The Atacama Cosmology Telescope: A Measurement of the Thermal Sunyaev-Zel'dovich One-Point PDF

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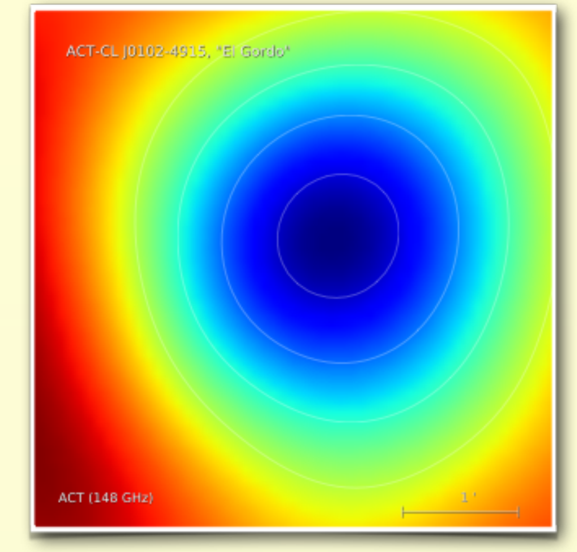


We present a measurement of the one-point probability distribution function (PDF) of the thermal Sunyaev-Zel'dovich (tSZ) decrement in the pixel temperature histogram of filtered 148 GHz sky maps from the Atacama Cosmology Telescope (ACT). The PDF includes the signal from all galaxy clusters in the map, including objects below the signal-to-noise threshold for individual detection, making it a particularly sensitive probe of the amplitude of matter density perturbations, σ_8. We use a combination of analytic halo model calculations and numerical simulations to compute the theoretical tSZ PDF and its covariance matrix, accounting for all noise sources and including relativistic corrections. From the measured ACT 148 GHz PDF alone, we find σ_8 = 0.793 +/- 0.018, with additional systematic errors of +/- 0.017 due to uncertainty in intracluster medium gas physics and +/- 0.006 due to uncertainty in infrared point source contamination. Using effectively the same data set, the statistical error here is a factor of two lower than that found in ACT's previous σ_8 determination based solely on the skewness of the tSZ signal. In future temperature maps with higher sensitivity, the tSZ PDF will break the degeneracy between intracluster medium gas physics and cosmological parameters.

Motivation

- Simple observable: histogram of pixel temperature values
- Use info from all clusters in the map, including SNR<5
- Optimal one-halo term tSZ statistic: very sensitive to σ_8
- Build on earlier ACT measurement of tSZ skewness [1]
- Possible route to breaking degeneracies between cluster gas physics and cosmological parameters [2]

Thermal SZ PDF: Theory

- Thermal Sunyaev-Zel'dovich (SZ) effect: change in temperature of CMB photons due to inverse Compton scattering off hot electrons in intracluster medium (ICM)

$$\frac{\tilde{T}}{T_{\rm CMB}} = g_\nu \frac{\sigma_T}{m_e c^2} \int P_e(l)\,dl$$

Filtered temperature fluctuation; Spectral function; Electron pressure profile; Line-of-sight integral

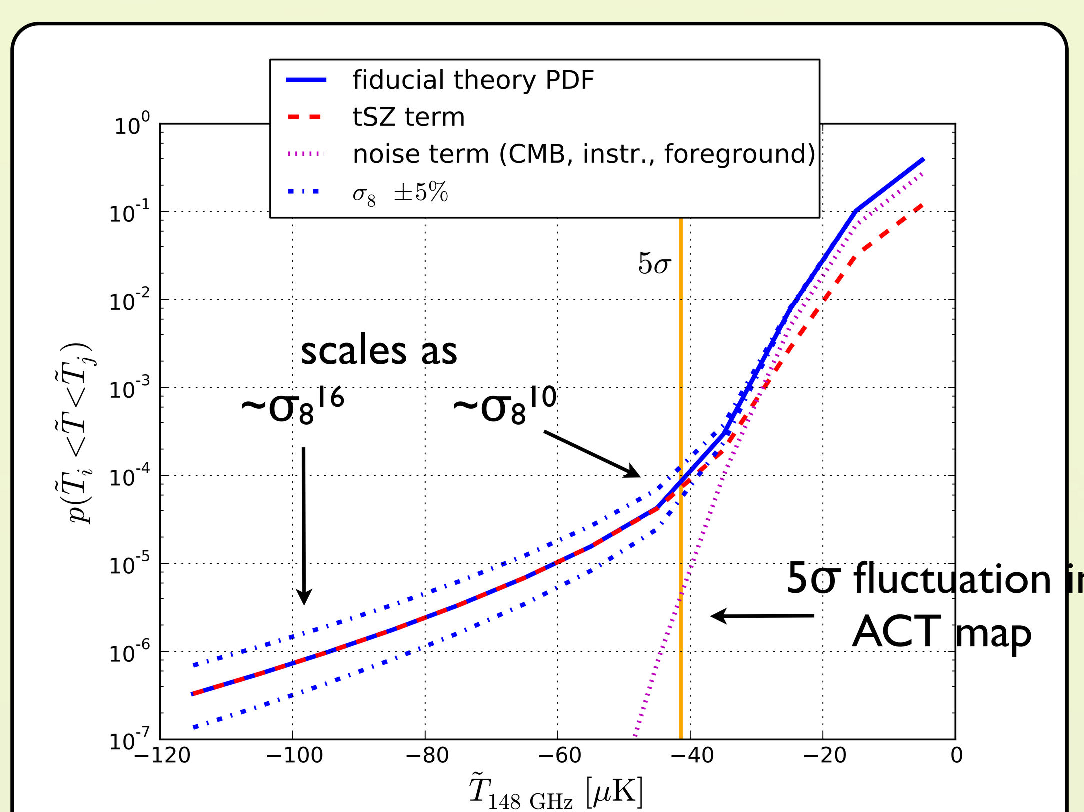
- Idealized tSZ PDF (for zero noise):
  - Sky area subtended by tSZ values within a given range
  - For a spherical cluster: area between two circles
  - Add up such areas for all clusters in the universe

$$p(\tilde{T}_i < T < \tilde{T}_{i+1}) = \int dz \frac{d^2V}{dz\,d\Omega} \int dM \frac{dn}{dM} \pi \left(\theta^2(\tilde{T}_{i+1}, M, z) - \theta^2(\tilde{T}_i, M, z)\right)$$

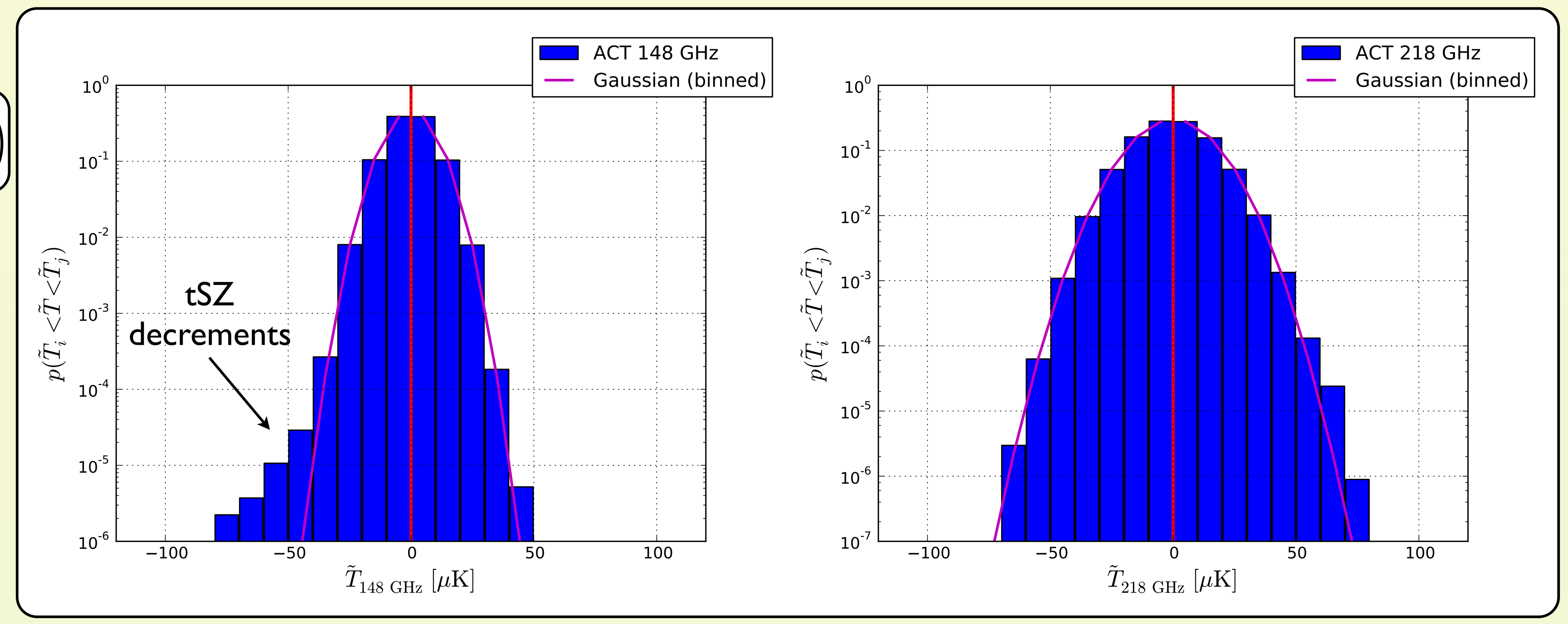
Volume element; Halo mass function; angular distance from cluster center to T

- Observable tSZ PDF:
  - Convolve with noise PDF
  - Convolve with other components (CMB, foregrounds)
  - Account for contributions from zero-tSZ pixels (pure noise)

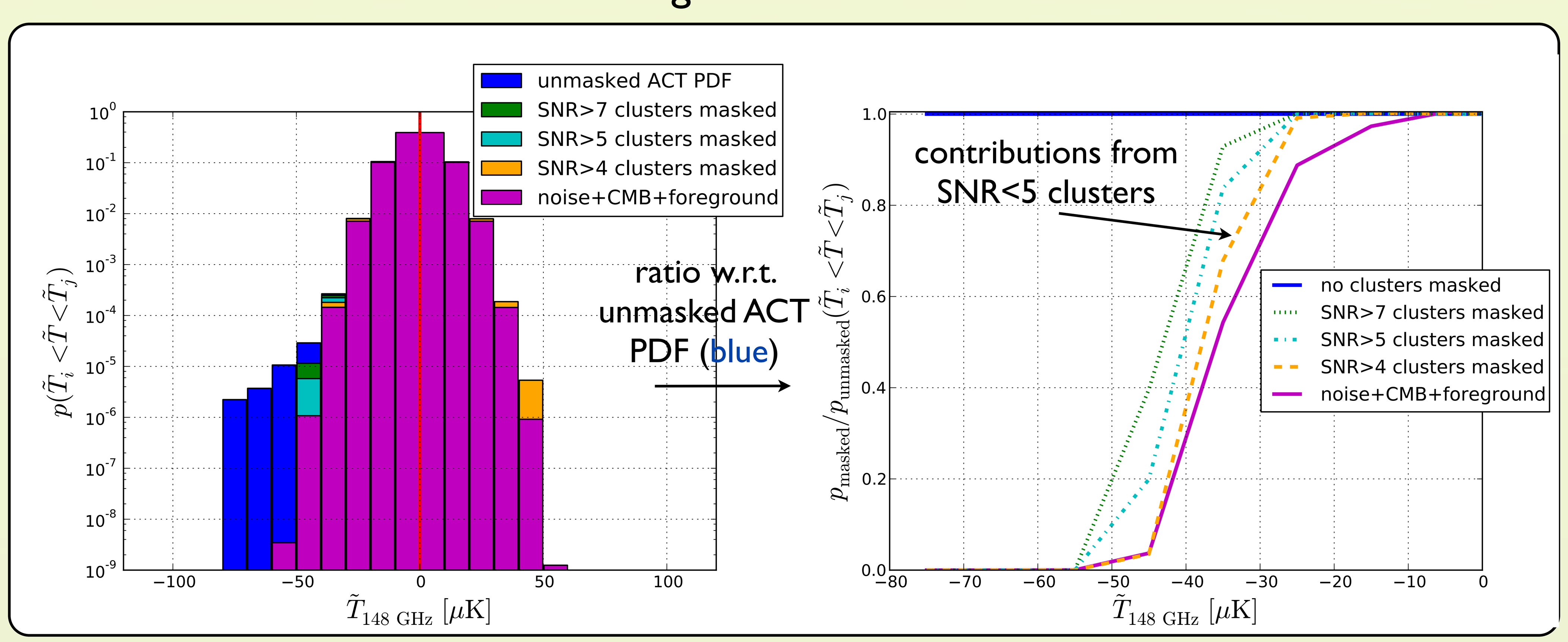
> - Fiducial theory PDF: WMAP9 cosmology + Tinker mass function [3] + Battaglia pressure profile [4]
> - Noise PDF, filter, beam specified to match ACT Equatorial 148 GHz data analysis



ACT Data



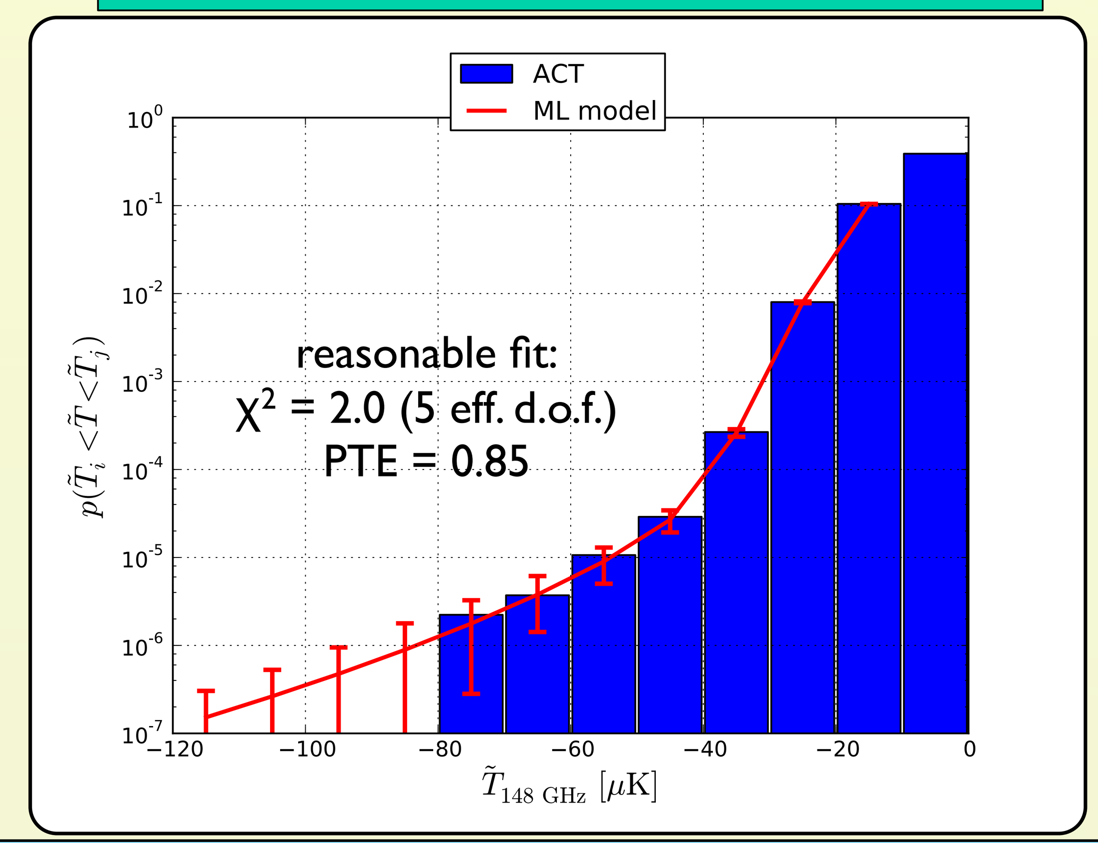
- Wiener-filter ACT Equatorial 148 GHz map → clear non-Gaussian negative tail
- No similar feature seen in identically-processed ACT Equatorial 218 GHz map
- Contributions to the 148 GHz negative tail from detected tSZ clusters:



Interpretation + Constraints

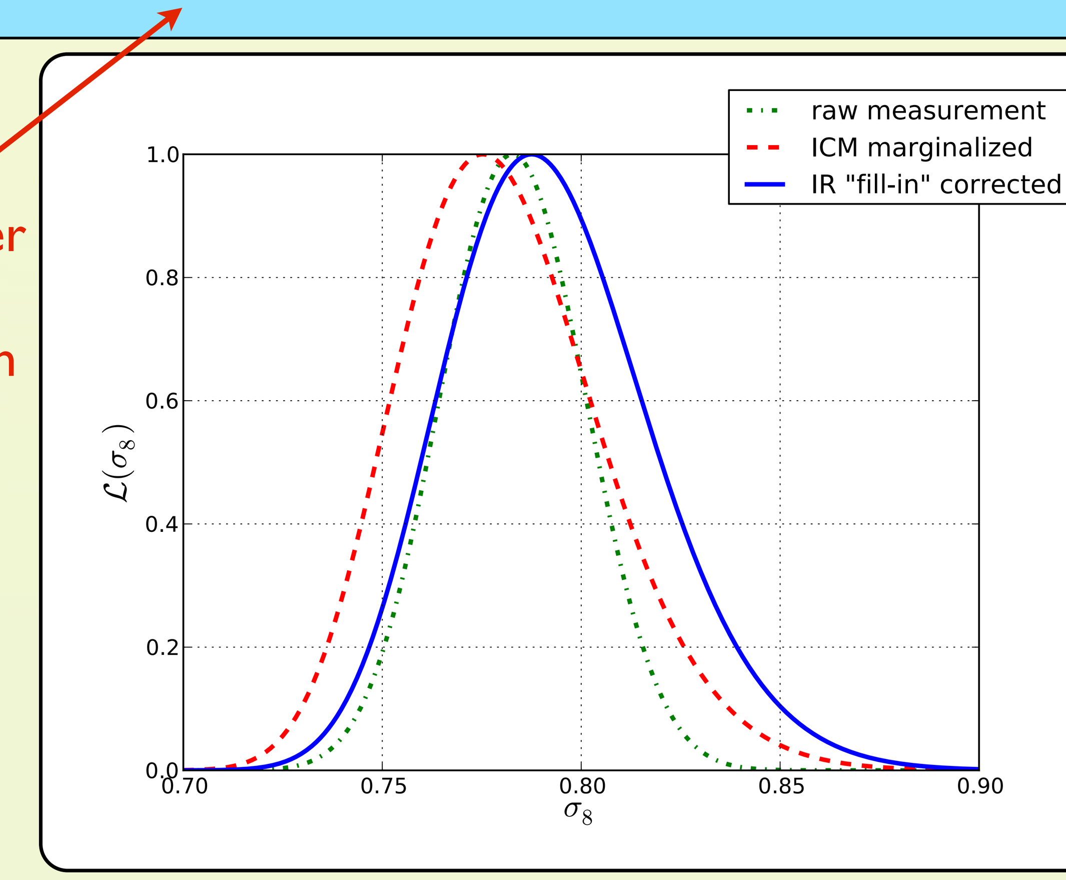
- Focus on constraining σ_8 (most sensitive parameter)
  - Fit only T<0 148 GHz PDF
  - Marginalize over non-tSZ foreground contribution
  - Discard smallest-|T| (noise-dominated) bin
  - Marginalize over parameterized ICM gas physics through normalization of $P_e(M,z)$
  - Correct for IR sources "filling in" tSZ decrements
- Monte Carlo simulations to compute covariance matrix (highly correlated) and validate pipeline

ACT 148 GHz vs. maximum-likelihood PDF model



$$\sigma_8 = 0.793 \pm 0.018\,(\text{stat.}) \pm 0.017\,(\text{ICM syst.}) \pm 0.006\,(\text{IR syst.})$$

~2x smaller than stat. error from skewness alone [1]



References

[1] M.J. Wilson et al. 2012, PRD, 86, 122005, arXiv:1203.6633

[2] J.C. Hill & B.D. Sherwin. 2013, PRD, 87, 023527, arXiv:1205.5794

[3] J. Tinker et al. 2008, ApJ, 688, 709, arXiv:0803.2706

[4] N. Battaglia et al. 2012, ApJ, 758, 75, arXiv:1109.3711