ZTF Solar System Working Group

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NEO Discovery (Bolin, Helou, Kramer, Masci, Prince)

156 NEOs discovered to date

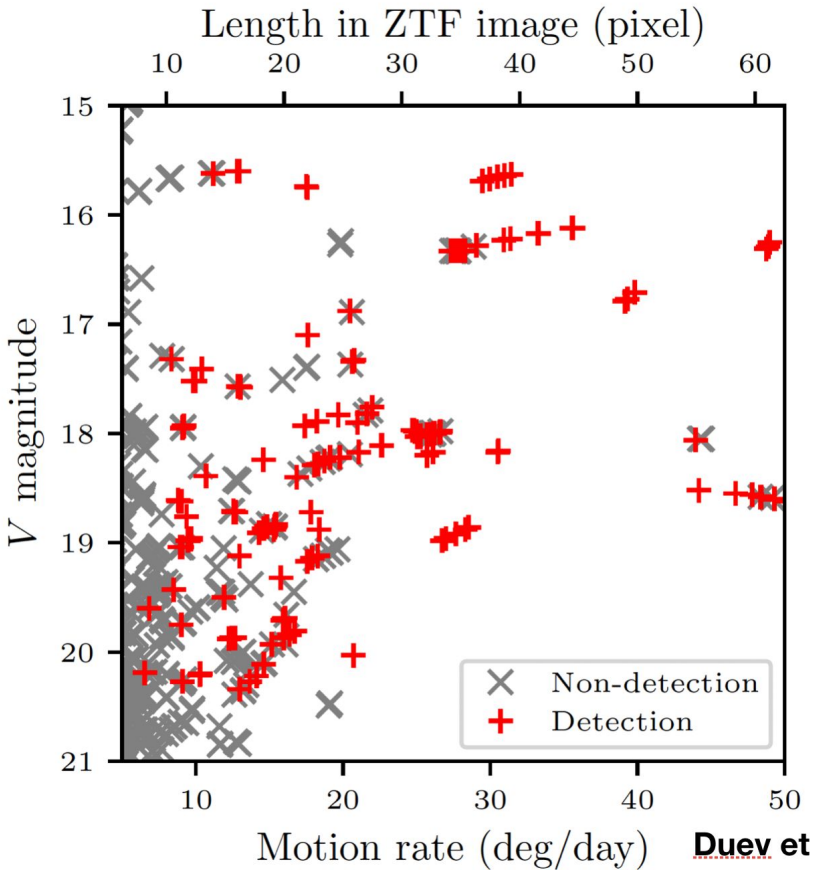
- ZMODE: detection of point-like moving object
  - Main-belt asteroids; distant NEAs; comets

  Masci et al. 2019

- ZSTREAK: detection of fast-moving objects (streaks)
  - Asteroids less than 0.01 au (~5 lunar distances) from the Earth
  - Also detect a lot of artificial satellites (a few dozens a night)
  - The new DeepStreaks algorithm reduced the false positive rate by 100x (thank you **Dima Duev** and **Ashish Mahabal**!)

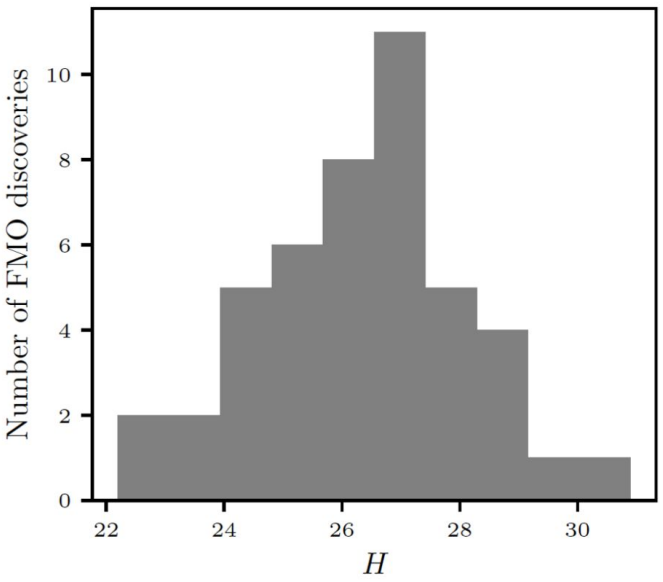
  Ye et al. 2019, Duev et al. 2019

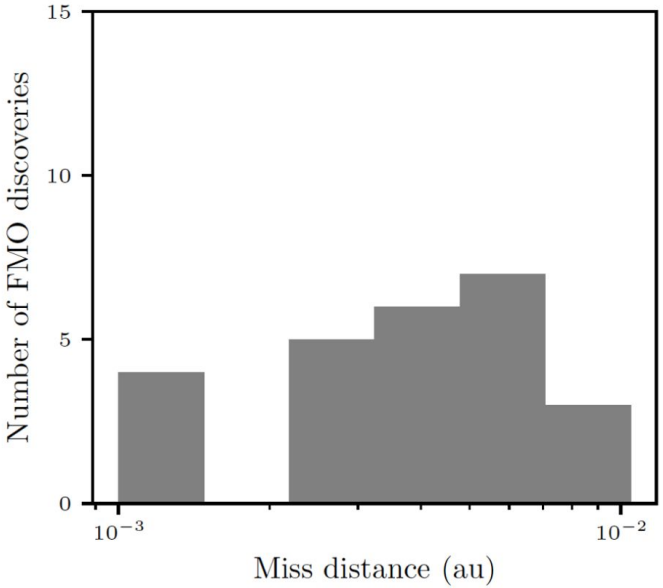
ZSTREAK Objects



Duev et al. 2019, Ye et al. 2019

ZTF in Numbers

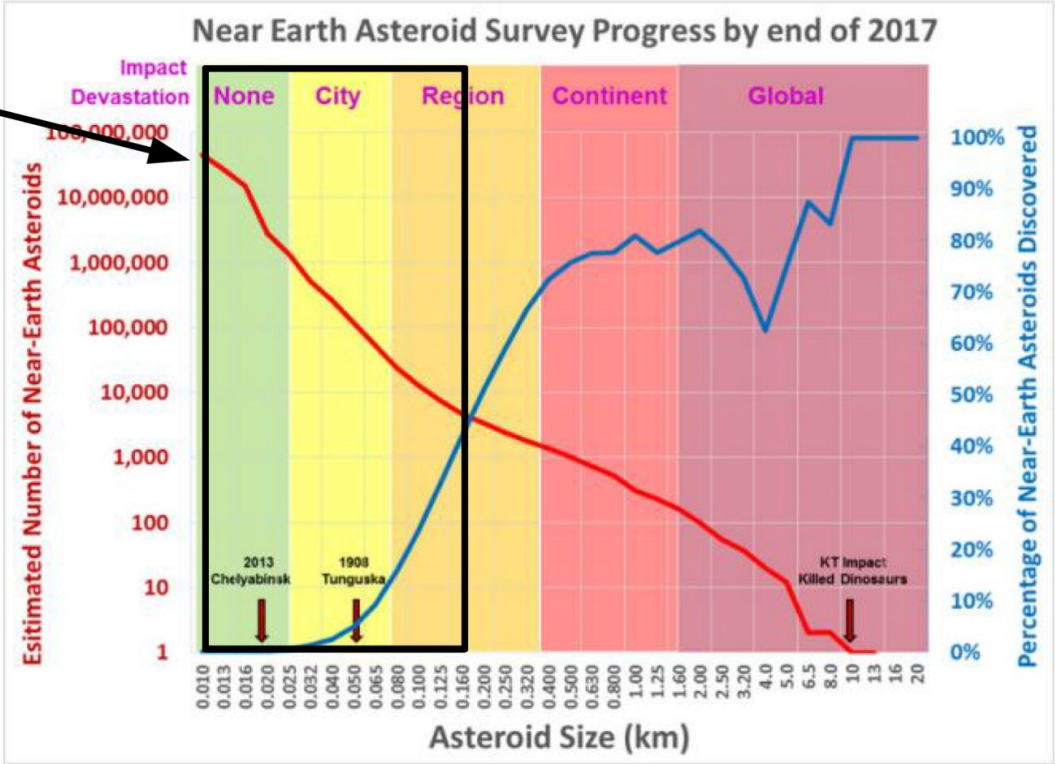




- **Discoverer of Small NEOs/ small miss distances**
  A. **Mean H 24.5 - 28.0**
  B. **Miss distance 0.001 - 0.01 au**

Ye et al. 2019

Niche for ZSTREAK!



NEO follow-up with GROWTH-India Telescope (Kunal)

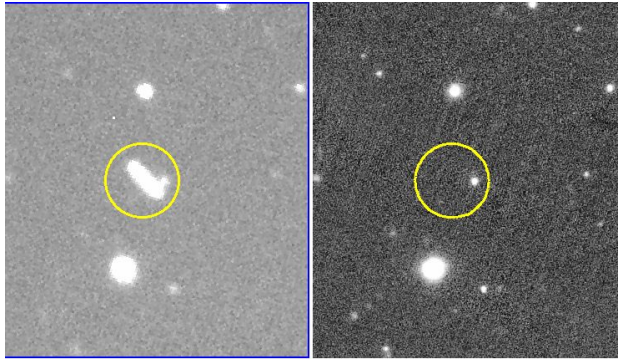
Operated by IIT Bombay and IIA

0.7m fully robotic telescope with 0.5 deg^2 field of view

Reaches magnitude 20 in 500 seconds

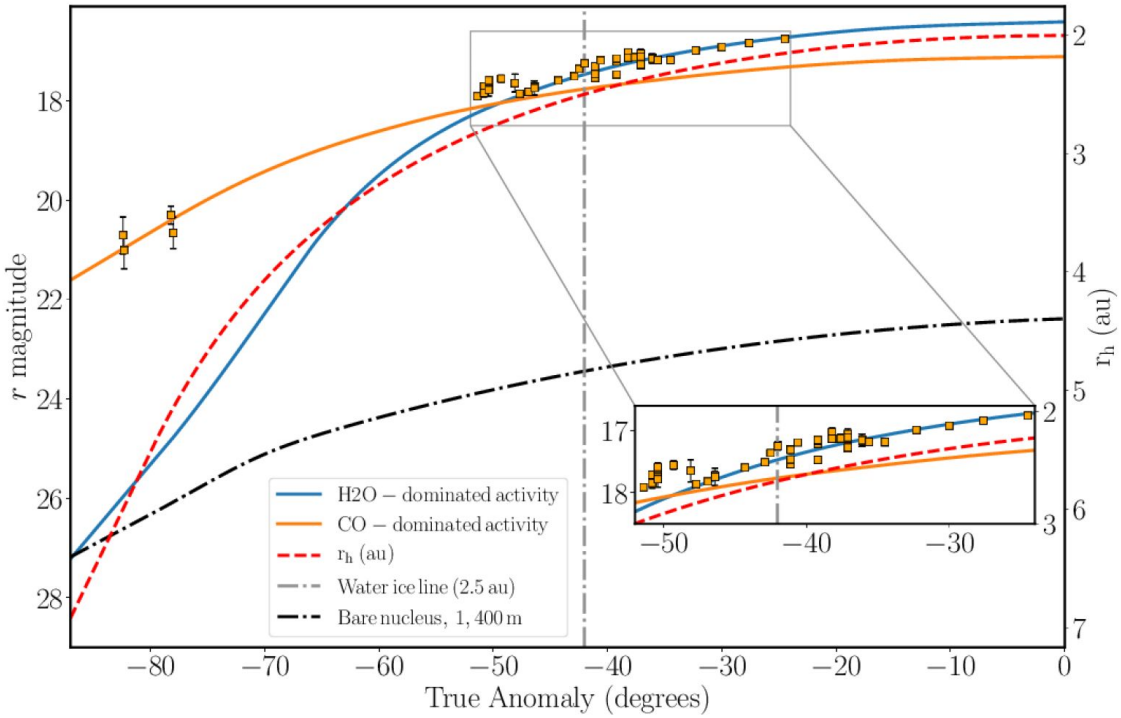
Capable of detecting main-belt asteroids as well as NEOs

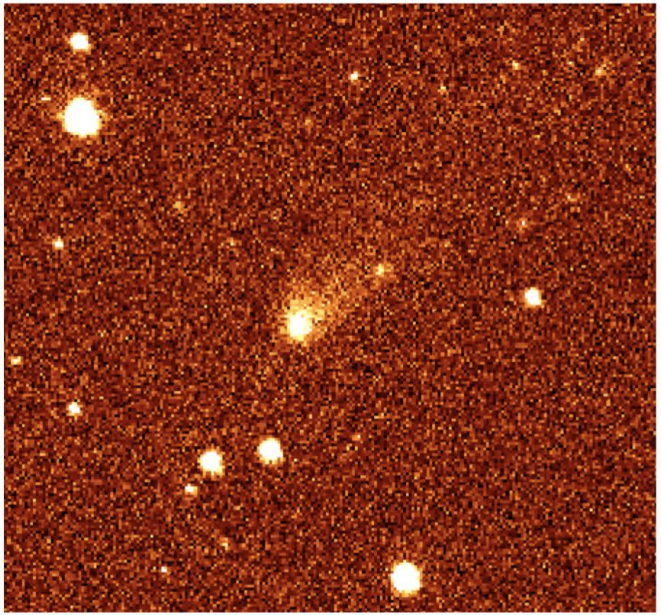
Non-sidereal tracking tested successfully and in place to assist in NEO discovery



Detection of main-belt asteroid 354030 in a 500 sec exposure

ZTF Observations of interstellar Comet 2I/Borisov

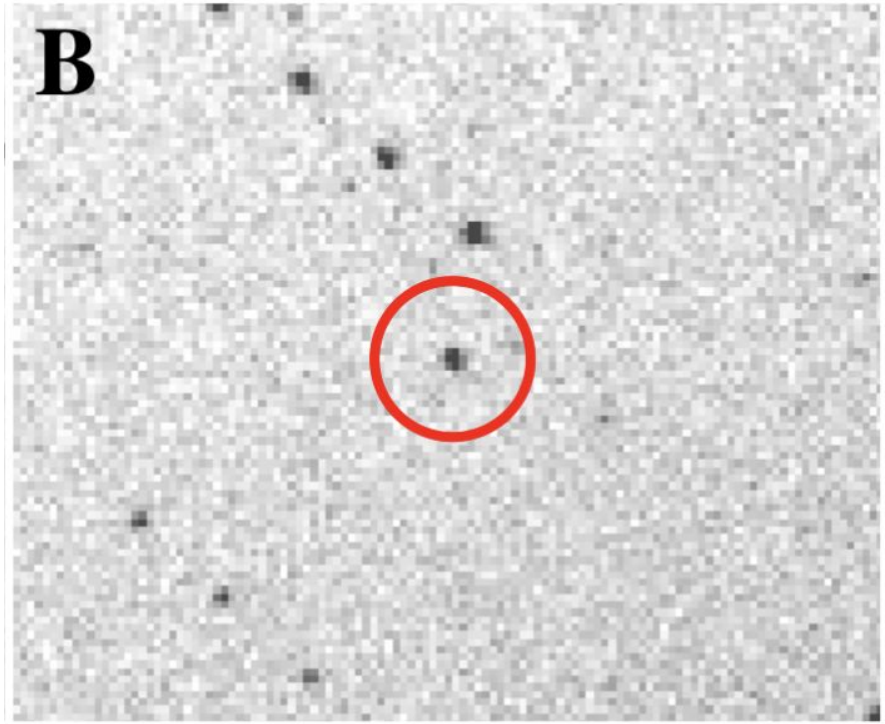


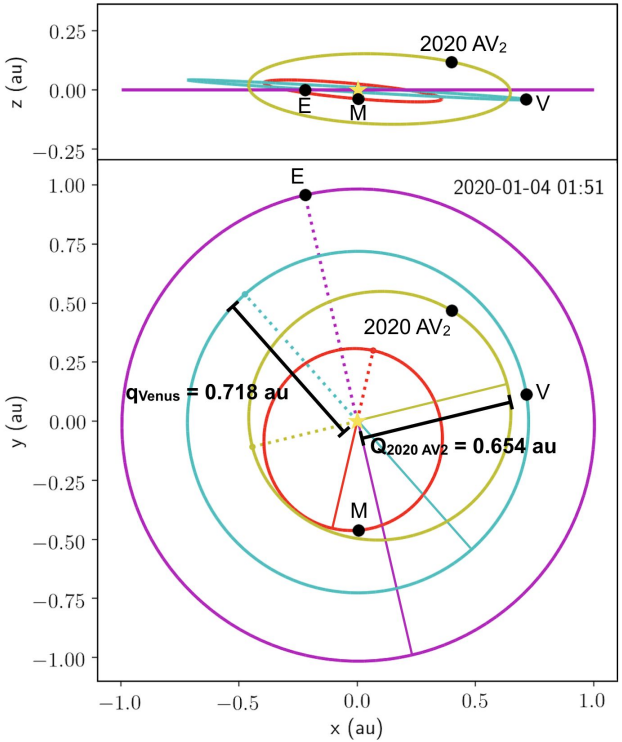


ZTF 2019-11-02 30 s r band image

pre-discovery/post-discovery observations indicate activity driven by H_2O and CO (Bolin et al. 2020, Ye et a. 2020)

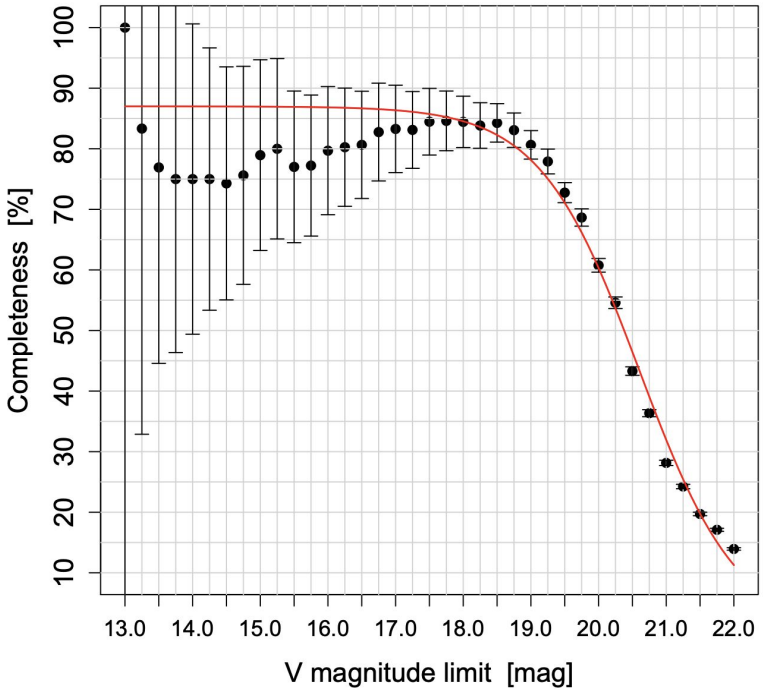
Discovery of the first Interior to Venus Object (IVO)





First known IVO discovered by ZTF on January 4, 2020.
Entirely located within the orbit of Venus with aphelion = 0.65 au
Found in evening twilight during the Twilight survey

ZMODE completeness



Peak completeness is ~87%, comparable to the fill factor of the ZTF camera.

Lightcurve analysis of comet 240P/NEAT

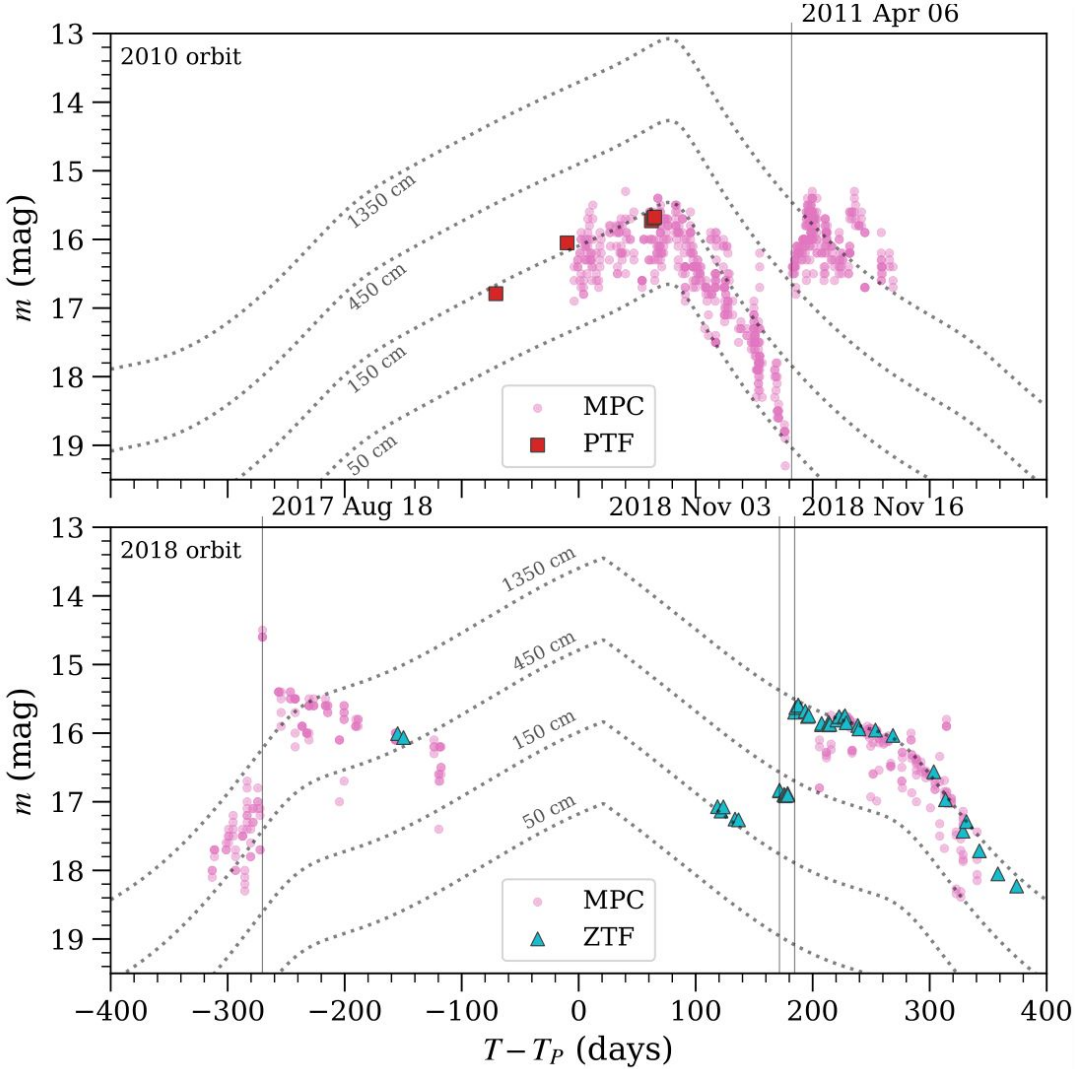
Published: [Kelley et al. 2019, ApJL](#).

The comet has had a repeated brightening event after it's perihelion distance decreased in 2007 from 2.5 to 2.1 au.

The comet brightens by a factor of ~6 about 180 days after perihelion.

An independent event ~270 days before perihelion in 2018 may be related.

Rubin Observatory/LSST should observe the pre-perihelion event in the next orbit, if it repeats.



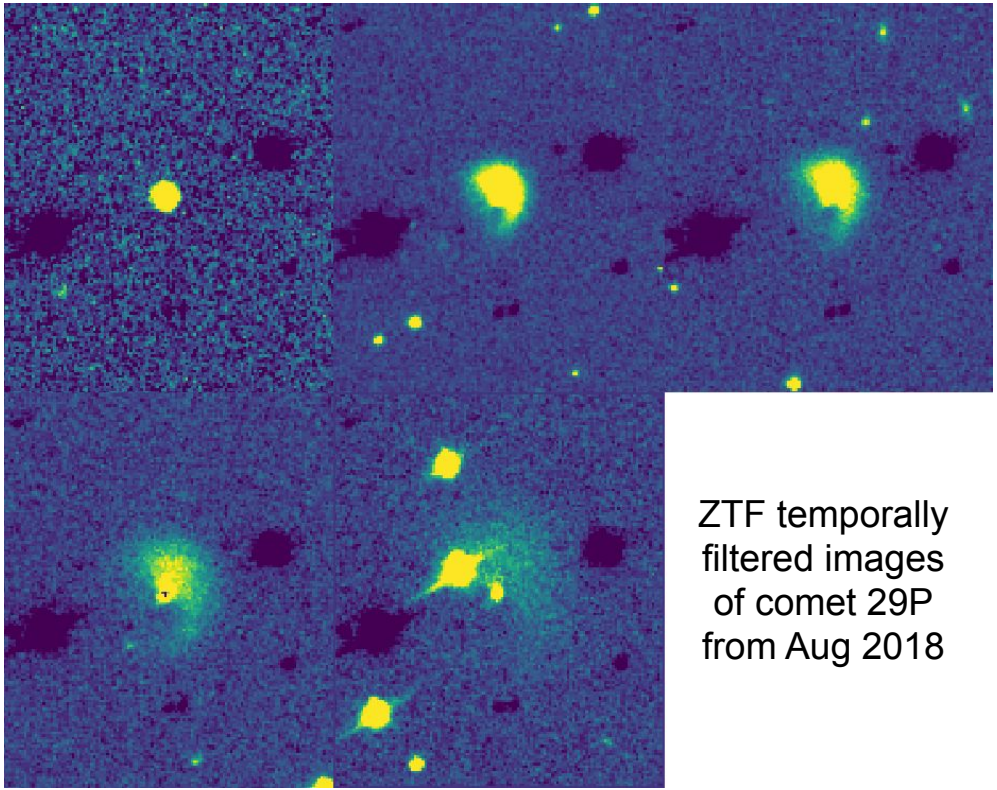
Possible fragment swarm at comet 29P?

Announced: Kelley et al. 2019, ATel #13164.

Most outbursts of this comet show a propagating arc (right).

In Sep. 2019, temporal differencing of ZTF images showed a small condensation moving ≤1"/day, suggesting a fragment cloud such as seen at comet 73P.

An initial examination of follow-up imaging with *Hubble* did not reveal any fragments. A final analysis is pending.



ZTF temporally filtered images of comet 29P from Aug 2018

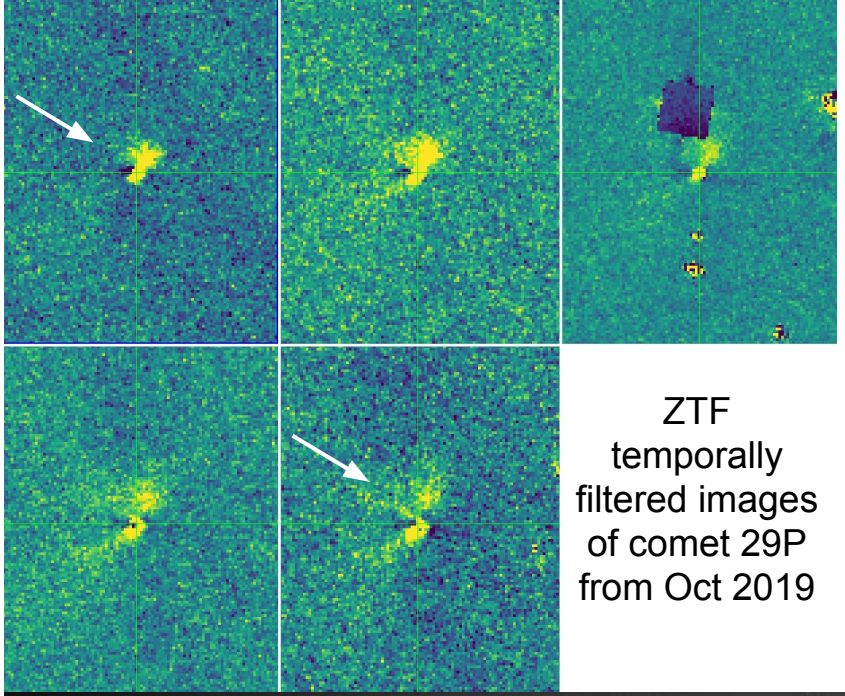
Possible fragment swarm at comet 29P?

Announced: Kelley et al. 2019, ATel #13164.

Most outbursts of this comet show a propagating arc.

In Sep. 2019, temporal differencing of ZTF images showed a small condensation moving ≤1"/day (upper right), suggesting a fragment swarm such as seen at comet 73P (lower right).

An initial examination of follow-up imaging with *Hubble* did not reveal any fragments. A final analysis is pending.



ZTF temporally filtered images of comet 29P from Oct 2019

Fragment swarm at comet 73P as seen by *Hubble*

Credit: NASA, ESA, Weaver, Mutchler and Levay