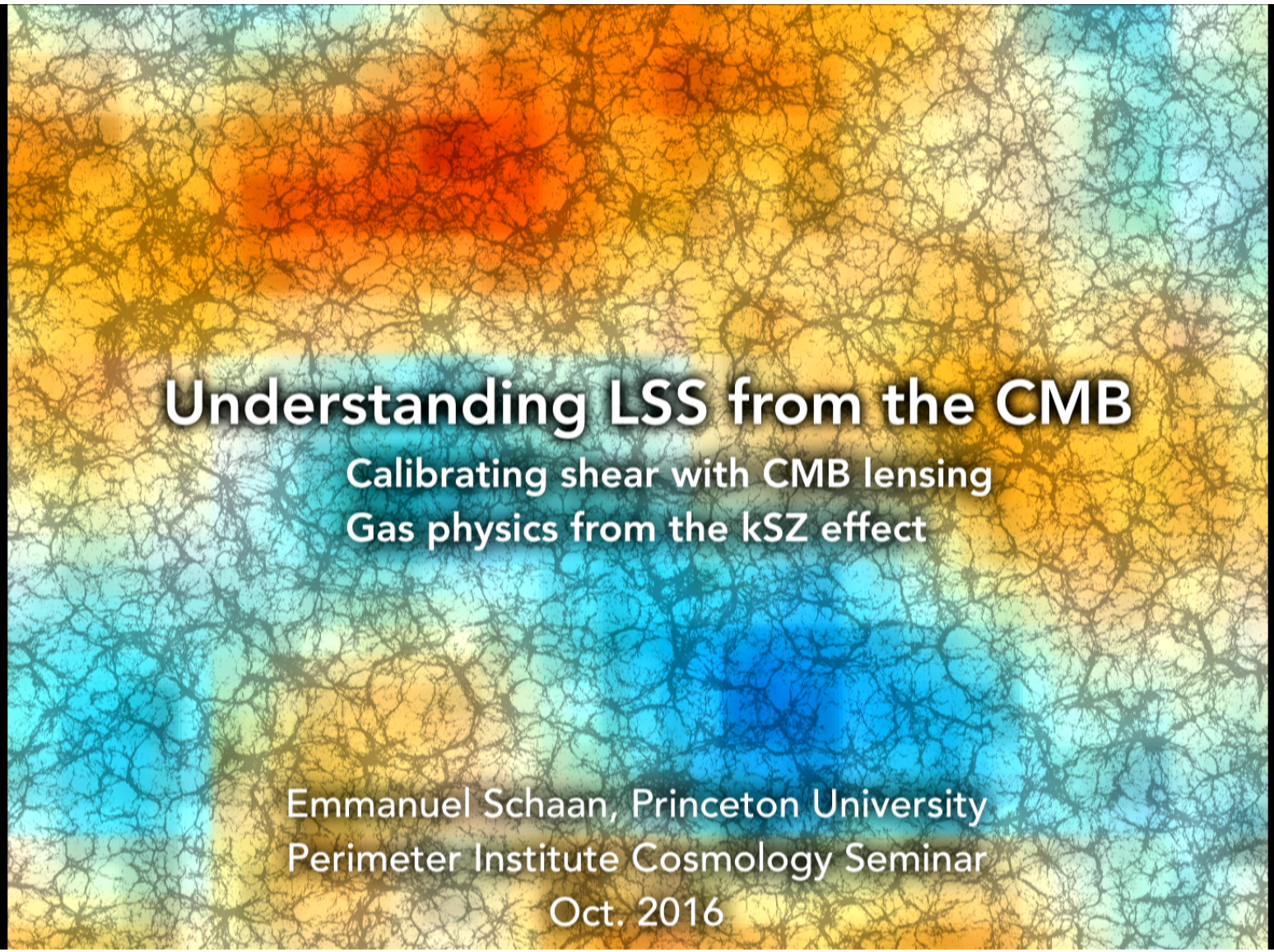
Title: Understanding large-scale structure from the CMB

Date: Oct 04, 2016 11:00 AM

URL: http://pirsa.org/16100045

Abstract: In this seminar, I will present two promising ways in which the cosmic microwave background (CMB) sheds light on critical uncertain physics and systematics of the large-scale structure.
 Shear calibration with CMB lensing (arXiv:1607.01761):
Realizing the full potential of upcoming weak lensing surveys requires an exquisite understanding of the errors in galaxy shape estimation. In particular, such errors lead to a multiplicative bias in the shear, degenerate with the matter density parameter and the amplitude of fluctuations. Its redshift-evolution can hide the true evolution of the growth of structure, which probes dark energy and possible modifications to general relativity. I will show that CMB lensing from a stage 4 experiment (CMB S4) can self-calibrate the shear for an LSST-like optical lensing experiment. This holds in the presence of photo-z errors and intrinsic alignment.
 Evidence for the kinematic Sunyaev-Zel'dovich (kSZ) effect (arXiv:1510.06442); cluster energetics:

Through the kSZ effect, the baryon momentum field is imprinted on the CMB. I will report significant evidence for the kSZ effect from ACTPol and peculiar velocities reconstructed from BOSS. I will present the prospects for constraining cluster gas profiles and energetics from the kSZ effect with SPT-3G, AdvACT and CMB S4. This will provide constraints for galaxy formation and feedback models.


Understanding LSS from the CMB
Calibrating shear with CMB lensing
Gas physics from the kSZ effect
Emmanuel Schaan, Princeton University
Perimeter Institute Cosmology Seminar
Oct. 2016

Large-scale structure: Tantalus's ordeal

Gigantic statistical power, but…

$N_{modes} \propto (k_{max}/k_{min})^3$ versus $N_{modes} \propto (l_{max}/l_{min})^2$

Non-linear physics

larger perturbations but harder to predict

Non-Gaussian statistics

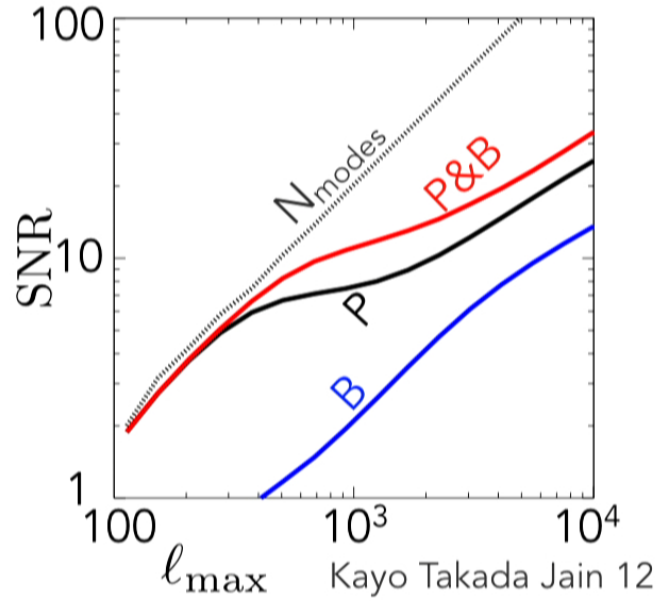
larger Shannon info but harder to extract

Complex baryonic effects

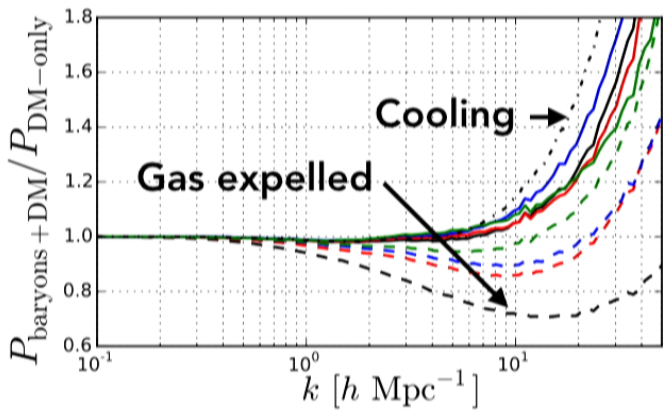
biasing, star formation and feedback

Complex observables

often systematics-limited



Kayo Takada Jain 12



Foreman Becker Wechsler 16

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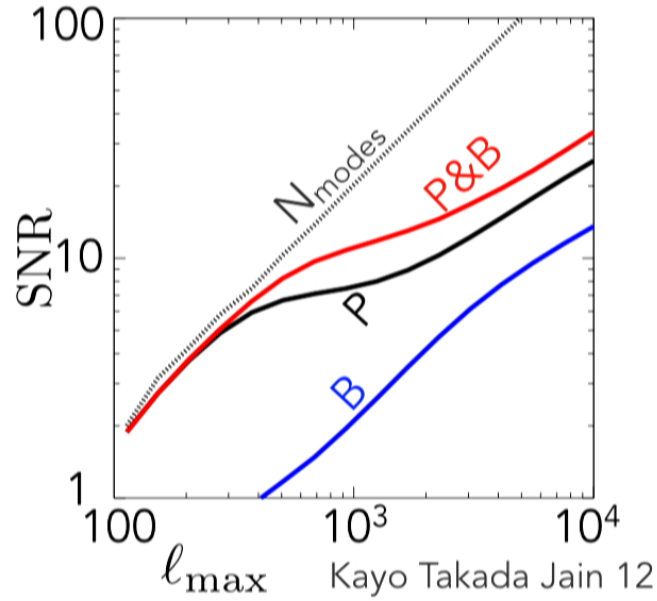

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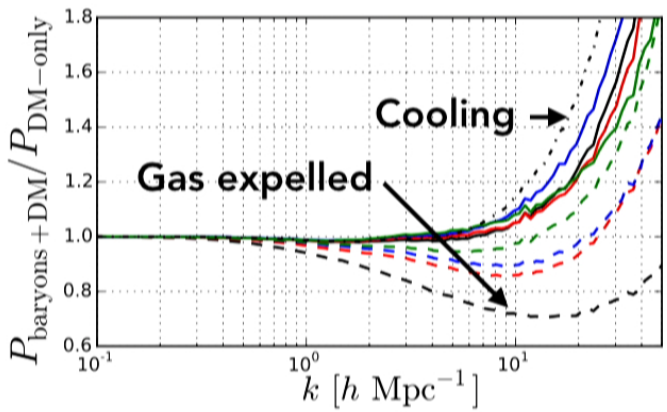

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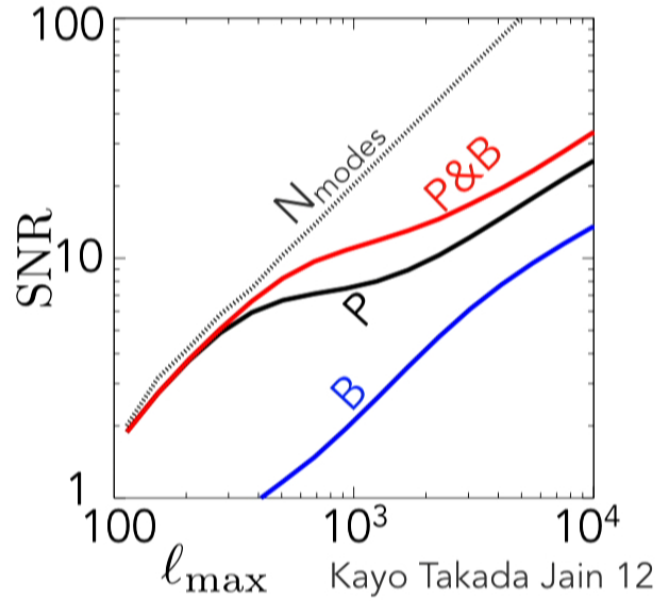

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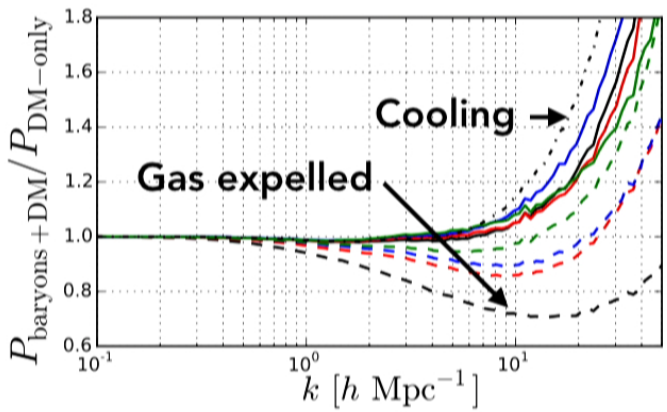

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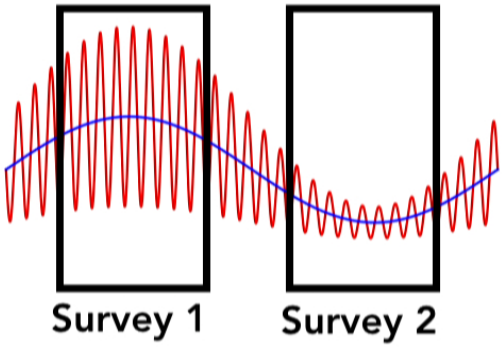
Not this talk…

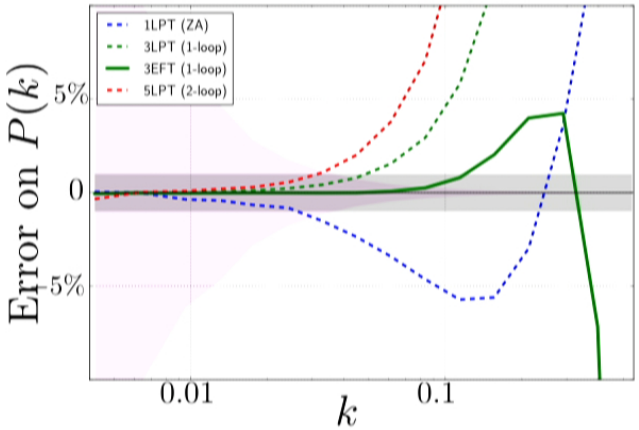


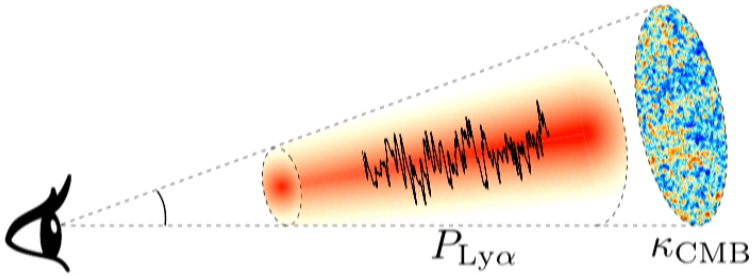
Statistics: Non-Gaussian covariances for n-point functions and halo counts

ES Takada Spergel 14, PRD, 1406.3330

Non-linearities: EFT of the large-scale structures

Baldauf ES Zaldarriaga 15a,b, JCAP, 1505.07098, 1507.01583



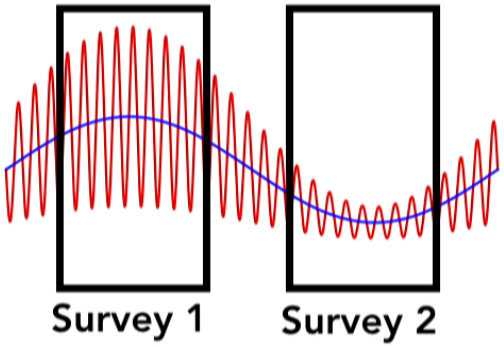


Baryons: First detection of the $\langle P_{\mathrm{Ly}\alpha}\kappa_{\mathrm{CMB}}\rangle$ bispectrum

Doux ES+14, PRD?, 1607.03625

Please come talk to me!

Not this talk…



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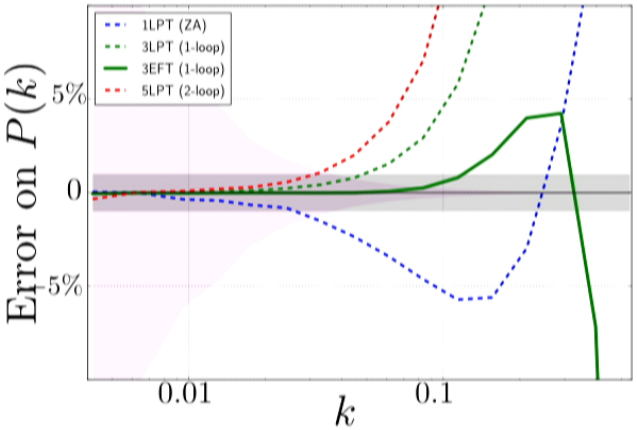

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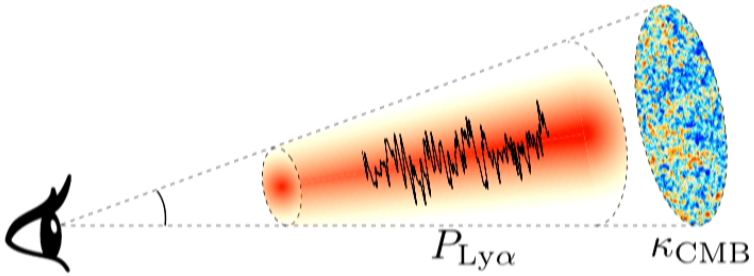

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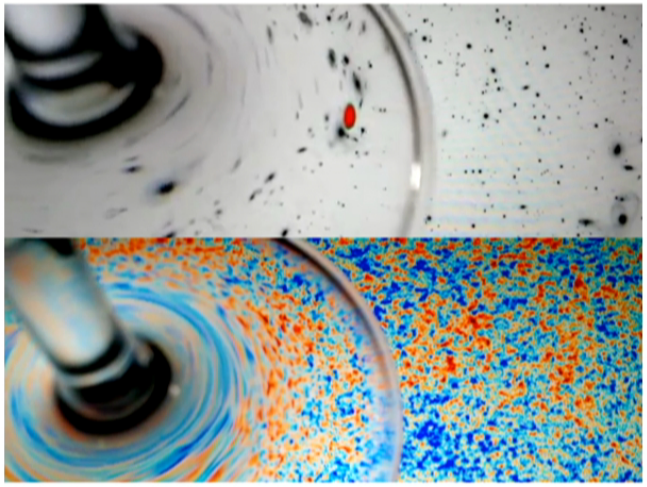
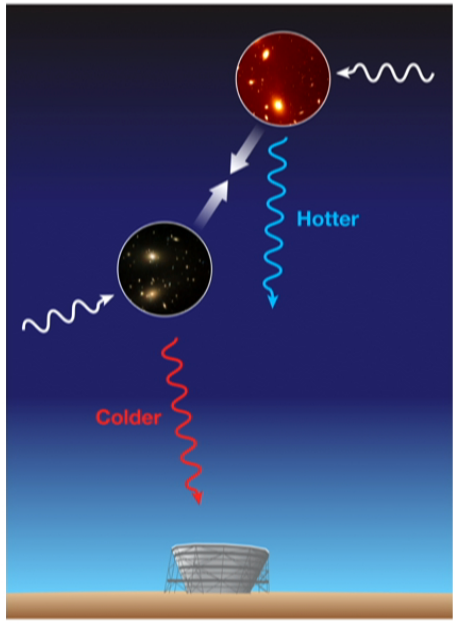
This talk: LSS from the CMB

Shear calibration with CMB lensing

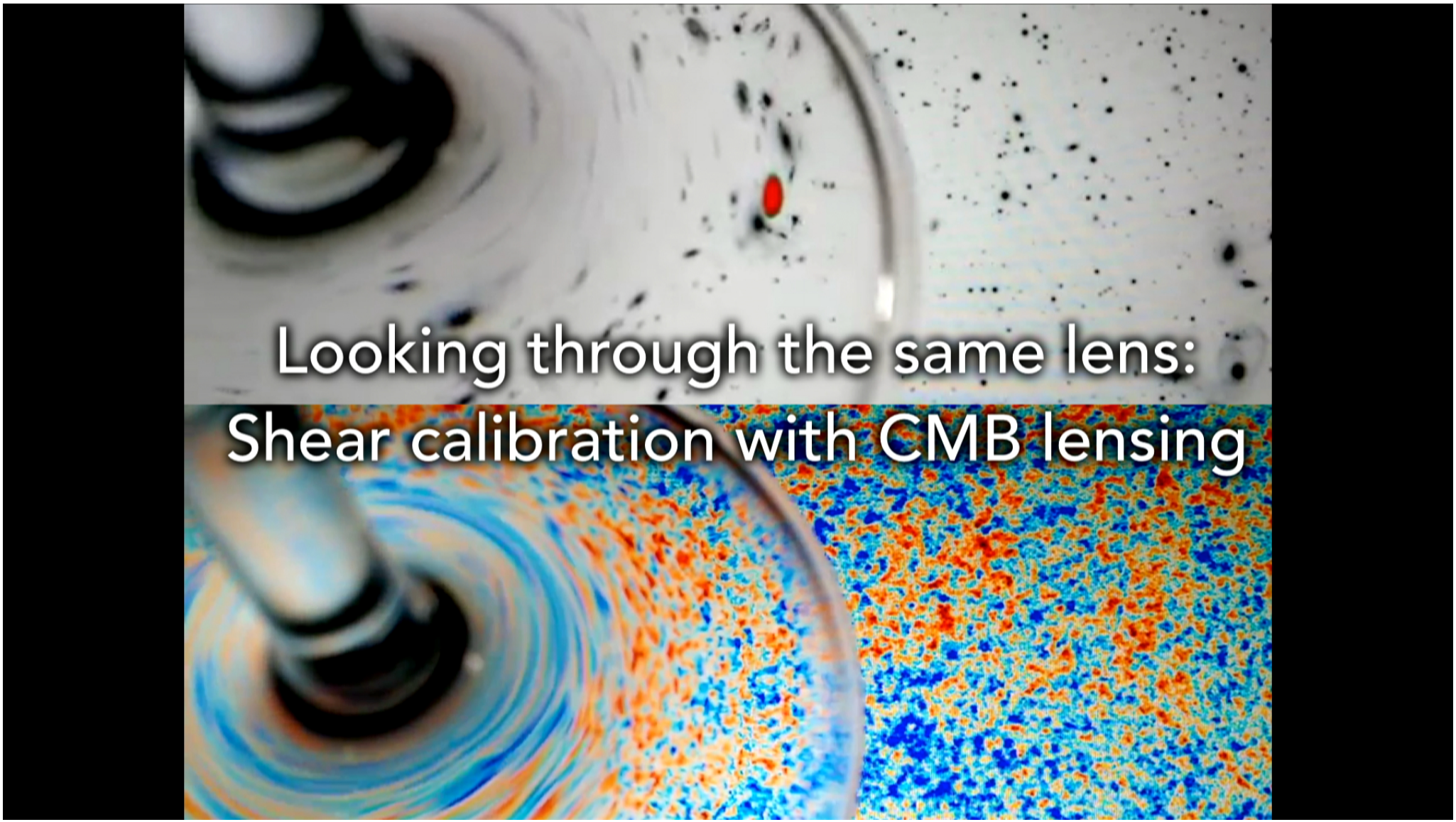
ES Krause Eifler Doré Miyatake Rhodes Spergel, PRD?, 1607.01761



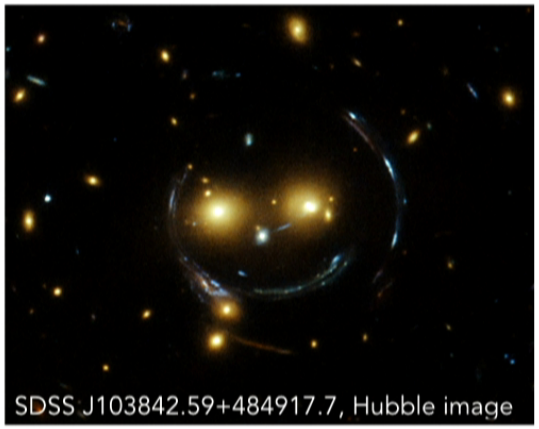


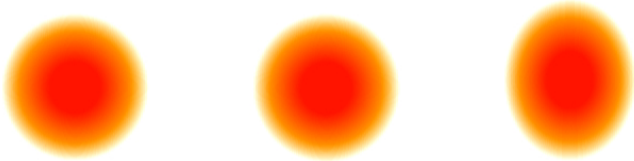
Detecting the kSZ signal from BOSS with ACTPol

ES Ferraro Vargas Smith Ho Spergel & ACTPol, PRD, 1510.06442


Looking through the same lens:
Shear calibration with CMB lensing

Optical weak lensing





perfect disk shear ~1% shape ~20%

→ SNR~5% for one galaxy, ~10^3 for 10^9 galaxies

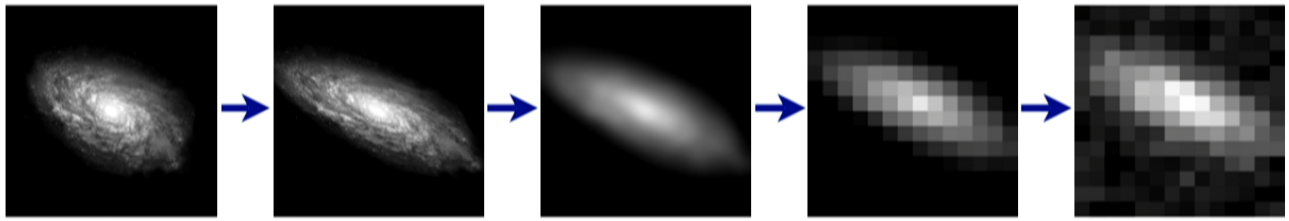
Complementary with clustering

geometry+growth

tests of GR: $\Psi+\Phi$ versus Φ

probes all the mass

biasing issue



Intrinsic galaxy (shape unknown) → Gravitational lensing causes a ***shear (g)*** → Atmosphere and telescope cause a convolution → Detectors measure a pixelated image → Image also contains noise

Heymans, Euclid Science Book 2010

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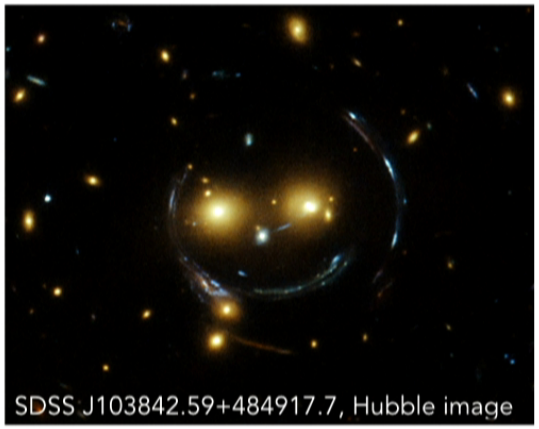

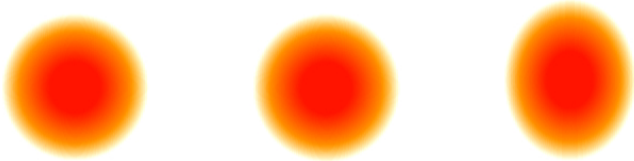

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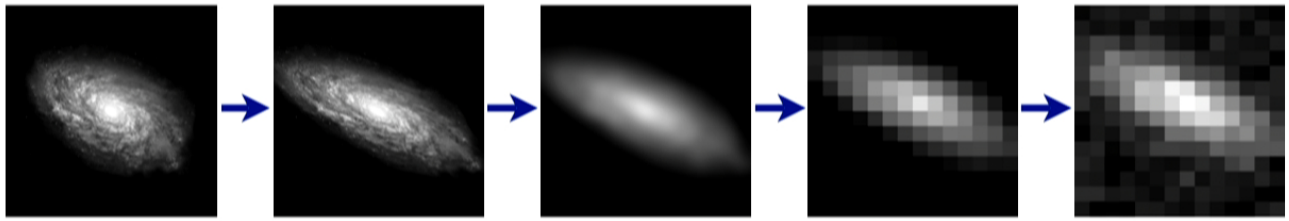

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Shear calibration: the case for redundancy

$$< e >= (1 + m)\, \gamma_{\rm true} + \alpha\, e_{\rm PSF} + c$$

Heymans+06
Taylor Kitching 16

Scary: m(z) degenerate with growth, hence dark energy EOS

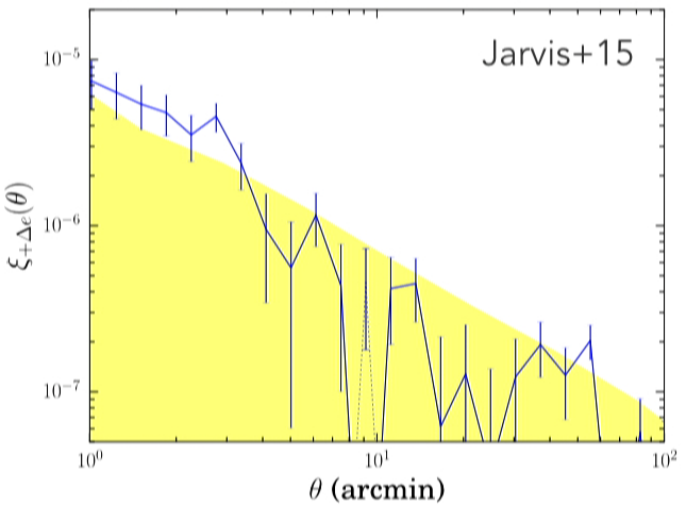
"Required" for LSST: < 0.5% (Huterer+06, Massey+12, ES+16)

Image simulations: 3-5% DES (Jarvis+15), 1% KiDS (Fenech-Conti+16)

Difficult:

- Noise/Model biases
- Selection bias: simulate below the detection limit (Hoekstra+15)
- Mode coupling: simulate below the image resolution
- PSF size error

→ **Redundancy is valuable**



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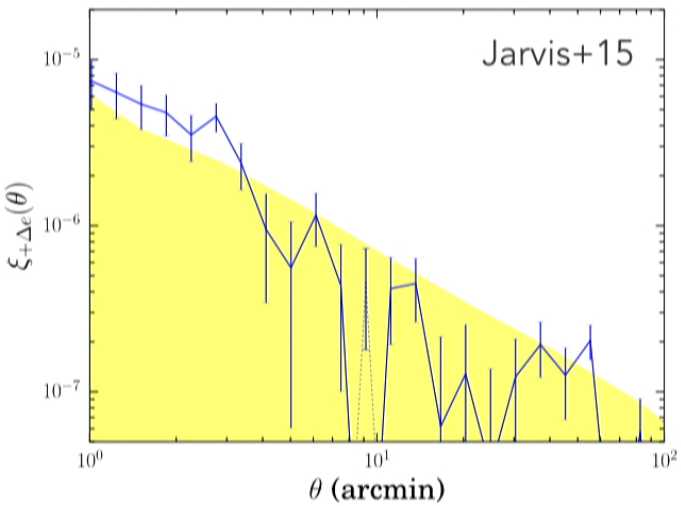


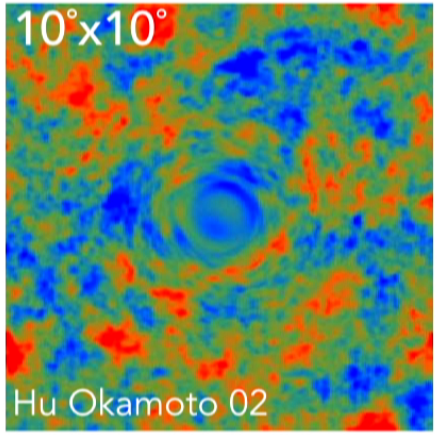
CMB lensing & reconstruction

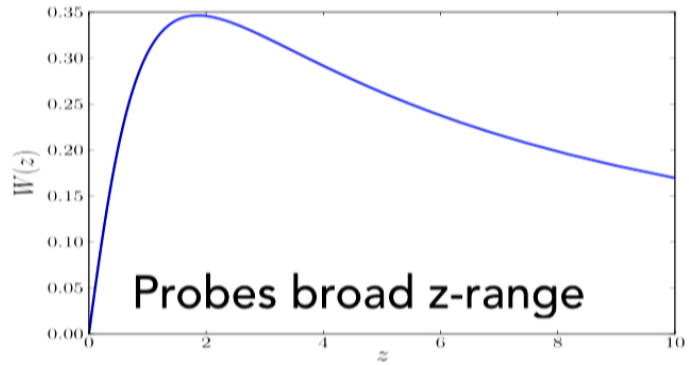
$$T(\hat{n}) = T_0(\hat{n}) + \vec{d} \cdot \vec{\nabla} T_0(\hat{n})$$

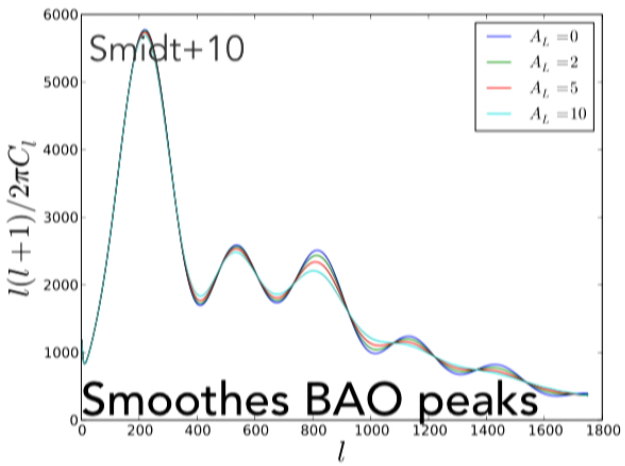
Arcmin deflections, coherent on degree scale

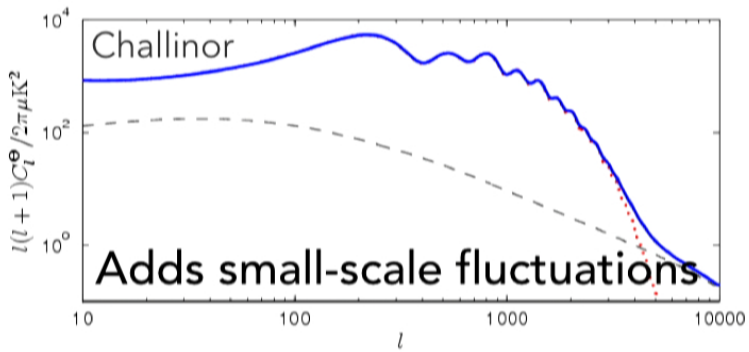
Breaks statistical isotropy → reconstruction

Different systematics (SZ, point sources)









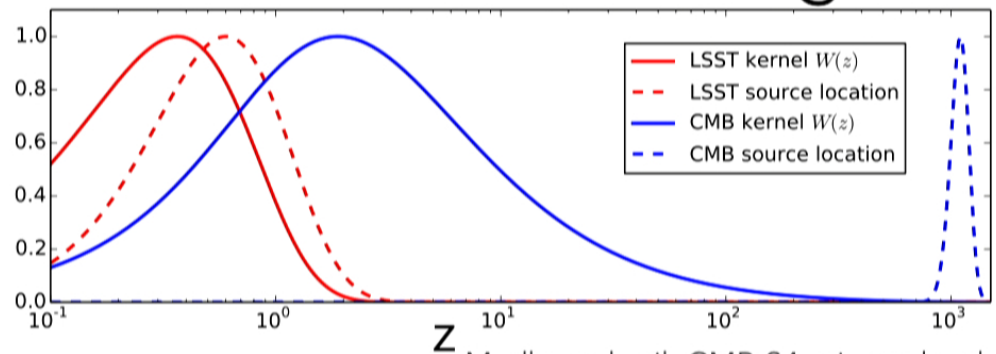
Shear calibration with CMB lensing

Principle:

Vallinotto12,13, Das+13

$\kappa_{gal} \sim (1+m)\ \sigma_8$

$\kappa_{CMB} \sim \sigma_8$



Madhavacheril, CMB S4 science book

Value:

Purely empirical, self-calibration

No assumption on galaxy population/morphologies

Just the beginning!

Liu+16, Baxter+16, Miyatake Madhavacheril+16, Singh+16 & many more!

~10-20% calibration, (mostly) fixed cosmology & nuisances

Questions:

Competitive with image simulations / requirements?

Varying cosmology & nuisance?

Robustness to photo-z, IA?

What combination is best?

Shear calibration with CMB lensing

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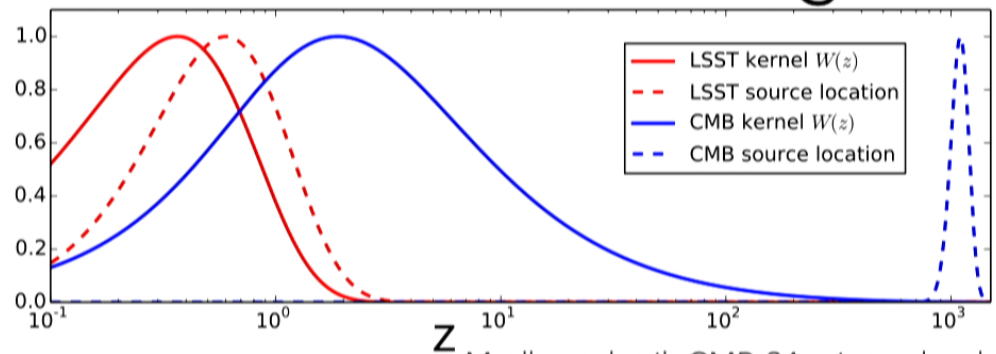

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Large Synoptic Survey Telescope

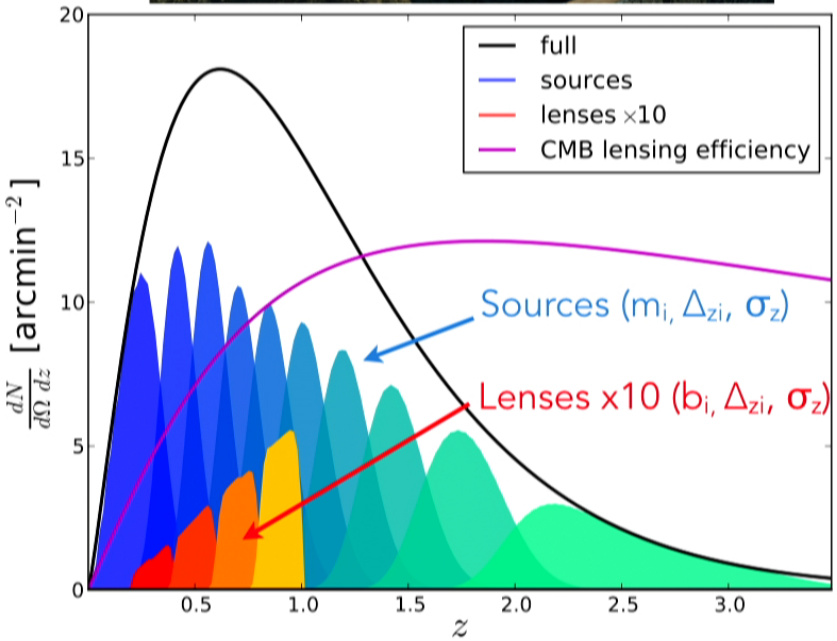
8.4m telescope in Chile

Survey starts 2022-23

~ half the sky

Sources: 26 arcmin^{-2}

Lenses: redmagic-like



18,000 deg^2, 26 sources/arcmin^2, 0.25 lenses/arcmin^2, shape noise = 0.26

$\sigma_z/(1+z)$ = 5% for sources, known to 0.2% for sources

$\sigma_z/(1+z)$ = 1% for lenses, known to 0.06% for lenses

CMB Stage 4 lensing

Stage 4: ~500,000 detectors

Beam: 1′, Sensitivity: 1μK′

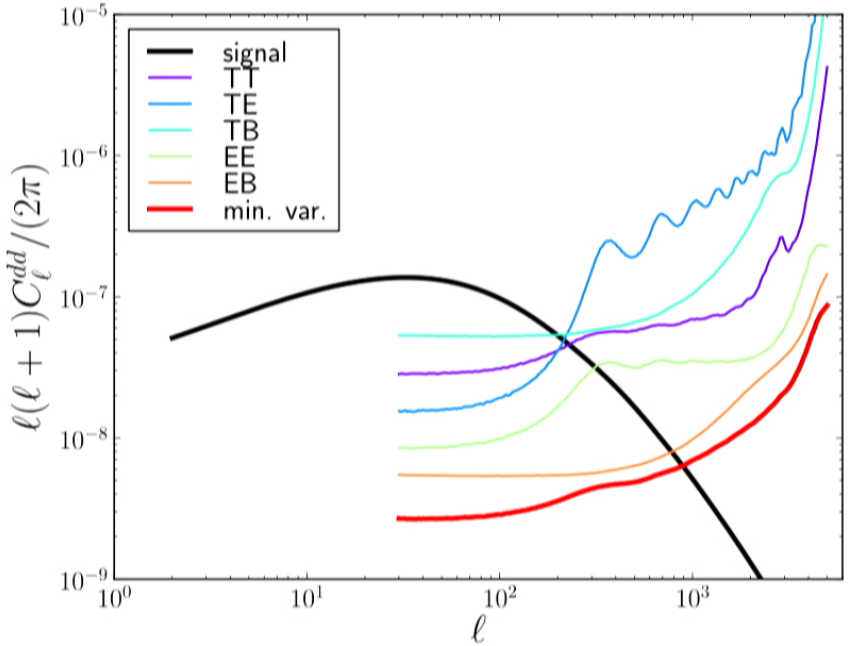
l_{min}=30, $l_{max,T}$=3000, $l_{max,E,B}$=5000

Quadratic estimator

Foreground cleaned input map

Assumed no systematics

Lensing only!



Forecast

- **Observables:** all combinations of {g, κ_{gal}, κ_{CMB}}

  clustering
  gal - shear
  shear - shear
  gal - CMB lensing
  shear - CMB lensing
  CMB lensing auto

- **Constrain:** cosmology, b_i, m_i, Δ_{zi}, σ_z
  No prior on b_i , m_i. Priors on Δ_{zi}, σ_z.

- **Realistic/conservative:**
  Full non-Gaussian covariances
  Explore likelihood with MCMC

- **Built on CosmoLike (Eifler Krause+14)**
  Extended to include CMB lensing
  Soon to be public!

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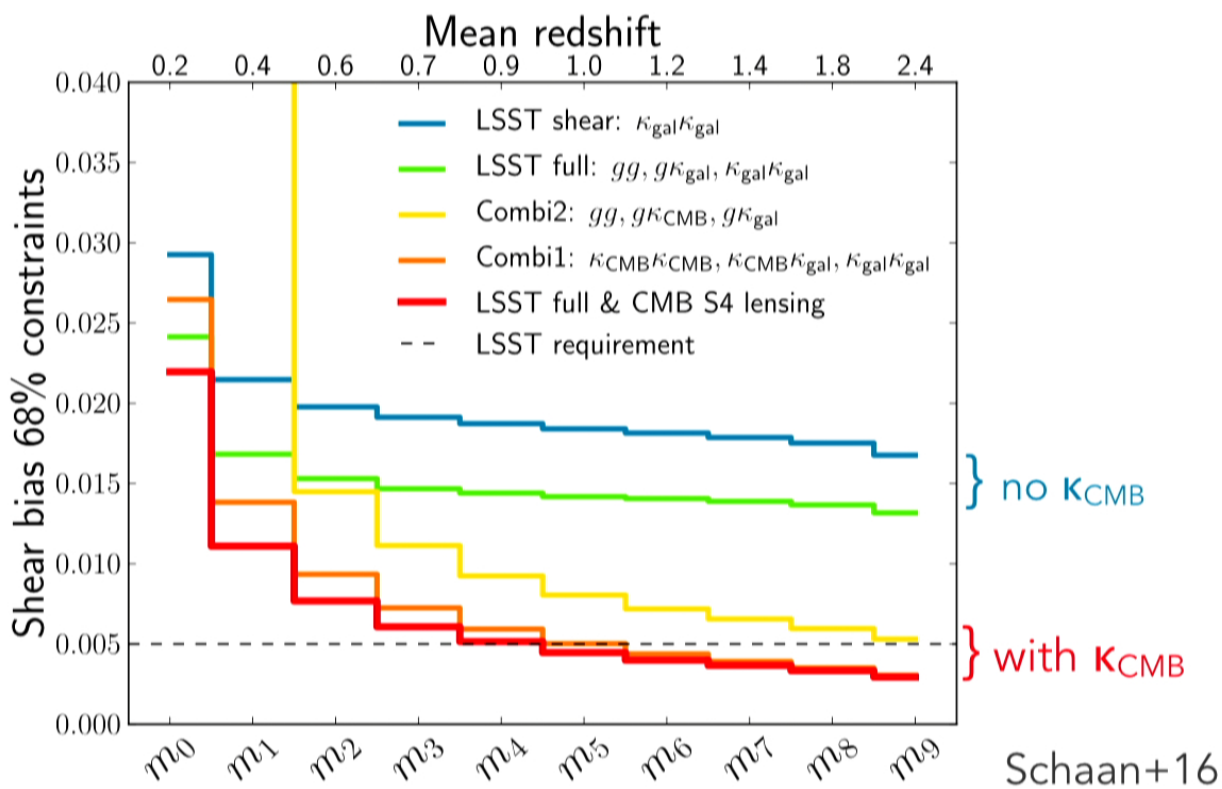
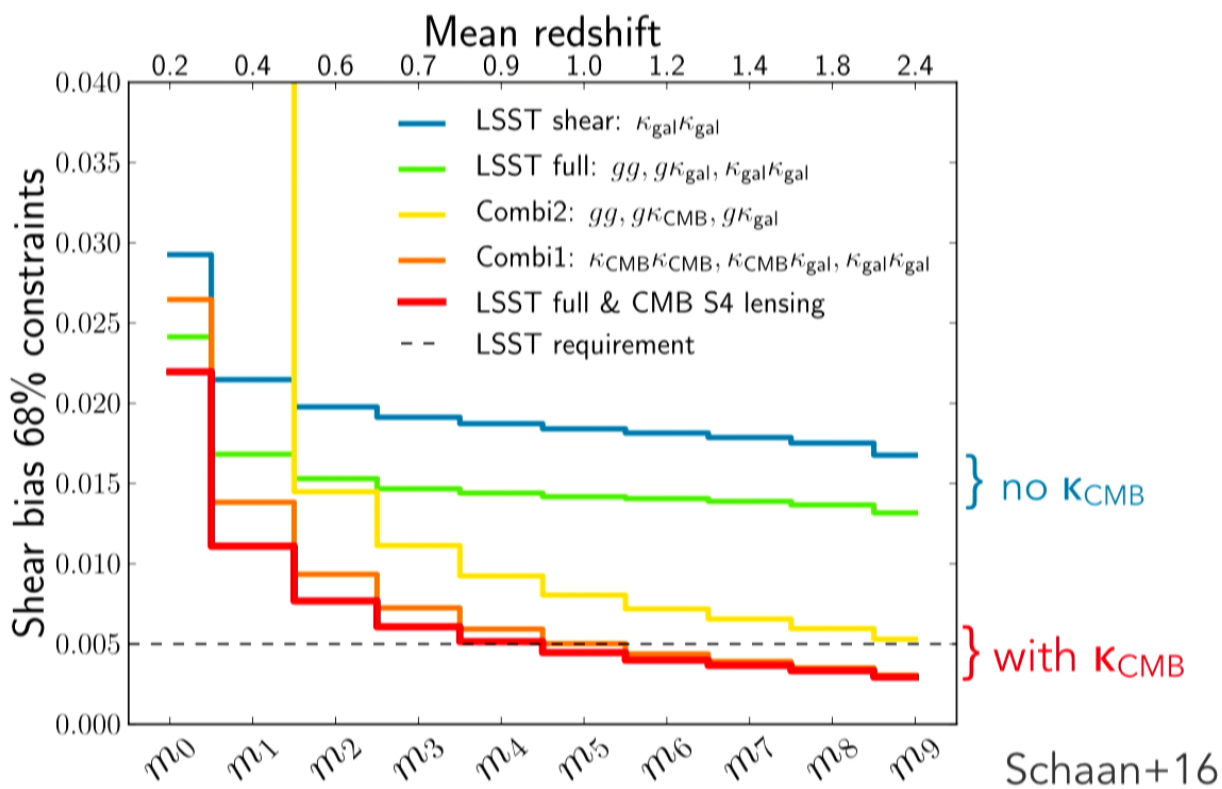


CMB S4 lensing can calibrate the shear ~ requirements

while varying cosmo & nuisance params

better at high z where most challenging

purely empirical, self-calibration



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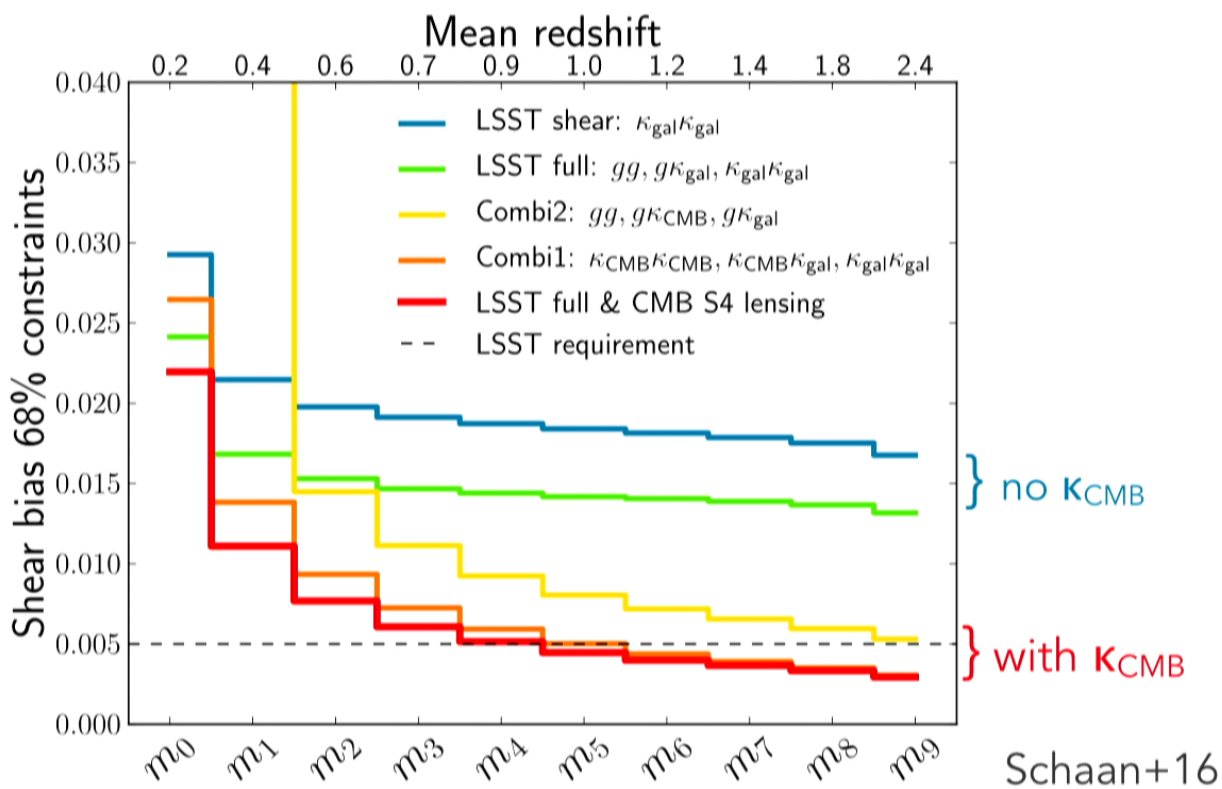

CMB S4 lensing can calibrate the shear ~ requirements

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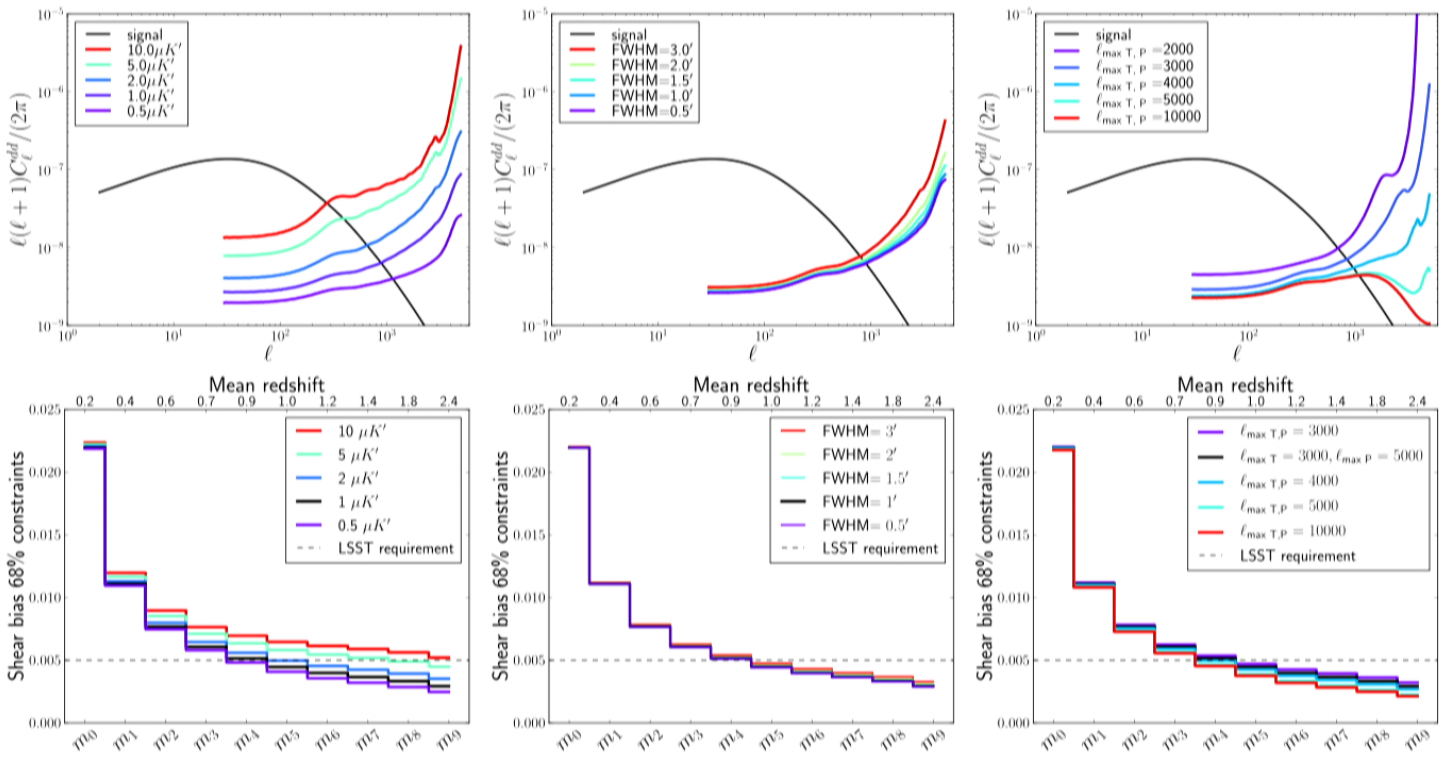
Summary: Shear calibration with CMB lensing

arXiv:1607.01761

- **CMB S4 lensing can constrain the shear bias to 0.5% ~ LSST requirements**
- **Purely empirical, self-calibration, no assumption on galaxy population/morphologies**
- **Works best at high z where most difficult**
- **Possible with AdvACT, SPT-3G, Simons Observatory**
- Robust to IA, photo-z degradation, non-linearities & baryons, CMB S4 specs
- In the works: "delensing" with CIB, iterative reconstruction, photo-z outliers, correlated mi

CMB S4 specs?

Noise | Beam | l_{max}



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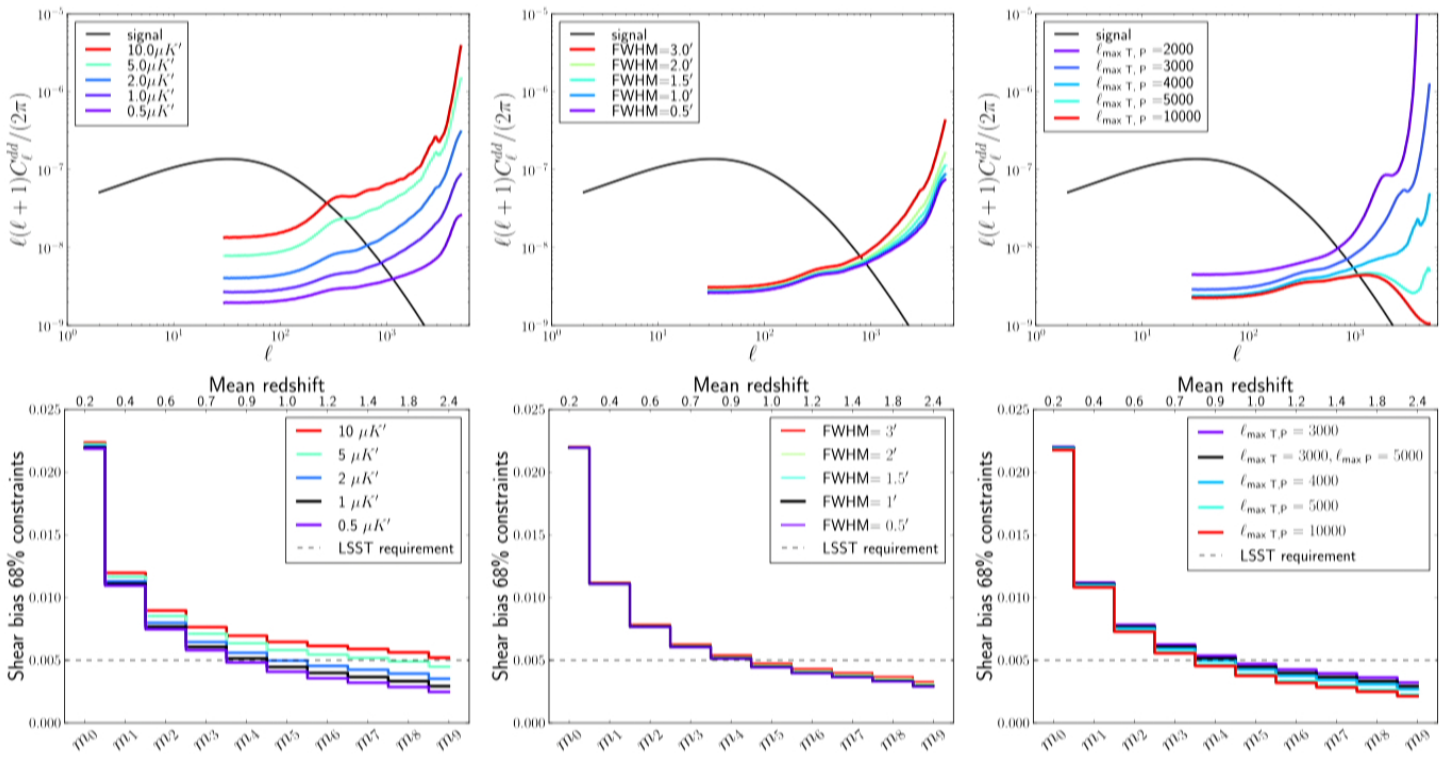
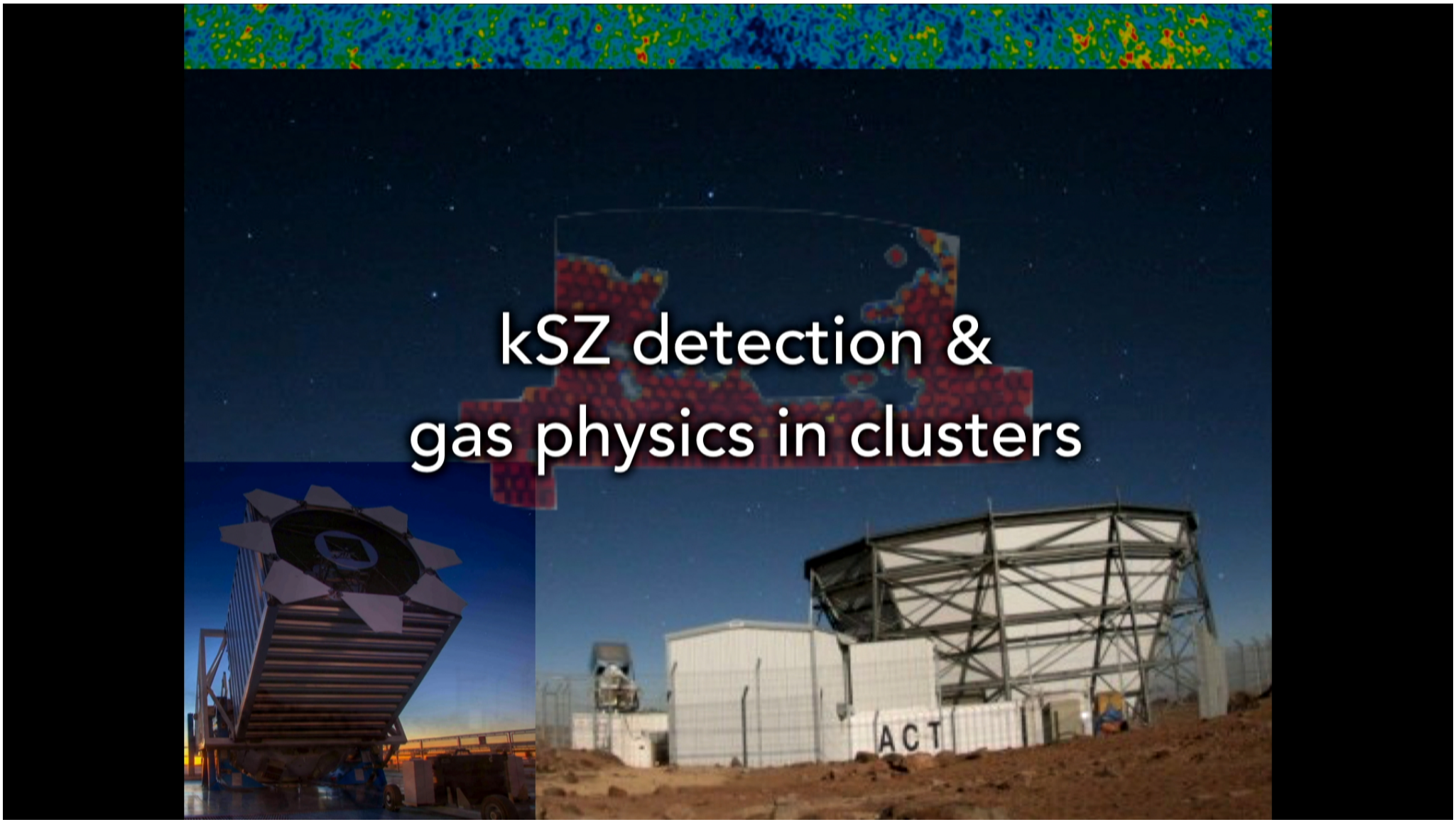



kSZ detection &
gas physics in clusters
ACT

Collaborators

arxiv:1510.06442

Simone Ferraro

Mariana Vargas-Magaña

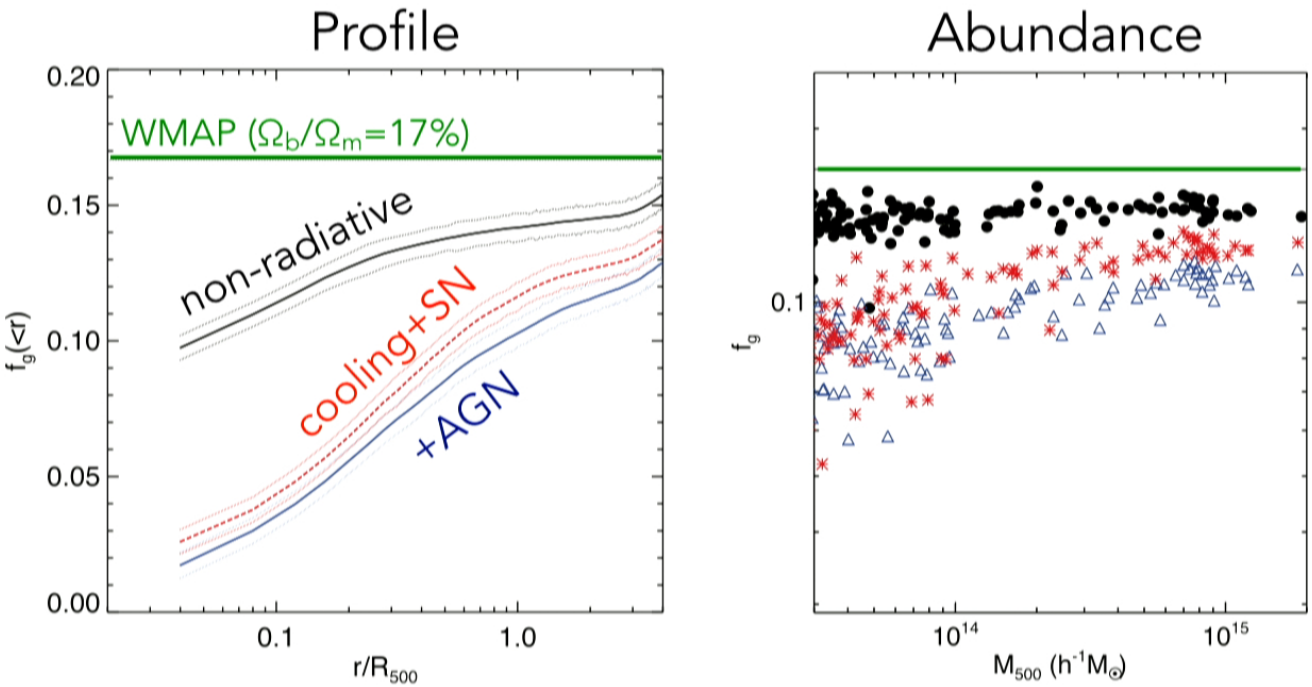
Kendrick Smith

Shirley Ho

David Spergel

Nick Battaglia

Gas in clusters & galaxy formation



from Planelles+13

→ Measuring gas profile and abundance can constrain feedback mechanisms

Kinematic Sunyaev-Zel'dovich effect

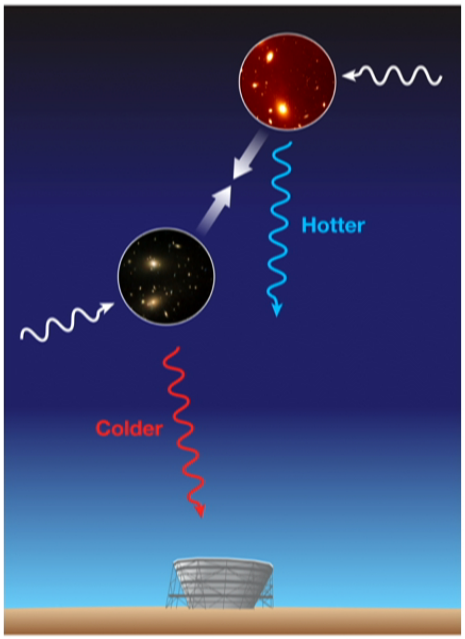
$$\frac{\delta T}{T} = \int \overbrace{\mathrm{d}l\, n_e \sigma_T}^{\tau} \frac{v}{c}$$

Counts all free electrons

Lower mass halos at higher z

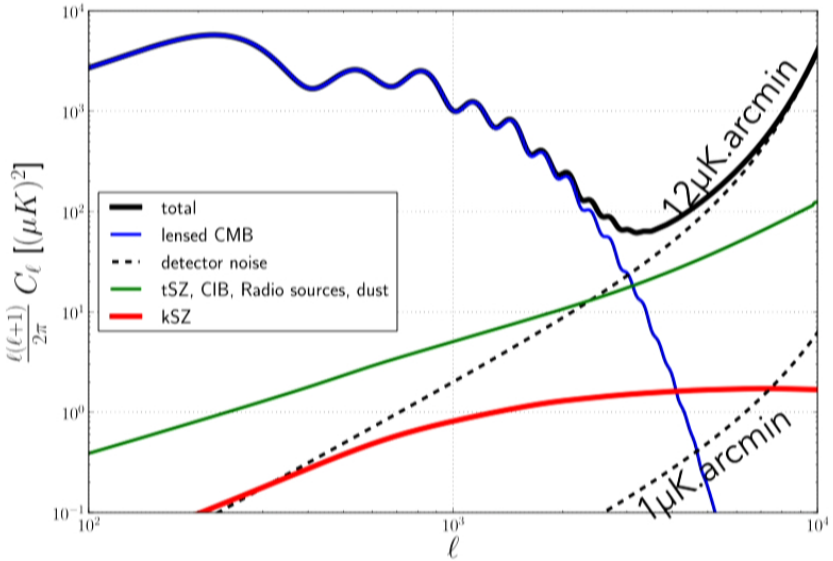
Small size: $\delta T_{\mathrm{kSZ}} \sim 0.1\mu\mathrm{K}, \delta T_{\mathrm{CMB}} = 110\mu\mathrm{K}$

Blackbody spectrum



Hand et al 2012

aps.org, ESO, ESA, Hubble, NASA



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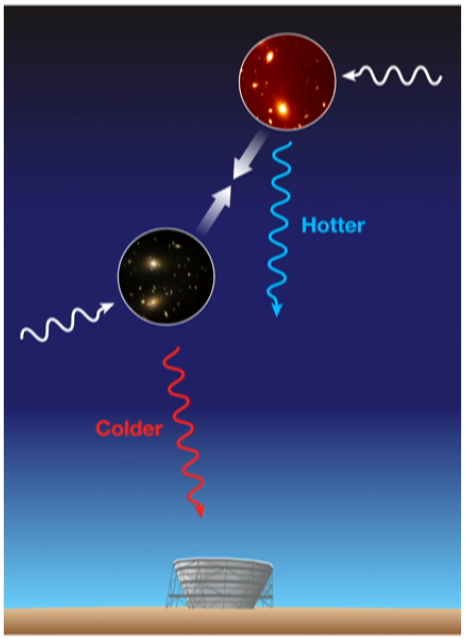

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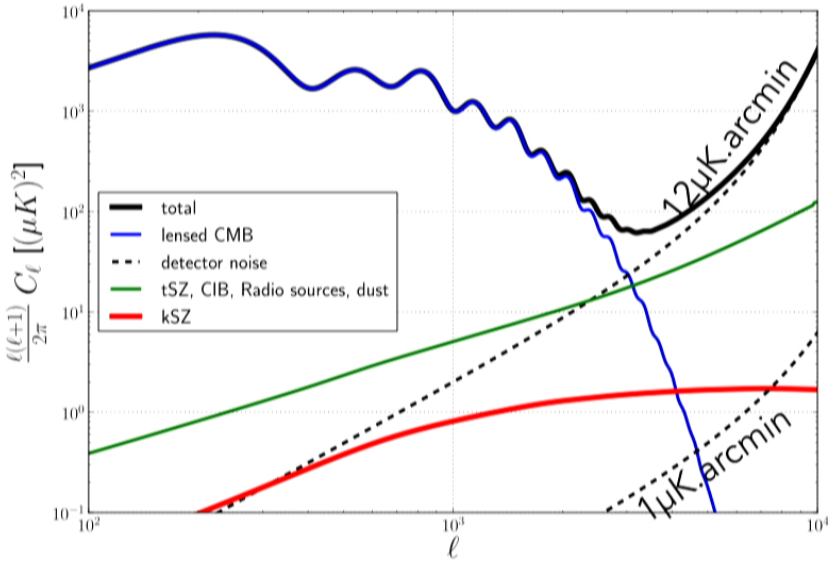
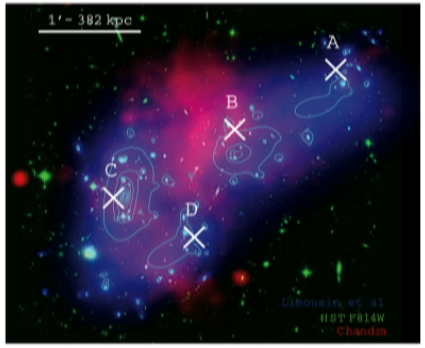


Detection methods



Individual (monster) cluster

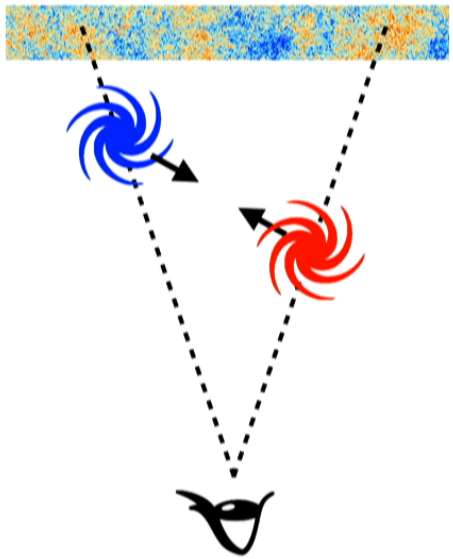
Sayers+13, 14

Pairwise velocities

Hand+12, Planck15, Soergel+16, de Bernardis+16

Velocity reconstruction

Planck15, ES Ferraro+16



$\langle T^2 \times \text{tracer} \rangle$, Hill+16, Ferraro+16

T Power spectrum, George Reichardt+14

T^2 power spectrum, Smith Ferraro 16

Velocity reconstruction

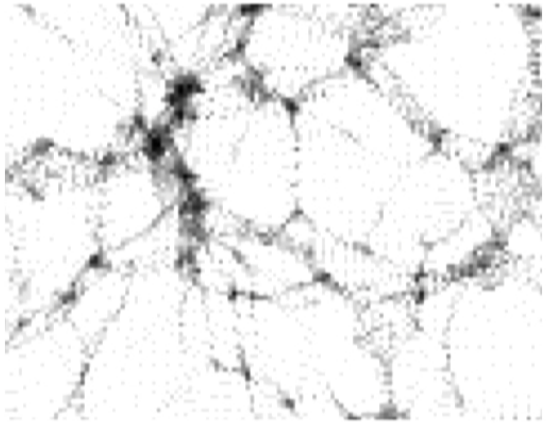
Peculiar velocity $\vec{v} = \frac{d\vec{r}}{dt} - H_{(t)}\vec{r} = \frac{d\vec{x}}{d\eta}$

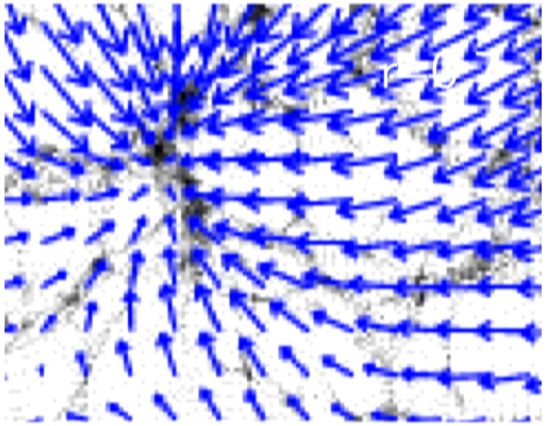
Mass conservation + linear approx.

$$\dot{\delta} + \vec{\nabla} \cdot \vec{v} = 0 \;\Rightarrow\; \vec{v} = -aHf\,\vec{\nabla}\Delta^{-1}\delta$$

$$\rightarrow v_{\mathrm{rms\ 1d}} \sim 300\ \mathrm{km/s}$$

150Mpc





Padmanabhan et al. 2014

Velocity reconstruction

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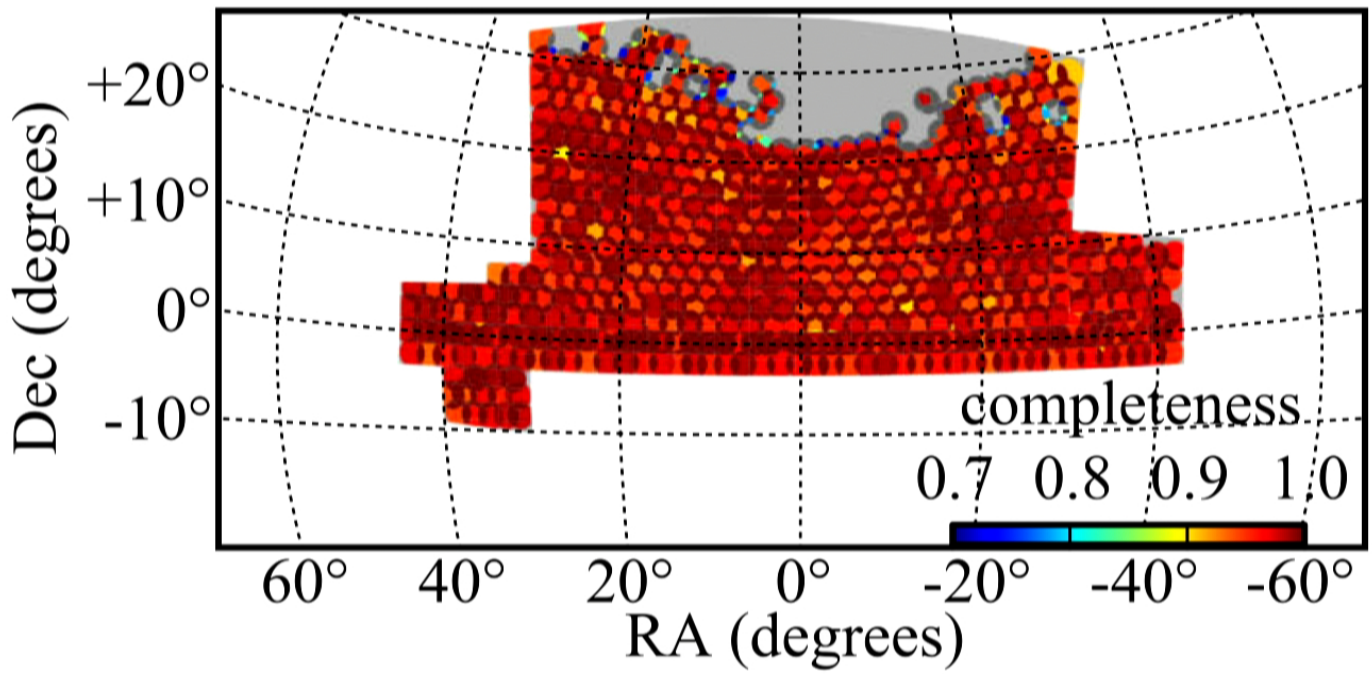
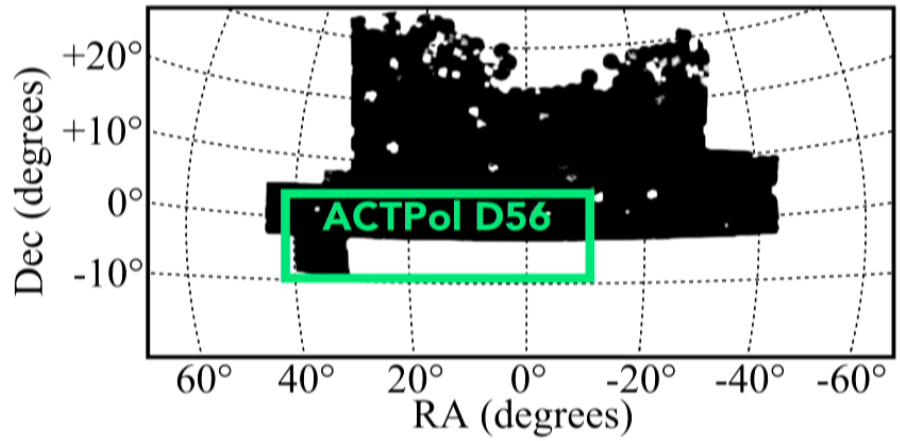


BOSS CMASS South DR11 footprint (sdss.org)

"Halos" from BOSS CMASS



25,000 CMASS DR10 galaxies, 0.4<z<0.7

Central fraction 85%

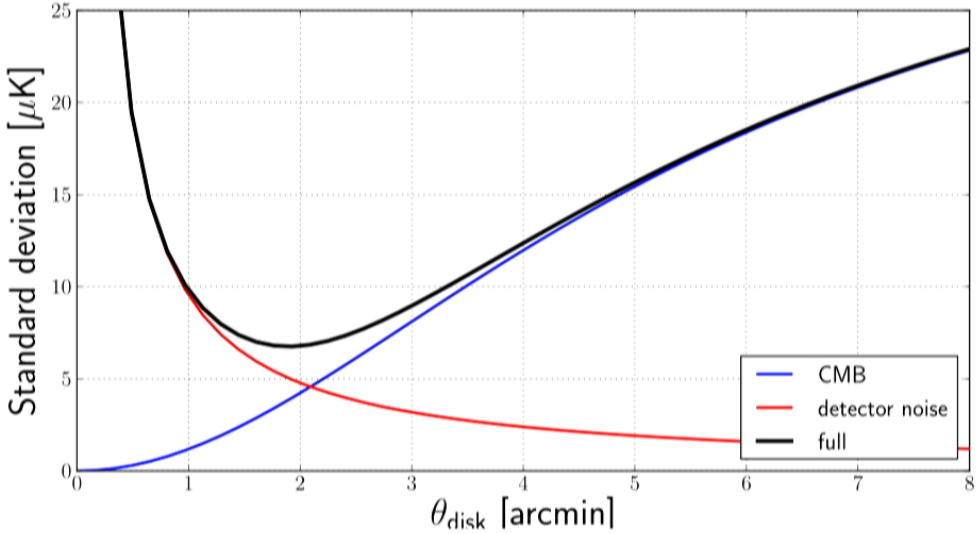
Stellar masses $M_* \sim 2 \times 10^{11} M_\odot$ $M_{\rm halo} \sim 2 \times 10^{13} M_\odot$ $\theta_{\rm vir} \sim 1.5{\rm arcmin}$

Reconstructed velocities (K. Smith , M. Vargas-Magaña, S. Ho)

→ τ and v_{rec} for each halo

Temperatures from ACTPol

Map at 148GHz
Area 600 sq. deg.
Noise 12muK.′
Beam FWHM 1.4′
Aperture photometry



→δT for each halo

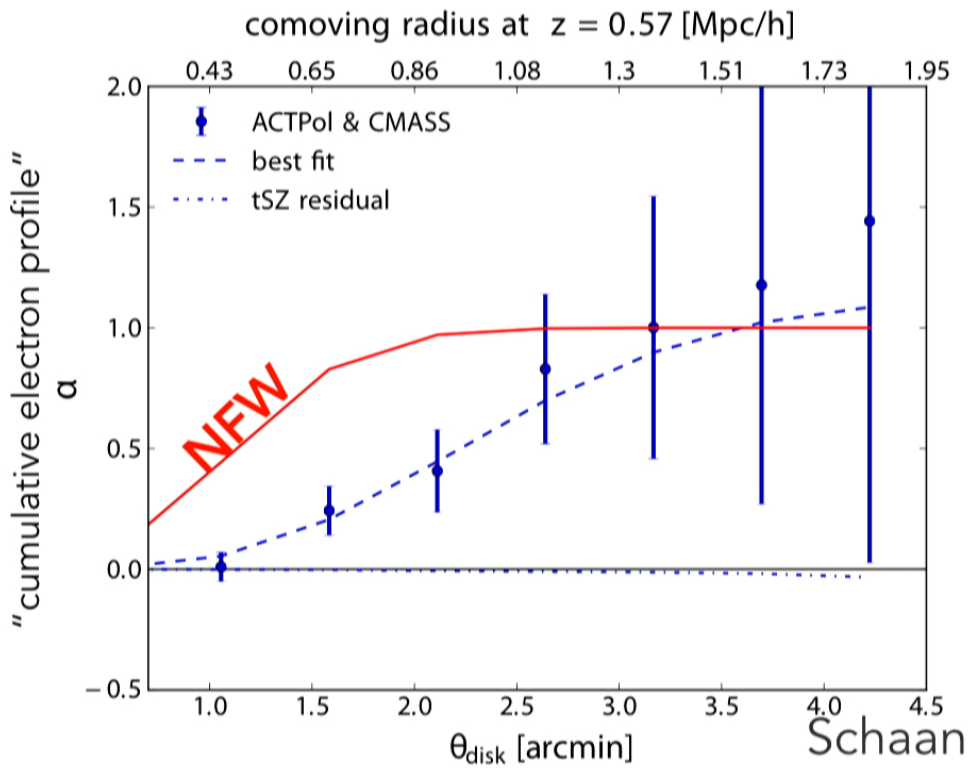
Baryon abundance & profile

Hypothesis: $\delta T \overset{?}{=} \alpha \, \tau \, v_{rec} + \text{noise}$

$$\rightarrow \alpha = \frac{\langle \delta T_{(\theta_{\rm disk})} \times \tau v_{\rm rec} \rangle}{\langle \tau v_{\rm rec} \times \tau v_{\rm rec} \rangle}$$

- $\alpha \simeq 0 \Leftrightarrow$ no detection
- $\alpha \simeq 1 \Leftrightarrow$ cosmological baryon abundance
- varying $\theta_{disk} \rightarrow$ profile information

Gas profile of CMASS halos



Schaan Ferraro +15

→ kSZ model preferred over null at 3 σ

→ Proxy for gas profile in clusters

Future prospects

Tracer sample: SNR ~ (1 to 2) * ($M_h/10^{13}M_{sun}$) * sqrt($N_{obj}/10^4$)

- this study (CMASS) 3×10^4 gal, $0.4<z<0.7$
- Full CMASS 4×10^5 gal, $0.4<z<0.7$
- PFS 10^7 gal, $0.8<z<2.4$
- DESI 2×10^7 gal, $z<2$

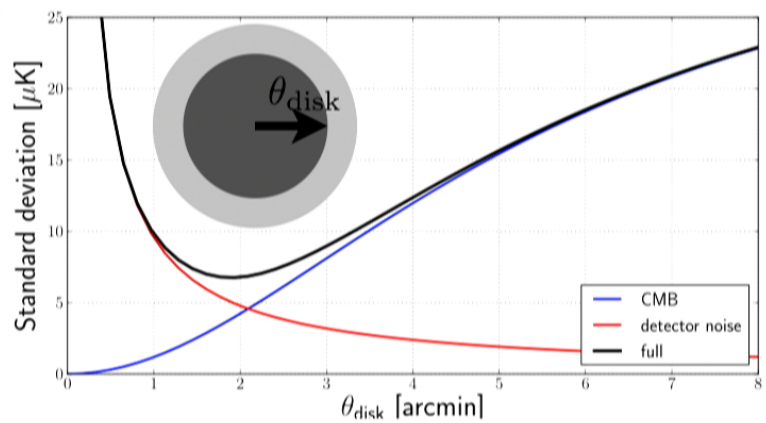
→ **SNR x ~30 from number of objects**

CMB map:

- this study (ACTPol) 14muK′, 1.4′
- AdvACT 7muK′, 1.4′, multifreq.
- CMB S4 1muK′, ?, multifreq.

→ **SNR x few from sensitivity**

→ **SNR x few from tSZ removal**



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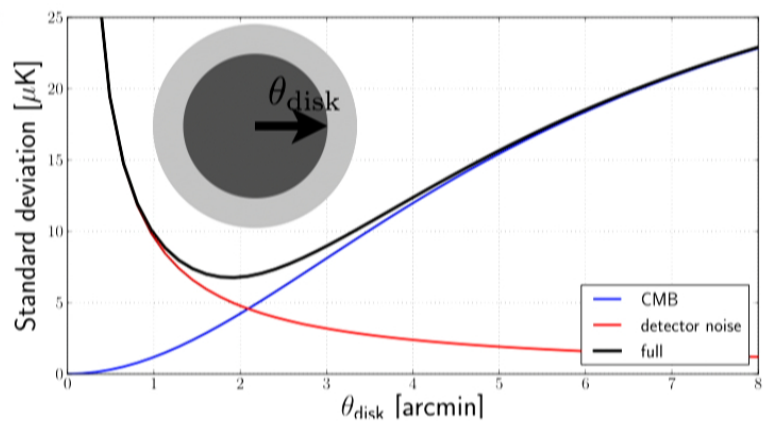

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Non-thermal pressure / energy injection

$$\begin{cases} \mathrm{kSZ} = \tau \left(\frac{v_{e,LOS}}{c}\right) \propto \rho_e \text{ gas density} \\ \mathrm{tSZ} = \tau \left(\frac{v_{e,th}}{c}\right)^2 \propto P_{e,th} \text{ gas thermal pressure} \end{cases}$$

Virial theorem:

$$\Phi_{\mathrm{gas+DM/gas}} + 3\mathcal{V}\left[< P_{\mathrm{th}} > + < P_{\mathrm{non\text{-}th}} > - P_{\mathrm{surface}}\right] = 0$$

kSZ lensing tSZ modeled from accretion rate

→ Constrain $P_{\text{non-th}}$, as a function of radius

→ Constrain energy injected?

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Summary: kSZ detection & gas physics in clusters

arXiv:1510.06442

- **Evidence for kSZ with ACTPol and velocity reconstruction from BOSS**
- **KSZ powerful baryometer: profile, abundance**
- **Constrain non-thermal pressure and energy injection with kSZ & tSZ**
- CMB S4 and DESI will multiply the SNR by ~100 → bin in mass/type/color