Twilight discovery of the first known inner-Venus asteroid, (594913) 'Ayló'chaxnim and naked-eye green comet C/2022 E3 at Palomar Observatory



Bryce T. Bolin (NASA/GSFC, NASA Postdoc Fellow) Rubin Project & Community Workshop August 8, 2023

5 near-Earth object classes Apollo Aten

Amor





1 au < perihelia < 1.3 au ~12,000 known

semi-major axes > 1 au ~15,000 known



semi-major axes < 1 au ~2,000 known

Atira

'Ayló'chaxnim



Aphelia, Q, < 0.98 au ~30 known



Aphelia, Q, < 0.72 au 1 known

5 near-Earth object classes Aten







1 au < perihelia < 1.3 au ~12,000 known



semi-major axes > 1 au ~15,000 known

semi-major axes < 1 au ~2,000 known





0.47 au < Q < 0.72 au 1 known

Inner-Earth objects

5 NEO classes: Atiras



 First discovered in 1998, 1998 DK₃₆ at Mauna Kea Obs. by Dave Tholen (Tholen & Whiteley 1998) Have aphelia, 0.72 au < Q < 0.98 au
 ~30 known, ~1% of NEOs: ~10,000 with H < 25 (Granvik et al. 2018)

5 NEO classes: 'Ayló'chaxnims



 First Aylo, (594913) 'Ayló'chaxnim, discovered at Palomar Observatory by Bryce Bolin (Bolin et al. 2020a, 2022a, 2023)

Have aphelia, 0.47 au < Q < 0.72 au, <1% of NEOs: ~2,000 with H < 25 (Granvik et al. 2018)

Atira and Aylo sky density



Atira/Aylo highest density < 60 degrees of the Sun and low ecliptic latitudes Masi 2003



Exterior asteroid

Earth

θ < 180° for exterior asteroids!</pre>

Sun





Finding Atiras and Aylos





Earth, Palomar Observatory (California), 1712m FOV 104° 59.8 FPS 😛 2020-01-03 +17:57:22

Zwicky Transient Facility





Mounted on the 48-inch Telescope at Palomar Mountain Large 47 sq. deg field of view, ~1 arcsec/pixel V~20.5 limiting magnitude with 30 s exposures in dark time Can point as low as 20 degrees elevation

Twilight survey



Discovery of 'Ayló'chaxnim



Discovered in the Zwicky Transient Facility survey on 2020-01-4 01:51 Detected in 4 x 30 s r band images, r ~18 Initially known as 2020 AV2 Bolin et al. 2020a, 2022a, 2023

Orbit



a ~0.55 au, Q ~ 0.65 au, diameter ~2 km i~15.8 degrees, period ~151 days

Bolin et al. 2022

Atira/Aylo discoveries



4 Atira objects, 1 Aylo object

- 4 Atiras: 2020 OV1 (Bolin et al. 2020b), 2021 BS1 (Bolin et al. 2021a), 2021 PB2 (Bolin et al. 2021b) and 2021 VR3 (Bolin et al. 2021c, MPEC 2021-158V)
- ~15% of all known Atiras (4 out of 30 known), 100% of known Aylos (just the 1) Bolin et al. in prep.

Survey completeness



NEO model predicts ~0.25 'Ayló'chaxnim asteroids with diameter >2 km
 Combined synthetic 'Ayló'chaxnims with simulation of ZTF survey
 <~5% chance of detection, 2-σ discrepancy with NEO model Bolin et al. 2023

Additional source of asteroids in the inner Solar System?

Venus Inner Mercurian-Belt

Sun



Mercu



Stable regions inside the orbit of Mercury ~0.1-0.2 au

Evans and Tabachnik 2002, Shannon et al. 2015, Bolin et al. 2023

Comet observations and ZTF



The ZTF pipeline rejects all extended sources, including comets

Possible solution

use Deep Learning to identify comets on a per-image basis

Training of 'Tails' Deep Learning Neural Network



(a) 114P/Wiseman–Skiff observed on 2019/10/19



(b) 29P/Schwassmann-Wachmann observed on <math>2019/10/19

(c) C/2019 D1 (Flewelling) observed on 2019/07/22

(d) 260P/McNaught observed on 2019/10/19

Trained using thousands of observations of known comets taken by ZTF between 2018-2020

Duev, Bolin et al. 2021

'Tails' Deep Learning Identification of comets

2I/Borisov (2019/10/05)

(2020/08/11)

(2020/08/07)

Run on just the ZTF Twilight survey data (5-10% of total ZTF data) Takes 5 h to run for 45 x 30 s exposures, 32 vCPUs, 32 GB memory, SSD False positive and false negative rate ~1-2%

Duev, Bolin et al. 2021

ZTF comet discoveries

Name	Discovery date	perihelion (au)	eccentricity	inclination (deg)	Total Magnitude
C/2020 T2	2020 Oct 07	2.05	0.99	27.87	9.4
C/2020 V2	2020 Nov 02	2.22	1	131.61	8.3
C/2021 D2	2021 Feb 19	2.95	1	83.83	13.3
C/2021 E3	2021 Mar 09	1.78	1	112.56	11.1
P/2021 N1	2021 Jul 02	0.96	0.68	11.5	17.8
C/2022 E3	2022 Mar 02	1.11	1	109.17	10.8
C/2022 P3	2022 Aug 02	2.56	0.99	59.52	14.5
P/2022 P2	2022 Aug 15	1.98	0.56	12.44	9.2

Discovery of 8 comets running tails on just 5-10% of total ZTF data 2020-2022.

Bolin et al. in prep.

The famous green comet C/2022 E3 (ZTF)

came within 0.28 au from the Earth in early February 2023

Reached V~5 and was visible from most of the northern hemisphere

Javier Caldera

Superstar Comet

Bolin et al. 2022, MNRAS:L, 517, 1, L49-L54

Bolin et al. 2023, Icarus, 394,115442

Duev, Bolin et al. 2021,

AJ, 394, 115442

Contributions

- Discovered (594913) 'Ayló'chaxnim , the first known inner-Venus asteroid (Bolin et al. 2022)
- May imply an additional source of asteroids, e.g. inner-Mercurian belt (Bolin et al. 2023)
- Co-developed Deep Learning neural network, Tails, to find comets in ZTF data (Duev, Bolin et al. 2021)
- Used Tails to find ~10 comets in 2020-2022, including naked-eye comet C/2023 E3 (Bolin et al. in prep.)

Publications

- Discovery and characterization of Aylos: Bolin et al. 2022a, MNRAS:L, 517, 1, L49-L54
- Aylo survey completeness estimate: Bolin et al. 2023, Icarus, 394, 115442
- Deep learning discovery of comets : Duev, Bolin et al. 2021, AJ, 394, 115442