Credit: X-ray: NASA/CXC/UVic./A.Mahdavi et al.
Optical/Lensing: CFHT/UVic./A.Mahdavi et al

Measuring the cross-section of dark matter in galaxy clusters

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Richard Massey, Durham University
Andy Taylor, University of Edinburgh
Eric Tittley, University of Edinburgh
Tom Kitching, UCL (MSSL)

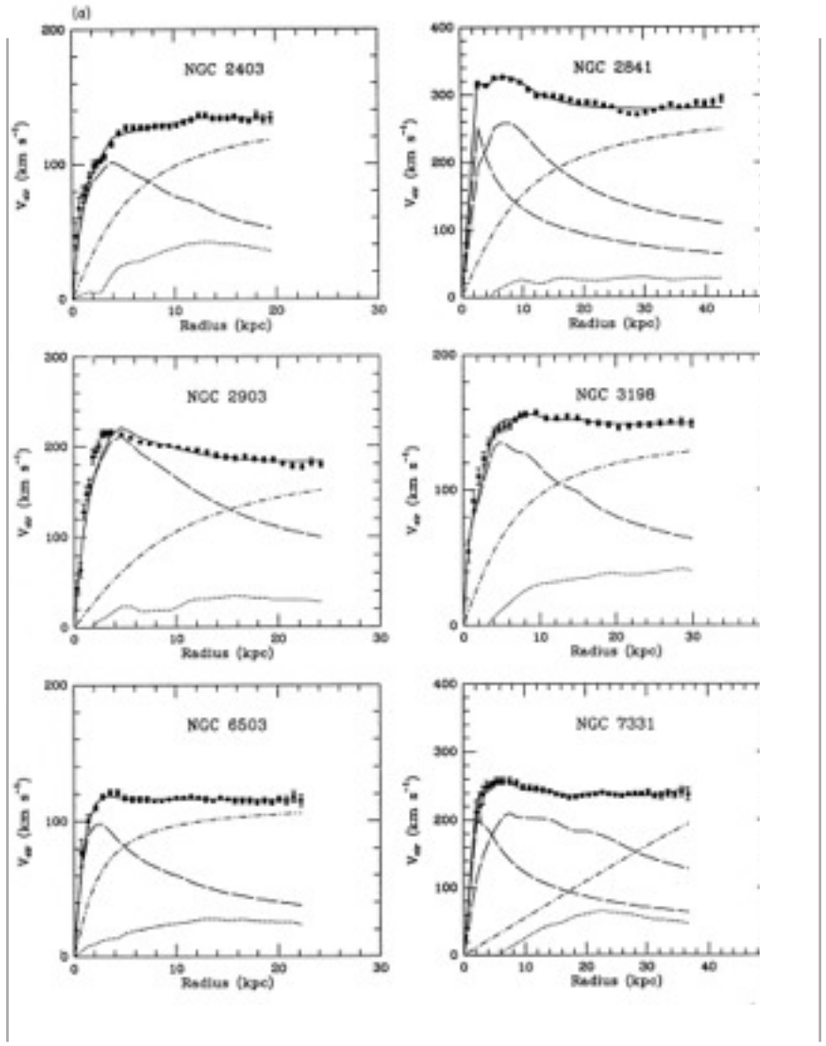
Overview

- Dark Matter and the accumulating evidence
- The Self Interacting Dark Matter Paradigm
- Extending the bullet cluster
- Potential Constraints from Hubble Archive
- Data Science in Astronomy

The evidence

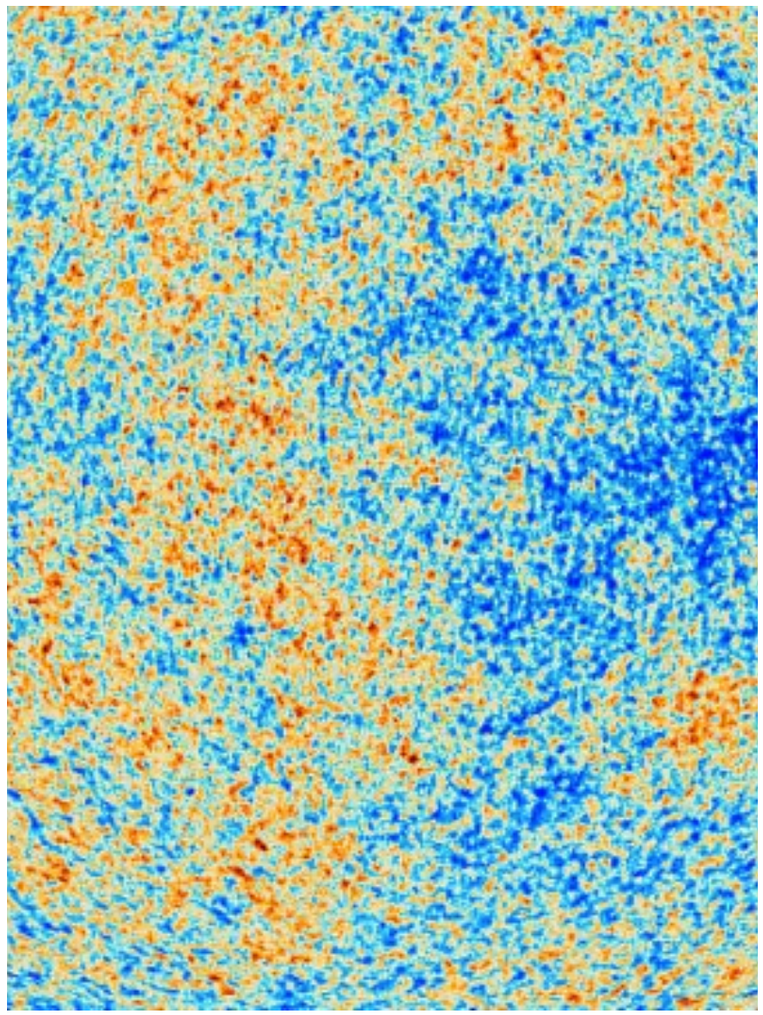
Galaxy Clusters

Nasa, Stsci, Jullo, Natarajan, Kneib



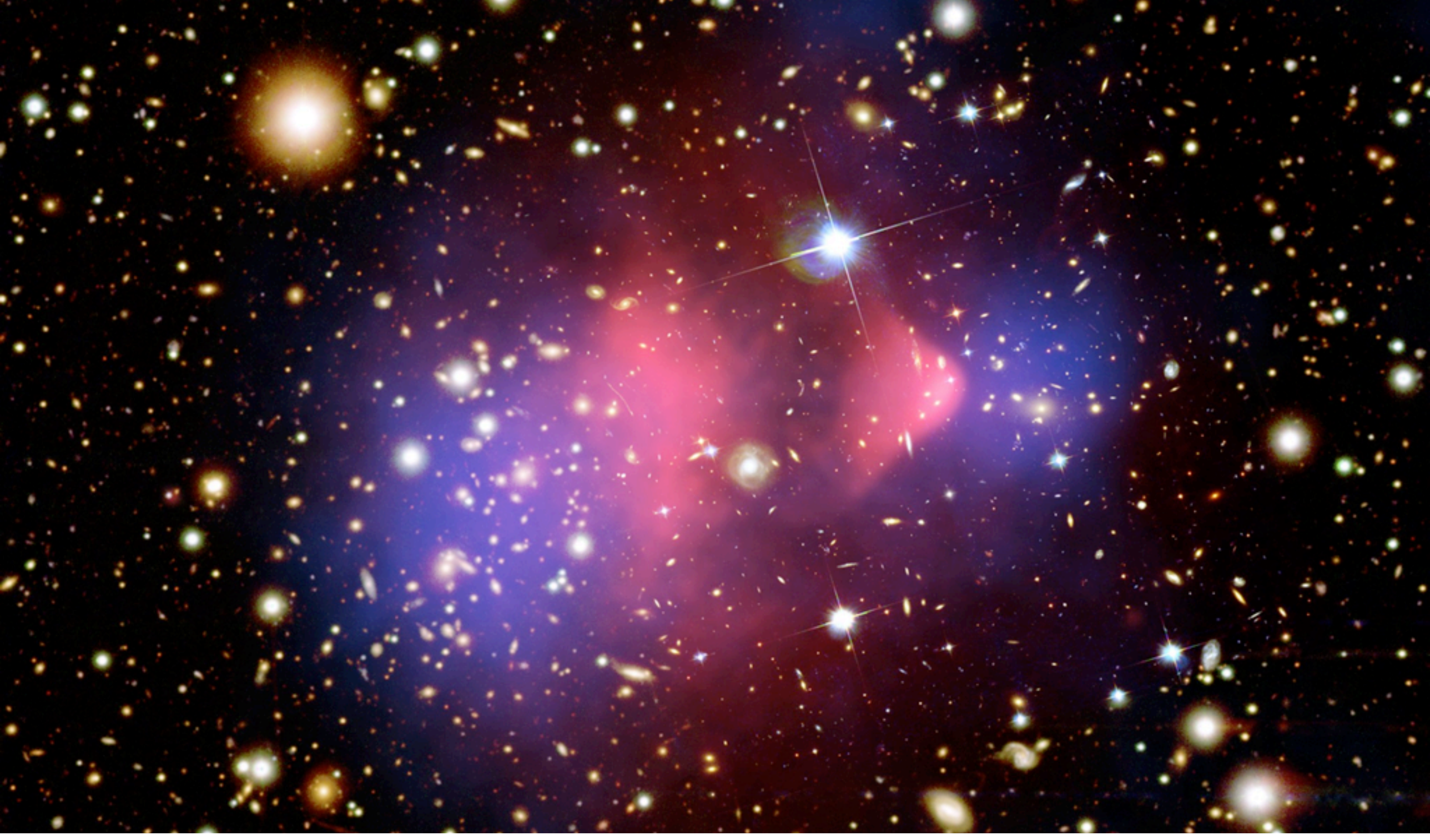
Rotation curves

Begeman, Broeils & Sanders, 1991



CMB

Planck Collaboration

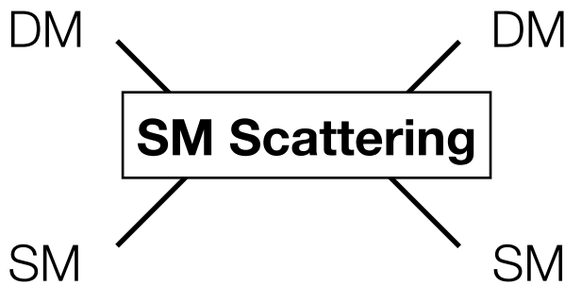


The Bullet Cluster

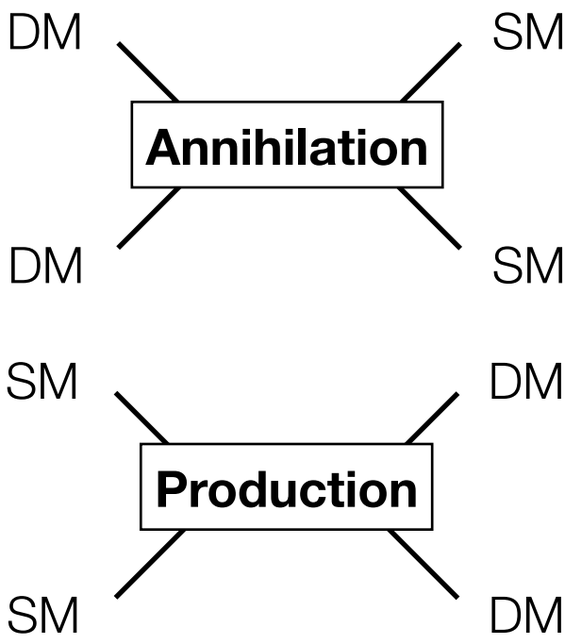
Clowe et. al., 2006

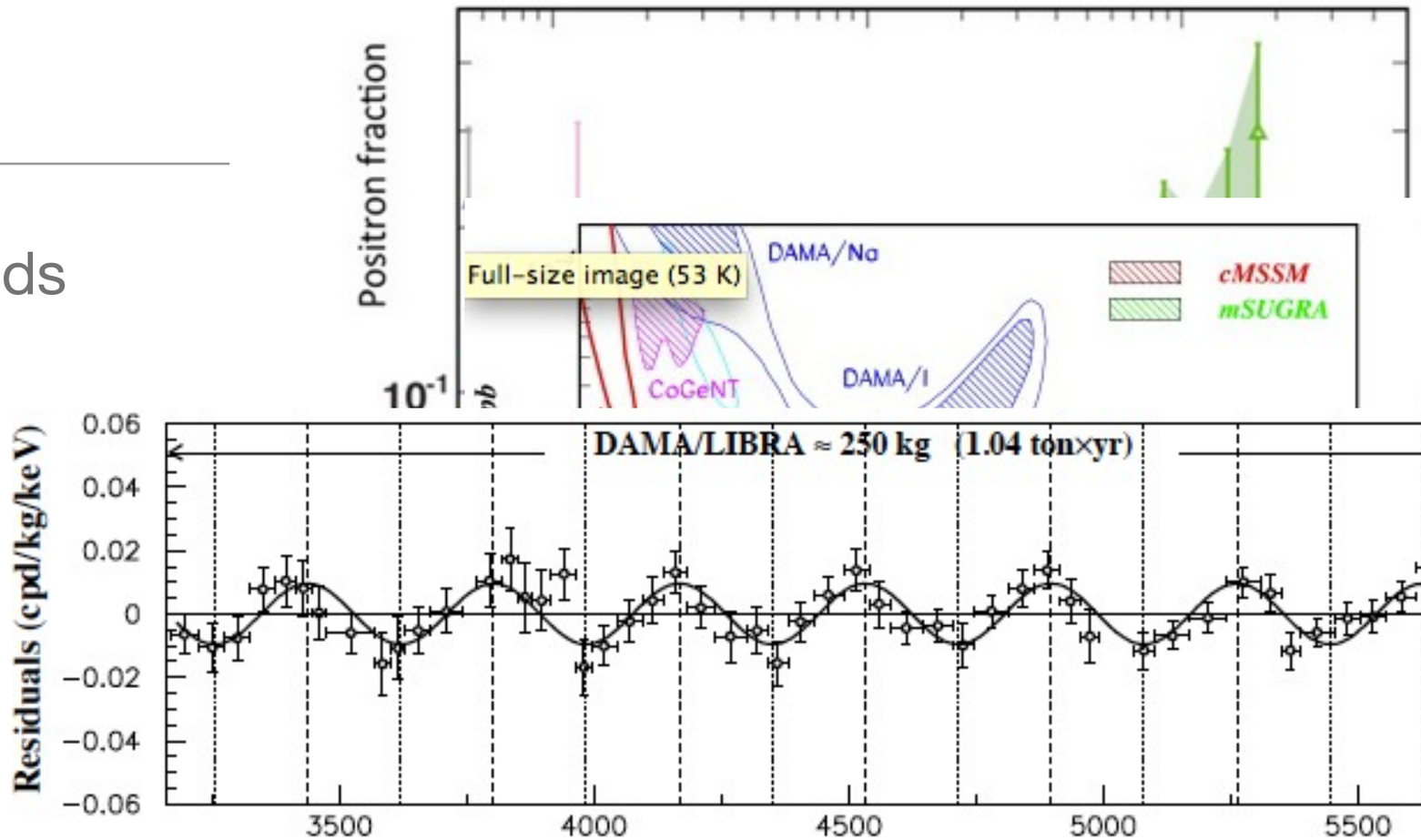
Detection

- Direct detection methods

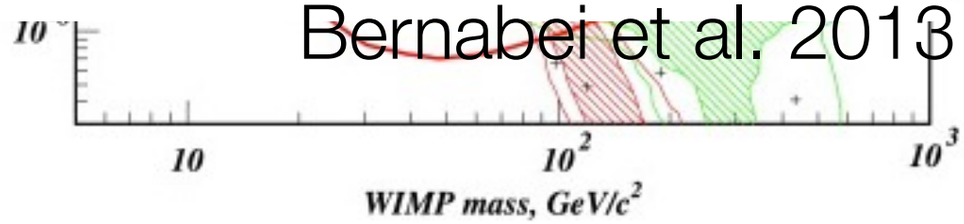


- Indirect detection





Bernabei et al. 2013



HEAT: J. J

M. A. DuV

AMS-01: M

PAMELA: P. Picozza, Proc. of the 4th International Conference on Particle and Fundament Physics

Yu et. al. 2012

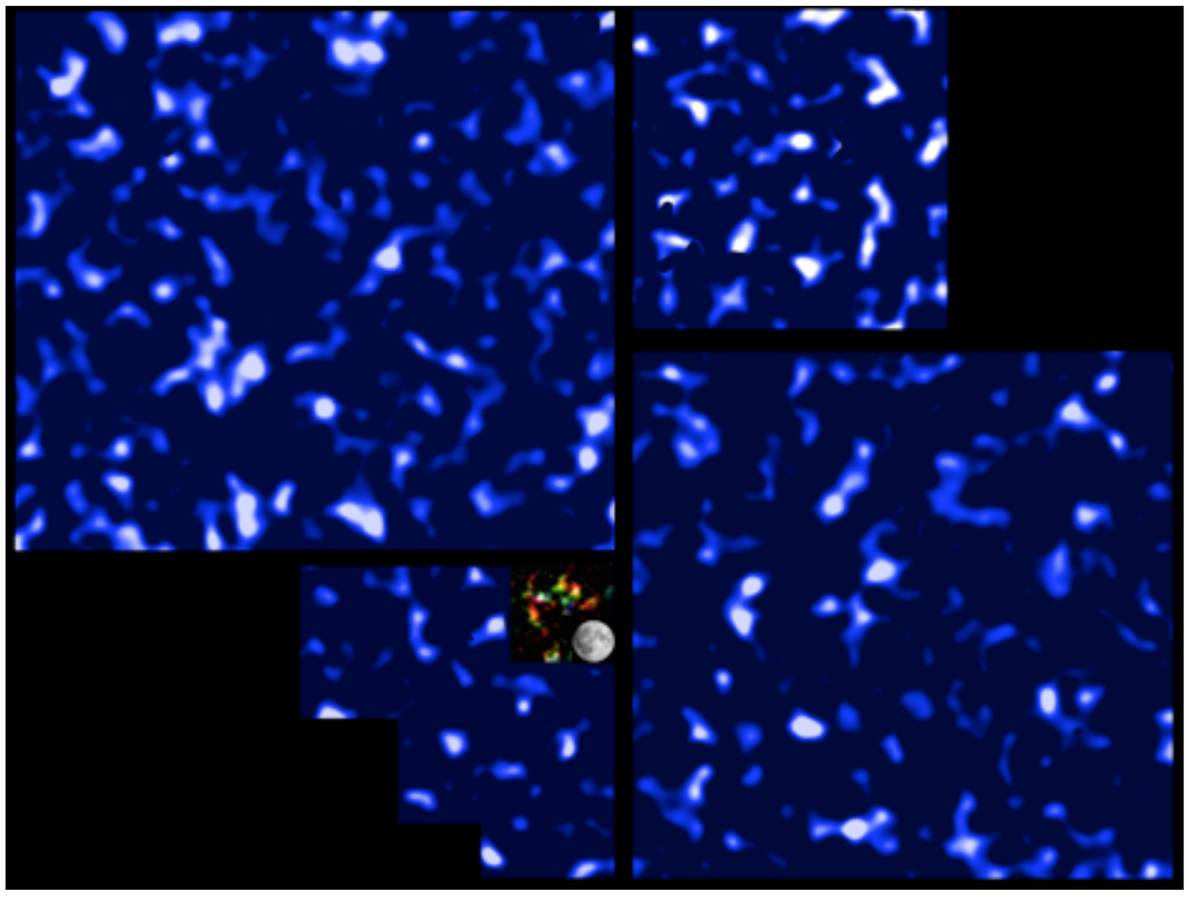
O. Adriani et al.,Astropart. Phys. 34 (2010) 1;

O. Adriani et al.,Nature 458 (2009) 607.

Fermi-LAT: M. Ackermann et al., Phys. Rev. Lett. 108 (2012) 011103.

What is dark matter?

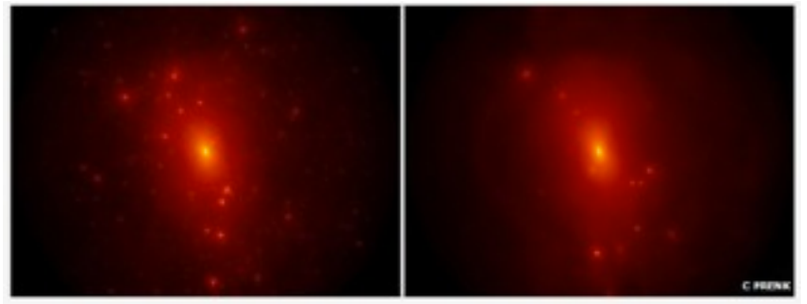
- Weakly Interacting Massive Particles?
- Modified Gravity?
- Standard model?
- New physics?
- Collisionless?



Cosmos credit: NASA, ESA, P. Simon and T. Schrabback
CHFT Credit: Van Waerbeke, Heymans, and CFHTLens collaboration.

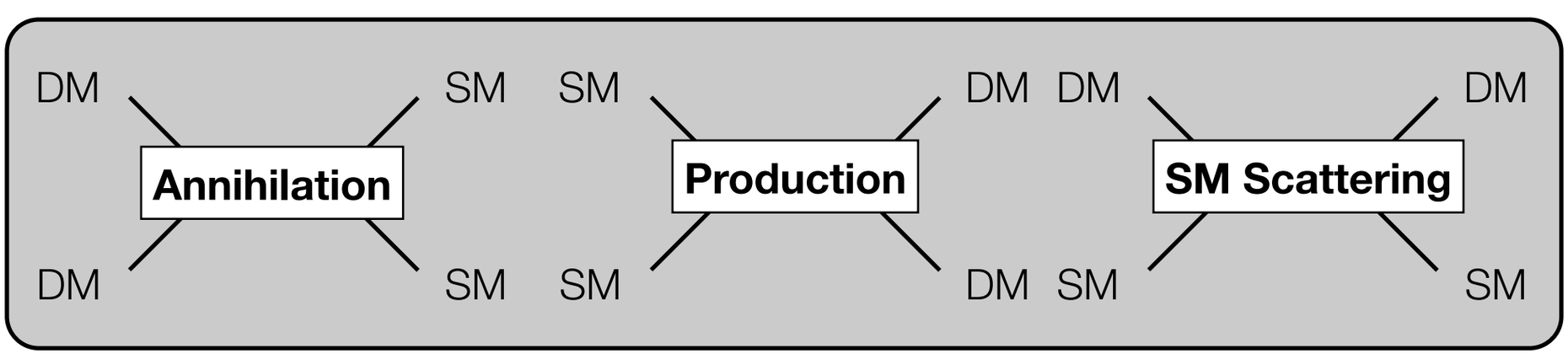
The self interacting dark matter paradigm

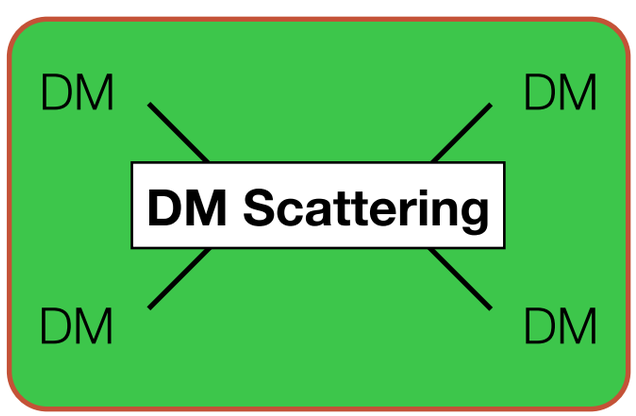
- What is it?
- What it will mean?
- What could it solve?



C. Frenk

- Can we compete with the particle physicists?





Markevitch et. al., 2006

$$\frac{\sigma}{m} < 1\,\mathrm{cm}^2\,\mathrm{g}^{-1}.$$

Bradac et. al., 2008

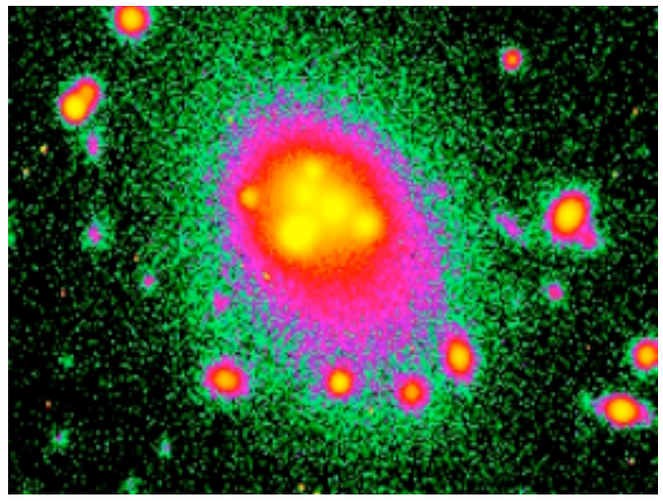
$$\sigma/m < 4\mathrm{cm}^2\mathrm{g}^{-1}$$

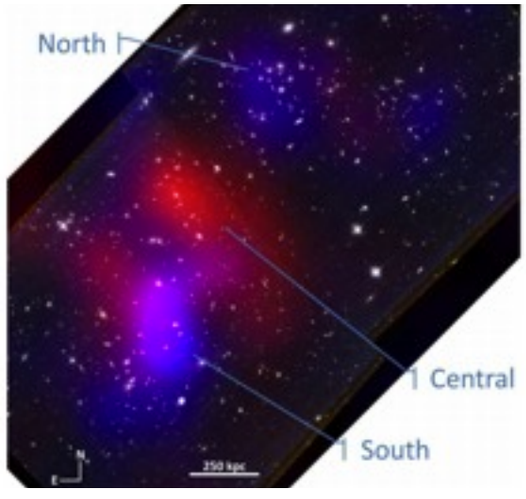
William & Saha, 2011

$$\sigma/m \gtrsim 4.5\ 10^{-7}\left(\frac{t}{10^{10}\mathrm{yr}}\right)^{-2}\mathrm{cm}^2\,\mathrm{gm}^{-1}.$$

Dawson et. al., 2012

$$\sigma_{\mathrm{DM}} m_{\mathrm{DM}}^{-1} \lesssim 7\,\mathrm{cm}^2\,\mathrm{g}^{-1}$$





How is the cross-section parameterised?

1. $$\chi\tau_{\rm m} = \frac{\sigma}{m}\Sigma_{\rm m}\left[1-2\left(\frac{v'_{\rm esc}}{v_0}\right)^2\right]$$

Markevitch et. al., 2006

Fraction of particles lost in collision

Probability of particles colliding

Probability of losing a particle

2. Scattering Depth $$\tau_{\rm s} = \frac{\sigma}{m}\Sigma_{\rm s}$$

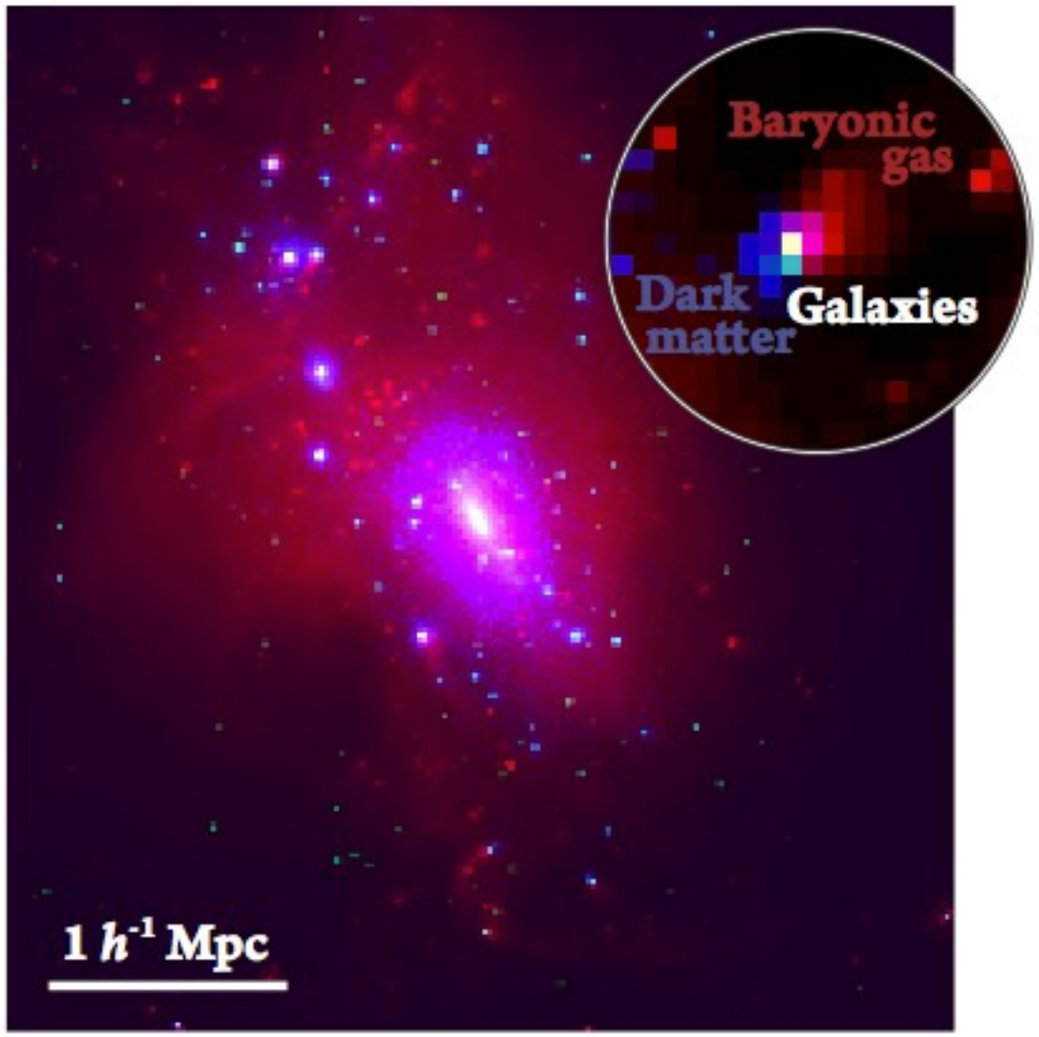
Markevitch et. al., 2006

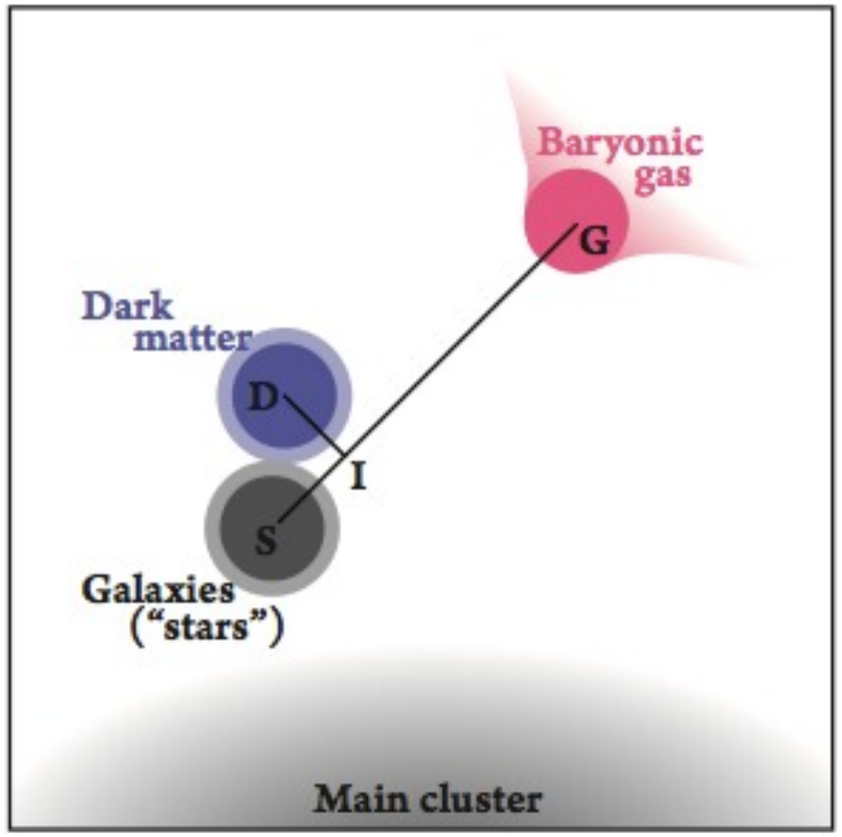
3. $$F_{dm} \sim \frac{GM_{co}M_{dm}}{r^2} \times \left[1 - \frac{M_{dm}\,\sigma/m}{\pi s^2}\right]$$

William & Saha, 2011

Force due to the cluster

Dimensionless covering factor

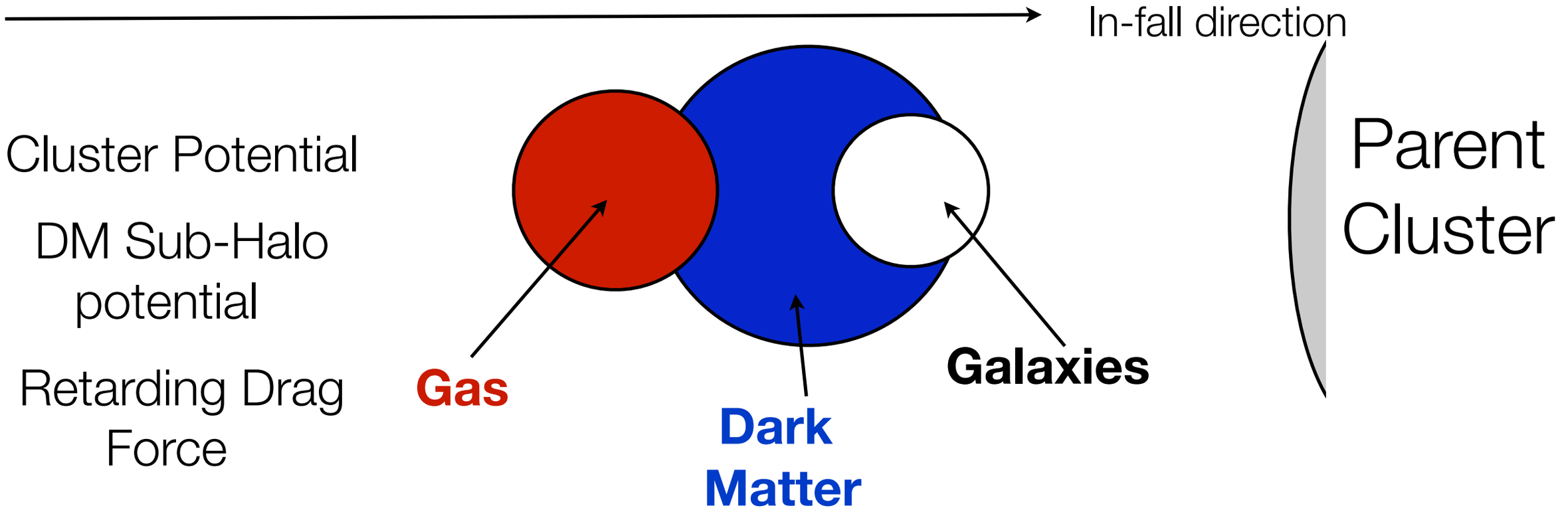




Accreting substructure

A new framework

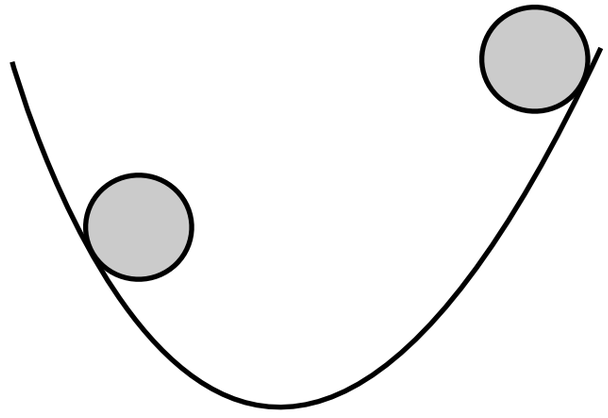
- Cluster Potential
- DM Sub-Halo potential
- Retarding Drag Force



Harvey et al 2013b (in prep.)

The DM Sub Halo Potential

- The dark matter sub-halo potential is dominant



- Extended Objects

- Three regimes
  1. Linear Regime
  2. Turn over
  3. Halo Separation

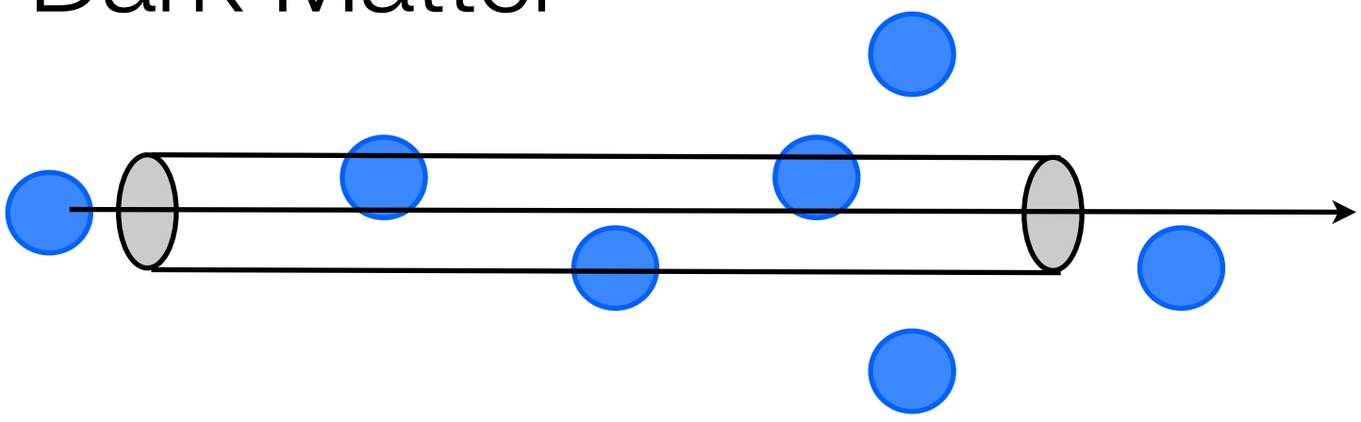
Gas & Dark Matter Drag

Gas

- Drag Equation

$$\mathbf{D}_{\mathrm{G}} = -\frac{1}{2} C_{\mathrm{G}} A_{\mathrm{G}} \rho_{\mathrm{G}}^{\mathrm{ICM}} v_{\mathrm{G}} \mathbf{v}_{\mathrm{G}}$$

Dark Matter



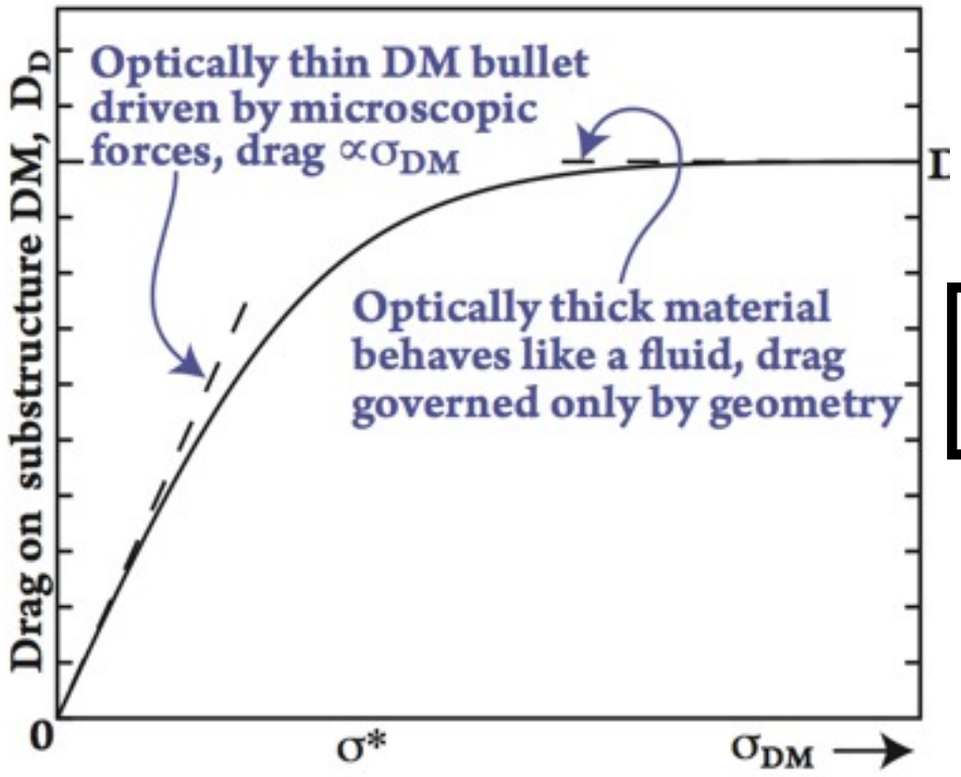
$$\mathbf{D}_{\mathrm{D}} \approx -\frac{1}{4} \frac{\sigma}{m} \rho_{\mathrm{D}} M_{\mathrm{D}} v_{\mathrm{D}} \mathbf{v}_{\mathrm{D}}$$

Assumptions

- Low cross-section
- Indistinguishable DM particles
- Instantaneous, elastic collisions

Dark Matter Drag

$$\mathbf{D}_{\mathrm{D}} \approx -\frac{1}{4}\frac{\sigma}{m}\rho_{\mathrm{D}} M_{\mathrm{D}} v_{\mathrm{D}} \mathbf{v}_{\mathrm{D}}$$



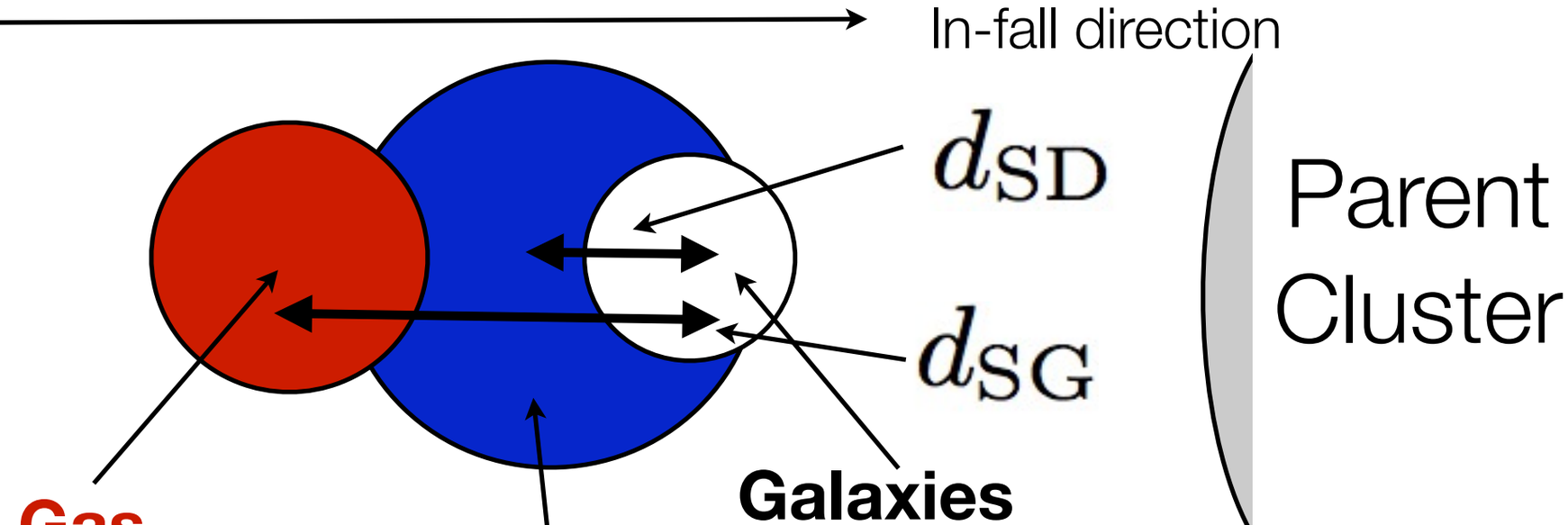
$$\mathbf{D}_{\mathrm{G}} = -\frac{1}{2} C_{\mathrm{G}} A_{\mathrm{G}} \rho_{\mathrm{G}}^{\mathrm{ICM}} v_{\mathrm{G}} \mathbf{v}_{\mathrm{G}}$$

$$\mathbf{D}_{\mathrm{D}} = -\frac{1}{2} C_{\mathrm{D}} A_{\mathrm{D}} \rho_{\mathrm{D}}^{\mathrm{ICM}} \left(1 - \mathrm{e}^{-\sigma_{\mathrm{DM}}/\sigma^{\star}}\right) v_{\mathrm{D}} \mathbf{v}_{\mathrm{D}}$$

$$\frac{\sigma_{\mathrm{DM}}}{\sigma^{\star}} = \frac{\sigma_{\mathrm{DM}} M_{\mathrm{D}}}{2 C_{\mathrm{D}} A_{\mathrm{D}} m}$$

Our analytical model of in-fall

- Cluster Potential
- DM Sub-Halo potential
- Retarding Drag Force



$$\beta \equiv \frac{d_{\rm SD}}{d_{\rm SG}} = 1 - {\rm e}^{-\sigma_{\rm DM}/\sigma^\star}$$

$$\boxed{\frac{\sigma_{\rm DM}}{\sigma^\star} = \frac{\sigma_{\rm DM} M_{\rm D}}{2\, C_{\rm D} A_{\rm D} m}}$$

Harvey et al 2013b (in prep.)

Testing on noise free simulations

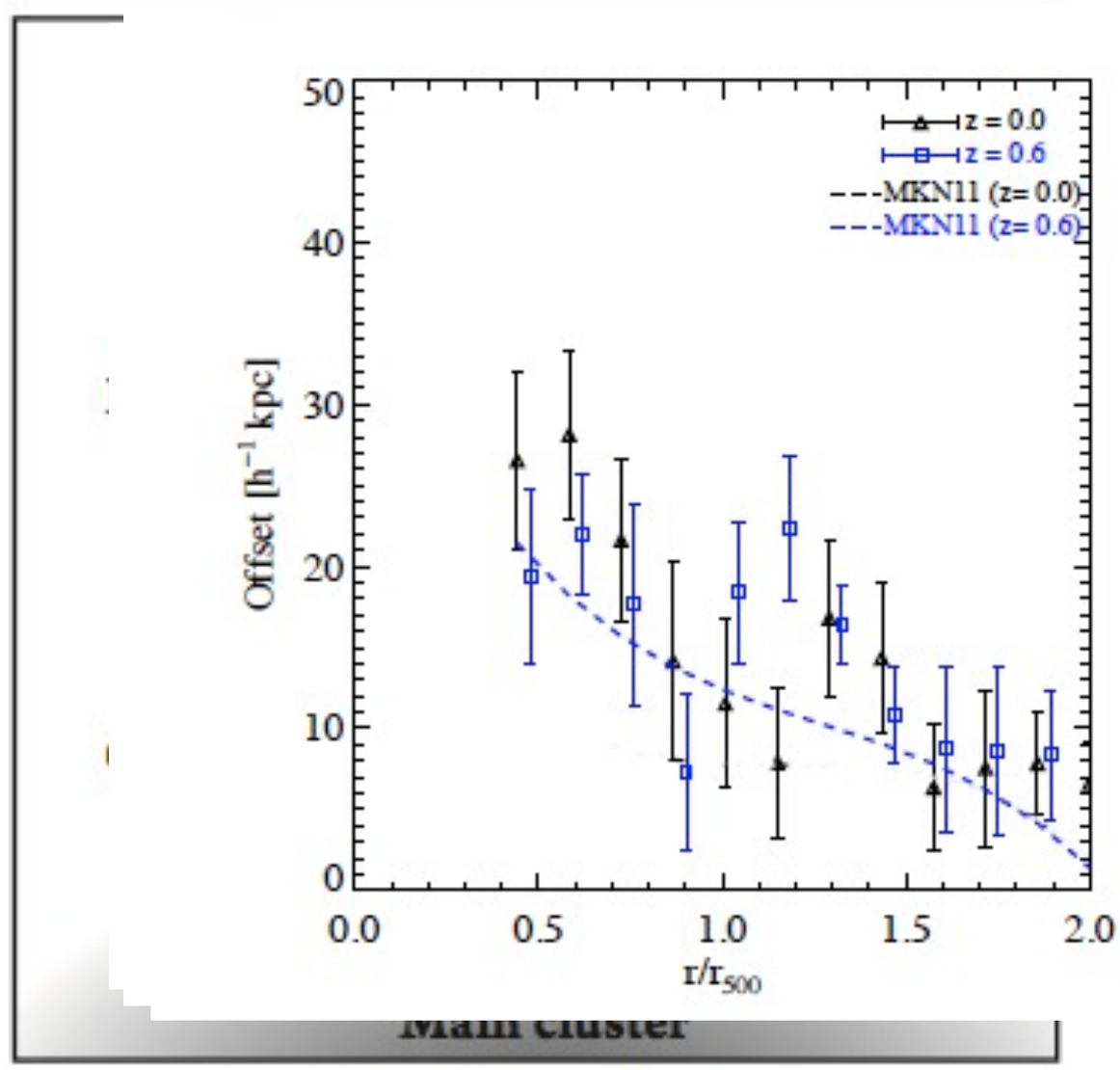
$$\beta \equiv \frac{d_{\mathrm{SD}}}{d_{\mathrm{SG}}}$$

Observables:

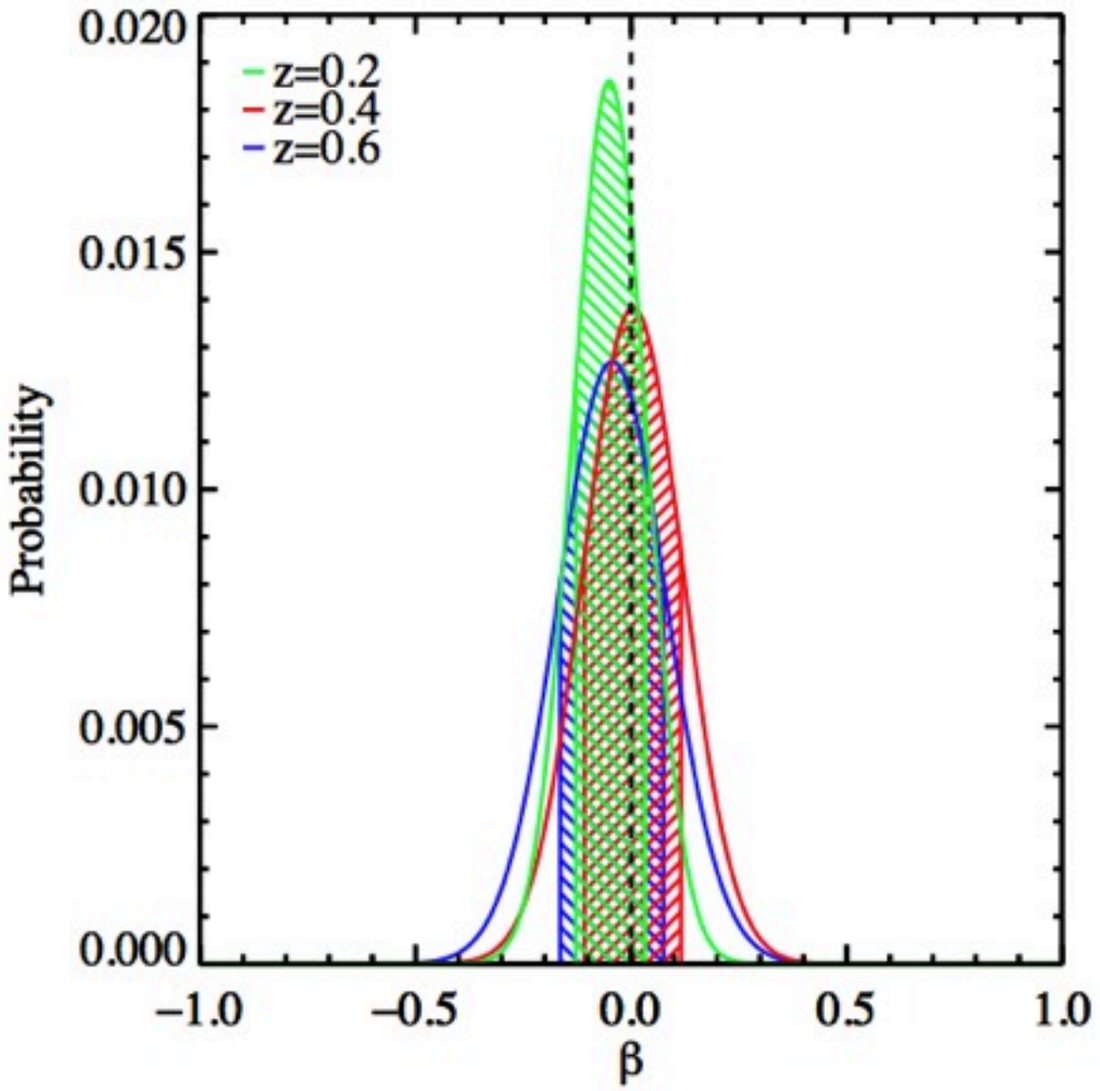
★d_SG

★d_SI

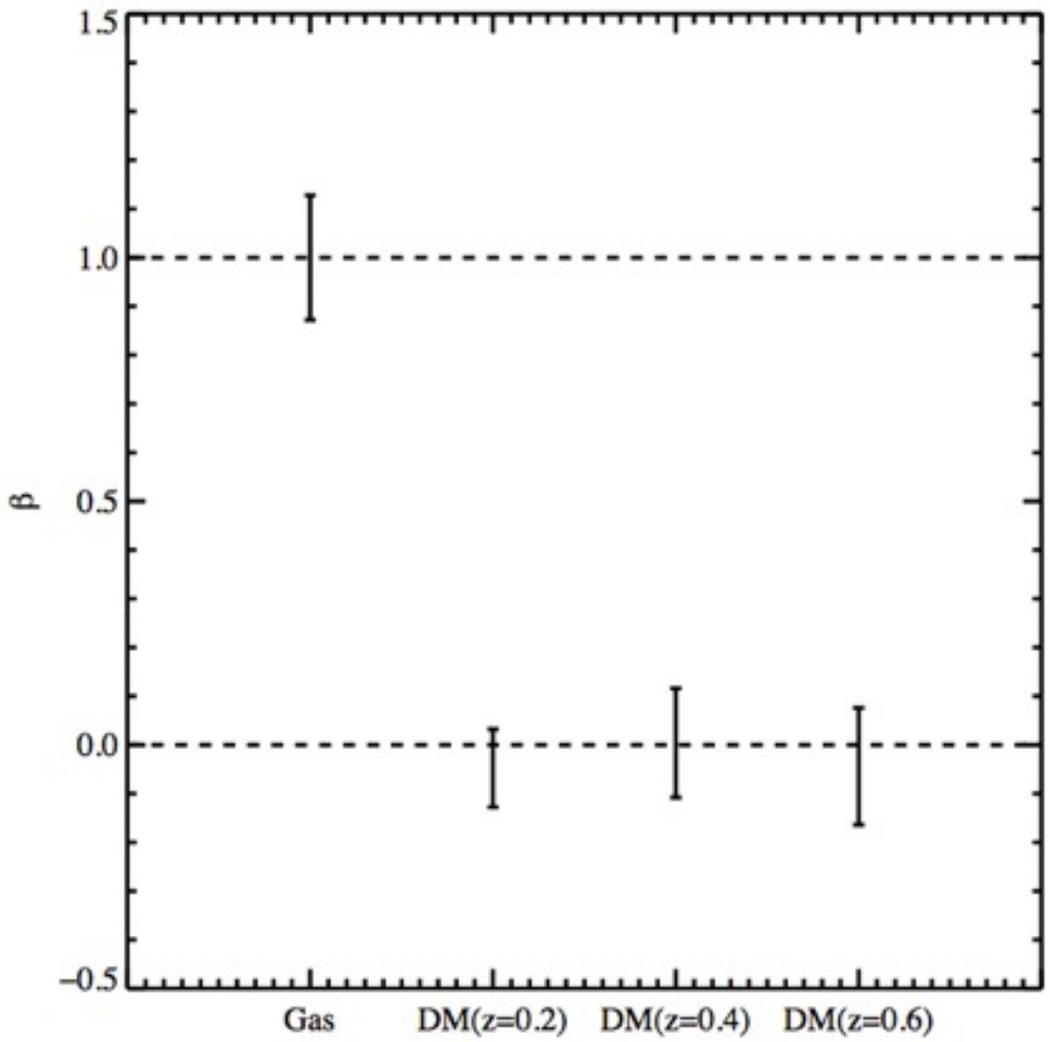
★d_DI



Harvey et al 2013b (in prep.)



$$\beta \equiv \frac{d_{\rm SD}}{d_{\rm SG}}$$

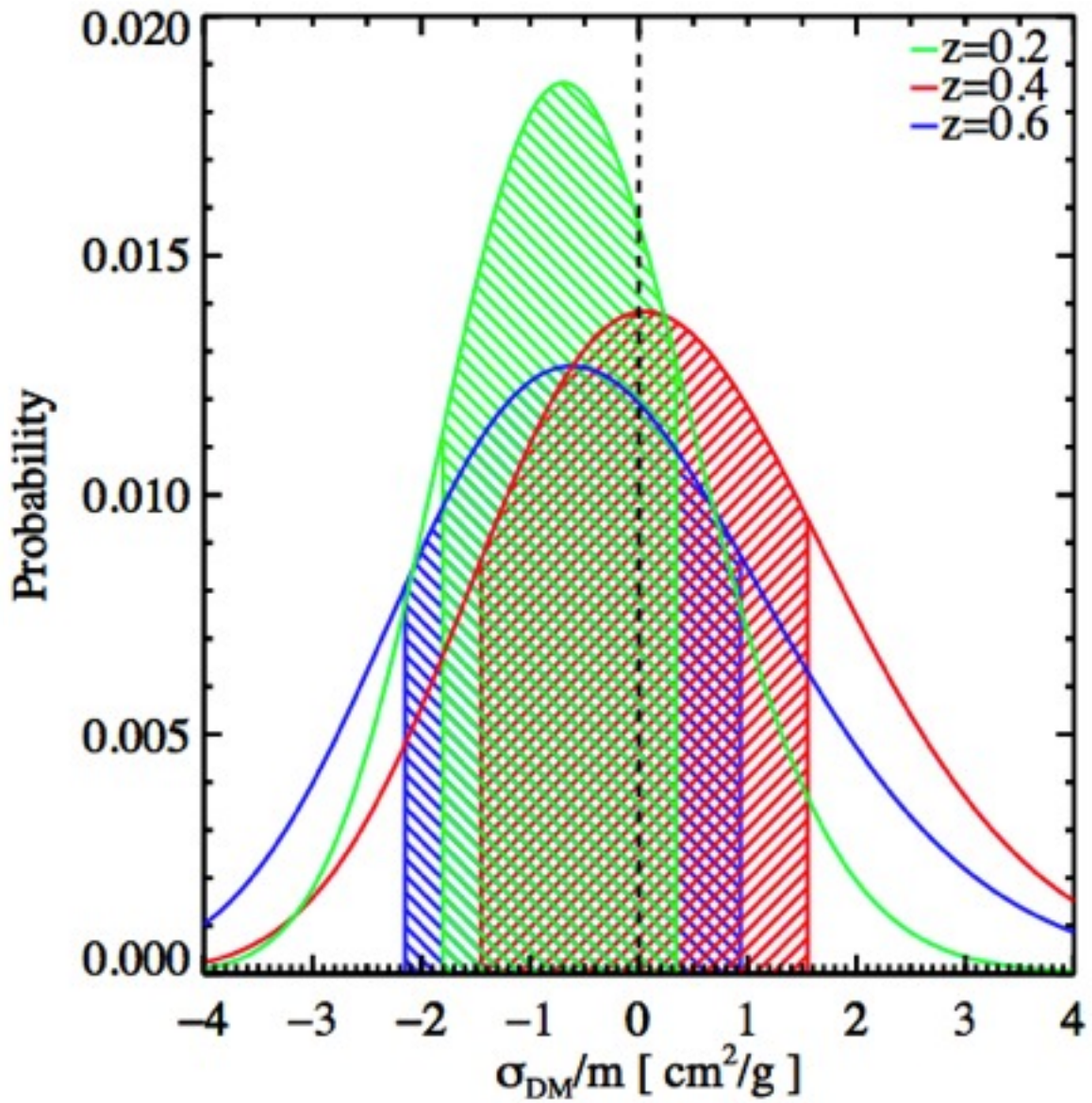


Harvey et al 2013b (in prep.)

Predicted constraints

Predicted constraints

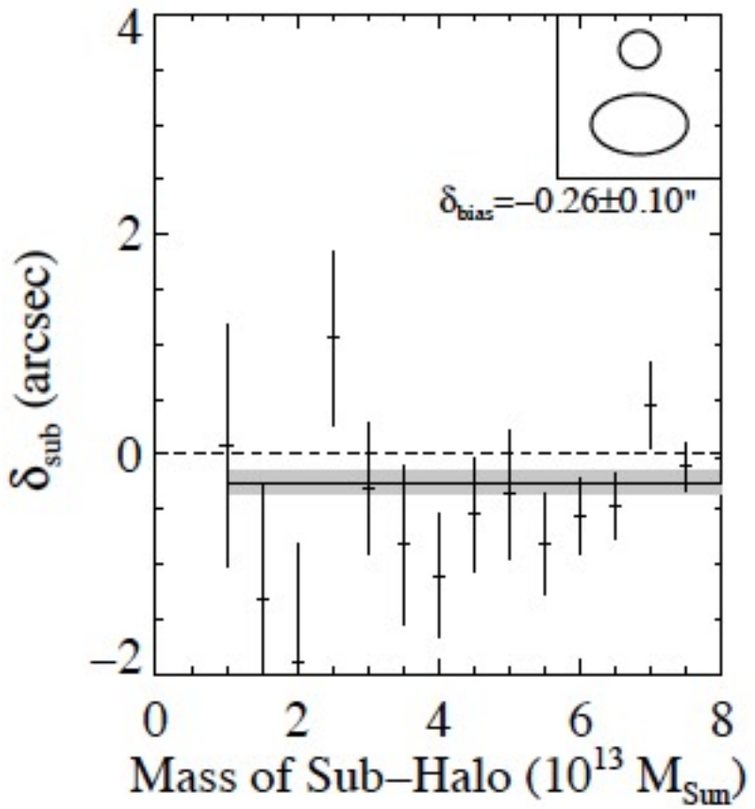
$$\beta \equiv \frac{d_{\rm SD}}{d_{\rm SG}} = 1 - {\rm e}^{-\sigma_{\rm DM}/\sigma^\star}$$



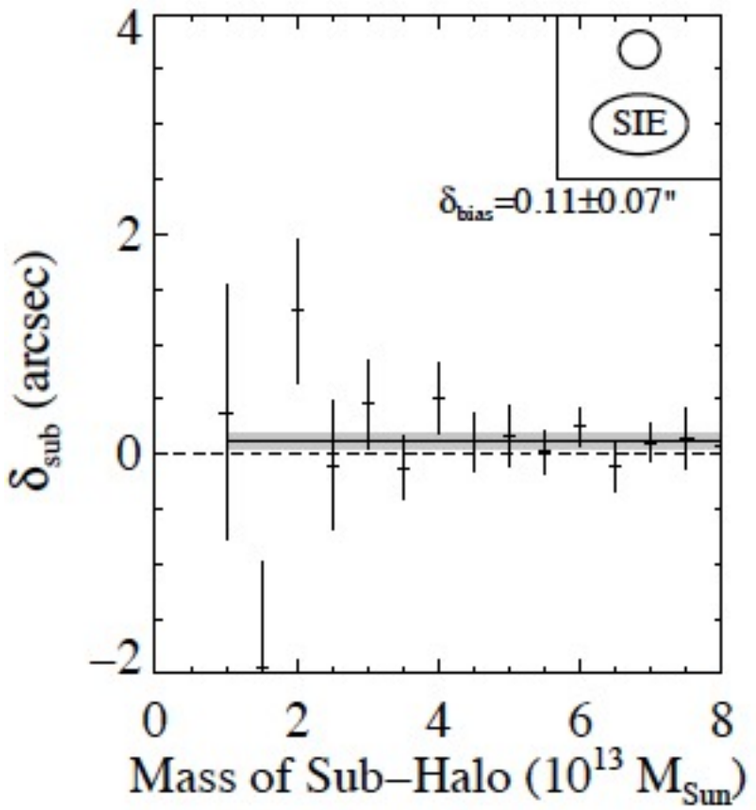
Harvey et al 2013b (in prep.)

Accuracy of sub-halos in galaxy clusters

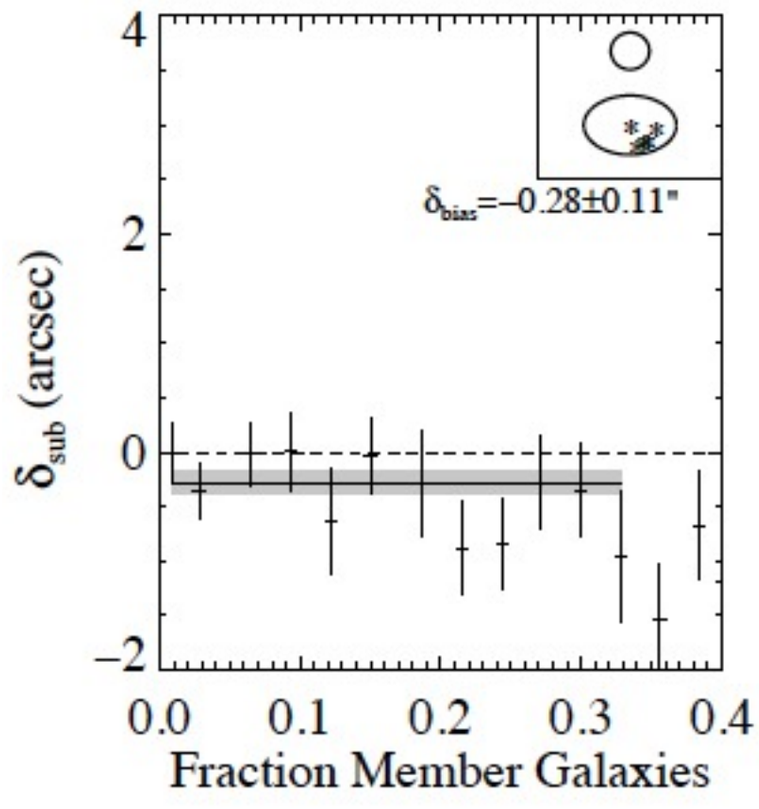
- Statistical efforts : testing for lensing systematics in controlled environments



Shape measurment bias
Different source redshift



Mis-identification of the dark matter halo profile

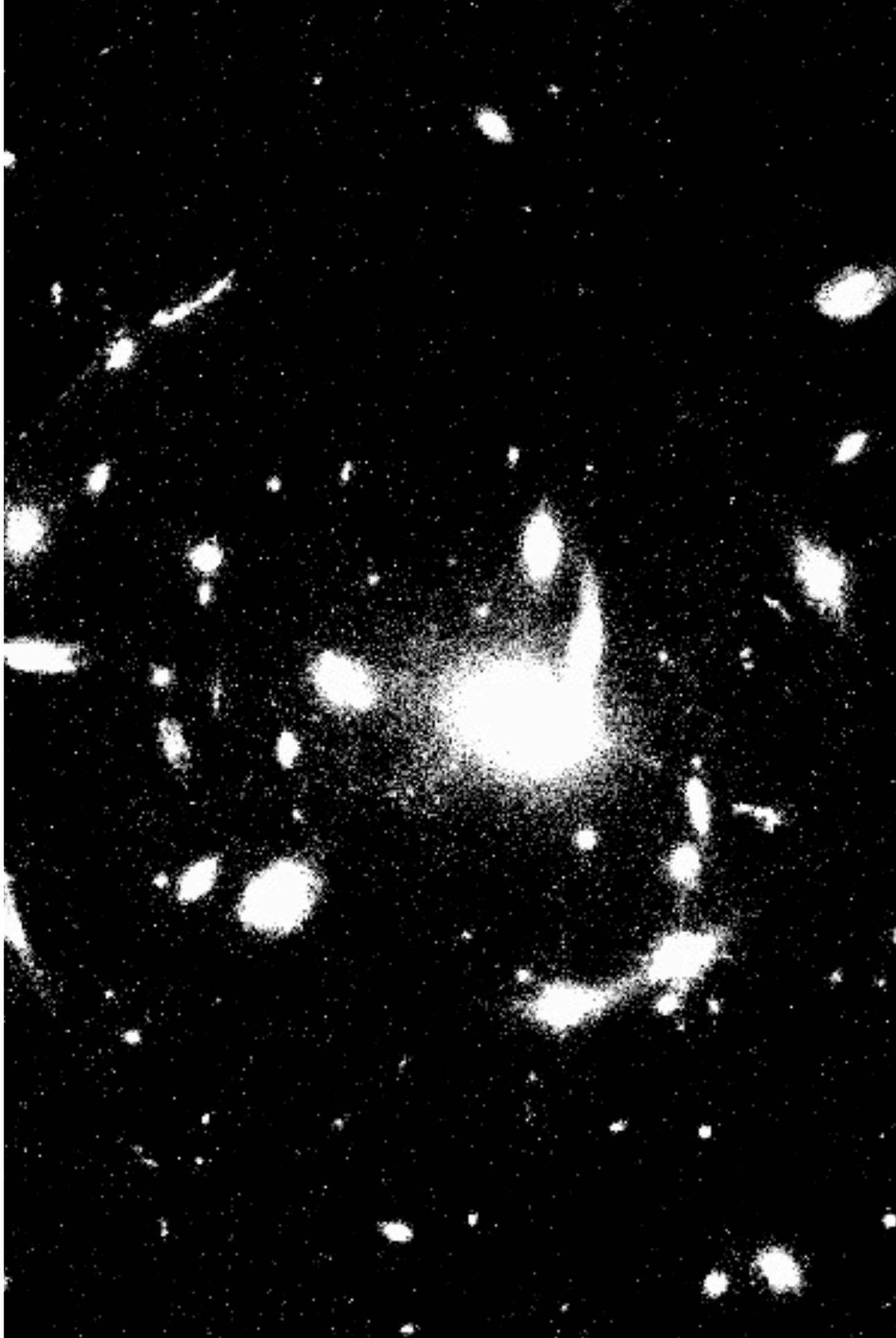


Inclusion of galaxy cluster members

Harvey et al 2013a

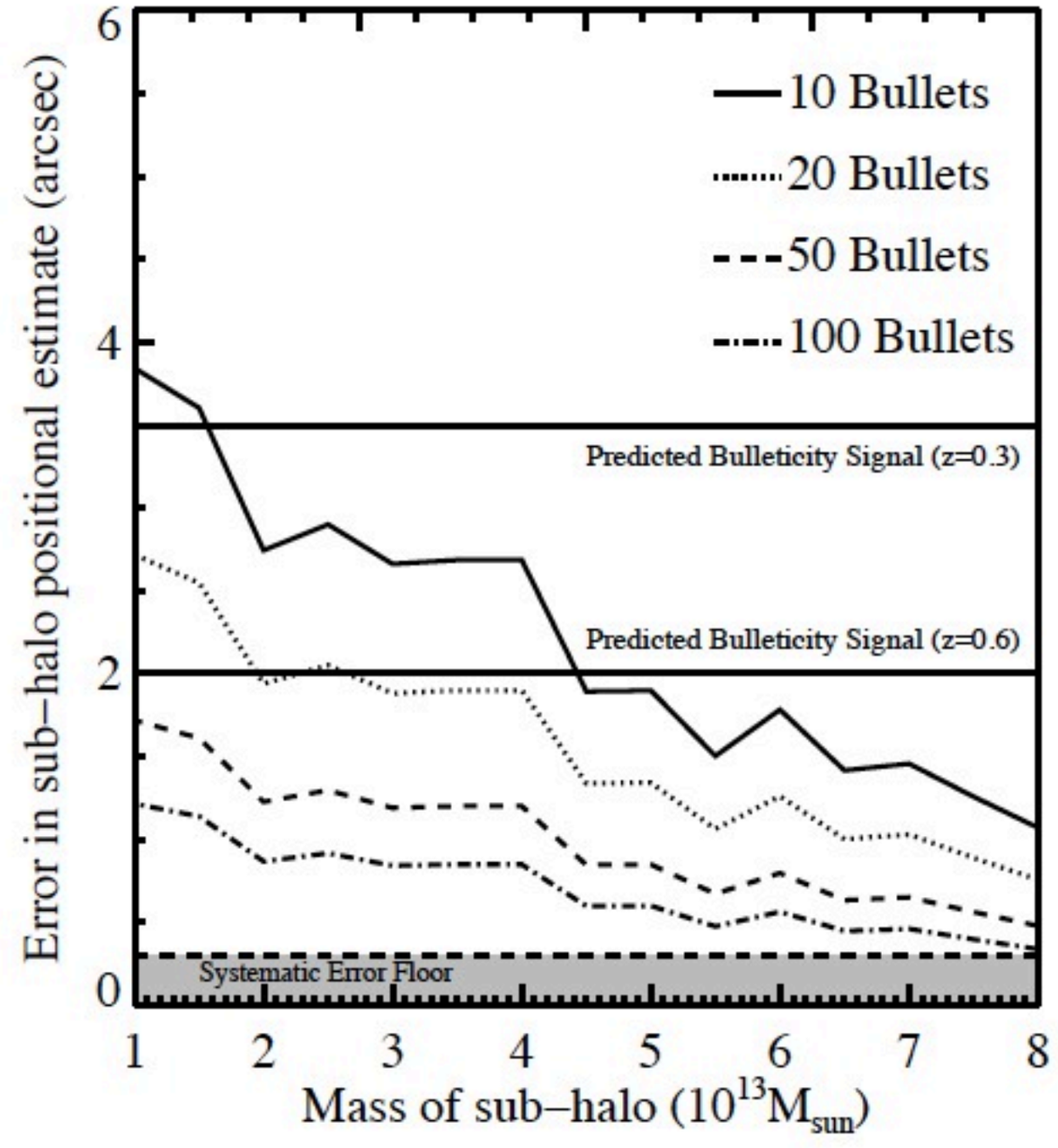
Current Work

Measure position of dark matter, gas and galaxies in 40 Hubble Clusters!



Future Surveys

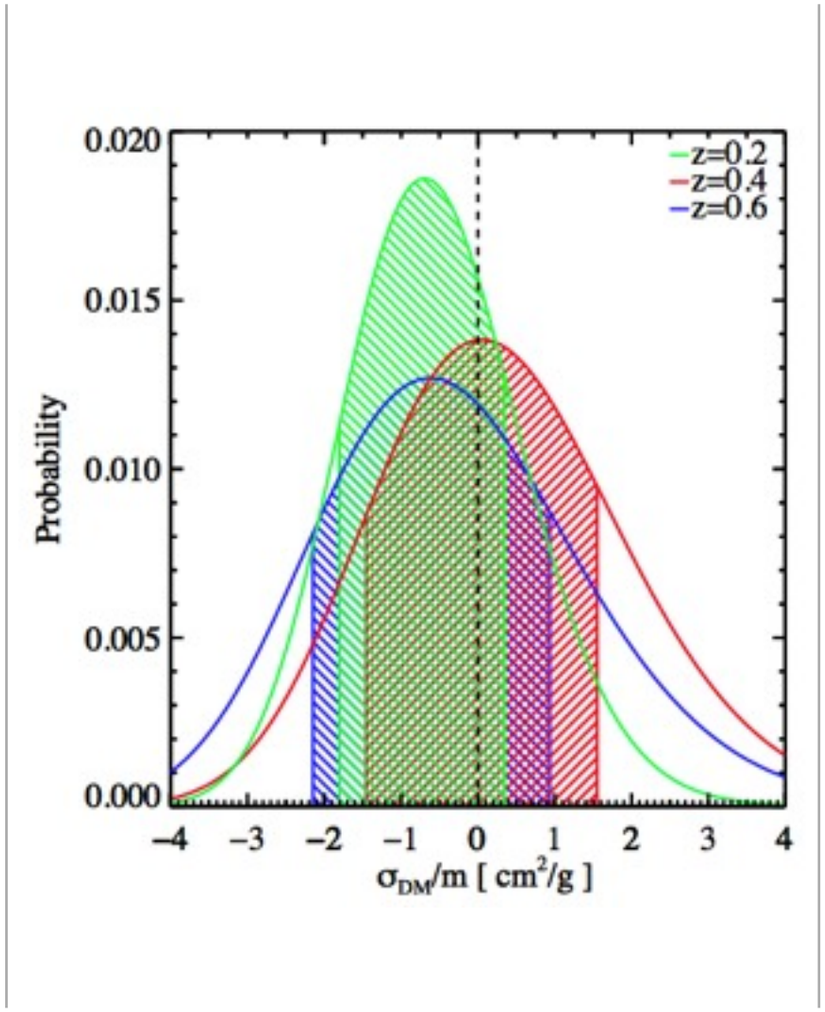
- Easily extended
- Shape measurement bias
- SIDM Simulations



Harvey et al 2013a

Take home messages

- Easily extended to larger samples
- No line of sight dependencies
- No time dependencies

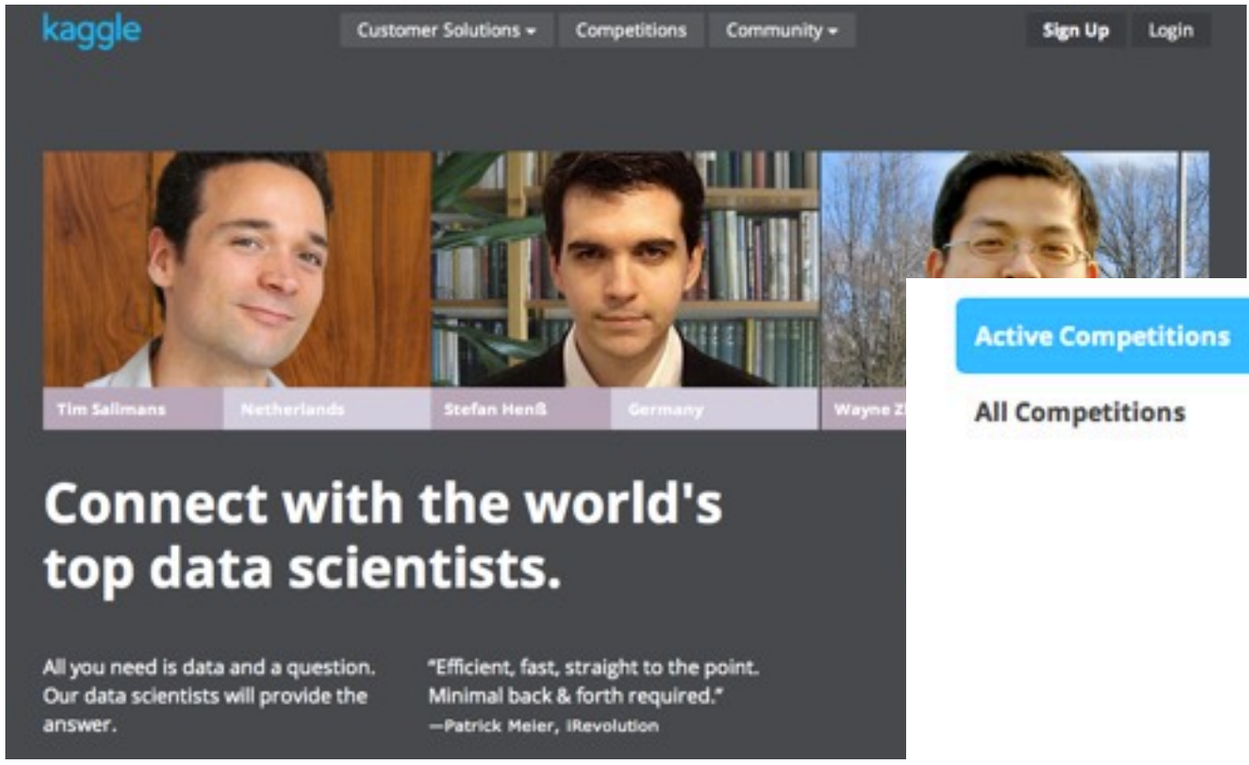


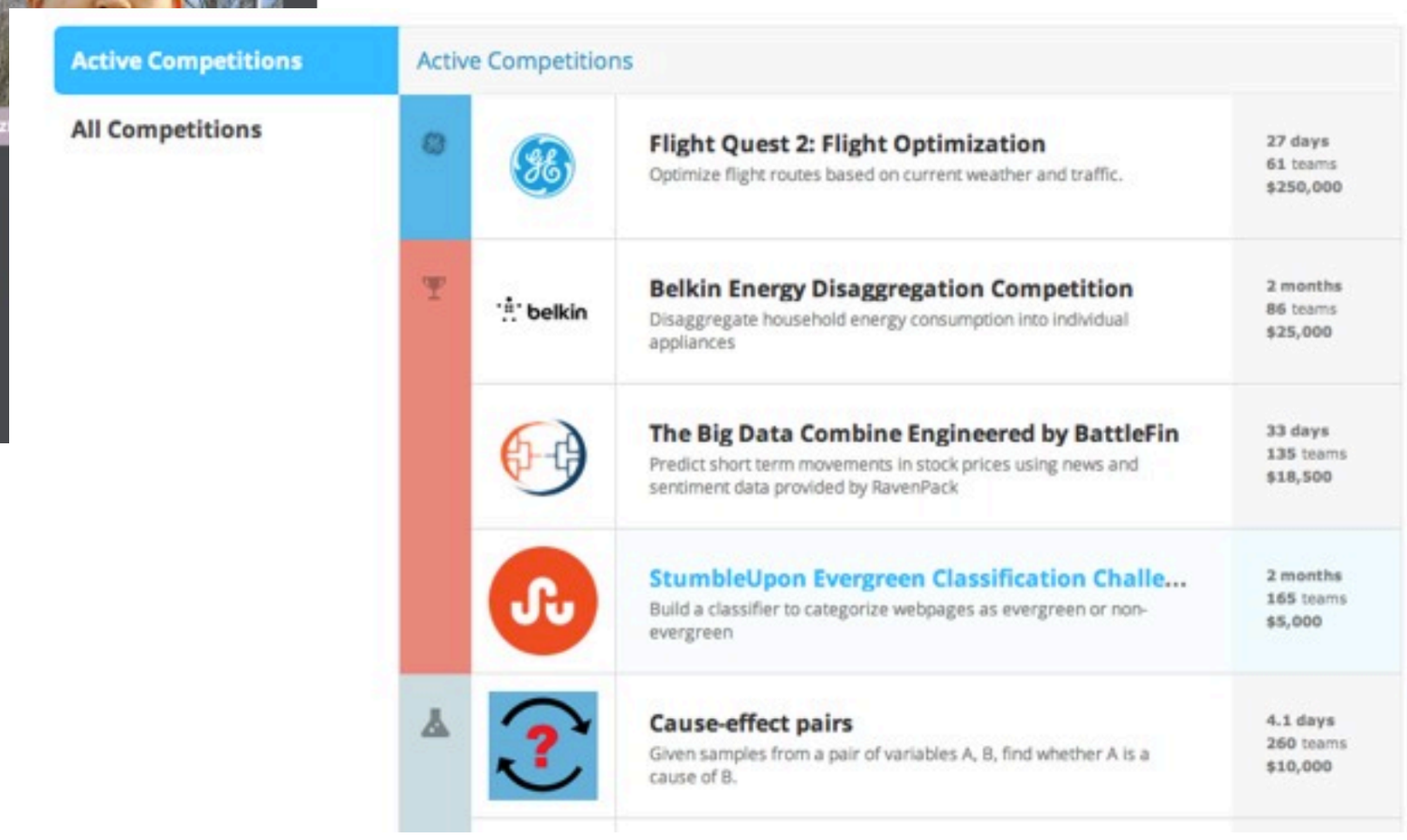
Current data: interpret via analytic model

Future data: will require full SIDM simulations

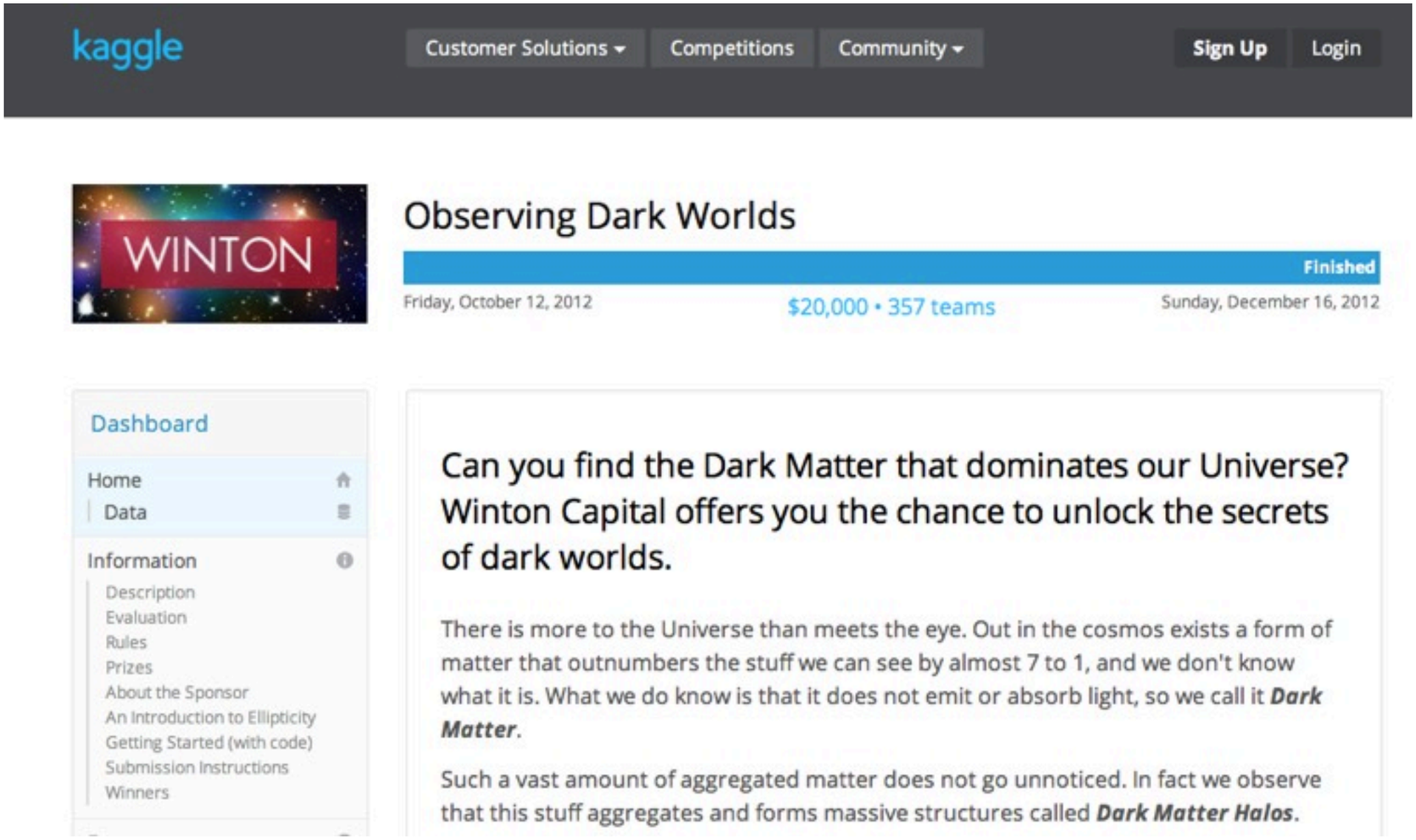
David Harvey, drh@roe.ac.uk
www.roe.ac.uk/~drh
@davidharvey1986

Data Science & Astronomy





Competitions



Crowd-Sourcing

Observing Dark Worlds

Finished

Friday, October 12, 2012 — $20,000 • 357 teams — Sunday, December 16, 2012

Dashboard

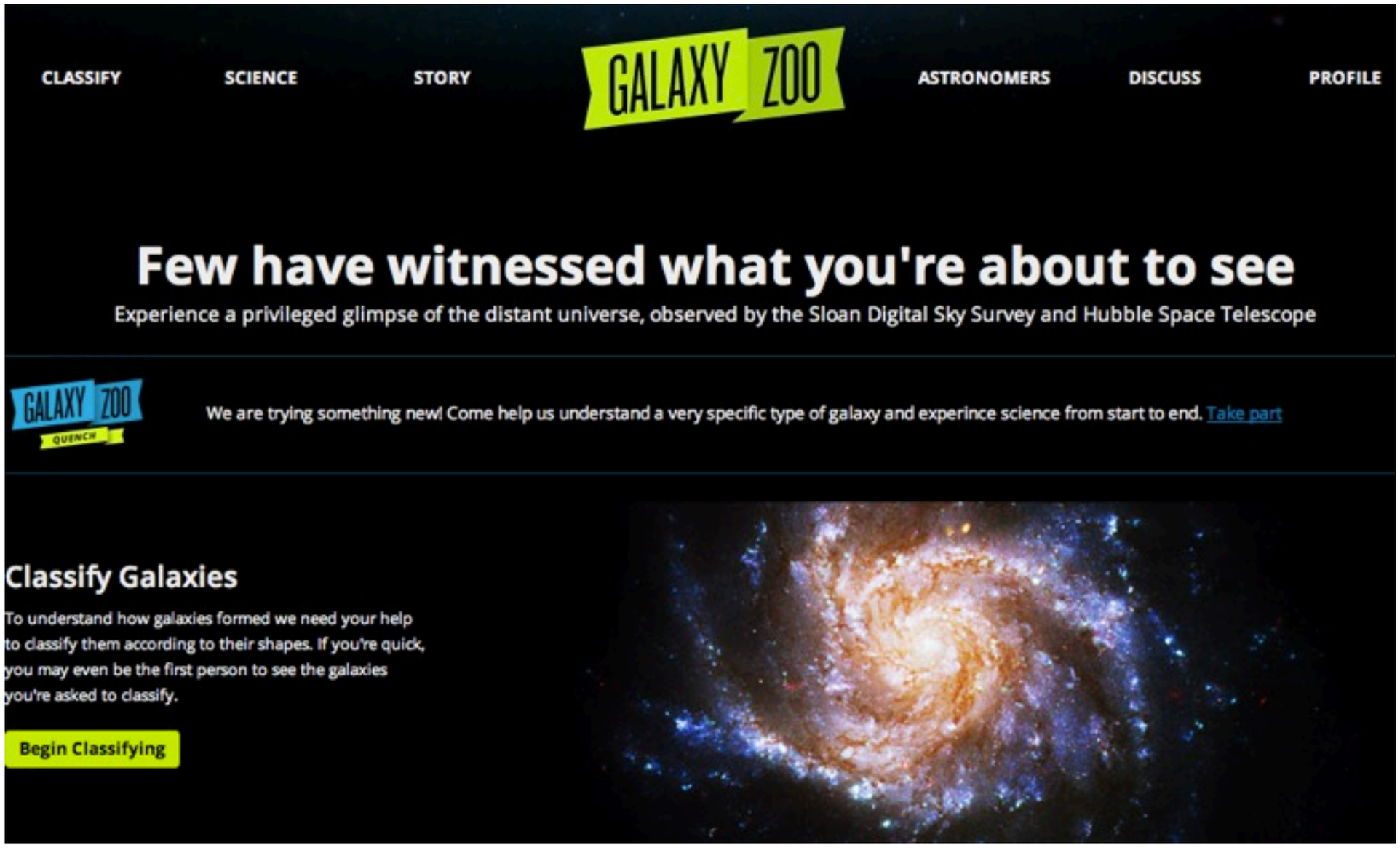
Public Leaderboard · **Private Leaderboard**

This competition has completed. This leaderboard reflects the final standings.

See someone using multiple accounts?
Let us know.

#	Δ1w	Team Name	Score	Entries	Last Submission UTC (Best – Last Submission)
1	-	Tim Salimans	0.67100	20	Sat, 15 Dec 2012 22:28:41 (-16.5d)
2	new	Iain	0.69562	7	Sun, 16 Dec 2012 16:46:58
3	↑73	AMPires	0.71786	35	Sun, 16 Dec 2012 23:27:16 (-24h)
4	↑2	Supernova	0.72645	104	Sun, 16 Dec 2012 20:05:49 (-2.2d)

Future


CLASSIFY
SCIENCE
STORY
GALAXY ZOO
ASTRONOMERS
DISCUSS
PROFILE
Few have witnessed what you're about to see
Experience a privileged glimpse of the distant universe, observed by the Sloan Digital Sky Survey and Hubble Space Telescope
GALAXY ZOO
QUENCH
We are trying something new! Come help us understand a very specific type of galaxy and experince science from start to end. Take part
Classify Galaxies
To understand how galaxies formed we need your help to classify them according to their shapes. If you're quick, you may even be the first person to see the galaxies you're asked to classify.
Begin Classifying