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Evidence of large-scale radial mixing in the early solar nebula from measurements of meteoroid bulk density

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Abstract

We have performed high resolution, multi-station, electro-optical video measurements of 92 meteors with the goal of measuring meteoroid bulk densities. Three different intensified video cameras were used having pixel scales from 0.01° per pixel and time resolution of 10 ms to 0.05° per pixel and 30 ms time resolution resulting in stellar limiting magnitudes ranging from +7.5 to +9. Triangulation baselines from 45-77 km were employed to provide trajectory solutions.

Through simultaneous measurement of each meteor deceleration and lightcurve at both stations we have modeled the detailed ablation per event using ablation model of Campbell-Brown and Koschny (2004). For each meteor, the entire phase space of model free parameters is explored to find ranges of parameters which fit the observations within the measurement uncertainty. This resulted in approximately 100000 model runs per meteor to find a best fit. We also determined the pre-impact orbit of each meteoroid. We find a very clear correlation between orbital class and bulk density (see Figure 1). Our sampled meteoroid population has a representative mass of $\sim 10^{-6}$ kg with 26% having orbits of asteroidal origin, 14% in Jupiter-family comet (JFC) orbits and the remaining 60% in Halley-type comet (HTC) or nearly-isotropic comet-type (NIC) orbits.

Our overall bulk density distribution shows three distinct peaks (see Figure 2). The lowest at $\sim$ 1000 kg m^{-3} corresponds to the high inclination HTC/NIC population, consistent with many other estimates of meteoroid cometary bulk density (e.g. Ceplecha et al., 1998). A peak at higher densities (4200 kg m^{-3} with a range of nearly 1000 kg m^{-3}) have orbits associated with the asteroidal meteoroid population. These densities are consistent with material made of a mixture of chondritic-rich bodies and some nearly pure iron particles consistent with results found from spectroscopic meteor measurements (Borovicka et al., 2005).

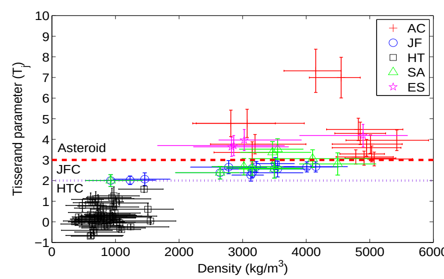

Figure 1: Tisserand parameter versus density for our sample of meteoroids. Two lines are drawn at $T_j = 2$ and $T_j = 3$ to mark clearly the boundaries of different dynamical classes following Levison (1996).

The final density peak near 3100 kg m^{-3} is associated with JFC meteoroids. Among observed events where a JFC origin is likely and taking measurement uncertainty into account, all events in our sample had bulk densities >2600 kg m^{-3} (see Figure 3), a surprising result as JFC material is believed to originate in the Kuiper-belt and/or scattered disk (Duncan, 2008). Whether such high bulk densities are due to evolutionary processes operating on the meteoroids or are indicative of primary materials from the parent bodies is unclear. If the latter is correct, our result is consistent with the recent finding of refractory grains among the Stardust returned samples from the JFC 81P/Wild 2 (Ishii et al., 2008) and implies that substantial, refractory material was transported outward from the inner solar system to the formation zone of the original JFC population.

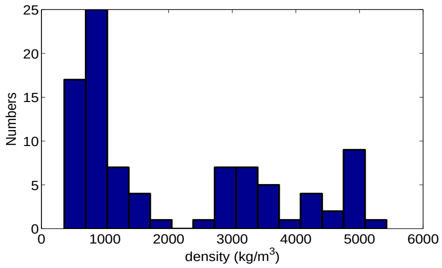

Figure 2: Histogram showing the distribution of the best fit value for our meteoroid densities from our model fit to data (92 meteoroids total).

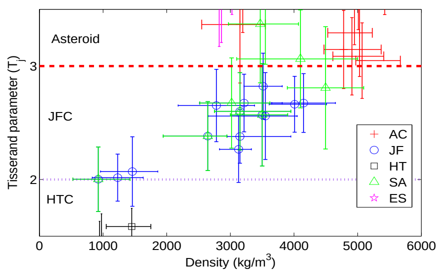

Figure 3: Same as Figure 1 with zooming in on meteoroids originating in JFCs.

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