International Program of Stellar Occultations by Trans-neptunian Objects
The Contribution of the Aosta Valley Astronomical Observatory

A. Carbognani (1), B. Bucciarelli (2), A. H. Andrei (2,3,4,5), F. Braga-Ribas (3,6), R. Vieira Martins (3,7), M. Assafin (2), J.I.B. Camargo (3), D. Nepomuceno da Silva Neto (8)

(1) Osservatorio Astronomico della Valle d'Aosta e Planetario di Lignan (OAVdA-IT)
(2) Osservatorio Astronomico di Torino (OATo/INAF-IT)
(3) Observatorio Nacional (ON/MCTI-BR)
(4) Syrte/Observatoire de Paris (OP/SYRTE-FR)
(5) Observatorio do Valongo (OV/UFRJ-BR)
(6) Observatoire de Paris-Meudon (OP/Meudon-FR)
(7) Observatoire de Paris, IMCCE (OP/IMCCE-FR)
(8) Universidade Estadual da Zona Oeste (UEZO-BR)

Abstract

The analysis of light curves from stellar occultations by trans-neptunian ojects (TNOs) observed from many sites can provide a direct measurement of TNOs' size/shape, as well as valuable information on atmosphere presence and profile down to the nanobar level. Since TNOs angular sizes do not exceed 50mas, such events are rare and of short duration (minutes or even seconds), therefore quite challenging to observe. For these reasons, astrometric catalogs along the TNOs' paths are compiled well ahead, and a substantial effort is put weeks before the event to narrow down the TNO/star positions and on the timing of the encounter. The event itself is followed from several locations, not only because more information can be gained from multiple observations, but also to account for the unpredictability of precise chord boundaries due to uncertainties in the astrometry of both the TNO and the star.

Recently, the Osservatorio Astronomico di Torino (OATo) and the Osservatorio del Valle d'Aosta (OVdA) joined the consortium coordinated by B. Sicardy from the Observatoire de Paris-Meudon. The OVdA seats at the NW of Italy, 1.6km altitude, and with about 250 cloudless nights per year. We review the aims, methods, and previous results of the whole program, and focus on the Italian observatories facilities and plans.

Scientific Goals

• The Trans-Neptunian Objects (TNOs) are located beyond Neptune in a region where small differentiation is expected with regard to temperature changes. This makes them 4.5 billion years old interplanetary fossils from the early stages of formation of the outer Solar System. Recent models of planetary migration put TNOs as a sensitive laboratory to the study of orbital dynamics.

• The analysis of light curves obtained from a stellar occultation observed from many sites allows for access to TNOs' sizes and shapes down to a few kilometers.

• The atmospheres can be probed down to the nanobar limit.

• Also, occultations can eventually lead to the observation or discovery of close binary companions, satellites or debris around the central body.

• For size determinations this is the best technique, as opposed to indirect estimations like those coming from albedo assumptions or from modelling of optical, IR and sub-millimetric observations.

• From these direct size measurements, one can derive better albedos and put better constraints on the surface composition of the TNOs.

Scientific Goals

• If the mass of the body can be estimated from the orbits of detected satellites or by other indirect means, the estimated density is improved and thus the internal composition and structure may be much better inferred.

• The detection of atmosphere around TNOs enlarges the current understanding of its dynamics and relationship with the surface.

• Detection of Chiron-like jets is also a possibility.

• Better characterization of companions/satellite orbits and rotational periods from stellar occultations and ground-based adaptive optics observations could also improve models for binary formation and collision.

• Large TNOs are most likely to possess atmospheres. In this case, even the utility of negative chords around positive ones is enhanced, giving valuable upper limits for atmosphere size and profile.

• Besides ,larger bodies favor smaller relative size errors.

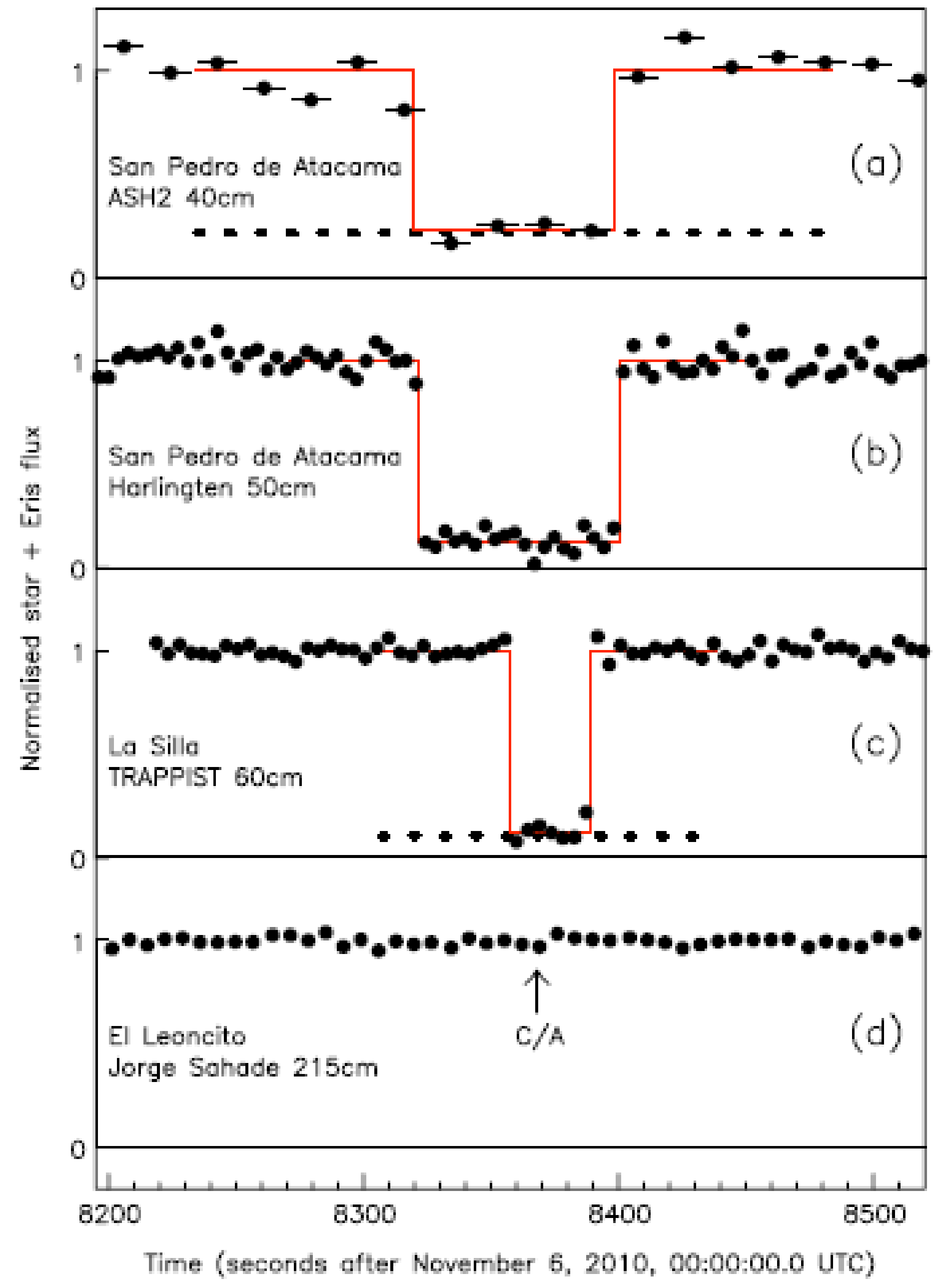
• Finally, the accumulation of positive and negative detections results in significant improvements in the TNO ephemeris, thus refining the orbit and substantially increasing the accuracy of the next occultation predictions.

Method

- Sicardy et al.; 2011; Nature 478 - Eris occultation
- Flux of the star plus Eris versus time. No filter was used at any of the telescopes.

a. Light curve from the ASH2 40-cm telescope at San Pedro de Atacama. 2x2 pixel binning. The horizontal bars indicate the total time intervals (15s) associated with each point.
b. Light curve from the Harlingten 50-cm telescope at San Pedro de Atacama. 2x2 pixel binning. Integration time of 3s.
c. Light curve from the 60-cm TRAPPIST telescope at La Silla. 2x2 pixel binning, Integration time of 3s.
d. Light curve from the 215-cm Jorge Sahade telescope at El Leoncito. 3x3 pixel binning. Integration time of 4s.

- The horizontal dotted lines at the bottom of the ASH2 and TRAPPIST light curves represent Eris' contribution to the flux, showing that the star completely disappeared during the event.



Method

- Apart from their small diameter, the main difficulty in deriving reliable predictions for the stellar occultation of TNOs is the lack of accurate orbital elements, implying ephemeris errors as large as a few hundreds of mas.
- As for the stars, predictions solely based on published catalog positions such as the USNO B1.0 or the 2MASS usually fail because of the poor precision (or lack) of proper motions and due to the relatively large zonal and/or random errors in their positions (up to 200 mas). Even individual positions for fainter stars in the UCAC2 catalog may need corrections as large as 70 mas.
- Further, the ephemeris of the TNO must be extrapolated to get realistic TNO positions at predicted occultation dates.
- Regular TNOs observations enable to derive astrometric ephemeris offsets along time. As successive positive occultations are collected, the ephemeris can be radically improved down to a few mas. Even an one-chord positive occultation helps to improve ephemeris, since the apparent diameter of TNOs are smaller than 30 mas.
- Regarding to the star positions, one strategy is to select possible occultations from the face values of positions given in any arbitrary astrometric catalog, then make follow-up observations to improve the star position and (after applying offsets to the TNO ephemeris) pin down the shadow path.

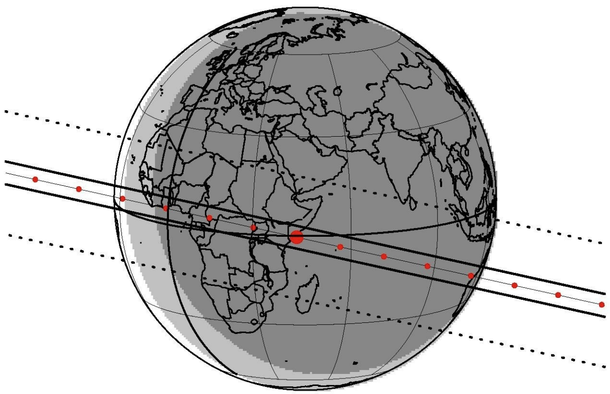
Method

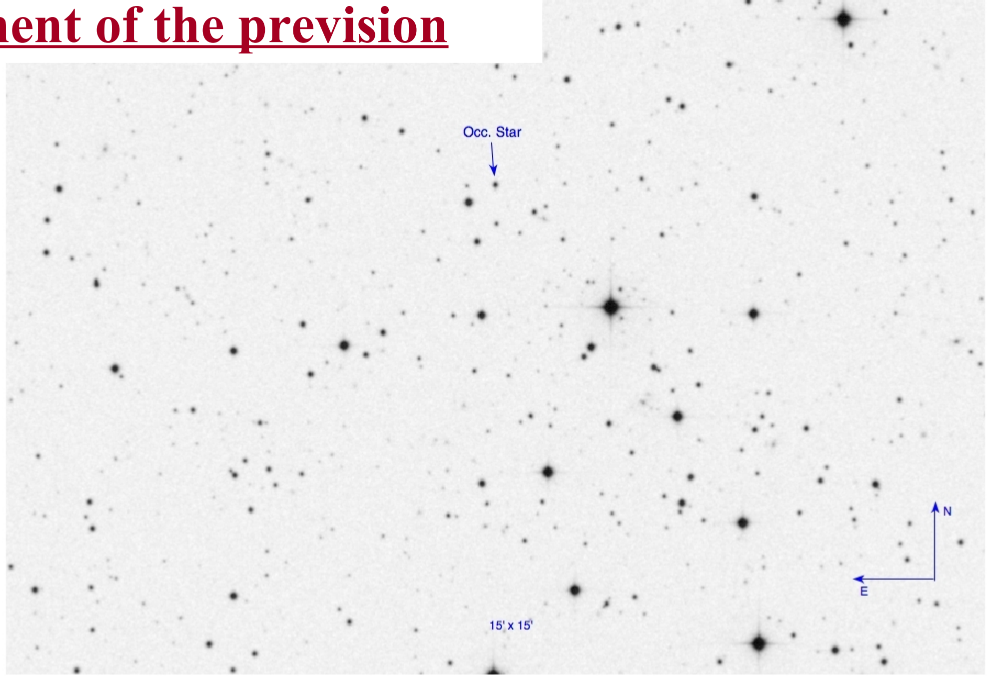
• A more suited tailored strategy worked out by the Rio team was to derive local astrometric star catalogs with sufficient position precision (50 mas at least), for the time span of the occultations, for stars in the magnitude range R = 13 to 19. In this way, we match the required position precision in the search, preserving faint stars without discarding bright objects. The addition of astrometrically trusted faint stars in the follow-up list, without inflating it with bad targets in turn improves the chances of finding more suitable candidates for TNO occultations, due to the increase of star density in the sky path.

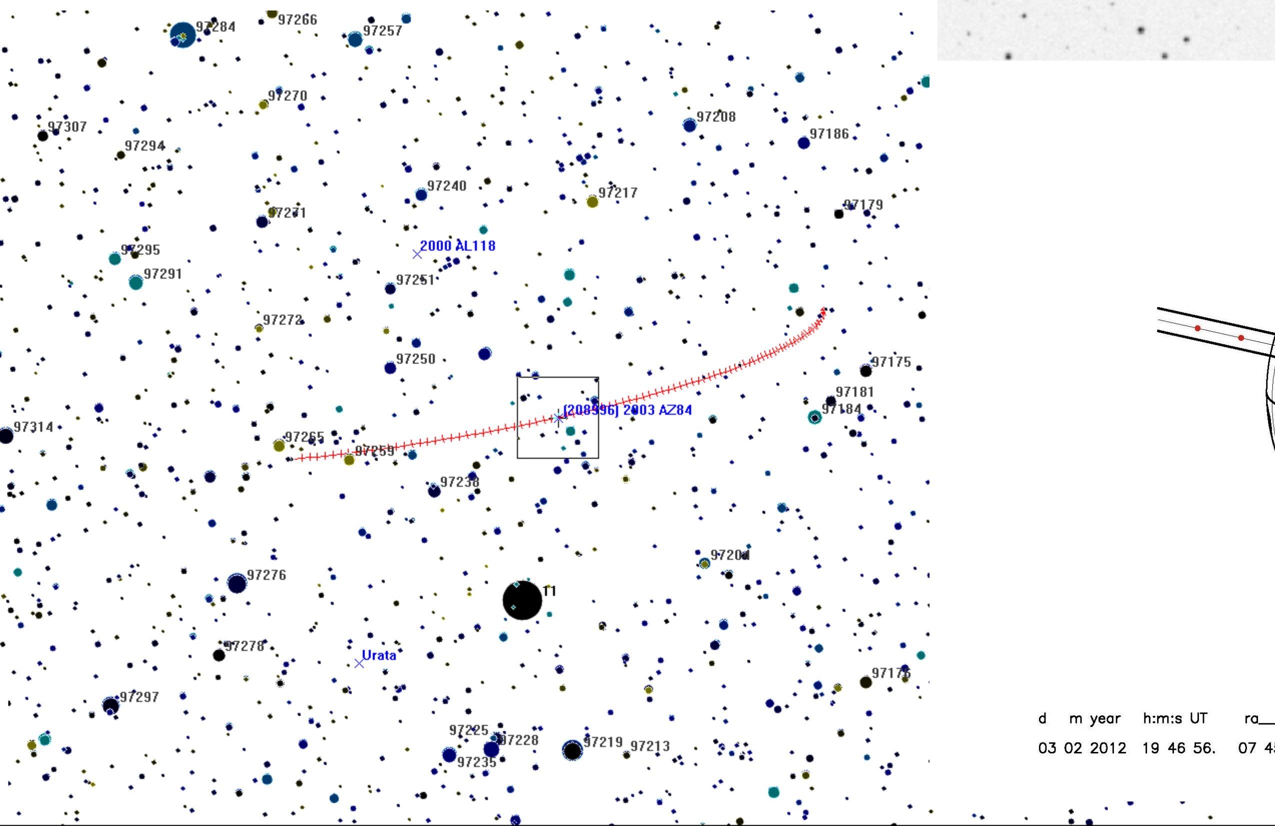
Thus,

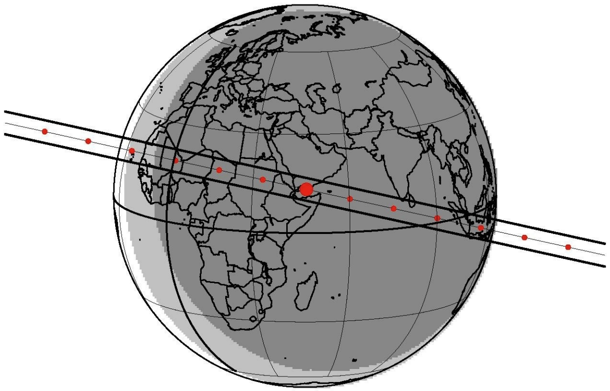
- Multiple site coverage is paramount
- Before the event to pin down the breadth of visibility of the event
- During the event to enable multiple chords determination.

Method – AZ84 in 03/02/2012 – Refinement of the prevision



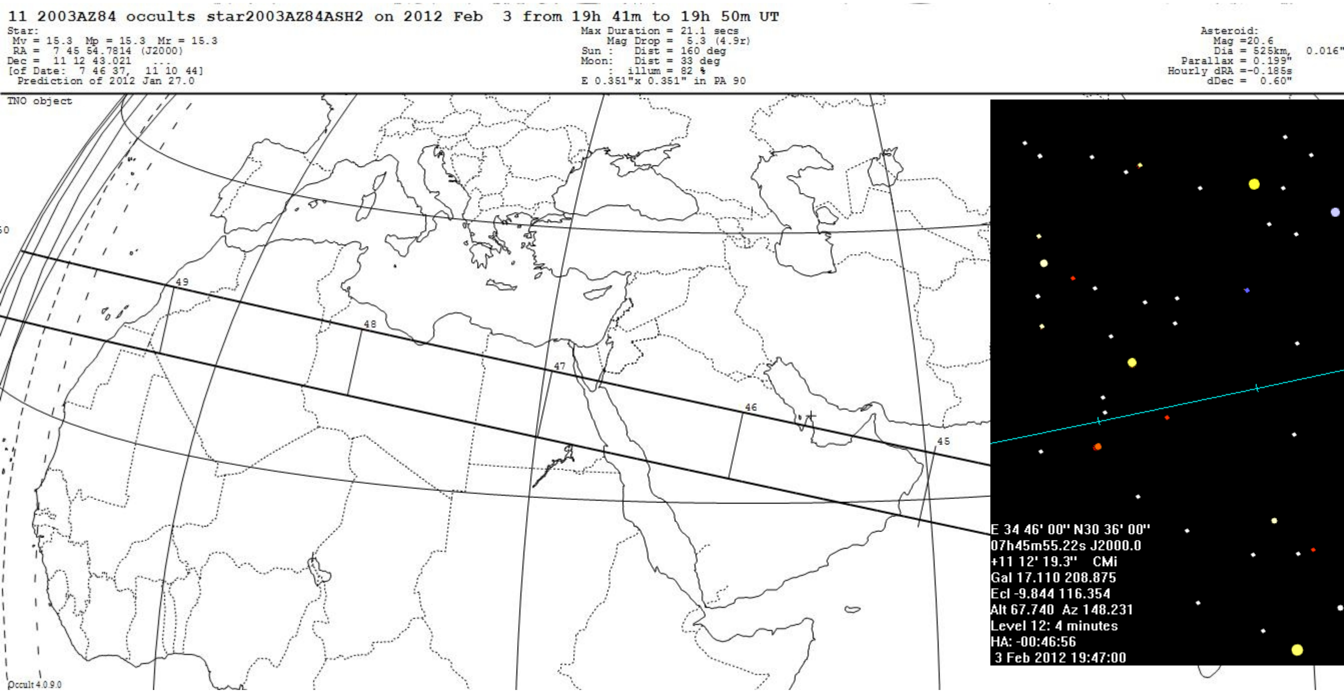


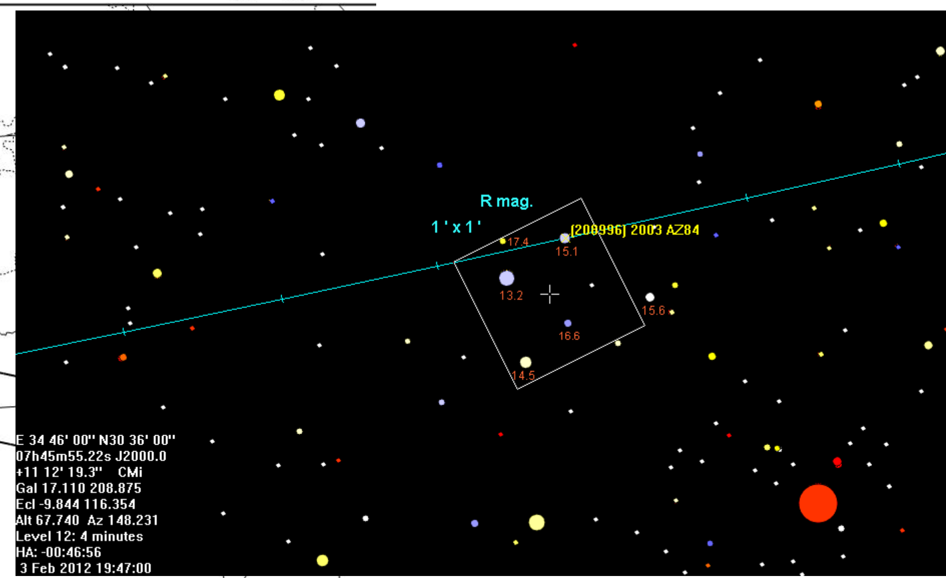


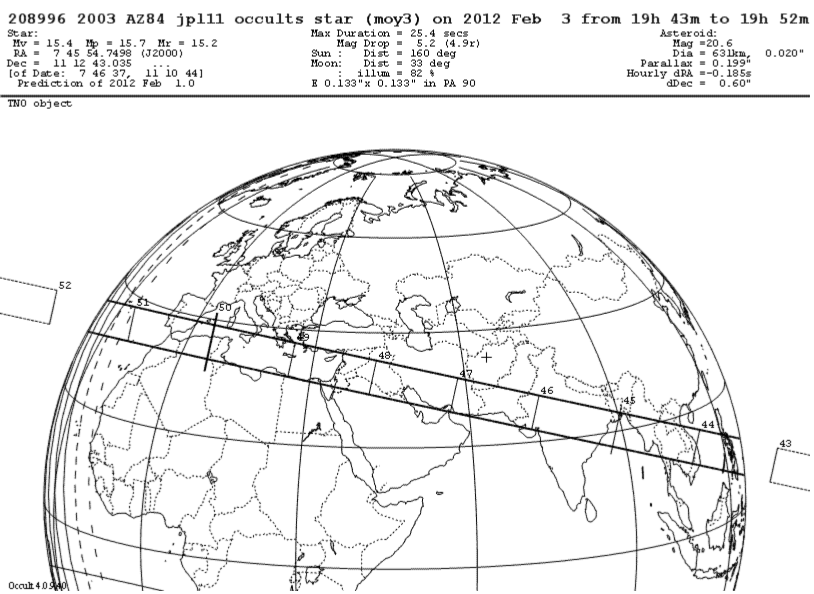


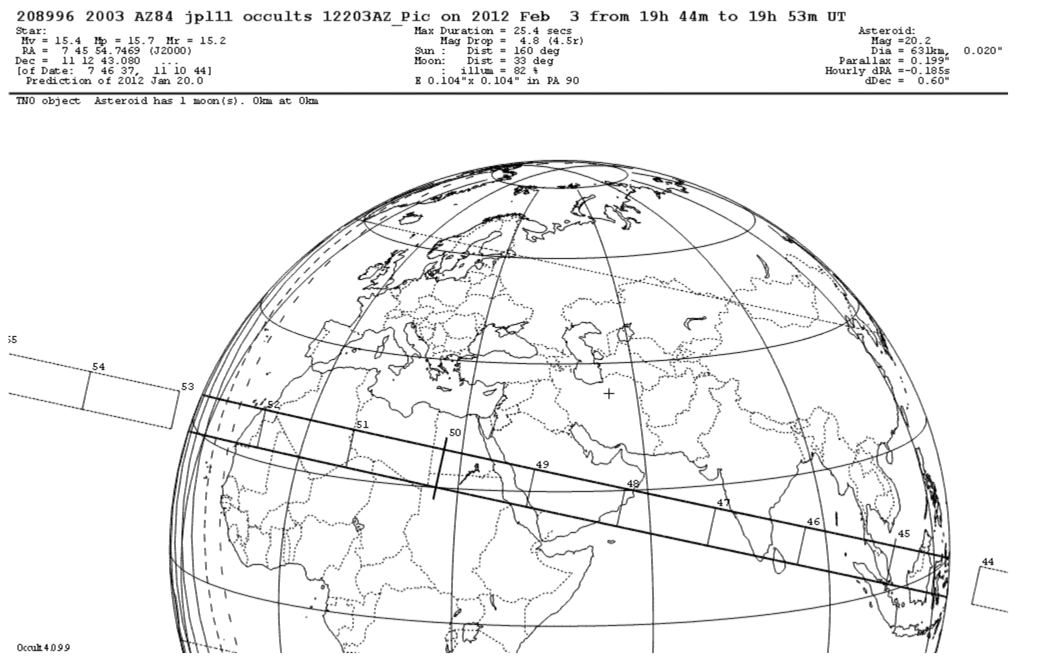
d	m year	h:m:s UT	ra___dec___J2000_candidate	C/A	P/A	vel	Delta	R*	K*	long
03	02 2012	19 46 56.	07 45 54.7673 11 12 43.064	0.007	12.44	−24.83	44.26	15.3	14.4	46.

Method – AZ84 in 03/02/2012 – Refinement of the prevision









The OAVdA

• OAVdA stands for Astronomical Observatory of the Autonomous Region of the Aosta Valley (Italy). The research centre is located in the northwestern Italian Alps, near the border with France and Switzerland (Lat: 45° 47′ 22” N, Long: 7° 28′ 42” E), at 1675m above sea level in the Saint-Barthélemy Valley and is managed by the “Fondazione Clément Fillietroz”, with funding from local administrations.

The OAVdA

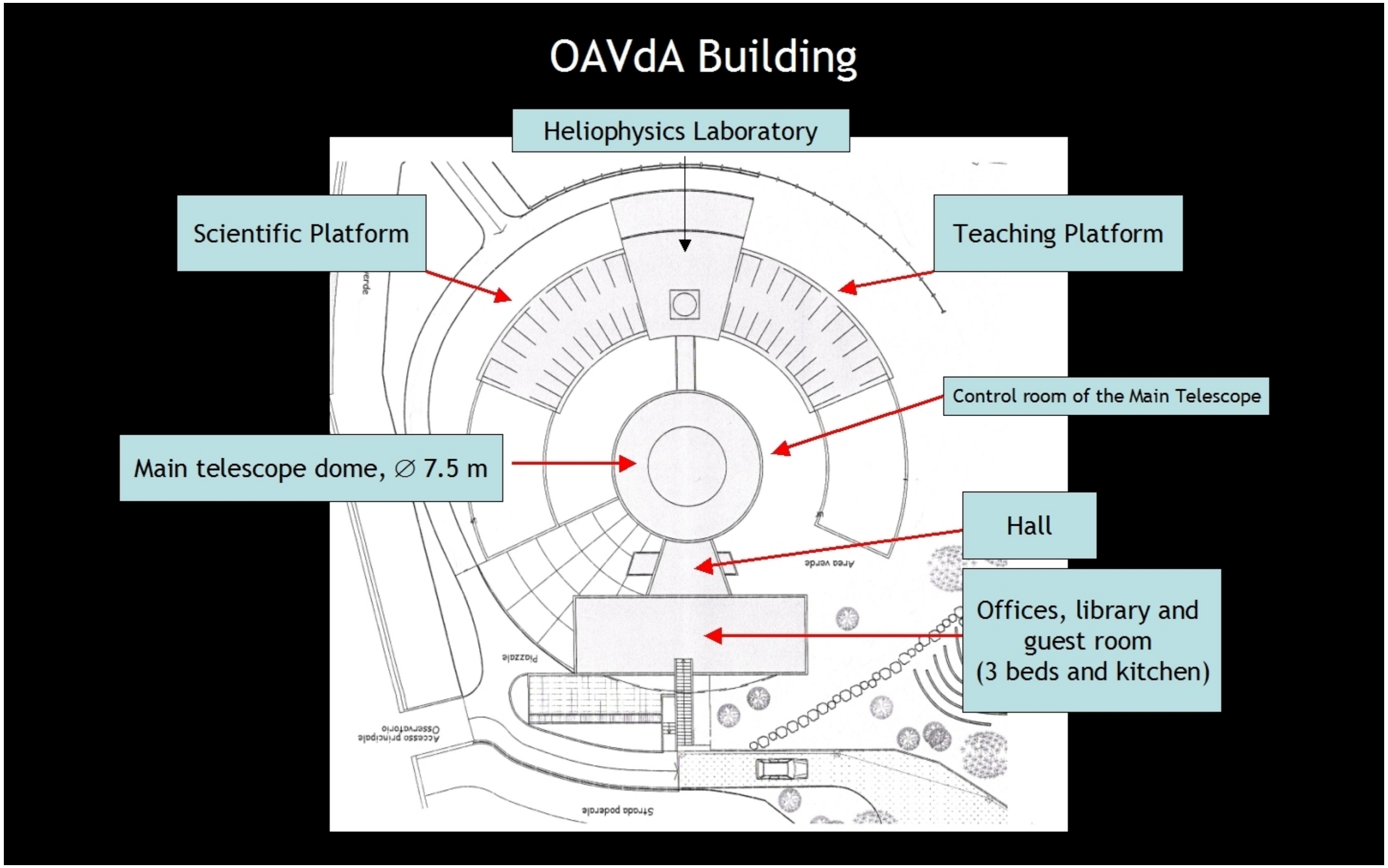
• OAVdA was opened in 2003 as a centre for the popularization of astronomy but, since 2006, the main activity has been scientific research, as a consequence of an official cooperation agreement established with the Italian National Institute for Astrophysics (INAF). In 2009, a planetarium was built near the observatory with a 10m dome and 67 seats, which is currently used for educational astronomy. In the year 2009 about 15,200 people visited OAVdA and the planetarium. The staff in 2012 was made up of 13 people, including a scientific team of 5 physicists and astronomers, partially on ESF (European Social Fund) grants, and permanently residing at the observatory.

The OAVdA

• As far as observing conditions are concerned, the mean seeing allows to have a Full Width at Half Maximum of the Point Spread Function (PSF) of about 1.5-2 arcsec. Light pollution is low because the surrounding mountains shield the site of the observatory from the lights of nearby Aosta, Turin and Milan, so the sky background is around +21.5 mag.

The OAVdA Building

The structure of the Observatory is shown below, with arrows indicating the main features. Around the dome of the Main Telescope (used for the occultation program, as well as for asteroids and blazar observations) are a Scientific Platform (used for extrasolar planet transit search), a Heliophysics Laboratory (for educational observations of the Sun), a Teaching Platform (meant for educational astronomy, which houses seven 250 mm f/10 Cassegrain reflectors with computerized pointing), offices, a library and a guest room.



The OAVdA Contribution to the Trans-neptunian Objects Program

- **Recently, OATo and OVdA joined the consortium coordinated by B. Sicardy from the Observatoire de Paris-Meudon.**

- **This is important not only because**
- The analysis of light curves from stellar occultations by trans-neptunian objects (TNOs) observed from many sites can provide a direct measurement of TNOs' size/shape, as well as valuable information on atmosphere presence and profile down to the nanobar level.
- Since TNOs angular sizes do not exceed 50mas, such events are rare and of short duration (minutes or even seconds), therefore quite challenging to observe.
- Though astrometric catalogs along the TNOs' paths are compiled by the group well ahead, a substantial effort needs to be made in the weeks before the event to narrow down the TNO/star positions and on the timing of the encounter.
- The event itself is followed from several locations, since more information can be gained from multiple observations, and also to account for the unpredictability of precise chord boundaries due to remaining uncertainties in the astrometry of both the TNO and the star.

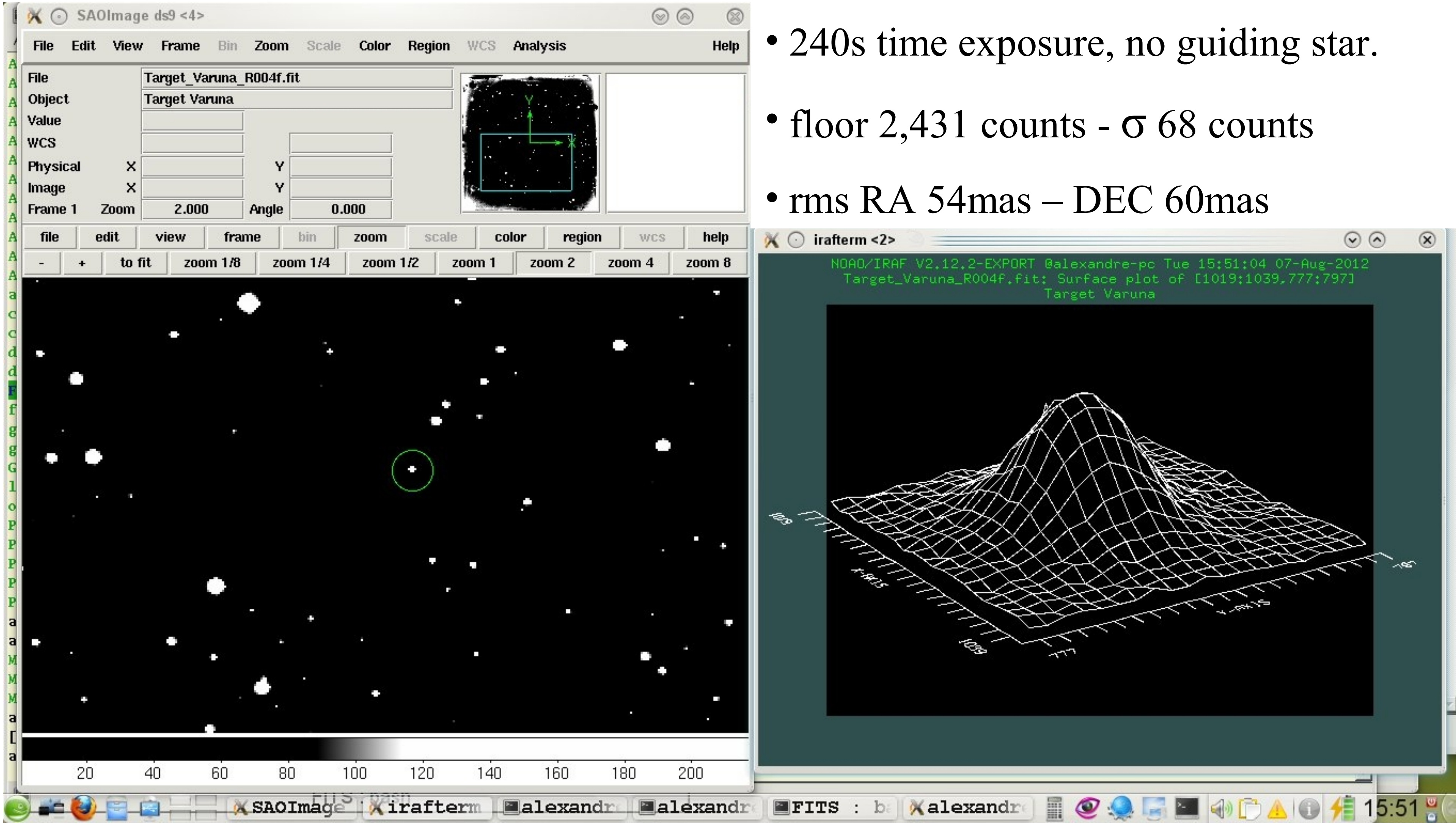
- **and also there aren´t many engaged/appropriated observing sites in Europe.**

The OAVdA Contribution to the Trans-neptunian Objects Program

- **Up to June/2012 there were observed target stars for the following occultation events:**
- **Haumea (December 7, 2011),**
- **Varuna (March 31, 2012),**
- **Quaoar (April 17, 2012),**
- **Pluto (June 4 and 14, 2012).**
- **The observations are made at the 810 mm f/7.8 Bowen-Vaughan reflector, with CCD FLI, Pro series, FLI--FL-PL304 1-1-BB Class 1 model back illuminated, 2048x2048, pixel size 15 micron (no binning).**
- **The images were taken with R and V filter with varying exposure times, depending on the magnitude of the target, between 60 and 240 s and with the CCD camera in 1×1 binning mode.**
- **The astrometric reductions were made using IRAF tasks, and the 2MASS, PPMXL, UCAC2, and UCAC3 catalogues. The R images consistently provided more precise astrometry, but the C images do not show systematic bias (thus they are useful for dim targets). The best results are on average at 50mas, on RA and DEC.**

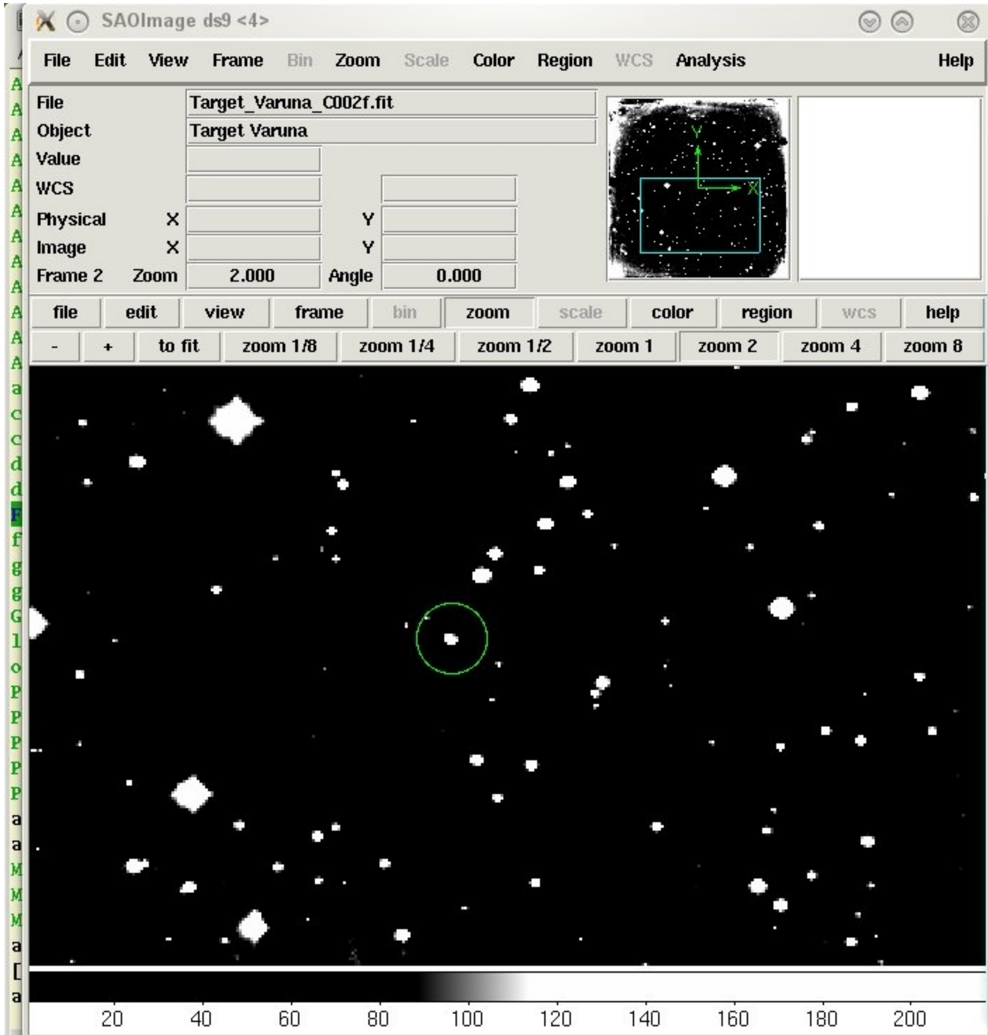
The OAVdA Contribution to the Trans-neptunian Objects Program

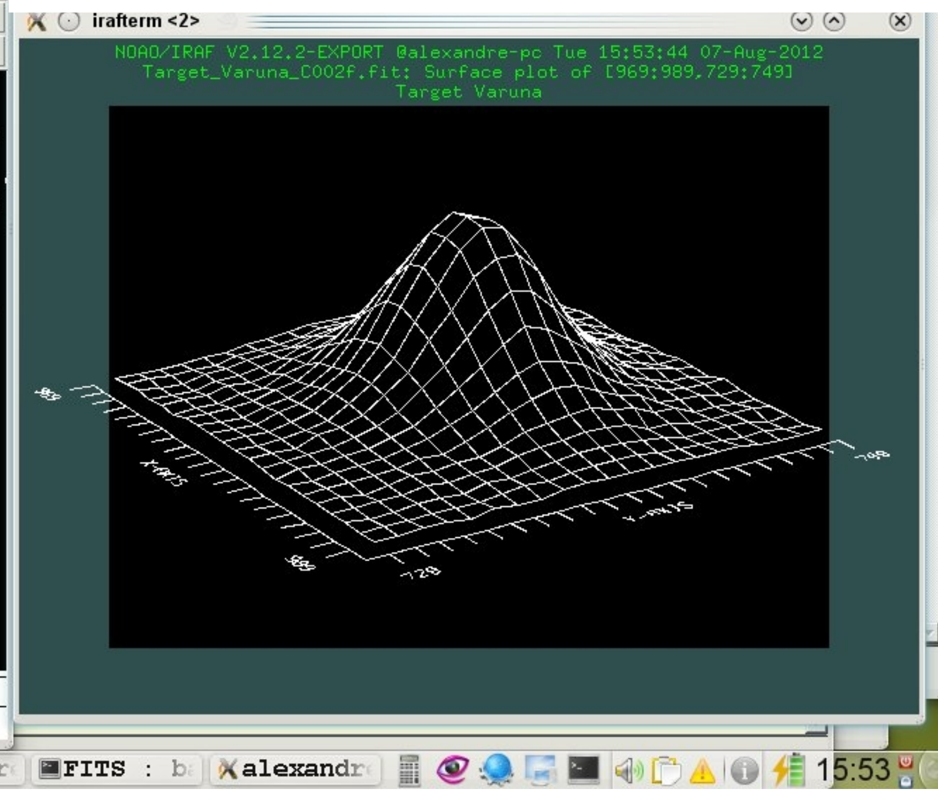
- R image
- 240s time exposure, no guiding star.
- floor 2,431 counts - σ 68 counts
- rms RA 54mas – DEC 60mas



The OAVdA Contribution to the Trans-neptunian Objects Program

- C image
- 240s time exposure, no guiding star.
- floor 5,043 counts - σ 184 counts
- rms RA 228mas – DEC 179mas





OAVdA – Main telescope and features

• The Main Telescope is a 0.81-m f/7.8 Ritchey-Chretien reflector with a field flattener near the Cassegrain focus. The instrument is equipped with a guide telescope (a refractor with a diameter of 120 mm open to f/9) and a back illuminated 16 bit CCD camera (FLI PL 3041-1-BB, 2048 × 2048 square pixels), with a pixel size of 15μ, field of view of 16.5 × 16.5 arcmin and image scale of 0.48 arcsec/pixel. The CCD camera is equipped with a filter wheel and a set of standard Johnson-Cousins B, V, R and I filters.

• The computers controlling the pointing of the telescope and CCD imaging are in the Control Room, which is separate (and warmer) from the dome housing the Main Telescope. The observations are schedulable via script, so it is possible to automate the pointing of the instrument, the CCD image acquisition, the length of the pose and the filter type.

Main Telescope: 0.81-m diameter, f/7.8, RC	**Field of view: 16.5 × 16.5 arcminutes**
Minor Planet Center Code: B04	**Image scale: 0.48 arcsecond/pixel (binning 1 × 1)**
Pointing accuracy: 1 arcminute	**Peak quantum efficiency: 96%@750 nm**
Tracking: 5 minutes exposure without autoguider	**Limit Magnitude on NEOs: +20.7 at 15-20 minutes exposure**
Average seeing condition: 1.5-2 arcsecond **Sky background: around +21.5 mag**	**Available nights: about 200/365**

OAVdA – other programs

• Observation of asteroids (NEOs, MBAs and Trojans), in collaboration with the Minor Planet Centre, INAF-OATo (Turin Astronomical Observatory) and DLR-German Aerospace Centre in Berlin (Mottola et al., 2011, AJ 141, 171). The research work is both theoretical (Carbognani, 2010, Icarus 205, 497; and 2011a, Icarus 211, 509) and observational (Carbognani et al., 2008, Minor Planet Bulletin 35, 61; Carbognani, 2008, Minor Planet Bulletin 35, 109; 2010, Icarus 205, 497; and 2011b, Minor Planet Bulletin 38, 57).

• Detection of small-size extrasolar planets in orbit around nearby M dwarfs using the photometric transit method. The research is conducted in cooperation with INAF-OATo and the University of Padova (Damasso et al., 2010, PASP 122, 1077).

• Monitoring of Active Galactic Nuclei (AGN) as part of the international Whole Earth Blazar Telescope (WEBT) organization in cooperation with INAF-OATo (Villata et al., 2009, A&A 504, L19).

• Observation of Solar Corona (K-corona), on an innovative polarimeter designed for space coronagraphic study by INAF-OATo (Abbo et al., 2008, COSPAR, Symp. D, D24-0038-08).

OAVdA – Extra-solar Planets Transit

• Since December 2008 OAVdA, in cooperation with INAF-OATo, has been actively involved in the field of extrasolar planets.

• A detailed feasibility study has been carried out to demonstrate that OAVdA is a well poised observing site to detect small size extrasolar planets around M dwarfs using the photometric transit method (Damasso et al., 2010).

• Since December 2009 a pilot study has been carried out on a small sample of nearby M dwarfs with accurate parallax measurements, mainly aimed at characterizing the photometric microvariabilty of the target stars. This study was a preliminary step toward a long-term photometric survey to search for transiting exoplanets.

• This survey is named APACHE (A PAthway toward the Characterization of Habitable Earths), and started in spring 2012. It uses an array of four identical f/8 Ritchey-Chretien 400mm telescopes, located in the Scientific Platform, on a GM2000 10-MICRON mount and equipped with a FLI Proline PL1001E-2 CCD Camera and Johnson-Cousins R & I filters. The telescope array is controlled by RTS2 system, developed by P. Kubanek (see www.rts2.org).

OAVdA – NEAs Astrometry

In July 2006, OAVdA was allotted the Minor Planet Center code B04. Around the time of the new Moon, NEAs follow-up is made of the new objects reported in the NEOCP page updated by the MPC. The typically observed NEOs have a magnitude between +19 and +20 with a sky motion of about 5 arcsec/minutes (see Fig. 2). The limiting magnitude reached on the NEOs is +20.7 with image stacking to compensate for the asteroid movement and a total exposure time of 15-20 minutes. So far, from 2006 to 2010, astrometric positions for 80 NEOs have been recorded. For the year 2010, from the Web page of “residuals statistics for observatory codes” mantained by MPC (MPC, 2011), the residues for B04 are less than an arcsecond in 98.99% of the cases. For the previous years the results are similar.