Tests of new physics with halos and voids

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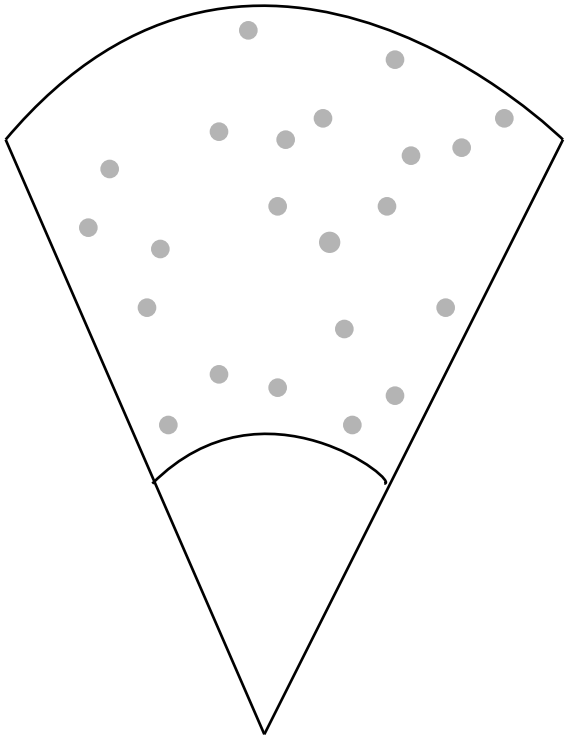
…and others, and…

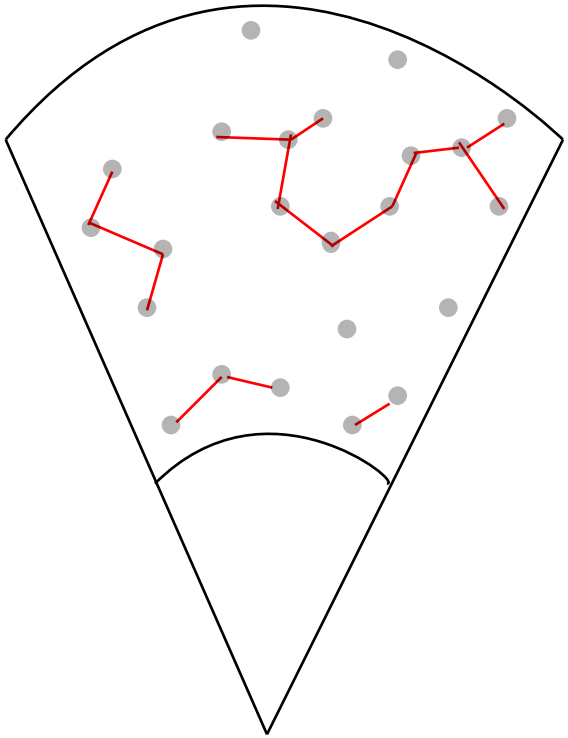
The Dark Energy Survey

Outline

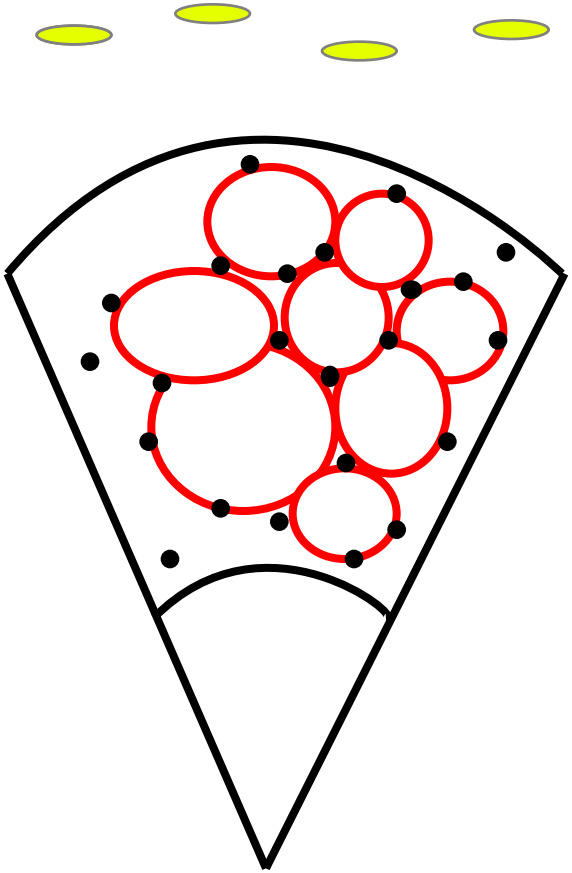
- What new empirical questions can we pose?
- Halos
- Voids
- New physics?



Halos



Filaments



Voids

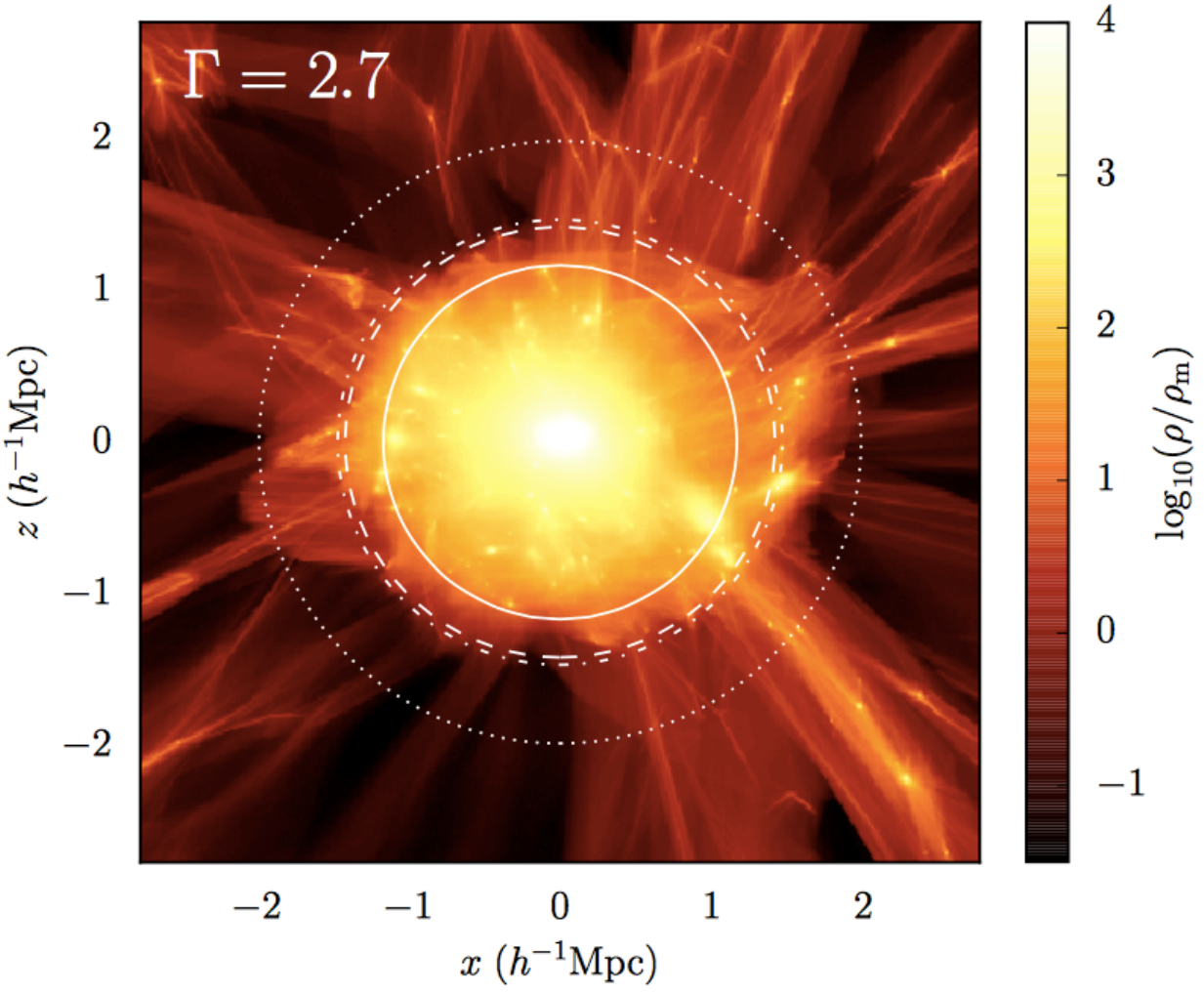
Basic Questions

- Do dark matter halos have an edge?
- How elliptical and lumpy are the halos of galaxies and galaxy clusters?
- How empty are voids? Do they cluster?

We can now measure both the light (galaxies) and the mass (lensing) – and answer these questions.

Theories that fit large scale data may predict deviations for halos or voids. Do calculate for your favorite theory!

The edge of halos: simulations

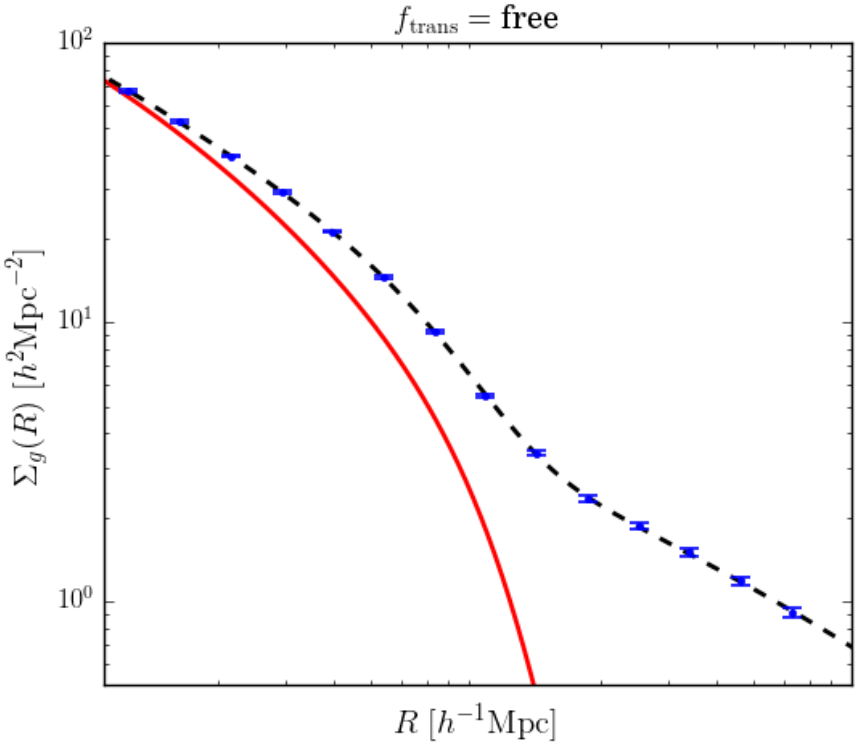


Dashed circle: radius at which accreted matter reaches apocenter

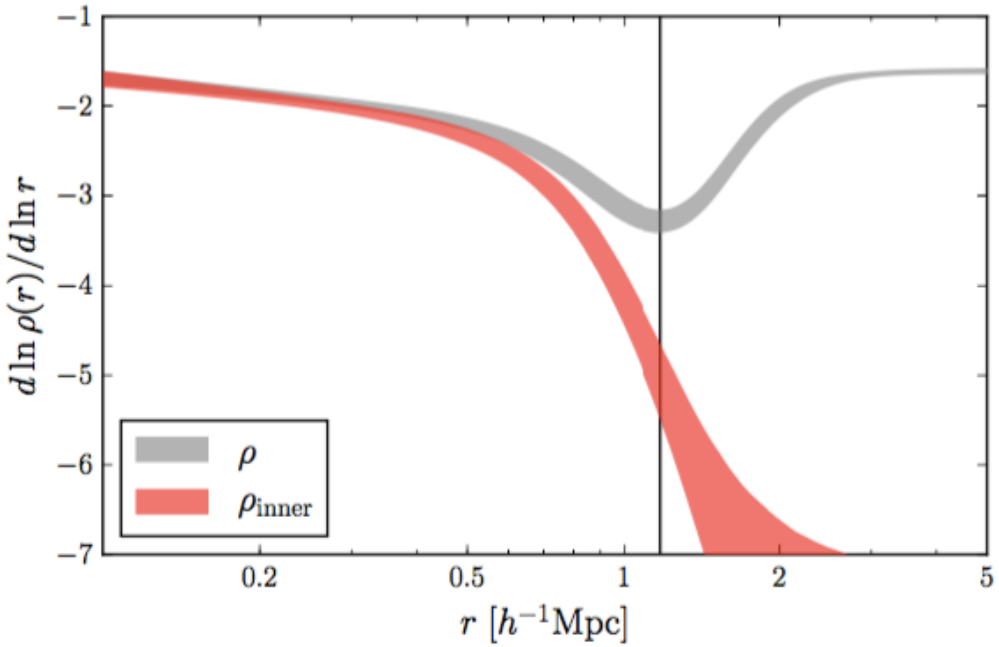
Gunn, Gott 85; Diemer, Kravtsov 2015; More et al 2015, 2016; Adhikari et al 2016

The edge of halos: galaxy clusters in the SDSS survey

Cluster galaxy profile



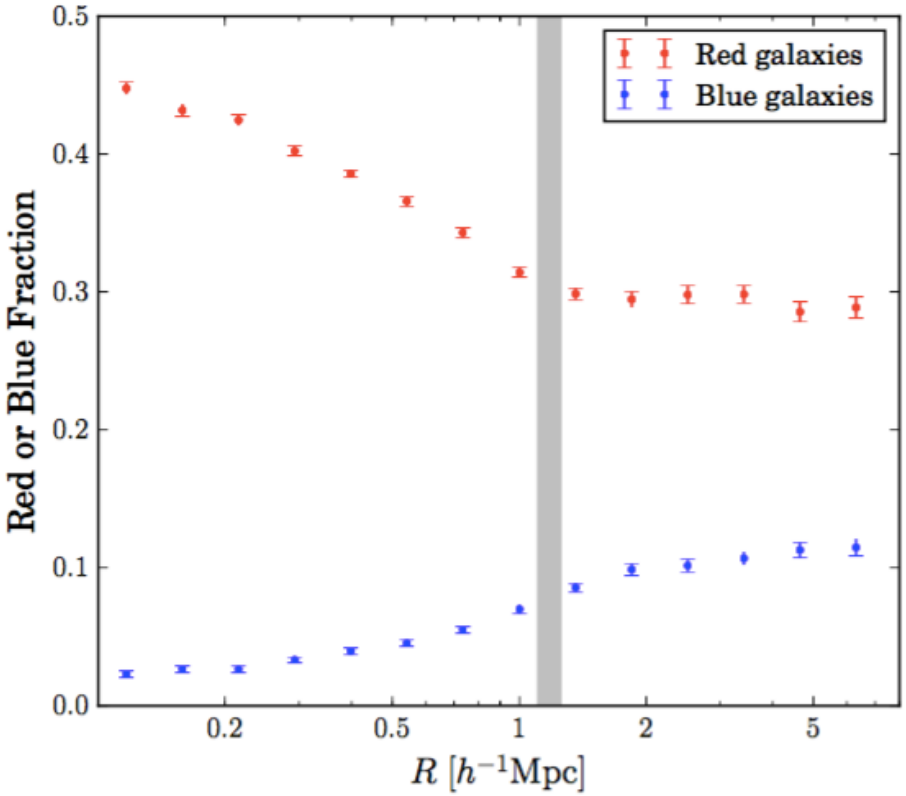
Cluster halos: slope of 3D profile



The halo profile is far steeper than dynamically mature CDM profiles like NFW. This halo `edge' is consistent with phase space caustics.

Baxter, Chang, BJ, et al 2017.
More et al 2016

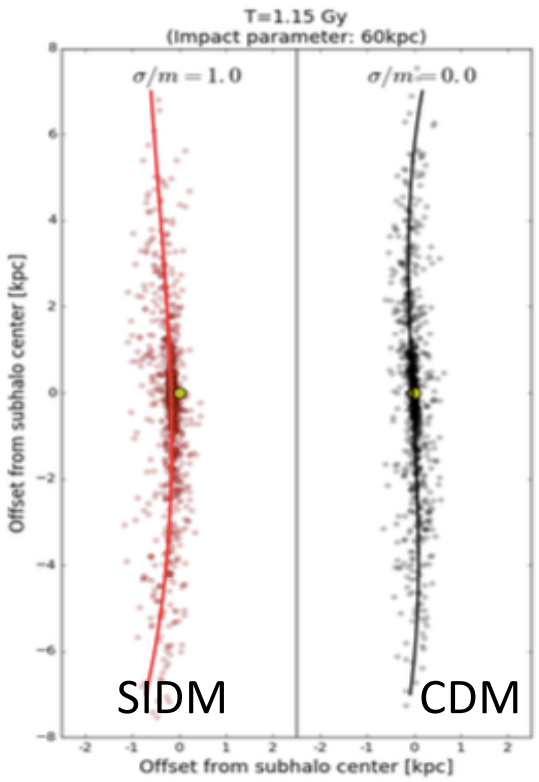
Tests of physics at halo boundaries

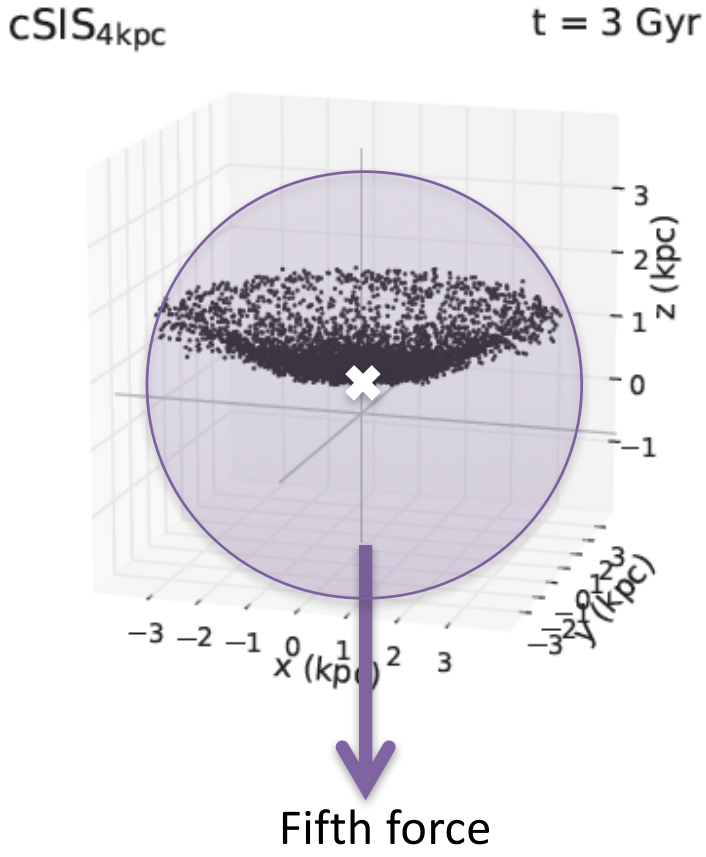


- Red and blue galaxies: suppression of star formation inside halo boundary

  Baxter, Chang, BJ, et al 2017
- Dynamical friction: bigger galaxies have smaller turnaround radii
- Dark matter interactions: small turnaround radii compared to CDM sims

Disk galaxies in dark matter halos





Tests of extra forces due to modified gravity or dark matter self-interactions.

BJ & VanderPlas 2011; Hui & Nicolis 2012; Secco et al, in preparation

Similar galaxy studies can reveal black hole–star offsets in Vainshtein theories. *Hui, Heyl*

Astrophysical tests

Test	Length Scale	Theories Probed	Current Status and Prospects
Growth vs. Expansion	100Mpc-1Gpc	GR + smooth dark energy	10% accuracy (2-4%[1])
Lensing vs. Dynamical mass[2]	0.01-100Mpc	Test of GR	20% accuracy[3] (5%)
Astrophysical Tests	0.01AU-1Mpc	MG Screening Mechanisms	$\sim$10% (Up to 10$\times$ improvement)
Lab and Solar System Tests	1mm-1AU	PPN $\rightarrow$ MG parameters[4]	Constraints are model dependent. (Up to 10$\times$ improvement)

BJ et al, Snowmass proceedings, 2013, arXiv: 1309.5389
Joyce, BJ, Khoury, Trodden 2014, arXiv:1407.0059

Much of what you've heard about at this meeting goes beyond what we reviewed!

Gravitational Lensing

Unlensed

Lensed

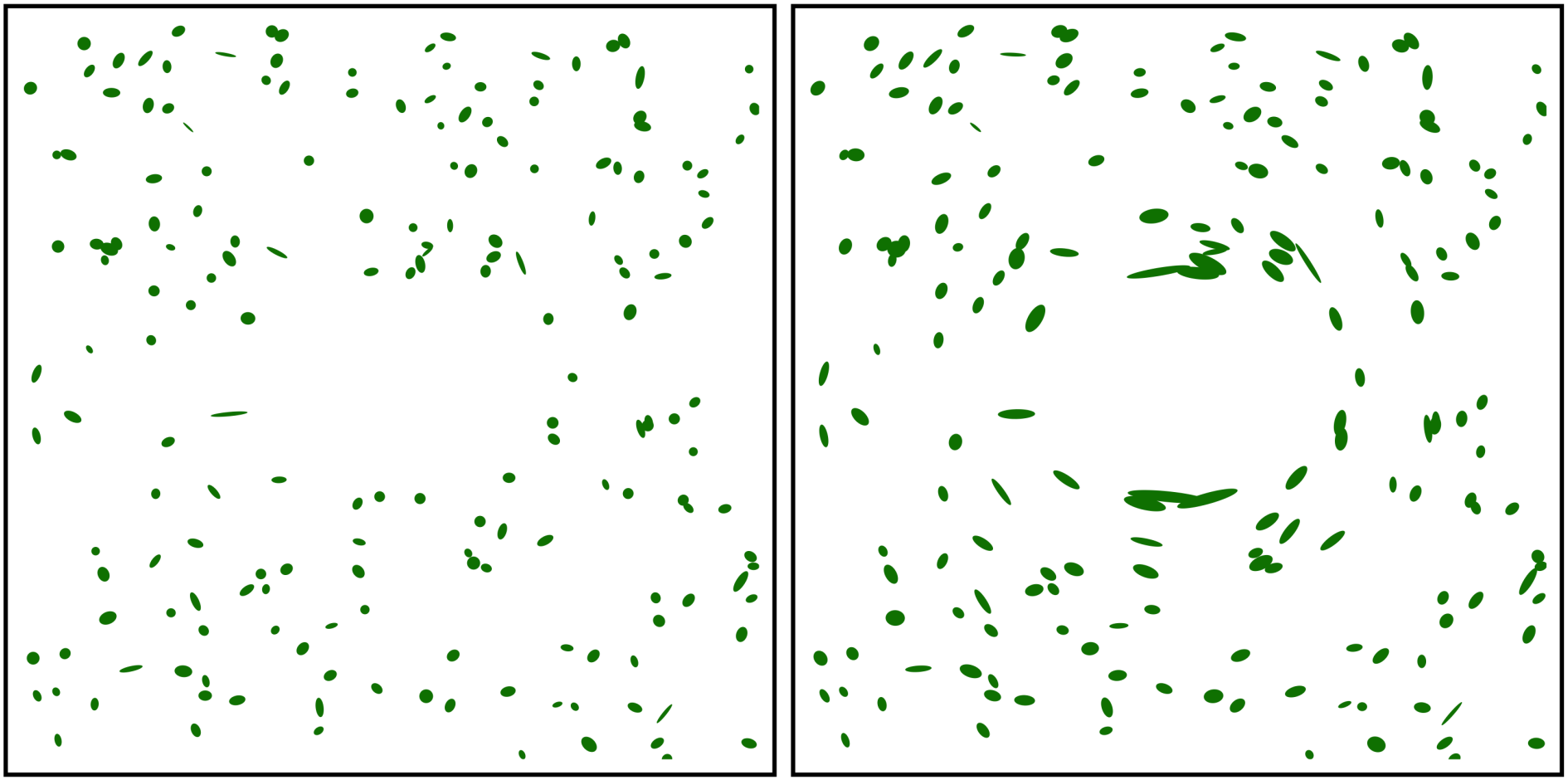
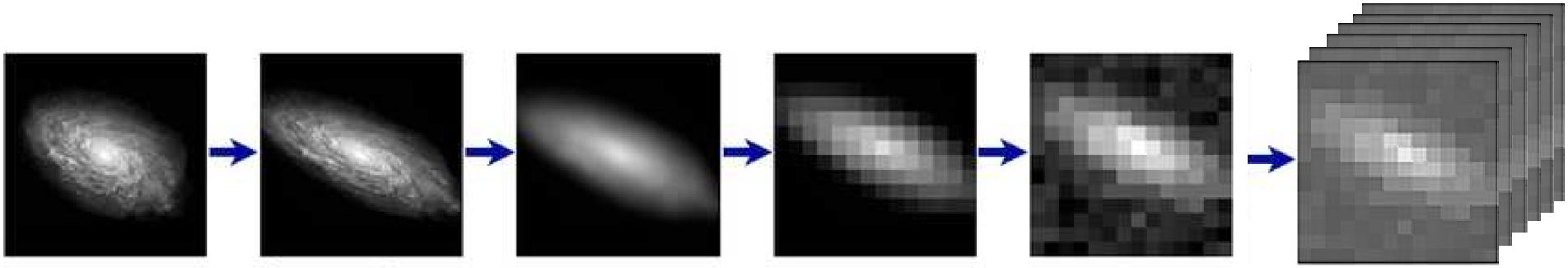


Image credit:
Jim Bosch

Weak Lensing

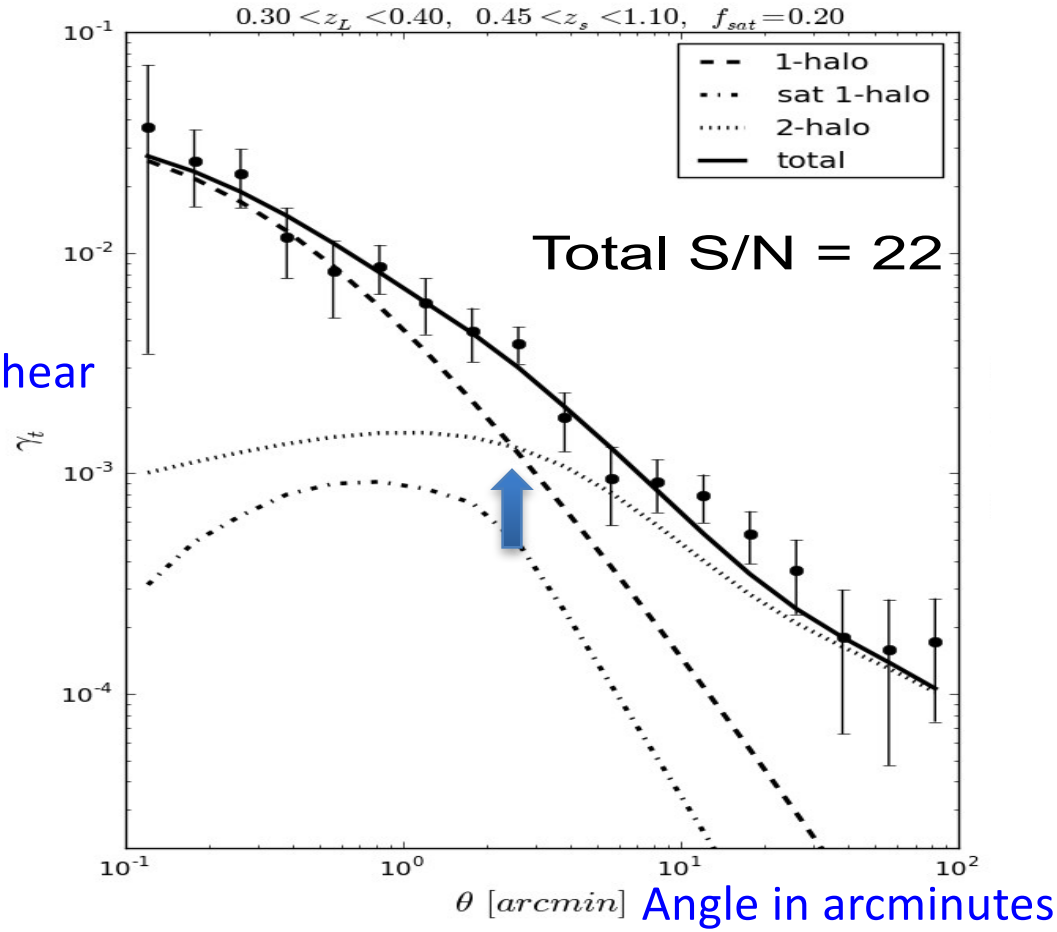


Galaxy with a 10% lensing shear and real-world effects. Great3 handbook

Cosmic shear ~ 1%, correlated piece on large scales ~ 0.1%
Halo quadrupole, voids: shear < 0.01%

Shear measurements using ~20 million galaxy images from the Sloan survey (SDSS) and the Dark Energy Survey (DES).

Halo mass profile

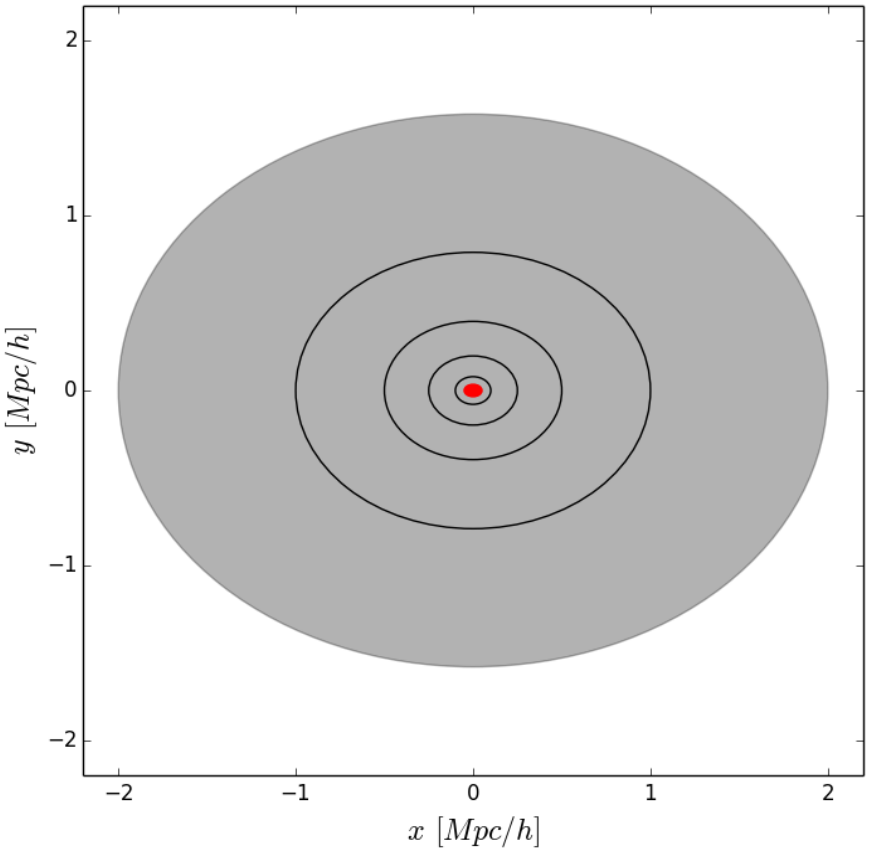


Tangential shear

Angle in arcminutes

Measurement and modeling of halo mass profiles: 1 and 2-halo terms
Clampitt et al 2016 (DES collaboration)

How round are halos?:
halo ellipticity, gravity and dark matter



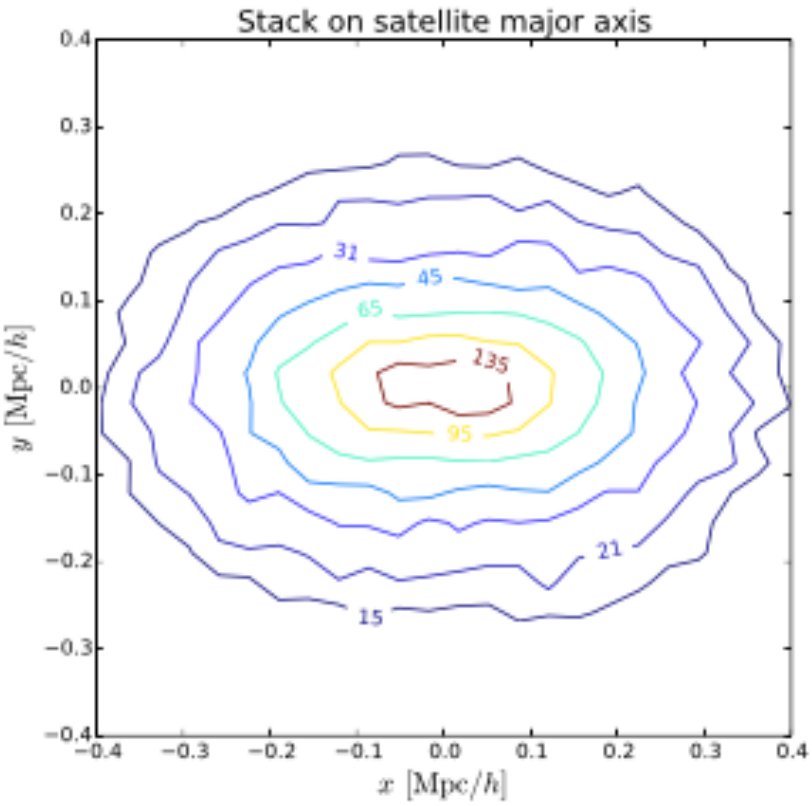
For typical galaxies, the halo virial radius is ~20x larger than the visible stars.

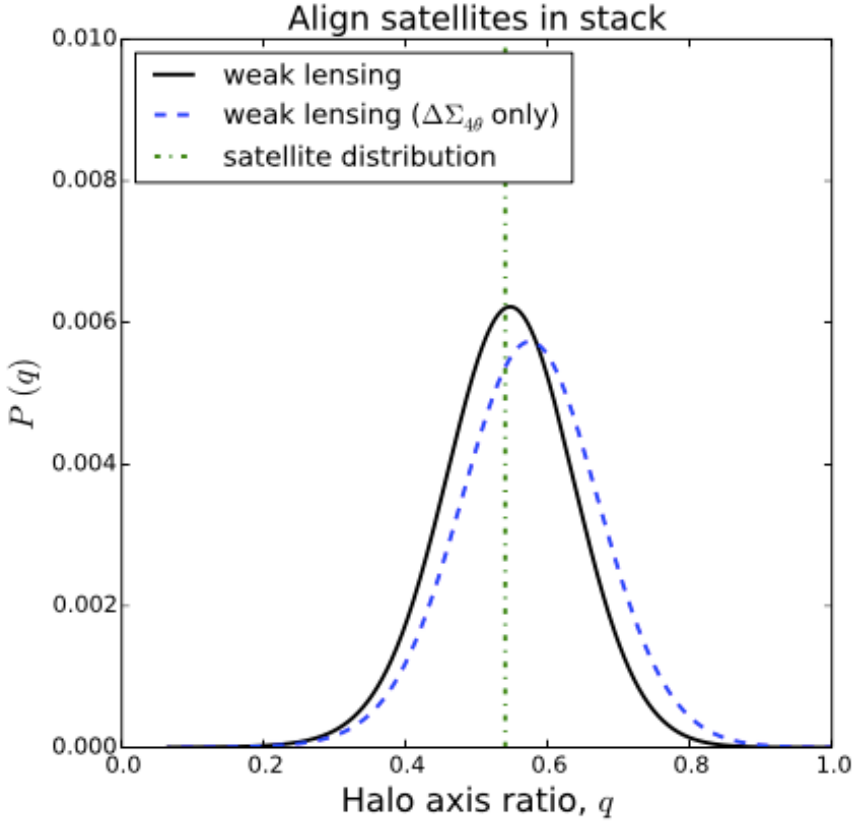
- How elliptical are the density contours?
- How do they change with radius?
- How do they relate to the light?

- Some attempts to modify gravity produce rounder contours with increasing radius.
- Self-interacting dark matter makes the halo rounder at small radii.

The shapes of cluster halos

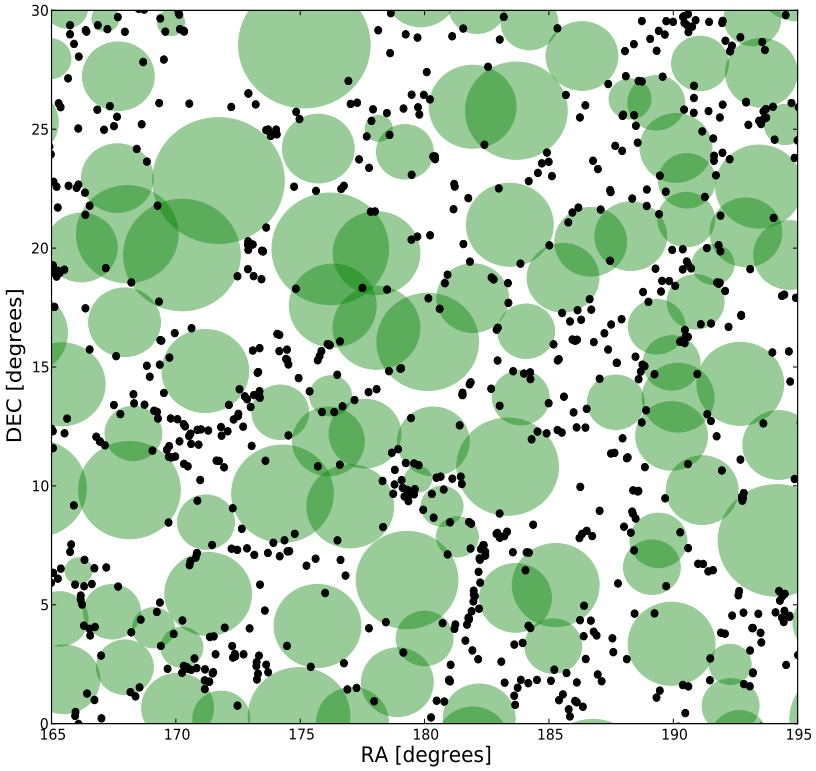
- We used a new estimator to measure halo ellipticity using lensing.
- The best fit axis ratio for clusters is below 0.6. About a 5-sigma detection.
- Satellite galaxies are an excellent tracer of halo shape.



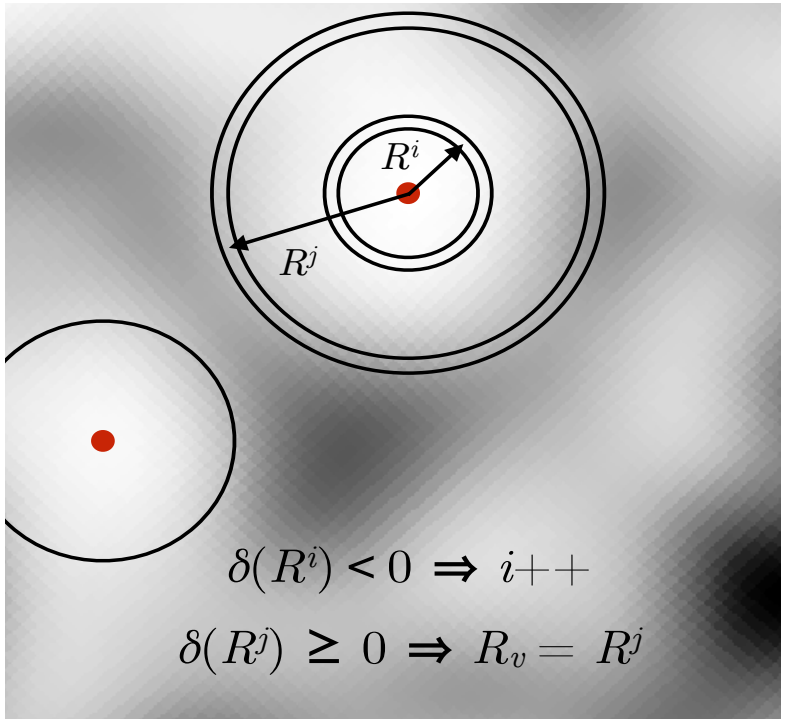


Clampitt & BJ 2015; van Uitert et al 2016; van Uitert & Joachimi 2017; Shin, Clampitt…2017;

Voids in galaxy surveys

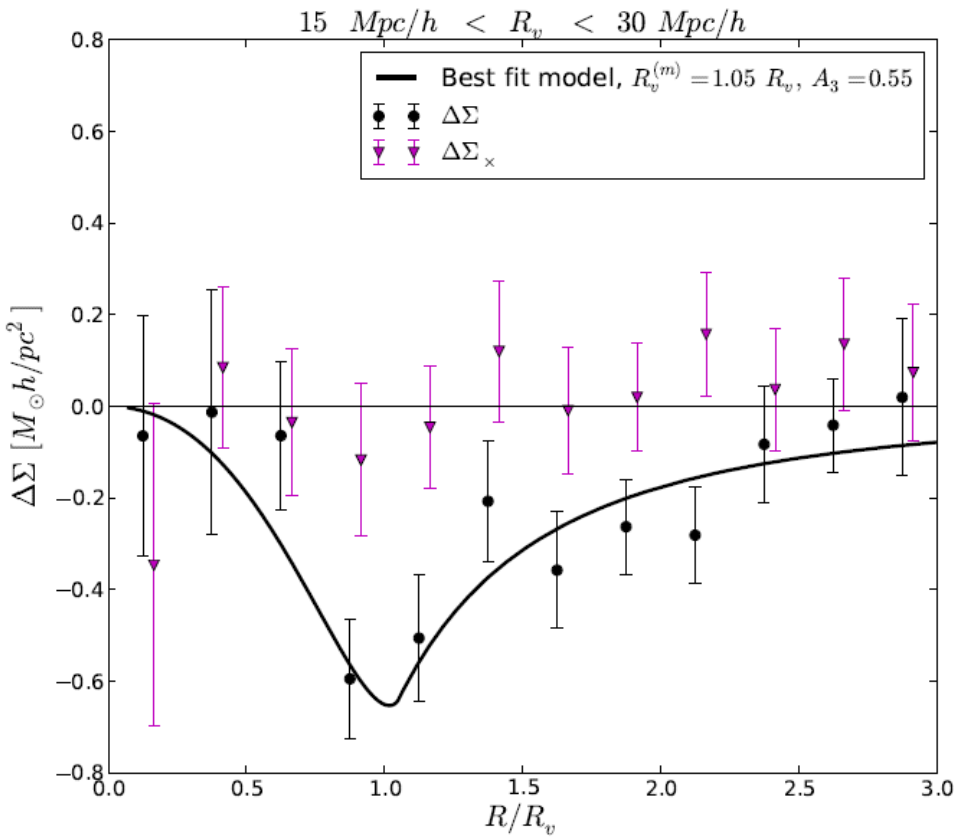


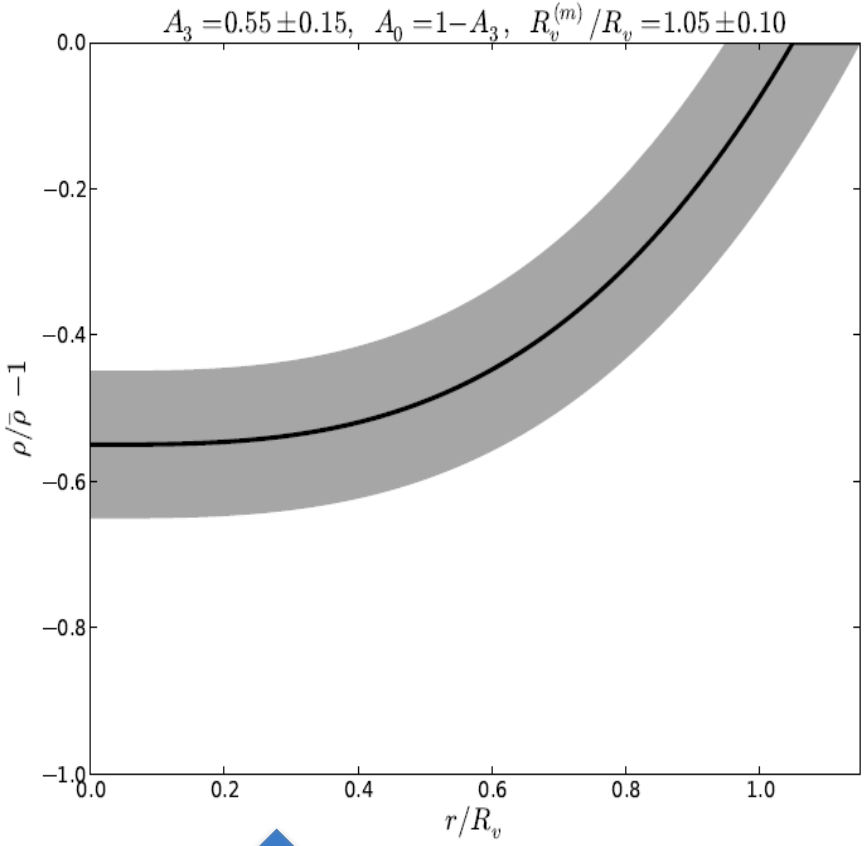
Void finder in SDSS (3D) data
Clampitt and Jain 2014



New void finder for DES imaging data.
Sanchez et al (DES collaboration), 2016

Void lensing



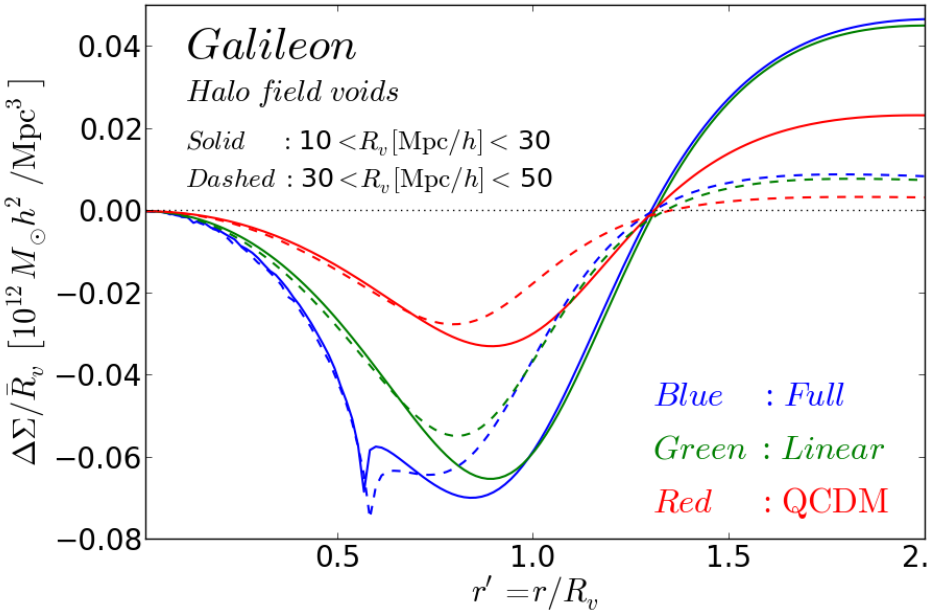


The lensing profile and the inferred 3d density profile of voids.

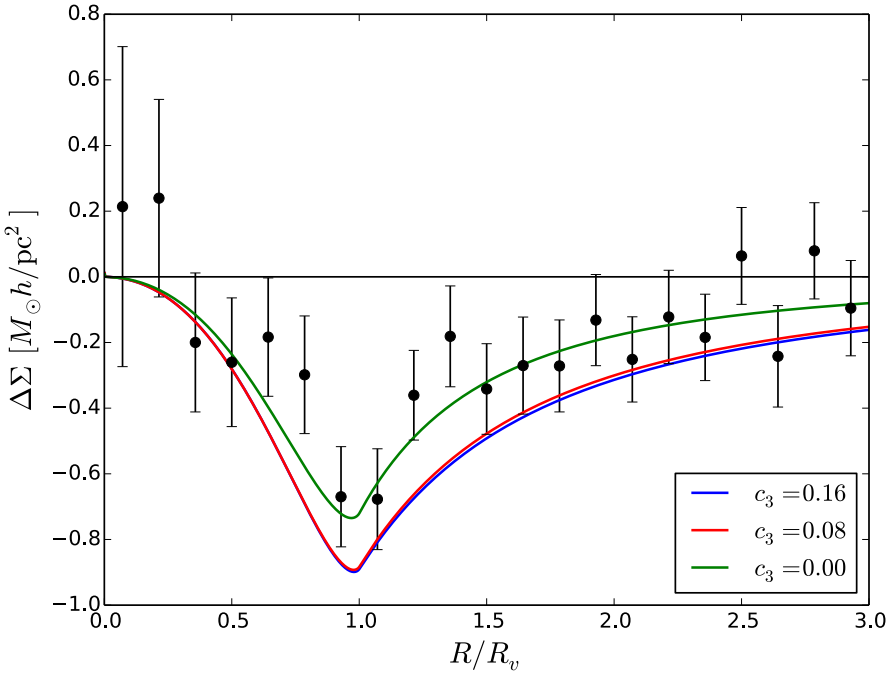
The measured shear signal is at the 0.01% level!

Clampitt and Jain 2014

Voids in modified gravity



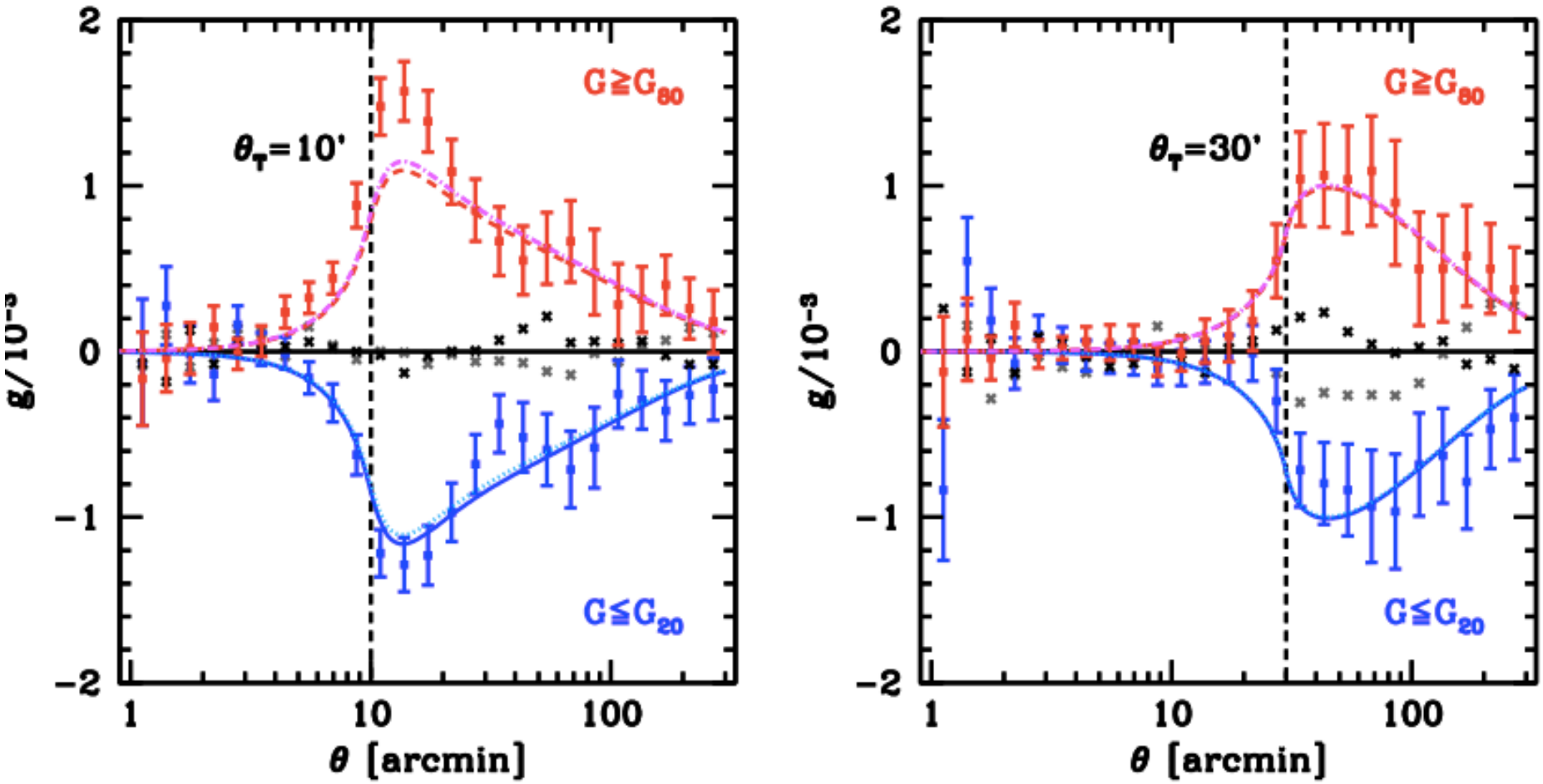
Barreira et al, 2015



In prep, with Baker, Clampitt, Trodden..

The modified gravity signature in voids can be much larger than in halos!

And “troughs”



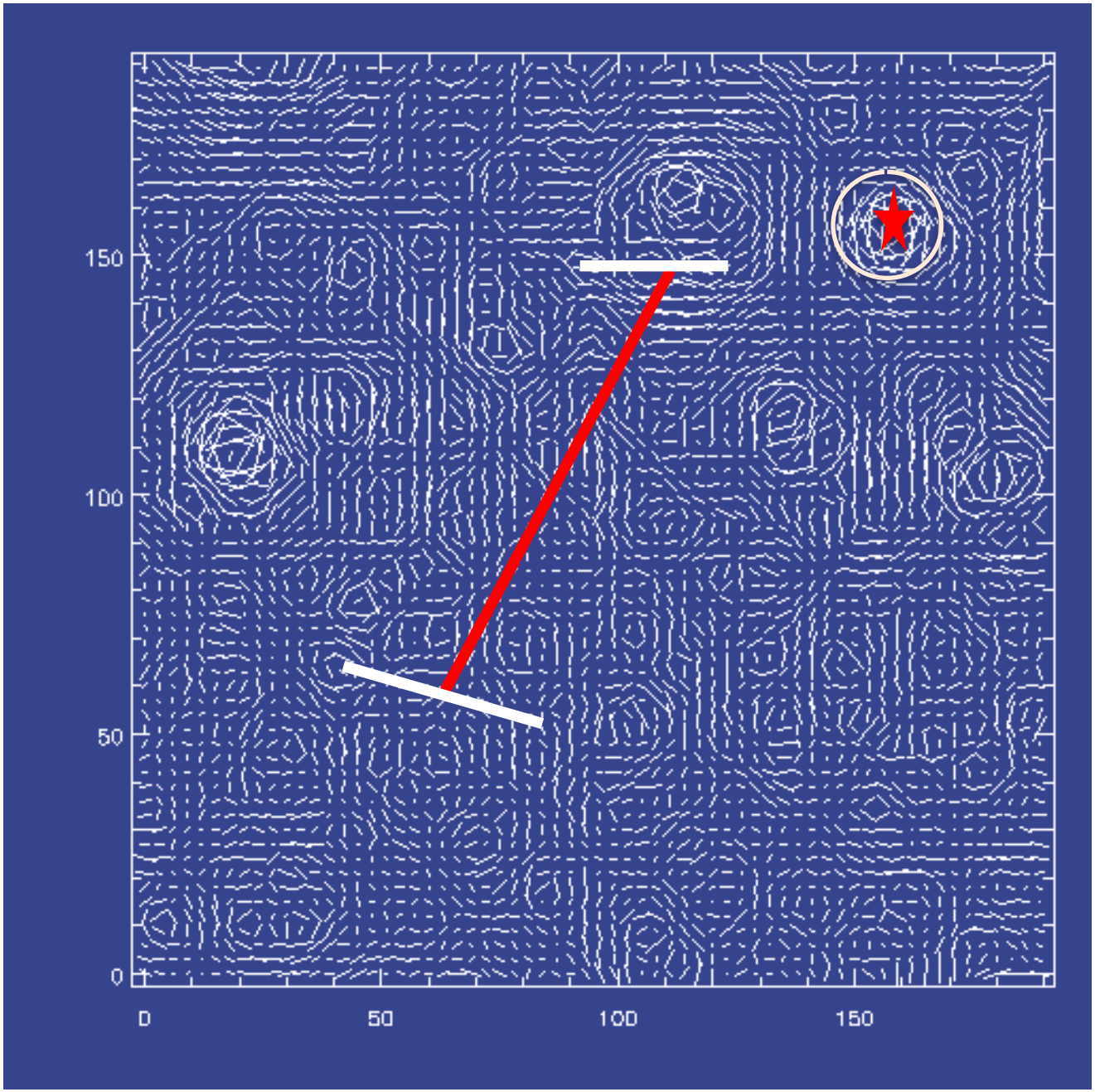
Gruen et al 2015 (DES)

Summary: halos and voids

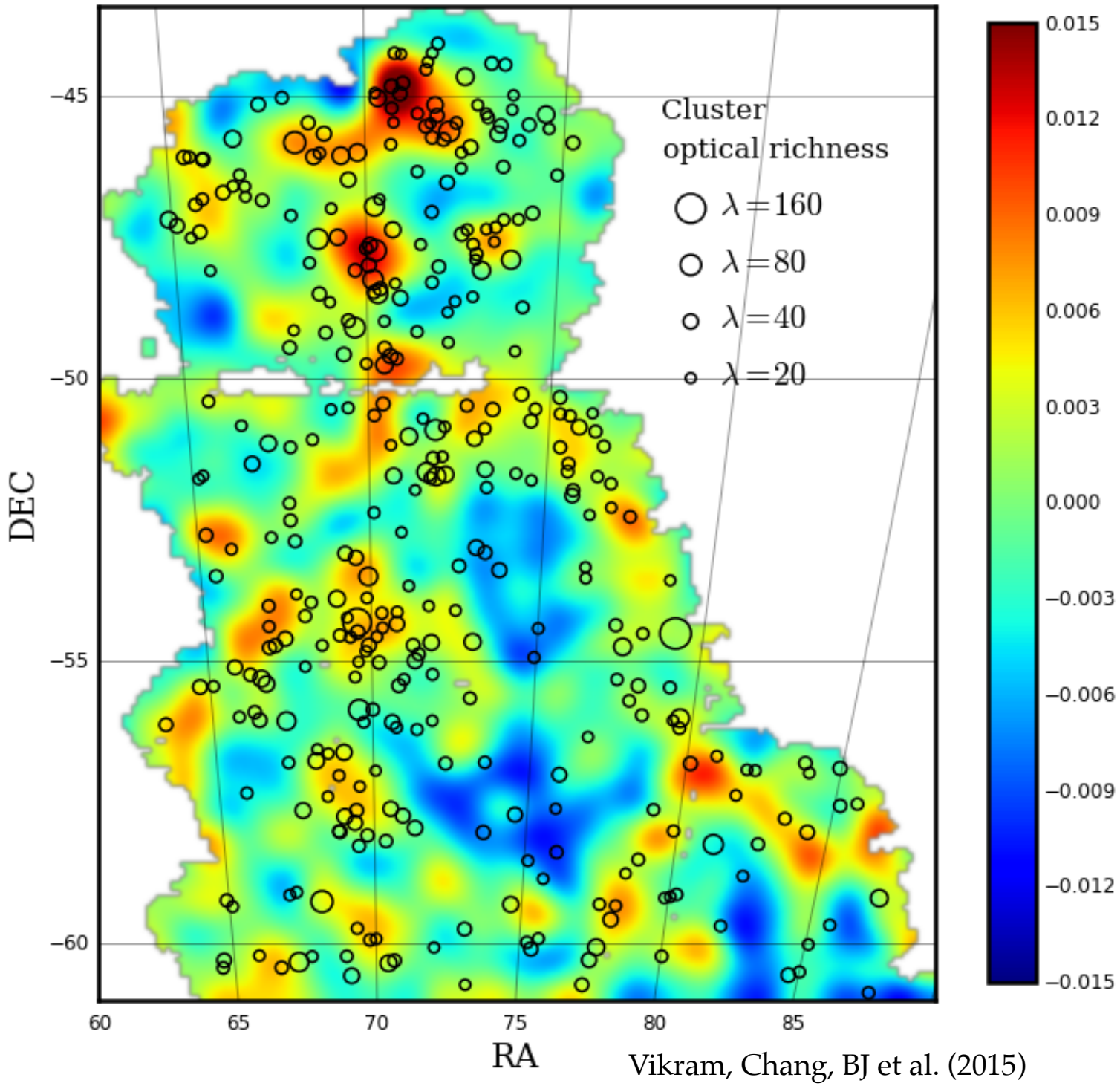
- Halo boundary: detection of the sharp edge of halos
- Halo ellipticity: measurements of how ellipticity changes with radius
- Voids: mass profiles inside voids, and clustering on large-scales

- Applications to galaxy-formation and dark sector interactions!

Shear auto and cross-correlations

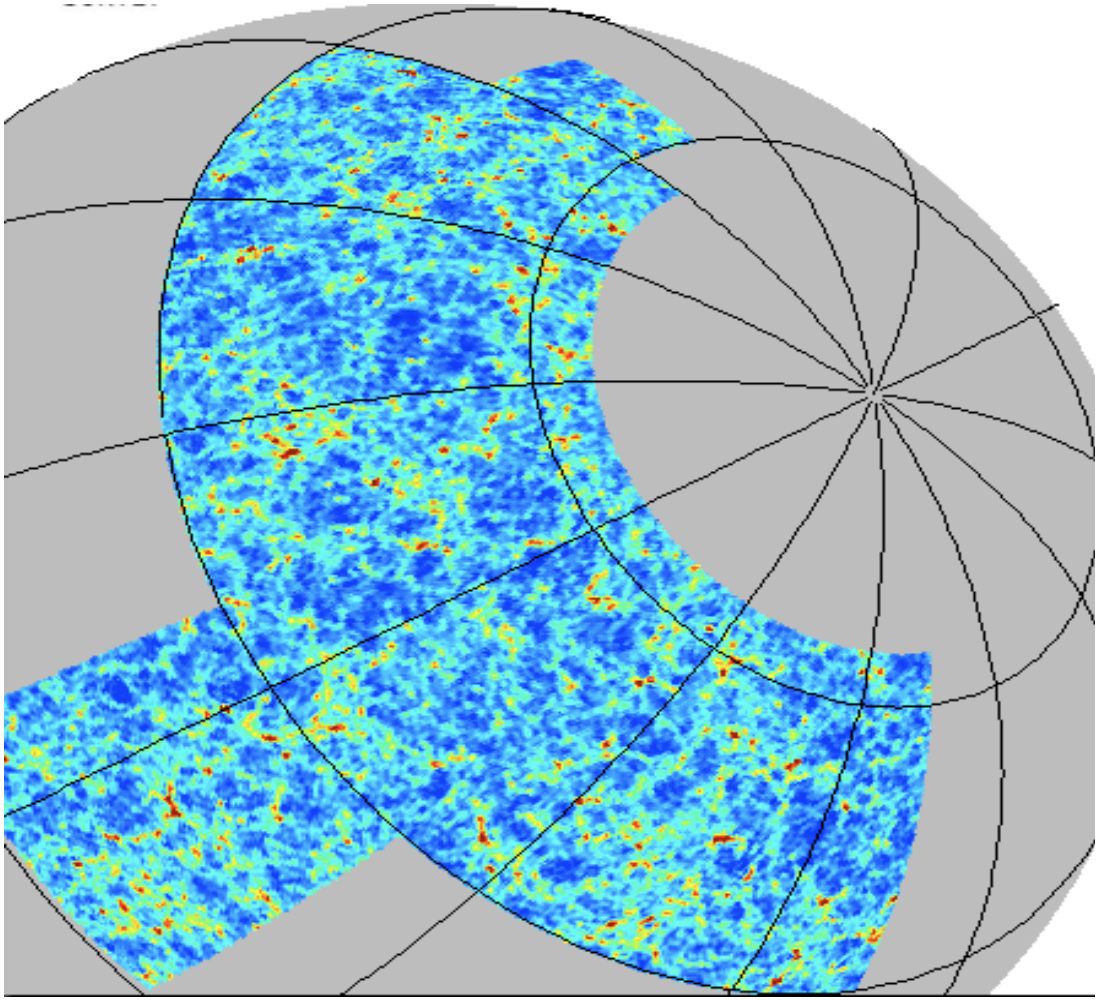


Mass and Light



Vikram, Chang, BJ et al. (2015)

Dark Energy Survey

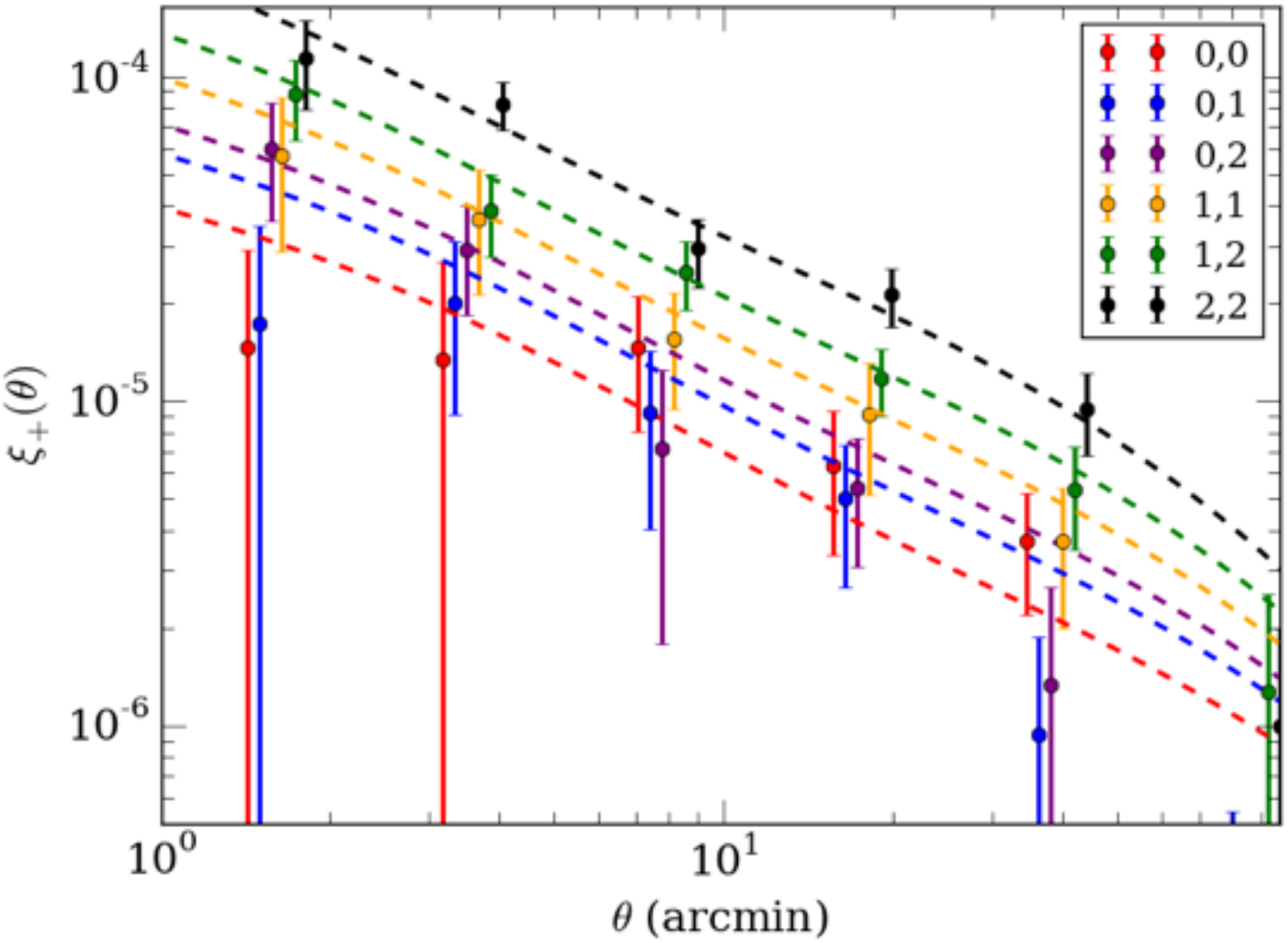


•500 Mpix camera for Cerro Tololo 4-meter telescope

•5-year, 5000-square-degree: 2+ years completed

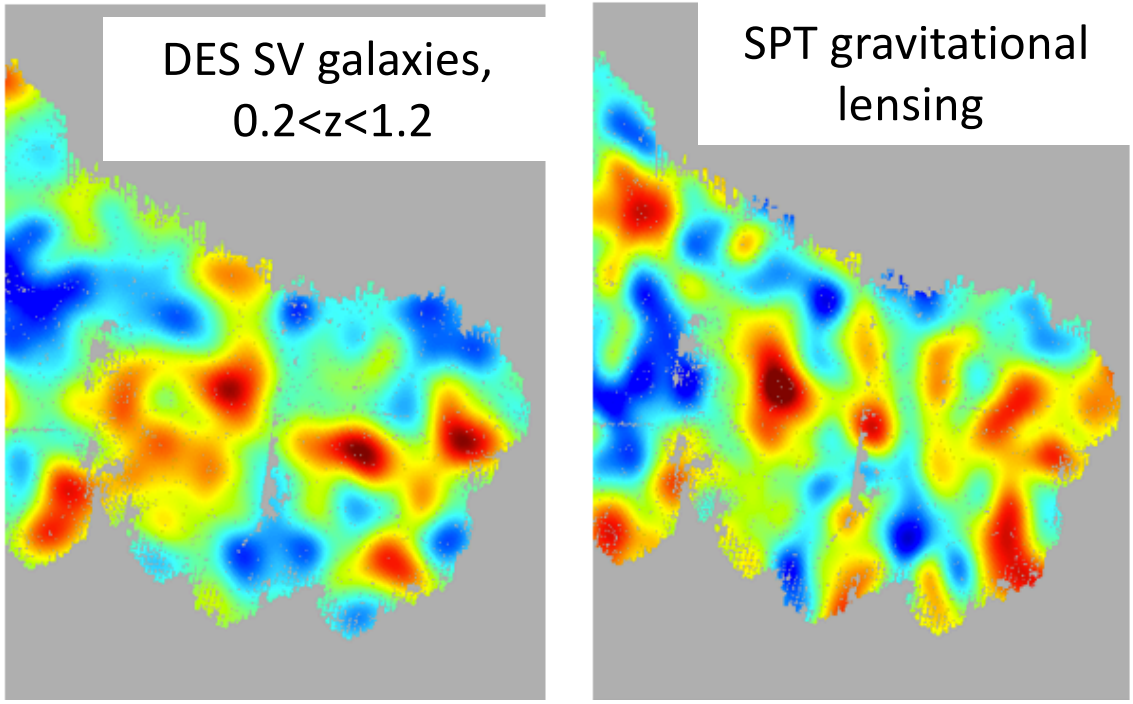
•Designed to overlap with the SPT CMB survey

Cosmic shear tomography



Becker et al 2015 (DES collaboration)

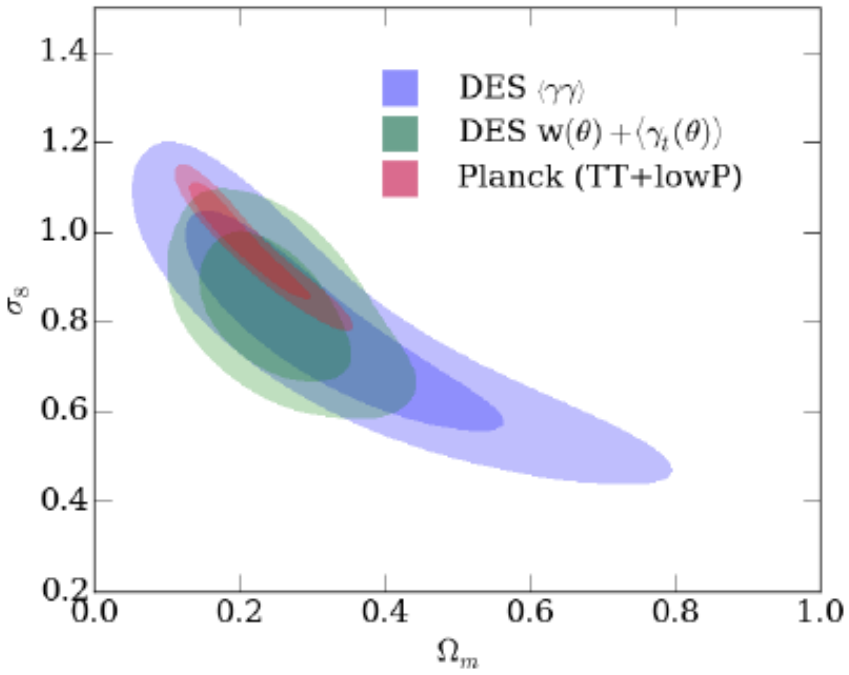
Galaxies x CMB



Giannantonio et al 2015; Saro et al 2015; Kirk et al 2016; Baxter et al 2016

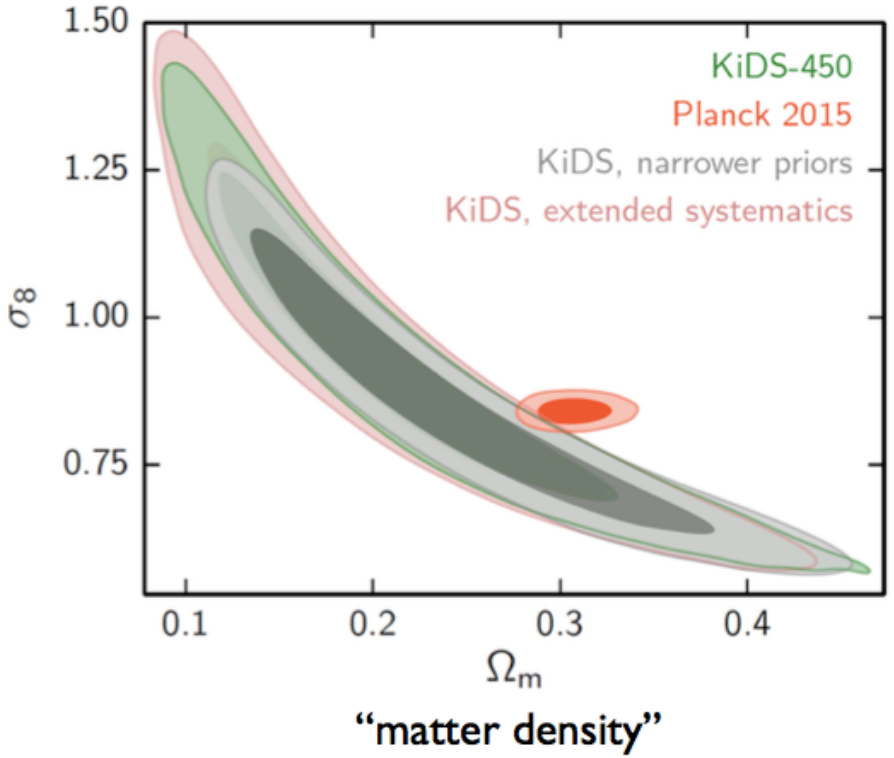
Galaxy clustering + Lensing

wCDM



LambdaCDM

Joudaki et al 2016



"matter density"

Constraints on the amplitude of mass fluctuations; see Pedro Ferreira's talk.

Kwan et al, DES Collaboration 2016; Cacciato et al 2012; van den Bosch et al 2012; Mandelbaum et al 2012; Joudaki, Mead et al 2016; Hildebrandt et al 2016

New analyses with DES are underway….including the impact of massive neutrinos

Where should we look?

- Precision cosmology on large scales can test few percent deviations in the coming years
- Much larger deviations can occur on small scales
- Astrophysical tests range from individual stars and black holes to huge cosmic voids
- Possible themes are:
  - Screening
  - Violations of the equivalence principle
  - Lensing vs dynamics