Cometary Lightcurves Revealing Nuclear Surface Evolution

Michael S. P. Kelley

University of Maryland

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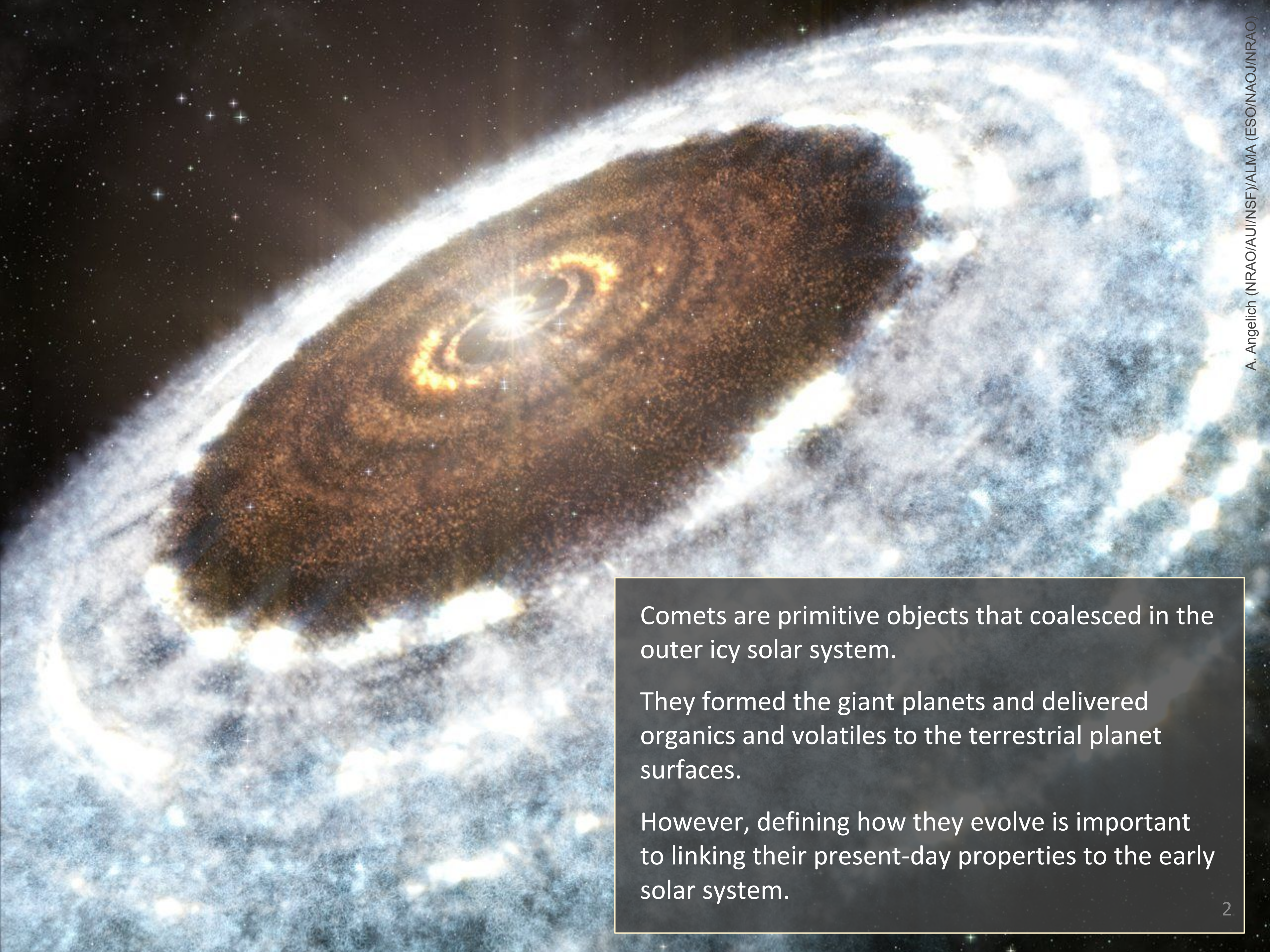


Comets are primitive objects that coalesced in the outer icy solar system.

They formed the giant planets and delivered organics and volatiles to the terrestrial planet surfaces.

However, defining how they evolve is important to linking their present-day properties to the early solar system.

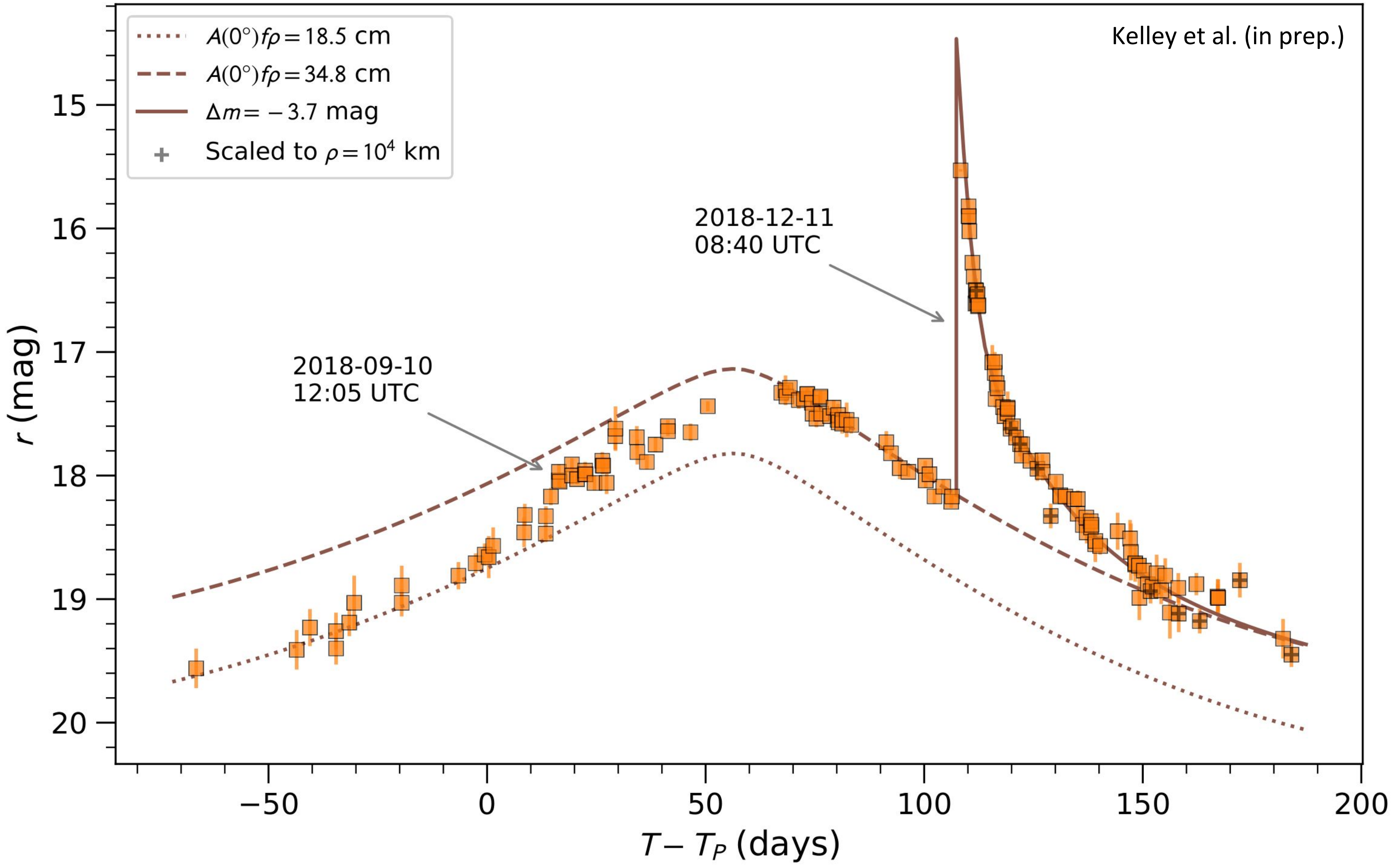
Cometary activity provides insights into the physical properties of cometary (sub)surfaces.

240P/NEAT

- Orbital perturbations may be used to determine subsurface volatile depths.

46P/Wirtanen

- Frequency of mini-outbursts reflects nuclear evolutionary state.



Cometary outbursts are impulsive events, characterized by a quasi-exponential lightcurve.

Comet 240P/NEAT

Discovered as P/2002 X2 (NEAT) by the NEAT survey at the P48 telescope (Lawrence et al. 2002, IAUC 8029).

A Jupiter-family comet with

- ➔ 8.1-year period
- ➔ Perihelion near 2.5 au
- ➔ Aphelion near 5.5 au
- ➔ 25° orbital inclination

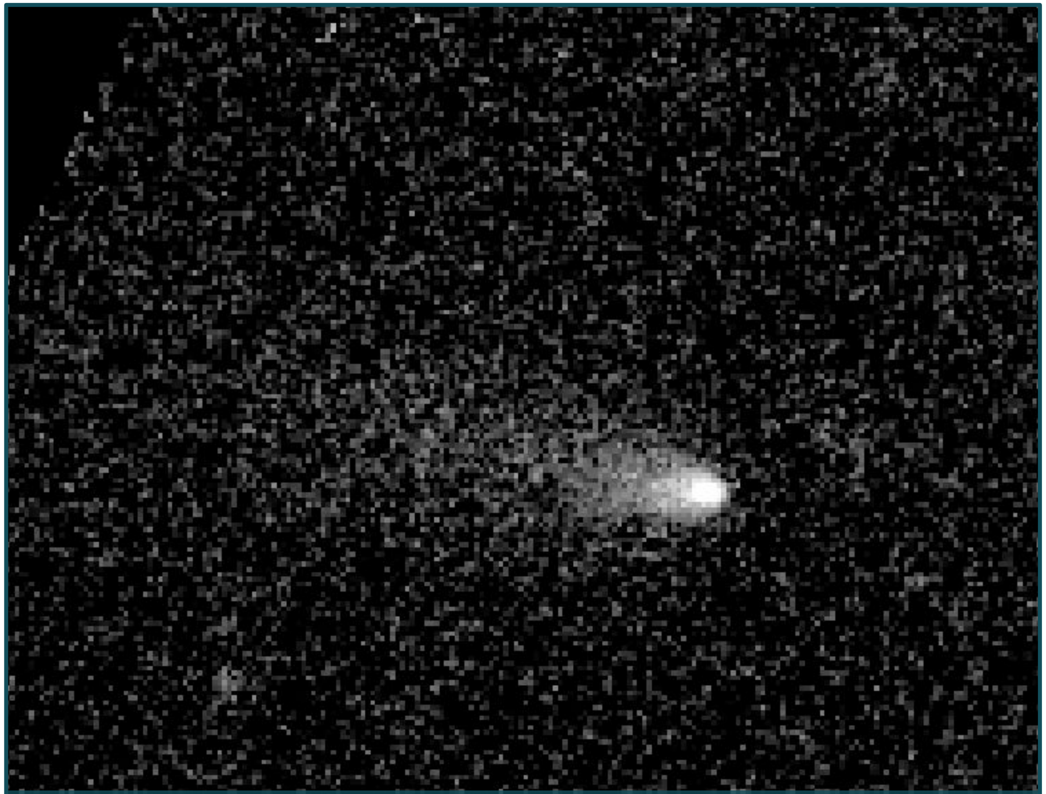
Perturbed by Jupiter in 2007

- ➔ Perihelion now near 2.1 au

Otherwise a stable orbit for at least 100 years.

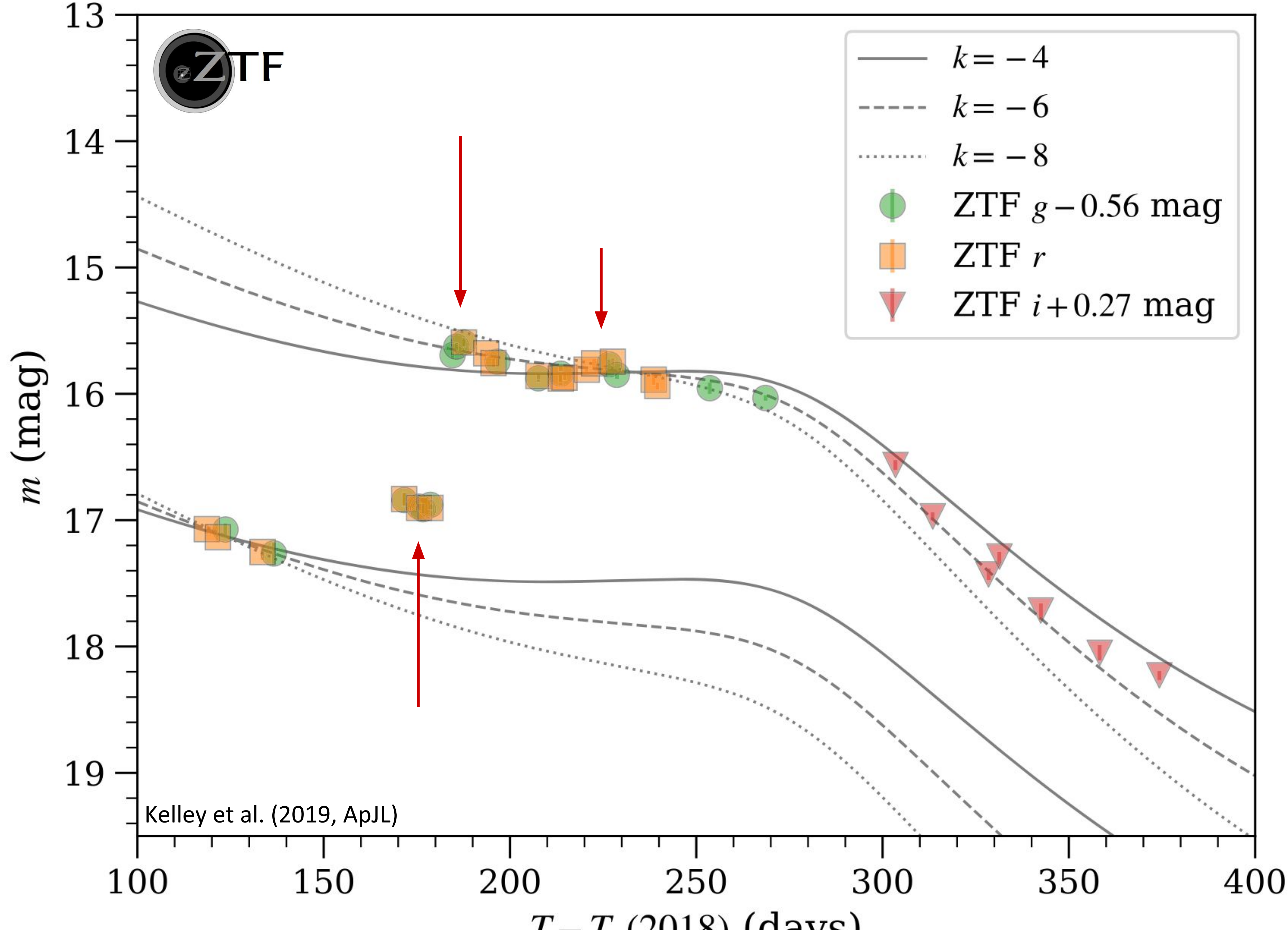
Small orbital perturbations like this are common in the JFC population.

Sources: NASA JPL; IAU Minor Planet Center.

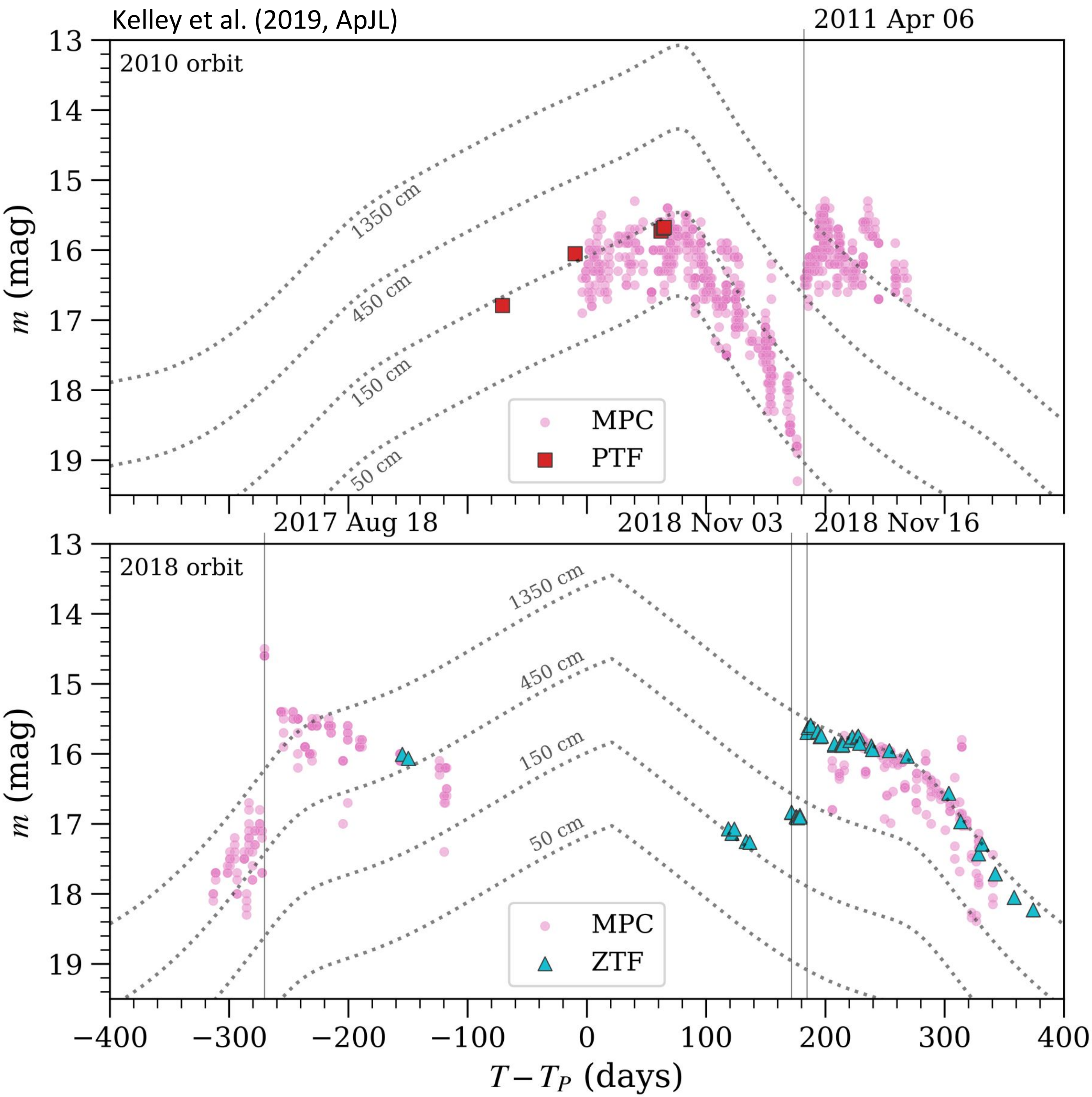


Stack of 5 ZTF *g*- and *r*-band images, 2018 Sep 11–29, r ~ 17.2 mag.

200"



ZTF
$k = -4$
$k = -6$
$k = -8$
ZTF $g - 0.56$ mag
ZTF r
ZTF $i + 0.27$ mag
m (mag)
13
14
15
16
17
18
19
100
150
200
250
300
350
400
$T - T_p(2018)$ (days)
Kelley et al. (2019, ApJL)



PALOMAR TRANSIENT FACTORY

ZTF

Photometry of comet 240P/NEAT over two orbits.

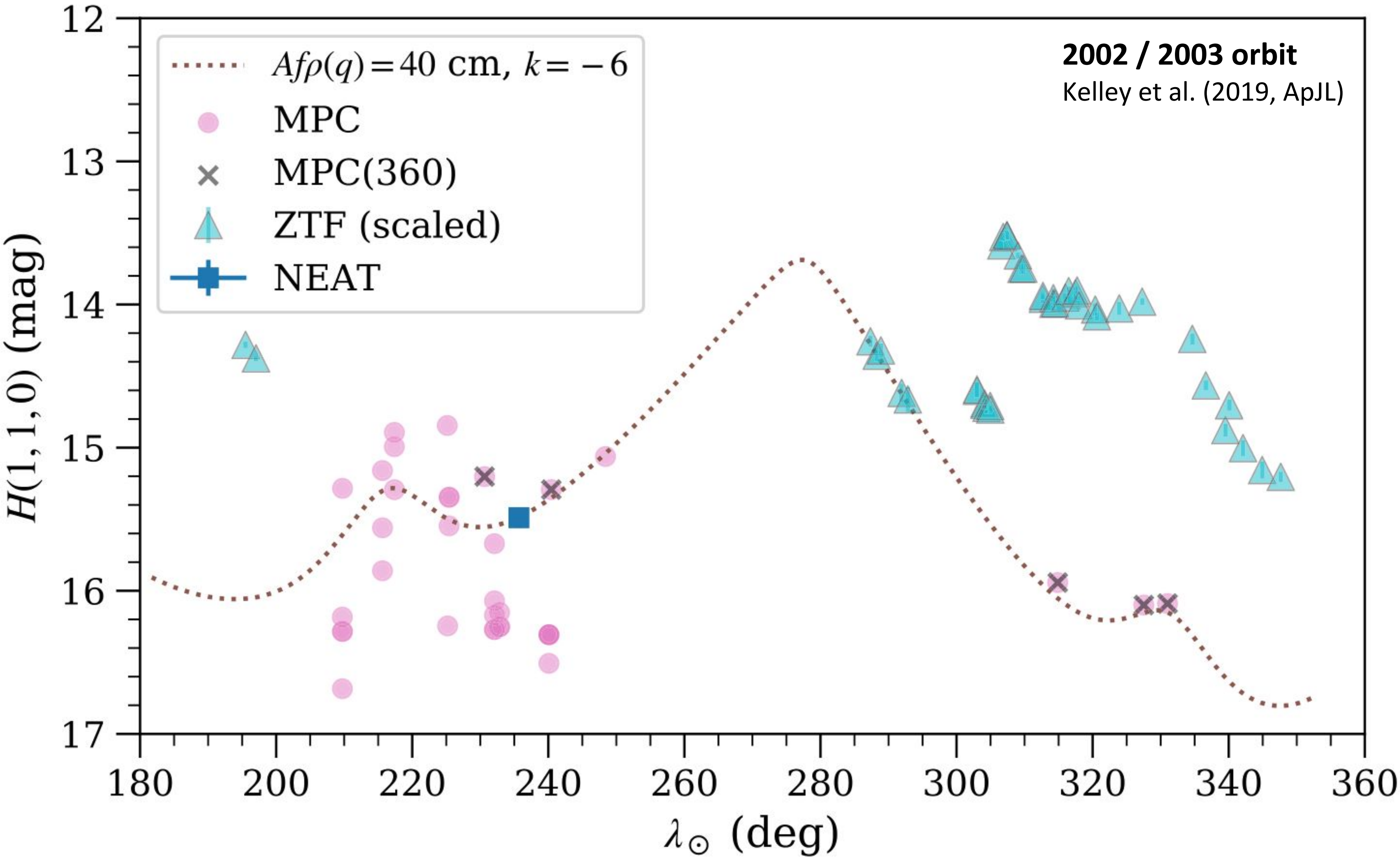
Sources:

- Zwicky Transient Facility
- Palomar Transient Factory
- Minor Planet Center, including:
  - ATLAS
  - Catalina Sky Survey
  - LONEOS

Scatter caused by different aperture sizes, bandpasses, magnitude systems.

Difficult to correct, but outbursts and general trends are evident.

The ZTF-observed event occurred in the previous orbit.



The data are sparse, but it appears the post-perihelion outburst did not occur in 2003.

Rosetta OSIRIS NAC image of 67P/Churyumov-Gerasimenko
https://imagearchives.esac.esa.int/picture.php?/177922/category/428

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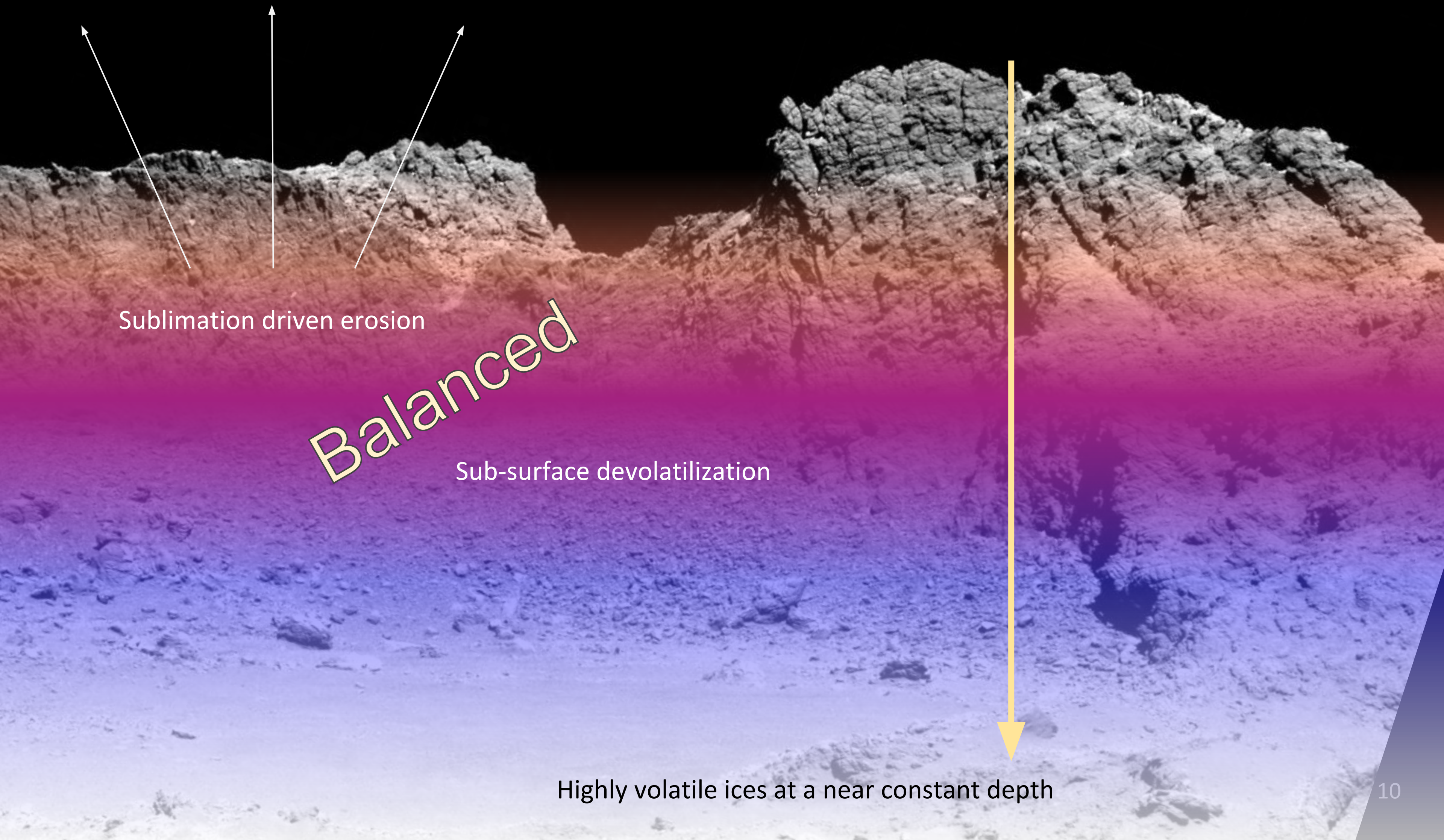
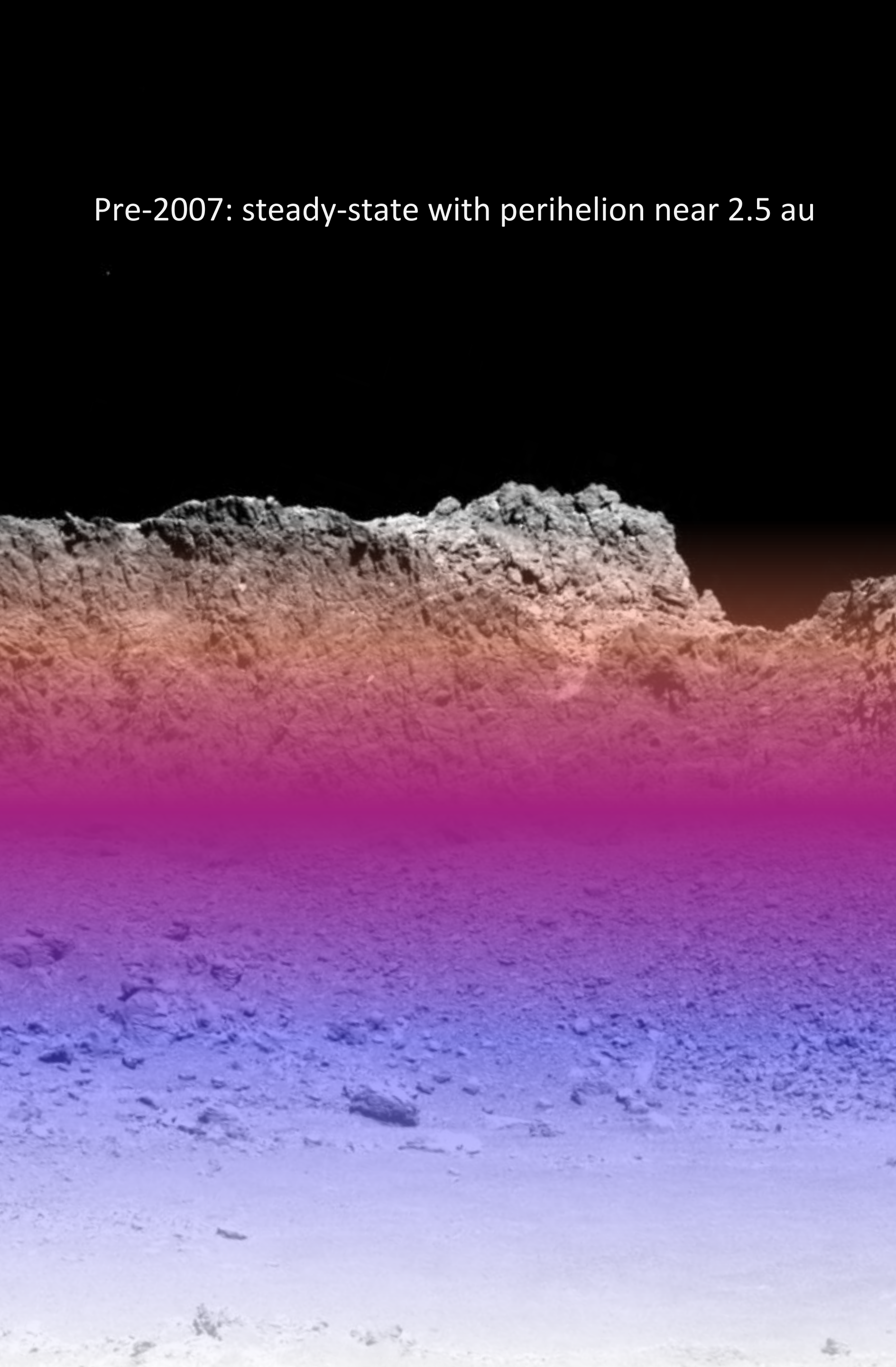
Pre-2007: steady-state with perihelion near 2.5 au

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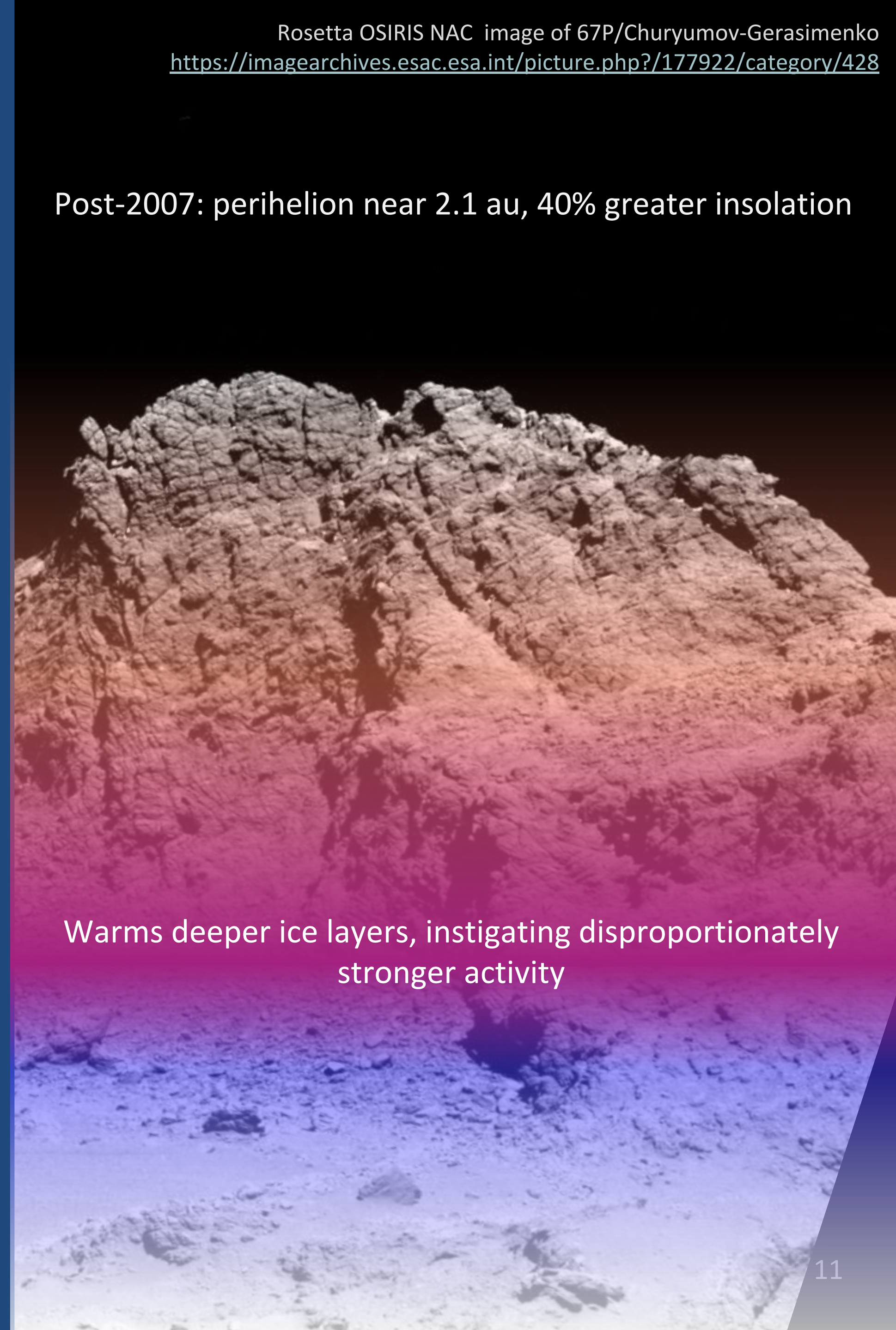

Rosetta OSIRIS NAC image of 67P/Churyumov-Gerasimenko
https://imagearchives.esac.esa.int/picture.php?/177922/category/428
Post-2007: perihelion near 2.1 au, 40% greater insolation
Warms deeper ice layers, instigating disproportionately stronger activity

ZTF *r*-band mosaic, 2018 Dec 4, r ~ 11 mag (5" aperture).

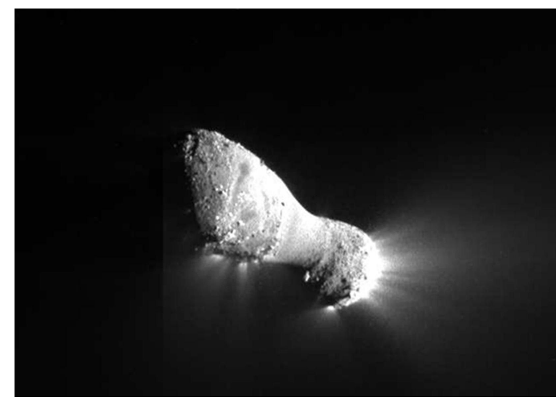
2°

Comet 46P/Wirtanen

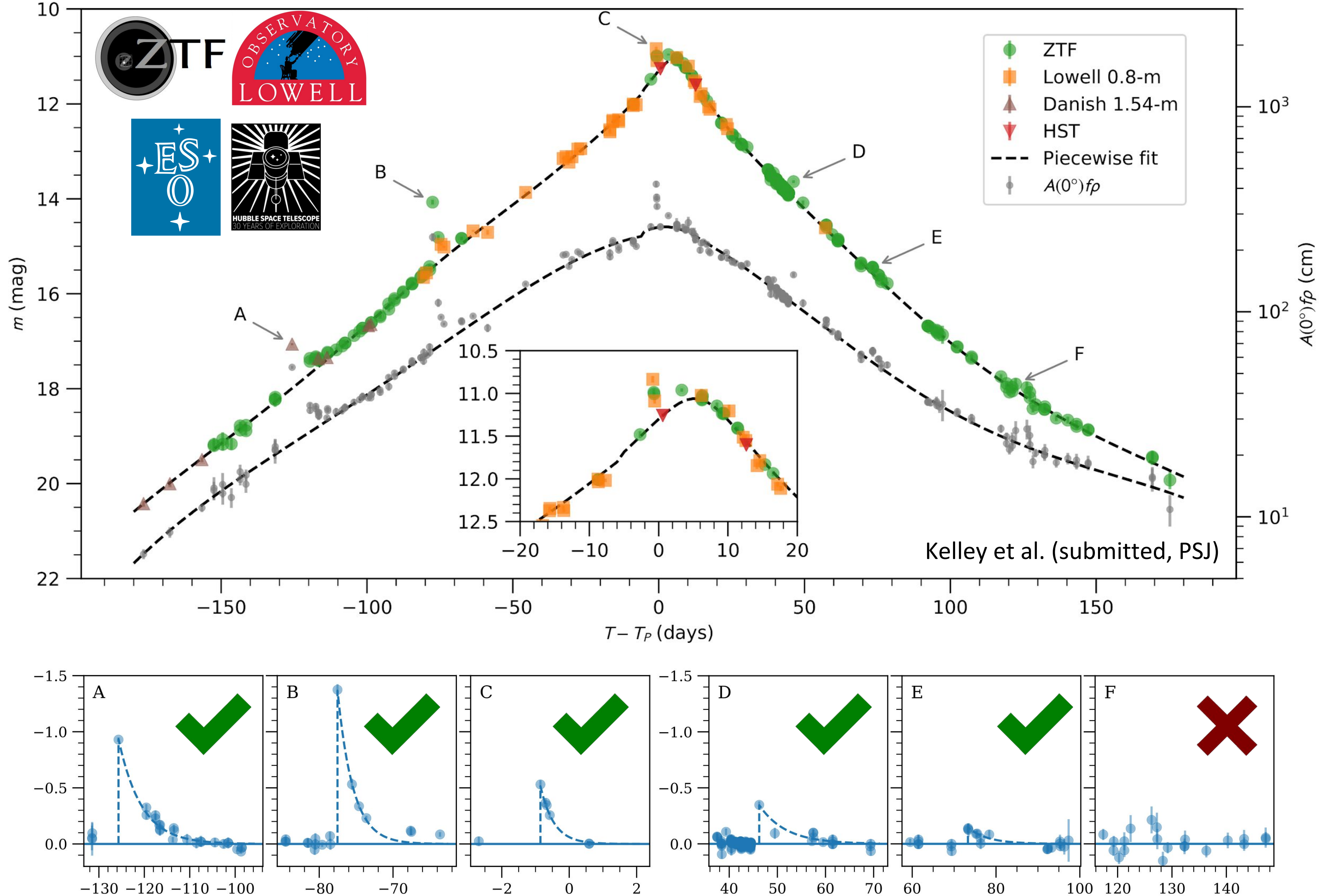
Historic close approach to Earth in December 2018 (0.077 au).

Similar properties to comet 103P/Hartley 2, a flyby target of the *Deep Impact* spacecraft.

- ➔ Sub-kilometer nuclei
- ➔ Similar mass-loss rates
- ➔ High water production rate given nuclear surface area



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



Total ejecta masses: ~10^4 to ~10^6 kg

Mini-outburst rates

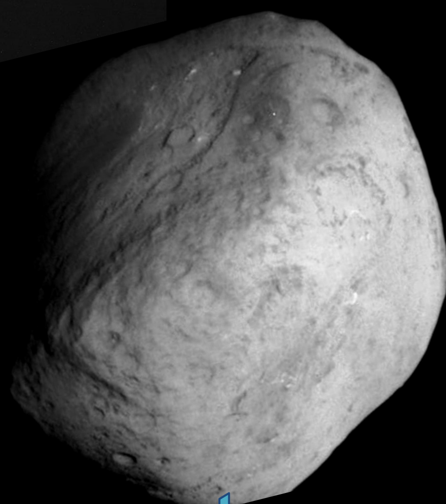
Comet	Rate (day^{-1} km^{-2})	Sources
67P/Churyumov-Gerasimenko	0.017	Vincent et al. 2016, MNRAS Jorda et al. 2016, Icarus
9P/Tempel 1	0.011	Belton et al. 2008, Icarus Thomas et al. 2013a, Icarus
46P/Wirtanen	0.0036	Kelley et al. submitted, PSJ Boehnhardt et al. 2002, A&A
103P/Hartley 2	<0.004	Kelley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

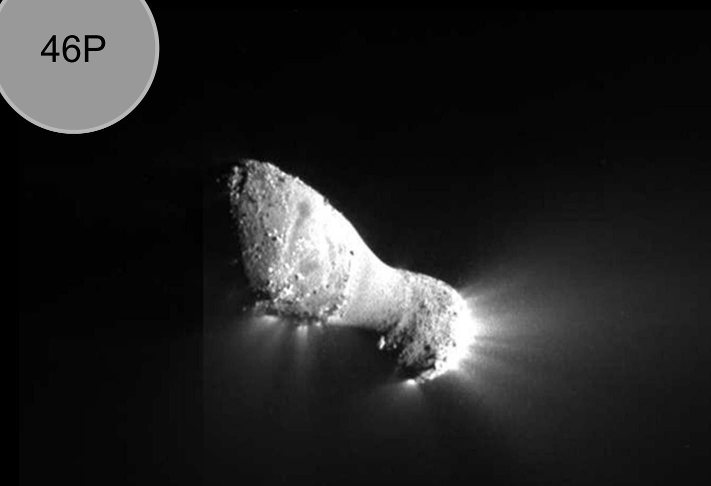
Primitive → Evolved

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

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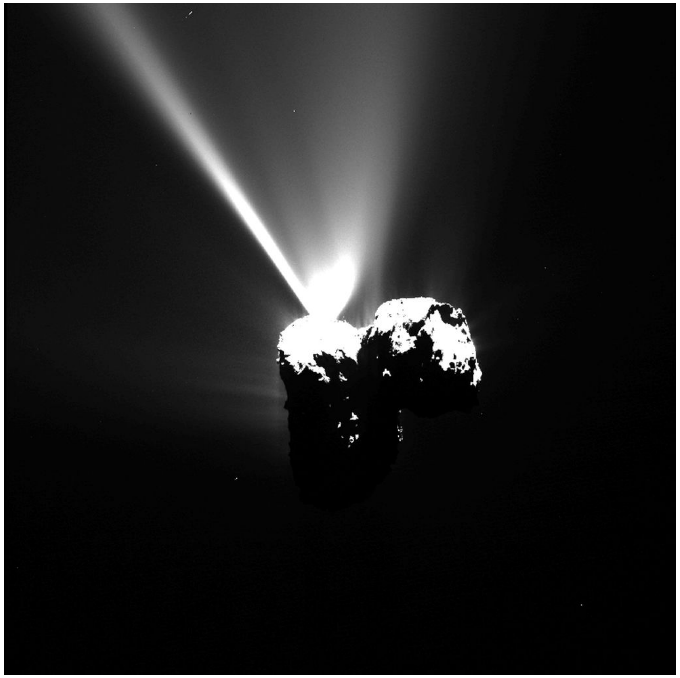
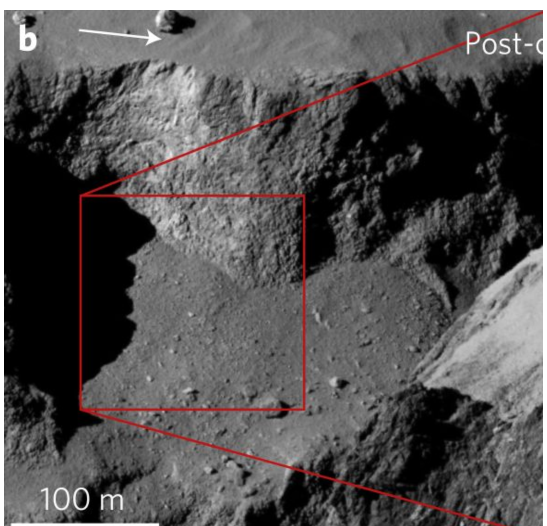
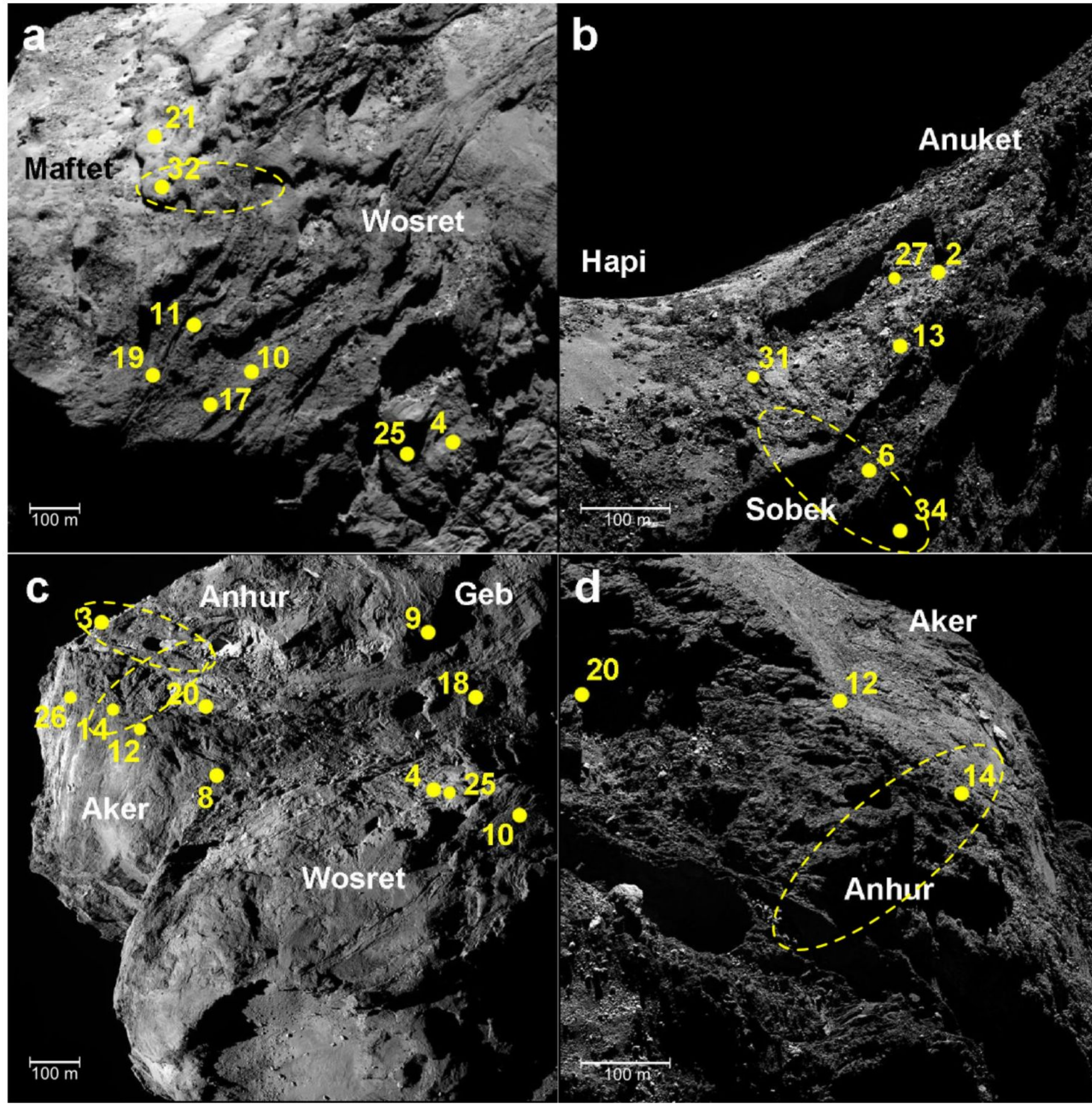


Top — Outburst at 67P/Churyumov-Gerasimenko, ESA / Rosetta / MPS for OSIRIS Team; MPS/UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA.

Right — Outburst locations at 67P (Vincent et al. 2016, MNRAS).

Bottom — Cliff collapse following an outburst (a) pre-outburst and (b) post-outburst (Pajola et al. 2017, Nat. Astron.).





At comet 67P/Churyumov-Gerasimenko, mini-outbursts (ejecta mass up to ~10^6 kg) are associated with cliffs, steep scarps, and similar topography.

Assume all mini-outbursts at all comets have a similar origin.