Exploring the Solar System with the NOIRLab Source Catalog

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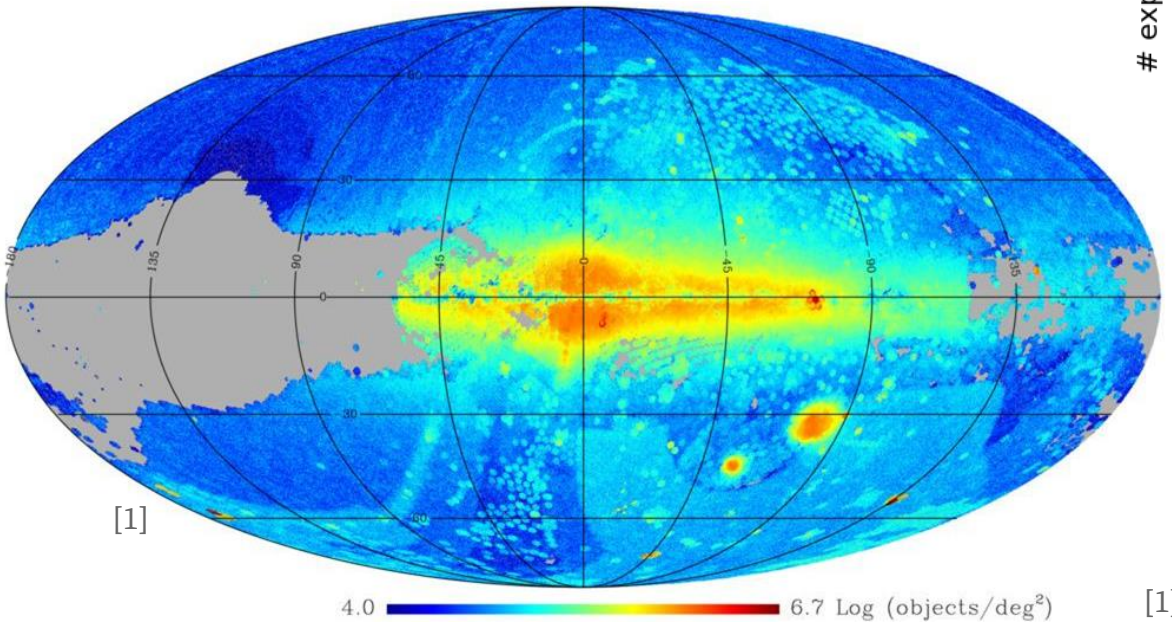
NOIRLab Source Catalog (NSC, Nidever et al 2018, 2021)

68 billion measurements (mmts) of 3.9 billion objects,

from 412,000 exposures in *ugrizY,VR* filters,

providing 7 years of coverage to >80% of the sky



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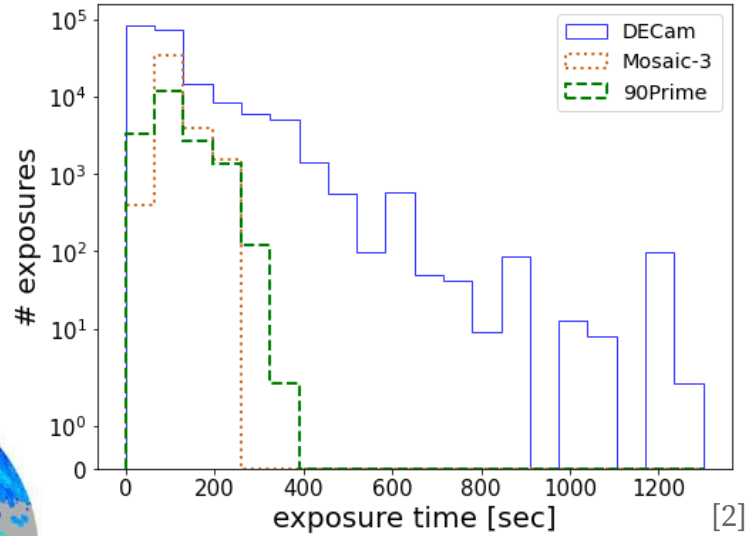


[2]

KITT PEAK NATIONAL OBSERVATORY

CERRO TOLOLO INTER-AMERICAN OBSERVATORY

[1] Nidever et al 2021, [2] Fasbender & Nidever 2021

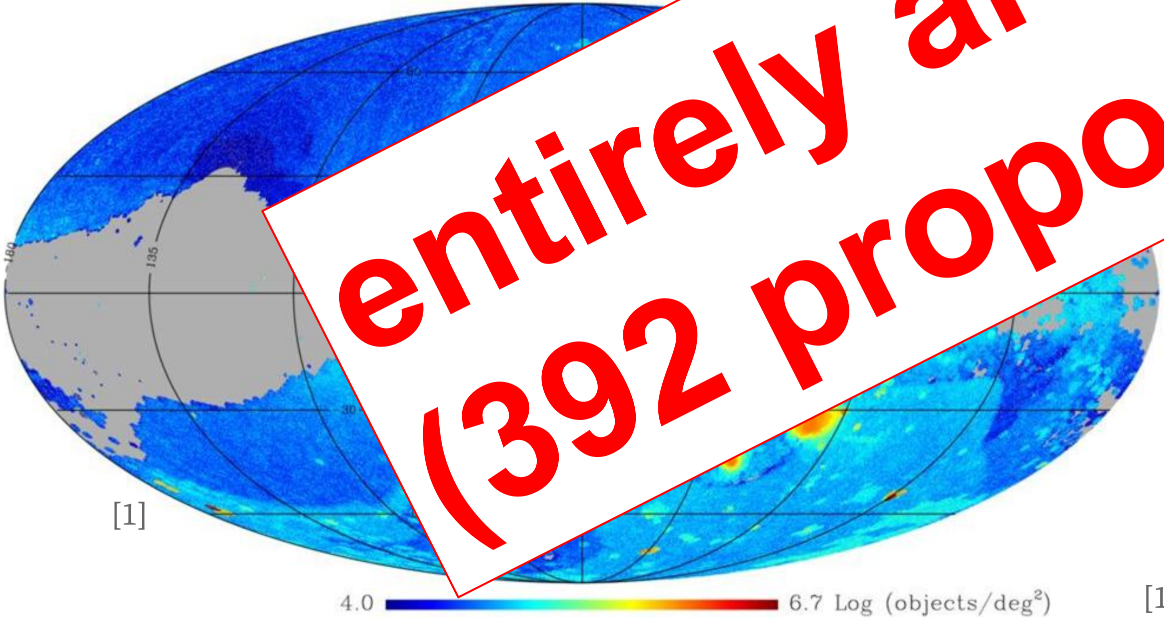
NOIRLab Source Catalog (NSC, Nidever et al 2018, 2021)

68 billion measurements (mmts) of 3.9 billion objects

from 412,000 exposures in *ugrizY,VR* filters

providing 7 years of coverage to >80

entirely archival (392 proposals)



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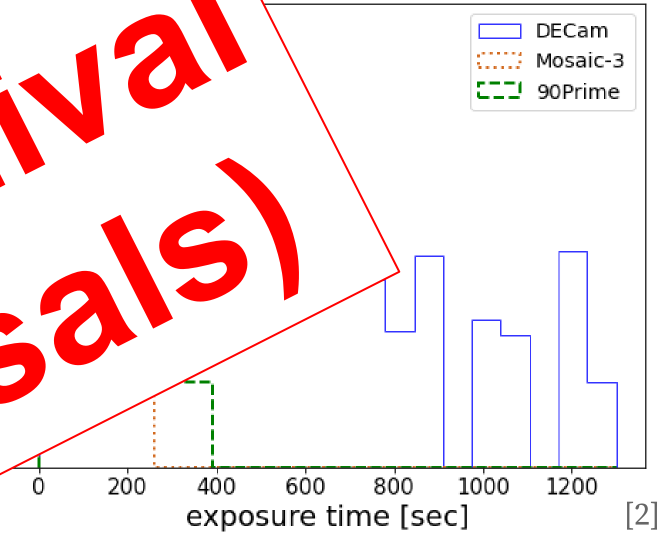

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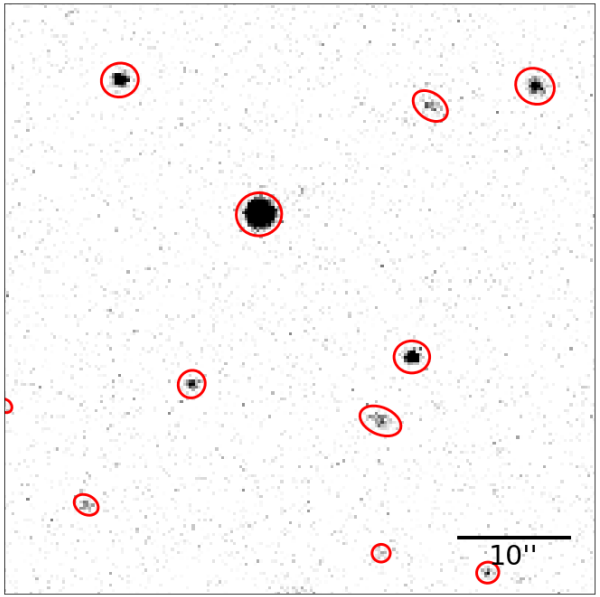
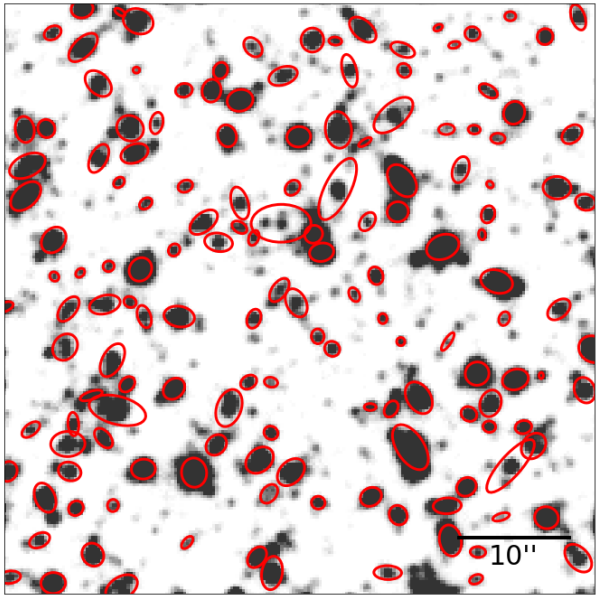
NOIRLab Source Catalog (NSC, Nidever et al 2018, 2021)

Data Release 3 - Better source extraction in crowded areas

DR1,2 Sparse field: good



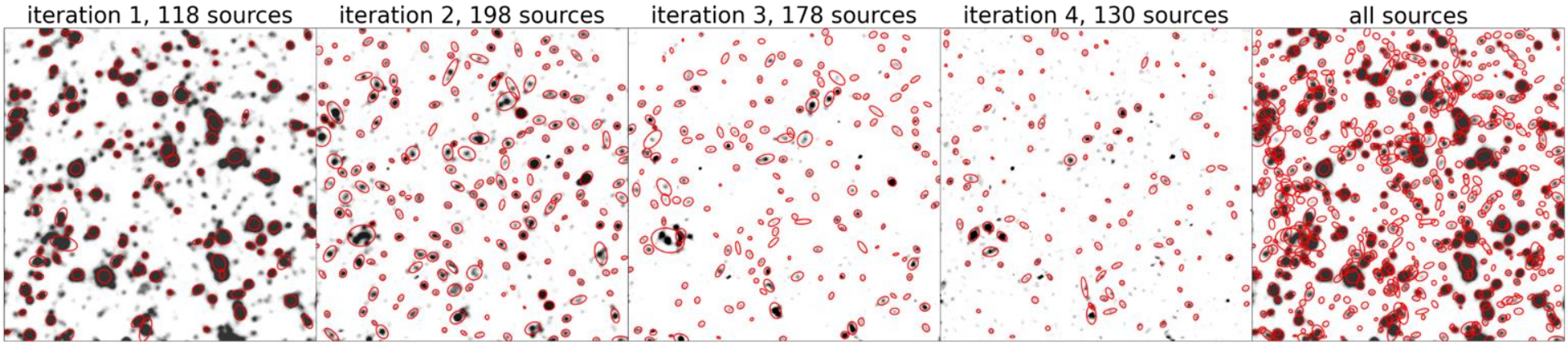
DR1,2 Crowded field: …less good



NOIRLab Source Catalog (NSC, Nidever et al 2018, 2021)

Data Release 3 - Better source extraction in crowded areas

Solution: source modeling + iterative source extraction/subtraction for each exposure



*this is hideously time consuming

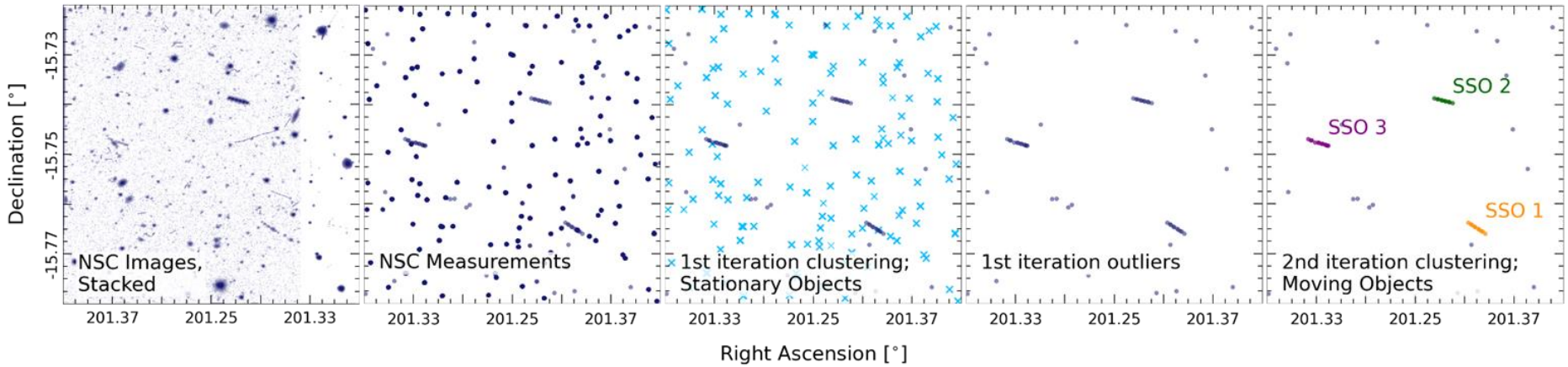
Why did we look for solar system objects in the NSC anyway?

Aspects of NSC	Relation to SSO study
Many measurements of many objects (68 billion measurements of 3.9 billion unique sources)	Millions of measurements of known and undiscovered “moving objects” (SSOs)
Excellent coverage (>80% sky covered, 7 years of observations)	Long SSO observational arcs can improve predictions of its movement. NSC covers areas of sky not often searched for SSOs (in & away from ecliptic)
Combines data from multiple different projects with varying exposure times, observation times/patterns	Diversity in measurements/objects. Can link measurements from different observing projects.
Measurements of objects in **7 photometric passbands** (ugrizY and VR), median magnitude = 21 in all bands	Can detect small/distant objects. Can study SSO color, sizes, dynamical and collisional history.

Identifying detections of Solar System Objects (SSOs) in the NSC - Methods

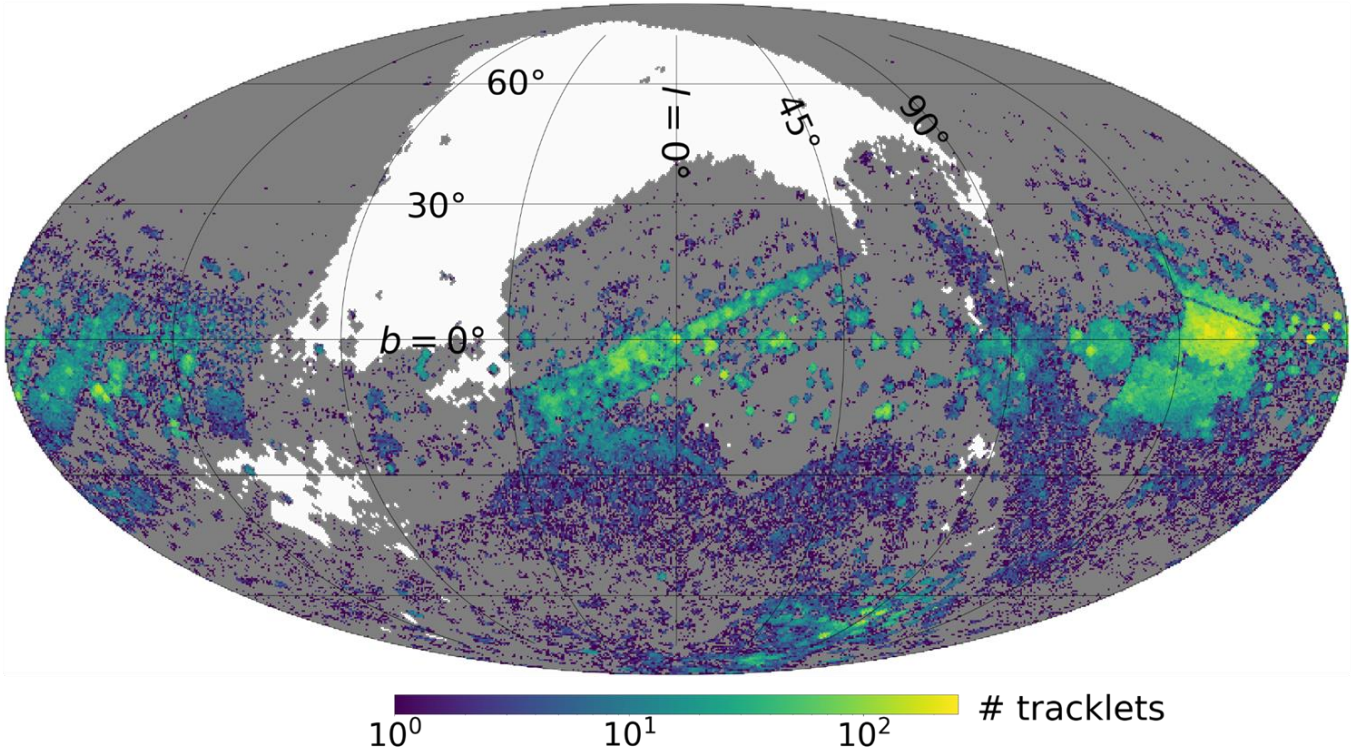
Two detection methods using the tracklet approach (tracklet = 3+ detections of a moving object over 1 evening of observation) to identify SSOs by ~high~ apparent motion

- The Computationally Automates NSC tracklet Finder (CANFind, Fasbender & Nidever 2021) uses DBSCAN to identify “stationary” stars/galaxies, then tracklets.
- The Tough Transform (Fasbender & Nidever, in prep.) identifies tracklets missed by CANFind



Identifying detections of Solar System Objects (SSOs) in the NSC - Results

628,211 tracklets in NSC DR2: **4,681,459 measurements of moving objects in all 7 filters**



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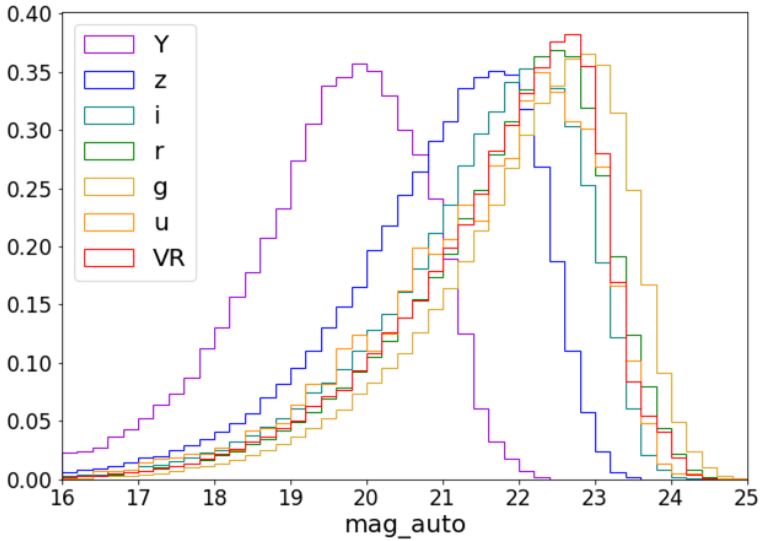


color	# tracklets	multicolor	# tracklets
g-r	193255	g+r+i	116184
r-i	145870	r+i+z	26140
g-i	142816	g+r+z	16276
i-z	53563	i+z+Y	14837
r-z	35268	g+i+z	14490
g-z	22008	r+i+Y	4550

Identifying detections of Solar System Objects (SSOs) in the NSC - Results

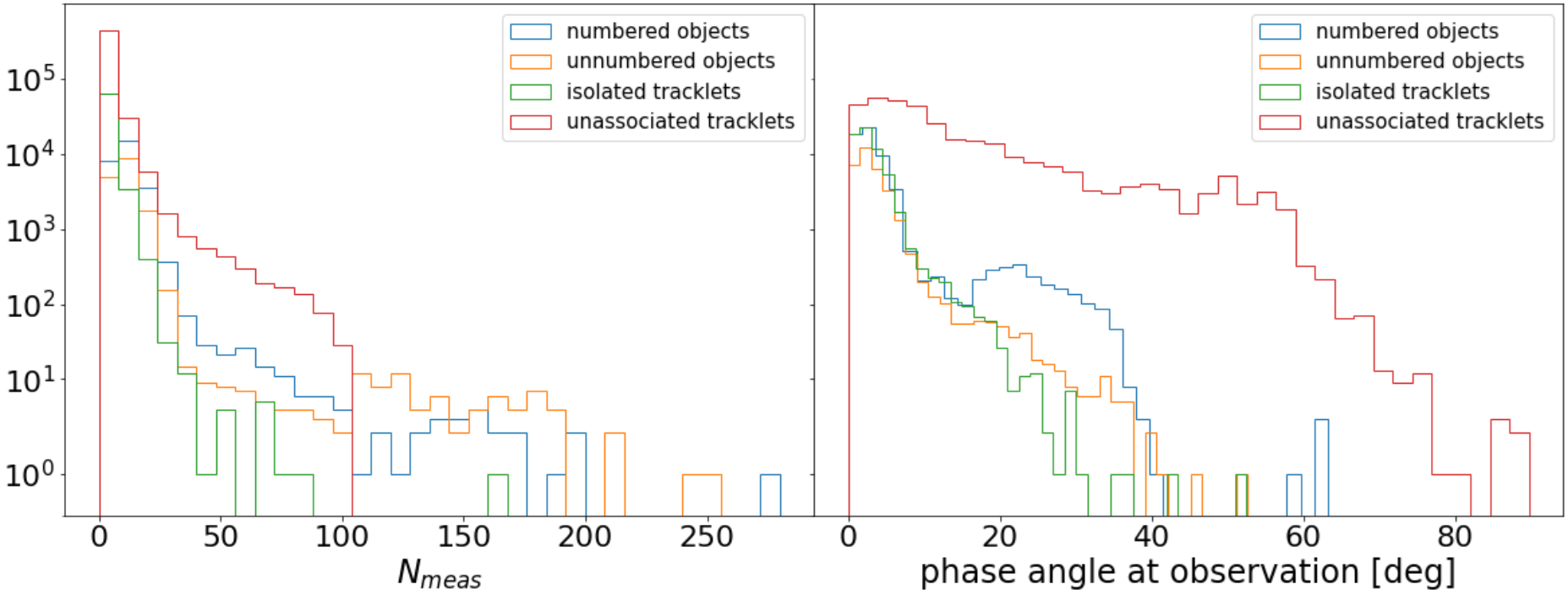
628,211 tracklets in NSC DR2: **4,681,459 measurements of moving objects in all 7 filters**

- 720,000 mmts crossmatched with observations of known objects from Minor Planet Center ($N_{meas}X$)
- 38,400 new mmts of known objects identified through tracklet association ($N_{meas}N$)
- 3,900,000 additional unreported mmts of moving objects

	Unassociated	Numbered	Minor Planet	Unnumbered	Minor Planet	Isolated	Tracklets
filter	$N_{meas}N$	$N_{meas}N$	$N_{meas}X$	$N_{meas}N$	$N_{meas}X$	$N_{meas}N$	$N_{meas}X$
u	364035	412	53	55	4	6	3
g	555538	2700	2959	2026	2355	5417	5407
r	584999	4821	5422	3692	4341	5692	7126
i	509898	810	1147	1110	1082	3977	2716
z	797654	1299	2070	1380	1506	1505	689
Y	666152	214	7	123	1	13	0
VR	427359	6156	271112	4862	151546	10586	262861
Total	3905635	4708	282657	3995	160088	29737	276261

Identifying detections of Solar System Objects (SSOs) in the NSC - Results

Variety!



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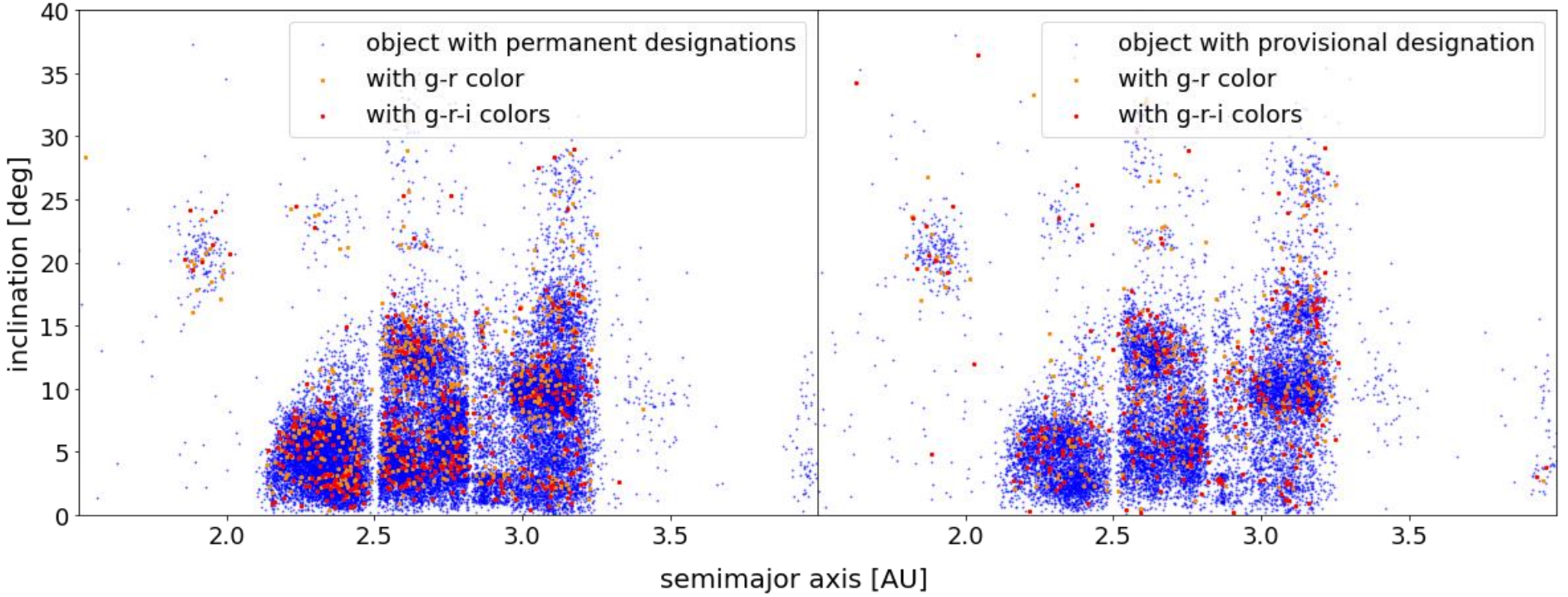
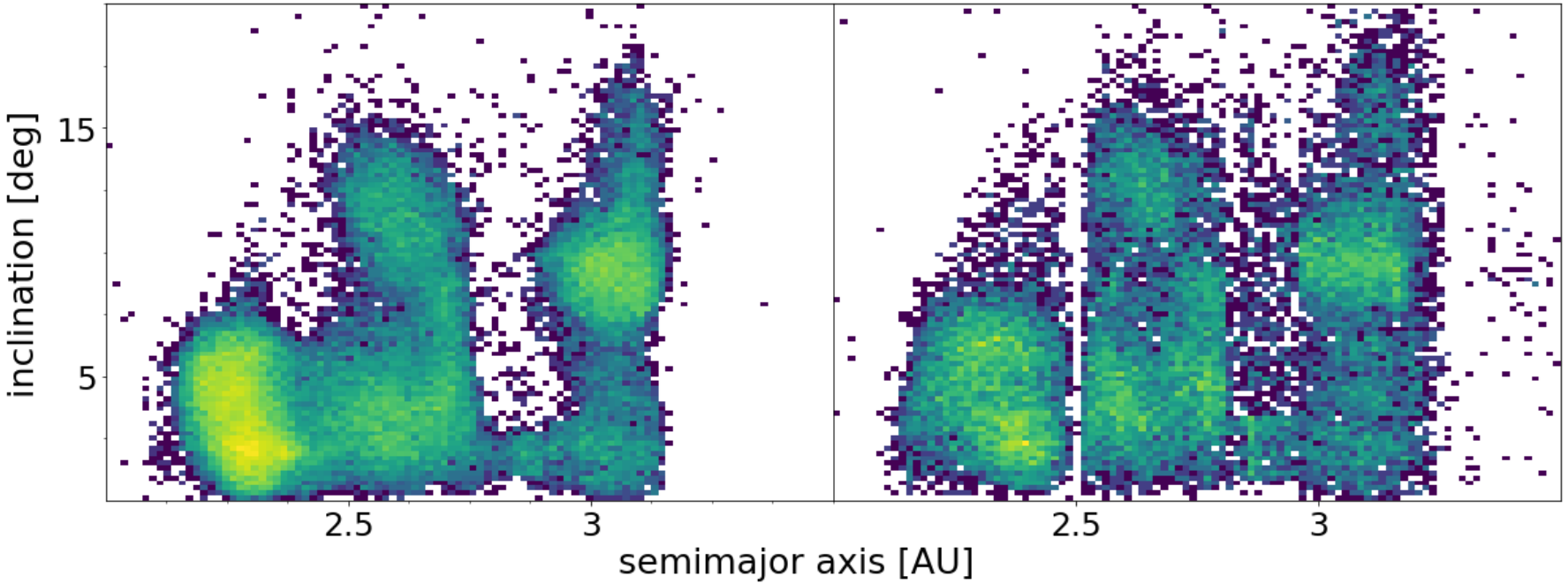


Identifying detections of Solar System Objects (SSOs) in the NSC - Results

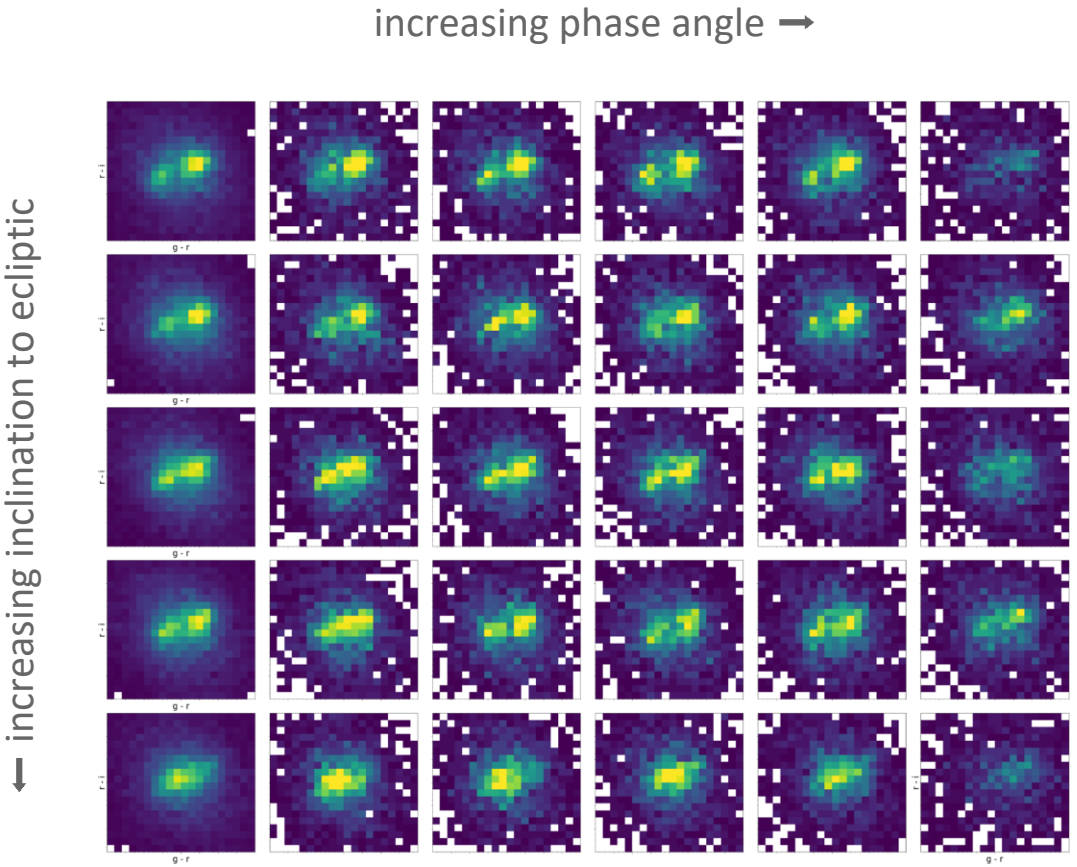
Initial orbit determination of all tracklets (Find_Orb, Gray 2022)



Identifying detections of Solar System Objects (SSOs) in the NSC - Results

Color, inclination, phase angle of unassociated tracklets in the Main Belt

g-r, r-i color-color diagrams



Summary & Future Work

- NOIRLab Source Catalog = archival photometry in the optical/infrared for most of the sky, updates to DR3 will improve accuracy in crowded regions (good for SSO search!)
- 4+ million detections of solar system objects in NSC DR2, 3+ million new
- Orbit determination from 1 night of observations give indication of relative tracklet location in solar system
- Next steps:
    - rotation periods for unassociated tracklets
    - Collisional family membership prediction & orbit prediction with machine learning

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