ALL IN THE FAMILY: UPCOMING CHANGES IN THE LCDB

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Since 2005, the asteroid lightcurve database (LCDB; Warner et al., 2009) used osculating orbital elements to assign family/group membership. Including special subgroups, e.g., inner main-belt (MB-I) versus inner main-belt comets (MB-IC), there were fewer than 33 families/groups. The LCDB release expected in 2021 April or May, will incorporate families defined by Nesvorny et al. (2015; Nesvorny, 2015) and additional families defined on the AstDys web site. The change will include revised default albedo and phase slope parameter (G on H-G system) values for each family. In addition, the LCDB will include provisions for data on the H-G12 or H-G1G2 system (Muinonen et al., 2010), which has been formally adopted by the International Astronomical Union. The details of these changes are explained here.

Barring specific data otherwise, the asteroid lightcurve database (Warner et al., 2009) uses osculating orbital elements to define broad asteroid families/groups. This is done to help assign default taxonomic class, albedo, and derived diameter for an object when actual values were not available. This allows the LCDB to be used for its most common purpose: to compare rotation frequencies (periods) against diameter (Figure 1).

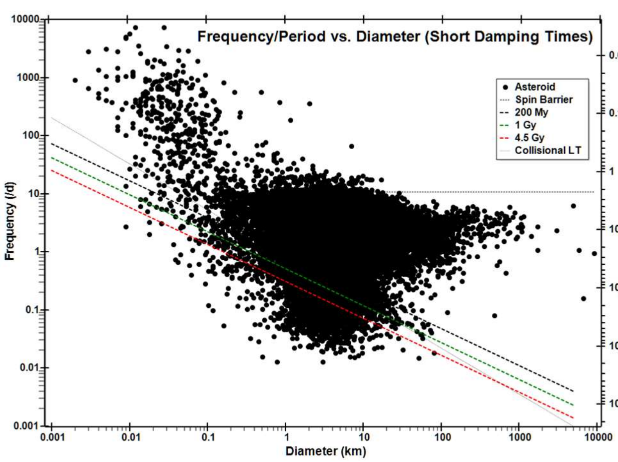

Figure 1. This frequency-diameter plot from the LCDB (2021 Apr 3) shows all objects with a statistically useful period, including those from dense and sparse wide-field surveys.

While these broad family/group assignments were generally sufficient, they didn't allow more refined statistical studies of the much larger number of true asteroid families, a number that is often under review and change.

In the 2021 April/May release of the LCDB, these broad groups will be replaced by adopting the dynamical families defined under Nesvorny (2015) and Nesvorny et al. (2015); *Nesvorny* refers to both references from here on) and AstDys (2021) web site (see the numerous references available there). The most important element of the revision is that family membership is based on proper elements, which are invariable over very long periods of time.

More so, *Nesvorny* used SDSS colors and WISE (Mainzer et al., 2019) albedos along with a parameter Cj to isolate objects that were more likely than not true family members (from the same parent) and those just occupying the orbital space of a family, what they called *dynamic interlopers*. For example, their list for the Hungaria family includes 2965 objects but 60 of those were flagged by the Cj parameter to by *dynamic interlopers*.

In the LCDB, any object not within one of the defined families is given an LCDB-defined family identification number (FIN; see *Nesvorny* for a discussion about the need and use of FINs) in the range 9000-9999.

Whether a true family member or a group member, a default albedo, taxonomic class, and *G* (on the H-G system) are assigned to an object when added to the LCDB, except in those cases when one or more of the actual values are known. These three values can have a complex relationship when the class and albedo are not directly obtained.

Nesvorny assigned default albedos and taxonomic class for most of the families in their list. As previously mentioned, the albedos are based on WISE observations, i.e., their *H* and the measured diameter were used to derive the albedo, while the taxonomic class was taken from the literature. When no actual values are available, the defaults are used. However, *Nesvorny* did not provide a default value for *G*. This value is assigned based on the adopted albedo as given in Table 1.

Taxonomic Classes	Albedo	G
C, G, B, F, P, T, D	0.057 ± 0.02	0.12 ± 0.08
M	0.16 ± 0.04	0.20 ± 0.07
S, Q	0.20 ± 0.07	0.24 ± 0.11
E, V, R	0.46 ± 0.06	0.43 ± 0.08

Table 1. Inter-relation of default taxonomic class, albedo, and *G* (H-G) from Warner et al. (2009)

Beyond this, Table 1 (originally in Warner et al., 2009) is used to assign default values when at least one of the three parameters is known. These defaults were based on objects with known values for all three parameters at the time.

It should be noted that if there is a measured *H* that is considered reliable, it will be used in lieu of value in the MPCORB file. Likewise, if there is a reliable diameter, e.g., from a spacecraft or occultation, it will be used in lieu of a default value or that measured by an IR survey. The associated values for *H* and albedo adjusted accordingly. In other words, whenever possible, a measured value takes precedence over its corresponding default value.

The *Nesvorny* family numbers were used for the initial assignments, including for those in AstDys families common to *Nesvorny*. However, there were 60 families in the AstDys list that were not in *Nesvorny*. These were assigned custom family numbers in the range 2000-2999.

Table 2 (after the References section) gives a full listing of the 202 family or orbital group assignments and default values used in the 2021 April/May release of the LCDB.

The *Number* column is the family number that appears in the LCDB text reports. Nesvorny numbers range from 001-999. Family numbers 2001-2060 are dynamical families that appear only in the list on the AstDys (2021) web site. Numbers > 9100 are "catch all" orbital groups for those objects that could not be tied to a dynamic family. The family name is appended with an asterisk.

The *Parent* is the MPC-assigned number of the parent (often largest) body of a family. The *Name* column gives the name of the parent body. The *Albedo* column value is usually that of the parent body as inferred by WISE (Mainzer et al., 2019) or, for a small number of families, the average of several albedos of family members, again using albedos inferred from WISE data.

If there is an asterisk after a class, it is assumed based on orbital location. Otherwise, it is the measured taxonomic class of the parent body. *Count* is the number of dynamic family members taken from the Nesvorny or AstDys lists.

Table 3 (after References section) gives the *osculating* orbital elements ranges for the broad groups with family numbers > 9000. For each core elements (a, e, i), the two columns represent the minimum and maximum values. Q is the aphelion distance and q is the perihelion distance.

Cave Usor – User Beware

We wish to make it clear as possible that an object being in the same orbital space defined for a family does not necessarily make it a member of that family but, instead, that it could be a *dynamic interloper*. The Hungaria family is just one example where there are numerous interlopers.

The true determination of family membership is possible only when its proper elements and taxonomic spectrum (not just broad taxonomic class) closely match those of a known family parent. The assignments in the LCDB are meant to be good starting points and may be useful in many cases but they are *not* the final word for critical studies.

The tabulation of absolute magnitude (H), phase slope parameter (G), and albedo (p_V or other band) are used to document how the value for diameter (D) was determined. These values are not intended to be fundamental or all that carefully edited. For the LCDB purposes, an error of even 50% in diameter is insignificant in a plot like Figure 1, which spans five orders of magnitude.

A Case in Point

For some time, 93 Minerva was considered the main (namesake) body for the Minerva family. Spectroscopic observations showed that it was actually an interloper among what is now called the Gefion family (after 1272 Gefion). What distinguishes the Gefion members is their higher than usual albedo for outer main-belt objects (pv ~ 0.25) instead of the more typical pv ~ 0.06.

The AstDys families list has only the Minerva group and contains only a relatively few members common to the *Nesvorny* Gefion family (516). The *Nesvorny* Gefion family is used in the LCDB. Members of the AstDys list not in the *Nesvorny* list were placed in the catch-all outer main-belt group (9106). However, they were not all set to use the defaults of class = C*, G = 0.12 ± 0.08, and p_V = 0.057. Instead, where available, WISE, AKARI, and/or SIMPS albedos were averaged and that value was assigned with the 'L' (details record) flag. Based on Table 1, objects with albedos < 0.12 were set to type "C*." Type "SC*" was assigned to objects within $0.12 \le p_V \le 0.18$ but the averaged albedo was used in lieu of the default of p_V = 0.1. Objects with p_V > 0.18 were assigned the "S*" class.

Another Case in Point

While there are some specific families within the common orbital space for the near-Earth asteroids, Hildas, Jupiter trojans, Centaurs, and TNO/KBO objects, in general these groups are treated without distinction between family and group members since there is no single parent body for each group.

For example, when searching the MPCORB file using the osculating elements limits for group 9107 (Hilda space in Table 3), a total of 4615 objects were found. However, looking deeper, 409 of those objects were in families or subfamilies defined by *Nesvorny* and/or AstDys other than the Hildas (e.g., Nesvorny 002, Schubart; AstDys 2022, Devine; and AstDys 2027, Mecklenburg).

The 2021 March 28 snapshot of the LCDB summary table found 1,484 objects, regardless of U rating, within the Hilda orbital space defined in Table 3. Of those, 258 were assigned to "outsider" families such as those in the previous paragraph.

These are just some of the many examples of the indefinite definitions of asteroid families and the possibility for numerous interlopers with "outlying" values in a presumed family. If trying to do critical studies based on true *family* membership, the LCDB should be considered a starting point but *not* the final destination.

"Cave Usor!"

The H-G, H-G12, and H-G1G2 Systems

To predict the magnitude of an asteroid and how it changes with phase angle versus a linear geometrical relationship, the H-G system (Bowell et al., 1989) was adopted by the IAU in 1985. A new system involving three parameters (Muinonen et al., 2010) was adopted by the IAU, although the H-G system still remains in wide use. Even so, the use of H-G12 system is becoming more common as large survey contribute large bulks of data. As a result, the LCDB tables have been altered to account for the new data format.

The H-G12 system uses only the first term of the two under the H-G1,G2 system and is most often used when there are limited data for finding a phase curve. The H-G1,G2 system uses two parameters that more effectively describe the asteroid's brightness at large and small phase angles. It has also been shown to be an effective tool for taxonomic classification (Shevchenko et al, 2016; Mahlke et al., 2021).

A strong discontinuity exists around G1 = 0.2 for the H-G12 and H-G1,G2 systems. See the Muinonen et al. (2010) paper for a discussion of this issue.

The large majority of G values given in the LCDB are under the H-G system. However, some surveys that produced large numbers of rotation periods also found G1 under H-G12 as part of their data reduction. To accommodate both systems, the Summary and Details of the LCDB tables include a "G" and "G2" field.

In both tables, if the *GSource* field has no value or one other than 'G', the *G* data field is on the H-G system. If the *GSource* field has 'G', then the value in the *G* field is G1 on the H-G12 or H-G1,G2 system. If the *G2* field has a value, then the *G* field is G1 on the H-G1,G2 system.

On-line Resource

The link below, to be updated prior to publication, allows you to retrieve information about a single object, including the new family/group membership.

minorplanet.info/PHP/OneAsteroidInfo.php

The search returns entries in the LCDB and dates of opposition, closest, and brightest through 2024 for the selected object, if found in the LCDB and/or opposition database, and a 30-day ephemeris (topocentric) based on unperturbed elements from a recent MPCORB file.

Acknowledgements

Development and maintenance of the current version LCDB, i.e., a relational database instead of single flat text file, has been carried out under five NASA and four NSF grants since 2005. We gratefully acknowledge the support of the two agencies over the past 16 years. The 2021 April/May release, carried out under 80NSSC18K0851, will be the last one under the auspices of either agency. We intend to carry on with LCDB maintenance in the foreseeable future but at a more "leisurely" pace. This includes providing a version of the 2021 April/May release for the NASA Planetary Data System (PDS) and, if possible, on the VizieR site (*http://vizier.u-strasbg.fr/*). The latter, however, usually requires the catalog be tied to a, preferably recent, published paper.

We also thank the many users of the LCDB for their feedback. Given the number of times we've seen a version of Figure 1 and papers based on LCDB data, we're gratified to know that the effort over the years has provided a useful and even important tool in asteroid research.

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