CCAT Special Session

Cosmology and cluster science with CCAT
A unique cosmological perspective

Broad cosmological surveys fully utilizing CCAT’s unique capabilities.

Immediate capabilities:
• Large field of view (1 deg total, 20 arcmin LWCAM)
• Full sky surveys possible (up to $3\pi$ steradians)
• Fine angular resolution (12” at 1 mm)
• Multi-frequency spectral coverage (350 $\mu$m to 3 mm)

Longer term:
• Integral field spectroscopy [570micron-1.5mm]
CCAT cosmology priorities

CCAT’s multi-frequency, high resolution survey will open up a new window on cluster astrophysics and cosmology

Immediate aims:
- Detailed characterization of cluster structure (fine & large scales)
- Unambiguous measurements of ICM velocities and temperature

To realize:
- A deeper understanding of cluster processes and evolution
- A dynamical imprint of the epoch of reionization
- A direct measure of cosmic flows, a distinct test of gravity
- Rich complementarity with upcoming X-ray, lensing & spectroscopic galaxy surveys

Longer term:
- A new redshift window (at z~3-5) on the cosmic expansion history and galaxy clustering. Complementary to optical /IR surveys at z<2

Figure credit: Daisuke Nagai
Sub-mm cluster surveys

- Sunyaev-Zel’dovich (SZ) signal from CMB photons interacting with clusters

- Multiple contributions to observed signal, both SZ and astrophysical
  - Thermal, Kinetic and relativistic SZ
  - Sub-mm galaxies (SMGs)
  - Radio sources

- Multi-frequency sensitivity and angular resolution are crucial to disentangle the various components
Multi-frequency measurements

\[ \Delta I \text{ (mJy/3mm Beam)} \]

\[ \lambda (\mu m) \]

- Sub-mm sources
- Radio sources
- Relativistic SZ
- Thermal SZ
- Kinetic SZ
- Combined
A unique multi-frequency and high-resolution survey

The Bullet Cluster
- color: X-ray
- blue contours: X-ray
- white contours: lensing

Planck beams
- 100 GHz
- 143 GHz
- 857 545 353 217 GHz

Rachel Bean
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A unique multi-frequency and high-resolution survey

The Bullet Cluster

color: X-ray
blue contours: X-ray
white contours: lensing

ACT, SPT beams

Atacama Cosmology Telescope

South Pole Telescope

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A unique multi-frequency and high-resolution survey

The Bullet Cluster
- Color: X-ray
- Blue contours: X-ray
- White contours: lensing

ACT, SPT beams
- 277 GHz
- 218 GHz
- 148 GHz
- 95 GHz
- 150 GHz
A unique multi-frequency and high-resolution survey

The Bullet Cluster

color: X-ray
blue contours: X-ray
white contours: lensing

CCAT beams

SWCam: 857 667 484 GHz
LWCam: 400 350 275 230 150 90 GHz
A unique multi-frequency and high-resolution survey

The Bullet Cluster
- CCAT beams
  - color: X-ray
  - blue contours: X-ray
  - white contours: lensing

SWCam
- 857 667 484 GHz

LWCam
- 400 350 GHz

275 230 150 90 GHz
Cluster profile reconstruction

Constrain cluster pressure profiles & non self-similar redshift evolution

Comparison of simulated CCAT and SPT radial profile recovery (with same noise)

more precise handle on cluster details e.g. halo triaxiality, non-thermal pressure modeling, studies of accretion at the virial radius

Cluster astrophysics parameters

non self-similar evolution $\epsilon$

Credit: [LH] Morandi, Nagai and Cui in prep
SZ power spectrum constraints

Secondary anisotropy power spectrum

Credit: Ramos-Ceja & Basu in prep,
Strong complementarity with lensing and X-ray measurements

- **CCAT SZ resolution commensurate with X-rays and lensing.**
  - A significant advance over prior SZ instruments.
  - Comparable to XMM (6" FWHM, 15" half-power diameter) and closer to Chandra (0.5" FHWM)

- **CCAT follow-up will improve eROSITA mass estimates by x4**
  - SZ masses from rSZ and tSZ independent of X-ray
  - eROSITA will detect 10,000s of clusters, but 0.5‘resolution does not permit core excision to estimate M from $L_X$

- **CCAT SZ at virial radius => joint lensing-SZ cluster mass and pressure profiles (and temp with rSZ)**
  - HSC, DES, and LSST will dramatically increase # of clusters with weak lensing out to virial radius
Utilizing the kinetic SZ signal

CCAT can unambiguously extract kSZ from tSZ & other astrophysical signals

kSZ gives strongest constraint on the duration of reionization

Cosmological bulk flows of clusters
• Interesting test of gravity
• first correlation ACT + BOSS (Hand et al 2012), tentative individual detection (Mroczkowski et al 2012)
• CCAT rich cross-correlation possibilities with a range of surveys (e.g. LSST, DES, HSC, BOSS)
A new redshift window on the cosmic expansion & growth history

C+ (158\,\mu m) line gives new redshift window $z\sim3-5$ with two applications:

- **Baryonic acoustic oscillations (BAO):**
  - Distances to spectroscopic $z$
  - Constrains expansion history
- **Redshift space distortions (RSD):**
  - Clustering properties over range of scales & $z$.
  - Constrains both expansion history & properties of gravitational collapse.

Unique constraints on dark energy/modified gravity and neutrino mass

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CCAT will give a unique cosmological perspective

CCAT’s unique combination of multi-band & high resolution sub-mm surveys will enable broad and unique cosmological insights:

• Unambiguous separation of the ICM velocities and temperatures
• Detailed characterization of cluster structure and evolution
• SZ mass estimates independent of X-ray data
• New insights from the kSZ signature:
  – How long reionization endured for
  – The bulk flow of clusters (dark energy, structure growth)
• A new redshift window on the cosmic expansion & growth history