Dynamical and Compositional Assessment of Near-Earth Object Mission Targets

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Using an H-plot analysis, we identify 234 currently known near-Earth objects that are accessible for rendezvous with a "best case" delta-V of less than 7 km/sec. We provide a preliminary compositional interpretation and assessment of these potential targets by summarizing the taxonomic properties for 44 objects. Results for one-half (22) of this sample are based on new spectroscopic measurements presented here. Our approach provides an easy-to-update method for giving guidelines to both observers and mission analysts in focusing on objects for which actual mission opportunities are most likely to be found. Observing prospects are presented for categorizing the taxonomic properties of the most accessible targets that are not as of yet measured.

1. Introduction

A convergence of scientific and practical interest has brought planning for missions to near-Earth objects (NEOs) to the forefront. Given that meteorites are near-Earth objects (by definition of their intersecting orbits) prior to their arrival, NEO observations represent the most direct study of the precursor population for a major proportion of our extra-terrestrial samples. This NEO population is comprised by asteroids perturbed from the main-belt and extinct comet nuclei, but their relative proportions remain uncertain. The diversity of taxonomic classes within near-Earth space is at least as diverse as that found in our meteorite collections (Keil 2000, Binzel et al. 2002). Understanding the NEO population is at the heart of understanding asteroid-comet-meteorite relationships.

As demonstrated by the NEAR Shoemaker mission and the MUSES-C mission, the technology for exploring near-Earth asteroids is advancing rapidly and shows promise for the future. New mission concepts, such as a multiple sample return scenario, have been studied within the framework of the *Hera* proposal (Sears *et al*. 2000). The *Simone* concept foresees a fleet of small low-cost spacecraft each one directed to a different target (Wells and Fearn 2001).

From a practical point of view, the recognition of the statistically small (but non-zero) hazard of NEO impacts has given pragmatic incentive for their understanding. Also there has been an increasing recognition that the same proximity to Earth that results in the hazard also brings with it opportunity. Near-Earth objects are among the most accessible bodies in the solar system in terms of the propulsion requirements to reach them. This accessibility enables their scientific study, their practical study, and their detailed assessment for their future utilization as space resources.

With scientific goals, technological capabilities, and practical incentives in mind, we bring together an analysis of both NEO target accessibility and preliminary assessments of their possible compositions. In Section 2 we present a dynamical evaluation of the accessibility of currently known NEOs. Newly obtained spectral measurements for 22 of these are described and presented in Section 3, and prospective mission opportunities taking into account both accessibility and taxonomic (with interpretations for possible compositions) diversity are discussed in Section 4. Herein we also tabulate future observing opportunities for these accessible objects, the majority of which have at present no preliminary taxonomic information.

2. Dynamical Evaluation

The “H-plot” as a measure of the accessibility of the NEO population has been introduced by Perozzi et al. (2001) for discussing the selection of targets when both scientific and mission analysis considerations are taken into account. We apply this method of analysis here and display the results in Fig 1. The H-plot method exploits Hohmann-like transfer trajectories for evaluating “best case” delta-V (ΔV) budgets for rendezvous missions to each individual member of the NEO population. The Hohmann strategy was originally developed at the beginning of the last century for finding the minimum energy orbital paths enabling a manned spacecraft to reach the Moon and the planets (McLaughlin 2000). The method has been subsequently generalized to any transfer between circular and coplanar orbits (e.g. Roy 1988), taking into account relative inclinations (e.g. Boden 1997). The Hohmann strategy is very useful for assessing the accessibility of celestial bodies because it foresees two simple orbital maneuvers whose magnitude can be straightforwardly computed from basic Keplerian motion. If we consider the case when the radius of the target orbit is larger than that of the departure orbit, the first maneuver injects the spacecraft into a transfer trajectory whose apocenter is tangent to the target orbit. The second maneuver - applied upon reaching the apocenter of the transfer orbit - increases the velocity of the spacecraft by the exact amount needed for circularization. By adding up the ΔV contribution of both maneuvers a reliable estimate of the energy requirements needed for performing a “rendezvous mission” is obtained. (At encounter, the spacecraft must have the same orbital velocity and thus the same orbit as its target.) A graphical representation of performing Hohmann transfers throughout the Solar System is shown in Fig.1, assuming that the departure orbit is that of the Earth. The two curves are representative of the strategy described above and have been obtained by varying continuously the radius of the target orbit while keeping fixed at 1 AU the radius of the departure orbit. These curves also represent optimal mission profiles, provided that the ratio between the semi-major axis of the final orbit and that of the departure orbit is not greater than 15.58, which is the threshold for bi-elliptic transfers to become more convenient (e.g. Roy 1988).

[FIG 1 goes here.]

The Hohmann formalism can also be used as a basic targeting strategy for performing rendezvous missions to the eccentric and inclined orbits characterizing most NEOs by properly rearranging the order and the magnitude of the orbital maneuvers (Hechler et al. 1998). Results can be compared to the classical Hohmann transfers by plotting in the diagram of Fig.1 the aphelion distance of the target asteroid versus the total velocity change needed to transform an initially zero inclination circular 1 AU orbit into one identical to that of the target. Note that this is equivalent, when treating the Earth escape branch of the transfer trajectory, to computing the hyperbolic excess velocity in the massless planet approximation, as described by Prussing and Conway (1993).

The dynamical framework we use is similar to that chosen by Shoemaker and Helin (1978) in that it has the advantage of being independent of the launch scenario. Factors such as Earth phasing, the different capabilities of launchers, and/or the use of intermediate parking orbits make it difficult to carry out meaningful comparisons among different missions to different targets. The ΔV values used for creating the H-plot are instead a self-consistent data set representing the lowest figures achievable when both ideal phasing occurs (corresponding to the most favorable launch window geometry) and ideal orbital maneuvers (i.e. strictly impulsive) are performed.

The general picture conveyed in Fig. 1 shows that the NEO population is widely dispersed in terms of ΔV, thus reflecting its dynamical variety. Because of the high eccentricities and inclinations frequently found among the NEOs, a fraction of the population displays ΔV requirements higher than the amount necessary for sending an orbiter around Jupiter (indicated by the corresponding open circle in Fig. 1). On the other hand some may have orbits closely resembling that of the Earth, thus being among the most accessible objects in the Solar System. Note that some basic dynamical characteristics of NEOs are also recognizable in Fig.1: the clustering of low inclination objects with aphelia slightly in excess of 3 AU and Δv between 8 and 9 km/sec, are possibly connected to the ν_6 secular resonance (Gronchi and Milani 2001). A detailed investigation on the existence of this clustering is in progress.

Within this framework, the H-plot can be fruitfully exploited for addressing scientific and technical issues at the same time. As an example, Fig. 1 shows that if the value of 7 km/sec is assumed as representative of the present trajectory limit when no planetary gravitational assists are utilized, only a sub-sample of the NEO population is readily accessible. If one adds typical scientific requirements on the target, such as an interesting spectral type and/or some specific reasons of interest (double object, cometary candidate, potential future Earth-impact, etc), the choice of potential targets is further reduced. Finally, once a time frame for a mission launch is fixed, the relative orbital phasing between the Earth and the objects on the potential target list will ultimately decide which of the preliminary candidates turn out to be realistic targets. When considering that the number of known NEOs is steadily growing, the advantage of focusing on targets falling within the <7 km/sec Δv region of Fig. 1 is twofold: a) potential new spacecraft targets can be immediately recognized by mission planners; b) as potential spacecraft targets, observers can give them priority for physical characterization.

To achieve our combined goals for mission planning and physical characterization, we constructed a table of NEOs (known through July 2002) having a calculated Δv requirement of less than 7 km/sec. We present this listing in Table I. Objects are listed in order of increasing Δv together with their basic orbital parameters and absolute magnitudes. (An absolute magnitude for an asteroid is the apparent visible brightness it would have if placed at a fictitious point 1 AU from the Earth, 1 AU from the Sun, with the Sun-asteroid-Earth angle being zero.) Table I also lists the taxonomic type (discussed in detail in the following sections) and the occurrence of future observing opportunities. Orbit quality can be examined for each object by comparing the number of oppositions for astrometric observations (or the length of the orbital arc in days, denoted by "d" in the fourth column) and the uncertainty in the revolution period, expressed as the normalized fractional error dP/P computed from the orbital data provided by the website NEOdys. In this respect one has to consider that even recently discovered asteroids can quickly become multi-opposition objects thanks to the finding of pre-discovery plates, and that the arc length alone may not be a significant parameter. The case for 1999 SF10 and 2000 UK11 (listed consecutively in Table I) is a striking example: both are faint objects observed along a very short arc, but the uncertainty in their period differs by three orders of magnitude. The improvement for 2000 UK11 arises from having high signal-to noise-ratio (SNR) radar measurements within a favorable geometry for constraining the orbit (Nolan et al. 2001).

[TABLE I goes here]

3. Compositional Evaluation

Preliminary taxonomic information is available for 44 (about 20 percent) of the currently identified mission targets, where these classes (and their published references) are included in Table I. Results for one-half of this sample (22 out of 44) are based on observations we report below.

Our visible wavelength spectroscopic measurements were obtained in the course of on-going programs at Kitt Peak, Arizona and Palomar Mountain, California to perform ground-based reconnaissance of the basic spectroscopic (visible wavelength) properties of NEOs. At Kitt Peak, we utilized both the Michigan-Dartmouth-MIT (MDM) 2.4-m Hiltner telescope and the National Optical Astronomical Observatory (NOAO) 4-m Mayall telescope (Binzel, P. I.). On the

MDM 2.4-m telescope we utilized the Mark III CCD-spectrograph and on the NOAO 4-m telescope we utilized the RCSP spectrograph. The performance and application toward asteroid spectroscopy over visible wavelengths by these instruments are described in detail by Bus and Binzel (2002a) and Binzel et al. (2001b). At the Palomar 5-m telescope (Harris, P. I.), we obtained visible wavelength spectra using the Double Spectrograph (Oke and Gunn 1982). Binzel et al. (2001a) describe our observing and analysis procedures for the Palomar data. For all observations we utilized Hyades 64 and 16 Cyg B as our primary reference stars for the solar analog spectrum. For further sky coverage and to allow 4-6 standard stars per night, we also utilized solar analog reference stars selected from Landolt (1973) that were verified to be within 1% of our primary reference stars.

The spectra are presented in Fig. 2 and the taxonomic results are listed in Table I. Taxonomic classes are within the system defined by Tholen (1984) and extended by Bus (1999) to take advantage of the additional information available from CCD spectra. We refer to Bus (1999) and Bus and Binzel (2002b) for the methods for making these taxonomic determinations. Even in the case of low SNR data, we believe these taxonomic determinations are robust. For example, objects within the X-, T-, and D-classes (as well as X-subclasses) are primarily determined by their spectral slopes and presence or absence of broad features. Even the lowest SNR spectrum (2001 SG286) has a robustly determined large slope, giving us confidence in its determination as a D-type. Similarly, 2002 AT4 appears to be a D-type, while the well determined slopes for 2001 AE2 and 2001 SK162 place them in the T-class. The X-class and subclasses are more subtle, but again their placement is primarily based on overall slope. Within the SNR available, 1992 BF, 1999 GT, and 2001 SG10 compare very well with the prototypes for the Xc-, Xk-, and X-classes of Bus (1999), but we note these classes are the most difficult for making unambiguous taxonomic distinctions. For the case of the MUSES-C target (25143) 1998 SF36, extensive near-infrared measurements have been published and analyzed (Binzel et al. 2001b). The tabulated classification for 1998 SF36 is given within the system of Gaffey et al. (1993). For six of these (2063, 3908, 7753, 1989 UQ, 1999 FA, and 1992 BF), the taxonomic types were included in the tabulation by Bus and Binzel (2002b), but their MDM spectra are presented here for the first time. Taxonomic classifications from other reported observations are also included and referenced within Table I.

[FIG 2 Goes here.]

For all objects, Table I also lists potential opportunities for new or confirming observations to be obtained through the years 2004 - 2010. Up to two opportunities are listed per object. (The "observability" criteria are that the object becomes brighter than V magnitude 21 with a solar elongation of at least 90 degrees. V 21 is a practical limit for the largest telescopes typically available for asteroid characterization.) For about 40 percent of the objects, no opportunities exist through 2010 for a variety of reasons: in many cases the objects are small and their discovery was during a rare close passage to the Earth; small and consequently faint objects may have short orbital arcs and relatively uncertain orbital elements such that future opportunities cannot be reliably calculated; objects may have synodic periods nearly commensurate with the Earth such that the repetitive viewing geometry from Earth towards the object may be unfavorable for long intervals. All of these factors point to the strong importance of achieving follow-up physical and astrometric measurements during the discovery apparition – otherwise an opportunity for study may be lost for a decade or more.

4. Mission Target Assessment

Fig. 3 presents a combination of both dynamical and interpreted compositional considerations for assessing mission targets. We broadly code objects as “chondritic/stony”, “achondritic”, “primitive”, and “X” with a *caveat emptor* advisory that such interpretations based on visible wavelength spectra must be treated with great caution, even great skepticism. (See Gaffey et al. 1989; 2002; and Burbine et al. 2002 for more detailed analyses of possible meteorite links based on spectroscopic measurements, including the pitfalls.) For the broad interpretive groupings given here, “chondritic/stony” objects (possibly related to ordinary chondrite and/or stony-iron meteorites) are those that fall within the S or Q taxonomic classes or one of the S sub-classes within the Bus (1999) system. Objects from the “O” and “L” taxonomic classes are included in this grouping as these classes generally appear as extensions to what Bus (1999) calls the “S-Complex”.

[FIG 3 goes here]

Those that fall in the “achondritic” group are interpreted as having undergone extensive heating. These objects may have diverse compositions as interpreted from their different taxonomies. The “V” taxonomy for (5604) 1992 FE suggests a possible basaltic achondrite, perhaps related to Vesta and the HEDs (Binzel and Xu 1993). Burbine (2000) and Cruikshank et al. (1991) also describe 3908 Nyx as a V-type, even though it comes out under the “U” (unclassifiable) category in the Bus taxonomy. Wisniewski (1991) gives a “V” classification to 3361, even though the filter photometry measurements extend only to 0.85 μm. An examination of these points (by RPB) leads to “Q” being an equally (or more) viable interpretation. Extending the spectra into near-IR wavelengths is likely the next best step for resolving the nature of these objects. The “Xe” spectrum of 4660 Nereus is interpreted by Binzel et al. (2003) to be a possible analog to aubrites (enstatite achondrites).

Those objects, if correctly interpreted as having “primitive” compositions, may be generally analogous to carbonaceous chondrite meteorites. Connections to different subclasses of carbonaceous chondrites have been proposed by several researchers (e.g. Vilas and Gaffey 1989; Vilas et al. 1993; 1994). These include the major taxonomic class “C” and the C subclasses. (Types “B”, “F”, and “G” are usually considered C subclasses.) Of special interest among the “primitive” category are the D and T classes, typically found in the outer asteroid belt and among Jupiter Trojan asteroids. If extinct or dormant comets reside within the near-Earth population, most researchers (e.g. Weissman et al. 2002) propose they will have spectral properties within the grouping we label as “primitive.”

Most difficult to interpret are “X” class objects within Table I and Fig. 3. These objects may be interpreted to have compositions like enstatite achondrites (revealed by their high albedos), like iron-meteorites (revealed by their moderate albedos and high radar reflectivities), or like carbonaceous chondrites (revealed by their low albedos). Thus in the absence of albedo information, our preliminary interpretation and assessment for these objects is ambiguous between strongly heated, differentiated, or primitive compositions.

We now assess Table I and Fig. 3 in terms of identifying the most desirable mission targets, summarizing the results in Table II. We note that the size of the object may be a highly important consideration if complex operations (such as surface landing, sampling, etc.) are contemplated. A number of researchers (e.g. Pravec et al. 2000; Pravec and Harris 2000; Whiteley et al. 2002) have found that almost all objects below 150-200 meters in size (absolute magnitude typically >22) are rotating with spin periods of just a few minutes and can be in non-principal axis rotation states. Whiteley et al. (2002) note a correlation between low ΔV objects and their fast rotation. Furthermore, we endorse the caution expressed by Whiteley et al. (2002) that for objects smaller than 150-200 m (absolute magnitude greater than 22), mission operations at the target may be especially problematic for such rotation states. We underscore the operational importance of knowing the rotation state as an integral part of mission operations planning. Binary near-Earth objects (Merline et al. 2002) present additional operational challenges.

[TABLE II goes here]

Among all objects in Table I having $\Delta V < 4$ km/sec (as an arbitrary lower range), only three have an absolute magnitude brighter than 22 (with a likely size larger than 200 m): 2000 EA14, 2001 SW169, and 2002 AW. No spectral information is available for any of these, and such measurements would be a high priority. Within the $\Delta V < 4$ km/sec category, the known spectral types are diverse: 2000 AE205 is an S-type (possibly related to ordinary chondrite or stony-iron meteorites) while 1998 KY26 is listed as "CP" for which our interpretation suggests primitive carbonaceous chondrite composition. The majority of objects have no groundbased reconnaissance information with generally limited prospects for immediate future measurements for the observability reasons outlined above. In general, objects having accessible Earth-like orbits are ones that present themselves with infrequent favorable opportunities.

Relatively large (absolute magnitude < 22) targets are proportionally more common within the $4 < \Delta V < 5$ range. They have a diverse range of spectral properties and presently interpreted compositions. Three objects may be primitive: 1989 UQ, 1999 JU3, and 2001 AE2, where the latter has a strong red spectral slope that may be interpreted as being due to the presence of organics. Objects that may be ordinary chondrite-like include 2000 AC6 and (25143) 1998 SF36, the MUSES-C target for which Binzel et al. (2001b) find the spectrum to be plausibly matched by a reddened LL chondrite. (10302) 1989 ML is classified as "X" owing to its neutral spectral characteristics. Binzel et al. (2001a) find a suggestive, but not convincing match between 1989 ML and a shock darkened ordinary chondrite meteorite. We note that there are no confirmed (metallic) M-type asteroids within the accessible sample. We can look forward to the discovery and / or determination of a confirmed M-type as a potential mission target, though we note there are diverse compositional interpretations for this taxonomic class (e.g. Rivkin et al. 2002).

5. Future Observing Opportunites

With only 7 of the 50 most accessible objects listed here having measured spectral properties (and a similar number having known rotational properties) the challenge for scientifically informed target assessment resides with obtaining physical measurements. Rotational information is also vitally important for mission operations, where such data are available for a similar number of objects. (See Whiteley et al. 2002.) Table III presents a chronological listing of the opportunities presented in Table I, providing a convenient reference for observers wishing to plan for future measurements.

[TABLE III goes here]

6. Conclusions

As increases occur in the discovered numbers of NEOs and in our technological capabilities to explore them, mission planning will be increasingly motivated by specific scientific questions that can be addressed by exploring objects based on their known physical properties. The H-plot diagram is used as a tool to bring together currently known physical and dynamical factors when considering mission opportunities, illustrating some of the intrinsic difficulties faced by mission analysts when focusing on specific cases. An estimate of the orbit quality for accessible NEOs is also important for considering mission opportunities as well as physical and astrometric observations.

The summary lists and plots presented here are naturally subject to being updated as new discoveries are made and as new observations accumulate. We are maintaining such updated information and making it available through the Spaceguard Foundation Central Node (http://spaceguard.ias.rm.cnr.it).

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Table I.

Potential spacecraft targets having Delta-V less than 7 km/sec.

Catalog Number	Name	**Preliminary** Designation	**Oppositions** or arc	**dP/P**	**P** (years)	**e**	**i** (deg)	**Absolute** Mag	**delta-V** (km/sec)	**Taxon.** Type	**Observation** Reference (a)	**Observing** Opportunity (MM/DD/YY)	**V** Mag	**Observing** Opportunity	**V** Mag
		2000 SG344	2	1.2E-06	0.966	0.067	0.1	24.7	1.00			none			
		1991 VG	173d	2.3E-07	1.041	0.049	1.4	28.5	1.26			none			
		2001 GP2	27d	7.4E-05	1.056	0.074	1.3	26.9	1.48			none			
		1999 AO10	33d	6.1E-05	0.871	0.110	2.6	23.9	2.14			none			
		2000 LG6	3d	1.2E-04	0.877	0.112	2.8	29.0	2.24			none			
		1999 VX25	5d	2.0E-04	0.854	0.139	1.7	26.7	2.30			none			
		2001 QJ142	32d	1.4E-04	1.094	0.086	3.1	23.5	2.50			none			
		2000 SZ162	8d	2.7E-04	0.895	0.167	0.9	27.3	2.56			none			
		2001 CQ36	28d	3.2E-05	0.911	0.176	1.3	22.6	2.73			none			
		2001 FR85	8d	7.1E-07	0.976	0.028	5.3	24.8	2.82			none			
		2001 BB16	63d	1.2E-04	0.791	0.172	2.0	23.2	2.86			none			
		1996 XB27	2	5.9E-07	1.297	0.058	2.5	22.0	3.01			9/26/2005	19.3	12/23/2009	20.2
		2001 QE71	25d	8.9E-05	1.119	0.159	3.0	24.4	3.08			2/01/2010	21.0		
		2000 AG6	7d	2.8E-05	1.023	0.190	2.5	25.3	3.15			none			
		1998 KY26	11d	7.8E-07	1.367	0.202	1.5	25.5	3.34	CP	O99	none			
		1999 CG9	24d	9.0E-05	1.093	0.063	5.2	25.2	3.35			8/23/2010	20.8		
		2001 AV43	54d	7.7E-06	1.443	0.238	0.3	24.7	3.39			none			
54509		2000 PH5	2	7.2E-09	1.000	0.230	2.0	22.6	3.55			7/28/2004	15.8		
		2001 GO2	5d	1.1E-04	1.008	0.168	4.6	24.3	3.60			none			
		2001 BA16	40d	4.3E-05	0.911	0.137	5.8	26.0	3.69			none			
		2002 AW	2	1.9E-06	1.105	0.256	0.6	21.1	3.70			none			
		2000 EA14	58d	1.8E-05	1.181	0.203	3.6	20.9	3.78			5/05/2006	19.5		
		1999 SF10	9d	3.0E-04	1.446	0.253	1.2	24.2	3.79			none			
		2000 UK11	8d	7.8E-07	0.833	0.248	0.8	25.3	3.80			10/29/2005	20.9		
		2002 CW11	14d	5.1E-04	0.804	0.226	3.1	26.1	3.81			none			
		2001 VE2	7d	2.3E-04	1.165	0.181	4.4	25.0	3.88			none			
		2001 SW169	2	1.2E-06	1.396	0.052	3.6	18.7	3.88			1/29/2005	17.5	9/11/2008	16.2
		2000 AE205	2	4.5E-05	1.316	0.137	4.5	22.9	3.89	S	B01a	8/14/2004	20.4	7/23/2009	20.7
		1998 HG49	53d	2.4E-06	1.254	0.113	4.2	22.0	3.89			7/05/2006	19.6	12/10/2010	19.3
		2000 YS134	60d	3.6E-04	0.793	0.225	3.5	23.1	3.89			2/06/2005	20.2		
		2001 KM20	13d	4.0E-04	1.288	0.209	3.7	23.6	4.04			4/22/2010	21.0		
		1989 UQ	5	1.0E-08	0.875	0.265	1.3	19.4	4.04	B	This work *(b)*	10/19/2010	16.0		
		2001 CC21	3	1.6E-08	1.048	0.219	4.8	18.6	4.19	L	This work	9/27/2004	15.8		
		2001 AE2	4	7.8E-08	1.569	0.082	1.7	19.2	4.22	T	This work	9/05/2006	18.1		
		1998 KG3	10d	1.5E-03	1.251	0.118	5.5	22.5	4.23			4/29/2008	19.6		
		2000 AF205	53d	1.6E-05	1.051	0.277	2.4	21.5	4.23			none			
25143		1998 SF36	2	3.1E-08	1.522	0.279	1.7	19.2	4.26	S(IV)	B01b	1/27/2004	17.8	6/30/2004	12.7
		2001 US16	26d	3.1E-04	1.581	0.253	1.9	20.6	4.30			5/03/2004	15.1		
		2001 FO127	19d	1.2E-04	0.834	0.160	7.2	27.5	4.38			none			
10302		1989 ML	4	1.2E-08	1.436	0.137	4.4	19.5	4.46	X	B01a	1/05/2006	18.7	3/03/2009	18.7
		2000 SJ344	200d	6.4E-06	1.217	0.174	5.8	22.5	4.51			none			
		2002 CD	93d	5.0E-05	0.970	0.177	6.9	20.4	4.54			3/07/2004	17.8		
		1998 RK15	11d	4.6E-02	1.689	0.121	0.2	22.0	4.61						
		1998 VD32	12d	8.5E-04	1.157	0.314	2.0	22.2	4.63			7/16/2007	20.7		
		1996 BG1	7d	7.4E-04	0.850	0.281	3.8	23.5	4.66			12/20/2006	20.6		

Catalog **Number**	**Name**	***Preliminary*** **Designation**	***Oppositions*** **or arc**	***dP/P***	***P*** **(years)**	***e***	***i*** **(deg)**	***Absolute*** **Mag**	***delta-V*** **(km/sec)**	***Taxon.*** **Type**	***Observation*** **Reference (a)**	***Opportunity*** **(MM/DD/YY)**	***V*** **Mag**	***Observing*** **Opportunity**	***V*** **Mag**
		2000 QX69	5d	2.2E-04	1.015	0.272	4.6	24.5	4.67			none			
		2001 QC34	304d	1.5E-06	1.196	0.187	6.2	20.2	4.69			9/11/2007	19.1	4/26/2008	18.4
		1994 UG	4d	1.1E-02	1.357	0.246	4.5	21.0	4.70			12/09/2005	21.0	11/17/2009	21.0
		2000 HA24	3	2.1E-07	1.216	0.319	2.2	19.0	4.71			8/25/2004	19.5	6/26/2005	18.6
		1999 RQ36	2	1.1E-07	1.200	0.205	6.0	20.9	4.72			9/16/2005	16.0	4/17/2006	19.4
		2000 QK130	114d	7.7E-06	1.283	0.262	4.7	21.1	4.78			11/14/2004	21.0	9/19/2009	18.6
		2002 BF25	45d	4.3E-05	1.113	0.222	6.2	22.4	4.78			7/13/2010	17.9		
		1999 JU3	2	6.5E-08	1.297	0.190	5.9	19.6	4.80	Cg	B01a	9/15/2007	18.3		
		2001 WC47	2	2.9E-07	1.653	0.241	2.9	19.0	4.82			9/22/2004	19.8	12/31/2006	17.5
3361	Orpheus	1982 HR	7	2.7E-09	1.329	0.323	2.7	19.0	4.85	Q?V?	W91*(c)*	10/03/2005	17.0	6/17/2006	18.3
		2002 JR100	16d	2.8E-05	0.888	0.298	3.8	24.1	4.86			5/05/2010	18.8		
		2000 SL10	69d	2.5E-04	1.607	0.339	1.5	22.2	4.86			none			
		1993 BX3	2	5.7E-08	1.648	0.281	2.8	21.0	4.87			none			
		1999 AQ10	42d	1.0E-05	0.907	0.235	6.6	20.3	4.88			11/13/2007	18.3	2/16/2009	14.8
		1998 XN17	2	1.4E-06	0.973	0.210	7.2	22.4	4.91						
		1997 YM9	13d	2.7E-04	1.146	0.104	7.9	25.0	4.92			none			
		2000 WG10	5d	1.3E-03	1.256	0.206	6.3	24.4	4.95			5/03/2006	21.0		
		2000 AC6	55d	5.1E-05	0.788	0.286	4.7	21.0	4.98	Q	B01a	12/23/2010	16.6		
		1997 XR2	28d	8.6E-05	1.118	0.201	7.2	21.0	5.03			4/25/2006	19.1	1/26/2007	19.9
		2000 TL1	2	8.7E-05	1.548	0.300	3.6	23.4	5.05			none			
		2001 FC7	3	2.1E-06	1.721	0.115	2.6	18.6	5.05			2/02/2006	18.8		
		2000 EE104	4	2.3E-08	1.008	0.294	5.2	20.3	5.08			3/06/2004	18.4		
		1997 UR	21d	3.8E-04	1.766	0.313	2.3	23.0	5.08			none			
		1991 JW	4	1.4E-07	1.058	0.118	8.7	19.3	5.12			5/13/2008	19.4	5/13/2009	15.0
		1993 KA	9d	9.6E-05	1.406	0.197	6.0	26.0	5.13			none			
		1996 FG3	5	1.3E-07	1.082	0.350	2.0	18.2	5.16	C	B01a	4/05/2009	15.9	2/24/2010	17.3
4660	Nereus	1982 DB	8	2.5E-09	1.817	0.360	1.4	18.2	5.17	Xe	B03	6/08/2004	19.8	7/09/2006	19.5
		2001 TE2	2	7.7E-07	1.127	0.197	7.6	20.0	5.18			10/09/2010	18.6		
		2000 FJ10	14d	1.7E-03	1.513	0.232	5.2	21.6	5.21			10/07/2008	19.7		
		1994 CJ1	22d	1.1E-03	1.815	0.325	2.3	21.4	5.23			none			
		2001 TD	8d	5.9E-06	0.932	0.166	9.0	25.1	5.29			none			
		1999 JV6	4	1.6E-07	1.011	0.311	5.3	19.9	5.30	Xk	B01a	4/06/2004	18.8		
		2002 FB	2d	9.6E-04	1.326	0.188	7.1	27.6	5.33			none			
		2002 JX8	41d	7.1E-05	0.676	0.306	4.3	20.8	5.36			none			
		1999 NW2	28d	1.0E-06	1.181	0.109	8.7	23.1	5.38			none			
		1998 HL3	36d	8.3E-05	1.200	0.366	2.7	20.0	5.40			4/28/2004	18.7	2/26/2005	19.6
		2001 KW18	5d	3.0E-03	1.386	0.158	7.2	26.0	5.43			none			
		1997 WB21	36d	4.8E-04	1.766	0.318	3.4	20.5	5.44			5/21/2004	20.7		
		1999 NA5	39d	2.2E-04	1.721	0.248	4.3	20.3	5.47						
		2000 EW70	16d	4.9E-07	0.908	0.320	5.4	21.1	5.47	F	W01	12/04/2007	19.4	1/24/2009	19.6
		2002 GR	48d	7.3E-05	1.318	0.208	7.3	23.2	5.47			none			
		1992 BF	3	3.7E-09	0.865	0.272	7.3	19.7	5.47	Xc	This work *(b)*	2/26/2005	16.0		
		1995 HM	55d	6.9E-05	1.764	0.220	4.0	23.0	5.48			none			
		2002 EM7	25d	3.4E-05	0.884	0.363	1.5	24.4	5.51			none			
		2002 DQ3	60d	1.1E-04	1.633	0.255	5.1	23.8	5.52	Sq	This work	none			
		2000 TE2	61d	8.9E-04	1.517	0.214	6.2	25.1	5.52			none			
		1993 BD3	5d	6.7E-03	2.091	0.375	0.9	26.0	5.53			none			
		1999 YB	2	5.7E-07	1.518	0.075	6.8	18.5	5.55	Sq	B01a	11/23/2005	18.0	11/06/2008	17.8
		1998 FG2	3	1.5E-07	1.481	0.357	4.1	21.6	5.58						

Catalog **Number**	**Name**	***Preliminary*** **Designation**	***Oppositions*** **or arc**	***dP/P***	***P*** **(years)**	***e***	***i*** **(deg)**	***Absolute*** **Mag**	***delta-V*** **(km/sec)**	***Taxon.*** **Type**	***Observation*** **Reference (a)**	***Opportunity*** **(MM/DD/YY)**	***V*** **Mag**	***Observing*** **Opportunity**	***V*** **Mag**
		1998 HM1	7d	3.2E-03	1.687	0.365	3.3	24.5	5.59			none			
		2002 AA29	28d	5.2E-05	1.002	0.012	10.7	23.9	5.59			1/09/2004	18.4		
		1994 CN2	5	1.9E-07	1.973	0.395	1.4	16.8	5.60			3/08/2004	19.0	3/01/2006	19.0
		2001 QE96	29d	1.1E-03	1.501	0.028	7.3	23.2	5.64			none			
		2001 SZ169	5d	2.4E-03	1.542	0.230	6.3	25.1	5.66			none			
		1999 TV16	6d	1.1E-03	1.977	0.409	1.1	23.4	5.68			none			
		2002 AL31	8d	4.3E-04	1.275	0.247	7.6	24.5	5.69	X	This work	none			
		2000 SD8	72d	3.7E-05	1.200	0.314	6.6	20.9	5.73			11/30/2005	20.8	9/12/2006	18.9
4581	Asclepius	1989 FC	2	7.2E-07	1.033	0.357	4.9	20.4	5.74			none			
52381		1993 HA	3	3.5E-07	1.445	0.144	7.7	20.2	5.75			4/25/2006	19.5		
		2002 LT38	11d	3.8E-05	0.775	0.316	6.3	20.2	5.76			6/07/2009	15.4		
		2001 UP	4d	1.1E-06	0.833	0.287	7.7	25.7	5.77			none			
		1999 VW25	3d	2.9E-04	0.895	0.112	10.8	25.3	5.77			none			
		1999 SH10	16d	4.0E-04	1.151	0.131	9.6	22.7	5.78			none			
		2001 XP88	61d	5.6E-05	1.563	0.194	6.7	20.5	5.78			6/06/2004	19.6		
		2001 JU2	150d	4.0E-05	1.870	0.269	4.0	19.6	5.79			1/01/2006	20.1		
		2001 VB76	218d	1.7E-05	1.761	0.348	4.2	20.7	5.81			10/27/2008	20.7	5/03/2009	20.7
		1999 RA32	326d	6.3E-07	1.041	0.090	10.5	21.2	5.81			none			
		2000 WP19	64d	2.7E-05	0.791	0.289	7.7	22.8	5.81			1/01/2005	20.5		
		2002 LY1	12d	2.4E-04	0.933	0.380	2.9	21.8	5.82			none			
		1996 FT1	9d	9.0E-03	1.764	0.401	2.7	24.0	5.82			none			
		2001 EC16	56d	1.0E-06	1.560	0.364	4.7	22.3	5.85			8/25/2004	21.0		
		2002 CZ9	33d	1.8E-05	1.525	0.360	5.0	21.9	5.87			8/27/2005	20.4	8/01/2008	20.0
		2001 WH49	1d	1.0E-01	1.777	0.320	4.8	26.0	5.90			none			
		2001 WJ4	1d	1.5E-04	1.406	0.216	7.9	27.4	5.91			none			
		2000 AH205	7d	1.9E-03	1.227	0.407	2.6	22.4	5.92	Sk	B01a	6/14/2009	18.5		
		2000 YJ11	95d	2.3E-04	1.501	0.231	7.3	21.0	5.93			12/16/2006	19.5		
		1991 BN	17d	3.1E-03	1.733	0.398	3.4	20.0	5.93			6/09/2009	18.6	1/05/2010	19.4
		1999 CQ2	6d	3.4E-03	1.843	0.381	3.7	27.3	5.96			none			
		2002 DU3	68d	6.0E-06	1.225	0.238	8.7	20.7	5.97	Sq	This work	12/02/2007	20.7		
		1999 FN19	32d	6.4E-07	2.114	0.391	2.3	22.5	5.98	Sq	This work	none			
		1994 EU	12d	2.3E-03	1.618	0.278	6.5	25.5	6.02			none			
		1998 HD14	4	2.9E-07	0.946	0.313	7.8	20.9	6.02	SQ	W01	none			
		2001 FC58	3	1.4E-07	1.030	0.343	6.8	20.6	6.03						
		1996 FO3	89d	2.8E-05	1.733	0.290	5.8	20.5	6.05			10/06/2007	20.8		
		2000 OK8	2	1.4E-07	0.978	0.221	10.0	20.2	6.08						
		1999 VG22	3	8.7E-07	2.114	0.330	2.9	18.7	6.10			8/25/2005	20.9		
		2001 BF10	126d	6.1E-06	2.049	0.441	1.5	22.6	6.11						
		1998 MW5	3	1.8E-07	1.035	0.363	6.3	19.2	6.12	Sq	B01a	none			
		2001 ED18	5d	3.6E-05	0.985	0.057	11.6	24.5	6.12			none			
		2002 LW	14d	5.8E-05	1.026	0.102	11.2	22.3	6.15						
		2000 SB45	3d	6.1E-03	1.948	0.397	3.7	24.5	6.17			none			
6239	Minos	1989 QF	4	1.5E-08	1.235	0.413	3.9	17.9	6.17			1/28/2004	14.1	11/02/2004	18.4
		2002 FW1	21d	8.6E-04	0.748	0.341	6.6	24.0	6.19			3/14/2005	18.4	3/20/2008	19.8
		1998 VS	32d	3.8E-04	1.658	0.278	6.8	21.9	6.20						
		2000 CK59	36d	4.8E-04	1.799	0.313	5.7	24.0	6.20			1/23/2009	19.5		
		1996 GT	4	7.7E-07	2.104	0.383	3.4	18.3	6.23	Xk	This work	6/23/2005	19.0		
		2001 CB21	2	9.4E-08	1.051	0.333	7.9	18.5	6.24			12/27/2003	18.2		
		1996 TD9	4d	5.8E-03	1.539	0.404	5.0	24.0	6.27			none			

Catalog Number	Name	Preliminary Designation	Oppositions or arc	dP/P	P (years)	e	i (deg)	Absolute Mag	delta-V (km/sec)	Taxon. Type	Observation Reference (a)	Opportunity (MM/DD/YY)	V Mag	Observing Opportunity	V Mag
		2001 WV1	3d	2.4E-03	1.664	0.453	1.5	22.5	6.27			11/18/2006	17.7		
		2001 RV17	63d	1.4E-05	0.874	0.342	7.5	19.9	6.28			7/22/2007	18.4	9/28/2008	17.5
		1990 OS	13d	7.1E-05	2.162	0.460	1.1	20.0	6.29			1/27/2004	20.5		
		2000 CR101	31d	7.4E-04	2.207	0.246	0.6	19.8	6.29			5/21/2009	20.5		
		2001 XP31	9d	5.2E-03	1.230	0.387	6.1	21.9	6.30			none			
		2001 SY169	22d	1.7E-03	1.359	0.408	5.1	22.4	6.30			none			
		1998 VO	37d	4.5E-05	1.113	0.227	10.1	20.4	6.30	S	W01	4/25/2007	17.4	1/16/2008	20.0
36017		1999 ND43	2	7.7E-08	1.880	0.314	5.6	19.2	6.32	Sl	B01a	3/13/2004	20.5	4/02/2006	21.0
		2002 GT	68d	7.8E-06	1.558	0.335	7.0	18.6	6.32			3/19/2005	19.5	2/25/2008	19.9
		1999 FP59	8d	1.1E-06	1.874	0.259	1.8	18.4	6.37			11/10/2006	18.3		
		2002 EW11	3	2.8E-03	2.215	0.429	3.8	25.0	6.37			none			
11284	Belenus	1990 BA	4	6.9E-09	2.295	0.338	2.0	17.8	6.37			5/27/2004	19.2	10/31/2005	17.7
		2001 SG10	63d	6.9E-05	1.744	0.424	4.3	20.3	6.37	X	This work	3/03/2008	20.4	10/07/2008	18.9
		2001 RB12	21d	1.4E-06	1.077	0.381	6.6	20.6	6.38			6/16/2004	20.0		
		1999 YR14	2	1.3E-06	2.127	0.401	3.7	19.4	6.40			none			
		2001 LL5	106d	1.0E-04	1.323	0.340	7.9	18.8	6.40			9/04/2004	19.0	5/11/2005	17.1
		2001 UN16	31d	2.9E-03	2.407	0.450	1.6	23.4	6.41			none			
		1999 LJ1	28d	8.1E-04	2.064	0.309	4.6	22.2	6.42			none			
		2000 AF6	2	2.5E-07	0.823	0.411	2.7	20.2	6.42			2/23/2005	17.6	12/24/2008	16.1
8014		1990 MF	2	2.4E-08	2.309	0.456	1.9	18.7	6.43			12/28/2004	20.4	4/06/2006	20.1
		2002 CQ11	90d	1.0E-04	0.969	0.428	2.5	19.8	6.43			1/31/2004	17.4		
		1991 VA	8d	1.9E-03	1.708	0.352	6.5	26.5	6.44			none			
		2000 EH26	140d	3.9E-06	2.522	0.477	0.4	21.8	6.44			7/11/2005	19.4		
		2001 QM142	2d	1.8E-02	1.346	0.413	5.6	23.3	6.46			none			
		2002 DC3	48d	9.9E-03	2.217	0.403	3.4	26.1	6.46			none			
5604		1992 FE	7	9.2E-09	0.893	0.405	4.8	16.4	6.48	V	This work	3/26/2009	14.6	5/22/2010	14.8
		1993 DA	5d	7.7E-05	0.904	0.094	12.4	26.0	6.48			none			
		2000 WO148	110d	2.4E-07	2.104	0.376	4.4	20.6	6.49			none			
		2000 LY27	4	2.1E-08	1.498	0.213	9.0	17.1	6.49			5/29/2006	17.2		
		2001 WN5	301d	2.1E-05	2.238	0.467	1.9	18.3	6.49			4/18/2010	18.8	10/17/2010	15.9
22099		2000 EX106	3	2.9E-08	1.160	0.276	9.8	18.0	6.50			4/21/2007	18.2	2/20/2008	17.3
		2001 SX169	23d	5.5E-04	1.563	0.462	2.5	17.9	6.50			8/23/2004	19.1	11/05/2006	17.8
		1998 WT30	15d	3.3E-02	2.397	0.331	0.4	20.4	6.52			5/14/2004	19.8	11/25/2010	20.4
		2000 JX8	3d	4.5E-03	1.907	0.333	6.0	25.4	6.53			none			
		2002 AT4	149d	6.1E-05	2.549	0.447	1.5	21.4	6.58	D	This work	none			
		2001 WT1	53d	1.6E-05	1.136	0.393	7.0	20.4	6.58			1/13/2009	19.6	12/04/2009	20.0
8034	Akka	1992 LR	3	8.2E-09	2.476	0.410	2.0	17.9	6.60	S	W01	11/17/2007	18.8	2/25/2009	20.4
		2000 YF29	2	1.3E-06	1.822	0.371	6.3	20.2	6.61	S	This work	10/24/2009	21.0		
		1994 CC	3	3.0E-06	2.094	0.417	4.6	18.0	6.66			12/08/2005	19.7		
		2002 LJ3	3	1.3E-07	1.768	0.275	7.6	18.2	6.66			2/05/2005	18.5	3/27/2007	19.8
		2001 UD18	1d	5.0E-03	2.407	0.440	2.8	27.6	6.66			none			
		2001 HY7	63d	1.1E-06	1.913	0.412	5.2	20.5	6.67			4/29/2008	18.4	7/03/2009	18.0
		1988 TA	2	8.2E-05	0.874	0.479	2.5	20.8	6.67	C		10/24/2009	20.5		
		2001 SG286	55d	2.7E-04	1.588	0.348	7.8	21.1	6.67	D	This work	5/14/2009	16.0	11/27/2009	20.8
		2002 JU15	12d	1.7E-03	1.280	0.211	10.6	26.2	6.68			none			
		1991 TU	0d	4.1E-02	1.685	0.333	7.7	28.5	6.70			none			
		2000 CH59	83d	1.5E-05	0.802	0.423	3.3	19.4	6.70			1/24/2004	17.2	1/17/2008	16.9
		2001 PJ29	15d	1.6E-03	1.742	0.392	6.6	22.9	6.71			none			
		1989 VB	46d	1.1E-03	2.547	0.461	2.1	19.9	6.73			none			

Catalog **Number**	**Name**	***Preliminary*** **Designation**	***Oppositions*** **or arc**	***dP/P***	***P*** **(years)**	***e***	***i*** **(deg)**	***Absolute*** **Mag**	***delta-V*** **(km/sec)**	***Taxon.*** **Type**	***Observation*** **Reference (a)**	***Opportunity*** **(MM/DD/YY)**	***V*** **Mag**	***Observing*** **Opportunity**	***V*** **Mag**
		2000 BM19	2	2.5E-07	0.638	0.359	6.9	18.3	6.73	O	This work	2/10/2009	16.4		
		2000 SS43	66d	3.3E-03	2.281	0.410	4.1	24.8	6.75			none			
		2002 GN5	55d	1.1E-04	2.030	0.290	6.1	22.3	6.76			none			
7350		1993 VA	4	7.5E-09	1.579	0.391	7.3	17.3	6.76			9/12/2004	17.1	4/10/2005	16.5
		1999 FA	3	5.6E-08	1.121	0.133	12.0	20.5	6.77	S	This work *(b)*	9/24/2007	18.2	5/03/2008	19.9
		2001 OC36	7d	5.1E-03	1.699	0.487	2.3	22.9	6.77			none			
		2002 AG29	2	7.8E-08	1.133	0.203	11.5	18.3	6.78						
7753		1988 XB	5	2.0E-08	1.779	0.482	3.1	18.6	6.79	B	This work *(b)*	4/25/2004	19.6	12/02/2004	15.5
		2001 QF96	22d	1.4E-03	1.919	0.362	6.6	24.4	6.79			none			
		1999 DB7	187d	5.7E-06	1.324	0.195	10.8	19.9	6.79			8/10/2003	18.8		
		1998 UM1	11d	3.3E-03	2.205	0.399	4.8	23.0	6.80			none			
		1999 FQ10	4d	2.5E-02	2.729	0.491	1.1	23.6	6.80			none			
		1995 FG	56d	3.4E-04	2.516	0.373	2.0	23.0	6.80			none			
		1998 HK49	5d	2.3E-02	1.665	0.344	8.0	22.4	6.80			11/16/2007	20.6		
		2001 SP263	5d	1.2E-02	2.512	0.499	1.4	25.8	6.81			none			
5189		1990 UQ	4	7.7E-08	1.932	0.478	3.6	17.3	6.82			1/14/2005	19.8		
		2001 SK162	2	3.4E-08	2.671	0.474	1.7	18.0	6.82	T	This work	6/01/2005	20.5	10/12/2009	18.0
		1998 XX2	4d	6.4E-03	0.639	0.366	6.9	20.1	6.82			11/02/2005	18.3		
		2002 MN	6d	6.2E-04	2.561	0.510	0.1	23.7	6.82			none			
2063	Bacchus	1977 HB	7	2.9E-09	1.119	0.349	9.4	17.1	6.83	Sq	This work *(b)*	6/23/2004	17.2		
		2002 BY	2	1.4E-06	2.451	0.347	2.7	17.5	6.84			10/19/2005	19.8		
18109		2000 NG11	4	4.5E-09	2.580	0.368	0.8	17.5	6.85			3/08/2004	20.2	7/05/2005	17.9
		1996 GQ	34d	2.9E-02	2.289	0.495	0.9	23.0	6.87			none			
		1997 WQ23	12d	9.2E-04	2.824	0.494	2.5	20.5	6.87			none			
		1999 BY9	2	2.1E-07	2.476	0.302	0.9	18.1	6.87			2/05/2004	17.0	3/23/2009	16.2
		2000 PO30	34d	2.1E-02	2.431	0.391	3.6	19.4	6.87			8/18/2007	19.8		
1943	Anteros	1973 EC	11	1.7E-09	1.710	0.256	8.7	15.7	6.88	L	This work	10/11/2004	16.9	12/11/2006	16.4
		2002 AN129	2d	2.7E-02	2.367	0.513	0.3	26.2	6.88			none			
		2001 VC2	210d	4.7E-07	1.062	0.132	12.5	21.0	6.89						
7474		1992 TC	4	3.1E-08	1.960	0.292	7.1	18.0	6.90	X	X95	2/10/2005	19.5		
		2000 HB24	10d	2.0E-04	0.737	0.430	2.7	23.3	6.91						
3908	Nyx	1980 PA	3	1.1E-09	2.673	0.459	2.2	17.4	6.92	V	C91, This work	11/24/2004	15.3		
		2002 EX11	85d	1.5E-04	2.592	0.409	2.5	20.7	6.93			none			
		1998 HE3	2	1.8E-06	0.824	0.441	3.4	21.8	6.94	SQ	W01	3/30/2007	20.1		
35396		1997 XF11	4	9.5E-08	1.732	0.484	4.1	16.9	6.95	Xk	This work	1/15/2005	18.8	2/15/2007	19.1
		2002 AM31	2	2.3E-06	2.226	0.452	4.6	18.8	6.96			11/15/2003	18.6		
		1977 VA	93d	2.7E-04	2.545	0.394	3.0	19.0	6.97	XC	D77	10/30/2005	15.4	7/27/2010	19.5
		2002 KM3	18d	1.6E-03	1.421	0.343	9.4	22.3	6.97			11/11/2009	18.2		
		2001 RQ17	36d	3.2E-03	2.837	0.492	1.3	22.2	6.97			none			
		1994 GV	2d	2.4E-03	2.856	0.520	0.5	27.5	6.97			none			
		2000 UQ30	52d	7.9E-04	2.307	0.455	4.3	22.1	6.97			none			
		1997 WT22	2	1.4E-08	1.811	0.306	8.2	19.0	6.97			11/01/2006	19.3	6/15/2009	19.1

Catalog **Number**	**Name**	**Preliminary** **Designation**	**Oppositions** **or arc**	**dP/P**	**P** **(years)**	**e**	**i** **(deg)**	**Absolute** **Mag**	**delta-V** **(km/sec)**	**Taxon.** **Type**	**Observation** **Reference (a)**	**Opportunity** **(MM/DD/YY)**	**V** **Mag**	**Observing** **Opportunity**	**V** **Mag**

<u>(a) References and Notes</u>

A data base on NEO physical properties with extensive references is maintained at: http://earn.dlr.de/nea/

Accessible targets are those known as of July 2002.

B01a	Binzel et al. (2001a)
B01b	Binzel et al. (2001b)
B03	Binzel et al. (2003)
C91	Cruikshank et al. (1991)
D77	Degewij (1977)
O99	Ostro et al. (1999)
W91	Wisniewski (1991)
W01	Whiteley (2001)
X95	Xu et al. (1995)
(b)	Taxonomic class also tabulated by Bus and Binzel (2002b)
(c)	Reference lists result as "V" but limited wavelength coverage makes "Q" an equally likely interpretation.

Table II.

Most accessible ($\Delta V<5.2$ km/sec) known objects
according to interpreted compositional groupings.

Objects having possibly "primitive" compositions

1998 KY26, 1989 UQ, 2001 AE2, 1999 JU3, 1996 FG3

Objects having possibly "chondritic/stony-iron" compositions

2000 AE205, 2001 CC21, (25143) 1998 SF36, 3361 Orpheus(?), 2000 AC6

Objects having possibly "achondritic" compositions

4660 Nereus, 3361 Orpheus(?)

TABLE III

Chronological Tabulation of Observing Opportunities
(2004 through 2010, brighter than V21)

Observing *Opportunity (MM/DD/YY)*	***Catalog*** *Number*	*Name*	***Preliminary*** *Designation*	***V*** *Mag*
1/09/2004			2002 AA29	18.4
1/24/2004			2000 CH59	17.2
1/27/2004	25143		1998 SF36	17.8
1/27/2004			1990 OS	20.5
1/28/2004	6239	Minos	1989 QF	14.1
1/31/2004			2002 CQ11	17.4
2/05/2004			1999 BY9	17.0
3/06/2004			2000 EE104	18.4
3/07/2004			2002 CD	17.8
3/08/2004			1994 CN2	19.0
3/08/2004	18109		2000 NG11	20.2
3/13/2004	36017		1999 ND43	20.5
4/06/2004			1999 JV6	18.8
4/25/2004	7753		1988 XB	19.6
4/28/2004			1998 HL3	18.7
5/03/2004			2001 US16	15.1
5/14/2004			1998 WT30	19.8
5/21/2004			1997 WB21	20.7
5/27/2004	11284	Belenus	1990 BA	19.2
6/06/2004			2001 XP88	19.6
6/08/2004	4660	Nereus	1982 DB	19.8
6/16/2004			2001 RB12	20.0
6/23/2004	2063	Bacchus	1977 HB	17.2
6/30/2004	25143		1998 SF36	12.7
7/28/2004	54509		2000 PH5	15.8
8/14/2004			2000 AE205	20.4
8/23/2004			2001 SX169	19.1
8/25/2004			2000 HA24	19.5
8/25/2004			2001 EC16	21.0
9/04/2004			2001 LL5	19.0
9/12/2004	7350		1993 VA	17.1
9/22/2004			2001 WC47	19.8
9/27/2004			2001 CC21	15.8
10/11/2004	1943	Anteros	1973 EC	16.9
11/02/2004	6239	Minos	1989 QF	18.4
11/14/2004			2000 QK130	21.0
11/24/2004	3908	Nyx	1980 PA	15.3
12/02/2004	7753		1988 XB	15.5
12/28/2004	8014		1990 MF	20.4
1/01/2005			2000 WP19	20.5
1/14/2005	5189		1990 UQ	19.8
1/15/2005	35396		1997 XF11	18.8
1/29/2005			2001 SW169	17.5
2/05/2005			2002 LJ3	18.5
2/06/2005			2000 YS134	20.2
2/10/2005	7474		1992 TC	19.5
2/23/2005			2000 AF6	17.6
2/26/2005			1998 HL3	19.6
2/26/2005			1992 BF	16.0
3/14/2005			2002 FW1	18.4
3/19/2005			2002 GT	19.5
4/10/2005	7350		1993 VA	16.5
5/11/2005			2001 LL5	17.1
6/01/2005			2001 SK162	20.5
6/23/2005			1996 GT	19.0
6/26/2005			2000 HA24	18.6
7/05/2005	18109		2000 NG11	17.9
11/05/2006			2001 SX169	17.8
11/10/2006			1999 FP59	18.3
11/18/2006			2001 WV1	17.7
12/11/2006	1943	Anteros	1973 EC	16.4
12/16/2006			2000 YJ11	19.5
12/20/2006			1996 BG1	20.6
12/31/2006			2001 WC47	17.5
1/26/2007			1997 XR2	19.9
2/15/2007	35396		1997 XF11	19.1
3/27/2007			2002 LJ3	19.8
3/30/2007			1998 HE3	20.1
4/21/2007	22099		2000 EX106	18.2
4/25/2007			1998 VO	17.4
7/16/2007			1998 VD32	20.7
7/22/2007			2001 RV17	18.4
8/18/2007			2000 PO30	19.8
9/11/2007			2001 QC34	19.1
9/15/2007			1999 JU3	18.3
9/24/2007			1999 FA	18.2
10/06/2007			1996 FO3	20.8
11/13/2007			1999 AQ10	18.3
11/16/2007			1998 HK49	20.6
11/17/2007	8034	Akka	1992 LR	18.8
12/02/2007			2002 DU3	20.7
12/04/2007			2000 EW70	19.4
1/16/2008			1998 VO	20.0
1/17/2008			2000 CH59	16.9
2/20/2008	22099		2000 EX106	17.3
2/25/2008			2002 GT	19.9
3/03/2008			2001 SG10	20.4
3/20/2008			2002 FW1	19.8
4/26/2008			2001 QC34	18.4
4/29/2008			2001 HY7	18.4
4/29/2008			1998 KG3	19.6
5/03/2008			1999 FA	19.9
5/13/2008			1991 JW	19.4
8/01/2008			2002 CZ9	20.0
9/11/2008			2001 SW169	16.2
9/28/2008			2001 RV17	17.5
10/07/2008			2000 FJ10	19.7
10/07/2008			2001 SG10	18.9
10/27/2008			2001 VB76	20.7
11/06/2008			1999 YB	17.8
12/24/2008			2000 AF6	16.1
1/13/2009			2001 WT1	19.6
1/23/2009			2000 CK59	19.5
1/24/2009			2000 EW70	19.6
2/10/2009			2000 BM19	16.4
2/16/2009			1999 AQ10	14.8
2/25/2009	8034	Akka	1992 LR	20.4
3/03/2009	10302		1989 ML	18.7
3/23/2009			1999 BY9	16.2
3/26/2009	5604		1992 FE	14.6
4/05/2009			1996 FG3	15.9
5/03/2009			2001 VB76	20.7
5/13/2009			1991 JW	15.0
5/14/2009			2001 SG286	16.0

Observing Opportunity (MM/DD/YY)	*Catalog Number*	*Name*	*Preliminary Designation*	*V Mag*
7/11/2005			2000 EH26	19.4
8/25/2005			1999 VG22	20.9
8/27/2005			2002 CZ9	20.4
9/16/2005			1999 RQ36	16.0
9/26/2005			1996 XB27	19.3
10/03/2005	3361	Orpheus	1982 HR	17.0
10/19/2005			2002 BY	19.8
10/29/2005			2000 UK11	20.9
10/30/2005			1977 VA	15.4
10/31/2005	11284	Belenus	1990 BA	17.7
11/02/2005			1998 XX2	18.3
11/23/2005			1999 YB	18.0
11/30/2005			2000 SD8	20.8
12/08/2005			1994 CC	19.7
12/09/2005			1994 UG	21.0
1/01/2006			2001 JU2	20.1
1/05/2006	10302		1989 ML	18.7
2/02/2006			2001 FC7	18.8
3/01/2006			1994 CN2	19.0
4/02/2006	36017		1999 ND43	21.0
4/06/2006	8014		1990 MF	20.1
4/17/2006			1999 RQ36	19.4
4/25/2006			1997 XR2	19.1
4/25/2006	52381		1993 HA	19.5
5/03/2006			2000 WG10	21.0
5/05/2006			2000 EA14	19.5
5/29/2006			2000 LY27	17.2
6/17/2006	3361	Orpheus	1982 HR	18.3
7/05/2006			1998 HG49	19.6
7/09/2006	4660	Nereus	1982 DB	19.5
9/05/2006			2001 AE2	18.1
9/12/2006			2000 SD8	18.9
11/01/2006			1997 WT22	19.3
5/21/2009			2000 CR101	20.5
6/07/2009			2002 LT38	15.4
6/09/2009			1991 BN	18.6
6/14/2009			2000 AH205	18.5
6/15/2009			1997 WT22	19.1
7/03/2009			2001 HY7	18.0
7/23/2009			2000 AE205	20.7
9/19/2009			2000 QK130	18.6
10/12/2009			2001 SK162	18.0
10/24/2009			2000 YF29	21.0
10/24/2009			1988 TA	20.5
11/11/2009			2002 KM3	18.2
11/17/2009			1994 UG	21.0
11/27/2009			2001 SG286	20.8
12/04/2009			2001 WT1	20.0
12/23/2009			1996 XB27	20.2
1/05/2010			1991 BN	19.4
2/01/2010			2001 QE71	21.0
2/24/2010			1996 FG3	17.3
4/18/2010			2001 WN5	18.8
4/22/2010			2001 KM20	21.0
5/05/2010			2002 JR100	18.8
5/22/2010	5604		1992 FE	14.8
7/13/2010			2002 BF25	17.9
7/27/2010			1977 VA	19.5
8/23/2010			1999 CG9	20.8
10/09/2010			2001 TE2	18.6
10/17/2010			2001 WN5	15.9
10/19/2010			1989 UQ	16.0
11/25/2010			1998 WT30	20.4
12/10/2010			1998 HG49	19.3
12/23/2010			2000 AC6	16.6

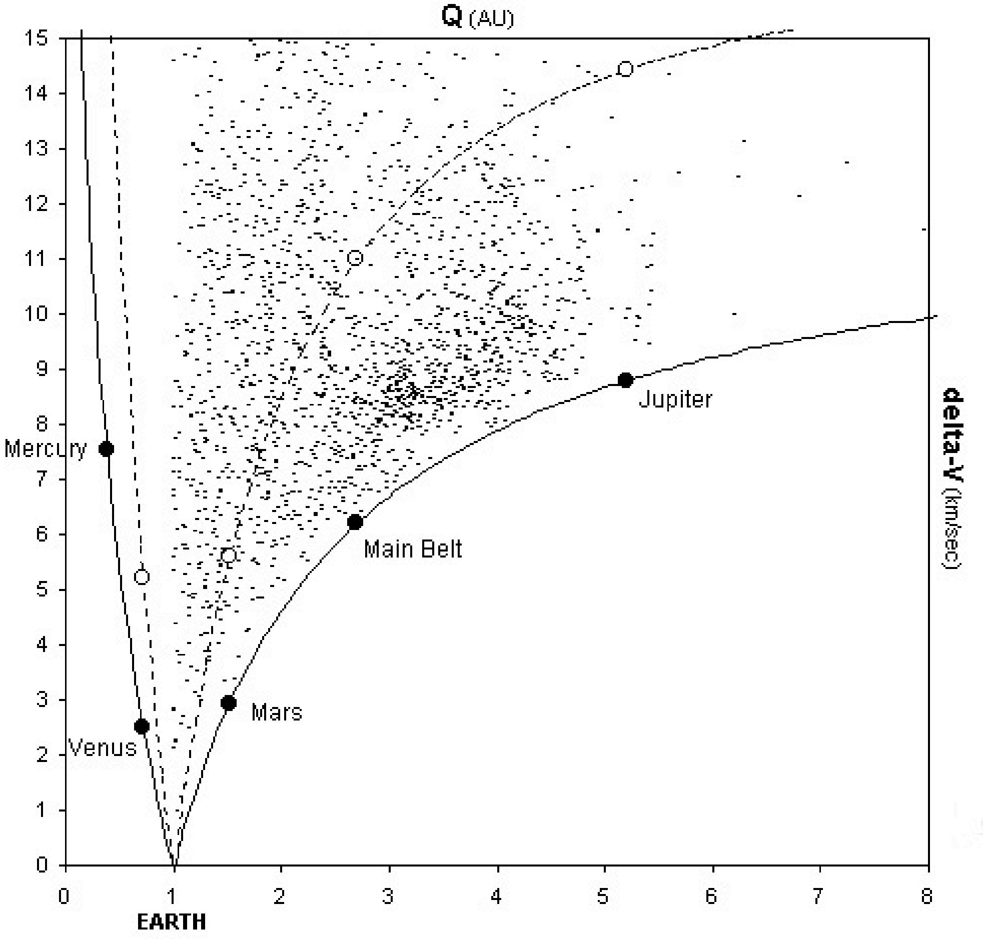
Figure Captions

Fig. 1. An “H-plot” diagram. The two solid-line curves indicate, in the classical Hohmann case (reaching a planet in a circular coplanar orbit, starting from a circular orbit at 1 AU), the magnitude of the ΔV impulse required for raising (right curve) or lowering (left curve) the orbital distance, depending if the target orbit is inside or outside that of the Earth. These solid curves are therefore representative of the minimum ΔV for performing “flyby” missions to any heliocentric distance. Dotted lines are obtained by adding to those flyby values the ΔV required for circularization at the destination so as to enable a rendezvous. The location of the planets are denoted by full and open circles, illustrating “best case” ΔV estimates for flyby (full circle) and rendezvous (open circle) missions. In this representation, a NEO in the same orbit plane as Earth, whose perihelion is tangent with the Earth’s orbit, would be located along the right-hand solid line according to the value of its aphelion distance. Displacements upward are a measure of the additional energy needed to enable a rendezvous, accounting for the difference in perihelion distance with respect to the Earth. Being out of the plane of the Earth’s orbit (a non-zero inclination) gives also a major contribution to the overall ΔV requirement to enable a rendezvous, because performing out-of-plane maneuvers is extremely expensive to the ΔV budget. This figure displays 1927 objects given in the Minor Planet Center catalogue as of 2 July 2002.

Fig. 2. Spectra for 22 of the 234 most easily accessible Near-Earth objects. All spectra are normalized to unity at 0.55 μm with 1σ error bars (often comparable in size to the plotted points.) The varying signal-to-noise arises from the range in brightness of the objects at the time of observation. Low detector efficiency at the short wavelength end and telluric water at the long wavelength end contribute to the lower signal-to-noise in these regions. A slight gap near 0.76 microns is due to telluric oxygen.

Fig. 3 An expanded “H-plot” diagram for objects having ΔV < 7 km/sec. Special symbols denote objects whose spectra may possibly be interpreted to correspond to “chondritic/stony” (ordinary chondrite or possibly stony-iron, open circles), “achondritic” (rhombs), “primitive” (squares), or indeterminate “X” compositional interpretations (crosses). (The latter could be achondritic, metallic, or primitive.) See text for *caveat emptor* warning about the difficulty of making definitive compositional assessments based on the interpretation of visible wavelength spectra. Table I gives the specific taxonomic types. At all values of ΔV, objects with a diverse range of interpreted compositions present themselves for spacecraft exploration. Small dots represent objects for which no physical measurements are currently available, offering a challenge to observers.

Figure 1.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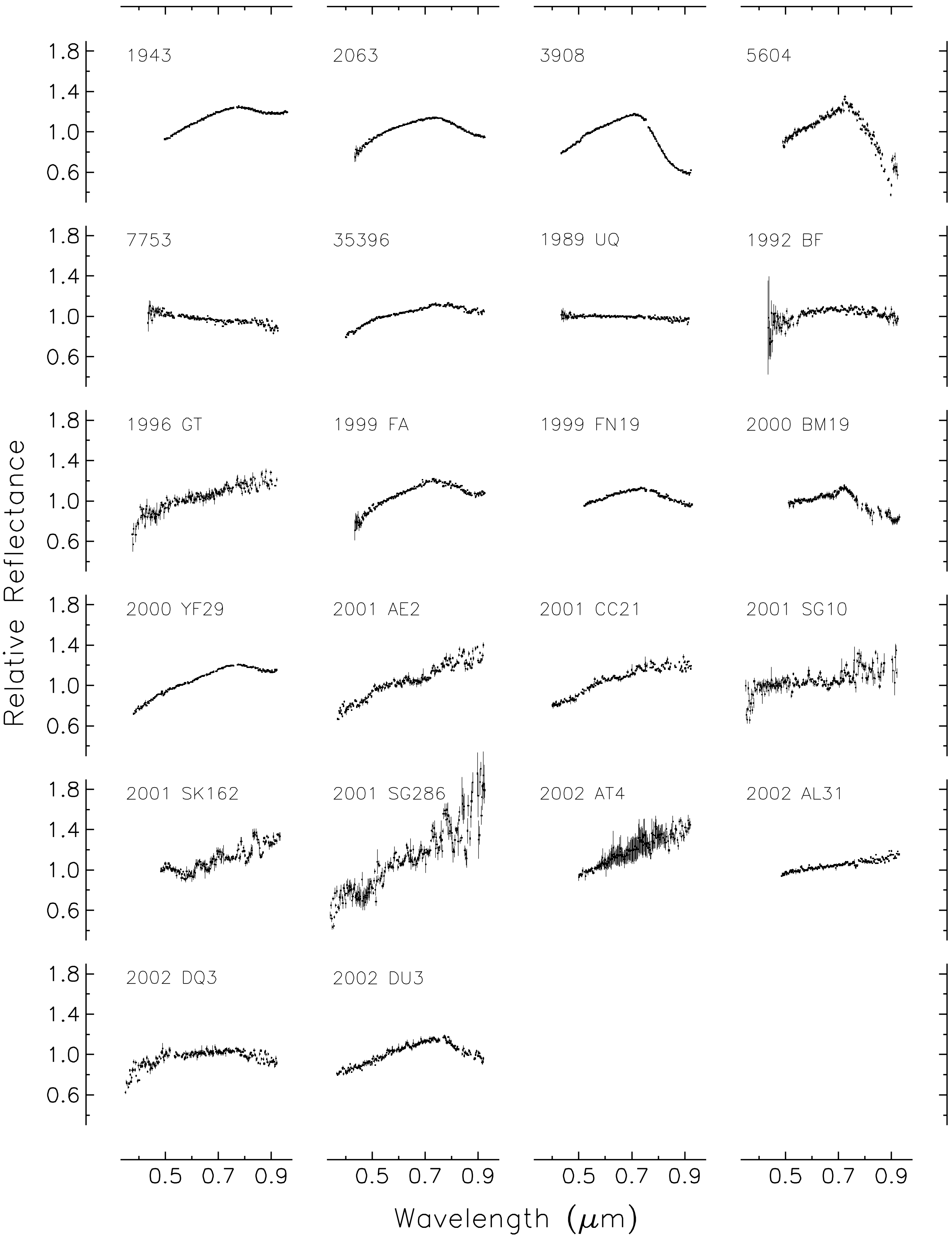
Venus
Mars
Main Belt
Jupiter
delta-V (km/sec)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1999 FA
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2001 AE2
2001 CC21
2001 SG10
2001 SK162
2001 SG286
2002 AT4
2002 AL31
2002 DQ3
2002 DU3
1.8
1.4
1.0
0.6
0.5
0.7
0.9
Relative Reflectance
Wavelength (μm)

Figure 3