# The Sunyaev-Zel'dovich effect in the Bullet Cluster

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z=0.3 kT\_e=13.9keV

Figure from NASA, Markevitch et al.

### The Sunyaev Zel'dovich effect

- Secondary anisotropy of the CMB
- Inverse Compton scattering of CMB photons by hot electrons in the cluster
- Shifts the spectrum of the CMB; the distortion has a characteristic signature
- Weak (<mK) but redshift independent (good for cosmology), depends on the amount and temperature of electrons



### **The Bullet Cluster**

- A massive merger of two galaxy clusters (total mass ~10^15M\_sun)
- z=0.3
- Main cluster with a "bullet" subcluster going through
- Dark matter, stars and gas behave differently when colliding
- The decoupling of dark matter from the gas has been observed → evidence for dark matter



APOD 2006 August 24

Pink: X-ray Purple: Total mass (mostly dark matter)

### **Previous SZ observations**

Instrument	Frequency (GHz)	Angular resolution (arcseconds)	
Australia Telescope Comp. Array	18	30	Malu et al. 2010
APEX-SZ	150	60	Halverson et al. 2009
South Pole Telescope	150,220	60	Plagge et al. 2009
Herschel	600, 850, 1200	35, 25, 18	Zemcov et al. 2009
APEX-Laboca	350	19.5	Johansson et al. 09, 10



Fig. 5.— The SZE map of the Bullet system from this work, in white contours, overlaid on an X-ray map from XMM observations. The green contours show the weak lensing surface mass density reconstruction from Clowe et al. (2006). The SZE contour interval is 100  $\mu$ K<sub>CMB</sub>.









- Bolometer array
- 870µm (345 GHz) continuum
- 295 channels
- Resolution 19.5", FOV 11.4'
- Undersampled → observation mode fills beam



- Comprehensive Reduction Utility for SHARC-2 (and more)
- Written by Attila Kovács
- Pipeline, timestream  $\rightarrow$  clean image
- Removes the correlated signal of the atmosphere
- Open source and constantly being updated

## 17 point sources (sub-mm galaxies) behind the Bullet cluster

- 3sigma~5mJy
- A highly magnified source!
- Sea of faint sources



Fig. 5. Gaussian filtered map, with the 17 detected sources marked with circles. The numbering of the sources is the same as in Table [2] The black contour corresponds to the 2 mJy/beam level in the noise map and the dashed circle marks the central 10' area of constant noise level used in the analysis.

Johansson et. al. 2010 Johansson, Sigurdarson & Horellou 2011

### **Detection of extended emission**





Colour: Laboca (Smoothed to 28") Black: APEX-SZ decrement (Halverson et al 2009, 85"), White: XMM

Colour: Laboca (Smoothed to 28") Black: Total mass

### SZ shifted?

- The SZ increment in the Bullet cluster seems to be shifted compared to the X-ray emission and the dark matter
- Shifted 27" in RA and 20" in dec (34" total to SW) relative to centroid of SZ decrement (uncertainty +-7")
- Effects of substructure?
  - X-rays sensitive to ∫n\_e^2\*Λ(T)
  - SZ traces ∫n\_e\*T
  - Clumps resolved or not due to different resolutions in SZ maps?
- Remaining contaminating point sources?
- Effects of lensing background population of sources?
- Effect of transfer function?

### Simulation of extended SZ emission + point-like sub-mm galaxies



### Conclusions

- High resolution observations of the SZ increment are complicated due to background sub-mm galaxies
- After removal of the brightest (>3sigma) sub-mm galaxies, we detect extended emission with an apparent shift compared to previous SZ, X-ray and weak lensing observations
- Shift due to contaminating faint sub-mm galaxies or other effects?
- Ongoing work on simulations to quantify this effect, including lensing and analyzing the transfer function
- ALMA will be able to detect contaminating faint sub-mm galaxies

