Recent Results from the Atacama Cosmology Telescope

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Outline

- Cosmology Today
- ACT Results
- ACTPOL
The universe is simple. We can fit all of our observations of the universe with five numbers:

- density of atoms
- age of the universe
- density of matter
- amplitude of fluctuations
- scale dependence of fluctuations

The universe is strange
Quick History of the Universe

- Universe starts out hot, dense and filled with radiation
- As the universe expands, it cools.
  - During the first minutes, light elements form
  - After 300,000 years, atoms form
  - After 100,000,000 years, stars start to form
  - After 1 Billion years, galaxies and quasars
Wilkinson Microwave Anisotropy Probe (WMAP)
What Have We Learned?

- Simple model fits a wide range of data (only 5 numbers)
- Age of universe: 13.7 Gyr
- Composition:
  - Atoms: 4%
  - Matter: 23%
  - Dark Energy: 73%
- Scale Invariant Fluctuations seed growth of galaxies
- First Stars formed ~200 Myr after the big bang
From Baby Pictures to Today's Universe
All of the pieces seem to fit....

- Supernova distances
- Hubble Constant
- Age of Universe
- Cluster Properties
- Gravitational Lenses
- Nuclear Abundances
- Lyman alpha forest
- Galaxy Velocities
The Universe is Simple?

- Fluctuations are accurately as Gaussian, Random Phase
- No evidence for spatial variations in fluctuation properties
- No evidence for interaction terms
- No sign of global topology
Decadal Survey Questions

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ACT

- Led by Lyman Page
- 80 scientists on 5 continents
- 6-meter telescope on Cerro Tocco (5190 m) in the Atacama Desert. Observing the sky at 128, 218 and 277 Ghz
2008: 300 sq deg
2009: 600 sq deg
2010: 1500 sq deg
(4% of sky)
NGC 1055
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.
First Lensing Detection

- Lensing deflects photons and produce non-Gaussian signal:

  \[
  T_{\phi\phi}(\hat{n}) = T(\hat{n} + \nabla \phi) \approx T(\hat{n}) + \nabla \phi \cdot \nabla T
  \]

- Non-trivial 4-pt function

- Lensing power spectrum is a measure of the amplitude of fluctuations along the line of sight

Das et al. arXiv 1103.0419
Direct Detection of Dark Energy from the CMB
CMB As a Backlight

- CMB Lensing: Mass
- Thermal SZ: Pressure
- Kinematic SZ: Momentum
- Includes 148GHz transition
– Includes 148GHz transition
- Includes 148GHz transition
Clusters as Cosmological Probes

- SZ signal measures integrated pressure in cluster
- SZ signal is redshift-independent, so an SZ-selected cluster sample should be a mass-selected sample.
- Potentially, number counts could be an important dark energy probe.
- Key step: lensing calibration

Subaru Image: Takada, Miyatake, et al.
Next Step: ACTPOL

- Funded by NSF for 2011-2016
- Camera now under construction... 25 times faster survey speed and polarization sensitivity
- First light in 2012
- Wide survey (~4000 sq. degrees)
- Deep survey (5 25 sq degree fields)
E + B modes

- Scalar fluctuations generate E-modes. They produce TT, TE and EE correlations.
- Tensor fluctuations generate equal amounts of E and B modes. They produce TT, EE and BB correlations.
- Gravitational lensing rotate polarization and converts E modes into B modes.

Figure from Dodelson et al. NAS White Paper astro-ph/0902.3796
Full sky polarization survey to $l = 5000$ would have 6 times the number of modes as
ACTPol’s Discovery Space

$k = 0.2-0.4$ Mpc⁻¹
Gravitational Lensing rotates E modes into B modes. Measurements of B modes can be used to construct the convergence field.

Amplitude of convergence field measure mass fluctuations at $z \sim 1-2$. 
ACTPol & Matter Distribution

2% measurement of amplitude of mass fluctuations at z ~2
ACT Wide

- Survey 4000 sq degrees with sensitivity of 28 microK/arcmin (polarization) and 20 microK/arcmin (temperature)
- Overlap SDSS III spectroscopy and imaging (600,000 LRGs, 80,000 quasar spectra)
- SUMIRE program: HSC imaging (under construction) + PFS (under review)
- Science goals:
  - EE power spectrum out to l ~2000
  - CMB lensing (and cross-correlations with low z surveys)
  - Clusters
  - Missing Baryons
  - Dark energy (calibrate BAOs; measure power spectrum at z ~ 1-2)
Deep observing program:
- 5 2x15 degree regions. Plan to target regions with extensive deep data
- 4 uK/arcmin in polarization

Science goals:
- high I EE tail
- stacking of astronomical objects
- characterization of foregrounds
- delensing gravity wave B-mode (see Smith et al. astro-ph/0811.3916)
ACT + HSC Deep

ACTPOL should get first light in late spring 2012 and being surveying in fall 2012.

The first target field is XMM-LSS field
- Herschel: 17 sq. deg
- XMM: 25 sq. deg
- UKIRT: J+K
- SWIRE
- VIPERS
- 2 uK-arcmin sensitivity
Neutrinos

ACTPol should be able to distinguish between inverted and normal mass spectra by constraining neutrino mass to 0.05 eV

Thanks to Sylvia Galli, A. Melchiorri and L. Pugano
Neutrino Number
Helium
Initial Conditions

- EE measurements unique window into small scale fluctuations
- Parameter estimates:
  - Estimates do not include beam uncertainties and foreground contamination
  - Data sets are complementary
  - Big gains on parameters that affect high l

Table 1. This table compares the expected constraints in an 8 parameter model (baryon density, matter density, slope, H_0, reionization mean, optical depth, Baryon abundance, amplitude) with the current constraints from WMAP5 and a 6 parameter model. Note that the WMAP5 ACIL null results on certain parameters in an 8 parameter model are worse than limits in a 6 parameter model for WMAP alone.
Non-Gaussianity

- Sensitive to number of modes measured on the sky.
  - WMAP: 2e5 modes in TT
  - Planck: 3e6 modes in TT, 7.5e5 in EE
  - Polarization (to l = 5000): 2.5e7 modes available.
- Polarization measurements have the potential to measure modes out to l~4000, a 4 fold increase in the number of modes over PLANCK. ACTPol is a step in this direction.
- ACTPol will be sensitive to small scale primordial non-Gaussianities (particularly cosmic strings).
Cosmic Strings

Polarization limits on strings

Fraisse et al. astro-ph/0708.1162
Conclusions

- Data continues to improve... the simple but strange model still fits
- Small scale CMB measurements enable observations of mass (through lensing), pressure (through SZ) and momentum (through kSZ). New tool to study evolution of the universe
- Beginning of multi-wavelength CMB astronomy