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CLUSTER OF EXCELLENCE
QUANTUM UNIVERSE

DESY.

Simulations of dark matter with frequent self-interactions

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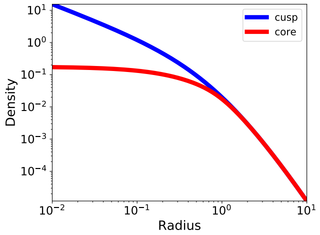
SIDM and Small-Scale Problems

- ΛCDM can explain cosmological large-scale structure remarkably well
- There are several issues on small scales (small-scale crisis)
- Self-interacting dark matter (SIDM) is promising, can solve or at least mitigate small-scale problems.
  - e.g. SIDM can form density cores



Modelling Dark Matter Self-Interactions

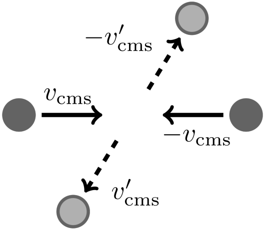
- SIDM is neither collisonless (like CDM) nor fully collisonal (like a fluid)
- Requires 6D phase-space information
- We have to solve the collisional Vlasov-Poisson / Boltzmann equation:

$$\frac{\partial f}{\partial t} + \vec{v} \cdot \nabla_x f - \nabla_x \Phi \cdot \nabla_v f = \left(\frac{\partial f}{\partial t} \right)_{\mathrm{coll}}$$

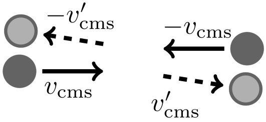
- Self-interactions are described by a collison term

The Collision Term

We distinguish two regimes:

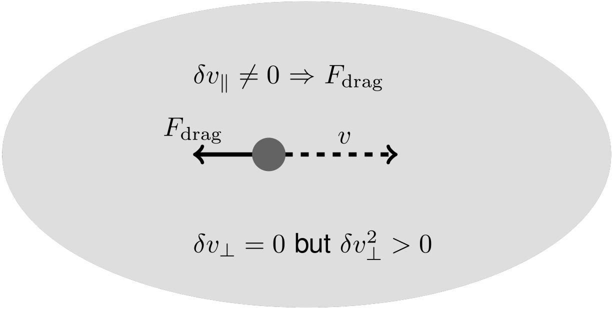


large-angle scattering
– rare –



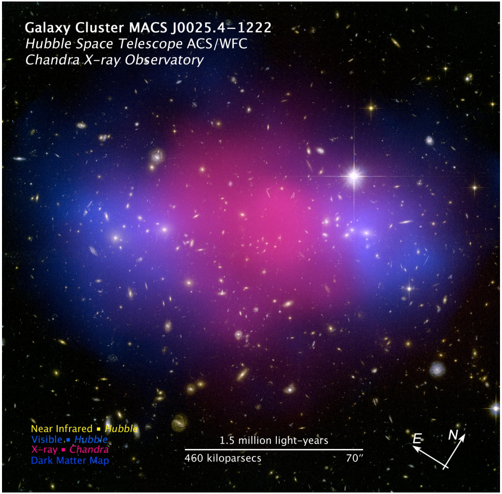
small-angle scattering
– frequent –

Effective Description: Drag Force



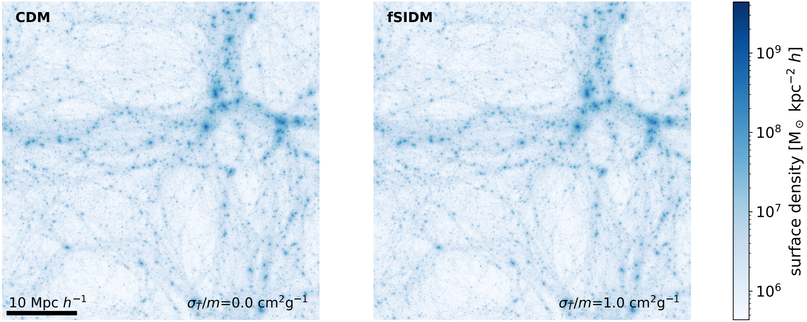
Description of drag force from Kahlhoefer et al. 2014

Galaxy Cluster Merger



Credits: NASA, ESA, CXC, M. Bradac (University of California, Santa Barbara), and S. Allen (Stanford University)

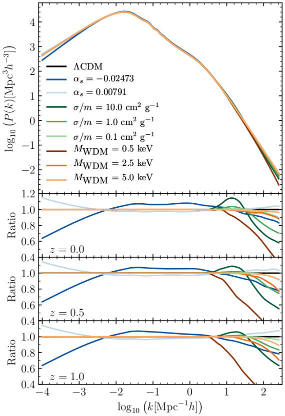
Cosmological Study

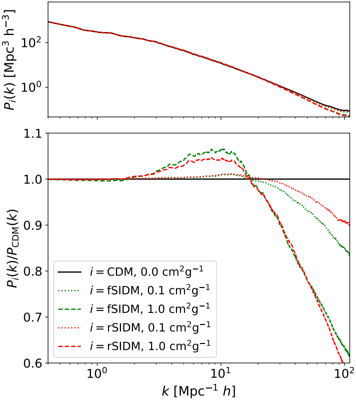


No differences on large scales

Cosmological Study: Power Spectrum

Credits: Stafford et al. 2020

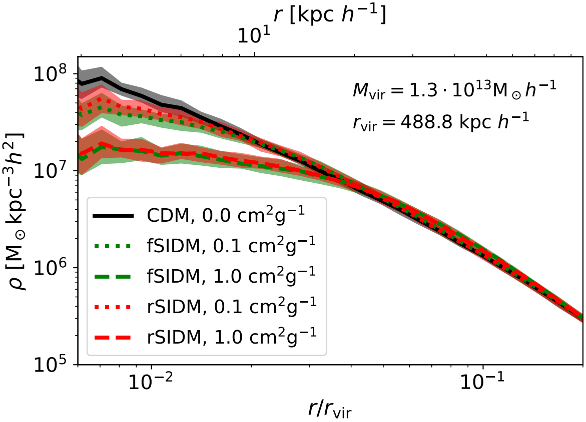




Difference only on small scales

Cosmological Study: Density Profile

Self-interactions produce density cores



Constraints on Frequent Scattering

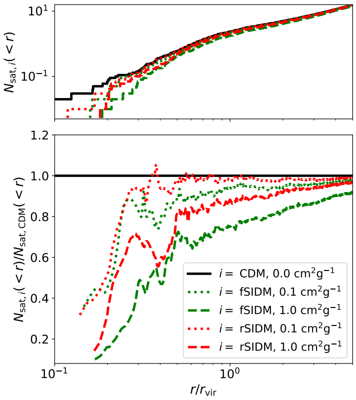
- The momentum transfer cross-section $\sigma_{\tilde{T}}$ can very roughly match rSIDM and fSIDM (density and shape profiles).

- Typically effects of fSIDM are stronger than for rSIDM (same $\sigma_{\tilde{T}}/m$).

- Thus rSIDM constraints can often be seen as a conservative limit for fSIDM.

- Sagunski et al. 2021: $\sigma_{\tilde{T}}/m \leq 0.55\,\mathrm{cm}^2\mathrm{g}^{-1}$ (groups, CL 95%), $\sigma_{\tilde{T}}/m \leq 0.175\,\mathrm{cm}^2\mathrm{g}^{-1}$ (clusters, CL 95%).

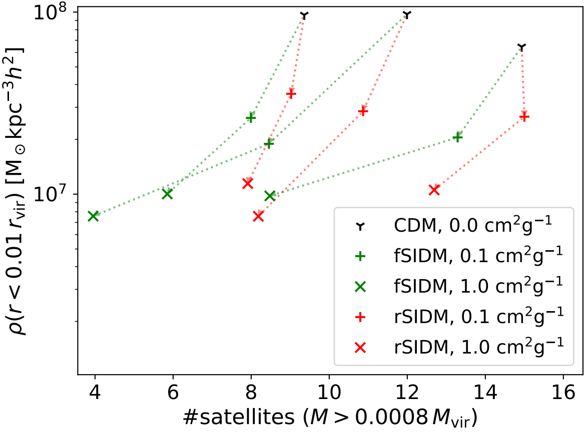
Cosmological Study: Satellite Abundance



Interestingly large suppression of satellites for fSIDM

Central Density vs. Number of Satellites

Qualitative difference between rare and frequent scattering



Take Home Messages

N-body simulations of fSIDM are ...

1. **possible**
   - We developed a new numerical scheme,
   - based on an effective description (drag force).

2. **important**
   - fSIDM and rSIDM have different phenomenology (offsets, satellite abundance),
   - significant difference also at small cross-sections ($\lesssim 1\,\mathrm{cm}^2/\mathrm{g}$).