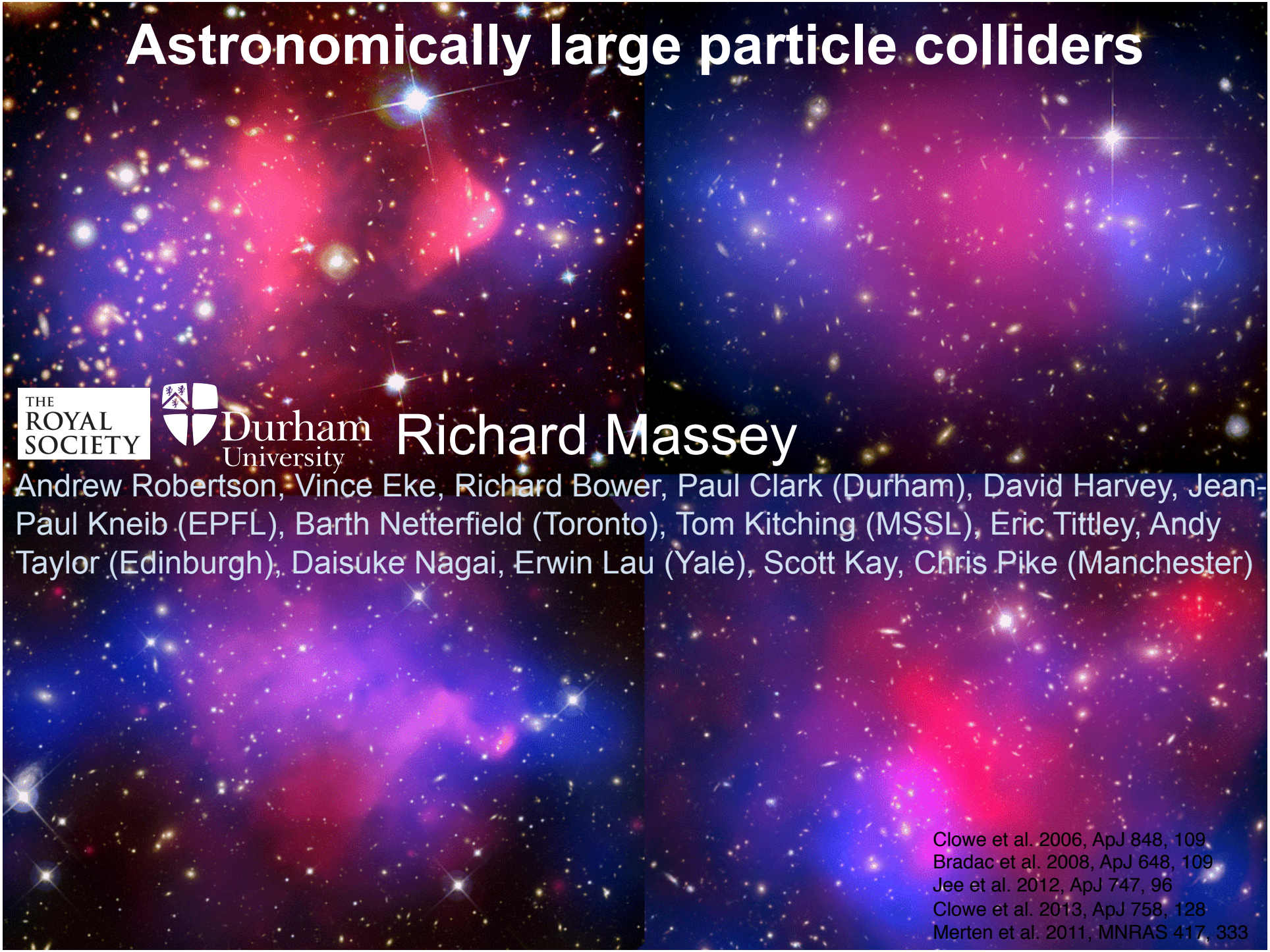
Astronomically large particle colliders

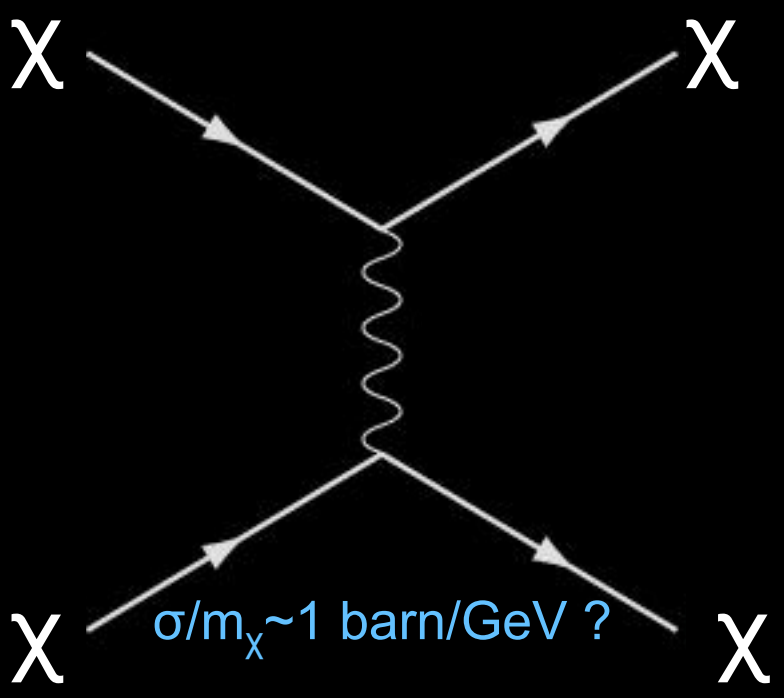


THE ROYAL SOCIETY
Durham University
Richard Massey

Andrew Robertson, Vince Eke, Richard Bower, Paul Clark (Durham), David Harvey, Jean-Paul Kneib (EPFL), Barth Netterfield (Toronto), Tom Kitching (MSSL), Eric Tittley, Andy Taylor (Edinburgh), Daisuke Nagai, Erwin Lau (Yale), Scott Kay, Chris Pike (Manchester)

Clowe et al. 2006, ApJ 848, 109
Bradac et al. 2008, ApJ 648, 109
Jee et al. 2012, ApJ 747, 96
Clowe et al. 2013, ApJ 758, 128
Merten et al. 2011, MNRAS 417, 333

DM-DM interactions unprobed by terrestrial expts



…but naturally predicted by lots of particle physics models:

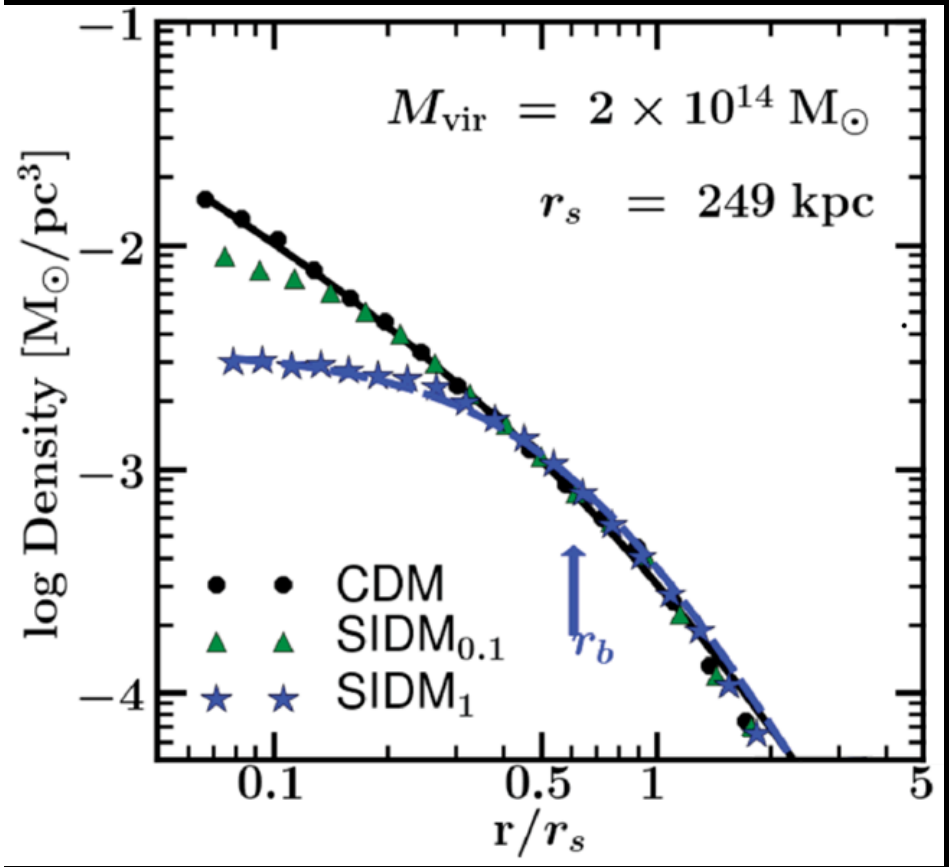
e.g.
Supersymmetric neutralino (Steigman & Turner 1985)
Kaluza-Klein photon (Griest 1988)
Gravitino (Jungman+ 1996)
SIDM (Spergel & Steinhardt 2000)
SuperWIMP (Feng 2003)
Axion (Baker 2007)
Dark photons (Pospelov 2008)
Glueball/Glueballino (Boddy+ 2014)
Mirror dark matter (Foot 2014)
…

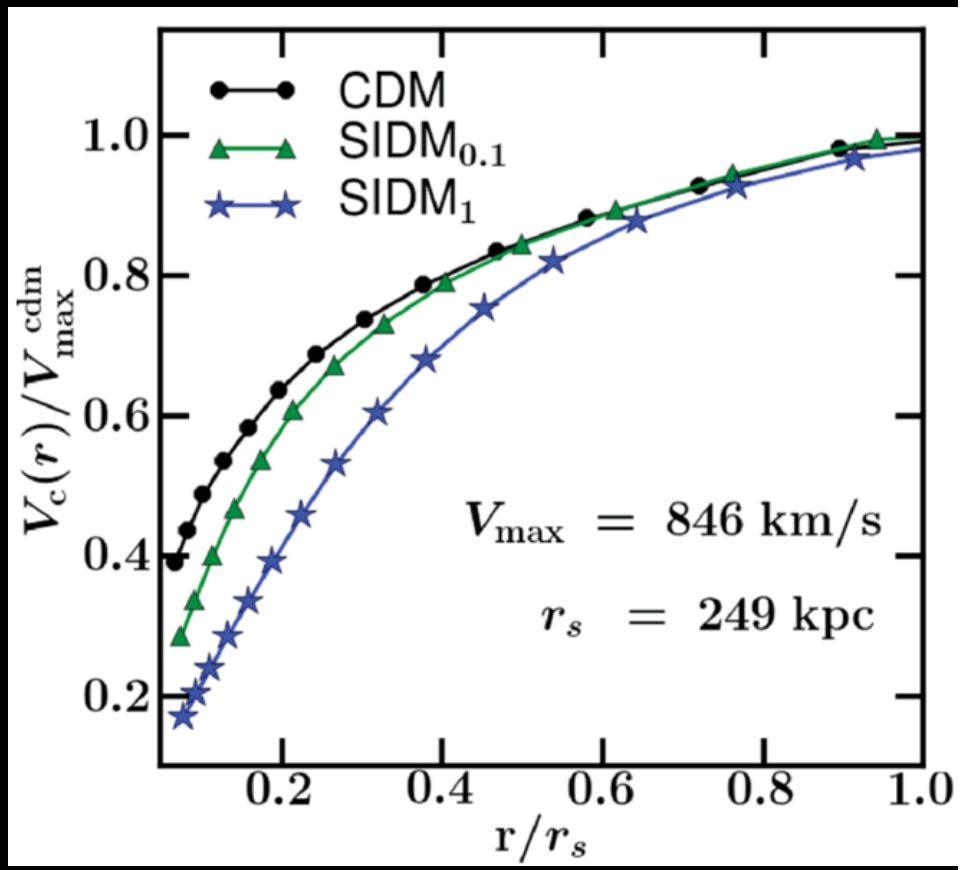
Phenomenological benefits of SIDM

Momentum transfer/mass loss from the centre of relaxed systems

➔ core formation (cusp/core)
removal of small substructure (missing satellites)
reduced circular velocity (too big to fail)

Potentially solves all of CDM's "small-scale crises"!





Rocha+ 2013

Phenomenological benefits of SIDM

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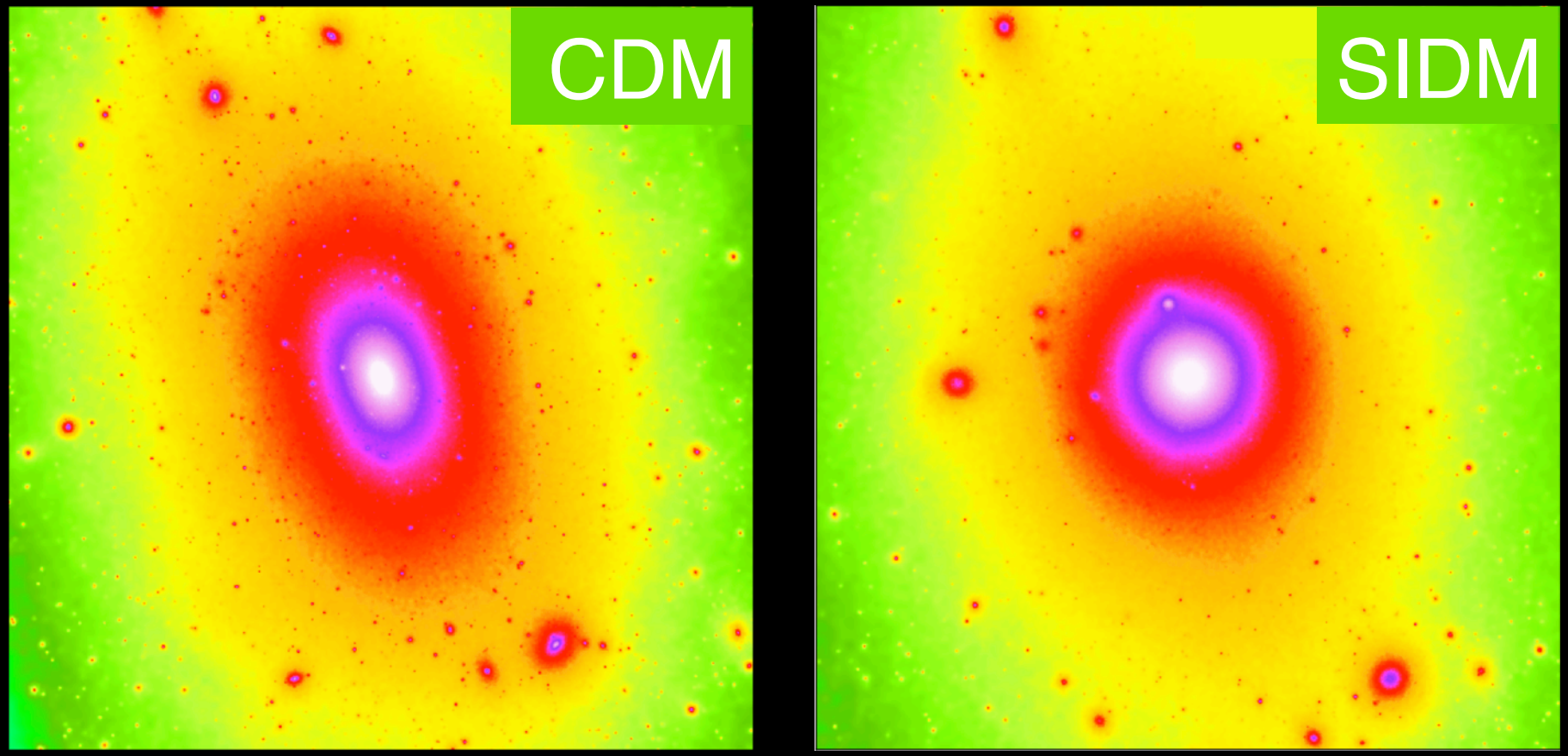
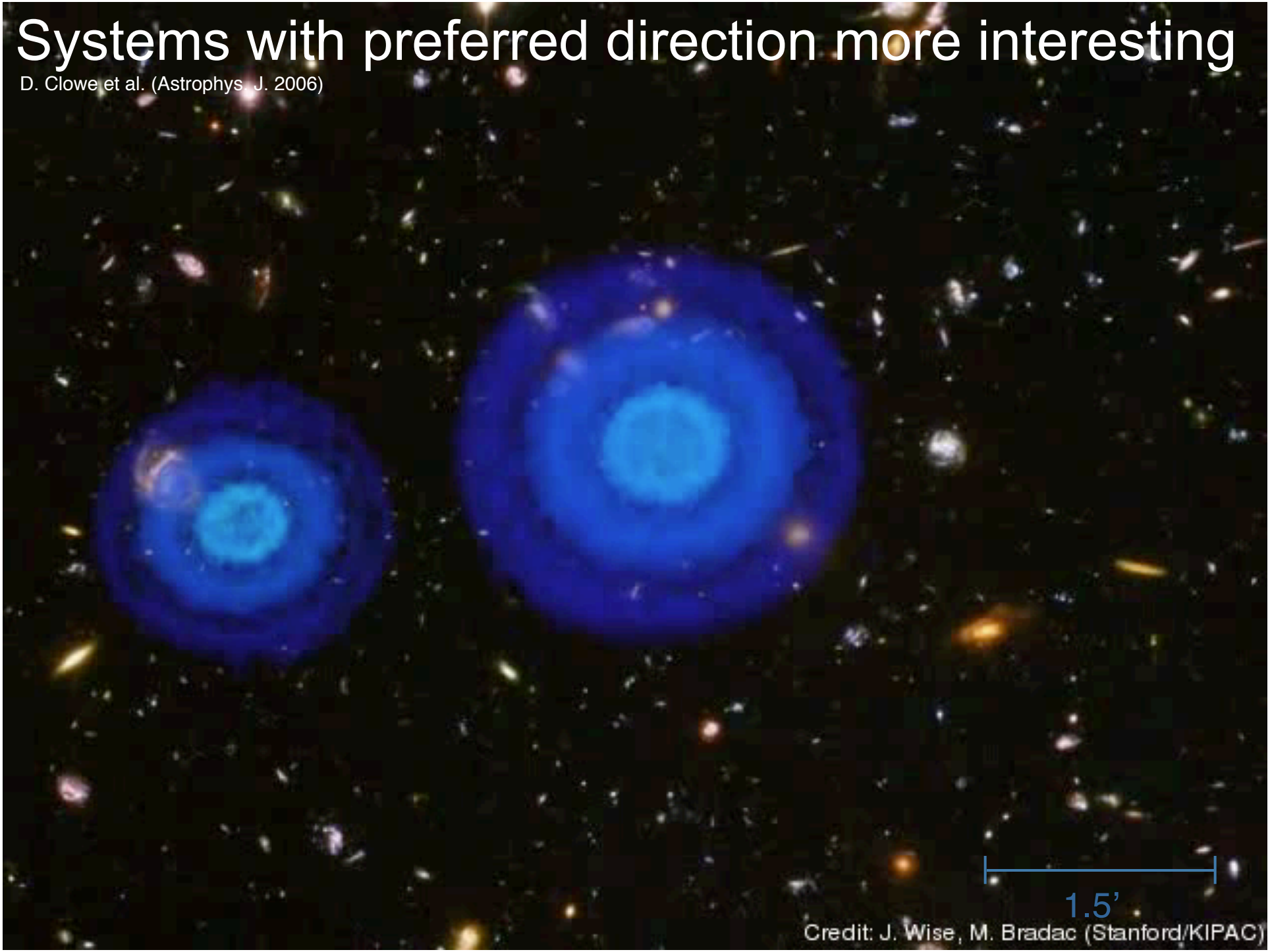


Vogelsberger+ 2012

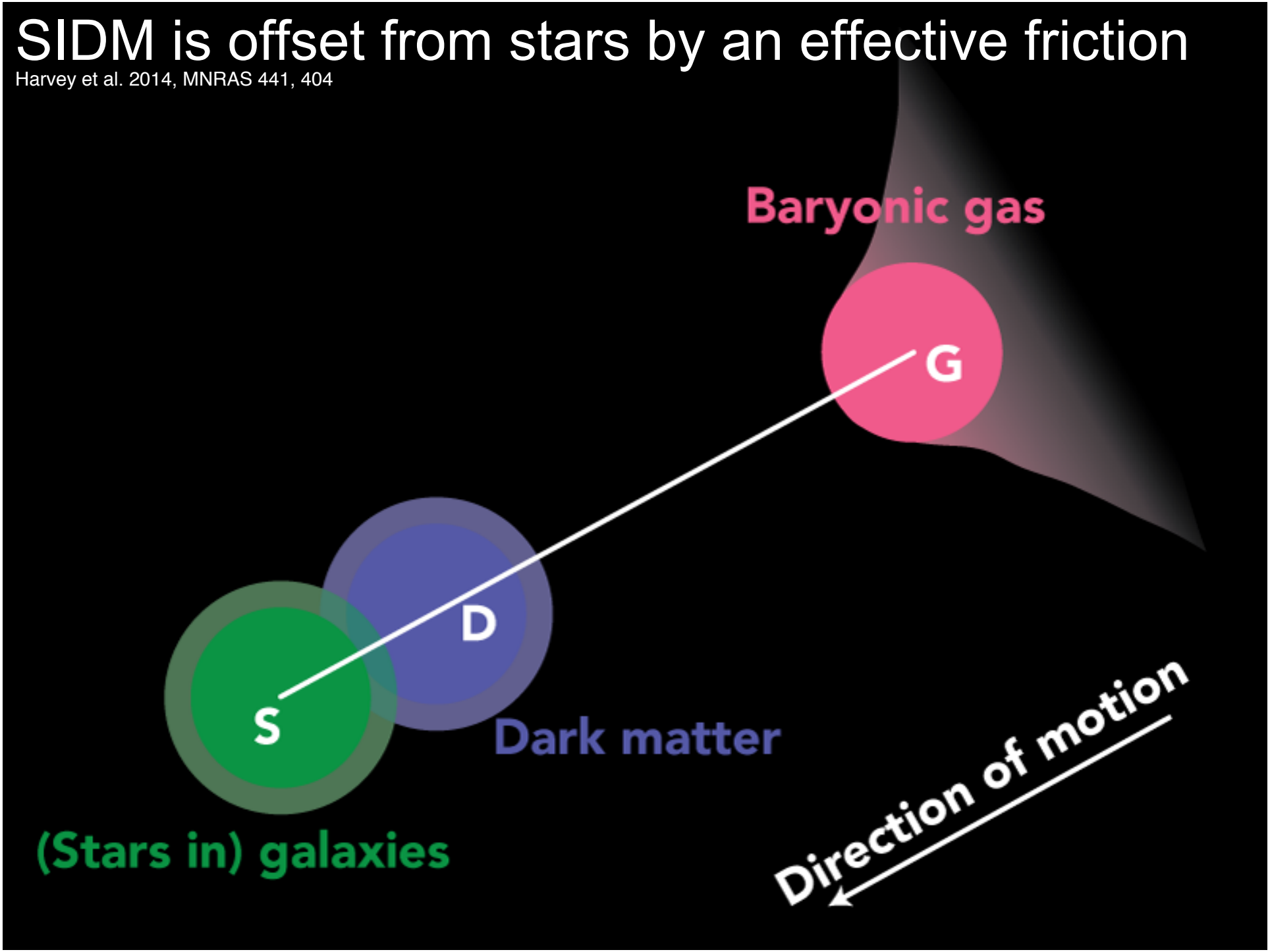
Systems with preferred direction more interesting

D. Clowe et al. (Astrophys. J. 2006)



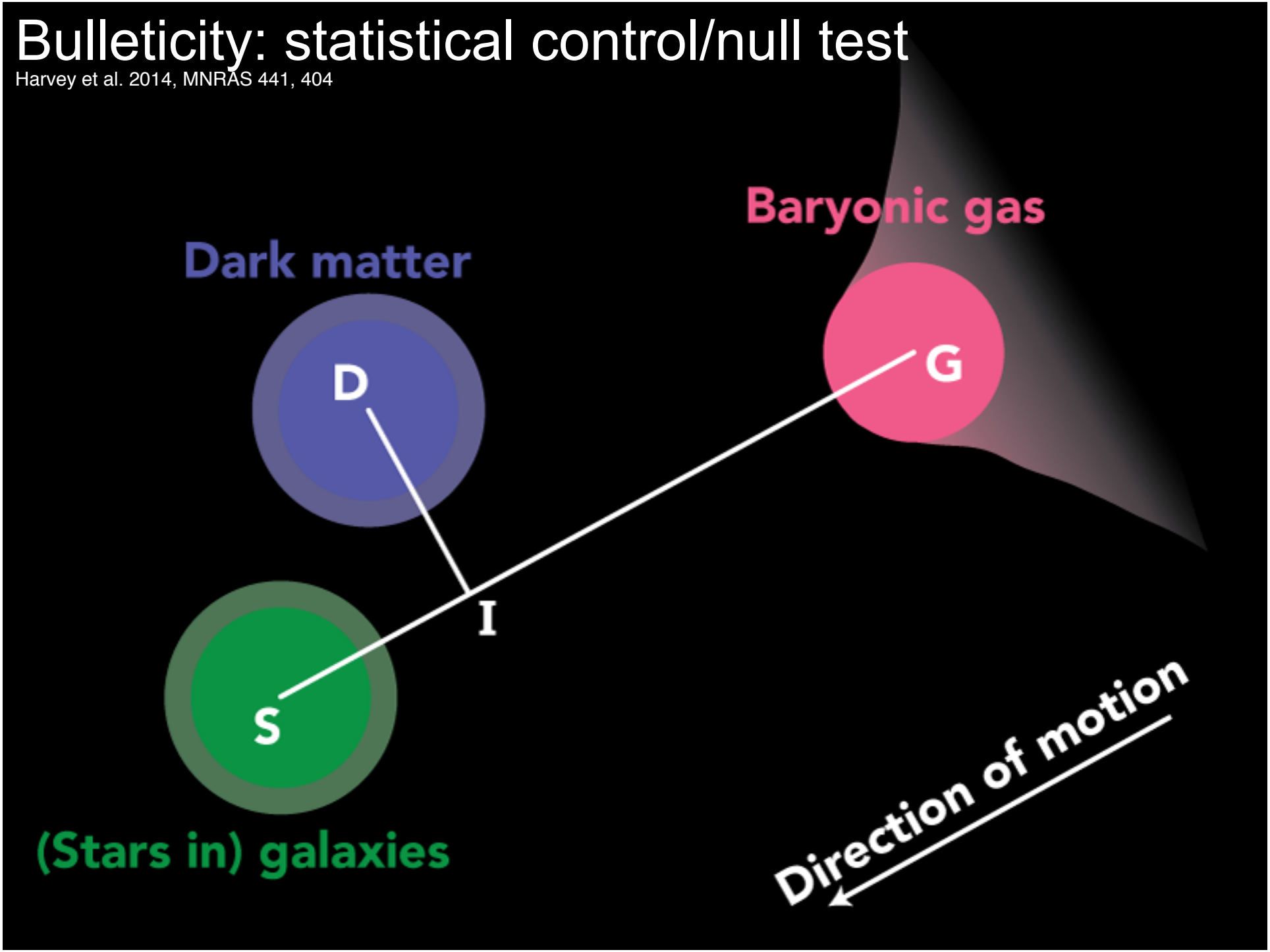
SIDM is offset from stars by an effective friction

Harvey et al. 2014, MNRAS 441, 404

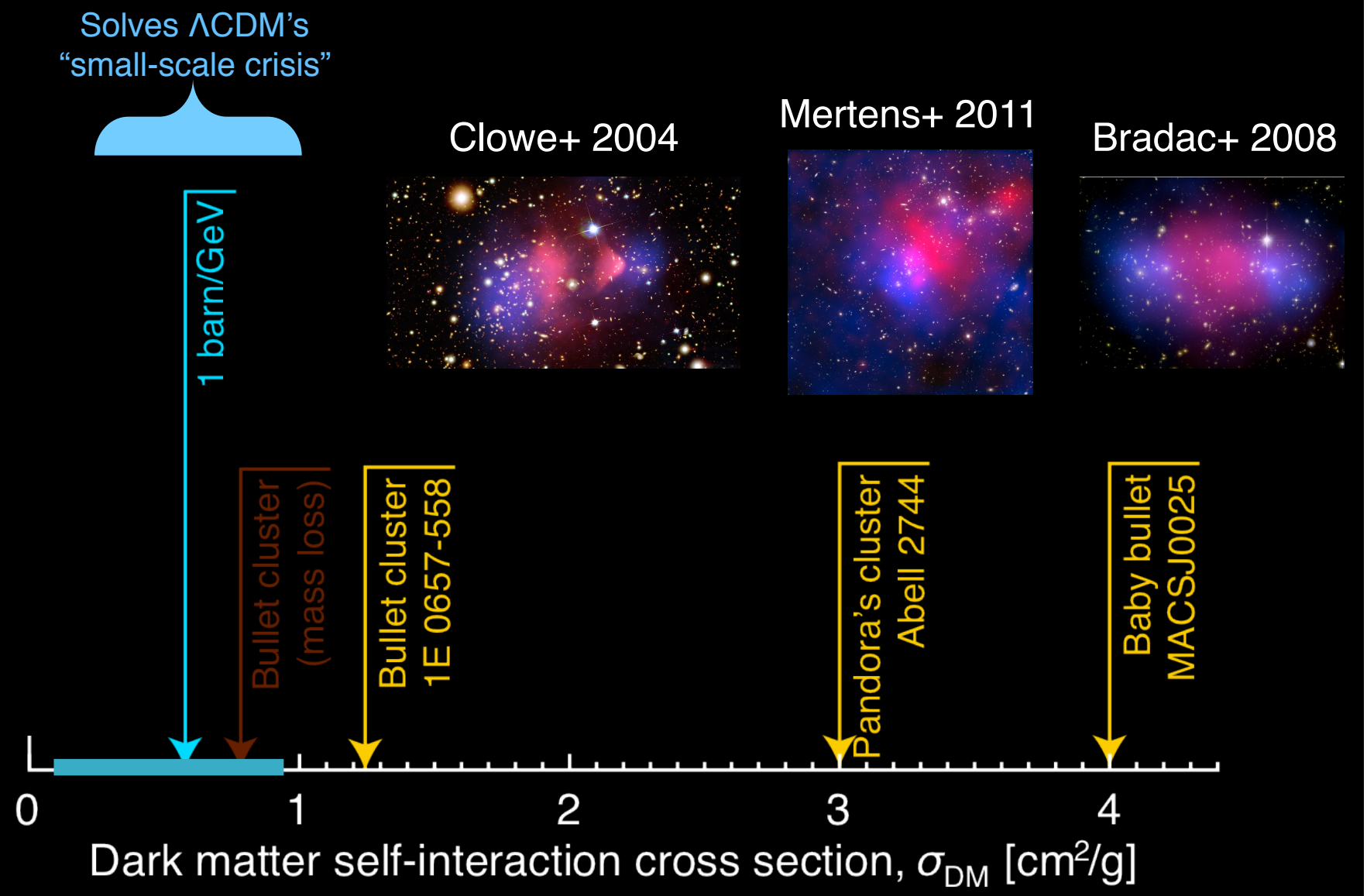


Bulleticity: statistical control/null test

Harvey et al. 2014, MNRAS 441, 404

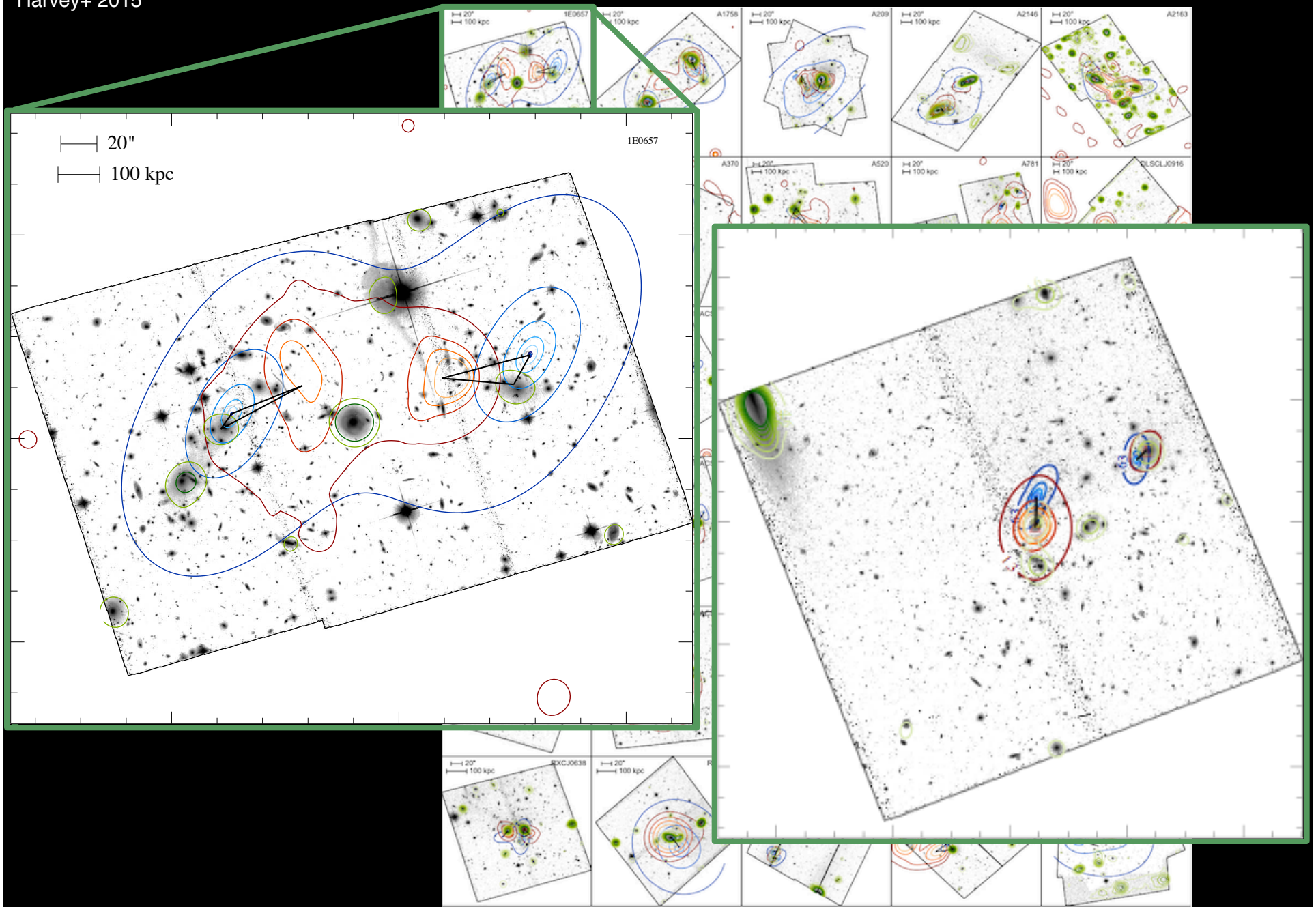


Upper limits from individual collisions are limited by uncertainty in pre-collision dynamics



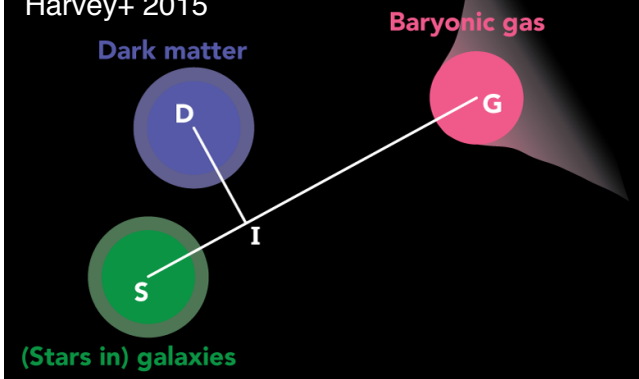
Bulleticity observations in 30 systems (72 bullets)

Harvey+ 2015

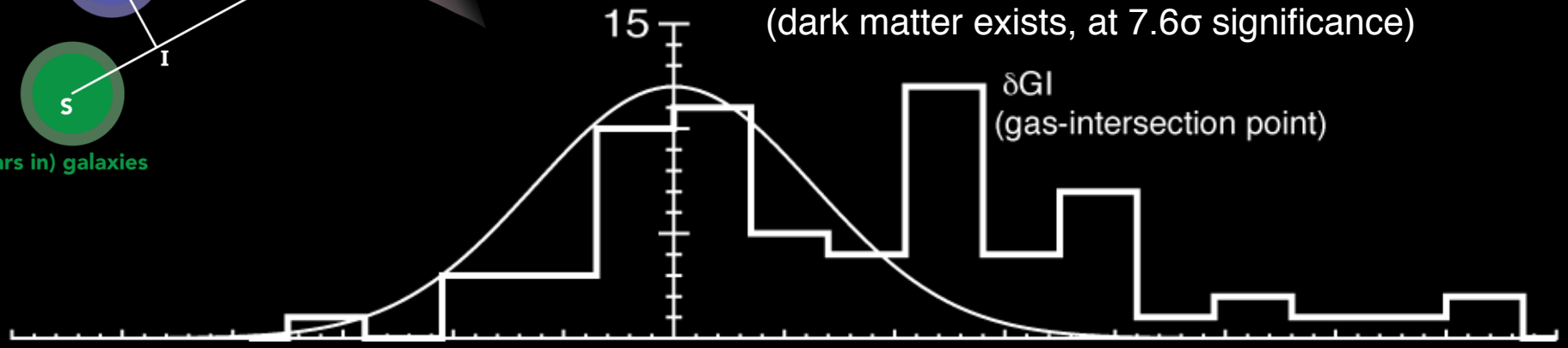


Observed offsets between components [kpc]

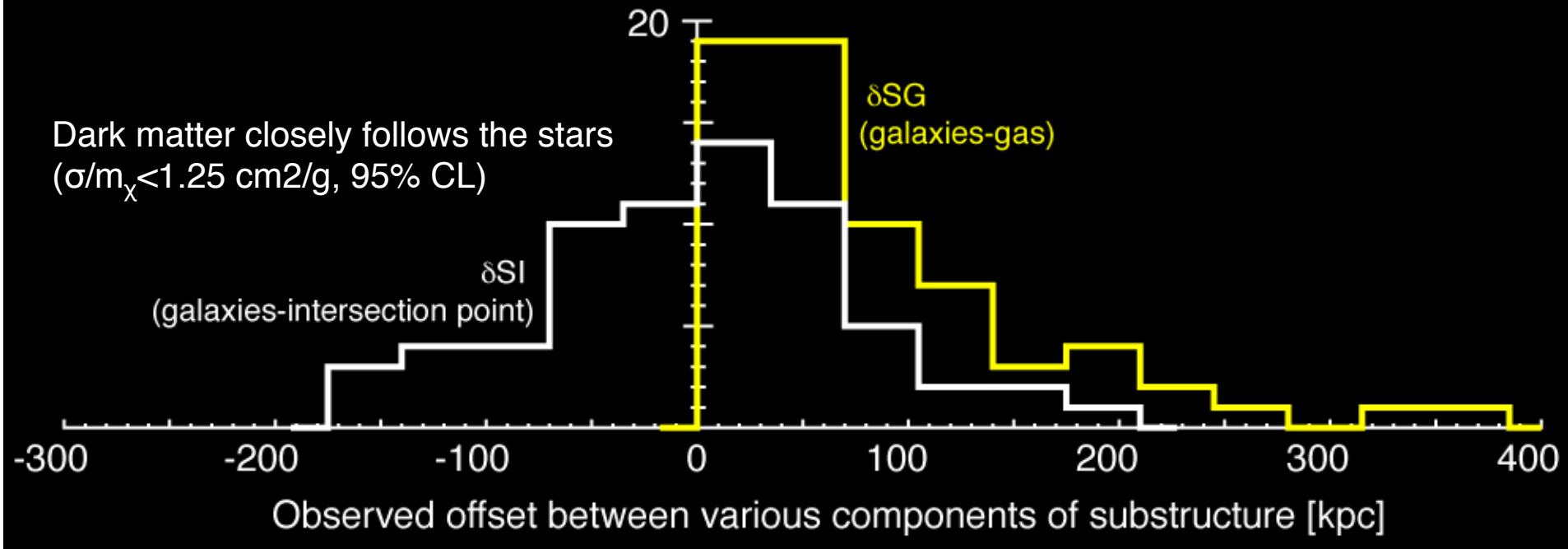
Harvey+ 2015



Mass is not in the same place as the bayons
(dark matter exists, at 7.6σ significance)

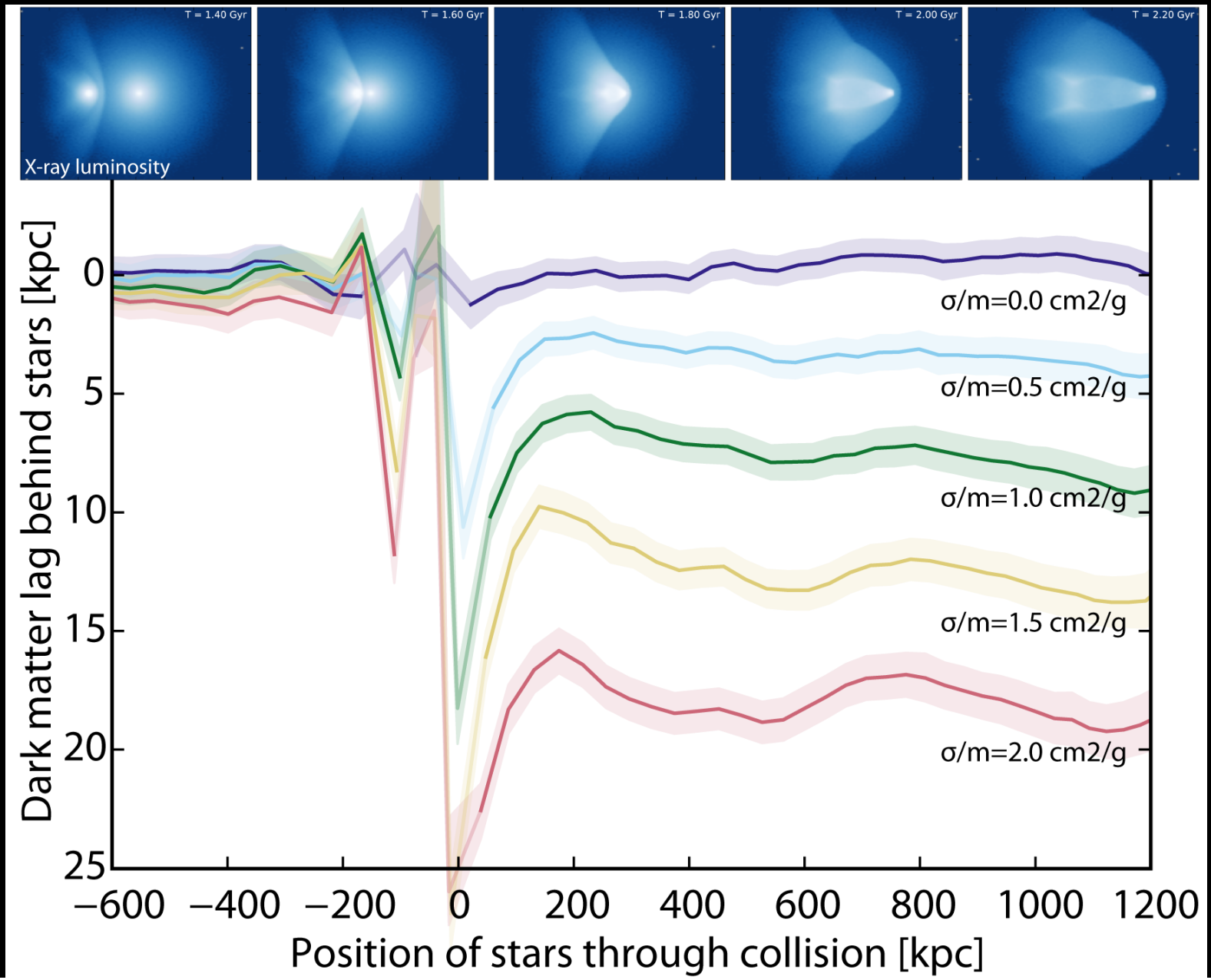


Dark matter closely follows the stars
(σ/m_χ<1.25 cm2/g, 95% CL)

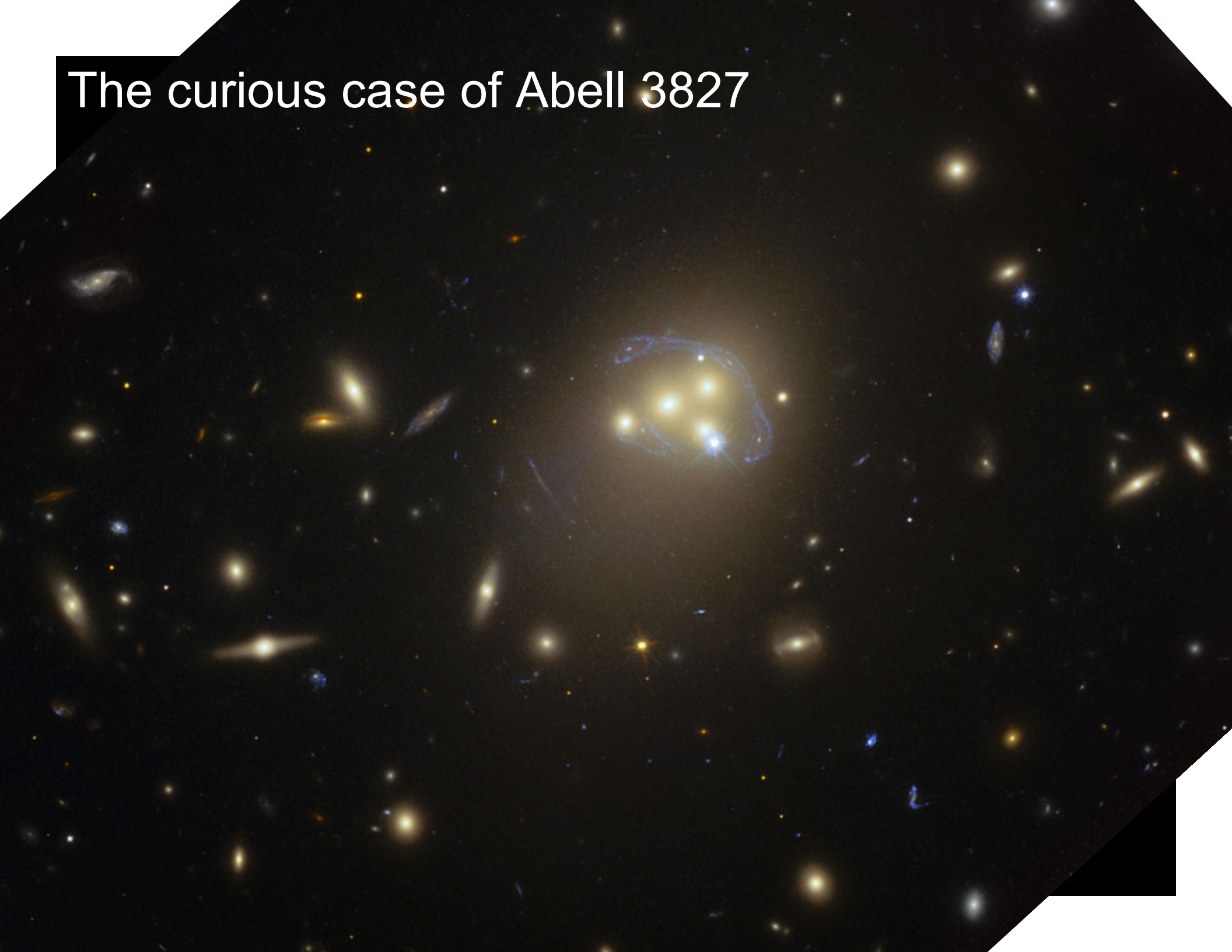


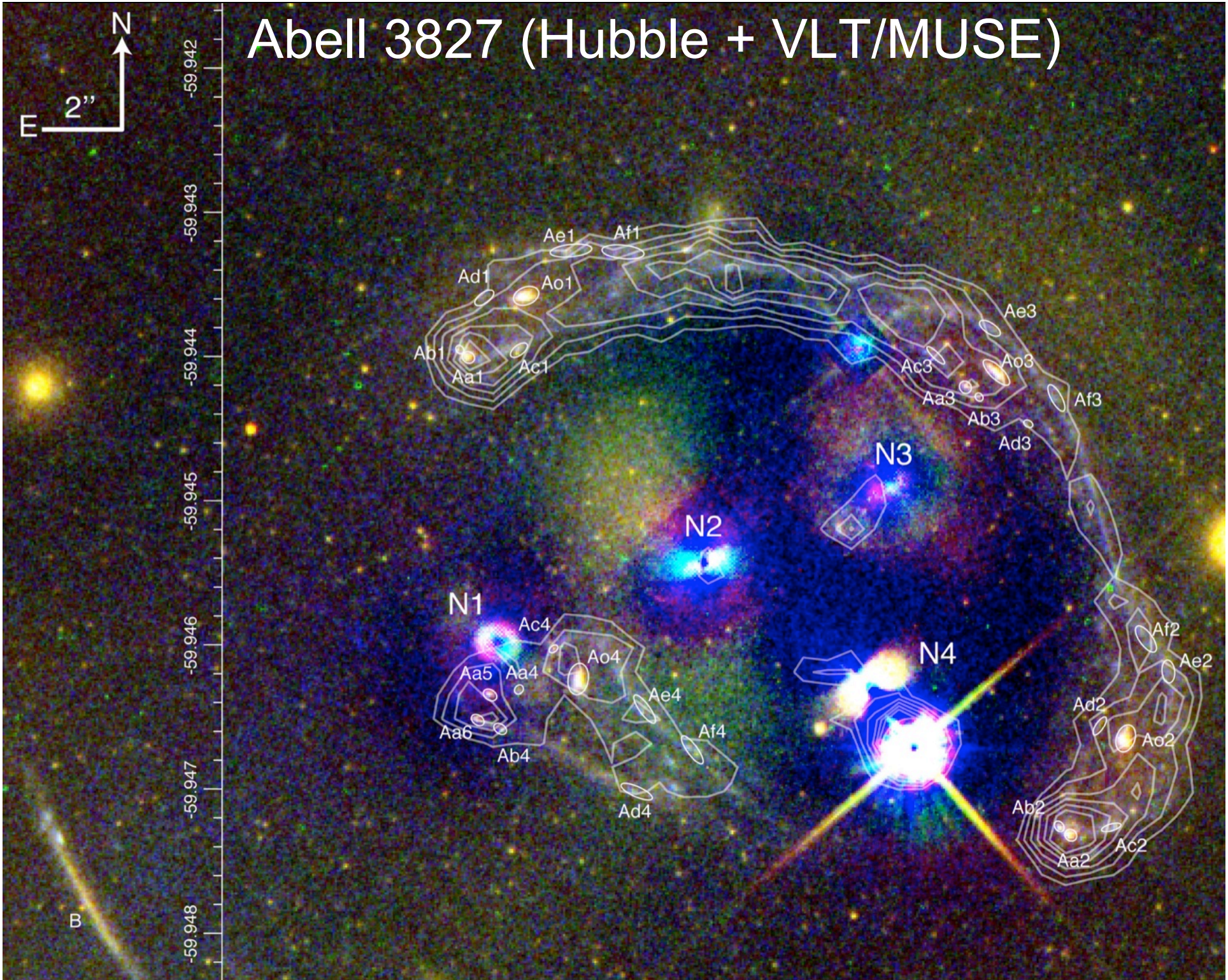
Calibrating DM-star offset with hydro simulations

Kahlhoefer+ 2014, Robertson+ 2016 (assuming a low mass force mediator particle)



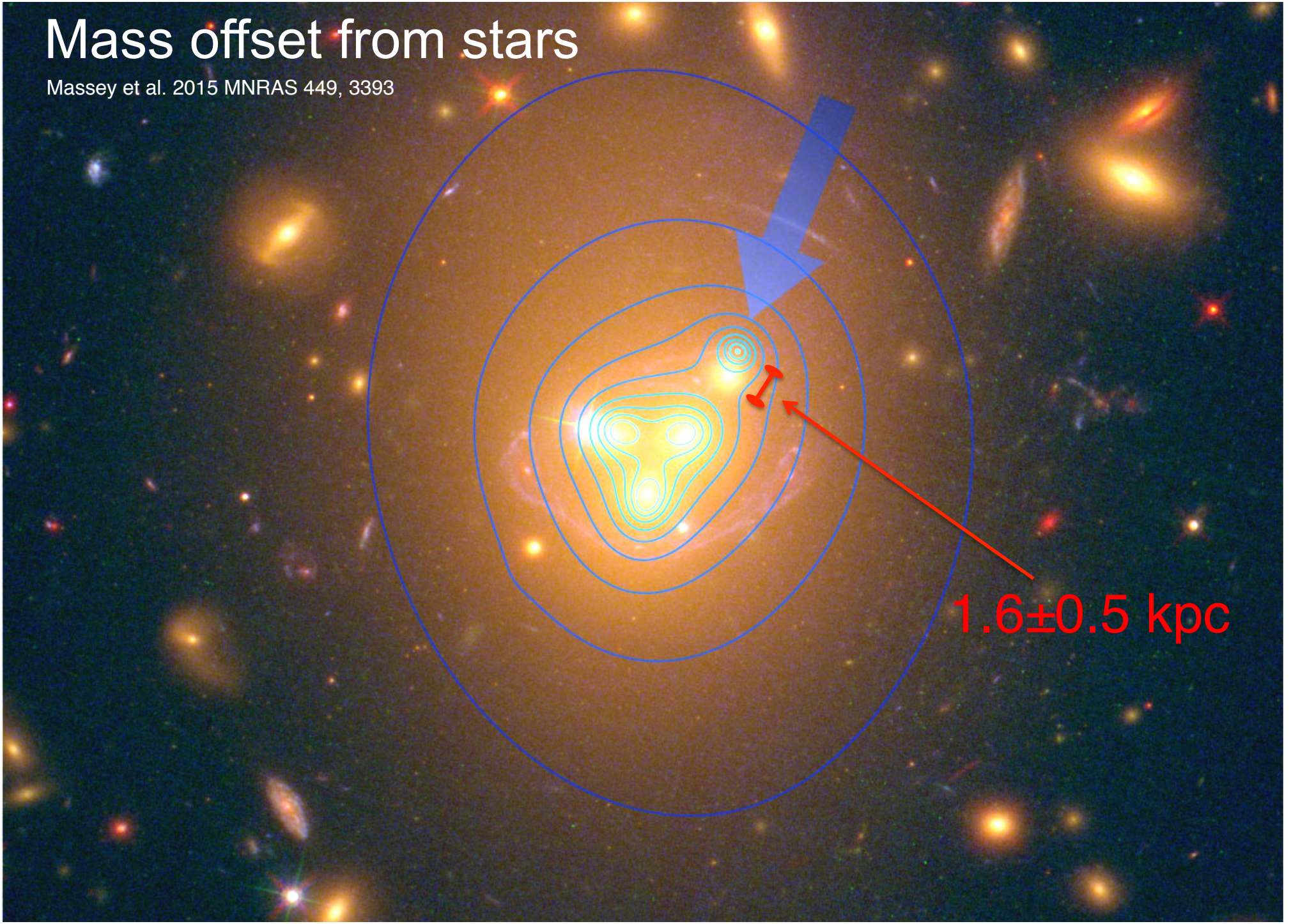
The curious case of Abell 3827




Abell 3827 (Hubble + VLT/MUSE)
N
E
2”
-59.942
-59.943
-59.944
-59.945
-59.946
-59.947
-59.948
B
Ae1
Af1
Ad1
Ao1
Ae3
Ab1
Aa1
Ac1
Ac3
Ao3
Aa3
Af3
Ab3
Ad3
N3
N2
N1
Ac4
Ao4
Aa5
Aa4
Ae4
Aa6
Af4
Ab4
Ad4
N4
Af2
Ae2
Ad2
Ao2
Ab2
Aa2
Ac2

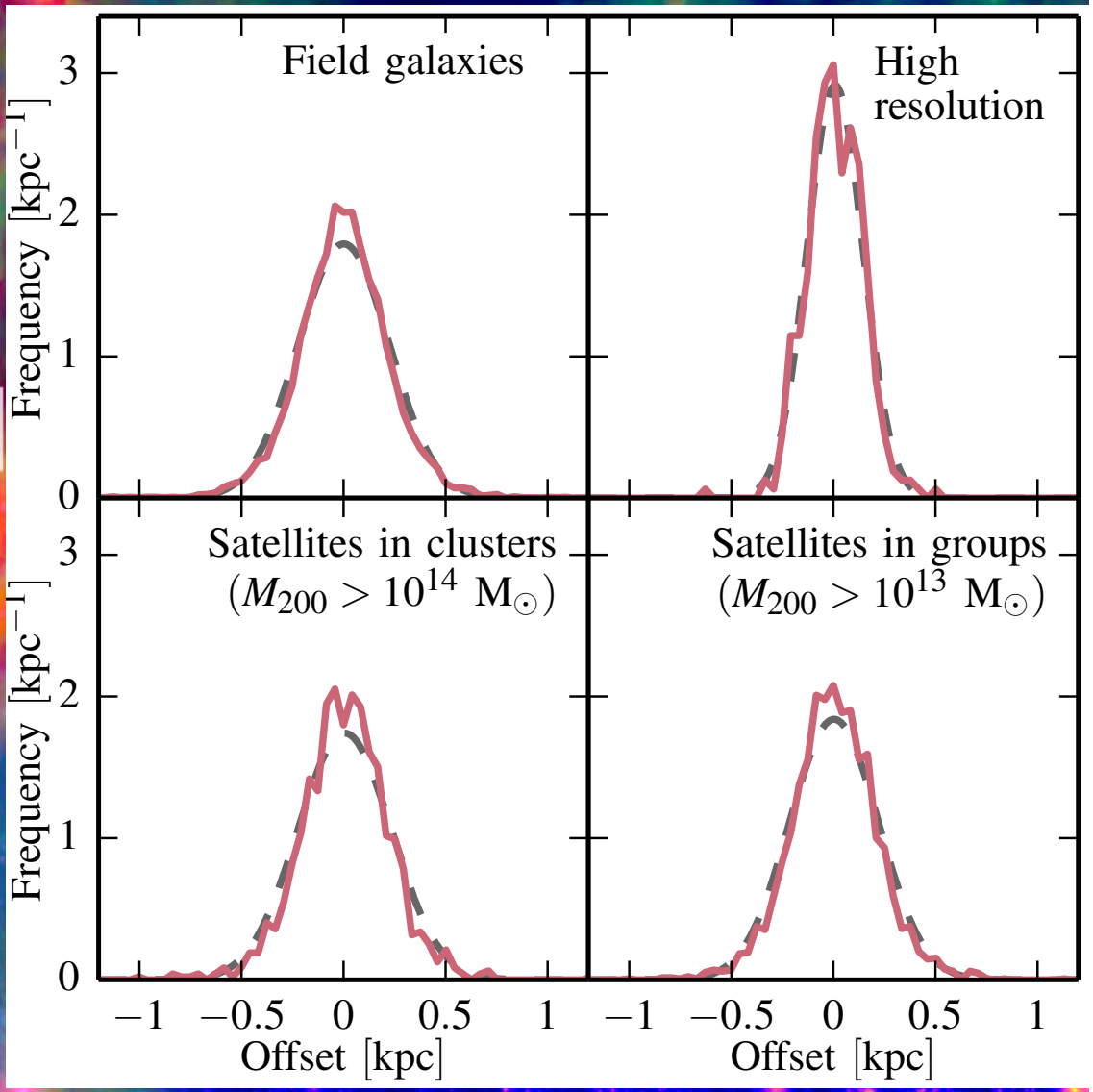
Mass offset from stars

Massey et al. 2015 MNRAS 449, 3393



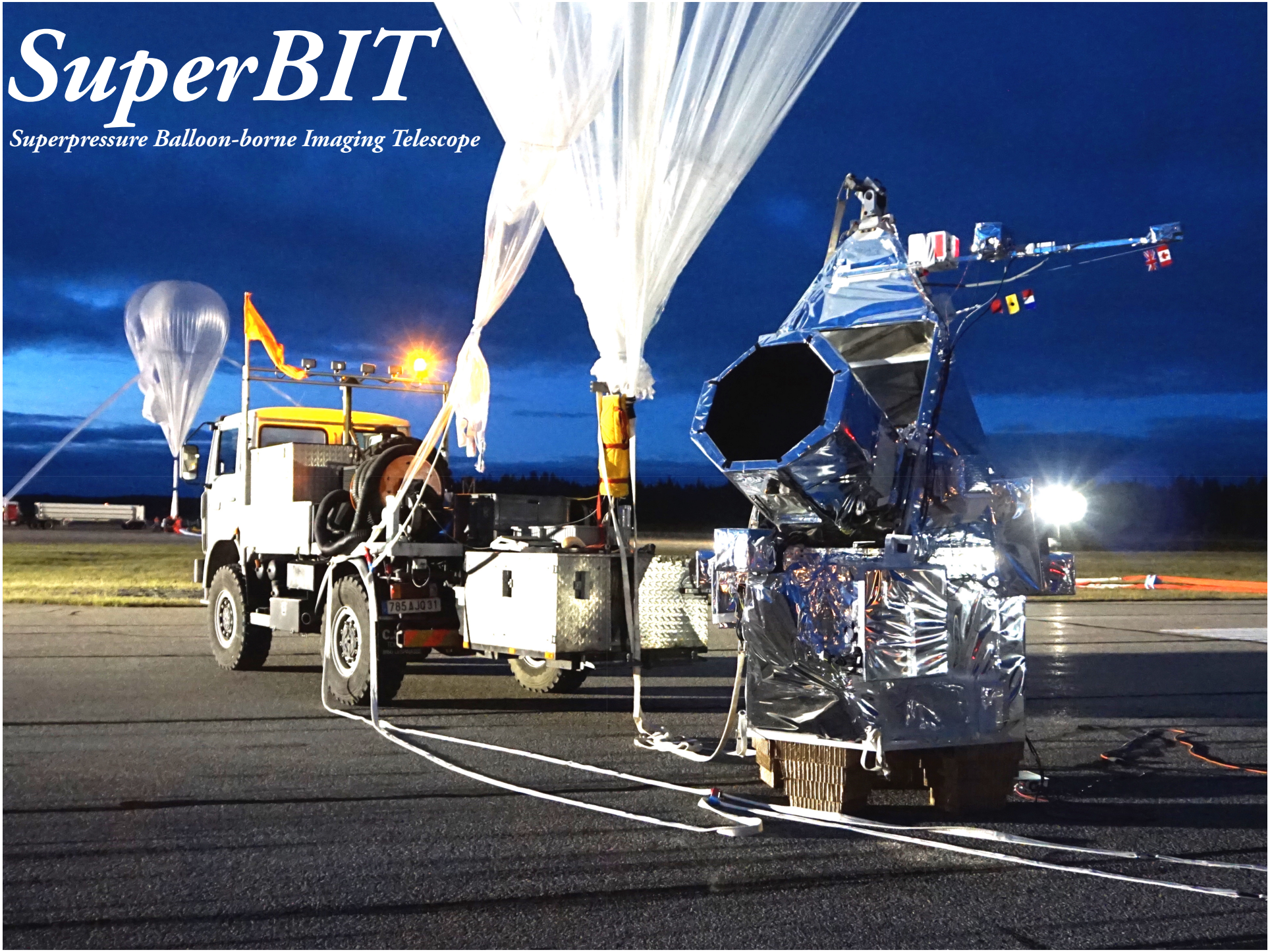
CDM+astrophysics doesn't produce large offsets

Schaller et al. (2015) MNRAS 453, 58



SuperBIT

Superpressure Balloon-borne Imaging Telescope



SuperBIT

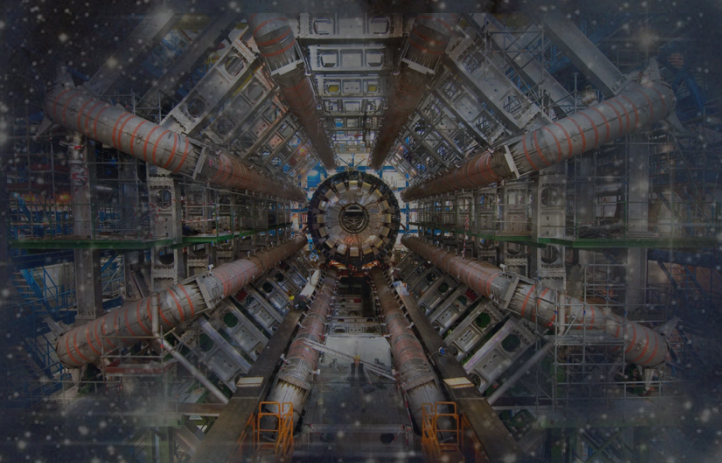
Superpressure Balloon-borne Imaging Telescope

Astronomical particle colliders

Weak lensing, X-ray & optical analysis of 72 minor mergers

- ✔ 7.6σ detection of dark mass
- ✔ DM and stars aligned within 5.8±8.2 kpc (68% CL)
- ✔ Tightest constraints on $\sigma_{DM}<0.47 cm^2/g$ (95% CL)
- ✔ Extendable to 10,000s with e.g. eROSITA & Euclid

(other satellite missions are available from your usual retailer)



Strong lensing & optical analysis of 1 infalling galaxy

- ✔ 1.6±0.5 kpc offset from DM to stars (68% CL)
- ✔ Consistent with prediction of SIDM; never created by CDM
- ✔ Lower limit on $\sigma_{DM}>1.7x10^{-4} cm^2/g$???
- ✗ Empirically, these systems are rare