DARK ENERGY SURVEY

# Towards observing the imprint of dynamical dark matter interactions within galaxy clusters

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# ΛCDM

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**Λ:** Dark energy properties and other parameters we can constrain from **large scale cosmological analyses**

**CDM:** The cold dark matter paradigm can be tested from small scale observations, **the non-linear evolution of the density field**

# ΛCDM

**Λ: Cluster cosmology**, through the halo mass function, requires cluster finder number counts, and weak lensing mass calibration

**CDM: Cluster Substructure: tidal stripping, subhalo lensing**

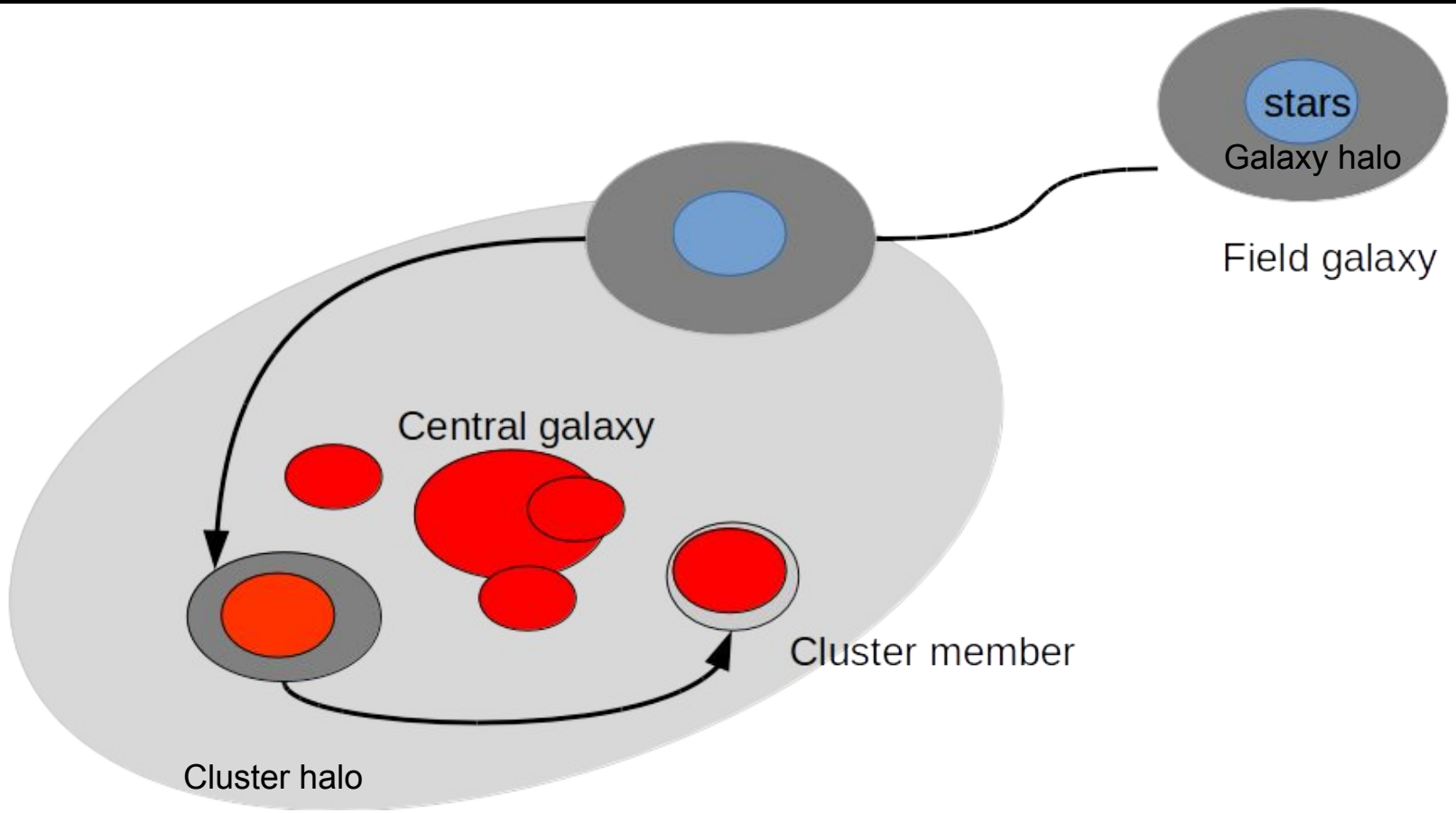
**Cold, warm, hot dark matter?**

**Fuzzy dark matter?**

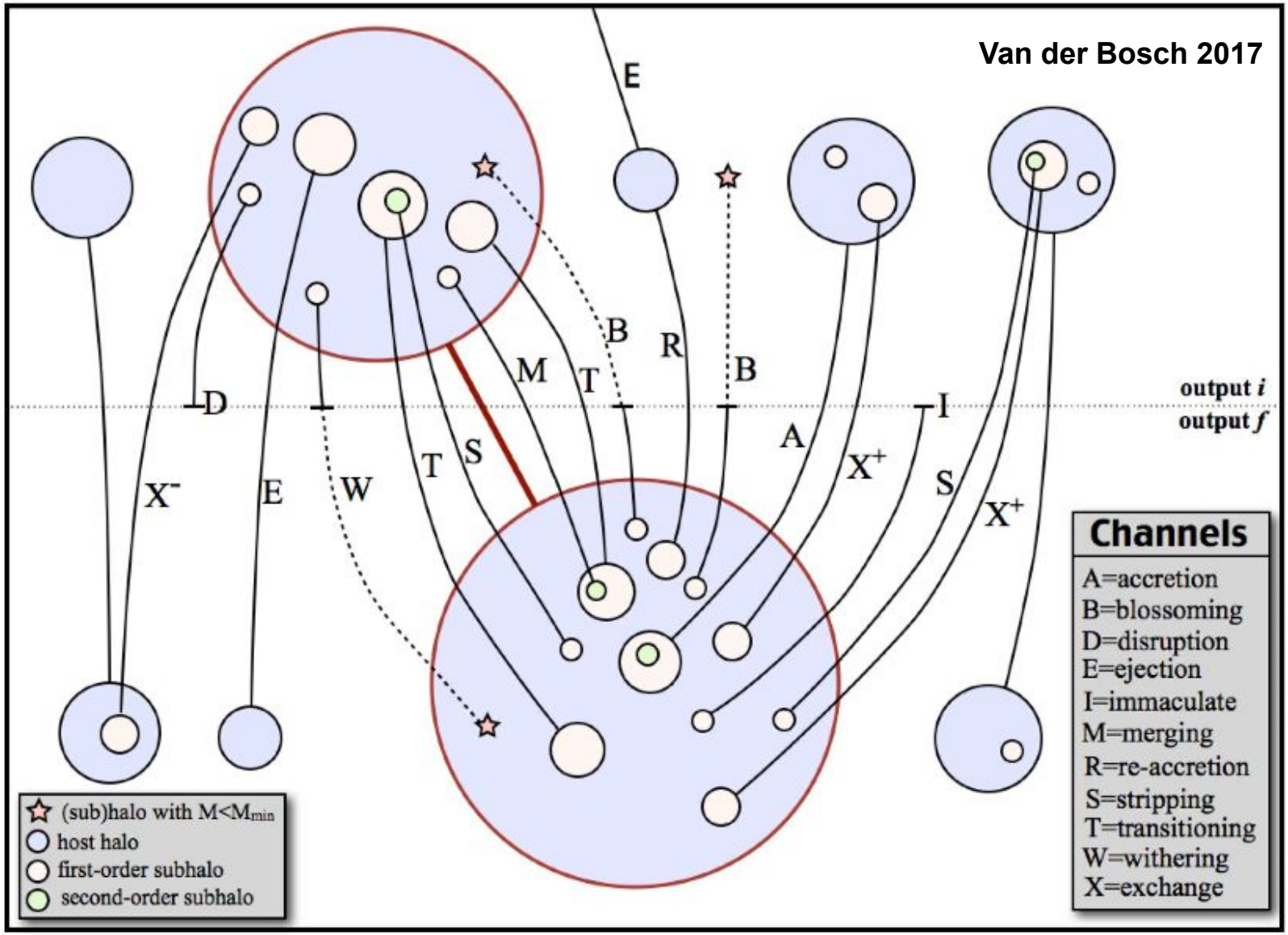
**Self interaction?**

**...**

# Cartoon version of what we are targeting

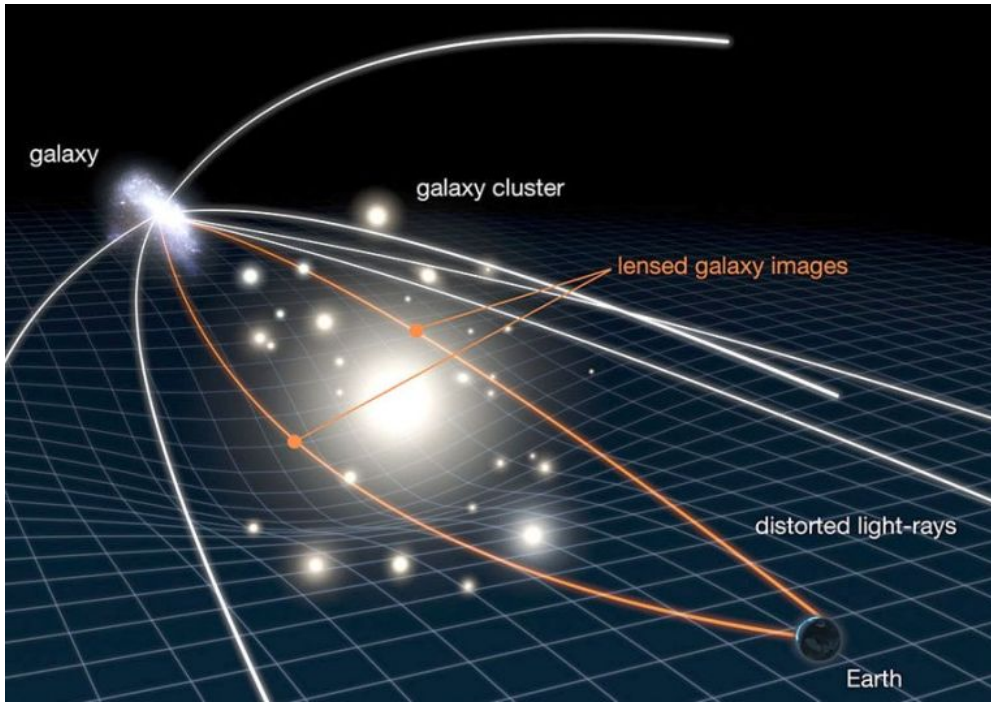


# In simulations the picture is a little bit more complicated ...



# Recap on Weak Gravitational lensing

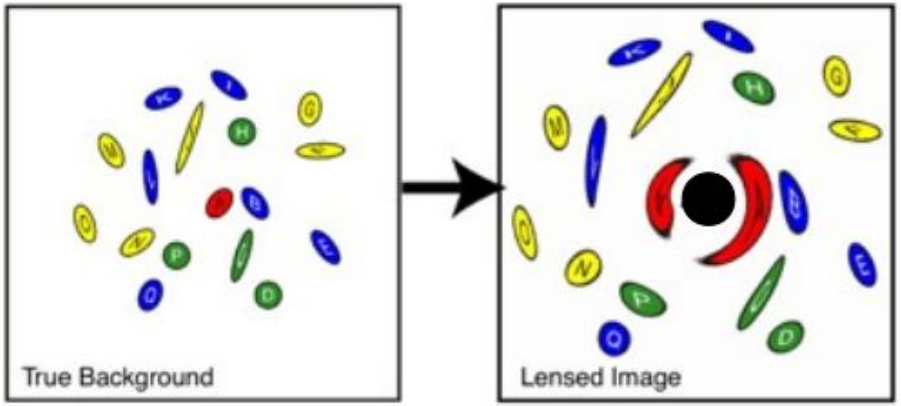
- The light from background "sources" is deflected by the gravitational potential of objects along the line of sight
- Gravitational shear ~ anisotropic shape distortion of background galaxies
- The mass properties of the "lens" can be reconstructed by tracking these image distortions



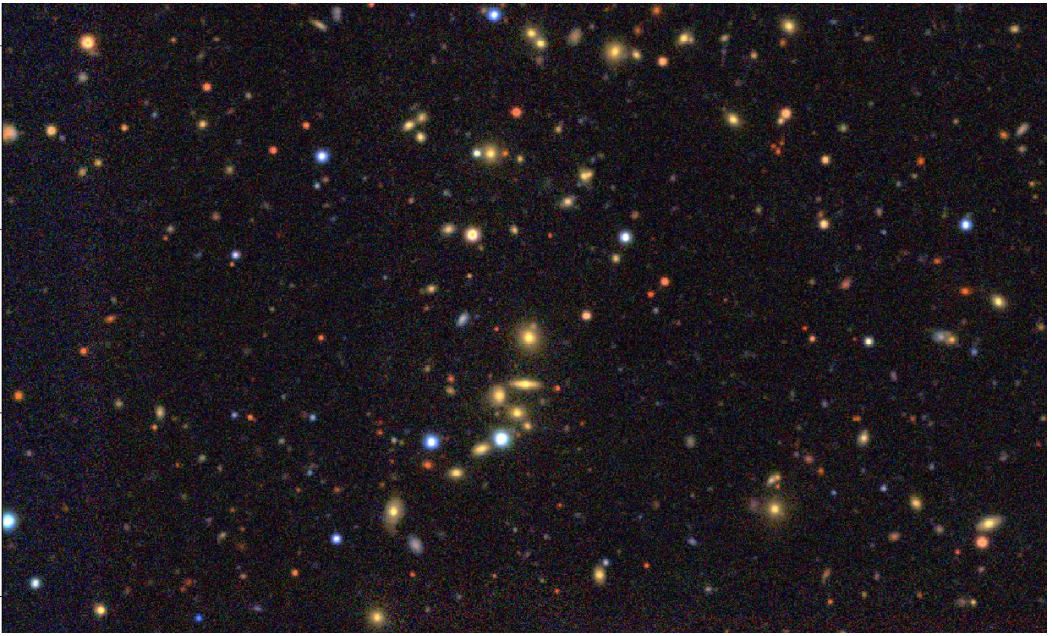

**Excess Surface Mass Density**

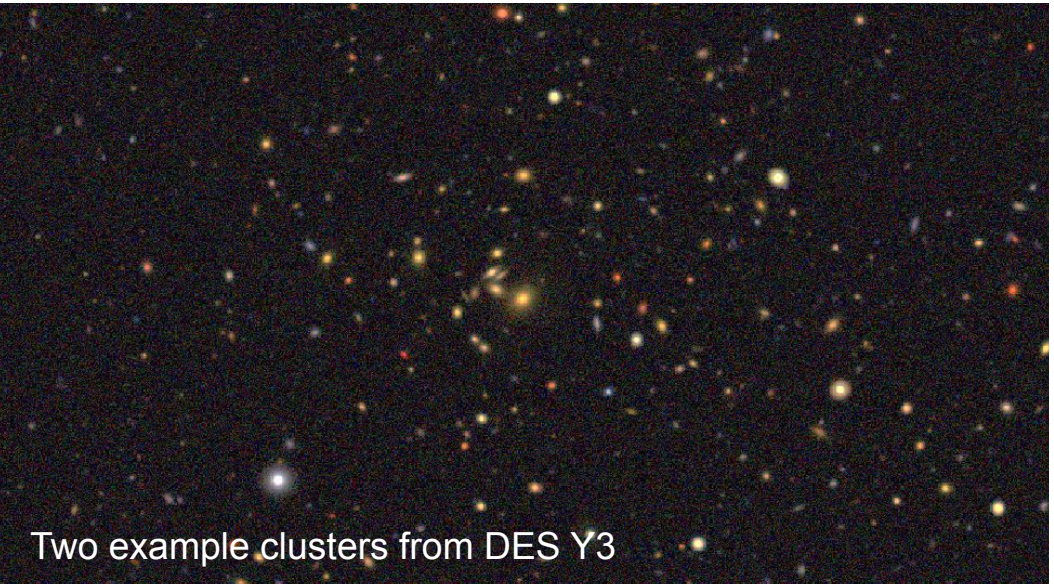
$$\Delta\Sigma \equiv \overline{\Sigma}(<R) - \overline{\Sigma}(R) = \Sigma_{\rm crit}\,\gamma^{\rm T}(R),$$

**Tangential shear**



# Observational scenario in the Dark Energy Survey





Two example clusters from DES Y3

**From similar images we extract:**

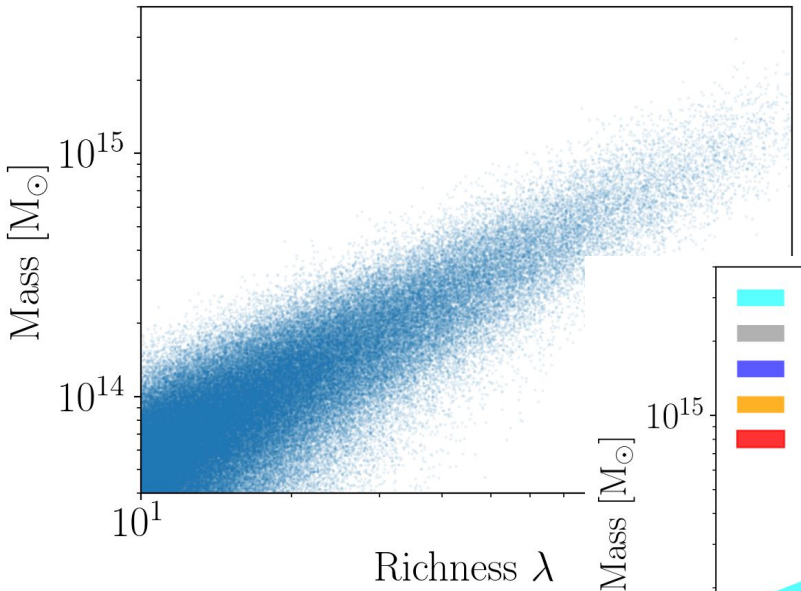
- **Galaxy catalog**
- **Galaxy Shapes**
- **Photometric Redshifts**
- **Galaxy Clusters**

*DES collaboration et al in prep*
*Varga et al. in prep*

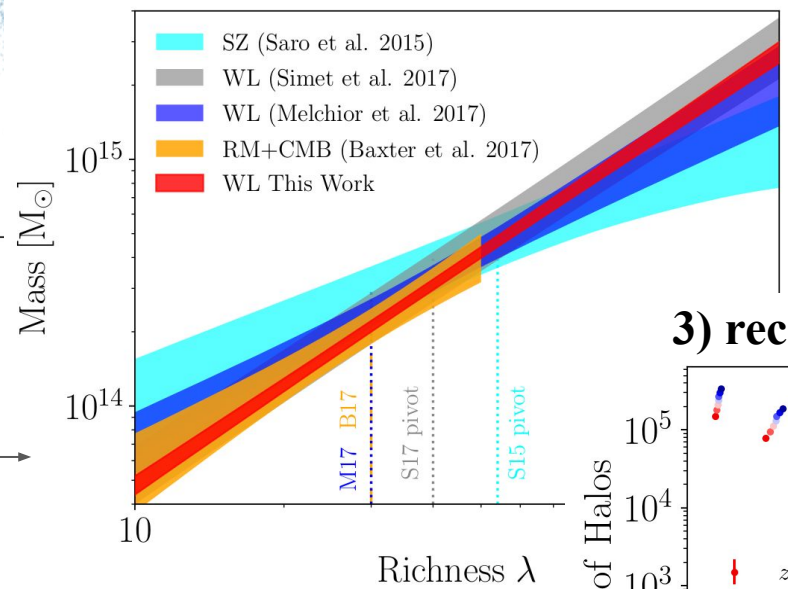
# Traditional WL science driver: Cluster cosmology

**1) Find clusters in nature by mass proxy**

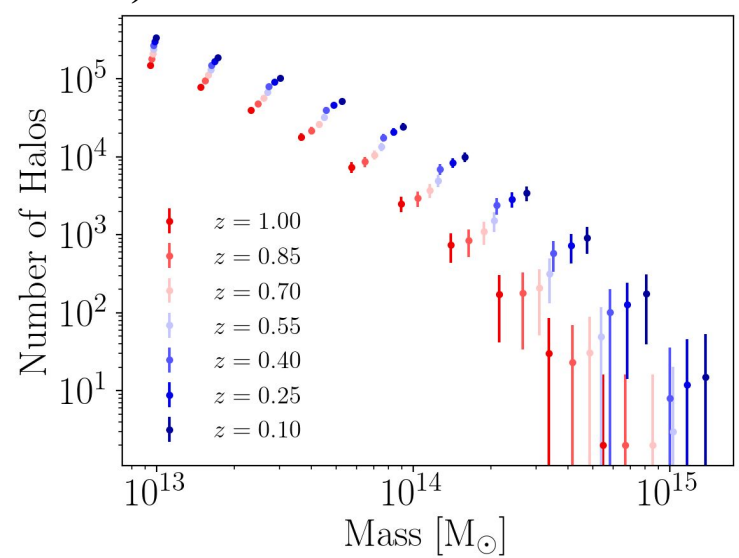
DES collaboration et al in prep
Costanzi et al 2019
McClintock & Varga et al 2019
Varga et al 2019
Zhang et al 2019




**2) calibrate masses from WL**

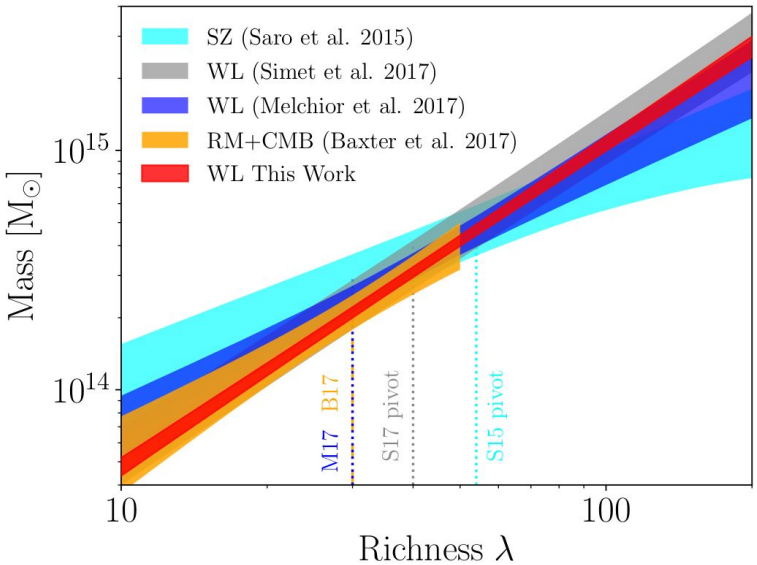



**3) recover halo mass function**




**We can constrain cosmology through the halo mass function...**

# DES Weak Lensing Cluster Mass Calibration



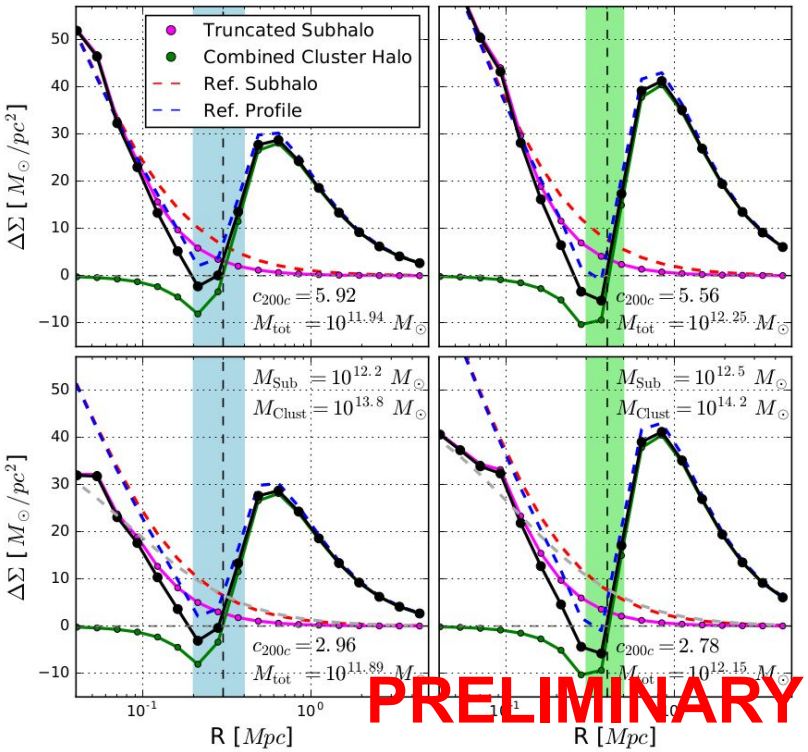

- Focus of most studies is mass calibration for cosmology
- These clusters nevertheless host the subhalos we are focusing on
- Drive great number of ancillary studies:
  - Redshift bias and calibration (Varga et al 2019)
  - Photometric projection effects (Costanzi et al 2019, Gruen et al in prep)
  - Photometric centersing (Zhang et al 2019)

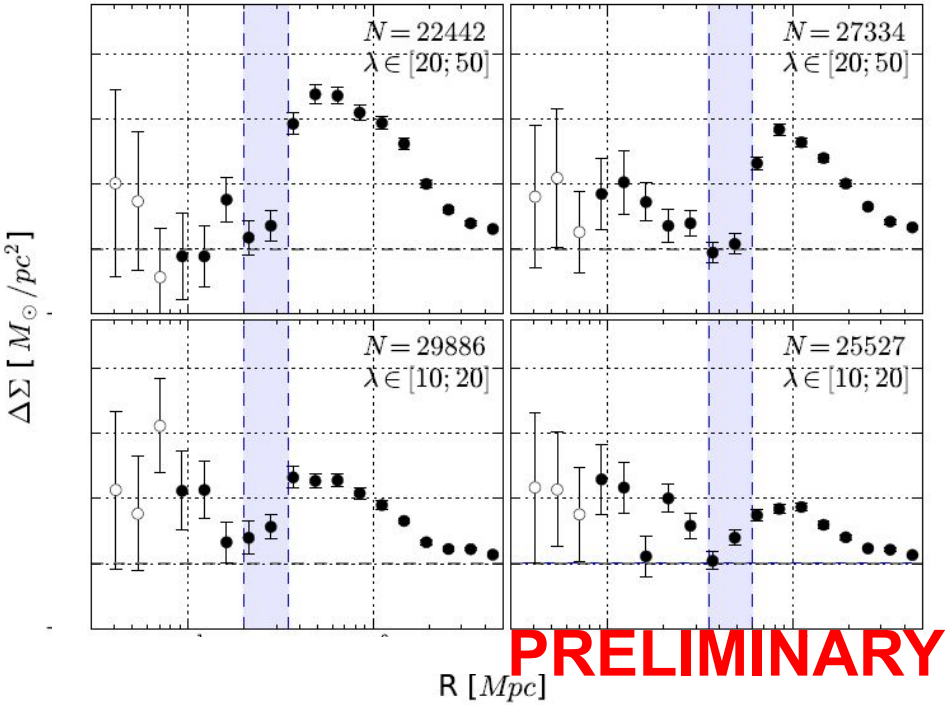
| Source of systematic | SV Amplitude uncertainty | Y1 Amplitude Uncertainty |
|---|---|---|
| Shear measurement | 4% | 1.7% |
| Photometric redshifts | 3% | 2.6% |
| Modeling systematics | 2% | 0.73% |
| Cluster triaxiality | 2% | 2.0% |
| Line-of-sight projections | 2% | 2.0% |
| Membership dilution + miscentering | $\leqslant$ 1% | 0.78% |
| **Total Systematics** | 6.1% | 4.3% |
| **Total Statistical** | 9.4% | 2.4% |
| **Total** | 11.2% | 5.0% |

**McClintock & Varga et al. 2018**

# Subhalo lensing outline

- **Measure the lensing signal around cluster galaxies in DES data**

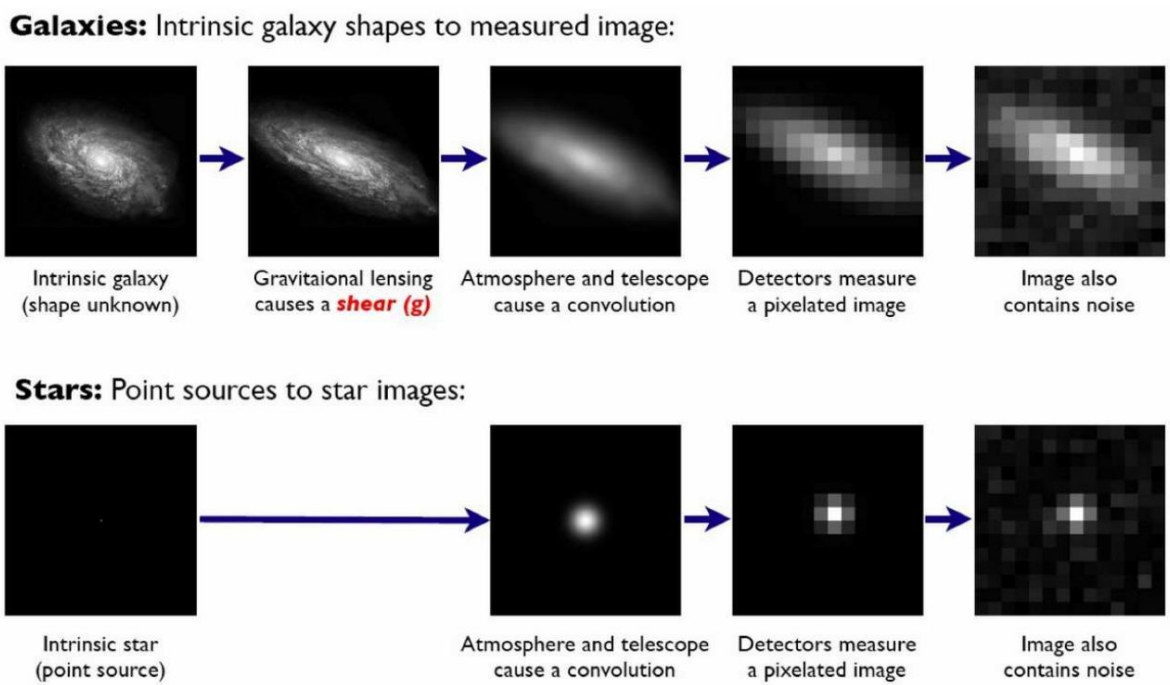



- **Physical interpretation**

Varga et al in prep
See also Niemiec et al 2017, Sifon et al 2016, Li et al 2014

# Estimators for gravitational shear




GREAT08 et al. 2008

**Use a model fit to estimate ellipticity**

The intrinsic bias of the estimator is **self calibrated on the data, but we still want to know the estimator bias**

$$g_i = (1 + m_i) g_i^{\mathrm{tr}} + \alpha^{\mathrm{PSF}} e_i^{\mathrm{PSF}} + c_i \,,$$

**Estimator response formalism:**

$$\langle \gamma \rangle \approx \langle \mathsf{R} \rangle^{-1} \langle \mathsf{R} \cdot \gamma_{\mathrm{true}} \rangle \approx \langle \mathsf{R} \rangle^{-1} \langle \mathbf{e} \rangle$$

$$\langle \boldsymbol{R} \rangle \approx \frac{\langle e_i^+ \rangle^S - \langle e_i^- \rangle^S}{\Delta \gamma_j} + \frac{\langle e_i \rangle^{S+} - \langle e_i \rangle^{S-}}{\Delta \gamma_j} \equiv \langle \boldsymbol{R}_\gamma \rangle + \langle \boldsymbol{R}_S \rangle,$$

Metacalibration, Huff & Mandelbaum 2017, Sheldon & Huff 2017, (DES Y1)

## Galaxy Clusters are different from the median line of sight

This present unique systematics:

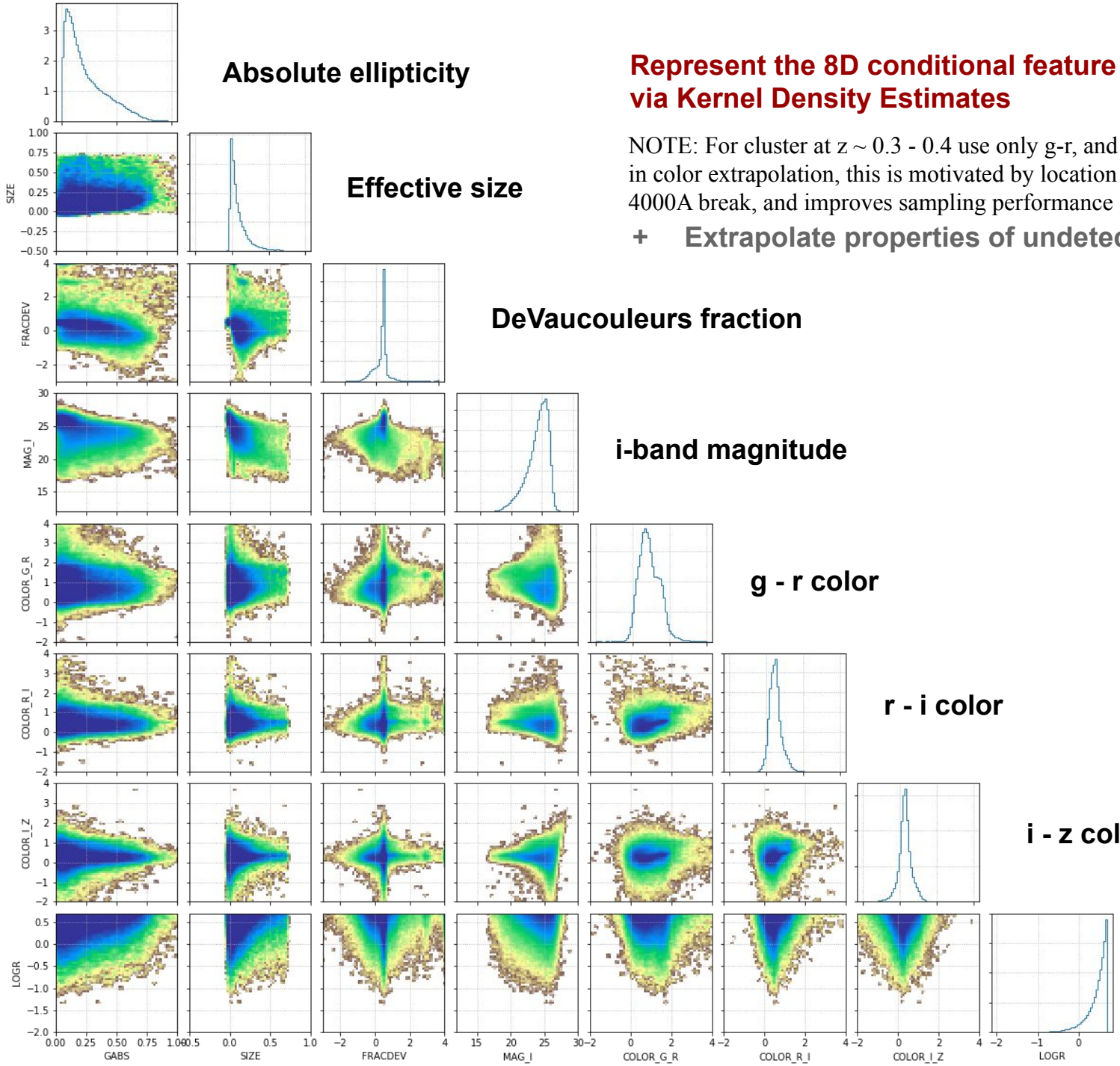
- Increased chance overlaps (blending) between the light of different galaxies, leading to increased shear bias
- Presence of intra-cluster light, leading to photo-z and shear bias
- Non-weak shear near cluster centers

# Construct plausible cluster mock simulations

**We have to simulate full line of sight, not just galaxy cluster**

- ❑ Galaxy distribution (CLF, radial population profile)
- ❑ Galaxy Morphology
- ❑ Intra Cluster Light

Render the mock clusters into multi-band observations and **process them with a DES-like pipeline**




## Represent the 8D conditional feature space via Kernel Density Estimates

NOTE: For cluster at z ~ 0.3 - 0.4 use only g-r, and r-i band in color extrapolation, this is motivated by location of 4000A break, and improves sampling performance

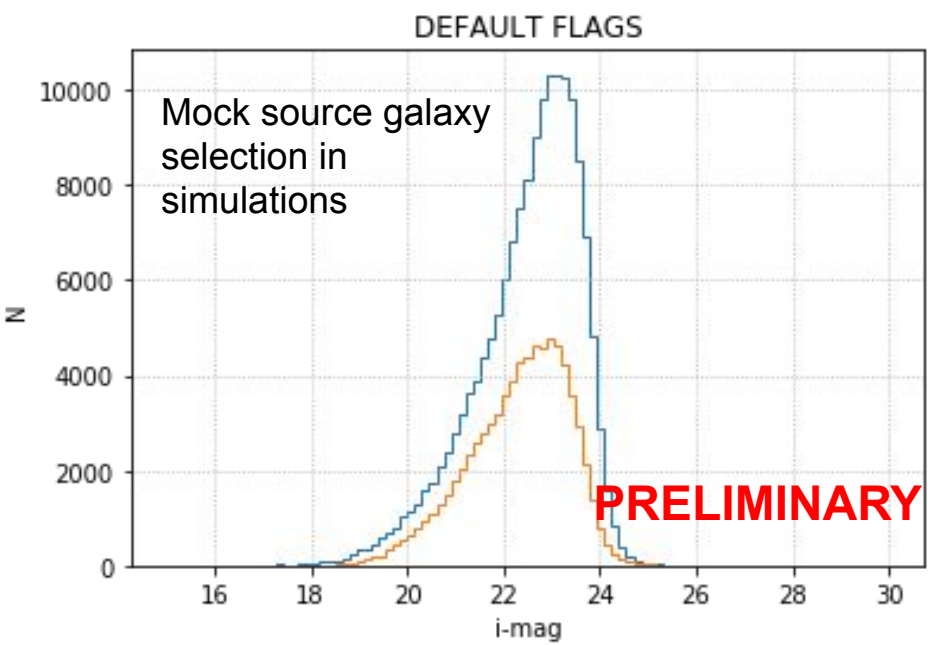
\+ Extrapolate properties of undetected galaxies

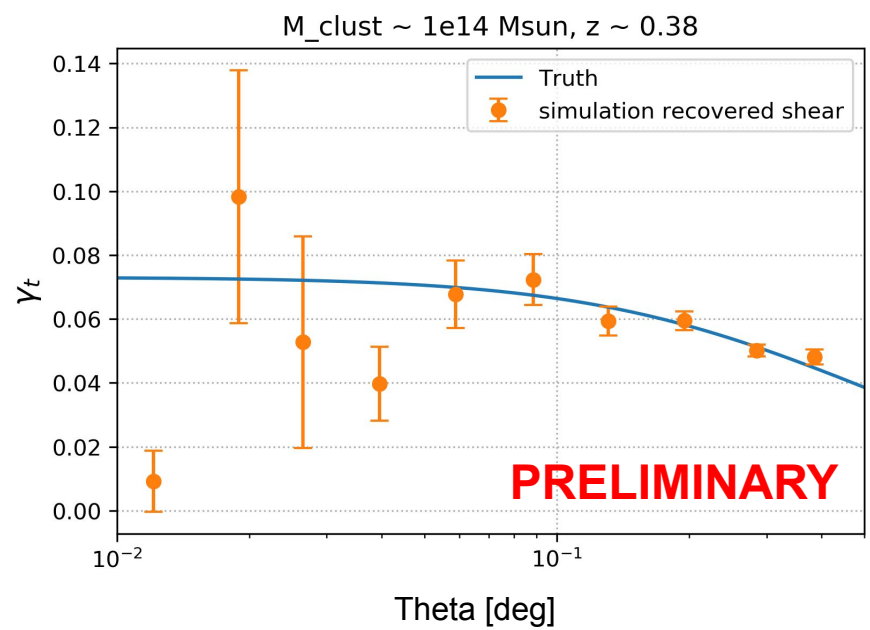
# Simulation Processing pipeline

- Create catalog of clusters as random draw from $P_D(\bar{s}, m, \bar{c}, R \mid \lambda, z)$

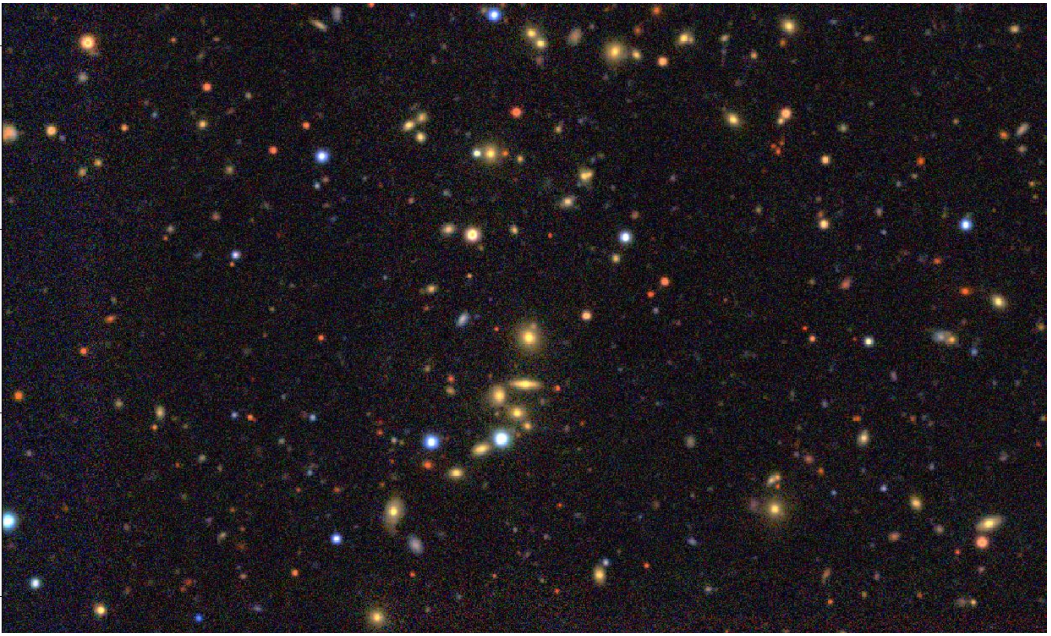
- Process with main DES simulation pipeline developed by Niall McCrann et al.

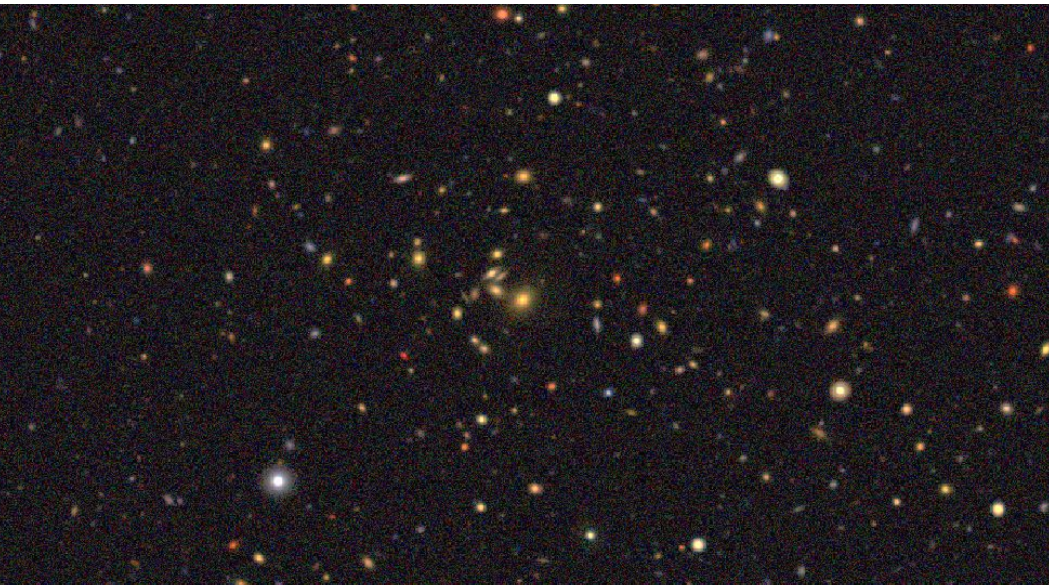
**Galsim** → **SWARP** → **Sextractor** → **MEDS** → **Metacalibration**



# The mock galaxies should look plausible...





*DES collaboration et al in prep*
*Varga et al. in prep*

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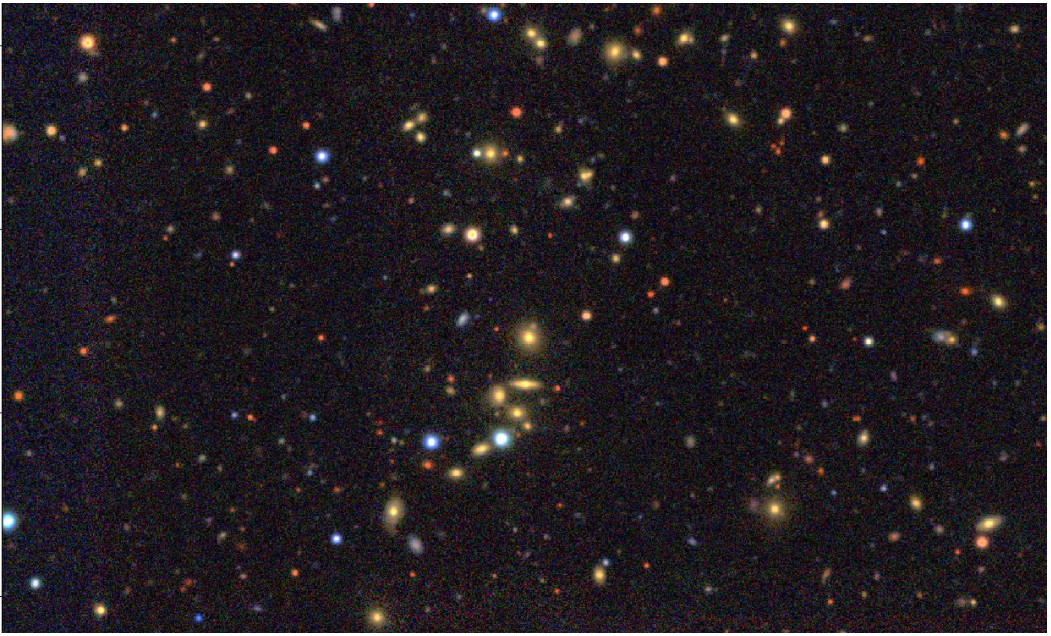

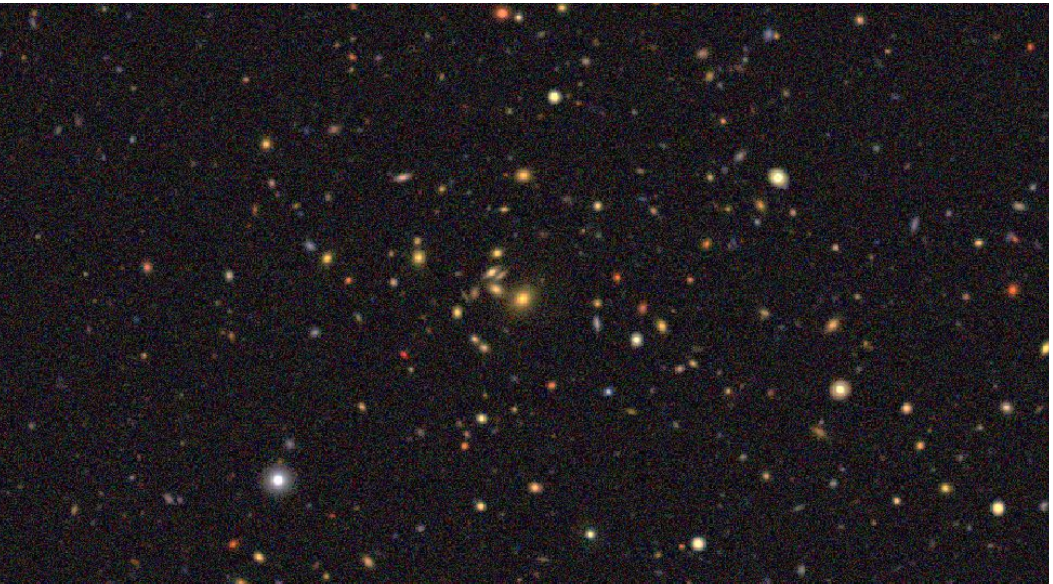

**Can you tell which one is real and which one is simulated?**

*DES collaboration et al in prep*
*Varga et al. in prep*

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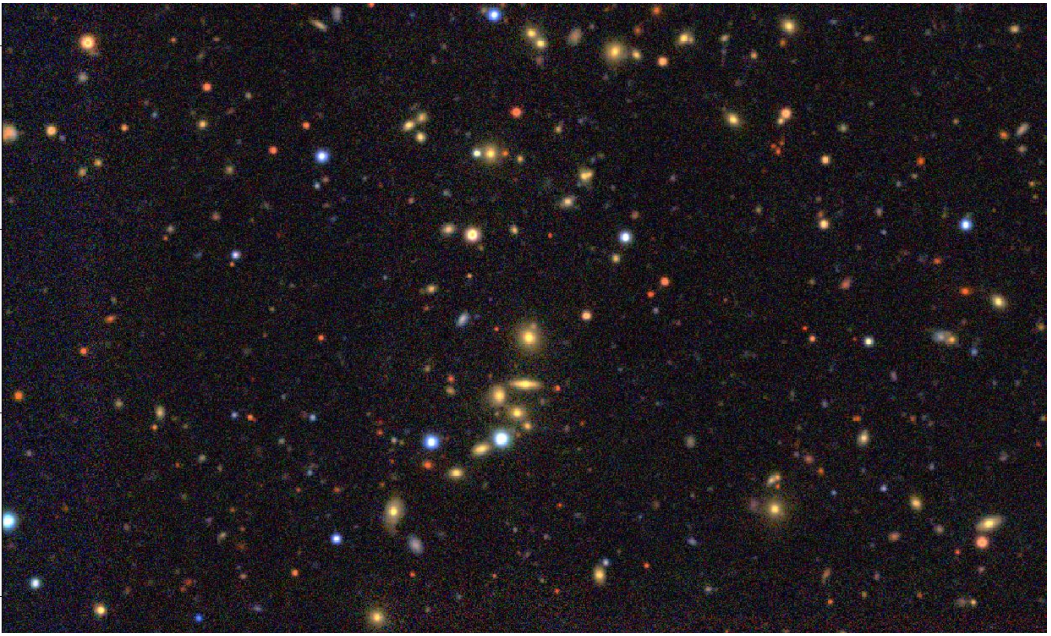

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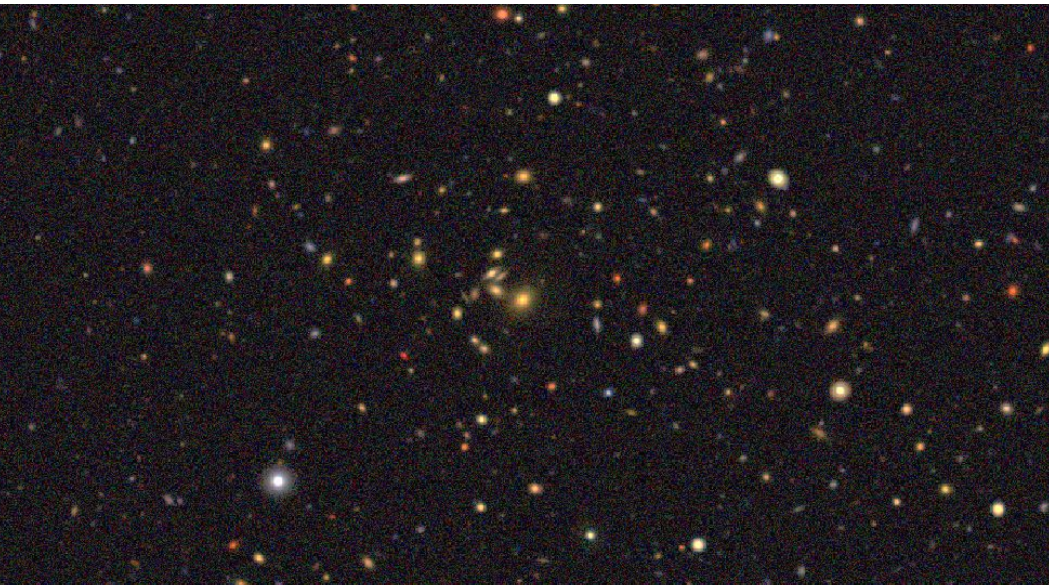
Galaxy cluster from DES Y3



MOCK galaxy cluster
rendered via emulator pipeline

*DES collaboration et al in prep*
*Varga et al. in prep*

# The path to subhalo weak lensing mass constraints

- **Reliable shear estimates** (Varga et al in prep, this work)
- **Reliable redshift estimates and contamination** (Varga et. al 2019)
- **Target selection function and projection effects** (Gruen et al in prep, Costanzi et al 2019)

**What is missing is theoretical predictions on what we expect to see assuming various DM models.**

**Subhalo truncation?** **Stratification?** **Disruption?**

# Summary & Conculsions

- **Weak Lensing mass constraints can inform us about the nature and outcome of tidal interactions in the highly non-linear regime of structure evolution**

- **The uncertainty budget of lensing measurements is now increasingly dominated by systematics, most of which we can calibrate out.**

- **At the present level we are relying on empirical relations scaling relations to interpret results**

- **What is missing is connecting physical theory of DM to measured behavior**