NATIONAL CENTER FOR CASE STUDY TEACHING IN SCIENCE

Moons or Rings?

Stellar Occultations and Chariklo the Centaur

by

Bruce C. Palmquist and Megan L. Rivard
Central Washington University, Ellensburg, WA

Part I – Occultations

"I think we just discovered strong evidence of two moons orbiting Chariklo!" said Ming excitedly as she ran into the astronomy graduate student office. "The light curve shows two short, skinny dips surrounding one deep and wide dip. This is great! Not many small objects in the solar system have two moons."

"Slow down, Ming," said Sanjay, a graduate student from the biology department. "What's Chariklo and what's a light curve?"

"Sorry, but I'm so excited! Chariklo is a centaur, one member in a family of objects that orbit our sun out past Jupiter. Centaurs are rocky objects, sort of like asteroids. But many of them are surrounded by a halo of particles, sort of like comets. One of the best ways to study small objects in the outer solar system is by occultations," explained Ming.

"Occultations?" asked Sanjay.

"Occultations occur when a relatively nearby object, such as an object in our solar system, blocks the light from a distant object, making that distant object disappear for as long as the closer object is in the way. If there are different scientists gathering data from different locations, they can start to infer the shape of the object doing the occulting. Here's how it works."

Ming showed Sanjay some sketches. The first one showed how different parts of the asteroid would block the distant star depending on where an observer was located on Earth (Figure 1). People either above or below the thick black line on Earth would not see an occultation at all. But these non-observations are important because they set a limit to the size of the object doing the occulting.

The three lines of sight shown in Figure 1 might result in the inferred shape shown in Figure 2. Each colored line represents the light from a star. Think of it as aiming a camera

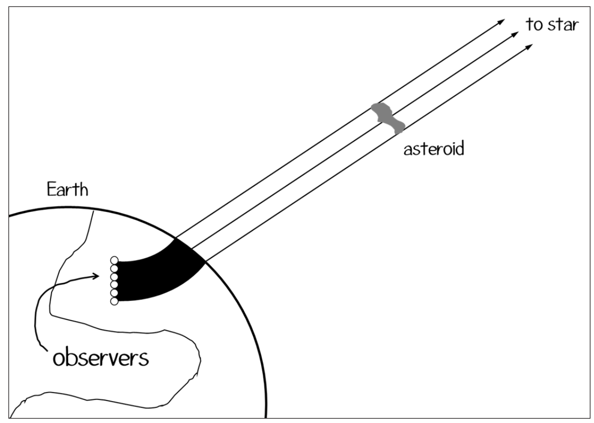

Figure 1. Different places on Earth have a different view of the occultation.

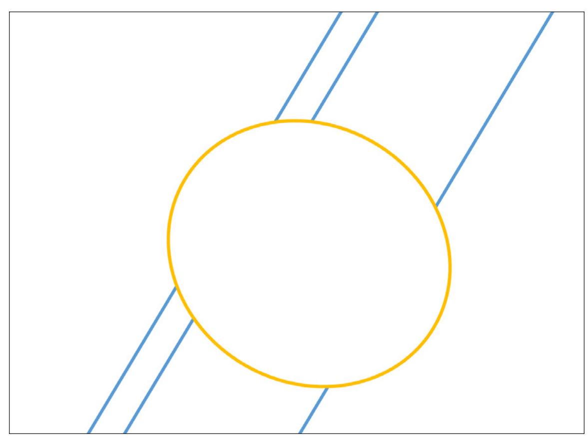

Figure 2. Determining the shape of the object occulting the distant star. The three solid lines, or chords, each represent the light from the same star as viewed from three different locations. The chords disappear in the sketch because they are being blocked by an object that is closer to the observer. The yellow oval represents the best guess of the shape of the solar system object based on how it blocks the light of the distant star.

at a star and recording. For most of the time while the camera is recording, the star will be visible. That continued visibility shows up as a streak of light. Each of these streaks is called a light chord. But when the solar system object moves between the Earth and star, the star's light is blocked for a while. That shows up as a gap in the streak of light. The length of time of the blockage corresponds to the width of the part of the object blocking the star from the point of view of the observer. The oval is the best guess at what the shape might be given the three points of view of the star being blocked. Each of the chords represents the same star being blocked but being viewed from a different place on Earth. In other words, the three lines in Figure 2 represent the light chord of the same star as seen from three locations on Earth. The oval represents the best mathematical model of the shape of the object doing the blocking.

Questions

1. Describe in your own words how an occultation occurs.

2. Ming said she may have discovered two moons around Chariklo. Redraw Figure 2 to show how it might look with a moon to the upper right and another moon to the lower left of the main object.

Part II – Light Curves

"Okay," said Sanjay. "Now I understand the whole idea of occultations. It seems to be a fairly basic way to determine the shape of something in the outer solar system. But I still don't know what you mean by a light curve."

"A light curve is a graph of light intensity as a function of time," said Ming. "Here's a simplified version of the light curve we measured for Chariklo and what we think are moons (Figure 3). Each point represents an instant when the camera detected light from the background star. Notice how the points dip down a little for a short duration, then jump back up, then dip down much more for a longer time, and repeat the little dip on the other side. Each of the dips represent the light of the distant star being blocked, or gaps in the light chords. Figure 3 shows the star being blocked for a little bit of time, then a relatively long time, then a little bit of time again. I think the little dips represent small moons and the big dip represents Chariklo."

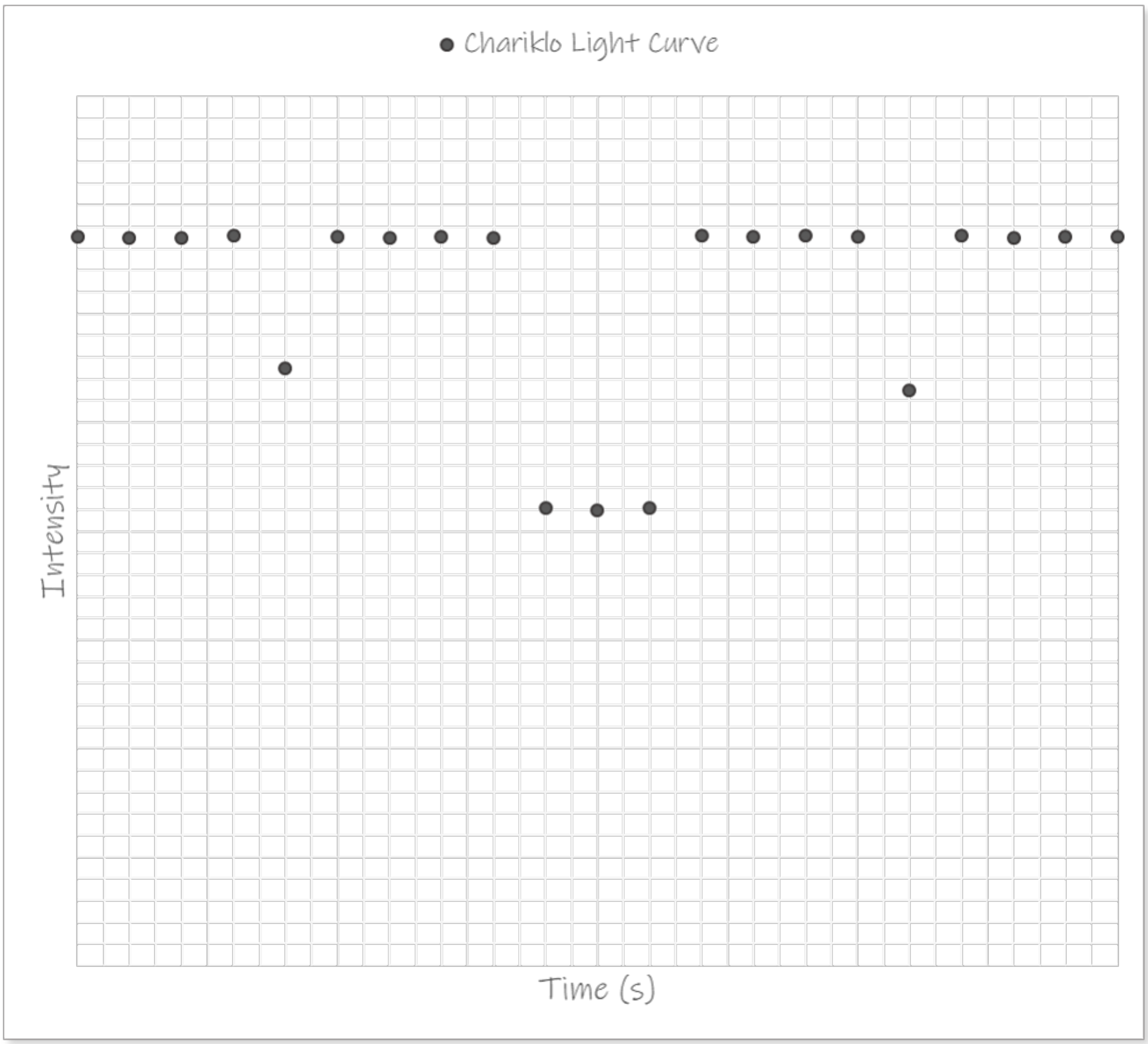

Figure 3. The big dip in light intensity represents Chariklo occulting a star. The little dips are what Ming thinks are moons.

At this moment, Riley, another astronomy graduate student walked in. "What are you two talking about?" Riley asked.

"Check out this light curve. I think we just discovered strong evidence of two moons orbiting Chariklo," exclaimed Ming.

"Do you mean those two dips? I don't think you discovered moons. I think you discovered a ring," replied Riley.

Ming countered, "There's no way this object is big enough to have a ring. Only the giant planets in our solar system have rings. But there are a few asteroids and Kuiper belt objects that have moons. After all, the best known Kuiper belt object, Pluto, has five moons. So, it's much more likely that Chariklo has moons than rings."

"It's true that rings are very uncommon for small objects," agreed Riley. "But look at your data. The two small occultations are almost exactly the same size and each of them is almost exactly the same distance from Chariklo. It's highly unlikely that Chariklo would have two moons that are the same size, the same distance from Chariklo, and line up nicely on opposite sides of Chariklo like this."

"These two little dips in the light don't *have* to come from moons that are the same distance away. For example, one of the moons could have just moved out from behind Chariklo on its way out to the farthest point in its orbit," explained Ming.

Questions

3. Do you think Ming's light curve provides stronger evidence for a ring or two moons? Give a justification for your answer.

4. What additional evidence would strengthen either Ming or Riley's argument? Outline an additional procedure that would help convince you.

Part III – More Evidence

"Ming, you seem preoccupied," said Sanjay at lunch the next day. "What's up?"

"I got an email with some data from Professor Paula Garcia, an astronomer at Yakima College. She and her team have a higher quality camera and they also obtained a light curve for Chariklo during that same occultation event."

"That's great. Why are you anxious?"

"Because I think we may have discovered something really important. You know how I thought I had discovered two moons but Riley thought I discovered a ring? Look at this." Ming showed Sanjay the image from Professor Garcia (Figure 4).

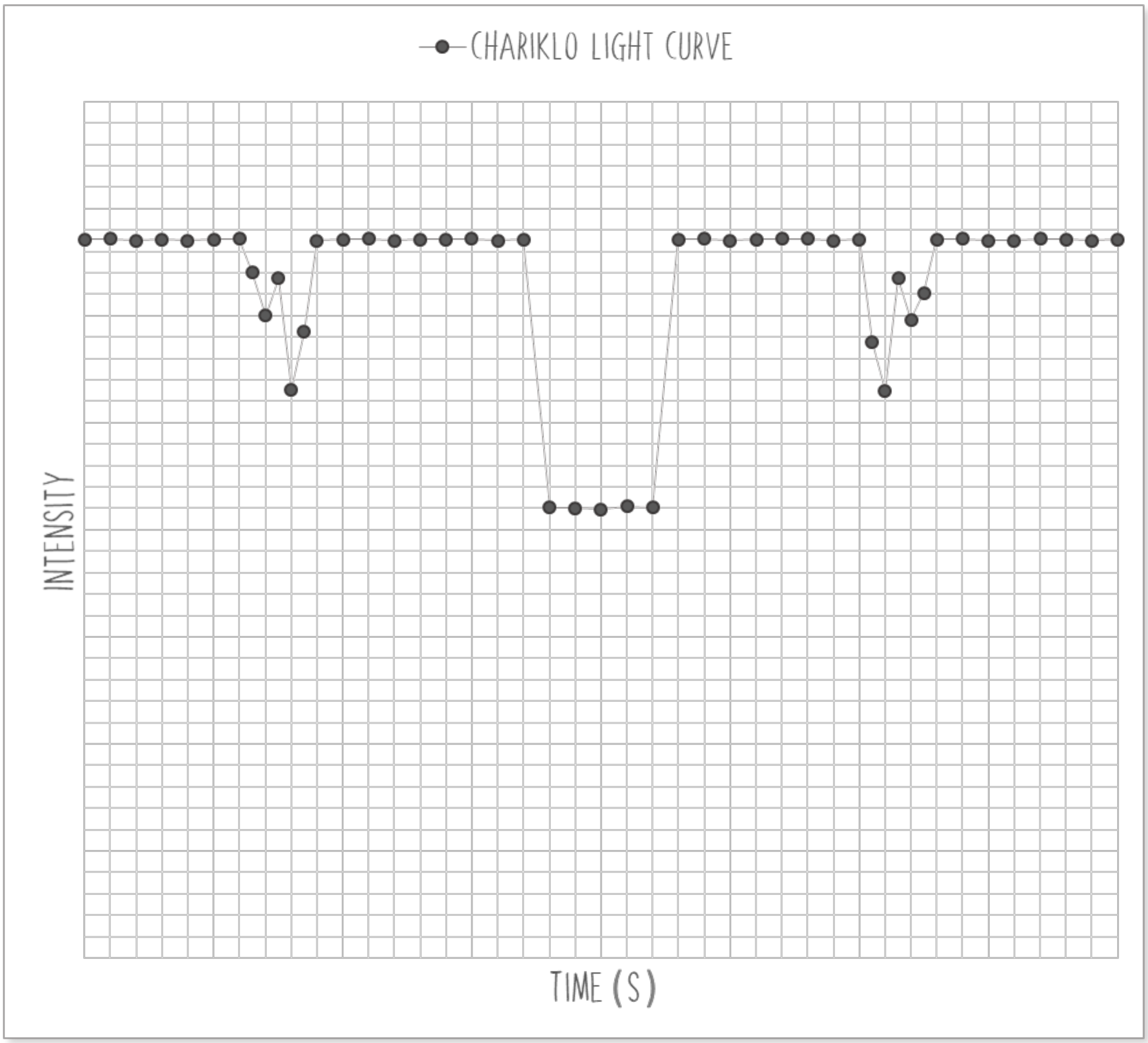

Figure 4. This data is more precise than Figure 3 because Professor Garcia's camera takes more images per second. This allows for better resolution. What Ming's camera showed as one dip on either side of Chariklo shows as two thinner dips with Professor Garcia's higher quality camera.

"I'm not sure what I'm looking at," said Sanjay. "It looks a lot like your image but with two little bumps on either side. And I guess the main dip is thinner."

"Professor Garcia's camera takes more images per second so her light curve is much more precise," replied Ming. "It's like the difference between those old dot matrix printers our parents had and a new laser printer. It can be hard to read the words with those old printers because some letters look too much alike."

Questions

5. What is the best way for Ming to explain this new data? Comment on the possible reason for the differences in the smaller dips on either side of the large main dip.

6. Does this new data support Ming's hypothesis that Chariklo has two moons, Riley's hypothesis that Chariklo has a ring, or a different hypothesis?

Part IV – A Decision (for Now)

Ming, Professor Garcia, and Riley met that afternoon to discuss the data. They decided that Ming and Professor Garcia had actually discovered two closely spaced rings orbiting Chariklo. Ming's camera did not have very high time resolution, meaning that multiple events that happen close together in time may be missed because they happen between the pictures being taken. Think of someone doing jumping jacks. Suppose that they do one jumping jack each second. If you take one picture of them each second, you'll miss a lot of the motion. For example, if your camera shutter was open only then they were on the ground, you'd miss the hand clap overhead. If the camera took a picture every half second, you would see the time the person is on the ground and the hand clap overhead.

From Ming's point of view, Chariklo's equator occulted, or blocked, the background star, making it disappear for the maximum amount of time. Professor Garcia's camera was about 70 km south of Ming's camera. From Professor Garcia's point of view, a narrower part of Chariklo occulted the star, making it disappear for less time. The two sets of data, taken together, give scientists a much better idea of what Chariklo and its rings look like than just one data set would.

Question

7. Draw a picture, similar to Figure 2, of what Chariklo might look like using the light curve in Figure 4.