# Quick reaction capabilities of ESA's NEO observing network

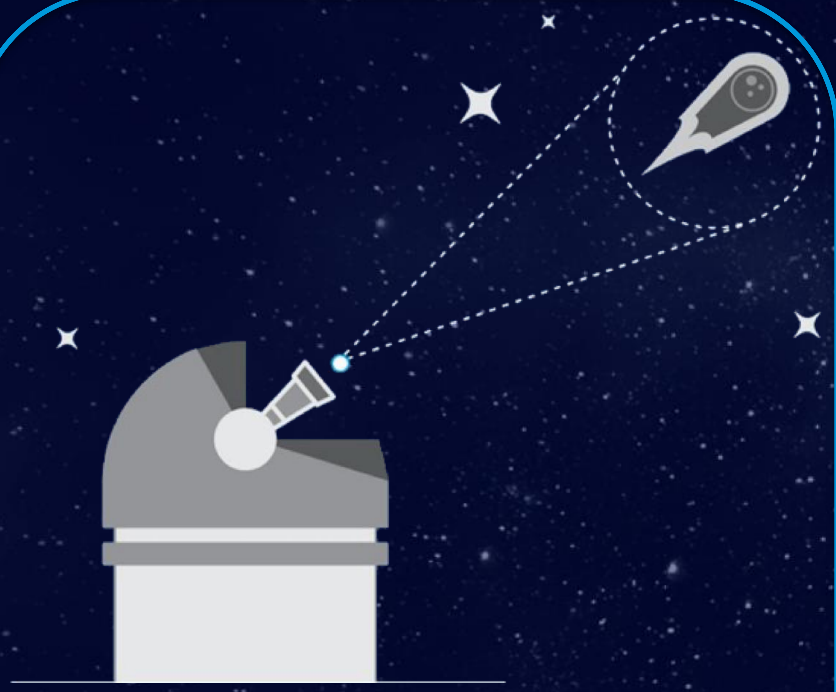
Marco Micheli

L. Conversi, R. Kresken, D. Föhring, F. Ocaña, T. Santana-Ros

*ESA NEO Coordination Centre*

*UA / ICCUB*

# The Three Pillars Of ESA Planetary Defence

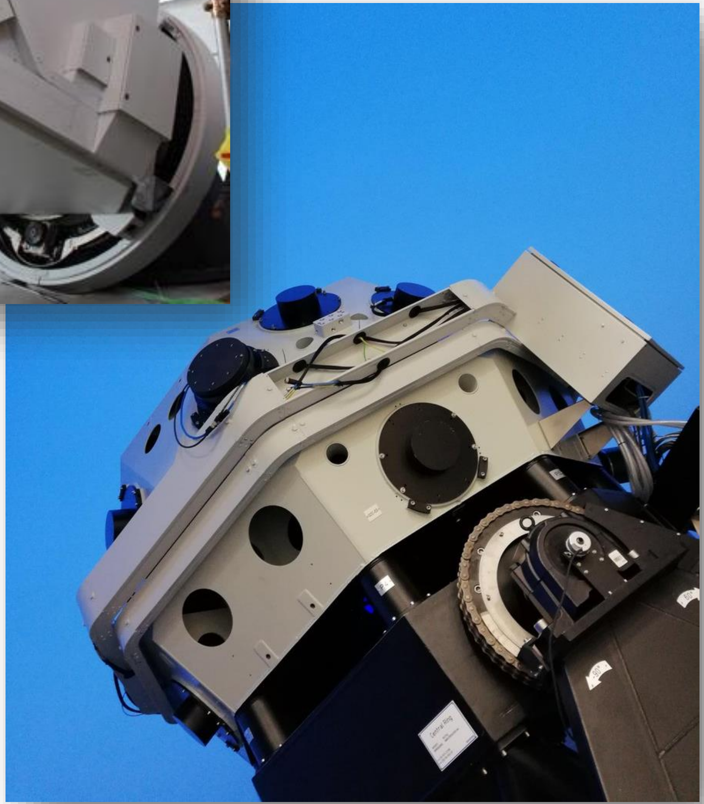


Detect


Assess

Mitigate

# Flyeye Survey Telescope

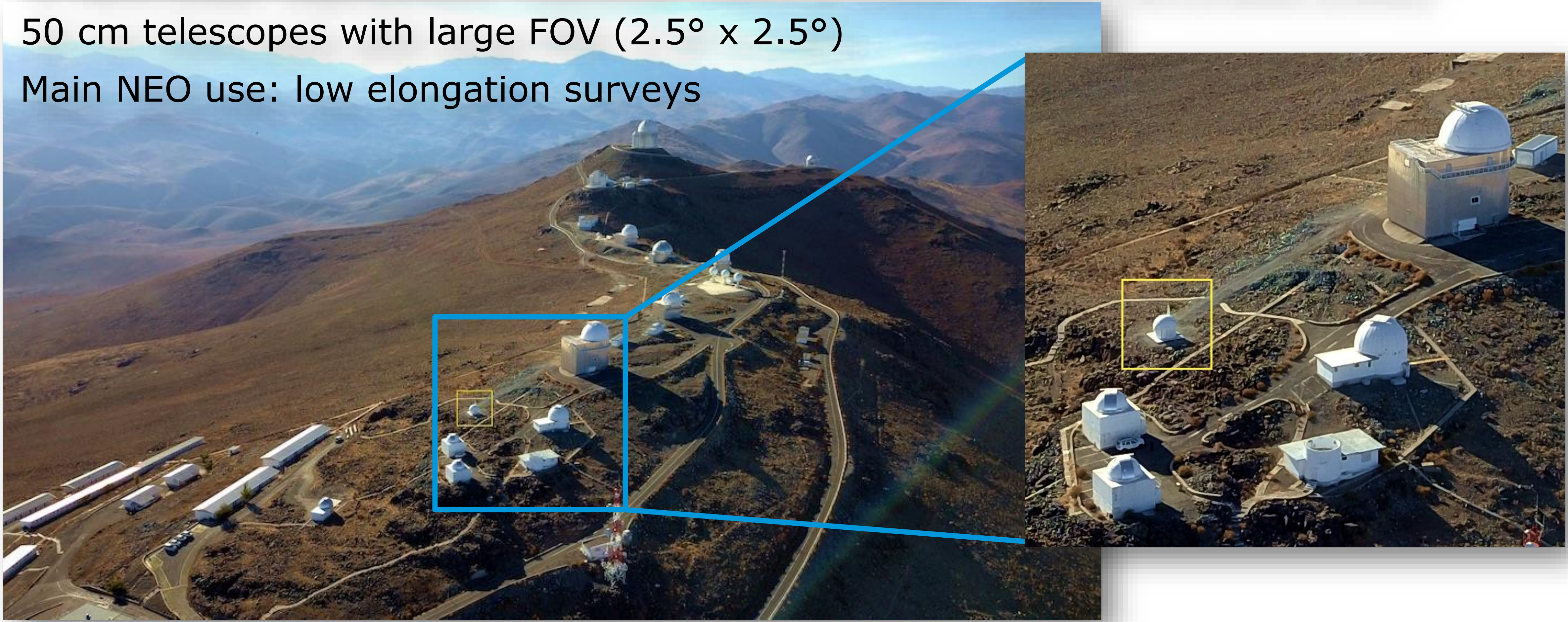



# Test-Bed-Telescopes (TBTs)

2 TBTs under deployment: Cebreros Tracking Station (Spain) & La Silla (Chile)

50 cm telescopes with large FOV (2.5° x 2.5°)

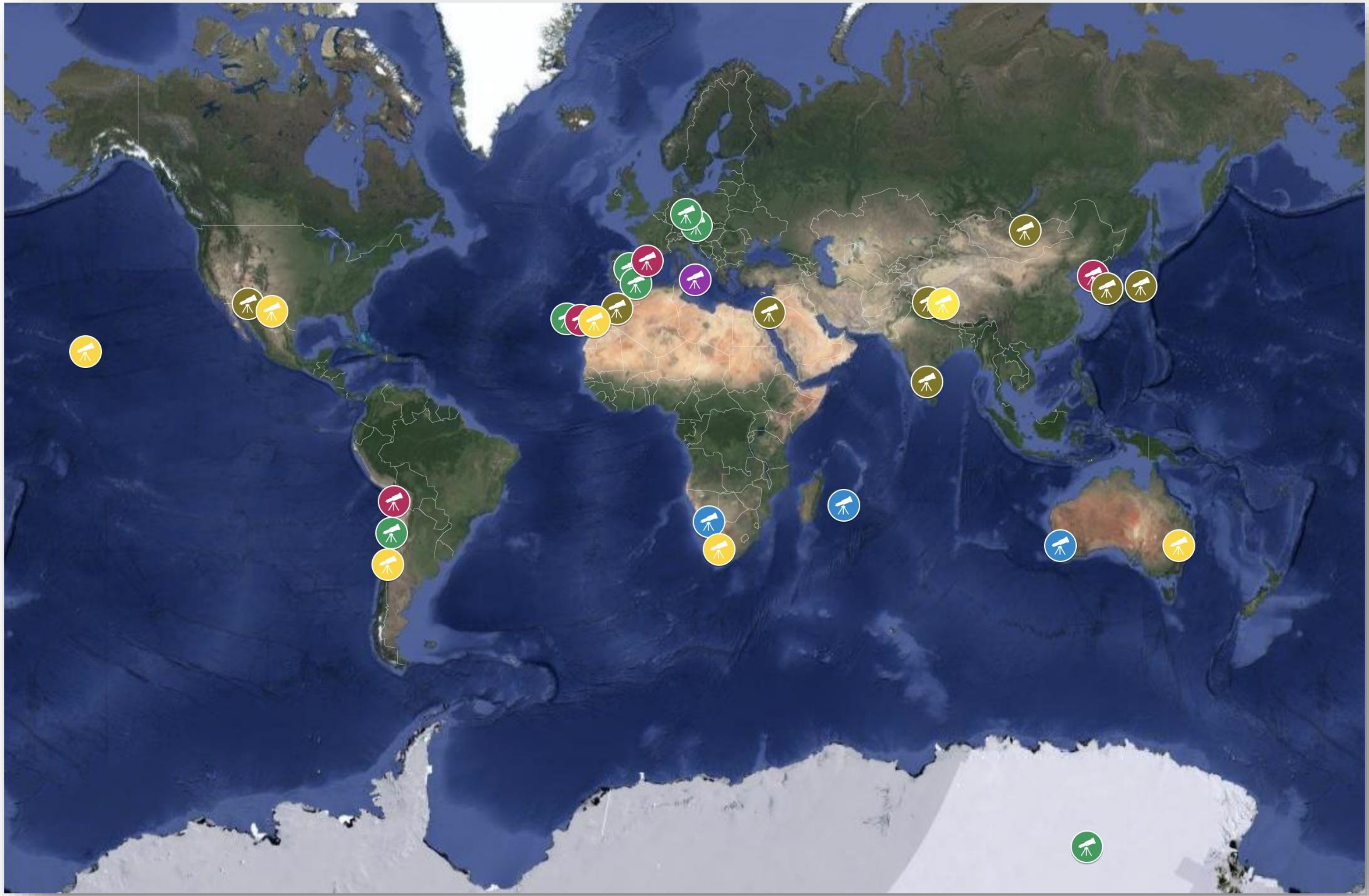
Main NEO use: low elongation surveys



# A wide telescope network

Legend

- Scientific Agreement
- ESA owned/funded
- 6ROADS Southern Hemisphere
- 6ROADS Asia
- LCO
- Flyeye #1



# How do we access these telescopes?

These telescopes are accessible to our team through a variety of forms:

- Direct ESA ownership and control (e.g. ESA’s OGS telescope).
- Full control of a telescope made available via contracts (e.g. CAHA Schmidt).
- Rapid response time to external facilities under contract.
- Institutional agreements (e.g. ESO VLT).
- Scientific collaborations with other teams.
- Traditional science proposals evaluated through the normal TAC route.
- DDT proposals in case of unforeseen high-profile targets.
- Financial support to external teams operating their observatories.

# What can we do with these telescopes?

We use our observational assets to obtain various types of observations:

- Collecting quick-reaction observations for urgent objects (e.g. imminent impactors or fly-bys). Typically, we need to be “on the sky” within minutes to hours.
- Obtaining extended follow-up of faint high-importance objects (e.g. risk list objects, Atiras or Trojans, ISOs).
- Organizing and/or participating in international campaigns (e.g. IAWN, DART).
- Observing objects in challenging conditions (e.g. low elevation, twilight).
- Experimenting with new observing techniques (e.g. synthetic tracking, non-linear stacking, timing calibration, CMOS sensors).
- Observing artificial objects that might be a source of confusion for NEO follow-up (high Earth orbiting satellites or debris, interplanetary launches or fly-bys).

# Astrometry is not just RA and Dec!

Two additional factors are extremely important for astrometry:

## Time

Nearby asteroids sometimes move faster than 1″/s.

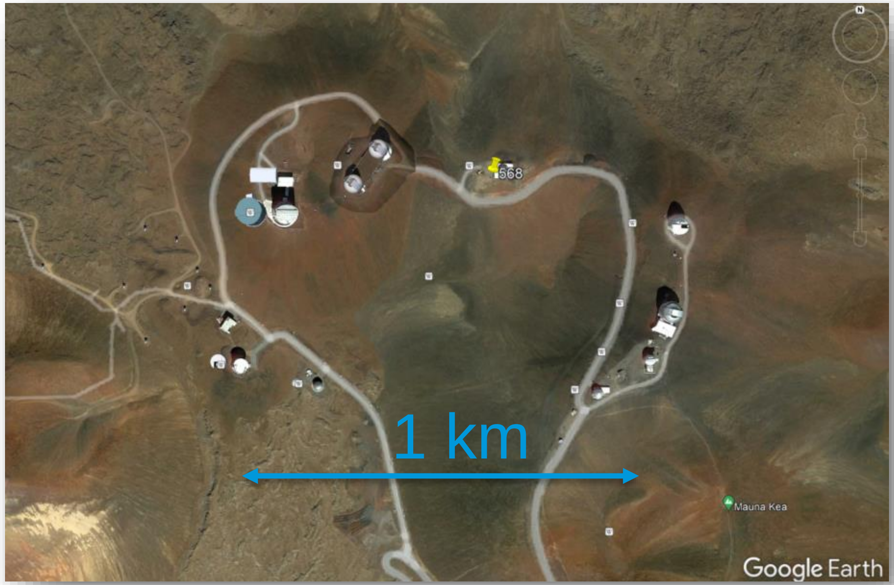
Therefore, it is important to know the time of the exposure to much better than 1 s.

- Proper synchronization of the clock
- Timing of the shutter
- Electronic or software delays

Even some professional facilities sometimes show huge minute-level biases!

## Geographic coordinates

If an asteroid is closer than the Moon, an error of ~1 km can bias by almost 1″.



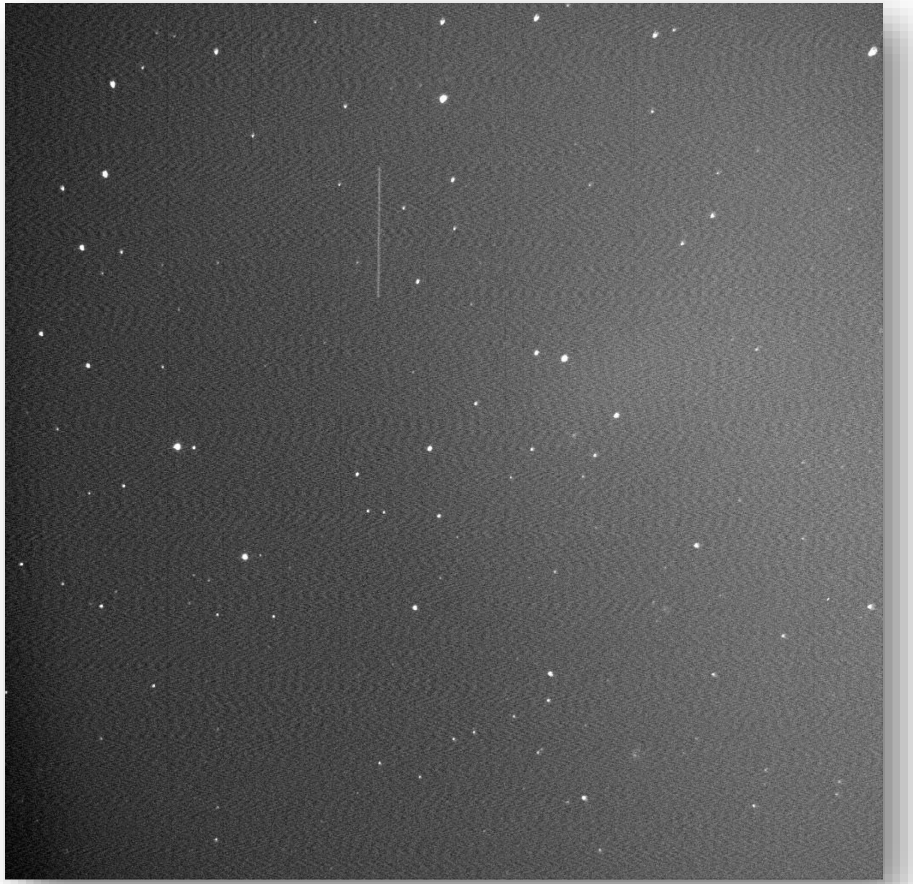
# Trail-fitted astrometry

Some observations, such as the rapid follow-up of imminent impactors, involve very fast moving objects, and result in trailed detections.

Extra care must be placed while extracting astrometry.

An example: the impact of 2022 EB5

- This object was discovered only a few hours before impact.
- Immediate access to telescopes is needed to get observations.
- It is necessary to think of the observing strategy in advance. Including timing!
- Astrometry of the obtained detections is often not trivial, requiring trail-fitting.



P. Bacci, M. Maestripieri, A. Carbognani

# Coverage from multiple stations

Some observations require the use of a network of telescopes covering a large longitude span, when coverage is needed over a timespan longer than hours, but shorter than a day. This is especially common with close fly-bys.

An example: the BepiColombo fly-by

- The fly-by geometry closely replicates the challenges of an imminent impactor.
- Rapid follow-up from 10 stations.
- Fly-by distance determined to <200 m, and close approach time to <0.04 s.
- Consistent with ground-based radio tracking.
- Many lessons learned on how to collect high-precision observations on short notice.

| Element (Unit) | Value | Uncertainty |
|---|---|---|
| $T_q$ (TT) | 04:26:06.418 | 0.033 |
| $q$ (km) | 19 064.016 | 0.180 |
| $e$ | 1.758959 | 0.000017 |
| $i$ (°) | 159.506332 | 0.000009 |
| $\Omega$ (°) | 149.52452 | 0.00022 |
| $\omega$ (°) | 252.95024 | 0.00038 |
| AMR ($10^{-3}$m$^2$/kg) | 16.2 | 1.6 |

See *Micheli et al.; Acta Astronautica, 184:251 (2021)*

# Two major hardware improvements

Two new technologies are changing the way we obtain astrometry observations today:

## CMOS sensors

These new sensors ensure extremely fast readout speeds.

↓

Very little time is lost downloading frames.

↓

It is now competitive to observe an object with many individual short frames (hundreds to thousands), instead of using longer individual exposures.

## GPUs

It is now not uncommon to obtain many GBs of imaging data on a single target.

↓

These images need to be combined, tracked on the motion of the asteroid.

If we know the motion, we can stack images in seconds.

If we don't, we can test all motion vectors (synthetic tracking).

# Synthetic tracking

CMOSs+GPUs allow small sub-meter telescopes to also contribute to asteroid discovery.

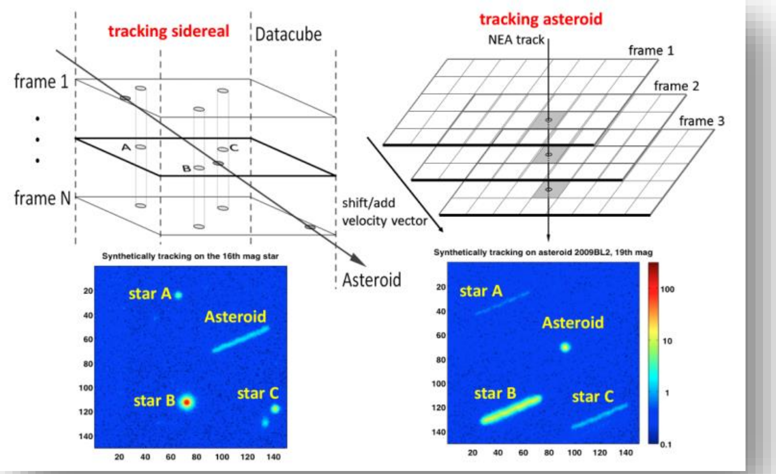
With a normal survey strategy, a telescope takes a few (3 to 5) exposures of a field, separated in time by 10-20 minutes each, and looks for moving objects.

Objects are detected as moving sources visible in each image.

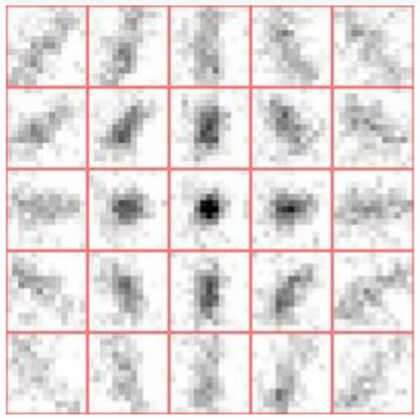
With synthetic tracking, the same telescope takes dozens of consecutive images.

The object is NOT visible in individual frames, but only after stacking them.

Since the motion is unknown, a large number of stacking rates must be tested, until a point-like source appears.



C. Zhai, M. Shao et al.

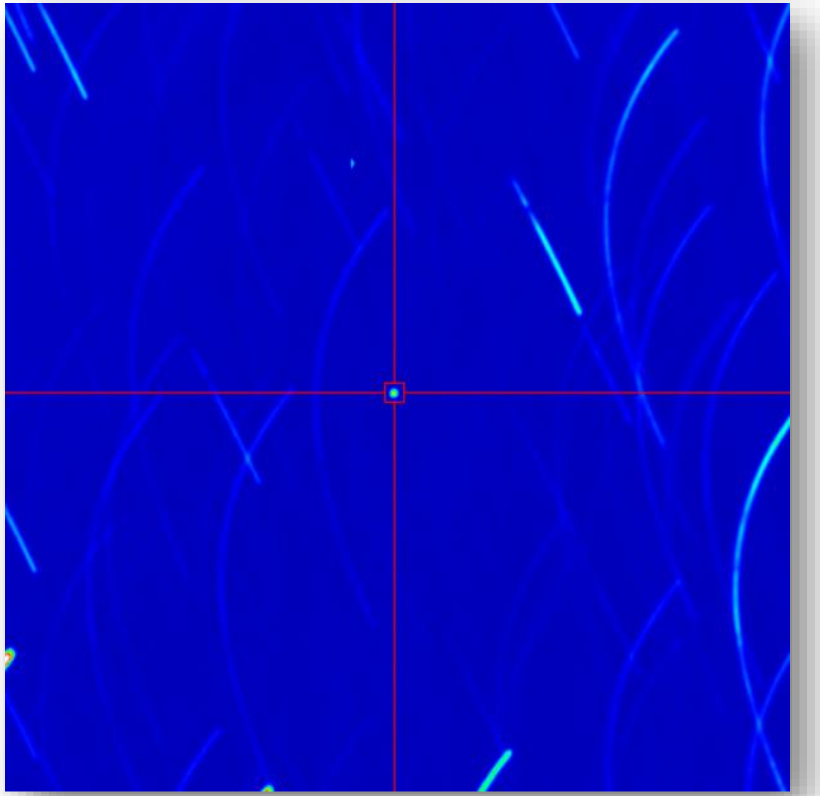

D. Parrott

# Nearby objects and challenging astrometry

Nearby objects, e.g. high-orbiting satellites, fly-bys of interplanetary hardware, and occasional recaptures of heliocentric objects, provide a critical test for many observational and orbit computing capabilities.

An example: stacking "2020 SO" = Surveyor 2 Centaur

- An object discovered while in Earth orbit, and later discovered to be artificial.
- Its motion in the sky was highly non-linear.
- Tools using GPU acceleration allow to quickly stack hundreds of images on an ephemeris.
- This capability is essential when performing stacked observations of nearby objects, where parallax is extremely prominent.



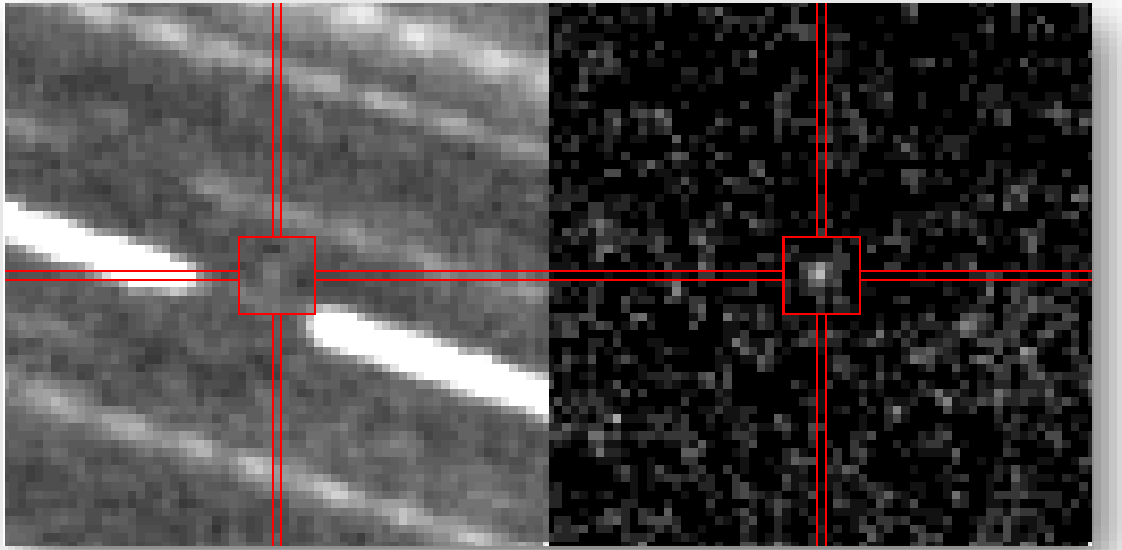
D. Parrott / M. Micheli, L. Conversi

# Quantity vs. quality (and importance)?

Most telescopes used for NEO astrometry are small, meter-class at most.

However, important follow-up targets are sometimes faint (even more in the LSST era).

- Using an 80 cm telescope
  (Schmidt telescope at Calar Alto, Spain)
- We could detect a V~24.2 asteroid.
- Obtained with 5 hours of exposure time.
- Stacking at variable rates is needed.



Calar Alto Observatory / ESA NEOCC

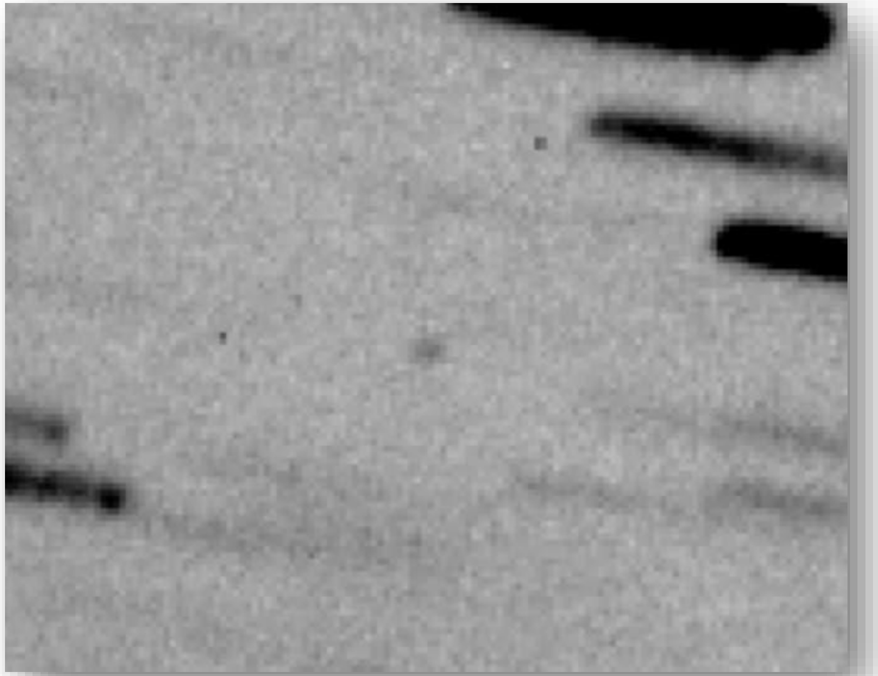
This unusual mode of operation for a small-class telescope could offer interesting follow-up opportunities for faint objects, that are typically only observed with larger professional facilities.

# Observing at low altitude

It is unfortunately not unusual that interesting NEOs are only visible when located at low elongation in the evening or morning sky. These observations are often challenging for most professional telescopes, with strict altitude constraints.

An example: follow-up of 2020 XL5, Earth's second Trojan

- The object approached low elongations quickly after discovery.
- We needed to obtain follow-up in order to make it recoverable at following apparitions.
- We were able to use various telescope to track it down to an elongation of almost 30°.
- This allowed us to find precovery data end extend the observed arc to many more apparitions.



See *Santana-Ros et al.; Nature Communications, 13:447 (2022)*

# Conclusions

Astrometry and follow-up need to grow, change and adapt to many novel factors:

- Be quick: targets like imminent impactors require reaction times of the order of minutes, not days or months.
- Be accurate: accuracy also means error bars, timing, location, and many other subtle aspects that are often neglected in the astrometric process.
- Be modern: new techniques, hardware and software are now available, they need to be understood and then embraced by the community.
- Be different: a lot of facilities are now performing routine follow-up. In order to provide useful data, it is often useful to be innovative in some particular aspect of the process.

**THANKS!**