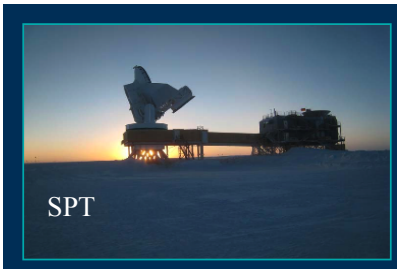


Multi-wavelength Surveys for Cluster Cosmology:

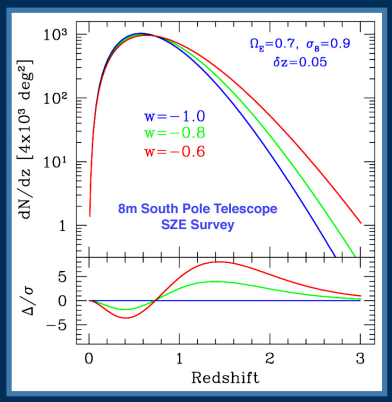
The South Pole Telescope, The Dark Energy Survey (and eROSITA)

Joe Mohr
Ludwig-Maximilians University
Max Planck Institute for Extraterrestrial Physics

NAM2012 – Manchester

Cluster Cosmology

- Traditional multi-λ science
  - 1) Optical (and NIR), 2) X-ray, 3) SZE
- Cluster survey ⇔ population evolution
  - Growth rate of structure
  - Distance-redshift relation
- Clustering of population ⇔ similar to galaxies
- Weak lensing ⇔ important for mass measurements



South Pole Telescope (SPT)

- (Sub) millimeter wavelength telescope:
  - 10 meter aperture
  - 1' FWHM beam at 150 GHz
  - 20 micron RMS surface
  - 5 arcsec astrometry
- SZ Receiver:
  - 1 sq. deg FOV
  - Observe in 3 bands between 95-220 GHz simultaneously
  - Sensitivity ~ 15-60 μK-arcmin

SPT Collaboration

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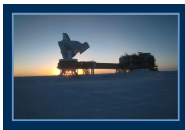
Antony Stark
Chris Stubbs
Brian Stalder
Mark Brodwin
Jonathan Ruell

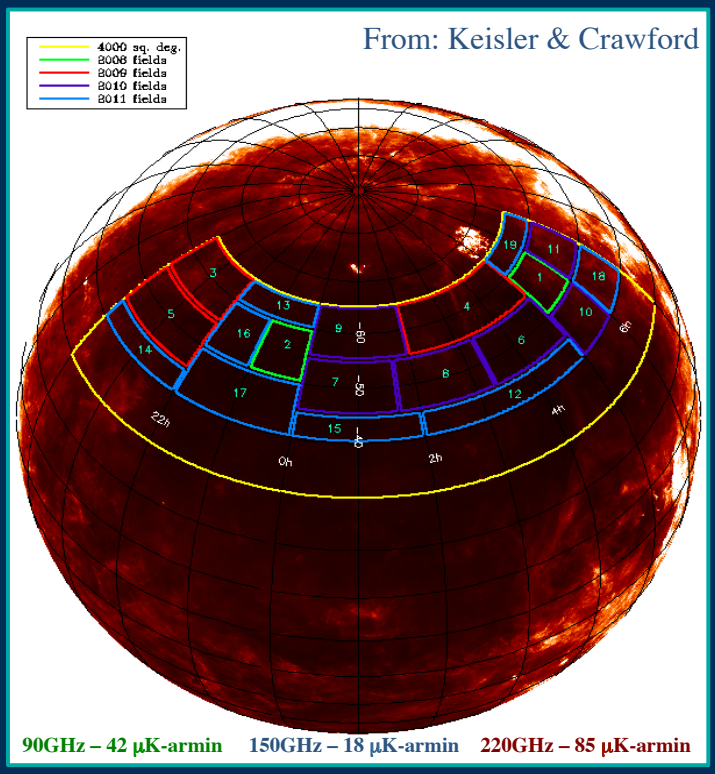
Cardiff University
Prifysgol Caerdydd

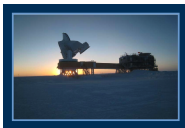
Peter Ade



SPT Survey Sky Coverage

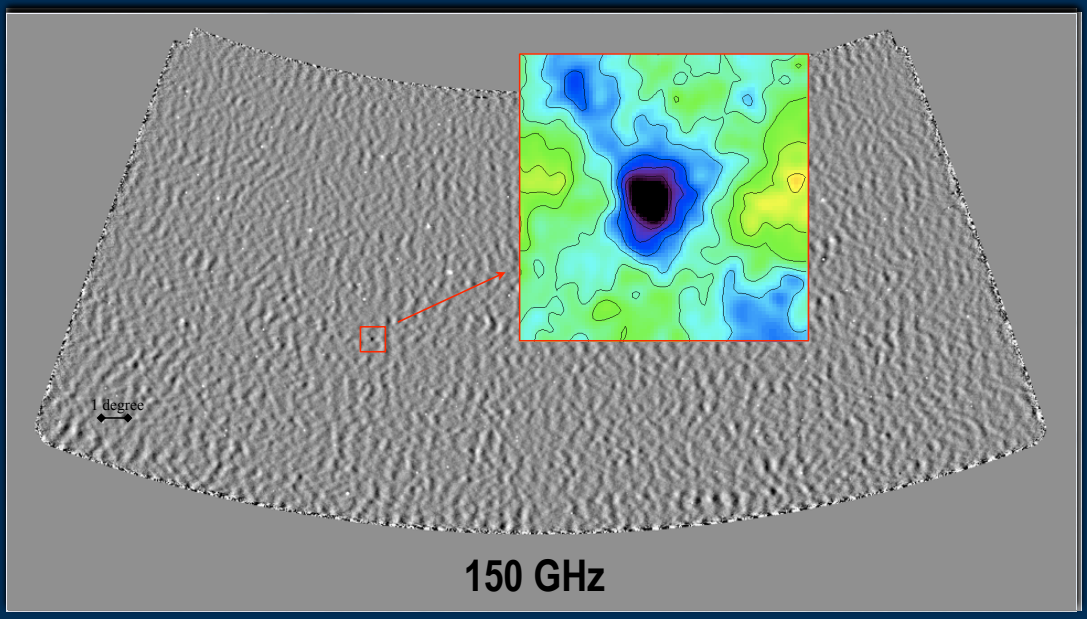
- Survey 2008-2011
  2491deg^2 complete
- Data used to study CMB anisotropy
- Select clusters through Sunyaev-Zel'dovich Effect
  Redshift independent
  Tied closely to cluster mass
- Cluster candidates found:
  657 at S/N>4.5

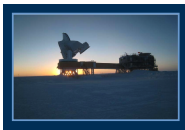




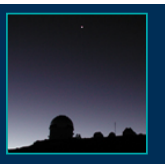
Finding a Cluster in SPT Maps

- Unique signature helps provide pure sample
- No redshift information – requires multi-λ followup

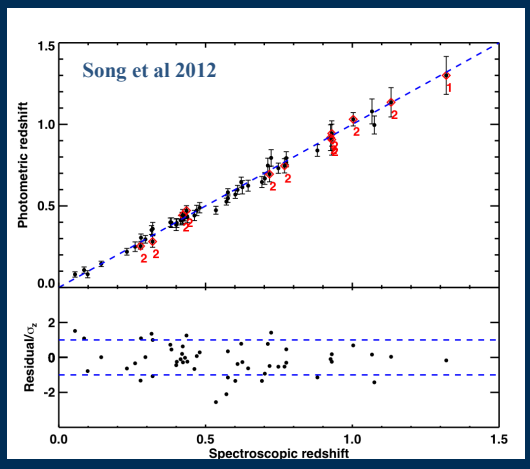




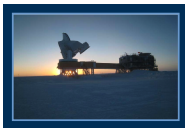
SPT Optical Followup



- We use multiband photometry to get red sequence cluster redshifts
- Began with dedicated survey
  Blanco Cosmology Survey –
  60 nights/ 80 deg^2/*griz*
- Now go cluster by cluster
  - ~100 nights on the telescope so far
  - Over 500 candidates imaged to date
  - Goal: finish by end of year

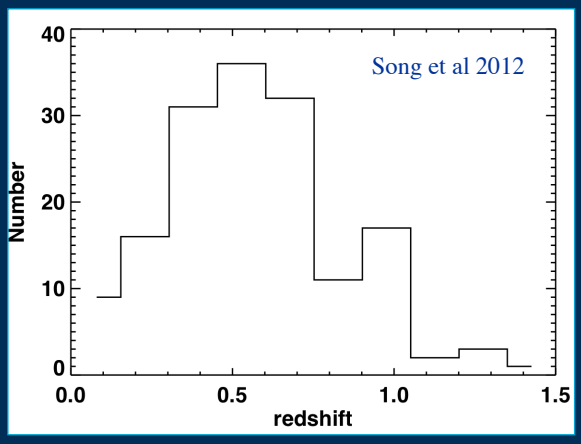


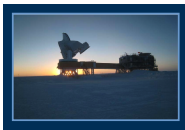
Characteristic scatter δz~0.018 for 0<z<1.4
For 53 clusters with spec-z's



SPT Clusters: Redshift Distribution

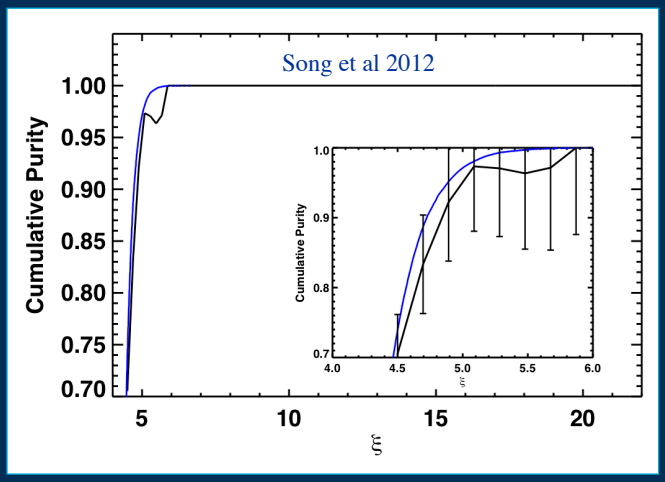
- Statistics of 750 deg^2 sample:
  - 224 candidates
  - 158 with measured photo-z's
  - Median redshift is ~0.54
  - 16% of sample at z>0.8



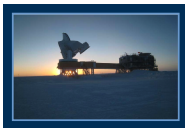


SPT Clusters: Contamination

- Negative noise peaks *can* masquerade as clusters
  - Stay at high S/N!
- Optical confirmation allows us to measure the contamination

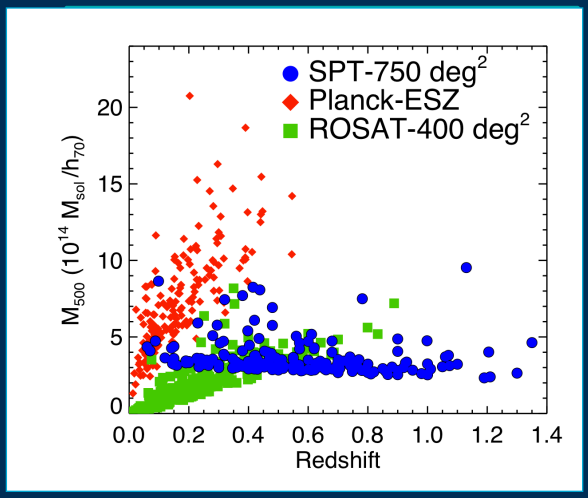


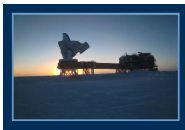
SPT-only selection produces >95% pure sample at S/N>5
SPT+optical followup produces ~100% pure sample at S/N>4.5



SZE Signature Good Mass Indicator

- We have leveraged X-ray mass indicators to calibrate our sample
  - Direct mass calibration underway
    weak lensing and velocity dispersions
- High-z massive SPT clusters are unique population
  - M_{200}>4x10^{14} M_o even at highest z
  - Large solid angle survey (2500 deg^2) allows us to find very rare objects
  - ~100 of these clusters over full survey

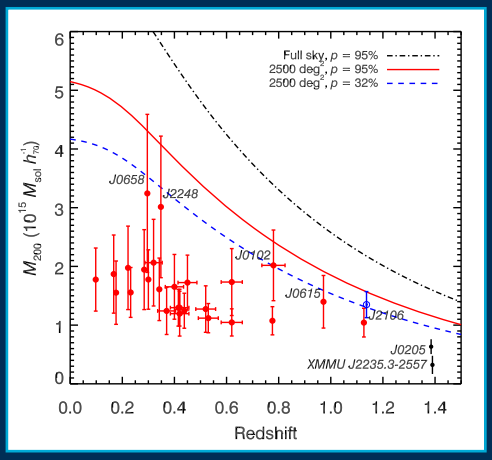


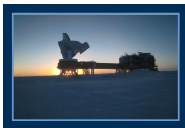


The Rarest, Most Massive Clusters

- In late 2010 SPT finished shallow "preview" scans of the full 2500deg^2
  - Adequate to select the 26 most massive clusters, independent of redshift
- Mortonson analysis suggests no single cluster in tension with ΛCMD
- More precise statements require improved mass measurements

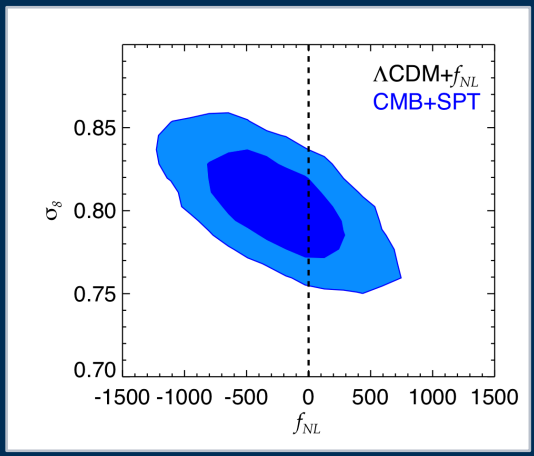
Williamson et al 2011



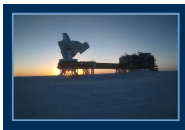


SPT Constraints on Non-Gaussianity

- SPT constraints on non-Gaussianity
  - f_{nl}=-192+/-310, 20+/-450
    (from full likelihood analysis including selection function of SPT sample)
- Interesting thread- combination of cluster counts and power spectrum greatly enhances constraints on f_{nl}
  (i.e. see Sartoris et al 2010 for discussion)



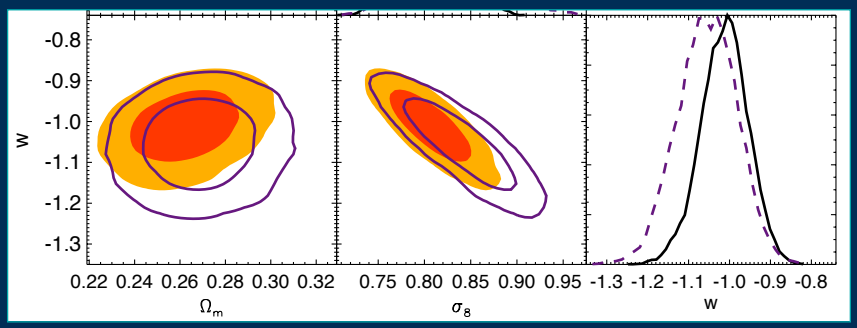
Williamson et al 2011
Benson et al 2011



SPT Constraints on Dark Energy

- 121 Clusters from 750 deg^2
  - Mass calibration from X-ray
- Cosmology limited by mass uncertainties
- Cosmological constraints:
  - WMAP+SNe+BAO+H0:
    - σ_8 = 0.84 (0.04)
    - w=-1.054 (0.073)
  - Above + SPT Clusters
    - σ_8 = 0.81 (0.03)
    - w=-1.010 (0.058)

Reichardt et al 2012



Consistent with X-ray cluster analyses- see Vikhlinin et al 2009, Mantz et al 2010

Dark Energy Survey

The Dark Energy Survey

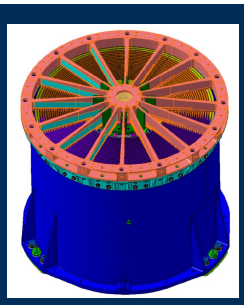
- 5000 deg^2 *grizY*
  - 10σ depths
    ~25.2, 24.8, 24.0, 23.4, 21.7
- First light August 15, 2012
- Multi-λ cluster cosmology
  - Weak lensing masses for SPT clusters
- Much, much more…

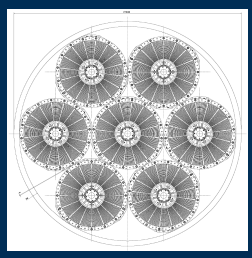
Blanco 4m on Cerro Tololo, Chile

Image credit: Roger Smith/NOAO/AURA/NSF

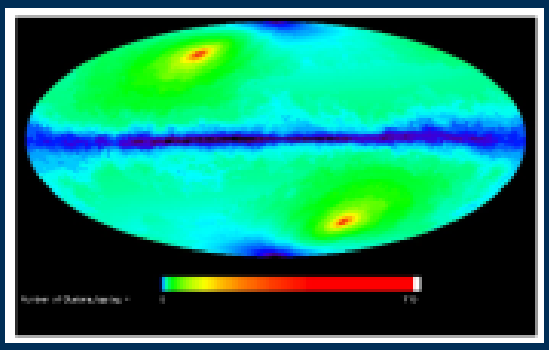
e-ROSITA All Sky X-ray Survey

PI Peter Predehl (MPE)





- Collecting area of 2 XMM's with 1 deg diameter FOV
- Good angular resolution – <30" averaged over field
  (similar to ROSAT PSPC pointed data within inner ring)
- Four year nominal mission
- Characteristic flux limit is ~2×10^{-14} erg/s/cm^2
  (~30X deeper than ROSAT All Sky Survey w/ CCD spectroscopy)



DES and PS1 Surveys Enable:
* Cluster confirmation
* Cluster photo-z's
* Weak lensing mass constraints

Summary

Multi-λ cluster cosmology coming of age

- Constrains expansion history + growth rate of structure
- Constrains any process that affects the power spectrum of density fluctuations (+ non-Gaussianity)

SPT cluster are in the bag, followup continues

- No apparent tension with WMAP+BAO+SNe
- Current constraints on *w* at 5% level
- Cosmology from ~550 SZE selected clusters coming in ~1 year
- Core need: Improved mass calibration with velocity dispersions, weak lensing and X-ray

Next steps with DES and eROSITA

- Improve mass calibration using stacked weak lensing
- Carry out eROSITA cluster followup using broad, wide area surveys

Cluster Selection: Optical/IR

- Optical/IR Surveys
  - Typical Optical/IR signature only crudely related to cluster mass- clean mass selection not possible
  - Problem: Galaxies (even red ones) exist everywhere, not just in clusters- contamination an issue
  - Completeness of red sequence methods seems quite good