Subaru weak lensing measurement of a high redshift cluster ACTJ0022-0036 discovered by the Atacama Cosmology Telescope Survey

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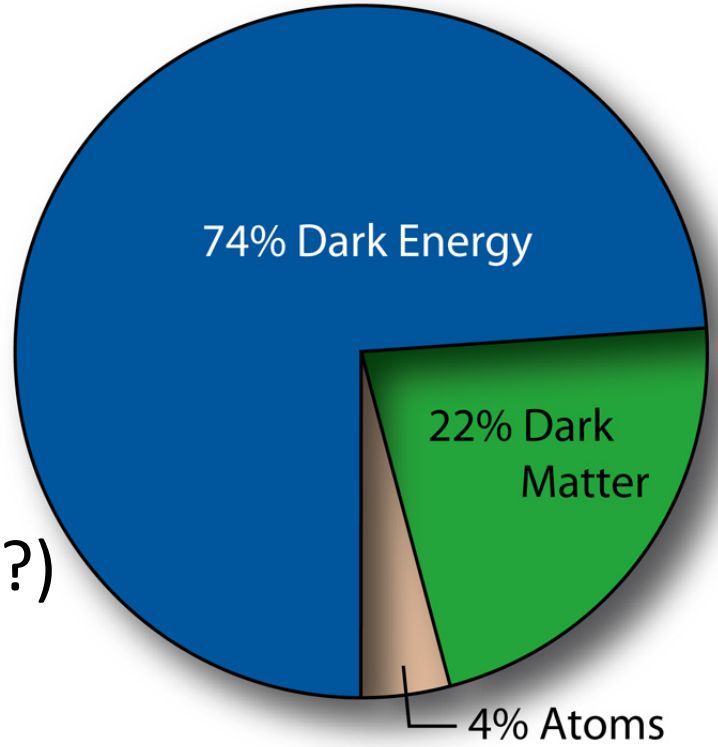
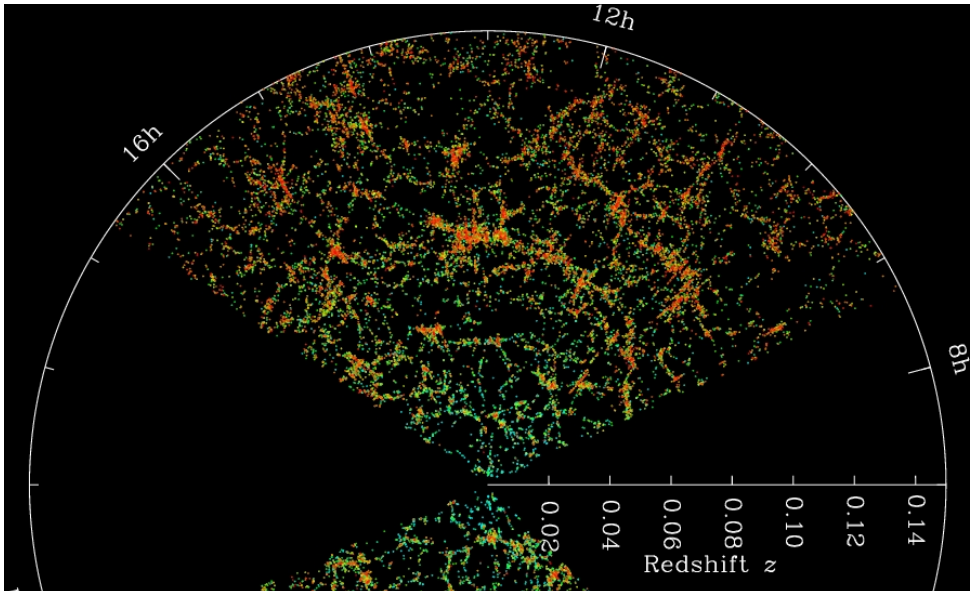
ΛCDM Model



- Accelerating universe
  →Cosmological constant(Λ)・
  Dark energy (time dependence?)

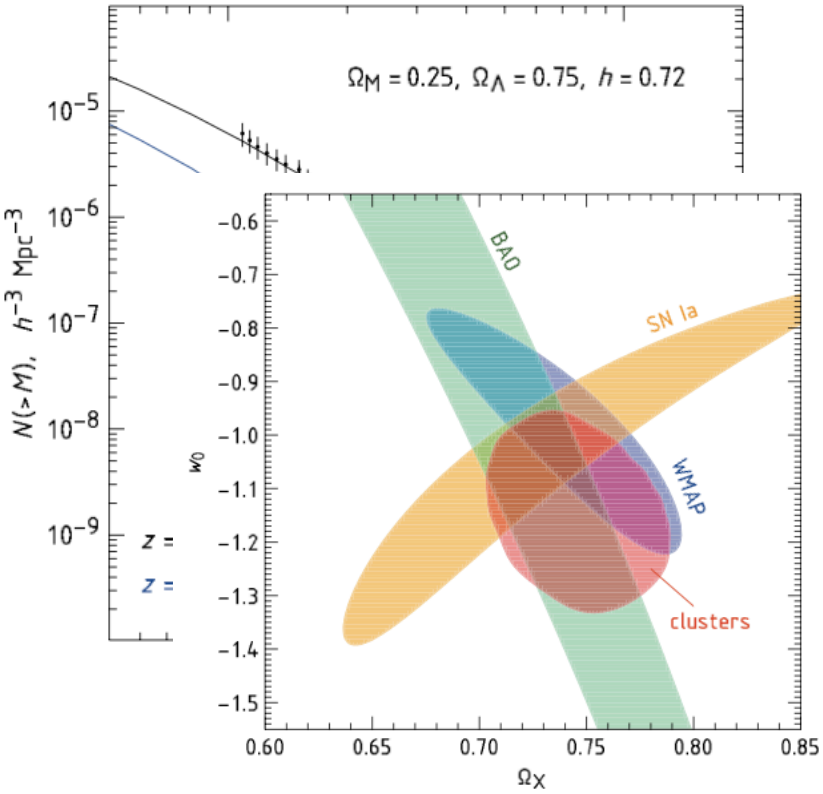
- Bottom-up structure formation
  →Cold Dark Matter



Nature of dark energy?

Cluster Cosmology

Vikhlinin et al. (2009)



Galaxy clusters

Most massive system in the universe

→sensitive to cosmology

explore the nature of dark energy

Mass function

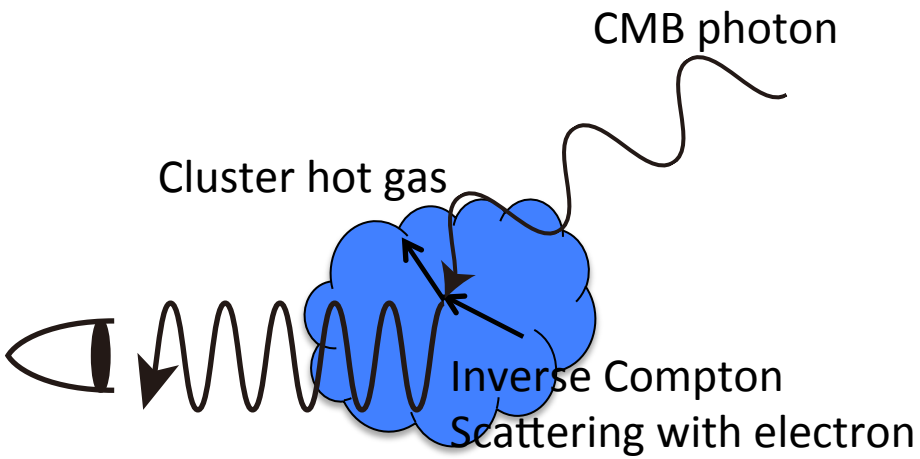
- The number of clusters as a function of M(incl. dark matter), z
- More clusters are needed.

How to find clusters?

How to measure cluster mass?

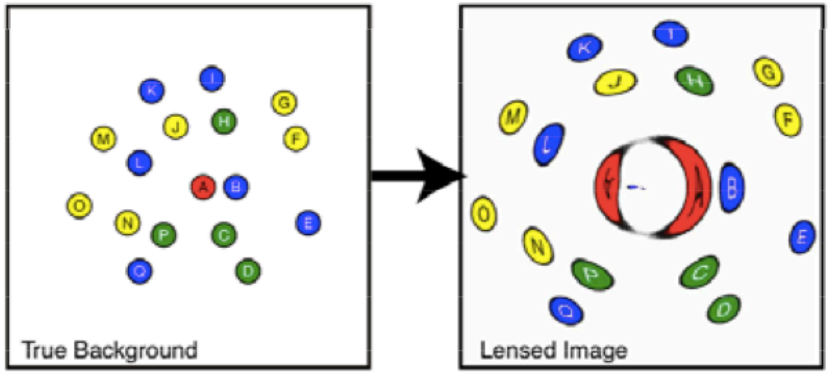
Sunyaev Zel'dovich (SZ) effect + weak lensing (WL)

Cluster finding: SZ effect



- Redshift independent (not like X-ray, optical…)
- Powerful tool for cluster finding

Cluster mass measurement: WL



- Estimate cluster mass including dark matter
- Does not need dynamical assumption

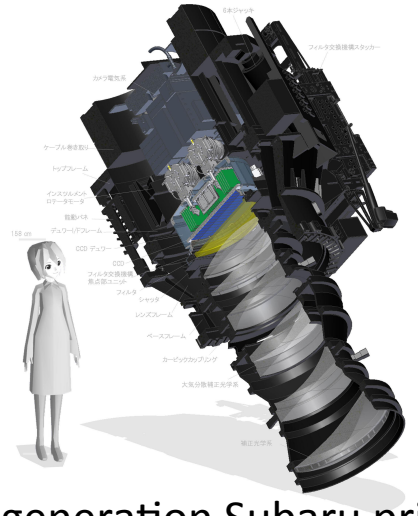
We can explore distant universe where the acceleration of the universe begins

Atacama Cosmology Telescope (ACT) + Hyper Suprime-Cam (HSC)

ACT: SZ survey

- Survey began from 2008
- Angular Resolution ~1'
- >1500 deg^2 observed
- >4000 deg^2 by ACTPol (2013-)

HSC: WL survey



- Next generation Subaru prime focus camera (1.5 deg diameter)
- First light: this May
- ~1500 deg^2 from 2013

WL measurement of clusters at z<~0.5 by Suprime-Cam: well-established (Okabe et al. (2010), Oguri et al. (2012))

→ **Need to test the feasibility of high-z cluster WL measurement!**

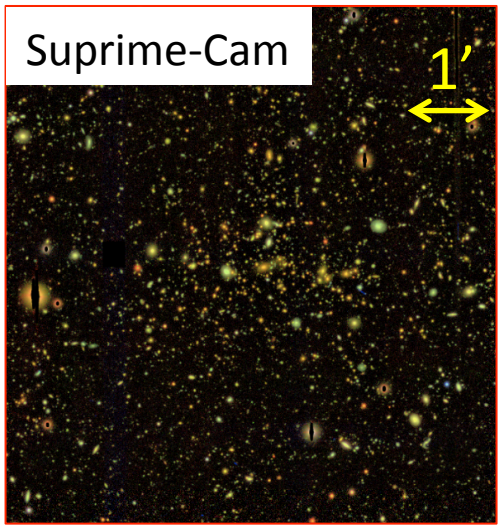
ACT-CL J0022-0036 (ACTJ0022)

- Discovered by ACT through SZ effect
- Highest SN in 200 deg^2 around equator
- Spectroscopic follow-up: z=0.81

Massive cluster?

Measure the mass through WL by Suprime-Cam follow-up observations

feasibility test of high-z WL mass measurement



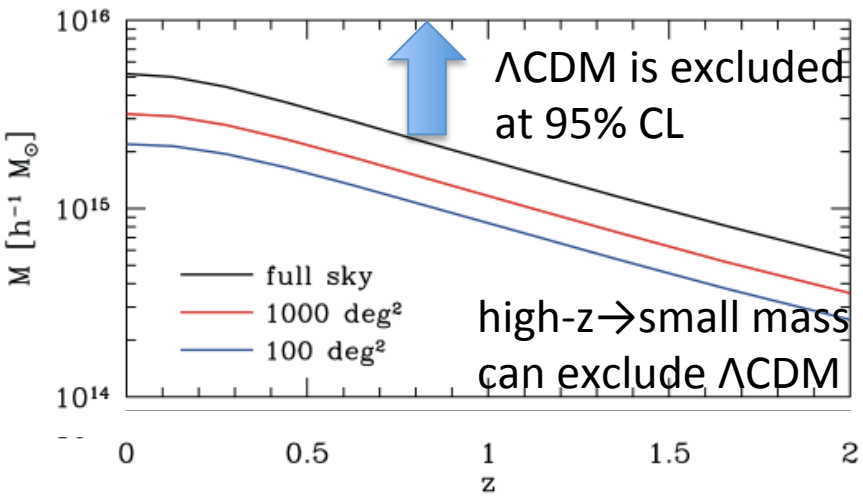
Testing ΛCDM

Is a distant, massive cluster consistent with ΛCDM model established by existing data set including WMAP, SDSS, etc…?

Mortonson et al. (2011)

Is ACTJ0022 consistent with ΛCDM?

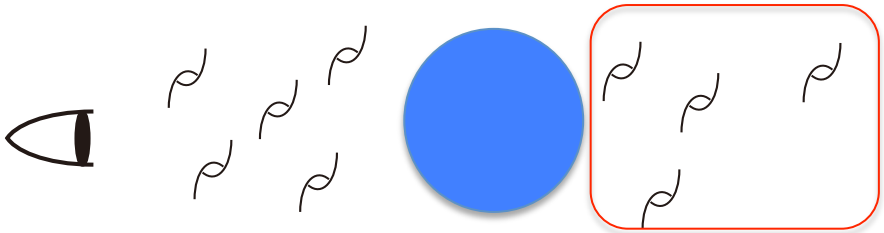
- 200 deg^2 survey region
- WL mass



First test with WL mass measurement of a cluster in a well-defined survey region

WL Measurement: Outline

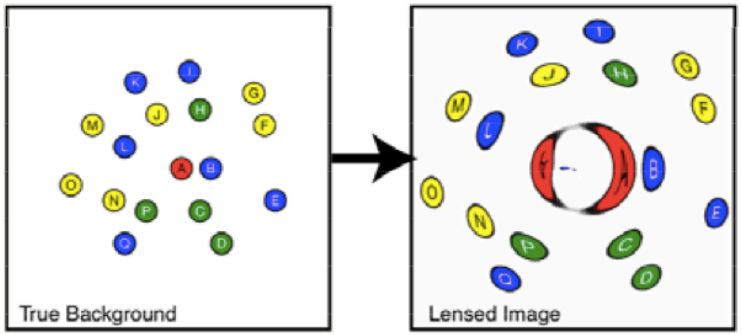
1. Data reduction(HSC pipeline)
2. Background galaxy selection

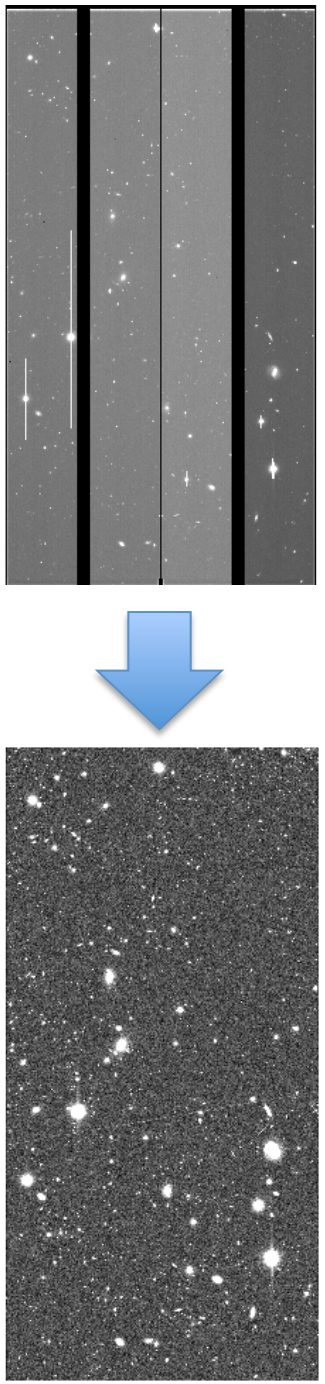


3. galaxy shape measurement

Intended to integrate into HSC pipeline

- PSF correction
- galaxy shapes

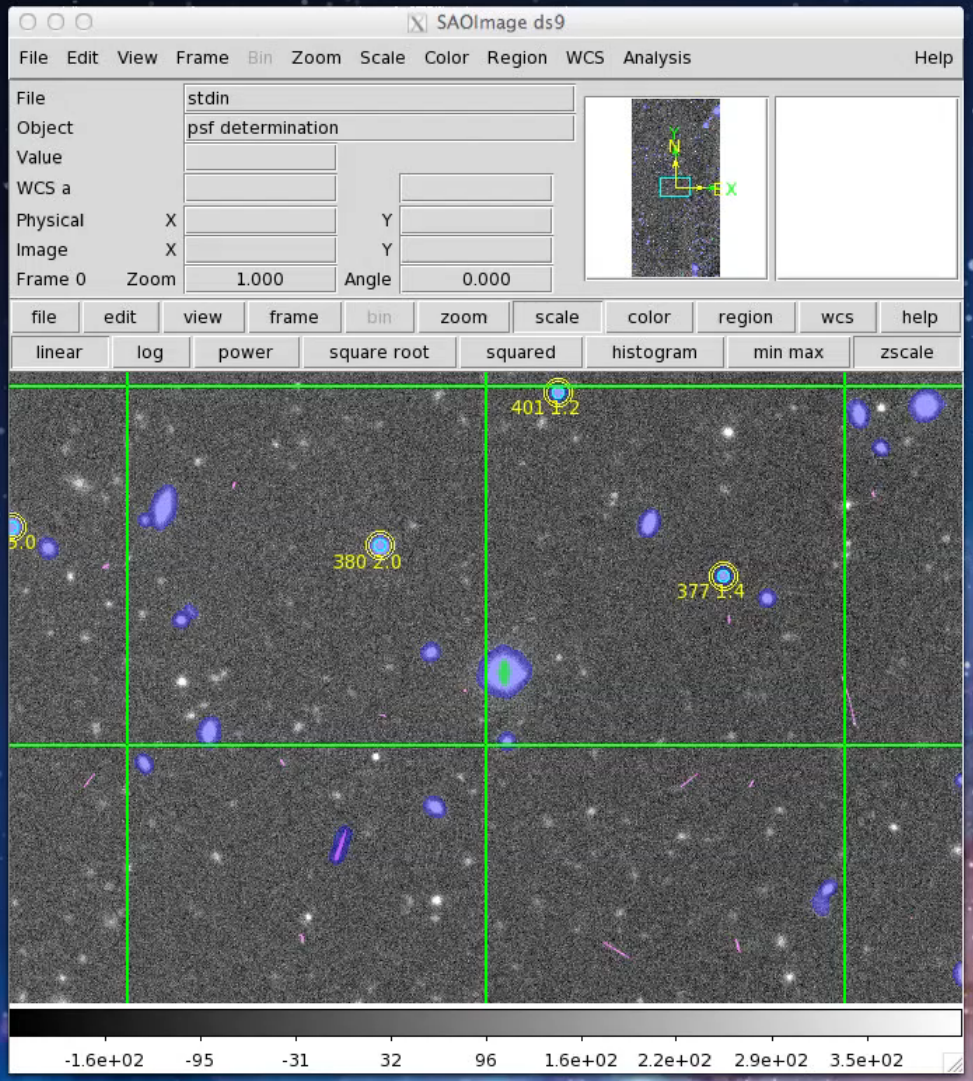


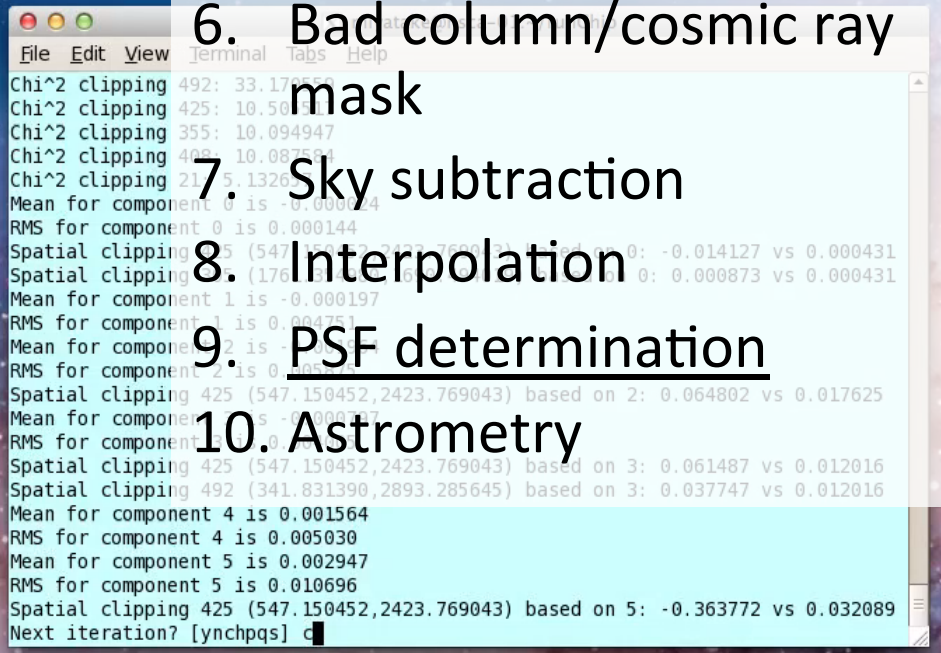


Data Reduction by HSC pipeline

First science output using HSC pipeline

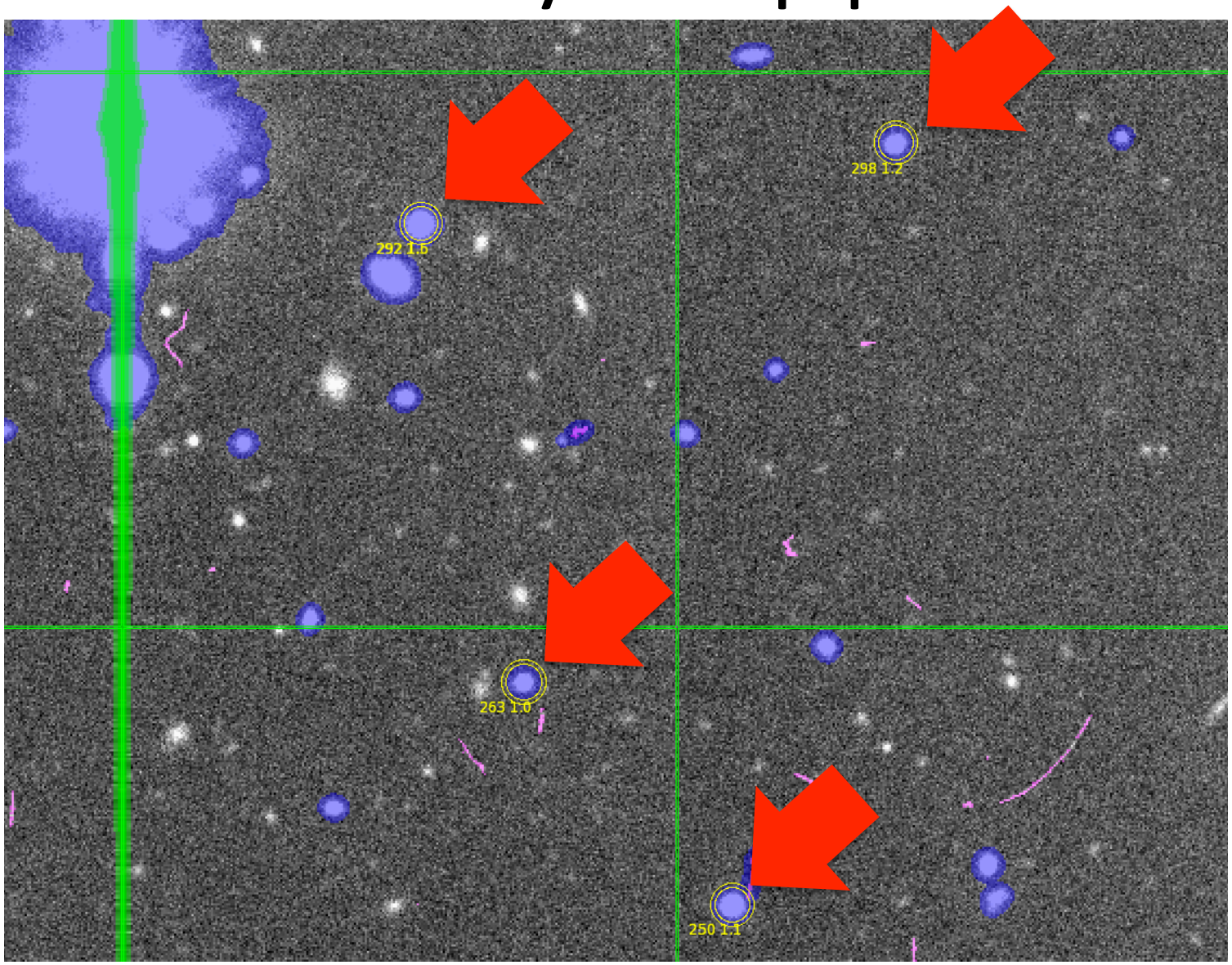
IPMU, NAOJ, Princeton





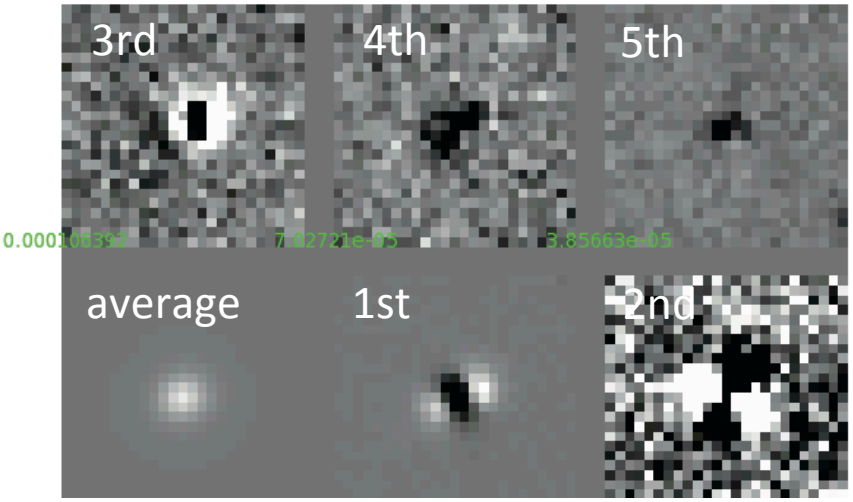
1. Saturation mask
2. Bias subtraction
3. Variance plane creation
4. Flat fielding
5. Fringe Correction
6. Bad column/cosmic ray mask
7. Sky subtraction
8. Interpolation
9. PSF determination
10. Astrometry

PCA PSF by HSC pipeline



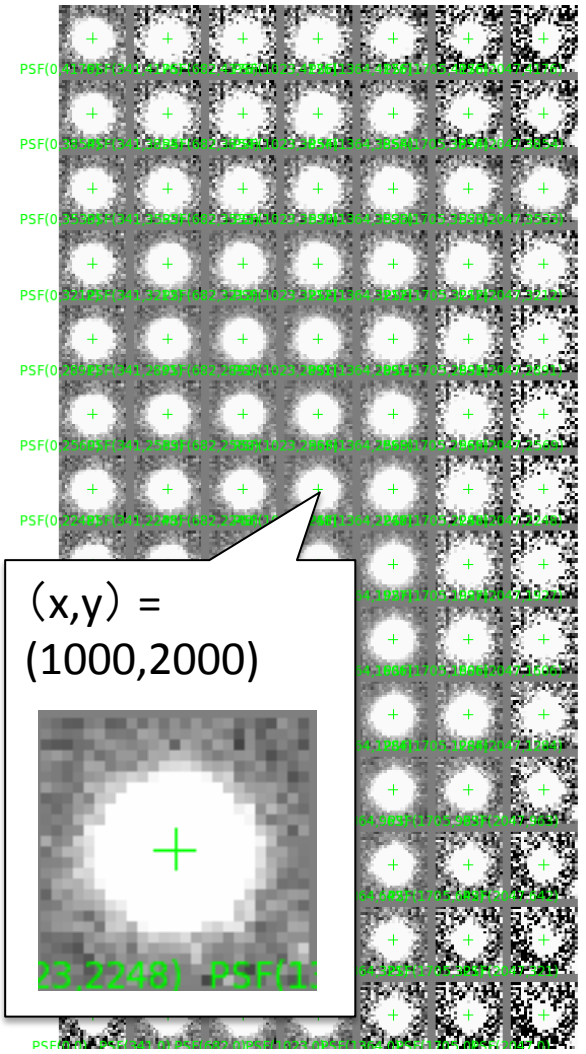
PCA PSF by HSC pipeline

Principal Components

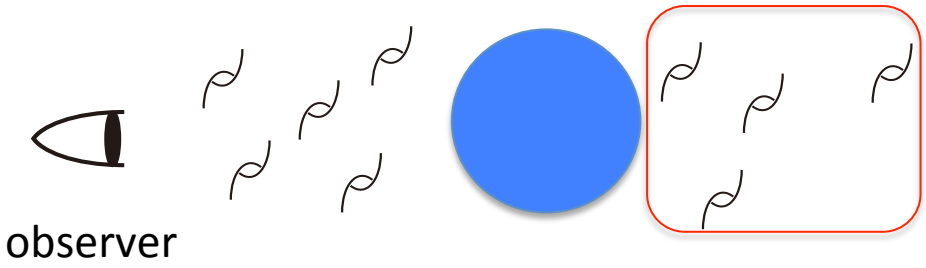


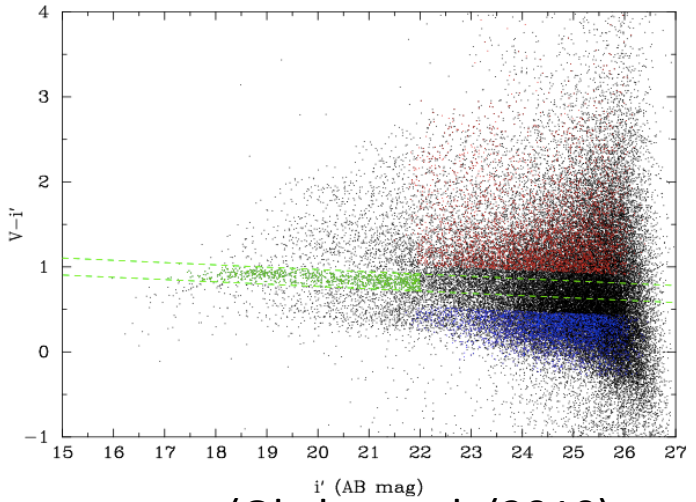
Determine orthogonal functions such that the variation of data is efficiently represented.

Reconstructed PSF

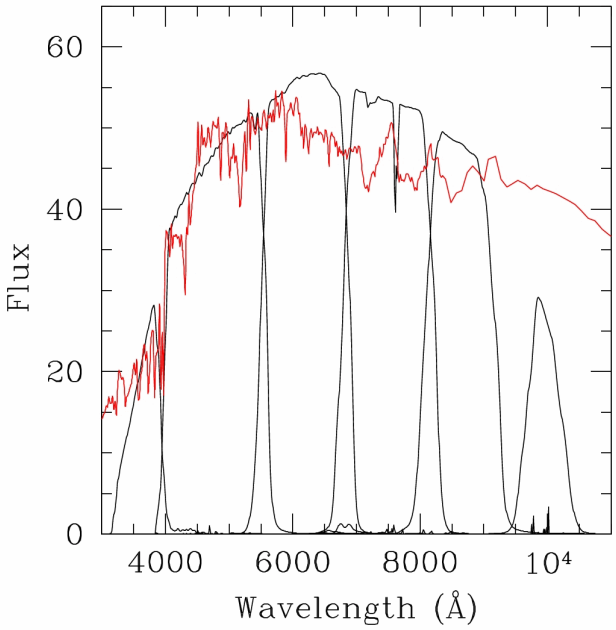


Background galaxy selection





(Okabe et al. (2010), etc…)

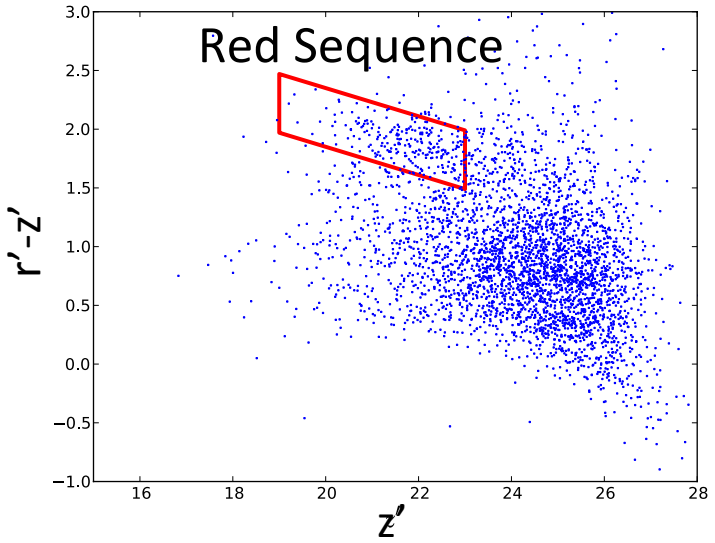


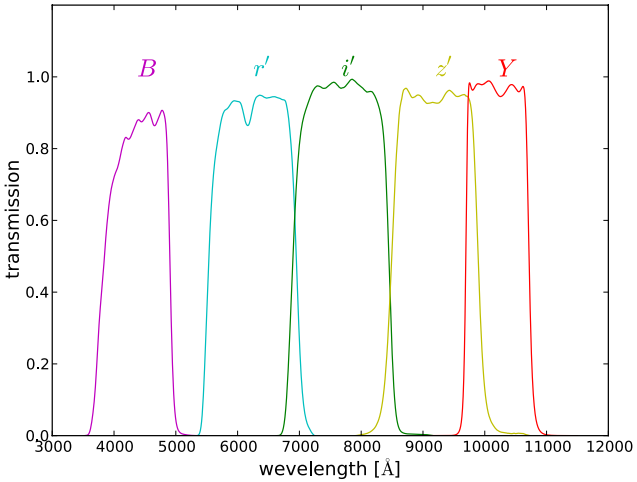
For low-z clusters observed by Subaru, 1 or 2 colors have been used. Most of galaxies in a field is background galaxies

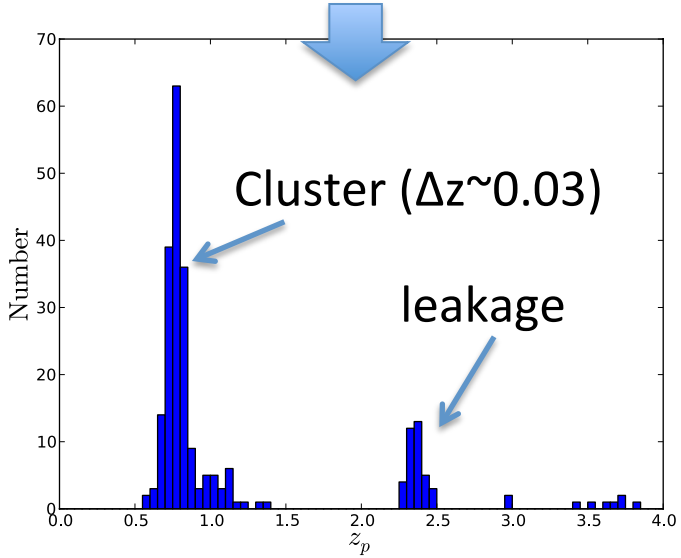
For our high-z cluster, we use photometric redshift

Photo-z: Result

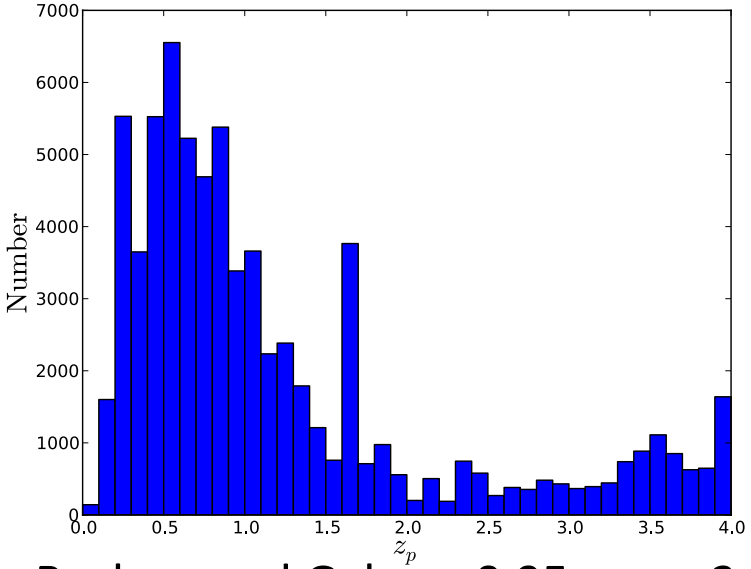
member galaxies of ACTJ0022







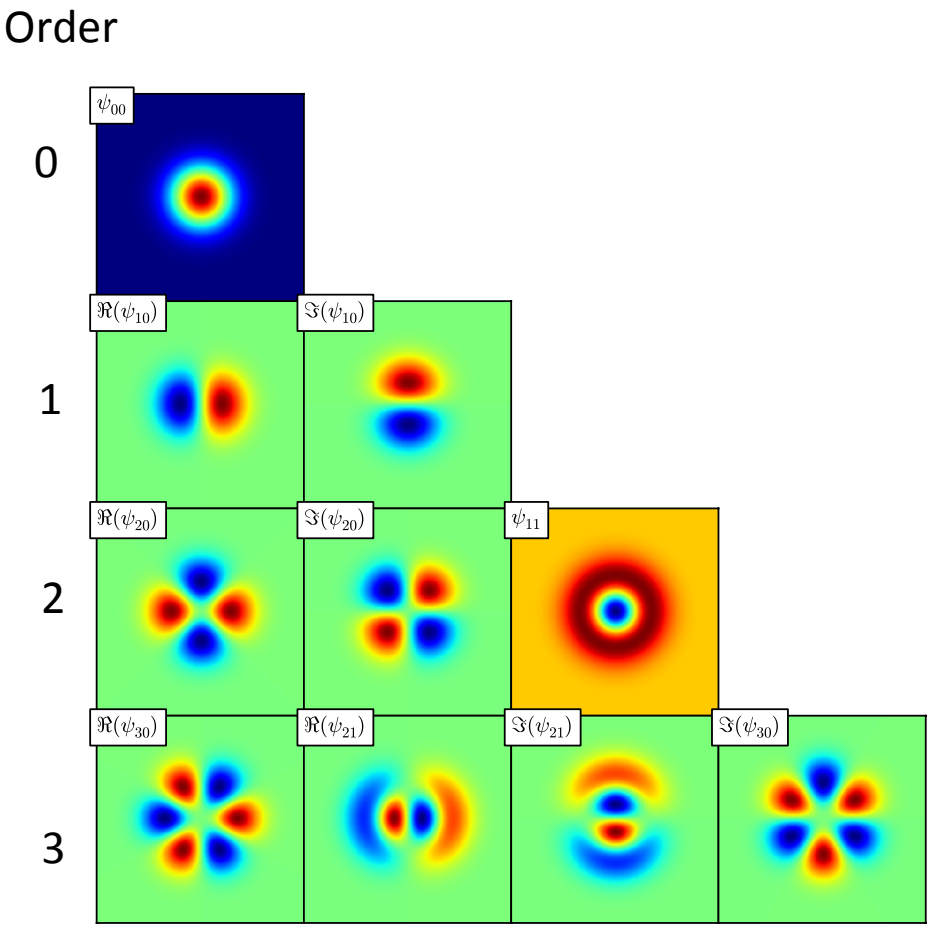
all galaxies

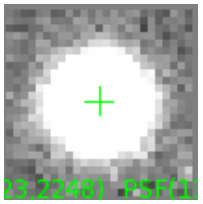


Background Galaxy: $0.95 < z_p < 2.0$

Bernstein & Jarvis (2002), Nakajima & Bernstein (2007)

Shape Measurement (EGL Method): Modeling PSF





modeling PSF given by the HSC pipeline

- Orthogonal functions: Gauss-Laguerre (GL)

$$\psi_{pq}^{\sigma}(r,\theta) = \frac{(-1)^q}{\sqrt{\pi}\sigma^2}\sqrt{\frac{q!}{p!}}\left(\frac{r}{\sigma}\right)^m e^{im\theta} e^{-r^2/2\sigma^2} L_q^{(m)}\left(\frac{r^2}{\sigma^2}\right)$$

- PSF is expanded as

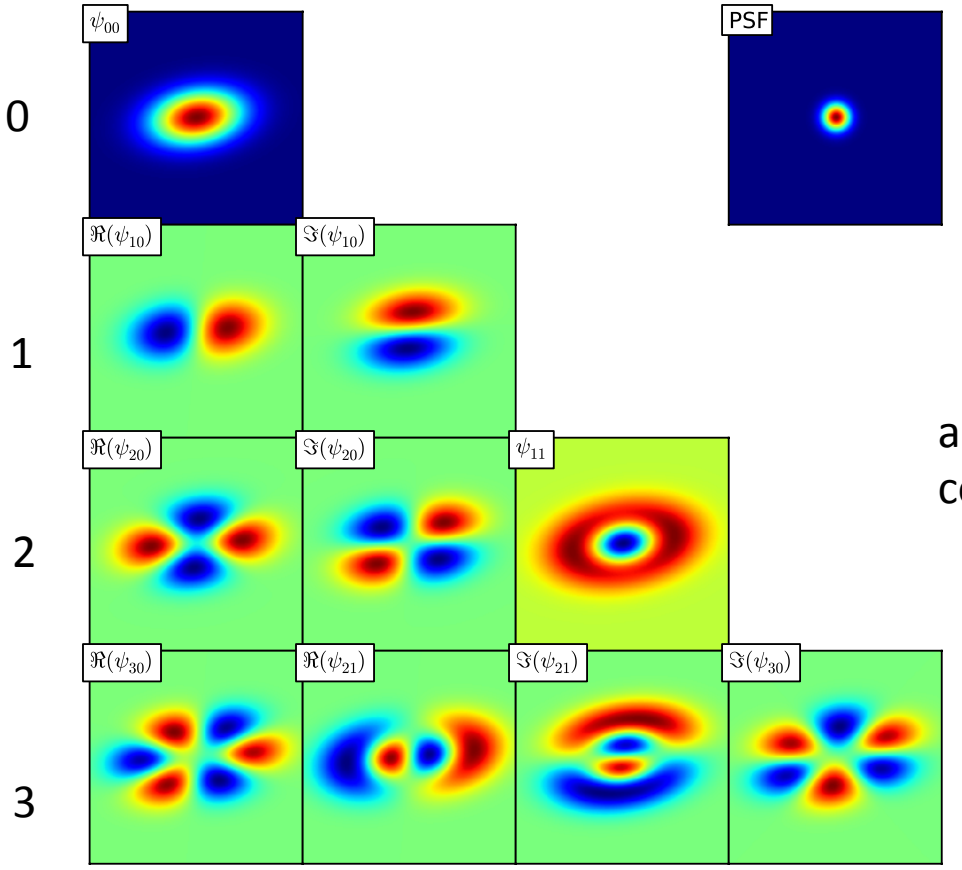
$$I^*(\boldsymbol{\theta}) = \sum_i b_i^* \psi_i^{\sigma *}(\boldsymbol{\theta} - \boldsymbol{\theta}_0)$$

PSF Information

$$\chi^2 = \sum_{\alpha=1}^{N_{\rm pix}} \frac{\left[I^*(\boldsymbol{\theta}_\alpha) - \sum_i b_i^* \psi_i^{\sigma *}(\boldsymbol{\theta} - \boldsymbol{\theta}_0)\right]^2}{\sigma_\alpha^2}$$

Measuring galaxy shapes

WL: elliptical coordinate transformation



galaxy PSF

$$I^{\rm model} = \left[\sum_i b_i \psi_i^{\sigma_g E}(\boldsymbol{\theta})\right] \otimes \left[\sum_j b_j^* \psi_j^{\sigma_*}(\boldsymbol{\theta})\right]$$

$$= \sum_i b_i \sum_{jk} b_j^* C_{ij}^k \psi_k^{\sigma_o E}(\boldsymbol{\theta})$$

$$\equiv \Phi_i^{\sigma_o E}(\boldsymbol{b}^*; \boldsymbol{\theta})$$

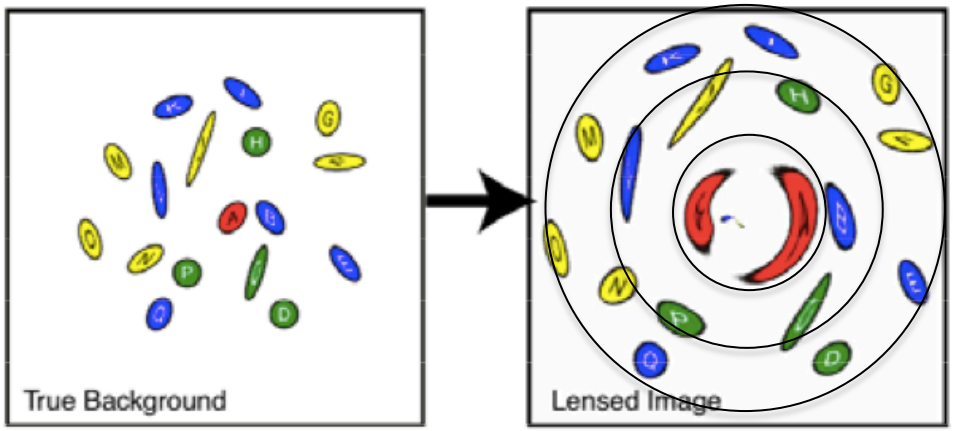
analytically convolved

galaxy shape

PSF info

$$\chi^2 = \sum_{\alpha=1}^{N_{\rm pix}} \frac{\left[I^{\rm obs}(\boldsymbol{\theta}_\alpha) - \sum_i b_i \Phi_i^{\sigma_o E}(\boldsymbol{b}^*; \boldsymbol{\theta}_\alpha)\right]^2}{\sigma_\alpha^2}$$

Weak Lensing Signal



Fitted by NFW profile

$$\rho_{\rm NFW}(r) = \frac{\rho_s}{(r/r_s)(1+r/r_s)^2}$$

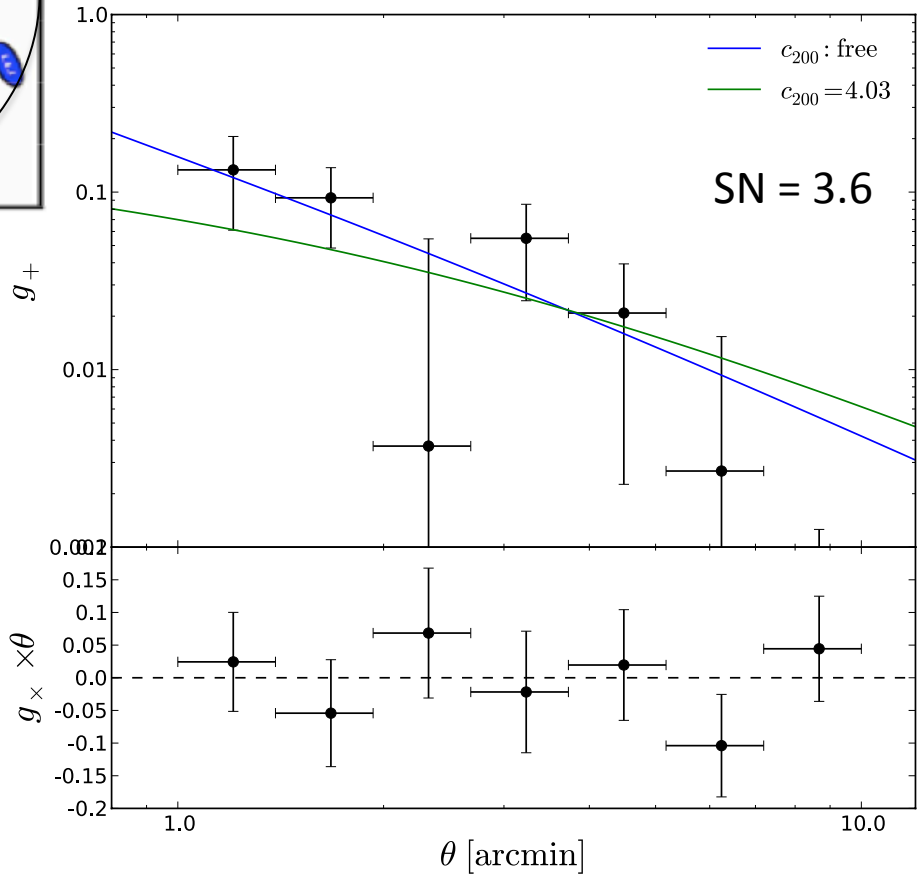
Parameters: $(\rho_s, r_s) \rightarrow (M_{200}, c_{200})$

c_{200}: free(χ^2/dof=0.83)

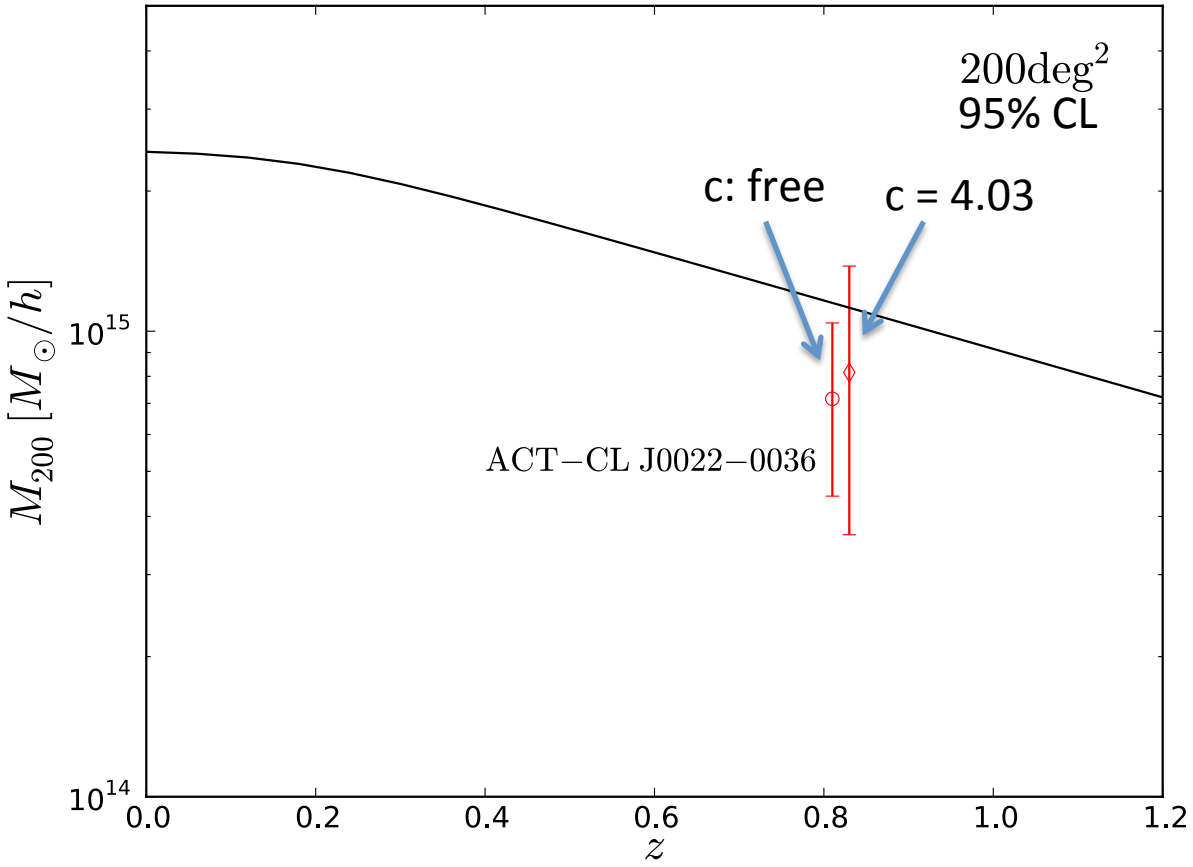
$$\mathrm{M}_{200} = 0.72^{+0.33}_{-0.27} \times 10^{15} M_\odot/h$$

c_{200}: fixed to 4.03(χ^2/dof=1.12)

$$\mathrm{M}_{200} = 0.83^{+0.54}_{-0.44} \times 10^{15} M_\odot/h$$



Testing ΛCDM: Exclusion Curve



Consistent with ΛCDM prediction

Summary

- WL measurement of high-z cluster ACTJ0022
  - HSC pipeline for data reduction
  - Photometric redshifts for background galaxy separation
  - EGL method for shape measurement

Exploring cosmology at z~0.8 by SZ-selected cluster is possible

c_{200}: free(χ^2/dof=0.83)

$$\mathrm{M}_{200} = 0.72^{+0.33}_{-0.27} \times 10^{15} M_{\odot}/h$$

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Consistent with ΛCDM prediction