SIZE DISTRIBUTION, STRUCTURE AND DENSITY OF COMETARY NUCLEI. Paul R. Weissman[1] and Stephen C. Lowry[2] [1]Jet Propulsion Laboratory, 4800 Oak Grove Drive, MS 183-301, Pasadena, CA 91109, paul.r.weissman@jpl.nasa.gov; [2]Queen's University Belfast, Astrophysics Research Centre, Dept. of Physics and Astronomy, Belfast, BT7 1NN, UK, S.C.Lowry@qub.ac.uk.

Introduction: The physical nature of cometary nuclei remains one of the most important unresolved mysteries in solar system science. However, it is slowly yielding to investigations by ground-based observers as well as *in situ* observations by flyby spacecraft. The picture that is emerging is providing us with new insights into the nature of these primitive bodies.

Size Distribution: The sizes of cometary nuclei are estimated through a variety of techniques. These include: 1) direct imaging by spacecraft; 2) simultaneous visual and IR imaging that permits a solution for both the size and albedo; 3) IR imaging providing an estimate of the nucleus radius; 4) HST imaging of comets close to the Earth and subtraction of the coma signal; 5) CCD imaging of distant nuclei, far from the Sun where they are likely to be inactive, and using an assumed albedo of typically 4%; and 6) radar imaging.

Of these techniques, (5) is the most widely used, followed closely by (4). Although both techniques rely on an assumed albedo, the consistency of results from numerous observers as well as the confirmation of size and shape estimates from flyby spacecraft show that they are indeed reliable. Spacecraft have only imaged four cometary nuclei to date.

We have compiled a catalog of CCD, IR, HST, and spacecraft measurements of the dimensions of cometary nuclei [1]. The catalog contains 120 measurements of 57 Jupiter-family and 4 Halley-type comets. The data have been normalized to an assumed albedo of 0.04 except in cases where the albedo was directly measured. We find that the cumulative number of Jupiter-family comets (JFCs) at or larger than a given radius can be described by a power law with a slope of -1.73 ± 0.06 (Figure 1). This corresponds to a slope of -0.35 ± 0.01 for the cumulative luminosity function (CLF), similar to values found by other researchers [2-4], which range from –0.32 to –0.38, with the exception of [5] who found a slope of -0.53 ± 0.05.

Typical values of the CLF slope for Kuiper belt objects (KBOs) are –0.64 to –0.69 [6,7]. The shallower slope of the JFCs, which are considerably smaller than the observed KBOs, is likely due to a change in the slope of the KBO size distribution at the smaller sizes of JFCs [8]. The JFC size distribution may also evolve from its primitive value in the Kuiper belt due to physical evolution as the nuclei lose mass through sublimation and fragmentation.

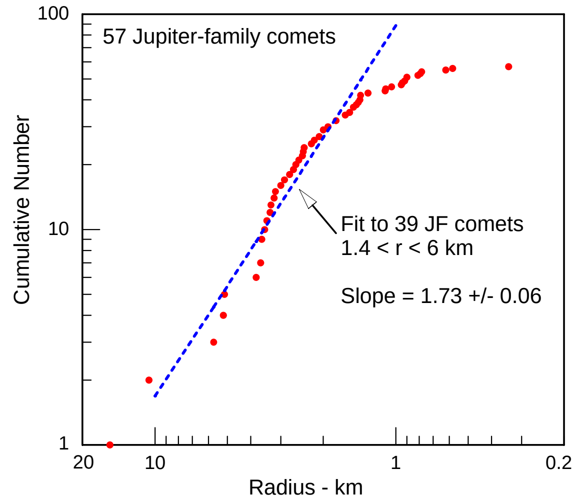

Figure 1. Cumulative size distribution of Jupiter family-cometary nuclei [1]. The least-squares fit is to the 39 nuclei with radii between 1.4 and 6 km. The data are observationally incomplete at radii < 1.4 km.

Nucleus Structure: The best models for the physical structure of cometary nuclei are the "fluffy aggregate" of Donn and Hughes [9] and the "primordial rubble pile" of Weissman [10]. These models suggest that comets are formed by the accretion of icy planetesimals at low encounter velocities, that did little to heat or crush the icy-conglomerate material. Since the comets are stored in low temperature environments and possess little self-gravity, this primitive, low density structure is believed to be preserved to the present day.

We now recognize that comets in both the Kuiper belt and the Oort cloud have likely undergone considerable collisional processing, *in situ* in the Kuiper belt in the case of ecliptic (Jupiter-family) comets [11], or during the ejection process from the giant planets region for the isotropic (Oort cloud and Halley-type) comets [12]. The consequences of this collisional evolution for the structure of present-day observed nuclei have not yet been explored.

The four cometary nuclei observed to date show vastly different shape and surface morphologies, though this may be due in part to the sharply different resolutions of the imagery for each nucleus. Comet 1P/Halley most clearly appears to be a rubble pile structure, with large topographic features and, at least, a binary shape. 19P/Borrelly also has a binary shape but has a smoother surface with less topography and some evidence of erosional processes.

Comet 81P/Wild 2 has a fairly spheroidal shape but a very unusual surface morphology, covered by numerous shallow and deep depressions that may be either eroded impact craters or sublimation pits, or some combination of the two. Large blocks protruding from the surface also suggest an underlying rubble pile structure. The orbital history of 81P/Wild 2 suggests that it may be a relatively young JF comet, new to the terrestrial planets region, and thus the surface may preserve features that are truly primitive.

The highest resolution images to date are of the nucleus of comet 9P/Tempel 1. These images reveal a complex surface morphology with strong evidence for erosional and geologic processes. There also appears to be two relatively well defined and large impact craters on the surface. Apparent layering in the surface images may be primitive, but more likely is further evidence of erosional processes acting on the nucleus. Some surface features on Tempel 1 resemble those on Borrelly and this may be consistent with both nuclei being older and more evolved, having had a long residence time in the terrestrial planets zone.

Nucleus Density: Densities of cometary nuclei are not well constrained. Most measurement methods are indirect, involving, for example, the modeling of non-gravitational forces on the nucleus based on its orbital motion and outgassing rate. These estimates have ranged from 0.1 to 1.5 g cm^{-3} [13-15]. The tidal breakup and re-assembly of comet Shoemaker-Levy 9 into ~21 major fragments in 1992 provided another means of indirectly estimating the bulk density of the nucleus, yielding values between 0.6 and 1.1 g cm^{-3} [16].

Most recently, the Deep Impact encounter with comet 9P/Tempel 1 obtained an estimate of the bulk density of the nucleus by observing the expansion of the dust plume resulting from the spacecraft impact. A value of 0.35 ± 0.25 g cm^{-3} was found [17]. This result is dependent on key assumptions about the impact event, namely that it was a gravity-dominated rather than strength-dominated impact.

Indirect lower limits on the density of nuclei can be obtained by studying their shape and rotational properties, if one assumes that they are strengthless rubble piles held together only by self-gravity. This method is analogous to that used for small asteroids, which shows a sharp cut-off in bodies > 150m diameter and with rotation periods < 2.2 hours.

A similar spin-period cut-off limit for cometary nuclei was first suggested by [18, 19], but at the longer period of 5.6 hours, which corresponds to a density lower-limit cut-off at 0.6 g cm^{3}. This continues to be supported as the cometary nucleus lightcurve sample continues to grow. Data on 20 cometary nuclei are shown in Figure 2 [20], along with contours of nucleus bulk density. Only one object shows a rotation period that would require a bulk density > 0.6 g cm^{-3} (rotation period < 5.6 hours). That object is 133P/Elst-Pizarro, which is in an asteroidal orbit and apparently a member of the Themis collisional family in the main belt. It is most likely that 133P is a volatile rich asteroid that has suffered a recent impact exposing buried volatiles.

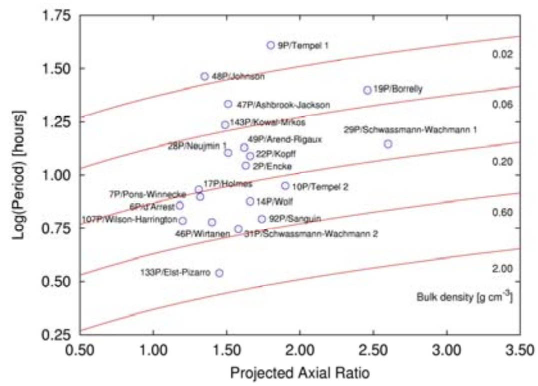

Figure 2. Measured rotation period versus axial ratio for 20 Jupiter-family nuclei [20]. If these objects are strengthless rubble piles held together only by their own self-gravity, then the data imply lower limits on the bulk density of the nuclei, shown by the contours.

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