NEOfixer Targeting Broker

Coordinating and Optimizing Global NEO Follow-up

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Catalina Sky Survey

On behalf of the NEOfixer / CSS team:

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NEOfixer: Toplevel goals

- Strategically improve the quality of the NEO catalog, *guided by Planetary Defense concerns*
  - Encourage unique, timely observations of important objects
  - Discourage observations that do little to improve orbits
  - Facilitate communication across the follow-up community
- Optimize worldwide NEO follow-up activities now, and scale to the demands of future surveys
- Answer the general question, *"What is the most valuable NEO observation a follow-up site can make at any moment?"*

NEOfixer: Scoring

Calculate and combine *five independent quantities*:

Per object:

- Importance of each NEO / NEOCP object
  - How large (H); how close (MOID); how dangerous (VI)?
- Confidence that the object exists (NEOCP objects only)
  - 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: under the hood

For ***every object***, for ***every observer***, for ***all times***, assign a value to potential observations:

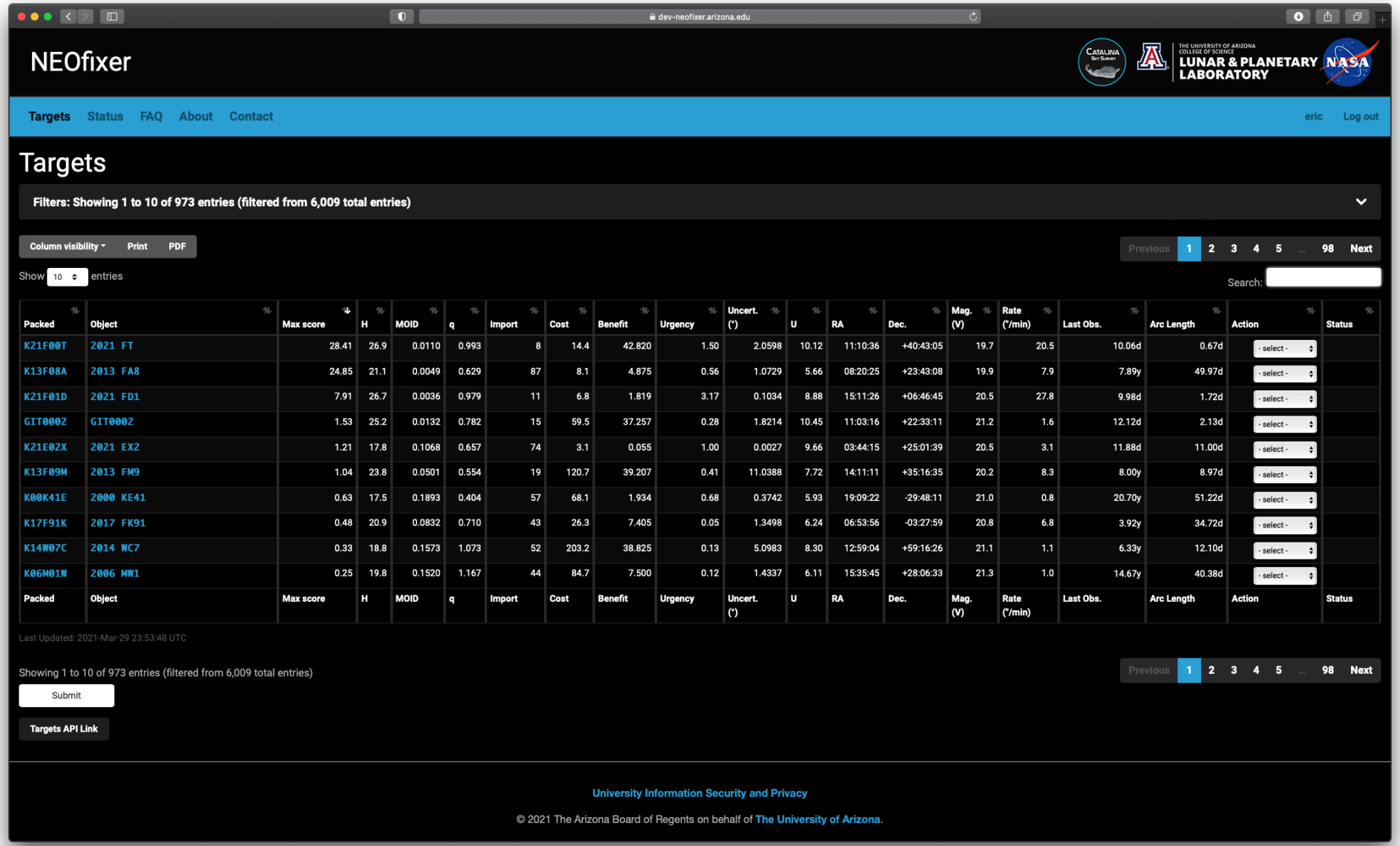
```
while {1} {
        GetAstrometry                                   // of NEOs and NEO candidates, from MPC services
        GetMetadata                                     // from JPL Scout/Sentry/NHATS/Yarkovsky, NeoDys
        GetObjectInterest                               // communications from observers about intent/success/failure to observe

        foreach object {                                // in NEO catalog, NEOCP
                SolveOrbit                              // using Find_Orb
                CalculateImportance                     // based on H, MOID, IP
                if {NEOCP} {CalculateConfidence} {      // based on num obs, reputation of submitter, confirming follow-up
                foreach site [I52, J04, J95, 204, Z80 …] {      // all subscribing sites
                        MakeEphem                       // topocentric, for ~14 days, 10-min step size
                        foreach ephemeris step {
                                CalculateCost           // based on V magnitude, uncertainty, sky brightness, airmass, stellar confusion
                                CalculateBenefit        // based on sky-plane uncertainty, U parameter
                                CalculateUrgency        // Ratio of min. cost tonight over min. cost after tonight
                                CalculateNEOfixerScore  // Combine Importance, Confidence, Cost, Benefit, Urgency
                        }
                }
        }
        Publish/update site-specific, rank-ordered targeting recommendations
        Publish/update object pages
}
```

NEOfixer: user interaction

- Will support programmatic, machine-to-machine interaction via an API
  - Useful for major programs with significant software expertise and compute resources
  - *https://neofixerapi.arizona.edu/targets/?site=I52&vmag-bright=0.0&vmag-faint=21.5&cost-min=0.0&cost-max=30.0&rate-min=0&rate-max=100000&uncert-min=0.0&uncert-max=1.0&dec-min=-90&dec-max=90&ra-min=0&ra-max=360*
- Will also offer web interface for manual interaction (see additional slides)
  - Useful for single observers or small teams
- NEOfixer is designed to serve a variety of NEO follow-up modes:
  - NEOfixer directly advises scheduling software: tight feedback loop between NEOfixer and queue management software / validation pipelines (CSS use case)
  - Follow-up observers advises NEOfixer: informs NEOfixer of targeting plans; target selection may be based on non-NEOfixer sources
  - Follow-up observers do not interact with NEOfixer, but NEOfixer picks up astrometry from MPC sources when published

NEOfixer summary

- NEOfixer will evaluate all possible targets and create prioritized lists, customized for each user
  - Based on site location and characteristics, equipment, and follow-up capabilities and preferences
- NEOfixer recommends targets; observers provide feedback to NEOfixer
- Object scoring is very dynamic – updates quickly in response to:
  - New astrometry
  - New impact probability
  - Communication from users about specific objects
- Goal is to improve community follow-up performance: more timely/targeted observations, less duplication of effort, overall better orbit catalog
- Will include built-in metrics to evaluate site performance, down to the tracklet level (e.g. “these observations were very useful, those were less useful, that one had little value”)
- Early evaluation suggests that NEOfixer may steer observers toward challenging targets
- Critical dependency on low-latency, reliable MPC publication of astrometry (NEOCP/NEO)
- Currently in development / internal beta testing; community beta testing soon. Public release Q3/4 2021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Search:
Packed Object Max score H MOID q Import Cost Benefit Urgency Uncert. (°) U RA Dec. Mag. (V) Rate (°/min) Last Obs. Arc Length Action Status
K21F00T 2021 FT 28.41 26.9 0.0110 0.993 8 14.4 42.820 1.50 2.0598 10.12 11:10:36 +40:43:05 19.7 20.5 10.06d 0.67d - select -
K13F08A 2013 FA8 24.85 21.1 0.0049 0.629 87 8.1 4.875 0.56 1.0729 5.66 08:20:25 +23:43:08 19.9 7.9 7.89y 49.97d - select -
K21F01D 2021 FD1 7.91 26.7 0.0036 0.979 11 6.8 1.819 3.17 0.1034 8.88 15:11:26 +06:46:45 20.5 27.8 9.98d 1.72d - select -
GIT0002 GIT0002 1.53 25.2 0.0132 0.782 15 59.5 37.257 0.28 1.8214 10.45 11:03:16 +22:33:11 21.2 1.6 12.12d 2.13d - select -
K21E02X 2021 EX2 1.21 17.8 0.1068 0.657 74 3.1 0.055 1.00 0.0027 9.66 03:44:15 +25:01:39 20.5 3.1 11.88d 11.00d - select -
K13F09M 2013 FM9 1.04 23.8 0.0501 0.554 19 120.7 39.207 0.41 11.0388 7.72 14:11:11 +35:16:35 20.2 8.3 8.00y 8.97d - select -
K00K41E 2000 KE41 0.63 17.5 0.1893 0.404 57 68.1 1.934 0.68 0.3742 5.93 19:09:22 -29:48:11 21.0 0.8 20.70y 51.22d - select -
K17F91K 2017 FK91 0.48 20.9 0.0832 0.710 43 26.3 7.405 0.05 1.3498 6.24 06:53:56 -03:27:59 20.8 6.8 3.92y 34.72d - select -
K14W07C 2014 WC7 0.33 18.8 0.1573 1.073 52 203.2 38.825 0.13 5.0983 8.30 12:59:04 +59:16:26 21.1 1.1 6.33y 12.10d - select -
K06M01W 2006 MW1 0.25 19.8 0.1520 1.167 44 84.7 7.500 0.12 1.4337 6.11 15:35:45 +28:06:33 21.3 1.0 14.67y 40.38d - select -
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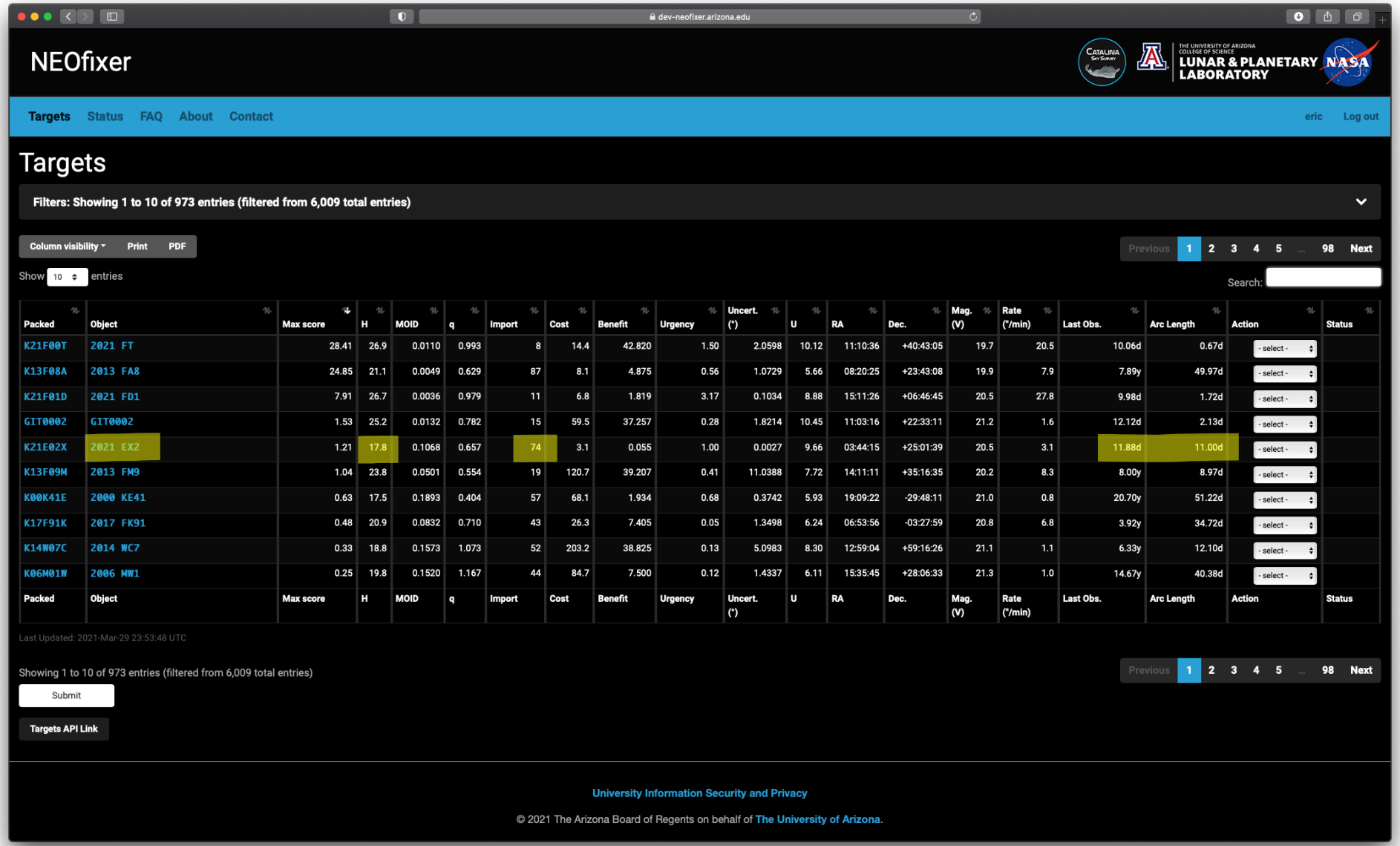
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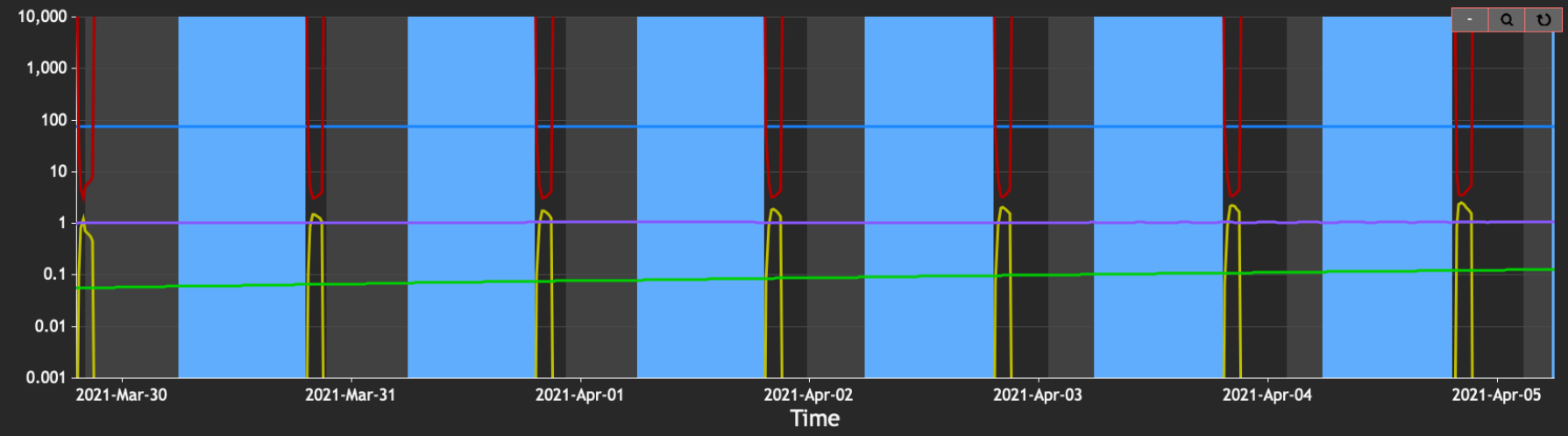
NEOfixer Plot



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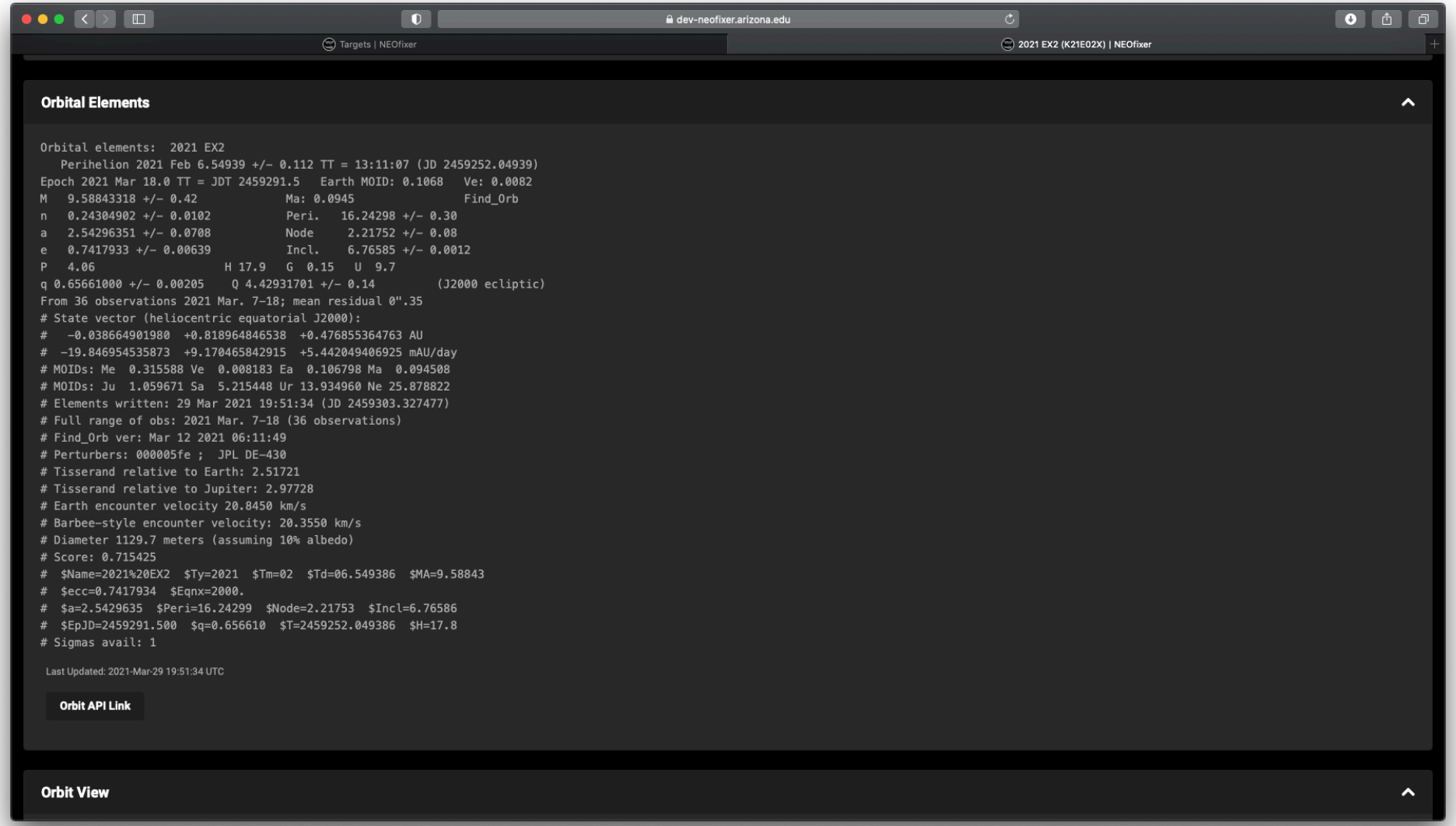
Scores API Link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Orbital Elements
Orbital elements: 2021 EX2
Perihelion 2021 Feb 6.54939 +/- 0.112 TT = 13:11:07 (JD 2459252.04939)
Epoch 2021 Mar 18.0 TT = JDT 2459291.5 Earth MOID: 0.1068 Ve: 0.0082
M 9.58843318 +/- 0.42 Ma: 0.0945 Find_Orb
n 0.24304902 +/- 0.0102 Peri. 16.24298 +/- 0.30
a 2.54296351 +/- 0.0708 Node 2.21752 +/- 0.08
e 0.7417933 +/- 0.00639 Incl. 6.76585 +/- 0.0012
P 4.06 H 17.9 G 0.15 U 9.7
q 0.65661000 +/- 0.00205 Q 4.42931701 +/- 0.14 (J2000 ecliptic)
From 36 observations 2021 Mar. 7–18; mean residual 0".35
State vector (heliocentric equatorial J2000):
−0.038664901980 +0.818964846538 +0.476855364763 AU
−19.846954535873 +9.170465842915 +5.442049406925 mAU/day
MOIDs: Me 0.315588 Ve 0.008183 Ea 0.106798 Ma 0.094508
MOIDs: Ju 1.059671 Sa 5.215448 Ur 13.934960 Ne 25.878822
Elements written: 29 Mar 2021 19:51:34 (JD 2459303.327477)
Full range of obs: 2021 Mar. 7–18 (36 observations)
Find_Orb ver: Mar 12 2021 06:11:49
Perturbers: 000005fe ; JPL DE-430
Tisserand relative to Earth: 2.51721
Tisserand relative to Jupiter: 2.97728
Earth encounter velocity 20.8450 km/s
Barbee-style encounter velocity: 20.3550 km/s
Diameter 1129.7 meters (assuming 10% albedo)
Score: 0.715425
$Name=2021%20EX2 $Ty=2021 $Tm=02 $Td=06.549386 $MA=9.58843
$ecc=0.7417934 $Eqnx=2000.
$a=2.5429635 $Peri=16.24299 $Node=2.21753 $Incl=6.76586
$EpJD=2459291.500 $q=0.656610 $T=2459252.049386 $H=17.8
Sigmas avail: 1
Last Updated: 2021-Mar-29 19:51:34 UTC
Orbit API Link
Orbit View

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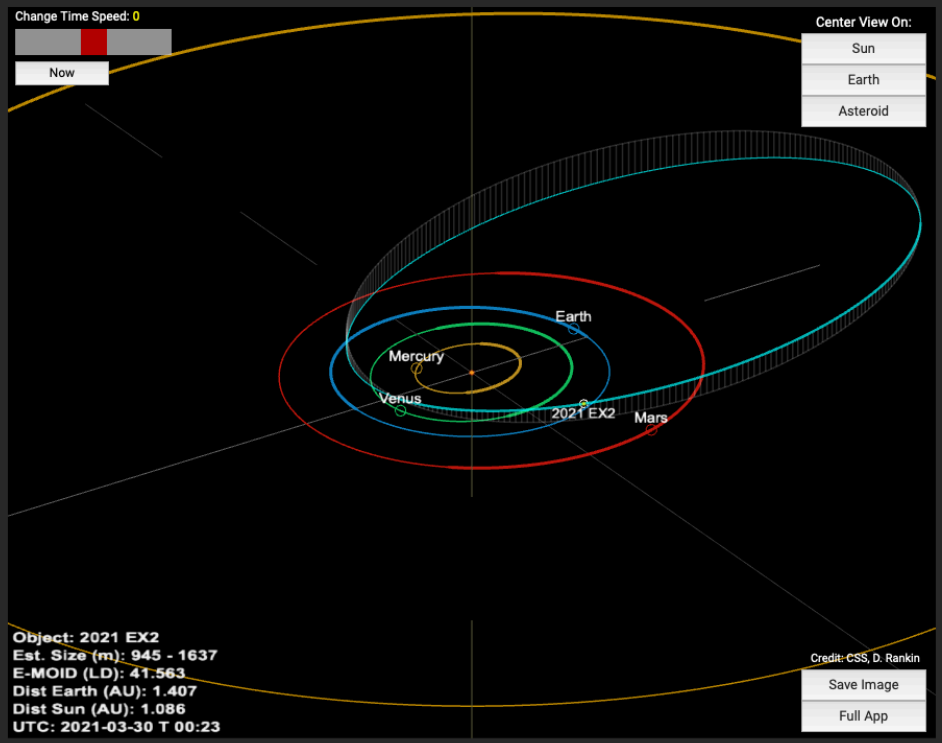
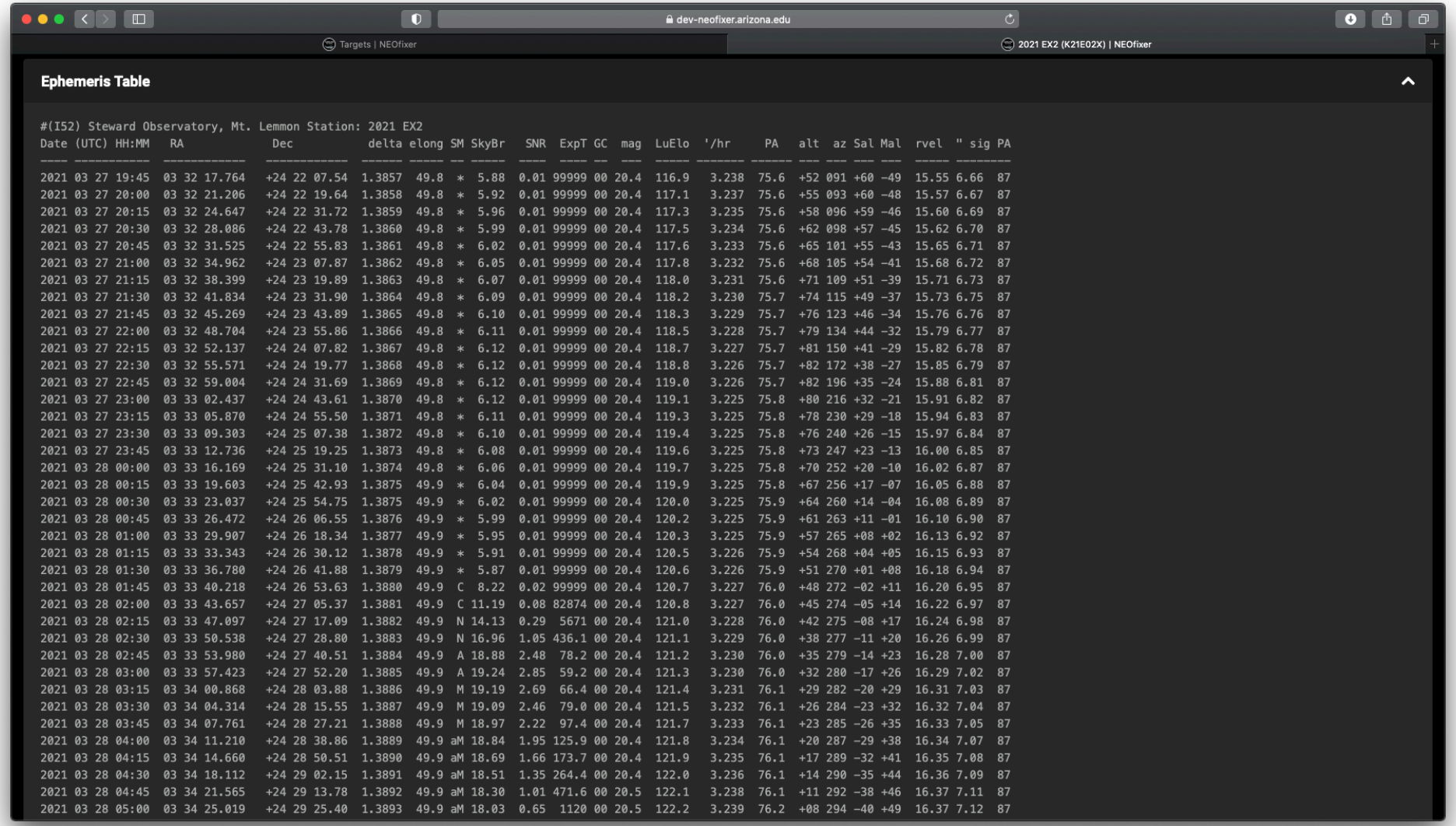


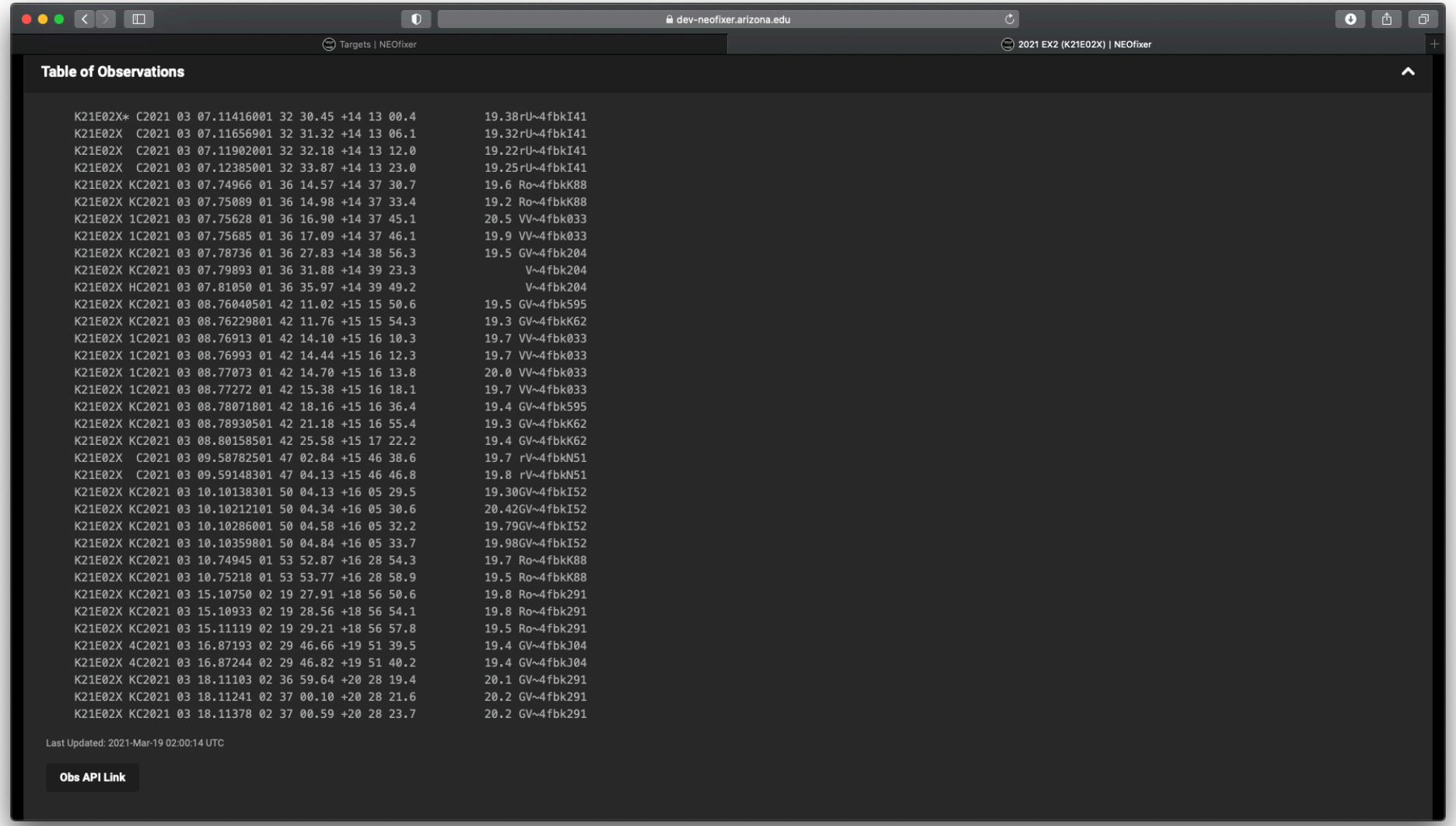
Ephemeris Table



Ephemeris Table

#(I52) Steward Observatory, Mt. Lemmon Station: 2021 EX2

Date (UTC) HH:MM	RA	Dec	delta	elong	SM	SkyBr	SNR	ExpT	GC	mag	LuElo	'/hr	PA	alt	az	Sal	Mal	rvel	" sig	PA
2021 03 27 19:45	03 32 17.764	+24 22 07.54	1.3857	49.8	*	5.88	0.01	99999	00	20.4	116.9	3.238	75.6	+52	091	+60	-49	15.55	6.66	87
2021 03 27 20:00	03 32 21.206	+24 22 19.64	1.3858	49.8	*	5.92	0.01	99999	00	20.4	117.1	3.237	75.6	+55	093	+60	-48	15.57	6.67	87
2021 03 27 20:15	03 32 24.647	+24 22 31.72	1.3859	49.8	*	5.96	0.01	99999	00	20.4	117.3	3.235	75.6	+58	096	+59	-46	15.60	6.69	87
2021 03 27 20:30	03 32 28.086	+24 22 43.78	1.3860	49.8	*	5.99	0.01	99999	00	20.4	117.5	3.234	75.6	+62	098	+57	-45	15.62	6.70	87
2021 03 27 20:45	03 32 31.525	+24 22 55.83	1.3861	49.8	*	6.02	0.01	99999	00	20.4	117.6	3.233	75.6	+65	101	+55	-43	15.65	6.71	87
2021 03 27 21:00	03 32 34.962	+24 23 07.87	1.3862	49.8	*	6.05	0.01	99999	00	20.4	117.8	3.232	75.6	+68	105	+54	-41	15.68	6.72	87
2021 03 27 21:15	03 32 38.399	+24 23 19.89	1.3863	49.8	*	6.07	0.01	99999	00	20.4	118.0	3.231	75.6	+71	109	+51	-39	15.71	6.73	87
2021 03 27 21:30	03 32 41.834	+24 23 31.90	1.3864	49.8	*	6.09	0.01	99999	00	20.4	118.2	3.230	75.7	+74	115	+49	-37	15.73	6.75	87
2021 03 27 21:45	03 32 45.269	+24 23 43.89	1.3865	49.8	*	6.10	0.01	99999	00	20.4	118.3	3.229	75.7	+76	123	+46	-34	15.76	6.76	87
2021 03 27 22:00	03 32 48.704	+24 23 55.86	1.3866	49.8	*	6.11	0.01	99999	00	20.4	118.5	3.228	75.7	+79	134	+44	-32	15.79	6.77	87
2021 03 27 22:15	03 32 52.137	+24 24 07.82	1.3867	49.8	*	6.12	0.01	99999	00	20.4	118.7	3.227	75.7	+81	150	+41	-29	15.82	6.78	87
2021 03 27 22:30	03 32 55.571	+24 24 19.77	1.3868	49.8	*	6.12	0.01	99999	00	20.4	118.8	3.226	75.7	+82	172	+38	-27	15.85	6.79	87
2021 03 27 22:45	03 32 59.004	+24 24 31.69	1.3869	49.8	*	6.12	0.01	99999	00	20.4	119.0	3.226	75.7	+82	196	+35	-24	15.88	6.81	87
2021 03 27 23:00	03 33 02.437	+24 24 43.61	1.3870	49.8	*	6.12	0.01	99999	00	20.4	119.1	3.225	75.8	+80	216	+32	-21	15.91	6.82	87
2021 03 27 23:15	03 33 05.870	+24 24 55.50	1.3871	49.8	*	6.11	0.01	99999	00	20.4	119.3	3.225	75.8	+78	230	+29	-18	15.94	6.83	87
2021 03 27 23:30	03 33 09.303	+24 25 07.38	1.3872	49.8	*	6.10	0.01	99999	00	20.4	119.4	3.225	75.8	+76	240	+26	-15	15.97	6.84	87
2021 03 27 23:45	03 33 12.736	+24 25 19.25	1.3873	49.8	*	6.08	0.01	99999	00	20.4	119.6	3.225	75.8	+73	247	+23	-13	16.00	6.85	87
2021 03 28 00:00	03 33 16.169	+24 25 31.10	1.3874	49.8	*	6.06	0.01	99999	00	20.4	119.7	3.225	75.8	+70	252	+20	-10	16.02	6.87	87
2021 03 28 00:15	03 33 19.603	+24 25 42.93	1.3875	49.9	*	6.04	0.01	99999	00	20.4	119.9	3.225	75.8	+67	256	+17	-07	16.05	6.88	87
2021 03 28 00:30	03 33 23.037	+24 25 54.75	1.3875	49.9	*	6.02	0.01	99999	00	20.4	120.0	3.225	75.9	+64	260	+14	-04	16.08	6.89	87
2021 03 28 00:45	03 33 26.472	+24 26 06.55	1.3876	49.9	*	5.99	0.01	99999	00	20.4	120.2	3.225	75.9	+61	263	+11	-01	16.10	6.90	87
2021 03 28 01:00	03 33 29.907	+24 26 18.34	1.3877	49.9	*	5.95	0.01	99999	00	20.4	120.3	3.225	75.9	+57	265	+08	+02	16.13	6.92	87
2021 03 28 01:15	03 33 33.343	+24 26 30.12	1.3878	49.9	*	5.91	0.01	99999	00	20.4	120.5	3.226	75.9	+54	268	+04	+05	16.15	6.93	87
2021 03 28 01:30	03 33 36.780	+24 26 41.88	1.3879	49.9	*	5.87	0.01	99999	00	20.4	120.6	3.226	75.9	+51	270	+01	+08	16.18	6.94	87
2021 03 28 01:45	03 33 40.218	+24 26 53.63	1.3880	49.9	C	8.22	0.02	99999	00	20.4	120.7	3.227	76.0	+48	272	-02	+11	16.20	6.95	87
2021 03 28 02:00	03 33 43.657	+24 27 05.37	1.3881	49.9	C	11.19	0.08	82874	00	20.4	120.8	3.227	76.0	+45	274	-05	+14	16.22	6.97	87
2021 03 28 02:15	03 33 47.097	+24 27 17.09	1.3882	49.9	N	14.13	0.29	5671	00	20.4	121.0	3.228	76.0	+42	275	-08	+17	16.24	6.98	87
2021 03 28 02:30	03 33 50.538	+24 27 28.80	1.3883	49.9	N	16.96	1.05	436.1	00	20.4	121.1	3.229	76.0	+38	277	-11	+20	16.26	6.99	87
2021 03 28 02:45	03 33 53.980	+24 27 40.51	1.3884	49.9	A	18.88	2.48	78.2	00	20.4	121.2	3.230	76.0	+35	279	-14	+23	16.28	7.00	87
2021 03 28 03:00	03 33 57.423	+24 27 52.20	1.3885	49.9	A	19.24	2.85	59.2	00	20.4	121.3	3.230	76.0	+32	280	-17	+26	16.29	7.02	87
2021 03 28 03:15	03 34 00.868	+24 28 03.88	1.3886	49.9	M	19.19	2.69	66.4	00	20.4	121.4	3.231	76.1	+29	282	-20	+29	16.31	7.03	87
2021 03 28 03:30	03 34 04.314	+24 28 15.55	1.3887	49.9	M	19.09	2.46	79.0	00	20.4	121.5	3.232	76.1	+26	284	-23	+32	16.32	7.04	87
2021 03 28 03:45	03 34 07.761	+24 28 27.21	1.3888	49.9	M	18.97	2.22	97.4	00	20.4	121.7	3.233	76.1	+23	285	-26	+35	16.33	7.05	87
2021 03 28 04:00	03 34 11.210	+24 28 38.86	1.3889	49.9	aM	18.84	1.95	125.9	00	20.4	121.8	3.234	76.1	+20	287	-29	+38	16.34	7.07	87
2021 03 28 04:15	03 34 14.660	+24 28 50.51	1.3890	49.9	aM	18.69	1.66	173.7	00	20.4	121.9	3.235	76.1	+17	289	-32	+41	16.35	7.08	87
2021 03 28 04:30	03 34 18.112	+24 29 02.15	1.3891	49.9	aM	18.51	1.35	264.4	00	20.4	122.0	3.236	76.1	+14	290	-35	+44	16.36	7.09	87
2021 03 28 04:45	03 34 21.565	+24 29 13.78	1.3892	49.9	aM	18.30	1.01	471.6	00	20.5	122.1	3.238	76.1	+11	292	-38	+46	16.37	7.11	87
2021 03 28 05:00	03 34 25.019	+24 29 25.40	1.3893	49.9	aM	18.03	0.65	1120	00	20.5	122.2	3.239	76.2	+08	294	-40	+49	16.37	7.12	87


dev-neofixer.arizona.edu
Targets | NEOfixer
2021 EX2 (K21E02X) | NEOfixer
Table of Observations
K21E02X* C2021 03 07.11416001 32 30.45 +14 13 00.4 19.38rU~4fbkI41
K21E02X C2021 03 07.11656901 32 31.32 +14 13 06.1 19.32rU~4fbkI41
K21E02X C2021 03 07.11902001 32 32.18 +14 13 12.0 19.22rU~4fbkI41
K21E02X C2021 03 07.12385001 32 33.87 +14 13 23.0 19.25rU~4fbkI41
K21E02X KC2021 03 07.74966 01 36 14.57 +14 37 30.7 19.6 Ro~4fbkK88
K21E02X KC2021 03 07.75089 01 36 14.98 +14 37 33.4 19.2 Ro~4fbkK88
K21E02X 1C2021 03 07.75628 01 36 16.90 +14 37 45.1 20.5 VV~4fbk033
K21E02X 1C2021 03 07.75685 01 36 17.09 +14 37 46.1 19.9 VV~4fbk033
K21E02X KC2021 03 07.78736 01 36 27.83 +14 38 56.3 19.5 GV~4fbk204
K21E02X KC2021 03 07.79893 01 36 31.88 +14 39 23.3 V~4fbk204
K21E02X HC2021 03 07.81050 01 36 35.97 +14 39 49.2 V~4fbk204
K21E02X KC2021 03 08.76040501 42 11.02 +15 15 50.6 19.5 GV~4fbk595
K21E02X KC2021 03 08.76229801 42 11.76 +15 15 54.3 19.3 GV~4fbkK62
K21E02X 1C2021 03 08.76913 01 42 14.10 +15 16 10.3 19.7 VV~4fbk033
K21E02X 1C2021 03 08.76993 01 42 14.44 +15 16 12.3 19.7 VV~4fbk033
K21E02X 1C2021 03 08.77073 01 42 14.70 +15 16 13.8 20.0 VV~4fbk033
K21E02X 1C2021 03 08.77272 01 42 15.38 +15 16 18.1 19.7 VV~4fbk033
K21E02X KC2021 03 08.78071801 42 18.16 +15 16 36.4 19.4 GV~4fbk595
K21E02X KC2021 03 08.78930501 42 21.18 +15 16 55.4 19.3 GV~4fbkK62
K21E02X KC2021 03 08.80158501 42 25.58 +15 17 22.2 19.4 GV~4fbkK62
K21E02X C2021 03 09.58782501 47 02.84 +15 46 38.6 19.7 rV~4fbkN51
K21E02X C2021 03 09.59148301 47 04.13 +15 46 46.8 19.8 rV~4fbkN51
K21E02X KC2021 03 10.10138301 50 04.13 +16 05 29.5 19.30GV~4fbkI52
K21E02X KC2021 03 10.10212101 50 04.34 +16 05 30.6 20.42GV~4fbkI52
K21E02X KC2021 03 10.10286001 50 04.58 +16 05 32.2 19.79GV~4fbkI52
K21E02X KC2021 03 10.10359801 50 04.84 +16 05 33.7 19.98GV~4fbkI52
K21E02X KC2021 03 10.74945 01 53 52.87 +16 28 54.3 19.7 Ro~4fbkK88
K21E02X KC2021 03 10.75218 01 53 53.77 +16 28 58.9 19.5 Ro~4fbkK88
K21E02X KC2021 03 15.10750 02 19 27.91 +18 56 50.6 19.8 Ro~4fbk291
K21E02X KC2021 03 15.10933 02 19 28.56 +18 56 54.1 19.8 Ro~4fbk291
K21E02X KC2021 03 15.11119 02 19 29.21 +18 56 57.8 19.5 Ro~4fbk291
K21E02X 4C2021 03 16.87193 02 29 46.66 +19 51 39.5 19.4 GV~4fbkJ04
K21E02X 4C2021 03 16.87244 02 29 46.82 +19 51 40.2 19.4 GV~4fbkJ04
K21E02X KC2021 03 18.11103 02 36 59.64 +20 28 19.4 20.1 GV~4fbk291
K21E02X KC2021 03 18.11241 02 37 00.10 +20 28 21.6 20.2 GV~4fbk291
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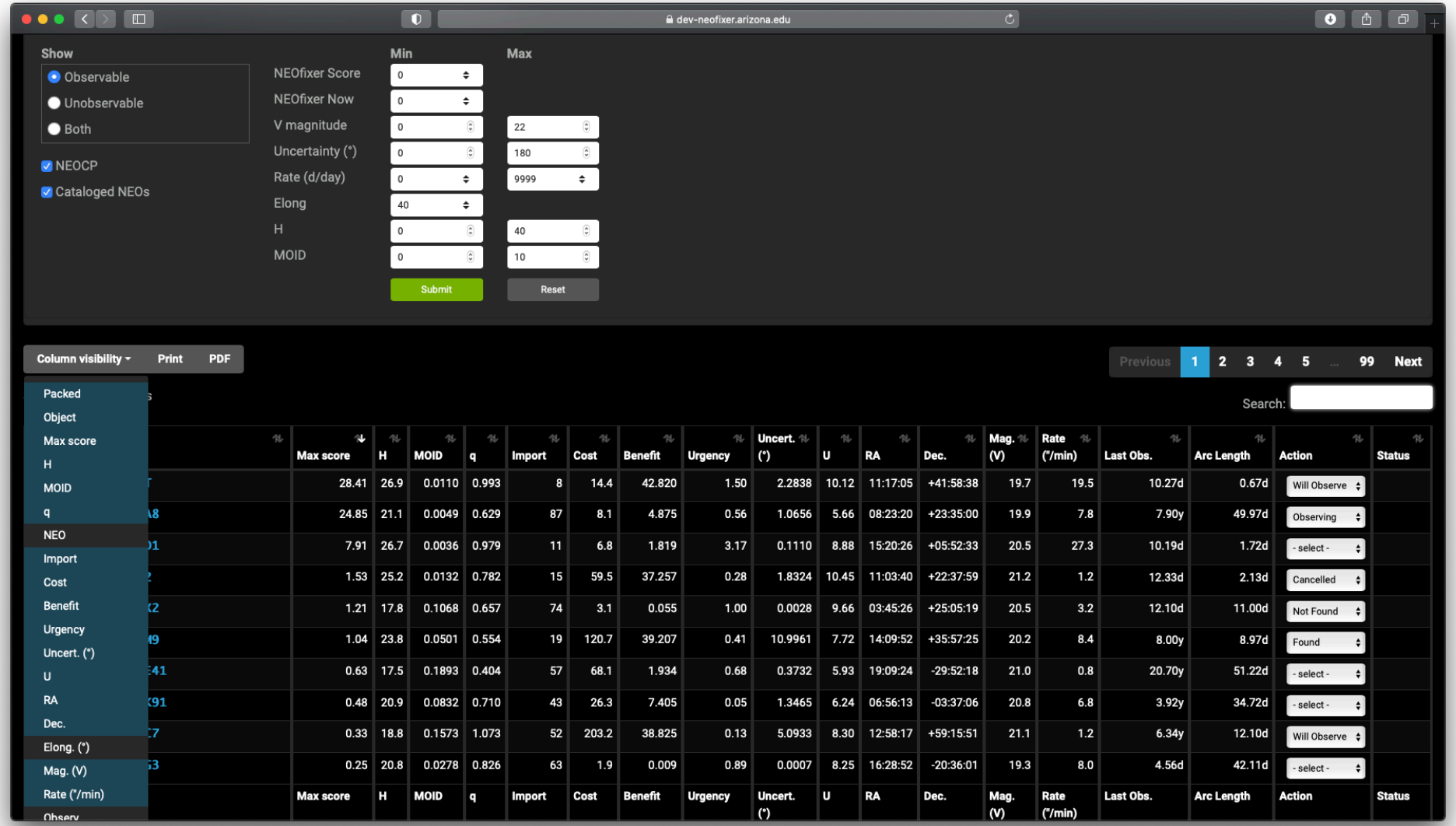
Last Updated: 2021-Mar-19 02:00:14 UTC
Obs API Link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Show
Observable
Unobservable
Both
NEOCP
Cataloged NEOs
Min
Max
NEOfixer Score
NEOfixer Now
V magnitude
Uncertainty (°)
Rate (d/day)
Elong
H
MOID
Submit
Reset
Column visibility
Print
PDF
Previous
1 2 3 4 5 ... 99
Next
Search:
Packed
Object
Max score
H
MOID
q
NEO
Import
Cost
Benefit
Urgency
Uncert. (°)
U
RA
Dec.
Elong. (°)
Mag. (V)
Rate (°/min)
Max score H MOID q Import Cost Benefit Urgency Uncert. (°) U RA Dec. Mag. (V) Rate (°/min) Last Obs. Arc Length Action Status
28.41 26.9 0.0110 0.993 8 14.4 42.820 1.50 2.2838 10.12 11:17:05 +41:58:38 19.7 19.5 10.27d 0.67d Will Observe
24.85 21.1 0.0049 0.629 87 8.1 4.875 0.56 1.0656 5.66 08:23:20 +23:35:00 19.9 7.8 7.90y 49.97d Observing
7.91 26.7 0.0036 0.979 11 6.8 1.819 3.17 0.1110 8.88 15:20:26 +05:52:33 20.5 27.3 10.19d 1.72d - select -
1.53 25.2 0.0132 0.782 15 59.5 37.257 0.28 1.8324 10.45 11:03:40 +22:37:59 21.2 1.2 12.33d 2.13d Cancelled
1.21 17.8 0.1068 0.657 74 3.1 0.055 1.00 0.0028 9.66 03:45:26 +25:05:19 20.5 3.2 12.10d 11.00d Not Found
1.04 23.8 0.0501 0.554 19 120.7 39.207 0.41 10.9961 7.72 14:09:52 +35:57:25 20.2 8.4 8.00y 8.97d Found
0.63 17.5 0.1893 0.404 57 68.1 1.934 0.68 0.3732 5.93 19:09:24 -29:52:18 21.0 0.8 20.70y 51.22d - select -
0.48 20.9 0.0832 0.710 43 26.3 7.405 0.05 1.3465 6.24 06:56:13 -03:37:06 20.8 6.8 3.92y 34.72d - select -
0.33 18.8 0.1573 1.073 52 203.2 38.825 0.13 5.0933 8.30 12:58:17 +59:15:51 21.1 1.2 6.34y 12.10d Will Observe
0.25 20.8 0.0278 0.826 63 1.9 0.009 0.89 0.0007 8.25 16:28:52 -20:36:01 19.3 8.0 4.56d 42.11d - select -
Max score H MOID q Import Cost Benefit Urgency Uncert. (°) U RA Dec. Mag. (V) Rate (°/min) Last Obs. Arc Length Action Status

NEOfixer Targeting Broker

Coordinating and Optimizing Global NEO Follow-up

Eric J. Christensen <*eric@LPL.Arizona.edu*>
Catalina Sky Survey

On behalf of the NEOfixer / CSS team:

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