New High Resolution SZ Measurements with MUSTANG on the GBT

Brian Mason, NRAO
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with
S. Dicker, P. Korngut, A. Mroczkowski, E. Reese, M. Devlin (UPenn)
M. Sun, C. Romero, C. Sarazin (UVA)
P. Koch, S. Molnar (ASIAA)
High Resolution SZE as an astrophysical tool

Directly image thermal electron pressure

\[ XRSB \propto \int d\ell \, n_e^2 T_e^{1/2} \]

High-contrast probe of dense gas

\[ \Delta T \propto \int d\ell \, n_e \, T_e \propto \text{thermal electron pressure} \]

Sensitive to hot gas
High Resolution SZE as an astrophysical tool

Directly image thermal electron pressure

Sensitive to hot gas

You need large collecting area plus good surface brightness sensitivity to do this measurement.

** Large single dish telescopes with bolometer arrays (GBT, LMT), or large, compact interferometer arrays (ALMA 30 GHz/ACA 90 GHz)
A new view of the ICM

Directly image thermal pressure

- Catalog incidence of hot phases, hard to see in X-rays; powerful indicator of dynamic state
- Measure electron/ion equilibration timescale in the ICM
- Measure Helium sedimentation profiles in the ICM
- Test the hypothesis that AGN bubbles are inflated by a relativistic, nonthermal fluid
- search for IGM infall shocks in the low-density outer regions of clusters
  - source of cluster CRs/radio halo electrons?
  - contribution to cosmic gamma ray background

Understand mechanisms Of ICM heating, feedback
Reduce scatter in dN/dM/dZ, distances
Understand selection effects

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Measuring the Electron/Ion Equilibration timescale

Fig. 34. Electron-ion equilibrium at shock in 1E 0657–56. Deprojected electron temperatures for the two outer post-shock bins of the temperature profile from Fig. 32, overlaid on the model predictions (with error bands) for instant equilibration (labeled “shock”, light gray) and adiabatic compression followed by collisional equilibration (dark gray). The velocity shown is for the post-shock gas relative to the shock. Error bars are 68%. (Reproduced from M06.)

Markevitch et al. (2006)
The Robert C. Byrd
Green Bank Telescope (GBT)

- 90GHz aperture efficiency is 35% (250 micron rms)
- Pointing accuracy (tracking) is 1.5-2"
- Frequency coverage from 200 MHz-50 GHz
- Spectral line, continuum, pulsar, VLBI backends
- MUSTANG bolometer array
  - 81-99 GHz
  - 8.5” beam
  - 64 detectors; 40”x40” FOV
  - sensitivity: 3’x3’ to 0.4 mJy RMS in one hour
  - publicly available - go to http://www.gb.nrao.edu/mustang and/or talk to me (bmason@nrao.edu)
250 micron Ruze-equivalent RMS surface
GBT effective collecting area is now equivalent to
>40 high-efficiency 10-meter antennas.
RXJ1347-1145

Komatsu et al. 2001

Kitayama et al. 2004: Nobeyama 150 GHz 7 beam rx (20 hours) + JCMT (350 GHz increment image)
MUSTANG+GBT

8 hours of observing spring 2009

Ridge continues to the north (consistent with 350 GHz increment image)

Shock-heated gas (>20 keV) confirmed at over 5 sigma

MUSTANG beam
10” resolution
< 50 kPc
Interpretation

- Presence of very hot (>20 keV) gas SE of cluster core clearly confirmed. Almost certainly due to ongoing, major merger.
- “B” cluster falls in to “A” (primary) cluster ~ in the plane of the sky
  - “A” has significant cool gas in its core
  - comparable masses
- First passage; currently at our near closest approach of BCGs
- Unaccounted for hot gas will increase the SZE by 10% at 1’ resolution (20% in $H_0$)

but the geometry is messy so it’s hard to do a lot of the astrophysics with the SZE in this system
New MUSTANG data
New MUSTANG

unexpected indication of dynamically significant merger

by P. Korngut (UPenn)
Cleaner systems with multiple known shocks will be observed by MUSTANG later this year.
Conclusions + Next Step

• Previously indicated, X-ray offset peak in the SZE in RXJ1347-1145 confirmed at high significance (>5 sigma) and higher resolution (10")
  – consistent with a major merger right at initial core passage generating ~25 keV gas.

• Observations of several more clusters are in hand with analysis underway; further, more astrophysics-optimized observations are planned.

• **MUSTANG is a pathfinder**: proven solutions to most of the difficult technical issues faced by a TES bolometer array and the GBT works great at 90 GHz!
  – MUSTANG detector array upgrade underway
  – working to obtain funding for next generation camera