Galaxy Cluster Science: 5-10 year view of the GBT's Role



Brian Mason (NRAO) Green Bank Observatory Transformational Science Workshop October 16, 2017

x-ray bremmstrahlung

Galaxy Clusters

Galaxies + Hot Intra-Cluster Plasma + Dark Matter





* Excellent view of density variations * Some Spectral Information — but not useful in lowdensity regions (outside cluster core) or hi-z

Sunyaev-Zel'Dovich Effect (SZE)



 * Outstanding sensitivity to hot gas
 * Redshift-independent: effective / tool at high-z
 * requires sensitive detectors

Abell 1689: HST + Chandra



We can learn about our cosmology by studying the abundance and properties of these extreme halos as functions of Mass and z.

Max Planck inst. Springel et al 2005; Dark Matter Only



Atacama Cosmology Telescope (Cerro Toco)



South Pole Telescope (SPT)

SZ Selected Clusters

2008: zero

2011:ACT (23) + SPT (26) + PLANCK (169+20)= 238 1/2 to 3/4 of the clusters found by ACT & SPT were previously unknown (missed by Abell, RASS, etc.).





Atacama Cosmology Telescope (Cerro

pe (SPT)

SZ Selected Clusters

2008: zero

Like nearly all SZ instruments these have low resolution (~1') and cannot usefully resolve the ICM.

The GBT @ 3mm (9") can

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MACS 0744+3927 [z=0.69, M-Y outlier]



Korngut et al. 2011

14" SZE Imaging reveals an M ~1.5 shock *evident in x-ray data a posteriori

Other MUSTANG SZ results

SZE reveals high-pressure structure not seen in previous x-ray data.

100 ksec XMM follow-up observation + 3hr ALMA Cycle4 observations obtained

MACS 1206-0847



RXJ1347-1145



Mason et al 2010 Romero et al. 2017

CSO+BOLOCAM SZE observations @140 & 268 GHz (Sayers et al. 2013) show cluster B to be a "line of sight Bullet cluster" [+3200 km/s]

First detection of the kinematic SZE in an individual object





Mroczkowski et al. 2012 VanWeeren et al. 2015

-0.1

-0.2

-0.3

-0.4

-0.5

-0.6

-0.7

-0.8

-0.9

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2017	Dark Energy Survey
2018	5,000 sq.deg. optical
2019	Survey
2020	Chandra
2021	(degrading)
2022	
2023	
2024	XARM
2025	ASTRO-H/ Hitomi roplocomont
2026	Πιοπιτεριαcement
2027	
2028	
2029	
	Athena?
KEY:	X-ray Optical SZE

Advanced ACTpol & SPT3G

10k-pixel class millimeter survey cameras

Simons Observatory

100k-pixel class millimeter survey cameras

eROSITA

1st X-ray all-sky survey since ROSAT 30x deeper



eROSITA currently in Moscow being integrated with SRG spacecraft



 GOAL: characterize dark energy by mapping massive halo density to z~1.5

detect > 2k massive galaxy clusters @ z > 0.8
25" FWHM, ~100 photons/cluster @ z=1

High-z clusters are very hard to study with x-ray or optical data — resolved SZE provides dynamical state, pressure profiles, masses

Ferrari et al. (2011)



MUSTANG SZE + GMRT 600 MHz show a strong connection between shockheated thermal & nonthermal ICM phases

Astrophysics with the SZE

ALMA Cycle 4 Lacy et al.



Possible outflow SZE

MUSTANG-2



U.Penn (Devin, Dicker, Stanchfield+)

NRAO (DAQ & control software; analysis software; receiver rotator, dewar)

NIST (detectors & MUX)

Detectors funded by NSF-ATI in 2015

- 64 pixels -> 215 pixels
- 42" FOV —> > 4' FOV
- greater sensitivity per beam

Available in Feb I GBO call for proposals (shared-risk in collab. w/PI)

OMC 2/3 Orion "Integral shaped Filament"

5' x 15'

MUSTANG-2

MUSTANG-2 Commissioning observation of SZE in

(winter 16/17)

2h integration time on source

40 minutes onsource (commissioning winter 16/17) <image><text>

Available in Feb I GBO call for proposals (shared-risk in collab. w/PI)

MUSTANG-2 SZ Science

From accepted proposals currently in the GBT observing Queue:

*more accurately determine the **masses and ICM pressure profiles in high redshift (z>1) clusters** which are very difficult and expensive to study with x-rays (17A-358, 17B-218)

*provide 10" resolution imaging of SZ-selected clusters discovered in ACT equatorial survey, **observationally quantifying scatter and bias in M-Y relationship**. (17B-334)

* cluster astrophysics: detect unknown shocks in the intra-cluster medium; probe shock mechanics (17B-266); probe AGN bubble composition (17A-340); study thermal/non-thermal ICM phase connections (17B-314)

* measure ICM pressure profiles in Weak-Lensing selected cluster sample (17B-101

* measure **ICM turbulence** from SZE pressure fluctuations (17B-082)



Summary



- SZE imaging has moved beyond single #s or detailed study of only the most extreme single cluster. We can trust our images and start learning from them!
- X-rays alone provide an incomplete view of the Intra-cluster medium and clusters' dynamical state
 - high resolution SZ data will provide essential information for maximizing the cosmological returns from existing & ongoing cluster surveys
- Looking to the future: there is abundant SZ science at 10" resolution
 - ALMA Band I in the south
 - Large cameras on Large mm single dishes: GBT@3mm
 - having a robust, sensitive, high-resolution SZ imaging capability routinely available will transform the field.

end