Analysis of 31 stellar occultations by Centaurs and Transneptunian Objects

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Introduction - Background

- Trans-Neptunian Objects (TNOs) are a population of small bodies orbiting the Sun beyond Neptune, in the Kuiper Belt region (30 - 100 UA);
- Centaurs are believed to be a transient population between TNOs and Jupiter-family comets, orbiting between Jupiter and Neptune;
- Stellar occultation (Fig. 1) happens when a small body temporarily blocks the light of a star to a given observer. The analysis of the resulting light curve allows the determination of sizes, shapes, topographic features as well the detection and characterization of rings, tenuous atmospheres and satellites;
- Astrometric positions from stellar occultations are more accurate than classic methods and help to improve the objects ephemerids.

Methods

Data reduction

- This study employs images obtained from stellar occultations to determine astrometric and physical parameters of TNOs and Centaurs. The basic steps are:
  - Aperture photometry of a sequence of images obtained in one (or more) site, to obtain a light curve ;

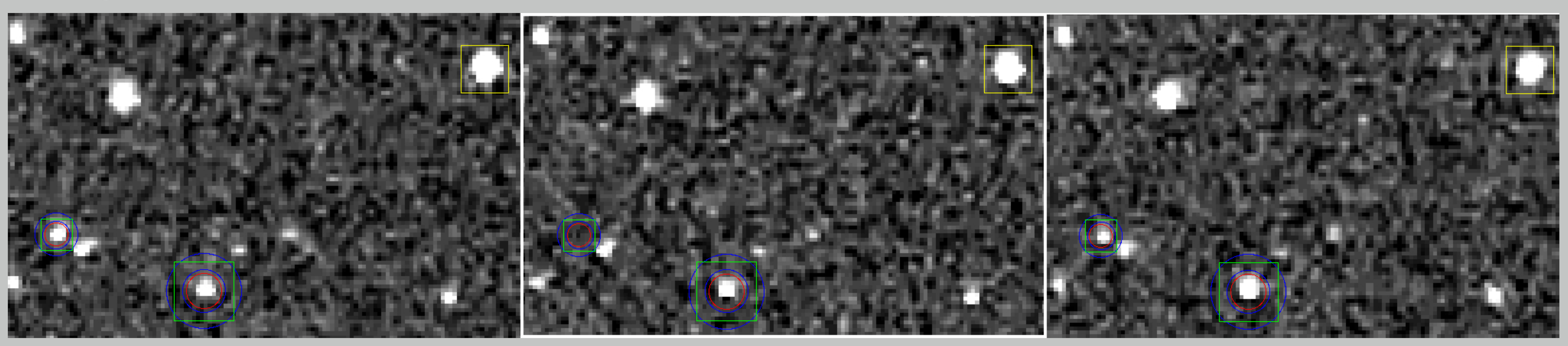

Figure 1: images acquired with a WATEC 910BD, with 0.32 seconds of exposure time. They ilustrates the occultation of an star by the TNO, 2002 VE_{95}, observed by Jonathan Bradshaw in Samford Valley/AU on December 03, 2015.

- From each data set it is possible to derive times of disappearance and reappearance of the star resulting in one chord along the body;
- Fit of an ellipse, or a circle, to determine the center of the object relative to the star, for an observer at the geocenter.

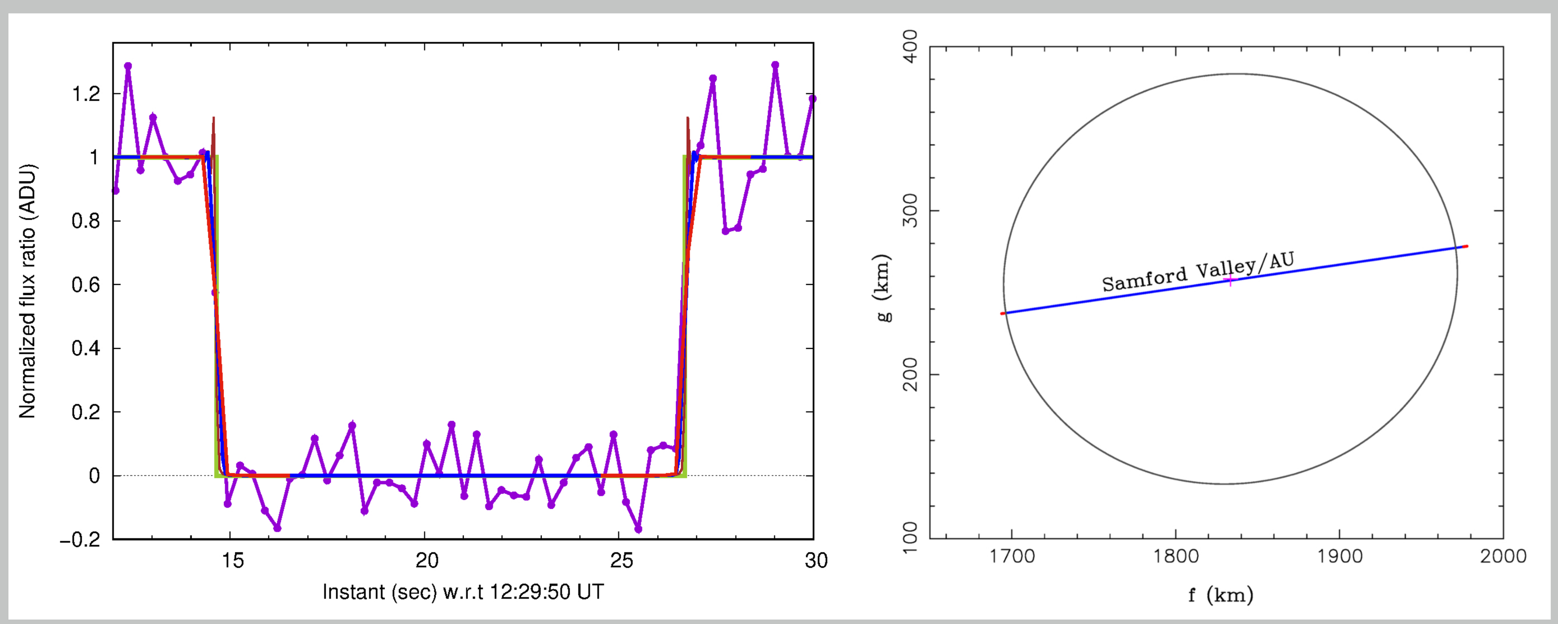

Figure 2: occultation light curve (left) and on the right side is the chord projected at sky plane. An ellipse with the same equivalent size as calculated using other technique, was fitted over the extremities of these single chord of occultation by 2002 VE_{95}.

Results: astrometric positions

- This work analyzes 24 events by TNOs and 7 events by Centaurs (Table 1), resulting on 31 accurate astrometric positions;
- Gaia DR2 star positions, corrected by proper motion at the date of the occultation;

	Centaurs	
Asbolus	2013-11-24	San Pedro de Atacama (Chile);
Bienor	2017-12-29	Yoron Island, Miharu, Hitachi and Musashino (Japan);
Bienor	2018-04-02	Konkoly (Hungary), Zeddam (Netherlands) and Borowiec (Poland);
Chiron	1993-11-07	Bus et al. 1996;
Chiron	2011-11-29	Ruprecht et al. 2015;
Echeclus	2012-06-25	Zeddam (Netherlands);
	TNOs	
2002 KX_{14}	2012-04-26	Alvarez-Candal et al. 2014;
2002 KX_{14}	2018-09-19	Murrumbateman and Yass (Australia);
2002 TX_{300}	2009-10-09	Elliot et al. 2010;
2002 VE_{95}	2015-12-03	Flynn, Murrumbateman and Samford Valley (Australia);
2002 WC_{19}	2018-12-30	Rockhampton (Australia);
2003 AZ_{84}	2011-01-08	Dias-Oliveira et al. 2017;
2003 AZ_{84}	2012-02-03	Dias-Oliveira et al. 2017;
2003 AZ_{84}	2013-12-02	Dias-Oliveira et al. 2017;
2003 AZ_{84}	2014-11-15	Dias-Oliveira et al. 2017;
2003 FF_{128}	2017-05-24	Flynn and Murrumbateman (Australia);
2004 NT_{33}	2017-11-16	Asiago (Italy);
2004 PF_{115}	2018-09-28	Santa Fe and Cerro Burek (Argentina);
2005 TV_{189}	2012-11-13	Kninice (Czech Republic);
2007 UK_{126}	2014-11-15	Benedetti-Rossi et al. 2016;
Eris	2010-11-06	San Juan (Argentina), San Pedro de Atacama and La Silla (Chile);
Eris	2013-08-29	Alice Springs and Samford Valley (Australia);
Haumea	2017-01-21	Ortiz et al. 2017;
Ixion	2014-06-24	Alice Springs (Australia);
Makemake	2011-04-23	Ortiz et al. 2012;
Quaoar	2011-02-11	Westford (United States of America);
Quaoar	2011-05-04	Braga-Ribas et al. 2013;
Quaoar	2012-02-17	Gnosca (Switzerland), Tourrette-Levens, Calern and Valensole (France);
Quaoar	2012-10-15	Cerro Tololo (Chile);
Quaoar	2013-07-09	Merida (Venezuela);
Sedna	2013-01-13	Cairns (Australia);

Results: astrometric positions

Table 1: stellar occultation events that participate in this study

Conclusions

- Before the launch of *Gaia* catalog our predictions had error bars of a few object radii at sky plane ($\approx$ **30** mas);
- With stellar positions from the first data release (DR1) we improved our positions errors to the order of 10 mas;
- Now DR2 + p.m + parallax gives the star's position with an error of the order of fractions of mas;

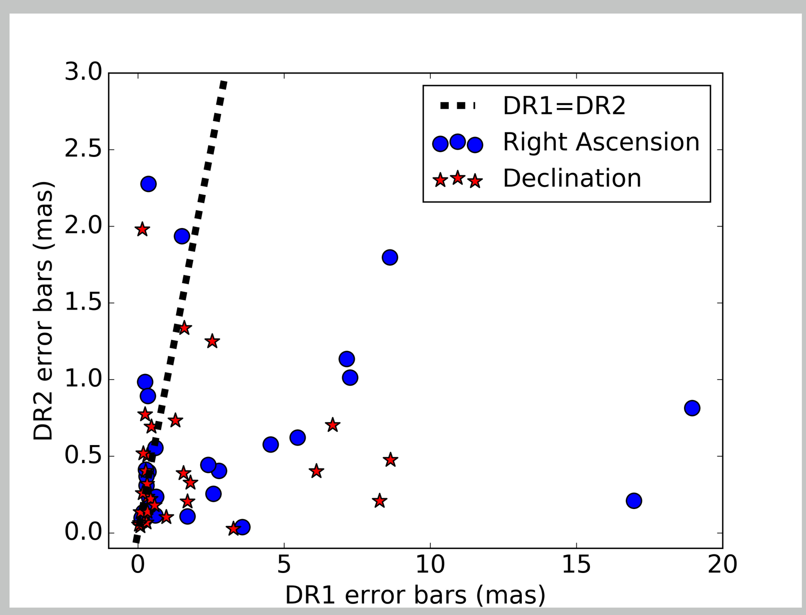

Figure 3: uncertainties of target stars right ascension (blue) and declination (red), taked from both *Gaia* catalog. The black dotted line represents the iguality between the two catalog's uncertainties.

- We use positions from classic astrometry and the ones obtained from stellar occultations to:
  1. improve the object's ephemeris and thus;
  2. have accurate predictions.

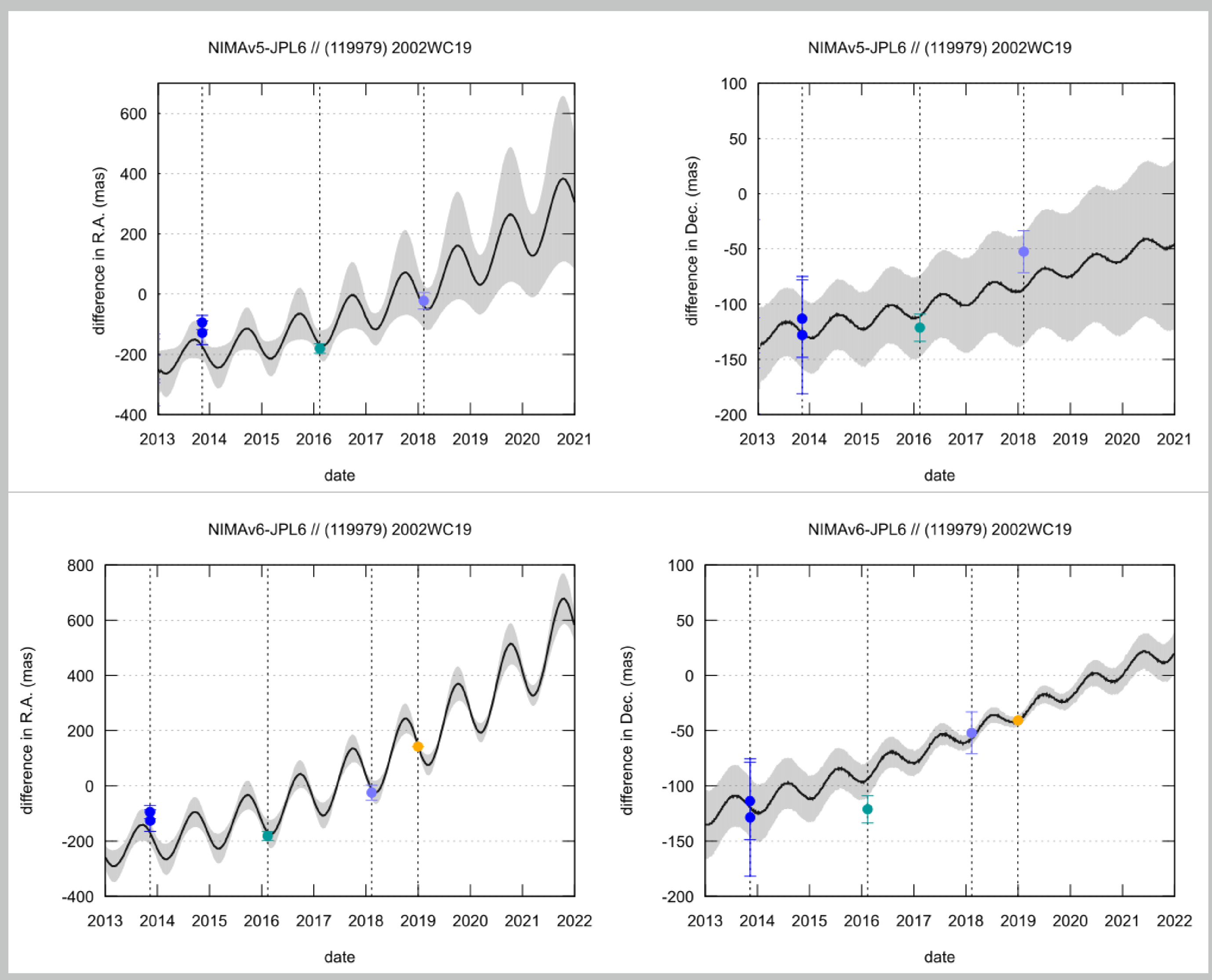

Figure 4: upper graphs presents the ephemeris of 2002 WC_{19} made by NIMA (Desmars, J. et al. 2015) and using just positions from classic astrometry. The lower fits were plotted adding one position from stellar occultation (yellow dot). The black lines are the ephemerids relative to JPL6 one, and the gray regions are the uncertainties of NIMA ephemerids.

References

Desmars, J. et al. Orbit determination of trans-Neptunian objects and Centaurs for the prediction of stellar occultations. **Astronomy & Astrophysics**, v. 584, p. A96, dez. 2015.

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