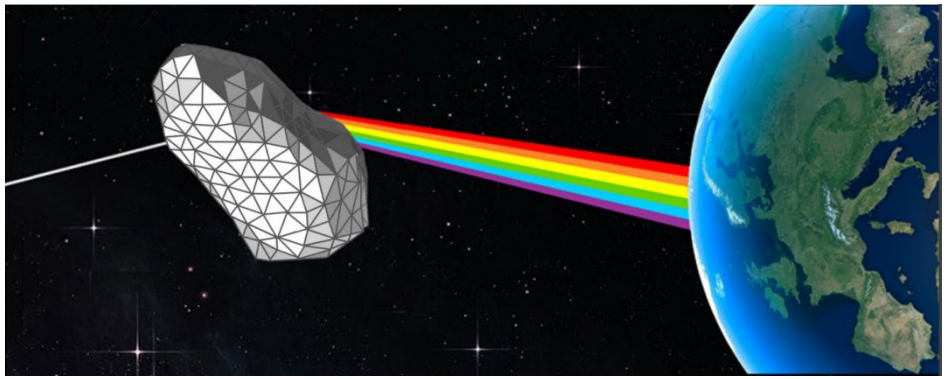
NEO ROCKS

Near Earth Object Rapid Observation, Characterization and Key Simulations

l'Observatoire de Paris

NEOROCKS PROJECT: SPECTROPHOTOMETRY OF SMALL NEAR-EARTH ASTEROIDS

M.A. Barucci[1], **M. Birlan[2,3]**, T. Hromakina[1,4], M. Fulchignoni[1], F. Colas[2], S. Fornasier[1,5], F. Merlin[1], A. Sonka[3], S. Anghel[3], I. Belskaya[1,4], D. Perna[6], E. Dotto[6] and the NEOROCKS team[★]



Affiliations and the NEOROCKS team

[1]*LESIA, Observatoire de Paris, Université PSL, CNRS, Université Paris Cité, Sorbonne Université, F-92190 MEUDON, France, antonella.barucci@obspm.fr*

[2]*IMCCE, Observatoire de Paris, CNRS UMRO 8028, PSL Research University, 77 av Denfert Rochereau, 75014, Paris Cedex, France*

[3]*Astronomical Institute of the Romanian Academy, 5 Cutitul de Argint, 040557, sector 4, Bucharest, Romania*

[4]*V. N. Karazin Kharkiv National University, 4 Svobody Sq., Kharkiv, 61022, Ukraine*

[5]*Institut Universitaire de France (IUF), 1 rue Descartes, 75231 PARIS CEDEX 05*

[6]*INAF – Osservatorio Astronomico di Roma, Via Frascati 33, 00078 Monte Porzio Catone, Italy*

(★)**The NEOROCKS team:** E. Dotto, M. Banaszkiewicz, S. Banchi, M.A. Barucci, F. Bernardi, M. Birlan, B. Carry, A. Cellino, J. De Leon, M. Lazzarin, E. Mazzotta Epifani, A. Mediavilla, J. Nomen Torres, D. Perna, E. Perozzi, P. Pravec, C. Snodgrass, C. Teodorescu, S. Anghel, A. Bertolucci, F. Calderini, F.Colas, A. Del Vigna, A. Dell'Oro, A. Di Cecco, L. Dimare, P. Fatka, S. Fornasier, E. Frattin, P. Frosini, M. Fulchignoni, R. Gabryszewski, M. Giardino, A. Giunta, T. Hromakina, J. Huntingford, S. Ieva, J.P. Kotlarz, F. La Forgia, J. Licandro, H. Medeiros, F. Merlin, F. Pinna, G. Polenta, M. Popescu, A. Rozek, P. Scheirich, A. Sergeyev, A. Sonka, G.B. Valsecchi, P. Wajer, A. Zinzi.

NEOROCKS

stands for the NEO Rapid Observation,
Characterization and Key Simulations.

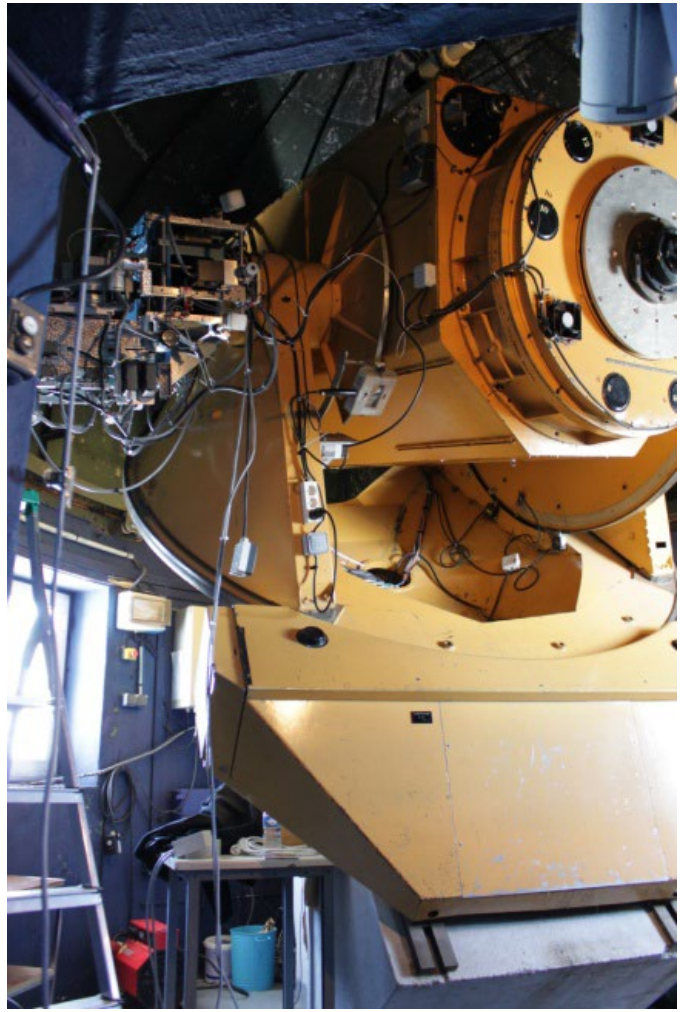
The team at Paris Observatory is taking charge of the photometric properties of small near-Earth objects (NEOs). In particular, the main objectives are:

- Execute the programmed observations using the guaranteed rapid access small telescopes for colour observations with different standard filters (Johnson-Cousins, SLOAN…);
- Data reduction and analysis in order to obtain the surface colour (with their variation, if any);
- Determine the preliminary taxonomic type of the observed objects;

French assets involved in the NEOROCKS project

Pic du Midi Observatory

Coordinates:
Latitude: 42°56’11’’ N
Longitude: 0°08’34’’E
Altitude: 2876m
MPC Code: 586



T1M – 1.05m telescope

Devoted mainly to Solar System programs
iKon-L Andor camera 2kx2k E2V (pixel scale 0.22’’/pixel), FOV 8’x8’
Sloan filters were used

Observational runs:

February-March 2020 (3 out of 7 nights - observations stopped due to pandemic).

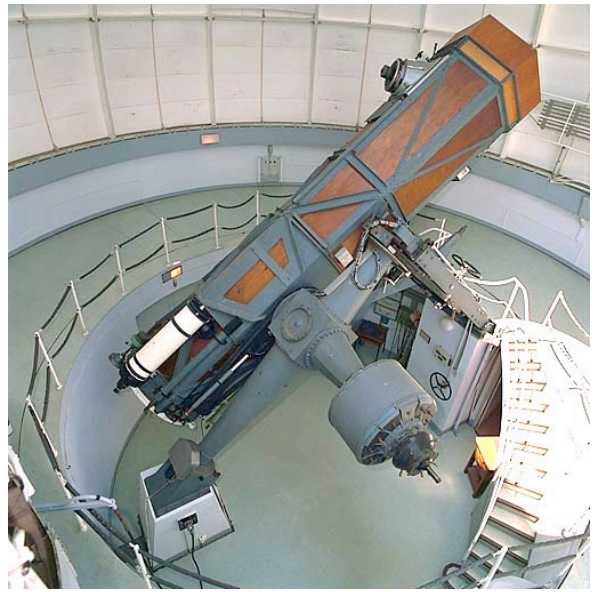
French assets involved in the NEOROCKS project

Observatoire de Haute Provence

Coordinates: Latitude: 43°55’51’’ N, Longitude: 5°42’48’’E
Altitude: 650m
MPC Code: 511

1.2m telescope

Programs granted by the Time Allocation Committee
iKon-L 936 Andor camera 2kx2k E2V, FOV 13.1’x13.1’
B-V-R-I filters were used

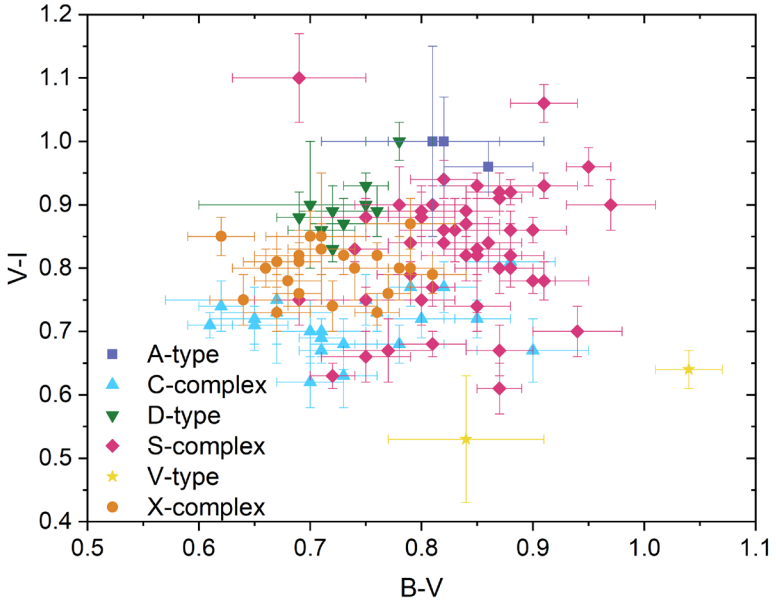


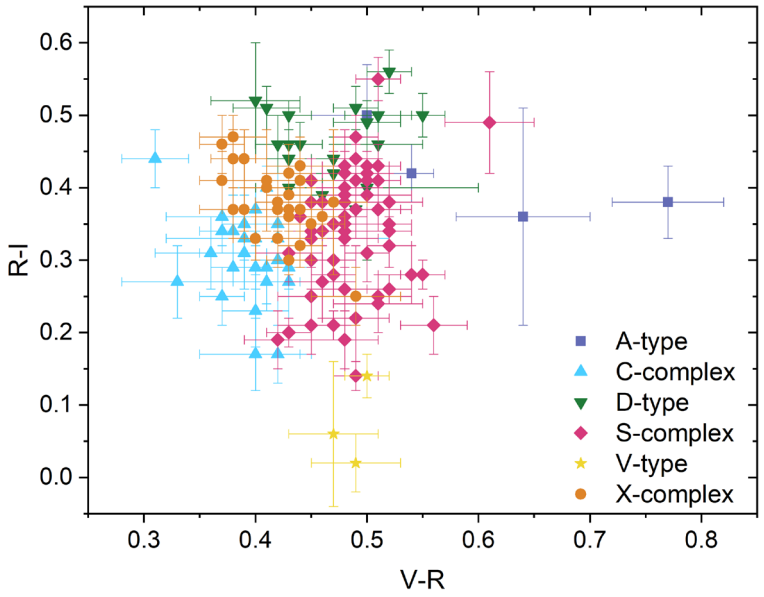
Observational runs (58 nights):

June 2020 (5 nights)
November 2020 (5 nights)
January 2021 (5 nigths)
April 2021 (4 nights)
June 2021 (5 nights)
October 2021 (4 nights)
November 2021 (4 nights)
January 2022 (4 nights)
April 2022 (5 nights)
May 2022 (5 night)
September-October 2022 (6 nights)
November 2022 (6 nights)

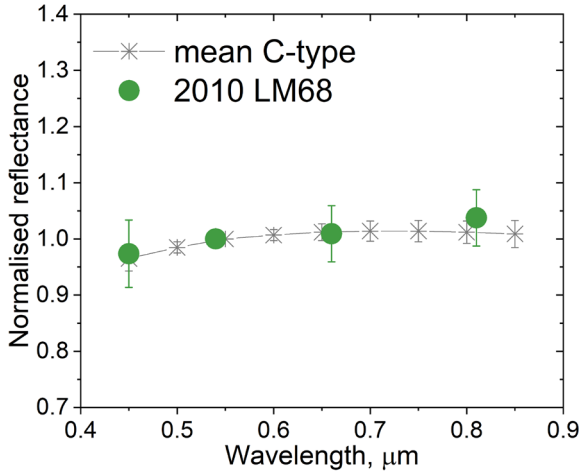
Observations and photometry results

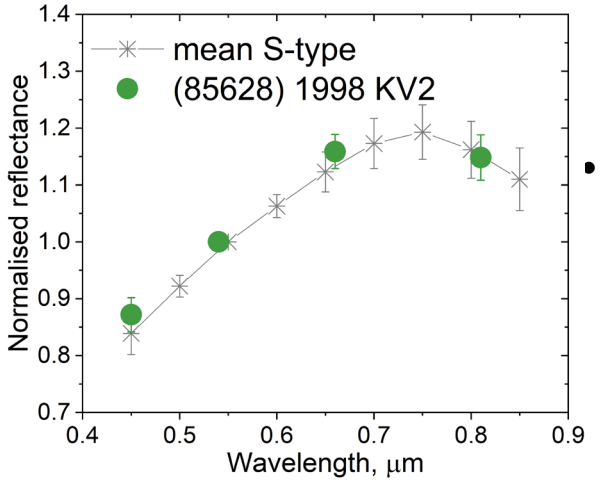
- In total, about 150 NEOs were observed up to now. Among them, 76 Potentially Hazardous asteroids (PHAs). More observations are planned in March and April 2023.
- The images in each filter were taken sequentially in order to minimize possible magnitude variation due to the rotation of an object.
- Absolute calibration computed using the Pan-Starrs catalogue and the transformation equations from Sloan to Johnson-Cousins system introduced by Kostov & Bonev (BAJ, vol 28, 2018).



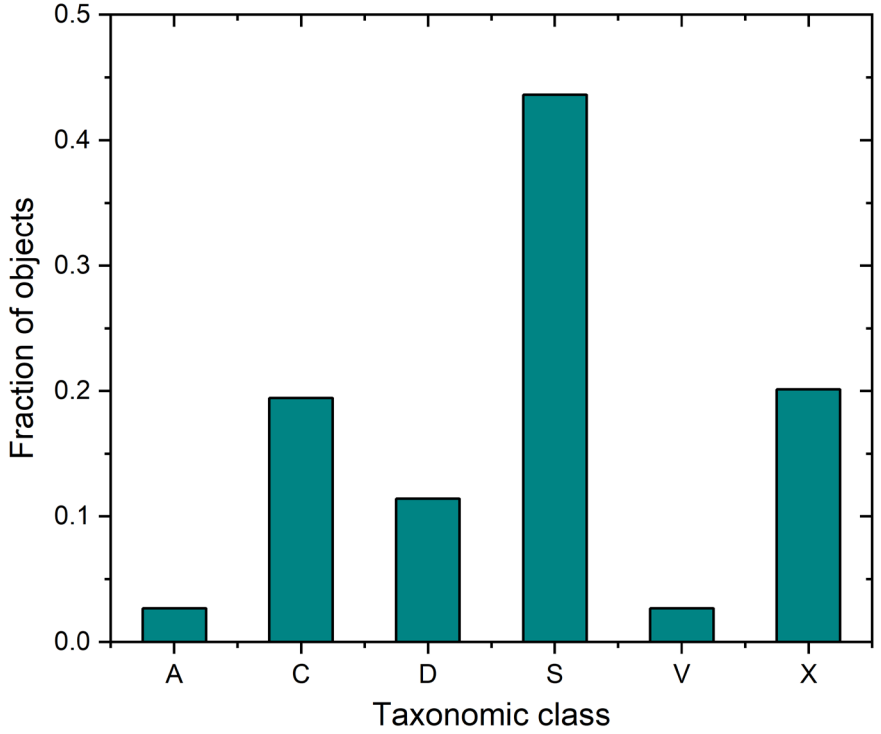


Taxonomic classification





- Taxonomic classes were estimated following the classification by DeMeo et al. (2009).
- With the use of M4AST service (Popescu et al. 2012) we compared the spectrophotometric data of the observed NEOs with the mean spectra of the main taxons (S-, X-, C-complex, D-type, V-type, and A-type).
- Over 40% of analysed NEOs belong to the S-complex, whereas the fraction of C-, X-complex and D-type is in the 10-20% range. The fraction of A- and V-type asteroids does not exceed a few percent.
- We found no significant differences in the compositional distribution of PHAs and non-PHAs.



List of observed objects

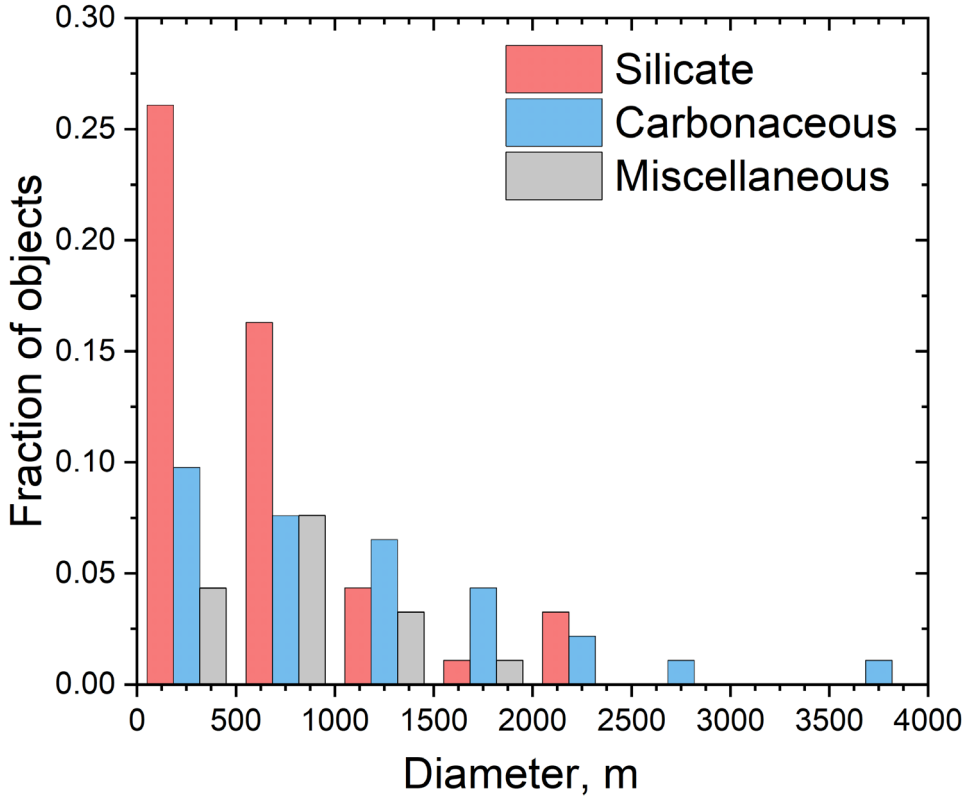
#	Object	Type	Taxon
1	(10302) 1989 ML	Amor	X
2	(12923) Zephyr	Apollo, PHA	Q/S
3	(52768) 1998 OR2	Amor, PHA	X
4	(54789) 2001 MZ7	Amor	D
5	(66251) 1999 GJ2	Amor	S
6	(66391) 1999 KW4	Aten, PHA	S
7	(68278) 2001 FC7	Amor	C
8	(85628) 1998 KV2	Amor	S
9	(85713) 1998 SS49	Apollo, PHA	S
10	(85989) 1999 JD6	Aten, PHA	D
11	(87024) 2000 JS66	Apollo	X
12	(88188) 2000 XH44	Amor	Q/S
13	(89958) 2002 LY45	Apollo, PHA	Q/S
14	(90147) 2002 YK14	Apollo	S
15	(98943) 2001 CC21	Apollo	S
16	(99935) 2002 AV4	Apollo	X
17	(99942) Apophis	Aten, PHA	S
18	(136897) 1998 HJ41	Amor	S
19	(137044) 1998 UC50	Amor	S
20	(138971) 2001 CB21	Apollo, PHA	C
21	(140158) 2001 SX169	Apollo, PHA	Xe/X
22	(143649) 2003 QQ47	Apollo, PHA	S
23	(152978) 2000 GJ147	Apollo, PHA	Sq/S
24	(154302) 2002 UQ3	Apollo, PHA	S
25	(159402) 1999 AP10	Amor	S
26	(162913) 2001 MT18	Apollo	D
27	(163014) 2001 UA5	Apollo, PHA	D
28	(163348) 2002 NN4	Aten, PHA	Cg/C
29	(163692) 2003 CY18	Apollo	S
30	(163902) 2003 SW222	Amor	D
31	(177614) 2004 HK33	Apollo, PHA	D
32	(185853) 2000 ER70	Amor	?
33	(186822) 2004 FE31	Apollo	X
34	(194386) 2001 VG5	Apollo	S
35	(215188) 2000 NM	Apollo	S
36	(226554) 2003 WR21	Apollo, PHA	A
37	(242216) 2003 RN10	Amor, PHA	D
38	(265962) 2006 CG	Amor	Q/S
39	(271480) 2004 FX31	Apollo	Xk/X
40	(276786) 2004 KD1	Amor	X
41	(285179) 1996 TY11	Apollo	X
42	(285625) 2000 RD34	Amor	S
43	(297418) 2000 SP43	Aten, PHA	Sq/S
44	(301011) 2008 JO	Apollo	Q/S
45	(313276) 2002 AX1	Aten	Xe/X
46	(317643) 2003 FH1	Apollo	D-type
47	(318160) 2004 QZ2	Amor	Sq/S
48	(332446) 2008 AF4	Apollo, PHA	Xe/X
49	(338292) 2002 UA31	Aten	D
50	(363027) 1998 ST27	Aten, PHA	C
51	(363599) 2004 FG11	Apollo, PHA	Xe/X
52	(366746) 2004 LJ	Apollo, PHA	Sq/S
53	(374855) 2006 VQ13	Apollo, PHA	X
54	(377732) 2005 XJ8	Apollo, PHA	S
55	(380359) 2002 TN30	Amor	V
56	(388945) 2008 TZ3	Apollo, PHA	Cg/C
57	(410195) 2007 RT147	Amor	Q/S
58	(414286) 2008 OC6	Aten, PHA	S
59	(414429) 2009 DC43	Apollo	B/C
60	(415029) 2011 UL21	Apollo, PHA	S
61	(416694) 2004 YR32	Apollo	D
62	(422787) 2001 WS1	Apollo, PHA	Q/S
63	(438902) 2009 WF104	Amor	D
64	(443880) 2001 UZ16	Apollo, PHA	Xe/X
65	(450263) 2003 WD158	Apollo, PHA	S
66	(453707) 2010 XY72	Apollo	S
67	(455591) 2004 SV26	Amor	C
68	(464798) 2004 JX20	Aten	C
69	(465749) 2009 WO6	Amor	X
70	(475665) 2006 VY13	Amor	C
71	(482250) 2011 LL2	Apollo, PHA	S
72	(482505) 2012 TQ78	Apollo	Sq/S
73	(491567) 2012 RG3	Apollo	D
74	(492143) 2013 OE	Apollo	X
75	(495615) 2015 PQ291	Aten	S
76	(505093) 2011 VQ5	Amor	Xc/X
77	(506459) 2002 AL14	Apollo	S
78	(516396) 2000 WY28	Amor	C
79	(516428) 2003 UR12	Amor	Cg/C
80	(523823) 2015 BG311	Amor	Cg/Xe
81	(612143) 2000 BO28	Apollo, PHA	Ch/C
82	(612443) 2002 RR25	Aten	Xe/X
83	(613291) 2005 YX128	Apollo	C
84	(613403) 2006 GB	Aten, PHA	C
85	1999 LV7	Amor	D
86	2001 FF90	Apollo	X

List of observed objects (continued)

#	Object	Type	Taxon
87	2002 GZ8	Amor, PHA	X
88	2002 TP69	Amor	S
89	2003 AF23	Aten, PHA	X
90	2003 YM1	Amor	Q/S
91	2004 TP1	Apollo, PHA	Sq/S
92	2005 JT108	Apollo	X
93	2005 LW3	Apollo, PHA	C
94	2008 TB27	Amor	C
95	2009 CC3	Amor, PHA	S
96	2010 EC135	Amor	V
97	2010 JV153	Amor	Sq/S
98	2010 LM68	Apollo	C
99	2010 TV149	Apollo, PHA	X
100	2010 WQ7	Amor	Sv/S
101	2011 GD62	Apollo	Xe/X
102	2011 OL51	Amor	D
103	2011 YQ10	Amor	Q/S
104	2012 SA22	Amor	B/C
105	2013 GG69	Apollo, PHA	D
106	2013 PY6	Amor	Cgh/C
107	2013 UX14	Amor	S
108	2014 HK129	Apollo, PHA	S
109	2015 AS45	Amor	X
110	2015 BF4	Amor	D
111	2015 NU13	Apollo, PHA	S
112	2016 CO247	Apollo, PHA	C
113	2017 SE19	Apollo, PHA	A
114	2017 UW42	Amor	S
115	2017 VT12	Apollo	Cg/C
116	2018 CW13	Apollo	Cg/C
117	2018 XV5	Apollo, PHA	S
118	2018 XZ1	Amor	Sq/S
119	2019 AN5	Apollo, PHA	S
120	2019 CV	Amor	C
121	2020 DT3	Apollo, PHA	S
122	2020 QL6	Amor	X
123	2020 RO6	Amor	Sq/S
124	2020 ST1	Amor, PHA	S
125	2020 TG3	Amor	A
126	2020 TG4	Amor	D
127	2020 UZ5	Apollo	Sq/S
128	2020 WP1	Apollo, PHA	A
129	2020 YQ3	Apollo, PHA	Q/S
130	2021 JQ24	Amor	Xc/X
131	2021 LN3	Apollo	Q/S
132	2021 SR41	Apollo	C
133	2021 VM25	Apollo	D
134	2021 WX3	Amor	C
135	2022 BH3	Apollo	Sv/S
136	2022 BK	Amor	X
137	2022 BQ3	Amor	V
138	2022 DC5	Apollo	S
139	2022 GA4	Amor	S
140	2022 GC1	Apollo	S
141	2022 GY2	Apollo, PHA	?
142	2022 KD2	Amor	C
143	2022 LL3	Amor	S
144	2022 OW5	Amor	S
145	2022 PT1	Amor	Q/S
146	2022 QN47	Amor	S
147	2022 RB5	Apollo	S
148	2022 VV2	Apollo	D
149	2022 WG5	Apollo	X
150	2022 WS4	Apollo, PHA	X

Size distribution

- Diameters of the observed objects were estimated based on the absolute magnitude and the mean albedo of their taxonomic class.
- The estimated sizes spread out from about 20 m to almost 4 km, with the majority of objects being in the D<1 km range.
- The relative ratio of carbonaceous (C- D-, P-types) to silicate (A, S-, V-types) objects with D<500 m is 28% to 72%, and for objects with D>500 m the ratio is 46 to 54%. Such distribution is most probably caused by the bias towards higher albedo objects.

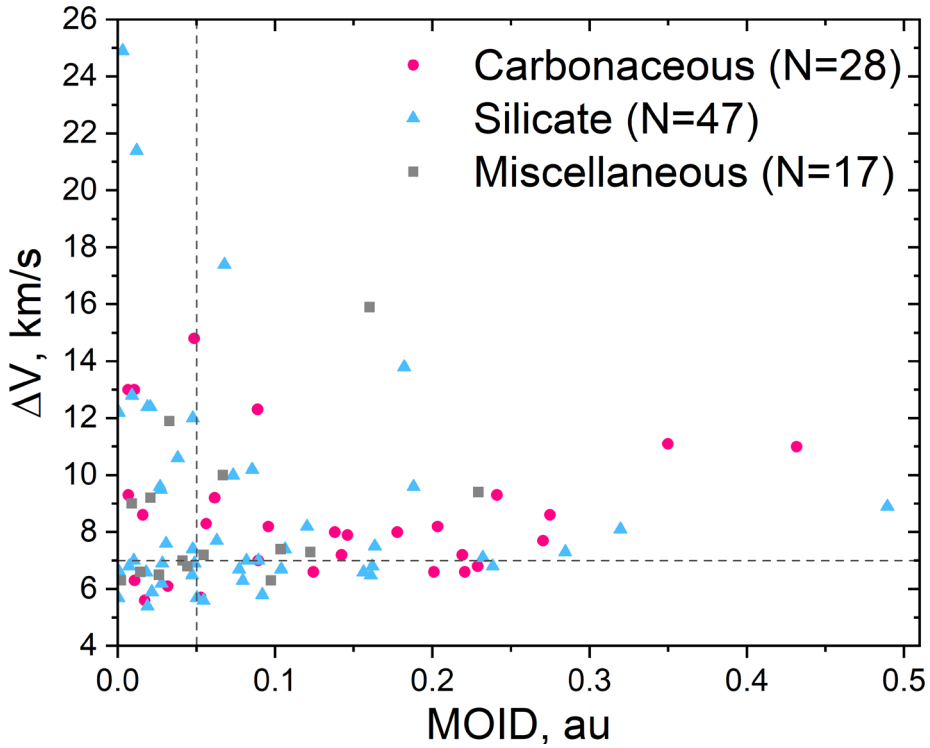


Low ΔV objects

- Asteroids with low Earth's MOID and ΔV (the impulse necessary for a spacecraft to reach the asteroid's orbit) are better candidates for space mission targets.

- The image shows the Earth's MOID and ΔV for the observed objects. We selected 14 objects that have both MOID<0.05 au and ΔV<7 km/s.

- Of particular interest are D-type and rare A-type asteroids, because they have not yet been visited by space missions. In this regard, we can mention two objects from our data: D-type (163014) 2001 UA5 and A-type 2017 SE19.



Summary

- This work was done in the framework of European Community called NEOROCKS. Within the project about 150 small NEOs were observed for colors.
- Over 40% of analysed NEOs belong to the S-complex, whereas the fraction of C-, X-complex, and D-type is in the 10-20% range. The fraction of A- and V-type asteroids does not exceed a few percent.
- The estimated sizes of the objects spread out from about 20 meters to almost 4 km, with the majority of objects being in the D<1 km range.
- Among the observed NEOs we selected 14 objects that could be accessible by a space mission based on their low Earth's MOID and ΔV values, and mention particularly interesting ones.

NEOROCKS project: surface properties of small near-Earth asteroids
Hromakina, Birlan, Barucci, Fulchignoni, Colas, et al, ***MNRAS, 520****, 2 (April 2023)*

Thanks!

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no. 870403.