

Lunar distance with parallax during occultations in the context of the "Caravana Luar do Sertão"

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Abstract. In this work, we present a didactic observational activity to measure the distance between the Earth and the Moon through parallax in lunar occultations. As examples, we use the events involving Antares (05/23/2024) and Saturn (08/20/2024), observed from four cities with different combinations of telescopes, mounts, and digital recording resources. The images and videos obtained were analyzed using the DS9 and Tracker software, allowing us to follow the temporal evolution of the angular distances between the lunar center and the object being occulted in each location. We were then able to estimate parallaxes and calculate the distance to the Moon with errors below 3%. This study also enabled us to develop methods for teacher training and the planning outreach activities, employing parallax and the results obtained to address misconceptions. These actions align with the initiatives of the Caravana Luar do Sertão project, which seeks to popularize the scientific method and demystify conspiracy theories.

Resumo. Neste trabalho apresentamos uma atividade observacional didática para medir a distância entre a Terra e a Lua por meio da paralaxe em ocultações lunares. Como exemplos, utilizamos os eventos envolvendo Antares (23/05/2024) e Saturno (20/08/2024), observados em quatro cidades com diferentes combinações de telescópios, montagens e recursos digitais de registro. As imagens e vídeos obtidos foram analisados nos softwares DS9 e Tracker, permitindo acompanhar a evolução temporal das distâncias angulares entre o centro lunar e o objeto sendo ocultado em cada localidade. Dessa forma, foi possível estimar paralaxes e calcular a distância até a Lua com erros inferiores a 3%. Este estudo também possibilitou desenvolver métodos voltados à formação docente e ao planejamento de ações de ensino e extensão, utilizando a paralaxe e os resultados obtidos para corrigir concepções equivocadas. Essas ações se alinham às iniciativas do projeto Caravana Luar do Sertão, que busca popularizar o método científico e desmistificar teorias da conspiração.

Keywords. Teaching of Astronomy – Parallaxes – Occultations

1. Introduction

The measurement of cosmic distances is a challenge that reflects the very early history of Astronomy and has always relied on the phenomenon of parallax de Carvalho Neto et al. (2016); Hirshfeld (2013).

Hipparchus of Nicaea (2nd century BCE) was the first to employ the concept of parallax to estimate the Earth–Moon distance Hirshfeld (2013), by comparing the portion of the solar disk obscured during a solar eclipse – observed partially in Alexandria and in totality in the Hellespont. Measurements like this were steps toward successive leaps to increasingly larger scales, including: 1-) the Earth–Sun distance, using Aristarchus's method later refined by Hipparchus; 2-) planetary distances and consequently Solar System dimensions, through the technique of Venus transits by Halley and the parallax of Mars at opposition by Cassini and Richer (17th century), leading to the determination of the Astronomical Unit (AU) Henderson (2023); de Souza & de Andrade (2016); ?); Hirshfeld (2013); 3-) stellar distances, by extrapolating the concept from geocentric to heliocentric parallax, which culminated in the first successful stellar parallax measurement in 1838 by Friedrich Wilhelm Bessel Hirshfeld (2013).

As a result, it became possible to scale distance measurements through the verification of brightness patterns in stars – for example, RR Lyrae, Cepheids, and even supernovae, successively calibrated against one another based on parallax-derived distances. These became standard references, including distance measurements on modern cosmological scales Bassalo (1996); Santos (2017).

Given the importance of this method, the aim of the present work was to design and test a practical procedure, using the

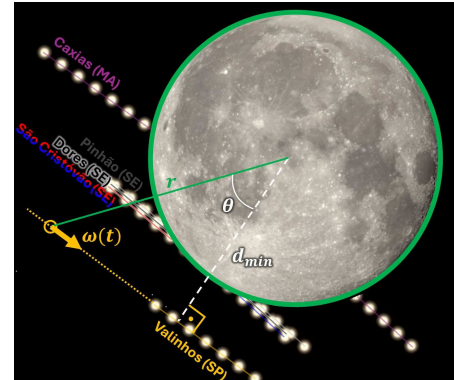


FIGURE 1. Composition of the evolution of lunar and Saturn's apparent positions for different cities.

parallax, that would be feasible for groups training in introductory concepts of astronomy and would help mitigate misconceptions in the field, such as flat-Earth conspiracy theories.

As a first step, we developed a project called Caravana Luar do Sertão, funded by CNPq, grant 408662/2022-0 Scarano Jr. et al. (2022). Among its objectives, associated with the National Professional Master's Program in Physics Teaching (MNPEF) of the Brazilian Physical Society (SBF), we established a collaborative network and equipped centers in six northeastern states with instruments such as telescopes, computers, and support and training materials, to be used in the preparation of multipliers during their graduate studies in the participating regions.

The second step, which constitutes the essence of this work, was the development of observational procedures and data anal-

ysis methods to be applied in partnership with the participating groups and the Valinhos Observatory, in order to determine the lunar parallax using observations of celestial occultations and thereby calculate the Earth–Moon distance during lunar occultation events of stars and planets (Fig. 1).

2. Methodology

We selected two occultation events to valuate the procedures: one of Antares, occurred on May 23, 2024, and the other of Saturn, occurred on August 20, 2024. For each event, we took images and videos of the Moon before and/or after the occultation. We analyzed these records using the software DS9, for Antares, and Tracker, for Saturn, to measure the angular distance between each occulted object and the Moon over time.

The observational set up used in each location are described below.

- Set 1: Motorized altazimutal mount + DSLR + 4 inch MK telescope, located at Aracaju (SE) and Nossa Senhora das Dores (SE), used as reference for calculation of lunar distances in all events;
- Set 2: Motorized equatorial mount + astronomical camera + 8 inch MK telescope, located at São Cristóvão (SE) in both events.
- Set 3: Manual equatorial mount + cell phone camera + holder + 5 inch newtonian telescope, located at São Cristóvão (SE) in both events.
- Set 4: Manual equatorial mount + newtonian telescope + cell phone camera, without a cell phone holder. This set was located in the city of Pinhão (SE) only for Saturn occultation.
- Set 5: Motorized equatorial mount + astronomical camera + 12 inch SCT telescope, located at Valinhos (SP) observatory only for Saturn occultation.

The angular distance $r(t)$ between the objects evolves over time and can be calculated using a circular fit to the moon disk and trigonometric relations between the angle $\theta(t)$, the minimum distance d_{\min} and the distance to the point of closest approach $a(t) = a_0 + \omega \cdot t$ (see Fig. 1). It can be evaluated as follows:

$$r(t) = \frac{d_{\min}}{\cos \theta(t)} = \frac{d_{\min}}{\cos \left(\arctan \left(\frac{a_0 + \omega t}{d_{\min}} \right) \right)}. \quad (1)$$

We use this relationship to fit the data (Fig. 2) and calculate the parallaxes as differences in the residuals relative to the reference city (Set 1). These parallaxes allow us to determine the distance to the Moon according Rodrigues et al. (2019).

3. Results and Perspectives

Table 1 summarizes the results for each set, using the set 1 as reference. As can be seen, parallax angles can be measured for baselines larger than 50 km, which corresponds to parallax angles greater than 0.5 arcmin, even for our worst set (3).

Both events also allowed us precise measurements of lunar distances. Even for the shortest baseline (set ups 1, 2 and 3) we obtained parallaxes of 0.09 arcmin (Antares) and 0.51 arcmin (Saturn) and distance accuracies as good as 2% in the best cases.

Through the development of this work, we obtained results that demonstrate the potential application of these methods in outreach initiatives and teacher training activities. This is especially true for shorter baselines, which are less impacted by the

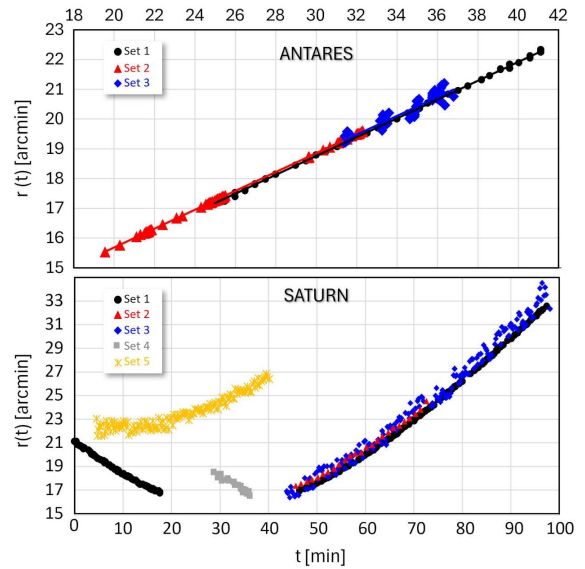


FIGURE 2. Angular distance $r(t)$ as a function of time for each one of the observational sets and events.

TABLE 1. Summary of the results for Saturn (first two lines) and Antares events (remaining lines) for each observational setup described in Sec. 2, using Set 1 as the baseline reference for the calculations. After the correction to the perpendicular linesight.

	Parallax [']	σ [']	Distance [km]	% Acc.
Set 2	0.09	0.01	389 500	1.8%
Set 3	0.09	0.17	389 500	1.8%
Set 2	0.52	0.10	340 000	3.9%
Set 3	0.51	0.51	346 400	2.2%
Set 4	0.62	0.29	323 000	8.8%
Set 5	8.01	1.45	343 000*	3.3%

effects of projection from linesights. Moreover, the results enable the implementation of this experiment even with ultra-short baselines (on the order of ~ 10 km, depending on the set up) and thus for all our MNPEF network. In addition, we establish a procedure for measuring lunar distances using the parallax method, which will be presented in future work.

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