CMB Halo Lensing

James G. Bartlett
Jet Propulsion Laboratory – California Institute of Technology
Astroparticule et Cosmologie – Université Paris Diderot

© 2016 California Institute of Technology
Government sponsorship acknowledged

CMB Halo Lensing

- What do we mean by CMB Halo Lensing?
- Theory
- Measurements
- Future

Some History

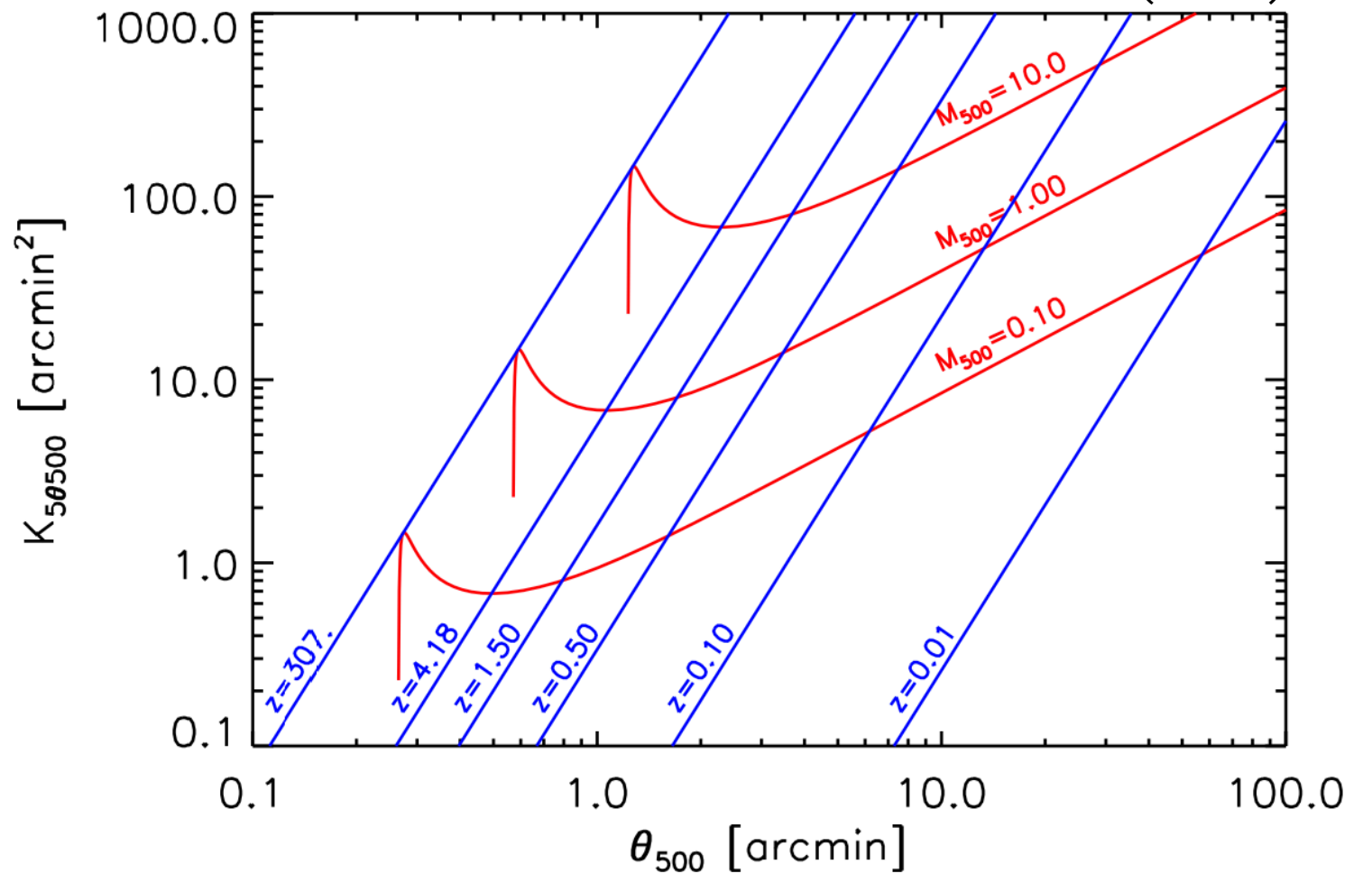
- Seljak & Zaldarriaga (2000)
- Lewis & Challinor (2006) Review of CMB lensing
- Maturi et al. (2005), Hu, DeDeo & Vale (2007)
- Melin & Bartlett (2015)
- First measurements: Baxter et al. (2015), Madhavacheril et al. (2015), *Planck* Collaboration XIV (2015)

Theory

1. Cut-out sky area around each source
   - Set of frequency maps
2. Construct clean CMB map
   - Internal Linear Combination (ILC) constrained to null thermal SZ effect
   - Temperature: need good frequency coverage
   - Polarization: less of an issue
3. Reconstruct lensing potential
   - Quadratic estimator
4. Matched filter
   - Permits low S/N measurements that can then be binned.

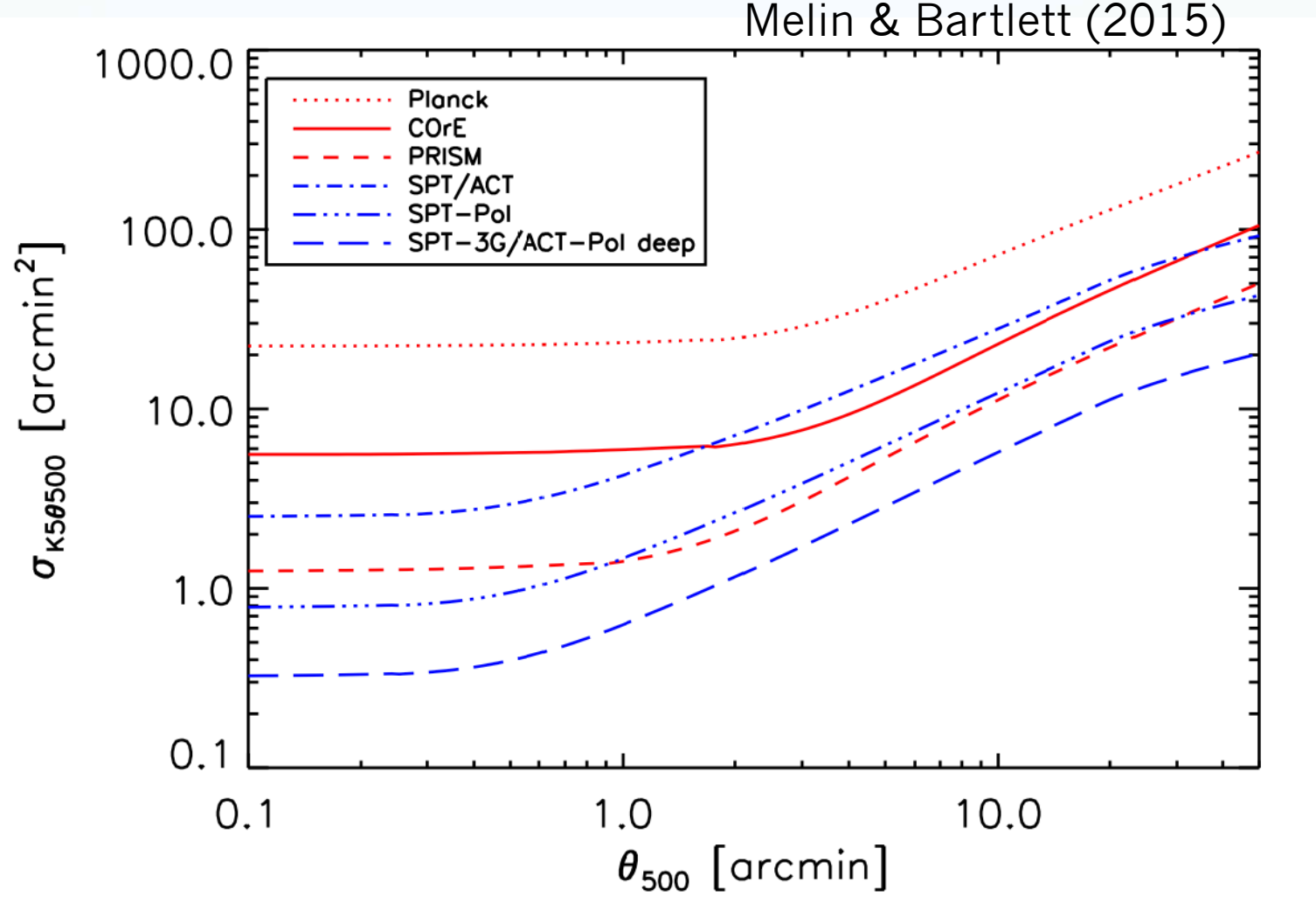
Matched Filter Signal

Melin & Bartlett (2015)



Matched Filter Noise

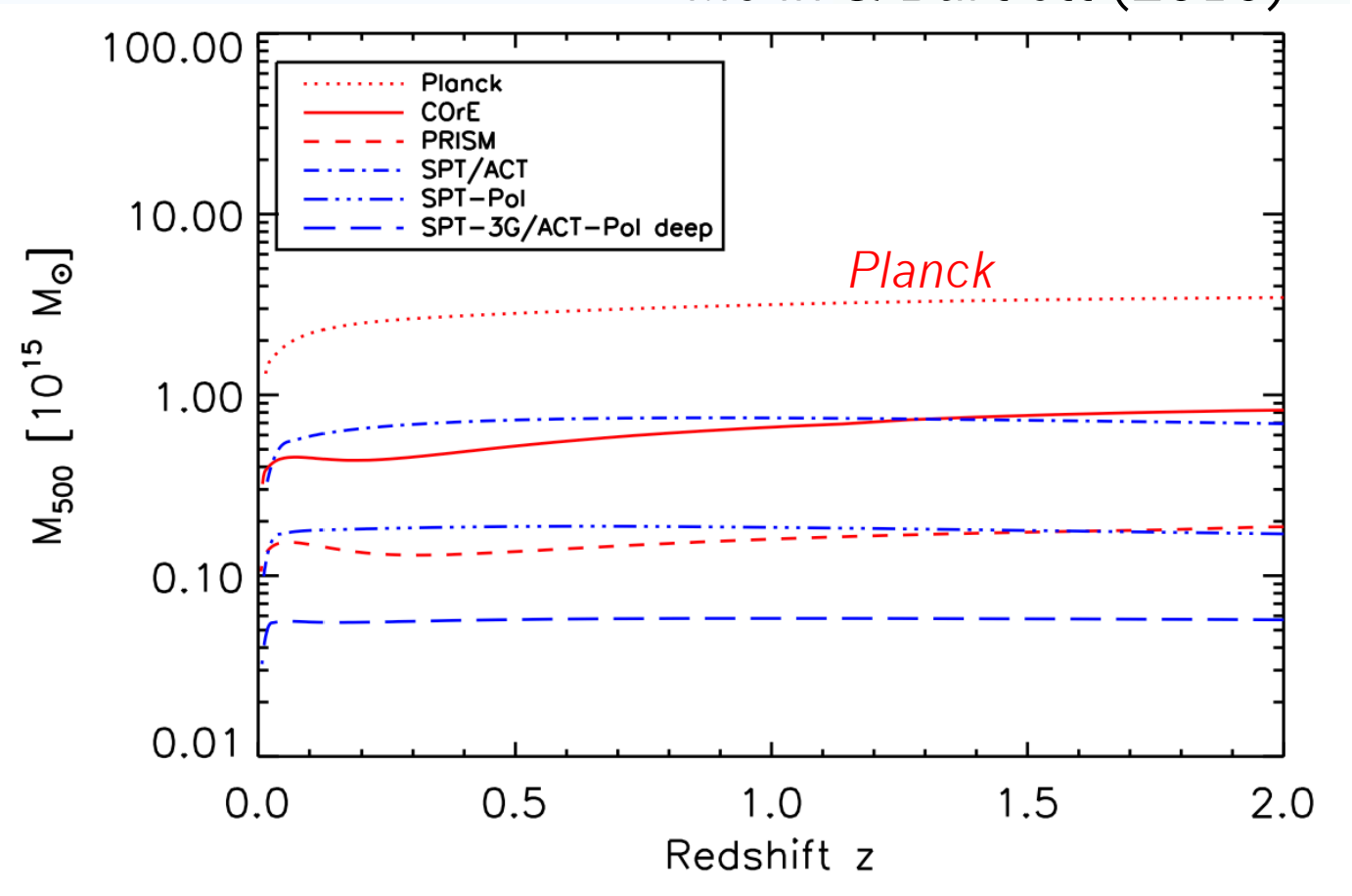
Melin & Bartlett (2015)



Matched Filter Sensitivity

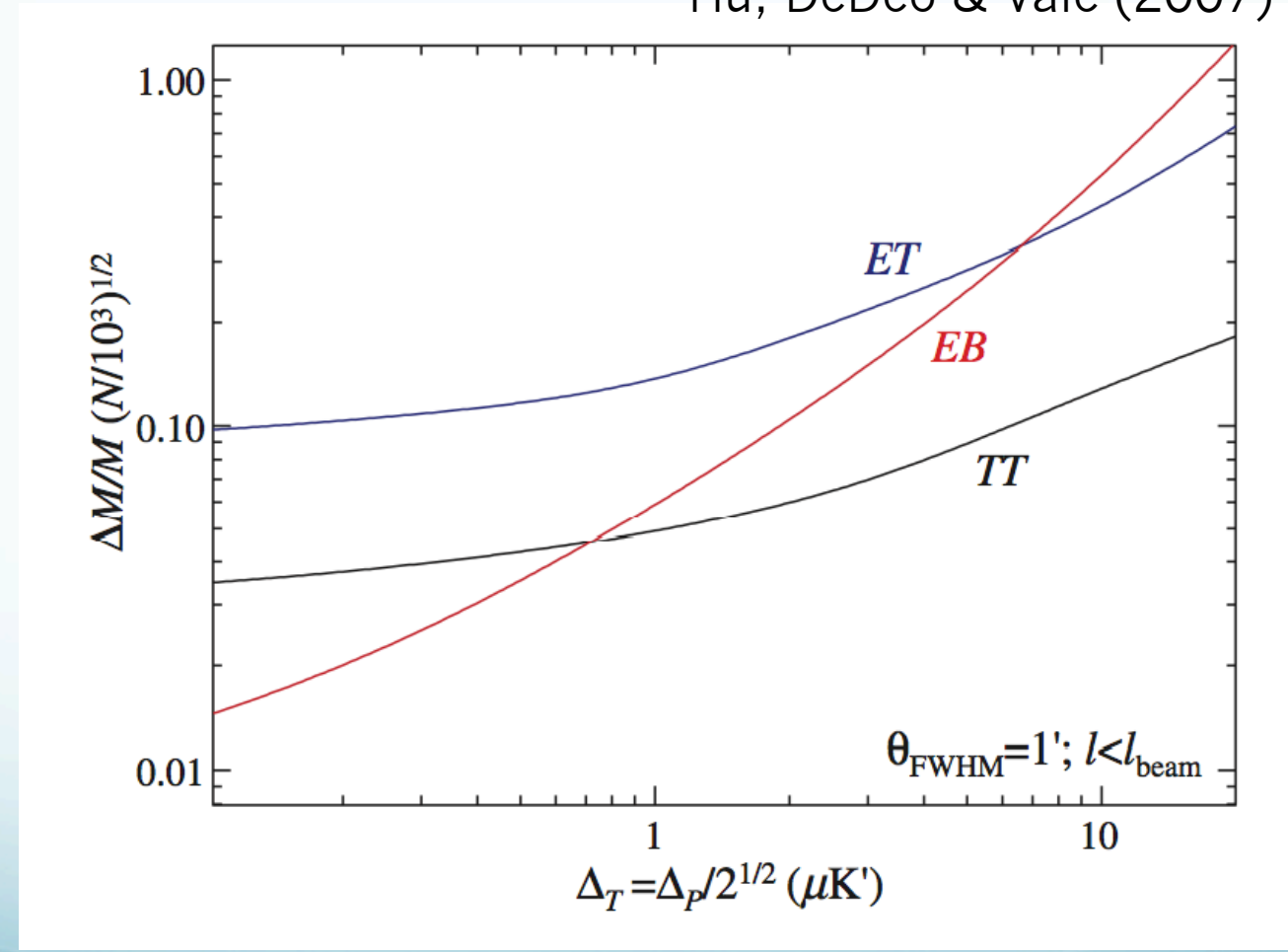
Melin & Bartlett (2015)

Predictions for cluster mass detectable with S/N=1



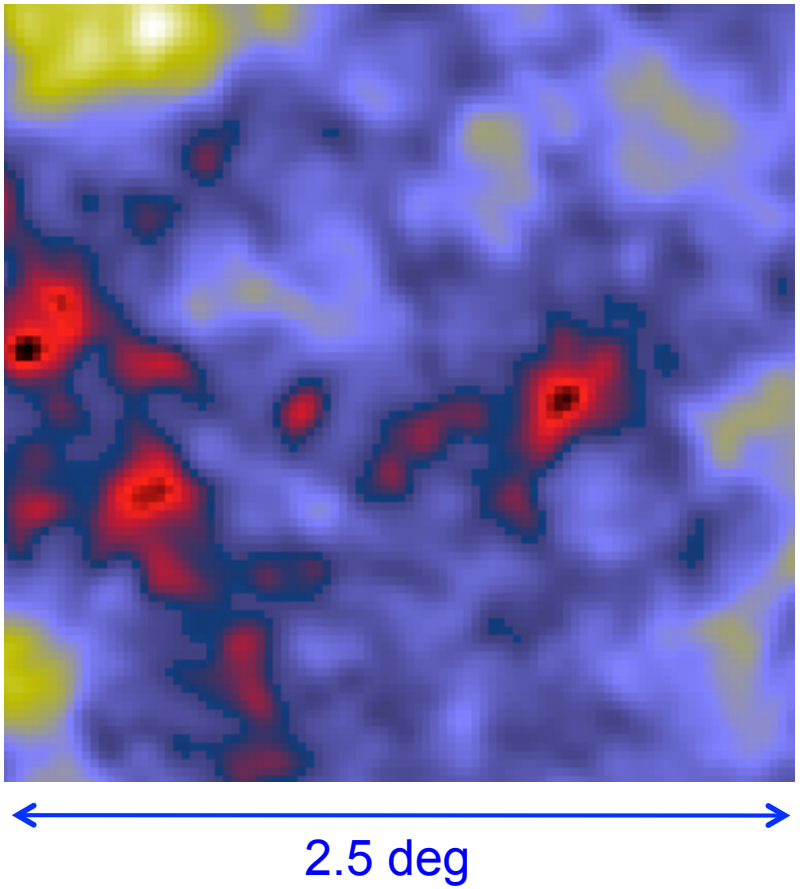
Polarization

Hu, DeDeo & Vale (2007)



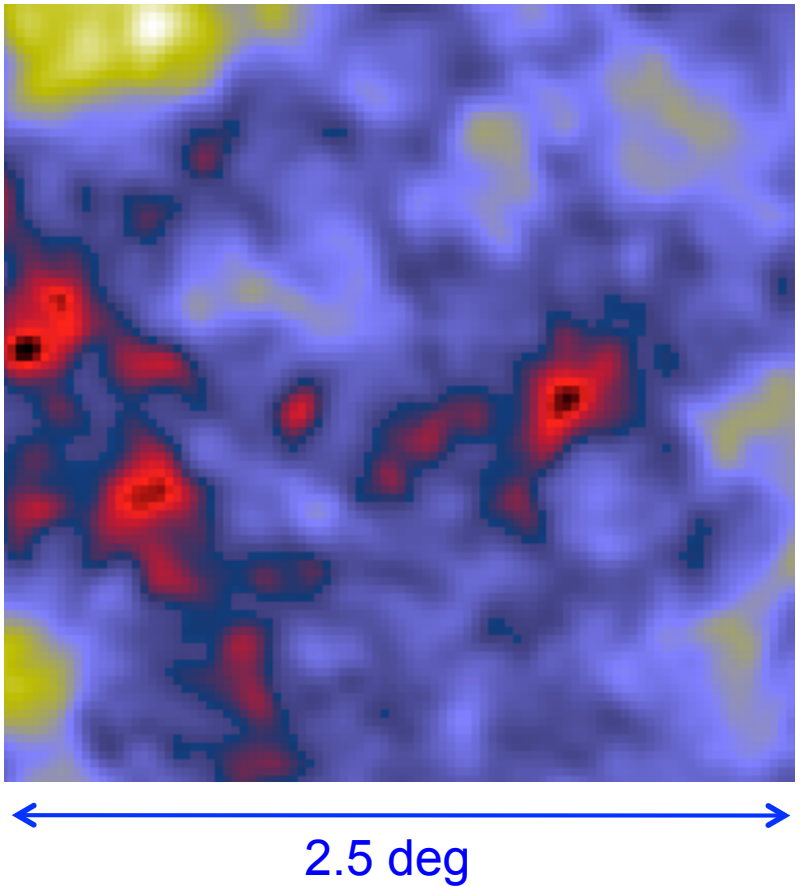
Planck Simulation of A2163

Cluster-CMB lensing with *Planck*
(Melin & Bartlett 2015)



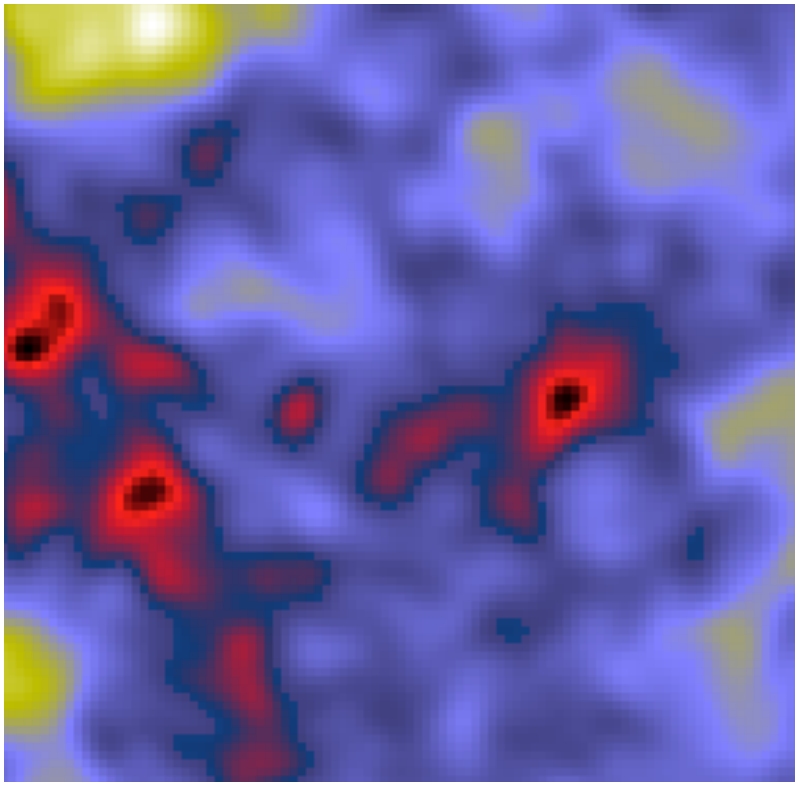
Unlensed CMB

Planck Simulation of A2163



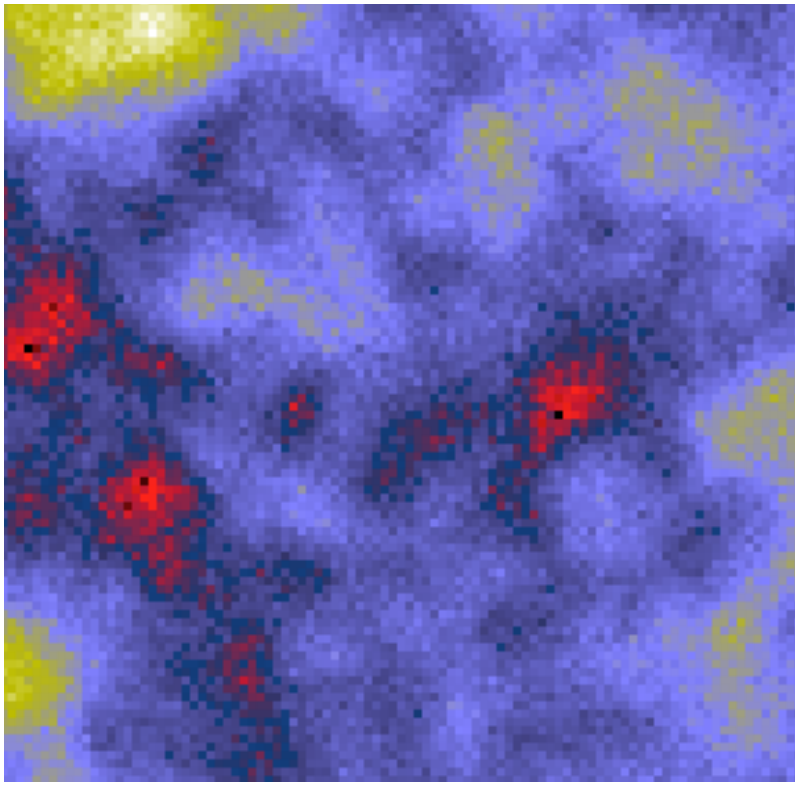
Lensed CMB

Planck Simulation of A2163



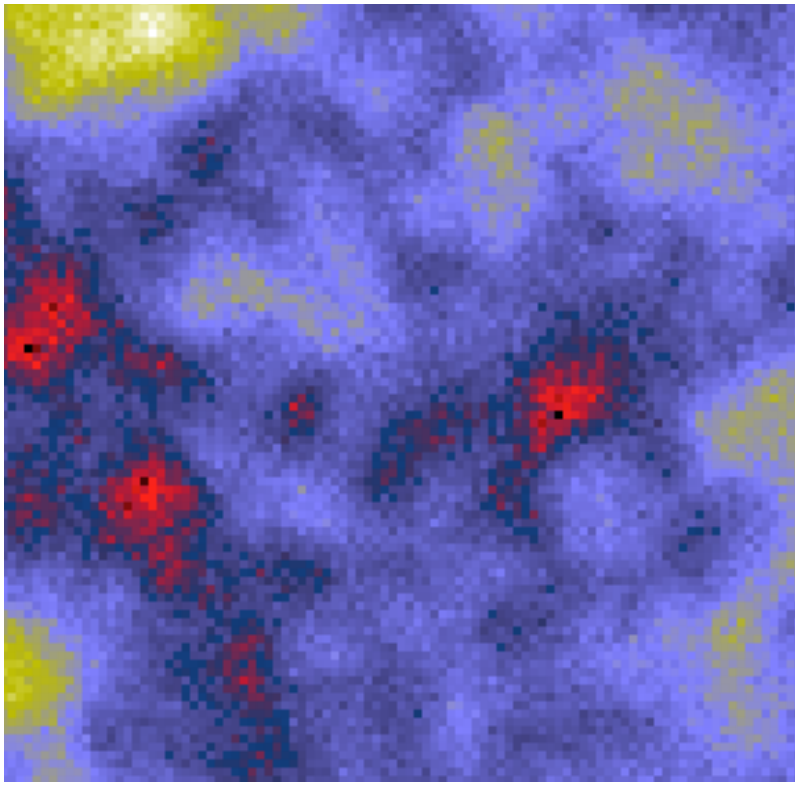
Lensed CMB
+ 5arcmin beam

Planck Simulation of A2163



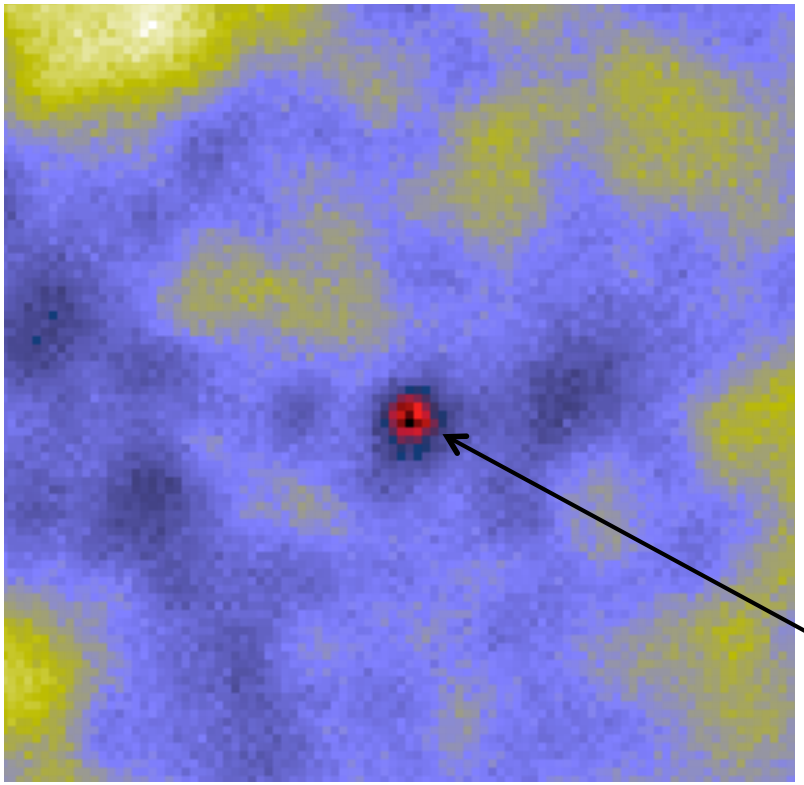
Lensed CMB
+ 5arcmin beam
+ instrumental noise

Planck Simulation of A2163



Unlensed CMB
+ 5arcmin beam
+ instrumental noise

Planck Simulation of A2163



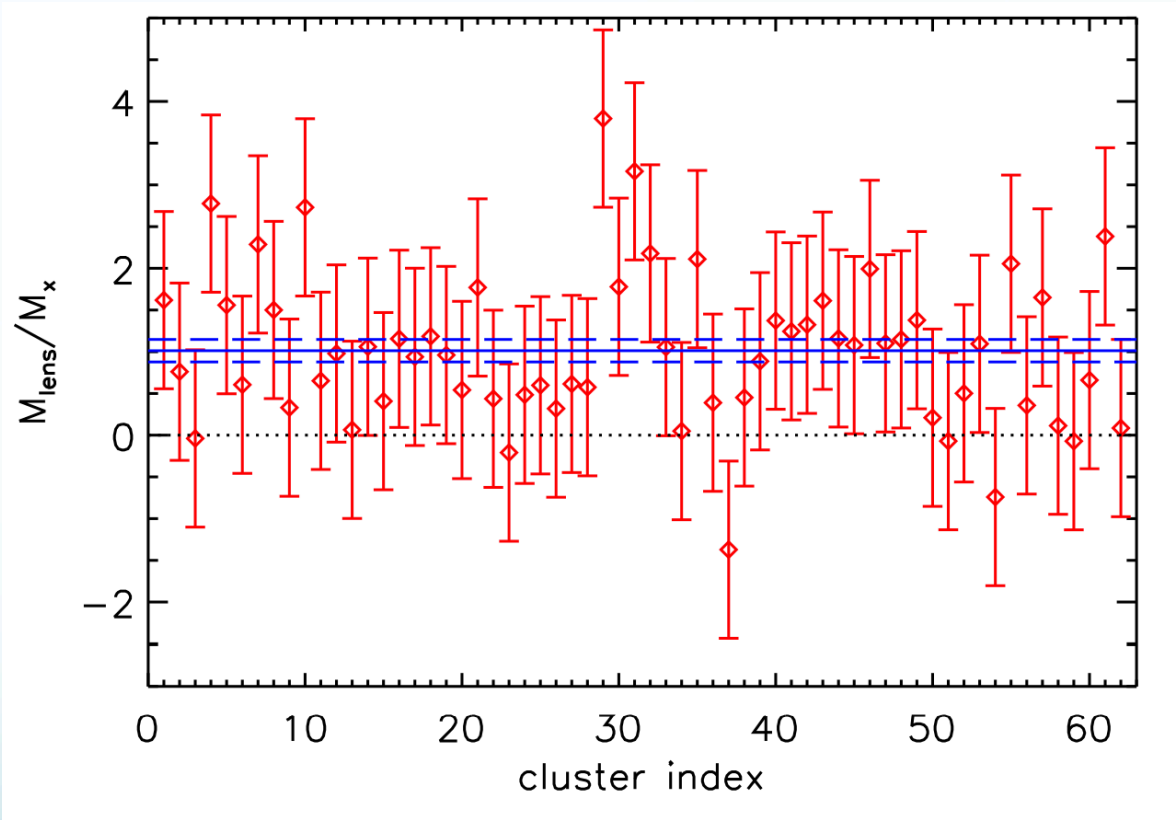
Planck observation
@ 143GHz

SZ !

Simulation: 62 times A2163

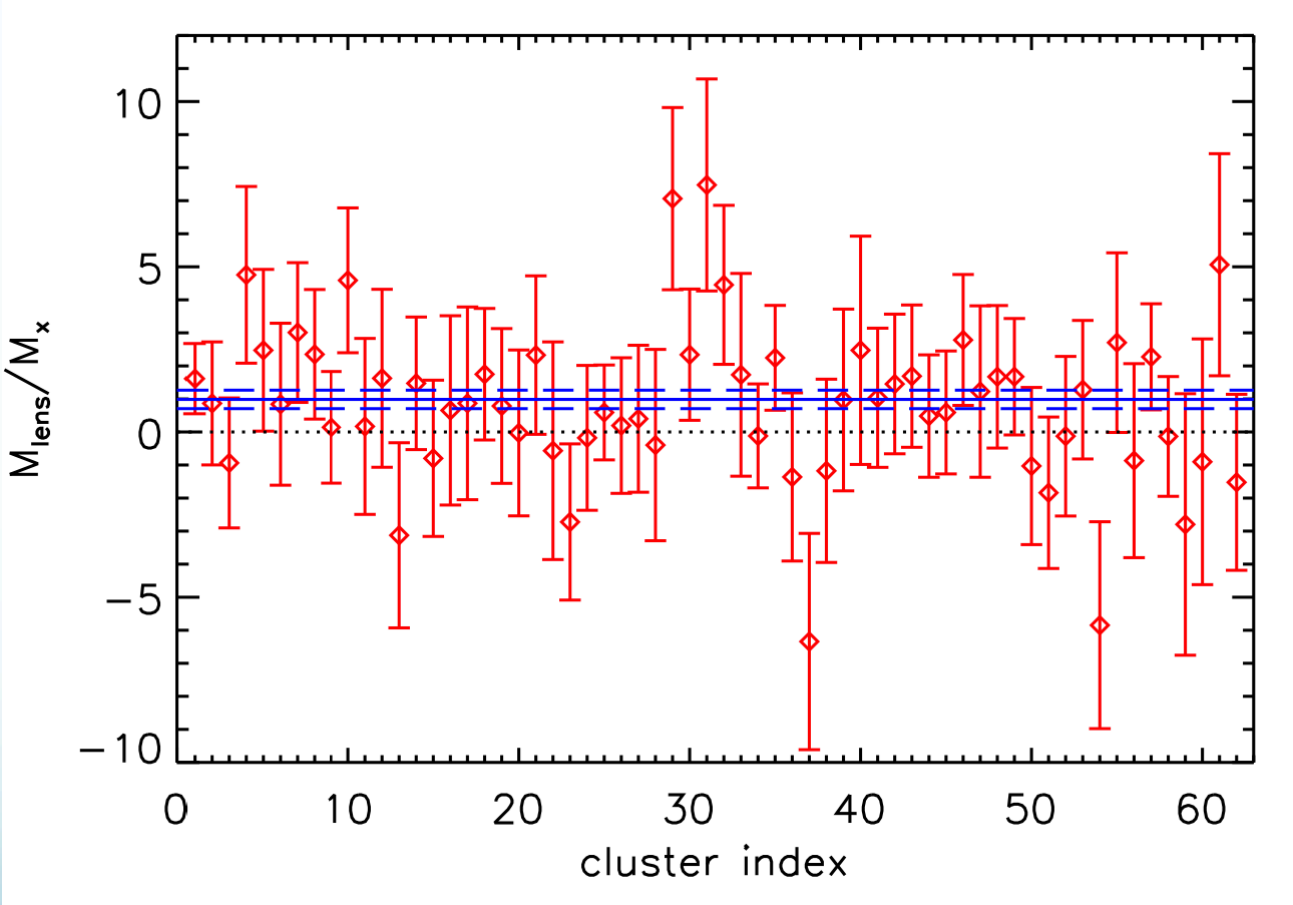
Unbiased recovery sample mean

$$\frac{M_{\rm lens}}{M_{\rm X}} = 1.01 \pm 0.13$$



Simulation: XMM-ESZ

XMM-ESZ Sample:
62 massive clusters
with detailed XMM
observations



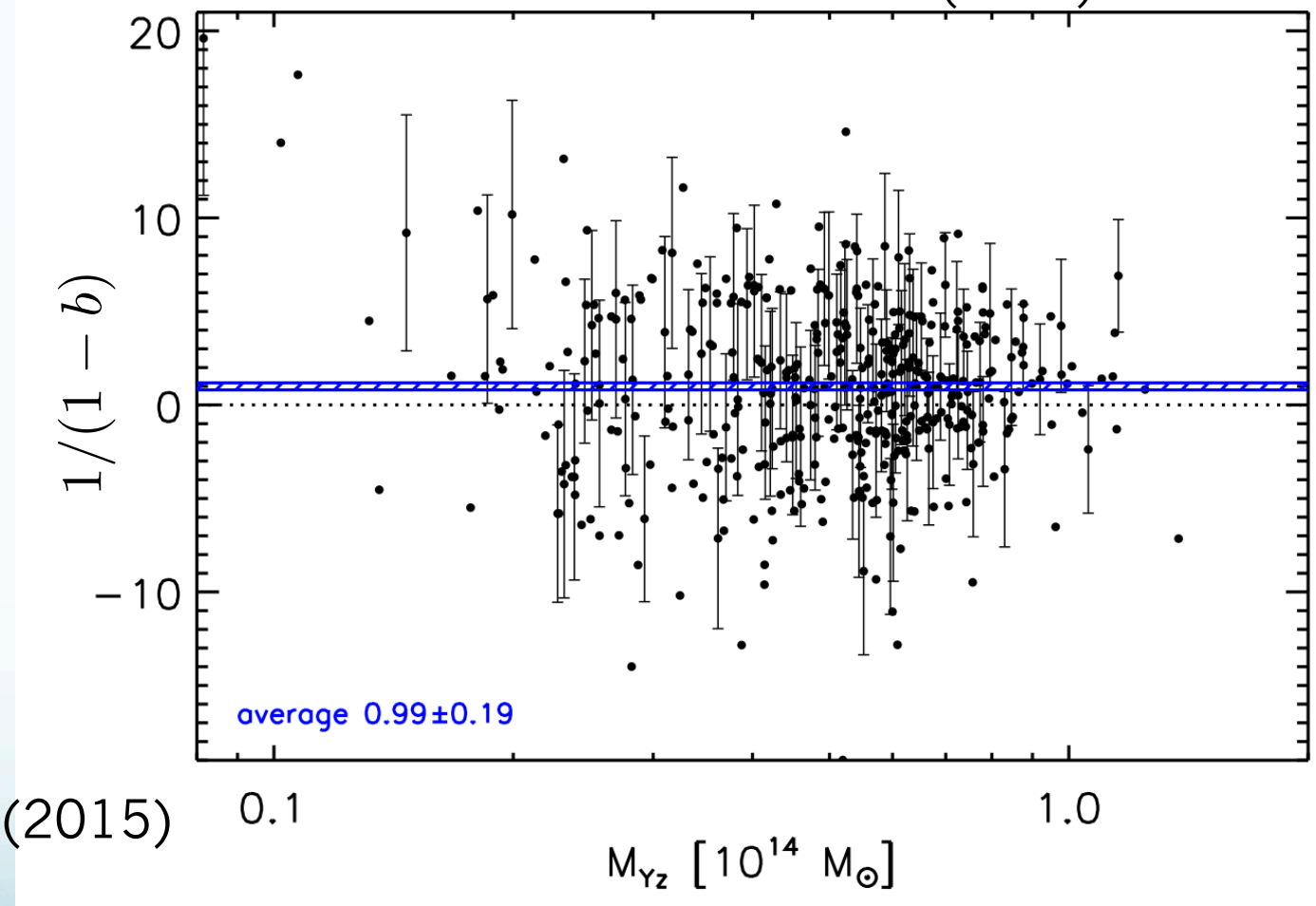
Unbiased recovery sample mean:

$$\frac{M_{\rm lens}}{M_{\rm X}} = 0.99 \pm 0.28$$

Cluster-CMB Lensing

439 *Planck* 2015 cosmology clusters: 5 σ measurement

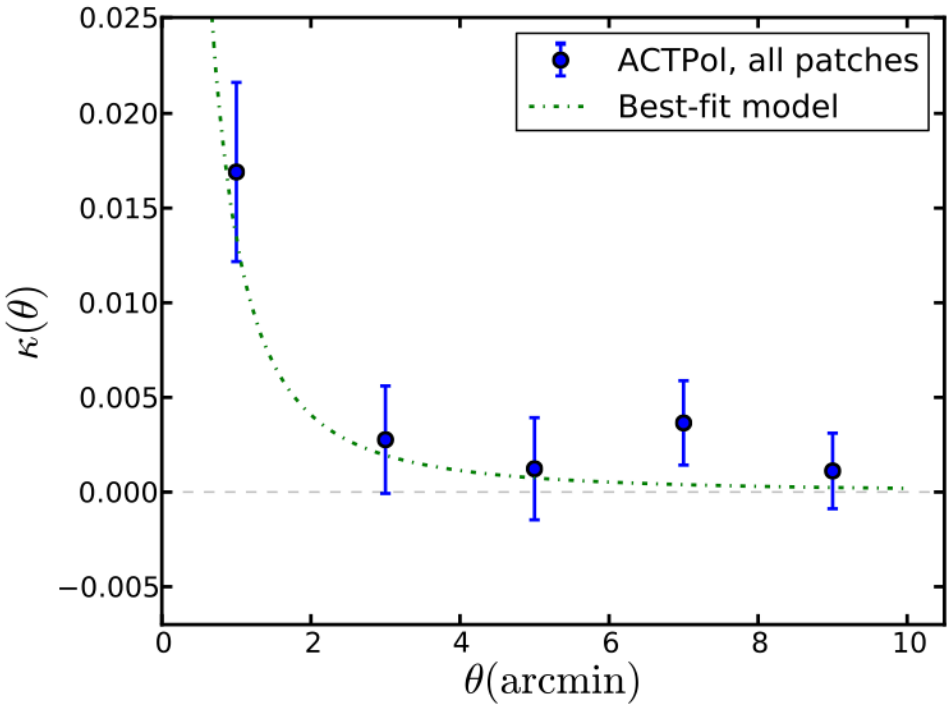
Planck Collaboration XXIV (2015)

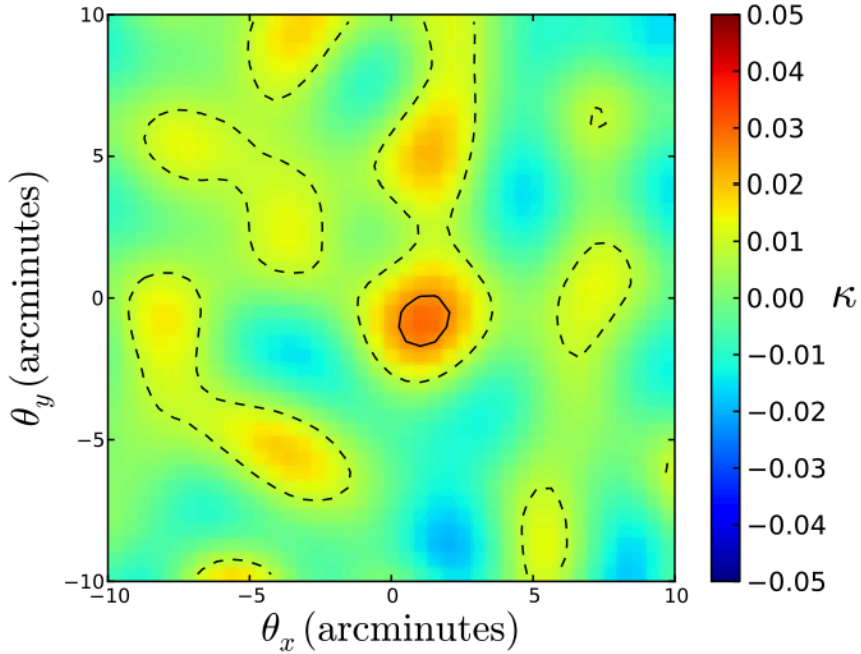


See also:
Madhavacheril et al. (2015) (ACT)
Baxter et al. (2015) (SPT)

Atacama Cosmology Telescope

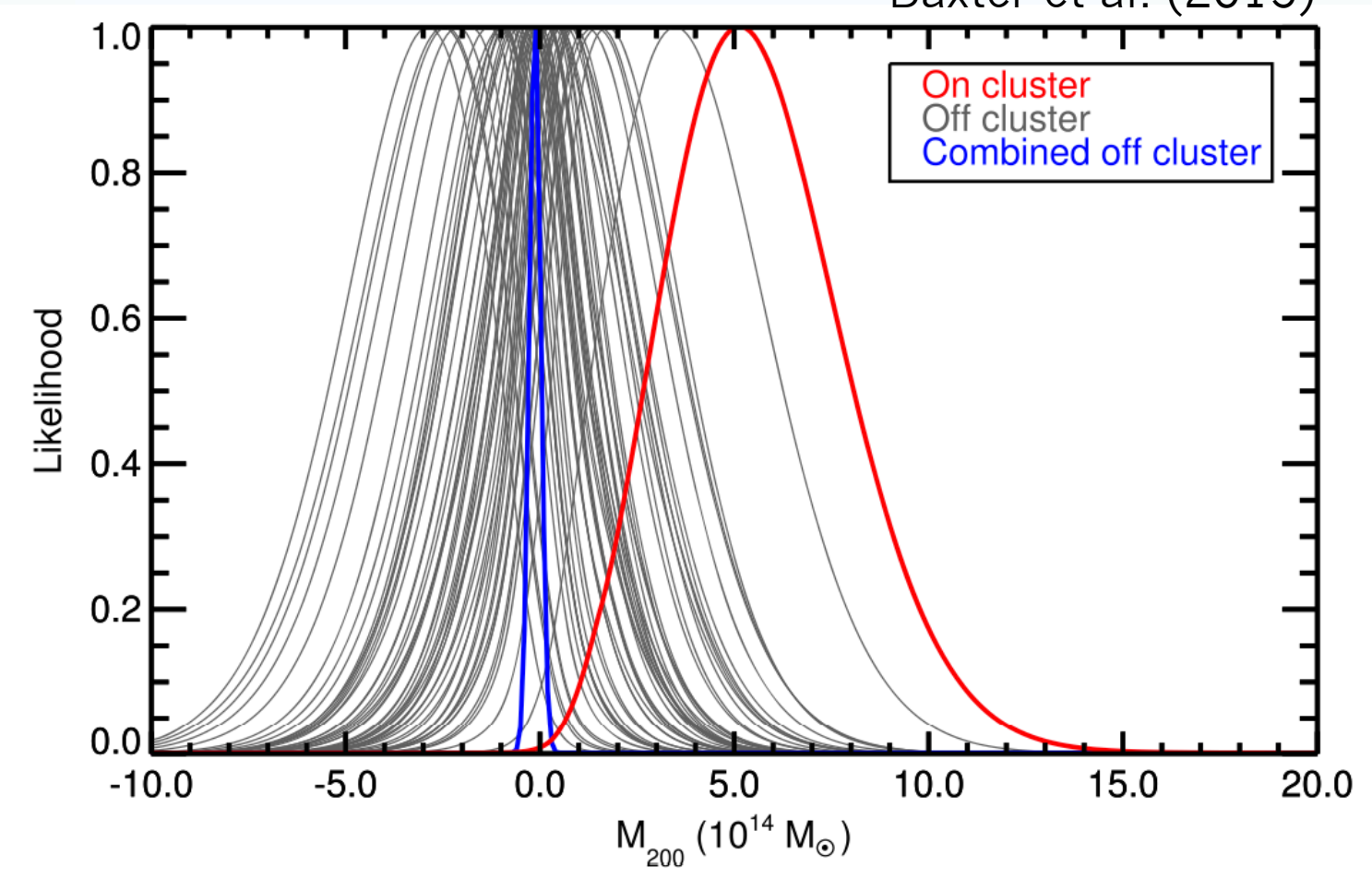
Madhavacheril et al. (2015)





South Pole Telescope

Baxter et al. (2015)



What's Next?

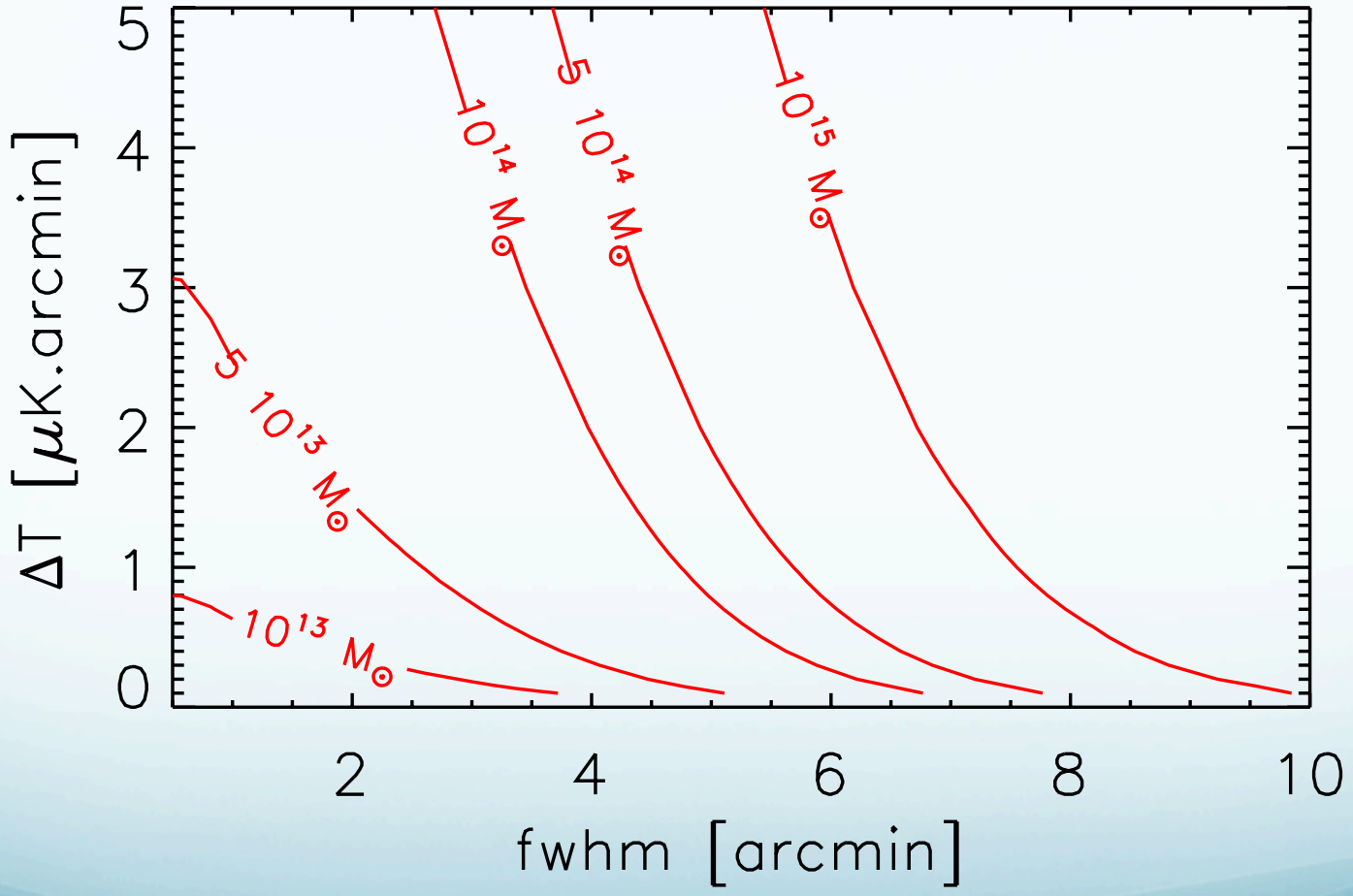
Systematics to Explore

- Miss-centering
- Profile mismatch; variations in density profiles
- Correlated structure/2-halo term (esp. for large beams like those of *Planck*)
- Other emission from cluster region
- Instrumental systematics: beams, polarization leakage,...

What's Next

- Next generation CMB experiments/missions
  - Adv. ACT, SPT-3G, CMB-S4
- COrE+ (ESA)?, Far-IR Surveyor (NASA)?
- Design considerations

Design Considerations



Conclusions

- Bright future for CMB lensing
  - Proven concept
  - New instruments coming on line now
  - Future instruments
  - Wide sky coverage
- Key points
  - Methods that permit easy binning/statistical analysis are important
- Strong points
  - High redshift ($z>2$)
- Limitation
  - Low angular resolution