

Consejo Superior de Investigaciones Científicas Instituto de Astrofísica de Andalucía



JWST observations of stellar occultations by solar system bodies and rings

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Exploring the Universe with JWST: ESA-ESTEC, The Netherlands, 13th October 2015

2/16 JWST stellar occultations by solar system bodies & rings JWST stellar occultations focus group

22 people working on Solar System Sciences: planets, minor bodies, occultations, rings...from 8 different Countries: US, Brazil, Uruguay, Argentina, Spain, France, Germany and Taiwan.

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Subtopics

1) Predictable stellar occultations

- Planets/Satellites
- Minors Bodies: Asteroids/NEOs/KBOs/Centaurs/Others

2) Occultations by rings

3) Serendipitous stellar occultations

Santos-Sanz, French, Pinilla-Alonso and the JWST SS Occultations focus group

1.- Predictable stellar occultation: the technique

Strengths

- Simple method to obtain high precision sizes/shapes (uncertainty ~km) and albedos of •
- Multiple chords permit fit shape model
- Detection/Characterization of atmospheres and rings 0
- Possibility to distinguish very fine structures/details not possible by direct imaging \bullet
- Predictions improved a lot last few years thanks to improved ephemerides/star catalogs (UCAC4, URAT1) \rightarrow will be even better with GAIA catalogs

Challenges

- Predictions Centaurs/TNOs \rightarrow large orbit uncertainties/small apparent sizes (~10mas)
- For JWST:
 - Accuracy of JWST's predicted orbit around L2 currently under study •
 - We only will get single-chord light curves •

bodies measuring timing of disappearance/reappearance of a star





1.- Predictable stellar occultation: the technique

Successful occultation predictions require:

- i) Accurate knowledge of the target orbit and ephemeris
- ii) The (approximate) size of the body
- iii) An accurate catalog of the positions and apparent magnitudes of stars in the vicinity of the occultation track
- iv) Accurate knowledge of the location of potential observers (this is very relevant, in particular, for space-based observatories)

Body	R_JWST (AU)	Angular Size	Target Diameter (1000 km)	Parallax uncertainty associated with 100 km uncertainty of JWST Orbit (mas)
Jupiter	4.2	45.9"	139.8	32.8
Saturn	8.5	18.9"	116.5	16.2
Uranus	18.2	3.8"	50.7	7.6
Neptune	29.0	2.3"	49.2	4.8
Pluto	38.4	82.8 mas	2.31	3.6
TNO	39.0	14.1 mas	~0.4	3.5
Centaur	16.6	8.3 mas	~0.1	8.3

Apparent sizes and target/shadow diameters for different solar system bodies as observed from JWST (Santos-Sanz et ant2095) French, Pinilla-Alonso and the JWST SS Occultations focus group

1.- Predictable stellar occultation: science with JWST

Single chord occultation can be scientifically valuable:

- Discovery/characterization atmospheres at nbar-to-µbar level: P(z),T(z)
- Detection central flashes due to atmosphere (if chord central) → probing deeper levels
- Airless bodies: TNOs/Centaurs sizes
 - Measurements of small TNO sizes (<=100km) constrain collisional history
- Rings/ satellites: discovery, structure, astrometry \rightarrow orbit evolution

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 VS2)		1	1		3	7	24	
136108 Haumea						1	3	
225088 (2007 OR10)								
120347 Salacia							4	
90482 Orcus						1		100
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				

Predicted occultation appulses (<= 100 mas) for 13 outer solar system minor bodies visible from JWST from Dec 1, 2018 to Jan 31, 2023 (Santos-Sanz et al. 2015)

1.- Predictable stellar occultation: requirements on JWST

- Moving target tracking not needed for stellar occultations
- High time resolution and sensitivity needed (> 5 Hz)
- JWST best suited instrument: NIRCam



- Cadence ~6.7 Hz using 64x64 subarray → provides nearly diffractionlimited km-scale resolution of minor body occultations
- Wide coverage: from 0.7 to 4.8µm → optimum filter to maximize SNR of occulted star (minimize light reflected by the object, see next slide)
- Knowledge of JWST position near L2 critical for predicting occultation events:
 - Expected accuracy of the JWST ephemeris is currently under study
 - JWST will do station-keeping maneuvers every 21 days (worst case)
 - Need predictions accurate to:
 - ~ 300 km for ~ 1 year in future (proposal planning)
 - < 100 km for ~ 1 month in future (observation refinement)

Without accurate JWST orbit knowledge, occultation proposals will be ToO



Best-choice NIRCam filter(s) for TNOs and Centaurs

8/16 JWST stellar occultations by solar system bodies & rings 2.- Occultations by rings: motivation

- Ring systems around Uranus, Neptune & Chariklo were 1st discovered by occultations
- Much very detailed structure of rings of Saturn, Uranus, and Neptune revealed by stellar and radio occultations (very fine structures not visible in direct imaging)





High-SNR earth-based occultation observations of three Uranian rings, from the SAAO

9/16 JWST stellar occultations by solar system bodies & rings 2.- Occultations by rings: science with JWST

 We propose to use JWST to observe stellar occultation by giant planet and minor body (e.g. Chariklo) rings...but...

What could JWST add to our scientific understanding of planetary rings?

- Extend the time baseline of observations of time-variable structures (precessing rings, evolving ring structures, density waves associated with satellites)
- Provide exceptionally high-quality occultation profiles of ring systems: large aperture + space environment → great sensitivity / very high SNR
 - With appropriate IR filters, scattered light from the planet and rings can be minimized

 Extend occultations to fainter stars → increase the frequency of events, reduces the smoothing effects due to finite angular diameter of occulted star

10/16 JWST stellar occultations by solar system bodies & rings 2.- Occultations by rings: preferred JWST facilities

- NIRCam is the preferred instrument → can provide km-scale resolution of giant planet rings
- Preferred filters → minimize scattered light from planet / rings: F300M, F335M, F360M or every filter above F300M



Reflectance spectrum of Saturn and water ice (pure model at 40 K), and bandpasses of NIRCAM's medium filters

11/16 JWST stellar occultations by solar system bodies & rings 2.- Occultations by rings: some predictions

- Projected dimensions of the rings ~10,000-70,000 km → possible to predict events well in advance (in spite of uncertain JWST orbit and imprecise star positions) → planning JWST and coordinated ground-based campaigns
- The potential value of JWST ring occultations depends critically on their frequency. Preliminary predictions occultations by rings visible from JWST:
 - Abundant for Saturn
 - Roughly annual for Uranus
 - Rather rare for Neptune
 - Jupiter's rings are not favorable during this period: nearly edge-on

Body	K < 9	9 < K < 10	10 < K < 11	11 < K < 12	12 < K < 13	13 < K < 14	14 < K < 15
Saturn	0	2	11	4	15	42	62
Uranus	0	0	0	0	2	3	3
Neptune	0	0	0	0	0	1	2

Number of stellar occultations by planetary ring systems observable from JWST between Dec. 1, 2018 and Jan. 31, 2023 (Santos-Sanz et al. 2015)

2.- Occultations by rings: some attractive predictions in 2019



Uranus 2MassID: 1263130636 Kmag=13.80 C/A: 2019 AUG 09 17:43:51

Uranus Duration= 20 h !

Tick marks= 30 min. apart







Neptune 2MassID: 1320182738 Kmag=13.98 C/A: 2019 JUL 04 04:39:41 Neptune Duration= ? (incomplete "arc-like" rings)



2.- Occultations by rings: looking further into the future



Ring opening angle as viewed from the earth for the giant planet ring systems

14/16 JWST stellar occultations by solar system bodies & rings 2.- Occultations by rings around small bodies

- Chariklo's narrow rings were detected in 2013 from stellar occultation
- Discovery of rings around other minor bodies would have high scientific value and address new questions.
 - How frequent are rings around small bodies?
 - How are they confined, etc...?
- Prediction challenges comparable to that for the body itself



Discovery observations of the Centaur Chariklo ring system by stellar occultation (Braga-Ribas et al. 2014)

3.- Serendipitous stellar occultations: by-product from other programs

- Detection of diffraction profiles of very small KBOs (100m<D<1km) (Roques 2000)
 - Diffraction profile gives distance (duration) and size (depth) of object ; advantage of IR vs optical: longer duration (but smaller drop in flux)
 - Access to sub-km scale, i.e. size range of dust-producing population of KBOs
 - Un-biased population statistics un-biased by albedo
 - A big amount of observing time is needed

Preferred instrument: JWST-FGS (Fine Guidance Sensor) ~ 5,000 star hours per year ! FGS will monitor only 1 star in 8x8 pixel box at ~12 Hz, SNR≥ 200 for majority guide stars. We propose using these data from other projects to obtain very scientific valuable by-product.



Simulated light curves expected from a stellar occultation event produced by a TNO located at 43 AU for different body sizes (Santos-Sanz et al. 2015) 16/16 JWST stellar occultations by solar system bodies & rings and...last, but not least...

 Predictable stellar occultations by solar system minor bodies require very little telescope time, while serendipitous stellar occultations can be obtained as a by-product of other projects: both have a low observational cost and a very important scientific return

 Even a few JWST ring occultation observations could yield a substantial scientific return



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