NEOWISE Views of Small Bodies

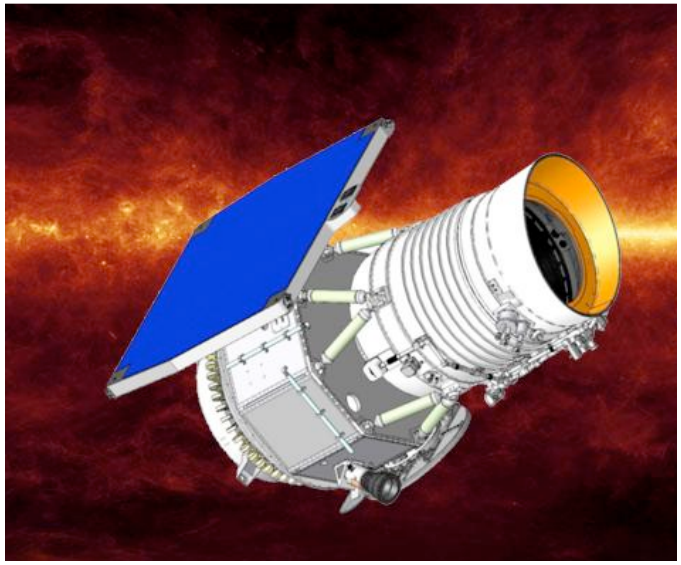
November 8, 2015

A. K. Mainzer, J. M. Bauer, R.M. Cutri, T. Grav, J. R. Masiero, E. A. Kramer, C.R. Nugent, S. Sonnett, E. L. Wright, and the NEOWISE team.

Mission Overview

Salient Features

- PI-led (PI: Amy Mainzer, JPL) mission under NEOO Program (Lindley Johnson, Program Exec)
- Uses WISE S/C that was brought out of hibernation in October 2013
- 3.4 and 4.6 μm bands (W1 and W2) at 75K
- Similar observing strategy to WISE/NEOWISE
  - Terminator-following pole-to-pole orbit
  - Surveys entire sky roughly every 6 months
- Science operations: 3 years starting 12/2013



Science

- Expand the NEOWISE survey of Near-Earth Objects (NEOs) at mid-infrared wavelengths using WISE W1 and W2 channels
- Obtain physical characterization (including diameters and albedos) of these NEOs and the thousands of other small bodies detected by NEOWISE

Prime Mission NEO Results

- Observations of ~430 NEOs from fully cryogenic mission (14 Jan 2010 – 5 Aug 2010) used to set constraints on population numbers, size distribution, albedos, orbital elements

- Results: 20,500±3000 near-Earth asteroids (no comets) >100 m;
  - shallow slope size distribution
  - ~25% survey completeness to date

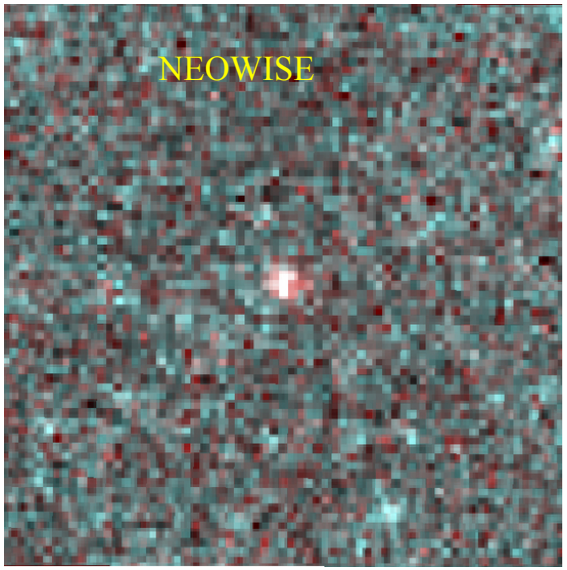
- Roughly 36% of NEOs are dark: p_V<0.1
  - Mainzer et al. 2011

NEO Results cont'd.

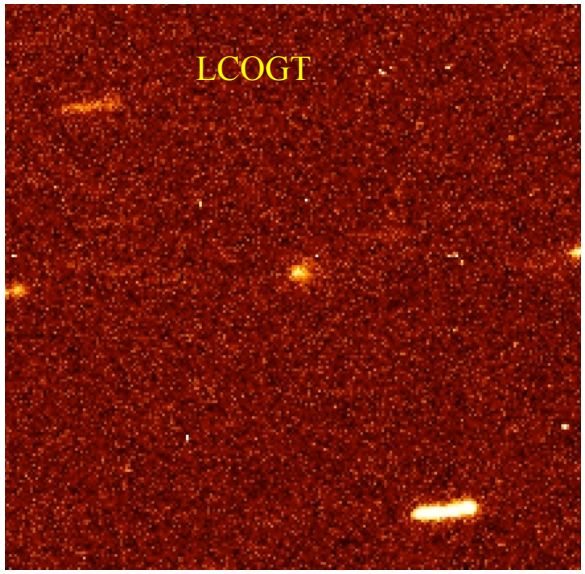
- 25% of NEOs detected by NEOWISE were potentially hazardous (PHAs; MOID<0.05 AU)
- For PHAs, there are 4700±1500 larger than 100m
- About 2x in low-inclination orbits compared to model prediction using Bottke et al. (2002) orbital elements
  - In good agreement with Greenstreet & Gladman (2013)
  - Mainzer et al. 2012

NEOWISE Restart

- Since the start of operations, NEOWISE has obtained **~350,000** infrared measurements of **16,569** solar system objects, including **419** NEOs, of which **68** are new discoveries
- Recent NEO discovery **2015 KL157** is a PHA with a MOID of 0.003AU (~1 lunar distance), diameter of 0.58km and V albedo of 0.05
- Fourth comet discovery: **2015 J3 (NEOWISE) –** Jupiter family

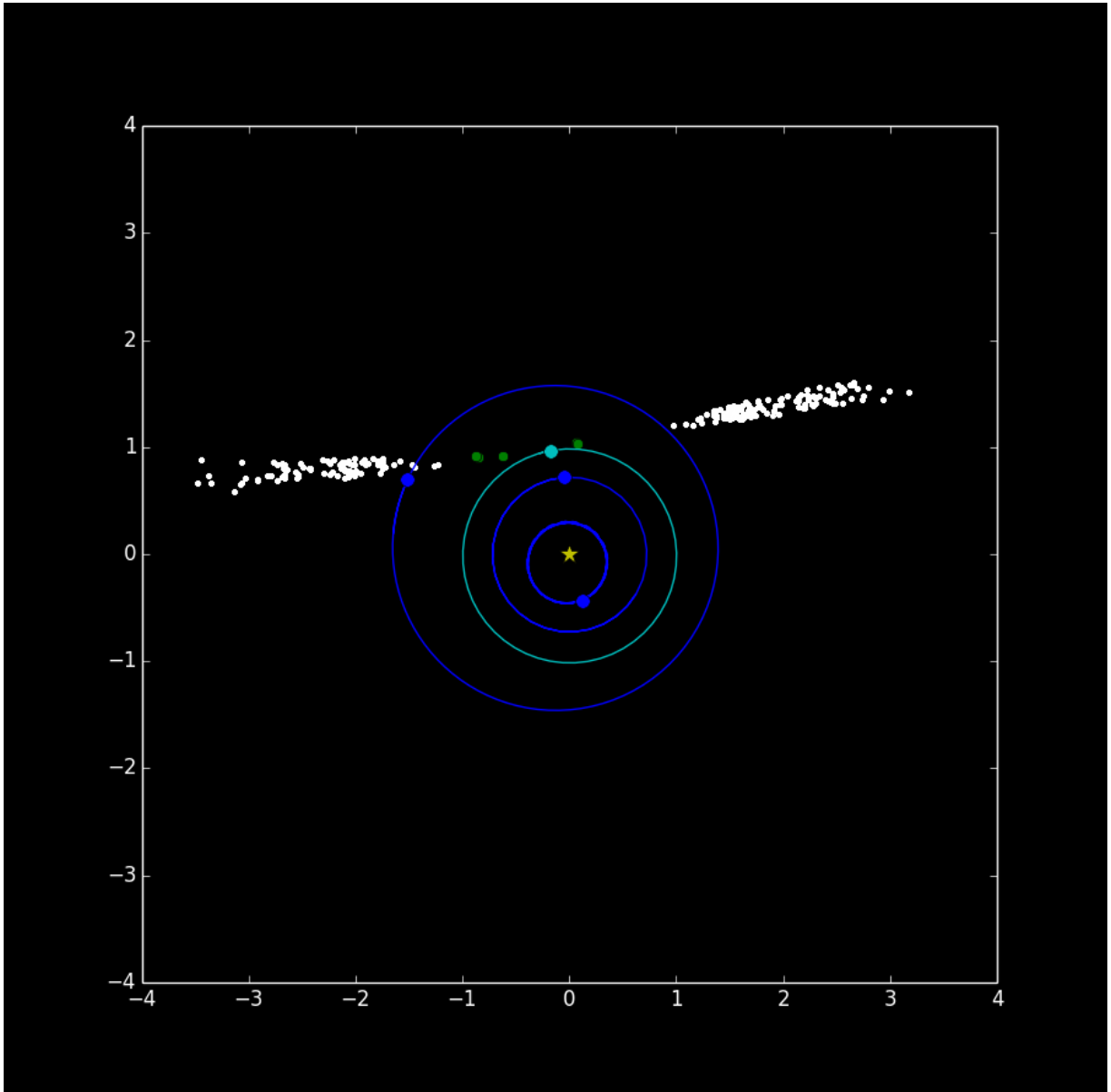


< 3 arcmin >



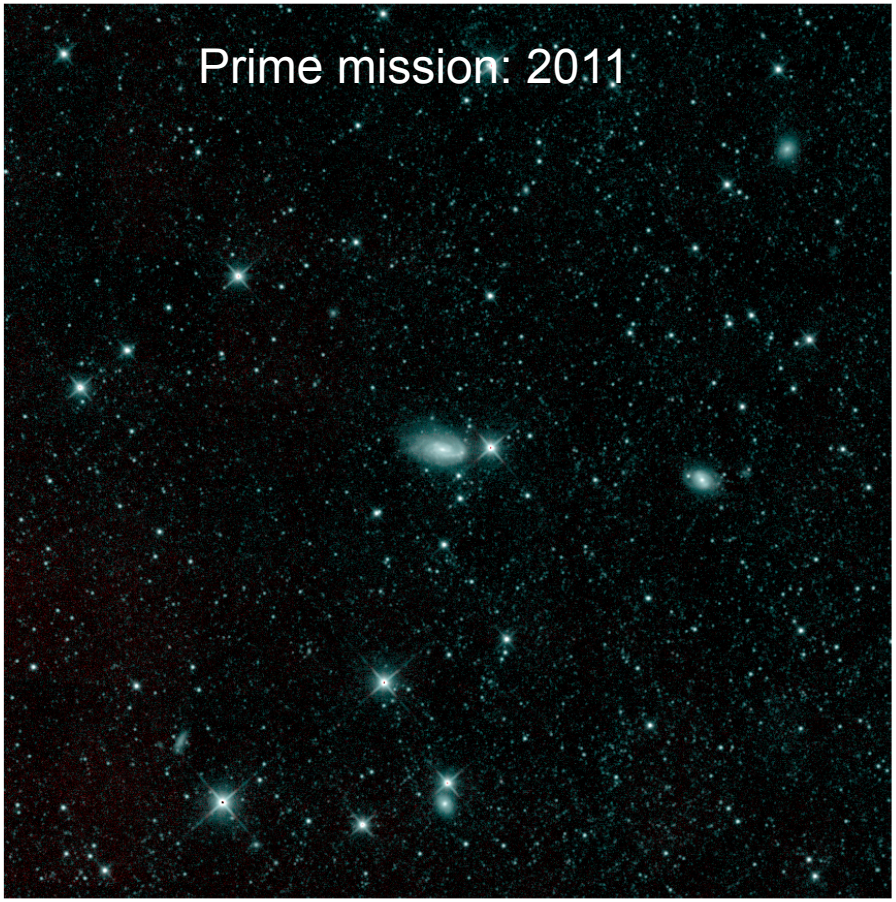
< 1 arcmin >

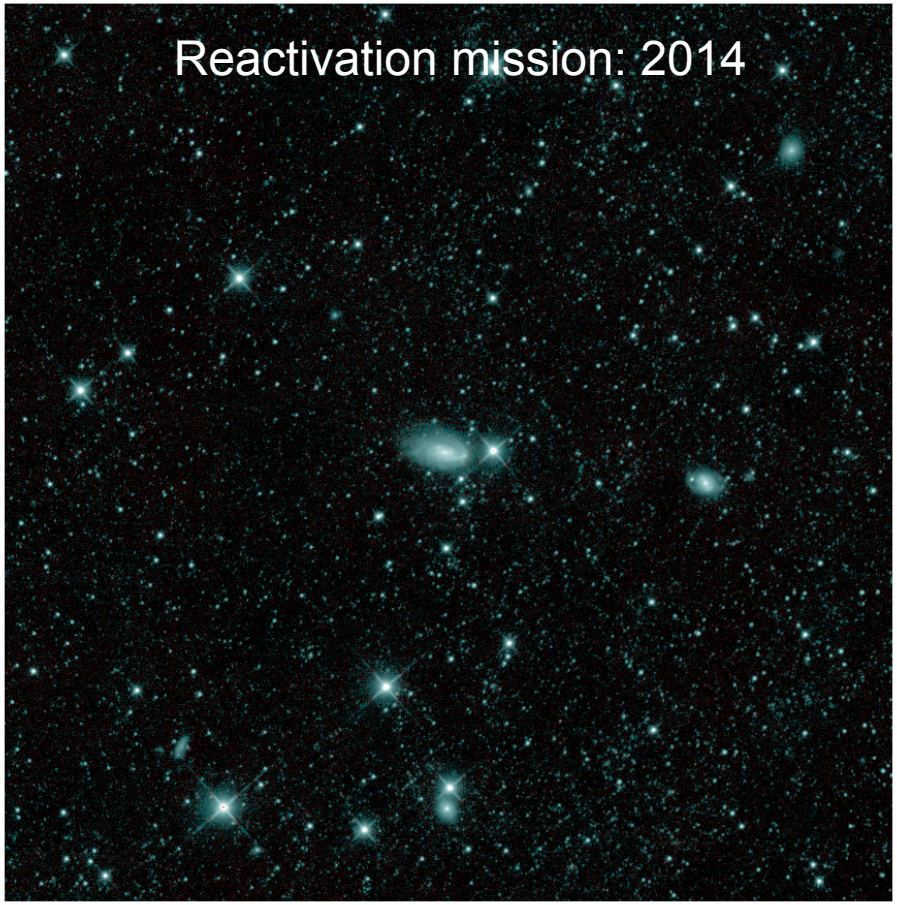
NEOWISE Year 1



Instrument Performance

- Image quality, photometric accuracy, astrometry, sensitivity all unaffected by 32 month hibernation





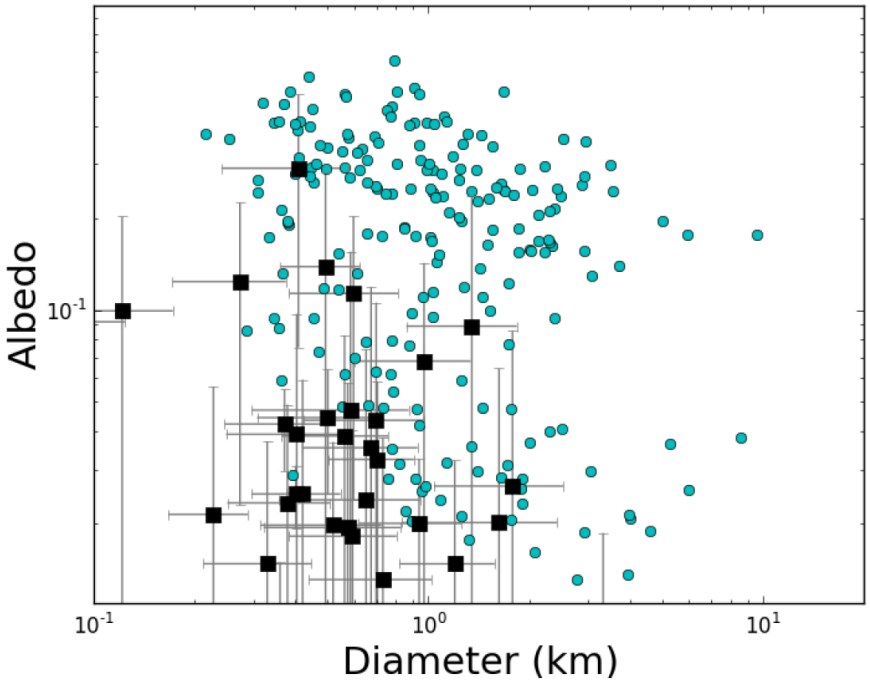
Single-exposure Source Database Characteristics

		W1	W2
Sensitivity (SNR=10)	**mag**	**15.0**	**13.7**
	microJy	300	565
Completeness (>90%)	**mag**	**15.8**	**14.4**
	microJy	150	300
Reliability (>95%)	**mag**	**15.0**	**13.5**
	microJy	300	680
Astometric Accuracy	70 mas (high SNR)		

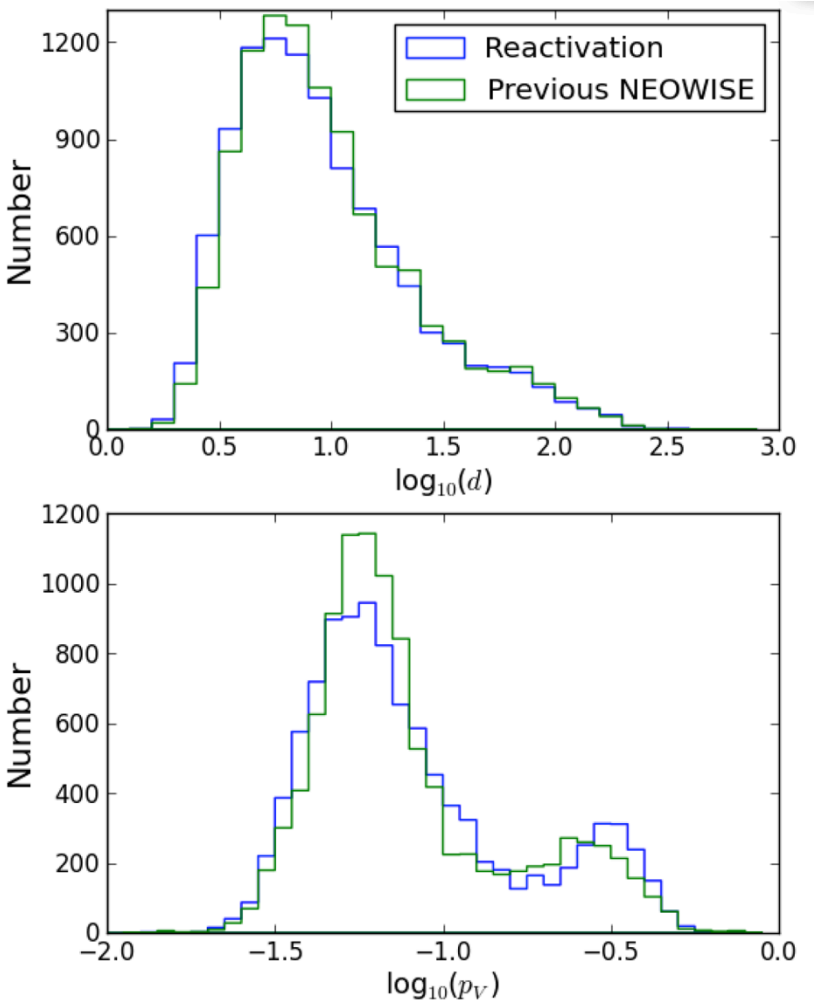
- Sensitivity nearly identical to prime mission

Diameters and Albedos for 9,309 Asteroids Detected During First Year

- Nugent et al. (2015 ApJ in press)
- Diameters accurate to ~20%, albedos to ~50%



- NEOWISE preferentially detects large NEOs
- NEO discoveries tend to be dark
- Nearly a quarter are PHAs



Diameters and albedos consistent with values from original NEOWISE mission

NEOWISE 2015 Data Release
March 26, 2015

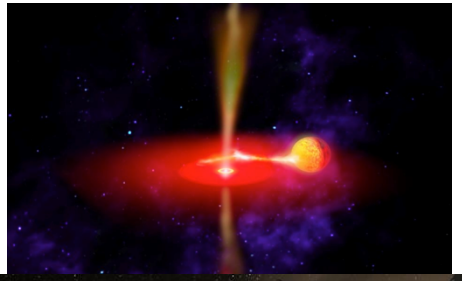
http://wise2.ipac.caltech.edu/docs/release/neowise

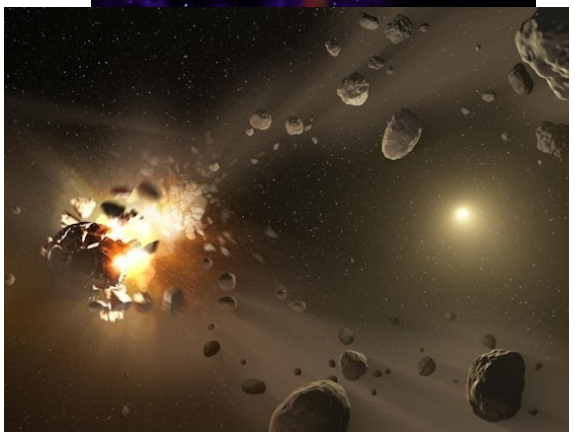
- **Single-exposure data** from the first year of the NEOWISE Reactivation Mission
- **2,497,867** calibrated 3.4 and 4.6 μm FITS images, uncertainty maps and bit masks
- **18,468,575,596** source extractions (positions and W1/W2 fluxes, ancillary information) from those images
- **Data access**:
  - Image and source database from the NASA/IPAC Infrared Science Archive (IRSA)
  - Moving Object tracklets from the IAU Minor Planet Center

NEOWISE Data Use

- Total citation count using NEOWISE data & discoveries: >200 refereed publications
  - Total citation count for WISE >1400 refereed publications

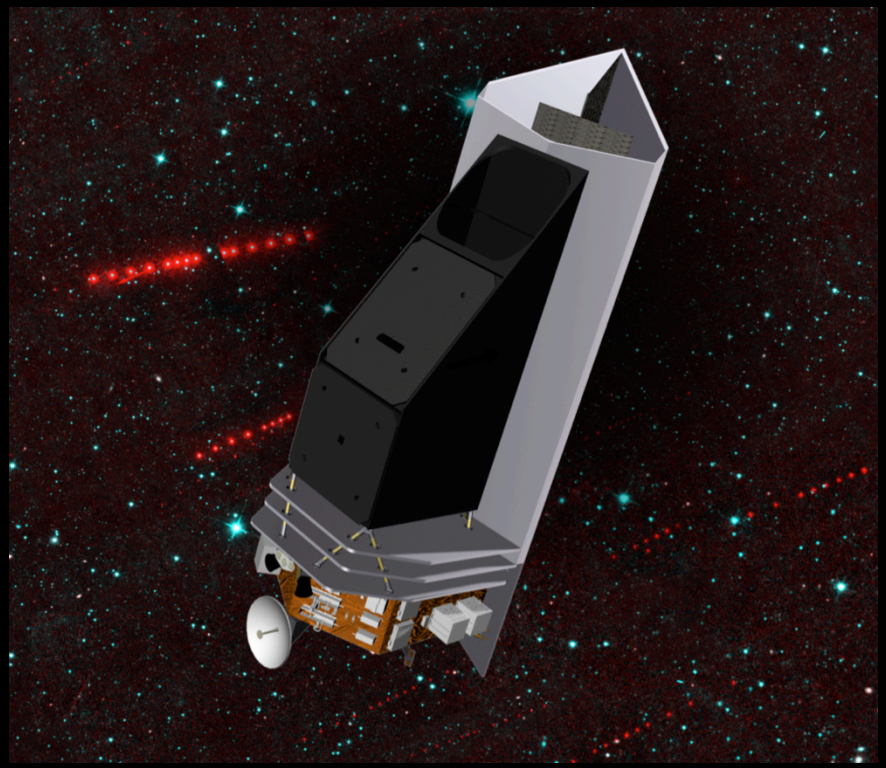
- NEOWISE is a multi-epoch mid-infrared all-sky survey, so its science spans many areas of astrophysics & planetary science:
  - Asteroids
  - Meteoritics
  - Giant planet migration
  - Variable stars
  - Icy bodies in the outer solar system
  - Distance ladder determinations for cosmology
  - Human exploration
  - Supernovae
  - Pulars
  - Exoplanets
  - Black hole accretion disks





NEOCAM

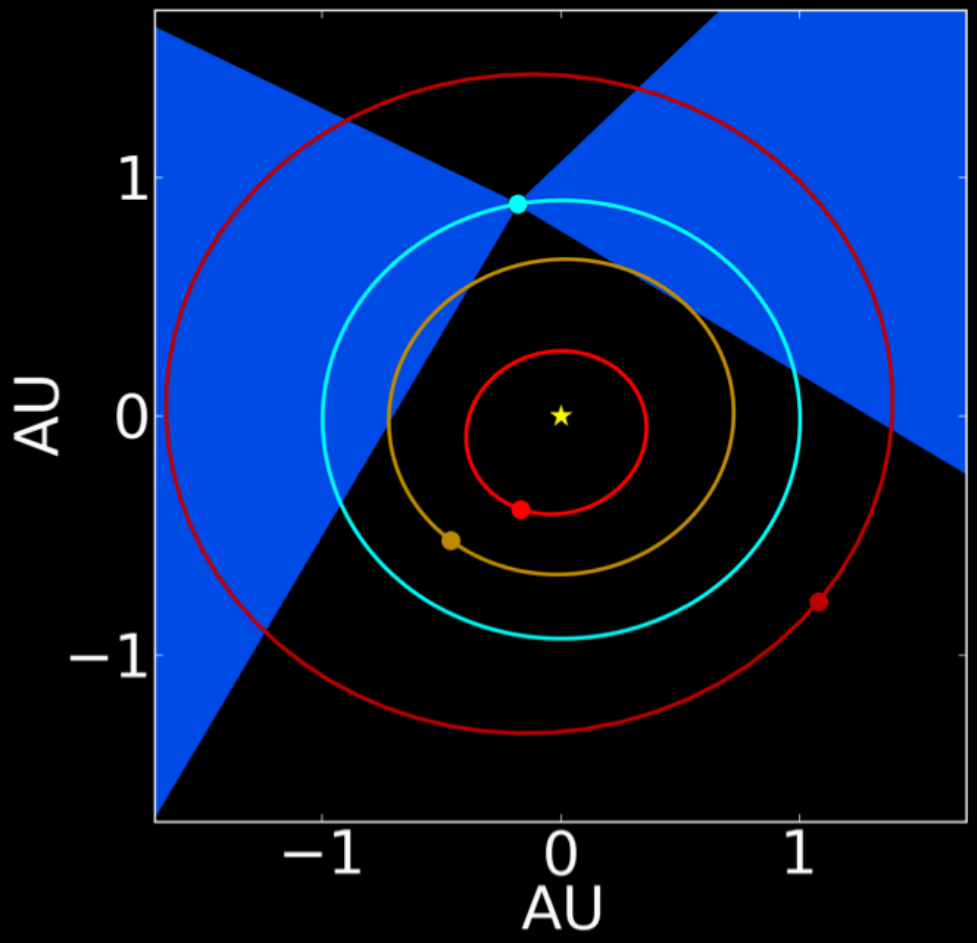
NEAR-EARTH OBJECT CAMERA



NEOCam is a dual-channel imager operating in a single step-and-stare survey mode. It includes:

- 50 cm telescope
- Two 16 megapixel HgCdTe focal planes at 4-5.4 and 6-10 μm simultaneously imaged
- Detectors passively cooled to 40K
- Sun-Earth L1 orbit
- First proposed 2005: Category II
- Awarded technology development funding in 2011 Discovery
- Step 2 Discovery (Phase A)

Orbit: Sun-Earth
L1 Lagrange Point



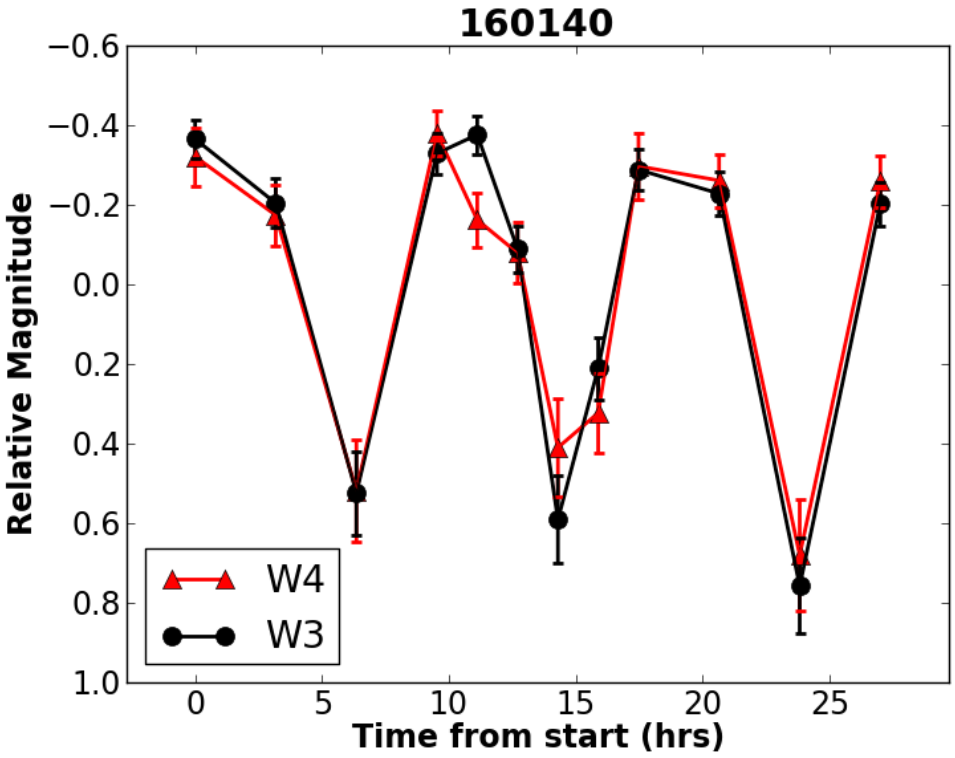
- Allows wide instantaneous viewing zones
- Close, constant distance from Earth allows full-frame images to be downlinked
- Thermal environment allows passive cooling to 40 K

NEOCam Science

- Planetary Defense
  - Detect millions of small bodies throughout the solar system, including 2/3 of PHAs >140m
  - Constrain impact probability for NEOs & comets of all sizes
- Origins & Evolution
  - Population studies: numbers, orbital distribution, physical properties
  - Origins of collisional families, NEOs
  - Identify and characterize rare populations: Earth Trojans, interior NEOs
  - Most comprehensive collection of comet orbit distributions, sizes, & CO/CO_2 abundances
- Finding New Destinations
  - Find the most accessible targets for future exploration

BACKUP

Example: Possible Binary Asteroids Identified by Large Amplitude Lightcurves

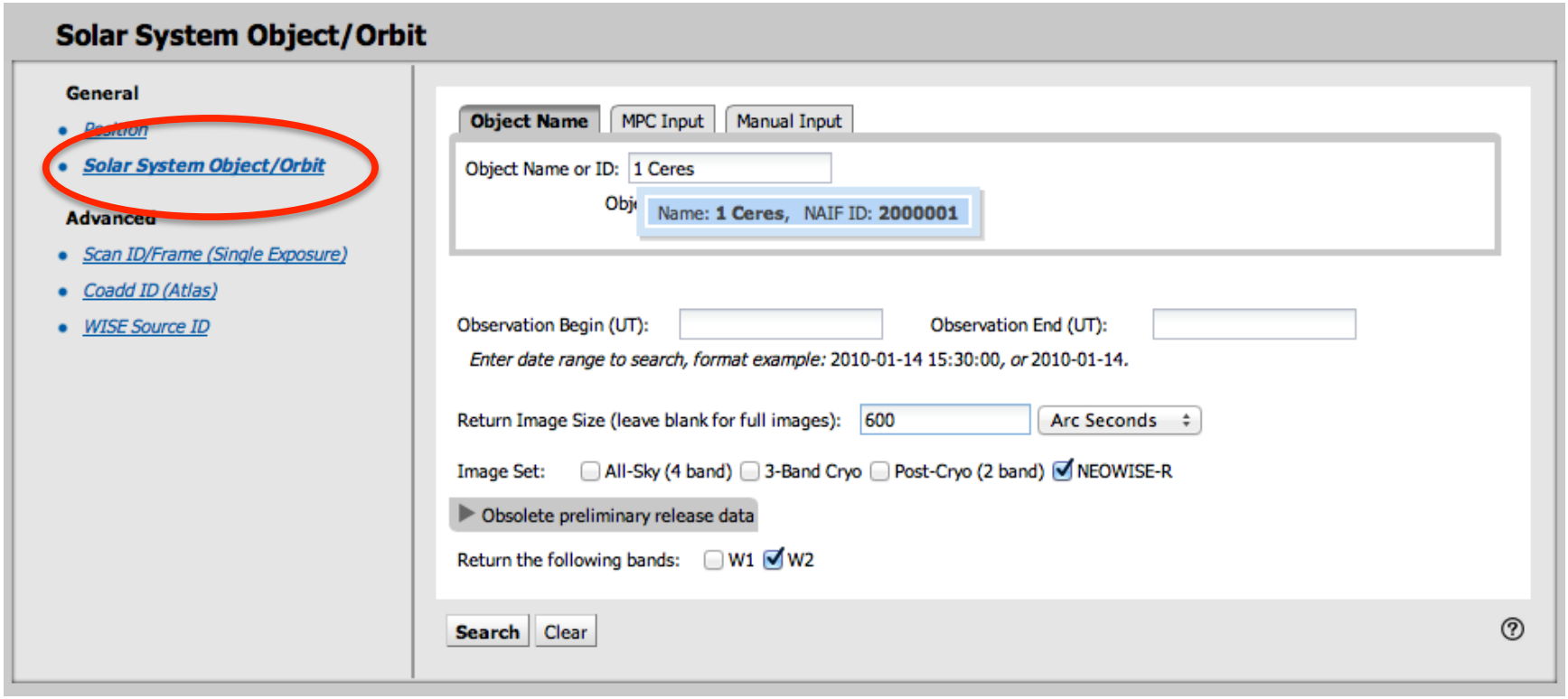


Sonnett et al. (2015)

- Close & contact binaries can sometimes be identified by their large brightness variations
- NEOWISE data record observations of asteroids every ~3 hours for ~30 hours
- 29 new binary candidates out of 953 Trojans (13-150 km)
- 48 new binary candidates out of 554 Hildas (4-36 km)

- Candidates are in need of follow-up to confirm binarity (follow-up underway)

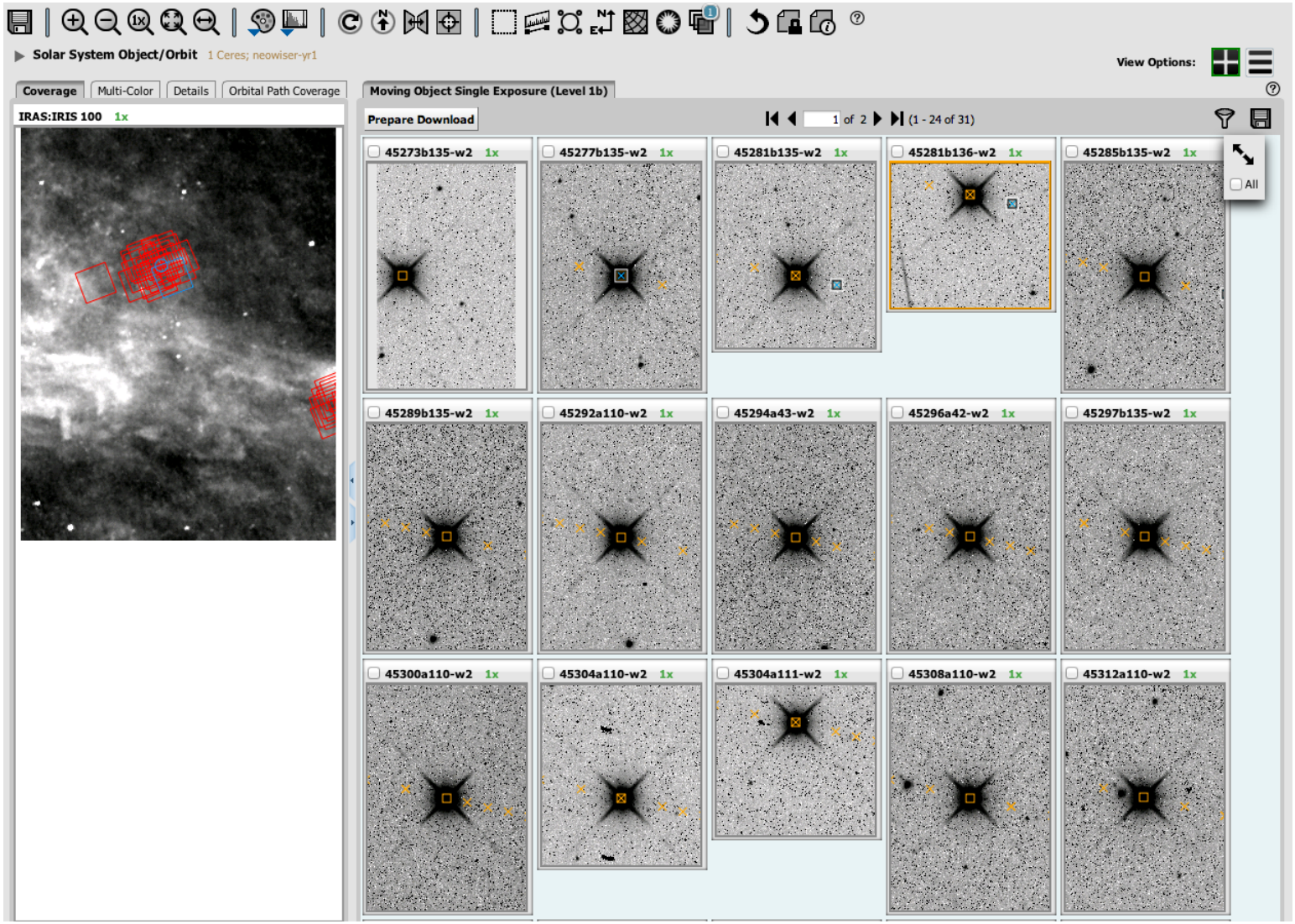
WISE/NEOWISE Image Server: Solar System Object Search



Search for Images that cover the position of Moving Objects at time of observation

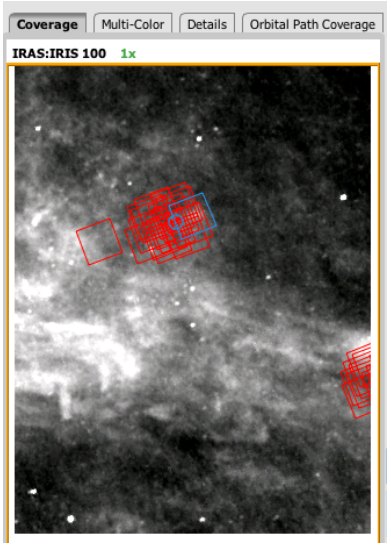
- Search by Object Name (Name resolution via JPL Horizons)
- Search using orbital elements with MPC format
- Search using manually input elements

Results of Solar System Search: Grid

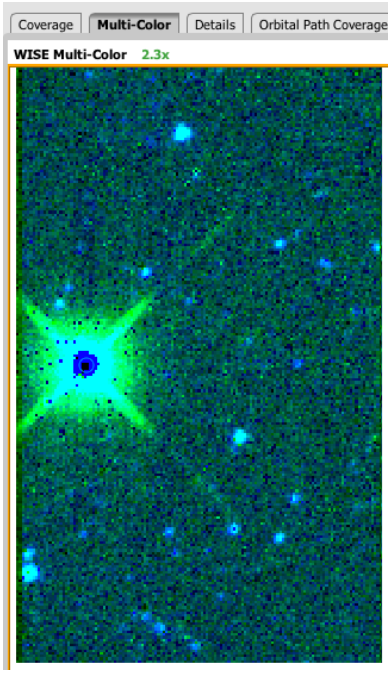


Results: left panel

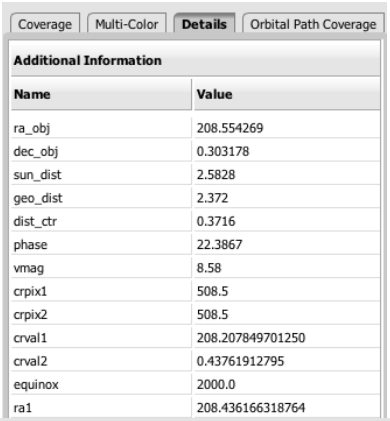
Coverage



Multi-Color

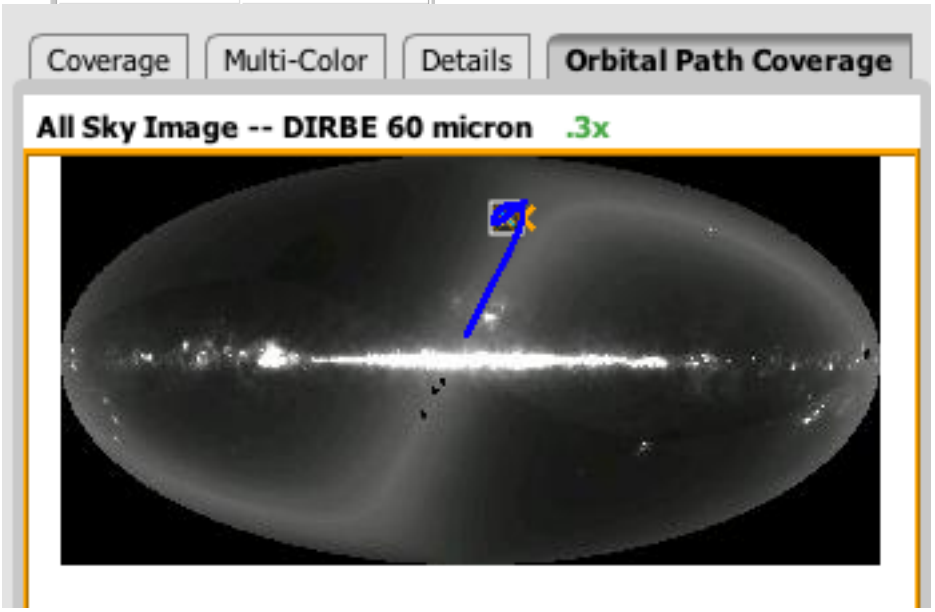


Details

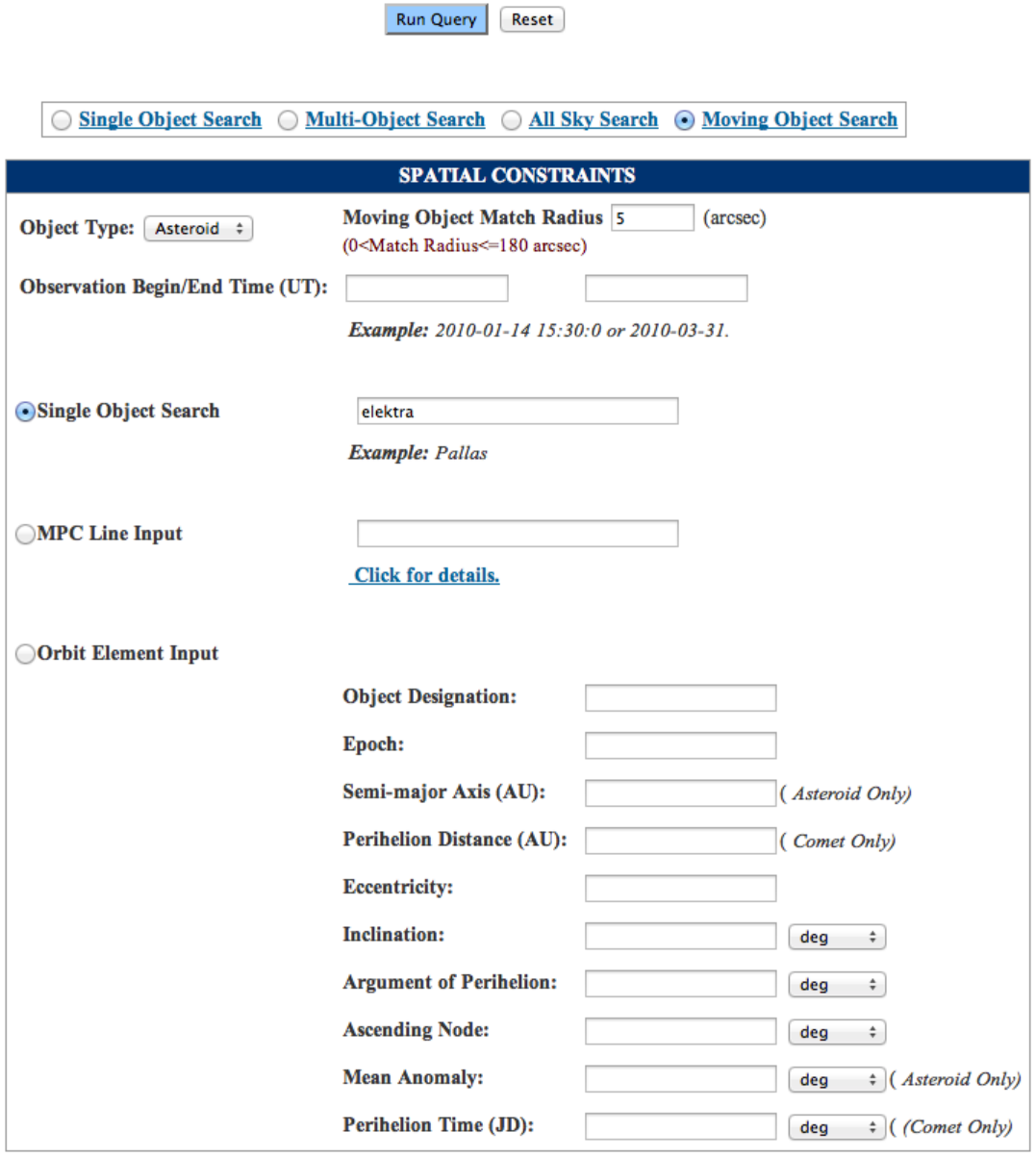


Name	Value
ra_obj	208.554269
dec_obj	0.303178
sun_dist	2.5828
geo_dist	2.372
dist_ctr	0.3716
phase	22.3867
vmag	8.58
crpix1	508.5
crpix2	508.5
crval1	208.207849701250
crval2	0.43761912795
equinox	2000.0
ra1	208.436166318764

Orbital Path Coverage



Catalog Query Engine: Solar System Object Search



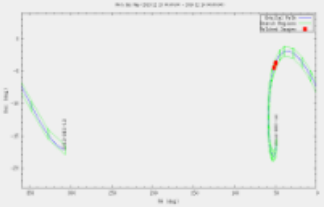
Search Source Database for Detections at predicted position of Moving Object at time of observation

- Search by Object Name (Name resolution via JPL Horizons)
- Search using orbital elements with MPC format
- Search using manually input elements

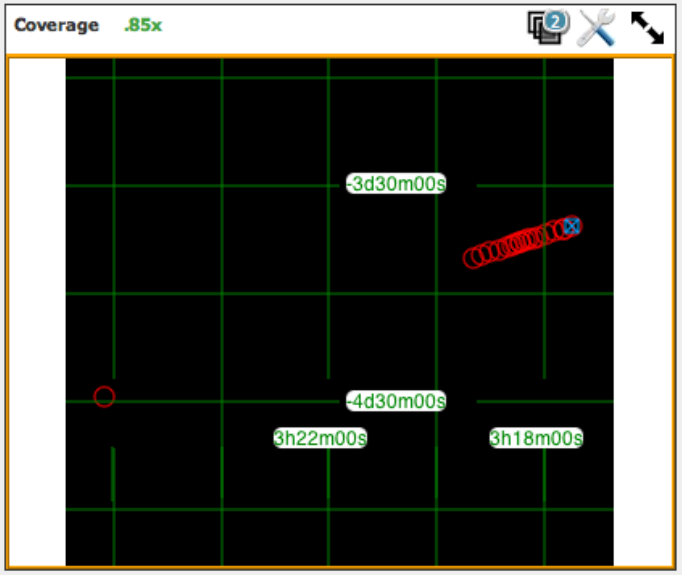
Catalog Search Result for NEOWISE-R Year 1 Single Exposure (L1b) Source Table

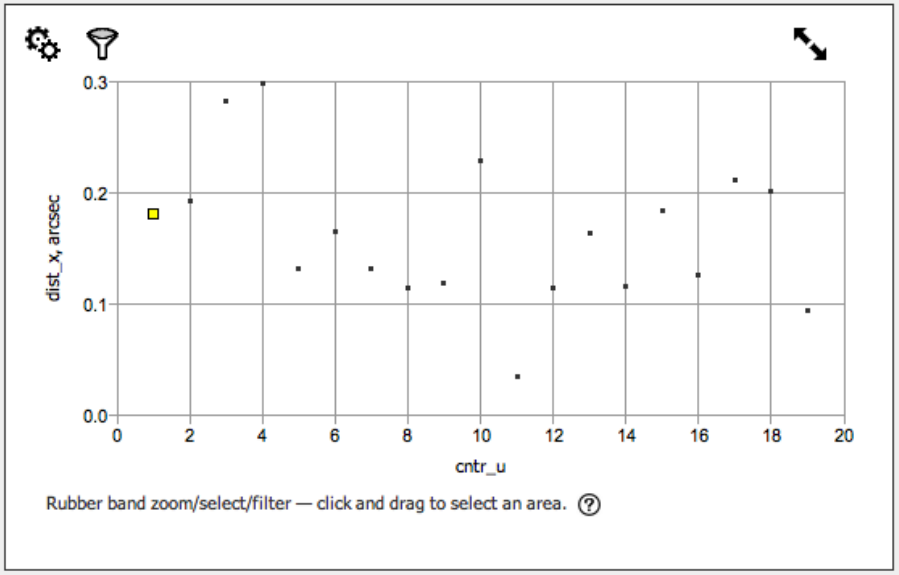
Moving Object		Observation Time	
Type	**Name**	**Begin**	**End**
Asteroid	130 Elektra	2013 12 13 00:00:00	2014 12 14 00:00:00
Designation	**Epoch (MJD)**	**Semi-major**	**Eccentricity**
130 Elektra	56639.00	3.123766383191	0.208587220463
Inclination (deg)	**Argument of Perihelion (deg)**	**Ascending Node (deg)**	**Mean Anomaly (deg)**
22.866505235768	235.628120738519	145.407982878680	317.995810613083

Matched Image List



All Sky Search Constraints: Yes **38 sources found.**





Result IPAC Table **Column Key**

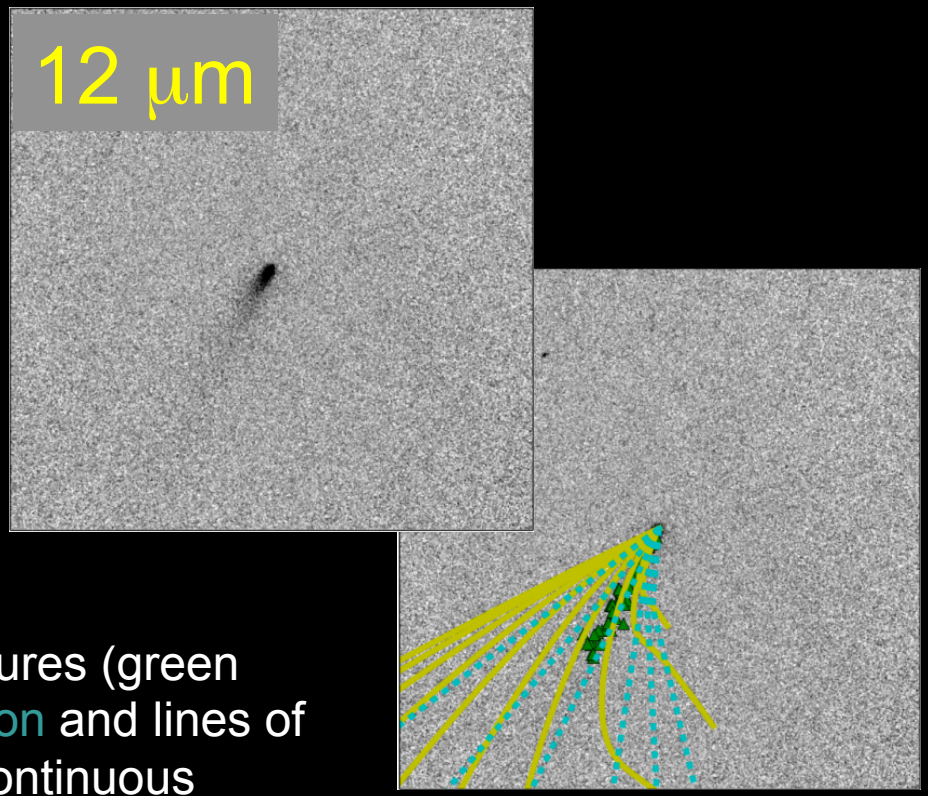
1 of 1 (1 - 19 of 19)

cntr_u	dist_x (arcsec)	pang_x (deg)	ra_u	dec_u	ra (deg)	dec (deg)	sigra (arcsec)	sigdec (arcsec)	sigradec (arcsec)	w1mpro (mag)	w1sig (ma
1	0.180826	40.666238	49.371581	-3.686568	49.3716138	-3.6865299	0.0276	0.0225	-0.0075	10.211	0.014
2	0.192727	16.236655	49.411816	-3.699347	49.4118310	-3.6992956	0.0274	0.0258	0.0039	10.293	0.018
3	0.281305	5.349284	49.411857	-3.699345	49.4118643	-3.6992672	0.0252	0.0226	0.0092	10.308	0.017
4	0.298546	5.108685	49.452031	-3.712170	49.4520384	-3.7120874	0.0266	0.0224	0.0080	10.080	0.016
5	0.130517	-13.854746	49.492144	-3.725041	49.4921353	-3.7250058	0.0262	0.0229	-0.0031	9.905	0.014
6	0.164148	19.429601	49.532194	-3.737959	49.5322092	-3.7379160	0.0252	0.0207	-0.0054	9.956	0.015

Cometary dust evolution

- NEOWISE data are particularly sensitive to large-grained dust (~mm) in cometary tails and comae.

- Kramer et al (2015): Evolution of emitted dust w/ gravitational & non-grav forces to characterize the outburst of comet C/2015 L5 (WISE) in 2010



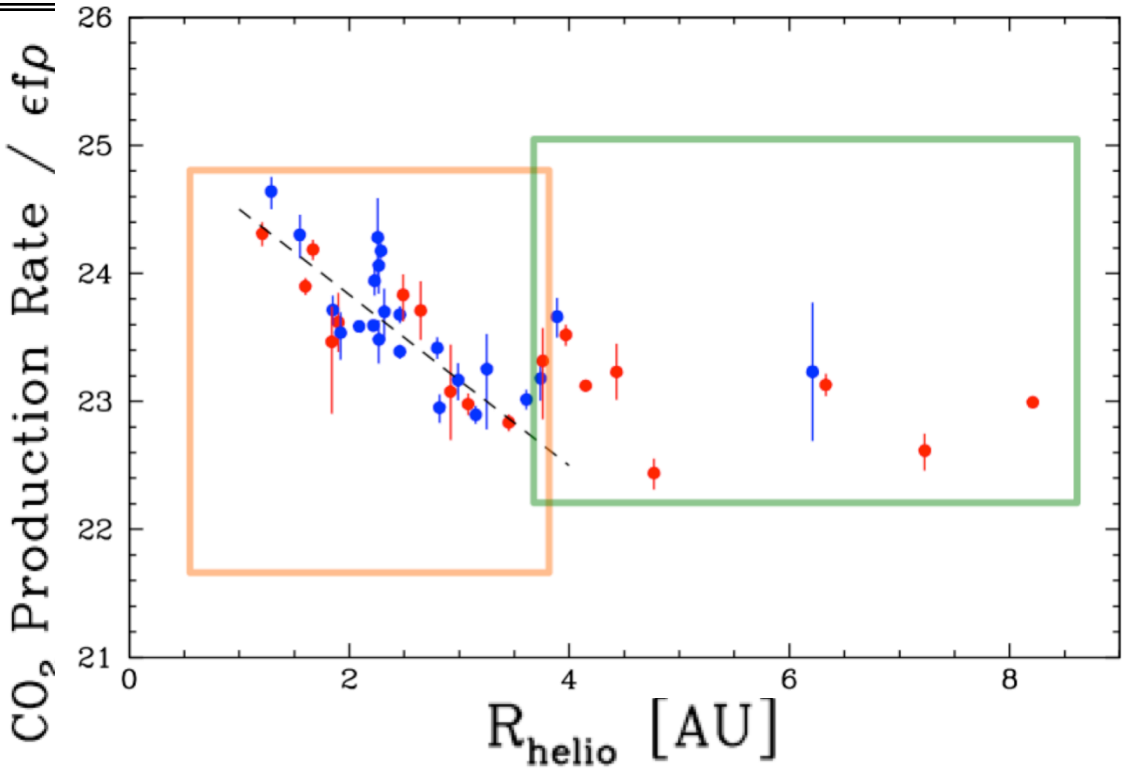
- Automated identification of tail features (green points), lines of unique time emission and lines of constant size particles assuming continuous emission.

- Activity on C/2015 L5 is most consistent with short, strong emission event within a few days of perihelion

- Tail particle sizes: 300 μm- 1 mm.

Properties of NEOWISE-Discovered Comets

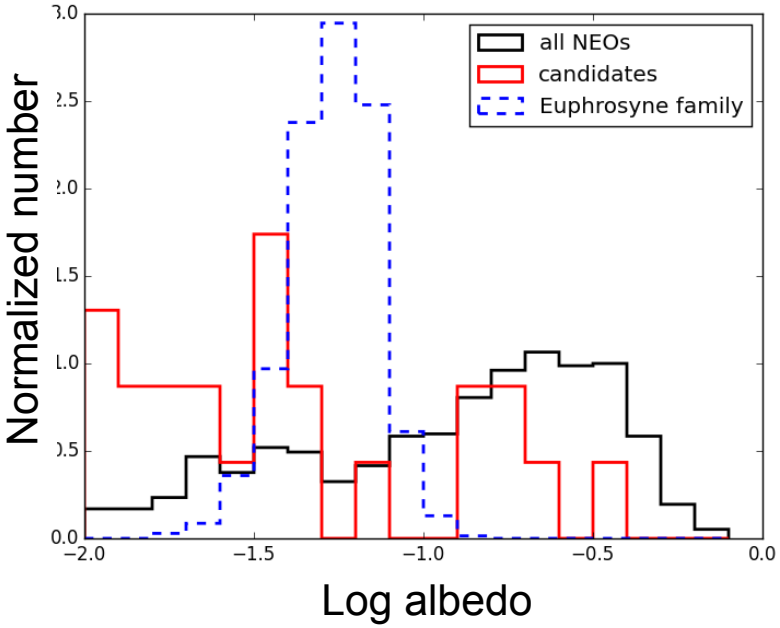
- 4.6 μm channel encompasses CO & CO_2 emission
  - Hard to observe from the ground
- Largest IR sample of comets to date, including long & short period comets
- CO_2 production rate measured for long-period & short-period comets.

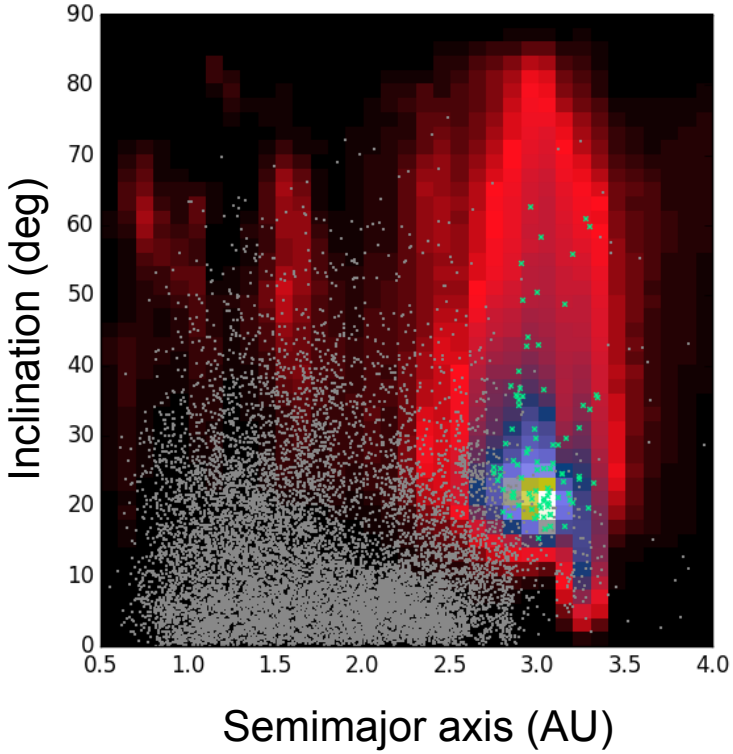


- Activity ~flat >4 AU; increases dramatically when the comets are closer to the Sun, indicating two distinct states of outgassing activity.
- Surprisingly, **no significant difference between the long- and short-period comets**, despite the common assumption that long-period comets are “fresh”!
- Bauer et al. (2015) ApJ accepted

Evolution of Euphrosyne Family Members into NEOs

- Using NEOWISE physical properties, Masiero et al. (2015) tracked the evolution of Euphrosyne family members from the Main Belt into NEO space.
- Family feeds an unusual region of the NEOs, meaning objects there have a high likelihood of having originated in this family: high inclination, dark





Probability density field (background colors) compared to all known NEOs (grey points). Known objects in the high-likelihood region are highlighted in green.

Conclusion

- NEOWISE is discovering & characterizing small bodies
  - Diameters accurate to ±20%, albedos to ±50%
  - Over 15,700 small bodies observed since restart
- Orbital precession will eventually force an end to the mission
- All data from prime mission (2010-2011) released; all data from Restart Year 1 released
- Data access: irsa.ipac.caltech.edu