
# Book of Abstracts

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# Session: Observations and Results

## Analysis of stellar occultations by asteroids observed from station in Borowiec

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The topic of presentation is observing stellar occultations by asteroids from station in Borowiec near Poznan in Poland, as well as the data reductions and its analysis. This pesentation describes procedure for performing observations of stellar occultations in the Borowiec Station and contains also own results from ten stellar occultations by main belt asteroids. For this purpose, light curves were determined for ten observed events and when the phenomenon had positive result, also the moments of disappearance and reappearance of the occulted star. Thanks to these results, for most asteroids it was possible to determine the chords from the occultation and to fit the ellipse or shape model to them. For all observations with a positive result, the lower limit of the asteroid size was estimated and compared with the asteroid diameter determined with other methods. This presentation is based on the author's bachelor thesis.

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## First results from stellar occultation campaign on slow rotators

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Our two campaigns target slowly rotating asteroids in two ways:  photometric observations for dense lightcurves, and stellar occultations by these asteroids. Asteroid light variations over time probe their spins and shapes, while stellar occultations provide their extended  "shadows" enabling us to determine their sizes and confirm shapes  reconstructed from lightcurve inversion.

Slow rotators are numerous, but have been avoided in the past studies,  so the selection effects arose. We are aiming at reversing these trends to improve the big picture of how asteroids rotate, reconstruct their 3D sizes, and precisely determine their sizes, e.g. for density determinations.

In this study we used the first results from a dedicated “Slow Rotators"  occultation campaign[1,2] and the events observed from multiple sites confirmed target shape models from lightcurves, and determined their sizes with very high accuracy. Some targets had previous size determinations discrepant by 30%, while our strategy allowed to scale them with only 5% uncertainty.

1 https://www.iota-es.de/neglected_asteroids.html
2 https://cloud.occultwatcher.net/events/tagged/SlowRotators

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## Some results from occultations by TNOs and Centaurs and prospects for the future.

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At our IAA team in Granada we have been working on the physical characterization of Transneptunian Objects (TNOs) and related bodies for many years. Because one of the key techniques to study solar system objects is through stellar occultations we teamed together with the Paris Observatory group and the Brazilian team to collaborate in this topic for TNOs, which gave rise to the currently called "Lucky-Star" collaboration. In this talk I will summarize some of the highlights and main results that we have achieved so far within the context of the collaboration, and I will also describe some ongoing activities and general goals, such as a statistical analysis of effective sizes, geometric albedos and shapes in comparison with other methods and techniques that provide information on these topics. I will also present some ideas and prospects for the future in this field.

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## Physical properties of the trans-Neptunian object (38628) Huya from a multi-chord stellar occultation

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As part of our international program aimed at obtaining accurate physical properties of trans-Neptunian objects (TNOs), we predicted a stellar occultation by the TNO (38628) Huya of the star Gaia DR2 4352760586390566400 (mG = 11.5 mag) on March 18, 2019. After an extensive observational campaign geared at obtaining the astrometric data, we updated the prediction and found it favorable to central Europe. Therefore, we mobilized half a hundred of professional and amateur astronomers in this region and the occultation was finally detected by 21 telescopes located at 18 sites in Europe and Asia. This places the Huya event among the best ever observed stellar occultation by a TNO in terms of the number of chords. The 21 positive detections of the occultation by Huya allowed us to obtain well-separated chords which permitted us to fit an ellipse for the limb of the body at the moment of the occultation (i.e., the instantaneous limb) with kilometric accuracy. The projected semi-major and minor axes of the best ellipse fit obtained using the occultation data are (a', b') = (217.6 ± 3.5 km, 194.1 ± 6.1 km) with a position angle for the minor axis of P' = 55.2º ± 9.1. From this fit, the projected area-equivalent diameter is 411.0 ± 7.3 km. This diameter is compatible with the equivalent diameter for Huya obtained from radiometric techniques (D = 406 ± 16 km). From this instantaneous limb, we obtained the geometric albedo for Huya (pV = 0.079 ± 0.004) and we explored possible three-dimensional shapes and constraints to the mass density for this TNO. We did not detect the satellite of Huya through this occultation, but the presence of rings or debris around Huya was constrained using the occultation data. We also derived an upper limit for a putative Pluto-like global atmosphere of about psurf = 10 nbar.

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# The search for material around (50000) Quaoar

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The Trans-Neptunian Object (50000) Quaoar orbits beyond Pluto at about 44 astronomical units. With a diameter of 1,110 km [Br13], it is about the size of Pluto and is a good candidate for being a dwarf planet. It has a satellite, Weywot, that orbits at 13,300 km from the primary object and has an estimated diameter of about 90 km [Fr10].

Several campaigns were conducted under the umbrella of the Lucky Star project[1] to observe stellar occultations by Quaoar and Weywot. Besides measuring Quaoar's and Weywot's size and shape, those campaigns aimed at searching for material around Quaoar. Here, we will present the results of this search, based on the following observations :

| Dates | Places of observations |
|---|---|
| 2 September 2018 | Namibia, HESS robotic 0.75m telescope |
| 5 June 2019 | La Palma Island, 10.4m Gran Telescopio Canarias |
| 11 June 2020 | ESA/CHEOP, 32cm space telescope |
| 27 August 2021 | Australia, three amateur telescopes (28, 36 and 51cm in diameter) |

This exploration was made in a context where rings are already known to exist around other small bodies of the solar system : the Centaur object Chariklo [Br14] and the dwarf planet Haumea [Or17].

These two ring systems, in spite of large differences in sizes and heliocentric distances, both orbit close to the 1/3 Spin-Orbit Resonance with the central body [Or17,Le17], meaning that the latter completes three rotations while a ring particle completes one orbital revolution. Because of their probable non-axisymmetric shapes, Chariklo and Haumea induce strong resonances effects on the rings [Si19].

Theoretical and numerical studies ([Si21], [Sa21]) show that the 1/3 resonance may indeed confine a narrow ring. If rings were to exist at the Quaoar resonance, it should be close to an orbital radius of 4,200 km, or 7.5 Quaoar's radii. This is well outside the Roche limit of the central body. So, if a dense ring were to be confined near this resonance, it is expected to accrete into a satellite, and thus disappear over a short time scale. We will discuss models that could maintain a colliding disk near the Quaoar 1/3 resonance. This would be the first example of its kind in the solar system, since no colliding rings have been detected so far outside the Roche Limit of their respective central bodies.

*Acknowledgments. The work leading to these results has received funding from the European Research Council under the European Community's H2020 2014-2021 ERC Grant Agreement no. 669416 "Lucky Star".*

[1] https://lesia.obspm.fr/lucky-star/

References:

[Br13] Braga-Ribas et al., ApJ 773, 26 (2013) ; [Fr10] Fraser & Brown, ApJ 714, 1547 (2010) ; [Le17] Leiva et al., Astron. J. 154, 159 (2017) ; [Or17] Ortiz et al., Nature 550, 219 (2017) ; [Sa21] Salo, H. et al., European Planetary Science Congress, EPSC2021-338 (2021) ; [Si19] Sicardy, B. et al., Nature Astronomy 3, 146 (2019) ; [Si21] Sicardy, B. et al., European Planetary Science Congress, EPSC2021-91 (2021)

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## Experiences of observing the 2017 October 5 Triton occultation

Alex Pratt[1,2]

[1] IOTA/ES : International Occultation Timing Association / European Section

[2] BAA: British Astronomical Association

On 2017 October 5, Neptune’s largest moon, Triton, occulted a magnitude 12.7V star in Aquarius for up to ~160 s, when its 2,700 km-wide shadow swept across Europe, North Africa and the eastern USA. It was a rare opportunity to obtain light curves of the event to study Triton's atmosphere and to compare any changes in its structure, density and winds since a previous campaign in 2008. The Lucky Star team led the 2017 pro-am campaign and over 90 light curves were obtained, including quality recordings of the central flash. The team published a definitive paper on the Triton 2017 occultation.

This talk illustrates the experiences of an amateur participant in the project, preparing for the event, recording the occultation, and processing and sending the data to Lucky Star staff. In conclusion, it summarises the lessons learnt and what equipment and online facilities we can utilise to improve the quality of data submitted to future major occultation campaigns.

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## On the stellar occultations by comets 28P/Neujmin 1 and 430P/Scotti

Mike Kretlow[1]

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The prediction and observation of occultations by (periodic) comets is still a challenging task. Their orbits are not known as accurate as for other (inactive) small bodies like asteroids, Centaurs or TNOs, mainly due to the larger error of astrometric observations used for the orbit determination, due to dynamical model limitations (non-gravitational effects), and due to other biasing effects like the photo-center offset. The latter can also affect 'last-minute' astrometric-offset updates of occultation predictions. Also, diameter estimates of cometary nuclei can be rather uncertain. Again, the activity (coma) introduces additional issues while measuring the reflective light (photometry) or thermal emissions in order to derive the size of the nucleus. On the other hand comets are interesting objects considering their relationship to objects like Centaurs or to the KBO and Oort cloud region. Thus, deriving accurate sizes, or even shapes of comets (nuclei) and probing their environment for material (coma, shells, rings etc.) by the stellar occultation method is highly desirable. Such data would help to complete and to shape our image of the small bodies of the Solar

System, helping us also to understand the origin and evolution of the Solar System itself. In my presentation I address these points in an introductional overview and will present and discuss recently reported occultation observations by the comets 29P/Neujmin 1 and 430P/Scotti.

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## ACROSS: The Campaign for occultations by DART target Didymos (and other NEA)

João F. Ferreira[1], Paolo Tanga[2], Kleomenis Tsiganis[1], Damya Souami[3], and Alexis Siakas[1]

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The ACROSS Project is driven by the breakthroughs in occultations brought thanks to the Gaia catalogues. It is now possible to start planning on a consistent basis events by Near Earth Asteroids (NEA). We’ve already seen that through the past few years campaigns featuring occultations by (3 200) Phaethon and (99 942) Apophis.

The ACROSS project provides mainly support to the Hera mission targets. It will focus at first on the binary asteroid (65 803) Didymos, soon to be hit by the DART spacecraft, and 9 potential Hera flyby targets. It will, nonetheless, also include other NEAs, especially once the astrometric data of Gaia’s DR3 is available, depending on their size and overall orbital quality.

Besides the occultation-derived astrometry mentioned above, we aim at measuring the sizes and shapes of these objects. Furthermore, in the case of Didymos, we keep are also planning for the possibility of measuring, through stellar occultations, the optical depth of the plume due to the DART impact. Within this framework, we show four past campaigns as well as future ones.

Also in the framework of the ACROSS collaboration we have access to several telescopes, that will be used for the astrometric followup of the targets, with special focus on Didymos around the time of the DART impact.

Our predictions for these events will be made publicly available, and we will pursue any and all collaborations with professional and amateur astronomers in the field of stellar occultations who are equipped to deal with short duration events.

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## Extraterrestrial occultations: the Beagle 2 experiment

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Since ancient times, astronomical investigation has been considered crucial to solving the problem of navigation, in other words finding out where one is and where one is heading to. Here I will describe an experiment originally conceived to support the Beagle 2 lander project that reached Mars on Christmas 2003. The experiment proposed to utilise the onboard UV photometer to obtain lightcurves of solar eclipses of Phobos as seen from Beagle 2 to estimate the location of the lander on Mars [Christou, PSS, 50, 781 (2002); Patel et al, Icarus 168, 93 (2004)]. Although the Beagle 2 lander did not operate on Mars as expected, this project was an early, and so far unique, attempt to utilise occultations for navigation on an extra-terrestrial body. During my talk I will describe the project context, work done to demonstrate the feasibility of the experiment and the expected outcomes.

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## Refraction at the horizon measured by sunrise and sunset timing

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Several sunrises and sunsets have been recorded at different observing quotes. At different quotes the visible horizon is below the horizontal line according to the square root of the the heigth in meters, this formula yields the arcminutes of the geometrical depression. Local temperatures and gradients, and humidity give significant influences on the horizon refraction. Finally the chromatic splitting of the image near the horizon enlarges by differential refraction the observed vertical diameter of the Sun. Ostia, Fiumicino and Pescara have been the observing points at sea level, to obtain the atmospheric refraction by five airmasses (according to Garstang 1989 atmospheric shell model). Lanciano is at 256 m above sea level, and the airmass on the line of sight with the horizon increases. Cumulonimbus at the top of the troposphere near 10 km of quote, reflect the last light of sunsets through more airmasses, but their measures are complicated either by the light contrast and the quote's determination of the clouds. The International Space Station eclipses offer another phenomenon linked to the atmospheric refraction, more frequent than lunar eclipses, in which all the atmosphere is involved in the refraction and extinction effects and the dry-air airmass at the horizon redoubles. The technique of video recording and timing is discussed, as well as the data analysis procedure with the Stellarium ephemerides, verified at the Clementine Gnomon (1702) at the arcsecond level. The differential refraction effects, so evident at the horizon, are present in much smaller amount, at all almucantarats, the same-angular-altitude circles.

The database of the observations described here is on the youtube channel https://www.youtube.com/channel/UCe18v3EZ8w2qmd8jW6mYV5w/videos

This research complements the techniques of measuring the solar diameter (Sigismondi, 2011) namely the one at sea horizon or zero almucantarat.

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## Diffraction effects at Eta-Leo's occultation in May 2022

Bernd Gährken[1]

[1] Bavarian Public Observatory, Munich

The disappearance of a star behind of the Moon limb is analogous to the well known physical phenomenon of light diffraction at an edge: a simple experiment in the laboratory, but difficult to prove in nature. This is an established but rarely used method in professional astronomy. But the observation of diffraction phenomena is also possible with amateur methods. This was shown at the eclipse of Eta-Leo on May 9, 2022. An ASI290 astronomical color-webcam was used for this test. This camera achieves over 500 fps by using the smallest ROI and binning. This color camera was used in combination with a dual-band filter. This makes it possible to record in two specific wavelengths at the same time. The dual-band filter is normally used to image gas nebulae in the OIII and HII lines. The obtained images showed very nicely the differences in the diffraction effects in the two frequency ranges. Eta Leo is a main sequence star. The small angular diameter allowed to show the Fresnel diffraction pattern clearly. With Eta Leo, the diffraction pattern at 500 nm spreads over 0.042s and a fading time of 0.027s was measured. Common measurements of lunar star-eclipses are mostly made with cameras over the complete visual spectral range at 25 fps. For an eclipse of a main sequence star diffraction has only a small influence on the accuracy of the measurement. Red giants such as Antares and Aldebaran have an angular diameter of about 20 µas. They do not have a typical Fresnel diffraction pattern and produce a longer fading. Since red giants have a different diameter in different spectral ranges, this has an impact on the diffraction.

Literature:
(1) http://www.astrode.de/esop22a.htm
(2) http://www.astrode.de/2alde23j18.htm
(3) Wolfgang Bischof: Wie groß ist Aldebaran?, VDS-Journal 68, Page 94

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## Baltic Adventure: Hyperborea, 23 Aug 2022

Robert Purvinskis

This talk discusses the planning for and observation of the occultation of a 9th magnitude TYC star by the main-belt asteroid Hyperborea on August 23, 2022. 3 observers watched for the event from Latvia, one from Lithuania. None of the observations were positive but valuable experience has been attained.

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## Your notes:

## Session: Predictions and Upcoming Events

### Stellar occultations by TNOs from JWST?

Pablo Santos-Sanz[1]

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The observation of stellar occultations produced by Kuiper Belt Objects (KBOs) and Centaurs with the James Webb Space Telescope (JWST) offers a unique possibility to extend our knowledge of these bodies by providing key information on the body's ability to retain volatiles, surface thermal properties, roughness, porosity, etc. I will present my Target of Opportunity (ToO) program accepted within Heidi Hammel's JWST Guaranteed Time Observations (GTO), dedicated to observing stellar occultations by trans-Neptunian objects (TNO) and distant dwarf planets or particularly interesting centaurs (such as the ringed centaurs Chariklo or Chiron). Predictions of such events visible from JWST are challenging due to the chaotic motion of the space telescope around the Lagrange 2 (L2) point. Statistically, we expect there to be approximately a 50% chance of such an occultation of a star brighter than K = 19 by a numbered TNO observable from JWST in Cycle 1. We will discuss the possible candidates for Cycle 1 occultations that we have identified so far. As JWST station-keeping maneuvers are executed, the list of possible occultations and their uncertainties will be revised. Very accurate relative astrometry will be performed using the latest releases of the Gaia catalog for particularly promising occultation events through established ground-based programs. Suppose a stellar occultation event is confirmed through such an astrometric revision to have a predicted impact parameter less than 3 times the estimated target radius and to have a 1 sigma uncertainty in prediction less than 2 times the target radius. In that case, the ToO observation will be triggered.

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### Prediction of stellar occultations by the space telescope CHEOPS

Altair Ramos Gomes Júnior[1]

[1] Federal University of Uberlândia, Brazil

Stellar occultations have been observed by spacecraft, for instance, by the Cassini and New Horizons missions. However, these were in-situ observations involving the objects they were visiting. From spacecraft orbiting Earth, the Hubble Space Telescope (HST) observed occultation by Saturn and its rings. Furthermore, an analysis of images taken by the Fine Guidance Sensors on board the HST identified two serendipitous occultations by small KBOs. In 2020, for the first time, an occultation by a TNO was predicted and observed by a spacecraft orbiting Earth, the occultation by Quaoar observed by CHEOPS.

The main difficulty in predicting such observation is due to the high uncertainties in the position of the spacecraft. For spacecraft orbiting Earth, the non-homogeneous distribution of Earth's mass creates an unstable orbit. Due to maneuvers and orbital corrections, obtaining the position of such

spacecraft in space with anticipation may not provide enough accuracy for a good prediction. Here we report the strategies used for predicting occultations to be observed by CHEOPS (with a proposal approved with priority 1).

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## Your notes:

## Session: Hardware, Software and Procedures

# SORA – Stellar Occultation Reduction and Analysis

Bruno Eduardo Morgado[1, 2], Altair R. Gomes Júnior[3, 4], Gustavo Benedetti Rossi[4, 2], Rodrigo C. Boufleur[5, 2], Flavia L. Rommel[5, 2] , and Martin V. Banda Huarca[2]

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[4] UNESP, Grupo de Dinâmica Orbital e Planetologia, Brazil

[5] Observatório Nacional/MCTIC, Brazil

Stellar occultation is a powerful technique for measuring sizes, shapes, astrometrical positions, and probing material around the occultation object, such as atmospheres, comas, and rings. With the Gaia catalogs, the number of observed stellar occultations increased drastically. In the future, with the Legacy Survey of Space and Time (LSST) to be observed in the Very C. Rubin Observatory, this number should increase a lot with the observation of more than 30.000 Transneptunian objects (TNO) with magnitude R brighter than 24.5 by this survey.

We developed the open-source SORA package based on the need to improve our numerical methods to deal with this large amount of data. SORA is a Python-based, object-oriented library for optimal analysis of stellar occultation data. The user can use this package to build pipelines to analyze their stellar occultation data. It includes processes starting with predicting such events to the resulting size, shape, and position of the Solar System object.

In this presentation, I will discuss SORA’s capabilities, highlighting the new developments made in its v0.3 version. This update includes features like 3D sizes and shapes, efficient numerical methods to improve the fitting procedures, and the use of Gaia DR3 or any stellar catalog the user may see fit.

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# Distribution of occultation observers in Europe and their equipment

Wojciech Burzynski[1]

[1] IOTA/ES : International Occultation Timing Association/European Section

The latest statistics on occultation observers in Europe were published in 2007 on the Euraster website. After more than 15 years of break, I consider it necessary to re-analyze the distribution of observers and the analysis of their equipment.

Such a statement can help newbies in the decision to buy the right equipment that is up-to-date. It is also important to consider the observer shortage in individual European countries and find ways to fill these gaps.

The presented data comes from the analysis of the observation reports submitted to the PLANOCCULT list.

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## Your notes:

# Poster session

## Topographic evidence in the Trojans (3451) Mentor, (2207) Antenor, and (58931) Palmys from Stellar Occultations

Chrystian Luciano Pereira[1,2] , Felipe Braga-Ribas[3,1], Bruno Morgado[4,1,2], Julio I. B. Camargo[1,2], Viviane Peixoto[5,1,2] , Feliphe Ferreira[1,2] , Eros O. Gradovski[6] , Altair R. Gomes-Júnior[7,2], Carles Schnabel[8] , Gregor Krannich[9] , Jordi Marco[8] , Matthieu Conjat[10] , Michel Boutet[11], Pierre Lecam[12], Thomas Wayne[13], occultation team.

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[10] Agrupació Astronòmica Barcelona, Barcelona, Spain

[11] Balcon des Étoiles du pays toulousain, observatoire des Pléiades, France

[12] Observatoire de la Côte d'Azur, France

[13] International Occultation Timing Association (IOTA-USA)

The Trojans are objects that orbit at ∼5.2 au in 1:1 mean motion resonance with Jupiter, forming two confined clouds around the stable Lagrange regions L4 and L5, 60 degrees ahead and behind in Jupiter's orbit, respectively. The study of the physical properties of the Trojans is fundamental since these objects have critical relevance to understanding the formation and evolution of the Solar System.

The European Research Council (ERC) Lucky Star project aims to study and characterize the Solar System through stellar occultations, predicting events by TNOs, Centaurs, and Trojans. These predictions are publicly available on the Lucky Star website and Occult Watcher feed and managed on the Occultation Portal platform. This helps the observers stay tuned in the upcoming events and allow the collaboration between professional and amateur astronomers, that play an essential role in unexpected discoveries in the Solar System.

In this work, we present the preliminary results of the (58931) Palmys, (2207) Antenor, and (3451) Mentor stellar occultations observational campaigns. The data analysis from these stellar occultations showed unusual light curves, revealing possible topography or binarity. Although these objects have multi-epoch events, these features were observed in only one light curve of a multi-chord event by Mentor (2021 October 15), and single-chord events by Antenor (2021 June 12) and Palmys (2021 April 14). These preliminary and surprising results highlight the importance of pro-am collaboration in stellar occultations to understand these objects better and obtain new evidence of topography or binarity in the Trojans.

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## An expedition to observe an occultation by the Near Earth Object Didymos on August 24, 2022 in southern Spain.

Javier Flores[1]

[1] Sociedad Astronomica Granadina (SAG), Spain

A deployment of 8 telescopes with apertures ranging between 11 and 24 inches was made in southern Spain to measure the shadow of Didymos. Didymos is a sub-kilometric asteroid (0.78±0.08 km) which has a moon called Dimorphos. This is a binary system and is classified as a potentially hazardous asteroid due to its proximity to the Earth. This binary system will be visited by the DART and HERA Space missions and because of that the ACROSS team got in contact with us to arrange a campaign to observe the occultation event of the 12-mag star UCAC4 314-251595. In the end, we could observe with 7 of the telescopes while the ACROSS team deployment in Porto (Portugal) failed to weather. In this poster we summarize the efforts we made and the ongoing analysis of the observations.

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