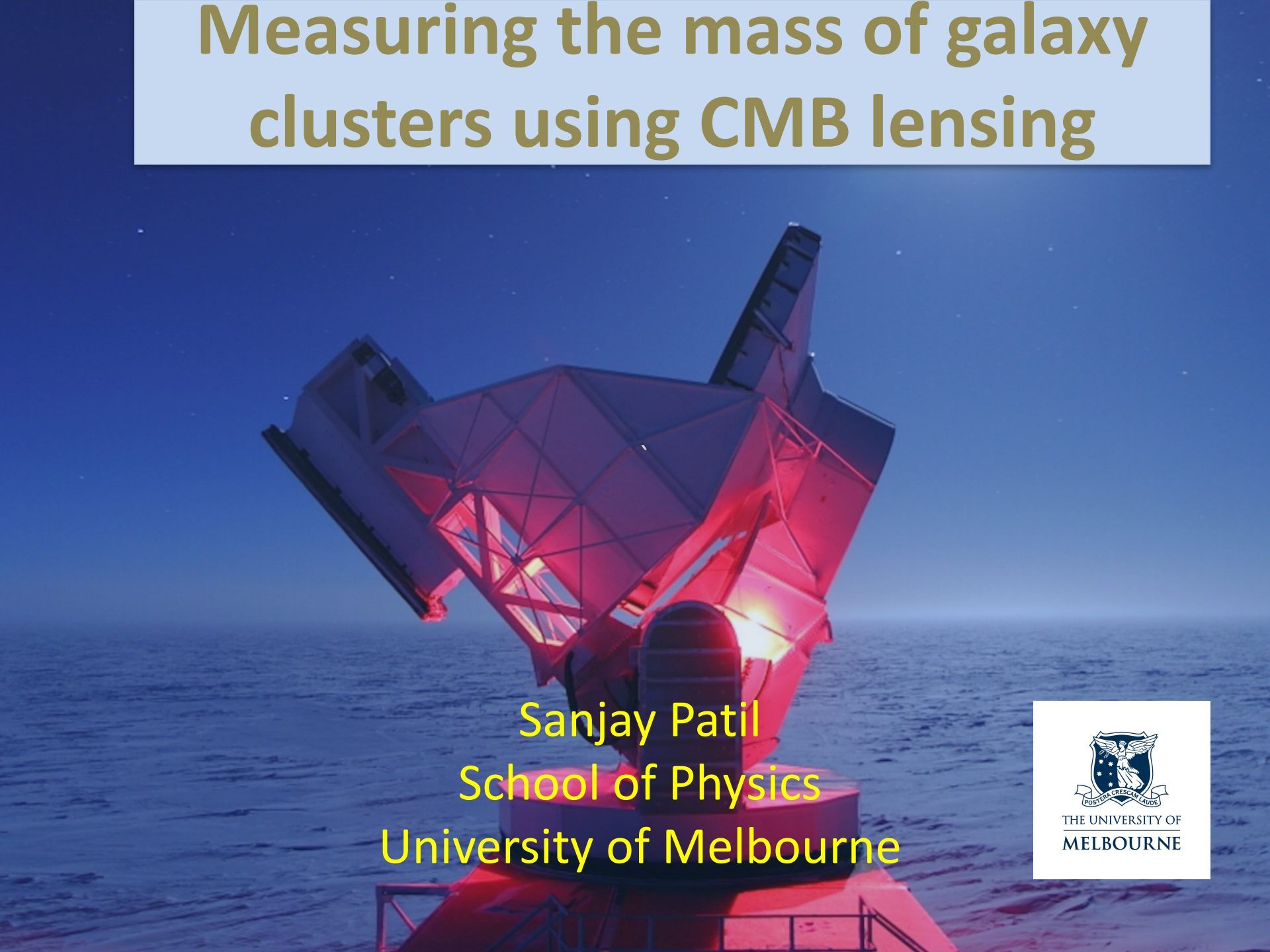
Measuring the mass of galaxy clusters using CMB lensing



Sanjay Patil
School of Physics
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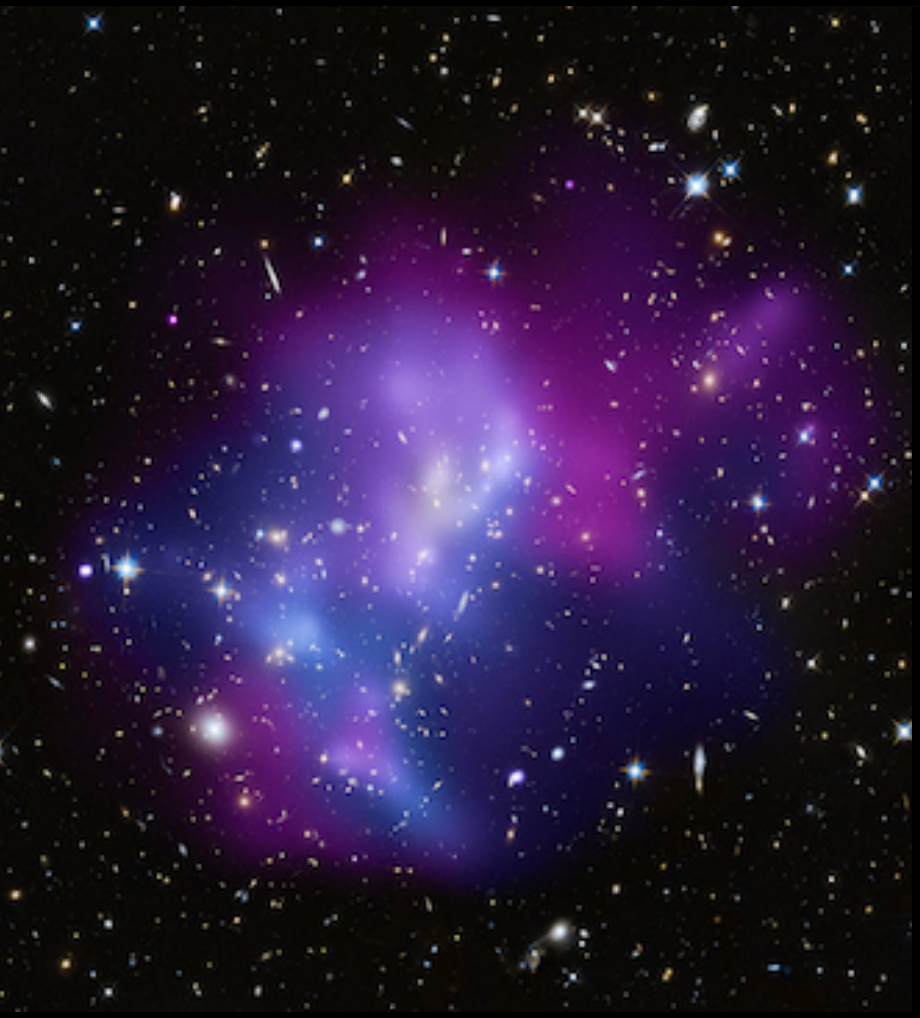
THE UNIVERSITY OF MELBOURNE

Overview

- Introduction to Galaxy clusters
- CMB cluster lensing
- South Pole Telescope and Dark Energy Survey

What are galaxy clusters?



MACS/0416 galaxy cluster -chandra

- largest gravitationally bound objects in the Universe.
- Mass ~ 10^{13} – 10^{15} $M_{\odot}$
- Three main components
  - 1 % galaxies
  - 9% ICM
  - 90% dark matter

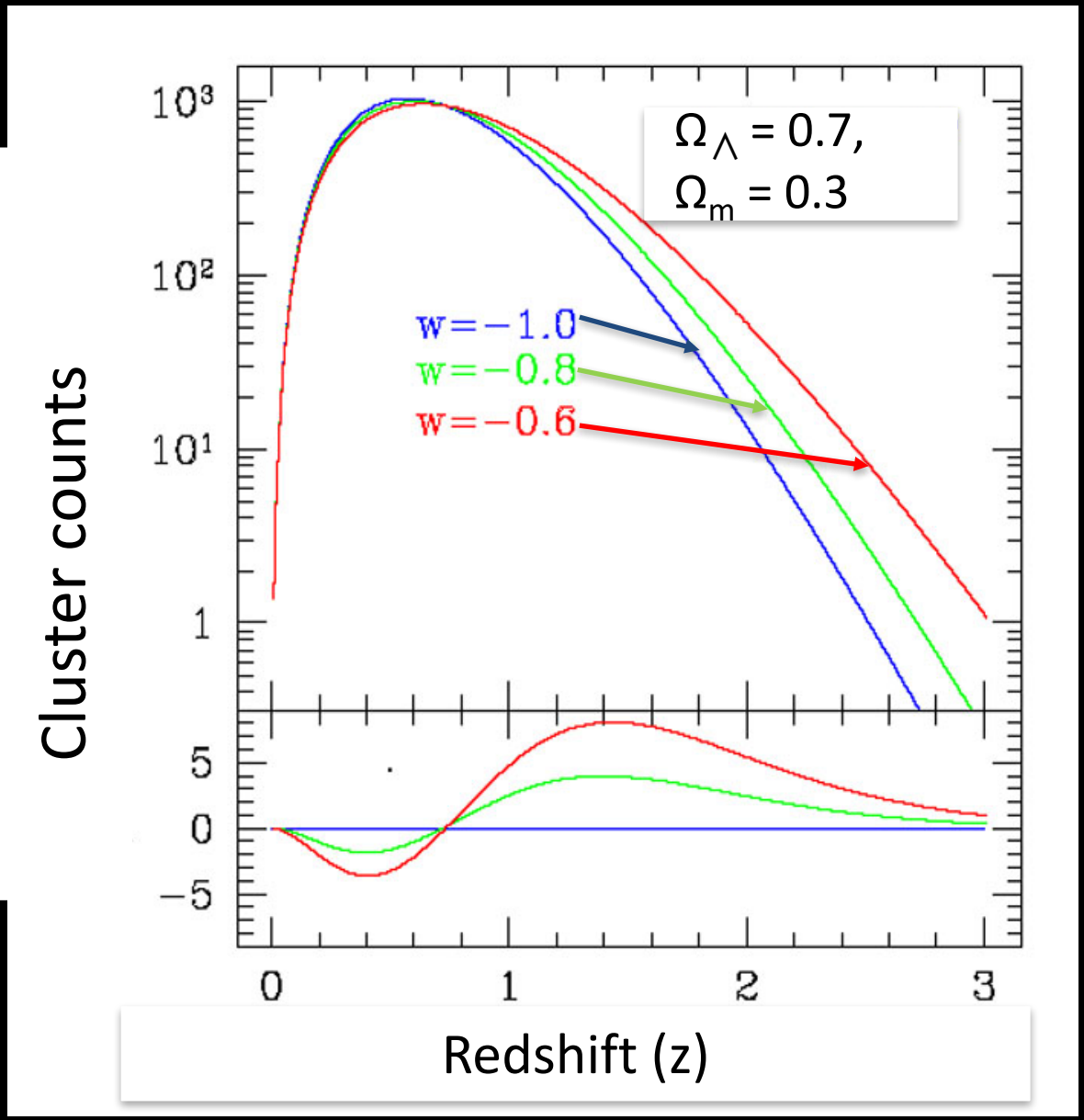
Why study Galaxy clusters?

- **Number density** of galaxy clusters is **sensitive to dark energy.**

$$\frac{d^2N(z)}{dz\,d\Omega} = \frac{r^2(z)}{H(z)} \int_0^{\inf} f(O,z)\,dO \int_0^{\inf} P(O|M,z) \frac{dn(z)}{dM} dM$$

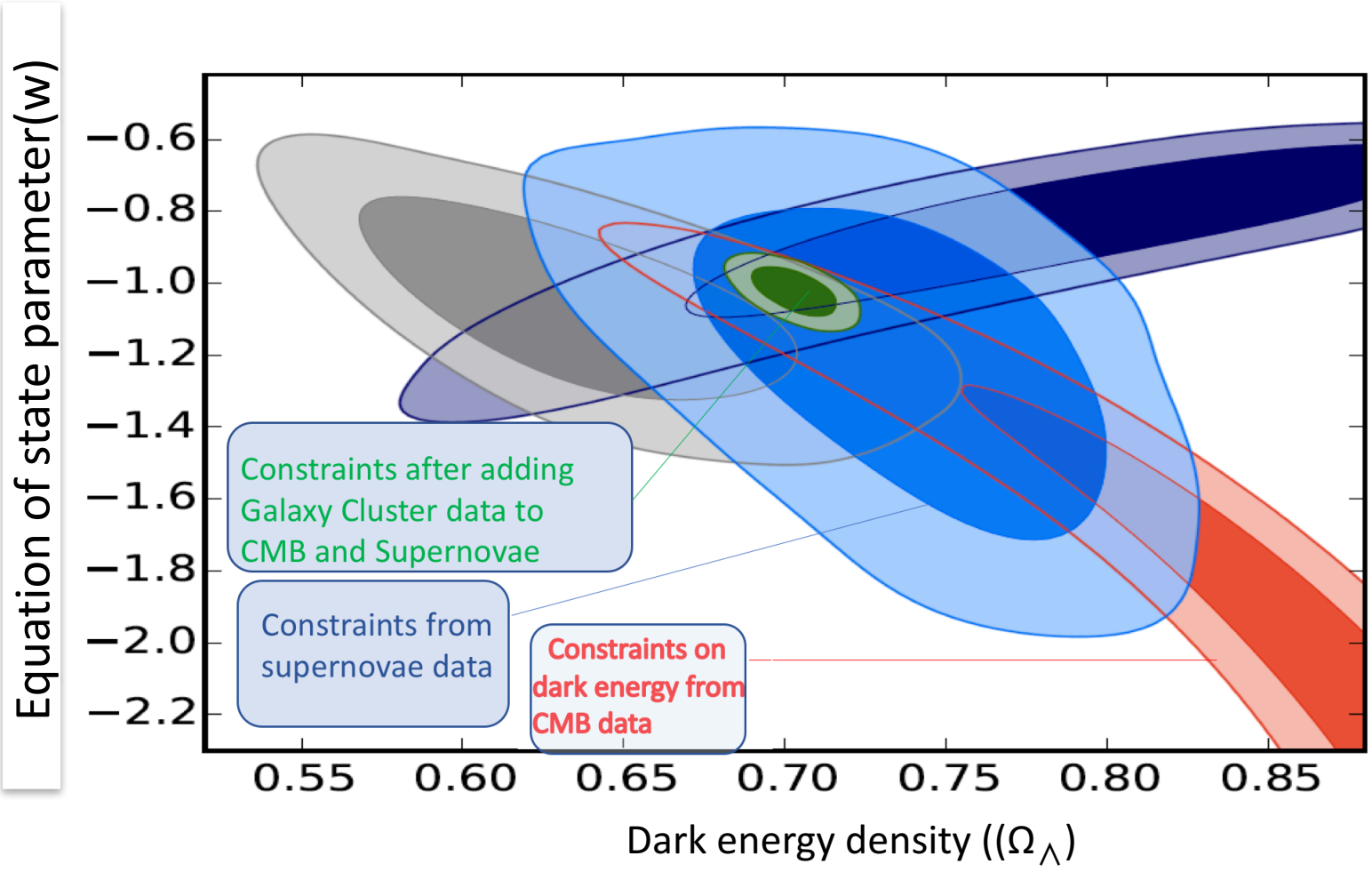
Volume element

Growth rate of perturbations



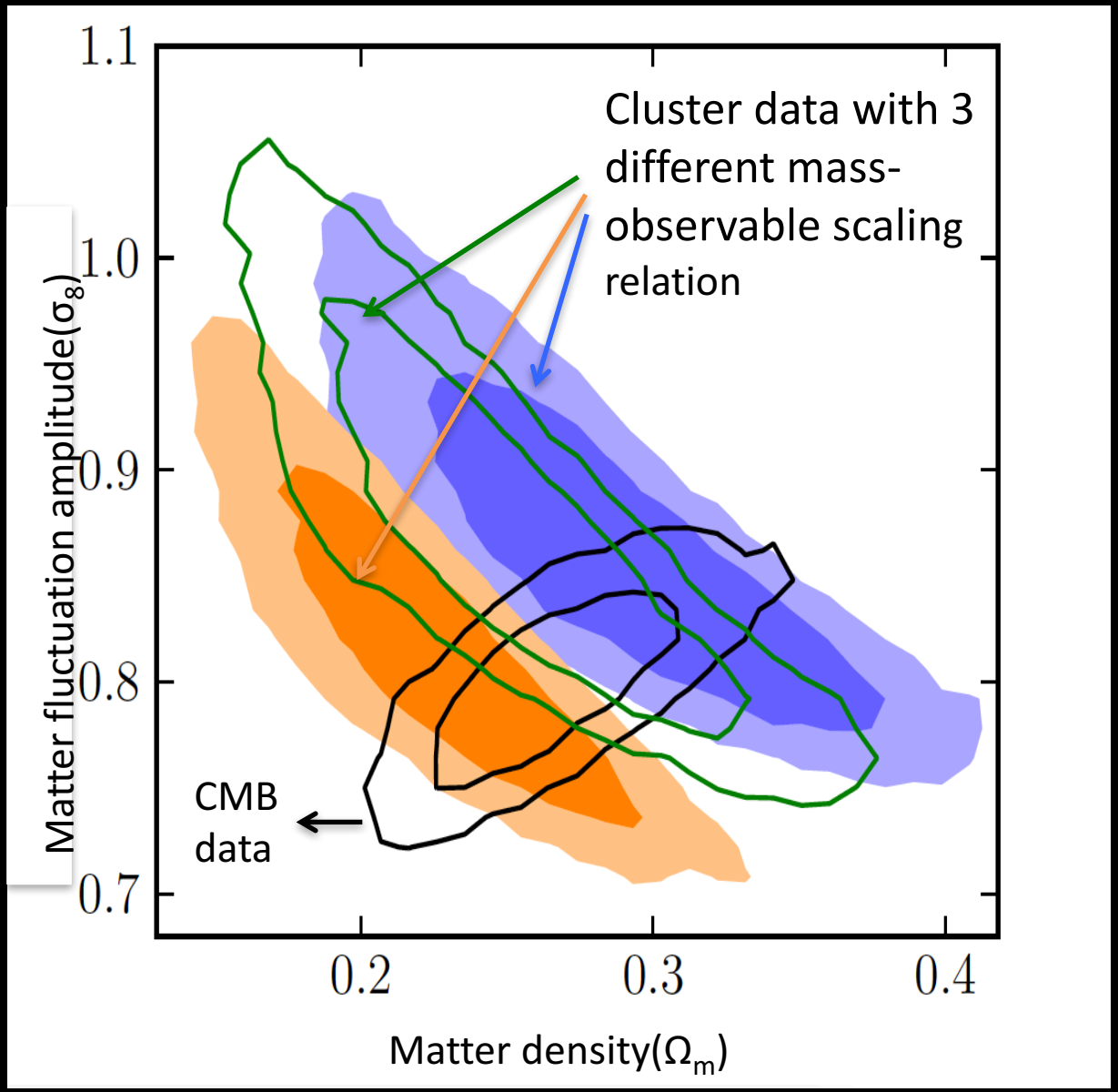
Mohr et al., 2005

Clusters improve dark energy



Tijmen de Haan et al., 2016

But limited by mass calibration…



Hasselfield et. al, (2013)

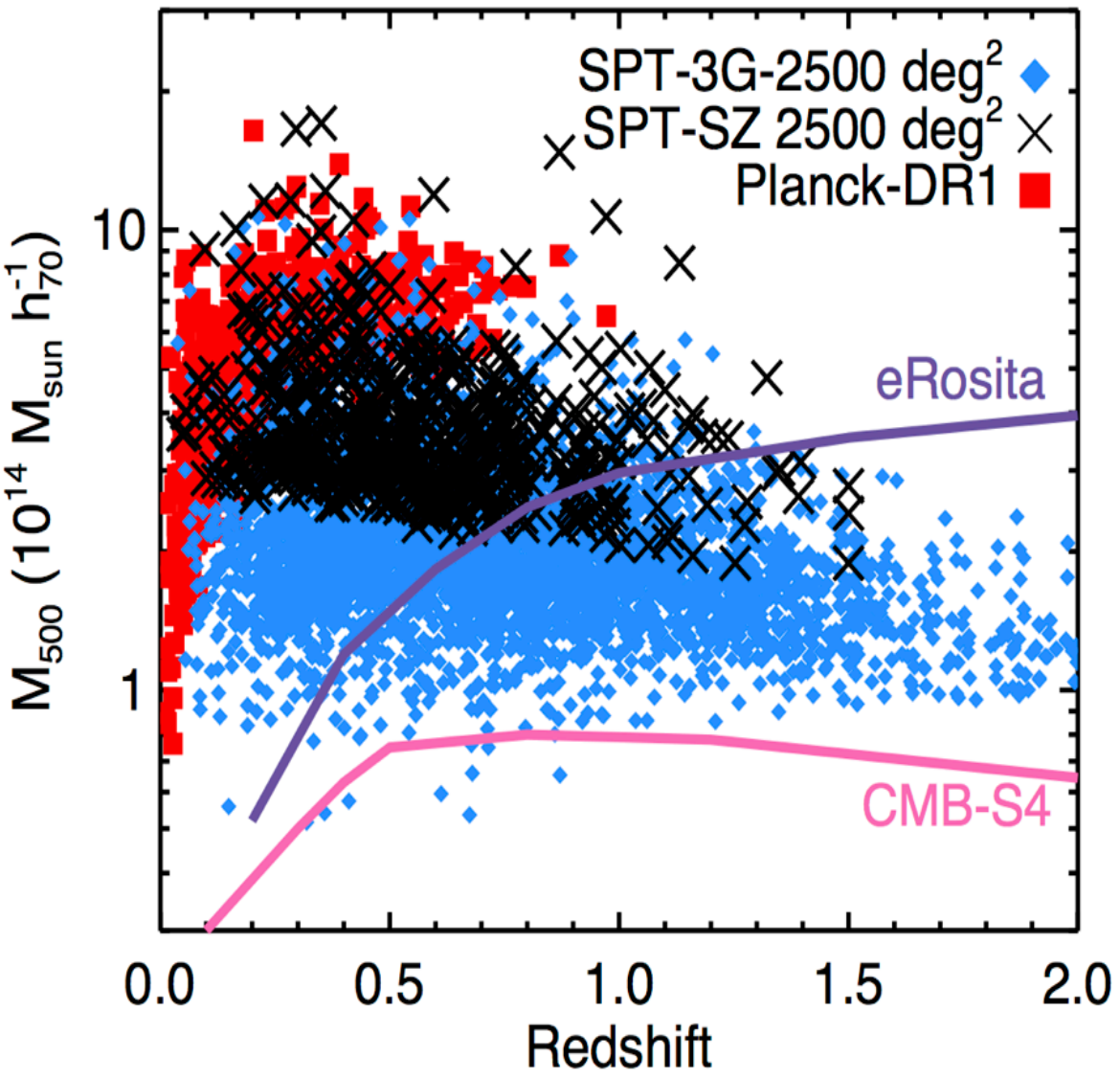
Current uncertainity ~20%

Mass scaling relation

Several mass proxies: SZ flux, cluster richness, X-ray

- Depends on baryonic physics

Larger cluster samples in future…



Benson et al ., 2014

SPT-3g is an on going experiment

expected ~10,000 clusters

eRosita is an X-ray survey

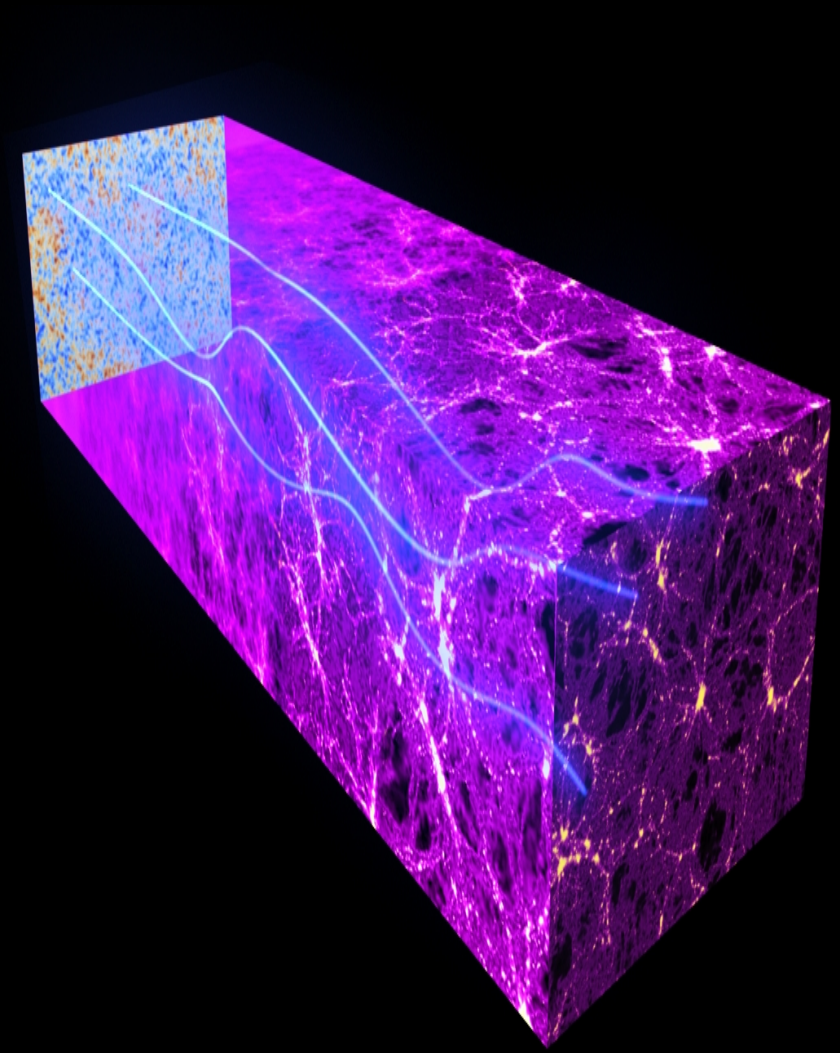
expected 75,000 galaxy clusters

To fully realize the potential of these samples we need accurate mass estimation

Overview

- Introduction to Galaxy clusters✔
- ***CMB cluster lensing***
- South Pole Telescope and Dark Energy Survey

CMB lensing



1 arcminute distortion for a galaxy cluster of mass ~10^{15} solar masses at redhsift ~1

Weaker signal than optical lensing

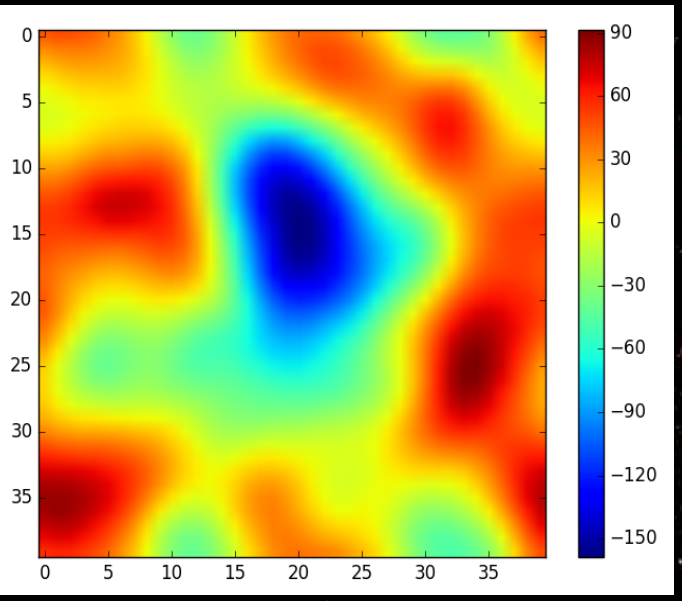
CMB is behind all the galaxy clusters

Easy to model

ESA and Planck collaboration

Extracting cluster lensing signal

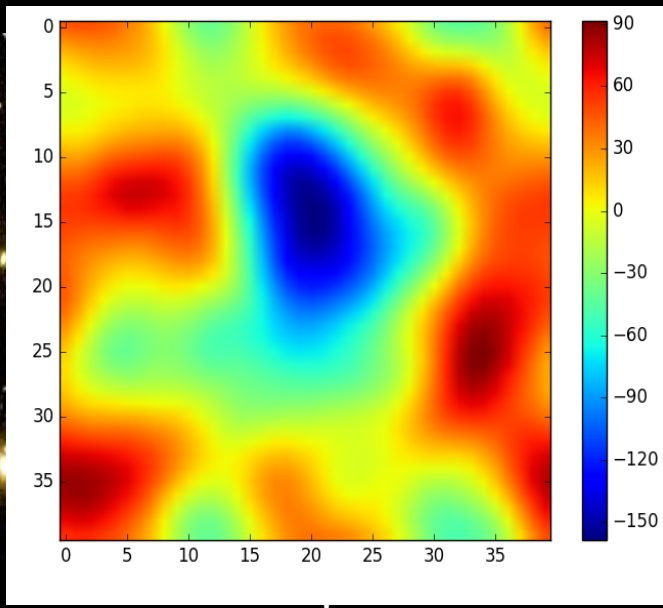
NFW profile



arcmins

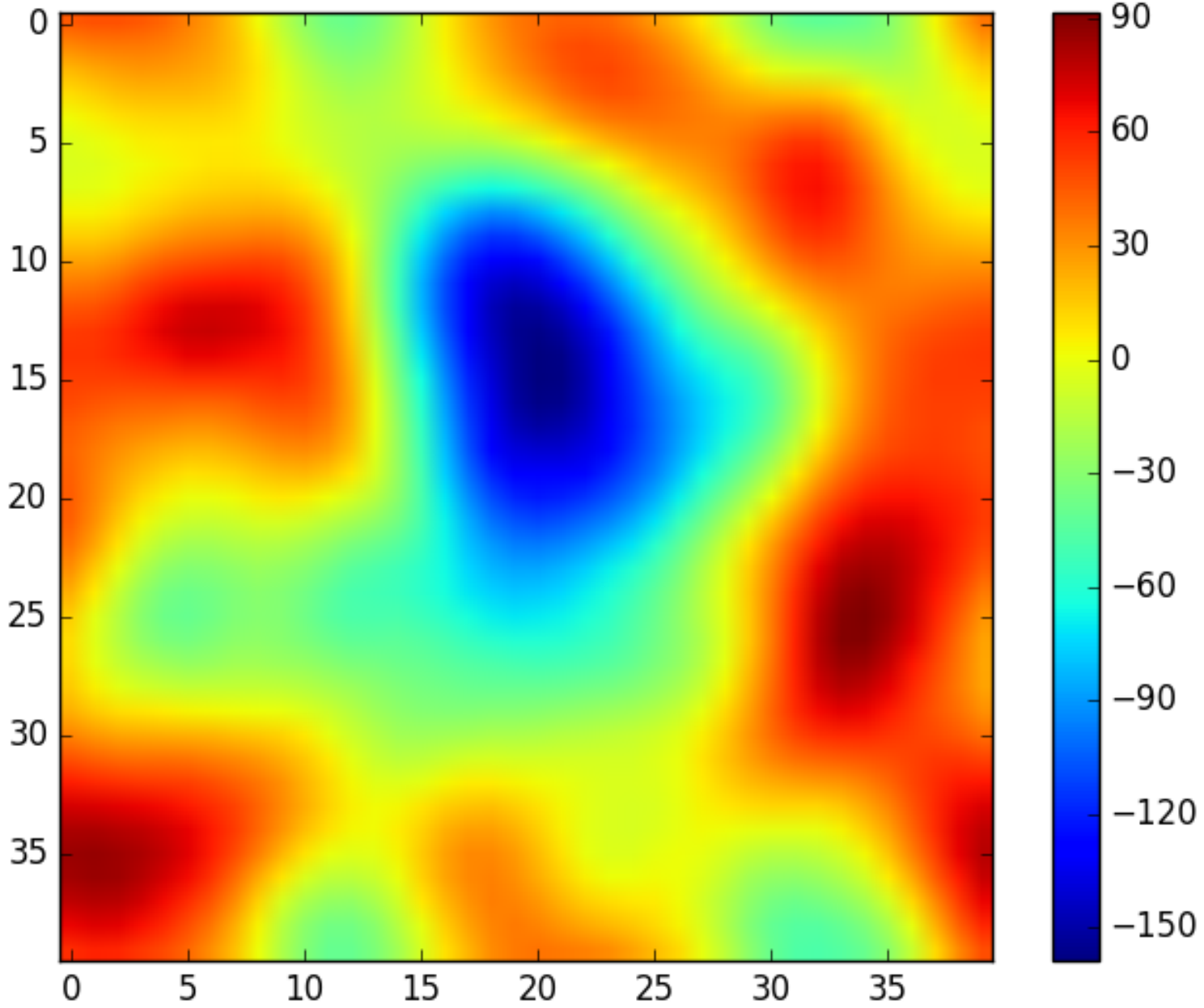
Unlensed CMB

Galaxy Cluster



arcmins

Lensed CMB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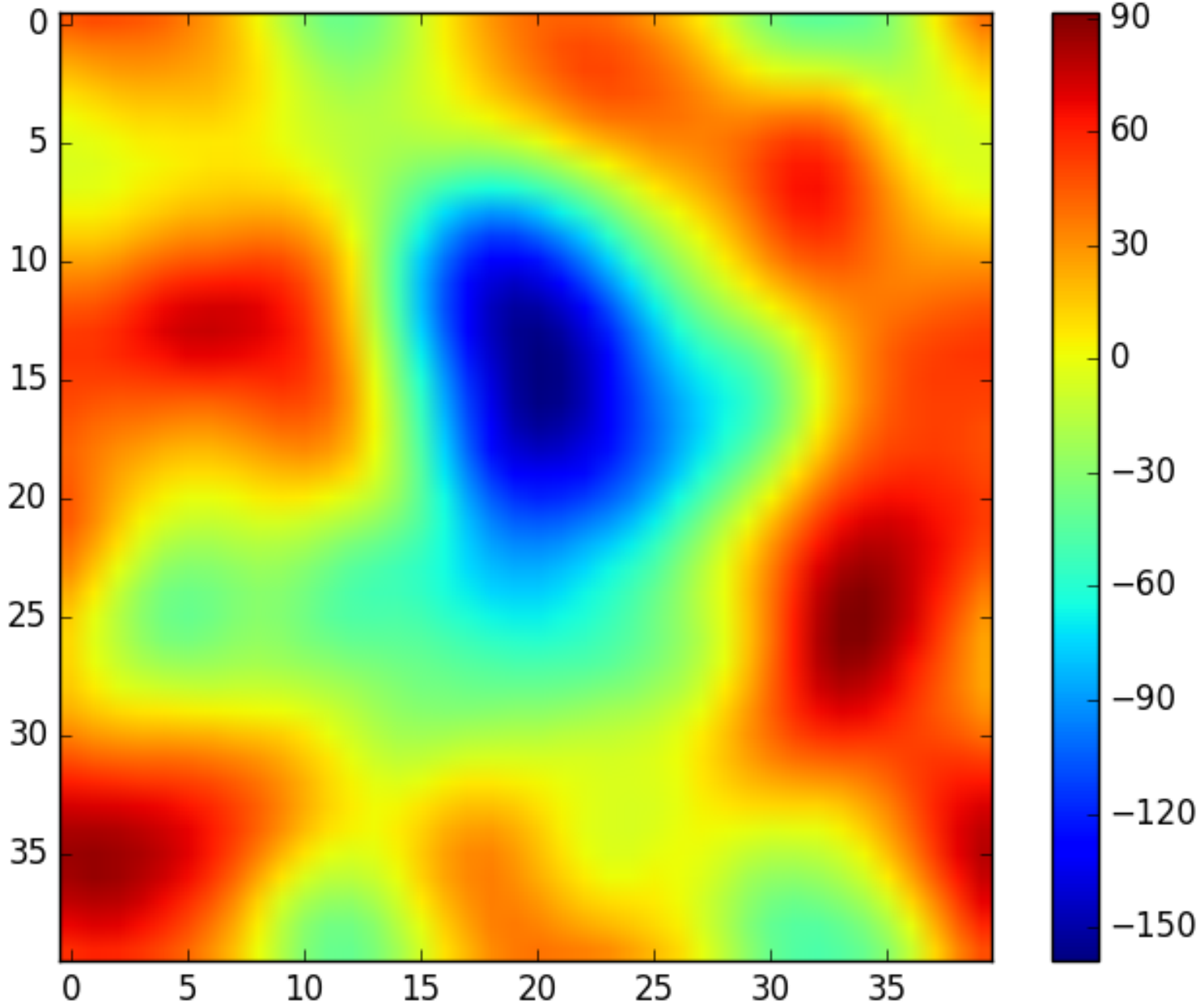
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−150

Maximum likelihood estimator

Covariance matrix of the model

Temp. or polarisation CMB data

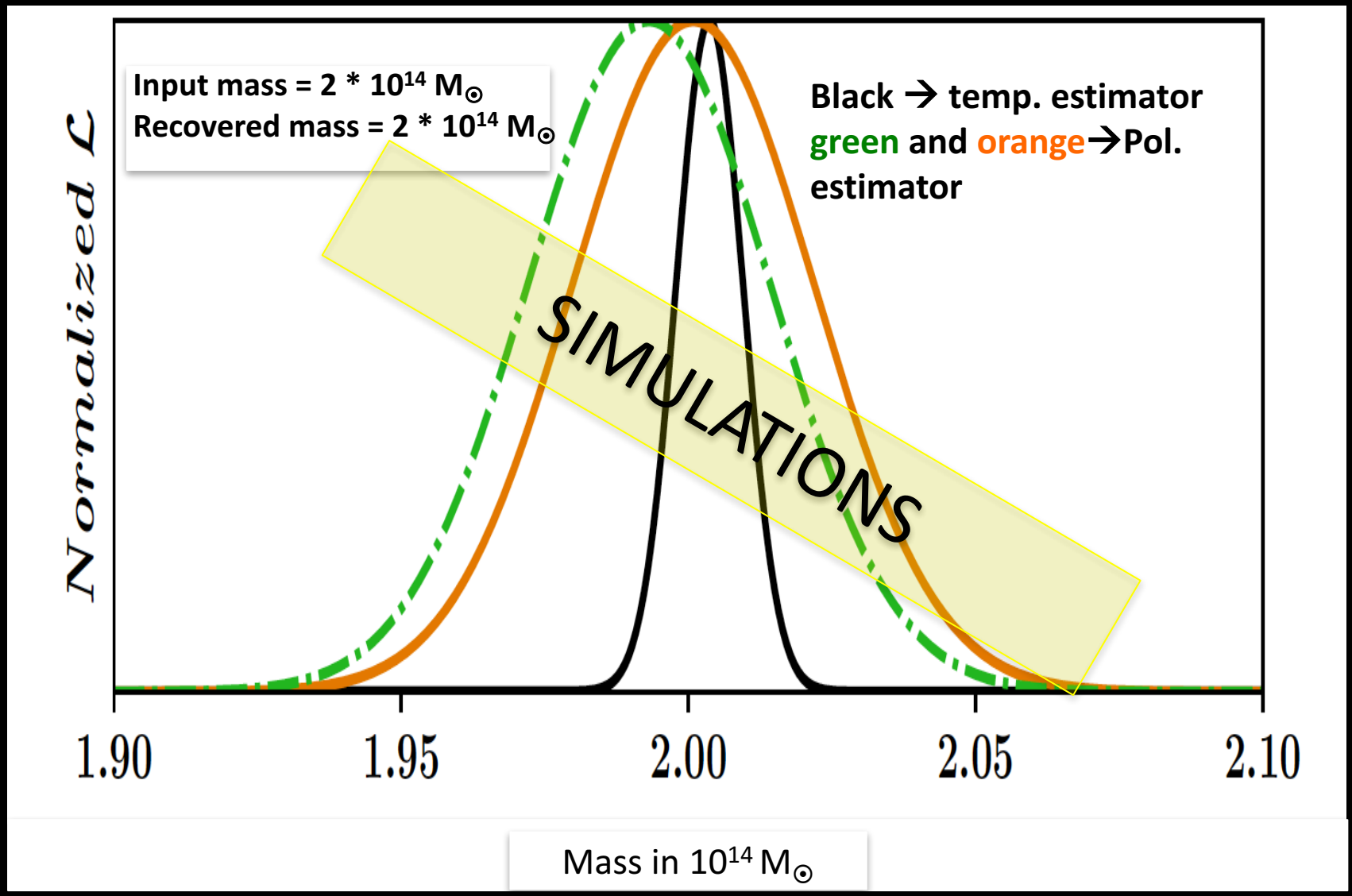
$$-2lnL(d|\Sigma_{lens}) = ln|\Sigma_{lens}| + d^T\Sigma_{lens}^{-1}d$$

Stack to increase signal to noise

weighing

$$-2lnL(d|\Sigma_{lens}) = \sum_{i=0}^{n} w_i[ln|\Sigma_{lens}| + d^T\Sigma_{lens}^{-1}d]$$

Recovers true cluster mass



S. Raghunathan, S. Patil et al

Overview

- Introduction to Galaxy clusters✔
- CMB cluster lensing✔
- ***South Pole Telescope and Dark Energy Survey***

South Pole Telescope (SPT)

- Located at Amudsen-Scott south pole station
- 10m microwave telescope operating at South Pole
- Measures sky temperature at 90, 150 and 220GHz
- Surveys:
  - SPT-SZ(2007-2011) covering 2500deg^2
  - SPTpol(2012-2016) covering 500 deg^2
  - SPT-3g(2017-) covering 2500deg^2

South Pole Telescope

Dark Energy Survey

- 5 year optical survey of 5000 sq. deg of southern sky
- Dark energy camera which is mounted on the Blanco 4m telescope at Chile
- Year 1 results are out and more on the way

Blanco Telescope Dome
Credits: Reidar Hahn, Fermilab

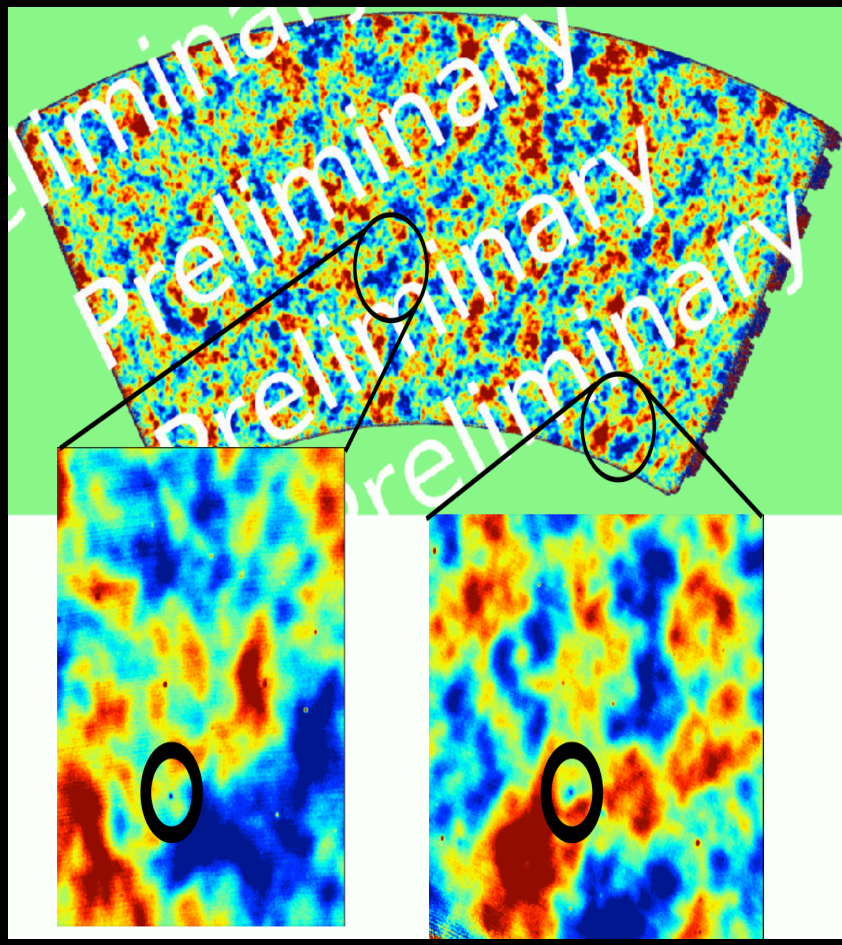
SPTpol X DES year 1

SPTpol (500 sq.deg.):

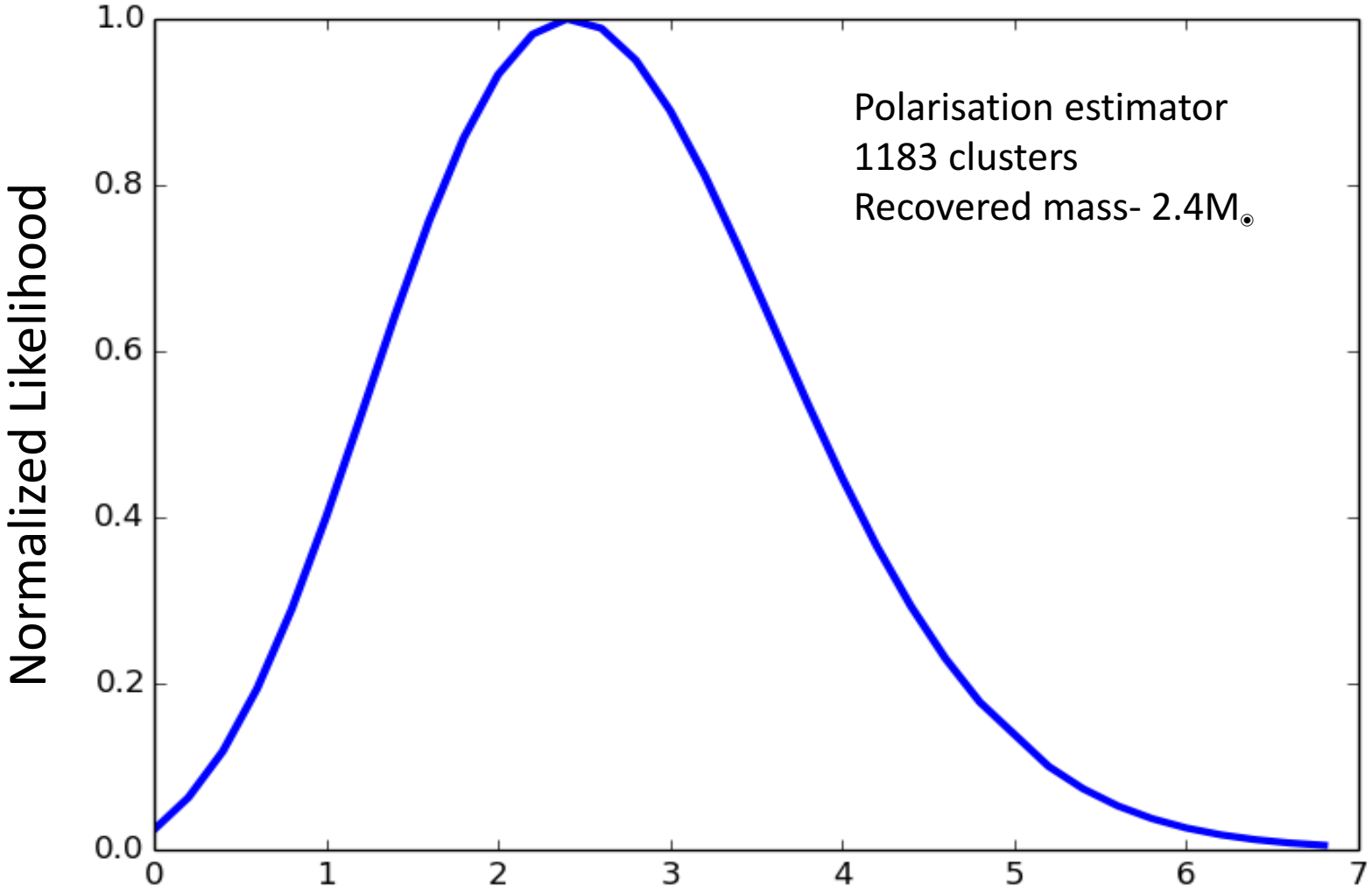
- Combined data from 2013 - 2016
- Use temperature and polarisation QU maps

DES:

- Overlaps with SPT survey
- Year one has approximately 15000 cluster
- In the SPTpol area we have 1300 clusters



Preliminary Results



Conclusions

- Galaxy clusters are powerful probes of cosmology
- Galaxy cluster cosmology is limited by 20 percent mass uncertainity
- With CMB cluster lensing
  - Expect 3-4% from current CMB experiments (SPT-3G, AdVACT)
  - Expect 1% from next generation (CMB-S4)

Overview

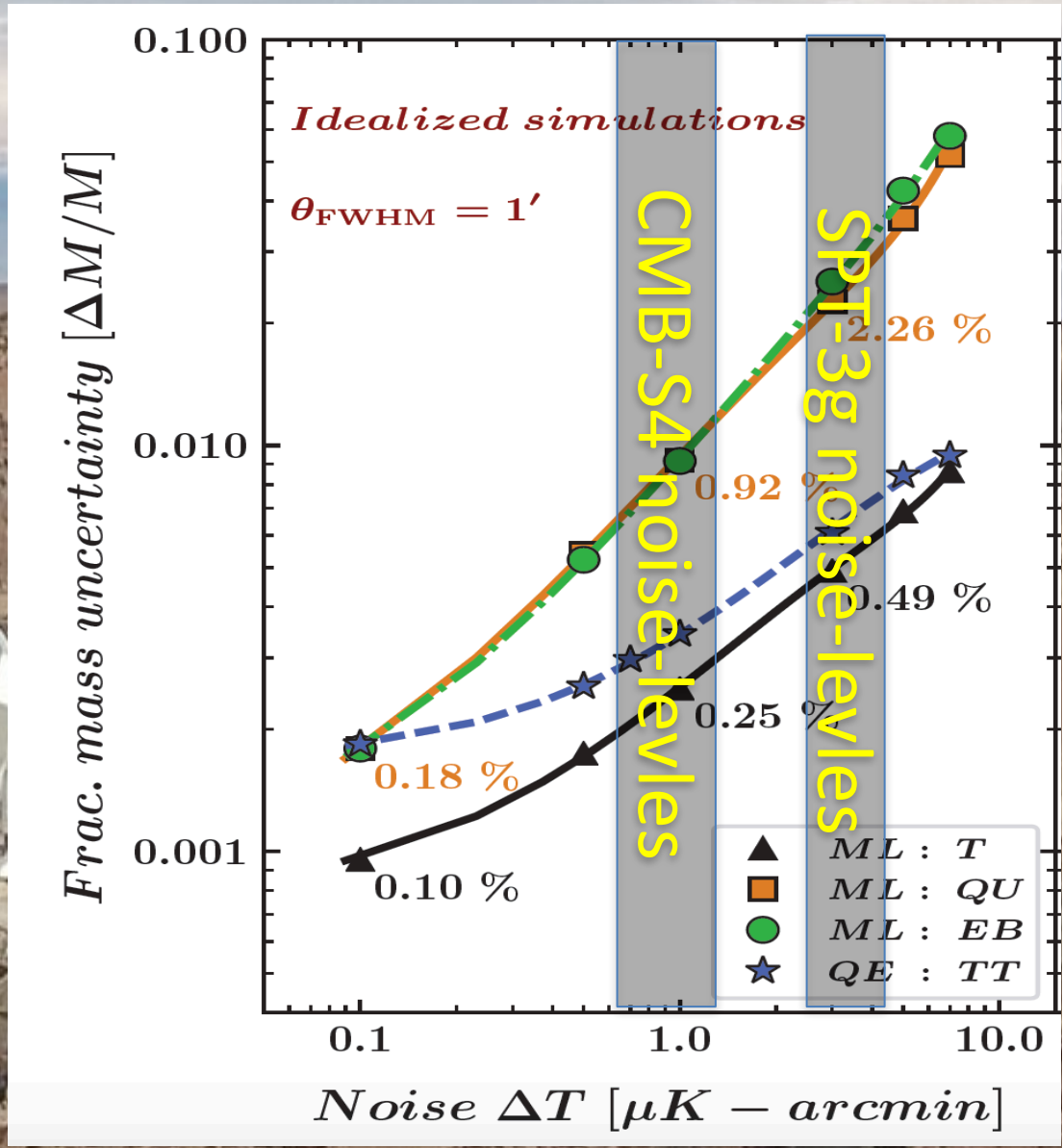
- Introduction ✓
  - Cosmic microwave background
  - Galaxy clusters
- CMB cluster lensing ✓
- ***South Pole Telescope and Dark Energy Survey*** ✓
- ***Future CMB experiments and forecasts***

Future Surveys

SPT- 3g

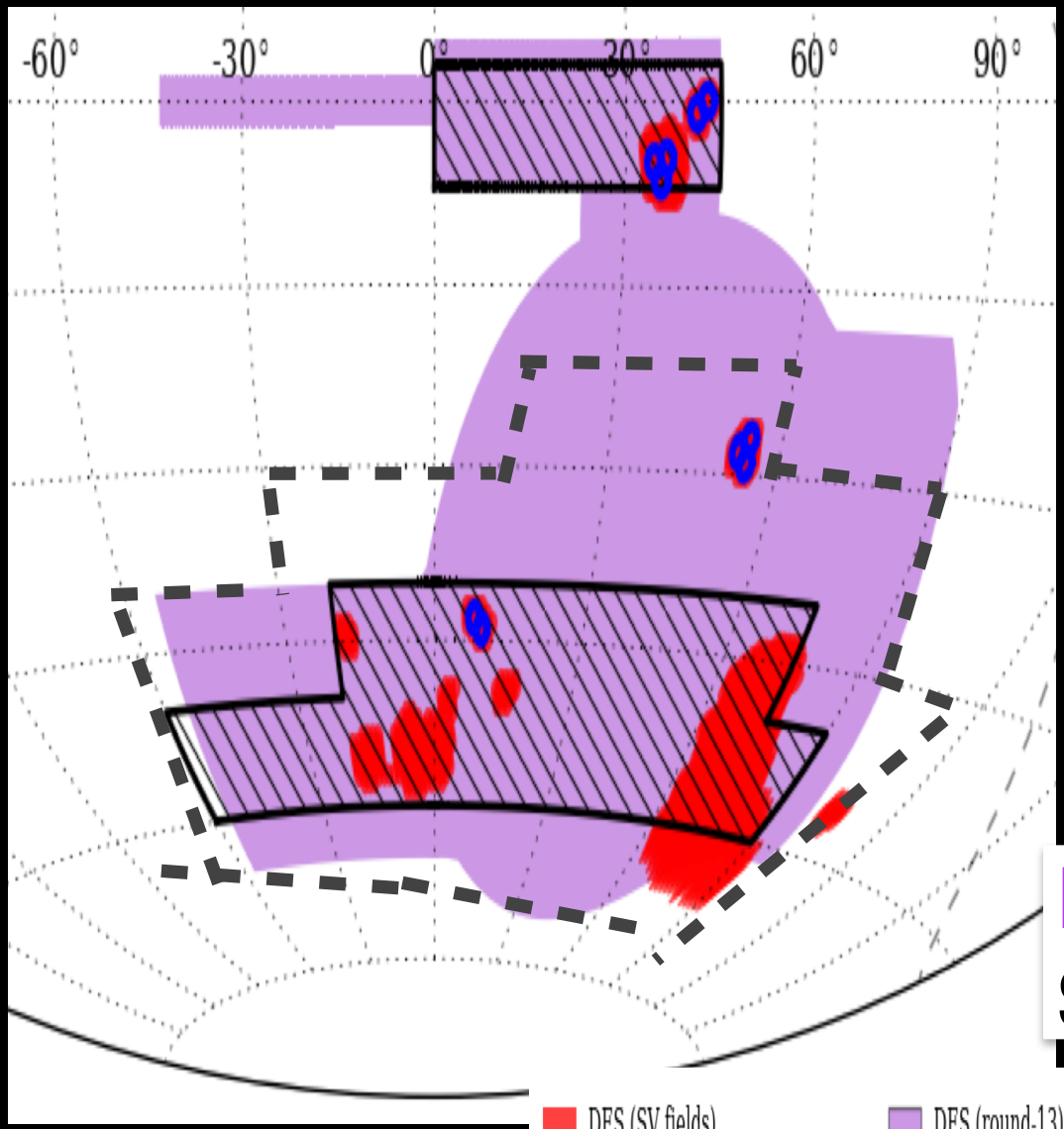
Beam size -1.2’
Noise levels – 2.5uK’
clusters – 10,000
Temp. estimator ~3.28%
Pol. Estimator ~ 6.12%

CMB-S4:
Beam size -1.0’
Noise levels – 1uK’
clusters – 100,000
Temp. estimator: ~0.87%
Pol. Estimator ~ 0.83%




THANK YOU

Dark Energy Survey



DES 100,000 Clusters

DES survey area 5000 deg^2

SPTpol 500deg^2

DES Footprint

SPT Footprint --

DES (Year 1)

DES (SN fields)

Standard model of Cosomology

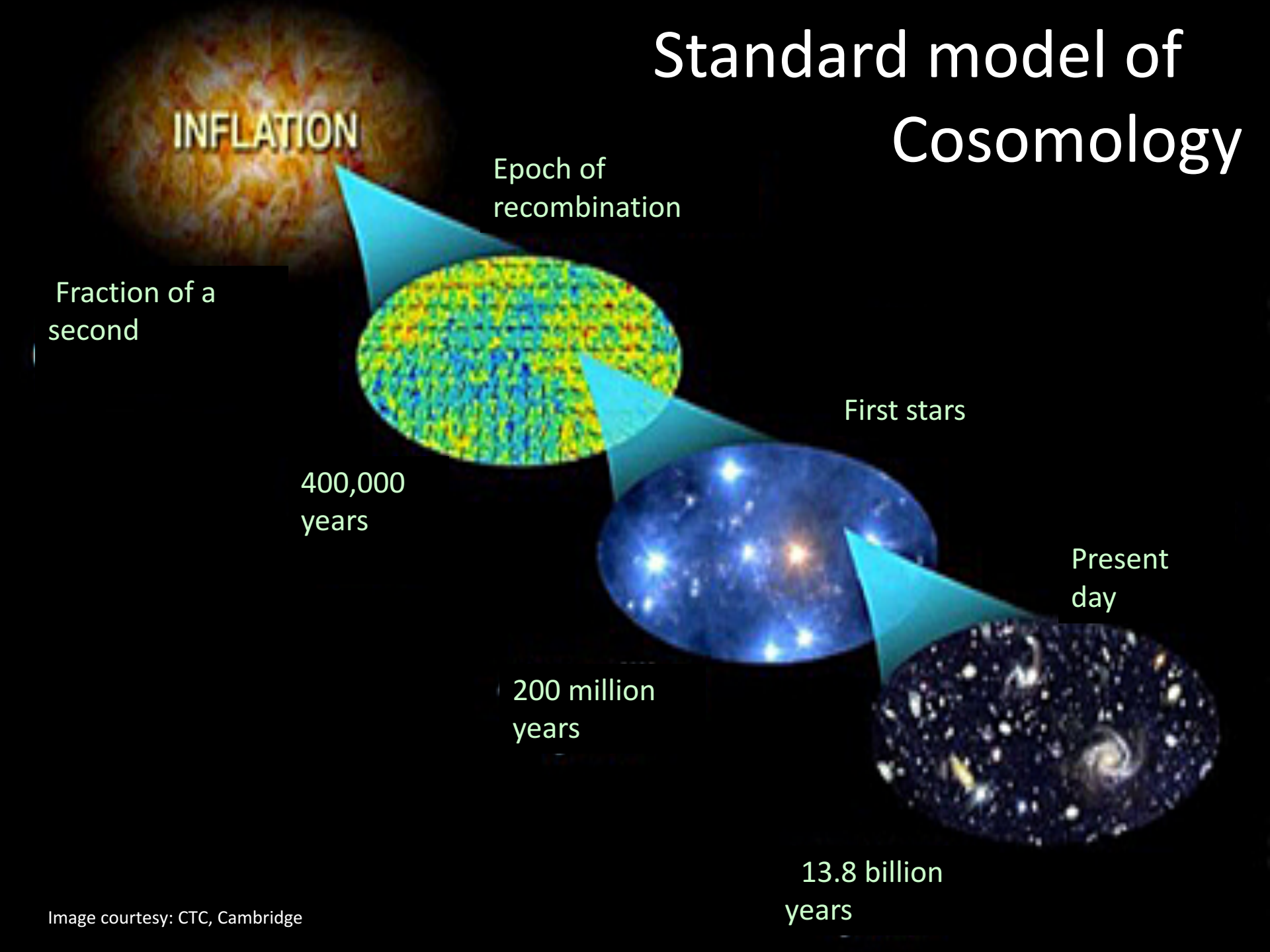
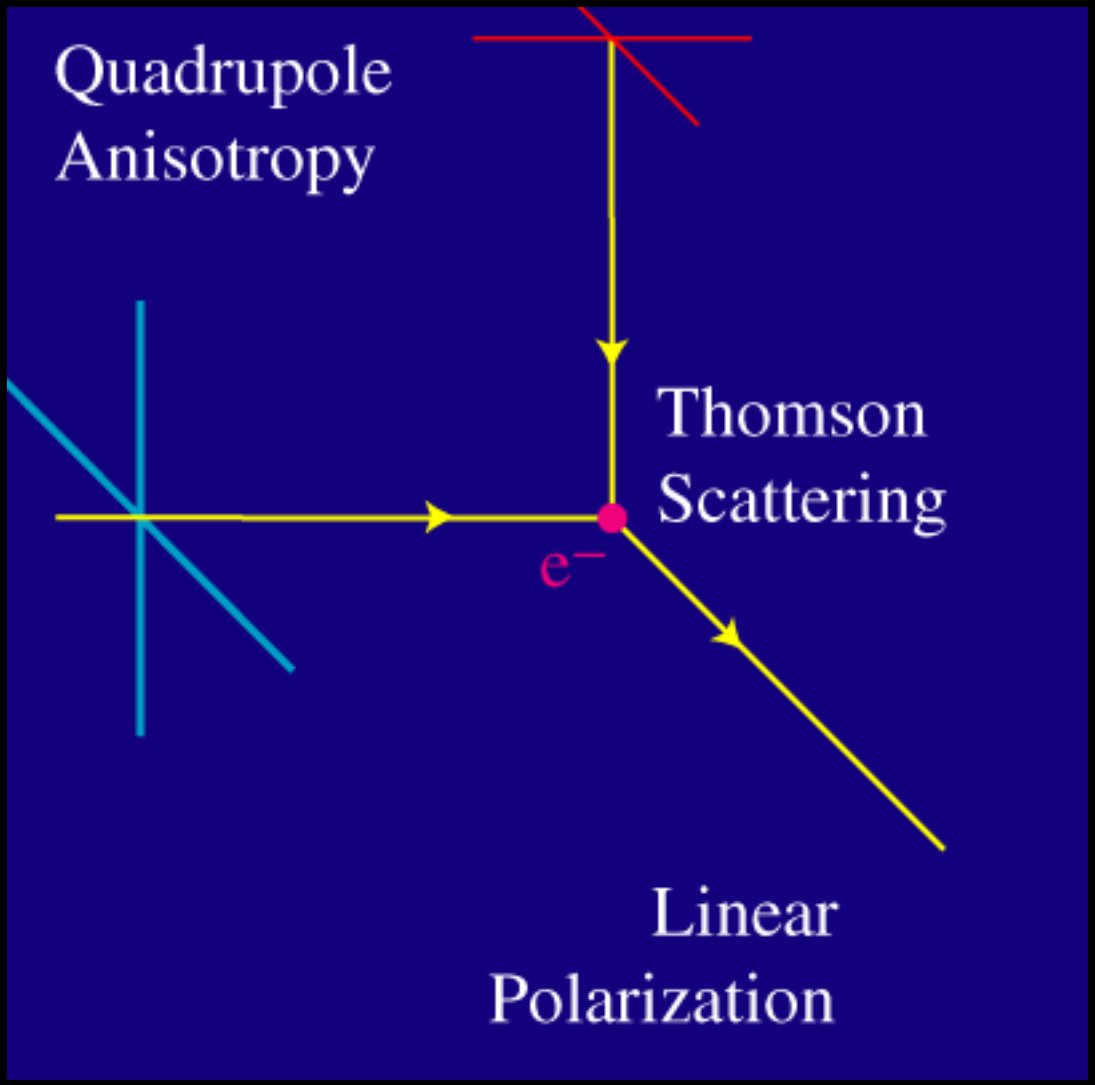


Image courtesy: CTC, Cambridge

Partially polarised



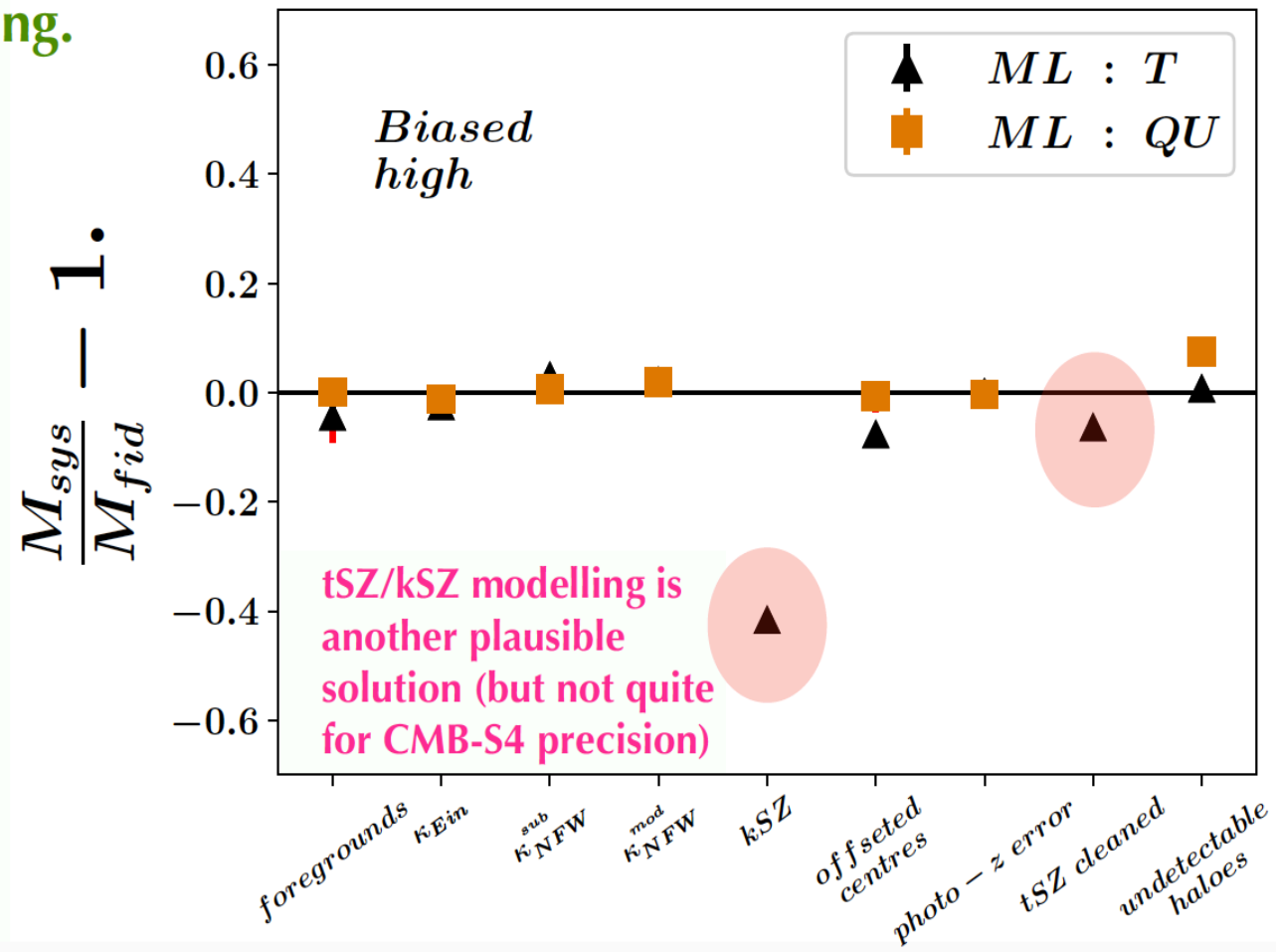
Electromagentic wave is incident on free electron is polarized in perpendicular direction

Quadropole anisotropy leads to polarisation

~10% of CMB was polarized

What about systematics?

- Cluster SZ signals are the most important for temperature.
- tSZ - can be cleaned using ILC.
- kSZ - most challenging.



Observational Cosmology at University of Melbourne

Christian Reichardt
ARC future fellow and
senior lecturer

What about systematics?

- Cluster SZ signals are the most important for temperature
- tSZ - can be cleaned using Hu
- kSZ - most challenging
- Spec-z not required for CMB cluster lensing.
- Offsets can be marginalised.

— Can be handled — Go for Pol. —

Bias source	Bias % at $\Delta T = 1.0\ \mu$K−arcmin			
	Temperature $T_{\rm ML}$		Polarization $QU_{\rm ML}$	
	% bias	error	% bias	error
tSZ cleaning (1% residual signal)	-6.3	0.50	0	-
kSZ fitting (20% uncertainty)	-7.3	0.31	0	-
DG in the cluster	-4.5	1.70	-1.3	1.20
Redshift uncertainty	0.2	0.25	-0.3	0.90
Cluster positions	-7.5		-2.0	
Presence of undetectable haloes	2.5	0.25	6.3	0.92
Uncertainties in cluster mass profile				
$\kappa_{\rm NFW} + \kappa_{sub}$	3.1	0.25	-0.6	0.92
$\kappa_{Einasto}$	-2.4		-2.5	
$\kappa^{mod}_{\rm NFW}$	2.2		0.6	