# RESULTS OF RECENT STELLAR OCCULTATIONS BY (60558) ECHECLUS

**XI Taller de Ciencias Planetarias**
XI Reunião de Trabalho sobre Ciências Planetárias
2022 February 16 (Virtual Edition)

**C. L. Pereira[1,2]**, F. Braga-Ribas[1,2,3,4], M. Emilio[1,3,5], B. Sicardy[4], B. E. Morgado[1,2,4], M. Assafin[7,2], Echeclus Occ. Team

[1] Observatório Nacional/MCTI, Brazil
[2] Laboratório Interinstitucional de e-Astronomia, LIneA, Brazil
[3] Federal University of Technology - Paraná (UTFPR-CT), Brazil
[4] LESIA, Observatoire de Paris, France
[5] Universidade Estadual de Ponta Grossa (UEPG), Brazil
[6] São Paulo State University - UNESP (GDOP), Brazil
[7] Universidade Federal do Rio de Janeiro, Obs. Valongo, Brazil

# Abstract


- Centaur objects seem to be in a transitory region between the Kuiper Belt Objects and short-period comets, distributed in unstable orbits from 5.2 to 30 astronomical units [1]. Several Centaur objects showed cometary activity along their orbits, such as (2060) Chiron, (60588) Echeclus, and 29P/Schwassmann–Wachmann. After the discovery of two narrow and dense rings around centaur object Chariklo [2] and the Dwarf Planet Haumea [3], we noticed that other objects present similar properties, be they rings, shells, or jets;

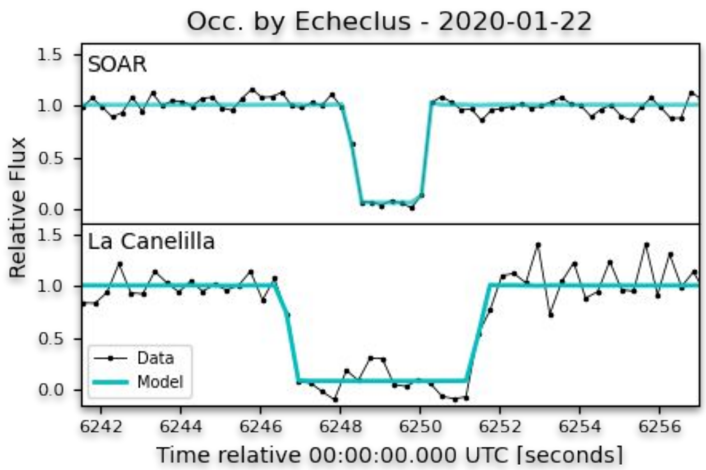
- Considering the outbursts observed in the Echeclus nucleus in 2005 and 2011, we predicted and observed stellar occultations by this body in 2019, 2020, and 2021 to i) determine the size and shape of the main body and ii) search for signatures of confined or diffuse ejected material around this body;

- In this work, we present the results of a double-chord detection in January 2020 and a single-chord detection in 2021 January. In addition, the 2019 October appulse was used to determine the detection limit of material around the main body.

# Methods

- The photometric analysis of all data sets was made using the differential aperture photometry with the Package for the Reduction of Astronomical Images Automatically (PRAIA) [4];

- The instants of ingress and egress for the positive detections and the limb fit for the 2020 and 2021 events were made using pipelines built using the SORA library [5];



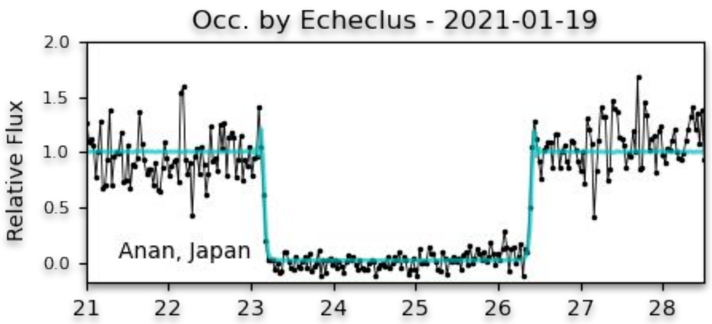




**Figure 1:** Modeled light curves obtained from 2020 (top) and 2021 (left).

# Methods

- The negative chords 2019 appulse and 2020 and 2021 stellar occultations were used to look at the regions near the Echeclus nucleus, aiming to detect secondary drops in flux and confined or diffuse material characteristics.

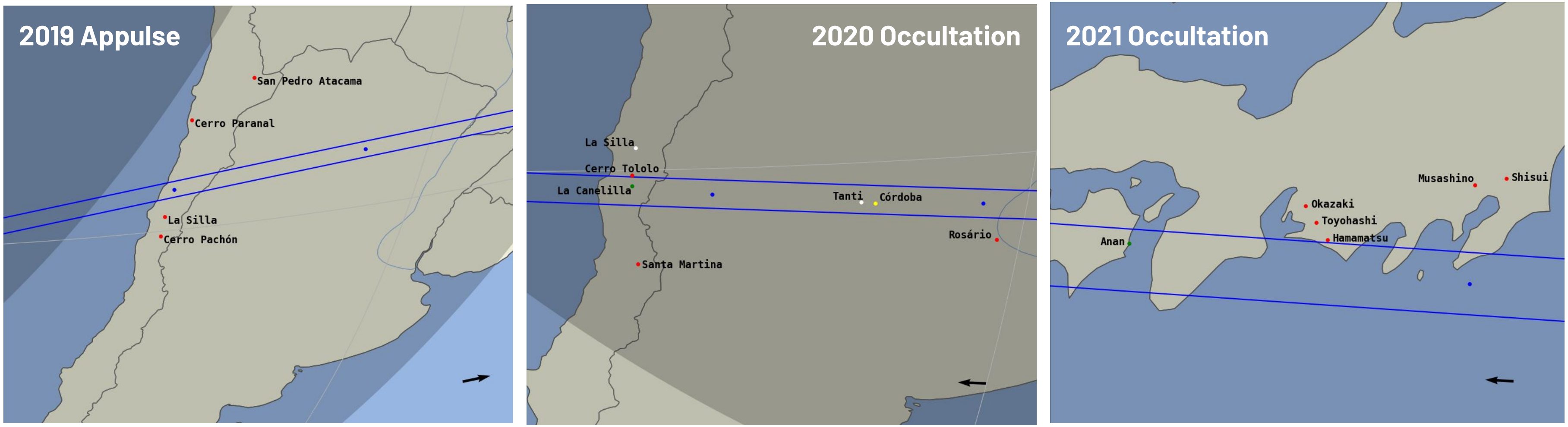



**Figure 2:** Pos-occultation map of all three events in this work shows the shadow's path over South America and Japan (2021)

# Methods

- By applying a Savitzky-Golay filter to smooth the signal and improve the sensibility, we can determine the detection limits for apparent opacity of a broad and diffuse material by calculating the dispersion of the smoothed curve;
- The detection limits for RAW data, i. e., for the data with full spatial resolution, provide us with the limitations of apparent opacity for a confined material (rings, jets) ;
- This procedure was made on the best LC of each event.

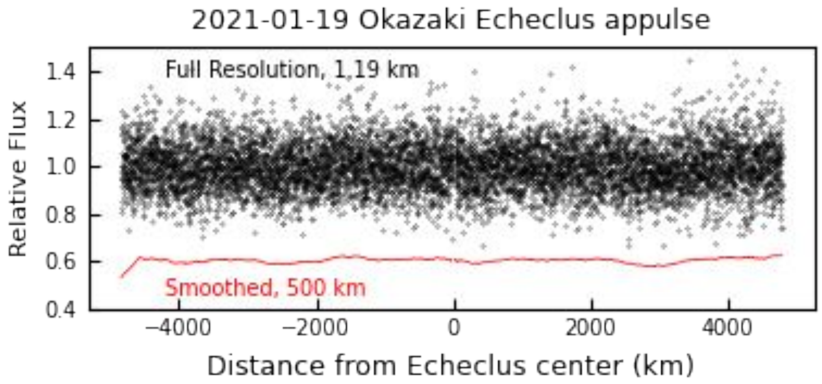
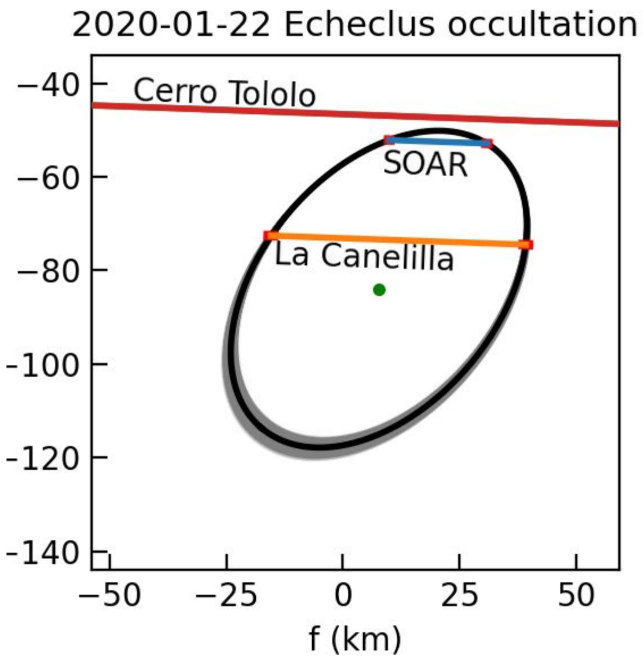



**Figure 3:** Light curve obtained in Okazaki, Japan, on 2021. The red line is a 500km-smoothed LC to search for diffuse material and the black dots represents the full resolution data points to search for confined material.

# Methods

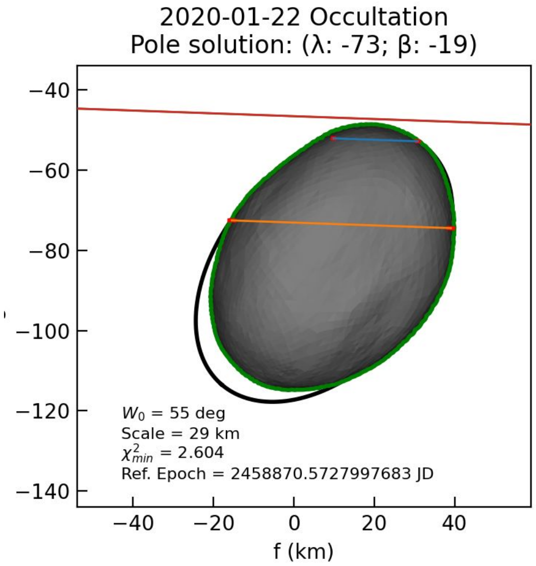
- The 2020 stellar occultation provides us with two positive detections. By projecting the chords in the sky plane, we can determine a snapshot of Echeclus at the event epoch projecting an ellipse in the chord's extremities;
- We compared the ellipse fitted in the sky plane with the 3D model presented by Rousselot et al. (2021). We set the prime meridian position as a free parameter for all the six possible pole solutions;
- By minimizing the chi-square statistics, we found the best results on the 2020 event and propagated the result for the 2021 event;



# Results

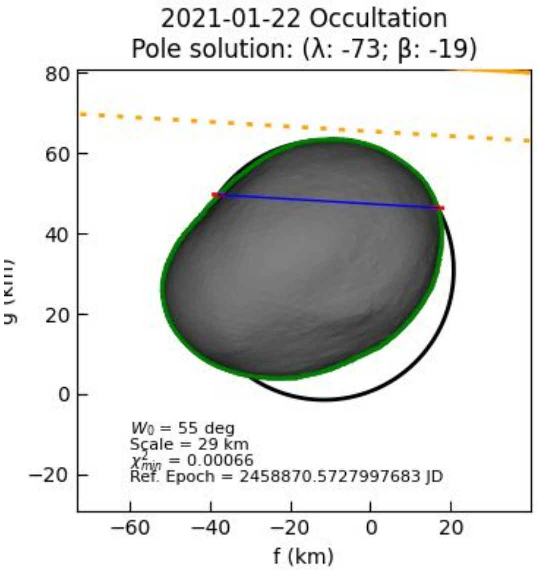
Sub-observer longitude, latitude, and pole position angle at 2020-01-22 01:44 UTC:

$\lambda = 258^{\circ}.57$ $\phi = +49^{\circ}.55$ PA = $226^{\circ}.43$




Sub-observer, longitude, latitude, and pole position angle at 2021-01-19 09:10 UTC:

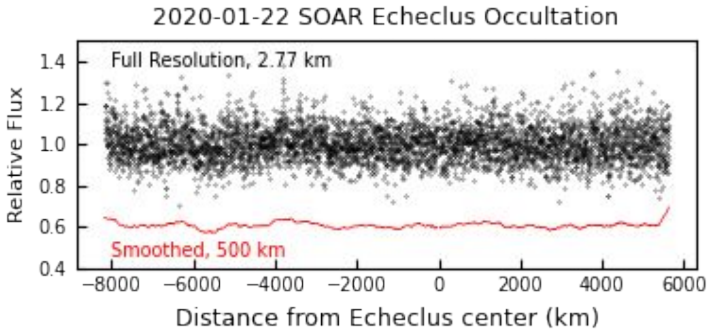
$\lambda = 104^{\circ}.38$ $\phi = +58^{\circ}.53$ PA = $218^{\circ}.83$

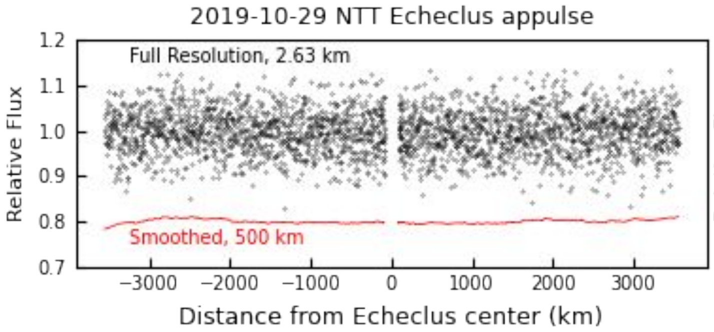


# Results

The best light curves in terms of spatial resolution and dispersion for the three events were used:

- 2019, NTT/La Silla, Chile - covering ~7000 km in the sky plane;
- 2020, SOAR, Chile - covering 14000 km in the sky plane ;
- 2021, Okazaki, Japan - covering 9000 km in the sky plane.



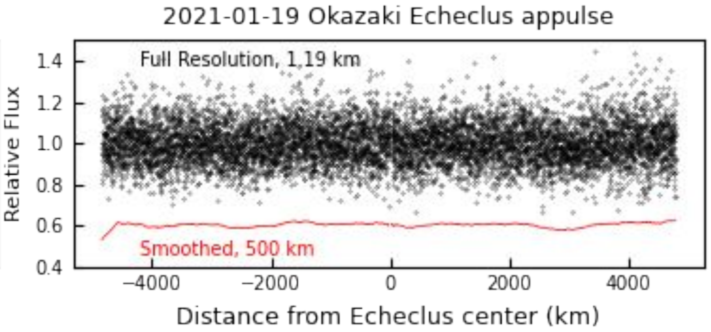




**Figure 3:** Light curves for radial distance from Echeclus with RAW data (black) plotted over the 500-km smoothed data (red). Note that the negative chords of 2019 and 2021 got as close to 90km and 25km from the object's center, respectively..

# Conclusion

- By testing the shape models on the 2021 occultation, we can see that only two pole solutions provided by Rousselot et al. (2021) are compatible with the 2020 occultation analysis. The pole $\alpha_p$ = 90°.0; $\delta_p$= 51°.44 was chosen as preferential due to low radial dispersion;

- We found the dimensions of (60588) Echeclus as:

  a x b x c = 36.5 x 28 x 24.6 km

  This corresponds to an equivalent radius $R_{equiv}$= 29.3 km, coherent with 59± 4 km obtained by Bauer et al. 2013

- In search of secondary events, we found minimum apparent opacity detectable in 3σ level:
  - for RAW data: 0.135 (NTT/2019), 0.189 (SOAR/2020), 0.258 (Okazaki/2021);
  - for 500-km smoothed data: 0.015 (NTT), 0.042 (SOAR), 0.034 (Okazaki);

- Limits for the apparent equivalent width [7] were calculate to:
    - 166 meters for the NTT (2019); 331 meters for SOAR (2020); 162 meters for Okazaki (2021).

  - These limits imply that the material confined in rings around Chariklo ($E_p$~1,8 km for C1R and $E_p$~0,2 km for C2R) would be detected above to the 3$\sigma$ level in the bests light curves of Echeclus events.

# References

[1] D. Jewitt: 2009, The Astronomical Journal, 137, 4296.
[2] Braga-Ribas, F., Sicardy, B., Ortiz, J. L., et al.: 2014, Nature, 508, 72
[3] Ortiz, J. L., Santos-Sanz, P., Sicardy, B., et al.: 2017, Nature, 550, 219
[4] Assafin, M. et al.: 2011, Gaia FUN-SSO workshop proceedings. 85
[5] Gomes-Júnior et al.: 2022, MNRAS.
[6] Rousselot, P., Kryszczyńska, A., Bartzack, P., et al.: 2021, MNRAS, 507
[7] Bérard, D., Sicardy, B., Camargo, J. I. B., et al. 2017, AJ, 154

**Acknowledgements**: This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES)

Thank you!
¡Gracias!