Self-Interacting Dark Matter: An Introduction

Yi-Ming Zhong

C.N. Yang Institute for Theoretical Physics, Stony Brook University

Stony Brook University, 02/23/2015
Outline

• Problems with Cold Collisionless Dark Matter (CDM)

• The rise of Self-Interacting Dark Matter (SIDM)
Cold Collisionless Dark Matter

• Cold Collisionless Dark Matter (CDM) is a necessary ingredient of ΛCDM.

• \(\Lambda\)CDM very successfully predicts cosmology at \textit{early times} (BBN, CMB) and at \textit{large scales} (\(\gtrsim 1\) Mpc).

• CDM meets challenges at \textit{small scales} (\(\lesssim 1\) kpc).

from Tegmark
\(1\text{Mpc} \approx 3\text{ Mlyr}\)
Cusp vs. Core

• N-body simulations of CDM only consistently show cuspy halo density profiles (e.g., Navarro-Frenk-White) are universal.

\[
\rho(r) = \frac{\rho_s}{(r/r_s)^\alpha (1 + r/r_s)^{3-\alpha}}
\]

• A core density profile is favored by the measurements of rotation curves of galaxies and others, e.g. THINGS survey gives \(\alpha = 0.29\pm0.07\). Oh et al 2011


from Kuzio de Naray et al 2008
Missing satellites

- N-body simulations of CDM predict an overly large number of halos within galaxies.
- Those halos are missing from observations.


Milky Way: \( M_{\text{halo}} \sim 10^{12} M_\odot \)
Bright spheroidal satellites: \( M_{\text{halo}} \sim 10^8-10^9 M_\odot \)

from Moore et al 1999

\[
V_c = \left( \sqrt{G M(r)/r} \right)_{\text{max}}
\]
“Too big to fail (TBTF)”

Simulation predicts most massive Milky Way satellite galaxies should be more massive than they are observed to be.

Biggest predicted satellites: \( M_{\text{halo}} \sim 10^{10} \, M_\odot \)

Bright spheroidal satellites: \( M_{\text{halo}} = 10^8 - 10^9 \, M_\odot \)

from Boylan-Kolchin et al, 2012
The rise of SIDM

Spergel and Steinhardt (2000) proposed the SIDM to solve the small structure problems.

A. the relaxation time at the solar radius < the age of the universe
\[ (\rho_0 (\sigma/m) v_0)^{-1} \leq H_0^{-1} \]

\[ \rho_0 = 0.39 \text{ GeV/cm}^3 \]
\[ v_0 = 220 \text{ km/s} \]

B. Clusters are triaxial rather than spherical ⇒
the relaxation time at the halo viral radius > the age of the universe
\[ (\rho_{\text{vir}} (\sigma/m) v_{\text{vir}})^{-1} \geq H_0^{-1} \]

\[ \rho_{\text{vir}} \approx 2.7 \times 10^{-4} \text{ GeV/cm}^3 \]
\[ v_{\text{vir}} \approx v_0 \]

⇒ 0.1 cm\(^2\)/g ≤ \(\sigma/m\) ≤ 200 cm\(^2\)/g

1 cm\(^2\)/g ≈ 2 barn/GeV
The rise of SIDM

• (B) ensures self-interaction has minimal effects on the large scale

• At the inner halo, dark matter scatters many times. ⇒
  orbits distributed isotropically rather than radially
  ⇒ shallow density profile
  ⇒ at galaxy scale, solve cusp vs. core problem

• scattering between subhalos and the host halo
  ⇒ subhalo evaporation
  ⇒ solve missing satellites problem