Consejo Superior de Investigaciones Científicas
Instituto de Astrofísica de Andalucía

Physical characterization of Kuiper belt objects from stellar occultations and thermal measurements

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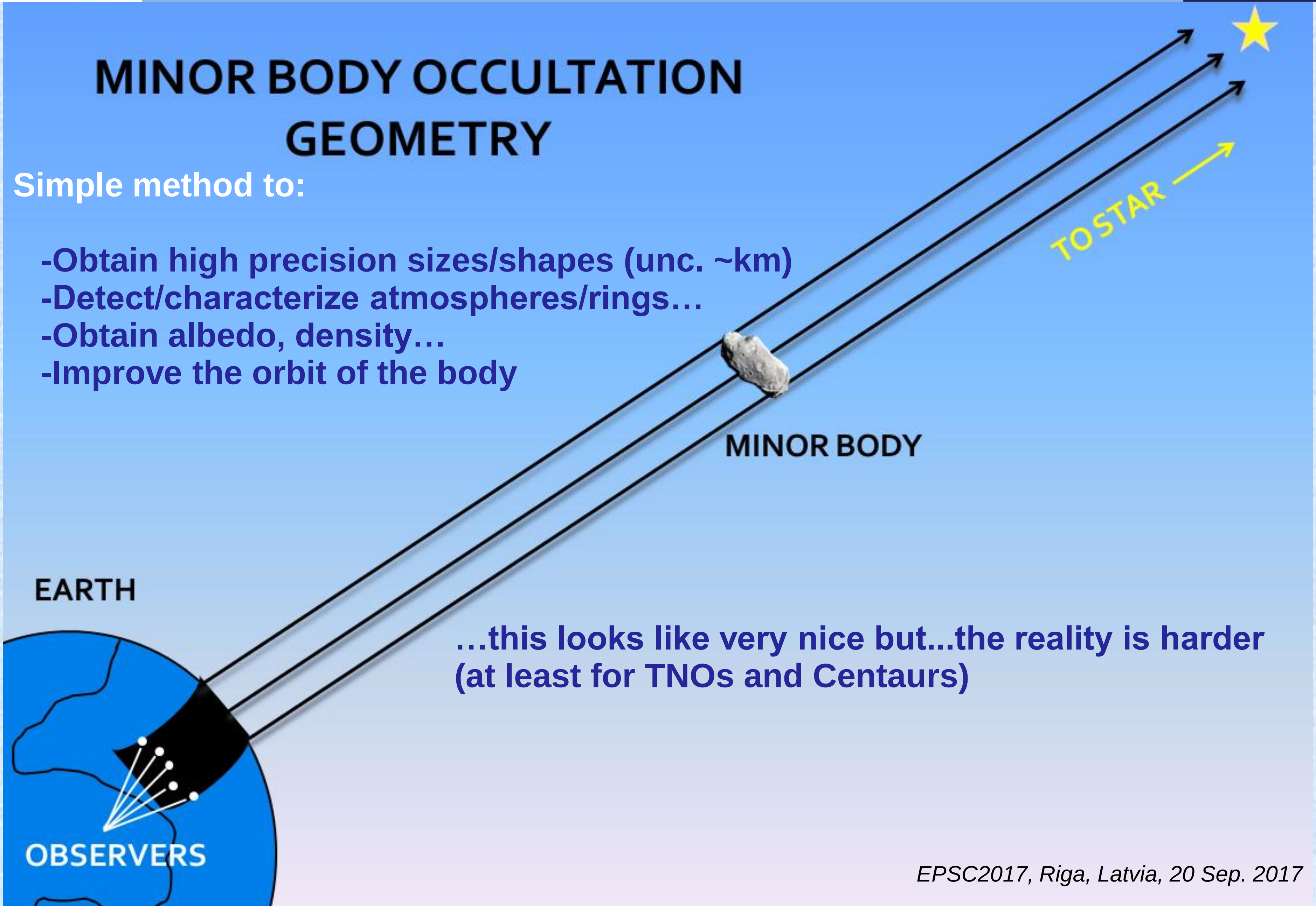
Small Bodies Near And Far

Stellar occultations

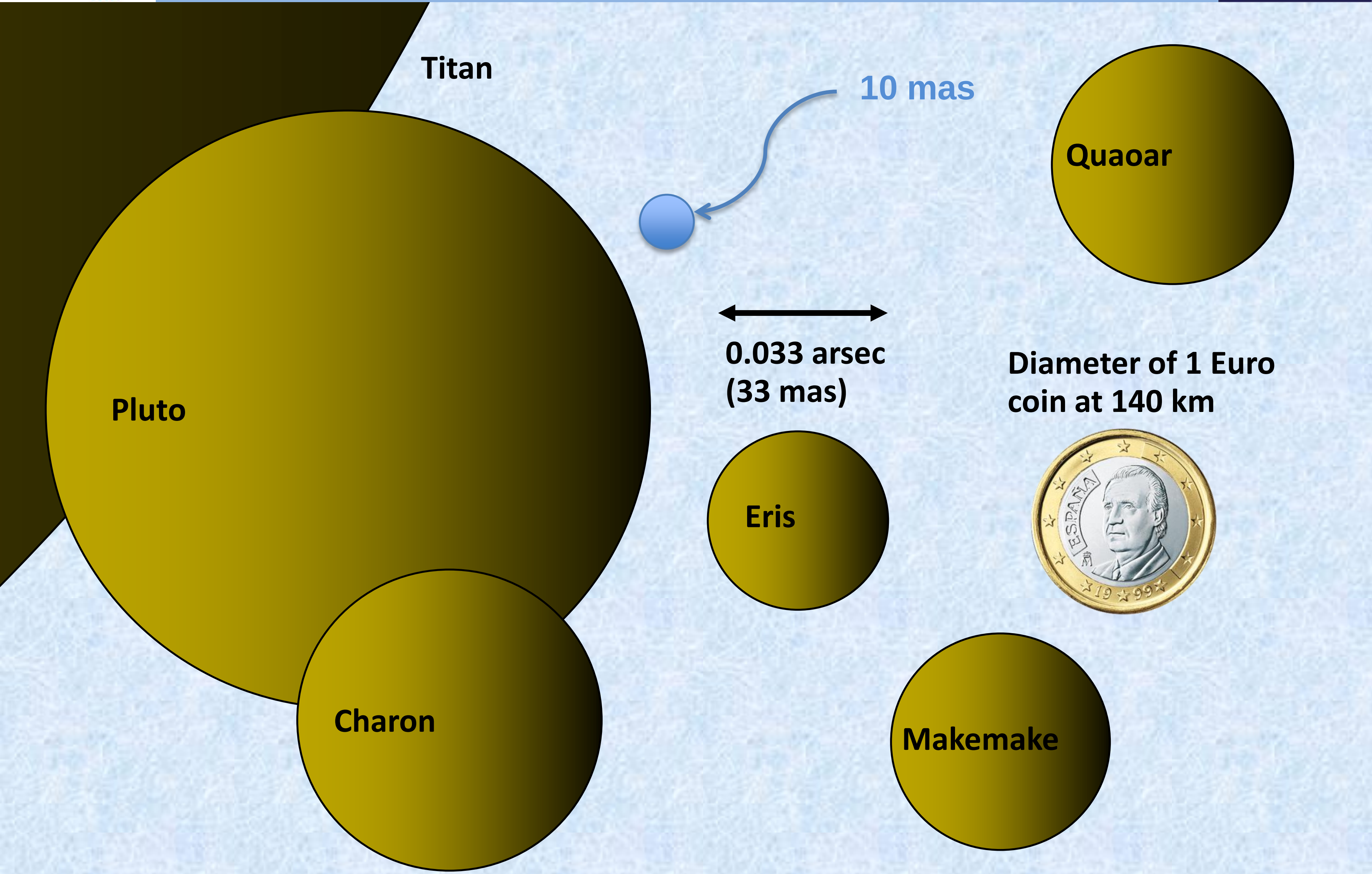


Simple method to:

- -Obtain high precision sizes/shapes (unc. ~km)
- -Detect/characterize atmospheres/rings…
- -Obtain albedo, density…
- -Improve the orbit of the body

…this looks like very nice but...the reality is harder (at least for TNOs and Centaurs)

Stellar occultations



Stellar occultations

~25 occultations by 15 TNOs (+ Pluto/Charon + Chariklo + Chiron + 2002 GZ_{32})

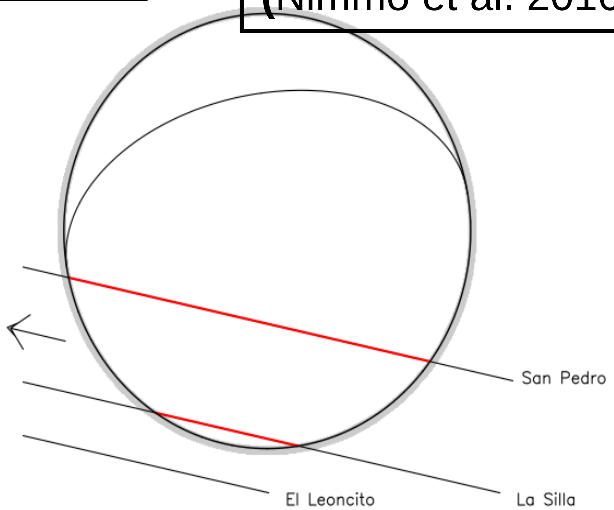
Stellar occultations: Eris & Chariklo

Eris: 6 November 2010

- Size ~ Plutón
- Albedo= 96%
- Density= 2.5 g/cm^3
- Atmosphere < 1nbar (10^{-4} x Pluto)

Eris' radius 1163±6 km

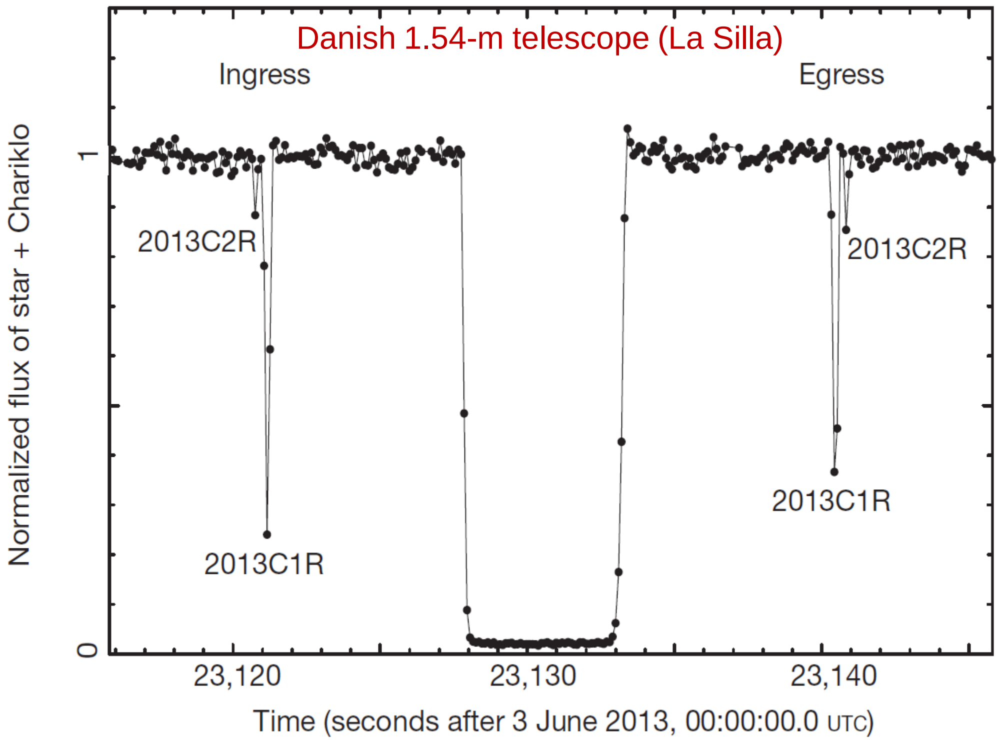
Pluto's radius 1188.3±1.6 km (Nimmo et al. 2016)



Sicardy et al. 2011 (Nature)

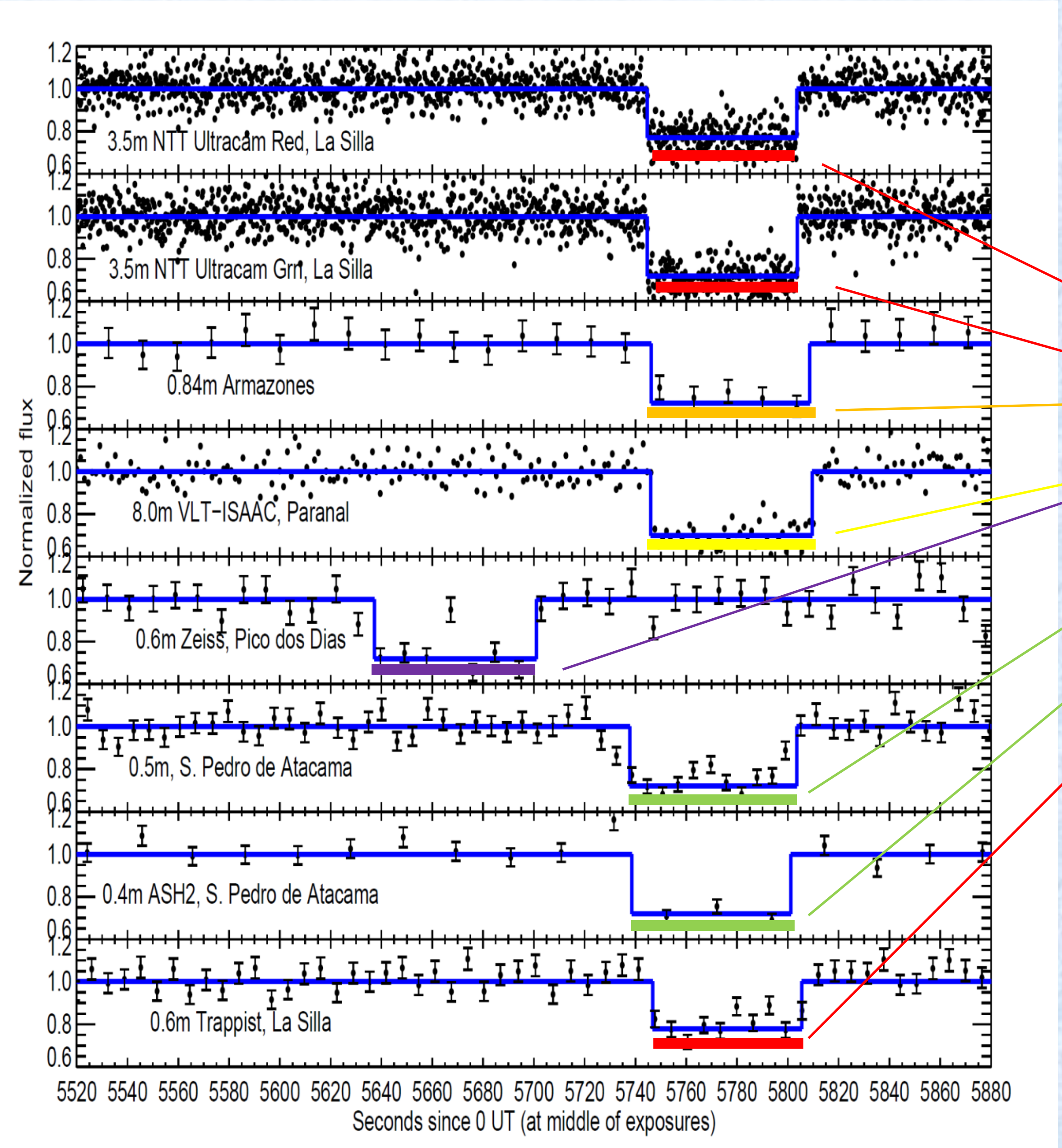
Chariklo: 3 June 2014

- It has rings!

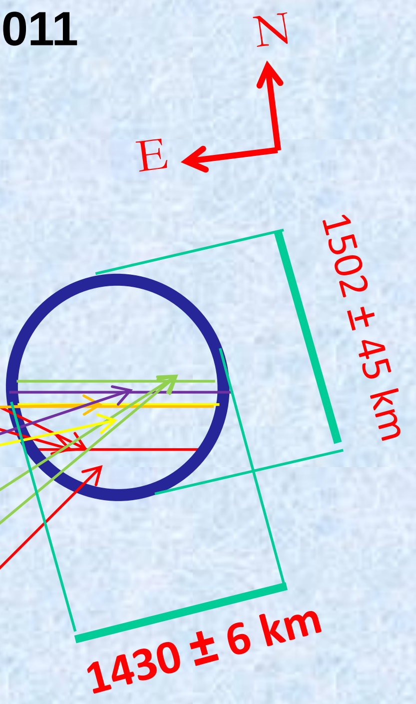


Braga-Ribas et al. 2014 (Nature)

Stellar occultations: Makemake



23 April 2011

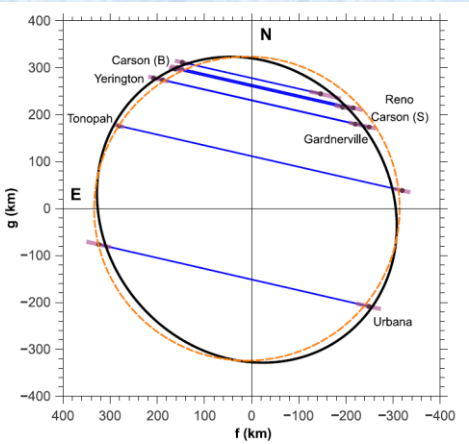


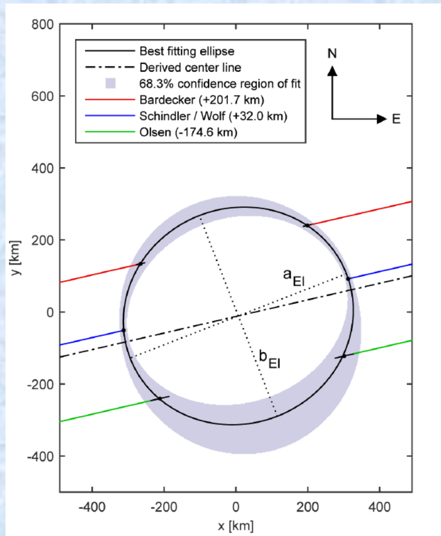
Geometric Albedo = 77%
(betwen Pluto and Eris)
Possible local atmosphere!

Ortiz et al. 2012 (Nature)

Stellar occultations: latest “catches”

2007 UK_{126}: 15 November 2014





Benedetti-Rossi et al. 2016 (7-chords)

D_{eq} = 638+14-28 km

p_V = 15.9-18.9%

Maclaurin spheroid (ε= 0.105-0.118)

ρ < 1.74 g·cm^{-3} (P = 11.05 h)

Schindler et al. 2017 (3-chords)

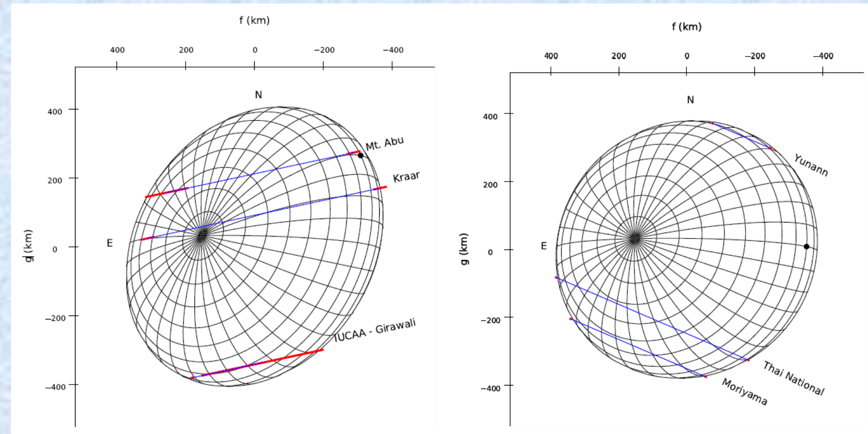
D_{eq} = 599-629 km

p_V = 15.0 ± 1.6%

Maclaurin spheroid (a/c ≤ 1.4870)

ρ ≥ 0.73 g·cm^{-3} (P ≥ 8 h)

2003 AZ_{84}: 8 Jan. 2011 single, 3 Feb. 2012 multi, 2 Dec. 2013 single, 15 Nov. 2014 multi.



Dias-Oliveira et al. 2017 (multi-chord)

D_{eq} = 772 ± 12 km

p_V = 9.7 ± 0.9%

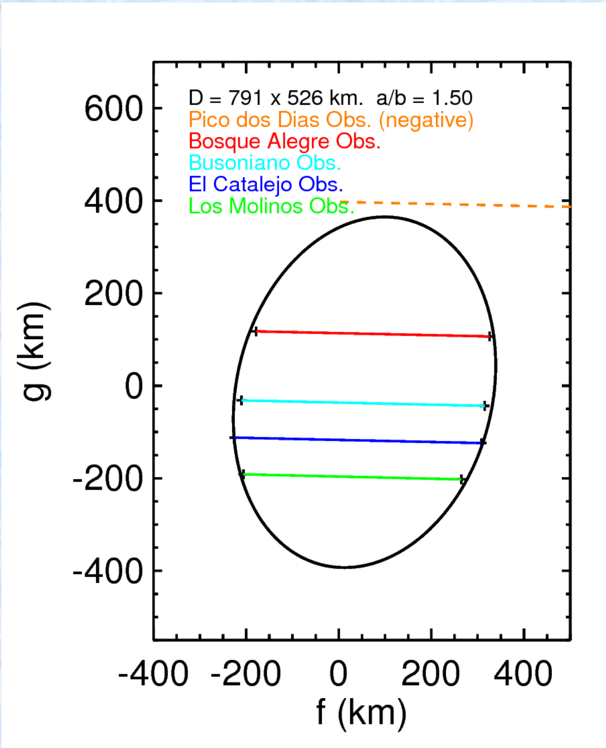
Jacobi ellipsoid (470 x 383 x 245 km)

ρ = 0.87 ± 0.01 g·cm^{-3} (P = 6.75 h)

Possible detection of a chasm!

Stellar occultations: latest “catches”

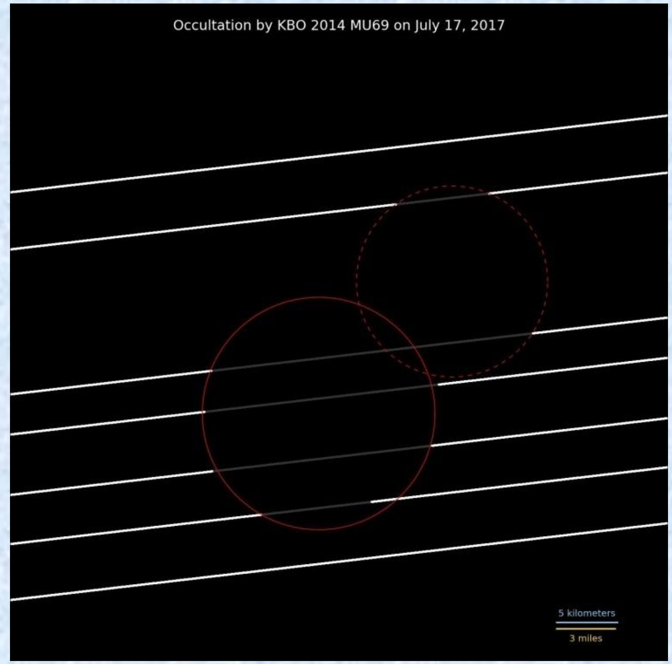
2003 VS_2: 7 November 2014



Santos-Sanz et al. 2017 (4-chords)

- D_{eq} = 562 km
- Jacobi ellipsoid
- ρ= 0.708-0.725 g·cm^{-3} (P = 7.42 h)

2014 MU_{69}: 17 July 2017



Credit: NASA/JHUAPL/SwRI/Alex Parker

Preliminary results:

- Very irregular shape
- Close or contact binary?
- 2 "lobes", with D’s of ~20 km and ~18 km

Stellar occultations from JWST?

Small Bodies Near And Far

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

P. Santos-Sanz[1], R. G. French[2], N. Pinilla-Alonso[3], J. Stansberry[4], Z-Y. Lin[5], Z-W. Zhang[6], E. Vilenius[7,8], Th. Müller[7], J. L. Ortiz[1], F. Braga-Ribas[9], A. Bosh[10], R. Duffard[1], E. Lellouch[11], G. Tancredi[12], L. Young[13], Stefanie N. Milam[14], and the *JWST* "Occultations" Focus Group

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JWST/NIRCam, cadence ~6.7 Hz, 64x64 subarray, 0.7 to 4.8μm
Stellar occultations by KBOs: JWST-GTO time approved !

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 – techniques: photometric – telescopes

Thermal measurements

- **Thermal emission of TNOs (T= 20-50 K) have their maxima at 70-160 μm**
- **Thermal emission of few TNOs from ground** (Jewitt et al. 2001, Lellouch et al. 2002, Margot et al. 2002, Bertoldi et al. 2006, Gerdes et al. 2017, Brown & Butler 2017, Lellouch et al. 2017)
- **Thermal observations of ~60 TNOs w/ Spitzer/MIPS (@ 23.68 and 71.42 μm)**

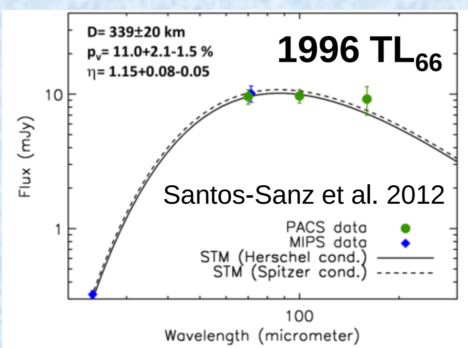
- **Herschel:** observed 140 TNOs/Centaurs within the open time key programme **"TNOs are Cool: a survey of the Transneptunian region"**

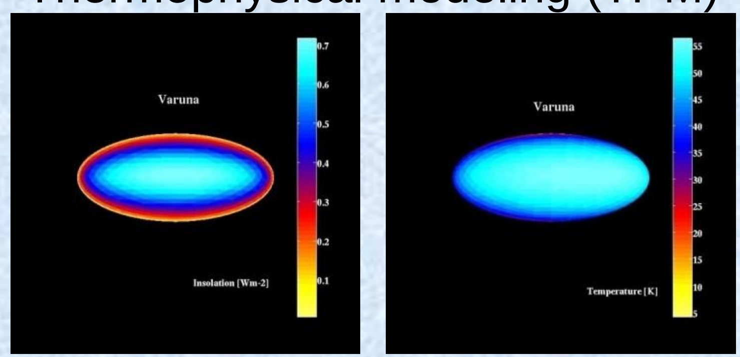
  - **Main goal:** determine Diameters and Albedos by means of:

3-band photometry w/ Herschel/PACS (@ 70.0, 100.0 and 160.0 μm)

\+

Thermal and/or Thermophysical modeling (TPM)





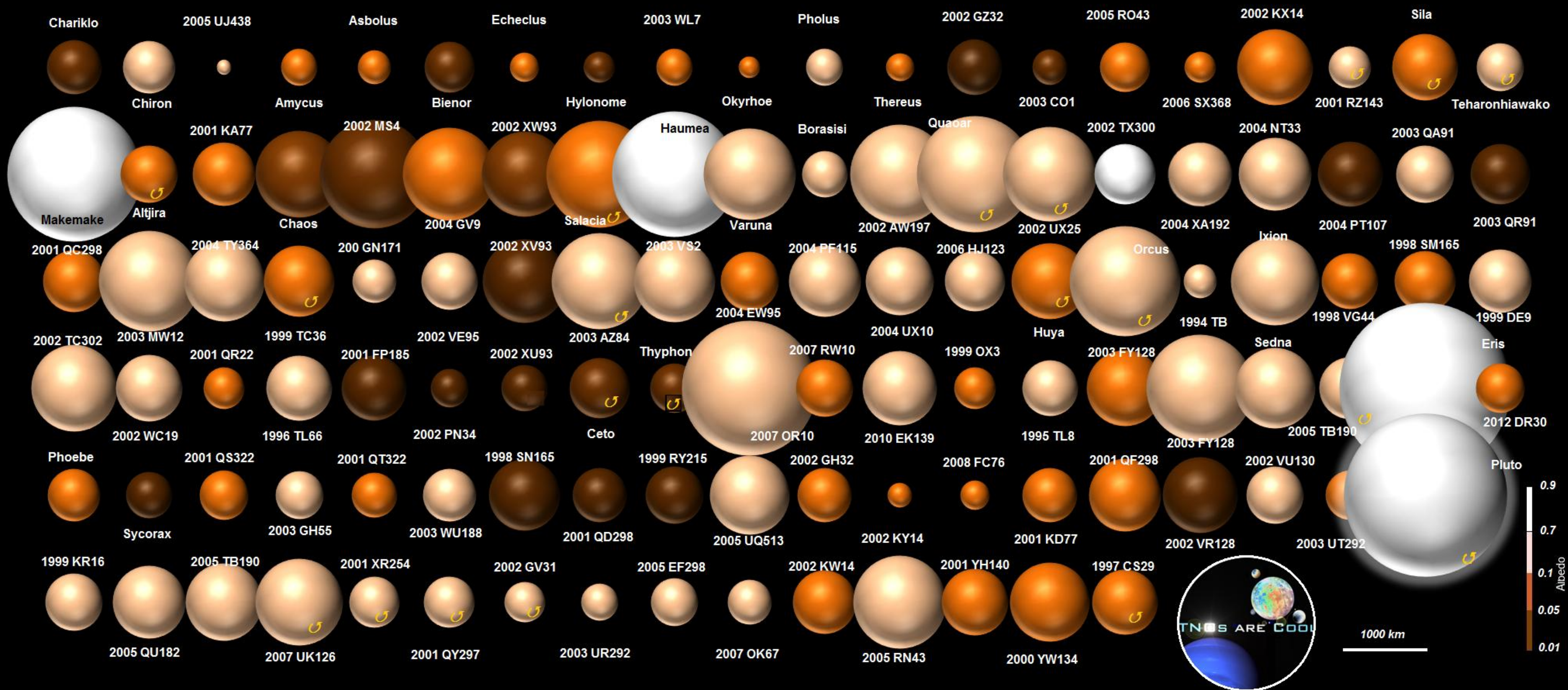
Herschel observations expand / complement Spitzer observations

Thermal measurements

TNOs are Cool!

sizes, albedos, thermal properties and mass densities

Typical uncertainties ~10% Diameters and ~ 20% Albedos



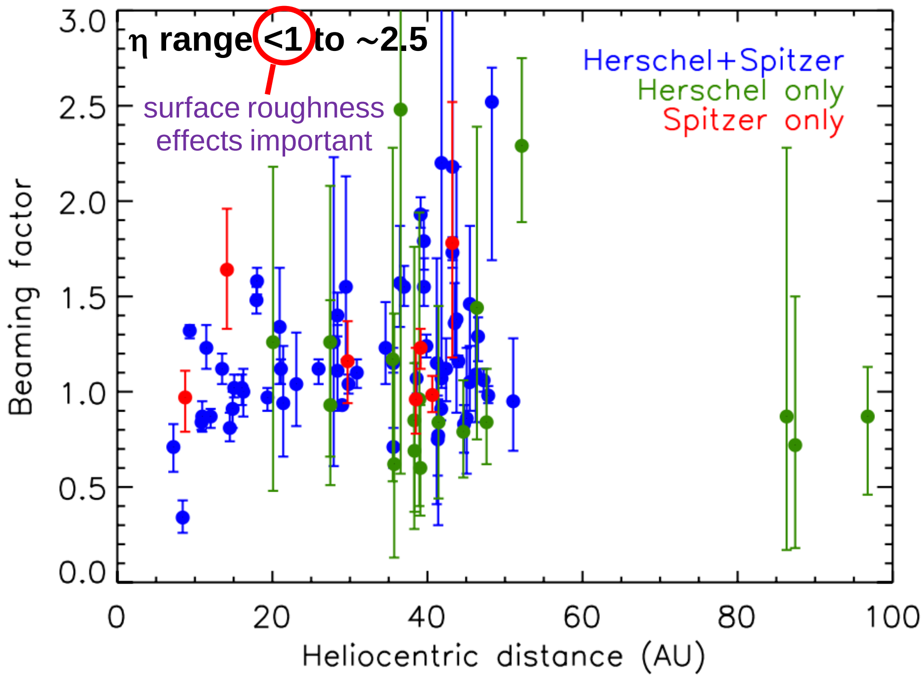
(Müller et al. 2010, Lellouch et al. 2010, Lim et al. 2010, Santos-Sanz et al. 2012, Mommert et al. 2012, Vilenius et al. 2012, Pal et al. 2012, Fornasier et al. 2013, Lellouch et al. 2013, Vilenius et al. 2014, Duffard et al. 2014, Santos-Sanz et al. 2017)

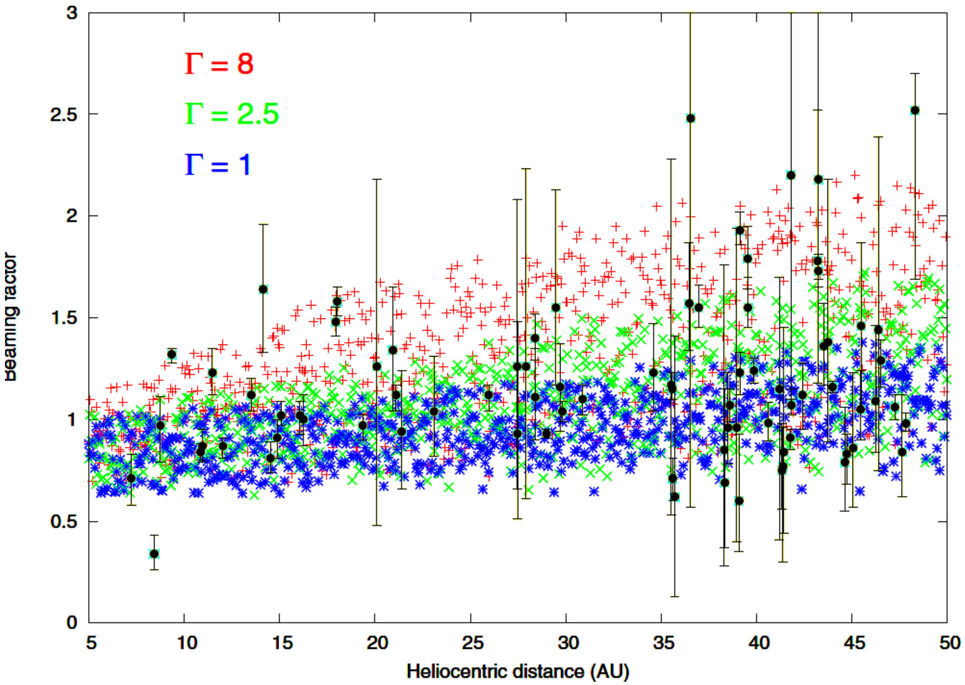
http://public-tnosarecool.lesia.obspm.fr/

Thermal measurements: mass density

Object	ρ (g·cm^{-3})	Reference
(136199) Eris	**2.40+0.46-0.37**	Santos-Sanz et al. 2012
(50000) Quaoar	**2.18+0.43-0.36**	Fornasier at al. 2013
(90482) Orcus	**1.53+0.15-0.13**	Fornasier et al. 2013
(120347) Salacia	**1.29+0.29-0.23**	Fornasier et al. 2013
(174567) Varda	**1.27+0.41-0.44**	Vilenius et al. 2014
(47171) 1999 TC36	**0.64+0.15-0.11**	Mommert et al. 2012
(79360) Sila-Nunam	**0.73 ± 0.28**	Vilenius et al. 2012
(148780) Altjira	**0.30+0.50-0.14**	Vilenius et al. 2014
2001 QC298	**1.14+0.34-0.30**	Vilenius et al. 2014
(26308) 1998 SM165	**0.51+0.29-0.14**	Stansberry et al. 2008, Spencer et al. 2006
(65489) Ceto	**0.64+0.16-0.13**	Santos-Sanz et al. 2012
(275809) 2001 QY297	**0.92+1.30-0.27**	Vilenius et al. 2014
2001 XR254	**1.00+0.96-0.56**	Vilenius et al. 2014
(88611) Teharonhiawako	**0.60+0.36-0.33**	Vilenius et al. 2014
(66652) Borasisi	**2.1+2.6-1.2**	Vilenius et al. 2014
(42355) Typhon	**0.60+0.72-0.29**	Stansberry et al. 2012
(42355) Typhon	**0.36+0.08-0.07**	Santos-Sanz et al. 2012

Thermal measurements

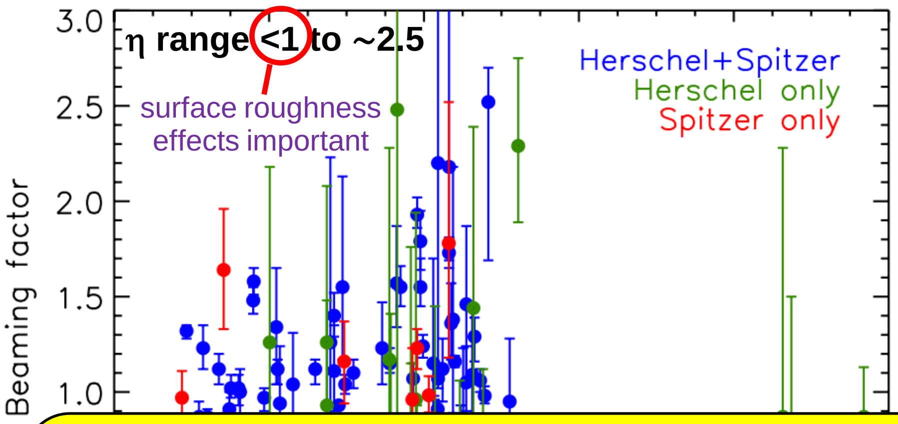


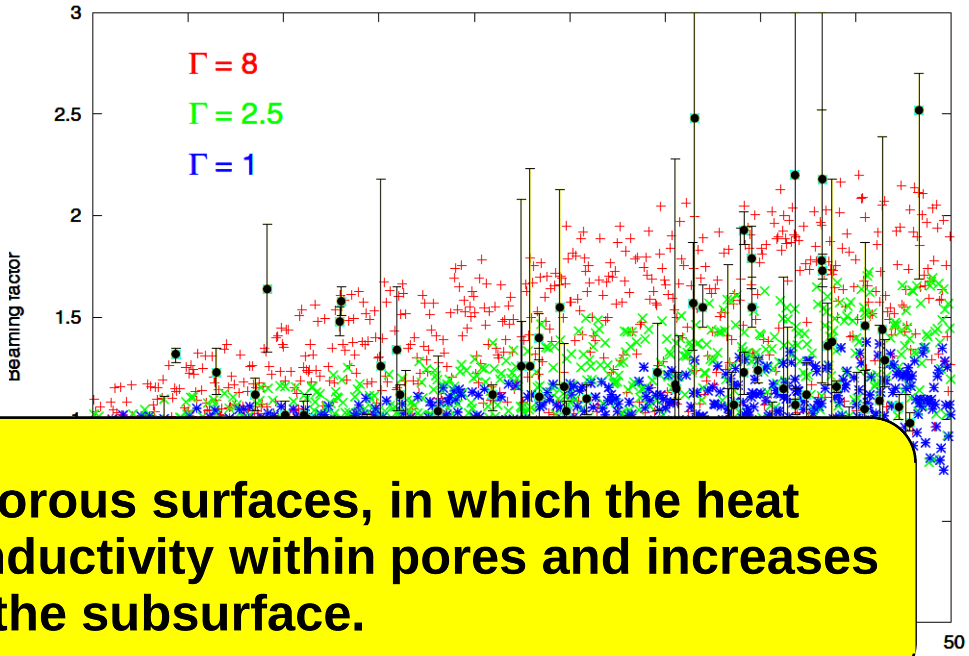


Lellouch , Santos-Sanz et al. 2013

- Γ_{mean} **= (2.5 ± 0.5) MKS**
- **Strong suggestion that T.I. (Γ) decreases with heliocentric distance (r_h)**
- **Γ 's 2-3 orders of magnitude lower than expected for compact ices**

Thermal measurements





Our results suggests strongly porous surfaces, in which the heat transfer is affected by radiative conductivity within pores and increases with depth in the subsurface.

Lellouch , Santos-Sanz et al. 2013

- **Γ_{mean} = (2.5 ± 0.5) MKS**
- **Strong suggestion that T.I. (Γ) decreases with heliocentric distance (r_h)**
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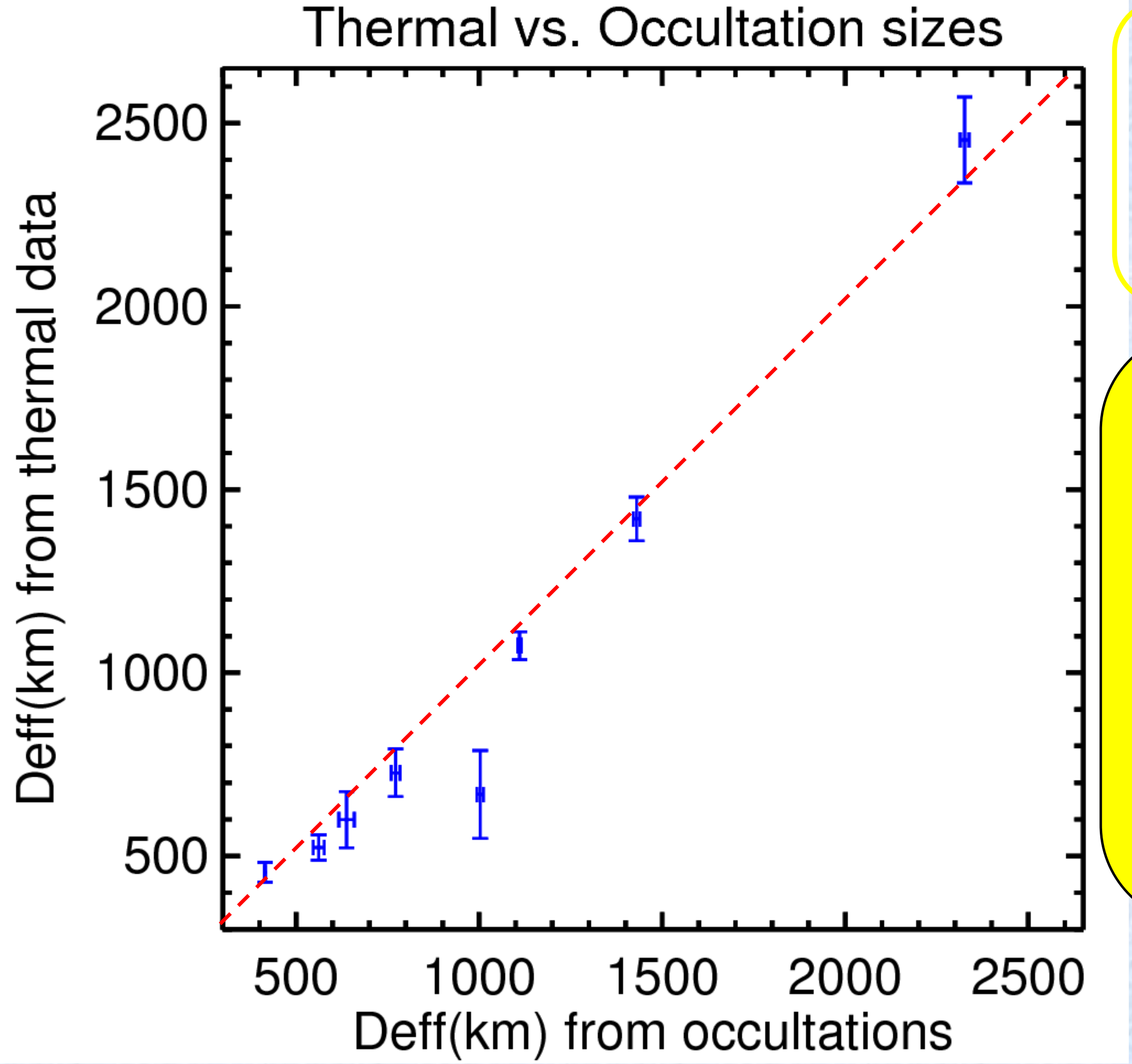
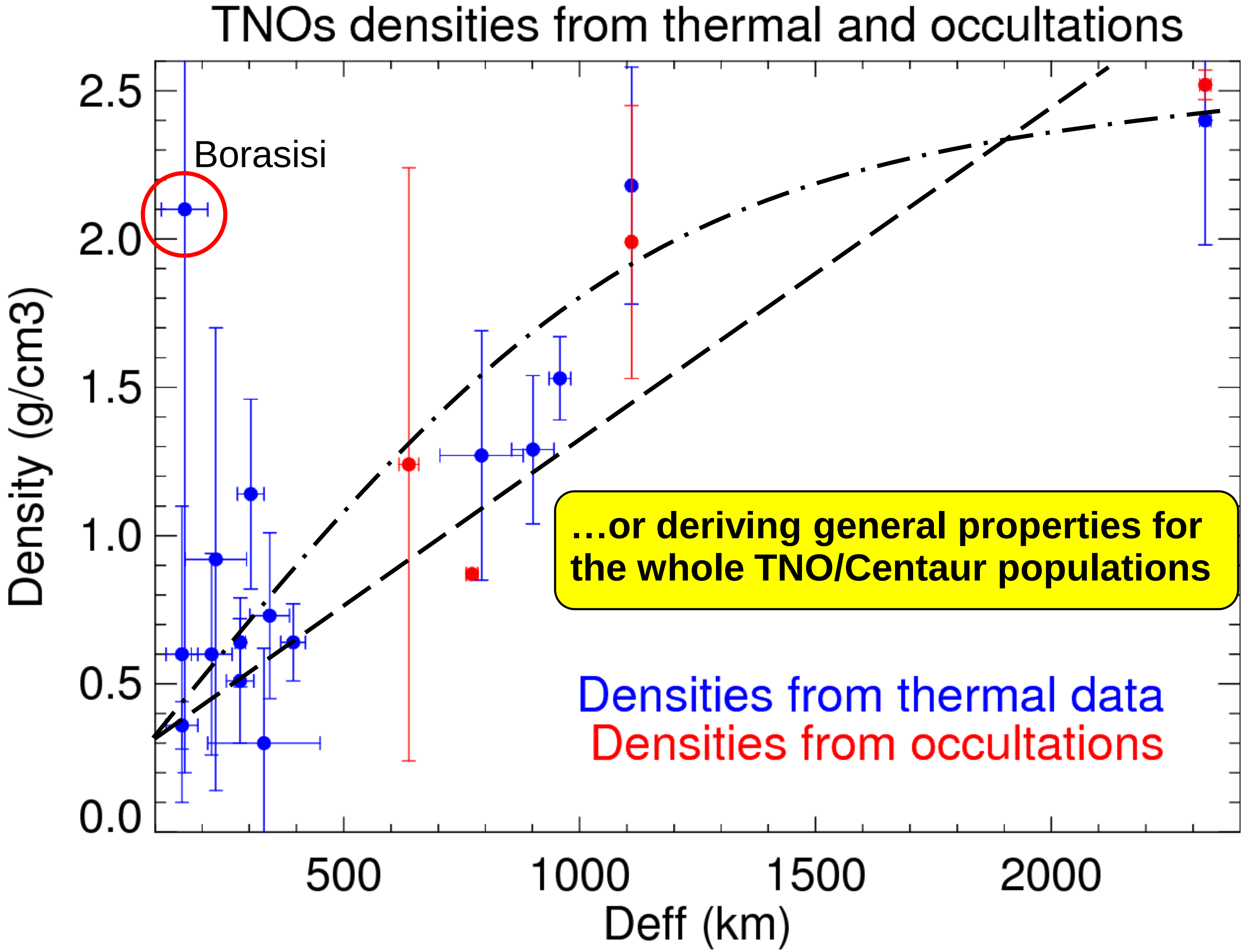
Merging techniques



Stellar occultations and thermal measurements are complementary techniques with clear and important synergies:

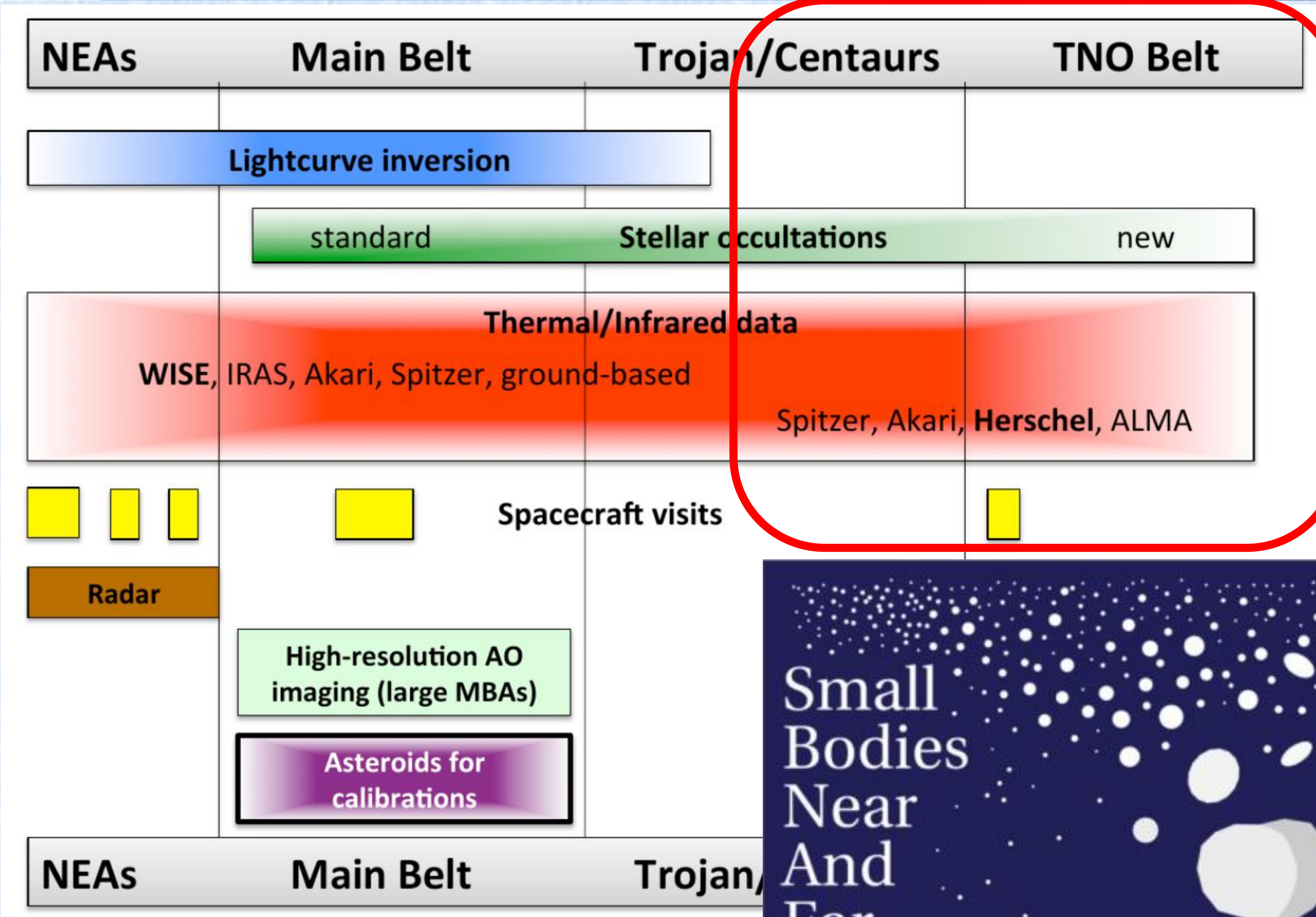
- Refining of TPMs using results from occultations
- Obtaining a detailed physical and thermal characterization of **selected TNOs/Centaurs**: diameter, albedo, shape, mass density, surface properties (Γ, roughness, emissivity), etc.

Merging techniques



…or deriving general properties for the whole TNO/Centaur populations

Merging techniques

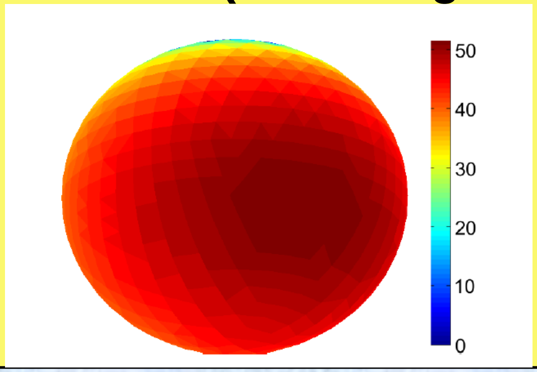


Merging techniques within SBNAF

2007 UK126 (Schindler et al. 2017) → 3-chords stellar occultation + thermal data

Results from the occultation used to constrain the TPM (assuming P = 8 h):

- D_{eff} = 599-629 km, a/c = 1.08-1.22
- T_{ss} ~ 50-55 K
- **Orientation near equator-on (θ=45-90º)**

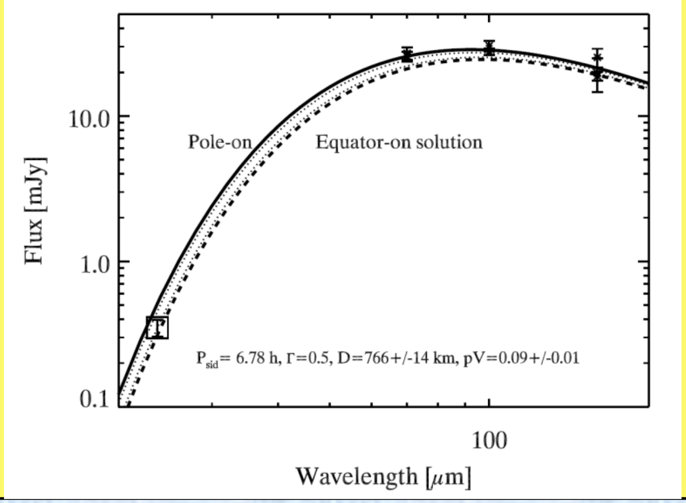


Surface T distribution on 2007 UK_{126}, as predicted by the best TPM

2003 AZ84 (Santos-Sanz et al. 2017) → thermal data + multi-chord stellar occultation

Results from the occultation used to constrain the TPMs (P = 6.78 h):

- **Orientation near pole-on ±30º**



Thank you!

http://www.mpe.mpg.de/~tmueller/sbnaf/

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