AMiBA Sunyaev-Zel’dovich Effect and Multiwavelength Study of Galaxy Clusters

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@CLJ2010+0628

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   – 524-orbit Hubble Multi-Cycle Treasury program (PI: Marc Postman, Co-PI: Holland Ford)

http://www.stsci.edu/~postman/CLASH/

1. Fundamental Questions

Galaxy clusters as sensitive cosmological probes

Providing testable predictions of models of structure formation on Mpc/sub-Mpc scales at z<1-2, complementary to CMB and LSS in terms of scale/epoch:

1) **DM and Dark Energy – Precision Cosmology**
   - Precision cosmology with cluster abundance, X-ray gas fractions, tSZE Cl, …
   - Calibration of mass-observable relations; characterization of intrinsic scatter

2) **Quasi-Equilibrium DM mass profile shapes**
   - Inner-cusp and outskirt density slopes, $d\ln\rho(r)/d\ln r$
     - DM nature, structure formation (w/ baryons)
   - DM Halo triaxiality
     - DM collisional nature, structure formation (M. Oguri's talk)
     - $\sigma 8$ – e.g., Ho et al. '06
   - Degree of DM mass concentration, $C_{vir}(M_{vir},z)$
     - Structure formation, cosmology, cluster formation epoch – e.g., Duffy et al. 2008

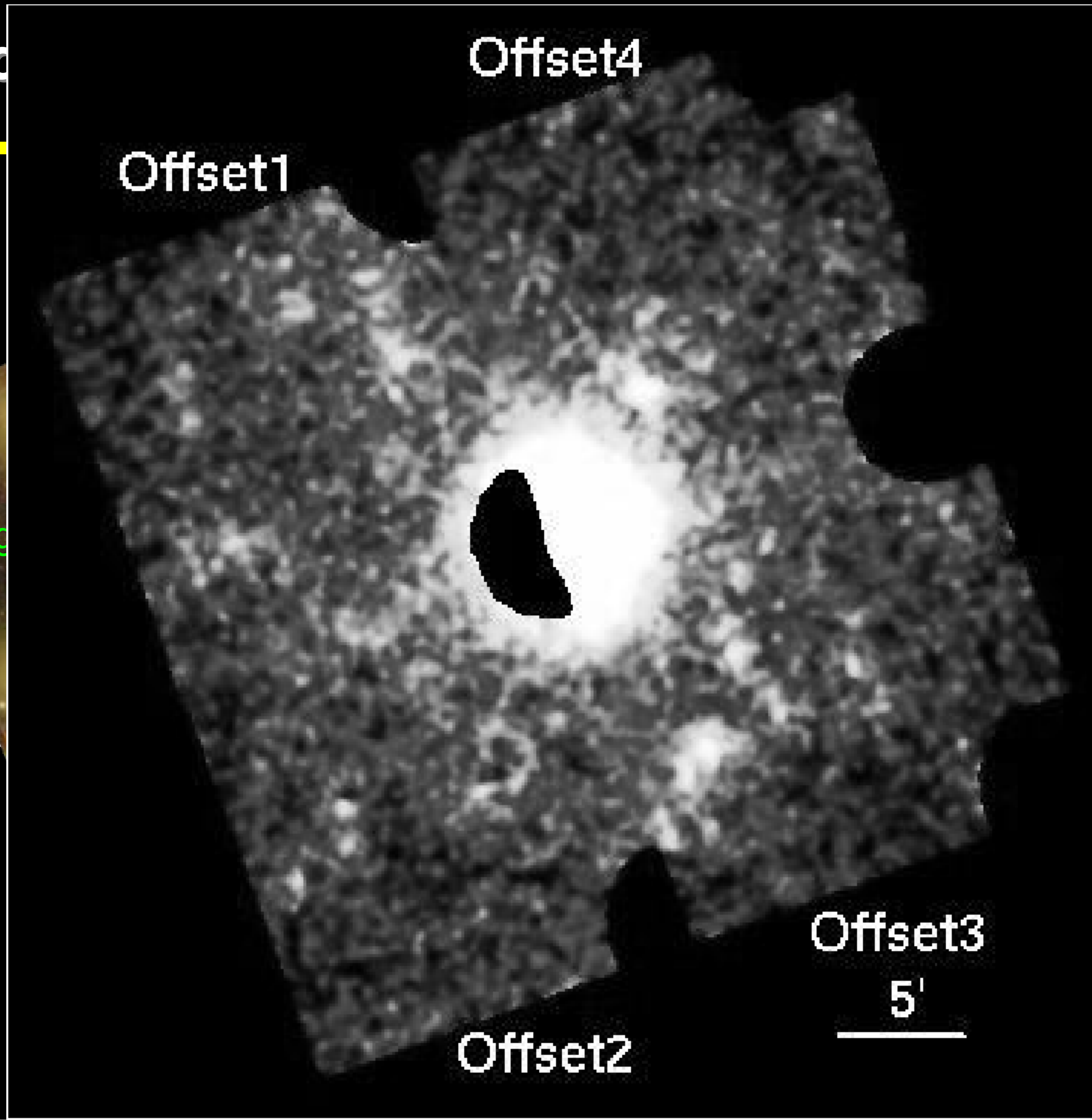
3) **DM and Baryons**
   - Gas mass fractions
   - Level of Hydrostatic equilibrium (S. Borgani's talk)
     - Y-M_{tot} bias in disturbed clusters (E. Komatsu's talk)
     - Thermal vs. equilibrium pressure profiles P(r) - Kawaharada, Okage, Umetsu+2010, ApJ
   - Degree of thermalization
     - Temperature and entropy profiles in cluster outskirts - Kawaharada, Okabe, Umetsu+2010
     - Anisotropic nature associated with surrounding LSS and filaments - Kawaharada, Okabe, Umetsu+2010

Complementary multi-wavelength observations of individual clusters needed for understanding Clusters

Clusters as c

Abell 1689 (z=0.183)

- *Subaru* Suprime-C
  34'x27'
- *HST ACS* 3.3'x3.3'
- *Chandra* ACI
- AMiBA
- VLT/VIRMOS
- Suzaku/XIS



2. Array for Microwave Background Anisotropy (AMiBA)

The AMiBA Project (since 2000)

PI:	Paul T.P. Ho (ASIAA/SAO)
Project manager:	Ming-Tang Chen (ASIAA)
Project scientists:	J.-H. Proty Wu (NTU)
	Keiichi Umetsu (ASIAA)
System scientist:	Patrick Koch (ASIAA)
System engineer:	Chao-Te Li (ASIAA)
Scientists:	Kai-Yang Lin (ASIAA)
	Hiroaki Nishioka (ASIAA)
	C.W. Locutus Huang (NTU)
	Yu-Wei Liao (ASIAA)
	Sandor Molnar (ASIAA)

Poster #21 "AMiBA Science and Recent Upgrade"

AMiBA – The Largest Hexapod Telescope

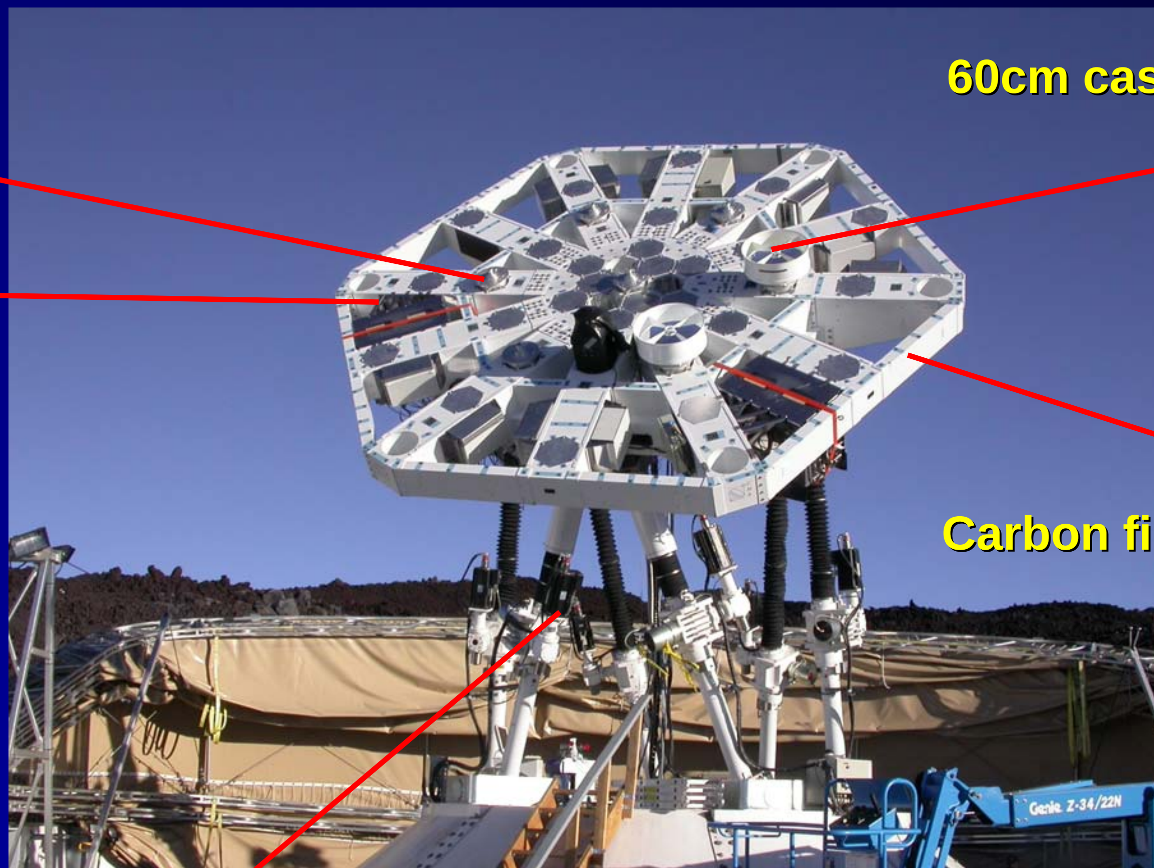
Mauna-Loa Observatory (3300m), Hawaii

Receiver

HEMT, 94GHz
(84-104GHz)

Correlator box

Analog 4-lag,
wide-band:
Δf/<f>=0.21



60cm cassegrain antenna

Carbon fiber platform (6m)

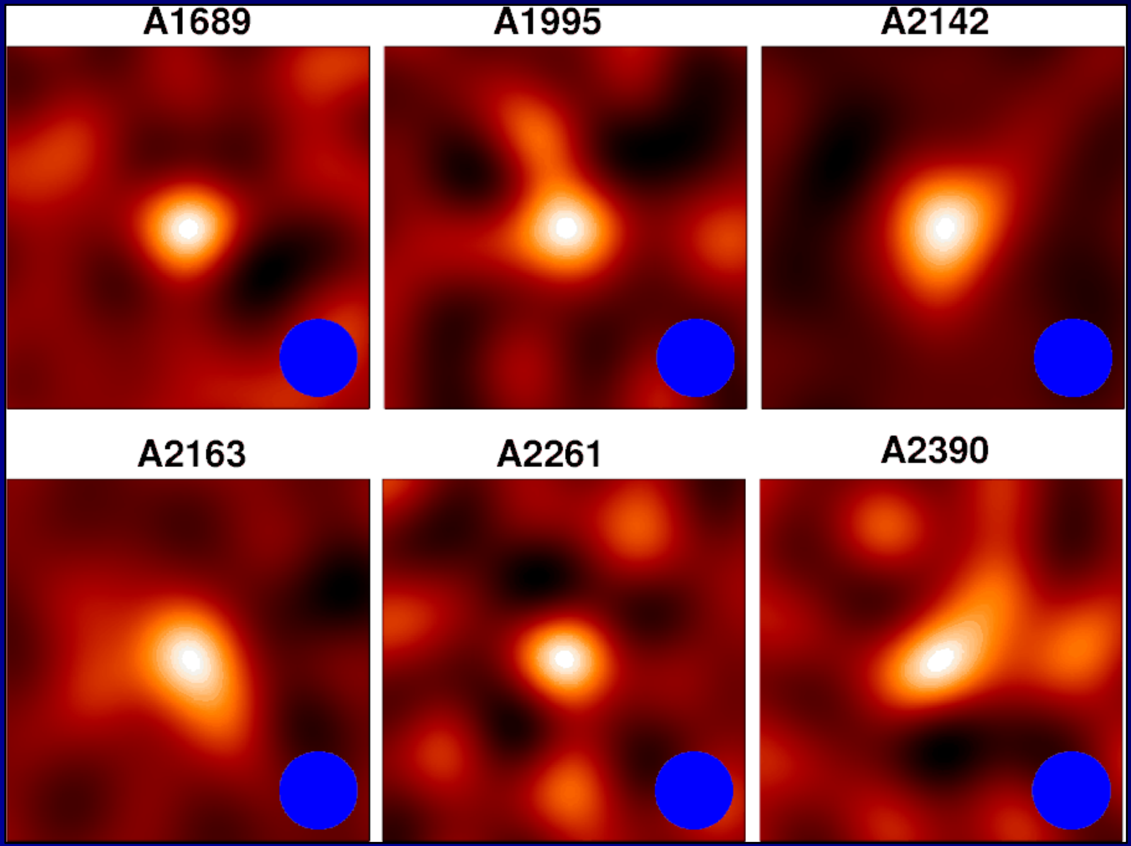
Hexapod jack

Constrained 6 degrees-of-freedom

0<Azimuth<360deg, Elevation > 30deg

Polarization: +/-30deg

AMiBA Focus: Cluster Astrophysics with Thermal Sunyaev-Zel'dovich Effect (tSZE)



Power of tSZE:

tSZE brightness is

① Independent of D(z)

i.e., free from cosmological brightness dimming,

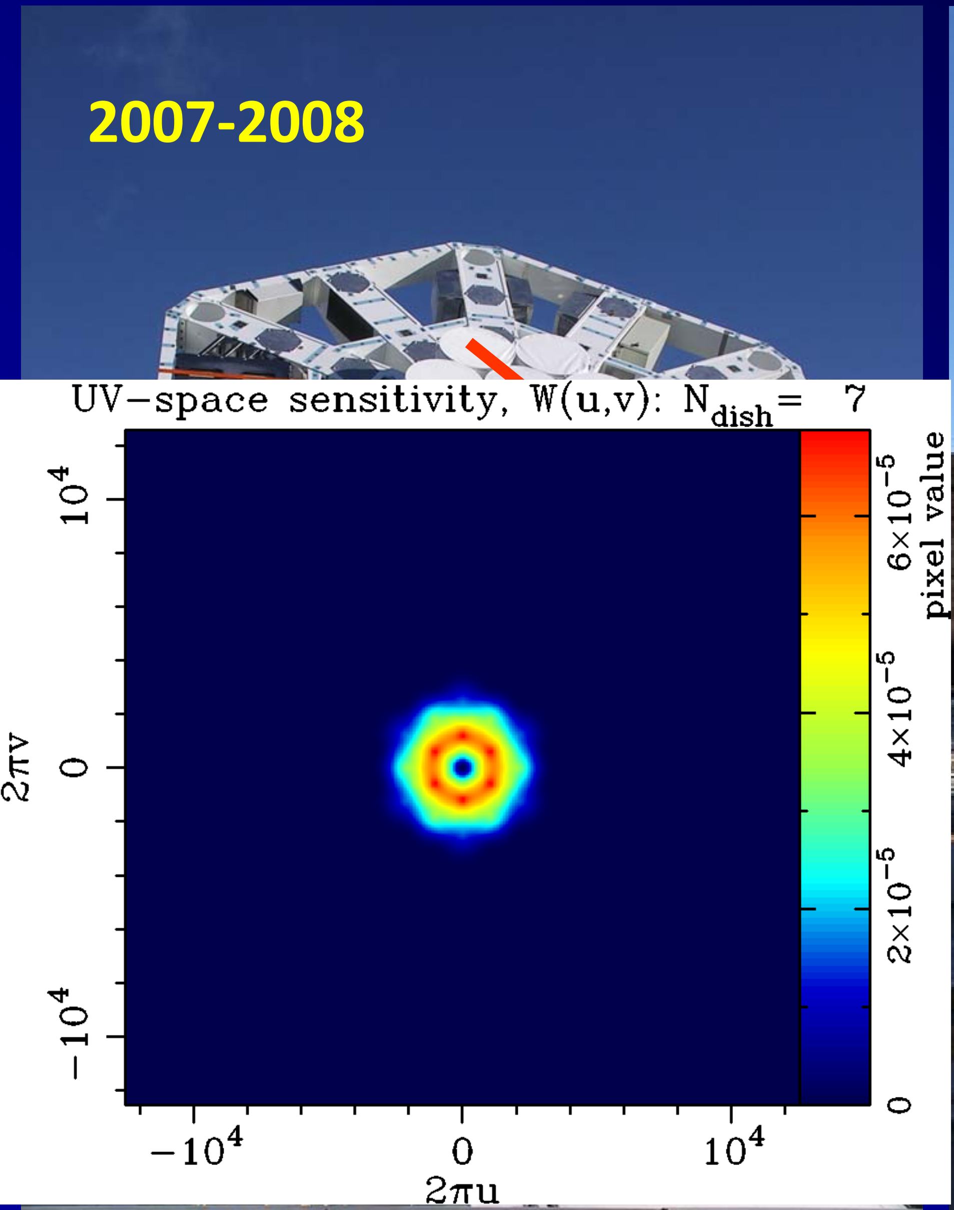
$$(D_A / D_L)^2 \propto (1+z)^{-4}$$

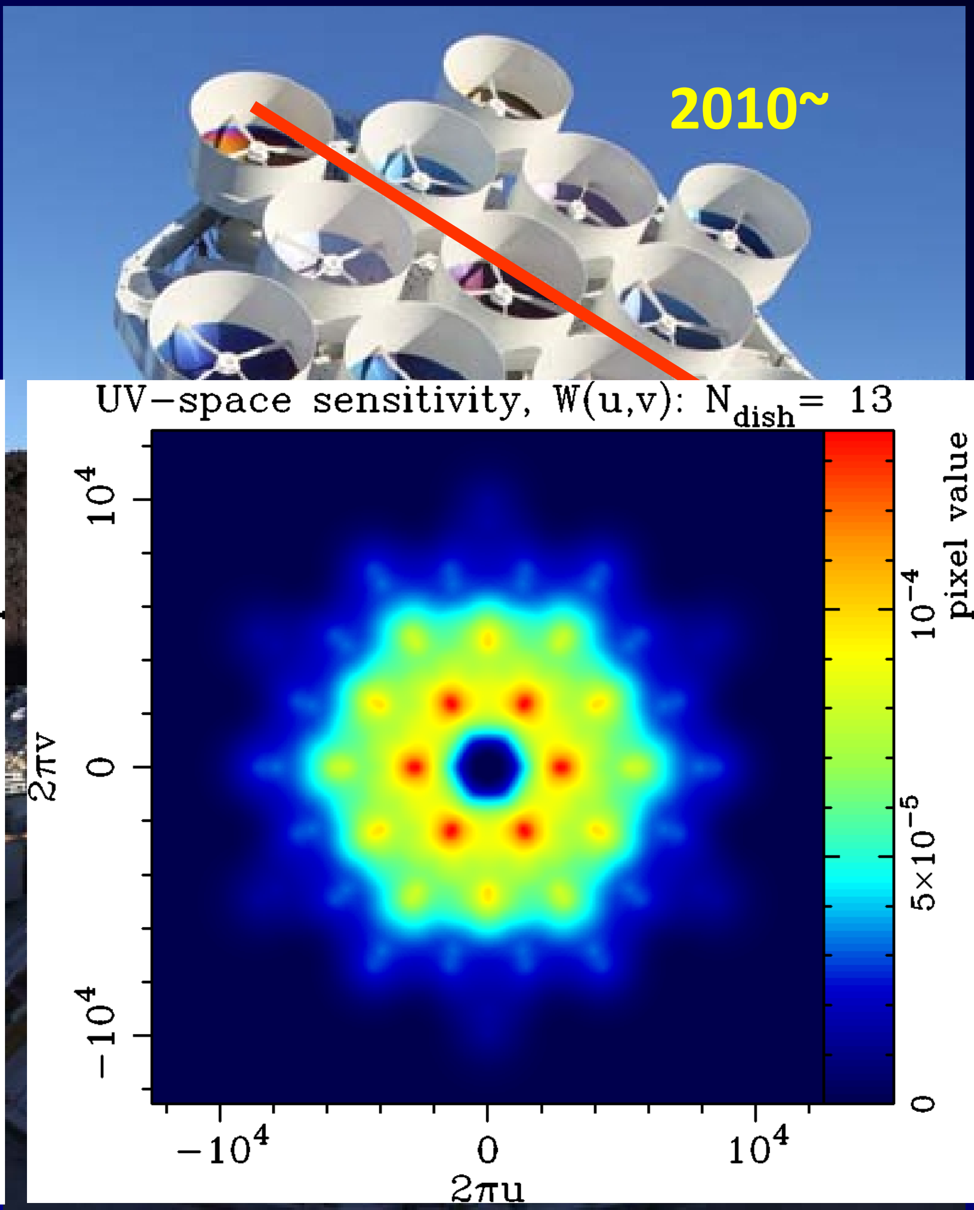
② A measure of projected thermal electron pressure

Low-frequency radio signal strength of SZE

$$y \equiv \int_0^{\lambda_{\rm LSS}} d\tau \, \frac{k_{\rm B}(T_e - T_{\rm CMB})}{m_e c^2} \approx \int \frac{k_{\rm B} T_e}{m_e c^2} \sigma_{\rm T} n_e dl \propto \int dl \, P_e$$

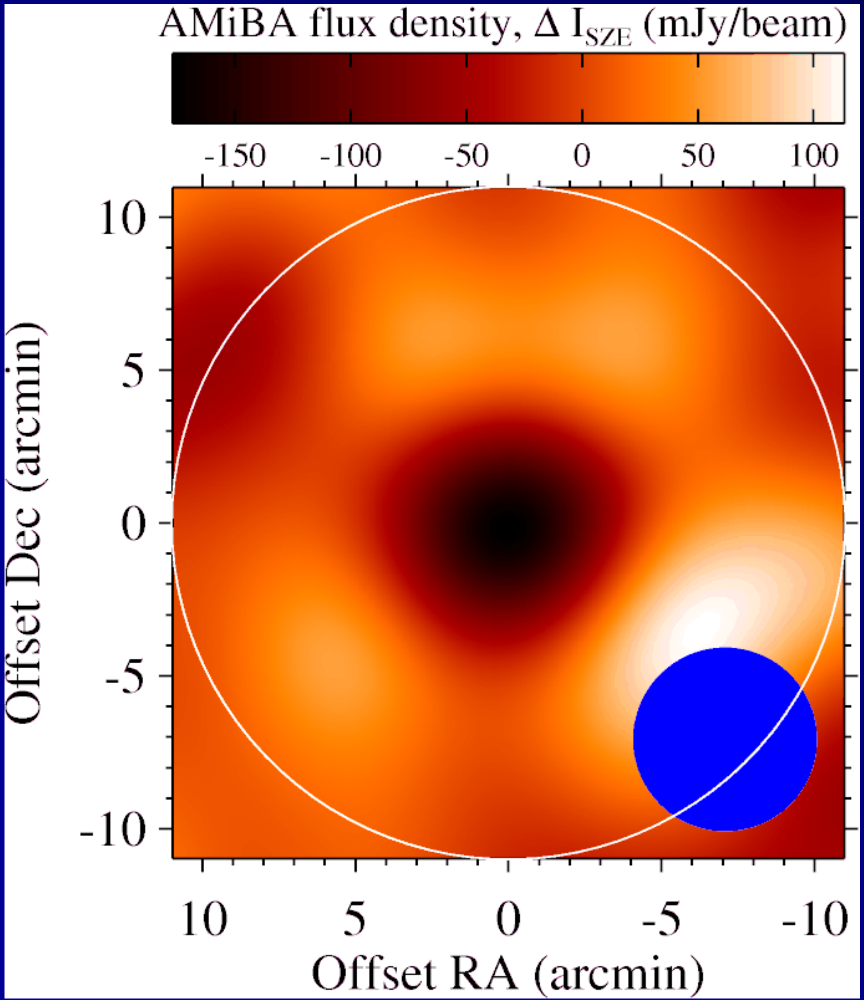
AMiBA-7 vs. AMiBA-13: Dish Configurations





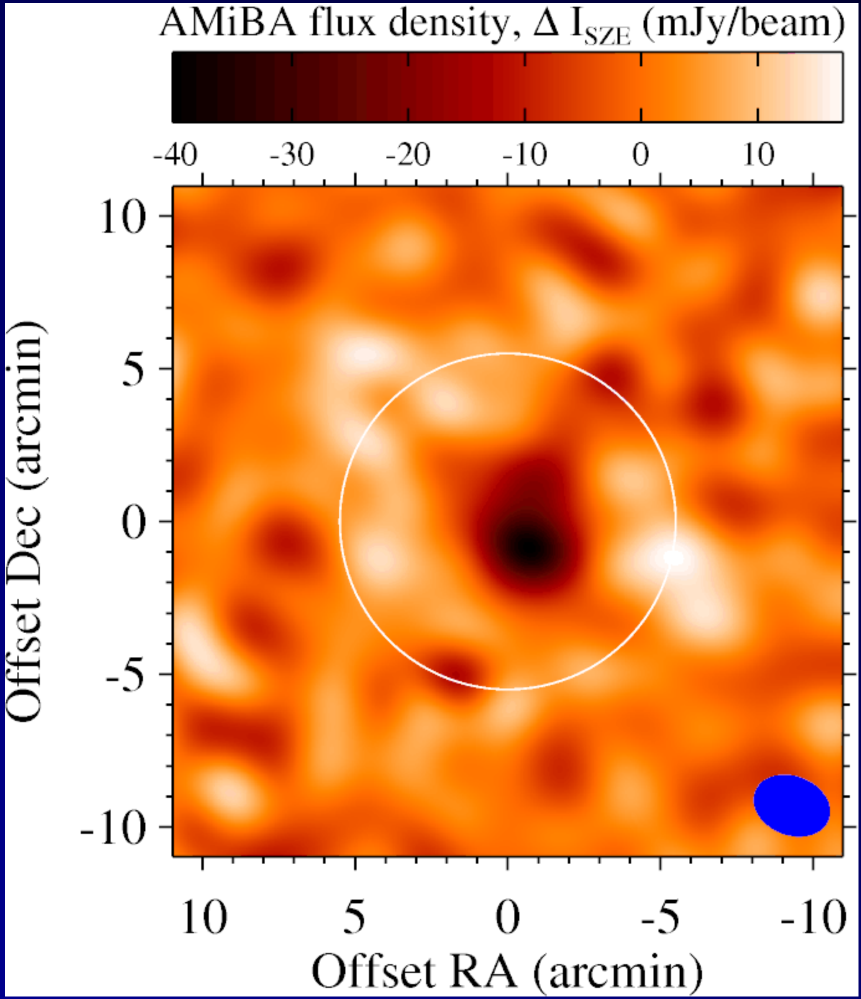
AMiBA-7 vs. AMiBA-13 Maps: A1689

60cm x 7 (6' sbFWHM)



7.1hr on-source integration (6σ)

120cm x 13 (2' sbFWHM)



3.4hr on-source integration (10σ)

First Science Results with AMiBA-7

<u>10 Papers Published as of June 2010:</u>

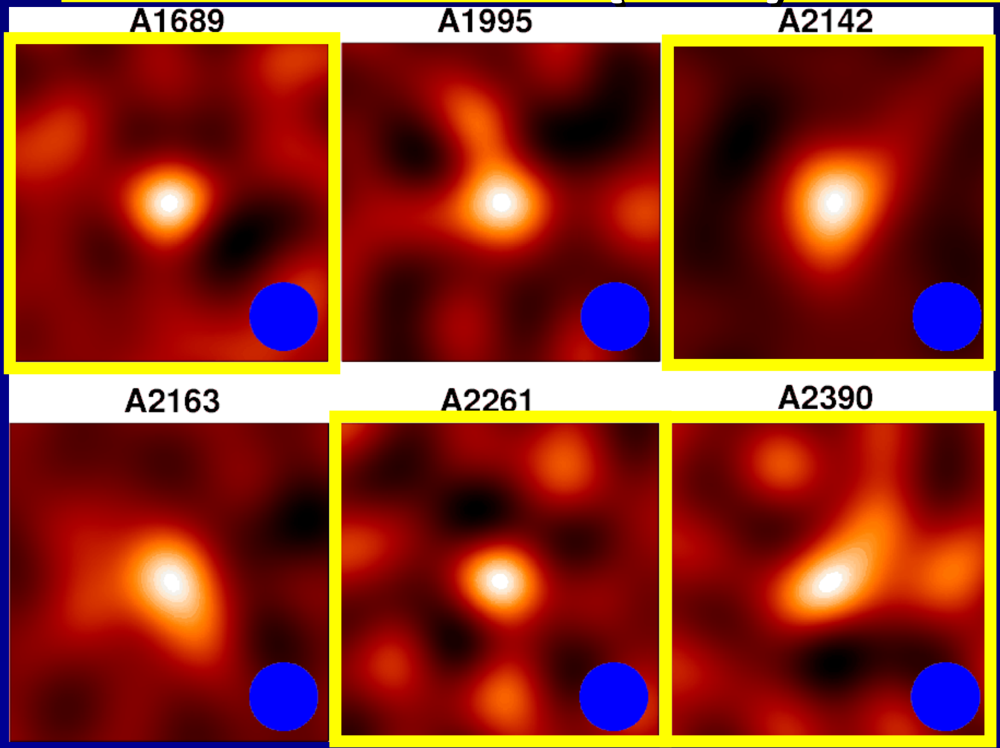
- **Design/Results:** **Ho+** 2009, ApJ, 694, 1610
- **tSZE + Analysis pipeline**: **Wu+** 2009, ApJ, 694, 1619
- **System performance**: **Lin+** 2009, ApJ, 694, 1629
- **Data integrity tests**: **Nishioka+** 2009, ApJ, 694, 1637
- **tSZE + Weak Lensing:** **Umetsu+** 2009, ApJ, 694, 1643
- **Instrumentation:** **Chen+** 2009, ApJ, 694, 1664
- **Hexapod mount:** **Koch+** 2009, ApJ, 694, 1670
- **tSZE cluster properties**: **Liao+** 2010, APJ, 713, 584
- **Wide-band correlator**: **Li+** 2010, ApJ, 716. 746
- **tSZE+X scaling relations**: **Huang+** 2010, ApJ, 716, 758

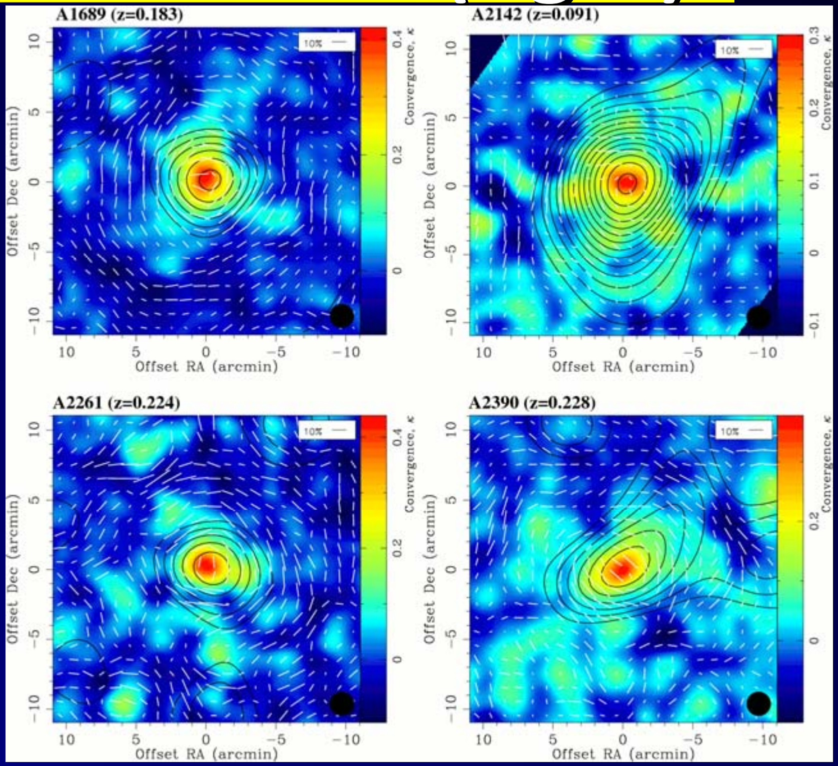
3 more papers in various stages of the review process:

Liu et al. 2010, **Koch** et al. 2010, **Molnar** et al. 2010

See P21 “AMiBA Science and Recent Upgrade” by Kai-Yang Lin (ASIAA)

Galaxy Clusters as "seen" by AMiBA tSZE (left) and Subaru WL (right)



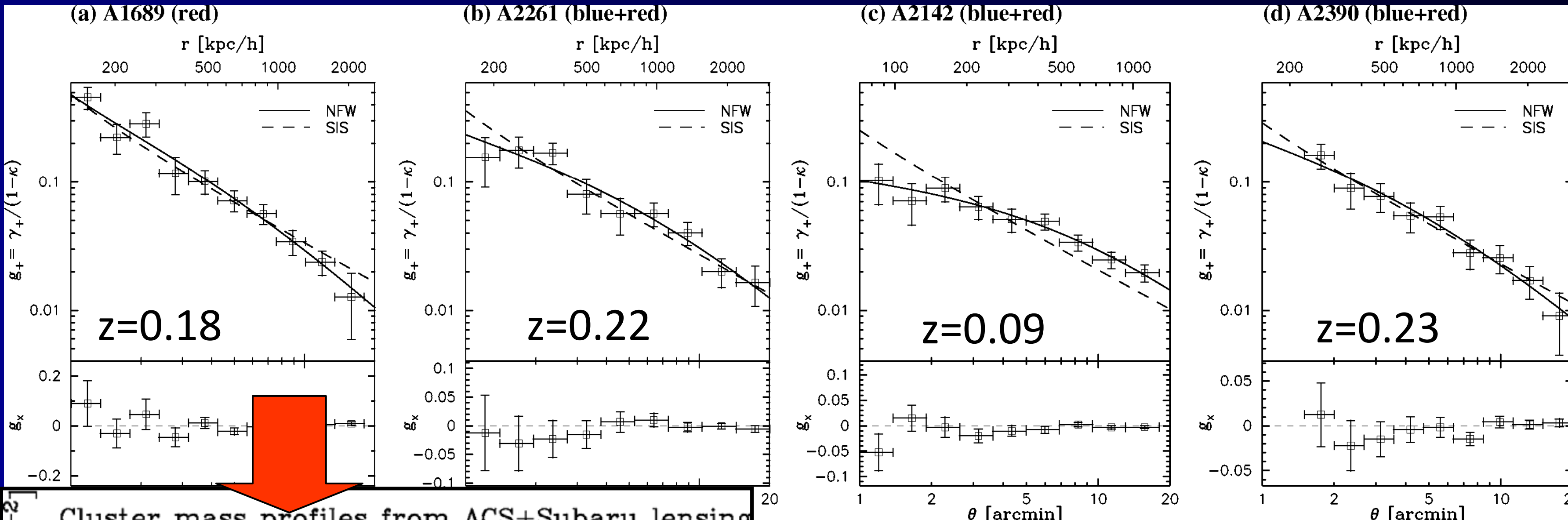


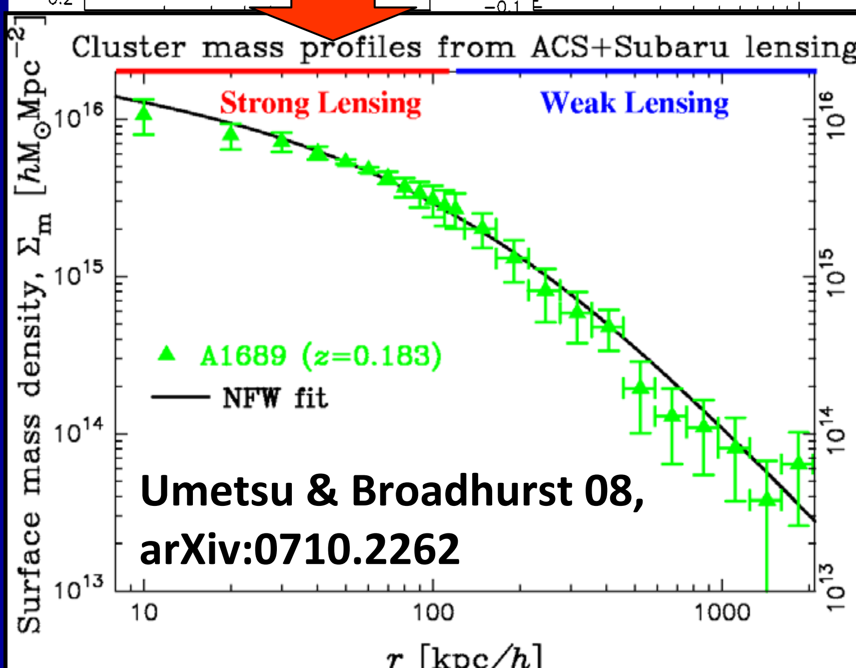
Hot baryons as imaged by AMiBA-7 (Wu+ '09): 200-600mJy tSZE decrement, 5-7% relativistic correction at 94GHz

DM structure as revealed by Subaru WL (Umetsu+ 2009)

- AMiBA tSZE@3mm maps from 6 months of early science operation ('07-'08)
- $<t_{obs}>$ = 7 nights per cluster in 2-patch differencing observations
- Uncertainty dominated by primary CMB at a mean level of ±100mJy (d_min=200λ)

Subaru Weak Lensing

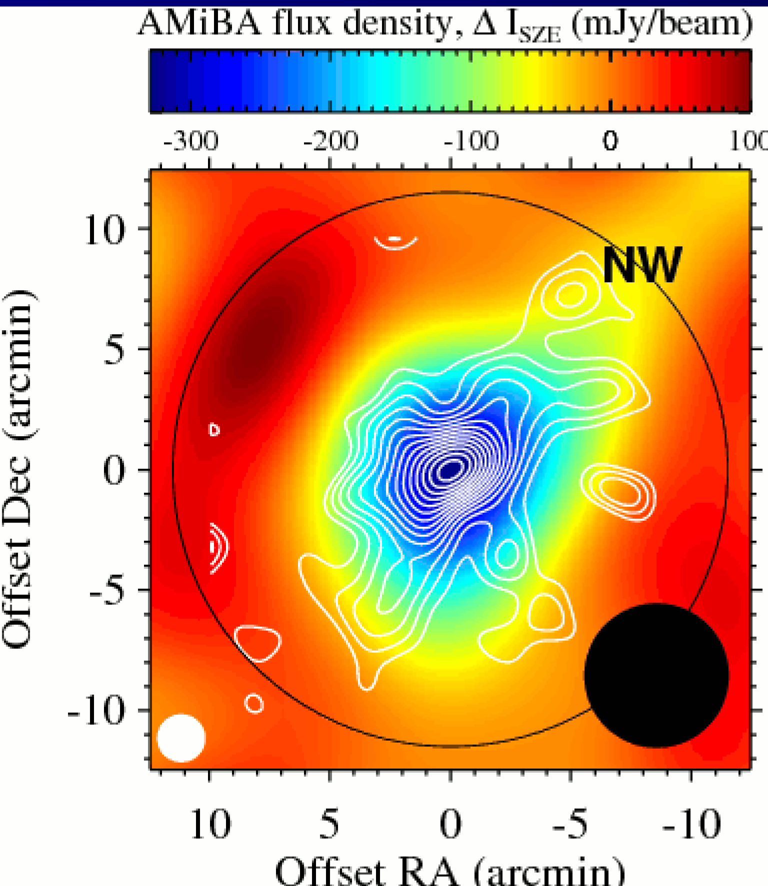




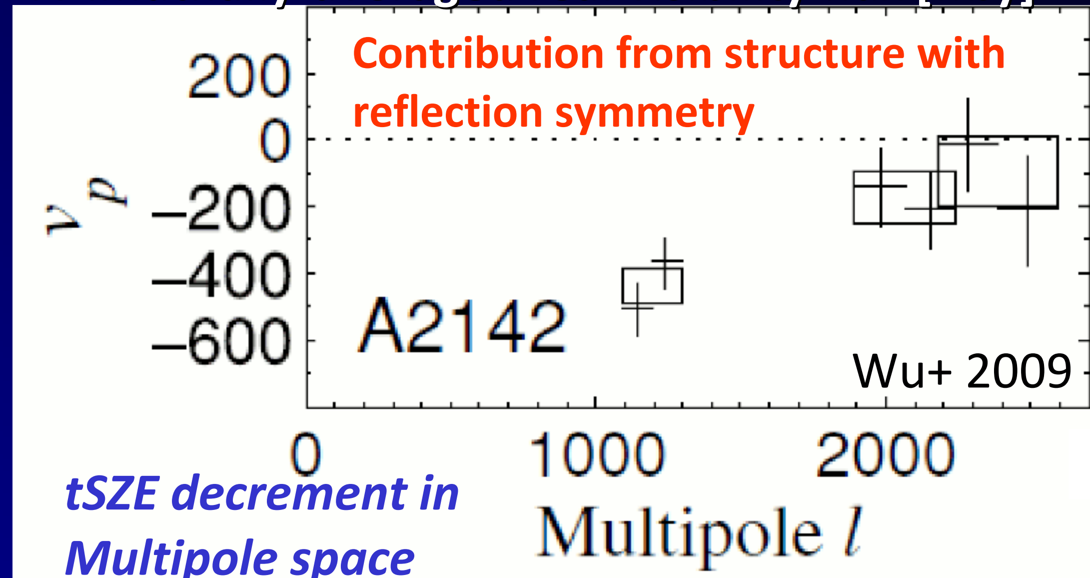
Shallow **SIS** ($d\ln\rho_{DM}/d\ln r = -2$) strongly rejected for **A2142 (WL)** and **A1689 (WL+SL)**

For all four clusters, **continuously steepening NFW** profiles are statistically favored (Umetsu et al. 2009, arXiv:0810.0969)

AMiBA-7 tSZE Example: A2142 (z=0.09)



Azimuthally-averaged real visibility flux [mJy]



Imaginary visibility flux due to primary CMB etc.

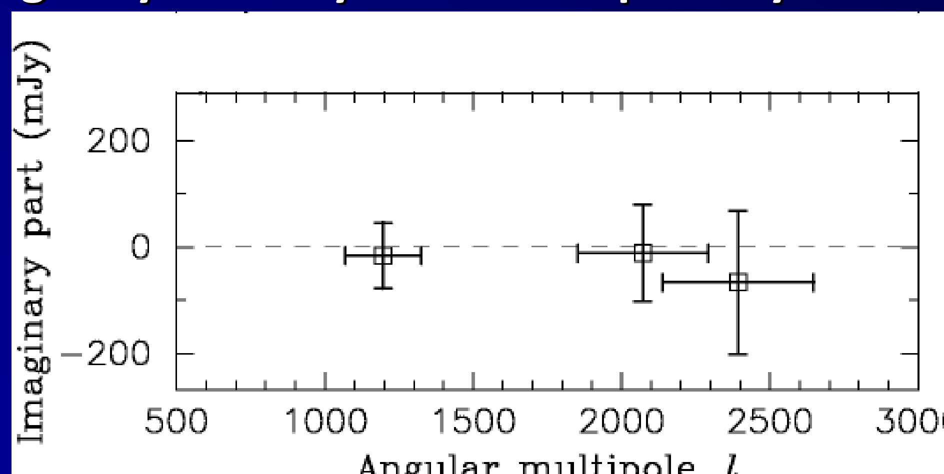


Figure from Ho et al. 2010

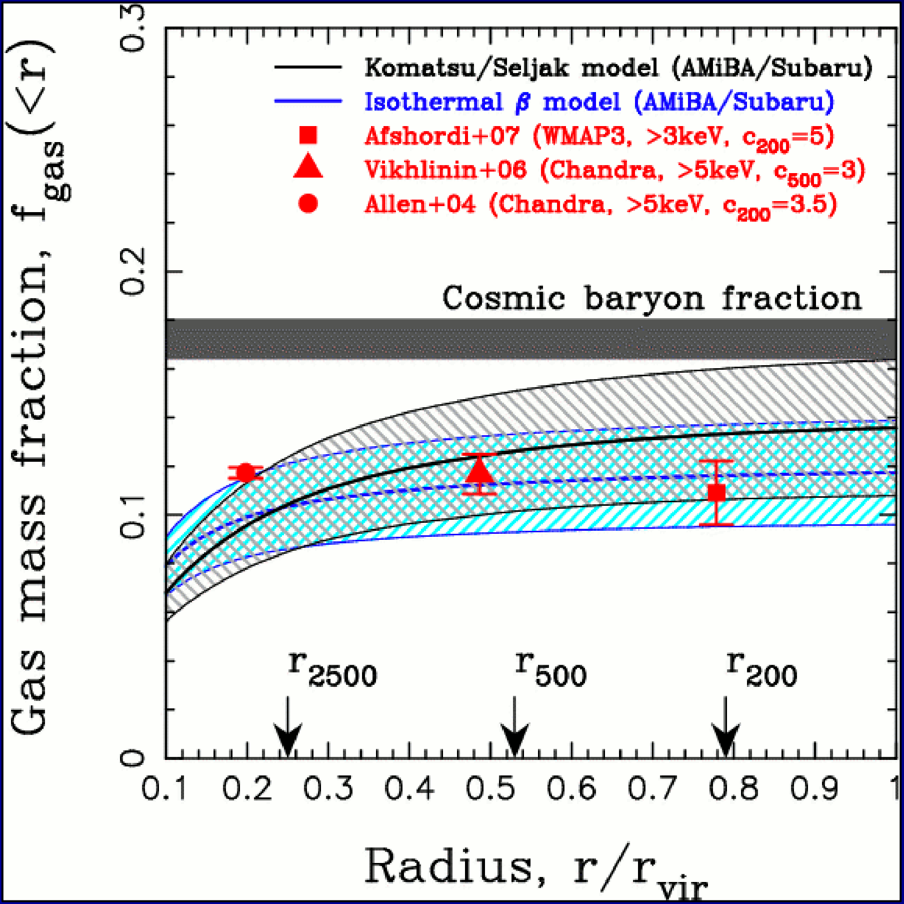
Color image: tSZE map (Wu+2009)

Contours: WL κ map
(Okabe & Umetsu 2008, Umetsu+2009)

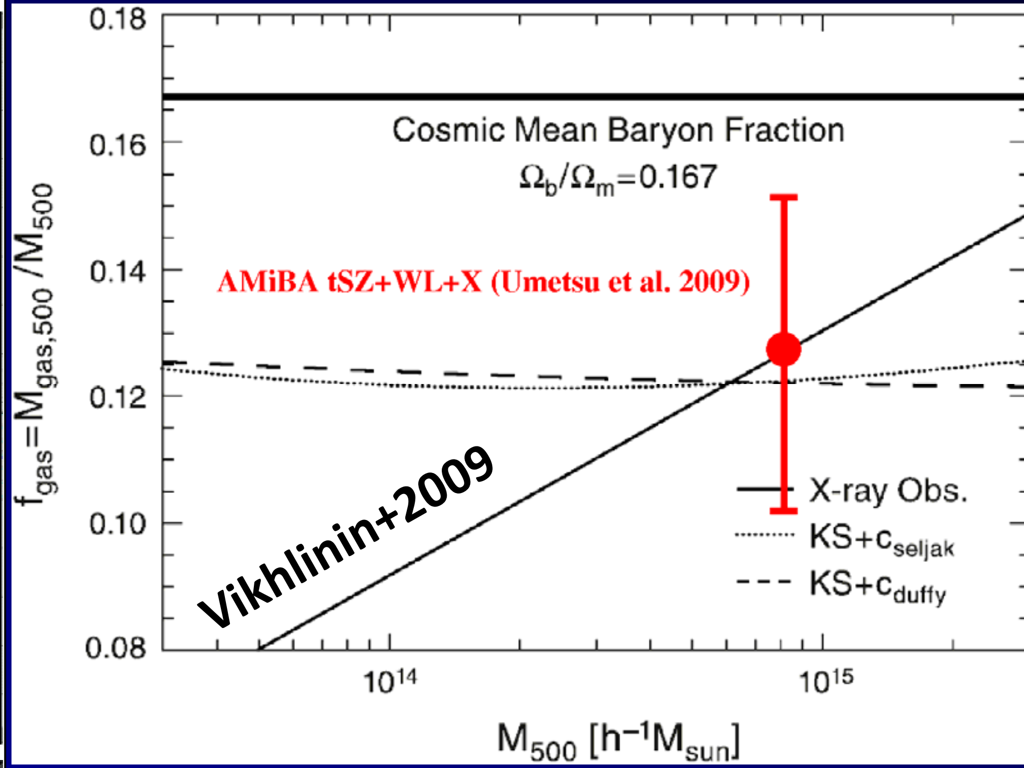
Baryon Fractions in High-Mass Clusters

Large-scale f_{gas} constraints (~$0.8r_{vir}$, <z>=0.2) from tSZE+WL+X, independent of dynamical state and level of hydrostatic equilibrium

AMiBA-7 tSZE + WL + X-ray



WMAP7 tSZE and X-ray constraints



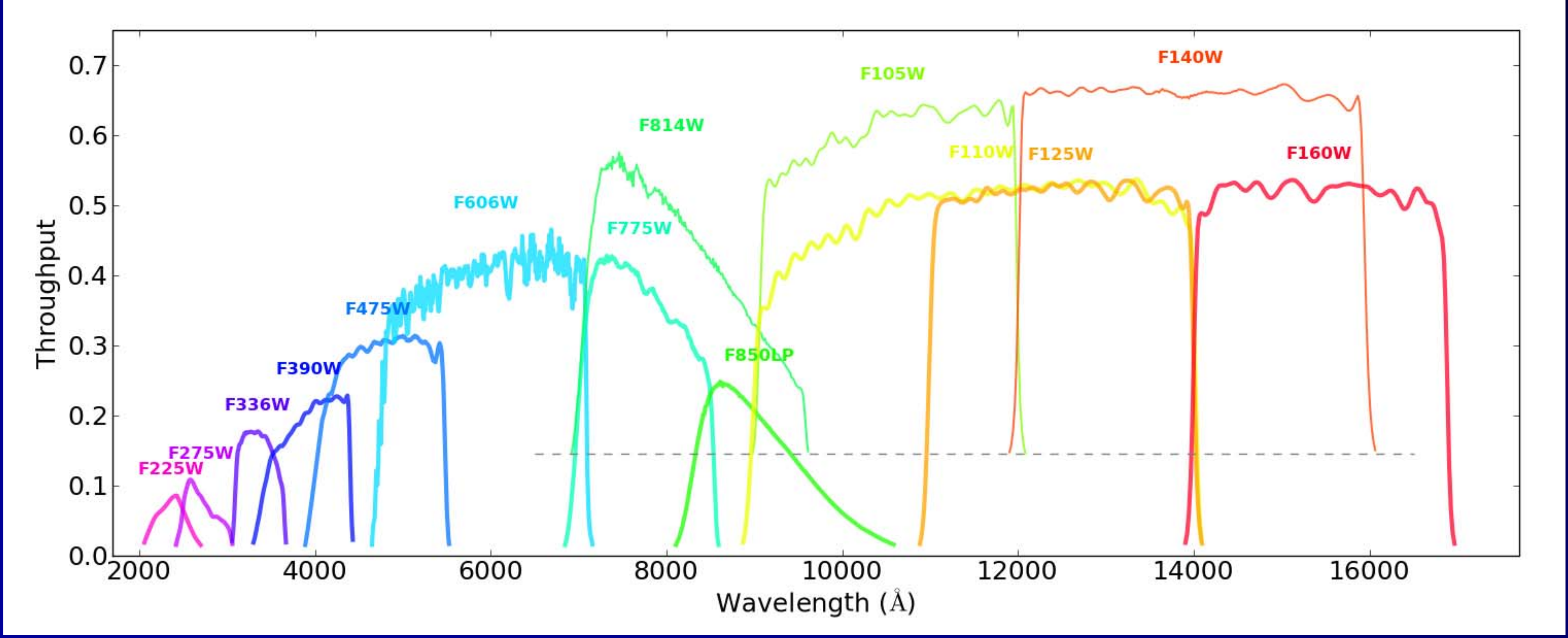
Komatsu et al. 2010, WMAP-7yr

Umetsu, Birkinshaw, Liu et al. 2009, ApJ (arXiv:0810.969)

3. Cluster Lensing And Supernova survey with Hubble: CLASH

A 524-orbit HST MCT Program (HST Cycles 18-20 over the next 3 years)

PI: Marc Postman (STScI)



http://www.stsci.edu/~postman/CLASH/

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Rychard Bouwens	Leiden University
Larry Bradley	STScI
Thomas Broadhurst	Tel Aviv University (TAU) / IAA
Dan Coe	Jet Propulsion Laboratory (JPL) / Caltech
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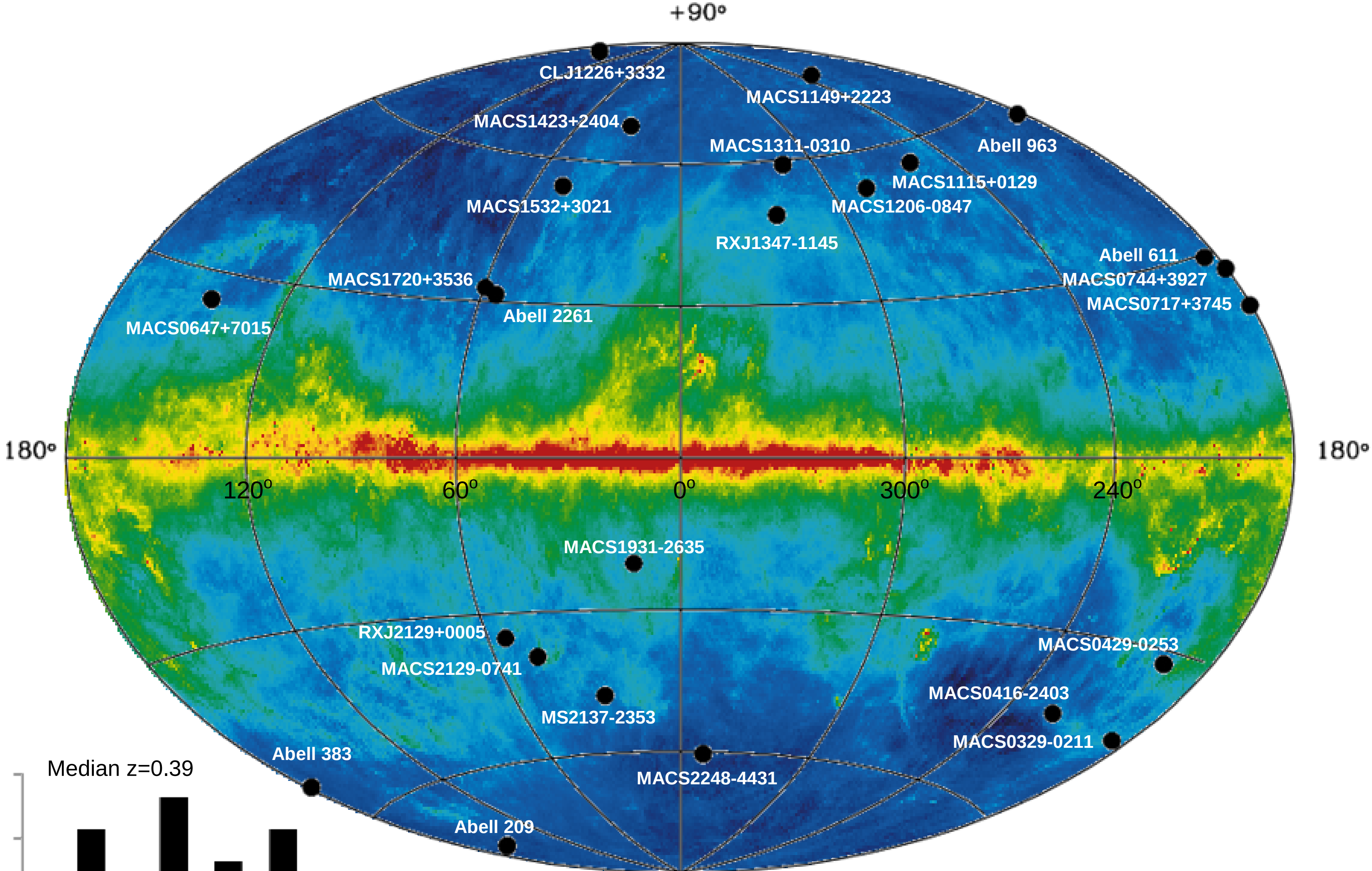
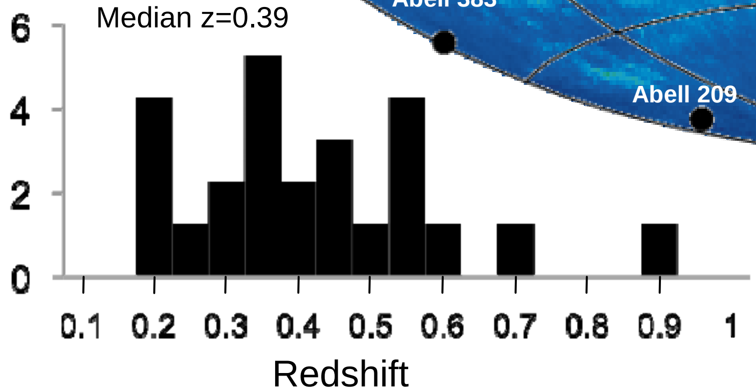




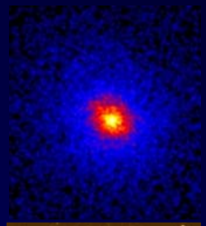
CLASH CLUSTER SAMPLE
(Galactic Coordinates)

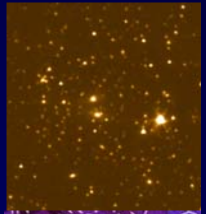
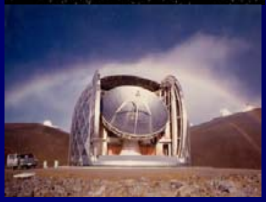
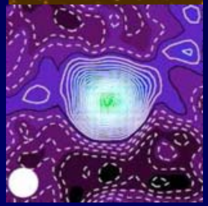
Background: Schlegel et al. Galactic Extinction Map

Multiple Facilities Will be Used

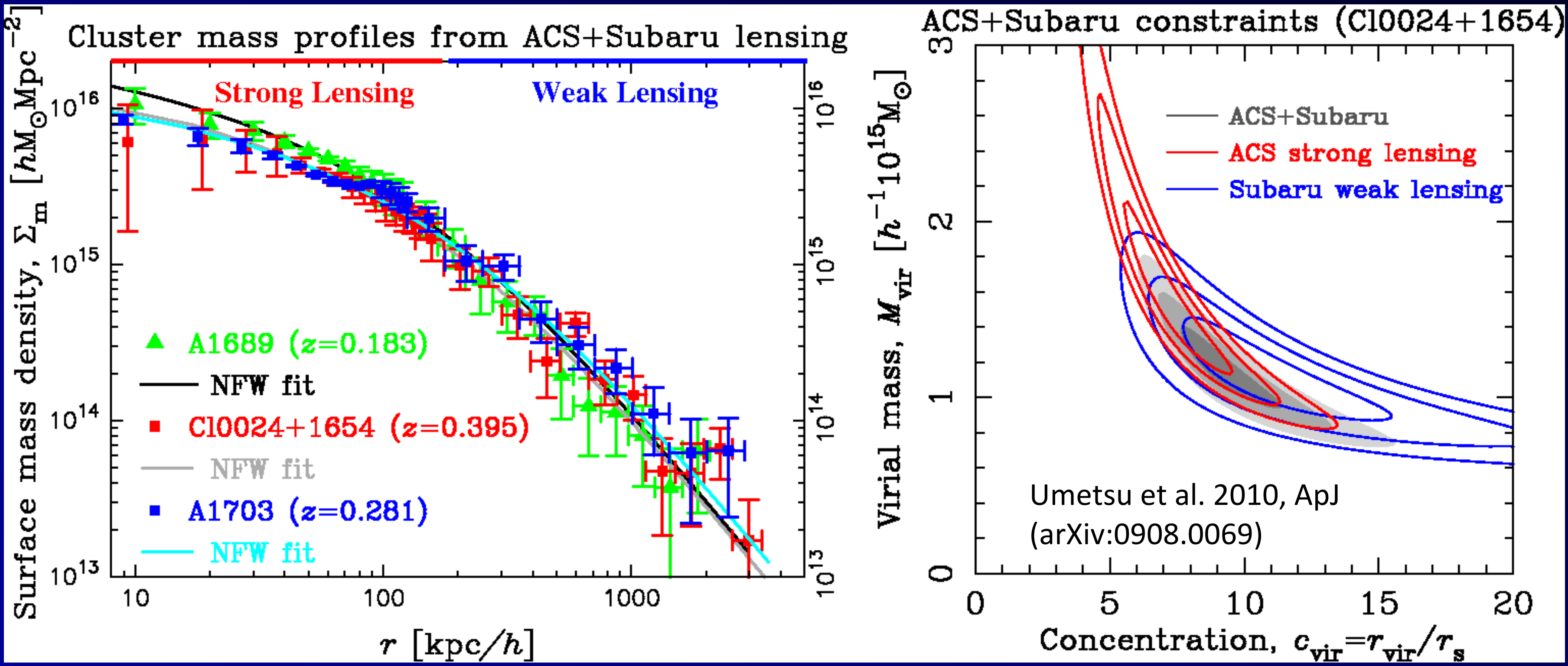
- HST 524 orbits: 25 clusters, each imaged in 14 passbands with ACS/WFC3 (0.23 – 1.6 μm)
- Chandra X-ray Observatory archival data and possibly new data. (0.5-2keV)
- Spitzer IR Space Telescope archival data (3.6, 4.5 μm)
- tSZE observations proposed to augment existing data (Bolocam@150GHz, AMiBA@94GHz)
- Subaru wide-field imaging (0.4 – 0.9 μm)
- GTC, VLT, and Magellan Spectroscopy



Both Strong & Weak Lensing Measurements Needed for Good Constraints



Umetsu+2010b, in prep (Full weak-lensing constraints from distortion + magnification MCMC analysis for 5 massive clusters)

Broadhurst, Takada, Umetsu+2005; Umetsu & Broadhurst 2008 (A1689); Zitrin, Broadhurst, Umetsu+ arXiv.1004.4660: (A1703); Umetsu+ 2010a (Cl0024+1654)

CLASH data will allow us to definitively derive the representative mass profile shapes and robustly measure the cluster DM concentrations and their dispersion as a function of cluster mass *and their evolution with redshift.*