The ATACAMA COSMOLOGY TELESCOPE: PRELIMINARY RESULTS

SUDEEP DAS
Berkeley Center for Cosmological Physics
University of California, Berkeley
With ACT, we are entering a new regime in CMB physics.
Dusty Galaxies
SZ
Unlensed
Lensed

ACT’s precision measurements

Inflation
Lensing

Multipole $\ell$
$\ell(\ell+1)C_\ell/(2\pi)$

Friday, January 29, 2010
The Atacama Cosmology Telescope (ACT) is a six-metre telescope on Cerro Toco in the Atacama Desert in the north of Chile. It is designed to make high-resolution, microwave-wavelength surveys of the sky in order to study the cosmic microwave background radiation (CMB). At an altitude of 5190 metres (17030 feet), it is currently the highest permanent, ground-based telescope in the world.
THE TELESCOPE: LOCATION

- 5200 meters (17,000 ft)
- “High and dry”: 0.49 mm median Precipitable Water Vapor (PWV).
- Latitude 23 degrees South - good for cross-linked observations.
THE TELESCOPE: DESIGN

- 6 m primary mirror. Off-axis Gregorian telescope
- ~1 arcmin resolution
- 148, 218, 277 GHz channels
THE TELESCOPE: DETECTORS + OPTICS

Transition Edge Sensors

148 GHz

The Millimeter Bolometric Array Camera (MBAC)

Window

4He Fridge

3He Fridge

Pulse Tube

Optics

Detectors

40K Shield

3K Shield

1 m

Beams

1.4'

1.0'

0.9'

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The Observations: Coverage

ACT has taken 12 months of data at 3 frequencies already, over ~1300 deg². For results in this talk, we used 4 months at one frequency (148 GHz), over 200 deg².
THE OBSERVING STRATEGY

- Observe mainly during the night (20:00 to 09:30 local time)
- Scan at fixed elevation, 6 degree/8 seconds azimuthal chop.
- Observe facing South East before mid-night m South West afterwards to catch the same region at different angles.
- Spend 10 min per night observing planets - for beams, calibration and pointing
THE ANALYSIS: DATA TO MAPS

Solve for the maximum-likelihood map: true representation of the sky. Gain back modes suppressed by filtering. Iterate until maps converge and transfer function is unity.

Data set is enormous. 3000 detectors, ~10 hours CMB/night, 400 hz sampling rate, 4 bytes/sample = ~200 GB/night. We have written fully parallel map making code. Runs on UToronto SciNet cluster. 30,000 2.53 GHz Nehalem cores, 8 cores, 16 GB/node. Takes ~100,000 CPU hours for one season of data.
We use a cross-spectrum based estimator - no noise bias

- For each of 13 patches, we have 4 submaps for each quarter of the season.
- Take cross-spectra between the submaps using the adaptive multitaper method (Das, Hajian, Spergel 2008).
- Take the weighted mean of the cross-spectra to report the final spectrum.
- Use scatter between patches to report error bars (verified analytically).
The ACT Power Spectrum

One of 3 Jacknives from 4 submaps
The Power Spectrum

2D power spectrum is isotropic!

Cross-correlation with WMAP

\[ B^\text{th}_\ell = B^\text{CMB}_\ell + A_{SZ} B^\text{SZ}_\ell + A_p \left( \frac{\ell}{3000} \right)^2 + B^\text{corr}_\ell \]

\[ A_{SZ} < 1.63 (95\%) \]

\[ A_p = 11.2 \pm 6.6 (2\sigma) \mu K^2 \]
The SZ Power

\[ B^\text{th}_\ell = B^\text{CMB}_\ell + A_{SZ} B^\text{SZ}_\ell + A_p \left( \frac{\ell}{3000} \right)^2 + B^\text{corr}_\ell \]

- **SZ template** depends on gas model, and may be degenerate with a correlated dusty galaxy component.

- With 220 (and 270) GHz data we should be able to break degeneracies.

- Also, higher point correlation functions will help separate SZ from extragalactic point sources.

\[ \sigma^\text{SZ}_8 \]  \[ A_{SZ} \] (no correlated IR PS)

\[ < 0.86 \quad < 1.63 \]  \[ < 0.84 \quad < 1.36 \] (correlated IR PS)

No indication of an SZ excess!
Extragalactic Point Source Power

\[ B^\text{th}_\ell = B^\text{CMB}_\ell + A_{\text{SZ}} B^\text{SZ}_\ell + A_p \left( \frac{\ell}{3000} \right)^2 + B^\text{corr}_\ell \]

\[ B^\text{corr}_\ell = A_c \left( \frac{\ell}{3000} \right) \]

\[ A_p(\ell = 3000) \quad C_p \quad \frac{C_p}{10^{-5} \mu K^2} \quad \frac{C_p}{Jy^2 sr^{-1}} \]

\begin{array}{c|c|c}
11.2 \pm 3.3 & 0.784 \pm 0.23 & 1.22 \pm 0.36 \\
9.7 \pm 2.8 & 0.68 \pm 0.2 & 1.05 \pm 0.3 \\
\end{array}

Two populations at 148 GHz below 17 mJy detection limit.

1. Radio galaxies: \( A_p = 4 - 7 \mu K^2 \) at \( \ell = 3000 \), \( C_p = 0.3 - 0.5 \times 10^{-5} \mu K^2 \)
   From number counts, matches Toffalatti model.

2. Infra-red dusty galaxies: Also \( A_p = 4 - 7 \mu K^2 \). Can compare to SCUBA at 353 GHz and BLAST at 600 GHz (\( 2.7 \pm 0.2 \times 10^3 Jy^2/sr \)). Spectral index \( \alpha = 2.9-3.1 \).
Detecting SZ clusters and point sources

Original Map

Filtered Map

Match Filtering and Extraction

Cluster

Source
SZ CLUSTERS

Followup Program:
- XMM observations approved
- VLT/Gemini spectroscopy and deep imaging
- SALF spectroscopy later this year
- Chandra and HST proposals planned

Only 148 GHz 2008 Data

SZ-Selected Clusters with Optical Confirmation

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INTERESTING
SZ CLUSTERS

from Hincks et al. 2009

ACT map of the “Bullet”
cluster
with X-ray and WL shear
contours

ACT map of Abell 3128
with X-ray contours
Note double cluster in
X-rays, but only one
component in SZ – due
to mass threshold
HIGH Z
MASSIVE
CLUSTERS!

New Massive
$z=0.81$ cluster in
the Southern
Strip

New Massive $z = 0.81$
Equatorial Cluster
POINT SOURCE POPULATIONS

Flat Spectrum Radio Sources

Cen A, LABOCA
Dusty, Starbursting Galaxies

ARP 220, HST

Spectral Energy Distributions

- SUMSS
- PMN
- ATG20
- ACT 148 GHz
- ACT 220 GHz
Point Source Model

Toffolatti et al. (1998) 143 GHz radio model, rescaled by 0.53
Toffolatti et al. (1998) 143 GHz FIR model
Lagache et al. (2004) 143 GHz model

\[
\log_{10}(S^{5/2} dN/dS [\text{Jy}^{3/2}/\text{sr}])
\]

\[
\log_{10}(S [\text{Jy}])
\]
FUTURE PLANS

This is only the beginning!

- ACT has taken 12 months of data at 3 frequencies already, over ~1300 deg².
- We have shown 4 months at 1 frequency, over 200 deg².
- Mapmaking and power spectrum pipeline are now in place for extended analysis of the full data set.
- Explore Silk damping regime of power spectrum with multi-frequency analysis.
Gravitational Lensing

Intervening large-scale potentials deflect CMB photons and distorts the CMB.

The rms deflection is about 2.7 arcmins, but the deflections are coherent on degree scales.
We hope to have a $\sim 6$ sigma internal detection from season 1.

**Deflection field auto-spectrum:**
Measurement of $\sigma_8$. Neutrino mass, Dark Energy, curvature.

**Cross-correlations:**
Matter-Infrared Galaxies
Matter - Radio Sources
Matter- SZ clusters
Matter- Lyman-alpha
Matter - weak lensing.
Matter - galaxy counts
Next Step: ACTPOL

2010-2015 – measure temperature and polarization of CMB to arcminute scales over \(4000\) deg\(^2\), plus deep regions over \(300\) deg\(^2\).

Measure primordial polarized spectrum (\(17\%\) pol) to \(l=3500\). Low foreground contamination.
- Test inflation: spectral index, running index, isocurvature fraction, cosmic strings
- Probe early universe: number of relativistic species, primordial abundances.

Measure lensing deflection field: distortion of CMB by large-scale structure
- Sensitive to early dark energy, unique probe at \(z = 2-3\) and ideal for cross-correlations.
- Geometry of the universe
- Neutrino mass (0.07 eV limits).

\[
\Theta(\hat{n}) = \tilde{\Theta}(\hat{n} + \nabla \phi)
\]
Lensed Unlensed Deflection Field

\[
\phi = -2 \int \frac{d_A(\eta_0 - \eta)}{d_A(\eta) d_A(\eta_0)} \Phi(\eta \hat{n}, \eta)
\]
Geometry Matter potential