

Stellar occultations by TNOs from JWST?

P. Santos-Sanz and the JWST occultation collaboration
psantos@iaa.es



James Webb Space Telescope Observations of Stellar Occultations by Solar System Bodies and Rings

P. Santos-Sanz¹, R. G. French², N. Pinilla-Alonso³, J. Stansberry⁴, Z-Y. Lin⁵, Z-W. Zhang⁶, E. Vilenius^{7,8}, Th. Müller⁷, J. L. Ortiz¹, F. Braga-Ribas⁹, A. Bosh¹⁰, R. Duffard¹, E. Lellouch¹¹, G. Tancredi¹², L. Young¹³, Stefanie N. Milam¹⁴, and

the *JWST* “Occultations” Focus Group

¹ Instituto de Astrofísica de Andalucía, IAA-CSIC, Glorieta de la Astronomía s/n, E-18008 Granada, Spain; psantos@iaa.es, ortiz@iaa.es, duffard@iaa.es

² Department of Astronomy, Wellesley College, Wellesley, MA 02481, USA; rfrench@wellesley.edu

³ Department of Earth and Planetary Sciences, University of Tennessee, Knoxville, TN 37996, USA; npinilla@utk.edu

⁴ Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218, USA; jstans@stsci.edu

⁵ Institute of Astronomy, National Central University, Jhongli District, Taoyuan City 32001, Taiwan; zylin@gm.astro.ncu.edu.tw

⁶ Institute of Astronomy and Astrophysics, Academia Sinica, P.O. Box 23-141, Taipei 10617, Taiwan; zwzhang@asiaa.sinica.edu.tw

⁷ Max Planck Institute for extraterrestrial Physics, Garching, Germany; vilenius@mpe.mpg.de, tmueller@mpe.mpg.de

⁸ Max Planck Institute for Solar System Research, Göttingen, Germany

⁹ Federal University of Technology—Paraná (UTFPR/DAFIS), Curitiba, Brazil; ribas@on.br

¹⁰ Department of Earth, Atmospheric, and Planetary Sciences, MIT, Cambridge, MA, USA; asbosh@mit.edu

¹¹ LESIA-Observatoire de Paris, CNRS, UPMC Univ. Paris 6, Univ. Paris-Diderot, Meudon, France; emmanuel.lellouch@obspm.fr

¹² Departamento de Astronomía, Facultad de Ciencias, Montevideo, Uruguay; gonzalo@fisica.edu.uy

¹³ SwRI, 1050 Walnut Street, Boulder, CO 80302-5150, USA; layoung@boulder.swri.edu

¹⁴ NASA Goddard Space Flight Center, Greenbelt, MD, USA; stefanie.n.milam@nasa.gov

Received 2015 July 16; accepted 2015 October 2; published 2016 January 4

Abstract

In this paper, we investigate the opportunities provided by the *James Webb Space Telescope (JWST)* for significant scientific advances in the study of Solar System bodies and rings using stellar occultations. The strengths and weaknesses of the stellar occultation technique are evaluated in light of *JWST*'s unique capabilities. We identify several possible *JWST* occultation events by minor bodies and rings and evaluate their potential scientific value. These predictions depend critically on accurate a priori knowledge of the orbit of *JWST* near the Sun–Earth Lagrange point 2 (L2). We also explore the possibility of serendipitous stellar occultations by very small minor bodies as a byproduct of other *JWST* observing programs. Finally, to optimize the potential scientific return of stellar occultation observations, we identify several characteristics of *JWST*'s orbit and instrumentation that should be taken into account during *JWST*'s development.

Key words: Kuiper belt: general – methods: observational – occultations – planets and satellites: rings –

Predicted Occultation Appulses for 13 Outer Solar System Minor Bodies










































Body	$K < 9$	$9 < K < 10$	$10 < K < 11$	$11 < K < 12$	$12 < K < 13$	$13 < K < 14$	$14 < K < 16$
136199 Eris
136472 Makemake	1	1	...	3
50000 Quaoar	...	1	2	3	11	7	...
90377 Sedna	1	...	2
84922 (2003 VS ₂)	...	1	1	...	3	7	24
136108 Haumea	1	3
225088 (2007 OR ₁₀)
120347 Salacia	4
90482 Orcus	1	...
28978 Ixion	4	4	8	16	21	5	1
10199 Chariklo	...	1	...	3	1	4	2
60558 Echeclus	1	4	5	13	41
2060 Chiron	1

Note. Predicted occultation appulses for 13 outer Solar System minor bodies (TNOs and Centaurs), based on the UCAC4 and (incomplete) URAT1 catalogs and the nominal *JWST* ephemeris, for the period of 2018 December 1 to 2023 January 31. All events within the *JWST* field of regard and with a miss distance of 100 mas or less are included. The number of events for each object is listed by K magnitude range of the occultation candidate stars. Ixion is passing across a dense star field in the Milky Way, accounting for the large number of possible events for this tiny object. It is important to note that these appulse predictions are just notional because we cannot yet predict where *JWST* will be in its orbit accurately.

(Santos-Sanz et al. 2016)

LETTER TO THE EDITOR

A stellar occultation by the transneptunian object (50000) Quaoar observed by CHEOPS^{★,★★}

B. E. Morgado^{1,2,3} , G. Bruno⁴ , A. R. Gomes-Júnior^{5,6,3} , I. Pagano⁴ , B. Sicardy⁷, A. Fortier^{8,9} , J. Desmars^{10,11} , P. F. L. Maxted¹², F. Braga-Ribas^{13,2,3} , D. Queloz^{14,15}, S. G. Sousa¹⁶ , J. L. Ortiz¹⁷, A. Brandeker¹⁸ , A. Collier Cameron¹⁹ , C. L. Pereira^{2,3} , H. G. Florén¹⁸ , N. Hara²⁰ , D. Souami^{21,7,22} , K. G. Isaak²³, G. Olofsson¹⁸, P. Santos-Sanz¹⁷, T. G. Wilson¹⁹ , J. Broughton^{24,25}, Y. Alibert⁸ , R. Alonso^{26,27} , G. Anglada^{28,29}, T. Bárczy³⁰, D. Barrado³¹ , S. C. C. Barros^{16,32} , W. Baumjohann³³ , M. Beck²⁰, T. Beck⁸, W. Benz^{8,9}, N. Billot²⁰, X. Bonfils³⁴, C. Broeg^{8,9}, J. Cabrera³⁵ , S. Charnoz³⁶, S. Csizmadia³⁵, M. B. Davies³⁷, M. Deleuil³⁸ , L. Delrez^{39,40}, O. D. S. Demangeon^{16,32} , B. O. Demory⁹ , D. Ehrenreich²⁰ , A. Erikson³⁵, L. Fossati³³, M. Fridlund^{41,42}, D. Gandolfi⁴³, M. Gillon³⁹, M. Güdel⁴⁴, K. Heng^{9,45}, S. Hoyer³⁸ , L. L. Kiss^{46,47} , J. Laskar⁴⁸, A. Lecavelier des Etangs⁴⁹ , M. Lendl²⁰ , C. Lovis²⁰, D. Magrin⁵⁰ , L. Marafatto⁵⁰, V. Nascimbeni⁵⁰, R. Ottensamer⁵¹ , E. Pallé²⁶ , G. Peter⁵², D. Piazza⁸, G. Piotto^{50,53} , D. Pollacco⁴⁵, R. Ragazzoni^{50,53}, N. Rando⁵⁴, F. Ratti⁵⁴, H. Rauer^{35,55,56}, C. Reimers⁵¹, I. Ribas^{28,29} , N. C. Santos^{16,32} , G. Scandariato⁴, D. Ségransan²⁰, A. E. Simon⁸ , A. M. S. Smith³⁵ , M. Steller³³, G. M. Szabó^{57,58} , N. Thomas⁸, S. Udry²⁰ , V. Van Grootel⁴⁰ , N. A. Walton⁵⁹ , and K. Westerdorff⁵²

(Affiliations can be found after the references)

Received 8 June 2022 / Accepted 9 August 2022

ABSTRACT

Context. Stellar occultation is a powerful technique that allows the determination of some physical parameters of the occulting object. The result depends on the photometric accuracy, the temporal resolution, and the number of chords obtained. Space telescopes can achieve high photometric accuracy as they are not affected by atmospheric scintillation.

Aims. Using ESA's CHEOPS space telescope, we observed a stellar occultation by the transneptunian object (50000) Quaoar. We compare the

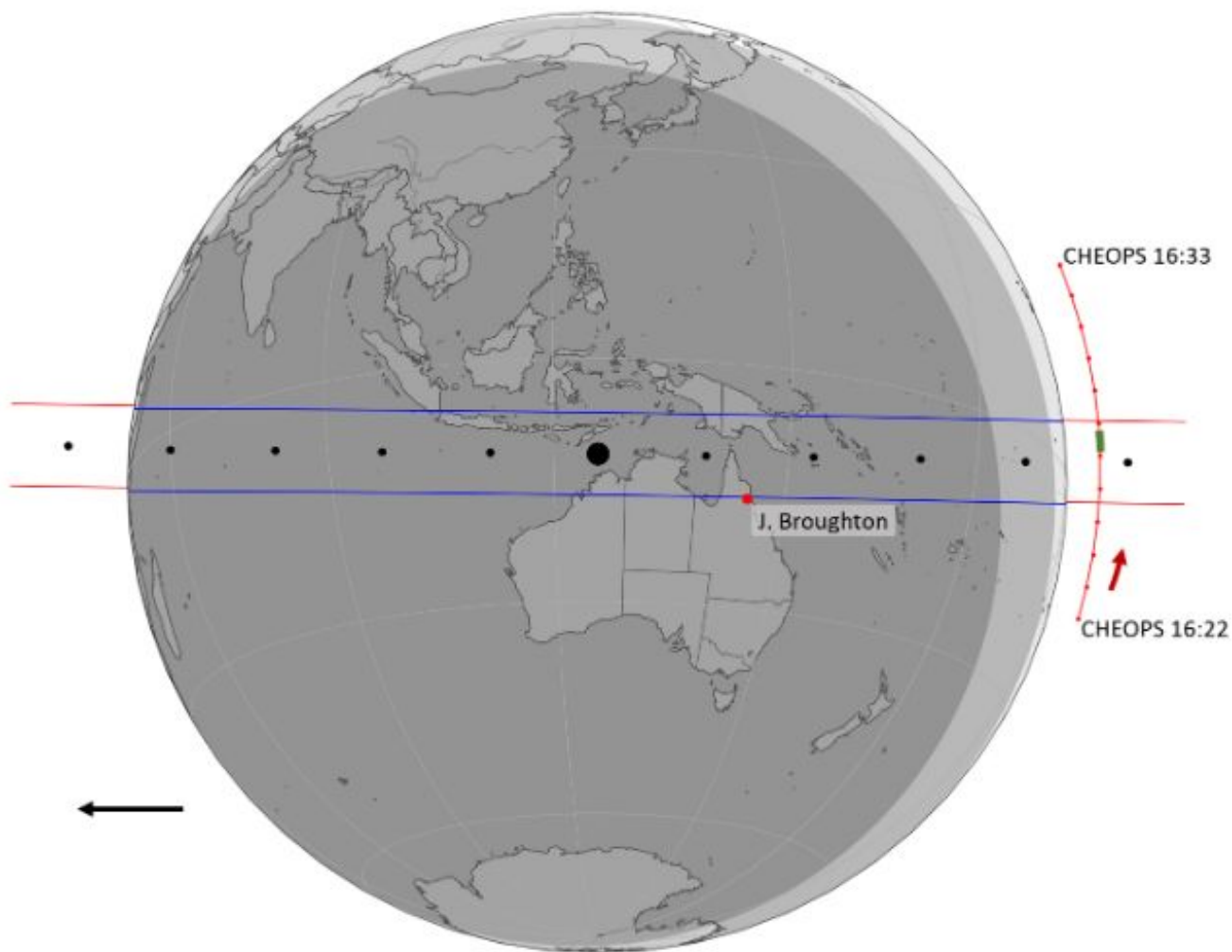


Fig. 1. Prediction map of the Quaoar event on 2020 June 11, the black arrow on the lower left corner shows the direction of the shadow's movement. The blue lines stand for the shadow limits, and the black dots are the centre of the shadow, separated by one minute, with the biggest one representing the geocentric closest approach time. The red dot on the map represents the position of the ground-based observer who participated in this campaign. The red line on the right side of the map shows the projected position of CHEOPS from 16:22 to 16:33 UTC, two consecutive red dots are separated by one minute in time, and the red arrow emphasises the direction of motion. The green line shows when and where CHEOPS obtained the positive chord.

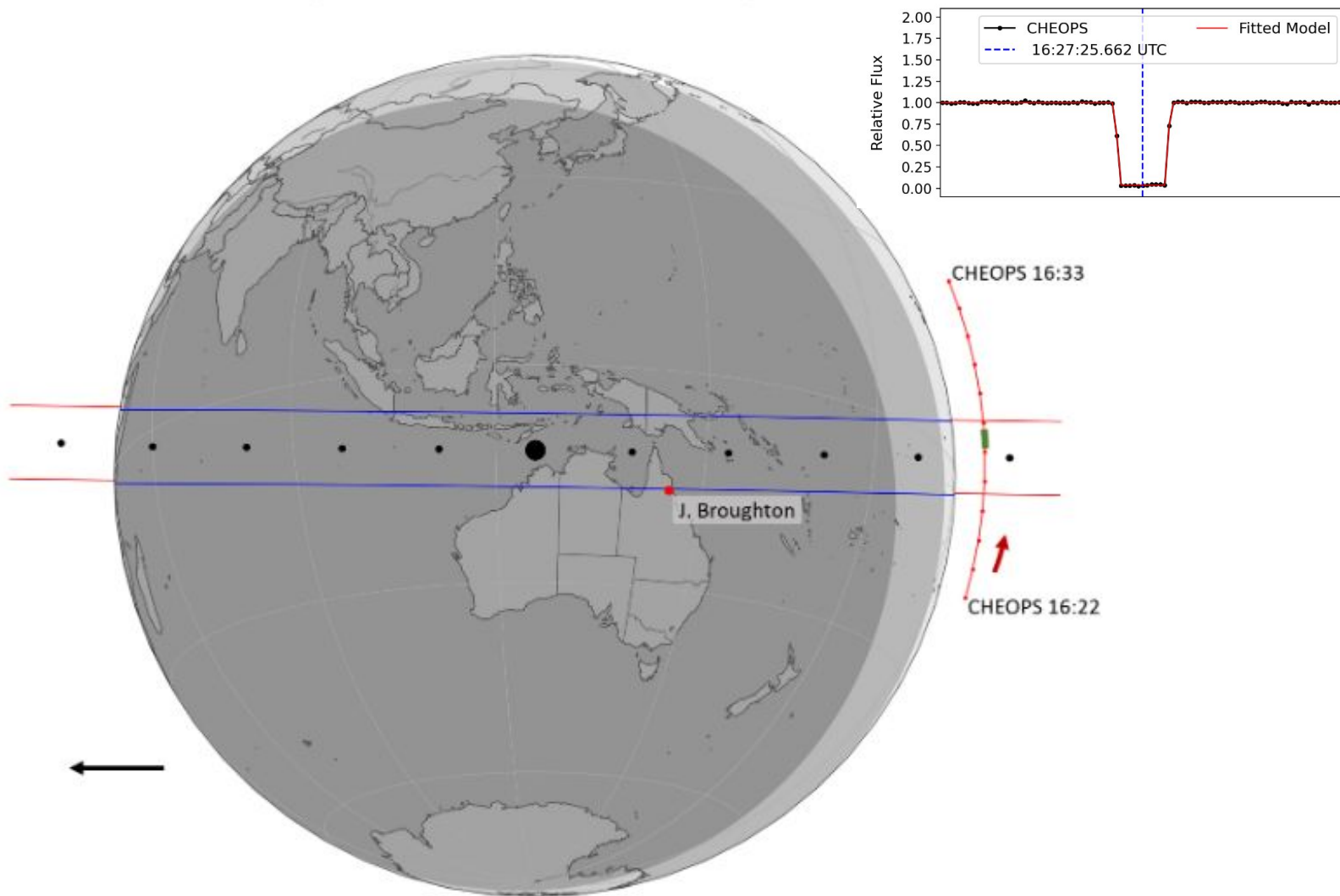
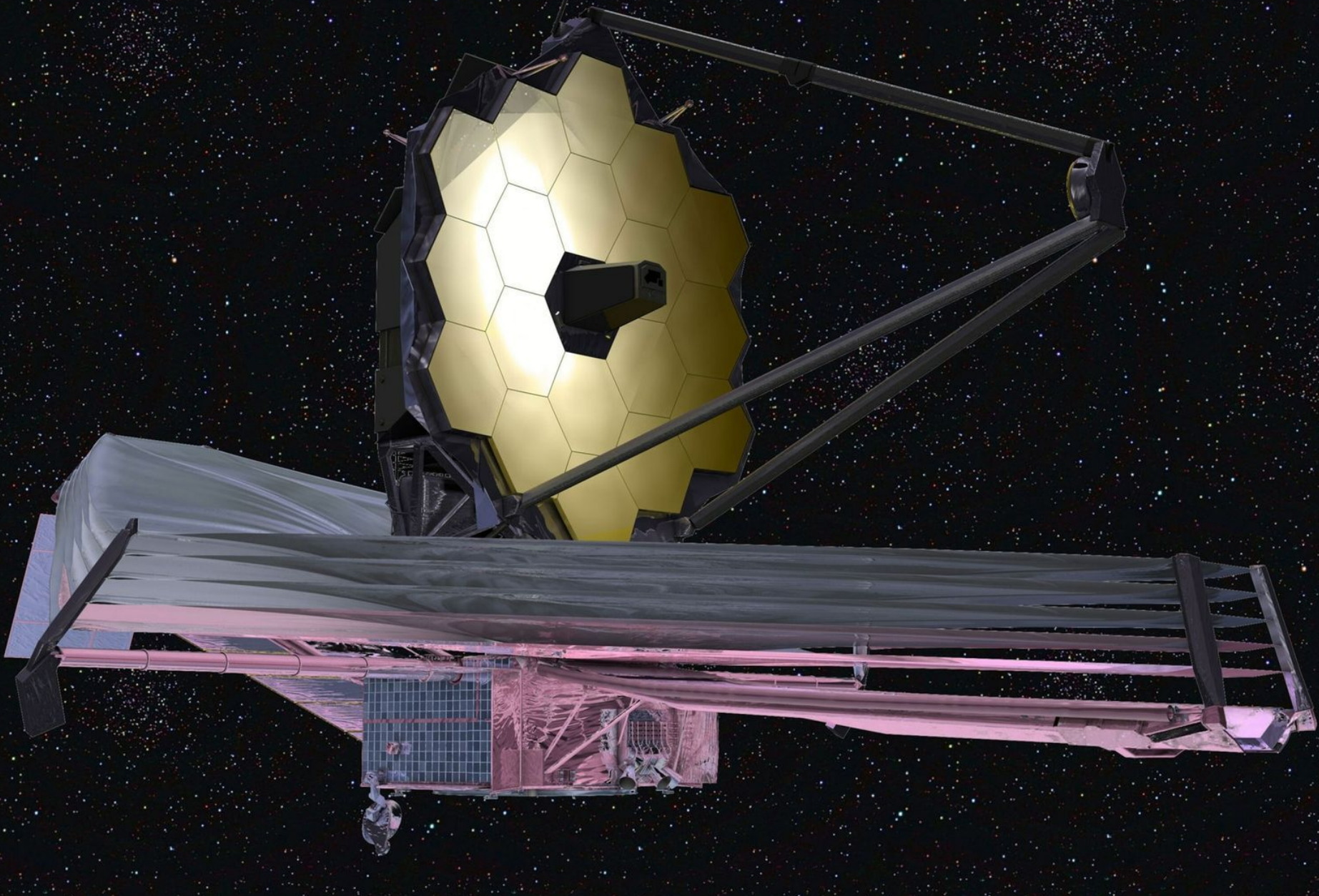


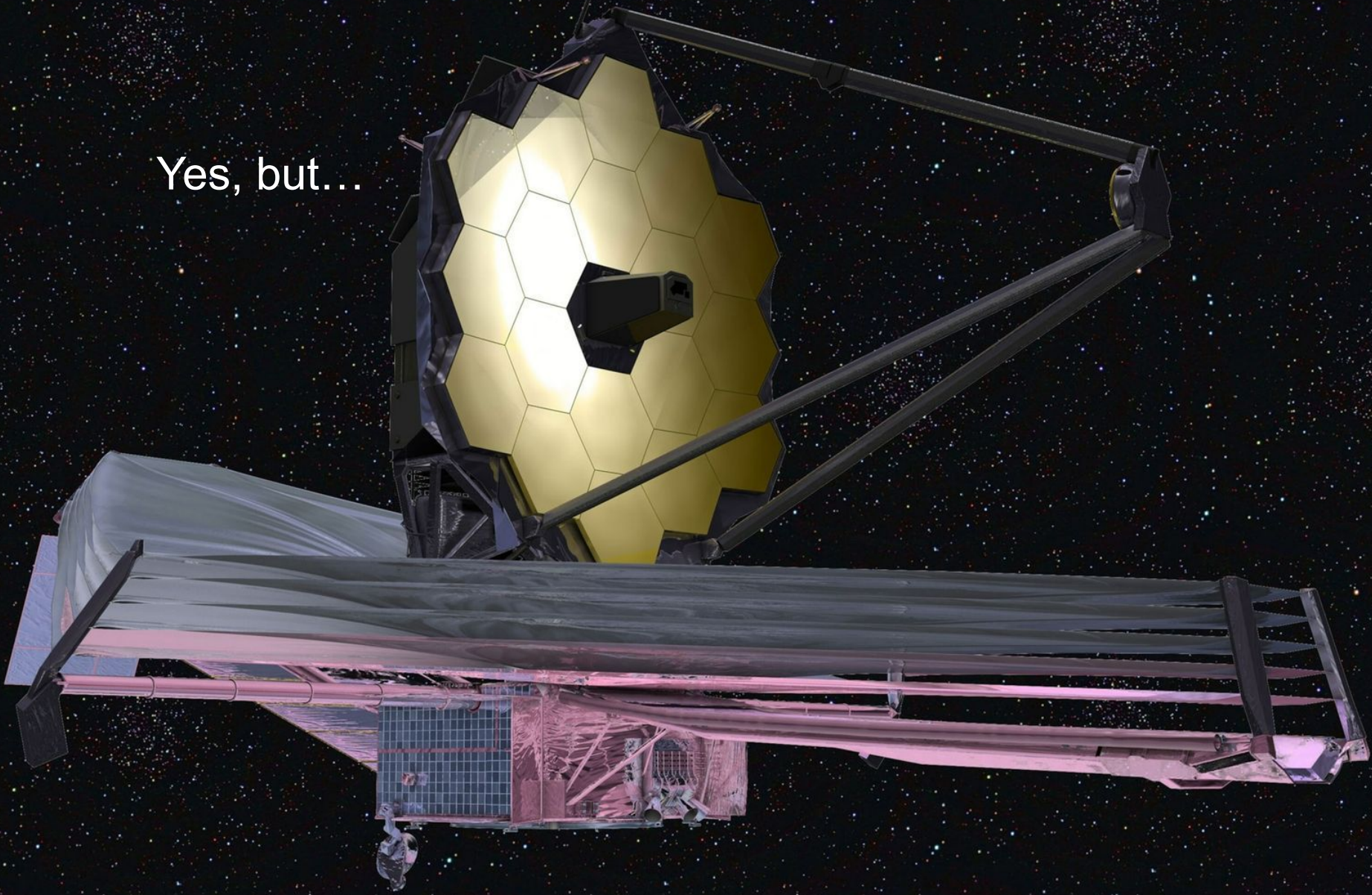
Fig. 1. Prediction map of the Quaoar event on 2020 June 11, the black arrow on the lower left corner shows the direction of the shadow's movement. The blue lines stand for the shadow limits, and the black dots are the centre of the shadow, separated by one minute, with the biggest one representing the geocentric closest approach time. The red dot on the map represents the position of the ground-based observer who participated in this campaign. The red line on the right side of the map shows the projected position of CHEOPS from 16:22 to 16:33 UTC, two consecutive red dots are separated by one minute in time, and the red arrow emphasises the direction of motion. The green line shows when and where CHEOPS obtained the positive chord.

Stellar occultations by TNOs from JWST?



Stellar occultations by TNOs from JWST?

Yes, but...



Stellar occultations by TNOs from JWST?

Yes, but...

...predictions of such events visible from JWST are **challenging** due to the chaotic motion of the space telescope around the Lagrange 2 (L2) point.

Stellar occultations by TNOs from JWST?

JWST Proposal 1271 (Created: Tuesday, June 23, 2020 at 11:00:55 PM Eastern Standard Time) - Overview



1271 - ToO TNOs: 'Unveiling the Kuiper belt by stellar occultations'

Cycle: 1, Proposal Category: GTO

INVESTIGATORS

<i>Name</i>	<i>Institution</i>	<i>E-Mail</i>
Dr. Pablo Santos-Sanz (PI) (ESA Member)	Instituto de Astrofisica de Andalucia (IAA)	psantos@iaa.es

OBSERVATIONS

<i>Folder</i>	<i>Observation</i>	<i>Label</i>	<i>Observing Template</i>	<i>Science Target</i>
OCCULTATION				
	7	NIRCAM	NIRCam Time Series	(3) STAR

ABSTRACT

Observation IDs: HAMMEL_1000

The stellar occultation technique is a powerful tool to determine sizes and shapes of Solar System bodies with accuracies 0.1%. The size determination allows estimating geometric albedos and, for binary/multiple objects, even the bulk density can be obtained. Satellites, atmospheres and rings can also be detected/characterized. Observing stellar occultations by Kuiper Belt Objects (KBOs) and Centaurs with JWST is a unique possibility to expand our knowledge of these bodies by providing key information on e.g. the capacity of the body to retain volatiles, the thermal properties of the surface, roughness and porosity.

This ToO is dedicated to observe stellar occultations by trans-Neptunian Objects (TNOs) or specially interesting Centaurs (e.g. like the ringed centaurs objects Chariklo or Chiron). Predictions of such events can only be made after JWST launch and initial mid-course correction maneuvers

Some technical aspects

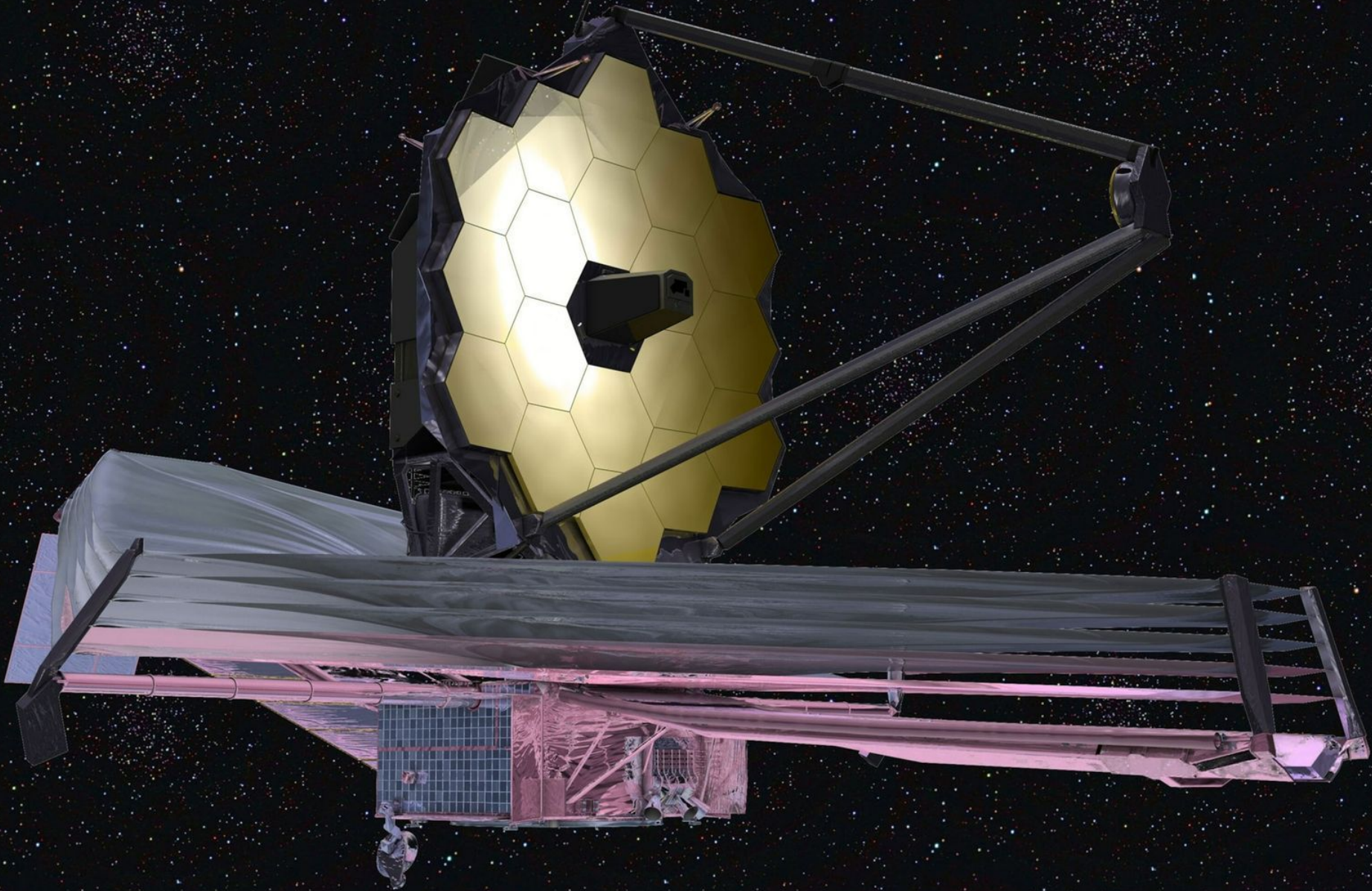
- The observations will be made with NIRCcam and the F070W and F277W filters.
- These filters maximize the flux from the star while minimizing the reflected flux from the TNO or Centaur.
- The smallest subarray (SUB64P) will be used with the RAPID readout mode to increase the frequency of the observations (~ 6.7 Hz).
- Total time: 2.2 h (we expect to activate the ToO 3 or 4 times).
- The ToO response time is set to 14 days: minimum value for a non-disruptive ToO.

1271 - ToO TNOs: 'Unveiling the Kuiper belt by stellar occultations

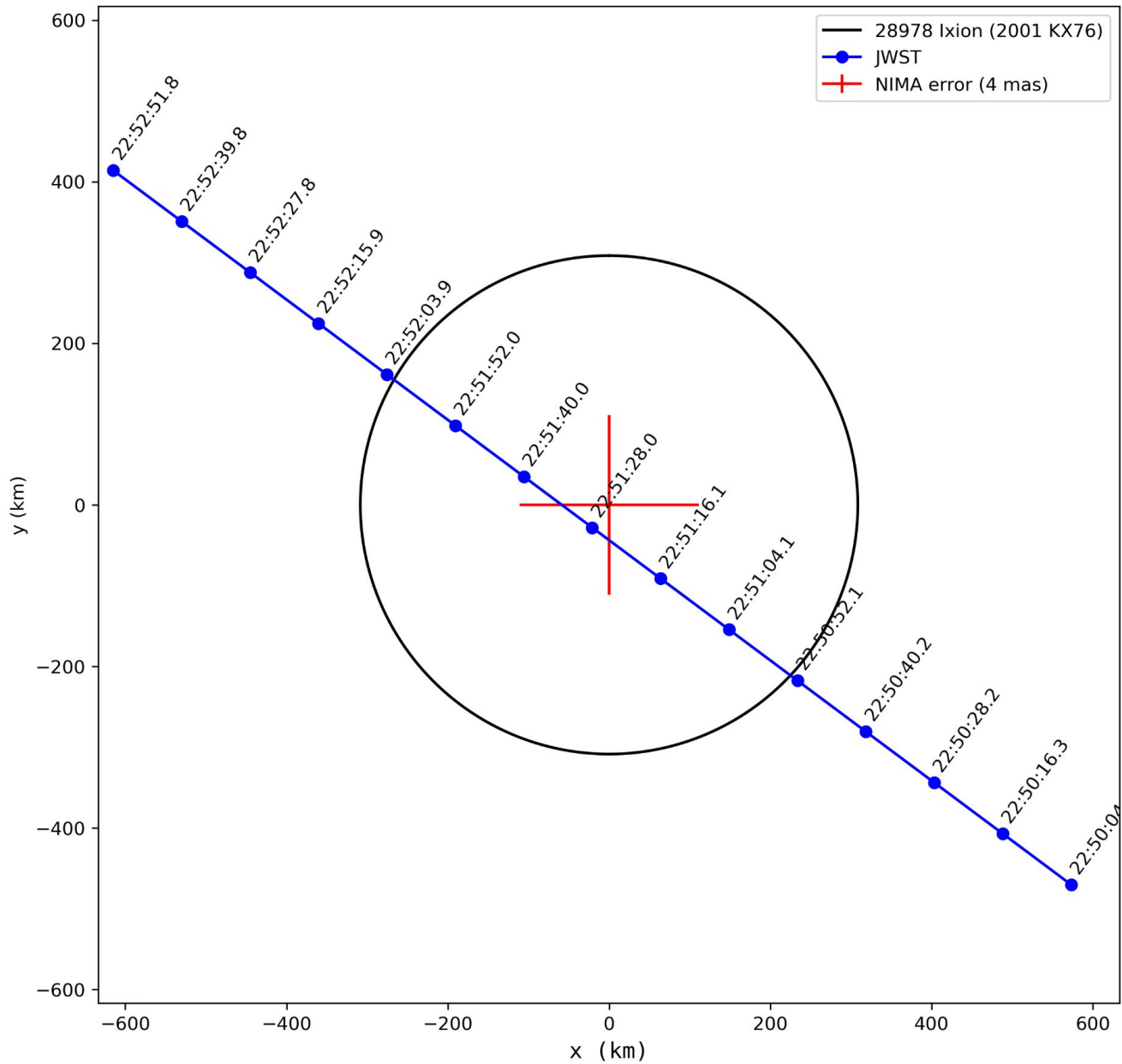
The strategy

- Targets selection: the 40 largest TNOs/Centaurs (36 TNOs + 4 Centaurs).
- Run, on a weekly basis, predictions for the 40 selected targets for Gaia DR3 stars up to mag. 20 (station keeping maneuvers!)
- Take a look at the predictions to identify favorable events.
- Refine the favorable events with new astrometric data and rerun the prediction for these objects.
- After all, if we are confident with the prediction: activate the ToO (at least 14 days in advance).

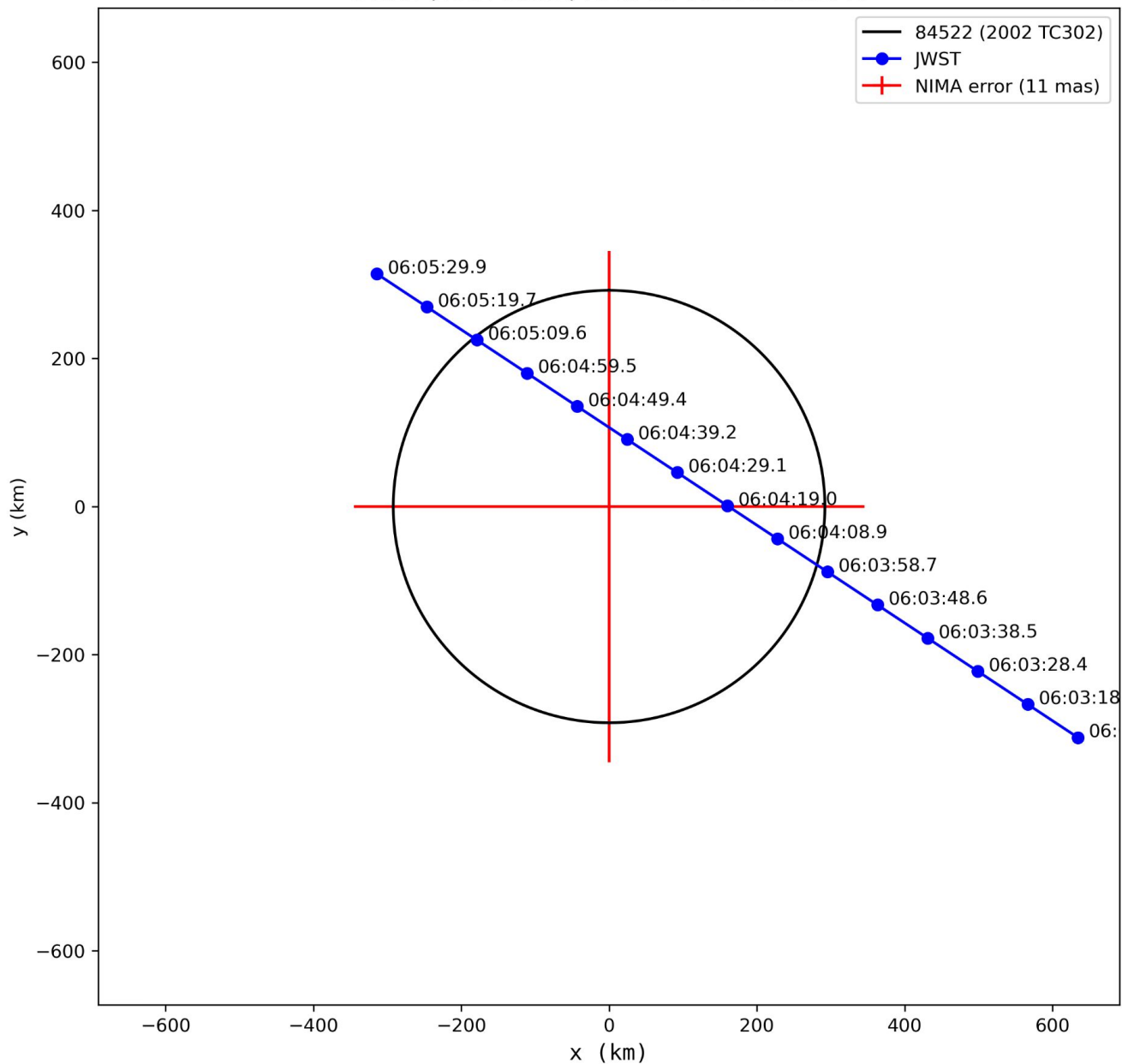
Some (preliminary) favorable events



28978 Ixion (2001 KX76) 2023-03-21 22:51:28.080

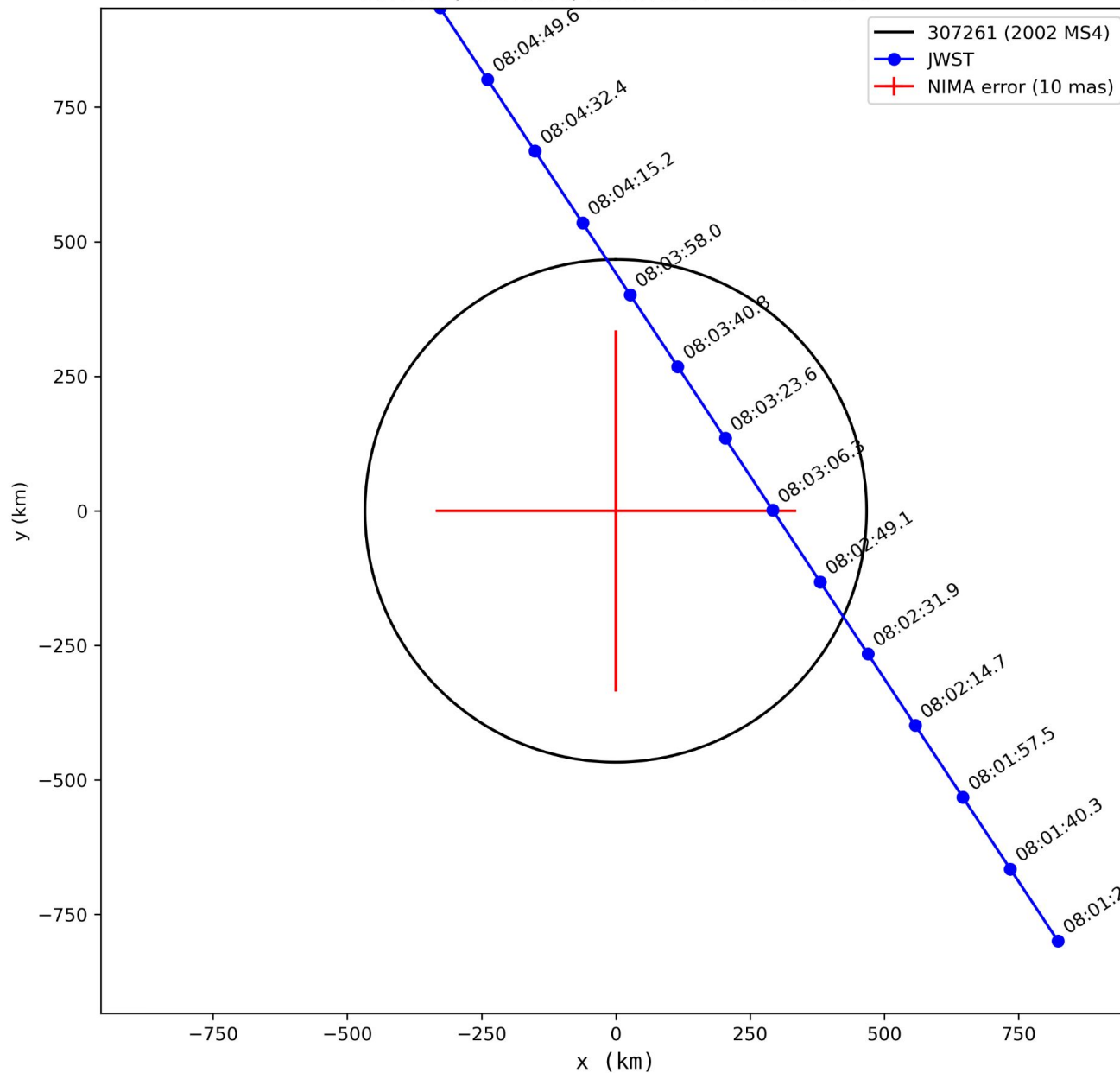


year-m-d	h:m:s UT	ra_dec_J2000_candidate	C/A	P/A	vel	Delta	G	S-O-T
2023-03-21	22:51:28.080	18 19 27.9861 -30 51 36.497	0.001	36.55	8.84	38.33	18.4	86.4



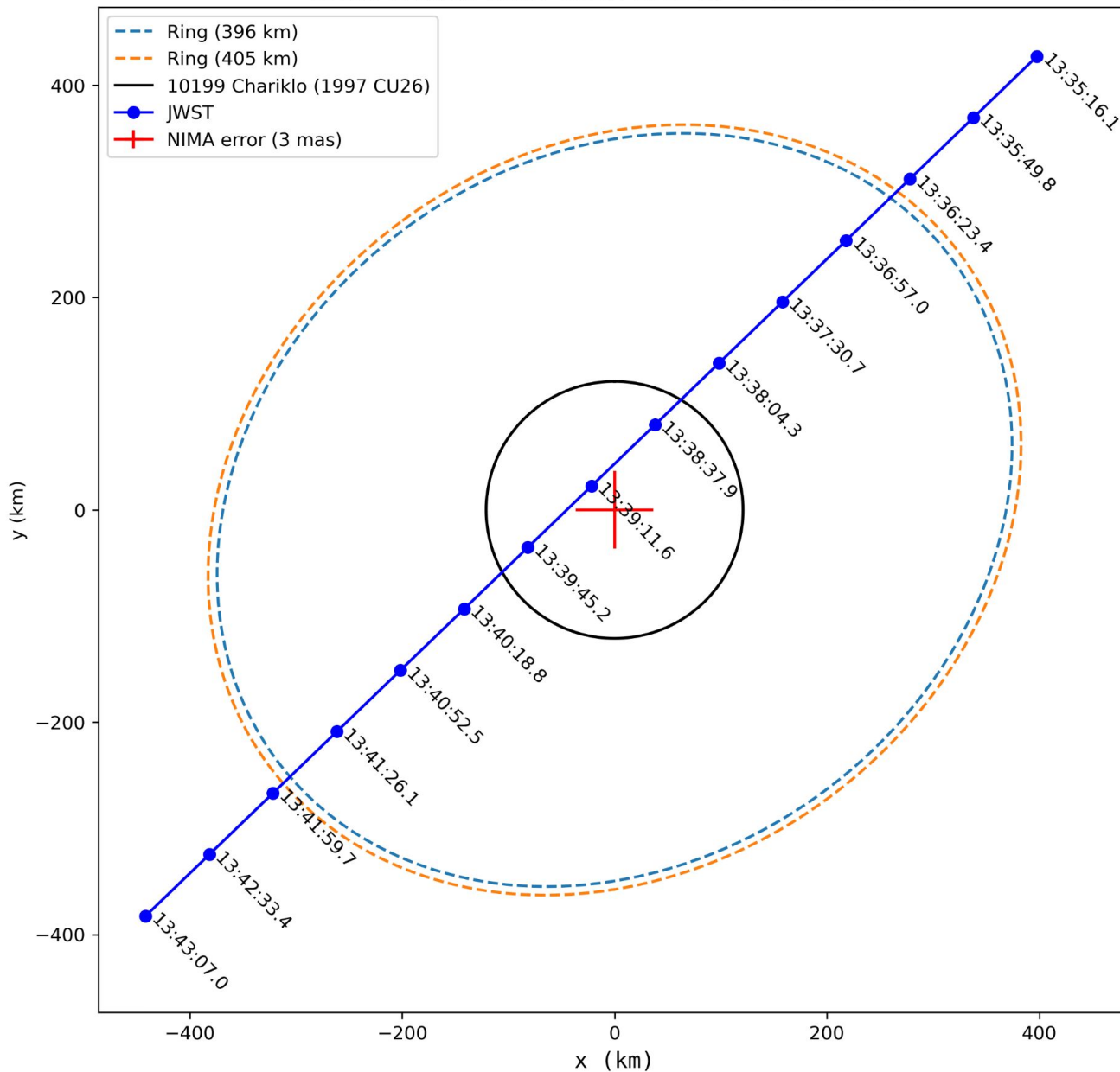
year-m-d	h:m:s UT	ra_dec_J2000_candidate	C/A	P/A	vel	Delta	G	S-0-T
2023-08-16	06:04:19.040	02 55 35.7241 +34 53 00.621	0.005	269.52	-11.70	43.31	18.5	90.8

307261 (2002 MS4) 2022-10-07 08:03:23.600



year-m-d	h:m:s UT	ra_dec_J2000_candidate	C/A	P/A	vel	Delta	G	S-0-T
2022-10-07	08:03:23.600	18 54 32.2669 -06 08 45.042	0.007	236.47	9.31	46.31	18.2	90.4

10199 Chariklo (1997 CU26) 2022-10-18 13:39:11.620



year-m-d	h:m:s UT	ra	dec	J2000	candidate	C/A	P/A	vel	Delta	G	S-0-T
2022-10-18	13:39:11.620	20 21	45.6820	-16 26	21.840	0.003	135.97	2.48	16.81	17.5	98.9

Stay tuned!

Thank you!