Cosmological Analysis of South Pole Telescope-detected Galaxy Clusters

March 22nd

Tijmen de Haan (UC Berkeley) - Moriond

2500 square-degree SPT-SZ survey

- 5 year survey (2007 to 2011)
- 95 GHz: 40 μK-arcmin
- 150 GHz: 18 μK-arcmin
- 220 GHz: 70 μK-arcmin
Planck 143 GHz

~70 deg$^2$
Cluster Catalog

~400 clusters in cosmology sample (detected at >5σ)
Counting Galaxy Clusters

- Abundance as a function of mass and redshift ("mass function") is robustly predicted from N-body simulations
- Mass function is extremely sensitive to cosmological parameters
  - $\Lambda$CDM $\sigma_8 (\Omega_M / 0.27)^{0.3}$
  - Dark energy $(w, w_a)$
  - Neutrino Mass $\sum m_\nu$

![Expected number density of galaxy clusters](image1)

$\frac{dn}{d \ln(M)}$ (per 177.5 deg$^2$)

$\sigma_8 = 0.77$, $\sigma_8 = 0.82$

$dN \propto \sigma_8^{8-12}$

![Expected number density of galaxy clusters](image2)

$cN / dz$ (M$>4\times10^{14} M_{\odot}$ per 177.5 deg$^2$)

Volume effect

Growth effect

$w = -0.8$

$w = -1$
Selection Function

![Graph showing the selection function with different redshift ranges](image-url)
Mass Scale of the SPT-SZ Sample

- Statistical (Poisson) uncertainties are very good
  - Error on measured number counts: $1/\sqrt{400}$
  - Implies 0.5% on $\sigma_8$ (compare to 2% Planck measurement of $0.829 \pm 0.14$ in $\Lambda$CDM)
  - Ability to break degeneracies in extensions to $\Lambda$CDM

- Systematics limited ->
- We assume a 30% error on SZ normalization from cosmo-OWLS simulations
- Dominates uncertainties on cosmological parameters
- Need for determining the mass scale from multi-wavelength follow-up
Multi-wavelength mass measurements

Chandra

http://www.iras.ucalgary.ca/satellites/Xray/index.html

Magellan

http://obs.carnegiescience.edu/Magellan

HST

http://spaceflight.nasa.gov/gallery/images/shuttle/sts-119/hires/s125e011848.jpg

XMM

http://spaceflight.nasa.gov/gallery/images/shuttle/sts-119/hires/s125e011848.jpg

Image Credit: ESA/C. Carreau
Chandra Observations

- Awarded 3.2 Ms of Chandra time
- ~90 clusters observed @ ~2k photons
- $Y_X = T_X \times M_{gas}$
- $Y_X - M$ relation determined through hydrostatic mass estimates at low redshift
Determining the Mass Scale

- Unlike previous SPT cluster cosmology results, we now rely purely on weak lensing observations.
  - "hydrostatic mass bias" calibrates out.
- Weak lensing data from Canadian Cluster Comparison Project (CCCP) and Weighing the Giants (WtG).

March 22nd  Tijmen de Haan (UC Berkeley) - Moriond
Cosmological Analysis

- Explore cosmological parameter space using CosmoMC+cluster module
- Marginalize over nuisance parameters
  - Scaling of SZ signal with cluster mass & evolution with mass, redshift
  - Scaling of X-ray signal with cluster mass & evolution with mass, redshift
  - Intrinsic scatter in the scaling relations, including correlations
  - For SPT-SZ+Chandra, that's 9 nuisance parameters
- Bayesian likelihood code, fully taking into account selection effects, self-consistently and efficiently incorporating any number of mass proxies, including correlations
Evolution of SPT Cluster Cosmology

- 178->720->2568 square degrees of the SPT-SZ survey
- 18->100->377 clusters
- 14->14->82 clusters with high-quality Chandra $Y_X$
- Revisited mass scale relying purely on weak lensing
ΛCDM Results

- Consistent with ΛCDM parameters from CMB power spectrum measurements
Constraints on the Species-summed Neutrino Mass

- Addition of cluster count information causes the posterior to peak at positive values.
- Consistent with minimal allowed value of $\Sigma m_\nu = 0.06$ eV from atmospheric neutrino oscillation experiments.
Dark Energy

- Consistent with other probes
- Clusters are a growth-based probe, providing a powerful complementary probe of dark energy
- Consistent with $\Lambda$CDM where $w = -1$
Dark Energy

- When adding to other datasets, cluster counts improve $w$ constraint primarily by breaking $\sigma_8 - w$ degeneracy
Cluster Weak Lensing of the CMB

Lewis & Challinor, 2006

Baxter et al. 2015
- ~10,000 clusters
- Lower mass threshold implies the sample will go out to much higher redshift
- Powerful constraints on the mass scale from CMB cluster lensing
- Deploying at the end of this year
Summary

• 2500 square degree SPT-SZ sample ~400 clusters, spanning 0.1<z<1.5
• Chandra $Y_X$ mass calibration, recalibrated using optical weak lensing
• $\Lambda$CDM constraints on $\sigma_8$ and $\Omega_m$ consistent with CMB measurements
• Neutrino mass constraints $\Sigma m_\nu = 0.14 \pm 0.08$ eV consistent with minimum allowed value
• Dark energy constraints from cluster counts alone
• Exciting future ahead with SPT-3G which will find ~10,000 clusters and will be able to weigh in on the mass scale with CMB cluster lensing