Atacama Cosmology Telescope: Select results, ACTPol status, and Future Plans

Michael Niemack
Cornell University

Recontres du Vietnam
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CMB Temperature Surveys

Small angular scale CMB probes additional physics
(larger telescopes can be built on ground)

Planck + ACT & SPT have measured temperature to \( l \sim 10,000 \)

\[
\ell (\ell + 1) C_\ell / 2\pi \sim 10,000
\]

Planck 2013 - arXiv:1303.5076

- WMAP 7yr
- ACT: Das et al.
- SPT: Keisler et al. & Reichardt et al.
- COBE 420’ 6 det.
- WMAP 12’ 20 det.
- Planck 5’ 74 det.
- CMB
- DSFGs
**Science:**
- Cosmology Params.
- Inflation
- Neutrino properties
- $\Lambda$ Eqn. of state
- Growth of structure

**Observations:**
- CMB to $l \sim 10,000$
- Cluster (SZ, X-ray, & optical)
- Grav. Lensing

**Atacama Cosmology Telescope**

**Collaboration:**
- PI: Lyman Page, Princeton U.
- ACT

**X-ray**

**Optical**

**Theory**
Sunyaev-Zel’dovich (SZ) Effects

- Compton scattering of CMB
- Redshift independent
  ⇒ no $1/r^2$ cluster selection bias
- Thermal SZ Spectral Signature
- Cosmology: dark energy, neutrino properties (with redshift & mass)
- Kinematic SZ from cluster peculiar velocities
  ⇒ potential DE (and modified gravity) constraints
How Are We Doing It?

- Location: Atacama desert
  5190 meters

- Careful optical design

- Superconducting Transition-Edge Sensor (TES) arrays
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ACT Optical Design

Off-axis Gregorian telescope
6 meter aperture primary mirror

Receiver

3 Diffraction-limited optical paths
at 148, 218, & 277 GHz

( Fowler et al., AO 2007 )

( Swetz et al., ApJS 2011 )
Largest Superconducting Detector Arrays - 2008

( Niemack et al., JLTP 2008; Swetz et al., ApJS 2011 )

- 3 array observations from 2008-2010
- Raw data rate over 2 TB per month
- Transport method: HDOA
- Mapmaking on SciNet, U. Toronto
ACT Temperature Observations

Easily observed by ACT

SDSS BOSS

ACT Observations to 2010

Stripe 82

BCS

BOSS

GAMA

ACT Range

Mask
Zoom in on ACT Map

Unbiased estimate of all modes from $ell \sim 100 - 10000$

Atmosphere: 2 deg
(Filtering Here)

CMB: 1 deg

Clusters*: (>1.4')-4'

Sources*: 1.4'

* Minimum size set by beam

Image courtesy of T. Marriage
- Pre-Planck Cosmology Params – PRD, arXiv:1302.1841
- DSFG and AGN sources – arXiv:1306.2288
- Beams and Planet temperatures – arXiv:1303.4741
- 3-season Lensing and power spectra – arXiv:1301.1037
- 3-season Cosmological parameters – arXiv:1301.0824
- 3-season SZ clusters – arXiv:1301.0816
- Equatorial Cluster Follow-up – arXiv:1210.4048
- Stellar content of clusters – arXiv:1301.0780
- SZ cluster weak lensing – arXiv:1209.4643
- “El Gordo” most massive known cluster at z > 0.6 – ApJ, arXiv:1109.0953

First Detection of kinematic SZ

‘El Gordo’ Massive Cluster at z > 0.6

CMB Lensing & Dark Energy

Constraints on Gravity waves, Cosmic strings, Neutrino number

Blind SZ discoveries
ACT SZ-discovered Clusters

\( z = 0.39 \)
\( z = 0.42 \)
\( z = 0.53 \)
\( z = 0.56 \)
\( z = 0.61 \)
\( z = 0.87 \)

( Hasselfield et al. JCAP, arXiv:1301.0816 )
ACT SZ-discovered Clusters

$z = 0.39$

$z = 0.42$

$z = 0.53$

$z = 0.56$

$z = 0.61$

$z = 0.87$

‘El Gordo’ a $z = 0.87$ Bullet Cluster?

- ACT detected – follow up with SOAR, VLT, Chandra, Spitzer
- Cluster merger 2:1 mass ratio, total mass $M_{200a} = (2.2 \pm 0.3) \times 10^{15} \, M_{\odot}$
- Most massive and X-ray luminous cluster at $z > 0.6$
- Unlikely to find cluster this massive in $\sim 800$ sq. deg ACT survey, but not whole sky.

Most massive clusters in $\Lambda$CDM

$\Lambda$CDM exclusion curves and ‘El Gordo’


Fine for All-sky

Outlier for ACT survey area

Planck SZ catalog

With Planck, El Gordo went from: most massive at $z > 0.6$ to most massive at $z > 0.65$ => Consistent with $\Lambda$CDM

(Planck Collaboration SZ Catalog 2013)
First Detection of CMB Lensing Spectrum

- 4-point function analysis => Deflection field
- 4σ detection => matter fluctuations to 12%

(Lensng Deflection Field, Convergence Power Spectrum)

(Das et al. PRL, arXiv:1103.2124)
Evidence for Dark Energy from CMB Alone

Lensing adds $3^{rd}$ dimension, breaking CMB geometric degeneracy

$\Lambda$CDM model favored at $3.2\sigma$ over best model with no $\Lambda$

$\text{Planck} > 25\sigma$ lensing detection

$\Rightarrow$ Using CMB lensing as a new cosmological probe

(Sherwin et al. PRL, arXiv:1105.0419)
First Detection of Kinematic SZ Effect

ACT data plus SDSS BOSS redshifts enables measure of momentum difference between proximate cluster pairs via kSZ

(Hand et al., PRL, arXiv:1203.4219)
What’s Next?

CMB Polarization

- Polarization Anisotropies
  - Curl free ‘E-modes’
  - Divergence free ‘B-modes’

Recent SPTpol cross-correlation detection!

( Hanson et al. arXiv:1307.5830 )
A polarization sensitive receiver for ACT

- Measure small angular scale CMB polarization
- Improve temperature sensitivity by ~4x plus polarization
- First light two weeks ago!
ACTPol Science

- High $l$ power spectra
  - Inflation potential
  - BBN and “neutrino” number

- Gravitational Lensing

- Cross-correlations

( Niemack et al., 2010, arXiv 1006.5049 )
**ACTPol Science**

- High $l$ power spectra
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- Gravitational Lensing
- Cross-correlations

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ACTPol Science

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Help Break Degeneracies in Temperature Data!

( Niemack et al., 2010, arXiv 1006.5049 )
ACTPol Science

- High $l$ power spectra
  - Inflation potential
  - BBN and “neutrino” number

- Gravitational Lensing
  - Matter fluctuations at $z \sim 2$
  - Measure neutrino mass sum and early dark energy

- Cross-correlations

\[ \sigma(\Sigma m_\nu) \approx 0.06 \text{ eV} \] (ACTPol + Planck)

( Niemack et al., 2010, arXiv 1006.5049 )
ACTPol Cross-correlations

- **Wide survey** ~ 4000 deg$^2$
  - Overlap with SDSS-III BOSS
  - Neutrino mass constraints
  \[ \sigma(\Sigma m_\nu) \approx 0.05 \text{ eV} \]

- **Deep survey** ~ 200 deg$^2$ (multiple fields)
  - Overlap with optical (Subaru HSC), X-ray, ...
  - Cluster physics
  - Dark energy constraints

(Niemack et al., 2010, arXiv 1006.5049)
Critical enabling technologies

- **Optics**
  - Increased throughput
  - Wide bandwidth silicon lenses

- **Detector arrays**

- **Cryogenics**

(Niemack et al., 2010, arXiv 1006.5049)
ACTPol

Critical enabling technologies

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Lenses led by U. Michigan
( Datta et al. arXiv:1307.4715 )
Polarization Sensitive Detectors

Truce Collaboration: ABS, SPTPol, and ACTPol


- Feedhorn Coupled TES Polarimeters
- Bulk absorption vs. Superconducting circuits

150 GHz ABS detector

Old ACT detector

( Yoon et al. JLTP 2008 )
Silicon Polarimeter Arrays

- Three arrays (1012 TES each)
  - Fabricated at NIST
  - Assembled/tested at Princeton
- 0.1K bath temperature (0.3K previously)
  - Receiver developed at U. Penn
Silicon Polarimeter Arrays

- Three arrays (1012 TES each)
- 0.1K bath temperature (0.3K previously)
  - Receiver developed at U. Penn

Better detectors + optics + cryogenics

⇒ Increased 150 GHz sensitivity
Deployment

First Light
~ 2 weeks ago!
Multi-chroic Polarimeters

- Multi-chroic advantages
  - Focal plane efficiency
  - Dual frequencies & detectors

- First multi-chroic CMB array deployment in ACTPol soon

- What’s next?

(McMahon et al., JLTP 2012)
Advanced ACTPol

Unique Instrument Capabilities:
- Arcmin resolution across ~2/3 sky
- 30 – 300 GHz coverage
- > 10,000 multichroic detectors

Enable Rich Next Generation Science
Thank you

Thanks to my collaborators on ACT/ACTPol and the Truce collaboration.