



*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

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

Overview

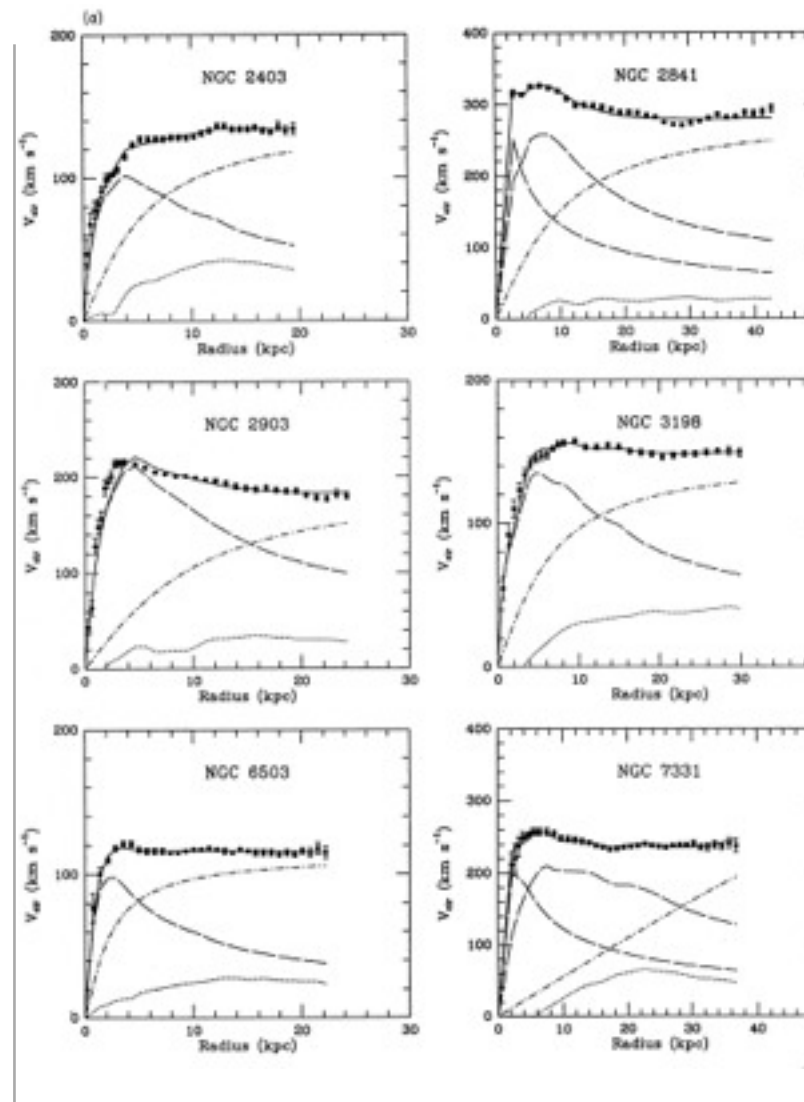
- Dark Matter and the accumulating evidence
- The Self Interacting Dark Matter Paradigm
- Extending the bullet cluster
- Potential Constraints from Hubble Archive
- Data Science in Astronomy

The evidence



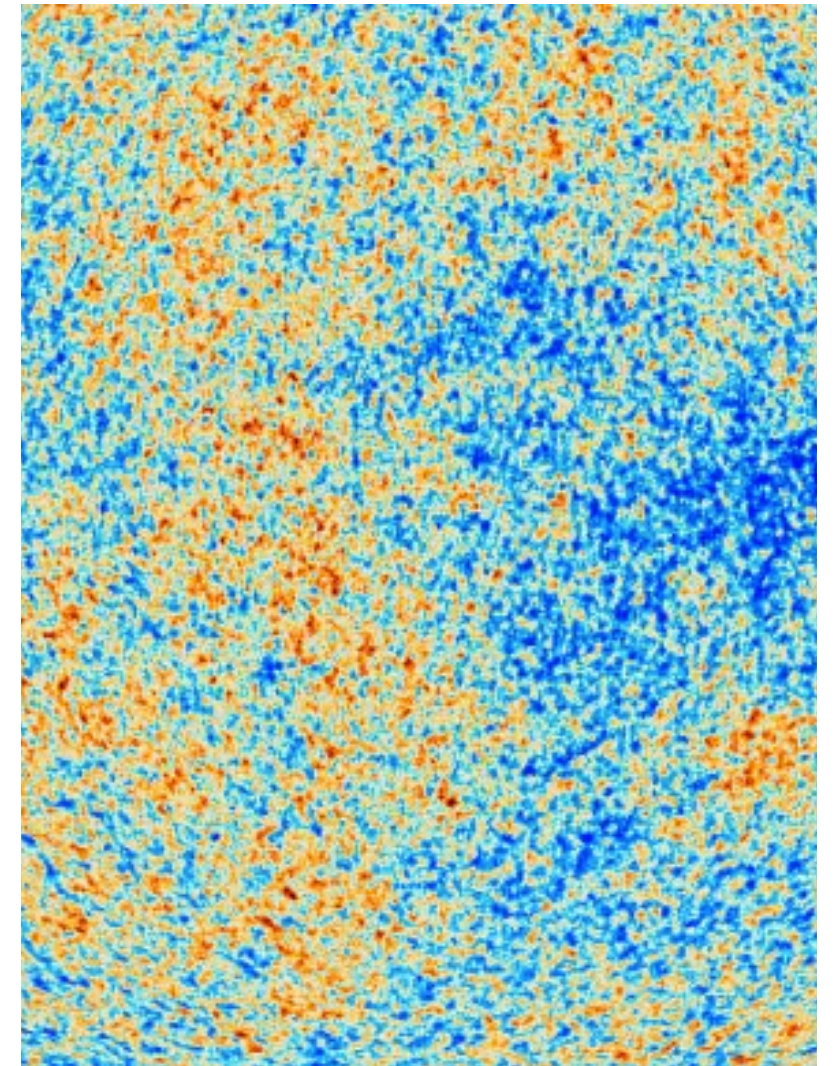
Galaxy Clusters

Nasa, Stsci, Jullo, Natarajan, Kneib



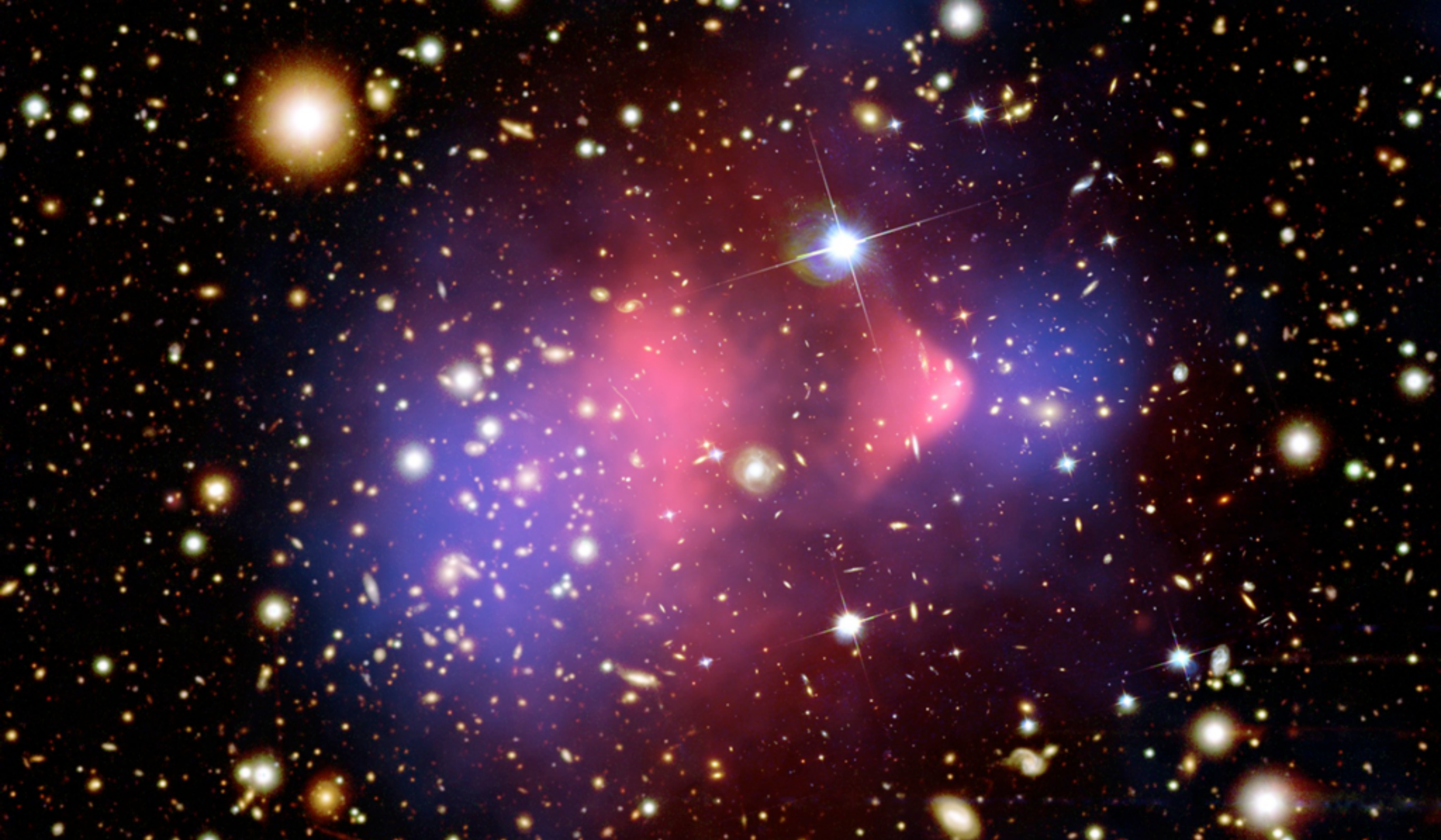
Rotation curves

Begeman, Broeils & Sanders, 1991



CMB

Planck Collaboration

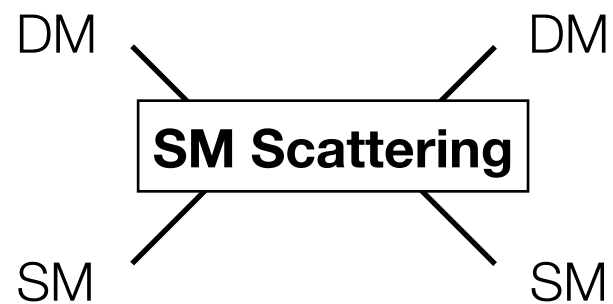


The Bullet Cluster

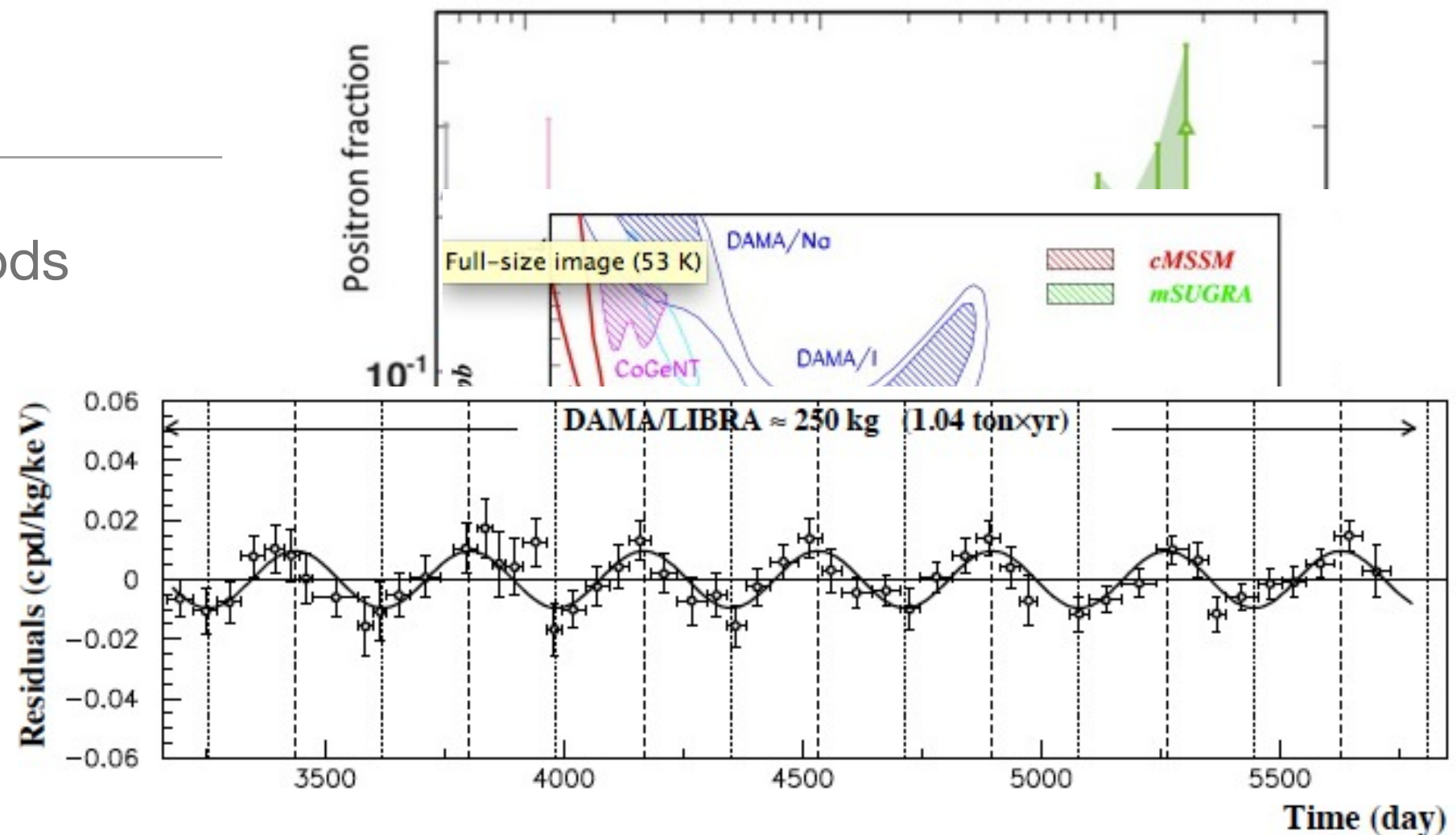
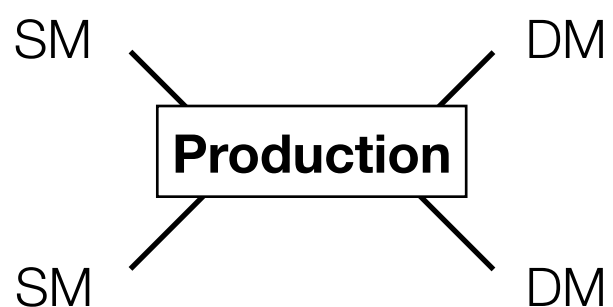
Clowe et. al., 2006

Detection

- Direct detection methods



- Indirect detection



HEAT: J. J.

M. A. DuV.

AMS-01: M.

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

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

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

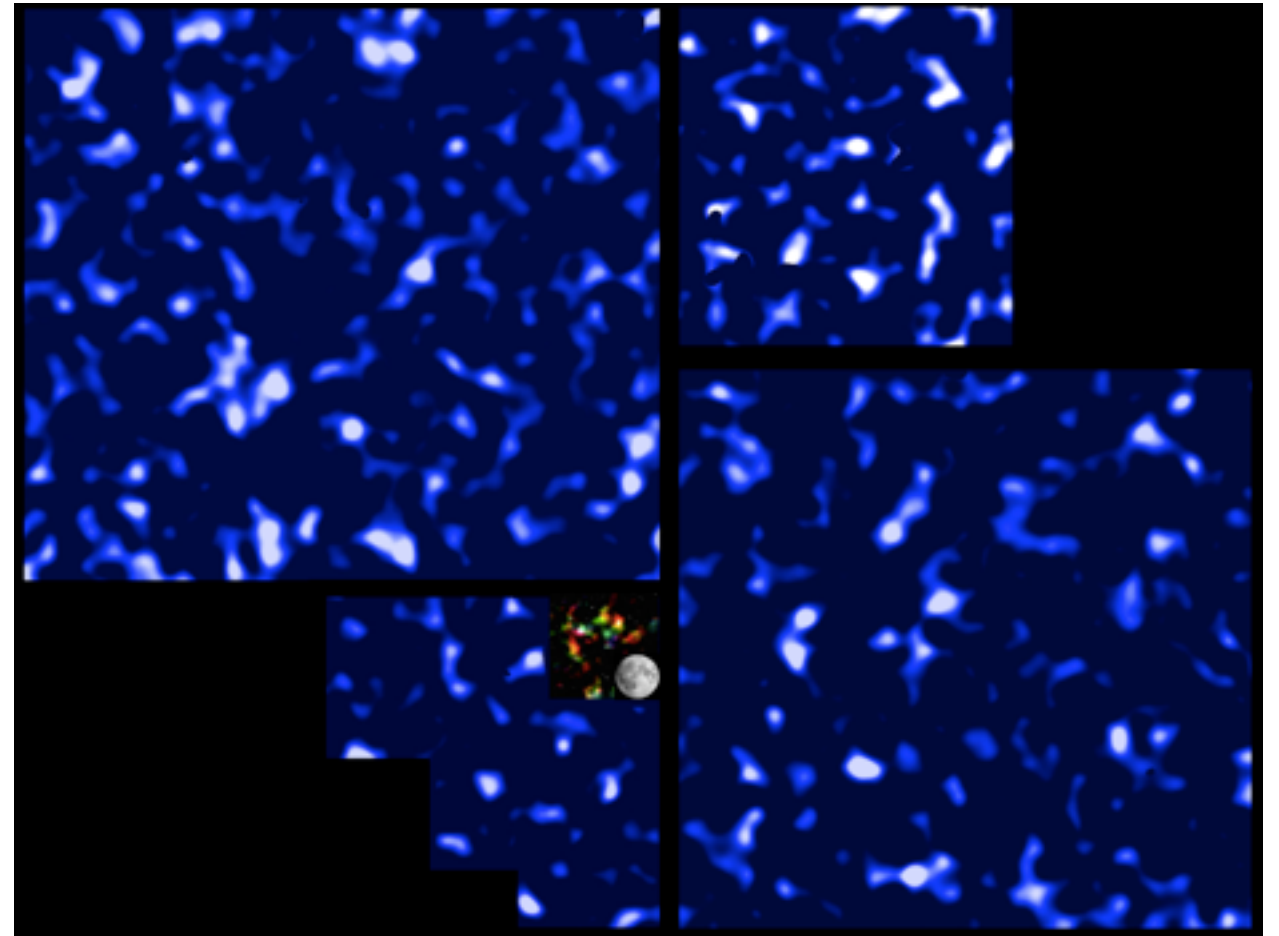
Fermi-LAT: M. Ackermann et al., *Phys. Rev. Lett.* 108 (2012) 011103.

Bernabei et al. 2013

Yu et. al. 2012

What is dark matter?

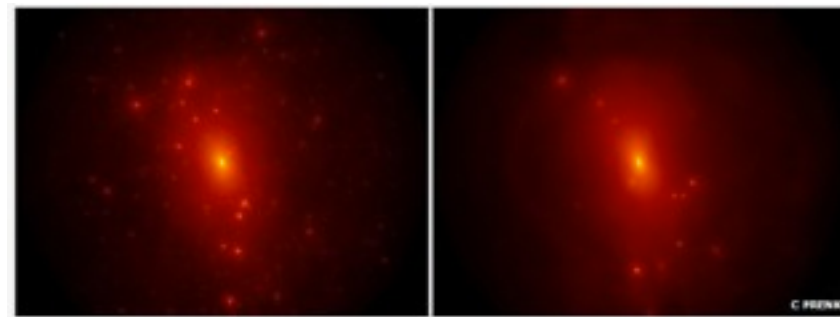
- Weakly Interacting Massive Particles?
 - Modified Gravity?
 - Standard model?
 - New physics?
- Collisionless?



Cosmos credit: NASA, ESA, P. Simon and T. Schrabback
CHFT Credit: Van Waerbeke, Heymans, and [CFHTLens](#) collaboration.

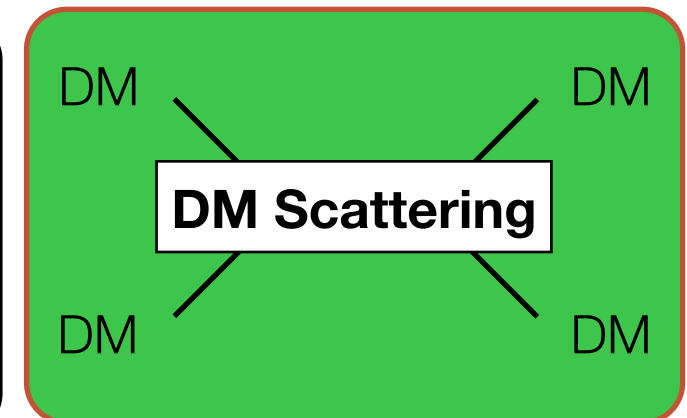
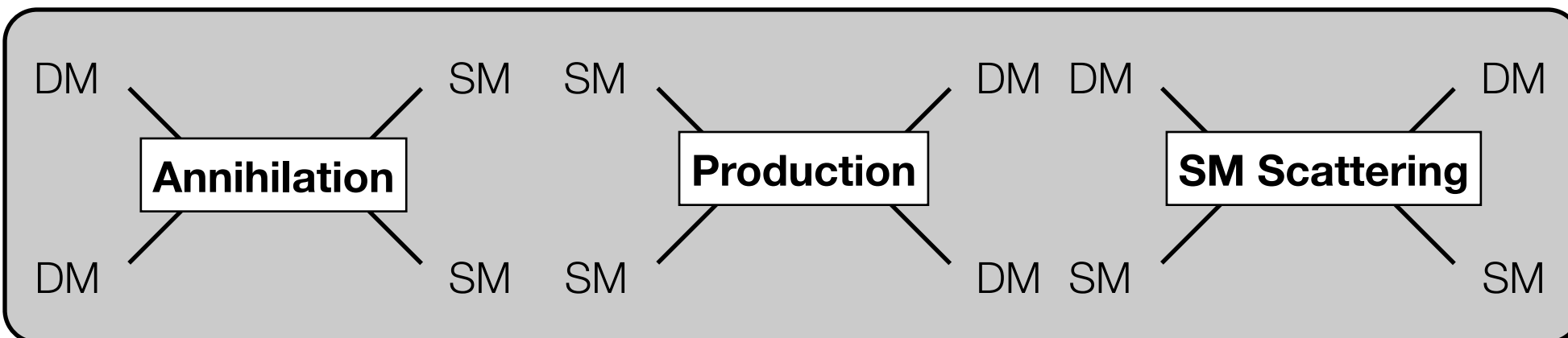
The self interacting dark matter paradigm

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



C. Frenk

- Can we compete with the particle physicists?



Markevitch et. al., 2006

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

Bradac et. al., 2008

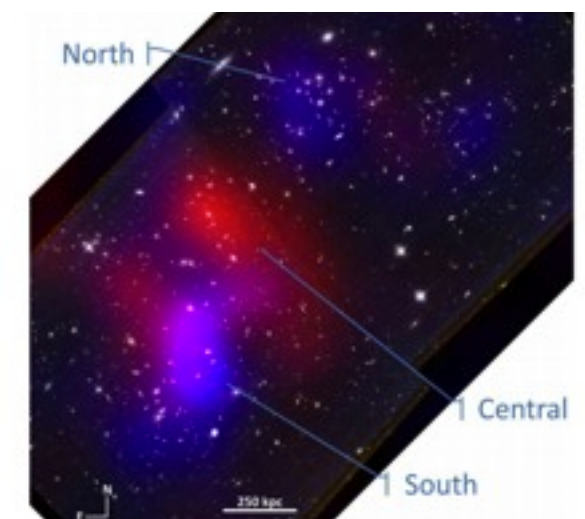
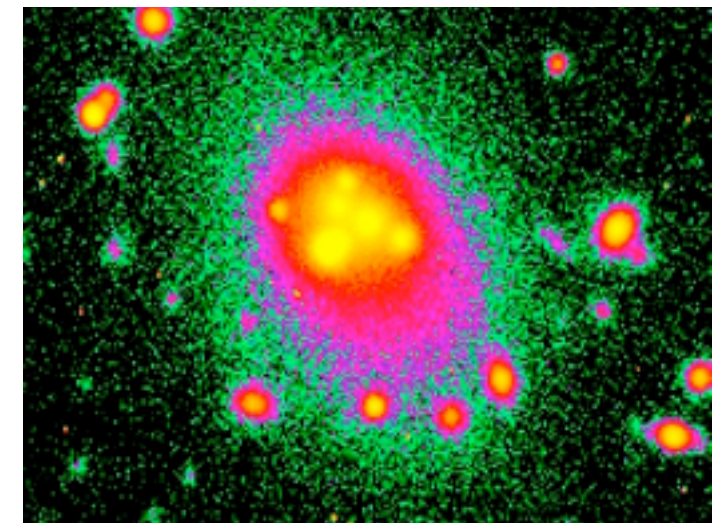
$$\sigma/m < 4 \text{ cm}^2 \text{ g}^{-1}$$

William & Saha, 2011

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

Dawson et. al., 2012

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



How is the cross-section parameterised?

1.

$$\chi\tau_m = \frac{\sigma}{m} \Sigma_m \left[1 - 2 \left(\frac{v'_{\text{esc}}}{v_0} \right)^2 \right]$$

Markevitch et. al., 2006

Fraction of
particles lost
in collision

Probability
of particles
colliding

Probability
of losing a
particle

2.

Scattering
Depth

$$\tau_s = \frac{\sigma}{m} \Sigma_s$$

Markevitch et. al., 2006

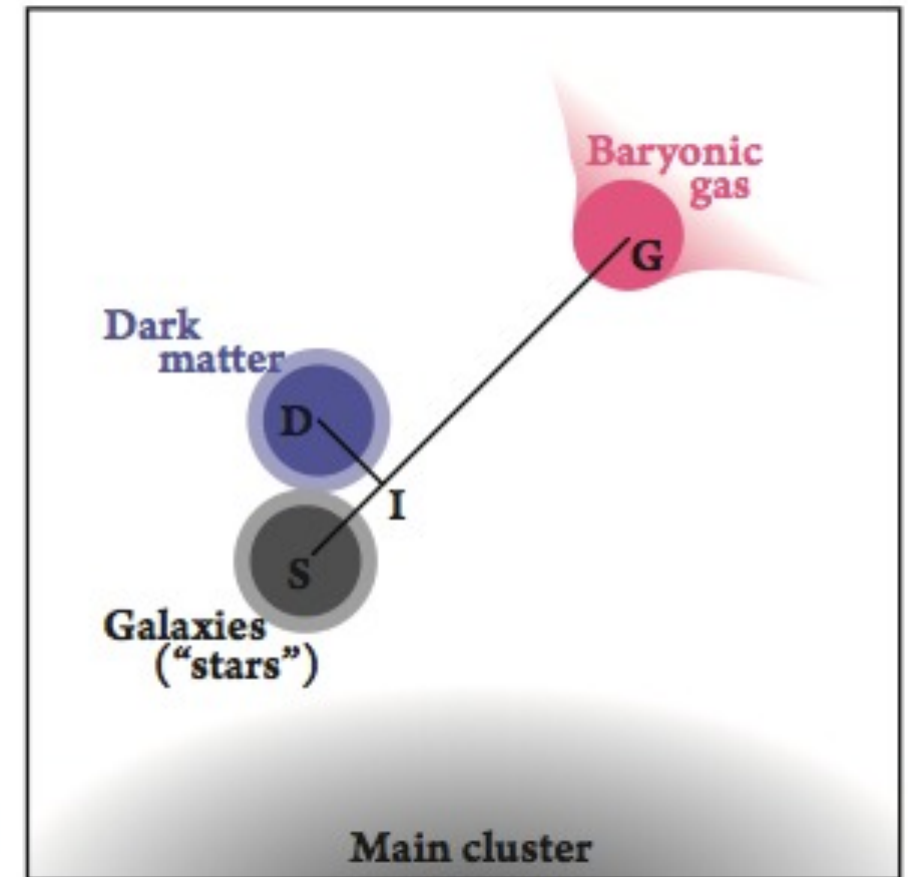
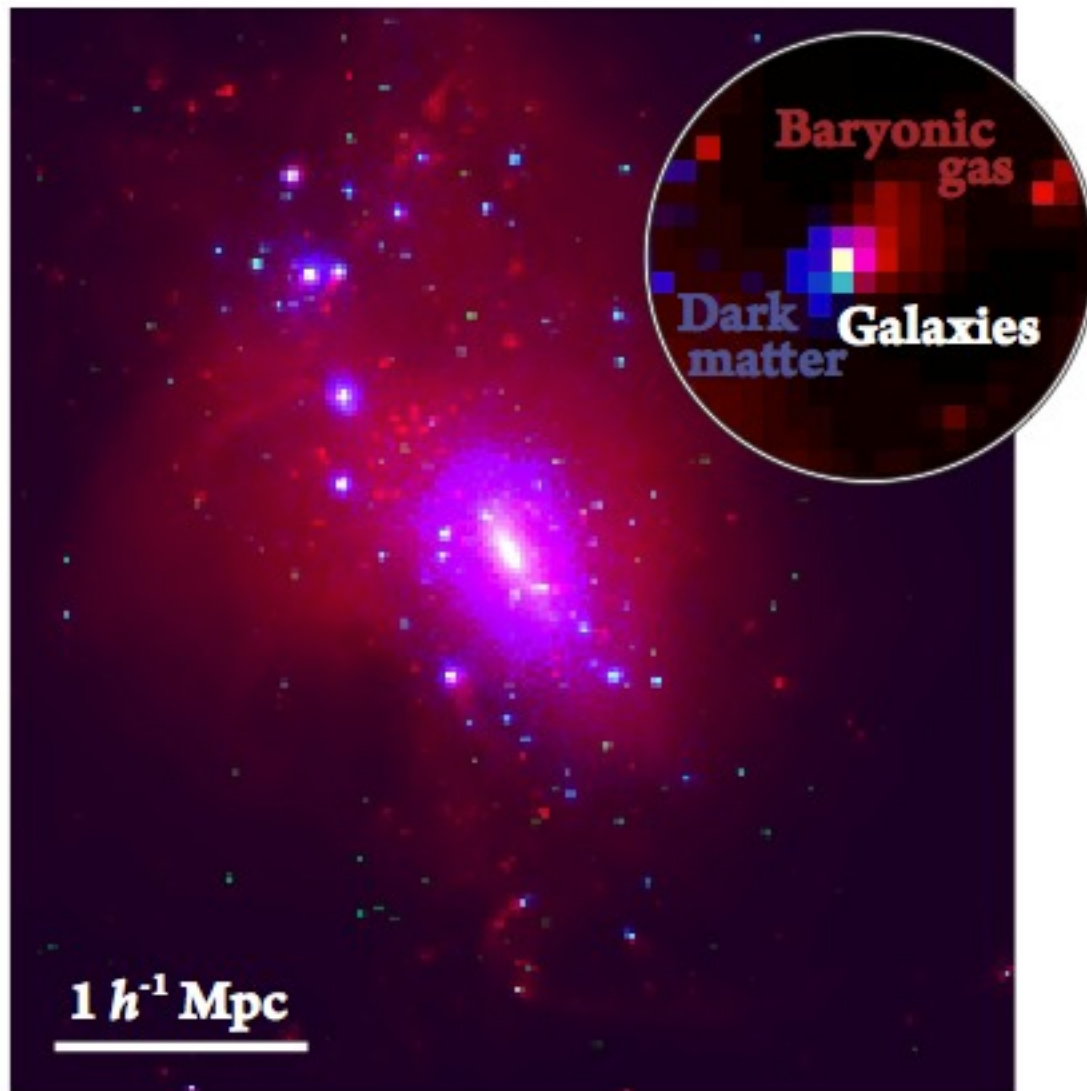
3.

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

William & Saha, 2011

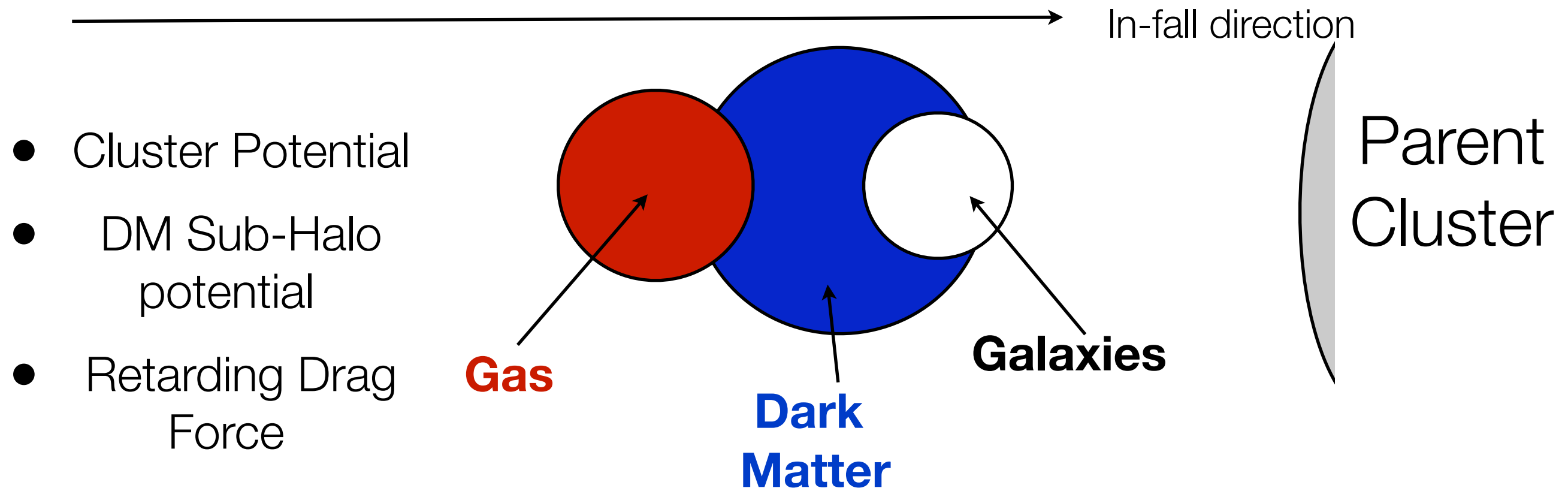
Force due
to the
cluster

Dimensionless
covering
factor



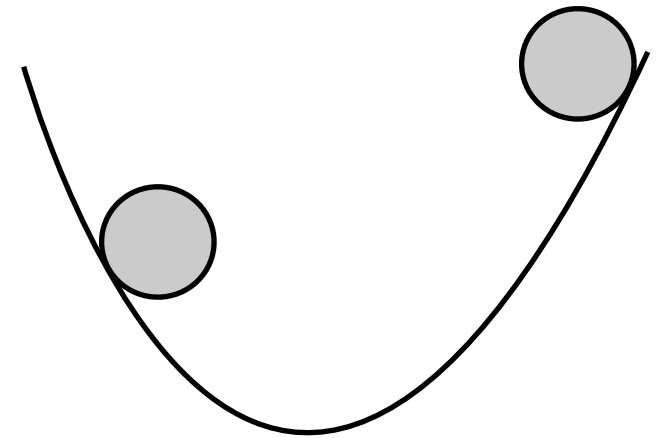
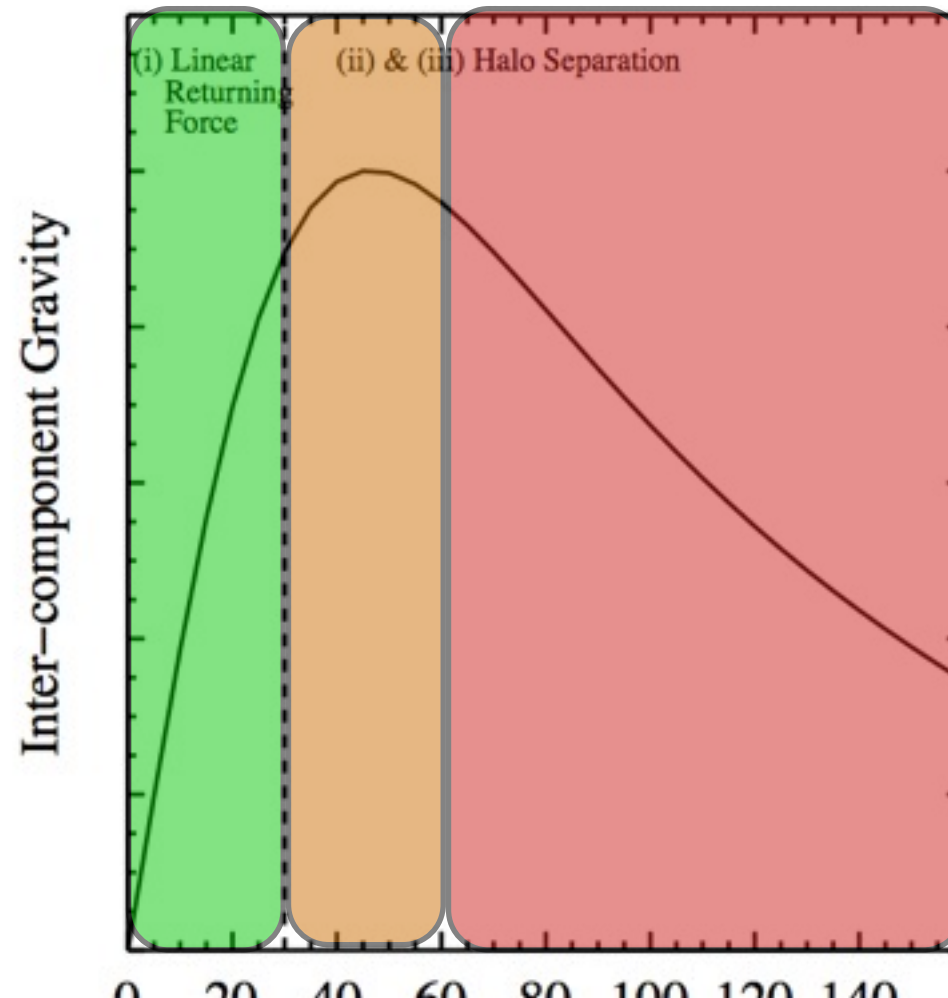
Accreting substructure

A new framework



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



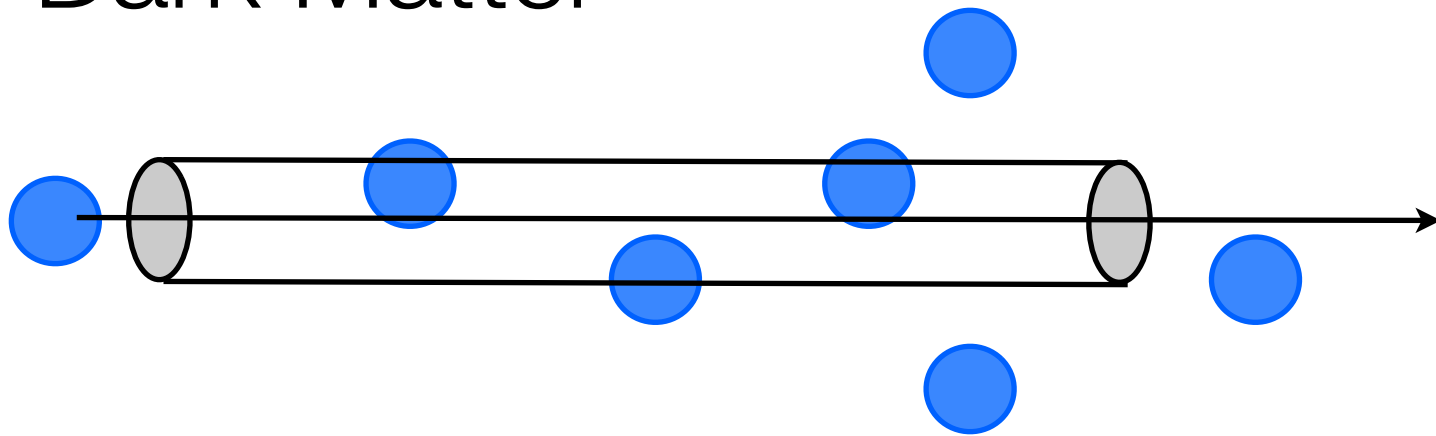
Gas & Dark Matter Drag

Gas

- Drag Equation

$$\mathbf{D}_G = -\frac{1}{2} C_G A_G \rho_G^{\text{ICM}} v_G \mathbf{v}_G$$

Dark Matter



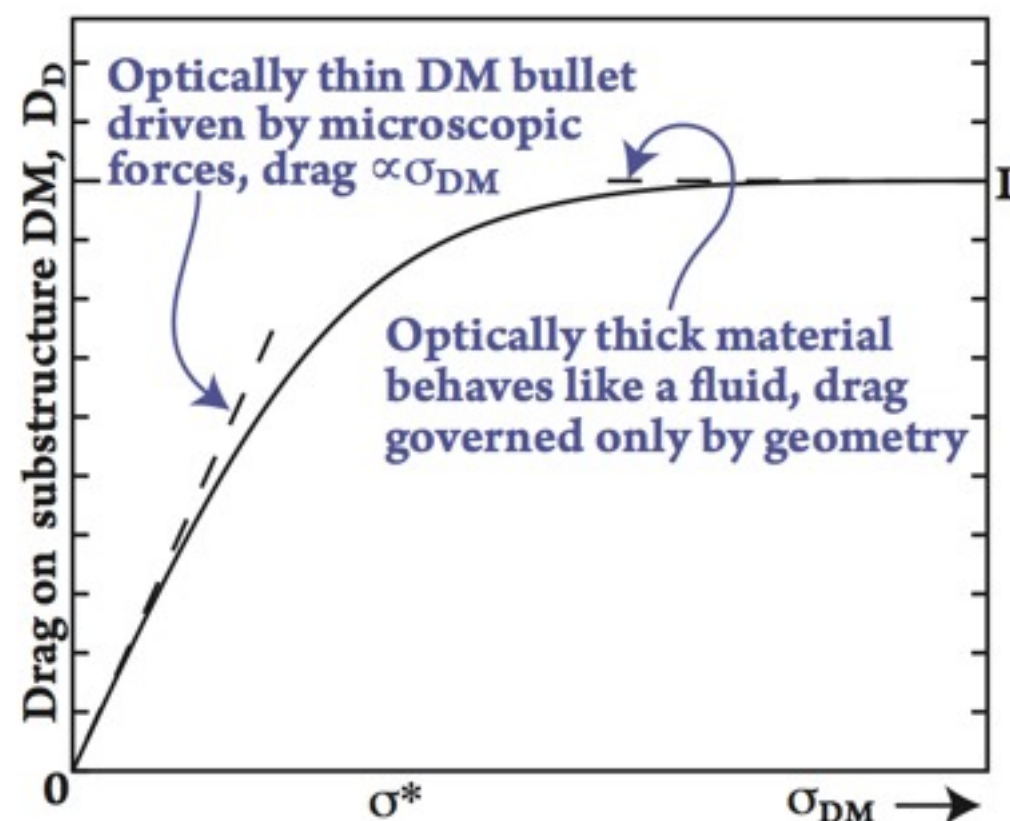
Assumptions

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

$$\mathbf{D}_D \approx -\frac{1}{4} \frac{\sigma}{m} \rho_D M_D v_D \mathbf{v}_D$$

Dark Matter Drag

$$\mathbf{D}_D \approx -\frac{1}{4} \frac{\sigma}{m} \rho_D M_D v_D \mathbf{v}_D$$



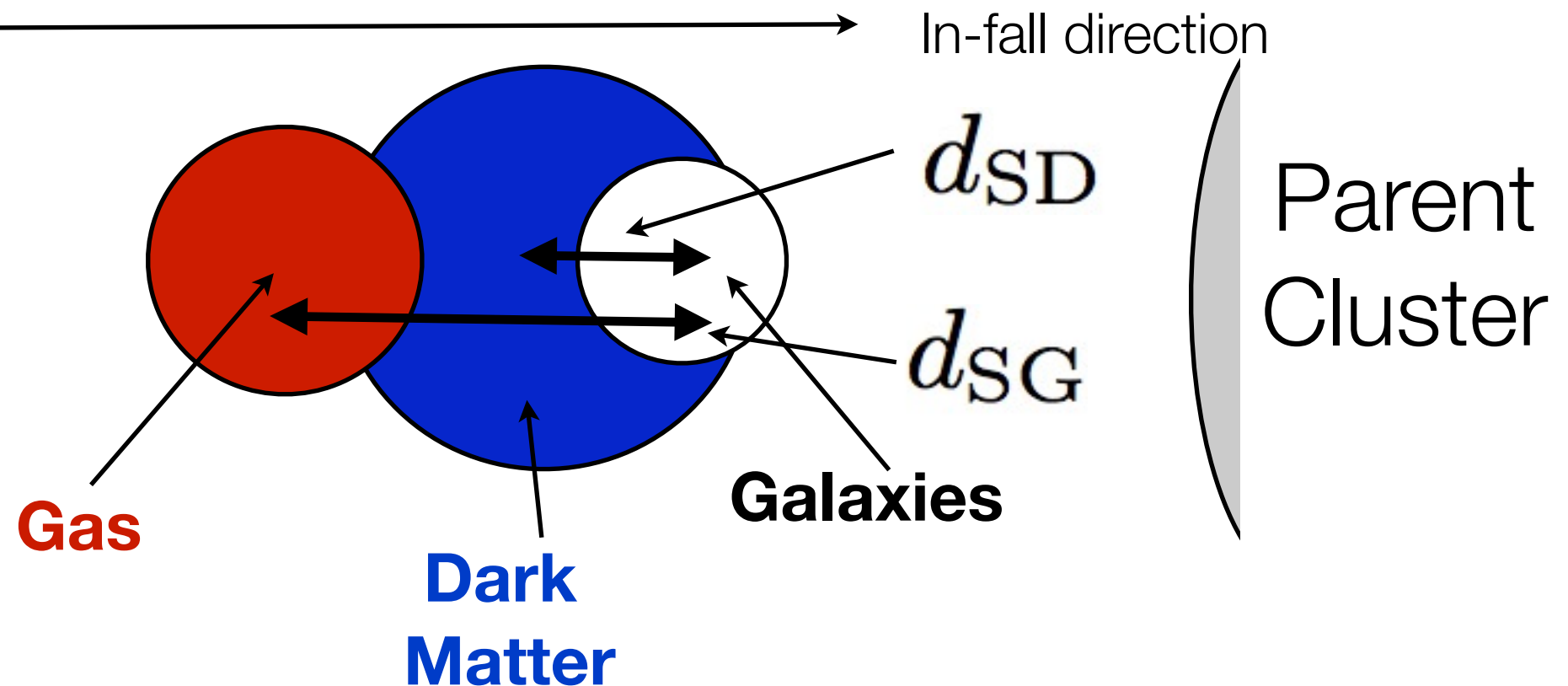
$$\mathbf{D}_G = -\frac{1}{2} C_G A_G \rho_G^{\text{ICM}} v_G \mathbf{v}_G$$

$$\mathbf{D}_D = -\frac{1}{2} C_D A_D \rho_D^{\text{ICM}} \left(1 - e^{-\sigma_{\text{DM}}/\sigma^*} \right) v_D \mathbf{v}_D$$

$$\frac{\sigma_{\text{DM}}}{\sigma^*} = \frac{\sigma_{\text{DM}} M_D}{2 C_D A_D m}$$

Our analytical model of in-fall

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



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

$$\frac{\sigma_{DM}}{\sigma^*} = \frac{\sigma_{DM} M_D}{2 C_D A_D m}$$

Testing on noise free simulations

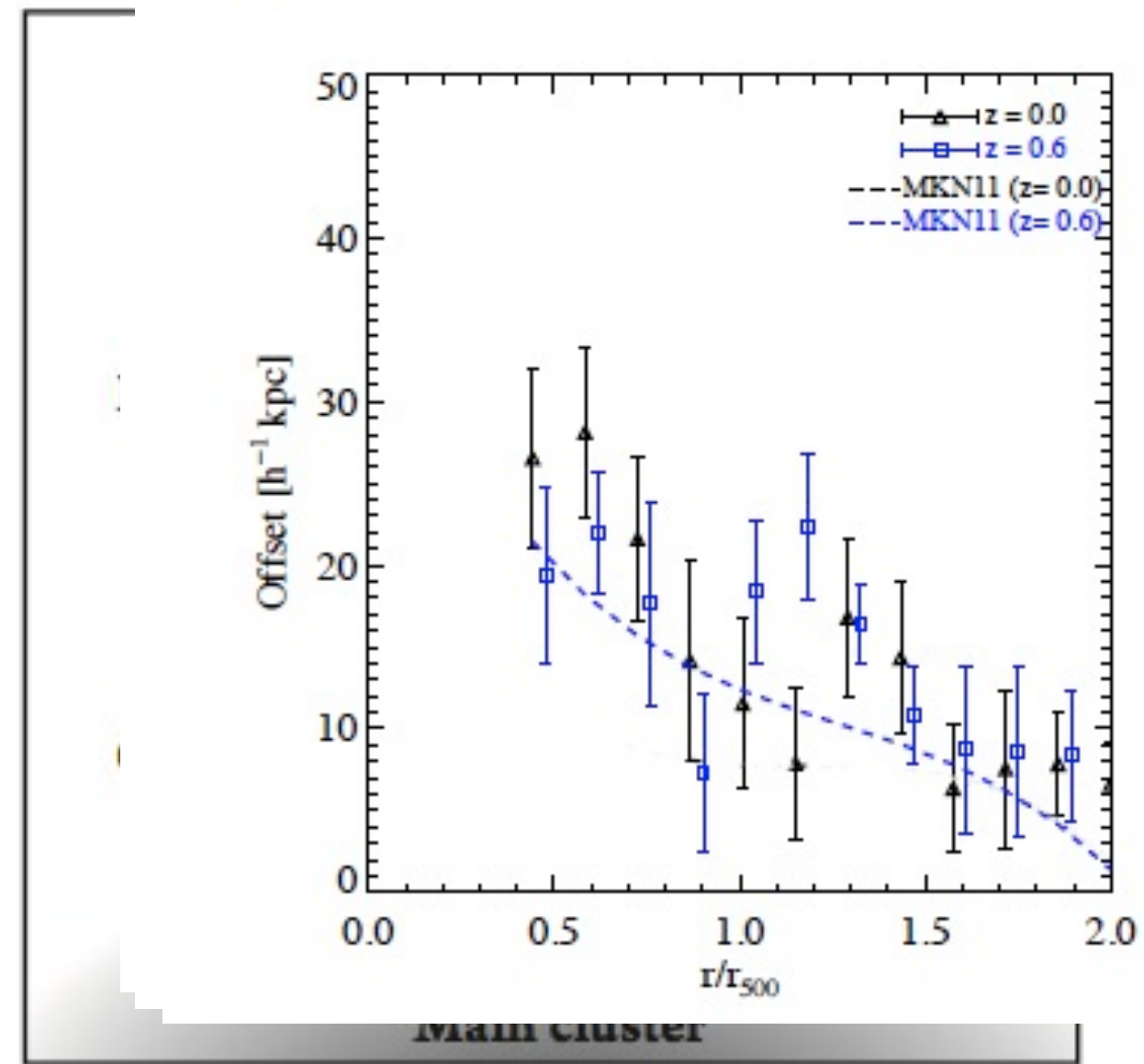
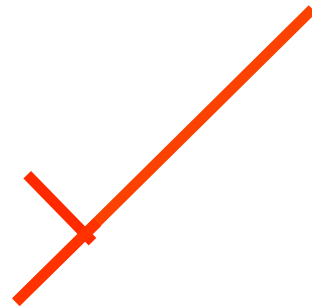
$$\beta \equiv \frac{d_{SD}}{d_{SG}}$$

Observables:

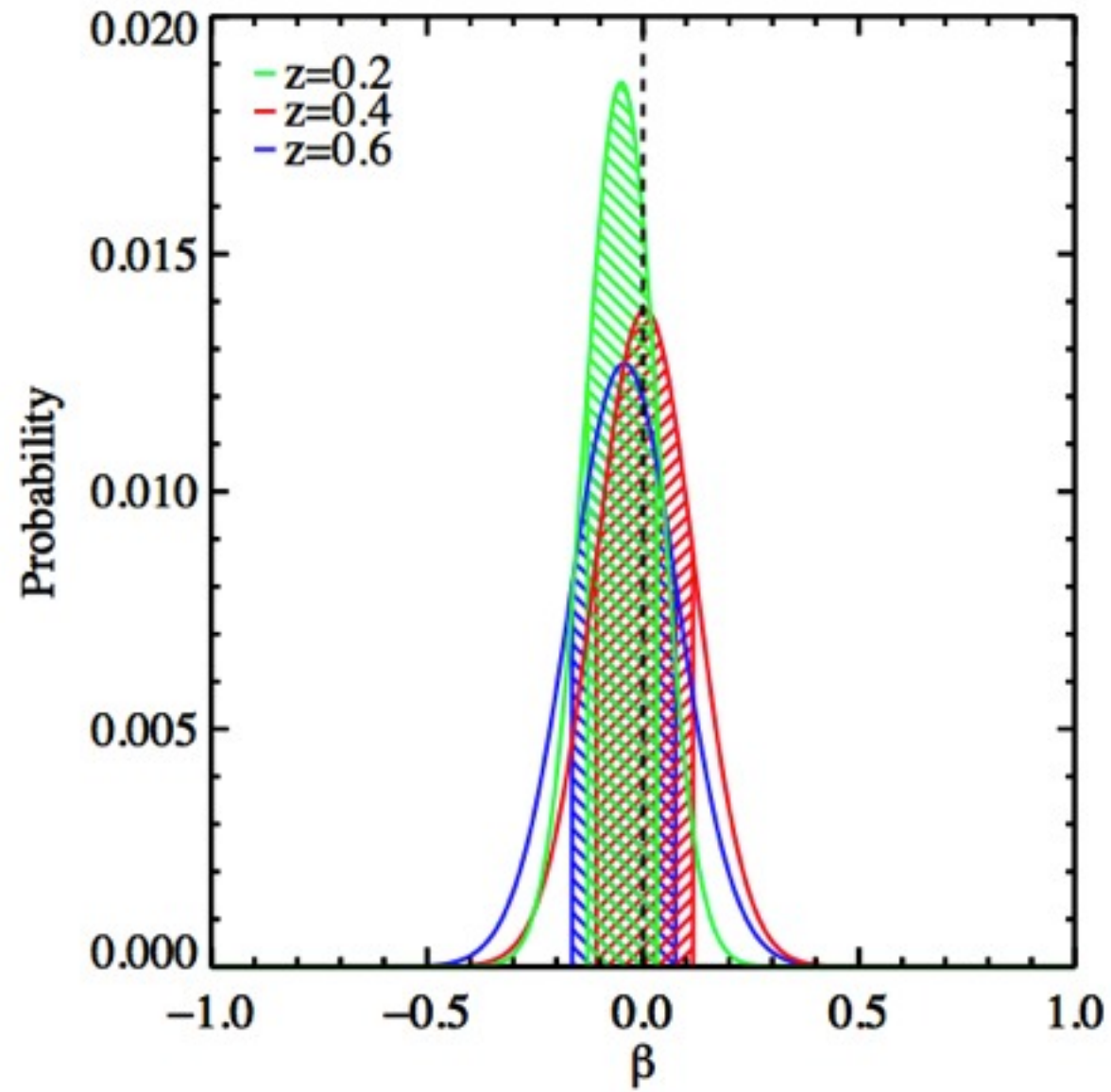
★d_SG

★d_SI

★d_DI

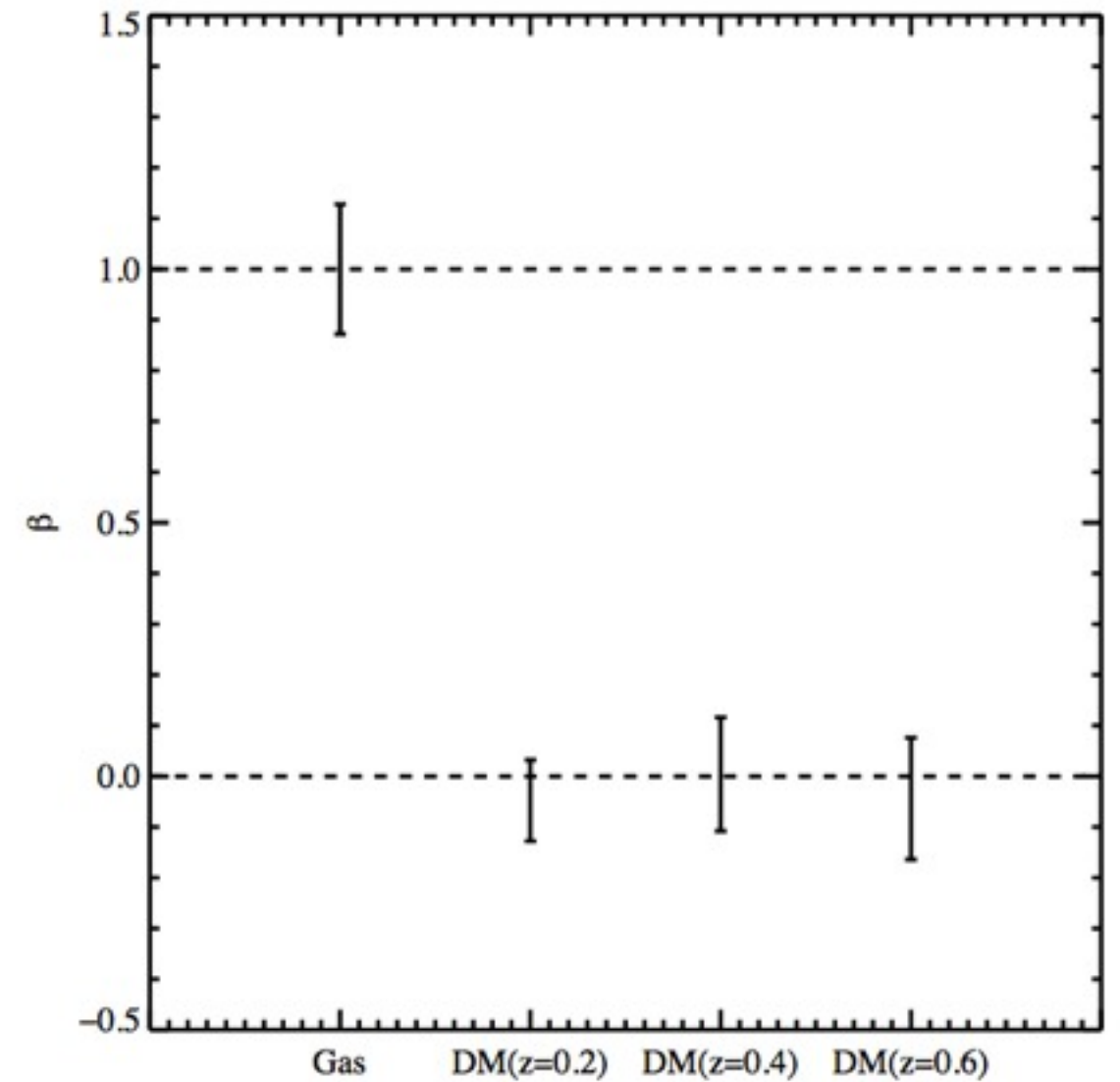


Harvey et al 2013b (in prep.)



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

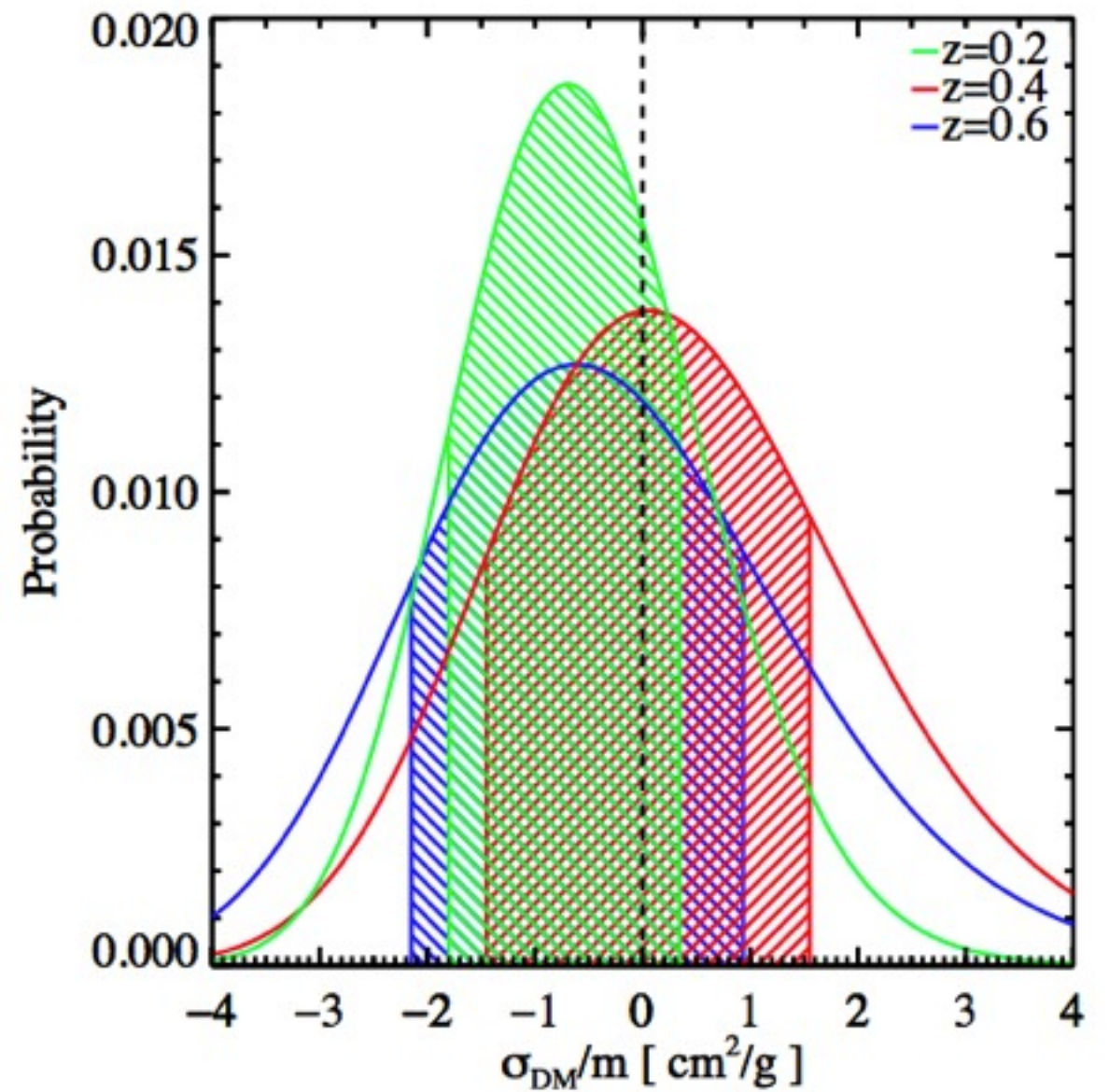
Predicted constraints



Harvey et al 2013b (in prep.)

Predicted constraints

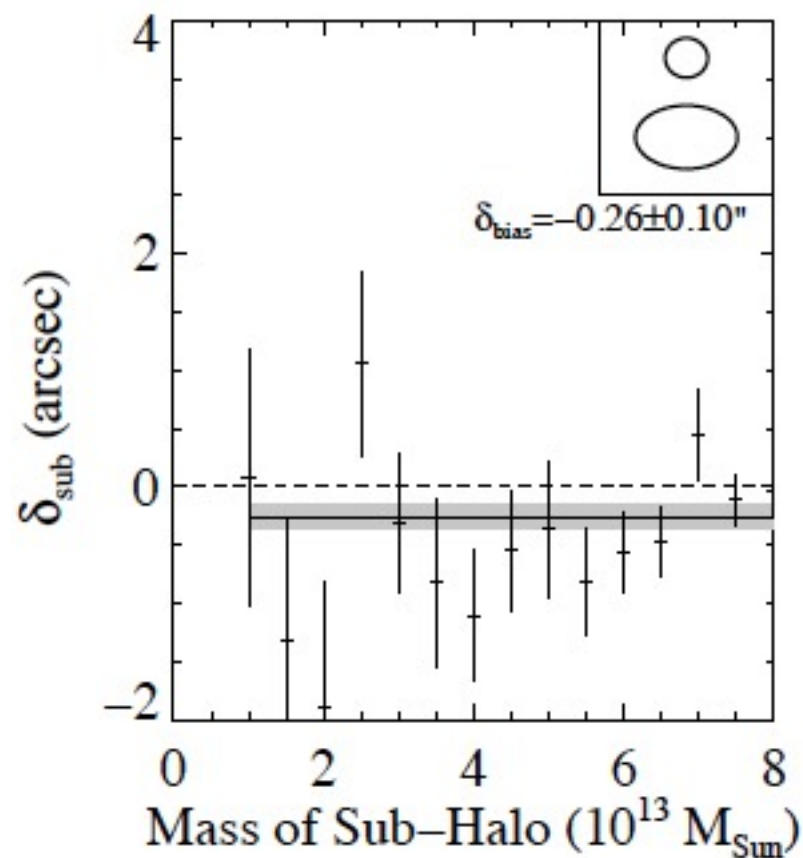
$$\beta \equiv \frac{d_{\text{SD}}}{d_{\text{SG}}} = 1 - e^{-\sigma_{\text{DM}}/\sigma^*}$$



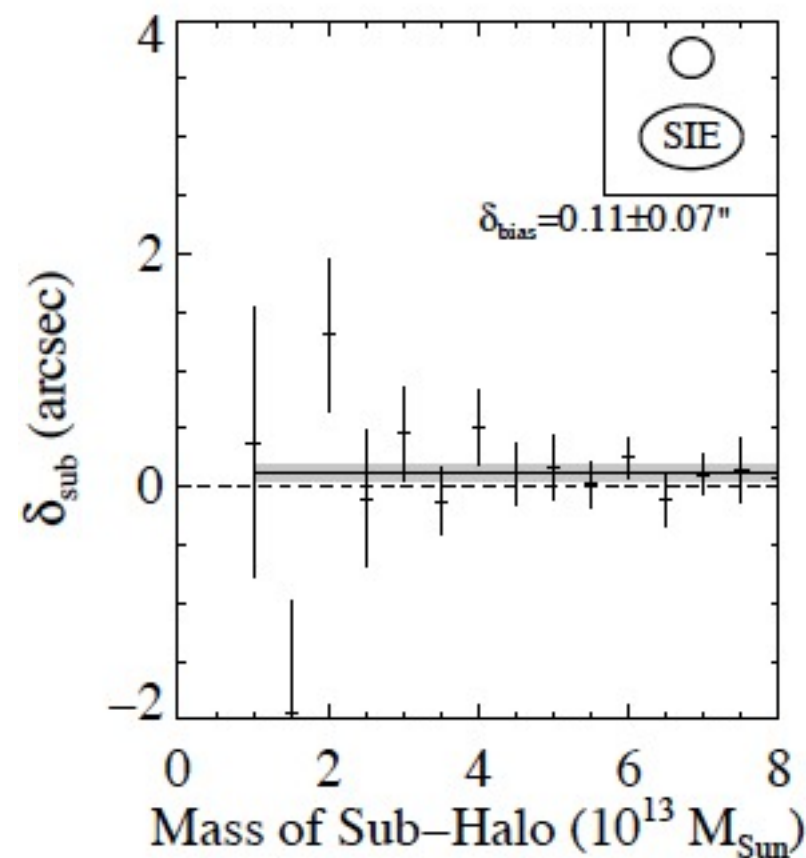
Harvey et al 2013b (in prep.)

Accuracy of sub-halos in galaxy clusters

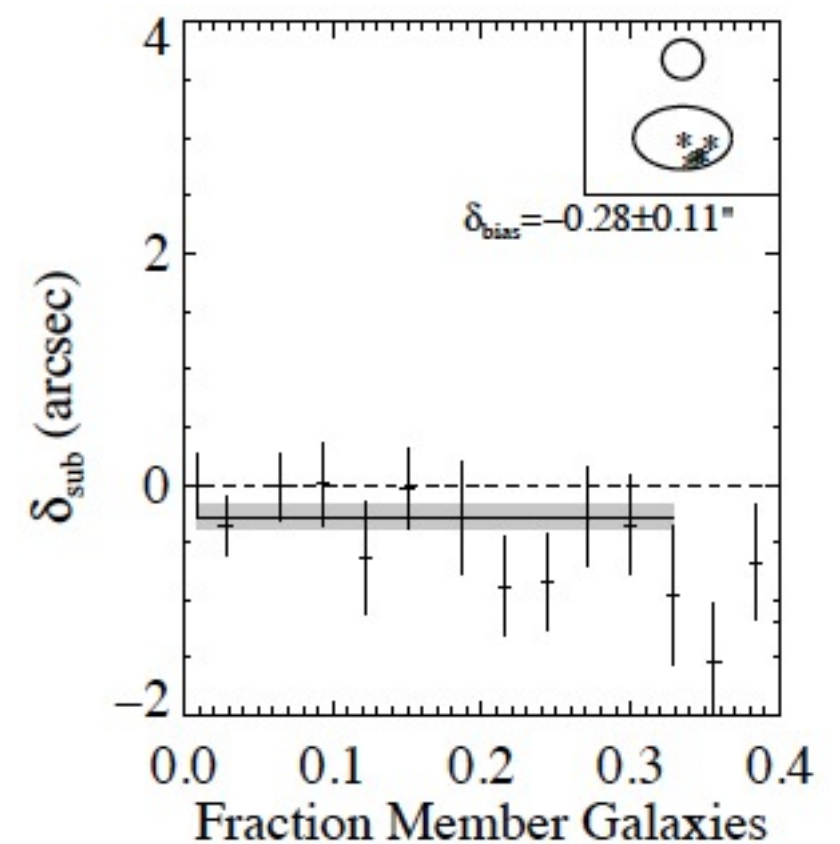
- Statistical efforts : testing for lensing systematics in controlled environments



Shape measurement bias
Different source redshift



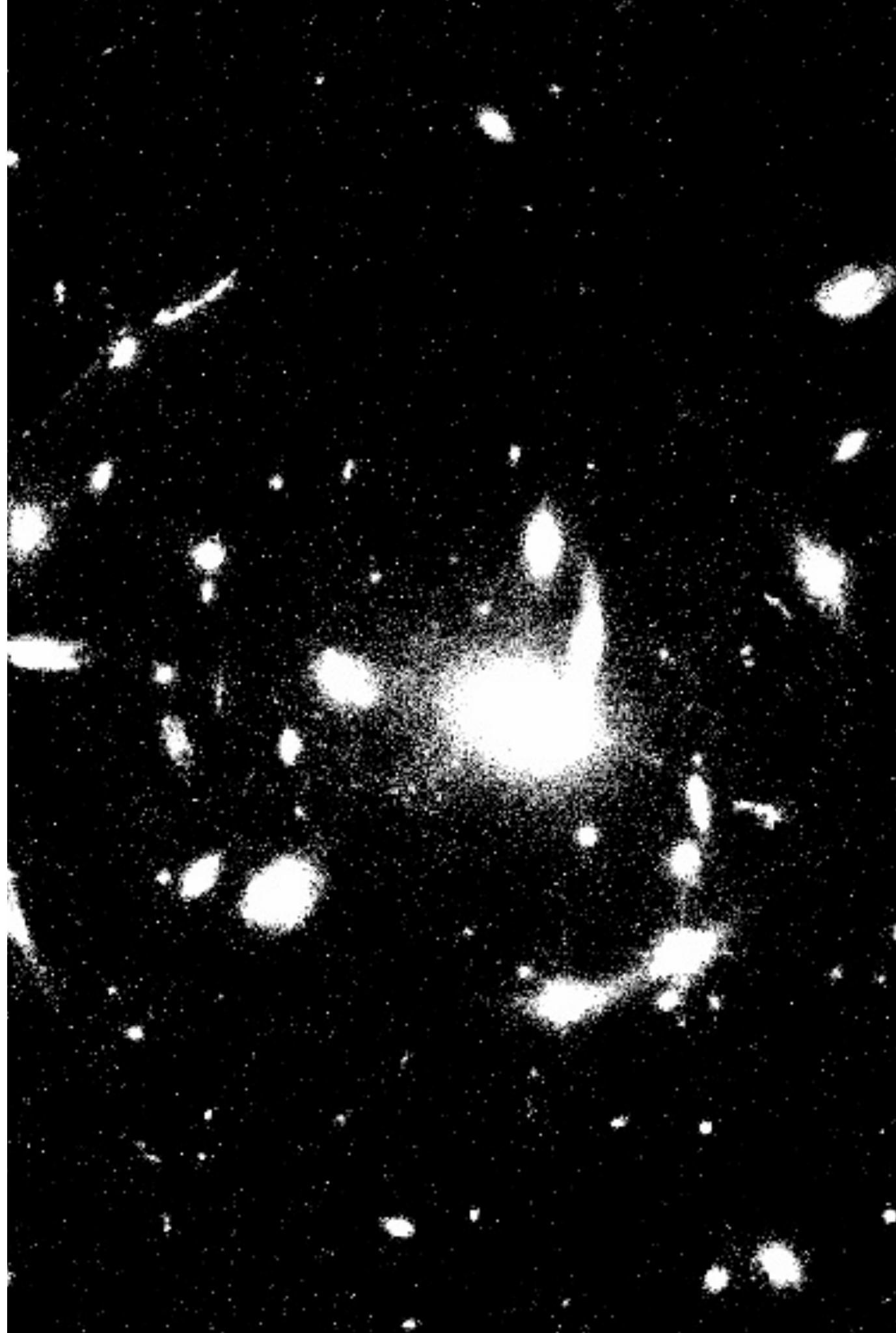
Mis-identification of the
dark matter halo profile



Inclusion of galaxy cluster
members

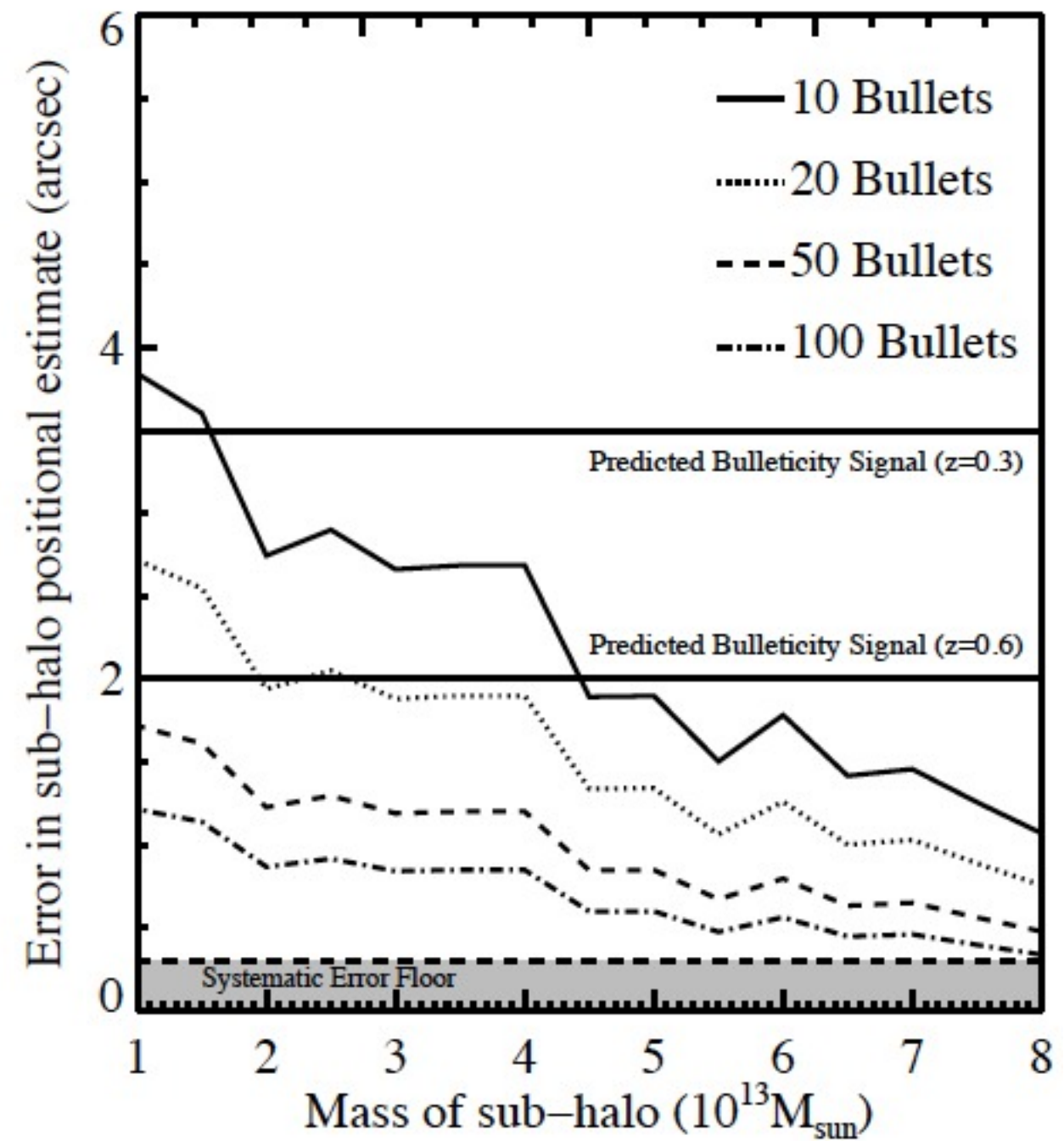
Current Work

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



Future Surveys

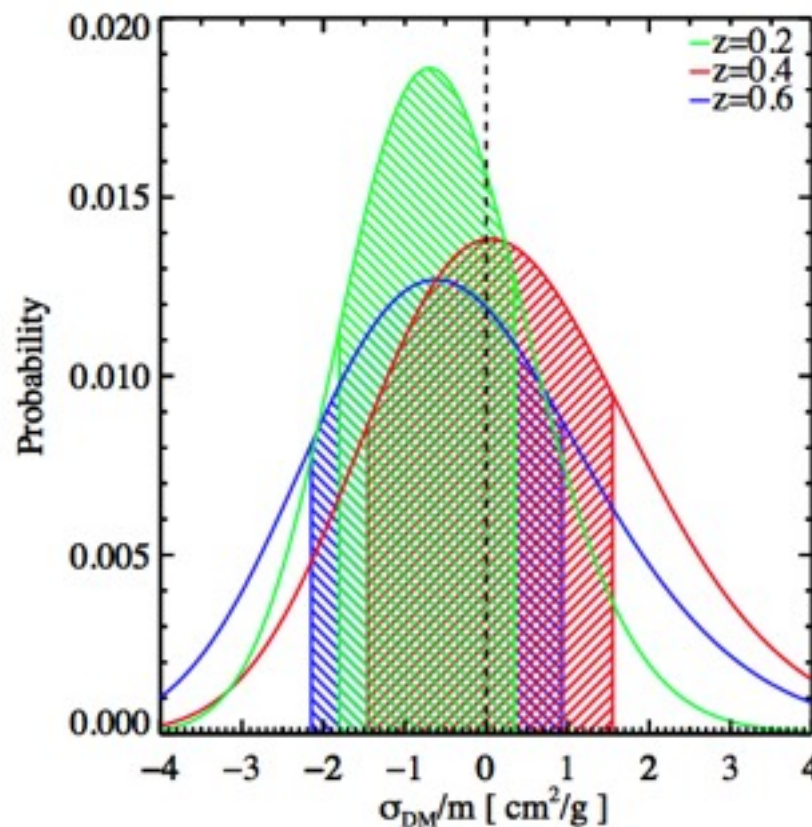
- Easily extended
- Shape measurement bias
- SIDM Simulations



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](https://twitter.com/davidharvey1986)

Data Science & Astronomy

kaggle

Customer Solutions ▾ Competitions Community ▾ Sign Up Login



Tim Sallmans Netherlands Stefan Henß Germany Wayne Z

Connect with the world's top data scientists.

All you need is data and a question. Our data scientists will provide the answer.

"Efficient, fast, straight to the point. Minimal back & forth required."
—Patrick Meier, iRevolution

Active Competitions

All Competitions

Active Competitions

	Flight Quest 2: Flight Optimization Optimize flight routes based on current weather and traffic.	27 days 61 teams \$250,000
	Belkin Energy Disaggregation Competition Disaggregate household energy consumption into individual appliances	2 months 86 teams \$25,000
	The Big Data Combine Engineered by BattleFin Predict short term movements in stock prices using news and sentiment data provided by RavenPack	33 days 135 teams \$18,500
	StumbleUpon Evergreen Classification Challenge Build a classifier to categorize webpages as evergreen or non-evergreen	2 months 165 teams \$5,000
	Cause-effect pairs Given samples from a pair of variables A, B, find whether A is a cause of B.	4.1 days 260 teams \$10,000

Competitions



Customer Solutions ▾CompetitionsCommunity ▾

Sign UpLogin



Observing Dark Worlds

Finished

Friday, October 12, 2012\$20,000 • 357 teamsSunday, December 16, 2012

Dashboard

HomeDataInformation

DescriptionEvaluationRulesPrizesAbout the SponsorAn Introduction to EllipticityGetting Started (with code)Submission InstructionsWinners

Can you find the Dark Matter that dominates our Universe? Winton Capital offers you the chance to unlock the secrets of dark worlds.

There is more to the Universe than meets the eye. Out in the cosmos exists a form of matter that outnumbers the stuff we can see by almost 7 to 1, and we don't know what it is. What we do know is that it does not emit or absorb light, so we call it **Dark Matter**.

Such a vast amount of aggregated matter does not go unnoticed. In fact we observe that this stuff aggregates and forms massive structures called **Dark Matter Halos**.

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](#)[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



We are trying something new! Come help us understand a very specific type of galaxy and experience 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](#)