“Large” hadron collider? What, *that* little thing?

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THE ROYAL SOCIETY

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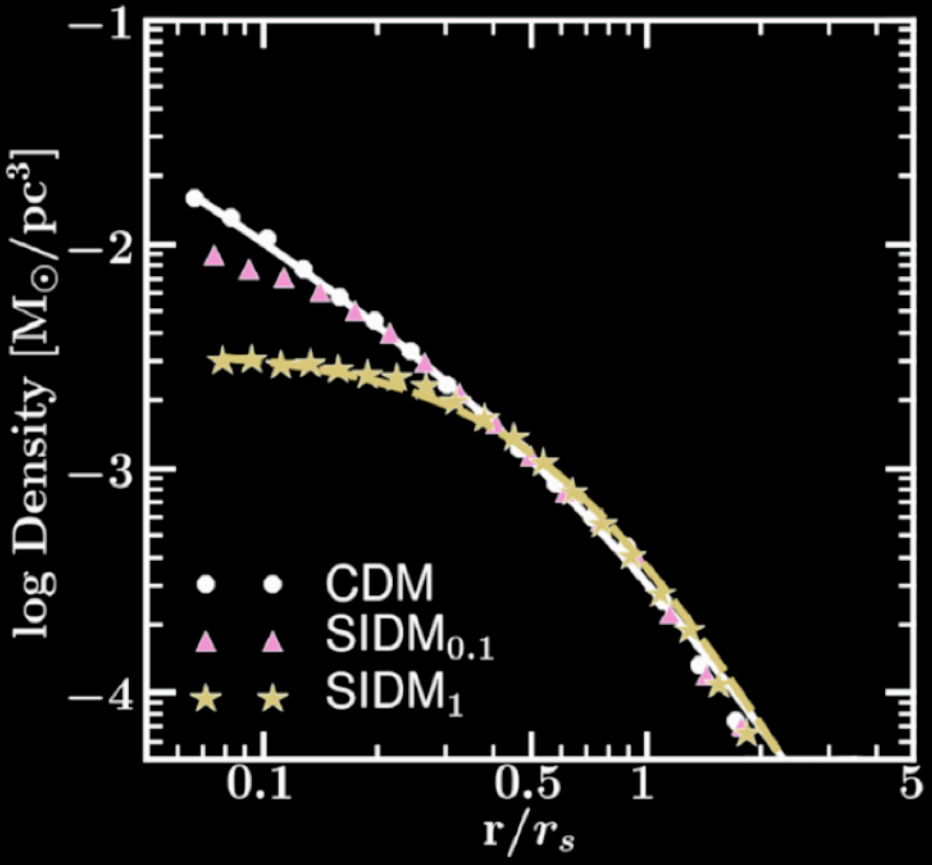
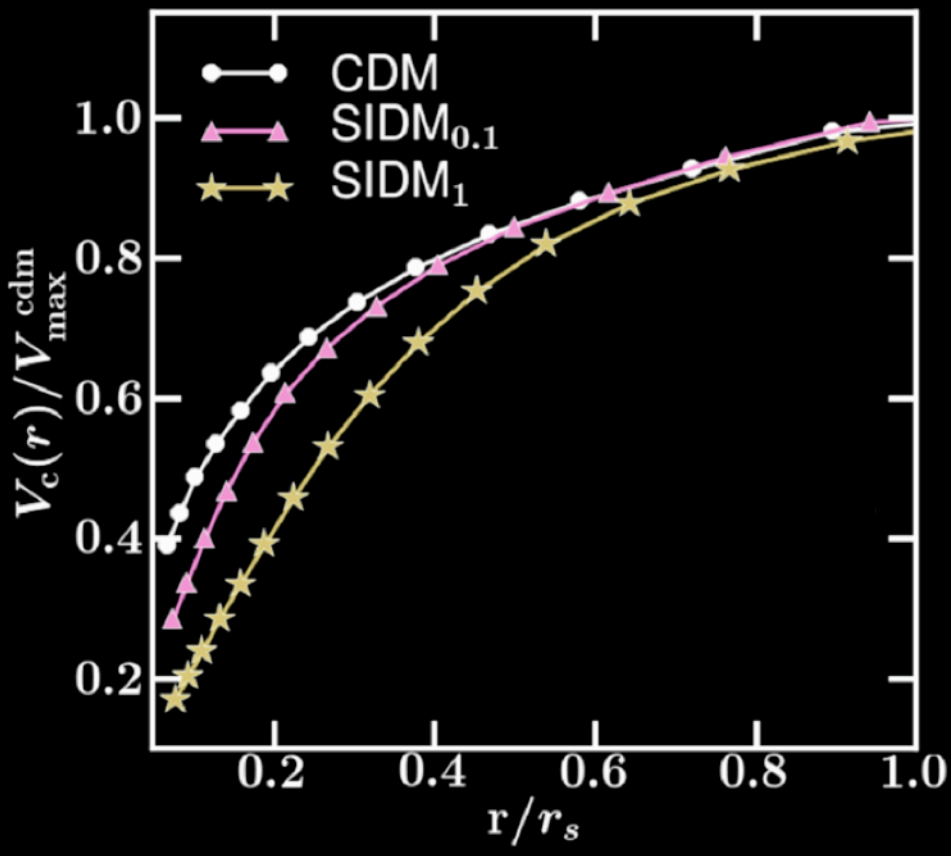
SIDM solves all of ΛCDM's "small-scale crises"

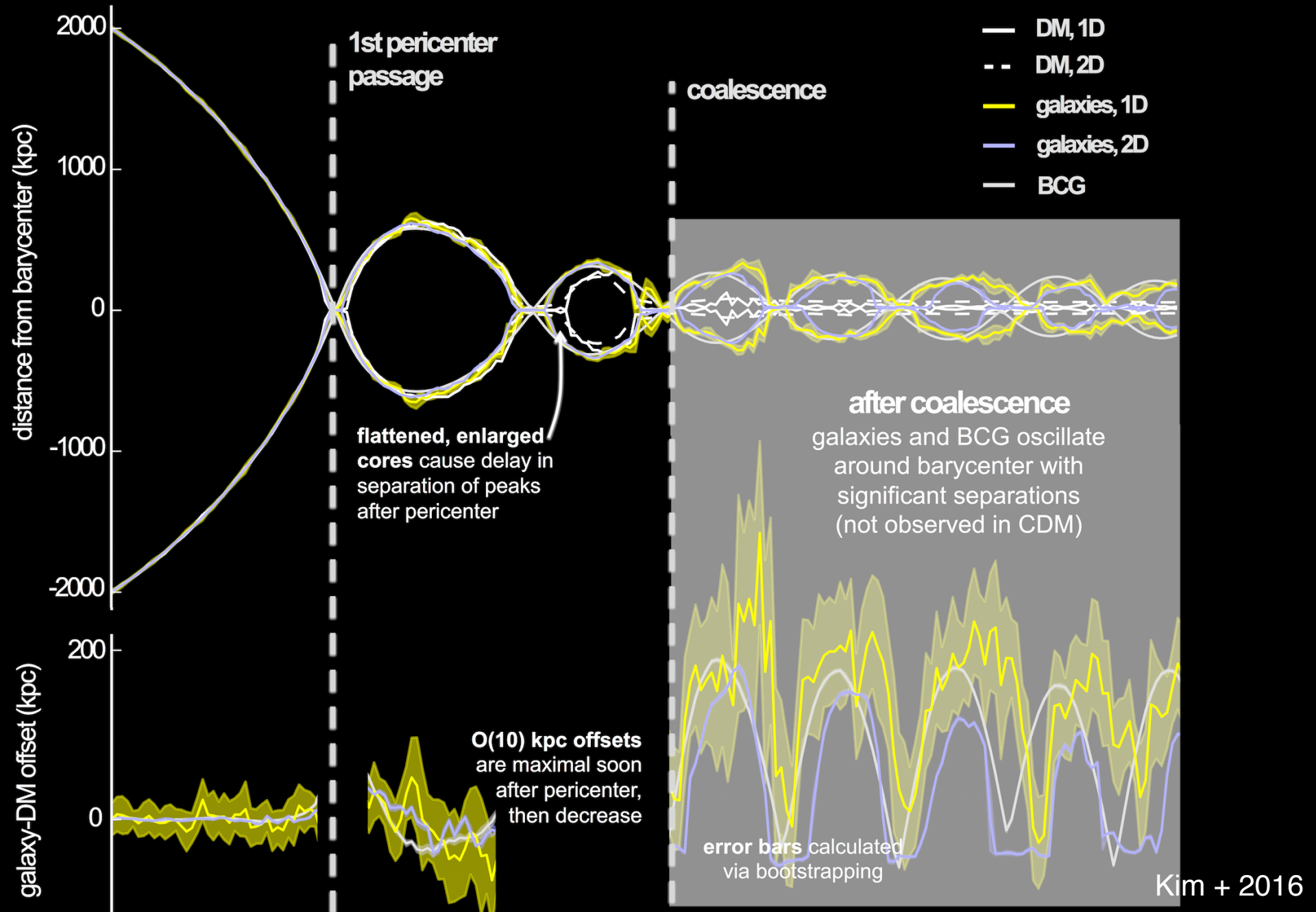
- ➔ core formation **(cusp/core)**
- ➔ removal of small substructure **(missing satellites)**
- ➔ reduced circular velocity **(too big to fail)**
- ➔ core size sensitive to baryons **(diversity of rotation curves)**





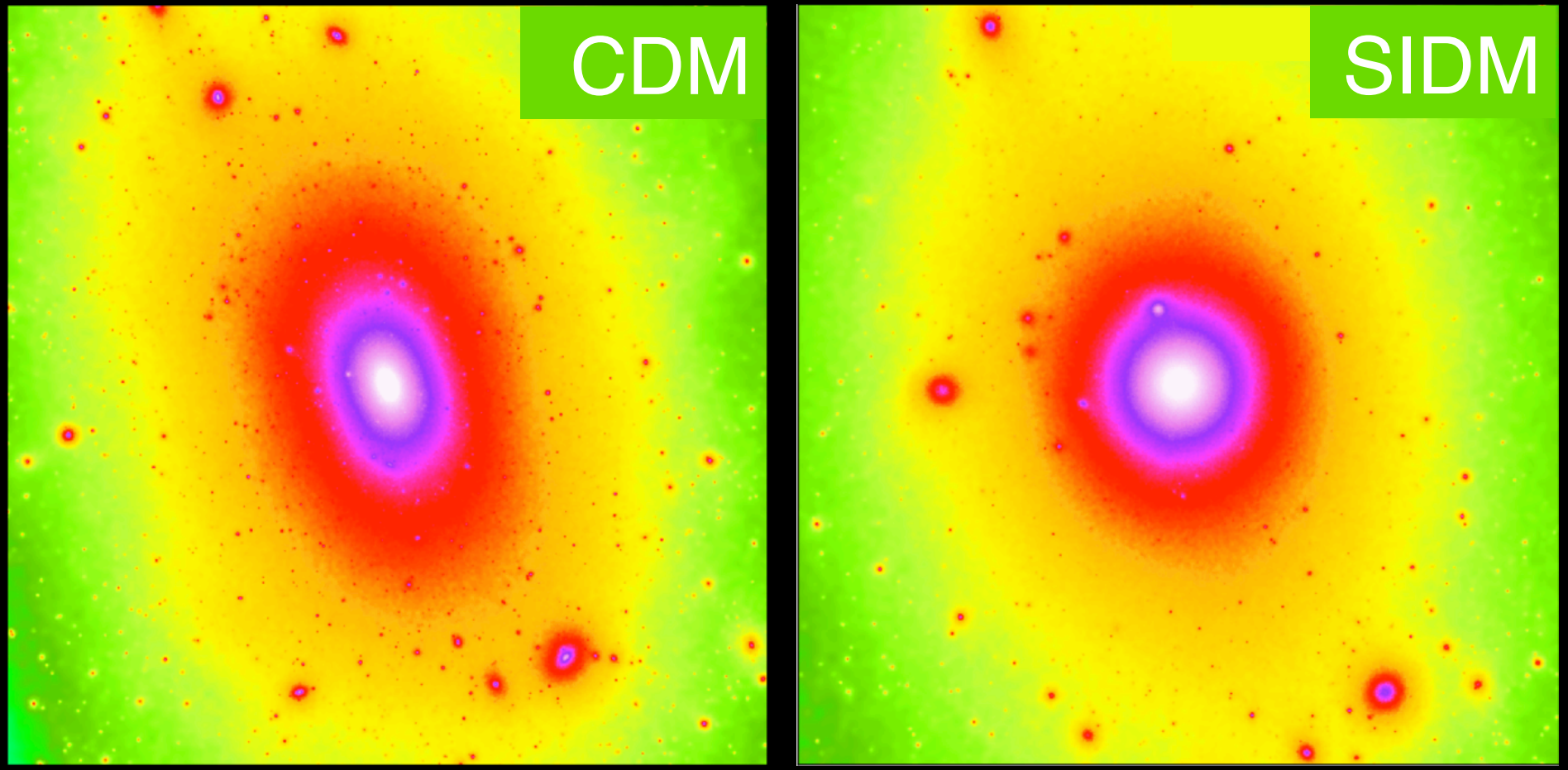
Rocha+ 2013

Observable tests of SIDM - 1: BCG oscillations



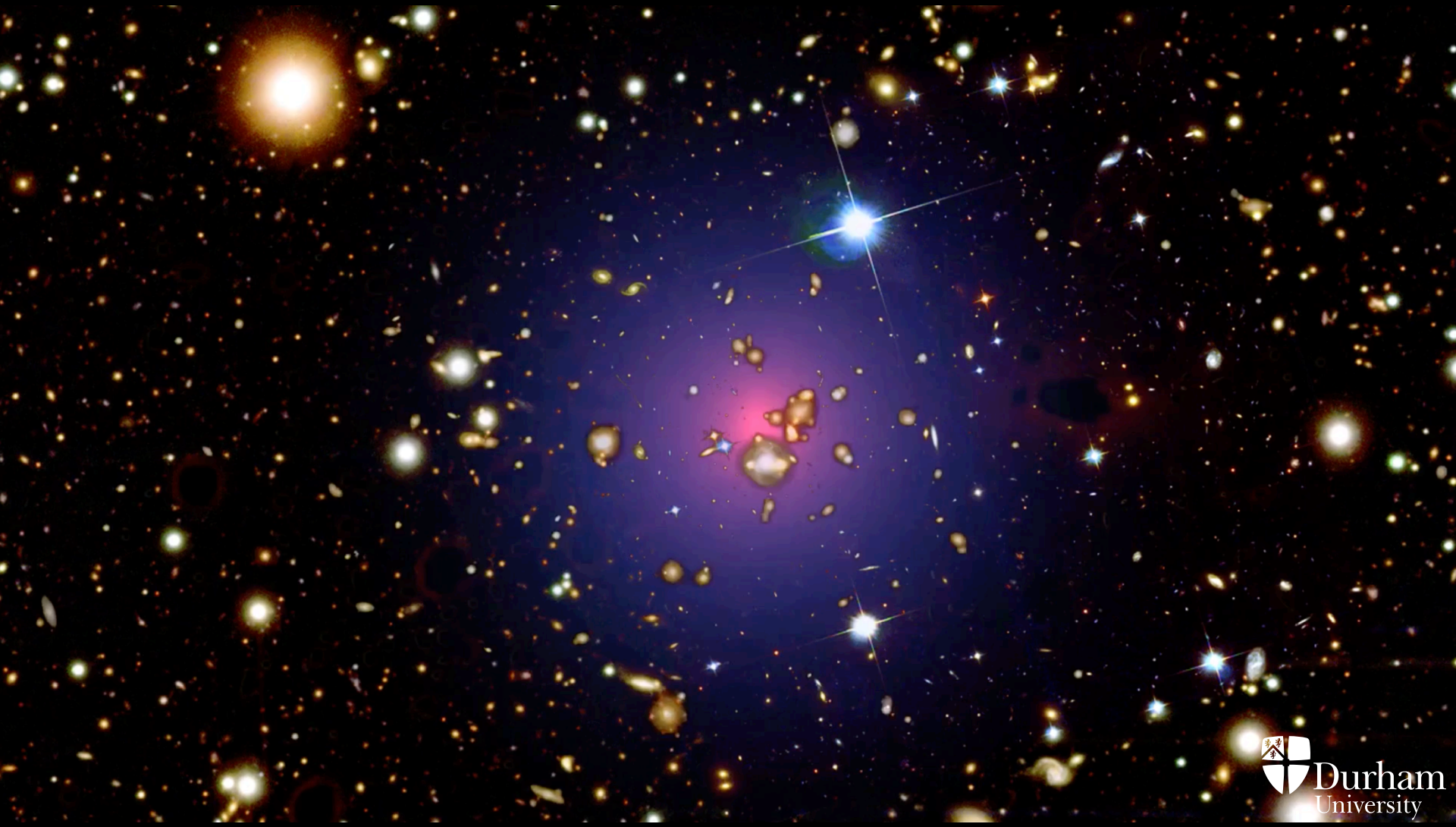
Kim + 2016

Observable tests of SIDM - 2: sphericity



Vogelsberger+ 2012

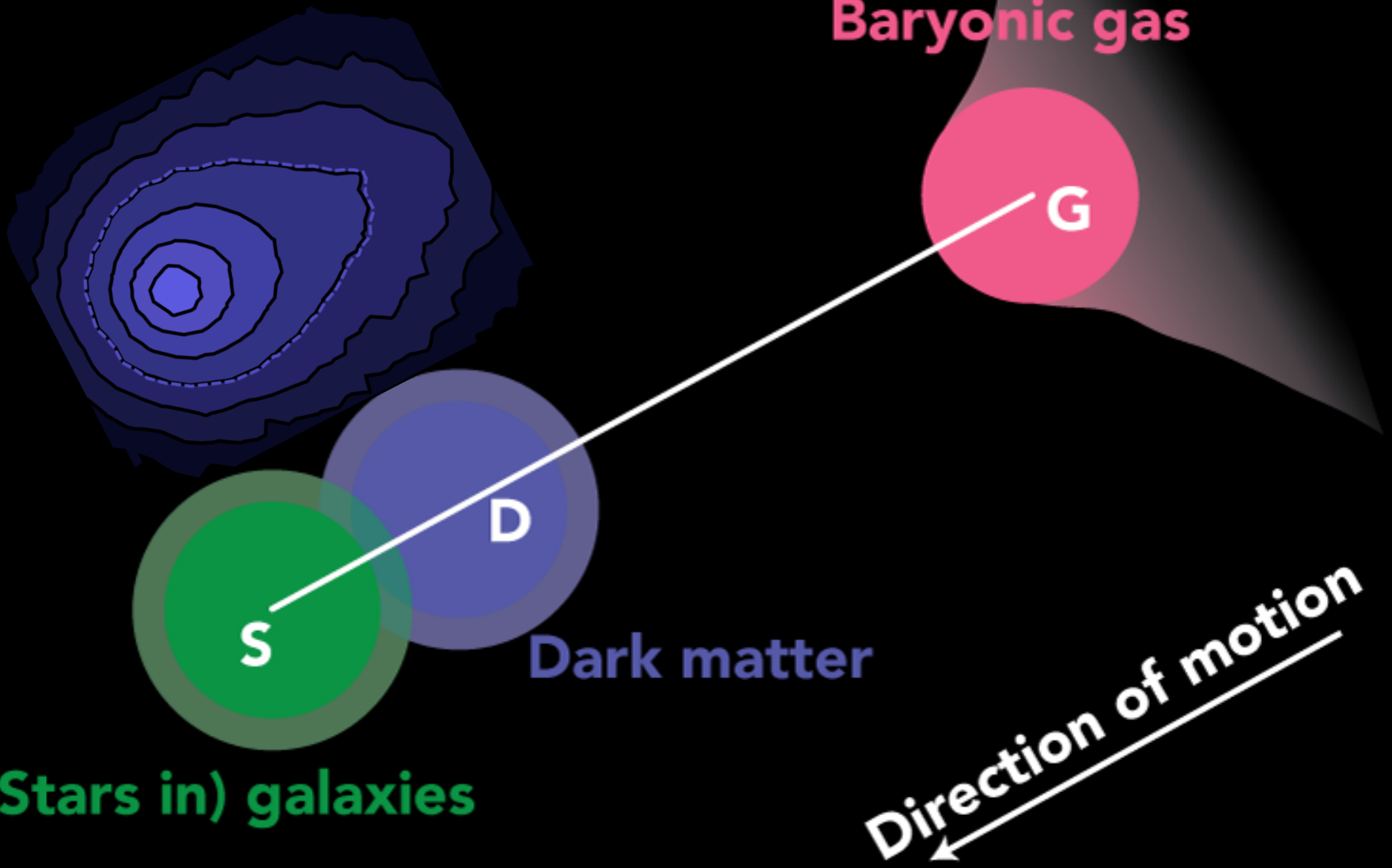
Observable tests of SIDM - 3: particle colliders



D. Clowe et al. (Astrophys. J. 2006)
A. Robertson et al. (MNRAS 2016)

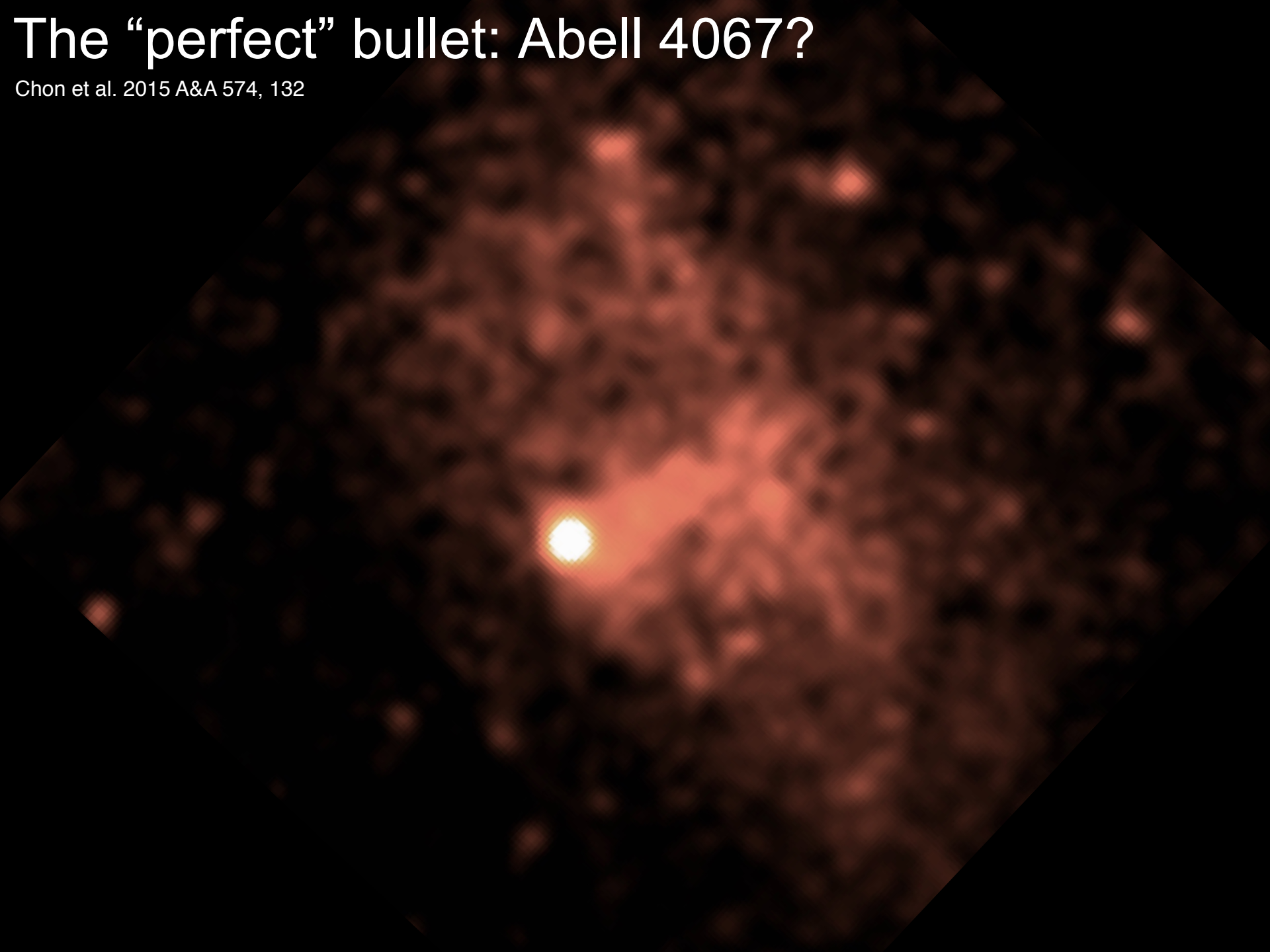
Friction on SIDM makes it lag behind the stars

Harvey et al. 2014, MNRAS 441, 404
Kahlhoefer et al. 2014, MNRAS 437, 2865



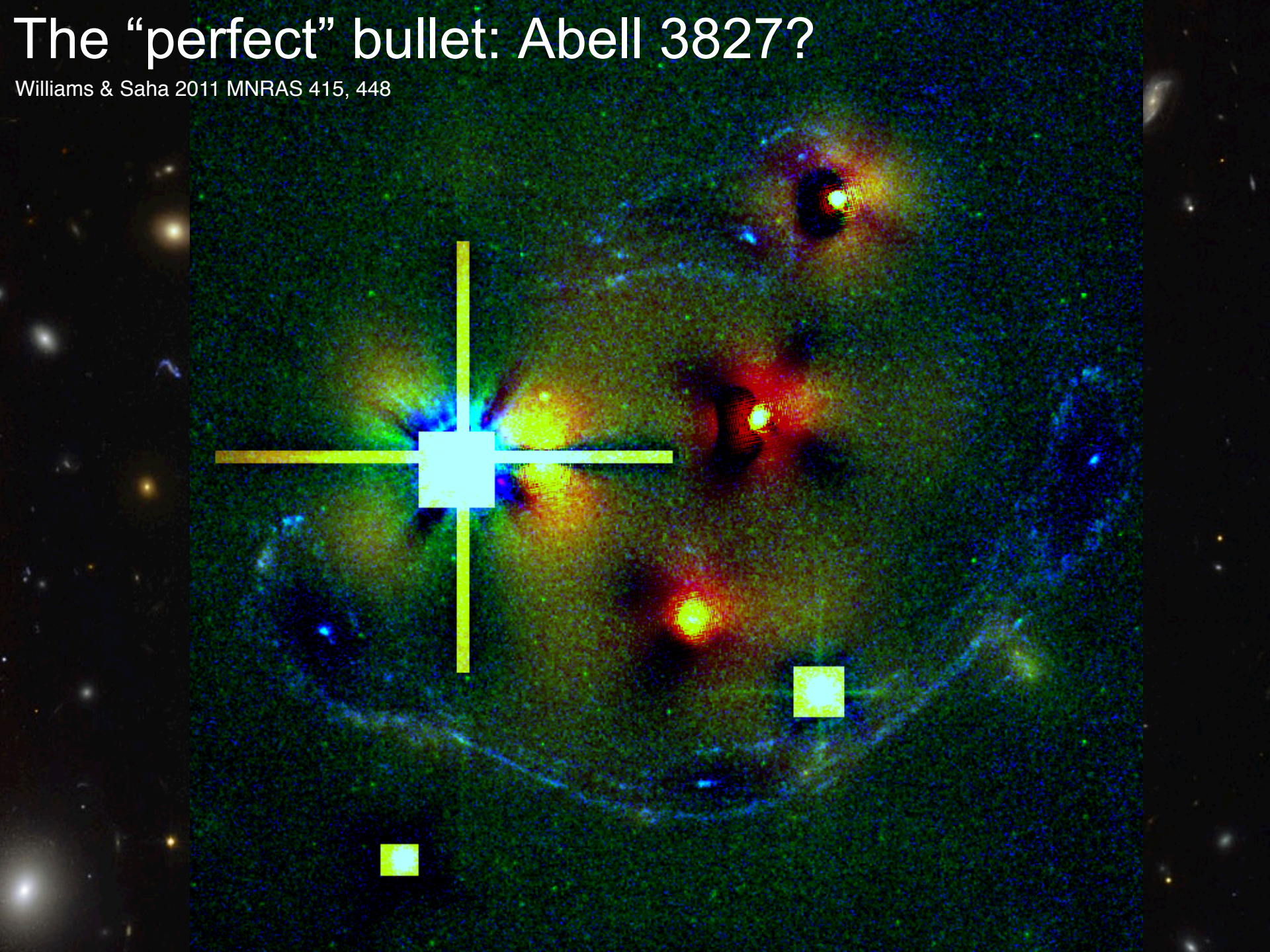
The “perfect” bullet: Abell 4067?

Chon et al. 2015 A&A 574, 132



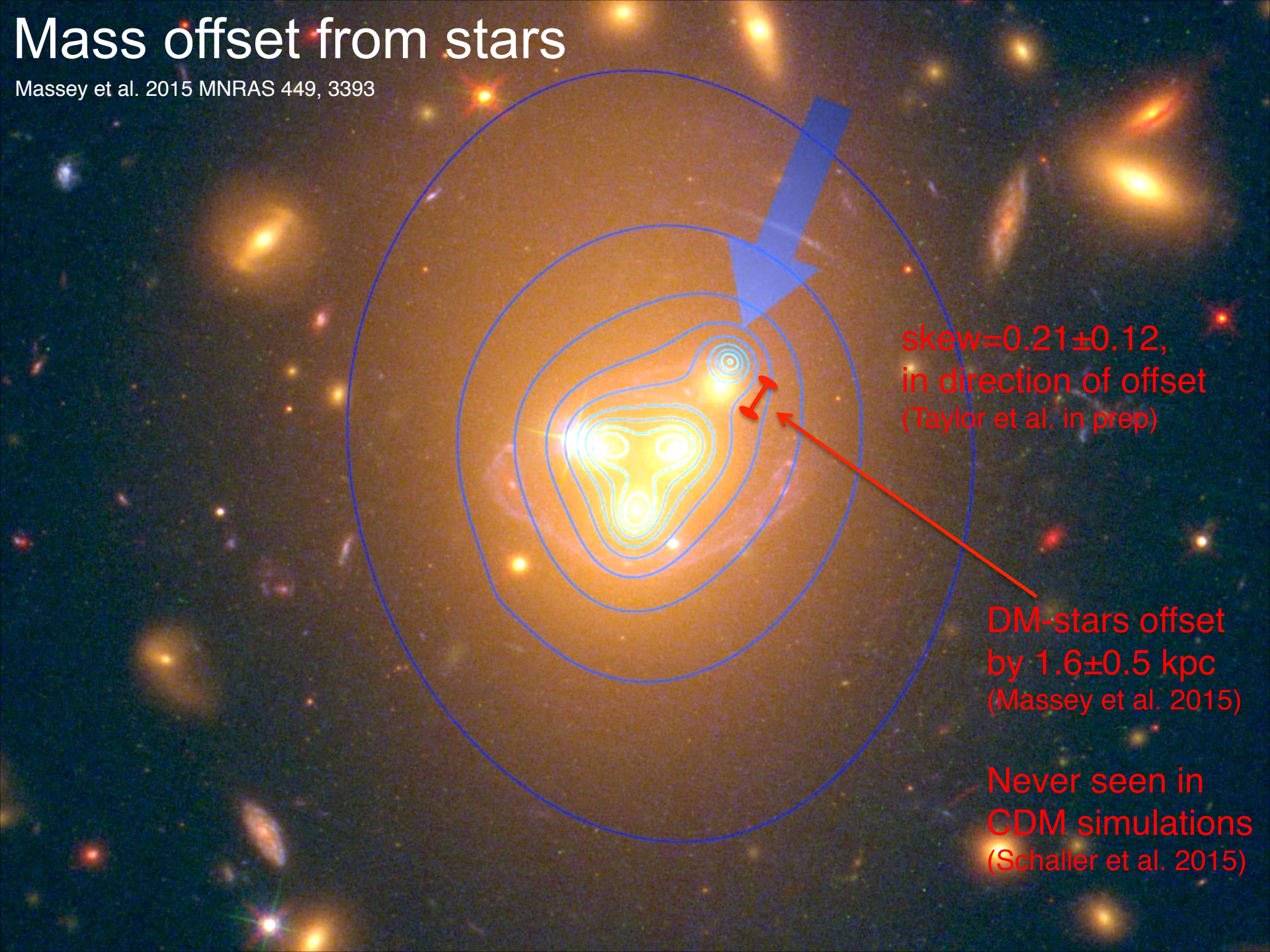
The “perfect” bullet: Abell 3827?

Williams & Saha 2011 MNRAS 415, 448



Mass offset from stars

Massey et al. 2015 MNRAS 449, 3393



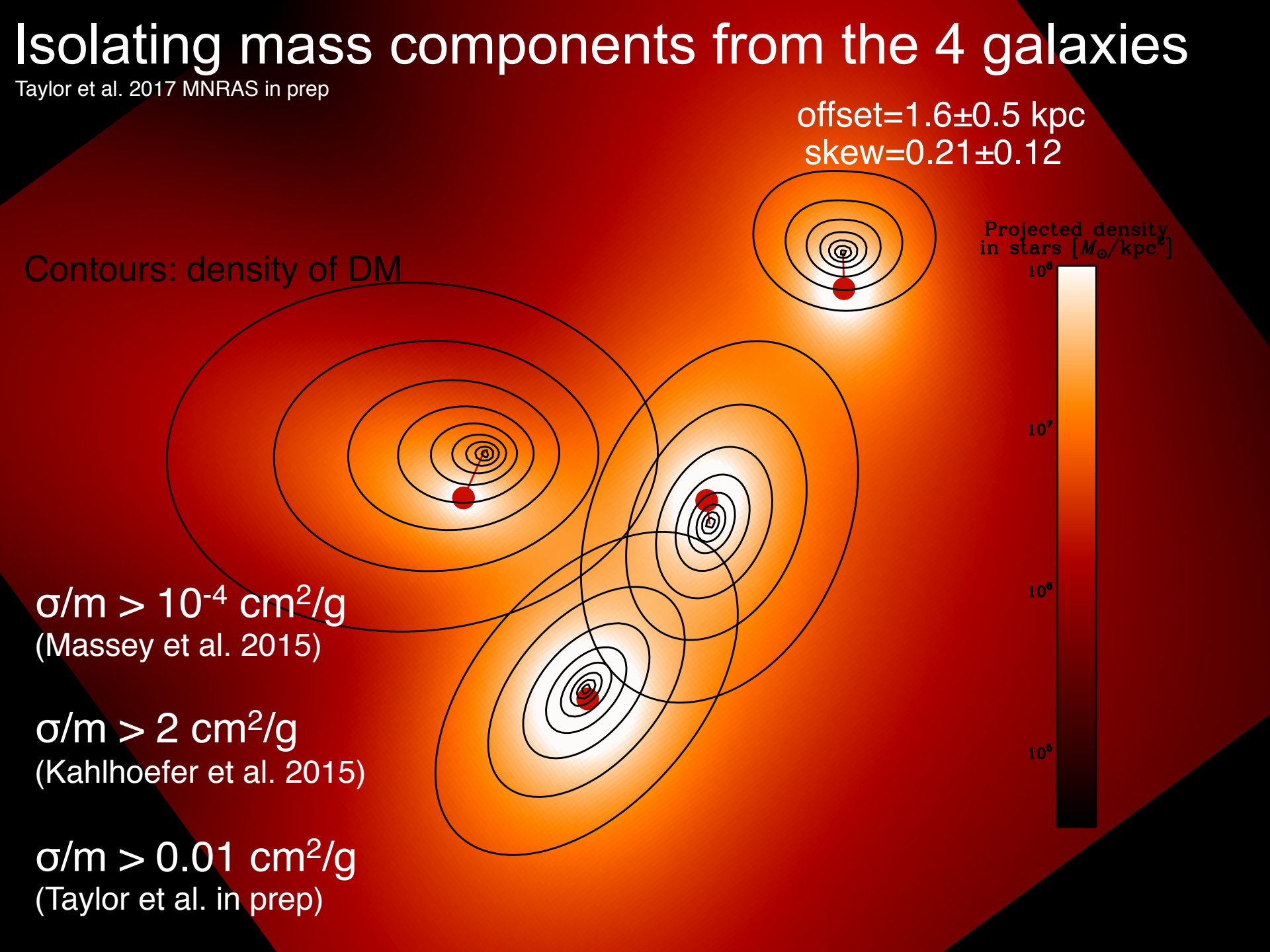
skew=0.21±0.12,
in direction of offset
(Taylor et al. in prep)

DM-stars offset
by 1.6±0.5 kpc
(Massey et al. 2015)

Never seen in
CDM simulations
(Schaller et al. 2015)

Isolating mass components from the 4 galaxies

Taylor et al. 2017 MNRAS in prep



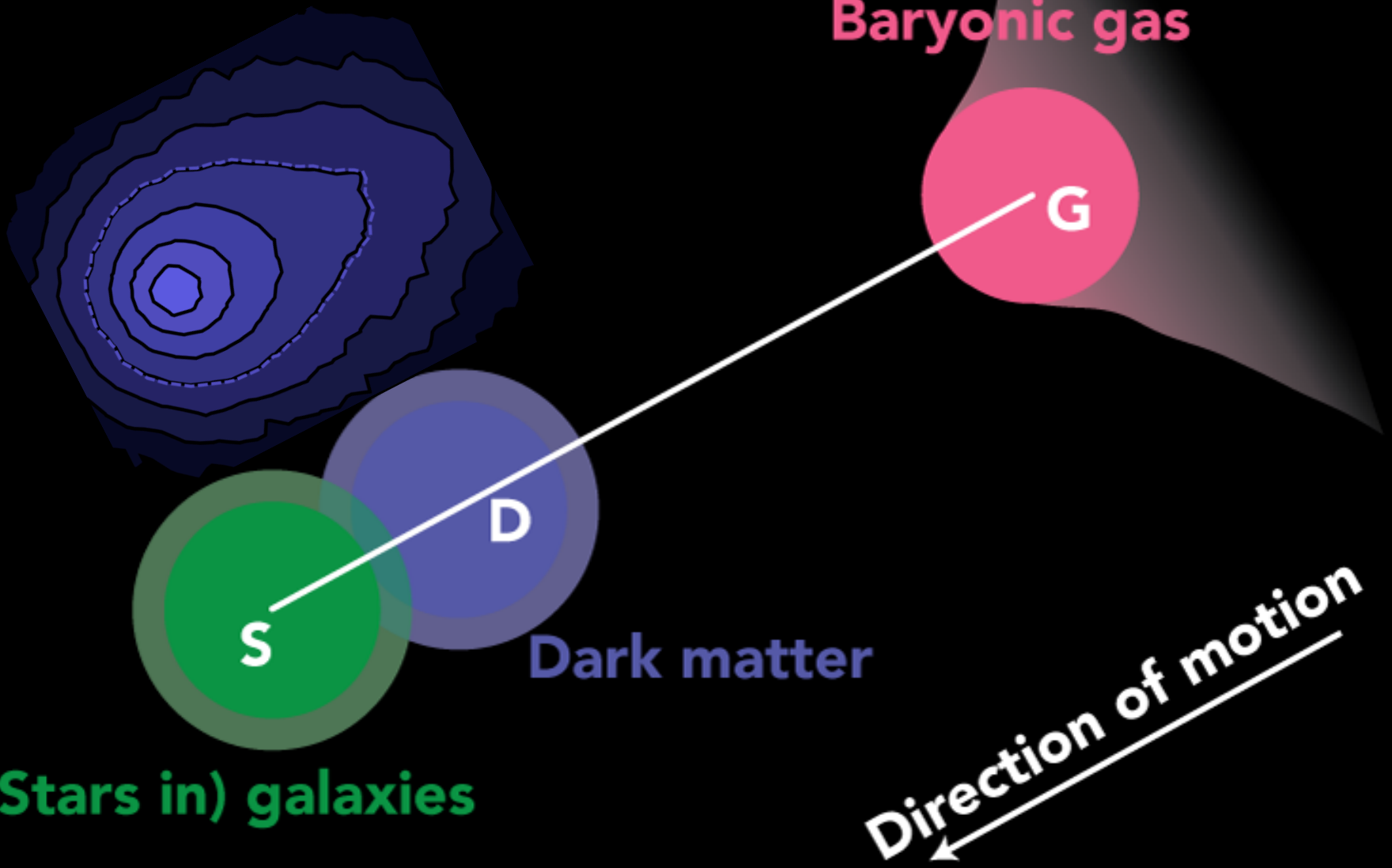
$\sigma/m > 10^{-4}$ cm^2/g
(Massey et al. 2015)

$\sigma/m > 2$ cm^2/g
(Kahlhoefer et al. 2015)

$\sigma/m > 0.01$ cm^2/g
(Taylor et al. in prep)

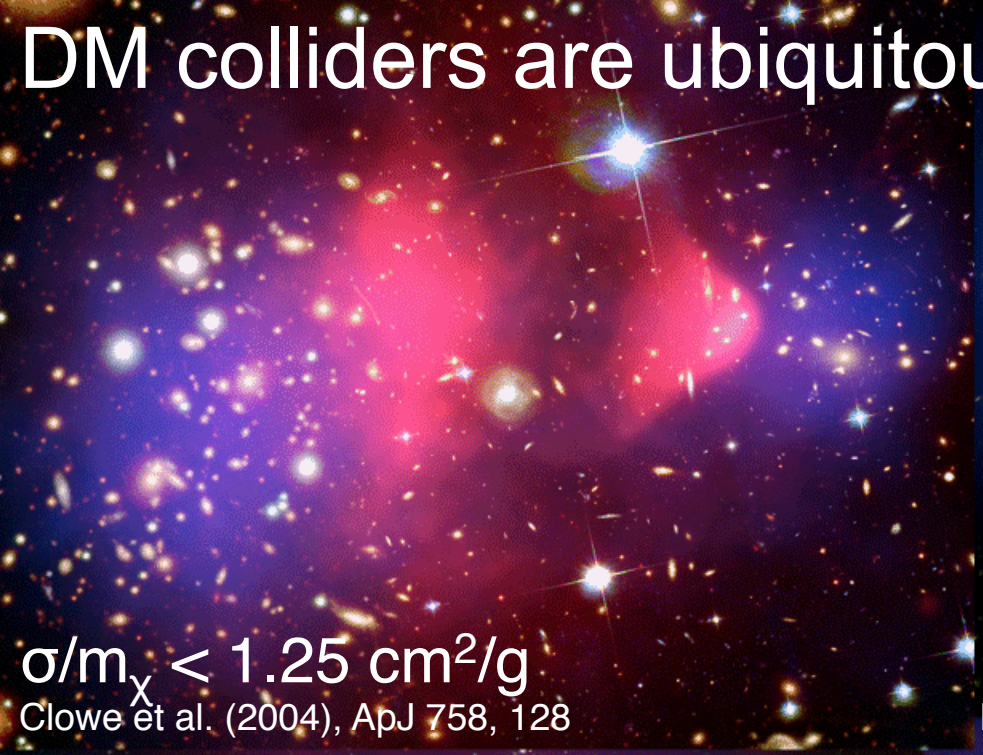
Friction on SIDM makes it lag behind the stars

Harvey et al. 2014, MNRAS 441, 404
Kahlhoefer et al. 2014, MNRAS 437, 2865



“Jellyfish” galaxies show the direction of motion, long after the gas has been removed

DM colliders are ubiquitous



$\sigma/m_\chi < 1.25\ cm^2/g$

Clowe et al. (2004), ApJ 758, 128

$\sigma/m_\chi < 4\ cm^2/g$

Bradac et al. (2008), ApJ 648, 109

$\sigma/m_\chi < 3.8\ cm^2/g$

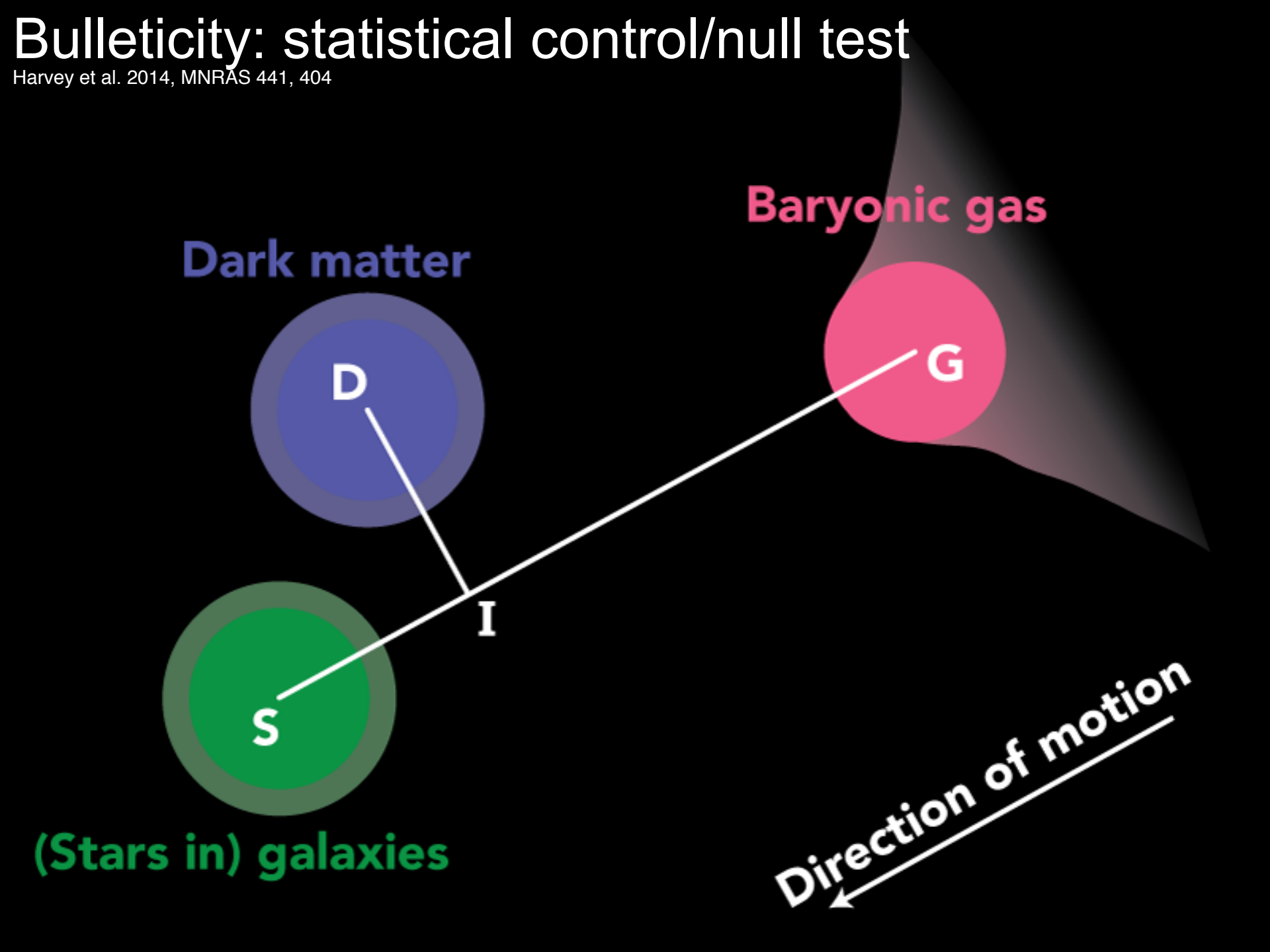
Mahdavi et al. (2007), ApJ 668, 806

$\sigma/m_\chi < 3\ cm^2/g$

Merten et al. (2011), MNRAS 417, 333

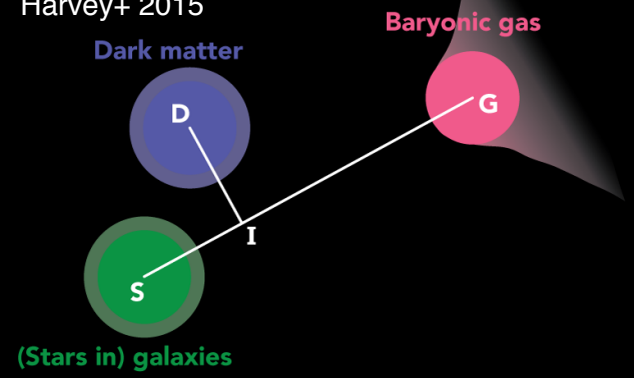
Bulleticity: statistical control/null test

Harvey et al. 2014, MNRAS 441, 404



Statistical bulleticity in 72 colliding DM halos [kpc]

Harvey+ 2015

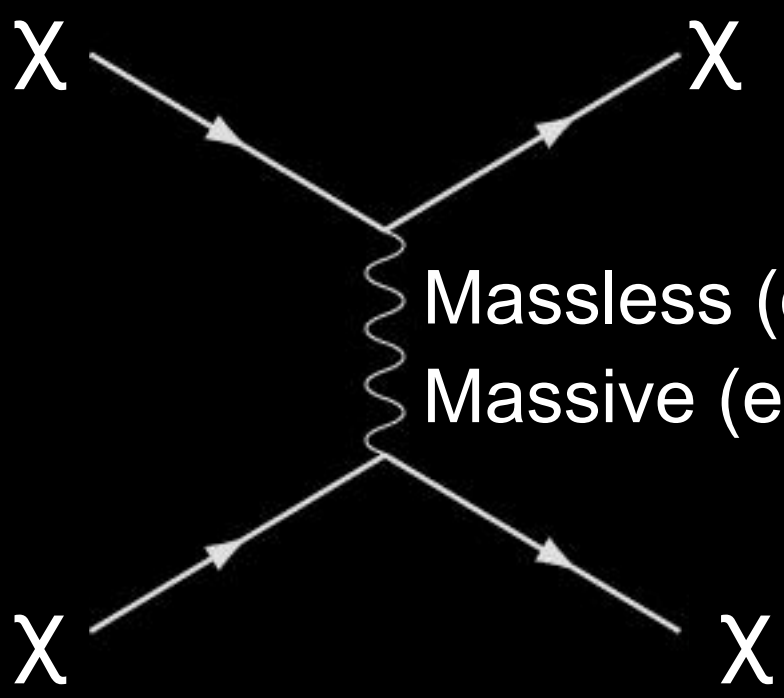


Mass is not in the same place as the baryons
(dark matter exists, at 7.6σ significance)

Dark matter closely follows the stars
($\sigma/m_\chi < 0.47$ cm2/g, 95% CL)

Future prospects: physics of DM self-interaction

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



Long range – frequent interactions, with low momentum transfer

Directional scattering $d\sigma/d\Omega$ (θ, v)

➔ **Substructure deceleration**

Short range – rare interactions, with high momentum transfer

Isotropic scattering σ

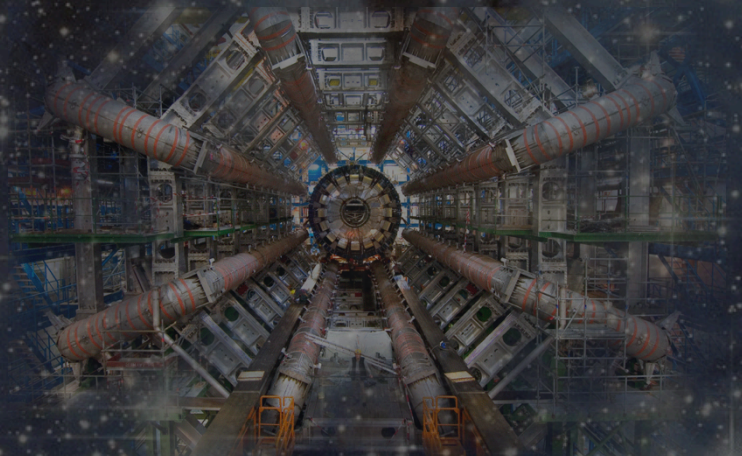
➔ **Substructure evaporation**

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)
- ✔ Upper limit $\sigma_{DM}<0.47 cm^2/g$ (95% CL)
- ✔ Extendable to 10,000s with eg eROSITA, SuperBIT/WFIRST

(other experiments 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 $\sigma_{DM}>0.01\ cm^2/g$, but uncertain dynamics
- ✗ The right conditions to enable all measurements are rare