Quark Nuggets and the “Meter Barrier” in Planetary Formation

DM is rarely considered to be important in the formation of the Solar System, but under very general assumptions there would be gravitational “primordial capture” of DM during the collapse of the protoplanetary nebulae. For reasonable models of galactic DM velocity distributions and assuming a giant molecular cloud comparable to the Orion-A star-forming region, the total amount of primordially captured DM for a Sun-type star would be \( \sim 10^{-12} \) to \( 10^{-11} \) M☉. Although almost any sort of DM would be subject to this process, the primordial capture of quark nuggets would lead to interesting consequences for the Solar System. In particular, masses in the range allowed by the Zhitnitsky theory could resolve the “meter barrier” of planetary formation, serving as nucleation centers for protoplanetesimal and leading directly to a prediction that quark matter would reside today in the cores of the planets and asteroids.

Evidence for Quark Nuggets in “Strange Asteroids”

Quark Nuggets with mass range predicted by the Zhitnitsky theory would have masses comparable to asteroids with \( 100 \) m. An asteroid in this mass range can thus be predicted to either not have a quark nugget core at all, or be profoundly influenced by its strange matter core. Such “strange asteroids” would have unusually large masses and strong gravitational binding, but would have “normal” moment of inertia to mass ratios, leading to a prediction that some would sustain unusually fast rotation rates under Verhovsky-O’Keefe-Radzievski-Paddack (YORP) radiative torque. The small Near Earth Objects (NEO) do indeed contain a population apparently consistent with these predictions, implying that if these are gravitationally bound, core masses of \( 10^6 \) to \( 10^8 \) kg, which overlaps with the stable nugget mass range predicted by the Zhitnitsky theory, supporting (but not proving) the strange asteroid hypothesis.

While Strange Asteroids would be subject to YORP torquing, and thus would be expected to rotate rapidly, their large mass to area ratios means that they would not be strongly subject to Verhovsky radiative accelerations, and would thus have a longer lifetime in Near Earth orbits than their ordinary matter counterparts, and would thus be expected to be over-represented in the small NEO population, which appears to be consistent with this rotation data.

The interpretation of these asteroids as strange objects is complicated by the non-negligible cohesion expected from van der Waals forces, or a reasonable asteroid tensile strength, leaving a ~ 16 meter diameter shadow at the accelerator antipode. The discovery of even a single quark nugget in the Solar System would of course be of immense scientific value. The remarkable agreement between the predictions of the Zhitnitsky theory (based on QCD) and the tensile strength models motivates further investigation of this potential. The strange asteroid hypothesis is likely to be confirmed or disarmed as a consequence of the exploration and mining of NEO, as the existence of a quark core should be evident to in situ spacecraft examination.

A completely independent way to search for quark matter is through neutrino radiography of the Earth’s core; as quark matter is opaque to neutrinos, the Earth should be roughly 4 meters in radius, a beam passed directly through the center of the Earth’s core would be absorbed by an ~ 16 meter diameter shadow at the accelerator antipode. The existing long baseline experiments possess sufficient sensitivity to perform this experiment, assuming they were suitably located.

The Tensile strength required to maintain fast rotating asteroids against destruction (assuming no quark nugget cores), compared to a tensile strength model based on the destruction of meteorites under atmospheric decelerations (triangles, left) and comet Shoemaker-Lerry 9 under jovian tidal stress (large dot, right). Roughly one sixth of the IA-VFR asteroids would need tensile strength beyond this model to avoid destruction. These objects are thus the best candidates for possession of a quark matter core.