ZTF-II Solar System Science

Michael S. P. Kelley
University of Maryland

Summary of ZTF solar system studies

- Small NEO discovery engine.
- Unveiling of asteroid populations interior to the Earth's orbit.
- Unique observations of the first interstellar comet.
- Testbed for new techniques.
- Revealing an evolutionary sequence in cometary activity.

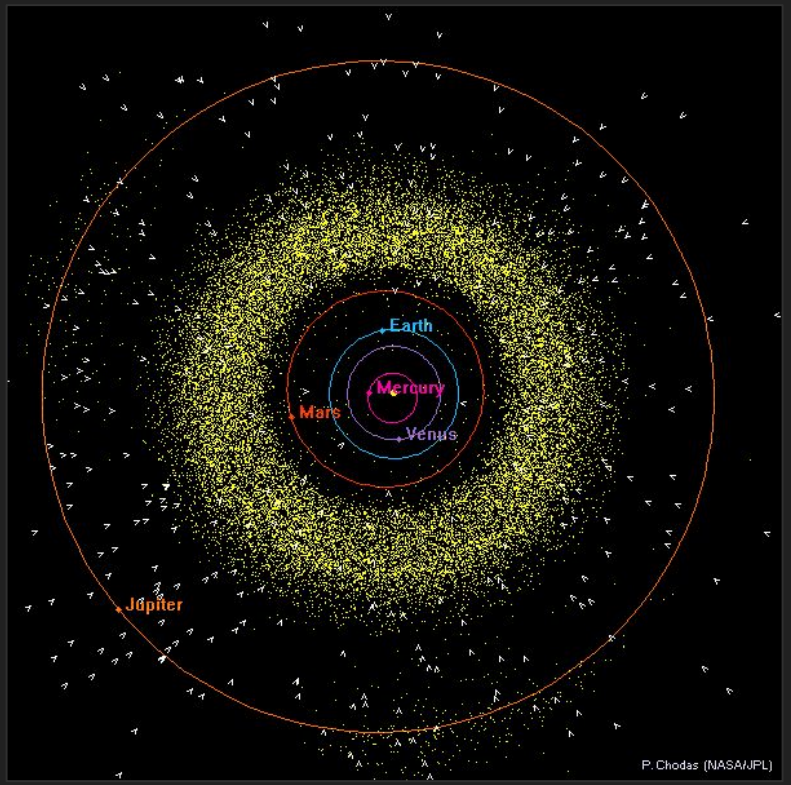
Planetary defense

ZTF discovered its first Near-Earth Object (2018 CL) in February 2018 (Ye et al. 2018), and 174 discovered to date.

ZTF specializes in discovery of small NEOs down to Chelyabinsk impactor size (~20 m) and smaller.

→ These are the most immediate Earth impactors.

→ 143 NEAs with diameters smaller than ~140 m.



ZTF's Twilight Survey

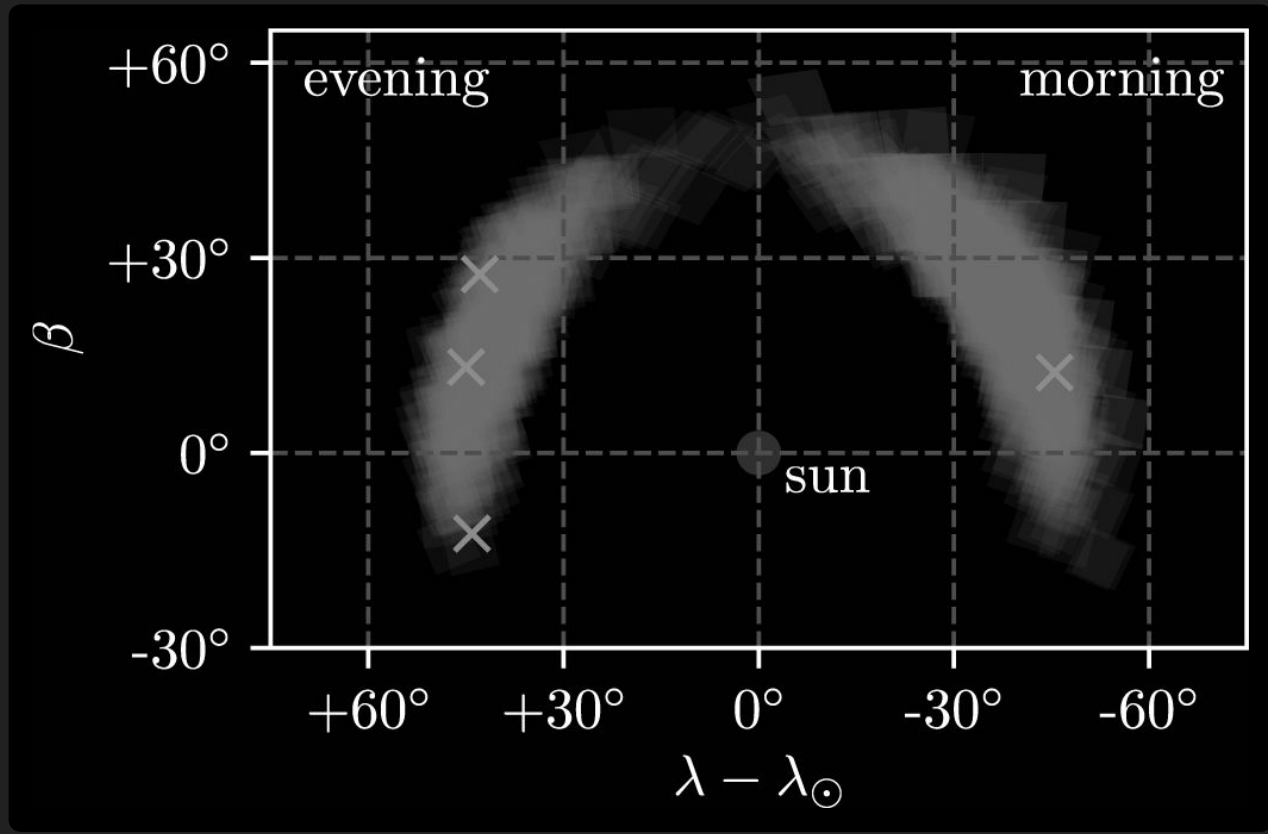
Search for Atiras, "Vatiras", and Earth co-orbital asteroids (Ye et al. 2020).

17 Atiras, asteroids interior to Earth's orbit, were known at the start of 2018.

→ 6 more discoveries, 4 are from ZTF.

→ Includes 2020 AV2, with an orbit wholly interior to Venus (Ip et al., submitted).

All are large, >0.5 km, indicating many more to be found.

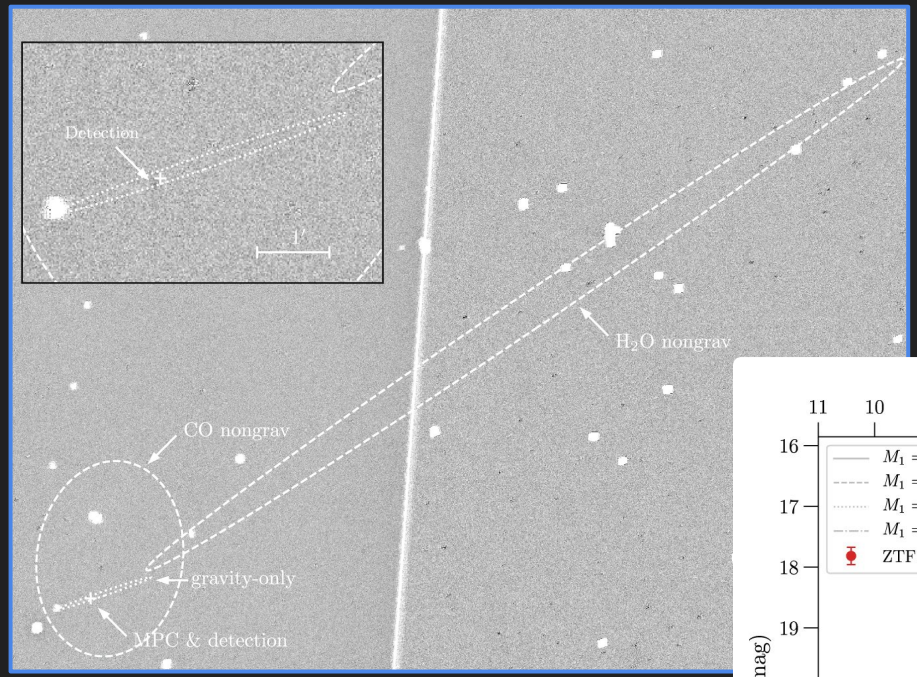


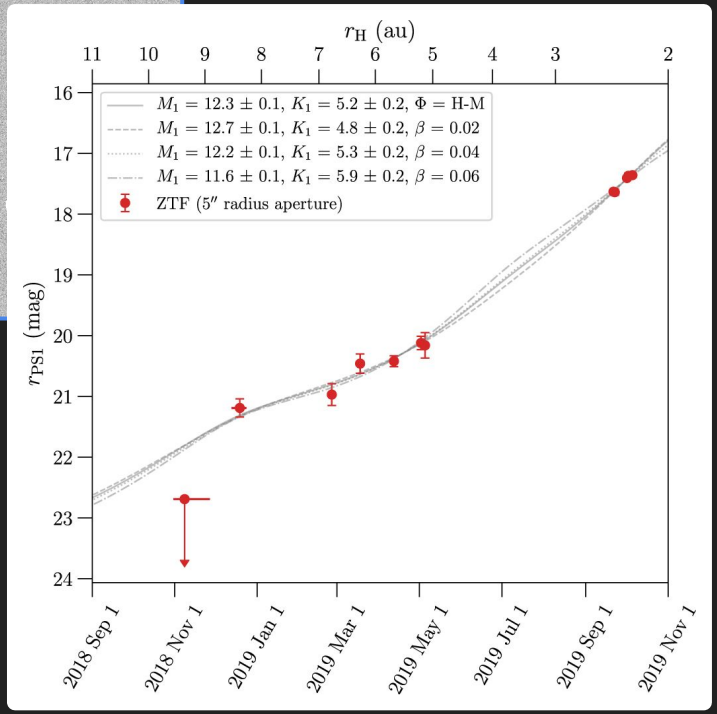
Ye et al. 2020

2I/Borisov

Discovered 2019 August 30 and quickly recognized to have an interstellar origin (e~3).

ZTF Twilight Survey observed 2I in May 2019. Our "precovery" allowed us to measure photometry out to 5 au (Ye et al. 2020; Bolin et al. 2020).



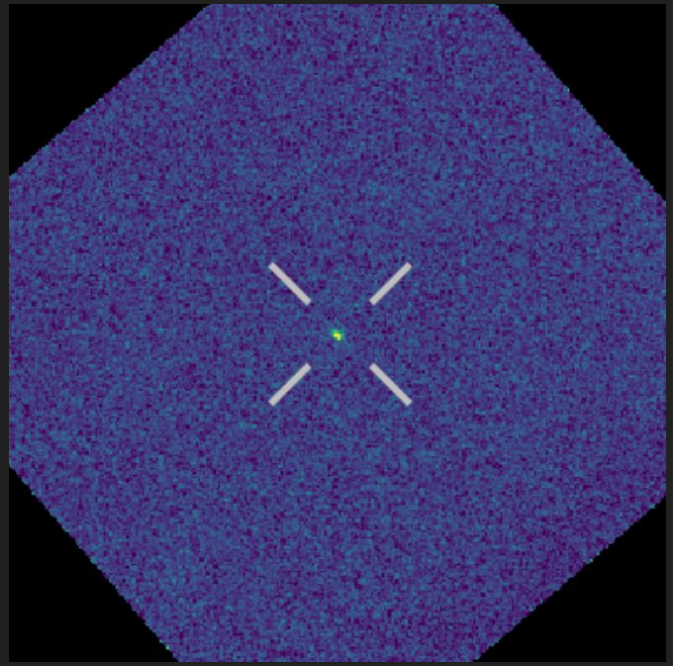


The distant activity indicated CO or CO_2 sublimation. This was later confirmed by ALMA and HST spectroscopy (Cordiner et al. 2020, Bodewits et al. 2020).

ZTF as a testbed

Several projects are using ZTF data as a source to develop new technologies for Solar System science:

- Deep Learning techniques to discover NEOs and comets (Duev et al. 2019, and in prep.).
- Synthetic tracking to discover solar system objects in "deep drilling" data sets (Zhai et al. 2020).
- LSST solar system alert stream broker prototyping, e.g., SNAPS (PI: D. Trilling, NAU).

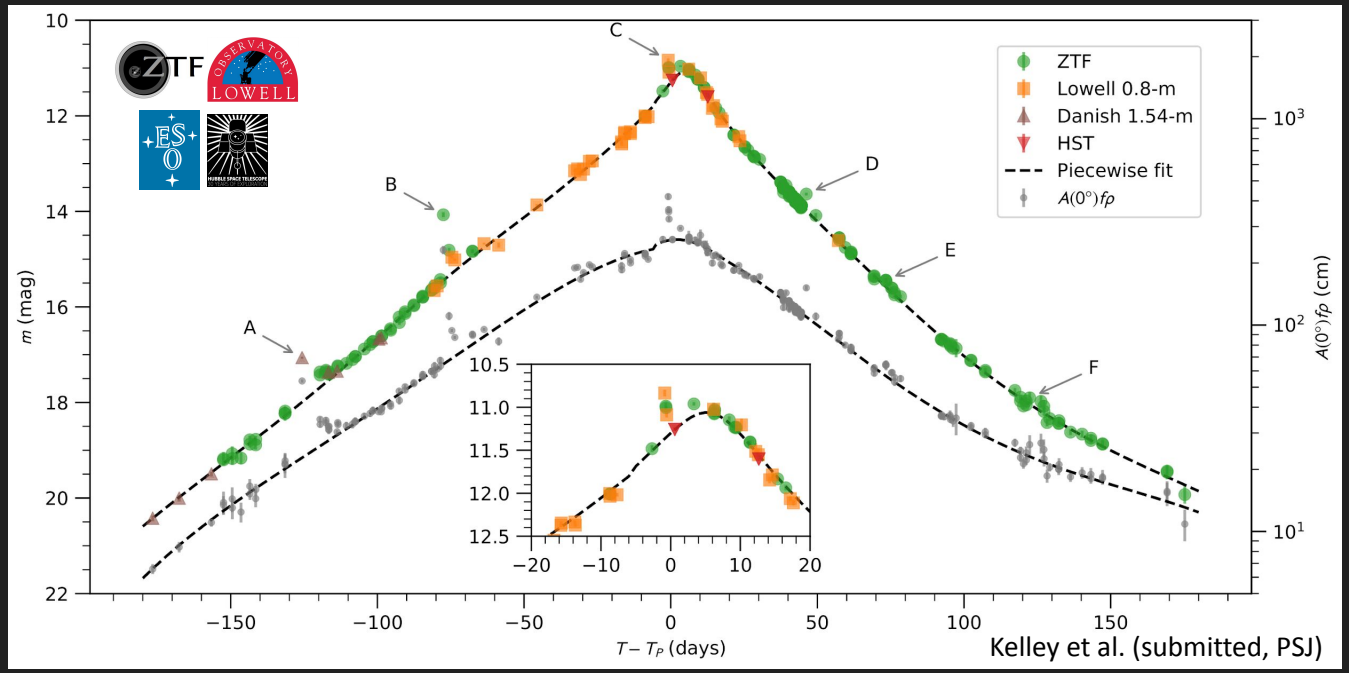


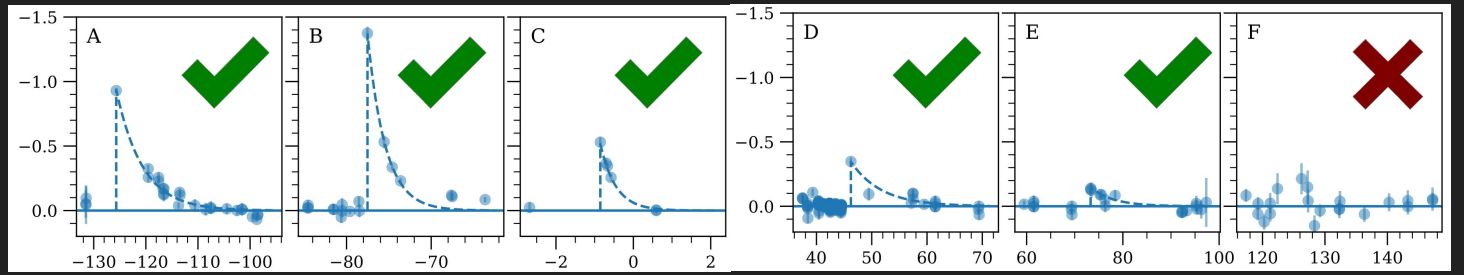
C/2020 T2 (Palomar), first AI-assisted comet discovery

Cometary mini-outbursts

Kelley et al. studied a year-long lightcurve of comet 46P/Wirtanen, taken during its close approach to Earth (0.077 au).

5 outbursts with masses ~10^4 to 10^6 kg identified.



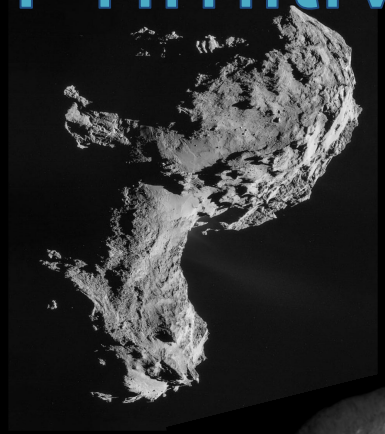


Mini-outburst rates

Comet	Rate (day^{-1} km^{-2})	Sources
67P/Churyumov-Gerasimenko	0.017	Vincent et al. 2016, MNRAS Jorda et al. 2016, Icarus
9P/Tempel 1	0.011	Belton et al. 2008, Icarus Thomas et al. 2013a, Icarus
46P/Wirtanen	0.0036	Kelley et al. submitted, PSJ Boehnhardt et al. 2002, A&A
103P/Hartley 2	<0.004	Kelley et al. submitted, PSJ Thomas et al. 2013b, Icarus

Primitive → Evolved

Vincent et al. (2017, MNRAS)



Based on the outburst rates and the evolutionary sequence of Vincent et al. (2017, MNRAS), 46P/Wirtanen appears to have an evolved (eroded, smooth) surface.

46P

Frequent mini-outbursts → Infrequent mini-outbursts

67P/Churyumov-Gerasimenko
ESA/Rosetta/NAVCAM

9P/Tempel 1
NASA/JPL-Caltech/Cornell

103P/Hartley 2
NASA/JPL-Caltech/UMD