Observational Constraints on Ultra-Dense Dark Matter

T. Marshall Eubanks[1*]
[1]Asteroid Initiatives LLC, 7243 Archlaw Drive, Clifton, Va 20124, USA
*To whom correspondence should be addressed; E-mail:tme@asteroidinitiatives.com.

There have been numerous suggestions that macroscopic ultra-dense objects, either quark nuggets or Primordial Black Holes (PBH), formed in the early universe, persisted until the present, and provide the Dark Matter (DM) required by a variety of astrophysical and cosmological observations (*1–7*). An important check on these DM theories comes from the condensed object mass spectrum, observational estimates of space density or flux compared to the known DM density. The three conventional checks on macroscopic DM, observations of the flux through laboratory detectors, planetary detectors and ground-based gravitational microlensing surveys, allow two disjoint mass regions for viable macroscopic DM particle masses. New *Kepler* satellite microlensing data (*8, 9*) restrict the allowed DM region somewhat, while a search for femtolensing of Gamma Ray Bursts (GRBs) (*10*) provides a new set of DM constraints, greatly restricting the allowed region for larger masses and leaving three allowed "windows" in the mass spectrum. Combining all of these constraints, DM made up exclusively of a particle of mass M_{DM} would not violate current observational constraints if 6×10^{-6} kg $\leq M_{DM} \leq 10$ kg, or 10^5 kg $\leq M_{DM} \leq 10^{18}$ kg, or 10^{20} kg $\leq M_{DM} \leq 10^{22}$ kg.

Primordial capture of any macroscopic DM in the Solar System and other

planetary systems provide a different means of observing DM that may provide profound constraints on DM over a wide range of particle masses. In particular, primordial capture can be immediately used to derive severe restrictions in the mass range of PBH, which would *consume* any ordinary matter objects they come in contact with, a process easily detectable in the Solar System. Capela *et al.* (*11*) considered primordial capture as part of stellar formation, and concluded that it can be used to exclude PBH with $M_{PBH} > 10^{13}$ kg, with smaller PBH not being excluded as they would not have sufficient time to consume their host stars. The extension of primordial capture of PBH to planetary formation can be used to exclude all smaller masses of PBH as such PBH, if captured, would rapidly consume their host planets or asteroids. As the Solar System has manifestly not been consumed, and as other planetary systems appear not to be in the process of being consumed, this implies that M_{PBH} must be $> 10^{-8}$ $M_{\odot}$, or $> 10^{22}$ kg, to be viable. If this exclusion is combined with the *Kepler* and other microlensing constraints, then there is very little possibility of PBH making the DM at any mass up to ~ 30 $M_{\odot}$, effectively ruling out PBH as a viable DM candidate.

References and Notes

1. J.-E. Alam, S. Raha, and B. Sinha. Quark Nuggets as Baryonic Dark Matter. *Ap. J.*, 513:572–575, March 1999.

2. B. J. Carr and M. Sakellariadou. Dynamical Constraints on Dark Matter in Compact Objects. *Ap. J.*, 516:195–220, May 1999.

3. Ariel Zhitnitsky. Dark matter as dense color superconductor. In *Nuclear Physics B Proceedings Supplements*, volume 124, pages 99–102, July 2003.

4. M. R. S. Hawkins. The case for primordial black holes as dark matter. *Mon. Not. R.A.S.*, 415:2744–2757, August 2011.

5. P. W. Gorham. Antiquark nuggets as dark matter: New constraints and detection prospects. *Phys. Rev. D*, 86(12):123005, December 2012.

6. J. Rafelski, C. Dietl, and L. Labun. Compact Ultradense Objects in the Solar System. *Acta Physica Polonica B*, page 2251, 2012.

7. K. Lawson and A. R. Zhitnitsky. Quark (Anti) Nugget Dark Matter. In *Cosmic Frontier Workshop (CF3 and CF6 groups), SLAC 2013. Snowmass 2013 e-Proceedings,* May 2013.

8. K. Griest, M. J. Lehner, A. M. Cieplak, and B. Jain. Microlensing of Kepler Stars as a Method of Detecting Primordial Black Hole Dark Matter. *Physical Review Letters*, 107(23):231101, December 2011.

9. K. Griest, A. M. Cieplak, and M. J. Lehner. New Limits on Primordial Black Hole Dark Matter from an Analysis of Kepler Source Microlensing Data. *Physical Review Letters*, 111(18):181302, November 2013.

10. A. Barnacka, J.-F. Glicenstein, and R. Moderski. New constraints on primordial black holes abundance from femtolensing of gamma-ray bursts. *Phys. Rev. D*, 86(4):043001, August 2012.

11. F. Capela, M. Pshirkov, and P. Tinyakov. Constraints on primordial black holes as dark matter candidates from star formation. *Phys. Rev. D*, 87(2):023507, January 2013.