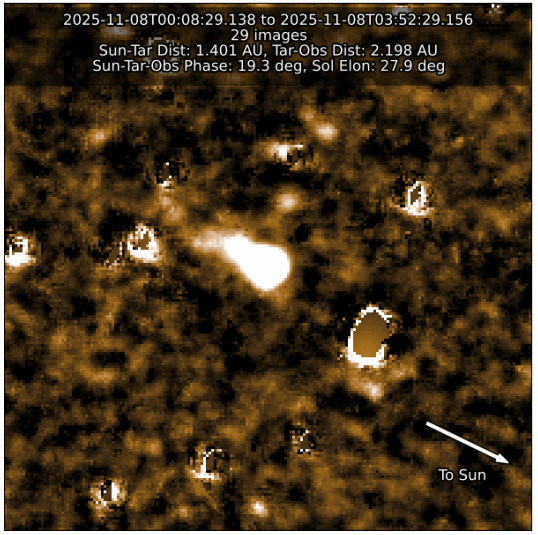
Initial Exploration of Comets with PUNCH WFI



Simon Porter and Kevin Walsh
SwRI Boulder

The Low Elongation Solar System

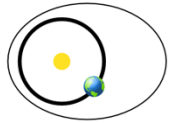
- What's in the field and interesting?
  - Planets (too bright)
  - Main belt (not unique phase angles)
  - Kuiper Belt, Centaurs, Trojans (too dim)
  - Earth-interior asteroids
  - Sungrazers
  - Long Period Comets and Interstellar Objects

Earth-Interior Asteroids

- Earth orbit crossing asteroids (Apollos & Atens) are potentially hazardous and spend some time visible in WFI field
- Earth-interior asteroids (Atiras) spend much of their orbit only near the Sun, and can evolve to

Amors

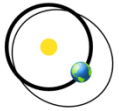
Earth-approaching NEAs with orbits exterior to Earth's but interior to Mars'
(named after asteroid (1221) Amor)



$a > 1.0$ AU
$1.017 \text{ AU} < q < 1.3$ AU

Apollos

Earth-crossing NEAs with semi-major axes larger than Earth's
(named after asteroid (1862) Apollo)



$a > 1.0$ AU
$q < 1.017$ AU

Atens

Earth-crossing NEAs with semi-major axes smaller than Earth's
(named after asteroid (2062) Aten)

$a < 1.0$ AU
$Q > 0.983$ AU

Atiras

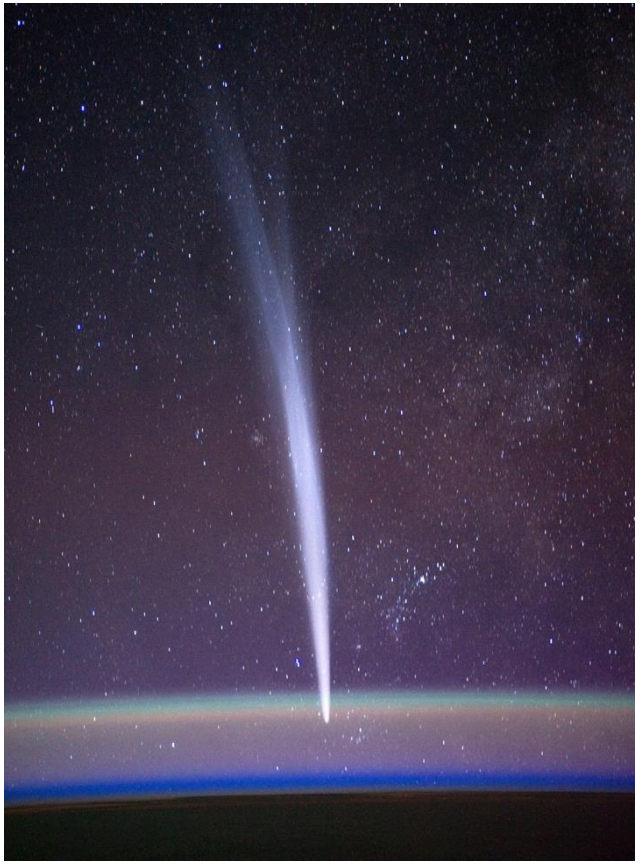
NEAs whose orbits are contained entirely within the orbit of the Earth
(named after asteroid (163693) Atira)

$a < 1.0$ AU
$Q < 0.983$ AU

(q = perihelion distance, Q = aphelion distance, a = semi-major axis)

Sungrazing Comets

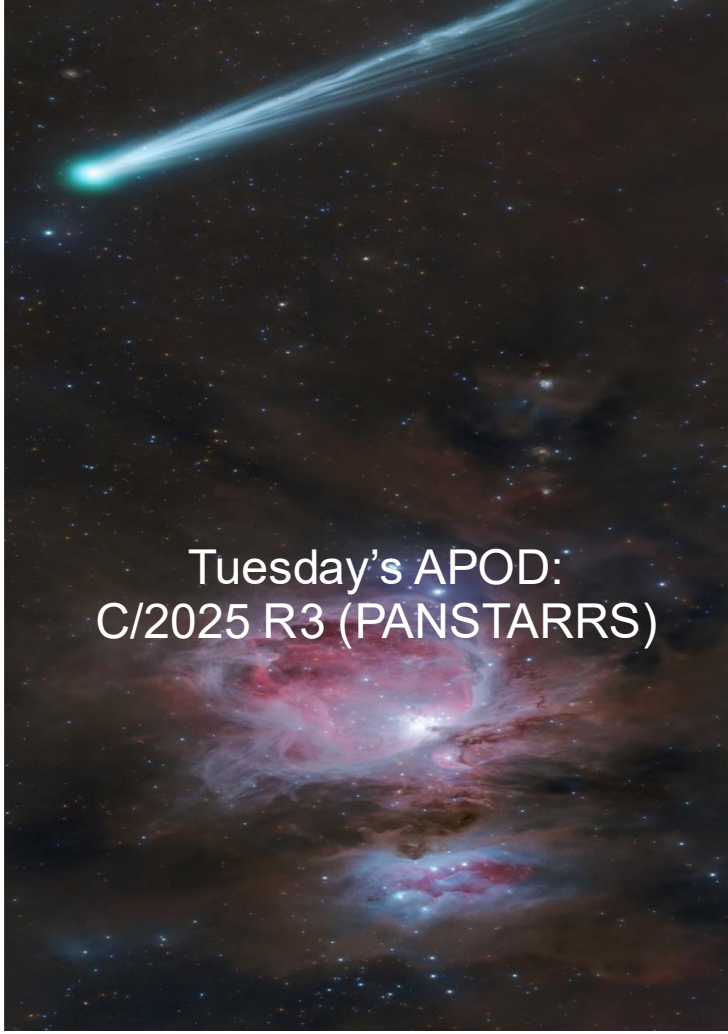
- Generally Oort Cloud comets coming in on near-rectilinear orbits with very low perihelions (<12 solar radii)
- Many (but not all) are members of Kreutz family, produced by a breakup in ~371 BCE



C/2011 W3 (Lovejoy) from ISS

Long Period & Interstellar Comets

- Interstellar objects only appear once, some long period comets once per lifetime
- Want to track as long as possible, even if on other side of Sun
- Expect *a lot* more in coming years from



General Asteroid/Comet Analysis

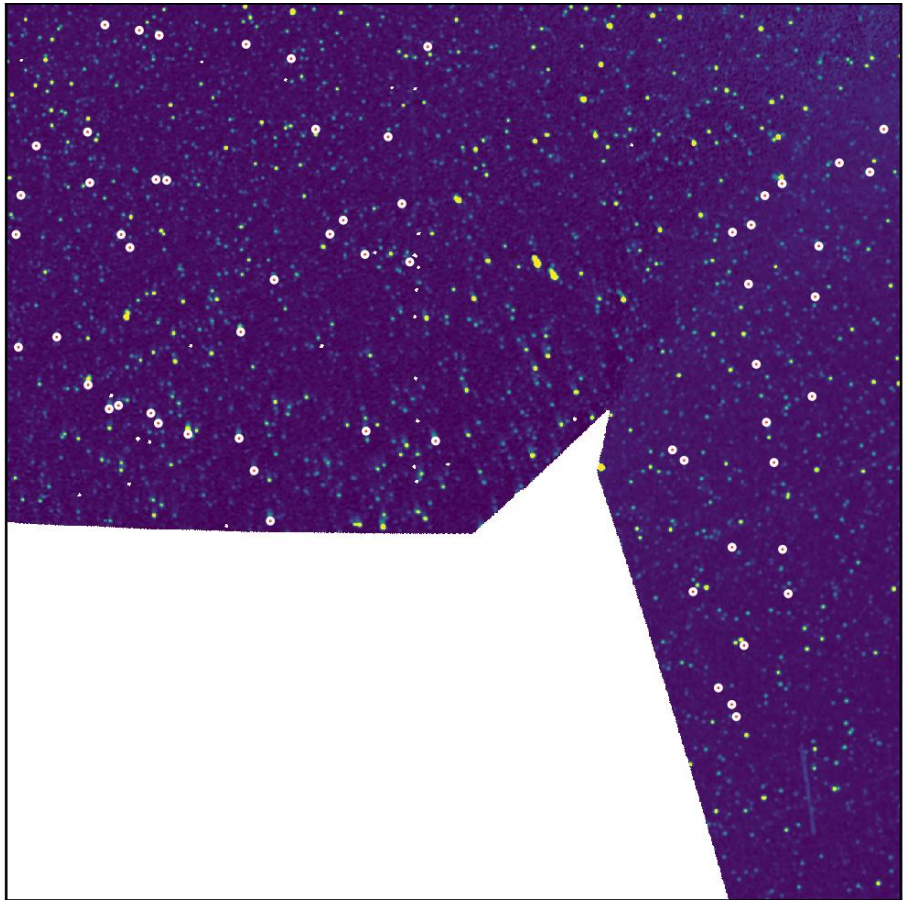
- Industry standard star subtracted shift-stacking
  - Star-subtract source image
  - Extract window centered on target from each source image
  - Extract effective PSF from stars around target
  - Stack images over set amount of time
  - PSF fit astrometry
  - Aperture photometry

Processing CIMs/PIMs

- All analysis here based on v0k L2 CIMs and PIMs
- Break sky in “tracts” based on LSST algorithm
- Extract tracts that have an object of interest in them at any time
  - PIMs get converted to B/pB/pB’ with solpolpy
  - Ultimately we care about pB/B for polarization
- Make 6-hour CIM + PIM B stacks for each tract

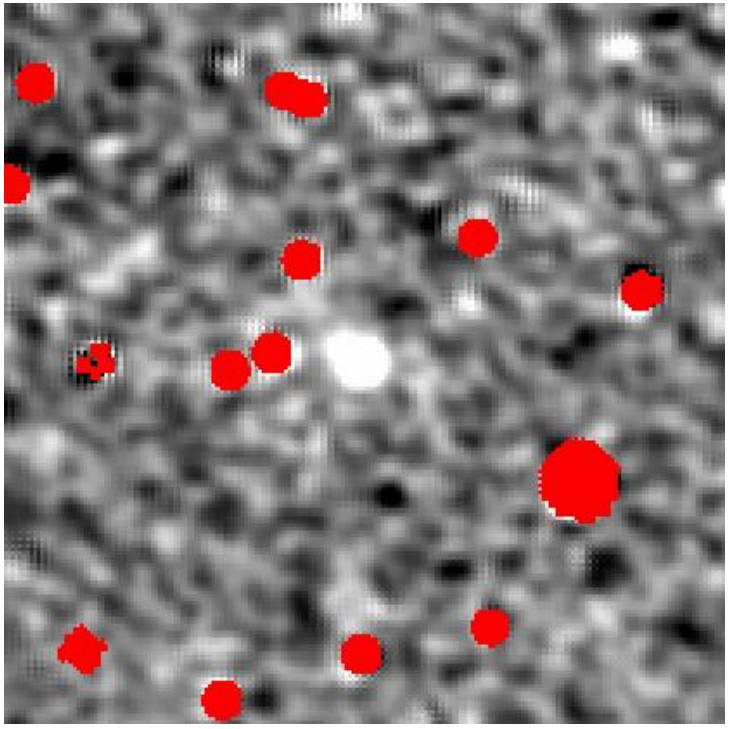
Star-Fitting CIMs/PIMs

- Reproject CIM/PIM to tract, extract stars, compare to Gaia DR3 stars
- Calculate modified WCS for source image, reproject to tract again
- Repeat until convergence (1-3 times, generally)



Extracting Objects from CIMs/PIMs

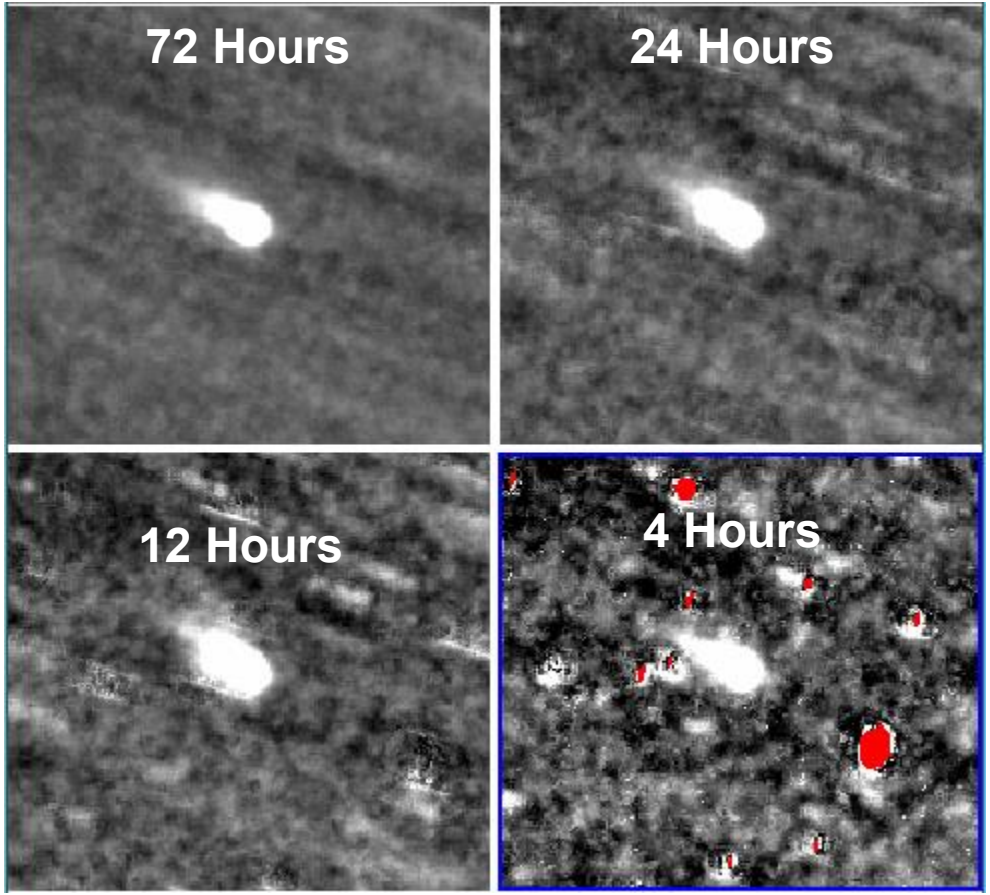
- Reproject images with target from tracts to target-centered window
- Upsample by 2x
- Refit WCS again against Gaia DR3 with stars around target
- Extract PSF, calculate zero



3I CIM_20251108113629_v0k

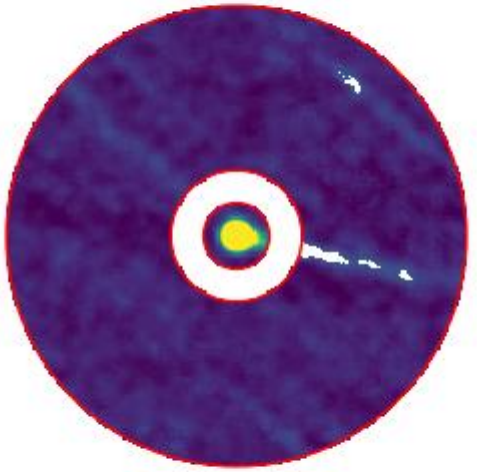
Stacking Objects from CIMs/PIMs

- Stack objects with temporal bins, 1 hr – 168 hr (3 weeks)
- Find mean PSF and ZP
- In clear, weighted mean to favor deeper PIMs
- Can make CIM-only stacks to take



Photometry from CIMs/PIMs

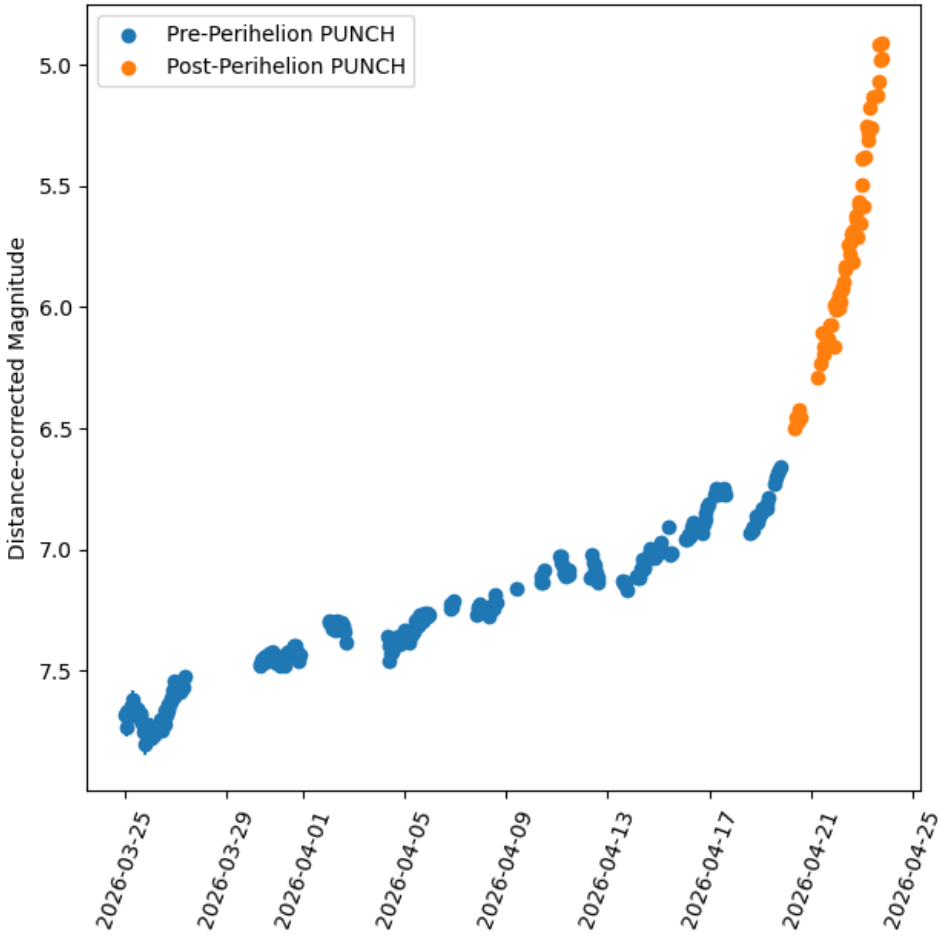
- Use aperture 10^6 km diameter at target
- Calculate sky flux and noise from outer sigma-filtered annulus
- Add noise from sky to aperture to calculate noise



MAPS with inner and sky aperture

C/2025 R3 PANSTARRS

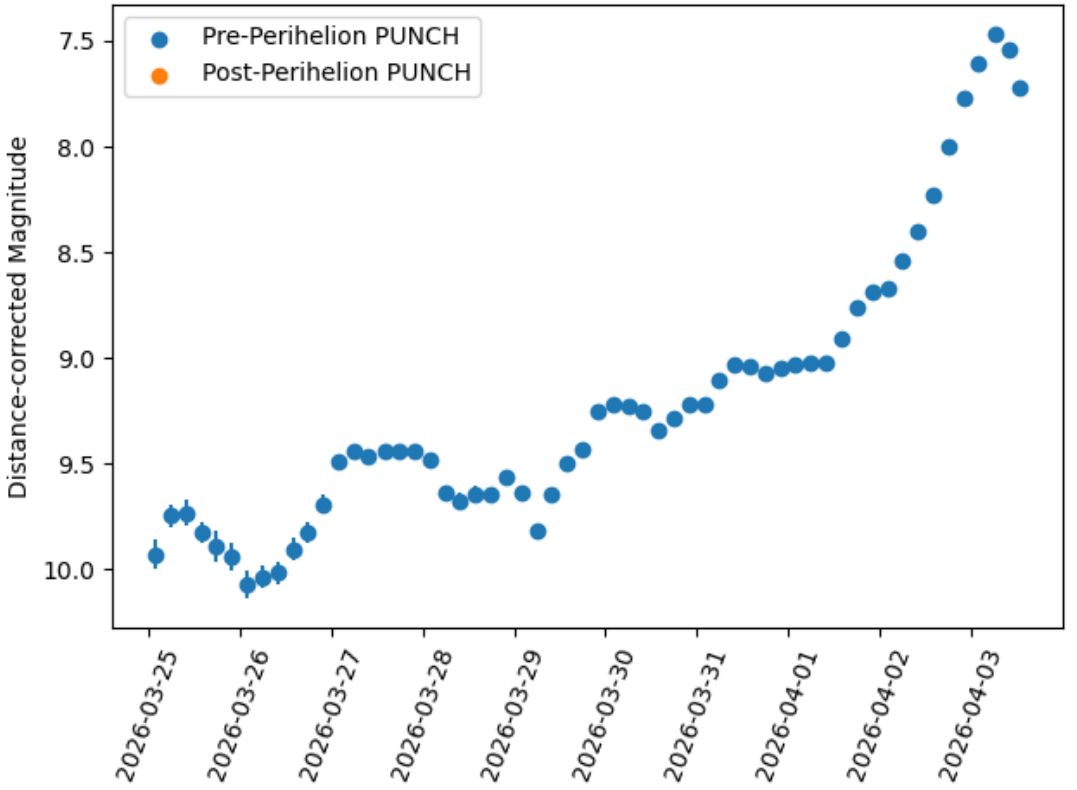
- Oort Cloud comet discovered in Sep 2025
  - e = 0.99984 → 1.00025
  - Perihelion 0.499 AU
- Survived perihelion pass
- Rapid brightening after perihelion



C/2025 R3 PANSTARRS

C/2026 A1 (MAPS)

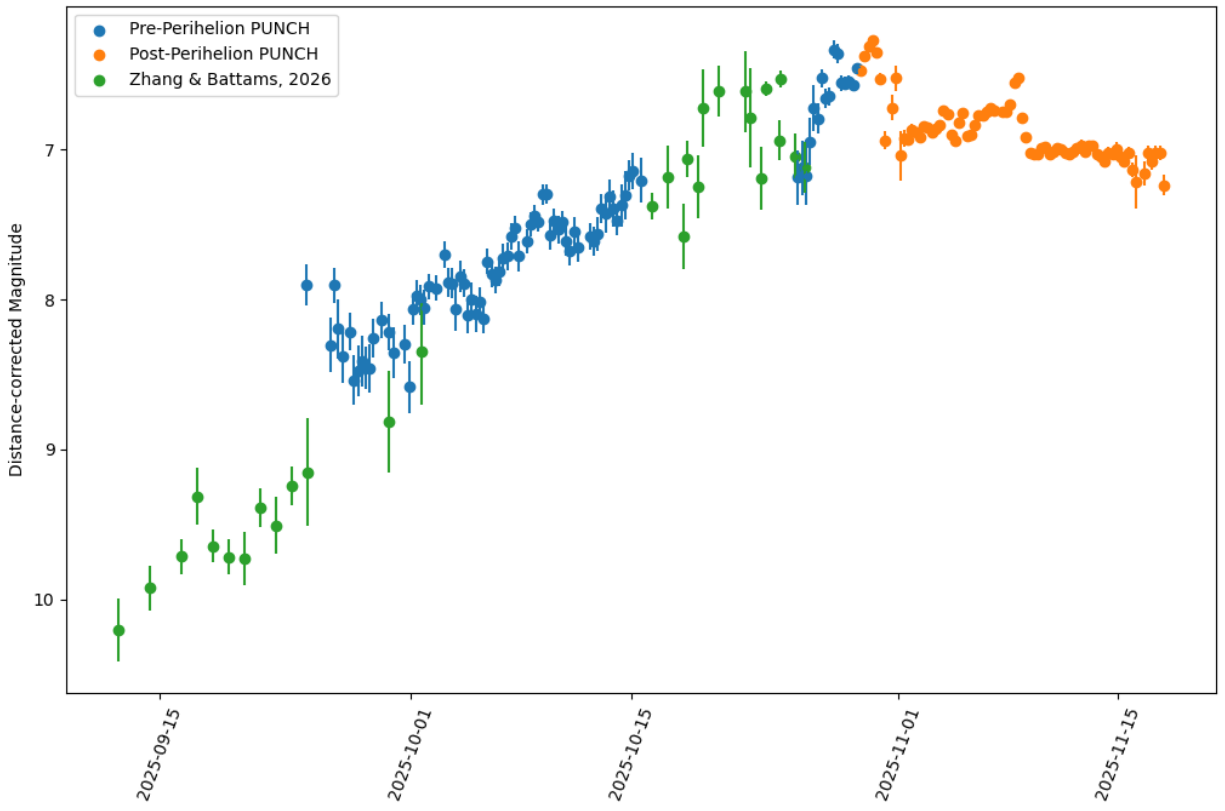
- First big Kreutz of the year
- Rapid brightening towards perihelion
- Then dimming, because coma expanding beyond 10000 km aperture



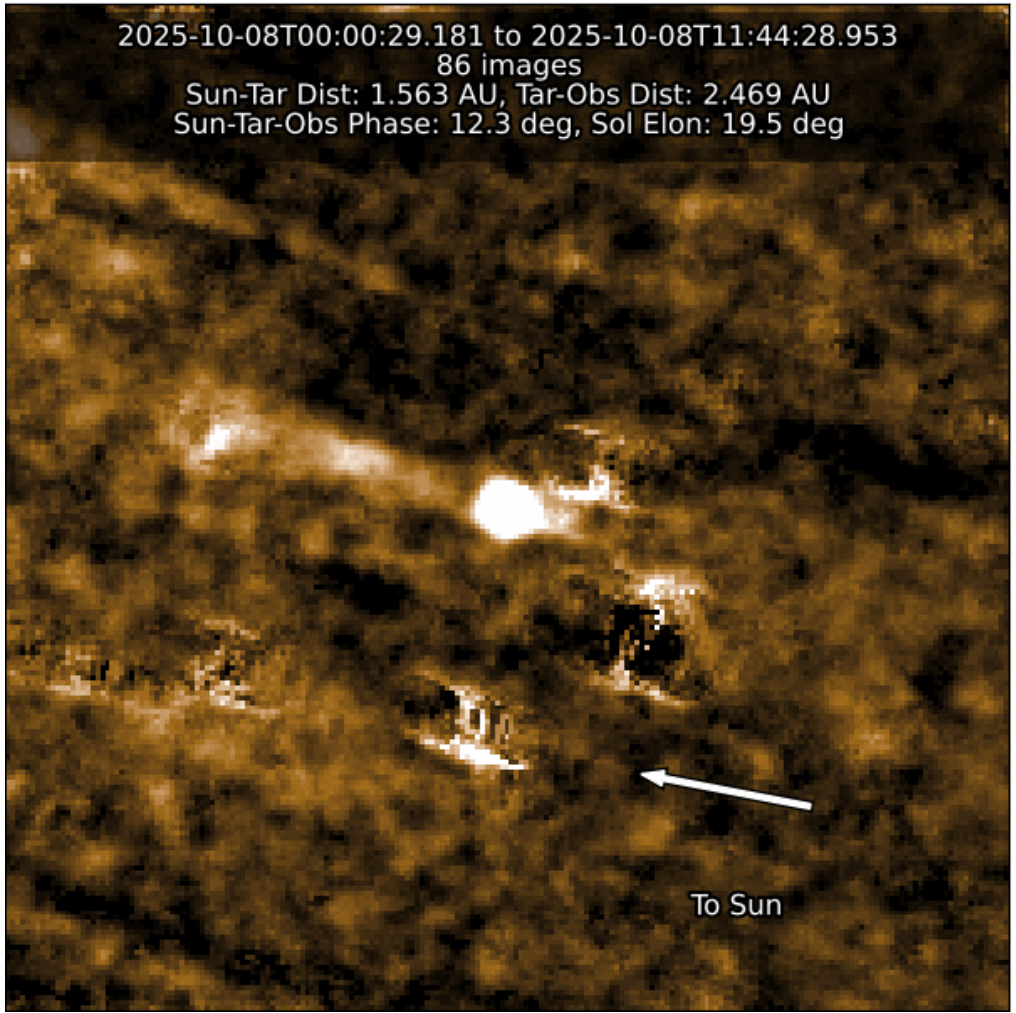
C/2026 A1 (MAPS)

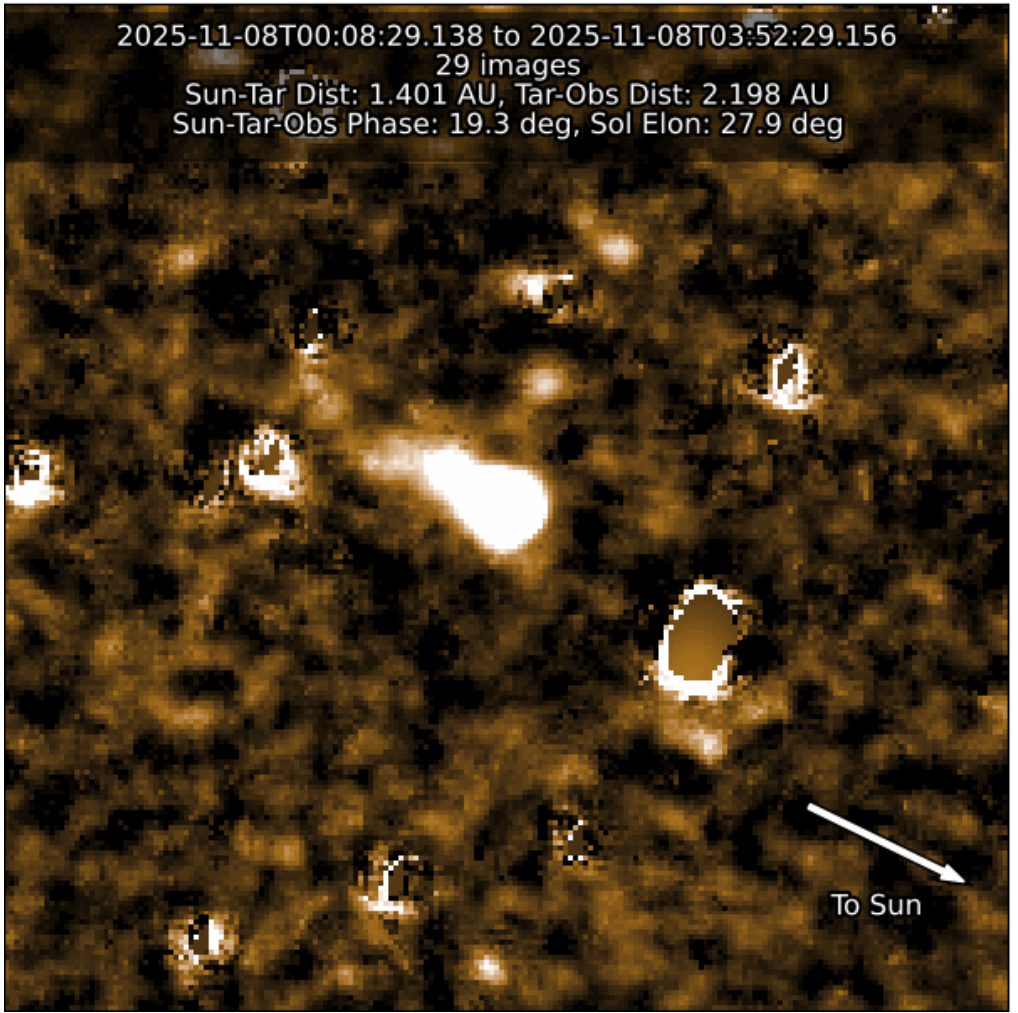
3I/ATLAS

- Third InterStellar Object (ISO)
- Discovered in July 2025 from ground
- PUNCH was able to uniquely observe significant period of time in 2025



3I Tail Detachments





Summary

- WFI is great for bright comets!
- High cadence photometry working for times when no other facility can look
- 3I paper coming soon
- Looking forward to