A Planetary Defense Follow-up Broker

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on behalf of Catalina Sky Survey and the NEOfixer team:

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NEOfixer

- NEOfixer is a target brokering service for NEO observers
- NEOfixer is NOT an LSST “community broker” – it will not be plugged directly into the LSST alert stream. It also accepts user feedback (unlike one-way brokers)
- Primary data sources are Minor Planet Center observations database (direct replication from MPC and/or PDS-Small Bodies Node)
- NEOfixer **will** receive LSST solar system observations filtered through the MPC:
  - NEO Confirmation Page objects
  - Cataloged, published NEOs
  - Non-NEO astrometry is ignored
- Secondary data sources include external lists of objects (JPL impact probability, radar schedules, Yarkovsky candidates)
- NEOfixer is extensible – can accept or publish other data products

NEOfixer

- NEOfixer goals:
  - Improve the NEO orbit catalog, from a planetary defense perspective
  - Provide NEO follow-up observers with customized recommendations for “tonight” and the near future
  - Highlight NEOs in need of observation (and suppress those that do not)
  - Foster coordination among follow-up observers
- NEOfixer considers and scores all cataloged NEOs and all NEOCP/PCCP objects

NEOfixer

- Each list is customized to a particular site's capabilities
- Object priorities are dynamic, changing throughout the night
  - As cost changes (e.g. sky brightness, airmass)
  - When new astrometry is published
  - When external lists change (Scout, Sentry, NHATS, radar, Yarkovsky)
- Built-in coordination mechanism
- Primary data source is astrometry, directly from MPC databases
- Orbits, ephemerides + uncertainties are independently calculated by Find_Orb

NEOfixer

Catalina Sky Survey | LPL Lunar & Planetary Laboratory | NASA

Targets | Status | FAQ | API | Contact | eric | Log out | Register | Search site

Targets (I52)

Filters: Showing 1 to 53 of 53 entries (filtered from 1,199 total entries)

Telescope: I52

Column visibility | CSV | Print | PDF

Previous 1 Next

Show 100 entries

Search:

Packed	Object	Priority	Score	Cost (min)	Import	Urgency	RA (hr)	Dec. (°)	Mag. (V)	Uncert. (")	Rate ("/min)	Elong. (°)	GC	Num. Obs.	Last Obs.	Arc Length	RMS (")	U	H	q	MOID (AU)	NEO	Impact	NHATS	Radar	Yarkov.	Interest	Status	Action
C3R7HJ1	C3R7HJ1	critical	12.72	3	18	2.8	16:23:53	+08:09:30	10.8	0.3172	252.0	144	1	14	19.4h	1.2h	0.6	7.6	26.8	0.99	0.000	100	4	-	-	-	-	-	- select
C3R7GH1	C3R7GH1	critical	11.73	2	6	1.3	11:07:56	+01:14:55	17.3	0.0847	488.3	84	0	14	22.3h	1.9h	0.7	8.4	31.7	0.63	0.000	100	4	-	-	-	0.80	observed	observe
P21G0FQ	P21G0FQ	critical	9.79	6	105	100.0	21:34:38	+00:24:08	20.9	0.1191	0.2	117	1	4	14.6h	1.0h	0.6	12.1	15.7	0.65	0.069	68	-	-	-	-	-	-	- select
P21G0G2	P21G0G2	critical	9.21	22	101	100.0	21:08:56	+03:55:49	21.6	0.1281	0.3	121	1	3	14.6h	1.0h	0.2	12.0	16.3	0.90	0.069	61	-	-	-	-	-	-	- select
K22M01M	2022 MM1	very high	8.64	21	20	8.6	18:12:13	-14:10:41	20.3	0.7184	3.0	167	5	24	350d	8.8d	0.5	7.0	24.6	0.66	0.009	100	-	5247	-	-	-	-	- select
C9CWMP2	C9CWMP2	very high	8.12	11	33	-	00:15:29	+04:03:27	20.2	1.0819	27.9	79	0	8	17.8h	0.7h	0.3	13.1	24.6	0.41	0.001	87	-	-	-	-	-	-	- select
K19P02D	2019 PD2	high	7.79	41	55	1.0	00:18:38	+44:20:05	21.1	0.7650	1.9	66	2	46	3.7y	42d	0.6	6.8	20.0	0.91	0.085	100	-	-	-	-	-	-	- select
K20Y01L	2020 YL1	high	7.23	147	66	0.9	01:00:48	+33:51:04	22.2	0.5742	5.2	60	0	74	2.4y	30d	0.5	6.9	20.5	0.79	0.034	100	-	-	-	-	-	-	- select
K20X00S	2020 XS	high	7.21	115	40	1.3	10:02:19	+13:49:58	21.9	0.5725	7.4	64	0	54	2.5y	30d	0.8	6.6	21.2	0.80	0.078	100	-	-	-	-	0.00	canceled	cancele
K18L06Q	2018 LQ6	med-high	6.90	61	17	0.7	15:13:21	-24:34:32	20.8	1.4732	3.4	148	2	36	4.9y	21d	0.6	6.9	20.5	1.29	0.427	100	-	-	-	-	0.00	canceled	cancele
K07Y00H	2007 YH	med-high	6.56	166	38	0.6	23:47:14	+22:54:29	21.8	1.6627	4.5	78	1	83	15y	46d	0.5	6.3	20.2	0.82	0.163	100	-	-	-	-	-	-	- select
K20R05C	2020 RC5	med-high	6.45	159	20	0.6	22:22:21	-23:23:42	22.0	0.6590	2.2	114	0	24	2.7y	31d	0.7	6.6	21.7	1.22	0.223	100	-	-	-	-	-	-	- select
K10A02N	2010 AN2	med-high	6.28	73	30	0.2	23:06:26	-26:28:24	20.8	2.0864	4.6	106	0	44	13y	54d	0.7	6.3	22.2	0.84	0.068	100	-	-	-	-	-	-	- select
C9CU8E2	C9CU8E2	medium	5.84	2	36	0.8	20:53:55	-24:51:54	19.3	0.0003	2.5	134	1	19	1.7h	17.8h	0.2	10.2	20.8	1.15	0.134	100	-	-	-	-	-	-	- select
P21FZuX	P21FZuX	medium	5.80	15	19	0.9	15:14:17	+26:21:41	21.9	0.0024	1.0	120	0	9	15.6h	6.2h	0.3	11.5	23.0	1.11	0.110	100	-	-	-	-	-	-	- select
C9CHDU2	C9CHDU2	medium	5.48	7	20	0.5	22:19:26	-17:22:29	21.1	0.0009	2.2	113	0	13	19.4h	23.3h	0.4	10.0	23.8	0.57	0.038	100	-	-	-	-	-	-	- select
A10VGGW	A10VGGW	medium	5.38	84	60	93.0	23:34:50	-17:49:00	19.3	17.7585	7.3	97	0	4	19.4h	0.7h	0.5	12.3	20.6	0.97	0.041	93	-	-	-	-	-	-	- select
K19X01F	2019 XF1	medium	5.10	164	19	0.9	13:44:06	-33:00:23	22.3	0.0323	1.8	130	2	58	3.4y	58d	0.6	5.1	22.3	1.05	0.179	100	-	-	-	-	-	-	- select
K23F01O	2023 FO1	med-low	4.96	73	41	1.5	22:11:39	+64:34:06	22.1	0.0016	1.5	77	5	48	52d	38d	0.5	6.7	21.5	0.93	0.056	100	-	-	-	-	-	-	- select
K12TP9A	2012 TA259	med-low	4.83	96	36	0.3	12:46:54	+29:33:15	20.7	10.3241	6.3	94	0	52	11y	23d	0.5	7.4	20.3	0.49	0.171	100	-	-	-	-	-	-	- select
K23K00W	2023 KW	med-low	4.79	32	26	1.2	11:53:14	-13:43:35	22.0	0.0008	2.6	100	0	28	8.2d	20d	0.7	7.3	22.9	0.69	0.046	100	-	-	-	-	-	-	- select

API

View Edit Delete Revisions Devel

Contents

Overview

The NEOfixer API allows programs to retrieve all the information that is available on the website, excluding plots. This includes customized lists of targets and the details about specific objects. The API can also be used to report your observing status for an object to facilitate better coordination between stations.

The NEOfixer API is easy to use. The target and object pages contain **API Link** buttons with the API link for the data you are viewing. The target list web page also provides an API link that includes the filters you've chosen, called **Filtered Targets API Link**, making it very easy to build an API call for a customized list of targets. Those links can be used directly by programs.

API calls start with the following URL, which on it's own does nothing except return some built-in help:

https://neofixerapi.arizona.edu

NEOfixer scoring

Calculate and combine *five independent quantities*:

Per object:

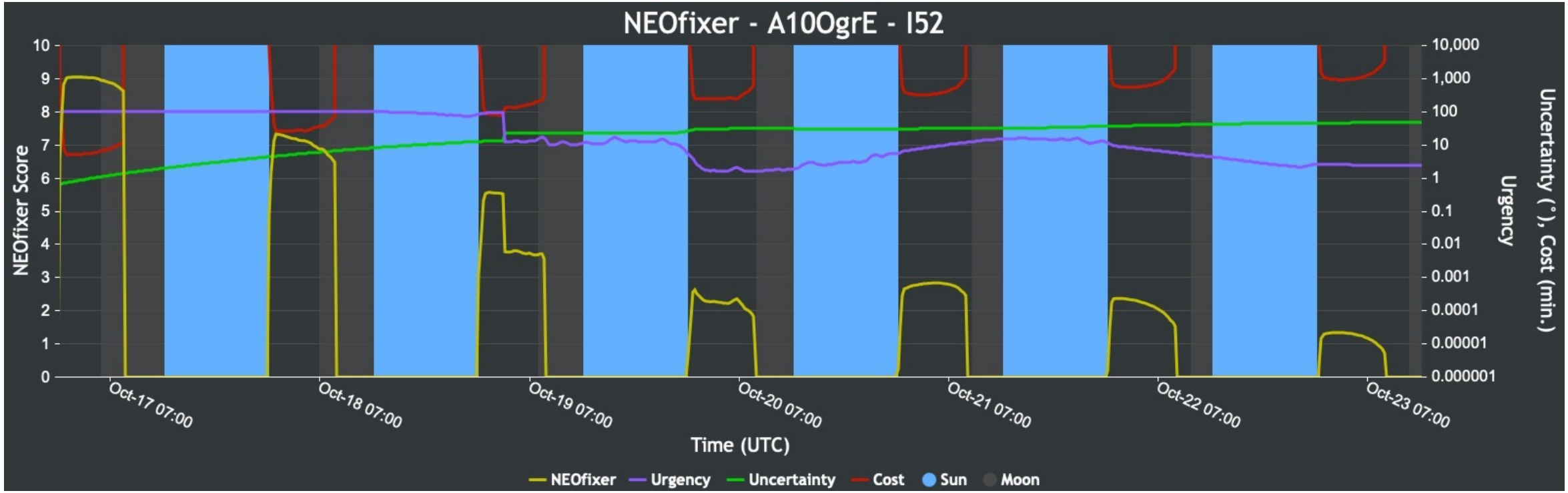
- Importance of each NEO / NEOCP object
  - How large (H); how close (MOID), potential impacts or other interest?
- Confidence that the object exists + linkage is correct
  - How reputable is the submitter; confirming observations?

Per observation:

- Cost to observe
  - Calculated per telescope+instrument+site combination
- Benefit to object's orbit
  - Sky-plane uncertainty as a proxy for orbital uncertainty
- Urgency to observe
  - Becoming easier or more difficult to observe? What are other sites' intentions?

NEOfixer scoring

Scores are calculated for every ephemeris step (15 min). Plot shows NEOfixer scores for NEOCP object for the upcoming week. Best time to observe A10OgrE from I52 is now!



Verbose scoring breakdown for “tonight” is also available in Scores and Interest tab

Scores and Interest

NEOfixer Score for A10OgrE at I52

Quantity	Value	ΔScore
Importance	5.790	0.76
Benefit	17.424	1.24
Urgency	99.776	2.00
Cost	5.712	-0.76
Confidence	0.064	-1.19
Interest	1.000	0.00
Time of max tonight (t_{max})	2022-10-17 03:00:00 UT	
NEOfixer (at t_{max})	112.9493	critical 9.05

Importance

Quantity	Basis	Value	ΔScore
S_H	H = 28.82	2.201	0.34
S_{MOID}	$MOID_\odot$ = 0.002226 AU	2.652	0.42
P(NEO)	find_orb p_NEO = 99.2%	0.992	-0.00
S_{Scout}	Scout rating = 0	1.000	0.00
Base Importance (target table)		5.838	--
Importance		5.790	0.76

Benefit

Quantity	Basis	Value	ΔScore
S_{uncert}	1σ uncert. = 0.786351° = 2830.86"	1.742	0.24
S_U	U = 12.31	10.000	1.00
Benefit		17.424	1.24

Urgency

Quantity	Basis	Value	ΔScore
$Cost_1$	Optimal cost score in near future	1040.459	--
$Cost_0$	Optimal cost score tonight	4.952	--
Ratio (r)		210.127	--
Urgency		99.776	2.00

Cost

Quantity	Basis	Value	ΔScore
$t_{integrate}$	One visit integration time (minutes)	0.062	--
N_{fields}	1σ uncert. = 0.786351° = 2830.864"	5.017	--
C_{fields}	1σ uncert.	6.034	--
$C_{confusion}$	Galactic confusion (GC) = 0.000	1.200	--
Base cost in minutes (target table)		4.876	--
Cost		5.712	-0.76

Confidence

Quantity	Basis	Value	ΔScore
P	Raw confidence	0.881	--
Confidence		0.064	-1.19

Interest

Site	Time (UTC)	Status	Value	ΔScore
No observing interest reported				
All interest (target table)			0.0	--
Others' interest (besides I52)			0.0	--
Interest			1.000	0.00

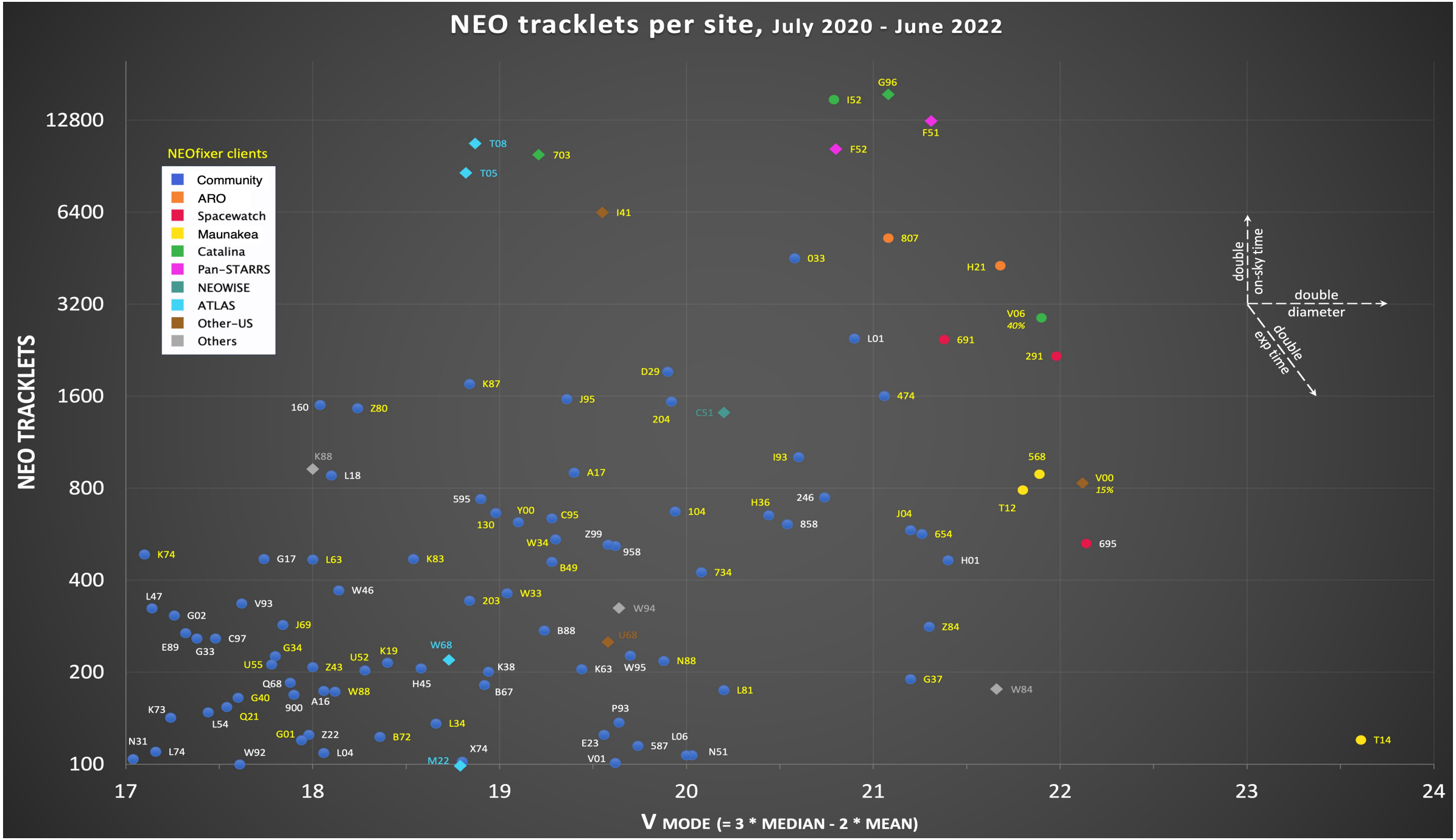
Last Updated: 2022-Oct-16 23:43:54 UTC

Coordination / communication

- Subscribing sites can communicate with NEOfixer about observation actions
- Sites can tell NEOfixer: *may observe, will observe, observing, observed, found, reported, not found, canceled*
- These actions adjust the priority scores for all other sites
- Can be communicated via the website or the API
- Everyone's action messages are visible to NEOfixer users

Who's using NEOfixer?

- ~130 user accounts
- 100+ unique, user-defined telescope sites have been created
  - Apertures range from 0.2-m to 8-m
  - More sites are welcome – NEOfixer is designed with everyone in mind:
    - Full-time professional follow-up stations
    - Dedicated amateur observers
    - Occasional use of high-value telescopes
- Non-observers are also welcome to browse NEOfixer
  - All 32,000+ NEOs have object pages from MPC code 500 (geocenter)
  - Object pages have orbits, ephemerides, benefit plots, orbit viewer, etc.

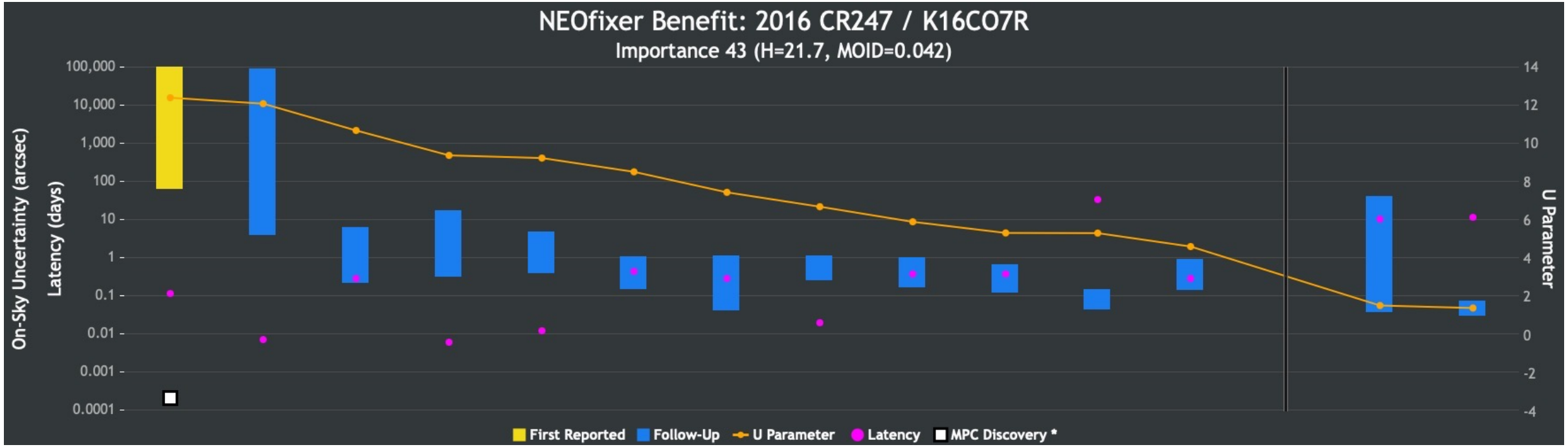

NEO tracklets per site, July 2020 - June 2022
NEOfixer clients
Community
ARO
Spacewatch
Maunakea
Catalina
Pan-STARRS
NEOWISE
ATLAS
Other-US
Others
NEO TRACKLETS
12800
6400
3200
1600
800
400
200
100
17
18
19
20
21
22
23
24
V MODE (= 3 * MEDIAN - 2 * MEAN)
double on-sky time
double diameter
double exp time
G96
I52
F51
T08
703
F52
T05
I41
807
033
H21
V06
40%
L01
691
291
D29
K87
J95
474
160
Z80
204
C51
K88
L18
I93
568
A17
V00
15%
595
H36
246
T12
Y00
C95
104
J04
130
858
654
W34
Z99
958
695
K74
G17
L63
K83
B49
H01
734
W46
L47
V93
203
W33
W94
G02
J69
B88
U68
Z84
E89
G33
C97
G34
W68
U52
K19
U55
Z43
K38
K63
W95
N88
Q68
H45
B67
L81
G37
W84
G40
W88
900
A16
K73
L54
Q21
P93
L34
G01
Z22
B72
E23
L06
587
N51
N31
L74
W92
L04
X74
M22
V01
T14

Benefit estimates

- NEOfixer estimates benefit from sky-plane uncertainty, in service of assigning target priorities
- BUT – this technique can be used retroactively, to estimate benefit for *any tracklet*
- Iteratively solve an orbit, adding one tracklet at a time, in order of *submission time*
- Generate sky-plane uncertainty estimates both with and without the tracklet; ratio of pre-tracklet uncertainty to post-tracklet uncertainty is the benefit.
- Benefit can be weighted by NEOfixer's object Importance metric

Benefit plots

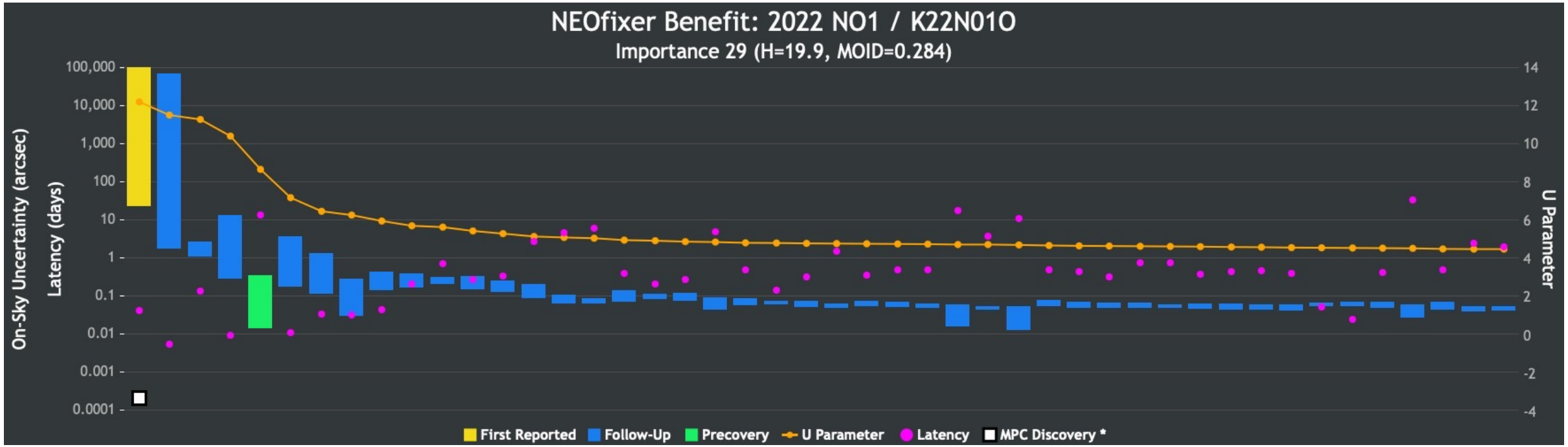
Some orbits are efficiently constructed – nearly all tracklets provide substantial benefit to the orbit. Height of rectangle correlates with benefit.



Benefit plots

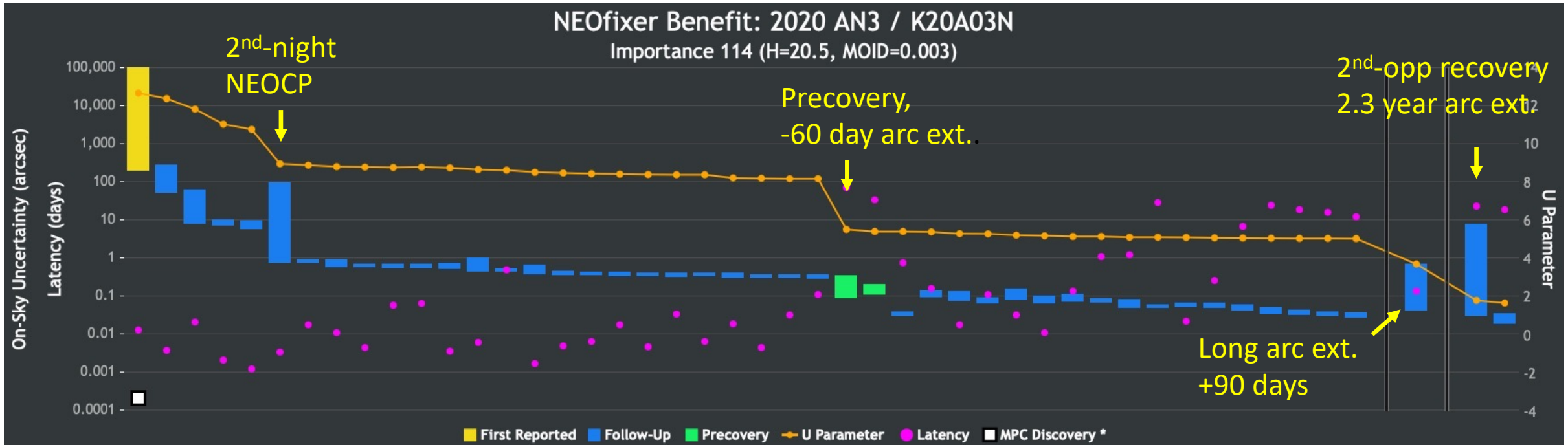
Other orbits contain unnecessary or minimally beneficial tracklets:

(Benefit plots are interactive at https://neofixer.arizona.edu)



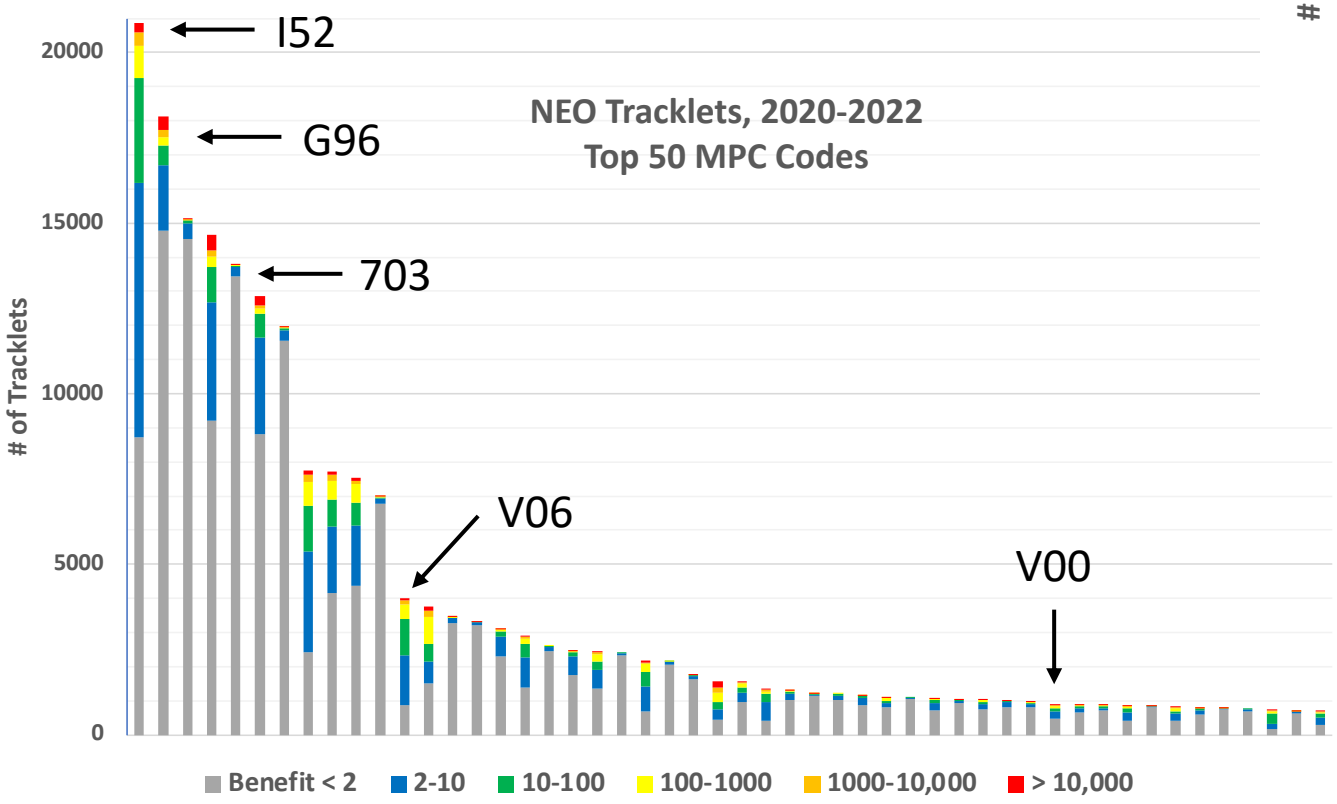
Benefit plots

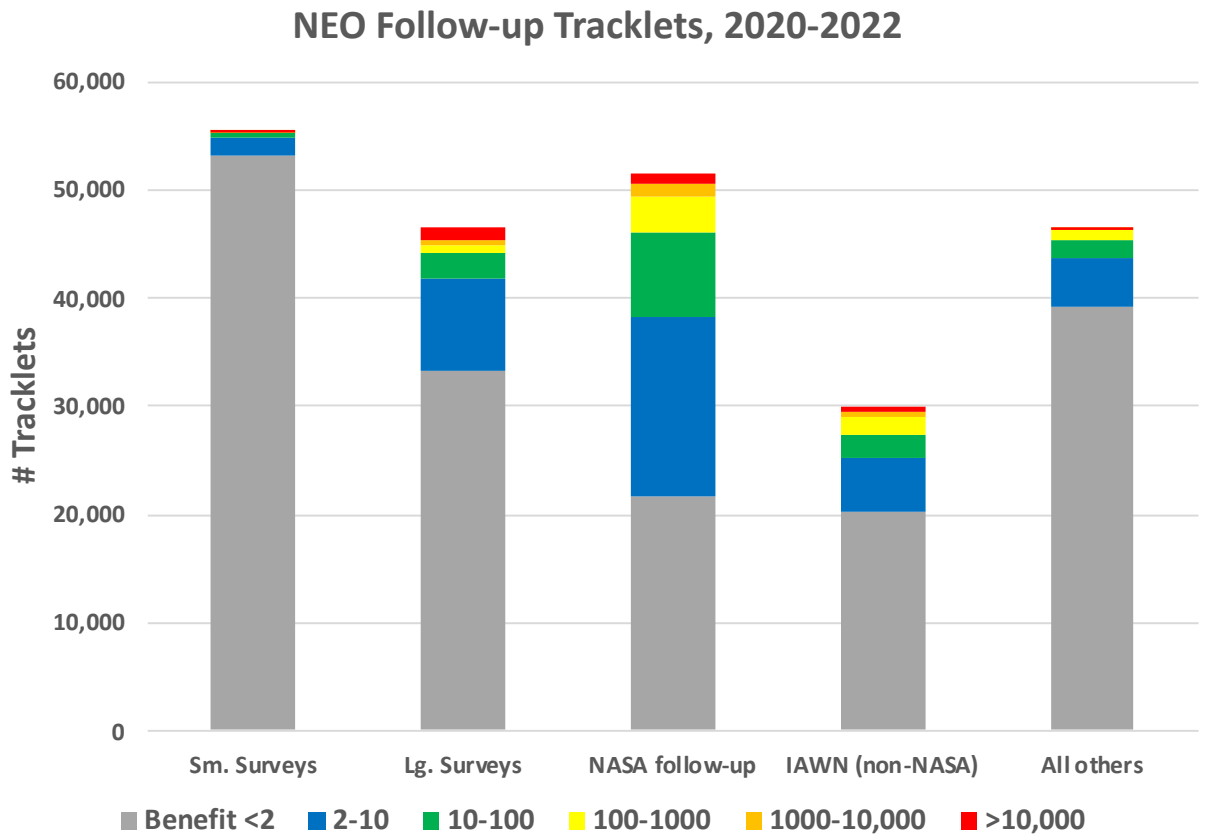
The most beneficial tracklets are often early NEOCP observations or second-apparition recoveries



Follow-up Benefit

- Benefit information can help measure performance of MPC codes or groups of codes

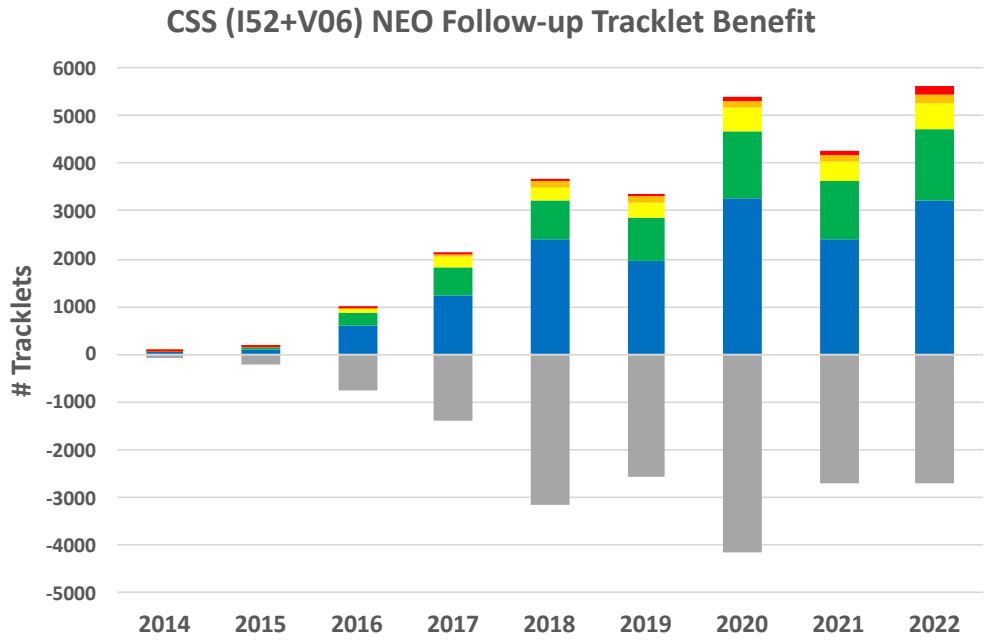


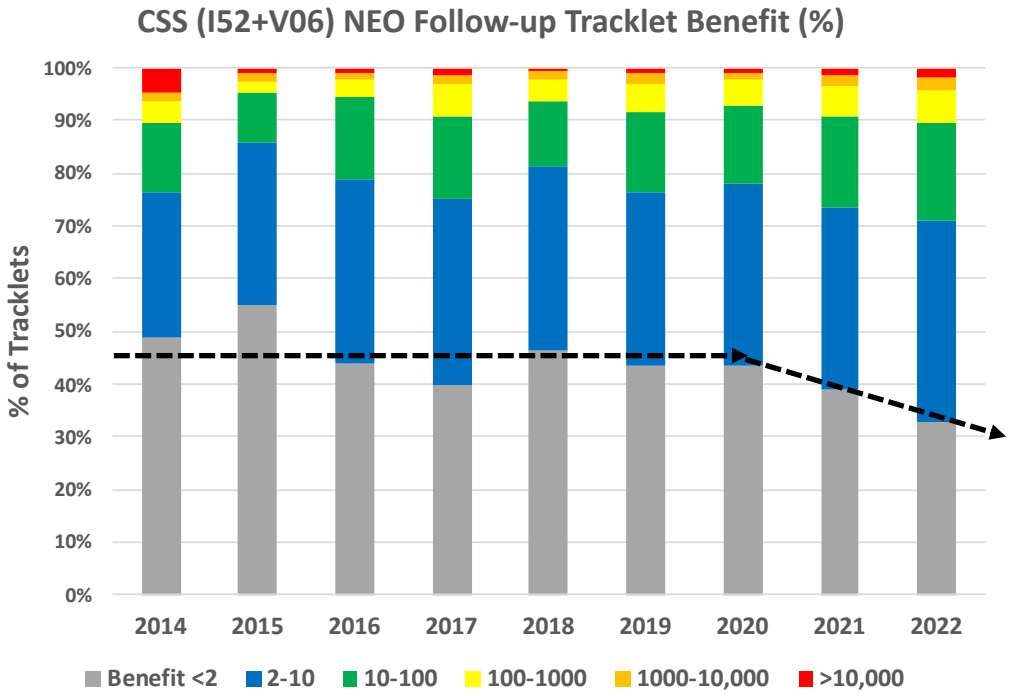


- Benefit <2 is considered “low-benefit”
- Follow-up programs should avoid creating low-benefit tracklets!
- NEOfixer can help….

Follow-up Benefit

- Can track follow-up station performance over time, for example CSS NEO follow-up (I52 + V06) since 2014
- Working to improve aggregate benefit. Note low-benefit fraction trending downward →
- NEOfixer integration began in 2021





Future NEO follow-up challenges

- LSST may publish observations through multiple paths:
  - 3 linked tracklets (pairs) over multiple nights
    - Decent orbits, ready for publication as new objects.
    - Published “next day,” after collection of third tracklet
    - Follow-up not required except for interesting objects
  - Streaked pairs of observations, from the alert stream
    - Insufficient to calculate orbit – prompt follow-up required
    - Published immediately, during the night (assumes someone is linking streaked pairs)
  - Serendipitous triples or quads – from standard cadence or field overlap
    - Insufficient to calculate orbit – prompt follow-up required
    - Published next day

Future NEO follow-up challenges

- Current follow-up assets are well-matched to current survey capability, but…
- Future surveys (LSST and NEO Surveyor) will discover NEOs at fainter magnitudes (V>23) and at greater volume (~10x current rates)
- Traditional methods for identifying NEO candidates (e.g. digest2) may not scale
- Important for LSST to deliver high-confidence, high-purity observations/orbits to the Minor Planet Center!
- False linkages are often exotic and may waste follow-up resources, attract unwanted attention

Too Much of a Good Thing? Rapid NEO Follow-up Strategies in the Era of LSST

T. Wagg [1], M. Juric [1], P. Yoachim [1], S. Cornwall [2], J. Moeyens [1], S. Eggl [2], and R. L. Jones [1]

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ABSTRACT

We present new predictions for the impact that the Rubin Observatory Legacy Survey of Space and Time (LSST) will have on the Near Earth Object (NEO) follow-up system, and especially the NEO Confirmation Page (NEOCP). NEO candidates are currently found at a rate of 10-30/night and, if they meet certain criteria, announced on the NEOCP for community follow-up. We use mock LSST observations and the `digest2` code to quantify the effect of Rubin on the NEOCP. We find that, when using current submission criteria, Rubin would typically contribute 1100 new objects to the NEOCP each night, 2 orders of magnitude higher than the current rates. Typically only 3% of these candidates would be NEOs, where the rest are main belt asteroids (MBAs). As such an increase would overwhelm the NEO follow-up system, we consider mitigation strategies. We develop an algorithm that predicts (with 76% efficiency) whether Rubin itself will self follow-up the object; these can then be flagged on the NEOCP. However, even with this algorithm enabled, Rubin would still submit around 170 NEO candidates per night (with only ∼1.5% purity). We conclude that the main challenge is the large background of undiscovered 22-24th mag MBAs masquerading as NEOs. We recommend that in the first 1-2 years the community focuses on following up only the highest probability Rubin-reported NEO candidates, until most of the MBA background is catalogued. We show that a pure sample can be attained using ecliptic latitude cuts or focusing on NEOs exhibiting trails.

Keywords: Near-Earth objects, Asteroids, Solar system, Small Solar System bodies, Surveys

Future NEO follow-up challenges

- Wagg et al. suggest predicting which NEO candidates might be incidentally self-followed up by LSST
- Lots of open questions about how external follow-up resources can optimally behave to supplement LSST observations
- Tools like NEOfixer can help identify high-priority targets and coordinate scarce follow-up resources (for planetary defense)
- NEOfixer architecture could be extended to:
  - Accept “possible future pointings” from surveys
  - Incorporate Rubin-provided estimates of likely self-follow-up
  - May need to modify scoring algorithms for Confidence and Urgency
  - Open to suggestions!

NEOfixer quick start guide

- Go to https://neofixer.arizona.edu/
- Read the FAQ
- Browse site 500 for all 32,000+ NEOs, or load a sample site (I52, T14, J95)
- Filter target lists, add/hide columns, sort by any table column
- For observers:
  - Register for an account
  - Create or request authorization for a telescope site
  - Communicate intentions/actions to NEOfixer via the website or API
- See ACM poster #2328 by D. Carson Fuls
- Send questions or comments through the Contact form, or directly to me, *eric@arizona.edu* *

* but only until July 28…!