LABORATÓRIO NACIONAL DE ASTROFÍSICA

SOAR TELESCOPE - Brazilian National Office

Observing Time Application Form (Version 5.0.0)
Semester: *2026B* (Aug/2026 - Jan/2027)

Proposal ID : **SO2026B-009**
Data Received : 15/04/2026 13:47

A.M.(<=)	Any	**Moon P.**	Gray
Image Quality		Seeing < 1.3"	
Cloudy Cover		Any	

Title of Proposal: ***Study of small bodies in the Solar System with stellar occultations***

Abstract:

A relevant characterization of small bodies in the Solar System is possible from the stellar occultation technique. Such characterization includes the determination of accurate shapes/sizes, the detection of atmospheres down to few nanobars, as well as the detection of satellites, jets, debris, rings and other structures around those objects. Continuous observations of occultation events, combined with data from different techniques, also contributes to a broad description of small bodies and to a better understanding of the history and dynamical evolution of the Solar System. Here, we propose to observe events by Quaoar (ringed TNO, needs deeper dynamical analysis of ring stability), comet Bernardinelli-Bernstein (size estimated, so far, from thermal measurements only), 2010 RO64 (TNO, never observed in an occultation) and Dziewanna (Scattered Disk Object - its high inclination and resonance with Neptune makes it a very interesting object in the study of the Solar System evolution).

Category: Solar System: Small Bodies (Asteroids, Comets, Moons, Kuiper Belt, Near Earth Objects)

Time requested: 5 hours.

Minimum time accepted: 4 hours.

Observing Mode: Classical Remote (CR)

Program Type: Regular Proposal (RP)

Principal Investigator (PI): Julio Ignacio Bueno de Camargo

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Is there a thesis or dissertation that will benefit from the data?: NO

Instruments:

Visitor Instrument

Optimal dates:

16/SEP, 01/OCT, 21/OCT, 21/JAN

Impossible dates:

Any other

Scientific Justification

Small bodies in the Solar System are objects orbiting the Sun (natural satellites excluded) that do not have enough gravity to pull their shapes into a nearly spherical one. This includes (but not all) Main Belt Asteroids, Centaurs, Trans-Neptunian Objects (TNOs), comets, trojan asteroids.

TNOs and Centaurs have been our main targets at OPD, but also some trojans and comets. TNOs are further from the Sun than 30 AU (Neptune's heliocentric distance). Centaurs are objects in unstable orbits between those of Jupiter and Neptune, and they are as rich a class as TNOs alone [1]. They are thought to have, in addition, a common origin with the TNOs [2], so that Centaurs can be considered as brighter proxies of the more distant TNO population.

Their importance resides in the fact that distant small bodies are relatively unchanged relics of an evolved planetesimal disc [3-4]. Therefore, they are records of the original material that formed the solar nebula and a treasure trove to access the history and evolution of the outer Solar System. Given their faint magnitudes, there is still much to be learned from this cold and distant world.

In this study, we propose the use of the stellar occultation technique, where the flux of a star is recorded with a high temporal resolution when it is blocked by a passing small body. In this way, it is possible to characterize the body's physical properties on an individual basis that also helps to build a broader general scenario, giving a crucial view about the processes involved in the formation and evolution of the Solar System. Two striking features of stellar occultations are: possibility to translate high temporal resolution into high spatial resolution and to observe small sized objects beyond our current capability of detection (in a context of serendipitous observations).

On an individual basis, occultations deliver dimensions with kilometric accuracies [5-8]. Shapes are also accurately determined and related to density (therefore, mass), elongation, and rotation for large TNOs [8]. Accurate albedos (a measurement of the ratio between the incident and reflected light fluxes) are derived from accurate sizes and better constrain the nature of surfaces (for example, fresh ice or cometary type material, darkened by space weathering [9]). Sizes, from Kepler's laws, provide information on density for TNOs with satellites (Pluto, Eris, Haumea, etc). Densities tell about the internal structure of these objects, like the ice/rock ratio. Given the high temporal resolution in image acquisition, stellar occultations are unrivalled in providing details about the neighbourhoods of the occulting bodies (e.g., the discovery of rings around the Centaurs Chariklo and Chiron and the TNOs Haumea and Quaoar [6,19-22]). The presence of tenuous atmospheres (down to few nanobars) [5-6][10], as well as other interesting physical properties [11-15], are natural byproducts of an occultation light curve analysis.

In a general scenario, sizes of many TNOs lead to their size distribution (giving insights into the total mass in the transneptunian region) and the balance between accretion and collisional erosion [16]. Physical surface properties of TNOs tell us about the thermal and chemical processes in the outer protoplanetary disk, indicating when and where the objects formed [17] - generally, objects that formed closer to the Sun tend to display more neutral colors; objects that formed further from the Sun are redder due to, e.g., differing compositions and space weathering. Planetary migration (Neptune mainly) then placed these objects into their current places. Albedos, a basic quantity to the study of small bodies, are fundamental to constrain the concentration of ices, carbons, and organics, which can have widely differing reflectivities [18]. As mentioned above, accurate albedos can be determined from accurate diameters - a direct measurement from stellar occultations - and absolute magnitudes.

After one decade of these proposals, we have contributed greatly to the knowledge of the physical properties of many individual objects. In a broader scenario, for instance, sizes/shapes of TNOs and Centaurs are related to their migration history and dynamical evolution - but an accurate knowledge in this context is built slowly.

Here, we propose the observe events by (5000) Quaoar (ringed TNO), C/2014 UN271 Bernardinelli-Bernstein (largest Oort Cloud comet ever detected), 2010 RO64 (TNO) and Dziewanna (TNO in the scattered disk). New detections of Quaoar's rings help to understand their confinement and stability mechanism [20]. Comet B-B has a diameter estimated, so far, from thermal measurements only [25] and needs ephemeris improvement. (523640) 2010 RO64 is a low albedo, relatively large (diam. $\sim$ 440 km) TNO never observed in a stellar occultation. (471143) Dziewanna is a suspected binary from one of our light curves. In addition, its high inclination and the fact that it is now trapped in a resonance with Neptune for a time much shorter than the Solar System age makes it a rare object to study the Solar System dynamical evolution.

Experimental Design

Sample and target selection: Targets are selected following basic criteria: visibility from SOAR (do predictions indicate that the event shadow will cross the telescope site?); magnitude limit (magnitude of the occulted star and contrast between it and the occulting object); scientific interest (has the object ever been observed?; does it need more observations (to pin down size/shape, ring density/dynamics, is it targeted by a space mission, etc)?; is there any special feature - presence of ring, satellite, atmosphere, cometary activity, topography - that needs confirmation?

Observing strategy: The basic point of the observational strategy is founded on the sampling of the target star flux with the highest possible temporal resolution. In other words, we want to observe the occultation event (before, during and after it) with short exposure times and ideally no dead time between consecutive images. Filters are useful to help, for instance, characterize atmospheres and ring particle size. However, most frequently, no filters are used as a way to gather as much light as possible and improve SNR. HRCam2, a fast readout camera - is equipped with *g*, *r* and *i* filters (but not only), close to the Sloan system, ready to be used if necessary.

Observables: The observable is the flux variation of the event so that the variation of this flux, as a function of time, can be investigated. Stellar occultation translates temporal resolution into spatial resolution. Therefore, the shorter the exposure and dead times the more details about the occulted object and its neighborhoods will be contained in the light curve. Since light curves from different observatories are combined to recover the object's size and shape (and, consequently, its center), clocks should present no offsets. Therefore, not only should a clock be precise but accuracy is also of the highest importance. GPS or internet protocols are frequently used to correct clocks from different sites for any offsets.

Achieving kilometric accuracy in determining the sizes of small solar system bodies from stellar occultations requires a meticulous approach to analyze the light curves. This involves fitting a model to the observational data that accounts for the finite exposure time, the apparent angular size of the occulted star at the distance of the occulting body and Fresnel diffraction effects (particularly important for precisely measuring features like rings).

Once the precise instants of the disappearance and reappearance of a star (ingress and egress times) are determined from the light curves of a given event, the projected shape of the object onto the sky plane can be reconstructed and, from some assumptions, the ellipsoidal figure and orientation can be determined. Here, the position of the occulted star, the object's ephemeris, the positions of the observing sites on the Earth as well as a model of the Earth's shape, are necessary.

Timing issues are frequently present in a few of the observations. These include constant time offsets, which can be corrected using a reliable site as a reference, and truncated timestamps (showing only the integer part of the second), which can be fixed - assuming that the acquisition cycle is regular - by performing a linear fit on the image-sequence $\times$ time to determine the acquisition cycle (the slope from the fit gives the cycle time). Combining data from multiple telescopes at one site can also help compensate for data gaps caused by long camera readout times.

Quantifications: SNR determination in the present context takes into consideration the magnitude drop of the event, determined when both star and small solar system body are no longer resolved, and the magnitude of the occulted star. The magnitude drop is given by the combined fluxes of the star+object and that of the object only (in the absence of an atmosphere, the total obstruction of the stellar flux is an accepted simplification). This is given by $\Delta m = -2.5 * \log(1 + 10^{(\mathrm{m_a} - \mathrm{m_e})*0.4})$, where m_a and m_e are the solar system body and star magnitudes respectively. Obviously, although it is not necessary to detect the object's flux during the observation, the flux of the occulted star and that of the sky are of fundamental importance (if the star is too faint, the magnitude drop may not be detected regardless the occurrence of the event and the magnitude of the occulting body). The value of Δm for the events proposed in this work ranges from -5.7 to -1.9. Considering that the magnitude uncertainty can be estimated from $\frac{2.5}{\ln(10)} \times \frac{1}{SNR}$, a SNR of 10, for instance, is enough. The speed of the occultation shadow on the ground is also of relevance, as slow speeds accept longer exposure times without prejudice to spatial resolution. In practice, exposure times ranging from fractions of a second to few seconds are used. Since occultations are serendipitous and transient events, observations are done regardless seeing, moon or clouds presence (limited to the safety of the telescope). Also, if necessary but at the cost of time (and spatial) resolution, images can be co-added to improve SNR.

Technical Description

Instrument configuration: `HRCam2`: we have already had a first experience with the command interface of the camera, but never observed with it. Overall, the camera seems to be suitable to observe stellar occultations (tests related to the accuracy of the time registered in the header are ongoing) but we are confident that the instrument is suitable to the proposed task. It is relevant to say that images will be acquired on a frame by frame mode (as opposed to a cube of images) and exposure times should not be shorter than 0.2 s [26] to avoid inaccurate registration of the time of image acquisitions.

Sky conditions: Since occultations are serendipitous and transient events, observations are made regardless of seeing, moon or cloud presence (limited to the safety of the telescope). Objects may potentially hide features that only high spatial resolution can unveil and stellar occultation is the unrivaled and cheapest ground-based technique for this task. With little telescope time and simple instrumentation, moons, rings, close binary systems (where we thought to exist a single object), atmospheres and other features can be discovered at very large distances from the Sun. Therefore, image acquisition, even under poor conditions, is our preferred option.

Exposure times and SNR: From our experience with the Raptor fast readout camera, a star with R=14.5 is observed at SOAR with an SNR of $\sim$ 30 from an exposure time of 0.05 s. A star with R=17.0 profits from the same SNR from an exposure time of 0.5 s and the faintest star to be occulted in this proposal is G$\sim$18 (event by Dziewanna). Therefore, given the expected magnitude drops, exposure times of 1 s or shorter (but not shorter than 0.2 s - [26]) are expected, weather permitting. Note that `HRCam2`'s QE is higher than that of Raptor [27] so that we expect a better performance on this subject.

Total observing time and overheads: In general, a total of 30 minutes per event is enough. In practice, from our experience with Raptor, we have required 75 minutes/event. The extra 45 minutes were used to adjust focus but mainly to point the telescope since there is an offset between the nominal telescope pointing and the center of Raptor's FOV at the telescope's Nasmith focus. The correct field was frequently seen, but not always, after compensating for the pointing offset. The field identification may be particularly difficult for low density stellar fields. Since HRCam2 will occupy the Raptor's current place at the telescope, we prefer to keep the extra 45 minutes for the time being. Four events are proposed here for four objects listed below (see also Fig. 1). In this way, **a total of 5 hours is requested**.

1. Quaoar: 2026SEP16T23:45:00 UTC - 2026SEP17T01:00:00 UTC
2. B-B: 2026OCT02T02:56:00 UTC - 2026OCT02T04:11:00 UTC
3. 2010 RO64: 2026OCT21T23:53:00 UTC - 2026OCT22T01:08:00 UTC
4. Dziewanna: 2027JAN22T05:46:00 UTC - 2027JAN22T07:01:00 UTC

Minimum observing time: We would like to observe as many occultations as possible, taking into account the relevance of the events proposed here. The event with lowest priority to us is that by 2010 RO64 (which could be skipped if necessary). However, we stress that stellar occultations offer excellent results with relatively small telescope time. In addition, this object has never been detected in an occultation event. In this context, we propose 3.75 hours as the minimum observing time, although each observation is precious by itself.

Figures and Tables

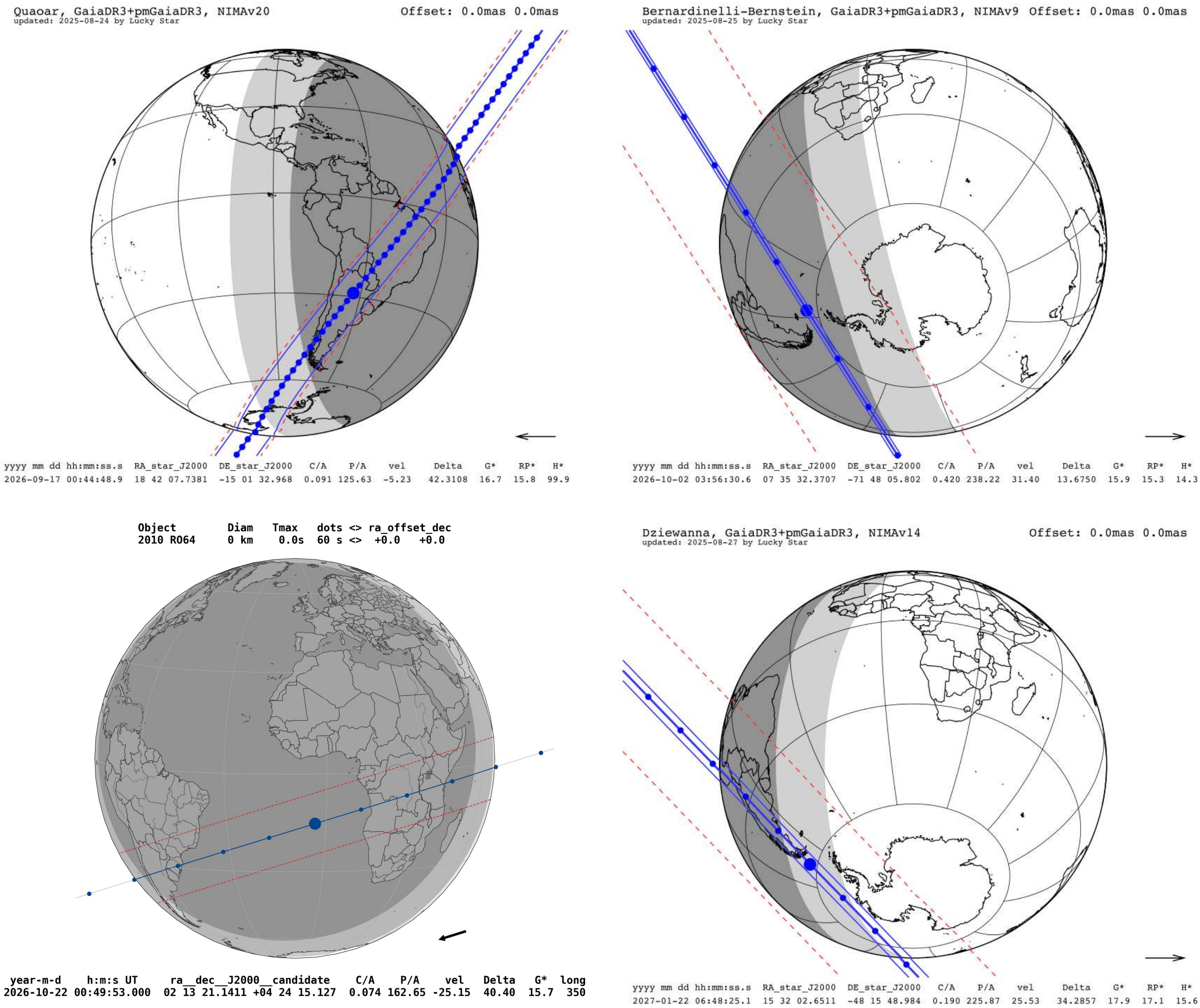

Figure 1: Selected occultation events to SOAR 2026B. Left to right, top to bottom: Quaoar (SEP), Bernardinelli-Bernstein (OCT), 2010 RO64 (OCT), and Dziewanna (JAN/2027). Blue lines indicate the shadow's path. Red dashed lines indicate the 1-σ uncertainty in the path's location. A big blue dot indicates the closest point to the geocenter. Dots are spaced by 1 minute. International observational campaigns are underway and alerts should be sent to collaborators close to some of the shadow paths of these events.

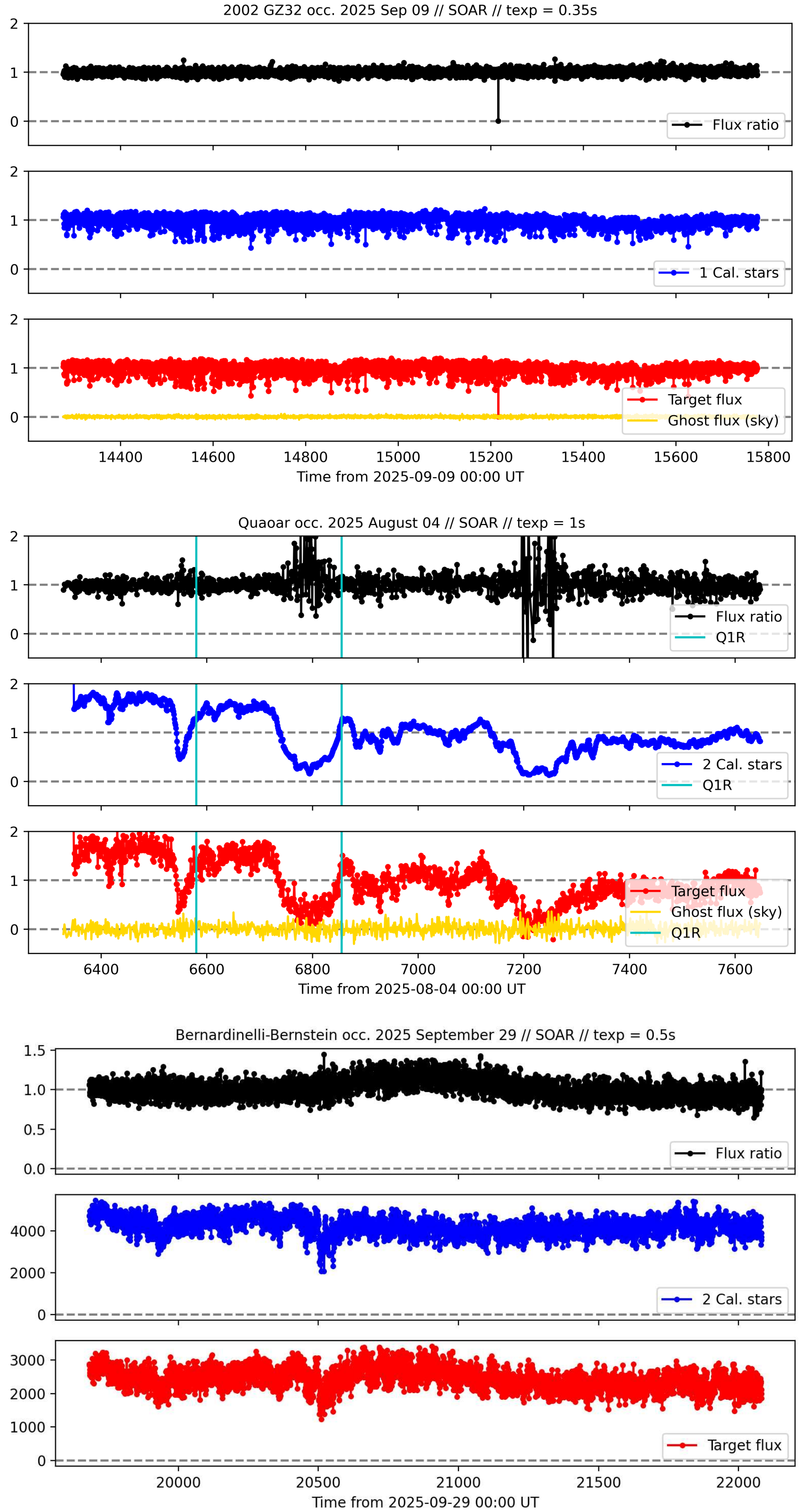

Figure 2: Preliminar analysis of events observed in 2025B (all negatives). Top panels (Event by 2002 GZ32): the flux drop close to x = 15200 is the result of an image artifact; Middle panels (Quaoar): large variations related to the sky conditions; Lower panels (Comet B-B): No clear reason for the small flux increase in the top panel.

References

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27. A. Tokovinin, personnal communication

Previous missions of this proposal to this telescope

1. 2015A: project to install a fast readout camera as visitor instrument. The complete installation comprised a fast readout Raptor Merlin EMCCD camera, a filter wheel with g, r, i sloan filters, a GPS, and a laptop (remote access) to control the camera, the filter wheel, and to launch the GPS software. All components are mounted at the Nasmyth focus of the telescope.
2. 2015B and 2016A: we tried an occultation by Chariklo with our visitor instrument. Although the shadow of the event was predicted to pass south and north of SOAR, respectively, a ToO (coordinated with the VLT) was triggered considering the uncertainties in the prediction. No event was detected, but it was possible to check the photometric performance of the visiting instrument.
3. 2016B: a ToO was triggered but we could not observe due to clouds.
4. 2017A: Our best prediction to SOAR was a grazing occultation by Chariklo's rings on 2017/JUL/23. A ToO was triggered but strong winds prevented us from observing.
5. 2017B: No ToO triggered within this project. However, in cooperation with researchers from the SwRI (Southwest Research Institute), fast readout observations aiming at the preparation of the flyby of the TNO (486958) 2014 MU69 by New Horizons were made with our visitor instrument (see next session).
6. 2018A: **Two events successfully observed** in June (Phoebe) and July (2010 EK139). Results related to Phoebe are described by [6] (see next Section). Timing issues made the analysis for 2010 EK139 difficult. Along with SOAR, two other sites (La Silla and Casleo) detected the event but the ingress/egress instants were not compatible (that is, we could not form a reasonable shape from those instants, the duration of the occultation, and the site coordinates). However, the position derived from this event helped to predict and observe another occultation by this TNO in Melbourne (MAY/2019). We stress that an occultation provides a very accurate (milli-arcsecond level) relative position between the occulted star and the occulting body. Since the star position is well known from Gaia, the occulting body position is also accurately obtained.
7. 2018B: One ToO triggered (occultation by Chiron). The main body shadow was expected to pass to the north of SOAR. However, the observation - coordinated with the VLT and NTT - was important to support a possible detection of debris, jets, rings. No event was detected (bad weather or simply no flux variation of the star) by any of the telescopes involved in the run, unfortunately. The Danish and Trappist telescopes (ESO) also participated in the observations. SOAR also observed Orus (Jupiter trojan), along with the Danish (ESO) telescope and telescopes in San Pedro de Atacama and at Universidade Estadual de Ponta Grossa (UEPG). No obvious event detected.
8. 2019A: Events by Quaoar, Phoebe, and 2002 MS4 were observed. Stellar occultations by Quaoar have profited from observations made in Brazil since 2011, including observations from SOAR. A new approach to analyze all these events as a unique data set was developed and is allowing us to determine the 3D shape of Quaoar. Part of this work and results were presented during the XLVI RSAB and will be the main subject of a MSc. work (student: G. Margoti) and a paper, both being prepared. The event by Phoebe in 2019A was negative to SOAR (but it is reported in [6], next Section). Predictions indicated a grazing event for Phoebe 2019A within the uncertainties. The observation was however worth trying because a negative chord close to the body is useful to set upper limits to its dimensions. 2002 MS4: SOAR, Pico dos Dias (OPD), San Pedro de Atacama and UEPG tried to observe the event. Positive detections were obtained at San Pedro de Atacama and OPD. Negative from SOAR (overcast, but SOAR was outside the shadow anyway) and UEPG. As explained before, certain observations outside (but close to) the shadow are useful to size determination and to investigate the neighbourhoods of the body. Note that, although there was no detection by SOAR for 2002 MS4, the 2019A campaign helped to make possible a huge and successful campaign in 2020 involving over 100 observatories. It brought the first precise measurement of this object, with 60 positive chords detected over Europe. A summary of the results were presented during the Europlanet Science Congress (EPSC) 2021[1] and in presentations at the Annual Meeting of the Division for Planetary Sciences - DPS 2022[2] and at the XLV Meeting of the Brazilian Astronomical Society - XLV

[1] http://doi.org/10.5194/epsc2021-440

[2] https://submissions.mirasmart.com/DPS54/Itinerary/PresentationDetail.aspx?evdid=49

SAB, 2022[3] by the then PhD student F. Rommel. A paper describing the results from these observations (2002 MS4), that mentions the participation of SOAR, is report in [1], section ”Previous results in the field by the P.I.”.

9. 2019B: Occultation by (3793) Leonteus (large Jupiter trojan). SOAR got a **positive detection**, other sites did not observe (overcast). This individual event was used to refine its orbit. An event by Quaoar could not be observed due to bad weather and instrumental problems. A first event by (60558) Echeclus was lost by little as SOAR was at the southern border of the shadow. Such events are useful to impose upper limits in the dimensions of the body. A second event by (60558) Echeclus was **positive** at SOAR. It is also important to mention that another occultation by Echeclus was recorded in JAN/2021 (Japan) and both sets of data (SOAR-Japan) are being treated together and appears in a publication describing the object and its neighbourhoods (see next section). A PhD student, C. Pereira, is deeply involved in this study and **presented results about Echeclus** from positive chords obtained at, among other places, SOAR (2020) and Tokushima/Japan (2021), at the Europlanet Science Congress (EPSC), 2022[4]. Numerous other sites were involved in these campaigns.
10. 2020A: No observations due to the COVID-19 pandemic.
11. 2020B: No observations due to the COVID-19 pandemic.
12. 2021A: A predicted event by the large TNO 2002 MS4 was observed. Although the grazing geometry (the target appeared just high enough above the horizon for SOAR in the end of the night and close to the predicted beginning of the flux drop), images were acquired successfully. The event was negative at SOAR but, a little to the north, two telescopes at San Pedro de Atacama registered the occultation shadow. Anyway, observations of this object have been reported above (see 8.) and the participations of SOAR are reported in [1], section ”Previous results in the field by the P.I.”. Ixion (2021APR28): we had difficulties to confirm that the telescope was on target and the zenith distance limit was reached a little before the event started so that, unfortunately, we could not acquire the necessary data. In any case, the event was worth trying since a campaign for this event had been organized and SOAR was under the occultation shadow. The two next events by the TNO Ixion (2021MAY11 and 2021JUN20) in 2021A were dropped after communicating SOAR that recent updates in Ixion’s ephemeris had confirmed that SOAR was outside the occultation shadow.
13. 2021B: We could not observe the event by 2004 PF115 due to the presence of ice on the dome. Events by 2002 GZ32 and Lempo were successfully observed and the results about Lempo were reported in a previous proposal (2022A) by us. A light curve from the predicted occultation by 2002 GZ32 shows a negative event.
14. 2022A: Three - 2002 WC19, 2002 GZ32 and 2007 JH43 - out of four events were observed. A light curve from the predicted occultation by 2002 WC19 (already reported in the proposal for 2022B) shows a negative event. The events by 2002 GZ32 and 2007 JH43 were also negative from SOAR. Other observatories that also tried to observe these two events reported either clouds or negative. The fourth event, an occultation by the jovian trojan (1172) Äeneas, could not be observed because the event happened in a period when the optical side of the telescope was not operational.
15. 2022B: Two events (Salacia and 29P/S-W 1) were proposed: the occultation by the TNO Salacia was negative. The occultation by the active comet 29P/S-W 1 was observed and the results have been used to greatly improve its orbit[5]! This was the **first detection of an occultation by this object**, and it allowed to refine its orbit leading to a multi-chord detection a few weeks later from the USA. The occultation observed with SOAR is reported in *Philosophical Transactions A* (Centaur 29P/Schwassmann-Wachmann 1 and their vicinity from a stellar occultation), C.L. Pereira *et al.* (2025) (see Sect. ”Previous results in the field by the Principal Investigator)”.
16. 2023A: Three events were proposed: Varda, 2007 JJ43 and Ixion. The first one could not be observed due to the presence of ice on the dome a little before the scheduled time. The two other ones were **successfully**

[3] https://www.eventweb.com.br/sab2022/on-site/pdf/viewer.html?file=../../../specific-files/manuscripts/sab2022/128_1653947556.pdf

[4] https://meetingorganizer.copernicus.org/EPSC2022/EPSC2022-557.html

[5] See https://lesia.obspm.fr/lucky-star/obj.php?p=1009 for the current orbit uncertainties.

observed with positive events and reported in the previous proposal.

17. 2023B: Eight events were proposed, the first four ones being Quaoar, Chiron, comet Bernardinelli-Bernstein (BB) and Salacia. Quaoar was **successfully observed with positive events** and reported in the previous proposal. Chiron and BB were clouded out. The event by Salacia could not be observed due to technical problems (pointing issues). The other targets (1998 SN165, Echeclus - NOV and DEC, and 2002 WC19) were successfully observed but there is no indication of an occultation in any of the cases.
18. 2024A: Observations of events by 2007 JJ43 (APR) and 1999 KR16 (JUL) were successfully observed. The analysis of both light curves indicate negative events. A third event, by 2002 KX14 (JUL) was lost due to bad weather. All three objects are trans-neptunians.
19. 2024B: Two (Quaoar and Neptune plus rings) of three events were lost due to bad weather (snow and humidity). The third one, involving the comet C/2014 UN271 (Bernardinelli-Bernstein) needed a careful analysis of the light curve and proved to be a negative.
20. 2025A: Six events were proposed: (624) Hektor (Trojan), Dziewanna (twice), 2007 JH43, 2002 KX 14 and 2002 MS4. Only the two first have been observed do far. The events by Diziewanna and 2002 MS4 were negative. The one by Hektor was **POSITIVE, with a surprising detection in the light curve**, and reported in our last proposal. A publication combining SOAR data with those of other telescopes is still underway. The event by 2007 JH43 was **POSITIVE** and a partial analysis was presented in past proposals.
21. 2025B: Quaoar, Comet C/2014 UN271 (Bernardinelli-Bernstein) (twice) and 2002 GZ32. The first observation of the comet B-B was lost due to technical problems. The other ones were successfully obtained and are under analysis, see Fig. 2.
22. 2026A: 2004 GV9, Orcus, Ixion (twice) and Eurypylos. So far only the first event was observed under a cloudy sky (no useful data).

Previous missions of other proposals to this telescope

1. “The influence of radio-extended structures on offsets between the optical and VLBI positions of sources in the ICRF2”, Camargo, J. I. B. et al. (2011), DOI:10.1051/0004-6361/201016201.
2. “A ring system detected around the Centaur (10199) Chariklo”, Braga-Ribas et al. (2014), Nature, DOI: 10.1038/nature13155.
3. Surface Characteristics of Multiple System Asteroids (SO2011B-014) and (SO2012A-014) - “Composition, Mineralogy, and Porosity of Multiple Asteroid Systems from Visible and Near-infrared Spectral Data”, Sean S. Lindasy et al. (2015), Icarus, DOI: 10.1016/j.icarus.2014.08.040.
4. **Observations related to the preparation for the flyby of the TNO (486958) 2014 MU69 by New Horizons (NOAO time at SOAR using the Raptor camera). CONTROL ID: 2817945, submitted to the DPS - Division of Planetary Sciences, American Astronomical Society, 2017**. TITLE: Debris search around (486958) 2014 MU69: Results from SOFIA and ground-based occultation campaigns Abstract: The New Horizons spacecraft is scheduled to fly by the cold classical KBO 2014 MU69 on 1-Jan-2019. The spacecraft speed relative to the MU69 will be in excess of 14 km/s. At these encounter velocities, impact with debris could be fatal to the spacecraft. We report on searches for debris in the neighborhood of MU69 conducted from SOFIA and ground-based sites. SOFIA observed the star field around MU69 on 10-Jul-2017 (UT) with their Focal Plane Imager (FPI+), operating at 20 Hz from 7:25 to 8:10 UT, spanning the time of the predicted occultation. Several large fixed telescopes observed the 3-Jun-2017, 10-Jul-2017 and/or the 17-Jul-2017 occultation events, including the 4-meter SOAR telescope, the 8-meter Gemini South telescope, and many 16-inch portable telescopes that were arranged in picket fences in South Africa and Argentina. We report on the light curves from these observing platforms and constraints on the optical depth due to debris or rings within the approximate Hill sphere (about 60,000 km across) of MU69. This work was supported by the New Horizons mission and NASA, with astrometric support from the Gaia mission and logistical support from Argentina and the US embassies in Buenos Aires and CapeTown. At SOAR, data acquisition has been done with a Raptor camera (visitor instrument) funded by the Observatorio Nacional/MCTIC. CURRENT * CATEGORY: Centaurs and Kuiper Belt Objects: Observational

surveys AUTHORS (FIRST NAME, LAST NAME): Eliot F. Young(1), Marc W. Buie(1), Simon B. Porter(1), Amanda M. Zangari(1), S. Alan Stern1, Kimberly Ennico(2), William T. Reach(3), Enrico Pfueller(4), Manuel Wiedemann(4), Wesley C. Fraser(5), Julio Camargo(6), Leslie Young(1), Lawrence H. Wasserman(7) INSTITUTIONS (ALL): 1. Southwest Research Inst., Boulder, CO, United States. 2. NASA/ARC, Moffett Field, CA, United States. 3. USRA, Columbia, MD, United States. 4. Deutsches SOFIA Institut, University of Stuttgart, Stuttgart, Germany. 5. Queen's University Belfast, Belfast, Northern Ireland, United Kingdom. 6. Observatorio Nacional/MCTIC and LIneA, Rio de Janeiro, Brazil. 7. Lowell Observatory, Flagstaff, AZ, United States. Contributing Teams: New Horizons MU69 Occultation Team

5. "Chariklo's rotation light curve for 3D shape characterization" (SO2019B-008). No useful data obtained due to technical limitations and sky conditions.
6. "Rotation light curve for the high-inclination TNO 2004XR190" (SO2021B-012): six half-nights of data obtained. **Results from these observations were recently presented at the XLV Meeting of the Brazilian Astronomical Society (2022)[6].**

Previous results in the field by the Principal Investigator

1. "Constraining the size, shape, and albedo of the large trans-Neptunian object (28978) Ixion with multi-chord stellar occultations", Kilic, Y., (2026), A&A, DOI: 10.1051/0004-6361/202557970
2. "Accurate geometric albedo, shape, and size of Hi'iaka from a stellar occultation", Férnandez-Valenzuela, Estela (2025), NatCo, DOI: 10.1038/s41467-025-65749-1
3. "A high geometric albedo and small size for the Haumea cluster member (24835) 1995 SM55 determined from a stellar occultation and photometric observations", Ortiz, J.L. et al. (2025), A&A, DOI: 10.1051/0004-6361/202556498
4. "The Rings of (2060) Chiron: Evidence of an Evolving System", Pereira, C.L. et al. (2025), ApJL, DOI: 10.3847/2041-8213/ae0b6d
5. " Size and Shape of Jupiter Trojan (2207) Antenor from Stellar Occultations", Ferreira, F.S. et al. (2025), AJ, DOI: 10.3847/1538-3881/adefdc
6. "The trans-Neptunian object (119951) 2002 KX14 revealed via multiple stellar occultations", Rizos, J.L et al. (2025), A&A, DOI: 10.1051/0004-6361/202554154
7. "Centaur 29P/Schwassmann-Wachmann 1 and its near-nucleus environment from a stellar occultation", Pereira, C.L. et al. (2025), Philosophical Transactions A, DOI: 10.1098/rsta.2024.0189
8. "A study of centaur (54598) Bienor from multiple stellar occultations and rotational light curves", Kretlow, M. et al. (2024), A&A, DOI: 10.1051/0004-6361/202450833
9. "Constraints on the evolution of the Triton atmosphere from occultations: 1989-2022", Sicardy, B. et al. (2024), A&A, DOI: 10.1051/0004-6361/202348756
10. "Physical properties of Centaur (60558) 174P/Echeclus from stellar occultations", Pereira, C.L. et al. (2024), MNRAS, DOI: 10.1093/mnras/stad3318
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12. "A large topographic feature on the surface of the trans-Neptunian object (307261) 2002 MS4 measured from stellar occultations", Rommel, F. et al. (2023), A&A, DOI: 10.1051/0004-6361/202346892
13. "Changing material around (2060) Chiron revealed by an occultation on December 15, 2022", Ortiz, J.L. et al. (2023), A&A, DOI: 10.1051/0004-6361/202347025
14. "Constraints on (2060) Chiron's size, shape, and surrounding material from the November 2018 and September 2019 stellar occultations", Braga-Ribas, F. et al. (2023), A&A, DOI: 10.1051/0004-6361/202346749
15. "The two rings of (50000) Quaoar", Pereira, C.L. et al. (2023), A&A, DOI: 10.1051/0004-6361/202346365

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16. ”A dense ring of the trans-Neptunian object Quaoar outside its Roche limit”. Morgado, B.E. et al. (2023), Nature, DOI: 10.1038/s41586-022-05629-6
17. ”The multichord stellar occultation by the centaur Bienor on January 11, 2019”, Fernández-Valenzuela, E. et al. (2023), A&A, DOI: 10.1051/0004-6361/202243214
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24. “A multi-chord stellar occultation by the large trans-Neptunian object (174567) Varda”, Souami, D. et al. (2020), A&A, DOI: 10.1051/0004-6361/202038526
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27. “Stellar occultation by TNOs: from predictions to observations”, Ortiz, J.L. et al. (2020), The Trans-Neptunian Solar System, Edited by Dina Prialnik, Maria Antoinetta Barucci, Leslie Young. ISBN: 9780128164907. Elsevier, p.413-437, DOI: 10.1016/B978-0-12-816490-7.00019-9
28. “The trans-Neptunian object (84922) 2003 VS2 through stellar occultations”, Benedetti-Rossi et al. (2019), AJ, DOI: 10.3847/1938-3881/ab3b05
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30. “Pluto’s ephemeris from ground-based stellar occultations (1988-2016)”, Desmars, J., Meza, E., Sicardy, B., Assafin, M., Camargo, J.I.B. et al. (2019), A&A, DOI: 10.1051/0004-6361/201834958
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32. “Astrometry and Occultation Predictions to Trans-Neptunian and Centaur Objects Observed within the Dark Energy Survey”, Banda-Huarca, M. V., Camargo, J.I.B., Desmars, J. et al. (2019), AJ, DOI:10.3847/1538-3881/aafb37
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34. “The size, shape, density and ring of the dwarf planet Haumea from a stellar occultation”, Ortiz, J.L., et al. (2017), Nature, DOI:10.1038/nature24051
35. “The Structure of Chariklo’s Rings from Stellar Occultations”, Bérard, D., Sicardy, B., Camargo, J. I. B., et al. (2017), AJ, DOI:10.3847/1538-3881/aa830d
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38. “Results from a triple chord stellar occultation and far-infrared photometry of the trans-Neptunian object (229762) 2007 UK126”, Schindler, K. et al. (2017), A&A, DOI: 10.1051/0004-6361/201628620
39. “Results from the 2014 November 15th Multi-chord Stellar Occultation by the TNO (229762) 2007 UK126”, Benedetti-Rossi, B. et al. (2016), AJ, DOI:10.3847/0004-6256/152/6/156
40. “Pluto’s Atmosphere from the 2015 June 29 Ground-based Stellar Occultation at the Time of the New Horizons Flyby”, Sicardy, B. et al. (2016), ApJ, DOI:10.3847/2041-8205/819/2/L38
41. “Pluto’s Atmosphere from Stellar Occultations in 2012 and 2013”, Dias-Oliveira, A. et al. (2015), ApJ, DOI:10.1088/0004-637X/811/1/53
42. “Results of two multichord stellar occultations by dwarf planet (1) Ceres”, Gomes-Junior, A.R. et al. (2015), MNRAS, DOI:10.1093/mnras/stv1081
43. “A ring system detected around the Centaur (10199) Chariklo”, Braga-Ribas et al. (2014), Nature, DOI: 10.1038/nature13155
44. “An exploration of Pluto’s environment through stellar occultations”, Boissel et al. (2014), A&A. DOI: 10.1051/0004-6361/201321836
45. “Candidate stellar occultations by Centaurs and trans-Neptunian objects up to 2014”, Camargo et al. (2014), A&A, DOI:10.1051/0004-6361/201322579
46. “The Size, Shape, Albedo, Density, and Atmospheric Limit of Transneptunian Object (50000) Quaoar from Multi-chord Stellar Occultations”, Braga-Ribas et al. (2013), ApJ, DOI: 10.1088/0004-637X/773/1/26
47. “Albedo and atmospheric constraints of dwarf planet Makemake from a stellar occultation”, Ortiz, J.L. et al. (2012), Nature, DOI:10.1038/nature11597

PI and Co-Is publications relevant to this proposal

These are publications that summarize theoretical and conceptual subjects related to stellar occultations

1. ”Stellar occultations by trans-Neptunian objects”, Sicardy, B. et al. (2024), A&ARv, DOI: 10.1007/s00159-024-00156-x
2. ”Stellar occultation by TNOs: from predictions to observations”, Ortiz, J.L.(2020), The Trans-Neptunian Solar System, DOI: 10.1016/B978-0-12-816490-7.00019-9

Objects List.

Object	A.R.(h,m)	Dec.(deg)	Mag.	Band	Type	Comments
(5000) Quaoar	18:42:07.74	-15:01:32.97	16.7	G	Sci	Occultation event by Quaoar on 2026SEP17T00:45:00 UTC
Bernardinelli-Bernstein	07:35:32.27	-71:48:05.80	15.9	G	Sci	Occultation event by comet B-B on 2026OCT02T03:56:00 UTC
(523640) 2010 RO64	02:13:21.14	+04:24:15.13	15.7	G	Sci	Occultation event by 2010 RO64 on 2026OCT22T00:53:00 UTC
(471143) Dziewanna	15:32:02.65	-48:15:48.98	17.9	G	Sci	Occultation by Dziewanna on 2027JAN22T06:46:00 UTC