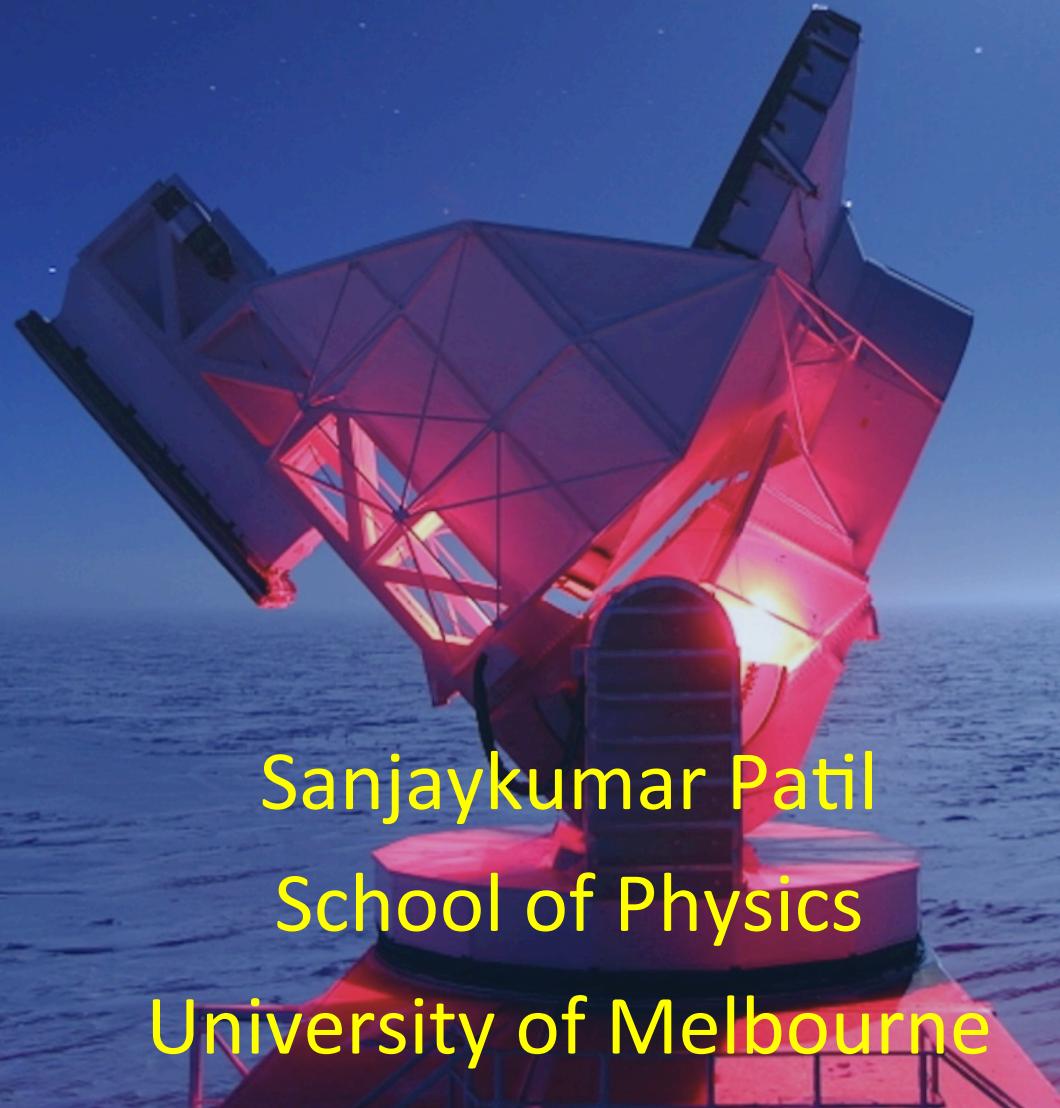


Measuring the mass of galaxy clusters using CMB lensing



Sanjaykumar Patil

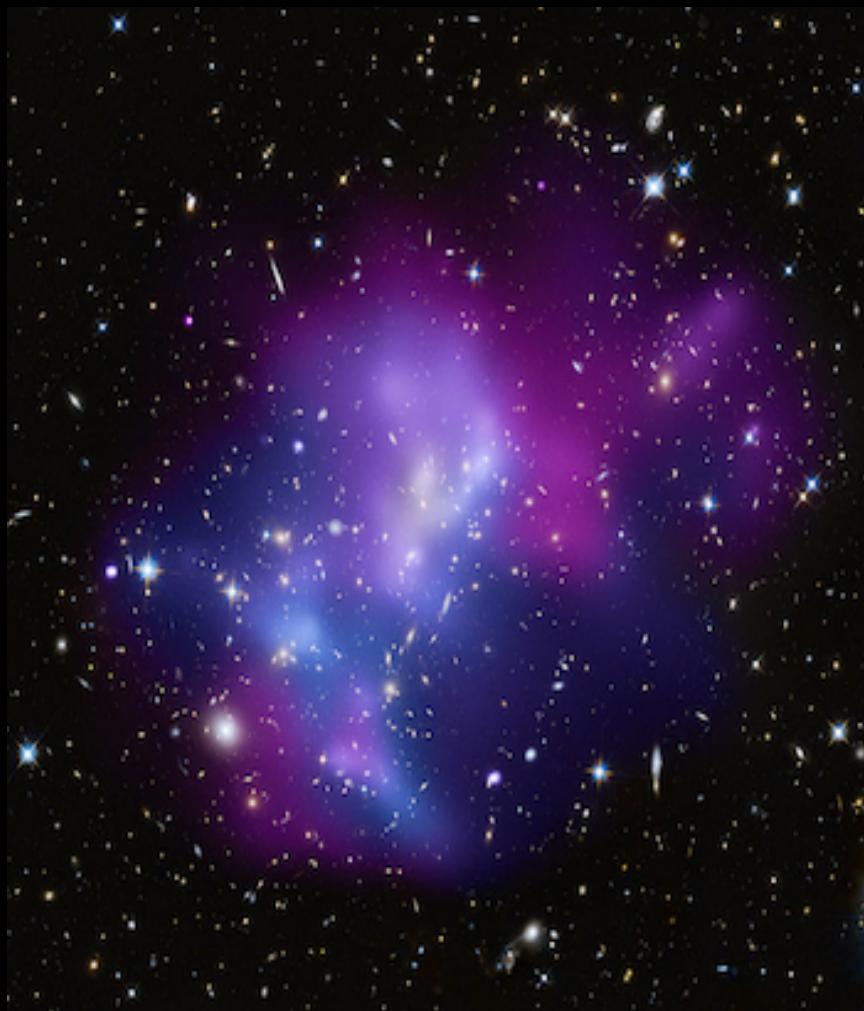
School of Physics

University of Melbourne

Overview

- Probing Dark Energy with Galaxy Clusters
- Better mass estimates with CMB lensing

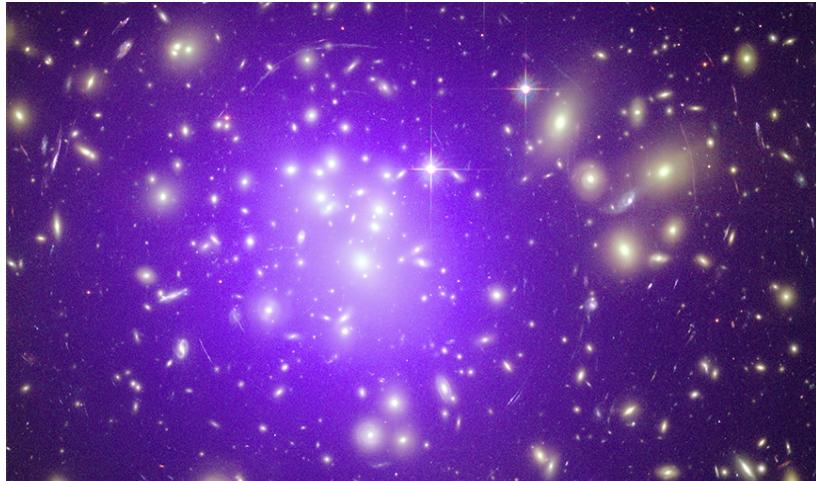
Galaxy clusters



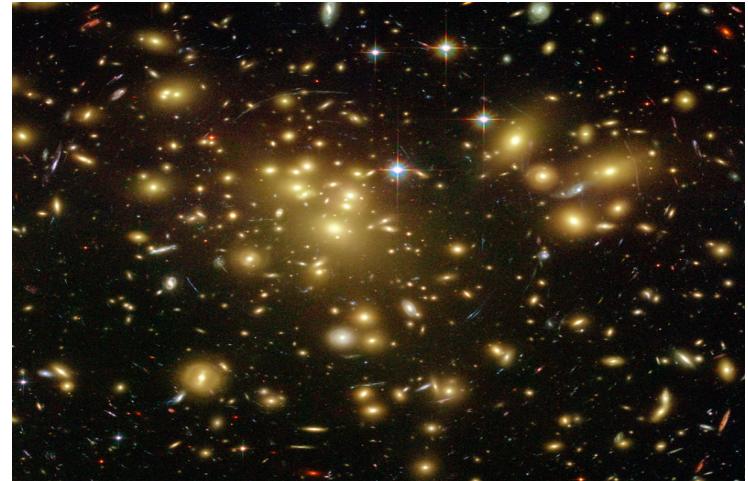
- largest gravitationally bound objects in the Universe.
- 100s to 1000s of galaxies
- Mass ranging from 10^{13} – 10^{15} solar masses

MACS/0416 galaxy cluster -chandra

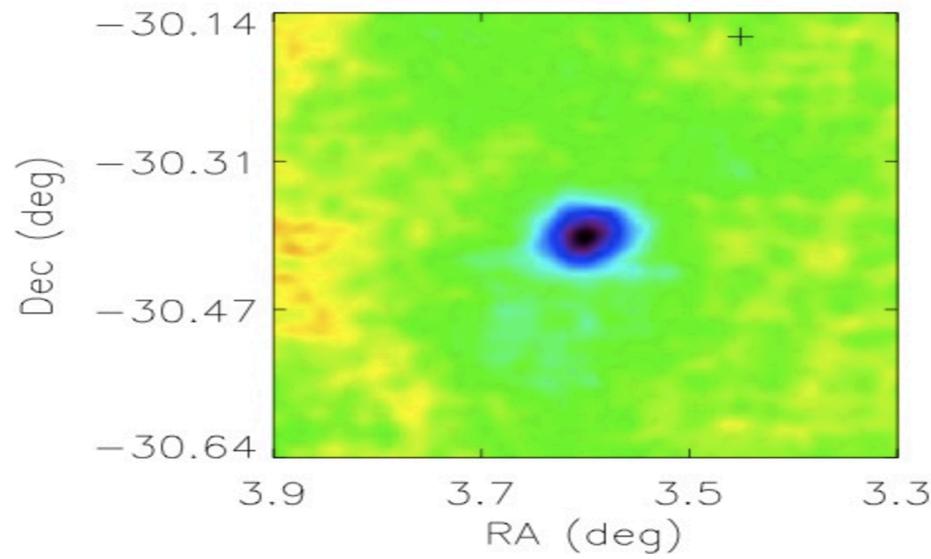
Clusters at multiple wavelengths



Abell 1689 in X-ray



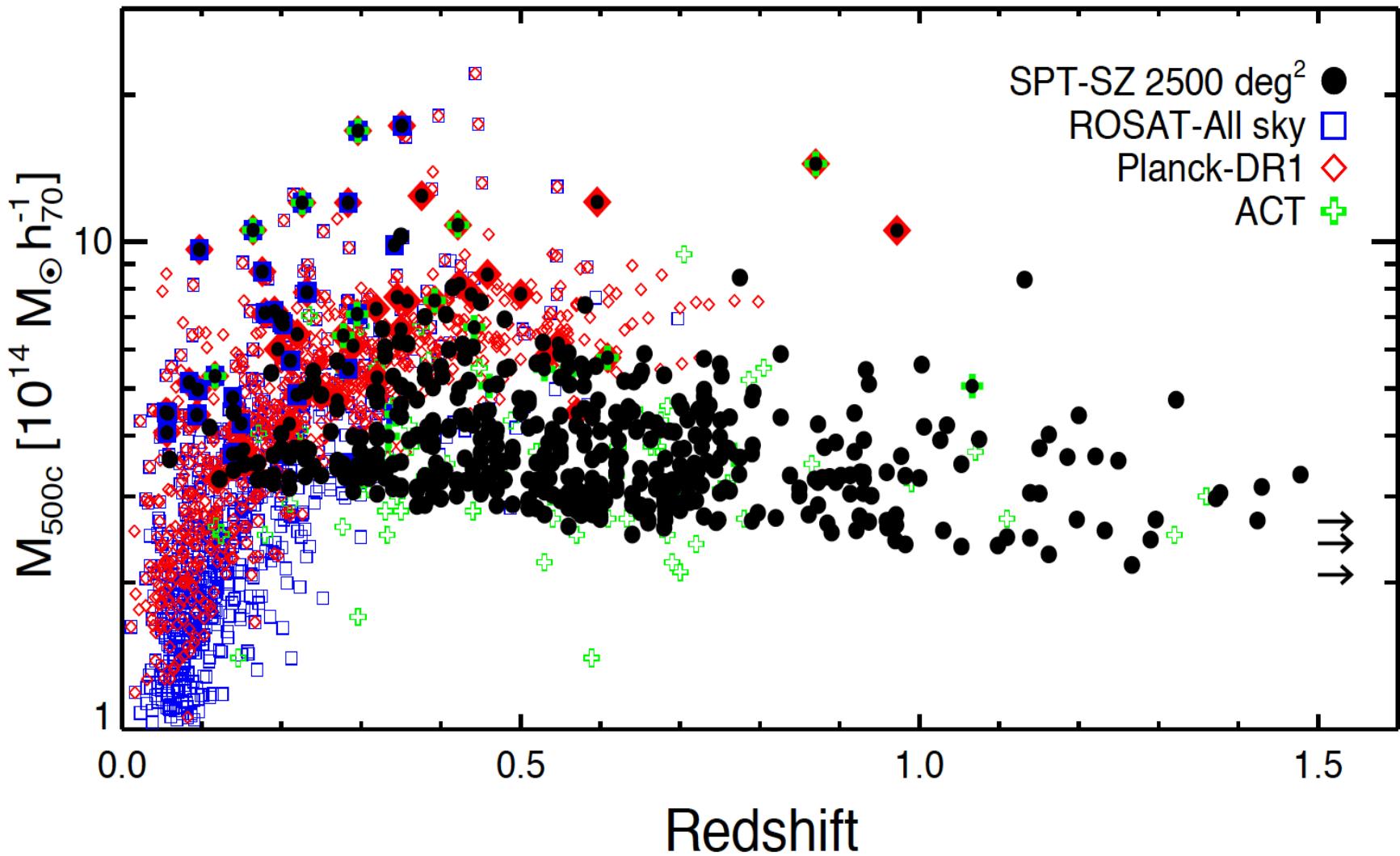
in Optical



At mm-waves (150 GHz)

Mass vs Redshift distribution

13



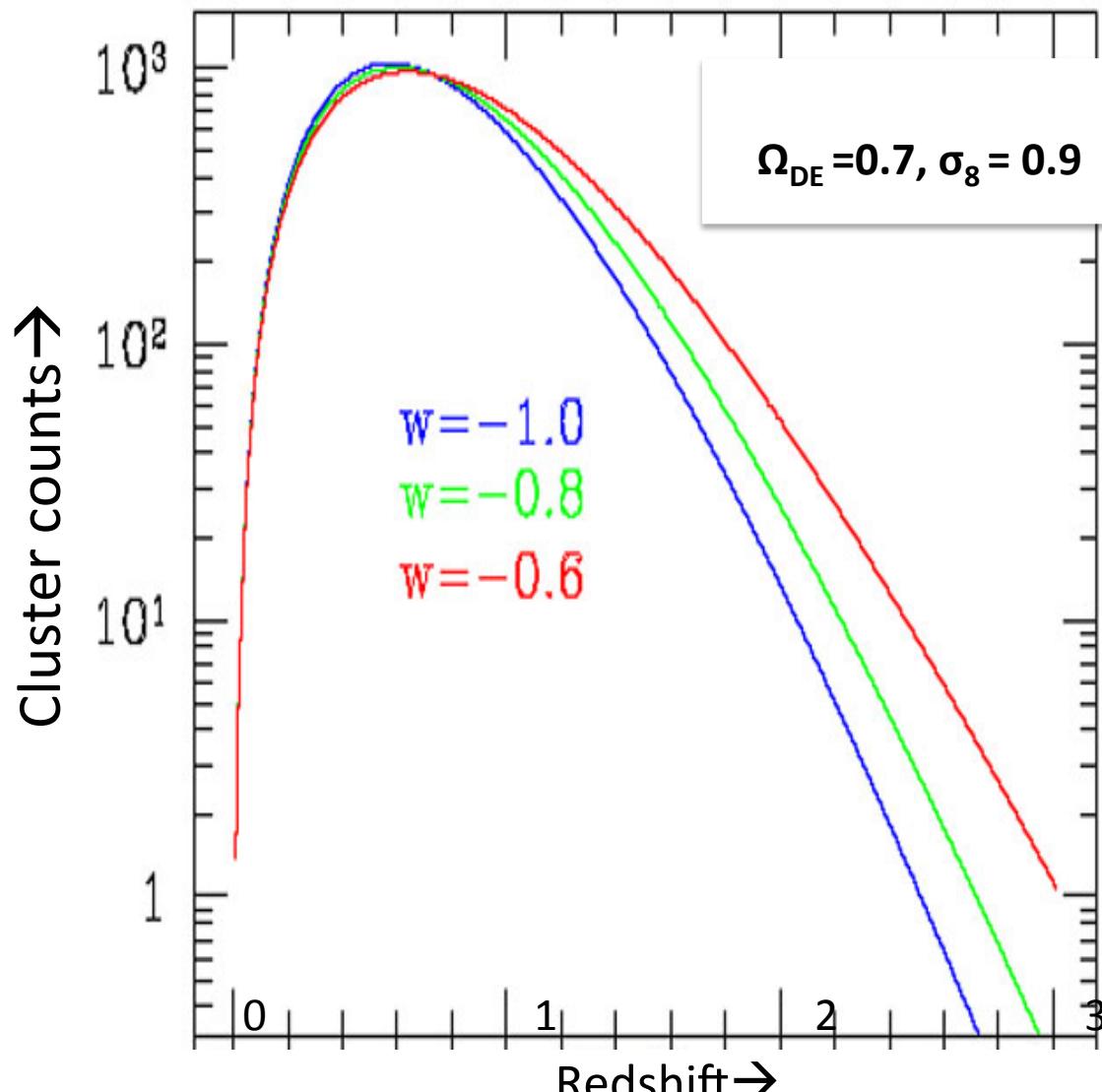
Source: Bleem et al., 2015

Tug of war

- Gravity pulls matter together
- Dark energy accelerates the expansion of the universe
- Slows down the process of structure formation
- Study of the large scale structure gives essential information on dark energy

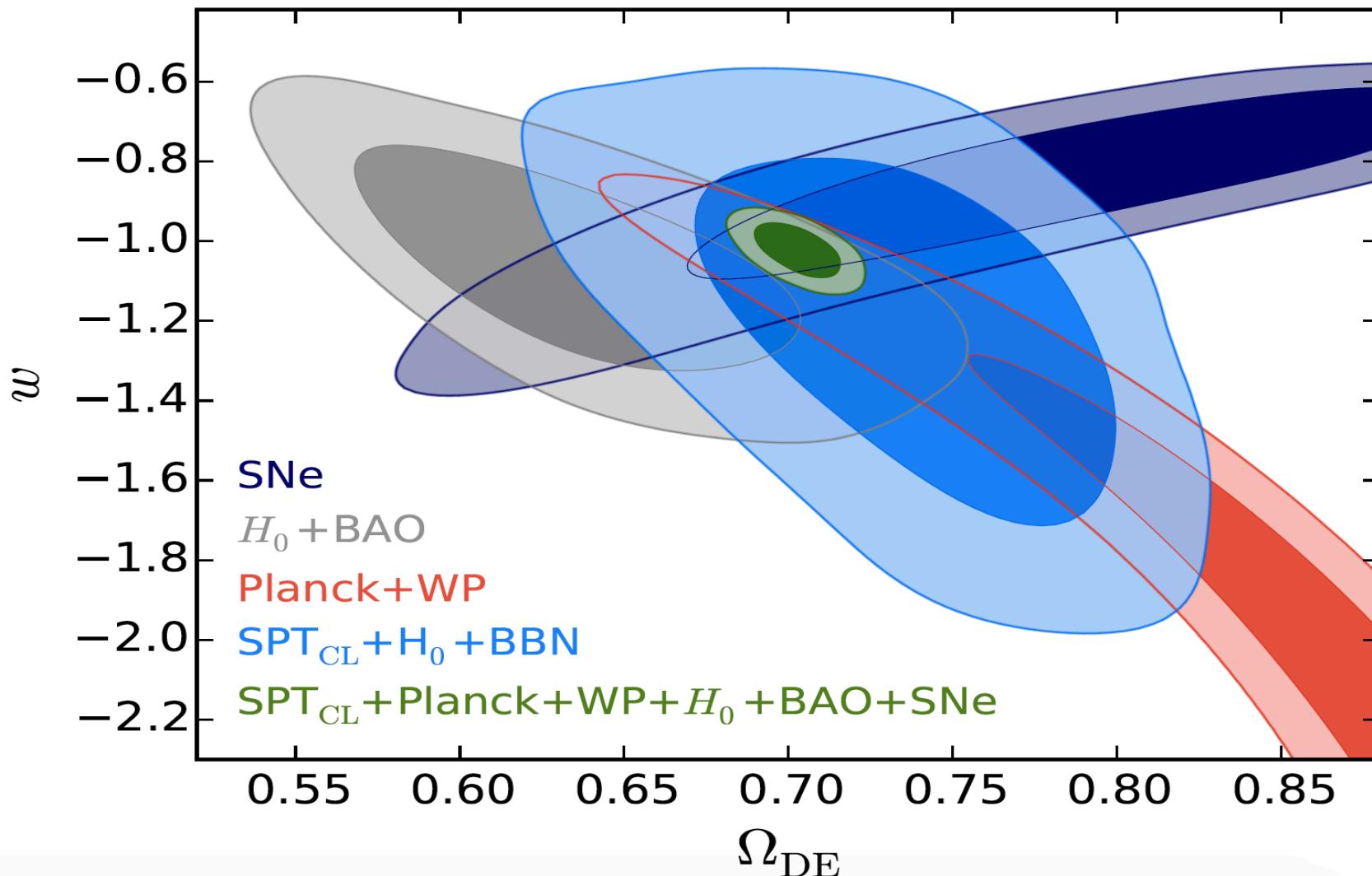
Dark energy constraints from Clusters

- It takes billions of years to form galaxy cluster.
 - late enough to feel dark energy
- Number density of galaxy clusters is sensitive function of dark energy parameters



Mohr et al., 2005

Current probes of dark energy



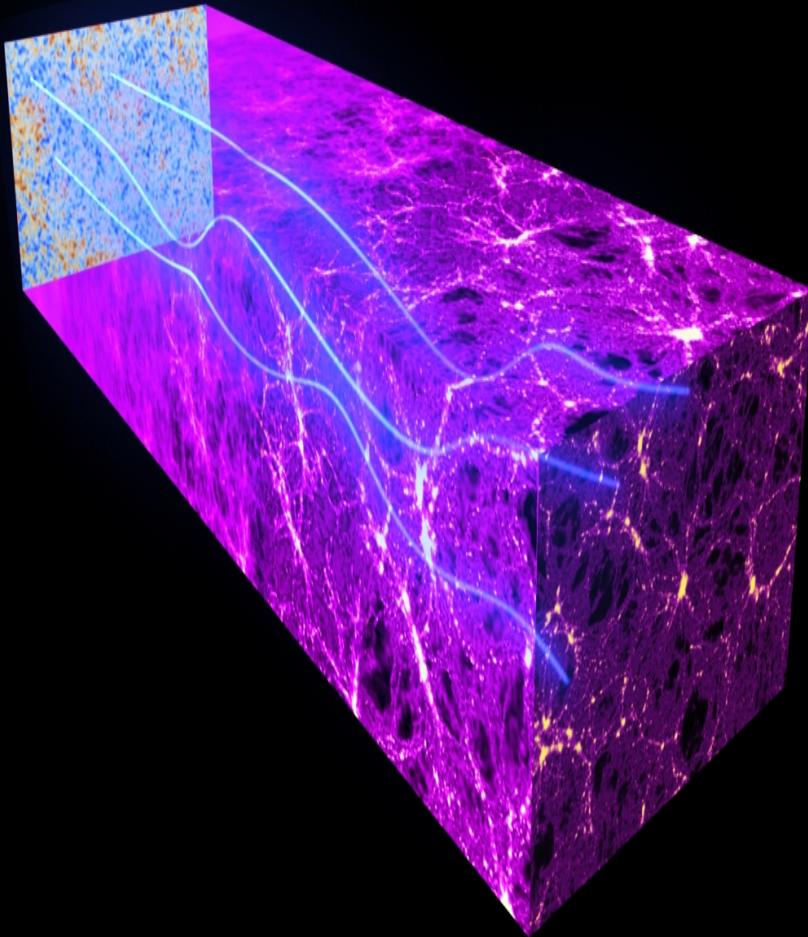
Different mass estimators

- Y_{sz} – Mass scaling relation
 - No relativistic effects
- Y_x – Mass scaling relation
 - Hydrostatic assumption
- Gravitational lensing
 - unbiased

Overview

- Probing Dark Energy with Galaxy Clusters
- *Better mass estimates with CMB lensing*

CMB lensing



1 arcminute distortion for a massive cluster at high redshift

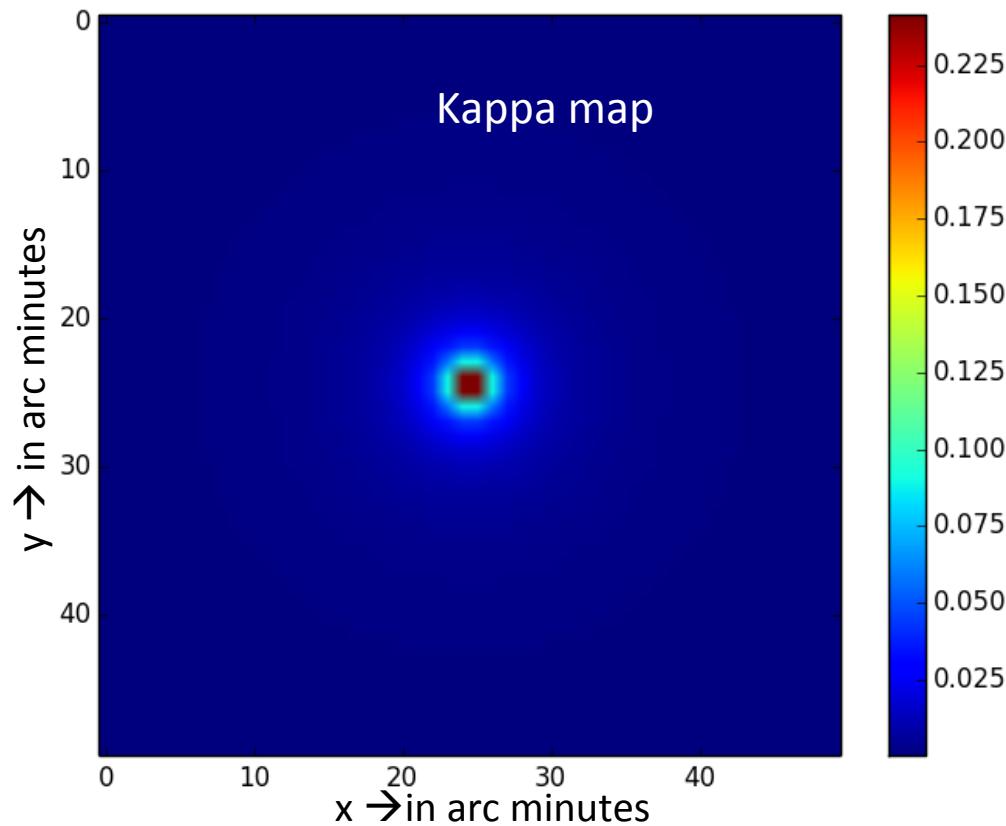
Weak signal $\sim 5 \text{ uK}$ in Temperature and 0.2 uK in Polarisation

Gives an unbiased estimate of average mass of cluster sample

Compared to optical

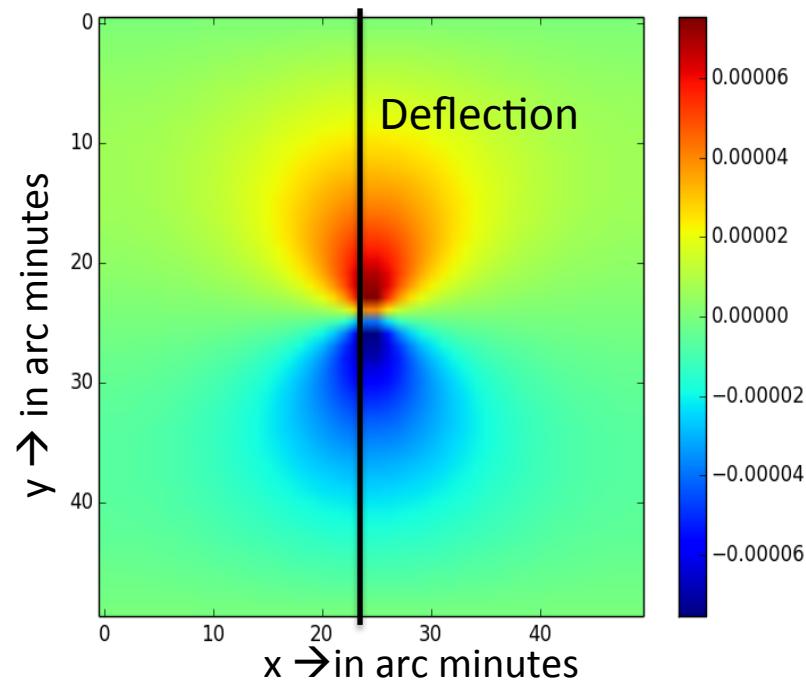
- CMB well behind all the clusters
- At known red shift
- Has well understood statistical properties

Extracting lensing signal

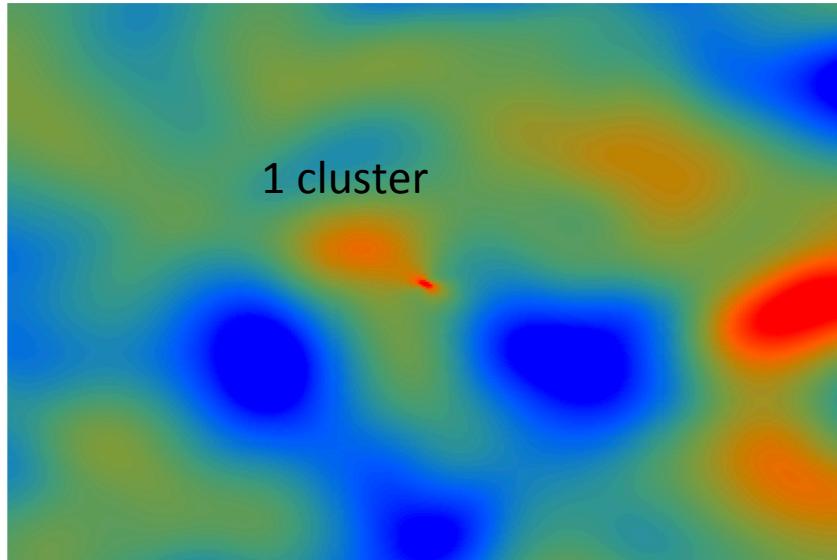


Background CMB on galaxy cluster length scales is approximated as gradient
Lensing results a dipole along the gradient direction

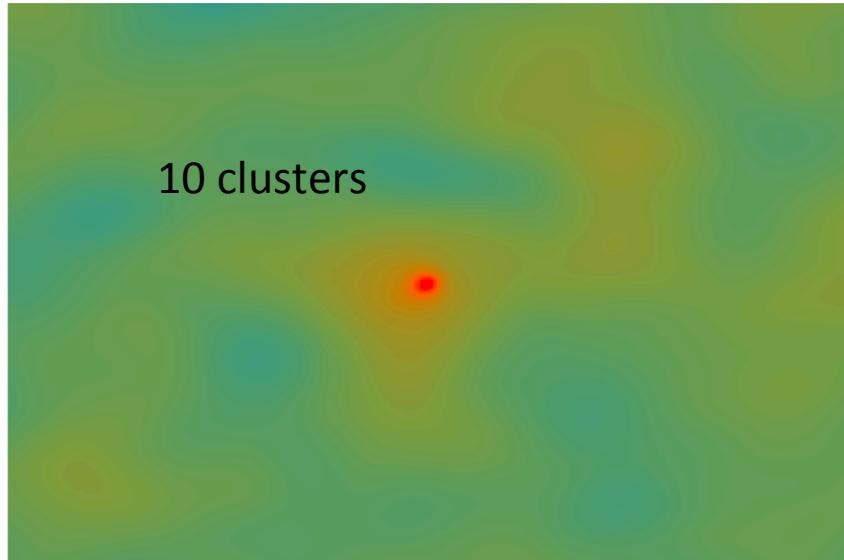
Cluster mass : $5 * 10^{14}$ solar mass
Redshift : 0.7
NFW profile (concentration parameter : 3.0)



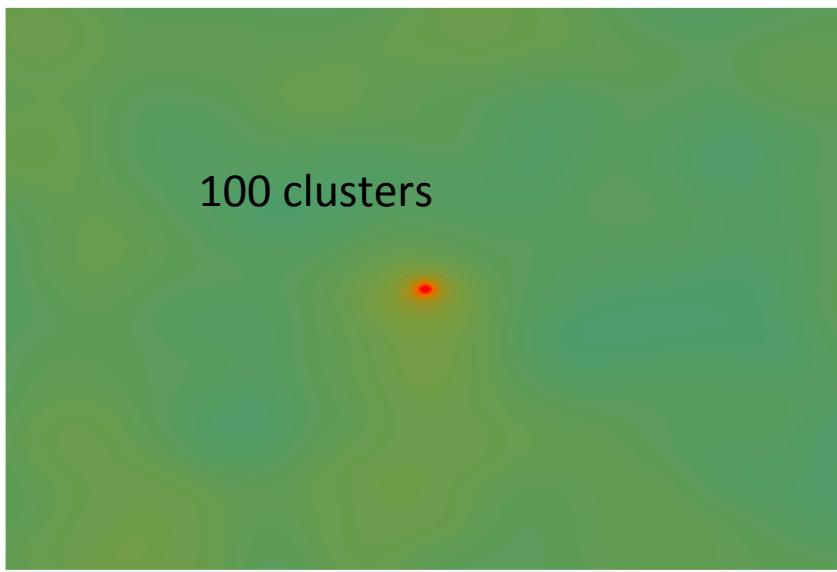
Stack galaxy clusters to improve SNR



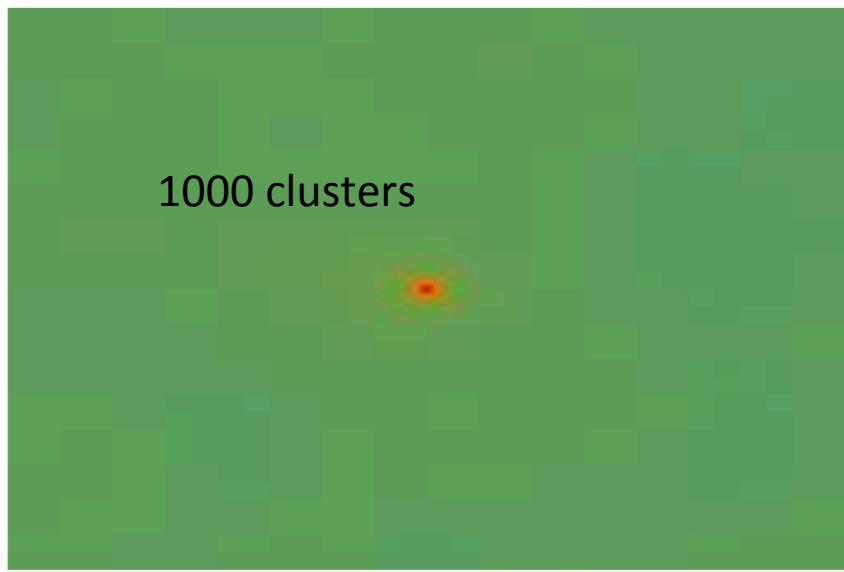
1 cluster



10 clusters

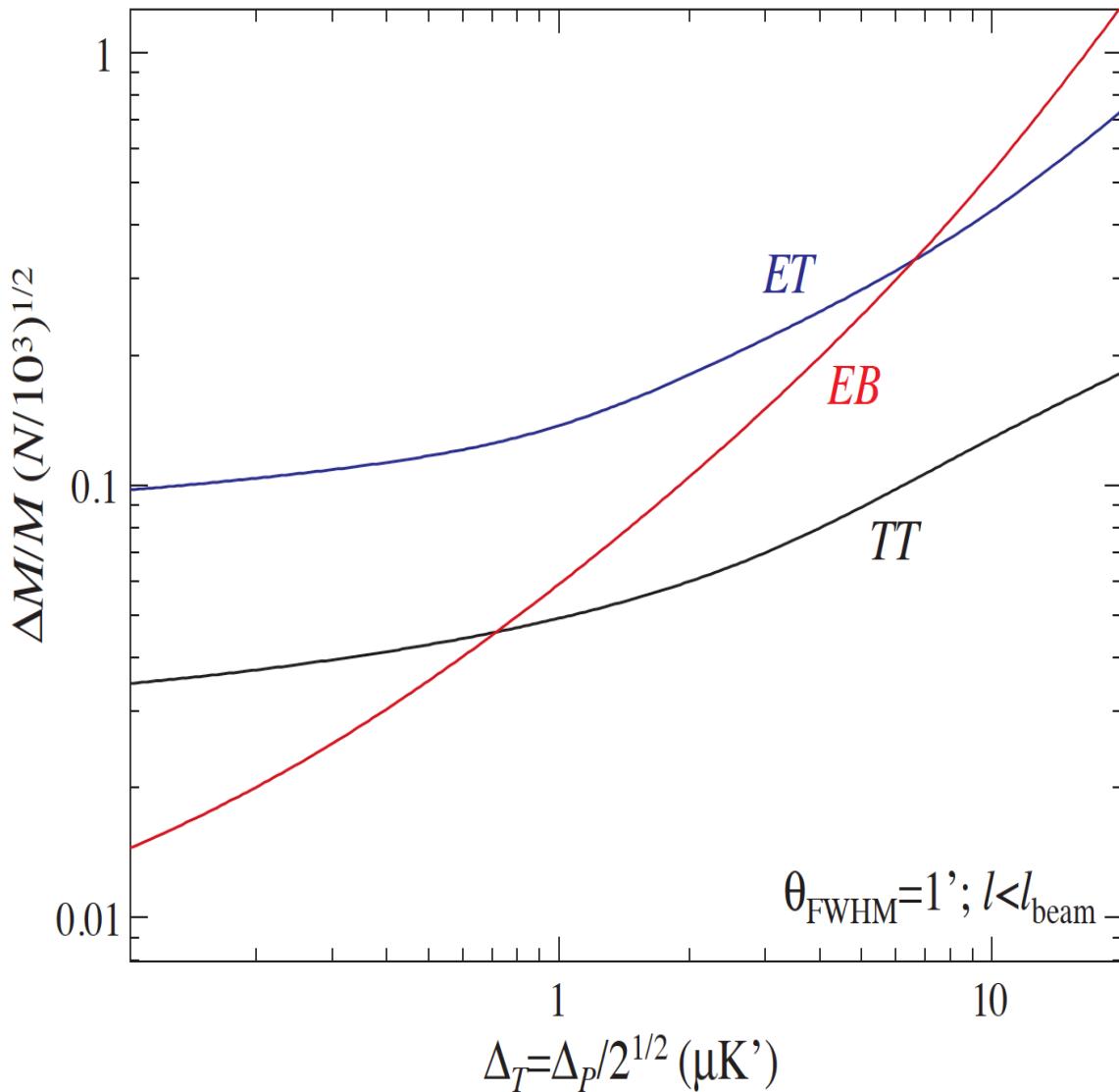


100 clusters



1000 clusters

Future is polarisation



Foregrounds hurt TT

SPTPol noise:

Pol: 10uK

T: 8uK

FG-cleaned T: 27uK

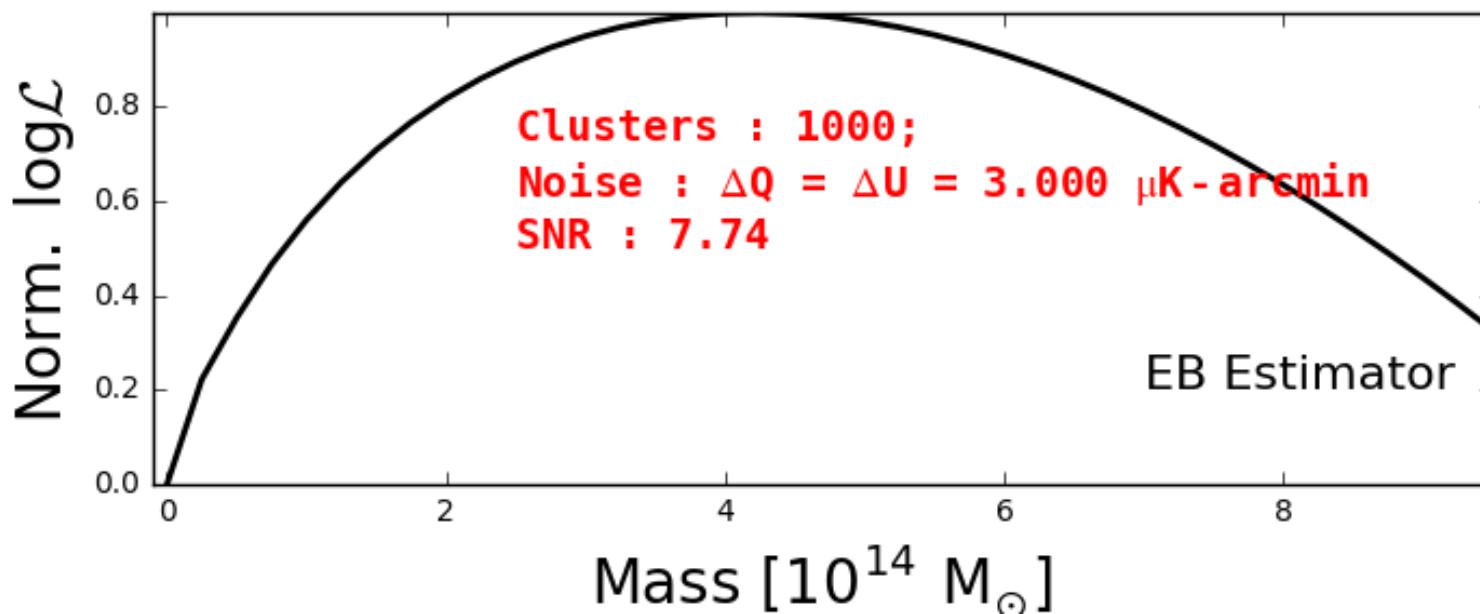
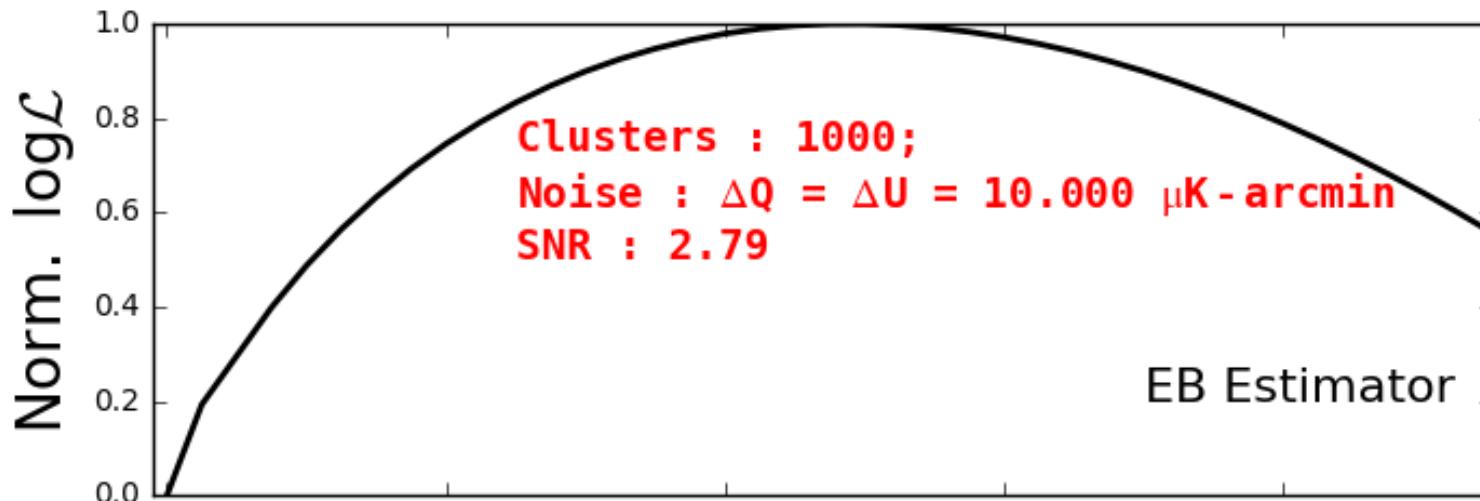
SPT-3g noise:

T = 2.5 uK

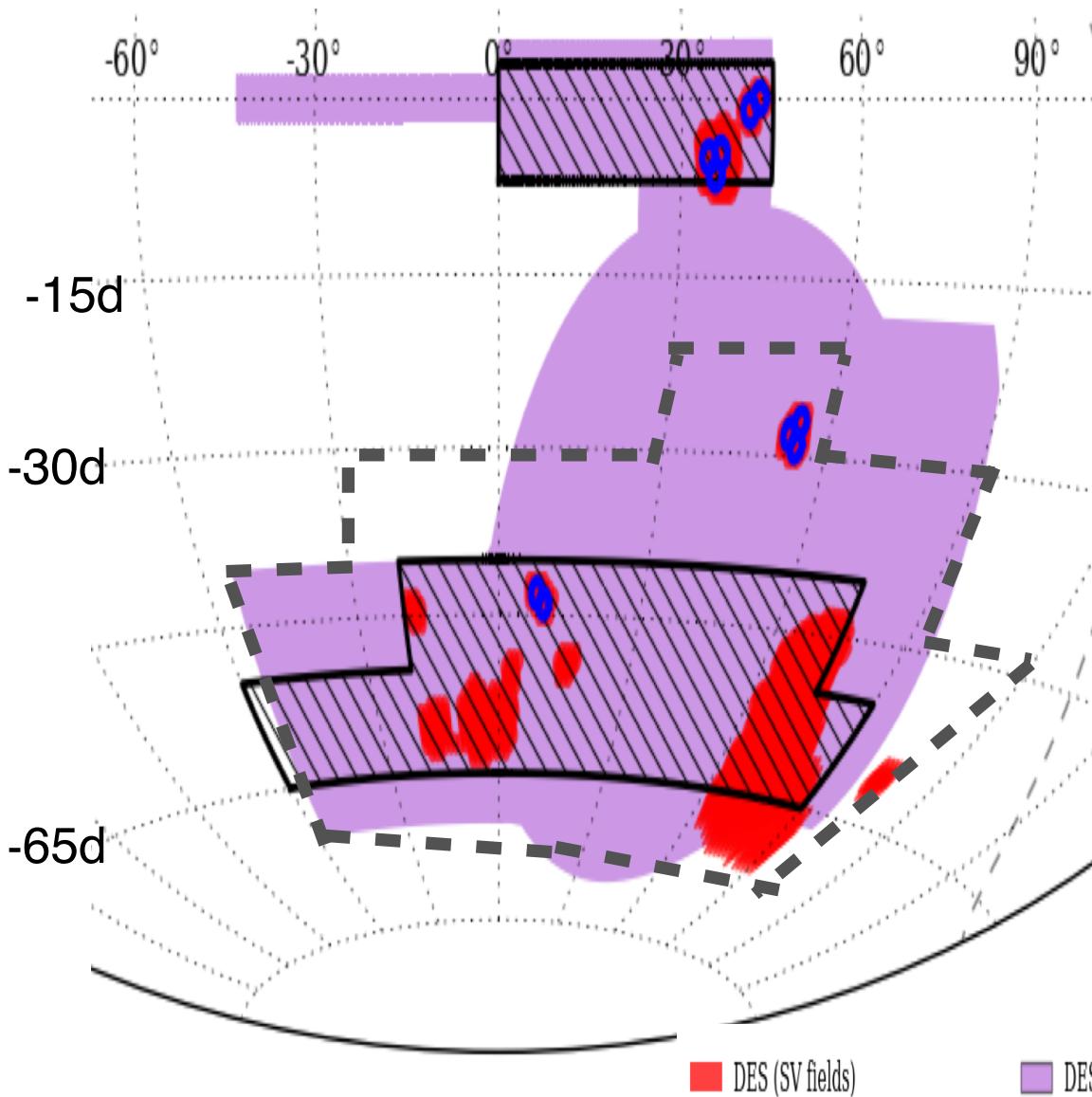
Pol = 3.5 uK

FG-cleaned T: 9uK

Expected SPTpol results



Dark Energy Survey



DES 100,000
Clusters

DES survey area
5000 deg²

SPTpol 500deg²

DES Footprint
SPT Footprint --

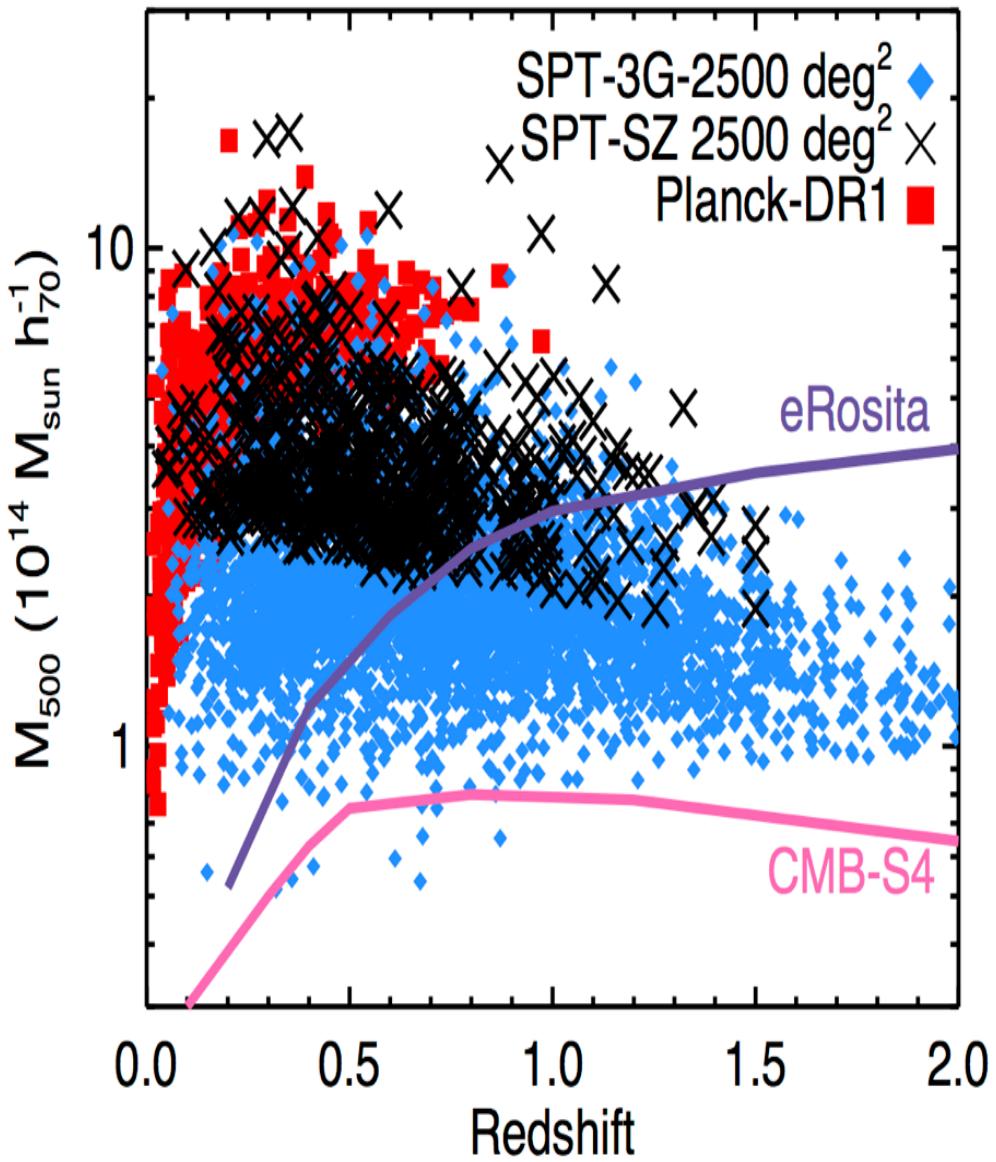
■ DES (SV fields)

■ DES (round-13)

■ DES (Year 1)

■ DES (SN fields)

SPT – 3g



Third generation polarization sensitive camera

2500 deg 2 , 15k detectors

~10 times lesser noise levels

~ 8000 galaxy clusters

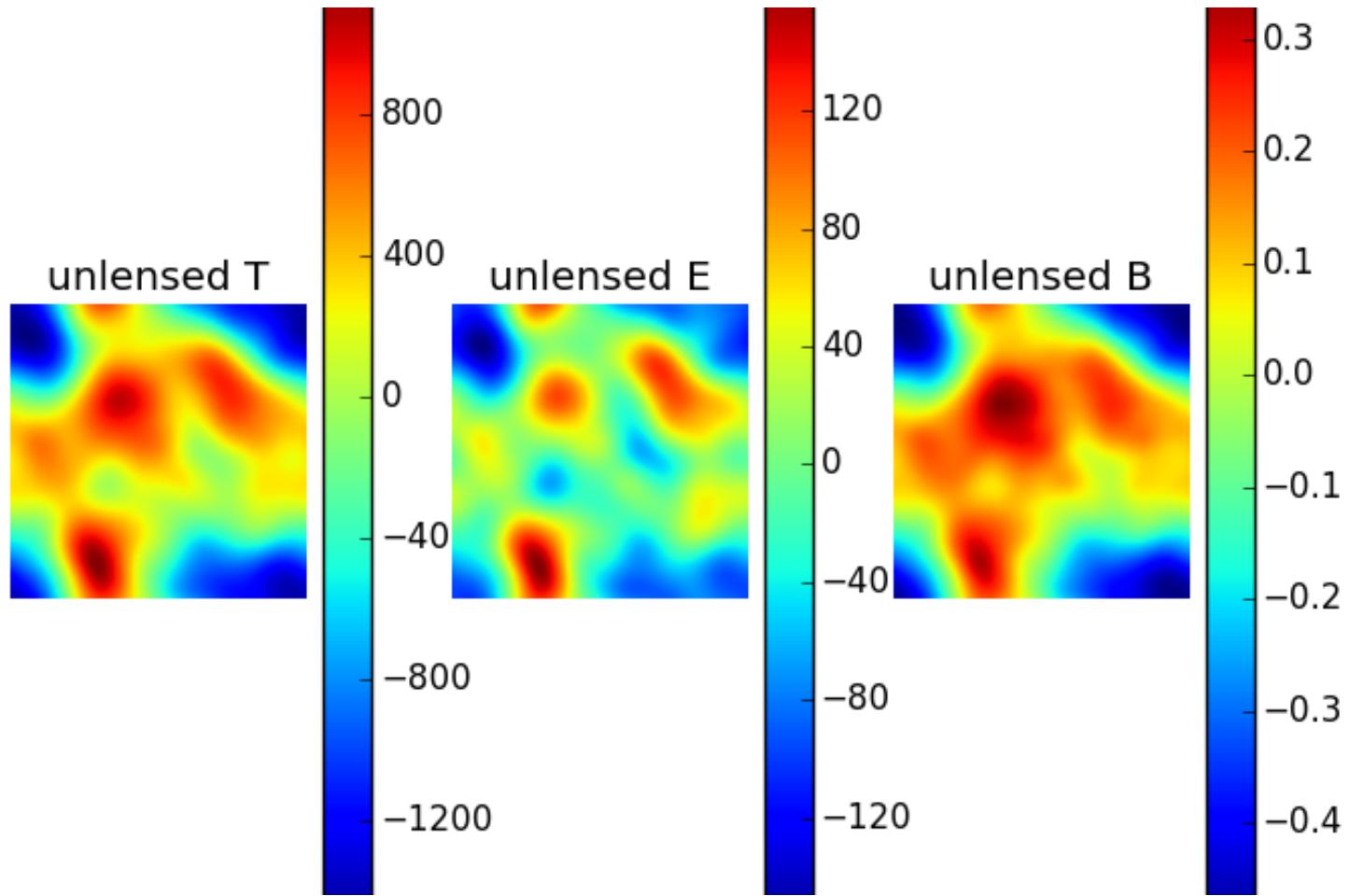
SPT-3G: $\sigma(M) \sim 3\%$

CMB-S4: $\sigma(M) \sim 1\%$

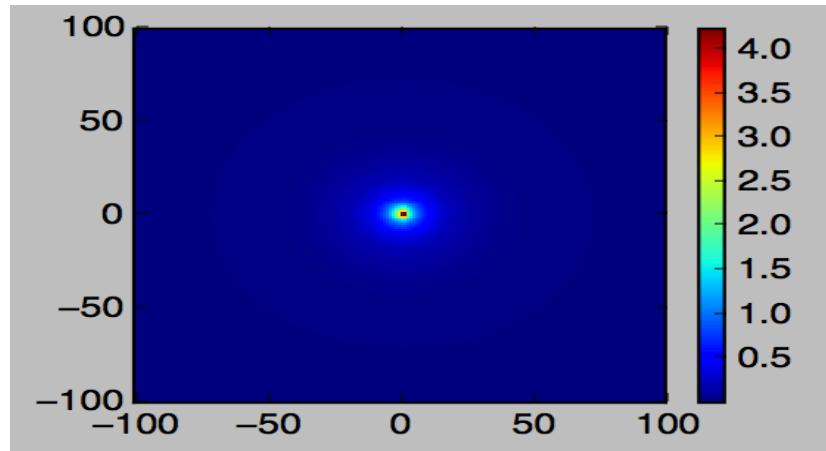
Conclusion

- Galaxy clusters are powerful probes of cosmology
- Current constraints are limited by 15 percent mass uncertainty
- For SPT 3g with CMB lensing we can reduce this to 3% and 1% for CMB-S4

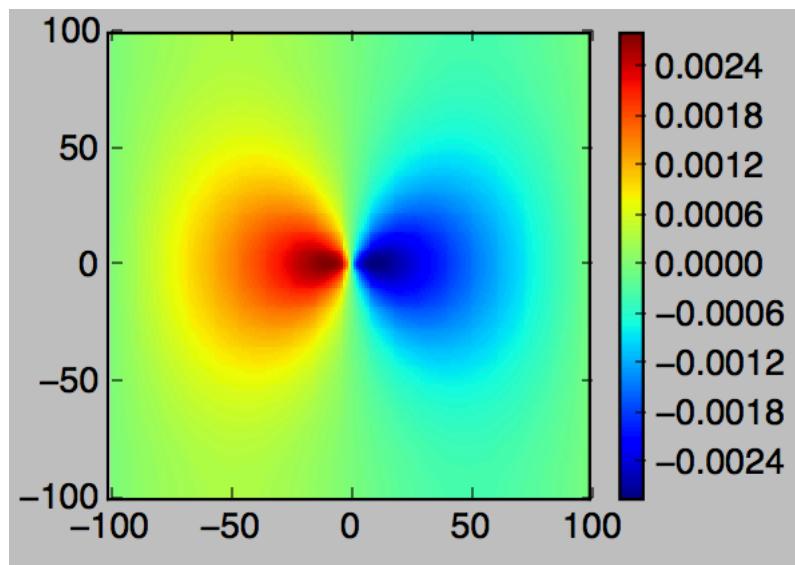
Unlensed modes



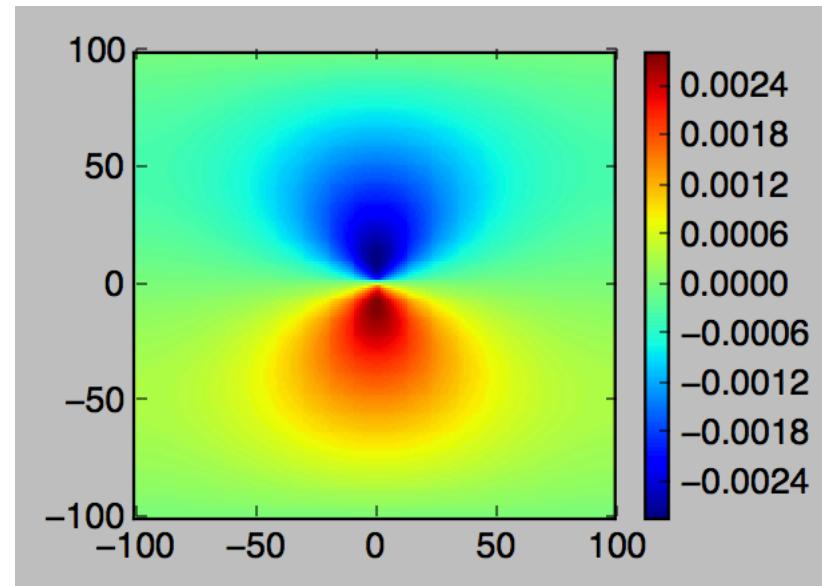
Modeling the lensing.



Deflection
Potential due to
galaxy cluster

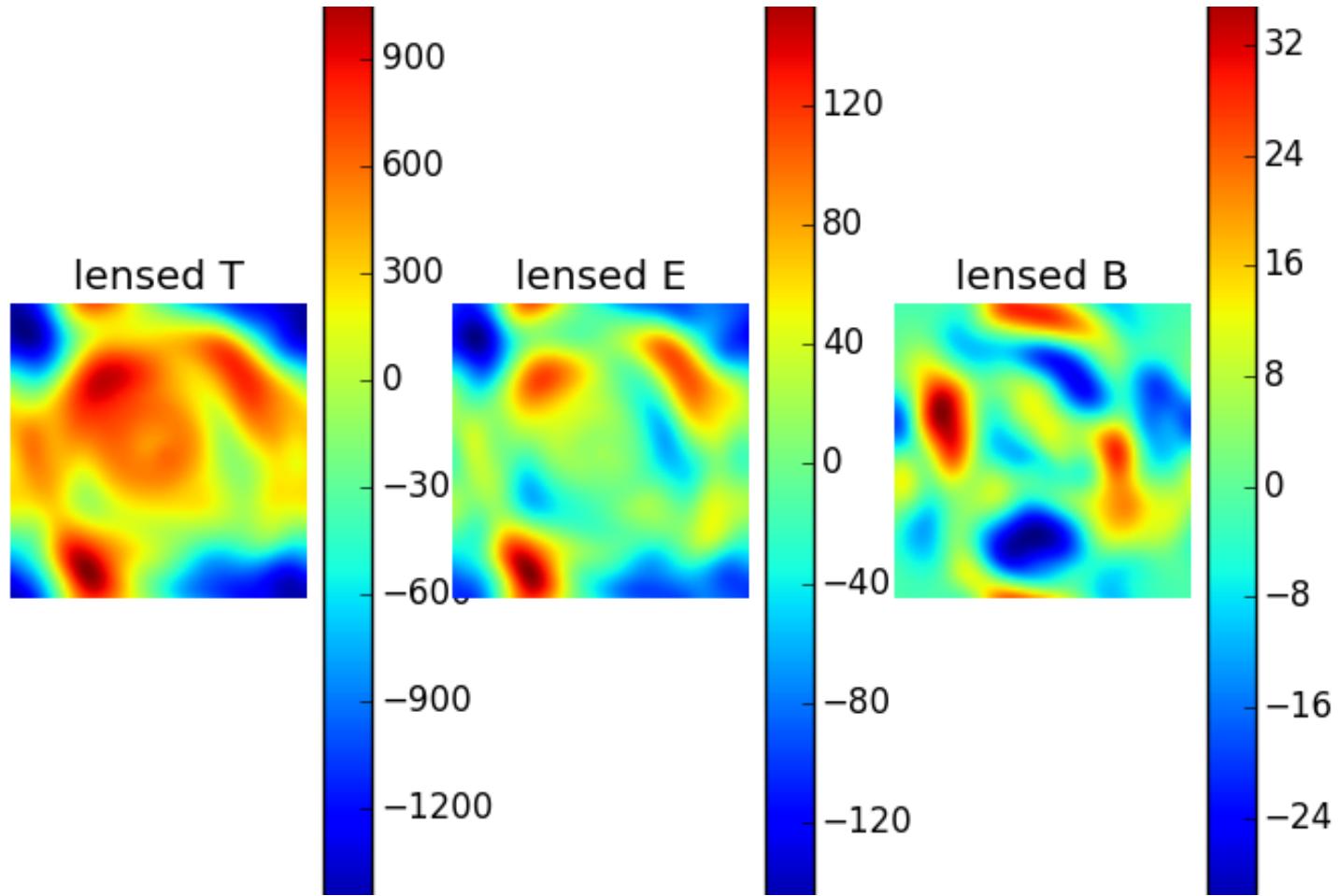


Deflection field along X



Deflection field along Y

Lensed modes



Maximum Likelihood

$$L(\mathbf{C}|\vec{d}) = \frac{1}{\sqrt{(2\pi)^{N_{pix}} \det \mathbf{C}}} \exp\left[-\frac{1}{2} \vec{d}^T \mathbf{C}^{-1} \vec{d}\right]$$

$$\mathbf{C}_{CMB} + \mathbf{C}_{foregrounds} + \mathbf{C}_{noise}$$

\mathbf{d} → is the pixelized polarization data

\mathbf{C} → is the covariance between these pixels

Combining Likelihood

- Signal from single galaxy cluster is weak.
- Combine constraints from many clusters to obtain significant detection

$$L_{total}(M) = \prod_i^{N_{clusters}} L_i(M)$$

- T estimator: noise = 3.0 → 1000 clusters = 25.2; 8000 clusters = 71.215
- noise = 10 uK-arcmin → 1000 clusters = 11.87
- EB; noise = 3.0 → 1000 clusters = 7.74; 8000 clusters = 21.9
- noise = 10.0 uK-arcmins → 1000 clusters = 2.79