Far Future Observations: SPT

The South Pole Telescope

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(Red = Here today)

Science Objectives:

1. Count SZ clusters; use densities to constrain cosmological parameters… (and “functions” :)

2. Map secondary “CMB anisotropies” at very small angular scales. (PS and “beyond PS”)

3. Measure polarization in the CMB

Instrument:

- Operate (for cosmology) from $\lambda = 1$ to 3 mm
- 8m diameter primary $\Rightarrow < 1.3'$ beam at 150 GHz
- 1º diameter F.O.V. $\Rightarrow$ can use large bolometer arrays
The South Pole Site

Superb atmospheric transmission and stability.
(38 year record… typical precipitable water vapor in winter is 0.25mm!)

Geography: allows deep integrations of fields that do not rise or set. Sun can be shielded for ~9 months.
(eg DASI observed CMB polarization toward two fields for 196 continuous days last austral winter season)

Excellent station and support: transportation, communications, construction support, electrical power, cryogens, technical support, laboratory space, accommodations… all in place.

The South Pole: a gentle environment

• Median wind speed: (summer =4 m s\(^{-1}\), winter = 6 ms\(^{-1}\))
• 90% of months, the wind speed does not exceed 12 m s\(^{-1}\)
• Maximum recorded wind speed since 1958 is 25 m s\(^{-1}\), the lowest “highest recorded wind speed” of any U.S. Weather Service station
• Low snow accumulation (it’s a desert). No rain.

⇒ The only “interesting” engineering is for the cold… otherwise, it’s a very benign environment.
South Pole Telescope Optics

8m diameter:
To achieve at 150GHz the desired 1.3’ resolution for SZE survey

Off-axis Gregorian:
To achieve a wide field with no blockage

Diffraction limited:
over ~ 1 deg² field at λ=2mm

Chopping flat:
placed at image of the primary => low offsets.

8m South Pole Telescope
(old drawing... lower it by one floor.)
A full ground shield will surround the telescope, so we can do low-level CMB observations...

Viper/ACBAR

MAPO, January 2001
fully equipped modern lab

SPT 10\(^3\) element bolometer array
(Lee and Holzapfel and company at UCB)

Smooth conical horns used w/ “Lyot” stop.

One wafer, many detectors (a la Bolocam)

Cutaway of 1027 element array

Note: reading out 1000 channels isn’t easy!
Single SQUID multiplexer \((UCB)\)

- One SQUID per row
- AC-bias => sum signals => demodulate

8-ch prototype has been tested with resistors

SZE with the SPT

- Cluster counting
- Constraining functions \((\text{wake up, Max})\)
- Measuring parameters \((\text{go back to sleep, Max})\)
  - \((\text{skip… } H_0, \text{ baryon fraction, peculiar v’s…})\)

4000 sq. deg. to \(\Delta T_{\text{CMB}} \sim 10 \mu K\) with a 1.3’ beam

\[ M_{\text{cluster}} > 4 \times 10^{14} M_{\odot} \]

Expect \(\sim 20,000\) clusters
Mock Observations of Simulated Clusters
(Pryke and Mohr)

Mass Limits from Mock Observations

5σ detection corresponds to:
4.2x10^{14} M_\odot (10 \mu K)
3.8x10^{14} M_\odot (5 \mu K)
3.4x10^{14} M_\odot (2 \mu K)

5σ detection (10\mu K noise) corresponds to:
4.2x10^{14} M_\odot (1.3′ beam)
6.2x10^{14} M_\odot (1.8′ beam)
1.6x10^{15} M_\odot (4.4′ beam)
Anticipated cluster yields from SPT Survey

This is enough that you can start making mass histograms as a function of redshift, i.e., test that Press-Schechter “function”.

Potential Constraints on Dark Energy

- South Pole 8m cluster survey
  - \( M_\text{lim} = 4 \times 10^{14} \text{M}_\odot \) over 4\times10^3 deg^2
  - ~17,000 clusters detected

- Statistical uncertainties on \( w \) and \( \Omega_E \)
  - \( \Delta \Omega_E \) to 0.01
  - \( \langle w \rangle \) to 0.05
  - Marginalized over \( \sigma_z \)

- Important factors not included:
  - Non-flat geometries
  - 10% uncertainty in \( H_0 \) (20% broadening)
  - Cosmic variance
  - Systematic uncertainties

Just when we thought we could test the a(t) “function”, they throw in a new “parameter”!
Potential CMB targets for the South Pole Telescope

*The 8m aperture and excellent site offer incredible opportunities for the next generation of CMB observations:

- **CMB secondary anisotropies**
  (Ostriker-Vishniac effect; Gravitational lensing)
  - Map the Dark Matter, Understand LSS formation

- **CMB polarization**
  (Induced by lensing; B-mode from gravitational waves)
  - Map the Dark Matter, Understand Inflation

(These observations will require receivers beyond the first array…)

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Survey Followup: The Importance of Cluster Redshifts
(very important)
CMB: Secondary Anisotropies

CMB photons pass through structure in the universe that introduces secondary anisotropies that dominate the primaries above 1~3000

From Hu & Dodelson, Ann. Reviews 2002

SPT Sensitivity w.r.t. SZ/OV/KSZ

Need other frequencies (90 to 345GHz) to deal with dusty galaxies, etc

150 GHz

217 GHz

John Ruhl, Case Western (KITP New Cosmology Conference 8/20/02)
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Dark Matter Mapping
Gravitational lensing by large scale structure imprints a signature on the CMB, which can be used to reconstruct the projected mass.

$10^\circ \times 10^\circ$ simulations by W. Hu

Reconstruction with Temperature  Projected Mass  Reconstruction with Polarization

4′ beam, 1uK/arcmin$^2$ errors in Temperature map

Stop.
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CMB Polarization

Errors shown are for Planck...

Lensing B-modes
(a foreground)

Primordial B-modes, fingerprint of Inflation!

Water vapor and atmospheric transmission

TOP: The upper plot is calculated atmospheric transmittance at zenith. [Pardo, Cernicharo, and Serabyn 2001].

PWV values of 0.2 mm for South Pole, 0.6 mm for Chajnantor and 0.9 mm for Mauna Kea, corresponding to the 25\textsuperscript{th} percentile winter values at each site.

NEW: The 1.5 THz measured transmission at the Pole exceeded 20\% about half the time during July 2001.

MIDDLE AND BOTTOM PLOTS:
Plots of the calculated values of dry air and water vapor opacity.
Dark Energy and Mass Limit Systematic Errors

- Statistical Uncertainty in Mass Estimates
  - Can account for this in analysis

- Systematic Errors in Mass Estimates
  - What is the effect of a constant fractional mass error with redshift?

- Controlling systematic mass errors is primary challenge in doing precision cosmology

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