

Evidence for Self-interacting Dark matter

Will Dawson

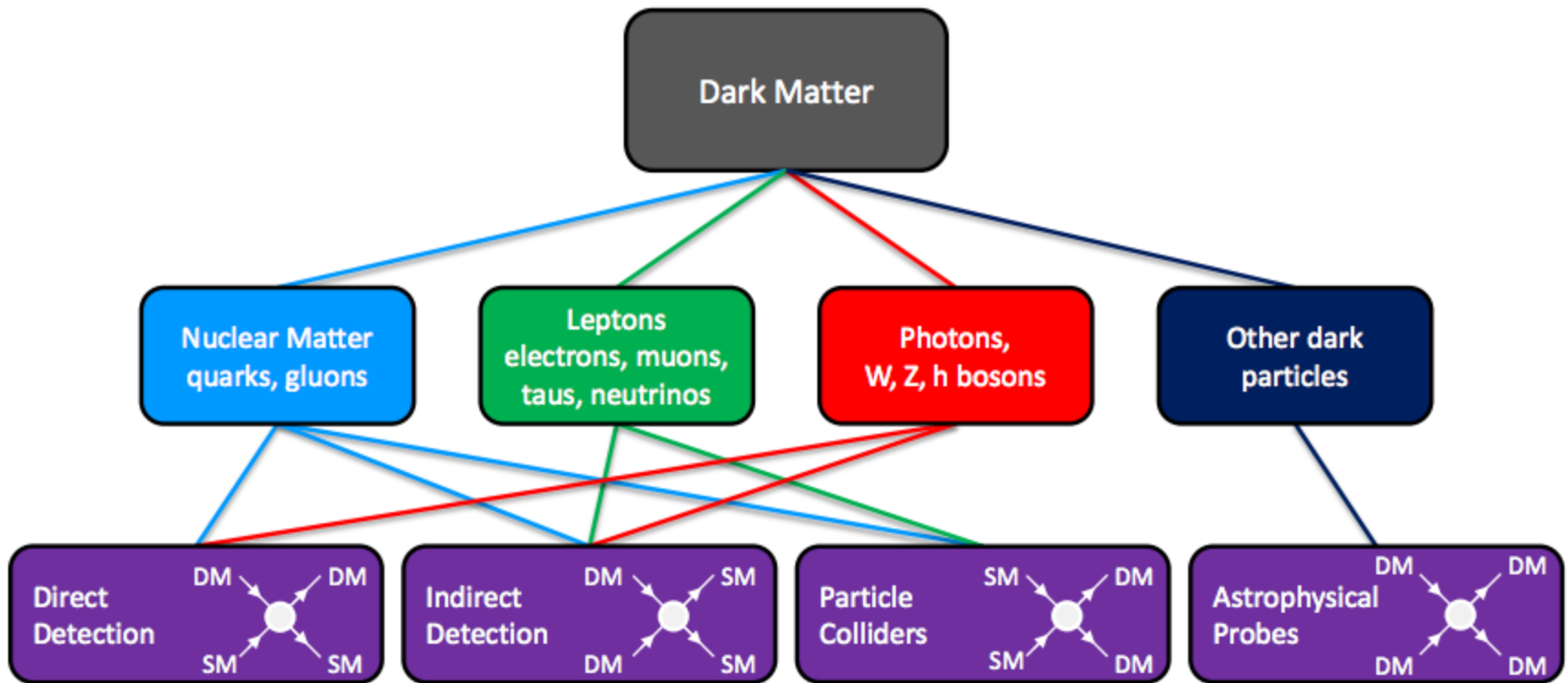
UC DAVIS
UNIVERSITY OF CALIFORNIA



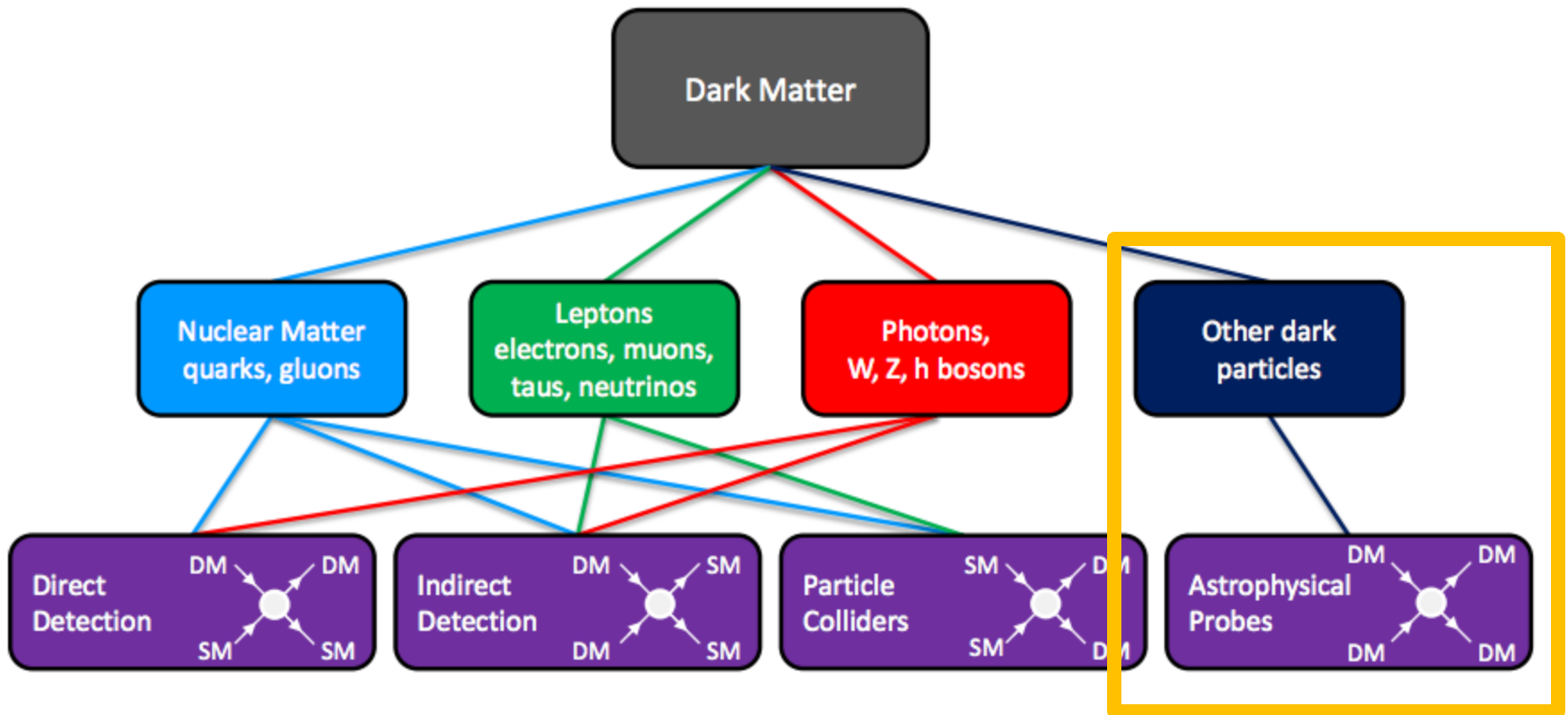
MERGING
CLUSTER
COLLABORATION

Identifying and Characterizing Dark Matter via
Multiple Probes
5/15/2013

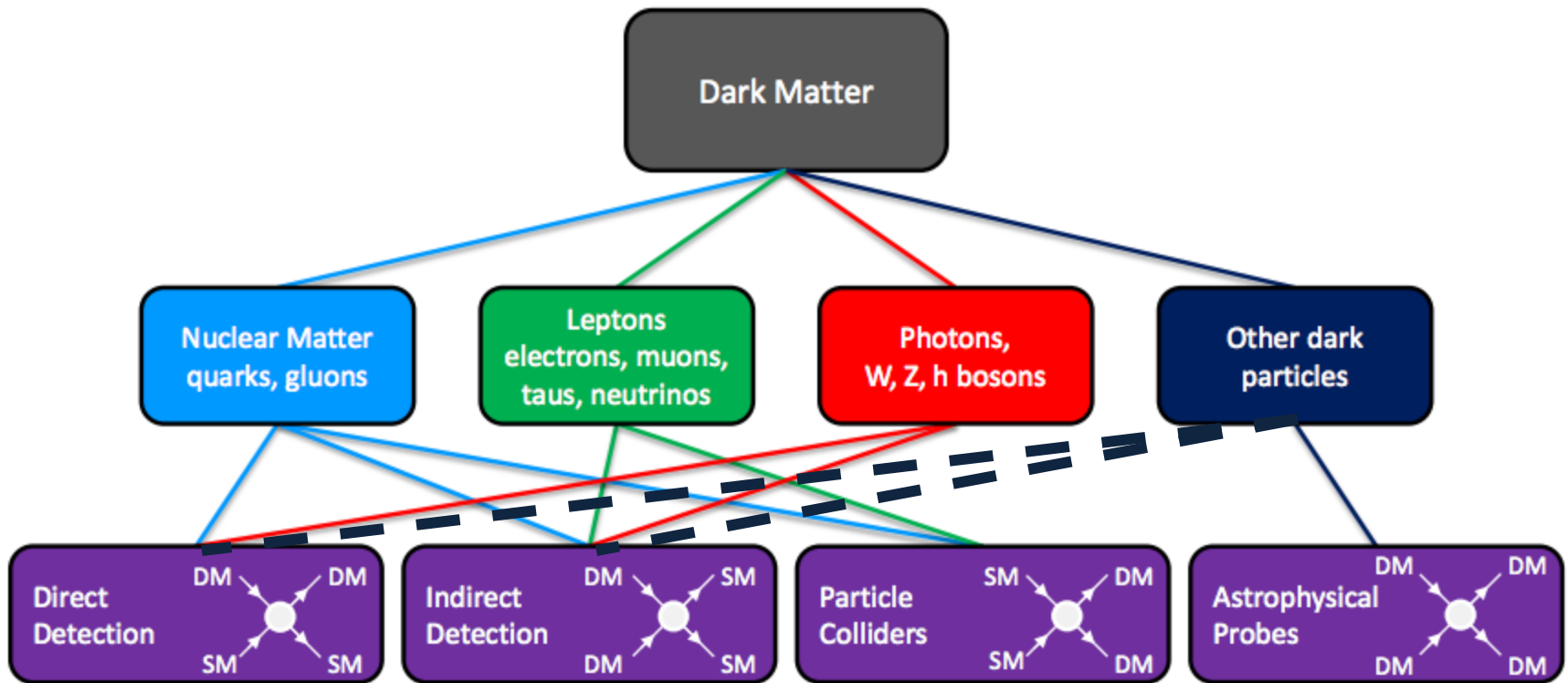
Complementary approaches to constraining dark matter



New fundamental force will be required

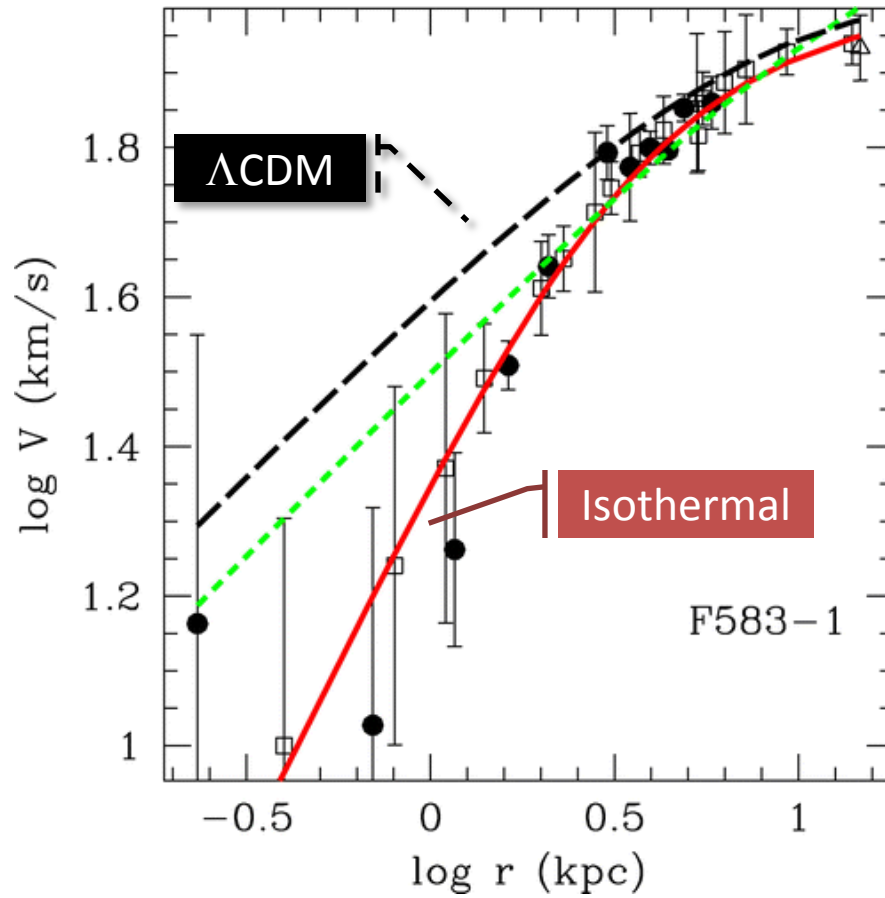


Why you might care.



WHY STUDY SIDM

Cold Dark Matter (CDM) halos too cuspy



Think mass
within radius r

Dwarf core problem
(Kuzio de Naray et al. 2008)

Multiple other CDM halo problems

Missing satellites “problem”

(Moore et al., Klypin et al. 1999)

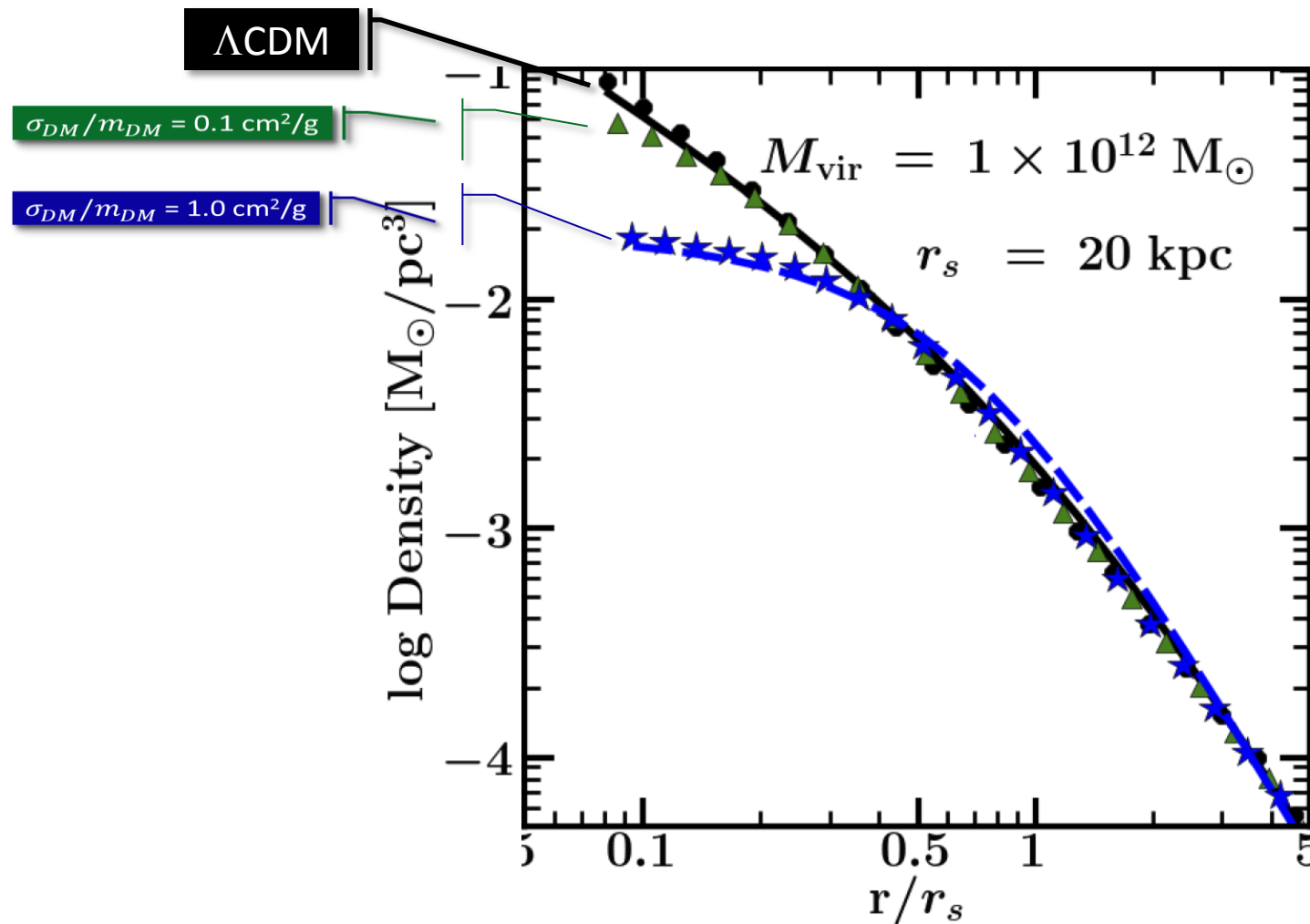
Too Big to Fail simulations of Milky Way

(Boylan-Kolchin et al. 2012)

Central densities of clusters

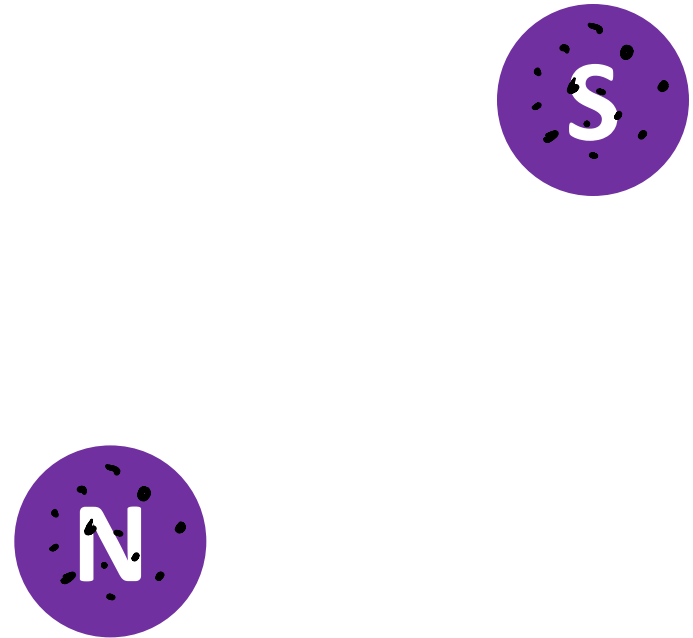
(Newman et al. 2012)

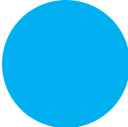

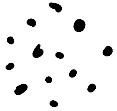
SIDM allows heat flow \rightarrow cored halo



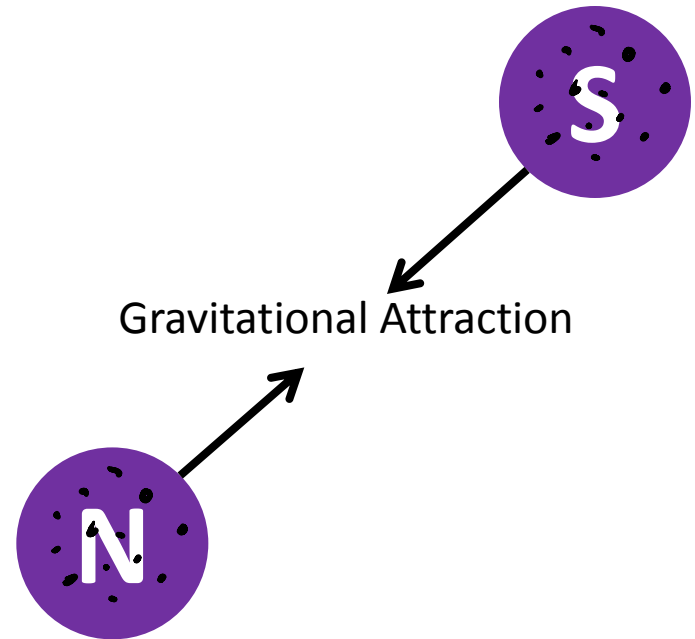
CONSTRAINING DARK MATTER WITH MERGING CLUSTERS

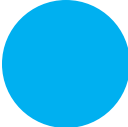
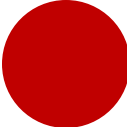

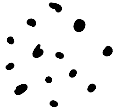
Merger Scenario



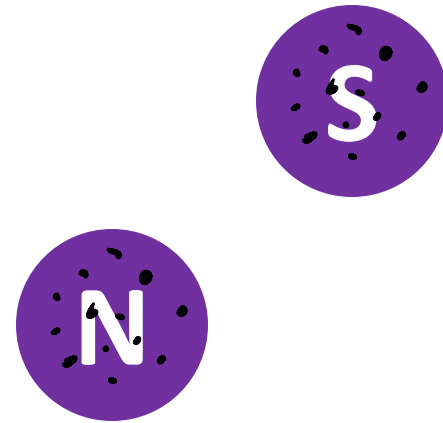
key	Dark Matter	Gas	Dark Matter + Gas	Galaxies
				

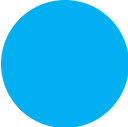
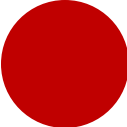

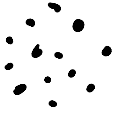
Merger Scenario



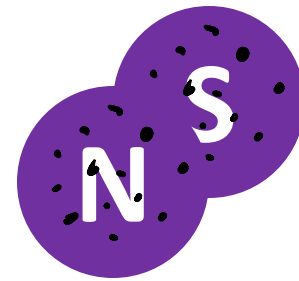
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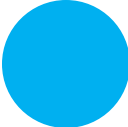
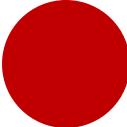

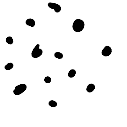
Merger Scenario



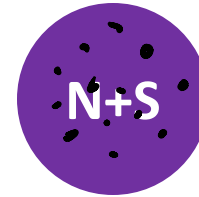
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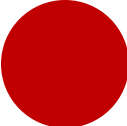

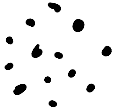
Merger Scenario



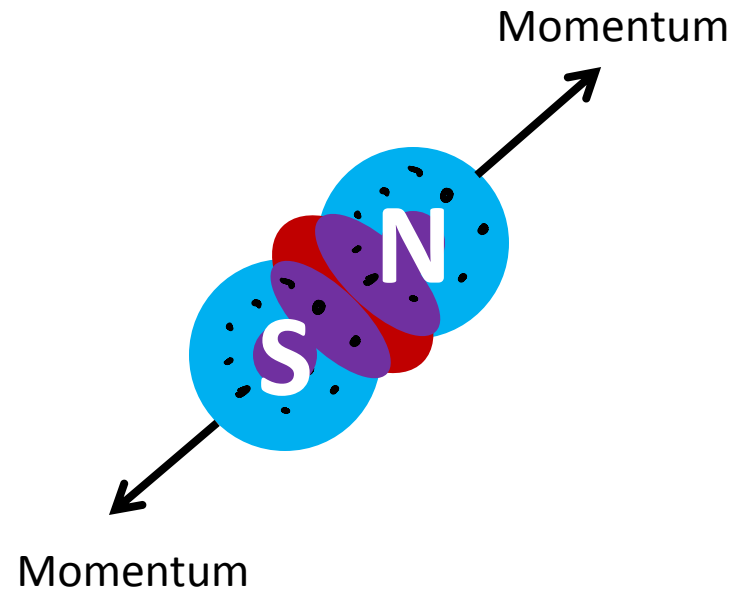
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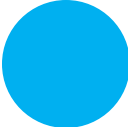
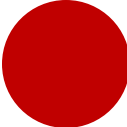

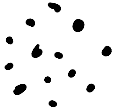
Merger Scenario



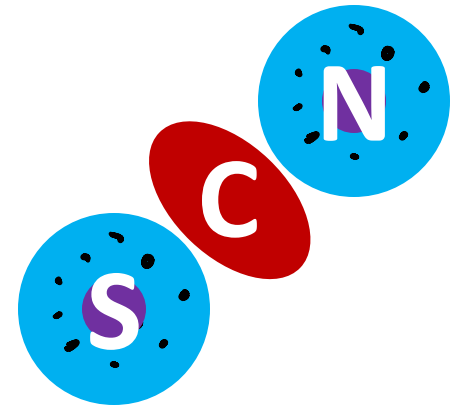
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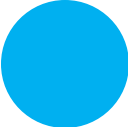
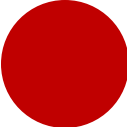

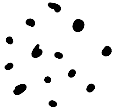
Merger Scenario



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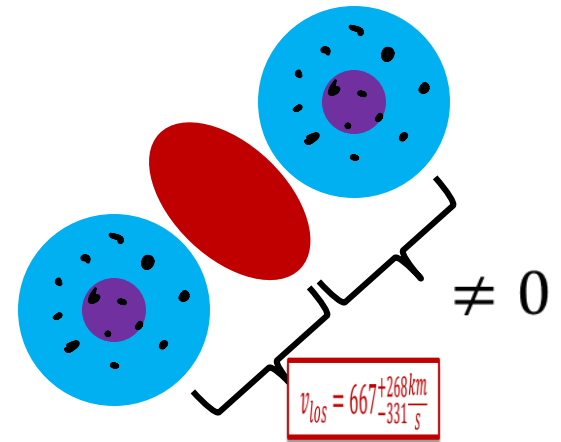
Merger Scenario

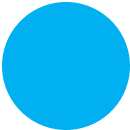
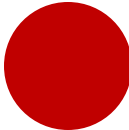




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4 ways to constrain σ_{DM} with dissociative mergers

Gas and dark matter offset



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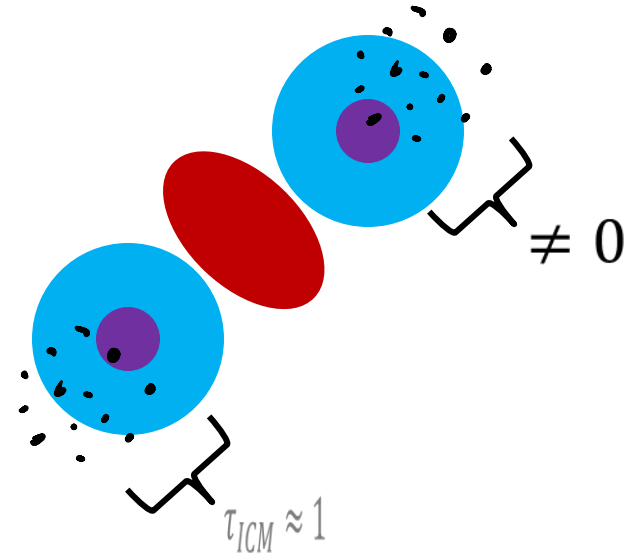
4 ways to constrain σ_{DM} with dissociative mergers

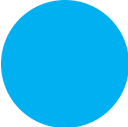
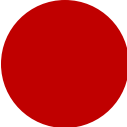

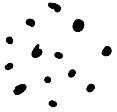
Gas and dark matter offset

Slowing of the subclusters

M/L ratio of subclusters

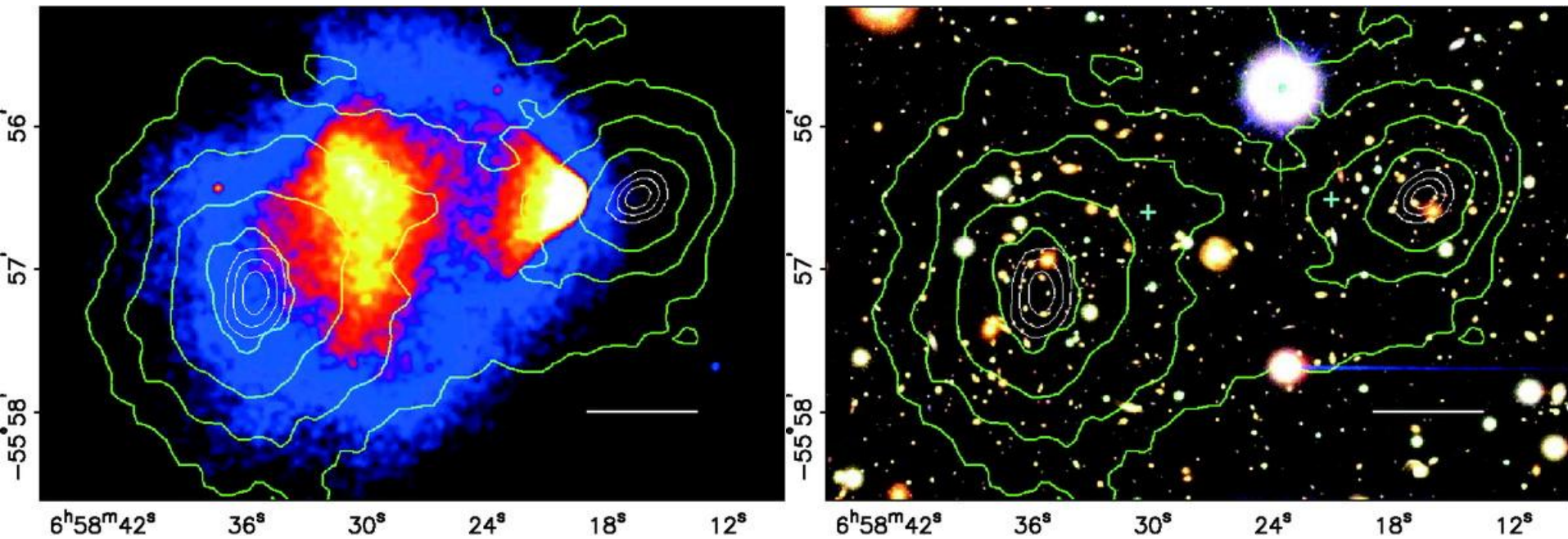
Galaxies and dark matter offset



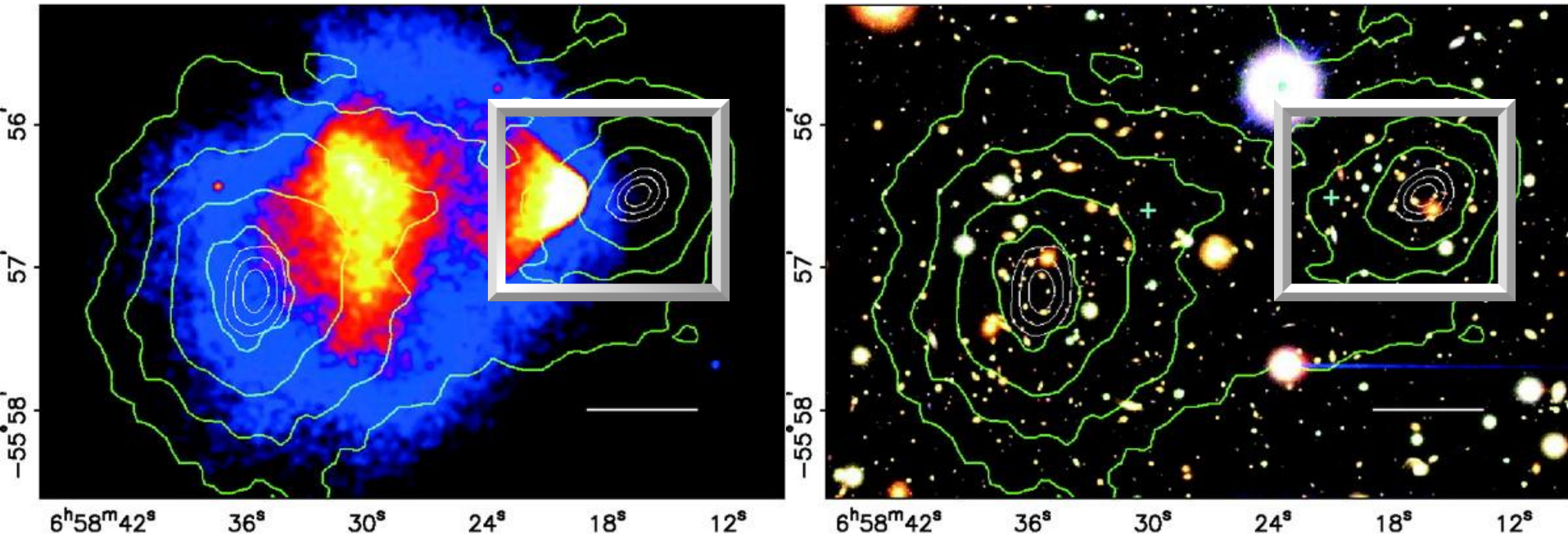
key	Dark Matter	Gas	Dark Matter + Gas	Galaxies
				

Bullet Cluster

Gas, mass, and galaxies

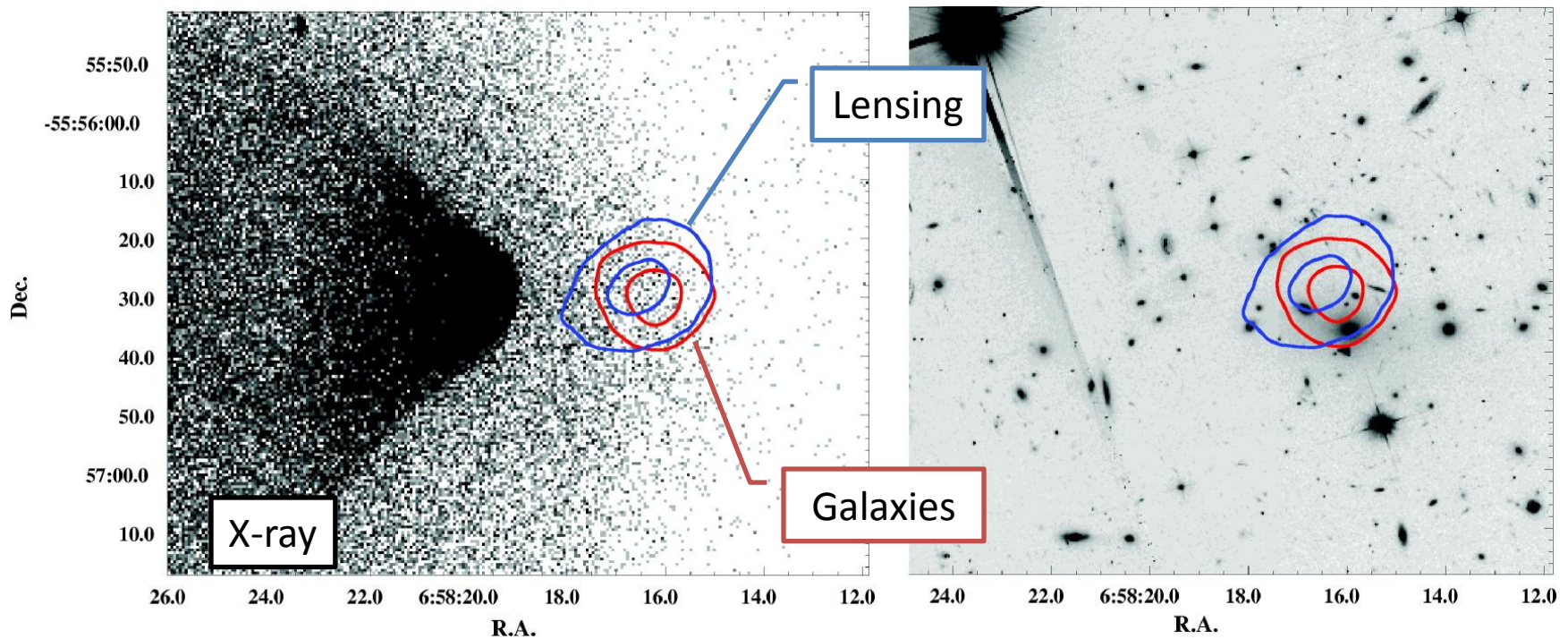


Randall et al. (2008) studied the galaxy-WL offset of the bullet

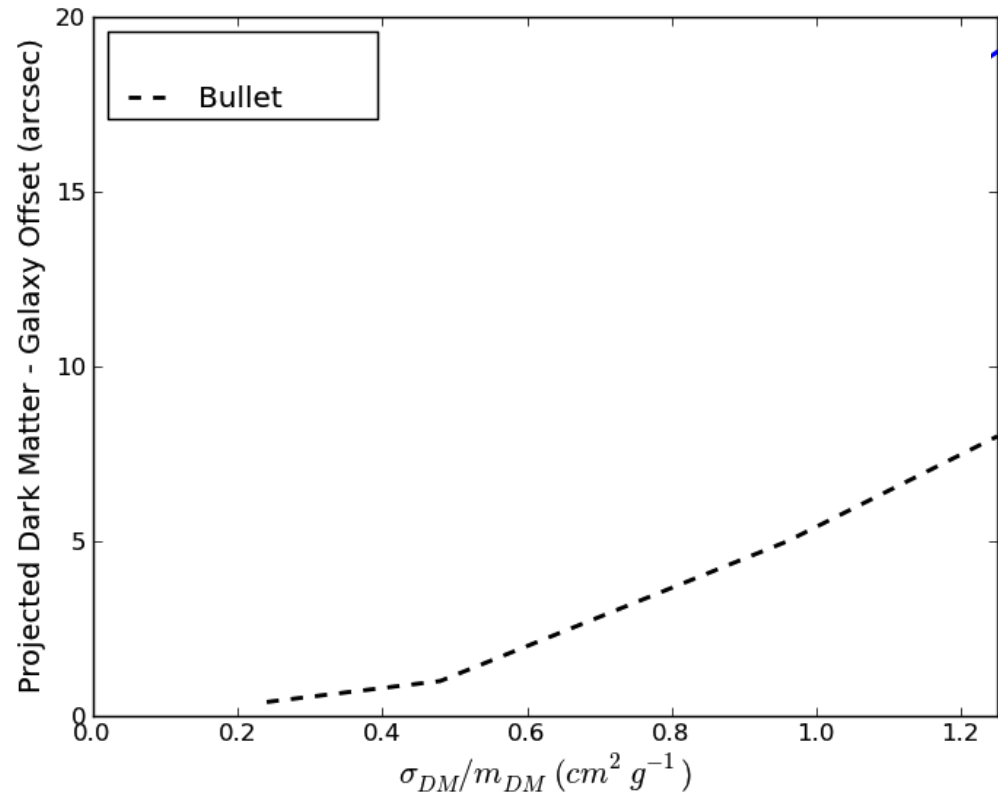


Bullet Cluster

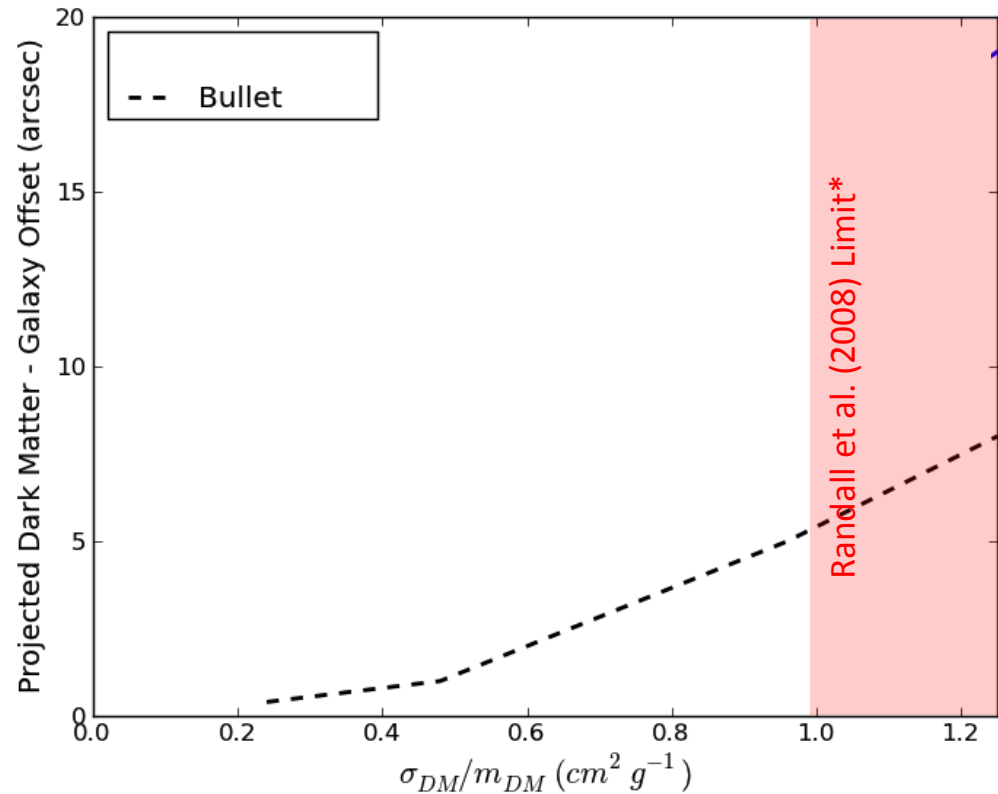
lensing and galaxy centroids consistent



N-body simulations show offset increases with increasing σ_{DM}

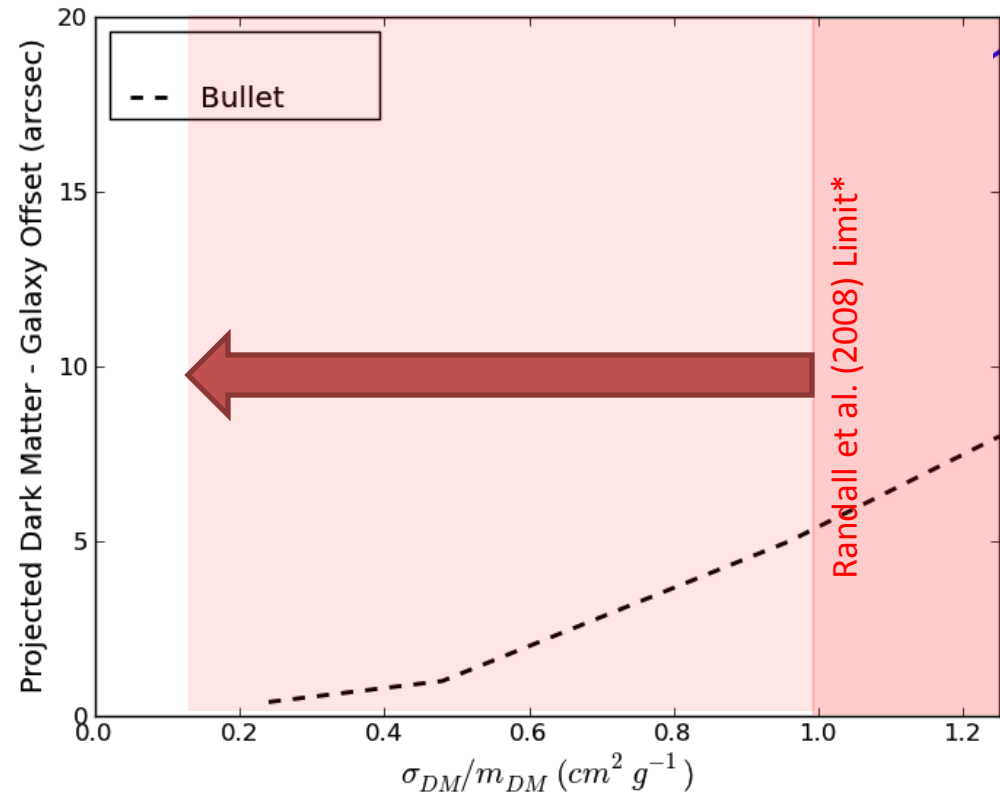


Bullet Cluster provides current tightest constraints to σ_{DM}



*I corrected for 30° projection angle (Dawson 2012b).

Constraint not as good as we need it to be

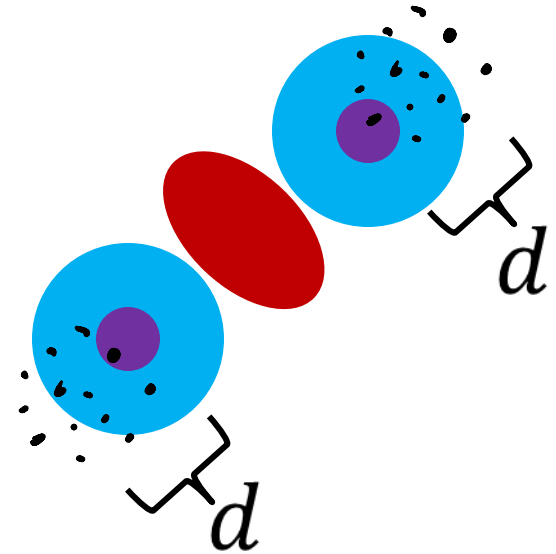


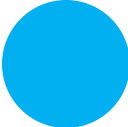
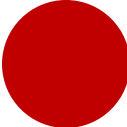

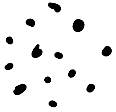
*I corrected for 30° projection angle (Dawson 2012b).

Need to measure d

Centroid errors a key problem

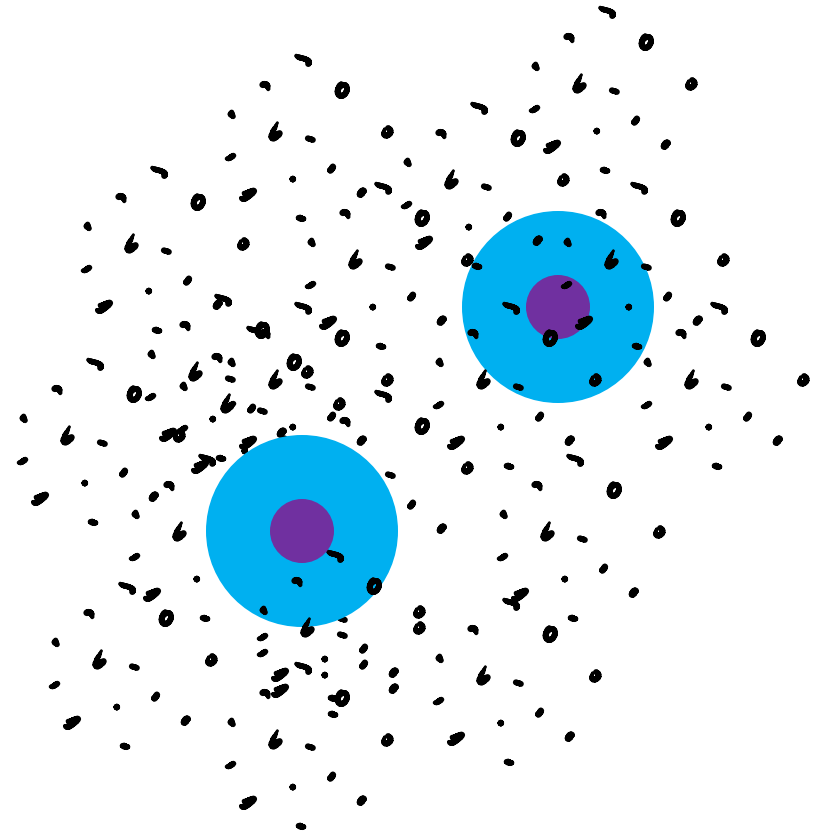
$d_{\pm}?$



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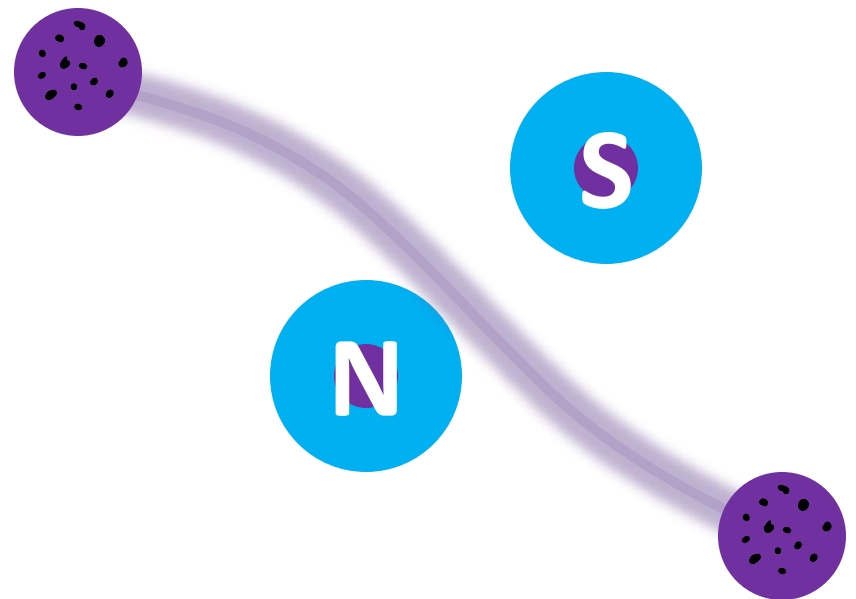
Centroid errors

- 1. Noise of the centroid measurements**
2. Line of sight structures
3. Mass of the other subcluster
4. Mass of the gas that is offset due to the merger



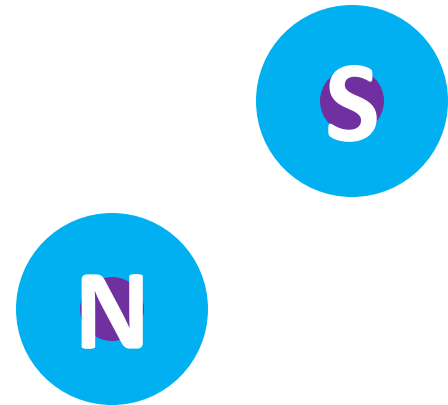
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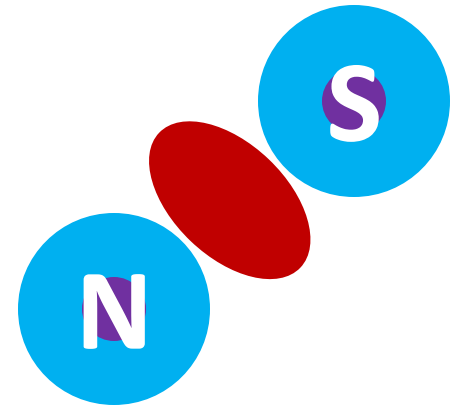
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Centroid errors

1. Noise of the centroid measurements
2. Line of sight structures
3. Mass of the other subcluster
4. **Mass of the gas that is offset due to the merger**



Centroid Error Budget

Galaxy Centroid

random ~ 1 to $4''$

Dark Matter Centroid

random $\sim 4'' + 5$ to $25''$

correctable systematic $\sim 3'' + 4''$

Significant fraction of error budget is random noise

Galaxy Centroid

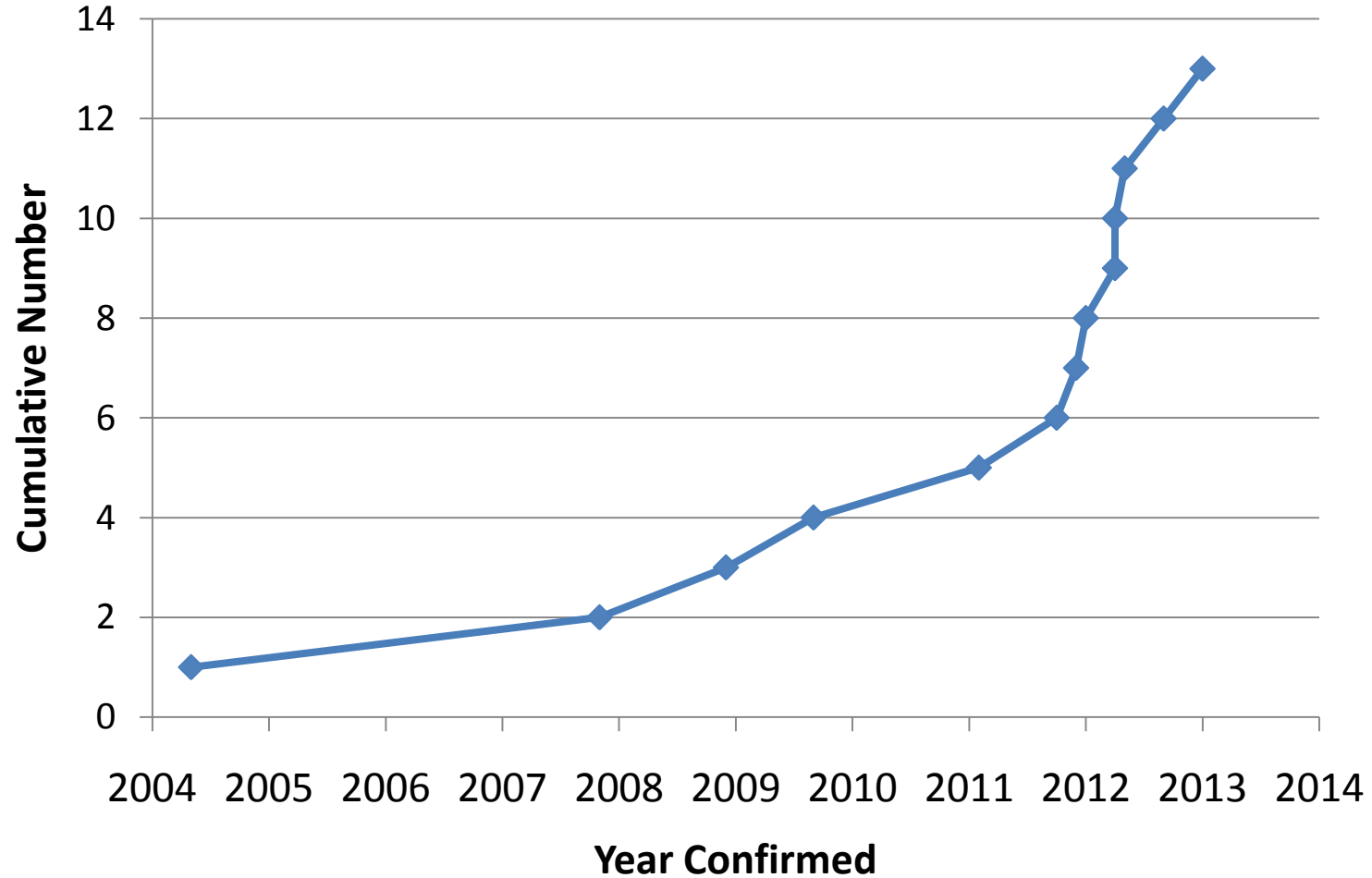
random ~ 1 to 4"

Dark Matter Centroid

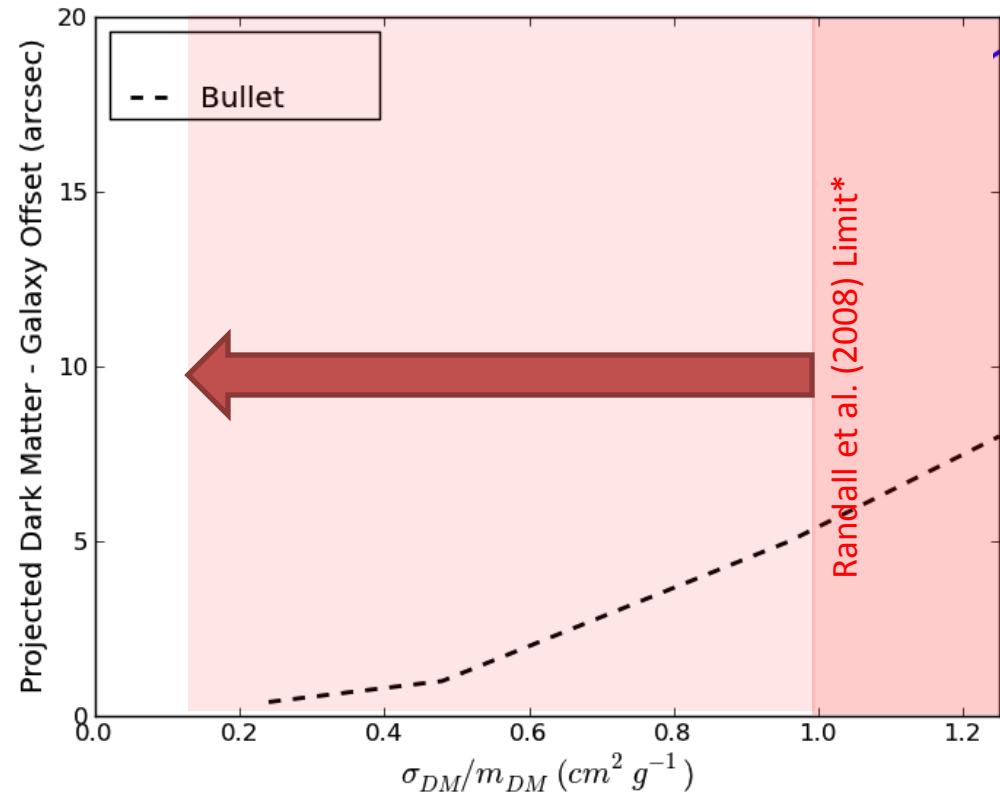
random ~ 4" + 5 to 25"

correctable systematic ~ 3" + 4"

Number of dissociative mergers increasing exponentially

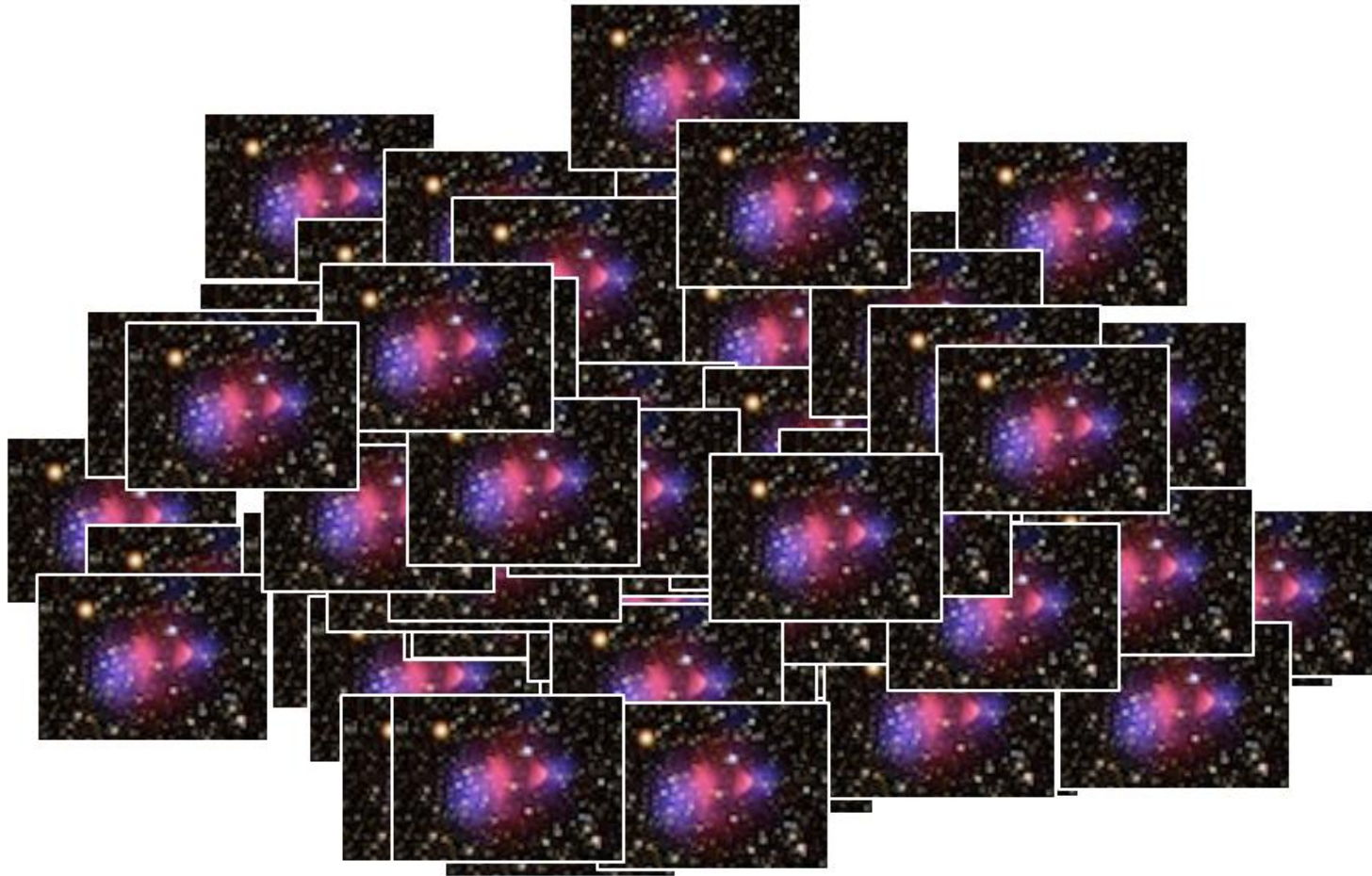


Improve centroid accuracy by factor of 10 (for Bullet-like merger)



*I corrected for 30° projection angle (Dawson 2012b).

Bullet Cluster is rare
getting 100 is a problem

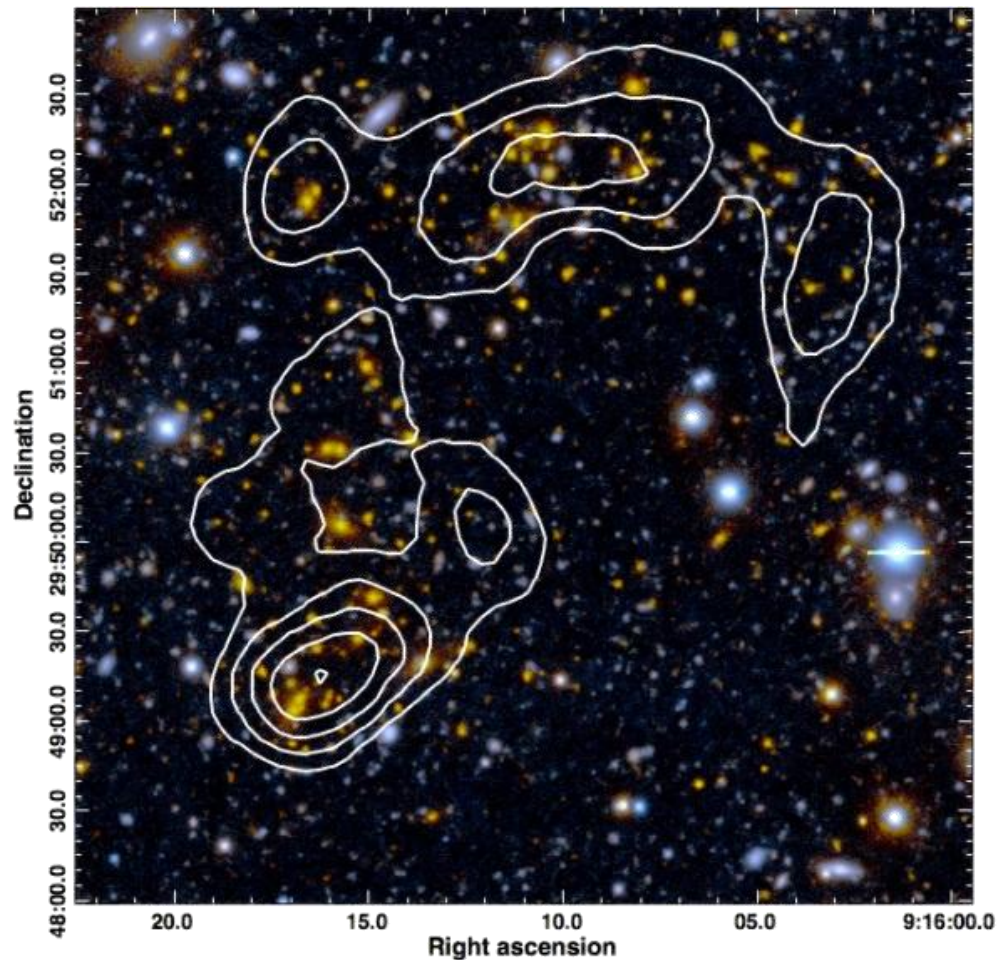


GAME OVER?

MUSKET BALL CLUSTER

DLSC J0916.2+2951

*Deep Lens
Survey*



Galaxy
Density
Contours

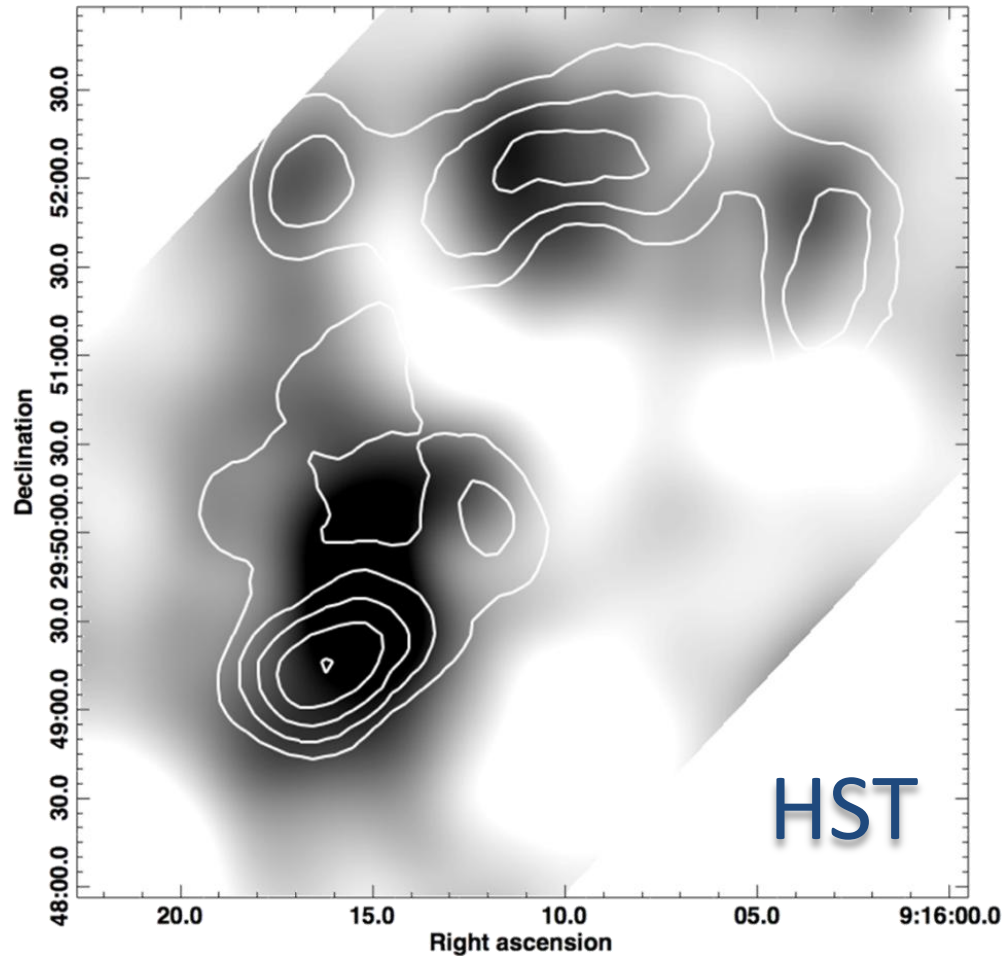
$$z_{\text{phot}} = 0.53 \pm 0.1$$

Weak Lensing *Tomography* Mass Map

Mass Map

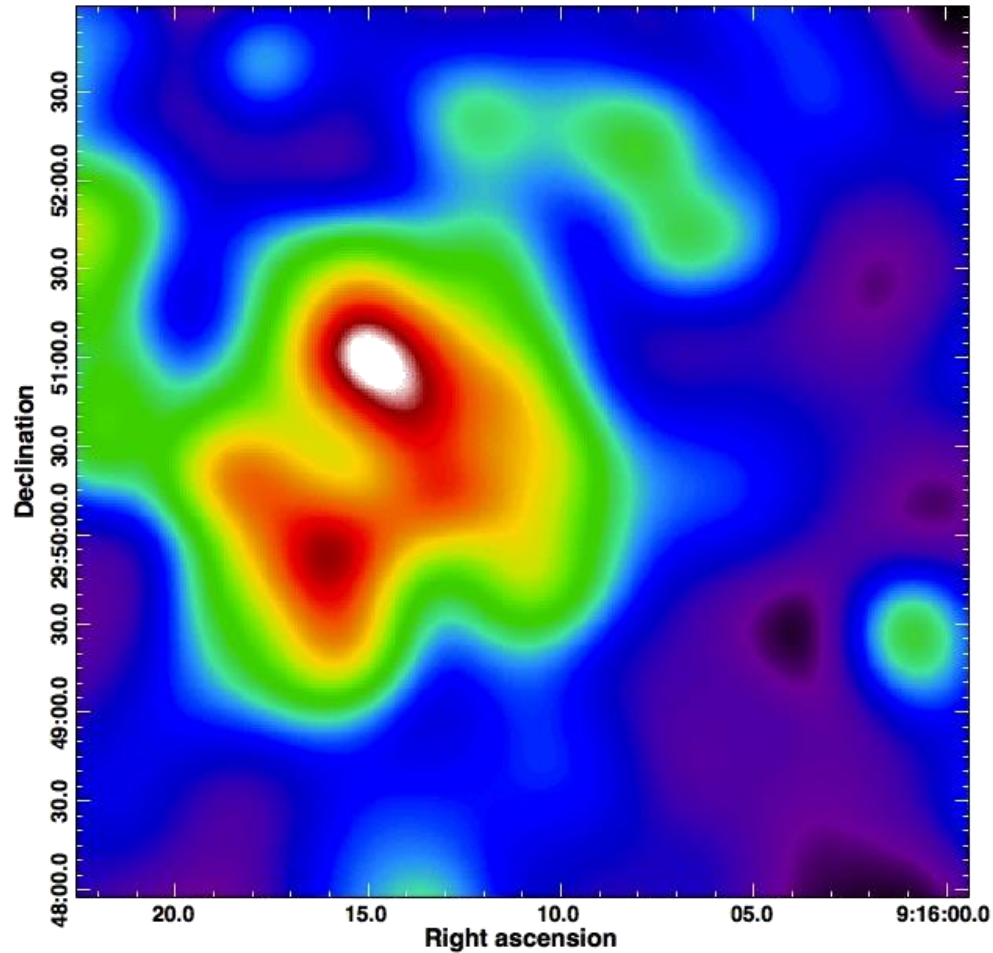
with

Galaxy Density
Contours (white)

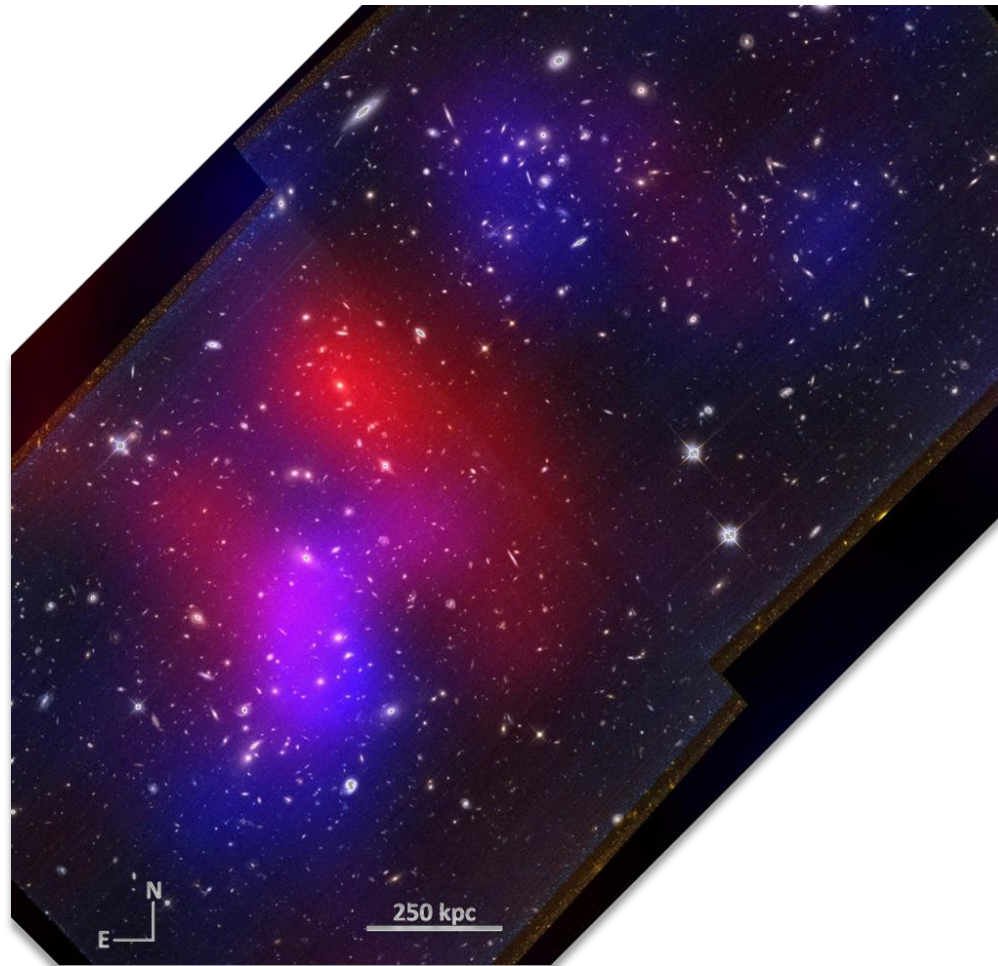


X-ray Luminosity Map

Chandra
40 ks



Dissociative Merger



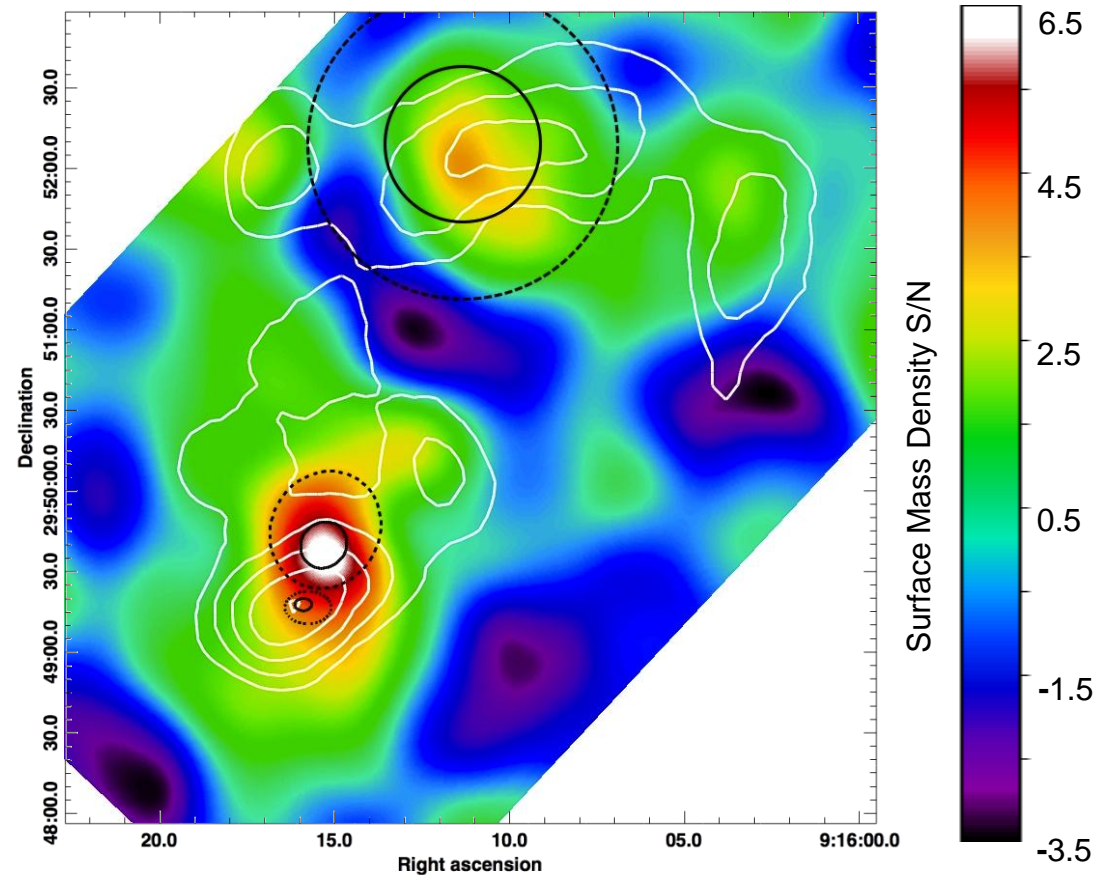
MUSKET BALL: GALAXY & DARK MATTER LOCATIONS

The Musket Ball mass & galaxy maps generally agree, but...

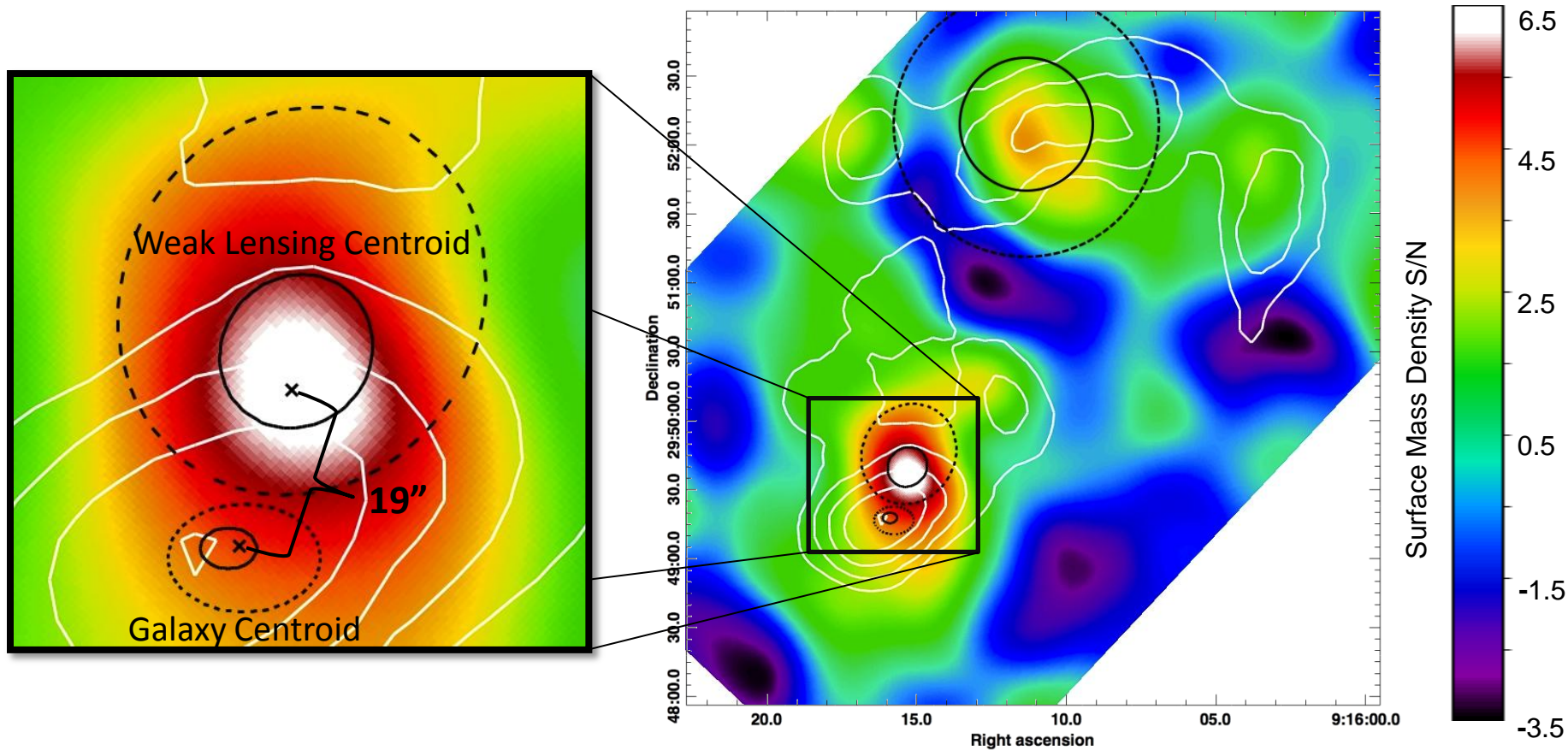
Surface mass density
S/N map

Galaxy density
(white contours)

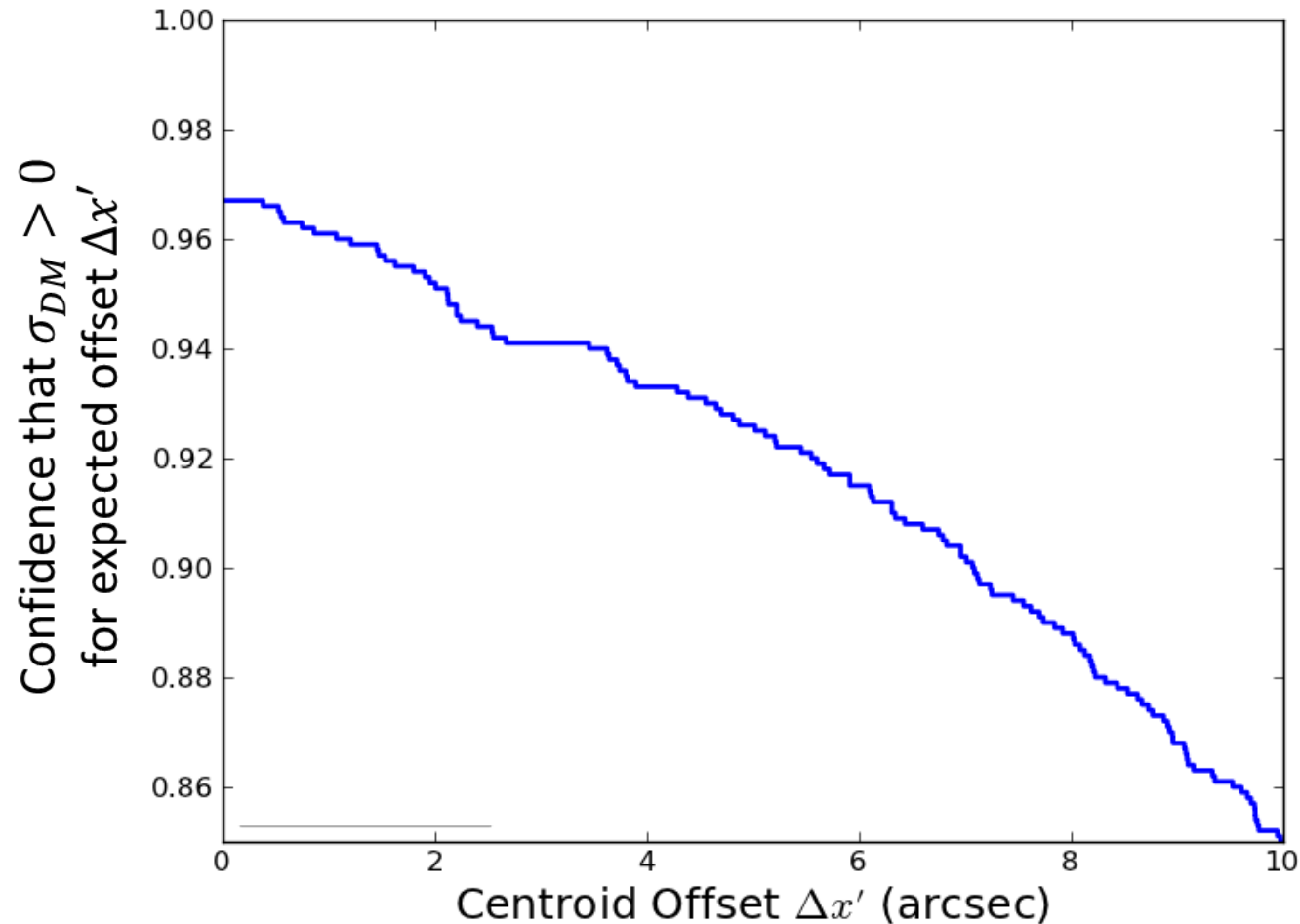
Centroid errors;
68%, 95% Confidence
(black contours)



The Musket Ball shows an offset between galaxies and WL



Significance of weak lensing – galaxy offset



Two remaining issues

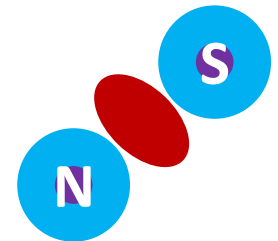
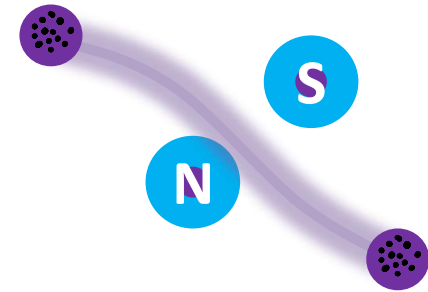
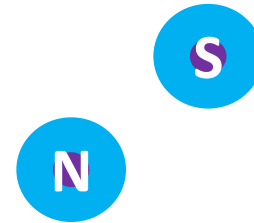
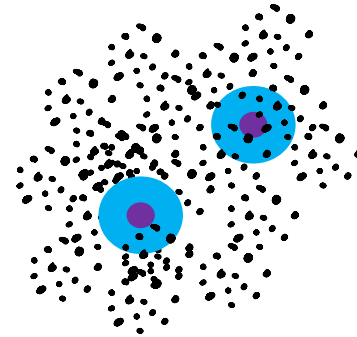
Other systematics and sources of noise

Contradicts Bullet Cluster null offset

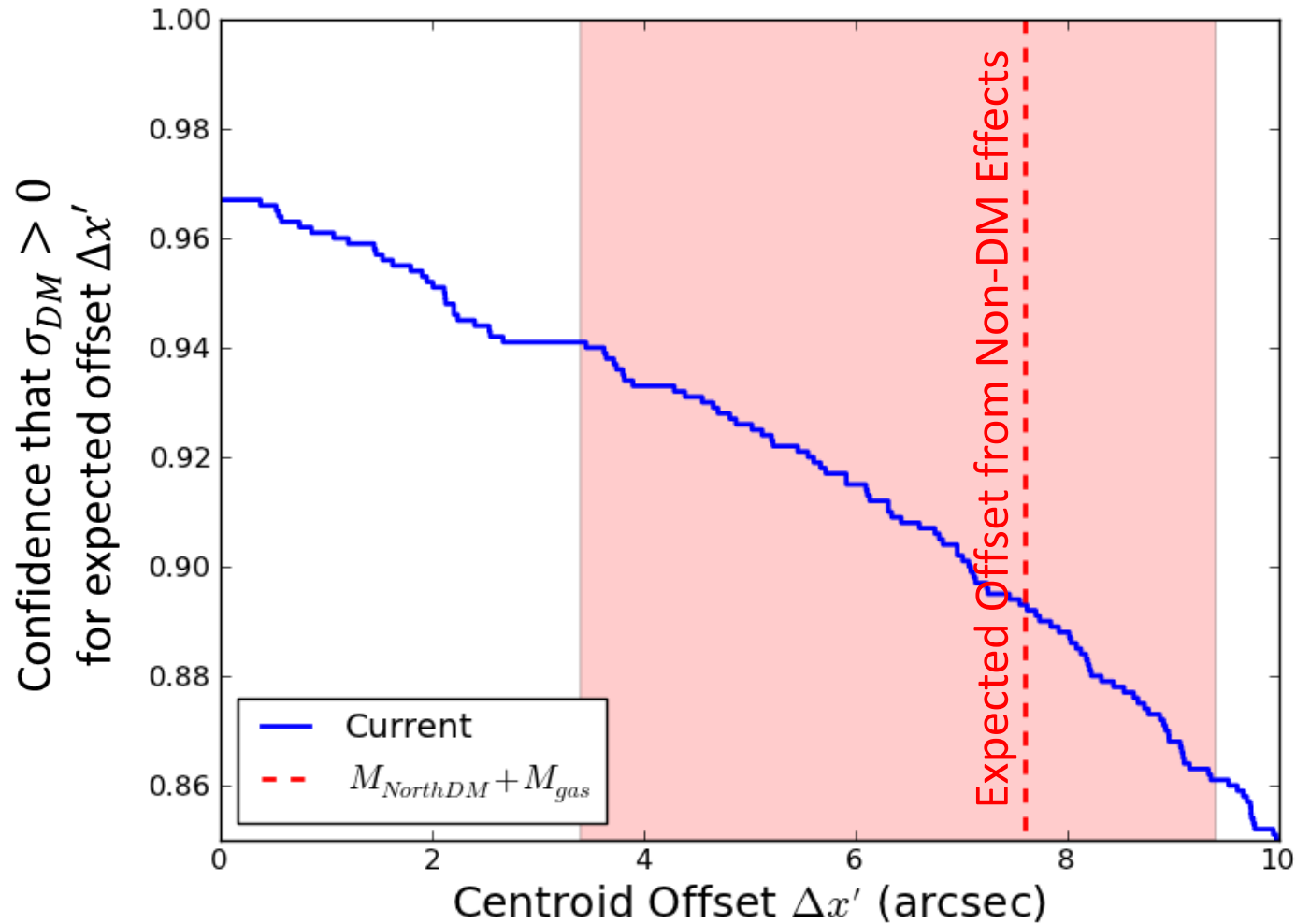
Randall et al. (2008) SIDM simulations

Centroid errors

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2. Line of sight structures
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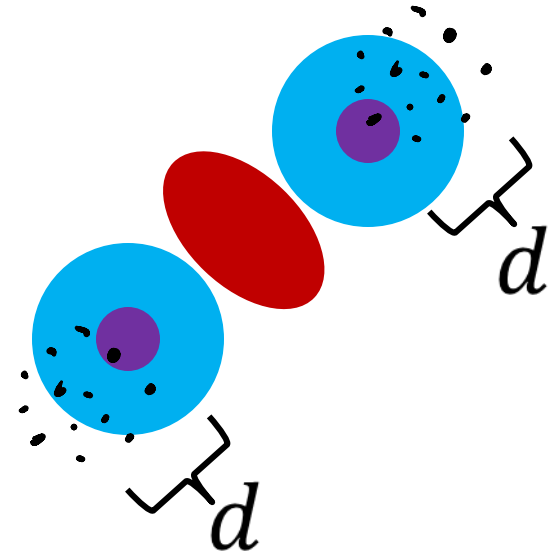
Significance Accounting for Expected Offset

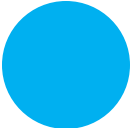
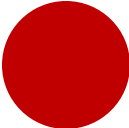

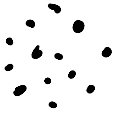


INCONSISTENT WITH THE BULLET CLUSTER?

Need to measure d
to actually measure σ_{DM}

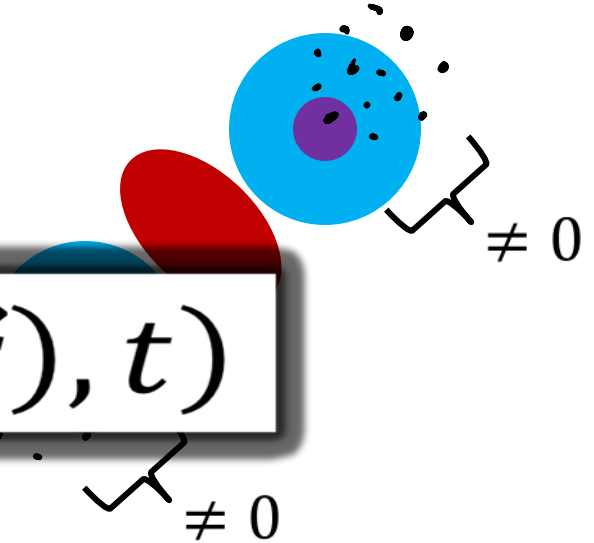
$$d(\sigma_{DM})$$

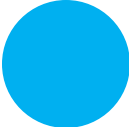
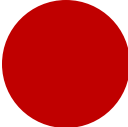

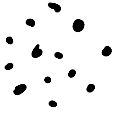


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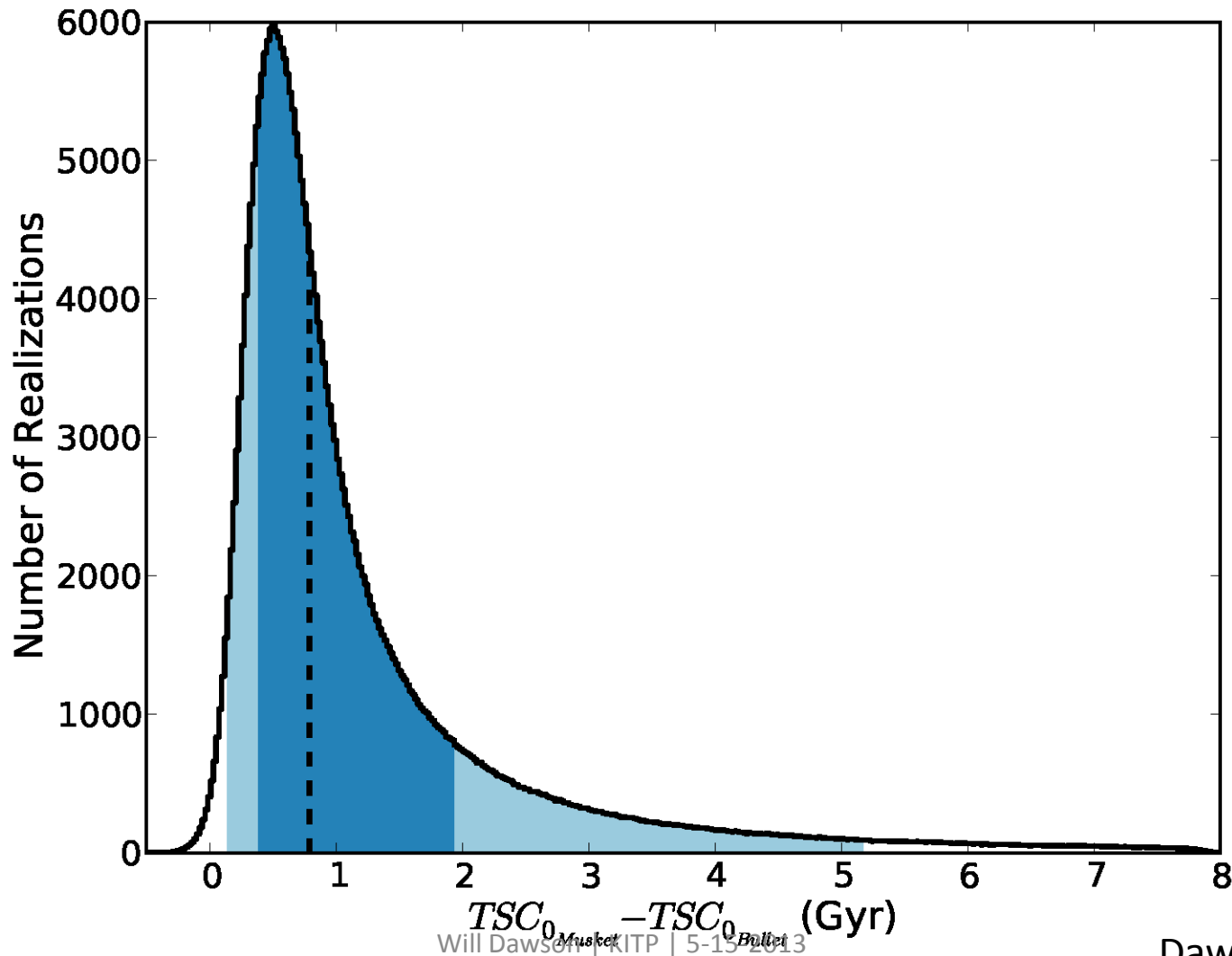
d is a
very complex function

$$d(\sigma_{DM}, v(t), \Sigma_{DM}(\vec{r}), t)$$



key	Dark Matter	Gas	Dark Matter + Gas	Galaxies
				

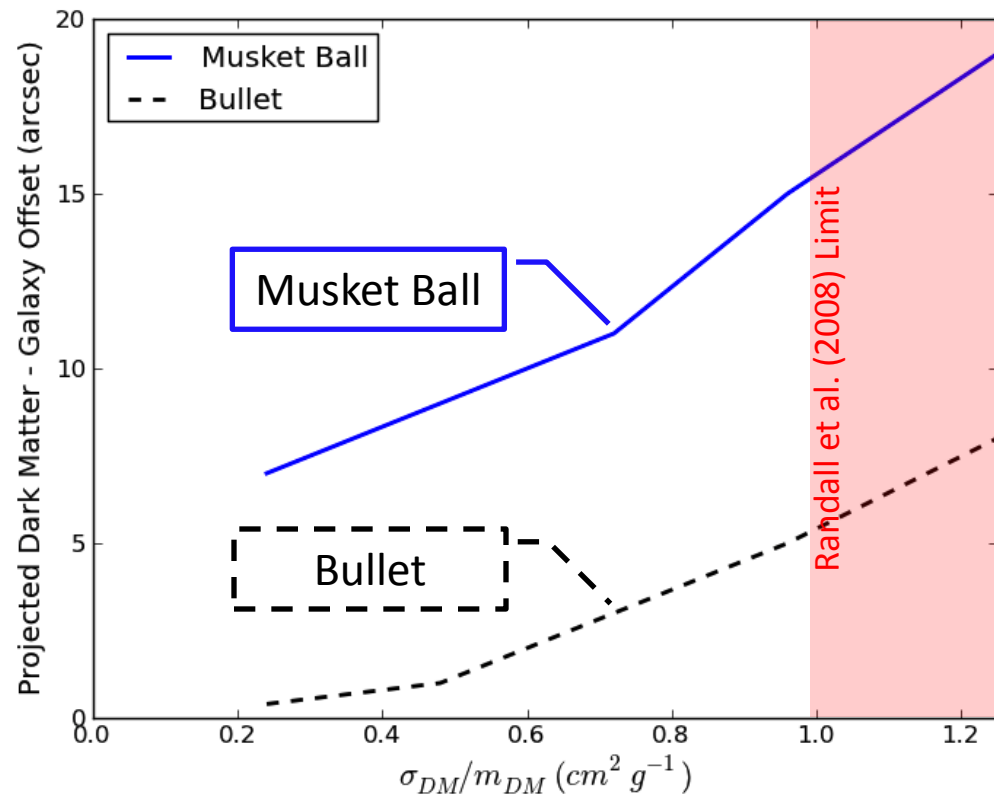
Musket Ball is ~ 0.8 Gyr further progressed than Bullet



Musket Ball provides considerably more constraining power

Expectation of galaxy-dark matter offset for Musket Ball

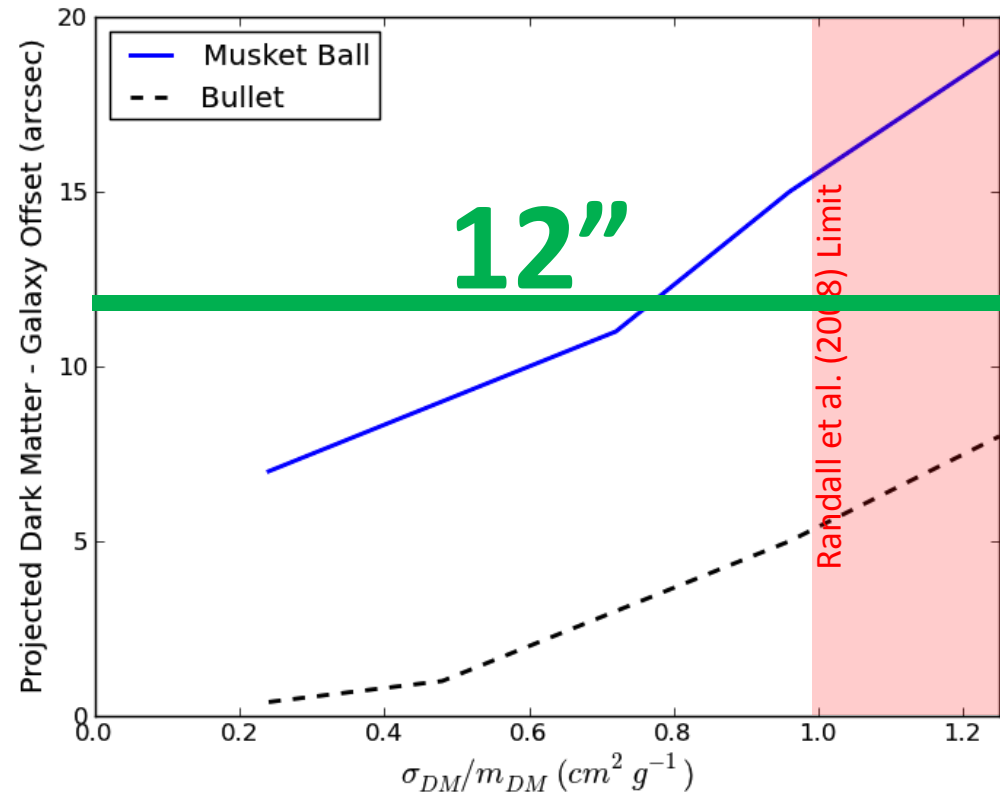
Extrapolated from Randall et al. (2008)



Expectations are consistent with observations

Expectation of galaxy-dark matter offset for Musket Ball

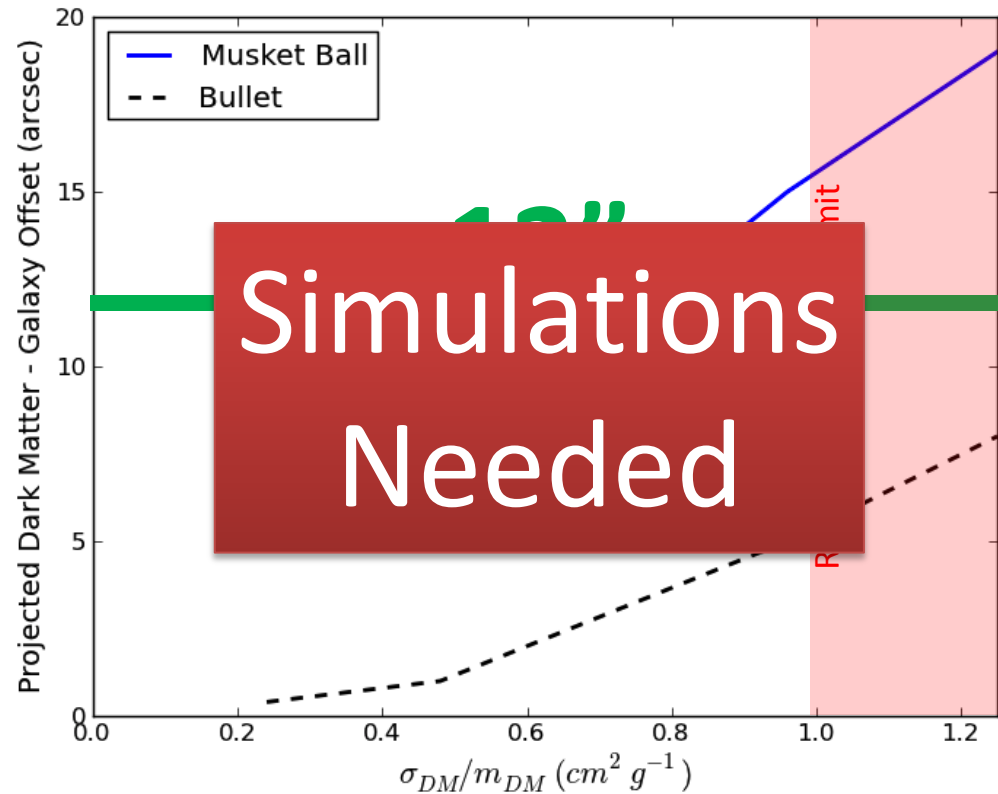
Extrapolated from Randall et al. (2008)



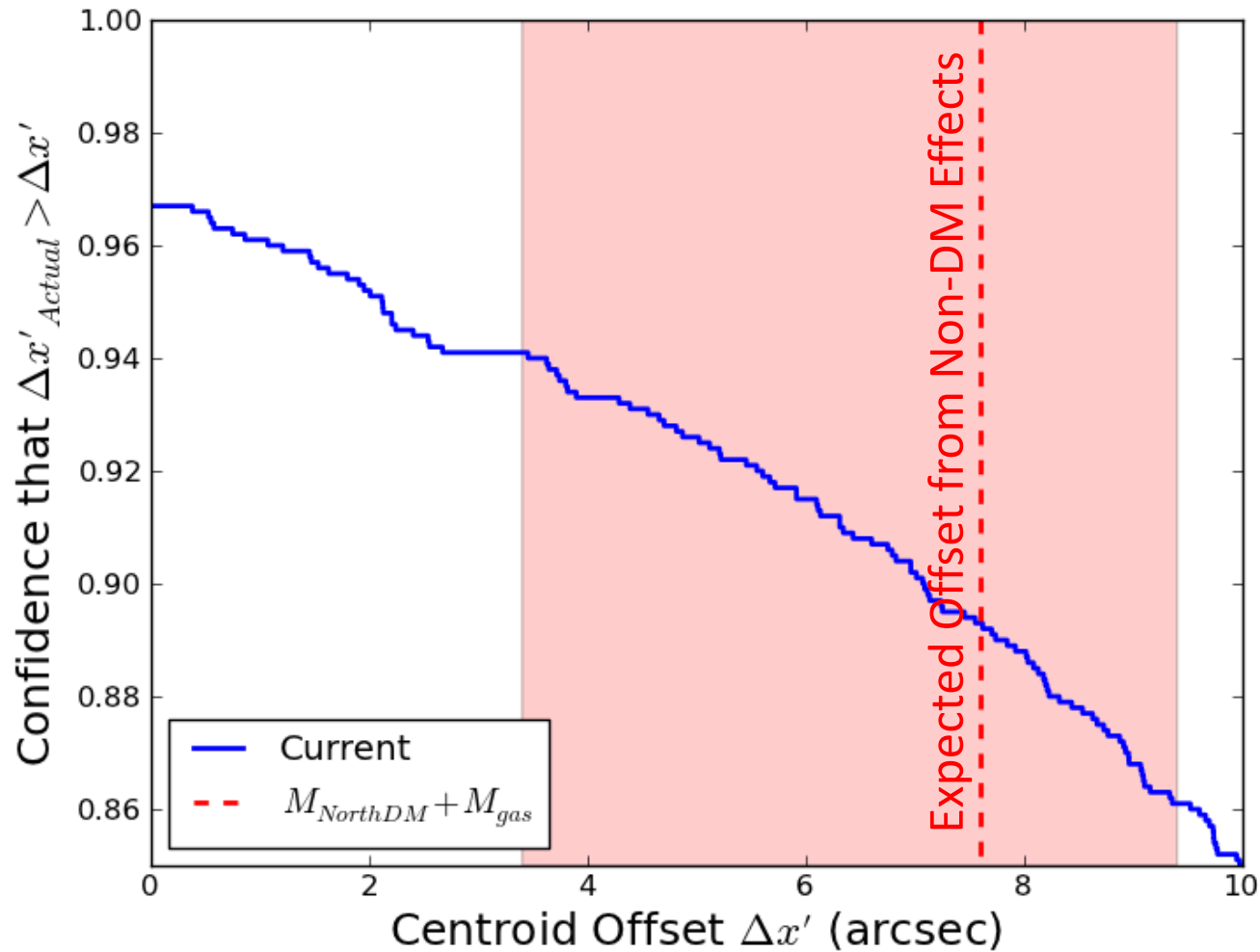
Back of the envelope calculations need verification

Expectation of galaxy-dark matter offset for Musket Ball

Extrapolated from Randall et al. (2008)

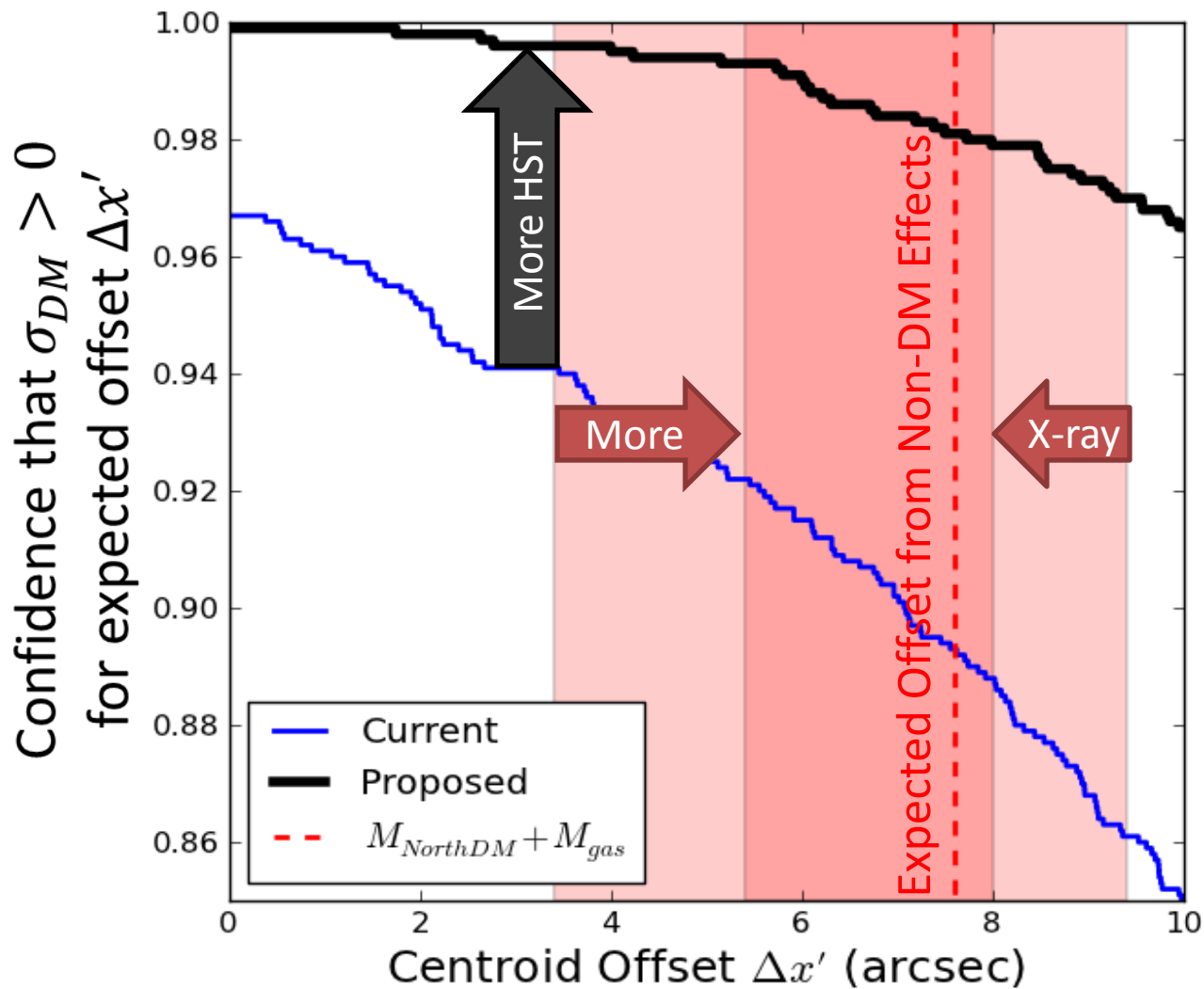


Although consistent still not significant



IMPROVING MEASUREMENT SIGNIFICANCE

Better observations improve significance



Significant fraction of error budget is random noise

Galaxy Centroid

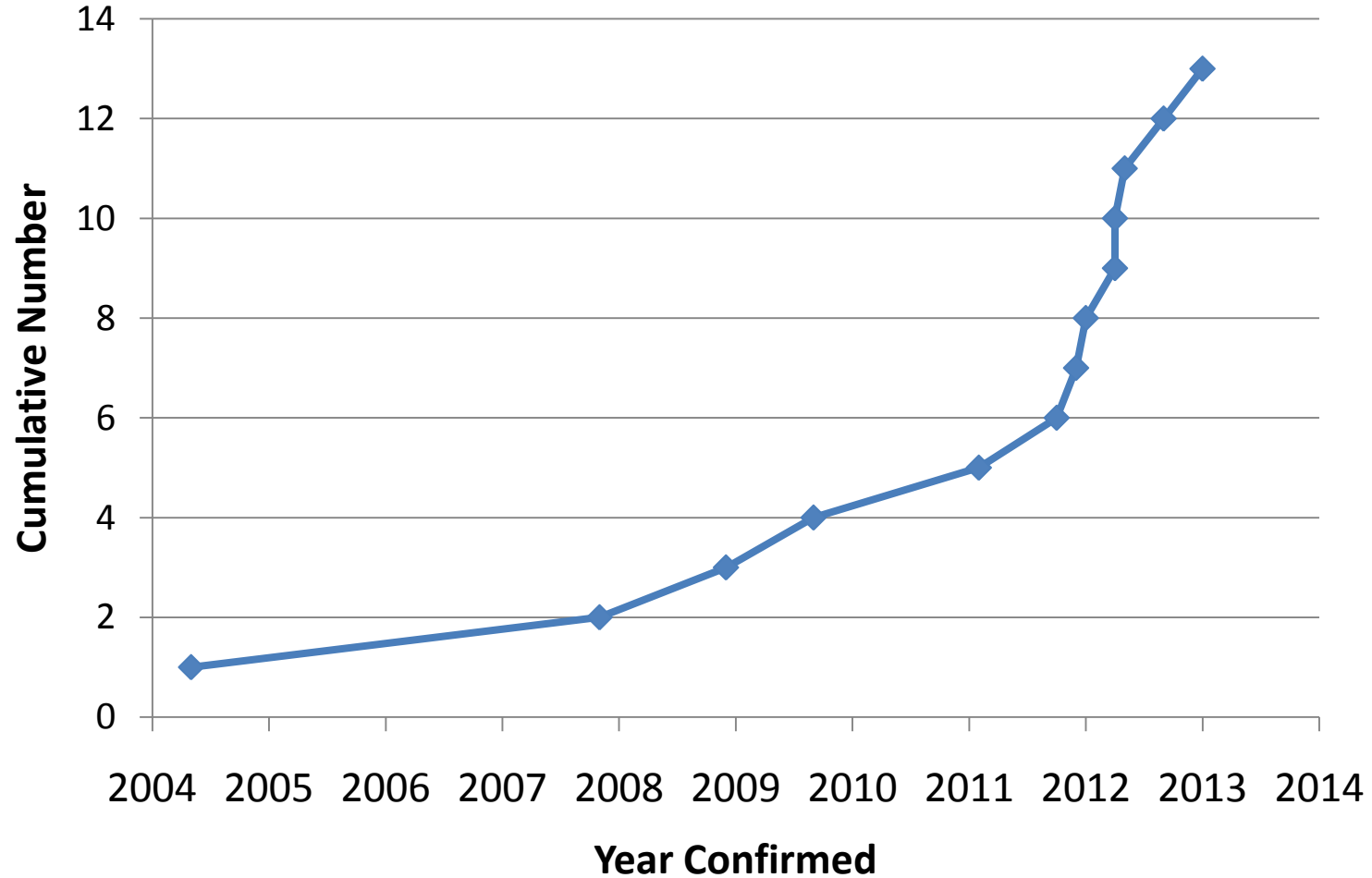
random ~ 1 to 4"

Dark Matter Centroid

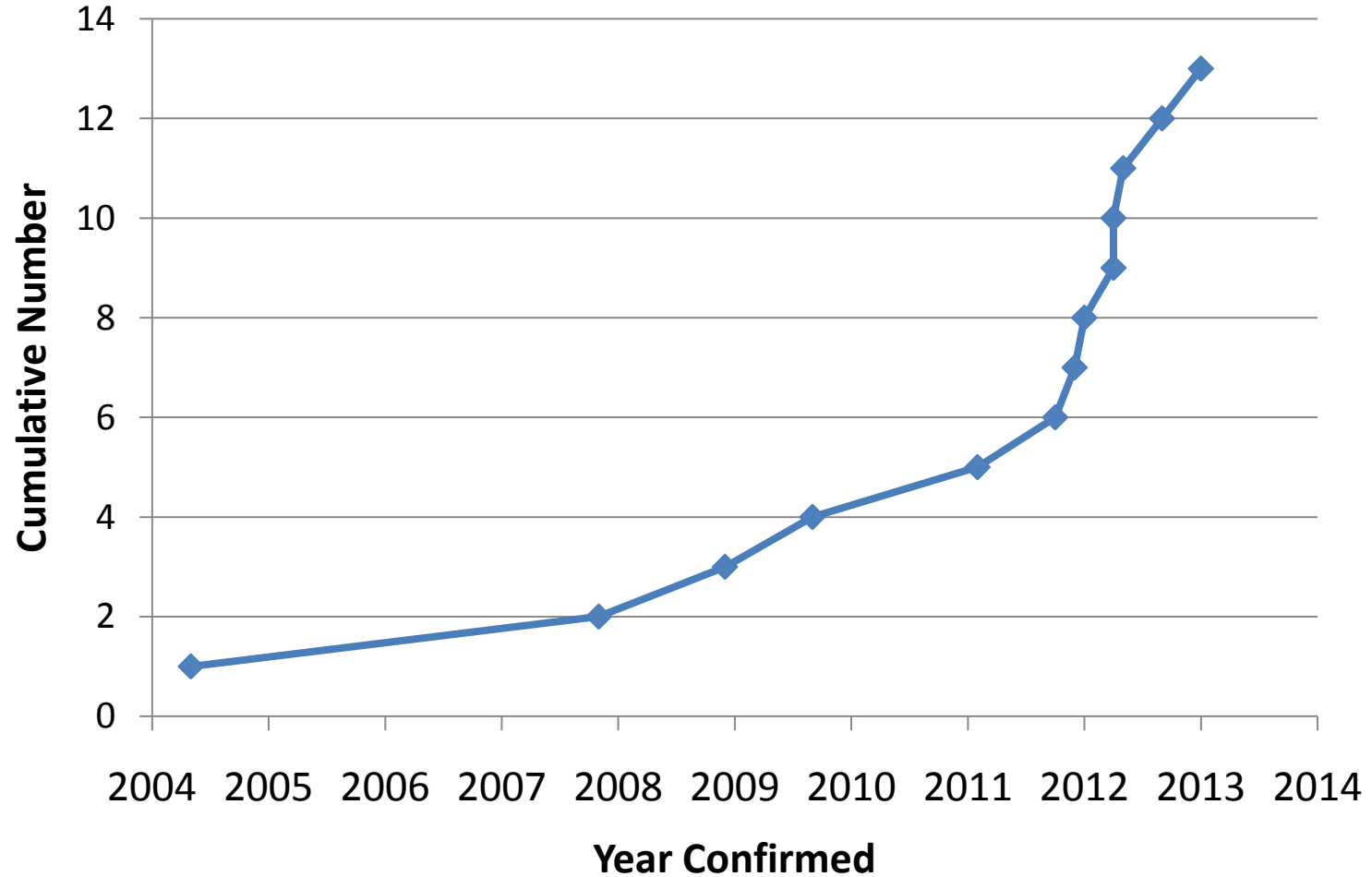
random ~ 4" + 5 to 25"

correctable systematic ~ 3" + 4"

Number of dissociative mergers increasing exponentially



Time for a New Regime



A new regime of dark matter constraint with mergers



Expert and balanced team



Observation

Will Dawson (PI, Co-founder, UCD)

Marusa Bradac (UCD)

James Jee (UCD)

Julian Merten (Caltech/JPL)

Dave Wittman (UCD)

Reinout van Weeren (CfA)

Theory/Simulation

James Bullock (Co-founder, UCI)

Marcus Bruggen (Hamburg/Jacobs)

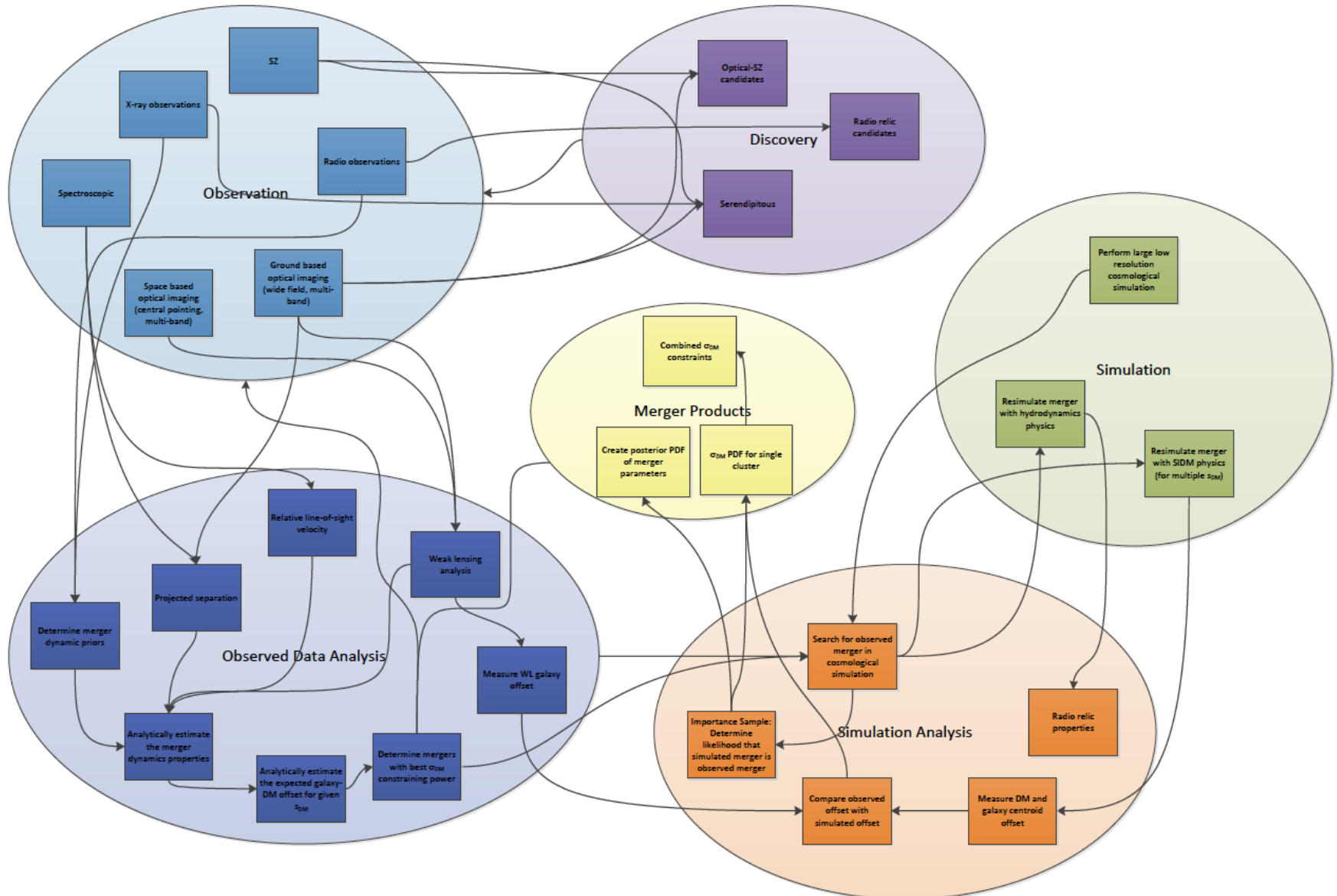
Oliver Elbert (UCI)

Manoj Kaplinghat (UCI)

Annika Peter (UCI, OSU)

Miguel Rocha (UCI)

The MC² analysis plan



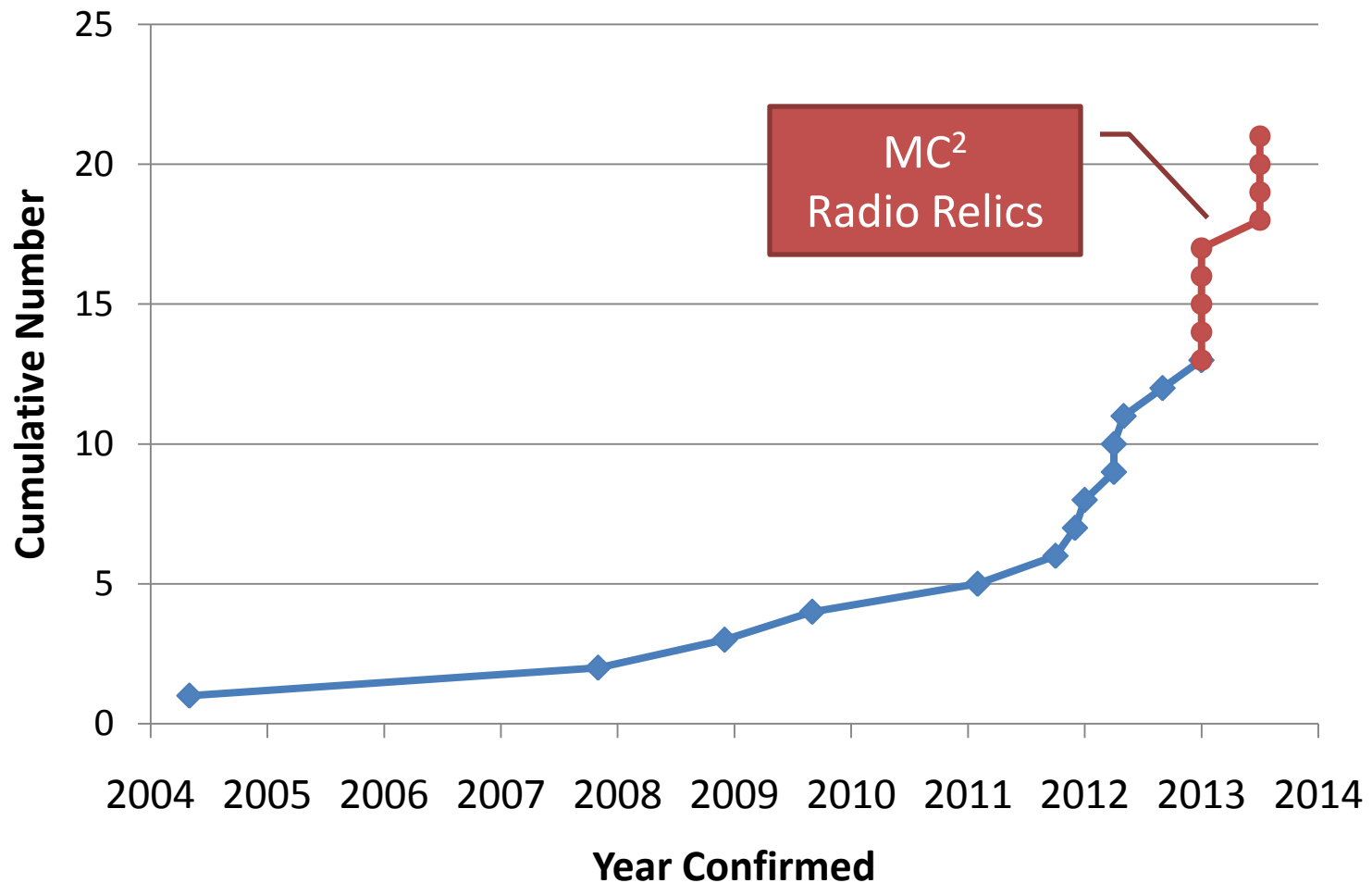
The MC² analysis plan in a nutshell

Find and observe dissociative mergers

Simulate those mergers with SIDM

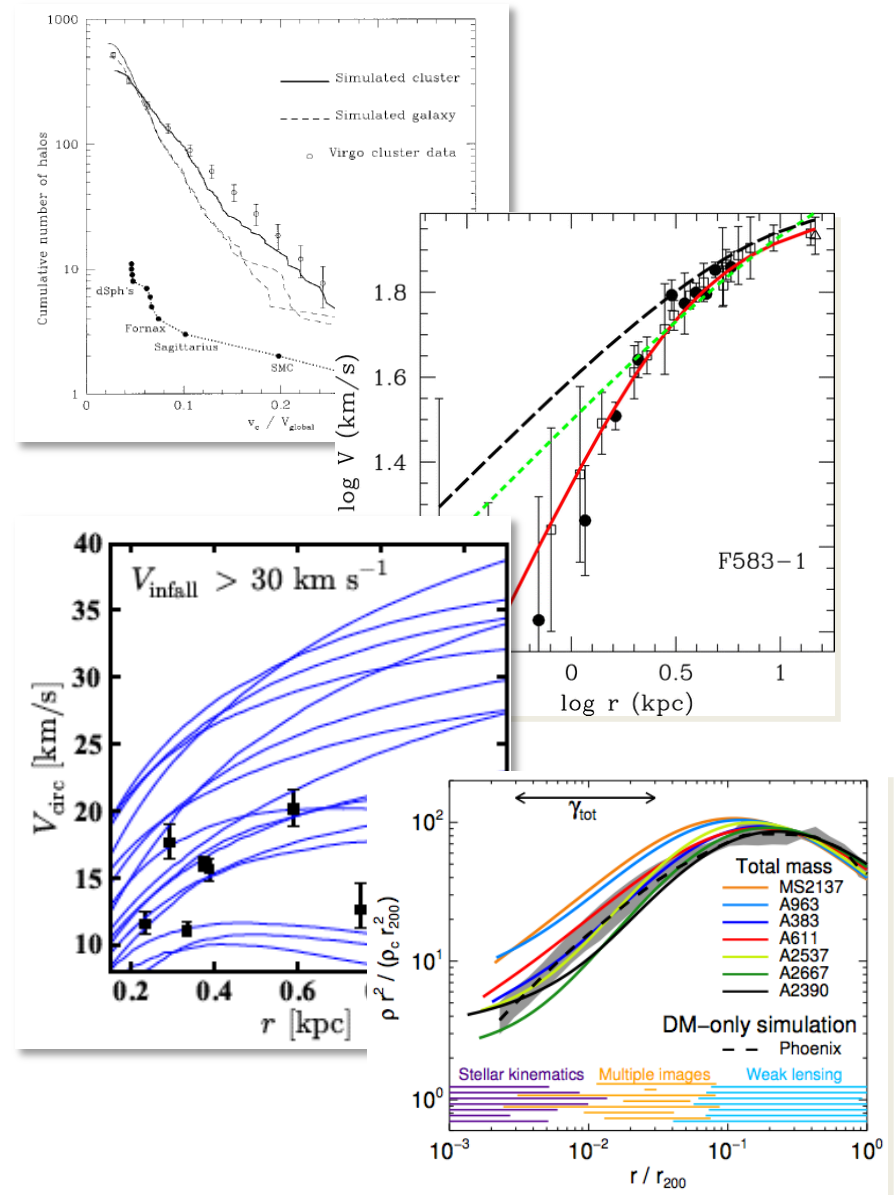
Analyze sample in a consistent and coherent
fashion

We expect to confirm 9 new dissociative mergers this year



Summary

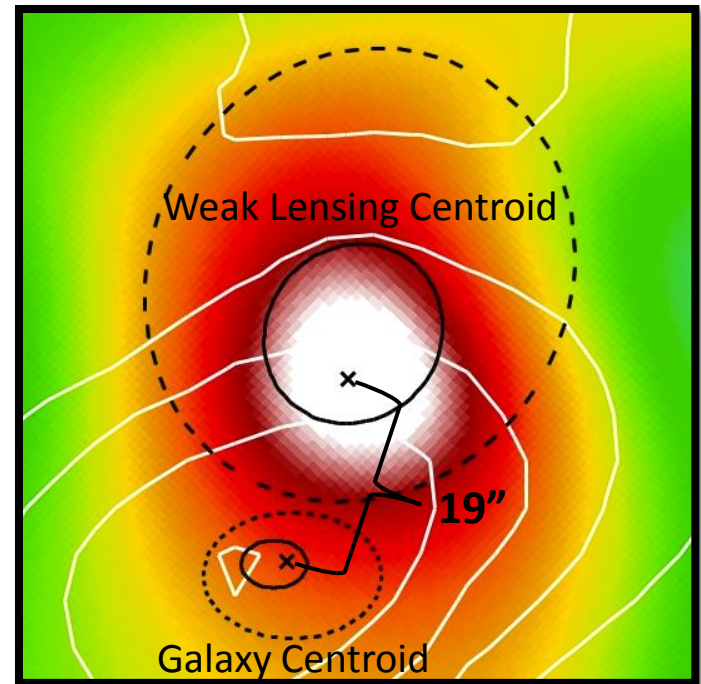
Motivated



Summary

Motivated

Evidence for SIDM

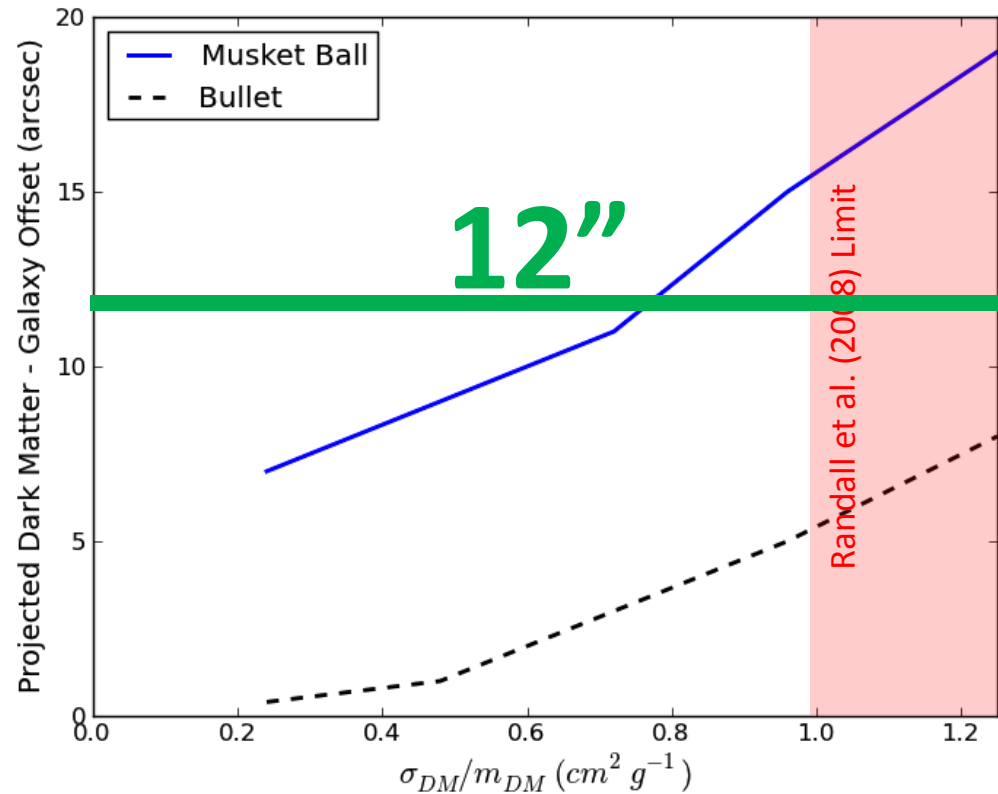


Summary

Motivated

Evidence for SIDM

Consistent but not significant



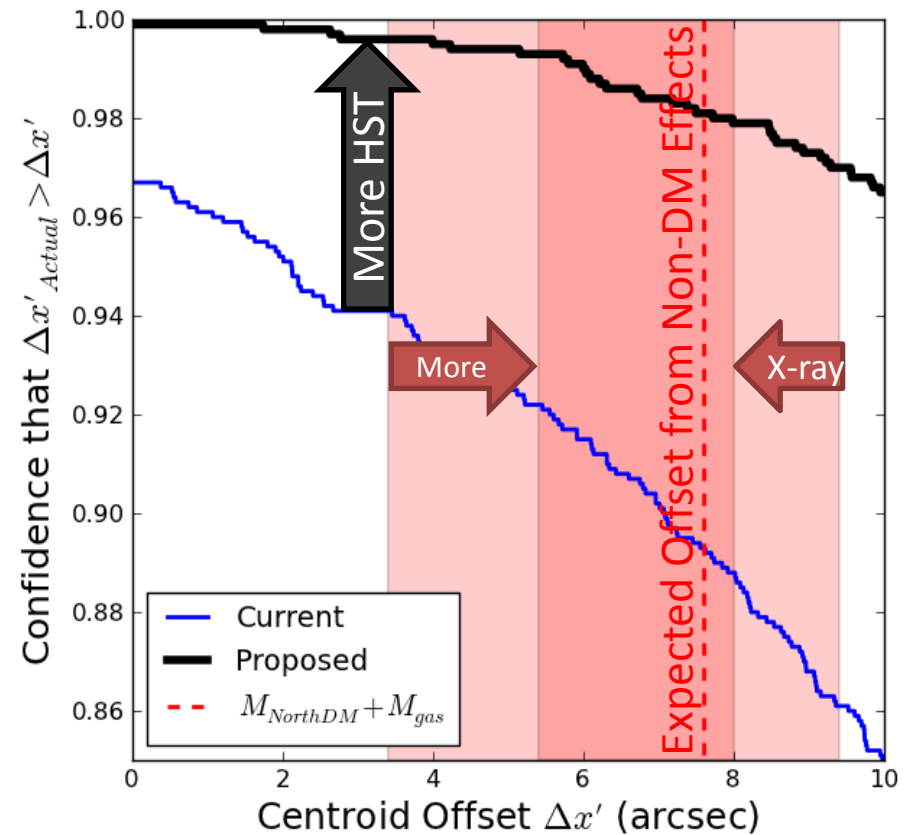
Summary

Motivated

Evidence for SIDM

Consistent but not significant

More observations only get us part of the way



Summary

Motivated

Evidence for SIDM

Consistent but not significant

More observations only get us part of the way

MCC will *measure or significantly constrain* σ_{DM}



Musket Ball Collaborators

David Wittman (UC Davis)

M. James Jee (UC Davis)

Perry Gee (UC Davis)

Jack Hughes (Rutgers)

Tony Tyson (UC Davis)

Sam Schmidt (UC Davis)

Paul Thorman (UC Davis)

Maruša Bradač (UC Davis)

Satoshi Miyazaki (GUAS, Tokyo)

Brian Lemaux (Laboratoire d'Astrophysique de Marseille)

Yousuke Utsumi (GUAS, Tokyo)

MC² Collaborators

Marusa Bradac (UC Davis)

Marcus Bruggen (Hamburg/Jacobs)

James Bullock (UCI)

Oliver Elbert (UCI)

M. James Jee (UC Davis)

Manoj Kaplinghat (UCI)

Julian Merten (Caltech/JPL)

Annika Peter (UCI, OSU)

Miguel Rocha (UCI)

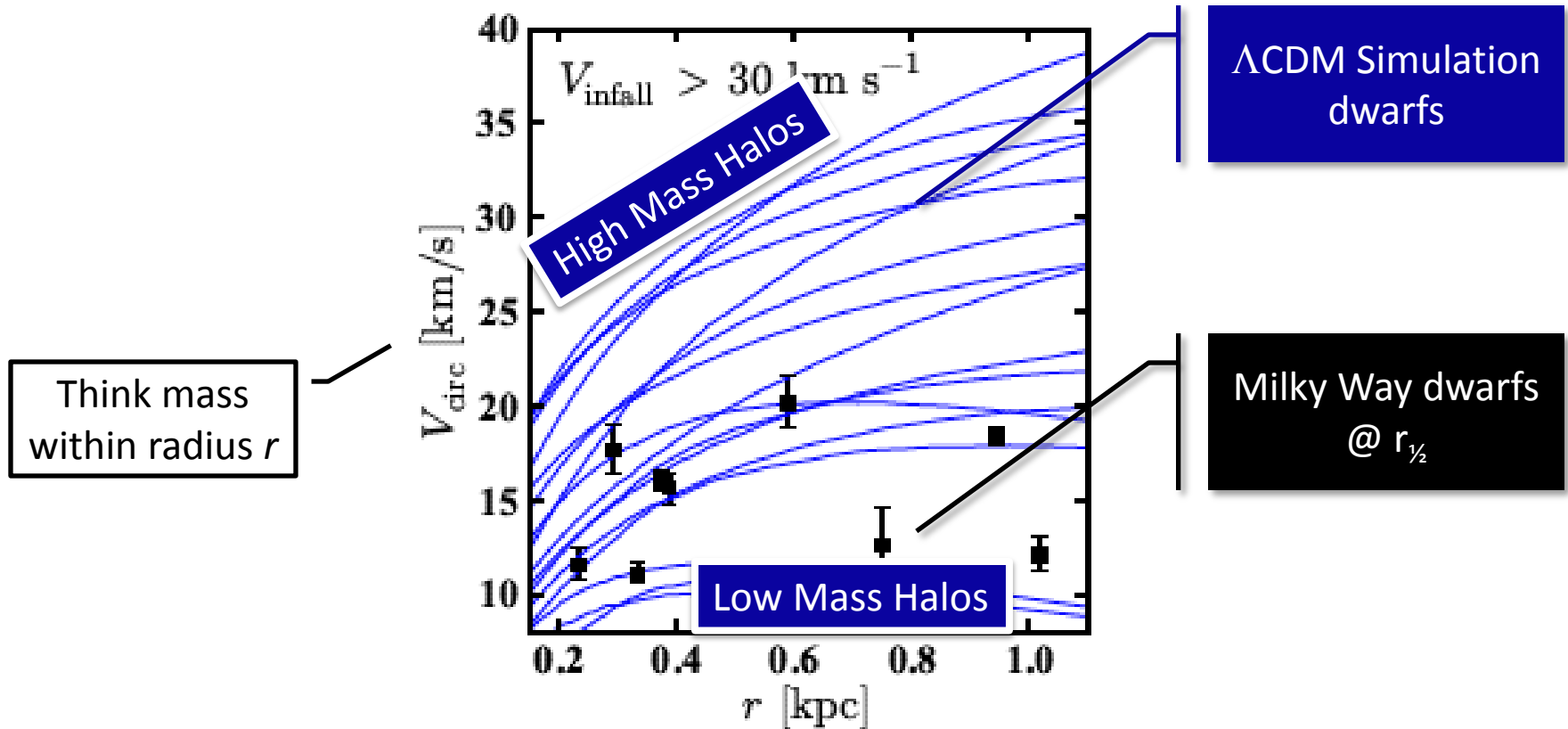
David Wittman (UC Davis)

Reinout van Weeren (CfA)

EXTRA SLIDES

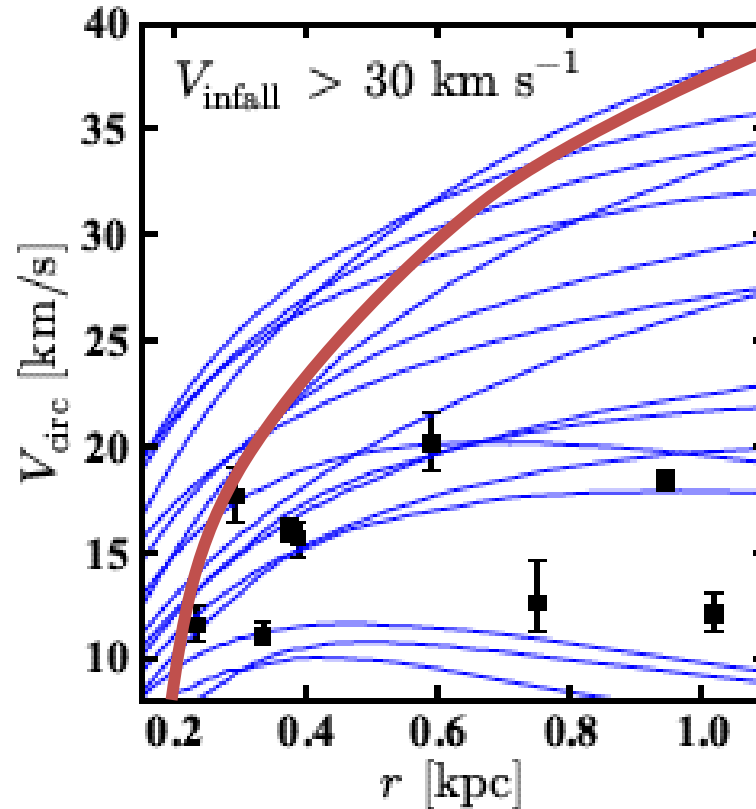
EXISTING CONSTRAINTS

Better measurements/simulations: *cusp/core problem* still a problem



Problem solved by cored halos

Think mass
within radius r

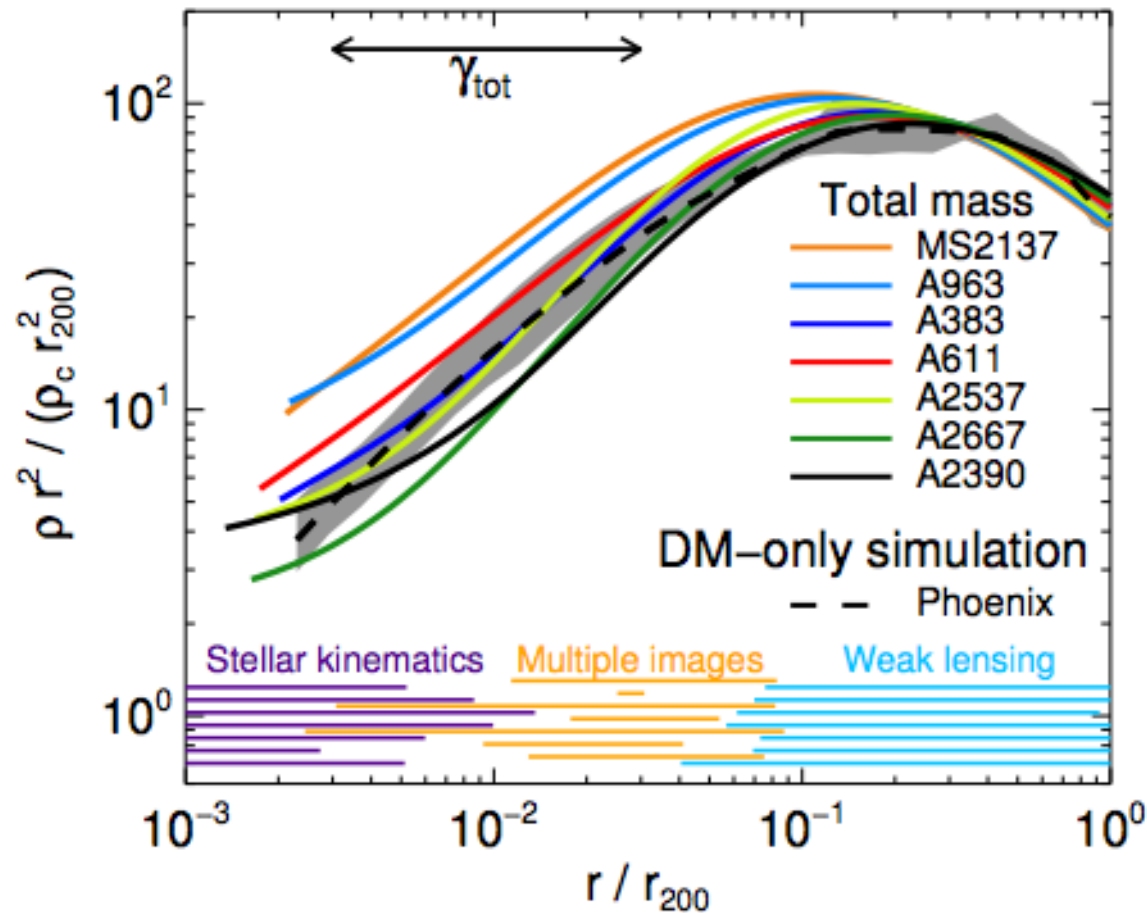


Cored Halo

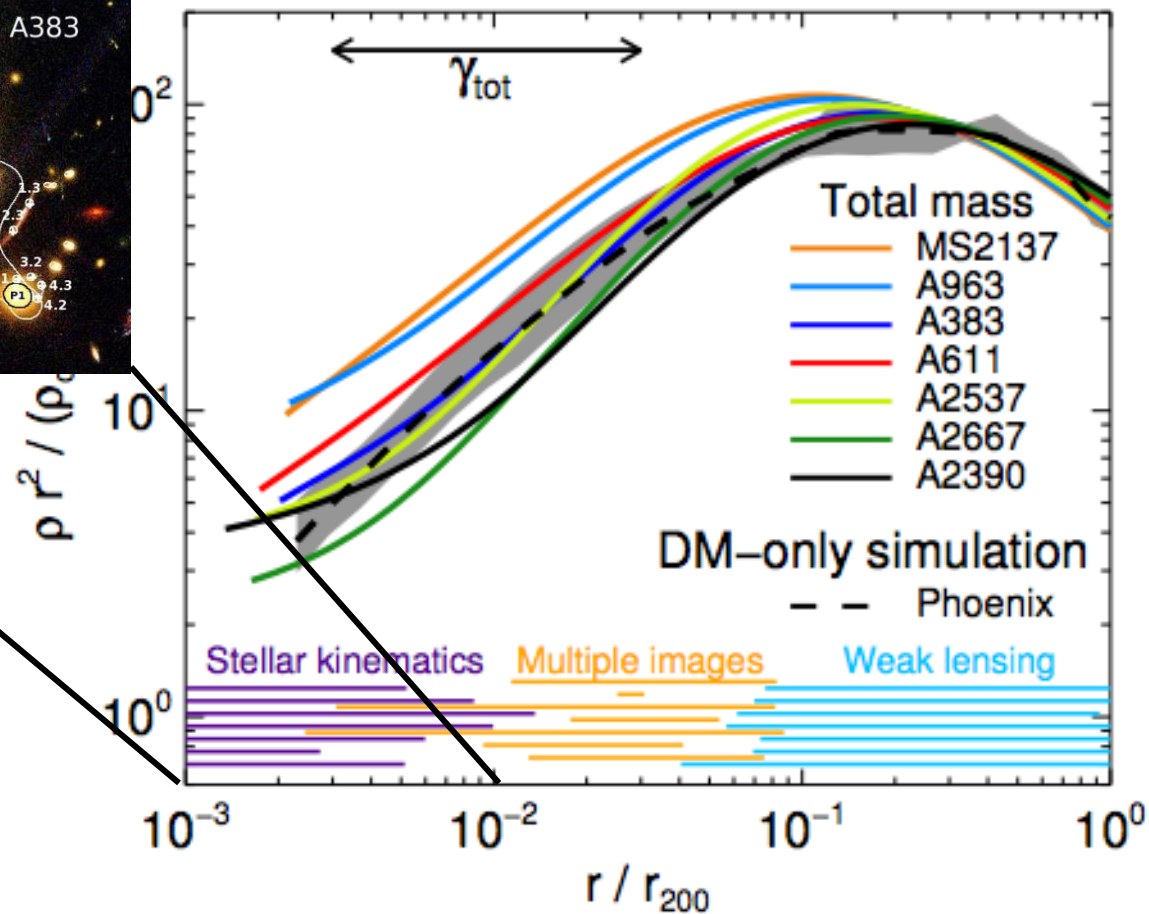
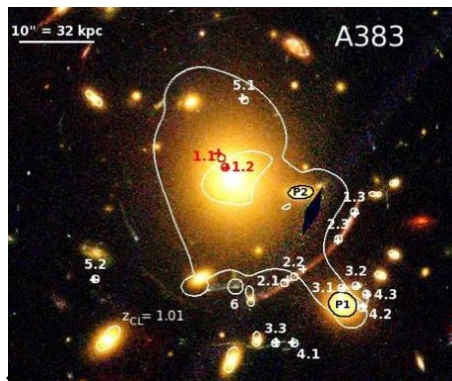
“Too big to fail”

Boylan-Kolchin et al. (2012)

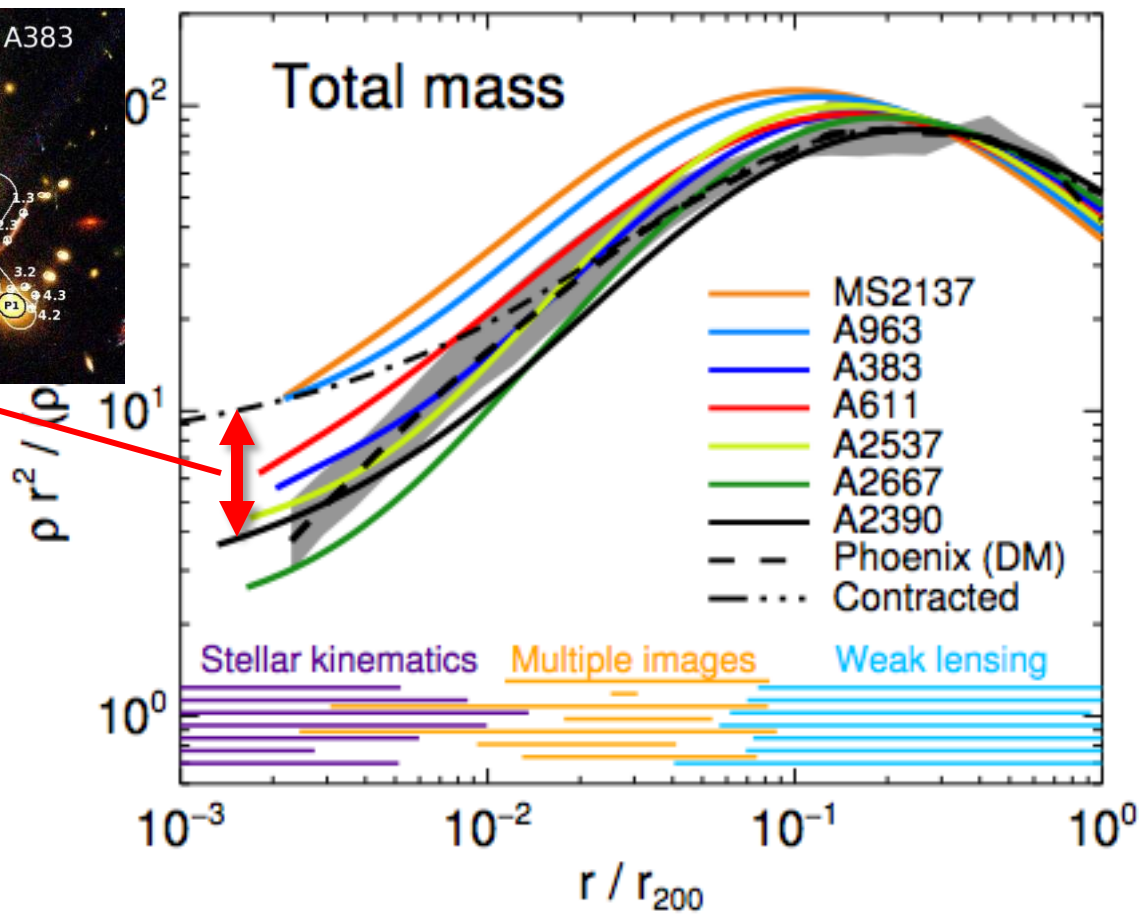
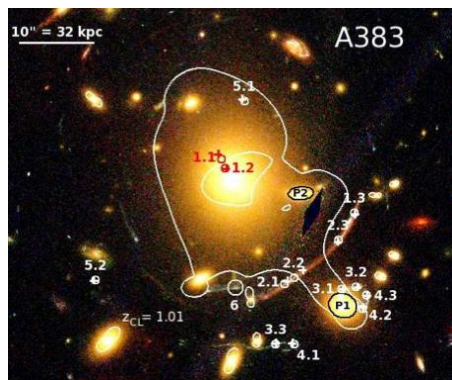
Clusters actually show agreement with CDM expectations



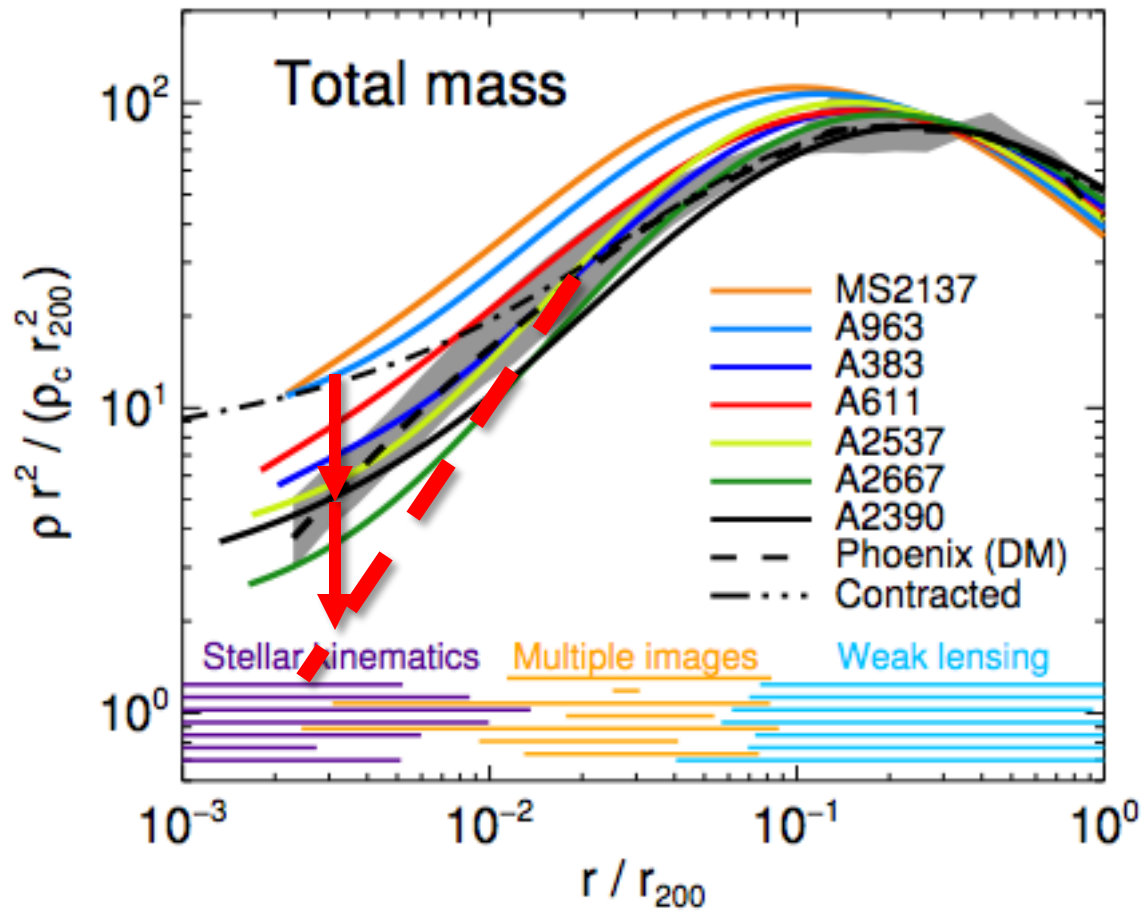
Cluster profiles shouldn't match DM only profiles



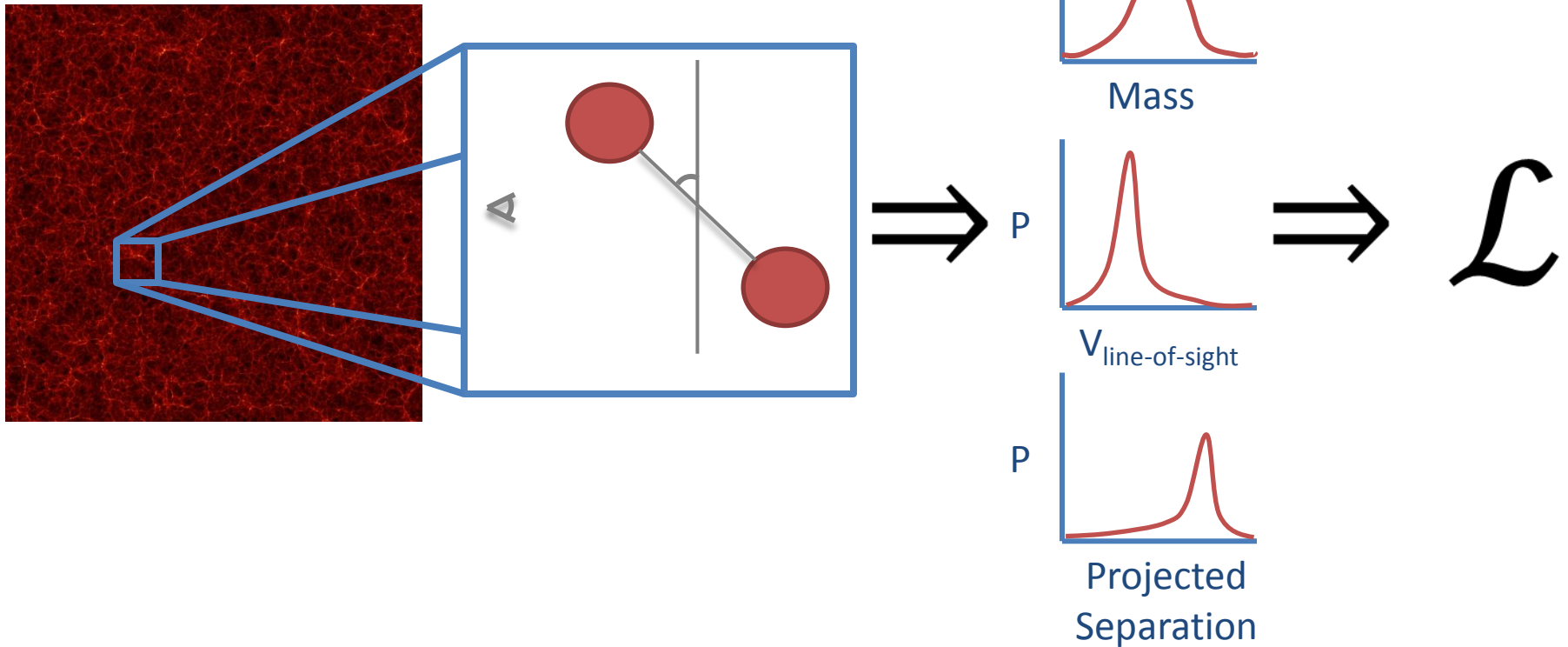
Because of the BCG some models predict a denser core



This too can be solved by cored DM halo



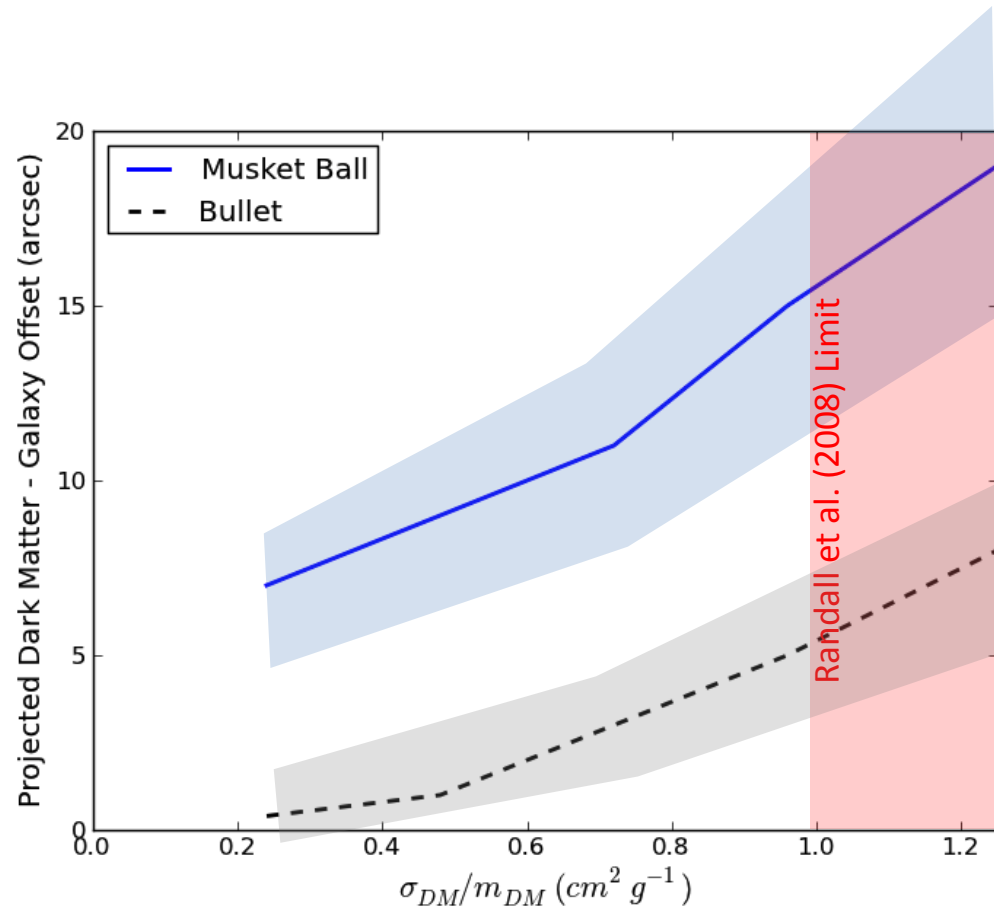
Importance sampling



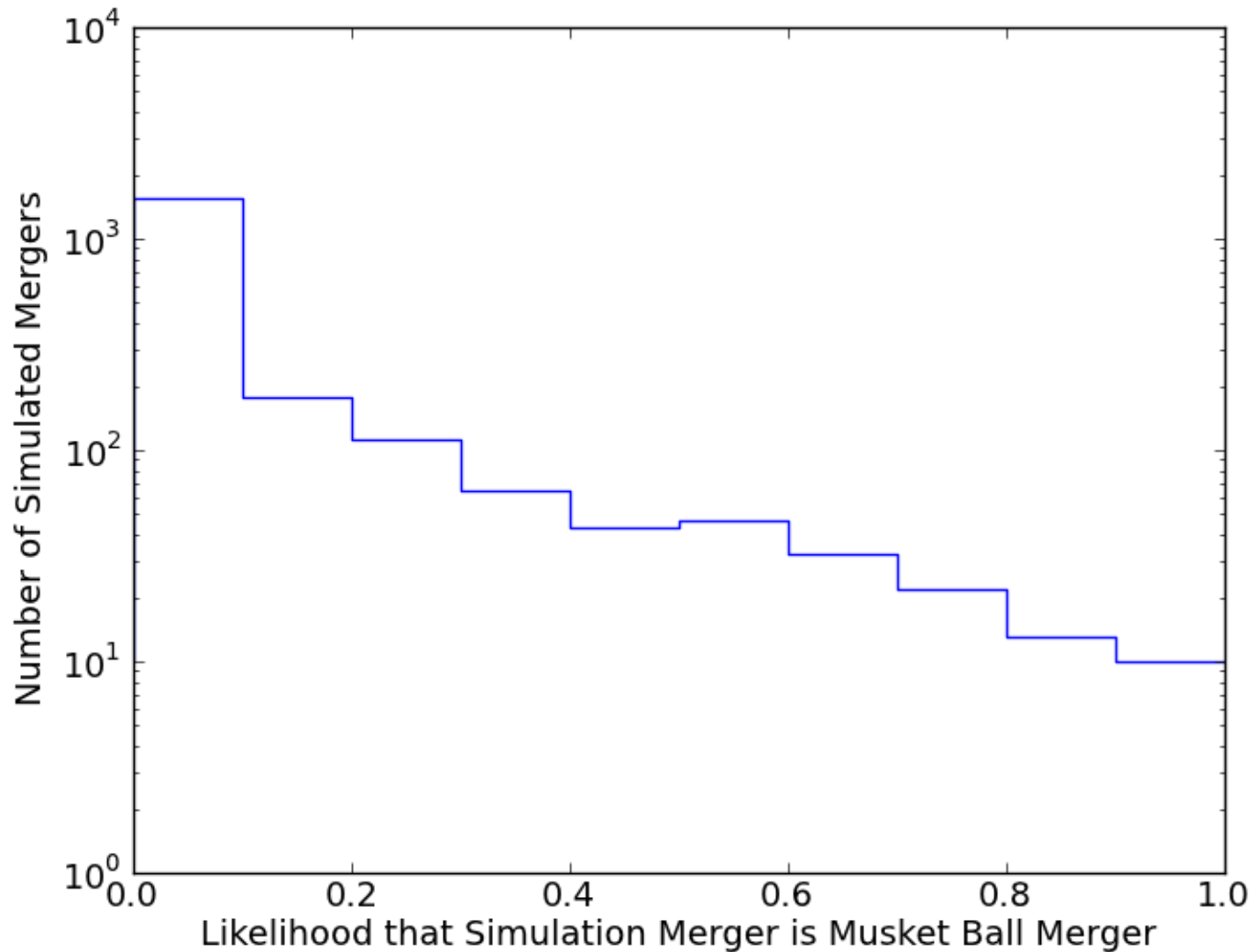
Importance sampling method provides σ_{DM} uncertainty

Plus incorporates
cosmological priors

One simulation to
sample them all



We are finding likely realizations of the Musket Ball Cluster



Previous Constraints

Reference	Constraint [cm^2 / g]	From	Problem
Yoshida et al. 2000	$\sigma/m < \sim 0.1$	Cluster density core	One cluster
Dave et al. 2001	$\sigma/m = 0.1-10$	Dwarfs density Cores	Narrow mass range
Gnedin & Ostriker 2001	$\sigma/m < 0.3$	Subhalo evaporation	Overestimated subhalo evaporation
Miralda-Escude 2002	$\sigma/m < 0.02$	Halo shapes	Overestimated halo sphericity
Randall et al. 2008	$\sigma/m < 0.7-1.25$	Bullet Cluster	High central densities and relative vel.

Previous Constraints

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Gnedin & Ostriker 2001	$\sigma/m < 0.3$	Subhalo evaporation	Overestimated subhalo evaporation
Peter et al. arXiv:1208.3026	$\sigma/m < 1$	Halo shapes	✓
Randall et al. 2008	$\sigma/m < 0.7-1.25$	Bullet Cluster	High central densities and relative vel.