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A new method to retrieve the orbital parameters of the Galilean satellites using small telescopes: A teaching experiment

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Abstract

In this work we show how it is possible to deduce the radius of the orbits of Galilean satellites around Jupiter using a small number of well-planned observations. This allows the instructor to propose a complete student activity that involves planning an observation, the observation itself, processing and analyzing the images and deduction of relevant magnitudes.

1. Observation techniques

The Galilean satellites are easy astronomical targets due to their usually large separation from Jupiter (several times the planet's diameter, in the range of 31 - 50 arc sec) and their high astronomical magnitude (between 4.6 and 5.6 in the visual range). For the method we propose here, we recommend the use of a telescope with a diameter in the range of 10-30 cm or larger. In our case, the observations were performed with a Celestron 11” telescope pertaining to the Aula EspaZio Gela [1]. The telescope must be equipped with a video filming camera to use the “lucky imaging" technique [2]. The images are processed and navigated to measure satellite positions. This can be done with the use of free software like LAIA [3] or WINJUPOS [4].

For planning the observations we recommend the Sky and Telescope magazine web page or the JPL Horizons web page. [5]

2. Distance from Jupiter to Io and Europa using parallax

A well planned observation, in which both a satellite and its shadow transit the planet, will allow us to deduce the radius of the orbit of the corresponding satellite from a single image. The position of the shadow of a satellite in the surface of Jupiter and the apparent position of the satellite in the disk will be considered as two different observation points, and the parallax, that is, the difference in apparent position of the satellite when viewed from those two different points, will give information on the distance between the moon and the planet.

An example of the kind of images needed is shown in Figure 1. In order to determine the distance of the satellite to the center of Jupiter, we retrieve from the ephemeris both Sun and Earth central meridians (CM_S and CM_E). Then, with the aid of WinJupos, we measure the longitude of the shadow and projection of a given satellite (λ_{SH} and λ_{ST} respectively) and we determine the longitudinal distance of the shadow to Sun’s central meridian $Z_S = \left|\lambda_{SH} - CM_S\right|$ and the equivalent magnitude for the Earth $Z_E = \left|\lambda_{ST} - CM_E\right|$.

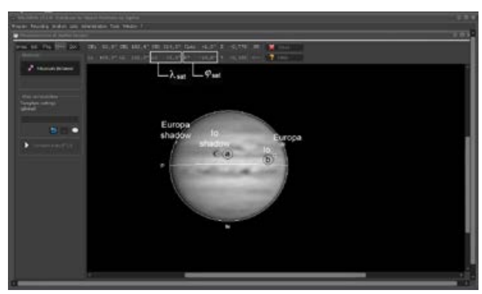

Figure 1: Screenshot of Winjupos program, with which measurements have been made on the images. The image was taken on October 12, 2013, during the transit of Io and Europa and their shadows on Jupiter

Once these quantities are measured, and ignoring the tilt of Jupiter system, a geometrical analysis of the parallax allows one to calculate the distance to the planet with a good level of approximation with the aid of the following expression [6]:

$$D = R\frac{|\sin Z_E + \sin Z_S|}{|CM_E - CM_S|} \quad (1)$$

where $R = R_\varphi \cos\varphi$ is the radius of the parallel at the latitude of the shadow or projection [6].

4. Distance using latitude of the shadows

Applying the parallax method to determine the distance to the satellites is only effective if we can measure simultaneously the longitudes of the shadow and that of the satellite projection on the disk. This simultaneous transit of satellite and shadow occurs frequently in the case of Io and Europa. In the case of Ganymede and Callisto, the phenomenon less common, and due to their larger distance to the planet, transits (satellite and shadow) occur at higher latitudes and the required precision is more difficult to achieve. However, taking into account the slight tilt of the Jupiter system it is possible to determine the distances of the distant moons. In order to use this method, we need images such as those in Fig. 2, in which the shadows of at least two satellites are simultaneously visible on Jupiter's disk. The latitude of the shadow of a satellite of known distance is used to calculate the tilt of the Jupiter system γ and once the tilt is know, a measurement of the latitude of the shadow of the second satellite φ_{SH} allows one to calculate the distance to the center of Jupiter [6]:

$$D = \frac{R_\varphi \sin\varphi_{SH}}{\tan\gamma} + R_\varphi \cos\varphi_{SH} \quad (2)$$

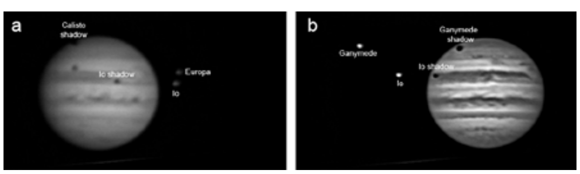

Figure 2: Images used to determine the distance from Jupiter to Ganymede and Callisto. In this case, we need the shadow of Io and the target satellite. Panel **a:** Callisto shadow on October 12,2013. Panel **b:** Ganymede shadow on January 3, 2013.

5. Results

As a proof of the validity of our methods, we compare our results with the values for the distances of the Galilean satellites to Jupiter given in NASA Planetary Data System. Discrepancies are in the range 2-8%.

Table 1: Comparison of calculated distances of the Galilean satellites to the center of Jupiter with values in the literature [5]

Satellite	Calculated D (10^3 km)	Literature D (10^3 km)
Io	423	421.6
Europa	686	670.9
Ganymede	1044	1070.4
Callisto	1733	1882.7

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[2] Peach, D. (2013) High Resolution Lunar and Planetary Imaging, in Lessons from the Masters: Current Concepts in Astronomical Image Processing The Patrick Moore Practical Astronomy series 179 Springer London, Limited.

[3]LAIA: http://www.astrogea.org/soft/laia/laia.htm

[4]WinJupos:http://www.grischa-hahn.homepage.t-online.de/astro/winjupos/index.htm

[5] Horizons JPL/NASA: http://ssd.jpl.nasa.gov/

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