ZWICKY TRANSIENT FACILITY

UNIVERSITY OF MARYLAND

Search for Known Comets and Their Outbursts

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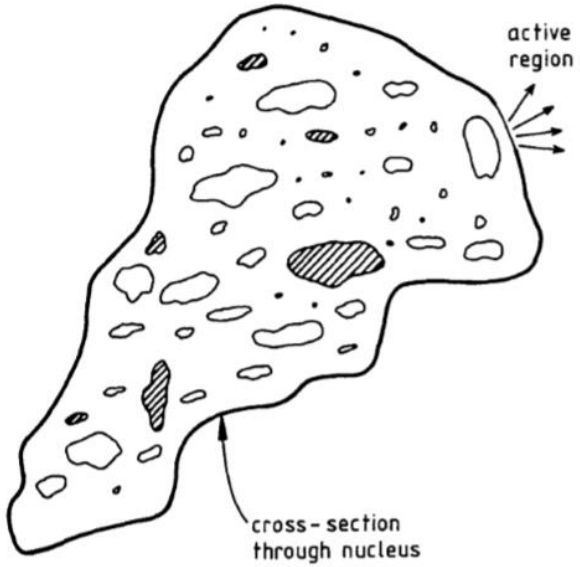
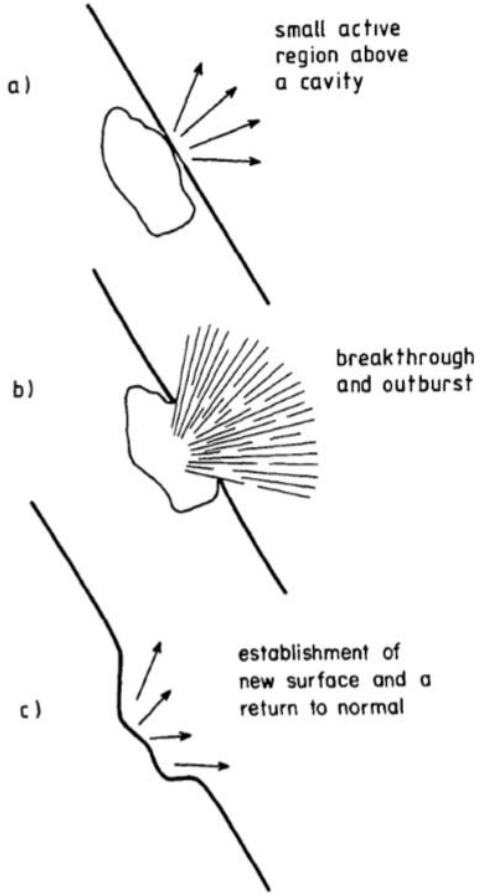
For the ZTF Solar System Working Group

ZTF Collaboration Meeting - 21 Mar 2018

Cometary outbursts

Hughes 1990





A sudden and short-lived increase in mass-loss rate.

Caused by:

- rotational break up
- sub-surface gas pressure and catastrophic surface failure
- thermal stress, cracking, and landslides
- other

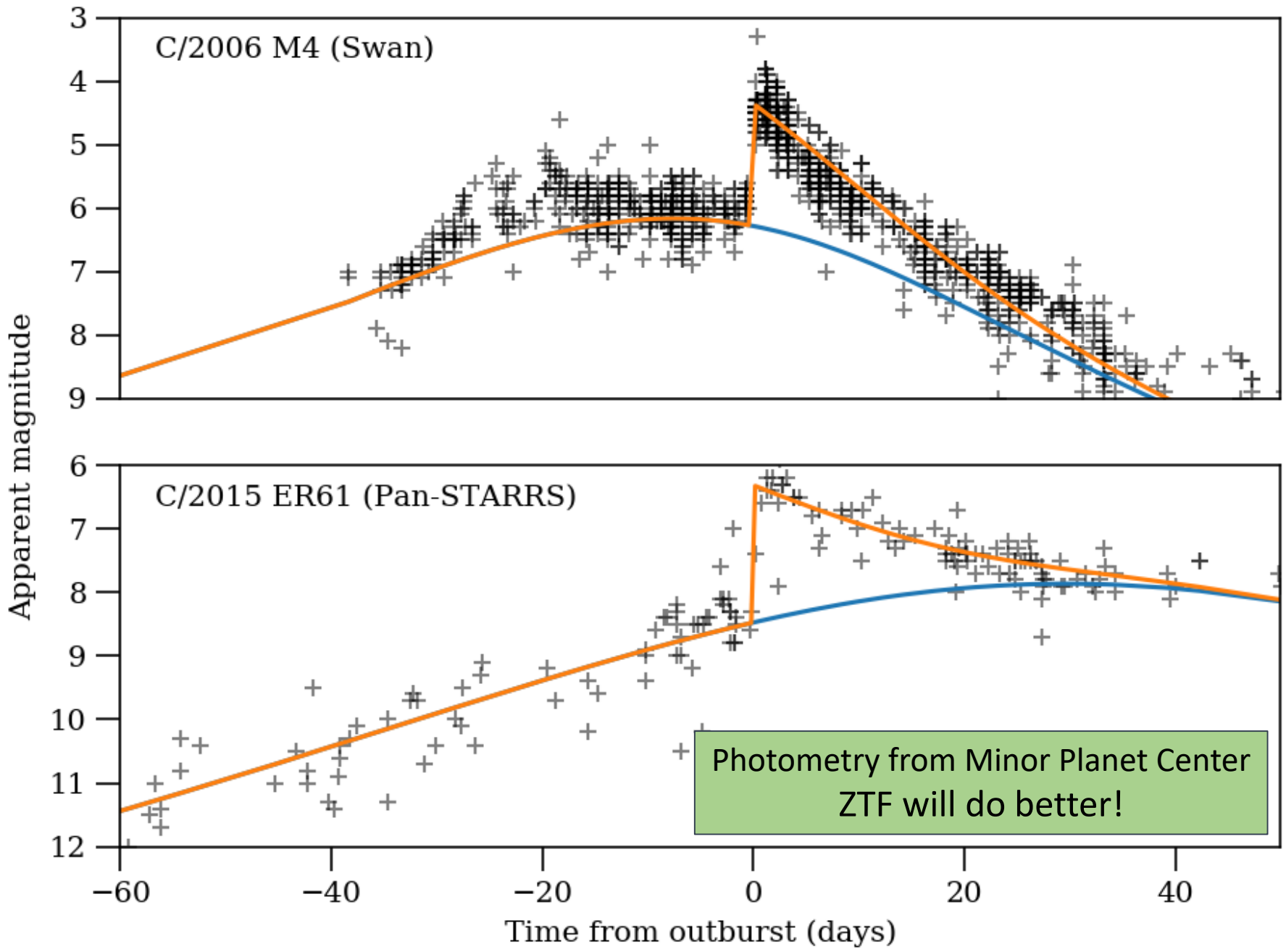
The outburst may yield

- fragments, short- and long-lived
- temporary increase in activity

Δm~2 mag

~9 day exponential decay in total magnitude

These both produced fragments, which helped sustain the activity.

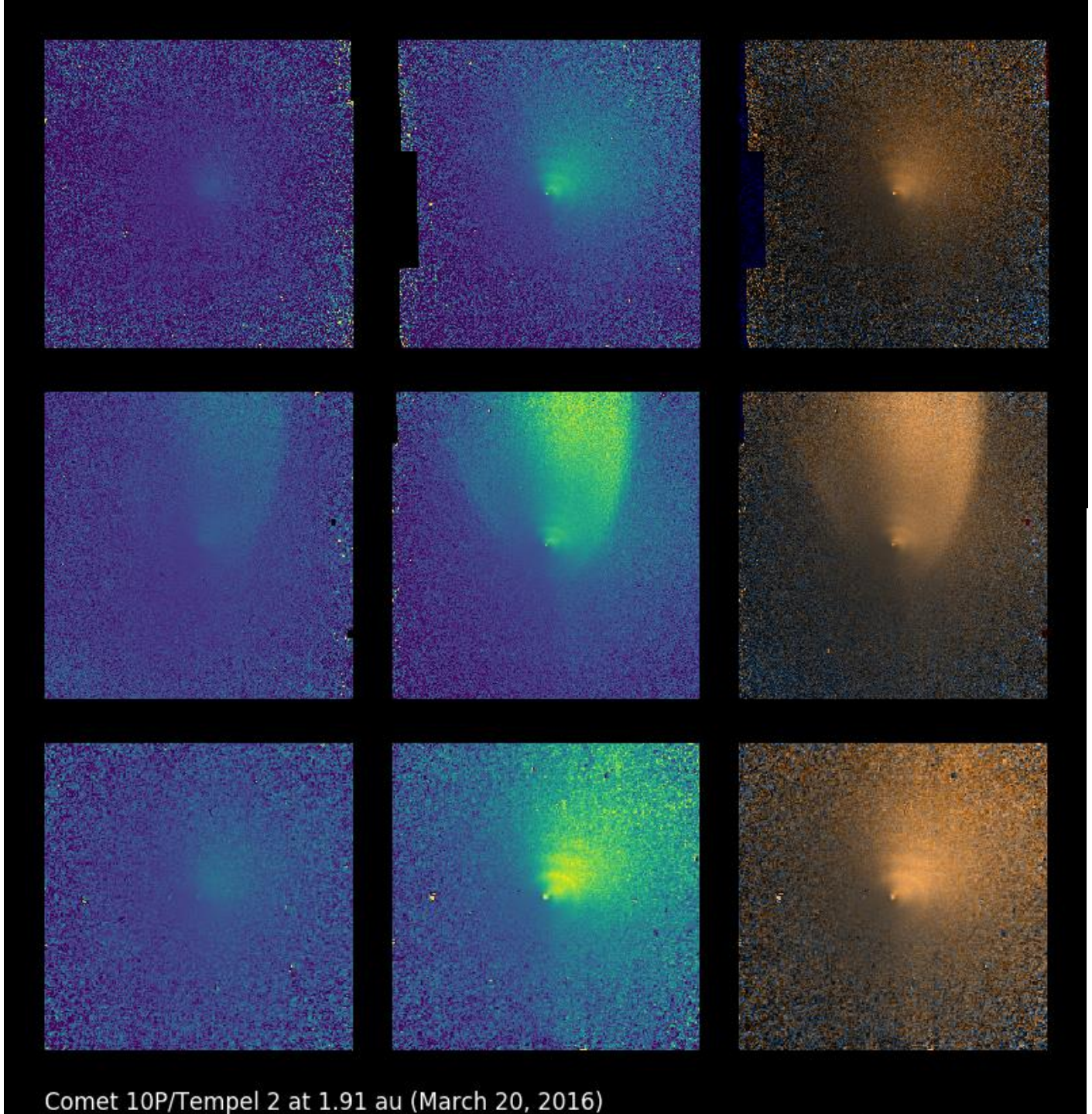


Comet 10P/Tempel 2

Morphologically enhanced
(ignore relative brightness)

Spitzer/IRAC
3.6 µm / 4.5 µm / color combo

Kelley et al., in prep.

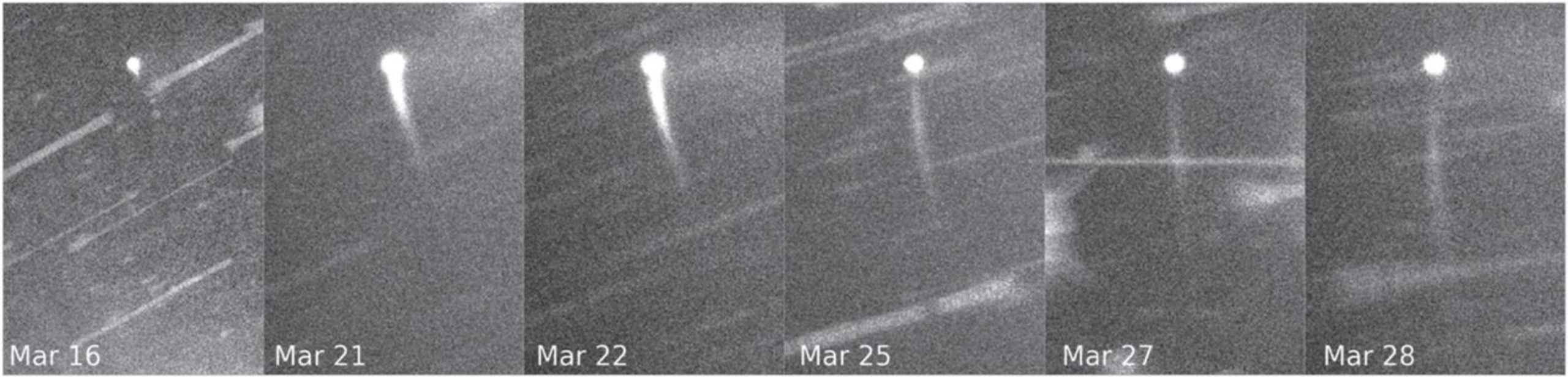


2016 Feb 26

2016 Mar 08

2016 Mar 20

49P/Arend-Rigaux (Eisner et al. 2017)



0.3 mag outburst, returned to ambient in 10 days.

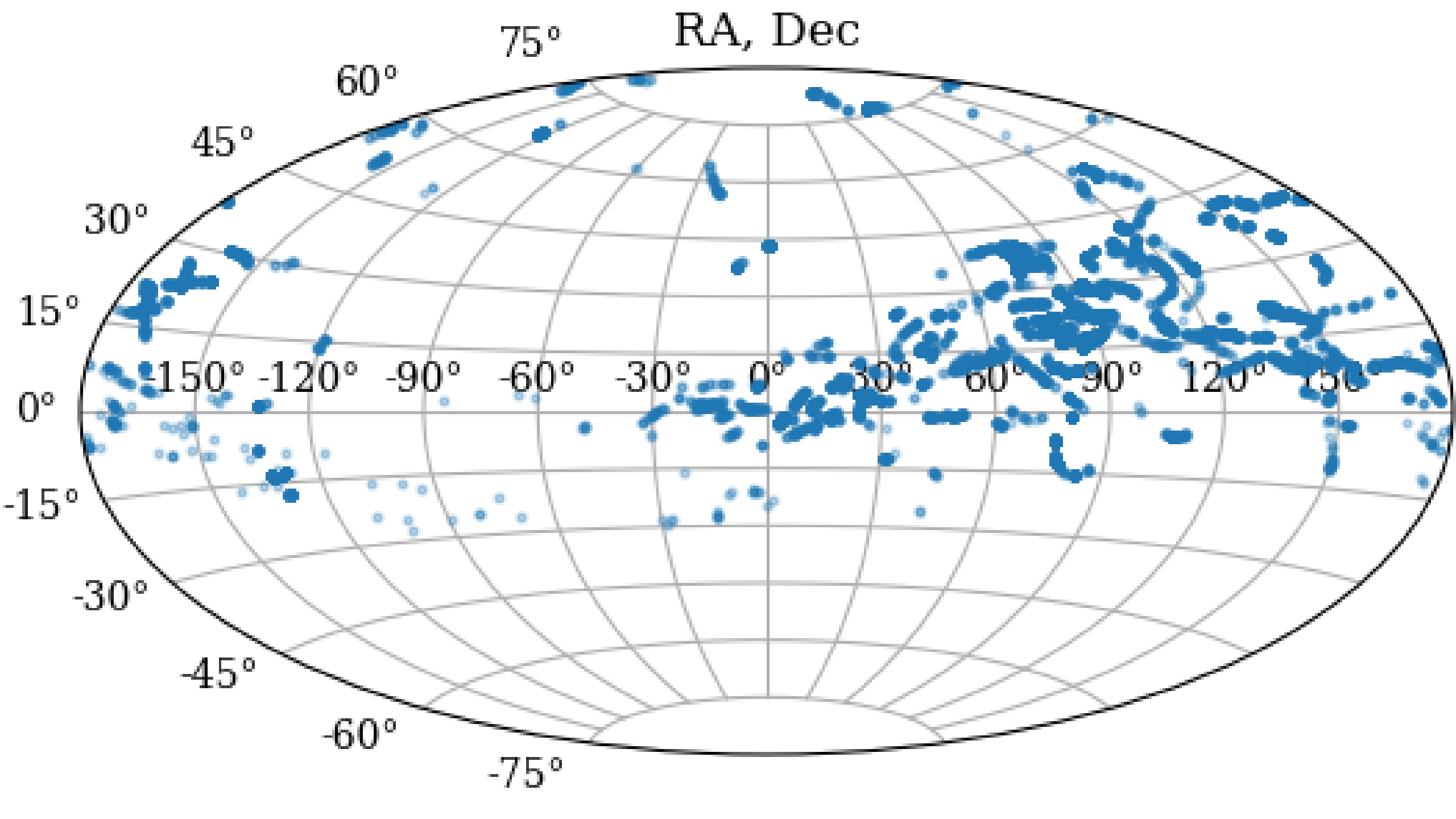
Observed with Lowell's 42" and 31" telescopes.

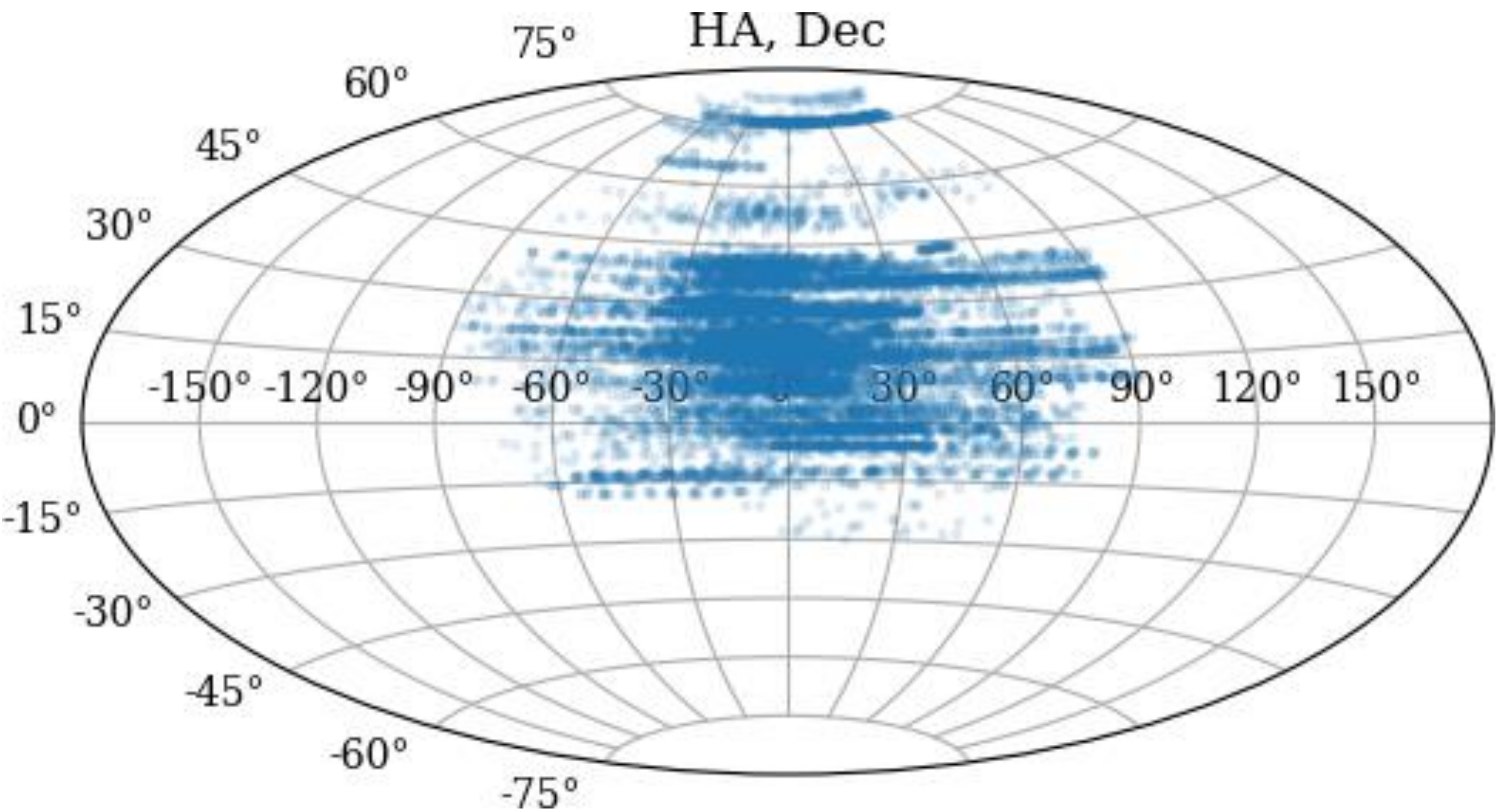
Immediate goal is to increase discoveries and enable rapid follow-up.

ZChecker – A moving object image finder and management tool

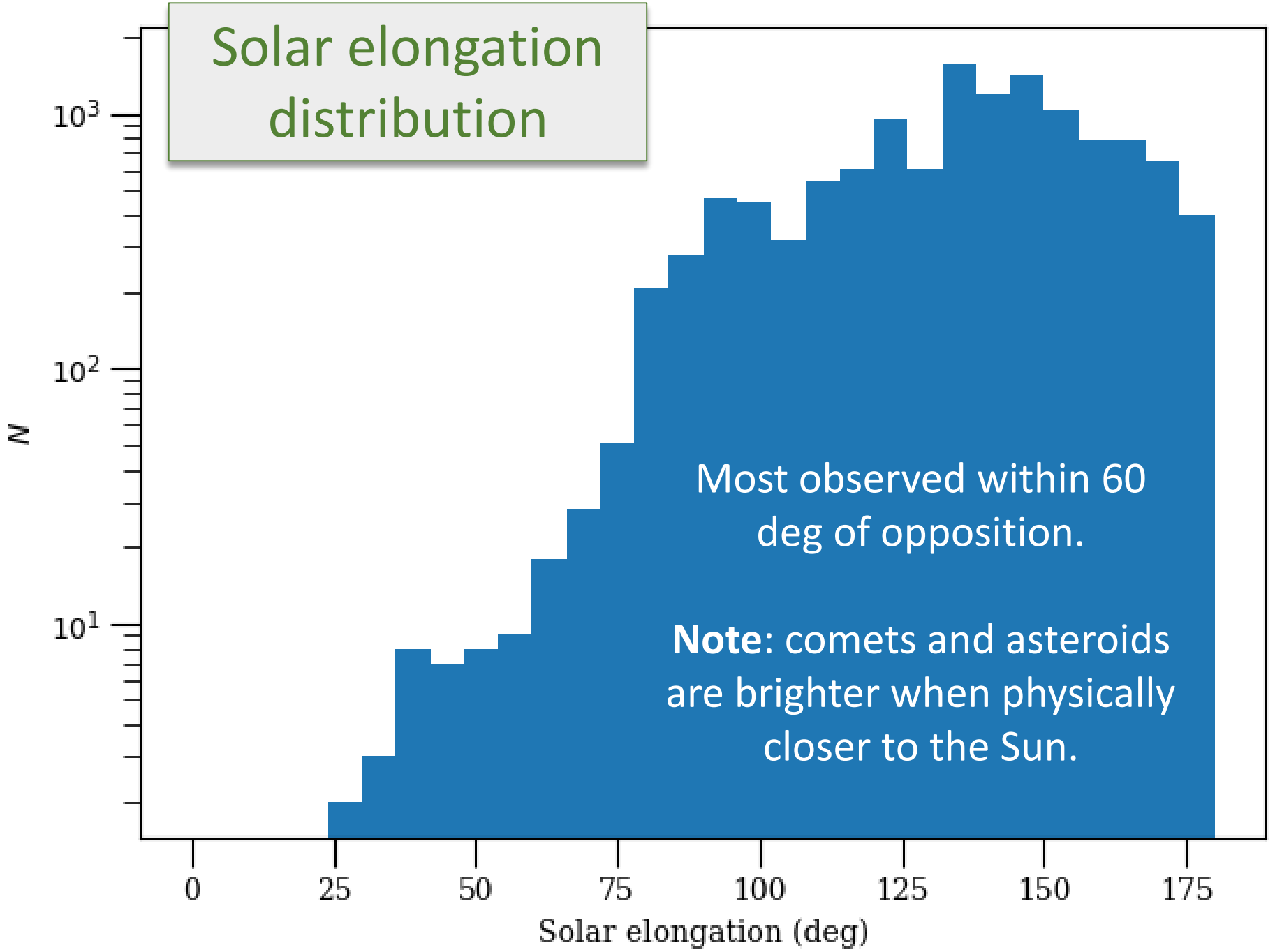
- Python & Astropy, supported by a SQLite database.
- Best for short lists of known objects, up to ~1000.
- Ephemeris-based, not detection based.
- Nearly 100% automated, just needs a target list.
- Runs daily at 7:00 PT.

- Identified 14,500 cutouts covering 176 comets brighter than ~22 mag.
  - 8000 cutouts of 96 comets brighter than 20 mag.
  - 3100 cutouts of 37 comets brighter than 18 mag.


RA, Dec
75°
60°
45°
30°
15°
0°
-15°
-30°
-45°
-60°
-75°
-150°
-120°
-90°
-60°
-30°
0°
30°
60°
90°
120°

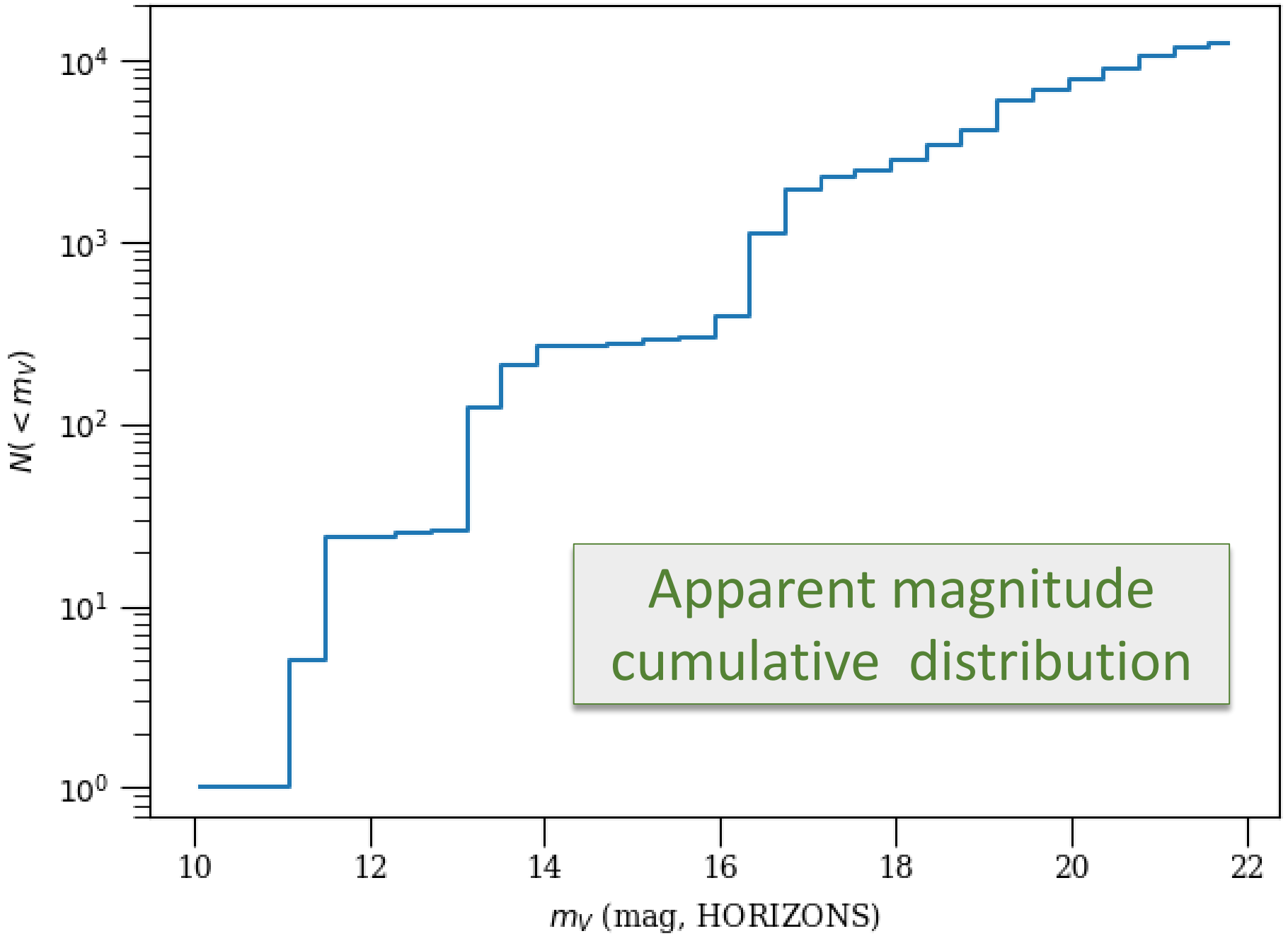

HA, Dec
75°
60°
45°
30°
15°
0°
-15°
-30°
-45°
-60°
-75°
-150°
-120°
-90°
-60°
-30°
30°
60°
90°
120°
150°

Solar elongation distribution

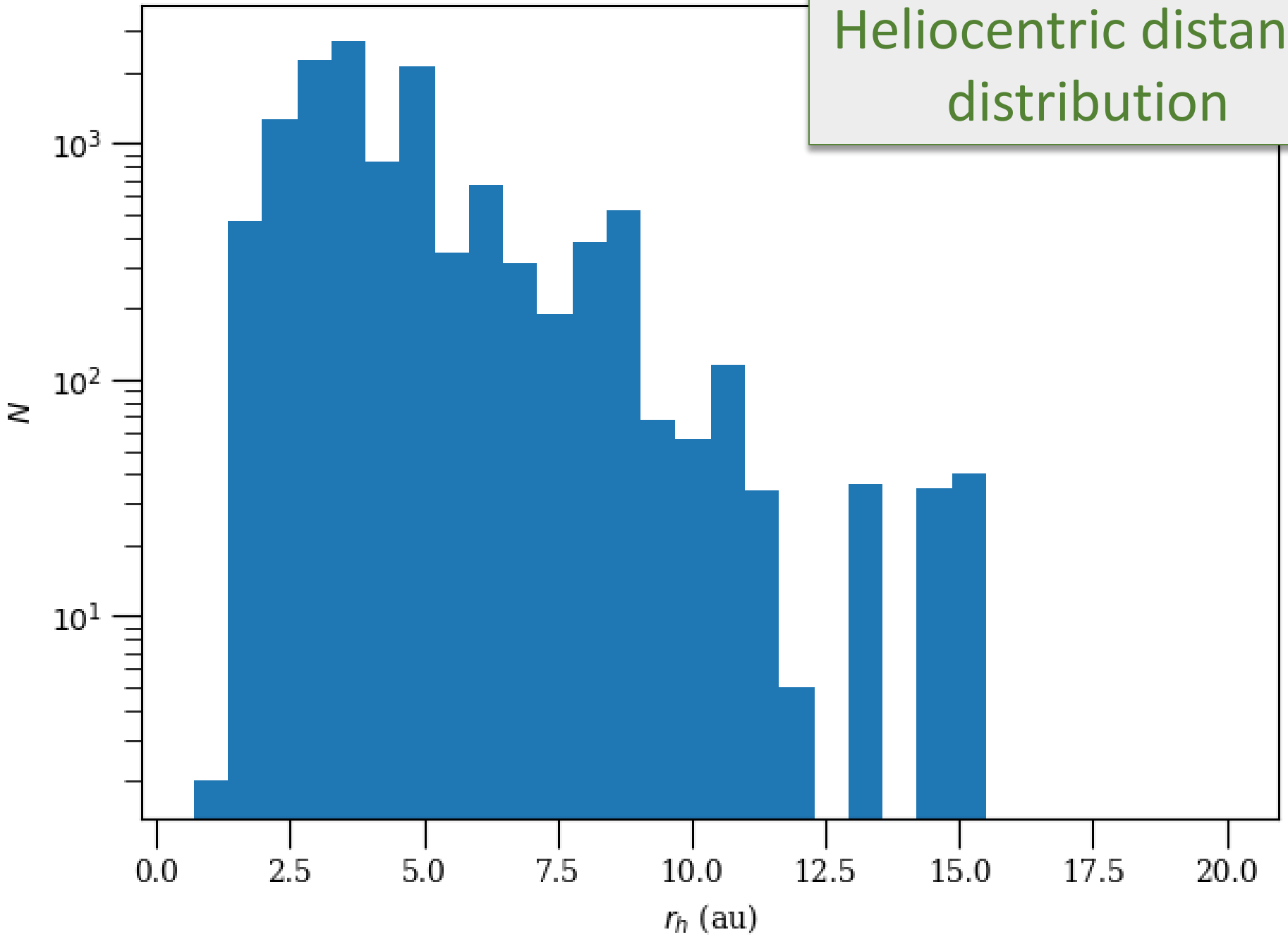


Most observed within 60 deg of opposition.

Note: comets and asteroids are brighter when physically closer to the Sun.

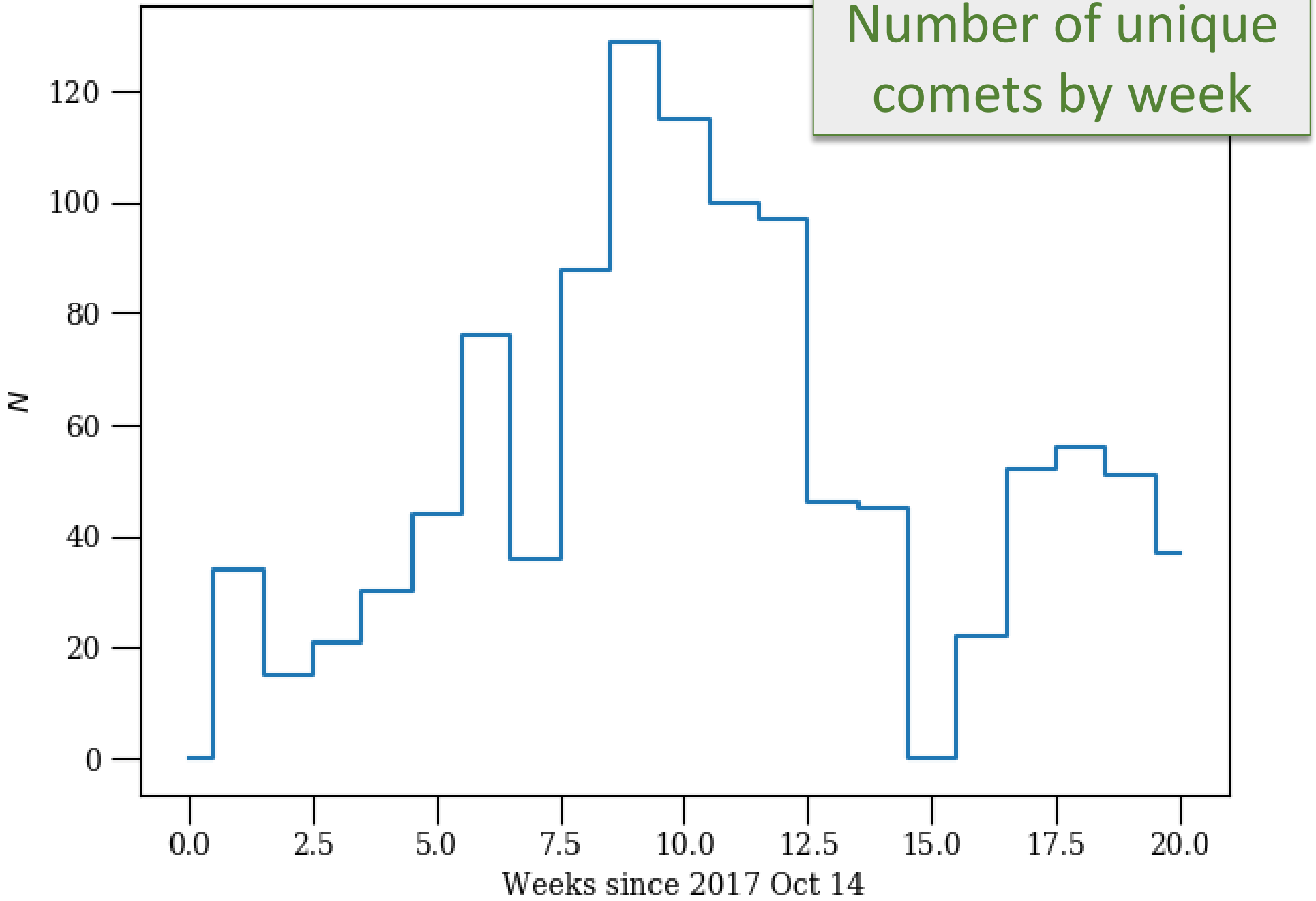

10^4
10^3
10^2
10^1
10^0
$N(<m_V)$
10
12
14
16
18
20
22
m_V (mag, HORIZONS)
Apparent magnitude
cumulative distribution

Heliocentric distance distribution



ZTF

Number of unique comets by week



Identifying outbursts

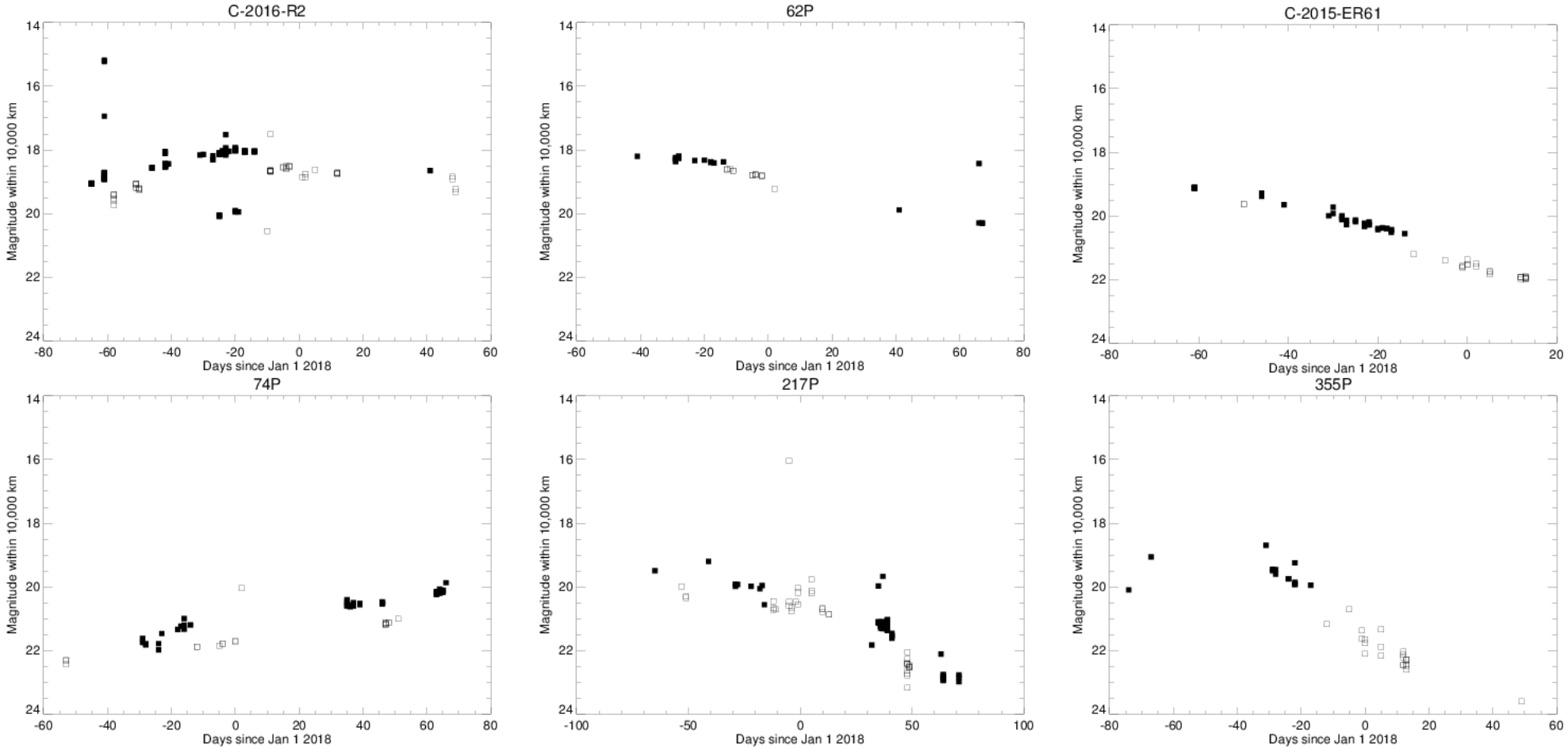
Photometry – Identify abrupt changes in absolute magnitude.

Morphology – Identify abrupt changes in surface brightness distribution.

Independent tests lead to fewer false positives.

Morphological analysis can identify other interesting changes.

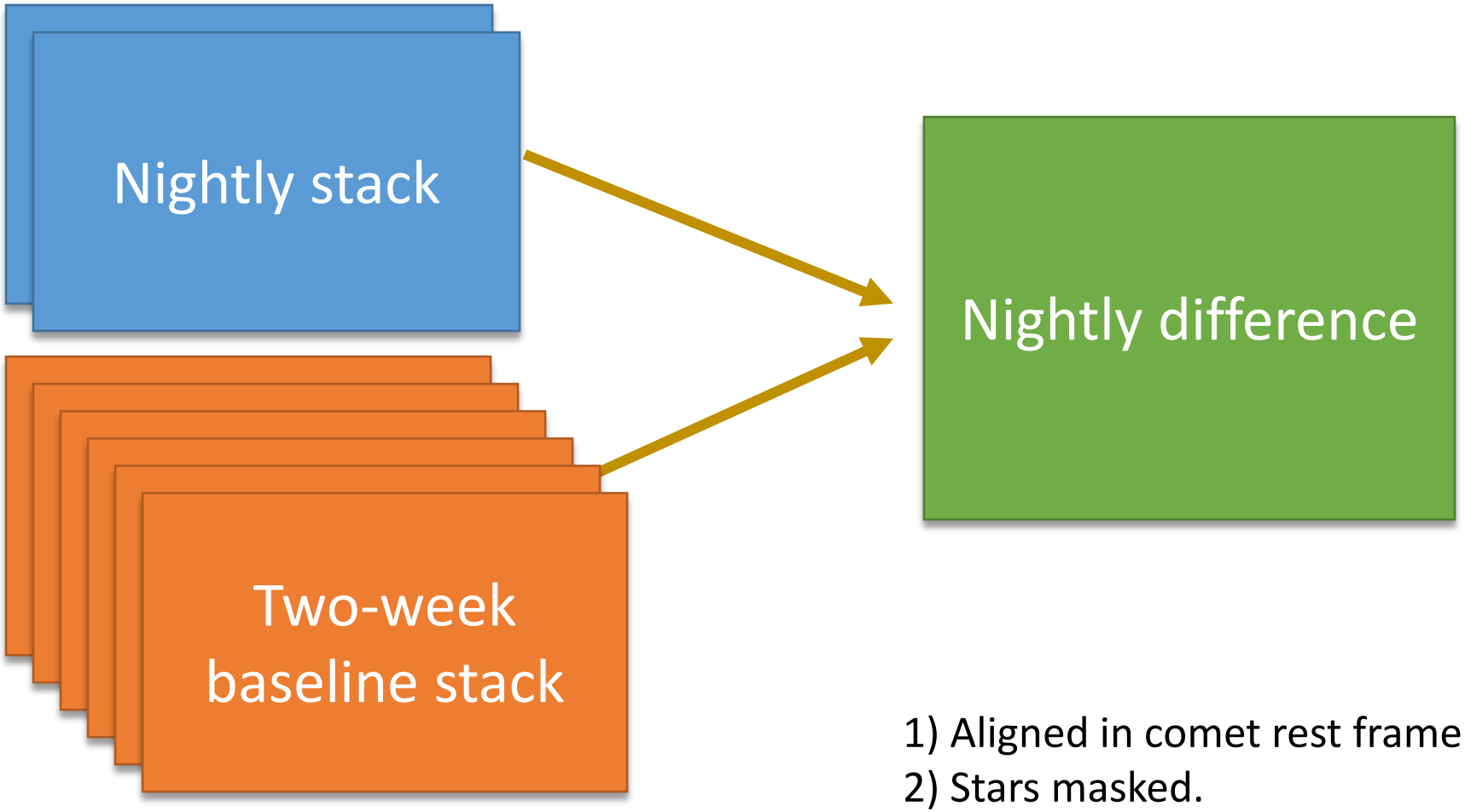
Comet light curves



Goal is <=0.1 mag accuracy, reference subtracted images will help.

Work in progress…

Rest-frame difference images



1) Aligned in comet rest frame with Montage.
2) Stars masked.
3) Mean/median combined

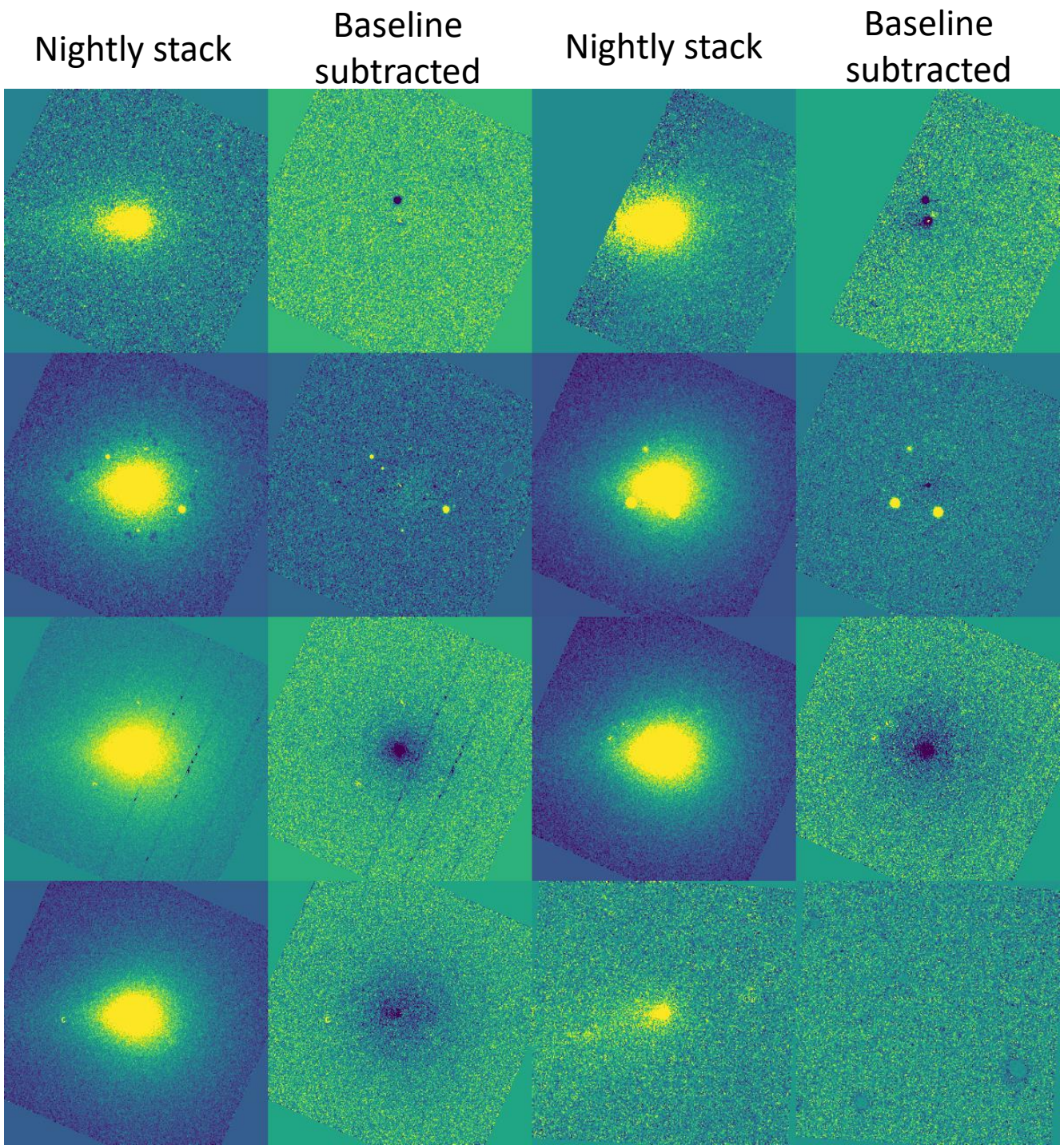
Warning!

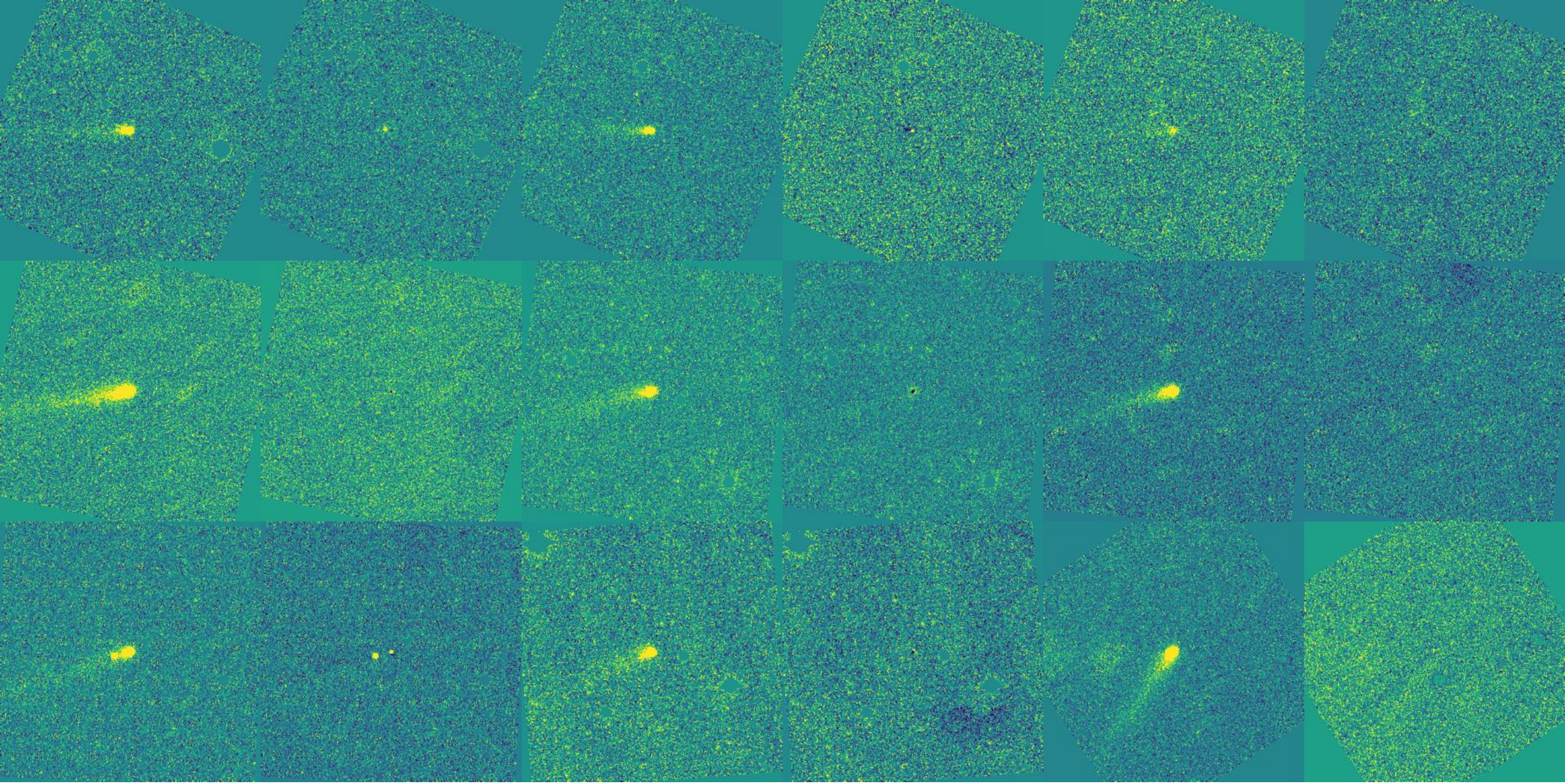
The following are prototype plots intended for technique assessment.

62P/Tsuchinshan 1

Mix of zr and zg

Good subtractions at first, then large negatives suggesting rapid decline of activity.





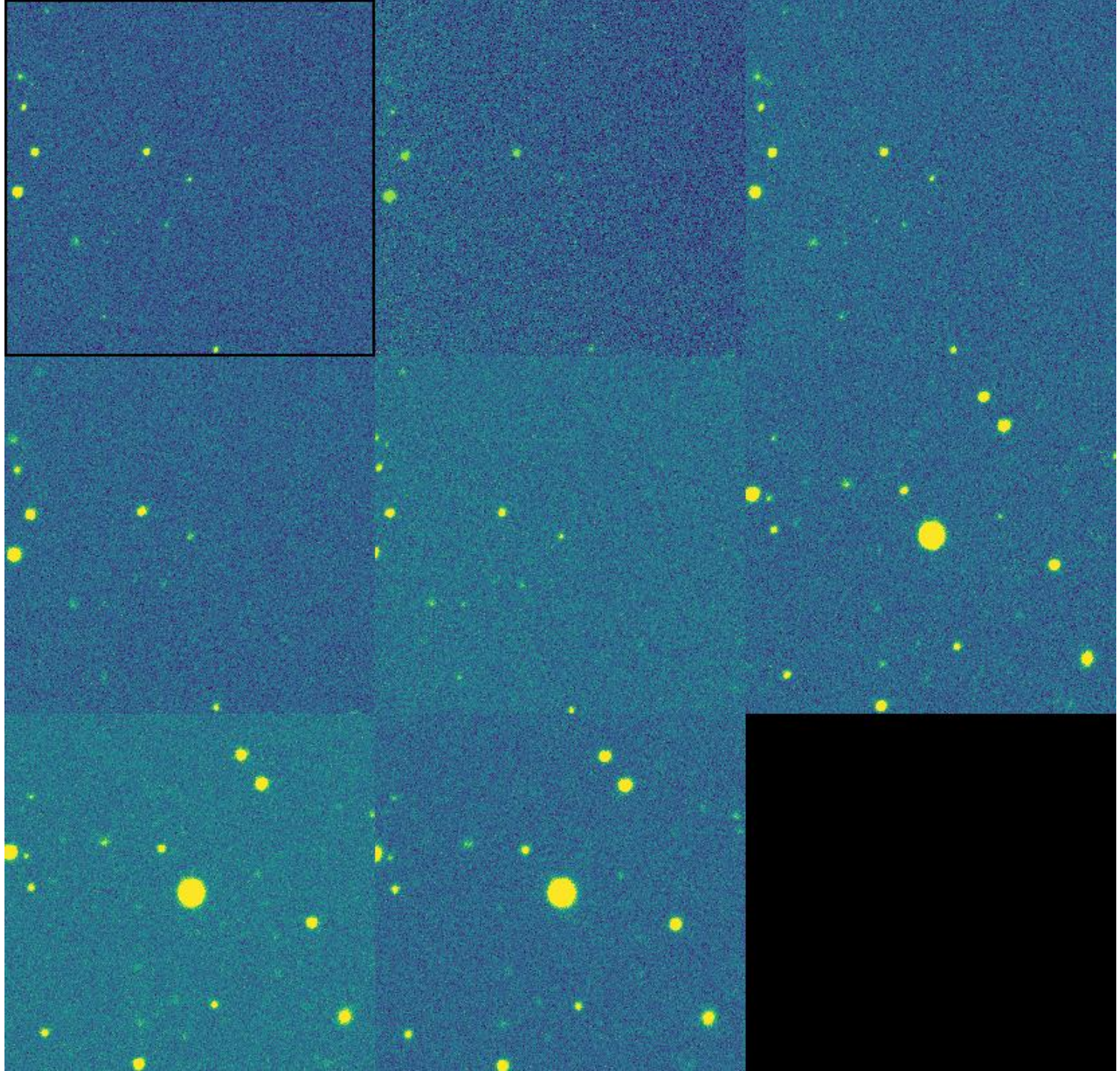
74P/Smirnova-Chernykh – Great subtractions

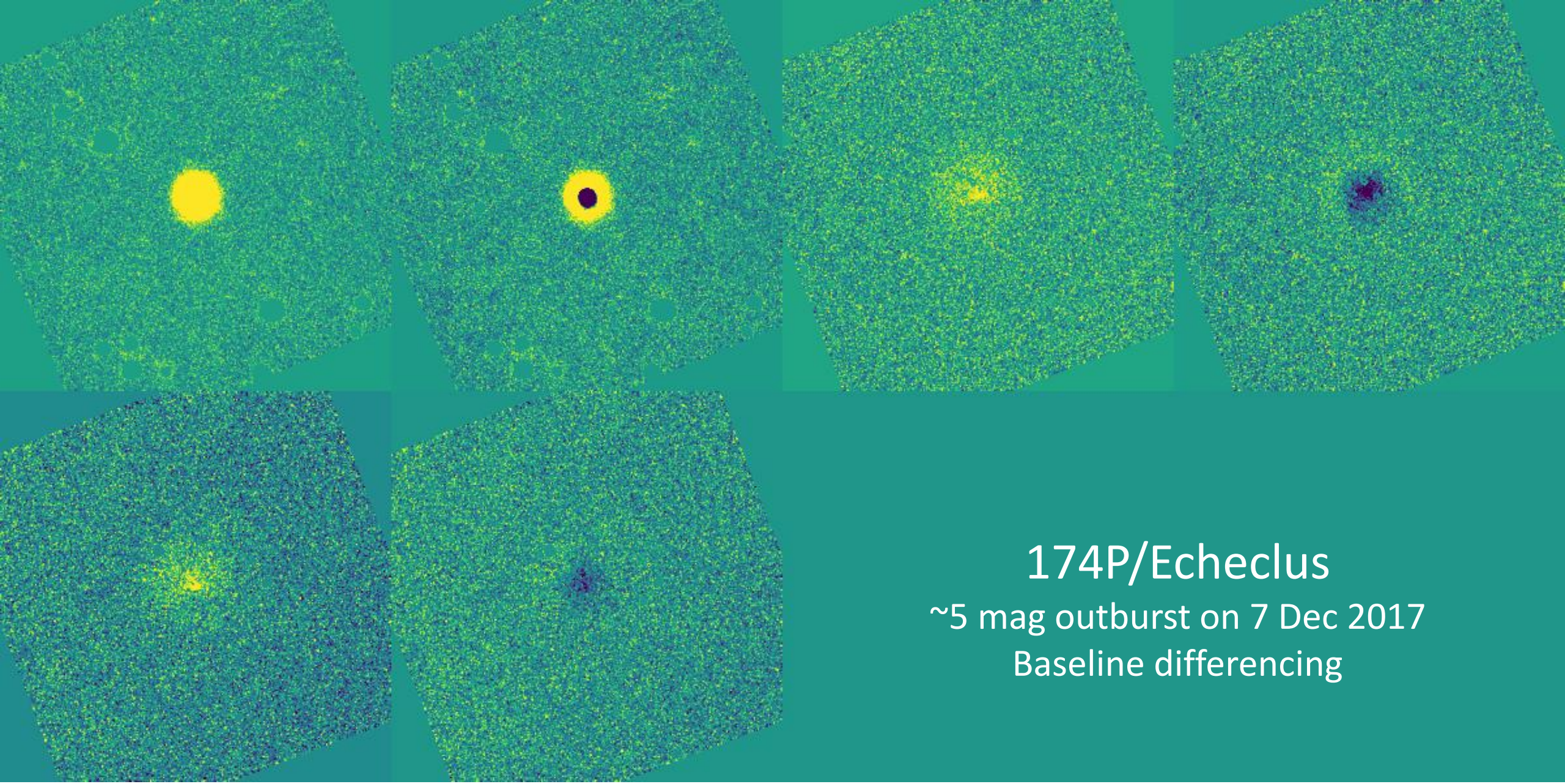
ZTF

174P/Echeclus

~5 mag outburst on
7 Dec 2017

Cutouts; no stacking,
no subtraction.

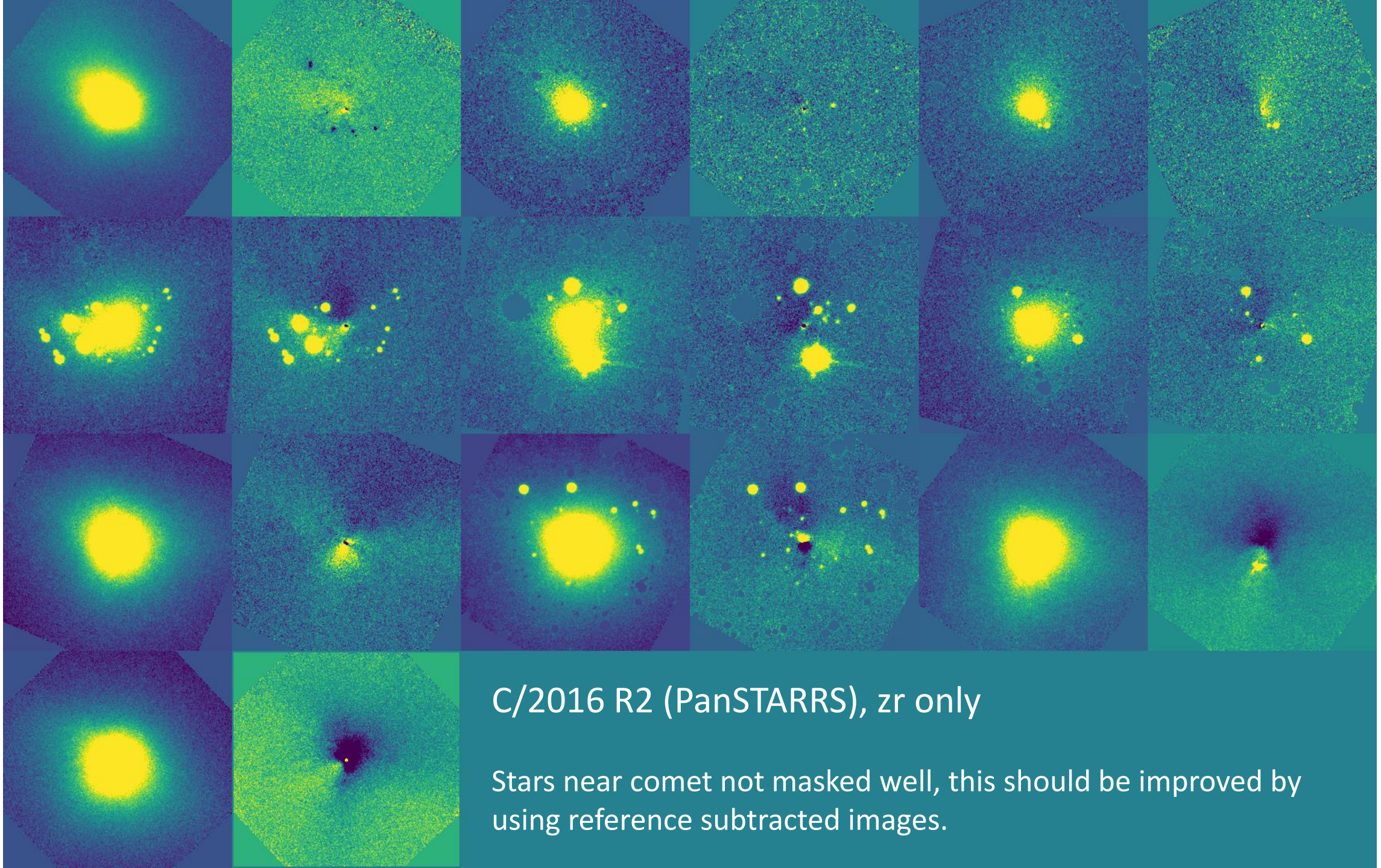




174P/Echeclus

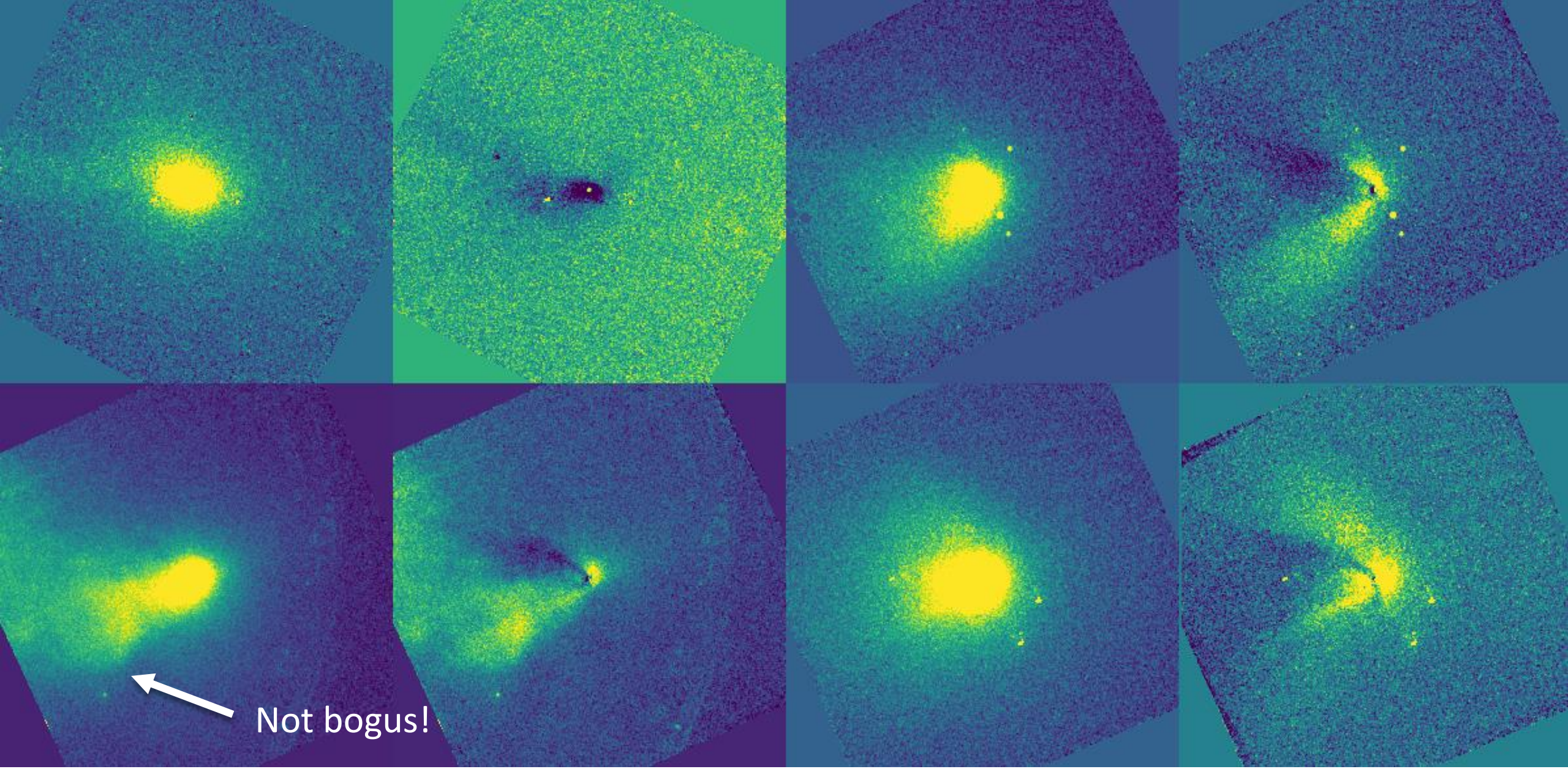
~5 mag outburst on 7 Dec 2017

Baseline differencing



C/2016 R2 (PanSTARRS), zr only

Stars near comet not masked well, this should be improved by using reference subtracted images.



C/2016 R2 (PanSTARRS), zg only – Plasma tail!

What's left

- Make baseline image generation robust against filter change.
- Incorporate poorer-quality data (SNR weighting).
- Use difference images for better background object removal.
- Improve performance → on-demand processing?
- Deploy or re-develop for Solar System Marshal.

Expecting lessons learned will be transferred to LSST
via Solar System Science Collaboration
Software/Infrastructure Working Group

Additional slides

Methods

Inspect all ZTF exposures for coverage of known objects.

- Cutouts around each ephemeris position
- Photometry
- Morphological analysis

ZMODE is not efficiently detecting comets

- Maybe it will in the future
- Biased toward point sources, so comets can be filtered out
- For now, using an independent approach

ZChecker – A moving object image finder for ZTF

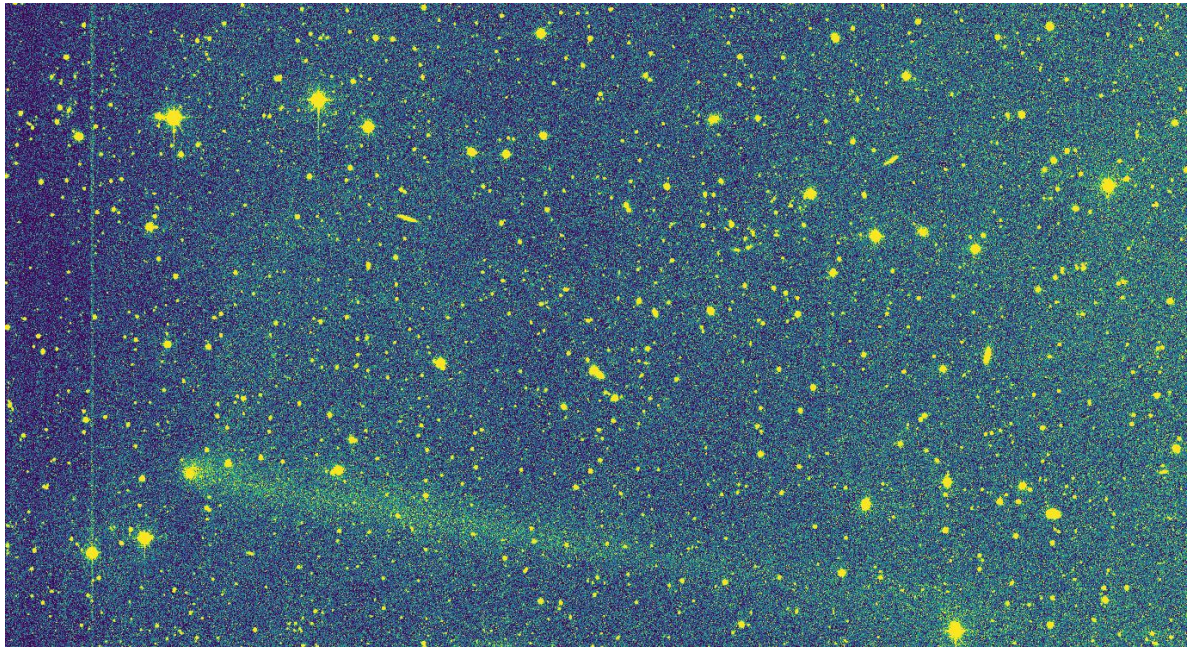
1. JPL/HORIZONS coarse ephemeris (once per month)
2. ZTF exposure history from IRSA
3. Finds targets near exposures using coarse ephemeris and interpolation
    1. Get precise ephemeris from HORIZONS
    2. Check if photons landed on silicon using WCS keywords in archive
4. Download 5’ cutouts around ephemeris position
    1. Science data
    2. Mask
    3. PSF
    4. Difference image is TBD

Discovery and follow-up

- What is the magnitude-frequency distribution of outbursts in the comet population?
- How often are fragments produced?
- What are the gas-to-dust ratios? ESA's *Rosetta* mission saw everything from gas-rich to dust-rich.
- How does the material released in an outburst compare to the ambient coma?
  - Dust properties
  - Ice properties
  - Gas composition

Plots and image stacks

- The following data are limited to “good” data:
  - Predicted V<22 mag
    - Comet brightness models can easily be off by a few magnitudes
    - Comet not necessarily detected
  - Infobits == 0
- Image stacks additionally require
  - maglimit > 19.5 mag



C/2015 ER61 (PanSTARRS) - 0.5 deg long debris tail

Rest-frame difference images

- Find images taken in the last night
  - MSIP: 2 images/target
  - Mask sources, combine images
- Find images taken in the last two weeks
  - MSIP: ~2 to 4 nights
  - Mask sources, combine images
- Scale all images, accounting for maglimit, heliocentric distance, comet-observer distance.
- Rest-frame alignment via Montage