Self – interacting DM, why ?

- CDM simulations – very sucessful at explaining LSS but problem exist at galactic scales:
  - core versus cusps in galaxy DM distribution
  - missing satellite problem
  - …

- CDM candidates: WIMPs - collisionless particles (no 'viscosity'), weak-like interaction with standard particles, gravitational interaction only

- How to fix CDM problem at small scales?
  → MOND
  → Include baryonic feedback… works well and the most favored and studied solution
  → Have **self-interacting** DM (SIDM) – particles interacting with each other through gravity other 'strong interactions' (→ billiard balls collisions), but still interacting weakly with standard model particles

- There are particle physics models (hidden sector, mirror DM) that fullfils these conditions.

Self-interacting DM – methods and limits

- **Steady-state shape and sphericity of relaxed galaxy clusters:**

  If SIDM, halos (inner regions) should become spherical once most particle have interacted

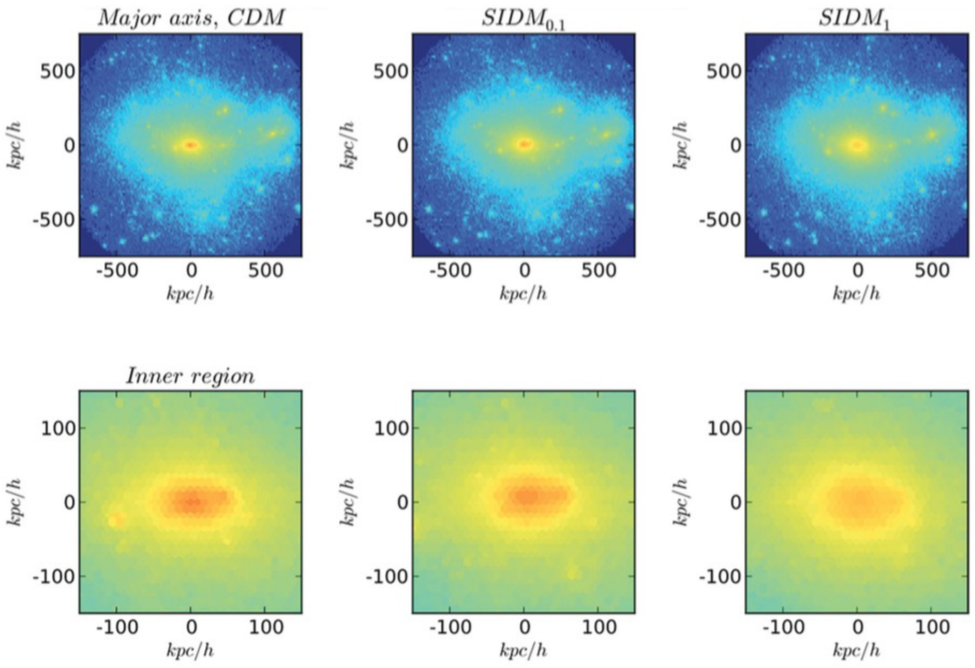
  → check galaxy cluster morphology through strong gravitational lensing

Miralda-Escudé (2002)

→ MS 2137-23 is elliptical down to small radii → $\boldsymbol{\sigma_X/m_X < 0.02}$ **cm²/g**

Peter et al. (2013)

→ Use set of cosmological simulations



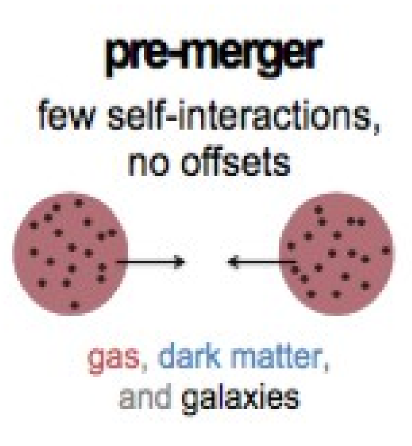
- Core ellipticity does not disappear with SIDM
  → Beware of projection effects! Surface densities affected by material well outside the core.
- Re-analyse MS 2137-23
  → $\sigma_X/m_X \sim 1$ cm²/g!
- Other clusters → $\boldsymbol{\sigma_X/m_X \sim 0.1}$ **cm²/g**

… and baryons/DM degeneracy
→ not the best approach

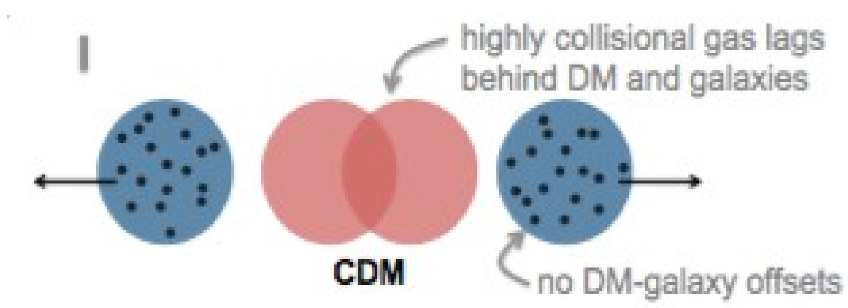
Self-interacting DM – methods and limits

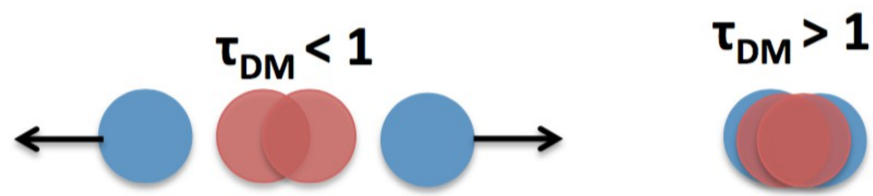
- **Colliding galaxy clusters – Gas-DM offset, single cluster**
  → limits based on the displacement between X-ray emitting gas and DM (WL)

From Kim et al. (2016)



After first pericenter passage

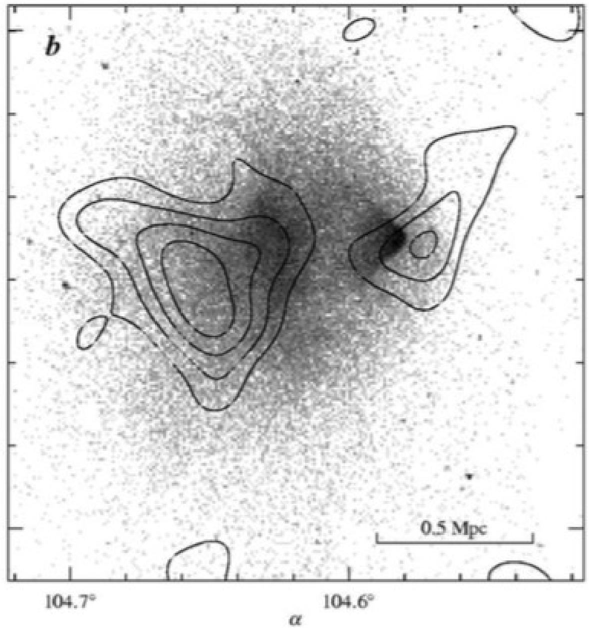




Self-interacting DM – methods and limits

- **Colliding galaxy clusters – Gas-DM offset, single cluster**
  → limits based on the displacement between X-ray emitting gas and DM (WL)

Markevitch et al. (2004)
→ 1E 0657-56 , aka Bullet cluster
- Gas-DM offset, $\boldsymbol{\sigma_x/m_x < 5\ \mathrm{cm^2/g}}$
- High velocity of the subcluster, $\boldsymbol{\sigma_x/m_x < 7\ \mathrm{cm^2/g}}$
- Survival of the DM subcluster, $\boldsymbol{\sigma_x/m_x < 1\ \mathrm{cm^2/g}}$



Bradac et al. (2008), Merten et al. (2011), Dawson et al. (2012) → other cluster mergers
$\boldsymbol{\sigma_x/m_x < 3 - 7\ \mathrm{cm^2/g}}$

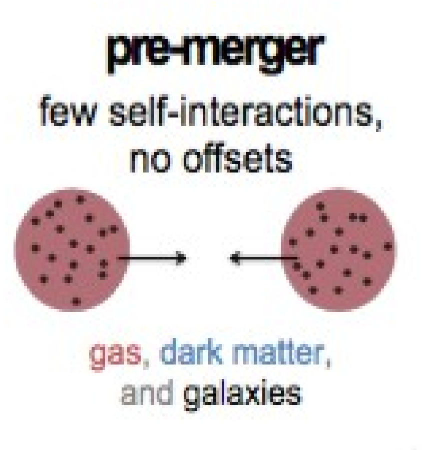
Randall et al. (2008)
→ simulation of the Bullet cluster, elastic collisions, isotropic scattering angle
$\boldsymbol{\sigma_{x,\,\mathrm{ISO}}/m_x < 0.7\ \mathrm{cm^2/g}}$

Results dependent of single cluster merger unknowns → stack...

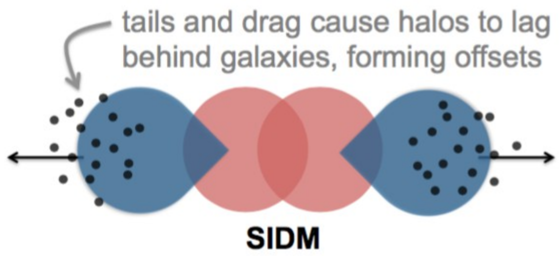
Self-interacting DM – methods and limits

- **Colliding galaxy clusters – Average DM-galaxy offset (Harvey et al. 2015)**
  → limits based on the relative displacement between X-ray emitting gas, DM (WL) and galaxies using 'large' sample of mergers

From Kim et al. (2016)



After first pericenter passage



Self-interacting DM – methods and limits

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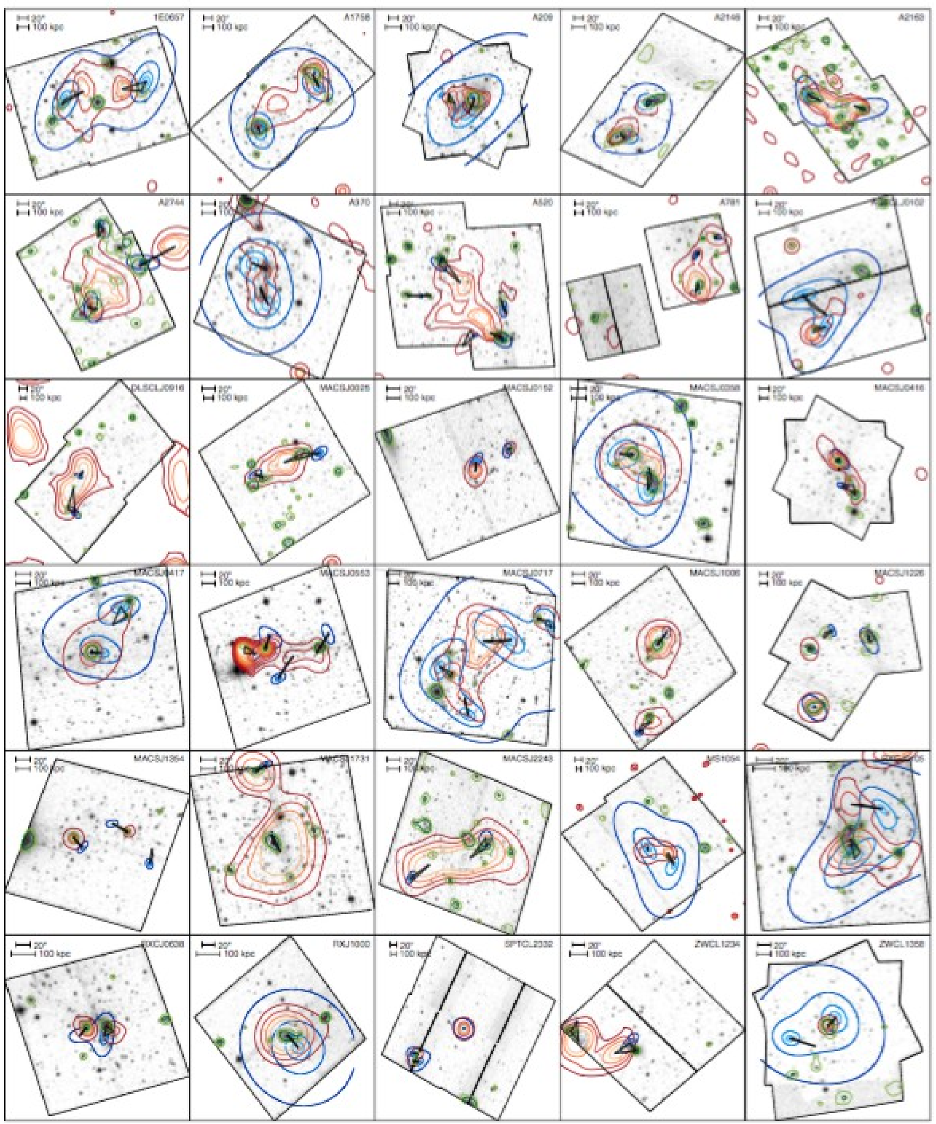
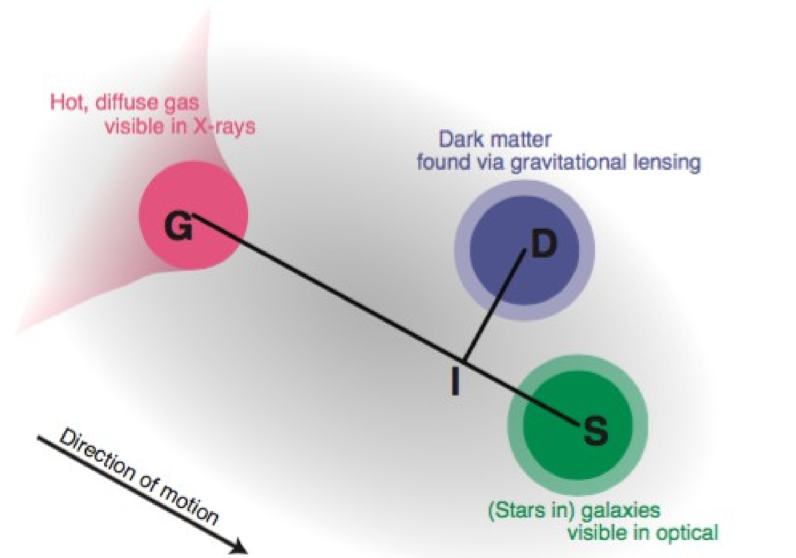


Harvey et al. (2015) – 30 merger systems



$$\beta \equiv \frac{\delta_{\rm SI}}{\delta_{\rm SG}} = B\left(1 - e^{\left(\frac{-(\sigma_{\rm DM} - \sigma_{\rm gal})}{\sigma^{\star}/m}\right)}\right)$$

If no SIDM, no extra drag and β=0

Self-interacting DM – methods and limits

- **Colliding galaxy clusters – Average DM-galaxy offset (Harvey et al. 2015)**
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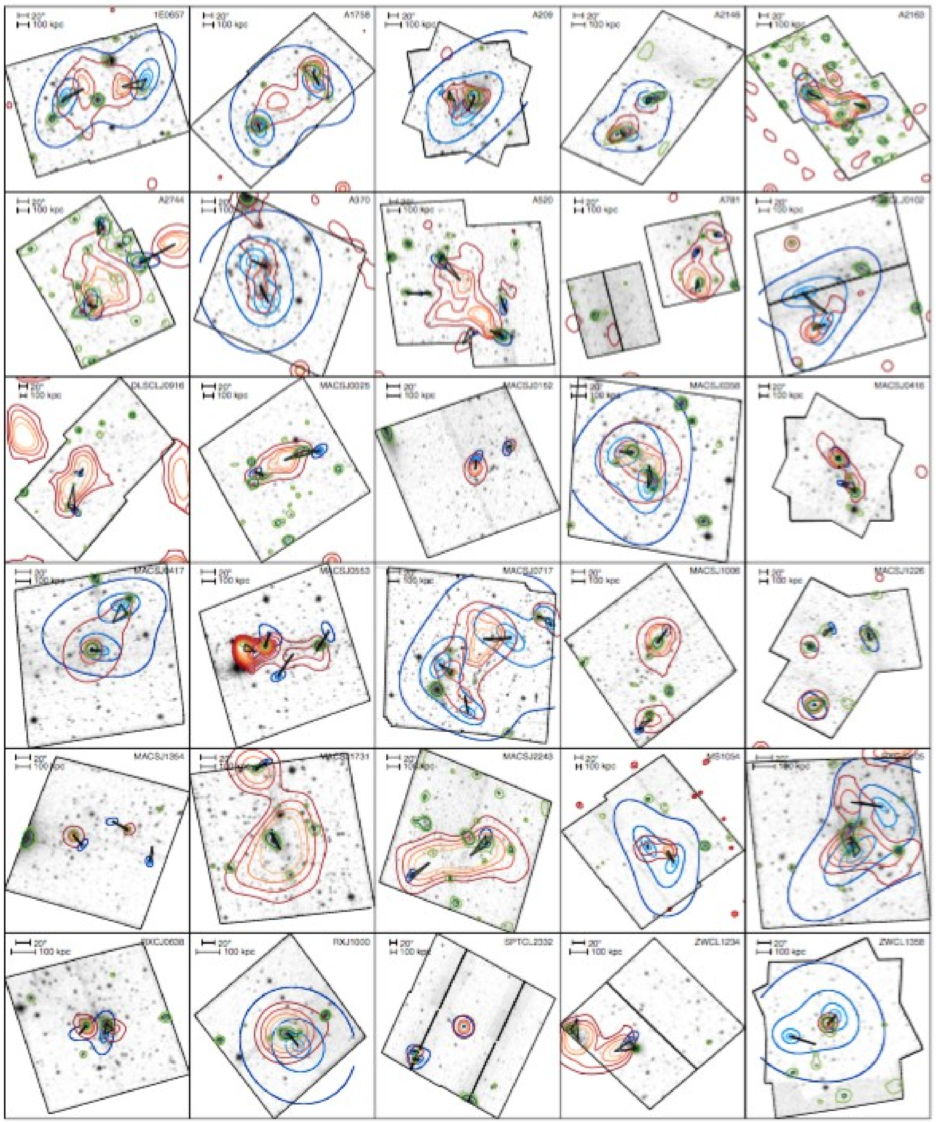
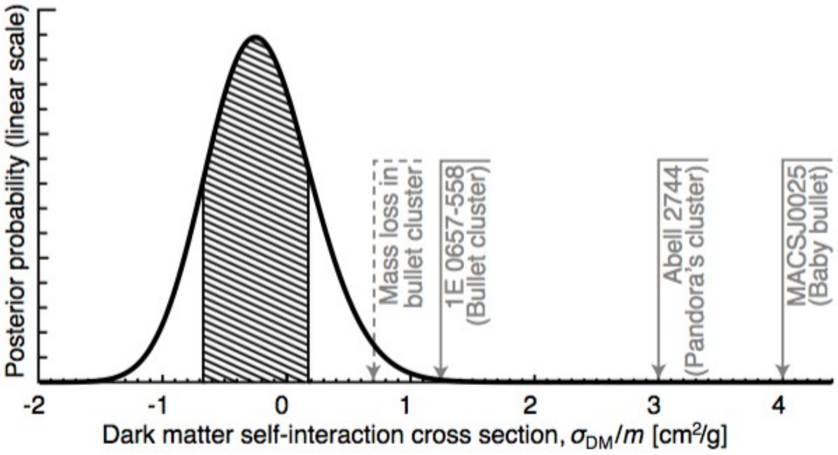


Harvey et al. (2015) – 30 merger systems

Average β over 72 substructures
→ <β>= -0.04 +/- 0.07 (68%CL)

→ σ_x/m_x < 0.47 cm²/g (95%CL)



Rules out hidden sector DM models that predict σ_x/m_x ~ 0.6 cm²/g

Self-interacting DM – methods and limits

Looking for dark matter trails in colliding galaxy clusters

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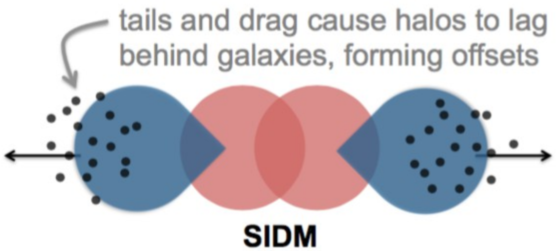

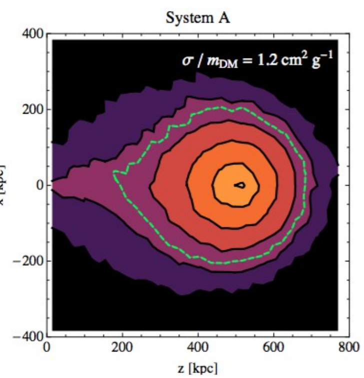

Kahlhoefer et al. (2014)

ABSTRACT

If dark matter interacts, even weakly, via non-gravitational forces, simulations predict that it will be preferentially scattered towards the trailing edge of the halo during collisions between galaxy clusters. This will temporarily create a non-symmetric mass profile, with a trailing over-density along the direction of motion. To test this hypothesis, we fit (and subtract) symmetric halos to the weak gravitational data of 72 merging galaxy clusters observed with the *Hubble Space Telescope*. We convert the shear directly into excess κ and project in to a one dimensional profile. We generate numerical simulations and find that the one dimensional profile is well described with simple Gaussian approximations. We detect the weak lensing signal of trailing gas at a 4σ confidence, finding a mean gas fraction of $M_{\rm gas}/M_{\rm dm} = 0.13 \pm 0.035$. We find no evidence for scattered dark matter particles with a estimated scattering fraction of $f = 0.03 \pm 0.05$. Finally we find that if we can reduce the statistical error on the positional estimate of a single dark matter halo to $< 2.5''$, then we will be able to detect a scattering fraction of 10% at the 3σ level with current surveys. This potentially interesting new method can provide an important independent test for other complimentary studies of the self-interaction cross-section of dark matter.

Key words: cosmology: dark matter — galaxies: clusters — gravitational lensing