

PHY300 Practical: Orbits of Jupiter's Galilean Satellites

Assigned: Wednesday 20-May-2015

Due: Wednesday 27-May-2015

Introduction

Jupiter has more than 50 moons. Most of these are faint (magnitudes $M_v=15-20$ from Earth). But four of them are bright and easily observed in a small telescope. These are the four 'Galilean satellites,' so called because they were among the first objects discovered by Galileo Galilei in 1610 when he was among the first to use a telescope for astronomical purposes. These moons have magnitudes of 5-6 (see table), and as a result are easily imaged in a small telescope with a CCD, in less than one second.

We observed the Galilean moons at the first night-time practical, and took CCD images of them at the second one. In the past weeks, I've supplemented these observations with observations I've taken of the moons myself. I have taken a few images a night on clear nights, for a total of a dozen or so images.

The moons all orbit with periods on the order of a few days. Jupiter's equatorial plane is currently nearly edge-on to Earth, meaning that the moons orbit in essentially a straight line, back-and-forth around Jupiter. Like any Keplerian body, their periods can be described by

$$p = \sqrt{2\pi r^3 / GM}$$

where M_J is the mass of Jupiter (1.9×10^{27} kg) and G is the gravitational constant. Their orbits are nearly circular (eccentricity ~ 0), so their projected distance from Jupiter is very close to a sinusoid,

$$d_i = r_i \sin(2\pi t/p_i + k_i)$$

where i refers to each individual body (1-4).

Galilean Satellites, ordered by distance from Jupiter

Body	Magnitude
Io	5.5
Europa	5.7
Ganymede	5.1
Callisto	6.3

Your project is to analyze the observational dataset, and determine the orbital period for each satellite.

What I suggest doing is doing a process something like this:

1. Examine each image. I suggest the free image viewer 'SAOImage DS9,' which is available on the lab PCs, or downloadable for Linux / Windows / Mac from <http://ds9.si.edu/site/Download.html>. But you may use other software (Photoshop, Python, MATLAB, etc.) if you desire.
2. Find Jupiter and the four moons on each image. Tabulate their locations (e.g., X and Y pixel positions).
3. Figure out the projected distance of each moon from Jupiter's center.
4. Make a plot of the position of each moon vs. time.
5. Fit a sinusoid to the data. Or rather, fit four sine curves — one to each moon. You don't need to use a robust fitting algorithm or do a χ^2 minimization — a fit by eye is OK, as long as it's a decent fit. You will find a period (p_i) for each moon.
6. As a reality check, you can use each moon's orbital period to measure Jupiter's mass. (Note that the orbital period depends on M_J but not the mass of each moon!) You should get roughly the same answer for each moon. To do this you'll need to convert the distance (in pixels) to a distance in km. We've talked about how to do this in class. You'll need the focal length of the telescope (1000 mm), the pixel size (8.5 μ m) and the distance to Jupiter (assume 4.5 AU).

Keep the following things in mind:

- Jupiter's moons have periods on the order of a few days (that is, it's more than hours, and less than months).
- Because this telescope has an alt-az mount — not a polar mount — the image rotates: 360° per sidereal day, or about 60° through the ~4-hour span of these observations each night. You can ignore the rotation and only look at projected 1D distance from Jupiter's center (though be careful of sign flips: don't rotate the images a full 180°).
- You can also ignore overall shifts in the whole image. Sometimes Jupiter is centered in the frame and sometimes not, but this isn't important.
- The date, time, filter, and exposure time are part of the filename. Most of the images are clear-filter (that is, no filter at all, 'CL'). A few are in green ('G'). The difference isn't important.
- Jupiter is so bright compared to the moons, that it is usually saturated (that is, DN values of ~65,000, the maximum possible in a 16-bit detector). This is why you can't see the bands red spot, etc.
- Because all of Jupiter's moons are in the same plane, they'll appear in a (nearly) straight line in the sky. If something looks like a moon but is far away from that line, it's probably a star and not a moon.
- There is also glare from Jupiter, because there is thousands of times more flux from Jupiter than the satellites. If you don't see the moon at first, play with the image stretch... it may be hidden in Jupiter's glare. Or, it may be in front of / behind Jupiter, in which case you won't see it at all no matter how hard you hunt.
- You'll need to convert the UTC time into a quantity that you can plot, keeping in mind that the data were taken at irregular intervals. I suggest making the x-axis of your plot "Hours since the start of the first observation in the whole data set", but that's only a suggestion.
- You may be able to easily tell from the motions which moon is which. But feel free to use their magnitudes to help. In DS9, you can measure the peak brightness of a body by putting the cursor over it and reading the DN. The brightest one will usually be Ganymede.
- Be accurate in your positions, but not insane about it. Accuracy to a pixel or two is fine.

- I have given you files as both TIFF (a standard image format) and FITS (a standard astronomy format). SAOImage will only read FITS, but many programs will only read TIFF. Use whichever you like.

Write up a report (~3-5 pages total) about how you did the project and what you found. Include all of your measurements and your fits.

Your final report should include a table which includes the orbital period (in days), the orbital distance (in km and in pixels), and the inferred M_J for each of the four satellites. You should also (of course) include a nice plot which contains all of the data, and your fits (plotted as four curves which go through the data points). Also include at least one image, where you identify which moon is which.