Probing trans-Neptunian Objects with stellar occultations in Gaia era

Bruno Sicardy
Observatoire de Paris - LESIA
& université Pierre et Marie Curie

Solar system science before and after Gaia
Pisa 4-6 May 2011
Doressoundiram & Lellouch, "Aux confins du système solaire"
airless Trans-Neptunian Objects (TNO's)

- radius, shape & limb features at kilometric accuracy
- density, if mass known from satellite motion ---\> internal structure
- albedo ---\> composition, state of surface
- if double occultation primary/secondary: accuracy \~ 10 km, e.g. Pluton/Charon ---\> better orbital elements
TNO's with atmosphere

- Density & temperature profiles down to nbar levels
- Variations with time
- Detection of activity (e.g., gravity waves)
- Zonal winds measurements through central flash
- Haze properties through chromatic dependence
strength: can achieve what nobody else can do

weakness: difficult to predict, and thus to plan, especially on large telescopes

⇒ depending on body and background stellar field: one occultation of interest every month, year, decade
~ 3x3 arcmin fields of view

Pluton ~ 240 candidates in 2011

Eris ~ 1 candidate 06 Nov. 2010 next: 29 August 2013
thousands of stars measured against UCAC2 stars positions →
r.m.s. deviations ~ 50 mas

THEN updates 1-3 weeks before → accuracy 20-30 mas

M. Assafin et al. (ON, Rio de Janeiro)
R. Behrend (Geneva Obs)
J.L. Ortiz et al. (IAA Granada)
Pluton

Charon

Eris

Makemake

Titan

quaoar

stamp at 140 km

0.033 arcsec (33 mas)
Les plus grands objets transneptuniens connus:

- Pluton
- Éris
- Makemake
- Haumea
- Sedna
- Orcus
- Quaoar
- Varuna
- 2003 AZ₈₄
0.89"

2UCAC 26257135
(D. Herald, Aug. 2004)
Charon

Charon UCAC2 2625 7135, correction DE413: 0.021 −0.011 (post-event)

11 July 2005, 03:36 UT, 1″ = 21809 km, JPL, DE–0413 Plu013
Sicardy et al., *Nature* 439, 52, 2006
« Charon’s size and an upper limit on its atmosphere from a stellar occultation »

$R = 603.6 \pm 1.4$ km
distance: 42.75 UA

predicted
Rio de Janeiro group & Raoul Behrend (Geneva)

observed

45 mas
(\Delta t = 36 \text{ sec})
São Luis, Brazil
telescope 12.5 cm, alt.: 2 m
F. Colas
something expected at Quixadá around here
dark ($p_v=0.04$) least elongated probability $\sim 0.610 \times 525$ km

brightest possible ($p_v=0.12$) probability $\sim 0.502 \times 218$ km

most probable in this corner

dark ($p_v=0.04$) most elongated probability $\sim 0.3860 \times 375$ km
Eris

6 novembre 2010, Sicardy et al. Nature 2011, to be submitted
Occultation by 136199 Kris
San Pedro de Atacama
Celestial Exploration
November 5th 2010

Alain Maury, 50 cm
Sand Pedro de Atacama

Emmanuel Jehin, 60 cm
La Silla
most remote object observed in solar system (97 AU, 15 billions km)

$p_v$ close to one → one of brightest objects of solar system

atmospheric limit of $N_2$~ 1 nanobar ($10^{-4} \times$ Pluton atmosphere)
The trans-neptunian object UB₃₁₃ is larger than Pluto

F. Bertoldi¹,², W. Altenhoff³, A. Weiss², K.M. Menten² & C. Thum³

Pluto is again a harbinger

New astronomical and laboratory data show that the abundances of the two dominant ices, nitrogen and methane, on the surfaces of the Solar System's two largest dwarf planets are surprisingly similar — raising fresh questions.

S. ALAN STERN

9 DECEMBER 2010 | VOL 468 | NATURE | 775
Dear Mr. Sikardy,[...] I am an artist/writer/attorney and have loved Pluto since I first learned about as a little boy. I asked President George W. Bush in July 2002 when I met him in Portland, Oregon [...] Anyway, I am very glad that Eris will lose more diameter based on the final calculations of the stellar occultation. Given the bad behavior of Mike "Pluto-Killer" Brown, it would make it even more joyous, I must admit, if Eris were to lose enough diameter to make it virtually certain that Pluto is larger. Alan Stern told me that New Horizons, baring a mishap, will measure Pluto's diameter, too.
2003 AZ84

Credits: Rio Team & B. Sicardy
2003 AZ84
Makemake
Quaoar

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<tr>
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<td>05</td>
<td>2011</td>
<td>02</td>
<td>40</td>
<td>35</td>
<td>0</td>
<td>01</td>
<td>28</td>
<td>50.8035</td>
<td>-15.27</td>
<td>42.735</td>
<td>0.117</td>
<td>191.77</td>
<td>-18.28</td>
<td>42.35</td>
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Credits: Bia Team & B. Sicardy
Quaoar

~30 mas
Quaoar, San Pedro de Atacama 50-cm, 4 May 2011
<table>
<thead>
<tr>
<th>Date</th>
<th>Object</th>
<th>Site</th>
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<tbody>
<tr>
<td>22 June 2008</td>
<td>Pluto &amp; Charon</td>
<td>Australia, Indian Ocean</td>
</tr>
<tr>
<td>24 June 2008</td>
<td>Pluto</td>
<td>Pacific</td>
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<td>15 August 2008</td>
<td>Pluto</td>
<td>W. USA</td>
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<td>29 December 2008</td>
<td>2003 AZ84</td>
<td>Run 082.C-0500 (ESO - VTL &amp; NTT)</td>
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<td>04 March 2009</td>
<td>Nix</td>
<td>Hawaii</td>
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<td>21 April 2009</td>
<td>Pluto</td>
<td>La Réunion Island</td>
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<tr>
<td>23 August 2009</td>
<td>Pluto</td>
<td>Australia &amp; New Zealand</td>
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<tr>
<td>05 June 2009</td>
<td>Nix</td>
<td>Australia &amp; New Zealand</td>
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<td>30 June 2009</td>
<td>2002 MS4</td>
<td>Run 083.C-0451 (ESO – VTL &amp; NTT)</td>
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<td>14 February 2010</td>
<td>Pluto</td>
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<td>19 February 2010</td>
<td>Varuna</td>
<td>South Africa, Namibia, Brazil</td>
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<tr>
<td>19 May 2010</td>
<td>Pluto</td>
<td>Run 085.C-0225 (ESO – VTL &amp; NTT)</td>
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<td>Pluto</td>
<td>Australia &amp; New Zealand</td>
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<td>Quaoar</td>
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<td>Southern Africa, Brazil, Argentina, Chile</td>
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<td>06 November 2010</td>
<td>Eris</td>
<td>Europe, Brazil, Argentina, Chile</td>
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<td>2003 AZ84</td>
<td>Chile</td>
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<td>03 March 2011</td>
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<td>Europe</td>
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<td>Quaoar</td>
<td>Chile</td>
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<td>23 April 2011</td>
<td>Makemake</td>
<td>Brasil, Argentina, Chile</td>
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<td>01 May 2011</td>
<td>Huya</td>
<td>off Earth</td>
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<td>04 May 2011</td>
<td>Quaoar</td>
<td>South Africa, South America</td>
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<td>14 May 2011</td>
<td>Quaoar</td>
<td>Europe</td>
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<tr>
<td>16 May 2011</td>
<td>Quaoar</td>
<td>Europe (off Earth ?)</td>
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<tr>
<td>17 May 2011</td>
<td>Hydra</td>
<td>North America</td>
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<td>21 May 2011</td>
<td>Chariklo</td>
<td>Africa (bright)</td>
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<td>Pluto &amp; Charon</td>
<td>Pacific</td>
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<tr>
<td>27 June 2011</td>
<td>Pluton &amp; Hydra</td>
<td>Pacific</td>
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ABOUT 1400 EVENTS posted on B. Sicardy’s home page
Conclusions

TNOs occultations in Gaia's era

at < 1 mas accuracy:

_allocates huge relieve in occultation planning (now 99% time spent in astrometric predictions & updates)

_allocates chose TNO, chose telescope, get many chords on body (size, shape & limb features at km-accuracy)

_allocates TNOs with atmosphere (Pluto,...): central flash → zonal winds, haze properties

_allocates get satellites: shape & orbital elements