QUANTUM

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The student magazine of math and science

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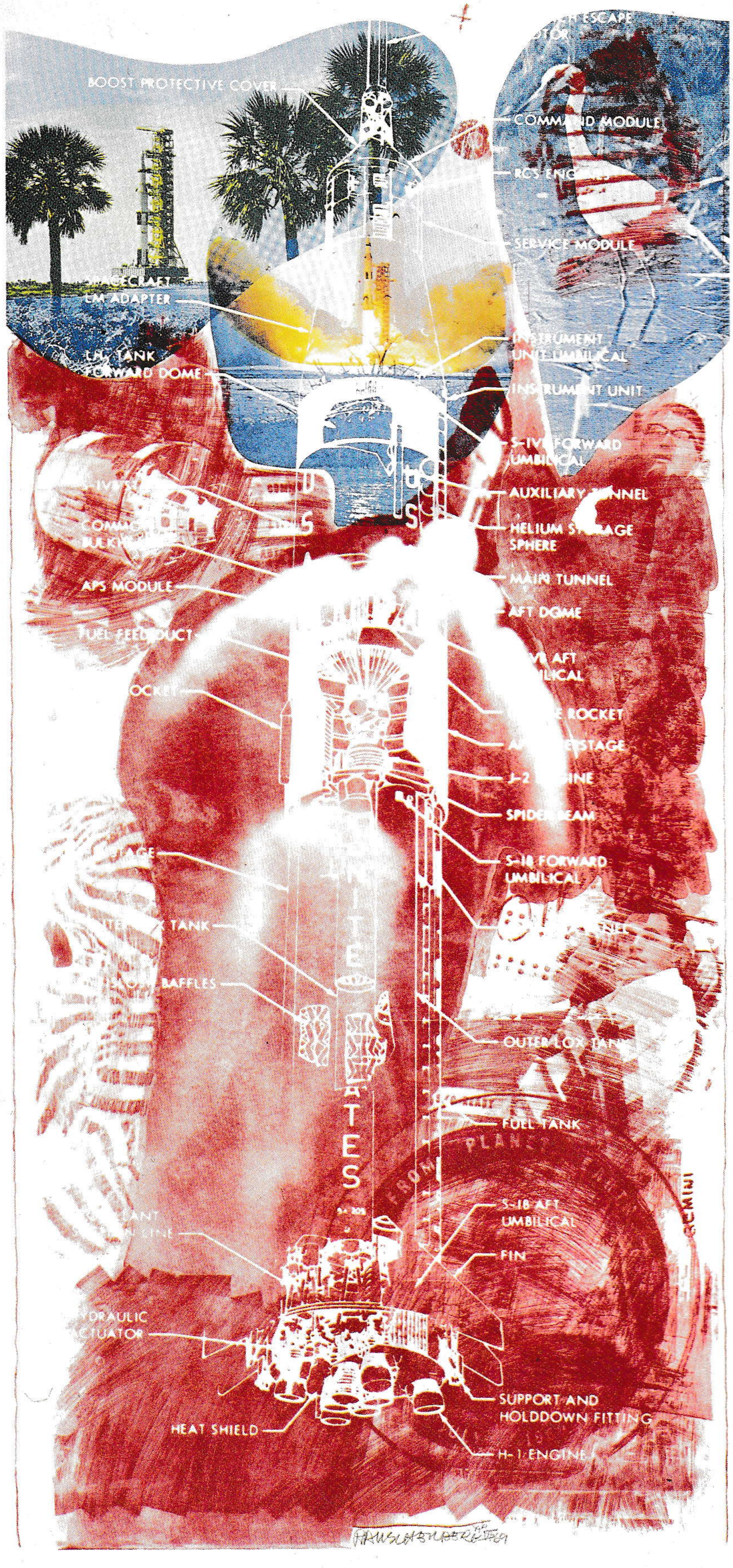
GALLERY



National Gallery of Art, Washington (Gift of Gemini G.E.L.) © NGA

Sky Garden (1969)
by Robert Rauschenberg

NINETEEN SIXTY-NINE WAS A momentous year in the annals of space exploration. Eight years after President John F. Kennedy declared the goal of sending a man to the Moon and returning him safely before the decade was out, Neil Armstrong stepped silently onto the barren lunar soil.

In the same year, Robert Rauschenberg (b. 1925) planted his "sky garden," a dynamic pastiche of images: the Apollo rocket at rest on the launch pad and during blastoff, a cutaway technical drawing with labels, ground controllers tracking the spacecraft's progress through the heavens, and a long-legged, long-beaked Cape Canaveral resident watching it all, no doubt with some bemusement. The color scheme is something to puzzle over: why is most of the picture exclusively red? This question leads to the overall problem of the work's structure. Are the bluish areas at the top meant to be "petals" from some cosmic flower? The red, white, and blue symbolism is rather obvious, but we should keep in mind that, according to the technical description, this is a *six*-color "lithograph (stone and aluminum) and screen print" (sounds complicated—rather like a Moon shot).

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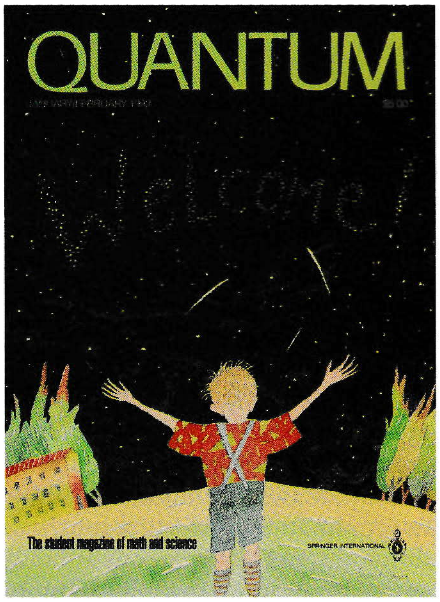

Cover art by Leonid Tishkov

When the ancients gazed up at the starry vault, they saw shapes. They noticed they were constant, and they gave them names: Ram, Archer, Water Carrier, and so on—the signs of the zodiac. (The modern eye is hard-pressed to see the same shapes—a failure of the modern imagination?) They also noticed that they moved in a regular and predictable way. Not only were the heavens an object of contemplation, the patterns and cycles there proved useful to the mariners and farmers of antiquity.

Powerful, omnipresent street lights have dimmed the heavens for modern city dwellers. Some of the major constellations can barely be seen, if at all. So a trip to the countryside can offer an astonishing view to the jaded cosmopolite. And on a clear night, far from the bright lights and commotion, you may feel a pull from above, may even see the message on our cover . . .

FEATURES

DEPARTMENTS

Welcome to International Space Year!

A celebration of discovery and teamwork

THE NEW YEAR, 1992, IS JUST a few weeks old, but it's already a busy one for the international community. The Olympic games will soon be underway in Barcelona, Spain, and all eyes are on the European Community during this much-awaited year of integration. Nineteen ninety-two is also devoted to a year-long worldwide celebration of space.

International Space Year (ISY) commemorates the themes of discovery, exploration, education, and international cooperation on the 500th anniversary of Columbus's first voyage to the New World and the 35th anniversary of International Geophysical Year, which launched the world's first artificial satellites. ISY will highlight the achievements of space programs across the globe by emphasizing the cooperation between developed and developing countries.

ISY is a celebration of all nations and peoples. Worldwide there has been tremendous "grass roots" endorsement of ISY and growing excitement. In this country, the US ISY Association (US-ISY) was created to serve as a public clearinghouse for information on ISY. To respond to similar public support, a European ISY Association (EURISY) and a Japanese ISY Association have also been established.

Many hundreds of exciting activities have been organized to celebrate ISY. For example, in a project organized by the Aspen Global Change Institute, students in grades kindergarten through 12 will collect field measurements of their local environment to serve as "ground truth" to support and verify some of the National Aeronautics and Space Administration's "Mission to Planet Earth" satellite data. During ISY Australia will host "Space Enough to Learn." At this special conference, teachers and administrators from science centers and museums worldwide will exchange knowledge, skills, and accomplishments and investigate ways to overcome obstacles in teaching space science and technology to students at all levels. Literally hundreds of other student and teacher activities, conferences, publications, seminars, films, exhibitions, television specials, and the like are being planned for 1992.

Although ISY is a public celebration of space, space agencies worldwide are also involved in the commemoration of ISY. Under the aegis of the Space Agency Forum for International Space Year (SAFISY), space agencies in different countries have organized dozens of international activities for 1992. Established in 1988 to coordinate ISY efforts throughout the world, SAFISY now consists of 29 space agencies and 10 affiliated international organizations. Three panels of experts assembled under SAFISY coordinate ISY activities.

The panel on Earth Science and Technology has organized projects that celebrate "Mission to Planet Earth," one of the key themes of ISY. For example, the Global Change Encyclopedia Project, led by the Canadian Space Agency, will develop an electronic encyclopedia for monitoring and analyzing environmental phenomena on a global scale. The encyclopedia will use spacecraft data from a number of countries.

The panel on Education and Applications is supporting projects that demonstrate a strong interaction between education and space activities, the importance of space applications in meeting a growing set of economic, cultural, and social needs, and a commitment to training professionals. One of the many creative projects on this panel is the prime-time television series "Space Age," which will investigate how space science and exploration reflect, and perhaps also shape, the cultural, political, and economic environment of mankind. Produced jointly by WQED in Pittsburgh and NHK in Japan, it embodies the international vision of ISY. Another key project, led by France, is to train developing countries in the use of remote sensing data.

The projects of the third SAFISY panel, the panel on Space Science, celebrate another major ISY theme: "Perspectives from Space." By venturing out into space, we gain a perspective on many things here at home—for example, on the Earth as both a complex, interactive system and as one planet among many in the solar system; on the Sun as a star; on our place in the cosmos; and so on. One project, led by Arizona State University and NASA, is compiling results of planetary mapping to produce a high-quality atlas of the solar system.

This ground swell of activity serves to underscore the inherent fascination space holds for humankind and the challenges and opportunities it provides. Space is the frontier that is best explored through global cooperation and scientific research. This year, International Space Year, is dedicated to this fascination, collaboration, and quest for knowledge. I believe that the international cooperation, enthusiasm, and emphasis on excellence in education celebrated during ISY will continue long beyond 1992.

—L. A. Fisk,
Associate Administrator for
Space Science and Applications,
National Aeronautics and Space
Administration

More information on ISY and the activities planned for 1992 can be obtained by writing to the US International Space Year Association, 600 Maryland Avenue SW, Suite 600, Washington, DC 20024.

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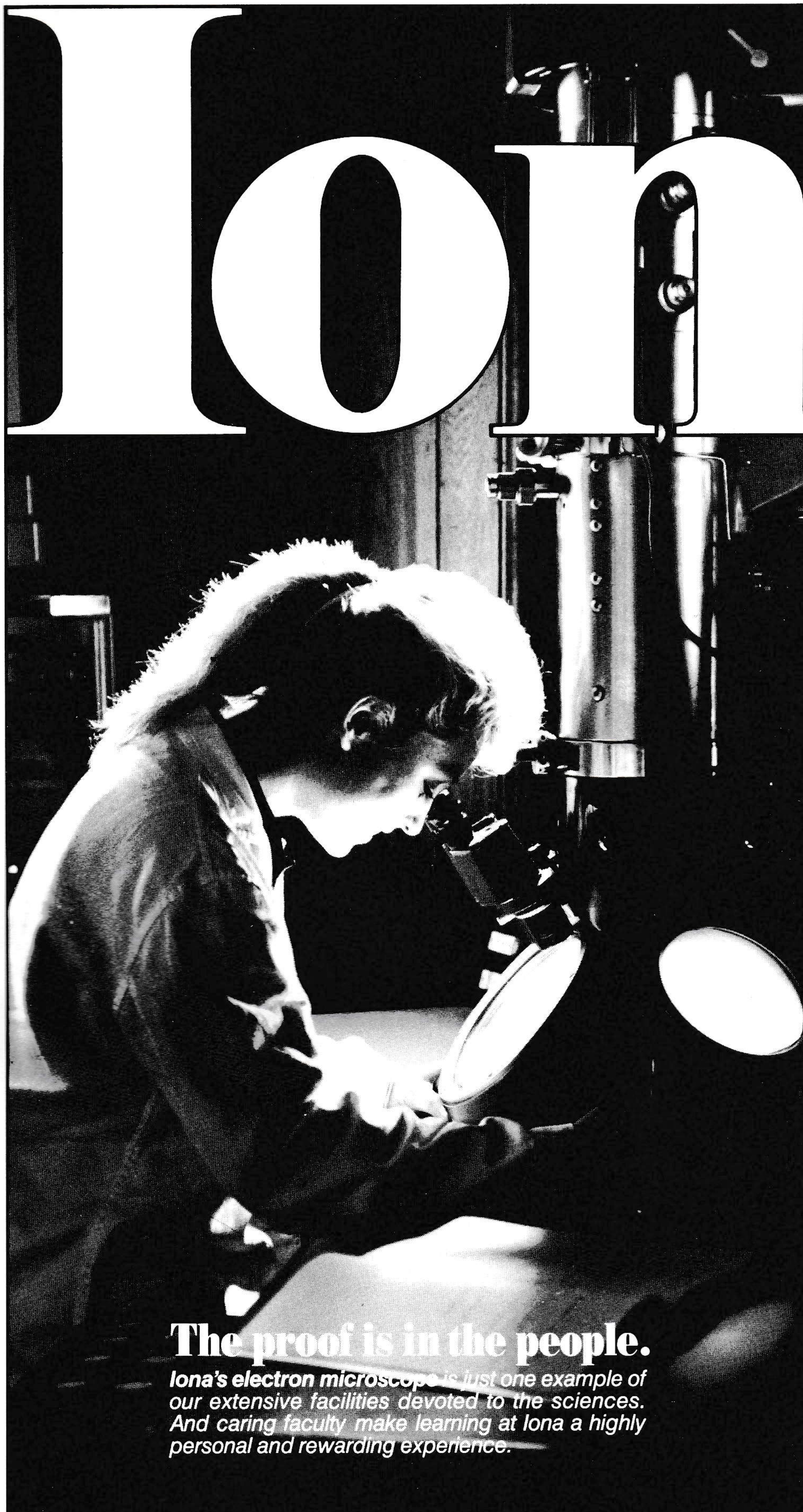

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A universe of questions

And a healthy dose of answers

by Yakov Zeldovich

SOME YEARS AGO the colleagues of Y. B. Zeldovich encountered an almost insoluble problem: how to select, from his vast scientific legacy, papers for a two-volume edition of his works. The physicists managed somehow to make the selection, but they also fudged a bit and appended to each volume a long list of monographs, textbooks, and papers in virtually every branch of modern chemical physics and hydrodynamics, elementary particle physics and nuclear physics, astrophysics, astronomy, and cosmology.

It's hard to understand how Zeldovich managed to leave his mark in all these fields. The story goes that the prominent English physicist and mathematician Stephen Hawking wrote after meeting him, "Now I know that you are an actual person and not a group of scholars, like Bourbaki."[1] *Zeldovich was one of the rare physicist-universalists of our age. His scientific merits are widely acknowledged, and not only in the Soviet Union, where he was elected a member of the Academy of Sciences. He was a member of many scientific societies and academies in different countries, including the Royal Society in Great Britain and the National Academy of Sciences in the US. International recognition of Zeldovich's merits in cosmological science was also evident in his election as the first president of the cosmological commission of the International Astronomical Union.*

Erudition, extraordinary efficiency, the ability to dig down to the quintessence of a problem, a nontrivial approach to solutions—all these qualities formed the basis of the talent of Yakov Borisovich Zeldovich: theoretician, remarkable teacher, popularizer of science.

On the eve of his seventieth birthday Academician Zeldovich wrote an article for high school students about the universe—about how he studied it over the course of a quarter-century and tried to construct a theory of its evolution. In it he discussed the most pressing questions of cosmology—the science Zeldovich loved so much and understood so deeply. The article first appeared in Russian in Kvant *(1984, No. 3).*

The author of this article was always most interested in the final result, in the physical truth. He said, "Would that I had strength enough to understand this truth." Reading "A Universe of Questions," perhaps you, too, will touch the truth and find joy in it.

[1] "Nicolas Bourbaki" is the collective pseudonym of a group of predominantly French mathematicians engaged in writing what they consider a definitive survey of all mathematics. Since 1939 "Bourbaki" has published more than 35 volumes in this massive project.—*Ed.*

HOW IS THE UNIVERSE constructed? What does its past, present, and future hold?

These questions have naturally arisen after we came to understand in general terms the design of the parts nearest to us: the Earth, Sun, solar system, other stars and galaxies. Cosmology is the science that investigates the universe as a whole, and it is the most difficult branch of astronomy. The last several decades have seen substantial progress in our comprehension of the current state of the universe and its evolutionary stages. This success is the result of the hard work of many people—the joint efforts of astronomers and physicists.

Nowadays we know a lot about the universe, and our knowledge is rather well founded. Here are the main facts.

Uniformity

The universe is uniform. This means it's quite the same everywhere, but its "uniformity," its "sameness," should be understood in a certain static state. For example: air in a vessel is uniform. There is the same number of oxygen molecules and the same number of nitrogen molecules in each cubic centimeter. But if we take tiny volumes—for example, cubes with edge $3 \cdot 10^{-7}$ cm, whose volume is approximately 10^{-20} cm^3—then they contain only one molecule of oxygen or nitrogen on average. So at any given moment

Art by Leonid Tishkov


Tishkov

there isn't a single molecule in this cube or several cubes, while other cubes can contain one molecule of N_2 or one of O_2 or, perhaps, two or three molecules (of the same or different elements).

We can see uniformity only when we consider rather large volumes. In the universe uniformity occurs in volumes (cubes) with edges greater than 300 megaparsecs (1 megaparsec (Mps) = 10^6 parsecs (ps) $\cong 3 \cdot 10^6 \cdot 10^{18}$ cm = $3 \cdot 10^{24}$ cm). We'll take into account that 1 year $\cong 3 \cdot 10^7$ seconds and the speed of light $c = 3 \cdot 10^{10}$ cm/s. This means that in one year light covers $3 \cdot 10^{10} \cdot 3 \cdot 10^7$ cm $\cong 10^{18}$ cm. This unit is called a light-year; 1 parsec $\cong$ 3 light-years. These units are often used in theoretical physics as well as cosmology.

The uniformity of the universe on the scale of 300 Mps and greater means that if a cube of such an edge is "located" anywhere in the universe, it will contain approximately the same number of galactic clusters. These clusters of galaxies are the largest structural units in the universe and may be likened to the molecules of gas in the example above. The universe is not uniform on scales of the order of 30 Mps. Notice that distances ~300 Mps are much shorter than the distance that can be investigated with modern telescopes.

Galactic clusters

As I mentioned, the greatest structural unit in the universe is the galactic cluster. There are thousands of galaxies in vast clusters, whose linear dimensions are several megaparsecs. The galactic clusters comprise hundreds of billions of stars. The stars consist of hot gas formed by atomic nuclei and electrons. A small portion of the gas is in outer space, between the stars. If we take a rather large volume of the universe and divide all its matter by the volume, we'll get an average density. The average density of the matter in the universe is in the range 10^{-30} to 10^{-31} g/cm^3. A vast volume has to be taken so that one doesn't happen to get into an area where the matter is much more (or less) prevalent than the average.

As we know, atomic nuclei consist of protons and neutrons (which, in turn, consist of quarks, but that's of no importance to us for now). There are mostly free protons (that is, hydrogen nuclei) in the universe. They constitute ~70% of the entire number of nucleons (protons and neutrons). About 15% of the protons are in other nuclei, mainly the nuclei of helium. And finally, ~15% are neutrons, which are in nuclei, too. Overall 25–28% of the matter in the universe is helium; only about 2% of nucleons are in the nuclei of heavy elements. The density of electrons (in one cubic centimeter) is equal to the density of protons, so that their electrical charges put them in equilibrium with each other.

On average the universe is electrically neutral. Protons and neutrons have an approximately equal mass: $1.67 \cdot 10^{-24}$ g; the mass of an electron is much less: $9.1 \cdot 10^{-28}$ g. It's clear now that an average quantity (for vast volumes) of neutrons and protons can be calculated if we divide 10^{-30}–10^{-31} g/cm^3 by $1.67 \cdot 10^{-24}$ g. It turns out that on average $6 \cdot 10^{-7}$–10^{-8} nucleons exist in 1 cm^3 of the universe. That is, one nucleon (proton or neutron), on average, exists in several cubic meters!

I'd like to emphasize once more that the matter is distributed extremely disproportionately within the vast volumes I've been talking about. For example, the density in the center of the Sun is about 100 g/cm^3—that is, it's 10^{32}–10^{33} times greater than the mean density. There are stars whose density is much greater; the density in the centers of neutron stars is ~10^{14} g/cm^3. And at the same time the density of matter between galaxies is less than the average.

Radiation

The universe is filled with primary radiation with wavelengths from 1 meter to 1 millimeter. This radiation is called "relict" because it goes back to the very beginning of the universe. The radiation isn't connected with any source—for example, stars or radio galaxies.

Quantum readers surely know that radiation can be considered a flux of particles, quanta of an electromagnetic field—that is, photons. So not only can we speak about flux and radiation energy density, we can now calculate the number of photons in a volume.

This photon number proves to be large—500 photons per cubic centimeter. The average photon energy is $1.6 \cdot 10^{-15}$ erg = $1.6 \cdot 10^{-22}$ joule. The total energy of all photons per unit volume is about $8 \cdot 10^{-13}$ erg/cm^3 = $8 \cdot 10^{-14}$ joule/m^3. Let's express photon energy in terms of mass to compare it with the average density of matter in the universe. We'll take Einstein's formula $E = mc^2$. Then the corresponding "photon mass density" is $8 \cdot 10^{-13}$ erg/cm^3 divided by $(3 \cdot 10^{10}$ cm/s$)^2 \cong 8 \cdot 10^{-34}$ g/cm^3. So the photon mass density is of the order of 10^{-33} g/cm^3.

An interesting picture is developing: the *number* of photons is much greater than that of protons, neutrons, and electrons. But if we calculate the density—that is, the *mass* per unit volume—then protons and neutrons are 100 or 1,000 times more prevalent than photons (radiation).

I'd compare this situation with elephants in a forest where there are many ants: the number of elephants is less than that of the ants, but they're heavier and their total mass is much greater than that of the ants. Of course, this comparison isn't exact. Photons aren't ants—they don't stay around anthills; they fly at the speed of light in all directions, and they don't gather in heaps or groups because they're "light." Protons and neutrons are "heavy," so the forces of gravity pack them together in dense heaps—planets, stars, galaxies.

Calculations of the number of relict photons are made by means of radio telescopes. The task is complicated from the technical point of view since there are many photons on Earth of local (terrestrial and solar) origin. Having overcome all these difficulties, radio astronomers have measured the total flux of photons of relict radiation. It turned out to be $1.3 \cdot 10^{12}$ $(\text{cm}^2 \cdot \text{s} \cdot \text{steradian})^{-1}$. And so the concentration of relict photons in the universe was estimated.

There are grounds to suppose that, besides photons, the universe is permeated by other particles—in particular, by various kinds of neutrinos and antineutrinos. If the rest mass of a neutrino is zero, the contribution of these particles to the total density is approximately the same as the contribution due to the radiation. But even a very small rest mass for one kind of neutrino (smaller than the electron mass by a factor of 25,000) would radically change our ideas of the average density of matter in the universe. Modern physics can accommodate a small rest mass for neutrinos though it doesn't give a definite value. Astronomers advance reasons for the fact that the masses of galaxies and galactic clusters are greater than the mass of visible matter. It's supposed that "dark matter" exists; it can be revealed only by the force of gravity, which it creates itself.

Evolution

The universe doesn't remain static—it's constantly evolving. We can guess that by measuring the motion of remote galaxies. Observations have shown that remote galaxies are receding from us at a speed u proportional to the distance r (the distance between our solar system and the galaxy). The formula $\mathbf{u} = H\mathbf{r}$ presents Hubble's well-known law. The proportionality coefficient H is called Hubble's constant and is approximately 50 (km/s)/Mps. Notice that the word "constant" indicates only the independence of H with respect to the vector $\mathbf{r}$, while H does depend on time.

To state this law one had to learn how to measure the velocities of galaxies and the distances between them. The procedure for determining velocity is as follows.

Galactic radiation includes the spectral lines of some chemical elements (no doubt you're familiar with the "yellow line" of sodium when NaCl is put in the flame of a bunsen burner). The laws of physics are the same everywhere. The wavelength of a definite line at the moment it's radiated—λ_{rad}—is one and the same on Earth and in any remote galaxy. If the source is receding, then according to the Doppler effect an observer at rest will perceive the radiation as displaced toward the red end of the spectrum—that is, the wavelength will appear to be a little longer: λ_{obs}. In cosmology the relative value of displacement is denoted by z and defined by the formula

$$z \equiv \frac{\lambda_{obs} - \lambda_{rad}}{\lambda_{rad}}.$$

When the velocity u is much less than the speed of light c, $z \cong u/c$. But when the velocity u approaches c, the formula connecting u and z becomes more complicated (we won't use it).

It's clear now that, by measuring the displacement of lines in the spectra of celestial bodies and galaxies, one can compute their recession velocity (that is, the component of the velocity at which they recede along the "line of sight").

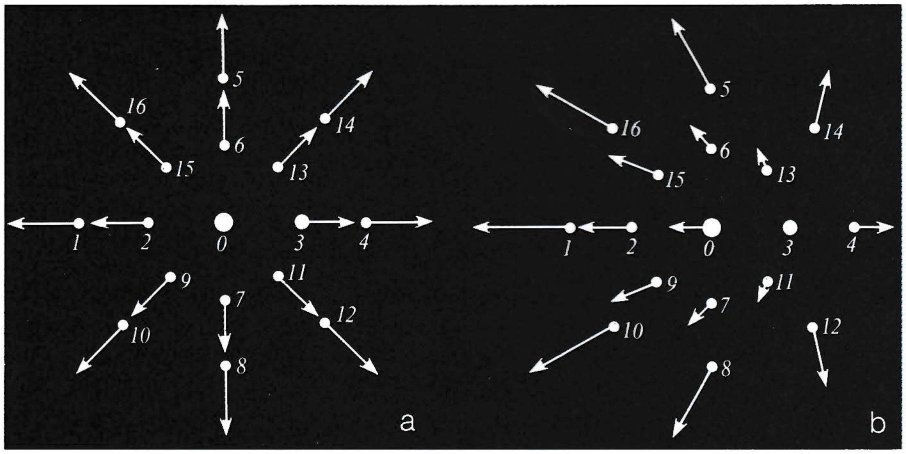
The Doppler effect not only offers an opportunity to measure the velocity of receding galaxies, it's also put to work on the street. Police cars are equipped with radar that can measure the speed of approaching and receding cars. Unlike cosmic bodies, cars don't radiate, they reflect electromagnetic radiation from the radar device. How does this affect the magnitude of the Doppler effect? Take a guess!

How can we determine how far away the galaxies are? This is one of the most important and most difficult problems in cosmology. It's said we need to have a "standard meter" and a "standard candle." What does *that* mean?

If there is a remote object with known dimension d (a "meter"—we mustn't identify it with a unit of length in the International System of Units), and if we're able to measure the angle θ the object subtends, then $d = r\theta$; this means $r = d/\theta$.

Imagine another situation. Suppose we know the luminosity of a remote object (a "candle"). Let the object radiate L units of energy per second; then the flux of energy per unit area from this object detected by receivers on the ground is

$$F = \frac{L}{4\pi r^2},$$



This figure illustrates Hubble's law: (a) shows the distribution of the velocities of receding galaxies from the point of view of an observer in our galaxy (0); (b) is the velocity distribution of the same galaxies but from the point of view of an observer in galaxy 3. The arrows denoting velocities in both (a) and (b) are directed away from the observer, but their lengths are proportional to the distance from the observer to the corresponding galaxy.

from which we get

$$r=\sqrt{\frac{L}{4\pi F}}.$$

Studying and classifying objects that are relatively close to us, astronomers have found some whose luminosity and dimensions are approximately known. It helped them estimate distances to analogous remote objects. Comparing the distances with the displacements of spectral lines, the astronomers established Hubble's law and determined the constant H. On the other hand, once Hubble's constant H was known, measuring the distances could be reduced to determining the velocity u (or displacement z).

Of course, we don't have any reason to believe that our planet occupies a special place in the universe. It's quite natural to suppose that an observer can watch receding remote galaxies from any other galaxy. The relative velocity of any two galaxies is proportional to the distance between them. This is a statement of Hubble's law. (Check it yourself!)

The big bang

The fact that galaxies recede means that the distances between them are increasing. The question naturally arises: "When did that process begin?" The moment at which all matter in the universe began to expand is called the "big bang." When did the big bang go off?

To determine when all the galaxies were in one and the same place ("at a point") is very simple if we suppose that the recession velocity u of each galaxy remains constant over time. It's sufficient to divide the distance r by the velocity u and we get

$$t=\frac{r}{u}=\frac{r}{Hr}=\frac{1}{H}=20 \text{ billion years.}$$

The supposition that u is constant doesn't contradict Hubble's law; although the distance r increases over time, H also depends on time, as I've already mentioned. More accurate considerations show that the recession velocity of each galaxy decreases over time because of the braking effect of gravity from other galaxies. So the time from the beginning of galactic recession (that is, the age of the universe) proves to be closer to

$$t_0=\frac{2}{3}\frac{1}{H}\cong 13 \text{ billion years.}$$

(Calculating the age, we now substitute this new value of Hubble's constant into the formula. The constant was larger before.)

So it has been firmly established that the big bang occurred about 13 billion years ago. The sequence of events that began with the expansion of very dense matter has also been studied. This matter was very hot, so the theory of a "hot" universe was proposed. Expansion was followed not only by a decrease in density but also by a decrease in temperature. Obeying well-known laws of physics, we can reliably follow the processes that occurred in the universe from the time when the temperature of matter was ~10^{13} degrees, its density was ~10^{33} g/cm^3, and its pressure was ~10^{54} dyne/cm^2 = 10^{53} N/m^2 ≅ 10^{48} atm. Under these conditions the substance resembled a "soup" of various particles and antiparticles. "Heavy" particles and antiparticles are generally annihilated, whereas quanta of electromagnetic radiation (photons) and neutrinos "survive." The amount of matter in the soup wasn't much greater than the amount of antimatter.

So some small (compared to photons and neutrinos) quantity of protons, neutrons, and electrons survived. The neutrons that survived and some of the protons combined in helium nuclei. Much later (in 300,000 years) protons and helium nuclei combined with electrons to become neutral atoms. The calculated amount of helium formed coincides well with the observed value. It bolsters our confidence in the fact that the theory of a hot universe is correct. Meanwhile the universe as a whole continues to expand.

Photons remained uniformly distributed in space. It is the photons that make up the cosmic background radiation—that is, relict radiation. But atoms, along with the total expansion, formed local "condensations"—stars, quasars, galaxies, and galactic clusters. Heavy elements were born later in the processes of nuclear combustion in stars. When stars burst, heavy elements were thrown out and began their travels within galaxies; a portion of them became a part of second-generation stars (the Sun!) and planets (the Earth!). However, the total number of atoms of heavy elements isn't large (as I mentioned earlier).

Problems

This is a very short rough draft of the evolution of the universe. We're quite sure that our theory is correct as a whole, yet hard work on it will continue, and new discoveries and mistakes are possible.

It's necessary, for example, to examine the last stage of this evolution, connected with the formation of celestial bodies and galaxies and their positions in space. One of the major problems in cosmology today is the problem of the universe's structure and formation.

Some problems concerning the origin of galactic clusters and superclusters are important as well. Settling these questions depends on the initial minor nonuniformity of the density, which was later increased by gravitation. The increase in the nonuniformity of the density develops during condensation and compression of gaseous matter. In three-dimensional space a "gaseous cloud" could be compressed in each of the three perpendicular directions. However, strong simultaneous compression along two or three axes doesn't often occur. As a rule, the compression of each cloud takes place in one specific direction. The process results in the formation of thin layers, or "pancakes." The more these layers are compressed, the greater the density of the matter. When new portions of the gas get into the pancakes they become hotter and enlarge in the direction of their plane. Later the pancakes start crossing one other. This results in a complex cell structure like honeycombs. In this structure the layers of compressed gas are surrounded by areas practically devoid of gas. Some cells are hundreds of megaparsecs in size, and their "walls" are formed of greatly flattened superclusters. It's in these pancakes that stars, galaxies, and galactic clusters are born.

The problem of structure is closely linked with the fact that other particles (besides atomic nuclei, electrons, and photons) are in the universe and determine its average density. The problem of "dark matter" mentioned above, along with the problem of the universe's structure, keeps astronomers working hard. It's necessary for physicists studying elementary particles to complete a thorough catalog of particles, specifying their mass and other properties.

There's another part to the problem: what is the universe as a whole? Einstein's general theory of relativity states that the geometry of space doesn't obey Euclid's laws. Space can be closed; it can have a limited volume but at the same time not have boundaries. In speaking of this feature of space we use a two-dimensional analogy: the surface of a sphere has a definite area ($4\pi R^2$), it's closed, but it has no boundaries, and all its points are equivalent. At the same time, a small portion of a sphere possesses geometrical properties very close to those of a small portion of a flat plane. The answer to the question "Is the universe closed?" is connected with the question "How much 'dark matter' is there?"

I'd like to emphasize that the solution to all these problems won't alter the expansion scenario mentioned above.

There are more profound and difficult problems. What is the initial state with high temperature and density? How did it originate? Why is the universe receding?

We've spoken about the big bang. But the big bang of the universe doesn't resemble the explosion of even the largest bomb. The charge of an ordinary explosive turns into gas with a pressure of the order of hundreds of thousands of atmospheres as a result of a chemical reaction. This gas is surrounded by air with a pressure of 1 atm = 10^5 Pa. The pressure difference between the gas and the atmosphere is the very force that provokes the motion of gas and air, gas expiration, and a whole set of phenomena that goes by the name "explosion."

During the big bang in the universe, on the other hand, the density, temperature, and pressure are the same at all points in space at the same time. The big bang results from a certain original distribution of velocities in the hot matter. The particles continue to fly off because of inertia. High pressure, however, doesn't accelerate their expulsion, and the forces of gravity even slow it down. From the very beginning the relative velocity at which any two small particles fly off is proportional to the distance between them—that is, Hubble's law is operative from the very start.

The big bang theory needs very specific initial conditions to explain everything that happens later. Only recently have we succeeded in figuring out how these initial conditions arose. The modern theory supposes the existence of a state with negative pressure, when gravitational forces make particles repel rather than attract. Those who don't believe this statement and are eager to verify it will have to study the general theory of relativity.

In this article I've touched only a few of the problems concerning the history and evolution of the universe. A complete theory of the origin of the universe hasn't been devised yet; though it has made some progress, cosmology isn't complete either. Some definite, perfectly outlined problems remain to be investigated and solved. More thorough observations, progress in theoretical physics, and some scientific boldness are necessary to develop cosmology further.

According to my approximate calculations you, my readers, are a quarter or a fifth my age. Speaking in the language of cosmology you are "at another stage of evolution." Can I give you a few pieces of advice?

(1) Learn how to pose problems. Do it always and everywhere. Almost any phenomenon in life, in nature, can be a source of "problems," a source of meditation. The way a drop of water falls, the process of waiting for a bus, the trajectory of a thrown stick, the shimmering pattern when two fences line up, the color of a greasy film . . . As Kozma Prutkov[2] once said, "When you throw stones in the water, pay attention to the rings produced; otherwise this habit would be a mere waste of time."

Exams and olympiads are for solving problems *other* people have posed. As a rule, to discover something—big or small—means posing problems.

(2) Physics and mathematics are inseparable. The laws of physics can be stated only by means of mathematics.

(3) Study independently! Look for problems and solve them yourself—or even better, with somebody else. If your fellow problem solver is wiser than you are, you're sure to learn a lot. If your partner is weaker, you'll gain a deeper understanding of the problem while helping your friend comprehend it.

CONTINUED ON PAGE 17

[2]"Kozma Prutkov" is another collective pseudonym, this one of nineteenth-century vintage. Several Russian writers banded together under this name to publish maxims and musings that had the flavor of folk wisdom.—*Ed.*

It all depends on your attitude

Getting your bearings in outer space

by Bernice Kastner

HERE ON EARTH, GRAVITY keeps our feet pointed downward. We can also locate our position conveniently with reference to nearby objects fixed on Earth's surface. Once we leave Earth, we can no longer take advantage of our built-in gravity-dependent orientation mechanism. There is no up or down; everything, including ourselves, is moving relative to everything else; and the motion often involves spinning around an axis (rotation) as well as movement along a trajectory (translation). How do we cope with these new conditions, which come with exploration of the (nearby) universe?

The key is to use our intelligence in place of our instincts. We make use of our painstakingly acquired store of mathematical knowledge. In this article, we'll focus on one of the most useful mathematical tools—angles and their properties.

It's almost impossible to overstate the importance of angles in space travel. To send a spacecraft where we want it to go, and to have it do its job when it gets there, control of how the spacecraft is pointed, technically known as its *attitude,* is paramount. It's necessary to both describe and make desired changes in the spacecraft's attitude, relative to several reference systems: that of the spacecraft itself; those at monitoring stations on Earth; and possibly a reference system based on the Sun, one of the planets, or even the background "fixed" stars, depending on the spacecraft's mission.

It would take several books to really cover the mathematical background, and a few more to deal with the instrumentation that has been designed for attitude determination and control, so we'll confine ourselves here to some of the fundamental underlying ideas. Let's begin by considering (1) how we describe where we are here on Earth and (2) how we aim an Earth-based telescope at a star or a planet.

The geocentric system

No doubt you're familiar with the first of these: society has devised a coordinate system for Earth, shown on most globes and maps, consisting of circles that we call latitudes and longitudes. There's a difference in the nature of these two systems of circles. Longitudes are all halves of *great circles,* whereas latitudes, except for the equator, are *small circles.* If a sphere is sliced by a plane that passes through its center, the plane meets the sphere in a great circle. Since the equator is the only latitude whose center is coincident with the center of the sphere, all other latitudes are small circles. A given latitude is identified with the angle subtended at the center of Earth by an arc of a longitude circle with one endpoint on the equator and the other on that latitude. Similarly, longitudes are named by the angle subtended at the center of Earth by an arc of the equator, with one endpoint on the *prime meridian* (0° longitude) and the other on that longitude. (See figure 1.)

In this coordinate system, the equator was chosen as the zero of latitude, and latitude angles are stated in terms of the number of degrees (up to 90) north or south of the equator. The zero of longitude was chosen to be the half of the great circle passing through Greenwich, England, and

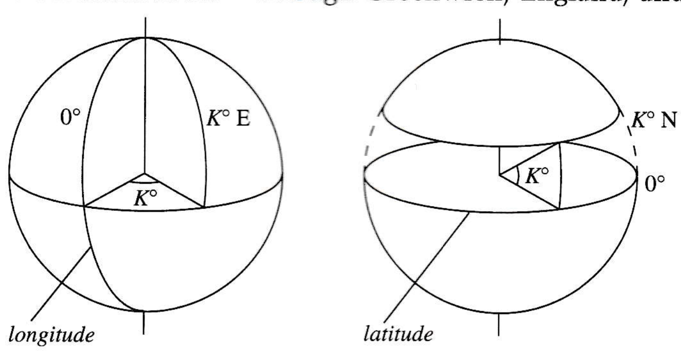


Figure 1

Art by Sergey Ivanov

longitudes are stated in terms of the number of degrees (up to 180) east or west of this longitude. For example, to the nearest degree, the city of Washington is at 39° north latitude, 77° west longitude; Moscow is at 56° north latitude, 38° east longitude; and Quito, Ecuador, is almost on the equator, at 0° latitude, 78° west longitude.

We note that although a sphere is three-dimensional, its surface is only two-dimensional, so two coordinates are sufficient to locate a point. Also, the numbers used as coordinates are actually angle measures rather than distance measures; this works because all distances are thought of as arcs of great circles that are no greater than half of such a circle, and there is a natural correspondence between the length of such an arc of a great circle and the measure of the angle this arc subtends at the center of the sphere.

Exercise 1. If the radius of Earth is R, express the distance from 0° latitude, 0° longitude, to K° north latitude, 0° longitude, in terms of R and K.

The celestial system

Astronomers have developed a similar system to locate objects such as planets and stars by imagining that Earth is at the center of an imaginary *celestial sphere* whose radius is infinite, and all the stars are "on" this sphere. A coordinate system analogous to latitude and longitude can then be imposed on the celestial sphere by projecting Earth's axis of rotation on the sphere to identify the north celestial pole (NCP) and south celestial pole (SCP) as shown in figure 2. (Since the radius of the celestial sphere is assumed to be infinite—which, of course, can't be shown in the diagram—all parallel lines point to the same spot on the sphere, defining a *direction* in the three-dimensional space inside the sphere, and so every line parallel to Earth's rotation axis points to the north and south celestial poles.)

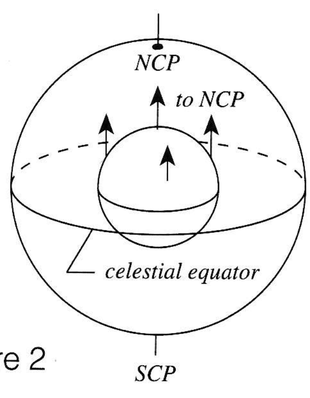


Figure 2

The extension of Earth's equatorial plane then intersects the celestial sphere in a great circle called the *celestial equator*. Now a system of small circles of *declination* (δ), comparable to latitude circles on Earth, can be imagined on the celestial sphere, and a system of great circles called *right ascension* circles (α), comparable to longitude, passing through the two poles, completes the coordinate system. The half of the great circle containing the poles and the vernal equinox[1] has been designated as right ascension 0°, as shown in figure 3. Every star or celestial object can now have its position—really a particular direction in space—identified by the ordered pair (α, δ). Differences in the positions of two objects on the celestial sphere can then be expressed in terms of the angle subtended at Earth by the arc of a great circle joining the positions of the objects.

Because Earth rotates with respect to the celestial sphere, you can see that an Earth-based observer needs to know the time of observation in using the celestial coordinate system to locate a star. To understand how the celestial coordinate system is used, we must consider the implications of Earth's rotation on its axis as well as its orbit around the Sun. Along the same lines, to track an orbiting spacecraft, we must account for the fact that Earth is rotating on its axis while the spacecraft is moving around Earth. To see the nature of the reasoning, try the following exercises.

[1]The vernal equinox is one of the two points on the celestial sphere where the projection of Earth's equatorial plane intersects the projection of the plane of its elliptical path around the Sun (the "ecliptic").

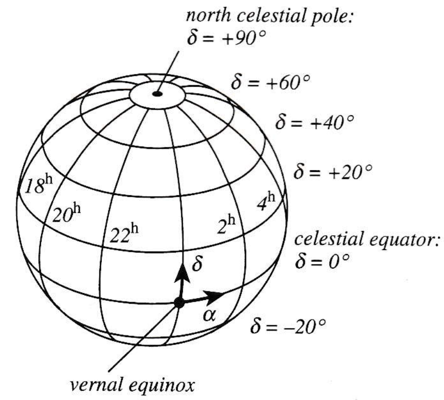


Figure 3

Exercise 2. How many minutes elapse between successive alignments of the hands of a clock?

Exercise 3. Suppose an observer at NASA's tracking station in Quito (remember, it's virtually on the equator) sees a satellite pass directly overhead moving from west to east. If the satellite takes 8 hours to make one complete orbit of Earth, how long will it be before the satellite is again directly overhead at Quito?

The time required for an orbiting satellite to make one complete revolution of Earth is called its *period*. The length of the period depends on the location of the observer making the measurement.

Suppose the observer is located far out in space and views the satellite against the background of the fixed stars. The period measured in this manner is called the *sidereal* period of revolution—that is, the period in relation to the stars. Notice that the rotation of Earth doesn't affect the sidereal period.

If you did exercise 3, you saw that when the satellite has made one complete transit of its orbit in the same direction that Earth rotates, it won't yet be overhead for the observer, because the rotation of Earth will have carried the observer away from the spot in the satellite's orbit that was over the observer's head in the previous pass. The satellite must travel an additional distance to again be over the observer's head. The observer measures the period of the satellite as the time elapsing between successive passes directly overhead. This period is called the *synodic* period of revolution, and it takes into account the rotation of Earth.

When the satellite is orbiting in the same direction as Earth's rotation, it is said to be in a *posigrade* orbit. In this case, the synodic period is greater than the sidereal period. If the direction of orbiting is opposite to Earth's rotation, the orbit is said to be *retrograde*. In this case, an Earth observer would meet the satellite before it made one complete revolution around Earth, and the synodic period would be less than the sidereal period.

Time-dependent angles

We have two natural units of time here on Earth: the *tropical year*, based on the length of time it takes Earth to complete one trip around the Sun; and the *solar day*, based on the length of time it takes Earth to complete one rotation on its axis with respect to the Sun. The month was at one time also a natural unit, based on the length of time it takes the Moon to complete one orbit of Earth. The definition of the months has since changed, and the months are now only loosely related to the lunar period. Society has also found it necessary to redefine the calendar from time to time, since the day and the year are fundamentally incompatible units—it takes about 365.2422 solar days to complete a tropical year—and this is why we have leap years.

The situation is further complicated when we want to locate objects represented on the celestial sphere. From the point of view of an Earth-based observer, the celestial sphere appears to rotate while the observer appears fixed. The *sidereal day* is defined as the length of time it takes for a given point (say, a certain star) on the celestial sphere to make one complete revolution with respect to the observer. This differs from the solar day, since Earth's revolution around the Sun results in the Sun's being in a slightly different position (about 1° eastward) on the celestial sphere after one solar day (just as the hands of a clock aren't together at successive hours, as you saw in exercise 2). We can find the number of sidereal days in a year by asking how many sidereal days elapse between successive alignments of the Sun with our chosen point on the celestial sphere.

Suppose we start when the Sun is at the first point in the constellation Aries (which corresponds to the vernal equinox). We'll call this point V. After one sidereal day, V will have returned to the same position with respect to the viewer, but the Sun will not quite have reached it. Let D be the number of degrees between the positions of V and the Sun, and let T be the number of sidereal days in a year—that is, between successive alignments of V and the Sun. Then $D = 360/T$, and the Sun moves through $(360 - D)$ degrees each sidereal day. In one year, the Sun has moved through $T(360 - D) = T[360 - (360/T)] = 360(T - 1)$ degrees. In this same year, expressed in terms of solar days, the Sun has moved through (360×365.2422) degrees. So we have $T - 1 = 365.2422$, and $T = 366.2422$. In other words, a year has 365.2422 solar days but 366.2422 sidereal days, and the sidereal day is about four minutes shorter than the solar day.

The conventions for weeks, hours, minutes, and seconds grew out of other social needs. Our practice of subdividing both hours and degrees into 60 minutes is due to our heritage from Babylonian astronomy. The Babylonian number system used a base of 60; while the decimal (base 10) numeral 54.32 means $5 \times 10 + 4 + 3 \times 1/10 + 2 \times 1/10^2$, the base 60 numeral 54.32 means $5 \times 60 + 4 + 3 \times 1/60 + 2 \times 1/60^2$. In fact, the word "minute" comes from the Latin expression for "little parts"—*partes minutiae*—and the word "second" from the Latin words for "little parts of little parts"—*partes minutiae secundae*.

These societal conventions have been the source of even more confusion for novice astronomers. While declination and right ascension are both angles, it's customary in astronomy to measure declination in degrees (from 0 to ±90) and right ascension in hours (from 0 to 24). This is because a given line of sight from Earth toward the sky corresponds to a constant declination but to constantly changing right ascension as the celestial sphere rotates with respect to the observer. Earth rotates through 360 degrees in 24 hours, so 1 hour of right ascension corresponds to 15 degrees of rotation; this means that 1 minute of right ascension is 1/60 of 15 degrees, or 1/4 degree. To prevent confusion between units of time and angle measurement, many astronomers use the terms *arc-minute* for 1/60 of a degree and *arc-second* for 1/60 of an arc-minute.

Before the advent of the calibrated equatorial telescope mount and modern computer software, anyone making observations with a telescope had to do some complex calculations. The first step was to convert the observer's longitude to time units. You may be interested in trying the next exercise.

Exercise 4. An amateur astronomer in Cleveland, Ohio, has looked up her longitude and found it to be 81° 45′ W. Express this in units of time.

The spacecraft-based celestial sphere

A spacecraft is equipped with sensor instruments that are used to determine its attitude—that is, its orientation relative to the Sun, Earth, or stars (independent of its distance from any of these objects). Imagine a sphere, again with an arbitrarily large radius, whose center is now at the spacecraft's center of gravity. This is the *spacecraft-centered celestial sphere*. Sun sensors can provide the direction of the center of the Sun, and

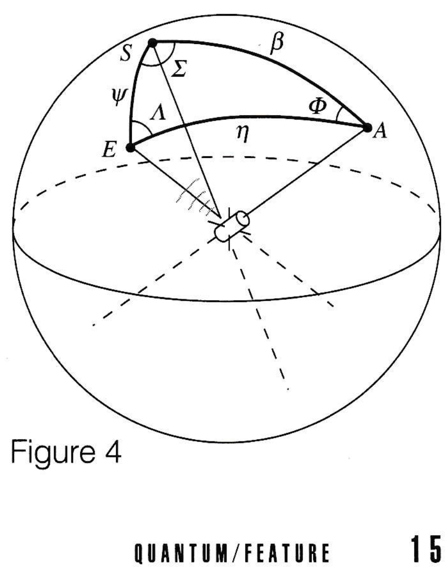


Figure 4

this points to a particular location S on the spacecraft-centered celestial sphere, as shown in figure 4. Notice that the Sun's location (direction) will be different on the previously described Earth-centered celestial sphere. (Why?)

The spacecraft's horizon sensors determine Earth as a circular disk; the center of this disk is called the *nadir* or *subsatellite point*, and its projection on the spacecraft-centered celestial sphere is shown as E in figure 4. The direction of the spacecraft's major axis provides a third point A (for attitude) on this sphere. These three points define a *spherical triangle*, and the established techniques of spherical trigonometry are applied to analyze the angles and arcs of this triangle. I won't go into the details of these techniques here, but interested readers may refer to standard references on this subject.[2]

Spacecraft rotation axes

Another set of angle measurements is needed to describe the rotations of a spacecraft with respect to a coordinate system fixed in the spacecraft body. The axes are identified as R, P, Y for *roll*, *pitch*, and *yaw*—the names (from nautical terminology) given to the respective rotations about these axes, illustrated with curved arrows in figure 5. A system such as this one is called an *orthogonal, right-handed* coordinate system. The word "orthogonal" means that the three axes, labeled R, P, Y in the diagram, are mutually perpendicular. The term "right-handed" is associated with the convention that the positive direction of rotation maintains the cyclic order $R\ P\ Y\ R$. In this case, if the thumb of the right hand points in the direction established as positive for the R-axis, and the fingers of the right hand are closed to make a fist, the direction of curling of the fingers shows a positive roll angle—the path that would rotate the positive P-axis to the position occupied by the positive Y-axis. If the right thumb points in the $+P$ direction the fingers curl to show a positive pitch angle, which rotates the $+Y$-axis toward the $+R$-axis; and the right thumb pointing in the $+Y$ direction produces curled fingers that show a positive yaw, rotating the $+R$-axis in the direction of the $+P$-axis.

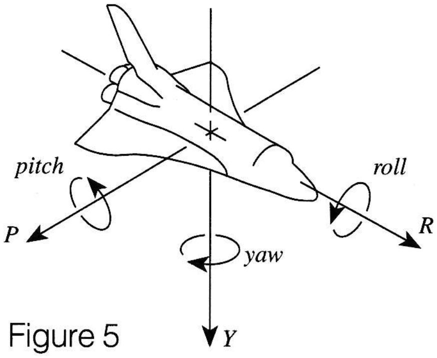


Figure 5

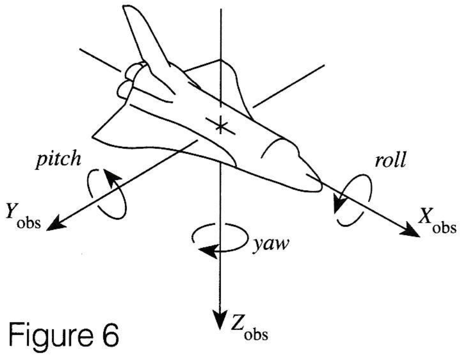


Figure 6

Observer-fixed coordinate axes

It's apparent that the roll, pitch, and yaw axes rotate along with the spacecraft. If we want to track the spacecraft attitude from Earth or from, say, a space platform, we have to relate the spacecraft rotations to a coordinate system that doesn't move relative to the observer. Suppose such an observer-based system is initially coincident with the spacecraft system of figure 4, with X_{obs}, Y_{obs}, Z_{obs} aligned with R, P, Y, respectively, as shown in figure 6.

If you have studied trigonometry, you'll be able to do the following exercises.

Exercise 5. Let (x, y, z) be the coordinates of a point on the spacecraft, in the observer's system, and let the spacecraft perform a roll through an angle R. If (x_R, y_R, z_R) are the new coordinates (in the observer's system) of this point after the roll, show that

$$x_R = x;$$
$$y_R = y \cos R + z \sin R;$$
$$z_R = z \cos R - y \sin R.$$

Exercise 6. What will the coordinates of this point be if instead of rolling through an angle R the spacecraft performs (a) a pitch through an angle P; (b) a yaw through angle Y?

Notice that if a spacecraft performs two rotations in succession with respect to the observer's frame of reference, the resulting attitude depends on the order in which these rotations are performed. The following diagrams show how this comes about. In figure 7 you can see first a rotation of 90° around X_{obs}, then a rotation of 90° around Y_{obs}. (Notice that an observer *inside* the spacecraft experiences this rotation as a yaw rather than a pitch!) Figure 8 presents first a rotation of 90° around Y_{obs}, then a rotation of 90° around X_{obs}.

The result of performing two motions in succession is called the *composition* of the motions. As you've just seen, composition of motions isn't necessarily commutative. That is, the *order* in which the motions are performed can make a difference in the result. You can try this for yourself using marching commands.[3] For example, let command A be "Forward march five steps!" and let command B be "Right face!" The composition of A and B (first do A, then do B) can be designated AB; BA then means the sequence "right face, forward march five steps." You can readily see that $AB \neq BA$.

Actually calculating the result of a sequence of rotations of a spacecraft is made feasible by applying techniques of matrix algebra to the ideas presented here. The expressions in exercises 5 and 6 are expressed compactly in matrix notation, and the result of two or more rotations in sequence is calculated by multiplying the appropriate matrices. While the

[2]For example, Carl E. Pearson, ed., *Handbook of Applied Mathematics*, New York: Van Nostrand Reinhold, 1974 (section 1.10.9).

[3]This will ring a bell if you read "Marching Orders" in the last issue of *Quantum*.

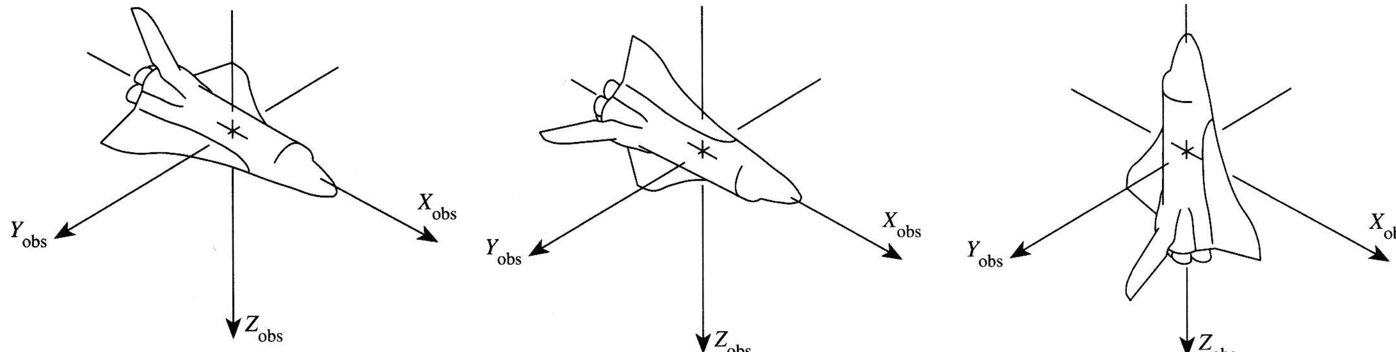


Figure 7

procedure may be cumbersome if it's done by hand, it's quite straightforward to instruct a computer to perform such calculations.

We've shown a little of the mathematics used to control and track spacecraft attitude. There's a lot more that could be said, and I haven't even mentioned the problem of finding the precise location of an object out in space—its distance as well as its attitude. It's a tribute to human imagination and ingenuity that we've developed both the mathematics and the machines to send men to the Moon, change the crew of the space station Mir, and explore the outer planets with Voyager, to mention only three of our many achievements in space travel. ◘

Bernice Kastner *is the author of* Space Mathematics, *published by NASA (EP-175), from which some of the material in this article was drawn.*

ANSWERS ON PAGE 82

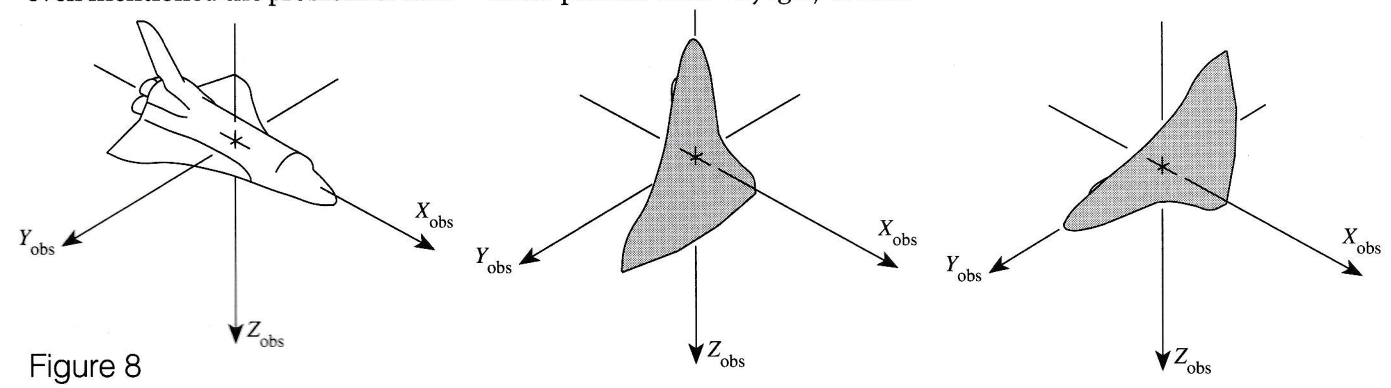


Figure 8

"A UNIVERSE OF QUESTIONS" CONTINUED FROM PAGE 11

(4) Alternate acquiring knowledge with putting it into action by solving problems that interest you. Not only that, try to bring a sense of research and discovery to your studying. You can open your textbook to a chapter and start reading page after page, step by step, formula after formula in order to understand the material. But you can choose another way: you can glance through the chapter very quickly to get a rough idea of what's going on, what kind of problems are posed and solved in that chapter. Then put the textbook aside and try to think of the solutions yourself or reconstruct the line of reasoning. After struggling with it for a few days, take the textbook and look carefully to see if the approach you came up with is sound, or how the difficulties you didn't overcome were handled in the book.

The time you spend searching for an answer isn't wasted. If you invent something that's already known, you won't waste your time either: you'll know the material better than if you learned it passively. Years will pass and you'll be able to discover something new in the same way you discovered something old. Even if you didn't find the answer, you've won because you've gotten a better grip on the difficulties of the problem, and you're better able to evaluate what's written in the textbook.

A future physicist (or any scientist) mustn't be satisfied with class work, with the standard curriculum and basic textbooks.

As I write all this I'm thinking back on my own school days. They weren't without complications, but they were inspiring nonetheless.

Learn how to create! And all the best to those who choose to take the more challenging path. ◘

Art by Elena Tchalikova

The fruits of Kepler's struggle

"The essence of the universe does not have the power within itself to withstand the courage of cognition."

—Georg Wilhelm Friedrich Hegel

by B. E. Belonuchkin

WHEN KARL MARX WAS asked "What's your idea of happiness?" he replied: "Struggle." But only a few people remember his answer to another question: "Who are your greatest heroes?" His answer: "Spartacus and Kepler." Now, Spartacus and struggle: that combination sounds reasonable. But Kepler and struggle? It's rather difficult to connect the image of the person who discovered the laws of motion of celestial bodies with that of a slave who battled for freedom. And yet Johannes Kepler was indeed a battler.

It seems Kepler battled with everyone, even with his teacher and benefactor Tycho Brahe. Brahe not only gave Kepler some priceless material—the results of his own astronomical observations—that were eventually generalized and became Kepler's laws; he also sheltered Kepler and provided material support. And that's what irritated Kepler most of all. Why wouldn't Brahe pay him a fixed salary instead of throwing him scraps? Kepler didn't know that the mounds of money that the Emperor Rudolf gave to Brahe had vanished long ago. The funds had been spent not so much on the construction of a "temple to astronomy" as on feasts in honor of famous visitors to the temple. Brahe arranged these celebrations not to entertain himself and his esteemed guests but to keep the city of Uraniborg safe from pillage by the local population. And the great astronomer had good reason to fear such a fate. No sooner did he die in exile, far from his native Denmark (he spent only four years away from his homeland), than Uraniborg was left in ruins.

Brahe and Kepler didn't agree on scientific questions either. Brahe was an adherent of a compromise theory of the solar system: the Sun orbits the stationary Earth, and the planets orbit the Sun. He didn't approve of the Copernican heresy. Brahe had a rather stormy temperament: it's known that he lost his nose in a duel precipitated by a scholarly disagreement. So we can just imagine how the arguments between the fiery Brahe and the vain and stubborn Kepler went.

Kepler struggled severely with himself, with his own views. But at the beginning everything went so smoothly! Let's inscribe a cube in a sphere with Saturn's orbit (circular, of course). Now let's inscribe a sphere with Jupiter's orbit in that cube. In Jupiter's sphere we'll inscribe a tetrahedron and a sphere inside that, which will have the orbit of Mars; and so on until all regular polyhedra and planets are exhausted. A "cosmographic mystery" was uncovered! (This is the title of one of Kepler's books.) The harmony of the spheres! How Pythagoras would envy him!

But . . . eight angular minutes of divergence between the predicted and observed positions of Mars forced Kepler to reject the concept of the regular revolution of the planets in circular orbits—an idea that had been accepted not for centuries but for millennia. We mustn't underestimate Tycho Brahe's role: he was the second (after Ulugbeck) to achieve an accuracy of two minutes in his measurements, which is practically the limit for the naked eye. Had his measurements been less accurate by a factor of three, Kepler wouldn't have been able to distinguish an ellipse from a circle.

These eight minutes . . . will give us the means to transform astronomy.

—Johannes Kepler

The "harmony of the spheres" did indeed collapse. It was replaced by the following laws.

Kepler's First Law: *The planets move along ellipses, and the Sun is one of the foci.*

Kepler's Second Law: *A line connecting the Sun and a planet sweeps*

Art by Elena Trofimova

out equal areas over equal intervals of time.

Kepler published these two laws in 1609. But his work, entitled *The New Astronomy*, saw the light of day only by a lucky accident. Strictly speaking, the work belonged to Rudolf , Emperor of the Holy Roman Empire, and it was written on his orders. But the Emperor couldn't pay the printing costs and the book was left at the author's disposal. Again Kepler was left without any means to support himself—books at that time didn't bring in any income, especially when they propagated the heretical views of Copernicus. Such books could only cause problems. As a Protestant, Kepler was persecuted by the Catholic Church; in Protestant countries he was persecuted by his "fellow believers" as a heretical Copernican.

Kepler's *Abridgment of Copernican Astronomy* was included in the *Index of Forbidden Books* long before it was even published.

The Thirty Years' War, which began in 1618, nearly prevented the publication of his *Harmony of the World*, which contained

Kepler's Third Law: *The squares of the times of revolution of the planets are proportional to the cubes of their distances from the Sun (to be more correct, proportional to the cubes of the semimajor axes of the orbits).*

So here we have all three of Kepler's laws. The first law concerns the orbits of all the planets; the second compares different portions of the orbit of a single planet; the third gives the correlation between the orbits of different planets. Now let's try to use these laws.

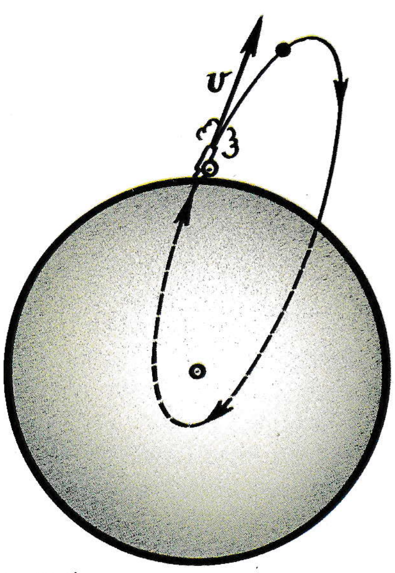


Figure 1

Problem 1. Can a satellite be launched with a gun?

Let's draw a picture of such a launch (fig. 1). A satellite moves along an ellipse; this means that after one revolution it must pass the launching point again with the same velocity vector. Actually, it's not important that the orbit be elliptical; all that matters is that it be a closed curve. Somewhere such a satellite is sure to slice into the Earth. And yet . . .

Let's look at figure 2. We'll launch the satellite from a high mountain. The best place would be Mt. Kilimanjaro. Why not Everest? Because Kilimanjaro is near the equator, and if we take into account the flattening of the Earth, then the top of Kilimanjaro is about 6 km farther from the center of the "sphere" than Everest is. Now the danger that the satellite will gouge into the Earth can be avoided, as long as its velocity is great enough. This is all true, but . . . we forgot about the air resistance. Kepler, in principle, wouldn't be against such a launch, yet all satellites are launched by rockets.

The next two problems will be devoted to Mars. Tycho Brahe investigated the motion of this planet in detail, and it was for Mars that Kepler established his first two laws. In general, Mars attracts more attention than any other planet. And at the time of the great opposition[1] in 1887, when the Italian astronomer Giovanni Schiaparelli discovered *canali* (channels) on Mars, a question reappeared in earnest that still hasn't been answered: "Is there life on Mars?" The American astronomer Percival Lowell asserted that these were in fact artificial structures—canals—dug by the intelligent inhabitants of Mars. The Soviet astronomer

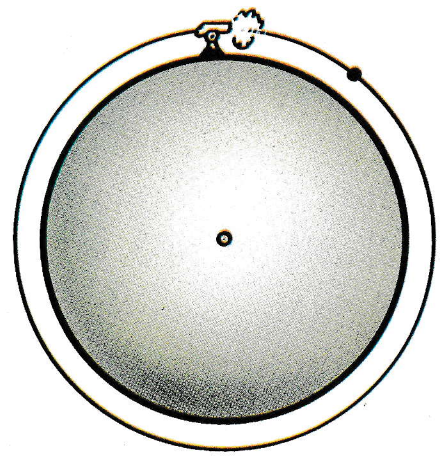


Figure 2

G. A. Tikhov enthusiastically searched for proof of life, albeit only vegetative, on Mars. Photographs taken by probes sent to Mars have conclusively shattered the myth of the existence of canals. Studies of Martian soil have produced no definite result: there are no organisms, but organic substances appear to exist. And not coincidentally the possibility of a joint Soviet–American expedition to Mars has been seriously discussed in recent years.

So let's begin our "investigation" of Mars.

Problem 2. The oppositions of Mars occur every 780 days. Let T_M be the period of the planet's orbit around the Sun. Determine this period T_M.

It takes more than one year to reach opposition because Mars moves along its orbit in the same direction as the Earth does. In $T = 780$ days the Earth makes a bit more than two revolutions—more precisely, $k = T/T_0 = 780/365.25 = 2.1355$ revolutions ($T_0 = 365.25$ days is the terrestrial year). It's not difficult to guess that the opposition can take place only if Mars has made not less than 1.1355 revolutions. This means that the period sought is $T_M = T/1.1355 = 687$ days.

(The attentive reader has probably noticed a certain "illiteracy" in my calculations: excessive precision. I confess, I gave in to a "dark urge" to adjust the result to the known value. I beg your pardon for my weakness, and I'll try to avoid it in the future.)

[1] When a planet is in "opposition," it and the Sun are on opposite sides of the Earth. See problem 3 for a description of a "great opposition."

Problem 3. At the time of great oppositions the distance between the Earth and Mars is the shortest and is equal to $r = 56 \cdot 10^6$ km. What is the maximum distance between the Earth and Mars at opposition?

Note: in problem 2 we silently got by with circular orbits. Now we can't. If the orbits are assumed to be circular, where do we get the great oppositions? The eccentricity of the Earth's orbit, however, is relatively small, so we'll consider it circular, as before. And so the orbit of Mars, of course, isn't.

Here are the data at our disposal: the period of the Earth's revolution $T_0 \cong 365$ days, that of Mars $T_M \cong 687$ days, and the radius of the Earth's orbit $R_0 \cong 1.5 \cdot 10^8$ km = 1 AU.[2] First, from Kepler's third law we'll find the large axis of the orbit of Mars:

$$2a_M = 2R_0\left(\frac{T_M}{T_0}\right)^{\frac{2}{3}} \cong 3.05 \text{ AU} \cong 4.57 \cdot 10^8 \text{ km}.$$

Then we need only look at figure 3 to understand that the distance we're looking for is

$$L = 2a_M - 2R_0 - l \cong 10^8 \text{ km}.$$

(This time the rounding is rather crude. The exact answer—that is, the value you can find in a reference book—is $97.5 \cdot 10^6$ km.)

In this calculation we've assumed that the orbital planes of the Earth and Mars coincide. This is quite reasonable, since in reality the corresponding angle is less than 2°. In general, the whole system of planets is rather flat. The maximum deviation from the ecliptic (that is, from the Earth's orbital plane) belongs to Pluto and is 17°; that of Mercury is only 7°; that of the other planets doesn't exceed 3.5°. None of this applies to comets, though, and it's to comets that we now turn.

[2]The astronomical unit (AU) is the average distance between the Earth and the Sun.

Along its egglike path
The mighty comet flies.
—Constantine Balmont

We can't help but agree that the trajectory of a comet is shaped like an egg. But rather than "mightiness" we might prefer to talk about "nothingness visible." Some three hundred years ago no one doubted the might of a comet. Comets brought war, drought, the death of kings and queens. True, by the 17th century there were freethinkers who ridiculed these beliefs, but one of the members of the French royal family retorted quite reasonably: "It's easy for you to joke about it, gentlemen—you are not princes." And in the 15th century Pope Calixtus III was really at a loss. A comet appeared in the early months of 1453, when the Christians had gotten the upper hand over the Moslems, so the pope considered the comet a harbinger of victory. But that very year the Moslems seized Constantinople and put an end to the Eastern Roman Empire. So the comet was cursed instead. Many years later this comet was identified as one of the most famous of all: Halley's Comet.

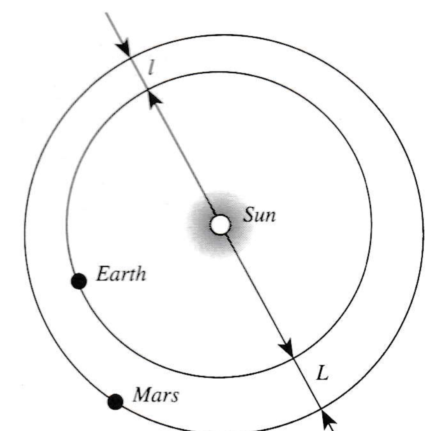


Figure 3

This comet is famous for many reasons. The main reason is that its trajectory was the very one used to define cometary orbits in general. Even Kepler and Galileo thought that comets traveled along straight paths. But in 1680 the English astronomer Edmond Halley showed that the trajectory of one comet was curved. It was, of course, the comet that was soon named after him. To be more exact, it was the 1682 appearance of Halley's Comet.

Wait—what *is* the date of Halley's Comet: 1680 or 1682? The problem is, comets often have double dates of appearance: the first date refers to the first observation and the second to the time when it reaches its perihelion. The second system is used more often for periodic comets, which Halley's Comet is, so in 1680 Halley saw the comet of 1682, and in 1453 Pope Calixtus III first blessed, then cursed the comet of 1456.

Fortunately, Halley didn't confine himself to defining the curved trajectory of the comet. He guessed that the comets of 1607 and 1531 were the same comet as that of 1682, and he predicted its appearance in 1758.

Problem 4. The period of revolution of Halley's Comet is $T_H = 76.7$ years. At its perihelion it reaches a distance of $r = 0.59$ AU from the Sun. What is the comet's greatest distance from the Sun?

If you managed problem 3, you'll be able to solve this problem without any difficulty. (You can check your answer at the back of the magazine.)

But what sort of figure is 76.7 years? If we compute with more precision the dates of the perihelion of Halley's Comet in 1456, 1531, 1607, 1682, and, finally, 1759 (not 1758!), we get the following set: 75.2, 76.2, 74.9, 76.5 years. The period 76.7 years is longer than any of these intervals. The question arises: is this comet absolutely periodic or not? Can we ultimately be sure that it's the same comet?

Halley turned out to be right. We "only" have to take into account perturbations in the comet's movement caused by planets in the solar system. This is exactly what the remarkable French mathematician A. Clairaut did when the comet arrived late for its first predicted rendezvous. According to Clairaut's calculations, in which he took the influence of Jupiter and Saturn into account, the comet should pass its perihelion not in 1758 but in April 1759 (plus or minus one month). And it passed its perihelion on March 13, 1759! But still—why 76.7 years?

After Halley discovered the periodicity of the comet named after him, people began to vigorously search for earlier appearances. They eventually managed to trace its history well back into antiquity. It was Halley's Comet that predicted the Mamayev slaughter in 1378, the Norman conquest of Britain in 1066, the death of prince Oleg in 912, the fall of Jerusalem and the destruction of Pompeii in 66; in 989 it marked the introduction of Christianity to Russia; the great Giotto painted it in 1301. A clay tablet from ancient Babylon relates the appearance of a bright object in the heavens in 164 B.C. and constitutes a "page" from the "biography" of Halley's Comet.

But it was the Chinese who collected the most data on this comet. The first reliable information in the Chinese chronicles is dated May 25, 240 B.C. But there's another date: March 7, 1057 B.C.! And eight centuries of absolute silence in between. What's the story?

It's a story of boundless human vanity. To ease ourselves into it, let's recall an episode from the work of the nineteenth-century satirist Saltykov-Shchedrin. A certain Archstrategius Stratilonius Takitin-Rakitin[3] rode into Stupidville on a white horse, and the first thing he did was to burn the school and abolish learning. As a result "history ceased its normal flow"—apparently only within the city limits. Now for the real thing. The Emperor Shih Huang-ti, founder of the Ch'in dynasty (and the "ideal governor," in Chairman Mao's opinion), decided that history should begin with his reign. So there would be no doubt about it, he executed 460 scholars and burned all historical books. Because some astronomical chronicles contained references to events that took place before the Ch'in dynasty, these manuscripts were destroyed as well. A few of them miraculously escaped the flames, and the description of the comet of 1057 B.C. was among these extracts. The "Great" Ch'in Dynasty ruled the Subcelestial Empire for all of 14 years . . . Two thousands years later, in the center of Europe the "Thousand-Year Reich" emerged, and again books were burned and scientists were persecuted. It lasted 12 years . . .

Let's get back to the comet. If the period May 25, 240 B.C., to February 9, 1986 A.D., is divided by the 29 revolutions Halley's Comet made during that time, we'll get one revolution every 76.7 years on average. All deviations are basically Jupiter's little joke. In general, Jupiter, whose mass is twice that of all the other planets combined, greatly distorts the orbits of many comets. It even has its own family of comets. Jupiter's family is a cometary group whose aphelia lie not far from its orbit. This giant caught them and won't let them go home to the remotest regions of the solar system. We'll get acquainted with one of such comet in the next problem.

Problem 5. Comet Grigg–Skjellerup belongs to the Jupiter group; its aphelion is 5.0 AU from the Sun and its period is 4.9 years. Might this comet intersect the Earth's orbit?

Computation (which we'll let you verify) gives the value of 0.77 AU for the shortest distance between the comet and the Sun—that is, the Comet passes closer to the Sun than the Earth does. So in principle Comet Grigg–Skjellerup can intersect the Earth's orbit.

As was already mentioned, however, a comet's orbit can have a noticeable inclination relative to the ecliptic plane. In this case the intersection of the projections of the comet's and planet's orbits onto this plane doesn't guarantee the intersection of the orbits themselves.

Halley's Comet reaches its perihelion at a distance of 0.59 AU, and the shortest distance between its orbit and that of the Earth at present is approximately 0.064 AU—that is, about 10 million kilometers. The nearest Halley's Comet passed the Earth was 0.04 AU (6 million kilometers). That was in 837. There is, of course, no direct evidence of this, nor could there be. Only after Halley was it possible to imagine the orbits of comets more or less clearly.

Nowadays (I'm speaking of the rendezvous of 1986) we use supercomputers to predict the comet's location with a precision to several angular seconds. A telescope with a five-meter mirror was used to scan the skies. But it wasn't a human being that peered into the eyepiece—a supersensitive photoreceptor capable of detecting individual quanta of light was used. Nevertheless, the comet was detected only about three years before it passed its perihelion. Armed to the teeth as we are with modern technology, we can follow this, the most studied comet of all time, for only one twelfth of its revolution, when it passes nearest the Sun.

If you solved problem 4, then you know the orbital parameters of Halley's Comet. To solve the sixth and last problem, you just need to recall Kepler's second law.

Problem 6. How long does Halley's Comet take to cover the half of its orbit nearest the Sun? (If you don't recall offhand the area of an ellipse, it's πab, where a and b are the semimajor and semiminor axes, respectively.)

After you solve this problem, you can compare your result with mine in the answer section.

HINTS AND SOLUTIONS ON PAGE 83

[3]Some commentators have associated this character with the repressive Tsar Nicholas I, who reigned from 1825 to 1855. (We have tried to repro-duce the jingly quality of the name in Russian: Arkhistratig Stratilatovich Perekhvat-Zalikhvatsky. "Takitin" is pronounced "take it in.")—*Ed.*

Challenges in physics and math

Math

M41

Simpler than it looks. Simplify the sum

$$\frac{1}{2!}+\frac{2}{3!}+\dots+\frac{n-1}{n!},$$

where $k!$ ("k factorial") denotes the product $1 \cdot 2 \cdot \dots \cdot k$. (V. Proizvolov)

M42

A cube from three squares. Prove that the sum of squares of three consecutive integers can never be the cube of an integer. (Y. Ionin)

M43

Hexagons and triangles. A hexagon $A_1A_2 \dots A_6$ is inscribed in a regular hexagon, one vertex of the former hexagon lying on each side of the latter (fig. 1). Three nonadjacent sides A_1A_2, A_3A_4, and A_5A_6 of the first hexagon are extended to form a triangle. Prove that if the vertices of this triangle lie on the lines containing the diagonals of the regular hexagon, then the same is true for the vertices of the triangle formed by the three other sides A_2A_3, A_4A_5, A_6A_1. (S. Orevkov)

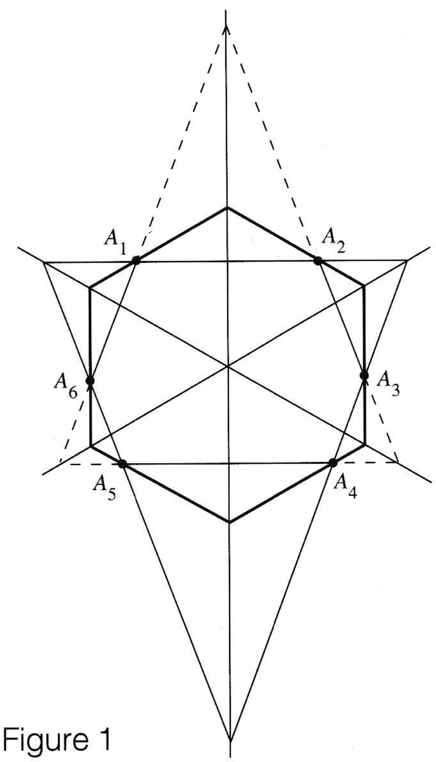


Figure 1

M44

Lost planet. On every planet of some planetary system sits an astronomer observing the closest planet. (All distances between planets are different.) Prove that if the number of planets is odd, then at least one of them is not observed.

M45

From sunrise till sunset. A spherical planet revolves in a circular orbit around a star and rotates about its own axis, tilted at angle α to the plane of its orbit (for the Earth α = 66.5°). How does the length T of the shortest day in the year at a certain point on the planet depend on the geographic latitude φ of this point? Write out the formula for the function $T = T(\varphi)$ and sketch its graph, assuming the diurnal rotation of the planet to be much slower than its orbital motion. (A. Savin).

Physics

P41

Receding stars. Some cosmonauts who are near one star of a certain cluster of stars see that all the other stars in the cluster recede from them at velocities proportional to the distances from these stars. What star motion will the cosmonauts see when they turn up near another star from this cluster?

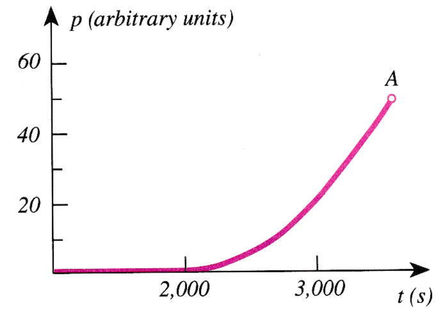


Figure 2

P42

Descent module. The descent module of a spacecraft approaches the surface of a planet along the vertical at a constant velocity, transmitting data on outside pressure to the spacecraft. The time dependence of pressure (in arbitrary units) is shown in figure 2. The data transmitted by the module after landing indicate that the temperature T = 700 K and the free-fall acceleration $g = 10$ m/s². Determine (a) the velocity v at which the module falls if the atmosphere of the planet is known to consist of carbon dioxide (CO_2); and (b) the temperature T_h at an altitude h = 15 km above the surface of the planet. (A. Buzdin)

CONTINUED ON PAGE 29

Grand illusions

How the universe plays tricks on us

by A. D. Chernin

COSMIC SOURCES OF radiation called quasars were found more than a quarter of a century ago—in 1963. But the riddle of their origin has yet to be unraveled completely. There is no end to the surprises they continue to throw at physicists and astronomers. Not so long ago amazing phenomena were discovered that had never been seen in the sky before: image doubling and motion at velocities greater than the speed of light.

This article won't go into the history of the discovery of quasars or the hypotheses and theories put forth to explain their properties. I'll just bring in the most basic facts about quasars; then I'll describe in detail the mirages and illusions in the quasar world and how we should interpret them.

The most powerful sources of radiation in the universe

Every quasar is a bright "lamp" that shines not only in the visible range of electromagnetic wavelengths but in all other ranges, from radio waves to gamma rays. The extent of the radiating region is most often comparable to the size of our solar system. But there's only one star in the solar system—the Sun; in the same volume of space a quasar is an energy generator more powerful by a factor of thousands than the entire galaxy with its hundred billion stars. How does this generator work? This is the main question of quasar physics, and there's still no definite answer.

The quasars detected are at the far, far reaches of the universe, where even with the largest telescopes we can't discern galaxies, let alone individual stars. The furthest known quasar is 13 billion light-years away. This means that its light takes 13 billion years to reach us, so we see this light such as it was 13 billion years ago. At that time the Earth and Sun didn't even exist, since the solar system is about 5 billion years old, according to the latest estimates.

We can tell how far away quasars and other distant bodies are by their radiation spectra. The emission lines of ordinary atoms—hydrogen, oxygen, carbon, and so on—are visible in the radiation spectra of quasars, but all these lines are shifted to the red end of the spectrum—that is, to the region of longer wavelengths. This shift—the famous "redshift"—is connected with the movement of the radiation source away from us. This movement away is itself a manifestation of the overall expansion of the universe. According to the laws of cosmology, the further quasars or galaxies are from us, the greater the speed at which they're receding.

If a source of light emits waves of period T_0 and moves at a velocity v with respect to us, the waves of visible light have the period

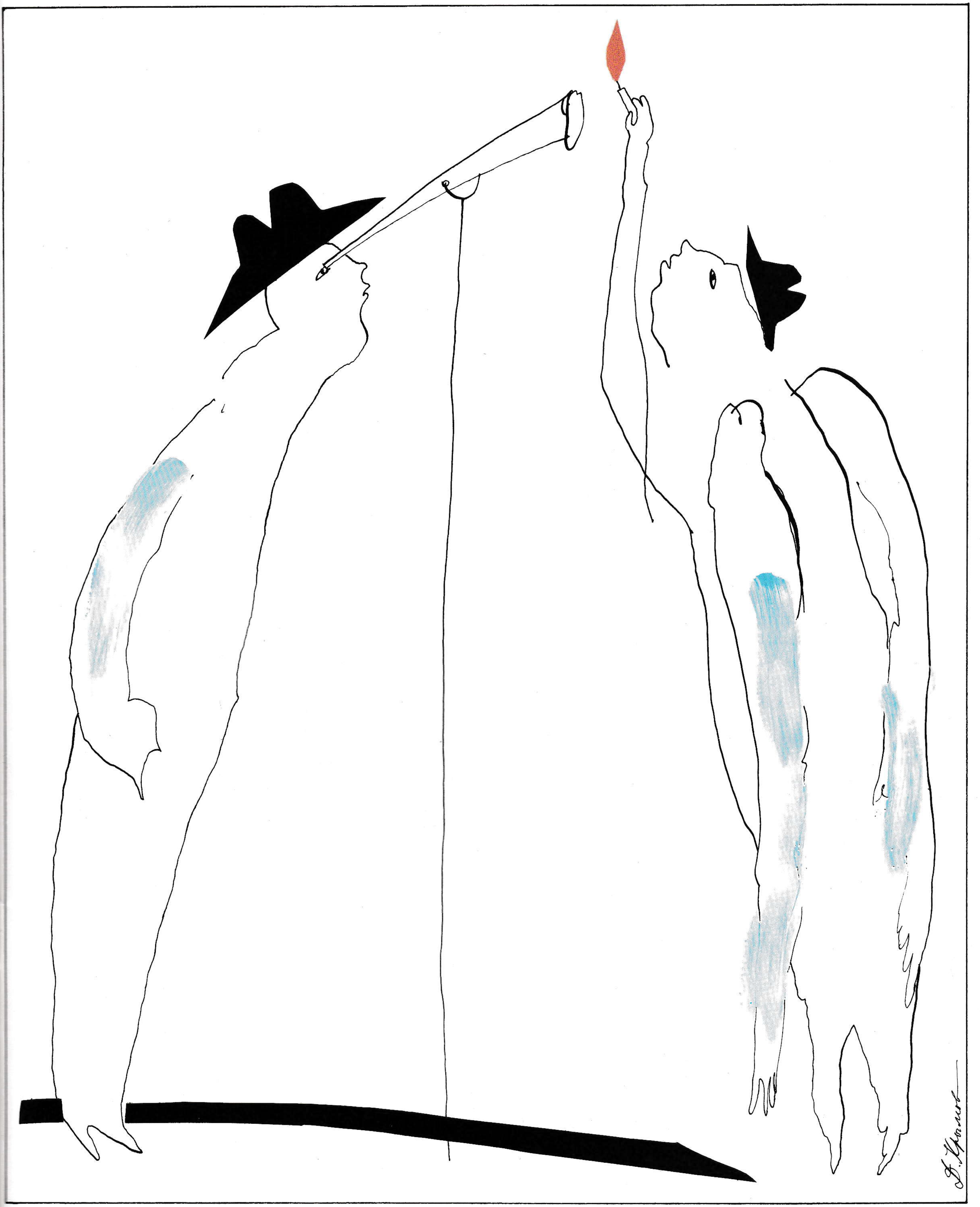
$$T = T_0 \frac{1-\frac{v}{c}\cos\vartheta}{\sqrt{1-(v/c)^2}}, \qquad (1)$$

where c is the speed of light, ϑ is the angle between the velocity vector and the line of sight (the line connecting the source and us—when the source moves straight at us, $\vartheta = 0$; when it moves directly away from us, $\vartheta = \pi$). For the most distant quasars, the period T is 4–5 times the period T_0. The change in the period and, consequently, in the frequency and wavelength because of the relative movement of the source is called the Doppler effect. It induces the redshift in the spectra of receding galaxies and quasars.

At present more than 2,500 quasars have been identified. They're spread out in the sphere of outer space more or less uniformly. The average distance between quasars, measured along the arc of the sky, is a few degrees (for comparison, the angular diameters of the Moon and the Sun are about 0.5 degree).

Two quasars that appear to be very close to each other have been known for quite some time. In fact, they're so similar they're called twin quasars. The distance between them is a mere 6 arc-seconds—that is, one thousandth the usual mean distance between quasars. They are practically equal in brightness; their spectra are similar as well—corresponding emis-

Art by Dmitry Krymov



sion lines are visible with the same intensity for both quasars. The redshift in their spectra is $T/T_0 = 2.4$, which is a rather significant value. It means that they're receding at a speed of 0.7c and that they're 7 billion light-years away from us.

Astronomers were astonished by the striking similarity of the twin quasars. And then they took a guess that, in reality, there weren't two different objects but two images of a single one. But how could such a doubling of a celestial image occur?

The gravitational lens

As you know, rays propagate in straight lines in the absence of refraction. The medium of outer space is so rarified that it causes practically no refraction. Nevertheless the paths of light can become distorted. The gravitational fields of heavenly bodies induce this distortion.

There's nothing so extraordinary about that. Even in the Newtonian theory of gravitation it's considered self-evident that a light ray, seen as a flow of particles (light "corpuscles") traveling at the speed of light, deviates from a straight trajectory when it passes near a gravitating body. The particles of light, like all particles and bodies in the universe, experience an attraction to that body.

Considerations about the deviation of a light ray by a gravitational field remain valid in the relativistic theory of gravity, which goes by the name of the general theory of relativity. According to this theory the angle of deviation of the ray passing at a minimum distance r from a body of mass M (fig. 1) is equal to

$$\alpha = \frac{4GM}{c^2 r}. \qquad (2)$$

Albert Einstein had proposed that the first attempts to observe this effect be directed at starlight passing near the Sun. Measurements can be made during a total eclipse of the Sun, when the Moon obscures the solar disk. Many observations, beginning with those of the total eclipse of 1919, have produced results that agree remarkably well with the prediction based on the general theory of relativity.

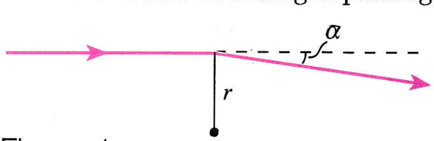


Figure 1
Deviation of a light ray in the field of a gravitating mass.

In 1936 Einstein published a short note in which he predicted a new phenomenon related to the deviation of light in a gravitational field—the so-called gravitational lens. If a gravitating body appears in the path of light from some distant source to an observer, under certain conditions more light reaches the observer than when this body is absent. The gravitational field is capable of directing rays to the observer that would otherwise have gone past. The gravitating body focuses rays like an ordinary lens.

The gravitational lens is both like and unlike an ordinary optical lens. In a convex lens, the nearer a ray is to the center of the lens, the smaller its deviation as it passes through. There is a point along the axis of the lens—its focus—through which *all* the rays entering the lens pass, not just the rays traveling along this axis. In the field of a center of gravity, the picture is different. The closer the ray's path to the center, the greater the deviation. This is evident from formula (2) above.

The gravitational lens can not only intensify the image, it can produce two images of a single object. Let's see how.

Figure 2 shows the trajectories of rays passing from a source (point S) to an observer (point O) past a center of gravity (point D). A ray propagating from the source passes the center of gravity at a minimum distance $r = DC$, deviates by an angle α, and proceeds to the point of observation. (For simplification the line is given a sharp bend at point C rather than a rounded one.) The observer sees the source not at point S (in the direction OS) but in the direction of ray OC (on the line OS'). (The angles α, β, and φ in the figure should be taken to be very small.)

How are the parameters assigning the mutual position of the source, gravitating body, and observer interrelated? From figure 2 we see that

$$AS' = AS + SS'.$$

Since the angles α, β, and φ are small (so that $\sin\alpha = \alpha$, $\sin\beta = \beta$, and $\sin\varphi = \varphi$),

$$AS' = L\beta,\ AS = L\varphi,\ SS' = l\alpha.$$

Substituting these three expressions in the first equation we get

$$L\beta = L\varphi + l\alpha.$$

Substituting in formula (2) $r = DC = (L - l)\beta$ and taking this expression into account, let's rewrite the correlation between the distances and angles in the following form:

$$\beta^2 - \varphi\beta - \frac{l}{L}\frac{4GM}{c^2(L-l)} = 0. \qquad (3)$$

This quadratic equation is called the equation of a gravitational lens produced by a center of gravity.

Let's consider the possible solutions of this equation. First of all we'll turn our attention to the case in which the gravitating body lies strictly on the line OS (that is, angle $\varphi = 0$). Then the solution of the equation takes the form

$$\beta = \beta_0 = \pm 2\sqrt{\frac{l}{L}\frac{GM}{c^2(L-l)}}.$$

The picture obviously has axial symmetry, so the observer sees not point S' but a ring obtained by rotating this point about the axis of symmetry OS (or OA, which coincides with it

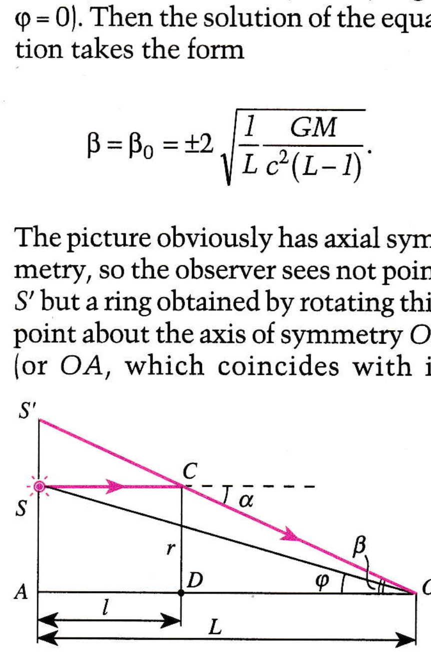


Figure 2
Path of a ray in a gravitational lens.

when $\varphi = 0$); the angular radius of the ring equals $\beta = \beta_0$.

If the center of gravity doesn't lie on the line connecting the source and observation point, the picture lacks axial symmetry. Equation (3) has two solutions when $\varphi \neq 0$:

$$\beta_{1,2} = \frac{1}{2}\varphi \pm \sqrt{\frac{1}{4}\varphi^2 + \frac{l}{L}\frac{4GM}{c^2(L-l)}}.$$

This means the lens produces two images, in the directions determined by the angles β_1 and β_2 (the first positive, the second negative). The path of the corresponding rays is shown in figure 3. The minimum distance from the center of gravity is different for the two solutions:

$$r_1 = (L - l)\beta_1,$$
$$r_2 = (L - l)\beta_2.$$

Obviously the deviation angles are also different for these two solutions.

The hypothesis that twin quasars are two images of a single quasar suggests the mutual placement of the light source, the center of gravity, and the observer given in figure 3. Direct proof could be provided by discovering the center of gravity itself at the necessary place in the celestial sphere: between the two images of the quasar but not at equal distances from them. And that's what happened. The center of gravity turned out to be a dim galaxy situated between the twin quasars and a little closer to one than to the other. The galaxy was about half the distance to the quasars.

Further observations showed that the actual picture was a bit more complicated. It became clear that one of the twin images was in fact two extremely close images that merged on earlier photographs. It's not hard to guess that a triple image can occur if the gravitational field responsible for the deviation is not a point but a voluminous body situated in the line of sight. The galaxy in question is just such a body. Light rays from the quasar can pass not only along its edge but also through it. The gravitating mass, which determines the deviation of the rays, is less for light passing near the center of the galaxy and more for light passing near the edge. The angle of deviation depends on the distribution of mass in the galaxy. The lens equation will now be more complicated than the quadratic equation, and this will produce greater variety in visualizing this phenomenon.

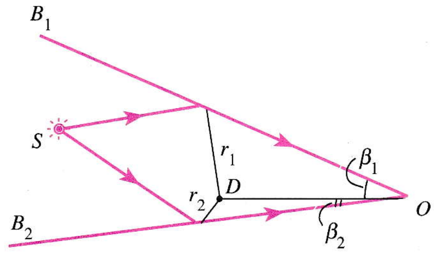


Figure 3
Two images of a single source.

We now know of several examples of double and triple images of cosmic bodies. In each case they are quasars. These mirages, without question, are produced by gravitational lenses.

But why do gravitational lenses work with quasars and not with light from stars or galaxies? Because quasars, as was mentioned above, are visible from a great distance—from much greater distances on average than galaxies, not to speak of stars. So the likelihood that light from them will meet a massive (but dim) object on the way to the observer is quite great. In addition, the quasar is visually very small—practically a point source; it can produce several individual images that don't blur and don't blend together, which isn't the case with more extensive sources such as galaxies.

Faster than light?

The very first quasar discovered was a source of radio waves. It was registered as No. 273 in the third *Cambridge Catalogue*.[1] This is the "ideal" quasar, so to speak. It has all the typical properties of quasars and is also convenient to observe. In its very center, where the radiation originates, some sort of violent processes occur that manifest themselves in changes in brightness. In addition, luminous clouds and streams of matter burst out of this inner region from time to time. Once a stream appeared that grew "right in front of everyone's eyes," and the bright spot at its tip raced away from the quasar's center. After four years the stream's bright jet tail had moved away from the center to a distance of 20 light-years. How fast was it moving? Dividing distance by time, we get a speed five times the speed of light.

[1]A mammoth list of celestial objects compiled by the radio astronomers at Cambridge University, England.

You can imagine how baffled the astronomers were. According to the theory of relativity no body can move at a speed greater than the speed of light in a vacuum. This is one of the most important physical laws. After their initial surprise and even confusion, scientists found the solution to this paradox, at least in principle. The speed greater than the speed of light was a cosmic optical illusion.

Here's the simplest possible example of how the illusion of motion faster than the speed of light can arise.

Let's imagine a lamp moving toward us at some angle ϑ relative to our line of sight (fig. 4). At the outset our lamp is turned off, then it's turned on twice at points S_1 and S_2 and sends two light signals to us. In the time between these two acts of switching the lamp on, the light source has traveled along the path S_1S_2 in the figure. The displacement visible to us is less: it's the projection S_1S' of this path. (Having fixed the source at point S_1, the observer projects further motion from point O

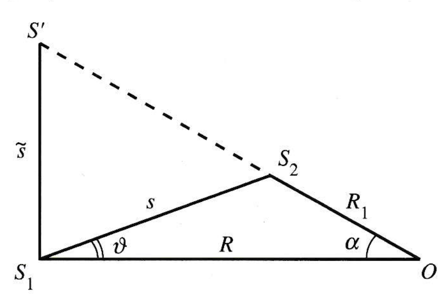


Figure 4
Example of illusory motion at a velocity greater than the speed of light.

onto the plane perpendicular to the line of sight OS_1.) How did the astronomers obtain their estimations of the speed? They divided the visible displacement (the segment S_1S') by the time between detection of the first and second signals. That's just it—they used the time between the moments they detected the signals, not the time between the moments they were emitted. These are different periods of time! The difference is caused by the Doppler effect, as was mentioned earlier.

Actually, the relation (1) between the periods T and T_0 of the light wave is more general in nature. It can also be used for processes that aren't periodic. The period T_0 is the time interval between, say, two adjacent maxima in an emitted wave; T is the time interval between these same maxima when they are recorded one after another by an observer. Each of the maxima can, of course, be considered a "signal," so that T_0 is the time interval between two signal emissions, and T is the interval between the times they are received.

When a light source moves in our direction, T is less than T_0. This means that in our example with the lamp the interval between the times of signal reception is smaller than the interval between the times of signal emission. If the object's speed is close to the speed of light (but, of course, not greater), the difference between these times may be arbitrarily large.[2]

In calculating the visible rate of displacement we lose, so to speak, in distance (S_1S' is less than S_1S_2—see figure 4) but we may gain a great deal in time. This is what causes the frighteningly large ratio of visible displacement to the interval between signal reception times; this ratio is what we had considered the velocity of the light source. A "visible" speed of this sort can certainly be greater than the speed of light. But the actual rate of displacement is the ratio of the distance traveled S_1S_2 to the interval between signal emission (not reception!) times. It may be close to the speed of light, but it can never exceed it. It works out that we can't calculate the velocity by dividing the distance traveled "there" by the time interval measured "here." This is precisely what the theory of relativity teaches us. And the Doppler effect, which gave us the solution to the paradox, is a direct consequence of the theory of relativity.

The birth of an illusion

The crux of the theory of relativity is the statement that light in a vacuum propagates at a definite, finite velocity that doesn't depend on whether the light source is moving or at rest relative to us. We'll use this fact now to directly obtain formulas that describe our example of the moving lamp. (I should add that we'll be talking about propagation of light in a vacuum with no strong gravitational fields in its path. We've seen that gravitational fields can bend the trajectory of light, but they can also change its speed. If there aren't any massive gravitating bodies between the source and us, the speed of light is c; we'll consider this to be the case.)

Let the first signal be emitted by the lamp at some moment $t = 0$, which we'll select as the beginning of our time count. The distance from us (the observer) to the light source at this moment is R, so the signal will be detected at $t_0 = R/c$.

Further, let the second signal be emitted at time $t_1 = s/v$, when the body, moving in a straight line at speed v, has covered the distance $s = S_1S_2$ (see figure 4). At time t_1 the distance to the source is

$$R_1 = \frac{R - s\cos\vartheta}{\cos\alpha} \cong R - s\cos\vartheta.$$

(We've taken into account that α is small, since the distances R and R_1 are much greater than s, and so $\cos\alpha \cong 1$). The second signal will reach us after the time

$$\frac{R_1}{c} = \frac{1}{c}(R - s\cos\vartheta)$$

and will be recorded at moment

$$t_2 = t_1 + \frac{R_1}{c} = \frac{s}{v} + \frac{R}{c} - \frac{s}{c}\cos\vartheta.$$

The interval between the moments at which our two signals are detected is

$$\Delta t = t_2 - t_0 = \frac{s}{v}\left(1 - \frac{v}{c}\cos\vartheta\right).$$

We can express the distance s traveled by the lamp as

$$s = \frac{v \cdot \Delta t}{1 - \frac{v}{c}\cos\vartheta}.$$

The visible displacement $\tilde{s}$ of the body is depicted as the projection of the segment s perpendicular to the line of sight:

$$\tilde{s} = s\sin\vartheta = \frac{v\sin\vartheta}{1 - \frac{v}{c}\cos\vartheta}\Delta t.$$

(Again we took into account that α is very small.) To find the "visible" velocity $\tilde{v}$ we have to divide the visible displacement $\tilde{s}$ by the time interval Δt:

$$\tilde{v} = \frac{\tilde{s}}{\Delta t} = \frac{v\sin\vartheta}{1 - \frac{v}{c}\cos\vartheta}.$$

Let's assume that $v = 0.8c$ and $\cos\vartheta = 0.8$; then $\sin\vartheta = 0.6$ and $\tilde{v} = (4/3)c$. When the actual rate of displacement of the source is high (but still below the speed of light), the visible speed exceeds the speed of light!

We can verify (as one does when finding the extremum of a function) that at a given velocity v of the source, the visible velocity has the maximum value when

$$\cos\vartheta = \cos\vartheta_0 = \frac{v}{c}.$$

[2] If you know how to compute limits, it's not hard to convince yourself that $T/T_0 \to 0$ as $v/c \to 1$.

Then

$$\sin\vartheta_0 = \sqrt{1-\frac{v^2}{c^2}},$$

and the maximum visible speed is

$$\tilde{v}_{max} = \frac{v}{\sqrt{1-\frac{v^2}{c^2}}}.$$

The speed $\tilde{v}_{max}$ approaches infinity as the actual speed of travel v approaches the speed of light c.

To complete our consideration, all that remains is to compare two values: the interval between signal emission times

$$(\Delta t)_0 = t_1 = \frac{s}{v}$$

and the interval between detection times

$$\Delta t = \frac{s}{v}\left(1-\frac{v}{c}\cos\vartheta\right).$$

Maybe the question will pop up: why didn't the ratio $(\Delta t)_0/\Delta t$ coincide with the ratio T_0/T from formula (1)? And where did the factor $\sqrt{1-(v/c)^2}$ go? The point is, this factor (which is called the relativistic root and appears in almost all formulas in the theory of relativity) is linked with a subtle effect that we can't adequately cover in our simple calculation. After all, we didn't apply the theory of relativity in all its glory, we just made use of the fact that the speed of light is finite. We might say our calculations were approximations in which we ignored all terms in $v/c < 1$ higher than the first. The formula for the Doppler effect, however, is an exact result of the theory of relativity.

I hope you've come to understand how illusory motion at speeds greater than the speed of light can arise. But the example of the lamp that we looked at isn't the only conceivable possibility. Here's another situation that you can figure out on your own. Let there be some band or strip perpendicular to the line of sight and at some moment all of it suddenly flashes. What will the observer see?

You might also consider not a band but a sphere that flashes. This could be the shell of a quasar illuminated by its inner source. In this case, the increase in the size of the flashing spot occurs at velocities greater than the speed of light. It's easy to imagine other models of this sort.

It's much more difficult to explain the true nature of the powerful explosions, flashes, and ejections that create the illusion of motion at speeds greater than the speed of light. This is a topic for further study. ◘

"CHALLENGES"
CONTINUED FROM PAGE 23

P43

Lots of voltmeters. All the voltmeters in figure 3 are identical. The emf of the battery $\varepsilon = 5$ V, its internal resistance is low. The upper voltmeter reads $V_1 = 2$ V. What are the readings of the other voltmeters? (A. Zilberman)

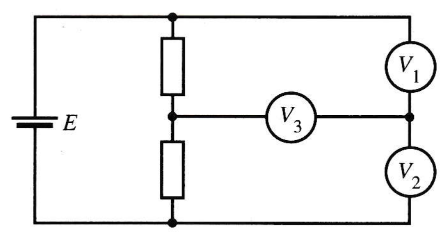


Figure 3

P44

Lunar radiolocation. In radiolocating the Moon rising above the horizon, a high-frequency radio signal emitter was coupled with an optical telescope to guarantee the correct direction. When there was an optical image of the Moon, however, no radio signal was reflected. And when a reflected radio signal was obtained, there was no optical image. Can you explain this phenomenon? (A. Zilberman)

P45

Under light pressure. How does light pressure orient a spacecraft relative to the Sun if one half of its surface is reflective and the other half is black and absorbs the Sun's radiation completely? The spacecraft's center of gravity is at the center of a sphere.

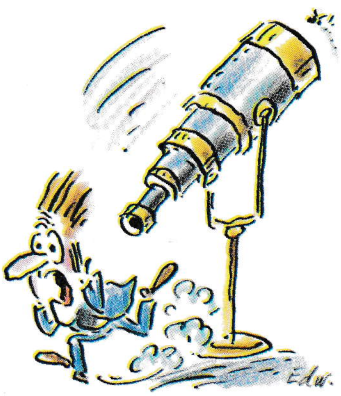
ANSWERS, HINTS & SOLUTIONS
ON PAGE 79

BRAINTEASERS

Just for the fun of it!

B41

Mystery of the stars. The moons in the accompanying number rebus denote one and the same digit. This scanty information is enough to uniquely restore all the figures represented by the stars, which denote different digits. Try to do it. (V. Denisenko).



B42

Look through the telescope. A fly has gotten onto the lens of a telescope. What will an observer looking through the telescope see? (V. Surdin)

B43

Enlightening eclipse. A girl watched a solar eclipse with her father.

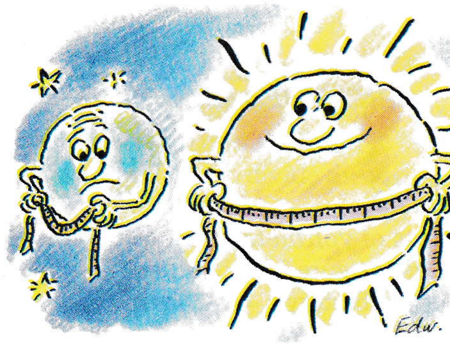
"Daddy, how much further away from us is the Sun than the Moon?"

"As far as I remember, 387 times further."

"Then I can figure out how much greater the Sun is in volume than the Moon."

Her father thought a bit and said, "I think maybe you can."

So what is the ratio of the volumes of the two heavenly bodies? (A. Kozlov)

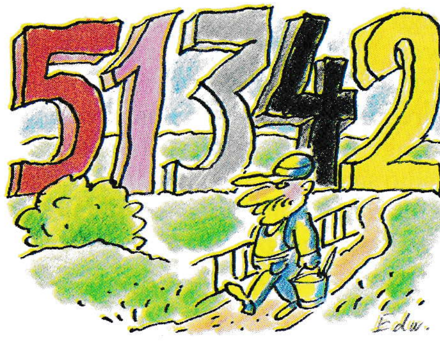


B44

Writing home. Can astronauts use a ballpoint pen on board a spacecraft? What about a fountain pen? What design would you recommend for a "space pen"? (A. Buzdin)

B45

Color-coded number-word. Decipher the word written in colored figures. (By the way, the painter insists the first color is "crimson," not "red.") (V. Dubrovsky, A. Shevtsov)



Art by Edward Nazarov

ANSWERS, HINTS & SOLUTIONS ON PAGE 82

MATH INVESTIGATIONS

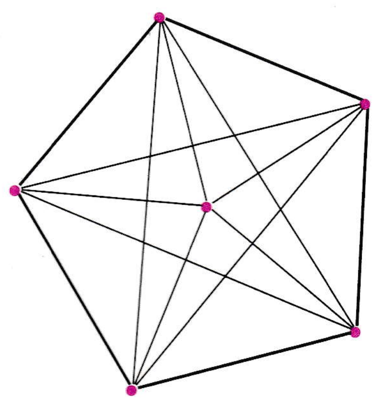
Restricted distances

Once again, let's go "off into space"

by George Berzsenyi

IN PROBLEM 4/3/2 OF THE USAMTS, featured in issue 37 of *Consortium*, students were asked to "show that for $n = 3, 4, 5$, and 6, it is possible to arrange n points in the plane so that any choice of three of these points forms the set of vertices of an isosceles triangle." You may wish to resolve this problem before reading further.

It turns out that for $n = 6$, the arrangement shown in the illustration is unique—that is, the points must be the vertices of a regular pentagon along with its center. Moreover, since it is easy to see that one can't add a seventh point to this configuration and still retain the desired property (of all triangles being isosceles), it follows that for n 7, there is no such arrangement in the plane. The proof of this fact was the objective of problem 36 of the 1967 Russian edition of volume 2 of *Selected Problems and Theorems in Elementary Mathematics*, which, unfortunately, was never translated into English. Neither was the third volume on solid geometry; and while at one time there were two different translations of the first volume (*The USSR Problem Book*, a translation of the third Russian edition, and *Selected Problems and Theorems in Elementary Mathematics—Arithmetic and Algebra*, a translation published by



Mir Publishers in 1979), at present both of these are out of print.

En route to solving the original Russian problem, you may wish to start by showing that if three of the points form the vertices of an equilateral triangle, then at most one point can be added so that all the triangles formed by the points as vertices are isosceles. This little fact turns out to be useful in proving the uniqueness of the arrangement for $n = 6$.

The main purpose of this article is to suggest to the reader the extension of the above problems to three dimensions. Surely, with the extra freedom given by the third dimension, it should be possible to arrange 7, 8, and maybe even 9 points so that each threesome yields an isosceles triangle!

A somewhat related question, which was problem 35 in the Russian source cited above, asks for the arrangement of n points so that the distances between pairs of them take on only two distinct values. This time one finds that in the plane, n must be 3, 4, or 5. But what happens if we allow the points to be in space? What if we allow three, or even more generally, k distinct values for the distances? While some of these questions have already been considered by various mathematicians, much more work is needed to settle them satisfactorily.

Adventures among P_t-sets

I was glad that several of my readers joined me in my "adventures among P_t-sets" (March/April 1991). My former coauthor, Vamsi Mootha, found that {5, 12, 45} is a P_t-set for $t = -56$, 136, and 616, while my most faithful reader, Brian Platt, went on to answer most of my challenges. He also found a set that is a P_t-set for three different values of t and made an extensive computer search for P_t-sets of five elements. Such sets were also found by Dr. Helmut Müller, a German mathematician, whose list consists of 27 quintuples with t in the range $-1{,}903 < t < 1{,}989$. Brian Platt's list is more extensive; it consists of 118 quintuples, but his t's are re-

CONTINUED ON PAGE 37

The purpose of this column is to direct the attention of *Quantum*'s readers to interesting problems in the literature that deserve to be generalized and could lead to independent research and/or science projects in mathematics. Students who succeed in unraveling the phenomena presented are encouraged to communicate their results to the author either directly or through *Quantum*, which will distribute among them valuable book prizes and/or free subscriptions.

PHYSICS CONTEST

What goes up . . .

"Whether this agent [of gravity] be material or immaterial, I have left to the consideration of my readers."
—Isaac Newton

by Arthur Eisenkraft and Larry D. Kirkpatrick

EVERY SCHOOL-AGE KID HAS heard the prediction "What goes up must come down." Many kids challenge it with a question relating to helium balloons. Some kids, many of whom now read *Quantum*, have wondered what would happen if that object thrown up was going terrifically fast. Would it still come down?

The first step that a physicist will take in analyzing what happens to an object thrown straight up at a high speed is to analyze what happens if it is thrown at a low speed. The object goes up, reaches a peak, and descends. If we increase the throwing speed, the object goes higher, stays in the air longer, and then returns to the ground.

Now we have to refine this description. One way to do that is to quantify it. We owe our ability to write these motion equations to Galileo Galilei. Galileo was the first person to make measurements of an object's motion and record them. He was also the first person to describe this rising and falling object in a mathematical language. What Galileo found, and you can also discover, is that the falling object changes its speed. When the object descends it goes faster and faster. Well, everybody knows that.

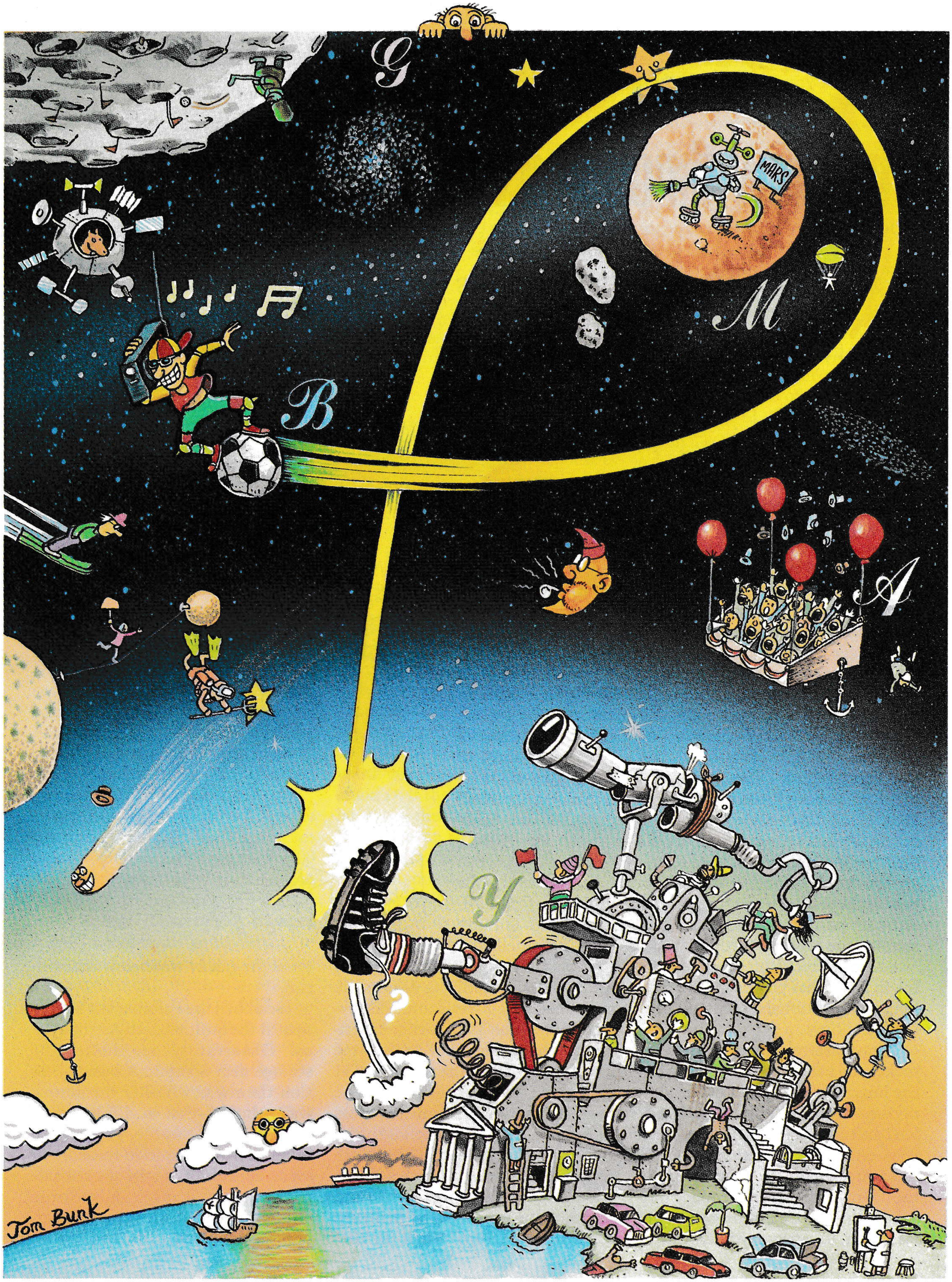
But not everybody knows this: if I look at the object every 2 meters, does its speed change by the same amount? Specifically, if the speed increases to 6 m/s in the first 2 meters, will it increase to 12 m/s in the next 2 meters? The answer is no. So, how about this: if I look at the object every 2 seconds, does its speed change by the same amount? The answer is yes. Galileo defined this change in speed for every unit of time as the acceleration of an object. Cars accelerate when they change their speed. A runner changes her speed as she races. An object accelerates when it's dropped. What's special about the falling object is that the acceleration is a constant. Very close to our Earth, an object falling will change its speed by 9.8 m/s each and every second. It's very hard for a car to have a constant acceleration. It's almost impossible for a human to have a constant acceleration. But every object dropped close to the Earth (and not appreciably affected by the air—no feathers, please) has a perfectly constant acceleration of 9.8 m/s every second.

This acceleration of 9.8 m/s every second works on the way up as well as on the way down. If you throw a ball up at 50 m/s (that's about 100 miles per hour), its speed will be only 40 m/s after the first second (it's really 40.2 m/s but we're going to use the approximation of 10 m/s every second instead of 9.8 m/s every second because we can subtract 10 faster than we can subtract 9.8). After the second second its speed is only 30 m/s; after the third second, 20 m/s; after the fourth second, 10 m/s; and after the fifth second, its speed is 0 m/s. Zero m/s is not moving at all. The ball is stopped in midair. In the sixth second, its speed still decreases by 10 m/s, so its new speed will be –10 m/s. The minus sign is the mathematical way of informing us that the ball is moving down.

From this simple analysis we should conclude that all objects that go up must come down. No matter what speed the ball starts with, it will eventually reach 0 m/s and start heading down. Oh, but that's only if the acceleration is constant at 9.8 m/s every second. Galileo found this to be true *near* the Earth. It's not true as we move far enough away from the Earth. As an object moves farther and farther from the Earth, the acceleration toward the Earth gets smaller and smaller. The acceleration of the Moon toward the Earth is only 0.0027 m/s every second. That's just the acceleration needed for the Moon to stay in a fixed orbit about the Earth. In this case, the change of 0.0027 m/s every second isn't a change in speed but a change in the direction of the velocity. If the Moon had no change in velocity, it would continue traveling on a straight path away from the Earth. The change in velocity keeps the Moon in orbit about the Earth. Pick up a physics textbook for a more complete (and mathematical) treatment of this.

CONTINUED ON PAGE 37

Art by Tomas Bunk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Tom Bunk

The view through a bamboo screen

From moiré patterns to black holes

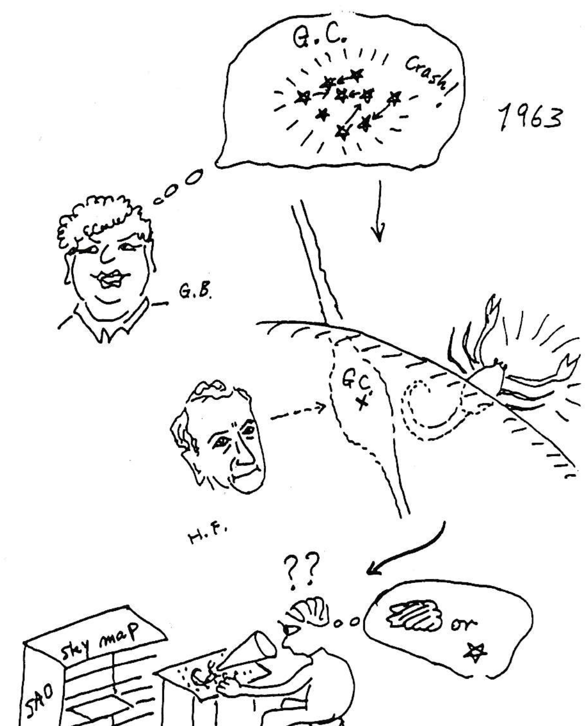
by Minoru Oda

HAVE YOU EVER NOTICED A strange shimmering pattern when you look through two lace curtains blowing gently at an open window, one behind the other? Or two sets of bamboo blinds? Or two handrails? What you're seeing is a *moiré pattern*, which arises when two geometrically regular patterns are superimposed, especially at an acute angle.

This charming effect pops up sometimes in unwanted places. For instance, when printing in color, four plates are used to layer varying amounts of black, cyan (blue), magenta, and yellow. On each plate the picture has been broken down into dots, which form geometric patterns. If a printer isn't careful to adjust the placement of the screen used to create the dots, a moiré pattern can appear in the picture when the four patterns are printed one atop the other, spoiling the finished product.

But this effect isn't always harmful. In fact, it has proven quite useful in the observational techniques of X-ray astronomy.

X-ray astronomy began with rocket and balloon observations after the initial discovery of a celestial X-ray source in 1962 by Bruno Rossi, Riccardo Giacconi, and their colleagues. Since X rays are absorbed by the atmosphere, our observation of the "X-ray sky" has to be made outside of the Earth's atmosphere, or at least from its upper layer.

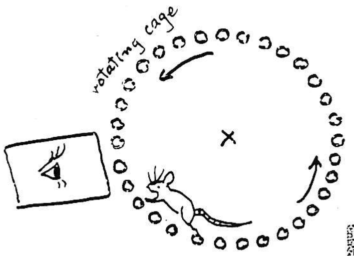


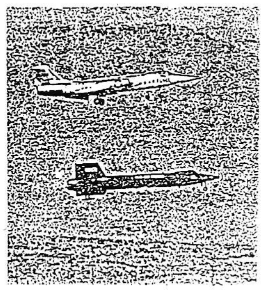
Art by Minoru Oda

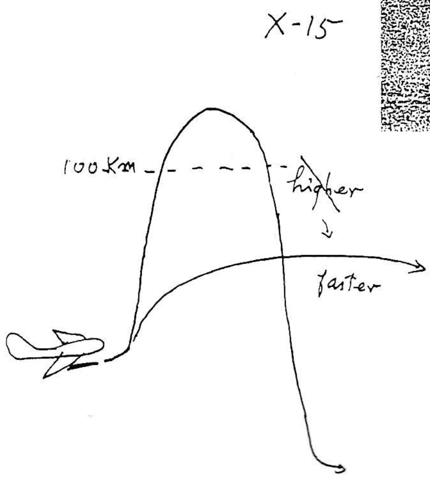
I was lucky then to be with Rossi's group at the Massachusetts Institute of Technology and near Giacconi and his associates at American Science and Engineering, Inc. (AS&E).

I recall that, when Geoff Burbidge of the University of California and Tommy Gold of Cornell University visited MIT, Bruno Rossi called a small meeting to discuss the bright celestial X-ray source discovered in the June 1962 rocket experiment. What could it be? At the time it was thought that the source was at or near the center of our galaxy. The theorists shot out a number of ideas to explain X-ray production in the center of the galaxy. Then Herb Friedman and his colleagues at the Naval Research Laboratory found that the source was still bright in the constellation Scorpio when the center of the galaxy was below the horizon.

I searched the Palomar sky survey map at the Smithsonian Astrophysical Observatory for something strange near Scorpio. A basic question then was whether the source was nebular—that is, diffuse—or a starlike point source. We needed some new technique to measure or set an upper limit on the angular size of the source. Lenses and mirrors can't be used for X rays except in certain special cases.







Mouse cage or bamboo screen?

I got the idea of looking at the source through a rotating "mouse cage": if the source was compact, the flow of X rays reaching the detector would be modulated by the rotation of the cage; if it was nebular, the transmitted flow would be steady.

It was suggested that we fly the instrument on NASA's X-15 rocket plane, which was set to go above 100 km. We negotiated with NASA to use the X-15 and built the instrument at MIT. Then NASA changed its flight plan from "going higher" to "going faster," so we had to abandon the experiment. Ironically, shortly thereafter George Clark of MIT demonstrated in a 1964 balloon experiment that the Crab Nebula is observable at 35 km—much lower than the 100 km we thought we had to reach!

Riccardo Giacconi, who was then preparing another rocket experiment at AS&E, kindly offered a flat space in front of the X-ray detector in the rocket's instrument bay. We changed the design of the modulation collimator[1] from a mouse cage to flat layers of parallel grids, which Rossi jokingly called the "Japanese bamboo screen collimator."

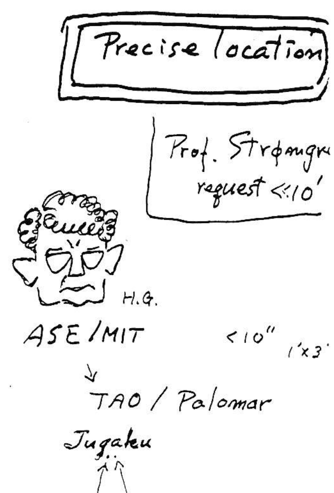
The collimator consists of two or more wire grids. The shadow of the front grid is cast on the rear grid. If the source is pointlike, it casts a sharp shadow, and the angular response of the multigrid collimator gives almost equally spaced parallel bands of transmission. The half-width of each band is equal to d/D radians, where d is the diameter of the wire and D is the distance between the two grids at both ends. When we look at a bright background through superimposed grids, we see a moiré pattern with a fringe width determined by d and D. If the angular size of the distant X-ray source is less than d/D radians, the transmission of the X-ray flux is modulated, as is expected from the angular response when the source traverses the field of view at approximately constant speed. On the other hand, if the source is diffuse, its shadow is diffuse, and the modulation is distorted or diminishes.

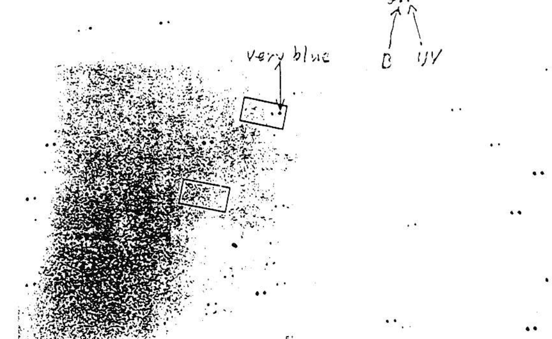
So the size or structure of the source can be determined to a precision of, say, d/D. The payload was flown aboard a sounding rocket, and the X-ray flux passing through the grid structure was found to have been modulated because of the rotation and wobble of the rocket, as expected for a source whose angular diameter is less than 10 arc-minutes. This placed a new and interesting upper limit on its size—that is, the X-ray source was starlike.

The modulation collimator, which was originally developed to estimate the angular size of the source, has become more widely used for other purposes: precisely locating a source, searching for new sources in a broad expanse of sky, and generating images of the sources.

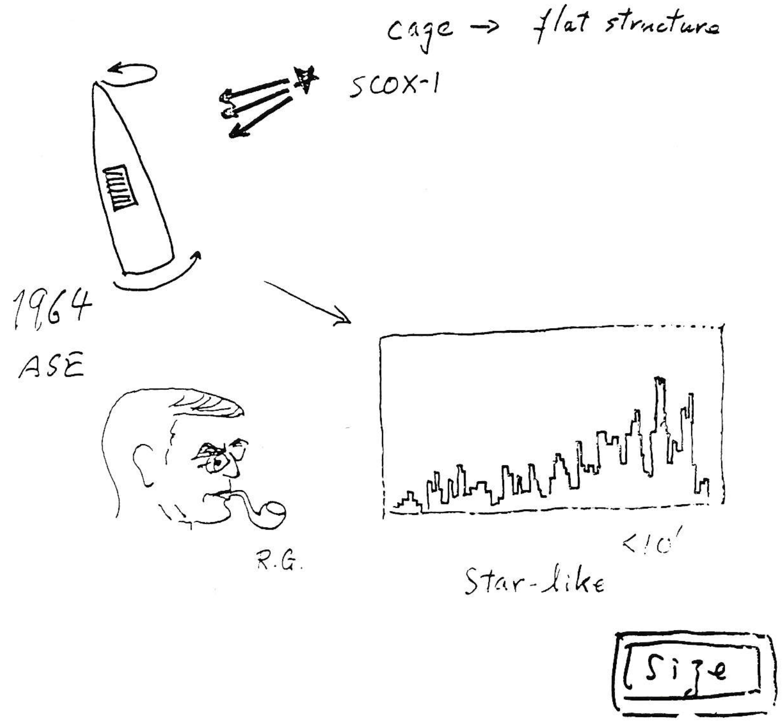
Locating Sco X-1 and its optical counterpart

I asked Professor Stroemgren, an eminent Danish astronomer who was then a visiting professor at MIT, the following question: How precisely must we locate an object to attract the interest of optical astronomers in undertaking a search for its optical counterpart? His answer: 10 arc-minutes. Then Herb Gursky of AS&E and I designed a rocket experi-





[1]A collimator is used to produce a parallel beam of radiation.—*Ed.*



ment to measure the position of Sco X-1, which was the first X-ray source discovered and the strongest, with this precision. (The name Sco X-1 is decoded as "the first X-ray source discovered in the constellation Scorpio.") The MIT/AS&E group constructed another modulation collimator. The rocket was launched from White Sands, New Mexico, in March 1966. Even during the flight, from real-time telemetry, Gursky could tell from the sharp modulations of the X-ray counting rate that the source is smaller than 10 arc-seconds.

The data analysis led to a location within two small possible areas with a total area of 4 square arc-minutes. Tokyo Astronomical Observatory and Palomar Observatory were prepared to search for the sky region and found an unusually blue star, which was proven to be in one of the areas identified earlier. This was the first optical identification of an X-ray source. Alan Sandage used the optical telescope at Palomar (the world's largest at the time) to make comprehensive photometric observations of this remarkable star.

Cyg X-1 as a black hole candidate

One virtue of the modulation collimator is that it combines the seemingly conflicting requirements of a position survey device: a wide field of view and pinpoint accuracy. With it one can survey a large area of the X-ray sky for transient sources as if hunting for a prairie dog that unexpectedly pop its head out of one of its innumerable burrows.

From 1970 to 1971 an unofficial contest was held to determine the precise location of Cyg X-1 (the brightest X-ray source in the constellation Cygnus) among (1) balloon and rocket observations with modulation collimators by Japan's Institute of Space and Astronautical Science (ISAS) and MIT, (2) slat collimator observations with the Uhuru satellite (America's first X-ray astronomy satellite), and (3) a rocket experiment by the Lawrence Radiation Laboratory. All the results were published or quoted in the same issue of *Astrophysical Journal Letters*. And all the results led to a bright blue supergiant star.

Subsequent analysis of the Doppler variation of the wavelengths of this star's spectral lines led Charles Thomas Bolton in 1972 to the conclusion that it was the companion of a massive black hole in a binary system—the first identification of an X-ray source as a binary system.

The rotating modulation collimator on MIT's X-ray astronomy satellite SAS 3 and the scanning modulation collimator on NASA's giant X-ray astronomy observatory HEAO-1 generated long lists of precise locations that have led to numerous identifications of optical counterparts of X-ray sources inside and outside our galaxy.

Creating images of solar flares

The concept of generating an image of an X-ray source with a modulation collimator emerged from the intention of producing hard X-ray[2] images of solar flares in the solar maximum period that occurs every twelve years or so. The mathematical techniques developed were similar to those developed independently for medical CAT scans.

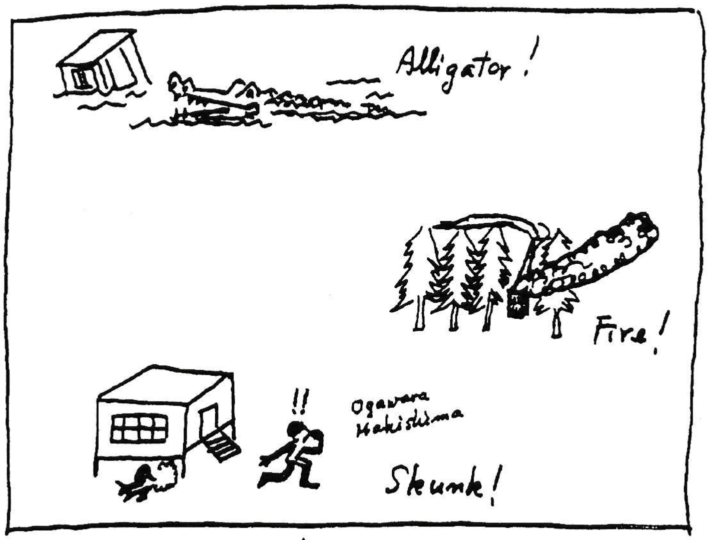
Preliminary imaging of hard solar flares was achieved with a balloon flight in 1970 near the end of the solar maximum. The rotating imaging modulation collimator on the solar physics satellite Hintori (named after a legendary Japanese phoenix and firebird), launched in 1981, produced a number of images of hard X-ray flares. Some looked like flying dragons on the solar disk, and some exhibited double fireballs far above the Sun's rim.

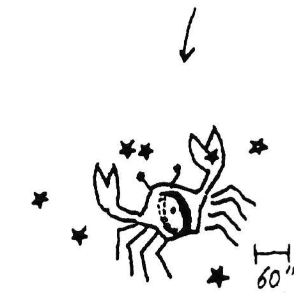
To carry out studies during the latest solar maximum period, which began a few years ago, the satellite Solar-A (renamed Yohkoh, which means "sunshine" in Japanese) was launched on August 19, 1991, with the collaboration of physicists in the US, United Kingdom, and Japan. A new design was adopted for the imaging collimator in this satellite. The idea behind the Fourier transform telescope, as might be gathered from its name, is to synthesize the images generated by a number of elementary collimators with a variety of modulation pitches and angular orientations.

[2]"Hard" X rays have short wavelengths and are more capable of penetrating matter than "soft" X rays, which have long wavelengths.

Imaging the Crab Nebula

I'll leave you with one last account of an interesting imaging experiment: the balloon observation of the Crab Nebula that was conducted at Palestine, Texas, in 1974–78 in a collaboration between ISAS and the University of California at San Diego. The balloons carried huge modulation collimators with angular resolutions of arc-seconds. The project was an ongoing tragicomedy. The first flight failed, but the instrument was recovered. The second flight failed and the payload landed in an alligator-infested swamp where the instrument was ruined by water. The third failed too, and this time the payload landed in the treetops, where it mysteriously caught fire by the next morning.





Beneath the floor of the trailer where the scientists stayed in Palestine, awaiting the fifth and finally successful flight, lived a skunk. It chose to set up housekeeping right next to the inlet for the air conditioner. The hapless scientists had to flee the place for a week.

One of the graduate students who took part in the Palestine experiments wrote a dissertation about it. I like to call it the New Testament of the Crab Nebula (Woltjer's well-known classic paper of 1957 being the Old Testament).

Minoru Oda *is president of RIKEN (The Institute of Physical and Chemical Research) in Japan and professor emeritus at the University of Tokyo and the National Institute of Space and Aeronautical Science (ISAS). He is a member of the Japan Academy and an associate of the Royal Astronomical Society. Dr. Oda has won numerous international awards and prizes, including the Japan Academy Award (Emperor's Award) for his work on the modulation collimator.*

"WHAT GOES UP..." CONTINUED FROM PAGE 32

If the acceleration decreases as we increase the distance from the Earth, then there is a possibility that the resulting decreases in speed will never slow the object down to zero. That means that the object will never return to the Earth. The object escapes! The speed that an object needs to escape from the Earth can be derived most simply by using the conservation of energy.

The more challenging Contest problems that follow are taken from the 1985 International Physics Olympiad, which was held in Portoroz, Yugoslavia. To simplify the problems, assume that all the planets revolve in circles about the Sun. Neglect air resistance and the rotation of the Earth on its axis. In parts B–D, neglect the energy used in escaping from the Earth's gravitational field. Assume that the orbital velocity of the Earth is 30 km/s and that the ratio of the distances of the Earth and Mars from the Sun is 2/3.

A. For our beginning physics students, derive the equations and values for the velocity required for a satellite to escape from the Earth.

B. For those of you who wish to attempt a bit more, derive the equations and values for the minimum velocity required for a satellite launched from the Earth to escape the solar system.

C. For our more advanced readers, suppose that the satellite has been launched with a velocity less than this escape velocity. Determine the velocity of the satellite when it crosses the orbit of Mars. Assume that Mars is not near the point of crossing.

D. Finally, let the satellite enter the gravitational field of Mars. Find the minimum velocity needed for the satellite to be launched from the Earth and escape from the solar system using the gravitational field of Mars. (This is often described as using Mars as a "slingshot.")

Send your answers to *Quantum*, 3140 North Washington Boulevard, 2nd Floor, Arlington VA 22201. If you're a student, please indicate your grade.

We'll comment on submissions in response to earlier Contest problems in subsequent issues.

"ADVENTURES IN P_t-SETS" CONTINUED FROM PAGE 31

stricted to perfect squares. It seems there is a greater abundance of P_t-sets of five members when t is the square of an integer.

I was also glad to hear several times from Kiran Kedlaya, who is probably the best mathematician among high school students in the US today. Kiran's findings will, I hope, be the subject of a separate article in *Quantum*. He attacked the problem from a more theoretical viewpoint and has already found a multitude of insightful results about P_t-sets in general.

As always, I am most appreciative of my readers' reactions and look forward to hearing from many more of you.

Catch as catch can

The history of the theory of gravitational capture

by Y. Osipov

HOW WAS OUR SOLAR system formed? It seems this question has occupied the minds of scientists ever since it became clear how the Sun, Earth, and other planets were situated in the expanses of space. The ancients believed the Earth to be the central figure in that space community. But the true picture turned out to be different: the planets, among them the Earth, revolve around the Sun in orbits close to circular and lying almost in the same plane. So how did this ring dance start?

In 1796 the French mathematician Pierre Simon Laplace put forth his famous cosmogonic hypothesis to answer this question. Laplace believed that the solar system was formed out of a revolving gas nebula. Forces of attraction acting among the gas particles caused the nebula to be compressed and, according to the law of conservation of angular momentum, to revolve with ever greater velocity. At a certain point the force attracting the particles at the equator of the revolving mass toward its center became equal to the centrifugal force of inertia, and the orbits of these particles stopped becoming narrower; the other particles, though, continued to approach the center. The nebula flattened to a plane perpendicular to the axis of its revolution. According to Laplace the nebula then divided itself into a central clump, out of which the Sun was formed afterwards, and outlying rings, which later turned into the planets.

P. S. Laplace (1749–1827), the great French mathematician and astronomer who proposed the hypothesis of gravitational capture.

Laplace's hypothesis explains the concentric character of the planetary orbits very well. But not only planets take part in the near-Sun ring dance. Comets move along with them around our luminary. Many of the comets have orbits that are far from circular—they look rather like elongated ellipses; what is particularly interesting is that the ellipses don't lie in the plane of planetary orbits but are oriented rather chaotically. How can we explain such disharmony?

In 1770 astronomers observed a comet, which was named after the Finnish-born astronomer Anders Jean Lexell. But while awaiting its next appearance they couldn't find it in the predicted sector of the sky. It turned out Jupiter was to blame: Lexell's Comet was knocked out of its orbit by the powerful pull of the giant planet when it passed nearby.

And so, faced with the need to insert the comets into the picture of the solar system's origin, Laplace brought forth a bold proposition: among the bodies forming the solar system there were not only the Sun's "natural children" but also "adopted children"—comets, those visitors from outer space. Comets that passed near a large planet while zipping through the solar system changed their orbit sharply, as did Lexell's Comet, and exchanged their prior path, out into infinity, for elliptical near-Sun orbits.

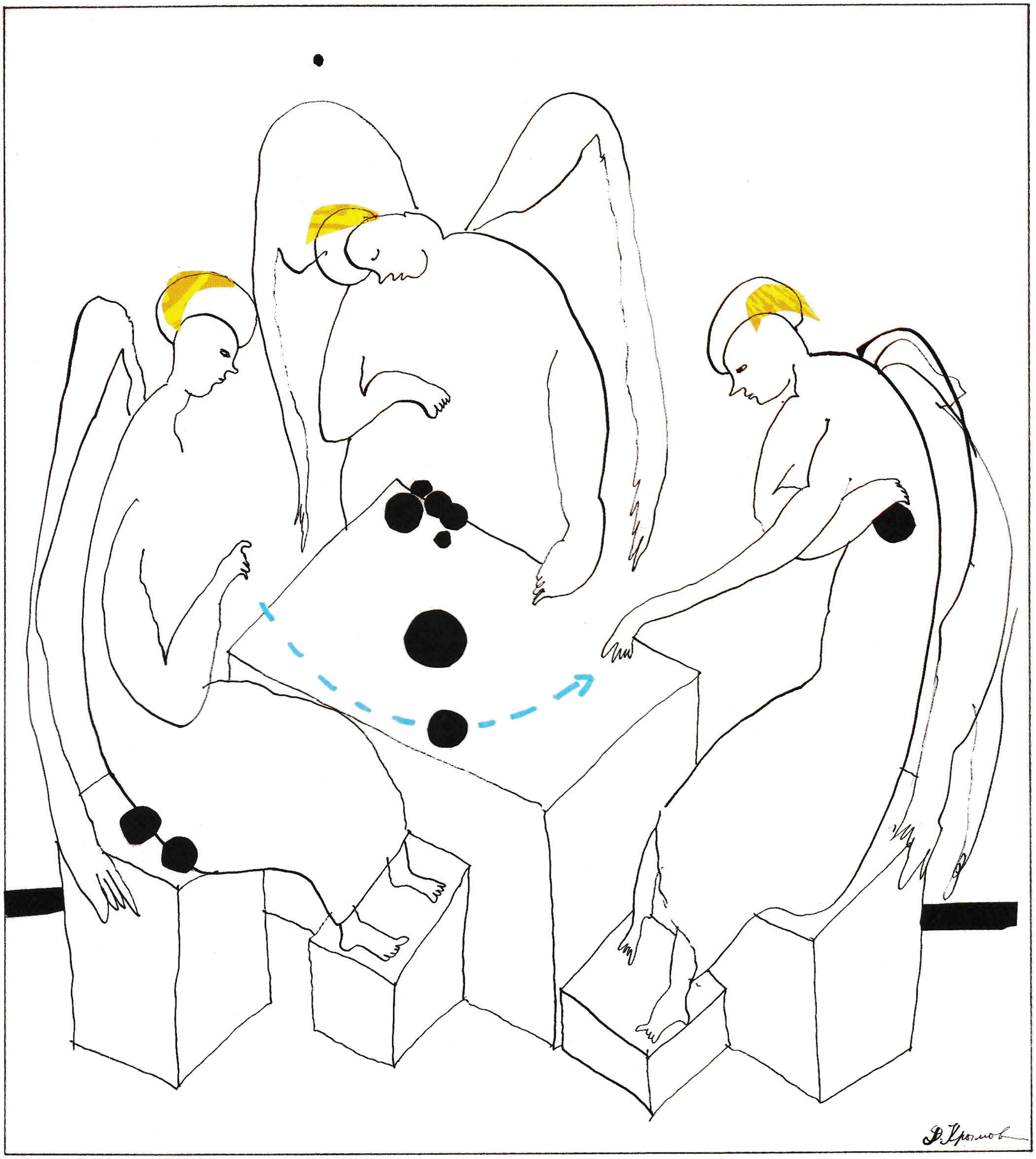
True, Laplace didn't prove his theory, apparently relying on its self-evident plausibility. This combination of plausibility and the absence of proof destined the hypothesis of gravitational capture to a hard lot in the history of science.

Some scientists, believing that the hypothesis would be firmly substantiated in the future, gave it a primary role in their deliberations on the origin of the solar system. Others were skeptical and did their best to refute it.

And the skeptics had good reason for their disbelief. Even the simplest examples of gravitational interaction aroused doubts.

Two-body problem

The simplest system of celestial bodies moving because of mutual attraction obviously consists of only two bodies. In studying the possibil-



Art by Dmitry Krymov

ity that one of them might capture the other through its force of attraction and make it revolve around itself, it's only natural to assume that the "capturing" body is extremely massive and the "captured" body is extremely light.

Let's agree to ignore the case in which the attracted body falls onto the attracting one. In other words, we'll assume the motion never ends and we can follow it forward and backward in time as far as we want.

To study this motion, let's use Newton's well-known formula for the force of gravitational interaction between two bodies of mass m_1 and m_2 that are a distance r apart:

$$F = \gamma \frac{m_1 m_2}{r^2}.$$

Since the mass of one body is assumed to be much greater than that of the other, it's natural to consider the more massive body (let's call it the Sun) fixed and to set the origin of the coordinate system at its center. Then r in the denominator of Newton's formula is the length of the vector drawn from the origin to the moving body (let's call it a comet).

Newton's formula gives the value

of the force attracting the comet to the Sun and consequently the acceleration of the comet. To describe its actual trajectory it's necessary to know its position and speed at a certain moment in time.

According to Newton the trajectory of the comet, depending on the specific data, can be of one of three types: an ellipse, a hyperbola, or a parabola (fig. 1). The easiest way to determine the type of trajectory is by the comet's speed at perihelion (the point of the orbit nearest the Sun): the orbit is parabolic for a certain speed, elliptical when the speed is lower, hyperbolic when it's higher. Roughly speaking, elliptical orbits are the "slowest" and hyperbolic the "fastest."

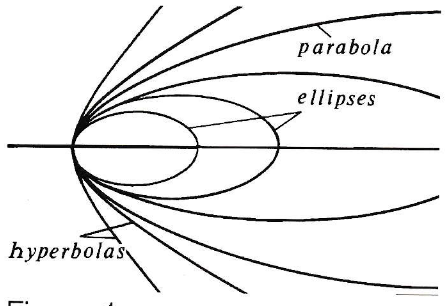


Figure 1
The family of ellipses, which turns into a parabola and hyperbolas.

In an elliptical orbit (fig. 2a) the comet moves periodically at a variable speed, attaining the maximum every time it passes its perihelion and the minimum when it passes the aphelion (the point of its orbit farthest from the Sun).

When traveling along a hyperbolic orbit (fig. 2b) the comet comes from infinity along an asymptote, makes a turn while approaching the Sun, moves around the Sun, and goes off along another asymptote to infinity. At a very great distance from the Sun the comet's speed may be considered constant; when the comet approaches the Sun its speed increases, reaching the maximum at the perihelion; after that it decreases again, and the comet continues to infinity at the former speed. So the Sun's role is reduced to turning the vector of the comet's velocity.

The parabolic orbit (fig. 2c) has no asymptote and, what's even more important, the velocity of the comet tends to zero as the comet heads off to infinity.

Hyperbolic and parabolic orbits are related: a comet traveling along either of them approaches the Sun from infinity, and to infinity it returns. Elliptical orbits are qualitatively different: the comet is always a finite distance from the Sun.

The words just used to compare orbits will help us define more clearly the process of gravitational capture of one body by another (or by a system of bodies): in the infinitely distant past the captured body stayed infinitely far from the capturing body, and throughout all the time after capture it stays near the Sun at a finite distance. So the picture of the captured body's motion is essentially asymmetrical in time with regard to the moment of capture.

Nothing of the kind can be found among the types of motion thoroughly described by Newton for the case of two bodies, which we agreed to call the Sun and a comet. In all three cases the character of the comet's motion in the infinitely remote past and infinitely remote future is the same.

In other words, gravitational capture is impossible in a two-body system.

But what if there are more than two bodies?

Three-body problem

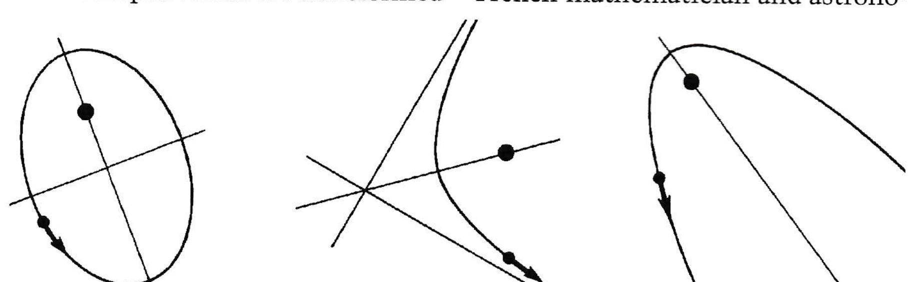
It would seem that the appearance of a third party in the ensemble of moving bodies won't seriously complicate the problem of calculating their motion. But actually it does: the two-body problem becomes much more complex when it's transformed into a three-body problem. The motion of two bodies can be calculated by anyone with a good grip on differential and integral calculus (though it takes some effort). The three-body problem is a famous problem, one that had many generations of mathematicians and astronomers racking their brains.

It's easy to write the motion equation for each of the bodies. But nobody could solve these equations and find the trajectories of the bodies in the general case, given their positions and velocities at a certain moment. By now it has been rigorously proven that it's impossible to find a general solution to the problem! And it's an exceedingly difficult task to describe solutions in geometric terms.

Why not try another tack and approach the three-body problem without trying to find an exact solution but just defining the types of motion involved? It turns out this approach does bears fruit.

To make things clearer we ought to restrict the problem somewhat, as we did when discussing the two-body problem. Let one of the three bodies be considerably more massive than the other two. Also let both light bodies (comets) stay near the heavy one (the Sun) for a certain period of time. We'll consider moments of time infinitely distant from this period either in the future or in the past and try to learn where each comet is at such moments: is it infinitely far from the Sun or within a finite distance from it? We'll classify the types of motion according to the answers to this question.

Such a classification for the three-body problem was proposed by the French mathematician and astrono-



a *elliptical* b *hyperbolic* c *parabolic*

Figure 2
Types of orbits in the two-body problem.

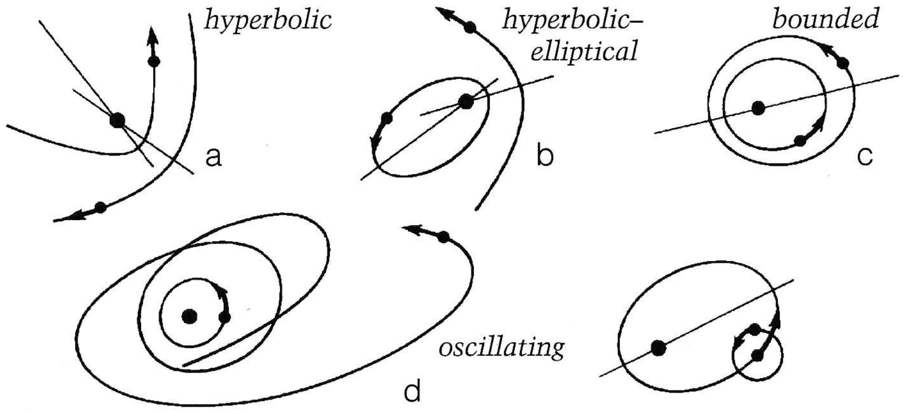


Figure 3
Classification of motion in the three-body problem.

mer Jean F. Chazy (1882–1955). All possible variants of the motion were divided into four types:

> **Hyperbolic** (fig. 3a): both comets are infinitely far from the Sun in both the infinitely distant past and future;
> **Hyperbolic-elliptical** (fig. 3b): one comet always stays at a bounded distance from the Sun and the other arrives from and returns to infinity;
> **Bounded** (fig.3c): all three bodies are at bounded distances from one another all the time;
> **Oscillating** (fig. 3d): in this rather exotic type of motion, a certain bounded region exists in space where all three bodies appear simultaneously from time to time, but there is no bounded region where they would stay forever.

As outgrowths of this classification, the notions of *partial* and *total capture* for the three-body case were defined. Capture is partial when the motion is hyperbolic in the past and hyperbolic-elliptical in the future. In other words, the two comets approach the Sun from infinity, one of them helps the Sun capture the second, and after playing its role it returns to infinity. Total capture occurs when the system consisting of the Sun and a comet moving in an elliptical orbit around it captures a second comet that has come from infinity—in other words, when the motion in the past is hyperbolic-elliptical and in the future is bounded.

Other combinations of different types of motion in the past and future are logically possible. For example, the so-called *exchange*: a comet arriving from infinity destroys a Sun–comet system in which the comet revolves in an elliptical orbit; the original comet goes off to infinity and the newcomer creates a new elliptical system with the Sun.

Chazy: Capture is impossible

The definitions of partial and total capture given in the preceding section are characterized by a striking feature: the behavior of the three-body system is different in the past and future.

This means that the problem of gravitational capture can be posed more broadly: can a gravitational interaction change the type of motion in the system?

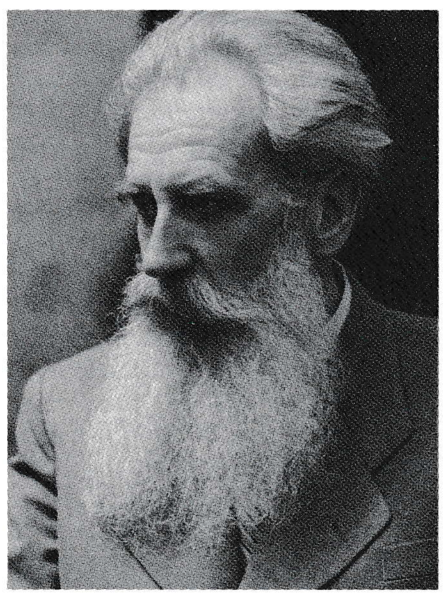
It was Chazy himself who made the categorical statement in the early thirties: such processes are impossible. That is to say, he claimed that gravitational capture, partial as well as total, is impossible in the three-body system.

And what about exchange? Chazy knew that at the beginning of the century examples of exchange were constructed by means of approximate numerical integration. But he found these examples unconvincing because he believed it was impossible to judge the behavior of the system in an infinite time interval on the basis of its behavior in a finite interval. In addition, he pointed out errors in the numerical integration that were difficult to take into account. Chazy even noted that "exact mathematical analysis here demonstrates its advantage over approximate numerical methods of investigation."

The idea that the motion of bodies can be different in the past and future, and the idea of gravitational capture in particular, came to be discredited. That's why many people doubted the cosmogonic hypothesis advanced in 1944 by the Soviet scientist O. Y. Schmidt. Its main idea was that the solar system originated in a cloud of gas and dust that was captured by the Sun with the help of a star traveling nearby.

Schmidt: Partial capture?

To persuade the skeptics, in the mid-forties Schmidt constructed an example of capture in the three-body problem, again by numerical integration. The orbits of all three bodies are illustrated in figure 4a in the frame of reference associated with one of them (P_0). The body P_1 comes from infinity at a moderate speed; the body P_2 arrives at an extremely high speed; they converge at a certain moment. During the short time of their convergence the relative motion of P_1 and P_2



O. Y. Schmidt (1891–1956), the outstanding Soviet mathematician and famous explorer of the North Pole. He suggested the first example of partial capture in the three-body problem.

could be treated as in the two-body problem—that is, as hyperbolic. As we already know, mutual attraction turns the bodies somewhat with respect to each other, which leads to a subsequent change in their velocities (as if two people running across each other's path decided to shake hands). As a result of the convergence body P_1 loses speed and passes from a hyperbolic orbit with respect to P_0 to an elliptical one; meanwhile body P_2 continues to move along a slightly changed hyperbola at a somewhat higher speed.

This example will probably become clearer if you imagine the opposite situation—"disintegration": body P_1 revolves "for ages" around P_0; at a certain moment body P_2 arrives at great speed, drags P_1 out of its orbit, sends it off to infinity, and continues to travel on to infinity with a slight loss of energy (fig. 4b). To derive an example of capture from this situation, we just have to imagine time running backward.

Schmidt's example suffered from the same defects as the examples of exchange: the calculation covered only a finite time interval; besides, the errors in numerical integration turned out to be too great: the values of the angular momentum were different at the ends of the integration interval. Schmidt's example proved unconvincing, and Chazy's point of view seemed to carry the day.

Sitnikov: Partial capture is possible!

A few years passed. Schmidt's example was reviewed. The results bore witness to the truth of Schmidt's basic idea: a celestial body flying toward the Sun at high speed is able to "knock" another body traveling nearby out of its hyperbolic orbit into an elliptical one and then go off to infinity. Moreover, it became clear that this idea could be used to construct trajectories by purely theoretical means, without resorting to numerical integration.

In 1952 K. A. Sitnikov constructed an analytical example of partial capture, and in 1956 V. M. Alexeyev provided an example of exchange. Such examples proved not to be isolated exceptions—the phenomenon didn't change qualitatively when the parameters of the celestial bodies were varied slightly.

So Chazy's assertion was refuted in comparatively simple cases.

But combinations of the other types of motion still caused doubts. It wasn't known if oscillating motions existed in general, or if total capture was possible. The problem was that even if such examples could be detected, they would be exceptions.

Isosceles three-body problem

The example of the two-body problem should have been enough to convince us how important at times a characteristic particular example can be in thinking about a general problem. When we analyzed the two-body problem we assumed that one body was much heavier than the other. This made it much easier to classify their motions. The classification remains valid for the general case as well, but if we had begun with this case at first, the explanation would have taken much more effort.

Success in analyzing oscillating motions also came as a result of a fortuitous example. The model was proposed by A. N. Kolmogorov and was later called the *isosceles three-body problem*. The word "isosceles" expresses the characteristic feature of this example: at any point in time the triangle formed by the three bodies turns out to be isosceles. The two bodies forming the base of the triangle have the same mass (quite considerable)—let's call them "stars"; the third body is much lighter and is naturally called a "speck of dust."

The stars in Kolmogorov's example move in the plane along elliptical orbits around their common center of mass, and the speck of dust moves along a line perpendicular to the plane through the center of mass (fig. 5).

In 1960 Sitnikov showed that the motion of the speck of dust could be oscillational—that is, the speck can oscillate with a variable amplitude (which can at times achieve arbitrarily large values).

These oscillations can also have a constant amplitude if the stars move along a circle as if they're chasing each other. But if the stars' orbits are elliptical, so that the stars continually converge and diverge even a little, then the swinging effect appears in the speck's motion.

This example proved the existence of oscillating motions in the three-body problem. One last bastion remained: the problem of total capture.

Alexeyev: Total capture is possible!

The catapult for the assault on this last bastion was the same isosceles three-body problem. In 1968, while investigating the problem, V. M. Alexeyev proved that the initial position and velocity of a speck of dust could be chosen in such a way that its subsequent motion would be either bounded or oscillating, and that the speck could have acquired such a position and speed even if it had come from infinity.

Overall the motion looks like this: a speck of dust coming from infinity approaches the plane of elliptical motion of two massive bodies and pierces it; during this time the massive bodies converge, and the forces of mutual attraction among the three

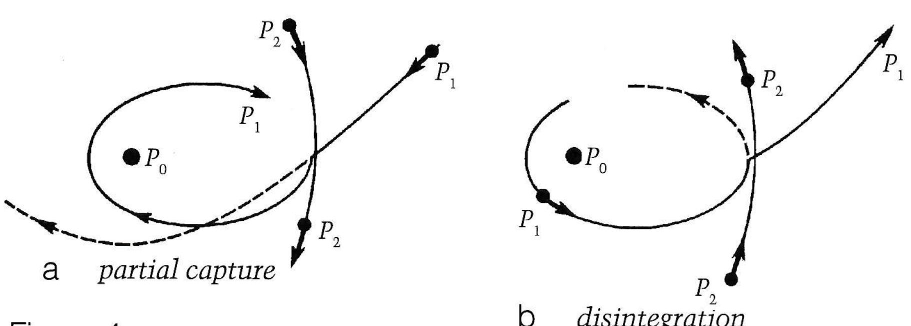


Figure 4
Examples of partial capture and disintegration.

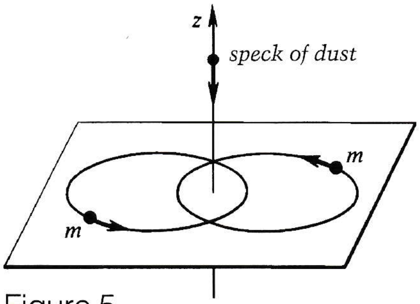
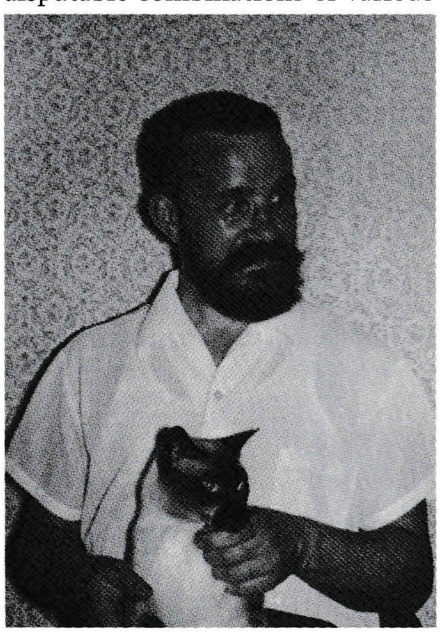


Figure 5
The isosceles three-body problem.

bodies increase to such an extent that they make the speck of dust slow down, turn back, and then oscillate with a bounded or unbounded amplitude. The first variation corresponds to total capture and the second to *capture into oscillation*, as the researchers expressed it.

As usual, the final steps are the most difficult. It was as if all the examples of motion having a different nature in the future and past and constructed before 1968 had been fished out of a vast ocean of uncertainty—the whole set of possible types of motion in the three-body problem. But Alexeyev's investigations shed light on the structure of this set.

Alexeyev's result capped the longstanding discussion of Chazy's assertion: it proved to be completely wrong! It turned out that the most disputable combinations of various



V. M. Alexeyev (1932–1980), the outstanding Soviet mathematician whose study of the three-body problem resulted in an impeccable example of total capture.

types in Chazy's classification, which were useful in describing three-body motion in the past and future, were indeed possible and were substantiated by rigorous analysis.

Comet Kwerns—Kwee: captured by Jupiter?

The refutation of Chazy's assertions still left some points of gravitational capture unclear. Some of the these questions could certainly be answered by an attentive reader equipped only with this short article.

For example: can a comet be captured the way Laplace visualized it—by passing near Jupiter or some other giant planet? There are reasons to believe that the answer is yes.

The capture might go something like this: after passing near Jupiter at hyperbolic speed (relative to the Sun), the comet is slowed by the planet and switches to an elliptical orbit around the Sun; when it meets up with Jupiter the next time, the comet switches back to another hyperbolic orbit; and so on.

For some time it was thought that Comet Kwerns–Kwee, discovered in 1963, was captured in just this way. Semiannual observations were used to calculate its current and previous orbits. As seen in figure 6, in 1961 Comet Kwerns–Kwee passed near Jupiter and changed from an orbit whose aphelion was between the orbits of Neptune and Uranus to a short-period orbit with a perihelion rather close to the Earth's orbit (which made its discovery possible). According to the calculations mentioned above, Jupiter pulled Comet Kwerns–Kwee out of its hyperbolic orbit back in 1855 and knocked it into a big elliptical orbit.

Unfortunately, subsequent calculations and observations failed to confirm the capture. The way astronomers see the past of Comet Kwerns–Kwee changes drastically with each recomputation and refinement of its present orbit. It's truly an "outlaw comet among calculated luminaries"! So the problem Laplace posed almost two hundred years ago

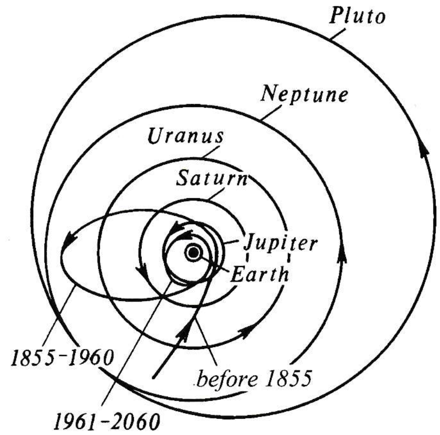


Figure 6
The catastrophic transformation of Kwerns–Kwee comet in 1855 and the evolution of its orbit (according to calculations by E. I. Kazimirchak-Polonskaya).

still causes intense discussion. Gravitational capture is possible—this fact has been proven rigorously and conclusively. At the same time, it's still unclear whether our solar system ever captured even one of the comets belonging to it. None of the comets observed to date is known for certain to have come from interstellar space. By 1979[1] the orbits of 659 comets had been defined reliably, and of these only 98 were hyperbolic. Yet where is the guarantee that the orbits were hyperbolic before they were observed for the first time?

At present it's thought that there's a giant cloud of comets at the edge of the solar system—the Oort cloud—exceeding the Earth's orbit in size by a factor of 100,000–150,000. It's believed that the comets' orbits, which appear parabolic or slightly hyperbolic, are actually greatly stretched ellipses that take the comets about 400,000 years to trace. The question is: was the Oort cloud formed at the same time as the solar system, or does it replenish itself from time to time by capturing comets traveling in interstellar space? Opinions differ on that account. Let's hope that the future holds the answer. ◘

[1]This article first appeared in our sister magazine *Kvant* in 1982.—*Ed.*

Off into space

The pleasures of jumping out of a plane

by Vladimir Dubrovsky and Igor Sharygin

DO YOU KNOW HOW TO PUT together six matches to make four equilateral triangles, each of whose sides is a whole match? If you've never heard about this puzzle, you'll find it really challenging. And not only that: maybe you'll find it unsolvable, at least as long as you're trying to do it on the plane. (It actually is—prove it!) So the clue is to leave the plane, to consider the problem as a three-dimensional one. With this hint you'll solve it fairly quickly: all you have to do is construct a triangular pyramid.

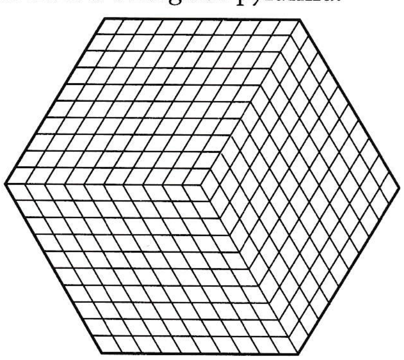


Figure 1a

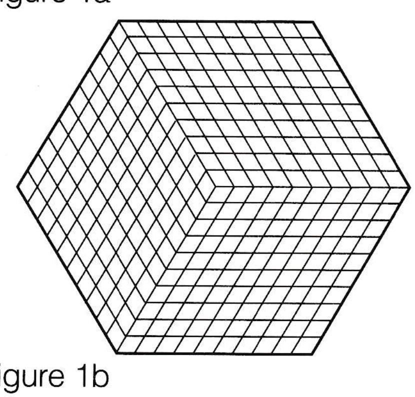


Figure 1b

In this example we were forced to "go off into space" to cope with our task. But there are many plane geometry problems in which adding the third dimension facilitates the solution or opens a new beautiful and unexpected approach (although they can also be solved within the plane). In some sense they can be compared to such terrestrial problems as forecasting the weather, drawing maps, or prospecting for minerals, which are more efficiently solved from outer space by means of satellites. That's why we decided to place this article in the "space issue" of *Quantum*.

Sometimes to solve a plane geometry problem you have merely to stare at its diagram until all of a sudden, by a stretch of the imagination, you grasp the three-dimensional nature of the shape you see, and the solution literally pops up at you in all its clarity. We'll start with one of the most impressive examples of this sort.

Rhombic tiling. *A regular hexagon with a side length of 10 is tiled by diamonds with a side length of 1, as illustrated in figure 1a. One can rearrange triples of diamonds as shown in figure 2. Prove that after a number of such operations it is possible to obtain the tiling in figure 1b, and that this number is not less than 1,000.*

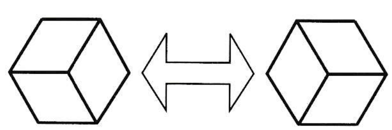


Figure 2

Figure 3 demonstrates the idea of the proof. (The hexagon in this figure has only four diamonds to a side, but the principle is the same.) An arbitrary rhombic tiling of the hexagon can be viewed as a big cube partly filled with smaller cubes congruent to one another; to help you see it better, the tiles in figure 3 are shaded in three different ways according to their three possible orientations. Then the initial tiling corresponds to just an empty 10 x 10 x 10 cubic box (with three adjacent faces removed); the final one corresponds to this box completely filled with 1 x 1 x 1 cubic blocks. The rearranging operations consist of (1) placing a new unit block in a niche formed by blocks already installed or (2) removing a block with no blocks resting on it from the box. Evidently the box can be completely filled by adding blocks

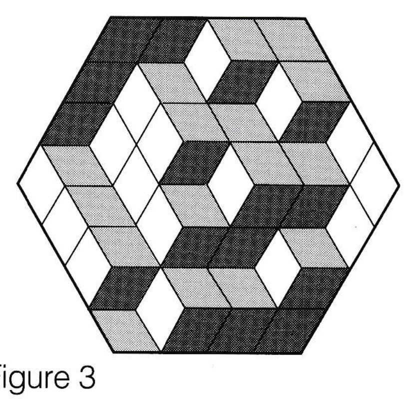


Figure 3

Art by Pavel Chernusky


П.Черн.

one by one, and it won't take less than $10^3 = 1{,}000$ such operations, so we're done. The reader can even try to prove that any two tilings can be transformed into one another in no more than 1,000 operations.

This tiling problem is relatively untraditional. Now comes a really classic example of "going off into space."

Desargue's Theorem (fig. 4). *Let ABC and $A_1B_1C_1$ be two triangles in the plane such that lines AB and A_1B_1, BC and B_1C_1, CA and C_1A_1 intersect in points P, Q, and R, respectively. If lines AA_1, BB_1, and CC_1 meet in one and the same point O, then points P, Q, and R lie on one and the same straight line.*

The proof of this theorem in the plane is far from easy. But it becomes almost trivial if you regard the given figure as the image of the corresponding three-dimensional configuration—three non-coplanar lines OA, OB, OC crossed by two different planes ABC and $A_1B_1C_1$. The points P, Q, and R in this configuration belong to both planes ABC and $A_1B_1C_1$. But the intersection of two different planes is a straight line, so these points as well as their images on the plane lie on one line.

To make the main idea of the above solution more distinct, we took for granted the existence of the spatial configuration corresponding to the given plane one. In other words, we actually had to prove that there is a set of lines and points not lying in one plane whose image (that is, parallel projection) is an arbitrary figure satisfying the conditions of Desargue's theorem (like figure 4). In this case such a proof isn't a problem, but sometimes, as we'll see below, the spatial interpretation of a plane figure needs a separate justification.

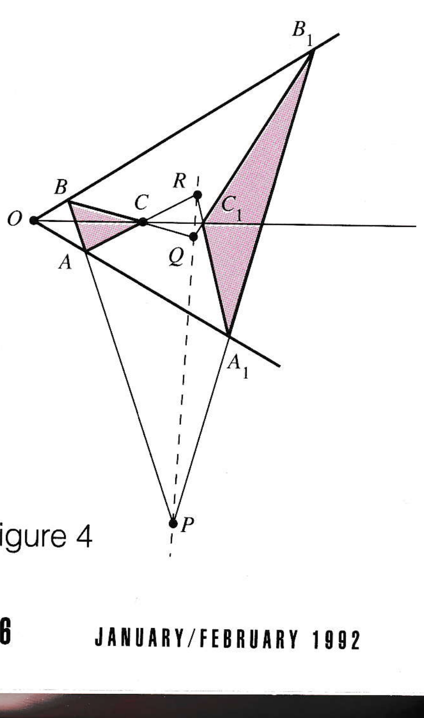


Figure 4

An articulate quadrilateral. *A quadrilateral $ABCD$ is circumscribed about a circle, its sides AB, BC, CD, and DA touching the circle in points K, L, M, N, respectively (fig. 5). Prove that if lines KL and MN intersect, then their common point lies on line AC.*

Let's bend the quadrilateral at its vertices and stretch its sides to turn it into a "spatial" quadrilateral $A_1B_1C_1D_1$, whose orthogonal projection onto the plane ABC is $ABCD$ and whose sides pass through the same contact points K, L, M, N (fig. 6).

If you're ready to believe this auxiliary quadrilateral into existence, we can immediately complete the proof. Let P be the common point of lines KL and MN. Then it belongs to both planes $A_1C_1B_1$ and $A_1C_1D_1$—that is, to their intersection line A_1C_1. It follows that P belongs to AC—the projection of A_1C_1 onto plane ABC. (I'll leave it to you to prove that when KL and MN are parallel to each other, line AC is parallel to them as well.)

Doesn't it seem to you that there's something wrong with this solution? What is the inscribed circle given for? We'll find the answer as soon as we try to accurately construct quadrilateral $A_1B_1C_1D_1$. We can draw perpendiculars to the plane of quadrilateral $ABCD$ through its vertices and successively choose points A_1, B_1, C_1, D_1 on the respective perpendiculars so that point B_1 would lie on line A_1K, C_1 on line B_1L, and D_1 on line C_1M. So the construction of three sides of our quadrilateral, A_1B_1, B_1C_1, and C_1D_1, doesn't raise any questions. But the fourth side, D_1A_1,

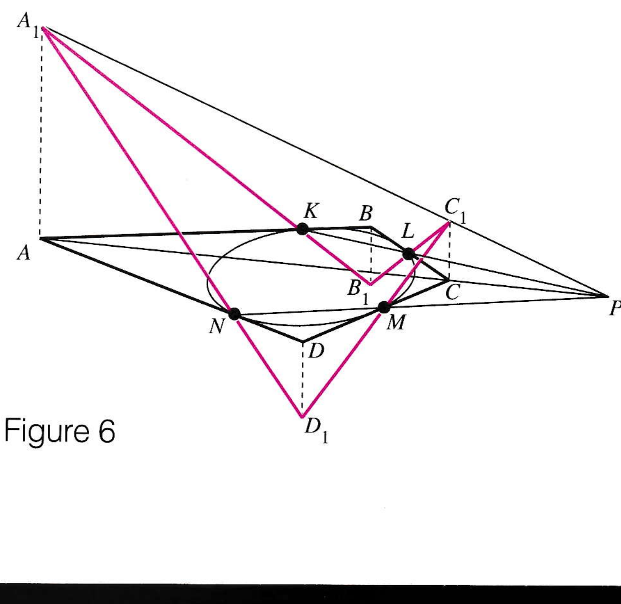


Figure 6

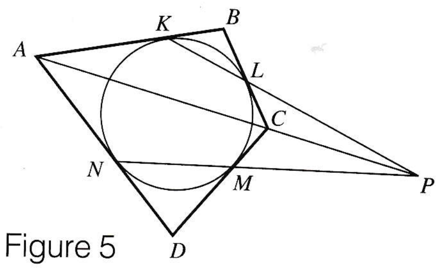


Figure 5

must pass through point N—and this ought to be proved! It suffices to prove that $\angle ANA_1 = \angle DND_1$. At just this point the circle will play its part. Since two tangents, AN and AK, drawn to the circle from point A are congruent, so are the triangles ANA_1 and AKA_1, yielding $\angle ANA_1 = \angle AKA_1$. Now, $\angle AKA_1 = \angle BKB_1$ (as vertical angles). Using a similar argument, we can continue this chain of equalities:

$$\angle BKB_1 = \angle BLB_1 = \angle CLC_1$$
$$= \angle CMC_1 = \angle DMD_1 = \angle DND_1,$$

so

$$\angle ANA_1 = \angle DND_1,$$

completing the proof.

By adding the third dimension here, we replaced the intersection of three lines with the intersection of three planes (ABC, $A_1B_1C_1$, and $A_1D_1C_1$). In the next example we'll consider three intersecting spheres to prove the well-known

Altitude Theorem. *The three altitudes of a triangle intersect at one point.*

Actually, we'll give the proof only for an acute-angled triangle ABC (fig. 7) because in this particular case our

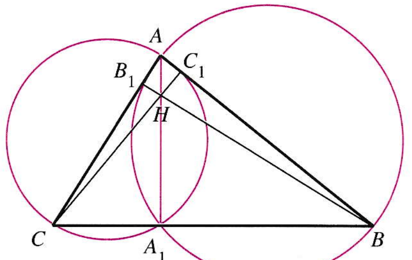


Figure 7

off-into-space method proves useful. The altitude AA_1 is the common chord of the circles with diameters AB and AC. The spheres with the same diameters intersect along a circle ω with diameter AA_1 lying in the plane perpendicular to the plane of the triangle (fig. 8). Therefore, altitude AA_1 is the orthogonal projection of the circle ω onto the plane ABC. Similarly, the two other altitudes are the projections of the circles along which the two spheres intersect with the third sphere, constructed on diameter BC. Now it suffices to show that the three spheres have a common point, because the projection H of this point onto plane ABC belongs to the projections of all three pairwise intersections of the spheres—that is, to all three altitudes. Since angle A is acute, point A lies outside the sphere with diameter BC; since angles B and C are acute, point A_1 lies on the segment BC, inside the sphere. Therefore, circle ω intersects this sphere. The points of intersection belong to all three spheres.

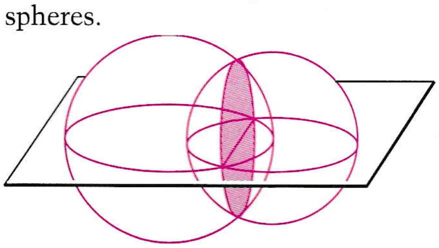


Figure 8

So far the solid geometry we've used in our "trips into space" for three-dimensional solutions of plane problems has been very visual and intuitively clear. We've managed to get by without any formulas and even without any rigorous formulations of theorems. Such solutions look extremely beautiful and seem deceptively easy to find. The next example, perhaps, lacks this easy touch—we'll have to apply a formula studied only in relatively advanced courses of solid geometry; what's remarkable is how this formula is applied in a what seems to be an "absolutely plane" situation.

Strips on a circle. *Prove that a circle cannot be covered by a set of strips whose total width is less than the diameter of the circle (fig. 9).*

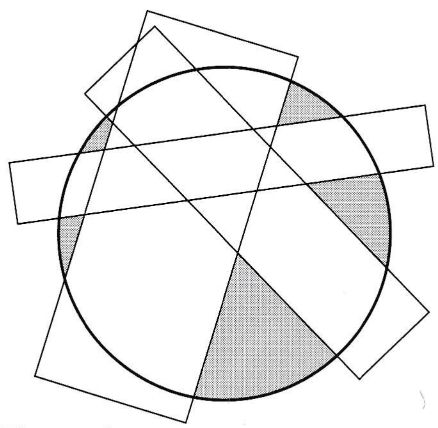


Figure 9

Consider a sphere with the same center and radius as those of the given circle. The part of the circle covered by an arbitrary strip is then the projection of the part of the sphere contained between two parallel planes (perpendicular to the circle's plane—fig. 10). The area of such a part of a sphere, called a "spherical zone," according to the formula mentioned above is equal to πDh, where D is the sphere's diameter and h the "thickness" of the zone (or the width of the initial strip). The total area of all spherical zones corresponding to the given strips is πDH, where H is the total width of the strips. Since $H < D$, the area of the zones is less than the area of the sphere πD^2. Therefore, the zones do not cover the whole sphere, and the projection of the uncovered part of the sphere onto the circle is not covered by the strips.

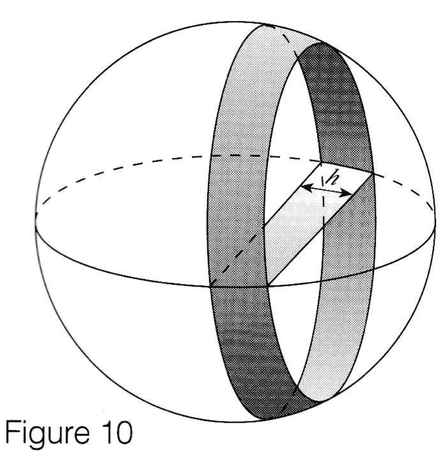


Figure 10

Our last example demonstrates the use of three-dimensional coordinates in a two-dimensional problem.

Lemoine's point. *Let x, y, z be the distances from a point P in a triangle ABC to its sides a, b, c. Prove that the sum of their squares* $x^2 + y^2 + z^2$ *achieves its minimal value at the point for which they are proportional to the respective side lengths (fig. 11):*

$$x : y : z = a : b : c.$$

Any point P of the given triangle can be associated with a point in space with coordinates (x, y, z), where x, y, and z are the distances in question.

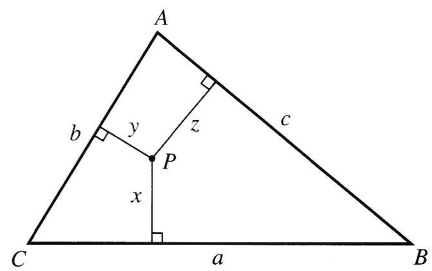
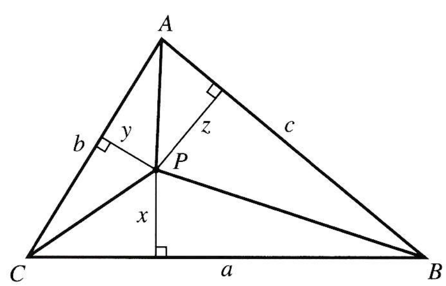


Figure 11

Point (x, y, z) lies in the first octant of the coordinate system (it has nonnegative coordinates) and satisfies the equation

$$ax + by + cz = 2 \cdot \text{Area}(ABC),$$

because triangle ABC can be cut into triangles BCP, CAP, and ABP, whose areas are equal to $ax/2$, $by/2$, and $cz/2$, respectively (fig. 12). Now we'll make use of two facts, proven in any



Area (ABC) = Area (BCP) + Area (CAP) + Area (ABP)

Figure 12

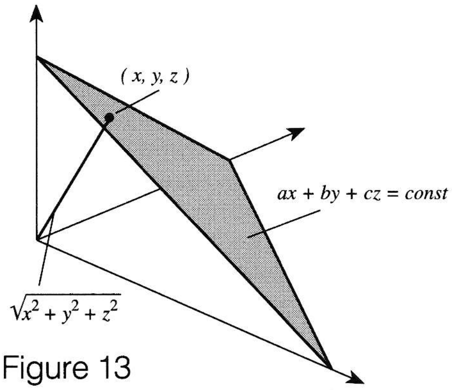


Figure 13

text on three-dimensional coordinates:

(1) The graph of the equation $ax + by + cz = const$ is a plane perpendicular to vector (a, b, c) (unless it's the zero vector).

(2) The distance from the point (x, y, z) to the origin equals $\sqrt{x^2 + y^2 + z^2}$.

It follows from (1) that the set of points in space corresponding to all the points of triangle ABC is also a triangle (fig. 13)—the section of the first octant by the plane given by the above equation. (By the way, the segments of the coordinate axes intercepted by this plane are equal in length to the heights of triangle ABC—prove it!) The point in triangle ABC with the smallest sum $x^2 + y^2 + z^2$ (called Lemoine's point) according to (2) corresponds to the point (x, y, z) of our plane closest to the origin—that is, to the base of the perpendicular dropped on the plane from the origin. But, as we've said, vector (a, b, c) is perpendicular to the plane too. Therefore, vectors (a, b, c) and (x, y, z) are parallel, and so (by a basic fact of vector geometry) their coordinates are proportional—which completes the proof. We leave it to you to derive from this problem that Lemoine's point is the point of intersection of the so-called symedians of the triangle—that is, lines symmetric to its medians with respect to the corresponding angle bisectors.

It goes without saying that there are plenty of other "pop-up problems." Some of them are given as exercises below; one more can be found among the math challenges on page 23.

Exercises

1. Given three rays with a common origin that divide the plane into three angles, and given three points, one in each angle, construct a triangle whose vertices lie on the rays and whose sides pass through the given points.

2. Points K, L, M, N are given on the sides AB, BC, CD, DA, respectively, of a quadrilateral $ABCD$. Prove that if three lines KL, MN, and AC have a common point or are parallel, then the same is true for the lines LM, NK, and BD.

3. Prove

Brianchon's Theorem. *The diagonals joining the opposite vertices of a hexagon circumscribed about a circle meet at one point.*

4. Three circles have a nonempty intersection. Prove that their three common chords have a common point.

5. Through a fixed point A inside a given circle an arbitrary chord is drawn. Tangents to the circle at the endpoints of the chord meet at point M. Find the locus of point M.

6. Four pedestrians A, B, C, and D walk at constant speeds along four straight roads, none of which is parallel to the other. Pedestrians A, B, and C meet each other; D meets A and B. Prove that D also meets C. ◘

SOLUTIONS AND HINTS
ON PAGE 82

Nature's fireworks

The inner workings of the auroras

by A. K. Kikoyin

THE AURORA IS A multicolored, seemingly unreal "light" that can be seen in the far north and far south—that is, in the polar regions.

The aurora borealis (as it's usually called) has been known for a long time. It was mentioned by ancient authors and described several times by medieval chroniclers. The aurora borealis was observed in England in 1716 and reported by Edmond Halley. The Russian scientist Mikhail Lomonosov, who spent his childhood and youth in the north of Russia and who often observed the aurora borealis, was among the first who supposed that the aurora is electrical in nature.

What does the observer see?

The auroras (both borealis and australis) are distinguished by great variety. They can look like homogeneous yellowish green stripes or arcs with a sharp lower edge and a diffused upper edge. The height of the lower edge is usually about 100 km; the upper edge is about 1,000 km high. They can look like arcs or stripes consisting of peculiar rays perpendicular to the surface of the Earth. Pulsating stripes and arcs can also be seen. The most impressive is the glowing aurora, which looks like luminous waves moving upwards. It resembles a dying fire, fanned by gusts of wind.

Green predominates with admixtures of yellow. Red also plays a significant role; blue and violet are seen less often.

Where can the auroras be seen?

The auroras (aurora borealis in particular) can be seen not only near the poles. They can be seen along the coast of the Black Sea and even in Rome. But as one approaches the poles, their frequency increases sharply.

Observations over many years have allowed scientists to draw isochasms (lines connecting points with the same frequency of auroras) on a map. They show that at the

Art by Dmitry Krymov

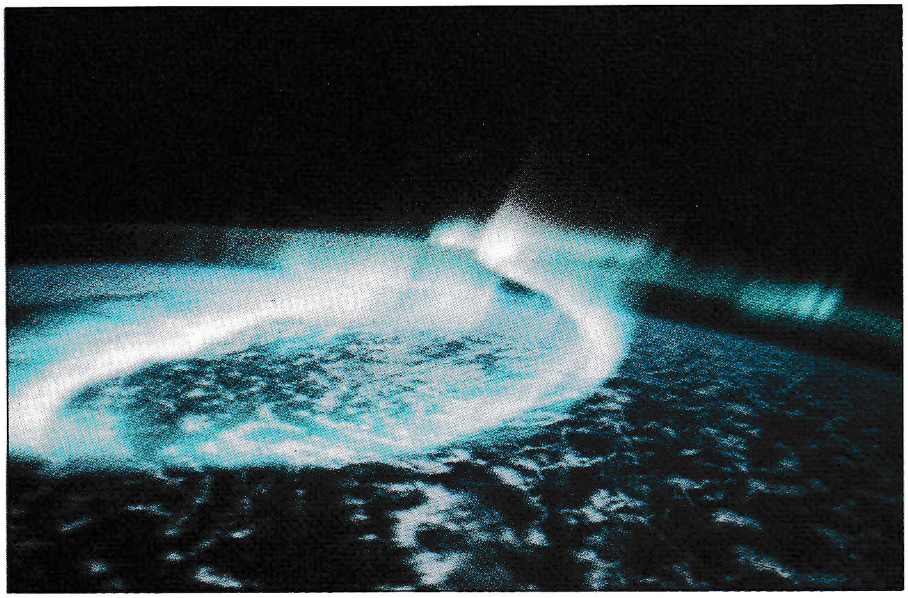


Photo courtesy of NASA

This view of the aurora australis (southern lights) was taken from the space shuttle Discovery (mission STS-39, April–May 1991). It shows a glowing band above the limb of the Earth that NASA photo experts have placed at an altitude of 80–120 km. They attribute this green glow to the excitation of atomic oxygen (at a wavelength of 5,577 Angstroms), although other atoms can also contribute to the effect.

coast of the Black Sea, an aurora is seen once (one night) in 10 years; in the north of England or at the Kola Peninsula, 100 nights a year; and on the coast of the Arctic Ocean, practically every night. Here the frequency of auroras is expressed by the number of nights per year. But this doesn't mean that auroras can be seen only at night. They appear in the daytime as well, but it's much more difficult to see the relatively weak light of an aurora against a background of bright sky.

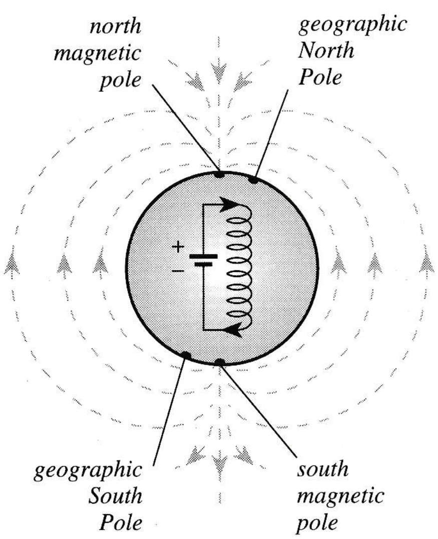


Figure 1

How and why do auroras appear?

It wasn't in vain that Lomonosov ascribed an electrical nature to auroras. But now it has been proven that magnetic phenomena also play an important role in the complicated processes causing auroras. And with good reason.

The Earth is a giant natural magnet, so it's surrounded by a magnetic field. This field looks like the one created by a magnetized rod or solenoid with a DC source. Figure 1 shows the Earth's lines of magnetic flux. The solenoid and current source shown in the figure don't actually exist, of course. But the electrical currents, which are the "culprits" behind the Earth's magnetic field, do indeed exist (in the liquid part of the Earth's center). Figure 1 shows that the arctic and antarctic magnetic poles do not coincide with the geographic poles, deviating by approximately 11°. The Earth's magnetic field stretches to a distance of about 3 Earth radii (from its center). The value of the field's magnetic induction is only about $5 \cdot 10^{-5}$ teslas = 0.5 gauss.

The second important "actor" involved in this process is the Sun. In addition to visible and invisible light, the Sun (its photosphere) constantly radiates plasma, which consists of fast protons and electrons. This flow of particles—the solar wind—"blows" on the Earth.

These two facts are enough to explain the phenomenon of auroras.

Solar wind and Earth's magnetic field

The Earth's magnetic field is heterogenous: the value of magnetic induction near the poles is nearly twice that near the equator. The heterogeneity of the magnetic field makes it, as we now know very well, a sort of trap for charged particles. If a particle falls into this field, it moves along lines of magnetic flux (spiraling around them) until it comes to the place where the lines of magnetic flux thicken—that is, to the region of the magnetic pole. Here the particle is reflected and goes to the other pole, only to be reflected from it, too. The particles end up being locked in a magnetic "bottle," so to speak, with two "corks" (the places where the lines of magnetic flux become denser near the poles). So the Earth is surrounded by a radiation belt, enveloping it all around except for the polar regions (fig. 2). The radiation belt is conventionally divided into two parts: an inner belt (A) and outer belt (B). The lower edge of the inner belt is about 500 km up, and it's several thousand kilometers thick. The outer belt sits at a height of 10,000–15,000 km.

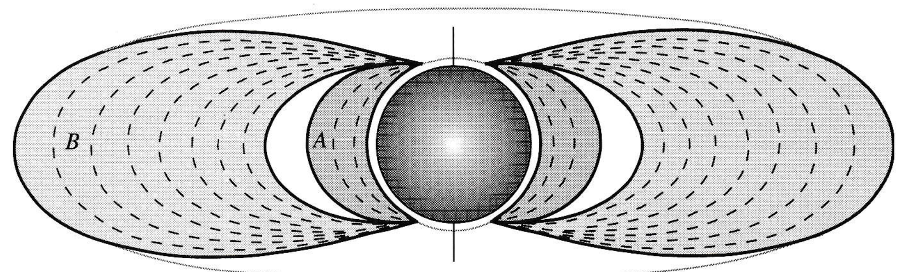


Figure 2

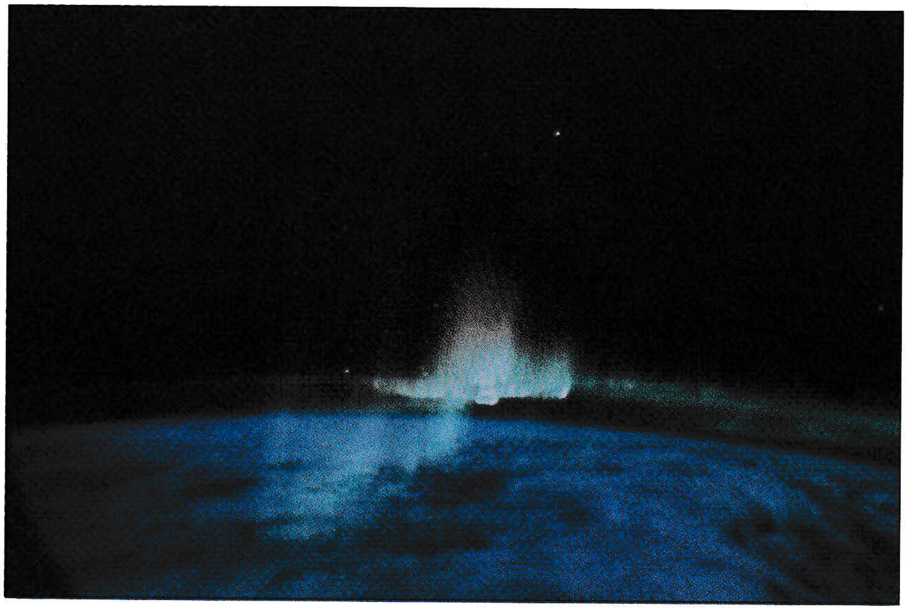


Photo courtesy of NASA

Another photograph from STS-39. One of the objectives of this space shuttle mission was to measure the spectral and spatial characteristics of auroral emissions. The red colors are due to oxygen emission lines at 6,300 and 6,364 Angstroms. Auroras caused by the excitation of atomic oxygen are usually most intense at latitudes around 65° north and south during the spring and fall.

It's interesting that the radiation belt is intimately connected with auroras. It turns out that certain features of plasma (which permeates the radiation belt) and certain processes occurring there loosen the magnetic "corks," in effect, so that a number of particles spill out of the "bottle." Then fast-moving charged particles collide with atoms or molecules of air (nitrogen and oxygen) and excite them—that is, knock them into states with higher energies. Then the molecules (atoms) drop back to their initial states, losing the extra energy by radiating corresponding packets (quanta) of light. And this is where the light in the "northern (and southern) lights" comes from.

Analysis of the spectrum of this light has shown that green light (and to some extent red) arises when oxygen atoms are excited. Red, dark red, light blue, and violet radiation is connected with the excitation of nitrogen molecules. It may seem strange that we're talking about atoms, not molecules, of oxygen. But in the upper layers of the atmosphere, the Sun's ultraviolet rays split oxygen molecules into their component atoms.

The auroras have been intensively studied in laboratories on Earth and by means of satellites in space. These investigations have given us important data on the Earth's magnetic field and on the different physical processes occurring in near-Earth space. ◘

Launch into International Space Year!

Your guide to what's happening in ISY 1992

HERE'S THE LATEST INFORMATION on events, resources, and ongoing activities related to International Space Year. New ISY activities and updated information on existing ones are being generated almost daily. Check with the organization conducting a particular project, or contact the US International Space Year Association (US-ISY) for the latest information:

US International Space Year Association
600 Maryland Avenue SW, Suite 600
Washington, DC 20024

Phone: (202) 863-1734
Fax: (202) 863-5240

Quantum readers are encouraged to create their own ISY activities or join any of those listed below. Please contact US-ISY, which is the US information clearinghouse for International Space Year, if you wish to provide updates on your ISY program or have a new one publicized.

Calendar of events

See also the list of ongoing year-long programs beginning on page 58.

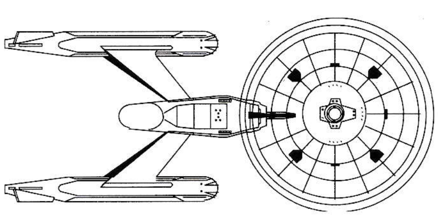
January 1992

January 1. Tournament of Roses Parade, including ISY floats by the Masons and other groups—Pasadena, California

January 10. *Scholastic News* student magazine issue on space

January 14–March 28. "Blueprint for Space" traveling exhibit appears at IBM Gallery of Science and Art, New York, New York—The Space & Rocket Center

January 25. "Star Trek: Federation Science" traveling space science exhibit opens at Oregon Museum of Science and Industry—Portland, Oregon



January. Launch of NASA's Extreme Ultraviolet Explorer (EUVE) spacecraft

January. ISY program on Finnish national television—Finnish Broadcasting Company and Finnish Technology Development Centre

January. Young Astronaut ISY spring curriculum materials distributed and Young Astronaut Reading Club introduced

January–February. *Final Frontier* magazine's ISY Directory

January–February. International Student Olympiad on Space Engineering—Moscow Technical State University—Moscow, USSR (*tentative*)

February 1992

February 9. Symposium on ISY at the annual meeting of the American Association for the Advancement of Science (AAAS)—Chicago, Illinois

February 10–13. ISY Conference on Earth and Space Science Information Systems—including presentations and demonstrations by selected SAFISY Earth and space science projects—Pasadena, California

February 10–21. World Congress on National Parks and Protected Areas—Caracas, Venezuela

February. EUVE ultraviolet sky survey begins, including SAFISY-coordinated amateur observations

February. Launch of NASA's space shuttle Discovery (STS-42 mission) carrying International Microgravity Laboratory

February. Launch of the Japanese Earth Resources Satellite JERS-1, Japan's first remote sensing satellite

February. ISY issue of *Ciencia Hoje/Ciencia Hoy* science magazine—Brazilian Society for the Advancement of Science

February. International winners announced in the "Together to Mars" international student essay contest—The Planetary Society

February. *Tennessee Teacher* magazine space issue in celebration of Tennessee Space Week

ISY

Participating organizations

Space agency participation in ISY is coordinated by the Space Agency Forum for International Space Year (SAFISY), which has 29 members and 10 international affiliates, including the United Nations and the International Council of Scientific Unions (ICSU). In addition, under SAFISY's inspiration many activities dedicated to ISY's ideals and objectives have been generated in the public sector.

SAFISY members

Argentina: National Commission on Space Research (CNIE)
Australia: Commonwealth Scientific and Industrial Research Organisation (CSIRO)
Austria: Austrian Space Agency (ASA)
Belgium: Recherche et Technologie Spatiale (RTS)
Brazil: Instituto Nacional de Pesquisas Espaciais (INPE)
Canada: Canadian Space Agency (CSA)
China: Chinese Academy of Sciences (CAS)
Denmark: Danish Research Administration (DRA)
EUMETSAT: European Organization for the Exploitation of Meteorological Satellites
ESA: European Space Agency
Finland: Finnish Space Committee (FSC)
France: Centre National d'Etudes Spatiales (CNES)
Germany: Bundesministerium für Forschung und Technologie (BMFT)
India: Indian Space Research Organization (ISRO)
Israel: Israel Space Agency (ISA)
Italy: Agenzia Spaziale Italiana (ASI)
Japan: Institute of Space and Astronautical Science (ISAS)
National Space Development Agency (NASDA)
Science and Technology Agency (STA)
Netherlands: Netherlands Agency for Aerospace Programs (NIVR)
Norway: Norwegian Space Center (NSC)
Pakistan: Pakistan Space and Upper Atmosphere Research Commission (SUPARCO)
Spain: Center for the Development of Industrial Technology (CDTI)
Sweden: Swedish Board for Space Activities (SBSA)
Thailand: Ministry of Science, Technology, and Energy (MSTE)
USSR: INTERCOSMOS Council
United Kingdom: British National Space Centre (BNSC)
United States: National Aeronautics and Space Administration (NASA)
National Oceanic and Atmospheric Administration (NOAA)

SAFISY affiliates

Committee on Space Research (COSPAR)
European Community—Joint Research Center, Ispra, Italy
International Astronautical Federation (IAF)
International Council of Scientific Unions (ICSU)
International Maritime Satellite Organization (INMARSAT)
INTERCOSMOS
United Nations Educational, Scientific, and Cultural Organization (UNESCO)
United Nations—Food and Agriculture Organization (UN/FAO)
United Nations—Outer Space Affairs Division (UN/OSAD)
United Nations—World Meteorological Organization (UN/WMO)

March 1992

March 4. NASA ISY Interactive Satellite Videoconference—first in a series for students and educators

March 9–13. UN/Japan Regional Workshop on Space Technology for Resource Development and Environmental Management—Quito, Ecuador

March 15. Contest entries due for NASA/NSTA Space Science Student Involvement Program (SSIP)

March 18–20. Satellites and Education Conference: International Space Year—West Chester University—West Chester, Pennsylvania

March 20. Delaware Valley ISY Colloquium—Space Exploration: The 21st Century—American Institute of Aeronautics and Astronautics (AIAA)—Philadelphia, Pennsylvania

March 23–26. Space Commerce Biannual Meeting—Montreux, Switzerland

March 26–29. SOAR '92 (Special Opportunities for Aerospace Resources) Forum on ISY, during NSTA National Convention—NSTA and Student Space Science Foundation—Boston, Massachusetts

March 27. The Planetary Society Day at NSTA National Conference—Boston, Massachusetts

March 30—April 4. European ISY Conference: Space in the Service of the Changing Earth—including presentations/exhibitions by selected SAFISY earth science, space science, and remote sensing training projects—Munich, Germany

March. SAFISY Polar Ice Extent Project demonstration

March. *Directory of Earth Observation Resources for Educators* and *Educator's Guide for Building and Operating an Environmental Satellite Receiving Station* published by NOAA

Spring 1992

Spring. SAFISY *Atlas of the Solar System* published (*tentative*)

Spring. Launch of Brazil's first satellite, the Earth observation spacecraft SCD-1

April 1992

April 6–10. European Geophysical Society Annual Meeting—Edinburgh, Scotland

April 19. Mission to Planet Earth Day global telecast

April 20–October 12. AmeriFlora exposition, including space pavilion—Columbus, Ohio

April 20–October 12. EXPO '92 World Exhibition, including ISY exhibits—Seville, Spain

April 25. Mission to Planet Earth Day worldwide activities

April 27–May 1. UN/US ISY Conference—Satellite Remote Sensing for Resource Management, Environmental Assessment, and Global Change Studies: Needs and Applications for the Developing World—Boulder, Colorado

April. International Seminar for Developing Countries on Space Communication—Moscow, USSR

April. Space Class (two sessions)—Space School, Brunel University—United Kingdom

April–May. International Student Congress—Youth for International Space Year, Moscow State Technical University—Moscow, USSR

May 1992

May 4–6. UN/US ISY Workshop: Strategies for Developing a Global Environmental Data Exchange Network through the United Nations Environmental Program (UNEP) Global Resource Information Database (GRID)—Boulder, Colorado

May 11. Dedication of space shuttle simulator—Wausau School District, Wisconsin

May 17–22. International Symposium on Remote Sensing in Geoecology—University of Boulder—Boulder, Colorado

May 24–27. Space Research Conference of European students—Association des Etats Généraux des Etudiants de l'Europe (AEGEE)—Delft, the Netherlands

May 26-29. International Geoscience and Remote Sensing Symposium (IGARSS) International Space Year: Space Remote Sensing—IEEE—Clear Lake, Texas

May 27–29. SAFISY World Forest Watch Conference—including results of SAFISY World Forest Watch project—São Paulo, Brazil

May 30–June 4. Space '92: International Conference on Engineering, Construction, and Operations in Space—American Society of Civil Engineers—Denver, Colorado

May. SAFISY MultiWaveLink project's target completion date for international expansion of its astrophysics database

May. Launch of NASA's space shuttle Atlantis (STS-45 mission)

May. Launch of NASA's space shuttle Endeavour on its maiden voyage (STS-49 mission)

May. Intergalactic Sculpture of laser beams launched into space—Bar-Giora Observatory—Midreshet Sde-Boker, Israel

May. International Meeting of Young Cosmonauts, Scientists, and Space Specialists—Moscow, USSR

May. Futures in Aerospace and Technologies Day—Maple Elementary School, Michigan (*tentative*)

May. International Conference on Space Biology and Medicine—Moscow, USSR (*tentative*)

Late May. "Marsville—The Cosmic Village" Regional Conferences—Challenger Center—100 sites worldwide

May–June. SAFISY Workshop on Current and Future Space Capabilities and Requirements for Disaster Prevention, Preparedness, and Relief

May–June. Space Oceanography Cruise—Marine Hydrophysical Institute of the Ukrainian Academy of Sciences (*tentative*)

June 1992

June 1-12. United Nations Conference on Environment and Development—Rio de Janeiro, Brazil—including presentation of SAFISY World Forest Watch project results

June 20–21. Flight Test 1992 launch of rockets with student payloads—Rocket Research Institute—Alamogordo, New Mexico

June 29–August 29. International Space University summer session—Kitakyusyu, Japan

June. SAFISY global change video available for distribution

June. UN ISY Telecast—New York, New York and worldwide

June. Launch of NASA's space shuttle Columbia (STS-50 mission)

June. Launch of NASA's Solar, Anomalous, and Magnetospheric Particle Explorer (SAMPEX) spacecraft, which will study solar energy particles, cosmic rays, and Earth's magnetic field

June. SolarTerrestrial Science Symposium—Ireland

June. International Young Astronauts Conference—USA

June–July. NASA International Space Life Sciences Training Program—Kennedy Space Center, Florida

June 21–September. UN ISY Exhibition "The Home Planet"—United Nations Headquarters—New York, New York

Summer 1992

Mid-1992. Conference on Remote Sensing and the Economy—USSR

Summer. International Young Astronauts Conference—Tokyo, Japan

Summer. International Young Astronauts Conference—Korea

Summer. International Summer Aerospace Campus Program for Soviet students—VAKO Soyuz, USSR (*tentative*)

ISY

July 1992

July 10. ESA's Giotto spacecraft encounters Comet Grigg–Skjellerup, with associated SAFISY Giotto Extended Mission Flyby Project activities

July 13–16. "Space Enough to Learn" conference of educators—University of Canberra—Canberra, Australia

Mid-July. "Marsville—The Cosmic Village" International Conference—Challenger Center—Kennedy Space Center, Florida

July 16–20. International Aerospace Convention—Aviation Space Education Association and Aerospace Ambassadors—Huntsville, Alabama

July 16–24. Spaceweek 1992

July 20–25. SAFISY World Astronomy Days

July 24–27. International Conference on Space Education and Public Awareness—Mourmelon, France

July 24–27. Worldwide Student Payload Launching Campaign of student-built rockets and experiments—Mourmelon, France

July. SAFISY Global Sea Surface Temperature Project report

July. SAFISY Polar Stratospheric Ozone Working Group meeting

July. Launch of joint US–French TOPEX/Poseidon satellite, which will use radar to study the oceans

July. Launch of Japan's Geotail spacecraft, which will study the Earth's magnetic field

July. American Space School 14-day resident program for high school students—West Chester University—West Chester, Pennsylvania

July. International Space Education Symposium—The Satellite Project (Wales) and The American Space School—United Kingdom

July. International Conference of Young Astronauts and Cosmonauts—Moscow, USSR

July. Satellite Technology Workshop for teachers—West Chester University—West Chester, Pennsylvania

July. Space Workshop for teachers, including an international teleconference—Space School, Brunel University—Uxbridge, England

August 1992

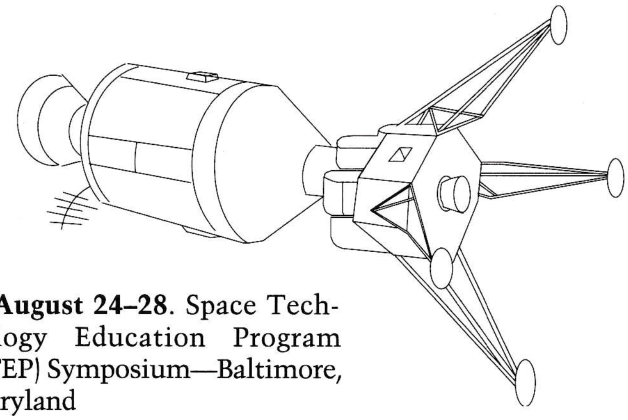
August 27. US National Model Rocket Competition, including ISY launch of rockets with student payloads—Rocket Research Institute and National Association of Rocketry—USA.

August 2–14. International Society for Photogrammetry and Remote Sensing (ISPRS)/ASPRS Congress—Washington, D.C.

August 6–7. UN ISY Workshop on Data Analysis Methods and Applications, in conjunction with ISPRS Congress—Washington, D.C.

August 7. Milky Way Day—Galactic Society

August 8–9. International Symposium on the Exploration of the Sun—Institute of Terrestrial Magnetism and Radio-Wave Propagation—Dnepropetrovsk, USSR (*tentative*)



August 24–28. Space Technology Education Program (STEP) Symposium—Baltimore, Maryland

August 24–29. Planetary Congress—Association of Space Explorers—Washington, D.C.

August 25–30. Pacific Ocean Remote Sensing Conference—Okinawa, Japan

August 28–September 9. World Space Congress—joint meeting of IAF and COSPAR, including presentations, workshops, and exhibitions by many SAFISY Earth and space science projects—Washington, D.C.

August 28–September 9. "Marsville—The Cosmic Village" student designs exhibited in conjunction with World Space Congress—Challenger Center—Washington, D.C.

August 28–September 9. Winners of "Together to Mars" student essay contest convene during World Space Congress—The Planetary Society

August. SAFISY University Education in Space Science and Engineering project report published

August EUVE ultraviolet pointed observations begin, including SAFISY coordinated amateur observations

August European Space School—Space School, Brunel University—United Kingdom or France

August. International Space Camp—The Space & Rocket Center—Huntsville, Alabama

August. ISY/World Space Congress special supplement in *Scientific American* magazine

August. Launch of rockets with student payloads—Rocket Research Institute—Colorado Springs, Colorado

August. "Where Next, Columbus?" exhibit opens—National Air and Space Museum—Washington, D.C.

August. Mobile exhibition on the Soviet space program opens in Washington, D.C. (*tentative*)

Late August. International Space University announces sites and plans for its permanent campus

August–September. UN ISY workshop/symposium—Washington, D.C.

August–September. International Space School—Space School, Brunel University—France or United Kingdom

September 1992

September 12. Rover Expo '92—The Planetary Society—Washington, D.C.

September 6. SAFISY Polar Ice Extent Working Group meeting—Ottawa, Canada

September 6–11. International Space Modeling World

Championships and Research and Development Conference, including Worldwide Student Payload Launching Campaign of student-built rockets and experiments—Rocket Research Institute and National Association of Rocketry—East Coast, USA.

September. SAFISY Global Consequences of Land Cover Change Project results

September. SAFISY Ocean Variability and Climate Project results

September. UN International Seminar on Space Communications for Developing Countries—INTERSPUTNIK—Dubna, USSR (*tentative*)

September. Launch of NASA's space shuttle Atlantis (STS-46 mission)—will place the EURECA-1 European experiment platform in orbit and conduct Italian tethered satellite experiments

September. Launch of NASA's space shuttle Endeavour (STS-47 mission)—will conduct joint experiments with Japan in the Spacelab manned laboratory

September. Launch of NASA's Mars Observer spacecraft en route to Mars

September. CAN-DO student Earth observation payload aboard the space shuttle—Charleston County Public Schools, South Carolina

September. Launch of rockets with student payloads—Rocket Research Institute Smoke Creek Desert, Nevada

September. Mars Observer launch event—The Planetary Society—Kennedy Space Center, Florida

September. Mission to Planet Earth student simulations begin at Challenger Learning Centers across the United States

September–October. SAFISY global change encyclopedia available for distribution—Canada Centre for Remote Sensing

Fall 1992

September–November. ISY art exhibit by Robert T. McCall—with accompanying book *Robert T. McCall's Cosmic Horizons: A Celebration of the International Year of Space*—Society of Illustrators—New York, New York

September or December. Pioneer Venus Orbiter spacecraft enters Venus's atmosphere—with ISY test of international space data distribution system

Fall. Launch of SOAR sounding rocket with student payloads—Rocket Research Institute and Sub-Orbital Academic Research (SOAR) Program—Huntsville, Alabama

Fall. Search for Extraterrestrial Intelligence (SETI) curriculum materials available for use and foreign-language translations get under way SETI Institute

Fall. "Space Age" TV series premieres, with accompanying *Space Age* book—WQED/Pittsburgh

Late 1992. SAFISY International Workshop, Productivity of the Global Ocean Project

Late 1992. SAFISY global change atlas available for distribution

October 1992

October 24. Space '92 conference—Hastings, England

October 3. Rocket City Classic model rocket event, including ISY launch of rockets with student payloads—Rocket Research Institute and Huntsville Area Rocketry Association—Huntsville, Alabama

October 7–10. Technospace 92 Conference and Exhibition: Space Serving Mankind Bordeaux, France

October 8–October 1993. "Blueprint for Space" traveling exhibit appears at National Air and Space Museum, Washington, D.C.—The Space & Rocket Center

October 11–15. International Congress of Aviation and Space Medicine—Tokyo, Japan

October 12. SETI Microwave Observing Project begins

October 14–20. Youth Space Education Week—nationwide activities

October 26–November 6. School on Geospace Physics for developing country scientists—ICTP—Trieste, Italy

October. SAFISY Assessment Symposium and initiation of the Enhanced Greenhouse Effect Detection Experiment (GEDEX)

October. SAFISY MAX '91/Flares 22 Workshop—Crimea

October. Completion of space station simulator—Wausau School District, Wisconsin

October. Educator workshops—The Planetary Society—Colombia and Costa Rica

October. International Symposium on Economic Benefits of Space Activities—Chinese Society of Astronautics and IAA—Beijing, China

October. SETI Microwave Observing Project educational program begins

October. "Space and Your Future" student videoconference—Countdown Foundation, Inc., and Countdown 2000

October–November. SAFISY Polar Stratospheric Ozone Workshop (*tentative*)

November 1992

November 16–20. Asia/Pacific ISY Conference—including presentations/workshops by selected SAFISY Earth science projects—Tokyo, Japan

November. Launch of NASA's space shuttle Columbia (STS-52 mission)—will deploy the Laser Geodynamics Satellite LAGEOS-2, which will measure movements in the Earth's crust

November. All-Union Conference of Museums of Cosmonautics: Man and Space—Moscow, USSR (*tentative*)

December 1992

December 8. Flyby of the Earth by NASA's Galileo spacecraft—to be made into an ISY video

December 8. Galileo encounter events—The Planetary Society—Pasadena, California

December 15–19. SAFISY World Astronomy Days

December. SAFISY Properties of Venus and Mars and Their Relation to Earth Project results published

December. Launch of NASA's Wind spacecraft, which will measure the solar wind

December. Launch of NASA's space shuttle Discovery (STS-53 mission)

December through 1993. SAFISY Polar Ice Monitoring Demonstration, Polar Ice Extent Project

Other activities in 1992

The specific dates of these activities are yet to be determined.

- UN/Indonesia Regional Conference on Space Technology for Sustainable Development—Indonesia
- UN/ICTP Workshop on Remote Sensing Technology—Trieste, Italy
- UN/ICTP Workshop: Bridging the Information Gap in Space Science and Technology—New York, New York
- UN/Sweden International Training Course on Remote Sensing in Education for Educators—Stockholm and Kiruna, Sweden
- Antares mission to the Soviet space station Mir, when a French astronaut will conduct experiments there
- German–Soviet mission to Mir, with a German astronaut conducting experiments on the Soviet space station
- Launch of the Soviet Priroda Ecological Module to dock with Mir, carrying international environmental experiments
- Launch of a Soviet Meteor weather satellite carrying French ScaRaB experiments to measure the Earth's radiation balance
- Launch of Soviet Bion 10 biological satellite
- Testing of German ATMOS Earth observation experiment prototypes
- Launch of Israeli X-Ray Space Telescope
- Launch of Israeli Ultraviolet Space Telescope
- Launch of ISY-METS Microwave Energy Transmission Experiment—Japan
- Press Seminars on Rain Forest Ecology—International Science Writers Association—Brazil
- Space Science Seminar for Teachers from Developing Countries—China
- "A Wrinkle in Time" space-based opera premieres, with student participation through the Opera, Spheres, and Space program—Delaware Aerospace Center
- International Conference on Space and the Global Problems Confronting Mankind on the Threshold of the 21st Century—Moscow, USSR (*tentative*)
- International Youth Congress: Potential Problems of Cosmonautics and Space Research—Moscow State Technical University—Moscow, USSR (*tentative*)
- Training Workshops on Space Science Education for Teachers in Developing Countries—Institute for Science and Math Education, University of the Philippines (*tentative*)

Activities in 1993

The following are selected ISY-related events that are scheduled to take place in 1993.

February. SAFISY Polar Ice Extent Workshop—Japan

March. SAFISY Impact of the Discovery of Extraterrestrial Life Project report published

March. Launch of German Synthetic Aperture Radar in the X-Band (X-SAR) instrument aboard the US space shuttle Columbia

Early 1993. SAFISY Symposia on Biomedical Consequences of Living in Space proceedings published

May. SAFISY World Astronomy Days results workshop

Mid/late 1993. SAFISY World Astronomy Days results published

1993 (no date set). UN/ESA Africa Space Conference—Nairobi, Kenya

1993 (no date set). UN/Greece International Seminar on Space Communications Systems—Greece

1993–94. Launch of Columbus 500 Solar Sail Race vehicles

Ongoing programs

See the calendar above for specific premiere or event dates.

SAFISY Earth Science Projects:

- Global Consequences of Land Cover Change
- Enhanced Greenhouse Effect Detection Project
- Ocean Variability and Climate
- Polar Stratospheric Ozone
- Productivity of the Global Ocean
- World Forest Watch
- Global Sea Surface Temperature
- Polar Ice Extent
- Global Satellite Image Mapping
- Space and Disaster Prevention, Preparedness, and Relief
- Global Change Encyclopedia
- Global Change Atlas
- Global Change Video

SAFISY Space Science Projects:

- Simultaneous Multispectral Information from Astrophysical Sources ("World Astronomy Days")
- Astrophysics Data System
- Compact Disk of Astronomical Catalogs
- MultiWaveLink
- Guest Observer Programs on Astrophysical Missions
- Gamma Ray Burst Patrol
- Symposia on Biomedical Consequences of Living in Space

- Biological Significance of Environmental Parameters of Space and Space Flight
- The Impact of the Discovery of Extraterrestrial Intelligent Life
- A Bibliography of Microgravity Environments on Spacecraft
- Symposium on International Microgravity Laboratory
- Properties of Venus and Mars and Their Relation to Earth
- Giotto Extended Mission Flyby
- International Halley Watch Archive
- Pioneer Venus Orbiter Entry Science
- Planetary Data System CD-ROM Plan
- Planetary Science Balloon Flights
- Solar SystemGalaxy Interaction
- Coordinated Studies of Solar Active Phenomena
- Max '91
- Middle Atmosphere Dynamics and Composition
- Thermosphere and Ionosphere Coupling Study
- Atlas of the Solar System
- University Education in Space Science and Engineering
- Solar System Visualization Coordinated Astrophysical Activities Using Data from EUVE and FAUST
- Perspectives from Space
- UN-assisted establishment of Centers for Space Science and Technology Education
- UN Educational Videos
- UN Monthly ISY Lectures—New York, New York
- UN/ESA Collection, Analysis, and Application of Satellite Data Sets for selected African countries
- UN/ICTP collection and distribution of literature on space science and technology to Third World libraries
- NASA Advanced Design Program for college engineering students
- NASA Aerospace Education Services Project ("Spacemobile")
- NASA National Space Grant College and Fellowship Program
- NASA Report to Educators
- NASA SpaceLink computer database
- NOAA Direct Readout Program
- Additional Japanese ISY activities (for example, an international directory of space data, television events, space science museum)
- Medgeobase Geographical Information System database programs in North Africa—European Community, World Bank, Centre National d'Etudes Spatiales (CNES—France)
- Mission to Planet Earth activities—Spain
- Remote Sensing for Forest Management activities—Sweden
- Acoustic astronomy research—Dr. Fiorella Terenzi, Italy
- Astronomy Education newsletter articles on ISY—Association of Astronomy Educators
- "Blue Planet" IMAX film—National Air and Space Museum, Washington, D.C., and other locations worldwide
- EURISY newsletter
- EURISY TV Newsflash bulletins on European television
- Gemini spacecraft model and simulations—Asa C. Adams Elementary School, Maine
- Ground Truth Studies Project—Aspen Global Change Institute
- ICASE teacher resource materials
- ISY comic book "Adventures on Santa María and Future Ships Sailing the Oceans of Space"—TADCORPS
- ISY Earth science program in China
- *La Lettre spatiale du Québec* space newsletter articles on ISY
- Maple Aerospace and Young Astronaut Program—Maple Elementary School, Michigan
- "Marsville—The Cosmic Village" student space simulation project—Challenger Center
- Opera, Spheres, and Space student project—Delaware Aerospace Center
- PROJECT ExPEDITE interdisciplinary use of satellite data in the classroom—Marple Newtown School District, Pennsylvania
- Shuttle and space station simulations—Wausau School District, Wisconsin
- Southern California Association of Science Specialists ($SCAS^2$) ISY activities
- SpaceArc collection of time capsule contributions—Rochester Museum and Science Center, New York
- "Spaceship Earth: A Global Geography" TV series—South Carolina Educational Television
- Space Technology Education Program (STEP)—ERIM
- Teachers Information Network computer database on ISY
- Teaching Space newsletter articles on ISY
- "A Thousand and One Mirrors Watching the Earth" video—EURISY
- "Visions of Exploration" curriculum materials—*USA TODAY*
- "A Year in the Life of Satellite Tracking" worldwide student collection of satellite images—Unionville High School, Pennsylvania
- Young Astronaut ISY curriculum and educational materials
- Young Astronauts/Cosmonauts joint projects
- International Continuing Education Program for Teachers—Moscow Aviation Institute, USSR (*tentative*)
- International E-Mail Teleconferences for students—BAITIC Educational Center, USSR (*tentative*)
- Student experiments and educational television programs aboard the Soviet space station Mir (*tentative*)

ISY

- UN Booklet on Mission to Planet Earth
- UN Booklet on Space Education
- UN Booklet on "Universariums"
- UN Marine Resources and Coastal Environmental Projects—West Africa, Indian Ocean, Caribbean Sea, and Latin America
- UN National Essay Contests
- UN/Houston Museum of Natural Science Program on Live Observation of Artificial Space Objects
- UN/USSR Project on Acquisition, Processing, and Transfer of Remote Sensing Data for developing countries
- NASA ISY Interactive Satellite Videoconferences for students and educators
- NASA/NSTA Space Science Student Involvement Program (SSIP)
- NOAA Directory of Earth Observation Resources for Educators
- NOAA Educator's Guide for Building and Operating an Environmental Satellite Receiving Station
- National Science Foundation science and engineering education programs
- Atlas of the Earth's Group of Planets and Their Satellites—Moscow Institute of Engineers for Geodesy, Aerial Photosurveying, and Cartography
- Cartography of Hazards from Geological Instabilities project—CNES, France
- Expansion and improvement of Earthnet Coordinated TIROS Network's Earth observation data system—ESA
- German applications of ERS-1 Earth observation data
- "Age of Discovery" video—Unionville High School, Pennsylvania
- Australian ISY activities (e.g., museum exhibits, media programs, educational projects)
- "Blueprint for Space" exhibit and book—The Space & Rocket Center, Huntsville, Alabama and other locations nationwide
- British Industry in Space Year 1992 (BISY92) activities—including satellite and television broadcasts, exhibitions, and a lecture series
- Cable News Network (CNN) NEWSROOM student news service programming on ISY
- CD-ROM Disk on Satellite Technology—Satellite Educators Association
- E.T., the Extraterrestrial, serves as ISY Ambassador for Children
- EURISY audiovisual show
- EURISY dinner debate series on space issues
- EURISY student ISY competition
- Global Laboratory student "ground truth" project—Technical Education Research Centers (TERC)
- Global Student Village international network of schools—Consortium for International Earth Science Information Network (CIESIN)
- Golden Gate Space Frontier Society activities—San Francisco Bay Area, California
- Institute for Security and Cooperation in Outer Space (ISCOS) International Exchange Program
- ISCOS Spaceline newsletter
- International Exhibition of Space Art—Moscow, USSR and elsewhere
- ISY Resource Compendium for Educators—NSTA
- *National Geographic World* children's magazine articles on ISY
- "Our Sun-Earth Environment" traveling exhibit—National Air and Space Museum, Washington, D.C. and other locations nationwide
- PEACESAT extension of Pacific region satellite network
- "Planet Earth" videodisc series—The Discovery Channel
- Project Horizon global computer network for educators, including local Delaware Valley DEVALnet—West Chester University, Pennsylvania
- Satellite maps of China
- SETI curriculum materials—SETI Institute
- "Space Age" TV series—WQED/Pittsburgh and NHK
- Spaceship Earth Teaching Classroom Project—ISCOS
- Space Visitor Center—National Space Research Institute (INPE)—São José dos Campos, Brazil
- Sri Lanka Science Students Association activities
- "Star Trek: Federation Science" traveling space science exhibit—Oregon Museum of Science and Industry, Portland, Oregon and other locations nationwide
- Student Satellite World Weather Watch—West Chester University, Pennsylvania
- "Students Watching Over Our Planet Earth" (SWOOPE)—Department of Energy
- Western Amateur Astronomers activities
- "Where Next, Columbus?" exhibit—National Air and Space Museum—Washington, D.C.
- World Timecapsule Fund—US students contribute essays for launch in the year 2000
- Worldwide Database of Satellite Data Applications—European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT)
- Academic Aerospace Correspondent Program—VAKO Soyuz, USSR (*tentative*)
- "Art of the Cosmos" ISY traveling art exhibit and video—International Association for the Astronomical Arts (*tentative*)
- Discovery Constellation space sculpture by James Pridgeon (*tentative*)
- Earth Observation from Space as an Educational Resource program—BAITIC Educational Center, USSR (*tentative*)
- International children's art competition—Association of Space Museums of the USSR (*tentative*)
- International Space Training Center for Granat spacecraft—Moscow Aviation Institute (*tentative*)
- ISY commemorative stamps—worldwide (*tentative*)
- ISY International Telecommunications Network—IEEE (*tentative*)
- ISY Sculpture on the Global Change Encyclopedia by Rhonda Roland Shearer (*tentative*)
- ISY Solar Sailing Telecommunications Simulation—

University School, Ohio (*tentative*)
- Israeli production of satellite maps for schools
- Mobile Exhibition on the Soviet Space Program—Washington, D.C., and New York, New York (*tentative*)
- Moscow Aviation Institute Journal articles on ISY (*tentative*)
- Music from the Galaxies by Dr. Fiorella Terenzi (*tentative*)
- Orbiting Ring Unification Satellite (OURS) sculpture in space (*tentative*)
- Phobos globe—Moscow Institute of Engineers for Geodesy, Aerial Photosurveying, and Cartography (*tentative*)
- "Protection of the Environment for Assuring a Cleaner Earth" (PEACE) international remote sensing mission planning (*tentative*)
- Scientific and Technical Olympiad on Space Topics student competition—Moscow Physical Technical Institute (*tentative*)
- Space encyclopedia—Progress Publishing House, USSR (*tentative*)
- Textbooks and electronic systems for satellite education—GEOSPACE, Austria (*tentative*)
- United States Space Foundation exhibits (*tentative*)
- Worldwide delivery by satellite of space research educational programs—European Space Agency (*tentative*)
- "You Experiment in Space" student competition—USSR (*tentative*)

Activities in 1992

Here's a descriptive list of ISY activities planned for 1992, organized under two broad headings: (1) SAFISY science projects and (2) ISY public and educational activities.

SAFISY science projects

Earth science

Space data for global change

Global Consequences of Land Cover Change—Space observations are being used to generate maps and numerical data on recent vegetation and soil trends in selected areas, to serve as a basis for continued monitoring and prediction of such phenomena as desertification, deforestation, pollution, and agricultural patterns (led by Australia, France, and the Soviet Union).

Enhanced Greenhouse Effect Detection Project—This effort is attempting to use satellite and ground-based data to establish a firm scientific foundation for the detection of global warming and its consequences, which many believe are caused by the buildup in the atmosphere of carbon dioxide and other gases that are byproducts of human activity (led by the United States).

Ocean Variability and Climate—Case studies will be published in 1992 to assess the interrelationship between

various sea phenomena and changes in climate, using new high-quality satellite data on ocean winds, surface waves, polar and sea ice, temperature, humidity, and other marine factors (led by the European Space Agency).

Polar Stratospheric Ozone—This effort is combining space-based, ground-based, and airborne measurements to lay foundations for an improved understanding of ozone in the Earth's atmosphere, including assessment of the ozone "holes" over the poles (led by Germany and the United States).

Productivity of the Global Ocean—Using satellite information on ocean color and related phenomena, this project will collect and distribute the entire global set of marine chlorophyll data and assess the role of phytoplankton (minute sea organisms) in the world's carbon cycle, which is a factor in global warming (led by Canada and the European Community's Joint Research Center).

World Forest Watch—This effort's goal is to improve the use of spaceborne data in inventorying the world's forests and monitoring changes in them, resulting by 1992 in a global survey of tropical and temperate zone vegetation and determination of the rate of deforestation in selected areas (led by Brazil and the European Community's Joint Research Center).

Global Sea Surface Temperature—To improve the ocean temperature data that is essential for global atmosphere/ocean circulation models and prediction of adverse weather phenomena such as El Niño in the central Pacific, this project will compile, calibrate, and verify satellite and ground-based information for selected sites by 1992 (led by Japan and the United Kingdom).

Polar Ice Extent—This program is producing a space-based data set on recent seasonal changes in the extent and motion of Arctic and Antarctic sea ice, resulting by 1992 in demonstration systems for real-time ice monitoring and prediction (led by the European Space Agency and Japan).

ISY

Global Satellite Image Mapping—The first high-resolution satellite maps of the entire Earth's land surface will be produced by this effort, with different versions providing a database for studies of land use, climate change, topography, and other factors. Pilot maps of selected areas will be completed by 1992, with the full project finished by the year 2000 (led by Austria).

Space and Disaster Prevention, Preparedness, and Relief—This project is designed to demonstrate the potential of space technology to improve warning systems, reduce hazards, and assist relief efforts for natural disasters such as volcanoes, landslides, severe storms, flooding, wildfires, and drought (led by the International Astronautical Federation).

Global change outreach

Global Change Encyclopedia—To increase public awareness of global change and the value of space observations of the Earth, an animated computer-based encyclopedia is being compiled for wide distribution that will show changes in the Earth's weather, vegetation, ocean currents, and other environmental phenomena, through movielike animation and interactive software (led by Canada).

Global Change Atlas—This reference publication and "coffee-table book" will provide satellite images, conventional maps, and basic global change data to scientists, educators, students, and the general public, especially in developing countries (led by Austria).

Global Change Video—A video composed of computer-animated satellite images of Earth is being produced to educate the public about global change, illustrating how natural processes and human activities have altered the planet's landscape and environmental conditions over the past two decades (led by Germany and the United Kingdom).

Space Science

Astrophysics

Simultaneous Multispectral Information from Astrophysical Sources ("World Astronomy Days")—The world's major astronomy facilities, including ground and space-based optical, infrared, radio, ultraviolet, X-ray, and gamma ray instruments, will for the first time simultaneously observe selected celestial objects on prearranged days in 1992 (led by the European Space Agency and the United States).

Astrophysics Data System—A new and comprehensive computer database system for astrophysics, which will allow users direct access to spacecraft mission data at their own terminals, will be established by 1992 across the United States, with a start made on expanding the system to include Europe and Japan (led by the United States).

Compact Disk of Astronomical Catalogs—To make astronomical data more accessible to scientists worldwide, at least 100 of the most requested astronomical catalogs—including such information as the positions and characteristics of stars and the results of space missions—are being placed on CD-ROM computer disk and distributed internationally (led by the United States).

MultiWaveLink—To assist astronomers in coordinating observations among facilities studying the heavens in different wavelengths (for example, visible light, radio waves, ultraviolet), an interactive computer database is being established providing such information as the schedules of major space-craft and ground observatories, lists of potential targets, and notices of observing opportunities (led by the United States).

Guest Observer Programs on Astrophysical Missions—Astronomers worldwide are being invited to submit proposals to analyze data from past space missions and participate in new observations using such spacecraft as the Hubble Space Telescope, Gamma Ray Observatory, and Extreme Ultraviolet Explorer (led by the United States).

Gamma Ray Burst Patrol—The Gamma Ray Burst Network, a coordinated international observing campaign, will seek to improve our understanding of gamma rays by comparing data obtained from ground observatories and such spacecraft as the Pioneer Venus Orbiter, Ulysses, the Gamma Ray Observatory, Mars Observer, and Wind (led by the United States).

Life sciences

Symposia on Biomedical Consequences of Living in Space—International symposia in March and August 1992 will assess the biomedical issues associated with human exploration of space, including limitations and problems posed by human space flight, effects of long-duration missions, space life science research, life support systems, space habitats, and radiation risks (led by the United States).

Biological Significance of Environmental Parameters of Space and Space Flight—This project is developing improved methods for the evaluation of physical data from space (for instance, radiation, temperature, pressure, atmosphere composition) as they relate to the study of life on Earth, resulting in a test case assessing a specific region of our planet by 1992.

The Impact of the Discovery of Extraterrestrial Intelligent Life—Scientists and other leaders will join together to assess issues related to the search for extraterrestrial intelligence (SETI), focusing on the consequences and the actions that should be taken in the event that intelligent life is discovered beyond the Earth (led by the United States).

Materials sciences

A Bibliography of Microgravity Environments on Spacecraft—An international committee is assembling, and will establish procedures to update, an ongoing database of vibration measurements and other information on the effects of microgravity ("weightlessness") in spacecraft (led by the United States).

Symposium on International Microgravity Laboratory—A multinational symposium in August 1992 will assess results of the February 1992 flight of the International Microgravity Laboratory aboard the US space shuttle, discussing both scientific findings and the implications for future long-term international missions aboard the space station Freedom (led by the United States).

Planetary exploration

Properties of Venus and Mars and Their Relation to Earth—Three international meetings in August 1992 will use the latest spacecraft data to assess the atmospheres and geology of Venus and Mars, future missions to these neighboring planets, and the insights they may give us about the Earth (led by the Soviet Union and the United States).

Giotto Extended Mission Flyby—This program will use existing data and the Giotto spacecraft's July 1992 flyby of Comet Grigg–Skjellerup to explore the origin and composition of comets, assess their role in the formation of the solar system and the emergence of life, and improve the worldwide distribution of related information (led by the European Space Agency).

International Halley Watch Archive—Results from the worldwide coordinated observations of Halley's Comet obtained during 1982–90 will be distributed in print and on a set of CD-ROM disks in 1992 (led by the United States).

Pioneer Venus Orbiter Entry Science—This project will utilize the Pioneer Venus Orbiter's late 1992 entry into the Venusian atmosphere to increase our understanding of that planet and to demonstrate improved methods for the rapid processing and distribution of spacecraft data (led by the United States).

Planetary Data System CD-ROM Plan—This project will expand worldwide access to NASA's 25-year archive of information on other planets by placing much of it on CD-ROM disks, beginning with data obtained from the Mariner 9 and 10, Viking, Voyager 1 and 2, and Magellan spacecraft (led by the United States).

Planetary Science Balloon Flights—A joint US–Soviet balloon campaign in 1992 will test prototype gamma-ray detectors over Antarctica to help evaluate and calibrate instruments that could be used in future missions to other planets, such as the US Mars Observer and Soviet Mars '94 (led by the Soviet Union and the United States).

Space physics

Solar System–Galaxy Interaction—Using current spacecraft data from Ulysses, Voyagers 1 and 2, and Pioneers 10 and 11, this effort will study the heliopause—the frontier between our solar system and interstellar space—and try to determine what effect the interaction between solar system and galactic material may have on the Earth's environment (led by the European Space Agency).

Coordinated Studies of Solar Active Phenomena—This worldwide campaign will coordinate spacecraft, balloon, and ground-based observations of the Sun to improve our understanding of solar flares, our star's variability over time, and the implications of solar activity for manned space flight (led by Japan, the Soviet Union, the United States, and the international Scientific Committee on the Solar–Terrestrial Energy Program).

Max '91—To improve our ability to predict solar flares, bulletins will be issued to coordinate the solar observations of space- and ground-based facilities worldwide, and new instruments will study the Sun from balloons launched over Antarctica during 1991–92 (led by the United States).

Terrestrial atmospheres

Middle Atmosphere Dynamics and Composition—Sounding rockets and ground-based instruments are being used in a multinational effort to improve our understanding of the movement and chemistry of selected layers in the Earth's atmosphere, focusing on such features as polar noctilucent clouds—the little-known highest clouds in Earth's skies (led by Germany, Norway, Sweden, Switzerland, and the United States).

Thermosphere and Ionosphere Coupling Study—This project will utilize ground-based instruments and global computer simulations to study the structure and flow of certain layers in our planet's atmosphere and the related aurora borealis ("northern lights") phenomenon (led by Norway and the United Kingdom).

Education and outreach

Atlas of the Solar System—High-quality maps, photo mosaics, and geologic charts of all the planets and moons in our solar system, including the latest data from the Magellan mission to Venus, are being compiled for the first time into a single atlas with a common format and descriptive text (led by the United States).

University Education in Space Science and Engineering—A worldwide survey of higher education in the various fields of space science and engineering is being conducted, initiating a process to improve and expand space education at the college level (led by Israel).

Solar System Visualization—A set of "movies" portraying all the major planets and moons of our solar system is being created, using the latest computer animation techniques to process spacecraft images collected over the past 25 years, as well as data from new missions such as Magellan's mapping of Venus and Galileo's Earth–Moon flyby in December 1992 (led by the United States).

Coordinated Astrophysical Activities Using Data from EUVE and FAUST—Amateur astronomy groups, schools, and universities around the world are being invited to participate in ground observations that will be coordinated with the findings of the Extreme Ultraviolet Explorer (EUVE) and Far Ultraviolet Space Telescope (FAUST) spacecraft (led by the United States).

ISY

The USSR Academy of Sciences hosted SAFISY IV, drawing representatives from 39 countries and international organizations (see page 54 for a list of SAFISY members and affiliates).

Perspectives from Space—A set of posters and associated teacher's guides is being produced to educate elementary school students on key concepts in space science and exploration—including the new perspectives we have gained on the Earth's environment, the solar system, the origin of life, international cooperation, and humanity's position in the cosmos (led by the United States).

Related contributions of SAFISY members

Atlas of the Earth's Group of Planets and Their Satellites—The Moscow Institute of Engineers for Geodesy, Aerial Photosurveying, and Cartography is producing an atlas with detailed maps, charts, and text describing the inner terrestrial planets Mercury, Venus, Earth, Mars, and their moons.

ATMOS—Germany is developing this satellite, scheduled for launch in 1995, that will study the chemistry of Earth's atmosphere and the productivity of the oceans. Prototypes of some of its instruments will fly aboard aircraft and/or the US space shuttle to obtain first results during ISY 1992.

Bion 10—The Soviet Union plans to launch this international biological satellite in conjunction with ISY, as well as compiling the results of the entire Bion series of spacecraft that have studied the effects on living things of microgravity, cosmic radiation, and other factors in the space environment.

Cartography of Hazards from Geological Instabilities—The French space agency, Centre National d'Etudes Spatiales (CNES), is conducting training for South American officials and developing improved methods for the use of remote sensing in assessing the risks of landslides in Colombia and volcanic eruptions in Peru.

Earthnet Coordinated TIROS Network—The European Space Agency's Earthnet system, which acquires, processes, catalogs, and distributes Earth observation satellite data, plans for ISY to expand, speed up, and reduce the cost of access to information from the Advanced Very High Resolution Radiometer (AVHRR) carried aboard TIROS/NOAA remote sensing satellites.

EURECA—The European Retrievable Carrier (EURECA) is an experiment platform scheduled to be placed in Earth orbit by the US space shuttle in September 1992; it will stay in space for six months to conduct materials and life science experiments and then be retrieved.

German Applications of ERS-1—Germany will be using initial results from the European Remote Sensing Satellite ERS-1, scheduled for launch in mid-1991, to produce a radar map of Germany, study ice coverage and geology in Antarctica, and conduct other applications of remote sensing technology.

German–Soviet Life Science and Materials Science Experiments—Germany and the USSR have agreed to undertake a joint mission to the Mir space station in spring 1992 that will conduct life science and materials science experiments in orbit.

International Space Training Center for Granat—The Moscow Aviation Institute is working to found for ISY '92 a new international center for the training of space scientists who will use the Soviet Union's new Granat space laboratories.

Israeli Space Telescopes—Israel plans to launch in 1992, as part of ISY, two satellites containing small space telescopes: one with new X-ray sensor equipment and another that will be able to generate ultraviolet images of distant stars that are 500 times fainter than those previously viewable from satellites.

ISY Earth Science Program in China—Researchers in the People's Republic of China are using satellite data to conduct studies of deforestation, desertification, soil erosion, and global warming, while others plan to publish satellite maps of China for ISY 1992.

ISY–METS Rocket Experiment—Japan is planning a Microwave Energy Transmission in Space (METS) experiment in which a two-part rocket will be launched in 1992 to test the beaming of microwave energy from one spacecraft to another, as a prelude to more advanced large-scale uses of solar power in space.

Japanese ISY Activities—In addition to playing a major role in several SAFISY science projects, Japan is planning such other ISY activities as satellite training seminars for developing countries, an ISY commemorative symposium for the Pacific region, an international directory system for space data, ISY television events, and creation of a space science museum.

Medgeobase Geographical Information System—With the help of the European Community, the World Bank, and the French space agency CNES, multidisciplinary teams in North Africa are being trained to set up and maintain an environmental and geographical database on Mediterranean coastal zones, using remote sensing data that complements the Corine Land Cover program of European Mediterranean countries.

Meteor Meteorological Satellites—Two of these Soviet spacecraft are scheduled for launch during 1991–92 carrying Franco–Soviet ScaRaB experiments to measure the

Earth's "radiation balance"—the amount of electromagnetic energy received by the Earth and emitted back into space—and American TOMS equipment to measure ozone in our atmosphere.

Monitoring Deforestation in Southeast Asia—The South East Asian Ministers of Education Organization (SEAMEO) is working with France, Japan, the European Community, and the UN Food and Agriculture Organization to train Third World forestry officials in the use of satellite technologies to evaluate deforestation.

NASA Earth and Space Science Missions—In addition to being a key participant in numerous SAFISY science projects, NASA is planning other contributions that would draw on the more than 30 Earth and space science missions the agency has planned between 1989 and 1992.

Phobos Globe—The Moscow Institute of Engineers for Geodesy, Aerial Photosurveying, and Cartography is manufacturing a globe of the Martian moon Phobos, which was recently visited by a Soviet spacecraft.

Priroda Ecological Module—The USSR, in cooperation with other socialist countries, plans to launch the Priroda ("Nature") module in 1992 to dock with the Soviet Mir space station and carry a variety of international experiments to monitor the state of the environment.

Remote Sensing for Forest Management—In conjunction with the SAFISY World Forest Watch project, Sweden is conducting a number of programs that use satellite data to monitor, map, and assess forests in the Sudan, Thailand, and the Philippines, as well as at home in Scandinavia.

SCD-1—Brazil's first satellite, the Earth observation spacecraft SCD-1, is scheduled for launch in the spring of 1992 as a contribution to ISY.

Space Oceanography Cruise—The Marine Hydrophysical Institute of the Ukrainian Academy of Sciences is planning a 60-day scientific cruise in May–June 1992 which will train students in the application of remote sensing technologies to oceanography.

Spanish Mission to Planet Earth Activities—Spain is contributing to ISY's Mission to Planet Earth by participating in European spacecraft projects such as Meteosat and ERS-1, conducting training courses in remote sensing applications and meteorology for Latin Americans, and hosting a November 1991 symposium in Seville on Remote Sensing and the Environment.

Study of Urban Pressure on Farming Land—The French space agency CNES is training town planners and managers in Africa on the use of satellite images in monitoring, managing, and planning for urban growth.

Worldwide Database of Satellite Data Applications—EUMETSAT, a satellite operations arm of the European Space Agency, plans to expand worldwide an applications directory now under development for European and US satellite data.

X-SAR—Germany is producing a Synthetic Aperture Radar in the X-Band (X-SAR) instrument that will fly aboard the joint US–Italian–German Shuttle Radar Lab mission in early 1993 and provide images of soil and vegetation on Earth, regardless of cloud cover or darkness. Germany is working with Brazil and Italy to use the radar images in a study of tropical rain forests.

Related contributions of the United Nations, a SAFISY affiliate

Acquisition, Processing, and Transfer of Remote Sensing Data—The USSR will make satellite photographs available free of charge in 1992 to a number of developing nations, providing them with environmental and Earth resources information on their countries.

Booklet on Mission to Planet Earth—The United Nations is producing a booklet describing the variety of Earth science programs that are being conducted around the world in conjunction with ISY's Mission to Planet Earth theme, to be made especially available to educators, scientists, libraries, and decision-makers in the developing world.

Collection, Analysis, and Application of Satellite Data Sets—The European Space Agency will provide data free of charge to selected African countries observed by existing US and French spacecraft and by the European Remote Sensing Satellite ERS-1 that is scheduled for launch in 1991, with training on remote sensing technology to be provided for African technicians.

Cooperation with Nongovernmental Organizations—The UN is developing a workshop/symposium on space applications for Third World countries in conjunction with the World Space Congress in August–September 1992 in Washington, D.C.

International Conference on Satellite Remote Sensing—A US-sponsored meeting on remote sensing applications for Third World resource management and environmental assessment will be convened in Boulder, Colorado, from April 27 through May 1, 1992, followed by a three-day workshop on environmental data exchange.

Marine Resources and Coastal Environmental Projects—The UN Outer Space Affairs Division is offering support to international cooperative projects that are studying and managing marine resources and coastal environments in the Indian Ocean region and possibly in other coastal areas of Africa, Latin America, and the Caribbean.

Regional Workshop on Space Technology for Resource Development and Environmental Management—This March 1992 workshop in Quito, Ecuador, cosponsored by the government of Japan, will expose resource managers and environmental planners from Latin America and the Caribbean to the capabilities and applications of current remote sensing spacecraft and of future programs such as

ISY

the Earth Observation System (EOS).

NOTE: *In addition to the above projects, many SAFISY members and the United Nations are developing or supporting educational activities (see the following section).*

ISY public and educational activities

A number of these activities were initiated through SAFISY, are supported by SAFISY members, or were inspired by SAFISY initiatives. For additional information on educational activities, please see the *International Space Year Educational Activities Catalogue* published by the Educational Affairs Division, NASA Headquarters, Code XE, Washington, DC 20546.

Confirmed activities

Films and television

"Space Age"—National public television in the US will air an eight-part series on space exploration in 1992, jointly produced by WQED of Pittsburgh and NHK of Japan in association with the National Academy of Sciences and supported by NASA. The series will be dedicated to the global themes of ISY and will include accompanying educational support materials.

"Age of Discovery" Video—In commemoration of ISY, the 500th anniversary of Columbus' voyage, and the 350th anniversary of Isaac Newton's birth, students of Unionville High School in Pennsylvania are producing a video about humanity's ongoing age of discovery, from the ancient Greeks to today's spacecraft. Contact: Helen E. Martin, (215) 347-1600.

"Blue Planet"—This IMAX/Omnimax large-format film, inspired by ISY and featuring footage of planet Earth taken from orbiting space shuttles, is playing at the National Air and Space Museum in Washington, D.C., and other theaters worldwide. Contact: NASM, (202) 357-2700.

British Industry in Space Year 1992 (BISY92) Broadcasts—BISY92, a joint effort of British industry and government, plans to establish satellite links for cultural, civic, and business exchanges between the United Kingdom and major international cities; pair up schools in the UK with those elsewhere in Europe via satellite video; and obtain media coverage for ISY events on television and radio.

Cable News Network (CNN) Programming—The CNN NEWSROOM student news service, distributed to more than 16,000 schools in the United States and overseas, will feature special ISY programming on Mission to Planet Earth throughout 1992. Contact: Gary R. Rowe, (404) 827-2145.

EURISY T.V. Newsflash—The European Association for International Space Year (EURISY) is producing an ongoing series of television bulletins providing European viewers with information on environmental questions using satellite data. The effort will be expanded in 1992 in cooperation with the United Nations.

Finnish Television Special—The Helsinki-based production company Oy Nordic Network Ab is producing a program in honor of ISY for the Finnish Broadcasting Company (YLE) and the Finnish Technology Development Centre (Tekes). It will air on Finnish national television in January 1992 and focus on Finnish, European, and international space research.

ISY Global Telecast—There will be a worldwide telecast dedicated to ISY's central theme of Mission to Planet Earth, broadcast from several world capitals on April 19, 1992, in honor of Mission to Planet Earth Day.

"Marsville" Videoconferences—In conjunction with its "Marsville—The Cosmic Village" educational program, the Challenger Center for Space Science Education will be conducting four interactive satellite videoconferences in which students from around the world will link up to assess key issues in a simulated mission to Mars. Contact: Richard A. Methia, (703) 683-9740.

NASA ISY Interactive Satellite Videoconference Series—NASA plans to expand internationally for ISY its series of satellite videoconferences for students ("Golden Years of Space Science") and educators ("Update for Teachers") on topics related to space science/technology and how it affects those on Earth. Contact: Sherri McGee, (202) 453-8344.

PEACESAT Expansion—PEACESAT, the University of Hawaii, and the US National Telecommunications and Information Administration are working together to expand by 1992 the PEACESAT satellite network and its educational television/telecommunications services to Pacific island nations. Contact: William Cooperman, (202) 377-5802.

"Planet Earth" Videodisc Series—The Discovery Channel is developing a set of three educational videodiscs based on WQED/Pittsburgh's "Planet Earth" television series, with accompanying interactive computer software, classroom guides, and student Earth science activities. Contact: Michael Heasley, (301) 986-0444, ext. 5608.

"Space and Your Future" Videoconference—This nationwide videoconference and associated events for students in grades 7–12, scheduled for October 1992, are designed to instill an interest in space exploration, science education, space-oriented careers, and the applications of space technology here on Earth. Contact: Countdown Foundation, (703) 352-2876.

"Spaceship Earth: A Global Geography"—South Carolina Educational Television is producing, in partnership with European broadcasters, a ten-part public TV series that will preview ISY's global Mission to Planet Earth theme in late 1991, using images from space and the ground to help viewers understand the Earth system and humanity's role in it. Videocassettes of the series and accompanying educational materials are available. Contact: SCETV, (800) 277-0829.

"A Thousand and One Mirrors Watching the Earth"—EURISY has produced this video explaining the usefulness of space technologies in monitoring and preserving the Earth's environment. Contact: EURISY, (33) (1) 47-05-1779.

UN Educational Videos—The United Nations is sponsoring the production, broadcast, and worldwide distribution of video programs to educate students and the general public on space science, technology, history, current missions, future trends, and global applications in such areas as communications, navigation, study of the environment, and food production. The Institute for Security and Cooperation in Outer Space (ISCOS) is handling production of the series.

UN ISY Telecast—A June 1992 global telecast on Mission to Planet Earth, broadcast in conjunction with the United Nations Conference on Environment and Development, will explain the role of space technology in solving environmental problems. The International Telecommunications Satellite Organization (INTELSAT) and its socialist counterpart INTERSPUTNIK are assisting with the telecast.

Young Astronaut Video and Satellite Broadcast—An ISY educational video, focusing on the benefits to mankind from space exploration and the human need to explore, will be broadcast via satellite and distributed on videotape to more than 25,000 US schools. Contact: Young Astronauts, (202) 682-1985.

Student and teacher activities

American Space School—This new school, headquartered at West Chester University in Pennsylvania, plans to become fully operational during ISY. Its objective is to provide space-related curriculum materials and summer and correspondence courses for high school students, including a two-week resident session in July 1992. Contact: Thomas W. Becker, (314) 997-0937.

CAN-DO Project—The Charleston County Public Schools in South Carolina are producing a student payload experiment that will be carried on the US space shuttle in 1992. Cameras will take some 1,000 visible-light and infrared photographs of Earth that will be disseminated widely among local and other schools.

CD-ROM Disk on Satellite Technology—The Satellite Educators Association, along with West Chester University and Unionville High School in Pennsylvania, have set ISY 1992 as their goal for completing the initial version of a CD-ROM computer directory of resources available to teachers who use satellite data in the classroom. Contact: Lisa M. Wilson, (215) 436-2233.

Centers for Space Science and Technology Education—The United Nations is assisting member countries, particularly in Africa and other developing areas, in the establishment of regional centers that will train educators in the integration of space science and technology into their nations' higher education programs.

Educator Workshops in Latin America—The Planetary Society is planning space science sessions for educators in Colombia and Costa Rica in October 1992.

European/International Space School—Space School, affiliated with Brunel University in the United Kingdom, conducts summer and vacation courses on space for European and international students at the secondary school and undergraduate college level. Contact: Rodney Buckland, (44) 895 271490.

European Student Competition—EURISY, the European ISY association, is organizing a Europe-wide ISY competition for young people at the secondary school and university level.

E.T.—Steven Spielberg's famous extraterrestrial science fiction character, E.T., has agreed to serve as the ISY Ambassador for Children, and specific E.T. activities for elementary school students are being planned.

Explorations in Space and Astronomy Day—The Johns Hopkins Space Grant Consortium has included sessions on ISY in this September 1991 event in Baltimore for students and their parents.

Gemini Spacecraft Model and Simulations—Students at Asa C. Adams Elementary School in Maine have built for ISY a full-size detailed model of a Gemini spacecraft and are conducting simulated missions. Contact: Richard Glueck, (207) 866-2151.

Global Laboratory—Technical Education Research Centers (TERC) is developing this student environmental monitoring project, which emphasizes the hands-on collection of "ground truth" data (for instance, temperature, rainfall, air/soil/water quality) by a worldwide network of students, whose observations can be used to verify satellite data. Contact: Robert F. Tinker, (617) 547-0430.

Global Student Village—The Consortium for International Earth Science Information Network (CIESIN) is conducting this program to encourage secondary schools to establish "direct readout" stations that pick up weather satellite signals and share the information they receive with counterpart schools around the world. Contact: Buzz Sellman, (313) 663-5650.

Ground Truth Studies Project—In this project organized by the Aspen Global Change Institute, students in grades K through 12 collect field measurements of their local environment to serve as "ground truth" to support and verify NASA's Mission to Planet Earth satellite data. Contact: Aspen Global Change Institute, (303) 925-7376.

International Exchange Program and Summer School—The Institute for Security and Cooperation in Outer Space (ISCOS) has initiated this program that will exchange US students and ISY project personnel with counterparts at the USSR's Moscow Aviation Institute, with the potential for expansion to other countries. A summer school in Moscow will also be held. Contact: Tom Cremins, (202) 462-8886.

International Set of Resource Materials—The International

ISY

Council of Associations for Science Education (ICASE), based in the United Kingdom, is leading an effort to develop by 1992 a space bibliography for science teachers and curriculum modules that enhance existing science lessons with examples from space science.

International Space Camp—The US Space and Rocket Center's successful Space Camp program, based in Huntsville, Alabama, will be expanded in August 1992 to include up to 60 students and 40 educators, from as many as 30 nations, in a ten-day series of simulations and briefings focusing on international cooperative space ventures. Contact: Scott Osborne, (205) 837-3400.

International Space University—The International Space University, which currently conducts graduate-level summer courses in interdisciplinary space studies, will announce in ISY 1992 its plans for establishing a permanent central campus, a two-year Master's degree program, and an electronically linked network of affiliate campuses around the world. Contact: ISU, (617) 354-1987.

Israeli Satellite Maps—Israel is producing thematic maps from US and French satellite data for educational use in schools.

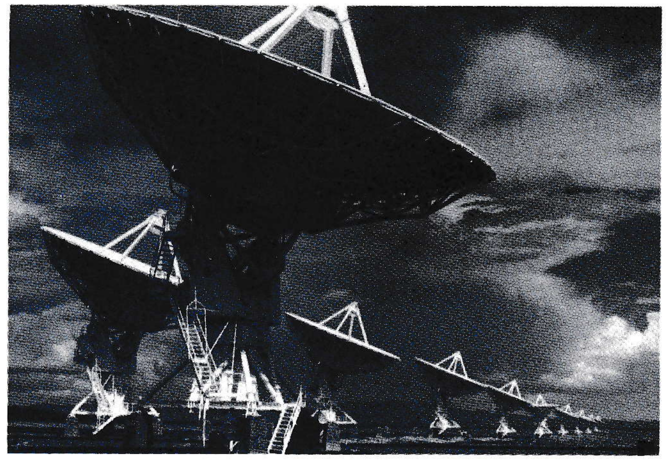
Maple Aerospace and Young Astronaut Program—Maple Elementary School in Michigan is incorporating ISY into its ongoing aerospace education program, which includes space curriculum materials, field trips, a space shuttle simulator, teacher seminars, and an annual Futures in Aerospace and Technologies Day. Contact: Karl Klimek, (313) 960-8420.

"Marsville—The Cosmic Village"—The Challenger Center for Space Science Education is planning in 1991–92 a year-long simulated mission to Mars and design of a Martian habitat, involving some 33,000 classrooms around the world and an international "crew" of high school students selected through a worldwide competition. Contact: Richard A. Methia, (703) 683-9740.

Maryland Pilot Earth Science and Technology Education Network (MAPS-NET)—This NASA-sponsored program, conducted under the auspices of the Johns Hopkins Space Grant Consortium and organized by WT Chen & Company, provides middle and high school teachers with information on establishing a satellite receiving station at their schools and using Earth observation data in the classroom. Contact: Theresa Schwerin, WT Chen, (703) 769-1800.

NASA Aerospace Education Services Project—ISY themes will be incorporated into the 1991–92 efforts of this "Spacemobile" program, in which a corps of aerospace education specialists drive NASA vans and conduct programs in schools around the United States. Contact: Sherri McGee, (202) 453-8344.

NASA International Space Life Sciences Training Program—In June-July 1992, NASA will expand international participation in its annual six-week residence training program, held at the Kennedy Space Center, for undergraduate science and engineering students interested in the life sciences in space. Contact: Dr. Ronald J. White, (202) 453-1525.



National Aeronautics and Space Administration

This is one of twenty-seven 82-foot diameter radio telescope antenna dishes at the Very Large Array (VLA) near Socorro, New Mexico. The telescopes are positioned on a Y-shaped railroad track, each leg of which is 10 miles long. In this arrangement, the VLA can receive signals from distant stars or galaxies as though it were a single large radio antenna dish 20 miles in diameter—the largest effective radio telescope in the world. Subscribers of an ISY computer database can look at the viewing schedules of this and other major observatories around the world.

NASA University Programs—Two NASA higher education programs, the National Space Grant College and Fellowship Program and the Advanced Design Program for engineering students, are incorporating ISY themes into their public service/outreach efforts and student projects. Contact: Sherri McGee, (202) 453-8344.

NASA/NSTA Space Science Student Involvement Program—NASA and the National Science Teachers Association are expanding internationally in 1992 their joint Space Science Student Involvement Program (SSIP) of student competitions. Participants can design their own space station and supercomputer experiments, write space articles for their school paper, or produce artwork illustrating a future Mars base. Contact: NSTA, (202) 328-5800.

NASA/NSTA Teacher Education Programs—NASA and the National Science Teachers Association are using their annual teacher workshops in the summer before ISY—NASA Educational Workshops for Elementary School Teachers (NEWEST) and NASA Educational Workshops for Math, Science, and Technology Teachers (NEWMAST)—to provide resources that will help primary and secondary school educators introduce ISY themes into their classrooms. Contact: Sherri McGee, NASA, (202) 453-8344.

National Essay Contests—All countries of the world are being encouraged by the United Nations to conduct nationwide essay contests during the 1991–92 school year in which high school students describe "my vision of outer space and the promise it holds for my country and mankind," with national winners receiving UN certificates and eligible for inclusion in a UN publication of the best essays.

NOAA Direct Readout Program—The US National Oceanic and Atmospheric Administration (NOAA) is expanding for ISY its Direct Readout program, in which some 2,000 schools in 120 countries have already set up their own stations to receive environmental satellite data in the classroom. Contact: Douglas L. Brown, (301) 763-4690.

NOAA ISY Educational Materials—NOAA plans several other ISY efforts keyed to its environmental satellites and data management programs, including publications describing the satellite/Earth observation resources available to educators and participation in projects to develop new textbooks and electronic education systems. Contact: Douglas L. Brown, (301) 763-4690.

NSF Science and Engineering Education Programs—The National Science Foundation plans to incorporate ISY into its ongoing programs for teacher enhancement and recognition, instructional materials development, informal science education (for instance, TV, museums, clubs), and enrichment programs for young scholars.

"Opera, Spheres, and Space"—The Delaware Aerospace Center hopes to expand nationwide its program in which school groups, in conjunction with space science curricula, attend and perform in space-based operas such as Menotti's "The Bride From Pluto" and a new work called "A Wrinkle in Time" that will premiere in 1992. Contact: Dr. Stephanie M. Gerjovich Wright, (302) 454-2432.

"Planet Earth" Curriculum Materials—The Discovery Channel is developing classroom guides and student activities to accompany its "Planet Earth" educational videodisc series. Contact: Michael Heasley, (301) 986-0444, ext. 5608.

PROJECT ExPEDITE—Marple Newtown School District in Pennsylvania has developed a program on "Exploring Planet Earth by Developing Imagery and Technology Education," which emphasizes student participation in ISY's Mission to Planet Earth and the interdisciplinary use of satellite data in school curricula. Contact: Alfred Capotosto, (215) 359-4200.

Project Horizon—West Chester University in Pennsylvania plans to establish a global computer network of satellite educators who will share data on the classroom uses of satellites among elementary and secondary schools throughout the world. A local network called DEVALnet is already in operation. Contact: Nancy R. McIntyre, (215) 436-2393.

Satellite Technology Workshop—A two-week graduate training workshop in July 1992, organized by Pennsylvania's West Chester University, will provide teachers with information on how they can incorporate satellite technology into the curriculum. Contact: Nancy R. McIntyre, (215) 436-2393.

SCAS² Activities—The Southern California Association of Science Specialists (SCAS²) is planning a variety of ISY activities for its member educational institutions.

Search for Extraterrestrial Intelligence (SETI) Foreign-Language Teaching Modules—In conjunction with ISY, the SETI Institute will produce foreign-language versions of NASA SETI teaching materials, designed to excite students about math and science by exploring the issue of life elsewhere in the universe. Contact: Thomas Pierson, (415) 961-6633.

Shuttle and Space Station Simulations—Wausau School District in Wisconsin is converting a school bus into a "space shuttle" that will take sixth-graders on day-long simulated missions. A trailer is also being made into a permanent "space station" that will serve as a science laboratory for all the district's elementary school students. Contact: Sharon Ryan, (715) 845-1353.

SpaceArc—A project of the Rochester Museum and Science Center, SpaceArc invites people of all ages to join in creating an international time capsule of essays, drawings, music, and poetry, to be sent into space aboard one of the Columbus 500 solar sail race vehicles in 1993–94 and archived in duplicate at stations around the world. Contact: James M. Ferren, (716) 271-4320.

Space Science Seminar for Teachers from Developing Countries—The State Education Commission of China proposes to hold, in China in 1992, a special one-month space science seminar for about 60 teachers from developing countries.

Spaceship Earth Teaching Classroom Project—Using this primary school teaching module, students and teachers design their classroom as a spaceship or space colony, with individual students taking on specific roles (for example, engineer, farmer, astronomer) and learning to work together in operating the community. Contact: Dr. Carol Rosin, ISCOS, (213) 225-1999.

"Spaceship Earth" Television/Video Guides—A teacher's guide written for grades 8–12 and a viewer's guide suitable for college students are available to accompany this PBS broadcast and videocassette series. Contact: South Carolina Educational Television, (800) 277-0829.

Space Technology Education Program (STEP)—This joint program of NASA and the Environmental Research Institute of Michigan (ERIM) seeks to improve secondary and university education through the use of telecommunications technologies, computer-aided instruction, and the direct readout of satellite data in the classroom. Contact: ERIM, (313) 994-1200.

Sri Lanka Science Students Association Activities—This student group in Sri Lanka is planning weekly space science seminars, three space science workshops, a poster contest and exhibition, a science fair of student projects, and an ISY Day of lectures and discussions at the International Conference Hall in Colombo.

ISY

Student Payload Rocket Launchings—Thousands of high school and college students will build rockets to launch their own science experiments during

1992 as part of a worldwide program of model rocket competitions and grassroots launchings coordinated by the Rocket Research Institute and its counterparts in other countries. Contact: George S. James, (202) 586-9472.

Student Satellite World Weather Watch—West Chester University and Unionville High School in Pennsylvania are working to create by 1992 an international network of students receiving environmental data directly from satellites and generating a "global mosaic" of shared weather images. Contact: Nancy R. McIntyre, West Chester University, (215) 436-2393.

"Students Watching Over Our Planet Earth" (SWOOPE)—This program, sponsored by the US Department of Energy, contributes to ISY's Mission to Planet Earth by having students measure water quality and background radiation levels near their homes. Contact: Roger Eckhardt, (505) 667-0396.

Teachers Information Network—Information on ISY is being included in this on-line computer database for educators that is available to users of Apple's "America Online" service and IBM's "PC Link" and "Promenade" services. Contact: Quantum Computer Services, (800) 227-6364, ext. 5276.

Textbooks and Electronic Systems for Satellite Education—GEOSPACE, an Austrian satellite imaging firm, is developing curriculum materials for primary/secondary schools and universities—including materials using the ISY global change encyclopedia and atlas—to introduce students to the principles and applications of satellite remote sensing.

"Together to Mars"—Created by The Planetary Society, this is an international ISY essay contest for students 18 years and younger on the theme of the human exploration of Mars, with student winners from around the globe participating in the 1992 World Space Congress in Washington, D.C. Contact: Barbara Brüning-La Belle, (818) 793-5100.

UN International Training Course on Remote Sensing in Education—The goal of this 1992 course in Stockholm and Kiruna, Sweden, organized in cooperation with the government of that country, is to help educators from developing countries gain a practical knowledge of remote sensing so that they can introduce this technology into their curricula.

"Visions of Exploration: Past, Present, Future"—The international newspaper *USA TODAY*, in partnership with NASA, has developed materials for students in grades 3–8 that will rekindle their interest in science and space exploration by challenging them to see space as the new frontier. Contact: Michele Wickham, (703) 276-5320.

"Where Next, Columbus?" Curriculum Materials—In conjunction with the opening of its ISY exhibit "Where Next, Columbus?" the National Air and Space Museum in Washington, D.C., will make available curriculum materials that will help students and teachers examine the future of space exploration and discovery. Contact: Dr. Valerie Neal, (202) 357-2828.

World Timecapsule Fund—Written, visual, and auditory information from individuals all over the world will be digitally recorded, preserved for posterity as a "history of mankind," and sent into space in the year 2000, with US schools asked to contribute student essays during ISY. Contact: Charles S. Smith, (612) 935-1206.

"A Year in the Life of Satellite Tracking"—Thousands of high school students from around the world are collecting weather satellite images of their home regions taken on the first days of spring, summer, fall, and winter to create a global mosaic illustrating the changing of the seasons. Contact: Helen E. Martin, Unionville High School, (215) 347-1600.

Young Astronaut Educational Materials—"Exploration and Discovery: The International Space Year" will be the theme of the Young Astronaut program during the 1991–92 school year, when students in grades K—9 in more than 25,000 US schools will receive monthly curriculum materials and an educational video on ISY. Contact: Young Astronauts, (202) 682-1985.

Young Astronaut Reading Club—This nationwide book club, featuring Young Astronauts engaged in science fiction activities, will be introduced in celebration of ISY in January 1992. Contact: Young Astronauts, (202) 682-1985.

Young Astronauts/Cosmonauts Joint Projects—The US Young Astronauts Council and the Soviet Young Cosmonaut organization, COYUZ, are planning a series of joint ISY celebration projects including educational materials and joint publications. Contact: Young Astronauts, (202) 682-1985.

Youth Space Education Week—ISY themes will be incorporated into the October 1992 version of this annual event, which focuses on space-related activities in the schools. Contact: Youth Space Education Week, (316) 945-5943 or (313) 943-8880.

Books and periodicals

***Astronomy Education* Newsletter**—The newsletter of the Association of Astronomy Educators carries regular articles on ISY. Contact: Chaz E. Hafey, (804) 367-0117.

***Blueprint for Space* Book**—The Smithsonian Institution Press is publishing a book written by Frederick Ordway and Randy Lieberman, with an epilogue by Arthur C. Clarke, to go with the "Blueprint for Space" traveling exhibit that compares science fiction and science fact.

***Ciencia Hoje/Ciencia Hoy* Special Issue**—The Brazilian Society for the Advancement of Science plans to devote a February 1992 special edition of its science magazine, published for the general public in both Portuguese and Spanish, to ISY and space science issues.

***Copycat* Magazine**—This magazine for elementary school teachers is producing a special issue on space, including information on ISY educational resources.

Collection and Distribution of Literature on Space Science and Technology—To assist developing countries in obtaining space-related publications, this joint project of the United Nations and Italy's International Centre for Theoretical Physics (ICTP) is designed to facilitate the "recycling" of donated scientific books and journals to Third World libraries.

Directory of Resources for Earth Observation in Education—NOAA will produce in 1992, in several languages, this comprehensive reference book for teachers containing background information on environmental satellites and lists of equipment manufacturers, training programs, curriculum materials, and schools already using satellite data in the classroom. Contact: Arlette Washington, (301) 763-4690.

Educator's Guide for Building and Operating an Environmental Satellite Receiving Station—In 1992, in conjunction with its Direct Readout program, NOAA will publish this manual containing practical construction/operating advice and curriculum suggestions for use of a satellite receiver in the classroom. Contact: Arlette Washington, (301) 763-4690.

EURISY Newsletter—The European Association for the International Space Year (EURISY) publishes a quarterly newsletter in English, French, and German on ISY activities in Europe. The organization also plans to start up a publication for young people by early 1992.

***Final Frontier* ISY Directory**—The bimonthly space magazine *Final Frontier* is dedicating its January/February 1992 issue to ISY and publishing a program guide that lists major ISY activities. Contact: *Final Frontier*, (612) 822-9600.

IEEE Publications—Various technical/professional publications of the Institute of Electrical and Electronics Engineers, such as *Transactions on Geoscience and Remote Sensing* and *Technology and Society* magazine, plan special issues and articles dedicated to ISY.

***INFOSEA* Newsletter**—This newsletter of the Satellite Educators Association will spotlight ISY activities during 1992 and share curriculum ideas on the use of satellites in the classroom. Contact: Nancy R. McIntyre, (215) 436-2393.

ISY Comic Book—TADCORPS, producers of a series of quality educational comic books on space for children, has created a special ISY comic called "Adventures on Santa María and Future Ships Sailing the Oceans of Space." Contact: "Dutch" von Ehrenfried, (202) 554-8677.

ISY Resource Compendium for Educators—The National Science Teachers Association and the PBS Elementary/Secondary Service are producing this reference book for K–12 teachers, listing hundreds of space-related classroom resources—from publications, videos, and software to training opportunities. Contact: Michelle Ward-Brent, PBS, (703) 739-5145.

La Lettre spatiale du Québec—This new space newsletter, published by the government of the Canadian province of Quebec, will include regular articles on ISY activities through 1991–92. Contact: Quebec Department of Industry, Trade, and Technology, (514) 873-6332.

***National Geographic World* Magazine**—This publication for elementary school youngsters will include articles on ISY student activities throughout 1992.

Robert T. McCall ISY Art Book—In conjunction with space artist Robert T. McCall's ISY art exhibition in New York, Bantam Doubleday Dell will publish a book entitled Robert T. McCall's Cosmic Horizons—A Celebration of the International Year of Space, with accompanying text by science fiction writer Ray Bradbury.

NASA *Report to Educators*—This NASA periodical disseminates information about ISY. Contact: Sherri McGee, (202) 453-8344.

***Scholastic News* Space Issue**—This magazine for elementary school students is producing a special issue on space in January 1992, including coverage of ISY activities.

***Scientific American* Supplement**—An ISY/World Space Congress supplement will appear in *Scientific American* magazine's August 1992 edition, published worldwide in six languages, including articles exploring the newest international developments in space science, technology, and policy.

***Space Age* Book**—Random House will publish a companion book by author Chip Walter to go with the ISY public television series "Space Age" being jointly produced by WQED/Pittsburgh and NHK/Japan.

***Space* Encyclopedia**—The Progress Publishing House in the Soviet Union will be producing a popular science encyclopedia on space in 1992.

***Spaceline* Newsletter**—The Institute for Security and Cooperation in Outer Space (ISCOS) will publish a monthly column on ISY in its *Spaceline* newsletter and plans special issues devoted to ISY. Contact: Tom Cremins, (202) 462-8886.

***Space News* ISY Section**—An issue of this weekly space periodical will include a special section on ISY activities.

***Spaceship Earth* Book**—Science writer Nigel Calder has created a book to accompany the public TV series "Spaceship Earth: A Global Geography," which is being produced by South Carolina Educational Television in partnership with European broadcasters.

***Teaching Space* Newsletter**—*Teaching Space*, a quarterly newsletter for educators interested in bringing space subjects into the classroom, is including coverage of ISY events and activities in its issues.

***Tennessee Teacher* Space Issue**—In conjunction with its annual Tennessee Space Week celebration, the Tennessee Education Association will devote the February issue of its magazine to space and include information on ISY resources for teachers.

UN Booklet on Space Education—A United Nations booklet is being published to educate policymakers, particularly those in developing nations, on current trends in space science and technology, on its potential applications and benefits, and on educational opportunities involving space systems.

A Year in the Life of Satellite Tracking—A book will be published in 1992 containing the year-long global mosaic of the best student-collected satellite images generated through this project, which is being coordinated by Unionville High School in Pennsylvania. Contact: Helen E. Martin, (215) 347-1600.

Public events and exhibitions

Acoustic Astronomy—Astrophysicist and musician Dr. Fiorella Terenzi, who works in Italy and the United States, is conducting research on computer music techniques that allow astronomical data to be represented as sound. She is exploring both the scientific development of a sound-based classification scheme for celestial objects and the performance of music using these techniques. Contact: David Reisner, (213) 207-3004.

AmeriFlora '92—This miniature world's fair and floral/garden exposition in Columbus, Ohio, running from April through October 1992, will include a space pavilion featuring science exhibits, a near-full-size model of the US space shuttle, and a special-effects science fiction production created by George Lucas's Industrial Light and Magic. Contact: SpacePort Systems Corporation, (213) 278-3900.

Astronomical Illustrations by Robert T. McCall—The Society of Illustrators is planning ISY-dedicated art exhibitions in 1992, highlighted by a one-man show of 75 works by noted space artist Robert T. McCall that will take place in New York in September–November, with an accompanying book celebrating ISY in art.

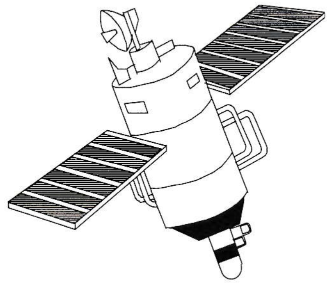
Australian ISY Activities—In addition to its participation in several SAFISY science projects, Australia is planning numerous ISY public activities, including museum displays, media programs, special postage stamps, and school projects.

BISY92 Exhibitions—The British organization BISY92 is organizing a comprehensive traveling display and permanent exhibitions at major tourist attractions in the United Kingdom, designed to inform students and the general public about the benefits of space technology.

BISY92 Lecture Series—BISY92 is planning a professional lecture series on space topics that will tour major cities in the United Kingdom during ISY.

"Blueprint for Space: Science Fiction to Science Fact"—The IBM Corporation is underwriting an exhibition of artwork, rare books/magazines, and space artifacts focusing on the theme of space travel in concept and reality, with showings scheduled during 1991–92 at the US Space and Rocket Center in Huntsville, Alabama, the IBM Gallery in New York, and the National Air and Space Museum in Washington, D.C.

Columbus 500 Space Sail Cup—At least three space vehicles using sails propelled by the solar wind—including one mission each from the Americas, Europe, and Asia—will be launched in 1993 or 1994 in an ISY-inspired race from Earth orbit to the Moon and Mars. One of them will carry the SpaceArc international time capsule of essays, drawings, music, and poetry. Contact: World Space Foundation, (818) 357-2878.



EURISY Audiovisual Show—EURISY, the European ISY association, is planning an ISY audiovisual show designed to increase the interest of the general public in space technologies, exploration, and Mission to Planet Earth.

EURISY Dinner Debates—A series of 1992 dinner debates on space issues is being organized by EURISY, with sites to include Scandinavia and possibly Eastern Europe.

Exhibition on Disaster Prevention and Relief Technology—An international exhibition of space technologies used in the prevention and relief of natural disasters is being held in China in September 1991.

Galileo Encounter Events—The Planetary Society is organizing activities in Pasadena, California, for the December 1992 flyby of Earth by the Galileo spacecraft. Contact: Susan Lendroth, (818) 793-5100.

Golden Gate Space Frontier Society Activities—This San Francisco Bay Area chapter of the National Space Society is planning a series of 1992 events around Earth Day, Space Day, and Columbus Day, including a lecture series, TV and radio public service messages, participation in an ecology fair, fund-raising events to benefit school science programs, and newsletter coverage of ISY activities.

"The Home Planet" United Nations Exhibition—From June to September 1992, UN Headquarters in New York will host an ISY Mission to Planet Earth exhibit that will give the public a high-tech "tour" of the best images of our planet from space, promoting a greater appreciation of the Earth as a global system and the role of space technologies in environmental management.

INPE Visitor Center—Brazil's National Space Research Institute (INPE) will establish in 1992 a new permanent exhibition hall at its headquarters in São José dos Campos, including exhibits on global change, Amazonia, and the use of space technologies to benefit the local, national, and international community.

Intergalactic Sculpture—Sculptor Ezra Orion, in cooperation with the Israel Space Agency, plans to create an intergalactic work of art by launching laser beams into space from locations around the world in May 1992.

International Exhibition of Space Art—The USSR plans to host an international art exhibit dedicated to ISY, which will begin in Moscow and then travel elsewhere.

Live Observation of Artificial Space Objects—To encourage public observation of orbiting spacecraft, the UN and the Houston Museum of Natural Science are developing a manual, an electronic bulletin board, and viewing schedules of spacecraft passes over major cities, for telefax distribution to planetariums worldwide. Contact: Paul D. Maley, (713) 639-4632.

Mars Observer Launch Events—In conjunction with the launch of the Mars Observer spacecraft, The Planetary Society will conduct a variety of activities at the Kennedy Space Center, including tours for society members and events open to the public. Contact: Susan Lendroth, (818) 793-5100.

Milky Way Day—The Galactic Society is organizing this event on August 7, 1992, designed to help young people and community groups learn about astronomy and the potential for exploration outside our own Milky Way galaxy.

Mission to Planet Earth Day—On April 25, 1992, in celebration of the traditional Earth Day, public activities will be organized around the theme of Mission to Planet Earth, including a program of events developed by the National Space Society and a global telecast.

Mobile Exhibition on the Soviet Space Program—The USSR is planning a mobile exhibit highlighting the achievements of the Soviet space effort, with US visits scheduled for Washington, D.C., and New York beginning in August 1992.

"Our Sun-Earth Environment"—An exhibit explaining the Sun's effects on the Earth and the nature of the heliosphere—the plasma of particles and fields that extends out into space from our star—will open in 1992 at the National Air and Space Museum in Washington, D.C., along with a traveling version for other museums.

Rover Expo '92—In September 1992, in conjunction with the World Space Congress in Washington, D.C., The Planetary Society will sponsor an ISY exposition and demonstration of planetary robots and related technologies for space exploration. Contact: Susan Lendroth, (818) 793-5100.

Spaceweek 1992—This week-long celebration of space, held every year on July 16–24 in commemoration of the first Apollo lunar landing, will key its 1992 activities to ISY. Contact: Spaceweek National Headquarters, (713) 333-3627.

"Star Trek: Federation Science"—The Oregon Museum of Science and Industry is developing a traveling science exhibit for ISY that will visit at least ten US sites and be keyed to the 25th anniversary of the "Star Trek" television series, exploring the scientific challenges of living and working in space today and in the future. Contact: Divonna Ogier, (503) 222-2828.

Tournament of Roses Parade—On January 1, 1992, this annual parade in Pasadena, California, will include an ISY float produced by the Masons entitled "Voyagers of Discovery" and depicting humanity's advancement through space. ISY-related floats by other groups have also been proposed.

"Universariums"—The United Nations will publish a booklet describing and encouraging the establishment of "universariums" in countries that do not yet have such space science centers, which include in one site such public facilities as planetariums, cinemas, exhibit areas, lecture rooms, and astronomical observatory equipment.

UN Monthly Lectures—Distinguished guest lecturers from all corners of the world will give monthly lectures at United Nations Headquarters in New York during 1992 on different topics related to ISY and outer space, with particular attention to Mission to Planet Earth.

Western Amateur Astronomers Activities—The Western Amateur Astronomers, an association of some 70 amateur astronomy clubs in the western United States, is planning ISY activities designed to encourage people to observe the skies.

"Where Next, Columbus?"—The National Air and Space Museum in Washington, D.C., will celebrate ISY and the 500th anniversary of Columbus's first voyage to the New World by opening a major new exhibit gallery in 1992 that will examine the future of space exploration and discovery over the next 500 years. Contact: Dr. Valerie Neal, (202) 357-2828.

World Expo '92—This world's fair in Seville, Spain, running from April through October 1992, will include elements focusing on ISY themes. EURISY is planning an ISY event during the exposition.

Conferences

AAAS Symposium on ISY—The February 1992 annual meeting of the American Association for the Advancement of Science (AAAS), convening in Chicago, will include a symposium on ISY as part of its series of discussions on "Fantastic Voyages: From Columbus to Space."

Asia/Pacific ISY Conference—This major regional ISY session will be convened in November 1992 in Tokyo on the theme of remote sensing applications for developing nations.

Conference of Museums of Cosmonautics—The USSR plans to hold a nationwide ISY conference of space museum officials in Moscow in November 1992.

Conference on Remote Sensing and the Economy—The Soviet Union is planning for mid-1992 a scientific conference on the most pressing problems associated with the use of remote sensing methods to benefit various sectors of the economy.

Delaware Valley ISY Colloquium—The Greater Philadelphia Section of the American Institute of Aeronautics and Astronautics will hold an ISY colloquium on space exploration in March 1992 at the Franklin Institute, where students, educators, and space experts will celebrate the Delaware Valley's participation in ISY. Contact: Clifford D. Reinert, (215) 354-2899.

ISY

European ISY Conference—A worldwide conference on global climate change, dedicated to ISY and entitled "Space in the Service of the Changing Earth," will bring together some 1,200 participants in Munich, Germany, on March 30—April 4, 1992, under the auspices of the European Community, the European Space Agency, and the German Space Agency (DARA).

International Aerospace Convention—This international convention of aerospace professionals, educators, and students will be convened in Huntsville, Alabama, in July 1992 and supplemented by space camp and teacher orientation programs. Contact: Debbie Roderick, (205) 551-2230.

International Conference on Space Biology and Medicine—The Soviet Union will host a world scientific conference on space medicine and related research in 1992 in Moscow.

International Geoscience and Remote Sensing Symposium (IGARSS)—The May 1992 theme of this annual conference, attended by 500–600 scientists and engineers in Clear Lake, Texas, will be "International Space Year: Space Remote Sensing."

International Space Education Symposium—This week-long international meeting of space educators at the secondary school level, dedicated to ISY and jointly organized by the American Space School and the Satellite Project in Wales, will convene in Britain in July 1992 and focus on ISY's Mission to Planet Earth. Contact: Thomas W. Becker, (314) 997-0937.

International Symposium on Economic Benefits of Space Activities—The Chinese Society of Astronautics and the International Academy of Astronautics are jointly sponsoring a meeting on the benefits of space technology in Beijing in October 1992.

International Symposium on the Exploration of the Sun—On August 8–9, 1992, the USSR will host in Dnepropetrovsk an international symposium on solar processes affecting the Earth's environment and human activity, based on the findings of international spacecraft projects studying the Sun and Sun–Earth interactions during the period of maximum solar activity.

ISPRS/ASPRS Congress—The International Society for Photogrammetry and Remote Sensing (ISPRS) and its American counterpart (ASPRS) will meet in Washington, D.C., on August 2–14, 1992, and dedicate one of the session's themes—"Mapping and Monitoring the Earth to Document Global Change"—to ISY.

ISY Conference on Earth and Space Sciences Information Systems—A conference will be hosted by the Jet Propulsion Laboratory in Pasadena, California, on February 10–13, 1992, to promote international cooperation, standardization, and planning for the 21st century in the area of space-related information systems, using ISY science projects as a focal point.

"Marsville" Regional and International Conferences—As the culmination of its year-long "Marsville—The Cosmic Village" program of simulated student space missions, the Challenger Center will convene 100 regional conferences worldwide in May 1992 and an international conference at the Kennedy Space Center in July. Contact: Richard A. Methia, (703) 683-9740.

1992 Planetary Congress—The Association of Space Explorers, whose international membership includes more than 80 current and former astronauts, will dedicate its August 1992 Planetary Congress to ISY and focus on the theme "To Mars Together" at this Washington, D.C., meeting, held in conjunction with the World Space Congress.

Pacific Ocean Remote Sensing Conference—This August 1992 session in Okinawa, Japan, dedicated to ISY and conducted in cooperation with SAFISY, will focus on the use of satellite technologies in oceanography, meteorology, environmental studies, and the management of marine resources.

The Planetary Society Day—A day of space science sessions for educators, sponsored by the Planetary Society, will be a part of the March 1992 national convention of the National Science Teachers Association in Boston, Massachusetts. Contact: Susan Lendroth, (818) 793-5100.

Press Seminars on Rain Forest Ecology—The International Science Writers Association is organizing a series of annual press seminars on rain forest ecology, with the first sessions planned for 1992 in Brazil in conjunction with the ISY World Forest Watch project.

Satellites and Education Conference—ISY will be the theme of the March 1992 session of this annual conference, designed for educators who use satellite data in the classroom and hosted by West Chester University in Pennsylvania. Contact: Nancy R. McIntyre, (215) 436-2393.

2nd Pacific ISY Conference—Scientists and space agency officials convened in October 1991 on Hawaii island—the site of the first Pacific ISY Conference that launched ISY internationally—to develop proposals for ongoing international coordination of space scientific activities that can begin during ISY and continue beyond 1992.

SOAR 1992—A SOAR (Special Opportunities for Aerospace Resources) Forum on ISY will be held during the March 1992 National Science Teachers Association annual convention in Boston. Contact: NSTA, (202) 328-5800.

"Space and the Global Problems Confronting Mankind on the Threshold of the 21st Century"—This Soviet-sponsored international conference dedicated to ISY will bring together scientists and space specialists in Moscow in 1992.

"Space Enough to Learn"—The University of Canberra in Australia will host this international ISY conference for space science and technology teachers and museum educators on July 13–16, 1992.

Space 92—This International Conference on Engineering, Construction, and Operations in Space, sponsored by the American Society of Civil Engineers and dedicated to ISY, will convene in Denver, Colorado, in May–June 1992. Participants will include elementary, secondary, and college students and teachers as well as engineering and space professionals. Contact: Marie McGuinness, (212) 705-7494.

Space Research Conference—ISY will be a major theme and ISY space science activities will be included in the Space Research Conference of European students, to be held in the Netherlands in May 1992 under the auspices of the Association des Etats Généraux des Etudiants de l'Europe (AEGEE).

Space Technology Education Program (STEP) Symposium—This session for scientists and educators, cosponsored by COSPAR, will convene in Baltimore, Maryland, in August 1992. For ISY, this will be the first international STEP conference.

Technospace 92—This ISY conference and exhibition, convening in Bordeaux, France, in October 1992, will focus on the contributions of space to the betterment of life on planet Earth, international cooperation and technology transfer, and the financing of space programs.

Training Program in Geospace Physics for Scientists in Developing Countries—A three-week school in October–November 1992 at the International Centre for Theoretical Physics in Trieste, Italy, will provide training for scientists from developing countries and explore ways in which their institutions can better participate in and utilize data from future space physics missions.

UN International Seminar on Space Communications Systems—This ISY-inspired meeting in 1993, hosted by the government of Greece, will allow officials in the surrounding region to assess telecommunications applications of space technology.

UN Regional Conference on Space Technology for Sustainable Development—This 1992 meeting, cosponsored by the government of Indonesia, is designed to promote cooperation among Southeast Asian and Pacific Rim nations in expanding space science, technology, and applications programs.

UN Seminar on Space Communications—The USSR is hosting a ten-day United Nations seminar in Dubna in September 1992, where up to 30 Third World representatives will familiarize themselves with recent developments in satellite communications technology that are applicable to such areas as rural education, medicine, and disaster relief.

UN Workshop on Remote Sensing—The UN Outer Space Affairs Division and the International Centre for Theoretical Physics are jointly organizing a major workshop on remote sensing technology in 1992 in Trieste, Italy, with emphasis on the needs of Third World countries.

UN Workshop on Space Science and Technology Information—In conjunction with the UN/ICTP project to promote the distribution of space science and technology literature to developing countries, a workshop on "Bridging the Information Gap in Space Science and Technology" will be held at the United Nations' New York headquarters in 1992.

UN/COSPAR/IAF Workshop on Space Technology in Developing Countries—This session, held in August 1992 in conjunction with the World Space Congress in Washington, D.C., will focus on how space-related technologies can be developed in Third World nations.

UN/ESA Africa Space Conference—An ISY-inspired conference to be held in Nairobi, Kenya, in 1993, cosponsored by the United Nations and the European Space Agency, will bring together African decision-makers and scientific leaders to establish priorities and programs using space technologies to harness Africa's natural resources and safeguard its environment.

UN/IAF Workshop on Space Programs for Developing Countries—This October 1991 session in Montreal, organized by the UN and the International Astronautical Federation in cooperation with Canada, is intended to assist Third World nations in identifying and establishing programs for space technologies that can help them meet their development goals.

UN/ISPRS Workshop on Data Analysis Systems and Applications—Developing country participants in the August 1992 Congress of the International Society for Photogrammetry and Remote Sensing (ISPRS) in Washington, D.C., will be able to attend this technical workshop addressing specific problems in the hardware, software, data analysis methods, and applications of remote sensing.

World Congress on National Parks and Protected Areas—The fourth World Congress on National Parks and Protected Areas, an international meeting of more than 1,000 park managers to be held in Caracas, Venezuela, on February 10–21, 1992, has invited ISY participation on the theme of Mission to Planet Earth.

World Space Congress—The International Astronautical Federation (IAF) and the Committee on Space Research (COSPAR) of the International Council of Scientific Unions will meet jointly in a World Space Congress dedicated to ISY, bringing at least 3,000 space experts to Washington, D.C., on August 28—September 9, 1992. Contact: Mireille Gerard, (202) 646-7450.

Young Astronaut National and International Conferences—Thousands of Young Astronauts and Young Cosmonauts from around the world will meet in Japan, Korea, the Soviet Union, and the United States in 1992 conferences dedicated to ISY. The year's major global meeting will convene in Moscow in July 1992. Contact: Young Astronauts, (202) 682-1985.

Proposed activities

Academic Aerospace Correspondent Program—VAKO Soyuz, the USSR's All-Union Youth Aerospace Society, plans to coordinate this student correspondence project.

"Art of the Cosmos"—The International Association for the

ISY

Astronomical Arts has proposed an ISY traveling exhibit that would include works by more than 50 artists from 14 countries. IAAA also plans to release a video entitled "Artists in Space" to go along with the artists' works.

Discovery Constellation—Artist James Pridgeon proposes an ISY space sculpture consisting of an orbiting set of tethered reflecting balloons that would be visible at dawn and dusk for a period of three months. In addition to being a symbol of international cooperation, the balloons would be used to study the dynamics of tethered satellites and would have associated educational materials.

"Earth Observation from Space as an Educational Resource"—The BAITIC Educational Center of the USSR's Troitsk Institute of Innovation and Thermonuclear Research (TRINITI) plans to coordinate this program on the use of spacecraft data in the classroom.

Educational Television Programs from Mir—Soviet cosmonauts plan to broadcast educational programs from the Mir space station during 1991–92.

International Art Competition—The Association of Space Museums of the USSR wishes to sponsor an art competition for children on space-related subjects.

International E-Mail Teleconferences—The BAITIC Educational Center in the Soviet Union is organizing a series of international computer teleconferences for secondary school students that would transmit electronic mail via satellite during 1992.

ISY Commemorative Stamps—More than 100 countries have been invited to design and produce their own ISY postage stamp, postmark, or commemorative envelope in 1992.

ISY International Telecommunications Network—The Institute of Electrical and Electronics Engineers proposes to create an ISY International Telecommunications Network to improve the transfer of ISY project information between different communications systems (for example, computers, teleconferences, satellites).

ISY Sculpture—New York sculptor Rhonda Roland Shearer, an artist who incorporates environmental issues into her work, plans to design a special sculpture on the theme of ISY's computer-animated global change encyclopedia.

International Student Olympiad on Space Engineering—College students from around the world will participate in this ISY competition hosted by Moscow State Technical University in January–February 1992.

International Summer Aerospace Campus Program—This annual summer program for Soviet students is organized by VAKO Soyuz, the All-Union Youth Aerospace Society.

International Youth Congress—This proposed meeting for college students, focusing on "Essential Problems of Cosmonautics and Space Research," would be hosted in 1992 by Moscow State Technical University in the USSR.

Mir Experiments—In 1992 the Soviet Union plans to carry on board its Mir space station a number of scientific experiments designed by young researchers, college students, and high school pupils from developing countries.

Moscow Aviation Institute Journal—This Soviet scientific and technical magazine proposes to include articles related to ISY and may also exchange articles with US publications.

Music from the Galaxies—Astrophysicist and musician Dr. Fiorella Terenzi, who works in Italy and the United States, proposes in 1992 to expand her work in acoustic astronomy into a lecture and concert series, where she will present compositions that transform the radiation from other galaxies into sound by means of computer music techniques. Contact: David Reisner, (213) 207-3004.

OURS—The Swiss-based OURS (Orbiting Unification Ring Satellite) organization is negotiating with the Soviet Union to launch the first in a series of OURS peace ring sculptures from the Mir space station in 1992.

"Protection of Environment for Assuring Cleaner Earth" (PEACE)—India has proposed an international ISY mission featuring remote sensing instruments that would be particularly geared toward environmental studies in developing countries.

Sources of information

The following agencies and organizations can supply more information on the items in this list:

NASA Educational Affairs Division—This office of the National Aeronautics and Space Administration (NASA) is committed to promoting excellence in education through an emphasis on science and technology. Contact: Sherri McGee, (202) 453-8344.

NASA/ISY SpaceLink—NASA has established an ISY menu on the agency's existing SpaceLink database of space information, which can be accessed by computer over regular telephone lines. Contact: Sherri McGee, (202) 453-8344.

US International Space Year Association—This nonprofit organization was established with support from NASA to provide information on ISY activities and encourage public participation. It publishes news releases, a newsletter, and other informational materials. Contact: US-ISY, (202) 863-1734.

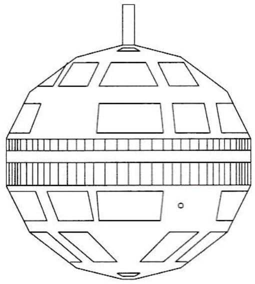
European Association for the International Space Year (EURISY)—This Paris-based association, a counterpart of US-ISY established with support from the European Space Agency (ESA), provides information on European ISY activities. Contact: EURISY, (33) (1) 45-55-83-53.

United Nations—The UN Outer Space Affairs Division has produced a guidebook on ISY activities sponsored and coordinated by the United Nations. Contact: United Nations, (212) 963-1234.

Scientific and Technical Olympiad on Space Topics—The Moscow Physical Technical Institute is organizing this science competition for secondary school students in the USSR.

SETI Microwave Observing Project Educational Program—The SETI Institute is planning an ISY program of math and science curriculum materials centered around the 1992 start of the Microwave Observing Project, where students will search for signals from Earth spacecraft as a test of future search techniques for extraterrestrial signals. Contact: Bob Arnold, (415) 604-5989.

Solar Sailing Telecommunications Simulation—University School in Ohio proposes to link students around the world via computer during 1992 to conduct a year-long simulation of ISY's Columbus 500 Solar Sail Race, in which vehicles propelled by the solar wind will voyage to the Moon and Mars.



Training Workshops on Space Science Education for Teachers in Developing Countries—This proposal, by the Institute for Science and Math Education at the University of the Philippines, is to organize regional training workshops in developing nations to discuss what to teach in space science and how to teach it.

United States Space Foundation Exhibits—The United States Space Foundation is developing a proposal for interactive educational exhibits on space exploration that would be geared toward students of all ages around the country.

Worldwide Space Research Educational Programs—The European Space Agency (ESA) has proposed the worldwide delivery via satellite of a variety of space education programs.

"You Experiment in Space"—This competition for secondary school students is being organized in the Soviet Union.

"Youth for International Space Year"—An international student congress in April–May 1992, hosted by Moscow State Technical University in the Soviet Union, has been proposed.

Bulletin board

Boston University sponsors PROMYS

The Program in Mathematics for Young Scientists (PROMYS) is a residential program designed for 60 ambitious high school students entering grades 10 through 12. Held at Boston University, the program offers a lively mathematical environment in which students explore the creative world of mathematics. Through their intensive efforts to solve a large assortment of unusually challenging problems in number theory, the participants practice the art of mathematical discovery—numerical exploration, formulation and critique of conjectures, and techniques of proof and generalization. More experienced participants may also study abstract algebra and dynamical systems. Each participant belongs to a problem-solving group that meets with a professional mathematician three times a week. Special lectures by outside speakers offer a broad view of mathematics and its role in the sciences. In addition, college-age counselors live in the dormitories and are always available to discuss mathematics with students.

Admission decisions will be based on applicants' solutions to a set of challenging problems included with the application packet; teacher recommendations; high school transcripts; and student essays explaining their interest in the program. This year's session will be held from June 28 to August 8, 1992. Financial aid is available. For application materials and more information, write to PROMYS, Department of Mathematics, Boston University, 111 Cummington Street, Boston, MA 02215, or call 617 353-2563. Applications will be accepted from March 1 until June 1, 1992.

Film series: the Origin and Evolution of the Universe

The astronomical sciences have developed beyond all recognition over the last 40 years. Until about 1950, astronomy meant optical astronomy, but since then a host of new astronomies have developed, each contributing essential facts about the origin and evolution of different classes of objects in the universe.

A new series from Films for the Humanities & Sciences combines this new knowledge derived from all the different types of astronomy into a coherent picture of our present understanding of the origin and evolution of the universe. This series of five films comes from the Royal Institution Lectures in London, making use of the foremost scientists in their field who traditionally address an audience of adults as well as young people. With the assistance of those in the audience, experiments are performed that explain and clarify the subjects under discussion. For rental or purchase information on this series, or for a video catalog, write Films for the Humanities & Sciences, PO Box 2053, Princeton, NJ 08543-2053, or call 800 257-5126.

Vermont Academy of Science and Technology (VAST)

Vermont Technical College in Randolph, Vermont, offers an unusual opportunity to high school seniors to complete their senior year on a residential college campus, where they can pursue their interests in science, engineering, mathematics, and technology. Students in this program, known as the Vermont Academy of Science and Technology (VAST), enroll as freshmen in one of the Vermont Technical College (VTC) engineering technology programs, or may pursue a curriculum designed to meet their specific interests and goals. The Academy program features guest speakers and field trips designed to enhance students' career planning. On completion of this one-year program, VAST students may remain at VTC to complete an associate's degree in engineering technology or applied science, or they may transfer to a four-year institution.

Admission to VAST is determined by means of an interview, recommendations from appropriate school personnel, and a written essay. Students must also show a strong interest or ability in high school math or science and an overall academic average of 85 or higher. For application materials and more information, write to David Grundy, VAST Headmaster, Vermont Technical College, Randolph Center, VT 05061.

Hampshire College Summer Studies in Mathematics

Mathematics students looking for a summer of intense, demanding, exciting, and productive study should consider the Hampshire College Summer Studies in Mathematics (HCSSiM). Funded in part by the National Science Foundation, HCSSiM takes a unique approach to teaching high school students mathematics. Students learn "fun" mathematics—the kind mathematicians don't usually get to until graduate school. The program aims to get students to discover and prove theorems by themselves, noncompetitively. They avoid the calculus and other topics from the late secondary and early college curricula, seeking instead topics (such as number theory, combinatorics, graph theory, chaos, and the algebra and geometry of complex numbers) that can engage students in the discovery of mathematics and the creation of proofs. Faculty from major colleges and universities live in the program dormitory and join students for meals and recreational activities, as well as for seven hours of classes and problem-solving seminars each day.

The 1992 program will take place from June 29 to August 9 in Amherst, Massachusetts. For application materials and more information, write to David Kelly, Director, HCSSiM, Hampshire College, Amherst, MA 01002.

ANSWERS, HINTS & SOLUTIONS

Math

M41

Since $k/(k+1)! = [(k+1)-1]/(k+1)! = 1/k! - 1/(k+1)!$, the sum in question equals

$$\frac{1}{2!}+\frac{2}{3!}+\cdots+\frac{n-1}{n!}$$
$$=\left(\frac{1}{1!}-\frac{1}{2!}\right)+\left(\frac{1}{2!}-\frac{1}{3!}\right)+\cdots+\left(\frac{1}{(n-1)!}-\frac{1}{n!}\right)$$
$$=1-\frac{1}{n!}.$$

M42

We'll examine the set of possible remainders when a cube is divided by 9 and the set of possible remainders when the sum of the squares of three consecutive integers is divided by 9. If we can show that the two sets of remainders are disjoint, then it follows that a cube can never be represented as the sum of the squares of three consecutive integers.

We can represent any three consecutive integers as $n-1$, n, and $n+1$ for some value of n. The sum of their squares is then $3n^2+2$. We first examine whether n is a multiple of 3. If it is, then $3n^2+2 = 3(3k^2)+2 = 9k^2+2$ for some k, so that the sum of the squares has a remainder of 2 when divided by 9. If n isn't a multiple of 3, then $n = 3k \pm 1$ for some integer k, and $3n^2+2 = 3(3k \pm 1)^2 + 2 = 3(9k^2 \pm 6k + 1) + 2 = 9(3k^2 \pm 2k) + 5$, which has a remainder of 5 when divided by 9. So the sum of the squares of three consecutive integers can only have a remainder of 2 or 5 when divided by 9.

We now turn to the cube of an arbitrary integer. The integer can be represented as either $3k$ (for a multiple of 3) or $3k \pm 1$ (for a nonmultiple of 3). In the first case, its cube has a remainder of 0 when divided by 9. In the second case, its cube can be written as $9(3k^3 \pm 3k^2 + k) \pm 1$, and so has a remainder of 1 or 8 when divided by 9.

Thus, the two sets of possible remainders are disjoint, and the assertion holds.

M43

We can use the method discussed in the article "Off into Space" in this issue. A regular hexagon can be considered the projection of a cube along a plane perpendicular to one of its main diagonals. Indeed, if we hold a cube so that two opposite vertices coincide, we'll be viewing this projection (fig. 1).

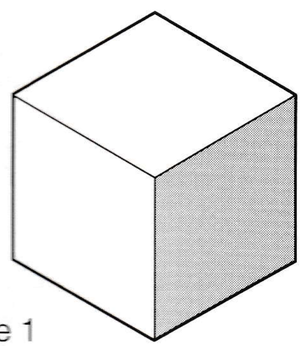


Figure 1

Figure 2 can be viewed, with a small stretch of the imagination, either as a diagram in space or as a diagram in the plane. We'll look at it as a diagram in space. We then see a cube, with vertex P closest to us and the opposite vertex Q directly behind it. The projection of this cube onto a plane pependicular to PQ gives us the original regular hexagon. We see this as the outline of the cube in figure 2. Notice that three edges of the cube (PX, PY, and PZ) project into the three diagonals of the hexagon and that the same is true of the (hidden) edges QX, QY, and QZ.

Let's extend PX, PY, and PZ. By the statement of the problem, these extensions will contain three points K, L, and M, which project into the intersection points of three pairs of opposite sides of the inscribed hexagon $A_1A_2A_3A_4A_5A_6$ on the plane (the figure shows points A_1', A_2', A_3', A_4', A_5', A_6', which project into the corresponding vertices of the inscribed hexagon). If we pass a plane through K, L, and M, then it's not difficult to see that the cross section of the cube along this plane must contain the points A_1', A_2', A_3', A_4', A_5', A_6'. For example, any point that projects onto line A_1A_2 must be on the plane determined by that line and by points K and L. The intersection of this plane with the "top" of the cube therefore contains K, L, A_1, and A_2. Similarly, L and M are collinear with A_3 and A_4, and M and K are collinear with A_5 and A_6.

Now let's extend QX, QY, and QZ to intersect the plane of KLM in points K', L', and M'. Then the line $K'M'$ is the intersection of the plane determined by K', M', and Q with the plane containing face PXZ of the cube. So line $K'M'$ must contain point A_2'. Similarly, this line contains point A_3'. In just the same way, we

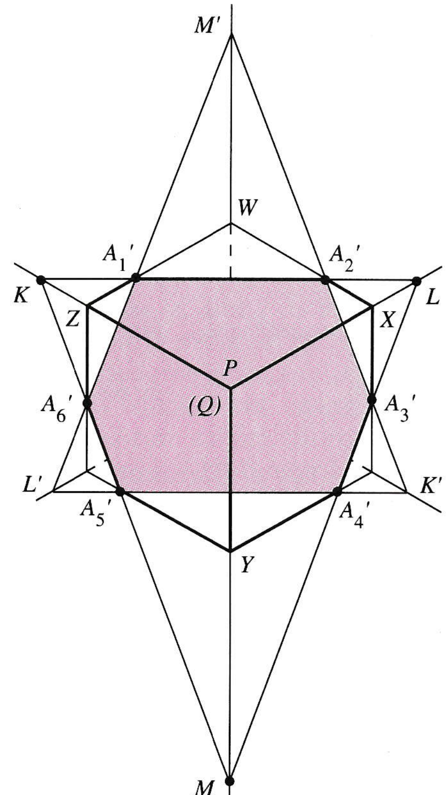


Figure 2

find that line $K'L'$ contains points A_4' and A_5', and line $L'M'$ contains points A_6' and A_1'. Projection back into our original plane shows that the pairs of segments $A_2'A_3'$, $A_4'A_5'$, and $A_6'A_1'$ intersect along the diagonals of the hexagon.

M44

Let's apply the "extremity rule" (see *Quantum*, Nov./Dec. 1990, p. 8), which prompts us—in a very general form—to "consider the extreme case." Here we choose from all the n planets of the system the two that are closest to each other. The astronomers on these planets observe each other's planet. If any of the remaining $n - 2$ astronomers also observes one of the two planets, then there won't be enough astronomers to observe the other $n - 2$ planets.

If, on the other hand, the chosen planets aren't observed by anybody except their own astronomers, we can simply discard them. Again let's choose the two closest planets from the $n - 2$ planets left and proceed as we did above. Every time we discard a pair of planets we'll still have some odd number of planets left; but this number can't decrease forever (it can't be negative), so sooner or later we must come across a planet that no astronomer observes. (V. Dubrovsky)

M45

The function $T(\varphi)$ is given by the formula

$$T(\varphi) = \begin{cases} \frac{1}{\pi}\arccos(k\tan\varphi), & \text{for } 0 \le \varphi \le \alpha, \\ 0, & \text{for } \alpha \le \varphi \le \frac{\pi}{2}, \end{cases}$$

where $k = \cot\alpha$. (The unit of time here and throughout is one day for the planet in question—that is, the period of its rotation about its axis.)

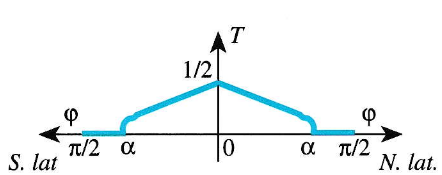


Figure 3

In figure 3, $T(\varphi)$ is graphed for both the north and south latitudes.

The boundary between day and night on the planet is a circle whose center coincides with the center O of the planet. This circle intersects the geographic latitude φ at the points P_1 and P_2 that separate day from night on this latitude. The length of daytime at latitude φ in our time units (days) is equal to $T = \gamma/2\pi$, where γ is the degree-measure of the arc P_1P_2 of the latitude illuminated by the star—that is, the size of the angle P_1MP_2, where M is the center of the circle of latitude (OM is the planet's axis). We must find the minimal value of γ. Chord P_1P_2 always passes through the point K in which the plane of our parallel of latitude cuts the perpendicular to the plane of the planet's orbit drawn through O. Since this perpendicular and the plane of the latitude always preserve their directions, point K remains fixed relative to the planet. Clearly the shortest arc P_1P_2 corresponds to the shortest chord P_1P_2, and the chord is shortest when it's perpendicular to MK. In this case

$$\cos(\gamma/2) = \cos\angle P_1MK = MK/MP_1.$$

By definition of φ and α,

$$\angle P_1OM = \frac{\pi}{2} - \varphi, \quad \angle MOK = \frac{\pi}{2} - \alpha.$$

So if R is the radius of the planet, then

$$MP_1 = OP_1 \sin\left(\frac{\pi}{2} - \varphi\right) = R\cos\varphi,$$
$$MK = OM\tan\left(\frac{\pi}{2} - \alpha\right) = R\sin\varphi\cot\alpha$$

(since $OM = R\sin\varphi$) and, finally,

$$T = \frac{\gamma}{2\pi} = \frac{\arccos(\tan\varphi\cdot\cot\alpha)}{\pi}.$$

Of course, this formula is valid only for $\varphi \le \alpha$. If $\varphi > \alpha$, then during the winter solstice (the shortest day) all of latitude φ lies in the unlit area, and the polar night sets in; so here $T(\varphi) = 0$. This area of the planet's surface is painted black in figure 4.

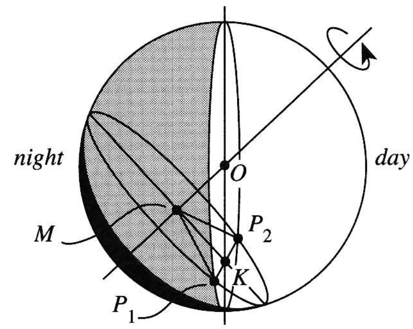


Figure 4

Physics

P41

Let's select a star and write its velocity in a coordinate system centered on the first nearby star. According to the statement of the problem, the velocity of the selected star relative to this first star is

$$\mathbf{v}_1 = \alpha\mathbf{r}_1,$$

where $\mathbf{r}_1$ is the vector from the first star to the one we've selected. In the coordinate system centered on the second star that the cosmonauts flew to, the velocity of our star is

$$\mathbf{v}_2 = \mathbf{v}_1 - \mathbf{v}_0,$$

where $\mathbf{v}_0 = \alpha\mathbf{r}_0$ is the velocity of the second star with respect to the first one. Drawing vector $\mathbf{r}_2$ from the sec-

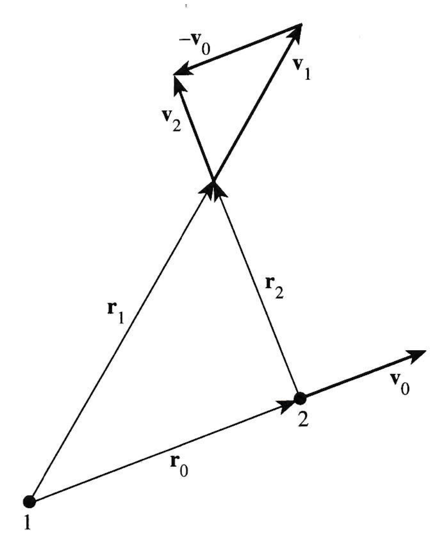


Figure 5

ond star to our star (fig. 5), it's easy to see that

$$\mathbf{r}_2 = \mathbf{r}_1 - \mathbf{r}_0.$$

Accordingly, the velocity of the star

$$\mathbf{v}_2 = \alpha(\mathbf{r}_1 - \mathbf{r}_0) = \alpha\mathbf{r}_2.$$

So the cosmonauts will again see that all the stars are receding at a velocity proportional to the distance to these stars.

P42

(a) First let's determine the velocity of the descent module. We note that the change in pressure Δp is connected with the change in altitude Δh according to the following relation:

$$\Delta p = -\rho g \Delta h, \qquad (1)$$

where ρ is the gas density. The equation of state for an ideal gas implies that $p = (\rho/\mu)RT$ (where T is the gas temperature at the point where the change in pressure is considered and μ is the gram molar mass of the gas). Taking into account that $\Delta h = -v\Delta t$, where v is the velocity of the descent and Δt is the duration of the descent, we can write expression (1) in the form

$$\frac{\Delta p}{p} = g\frac{\mu v \Delta t}{RT}. \qquad (2)$$

Knowing the ratio $\Delta p/\Delta t$—that is, the slope of the tangent at the final point A of the graph (fig. 6), we can determine the velocity v from equation (2). (It should be noted that since the left side of (2) contains the ratio $\Delta p/p$, the scale on the ordinate axis is immaterial). Having determined $(\Delta p/\Delta t)p^{-1} = 1/720$ s from the graph and substituting $\mu = 44$ g/mole for CO_2, we find that the velocity of the descent module of the spacecraft is

$$v = \frac{RT}{g\mu}\frac{\Delta p}{p\Delta t}$$
$$= \frac{8.3\ \text{J}/(\text{K}\cdot\text{mole})\cdot 7\cdot 10^2\ \text{K}}{10\ \text{m}/\text{s}^2\cdot 44\cdot 10^{-3}\ \text{kg}/\text{mole}\cdot 720\ \text{s}}$$
$$\cong 18.4\ \text{m}/\text{s}.$$

(b) Now let's solve the second part of the problem. Given that the module has a velocity of 18.4 m/s, it was at an altitude h = 15 km above the surface of the planet 820 s before landing—that is, this moment corresponds to t = 2,730 s. Using the relation $(\Delta p/\Delta t)p^{-1}$, we can find the required temperature T_h at this point of the graph from equation (2):

$$T_h = \frac{g\mu v}{R}\left(\frac{p\Delta t}{\Delta p}\right)_t \cong 420\ \text{K}.$$

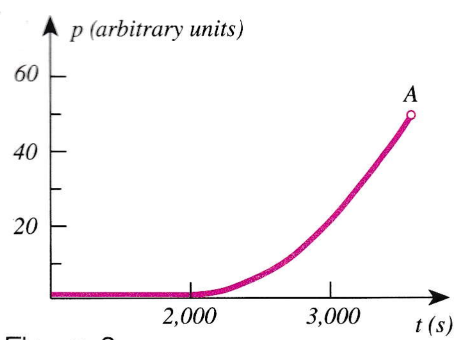


Figure 6

P43

The sum of the readings of the "upper" voltmeter V_1 and the "lower" voltmeter V_2 equals the battery's voltage—that is, the "lower" voltmeter will read 3 V. The voltmeters are identical; this means that the current of the "lower" voltmeter is 1.5 times that of the "upper" one—that is, the current of voltmeter V_3 is equal to one half of the "upper" voltmeter current, and so its reading will be 1 V.

P44

The phenomenon described in the problem has to do with the fact that the indices of refraction of light beams and radio waves in the Earth's atmosphere are different. The path of a light beam propagating from the Moon in the atmosphere deviates slightly from a straight line (that is, it refracts); the same thing happens with radio signals, but the magnitude of the deviation will be different. So the trajectories of radio signals and light beams from the Moon are different, which means that the telescope must be pointed in different directions for optical and radiolocation images of the Moon.

P45

Suppose the spacecraft is oriented so that the sunlight falls on both the reflective and black portions of its surface (fig. 7). Light pressure arises because the photons undergo a change in their momenta when they hit the surface. If light hits the reflective surface, it's reflected according to the law of reflection: the angle of incidence of a light beam equals the angle of its reflection. It's not hard to see that in this case the change in the photon's momentum is a vector perpendicular to the spacecraft's surface—that is, along its radius. According to Newton's second and third laws the force acting on the spacecraft is equal to the change in the photon beam's momentum per unit time. The force is directed along the spacecraft's radius. It doesn't create a torque that turns the spacecraft about its center.

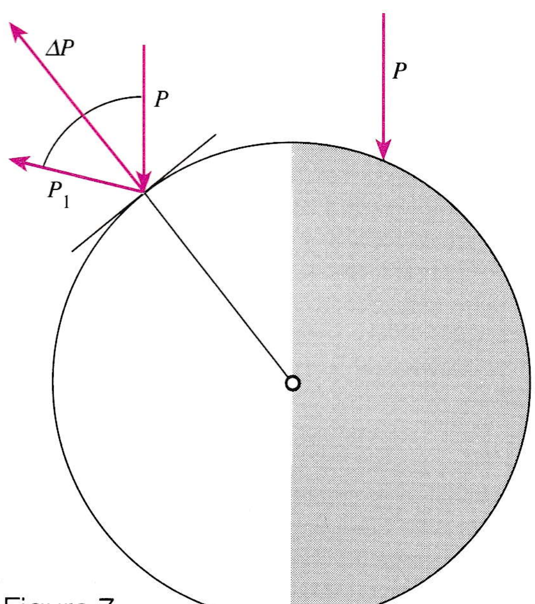


Figure 7

Something different happens with the pressure on the black portion of the spacecraft's surface. As it absorbs the Sun's radiation, the force acting on the spacecraft is in the direction of the beam. This force creates a torque that turns the spacecraft so that its reflective surface faces the Sun.

It's clear that the spacecraft will also be in equilibrium when the black portion of its surface faces the Sun. But the equilibrium isn't stable. If the spacecraft happens to turn slightly relative to the Sun, it will continue to rotate in the same direction.

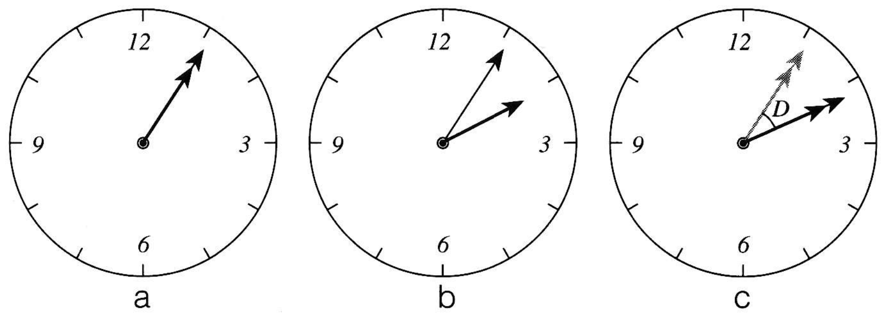


Figure 9

Brainteasers

B41

The answer is

```
    271
  x 205
   1355
  542
  55555
```

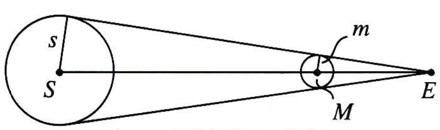
It follows from the very form of the sum that the second digit of the second factor is zero. The product has the form $11111m = 271 \cdot 41m$, where m is the digit denoted by the Moon. The numbers 271 and 41 are prime, so the first factor in the given sum is 271; to find the second we must choose m so that $41m$ is a three-digit number whose second digit is zero. The only suitable m is 5; then $41m$ = 205.

B42

Practically nothing will change: the fly won't be seen. But if it covers a rather large portion of the lens, remote objects will appear to be slightly less bright.

B43

During an eclipse the Moon covers the Sun almost completely. So the Sun's radius is to the Moon's radius as the Sun's distance from the Earth is to the Moon's distance from the Earth (fig. 8)—that is, 387:1. So the ratio of the volumes of the Sun and Moon is approximately 387^3:1.



$s/m = ES/EM = 387$

Figure 8

B44

A ballpoint pen can't be used in the state of weightlessness because the thick ink is pressed against the ball under the action of gravity. (If you've ever tried to write against a wall or with the tip of the pen pointed upward, you will have verified this fact.) The operation of a fountain pen, on the other hand, is based on capillary action. So a fountain pen will work in a state of weightlessness.

B45

Answer: SPACE. The clue to the cipher is given by the colors of the figures: crimson, **p**ink, gr**a**y, bla**c**k, y**e**llow. Each figure denotes which letter in the name of the color to select.

Attitude

1. Distance = $2\pi R \cdot \frac{K}{360} = \frac{\pi RK}{180}$.

2. Suppose the hands of the clock are initially aligned at any position (fig. 9a). In 60 minutes the minute hand will be back at this position, but the hour hand will have moved on a bit (fig. 9b). As the minute hand continues to move, it will soon be aligned with the hour hand again. Let D be the number of degrees in the angle formed by these two sequential positions of alignment (fig. 9c). The minute hand has moved through $(360 + D)^\circ$, while the hour hand has moved through D°. The minute hand rotates through 360° in 60 minutes, so its rate of rotation is 6° per minute. The hour hand rotates through 360° in 12 hours, or 720 minutes, for a rotation rate of 0.5° per minute. If T is the number of minutes between successive alignments, then from the relation (angular) rate x time = (angular) distance, we have $0.5T = D$ and $6T = 360 + D$. Then $6T - 0.5T = 360$, so $T = 360/5.5 = 65\ 5/11$ minutes.

3. The reasoning here is exactly analogous to that in exercise 2; the only difference is in the rates of rotation. Our observer at Quito rotates through 360° in 24 hours for a rate of 15° per hour. The satellite rotates through 360° in 8 hours for a rate of 45° per hour. Letting D be the number of degrees and T the time in hours between successive overhead sightings, the equations are, for the observer, $15T = D$; for the satellite, $45T = 360 + D$. Then $30T = 360$, and the satellite will be directly overhead again in $T = 12$ hours.

4. The longitude in units of time is 5 hours 27 minutes.

5. We leave this for you to do entirely on your own.

6. For pitch, $x_P = x \cos P - z \sin P$; $y_P = y$; $z_P = z \cos P + x \sin P$. For yaw, $x_Y = x \cos Y + y \sin Y$; $y_Y = y \cos Y - x \sin Y$; $z_Y = z$.

Off into space

1. The given configuration can be regarded as the image of a trihedral angle with three points on its faces. Then the problem is to construct the cross section of the angle by the plane drawn through these points. (Here's how it can be done. Construct a triangle with the vertices on the rays such that two of the given points—say, A and B—lie on its sides. Let P be the point where line AB meets the extension of the third side of the tri-

angle. Then the line joining P and the third given point C contains the side of the required triangle passing through C.)

2. Consider the given configuration as an image of a "spatial" (nonplanar) quadrilateral $ABCD$ with points K, L, M, N on its sides. Then the problem's condition, as well as the statement, is equivalent to the fact that these points lie in one and the same plane.

3. The solution is quite similar to that of the problem of an "articulate quadrilateral" in the article: the given hexagon can be represented as the projection of a "spatial" hexagon whose sides touch the circle at the same points; the diagonals of the spatial hexagon are the pairwise intersections of three different planes meeting at one point.

4. The proof virtually reproduces that of the Altitude Theorem in the article.

5. Construct a sphere with the same center and radius as those of the given circle. Let the perpendicular through A to the circle's plane intersect the surface of the sphere in points B and C. If XY is an arbitrary chord through A, and M is the point corresponding to this chord by the condition, then all the tangents from M to the sphere form a cone whose base is the intersection of the sphere with the plane XYB. It follows that MB is one of these tangents, so M belongs to the plane tangent to the sphere at B. The unknown locus is the straight line where this plane and the plane of the given circle intersect.

6. Let lines a, b, c, d be the graphs of the motion of A, B, C, D in (x, y, t) coordinates in space, where the (x, y)-plane is the plane on which the pedestrians walk and t is the time coordinate. Two pedestrians meet if and only if the corresponding graphs intersect. By the condition any pair of the lines a, b, c, d intersects except the pair c, d. It follows that they lie in one plane. So c and d intersect too (these lines can't be parallel, since their projections onto the (x, y)-plane aren't parallel).

Kepler

4. Comparing a comet's orbit with the Earth's and using Kepler's third law, we determine the semimajor axis of the comet's orbit: a = 18.05 AU. The greatest distance from the Sun is about 35.5 AU.

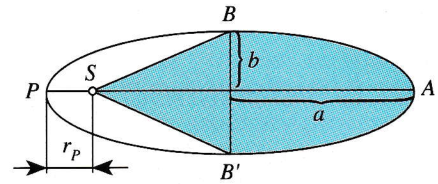


Figure 10

6. See figure 10. While traveling along the farther half of its orbit the comet covers the area of the geometric figure $SBAB'$. The area of this figure is $\pi ab/2 + b(a - r_p)$.

During the time of interest to us, the rest of the total area πab is covered. Computation then gives us the answer: 14.7 years.

Corrections

Mr. A. Dennard of Putaruru, New Zealand, wrote to point out that Ernest Rutherford (see "A Strange Box and a Stubborn Brit" in the March/April issue) was a New Zealander, not a Briton. Though he was the offspring of British-born parents, spent much of his career in England, and was buried in Westminster Abbey just down the aisle from Newton, Rutherford was born on a farm in the province of Nelson on the South Island and received his early education (through his master's degree) in New Zealand. Our apologies to New Zealanders everywhere. (And let this be a lesson to alliteration-crazed headline writers!)

In the last issue, a passage in the Toy Store was garbled. On the inside back cover, second column, the text reading "then repeat the last move . . . one more move" should be replaced with "then make two more moves according to the figure."

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Science vs. the UFO

You may find it an Unidentified Flummoxing Object!

by Will Oakley

NO! I'M NOT GOING TO GET mixed up in the perennial discussion of whether extraterrestrial aliens have ever visited the Earth. The UFO I'll tell you about is nothing more than a puzzle manufactured in Hungary in the early 1980s. You can get an idea of what it looks like from figure 1. There may be some doubt about whether it can fly, but it sure isn't easy to identify, is it?

The UFO is one of the so-called *transformational puzzles* that you may have gotten to know from the last installment of the Toy Store. Like Rubik's cube, it has a number of colored elements—16 cylindrical sections—that can be rearranged in lots of ways by rotating four cylinders, each consisting of four sections, and two horizontal layers, each containing four half-cylinders (or eight sections). Figure 1 shows the correct position of the sections; pay attention to the dots on the faces of sections, which allow us to discern sections of one color. The problem is to restore the correct arrangement of colors and dots after they've been randomly scrambled. So it's very similar to Rubik's cube and many other transformational puzzles; the methods of solving it are, in general, very similar too. But one important feature makes the UFO tangibly easier than the cube: a section of the UFO can take only one position in every location on the puzzle's frame, whereas a small "cubelet" of Rubik's cube can be rotated in its niche in two or three ways. So all you have to do for the UFO is put every section in its place.

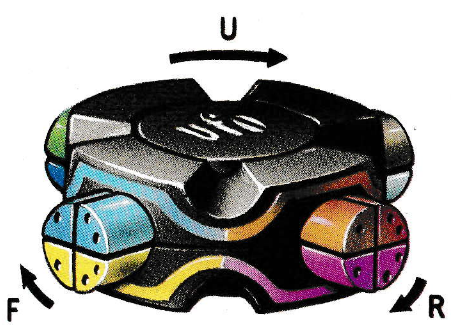
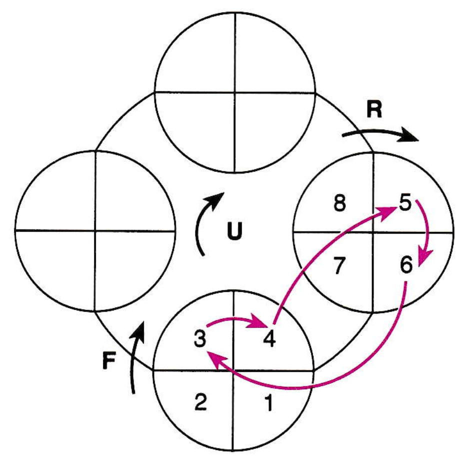


Figure 1

Because of the unbelievable popularity attained by the cube not so long ago and the abundance of math problems connected with it, Rubik's cube became (along with other transformational puzzles) an object of great attention for mathematicians all over the world. They developed a whole science—some call it "cubology"—of how to solve the cube and similar puzzles, how to describe all their possible states, and so on. It's not a gross exaggeration to say that using a few cubological "tools," we can solve in practically no time almost any transformational puzzle that was or ever will be invented. The UFO puzzle is an excellent visual aid for demonstrating these tools: it's very simple in structure, and you can follow the explanations by just looking at the illustrations or drawing your own diagrams, though it would be better, of course, to have the toy for practice.[1]

When we begin solving a transformational puzzle, the very first step is to try to do whatever is easy to do. For the UFO the relatively easy part is to put three of the four cylinders in order. At this stage the fourth cylinder is used as a sort of assembly turntable for coupling sections of the same color; the pairs are then moved to their "home" locations. After this stage of work

[1] The *Quantum* staff has not been able to locate a store that sells the UFO. Have any of our readers sighted it?—*Ed.*



$U^{-1}RU$

Figure 2

is completed, we can always turn the fourth cylinder, still unordered, so as to bring all four, or exactly two of its sections, to their correct places (it's not very obvious, but it's absolutely true: you can check it by simply sorting all the possibilities—there are only 24 of them). So we arrive at the problem of exchanging two sections of one cylinder—and this is where the "science" comes in.

We'll need some notations for the sequences of turns of the puzzle's parts and the rearrangements they produce. For our purposes three "elementary moves" will be enough (shown in figure 1 and the schematic figure 2): U—the clockwise 90° turn of the upper layer; F and R—similar turns of the front and right cylinders; the corresponding counterclockwise turns are denoted by U^{-1}, F^{-1}, and R^{-1}. If we number the sections of the front and right cylinders as in figure 2, then the F-turn results in a *4-cycle* $1 \to 2 \to 3 \to 4 \to 1$, conventionally denoted by (1, 2, 3, 4); and the R-turn results in another 4-cycle (5, 6, 7, 8).

The U-turn can be used to mix the elements of these two disjoint cycles: the process (sequence of turns) $U^{-1}RU$ yields the 4-cycle (3, 4, 5, 6) involving elements of both F- and R-cycles; this is shown in figure 2. This process, as well as any process of the form $A^{-1}RA$, where A is an arbitrary process, is called the *conjugate of R by A*. Conjugates are used to modify processes: they preserve the general structure of the initial process (here, a 4-cycle) but involve different elements. As the abstract diagram in figure 3a clearly shows, we now have a chain of three 4-cycles F, $U^{-1}RU$, and R. Such *interlacing cycles* are the "blocks" out of which we can construct more convenient and useful processes in a rather routine way.

So the first step in solving a transformational puzzle is to find such cycles or create processes producing them (like $U^{-1}RU$ here). The next step is to examine their *commutators*—that is, processes of the form $[A, B] = ABA^{-1}B^{-1}$. For the UFO, the commutator $C = [F, U^{-1}RU] = FU^{-1}RUF^{-1}U^{-1}R^{-1}U$ of two adjacent cycles (1, 2, 3, 4) and (3, 4, 5, 6) results in a very simple permutation of sections, consisting of two pair exchanges—(2, 6)(3, 4) (fig. 3b). (Actually, our readers have already seen just this commutator: the processes F and $U^{-1}RU$ move sections 1, 2, ..., 6 in much the same way as quarter-turns of two adjacent faces of Rubik's cube move six corners of these faces, and we looked at the commutator of these turns in the previous Toy Store.)

If we could get rid of one of the two 2-cycles (2, 6) and (3, 4), we'd obtain what we want: a single exchange of two elements. To annihilate an n-cycle we can simply repeat it n times: after the nth iteration all its elements arrive safely back at their initial places. But we can't do it right away with the process C because both of its cycles are of the same length 2 and will simultaneously vanish after an even number of iterations of C or be retained if this number is odd. So let's modify C by adding a third 4-cycle R = (6, 7, 8, 5) linked with (2, 6), thus turning the latter into a 5-cycle: the process CR consists of 2-cycle (3, 4) and 5-cycle (2, 7, 8, 5, 6) (fig. 3c). All we need to do now is repeat this process five times, wiping out the 5-cycle but preserving the 2-cycle: the process $T = (CR)^5$ (fig. 4) exchanges two sections 3 and 4, and we're done. The conjugates of T can be used to exchange any two sections; for instance, sections 2 and 6 are swapped by the process $(RU)T(RU)^{-1} = RUTU^{-1}R^{-1}$.

To sum up, here are the rules that helped me do the UFO and will help you solve any transformational puzzle:

1. Find or create interlacing cycles.
2. Examine their commutators to obtain processes that move as few elements as possible.
3. Use iteration and conjugates to improve and diversify your processes.

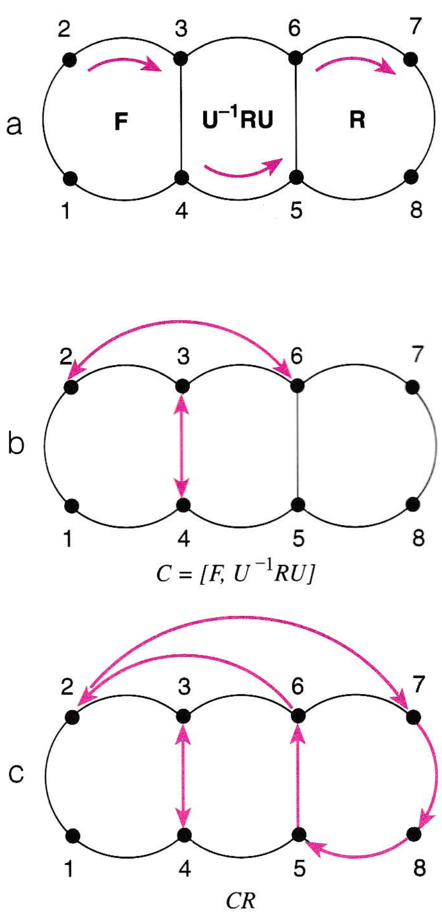
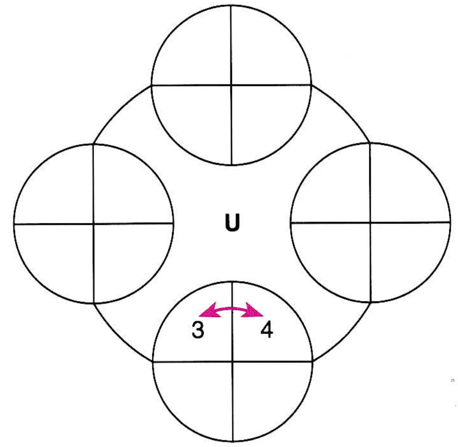


Figure 3



$T = (CR)^5$

Figure 4

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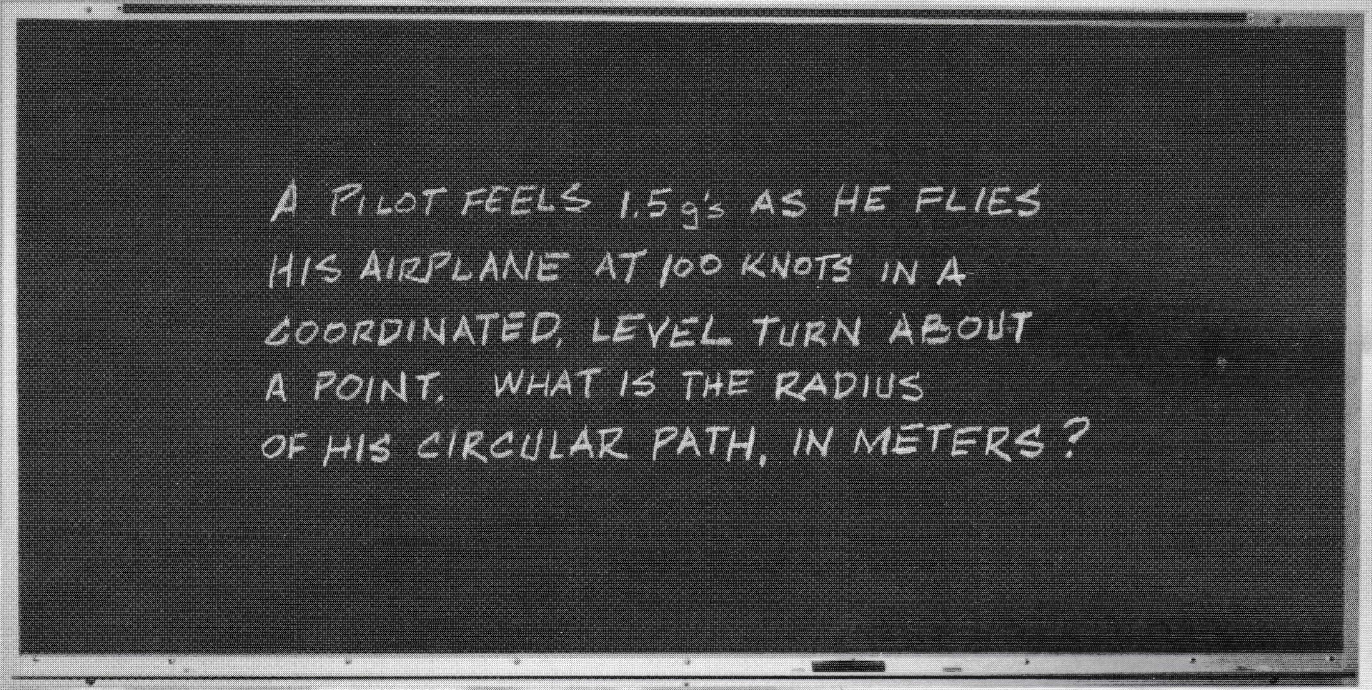

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