THE SIZE DISTRIBUTION OF JUPITER-FAMILY COMETARY NUCLEI. Paul R. Weissman and Stephen C. Lowry, Jet Propulsion Laboratory, Mail stop 183-601, 4800 Oak Grove Drive, Pasadena, CA 91109, USA (pweissman@lively.jpl.nasa.gov).

Introduction: We are continuing our program to determine the size distribution of cometary nuclei. We have compiled a catalog of 105 measurements of 57 cometary nuclei, drawn from the general literature, from our own program of CCD photometry of distant cometary nuclei (Lowry and Weissman [1]), and from unpublished observations by colleagues. We model the cumulative size distribution of the nuclei as a power law, $N(>r) \propto r^{-\alpha}$ where r is the radius, N is the number of comets with radius greater than r, and α is the slope of the cumulative power law. Previous determinations of the size distribution slope do not agree. Fernández et al. [2] found a slope of $\alpha = 2.65 \pm 0.25$ whereas Lowry et al. [3] and Weissman and Lowry [4] each found a slope of $\alpha = 1.60 \pm 0.10$.

Determination of Nucleus Radii: The radii of cometary nuclei are determined through a variety of methods. The most reliable is resolved spacecraft imaging of nuclei but this has only been accomplished to date for comets 1P/Halley (1986) and 19P/Borrelly (2001). A more common technique is CCD photometry of the nuclei when they are far from the Sun and presumably inactive or the coma contribution is likely insignificant. By assuming a typical nucleus albedo of 0.04, the photometric measurements can be converted to an estimated radius. If lightcurve information is also obtained, one can obtain lower limits to the axial ratio, a/b, of a presumably tri-axial ellipsoid with axes (a, b, c), where $a > b$ and $b = c$.

Radii have also been measured using the high spatial resolution of the Hubble Space Telescope when comets are close to the Earth, in which case the coma contribution to the brightness must be modeled and subtracted, and then the nucleus size is obtained by assuming an albedo of 0.04. A fourth method is simultaneous, ground-based visual and infrared photometry, which solves for both the radius and the albedo of the nucleus. IR measurements have also been made for a few cometary nuclei with the ISO spacecraft.

The Catalog: Our catalog consists only of reduced and calibrated measurements by professional astronomers. Of the 57 comets in the catalog, 54 are Jupiter-family comets (JFC: $P < 20$ years), which likely originated in the Kuiper belt, and three are Halley-type comets (HTC: $20 < P < 200$ years), which likely originated in the Oort cloud (Levison [5]). Since these are two distinct dynamical reservoirs, likely with different collisional histories, we limit our size distribution fit to the Jupiter-family comets.

We have normalized the measurements in our catalog to an assumed albedo of 0.04 except in cases where the albedo was directly measured. Multiple, independent measurements exist for 24 of the comets in our catalog and the agreement between observers is generally quite good. In cases of disagreement we favor spacecraft, HST, ISO, and simultaneous vis-IR measurements (in that order) over ground-based CCD measurements alone. We also favor CCD measurements of complete lightcurves over "snap-shot" observations that catch only a fragment of a nucleus rotation. In cases where there are no discriminating factors, we take the average of all observations.

Results: Results are shown in Figure 1, which plots the cumulative number of JFC nuclei larger than radius r as a function of r. The plot shows a fairly constant slope between ~15 and 1.4 km (containing 41 nuclei), and then a sharp roll-off at radii < 1.4 km. We believe the latter is due to observational incompleteness; nuclei smaller than 1.4 km are exceedingly faint at large solar distances and thus difficult to measure.

The least-squares fitted slope of the distribution for $r \geq 1.4$ km is 1.59 ± 0.03, in excellent agreement with our earlier study [4]. We have also determined the slope for a subset of our sample with perihelion distances $q < 2$ AU and the values are identical within
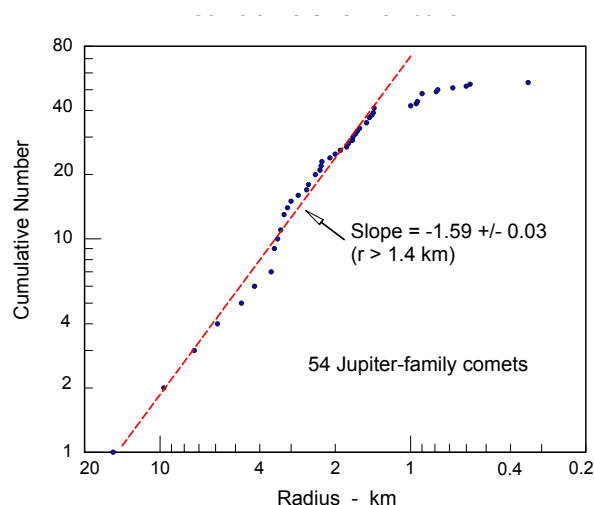
Figure 1. Cumulative size distribution for 54 Jupiter-family cometary nuclei, based on our catalog of spacecraft, HST, ISO, vis-IR, and CCD observations. The slope of -1.59 ± 0.03 is shallower than that for most other small body populations in the solar system.

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the error bars. This tends to rule out observational selection effects or a dependence of the size distribution on perihelion distance.

As noted earlier, this slope is considerably less than that found by Fernández et al. [2]. We believe we can account for this in several ways. First, Fernández et al. relied on measurements reported in the Minor Planet Electronic Circulars and IAU Circulars, which are often preliminary, uncalibrated estimates, and which may include coma contamination. Second, if one closely examines Figure 4 of their paper, one finds that the slope is fit to an arbitrary part of the distribution containing only nine nuclei, as compared with 41 nuclei for our result. The Fernández et al. fit covers only 1 magnitude in brightness, or only a factor of ~1.6 in radius, whereas our result covers a range of 5 magnitudes and a factor of 10 in radius. Thus, we believe that our result is the most robust to date.

Our result can be compared with power law slopes found for other small body populations in the solar system. These are shown in Table 1. Perhaps most interesting is the low slope found for the cometary nuclei as compared with that of Kuiper belt objects and Centaurs, since the Kuiper belt is believed to be the source of the JF comets, and the Centaurs are believed to be the transient population, evolving inward to orbits where comets can become active, i.e., where water ice will sublimate at detectable rates, < 3 AU.

We explain this difference by suggesting that the size distribution in the Kuiper belt is a broken power law, as proposed by Weissman and Levison [13]. They proposed, based on estimates of the Kuiper belt population in different size ranges, that the cumulative slope was 3.5 for objects > 10 km in radius, and ~2 for objects with radii < 10 km. The steep slope for the larger KBOs has since been confirmed by observations [9, 10]. However, KBOs smaller than ~10 km in radius are currently undetectable with ground-based telescopes, so the size distribution in that range is, at present, unknown.

In addition, we believe that the nucleus size distribution has been modified by mass loss during the comets' residence in the inner solar system. The nuclei lose mass through sublimation of volatiles and through shedding of fragments, i.e., splitting. If we conservatively model the mass loss of the nuclei as an average constant loss in radius for each comet, assuming typical parameters for water ice sublimation, we find that the slope of the "original" power law size distribution is steeper, on the order of α = 1.77.   The original slope is likely even steeper if we add the effect of fragment shedding.

Table 1. Cumulative Radius Distribution Slopes for
       Small Body Populations in the Solar System

Population	α	Reference
Jupiter-family comets	1.59 ± 0.03	this work
Near Earth asteroids	1.75 ± 0.10	[6]
	1.95 ± 0.07	[7]
Main belt asteroids	1.25 to 2.80	[8]
Kuiper belt objects	3.45	[9]
	3.15 ± 0.03	[10]
Centaurs	3.20 ± 0.10	[11]
	3.0	[12]

The shallow slope for the cometary nucleus size distribution is supported by several independent lines of evidence, including the size distribution of craters on the Galilean satellites [14], the size distribution of accreted planetesimals predicted by theoretical modeling [15], the size distribution of fragments of the disrupted comet LINEAR (1999 S4) [16] and the size distribution of asteroids in eccentric and inclined orbits, which likely are extinct Halley-type comets [17].

References: [1] Lowry, S. C. and Weissman, P. R. (2003) *Icarus*, in press. [2] Fernández, J. A. et al. (1999) *Astron. & Astrophys.* **352**, 327-340. [3] Lowry, S. C. et al. (2003) *Astron. & Astrophys.* **397**, 329-343. [4] Weissman, P. R. and Lowry, S. C. (2002) In *Cometary Science After Hale-Bopp*, IAU Colloquium 186, Tenerife, Spain (abstract). [5] Levison, H. F. (1996) In *Completing the Inventory of the Solar System*, ASP **107**, pp. 173-191. [6] Bottke, W. F. et al. (2002) *Icarus* **156**, 399-433. [7] Stuart, J. S. (2001) *Science* **294**, 1691-1693. [8] Jedicke, R. and Metcalfe, T. S. (1998) *Icarus* **131**, 245-260. [9] Gladman, B. et al. (2001) *Astron. J.* **122**, 1051-1066. [10] Trujillo, C. et al. (2001) *Astron. J.* **122**, 457-473. [11] Larsen, J. A. et al. (2001) *Astron. J.* **121**, 562-579. [12] Sheppard, S. S. et al. (2000) *Astron. J.* **120**, 2687-2694. [13] Weissman, P. R. and Levison, H. F. (1997) In *Pluto- Charon* (Univ. Arizona Press: Tucson), pp. 559-604. [14] Zahnle, K. et al. (2003) *Icarus*, submitted. [15] Weidenschilling, S. J. (1997) *Icarus* **127**, 290- 306. [16] Mäkinen, J. T. T. et al. (2001) *Science* **292**, 1326-1329. [17] Levison, H. F. et al. (2002) *Science* **296**, 2212-2215.