Gravitational Weak-lensing Maps with Galaxy Redshift Surveys

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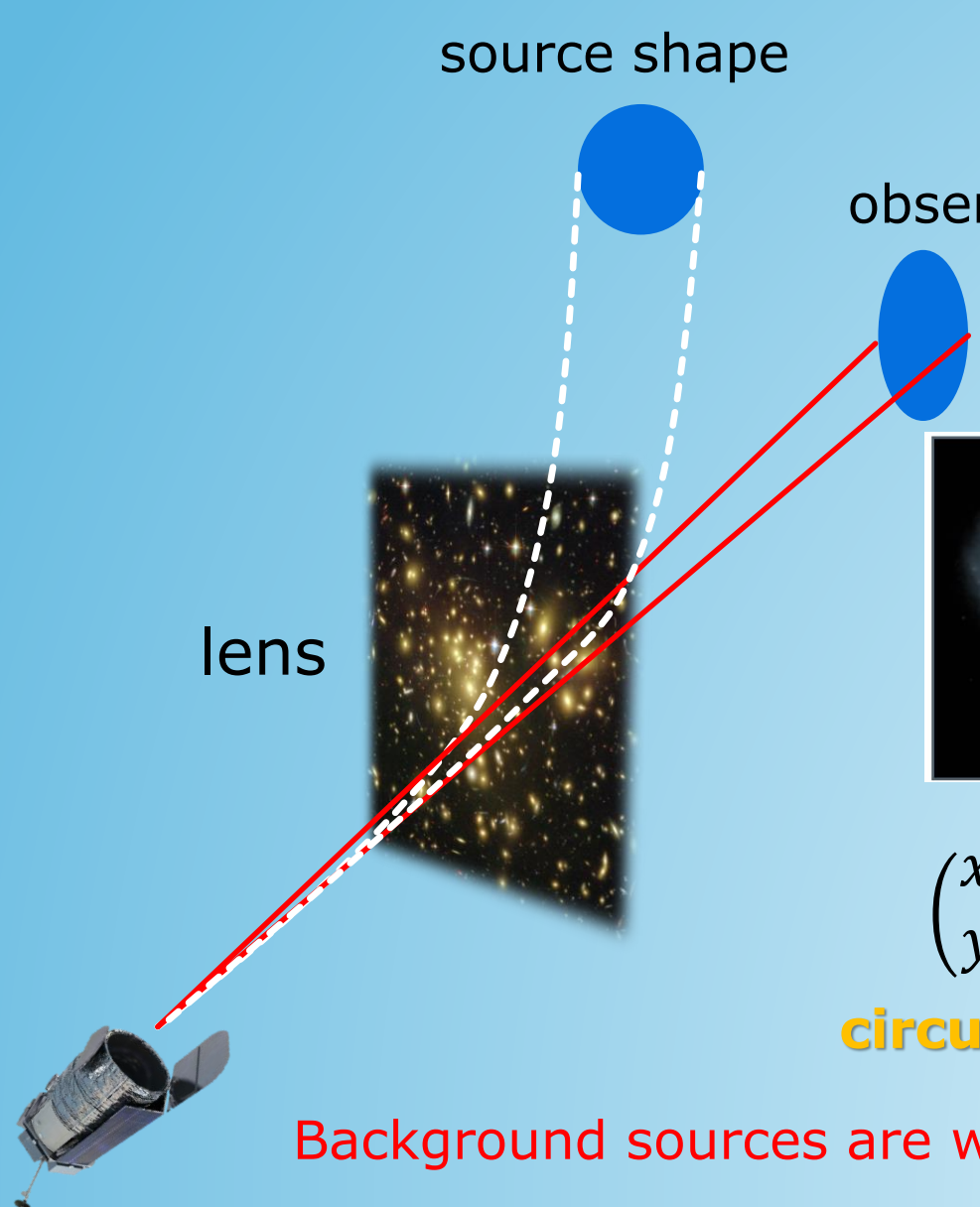
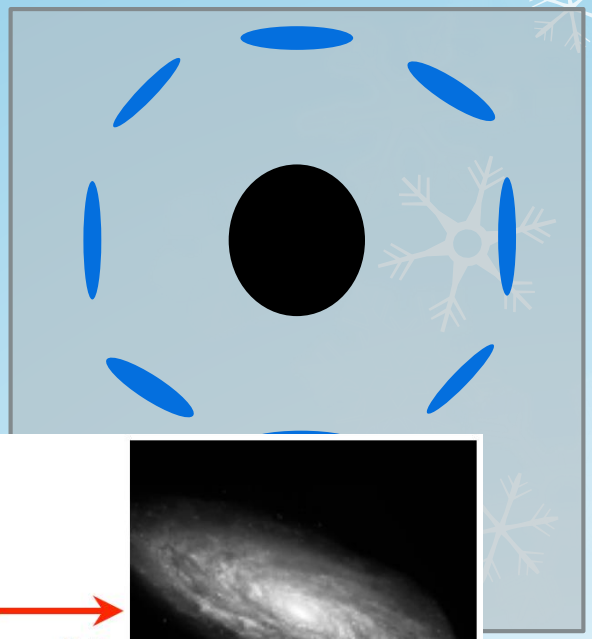
Gravitational lensing:
Einstein's telescope

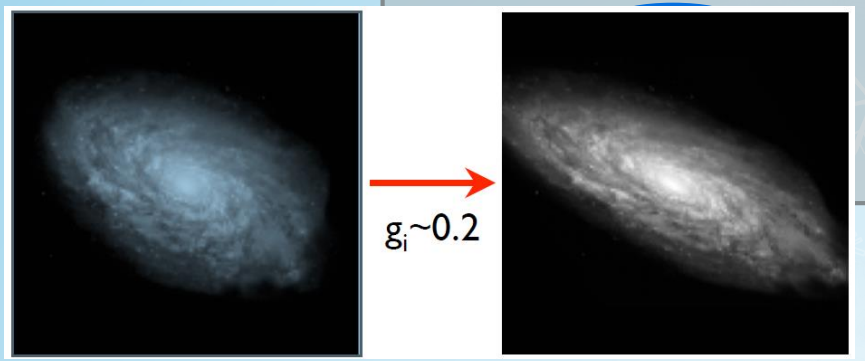
Example of strong distortion: arcs

Example of weak distortion: ?

Gravitational weak lensing







$$\begin{pmatrix} x_u \\ y_u \end{pmatrix} \sim \begin{pmatrix} 1-g_1 & -g_2 \\ -g_2 & 1+g_1 \end{pmatrix} \begin{pmatrix} x_l \\ y_l \end{pmatrix}$$

circular → ellipse

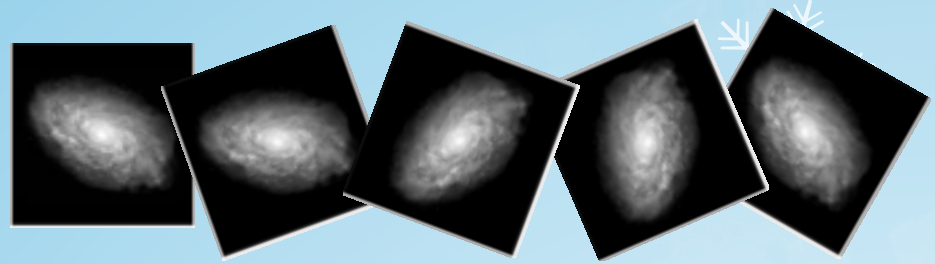
Background sources are weakly ***distorted and aligned!***

Gravitational weak lensing

$$e^{obs} = e^{source} + \gamma$$

$$< e^{source} > = 0$$

$$\gamma = < e^{obs} >$$

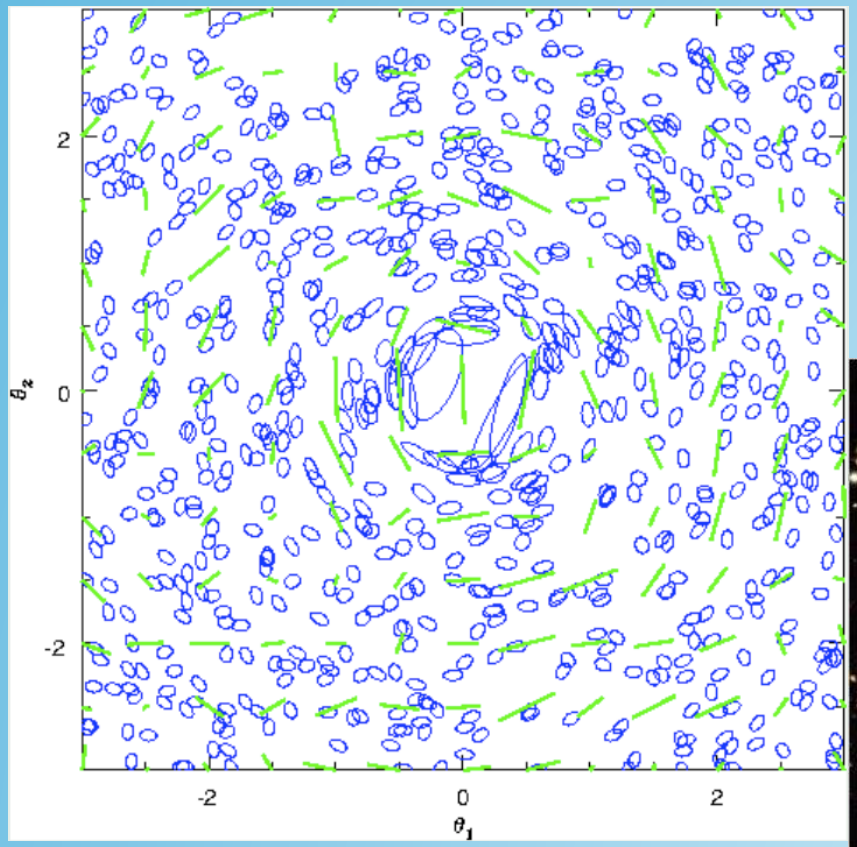


randomly oriented

So it's simple! Only measure the ellipticity

Gravitational weak lensing

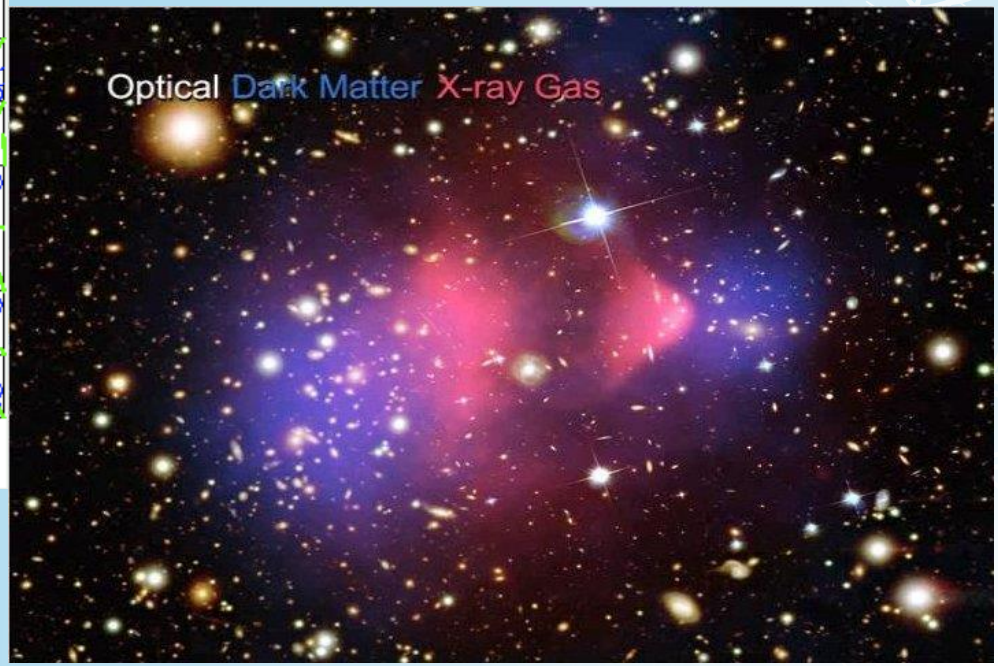
Schematic view of mass reconstruction from weak lensing:



Credit: Stella Seitz

Sticks: locally averaged ellipticity of bg. Galaxies (shear estimate)

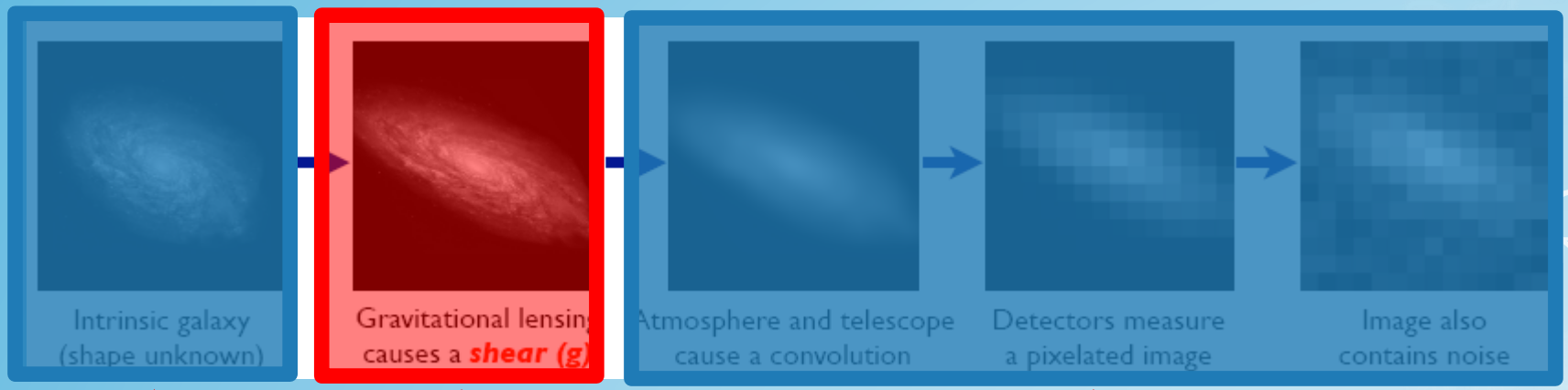
Then, smoothed shear field → smoothed mass map



But, several tricky issues…

Issue 1: ellipticity measurements

Credit: Catherine Heymans



Intrinsic ellipticity distribution (σ_e)

1-10%

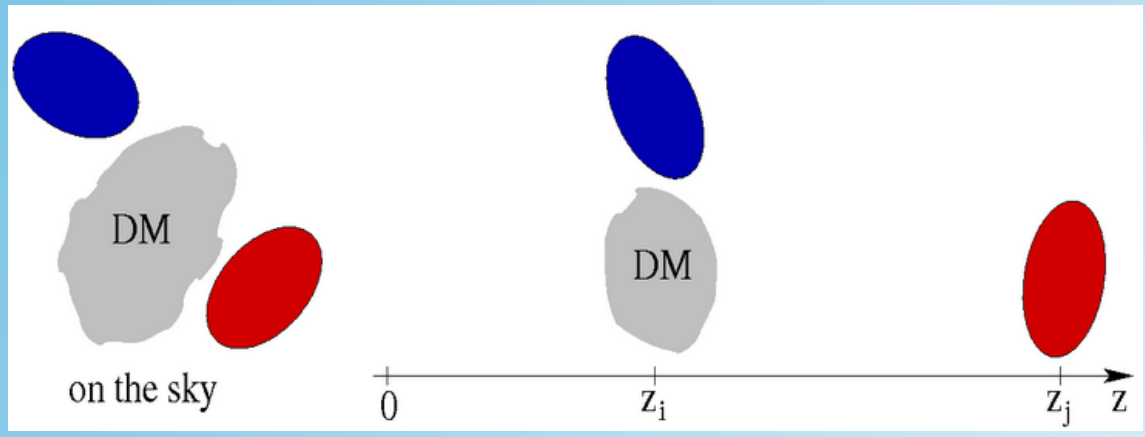
Order of 10%

Noise ~ $\sigma_e/\sqrt{N}$
→ High # density

Noise ~ shape measurements, PSF correction
→ Best images
→ High # of tests

Issue 2: projection effect and intrinsic alignments

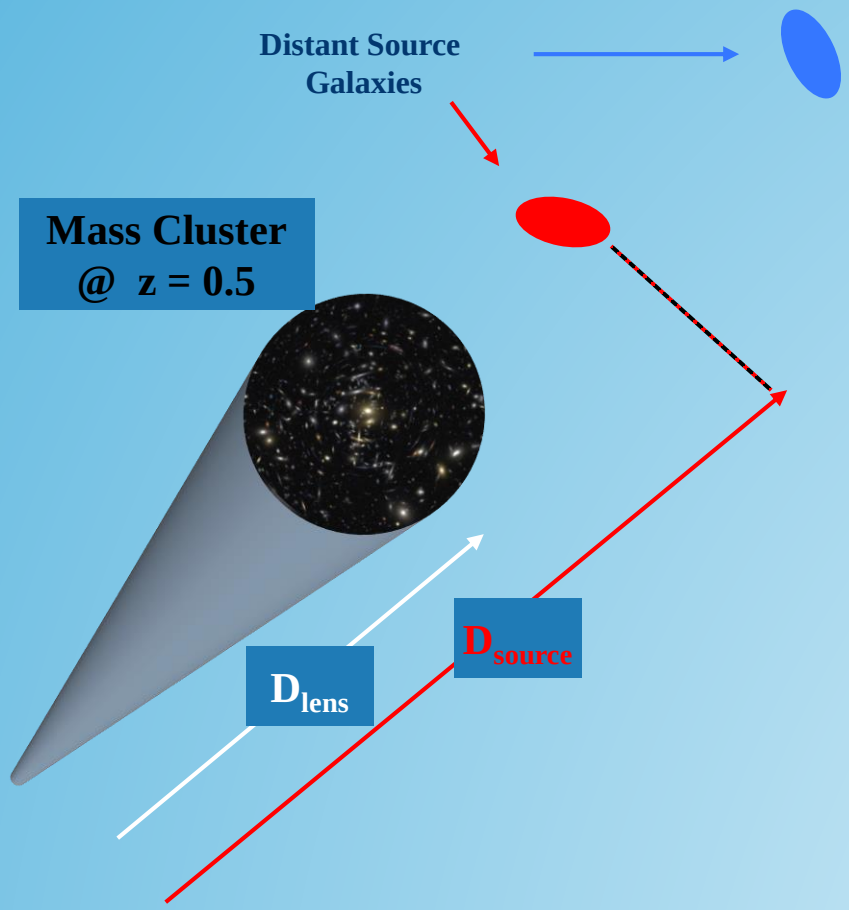
- **Projection effect:** foreground and background large-scale structures
- **intrinsic alignments:** mimic the coherent galaxy alignments due to gravitational lensing



Issue 3: photometric redshift

→ Deep galaxy redshift survey!

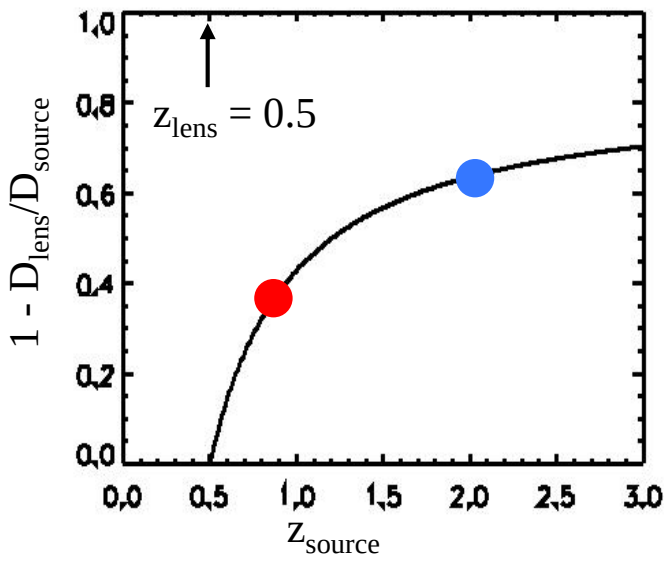
Weak lensing strength



Lens Strength

$$\gamma \propto \frac{\Sigma}{\Sigma_{crit}} \propto 1 - \frac{D_{lens}}{D_{source}}$$

Lens Strength



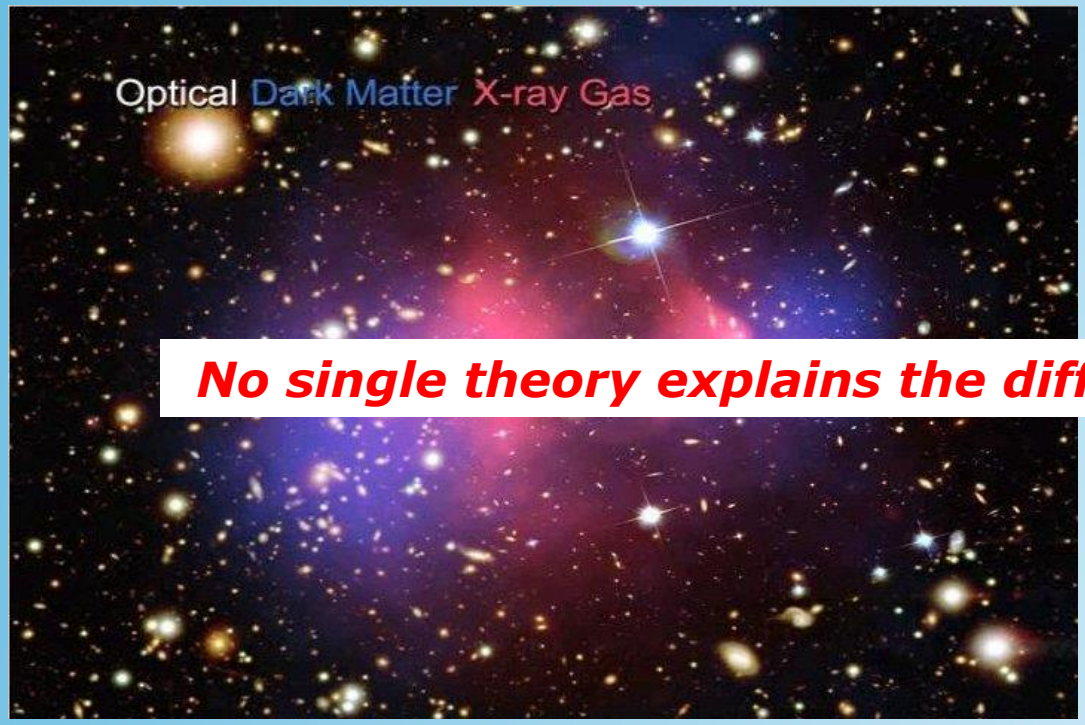
→ Deep galaxy redshift survey!

Credit: Tony Tyson

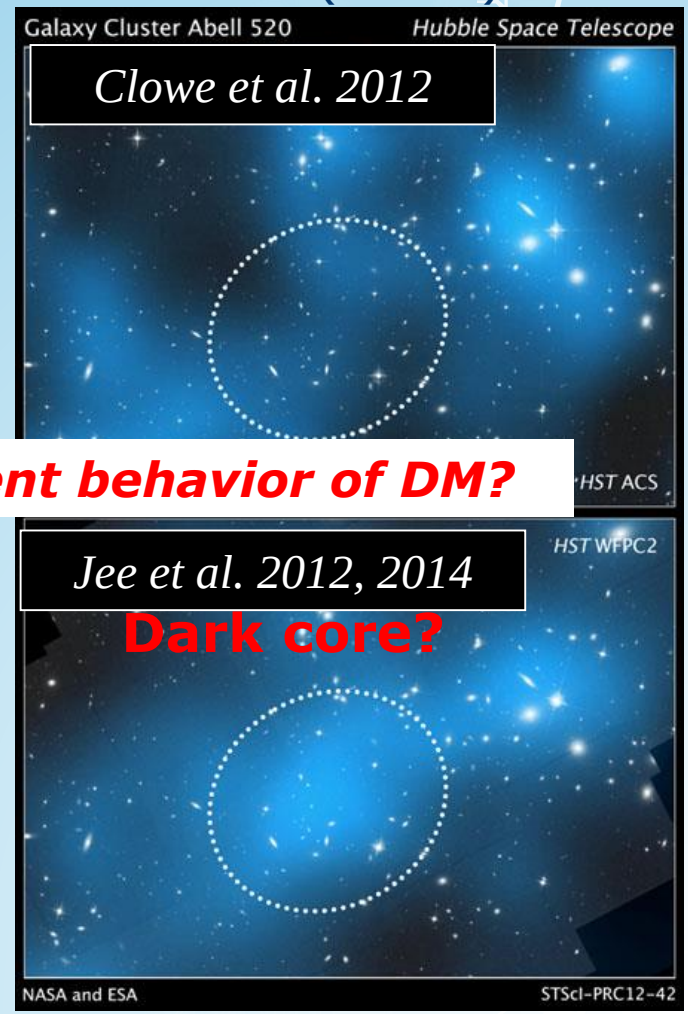
Why weak lensing is useful?

- DM existence and its properties *(collisionless?)*

Bullet cluster (z=0.3)



A520 (z=0.2)



No single theory explains the different behavior of DM?

The future of weak lensing: LSST, Euclid, WFIRST

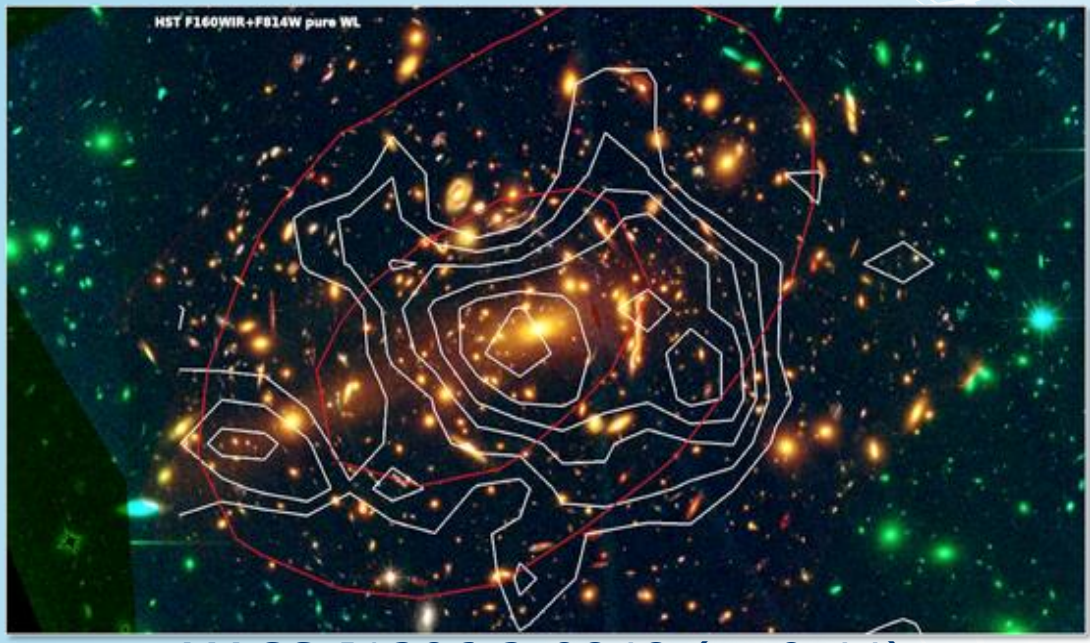
- Tracing weak lensing signals at various redshift to map the evolving DM distribution

- Mapping DM on groups, clusters, and super-clusters with high spatial resolution of ~ 40-50 kpc

  (*3-5 higher # density than 8-10m telescopes*)

Subaru (red)

HST/WFC3 (white)
→ WFIRST



MACS J1206.2-0848 (z=0.44)

Testing Weak-lensing maps with galaxy redshift surveys

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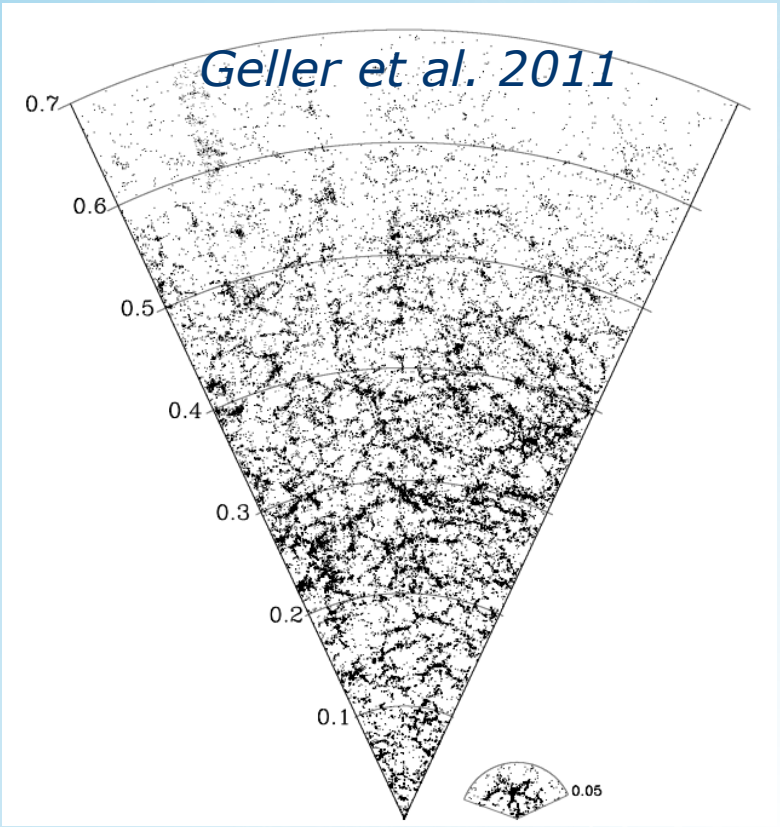
1st test

Spec. data:

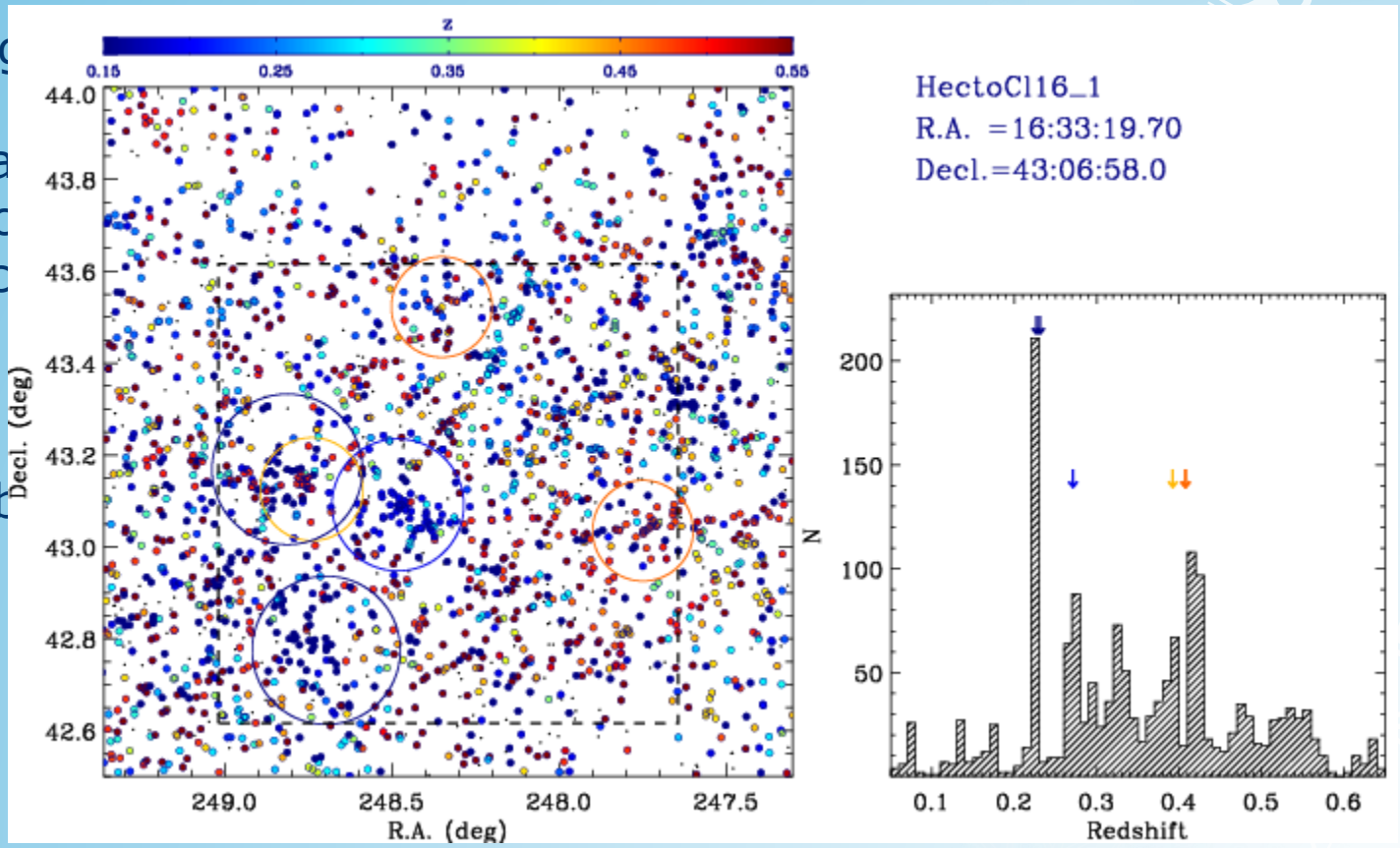
HectoMAP (PI: M. Geller)

- 6.5m MMT/Hectospec MOS
- A redshift survey of red galaxy with SDSS $r < 21.3$
- 50 deg^2 region
  (200° < RA < 250°,
  42.5° < Dec < 44°)
- ~80,000 redshifts



Phot. data: CFHT images (*g*, *r*)

- CFHT 2013B MegaCam: 0.187”/px, 1 deg^2 FoV
  - 3 fields containing GMBCG clusters
  - Good seeing
  - Deep optica
    (*r:* 12096 sec
    (*g*: 6678 sec
  - But, only 1
  - 2 field will b



A example of weak lensing analysis

1. A mosaic image construction: good astrometry! (ext. ~0.2”, int. ~0.03”)
   - SExtractor, SCAMP, WeightWatcher, Swarp

2. Source extraction: masking around saturated stars!
   - SExtractor, imcat

3. Separate the stars from the galaxies
   - not masked, no flags, S/N > 100, size-magnitude locus cut

4. Model the PSF with the stars and remove the effect of the PSF

5. Measure and correct galaxy shapes (ellipticities)

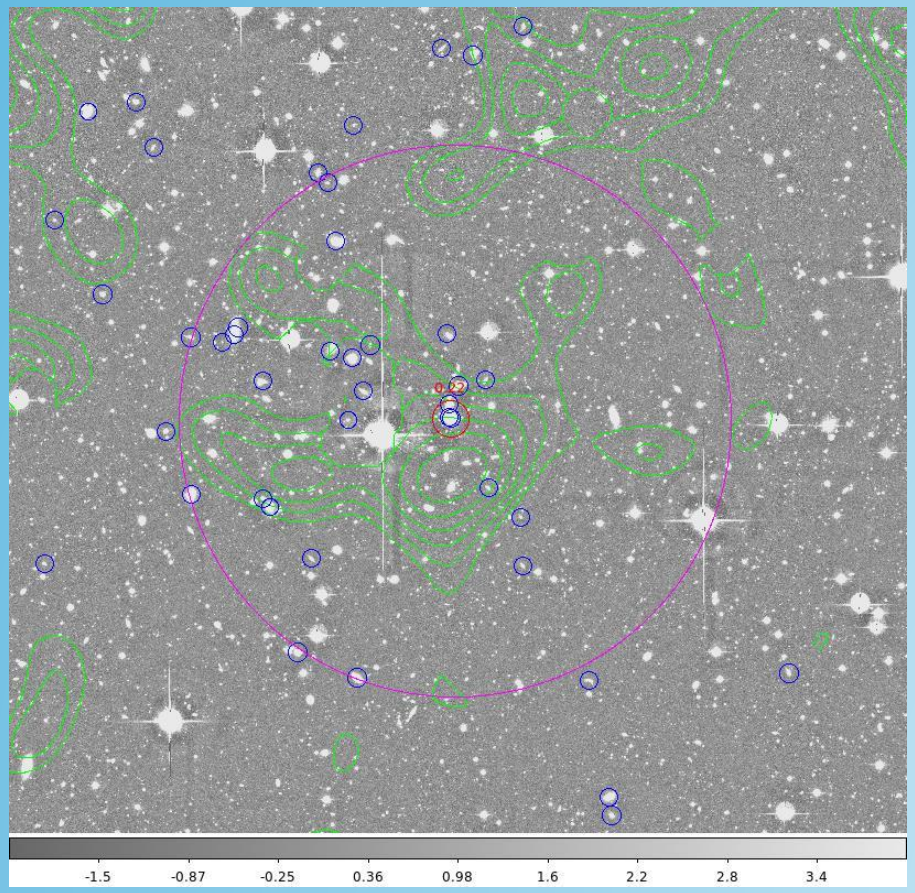
6. Select galaxies for shear measurement
   - very carefully select background galaxies! very sensitive!!

7. Shear estimate: Kaiser Squires and Broadhurst method (KSB)

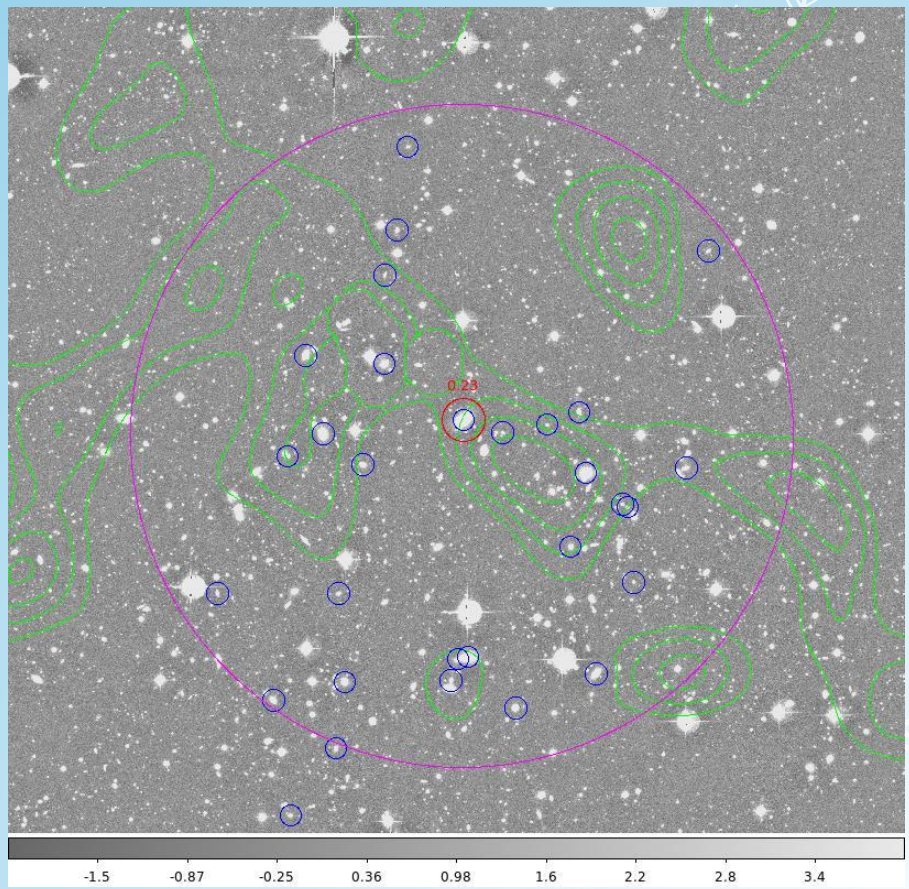
8. Make a mass map
   - Kaiser & Squires (1993) inversion algorithm
     from the shear field (measurable lensing distortion)

A example of weak lensing analysis

z = 0.22

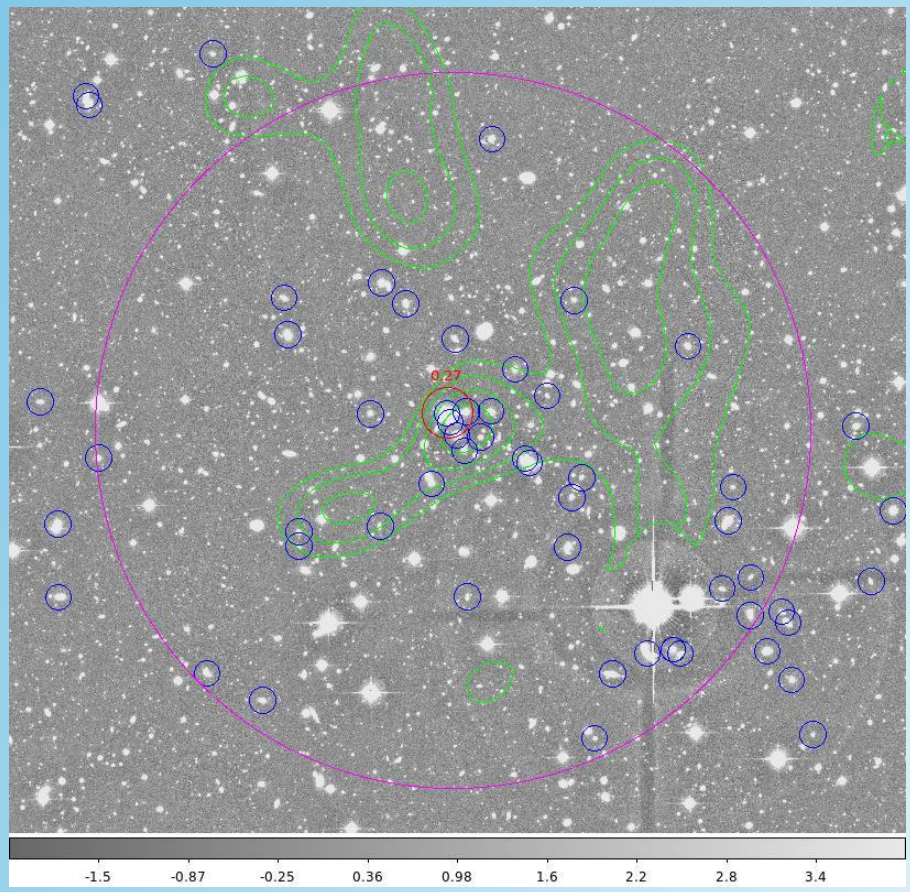


z = 0.23



A example of weak lensing analysis

z = 0.27



Summary

- Einstein's telescope (gravitational lensing) is the most powerful tools of the observational astronomer
- Weak lensing in the next decade will allow accurate, high-angular resolution **reconstructions of cluster mass distributions** down to ***10-25 kpc scale with WFIRST*!**
- Weak lensing analysis is tricky but ***the potential make it worth the effort*** (***how to mitigate systematics***!)