SPT Galaxy Cluster Cosmological Constraints: First Results from Mass Calibration with Velocity Dispersions

Ripples in the Cosmos - Durham - July 2013

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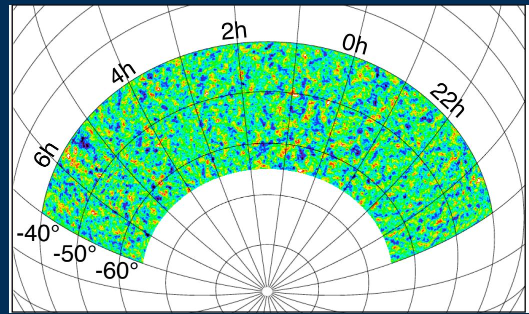
SPT-SZE Survey

- 2500 deg^2 regions $-40<\delta<-65$, $20hr<\alpha<7hr$
- Bolometer time stream: ~10^6 T's/s over 4 years, ~65% efficiency
- Uniform depth: σ_{150}~18 μK-amin, σ_{90}~40μK-amin, σ_{220}~60μK-amin
- Beam size: FWHM$_{150}$~1.0', FWHM$_{90}$~1.6', FWHM$_{220}$~0.7'



Dark Energy Survey Imaging Underway!

SPT Collaboration

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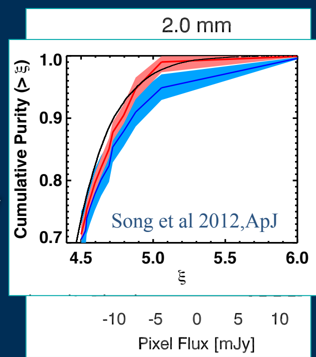
SPT Galaxy Cluster Selection

- Clusters selected using matched filter technique (Melin et al 2006):
  - We filter an SPT map and extract all negative sources with S/N>4.5 (ξ>4.5)
- Contamination- unique "negative" SZE signature means contamination is due only to noise fluctuations
  - Easily calculated using Gaussian noise distribution and S/N threshold
  - Confirmed using optical followup of all cluster candidates over 750deg^2 (Song et al 2012)



SPT-only selection produces >95% pure sample at S/N>5
SPT+optical followup produces ~100% pure sample at S/N>4.5

Completeness

- SPT clusters are selected by S/N or ξ- therefore to do cosmology we must understand the ξ-mass relation
- We break it into two parts:
  - ζ-mass: amplitude, slope, z evolution, log-normal scatter

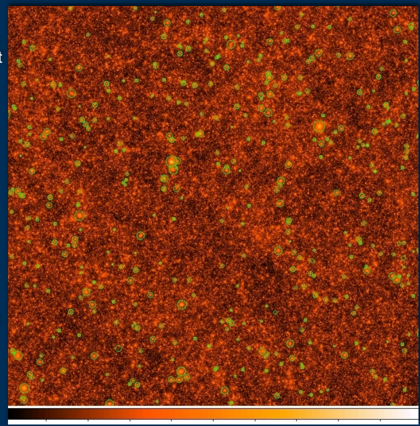
$$\zeta = A_{SZ}\left(\frac{M_{500}}{3x10^{14}h^{-1}M_{\circ}}\right)^{B_{SZ}}\left(\frac{E(z)}{E(0.6)}\right)^{C_{SZ}}$$

  - Measurement noise then scatters ξ about the true ζ (normal)
- We test selection model using mock observations

Mock Observations

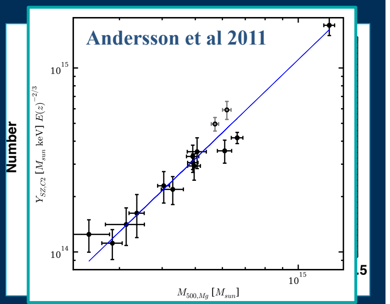
- Cosmological Hydrodynamical Sims
  - Cooling, star formation, and winds (Springel & Hernquist 02)
  - Metals, stellar population, and chemical enrichment, SNIa, SNII, AGB (Tornatore et al. 03,06; Wiersma et al. 09)
  - BH and AGN feedback (Springel & Di Matteo 06; Fabjan et al. 10)
  - Low viscosity scheme (Dolag et al. 05)
- Y_{sz} lightcones from Magneticum serve as inputs to our mocks
- Use SPT beam/noise characteristics, observe light cone and extract clusters using same matched filter tool
  - Ongoing work by Jiayi Liu

Magneticum Simulations (Klaus Dolag)



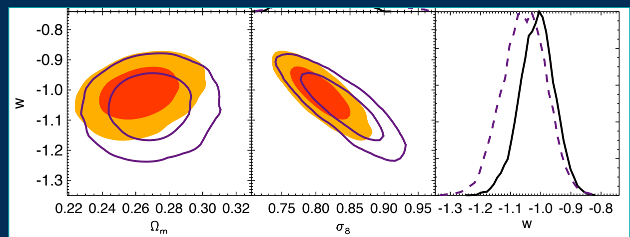
SPT Galaxy Cluster Cosmology

- With pure sample and model for selection, we can test cosmology
- Phase I: Vanderlinde et al 2010
  - First 21 systems, 178 deg^2
  - Mass calibration from simulations
- Phase II: Reichardt et al 2012
  - 100 systems (z>0.3, ξ>5), 720 deg^2
  - Mass calibration from 15 Chandra Y_x's
    - Andersson et al 2011
  - Y_x masses based on hydrostatic masses measured at z~0.3



Phase II Cosmology Constraints

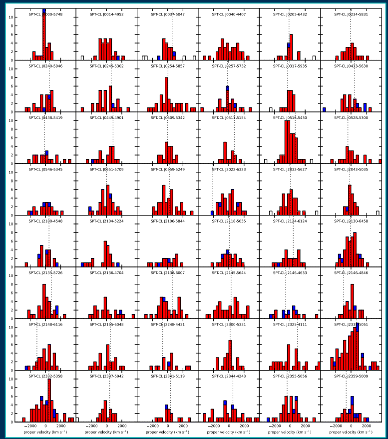
- Cosmological constraints:
  - WMAP+SNe+BAO+H0 / w/ SPT:
    - σ_8 = 0.84 (0.04) / σ_8 = 0.81 (0.03)
    - w=-1.054 (0.073) / w=-1.010 (0.058)



There is limited power in our dataset – we need more mass information. What can velocity dispersion mass information do for us?

Velocity Dispersions as Mass

- Velocity dispersions reflect depth of the potential well
  - Expect high scatter due to merging
  - Rely on simulations for calibration- to characterize biases and scatter
- Observing program
  - Data acquisition continuing at Gemini, VLT and Magellan
  - ~60 dispersions acquired
  - Typical N_{gal}~25 (2 masks/cluster)
  - Use red sequence selection



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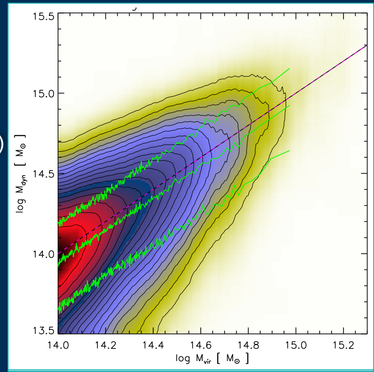
Calibrating σ-mass with Sims

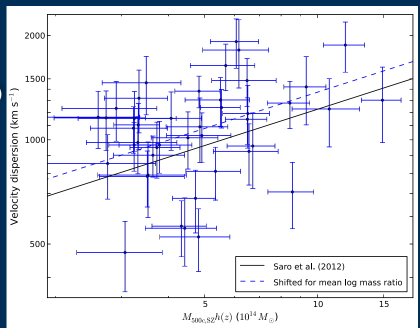
- Dispersion-Mass Relations:
  - 3D galaxies in cluster (~12%)
    Departures from equilibrium
  - 1D galaxies in cluster (~40%)
    Anisotropy
  - 1D color selected galaxies with velocity outlier rejection (~80%, depending on N_{spec})
    Interlopers
- Mock Observations
  - Model SPT dispersion program selection
  - Extract σ-mass relation as function of selection parameters
- Quantify imperfections in sims
  - Current results adopt 15% systematics floor in dispersion masses



Saro et al ApJ, 2013 (astro-ph/1203.5708)

Dispersion-M(ξ) Relation

- Dispersion-ξ relation shows high scatter, as expected
  - Scatter is 31% in σ about dotted line
  - Expectation is 27% (from Saro et al analysis)
- Solid line: expected mean relation assuming
  - Y_x based SPT masses
  - Saro et al dispersion-mass relation
- Dashed line: indicates that dispersion data will push SPT masses higher
  - Proper accounting of selection biases (Eddington bias) required



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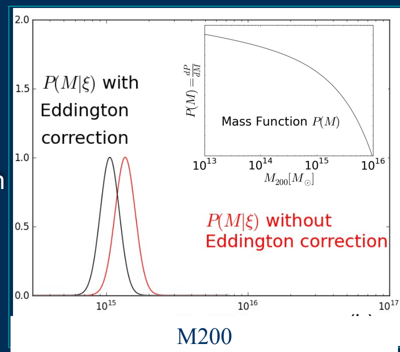
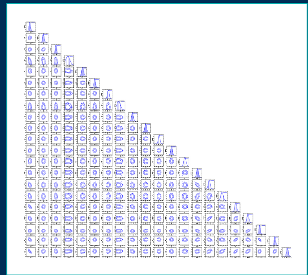
Calibrating ξ-mass with σ

- Selection effects can be accounted for in full likelihood analysis
- Mass calibration likelihood
  - For given choice of scaling relation params, for each cluster:
  - Use (ξ,z) to predict P(M|ξ, z)
    - including selection effects like Eddington bias
  - Use P(M|ξ, z) to predict P(σ)
  - Extract likelihood of consistency with observed σ
  - ξ−mass rel'n params varied to find best fit



Cosmology Runs with Dispersions

- Inputs:
  - SPT sample: 100 clusters, ξ>5, z.0.3
  - Mass information:
    - 48 dispersions, 16 Y_x measurements
  - Mass-observables and their treatment:
    - Power law, log-normal intrinsic scatter, obs noise
    - ξ-M: 4 params
    - σ-M: 5 params (Saro et al 2013)
    - Y_x-M: 4 params (Vikhlinin et al 2006)
- Cluster Likelihood:
  - Single likelihood from Counts
  - Individual likelihoods for each mass constraint
- Cosmology:
  - 5 params for cluster only (Ω_m, Ω_b, σ_8, n_s, H_0)
  - 6 params with CMB ($\Omega_m h^2$, $\Omega_b h^2$, Δ_R^2, τ, n_s, H_0)



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New Results with Dispersions

- Dispersions change A_{sz} and B_{sz}, prefer higher Ω_m/lower σ_8

Run		A_{sz}	B_{sz}	C_{sz}	D_{sz}	Ω_m	σ_8
SPT + Ω_b + H_o							
σ's		4.6(1.0)	1.6(0.12)	0.76(0.3)	0.22(0.12)	0.38(0.08)	0.74(0.05)
Y_x (B13)		5.3(1.0)	1.3(0.15)	0.90(0.3)	0.21(0.10)	0.29(0.08)	0.77(0.06)
SPT + WMAP + BAO + SNe + H_o							
σ's		3.8(0.6)	1.5(0.12)	0.37(0.2)	0.22(0.12)	0.28(0.01)	0.81(0.02)
Y_x(B13)		4.9(0.7)	1.4(0.15)	0.83(0.3)	0.21(0.09)	0.26(0.02)	0.80(0.02)

- Dispersions push the mass scale for a given SPT ξ up by +10%(+/-12%)
- CMB+BAO+SNe pushes mass scale up another +13% (+/-11%)
- Together, this ~23% increase in mass scale is a ~2σ shift
  - Probing this tension requires improved mass calibration

$$\xi = A_{sz}\left(\frac{M_{500}}{3x10^{14}h^{-1}M_\odot}\right)^{B_{SZ}}\left(\frac{E(z)}{E(0.6)}\right)^{C_{SZ}}$$

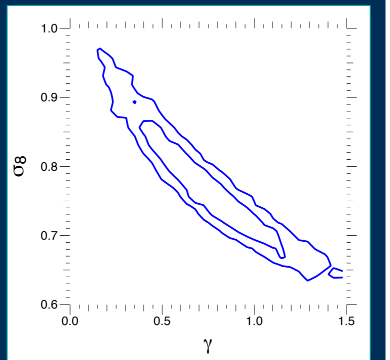
Consistency Test of GR

- Following Rapetti et al 2010, we introduce an additional free parameter γ to describe the linear growth of density perturbations:

$$\frac{d\ln\delta}{d\ln a} = \Omega_m^\gamma(a)$$

where for GR γ~0.55

- Within ΛCDM context with CMB+BAO +SNe+H_0 external datasets, we measure γ=0.74(0.27)
  - Significant γ-A_{sz} and γ-C_{sz} degeneracy



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Summary

SPT-SZE clusters
- High mass (M_{200}>4x$10^{14}M_o$) sample extending to z=1.5

SPT Cluster Cosmology
- Currently our cosmology is dominated by the external data
  - SPT clusters just shrink error bars a bit – δw~0.05
- Going beyond this requires improved mass calibration

Dispersion Mass Calibration
- Masses no longer based on assumption that clusters are in equilibrium
- Dispersions push SPT masses up by 10% (20% with CMB++)
- SPT constraint on $\sigma_8(\Omega_m/0.27)^{0.3}$=0.82

  No tension with Planck non-cluster result 0.86

Next Step: Include weak lensing information