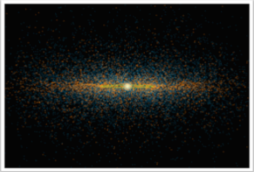
4167 Riemann and 4000 Hipparchus: A Tale of Two Asteroids

Ashok Aggarwal '15 and Amy Zhao '14
Advisor: Ms. Caroline Odden
Phillips Academy (Andover, MA)

Determining an Asteroid's Rotational Period: *FAQs*

What are Asteroids?

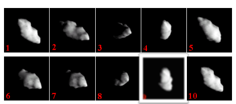
- Name derived from Greek: "looks like a star"
- "Minor Planets" or "Planetoids"
- Does not have a planetary disk and does not exhibit characteristics of a comet
- Asteroid belt: a band of asteroids that orbit our Sun between Mars and Jupiter
- When observed from Earth, asteroids look like stars, but move relative to the fixed stars

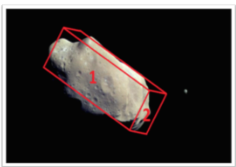


Horizontal View of Near-Earth Asteroids
(Image credit: NASA/JPL-Caltech)

Why Study Asteroids and Their Rotational Periods?

- Determine correlation between rotation period, size, (
- Great introductory research astronomy project





The four sides of the asteroid
(Two shown here)

Process of Measuring the Rotational Period

- *Imaging*
  Images taken with the equipment in the Phillips Academy Observatory (0.4-m f/8 reflecting telescope and an SBIG 1301-E CCD camera)
  Images taken of a specified target at a set interval during the night
- *Calibration*
  The images are then calibrated with dusk flats and dark fields
- *MPO Canopus*
  Astrometry and photometry computer program that generates lightcurves for astronomical objects (asteroids, variable stars). Employs differential photometry to make these measurements
- *Differential Photometry*
  Measurement of relative change in brightness of an object (compared to other nearby "set" comparison stars) with respect to time

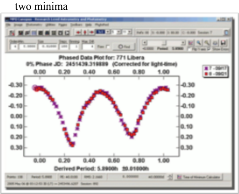
.

What is a Lightcurve?

- MPO Canopus measures the apparent visual magnitude of the specified target in each image
- Brightness plotted against time the images are taken → lightcurve!
- Most accurate period is determined by program

Why a Quadmodal Lightcurve?

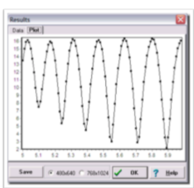
- Most asteroids rotate with respect to Earth
- Similar to "potato-shaped lumps" – large and small face
- When the long side faces earth, more light is directed towards the telescope, creating a local maxima in brightness
- short side = less light light, local minima in brightness
- By measuring the fluctuations in brightness, we are able to determine the rotational period
- During the full rotation, we should be able to see four modes - or "turning points" – two maxima and two minima



Example of MPO's Lighcurve Analysis Page
Image Credit: SBIG

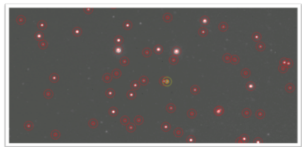
What is a Period Spectrum?

- MPO checks thousands of periods for the best period to match the lightcurve
- For each period it checks, it plots the data points and measures how well the data points fit the period (given by the Root Mean Square – RMS – value)
- Lower RMS = more accurate fit, better period measurement
- Period spectrum: graph of all RMS values with respect to their corresponding periods
- Lowest "dips" signify candidates for the asteroid's rotational periods



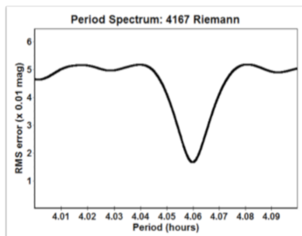
Example of a Period Spectrum generated by MPO Canopus. Here, the best period would be around 5.89
Image Credit: Minor Planet Bulletin

4167 Riemann: *The "Model" Asteroid*



Automatch of Riemann

Labeled Comparison Stars



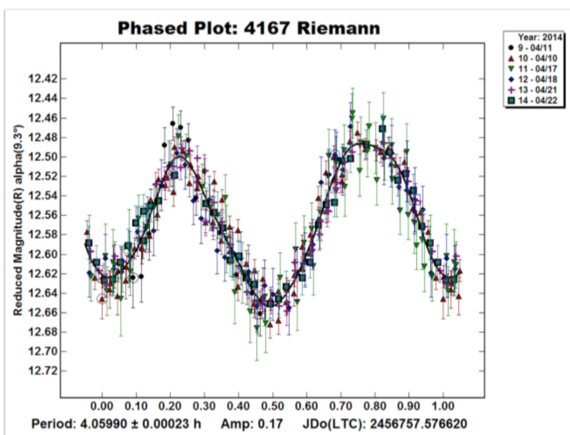
Period Search Results (dip is most probable period)

Riemann's Values

- Rotational Period: 4.0599 hours
- $R^2 = 1.6587$
- Total Number of Points: 288
- Images taken over six nights in April

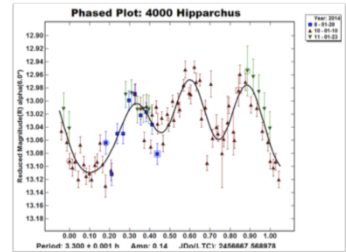
Why is Riemann a "Good" Asteroid to Study?

- Short rotational period
- Main-belt asteroid
- Bright enough to give a good signal for photometry
- Placed well in the sky s.t. it is above the horizon for at least 6 hours

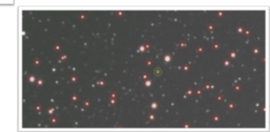


Phased lightcurve plot for 4167 Riemann
MPO Canopus

4000 Hipparchus: *The "Difficult" One*



Phased lightcurve plot for 4000 Hipparchus
MPO Canopus



Automatch of Hipparchus

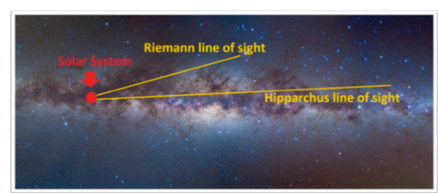
4000 Hipparchus vs. 4167 Riemann

Differences in Number of Stars

- The milky way, viewed from the plane of its disc, appears as a narrow band of stars.
- Due to the unique positioning of the asteroids, Hipparchus lies in the line of sight of the bright and dense center of the galaxy
- The center of the galaxy is full of stars → many appear in its images.
- Riemann is more inclined with respect to the plane of the galaxy; it lies in the line of sight of the exterior of the galaxy → there are significantly less stars in the images of Riemann.

Fluctuation in Brightness

- More stars in the images of Hipparchus, the asteroid often passes over, or eclipses, stars in images.
- The asteroid cannot be measured when this occurs because some of the brightness of the star is added to the brightness of the asteroid
- This addition of brightness adds false jumps and increases in the lightcurve, producing unwanted results.
- Hipparchus eclipses so many stars that good images are hard to come by, and when they do appear, there are often too few to adequately compare and measure with MPO Canopus.
- Riemann: fewer stars in images → asteroid eclipses very few stars and is easier to measure



Riemann has a period of about 4 hours, which means that its entire period can be imaged once or twice in a night. Furthermore, the magnitude of fluctuation, or amplitude, is relatively large. It is thus more clear that the period is about 4 hours.

Hipparchus, on the other hand, may have a small satellite (as seen in the illustration above). Small rises in the asteroid's brightness are evidence of a satellite reflecting more of the sun's light onto earth. However, because this hypothesis cannot be reliably tested, the actual period of the asteroid is very difficult to determine.