The Chariklo Occultation Campaign 2017

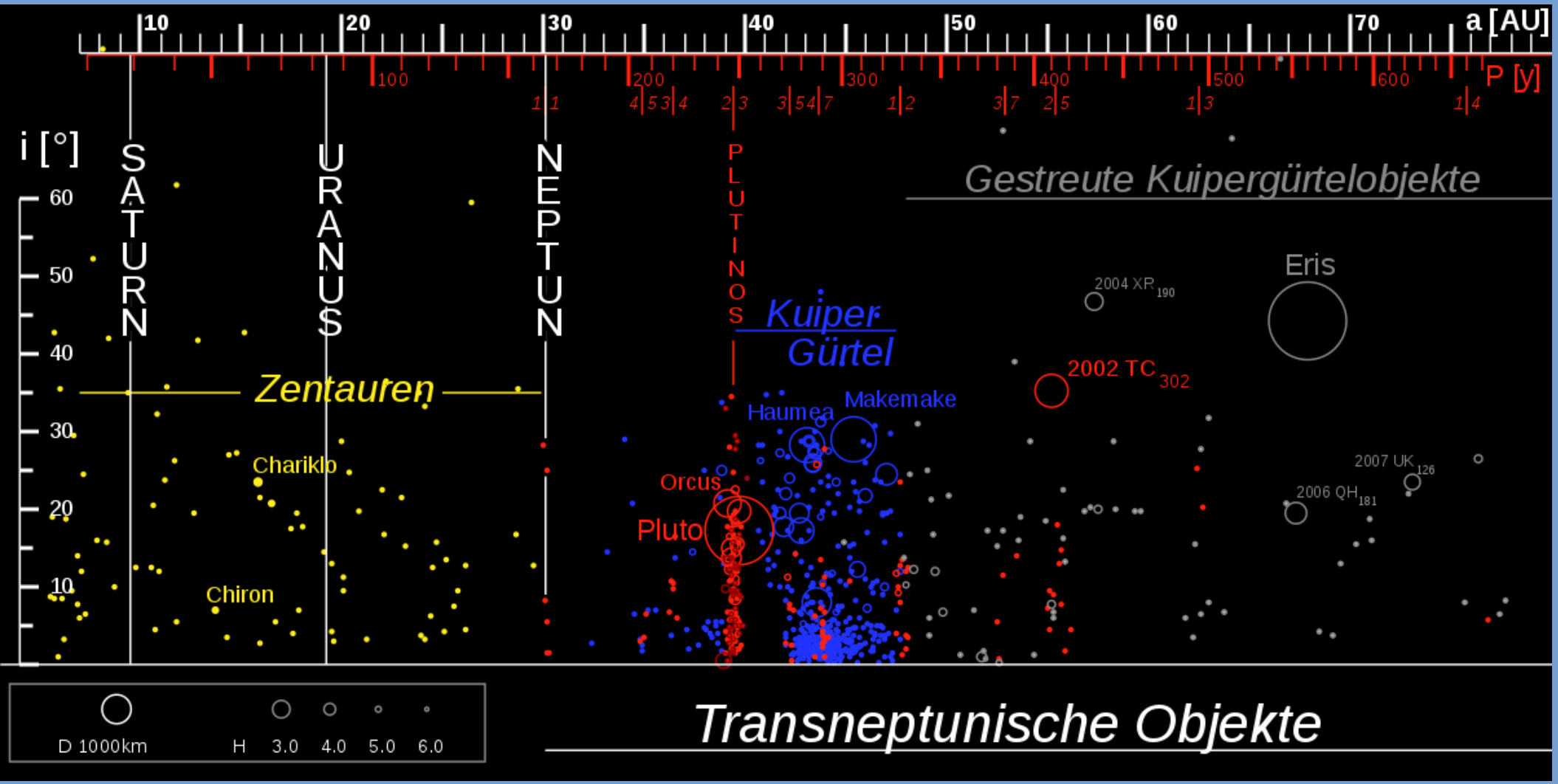
Mike Kretlow
IOTA - ES & Lucky Star Project
ESOP 36, Freiberg, Germany, 2017 Sep 15-17

(10199) Chariklo

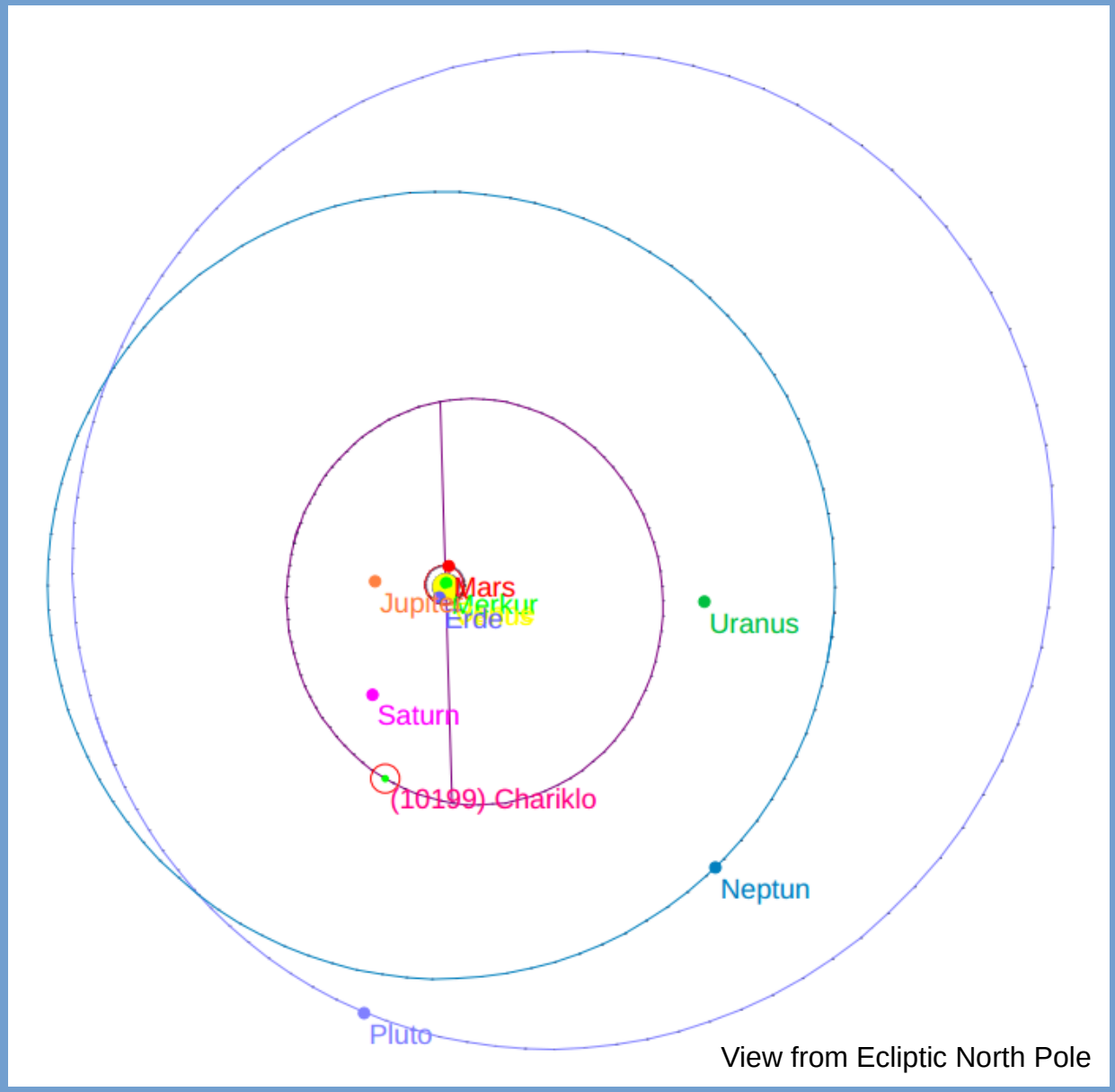
Largest known Centaur (D ~260 km)

Centaurs are objects from the Kuiper belt.

- Having perturbed inward by Neptune and / or Uranus.
- Dynamically (long-term-) unstable orbits.
- Will be ejected from SS, impact (planet, Sun) or change into short-period comet.

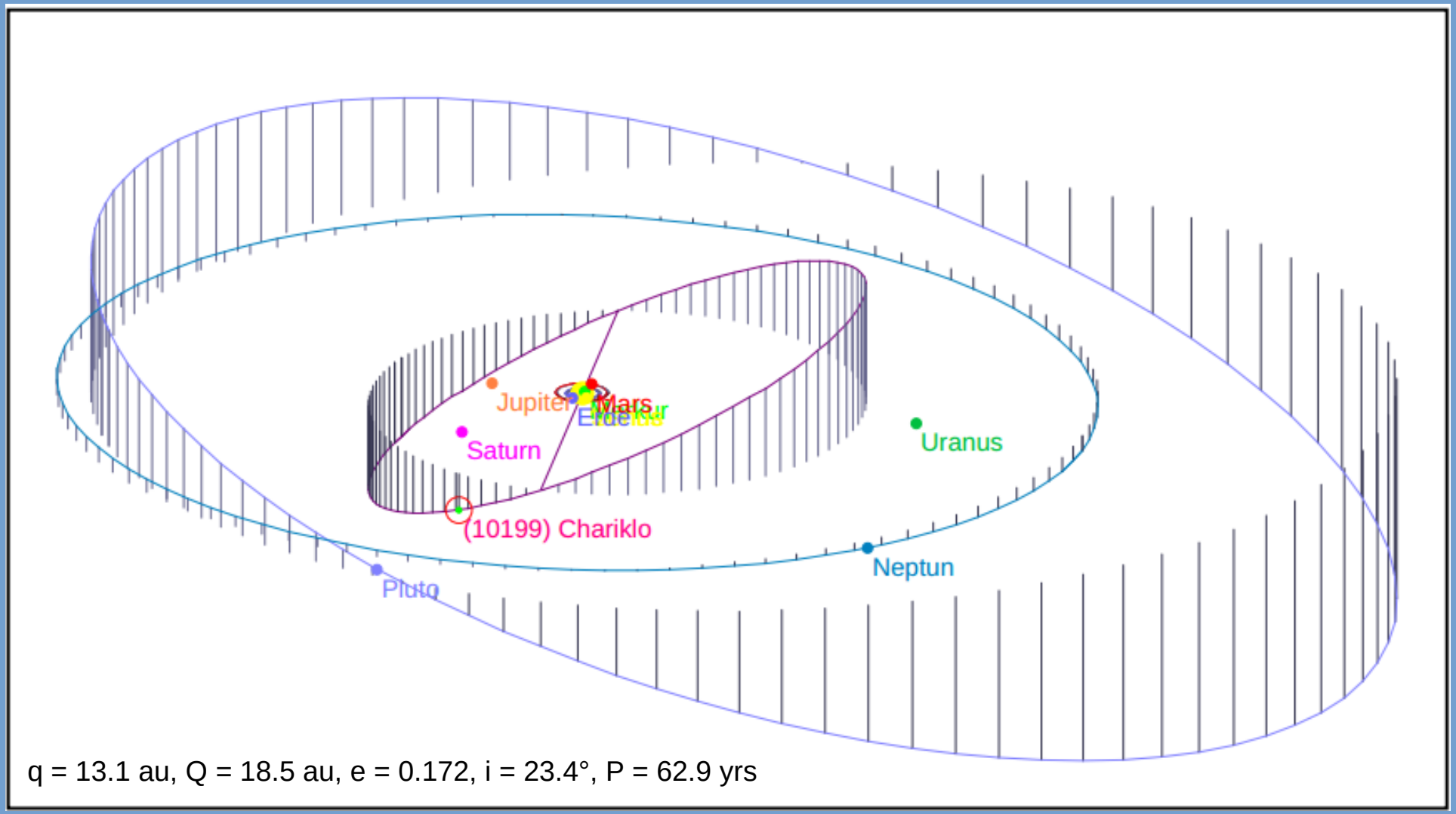

a [AU]
10
20
30
40
50
60
70
P [y]
100
200
300
400
500
600
1 1
4 5 3 4
2 3
3 5 4 7
1 2
3 7
2 5
1 3
1 4
i [°]
60
50
40
30
20
10
SATURN
URANUS
NEPTUN
PLUTINOS
Gestreute Kuipergürtelobjekte
Kuiper Gürtel
Zentauren
Eris
2004 XR 190
2002 TC 302
Haumea
Makemake
Orcus
Pluto
Chariklo
Chiron
2007 UK 126
2006 QH 181
D 1000km
H 3.0 4.0 5.0 6.0
Transneptunische Objekte

Orbit Diagram (2017-06-22)



q = 13.1 au, Q = 18.5 au, e = 0.172, i = 23.4°, P = 62.9 yrs

Solar System View (2017-06-22)



q = 13.1 au, Q = 18.5 au, e = 0.172, i = 23.4°, P = 62.9 yrs

Chariklo Skymap (2017-06-22)

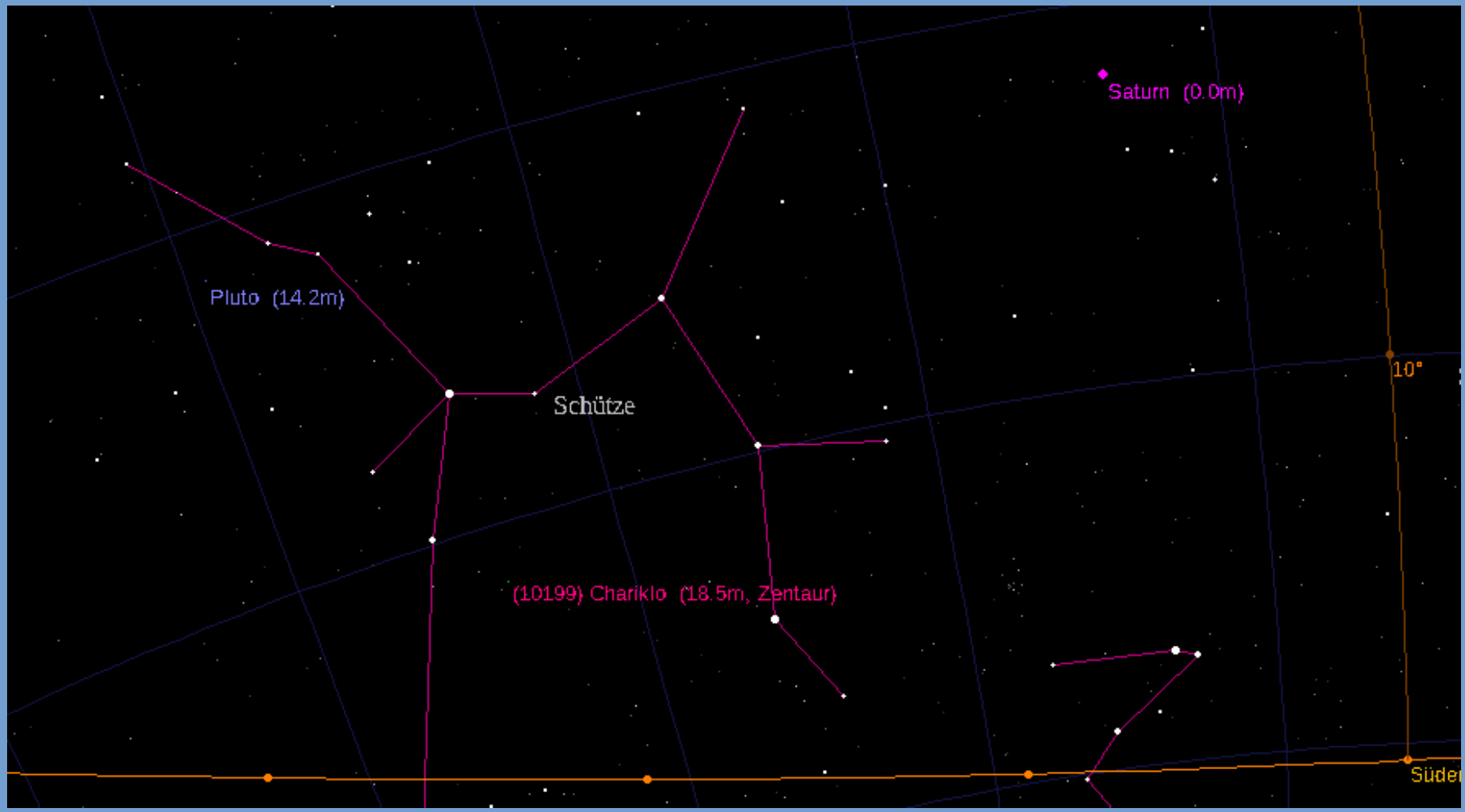


Table 7. Physical parameters of Chariklo from stellar occultations.

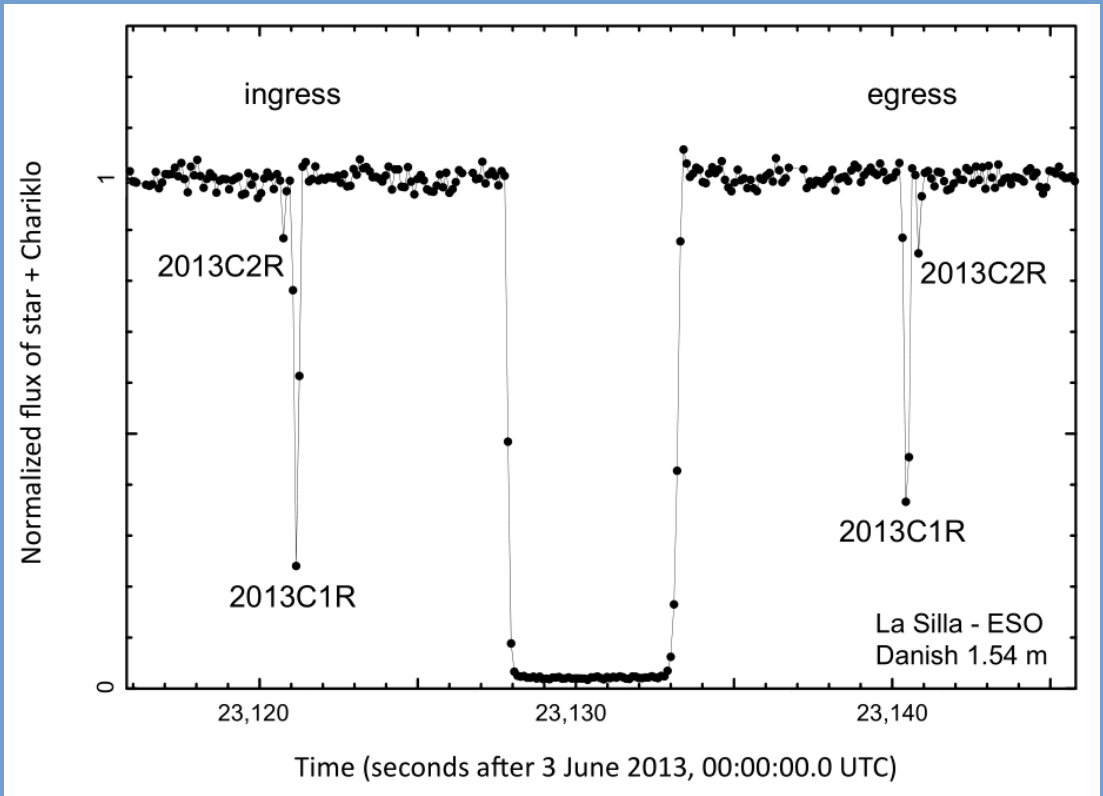
Parameter	Sphere	Maclaurin	Ellipsoid	Jacobi
ρ (kg m^{-3})	...	970^{+300}_{-180}	...	796^{+2}_{-4}
a (km)	129 ± 3	143^{+3}_{-6}	148^{+6}_{-4}	157 ± 4
b (km)	129 ± 3	143^{+3}_{-6}	132^{+6}_{-5}	139 ± 4
c (km)	129 ± 3	96^{+14}_{-4}	102^{+10}_{-8}	86 ± 1
$R_{\rm equiv}$ (km)	129 ± 3	126 ± 2	126 ± 2	123^{+3}_{-1}
σ_m (km)	11	7	6	6
$d_{\rm RMS}$ (km)	10	7	5	5
$d_{\rm max}$ (km)	+15	+11	+12	+9
Mass (kg)	...	$8 \pm 1 \times 10^{18}$	...	$6.1 \pm 0.1 \times 10^{18}$
p_b (%)	3.1 ± 0.1	3.8 ± 0.1	3.7 ± 0.1	4.2 ± 0.1
I/F (%)	8.9 ± 0.3	3.4 ± 0.3	4.9 ± 0.3	0.6 ± 0.4

From five occultations (2013-2016)

Leiva et al. 2017

Chariklo has rings !

- Inner denser ring 2013C1R, ~390 km distance to center.
- Outer tenous ring 2013C2R.
- Gap ~9 km.
- Confirmed in subsequent occultations (2014,...)
- Explains variation of H over time (instead of cometary activity, perspective effects etc.)



Braga-Ribas et al. 2014

Artist‘s impression of the Chariklo system

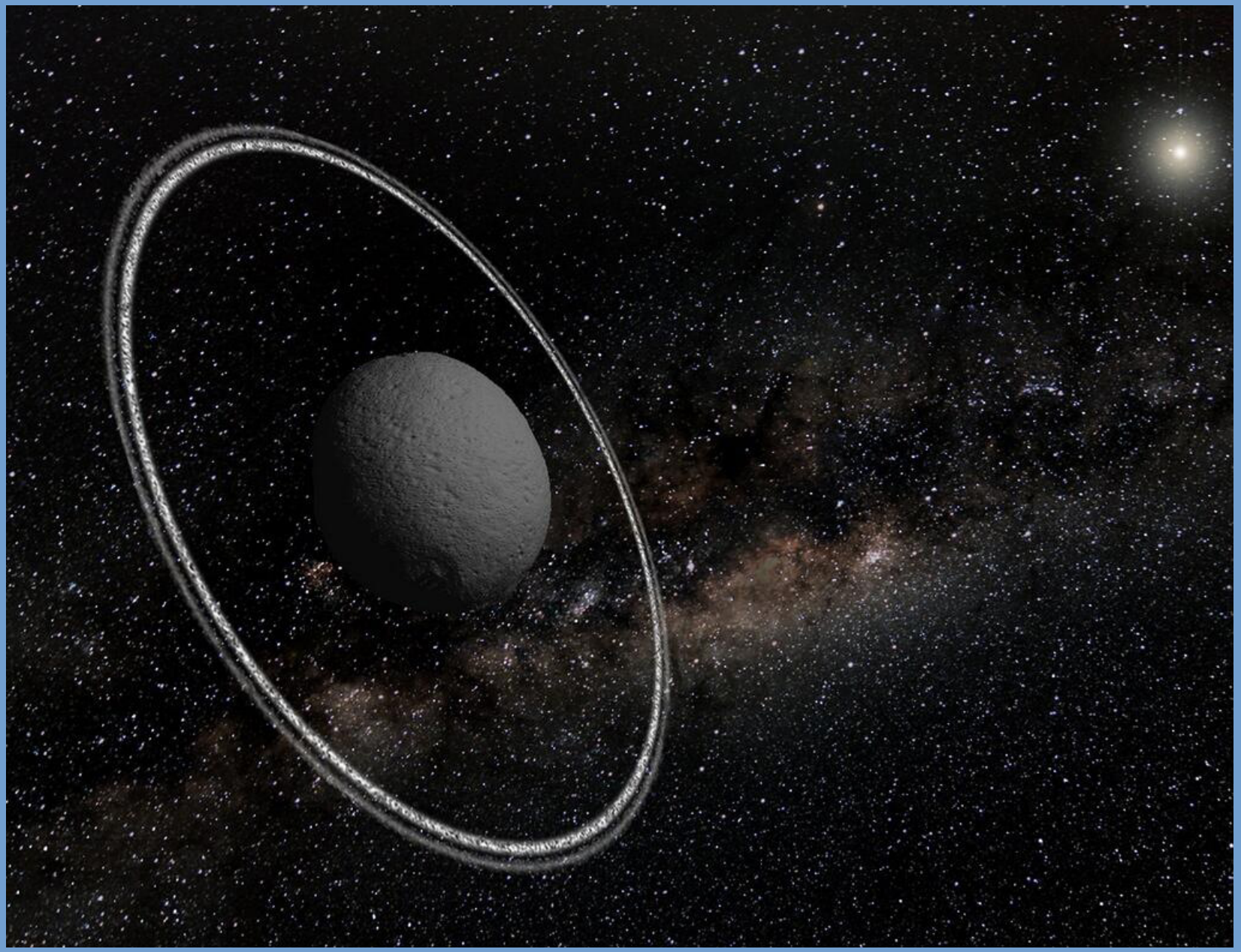
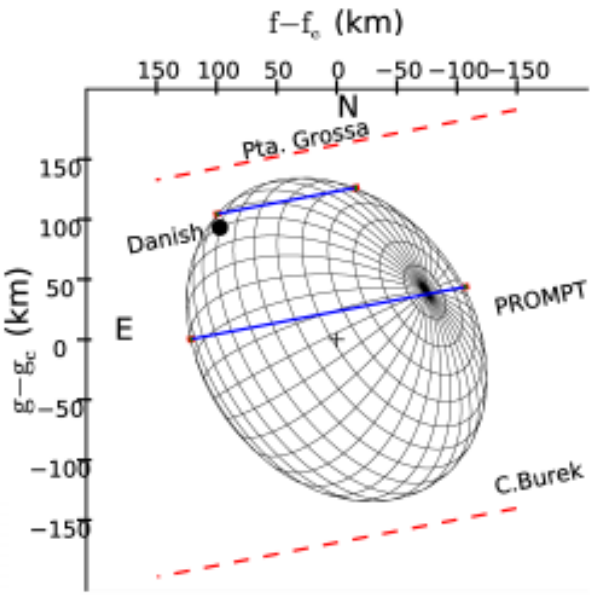
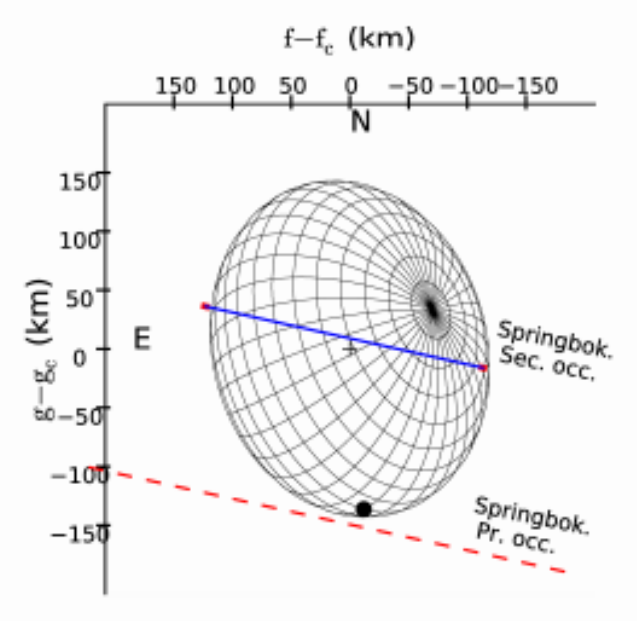


Image: Lucie Maquet

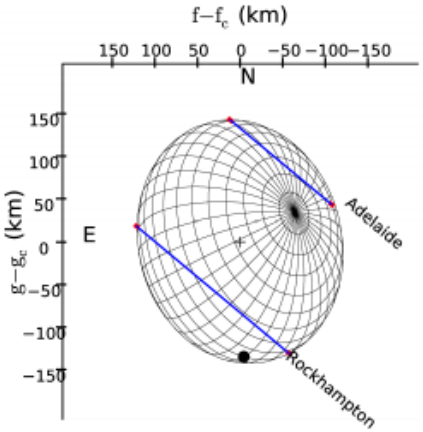
Leiva et al. 2017



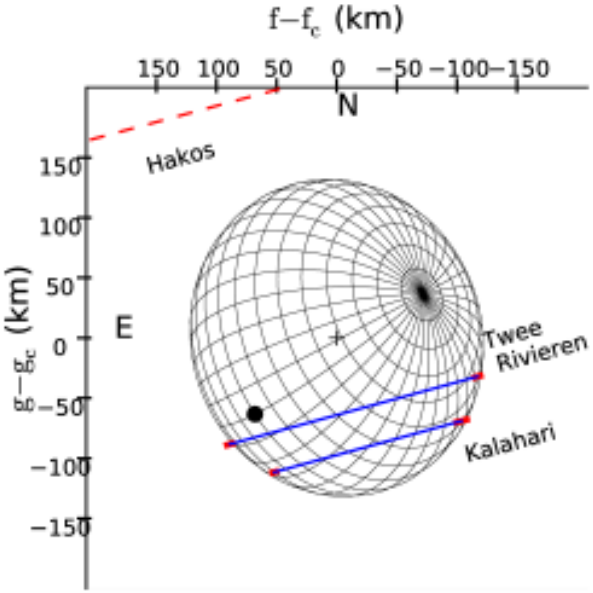
(a) 2013 June 3



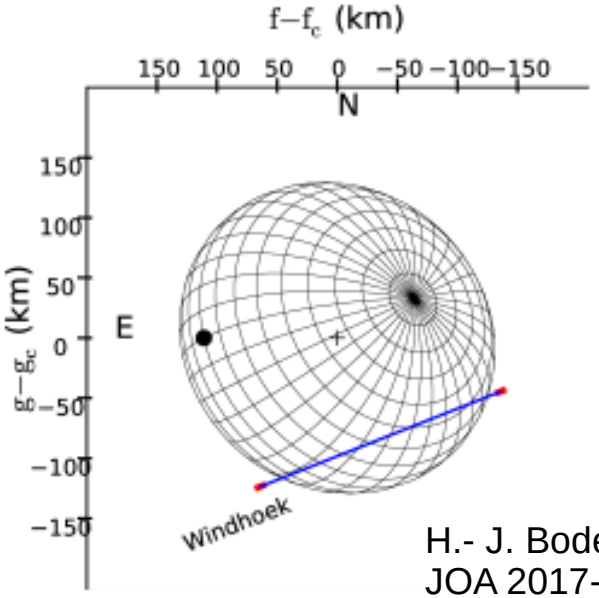
(b) 2014 April 29



(e) 2016 October 1



(c) 2014 June 28



(d) 2016 August 8

H.- J. Bode
JOA 2017-1

‚Only' single or double chord Observations.

Try to improve that in 2017…

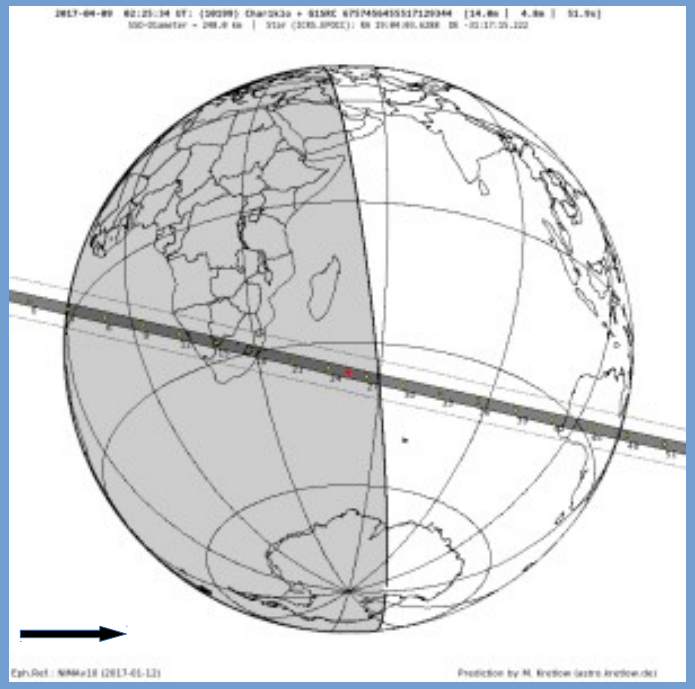
Goals / scientific objectives

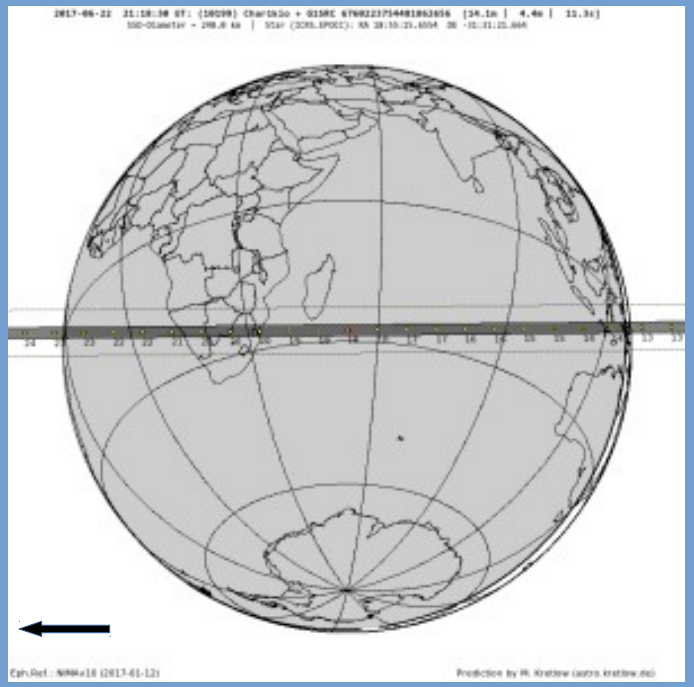
- Study the ring system: Diane Berard.
- Study the main body (physical parameters, shape, etc.): Rodrigo Leiva (2017 campaign).

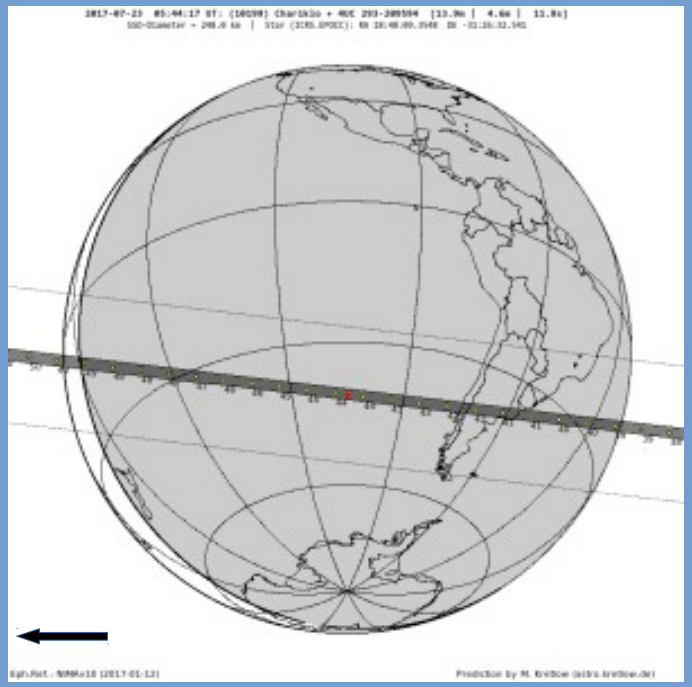
  Under supervision of Prof. Bruno Sicardy (Obs. Paris Meudon and Lucky Star project).
- „Spin-off“: astrometry, verification of Gaia based predictions etc.

Occultations 2017: Overview

Date & Time	April 09 @ 02:25 UT	June 22 @ 21:18 UT	July 23 @ 05:44 UT
Region	Southern Africa	Southern Africa	South America
Star Magnitude	14.0 G	14.1 G	13.9 G
Vel. : Max. Duration	4.8 km/s : 52 sec	22.0 km/s : 11 sec	21.0 km/s : 12 sec







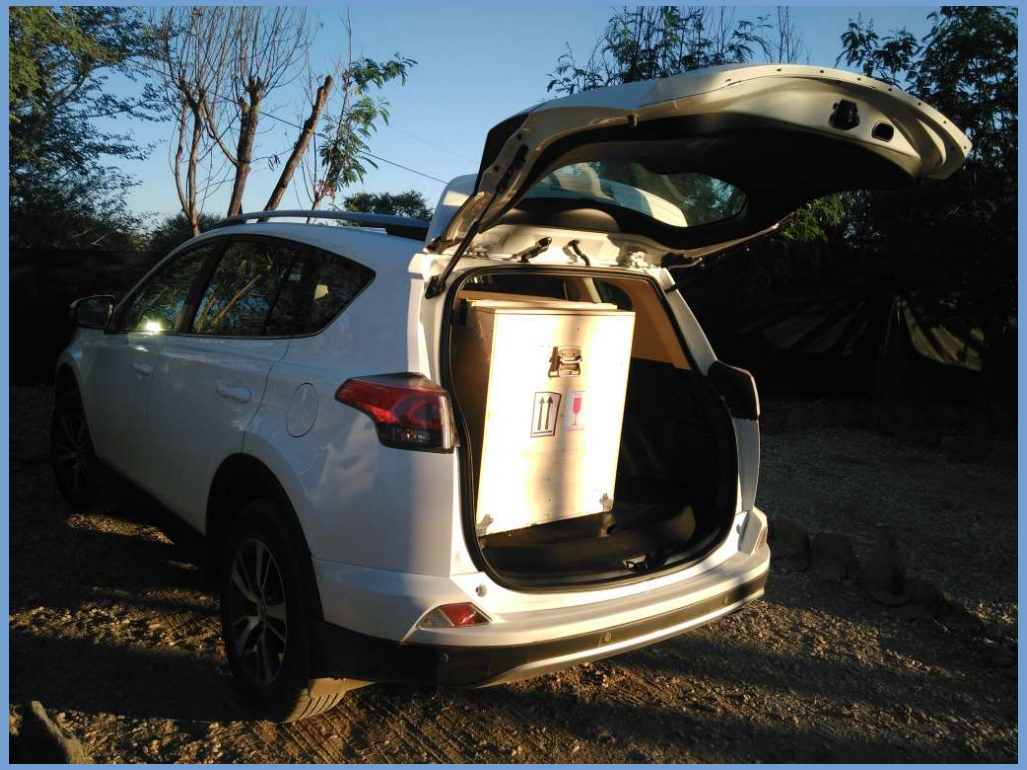
Chariklo: 18.5...18.9 V

What is this ?

Of course a telescope

IOTA-ES project “M2”

- 50-cm f/4 portable telescope for occultation expeditions (TNO’s etc.).
- Made (conversion) from a second-hand Skywatcher Alt-Az telescope.
- Weight including wooden transport box ~60 kg.
- Assembled alone* in ~20-30 minutes.



- 2 x Michael
  1 x Konrad (=> M2K … ?)

Occultation prediction: star pos. + ephemeris

- Gaia DR1 (~1 Billion stars) released Sept. 2016.
  - New area in (occultation) astronomy !
  - Positional accuracy some mas (< 1mas for 50%), but GDR1 has no PM (except TGAS, but only 2 Mio. stars).
- Most ‘catalog’ orbits (asteroids, TNOs, etc.) by MPC, JPL, etc. have typical ephemeris uncertainties of some ten mas.
- Chariklo’s distance to Earth Δ = 15.5 au (2017.5)
  1 mas in the Sky corresponds to ~11 km.
  => need for “better” orbits.

NIMA: Numerical Integration of the Motion of an Asteroid (Desmars et al.)

- Orbit calculation (differential orbit correction) and short term integration (ephemeris) for occultation predictions.
- Not ‘only’ MPC astrometric observations are used, but also dedicated astrometry made at ESO, Pic du Midi, Calar Alto, Sierra Nevada and Observatorio do Pico dos Dias, and astrometry derived from occultation observations.
- Special weighting scheme during the least squares fitting process, that considers the individual precision of the observation, the number of observations performed during one night by the same observatory, and the presence of systematic errors in the positions.

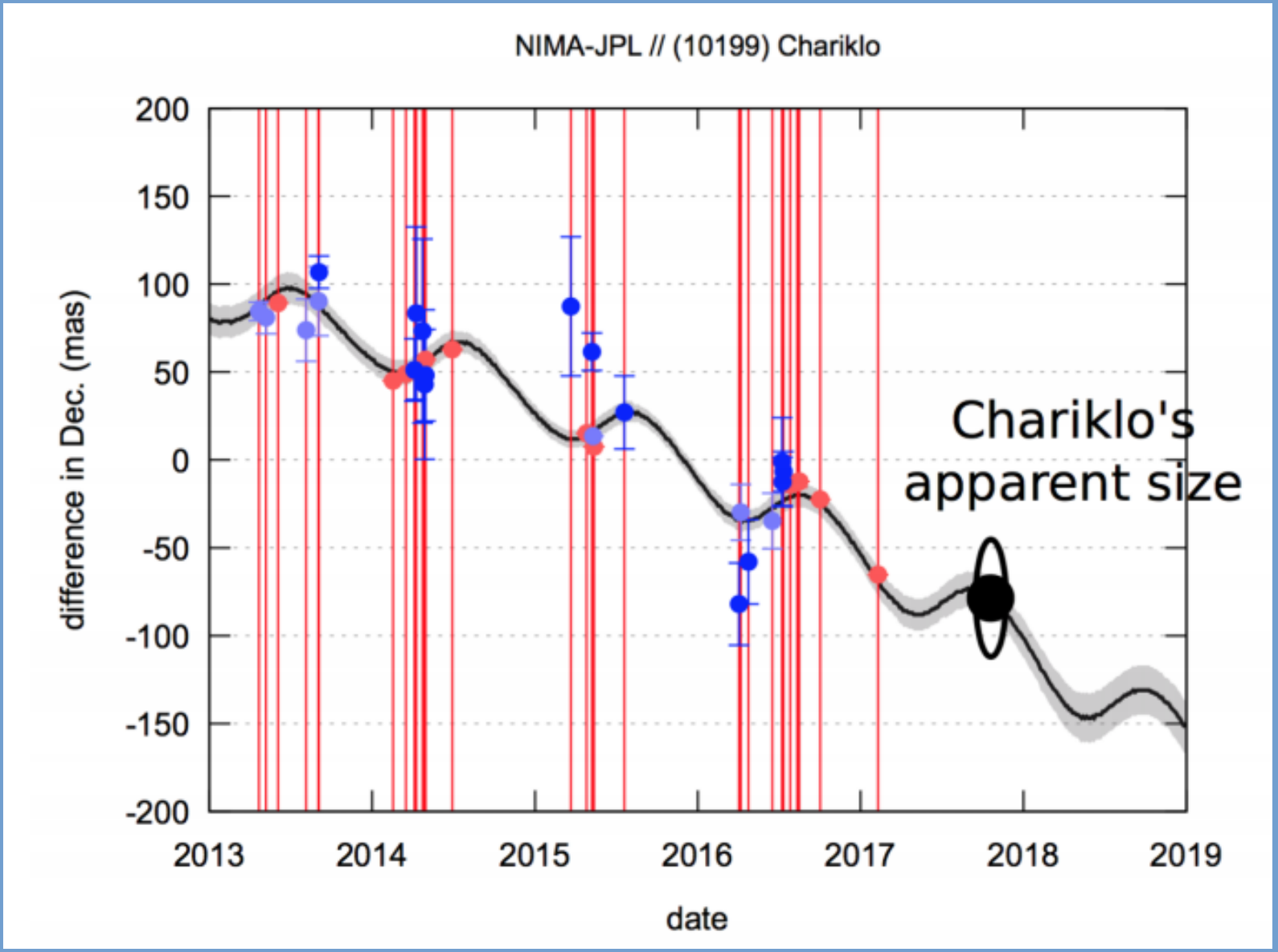
(10199) Chariklo

Ephemeris solution

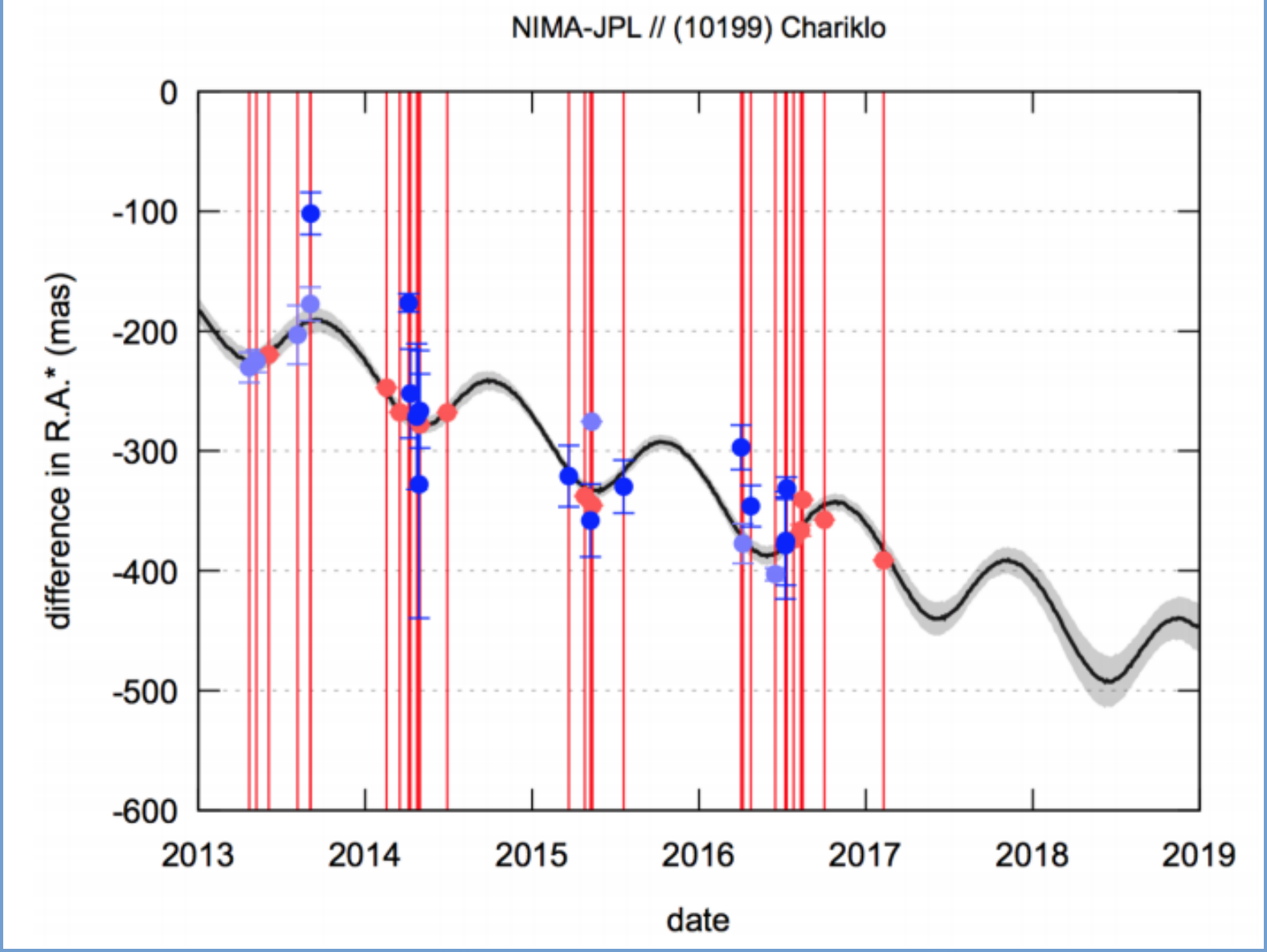
- ***Observations used***: MPC (1988-2011) + OPD (2011,2013,2014) + ESO (2013-2014,GaiaDR1+derivedPM)+ Cerro Tololo (2014) + Occ (2013.06.03,GaiaDR1+derivedPM) + Occ (2014.02.16,GaiaDR1+derivedPM) + Occ (2014.03.16,GaiaDR1+derivedPM) + Occ (2014.04.29,GaiaDR1+derivedPM) + Occ (2014.06.28,GaiaDR1+derivedPM) + THA (2015.03,GaiaDR1+derivedPM) + Occ (2014.04.26,GaiaDR1+derivedPM) + ESO (2015.05) + Occ (2015.05.12,GaiaDR1+derivedPM) + SOAR (2015.07) + ESO (2016.04,GaiaDR1+derivedPM) + SHOC (2016.04.12, offset) + OPD (2016.04) + ESO (2016.06,GaiaDR1+derivedPM) + OPD (2016.07,GaiaDR1+derivedPM) + Occ (2016.07.25,GaiaDR1+derivedPM) + Occ (2016.08.10a,GaiaDR1+derivedPM) + Occ (2016.08.15,GaiaDR1+derivedPM) + Occ (2016.10.01,GaiaDR1+derivedPM) + Occ (2017.02.08, GaiaDR1+derivedPM) + Occ (2017.04.09, GaiaDR1+derivedPM) + + OPD (2017.05, GaiaDR1)
- ***Observations not used***: OPD (2013.08.03) because of bad O-C + Occ (2015.05.12) from MPC (doublon) + Occ (2016.08.08) because bad O-C.
- ***Observations and residuals file***: omc_ast.res
- ***bsp file***: 10199_Chariklo_nima_v12.bsp
- ***Ephemeris file***: ephembsp.res
- ***Ephemeris version***: v12
- ***Comments***: This is an update version of v11 version with additional observations from OPD (2017.05) and position from OCC (2017.04.09)
- ***Date of creation***: 2017-05-31 14:17 (UTC)

time	+0	+6	+12	+18	+24
σ (α)	0.012	0.009	0.018	0.014	0.025
σ (δ)	0.008	0.009	0.012	0.012	0.017

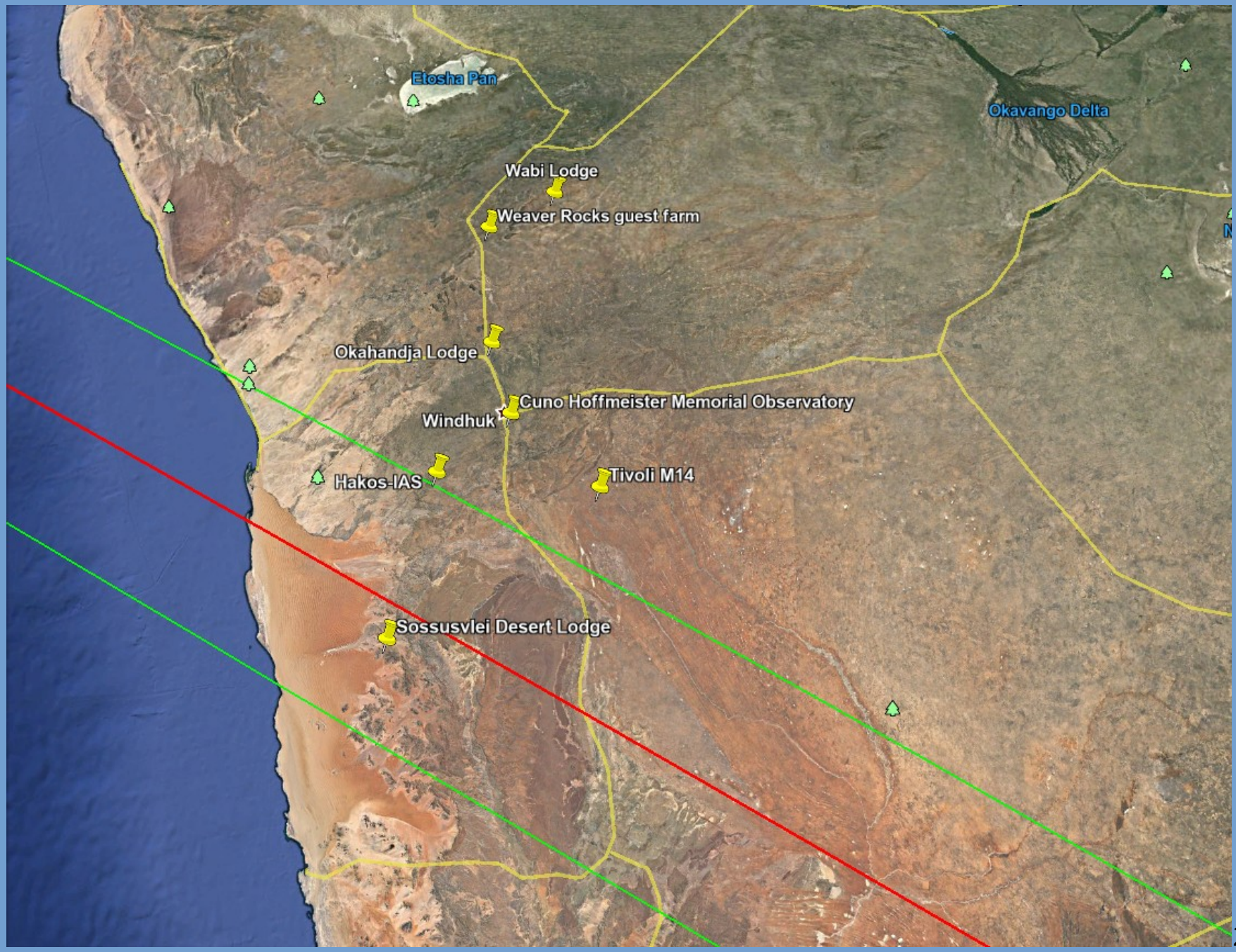
Time is number of months after last observation (2017-05-03) and σ are in arcsec.



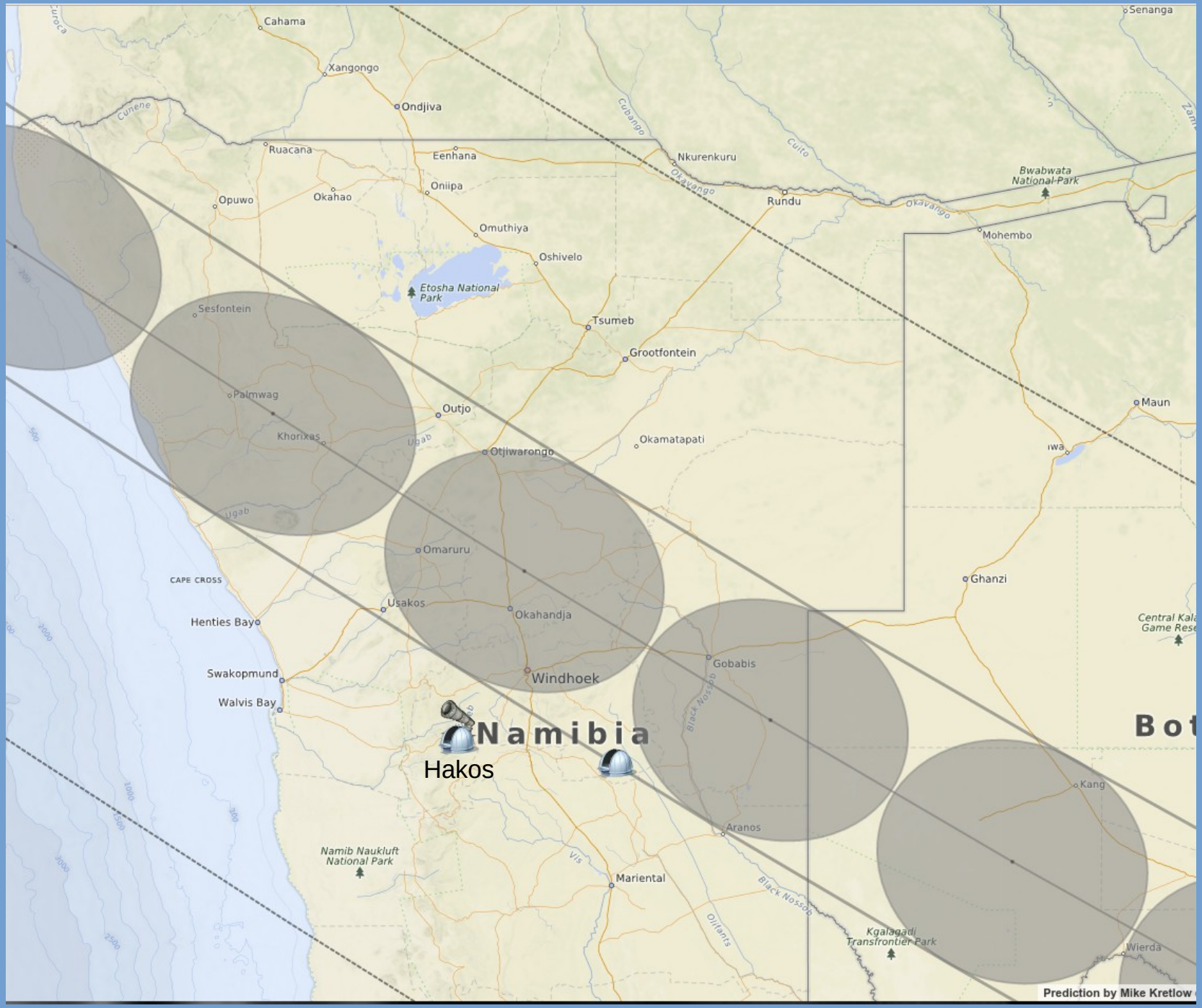
Difference in DE between last version of NIMA and JPL ephemerides.
Red dots are occultations positions. Blue dots are CCD observations.
Gray area represents the uncertainty of the NIMA ephemeris.


NIMA-JPL // (10199) Chariklo
0
-100
-200
-300
-400
-500
-600
difference in R.A.* (mas)
2013
2014
2015
2016
2017
2018
2019
date

2017 April 09: first prediction: Gaia DR1, but no PM !



Prediction using HSOY (GDR1 + PPMXL) + NIMA v11

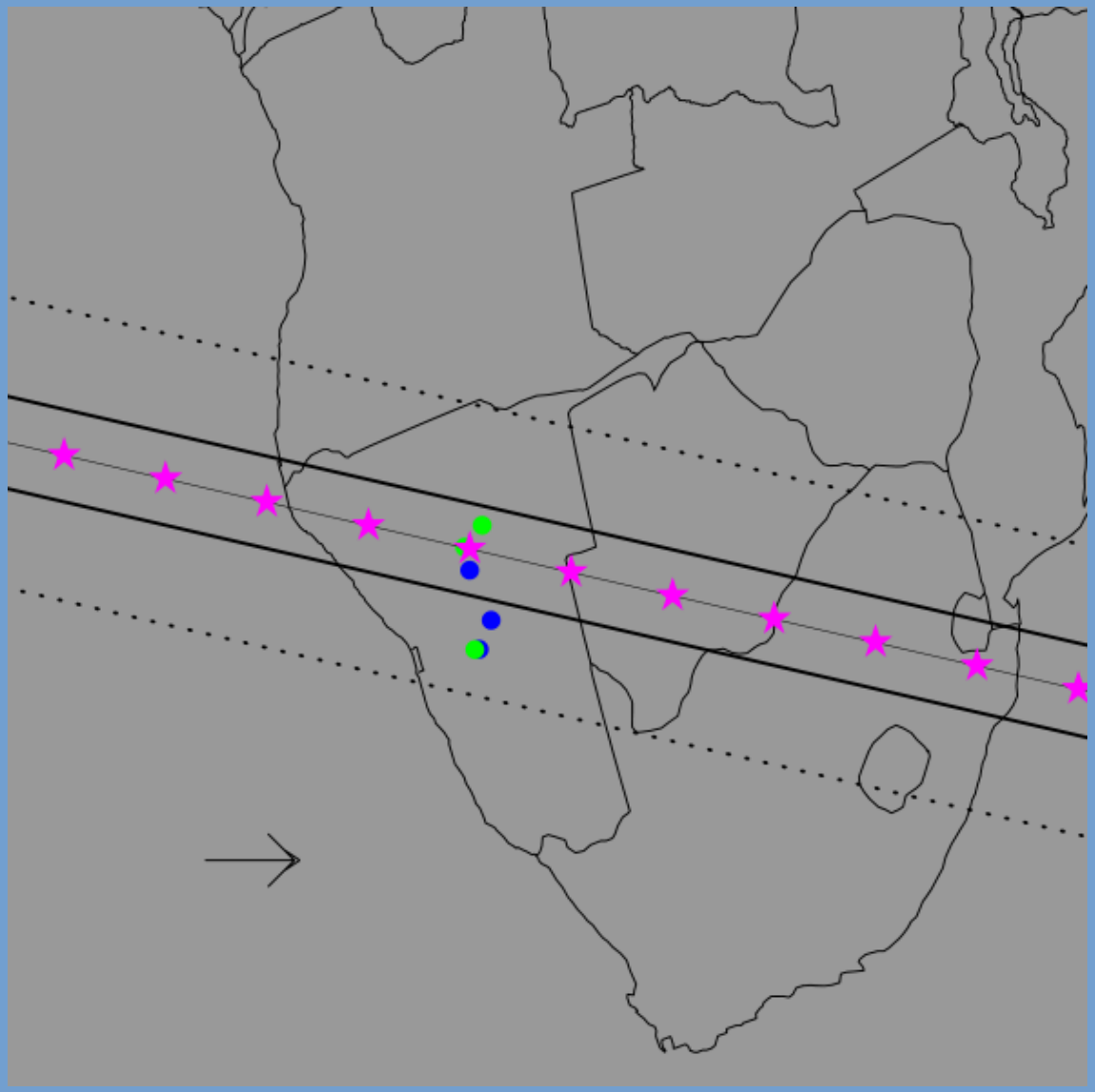


More than one path width shift to North compared to ‘plain’ GDR1 (no PM)

Final pre-occultation prediction: GDR1 + PM using UCAC4 as 2nd epoch

Occultation 2017 Apr 9 in Namibia

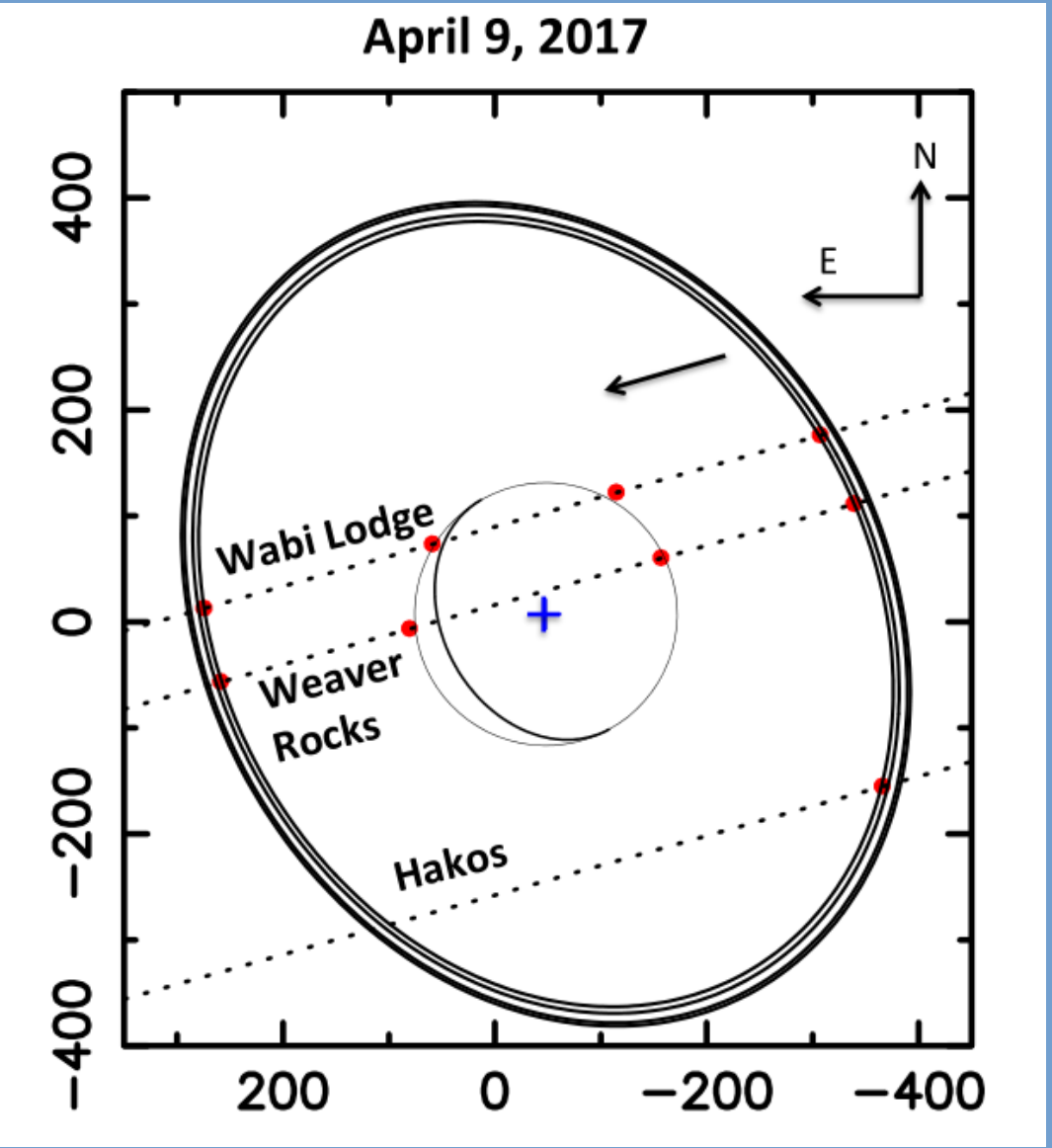
Post-occultation ground track



=> Prediction GDR1 + PM from UCAC4 + NIMA v11 was very accurate

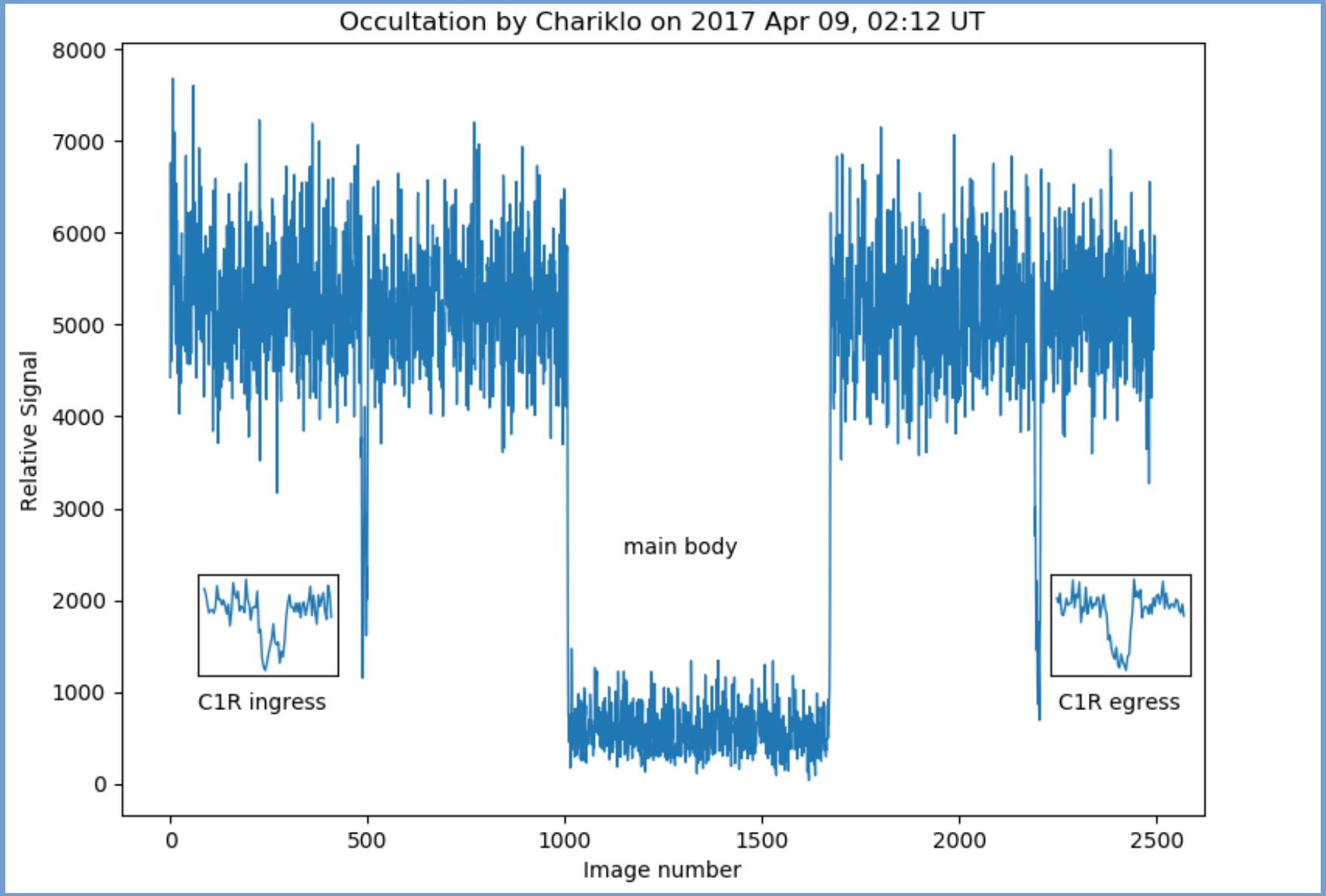
Credit: Diane Berard, LESIA, Obs. Paris Meudon

Occultation 2017 Apr 9 in Namibia



Credit: Diane Berard, LESIA, Obs. Paris Meudon

M2 telescope 50 cm f/4 @ ~12 Hz sampling rate



Observations Apr 9 (Namibia)

Station	Telescope	Body / Ring(s)	Observer(s)
Wabi Lodge	30-cm Meade SCT	Both	Jean-Luc Dauvergne
Weaver's Rock Guestfarm	50-cm Alt-Az telescope "M2"	Both	Mike Kretlow
Outeniqua Guestfarm	40-cm Alt-Az telescope	Clouds	Erick Meza, Martin Scheffel
Cuno Hoffmeister Memorial Observatory	36-cm Celestron SCT	Clouds	Michael Backes
ATOM (H.E.S.S. site)	80-cm telescope	Clouds	Felix Jankowsky
Hakos Astro-Farm (IAS)	50-cm telescope "AK3"	Ring ?	Karl-Ludwig Barth

6 stations, 2 positive observations

The M2 telescope in Namibia (Weaver's Rock Guestfarm, April 09)

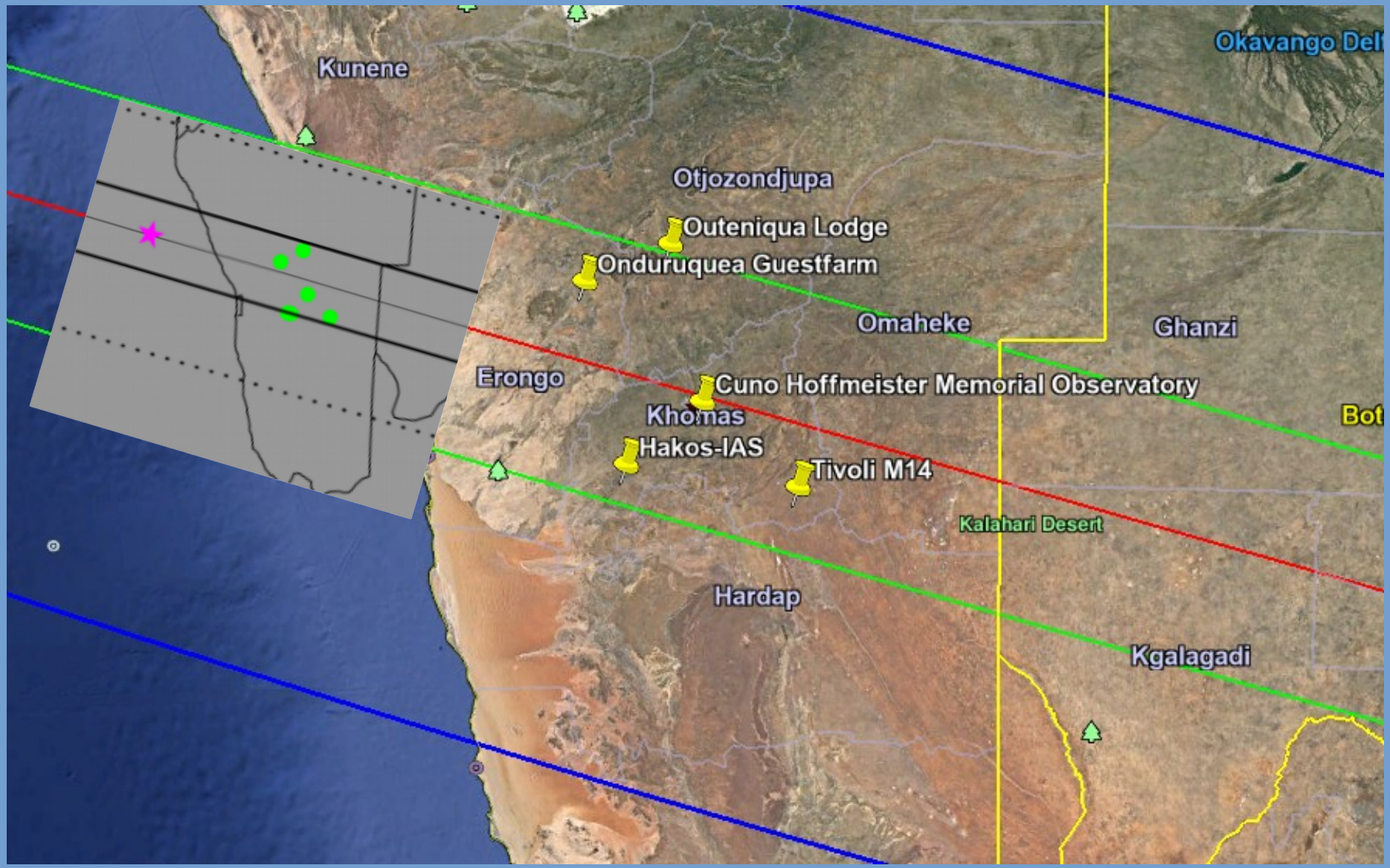
Prediction: 2017 Jun 22

In the table below Gaia presents the three stellar positions to the astronomy community, taken from preliminary Gaia DR2 data, for epoch 2015.5 in the ICRF reference frame.

Object to be observed	Description	Chariklo	Chariklo	Triton
Date of occulation event		22 June 2017	23 July 2017	5 October 2017
Gaia DR2 source ID		6760223758801661440	6737020112089260672	2610107911326516992
Epoch / Reference frame		2015.5 / ICRF	2015.5 / ICRF	2015.5 / ICRF
Right Ascension (RA) [degrees]	\alpha	283.81521653659905	282.038419778835	343.5768010149869
RA uncertainty [mas]	\sigma_{\alpha *}	0.0522238599934819	0.03963777263392541	0.026564074030629107
Declination (DEC) [degrees]	\delta	-31.522685159905006	-31.442346425165297	-8.002309358044462
DEC uncertainty [mas]	\sigma_{\delta}	0.05225161762414635	0.03900893618378824	0.022142168821058843
Proper Motion in Right Ascension (PM in RA) [mas/yr]	\mu_{\alpha *}	3.2099344713972338	4.026596025279473	27.513673140123508
Uncertainty of PM in RA [mas/yr]	\sigma_{\mu\alpha *}	0.12086068017989549	0.07293067963207914	0.053522387226693335
Proper Motion in Declination (PM in DEC) [mas/yr]	\mu_{\delta}	-2.010735262831512	-6.219325688340016	-1.8210553401369338
Uncertainty of PM in DEC [mas/yr]	\sigma_{\mu\delta}	0.10194645902097235	0.0655658281047265	0.045857682351872736
Parallax [mas]	\varpi	0.1572409701013944	0.14967444548457415	1.8956730873515917
Parallax uncertainty [mas]	\sigma_{\varpi}	0.06086506896517232	0.04228961058438762	0.028530840302218616

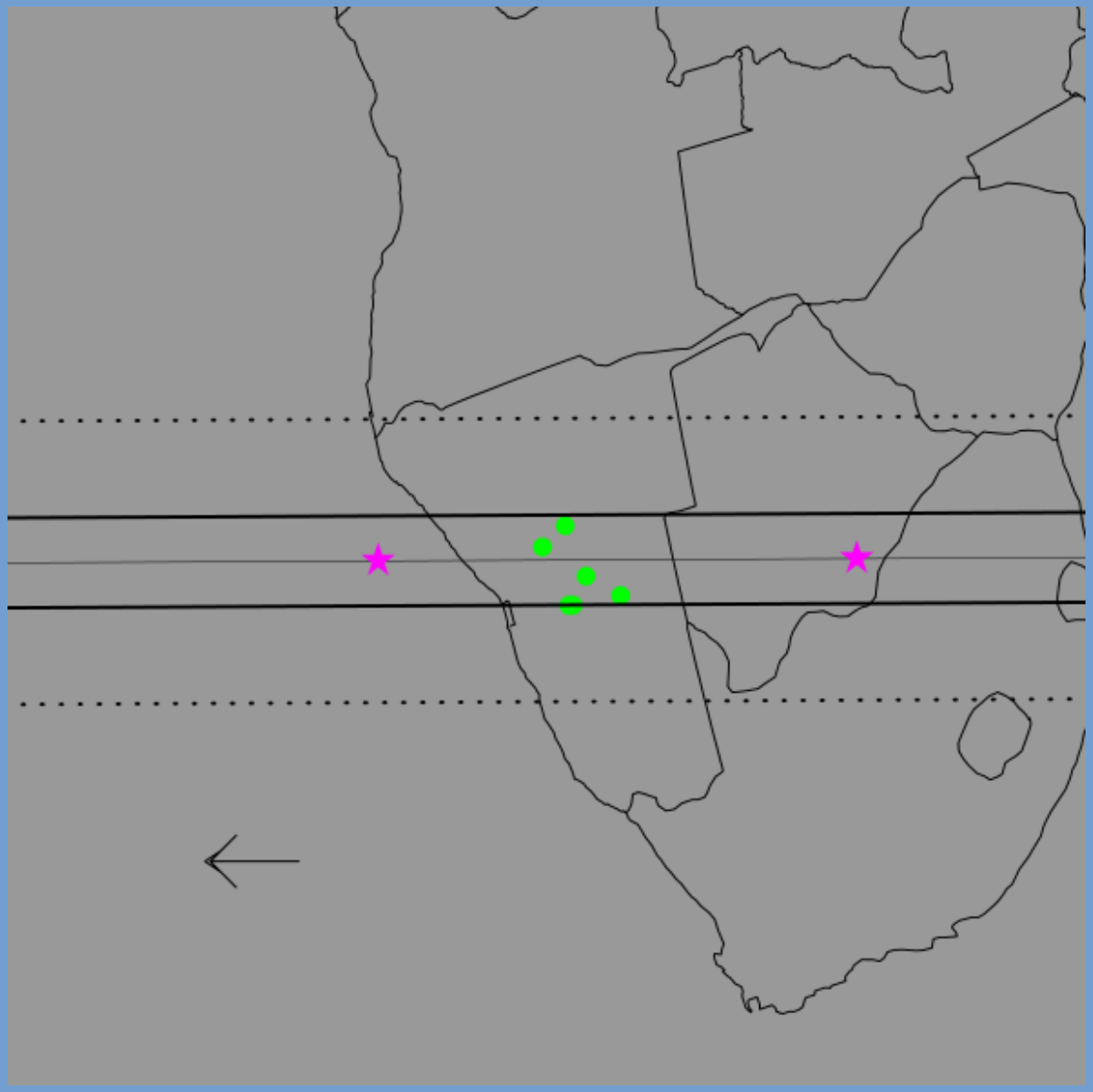
Table: Preliminary data from Gaia DR2 on three stars provided for occultation observations of Chariklo and Triton. (Credit: ESA/Gaia/DPAC, please follow the acknowledgment guidelines as given here and please also cite the Gaia mission paper)

Prediction: GDR2 + NIMA v12



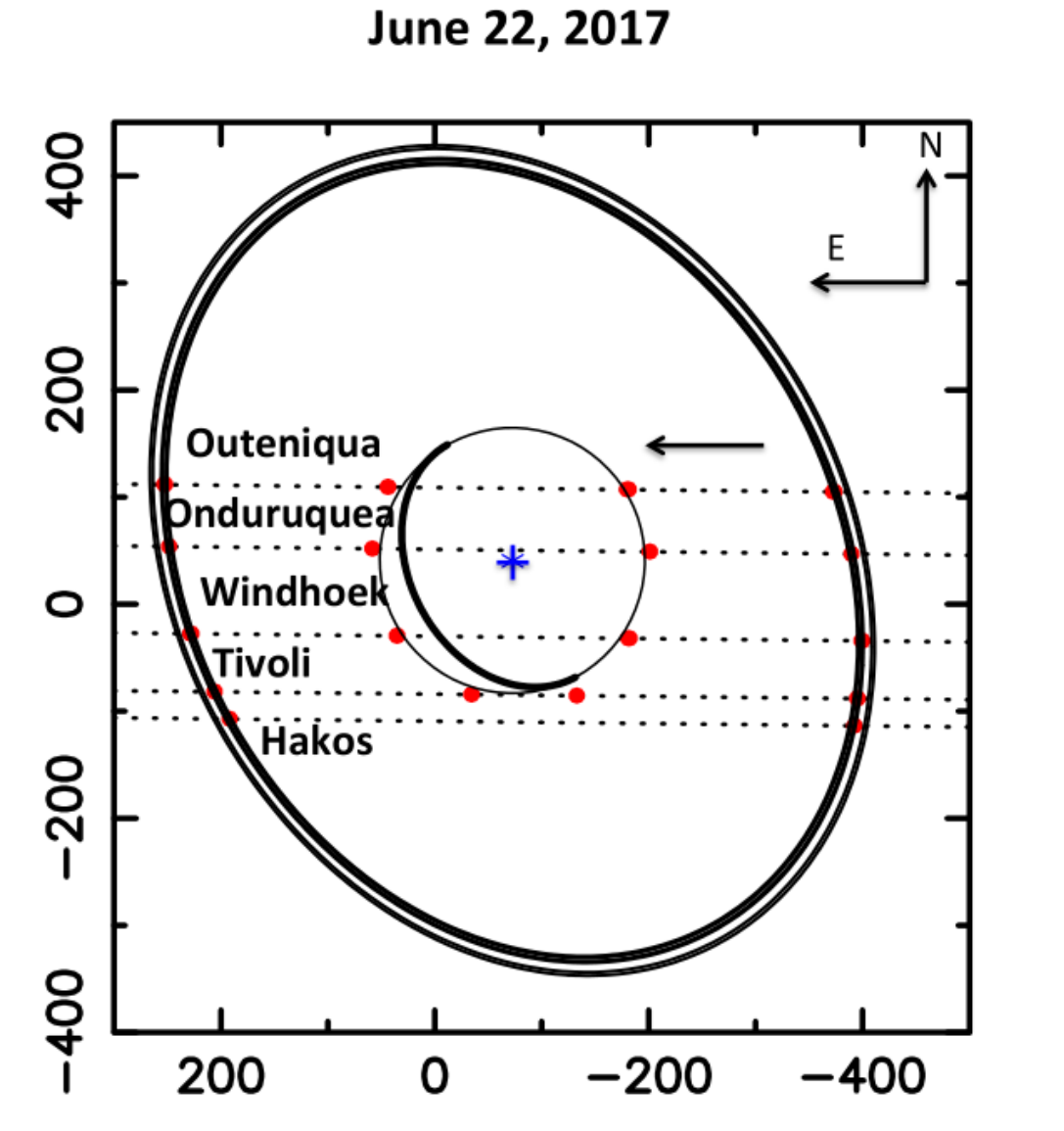
Occultation 2017 Jun 22: Namibia

Post-occultation ground track



Credit: Diane Berard, LESIA, Obs. Paris Meudon

Occultation 2017 June 22

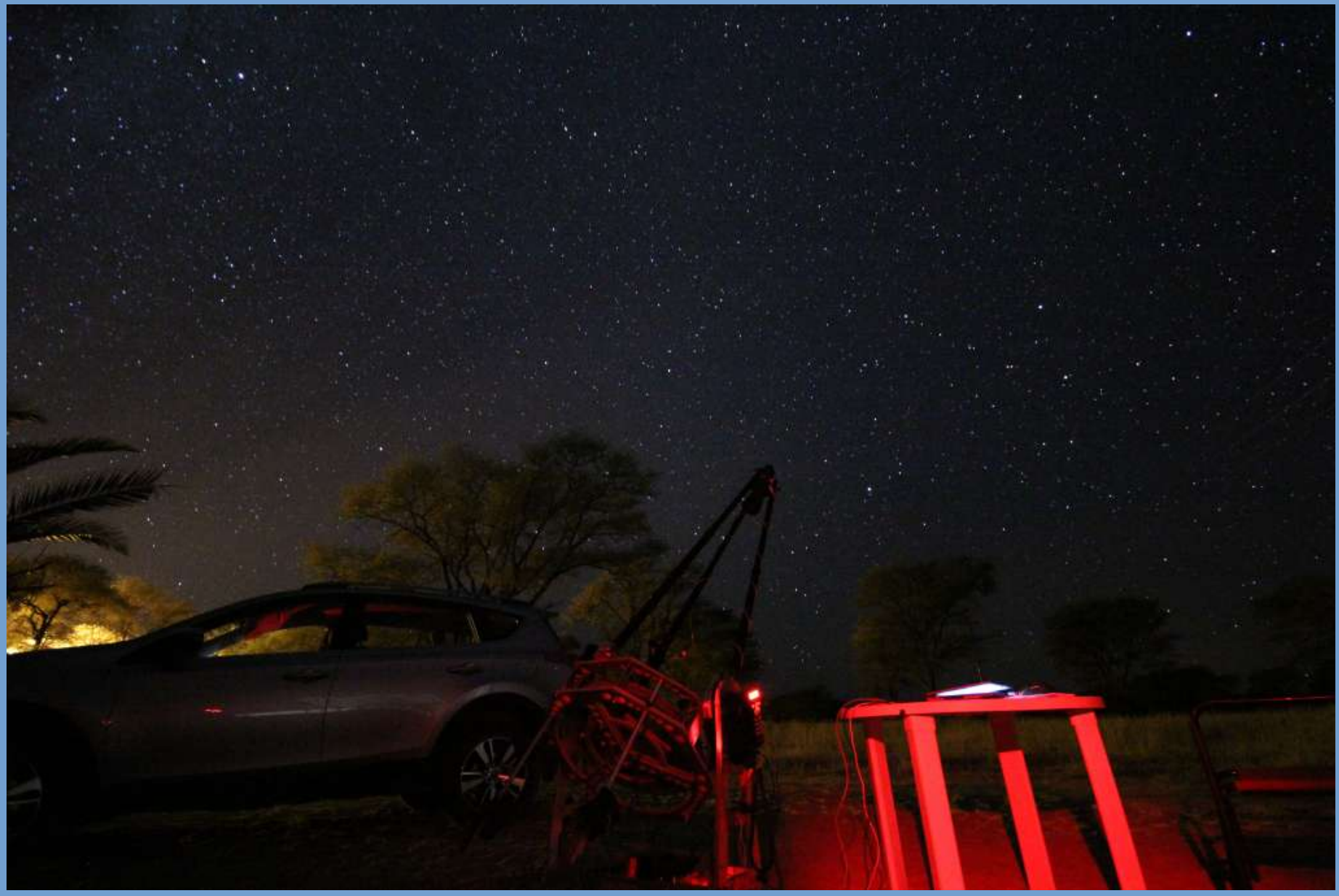


Credit: Diane Berard, LESIA, Obs. Paris Meudon

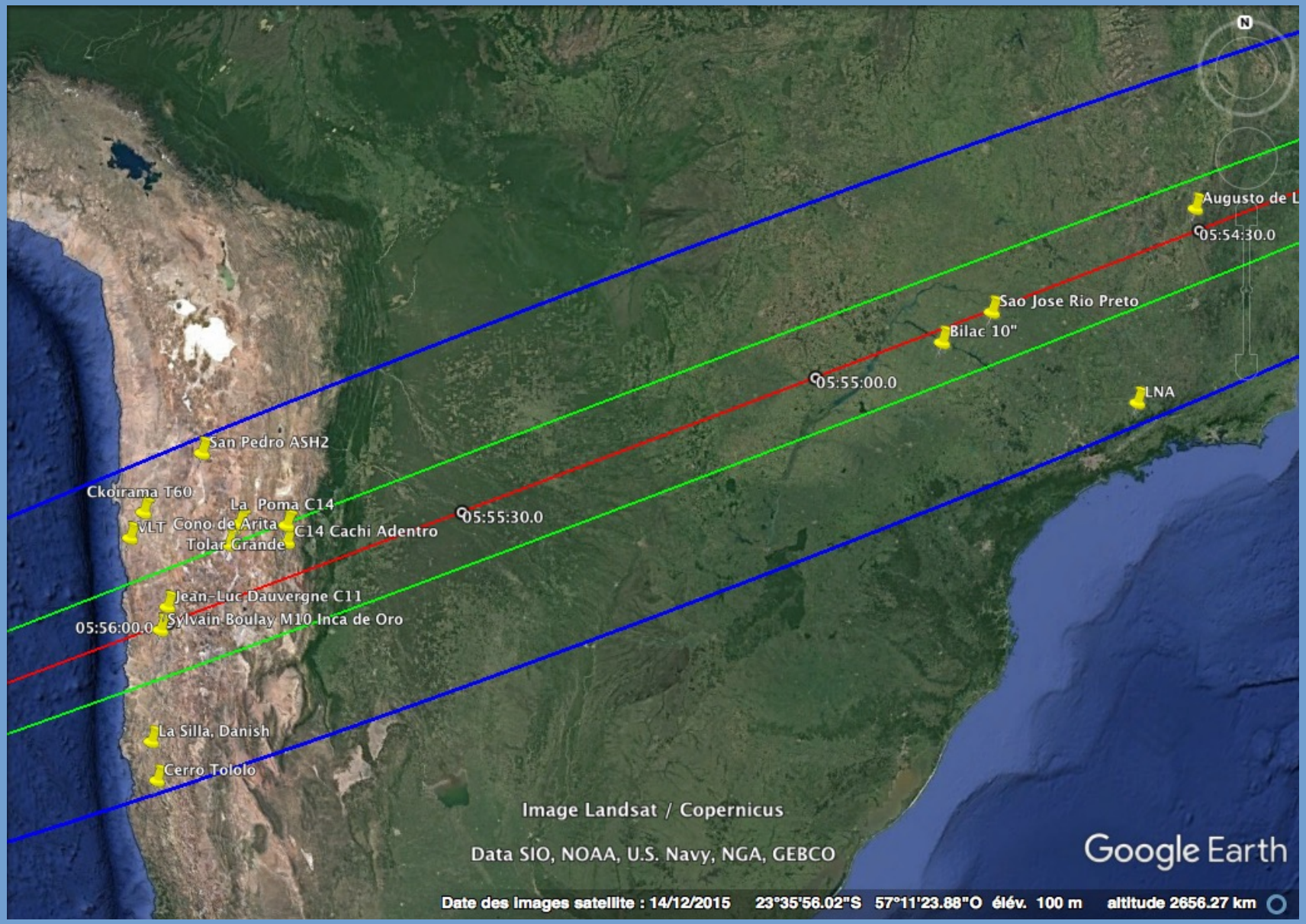
Observations June 22 (Namibia)

Station	Telescope	Body / Ring(s)	Observer(s)
Outeniqua Guestfarm	30-cm Meade SCT	Both	Francois Colas, Josselin Desmars
Onduruquea Guestfarm	50-cm Alt-Az telescope “M2”	Both	Mike Kretlow
Cuno Hoffmeister Memorial Observatory	40-cm Alt-Az telescope	Both	Erick Meza
Cuno Hoffmeister Memorial Observatory	36-cm Celestron SCT	Both	Michael Backes, Rhodri Evans
ATOM (H.E.S.S. site)	80-cm telescope	???	Felix Jankowsky
Tivoli Astro-Farm	36-cm Meade SCT	Both	Lucie Maquet, Konstantin v. Poschinger
Hakos Astro-Farm (IAS)	50-cm telescope “AK3”	Ring	Wolfgang Beisker

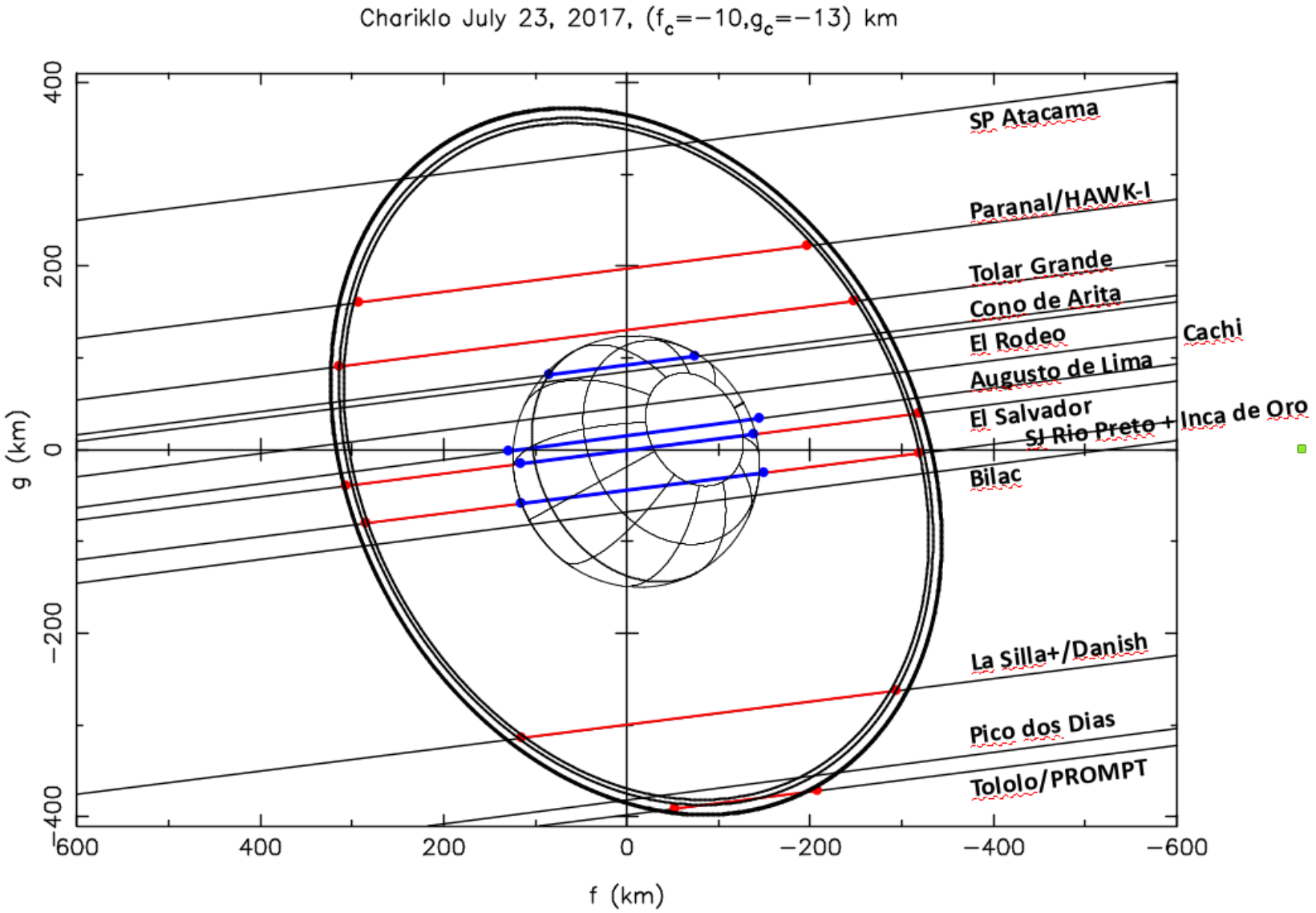
7 stations, 6 positive observations



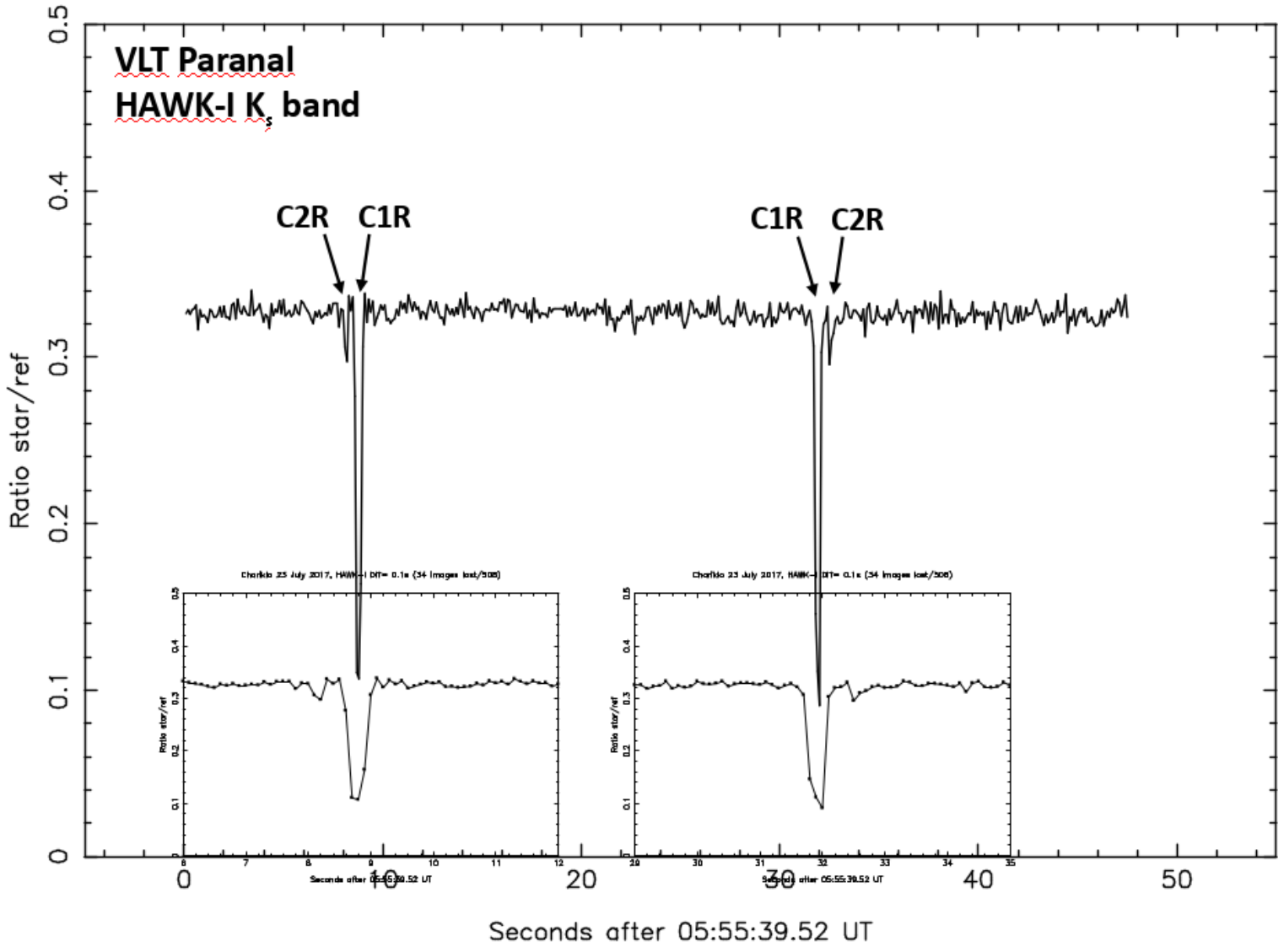
Occultation 2017 July 23



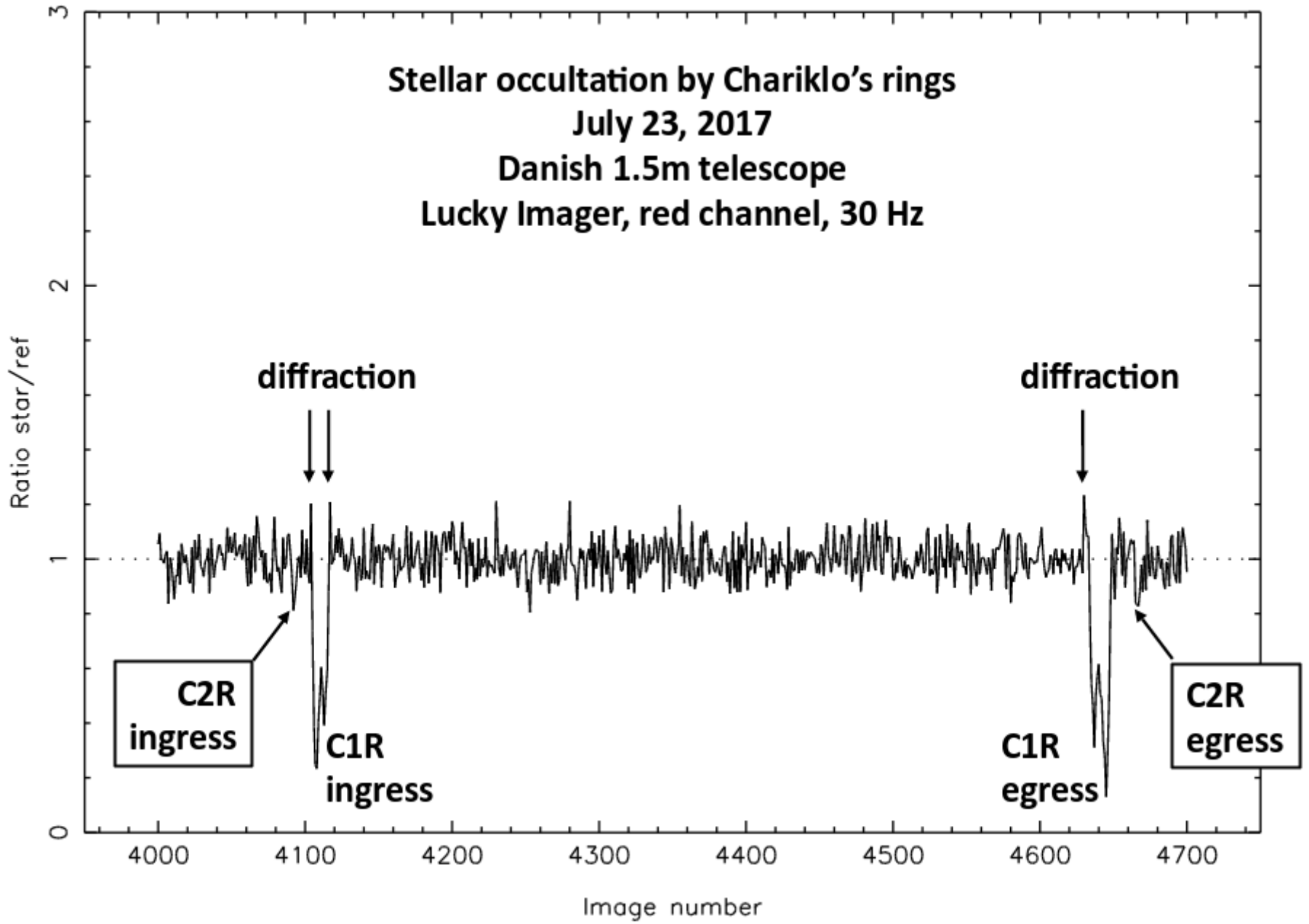
Credit: Bruno Sicardy, LESIA, Obs. Paris Meudon

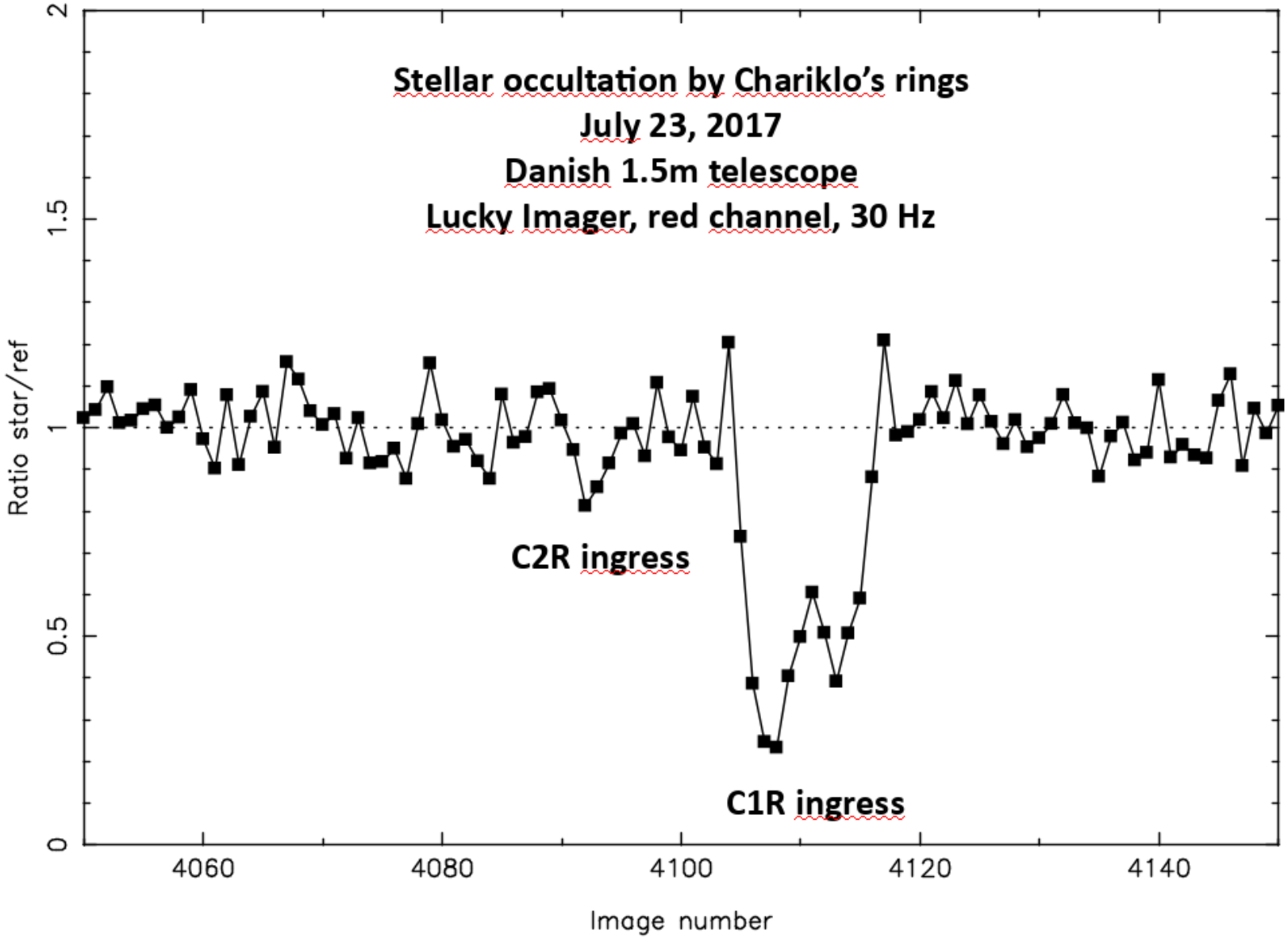


Credit: Bruno Sicardy, LESIA, Obs. Paris Meudon

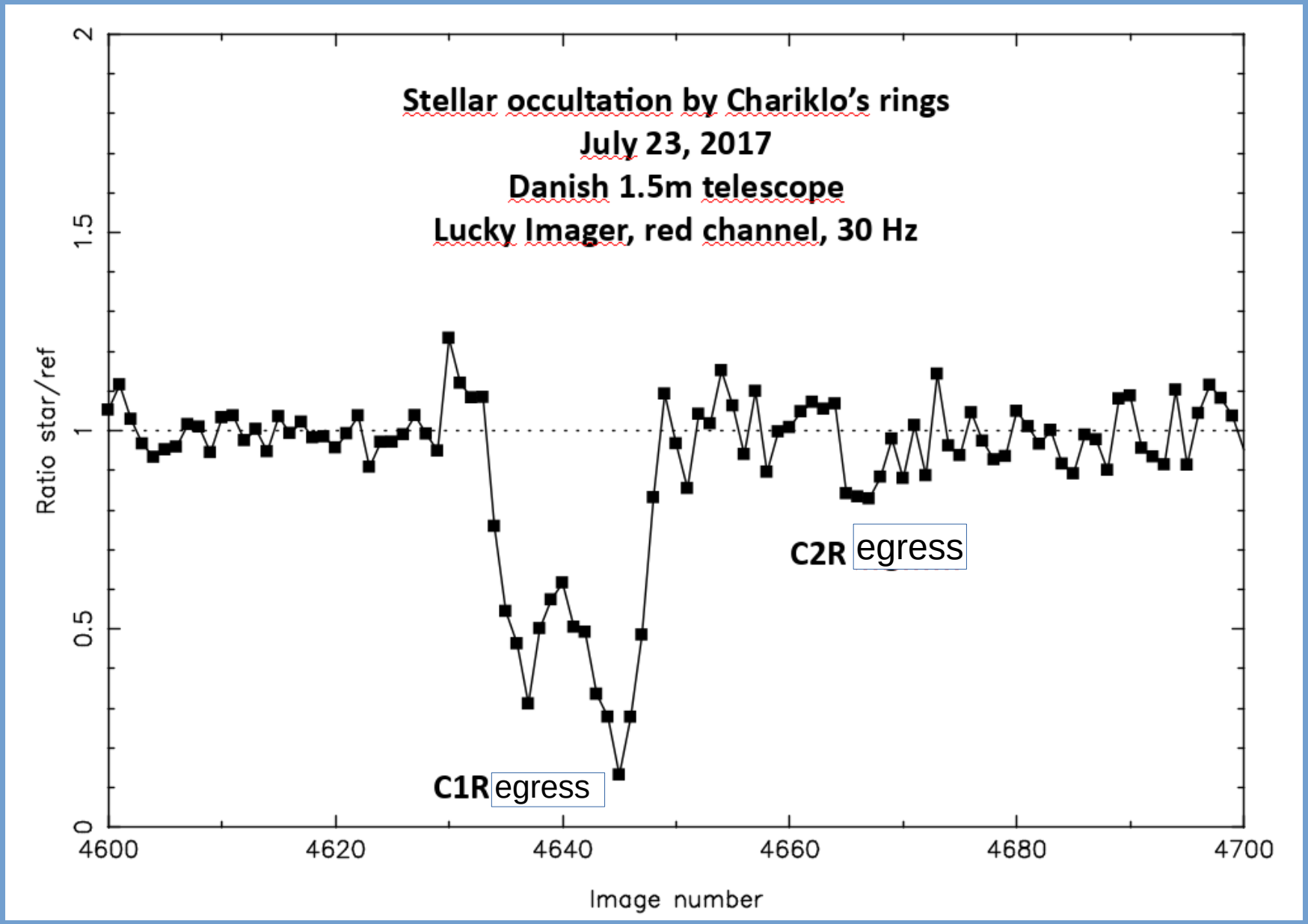


Credit: Bruno Sicardy, LESIA, Obs. Paris Meudon


Stellar occultation by Chariklo's rings
July 23, 2017
Danish 1.5m telescope
Lucky Imager, red channel, 30 Hz
diffraction
diffraction
C2R ingress
C1R ingress
C1R egress
C2R egress
Ratio star/ref
Image number
0
1
2
3
4000
4100
4200
4300
4400
4500
4600
4700

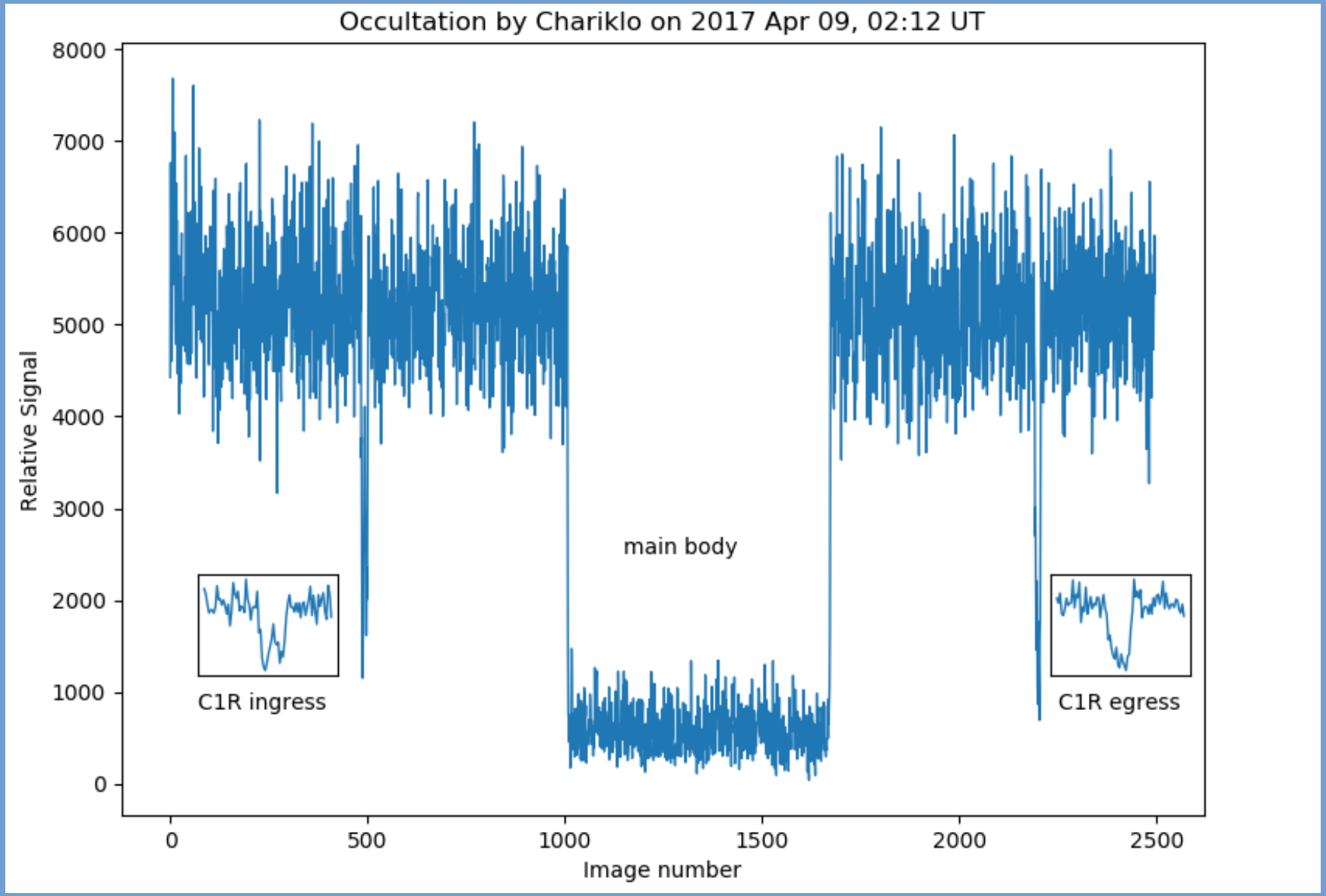


Credit: Bruno Sicardy, LESIA, Obs. Paris Meudon



Credit: Bruno Sicardy, LESIA, Obs. Paris Meudon

M2 telescope 50 cm f/4 @ ~12 Hz sampling rate



Tolar Grande, Argentina, 148 habitants (?)


MEADE

Summary of 2017 campaign

Date	# stations	# chords
April 9	6	2
June 22	7 (6)	6 (7)
July 23	>= 15	13
Total	>= 28	21 (8: 2013-2016)

Conclusion

- 2017 campaign was a big success. All three scheduled events were observed. July 23 is the best ever observed occultation by Chariklo, at least in terms of coverage, etc.
- A lot of new data to study the ring system and to (re-)constrain the physical parameters (shape etc.) of the main body.
- Even with GDR1 positions (epoch 2015.0) the knowledge of PMs for TNO occultation is important. GDR2 !
- NIMA ephemeris for specific objects like Chariklo is very accurate (< 100 km on FP).

Still enough room for more science / open questions

- Origin and evolution of the ring system.
- (Shepard) moons ?
- Ring arcs ?
- Improve constrains of physical parameters (dimension, shape (rings !), mass & bulk density).
- ...

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- All the expedition participants
- Local observers and helpers
- IOTA-ES
- ...

Thank You for Your attention !