The Self-Interacting Dark Matter Paradigm

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Small Scale Issues

- **Core VS. Cusp problem**
  
  ![Graph showing core and cusp profiles](image)
  
  \[ \rho \propto \rho_0 \] \hspace{1cm} \[ \rho \propto \frac{r_s r_s}{r} \]
  

- **Too-big-to-fail problem**
  
  ![Graph showing brightest observed galaxies and biggest predicted subhalos](image)
  
  See James Bullock’s talk

- **CDM halos contain more DM in the central region than indicated by data; the DM deficit problem**
  
  Boylan-Kolchin, Bullock, Kaplinghat (2011)
Even Galaxy Clusters

- Seven well-resolved galaxy clusters

- Remove DM from the central region of halos
Baryon Physics?

- Violent baryonic feedback process

Baryonic infall  

Supernova explosion

Gravitational binding energy VS. Energy injection from supernovae

Navarro, Eke, Frenk (1996)
Baryon Physics?

- Violent baryonic feedback process

  - depends on the stellar mass
    Governato+ (2012)
  
  - depends on when it occurs
    Onorbe+ (2015)
  
  - galaxies with cores larger than $r_*$
    Papastergis, Shankar (2015)
  
  - depends on the recipe of hydrodynamical simulations!
  
  Other group did not see the effect
  Oman+ (2015) (“NFW” group)

We are still debating!

Oman+ (2015)
**Dark Matter Physics?**

- **Self-interactions can reduce the central DM density**

Recent simulations: Irvine group, MIT group

\[
\frac{\sigma}{m_X} \sim 1 \text{ cm}^2/g
\]

\[
\Gamma \sim n\sigma v = \left( \rho/m_X \right)\sigma v \sim H_0
\]

\[
\sigma \sim 1 \text{ cm}^2 \left( \frac{m_X}{g} \right) \sim 2 \times 10^{-24} \text{ cm}^2 \left( \frac{m_X}{\text{GeV}} \right)
\]

**NOT a WIMP:**\[
\sigma \sim 10^{-38} \text{ cm}^2 \left( \frac{m_X}{100 \text{ GeV}} \right)
\]
SIDM Particle Physics

- SIDM indicates light mediators

\[ \sigma \approx 5 \times 10^{-23} \text{ cm}^2 \left( \frac{\alpha_X}{0.01} \right)^2 \left( \frac{m_X}{10 \text{ GeV}} \right)^2 \left( \frac{10 \text{ MeV}}{m_\phi} \right)^4 \]

in the perturbative and small velocity limit

- With a light mediator, DM self-scattering is velocity-dependent

[Diagram showing potential relation between masses and velocities]


See Kim Biddy’s talk for SIDM models
The SIDM Paradigm

- The SIDM paradigm is predictive


Indirect search: Boddy+ (2014); Kaplinghat, Linden, HBY (2015); Feng, Smolinsky, Tanedo (2015, 2016)

Direct search: Del Nobile, Kaplinghat, HBY (2015)

Focus on smoking-gun signatures, independent of DM-SM interactions
Idea 1: Tying SIDM to Baryons

- SIDM may follow the stellar distribution; halo morphology

Correlation between the stellar distribution and the SIDM distribution

Kaplinghat, Linden, Keeley, HBY (PRL 2013)
Backreaction of Baryons

- Baryons may also change the SIDM density profile

\[ \Sigma = \Sigma_0 e^{-r/R_d} \]

For a given total desk mass, vary the scale radius

The SIDM halo could be diverse depending on the baryon concentration

Kamada, Kaplinghat, HBY (in preparation)

We are analyzing the rotation curve data for \( \sim 170 \) galaxies
Idea 2: Dark Matter “Colliders”

Dwarf galaxies

MW-size galaxies

Clusters

“B-factory” (\(v \sim 30\) km/s)

“LEP” (\(v \sim 200\) km/s)

“LHC” (\(v \sim 1000\) km/s)

Self-scattering kinematics

Measure particle physics parameters \(\sigma_X, m_X, g_X\)

Observations on all scales
SIDM From Dwarfs to Clusters

- Consider 5 THINGS dwarfs (red), 7 LSBs (blue), 6 galaxy clusters (green)
- 8 simulated halos with $\sigma/m=1$ cm$^2$/g (gray) for calibration

Outliers:
Due to scatter in halo concentration
favors a mild $v$-dependence

Galaxies: $\sim2$ cm$^2$/g
Clusters: $\sim0.1$ cm$^2$/g
Bullet Cluster: $<1$ cm$^2$/g

Kaplinghat, Tulin, HBY (PRL 2015)
Example

Oman+ (2015)

Kaplinghat, Tulin, HBY (PRL 2015)
Measuring Dark Matter Mass

- Self-scattering kinematics determines SIDM mass

\[ V(r) = \frac{\alpha_X}{r} e^{-m_\Phi r} \]

\[ m_X \sim \text{vs. } m_\Phi \sim 10^{-3} m_X - m_\Phi \]

If \( m_X \) is too large, \( \sigma \sim 1/v^4 \), which is too small for clusters

If \( m_X \) is too small, \( \sigma \sim \text{const} \), which is too large for clusters

\( \alpha_X = 0.01 \)

\( m_X: \sim 15 \text{ GeV}, m_\Phi: \sim 15 \text{ MeV} \)

Kaplinghat, Tulin, HBY (PRL 2015)

\( \alpha_X = 0.001 - 0.1 \)

\( m_X: \sim 5 - 30 \text{ GeV} \)
Summary

• It is time to think about new approaches to the dark matter problem

• CDM has serious issues on galactic scales

• The SIDM paradigm provides a solution with novel features
  - Smoking-gun signatures in direct and indirect detection experiments
  - Measure dark matter mass via self-scattering kinematics
  - Tie dark matter to baryons

Go beyond the dark matter mass deficit problem