SMALL BODY DENSITY AND POROSITY: NEW DATA, NEW INSIGHTS.

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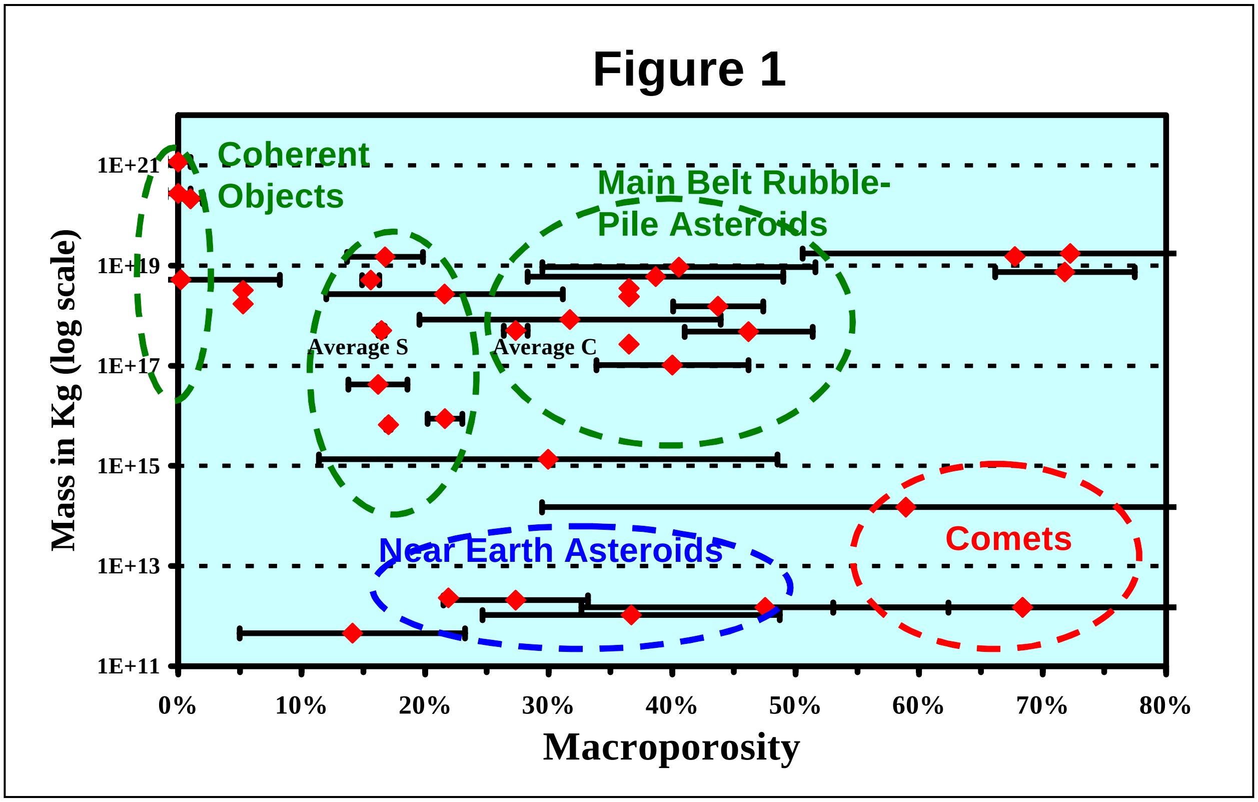
Introduction: Data on the bulk density of small bodies has exploded over the last 10 years. These observations and interpretations have led to significant insights into the structure of small bodies and has contributed to the consensus that most small bodies have relatively low bulk densities and significant porosity [1,2]. Recent new observations and planetary missions have provided a significantly expanded set of data broadening the range of object types, locations, and sizes. These include the small icy moons measured by the Cassini mission, new AO observations of asteroid moons, new observations of small binaries using lightcurve techniques, new observations of NEO and KBO binaries, new data on comet and Centaur density, observations of comet density and new observations of Trojan binaries. These data provide a window into new size ranges and into new zones of the solar system.

Data and Analysis: Shown in Figure 1 are the estimated macroporosity of 32 small bodies and averages for large S and C type asteroids [3]. Macroporosity is estimated the method described in [2] by comparing the small body's bulk density with the grain density of the object's spectroscopically determined meteoritic or mineralogical analogue. The difference between these two values provides the object's bulk porosity. Subtracting the average microporosity of the analogue material gives and estimate of the object's large-scale macroporosity.

The Main Asteroid Belt: As reported earlier, the small bodies of the main asteroid belt appear to divide into three groups. The three largest asteroids, 1 Ceres, 2 Pallas, and 4 Vesta have bulk densities similar to their analogue meteorites, indicating essentially zero macroporosity. These objects appear to have survived the age of the solar system with their primordial structure intact and have not been disrupted by impacts. The second group have been heavily fractured by impacts but remain coherent with between 15-25% macroporosity. The third main-belt group are objects that have greater than 30% macroporosity and probably represent bodies that have been shattered in collisions, disrupted, and re-accreted by self gravity. These are likely to be gravitationally-bound rubble piles. Interestingly, S type asteroids are more likely to be in the fractured-but-still-coherent group, while C-type asteroids are more likely to be in the rubble pile group.



There may be a bias in these data since most of the mass observations come from satellite tracking. Asteroids with satellites may be more likely to have been rubblized than other asteroids. However, the density numbers for asteroids with satellites are generally comparable with data derived from spacecraft flybys and average type data derived from astrometric observations. The one asteroid with a satellite that was discovered by a spacecraft flyby, 243 Ida, is likely not rubblized.

Near Earth Asteroids: The discovery of a number of NEA satellites has populated the low-mass portion of Figure 1 with new observations. The observational numbers are still small and the error bars large, however there are some interesting results. Most of the NEA observations are of S or Q type asteroids and most show rubble-pile level bulk densities and macroporosities. It is interesting that the lowest macroporosity in the group is 2000 DP107 which is a C-type. The rubble pile structure of most NEA's with satellites again may be an artifact because we would not have a system mass without the orbital data on the satellite. However, the spin data does suggest the rubble-pile structures may be common in the NEA population and the fissioning of a satellite may be a common result of a rubble pile that has undergone a spin-up.

Comets: Continuing work on comets has produced some indication of their bulk density. Analysis of ejecta trajectories observed during the Deep Impact encounter with Comet 9P/Tempel 1 indicates a bulk density of 0.62 +0.47/-0.33 g/cm^3 [4]. Davidsson and Gutierez [5.6] estimated densities for comets 19P/Borrelley and 81P/Wild 2 by analyzing non-gravitational orbital changes. Wild 2 is estimated at between 0.38-0.6 g/cm^3 and Borrelly comes in between 0.18-0.3 g/cm^3. Comet rotation period data also supports a strengthless rubble pile model with average bulk densities in the 0.6 g/cm^3 range. While all of these estimates are model dependant and have large error bars, it appears safe to say that comets have very low bulk densities. To put these numbers in perspective we need to look at comet composition and the grain density (porosity-free density) of those materials. To first order comets are mixtures of water ice with a dust composed of hydrated silicates, mafic silicates, and organics. While there are a number of other volatile species, water ice dominates the mass balance of the volatiles. Water ice has a grain density of 0.93 g/cm^3. Cometary dust compositions are not well known yet, but a reasonable analogue may be CI carbonaceous chondrites which are composed of the same sort of silicate and organic mixture thought to dominate the cometary dust. CI carbonaceous chondrites have a grain density of 2.27g/cm^3. Dust to ice ratios are thought to be on the order of 2 to 1, which would make the theoretical grain density of a comet to be approximately 1.8 g/cm^3. It is unlikely that cometary materials will have grain densities much lower than this number. Methane and Nitrogen ices have densities in the 0.8 to 0.9 g/cm^3 range, not much lower than water-ice and their low mass balance would not strongly affect the overall bulk composition of the comet. The dust is unlikely to be much less dense since the hydrated silicates have grain densities in the 2.2-3.0 g/cm^3 range and mafic silicates are much denser.

If the "grain density" of a cometary mix of materials is 1.8 g/cm^3 and comet bulk densities range around 0.5 g/cm^3, the implication is that comets have very large porosities. For Tempel 1, a 0.62 g/cm^3 bulk density would translate into a bulk porosity of 60%. For a nominal cometary bulk density of 0.5 g/cm^3 the bulk porosity would be approximately 65%. This level of porosity indicate that cometary structures are, not surprisingly, essentially fluff-balls with more empty space than solid material.

KBOs and Centaurs: These objects are thought to be source region for many comets and it should follow that these objects could also have very high porosities. Some observations of KBOs indicate low bulk density such as the data from 1999 TC36 which indicates a density range of 0.5-0.8 g/cm^3 [7]. The study by Consolmagno et al. [8] of KBO spins suggests that the mean density of these objects is approximately 0.45 g/cm^3, which is consistent with the emerging comet data. The KBOs would likely have similar bulk compositions to comets and thus similar nominal grain densities. As a result, KBO bulk porosities are likely to also be in the 60-70% range. However, this analysis seems to be limited to the "medium-sized" KBOs. The largest KBOs are substantially denser. Pluto has a bulk density of 2.0 g/cm^3. The Pluto-sized 2003 EL61 is a rapid rotator (period 3.9 hours) and may have a bulk density in the range of 2.6-3.3 g/cm^3 [9]. These objects, like the largest asteroids, are probably coherent with zero macroporosity.

References: [1] Merline, W.J. et al. (2002) Asteroids III (Bottke W. et al., eds, 289-312. [2] Britt D.T. et al., (2002) Asteroids III (Bottke W. et al., eds), 485-500. [3] Standish E.M. (2001) JPL Memo 312.F-01-006. [4] A'Hearn et al., (2005) Science 310, 258-264. [5] Davidsson B.J.R. and Gutierez P.J. (2004) BAAS 36, 1118. [6] Davidsson B.J.R. and Gutierez P.J. (2005) Icaurs 168, 392. [7] Margot J.L. et al. (2005) BAAS 37. [8] Consolmagno G.J. et al., (2006) this volume. [9] Brown M.E. et al. (2006) Astrophysical Journal Letters, in press.