SOLAR SCIENCE

EXPLORING SUNSPOTS, SEASONS, ECLIPSES, AND MORE

Dennis Schatz
Andrew Fraknoi

NSTA press
National Science Teachers Association

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Dedication

To Alan J. Friedman,
good friend, colleague,
and mentor, who inspired
everyone he met to remember
that science is a way of
thinking, not a list of facts.

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About the Authors

Dennis Schatz is the author of numerous resources for educators and museum professionals, including *Astro Adventures: An Upper Elementary Curriculum* (Pacific Science Center 2002) and *Astro Adventures II* (Pacific Science Center 2003). He is also the author of 23 science books for children that have all together sold almost 2 million copies worldwide and have been translated into 23 languages. These include *Astronomy Activity Book* (Simon and Schuster 1991) and *Stars and Planets* (SmartLab Toys 2004).

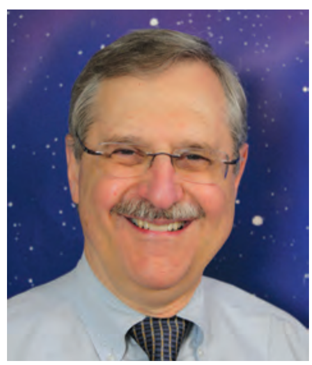
Dennis was a member of the five-person design team that developed the Earth and space sciences disciplinary core ideas for the National Research Council that are found in *A Framework for K–12 Science Education*, which was used to develop the *Next Generation Science Standards*.

For many years, Dennis was the senior vice president for strategic programs at the Pacific Science Center in Seattle, Washington. For four years he served as a program director for science education at the National Science Foundation. At the Pacific Science Center, he codirected Washington State LASER (Leadership and Assistance for Science Education Reform), a program to implement a quality K–12 science program in all 295 school districts in Washington State. He was also principal investigator for Portal to the Public, an initiative to develop programs—both on-site and off—that engage scientists in working with diverse audiences to enhance the public's understanding of current science research.

He has received numerous honors, including several from the National Science Teachers Association (NSTA): the 2009 Faraday Science Communicator Award, the 2005 Distinguished Service to Science Education Award, the 1996 Distinguished Informal Science Education Award, and the 1980 Ohaus Honorary Award for Innovations in Science Teaching.

More information about Dennis Schatz is available at *www.dennisschatz.org.*

Andrew Fraknoi is the author of *Disney's Wonderful World of Space* (an astronomy book for grades 5–7) and is the lead author of several successful introductory astronomy textbooks for nonscience majors (such as *Voyages Through the Universe*, 3rd ed., published in 2004 by Brooks-Cole/Cengage). In the 1980s, he also edited two books of science and science fiction for Bantam. He is editor and coauthor of *The Universe at Your Fingertips 2.0*, a collection of astronomy activities and teaching resources published by the Astronomical Society of the Pacific that is in use in formal and informal educational institutions around the world.



He is the chair of the astronomy department at Foothill College, Los Altos Hills, California, and appears regularly on local and national radio explaining astronomical developments in everyday language. Fraknoi was the cofounder and coeditor of *Astronomy Education Review*, the online journal and magazine published by the American Astronomical Society. The International Astronomical Union has named Asteroid 4859 Asteroid Fraknoi to recognize his contributions to astronomy education and outreach (but he wants us to mention that it's a very boring asteroid and no threat to the Earth!).

Andrew is the winner of the 2012 Faraday Science Communicator Award from NSTA, as well as the 2007 Andrew Gemant Award from the American Institute of Physics. Also in 2007, he was selected as the California Professor of the Year by the Carnegie Foundation for the Advancement of Teaching. His other awards include the Annenberg Foundation Award for astronomy education from the American Astronomical Society and the Klumpke-Roberts Award for public outreach in astronomy from the Astronomical Society of the Pacific.

For more about Andrew Fraknoi, see *www.foothill.edu/ast/fraknoi.php.*

Introduction

The Sun is not only the easiest astronomical object in the sky to observe, but it has a greater influence on our lives than any other cosmic object. The fundamental elements of how we mark time—the day and year—are based on the Earth's relationship with the Sun. The cycle of our seasons (from winter to summer and back to winter again) has to do with the tilt of the Earth toward or away from the Sun as a year passes.

The charged particles streaming from the Sun's surface (the solar wind) cause the spectacular auroras that people travel thousands of miles and brave the cold of northern nights to see (Figure I.1). When these particles overload our planet's storage capacity, they can disrupt our radio transmissions and interrupt electrical power distribution. As our civilization gets more and more interconnected on Earth and in space, the chances of serious problems from a storm on the Sun increase.

The unique relationship between sizes and distances in the Earth–Moon–Sun system also cause spectacular eclipses of the Sun and the Moon. Total solar eclipses that reveal the eerie glow of the Sun's outer atmosphere (the corona) are so beautiful and rare that people travel from all over the world to witness them (Figure I.2).

Both the new and the older science standards suggest that students need to have a good fundamental understanding of the Sun's effect on their daily lives. There's no better way of providing that understanding than through the kinds of eye-opening (indeed, mind-opening) experiences in this volume.

FIGURE I.2

Total solar eclipse showing the Sun's corona, which becomes visible during totality

This book is specifically designed for instructors of grades 5–8 who teach about the Sun and Moon and their cycles as well as eclipses, but some of the materials could easily be adapted for higher grades or (informal) settings outside of school. Throughout, we provide classroom-based activities, background information, and

FIGURE I.1

(*Left*) Aurora (northern lights) above Bear Lake in Alaska experience with the science practices and crosscutting concepts identified in the *Next Generation Science Standards* (*NGSS*). The core of the book is a series of student-centered learning experiences that put the students in the position of being scientists: asking questions; exploring phenomena; and drawing, discussing, and refining conclusions.

FIGURE I.3

A digital rendering of the Solar Dynamics Observatory satellite

Educators who use the experiences and suggested teaching strategies in this book will involve students in the three-dimensional learning process recommended by the *NGSS*, effectively integrating the teaching of the disciplinary core ideas, science practices, and crosscutting concepts related to the Sun and the Moon and their motion in the sky. Sections strategically located throughout the chapters identify especially good places to emphasize the three-dimensional learning that students are experiencing.

In addition, we provide a variety of resources that connect the content to best practices in mathematics and literacy, including the use of age-appropriate web pages and real-time data from observatories and satellites, such as the Solar Dynamics Observatory (Figure I.3).

Although the first edition of this book is timed to allow teachers to prepare for the Great American Eclipse of 2017, which will be visible throughout the United States, the book is not tied to that event and will be useful for teaching about the Sun and its effects on our culture and our understanding of nature in any year.

How This Book Is Organized

The book contains four chapters, each of which deals with disciplinary core ideas in the *NGSS*:

1. **Understanding and Tracking the Daily Motion of the Sun:** What does the Sun do in the sky each day, and how does that relate to our notions of time and direction?
2. **Understanding and Tracking the Annual Motion of the Sun and the Seasons:** How does the Sun's motion and position in the sky vary throughout the year, and how does that relate to our ideas of a calendar and the seasons?
3. **Solar Activity and Space Weather:** What phenomena do we observe on the surface and in the atmosphere of the Sun, and how do these influence what we observe and how we live our lives on Earth?

4. **The Sun, the Moon, and the Earth Together: Phases, Eclipses, and More:** How do the relationships among the Earth, the Moon, and the Sun produce solar and lunar eclipses?

Each chapter identifies the specific performance expectations, disciplinary core ideas, science practices, and crosscutting concepts in the *NGSS* that are addressed in the activities. Also listed are connections that the experiences make with the math and literacy standards in the *Common Core State Standards* (*CCSS*).

Learning experiences in each chapter move students from initially engaging with the disciplinary core ideas, science practices, and crosscutting concepts to having a deeper understanding of each of them. These experiences follow the successful 5E Instructional Model developed by Biological Sciences Curriculum Study (BSCS; see the more detailed explanation of the 5E Model, p. xviii), dividing the experiences into the following five categories:

Engage experiences hook the students into wanting to learn more about the topic and reveal their preconceptions about the subject.

Explore experiences allow students to build from their preconceptions by making observations (e.g., by viewing the Sun through special glasses [Figure I.4, p. xvi]), and using the scientific practices to generate questions and consider new ideas based on their observations.

Explain experiences allow the teacher, via continued student discussion and activities, to help students develop a deeper and improved understanding of the core disciplinary ideas, scientific practices, and crosscutting concepts.

Elaborate experiences provide opportunities for students to apply their new level of understanding to related questions or topics.

Evaluate experiences allow students (and teachers) to gauge how well they understand the concepts covered in the chapter.

Each learning experience in the book provides all you need to organize, prepare, and implement it, offering the following information:

1. Overall concept: A general description of the experience.
2. Objectives: What students will learn or produce by completing the experience.
3. Materials: Everything you need to have before you begin.
4. Advance preparation: Important steps that need to be completed before you are ready to have the students do the experience.
5. Procedure: Step-by-step directions for your students and you, plus answers to the questions we suggest asking. Also included are alternative approaches to deal with different classroom structures (e.g., a self-contained classroom vs. multiple sections throughout the day).

Finally, each chapter ends with suggestions for activities to connect to math and literacy concepts and other resources that allow for further exploration of the concepts by students and teachers.

We do not expect that every teacher will use every experience in each chapter. The goal is to provide you with a wealth of activities so that you can choose the ones that best fit your students' developmental level, your class structure, and your time limitations. At a minimum, we think it is important you include at least one each of the *engage*, *explore*, and *explain* experiences.

As students will learn using these experiences, what they discover about the Sun's motion across the sky, the phases of the Moon, and other astronomical phenomena will be different for people at different locations on the Earth. Given that this is a publication primarily for use in the Northern Hemisphere, some of the experiences will need modification to be effective at latitudes outside mid-Northern Hemisphere locations (i.e., outside the continental United States and southern Canada).

FIGURE I.4

Students learn about safe viewing of the Sun.

Use of an Astronomy Lab Notebook

If you already use notebooks or journals in your class, you can skip this explanation of their value, although it is important to understand the difference between notebooks and journals in general and why we refer specifically to using astronomy lab notebooks.

Journals are typically dominated by personal reflections on what the student is currently thinking and how the student is reacting to what is happening in his or her daily life—somewhat akin to a memoir. Science notebooks hold more structured, objective descriptions of science experiments and observations being made by students, plus conclusions reached based on the data collected. While a science notebook also allows for occasional reflection regarding students' initial understanding of a concept and how their thinking changes after analyzing the collected data and discussion with other students and the teacher, it always comes back to making sense of observations and data (see Figure I.5 for an example of Galileo Galilei's use of a notebook).

There are numerous reasons why having students keep astronomy lab notebooks is valuable:

- Students have a single place to document what they have done over an extended period of time and across a number of science experiences. This makes it easy to recover details that students may have forgotten.
- Students can reflect on how their understanding of a concept has changed from the beginning of a unit of study to the end. This type of reflection—especially written reflection—is key to deeper learning (an idea well confirmed by research on how people learn).

FIGURE I.5

Drawings of the Moon from Galileo's astronomy lab notebook

- Teachers can see—and assess, if necessary—what students have done step by step and how well the students understand the concepts being studied.
- It creates an entry point for discussion between student and teacher or among students, which can lead to deeper understanding of the concept being studied.
- Keeping the journal enhances students' writing skills, which support all areas of study by them.
- The process of keeping a contemporaneous lab notebook mirrors what scientists do in their daily lives to document and reflect on their area of research.

Although there is no one way to use notebooks, here are a few criteria that we think are important for creating an astronomy lab notebook:

1. Whatever you use as your notebook (e.g., commercial spiral notebook or composition book; student-created notebooks from 8 ½ × 11 paper), it is important to let the student personalize the notebook including his or her name on the cover along with artwork of an astronomical nature. This can consist of drawings made by the student or astronomical images printed from the internet or cut out of magazines.
2. Several pages at the beginning should be reserved for a table of contents, which is completed as students add material to the notebook.
3. The pages should be numbered so material can be easily referenced in conversations with the teacher and other students.
4. Each experience in our book suggests the minimum material that should be included in the notebooks to document what students are doing. Sometimes this calls for writing directly in the notebook, and other times it involves attaching observations or a worksheet into the notebook. You may wish to have students add more detail than we suggest regarding the procedures they follow or to reflect more on predictions and conclusions.

If you are new to the use of science notebooks, here are some of our favorite resources related to their use:

- *Science Notebooks in Middle School* (from the Full Option Science System program at the Lawrence Hall of Science): *http://goo.gl/glnddU*
- Science Notebooks (Washington State LASER [the website was formerly kept by the North Cascades and Olympic Science Partnership]): *www.wastatelaser.org/Science-Notebooks/home*
- Fulwiler, B. R. 2007. *Writing in science: How to scaffold instruction to support learning*. Portsmouth, NH: Heinemann. *www.heinemann.com/products/E01070.aspx*. (Read a free sample chapter at *www.heinemann.com/shared/onlineresources/e01070/chapter2.pdf*.)

Use of the 5E Instructional Model

The use of a learning cycle method to teaching science goes back to at least the 1960s and is based on a constructivist learning approach that emerged from what research tells us about how people learn (e.g., Bransford, Brown, and Cocking 1999). There are a number of learning cycles used by different curricula, but we have settled on the 5E Instructional Model developed by the BSCS because it is one of the most studied and widely used approaches (see *http://bscs.org/bscs-5e-instructional-model* for more background).

If you already use a learning cycle in your classroom, you can skip the rest of this section. If not, here are the key attributes to keep in mind during each step of the 5E Model:

ENGAGE

- **What it is time to do:** Hook the students' interest and curiosity to learn more, determine the students' current understanding and preconceptions, and raise questions the students want answered.
- **What it is not time to do:** Provide definitions, conclusions, or the right answer; lecture to students; or explain concepts.

EXPLORE

- **What it is time to do:** Provide opportunities to conduct and record observations, have students work together in research teams to compare results and discuss their data, have students suggest conclusions based on the data, ask probing questions of students that encourage them to reflect on their thinking and redirect their investigations if needed, make sure that everyone (including the teacher) is a good listener, and help all students be actively engaged in collecting and discussing data.
- **What it is not time to do:** Allow students to stop considering other conclusions once a single solution is offered, give students answers or provide detailed explanations of how to work through a problem, tell students they are wrong, or give information or facts that solve the problem immediately.

EXPLAIN

- **What it is time to do:** Encourage students to explain concepts and definitions in their own words, based on justification using data; explain concepts relying on experiments or observations; and build from students' previous experiences and preconceptions.
- **What it is not time to do:** Accept or propose explanations without justification or discourage or stifle students' explanations.

ELABORATE

- **What it is time to do:** Expect students to apply the concepts, skills, and vocabulary they have learned to new situations; make additional observations and collect data; and use previous learning to ask questions, design new experiments or observations, and propose appropriate solutions.
- **What it is not time to do:** Provide students with detailed solutions to new problems, provide answers before thorough discussion, or ignore previous data and evidence related to the concept.

EVALUATE

- **What it is time to do:** Have students demonstrate and assess their own learning regarding the concepts while the teacher assesses student progress.
- **What it is not time to do:** Introduce new concepts or subjects or test for isolated vocabulary and facts.

Teachers across the country have found the 5Es a useful and effective way to proceed through their science lessons. At first, individuals not used to the rhythm or pace of the 5Es might get impatient with them, but research shows that allowing students to learn through their own investigations makes for far deeper and longer-lasting learning than just lecturing to them or showing a video.

Use of Think-Pair-Share

The think-pair-share learning strategy is also encouraged throughout the book and is closely aligned with the 5Es. Like the 5Es, the think-pair-share sequence is based on many years of research regarding how people learn. It provides a mechanism for individual students to personally reflect (think) on a question or topic, typically in writing, before having a discussion with a partner or small group of students (pair). The sharing allows students to further reflect on their own and others' thinking about a subject, often leading to refined and improved understanding. Different groups may initially come up with different ideas or solutions about the problem at hand. When all the groups have a chance to discuss their thinking in front of the entire class (share), a wider range of ideas come to the fore. Guided by a skillful (and not too intrusive) teacher, the class can list, discuss, and evaluate the various ideas the groups have come up with and deepen everyone's understanding.

Personalizing the Use of This Book for Your Class

Although this book and its student handouts can be used effectively on its own, it may also be supplemented by a textbook, by student research in a library or on the internet, and by audiovisual materials that help reinforce or develop concepts that are hard to visualize. We have listed some of our favorite outside resources throughout the book.

We understand that different classes and groups have different schedules. Some teachers reading this book will have a class for most of each day and can apportion their time in such a way that experiments can be carried out throughout the day. Other teachers will have each class for only one period and—if experiments need to be continued at another time on the same day—may need to pool the work of several classes to obtain the data needed to continue. We have tried to take into account both kinds of classes in the instructions, but we also appreciate that no one knows a class better than its teacher, and thus you may want to modify our suggestions to fit your particular circumstances.

We also know (from our past experience leading professional development workshops for teachers) that the readers of this book will likely find ways to improve, expand, and personalize the experiences we suggest for their students. If you come up with great new ways of treating the subjects we cover or simply find a clever modification of our suggestions, we would love to hear from you. You can reach us by e-mail at *dschatz@pacsci.org* (Dennis) and *fraknoi@fhda.edu* (Andrew).

Both of us were trained as astronomers and have spent our professional careers explaining the wonders of the sky and the greater universe to students, teachers, museum educators, and museum visitors. Nothing gives us greater pleasure than when someone looks up and says, "Oh, I get it! For the first time, I get how that works." May you have many such experiences with your students as you use this book.

—Dennis Schatz and Andrew Fraknoi

Special Note of Acknowledgment

Student activities, like the experiences in this book, are often put forward by a number of authors independently. One version is often influenced by other adaptations that educators try and then report on in write-ups, conference sessions, and web pages.

We gratefully acknowledge inspiration for sections of a number of these experiences from the talented staff of the following institutions: the Stanford Solar Center; the NASA Science Missions Directorate Heliophysics Forum; the Exploratorium science museum in San Francisco; the University of California, Berkeley, Space Sciences Lab Center for Science Education; Hands On Optics; the Astronomical Society of the Pacific; the Pacific Science Center; David Huestis at Skyscrapers, Inc.; NASA's Goddard Space Flight Center; the Chabot Space and Science Center; the National Oceanic and Atmospheric Administration, NASA's Stratospheric Observatory for Infrared Astronomy (SOFIA), and others. We are particularly grateful to Deborah Scherrer of the Stanford Solar Center for many useful suggestions.

Finally, many thanks go to Paul Allan, coauthor of *Astro-Adventures II* (Pacific Science Center 2003), who developed and refined many of the activities that are the basis of a number of experiences in this book.

A Website for This Book

A special set of web pages to go with this book has been established at the National Science Teachers Association (NSTA) website. You can find it at *www.nsta.org/solarscience*.

The page includes the following:

- PDF versions of student forms, material templates, and handouts for the book
- An updated list of links from the book (so that you don't have to retype URLs)
- News and resources about upcoming eclipses and other topics related to the book
- New ideas and reader suggestions for the experiences in the book

REFERENCE

Bransford, J. D., A. L. Brown, and R. R. Cocking, eds. 1999. *How people learn: Brain, mind, experience, and school*. Washington, DC: National Academies Press.

Flares on the Sun

3.2

ENGAGE

EXPERIENCE 3.2

Be a Solar Astronomer

Overall Concept

A key part of science is that the answers aren't in a book or manual; scientists have to examine things and then find answers to interesting questions. In this open-ended activity, students do what scientists studying the Sun often do—examine a variety of images of the Sun taken over time. They are asked to discuss ideas and questions on the basis of looking at these images.

Objective

Students will notice that changes are visible on the Sun's disk on images of the Sun taken a few days apart, especially in the appearance and number of sunspots.

Advance Preparation

1. Make copies of the handout with the four images of the Sun, making sure the copies are good enough quality to clearly see the sunspots. Since the images are artificially colored, it is fine to copy them in black and white.
2. If you are going to compare these to the current image of the Sun taken with the same space instrument, check that you have a working connection to the internet before class starts.
3. There are many places on the web to obtain current images of the Sun. We recommend one that is relatively easy to use. If you have time, you may want to become familiar with an online application called Helioviewer at *http://helioviewer.org*. This website allows you to bring up an image of the Sun from many different space

MATERIALS

For the class:

- Space on a whiteboard, blackboard, or piece of poster paper to record the ideas that the whole class has shared

One per group of three to four students:

- "Sheet of Solar Images From the Solar Dynamics Observatory" (p. 177), showing visible-light images of the Sun on different days
- Computer with access to the internet if you want to show today's solar image taken with the same instrument that produced the image in Figure 3.10 (p. 176).

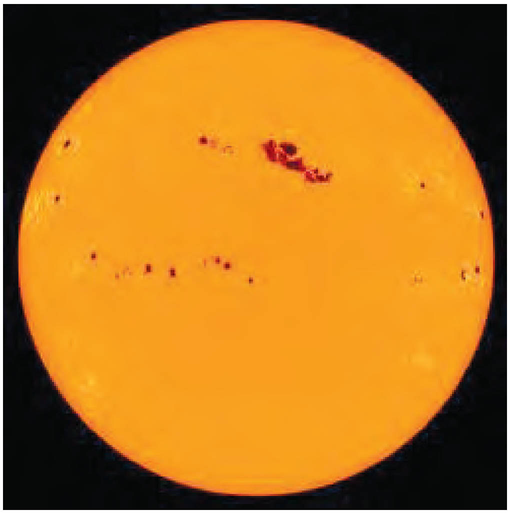
One per student:

- Astronomy lab notebook

observatories for any date. Note that you can get to the user's guide by clicking on the box at the upper right or by going to the small help button at the bottom.

FIGURE 3.10

Image of sunspots on the Sun

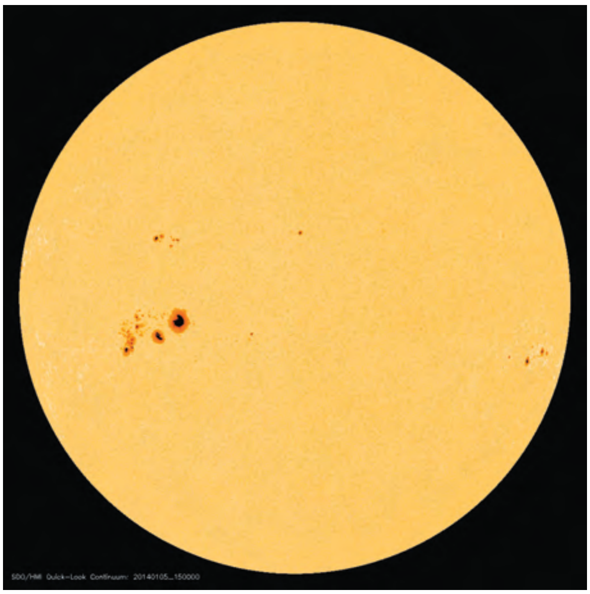


Note that the image has been artificially colored: The Sun is not orange.

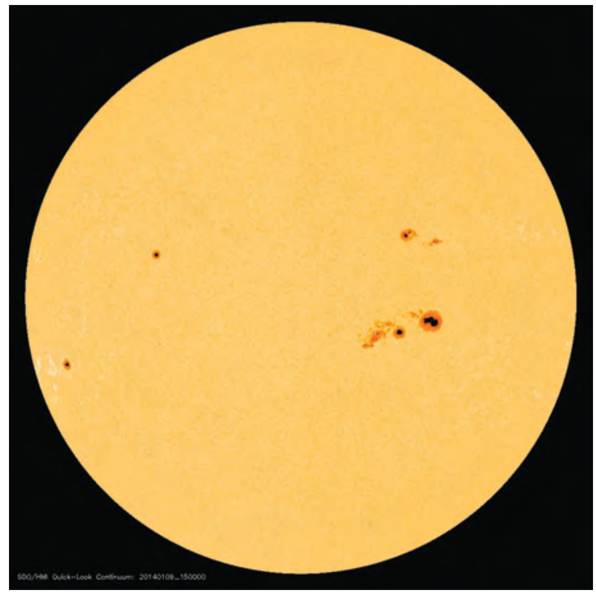
Procedure

1. Organize the students into small groups and give them a copy of the sheet with four visible light images of the Sun from 2014. Ask them to discuss what they notice on the images and what questions they have.
2. If you have access to the internet, show them today's image of the Sun taken with the same instrument. Go to *http://sohowww.nascom.nasa.gov/data/realtime/realtime-update.html* and click on the first image in the second row (the one labeled "SDO/HMI Continuum"). Clicking will enlarge the image. Ask student groups to discuss the differences between today's image and the ones on their sheet. Alternatively, show them Figure 3.10.
3. Have the groups report to the full class and make a list on the whiteboard or a poster paper of all their observations and any questions. (*The students should have noticed that there are dark spots on the face of the Sun and that the number, shape, and position of these spots changes.*) This is not the time to explain fully what sunspots are; instead, you could ask students what might make dark spots on the Sun and record all their suggestions on the whiteboard or poster paper. Students should make notes about their current thinking in their astronomy lab notebooks. These spots will be the subject of Experience 3.4.

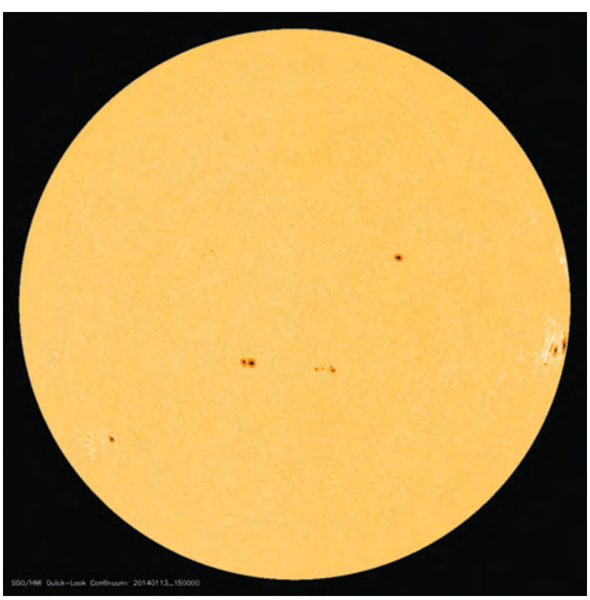
Sheet of Solar Images From the Solar Dynamics Observatory



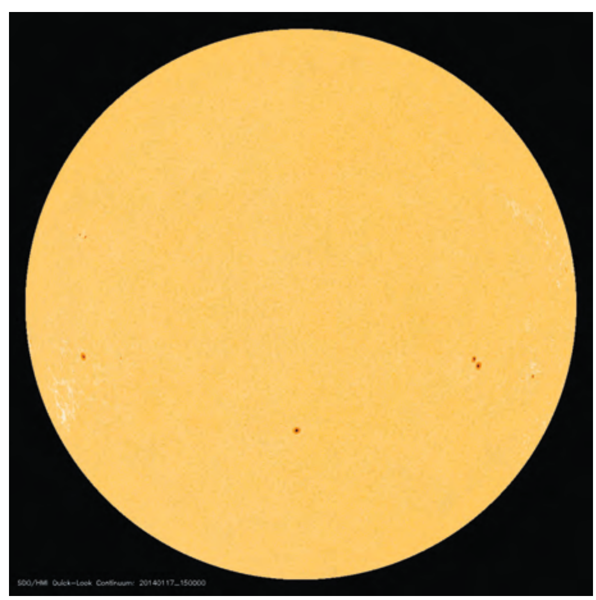
January 5, 2014



January 9, 2014



January 13, 2014



January 17, 2014

Note: If you have color images of the Sun, the color has been added. If you could see the Sun without burning your eyes, it would look generally white in color.

3.4

EXPLORE

EXPERIENCE 3.4

Discover the Sunspot Cycle

Overall Concept

Students learn about sunspots, the cooler areas on the visible surface of the Sun. They learn how to count sunspots and sunspot groups on images of the Sun. They then examine records of sunspot number (SSN) counts over 66 years and graph the number of sunspots versus time. This allows them to discover that the number of sunspots varies from day to day and year to year and that sunspots increase and decrease in a roughly 11-year cycle. Optionally, they can mark the birth years of members of their family on the horizontal (time) axis to give the timescale a more personal touch.

Objectives

Students will

1. count sunspots and sunspot groups on a sample photograph of the Sun (just like solar astronomers do) and calculate the SSN;
2. graph the number of sunspots at the end of each quarter for a period of 66 years; and
3. discover that SSNs increase and decrease on a regular cycle, lasting about 11 years.

Advance Preparation

1. If you are doing the optional personalization part, students should get the birth years of significant members of their families, such as siblings, parents, and grandparents.

MATERIALS

One per group of three to four students:

- "Sunspots Worksheet" (p. 189; since color has been added to the image of the Sun, it is fine to copy the sheet in black and white.)

One per student:

- "Graphing Chart A" (p. 190) or graphing paper
- "Sunspots Data Table" (pp. 191–193) showing the SSN at the end of each quarter from 1948 to 2014
- "Sunspots Handout" (pp. 194–195)
- Set of regular pencils and colored pencils for adding date dots
- (*Optional*) The year of birth of each student's family members (siblings, parents, grandparents, etc.)

2. After each group graphs a section of the SSN versus time data, the different plots will have to be pasted together and combined into a single graph. This means you will need to find a place where this large graph can be on display and students can add colored dots below the graph.
3. Prepare copies of the handouts.

Procedure

1. Tell your students that today they get to act like solar astronomers and do research about sunspots. They are especially going to look at how the number of spots on the Sun changes with time. If you have done previous experiences in which students observed sunspots on projected images or images you provided, this is a good time to remind them about those. You can also teach them a little bit more about what sunspots are and what causes them. (See the information in the Content Background section [pp. 163–164] or give out the "Sunspots Handout.")
2. If the students have drawings of the Sun that they made in a previous experience, ask them in their groups to count how many sunspots they saw on one of those drawings. Do the students agree on these counts? If they don't, ask them why that might be. How did the sunspots vary in size and shape?

   Teacher note: Different student drawings of the Sun made on the same day are likely to differ because some spots might be just at the edge of visibility and not all students may record them. Also, sunspots tend to come in groups, and some students may draw the entire group as one bigger spot, while others might draw the individual spots within the group.
3. Next, introduce students to the idea of the SSN, first defined by the Swiss astronomer Johann Rudolf Wolf in 1848. Astronomers found that some sunspots were seen by themselves, while others congregated in groups. Some smaller individual sunspots were hard to see; they were only visible in larger telescopes. The bigger groups, on the other hand, could often be seen even without the aid of a telescope.

Furthermore, counting overlapping sunspots in groups turned out to be harder than counting the individual spots. Different telescopes might lead to different counts, depending on their ability to make out fine detail. Since a typical sunspot group had 10 spots in it, Wolf suggested that astronomers define an official SSN as

SSN = (10 × # of groups) + # of individual spots

Teacher note: Actually, in the formula astronomers use there is also a factor that accounts for the different telescopes and weather conditions at different observatories, but we will leave that out in introducing students to sunspots at this level.

4. Now give students the worksheet with the practice image of the Sun, which shows a good number of sunspots. Divide students into groups of three to four to count groups and spots and calculate the SSN from the image. (The calculations and answers are given in the accompanying box and Figure 3.12.) They should

As you can see below, we have circled six groups of sunspots, so the number of groups = 6.

Counting individual spots on the picture is trickier, since some of the spots are quite hard to see. The number of spots inside each circle is shown, but if students didn't get the same counts, don't let them get discouraged. Even professional astronomers do not always agree on the count. It takes some time to get experience counting sunspots, and the pictures used by professionals generally show more details than the ones we see here.

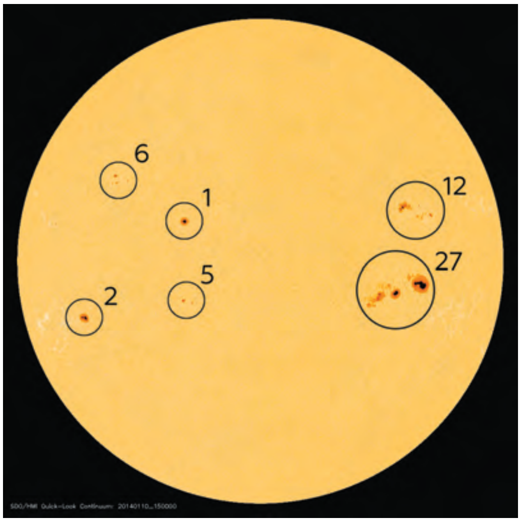
The number of spots (adding up all the numbers next to the circles) is **6 + 1 + 2 + 5 + 12 + 27 = 53**

So the **SSN = (10 × 6) + 53 = 60 + 53 = 113**

Students may point out that this number (113) counts each spot twice (roughly speaking) and they are right about that. The SSN is not a count of spots but a mathematical measure of how many spots are likely to be there, given that some sunspots are hard to spot.

FIGURE 3.12

Sunspots from the image shown to the students (p. 189) are circled



record their data and calculations (using the SSN formula) in their astronomy lab notebooks. Then have the groups share their results for the practice images and discuss any differences in their SSN values. It is not necessary that they all agree on the same value for each photograph. Counting sunspots is a tricky business because some of the spots are quite hard to make out.

5. This is a good time to discuss that the same discrepancies they experienced happen to scientists too. Different scientists might be analyzing the same photographs (or other data) and get different results. Ask students to brainstorm how such differences might be resolved, using SSNs as an example. *Good answers include that different numerical results could be averaged or that observers might practice doing such counts until they got better at estimating what was a spot and what was a group. Experts in sunspot counting could look at a number of photos and write out how they got the SSN in each case so beginners could see how the experts were thinking.*
6. Now that students see how SSNs are calculated, ask them to put away the Sun photo and give each group a copy of the table of SSNs for each quarter from 1948 through 2014 and a copy of "Graphing Chart A." Explain that solar astronomers all over the world have been counting sunspots in this way for many years. They can average their counts over a week, a month, a quarter of the year, or the full year. Have the students examine the table you just gave them. What period of time does each value in the table cover? *One quarter of a year.* Ask them how many years our data chart covers. *It covers 66 years.*
7. Assign each group a period of years to chart, explaining that when they are done, they will put the graphs together to see the complete record. The *x*-axis of their graphs will show the years divided into quarters, while the *y*-axis will show the SSN, which can range from 0 to 250. For each quarter, they should put a dot corresponding to the SSN for the last month in that quarter (so for the first quarter, it's month 3, or March; for the second quarter, it's month 6, or June, etc.).
8. (*Optional*) If the students had the homework of finding out their family's birth years, now ask them if anyone in their

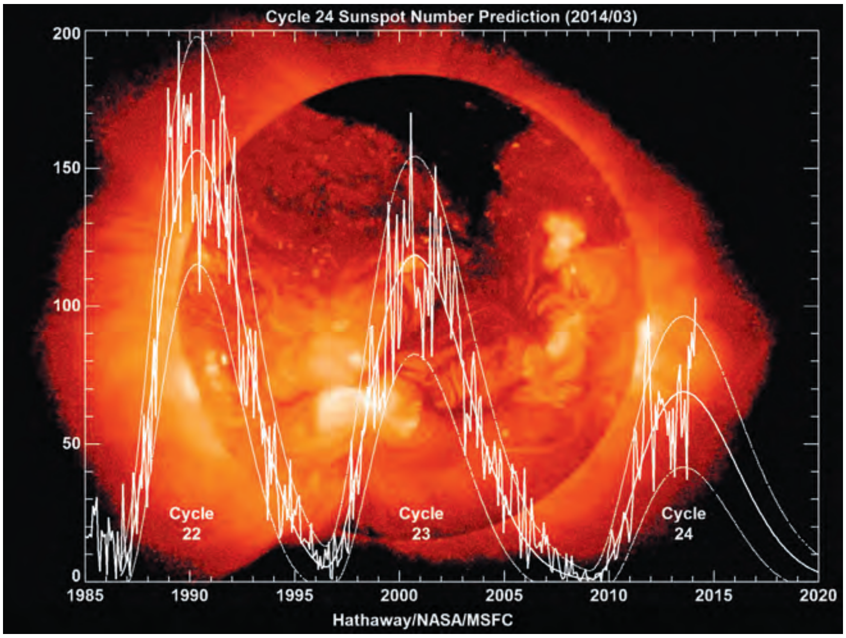
family was born during the years they are working on. If so, the student should put a colored dot at that year on the *x*-axis with his or her initials and how the person is related to them (e.g., mother, aunt, sister). It's helpful to assign a different color of pencil to each group.

9. Now put the graphs from different groups together on a wall or whiteboard, so that the whole 66-year record of SSNs shows. Ask the students individually or in small groups to go up, look at the way SSNs have changed over the years, and search for patterns. They should write in their astronomy lab notebooks about any patterns they see and be as specific as possible. If necessary, encourage them to measure the number of years between times that the number of sunspots was the largest or the smallest. You may need to remind them that each year has four entries, one for each quarter of the year. You may also need to prompt them to look for how much time passes before SSNs go from biggest to smallest and back to biggest (one cycle.) This is a bit tricky, so they should discuss their findings in their groups and then report their estimates to the whole class. Ask them to note their best estimates of when the sunspot minimum and maximum is for each cycle. *If all has gone well, they should be able to identify the roughly 11-year cycle of SSNs (some cycles take less time than this, some take more, but the average is about 11 years).*

   Teacher note: If students are new to working with graphs of real scientific data, they may at first be confused because simply connecting the dots by drawing a series of lines from dot to dot doesn't necessarily give them the whole picture. Within the same year, the quarterly SSN may go up and down, but we are interested in the longer-term trend. So, students should try to take in the overall cycle and not get "hung up" on short-term variations. In a sense, they will be visually averaging the points over time, to find the larger-scale trend within the data (Figure 3.13). If they are having trouble with this, you may need to help them out by drawing their attention to the large-scale variations, going from an overall maximum to a minimum and back to maximum. For your reference, a plot of the last few cycles from considerably more data than the students have,

FIGURE 3.13

Sunspot cycle data and predictions



This graph shows the sunspot cycle data compared with the prediction of experts from 1985 to 2015. You can see the current maximum is rather a low one, with fewer sunspots than usual.

and statistically smoothed, can be found at *www.sidc.be/silso/monthlyssnplot*.

10. Mention that although astronomers know that the increase and decrease of sunspots is connected with the magnetism of the Sun and its own cycles of change, the exact mechanism for the sunspot cycle is not fully understood. (This is a good opportunity to mention that there are many parts of astronomy—and science in general—that are not yet fully understood. That's what makes scientists get up in the morning and want to go to work—that they could be contributing to the understanding of things in nature we are still puzzled by.)
11. (*Optional*) The class can now look at the colored dots at the bottom of the graph showing the years that students and their relatives were born. (This doesn't have to be part of the class

work; it could be done during free time by interested students.) For fun, they can see if they and their relatives were born near a sunspot maximum or minimum. When everyone's dots are on the graphs, they should be able to see that there is no connection between birth dates and the Sun's cycle. As many people are born during a minimum or maximum as any other part of the cycle.

Teacher note: Depending on the class, you are likely to find that the colored dots are not randomly distributed. Parents may tend to cluster in a small range of years, as might siblings. The important thing to notice is that there is no correlation with the Sun's 11-year cycle.

12. Now ask students to answer the following questions in their astronomy lab notebooks (referring back to the full graph for the 66 years):

    a. Is the time between the greatest number of sunspots (maximums) always 11 years? How much did the time between the maximums in the graph vary? (Another way to say this is to ask which cycle was the shortest and which was the longest on the whole graph.)

    b. Were all the long-term maximums the same height (i.e., did the sunspot counts rise to the same number in each cycle?)? How much did the maximums vary? For example, what was the largest SSN at sunspot maximum and what was the smallest SSN at sunspot maximum over the 66 years?

    c. What are some other cycles in your life or environment that don't repeat exactly the same way each time? *Cycles of the weather and the seasons should come to mind.*

    d. What was the average number of sunspots in the year you were born? *Take the four quarterly numbers and find the average*. Were you born near sunspot maximum, sunspot minimum, or in between?

    e. What year will you graduate from high school? Will it be a solar maximum, minimum, or in between?

Sunspots Worksheet

Below is a photograph of the Sun taken on January 10, 2014, by an instrument aboard the Solar Dynamics Observatory spacecraft, which has been observing the Sun since 2010.

Please count the number of sunspots and sunspot groups you can see on this image and calculate the sunspot number (SSN) using the following formula:

SSN = (10 × # of groups) + # of individual spots

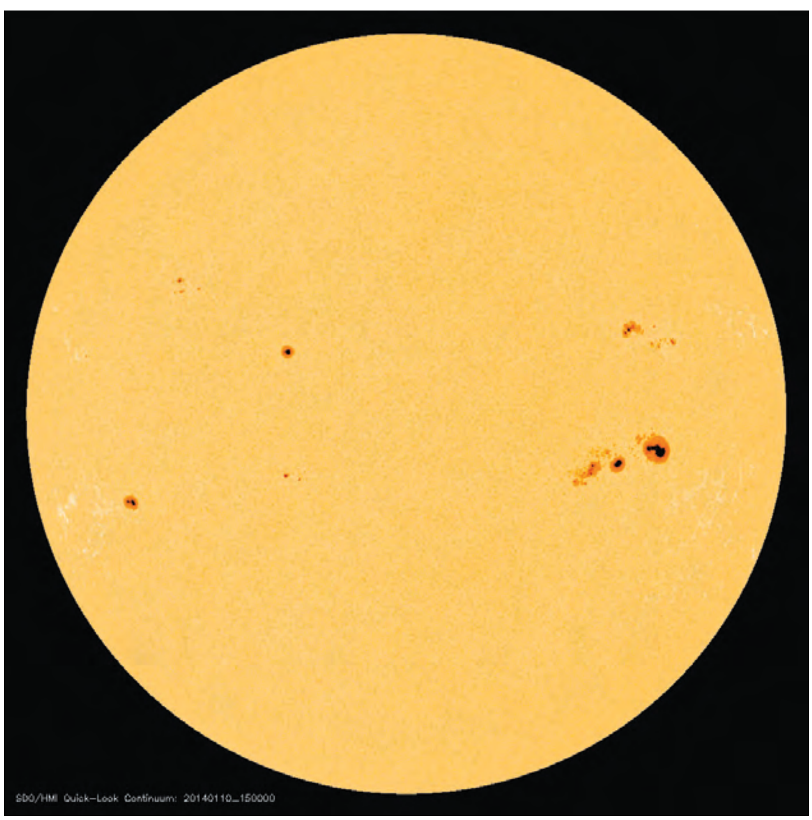
(If there are sunspots within groups, note that you will, in a sense, be counting them twice. That's OK.)

How many groups of sunspots do you see? ____________

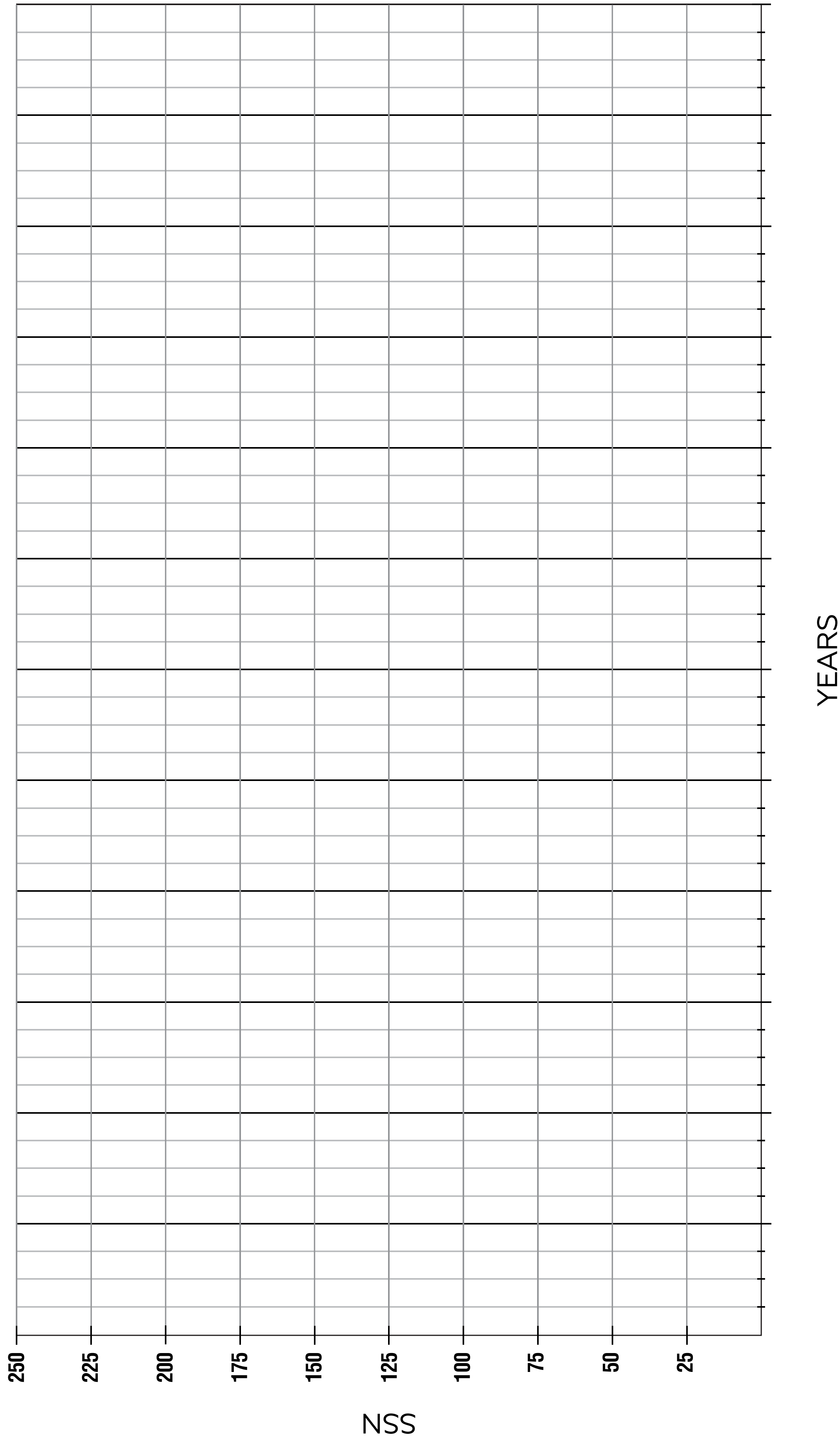
How many individual spots do you see (count all)? ____________

Use the formula to calculate the SSN:

____



Graphing Chart A



Sunspots Data Table

The table shows the monthly sunspot numbers (at the end of each quarter). The monthly averages (SSNs) were derived from International Sunspot Numbers.

Year	Month 3 SSN	Month 6 SSN	Month 9 SSN	Month 12 SSN
1948	94.8	167.8	143.3	138.0
1949	157.5	121.7	145.3	117.6
1950	109.7	83.6	51.3	54.1
1951	55.9	100.6	83.1	45.8
1952	22.0	36.4	28.2	34.3
1953	10.0	21.8	19.3	2.5
1954	10.9	0.2	1.5	7.6
1955	4.9	31.7	42.7	76.9
1956	118.4	116.6	173.2	192.1
1957	157.4	200.7	235.8	239.4
1958	190.7	171.5	201.2	187.6
1959	185.7	168.7	145.2	125.0
1960	102.2	110.2	127.2	85.6
1961	53.0	77.4	63.6	39.9
1962	45.6	42.0	51.3	23.2
1963	17.1	35.9	38.8	14.9
1964	16.5	9.1	4.7	15.1
1965	11.7	15.9	16.8	17.0
1966	25.3	47.7	50.2	70.4
1967	111.8	67.3	76.8	126.4
1968	92.2	110.3	117.2	109.8
1969	135.8	106.0	91.3	97.9
1970	102.9	106.8	99.5	83.5
1971	60.7	49.8	50.2	82.2

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Sunspots Data Table (*continued*)

Year	Month 3 SSN	Month 6 SSN	Month 9 SSN	Month 12 SSN
1972	80.1	88.0	64.2	45.3
1973	46.0	39.5	59.3	23.3
1974	21.3	36.0	40.2	20.5
1975	11.5	11.4	13.9	7.8
1976	21.9	12.2	13.5	15.3
1977	8.7	38.5	44.0	43.2
1978	76.5	95.1	138.2	122.7
1979	138.0	149.5	188.4	176.3
1980	126.2	157.3	155.0	174.4
1981	135.5	90.9	167.3	150.1
1982	153.8	110.4	118.8	127.0
1983	66.5	91.1	50.3	33.4
1984	83.5	46.1	15.7	18.7
1985	17.2	24.2	3.9	17.3
1986	15.1	1.1	3.8	6.8
1987	14.7	17.4	33.9	27.1
1988	76.2	101.8	120.1	179.2
1989	131.4	196.2	176.7	165.5
1990	140.3	105.4	125.2	129.7
1991	141.9	169.7	125.3	144.4
1992	106.7	65.2	63.9	82.6
1993	69.8	49.8	22.4	48.9
1994	31.7	28.0	25.7	26.2
1995	31.1	15.6	11.8	10.0
1996	9.2	11.8	1.6	13.3
1997	8.7	12.7	51.3	41.2

Page 3

Sunspots Data Table (*continued*)

Year	Month 3 SSN	Month 6 SSN	Month 9 SSN	Month 12 SSN
1998	54.8	70.7	92.9	81.9
1999	68.8	137.7	71.5	84.6
2000	138.5	124.9	109.7	104.4
2001	113.5	134.0	150.7	104.4
2002	98.4	88.3	109.6	80.8
2003	61.1	77.4	48.7	46.5
2004	49.1	43.2	27.7	17.9
2005	24.5	39.3	21.9	41.1
2006	10.6	13.9	14.4	13.6
2007	4.5	12.1	2.4	10.1
2008	9.3	3.4	1.1	0.8
2009	0.7	2.9	4.3	10.8
2010	15.3	13.6	25.2	14.4
2011	55.8	37.0	78.0	73.0
2012	64.3	64.5	61.4	40.8
2013	57.9	52.5	37.0	90.3
2014	91.9	71.0	87.6	N/A

Source: Original numbers courtesy of NASA's Marshall Space Flight Center.

Sunspots Handout

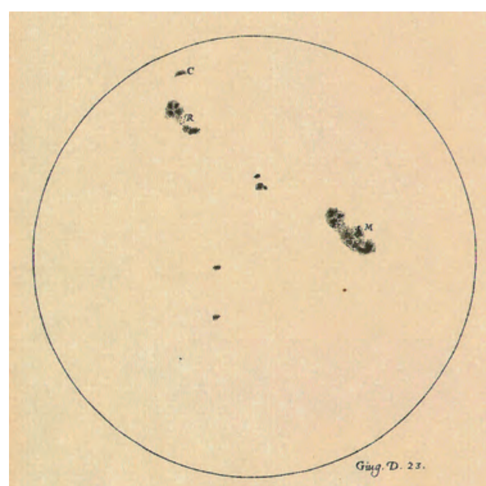
Some History

Galileo Galilei is often given credit for discovering sunspots in 1611, when he pointed his *spyglass* at the Sun. (Today, we call that spyglass a telescope.) We now know that he was not the first person to see sunspots by any means! There are records from ancient Greece and ancient China showing that people almost 2,000 years before Galileo had noticed dark spots on the Sun without a telescope but didn't know what they were.

Safety note: Looking directly at the Sun is dangerous to your eyes, so don't try viewing the Sun without your teacher's guidance. A telescope or a pair of binoculars makes everything brighter, so a view of the Sun through them can damage your eyes even more quickly.

Galileo looked at the Sun through his telescope only briefly and when the Sun was low in the sky and its light had to go through a large amount of the Earth's air. He could also look when clouds or mist cut down the Sun's light.

However, soon Galileo didn't have to look through his telescope at all to see the Sun. One of his students, Benedetto Castelli, came up with a better idea. He projected an image of the Sun through his telescope at a wall or a big sheet of paper. In this way, Galileo became one of the first people to observe the Sun over a long period of time using a telescope. He made drawings of the spots, which was necessary because the camera had not yet been invented to take photographs (see figure). (Others who did this at about the same time as Galileo include Christoph Scheiner in Germany and Thomas Harriot in England.)



One of Galileo's drawings of the Sun showing sunspots

All three observers found that the spots—whatever they were—moved across the face of the Sun as the days went on. Groups of spots would move out of sight on one edge of the Sun and, days later, would sometimes reappear on the other edge. Galileo also suggested that the spots must be on the Sun itself, that they were something that happened in its outer layer or atmosphere. If so, this showed that the Sun was rotating, that is, spinning on its axis just like the Earth. Galileo's idea turned out to be correct.

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Sunspots Handout

What Are the Spots?

Today we understand that sunspots are darker areas on the Sun's visible surface (see figure below). Like everything about the Sun, sunspots are huge compared with human sizes. The typical spot you can see with your eyes is bigger than the entire planet Earth. Some of the biggest spots we've seen were more than 100,000 mi. across—a size so big, it boggles our imaginations. The Earth is about 8,000 mi. across, for comparison, and Jupiter, the largest planet in our solar system, is 87,000 mi. across.

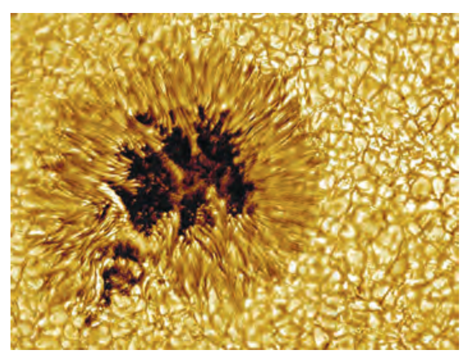
The spots last different amounts of time, depending on their size. Smaller ones last only a few hours, while the biggest spots can last for months. After a spot disappears from view, other spots often form in the same neighborhood of the Sun's surface.

Sunspots look darker because they are cooler than the rest of the Sun's outer layer (called the *photosphere*, meaning the sphere from which the Sun's visible light emerges). Temperatures in the dark sunspots can range from 2700°C to 4200°C, which is from 4900°F to 7600°F. The Sun's photosphere, on the other hand, is generally at 5500°C or 9900°F.

(By the way, those numbers are also pretty mind boggling. Water boils at 100°C or 212°F. When we are talking about the Sun's temperatures, it's good to bear in mind that things are so hot there that our bodies would not only boil but also evaporate. The heat would tear our bodies apart until we were just individual atoms of gas, by which time we would long be dead. The Sun is made entirely of superheated gases—so hot that the electrons are separated from their parent atoms.)

It's important to remember that the spots are only dark compared with how super-bright the rest of the Sun is. If, somehow, we could remove the sunspot regions from the Sun, they would glow a rich red and be bright with light.

What cools the sunspot areas? Twentieth century astronomers discovered that the Sun, filled as it is with negative electrons and positive atoms, is electric and magnetic in complicated ways. Astronomers now know that magnetic forces are so strong in the areas of sunspots that they keep hot material from flowing up from below, allowing the region of the spot to cool.



A close-up of a sunspot, taken with a large solar telescope

EXPERIENCE 3.5

How Fast Does the Sun Rotate?

Overall Concept

Students follow the movement of sunspots across the disk of the Sun on satellite images to determine how fast the Sun rotates.

Objectives

Students will

1. learn about measuring location on a round world (latitude and longitude systems) and
2. use the angular displacement of sunspots over a period of seven days to measure the rotation period of the Sun.

Advance Preparation

1. Prepare your demonstration ball by using the erasable marker to draw longitude lines at approximately 15° intervals. (That means 24 evenly spaced lines around the ball, going from the North Pole to South Pole.) Some people first wrap the ball in saran wrap to make removing the lines later less of a chore.
2. Using the marker, put several good-sized sunspots in the midnorthern latitudes.
3. Copy the two sets of solar images (sheet 1 and sheet 2) so that roughly equal numbers of student groups are working with each different set. Although the images are in color in our book, that color has been artificially added

MATERIALS

For the class:

- 1 medium-sized ball (such as a white soccer ball, a basketball, or a beach ball)
- (*Optional*) Saran or other plastic wrap
- Erasable markers
- 1 small paper plate made to look like a circular sunspot with a black center and lighter ring around the center

For the groups (each sheet is given to half of the groups):

- "How Fast Does the Sun Rotate? Sheet 1: Images of the Sun From the Solar Dynamics Observatory in May 2014" (p. 204)
- "How Fast Does the Sun Rotate? Sheet 2: Images of the Sun From the Solar Dynamics Observatory in November 2011" (p. 205)
- Transparency overlays with a grid of solar longitude measuring lines (Stonyhurst disks)

by the project scientists: The Sun would actually look white to you if you could look at it safely. So, it is fine if you photocopy the images in black and white.

4. Make transparencies of the Stonyhurst disk master and have one for each group. It's important that the disk on the transparency be the same size as the disk of the Sun on the photographs you are using to track sunspots. In this book, we have made the pictures on sheets 1 and 2 and on the transparency master the same size.

Procedure

1. If students did Experience 3.1, "What Do We Think We Know?" ask them to recall their thinking about the second prompt in that experience: "Does the Sun rotate, and if so, how can we tell?"

   If not, then ask students how we can determine whether the Sun rotates, and if it does, how we can figure out how long it takes to turn. These questions can be answered in small groups (which then share their answers with the whole class) or in a whole-class discussion. Someone in the class will likely suggest that we can follow sunspots until we see them make a complete circle around the Sun. If not, guide them in the direction of this suggestion and then tell them that they are going to follow a number of different sunspot groups to figure out how much time it takes the Sun to rotate.

   Teacher note: This could be a good time to mention to the students that about 400 years ago, Galileo Galilei (using his new spyglass, otherwise known as a telescope) watched groups of sunspots carefully as they moved across the face of the Sun, disappeared on one edge, and later reappeared on the other edge. His observation of sunspots and their shapes eventually led Galileo to conclude that sunspots were features on the surface of the Sun (and not, for example, objects in orbit around the Sun). This meant they could be used to show that the Sun rotated. Furthermore, they allowed him to demonstrate that the Sun was a sphere, something not everyone believed at the time.

2. Use the ball on which you have drawn one or more big dark spots (big enough so the class can see them). Turn it slowly and uniformly with the students watching. Ask them to keep an eye

on what happens when spots get close to the edge of the ball and are about to rotate to the ball's back side. Do this several times as students watch. They should notice that the spots foreshorten (see more on foreshortening in step 3) as they get to the edge of the ball. Also, students may be able to see that the spots appear to move faster near the center of the ball but then more slowly when they get to the edge.

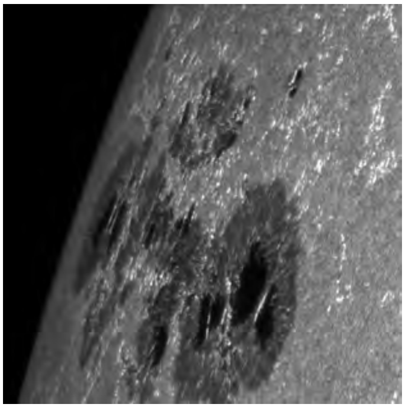
3. This is a good time to explain that the spots appear to move more quickly at the center because all the motion there is lateral (sideways.) Near the edge of a three-dimensional ball, more of the motion is front to back, so the spot appears to move more slowly. This is a subtle idea and may take a while for the students to understand. Being near the edge of the Sun also means that the sunspot looks shorter from front to back as it wraps itself around the curvature of the Sun (but it is not smaller from top to bottom). This is what we call foreshortened (Figure 3.14). You can use the small paper plate made to look like a sunspot (and attached to the rotating ball) to demonstrate this effect. You can also point out to the students that, for the same reason, the longitude lines on the ball appear closer together near the edge of the ball than in the center.

4. Tell the students that they are going to use the same process that Galileo used to measure how long the Sun takes to rotate. They will observe one set of spots over a period of time and measure how long the spots take to move across the Sun. From this, they will be able to figure out the time it takes the Sun to make one rotation.

   Teacher note: The Sun is not a solid body, and thus its parts don't have to "stick together" and move at the same pace. Sunspot groups and individual spots can change and even disappear as students

FIGURE 3.14

Sunspots appear foreshortened near the edge of the Sun.



This image, taken November 2, 2011, from the Solar Dynamics Observatory satellite, shows foreshortened sunspots near the left edge of the Sun.

watch them move on the Sun, which can be a source of confusion. Generally, the smaller the spot, the sooner it tends to disappear.

Teacher note: A dramatic one-minute animated movie showing a single large and complicated sunspot group moving and changing across the face of the Sun (from one side to the other) can be found at *http://apod.nasa.gov/apod/ap150629.html*. This was taken with NASA's Solar Dynamics Observatory. You can decide at what point in the experience you want to show this short film.

5. Before introducing the idea of the latitude and longitude of sunspots on the Sun, be sure that students are familiar with latitude and longitude as a system of locating things on the Earth.

Teacher note: If students are not sufficiently familiar with the latitude and longitude circles on Earth, you will need to remind them that latitude circles go around the Earth east–west; the system of circles starts at the equator (0° latitude) and extends north and south from there until it reaches 90° N at the North Pole and 90° S at the South Pole. Longitude circles, on the other hand, go around the Earth north–south; they begin with 0° on a circle connecting the poles with Greenwich, England (this circle is called the prime meridian). The system of circles goes around the globe to +180° as you go eastward and –180° as you go westward. So your latitude tells you your location north or south of the equator, and your longitude tells you your position east or west of the prime meridian. Specifying both latitude and longitude means you have fixed a specific point on the surface of the Earth.

Help students notice that you measure latitude relative to the equator and poles (which are easy to find for a spinning globe) but that you need some landmark or agreed upon starting place from which to specify longitude. (On Earth, there was a fierce struggle between countries about which European city would get the honor of being called the prime meridian. Greenwich, England, won!)

If examples are needed, have students use the internet to find the latitude and longitude of some favorite locations around the Earth (e.g., their home town, Honolulu in Hawaii, the pyramids in Egypt.) For example, they can use the NASA site *http://mynasadata.larc.nasa.gov/latitudelongitude-finder*.

Point out to the students that we can set up an equivalent system to specify locations on the Sun. We can set up a system of

FIGURE 3.15

An illustration of a solar disk, with latitude and longitude lines shown and labeled with degrees

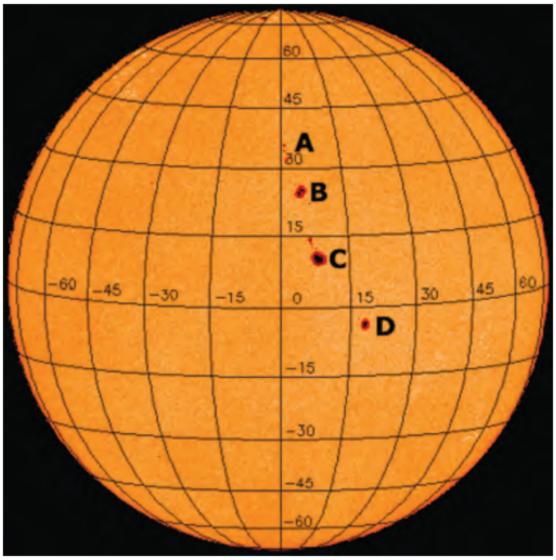
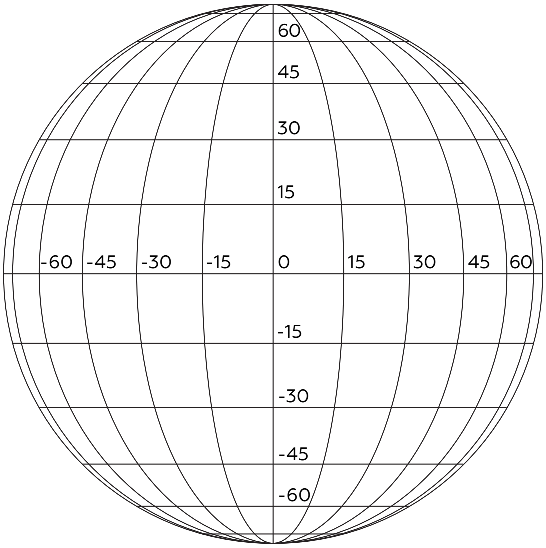


FIGURE 3.16

Stonyhurst disk grid overlay



latitude circles on the spinning Sun, just like on Earth, by using the equator and the poles; however, longitude is harder.

Since sunspots come and go and the Sun has no fixed markings on its surface (photosphere), we can be arbitrary about defining longitude for the Sun. For ease in measurement, we will take the 0° longitude to be the vertical line in the middle of the Sun's disk when we first measure the location of a sunspot or sunspot group (Figure 3.15) .

6. Distribute a Stonyhurst disk grid overlay (Figure 3.16; named after the observatory in New York State where they were first used) to each group, together with the images of the Sun that they will be analyzing (sheet 1 or sheet 2). Explain that the grids on these transparencies show a system of latitude and longitude for the Sun, which we can use to see how sunspots are moving on the Sun.

7. Students should assign a letter (A, B, C, etc.) to each sunspot group. They should line up the transparency so that the overlay fits exactly over the solar image and use it to estimate each

TABLE 3.3

Data table for recording sunspot locations

Date	Spot (group) letter	Latitude and longitude	Description of spot or group
	A		
	B		
	C		

spot's latitude and longitude (the angle east or west of the prime meridian [the line running straight up and down in the middle of the template]). Note that all the images of the Sun are taken at the same time on each of the days.

8. For each image, students should make a data table in their astronomy lab notebooks that looks like Table 3.3 (above):

   Students can add more rows if they see more than three large sunspots or sunspot groups on their images. The description column in the table is so that students can keep track of each sunspot or sunspot group as the days go on. It can be about the spot or group's size or shape or darkness. (Remind students that the larger the group of spots, the more stable it tends to be. Smaller spots can disappear in a day, so the larger the group they are working with, the more likely it will last.)

9. For each sunspot or group that they can follow, students should calculate the angular speed of the spot or group using the following formula:

$$\text{angular speed (in degrees per day)} = \frac{\text{(change in longitude in degrees)}}{\text{(number of days between measurements)}}$$

   So, for example, if in two days, a group has changed its longitude by 26°, the angular speed = 26°/2 = 13°/day.

   Teacher note: We are only considering change in longitude in the formula because sunspot groups tend to stay at the latitude where they emerge as they go around. That's something the students may discover for themselves as they look at the pictures, so you may want to hold back that information.

Teacher note: Several issues will come up as students make their measurements. The main one is what location in a sunspot group should be used to mark its location (e.g., the leading edge of the group, the middle, or the center of the largest spot?). This becomes even more of a problem if the sunspot group has changed size or shape between measurements. Reassure the students that solar astronomers doing this kind of work have to deal with this problem all the time. There is no perfect solution to being sure you have the right place to measure each time. This is why students should make measurements for several sunspot groups and get an average (as the instructions suggest). Also, there is the question of whether the images we are using were each taken at the same time of day. If they weren't, then the denominator in the formula might have to include nonintegers, such as 1.2 days. In fact, the images on sheets 1 and 2 were all taken at the same time of day.

10. Students should first measure the angular speed three days apart and then measure it for the entire six days. They can then average its angular speed over the full period to help eliminate the problems encountered because the positions of spots are hard to estimate precisely. They can also measure the angular speed of other spots and groups and compare their values for each.

11. Students now use their values of the average angular speed to calculate how long it takes the spots to go completely around the Sun—thus finding the rotation period of the Sun. If necessary, remind them that a full circle has 360° in it.

rotation period = (360°)/(angular speed in degrees / day)

So, for example, if the angular speed is 13° per day, then the period would be

360°/(13°/day) = 28 days

Each group should derive its own value of the rotation period and then students can come together as the whole class and share their answers, explaining how they calculated them. Have them suggest possible reasons why the groups reached different rotation periods.

Once the class has exhausted their possible explanations, you can sum up. In addition to the issues discussed above (spots changing with time, deciding just where to measure a spot or group, etc.) you may want to share with them that, unlike the Earth, which rotates as a solid body and thus has one rotation period, no matter where (at what latitude) you measure, the Sun is a ball of hot, electrically charged gas and its different layers don't have to rotate with the same period. Therefore, the answer students calculate will also depend on the latitude of the spot or group they are measuring.

Teacher note: At the equator, the Sun takes about 24.5 days to rotate relative to the stars. (Because the Earth in the meantime moves around the Sun, we on Earth see the Sun's equator take about 26.25 days to rotate once.) Near the poles, the Sun takes about 34 days to rotate relative to the stars. Such differential rotation is also seen on the large planets made mostly of gas and liquid, such as Jupiter. In the 1850s, Richard Carrington, a British amateur astronomer, made careful measurements of the rotation rate of the Sun at different latitudes. In honor of his work, astronomers often cite as the Sun's rotation period the Carrington rotation period, measured at a latitude of about 26° on the Sun, the latitude where sunspots are most likely to form. The Carrington rotation period is about 27.25 days relative to the Earth (and 25.4 days relative to the stars).

A QuickTime movie showing the Sun rotating over a period of 36 days can be found at *http://solarscience.msfc.nasa.gov/images/gongmag4.mpg*. (Note that it shows the magnetic intensity of the spots rather than a visible light photo, but it does show the rotation as seen via sunspots quite clearly.)

A more complex film showing the rotating Sun for January 2014 with views at many different wavelengths can be seen at *http://apod.nasa.gov/apod/ap140312.html*. (This is perhaps better to show after Experience 3.11, "The Multicolored Sun.")

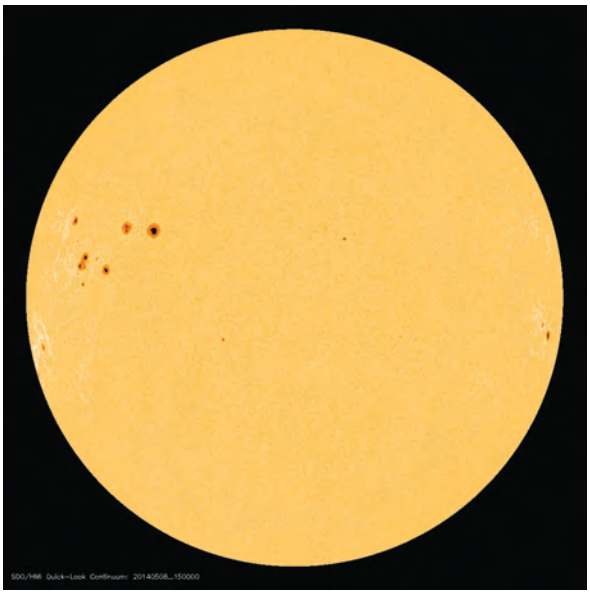
For More Advanced Classes

The Sun appears to wobble a bit as seen from Earth over the course of a year because the plane of our orbit is not exactly in the Sun's equatorial plane. To correct for this small effect, you can actually use a different Stonyhurst disk overlay for each of the 12 months, given that the Sun is tilted differently relative to Earth in each month.

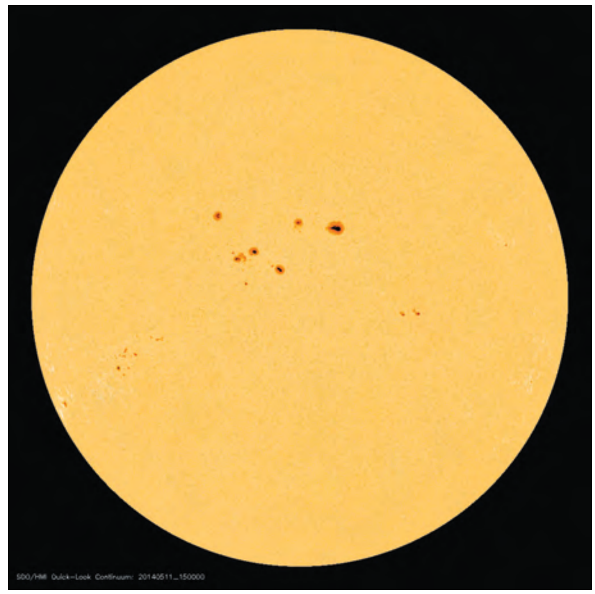
To obtain these disks and see this more advanced version of the activity, go to Space Weather Forecast, a curriculum and activity sequence developed at Chabot Space and Science Center for the Stanford Solar Center: *http://solar-center.stanford.edu/SID/educators/SpaceWeatherForecast-v.070507.pdf*.

How Fast Does the Sun Rotate?

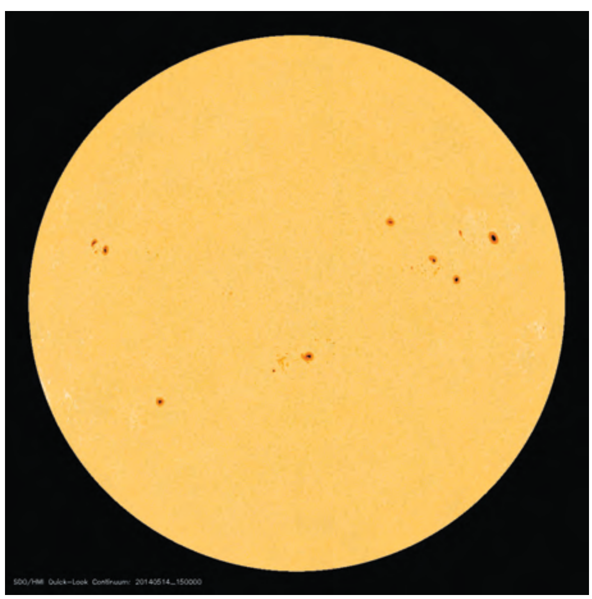
SHEET 1: IMAGES OF THE SUN FROM THE SOLAR DYNAMICS OBSERVATORY IN MAY 2014



May 8, 2014



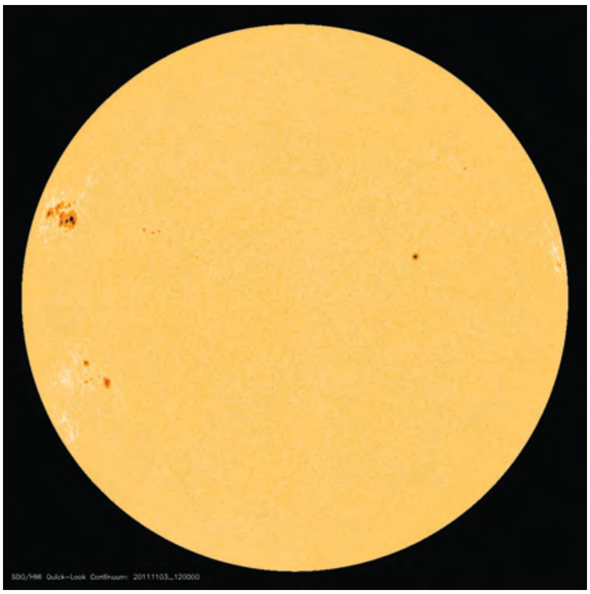
May 11, 2014



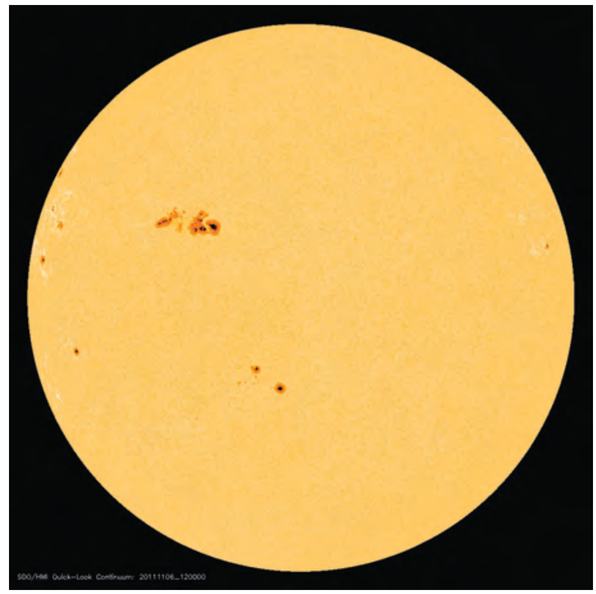
May 14, 2014

How Fast Does the Sun Rotate?

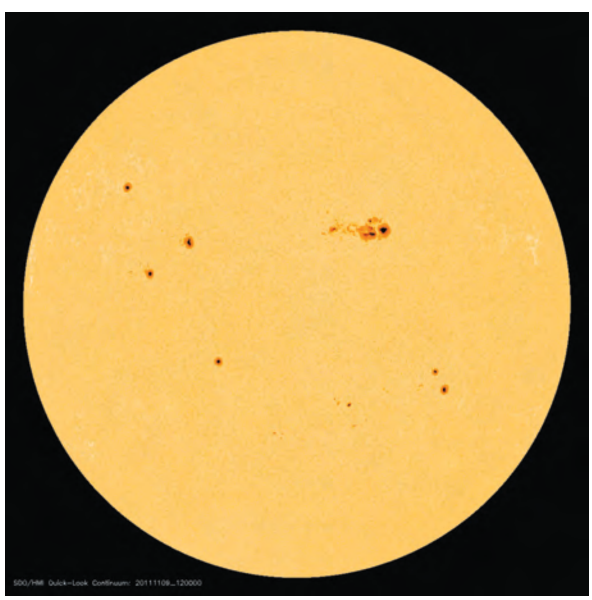
SHEET 2: IMAGES OF THE SUN FROM THE SOLAR DYNAMICS OBSERVATORY IN NOVEMBER 2011



November 3, 2011



November 6, 2011



November 9, 2011

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SOLAR SCIENCE

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Grades 5–8

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