Probing dark matter halo shapes using weak gravitational lensing

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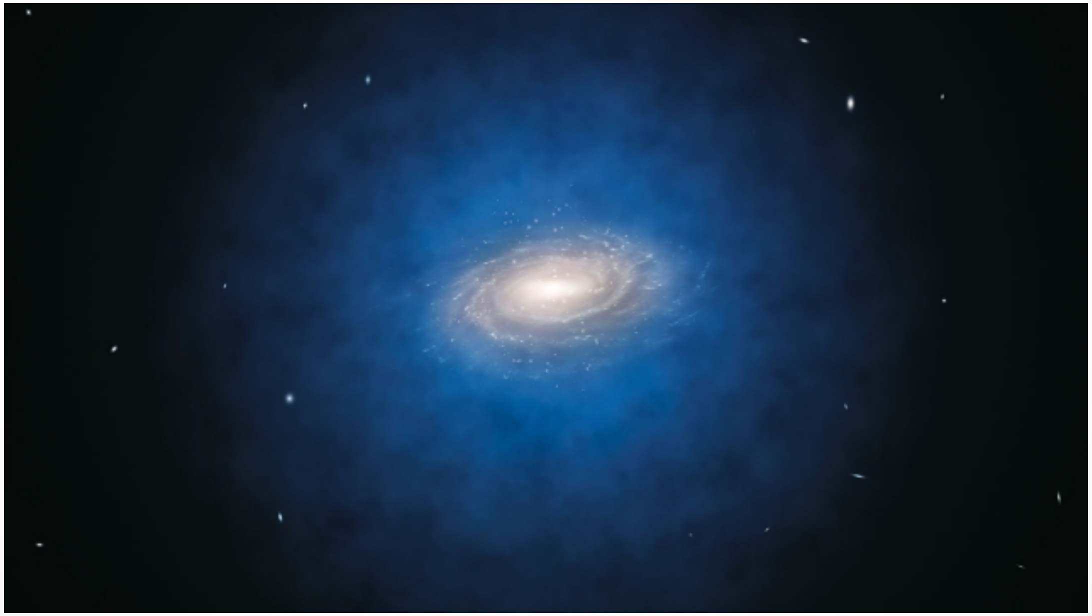
Adhikari, Chue & Dalal (2015)

Cosmology on Safari (Jan 28, 2015)

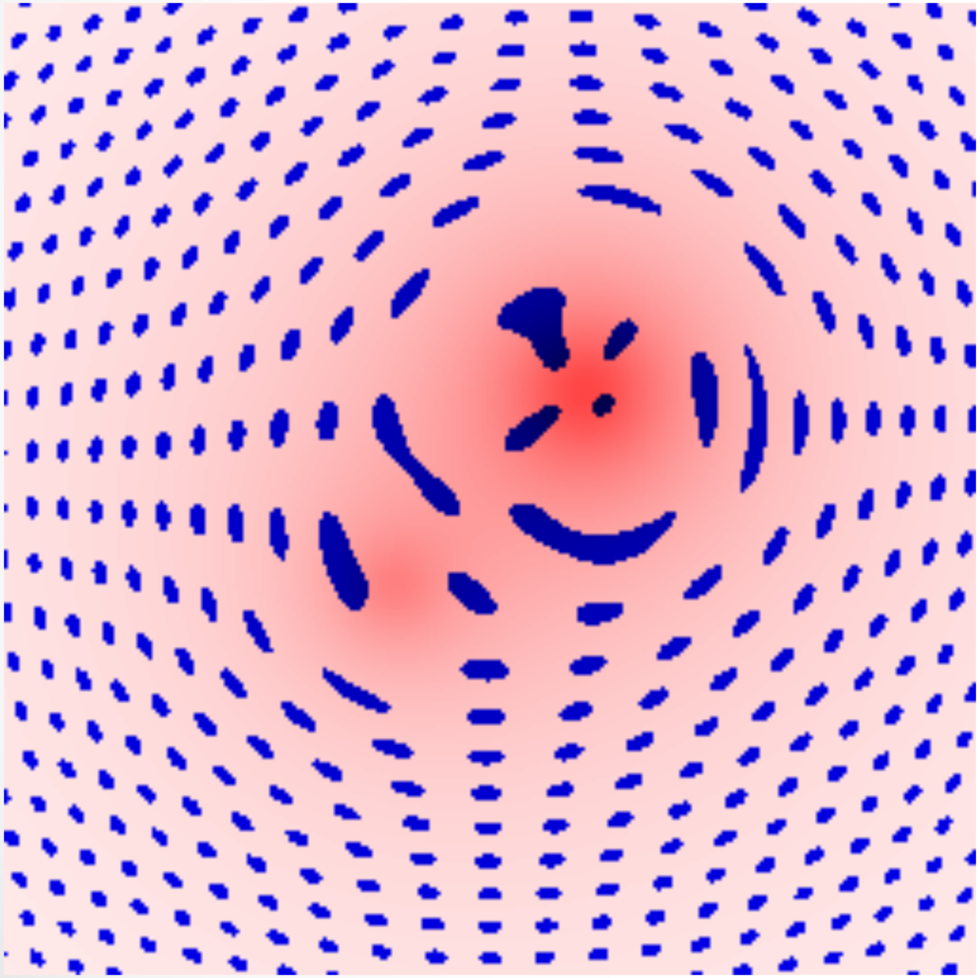
Dark matter halos

- **Prediction from N-body simulations.**
  - ✓ **Λ-CDM model** (Jing & Suto, 2002, Allgood et al., 2006)
    - Axis-ratio ~ 0.5:1
  - ✓ **Self-interacting DM** (Rocha et al., 2013, Peter et al., 2013, Dave et al., 2001)
    - Axis-ratio ~ 0.9:1



How to probe?

- **Gravitational lensing!**



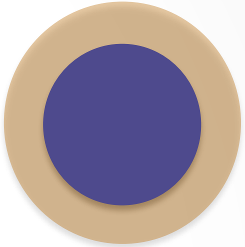


Image magnified

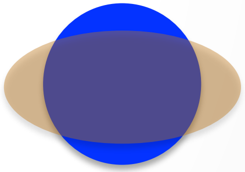
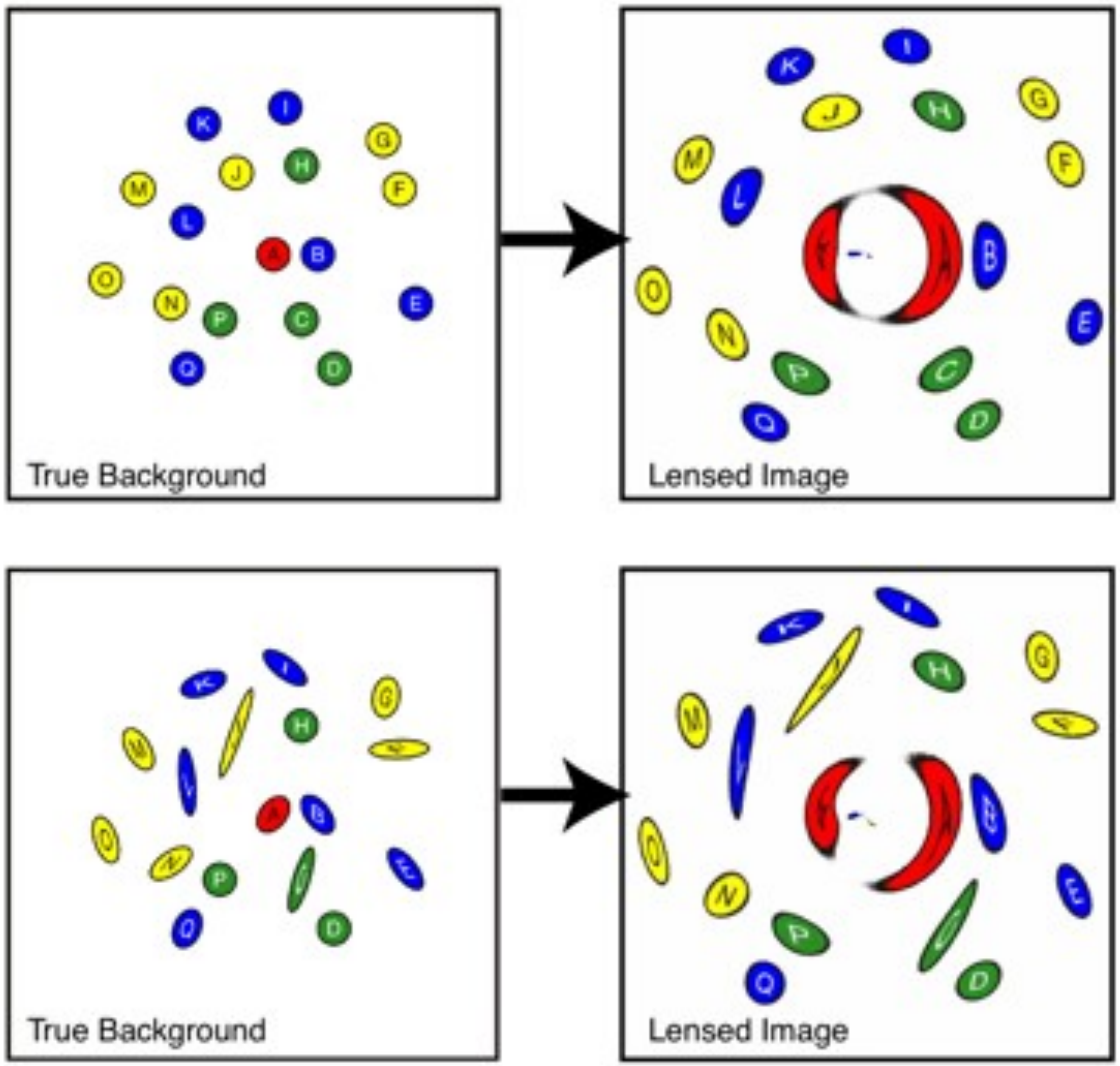


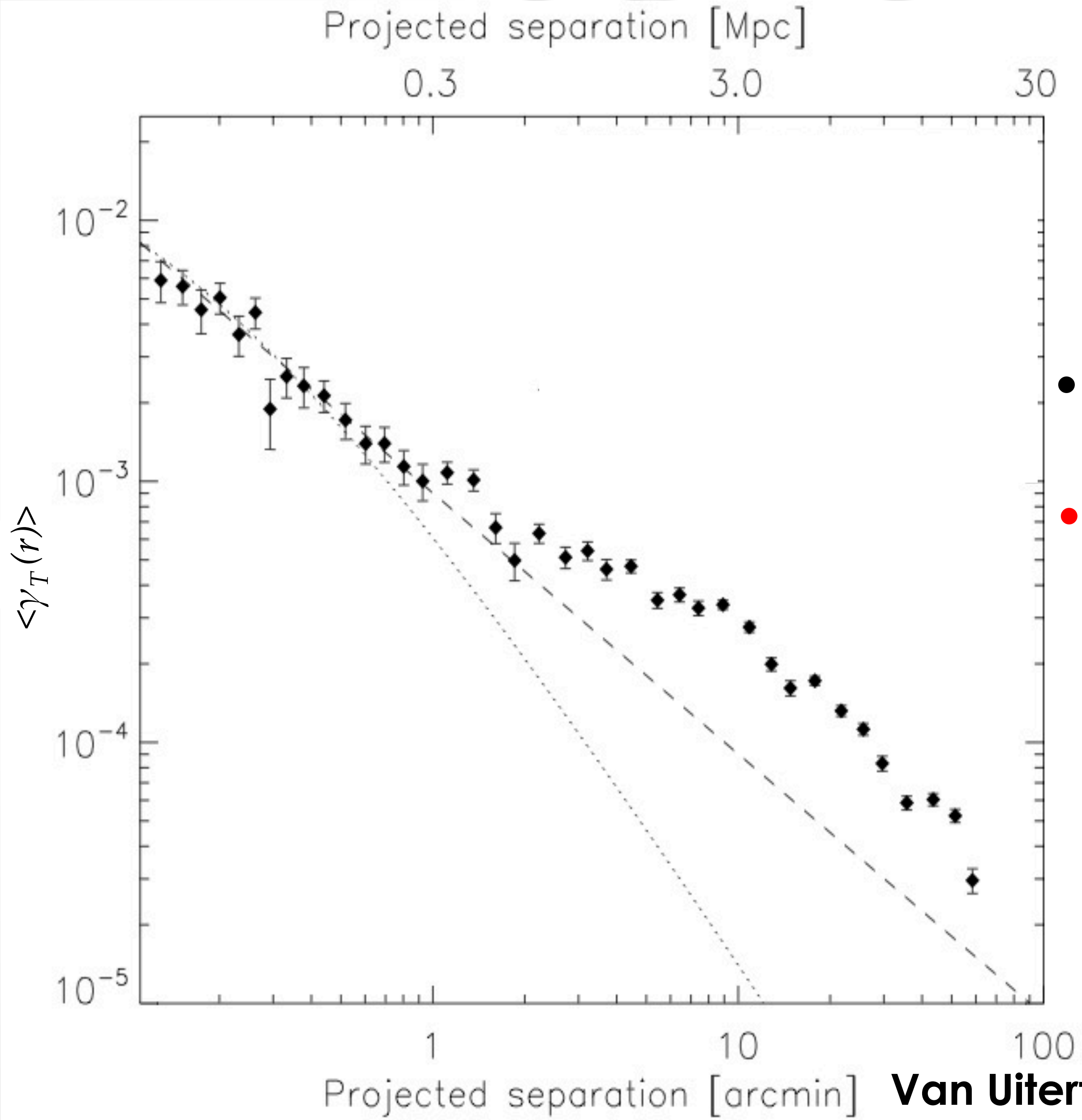
Image distorted (Shear, γ)

Image: http://www.astro.ucla.edu/~wright/cluster-lensing.html



- **Shear signal by weak lensing is sub-dominant to shape noise.**

Galaxy-galaxy lensing



- $<\gamma_T(r)>$ ➔ M(r)
- **Interested in azimuthal behavior of shear!**

Van Uitert et. al. (2011)

How to stack?

- **DM orientations unknown (they are DARK!)**
- **Galaxies are bright, align galaxies.**

(Hoekstra et al., 2004, Mandelbaum et al., 2005)

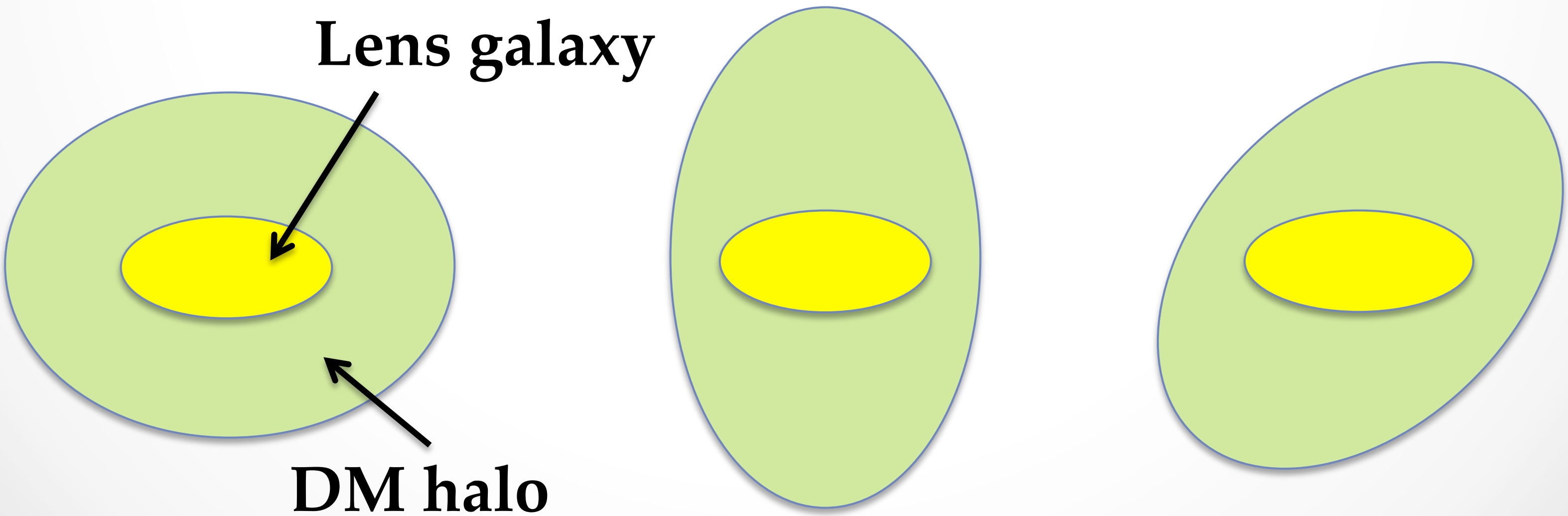
How well does it work?

- Results from previous work are inconclusive.
  - ✓ Prolate, oblate, or spherical halos?
  - ✓ ~50% uncertainty with ellipticity estimates.

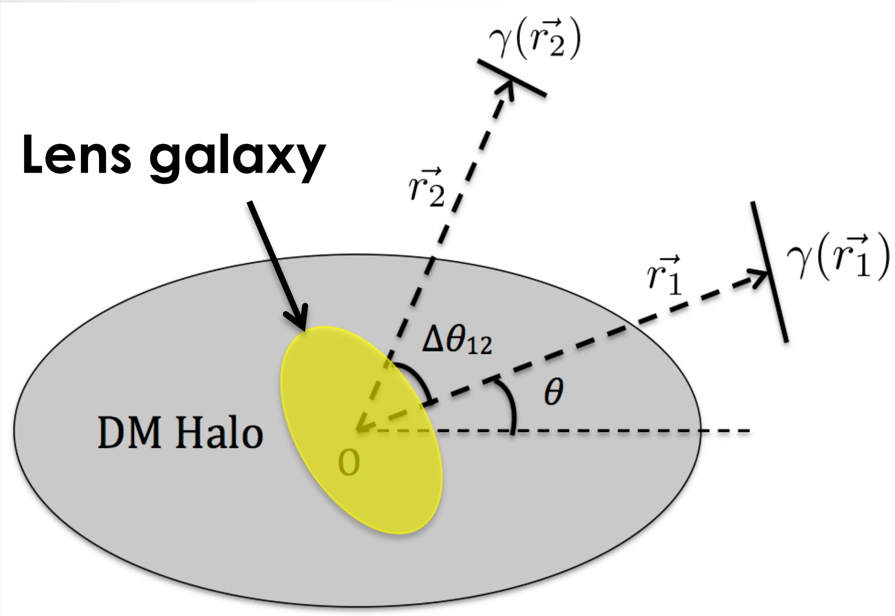
    (van Uitert et. al. 2012)

Possible problem

- P. Bett (2012) showed by simulation that misalignment is typical, median ~38°.
- Misalignment washes out anisotropic shear signal.



Lens-shear-shear 3-pt function



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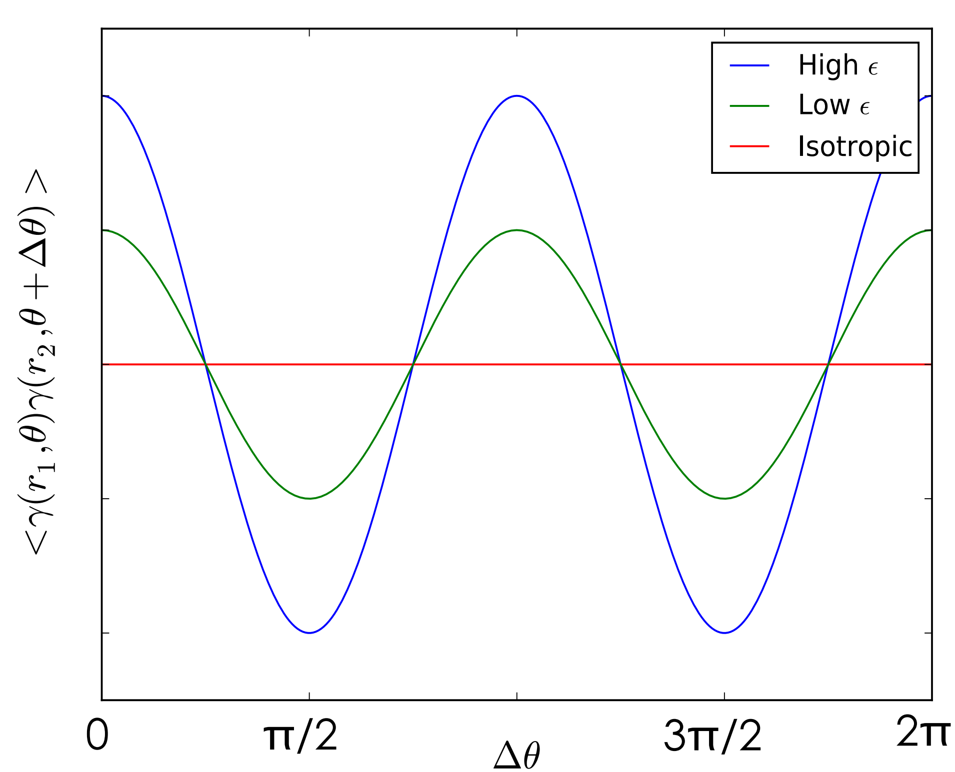
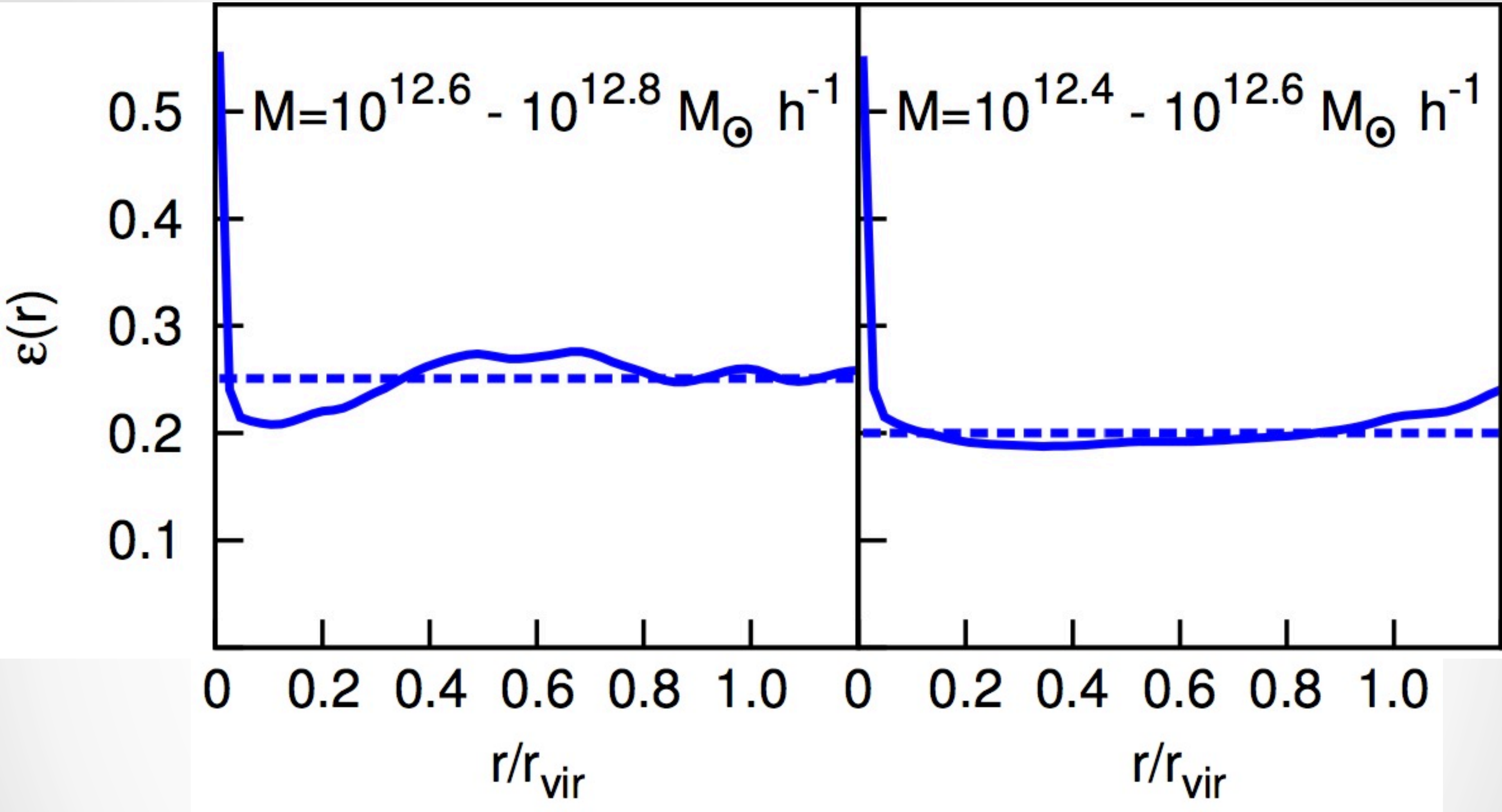


Ellipticity Estimator:

$$\langle \gamma(\vec{r_1}) \cdot F(r_1, r_2, \Delta\theta_{12}) \cdot \gamma(\vec{r_2}) \rangle$$



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- **Λ-CDM and self-interacting DM yield different ellipticities.**

Systematics

- Individual halos may have radial profiles vary from the mean. (~5% fractional bias)
- Contamination from projections of other halos.
  - ✓ Uncorrelated objects along line of sight.
    - ➢ Stack random sky points and subtract it away.
  - ✓ Galaxies that are correlated with the lenses.
    - ➢ Stack halos that are relatively isolated.

Conclusions

- **DM halo shape as a probe on DM physics.**
- **Lens-shear-shear 3-point function proved to be a better method than 2-point function.**
  - ✓ **Our 3pt correlator is immune to galaxy-halo misalignment.**

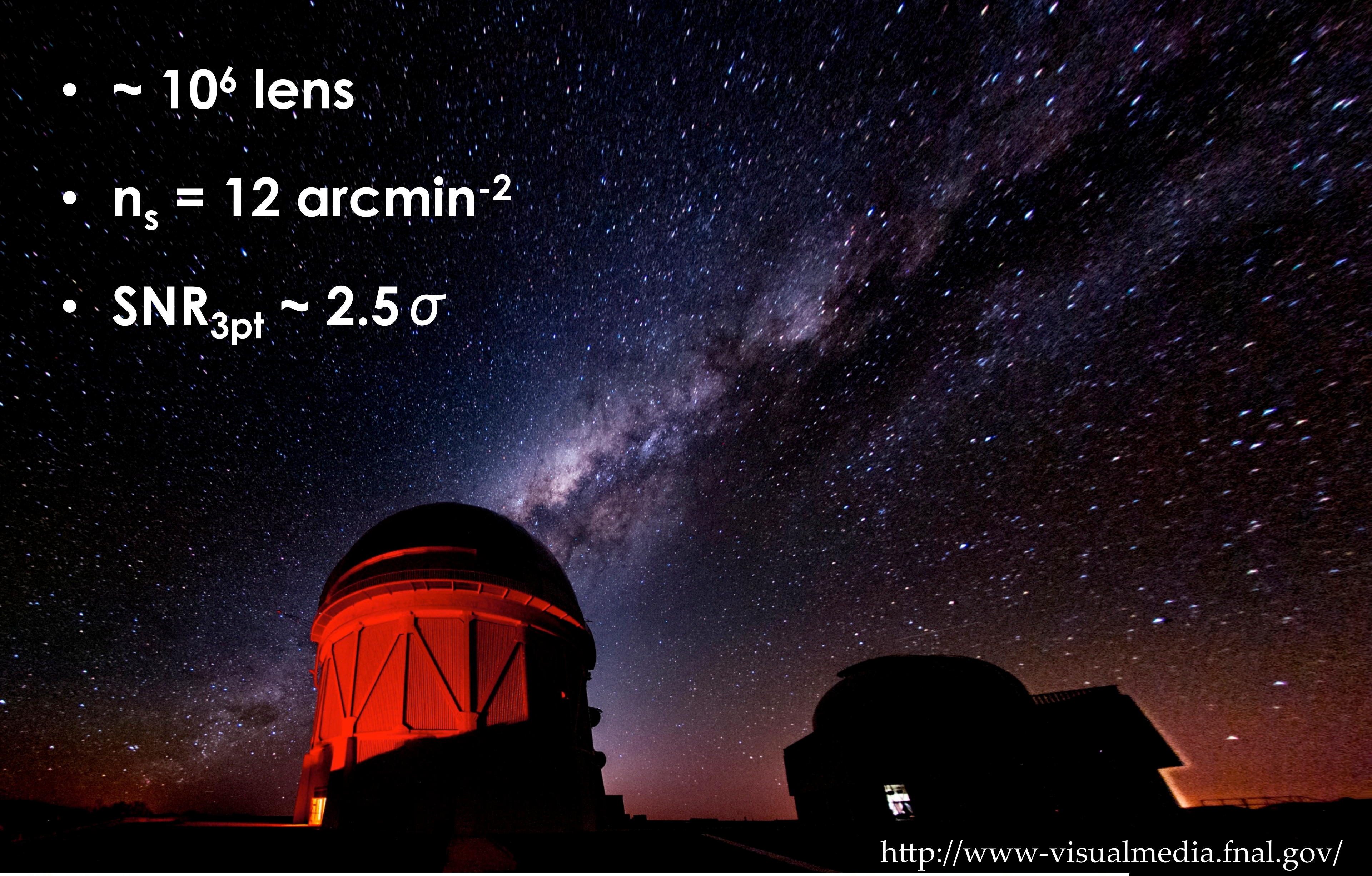
How well does it work?

- 3-pt has lower SNR than 2-pt per lens.
  - ✓ Correlating 2 shears instead of 1.

BUT!

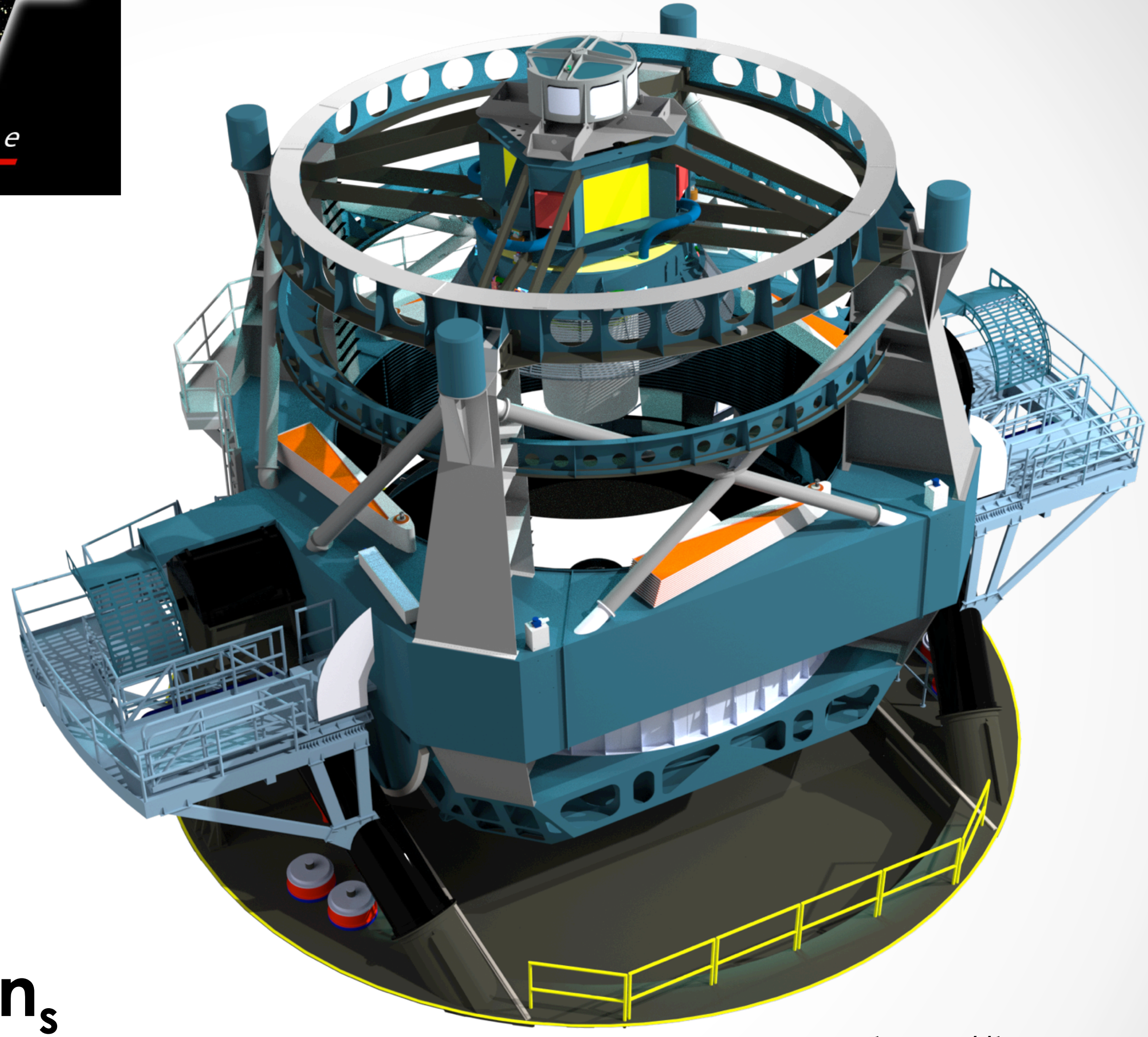
Fortunately,

- ~ 10^6 lens
- n_s = 12 arcmin^{-2}
- $\text{SNR}_{3pt} \sim 2.5\sigma$



THE DARK ENERGY SURVEY

NCSA



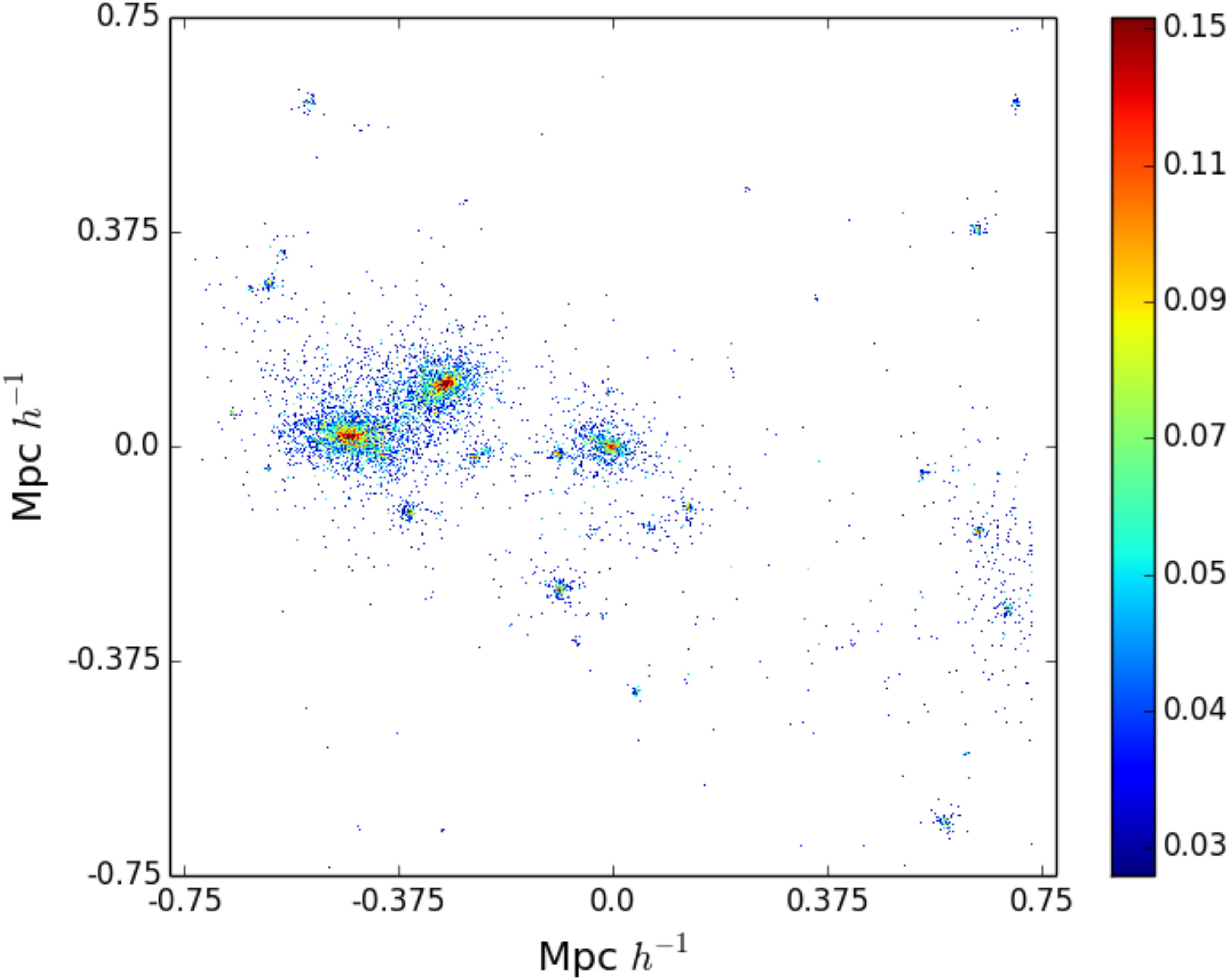
- **Doubling n_s**
- **Able to double SNR_{3pt}.**

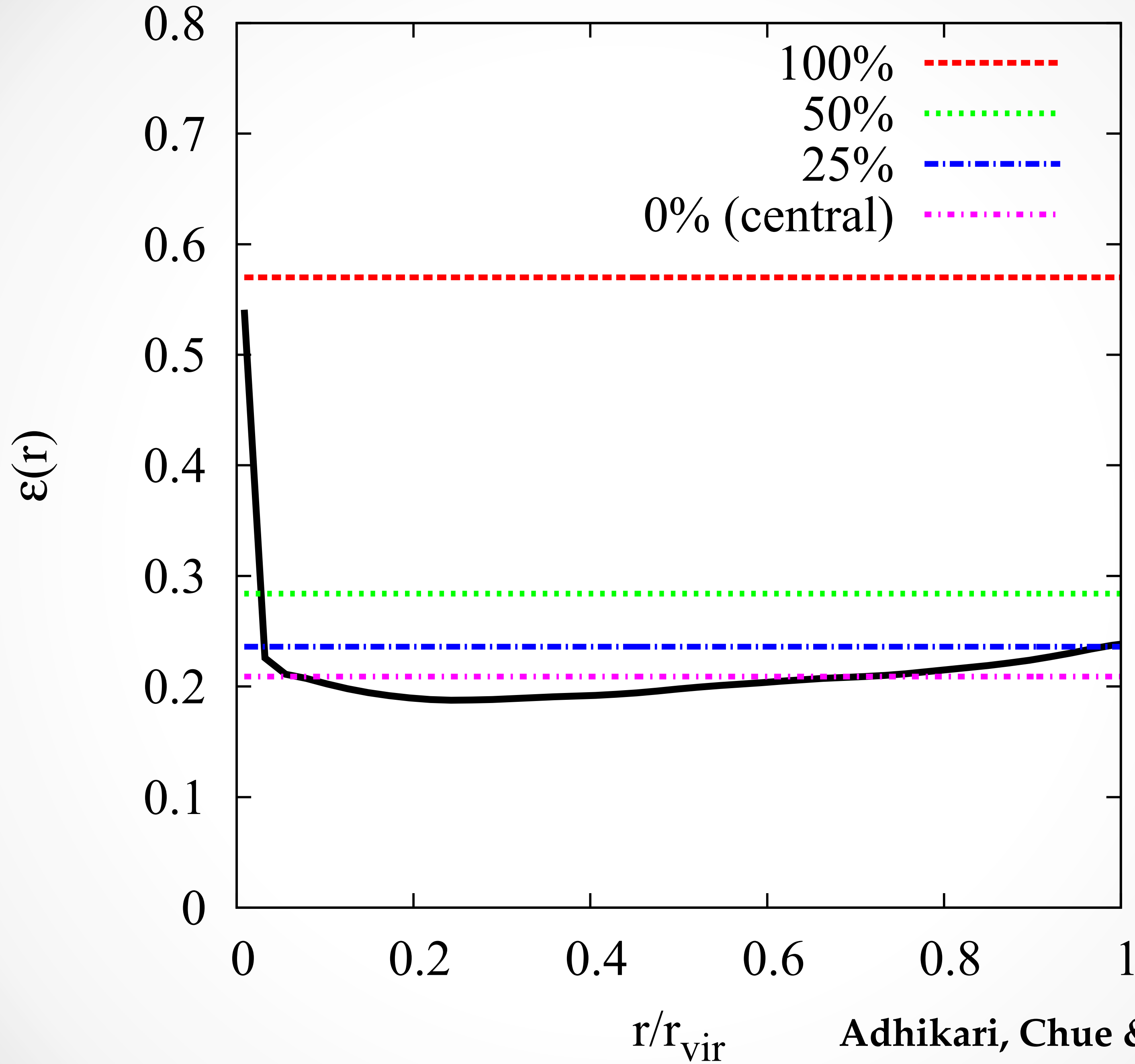
http://lsst.org

Drawbacks of 2-pt function

- Results from previous work are inconclusive.
  - ✓ Prolate, oblate, or spherical halos?
  - ✓ ~50% uncertainty with ellipticity estimates. (van Uitert et. al. 2012)
  - ✓ No idea about orientations of halos.
- Need a new method to probe halo shapes.

Adhikari, Chue & Dalal (2015)





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Systematic errors

- If PSF is uniformly anisotropic across virial radius of the halo, it may mimic the signal.
  - ✓ Stack random points, if PSF signal does not correlate strongly with number density of lens.
- Systematic alignment between source galaxies in same local environment due to long range tidal effects.
  - ✓ Exclude galaxy pairs with similar redshifts.
  - ✓ Error exceedingly small shown in SDSS.

Other systematic errors

- Contamination by nearby halos.
  - ✓ Galaxy auto-correlation function goes with r^{-2} in 3D.
  - ✓ Extracted particles out to $5r_{vir}$, have accounted for ~80% of correlated objects.
- Error in photo-z's.
  - ✓ ≤ 1% for modern surveys.
- Effect of baryons
  - ✓ Restrict limits of estimations. Set r_{min} to larger scales.

Other systematic errors

- ‘Twisting’ of halos.
  - ✓ Principal axes of isodensity surfaces are not constant with radius.
  - ✓ 10% biases when twisted by π radians.
  - ✓ Simulations show typical twists $\leq \pi/6$ radians.
- Magnification of lenses by foreground matter.
  - ✓ Third-order correlation error $< 10^{-7}$.