Deep Physics from Small Bodies : Macroscopic Dark Matter in the Solar System

T. Marshall Eubanks
Asteroid Initiatives LLC, Clifton Virginia

A New Look At Dark Matter

Nuggets of condensed strange quark matter are a viable theory for macroscopic Dark Matter (DM), consistent with astrophysical constraints despite their non-negligible cross sections, due to their very small cross section to mass ratios. This presentation describes the observable consequences of the nugget theory developed by Ariel Zhitnitsky and his collegues, which predicts a stable nugget mass (M_Q) in the range 10^5 kg < M_Q < 4 × 10^{10} kg.

Unlike most experimental DM work, which can only set upper bounds to the DM density, in this case there is positive evidence for condensed Quark matter as the source of DM.

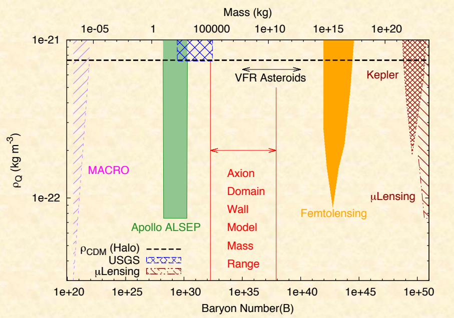
Quark Nuggets and the "Meter Barrier" in Planetary Formation

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 proto-planetary 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 ~ 10^{-8} to 10^{-6} $M_\odot$. 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 proto-planetesimals 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"

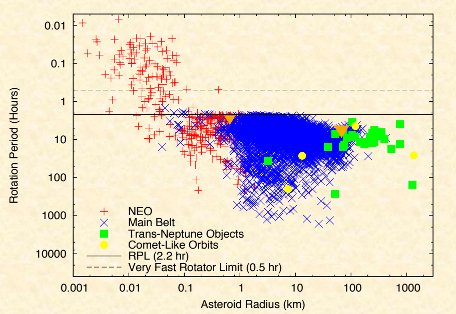
Quark Nuggets with mass range predicted by the Zhitnitsky theory would have masses comparable asteroids with radii ~ 100 m. An asteroids in this mass range can thus be predicted to either not have a quark nugget core at all, or be profoundly influenced by its strange matter core. Such "strange asteroids" 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 Yarkovsky- O'Keefe-Radzievskii-Paddack (YORP) radiative torquing. The small Near Earth Objects (NEO) do indeed contain a population apparently consistent with these predictions, implying, if these are gravitationally bound, core masses of 10^{10} < M_Q < 10^{12} kg, which overlaps with the stable mass range predicted by the Zhitnitsky theory; supporting (but not proving) the strange asteroid hypothesis.

Experimental Limits on Quark Matter as DM



Limits on the Mass Spectrum of Condensed Quark Matter, compared to the Halo DM density. Limits on the left are from laboratory neutrino searches, in the center from seismology, and on the right, from two forms of gravitational lensing (femtolensing of gamma rays and microlensing in the optical. None of these experimental limits impinge on either the predictions from the Zhitnitsky Axion Domain Wall Theory or the masses suggested by asteroid observations.

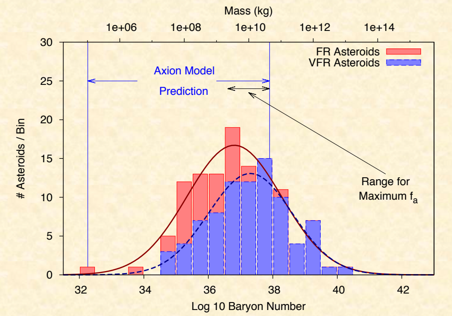
Asteroid Rotation Data as Evidence for Strange Asteroids



The asteroid rotation period-radius relation for all 4519 bodies with suitable data, based on the December 2013 Asteroid Light Curve Database7, after the removal of any flagged data. The change in the character of asteroid rotation rates at R ~ 200 m is obvious to the eye, with many asteroids with R < 200 m having rotation periods < 1 hour while almost all asteroids with R > 200 m have periods > 2 hours. The horizontal solid line is the 2.2 hour Fast Rotator (FR) "Rubble Pile" limit for a uniform density of 2300 kg m^{-3}, while the dashed line is the 0.5 hour Very Fast Rotator limit (which is too fast to be bound gravitationally by any ordinary matter).

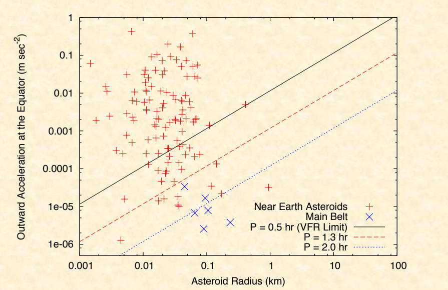
While Strange Asteroids would be subject to YORP torquing, and thus would be expected to rotate rapidly, their large mass to area ratios means that they would not be strongly subject to Yarkovsky radiative accelerations, would thus have a longer lifetime in Near Earth orbits than their ordinary matter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

Quark Nugget Mass Distribution from Asteroid Rotation



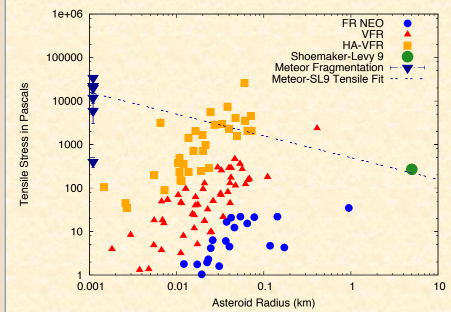
Histogram of the CCO core masses required to prevent rotational disruption for fast rotating asteroids, assuming gravitational binding only. Estimates assume an ordinary matter mantle with a default ρ = 2300 kg m^{-3} for all of the FR asteroids and for the VFR asteroid subset. Also shown (as vertical lines) is the CCO mass range allowed by the axion domain wall theory given current experimental constraints on the axion delay constant f_a and, as marked, the narrower range consistent with the maximum allowed value for f_a (2.8 × 10^{11} GeV). The displayed Gaussians result from fits to determine the histogram centroids; note that these centroids are within the mass region predicted (completely independently) by the axion domain wall theory.

Small Asteroid Binding : Gravitational or Intrinsic Binding ?



The interpretation of these asteroids as strange objects is complicated by the non-negligible cohesion expected from van deer Waals forces, and by the possibility that some such small bodies could be monolithic objects. At least for the fastest rotators it is hard, however, to see how either van der Waals forces, or a reasonable asteroid tensile strength, would be sufficient to protect these bodies against rotational disruption without some additional binding mechanism. This figure shows the surface outward acceleration for the fast rotators, assuming an absence of any quark matter and bulk density ρ = 2300 kg m^{-3}. The High Acceleration (HA) VFR asteroids (those with equatorial accelerations > 0.01 m s^{-2}) would be expected to rapidly lose any unattached surface matter.

Asteroid Tensile Strength Models



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 deaccelerations (triangles, left) and comet Shoemaker-Levy 9 under Jovian tidal stress (large dot, right). Roughly one sixth of the HA-VFR asteroids would need tensile strength beyond this model to avoid disruption. These objects are thus the best candidates for possession of a quark matter core.

Conclusions

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 asteroid observations should motivates further investigation of this potential. The strange asteroid hypothesis is likely to be confirmed or denied 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 the 1 - 10 GeV neutrinos currently used in long baseline neutrino experiments. The primordial capture model predicts that this core (for 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 any quark matter there, but not by the ordinary matter of the core, leaving a ~ 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.

Contact information

T. Marshall Eubanks
Asteroid Initiatives LLC

E-mail: tme@asteroidinitiatives.com