LABORATÓRIO NACIONAL DE ASTROFÍSICA
SOAR TELESCOPE - Brazilian National Office
Observing Time Application Form (Version 4.0.0)
Semester: *2026A* (Feb/2026 - Jul/2026)

Proposal ID : **SO2026A-007**
Data Received : 15/10/2025 10:35

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

Title of Proposal: ***Rotational Characterization of Trans-Neptunian Object 90568 Goibniu (2004 GV9)***

Abstract:

90568 Goibniu (2004 GV9) is a classical Trans-Neptunian Object (TNO) classified as a Cubewano (i.e., not in a mean-motion resonance with Neptune). It has a semi-major axis of 41.8 AU and a low orbital eccentricity of 0.076. Its high orbital inclination of 22 degrees places it within the dynamically Hot population of classical TNOs. Goibniu is also one of the largest objects in this population. Previous studies from 2008, derived from two nights of observations at the 3.5m New Technology Telescope (NTT), established a rotational period of 5.86 (0.03) hours and a rotational amplitude of 0.16 (0.03) magnitudes. Our interest in this object is to use precise rotation data, in conjunction with upcoming stellar occultation observations, to accurately determine its physical and orbital parameters. The acquisition of new, high-quality rotation light curves for 90568 Goibniu is therefore essential to the success of our comprehensive characterization project.

Time requested: 32 hours.

Minimum time accepted: 16 hours.

Observing Mode: Classical Remote (CR)

Program Type: Regular Proposal (RP)

Principal Investigator (PI): Giuliano Margoti

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Co-authors

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Is there a thesis or dissertation that will benefit from the data?: YES

Student	E-mail	Degree	Defense
Giuliano Margoti	giulianomargoti@on.br	PhD student	11/2028
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Instruments:

Instrument	Camera
Goodman (Imaging)	Red Camera

Instrument	Filter	Grating	Slit
Goodman (Imaging)			
	rÂ´ SDSS 4x4		
	iÂ´ SDSS 4x4		
	zÂ´ SDSS 4x4		

Optimal dates:

2026- May-10 to 2026-May-18,

Impossible dates:

before 2026-Mar-23 and multiple dates indicated in section Technical Description

Scientific Justification

The Trans-Neptunian Object (TNO) population provides a laboratory for studying the formation and evolution of the Solar System. The current orbital configuration (e.g., semi-major axis, eccentricity, and inclination) offers clues into the dynamics of giant planet migration history, and the distribution of masses and albedos provides constraints on the accretion process within the primordial protoplanetary disk [1].

The migration of the giant planets dynamically scattered the orbits of many bodies within the classical TNO belt (40 to 48 AU), exciting these orbits to high inclinations and eccentricities [1]. This may have been the case of 90568 Goibniu (2004 GV9). With an estimated diameter of 680 (34) km, Goibniu is a member of the Hot Classical family, defined by its orbital inclination greater than 5º [2]. Goibniu orbits the Sun with a semi-major axis of 41.8 AU and a low eccentricity of 0.076, yet its high inclination of 22º places it among the dynamically excited population.

The size estimate for Goibniu was determined using thermal observations obtained with the Herschel/PACS and Spitzer/MIPS instruments, which also yielded a geometric albedo of $0.0770^{-0.0077}_{+0.0084}$ [2]. Furthermore, Goibniu was observed in 2007 using the 3.5 m New Technology Telescope (NTT) across two nights (3 hours on the first night and 8 hours on the second). This observation yielded a light curve with sufficient resolution to derive a double-peaked rotation period of 5.86 (0.03) hours and a rotational amplitude peak-to-peak of 0.16 (0.03) magnitudes [3].

The albedo of Goibniu was estimated from the size obtained with the thermal data and the absolute magnitude in the visible, which is 4.23 (0.10) [2]. A minimum density for the object of 0.37 g/cm³ was also estimated. It is expected that, if the object is in hydrostatic Jacobi equilibrium and rotating with the period presented previously, its density is between 1.14 g/cm³ and 1.49 g/cm³ [3].

Goibniu is part of the same collisional class as Quaoar, which is known to be one of the most interesting TNOs, possessing two rings orbiting outside its Roche limit [4, 5], a confirmed satellite [6, 7], and a recently discovered possible second satellite or ring-arc [8]. We invested significant effort in determining Quaoar's three-dimensional shape, utilizing stellar occultation data combined with rotational photometry to obtain its 3D figure. These results were published in the PI's thesis [9] and are about to be submitted in two separate papers.

The upcoming occultation of Goibniu is predicted to have a slow event velocity, which will allow for the study of the object's surrounding environment with extreme precision, potentially revealing any material in its vicinity. It can become the first occultation detected for this body. The observational campaign for this event will involve multiple telescopes in South America, including SOAR (another proposal was submitted for this TAC). We intend to utilize the occultation data and the rotational data requested in this proposal to obtain Goibniu's refined physical and rotational parameters, thereby significantly increasing our understanding of this family of objects.

Given its faint apparent magnitude, approximately 20 in the V band, obtaining reliable rotation data for Goibniu is challenging when using smaller telescopes. Therefore, the SOAR telescope is essential for the execution of this project and the characterization of Goibniu.

References

[1] Gladman, B., Kavelaars, J. J., Petit, J.-M., et al. 2001, AJ, 122, 1051. doi:10.1086/322080
[2] Vilenius, E., Kiss, C., Mommert, M., et al. 2012, A&A, 541, A94. doi:10.1051/0004-6361/201118743
[3] Dotto, E., Perna, D., Barucci, M. A., et al. 2008, A&A, 490, 829. doi:10.1051/0004-6361:200809615
[4] Morgado, B. E., Sicardy, B., Braga-Ribas, F., et al. 2023, Nature, 614, 239. doi:10.1038/s41586-022-05629-6
[5] Pereira, C. L., Sicardy, B., Morgado, B. E., et al. 2023, A&A, 673, L4. doi:10.1051/0004-6361/202346365
[6] Brown, M. E., & Suer, T. -A. 2007, IAU Circ., 8812, 1.
[7] Braga-Ribas, F., Vachier, F., Desmars, J., et al. 2025, Phil. Trans. R. Soc. A, 383, 20240200. doi:10.1098/rsta.2024.0200
[8] Nolthenius, R., Bender, K., Cotton, D. V., et al. 2025, RNAAS, 9, 226. doi:10.3847/2515-5172/adfeda
[9] Margoti et al. 2024 Tese de Mestrado, UTFPR.

Experimental Design

Our objective is to accurately characterize Trans-Neptunian Objects (TNOs). Our interest is to use stellar occultation data and rotational light curves conjunctively for a complete determination of Goibniu's physical properties. Goibniu was selected for its visibility at SOAR and the possibility of supporting major occultation campaigns in 2026, including one at SOAR, where the slow shadow speed will allow us to study the object's vicinity with great precision.

Our observing strategy consists of observing Goibniu for more than 6 consecutive hours per night, totaling 32 hours over four consecutive nights. This strategy guarantees us approximately five complete rotations of the body. There is little data in the literature that definitively confirms Goibniu's rotation period, so we request this number of nights to ensure our observations encompass all possible rotation scenarios for the object. Our minimum acceptable observing time would be 16 hours, which would cover at least two rotations of the object.

Our observable is the target's flux variation due to rotation, as a function of time. To this end, a Signal-to-Noise Ratio (SNR) of at least 100 for the shortest exposure time (which we expect to be between 250 and 350 seconds) will provide us with a light curve uncertainty on the order of 0.01 magnitudes. Given our expected rotational amplitude of 0.16 magnitudes, this precision is sufficient to derive the rotation period, the ratio between the semi-axes (a/b and a/c), and the albedo. As a secondary result, we will constrain the object's bulk density when assuming hydrostatic equilibrium, as well as its expected minimum density.

We will reduce the data using standard flat and bias calibration. We will use differential photometry to construct the light curve and measure the rotation period. With the acquired light curve, we will search for periodic signatures using standard time-series analysis techniques.

Our group possesses extensive experience with differential aperture photometry data, having developed the PRAIA (Package for the Reduction of Astronomical Images Automatically - Photometry[1]) software package. We also have significant expertise in determining the physical parameters of objects using a combination of stellar occultation data and rotational light curves. This topic, in particular, was the subject of the PI's Master's thesis, which involved developing a method for determining the three-dimensional shape of Solar System objects using occultation and rotation data[2]. This tool was applied to TNOs for which rotation and occultation data are available, including Quaoar, Chariklo, 2003 VS2, Huya, and Máni, as well as objects with only occultation data, such as 2002 KX14 and Ixion, in addition to TNO satellites (Quaoar I) Weywot and (Haumea I) Hi'iaka. This work was presented by the PI at the Reunião da Sociedade Astronômica Brasileira 2025 (Caxambu-MG)[3] and is currently being prepared for publication.

To determine the object's shape using stellar occultations, we can utilize the following equations[4]:

$$a' = \frac{2A}{-B - \sqrt{B^2 - 4A}}; \quad b' = \frac{2A}{-B + \sqrt{B^2 - 4A}} \tag{1}$$

where:

$$\begin{aligned} A &= b^2c^2\sin^2\psi\sin^2\phi + a^2c^2\sin^2\psi\cos^2\phi + a^2b^2\cos^2\psi \\ -B &= a^2(\cos^2\psi\sin^2\phi + \cos^2\phi) + b^2(\cos^2\psi\cos^2\phi + \sin^2\phi) + c^2\sin^2\psi \end{aligned} \tag{2}$$

In Equations 1 and 2, a' and b' are the projected semi-axes of the object onto the plane of the sky. The parameters a, b, and c are, respectively, the equatorial and polar semi-axes, with the object rotating about the polar axis (c). The angles ψ and ϕ correspond to the angle between the rotation axis (c) and the observer's line of sight, and the rotational phase angle, respectively.

The rotational light curve amplitude can be derived by knowing the body's semi-axes and the angle ψ:

$$\Delta m = 2.5\log\left(\frac{a}{b}\right) - 1.25\log\left(\frac{a^2\cos^2\psi + c^2\sin^2\psi}{b^2\cos^2\psi + c^2\sin^2\psi}\right) \tag{3}$$

The largest light curve amplitude is observed when the phase angle ϕ is $0°$ or $270°$, which corresponds to the equatorial plane being oriented toward the observer.

[1] Assafin, M. 2023, P&SS, 239, 105816. doi:10.1016/j.pss.2023.105816

[2] Margoti et al. 2024 Tese de Mestrado, UTFPR.

[3] Abstract: https://www.eventweb.com.br/specific-files/manuscripts/sab2025/73_1749073106.pdf

[4] Kretlow, M., Ortiz, J. L., Desmars, J., et al. 2024, A&A, 691, A31. doi:10.1051/0004-6361/202451329

Technical Description

We request a total of 32 hours of observing time, plus 2 hours for overheads (for calibration, filter changes, etc.), using the Goodman RED (Imaging) to measure the rotational light curve of 90568 Goibniu (2004 GV9). Goibniu's rotation period is approximately 5.9 hours. We are requesting sufficient time to observe approximately five complete rotations of the body. The minimum acceptable time is 16 hours, which would secure more than two full rotations of the object.

Figure 1 shows our observation window for Goibniu, extending from February 1st to July 1st. The most favorable period for observation is mid-May, during which the object will be visible for the entire night. This period is particularly desirable as it coincides with the New Moon phase. Our preferred dates are therefore from 2026-May-10 to 2026-May-18, with the optimal night being around 2026-May-17. Within this window, we ask to avoid 2026-May-14, as the object passes critically close to a background star on that date.

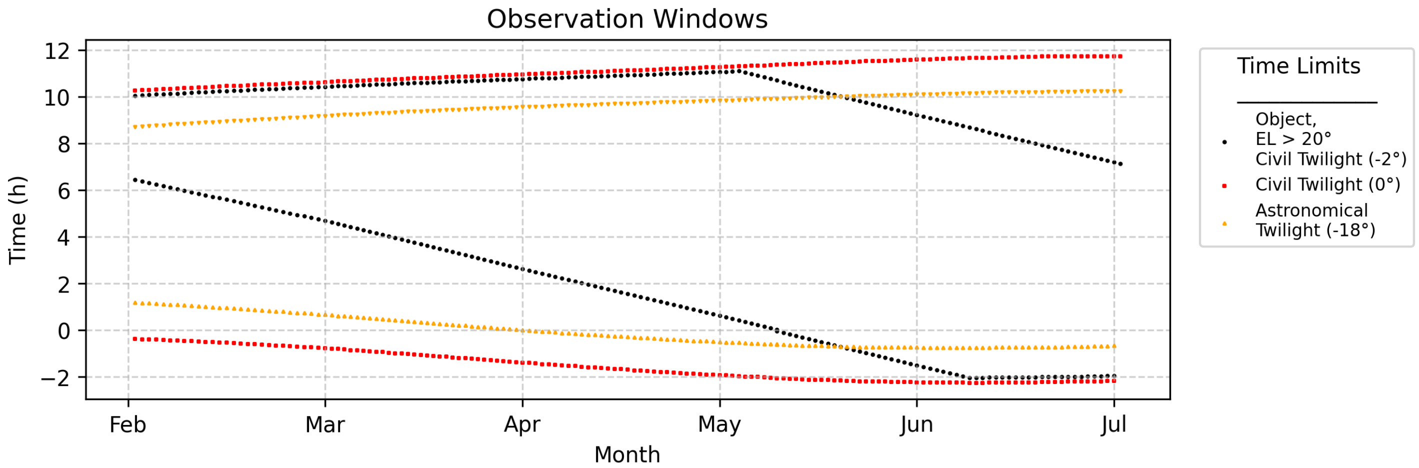

Figure 1: SOAR observation window from February 1st to July 1st. For the respective dates, red points indicate the Sun at $0°$, orange points indicate the Sun at $-18°$, and black points indicate when Goibniu is above $20°$ altitude while the Sun is below $-2°$.

We are working on a campaign to observe a stellar occultation by this object that will occur on March 5th. Therefore, if our preferred dates cannot be allocated, we request observing time closer to this occultation date. In this regard, we would like the observations to commence no earlier than 2026-Mar-23, as the object will be visible for more than 6 hours per night from that date onward.

We must exclude the following nights that star in the next dates due to the target passing critically close to a background star: 2026-Mar-31, 2026-Apr-10, 2026-Apr-12, 2026-Apr-18, 2026-Apr-20, 2026-Apr-22, 2026-Apr-25, 2026-Apr-26, 2026-May-07, 2026-May-12, 2026-May-13, 2026-May-17, 2026-May-23, 2026-Jun-03, 2026-Jun-07, 2026-Jun-11, 2026-Jun-13, 2026-Jun-14, 2026-Jun-22, and 2026-Jun-23. We also request that observations not be scheduled during nights of Full Moon, specifically with lunar illumination exceeding 75%, as this would severely compromise the project's viability.

The V magnitude of Goibniu on 2026-May-17 will be approximately 20.0 mag, and the expected brightness variation is 0.16 magnitudes. To achieve an uncertainty on the order of 0.01 magnitudes, we need to obtain a Signal-to-Noise Ratio (SNR) on the order of 100. We therefore intend to use an exposure time of 300 seconds. We choose the r' filter as it offers a good balance between photometric flux and image quality, but we may also take images with g', r', and i' filters to obtain a color index as a byproduct.

Previous missions of this proposal to this telescope

This proposal has not been submitted before.

Previous missions of other proposals to this telescope

- ”Studying small Solar System bodies through stellar occultations” (2026A): The proposal will be submitted and involves Goibniu.
- Fotometria rotacional multibanda de pequenos corpos do Sistema Solar. (2025B - P005). Observation will occur from October 23rd to 27th.
- ”Chiron’s rotation light curve for 3D shape characterization” (SO2023B-017): four half-nights of data obtained. The results is in analisys. PI: Chrystian Luciano Pereira
- ”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). PI: Flavia Luane Rommel

Previous results in the field by the Principal Investigator

Stellar occultation data that was obtained at SOAR was reduced and analyzed by the author of this proposal, which served as the basis for an undergraduate research project (scientific initiation) and a Master’s thesis:

- MARGOTI, GIULIANO; RIBAS, Felipe Braga; ROMMEL, Flavia Luane. Análise de Ocultações estelares por (50000) Quaoar e Determinação de Seu Tamanho. In: XXVI Seminário de Iniciação Científica e Tecnológica da UTFPR. 2021.
- MARGOTI, Giuliano et al. Determinação da forma tridimensional de (50000) Quaoar por ocultações estelares utilizando algoritmo genético para minimização. 2024. Dissertação de Mestrado. Universidade Tecnológica Federal do Paraná.

Furthermore, the author of the proposal reduced and analyzed fundamental data for the publication of the following papers:

- BRAGA-RIBAS, F. et al. Database on detected stellar occultations by small outer Solar System objects. In: Journal of Physics: Conference Series. IOP Publishing, 2019. p. 012024.
- SOUAMI, D. et al. A multi-chord stellar occultation by the large trans-Neptunian object (174567) Varda. Astronomy & Astrophysics, v. 643, p. A125, 2020.
- OLIVEIRA, J. Marques et al. Constraints on the structure and seasonal variations of Triton’s atmosphere from the 5 October 2017 stellar occultation and previous observations. Astronomy & Astrophysics, v. 659, p. A136, 2022.
- MORGADO, Bruno E. et al. A dense ring of the trans-Neptunian object Quaoar outside its Roche limit. Nature, v. 614, n. 7947, p. 239-243, 2023.
- PEREIRA, C. L. et al. The two rings of (50000) Quaoar. Astronomy & Astrophysics, v. 673, p. L4, 2023.
- BRAGA-RIBAS, Felipe et al. Constraints on (2060) Chiron’s size, shape, and surrounding material from the November 2018 and September 2019 stellar occultations. Astronomy & Astrophysics, v. 676, p. A72, 2023.
- ROMMEL, F. L. et al. A large topographic feature on the surface of the trans-Neptunian object (307261) 2002 MS4 measured from stellar occultations., v. 678, p. A167, out, 2023.
- ASSAFIN, M. et al. Kilometer-precise (UII) Umbriel physical properties from the multichord stellar occultation on 2020 September 21. Monthly Notices of the Royal Astronomical Society, v. 526, n. 4, p. 6193-6204, 2023.
- DUTRA, H. et al. Physical characteristics of Jupiter’s Trojan (1437) Diomedes from a tri-chord stellar occultation in 2020 and dimensionless three-dimensional model. Philosophical Transactions A, v. 383, n. 2291, p. 20240187, 2025.

- BRAGA-RIBAS, Felipe et al. Investigating the formation of small Solar System objects using stellar occultations by satellites: present, future and its use to update satellite orbits. Philosophical Transactions A, v. 383, n. 2291, p. 20240200, 2025.
- CHANDLER, Colin Orion et al. NSF-DOE Vera C. Rubin Observatory Observations of Interstellar Comet 3I/ATLAS (C/2025 N1). arXiv preprint arXiv:2507.13409, 2025.

PI and Co-Is publications relevant to this proposal

The collaborative work of our research group has directly utilized data from the SOAR telescope in previous successful campaigns. The following are examples of publications or software development that demonstrate our team's expertise in both the data acquisition and the analysis required for this proposal:

- ASSAFIN, M. Differential aperture photometry and digital coronagraphy with PRAIA. Planetary and Space Science, v. 239, p. 105816, 2023.
- GOMES-JÚNIOR, A. R. et al. SORA: Stellar occultation reduction and analysis. Monthly Notices of the Royal Astronomical Society, v. 511, n. 1, p. 1167-1181, 2022.
- VARA-LUBIANO, M. et al. The multichord stellar occultation on 2019 October 22 by the trans-Neptunian object (84922) 2003 VS2. Astronomy & Astrophysics, v. 663, p. A121, 2022.
- PEREIRA, C. L. et al. Centaur 29P/Schwassmann–Wachmann 1 and its near-nucleus environment from a stellar occultation. Philosophical Transactions A, v. 383, n. 2291, p. 20240189, 2025.
- PEREIRA, C. L. et al. Physical properties of Centaur (60558) 174P/Echeclus from stellar occultations. Monthly Notices of the Royal Astronomical Society, v. 527, n. 2, p. 3624-3638, 2024.
- SICARDY, Bruno et al. Stellar occultations by trans-Neptunian objects. The Astronomy and Astrophysics Review, v. 32, n. 1, p. 6, 2024.
- MORGADO, B. E. et al. Refined physical parameters for Chariklo's body and rings from stellar occultations observed between 2013 and 2020. Astronomy & Astrophysics, v. 652, p. A141, 2021.
- ROMMEL, F. L. et al. Stellar occultations enable milliarcsecond astrometry for Trans-Neptunian objects and Centaurs. Astronomy & Astrophysics, v. 644, p. A40, 2020.

Objects List.

Object	A.R.(h,m)	Dec.(deg)	Mag.	Band	Type	Comments
90568 Goibniu (2004 GV9)	15:52:45.49	-24:36:32.07	20.1	V	Sci	2026-Mar-23 04:00 UTC
90568 Goibniu (2004 GV9)	15:48:53.61	-24:23:15.21	19.9	V	Sci	2026-May-17 00:00 UTC