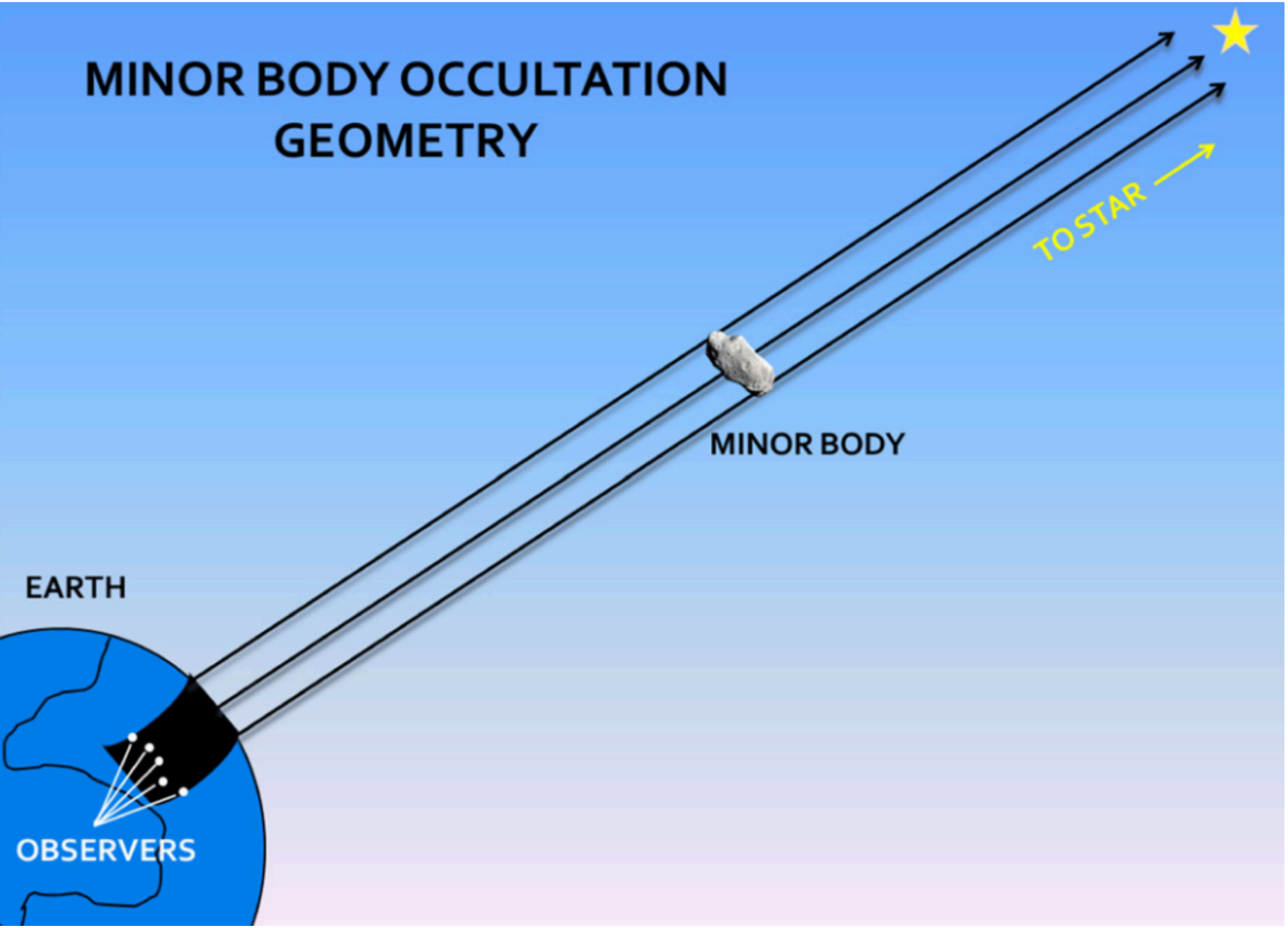
STRUCTURE AND EVOLUTION OF TRITON'S ATMOSPHERE USING STELLAR OCCULTATIONS

Joana Marques Oliveira

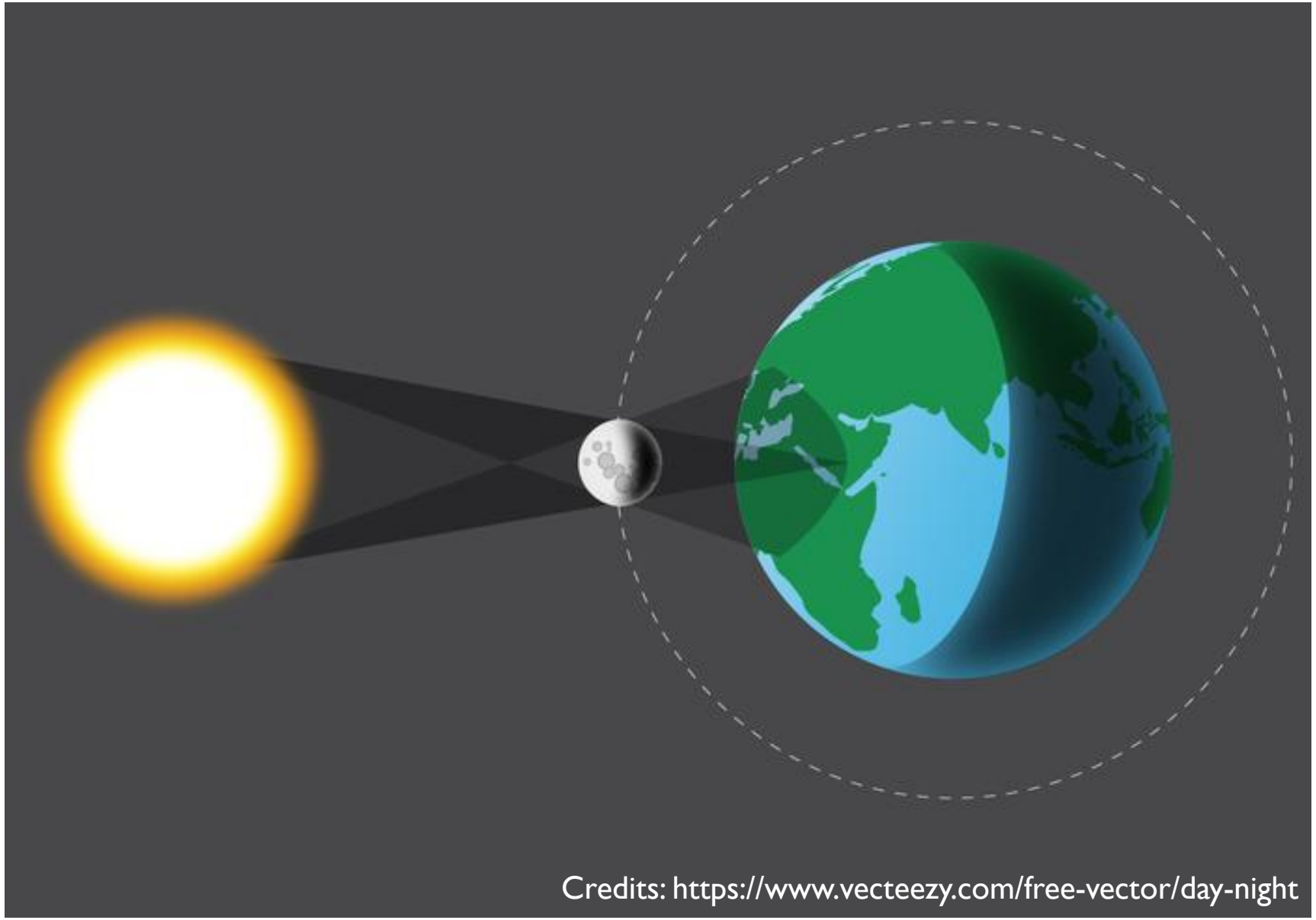
LESIA, Observatoire de Paris

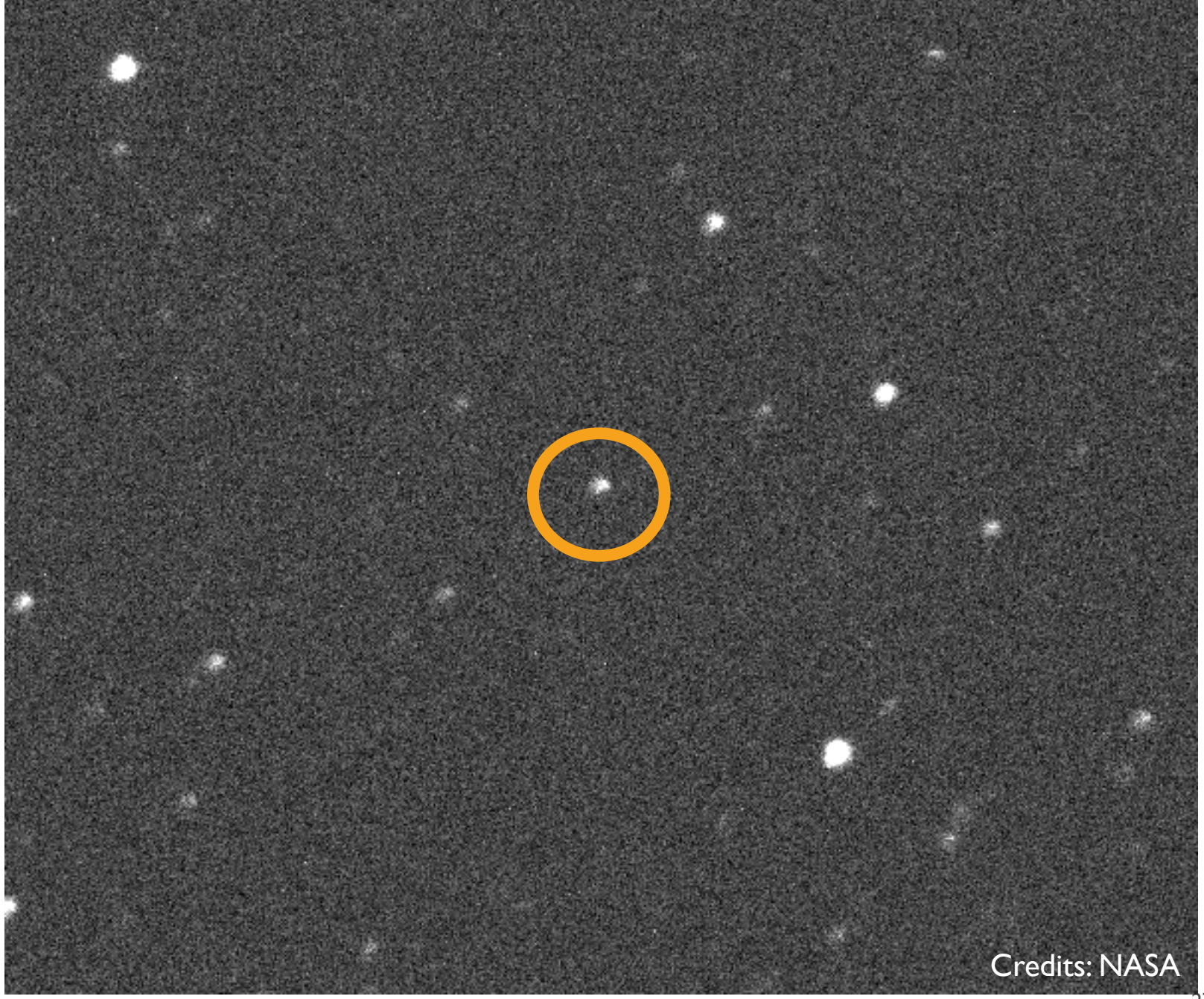
OCCULTATIONS

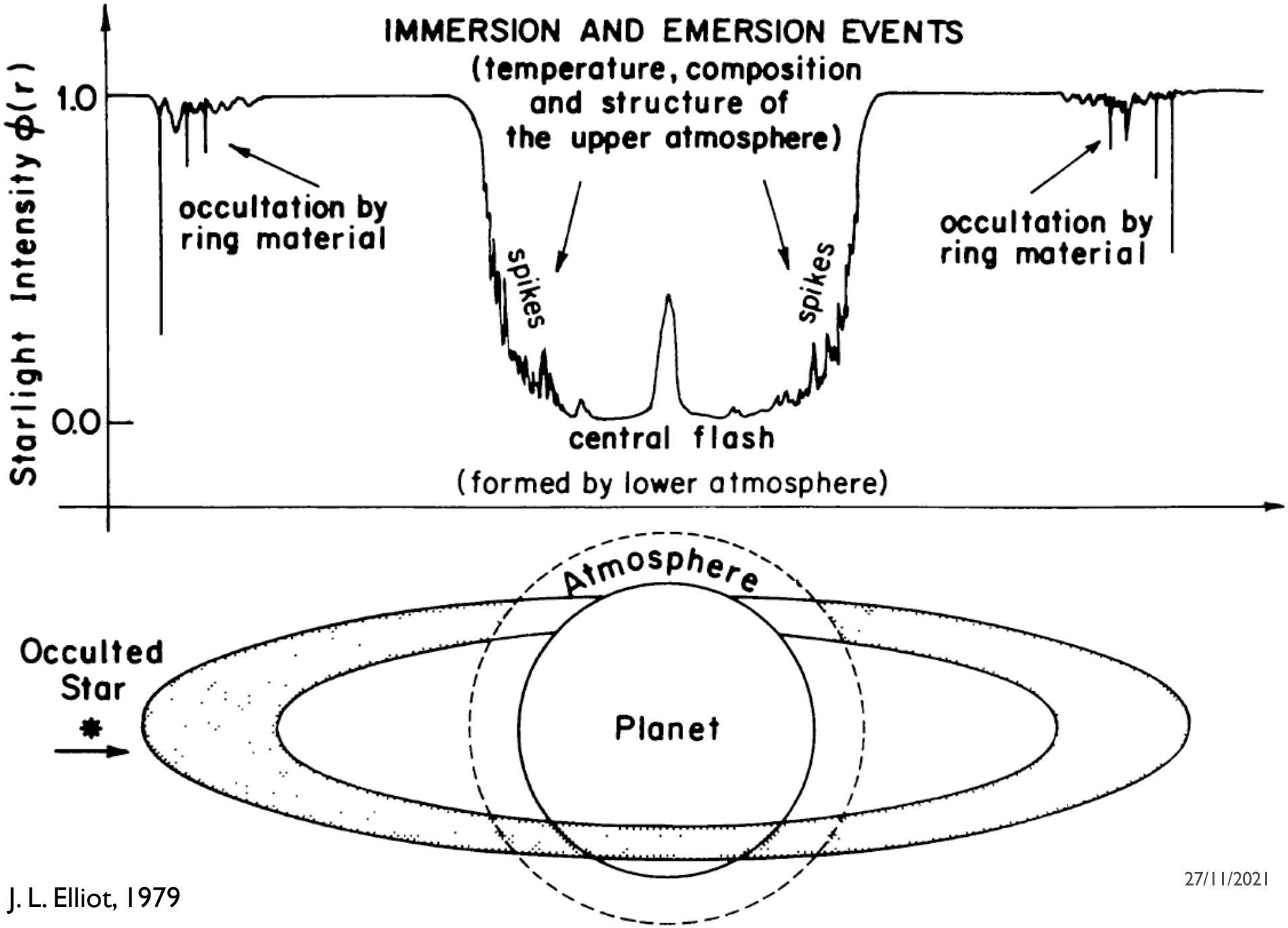
STELLAR OCCULTATIONS



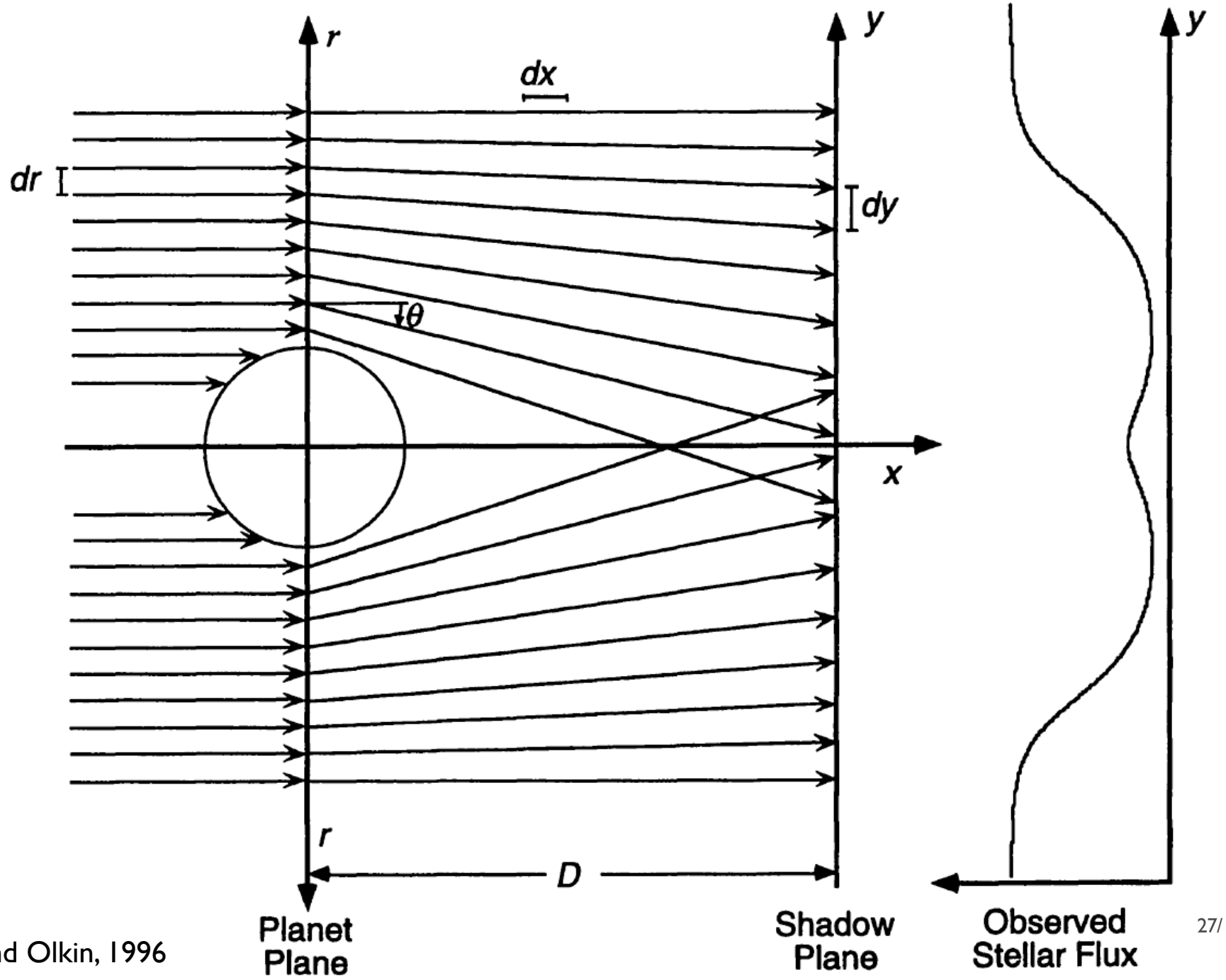
P. Santos-Sanz et al., 2016


Credits: https://www.vecteezy.com/free-vector/day-night

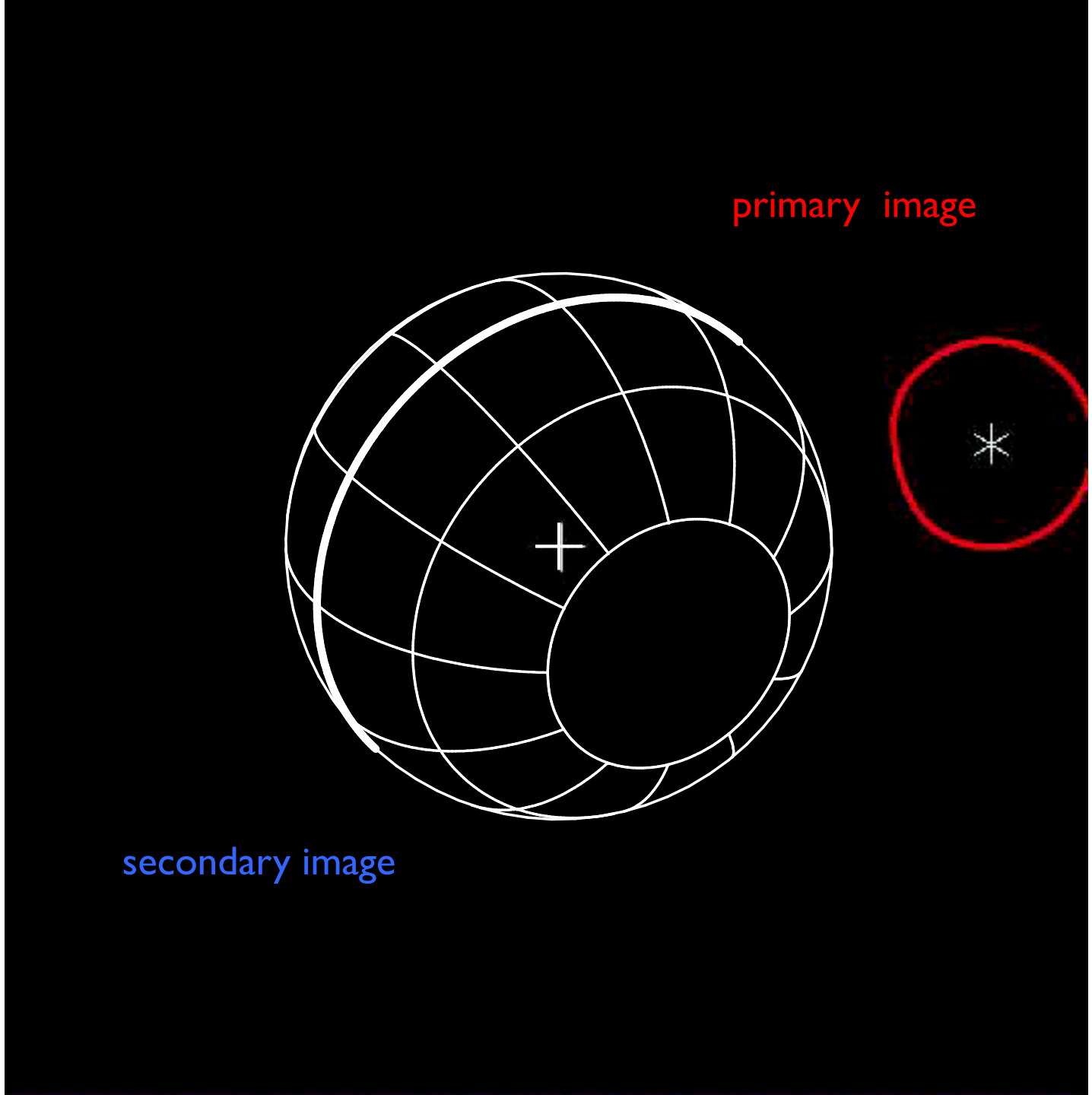

Credits: NASA

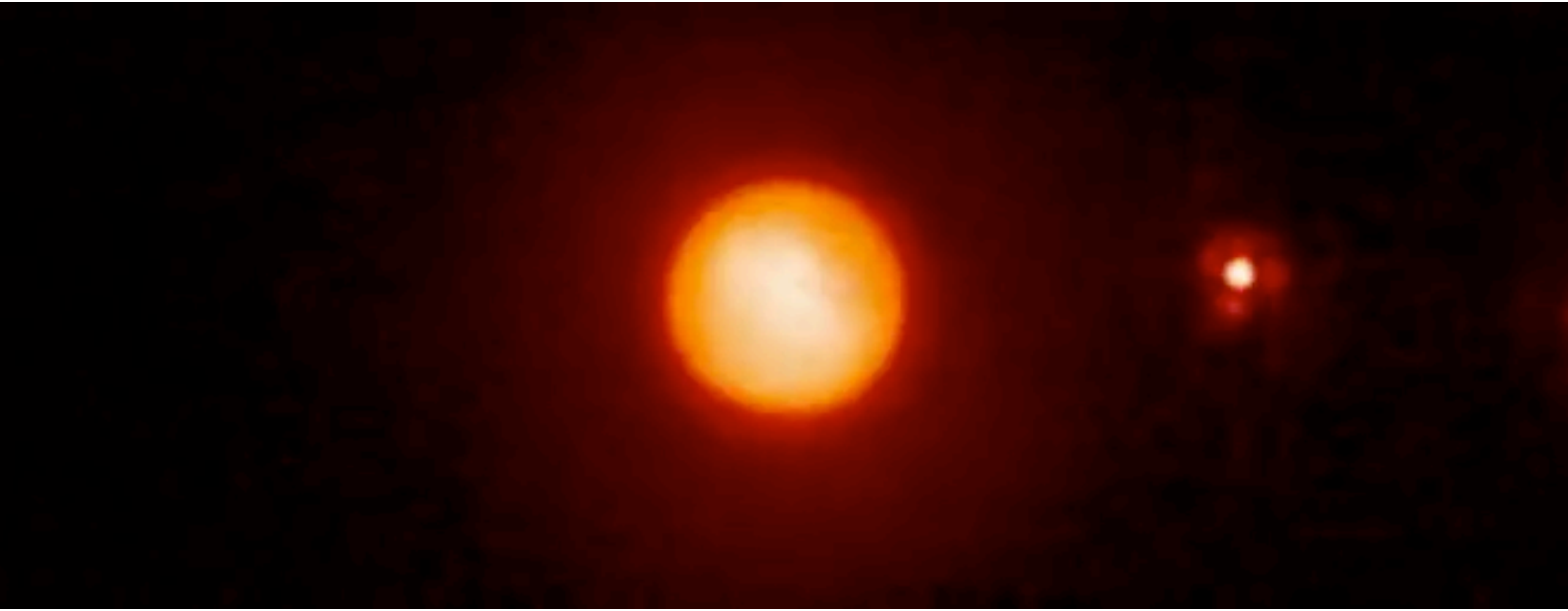


J. L. Elliot, 1979

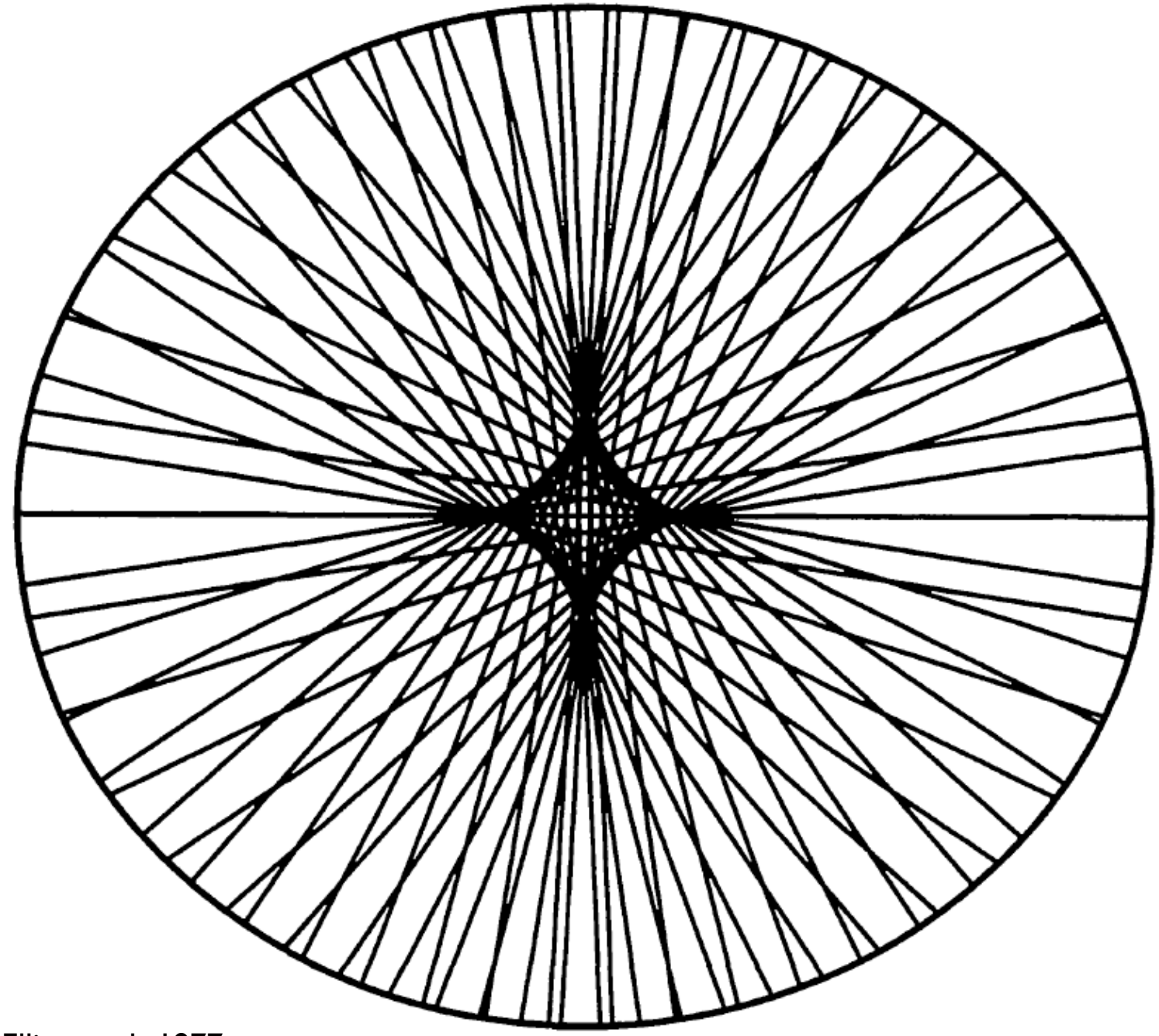


Elliot and Olkin, 1996

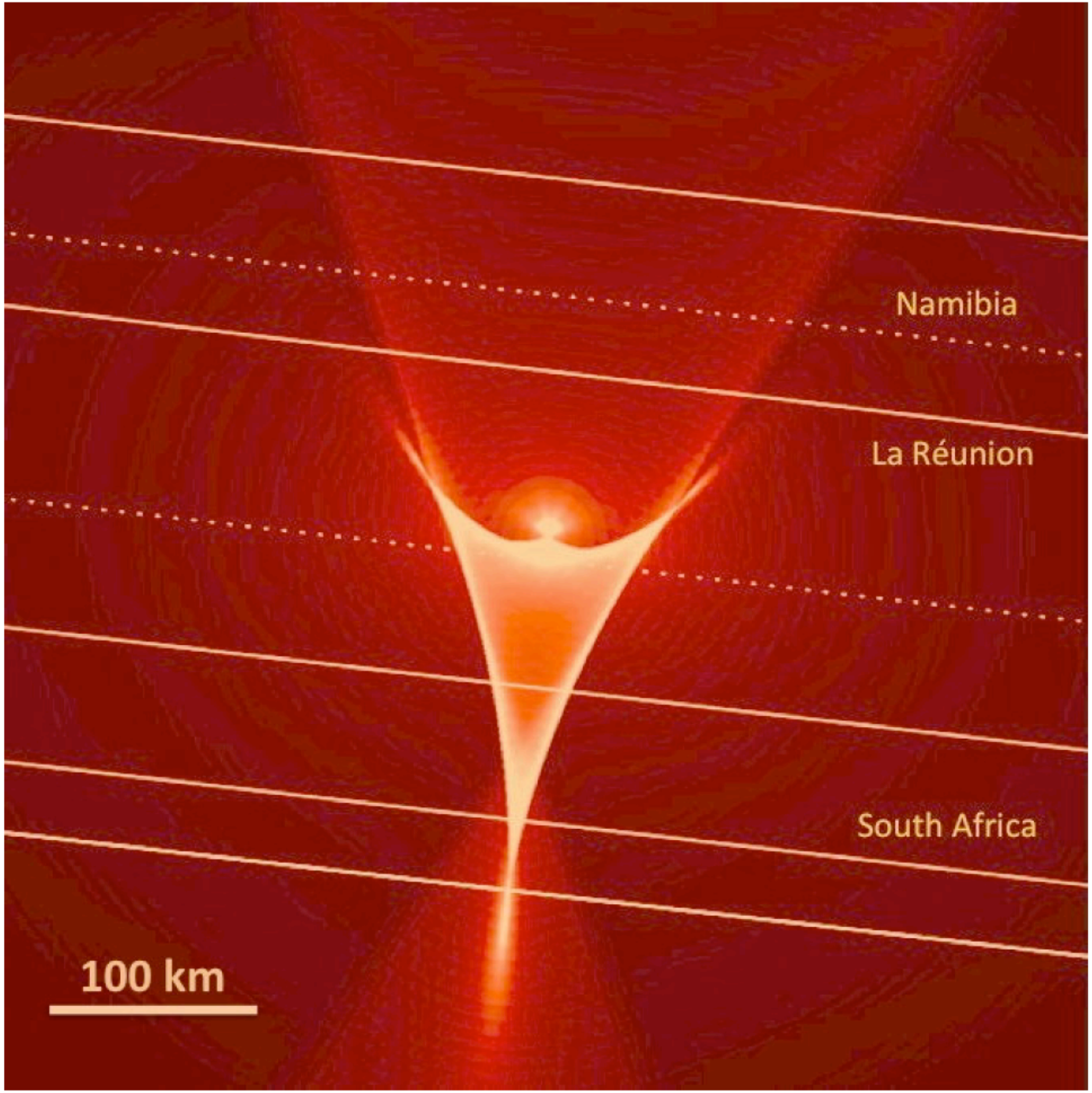

primary image
secondary image



A. H. Bouchez et al., 2003

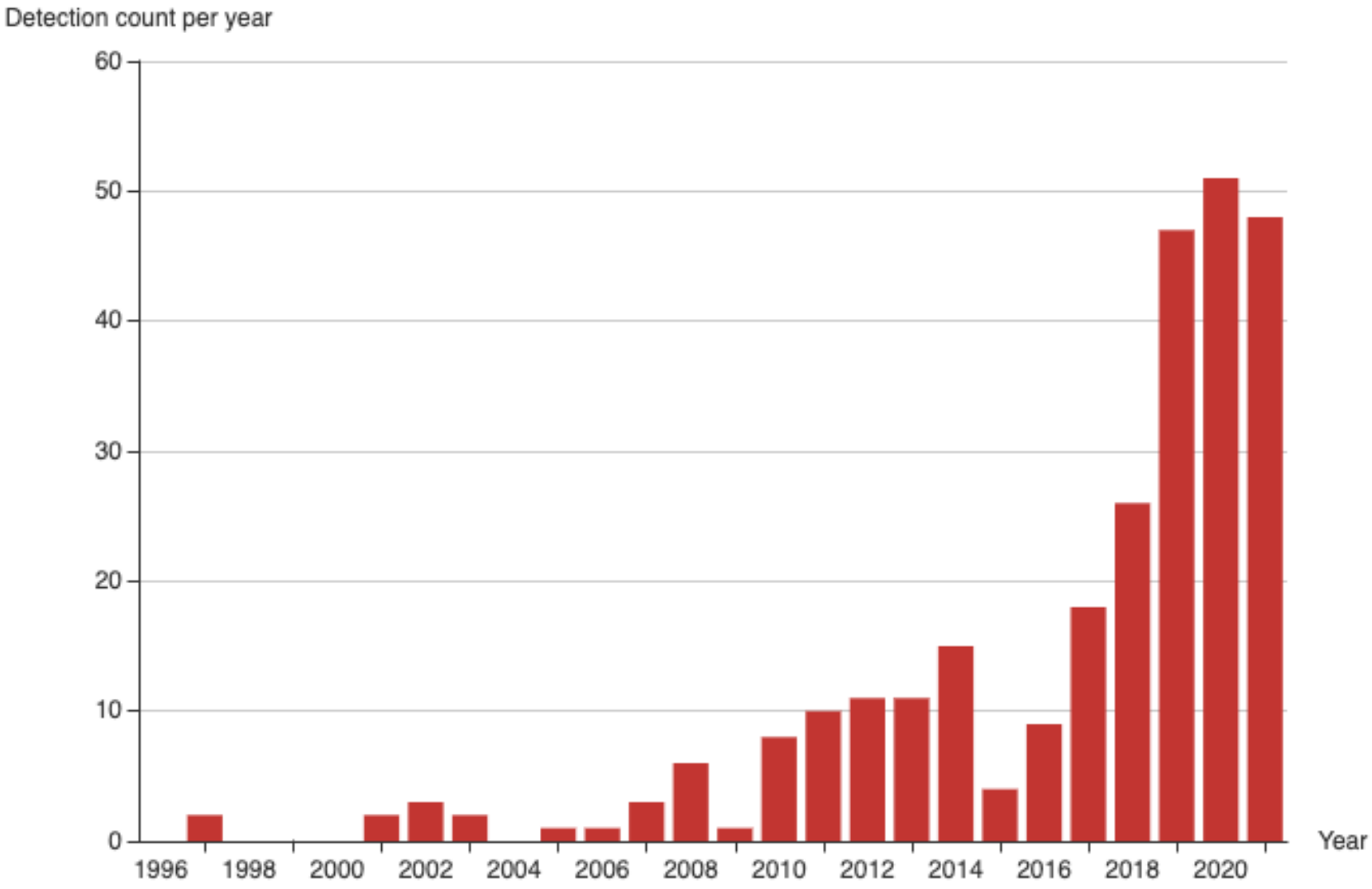


Elliot et al., 1977

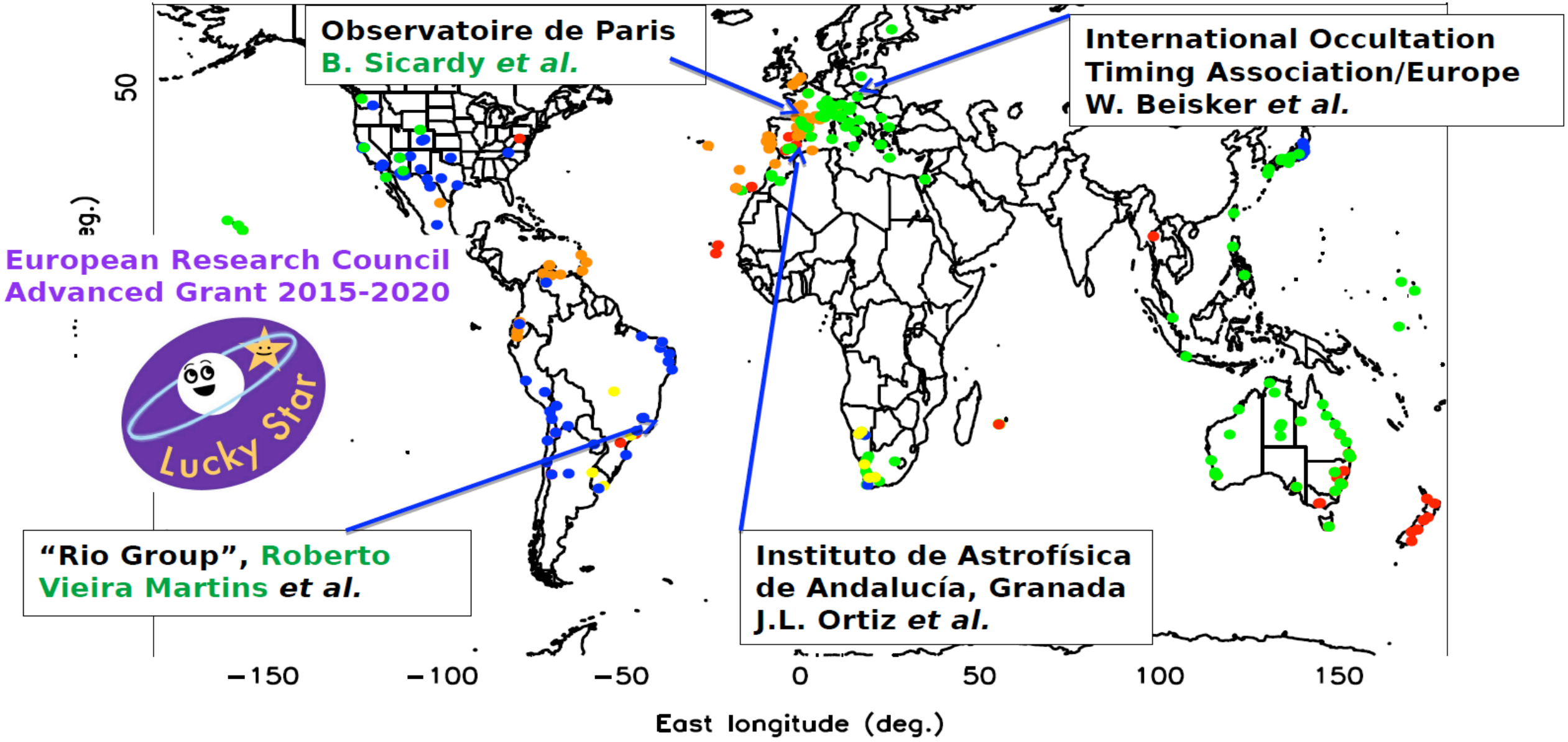


Sicardy et al., 2006

OCCULTATION EVENTS AND OBSERVATIONS



Credits: http://occultations.ct.utfpr.edu.br/results/


Observatoire de Paris
B. Sicardy et al.
International Occultation Timing Association/Europe
W. Beisker et al.
European Research Council
Advanced Grant 2015-2020
Lucky Star
"Rio Group", Roberto Vieira Martins et al.
Instituto de Astrofísica de Andalucía, Granada
J.L. Ortiz et al.
50
−150
−100
−50
0
50
100
150
East longitude (deg.)

ERC Lucky Star project

Laboratoire d'Études Spatiales et d'Instrumentation en Astrophysique

Home	Ephemerides	Predictions	Campaigns	Results	Publications	Team

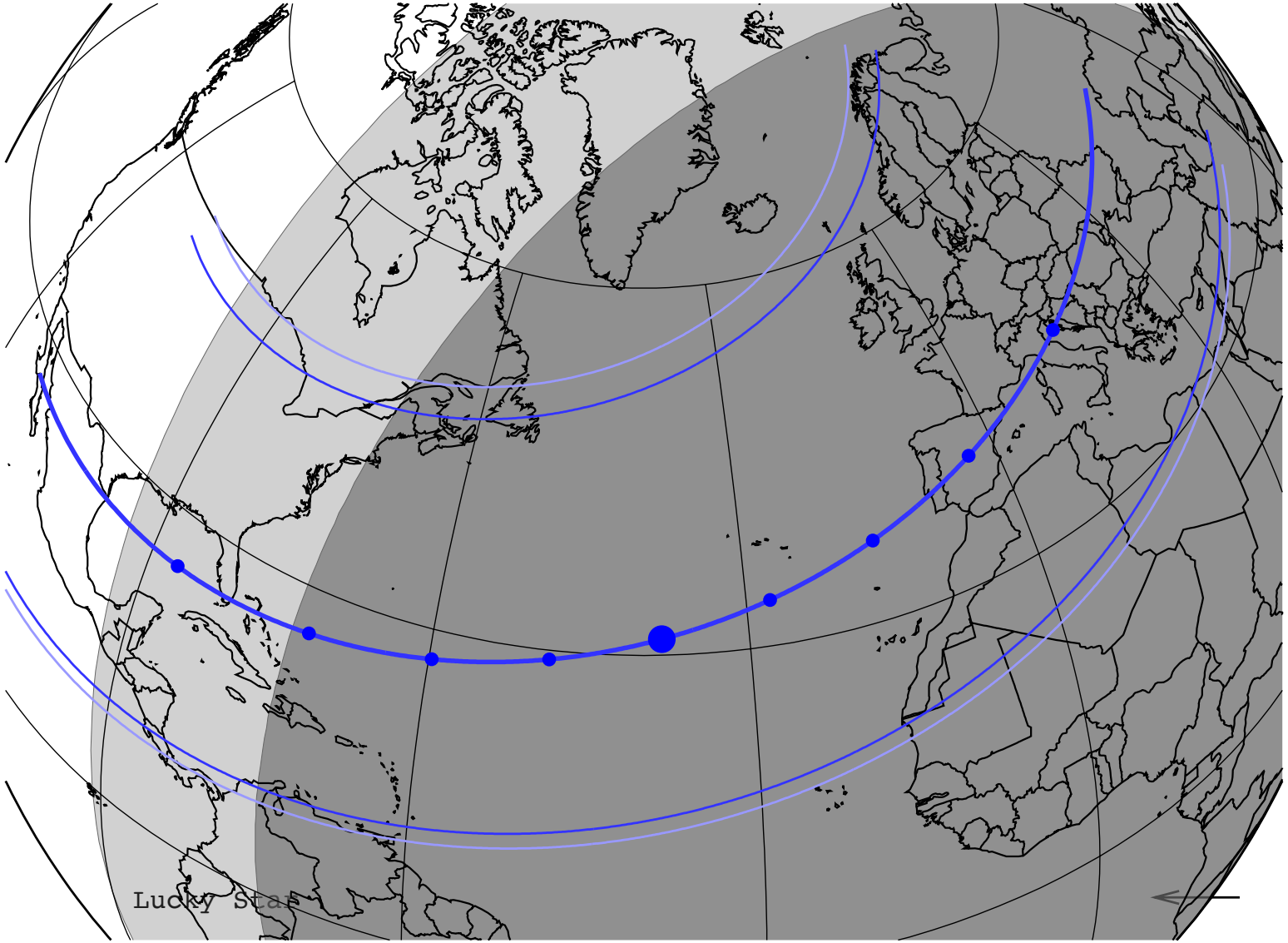
Lucky Star project

This page presents the **ERC project Lucky Star** whose aim is to study the solar system beyond Neptune with stellar occultations. The project is led by Bruno Sicardy in collaboration with groups from Paris, Meudon, Granada and Rio.

The solar system beyond Neptune contains largely unaltered material from the primordial circumsolar disk. It also kept the memory of the early planetary migrations, and thus contains essential information on the origin and evolution of our planetary system. The aim of the project is to study the Trans-Neptunian Objects (TNOs) using the stellar occultation technique. It consists in observing the passage of remote TNOs in front of those "*Lucky Stars*", that reveal shapes, atmosphere and rings of bodies from sub-km to thousand-km in size. Very few teams in the world

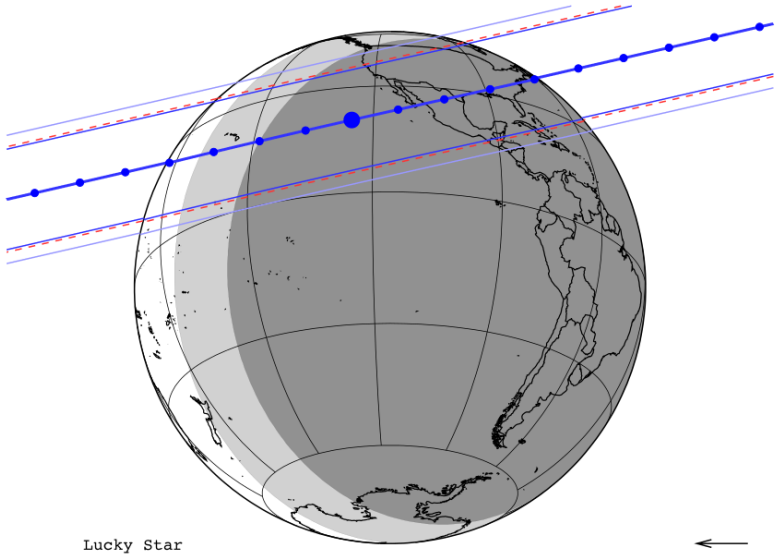
HTTPS://LESIA.OBSPM.FR/LUCKY-STAR/

Triton, GAIADR2+pmGaiaDR2, JPLnep081de435 Offset: 7.8mas -17.6mas



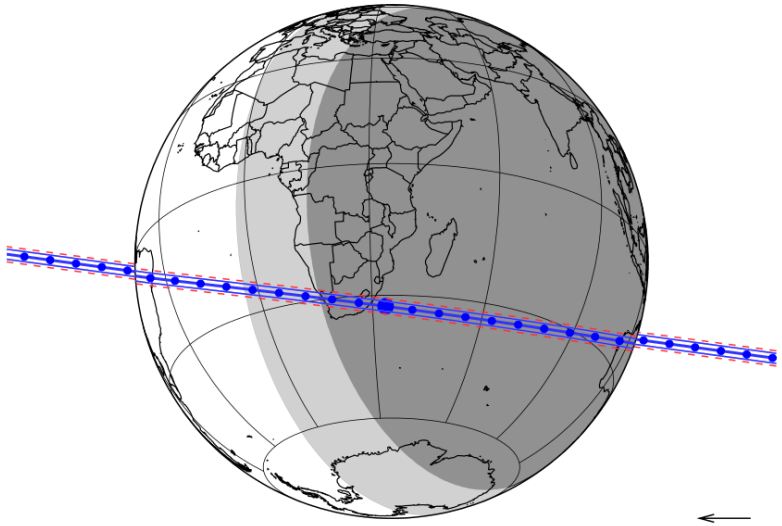
dd mm yyyy hh:mm:ss.s	RA_star_J2000	DE_star_J2000	C/A	P/A	vel	Delta	G*	J*
2017-10-05 23:51:36.5	22 54 18.4364	-08 00 08.318	0.195	347.50	-16.80	29.0807	12.0	11.0

Pluto, GAIADR2+pmGAIADR2, NIMAv6PLU055 Offset: 0.0mas 0.0mas



yyyy mm dd hh:mm:ss.s	RA_star_J2000	DE_star_J2000	C/A	P/A	vel	Delta	G*	RP*
2018-08-15 05:33:09.7	19 22 10.4687	-21 58 49.020	0.180	347.11	-19.33	32.7670	13.0	12.5

Chariklo, GAIADR2+pmGAIADR2, NIMAv17 Offset: 0.0mas 0.0mas
updated: 2019-09-07 by Lucky Star



yyyy mm dd hh:mm:ss.s	RA_star_J2000	DE_star_J2000	C/A	P/A	vel	Delta	G*	RP*	H*
2020-09-11 18:03:31.0	19 47 14.8167	-22 29 49.263	0.096	187.72	-10.79	15.8925	18.0	17.4	99.9

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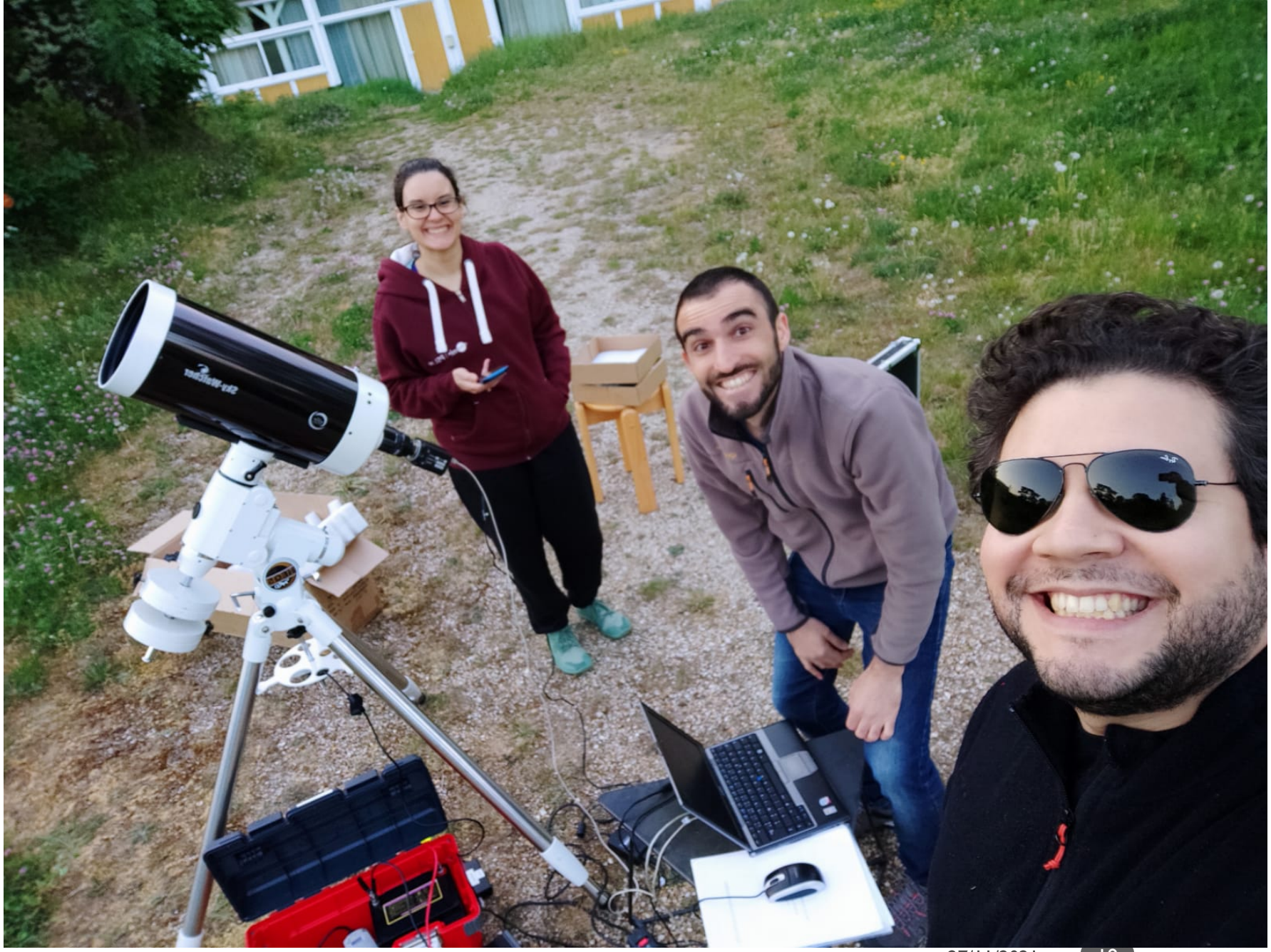
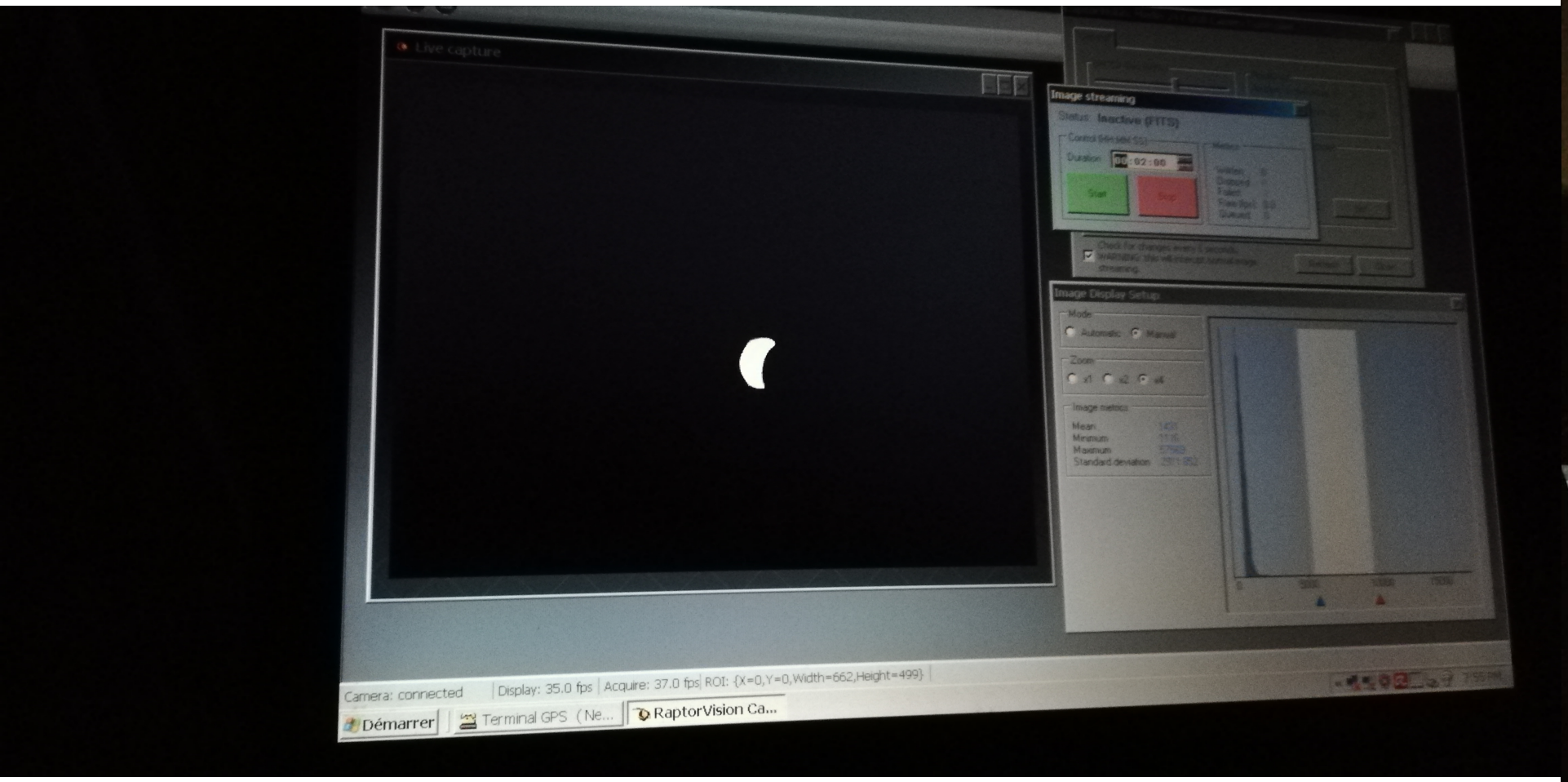
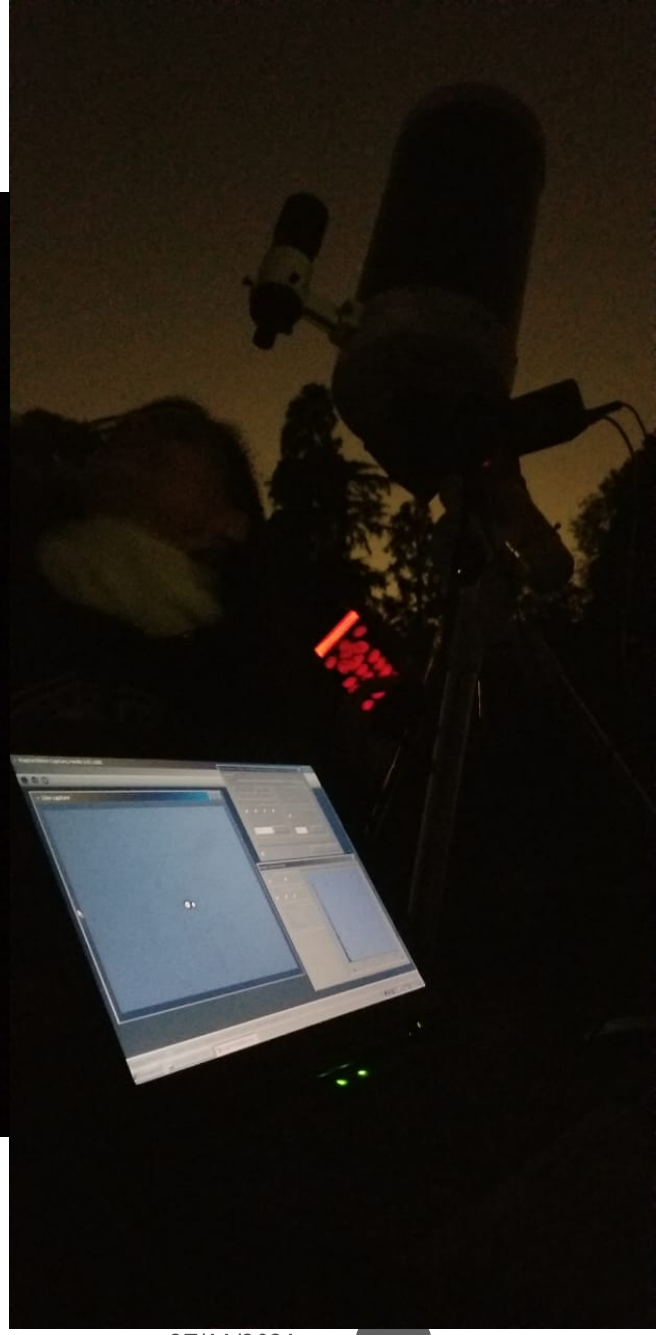
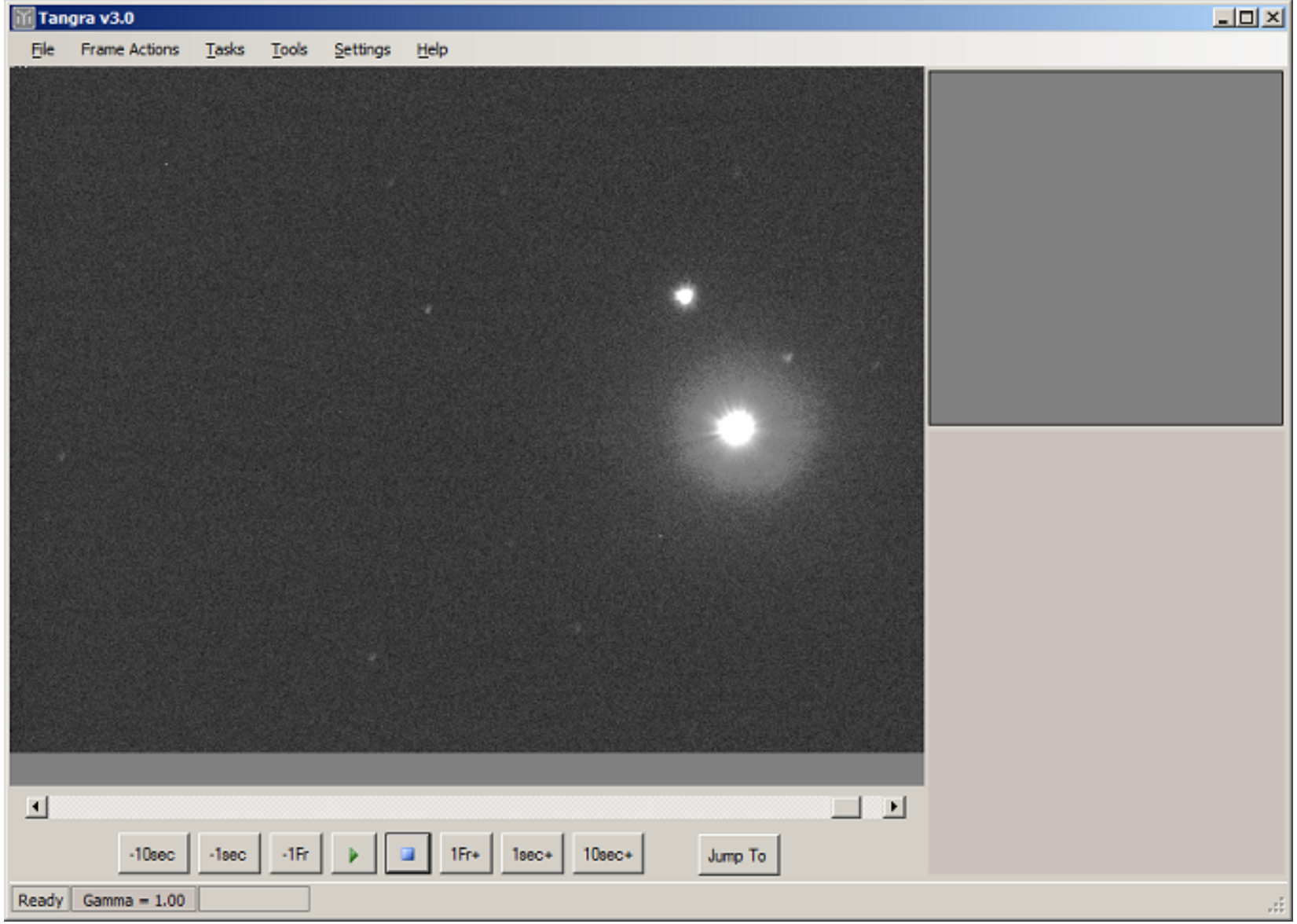
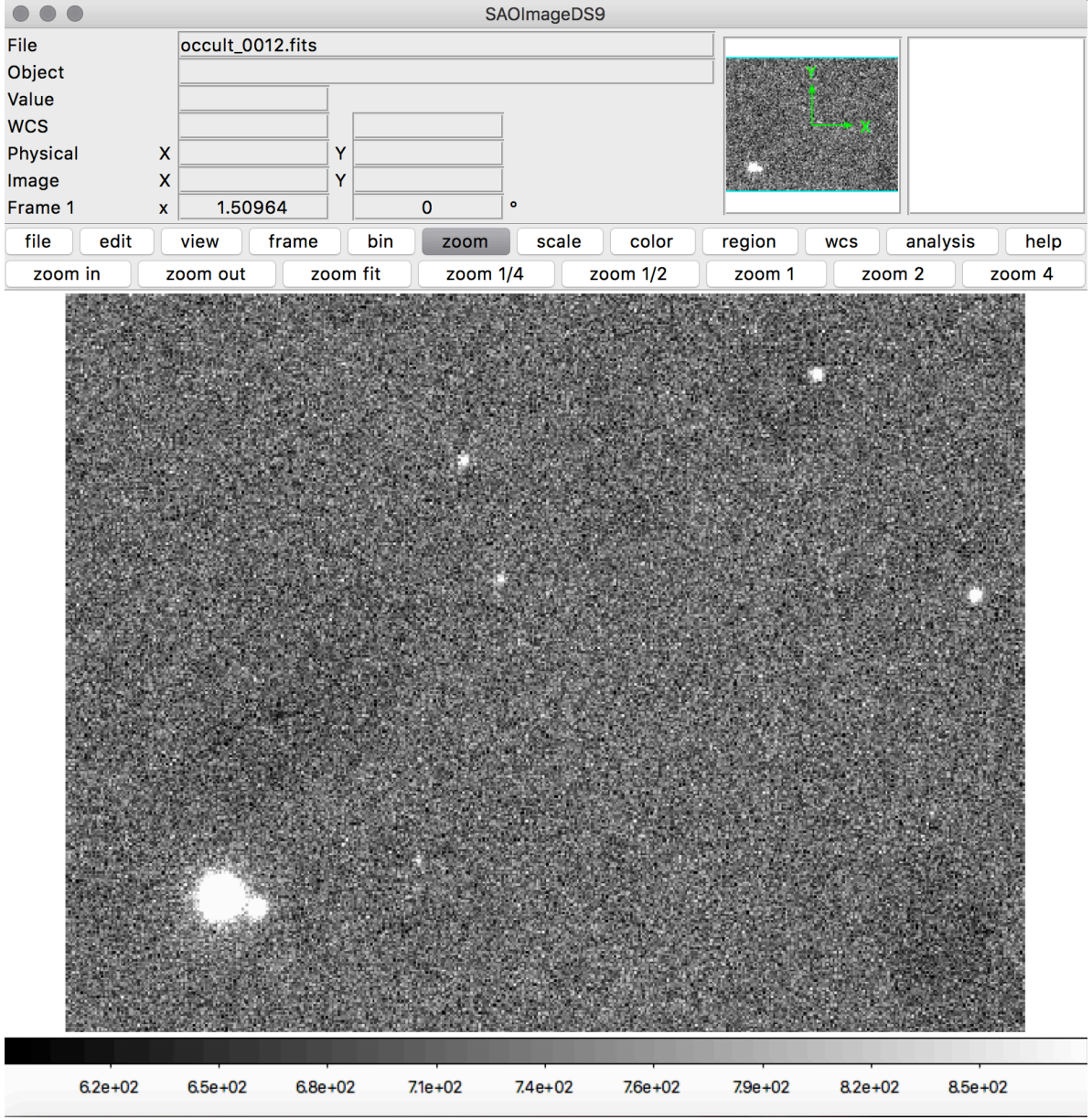



Live capture
Image streaming
Image Display Setup
Camera: connected
Display: 35.0 fps
Acquire: 37.0 fps
ROI: {X=0,Y=0,Width=662,Height=499}
Démarrer
Terminal GPS (Ne...
RaptorVision Ca...





http://www.hristopavlov.net/Tangra3/



https://sites.google.com/cfa.harvard.edu/saoimageds9/home

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Upcoming Events

Nov.	(202421) 2005UQ513
28	Star Mag. (G): 9.4
	Magnitude drop: 11.1m
	Maximum duration: 34.7 sec
17:59:09 (UT)	Dynamic class: cubewano

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HTTPS://OCCULTATION.TUG.TUBITAK.GOV.TR/

TRITON

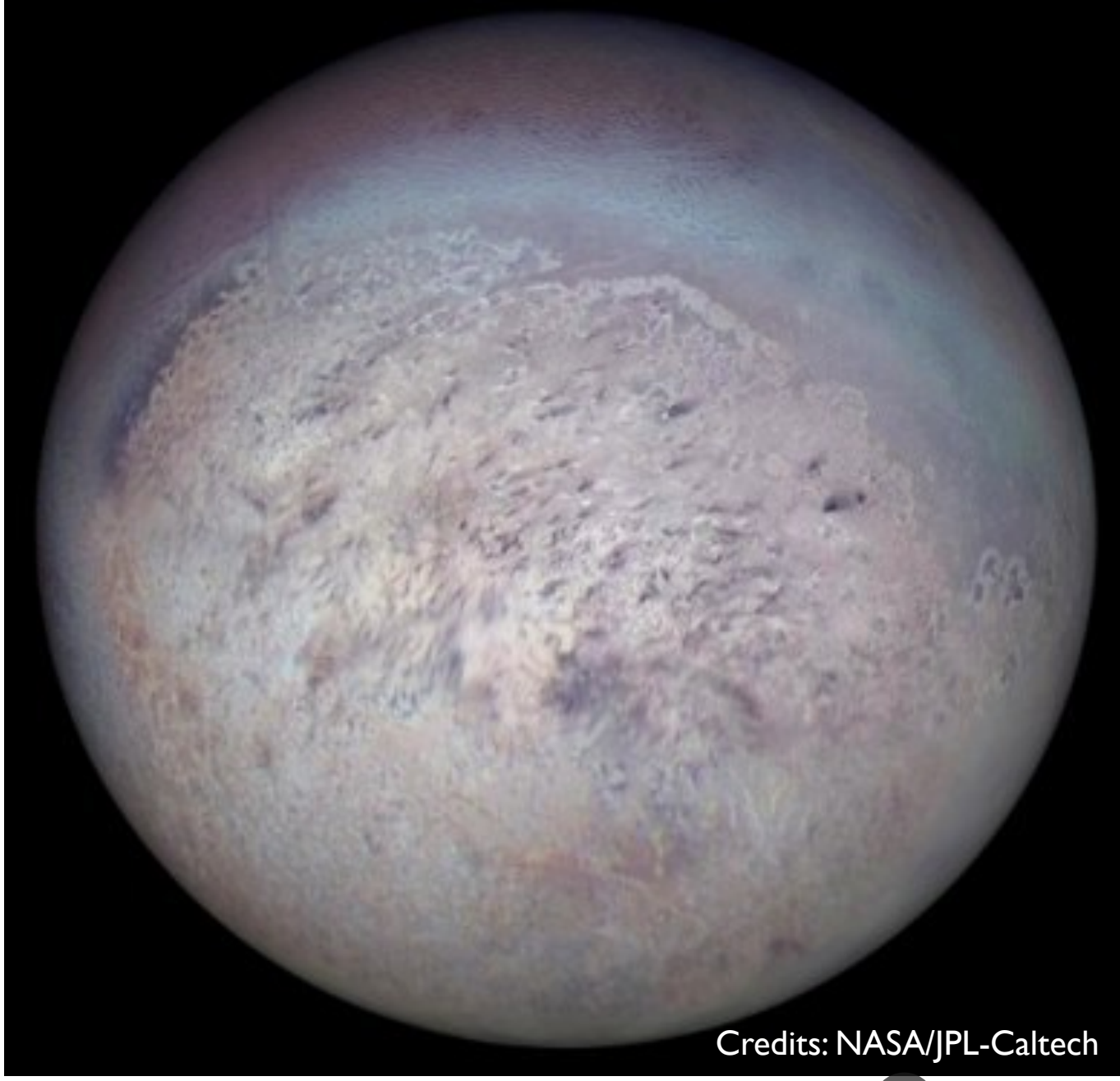
Largest of Neptune's satellites

Radius - 1353 km

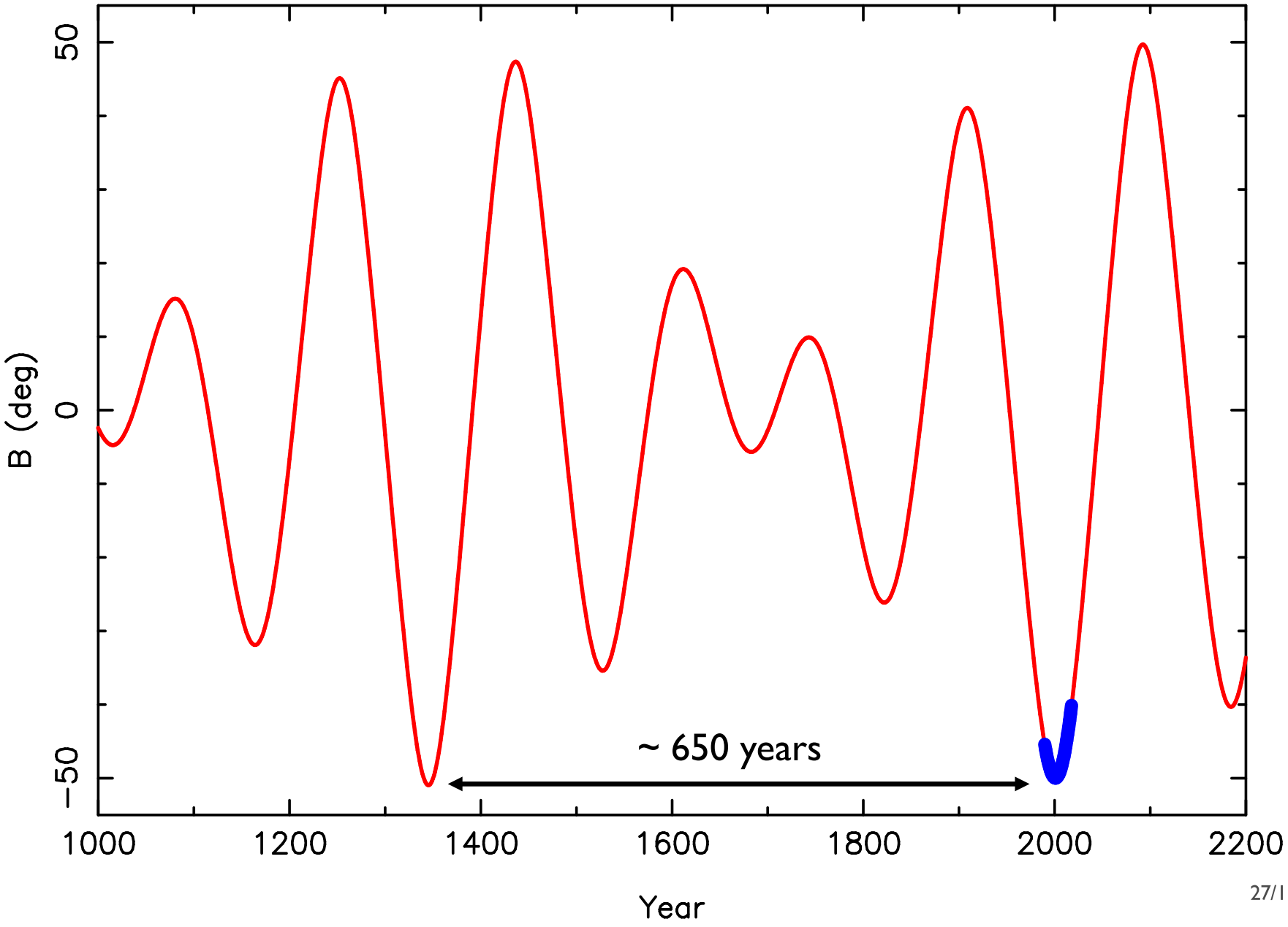
Atmosphere mainly composed of N_2 in vapour pressure equilibrium with the N_2 frost at the surface

$p_{surf} = 14 \pm 2$ μbar from Voyager 2 Radio Science 1989 (Gurrola, 1995)

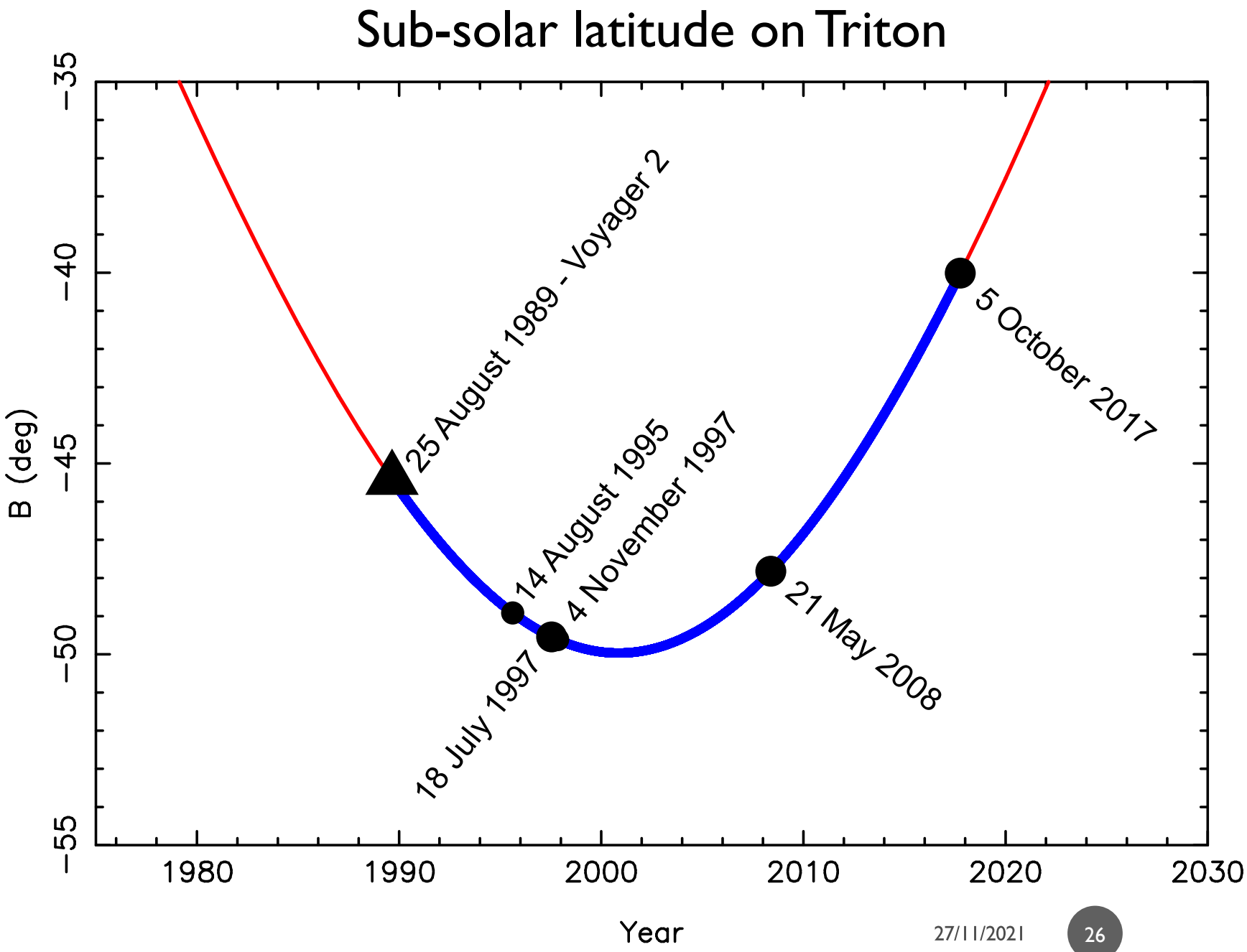
Potential ocean world


Credits: NASA/JPL-Caltech

Sub-solar latitude on Triton



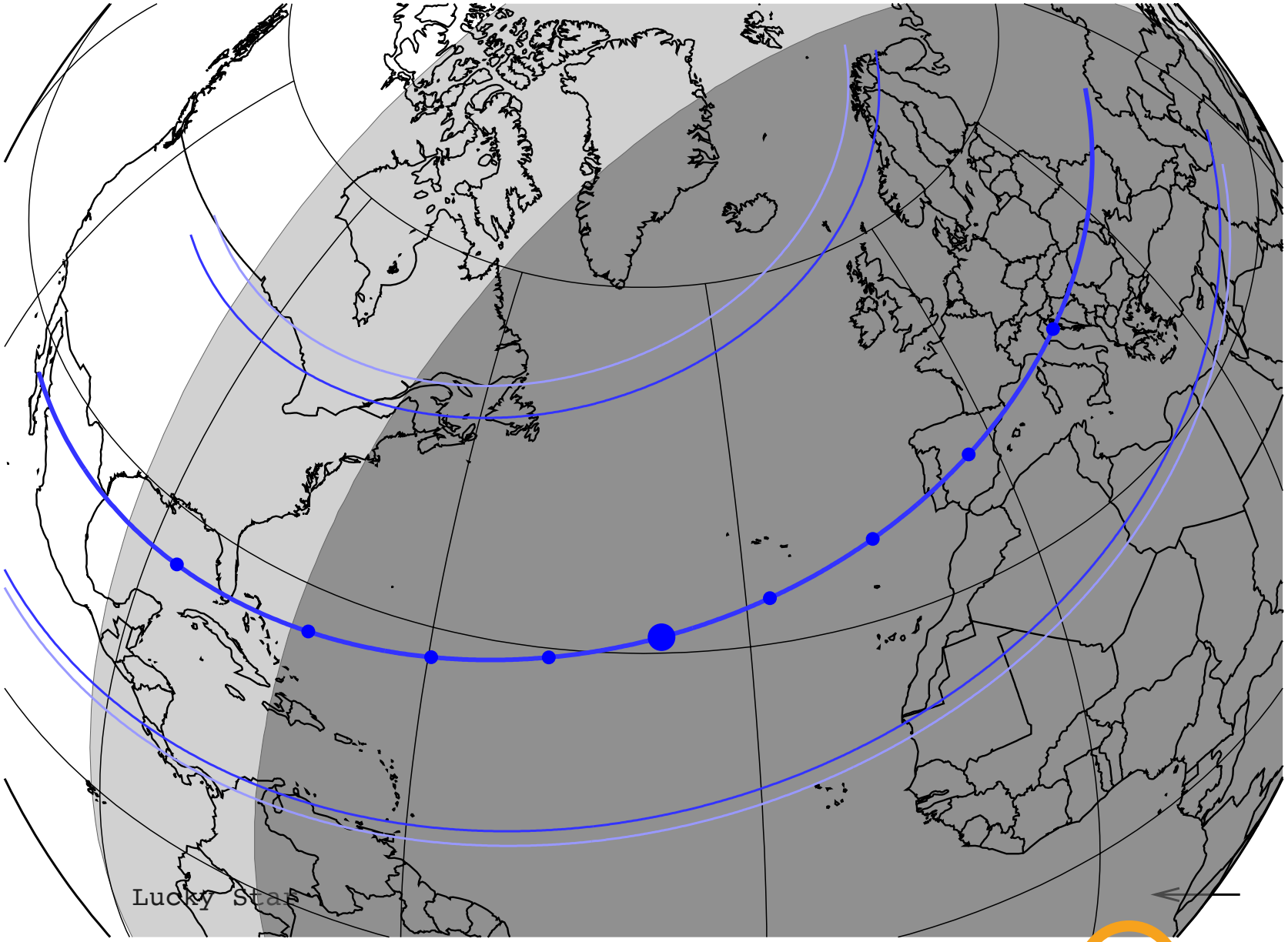
Did Triton's atmospheric pressure change during this extreme solstice?



OBSERVATIONS OF THE 5 OCTOBER 2017 EVENT

PREDICTION

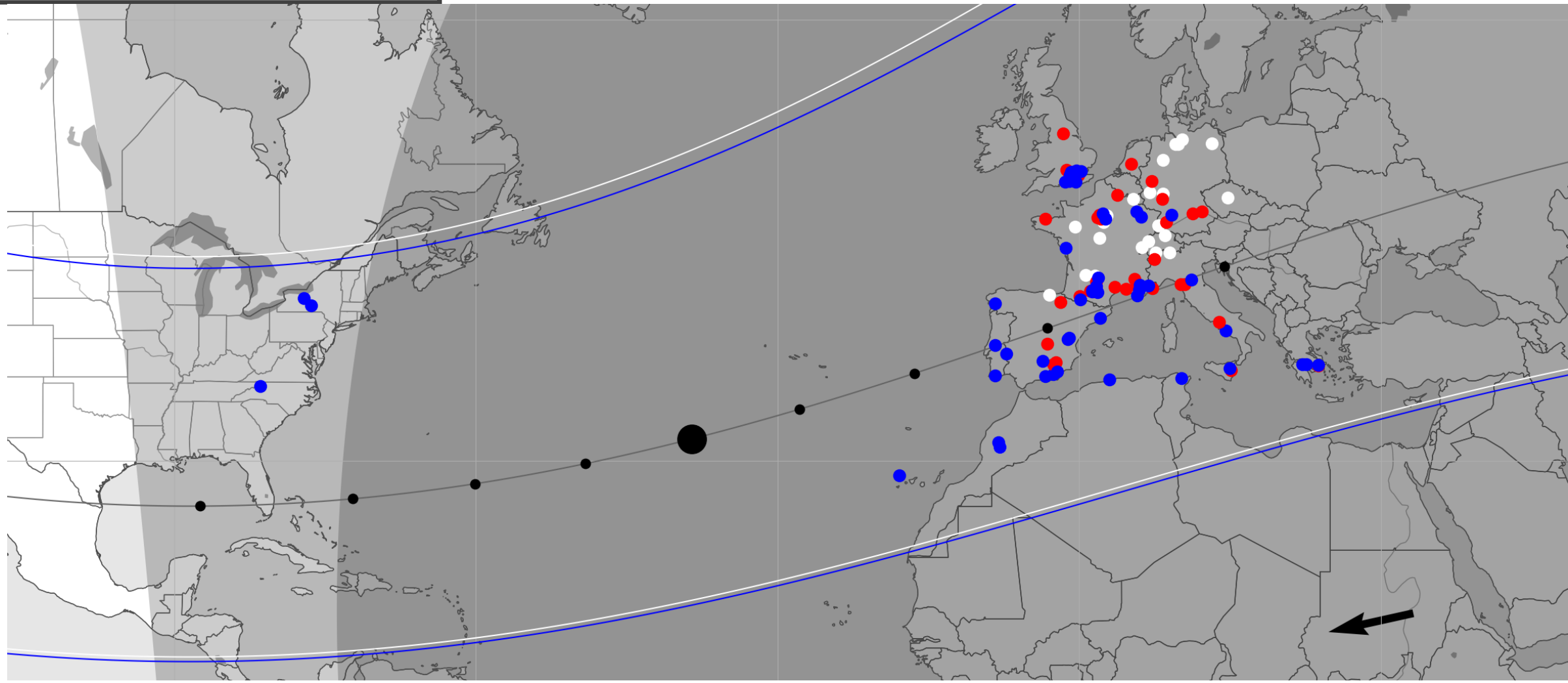
Triton, GAIADR2+pmGaiaDR2, JPLnep081de435 Offset: 7.8mas -17.6mas



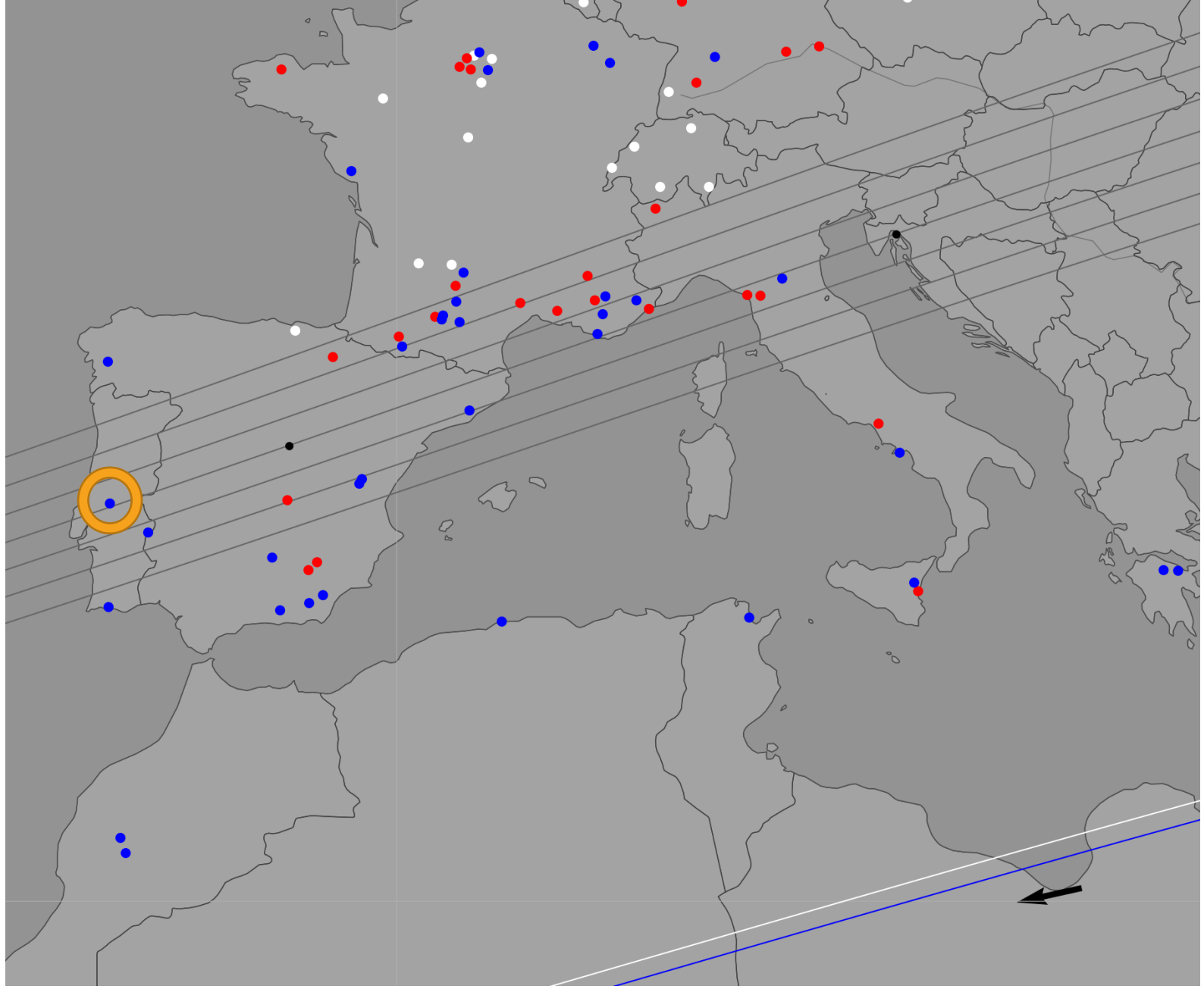
dd mm yyyy hh:mm:ss.s	RA_star_J2000	DE_star_J2000	C/A	P/A	vel	Delta	G*	J*
2017-10-05 23:51:36.5	22 54 18.4364	-08 00 08.318	0.195	347.50	-16.80	29.0807	12.0	11.0

OBSERVATIONS

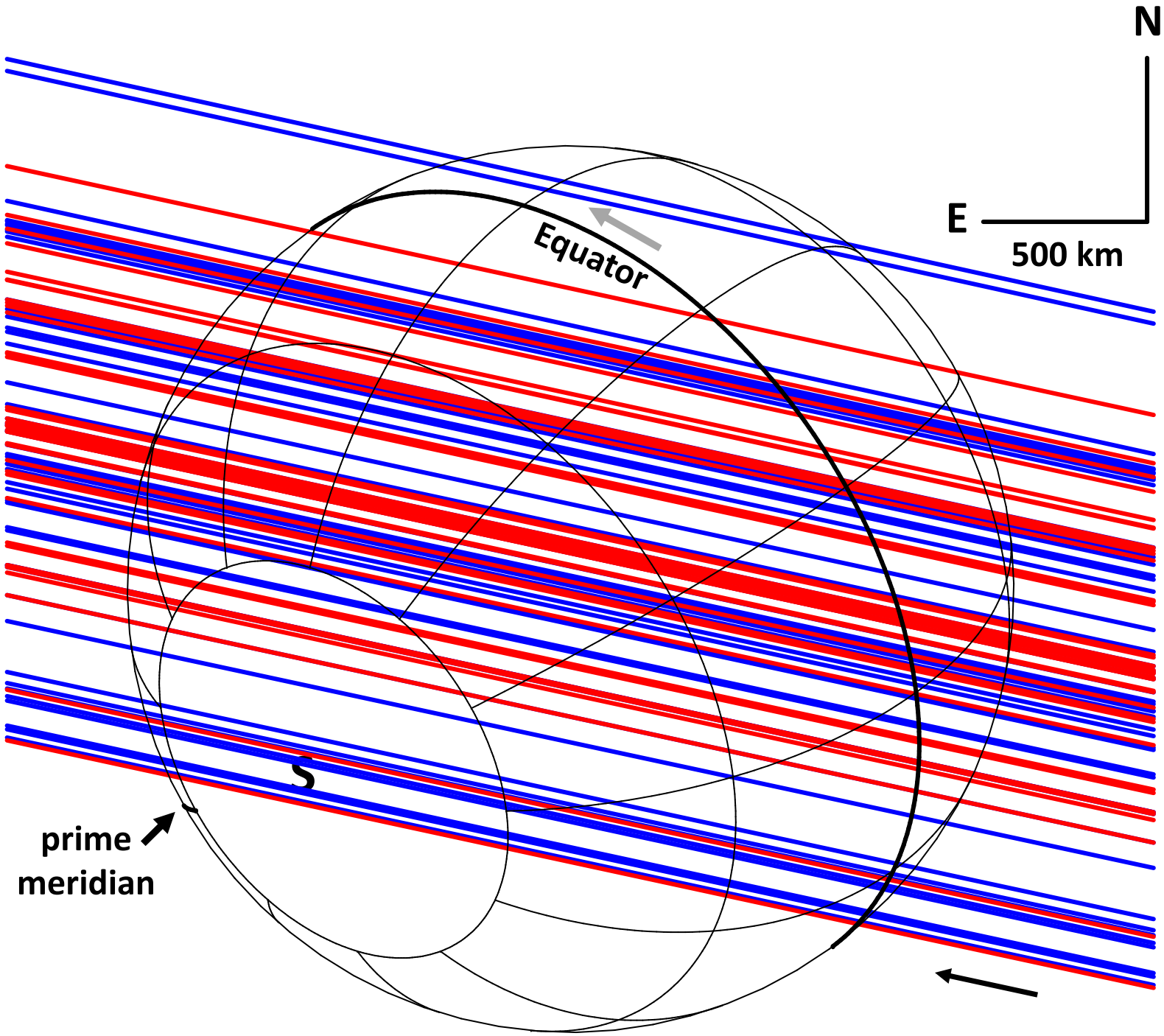
90 positive observations reported!



Gaia Press Release:
http://sci.esa.int/gaia/60011-chasing-a-stellar-flash-with-assistance-from-gaia/




Star + Triton
Neptune



Occultation chords for all stations

Coverage of summer and winter hemispheres

RESULTS

METHODOLOGY

- Boot-strap method
  1. Abel inversion
  2. Direct approach
  3. Ray-tracing
- Fitting central flashes

ASSUMPTIONS

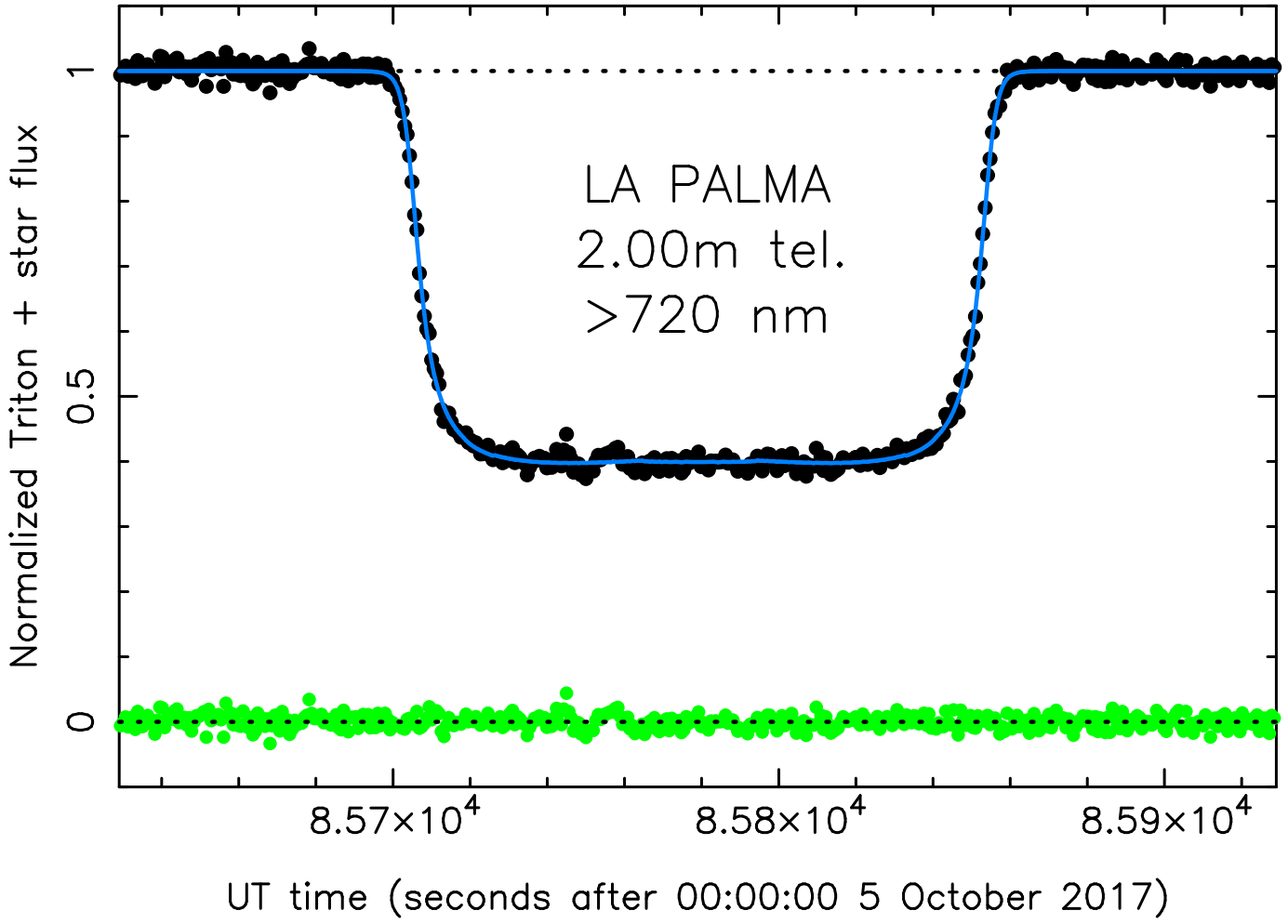
- Atmosphere is composed of pure N_2
- Atmosphere is transparent
- Upper atmosphere is spherical

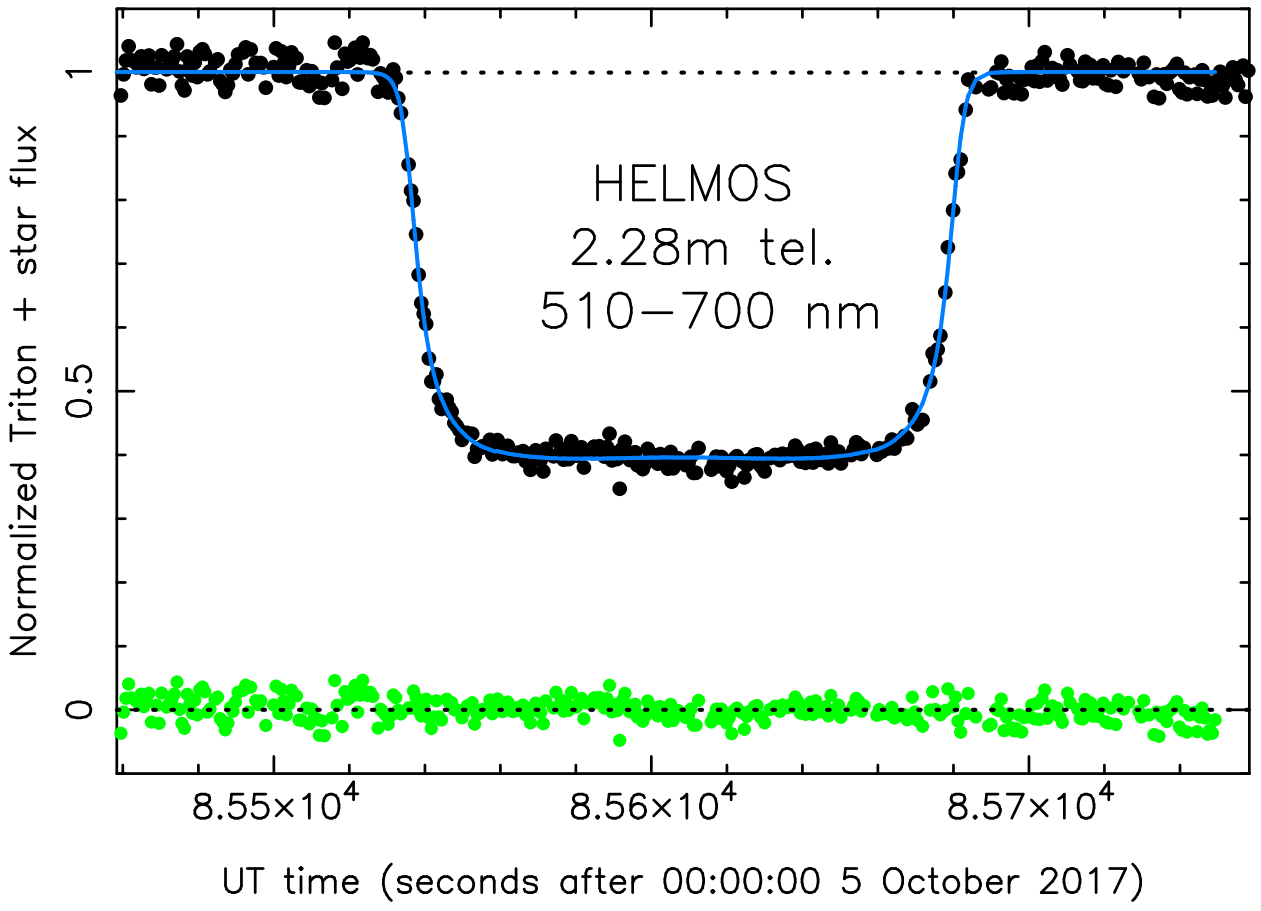
ABEL INVERSION

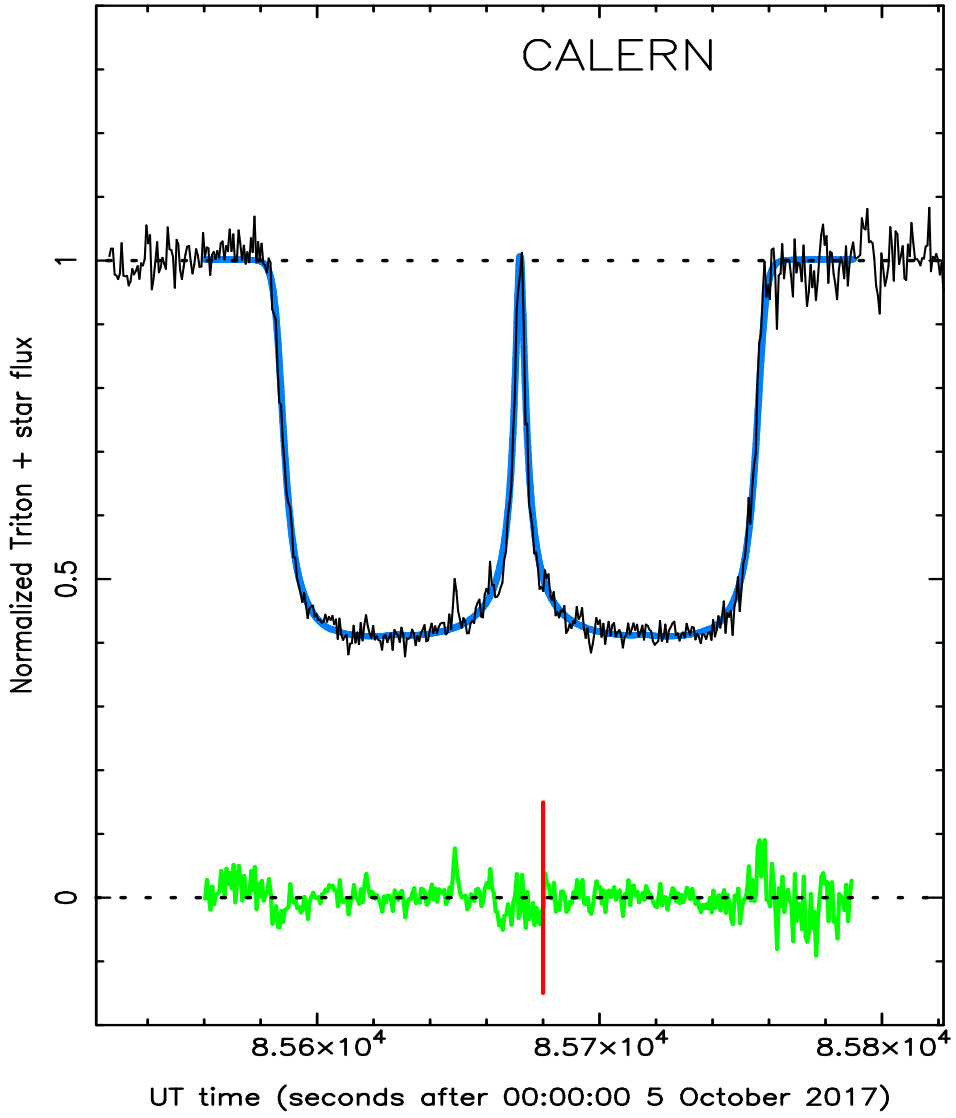
$$\phi_0 = \frac{F_T}{F_S + F_T}$$

$$\frac{F_S}{F_R} + \frac{F_T}{F_R} = \frac{F_S + F_T}{F_R}$$

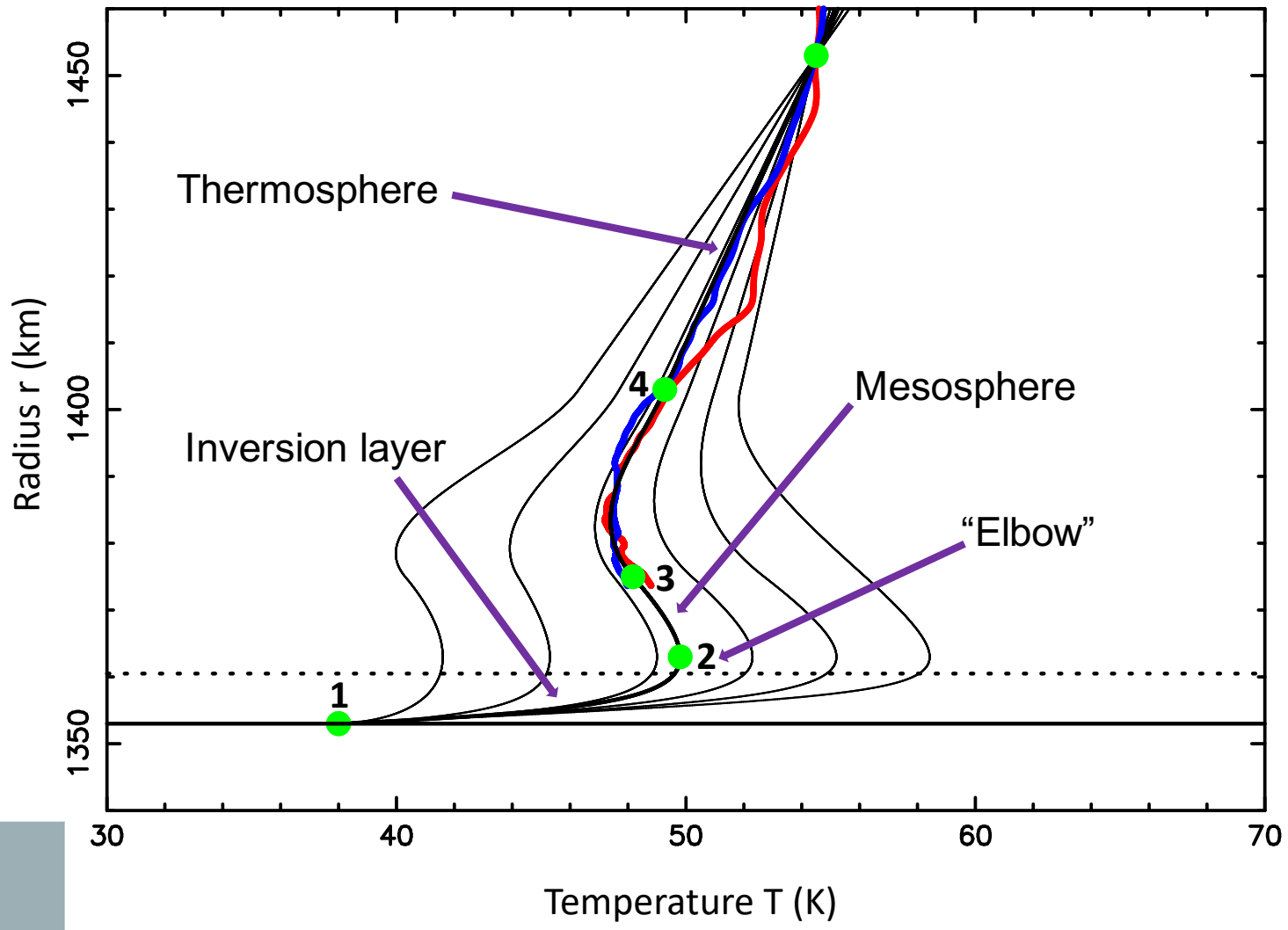
Separated Blended



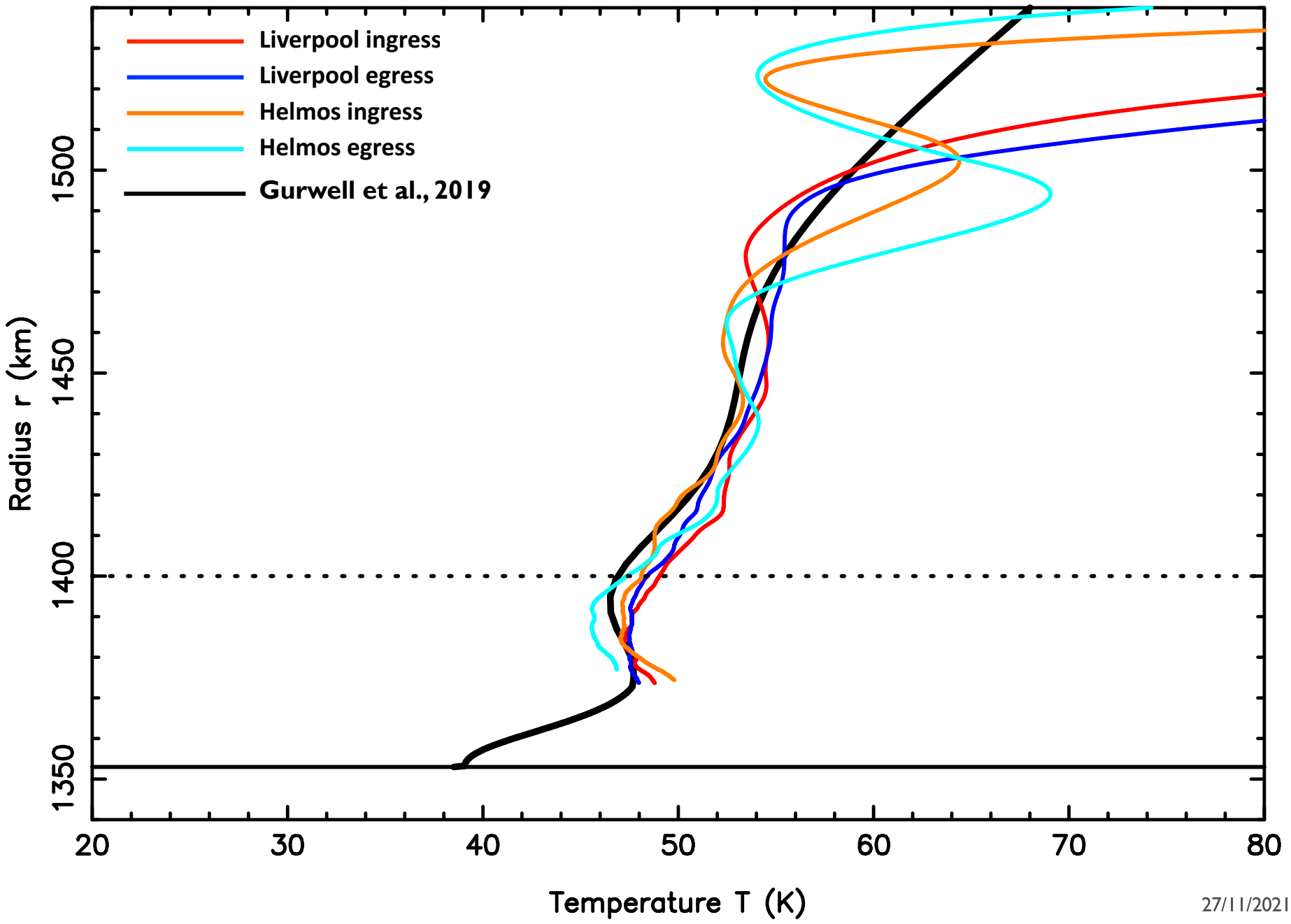

HELMOS
2.28m tel.
510–700 nm
Normalized Triton + star flux
1
0.5
0
8.55×10^4
8.56×10^4
8.57×10^4
UT time (seconds after 00:00:00 5 October 2017)

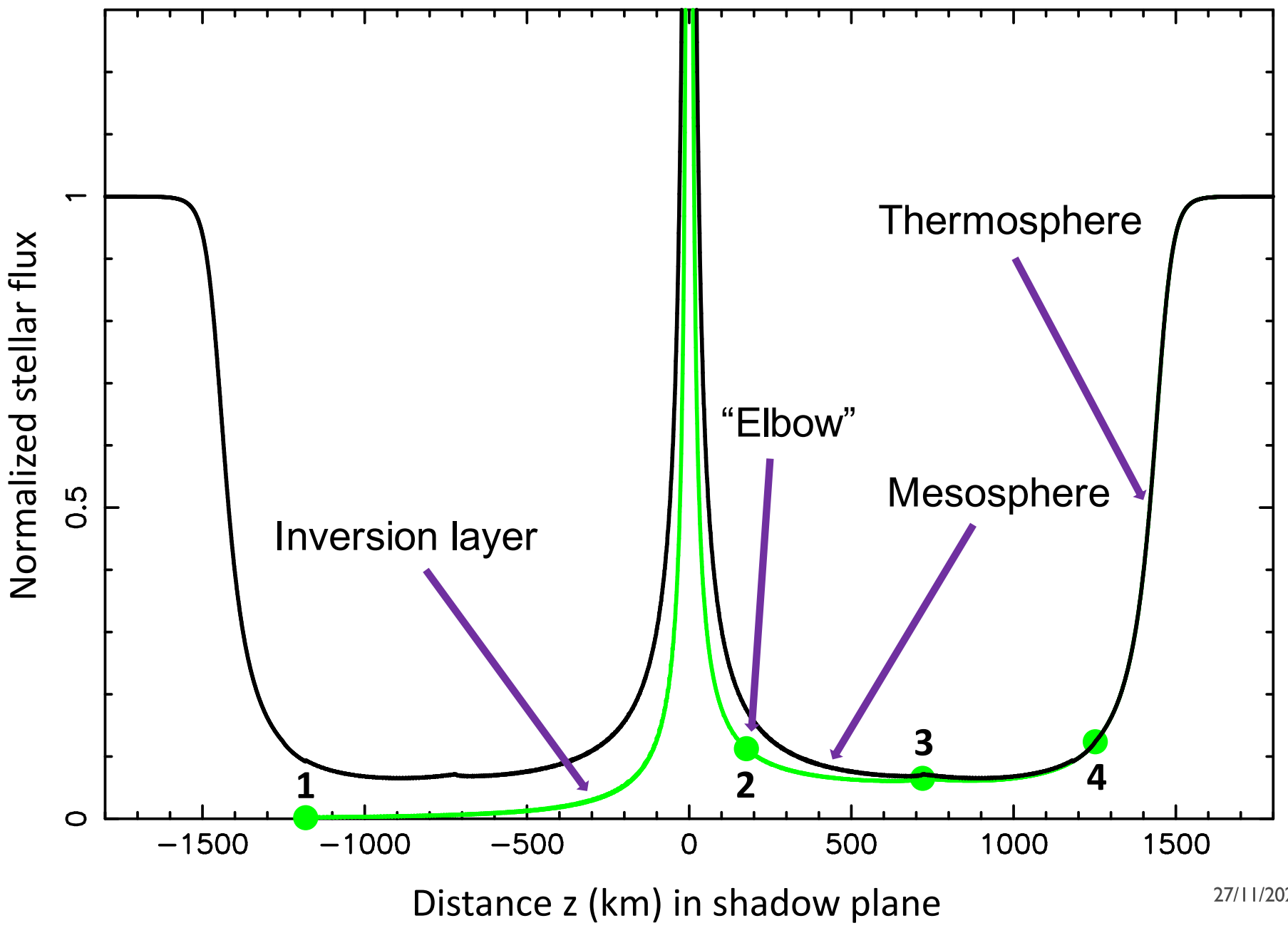

CALERN
Normalized Triton + star flux
1
0.5
0
8.56×10^4
8.57×10^4
8.58×10^4
UT time (seconds after 00:00:00 5 October 2017)

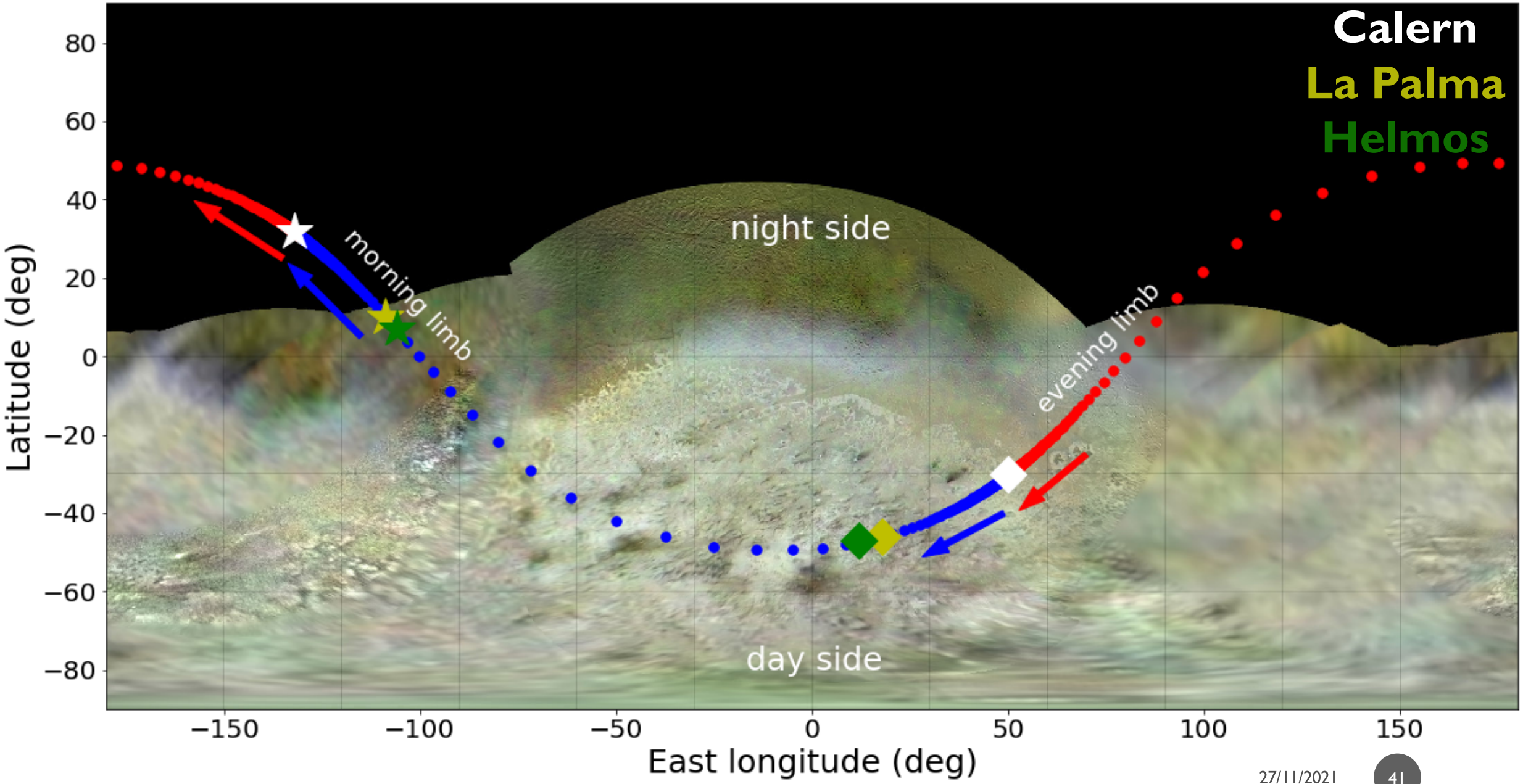
$$\phi_{0,best} = 0.35885$$



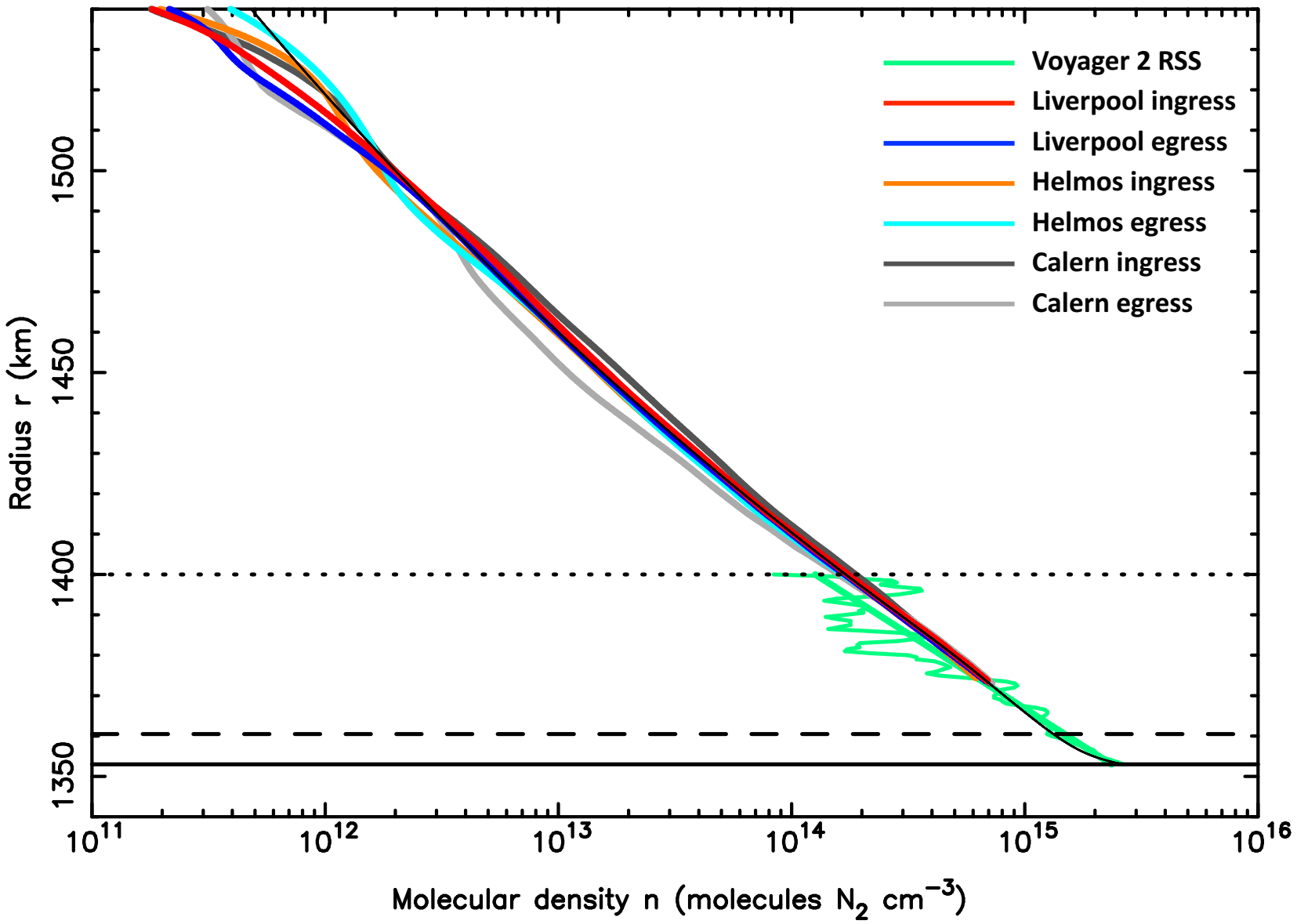
Number	r (km)	T (K)	dT/dr (K km^{-1})	
1	1353	38	5	Surface
2	1363	49.8	1.2	"Elbow"
3	1375	48.2	-0.2	Inflexion point
4	1403	49.3	0.105	Thermosphere

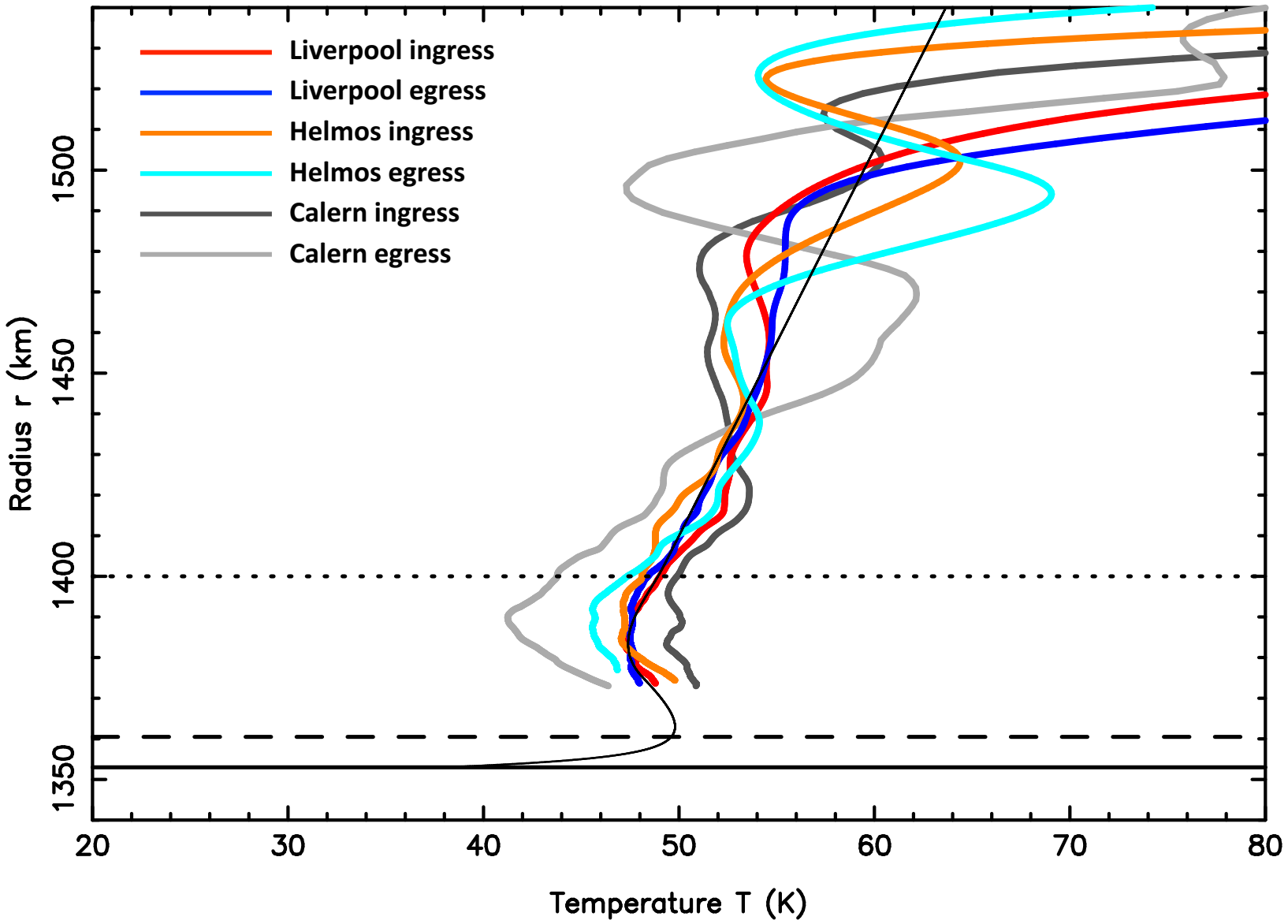

Liverpool ingress
Liverpool egress
Helmos ingress
Helmos egress
Gurwell et al., 2019
Radius r (km)
1350
1400
1450
1500
20
30
40
50
60
70
80
Temperature T (K)


Normalized stellar flux
0
0.5
1
−1500
−1000
−500
0
500
1000
1500
Distance z (km) in shadow plane
Thermosphere
"Elbow"
Mesosphere
Inversion layer
1
2
3
4

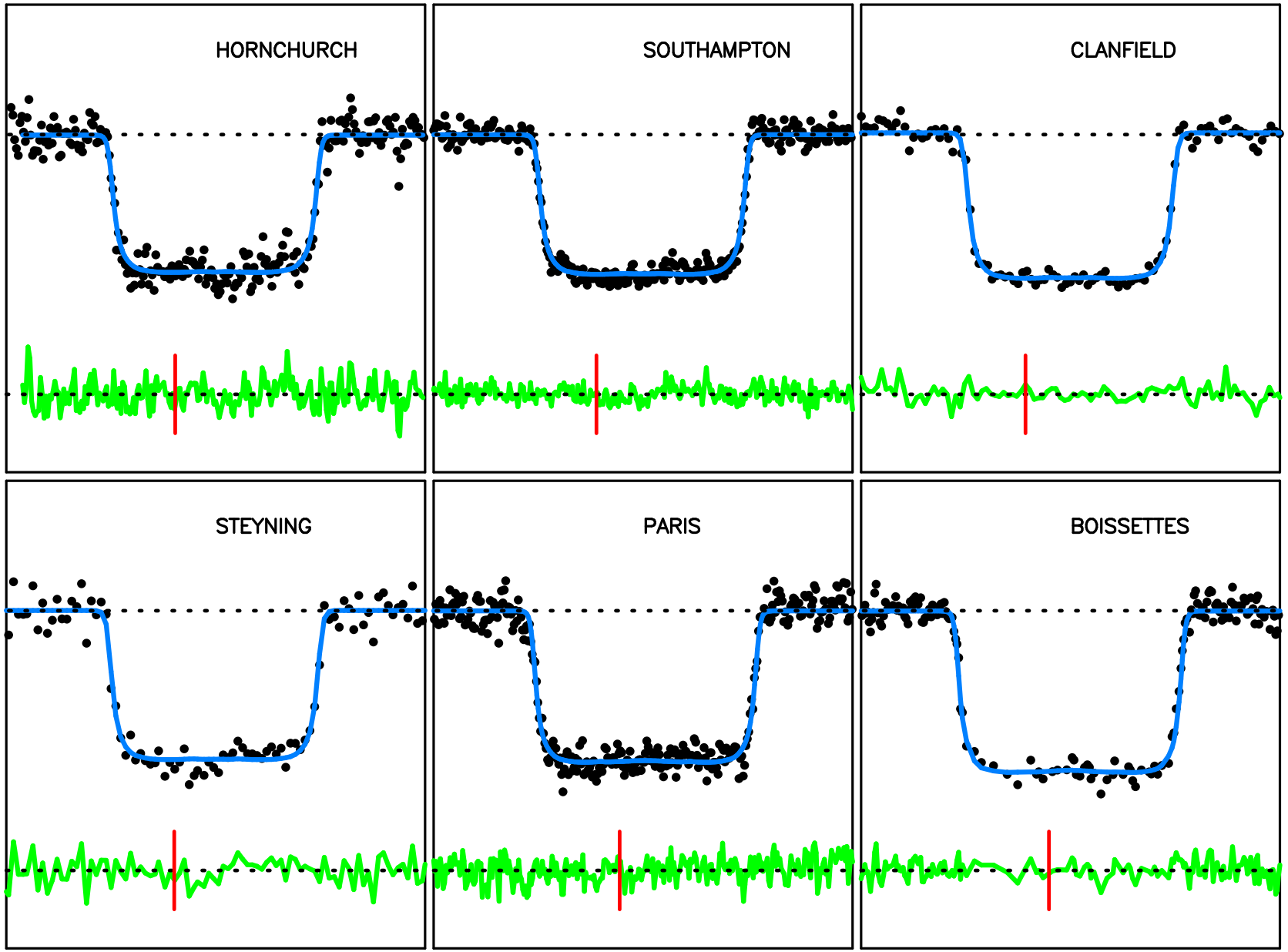


Background Image Credit: NASA/JPL-Caltech

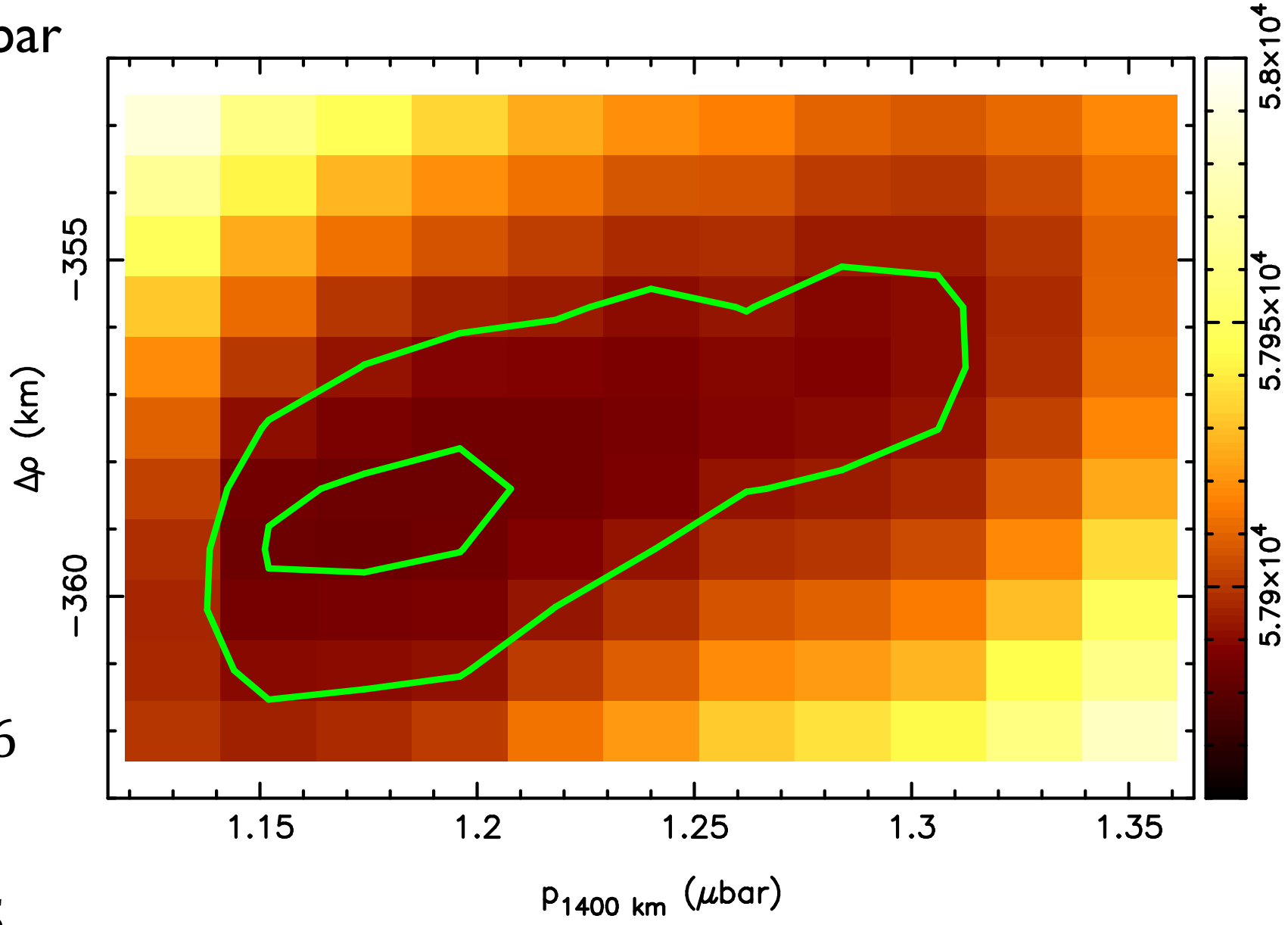

Voyager 2 RSS
Liverpool ingress
Liverpool egress
Helmos ingress
Helmos egress
Calern ingress
Calern egress
Radius r (km)
1350
1400
1450
1500
10^{11}
10^{12}
10^{13}
10^{14}
10^{15}
10^{16}
Molecular density n (molecules N_2 cm^{-3})


Liverpool ingress
Liverpool egress
Helmos ingress
Helmos egress
Calern ingress
Calern egress
Radius r (km)
1350
1400
1450
1500
20
30
40
50
60
70
80
Temperature T (K)

RAY-TRACING


HORNCHURCH
SOUTHAMPTON
CLANFIELD
STEYNING
PARIS
BOISSETTES

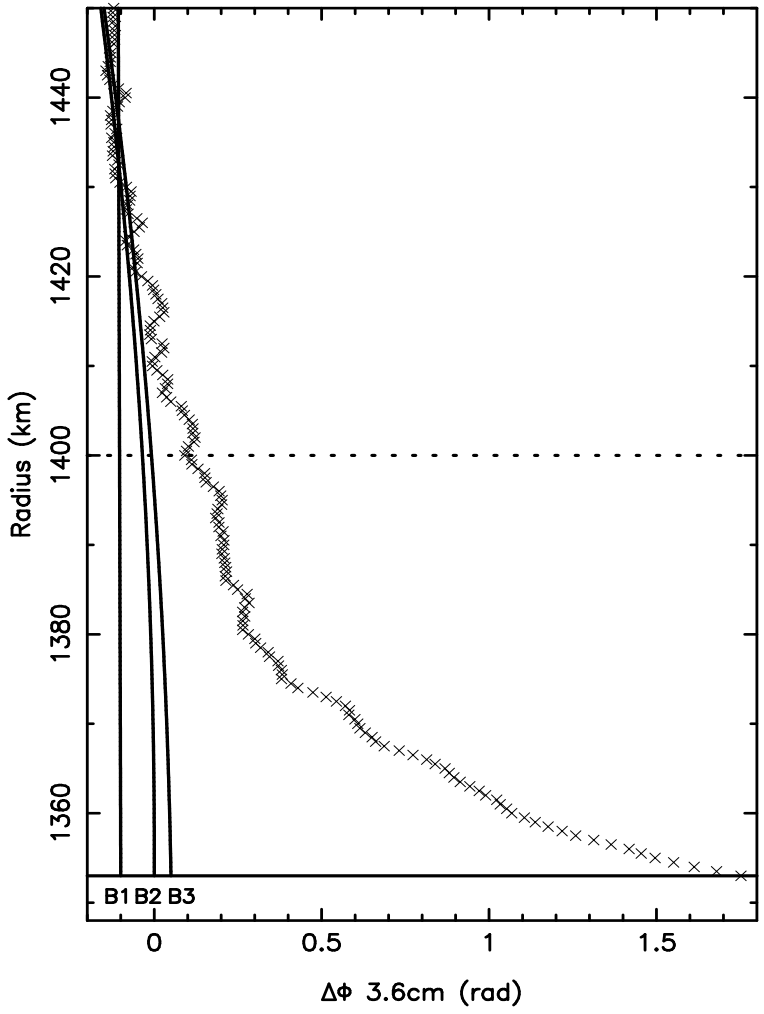
$p_{1400} = 1.18 \pm 0.03$ μbar

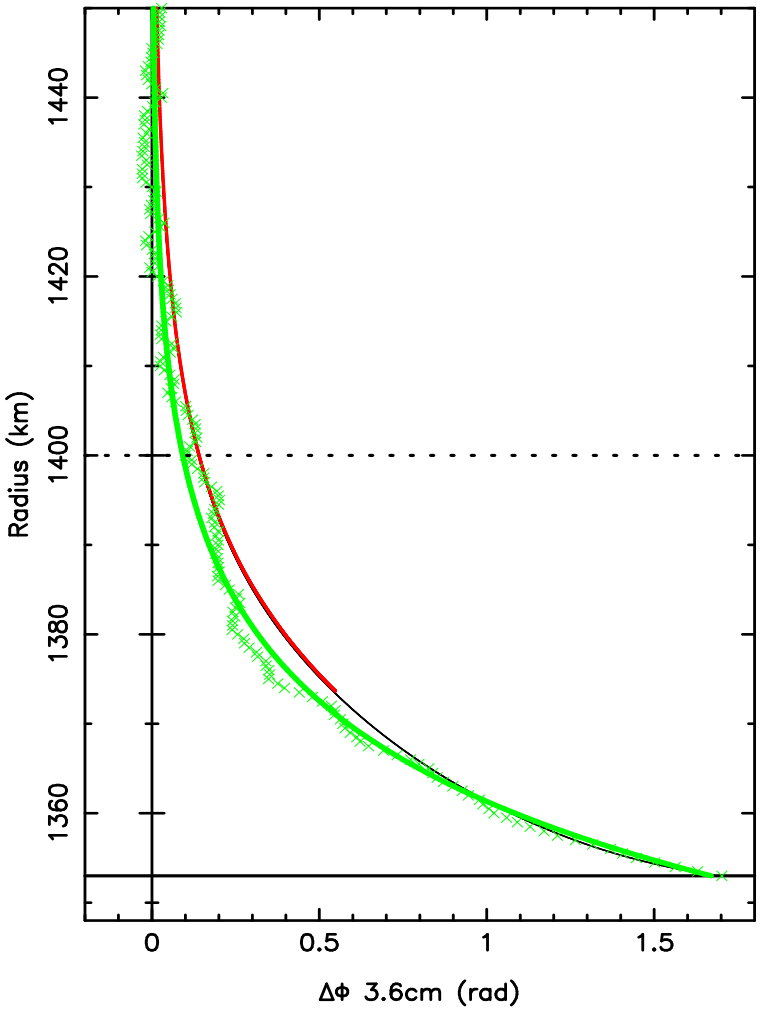


$M = 54; N = 68446$

$$\chi^2_{dof} = \frac{\chi^2_{min}}{N - M} = 0.85$$

VOYAGER 2 RADIO SCIENCE

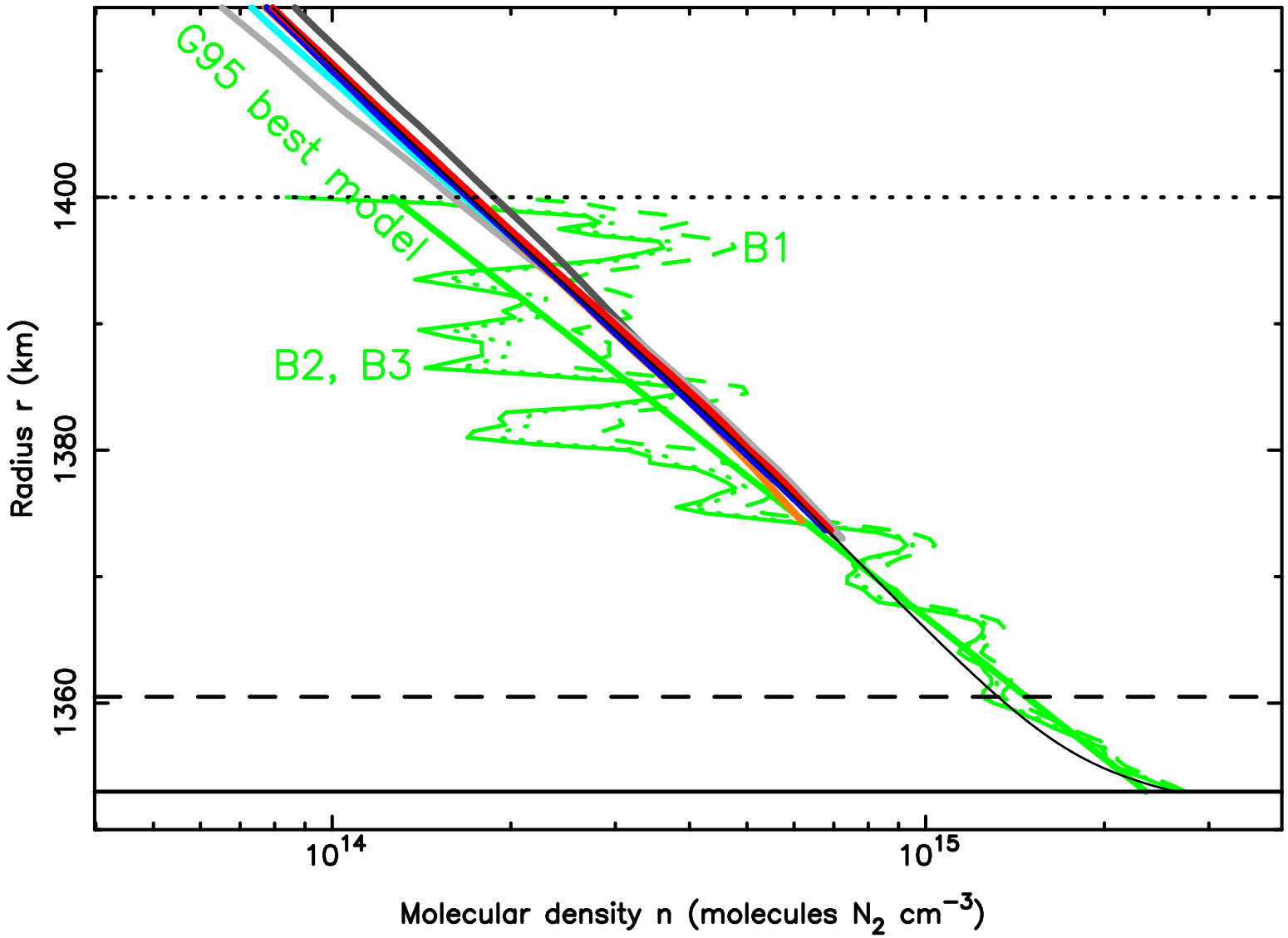




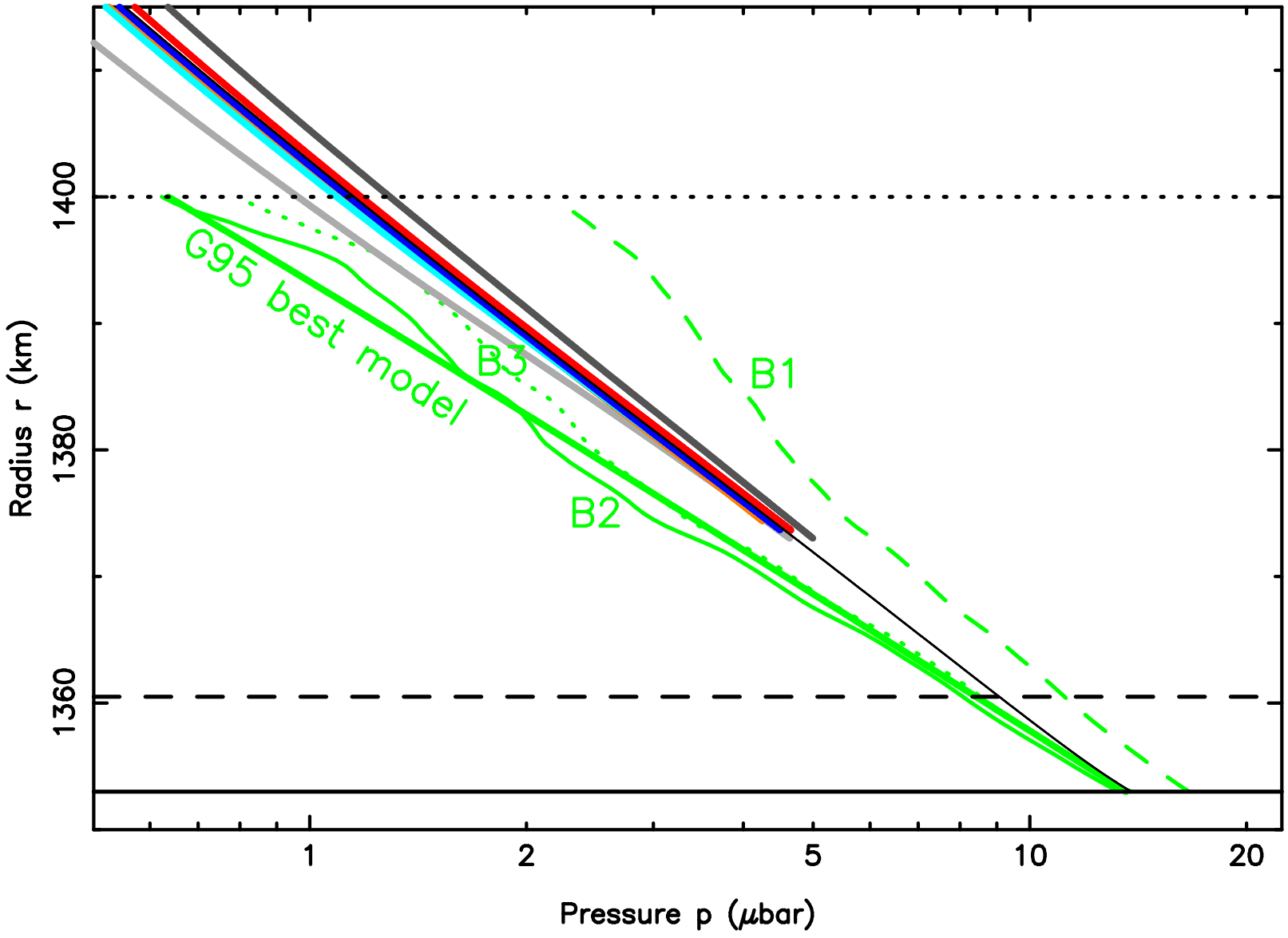
$$\Delta\phi = \frac{121}{112}\left(\phi_X - \frac{3}{11}\phi_S\right)$$

$$\Delta\phi(r) = \frac{2\pi}{\lambda} K \sigma_{N_2}(r)$$

$$\nu(r) = -\frac{\lambda}{2\pi}\int_r^{+\infty}\frac{d(\Delta\phi)}{dR}\frac{dR}{\sqrt{R^2-r^2}} \qquad n(r) = \frac{\nu(r)}{K}$$

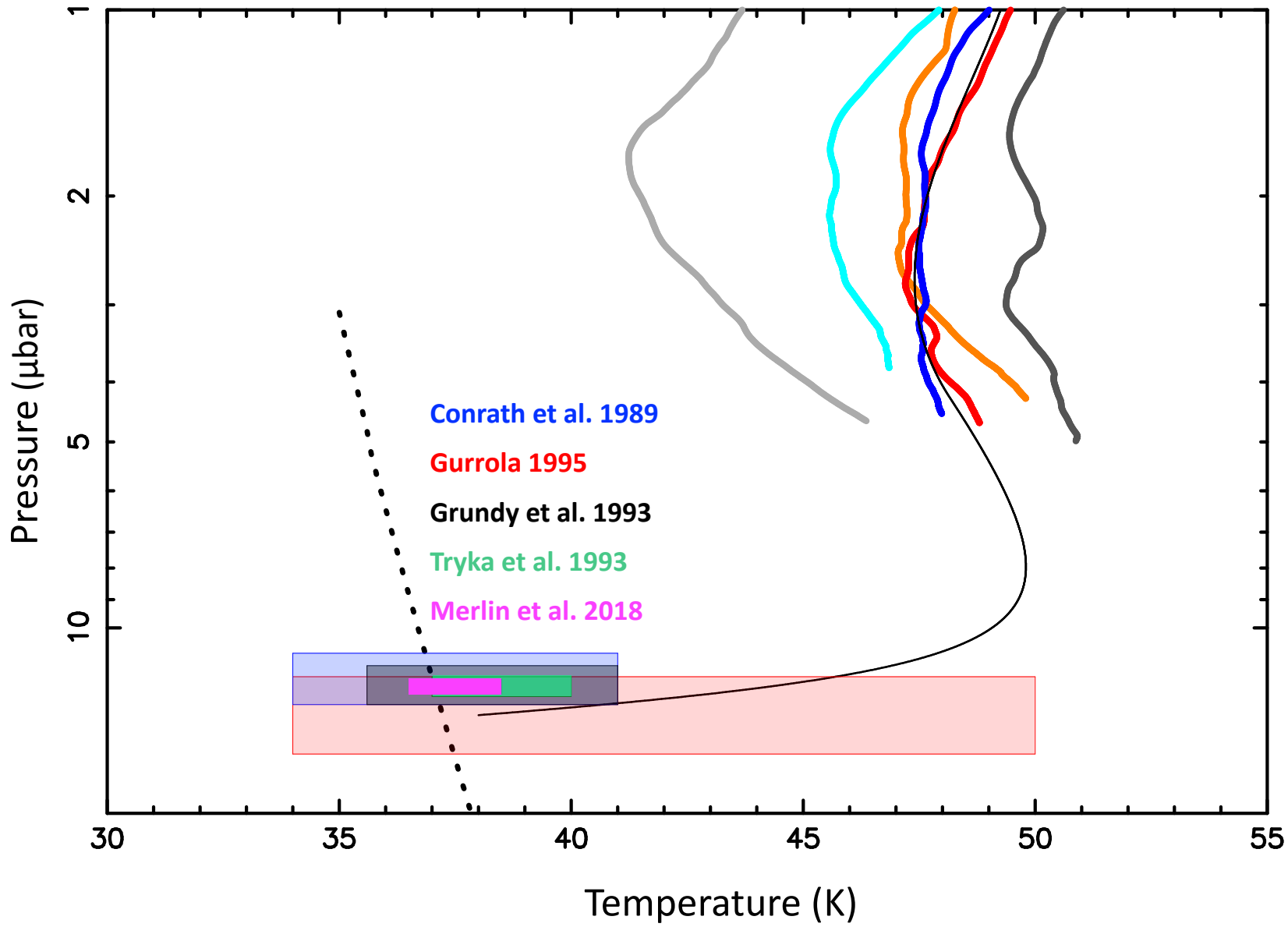


$$p_{surf,Voyager} - p_{1373,Voyager} = 9.82\ \mu\text{bar}$$

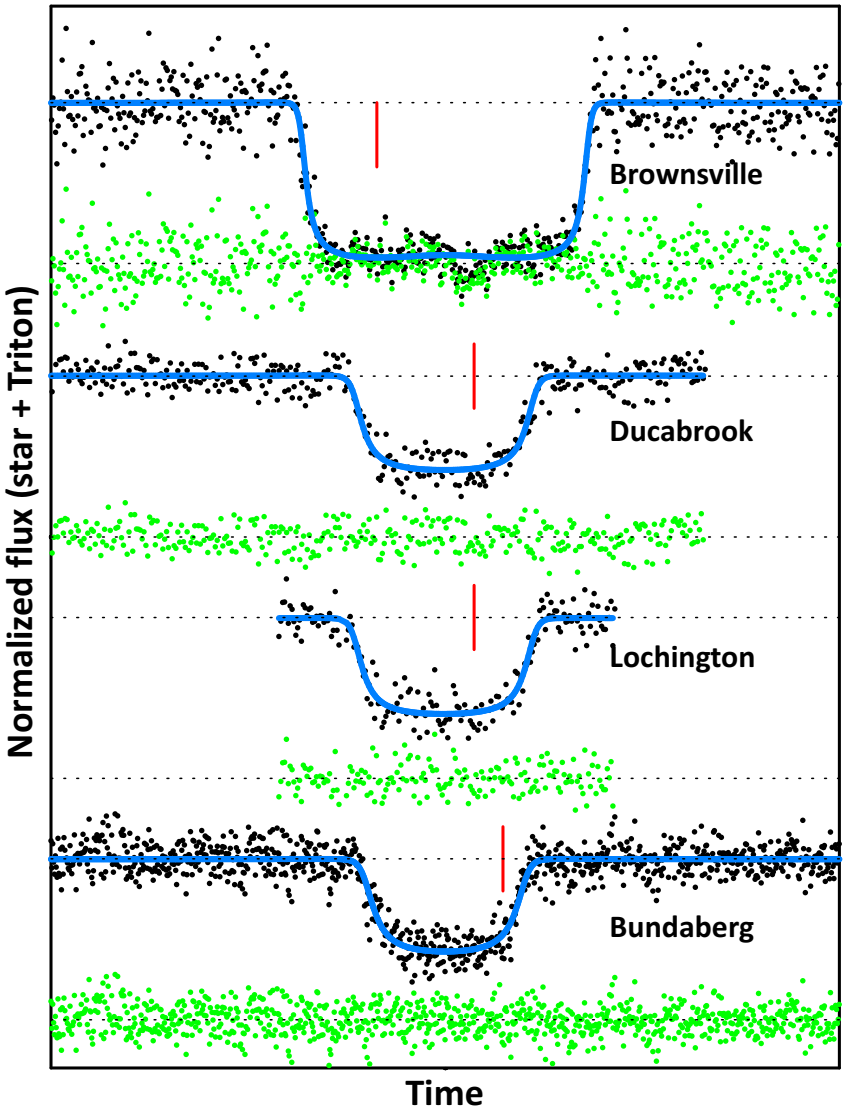


$p_{surf,Voyager} = 12.5 \pm 0.5$ μbar

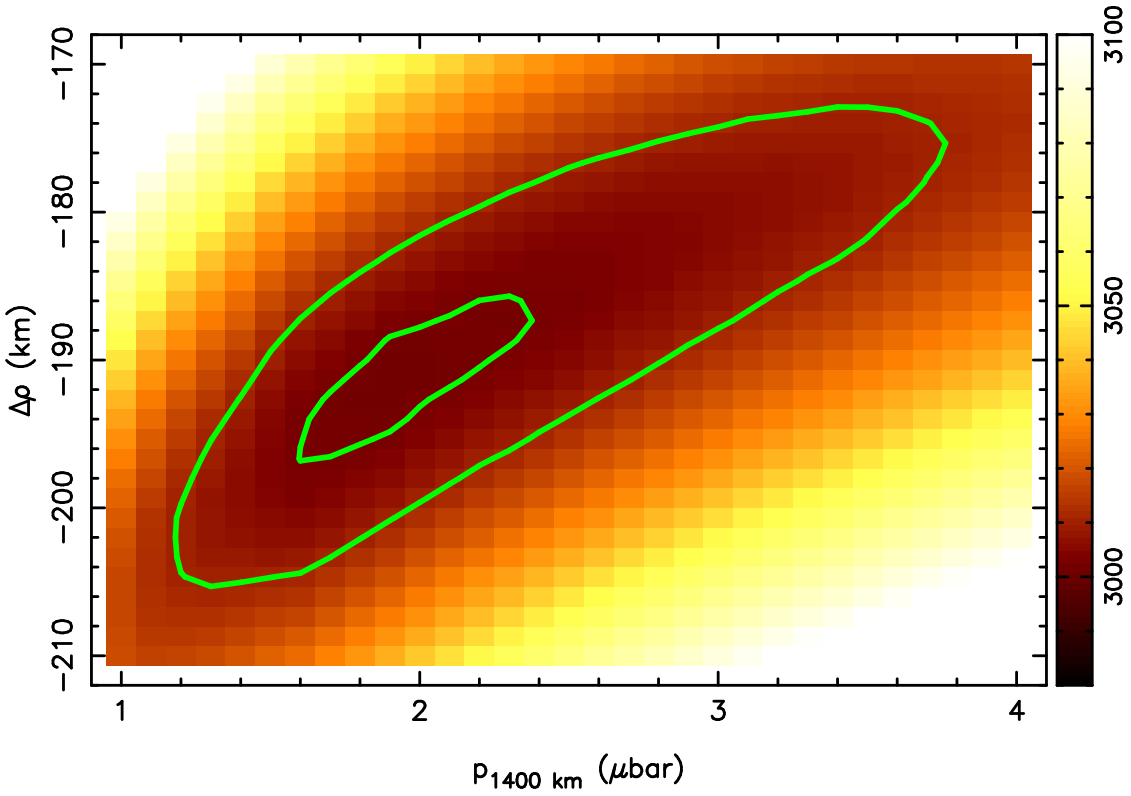
$p_{1400,Voyager} = 1.0 \pm 0.2$ μbar

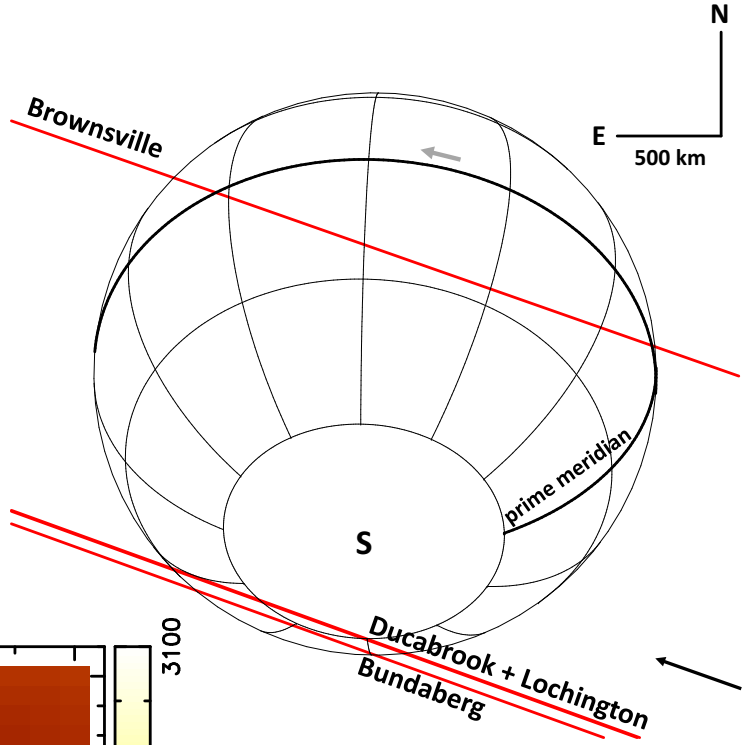


18 JULY 1997 OCCULTATION

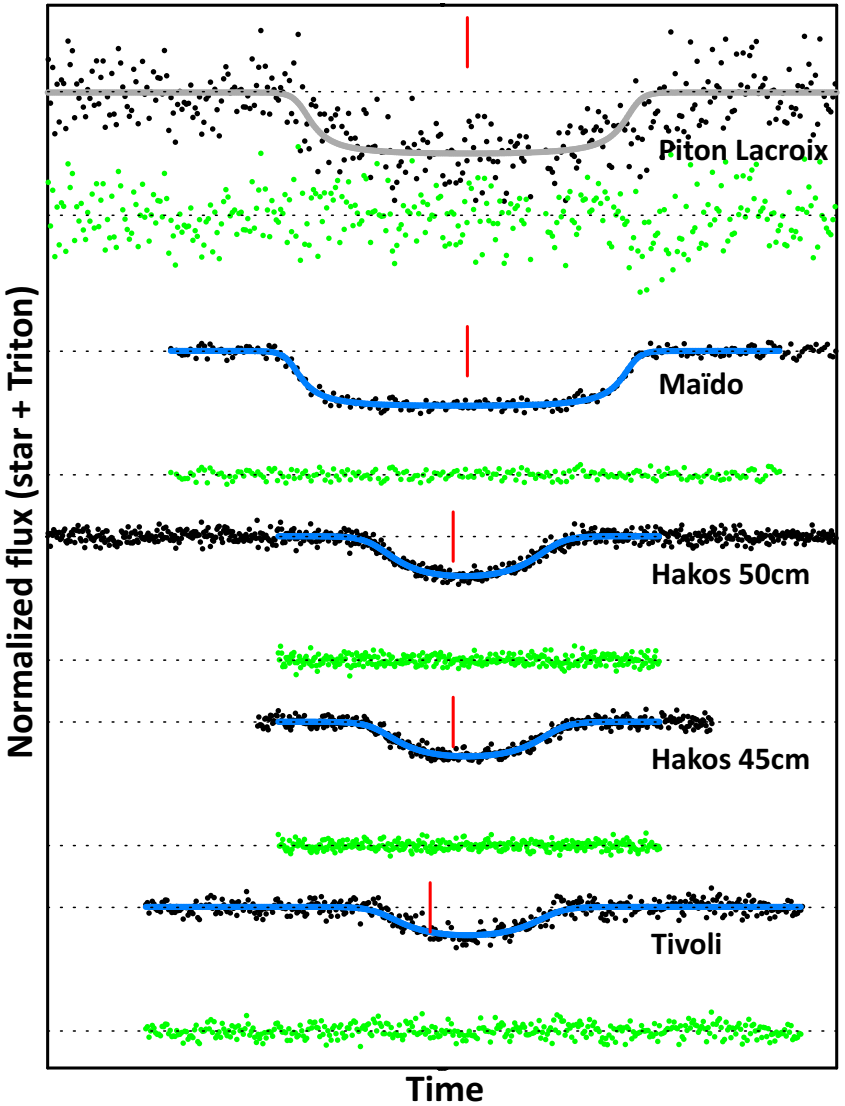


$$p_{1400} = 1.90^{+0.45}_{-0.30}\ \mu\text{bar}$$

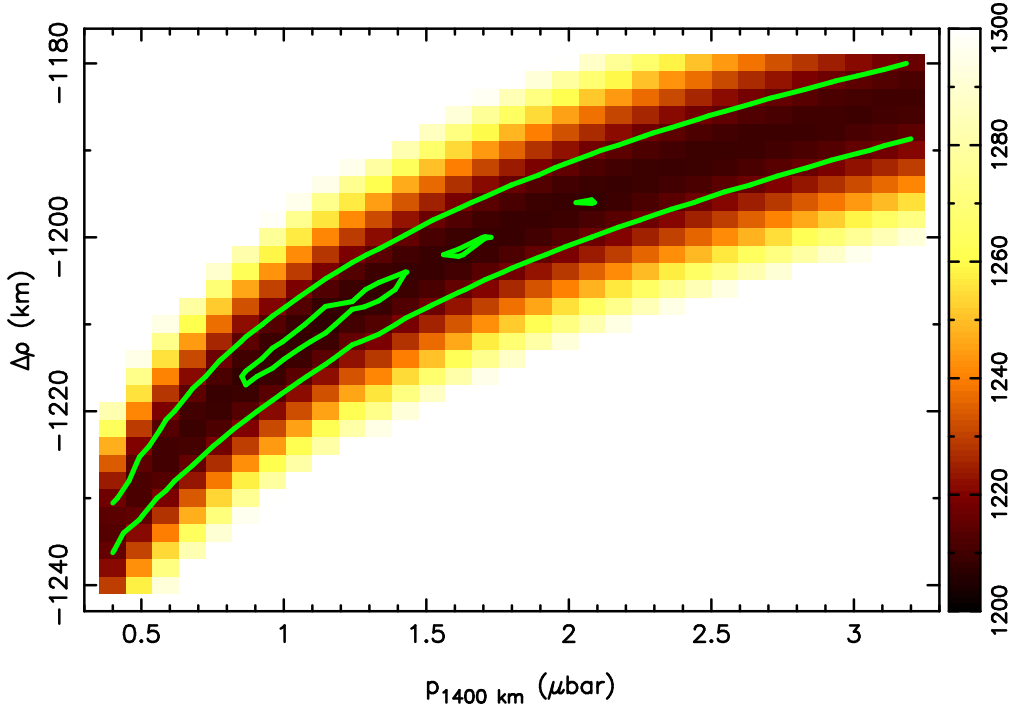


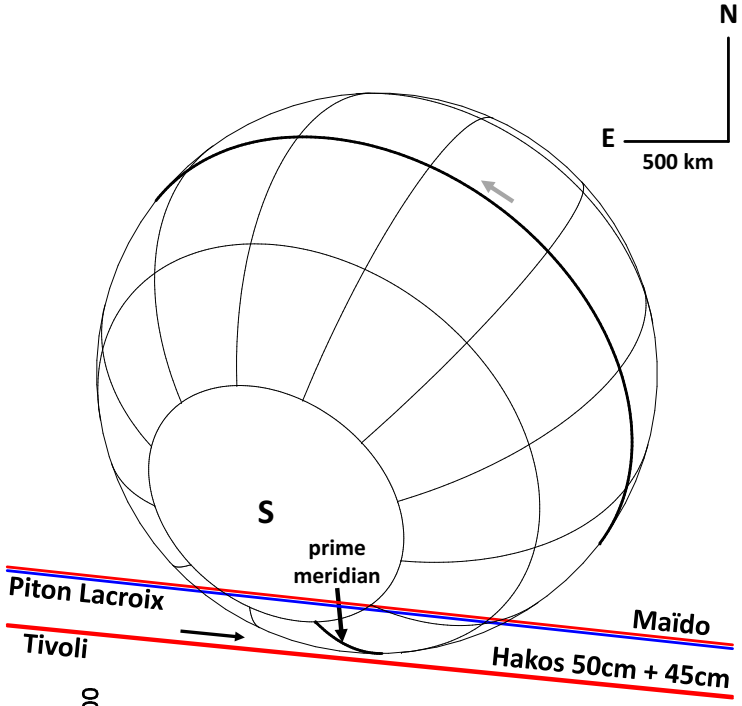


21 MAY 2008 OCCULTATION



$$p_{1400} = 1.15^{+1.03}_{-0.37}\ \mu\text{bar}$$

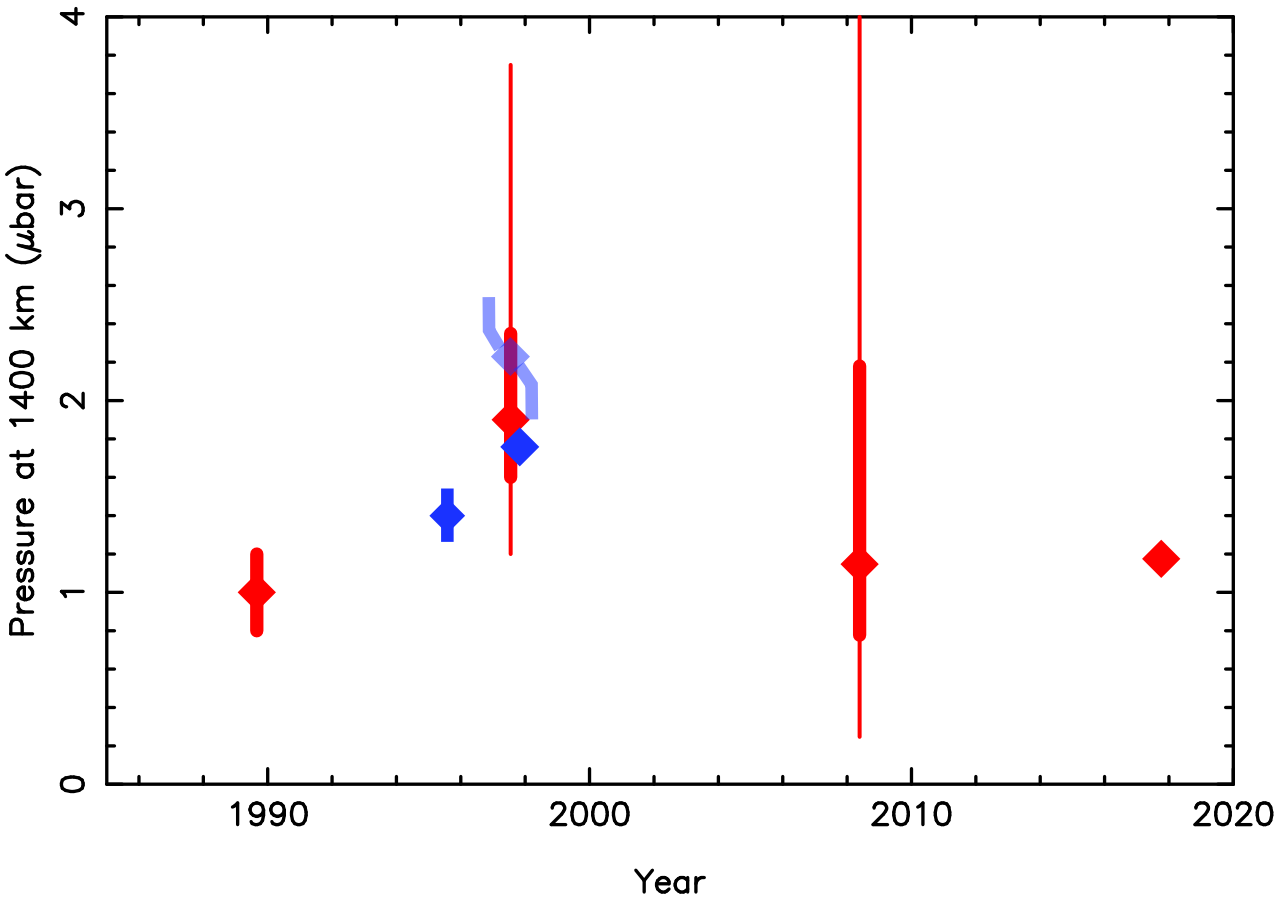




TRITON'S ATMOSPHERIC EVOLUTION AND STRUCTURE

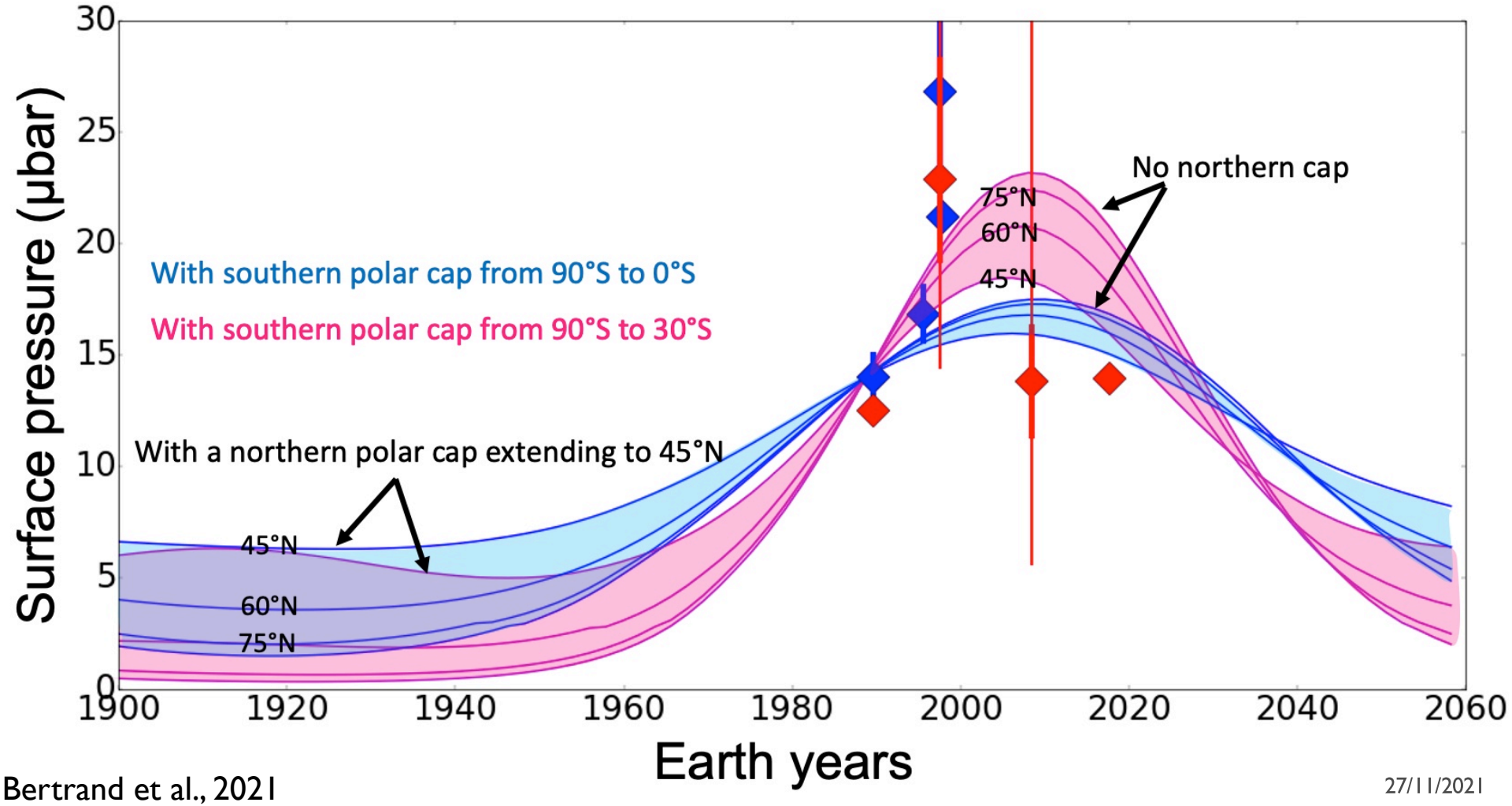
ATMOSPHERIC PRESSURE EVOLUTION

Date	Pressure at 1400 km (μbar)	Pressure at the surface (μbar)
	This work	
25 August 1989	1.0 ± 0.2	12.5 ± 0.5
18 July 1997	$1.90^{+0.45}_{-0.30}$	$(22.8^{+5.4}_{-3.6})$
21 May 2008	$1.15^{+1.03}_{-0.37}$	$(13.8^{+12.4}_{-4.4})$
5 October 2017	1.18 ± 0.03	(14.1 ± 0.4)
	Other works	
25 August 1989	N/A	14 ± 2
14 August 1995	1.4 ± 0.1	(17 ± 1)
18 July 1997	2.23 ± 0.28	(26.8 ± 3.4)
4 November 1997	1.76 ± 0.02	(21.1 ± 0.2)



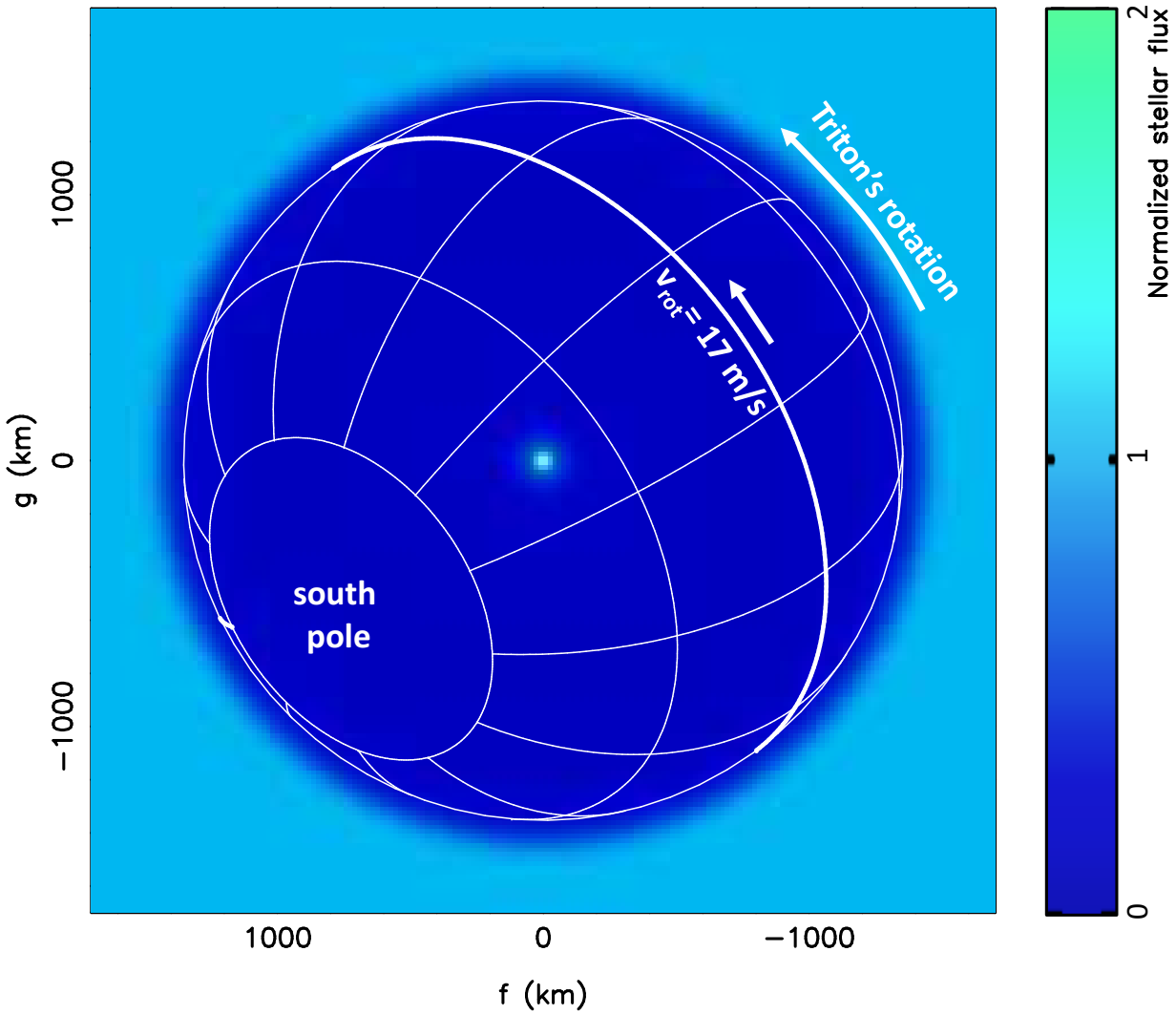
$$\frac{p_{surf}}{p_{1400}} = 12.0$$

VOLATILE TRANSPORT MODEL



Bertrand et al., 2021

CENTRAL FLASH ANALYSIS



$$\chi^2_{dof} = 0.80$$

OBLATENESS AND ZONAL WINDS

$$\epsilon \sim \frac{\epsilon'}{cos^2(B)} \qquad \epsilon' = \frac{a' - b'}{a'}$$

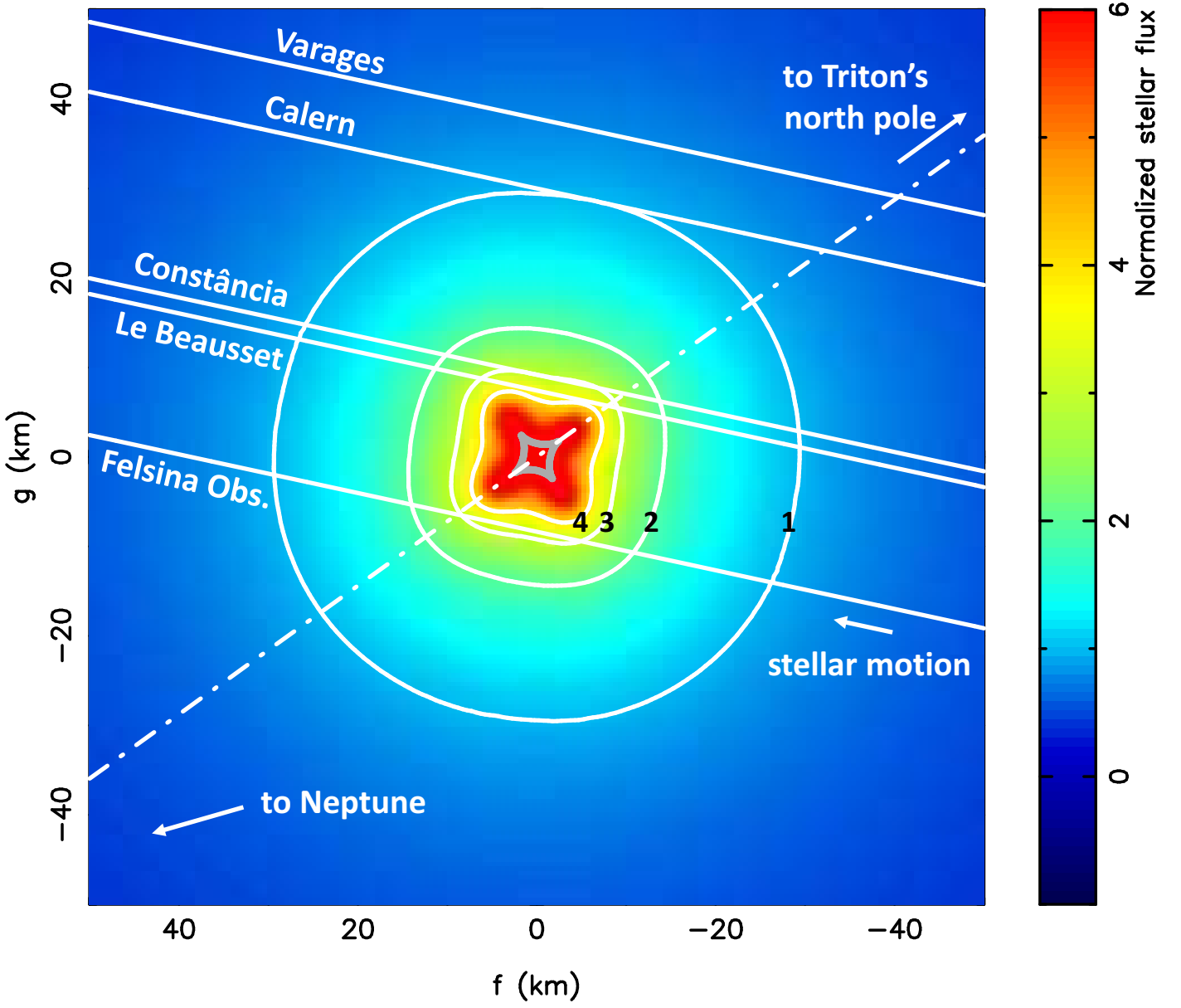
$$B = 40.5° \, S$$

$$v_e \sim 1450\sqrt{\epsilon} \pm 17 \text{ m/s}$$

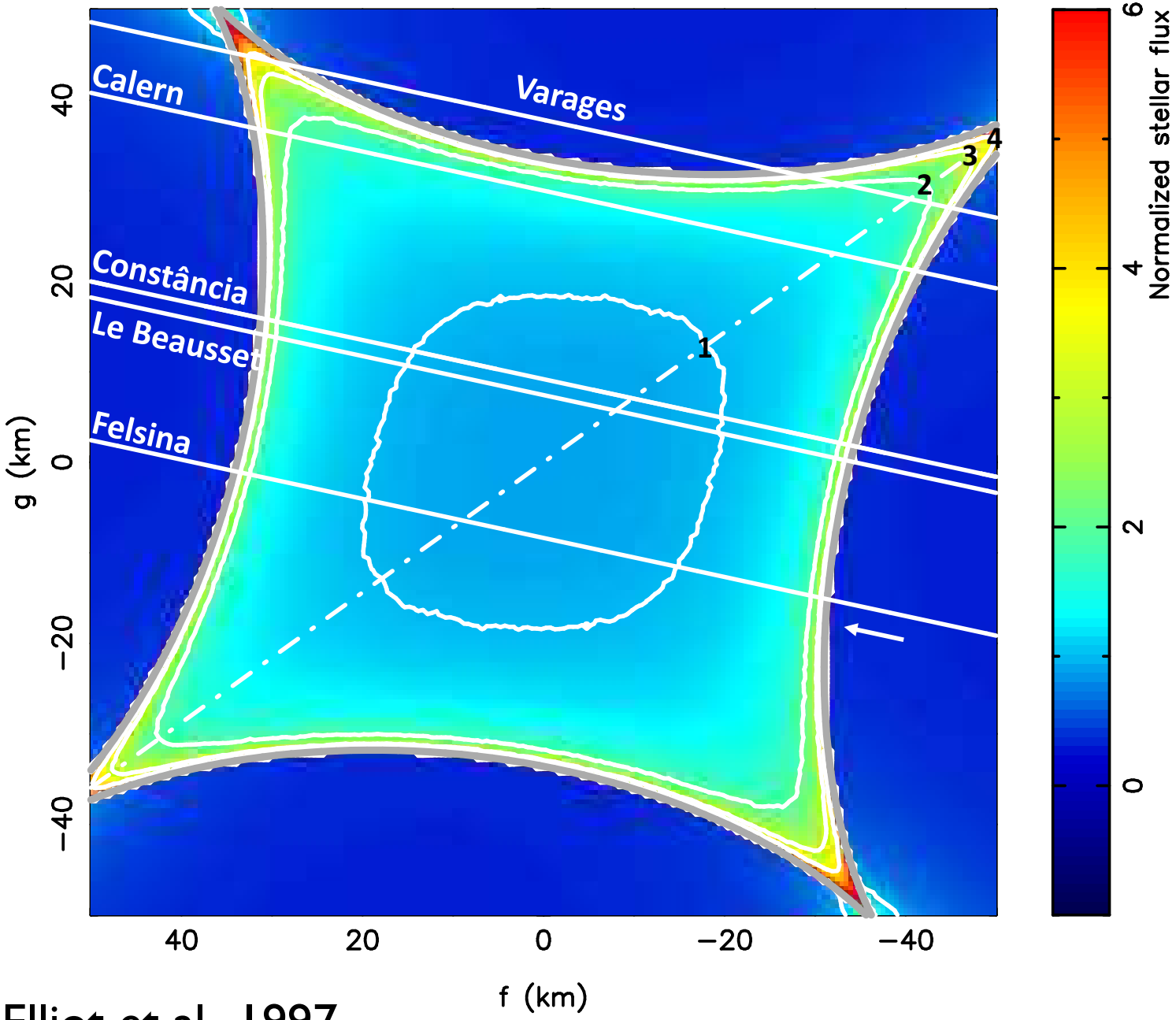
$$|v_e| < 80 \text{ m/s } (v_e < 0, \text{retrograde})$$

$$v_e < 46 \text{ m/s } (v_e > 0, \text{prograde})$$

$\epsilon = 0.0019$ (upper limit)



$\epsilon = 0.042$

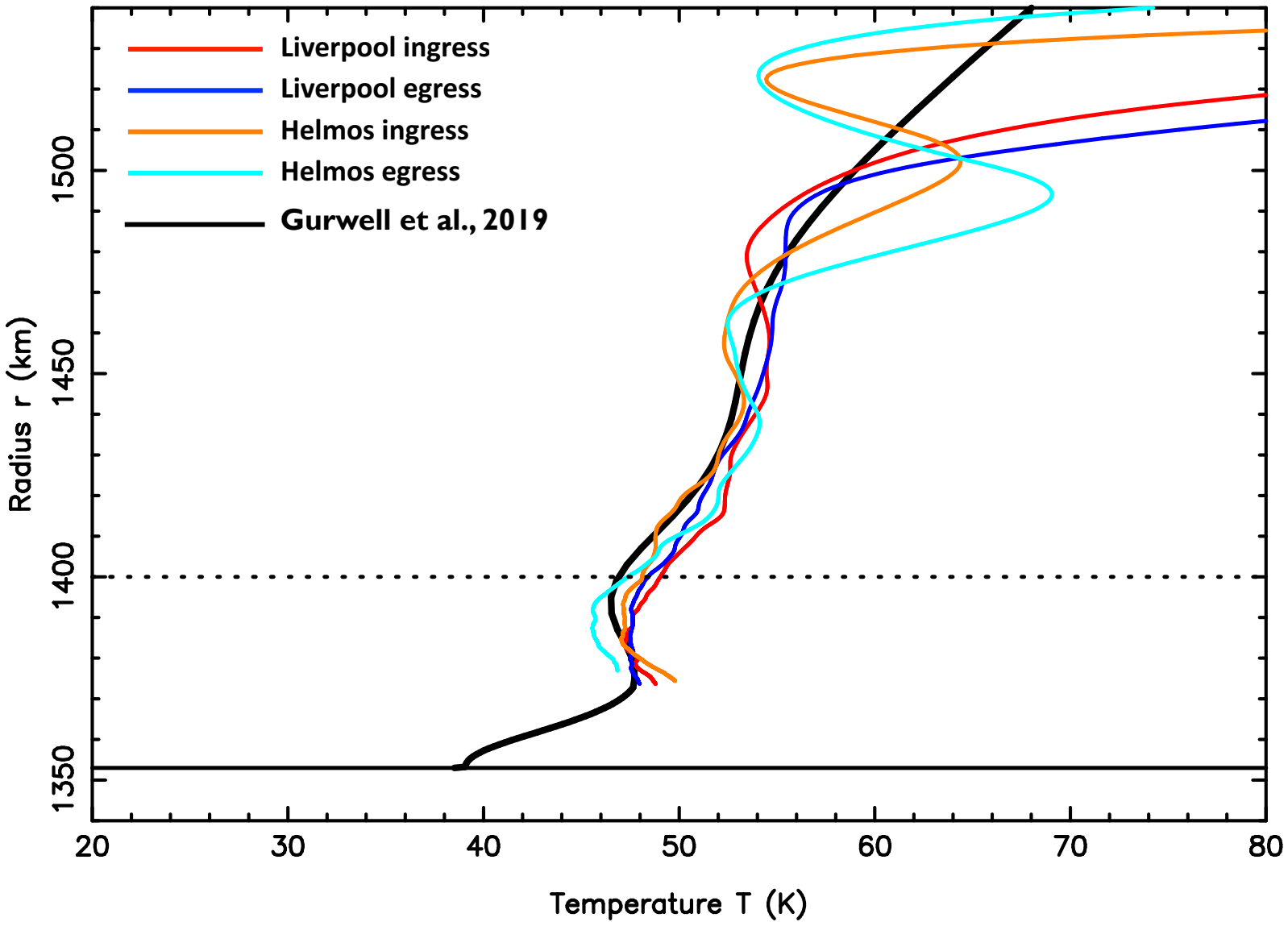


Elliot et al., 1997

HAZES AND CLOUDS

$$\tau_h \sqrt{\frac{2\pi R_T}{H_h}} exp\left(\frac{-8}{H_h}\right) \sim 0.07$$

$$\tau_c \sqrt{\frac{2\pi R_T}{H_c}} exp\left(\frac{-8}{H_c}\right) \sim 1.4$$



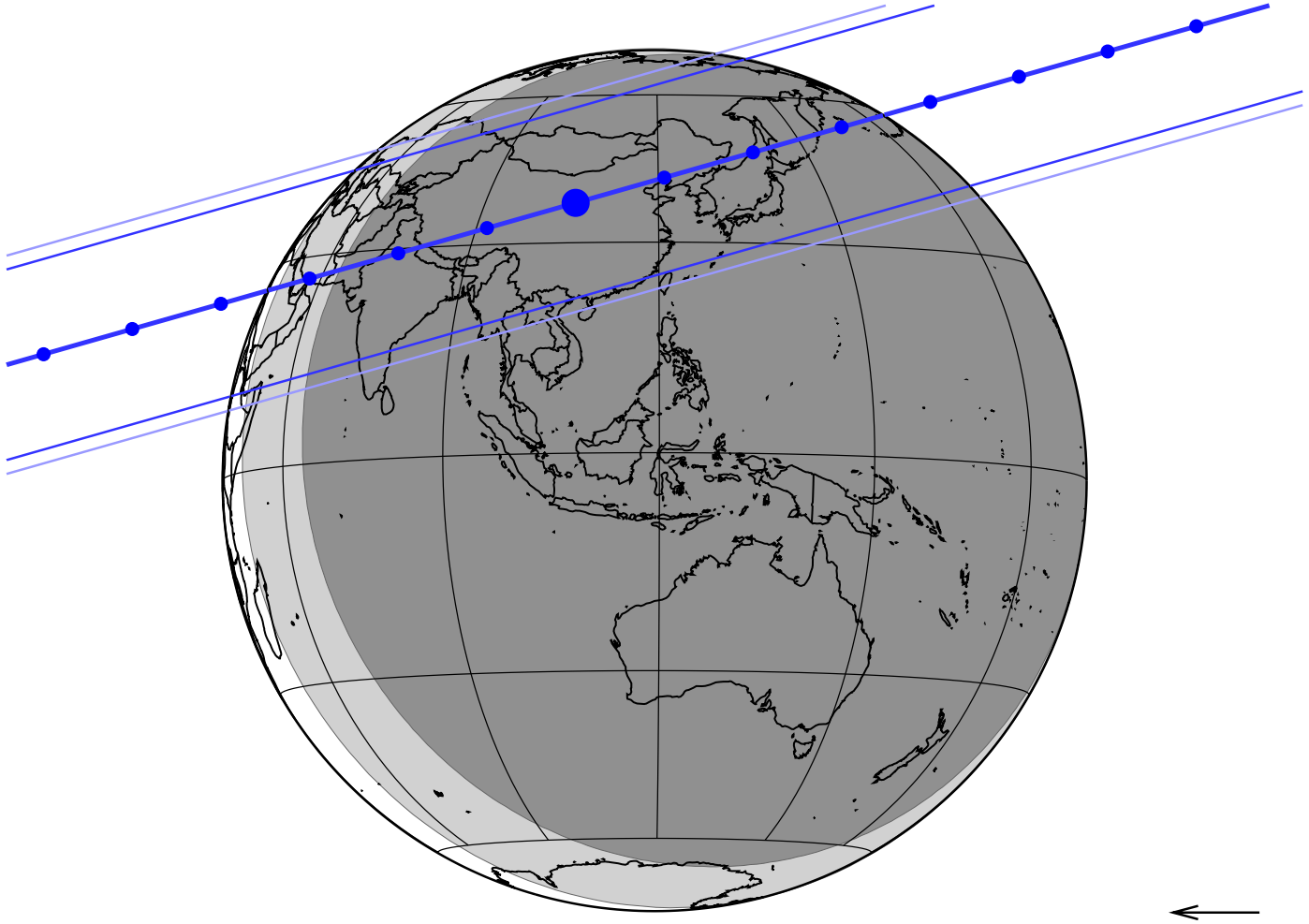
$H_h \sim 12$ km, $\tau_h = 0.005 \pm 0.001$, $H_c \gtrsim 20$ km, $\tau_c \geq 0.1$

(Krasnopolsky et al, 1993; Rages and Pollack, 1992)

FINAL REMARKS

NEXT TRITON OCCULTATION

Triton, *GaiaER3+pmGaiaER3, DE440NEP095 Offset: 0.0mas 0.0mas
updated: 2021-03-24 by Lucky Star



yyyy mm dd hh:mm:ss.s	RA_star_J2000	DE_star_J2000	C/A	P/A	vel	Delta	G*	RP*	H*
2022-10-06 14:39:38.0	23 36 52.4514	-03 50 09.796	0.203	344.13	-22.68	28.9716	11.5	11.1	10.3

CONCLUSIONS

Stellar occultations are one of the best techniques to study small bodies in the Solar System.

The technique benefits from professional and non-professional astronomers.

One of the most observed events, Triton's stellar occultation on 5 October 2017, with 90 positive light curves, provides a lot of science to study.

With novel analysis of the Voyager 2 data, we find that Triton's atmospheric pressure in 2017 is back to Voyager 2 epoch levels.

MERCI !

Acknowledgements:
This work has received support from the Portuguese Foundation for Science and Technology (FCT) through the PhD grant SFRH/BD/131700/2017.
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