NEOCC side-activities enabling precision astrometry

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Get ready to produce precision Astrometry!

This talk will go through some points of what we do here at ESA NEOCC to produce some NEO precision Astrometry, in the hope to spark some discussions after next talk.

- Know your telescopes/instruments
  - Timing
  - Location
  - Instrument technology (sensor, technology, read-out, shutter…)
  - Optics

- Train in different conditions

Timing (1)

It is frequent to have NEOs moving faster than ~10 arcsec/min, making timing uncertainties comparable to other astrometric uncertainties for most of our telescopes.

The best way to know the timing of your images it is using the same observational setup, and we can use spacecraft for it: GNSS satellites have public ephemeris (we use Bill Gray's Project Pluto GNSS astrometry tool) **Check** GNSS astrometry — **projectpluto**.com/gps_ast.htm

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Avg along-track (timing) (98±12) ms
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How do we report these values to MPC in the ADES format?

Timing (2)

ADES documentation
Updated May 2024

Bias 98 ms – correction to be applied to the obsTime

- uncTime – [tracklet] systematic uncertainty in obsTime – st. dev. of the bias (i.e., 12 ms)
- rmsTime – [observation] random uncertainty in obsTime – jitter (time signal, shutter jitter or syst, rounding error)

uncTime	PosDecimalTypeW8	Estimated time uncertainty in seconds. Unlike the preceding RMS fields, which indicate random errors, this field indicates a presumed level of systematic clock error. NB: This field is generally only to be used to communicate exceptions and problems with clock calibration and is not intended to be used in routine submissions where clock errors are not a significant source of astrometric error.

rmsTime	PosDecimalTypeW8	Random component of the obsTime 1σ uncertainty in seconds as estimated by the observer.

Timing (3)

Sensor and shutter technology can play quite a role:

- CMOS read-out is usually done line by line
    - Bias can change for each mode (read-out speed, cropping, binning…)
        - e.g. LCO 0.4m CMOS

bias = UTSTART + 0.373 s + 7.53e-5 s/row * row# ⚠

- Sliding-blade shutter create a different central time for each line of the CCD, and they are usually alternating directions (i.e., starting edge is ending edge next time). Shutter travel times can be up to 0.5 s for large format cameras

And if you don’t know all these values, you should add them (conservatively) to rmsTime

Timing (4)

Knowing your capabilities let you use the telescopes for different purposes, and it includes timing (and proper use of reporting it in ADES)

- Time-anchors facilities
    - We have a few telescopes (small/medium aperture) with very good timing capabilities
        - Negligible bias <0.01 s
        - Very stable, tiny jitter: rmsTime, uncTime ~0.02 s

    - We use these telescopes during close approaches, when the NEOs are bright and the expected astrometric accuracy (~0.5 arcsec) is smaller than the timing uncertainty projected in the sky

Timing (5)

General strategy:

- Do a dedicated campaign for your observational set-up:
    - All read-out modes, all binning options, your usual ROI/crop and measure many GNSS in different azimuth
    - Even check with different exposure times
- Use grey/bright time every night
- Do some random checks from time to time
    - OGS drift (GPS failed, synchronisation was taking place only at the system start up)
    - OGS jumps (unknown origin)
- For high-profile targets: one GNSS before, one after (ideally as close as possible)

Location

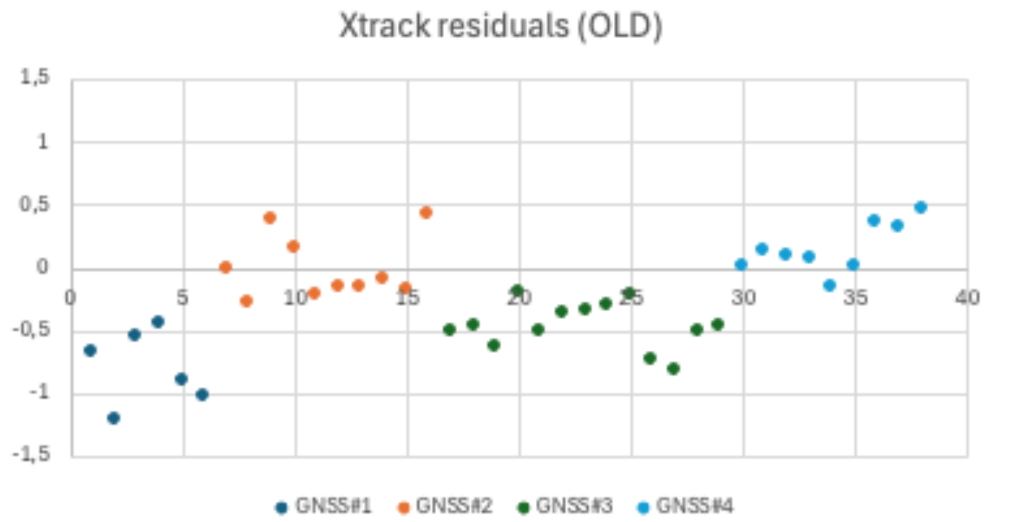
For the last years, we have learnt that it is essential to know your topographic location.

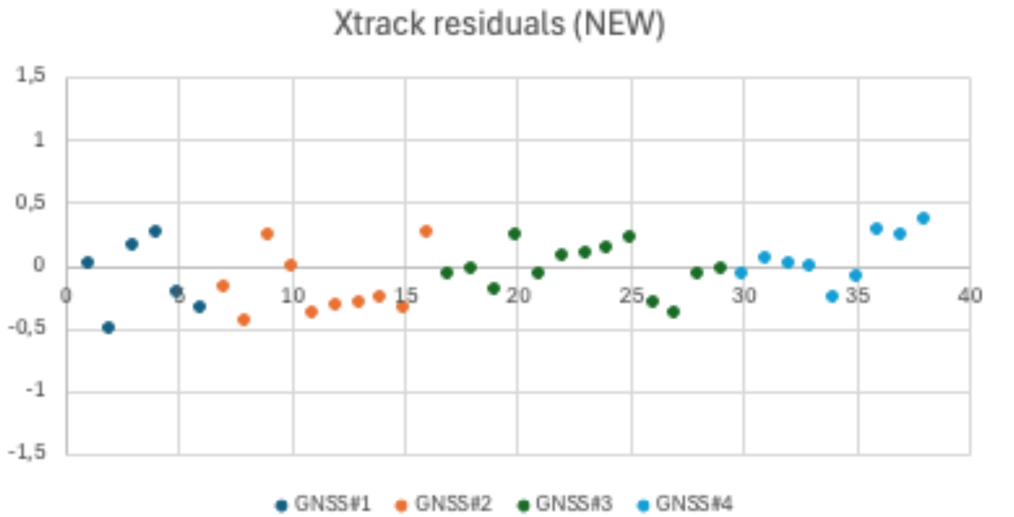
- Location is reported in WGS84 datum, therefore you should use ellipsoid altitude
- It is relevant to GNSS time determination

Check **GNSS** astrometry (**m**ovable observer) — projectpluto.com/gps_**m**ove.htm

```
COORDS REPORTED TO/BY MPC
Avg cross-track (-0.22±0.45)"
Avg along-track (timing) (46±33) ms

COORDS MEASURED BY CAHA STAFF
Avg cross-track (-0.05±0.31)"
Avg along-track (timing) (59±31) ms
```



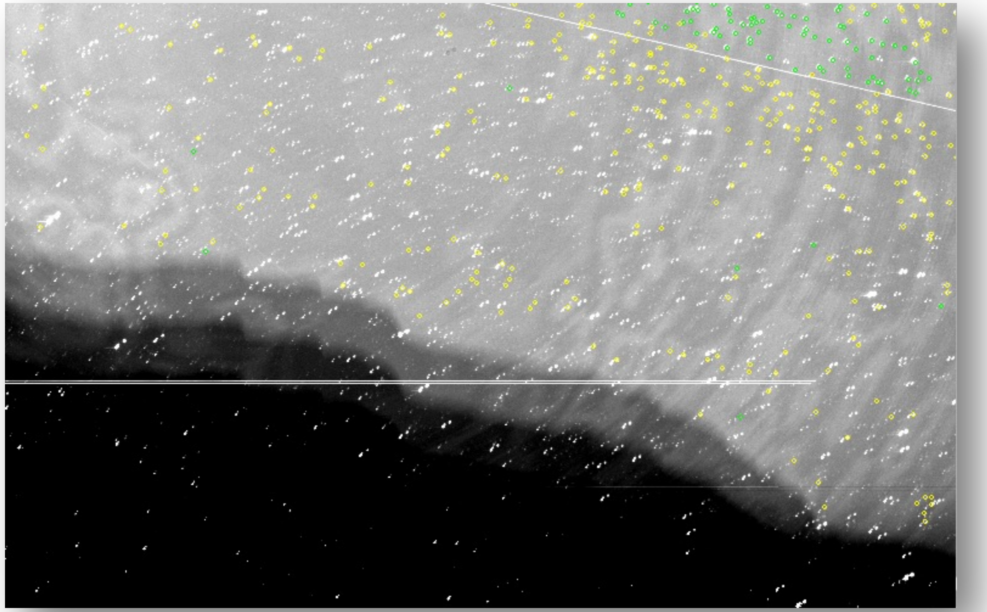


Training

We do not choose from where the NEOs are visible, and we do not choose the NEO visibility conditions. Therefore, we 'train' to be ready to face many observational challenges, that ultimately prove to be useful.

These are some of the scenarios:

- Low lunar elongation (when close to full illumination)
- Low elevation
- Low solar elongation / Recoveries
- Fast spacecraft: HEO, cis-lunar and fly-bys.
- Other spacecraft and rocket bodies in heliocentric orbits

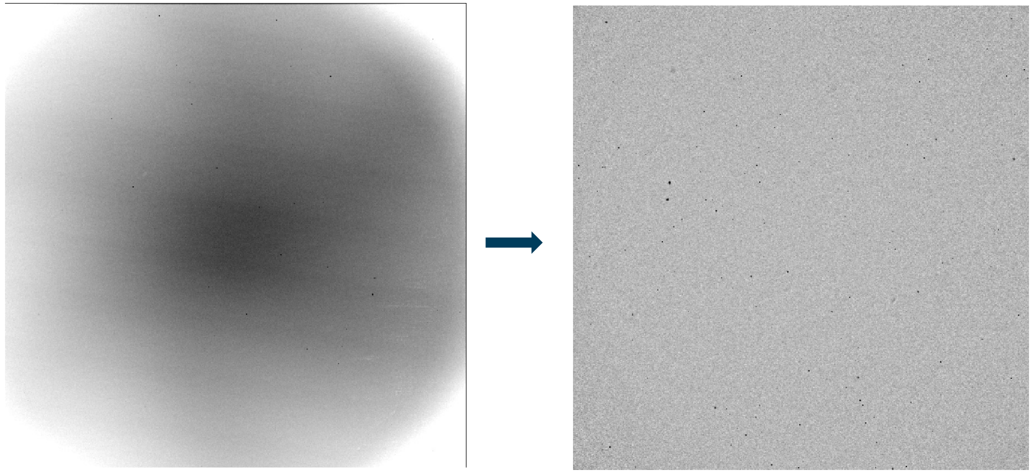


ESA PDO

Low lunar elongation

Occasionally we need to observe NEOs close to the Moon, but observationally is very challenging:

- Sky brightness models usually fail
- Straylight changes with the angle, and for every telescope
- Asteroid movement helps medianing out (self flattening)
- (very) short exposure times (not good for iris-type shutters)



But you can get reasonably deep, even during full moon. Data for Z84 (80-cm Schmidt camera)

Field	Exp. Time (s)	Limiting magnitude (1 exposure)	Moon % illum
2024 TS8	0.04	15.25 – 15.65	97
2024 XR6	1	16.90 – 17.20	96
2008 XN	1.2	16.95 – 17.25	57
2019 XB	10	~ 18.95	57

Field	Moon distance (degrees)	Dimmest asteroid	Stellar limiting magnitude
2024 TS8	2.8 - 2.4	17.8	
2024 XR6	9.5 - 9.6	19.0	
2008 XN	3.5 - 4.4	>19.8	20.0
2019 XB	15.4 - 15.2	>> 22	22.5

Low elevation

Likewise, sometimes we are forced to observe at low elevation (time-constraint, location-constraint, elongation-constraint).

So, what to expect at 4 degrees of elevation?

@ TBT La Silla, Chile (W57) – 60-cm telescope

- FWHM 7-8 "
-
Exp time (s)	Limiting magnitude
0.1	14.0
1	15.5
10	16.7
120	18.0

Pros

- Access to elongation ~ 20 degrees

Cons

- (Extremely) short dynamic ranges (and not constant ones)
- ETC - changes day to day, inhomogeneous FoV
- Changing conditions (lot of work - nothing can be automatic)
- Plate solving is problematic
- Differential chromatic refraction / sky colour
- Telescope/mount/operator… not happy

Low elongation / Recovery

A telescope with access to low elevation observations may give you access to low elongation observation (i.e., low horizon profile at E and W direction).

- High phase angle
  - Magnitude prediction has a large uncertainty
  - Large amplitude light-curves

- Object recovery/follow-up as science-enablers
  - C/2023 A3 (20° elong., for radioastronomy follow-up)
  - 2023 KU (70° elong., 1 arcmin uncertainty, radar ping ~24h later)
  - 2025 FA22 (IAWN target, magnitude 19.0, 30° elong.)
  - 3I/ATLAS (on-going, yesterday 20° elong., at 9° elevation)

Training with spacecraft

HEO, cis-lunar and fly-bys as impactor proxies/training (often we get TM to compare with):

- We regularly observe some these objects close to the NEO regime for training, especially flybys (BepiColombo / JUICE / OSIRIS-REx…) and the ones about to reenter.

- We provide some optical tracking for spacecraft. We participate in the Cluster II campaigns before reentry for Salsa (2024), Rumba (on-going), Tango and Samba (2026).

Salsa (CLUSTER FM II) last perigee	41 minutes after	61 arcsec/s (15000 km away)
Salsa (CLUSTER FM II) reentry	39 minutes before	86 arcsec/s (12900 km away)
Quequiao 2 booster reentry	24 minute before (until shadow entry)	390 arcsec/s (3400 km away)

We also observe spacecraft and rocket bodies launched into heliocentric orbit.

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