DARK-MALT at MIAPP

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Improved DM Clustering

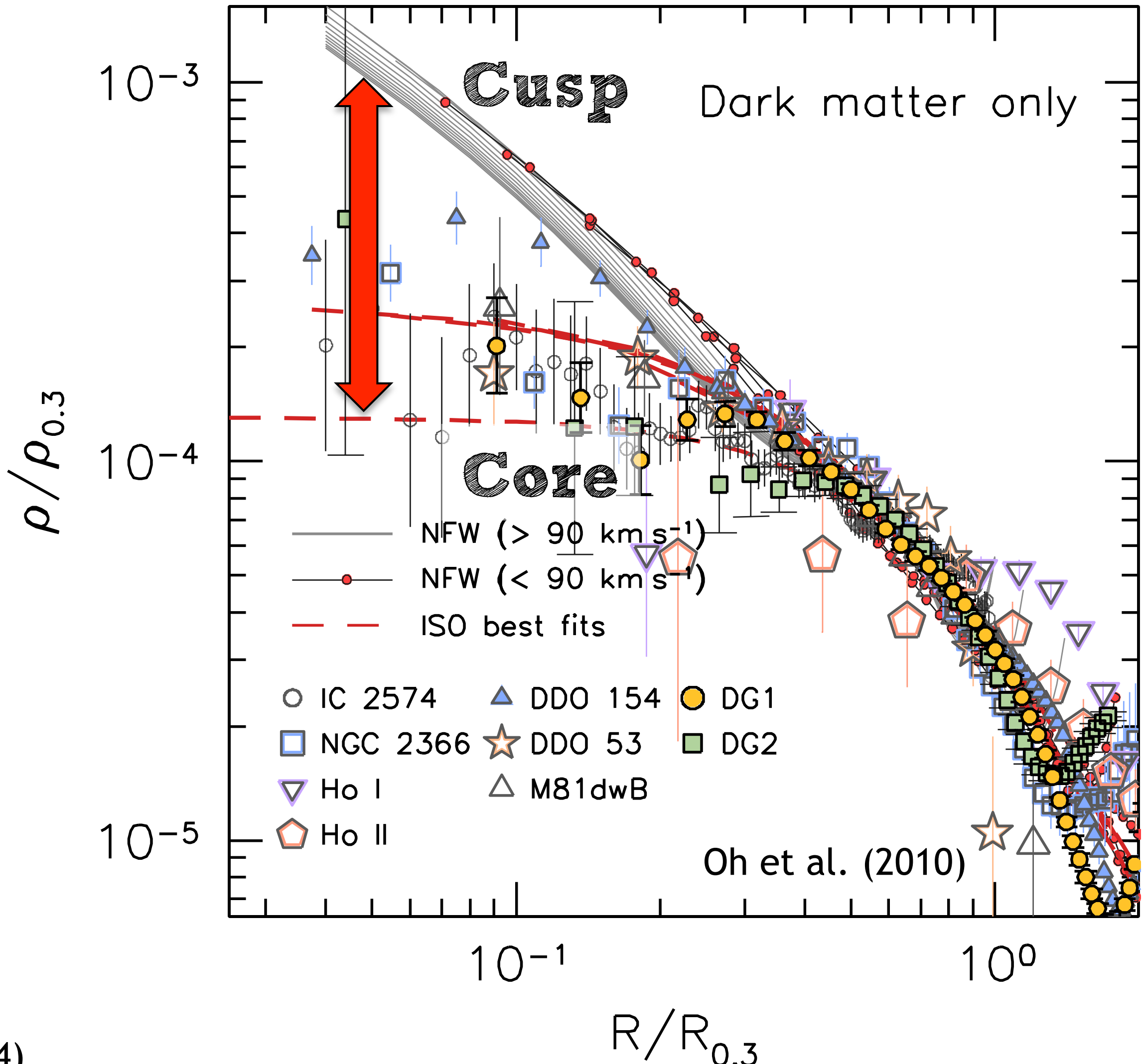
with or without νs

Basudeb Dasgupta,

TIFR, Mumbai

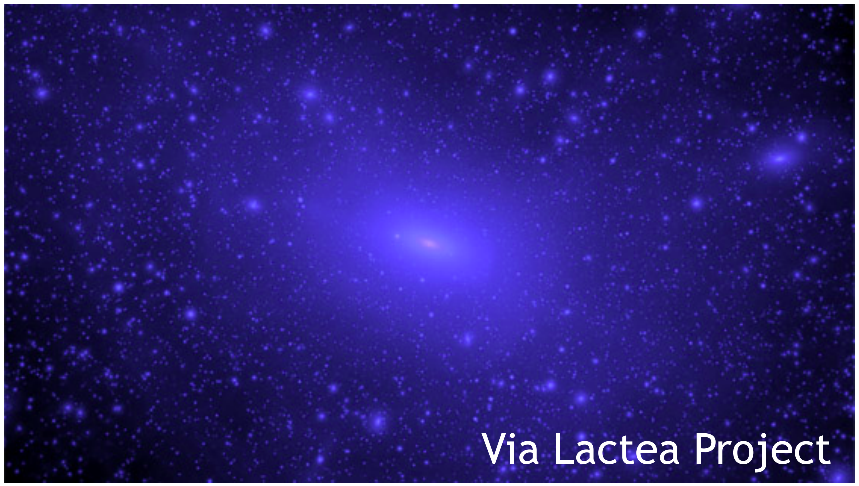
Core-vs.-Cusp Problem

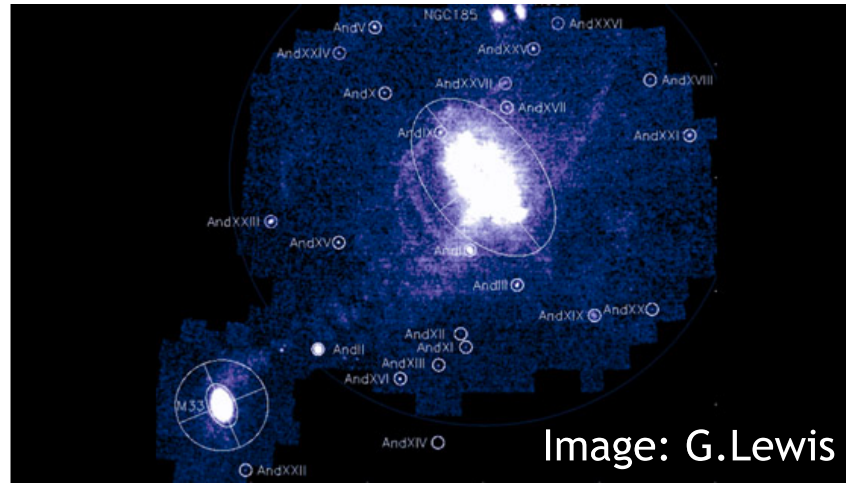
Cold collisionless DM predicts too cuspy inner structure of dwarf galaxies



Moore (1994); Flores and Primack (1994)

Missing Satellites Problem





"WIMP" Simulations

PAndAS Survey

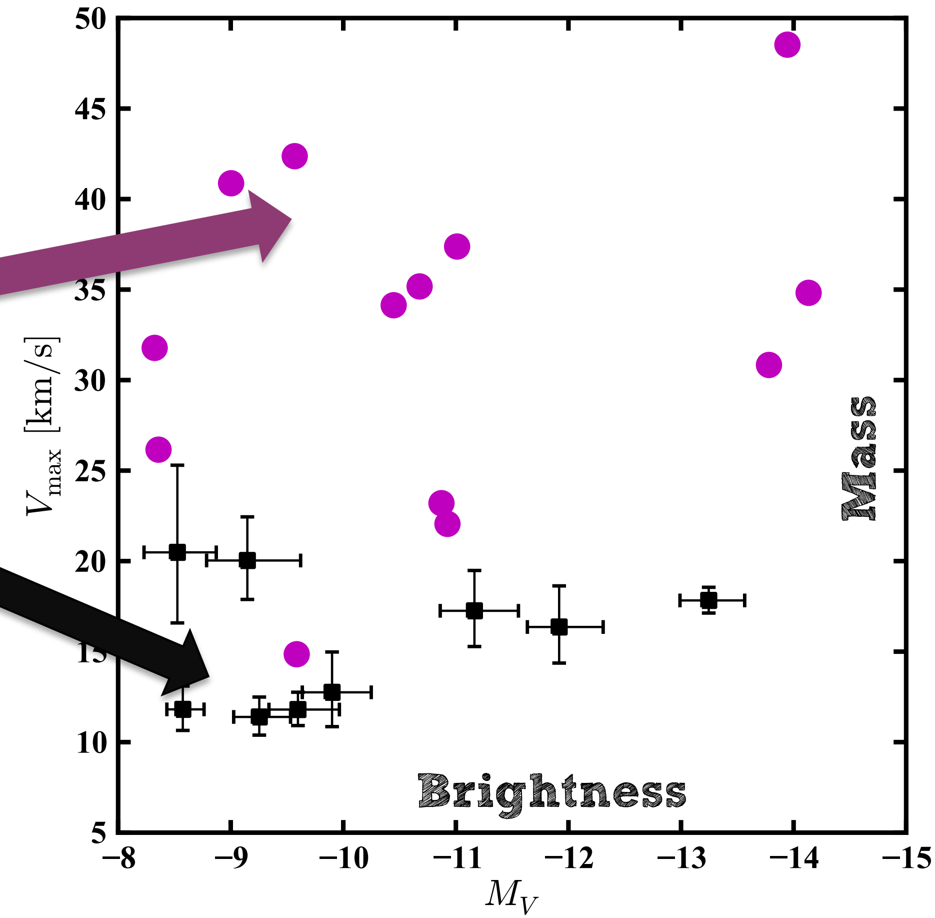
Where are all the satellites of Milky Way?

Klypin, Kravstov, Valenzuela, and Prada (1999)

Too-Big-to-Fail Problem

Predicted Halos

Seen Dwarfs



Why did the predicted massive dwarf-sized halos fail to host stars?

Boylan-Kolchin, Kaplinghat, and Bullock (2010)

How to improve structures ?

- Supernova feedback (blows out gas, no stars)
- Tidal effects (strips out small halos)
- Low star-formation (small halos have less stars)
- ... several astrophysical solutions...

- May be a particle physics solution?

Self-Interactions

DM – DM scattering before they fall into the cusp redistributes DM in phase space so that in they are very isotropic in velocity.

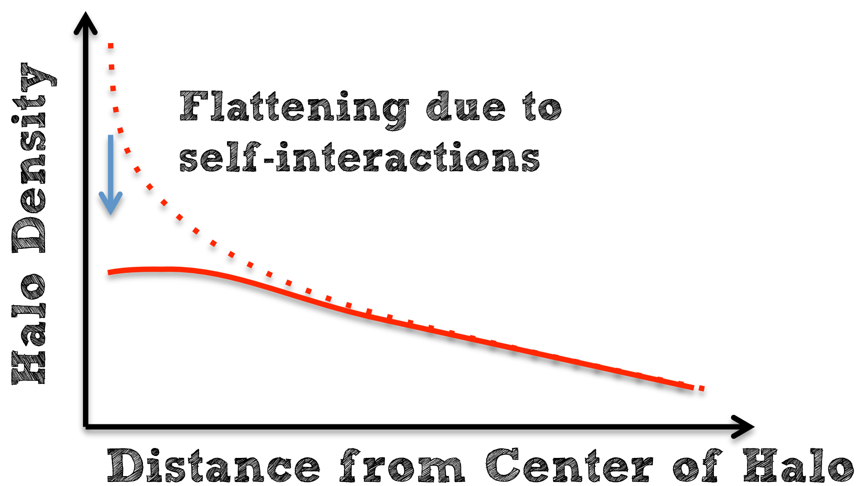
This leads to shallower density profiles.

The size of the core is where optical depth becomes order 1.

$$\frac{\rho}{m_\chi}\sigma_T L = 1$$

Put values of ρ and L

$$\frac{\sigma_T}{m_\chi} \approx (0.1 - 1)\mathrm{cm}^2\mathrm{g}^{-1}$$



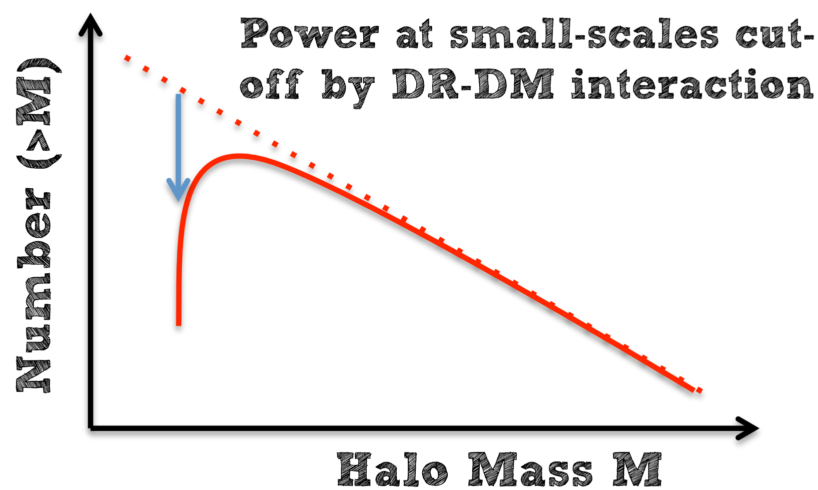
Spergel and Steinhardt (1999)

Late Decoupling

The DM "freestreaming" length determines the size of the smallest halo that can exist. DM scattering on relativistic particles keeps them in kinetic equilibrium and can delay decoupling when freestreaming length is large. This happens at a temperature called kinetic decoupling temperature.

$$\frac{T}{m_\chi} n_{\rm rel.} \sigma \simeq H$$

$$M_{\rm cut} \simeq 10^9 M_\odot \left(\frac{T_{kd}}{0.5\,{\rm keV}}\right)^{-3}$$



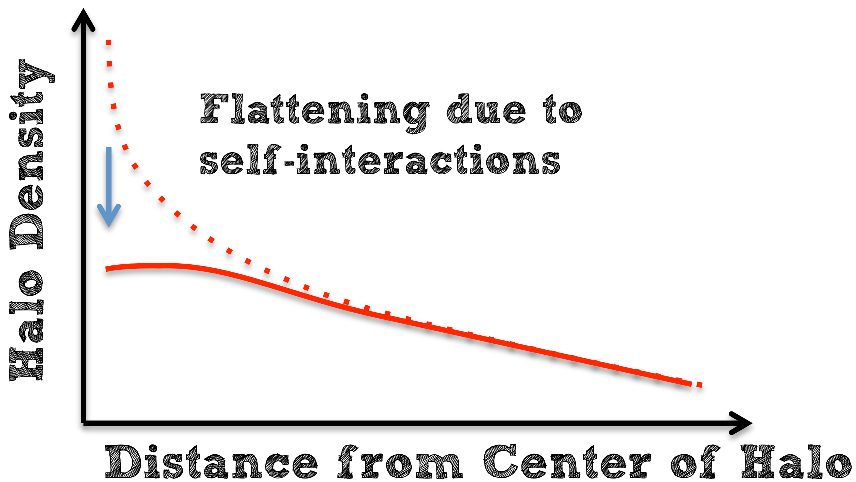
Boehm, Fayet, and Schaeffer (2001); Loeb and Zaldarriaga (2005)

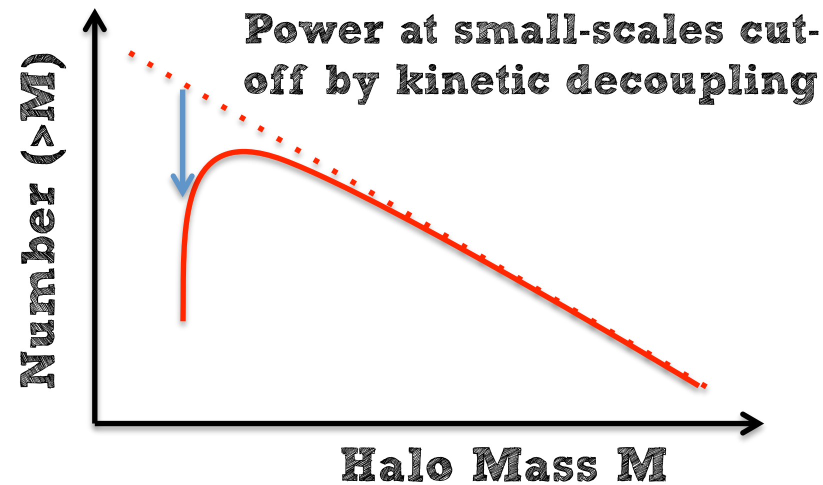
Pretty old game …

Spergel , Steinhardt (2000); Kamionkowski , Liddle (2000); Boehm, Fayet, Schaeffer (2001); Sigurdson, Kamionkowski (2003); Kaplinghat (2005); Borzumati, Bringmann, Ullio (2007); Feng, Kaplinghat, Yu (2009); Feng, Kaplinghat, Tu, Yu (2009); Bezrukov, Hettmannspurger, Lindner (2009); Loeb, Weiner (2010); …

But, again, not both mechanisms together

A two-step solution

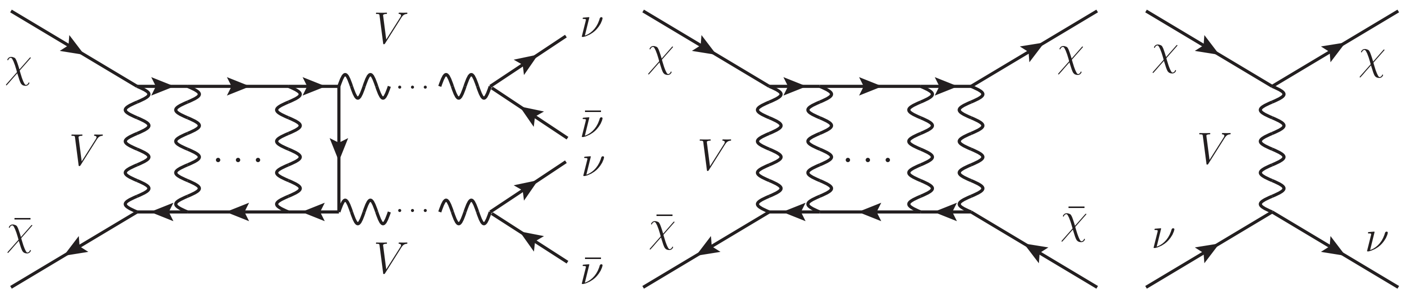




Core-Cusp problem and Too Big to Fail problem solved by halo flattening

Missing Satellites problem solved using late kinetic decoupling

A “ν” Connection

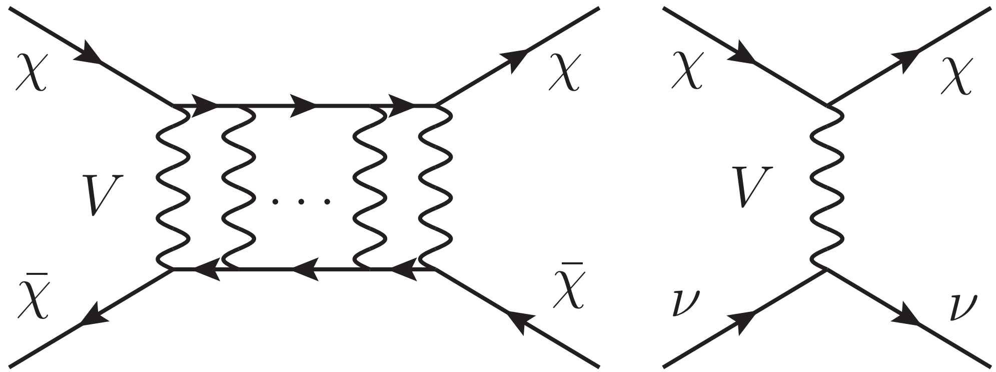


Relic Annihilation **Self-Scattering** **Late-Decoupling**

DM and Neutrinos share a common new interaction

vanDen Aarssen, Bringmann, Pfrommer (2012)

Neutrinos vs. Steriles



Self-Scattering Late-Decoupling

Sterile nus anyway benefit from an interaction – they become cosmologically viable.

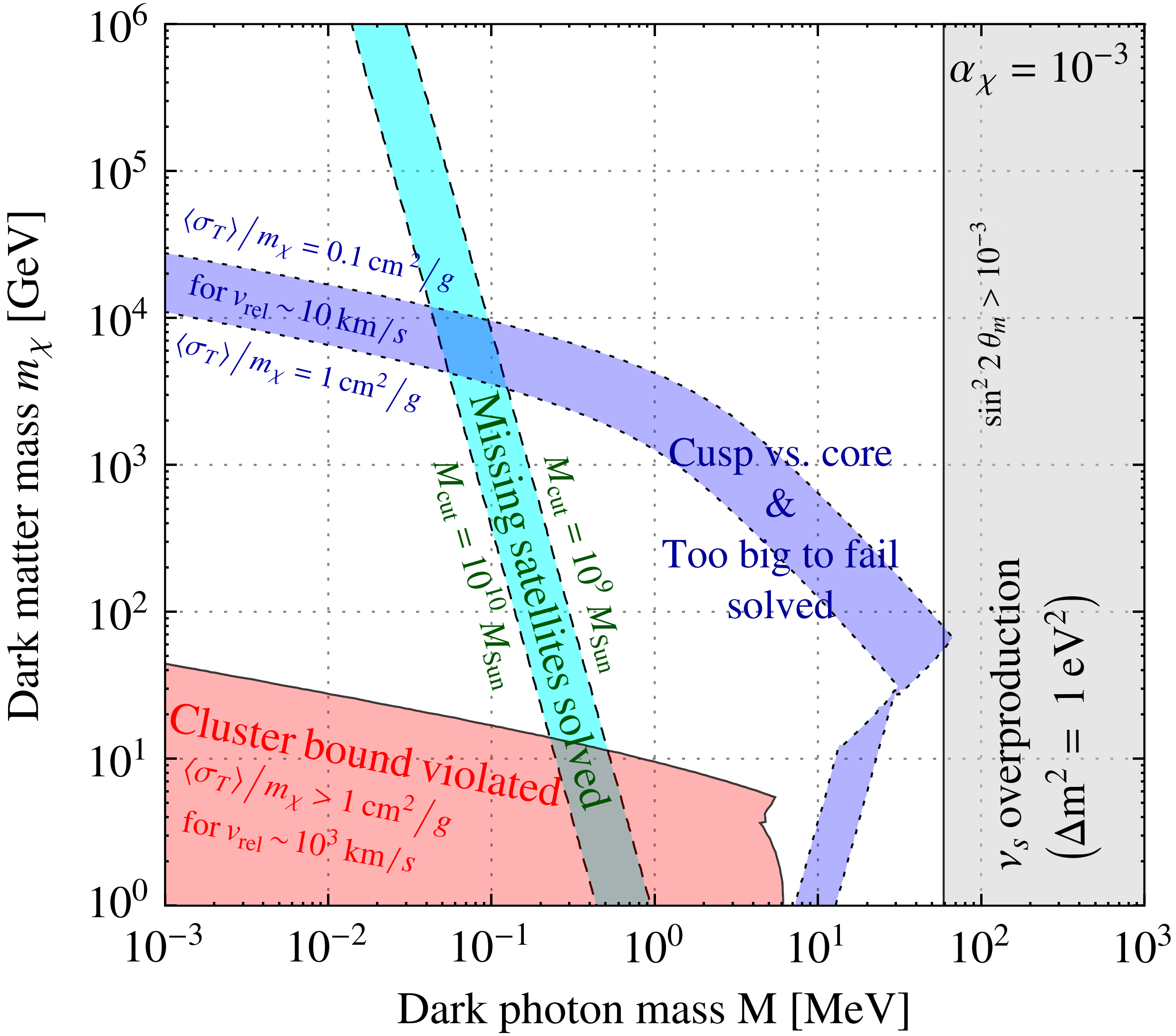
Dasgupta and Kopp (2014)

Same interaction rescues DM.

Dasgupta and Kopp (2014)

Also, Bringmann, Hasenkamp, Kersten (2014) and Ko, Tang (2014)

DM + Steriles



Dasgupta and Kopp (2014)

Getting Rid of Neutrinos

$$\mathcal{L}_{\rm dark} \ni \partial_\mu \phi^* \partial^\mu \phi + \mu_\phi^2 |\phi|^2 - \lambda_\phi |\phi|^4$$ **Complex Scalar**

$$+ i\bar{\chi}\gamma^\mu \partial_\mu \chi - M\bar{\chi}\chi - (\frac{f_{\rm d}}{\sqrt{2}}\phi\chi^T C\chi + h.c.)$$ **Fermion**

Weinberg (2013)

On spontaneous symmetry breaking

Garcia-Cely, Ibarra, Molinaro (2013)

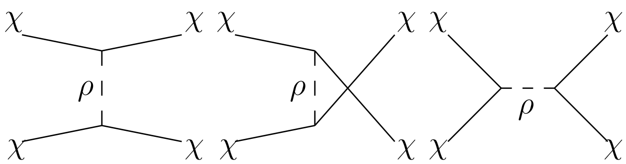
$$\phi \equiv (v_\phi + \rho + i\eta)/\sqrt{2}$$

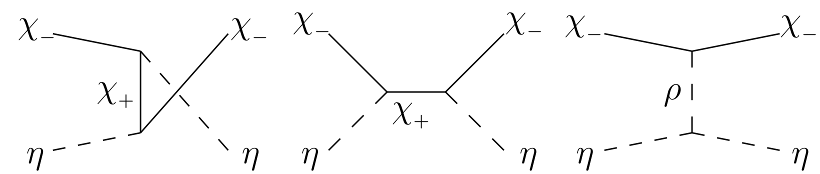
$$\chi_\pm \to -\chi_\pm \text{ and } (\rho, \eta) \to (\rho, \eta)$$

Residual Z2 symmetry ensures χ_- = DM is stable

Also η = DR

DM-DM and DM-DR Scattering





DM-DM Scattering

$$\sigma_T \simeq \frac{8\pi\alpha_{\rm d}^2}{m_\chi^2 v_{\rm rel}^4}\left[\log(1+R^2) - \frac{R^2}{1+R^2}\right]$$

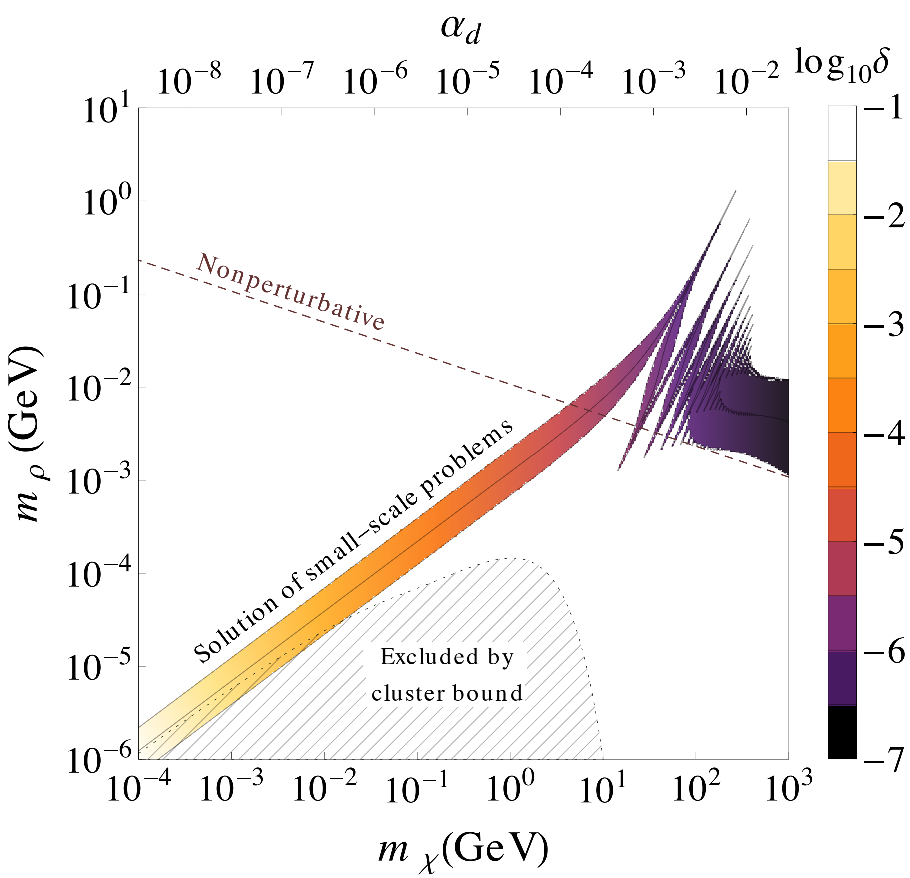
DM-DR Scattering

$$\sigma_{\eta\chi_-} = \frac{8\pi\alpha_{\rm d}^2\omega^4}{\Delta m_\chi^6}\left(1 + \frac{16\Delta m_\chi^2}{3m_\rho^2} + \frac{8\Delta m_\chi^4}{m_\rho^4}\right)$$

$$T_{\rm kd} \simeq 0.5\,{\rm keV}\frac{\delta}{10^{-4.5}}\left(\frac{m_\chi}{\rm GeV}\right)^{7/6}\left(\frac{10^{-4}}{\alpha_{\rm d}}\right)^{1/3}\xi_{\rm kd}^{-4/3}$$

Chu and Dasgupta (2014)

Impact on Small-scales



Relic Cross-section

$$\langle \sigma v \rangle \simeq \frac{\alpha_{\rm d}^2 \pi}{m_\chi^2}$$

Garcia-Cely, Ibarra, Molinaro (2013)

Chu and Dasgupta (2014)

Summary

Evidence for DM is overwhelming, but ...
... particle identity a mystery

Small-scale Structure may be providing us hints about what the leading non-gravitational DM interactions could be

One proposal is that DM self interacts and interacts with a radiation-like species

Uncertain and challenging, but we are on an exciting hunting expedition!

References:

Dasgupta and Kopp, arXiv:1310.6337, PRL (2014)
Chu and Dasgupta, arXiv:1404:6127, PRL (2014)