



CCAT Special Session

Cosmology and cluster science with CCAT

Rachel Bean (Cornell University)
On behalf of the CCAT Cosmology Working Group



A unique cosmological perspective

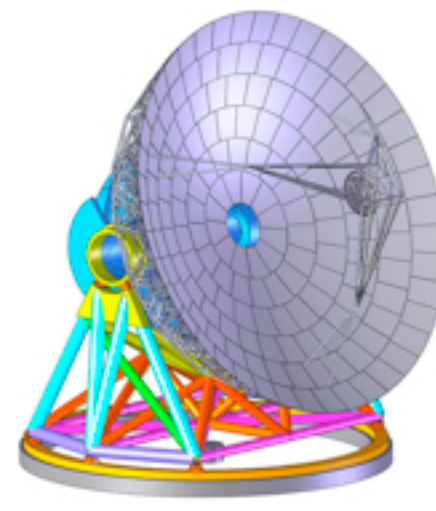
Broad cosmological surveys fully utilizing CCAT's unique capabilities.

Immediate capabilities:

- Large field of view (1 deg total, 20 arcmin LWCAM)
- Full sky surveys possible (up to 3π steradians)
- Fine angular resolution (12" at 1 mm)
- Multi-frequency spectral coverage (350 μm 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 $z \sim 3-5$) on the cosmic expansion history and galaxy clustering. Complementary to optical /IR surveys at $z < 2$

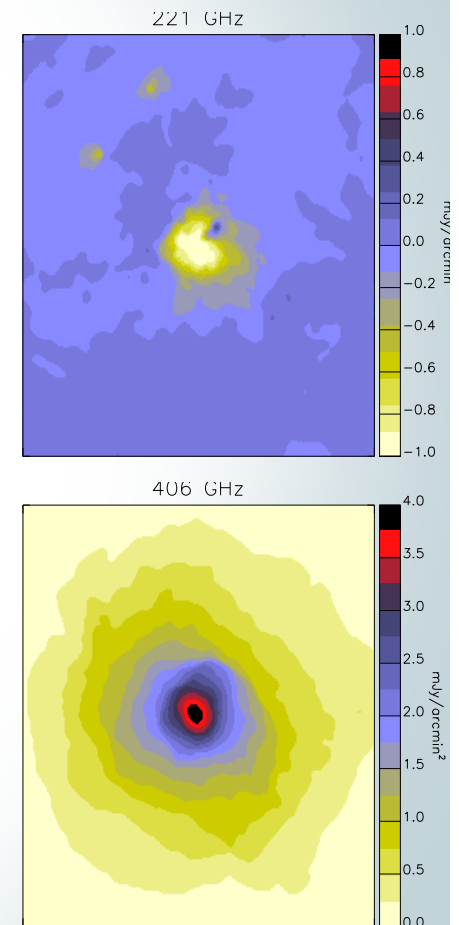
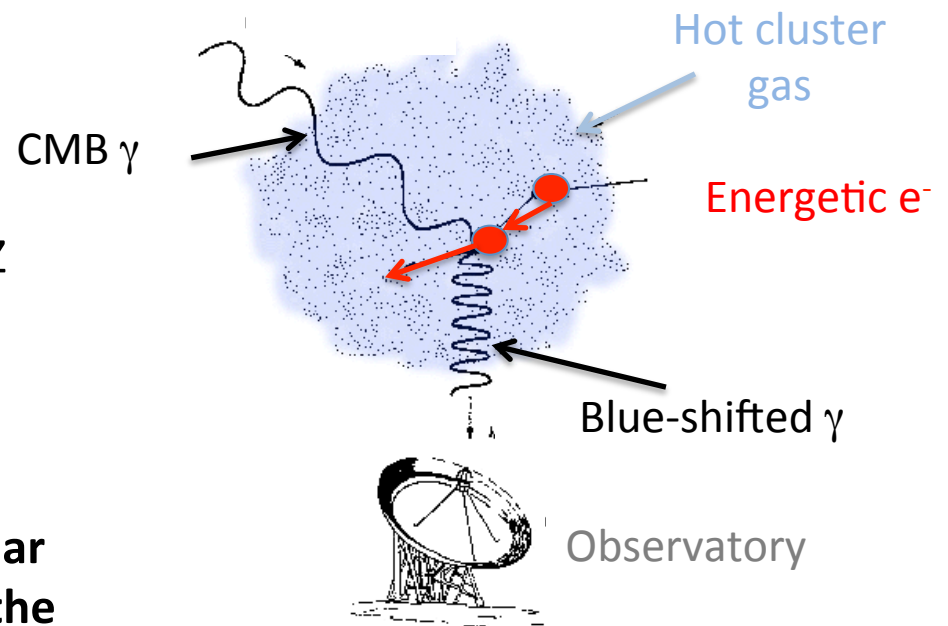


Figure credit: Daisuke Nagai

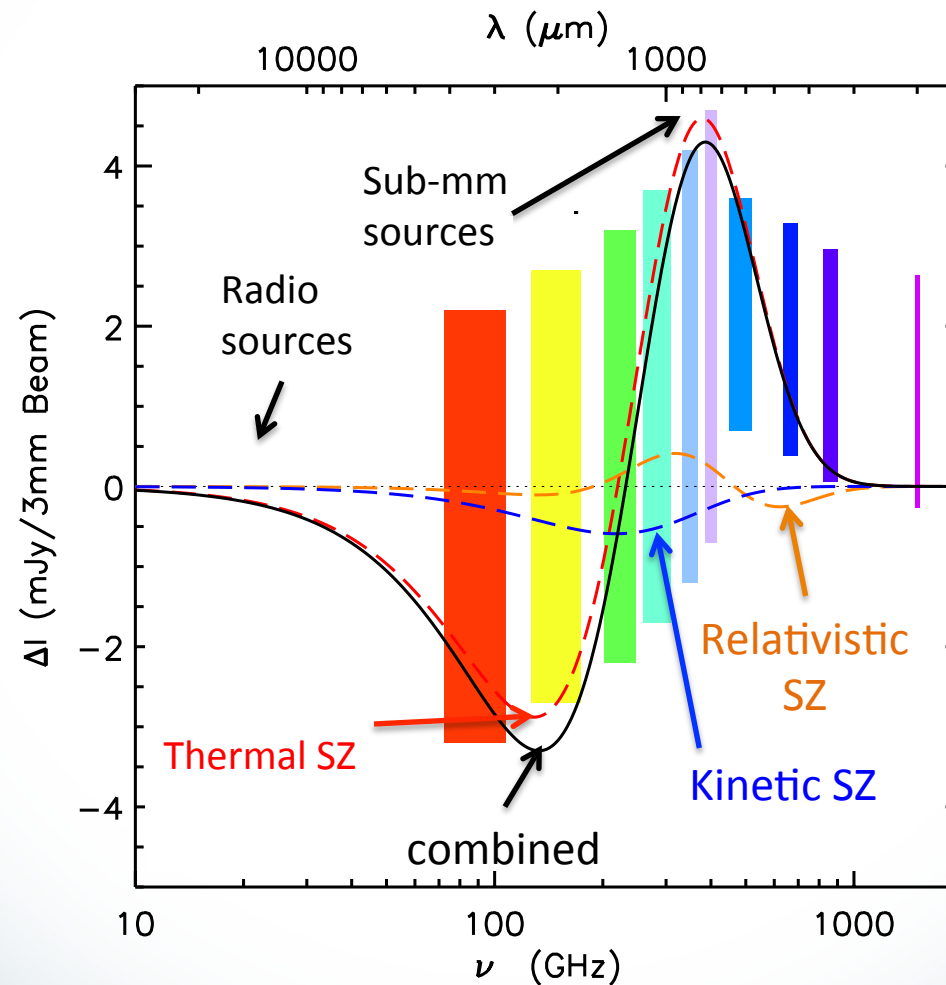
Sub-mm cluster surveys



- **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



A unique multi-frequency and high-resolution survey

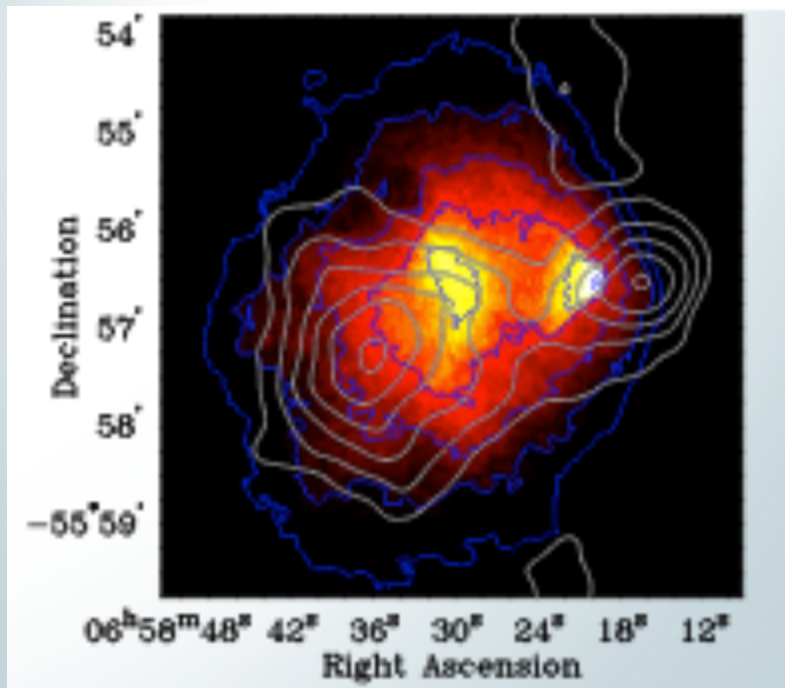


The Bullet Cluster

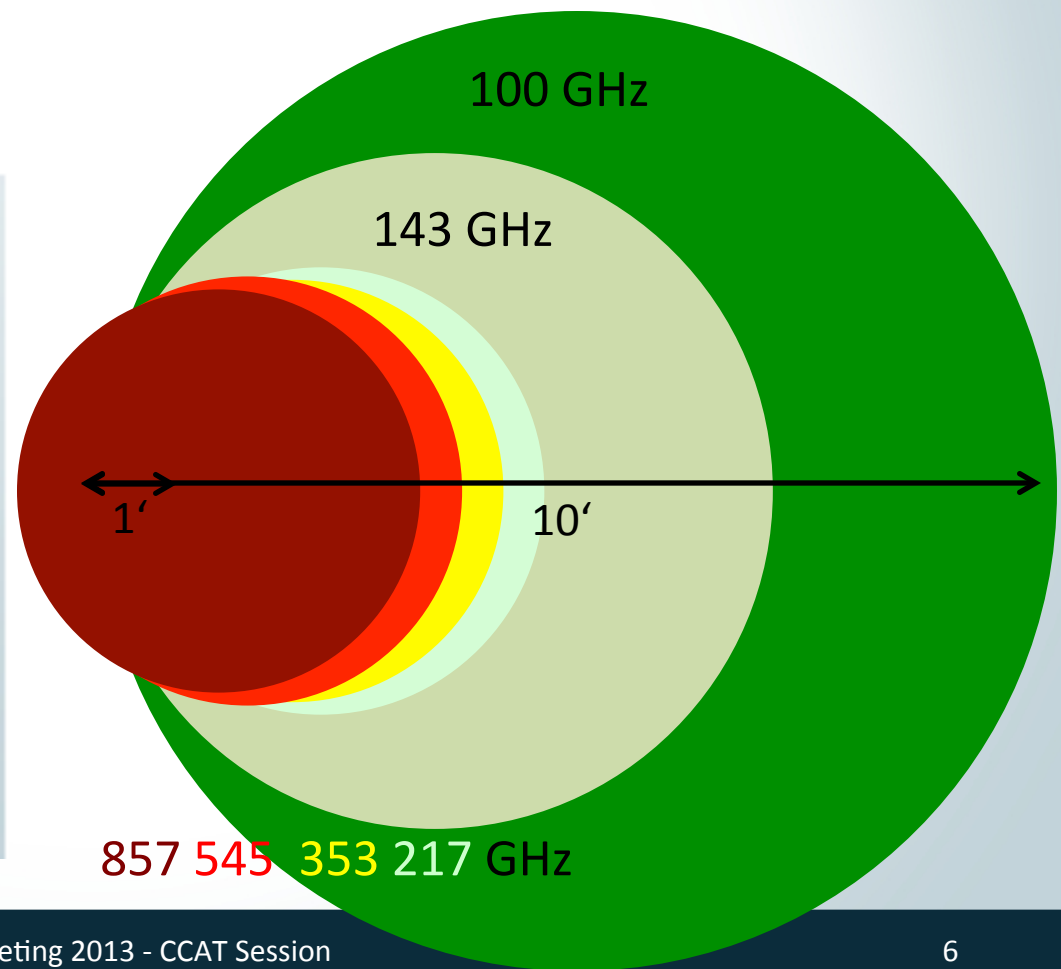
color: X-ray

blue contours: X-ray

white contours: lensing



Planck beams



A unique multi-frequency and high-resolution survey

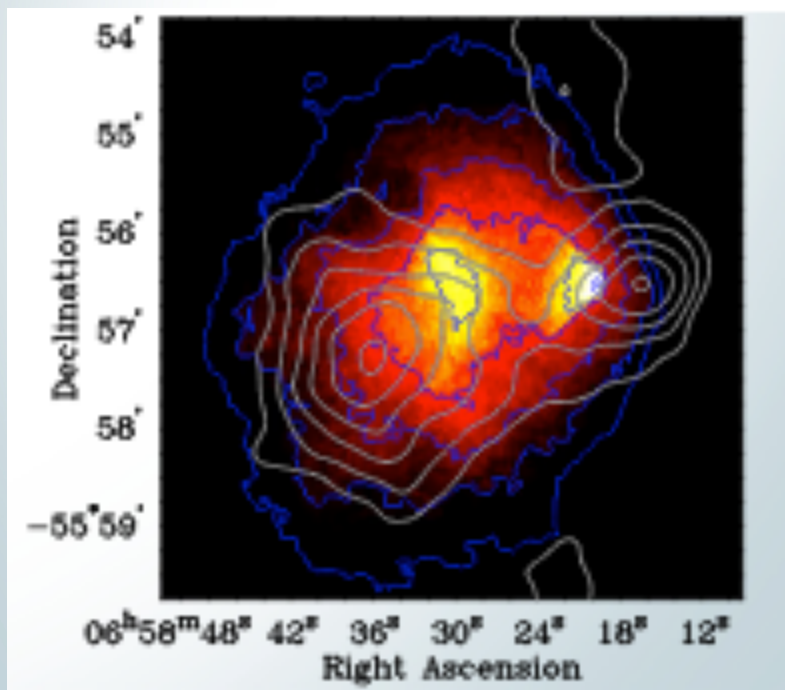


The Bullet Cluster

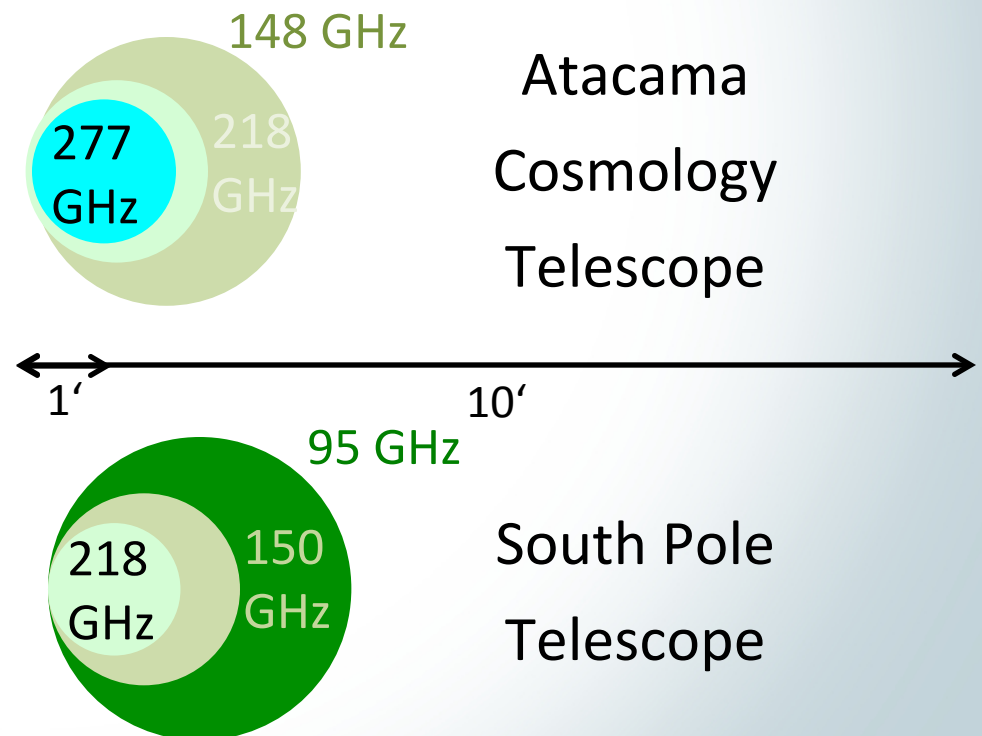
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ACT, SPT beams

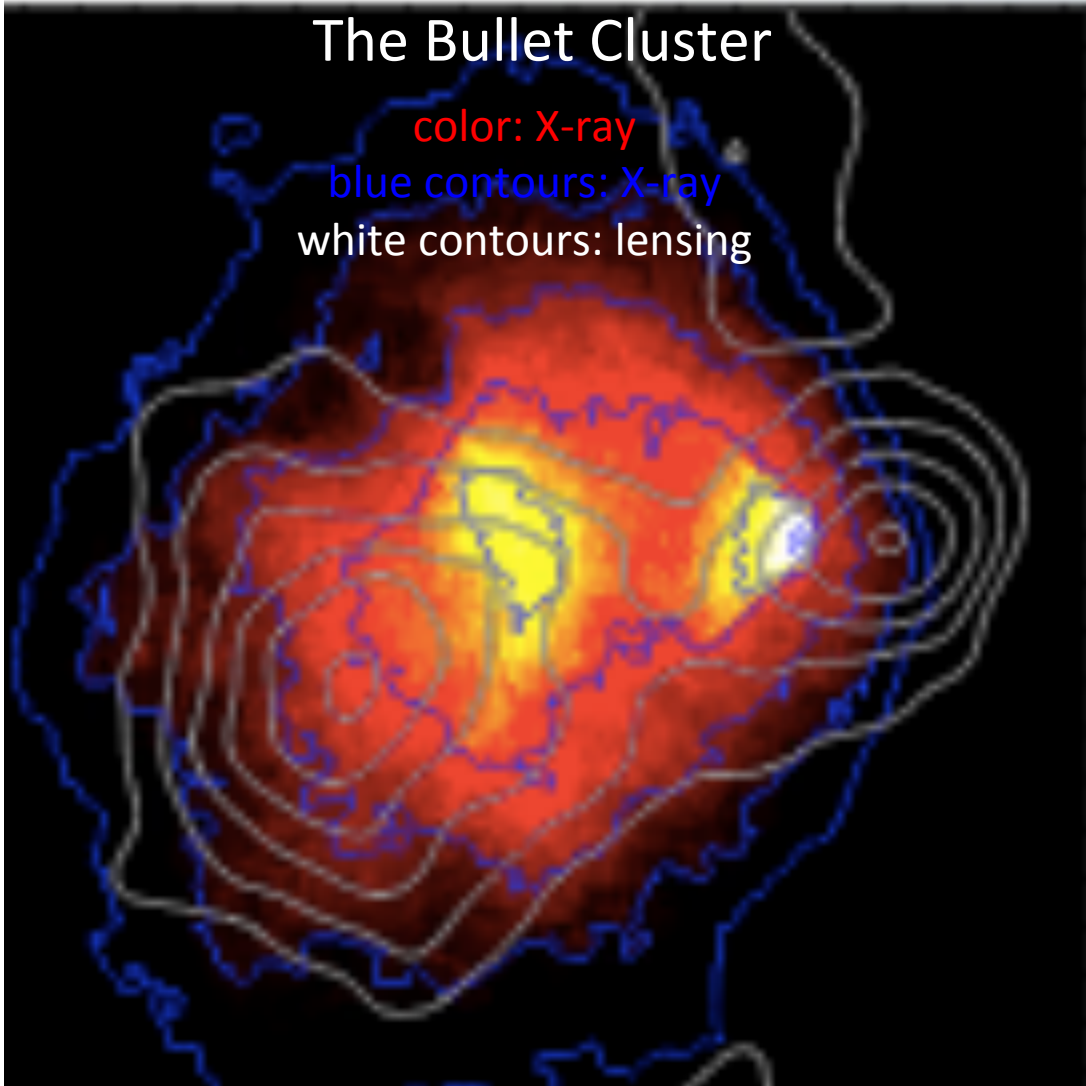


A unique multi-frequency and high-resolution survey

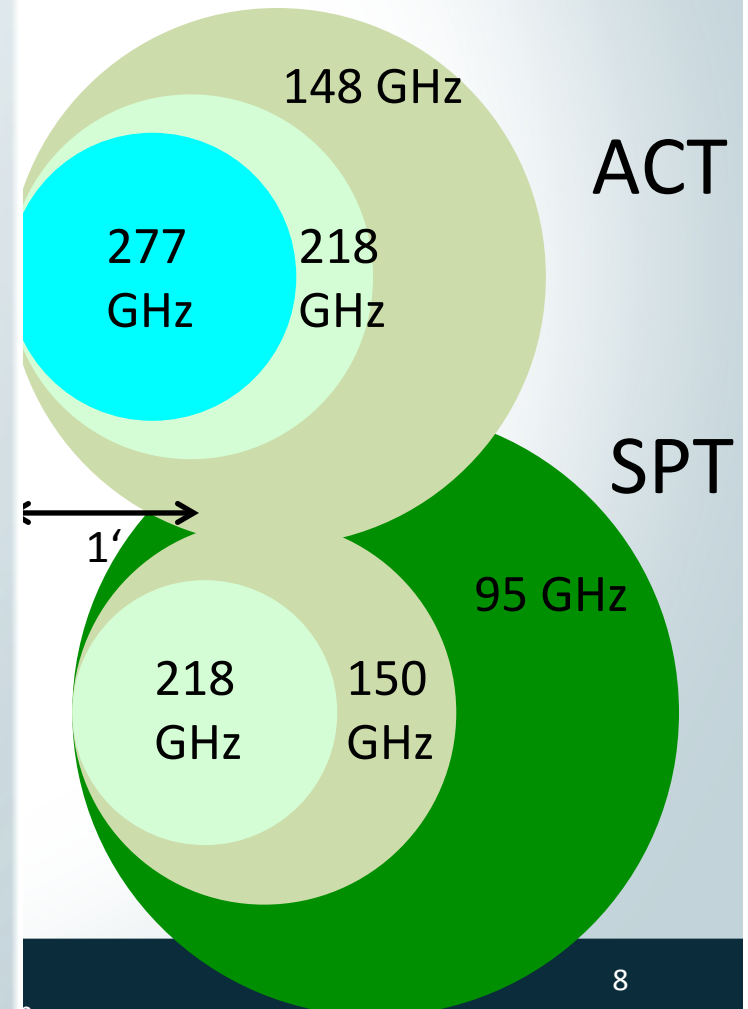


The Bullet Cluster

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ACT, SPT beams

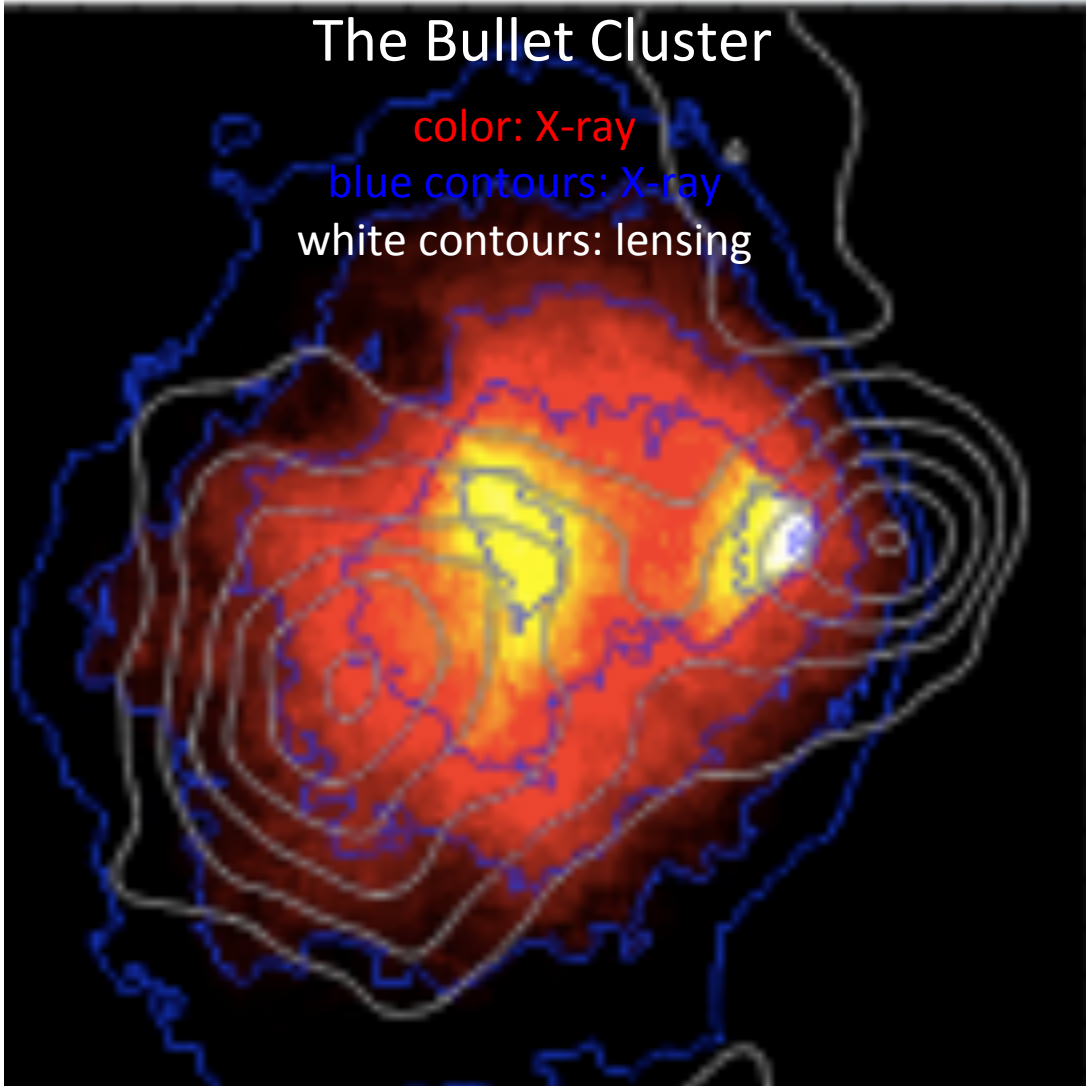


A unique multi-frequency and high-resolution survey



The Bullet Cluster

color: X-ray
blue contours: X-ray
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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

color: X-ray
blue contours: X-ray
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CCAT beams

SWCam

857 667 484 GHz

1'

400 350 GHz

LWCam

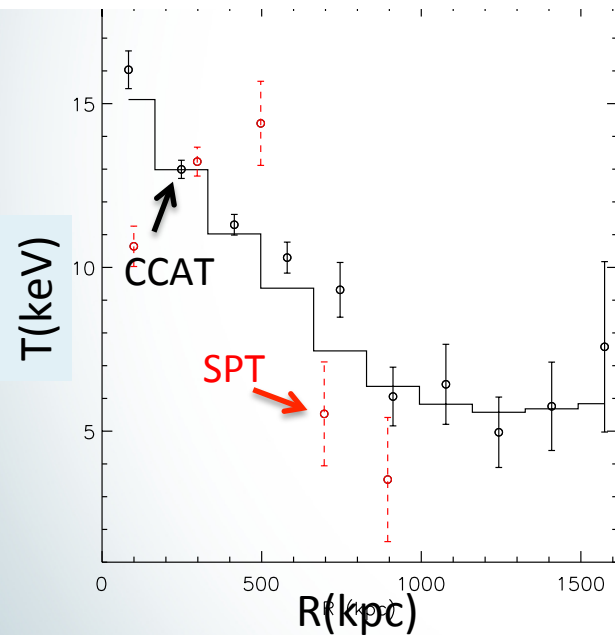
275 230 150 90 GHz

Cluster profile reconstruction



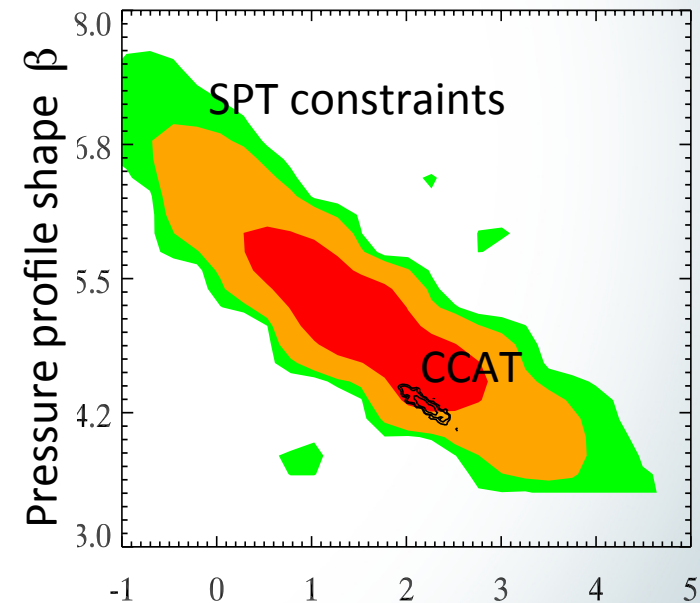
Constrain cluster pressure profiles & non self-similar redshift evolution

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

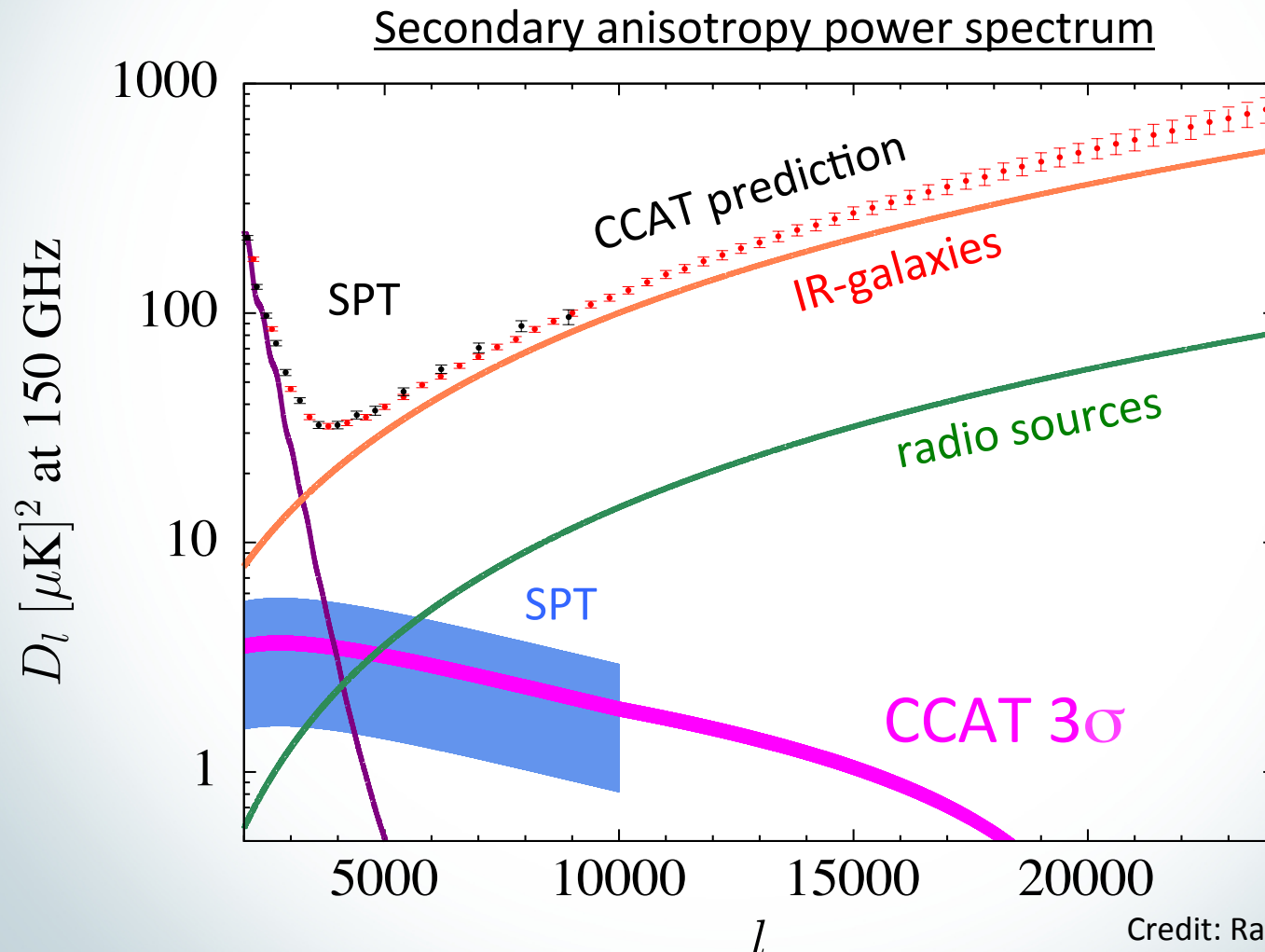
Cluster astrophysics parameters



non self-similar evolution ϵ

Credit: [LH] Morandi, Nagai and Cui in prep
[RH] Ramos-Ceja & Basu in prep.

SZ power spectrum constraints

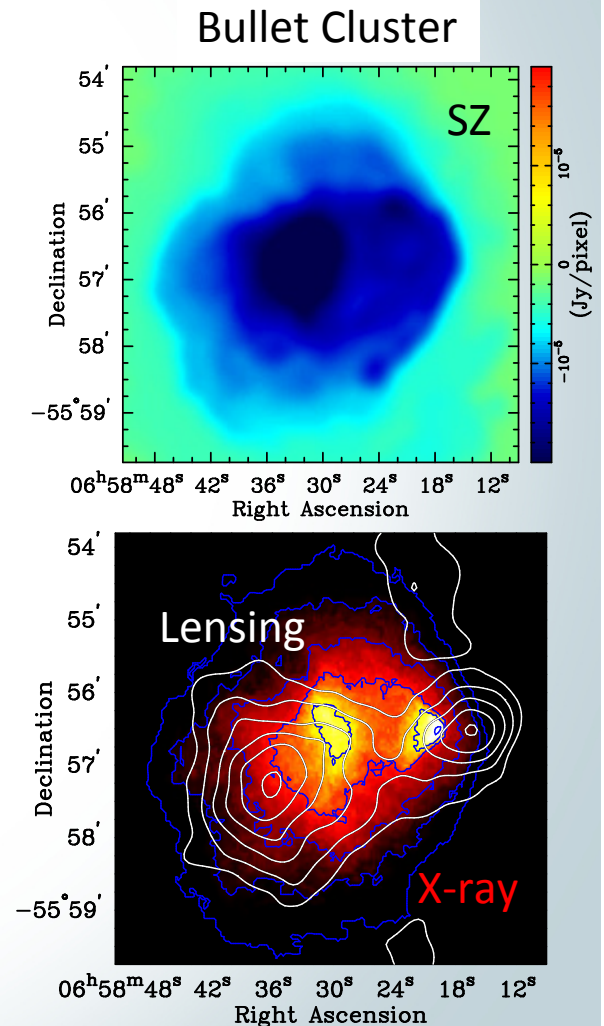


Credit: Ramos-Ceja & Basu in prep,

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" FWHM)
- **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

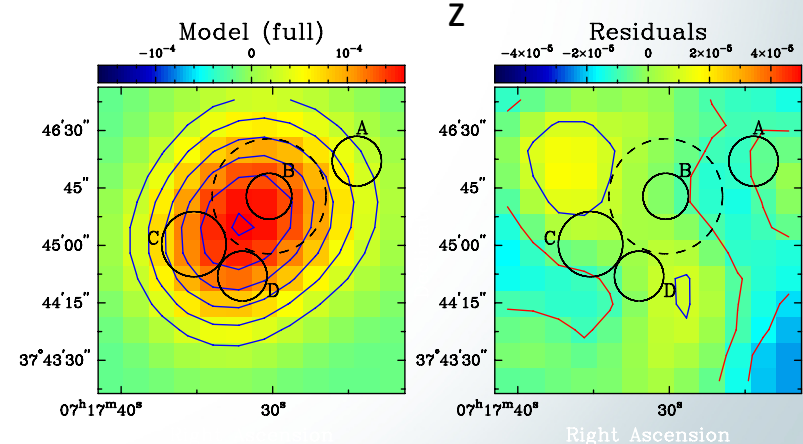
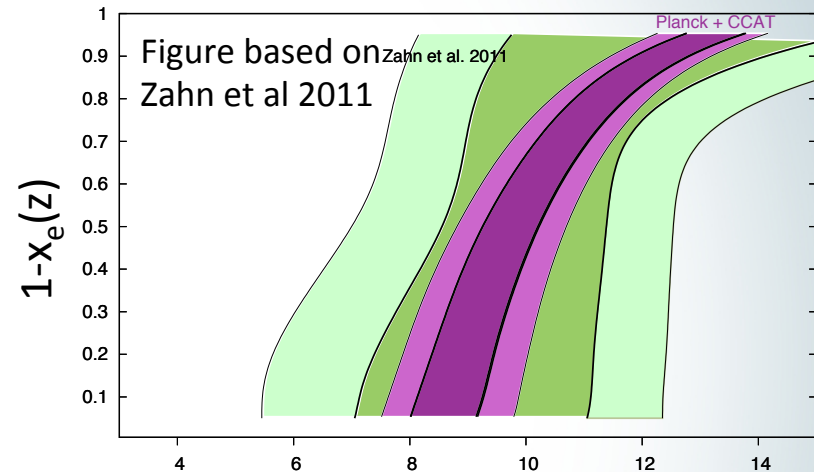


CCAT can unambiguously extract kSZ from tSZ & other astrophysical signals

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)



Mroczkowski et al 2012

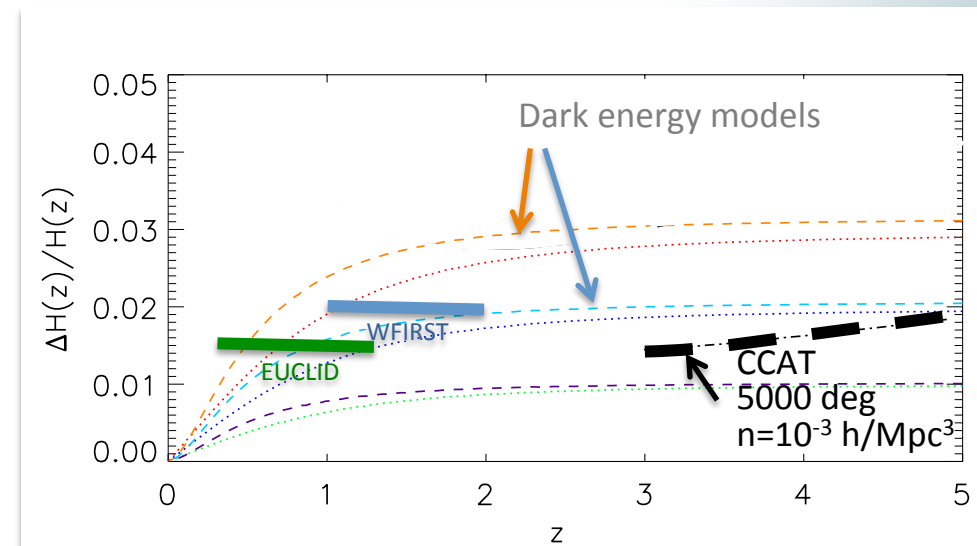
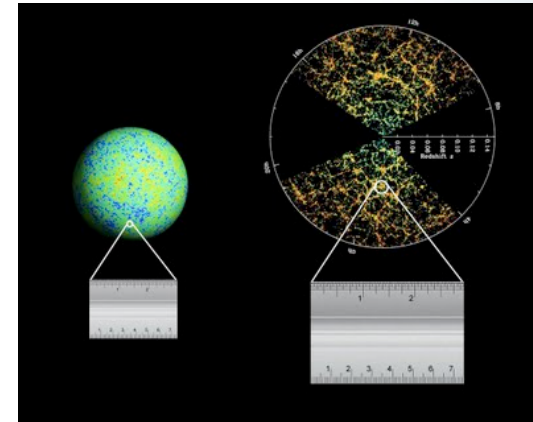
A new redshift window on the cosmic expansion & growth history



C+ (158 μ m) line gives new redshift window $z \sim 3-5$ 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**



Mueller and Bean in prep

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