Title: The APEX Sunyaev Zel'dovich Experiment Observations

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Abstract: The APEX Sunyaev Zel'dovich experiment will be described and its performance since first light in 2006 summarized. Recent results will be presented together with plans for future observations/analysis.
The APEX Sunyaev Zel'dovich Experiment Observations

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APEX Telescope

- 12 m on-axis ALMA prototype built by Vertex RSI
- Sited at the Atacama plateau, Chile, elevation 16,500 ft
- Submillimeter observatory
  - 18 μm surface accuracy goal
- 1’ resolution @ 150 GHz
- 0.4° field of view

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ESO
APEX-SZ Experiment Overview

- PI instrument on APEX
- First light: December 2005
  - 55 detectors, 1 week obs
- 280 TES Bolometer channels @ 150 GHz
  - 2007, 2008 – roughly 1 month/year of which we typically get 2 weeks good observing
- Demonstrates new technologies that are scalable to other experiments, i.e., SPT
  - TES bolometers
  - Frequency domain multiplexed readout
  - Pulse-tube cooler to eliminate liquid cryogens
- Powerful camera for targeted cluster observations
  - Overlaps with northern-hemisphere multi-wavelength observations

D. Schwan et al., in prep 2009
TES Detectors

- Fabbed at UC Berkeley by Jared Mehl
- 330 element array – 280 wired
  - 6 wedges of 55 detectors
  - Science results typically use ~170 bolometers.

- March 2009: 2 wedges replaced, optimizing optical coupling, thermal conductivity, bandwidth.
  - $\text{NET}_{\text{OLD}} = 870 \, \mu\text{K}_{\text{CMB}} \, \text{s}$
  - $\text{NET}_{\text{NEW}} \approx 500 \, \mu\text{K}_{\text{CMB}} \, \text{s}$
Multiplexed Readout

- Analog frequency domain multiplexed readout
- SQUID amplifiers
- First field implementation
- Developed at LBNL/UC Berkeley/McGill
- Used on APEX-SZ, SPT
- New digital system developed for EBEX, Polarbear, SPTpol
Cryogenics

- Mechanical Pulse Tube Cooler (3-4K)
  - SQUIDs live here.
  - No expendable cryogens
  - No nasty fills or LHe delivery issues.
  - Essential for remote locations

- 3 stage He⁴He³He³ Absorption fridge (260 mK)
  - Detectors live here.

APEX-SZ Camera shown mounted in cabin with pulse tube lines & ballasts visible.
APEX-SZ Beams & Calibration

Daily mappings of Mars
- Calibrated against Rudy Model, updated with 1% WMAP data

Calibration uncertainty 5.5%:
- 4% from beam area,
- 3% Mars temporal fluctuations,
- 1.7% Mars temperature, ...

Typically ~260/320 pixels active

Beams:
- Gaussian main lobe
- Near sidelobes increase real beam solid angle

Jupiter, Scan 356, Composite Map, 43 Channels

APEX-SZ Beam offsets and Beam FWHM (Mars)
23 sigma detection

no evidence for significant 150 GHz emission from 13.5 mJy @ 270 GHz point source reported by Aztec.
Bullet Cluster

- Mass weighted electron temperature, using:
  - Isothermal
  - Clowe et al., 2006, Chandra

\[ T_E = 10.7 \pm 0.8 \text{ keV} \]
\[ (\chi^2 = 1.003) \]

X-ray temperatures range from 10.6 keV with XMM (Zhang et al. 2006) to 13.9 keV with Chandra (Govini et al. 2004)
Cluster gas profile well-fit by a isothermal elliptical beta model (adequate for the sensitivity and resolution of these maps – despite the complex nature of this system).

Beta model parameters and gas-mass fraction are consistent with those derived from X-ray data

<table>
<thead>
<tr>
<th>$T_e$ (keV)</th>
<th>Mean Overdensity</th>
<th>$r_{int}$ ($'$)</th>
<th>$r_{int}$ (Mpc)</th>
<th>Gas Mass Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.6 ± 0.2</td>
<td>2531 ± 236</td>
<td>2.18</td>
<td>0.580</td>
<td>0.208 ± 0.031</td>
</tr>
<tr>
<td>10.6 ± 0.2</td>
<td>743 ± 67</td>
<td>5.32</td>
<td>1.42</td>
<td>0.171 ± 0.034</td>
</tr>
</tbody>
</table>

- Zhang et al. (2006) $f_{gas} = 0.161 \pm 0.018$ (1.42 Mpc)
- Bradac et al. (2006) $f_{gas} = 0.14 \pm 0.03$ (4.9' x 3.2')
A2163 with APEX-SZ & LABOCA


(27±9” offset)
Fig. 9. SZE spectrum of Abell 2163 (points) and best-fit models using different priors on the ICM temperature: 8 keV (solid line), 10 keV (long-dashed line), 12 keV (short-dashed line) and 14 keV (dotted line).
A2163 with APEX-SZ & LABOCA


Consistent with XMM (Markevitch, Vikhlinin 2001)

Shaded region: xray (Squires et al., 1997)
Solid line: APEX + xray
Assumes isothermal
APEX 150 GHz Power Spectrum

Reichardt, Zahn et al., arXiv:0904.3939

- 0.8 sq degrees at 150 GHz with 1' resolution
- 10 nights in Aug/Sept 2007, 2.9 k-bolo-hrs
- 12 \( \mu K_{\text{RMS}} \) per 1' pixel
- XMM LSS field, centered on XLSSU J022145.2-034614 (5 KeV x-ray cluster)

\( D_\ell \) vs. \( \ell \)

- Total Anisotropy < 105 \( \mu K^2 \) at 95%.
- \( \sigma_8 \) < 1.18 at 95%
  - Fitting for SZE & Poisson bright point source population
  - Properly accounting for non-Gaussian statistics (limit would be \( \sigma_8 \) < 0.94 assuming Gaussian noise only)
Point Source Power

- At 150GHz, expect significant power from distant dusty galaxies
  - Expect 20x less power from radio sources
- Negrello et al. (2007) model predicts $1.1 \times 10^{-5} \mu K^2$ in the absence of clustering.

- $C_t^{PS} \approx 1 \times 10^{-5} \mu K^2$
  - Nearly independent of flux cut for masking point sources
- With BLAST 600 GHz data $\rightarrow$
  - spectral index $\alpha = 2.64^{+0.4}_{-0.2}$
    - Agrees with MAMBO/SCUBA index, 2.65 Greve et al. (2004)
    - Knox et al., 2004.
- Dusty galaxies account for most power in APEX-SZ maps.
What’s Next?

- Couple dozen clusters in the can
- Gas mass fraction vs. radius
  - Constrain $H_0$, $w$
- Scaling relations: (Amy Bender)
  - Redshift evolution – good overlap with multi-wavelength data
    - Including high-Z clusters
  - Relaxed vs. complex systems
- Constraints for cluster simulations
  - Isothermal vs. universal temperature profiles
  - Radial profiles
  - Extended cluster emission
    - widen scan strategy to get beyond $r_{\text{virial}}$
Summary

- APEX-SZ is a 280 element 150 GHz bolometer array operating on the 10m APEX telescope
  - Technology pathfinder role: 280 element TES bolometer array, multiplexed readout, no expendable cryogens.

- New SZ observations of the Bullet and A2163
  - General consistency with expectations from x-ray.

- Power spectrum is consistent with WMAP5, with majority of power from dusty galaxies.
  - $\sigma_8 < 1.18$ at 95%
A2163 with APEX-SZ & LABOCA


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