Astrometry of TNOs to characterize astrometric binaries in the solar system

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Orbital couples: "Pas de deux" in the Solar System and the Milky Way, Paris, October 10-12, 2011.

Outline

Binaries in the Kuiper Belt

- In the Kuiper Belt ...
  - $\sim$ 1400 Transneptunian Objects discovered
  - $\sim$ 5% are binary or multiple systems
  - Probably much more binary systems

Binaries in the Kuiper Belt

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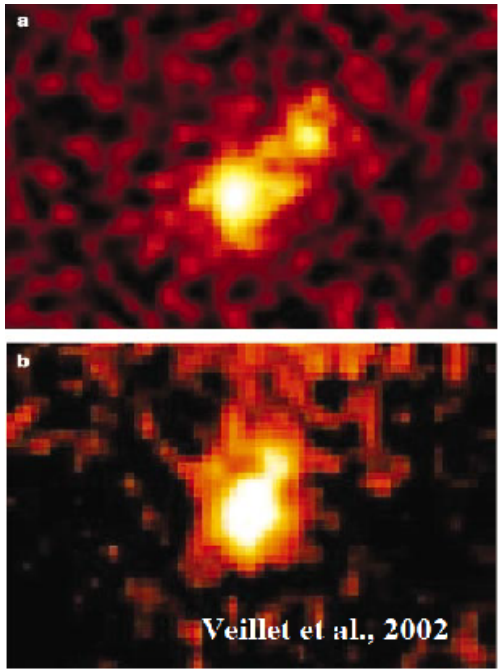
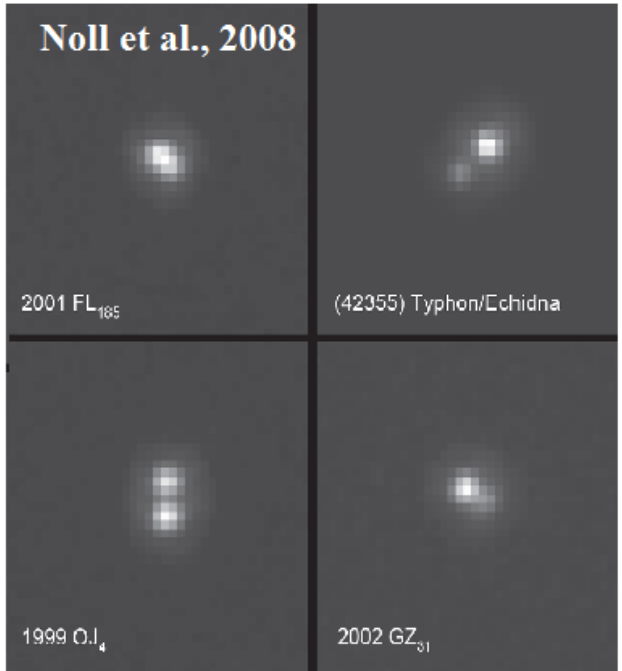
  - $\sim$ 1400 Transneptunian Objects discovered
  - $\sim$ 5% are binary or multiple systems
  - Probably much more binary systems
- Why are binary systems important?
  - Satellite orbit $\Rightarrow$ Mass of the system $\Rightarrow$ Density $\Rightarrow$ Size of the components
  - Mutual events $\Rightarrow$ orbital period, rotational period, diameter ratio

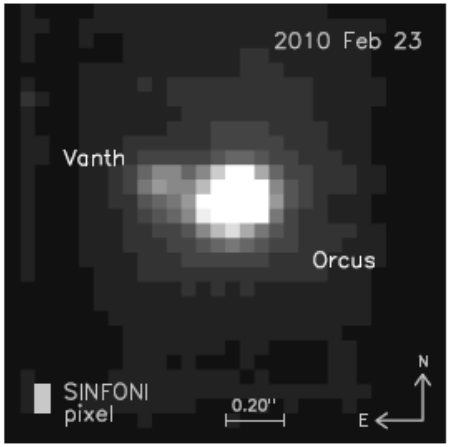
- Binary detection and study
  - Big telescopes and adaptive optic: first binary TNO, 1998 WW_{31} discovered with the CFHT $\Rightarrow$ Primary/satellite separation.
  - Majority of binary found with the Hubble Space Telescope $\Rightarrow$ highly demanded.
  - Is it possible to detect/study binary systems with small/medium telescopes?





- We want to detect ...
  - the satellite's rotation in our photometric study
  - the photocenter motion of the combined primary+satellite around the barycenter along an orbital revolution of the satellite.

Orcus and Vanth



SINFONI image *(Carry et al., 2011)*

(90482) Orcus (formerly 2004 DW)

- Discovered on February 17, 2004.
- Plutino, locked in a 3:2 resonance with Neptune.
- Rotational period: 10.47 h *(Thirouin et al., 2010)*; 10.08 h *(Ortiz et al., 2006)*

Vanth

- Satellite discovered using HST observations from November 13, 2005.
- Orbit: nearly face-on circular orbit with an eccentricity $<$ 0.0036. *(Brown et al., 2010)*
- Distance: (8980$\pm$20) km *(Brown et al., 2010)*
- Orbital period: (9.5393$\pm$0.0001) days *(Brown et al, 2010)*
- Magnitude difference: 2.5 *(Brown et al., 2010)*

System

- Mass: (6.32$\pm$0.01)$\times 10^{20}$ kg *(Brown et al., 2010)*
- Density: (1.5$\pm$0.3) g.cm^{-3} *(Brown et al., 2010)*
- Effective diameter: 850$\pm$90 km *(Lim et al., 2010)*; 940$\pm$70 km *(Brown et al., 2010)* $\Rightarrow$ $D_p \sim$800 km and $D_s \sim$260 km *(Carry et al., 2011)*

Observatory, Telescope and Instrument

Observatory

- Complejo Astronomico el Leoncito, CASLEO, in Argentina.

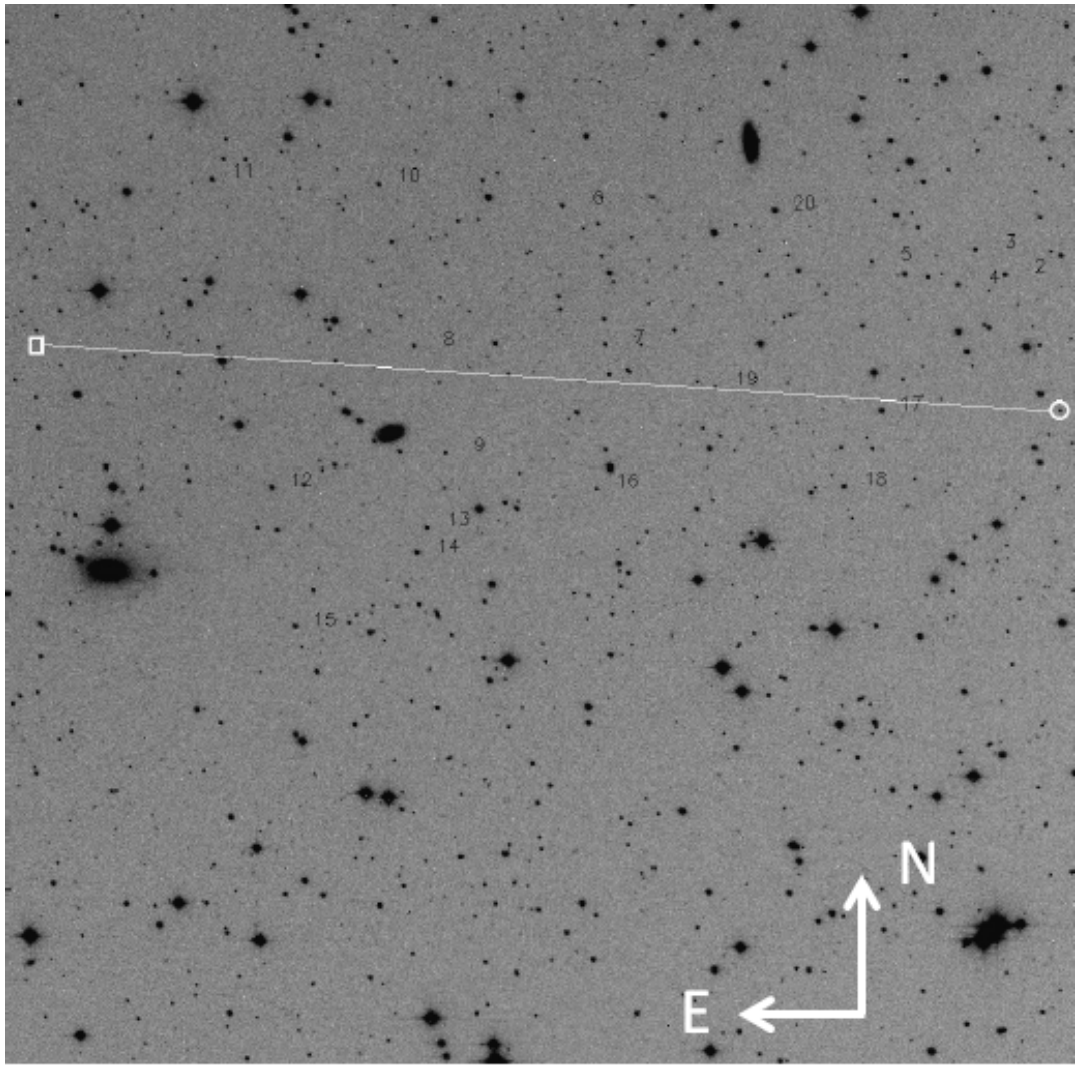
Telescope

- 45 cm f/2.8.
- Remotely controlled

CCD Camera

- 4008$\times$2672 pixels
- Pixel scale: 1.47 arcsec/pixel
- Total FOV: 98$\times$65 arcmin

Observations



Part of the field of view

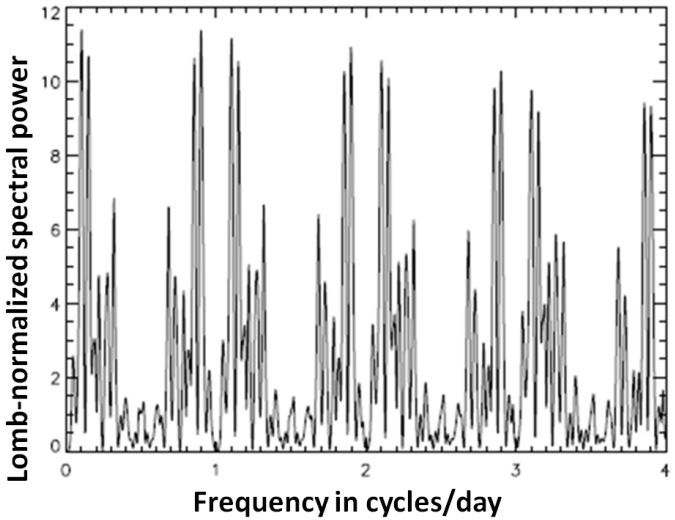
Negative image of the central 24.5×24.5 arcmin field that was traversed by Orcus.

Images

- 10 images × 18 nights of observations spanning a period of 33 days.
- Highest elevation
- Unresolved images of Orcus/Vanth.
- Exposure time: 300 s
- Broad-band filter
- Same field of view during all the campaign.

Photometric study

- Photometric study
  - Relative photometry
  - Data reduction as described in *Thirouin et al., 2010*
  - 20 reference stars
  - around 20% of the images were rejected
  - Several peaks with a high confidence level
  - Highest peak located at 0.1029 cycles/day $\Rightarrow 9.7 \pm 0.3$ days.



Lomb periodogram of Orcus' relative photometry (Ortiz et al., 2011)

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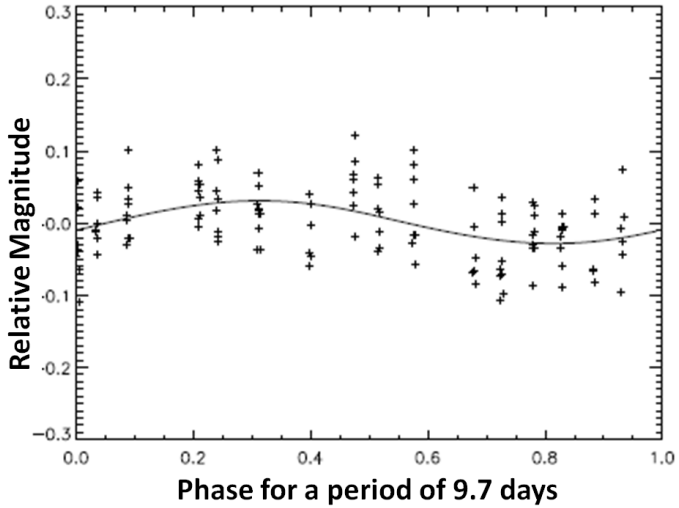

Lightcurve of Orcus (Ortiz et al., 2011)

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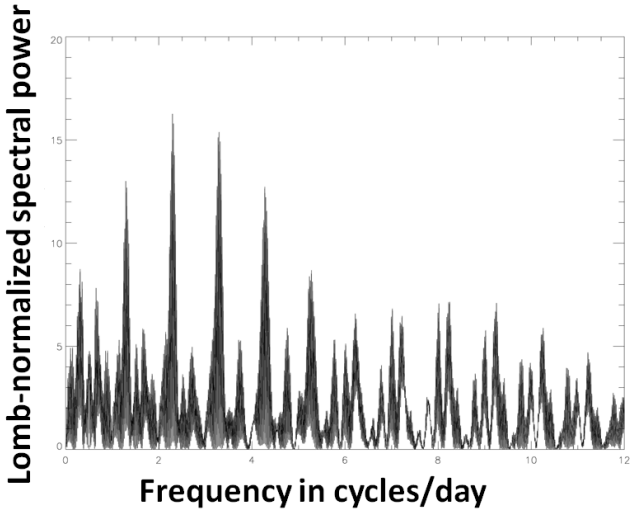

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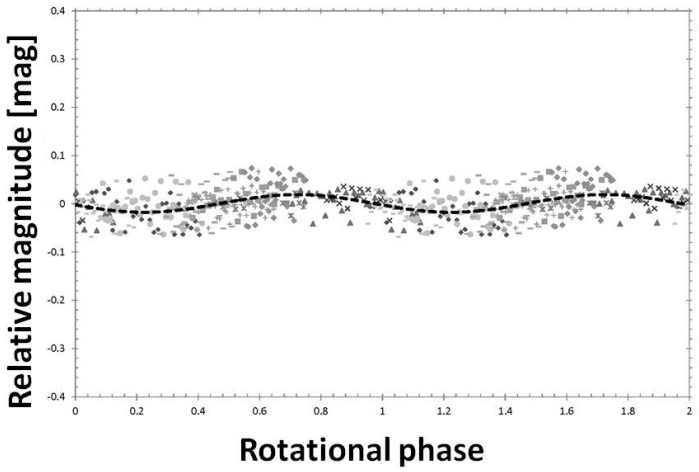

Lightcurve of Orcus(Thirouin et al., 2010)

- Rotational period
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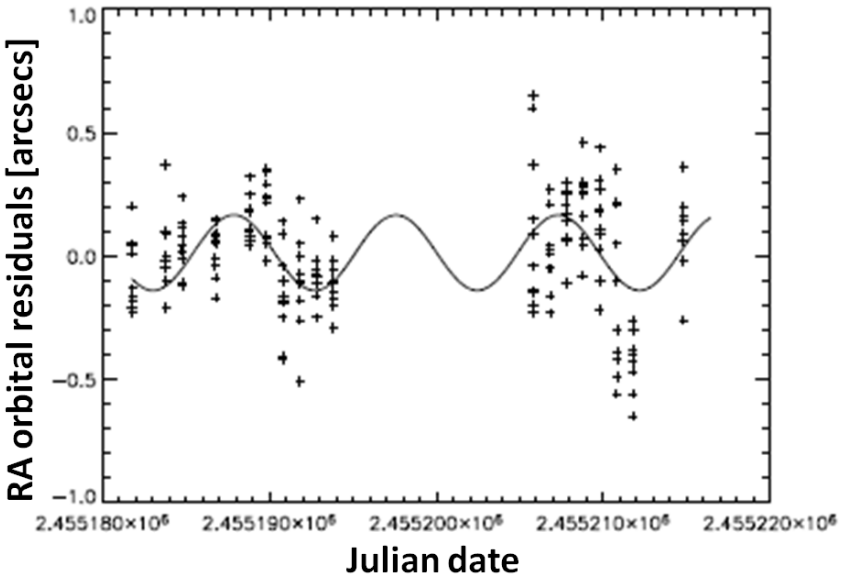
  - 9.7 ± 0.3 days $\Rightarrow$ not a rotational period
- New value?
  - 9.5393 ± 0.0001 days: orbital period *(Brown et al., 2010)*
  - Similar values
  - Orbital period? $\Rightarrow$ maybe ...

Astrometric study

- Astrometric study in RA, photocenter motion
  - Relative astrometry
  - Third-order polynomial fit
  - $\sim$ 500 UCAC2 reference stars
  - Source positions derived using SExtractor (3pix)
  - Right ascension (RA) residuals computed from an orbital fit to the astrometry



Right ascension residuals

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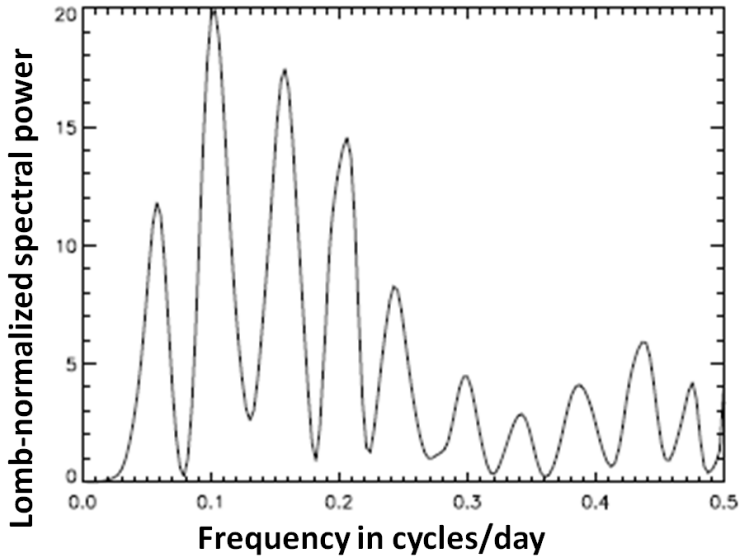
- Lomb Periodogram
  - Highest peak located at 0.1029 cycles/day $\Rightarrow$9.7$\pm$0.3 days



Lomb periodogram of the RA residuals

- Periodicity
  - 9.7 ± 0.3 days in the RA residuals
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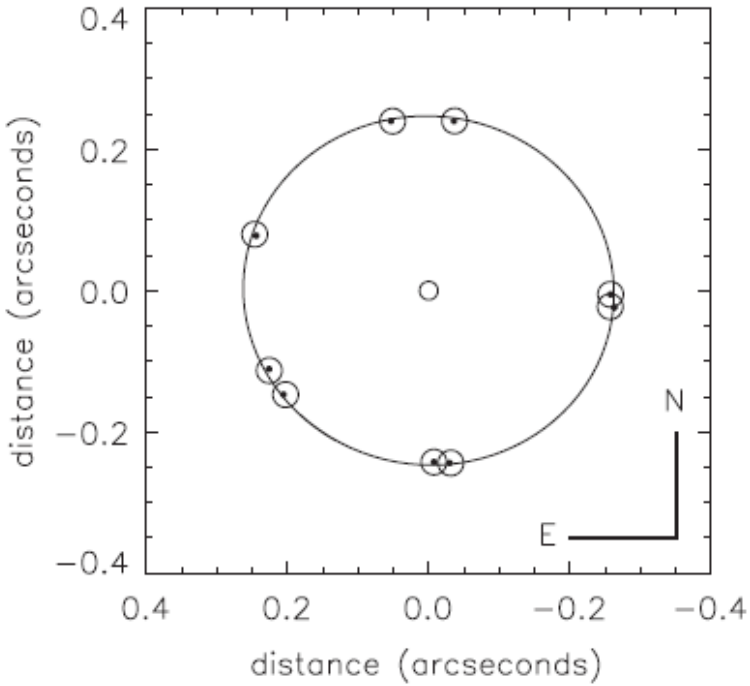
- So?
  - Orbital period? $\Rightarrow$ one more test ....

Astrometric study

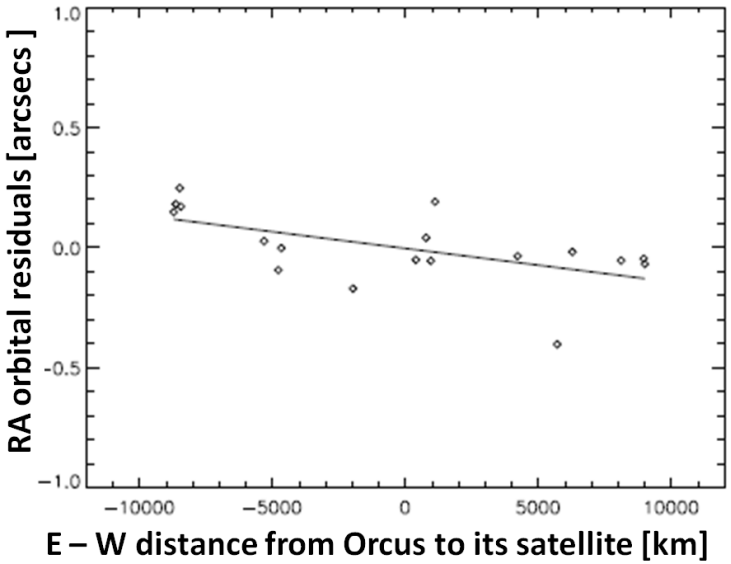
- Vanth orbit
  - Face-on circular orbit
  - Low eccentricity
  - Orbital Period= 9.5393 ± 0.0001 days



Orbit of Vanth (Brown et al., 2010)

Astrometric study

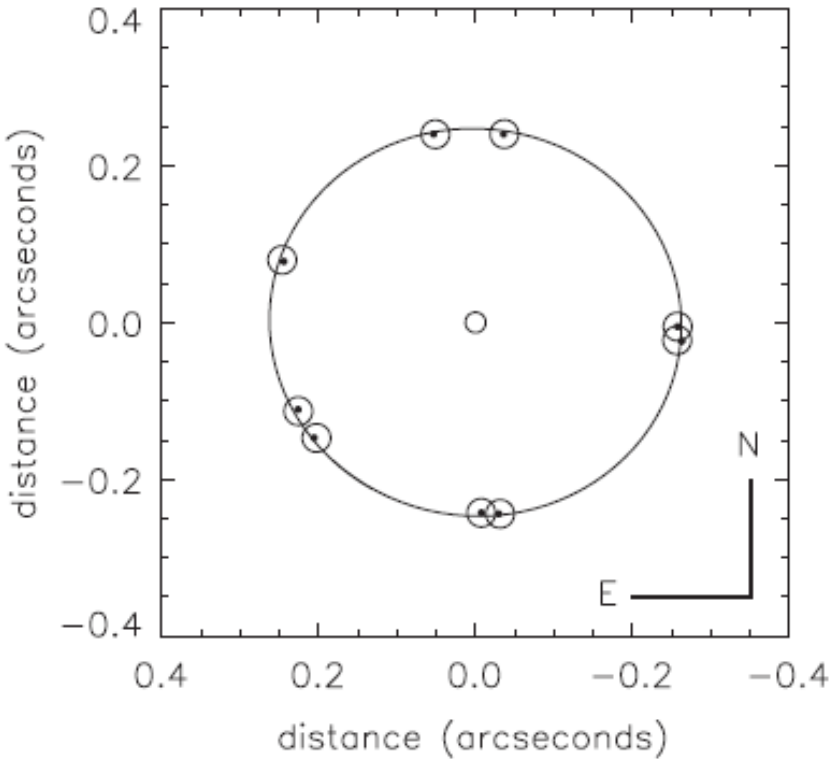
- Vanth orbit
  - Face-on circular orbit
  - Low eccentricity
  - Orbital Period= 9.5393±0.0001 days
- Are the residuals correlated with theoretical Vanth position?
  - Average of the residuals each night ⇒18 points.
  - Theoretical positions computed with the orbital information (*Brown et al., 2010*).
  - Spearman test: clear correlation with a significance level of 97%



Linear fit to the residuals Vs. E-W Vanth-Orcus distance (Ortiz et al., 2011)

Astrometric study

- Astrometric study in Declination
  - Relative astrometry
  - Third-order polynomial fit
  - $\sim$ 500 UCAC2 reference stars
  - Declination residuals computed from an orbital fit to the astrometry



Astrometric study

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  - Relative astrometry
  - Third-order polynomial fit
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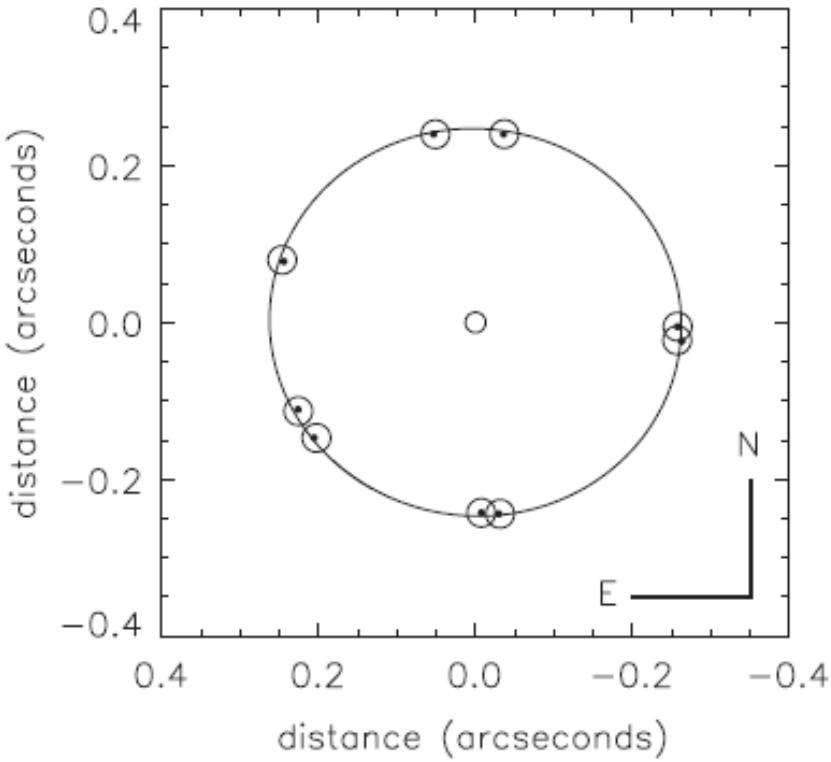
  - Declination residuals computed from an orbital fit to the astrometry
- Lomb Periodogram
  - Lack of detection in Declination residuals $\Rightarrow$ a smaller inclination of the orbital plane than the perpendicular to the line of sight.



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- Periodicity in the residuals are coincident with the orbital period and the residuals are correlated with the theoretical positions of Vanth.

Conclusion and future work

- We found an unambiguous periodic signal in the relative astrometry due to the satellite, despite the high magnitude difference between Orcus and Vanth
- Periodicity in the residuals are coincident with the orbital period and the residuals are correlated with the theoretical positions of Vanth.
- Detecting binary systems by means of high-precision astrometry with small to large telescopes is feasible provided that the barycenter and the photocenter of the system are separated by at least tens of mas.

Conclusion and future work

- Another option is to perform absolute astrometry, but, we need very good astrometic catalogs with faint stars. The GAIA mission will provide this kind of catalog.
- We want to try this technique:
  - known binary systems with a not well determined orbital period
  - TNO with no known satellite
  - with bigger telescopes