Macro Dark Matter

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(in collaboration with Glenn Starkman and Bryan Lynn)
Dark Matter: What is it?

- WIMPS? Axions? No detection yet
- Supersymmetry? Nothing (so far) from the LHC
- The “WIMP miracle” may not be so miraculous
- The standard paradigm is threatened
- Alternatives?
Dark matter in the Standard Model?  
(Witten, 1984)

- Considered a (1st order) QCD phase transition in the early universe
- Different stable phases of nuclear matter may exist (hadronic vs. quark)
- Hadrons plausibly produced alongside nuclear objects of $10^9$ to $10^{18}$ g

FIG. 3. Isolated shrinking bubbles of the high-temperature phase.
There should be $10^{16}$ g of dark matter within the Earth’s orbital radius.

Could this be the wrong picture?
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Could *this* be the right picture?
How could this be?

- Interaction rates go as

\[ \Gamma \sim n_x \sigma_x v \sim \frac{\sigma_x}{M_x} \rho_x v \quad \text{or} \quad \Gamma \sim n_x A_T v \sim \frac{1}{M_x} \rho_x A_T v \]

- Can make it small with small cross section or big mass, and therefore consistent with BBN, CMB, LSS, no Earth detection…

- We call \( \frac{\sigma_x}{M_x} \) the “reduced cross section”
Some other macroscopic models

- In the **Standard Model**
  - Strange Baryon Matter (Lynn et al., 1990)
  - Baryonic Colour Superconductors (+ **axion**) (Zhitnitsky, 2003)
  - Strange Chiral Liquid Drops (Lynn, 2010)
  - Other names: nuclearites, strangelets, quark nuggets, CCO’s, …
- Primordial Black Holes
- BSM Models, e.g. SUSY Q-balls, topological defect DM, …
What this work is about

- A systematic probe of “macroscopic” dark matter candidates that scatter classically (geometrically) with matter
- We call this macro dark matter and the objects macros
- Basic parameters: mass, cross section, charge, and some model-specific (e.g. elastic vs. inelastic scattering)

\[ M_x, \sigma_x = \pi R_x^2, V(R_x) \]
Strongly-interacting dark matter

- More or less constrained up to $\sim 10^{17}$ GeV
- Will extend the search to about 10 solar masses ($\sim 10^{58}$ GeV)
Effects on Large Scale Structure
(Self-interacting dark matter)

- Spergel and Steinhardt (2000) (cusp-core issue)
- Simulations vs. obs: e.g., Davé et al. (2000), Randall et al. (2007), Rocha et al. (2012)

\[
\frac{\sigma_{xx}}{M_x} \lesssim 1 \text{ cm}^2/\text{g}
\]

\[\Rightarrow \frac{\sigma_x}{M_x} \lesssim 0.25 \text{ cm}^2/\text{g}\]
Effects on Large Scale Structure
(Dark matter-baryon interactions)

- Chen et al. (2002)
- Dvorkin et al. (2014)

$\sigma_x / M_x \leq 3.3 \times 10^{-3}$ cm$^2$/g

Chen, et al. (2002)
Ancient Mica

- Old samples of mica buried deep (~km) underground
- Chemical etching reveals lattice defects
- Makes for a good exotic particle detector
- Rules out certain DM

\[ \lesssim 55 \text{ g} \]

FIG. 2. Geometry of collinear etch pits along the trajectory of a hypothetical monopole-nucleus bound state in three sheets of mica that had been cleaved, etched, and superimposed for scanning.

Price and Salamon (1986)
Elastically-scattering Macros

![Graph showing the relationship between $\sigma_x$ and $M_X$ for different scenarios including SIDM, LSS, Mica (elastic), and Skylab. The graph also includes lines for nuclear-density and atomic-density.]
Inelastically-scattering Macros
Gravitational Lensing
Gravitational Lensing

- Microlensing of stars in e.g. LMC (Paczynski, 1986)
- Femto-lensing of e.g. GRB’s (Gould, 1992)
Lensing constraints

**Femtolensing**
Marani et al. (1998), Barnacka et al. (2012)

**Microlensing**
Griest et al. (2013)
Model-dependent constraints

- Macros could absorb nucleons during primordial nucleosynthesis
Model-dependent constraints

- Macros could absorb nucleons during primordial nucleosynthesis
- Helium mass fraction $X_4^{\text{obs}} \simeq 0.25 \pm 0.01$ (Aver, et al. 2013)
Resonant-bar Gravitational Wave Detectors
DMJ, Starkman, Weltman (in prep)

**PROVISIONAL**
Conclusions

- Dark matter doesn’t have to interact weakly if it’s very massive. It could still arise from the Standard Model.
- Even if it is beyond-the-SM in nature, there are large regions of parameter space for what the dark matter could be so we need to improve the constraints.
- Existing data and new probes (including astrophysical) will be required, and work is on-going.
Thank you!