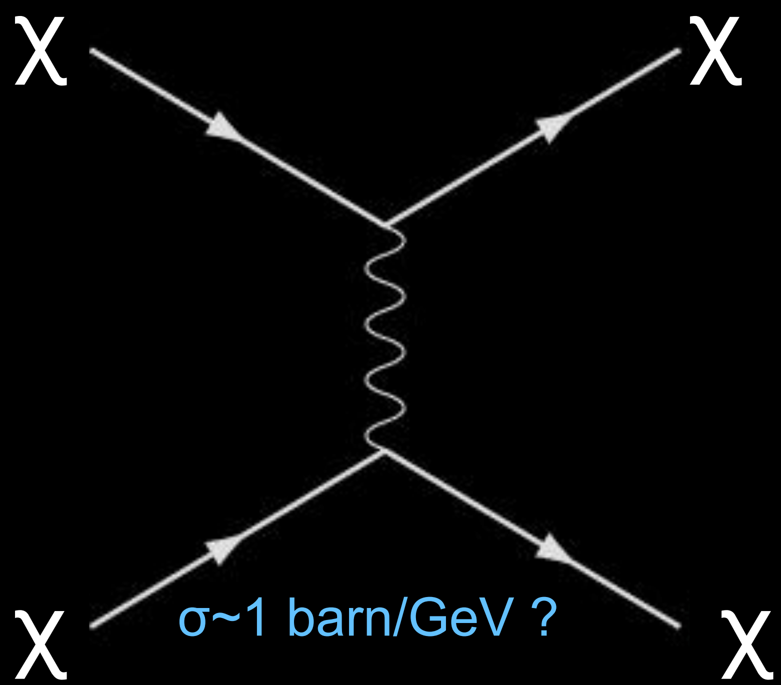
Astronomically large particle colliders

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 interaction unprobed by terrestrial expts



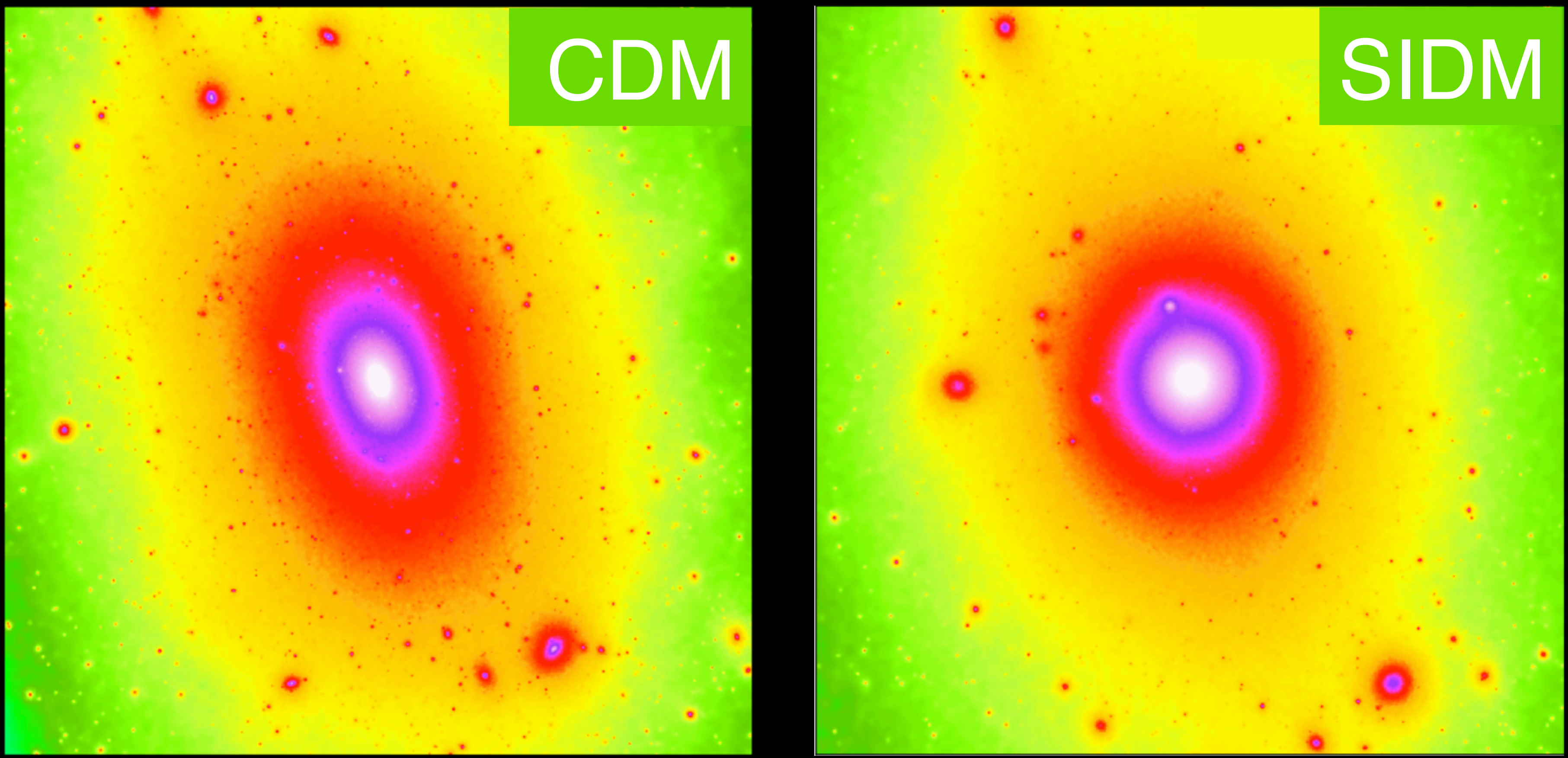
…but naturally predicted by lots of particle physics models:

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)
…

DM-DM interactions lead to energy transfer

Relaxed clusters become more spherical

…but (Y2K bug), not much & only in the innermost core

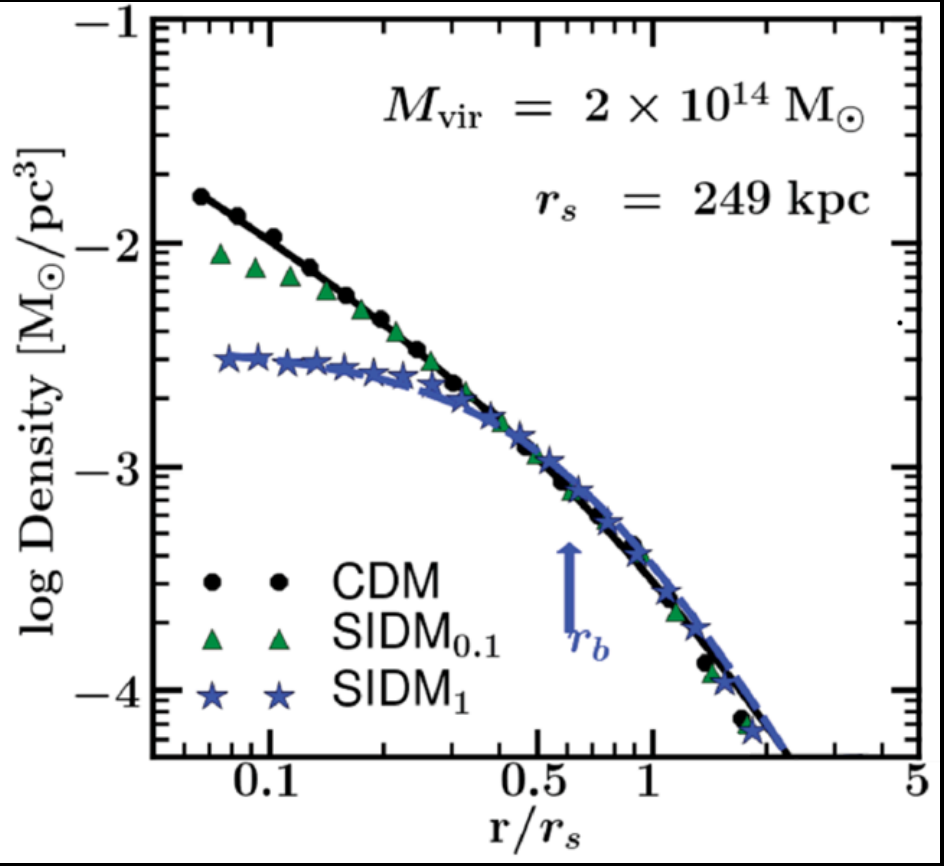


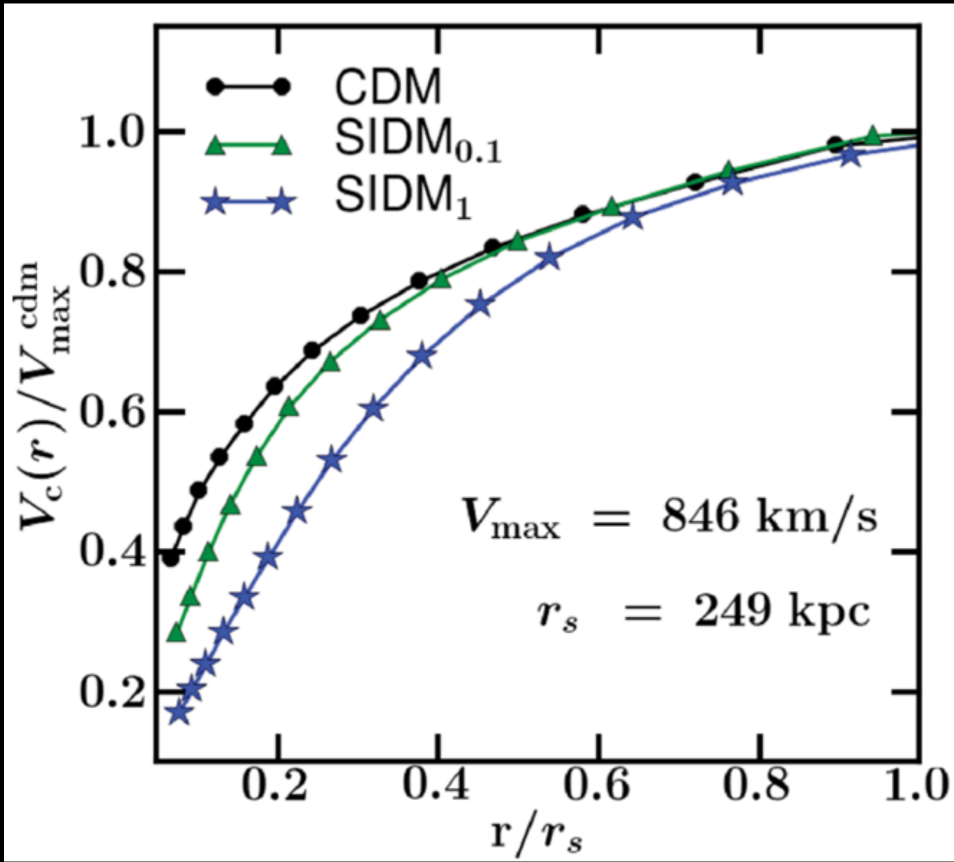
Vogelsberger+ 2012

Phenomenological benefits of SIDM

Mass loss from centre ➔ 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" problems in isolated halos

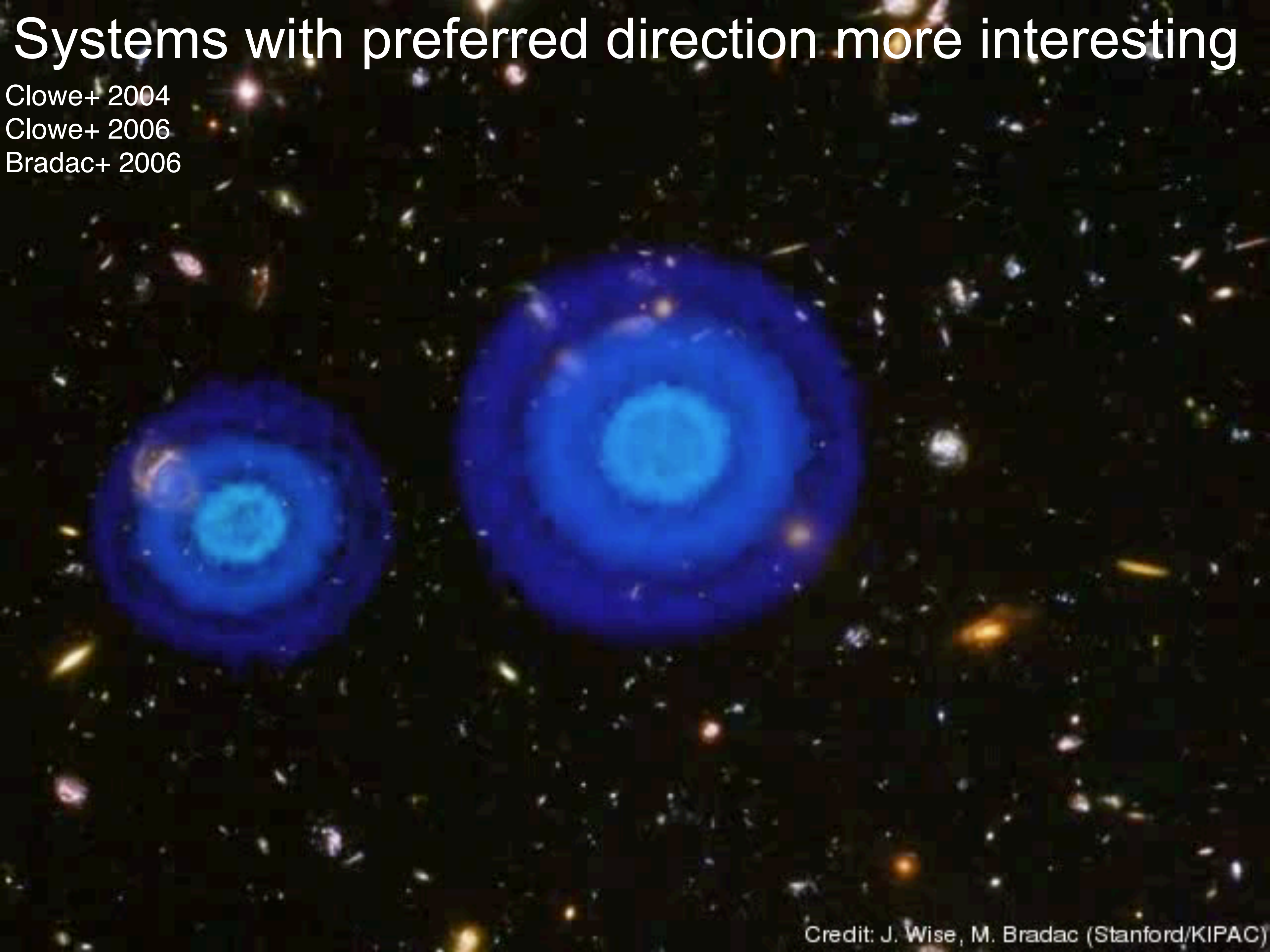




Rocha+ 2013

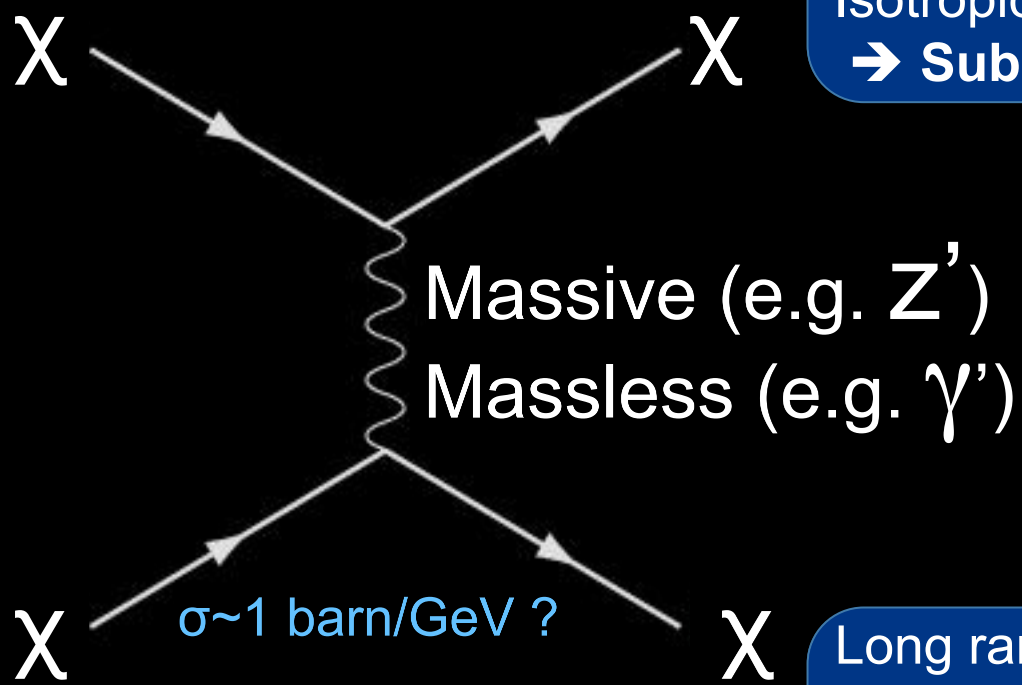
Systems with preferred direction more interesting

Clowe+ 2004
Clowe+ 2006
Bradac+ 2006



Particle physics of DM self-interaction

Kahlhoefer et al. 2014, MNRAS 437, 5865
Boehm et al. 2010, PRL 105, 1301



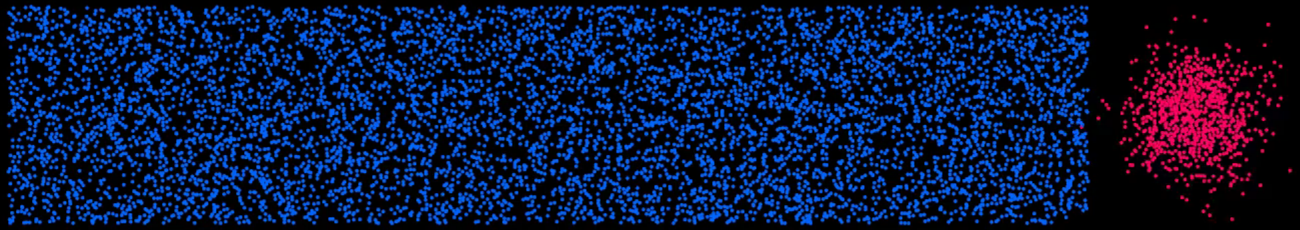
Short range force (like weak force)
Rare, high momentum transfer
(like billiard balls)
Isotropic scattering σ
➔ **Substructure evaporation**

Long range force (like electromagnetism)
Frequent, low momentum transfer
(like Thomson scattering)
Directional scattering σ(θ,v)
➔ **Substructure deceleration**

Rare, high momentum transfer -> evaporation

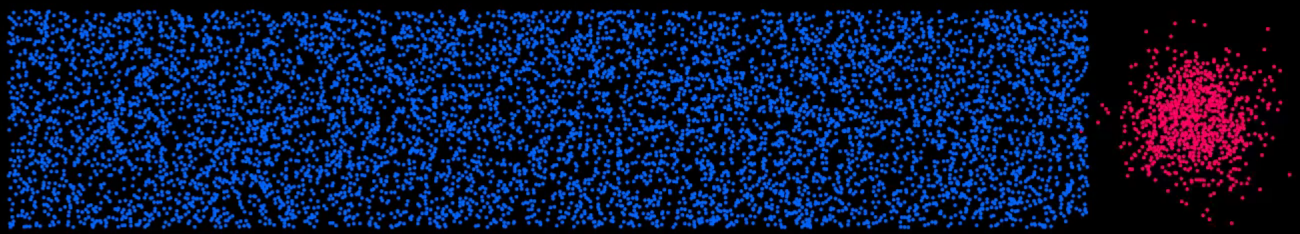
Robertson et al. in prep.

Short range force (like weak force)
Rare, high momentum transfer
(like billiard balls)
Isotropic scattering σ
➔ **Substructure evaporation**



Frequent, low moment'm transfer -> deceleration

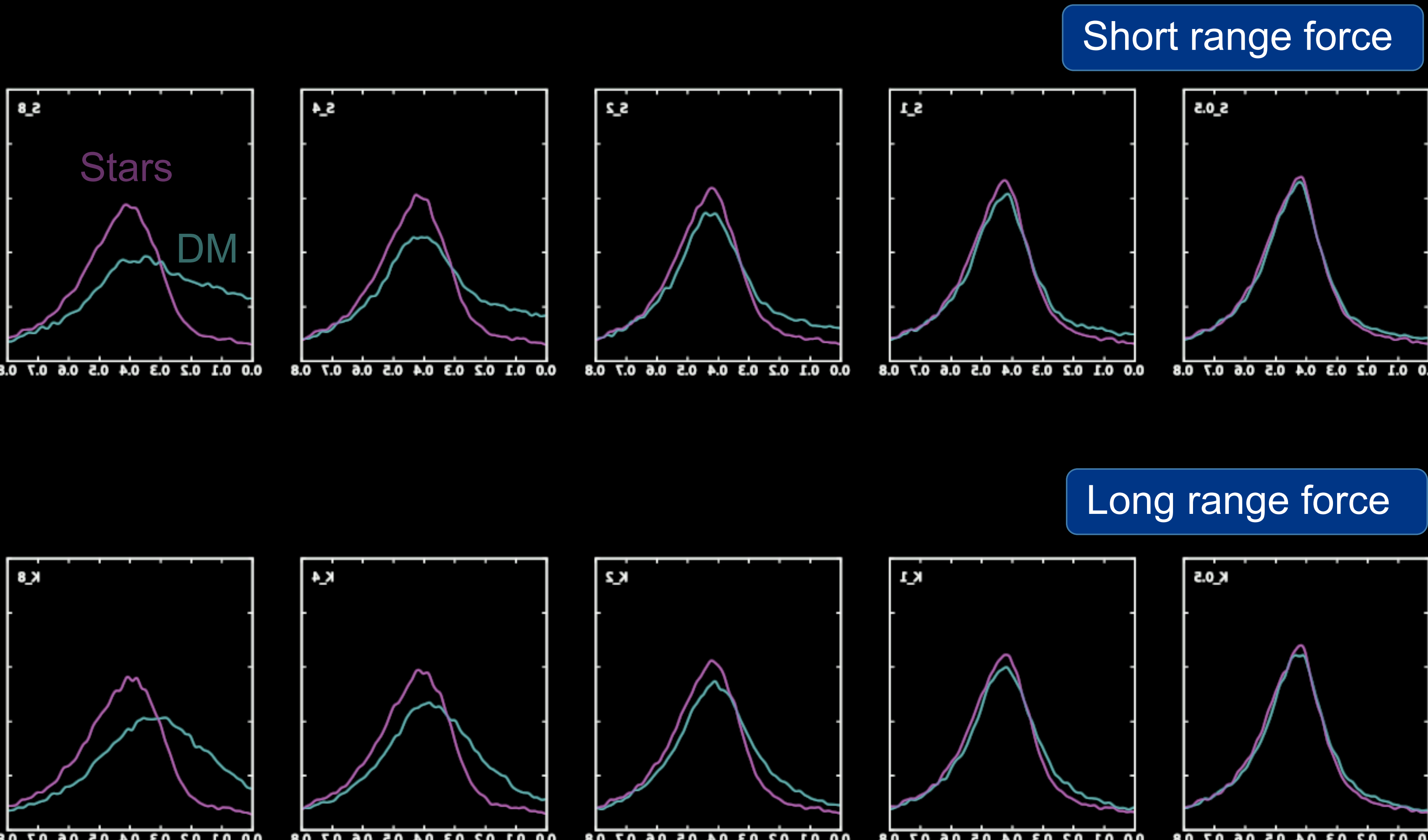
Robertson et al. in prep.



Long range force (like electromagnetism)
Frequent, low momentum transfer
(like Thomson scattering)
Directional scattering σ(θ)
➔ **Substructure deceleration**

Resulting distribution of DM in the smaller “bullet”

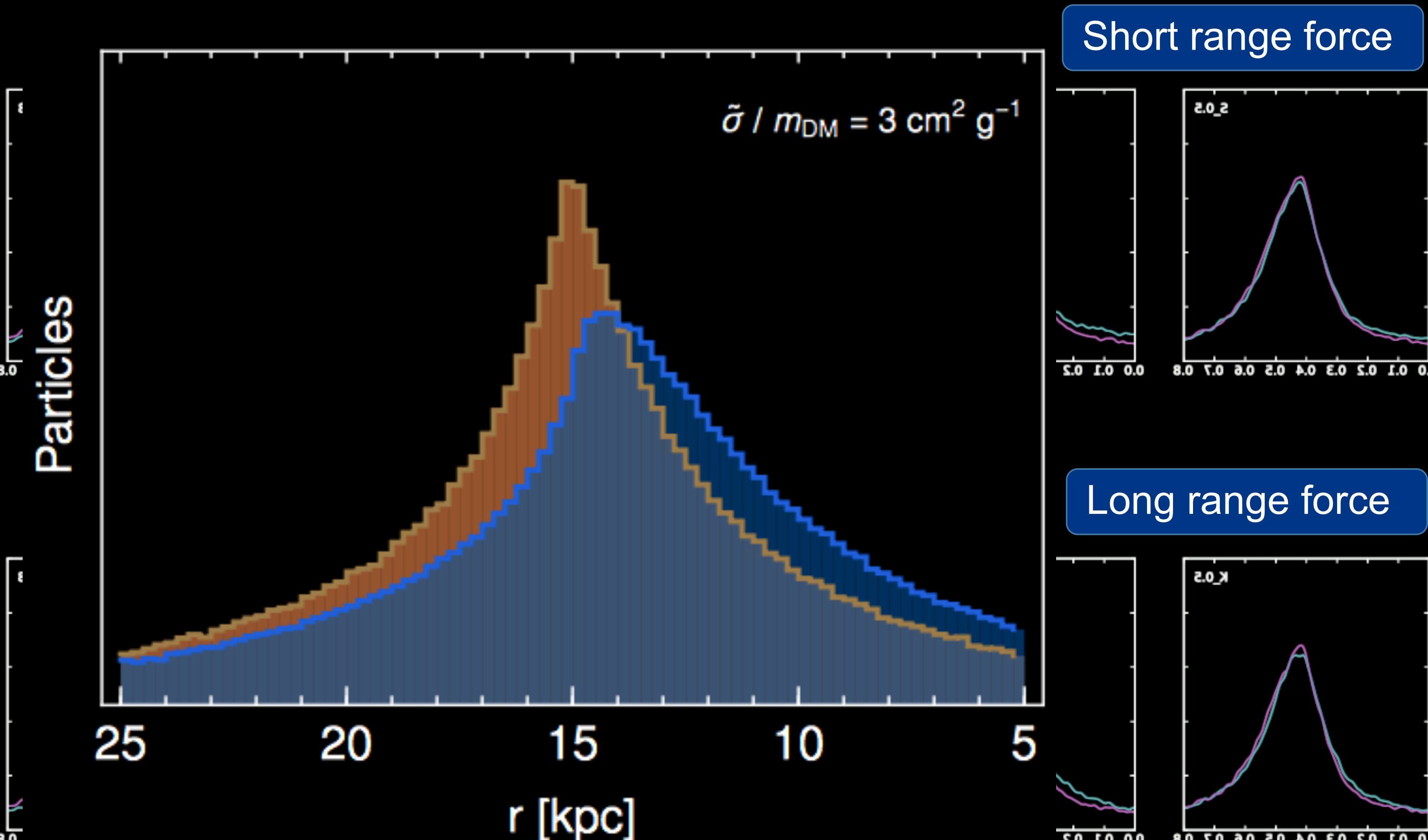
Kahlhoefer+ 2014, Robertson+ in prep



← Increasing collisional cross-section (interaction strength)

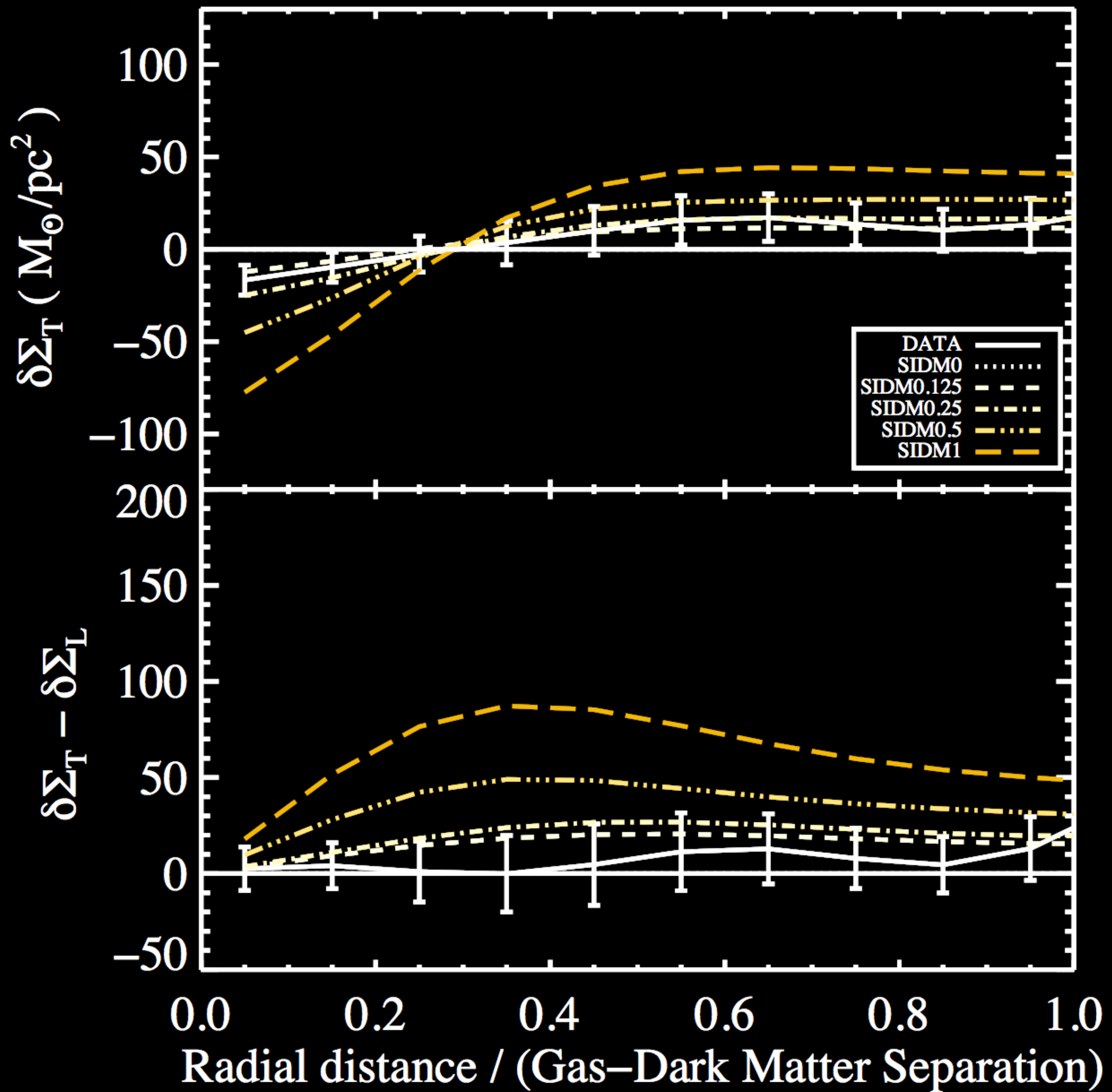
Resulting distribution of DM in the smaller “bullet”

Kahlhoefer+ 2014, Robertson+ in prep



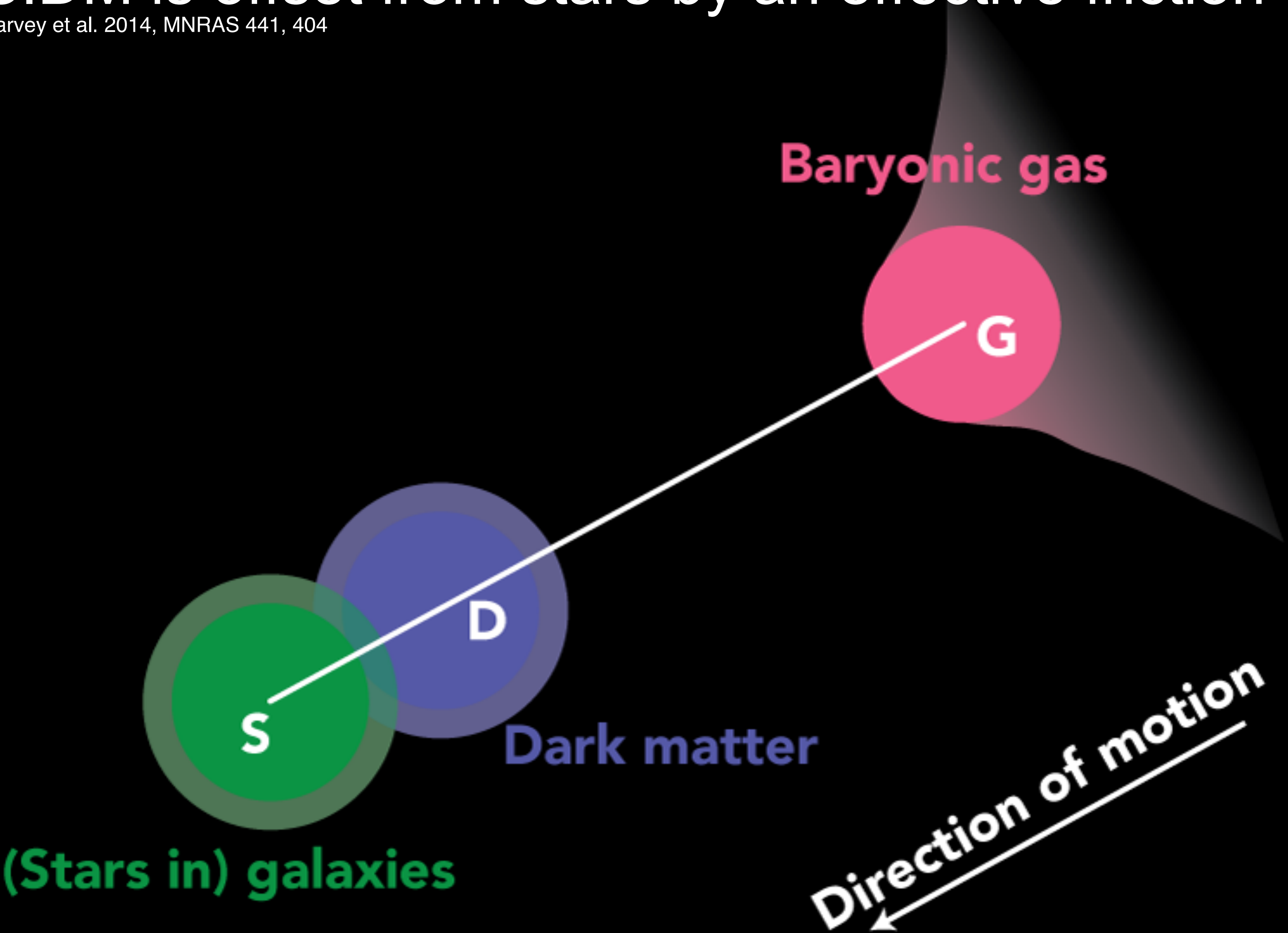
← Increasing collisional cross-section (interaction strength)

SIDM becomes skewed after a collision



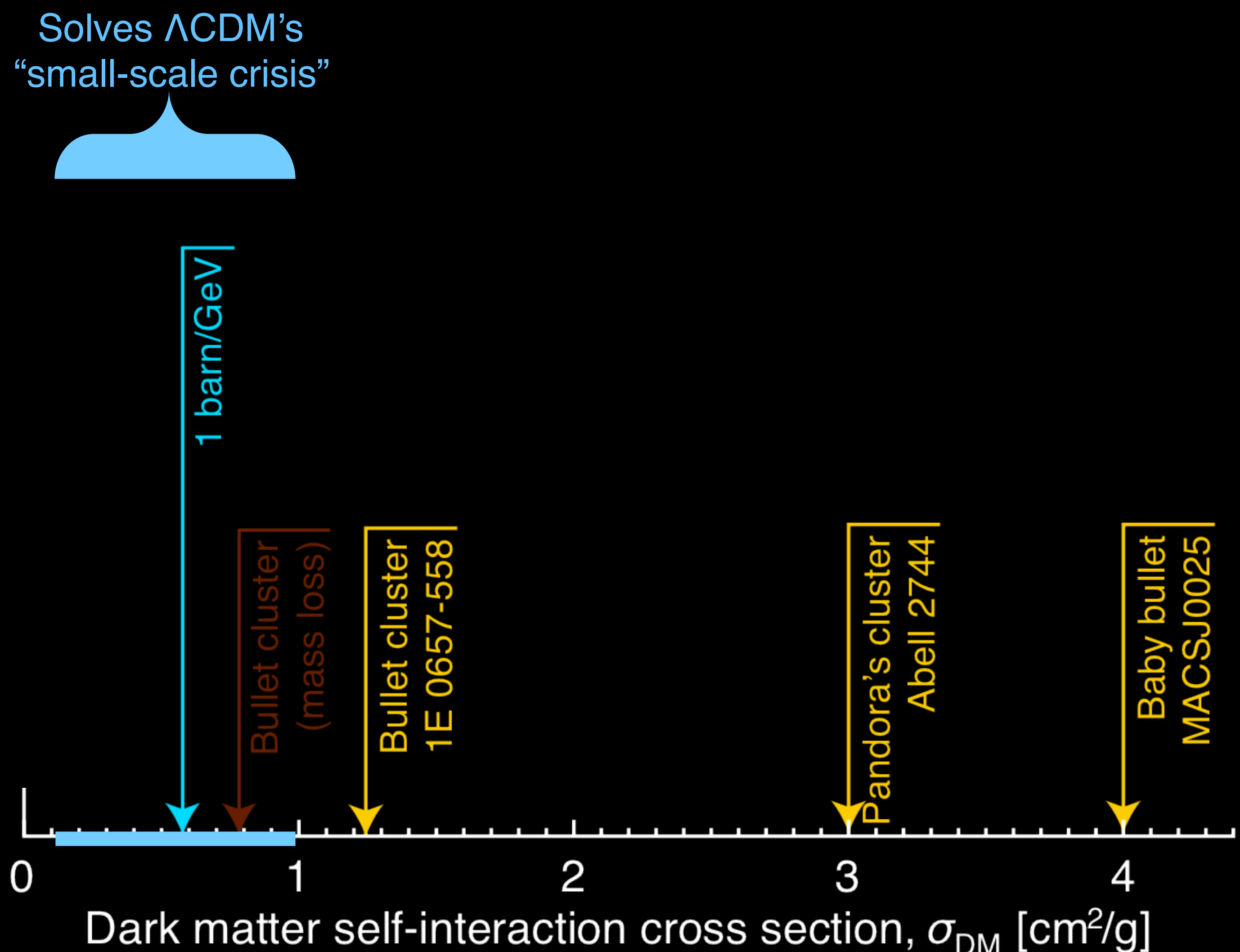
SIDM is offset from stars by an effective friction

Harvey et al. 2014, MNRAS 441, 404



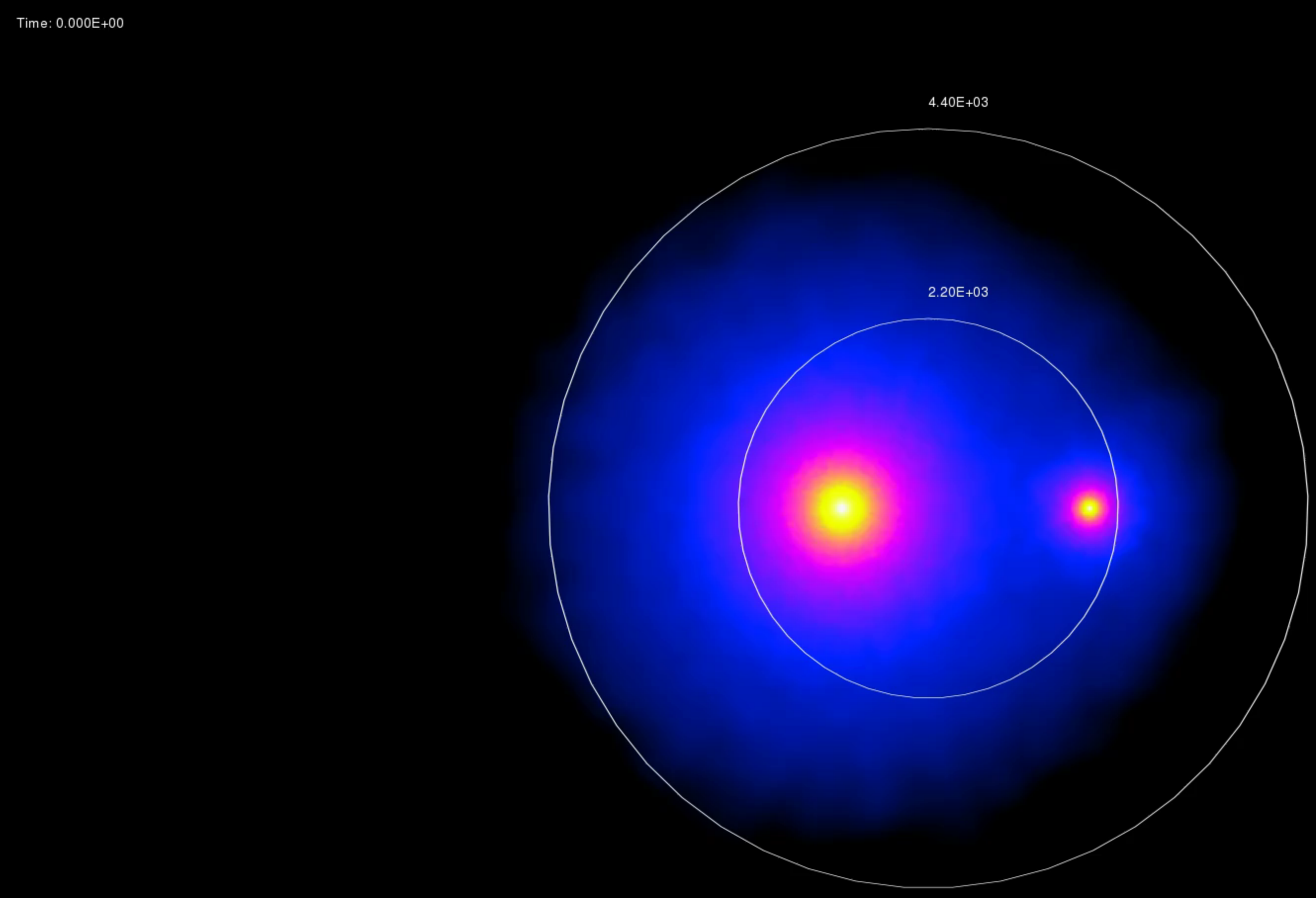
Current constraints from individual major mergers

Clowe et al. 2006, ApJ 848, 109
Bradac et al. 2008, ApJ 648, 109
Merten et al. 2011, MNRAS 417, 333



The problem with single collisions

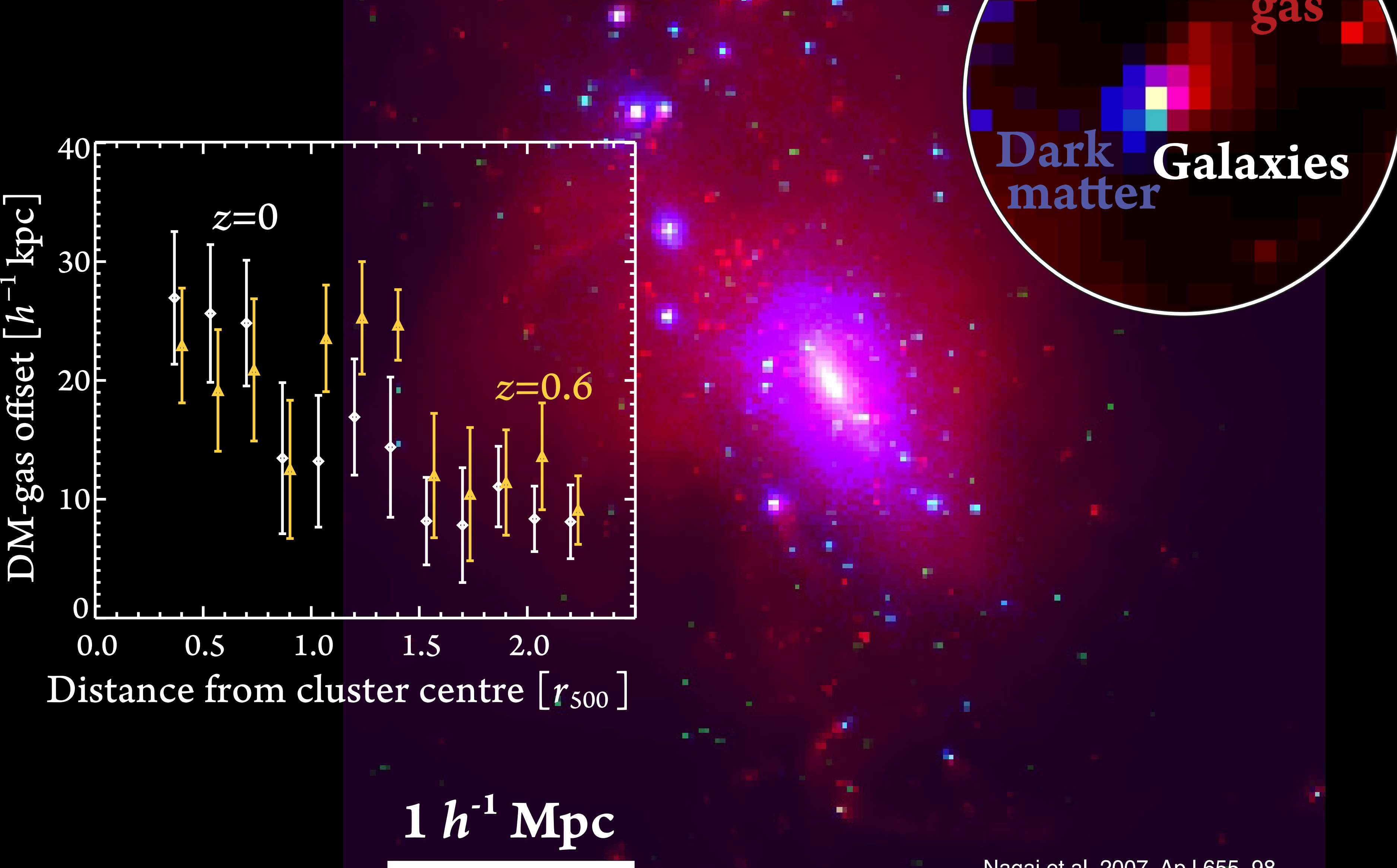
Robertson et al. in prep.



Uncertainty in merger geometry
Uncertainty in (pre-collision) concentration

Minor merger "bulleticity"

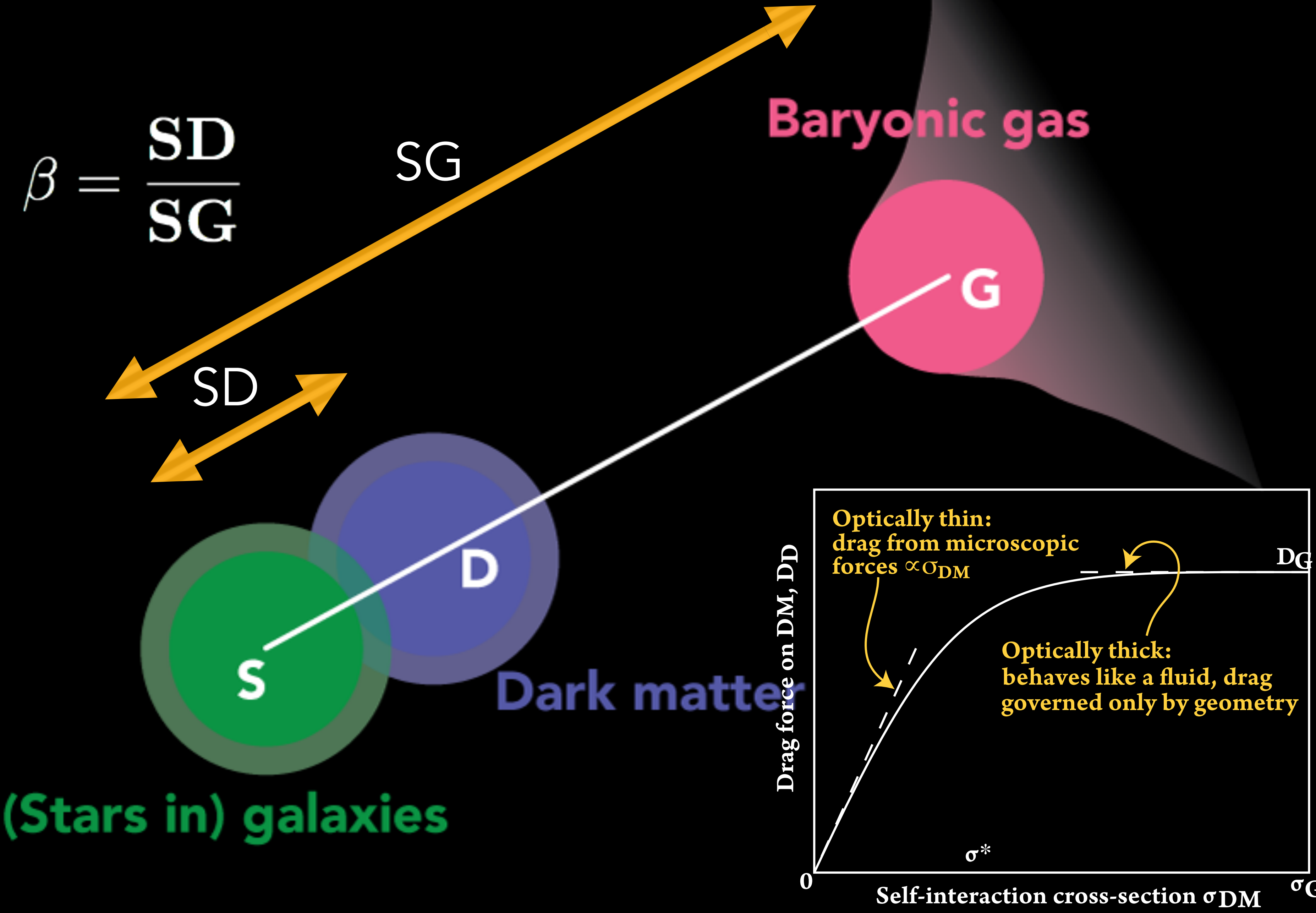
Massey, Kitching & Nagai 2010, MNRAS 413, 1709
Harvey et al. 2013, MNRAS 433, 1517
Kahlhoefer et al. 2014, MNRAS 437, 5865



Nagai et al. 2007, ApJ 655, 98
Kay et al. 2012, MNRAS 422, 1999

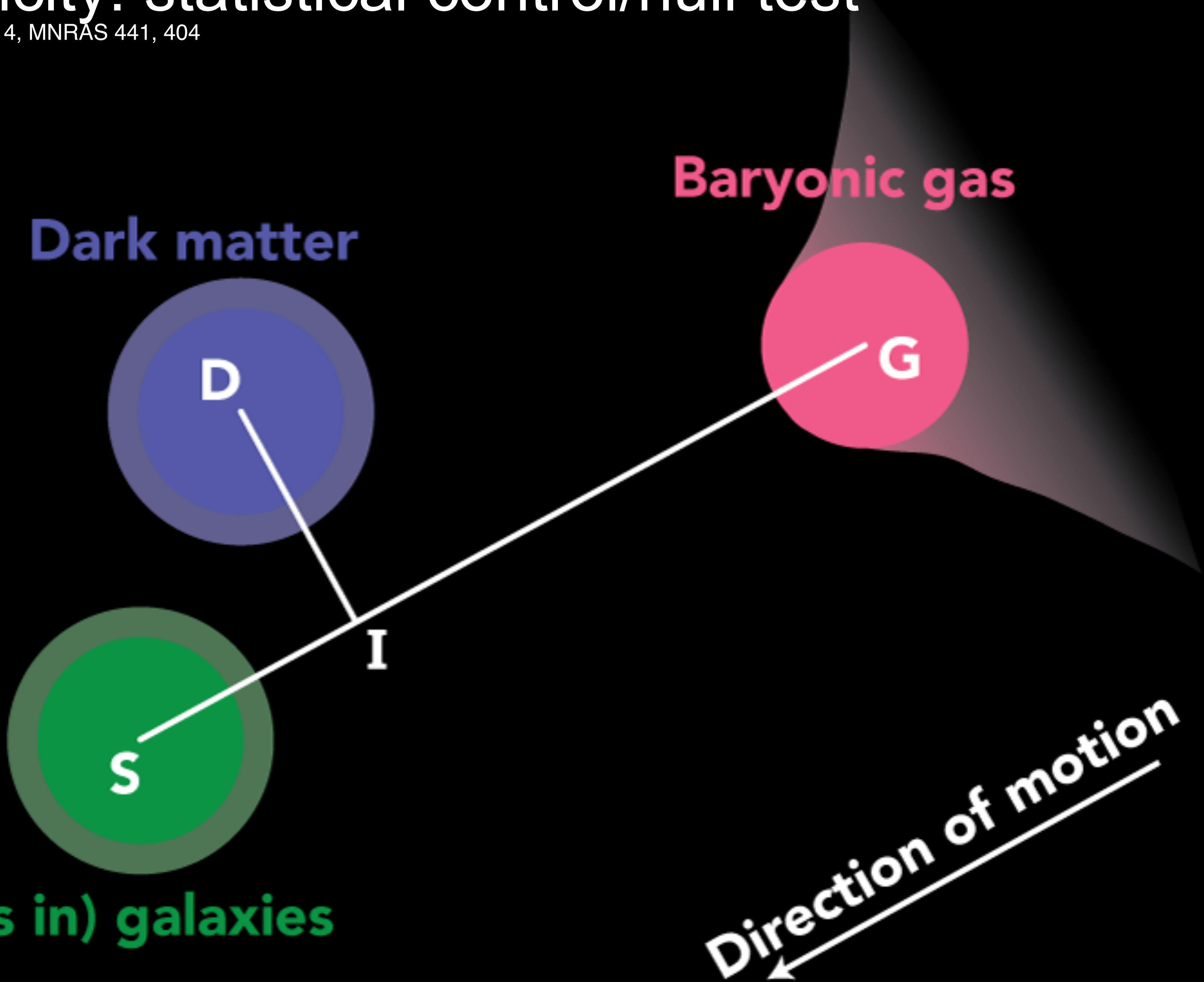
Bulleticity: observable

Harvey et al. 2014, MNRAS 441, 404

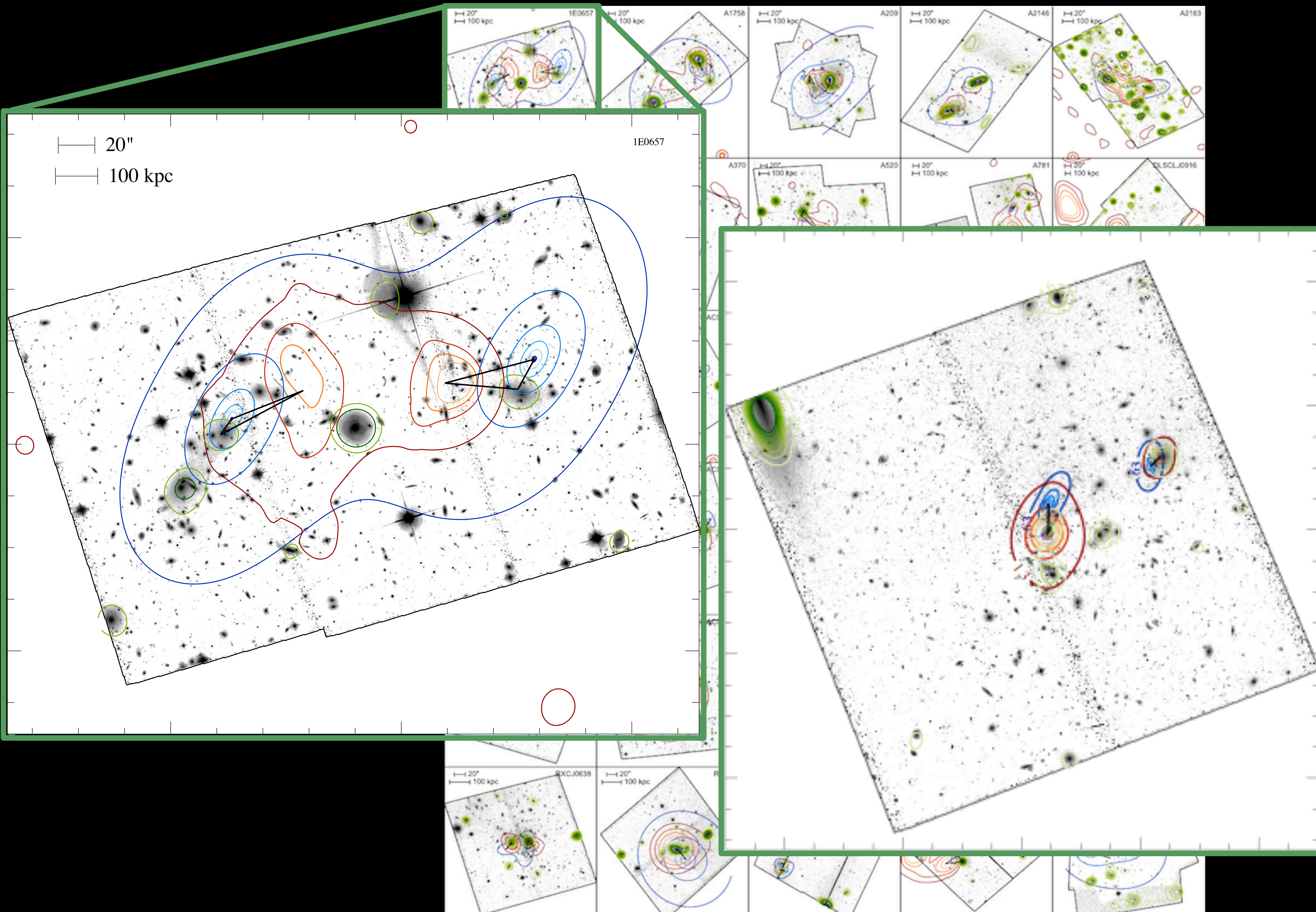


Bulleticity: statistical control/null test

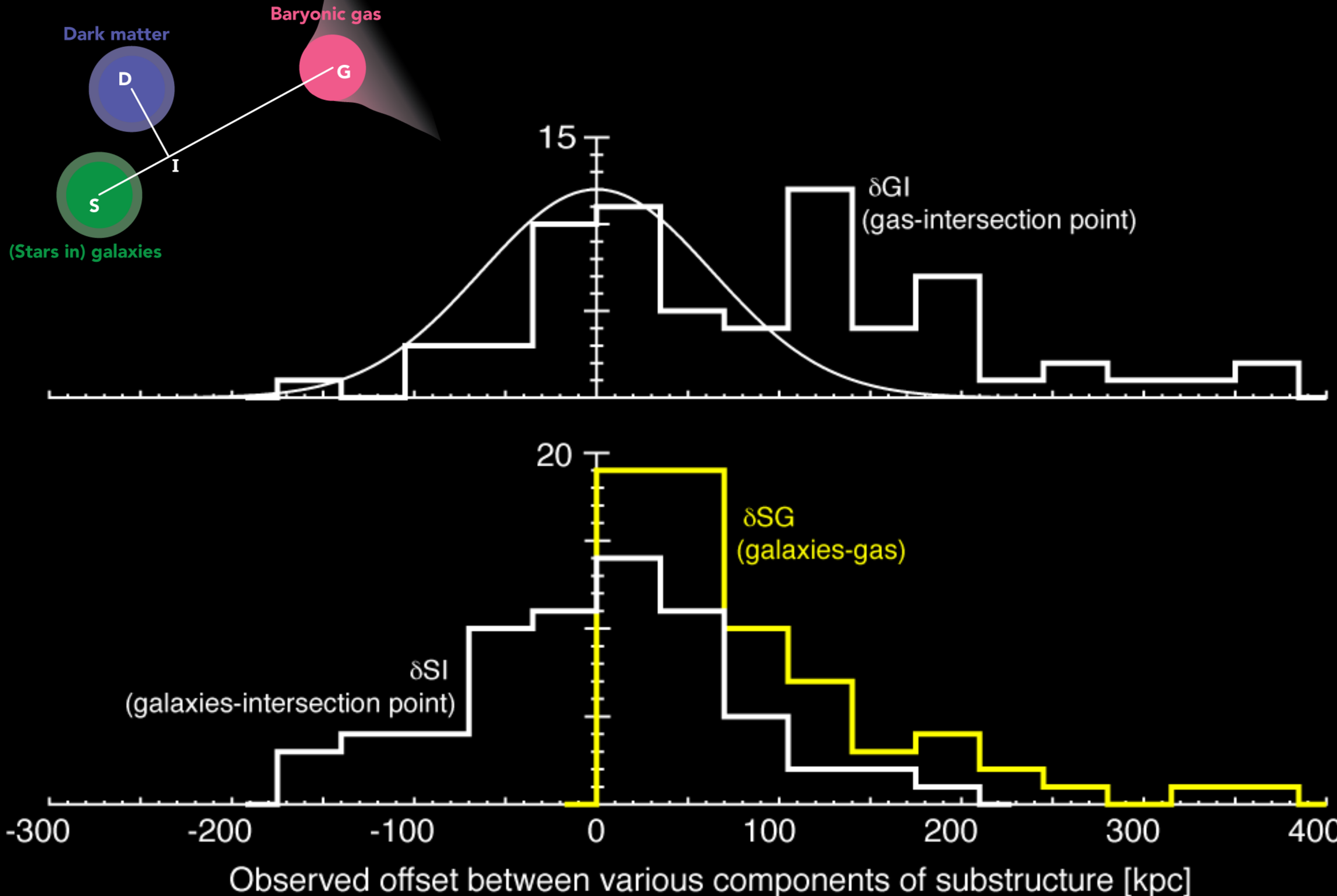
Harvey et al. 2014, MNRAS 441, 404



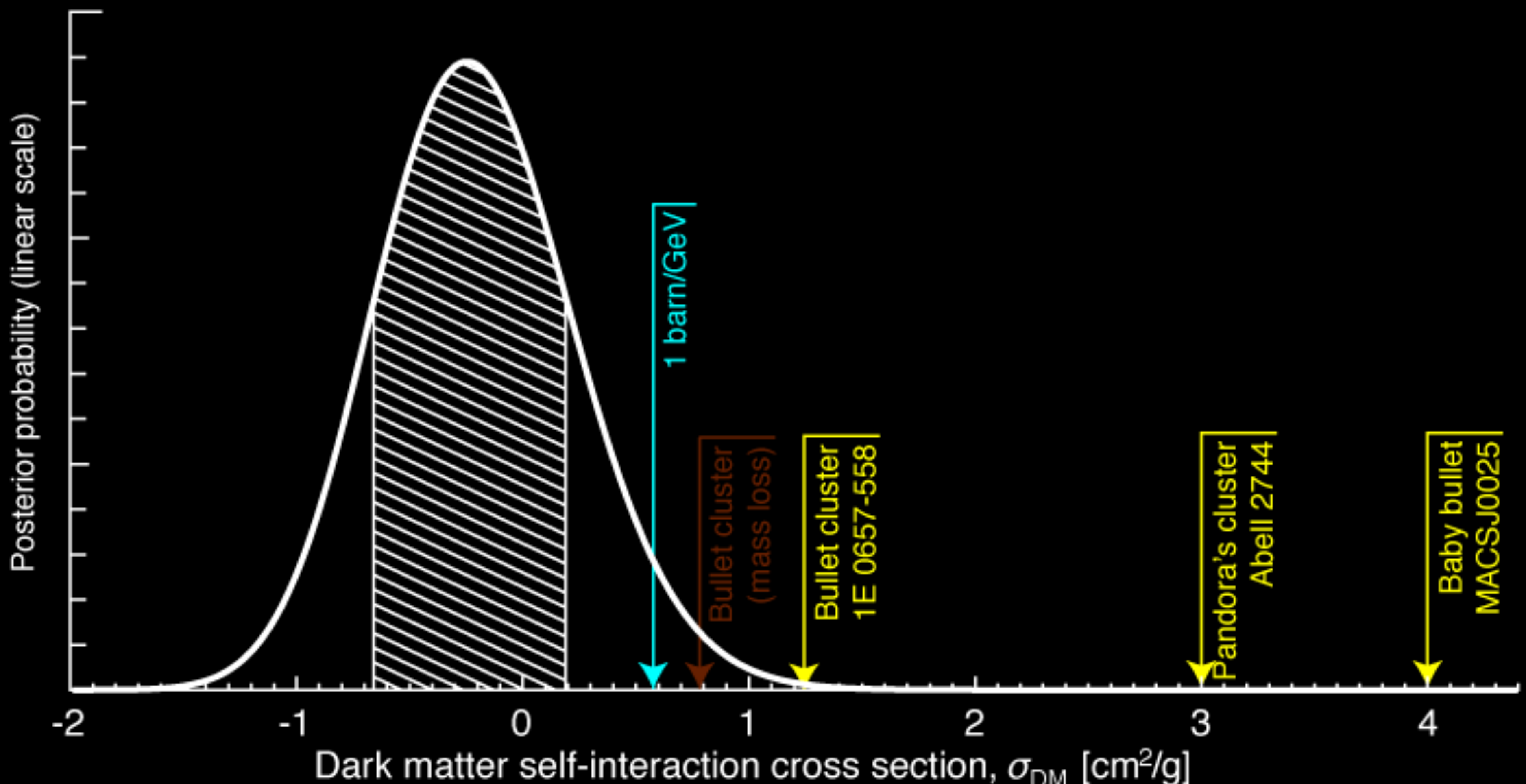
Bulleticity observations in 30 systems (72 bullets)



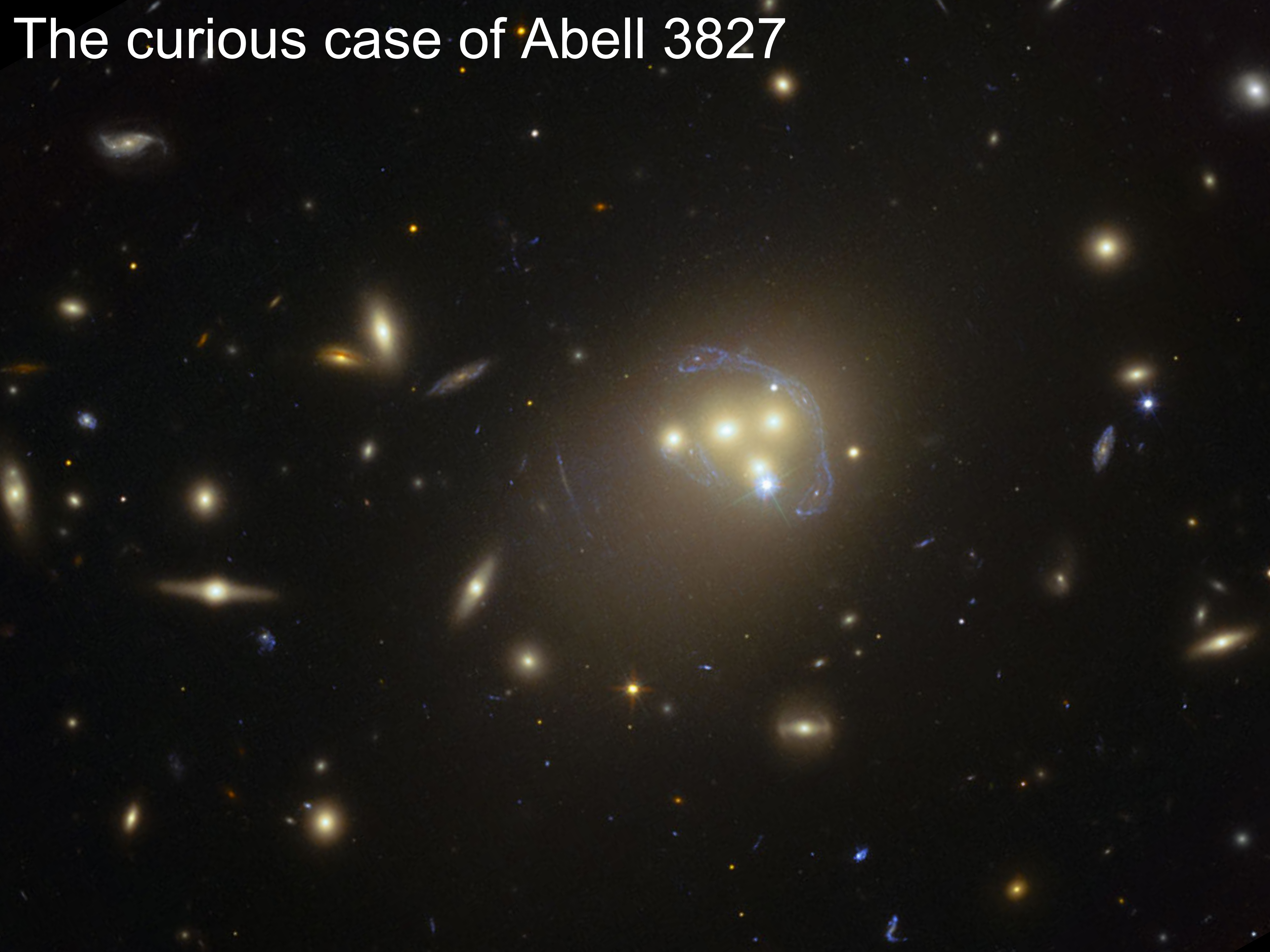
Observed offsets between components [kpc]

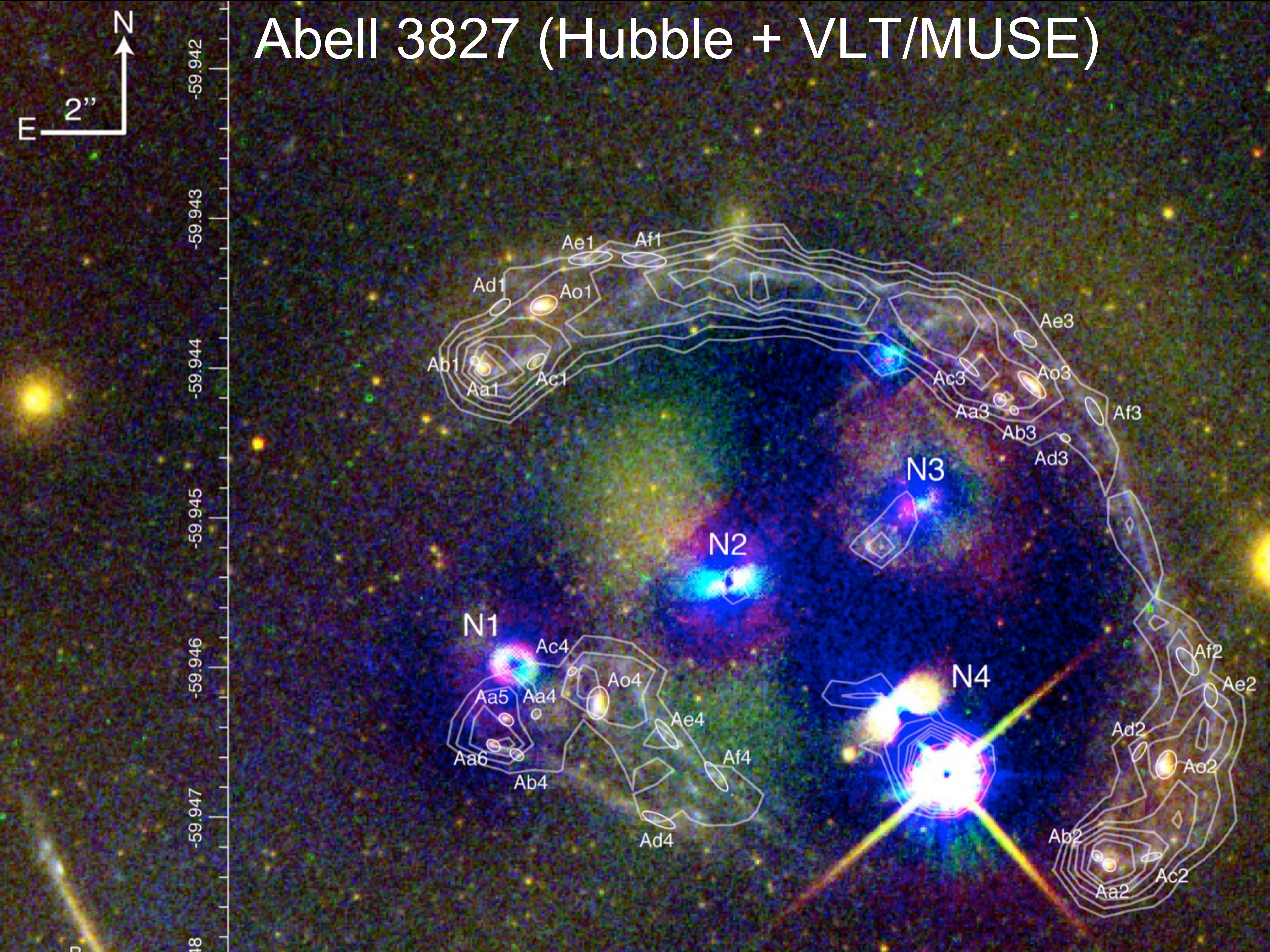


First sub-barn/GeV constraints on cross section



The curious case of Abell 3827



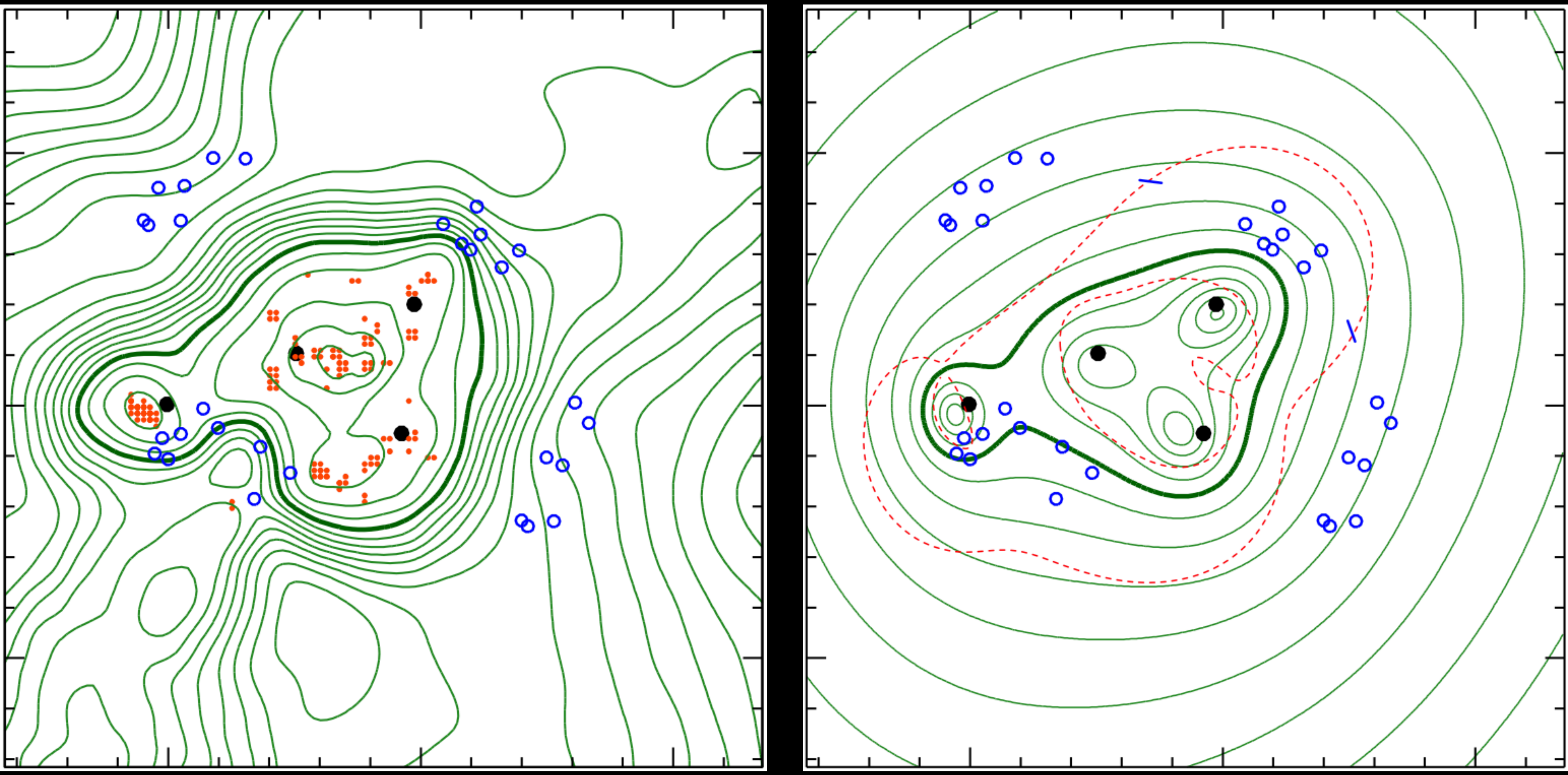


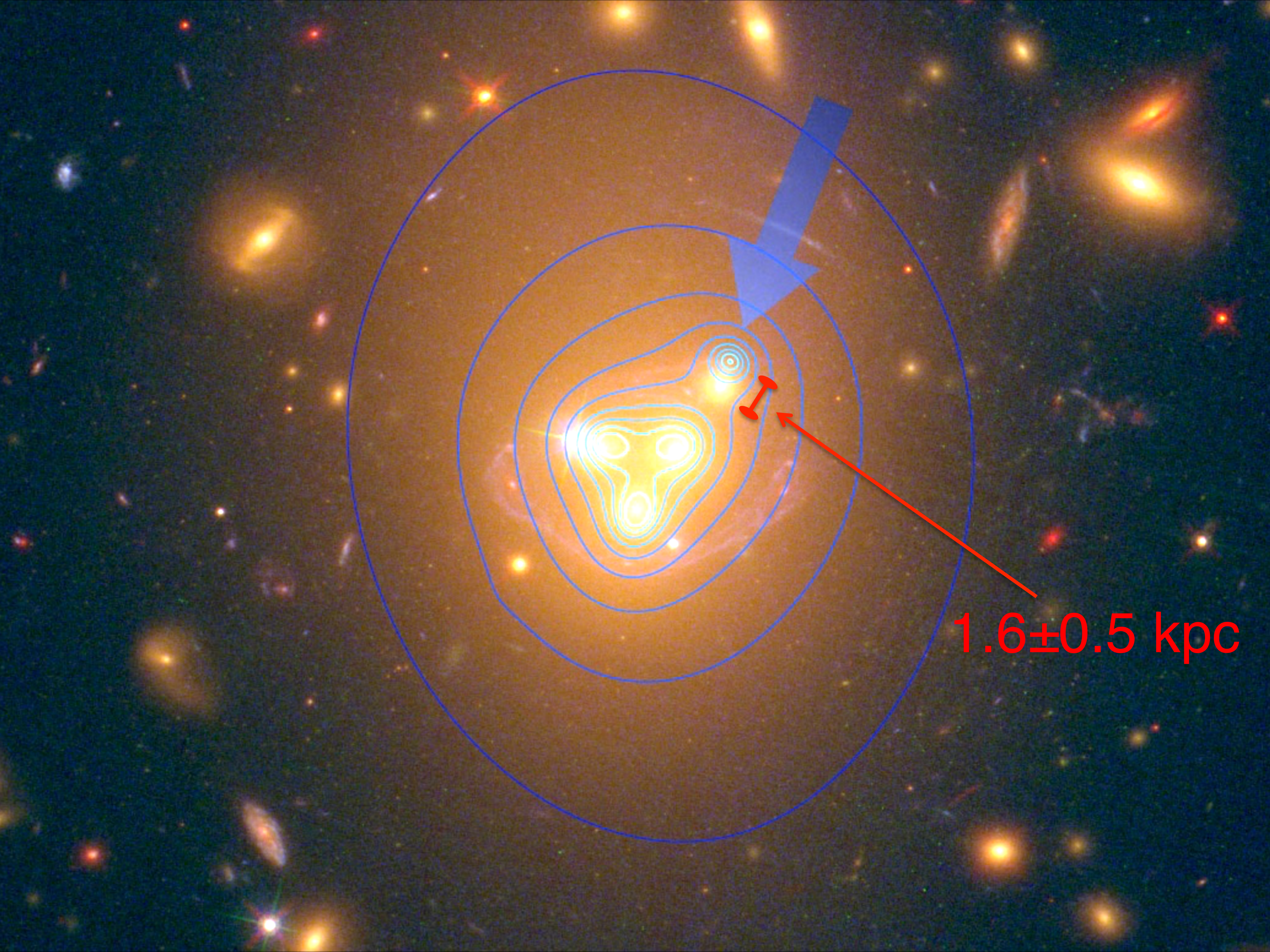
Abell 3827 (Hubble + VLT/MUSE)
N
E
2''
-59.942
-59.943
-59.944
-59.945
-59.946
-59.947
N1
N2
N3
N4
Ae1
Af1
Ad1
Ao1
Ab1
Aa1
Ac1
Ae3
Ac3
Ao3
Aa3
Ab3
Af3
Ad3
Ac4
Ao4
Aa5
Aa4
Ae4
Aa6
Ab4
Af4
Ad4
Af2
Ae2
Ad2
Ao2
Ab2
Ac2
Aa2

Mass offset from light, regardless of method

Massey et al. 2015 MNRAS 449, 3393

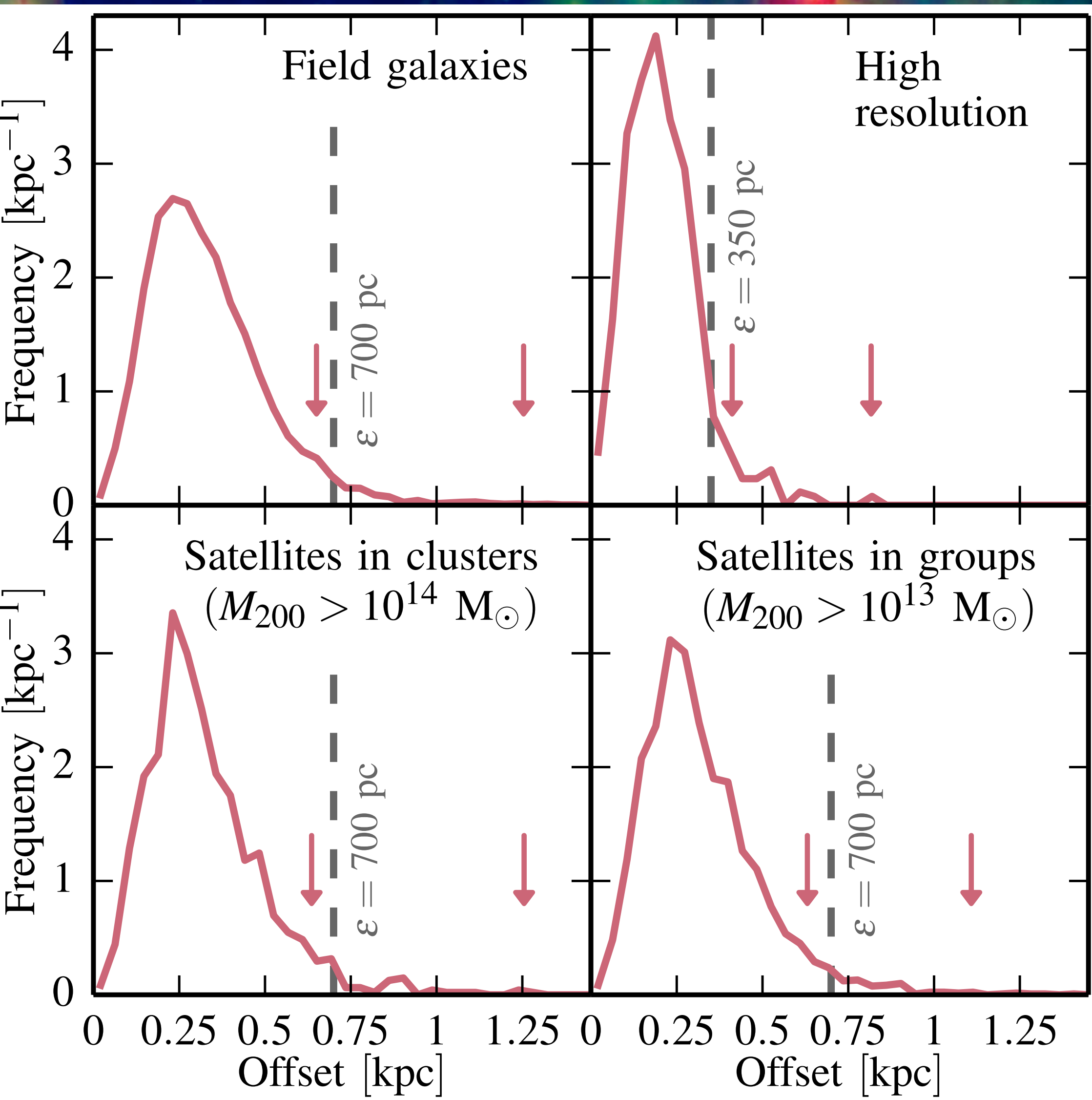
Non-parametric (GRALE) | Parametric (LENSTOOL)

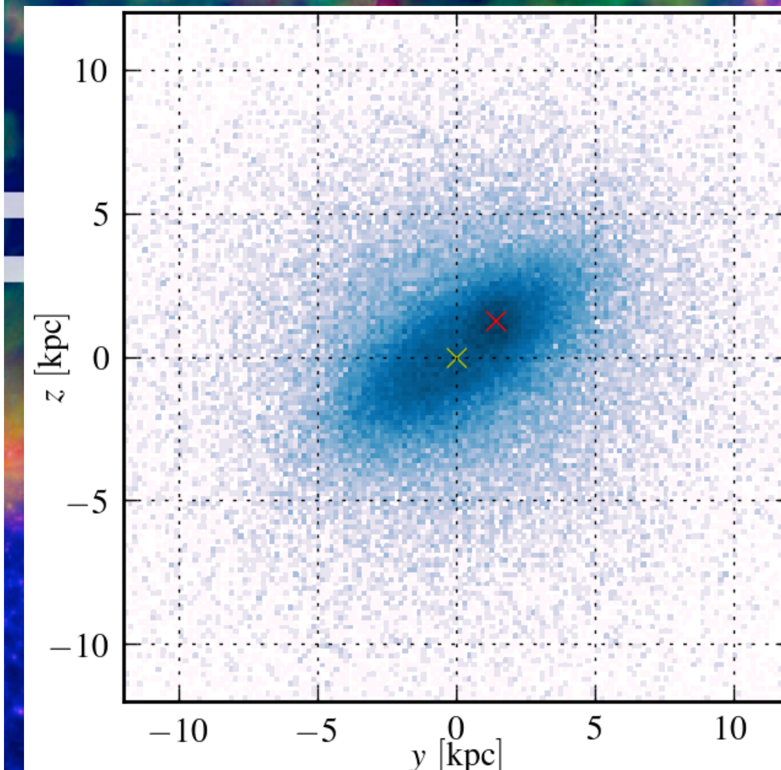



1.6±0.5 kpc

CDM+astrophysics doesn't produce large offsets

Schaller et al. (2015) MNRAS 453, 58





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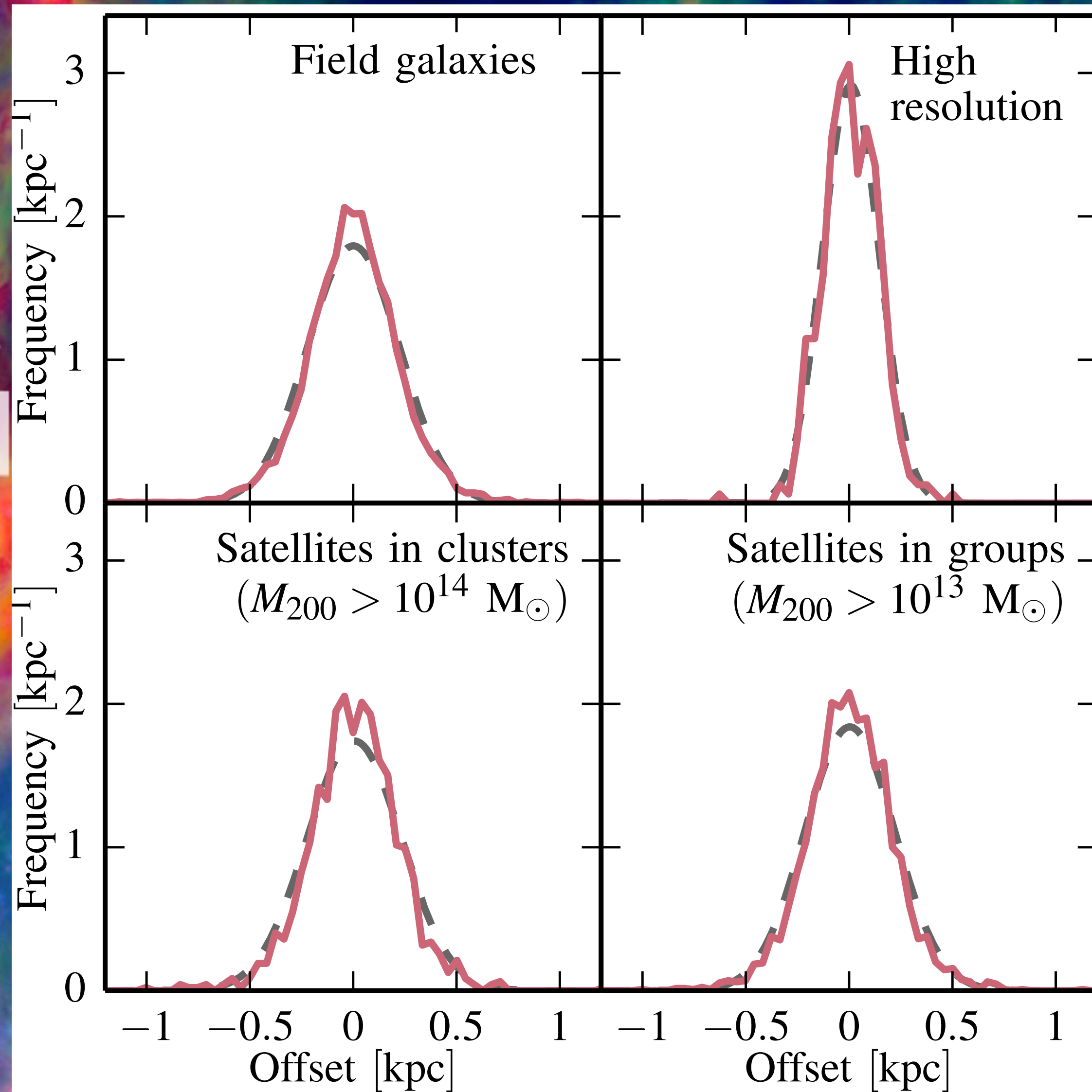
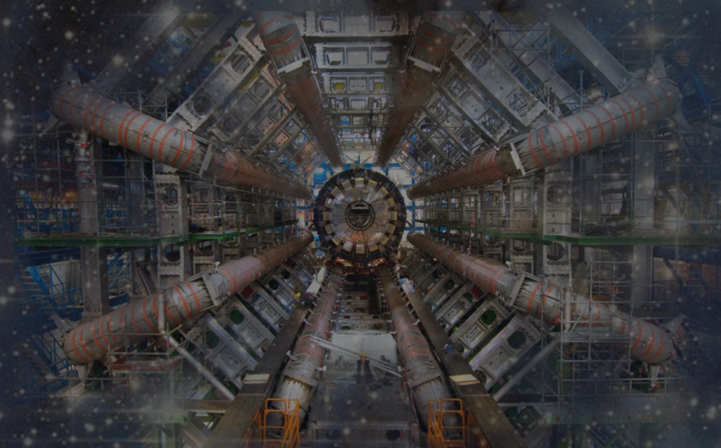


Astronomical particle colliders

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

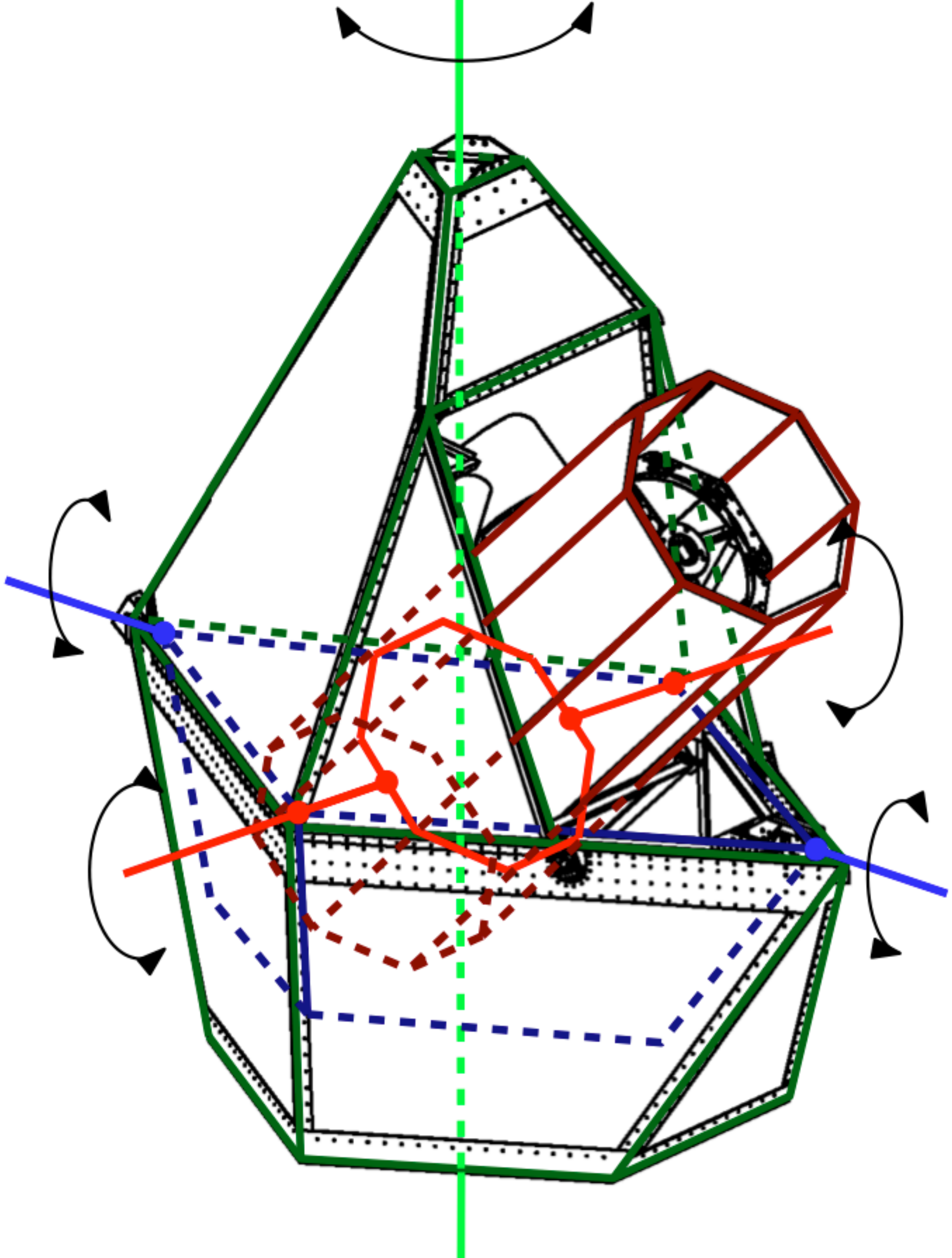
- ✔ 7.6σ detection of dark mass
- ✔ DM and stars aligned within 5.8±8.2 kpc (68% CL)
- ✔ Tightest constraints on σ_{DM}<0.47cm^2/g (95% CL)
- ✔ Extendable to whole sky with e.g. eROSITA & Euclid

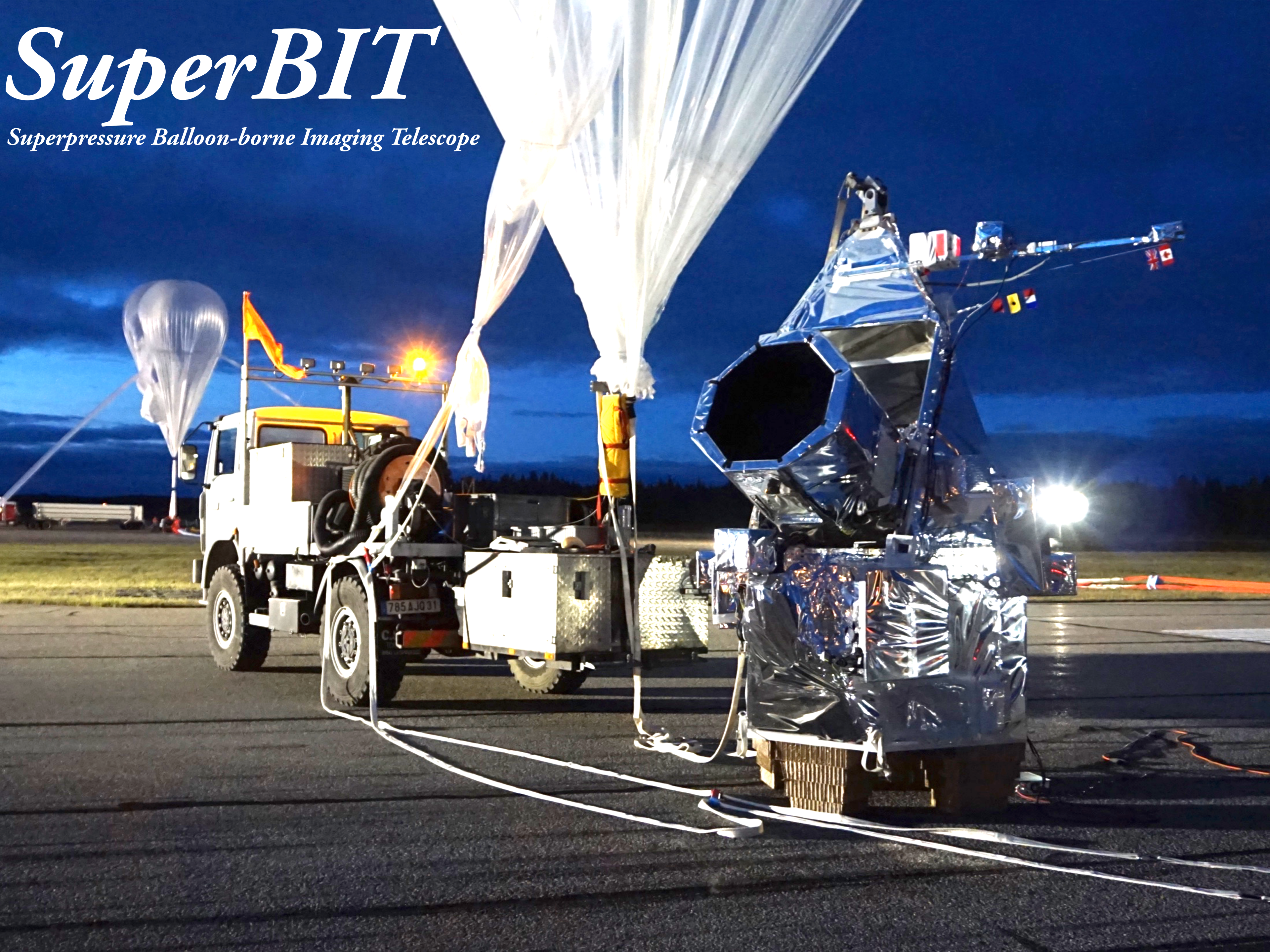
(other satellite missions are available from your usual retailer)



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 σ_{DM}>1.7x10^{-4}cm^2/g ???
- ✗ Empirically, these systems are rare




SuperBIT
Superpressure Balloon-borne Imaging Telescope

SuperBIT

Superpressure Balloon-borne Imaging Telescope

CSA ASC

PRINCETON UNIVERSITY

JPL

UNIVERSITY OF TORONTO

Durham University

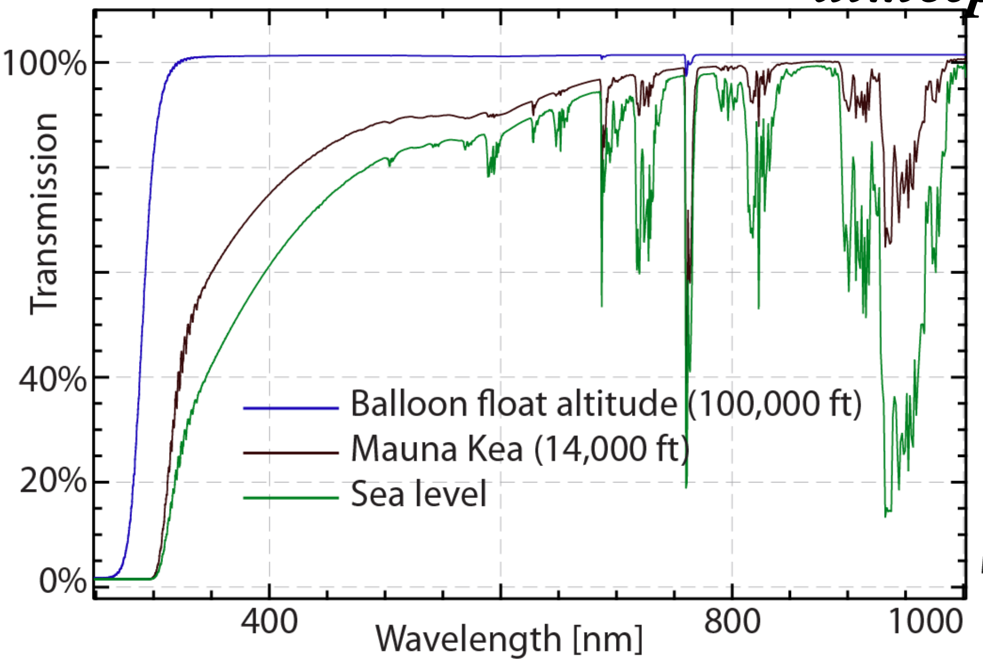
Above 99% of Earth's atmosphere, September 2015

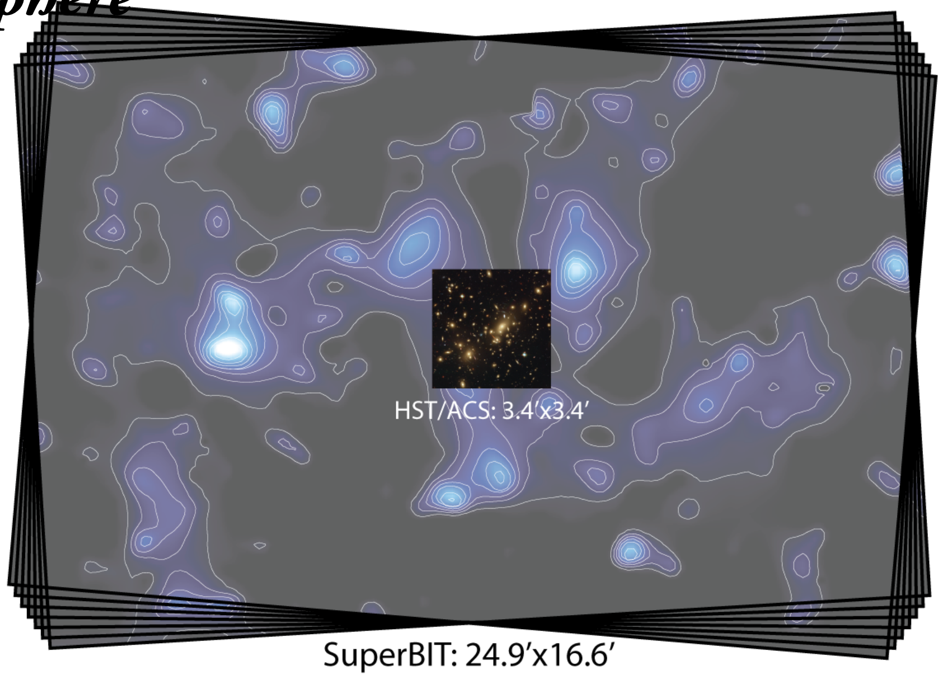
SuperBIT

Superpressure Balloon-borne Imaging Telescope

CSA ASC
PRINCETON UNIVERSITY
JPL
UNIVERSITY OF TORONTO
Durham University

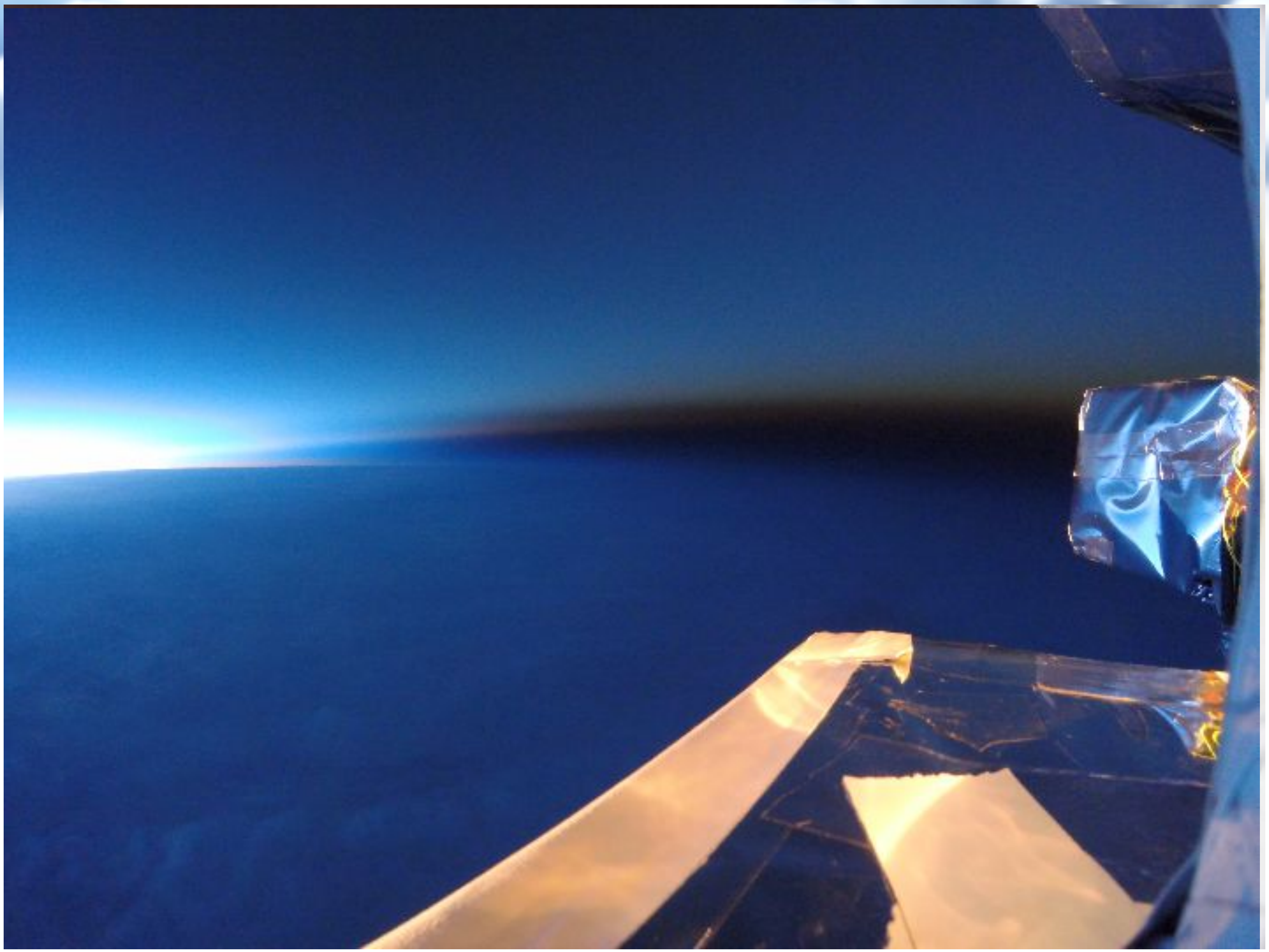
Wide-field, space-quality optical & UV imaging from above the Earth's atmosphere





SuperBIT

Superpressure Balloon-borne Imaging Telescope



Above 99% of Earth's atmosphere, September 2015

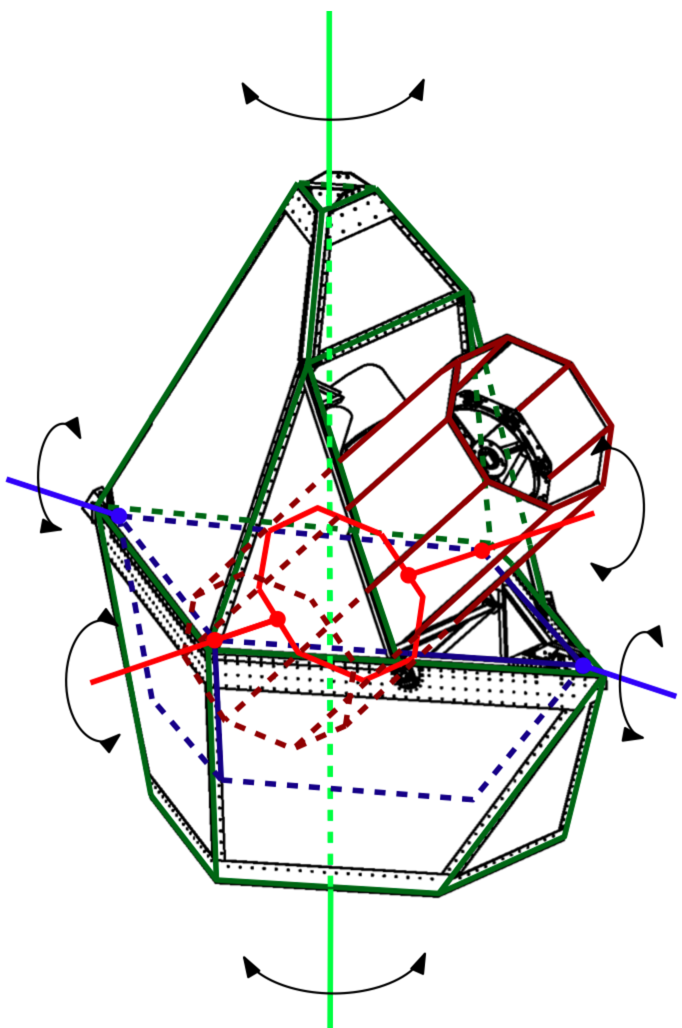

SuperBIT
Superpressure Balloon-borne Imaging Telescope
Size of a small stadium
Wobbly

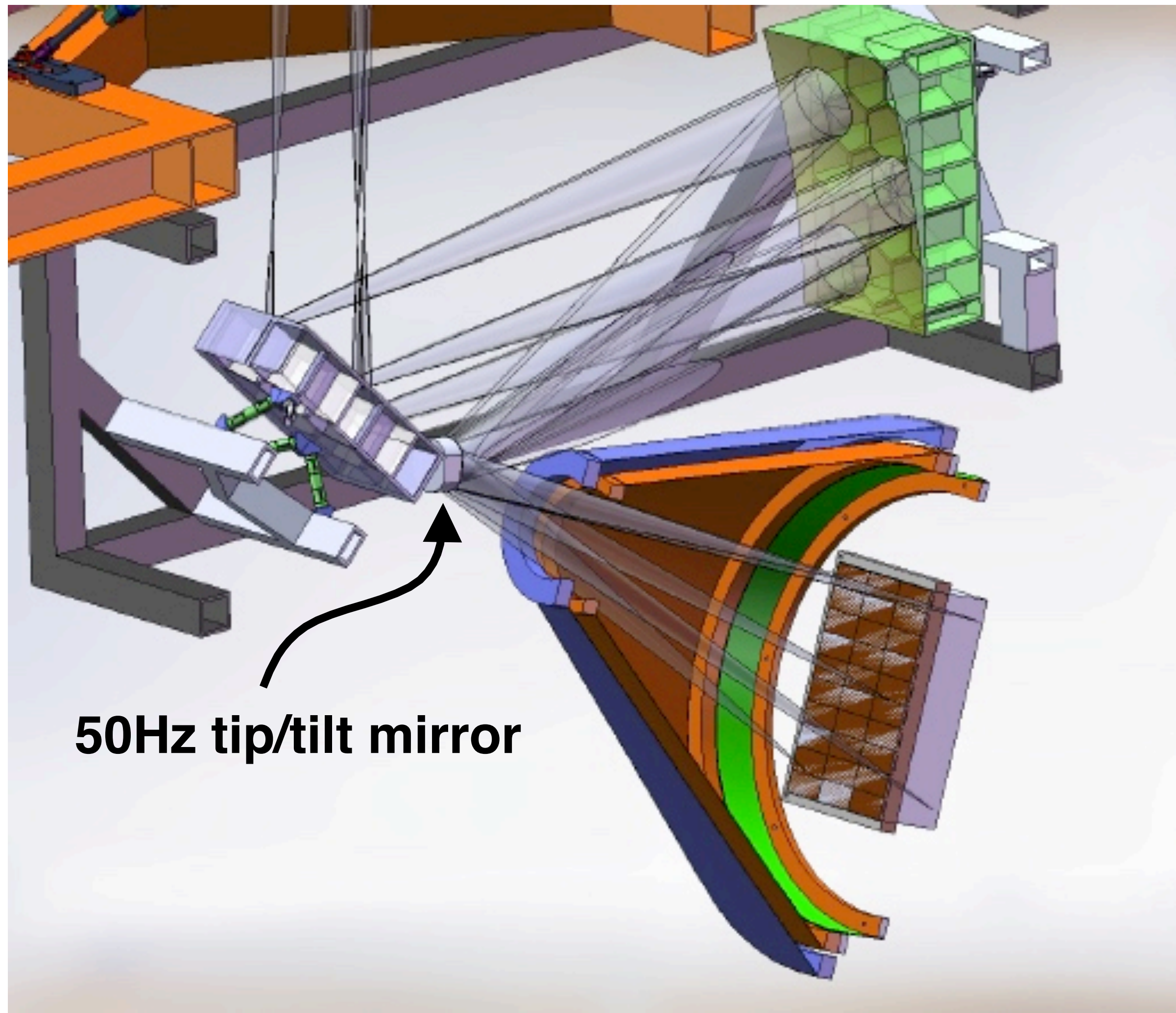
SuperBIT

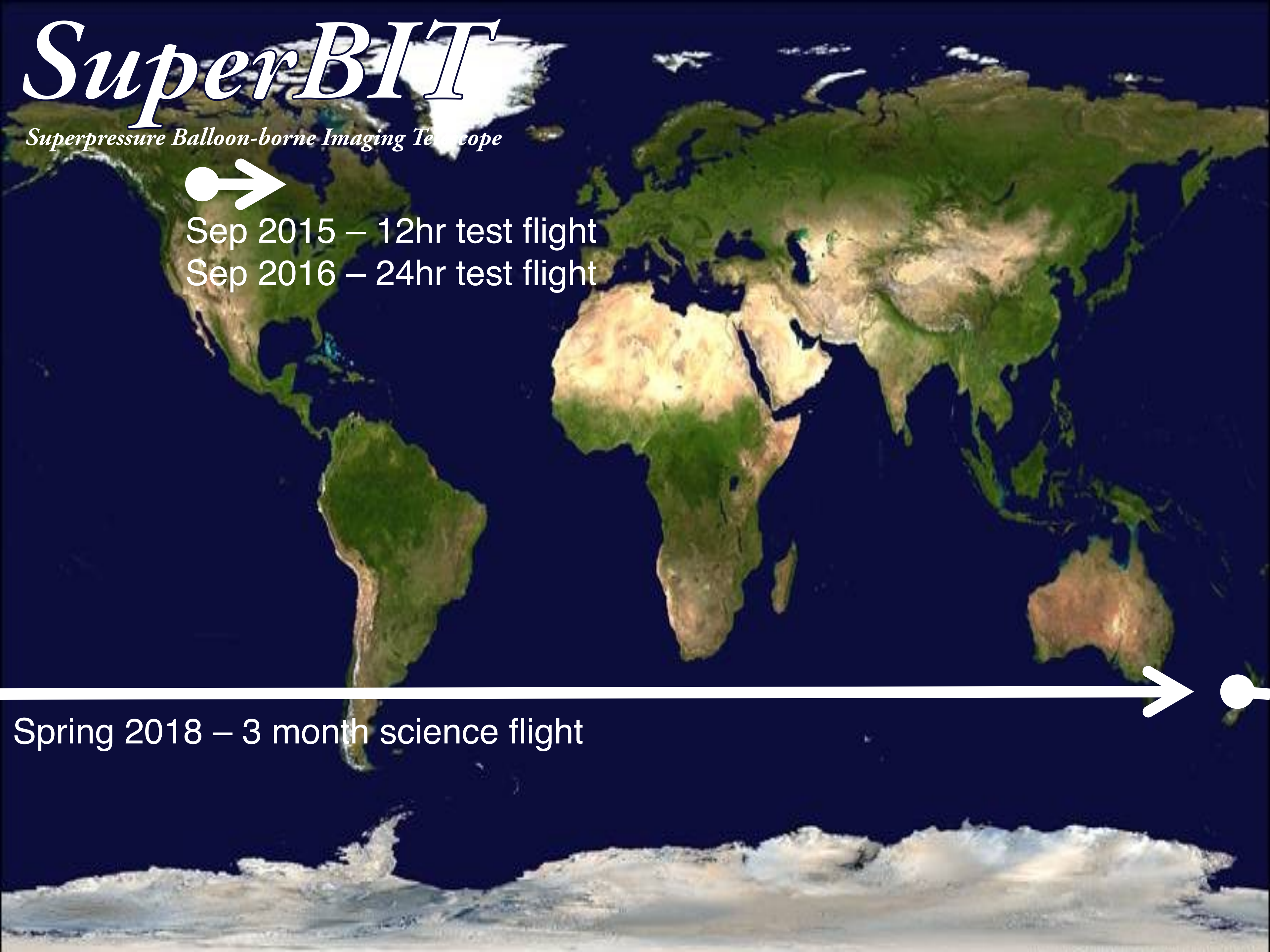
Superpressure Balloon-borne Imaging Telescope

Three steps to diffraction-limited imaging:

- **Passive damping of gondola ➔1’ rms**
- **Gyros on 3dof nested gimbals ➔ 1” rms**
- **Guide star + tip/tilt mirror in optics ➔ 0.1”**






SuperBIT
Superpressure Balloon-borne Imaging Te cope
Sep 2015 – 12hr test flight
Sep 2016 – 24hr test flight
Spring 2018 – 3 month science flight