Near Earth Asteroids Accessible to Human Exploration in 2020-2035

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Introduction

On April 15th, at the Kennedy Space Center, President Obama announced new goals for NASA's human spaceflight activities. One of the most exciting challenges that he gave to NASA was a human journey to an asteroid in 2025 as part of a path to human Mars missions in the 2030s.

This poster presents the results from a trajectory search for candidate asteroids for human exploration missions in 2020-2035. This search was conducted using independent methodologies by astrodynamics researchers at the NASA/JPL and ESA/ESTEC research centers.

Not much is known about the physical properties of many of these asteroids, and it is hoped that the asteroids identified in this search can be targets for both ground-based and space-based observations that will help to identify the most scientifically interesting targets for future human missions.

Search Parameters

Launch Years:	2020-2035
Maximum Launch V-Infinity:	5.5 km/s
Maximum Return V-Infinity:	5.5 km/s
Maximum Deep Space ΔV:	5 km/s
Minimum Stay Time:	30 days

ACT (ESTEC) Methodology

We optimize the total DV of the whole mission, which includes the DV to rendezvous with the asteroid, the DV to depart the asteroid, the first DSM on the Earth-Asteroid leg, the second DSM on the Asteroid-Earth leg, and any excess launch/arrival V-inf (more than 5.5 km/s).

We employ a parallel global optimization strategy to search for optimal round trip trajectories to asteroids taken from the Minor Planet Center's MPCORB database. A preliminary filter is put on the asteroid semi-major axis so that only orbits with a < 1.8 AU are considered (~4000 asteroids). In total ~16000 global optimization problems needed to be solved. Our search strategy employs as main algorithms are Differential Evolution and Nelder-Mead. In particular, eight populations of trajectories are optimized by Differential Evolution with migration allowed along a ring topology (that is, individual can migrate only between adjacent islands). After each migration, the best individual is sent for optimization to an instance of Nelder-Mead. The different optimizers are all running asynchronously. The optimization is left running for ten seconds for each target asteroid in an eight processor architecture. At the end, the best individual across all populations (generally the one coming from Nelder-Mead) is stored and a new optimization (next asteroid in the database) is started. All the code is available in open source as part of the PaGMO SourceForge project. The code used for the computations is included as one of the example files contained in the main distribution and named hm_2_asteroids.cpp

JPL Methodology

We conducted an exhaustive search of return trajectories across ~10,000 asteroids classified as Near Earth Objects (NEOs). This is done using a series of Lambert fits to conduct a broad, non-optimal search for trajectories. These trajectories were than filtered for the lowest ΔV cases within a flight time bin (e.g. 200 days or 400 days). These cases were then optimized using Sequential Quadratic Programming method to solve the constrained optimization problem.

About the ACT

The advanced concepts team (ACT) is part of the European Space Agency's Future Studies Office (DG-PF). The team is essentially a channel for the study of technologies and ideas that are of strategic importance in the long term planning of the Agency. Placed at corporate level, it serves the function of a think tank providing decision makers the support of a highly multidisciplinary research group.

JPL Acknowledgment

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≤ 200 Day Missions

Asteroid	Flight Time [d]	Total Deep Space DV [km/s]	Launch Date	Launch Vinf [km/s]	Launch C3 [km2/s2]	Arrival Date	Departure Date	Stay Time [d]	Earth Return Date	Earth Arrival Vinf [km/s]	Entry Speed [km/s]	Absolute Magnitude	Albedo	Diameter Est. [km]	Known Diameter [km]	Rotational Period [hr]	Spectral Type (SMASSII)	Spectral Type (Tholen)	Orbit SMA [AU]	Orbit Ecc.	Orbit Inc. [deg]	MOID [AU]	Orbit Condition Code
2007 UN12	200	2.087	23-Jun-20	1.70	2.9	25-Sep-20	15-Oct-20	20	3-May-21	2.19	11.29	28.7		0.006					1.05	0.06	0.23	0.00	4.00
2006 RH120	200	2.193	6-May-28	0.70	0.5	31-Jul-28	20-Aug-28	20	8-Mar-29	1.38	11.16	29.6		0.004					1.03	0.02	0.60	0.02	1.00
2008 EA9	200	2.894	27-Oct-31	2.04	4.1	12-Feb-32	3-Mar-32	20	19-Sep-32	2.78	11.42	27.7		0.010					1.06	0.08	0.42	0.00	5.00
2008 HU4	200	2.908	26-Jan-24	0.24	0.1	19-Apr-24	9-May-24	20	25-Nov-24	0.17	11.07	28.2		0.008					1.10	0.08	1.32	0.01	4.00
2005 UV64	200	3.093	3-Apr-20	4.04	16.3	5-Jul-20	25-Jul-20	20	10-Feb-21	3.99	11.77	26.6		0.016					0.96	0.12	5.42	0.03	6.00
2006 UQ216	200	3.120	29-Jul-28	2.81	7.9	2-Dec-28	22-Dec-28	20	10-Jul-29	4.20	11.84	27.3		0.012					1.10	0.16	0.47	0.00	6.00
2004 QA22	200	3.235	23-Apr-30	2.59	6.7	17-Aug-30	6-Sep-30	20	25-Mar-31	3.93	11.75	27.9		0.009					0.95	0.12	0.58	0.00	5.00
2007 VV83	200	3.300	22-Apr-26	5.50	30.3	15-Jul-26	4-Aug-26	20	20-Feb-27	5.79	12.49	24.8		0.038					0.97	0.10	10.12	0.04	4.00
2000 SG344	200	3.366	29-Mar-28	1.02	1.0	13-Jun-28	3-Jul-28	20	19-Jan-29	1.56	11.18	24.8		0.038					0.98	0.07	0.11	0.00	3.00
1999 RA32	197	3.489	7-Mar-25	5.68	32.3	29-May-25	18-Jun-25	20	28-Dec-25	5.50	12.36	20.9		0.226					1.03	0.09	10.52	0.06	2.00
2006 DQ14	200	3.493	3-Aug-30	3.57	12.7	25-Oct-30	14-Nov-30	20	2-Jun-31	3.77	11.70	27.0		0.013					1.03	0.05	6.30	0.02	6.00
2008 VC	200	3.554	31-Oct-27	4.85	23.5	14-Jan-28	3-Feb-28	20	21-Aug-28	4.79	12.06	26.9		0.014					1.12	0.17	5.72	0.01	6.00
1999 AO10	199	3.659	12-Aug-25	1.06	1.1	30-Dec-25	19-Jan-26	20	2-Aug-26	2.66	11.39	23.9		0.058					0.91	0.11	2.62	0.02	4.00
2009 DB43	200	3.755	2-Jul-30	3.40	11.6	4-Nov-30	24-Nov-30	20	12-Jun-31	4.96	12.13	26.5		0.018					1.10	0.17	0.93	0.01	7.00
2008 GL2	200	3.877	3-Apr-33	3.10	9.6	8-Jun-33	28-Jun-33	20	14-Jan-34	3.38	11.58	27.2		0.013					1.12	0.13	5.17	0.02	7.00
2008 UD95	200	3.976	1-Apr-30	3.05	9.3	19-Jul-30	8-Aug-30	20	24-Feb-31	3.54	11.62	25.7		0.025					1.14	0.14	4.36	0.04	7.00
2007 XB23	200	3.997	21-Nov-24	2.17	4.7	26-Dec-24	15-Jan-25	20	3-Aug-25	4.31	11.88	27.1		0.013					1.04	0.05	8.53	0.00	6.00
2009 OS5	200	4.012	3-Feb-20	1.18	1.4	23-May-20	12-Jun-20	20	29-Dec-20	2.11	11.27	23.6		0.066					1.14	0.10	1.69	0.03	5.00
2001 GP2	177	4.020	13-Apr-20	1.37	1.9	31-Aug-20	20-Sep-20	20	16-Dec-20	2.63	11.38	26.9		0.014					1.04	0.07	1.28	0.00	6.00
2006 UB17	200	4.029	19-May-34	1.10	1.2	30-Aug-34	19-Sep-34	20	7-Apr-35	0.95	11.11	26.3		0.019					1.14	0.10	1.99	0.03	7.00
2008 ON10	195	4.067	29-Jul-23	3.99	15.9	28-Sep-23	18-Oct-23	20	26-Apr-24	4.28	11.87	24.6		0.041					1.16	0.16	7.11	0.03	6.00
2007 BB	200	4.080	10-Jun-33	4.40	19.4	25-Sep-33	15-Oct-33	20	3-May-34	5.00	12.15	27.8		0.009					0.93	0.14	3.53	0.00	6.00
2008 CM74	200	4.087	21-Feb-33	4.01	16.1	13-May-33	3-Jun-33	21	19-Dec-33	4.94	12.13	28.0		0.008					1.09	0.15	0.85	0.00	6.00
2000 LG6	200	4.178	27-Dec-28	2.04	4.2	17-Apr-29	7-May-29	20	23-Nov-29	3.56	11.63	29.0		0.005					0.92	0.11	2.83	0.00	6.00
2001 QC34	200	4.200	13-Dec-31	4.78	22.9	16-Feb-32	7-Mar-32	20	23-Sep-32	4.59	11.99	19.9		0.356					1.13	0.19	6.23	0.03	0.00
2008 LD	200	4.265	8-May-24	3.65	13.3	6-Jul-24	26-Jul-24	20	11-Feb-25	3.51	11.61	28.9		0.006					0.89	0.15	6.54	0.00	5.00
2001 QJ142	200	4.288	30-Mar-24	1.63	2.7	5-Jul-24	25-Jul-24	20	10-Feb-25	1.90	11.23	23.4		0.071					1.06	0.09	3.11	0.01	6.00
2003 WT153	200	4.299	27-Apr-30	2.10	4.4	6-Sep-30	26-Sep-30	20	14-Apr-31	4.19	11.84	28.0		0.008		0.117			0.89	0.18	0.37	0.00	5.00
2008 JL24	200	4.314	1-Jan-26	0.56	0.3	10-Apr-26	30-Apr-26	20	16-Nov-26	1.67	11.20	29.6		0.004					1.04	0.11	0.55	0.00	3.00
2008 DL4	200	4.342	7-Oct-33	1.62	2.6	10-Feb-34	2-Mar-34	20	18-Sep-34	3.23	11.53	26.8		0.015					0.93	0.12	3.21	0.01	6.00
2000 SZ162	200	4.366	13-Mar-26	3.26	10.6	24-Jul-26	13-Aug-26	20	1-Mar-27	4.66	12.01	27.1		0.013					0.93	0.17	0.89	0.00	7.00
2005 TG50	200	4.380	19-Apr-21	3.01	9.1	15-Aug-21	4-Sep-21	20	23-Mar-22	4.81	12.07	24.8		0.038					0.92	0.13	2.43	0.01	6.00
2007 HL4	187	4.453	31-Oct-32	3.27	10.7	18-Feb-33	10-Mar-33	20	19-Aug-33	3.58	11.64	24.2		0.049					1.12	0.09	6.53	0.03	7.00
2006 SY5	198	4.597	23-Aug-22	4.73	22.4	9-Dec-22	29-Dec-22	20	11-Jul-23	5.50	12.36	22.1		0.132					1.04	0.15	7.57	0.10	3.00
1999 SF10	198	4.628	3-Jun-25	1.94	3.8	21-Oct-25	10-Nov-25	20	22-May-26	4.69	12.02	24.0		0.053		0.0411			1.28	0.25	1.23	0.00	6.00
1999 VX25	199	4.703	27-Apr-34	0.67	0.5	14-Sep-34	4-Oct-34	20	15-Apr-35	2.63	11.38	26.7		0.016					0.90	0.14	1.66	0.01	6.00
1998 KG3	192	4.866	11-Oct-32	3.07	9.4	8-Jan-33	28-Jan-33	20	30-Jul-33	2.92	11.45	22.1		0.131					1.16	0.12	5.50	0.10	0.00
2006 XW	200	4.992	17-May-21	4.20	17.6	31-Jul-21	20-Aug-21	20	8-Mar-22	4.34	11.89	23.7		0.062					1.10	0.04	8.21	0.06	7.00

≤ 400 Day Missions

Asteroid	Flight Time [d]	Total Deep Space DV [km/s]	Launch Date	Launch Vinf [km/s]	Launch C3 [km2/s2]	Arrival Date	Departure Date	Stay Time [d]	Earth Return Date	Earth Arrival Vinf [km/s]	Entry Speed [km/s]	Absolute Magnitude	Albedo	Diameter Est. [km]	Known Diameter [km]	Rotational Period [hr]	Spectral Type (SMASSII)	Spectral Type (Tholen)	Orbit SMA [AU]	Orbit Ecc.	Orbit Inc. [deg]	MOID [AU]	Orbit Condition Code
2000 SG344	300	0.964	6-Apr-28	1.08	1.2	6-Sep-28	26-Sep-28	20	23-Jul-29	1.54	11.18	24.8		0.038					0.98	0.07	0.11	0.00	3.00
2000 SG344	400	0.998	31-Jan-28	0.31	0.1	5-Aug-28	26-Aug-28	21	29-Sep-29	1.03	11.12	24.8		0.038					0.98	0.07	0.11	0.00	3.00
2006 RH120	400	1.192	29-Mar-28	0.28	0.1	1-Sep-28	21-Sep-28	20	26-Oct-29	0.73	11.10	29.6		0.004					1.03	0.02	0.60	0.02	1.00
2008 UA202	300	1.233	24-Dec-28	2.23	5.0	30-May-29	19-Jun-29	20	15-Apr-30	2.76	11.41	29.4		0.004					1.03	0.07	0.26	0.00	6.00
2001 GP2	400	1.244	9-Sep-20	1.52	2.3	2-Dec-20	22-Dec-20	20	26-Jan-22	3.55	11.63	26.9		0.014					1.04	0.07	1.28	0.00	6.00
2008 UA202	400	1.371	30-Sep-28	0.50	0.2	20-Jun-29	10-Jul-29	20	14-Aug-30	2.28	11.31	29.4		0.004					1.03	0.07	0.26	0.00	6.00
2001 GP2	281	1.398	1-Jan-20	2.44	6.0	21-May-20	11-Jun-20	21	25-Feb-21	2.58	11.37	26.9		0.014					1.04	0.07	1.28	0.00	6.00
2007 SQ6	391	1.442	5-Oct-23	5.14	26.4	30-Dec-23	19-Jan-24	20	9-Feb-25	5.43	12.33	21.9		0.143					1.04	0.15	9.10	0.01	3.00
2006 BZ147	400	1.581	6-Jan-35	1.12	1.3	15-Apr-35	20-Jun-35	66	10-Jun-36	2.72	11.40	25.4		0.028					1.02	0.10	1.41	0.00	3.00
2006 RH120	300	1.755	30-Mar-28	0.31	0.1	19-Aug-28	8-Sep-28	20	5-Jul-29	1.13	11.13	29.6		0.004					1.03	0.02	0.60	0.02	1.00
2007 UN12	400	1.762	5-Mar-20	0.22	0.0	29-Aug-20	18-Sep-20	20	23-Oct-21	0.80	11.10	28.7		0.006					1.05	0.06	0.23	0.00	4.00
(207945) 1991 JW	400	1.833	20-May-27	4.52	20.4	13-Sep-27	3-Oct-27	20	6-Nov-28	5.23	12.24	19.2		0.496					1.04	0.12	8.71	0.02	0.00
2007 UN12	300	1.852	27-Apr-20	0.59	0.3	13-Sep-20	3-Oct-20	20	30-Jul-21	1.22	11.14	28.7		0.006					1.05	0.06	0.23	0.00	4.00
2007 VU6	400	1.887	5-Aug-34	0.81	0.7	20-Nov-34	25-Dec-34	35	27-Jan-36	2.34	11.32	26.5		0.017					0.98	0.09	1.22	0.01	5.00
2008 EA9	400	1.925	14-Jun-31	0.28	0.1	18-Jan-32	7-Feb-32	20	13-Mar-33	1.02	11.12	27.7		0.010					1.06	0.08	0.42	0.00	5.00
2008 HU4	400	1.982	31-Mar-24	0.77	0.6	16-May-24	5-Jun-24	20	10-Jul-25	1.66	11.20	28.2		0.008					1.10	0.08	1.32	0.01	4.00
2008 EA9	300	2.053	23-Aug-31	0.85	0.7	29-Jan-32	18-Feb-32	20	14-Dec-32	1.51	11.17	27.7		0.010					1.06	0.08	0.42	0.00	5.00
2008 ST	400	2.094	10-Sep-25	0.95	0.9	30-Apr-26	20-May-26	20	24-Jun-27	3.47	11.60	27.1		0.013					0.96	0.13	1.91	0.00	5.00
2010 JR34	400	2.336	25-Apr-25	1.25	1.6	8-Dec-25	28-Dec-25	20	1-Feb-27	4.56	11.98	27.7		0.010					0.96	0.14	0.72	0.00	5.00
2007 XB23	378	2.341	14-Jun-24	2.83	8.0	4-Dec-24	24-Dec-24	20	14-Dec-25	4.37	11.90	27.1		0.013					1.04	0.05	8.53	0.00	6.00
2006 HE2	300	2.342	9-Dec-28	5.44	29.6	11-May-29	31-May-29	20	27-Mar-30	5.50	12.36	26.5		0.017					1.07	0.16	1.18	0.00	5.00
2008 CM74	300	2.356	3-Sep-24	2.11	4.5	23-Mar-25	12-Apr-25	20	6-Feb-26	4.26	11.86	28.0		0.008					1.09	0.15	0.85	0.00	6.00
2008 JL24	367	2.469	6-Apr-25	0.30	0.1	28-Dec-25	17-Jan-26	20	27-Oct-26	2.67	11.39	29.6		0.004					1.04	0.11	0.55	0.00	3.00
2008 JL24	300	2.482	8-Jun-25	0.56	0.3	26-Dec-25	15-Jan-26	20	11-Nov-26	2.82	11.43	29.6		0.004					1.04	0.11	0.55	0.00	3.00
2008 CM74	381	2.539	19-Jun-24	0.65	0.4	26-Mar-25	15-Apr-25	20	3-Mar-26	3.92	11.74	28.0		0.008					1.09	0.15	0.85	0.00	6.00
2009 YR	400	2.555	26-May-30	0.56	0.3	22-Nov-30	13-Dec-30	21	16-Jan-32	1.95	11.24	28.0		0.009					0.94	0.11	0.70	0.00	5.00
(99942) APOPHIS	366	2.563	15-Apr-28	2.09	4.4	20-Jan-29	9-Feb-29	20	1-Nov-29	5.50	12.36	19.7	0.33	0.266	0.27	30.4	Sq		0.92	0.19	3.33	0.00	0.00
2008 ST	300	2.588	22-Apr-25	1.85	3.4	23-Jul-25	3-Dec-25	133	6-Jul-26	3.46	11.60	27.1		0.013					0.96	0.13	1.91	0.00	5.00
2009 BD	400	2.596	30-Apr-20	1.67	2.8	27-Nov-20	17-Dec-20	20	21-Jan-22	3.20	11.53	28.3		0.007					1.00	0.05	0.38	0.00	1.00
2005 QP11	400	2.666	9-Aug-31	2.19	4.8	26-Feb-32	17-Mar-32	20	21-Apr-33	5.50	12.36	26.4		0.018					0.98	0.18	3.96	0.01	3.00
2009 YR	300	2.683	25-Jul-30	1.63	2.7	20-Dec-30	9-Jan-31	20	5-Nov-31	2.94	11.45	28.0		0.009					0.94	0.11	0.70	0.00	5.00
2008 GM2	400	2.689	16-Sep-20	2.25	5.1	8-Dec-20	4-Jan-21	27	2-Feb-22	3.47	11.60	28.4		0.007					1.05	0.16	4.10	0.00	5.00
2007 VU6	300	2.711	9-Sep-34	1.61	2.6	12-Nov-34	2-Dec-34	20	28-Sep-35	3.91	11.74	26.5		0.017					0.98	0.09	1.22	0.01	5.00
2006 HE2	400	2.727	9-Sep-28	1.17	1.4	3-Jun-29	23-Jun-29	20	28-Jul-30	4.93	12.12	26.5		0.017					1.07	0.16	1.18	0.00	5.00
2008 HU4	300	2.729	7-Jan-24	0.24	0.1	18-Apr-24	8-May-24	20	4-Mar-25	0.67	11.09	28.2		0.008					1.10	0.08	1.32	0.01	4.00
2007 UY1	400	2.744	16-Jan-21	1.35	1.8	14-Sep-21	4-Oct-21	20	8-Nov-22	5.44	12.34	22.9		0.091					0.95	0.17	1.02	0.01	2.00
2004 UT1	388	2.795	13-Oct-21	3.05	9.3	28-Jun-22	10-Oct-22	104	23-Jul-23	5.50	12.36	26.4		0.018					0.96	0.22	4.51	0.01	5.00
2009 HC	300	2.914	12-Oct-25	2.75	7.6	19-Dec-25	11-May-26	143	4-Dec-26	3.48	11.61	24.8		0.038					1.04	0.13	3.78	0.01	4.00
2010 HA	400	2.978	6-Jul-26	1.14	1.3	12-Apr-27	2-May-27	20	5-Jun-28	5.43	12.33	24.0		0.055					0.96	0.20	2.18	0.03	4.00
2009 UD	300	2.982	29-May-28	2.82	8.0	20-Oct-28	3-Mar-29	134	17-Sep-29	3.69	11.67	27.2		0.013					1.04	0.12	4.41	0.01	4.00
2008 EY84	400	2.994	11-Feb-30	2.16	4.7	10-Sep-30	30-Sep-30	20	4-Nov-31	5.50	12.36	26.8		0.015					1.03	0.17	4.33	0.01	6.00
2000 SZ162	368	2.999	2-Oct-25	0.52	0.3	9-Jul-26	29-Jul-26	20	28-Apr-27	4.03	11.78	27.1		0.013					0.93	0.17	0.89	0.00	7.00
2006 UQ216	355	3.025	2-Mar-28	0.35	0.1	7-Dec-28	27-Dec-28	20	5-Aug-29	3.61	11.65	27.3		0.012					1.10	0.16	0.47	0.00	6.00
1999 CG9	400	3.105	8-Jul-33	1.95	3.8	24-Feb-34	17-Mar-34	21	20-Apr-35	3.40	11.58	25.2		0.032					1.06	0.06	5.16	0.02	6.00
2009 BF2	300	3.110	21-Mar-31	5.00	25.0	17-Aug-31	9-Dec-31	114	28-Jul-32	5.50	12.36	25.9		0.023					1.06	0.18	4.55	0.01	6.00
2007 RC20	400	3.116	8-Sep-21	2.27	5.2	1-Apr-22	21-Apr-22	20	26-May-23	5.50	12.36	26.6		0.016					0.95	0.20	2.84	0.01	8.00
2000 SZ162	300	3.129	6-Dec-25	0.96	0.9	3-Jul-26	23-Jul-26	20	19-May-27	4.24	11.86	27.1		0.013					0.93	0.17	0.89	0.00	7.00
2006 UQ216	294	3.131	2-May-28	0.68	0.5	28-Nov-28	18-Dec-28	20	18-Sep-29	3.66	11.66	27.3		0.012					1.10	0.16	0.47	0.00	6.00
2009 HC	400	3.141	10-Sep-25	0.73	0.5	13-Dec-25	2-Jan-26	20	6-Feb-27	2.98	11.47	24.8		0.038					1.04	0.13	3.78	0.01	4.00
2006 FH36	391	3.155	30-Jun-34	0.97	0.9	1-Apr-35	21-Apr-35	20	21-Apr-36	5.42	12.33	22.9		0.090					0.95	0.20	1.59	0.02	3.00
2009 WR52	400	3.179	23-Oct-29	1.96	3.8	8-Jun-30	28-Jun-30	20	2-Aug-31	5.50	12.36	28.3		0.007					1.03	0.15	4.24	0.00	6.00
2008 WO2	400	3.188	7-Oct-34	1.63	2.7	1-Jul-35	21-Jul-35	20	24-Aug-36	5.50	12.36	29.8		0.004					1.03	0.19	2.01	0.00	6.00
2009 YF	400	3.192	15-Aug-28	0.61	0.4	25-Dec-28	18-Jan-29	24	20-Feb-30	1.96	11.24	24.7		0.040					0.94	0.12	1.52	0.02	7.00
2009 UD	400	3.202	3-Mar-28	0.81	0.7	5-Nov-28	14-Mar-29	129	10-Jan-30	3.20	11.53	27.2		0.013					1.04	0.12	4.41	0.01	4.00
2007 WA	300	3.265	12-Jul-28	4.27	18.2	21-Nov-28	7-Jan-29	47	29-Oct-29	5.26	12.26	24.7		0.039					1.04	0.15	6.16	0.01	6.00
2001 QJ142	400	3.274	9-Sep-23	1.16	1.4	30-May-24	8-Jul-24	39	27-Jul-25	1.88	11.23	23.4		0.071					1.06	0.09	3.11	0.01	6.00
2006 DQ14	390	3.308	23-Feb-30	0.56	0.3	2-Sep-30	22-Sep-30	20	3-Oct-31	3.64	11.65	27.0		0.013					1.03	0.05	6.30	0.02	6.00
2007 YF	380	3.340	27-Feb-21	0.46	0.2	4-Dec-21	24-Dec-21	20	11-Nov-22	3.73	11.68	24.8		0.038					0.95	0.12	1.65	0.01	5.00
2005 VN5	400	3.377	2-May-26	2.79	7.8	3-Nov-26	23-Nov-26	20	28-Dec-27	5.50	12.36	27.0		0.014					0.94	0.23	2.09	0.00	4.00
2007 YF	300	3.377	13-May-21	1.00	1.0	30-Nov-21	20-Dec-21	20	16-Oct-22	4.11	11.81	24.8		0.038					0.95	0.12	1.65	0.01	5.00
2004 FM32	370	3.414	1-Oct-33	2.03	4.1	12-Jan-34	1-Feb-34	20	22-Jan-35	2.57	11.37	26.6		0.017					1.10	0.16	3.76	0.00	6.00
(99942) APOPHIS	300	3.478	17-Jun-28	2.93	8.6	13-Jan-29	13-Mar-29	59	10-Dec-29	5.83	12.51	19.7	0.33	0.266	0.27	30.4	Sq		0.92	0.19	3.33	0.00	0.00
2008 YN2	400	3.512	15-Nov-25	2.48	6.2	22-Aug-26	23-Jan-27	154	24-Oct-27	5.50	12.36	26.3		0.019					1.04	0.22	3.49	0.01	6.00
2009 DB43	360	3.538	2-Feb-30	0.41	0.2	9-Nov-30	29-Nov-30	20	27-Jul-31	4.03	11.78	26.5		0.018					1.10	0.17	0.93	0.01	7.00
2010 GV23	300	3.552	12-Oct-27	5.02	25.2	7-Mar-28	27-Mar-28	20	21-Jan-29	5.70	12.45	27.6		0.010					0.93	0.20	3.62	0.00	5.00
2006 FH36	300	3.584	25-Sep-20	2.49	6.2	17-Mar-21	6-Apr-21	20	31-Jan-22	5.50	12.36	22.9		0.090					0.95	0.20	1.59	0.02	3.00
2006 DQ14	300	3.611	29-Apr-30	0.77	0.6	27-Aug-30	16-Sep-30	20	13-Jul-31	3.60	11.64	27.0		0.013					1.03	0.05	6.30	0.02	6.00
2005 TG50	377	3.613	18-Nov-20	0.38	0.1	25-Aug-21	14-Sep-21	20	20-Jul-22	3.14	11.51	24.8		0.038					0.92	0.13	2.43	0.01	6.00
2009 YF	300	3.625	14-Sep-28	1.12	1.3	24-Dec-28	1-Apr-29	98	30-Nov-29	3.50	11.61	24.7		0.040					0.94	0.12	1.52	0.02	7.00
2009 DB43	299	3.634	4-Apr-30	0.80	0.6	31-Oct-30	20-Nov-30	20	10-Sep-31	4.08	11.80	26.5		0.018					1.10	0.17	0.93	0.01	7.00
2004 QA22	351	3.641	6-Dec-29	0.32	0.1	21-Aug-30	10-Sep-30	20	8-May-31	3.14	11.51	27.9		0.009					0.95	0.12	0.58	0.00	5.00
2005 TG50	300	3.656	28-Jan-21	0.85	0.7	25-Aug-21	14-Sep-21	20	11-Jul-22	3.56	11.63	24.8		0.038					0.92	0.13	2.43	0.01	6.00
2008 DL4	400	3.673	31-Jul-33	0.91	0.8	14-Mar-34	1-May-34	48	13-May-35	1.81	11.22	26.8		0.015					0.93	0.12	3.21	0.01	6.00
2008 UB95	400	3.718	23-Feb-20	4.67	21.8	3-Oct-20	18-Jan-21	107	21-Dec-21	6.32	12.75	24.7		0.040					0.99	0.27	3.24	0.00	2.00
2007 BB	362	3.760	14-Jan-24	0.89	0.8	6-Oct-24	26-Oct-24	20	18-Jul-25	4.35	11.90	27.8		0.009					0.93	0.14	3.53	0.00	6.00
2007 RO17	392	3.766	11-Nov-32	0.85	0.7	18-Aug-33	7-Sep-33	20	8-Sep-34	5.19	12.23	25.7		0.024					0.93	0.20	2.46	0.03	7.00
2004 JN1	400	3.779	24-Apr-29	1.02	1.0	24-Jan-30	13-Feb-30	20	20-Mar-31	4.64	12.00	23.5		0.070					1.09	0.18	1.50	0.02	6.00
2009 BF2	400	3.883	11-Dec-30	1.12	1.3	6-Sep-31	28-Dec-31	113	9-Nov-32	5.46	12.34	25.9		0.023					1.06	0.18	4.55	0.01	6.00
2000 LG6	400	3.886	29-Oct-28	0.51	0.3	10-May-29	30-May-29	20	4-Jul-30	1.64	11.19	29.0		0.005					0.92	0.11	2.83	0.00	6.00
2007 WA	400	3.906	4-Apr-28	1.02	1.0	8-Dec-28	28-Dec-28	20	1-Feb-30	5.26	12.26	24.7		0.039					1.04	0.15	6.16	0.01	6.00
2002 AW	400	3.906	11-Feb-22	2.52	6.4	24-May-22	30-Jun-22	37	4-Aug-23	5.50	12.36	20.5		0.270					1.07	0.26	0.57	0.00	2.00
2005 UG5	300	3.923	27-Jun-31	2.54	6.4	21-Dec-31	10-Jan-32	20	5-Nov-32	5.50	12.36	24.4		0.046					1.06	0.19	2.87	0.02	7.00
1999 AO10	336	3.996	30-Mar-25	0.28	0.1	4-Jan-26	24-Jan-26	20	15-Jun-26	2.56	11.36	23.9		0.058					0.91	0.11	2.62	0.02	4.00
2009 UK20	400	4.002	21-Apr-23	2.20	4.8	9-Dec-23	29-Dec-23	20	1-Feb-25	5.50	12.36	26.4		0.018					1.06	0.21	2.86	0.01	6.00
2009 SH2	400	4.033	27-Aug-20	2.00	4.0	16-Mar-21	5-Apr-21	20	10-May-22	4.99	12.15	24.9		0.036					1.00	0.09	6.80	0.00	3.00
2001 BA16	400	4.045	5-Dec-31	1.96	3.9	11-Feb-32	2-Mar-32	20	6-Apr-33	3.88	11.73	25.8		0.023					0.94	0.14	5.77	0.00	5.00
2006 BJ55	400	4.050	8-Jul-31	1.30	1.7	4-Mar-32	16-Sep-32	196	3-May-33	5.50	12.36	24.2		0.049					1.03	0.13	5.92	0.03	6.00
2005 UG5	390	4.061	29-Mar-31	0.79	0.6	26-Dec-31	15-Jan-32	20	13-Jan-33	5.50	12.36	24.4		0.046					1.06	0.19	2.87	0.02	7.00
1998 KG3	383	4.081	2-Apr-32	2.88	8.3	20-Dec-32	9-Jan-33	20	16-Dec-33	2.93	11.45	22.1		0.131					1.16	0.12	5.50	0.10	0.00
2006 AN	386	4.110	14-Dec-29	3.97	15.7	23-Feb-30	23-Mar-30	28	8-Apr-31	5.50	12.36	24.5		0.044					1.09	0.22	7.40	0.01	7.00
2005 CD69	400	4.119	4-Jan-30	1.96	3.8	9-May-30	29-May-30	20	3-Jul-31	4.41	11.92	24.1		0.052					1.09	0.19	2.78	0.01	7.00
2002 XY38	400	4.122	9-Feb-29	1.43	2.1	2-Nov-29	22-Nov-29	20	27-Dec-30	5.50	12.36	22.9		0.089					0.91	0.22	2.10	0.00	1.00
2008 BT2	400	4.145	22-Jan-22	1.84	3.4	27-Apr-22	17-May-22	20	21-Jun-23	3.45	11.60	24.3		0.047					1.17	0.08	3.08	0.09	5.00
2008 CX118	400	4.163	12-Apr-24	1.07	1.1	1-Aug-24	21-Aug-24	20	25-Sep-25	2.82	11.43	24.4		0.045					1.14	0.04	2.42	0.09	7.00
2001 CQ36	367	4.191	6-May-21	0.64	0.4	28-Jan-22	17-Feb-22	20	27-Nov-22	4.81	12.07	22.7		0.099					0.94	0.18	1.29	0.01	2.00
1999 AO10	267	4.206	5-Jun-25	0.23	0.1	1-Jan-26	21-Jan-26	20	30-Jun-26	2.62	11.38	23.9		0.058					0.91	0.11	2.62	0.02	4.00
2009 TP	387	4.215	17-Aug-33	1.29	1.7	6-Mar-34	26-Mar-34	20	1-Apr-35	5.50	12.36	23.5		0.067					1.03	0.22	0.79	0.00	6.00
2004 SR	381	4.221	21-Mar-20	4.37	19.1	1-Jul-20	21-Jul-20	20	27-Jul-21	4.75	12.05	23.8		0.059					1.15	0.16	8.64	0.03	6.00
2010 JR34	300	4.242	1-Dec-24	1.06	1.1	2-May-25	22-May-25	20	18-Mar-26	3.62	11.65	27.7		0.010					0.96	0.14	0.72	0.00	5.00
2007 PS9	390	4.266	8-Feb-27	1.82	3.3	13-Aug-27	2-Sep-27	20	11-Sep-28	5.26	12.26	23.5		0.068					1.07	0.08	8.70	0.04	3.00
1999 VX25	400	4.266	10-Apr-28	0.37	0.1	12-Nov-28	2-Dec-28	20	6-Jan-30	2.09	11.27	26.7		0.016					0.90	0.14	1.66	0.01	6.00
2008 FJ7	400	4.279	28-Jul-24	1.76	3.1	1-Dec-24	27-Dec-24	26	28-Jan-26	5.49	12.36	25.9		0.023					1.13	0.29	0.47	0.01	7.00
2007 BB	300	4.338	12-Mar-24	1.01	1.0	30-Sep-24	20-Oct-24	20	16-Aug-25	4.58	11.98	27.8		0.009					0.93	0.14	3.53	0.00	6.00
2001 QJ142	300	4.341	24-Sep-23	0.47	0.2	10-Apr-24	30-Apr-24	20	24-Feb-25	2.00	11.25	23.4		0.071					1.06	0.09	3.11	0.01	6.00
2001 CQ36	300	4.341	8-Jul-21	1.04	1.1	22-Jan-22	11-Feb-22	20	8-Dec-22	5.15	12.21	22.7		0.099					0.94	0.18	1.29	0.01	2.00
2007 UW1	369	4.365	5-May-26	2.47	6.1	29-Sep-26	19-Oct-26	20	24-Sep-27	4.31	11.88	22.7		0.099					0.91	0.12	8.22	0.00	7.00
2007 TF15	400	4.389	20-Aug-28	2.09	4.4	15-Jan-29	4-Feb-29	20	11-Mar-30	4.83	12.08	25.0		0.035					1.11	0.04	4.18	0.06	8.00
2001 QE71	300	4.401	24-Sep-28	1.59	2.5	10-Apr-29	30-Apr-29	20	24-Feb-30	5.20	12.23	24.4		0.045					1.08	0.16	3.03	0.01	6.00
2003 SM84	400	4.402	6-Sep-33	1.06	1.1	4-May-34	24-May-34	20	28-Jun-35	3.94	11.75	22.7		0.097					1.13	0.08	2.79	0.05	1.00
2006 BA	400	4.402	15-Jun-31	1.61	2.6	6-Mar-32	26-Mar-32	20	30-Apr-33	5.50	12.36	27.6		0.010					1.12	0.22	3.55	0.00	6.00
2005 GE60	400	4.408	3-Nov-33	3.76	14.1	23-Feb-34	14-Apr-34	50	19-May-35	5.50	12.36	22.1		0.130					0.96	0.25	5.57	0.00	4.00
2007 HL4	400	4.417	11-Mar-20	1.84	3.4	10-May-20	3-Jun-20	24	5-Jul-21	4.47	11.94	24.2		0.049					1.12	0.09	6.53	0.03	7.00
2001 QE71	379	4.419	13-Jul-28	0.68	0.5	11-Apr-29	1-May-29	20	18-Mar-30	4.75	12.05	24.4		0.045					1.08	0.16	3.03	0.01	6.00
2010 FY9	346	4.437	16-Oct-31	1.41	2.0	23-Feb-32	14-Mar-32	20	19-Jan-33	2.60	11.37	26.6		0.017					0.89	0.15	4.34	0.01	7.00
2008 EV5	400	4.455	19-May-24	1.52	2.3	9-Dec-24	29-Dec-24	20	2-Feb-26	4.17	11.83	20.0		0.343	0.45	3.725			0.96	0.08	7.44	0.02	0.00
2008 ON10	391	4.471	18-Jul-33	2.92	8.5	7-Sep-33	27-Sep-33	20	21-Oct-34	3.69	11.67	24.6		0.041					1.16	0.16	7.11	0.03	6.00
2008 DB	400	4.488	13-Jan-20	1.88	3.5	4-Oct-20	24-Oct-20	20	28-Nov-21	5.50	12.36	25.7		0.025					1.05	0.23	4.22	0.00	6.00
2005 QP11	300	4.503	6-Oct-30	2.09	4.4	25-Mar-31	14-Apr-31	20	8-Feb-32	5.47	12.35	26.4		0.018					0.98	0.18	3.96	0.01	3.00
2010 GV23	400	4.524	21-Jul-27	1.28	1.6	24-Mar-28	13-Apr-28	20	18-May-29	4.69	12.02	27.6		0.010					0.93	0.20	3.62	0.00	5.00
2005 FG	400	4.538	17-Feb-24	2.38	5.7	17-May-24	6-Jun-24	20	10-Jul-25	4.31	11.88	24.0		0.054					1.12	0.21	3.88	0.02	6.00
2009 CV	400	4.561	15-Jul-22	1.31	1.7	2-Mar-23	22-Mar-23	20	25-Apr-24	4.86	12.09	24.3		0.048					1.11	0.15	0.96	0.01	3.00
2000 LG6	300	4.565	21-Oct-28	0.43	0.2	29-Apr-29	19-May-29	20	15-Mar-30	2.44	11.34	29.0		0.005					0.92	0.11	2.83	0.00	6.00
2008 GL2	300	4.584	20-Mar-33	2.30	5.3	20-May-33	16-Jul-33	57	13-Apr-34	3.41	11.58	27.2		0.013					1.12	0.13	5.17	0.02	7.00
2006 BZ147	300	4.599	4-Jan-35	0.99	1.0	29-Mar-35	18-Apr-35	20	12-Feb-36	3.87	11.73	25.4		0.028					1.02	0.10	1.41	0.00	3.00
2007 TH3	400	4.599	23-Feb-29	2.52	6.3	17-Sep-29	7-Oct-29	20	11-Nov-30	5.16	12.21	24.6		0.041					0.97	0.12	8.23	0.01	3.00
2009 OS5	400	4.633	3-Jan-20	0.32	0.1	8-Jun-20	28-Jun-20	20	2-Aug-21	1.19	11.14	23.6		0.066					1.14	0.10	1.69	0.03	5.00
2010 FY9	300	4.670	23-Nov-31	1.64	2.7	23-Feb-32	14-Mar-32	20	8-Jan-33	2.77	11.41	26.6		0.017					0.89	0.15	4.34	0.01	7.00
2009 OS5	249	4.704	1-Jan-20	0.36	0.1	25-May-20	14-Jun-20	20	16-Dec-20	1.82	11.22	23.6		0.066					1.14	0.10	1.69	0.03	5.00
2005 LC	400	4.705	8-Oct-33	0.72	0.5	17-May-34	6-Jun-34	20	11-Jul-35	1.72	11.20	26.8		0.015					1.13	0.10	2.80	0.02	6.00
2010 AN61	400	4.715	13-Jun-24	1.27	1.6	25-Jan-25	14-Feb-25	20	21-Mar-26	2.42	11.33	27.0		0.013					1.16	0.13	3.61	0.02	6.00
2006 UB17	400	4.719	20-Mar-34	0.08	0.0	31-Aug-34	20-Sep-34	20	25-Oct-35	1.04	11.12	26.3		0.019					1.14	0.10	1.99	0.03	7.00
2004 FM32	300	4.728	28-Oct-33	1.99	4.0	26-Jan-34	15-Feb-34	20	12-Dec-34	2.54	11.36	26.6		0.017					1.10	0.16	3.76	0.00	6.00
2003 RU11	368	4.767	1-Oct-28	1.50	2.3	28-Jun-29	18-Jul-29	20	28-Apr-30	4.75	12.05	25.6		0.026					0.89	0.18	4.66	0.01	3.00
2004 VJ1	354	4.769	4-Dec-25	0.55	0.3	17-Aug-26	6-Sep-26	20	16-May-27	4.41	11.92	24.3		0.048					0.94	0.16	1.29	0.01	6.00
2009 WC106	300	4.769	29-Jun-27	2.76	7.6	31-Dec-27	21-Feb-28	52	25-Nov-28	5.11	12.20	25.5		0.028					1.08	0.18	5.35	0.01	8.00
2005 VL1	400	4.773	5-Feb-32	1.16	1.3	15-Oct-32	4-Nov-32	20	9-Dec-33	5.50	12.36	26.7		0.015					0.89	0.23	0.25	0.00	6.00
2008 GL2	400	4.778	3-Sep-26	0.97	0.9	28-Apr-27	18-May-27	20	21-Jun-28	3.96	11.76	27.2		0.013					1.12	0.13	5.17	0.02	7.00
2008 DL4	293	4.784	23-Jul-33	0.38	0.1	18-Feb-34	10-Mar-34	20	4-Dec-34	2.36	11.32	26.8		0.015					0.93	0.12	3.21	0.01	6.00
2005 LC	300	4.795	3-Dec-33	2.02	4.1	24-May-34	13-Jun-34	20	9-Apr-35	3.04	11.48	26.8		0.015					1.13	0.10	2.80	0.02	6.00
1999 SF10	367	4.799	17-Dec-24	0.25	0.1	29-Oct-25	18-Nov-25	20	28-Jan-26	4.64	12.00	24.0		0.053		0.0411			1.28	0.25	1.23	0.00	6.00
1999 SF10	332	4.801	21-Jan-25	0.29	0.1	28-Oct-25	17-Nov-25	20	25-Mar-26	4.65	12.01	24.0		0.053		0.0411			1.28	0.25	1.23	0.00	6.00
2003 WT153	345	4.802	7-Dec-29	0.29	0.1	10-Sep-30	30-Sep-30	20	6-Apr-31	3.78	11.70	28.0		0.008		0.117			0.89	0.18	0.37	0.00	5.00
2001 VE2	400	4.811	5-Apr-30	1.26	1.6	1-Dec-30	21-Dec-30	20	25-Jan-32	5.50	12.36	24.6		0.041					1.11	0.18	4.39	0.01	6.00
2008 UD95	362	4.825	27-Oct-29	0.63	0.4	27-Jul-30	16-Aug-30	20	2-May-31	3.30	11.55	25.7		0.025					1.14	0.14	4.36	0.04	7.00
2003 WT153	283	4.852	7-Feb-30	0.45	0.2	5-Sep-30	25-Sep-30	20	9-May-31	3.86	11.73	28.0		0.008		0.117			0.89	0.18	0.37	0.00	5.00
1999 SF10	264	4.861	29-Mar-25	0.65	0.4	25-Oct-25	14-Nov-25	20	11-Apr-26	4.67	12.02	24.0		0.053		0.0411			1.28	0.25	1.23	0.00	6.00
(138404) 2000 HA24	400	4.866	28-Jul-21	3.58	12.8	24-Nov-21	14-Dec-21	20	18-Jan-23	5.50	12.36	19.0		0.552					1.14	0.32	2.17	0.03	0.00
2009 TD17	400	4.868	10-Feb-33	1.68	2.8	9-Jul-33	29-Jul-33	20	2-Sep-34	3.67	11.66	27.7		0.010					1.13	0.22	0.08	0.00	6.00
2007 EC	300	4.874	16-Jul-23	4.22	17.8	21-Jan-24	10-Feb-24	20	6-Dec-24	5.50	12.36	22.2		0.124					0.93	0.20	5.81	0.02	5.00
2004 VJ1	300	4.882	24-Jan-26	0.73	0.5	14-Aug-26	3-Sep-26	20	30-Jun-27	4.67	12.01	24.3		0.048					0.94	0.16	1.29	0.01	6.00
1999 VX25	267	4.895	18-Feb-34	0.20	0.0	16-Sep-34	6-Oct-34	20	14-Mar-35	2.56	11.36	26.7		0.016					0.90	0.14	1.66	0.01	6.00
2009 TP	300	4.911	21-May-34	2.85	8.1	2-Nov-34	22-Nov-34	20	18-Sep-35	5.50	12.36	23.5		0.067					1.03	0.22	0.79	0.00	6.00
2007 EK	400	4.923	21-Aug-25	2.31	5.3	28-May-26	23-Jun-26	26	27-Jul-27	5.50	12.36	29.3		0.005					1.13	0.27	1.21	0.00	6.00
2008 VC	399	4.929	23-Sep-27	1.56	2.4	20-Nov-27	10-Dec-27	20	12-Jan-29	3.55	11.63	26.9		0.014					1.12	0.17	5.72	0.01	6.00
2006 CT	400	4.930	26-Apr-20	2.03	4.1	7-Sep-20	27-Sep-20	20	1-Nov-21	5.42	12.33	22.4		0.116					1.10	0.23	2.74	0.00	2.00
2005 ER95	400	4.963	13-Feb-28	1.29	1.7	11-Apr-28	1-May-28	20	5-Jun-29	2.83	11.43	25.3		0.030					1.22	0.16	3.34	0.03	6.00
2006 UB17	300	4.989	16-Feb-34	0.07	0.0	30-Aug-34	19-Sep-34	20	16-Jul-35	0.86	11.11	26.3		0.019					1.14	0.10	1.99	0.03	7.00

If an object's albedo is unknown, it is assumed to be 15% to estimate the diameter; Objects with diameters of 100 m or larger are highlighted