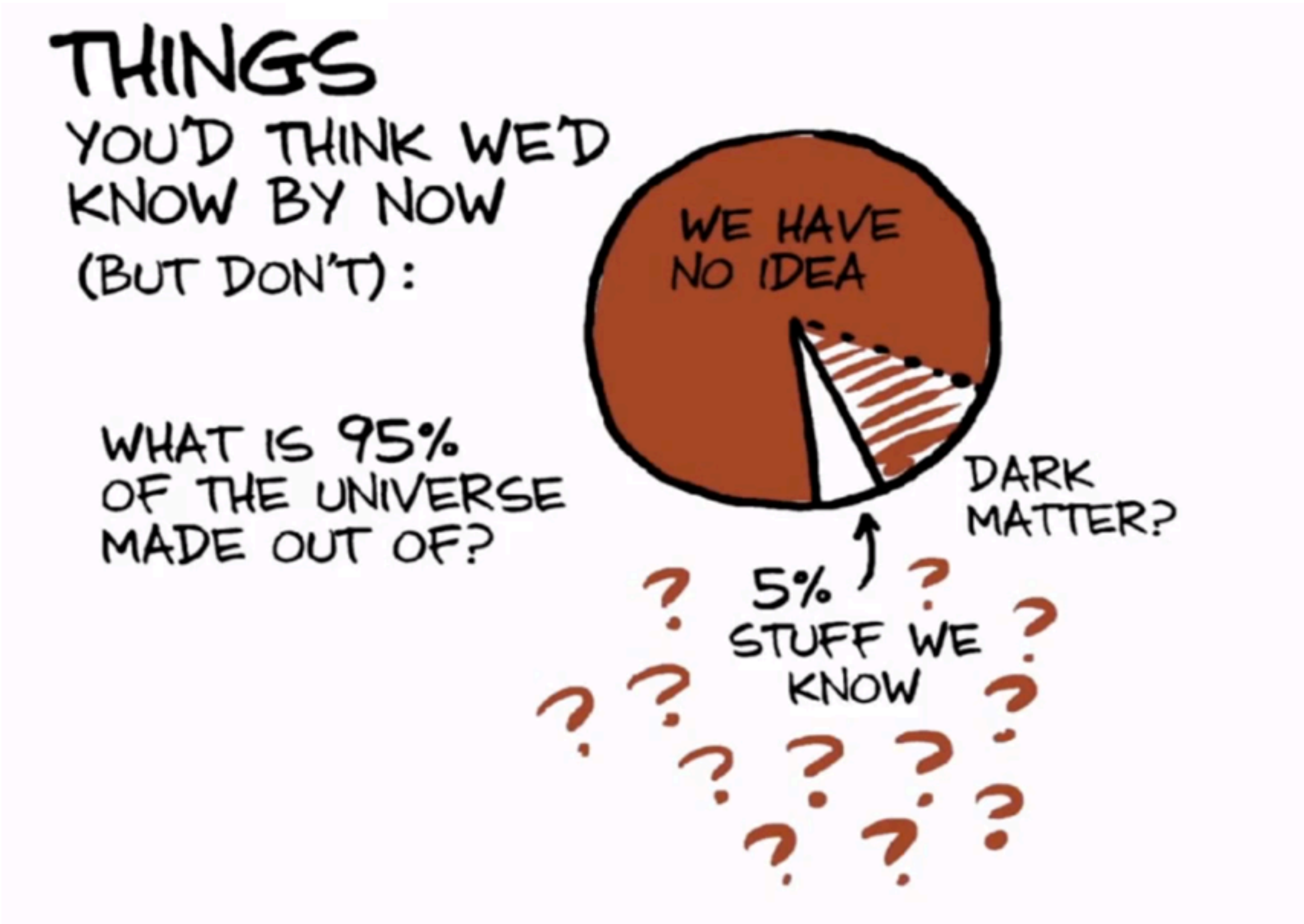
Studying Dark Matter with Cosmic Supercolliders

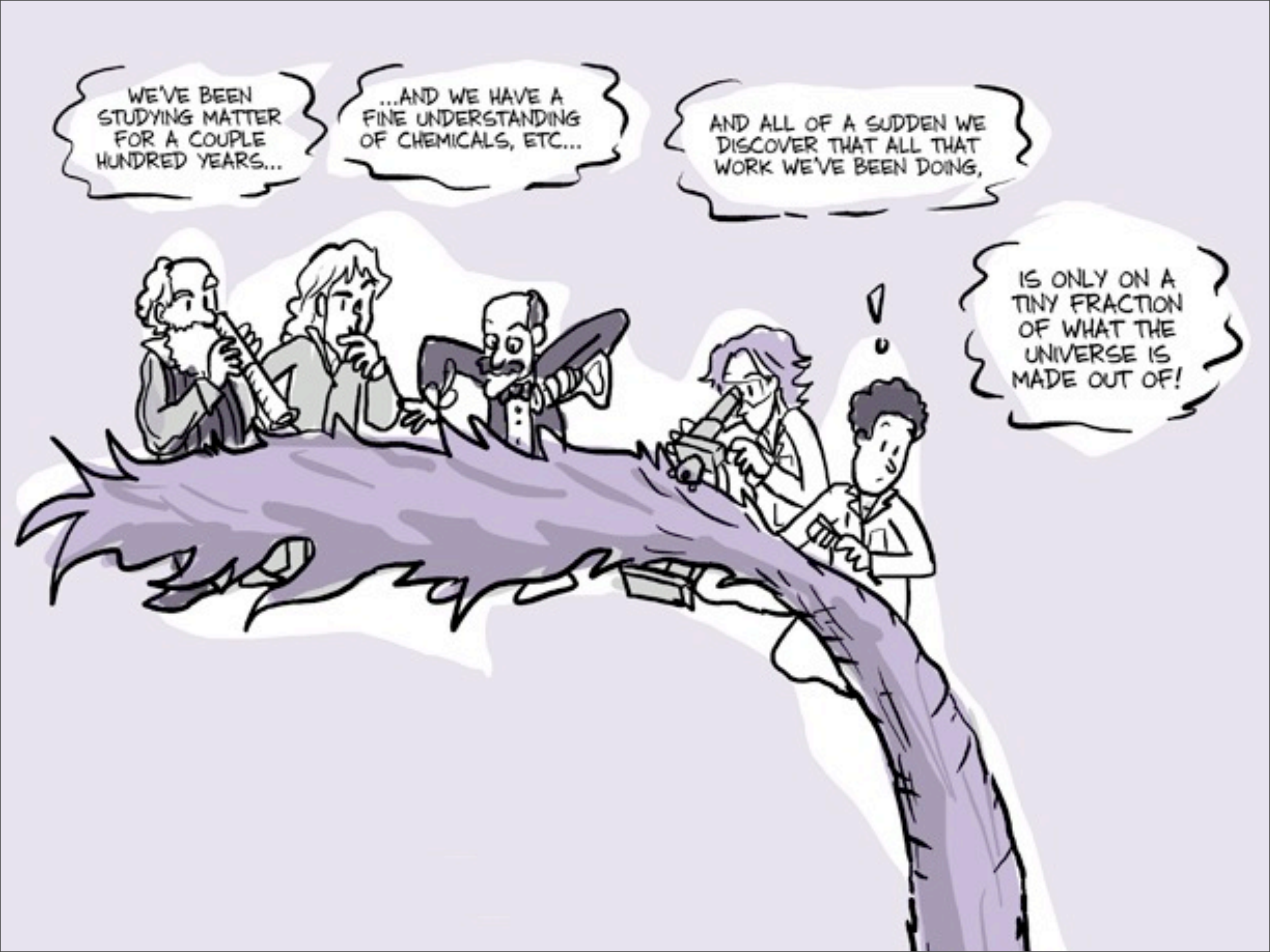
Maruša Bradač

DARK SIDE OF THE UNIVERSE

Nicholas Hall, Will Dawson, Annika Peter, Steve Allen, Douglas Clowe, Anthony Gonzalez, Maxim Markevitch, Bill Forman, Christine Jones, Tim Schrabback, Dennis Zaritsky, Richard Massey, Roger Blandford, Phil Marshall, Tommaso Treu, Anja von der Linden, Douglas Applegate



...the name of the royal baby....not to put pie charts in our talks...or use comic sans fonts...


WE'VE BEEN STUDYING MATTER FOR A COUPLE HUNDRED YEARS...
...AND WE HAVE A FINE UNDERSTANDING OF CHEMICALS, ETC...
AND ALL OF A SUDDEN WE DISCOVER THAT ALL THAT WORK WE'VE BEEN DOING,
IS ONLY ON A TINY FRACTION OF WHAT THE UNIVERSE IS MADE OUT OF!

IT'S LIKE YOU'VE BEEN STUDYING AN ELEPHANT'S TAIL FOR TWO HUNDRED YEARS AND YOU DISCOVER...
IT'S ONLY THE TAIL!
JORGE CHAM © 2011

ΛCDM: How well does it work

DM type	clustering	Halo mass functions	Growth function	Halo shapes	Halo density profiles	substructure
Cold, stable WIMP	On scales down to $<M_\odot$	Sharply falling function of mass	Linear regime-- scale independent	triaxial	Cuspy; $\rho \sim r^{-1}$ at center	$dN/dM \sim M^{-2}$ down to $M < M_\odot$
observations	Good fit down to $\sim 10^{11}\ M_\odot$	Good from galaxies to clusters	Consistent so far, $z < 0.7$	Ellipticity observed	Some uncertainty	Good fit down to $\sim 10^{11}\ M_\odot$

Talks by MR Lovell, CS Frenk

Talks Wed AM

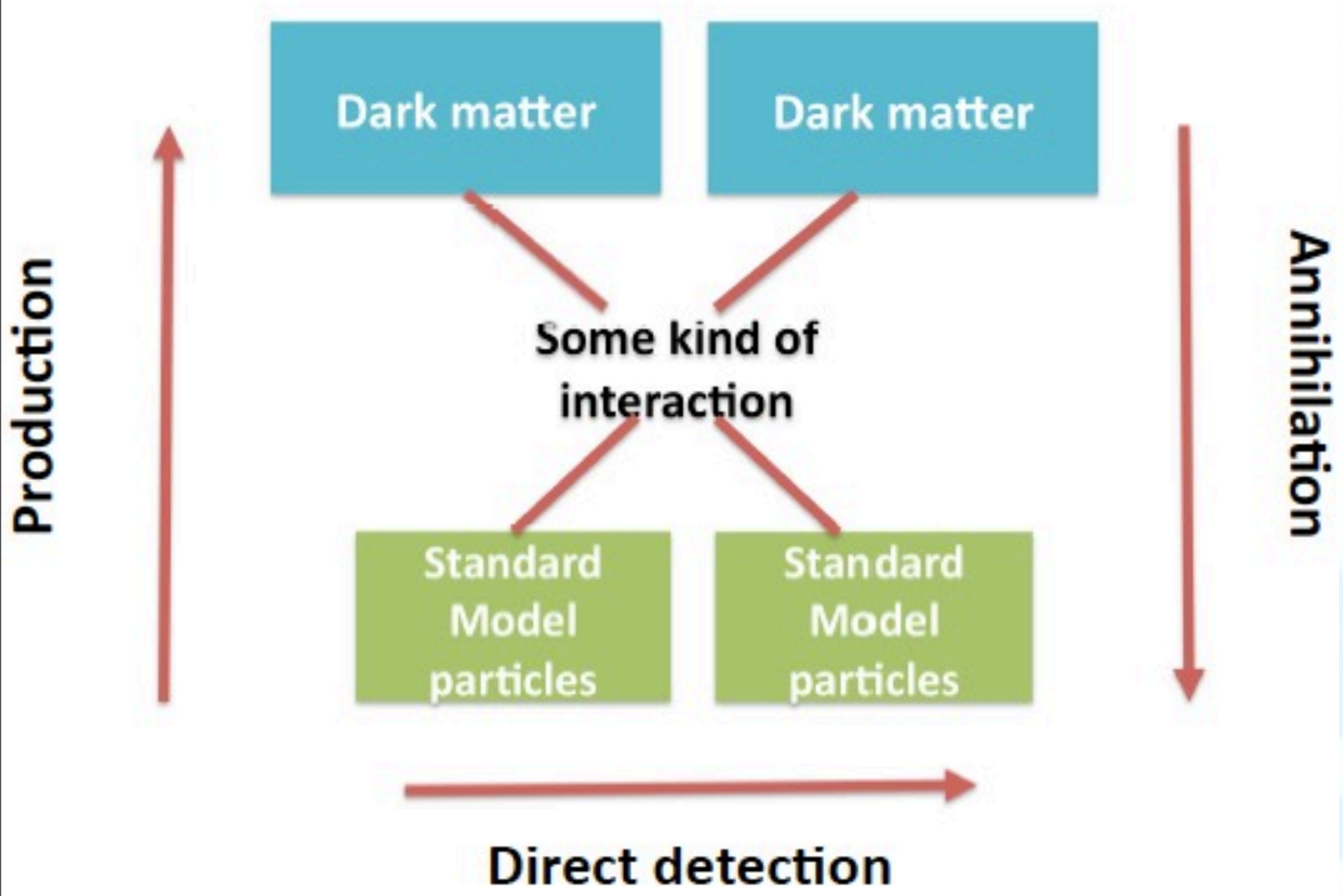
Another elephant = gastrophysics

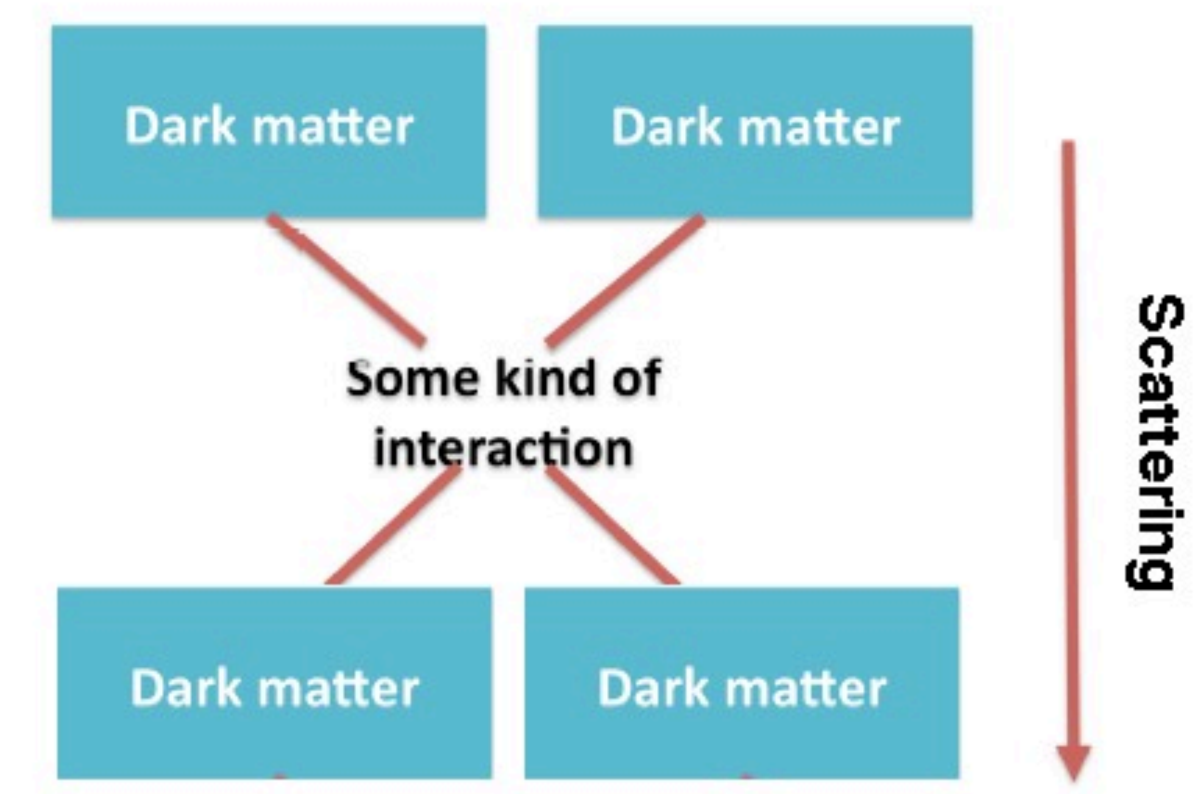
Looking at the elephant from many directions

LHC

Fermi, Early Universe

Galaxy formation



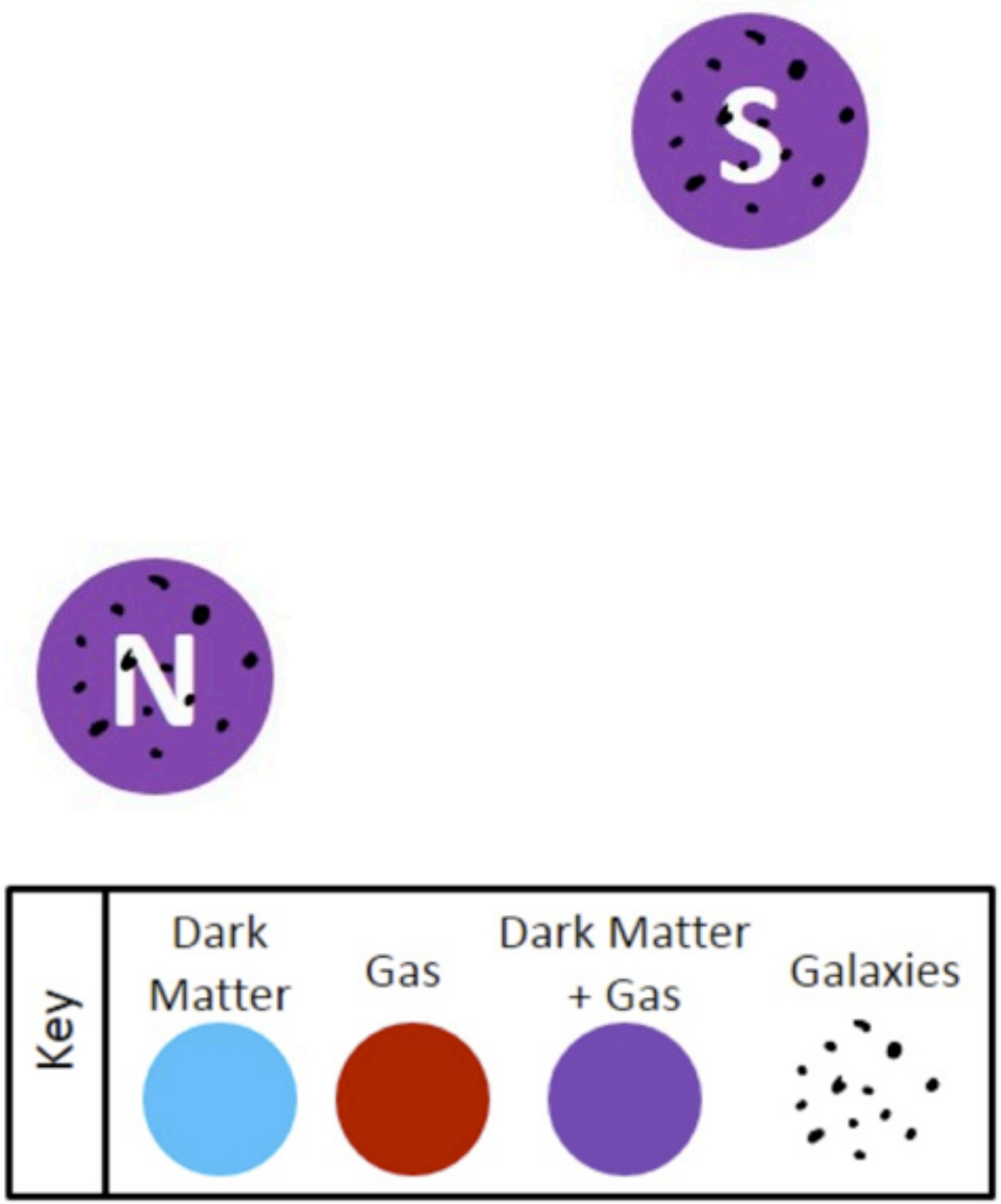


Xenon, CDMS, Dama, etc.

adapted from Peter et al. 2012

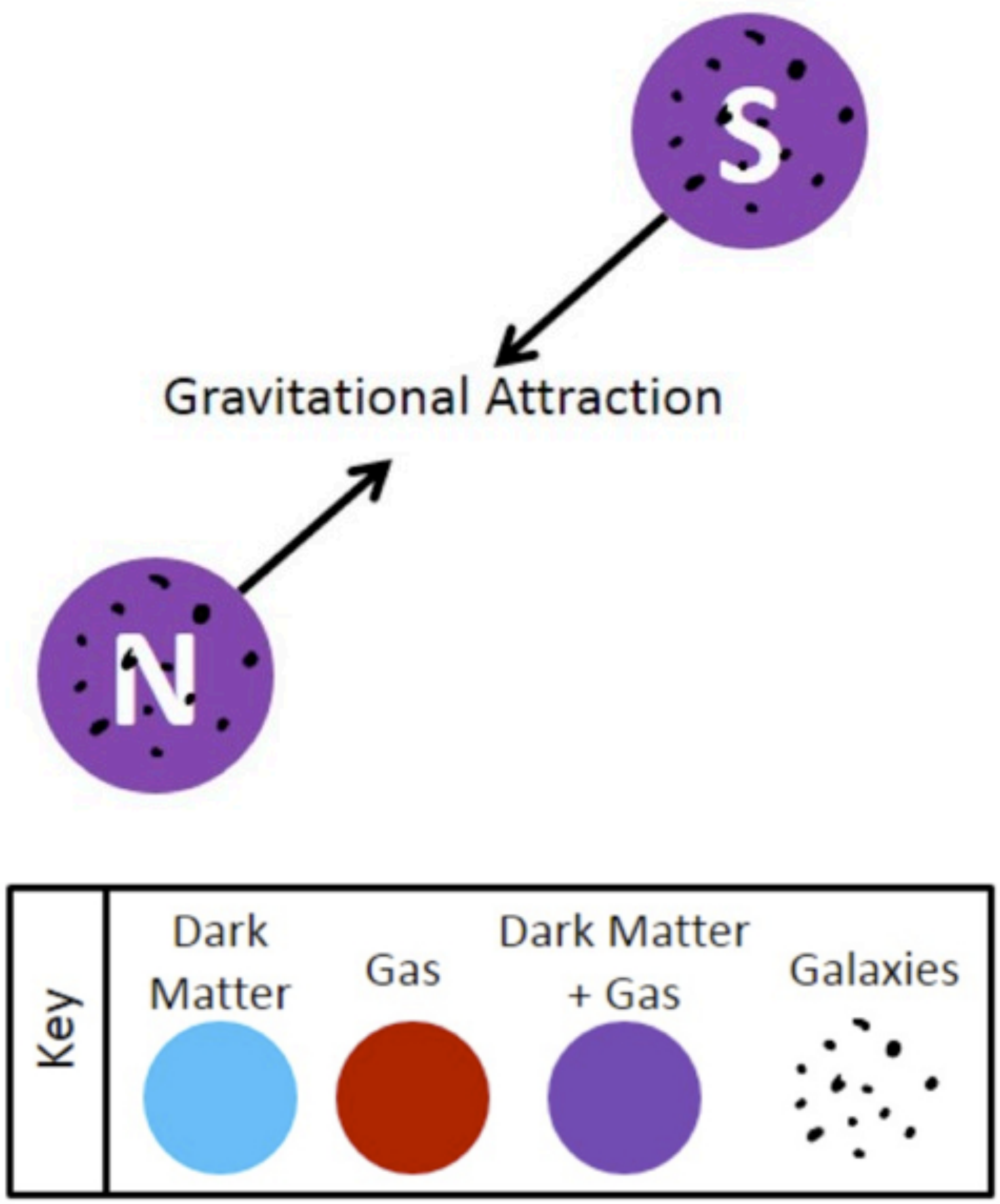
Can we measure cross-sections directly?

Galaxy cluster mergers to constrain DM

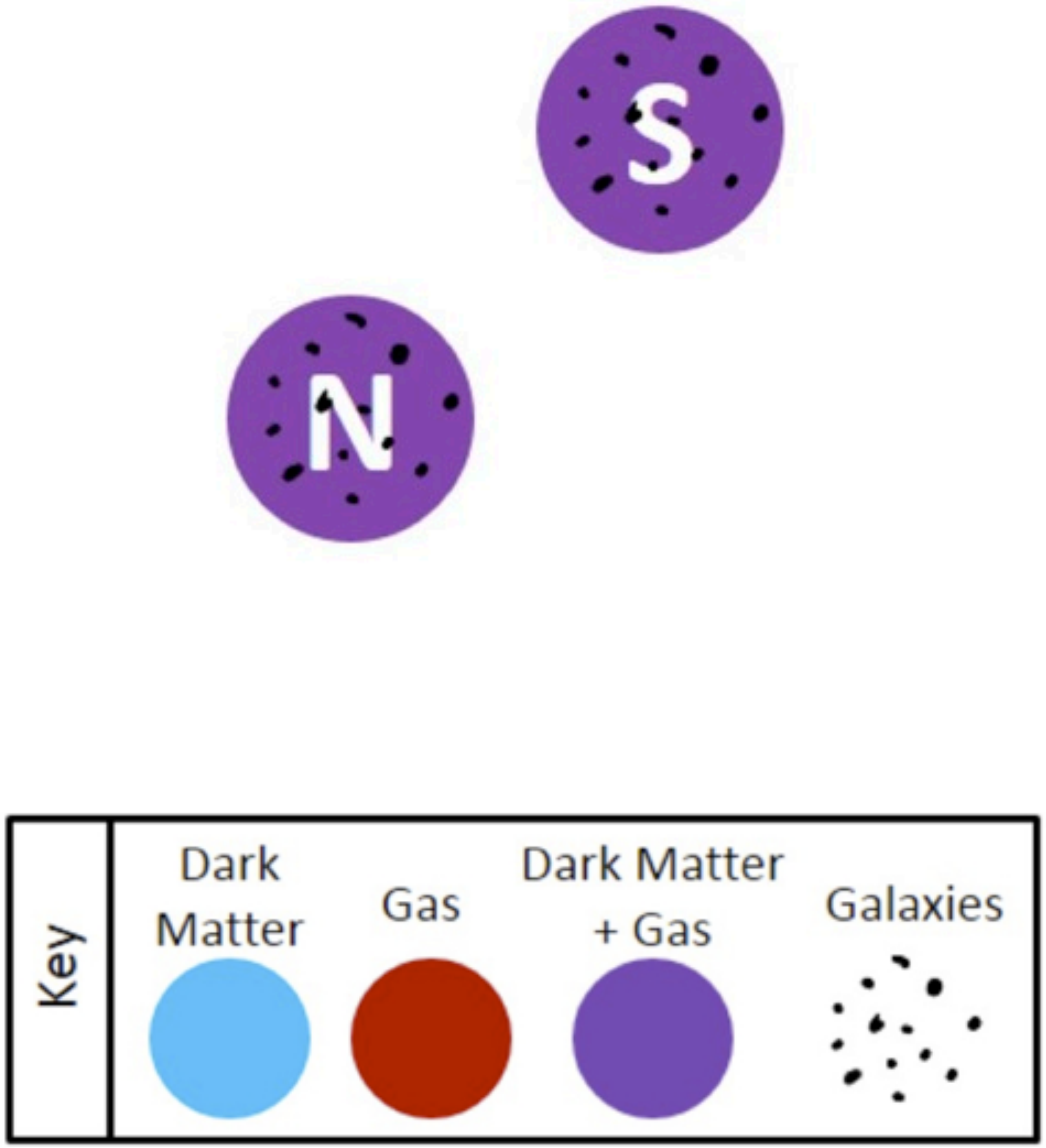


© Will Dawson

Galaxy cluster mergers to constrain DM

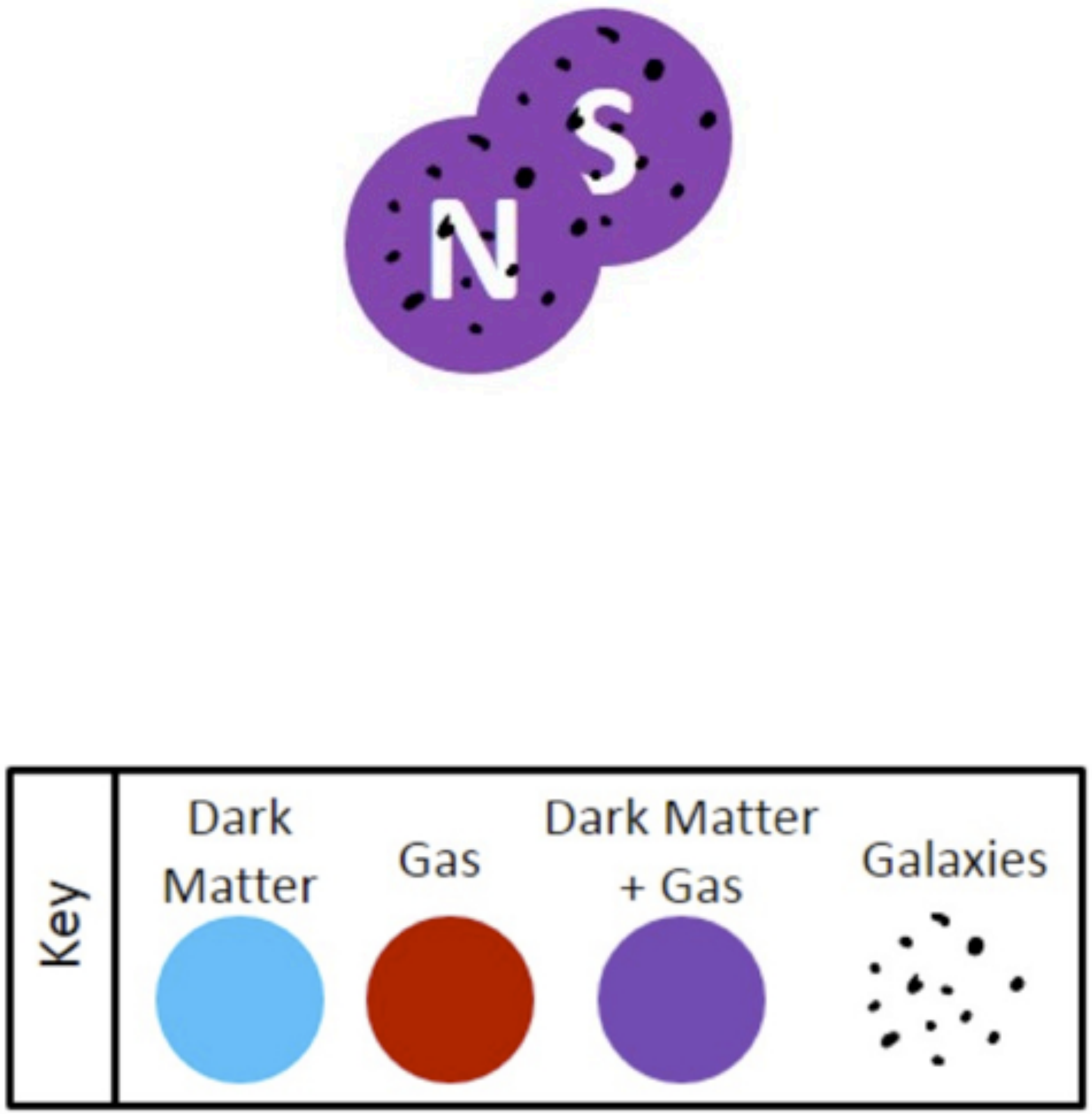


Galaxy cluster mergers to constrain DM



© Will Dawson

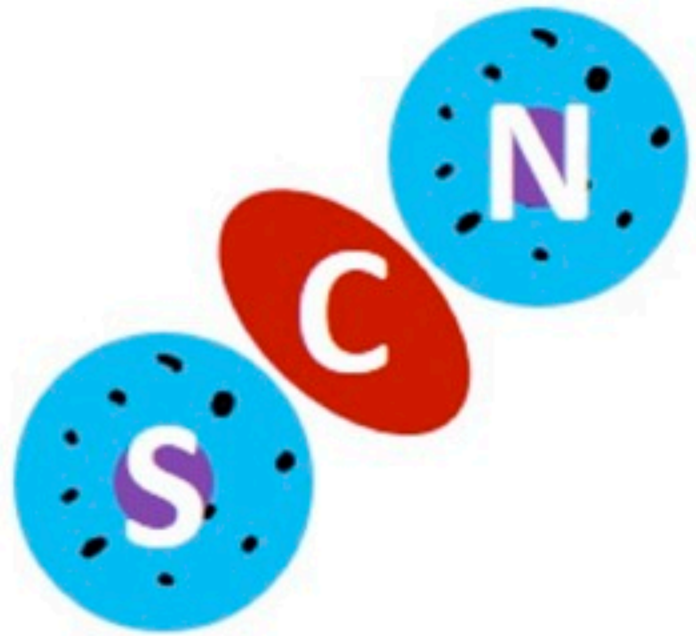
Galaxy cluster mergers to constrain DM



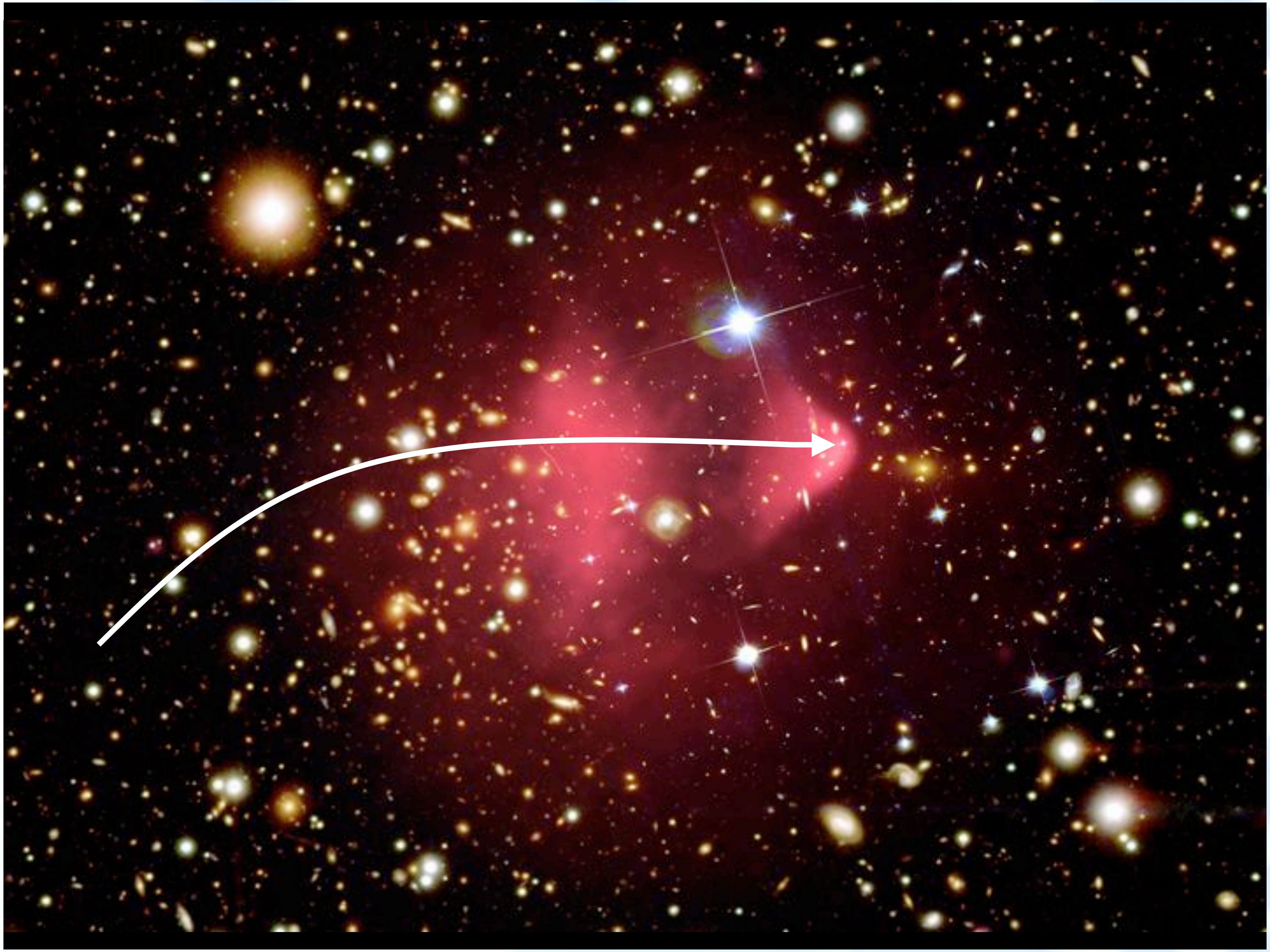
© Will Dawson

Galaxy cluster mergers to constrain DM

Galaxy cluster mergers to constrain DM



The Bullet Cluster 1E0657-56



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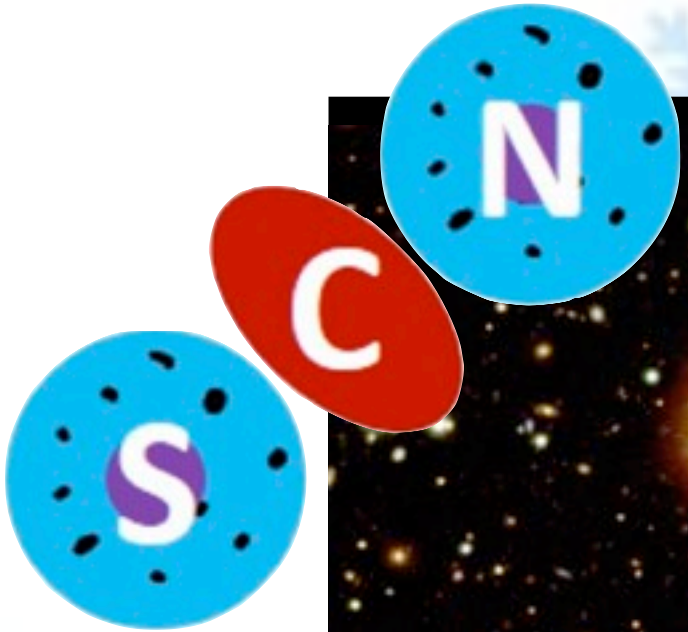
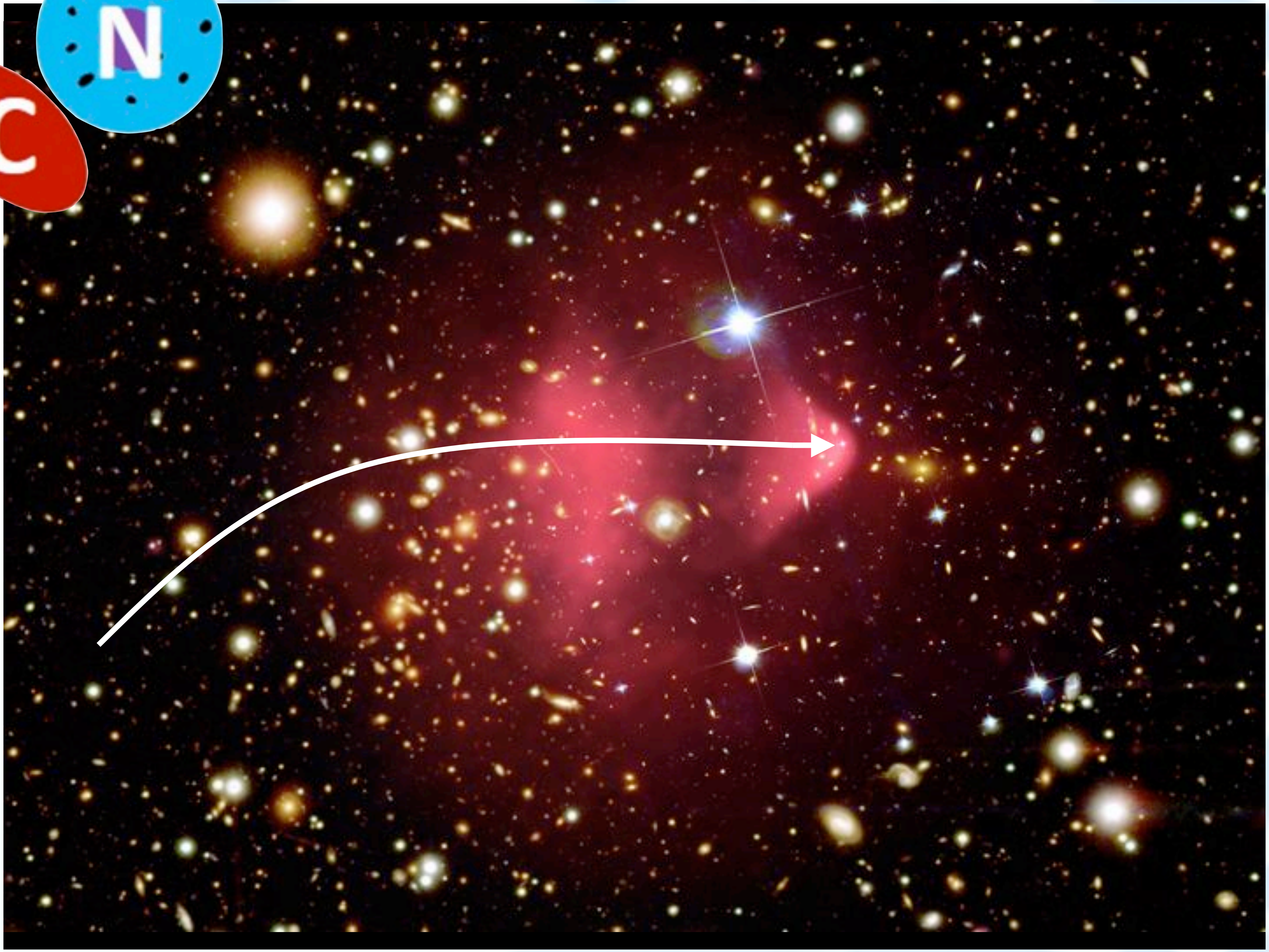
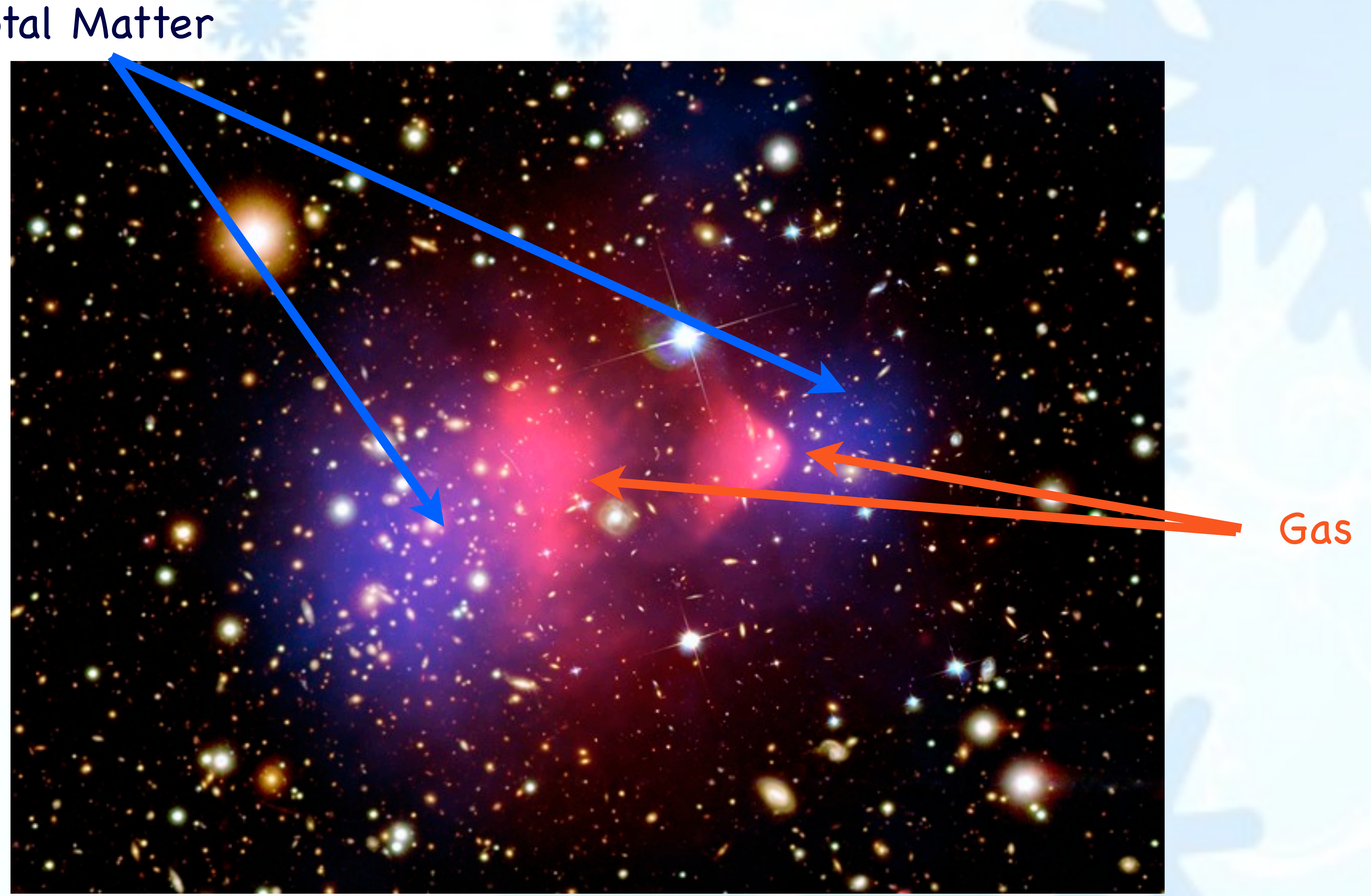




The Bullet Cluster 1E0657-56

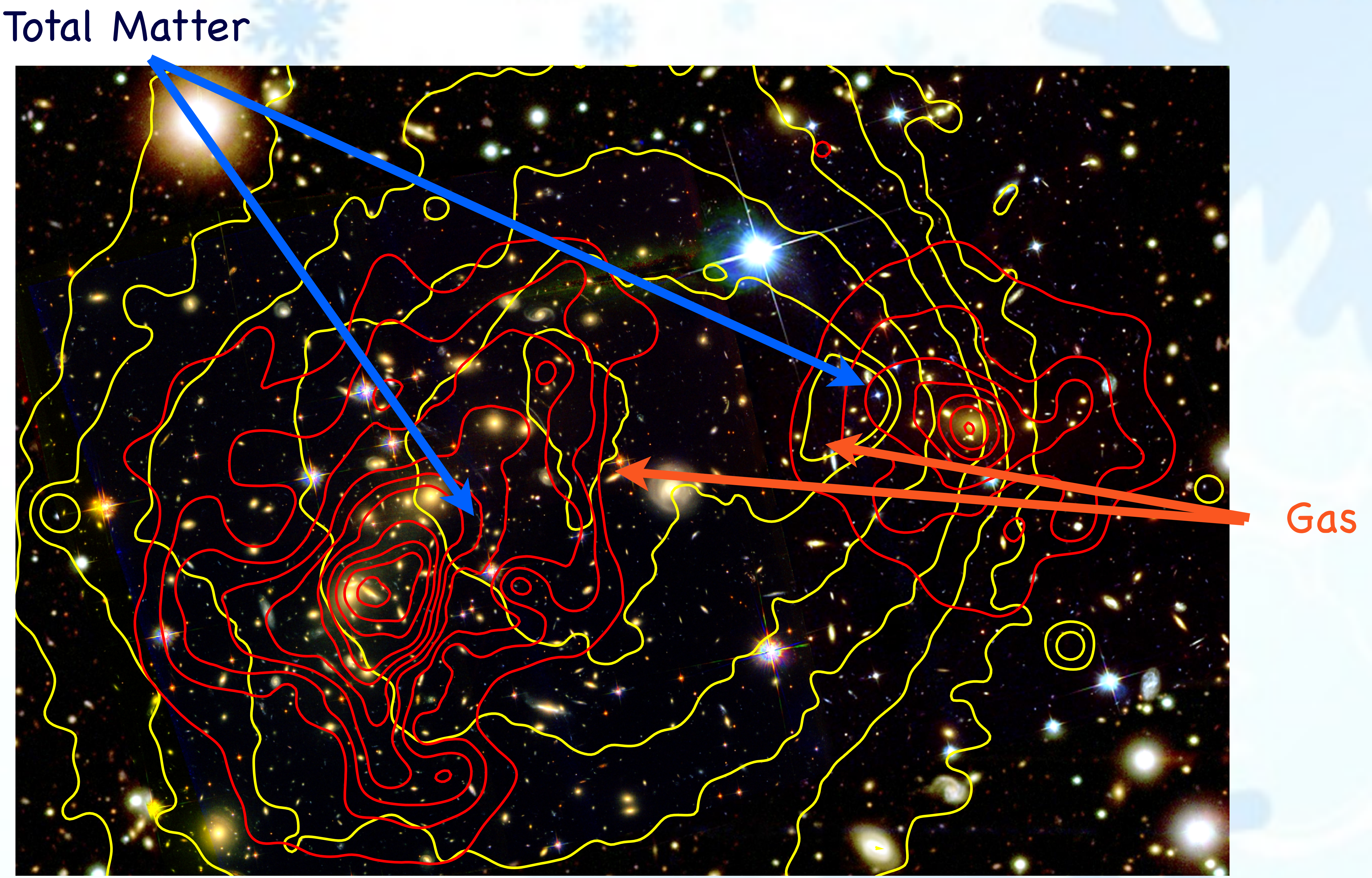
- One of the hottest and most luminous X-ray clusters known.
- Unique case of a major supersonic cluster merger occurring nearly in the plane of the sky (i < 15° , Markevitch et al. 2002).
- Using the gas density jump at the shock we derived a shock Mach number of 3.2 ± 0.8, which corresponds to a shock velocity 4500 ± 1000 kms^{-1}
- Subcluster velocity ~2700 kms^{-1} (Springel & Farrar 2007)

The Bullet Cluster 1E0657-56



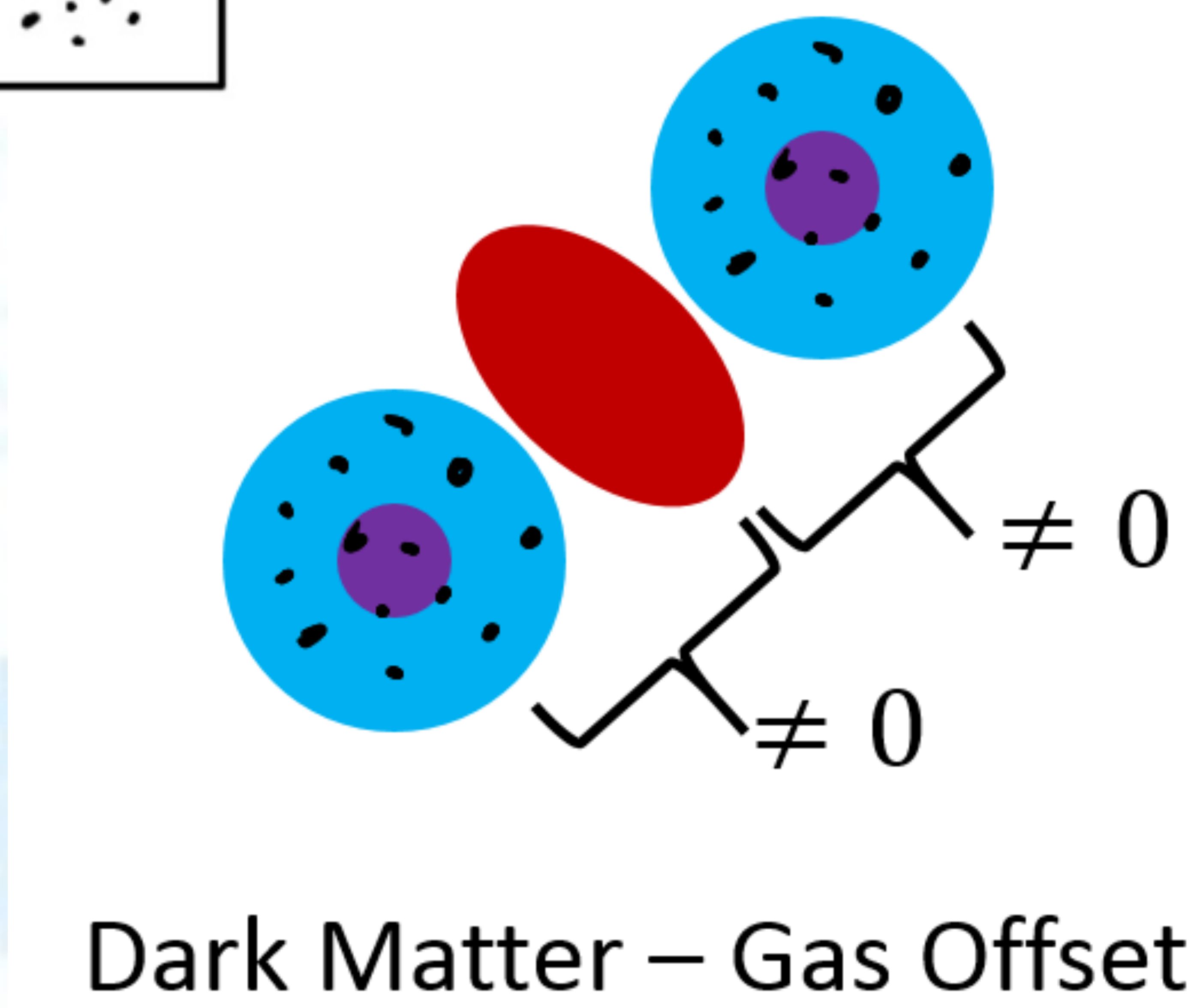
Clowe, MB et al. 2006

The Bullet Cluster 1E0657-56

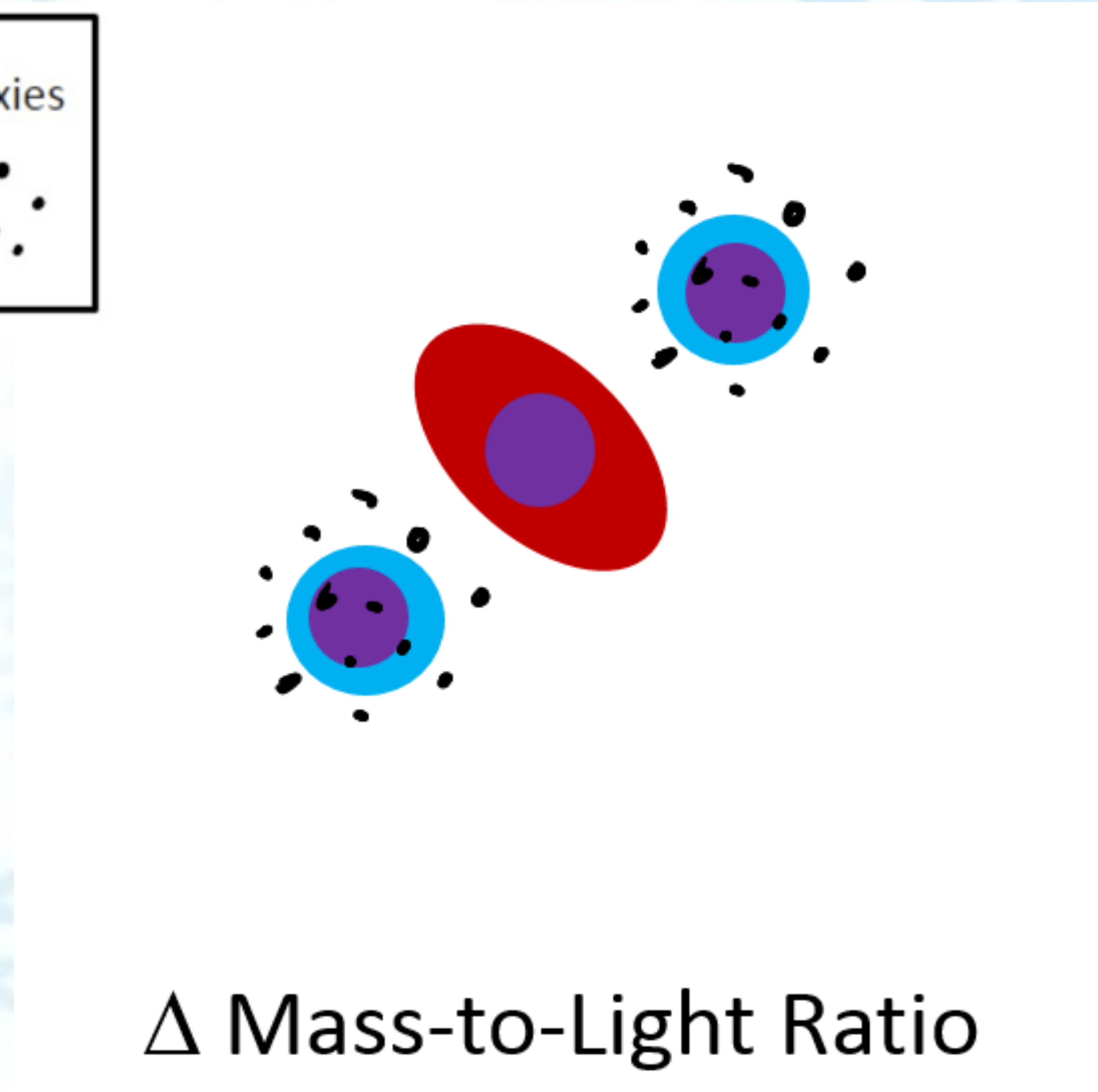


Hall, MB et al. 2012

DM self-interaction



DM self-interaction



Dark Matter Properties

* Combining the Chandra data with lensing mass maps -> place an upper bound on the dark matter self-interaction cross section $\sigma/m < 1\ \mathrm{cm^2g^{-1}} = 1.8\mathrm{barn/GeV}$ (Markevitch et al. 2004).

  -> Significant offset between subcluster X-ray gas core and dark matter peak gives $\sigma/m < 10\ \mathrm{cm^2g^{-1}}$

  -> Survival of the subcluster dark matter peak during interaction gives $\sigma/m < 3\ \mathrm{cm^2g^{-1}}$

  -> No loss of mass from subcluster during interaction gives $\sigma/m < 0.8\ \mathrm{cm^2g^{-1}}$

* $\sigma/m < 0.7\ \mathrm{cm^2g^{-1}} = 1.3\mathrm{barn/GeV}$ (Randall et al.2008)

* SI dark matter $\sigma/m < 0.5 - 5\mathrm{cm^2g^{-1}}$ (Davé et al. 2001).

Miguel's talk at JoelF

Previous Constraints

Reference	Constraint [cm^2 /g]	From	Problem
Yoshidal 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.

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


Optical Dark Matter X-ray Gas
DARK MATTER
Most of the universe can't even be bothered to interact with you.

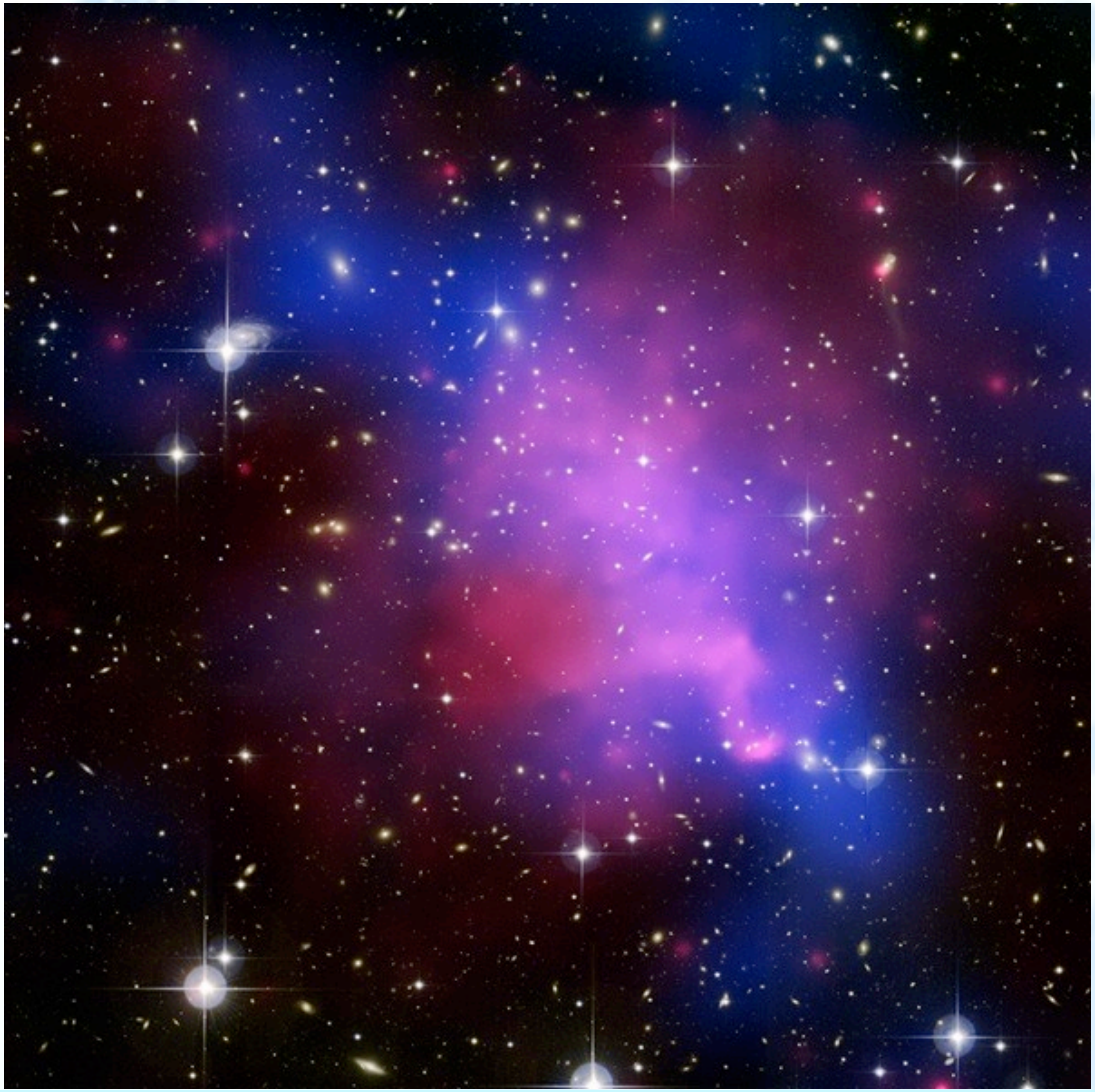
S.Caroll

Where do we go from here??

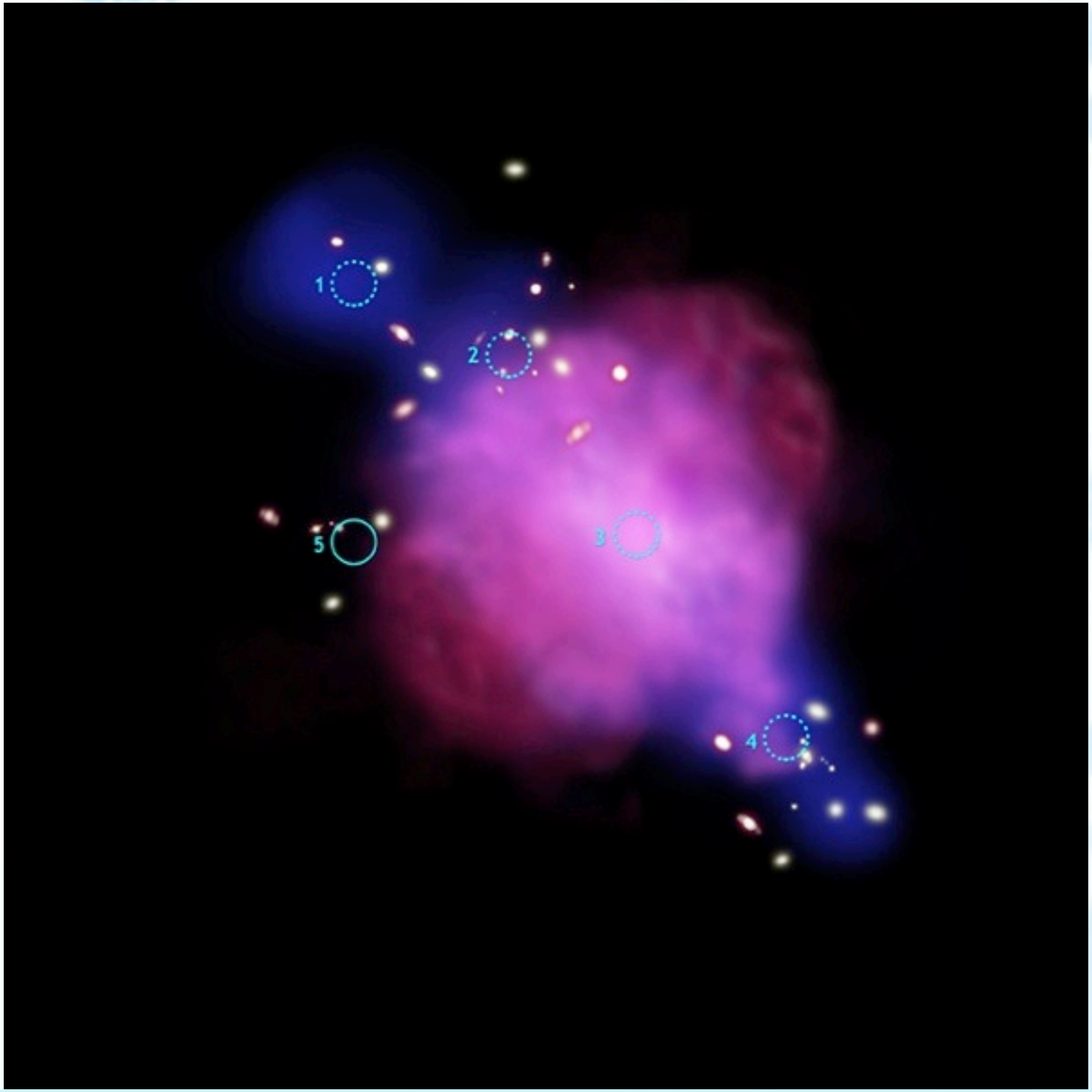
* Need more merging clusters.
* Need better simulations.

Bullets are rare....

A520 - Cosmic "Train Wreck"



A520 - Cosmic "Train Wreck"



A520 - Cosmic "Train Wreck"

- The galaxies originally in the dark core could have been ejected through a multiple-body interaction
- Weakly self-interacting dark matter: requiring $3.8 \pm 1.1\ cm^2g^{-1}$ (Bullet cluster constraints $\sigma/m < 0.7\ cm^2g^{-1} = 1.3 barn/GeV$)
- New HST data

Weight Loss Program

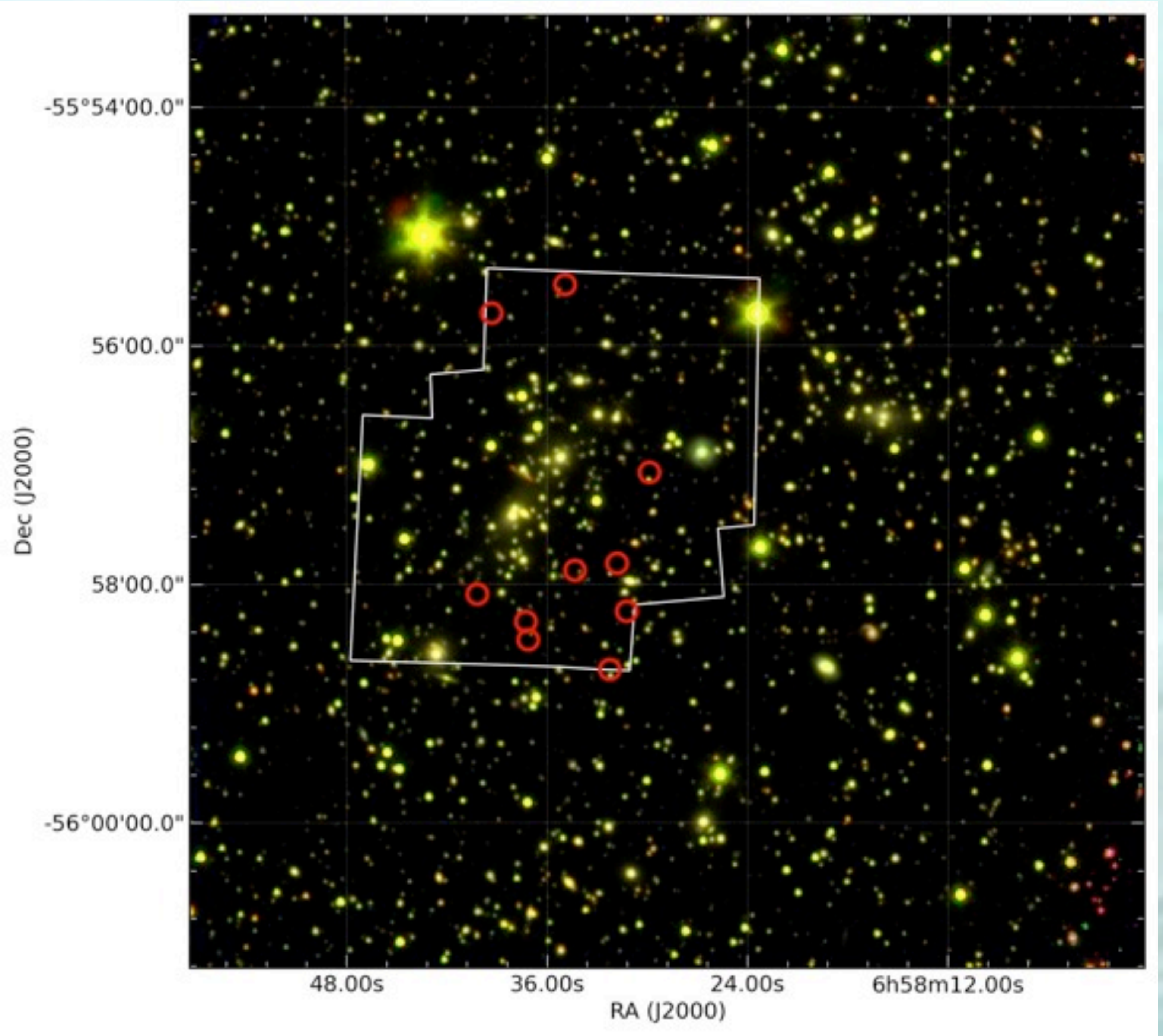
- New multi color HST data
- No dark core at position #3 (lower M/L than Jee et al. 2012)
- Twice the light, 60% the mass

Clowe et al. (MB) 2012

ADVERT

SURF'S Up: Spitzer UltRa Faint SUrvey

Bullet Cluster with Spitzer



Bradač et al. in prep, Ryan et al. in prep

- Sources responsible for reionization ($z \gtrsim 7$):

  → Star formation rates and stellar masses of a large number of galaxies (50 at $z \sim 7$ and 10 at $z \sim 8$) → reconstructing the cosmic SFR and EOR

ACS	orbits	ABmag	WFC3-IR	orbits	ABmag
F435W	18	28.8	F105W	24	28.9
F606W	10	28.8	F125W	12	28.6
F814W	42	29.1	F140W	10	28.6
			F160W	24	28.7

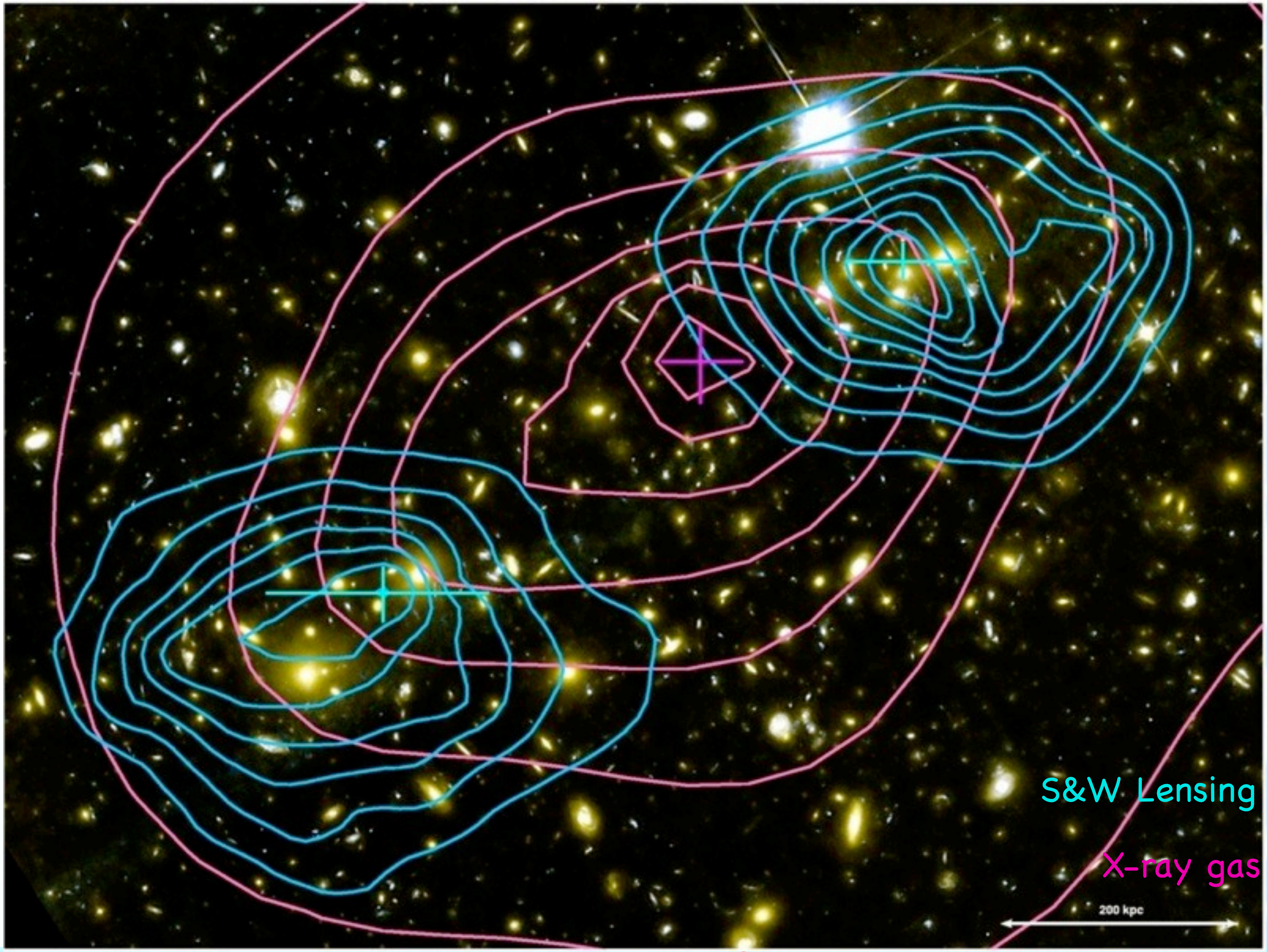
* 6 cluster strong lenses to UDF depth!

Cluster	Cycle	z	RA	Dec
Abell 2744	21	0.308	00:14:21.2	−30:23:50.1
MACSJ0416.1-2403	21	0.396	04:16:08.9	−24:08:28.7
MACSJ0717.5+3745	22	0.545	07:17:34.0	+37:44:49.0
MACSJ1149.5+2223	22	0.543	11:49:36.3	+22:23:58.1
RXCJ2248.7-4431	23*	0.348	22:48:44.4	−44:31:48.5
Abell 370	23*	0.375	02:39:52.9	−01:34:36.5

Cycle 23 observations are contingent on the results from preceding cycles.

Baby Bullet* Cluster MACSJ0025-1222

Baby Bullet* Cluster MACSJ0025-1222



* Neither baby nor bullet

Bradač et al. 2008b

Dark Matter Properties

- Combining the Chandra data with lensing mass maps -> place an upper bound on the dark matter self-interaction cross section $\sigma/m < 4\ \mathrm{cm^2 g^{-1}} = 8$ barn/GeV.

  -> Significant offset between subcluster X-ray gas core and dark matter peak

$$\tau = \Sigma \frac{\sigma}{m}$$

  -> ~~Survival of the subcluster~~ (need velocity info)

  -> ~~No loss of mass from subcluster~~

- The Bullet Cluster: $\sigma/m < 0.7\ \mathrm{cm^2 g^{-1}} = 1.3$barn/GeV (Randall et al.2008)

Musket Ball Cluster: DLSCL J0916.2+2951

Dawson et al.(MB) 2012

Musket Ball: DLSCL J0916.2+2951

* Discovered from Deep Lens Survey
* A merger at a later stage
* $\sigma/m < 7\ cm^2 g^{-1} = 15$ barn/GeV.
* z=0.58

Dawson et al.(MB) 2012

Challenge

$\sigma/m < 0.7\ cm^2g^{-1}$ Randall et al. 2008

$\sigma/m < 4\ cm^2g^{-1}$ Bradač et al. 2008

$\sigma/m < 3\ cm^2g^{-1}$ Merten et al. 2011

$\sigma/m < 3\ cm^2g^{-1}$ Clowe et al. 2012

$\sigma/m < 7\ cm^2g^{-1}$ Dawson et al. 2012

* Will we ever do better?
* $\sigma/m < 0.05\ cm^2g^{-1}$ will be effectively the same as CDM in terms of observables of structure (halo profiles, shapes, substructure fraction)

Will we ever do better?

- Merging Cluster Collaboration-MC^2
- UC Davis - UC Irvine collaboration led by PI Dawson (jump started by HIPPAC)

MC² Merging Cluster Collaboration

M C²

Merging Cluster Collaboration

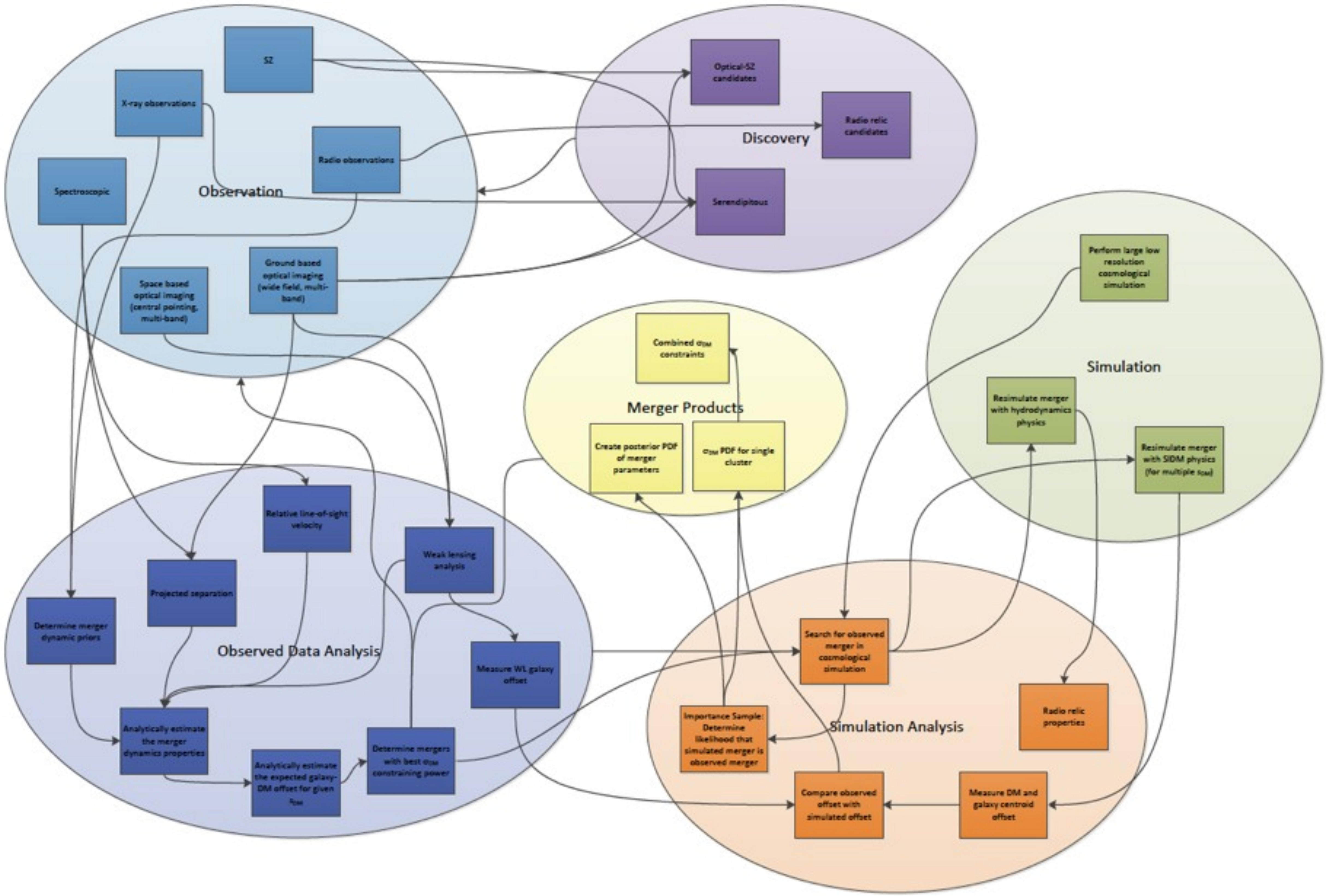
Observation

Will Dawson (PI, UCD)
Marusa Bradac (UCD)
James Jee (UCD)
Julian Merten (Caltech/JPL)
Dave Wittman (UCD)
Reinout van Weeren (CfA)

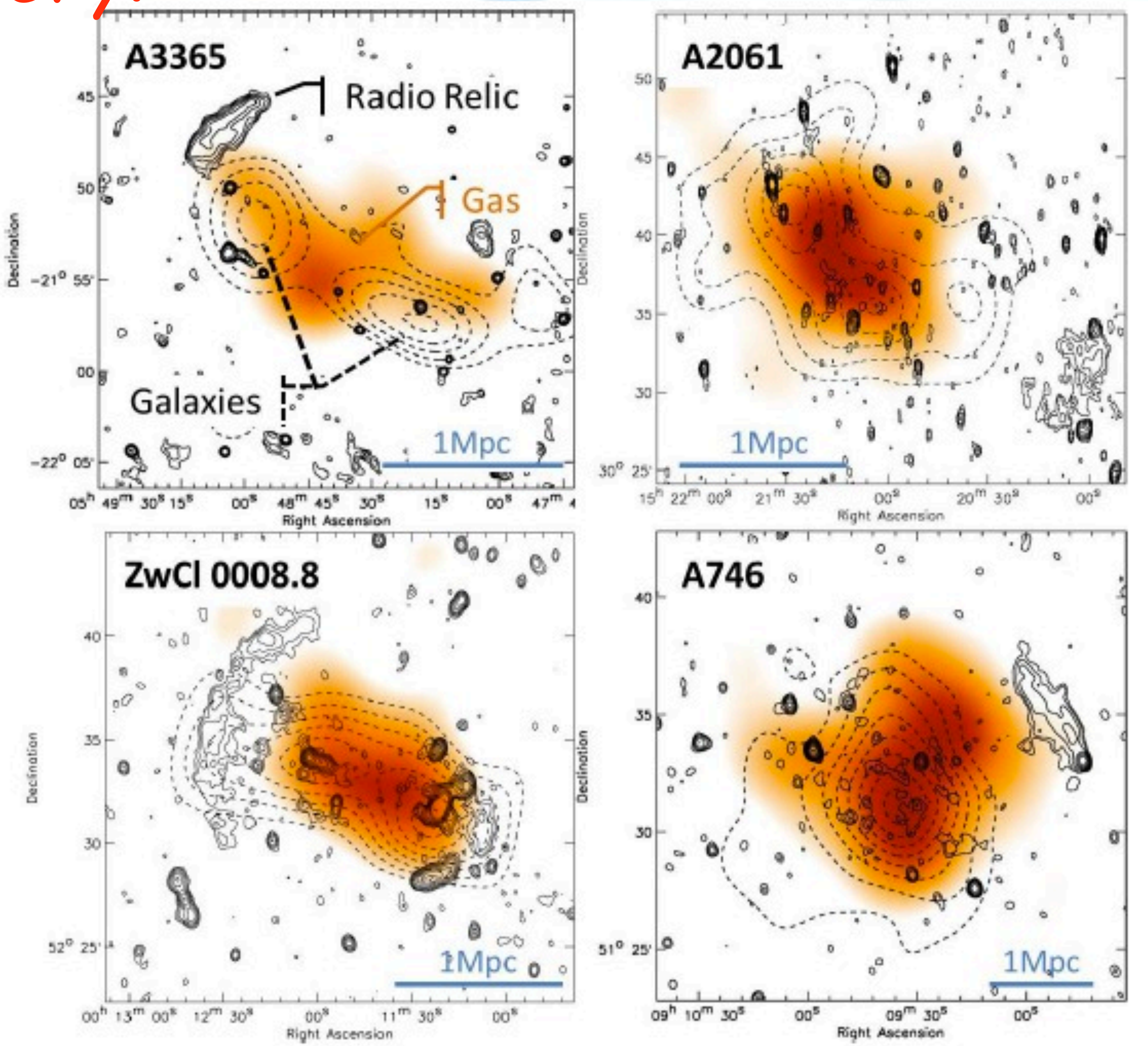
Theory/Simulation

James Bullock (Co-founder, UCI)
Marcus Bruggen (Hamburg/Jacobs)
Oliver Elbert (UCI)
Manoj Kaplinghat (UCI)
Annika Peter (UCI, OSU)
Miguel Rocha (UCI)

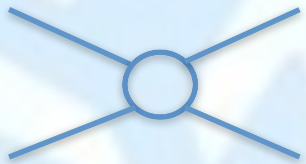
MC^2 Analysis Plan



Discovery!


A3365
Radio Relic
Gas
Galaxies
1Mpc
A2061
1Mpc
ZwCl 0008.8
1Mpc
A746
1Mpc
Declination
Right Ascension

Simulations: SI dark matter



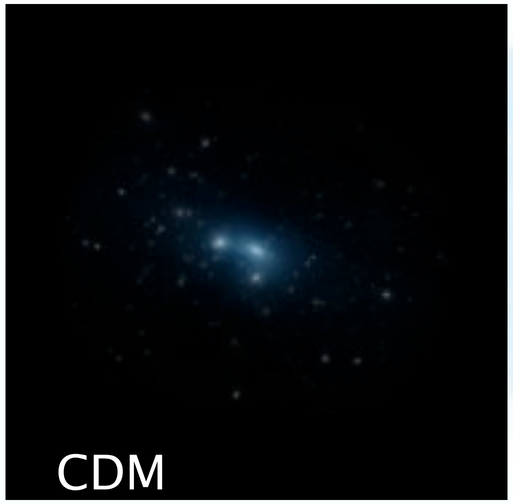
$$\Gamma \sim \rho\left(\frac{\sigma}{m}\right)v_{\rm rel}$$

- Generic predictions when $\Gamma/H_0 \gtrsim 1$:

  → Rounder halo in inner parts.

  → Cored (less dense) halo density profiles.

  → Fewer satellites close to the center.

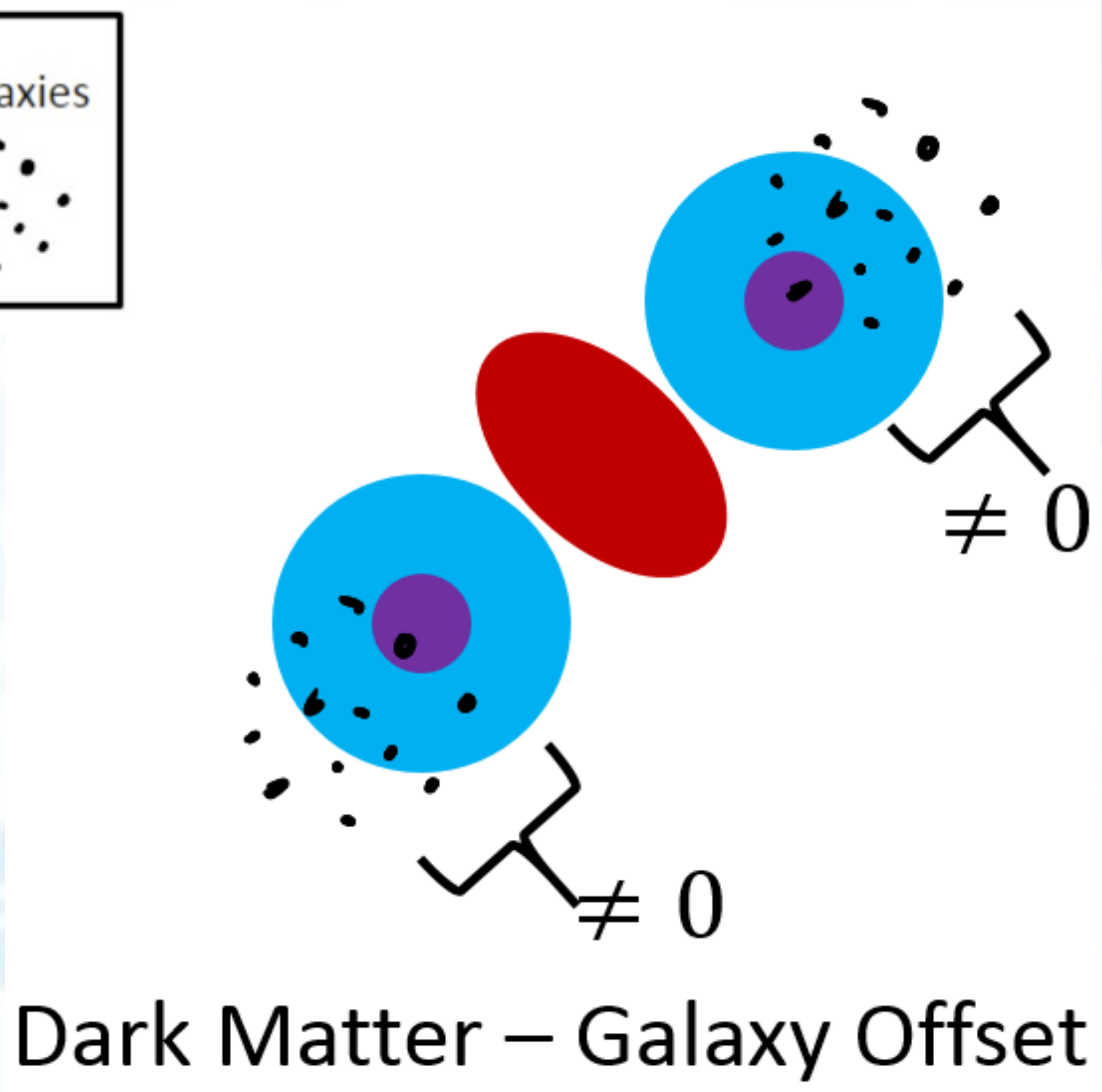


SI dark matter

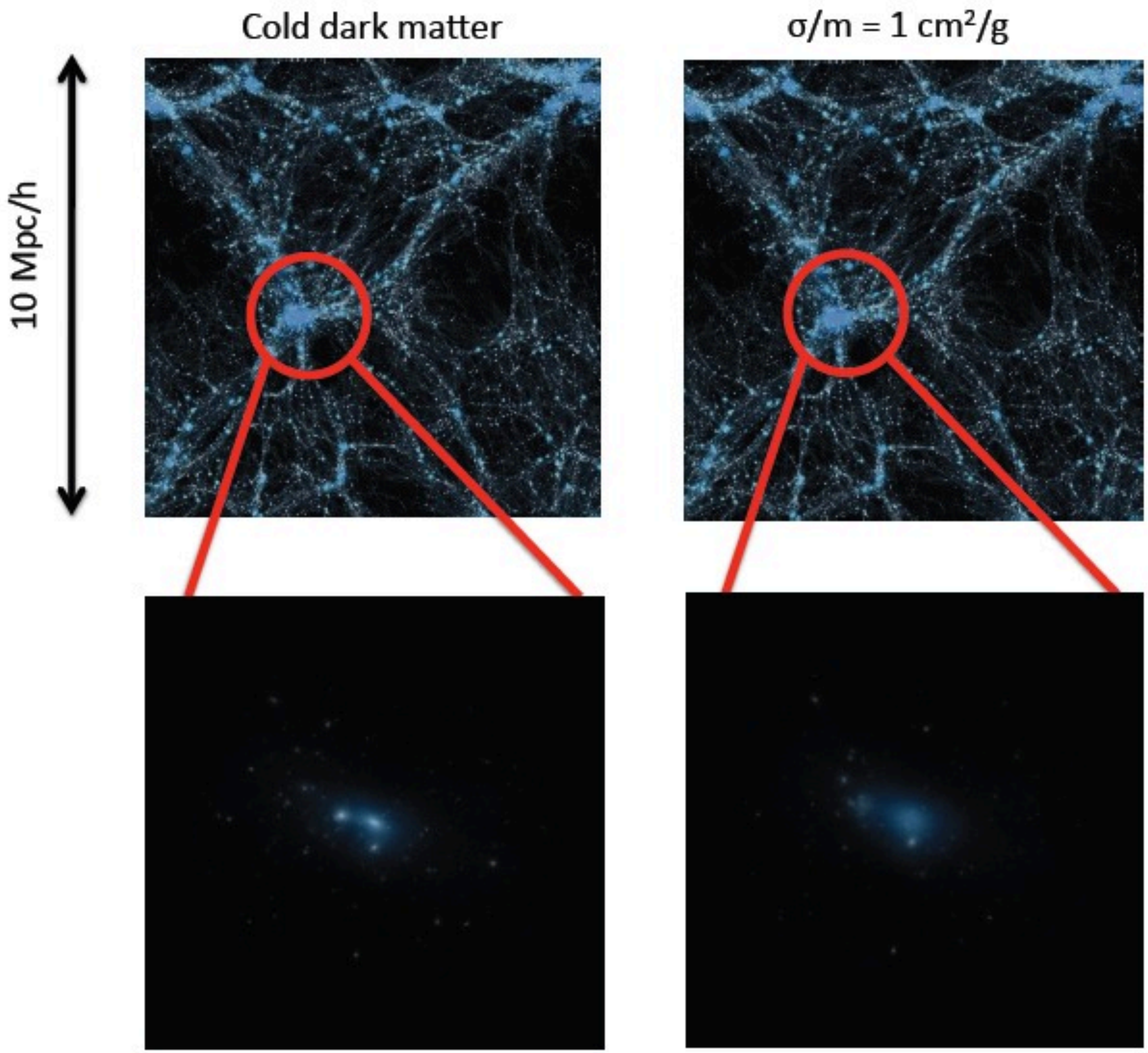
DM type	clustering	Halo mass functions	Growth function	Halo shapes	Halo density profiles	substructure
Cold, stable WIMP	On scales down to $<M_\odot$	Sharply falling function of mass	Linear regime-- scale independent	triaxial	Cuspy; $\rho \sim r^{-1}$ at center	$dN/dM \sim M^{-2}$ down to $M < M_\odot$
observations	Good fit down to $\sim 10^{11}$ $M_\odot$	Good for clusters	Consistent so far	Qualitative yes	Some uncertainty	Good fit down to $\sim 10^{11}$ $M_\odot$
Self-interacting SIDM	Same as CDM	Same as CDM	Same as CDM	**Less triaxial σ/m=1cm^2/g in tension**	**σ/m=0.1-0.5 cm^2/g?**	**Only modestly suppressed**

DM self-interaction: Measurement

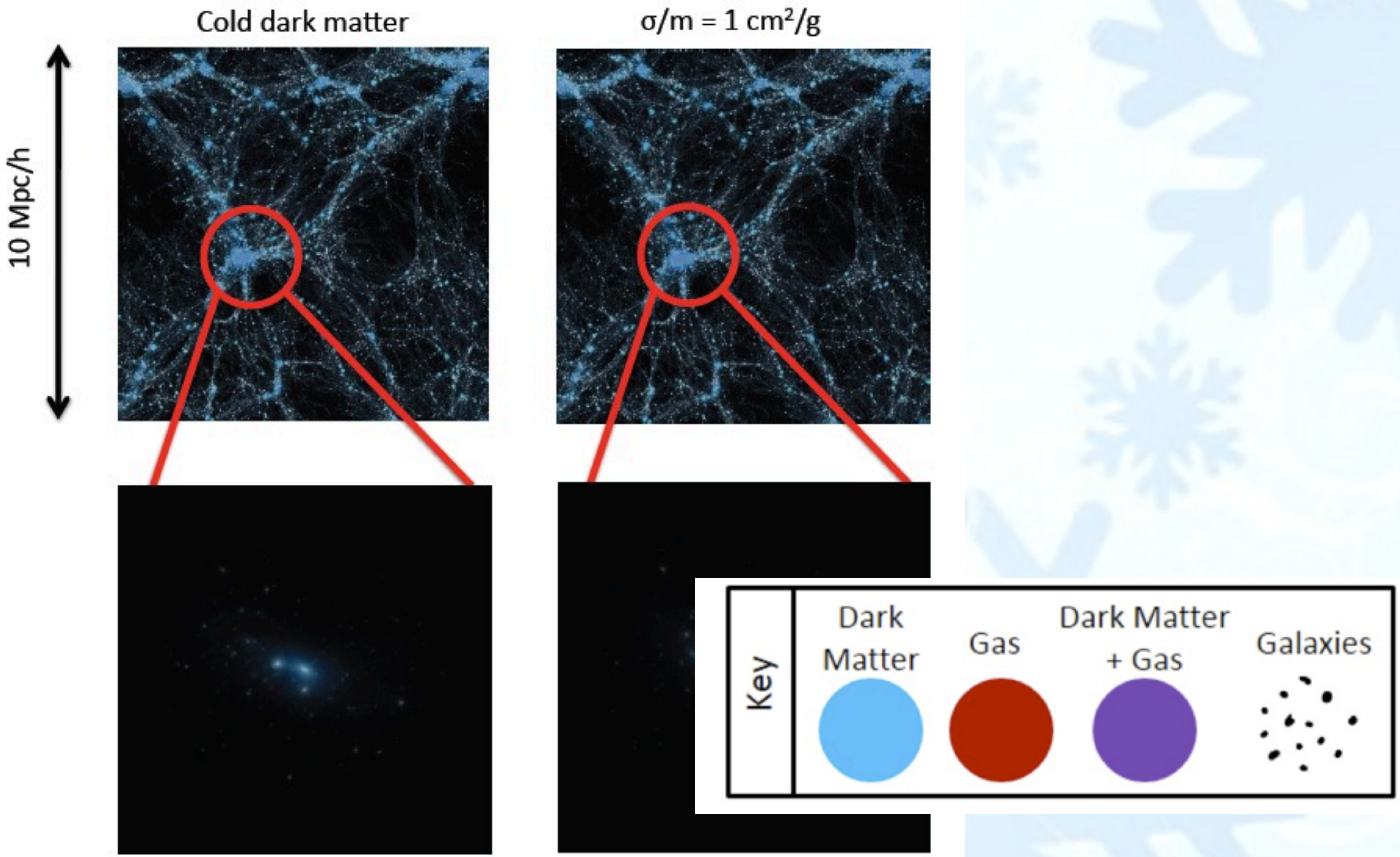
NEED BETTER SIMULATIONS!!!



Simulations



Simulations



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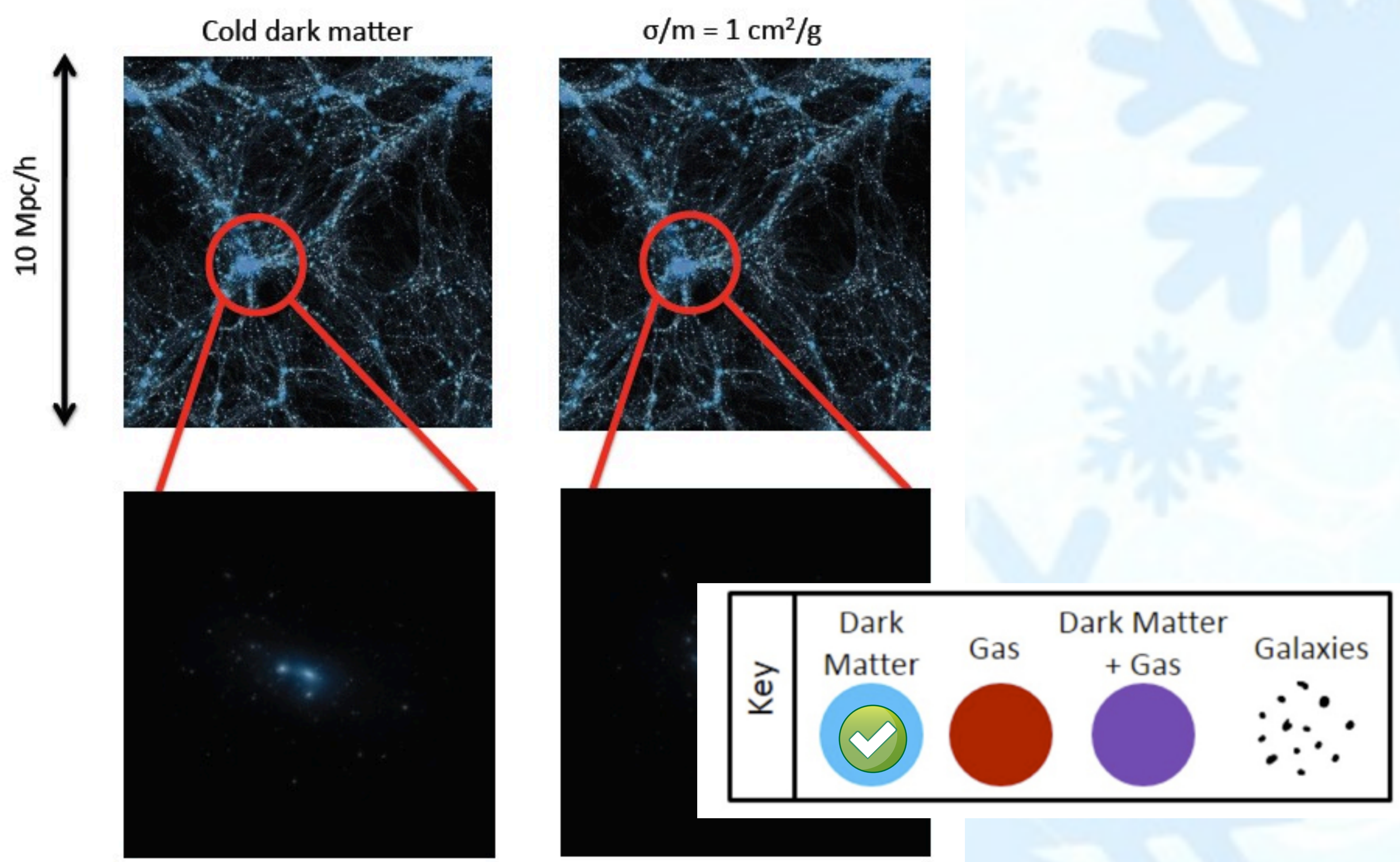

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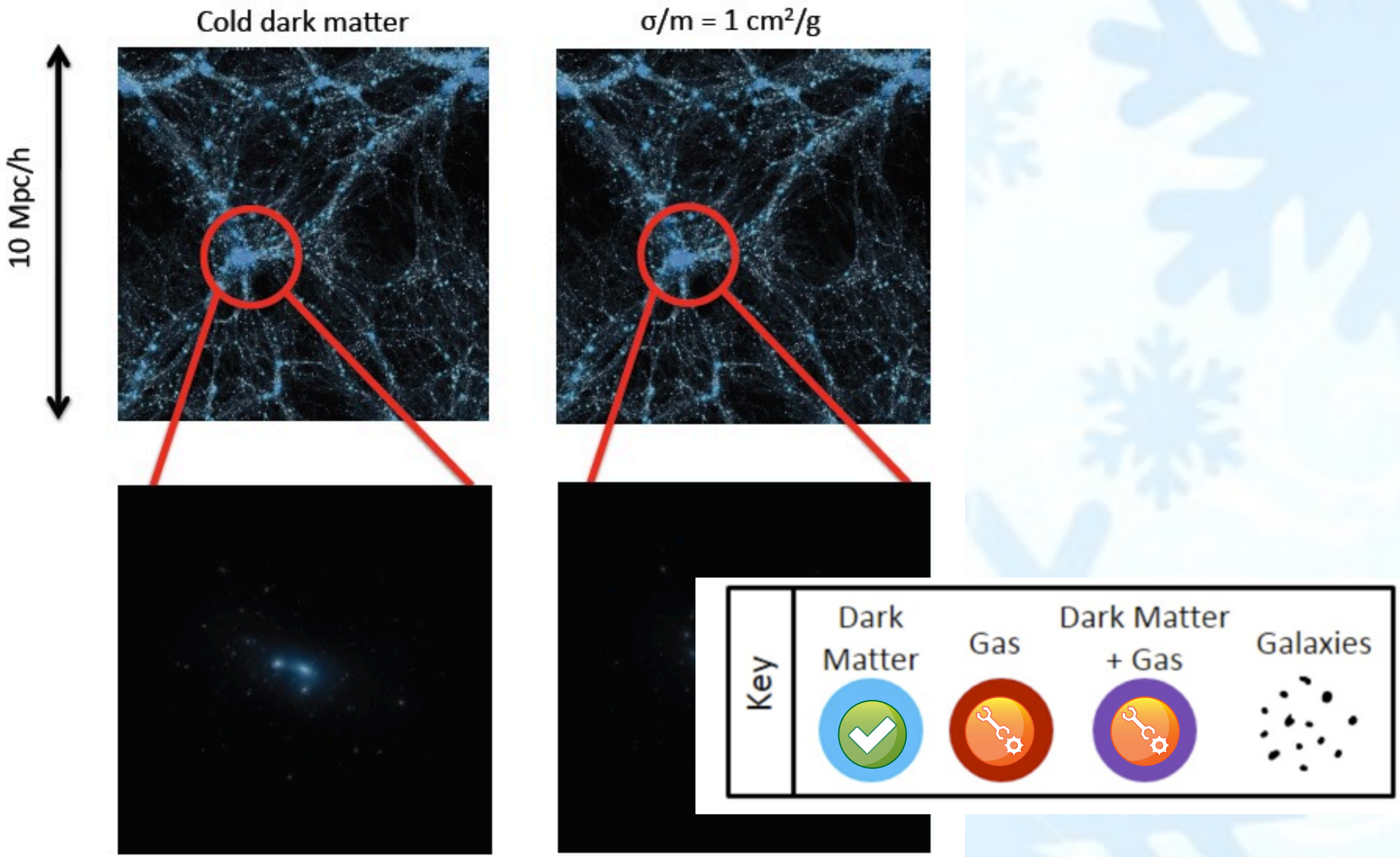

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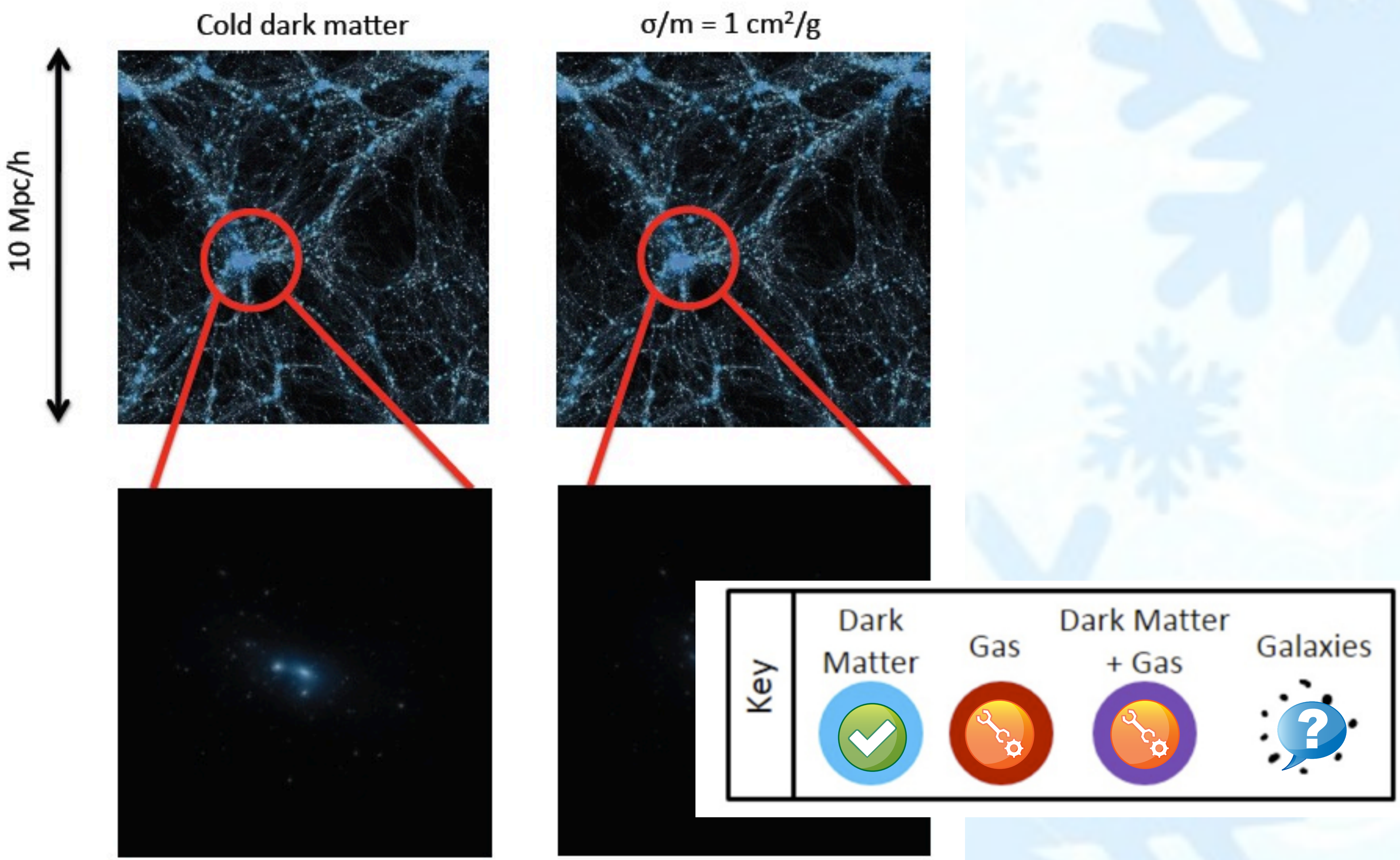

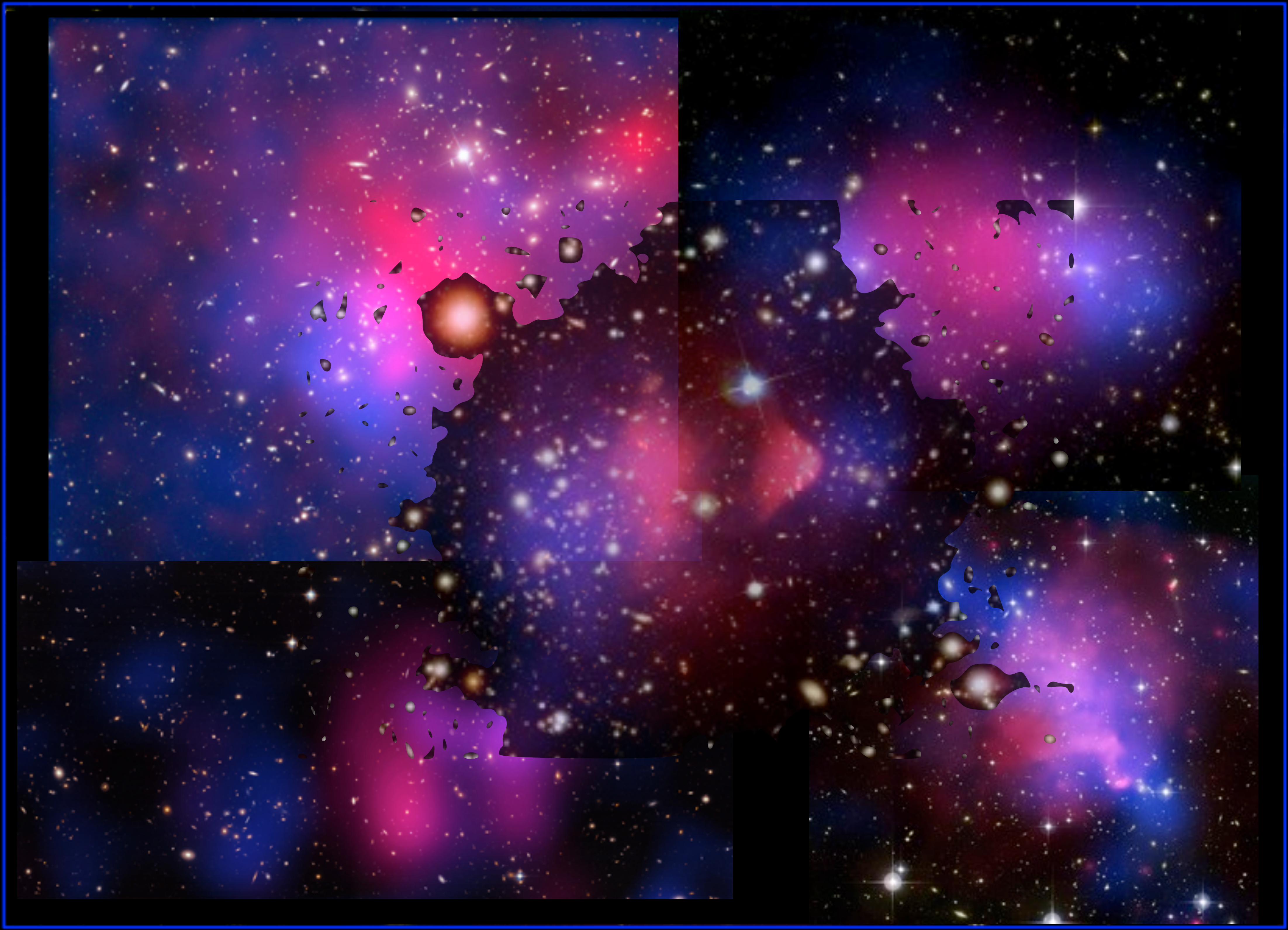

DARK MATTER

Most of the universe still can't be bothered to interact with you

S.Caroll