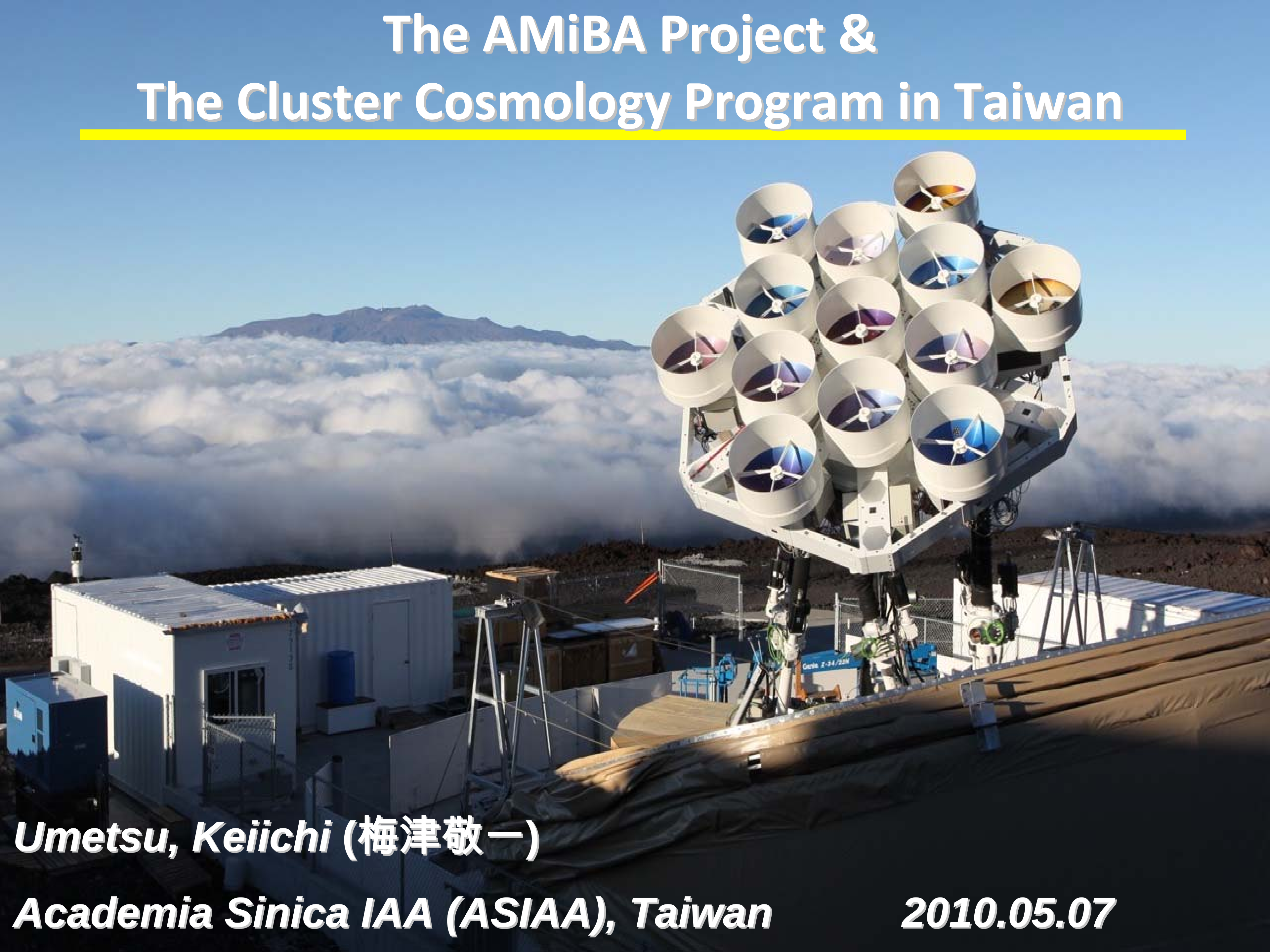
The AMiBA Project & The Cluster Cosmology Program in Taiwan



Umetsu, Keiichi (梅津敬一)

Academia Sinica IAA (ASIAA), Taiwan ***2010.05.07***

Topics of this talk (as requested by 服部さん)

1) **Thermal Sunyaev-Zel'dovich Effect (tSZE) Sciences and Results with AMiBA**

2) **Science Activities of the Observational Cosmology Group at ASIAA, Taiwan**
    - **Cluster Work Highlights**:
        - Joint *Suzaku* X-ray, *Subaru* weak lensing, and *HST* strong lensing analysis of A1689
    - **Upcoming lensing+ program**:
        - 524-orbit Hubble Multi-Cycle Treasury program "Cluster Lensing And Supernova survey with Hubble (CLASH)" (PI: Marc Postman)

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

1. ASIAA Galaxy-Cluster Program: Scientific Motivation

Massive Galaxy clusters as sensitive cosmological probes:

1) **Equilibrium dark matter (DM) mass profile shapes:**

“How the shape of a cluster’s DM potential depends on cluster mass and redshfit?”

2) **DM and Baryons:**

“How the baryons distribute within the gravitational potential wells of clusters?”

3) **DM and Dark Energy (DE):**

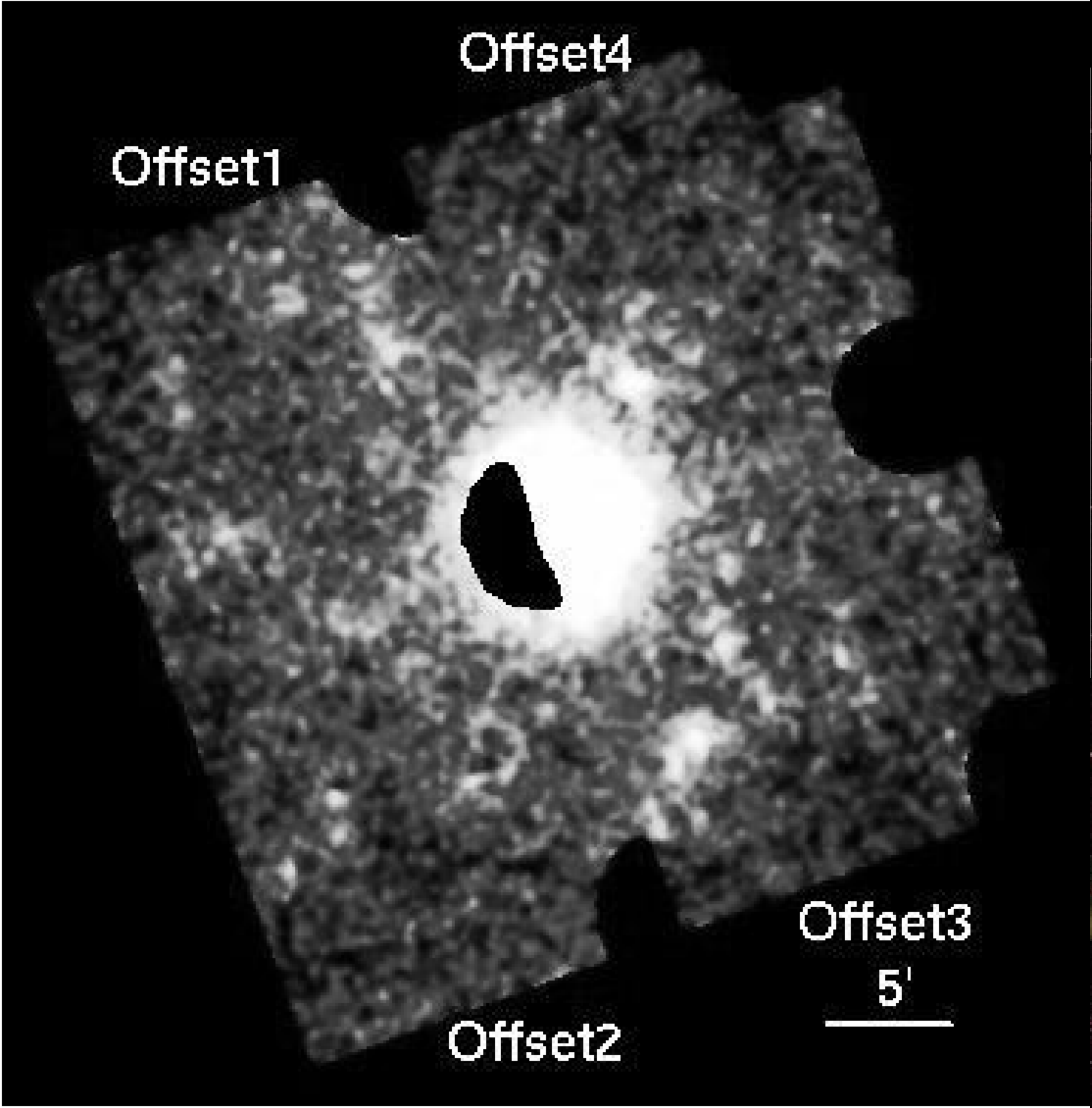
“How the number of clusters of a given mass should increase with time? How its growth rate depends on the background cosmology?”

Compare complementary cluster observations with testable predictions of models of structure formation

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

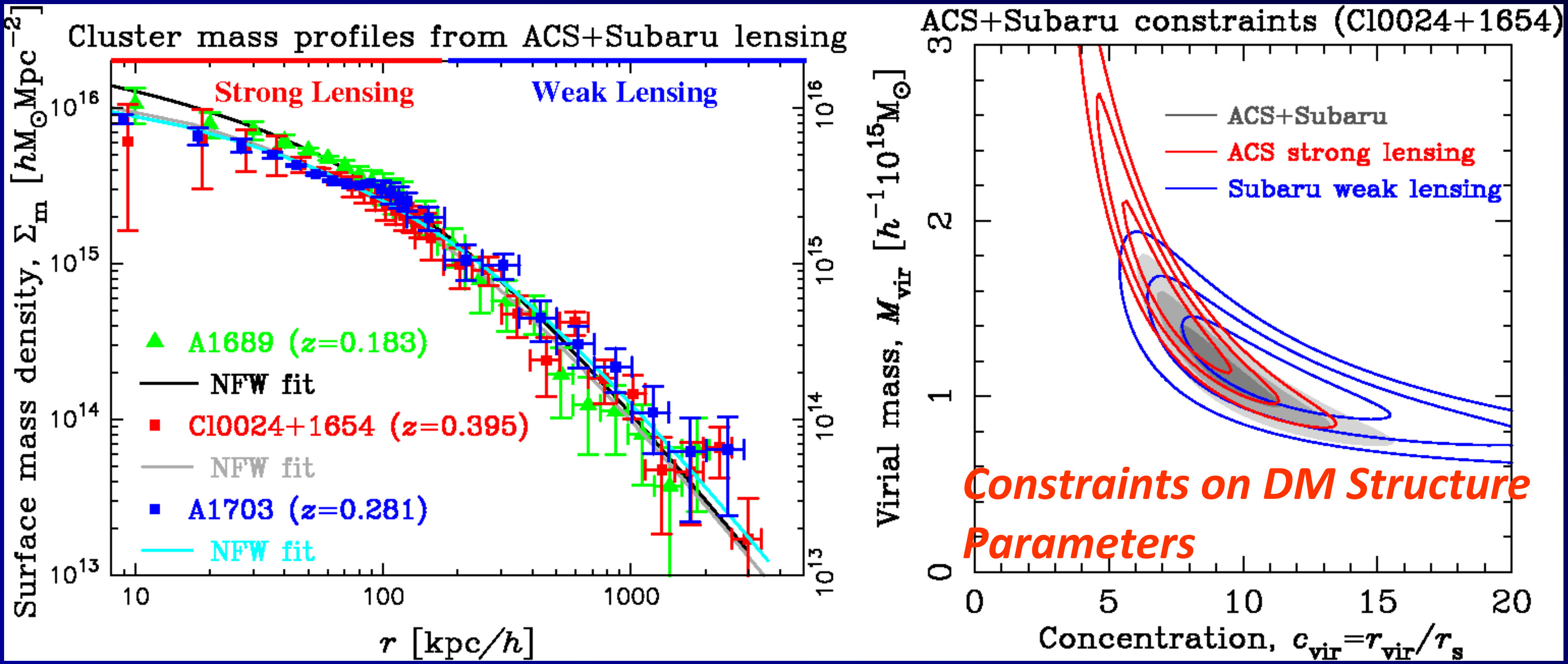


ASIAA’s Key Cosmology Program

Combining Weak (Subaru) and Strong (HST/ACS) lensing data

→ Probing full cluster mass profiles from 10kpc/h to 3000kpc/h

Results for Abell 1689 (z=0.183), CL0024+1654 (z=0.395), A1703 (z=0.281)



Constraints on DM Structure Parameters

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)

李遠哲 宇宙背景輻射 陣列望遠鏡

2. The Yuan-Tseh Lee

Array for **Mi**crowave **B**ackground **A**nisotropy (**AMiBA**)

The AMiBA Project (since 2000)

PI: Paul T.P. Ho (ASIAA)
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)

AMiBA Prototype Testing / Site Development / Commissioning (2002-2006)


April 2004


June 2004

October 2004


November 2004

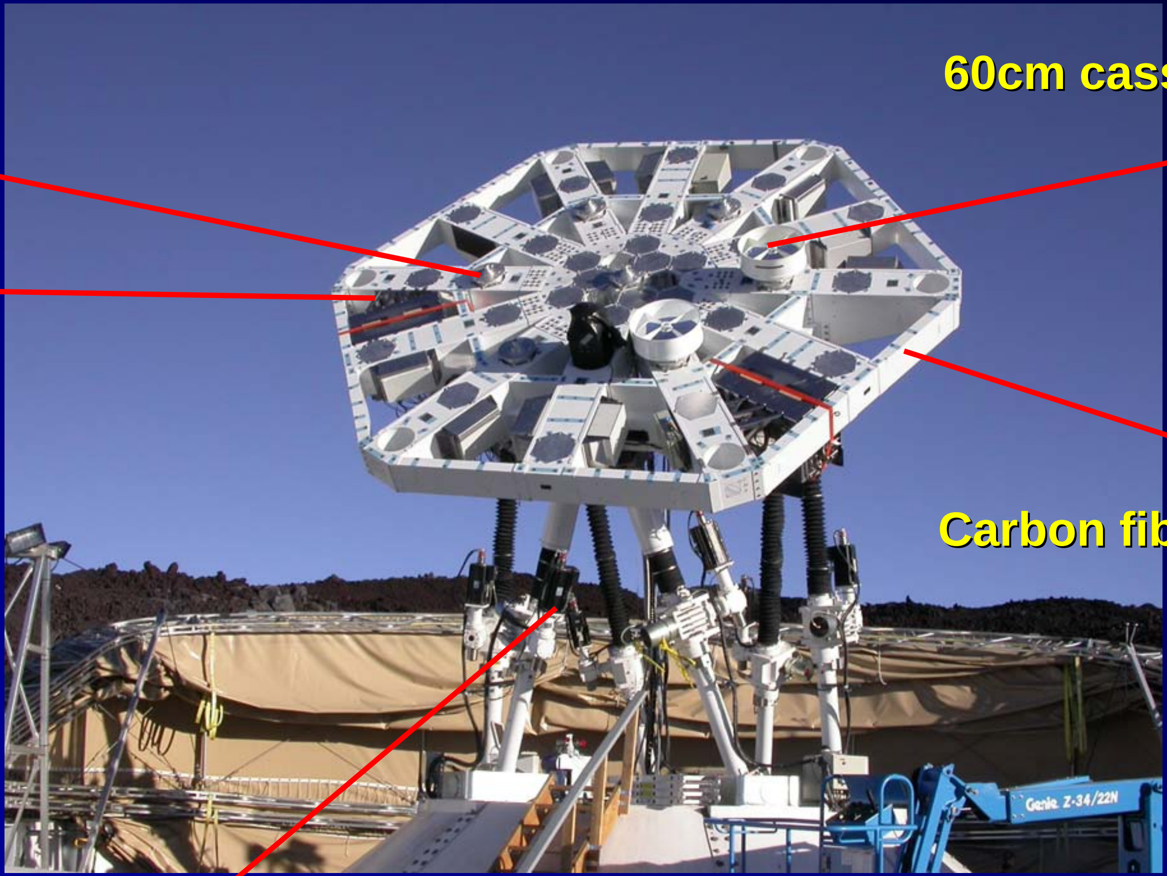

February 2005


August 2005

AMiBA Dedication: October 3, 2006

AMiBA – The Largest Hexapod Telescope

http://amiba.asiaa.sinica.edu.tw



Receiver

HEMT, 94GHz

60cm cassegrain antenna

Correlator box

Carbon fiber platform (6m)

Hexapod jack

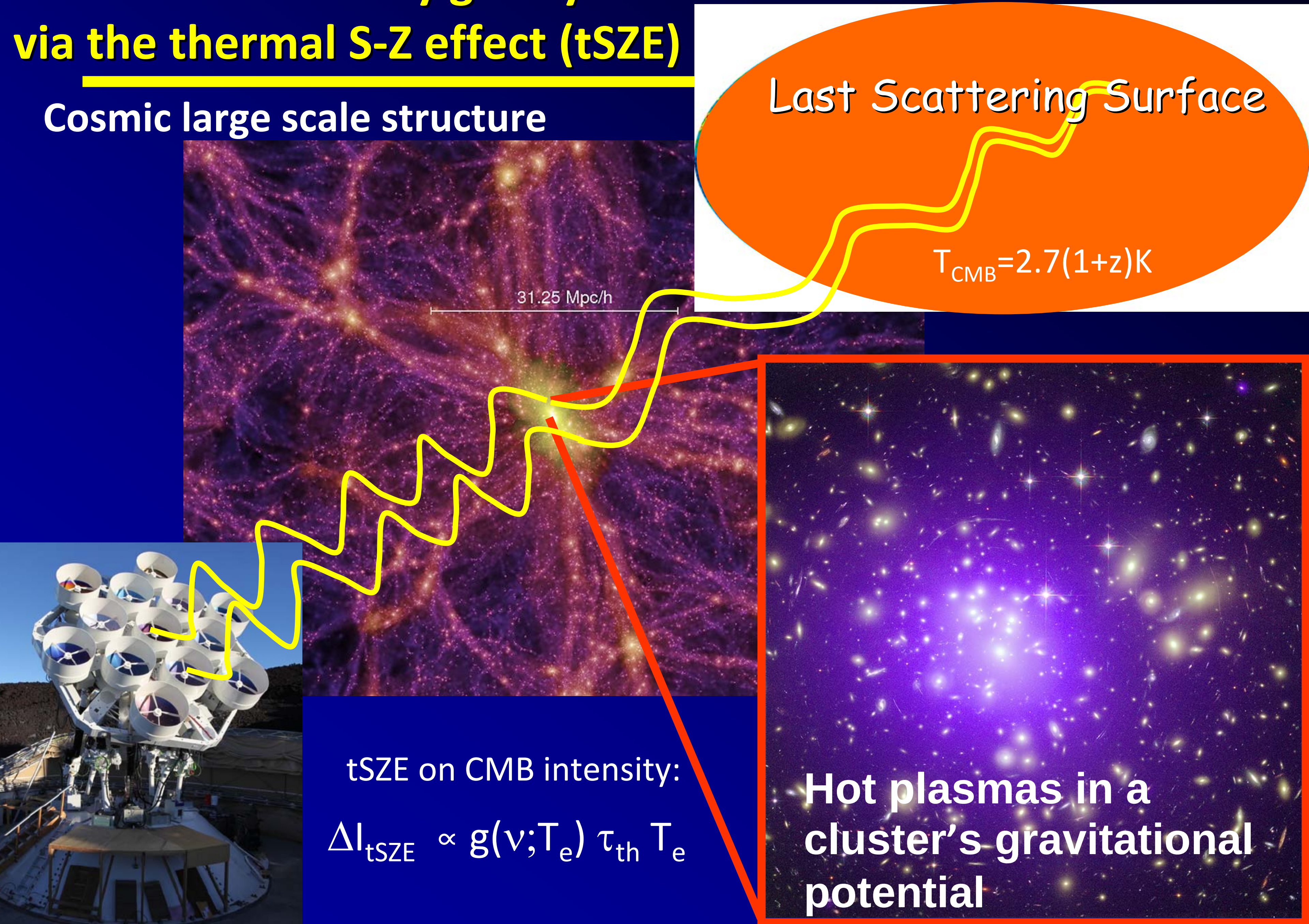
0<Azimuth<360deg, Elevation > 30deg

Polarization: +/-30deg

AMiBA Focus: Study galaxy clusters via the thermal S-Z effect (tSZE)

宇宙微波背景輻射 (CMBR)

Cosmic large scale structure

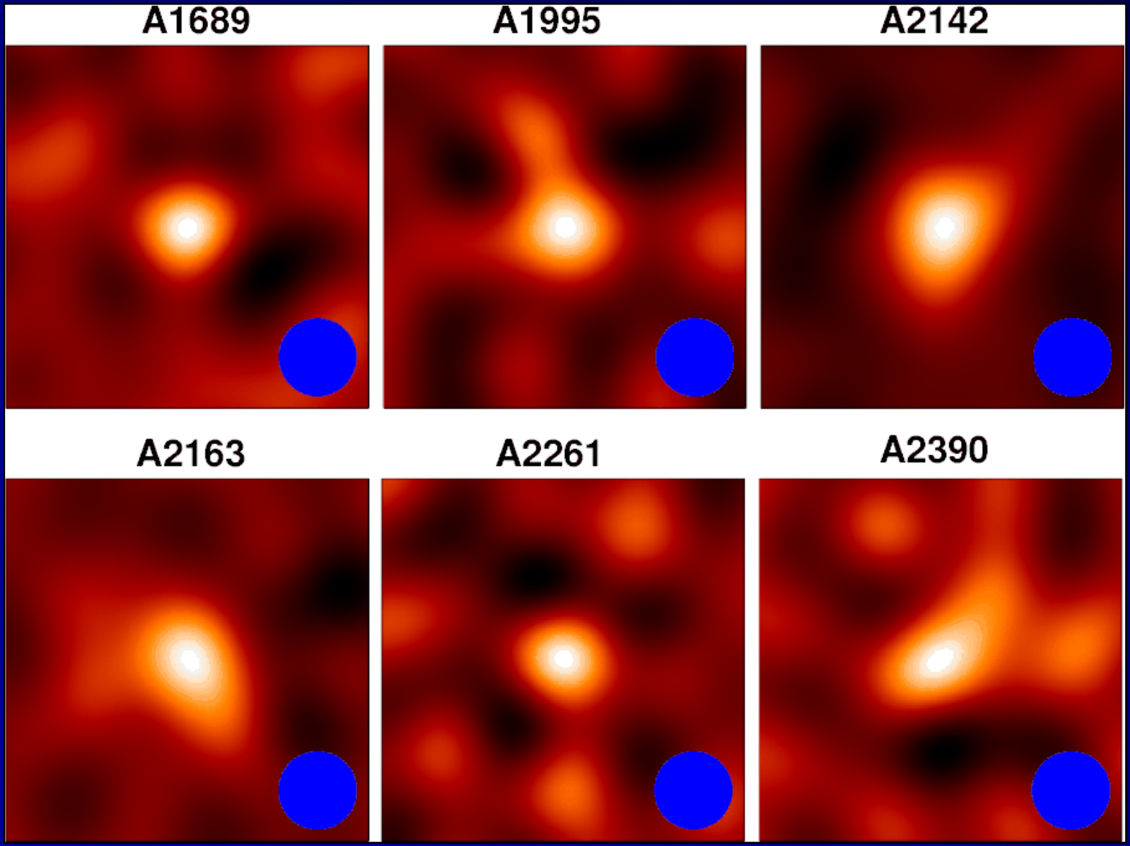


tSZE on CMB intensity:

$$\Delta I_{tSZE} \propto g(\nu;T_e)\,\tau_{th}\,T_e$$

Hot plasmas in a cluster’s gravitational potential

Power of tSZE



SZE brightness independent of distance (z),

Free from cosmological brightness dimming,

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

AMiBA-7 3mm tSZE images of 6 clusters at z=0.1-0.3 (Wu et al. 2009)

Low-freq radio signal strength of SZE

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

What we seek for is a 10-100 μK weak signal!!

Why 94GHz (3mm)?
Minimized Foreground Emission

Typical SEDs of Galaxies – most radio point sources have negative spectral index

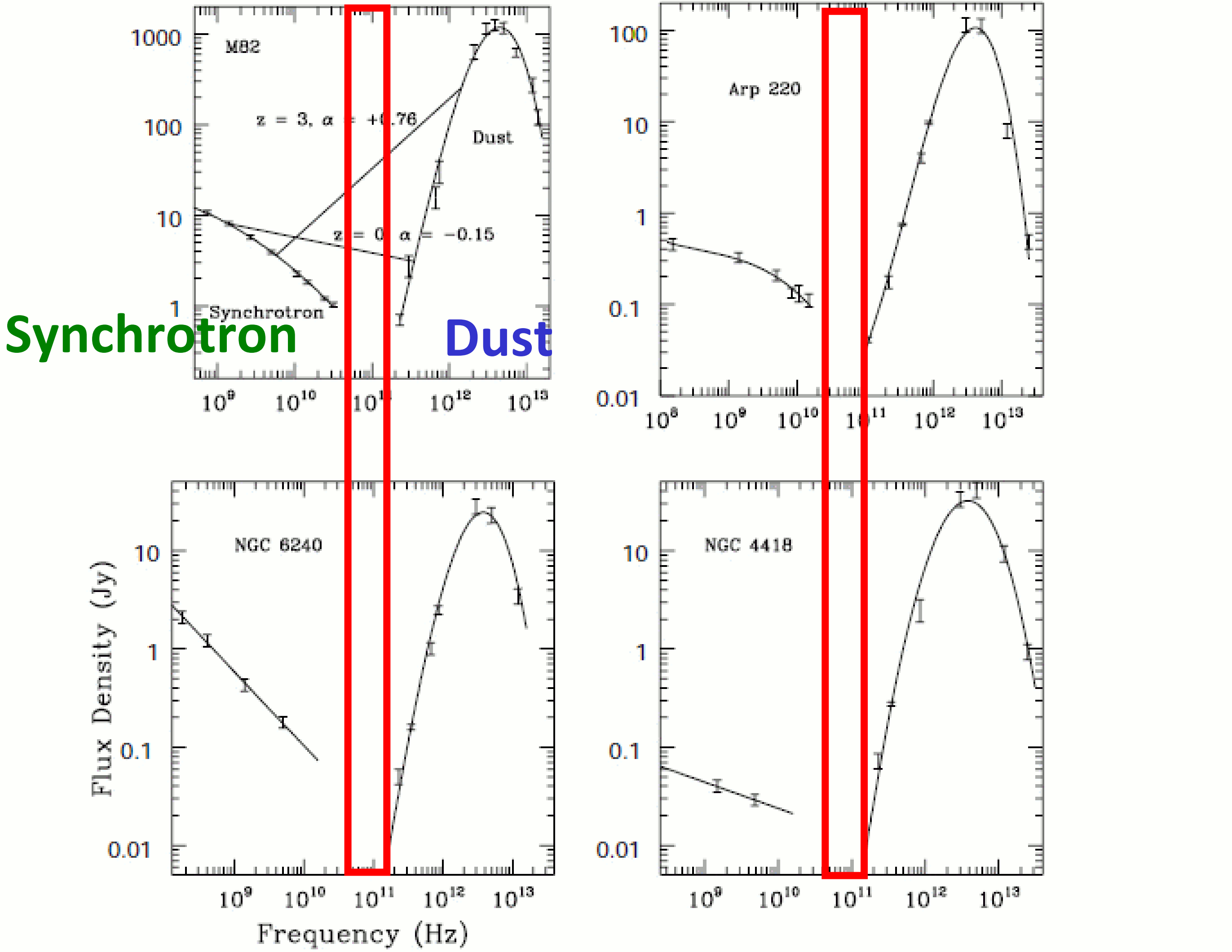


Fig. 1.—Data points show the radio through infrared spectral energy distributions of four representative galaxies from our sample of 17 listed in Table 1. The data are obtained from NED (*IRAS* data points), the NRAO VLA Sky Survey (Condon et al. 1998), the Westerbork Northern Sky Survey (Rengelink et al. 1997), and from Rigopoulou et al. (1996), Benford (1999), and Lisenfeld et al. (1999). The solid curves show polynimial fits to the data. For the M82 spectrum, the straight lines indicate the spectral index that would be derived for the source at $z = 0$ and $z = 3$ between observing frequencies of 1.4 and 350 GHz.

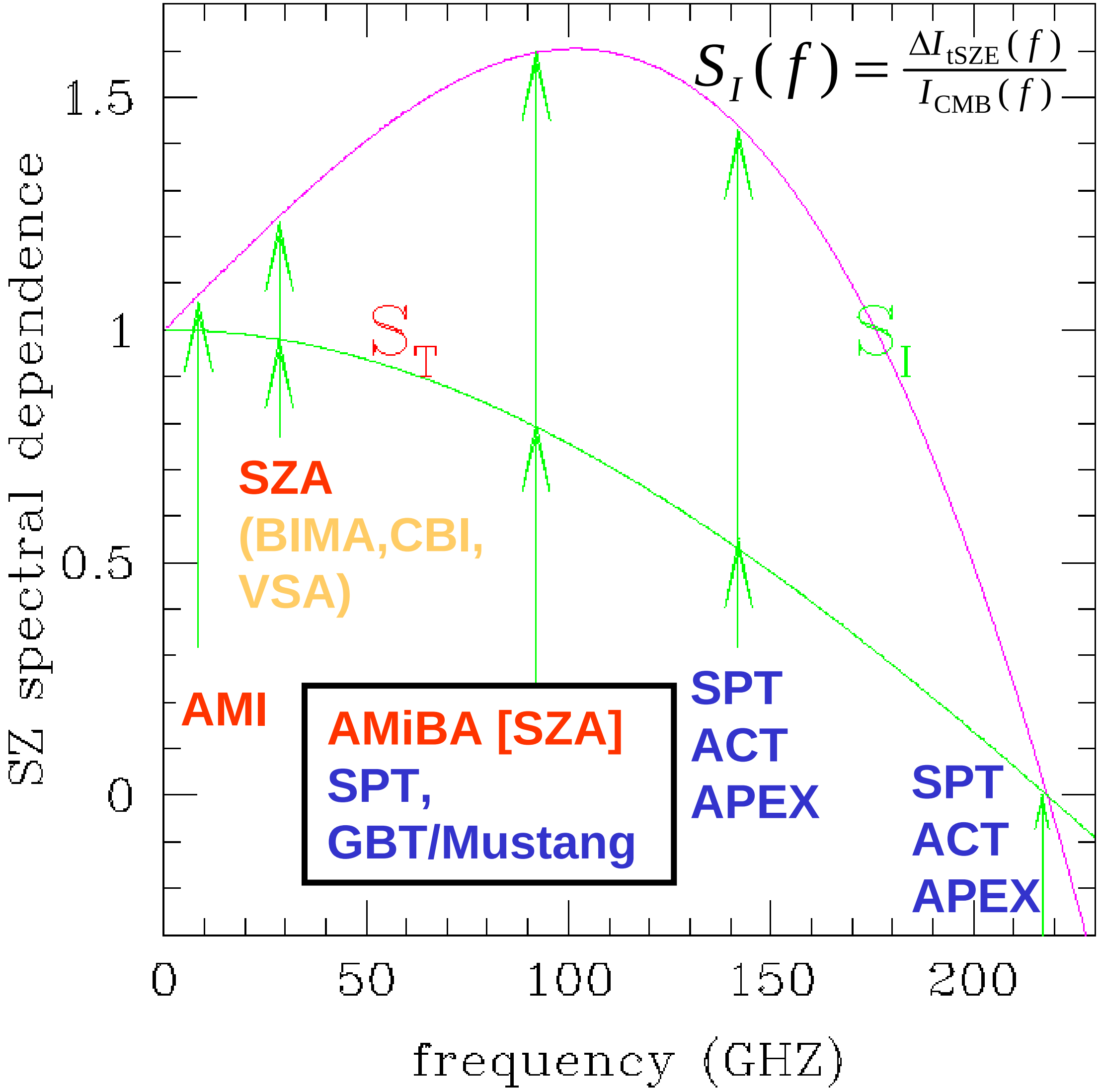
Other CMB interferometers:

CBI (@30GHz)

AMI (@15GHz)

SZA (@30/90GHz)

Niche of AMiBA



Red: Interferometer

Blue: Multi-pixel bolometer

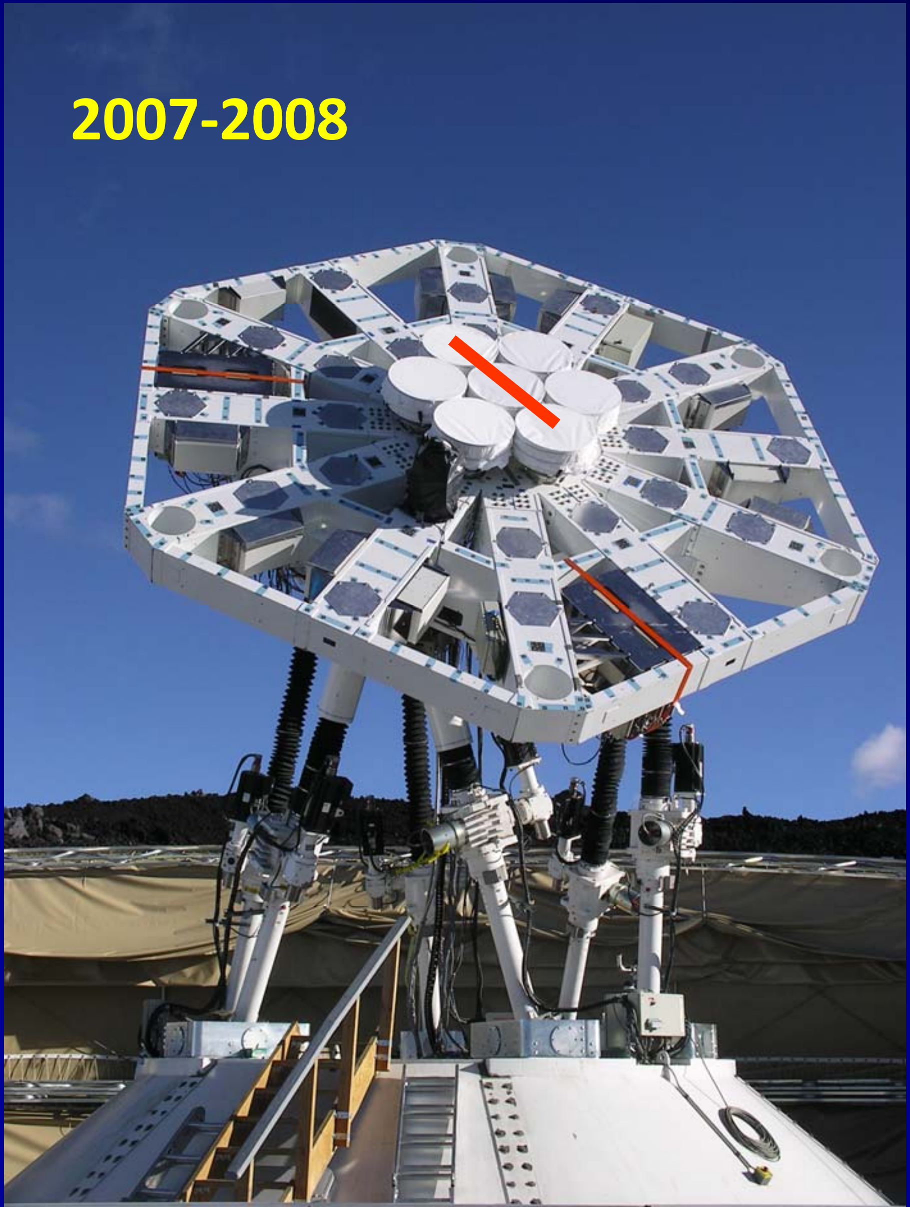
– Relative SZE strength w.r.t. **primary CMB** and **foreground emission** is maximized at 90-100GHz.

– AMiBA is one of few leading SZE instruments that operate on the arcmin-scale at 90GHz.

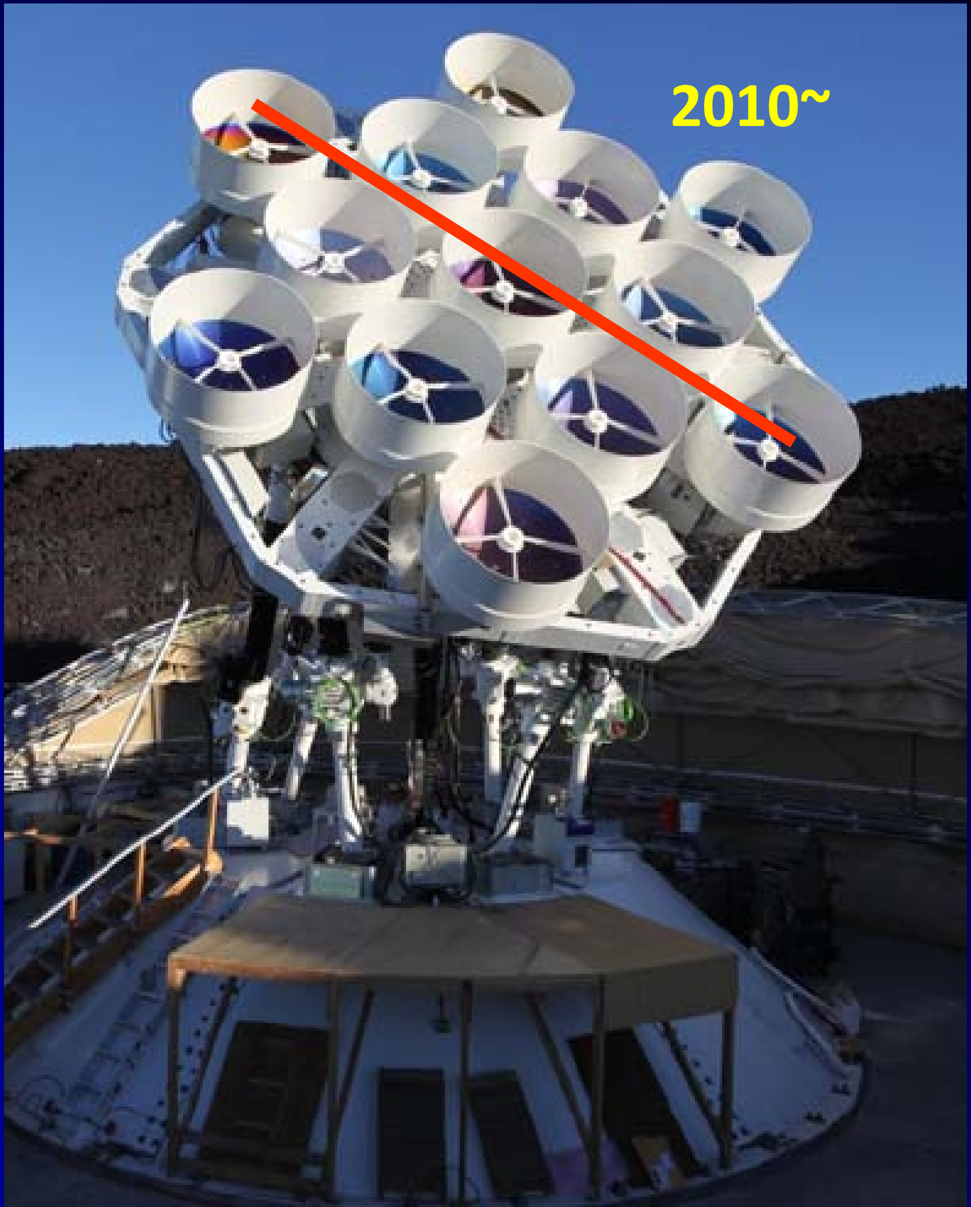
– AMiBA in the northern hemisphere serves as a unique SZE instrument for multi-wavelength cluster SZE studies.

Figure from Zhang+02

AMiBA-7 vs. AMiBA-13

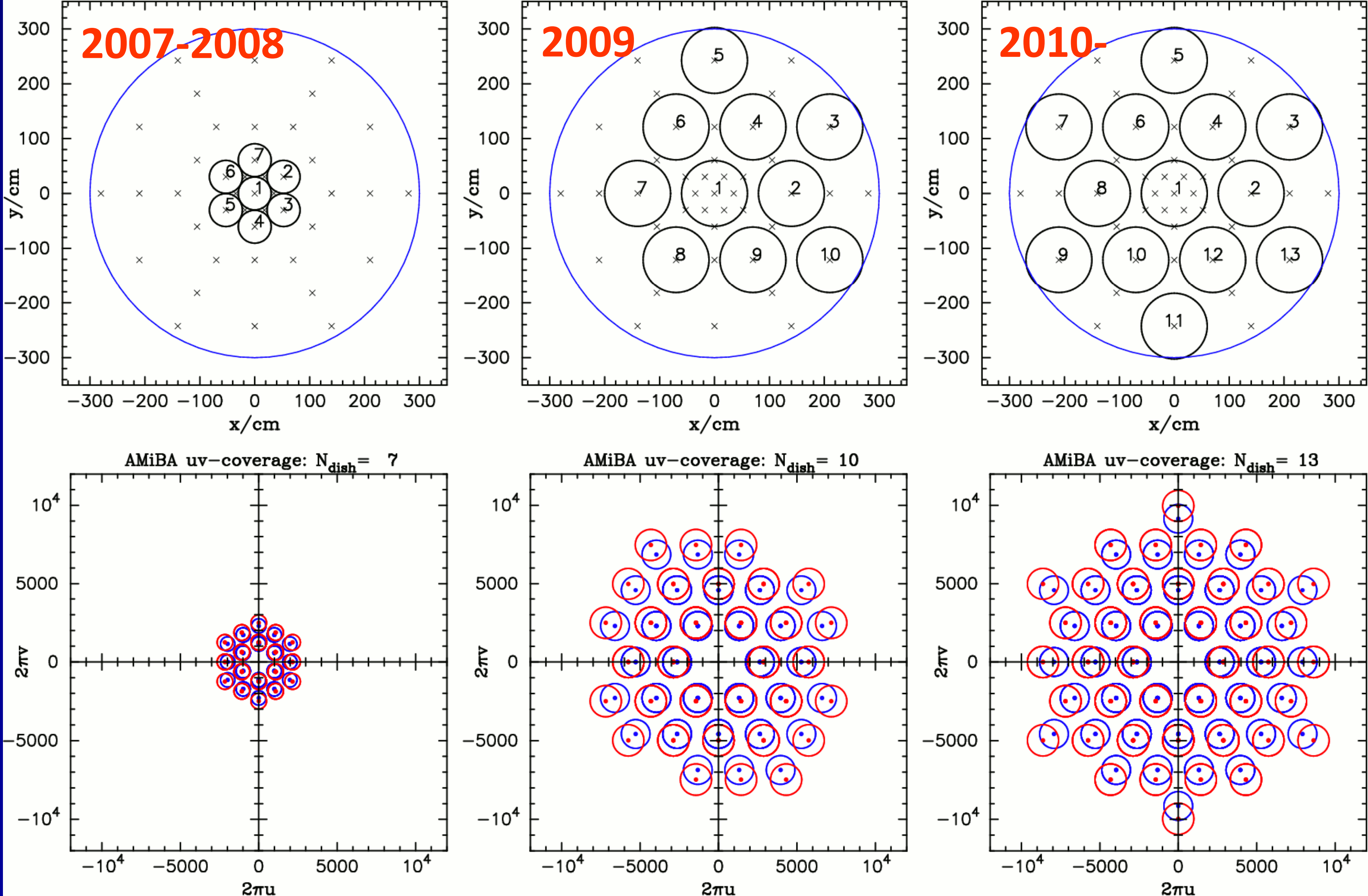


2007-2008



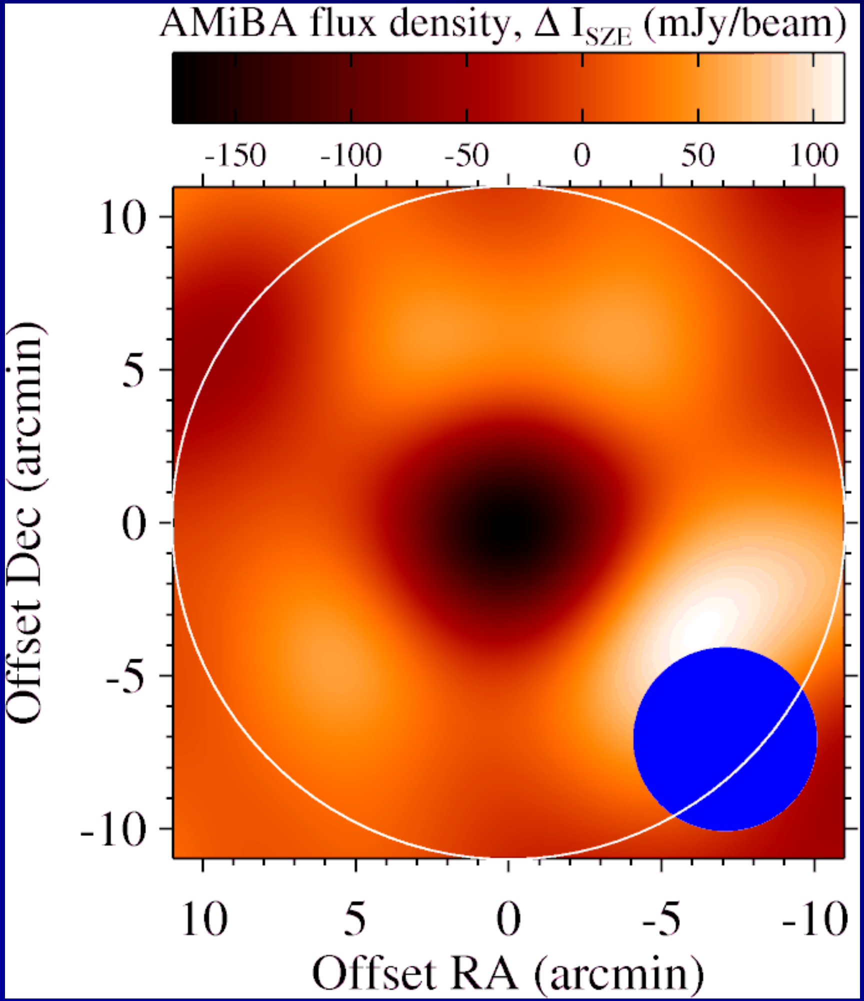
2010~

AMiBA-7 vs. AMiBA-13: (U,V) Coverage



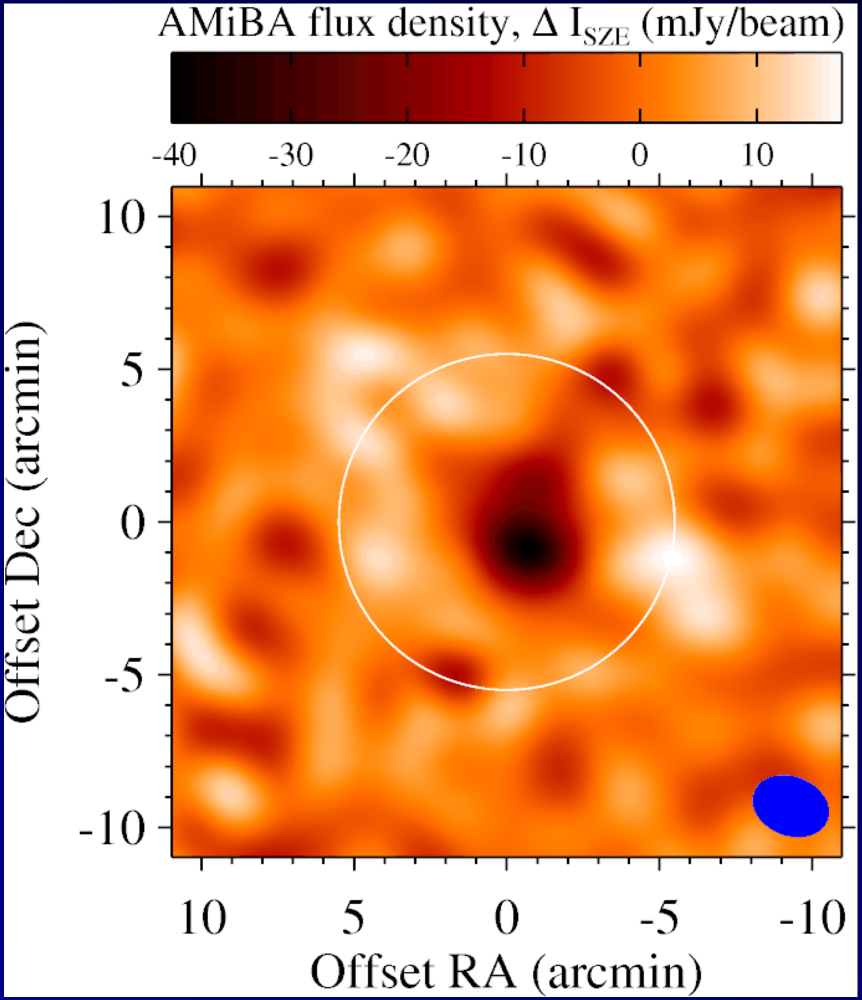
AMiBA-7 vs. AMiBA-13: A1689 tSZE

AMiBA-7: 60cm x 7



7.1hr on-source integration (6σ)

AMiBA-13: 120cm x 13



3.4hr on-source integration (10σ)

First Science Results with AMiBA-7

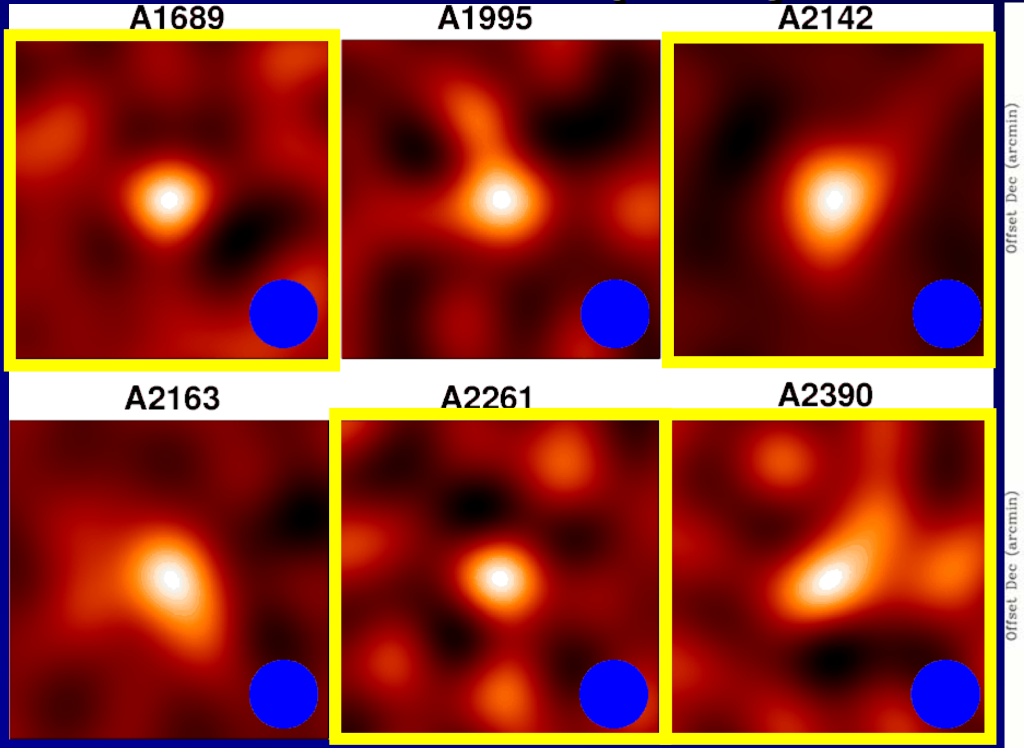
Ten Papers Published in ApJ as of May 2010:

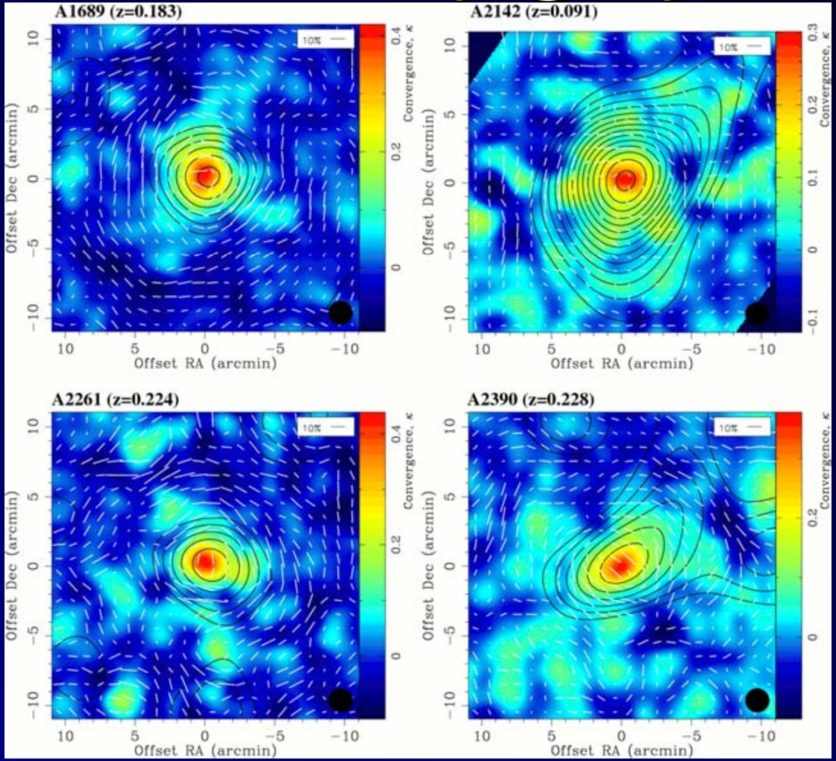
- **Design/Results:** **Ho+** 2009, ApJ, 694, 1610
- **tSZE + Analysis pipeline**: **Wu+** 2009, ApJ, 694, 1619
- **System performance**: **Lin+** 2009, ApJ, 694, 1629
- **Data integrity tests**: **Nishioka+** 2009, ApJ, 694, 1637
- **tSZE + Weak Lensing:** **Umetsu+** 2009, ApJ, 694, 1643
- **Instrumentation:** **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

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



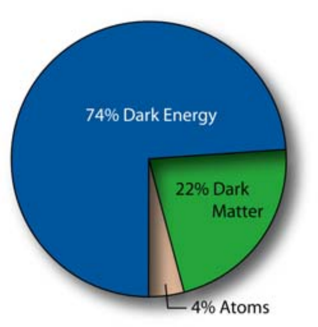


Hot baryons as imaged by AMiBA-7 (Wu+ '09): 200-600mJy tSZE decrement, 5-7% relativistic correction at 94GHz

DM structure as revealed by Subaru WL (Umetsu+ '09)

- Hot baryon fraction (~B/DM mass ratio) = 13±3% from the AMiBA tSZE vs. Subaru WL comparison.

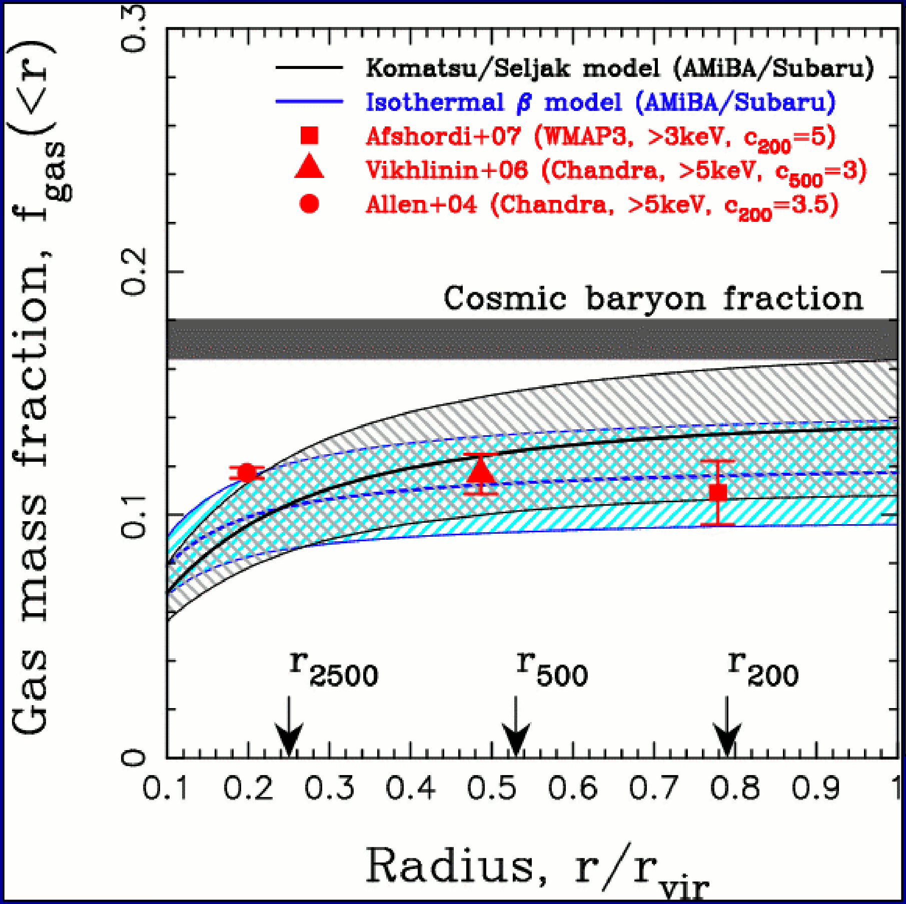
- 22±16% of the baryons missing from the hot plasma phase (WMAP $\langle f_b \rangle$ ~17%); ~several % expected in the cold phase (stars)



Baryon Fractions in Galaxy Clusters

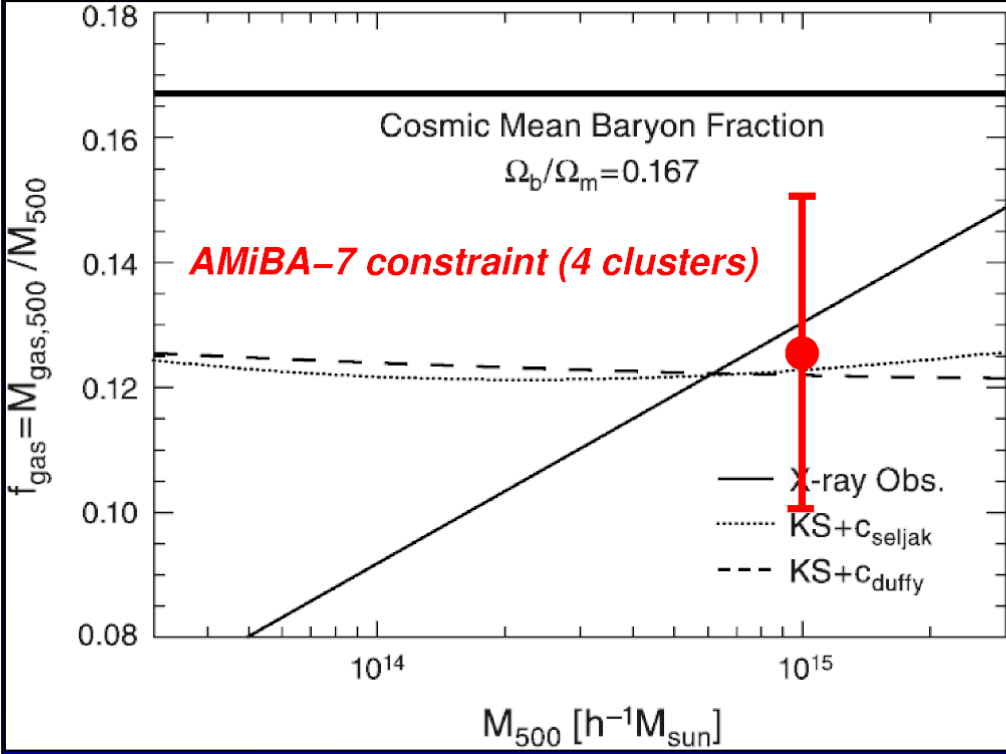
First tSZE + Lensing (+X) results, free-from H.E. assumption

AMiBA-7 tSZE + WL + X-ray



Umetsu et al. 2009

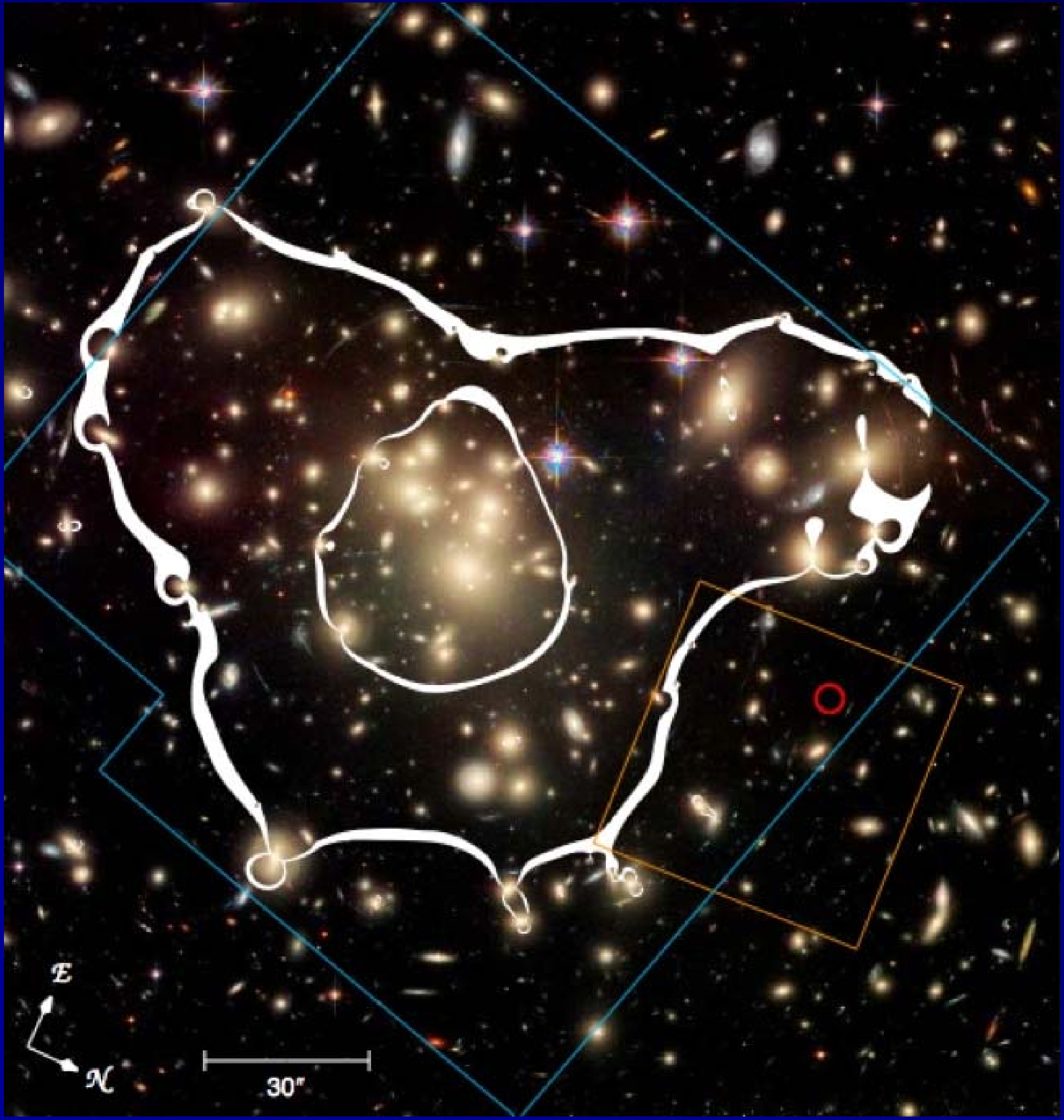
X-ray and WMAP7 tSZE constraints



Komatsu et al. 2010 (WMAP-7yr)

3-1. Multi-wavelength Cluster Cosmology Program at ASIAA

Strong Lensing Cluster A1689

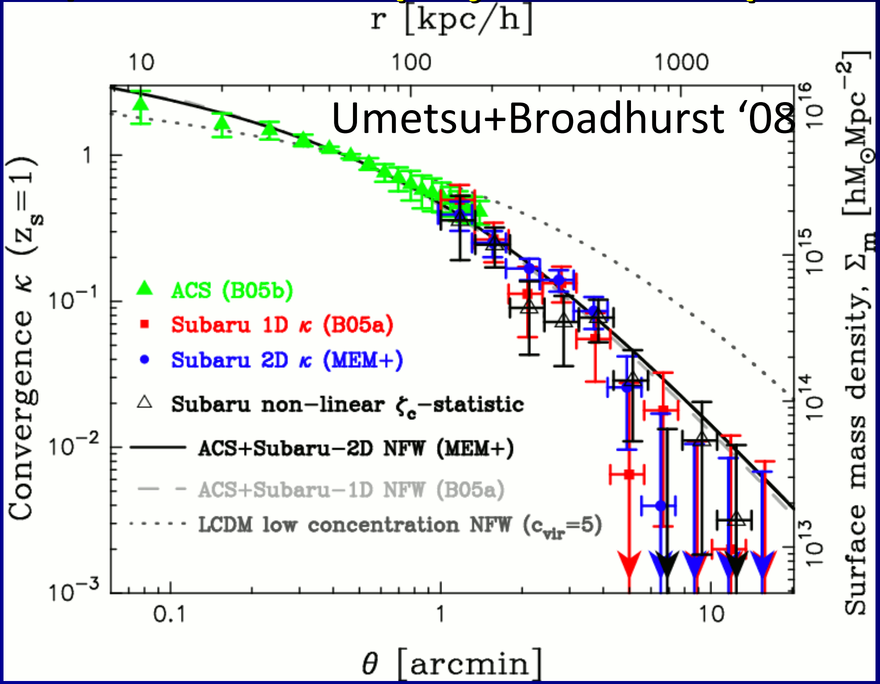


- Abell 1689
  - $z = 0.18$
  - $R_E \sim 50''$ ($z_s=3$)
- M_{2D} ($\leq R_E$) ~ $1.4 \times 10^{14}\ M_\odot/h$
- ACS/WFC data g, r, i, z (20 orbits)
- blue: NIC3 J_{110} (18 orbits)
- orange: NIC3 H_{160} (1 orbit)

Broadhurst et al. 2005

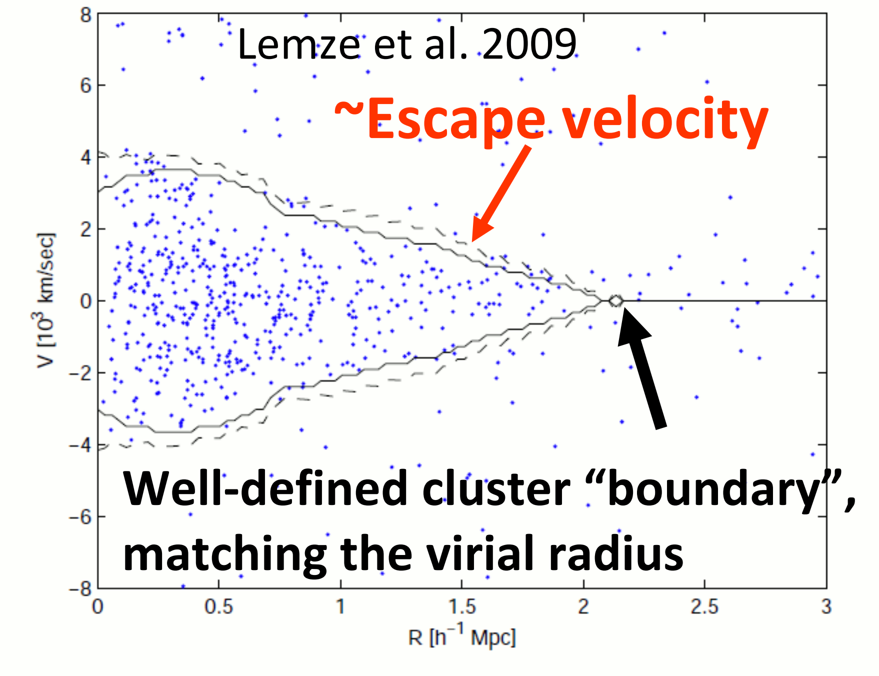
Mass and Velocity Structure of A1689

HST/ACS + Subaru projected mass profile



Umetsu+Broadhurst '08

VLT phase-space Caustic diagram



Lemze et al. 2009

~Escape velocity

Well-defined cluster "boundary", matching the virial radius

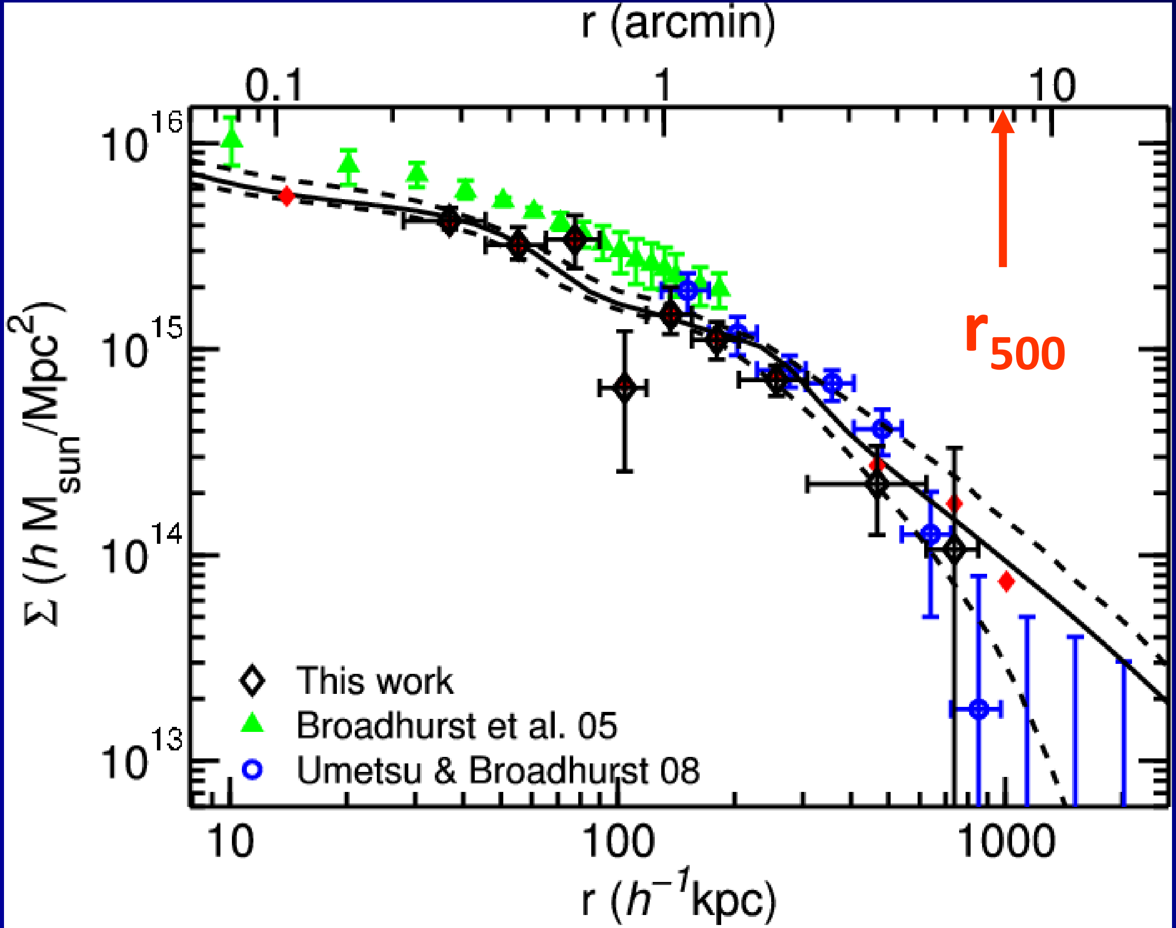
Recent lensing and dynamical mass measurements converging to consistent results (e.g. Umetsu & Broadhurst '08; Lemze+09; Coe+'10): **$M_{vir} \sim (1.3\pm0.3)\times10^{15} M_\odot$ /h**

- A1689 is very massive and has a well-relaxed appearance: symmetric and trumpet-shaped Caustic envelopes.
- It has no significant infalling structure in the cluster outskirts – an isolated environment, at least, along the line-of-sight?
- It has been well studied at various wavelengths.

X-ray vs. Lensing Mass Discrepancy

Detailed Chandra X-ray analysis by Peng et al. 2009 (up to r_{500}~$0.5r_{vir}$):

Comparison in terms of Σ obtained with *strict Hydrostatic Equilibrium* (HE) assumption, namely perfect thermal-pressure support:



Assuming strict H.E. underestimates the total mass density @ small radii (r<200kpc/h ~$0.1r_{vir}$).

Strong and weak lensing are consistent where the data overlap (r~100kpc/h).

Figure from Peng e tal. 2009

What causes the mass discrepancy?

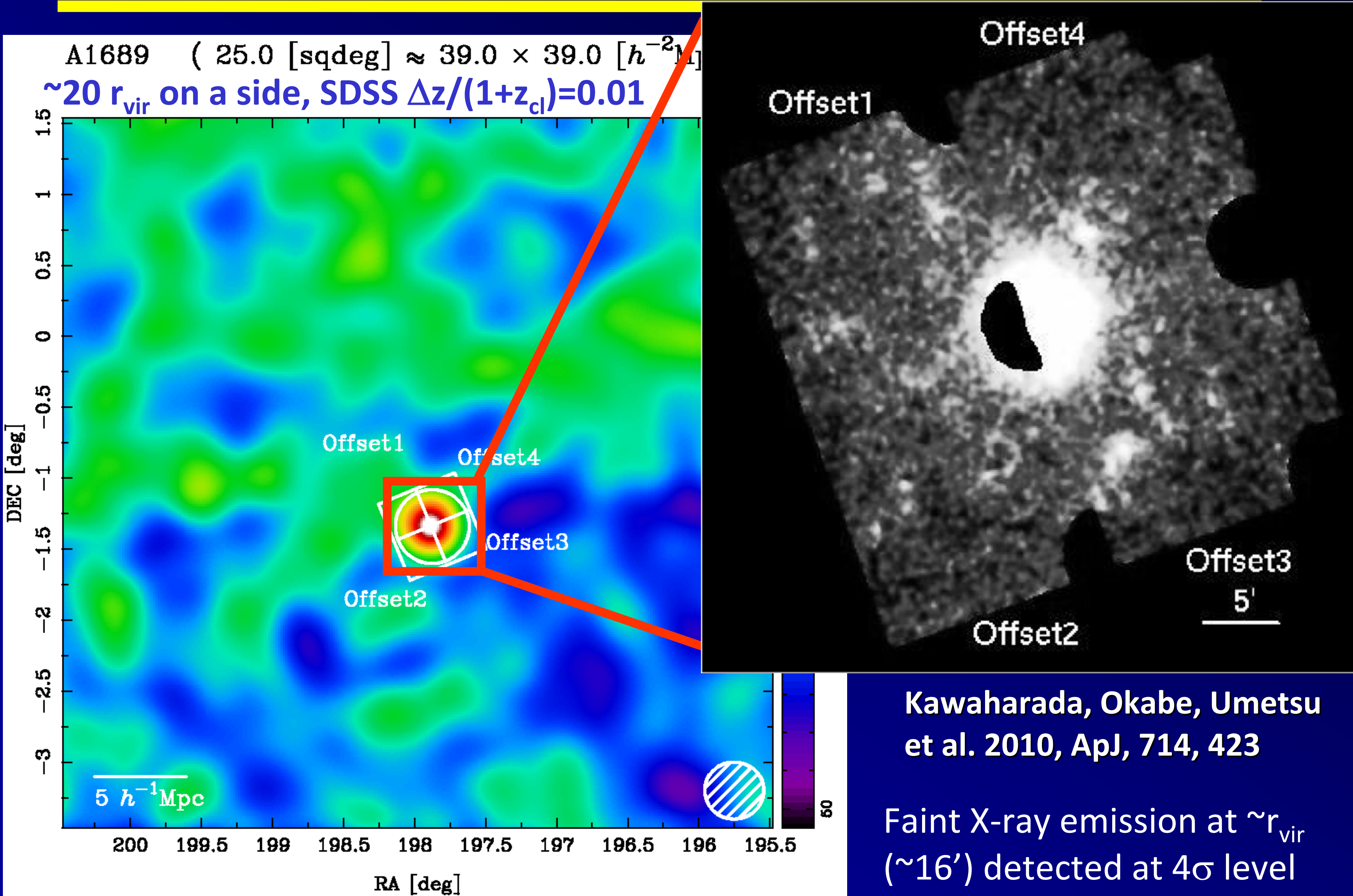
- Assuming a **prolate symmetry** (b/a=0.6-0.7 in X-ray gas) + **H.E.** can reconcile the mass discrepancy at small radii (Peng et al. 2009) as well as the “apparent” high mass concentration (Oguri et al. 2005).
- **Large halo triaxiality with H.E.,** however, overestimates the outer mass profile ($r \sim r_{500}$) by (25-40)% constrained by Subaru WL (Peng et al. 2009).

What is the level of Hydrostatic Equilibrium?

What is the degree of thermalization?

Suzaku/XIS Offset Observations (160ks)

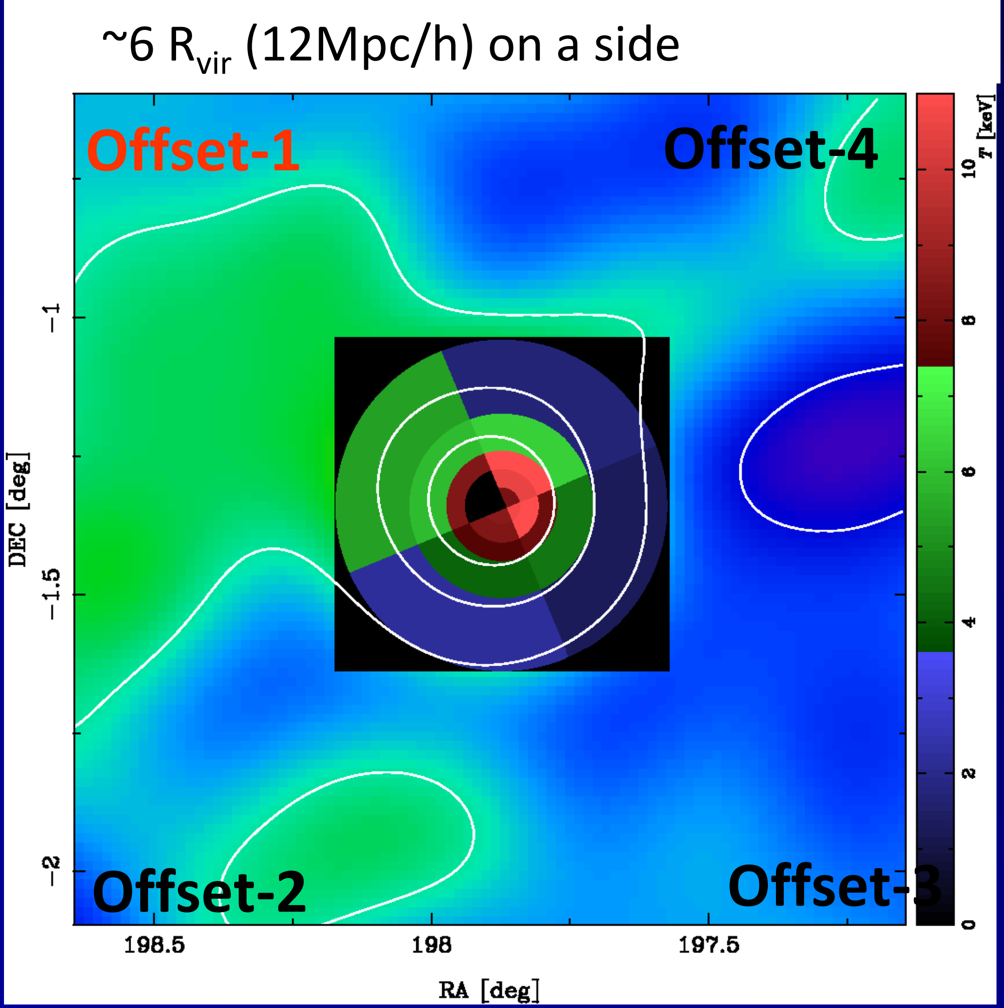
~20 r_{vir} on a side, SDSS $\Delta z/(1+z_{cl})=0.01$



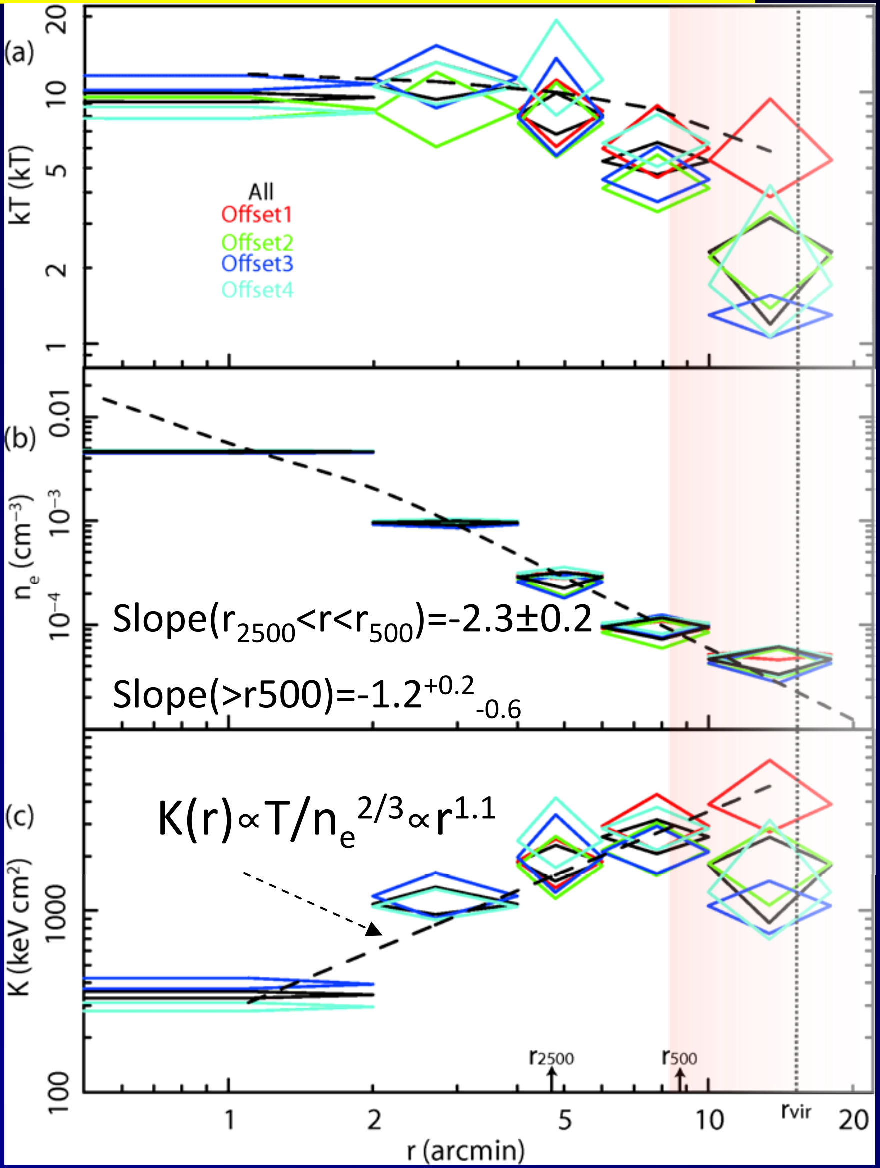
Kawaharada, Okabe, Umetsu et al. 2010, ApJ, 714, 423

Faint X-ray emission at ~r_{vir} (~16’) detected at 4σ level

Anisotropic Temperature & Entropy Distributions in A1689



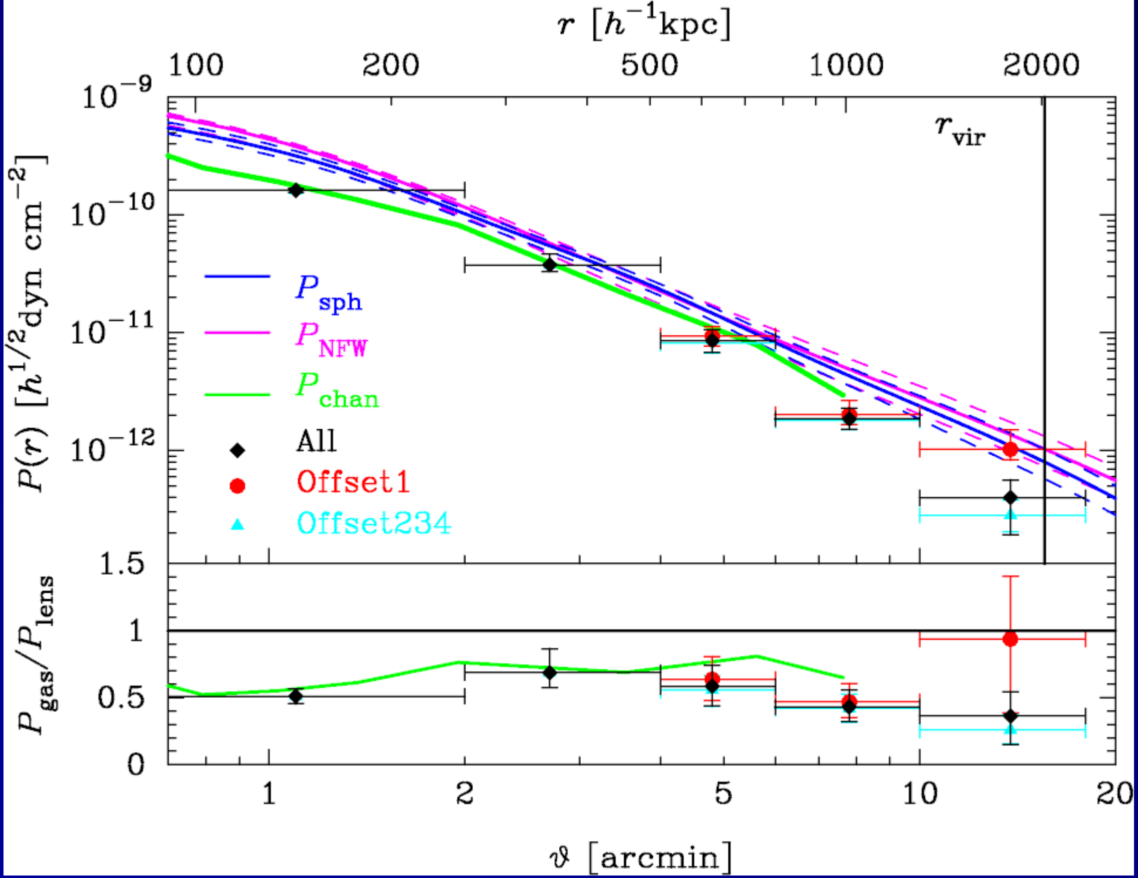
~6 R_{vir} (12Mpc/h) on a side



→ *Thermalization of the ICM occurs faster along overdensity filamentary structure than along low-density void regions?*

Kawaharada, Okabe, Umetsu et al. 2010, ApJ

Level of Hydrostatic Equilibrium



At r < r500, the thermal pressure $P_{th}(r)$ is **<60%** of the equilibrium pressure converted from the lensing mass assuming spherical symmetry.

The outskirt thermal pressure (Offset-234) is **~30%** (~100% in Offset-1) of the equilibrium pressure. All these values constitute lower limits when halo triaxiality is taken into account.

In the cluster outskirts (r>r500), these small relative contributions of $P_{th}(r)$ would require **additional sources of pressure, such as subsonic bulk and/or turbulent motions.**

@Offset-234 cluster outskirts:

$t_{ei}=0.4\mathrm{Gyr}\ (n_e/5\mathrm{e}{-5}\ \mathrm{cm}^{-3})^{-1}\ (T_e/2\mathrm{keV})^{3/2} \ll t_{dyn}$

3-2. Multi-wavelength Cluster Cosmology Program at ASIAA

CLASH:

Cluster Lensing And Supernova survey with Hubble

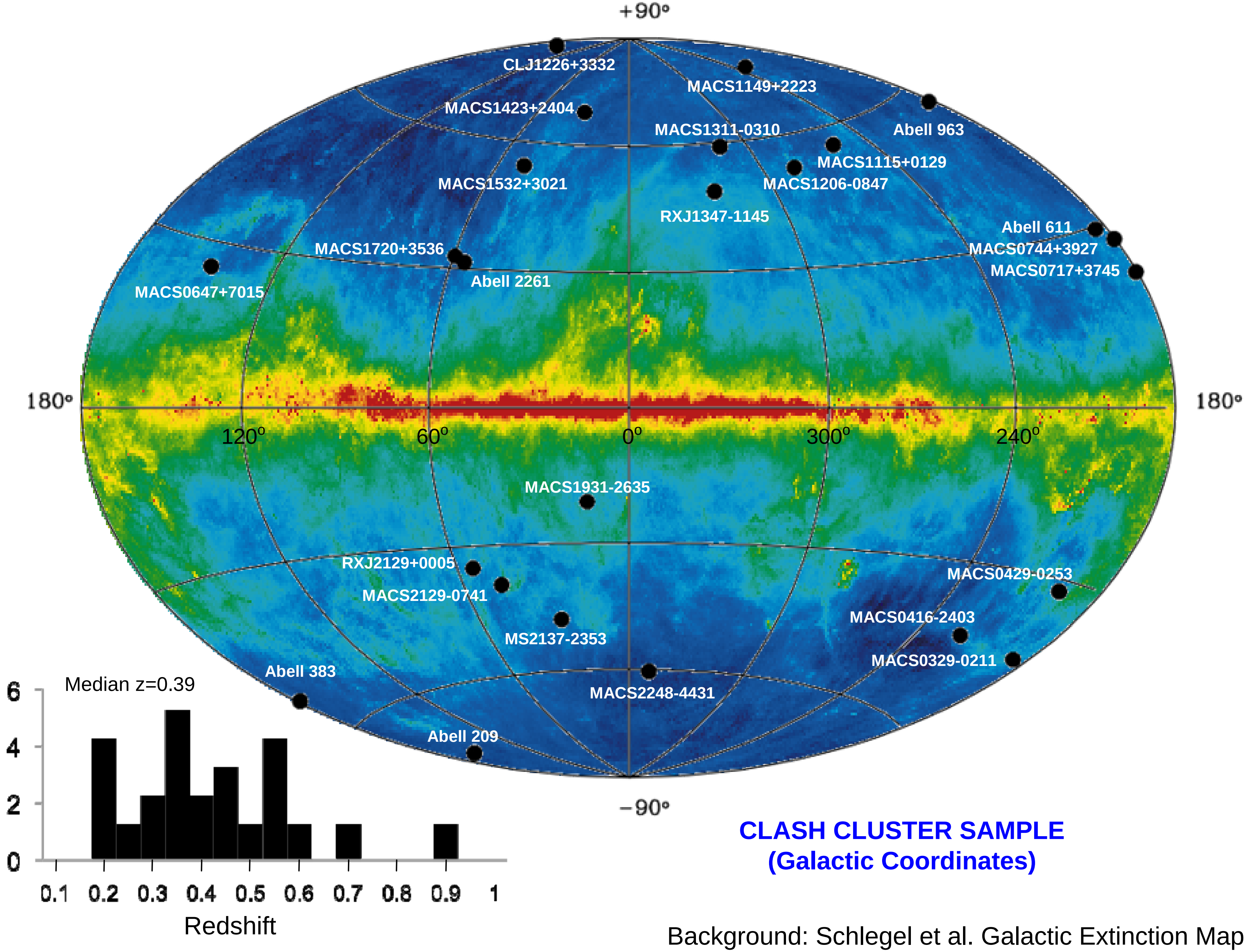
An HST Multi-Cycle Treasury Program designed to place new constraints on the fundamental components of the cosmos: dark matter, dark energy, and baryons.

WFC3 (UVIS + IR) and ACS will be used to image 25 relaxed clusters in 14 passbands from 0.22 - 1.6 microns. Total exposure time per cluster: 20 orbits.

Clusters chosen based on their smooth and symmetric x-ray surface brightness profiles. Minimizes lensing bias. All clusters have T > 5 keV with masses ranging from ~5 to ~30 x $10^{14}\ M_{\odot}$. Redshift range covered: $0.18 < z < 0.90$.

Multiple epochs enable a $z > 1$ SN search in the surrounding field (where lensing magnification is low).

Marc Postman (P.I.)
Matthias Bartelmann
Narciso Benitez
Larry Bradley
Tom Broadhurst
Dan Coe
Megan Donahue
Rosa Gonzales-Delgado
Holland Ford
Leopoldo Infante
Daniel Kelson
Ofer Lahav
Dani Maoz
Elinor Medezinski
Leonidas Moustakas
Eniko Regoes
Adam Riess
Piero Rosati
Stella Seitz
Keiichi Umetsu
Arjen van der Wel
Wei Zheng
Adi Zitrin



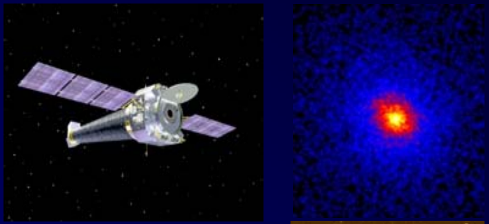
CLASH CLUSTER SAMPLE (Galactic Coordinates)

Background: Schlegel et al. Galactic Extinction Map

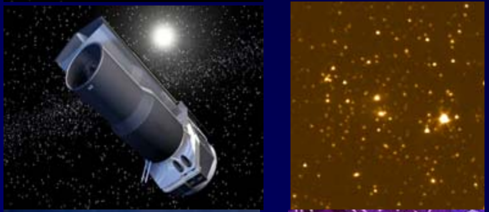
Multiple Facilities Will be Used

- HST 524 orbits: 25 clusters, each imaged in 16 passbands. (0.23 – 1.6 μm)

- Chandra x-ray Observatory archival data and possibly new data. (0.5 – 2 keV)

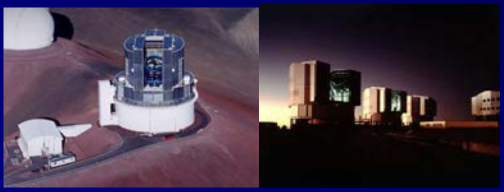


- Spitzer IR Space Telescope archival data and possibly new data (3.6, 4.5 μm)

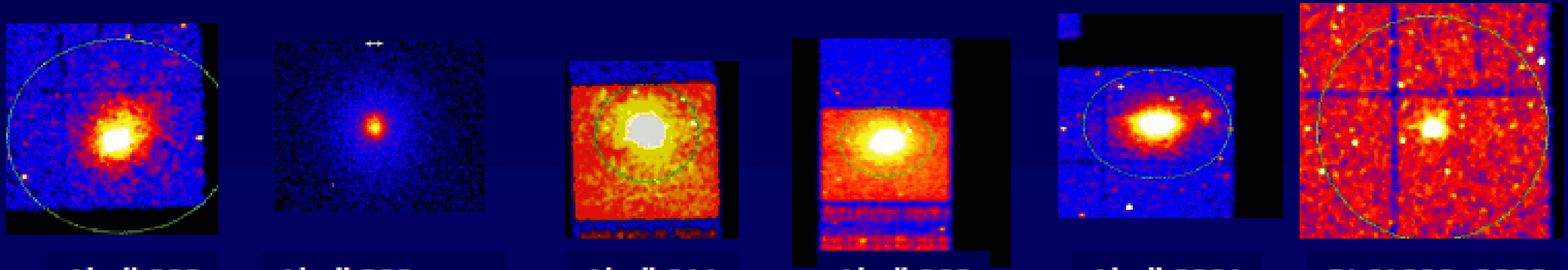


- tSZE observations proposed to augment existing data (Bolocam@150GHz, AMiBA)

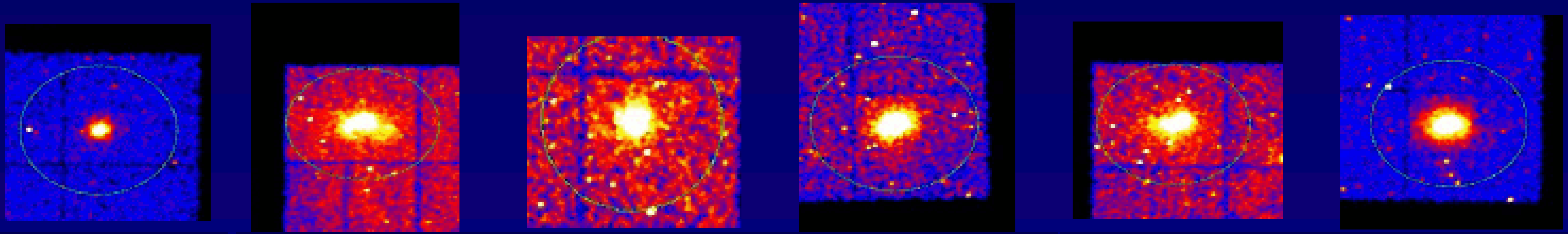
- Subaru wide-field imaging (0.4 – 0.9 μm)
- GTC, VLT, and Magellan Spectroscopy



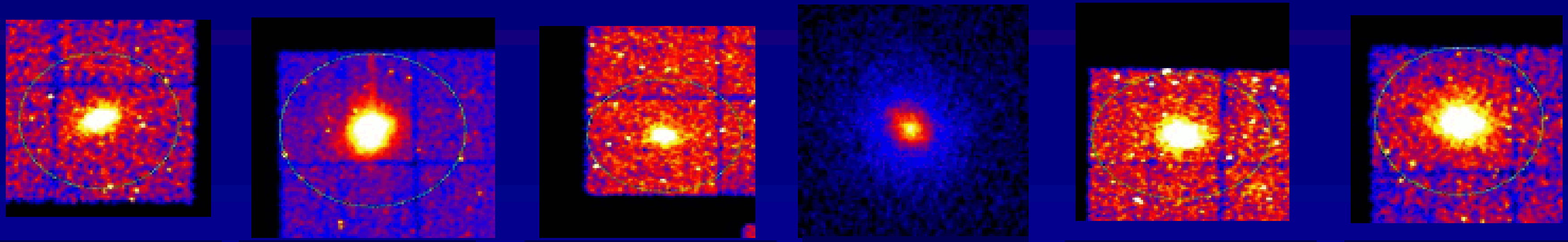
CLASH: An HST Multi-Cycle Treasury Program



Abell 209 | Abell 383 core | Abell 611 | Abell 963 | Abell 2261 | CLJ1226+3332



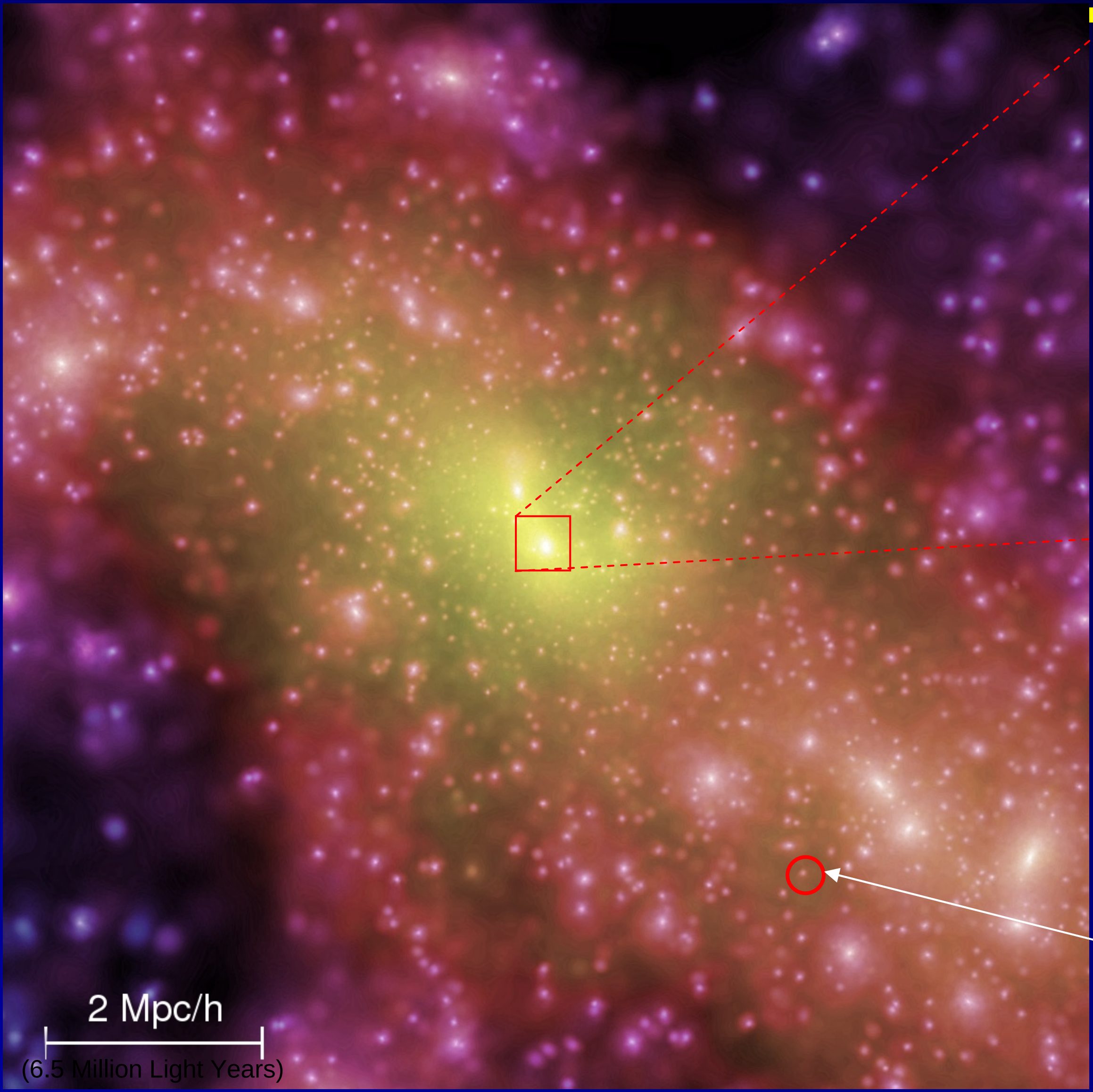
MACS 0329-0211 | MACS 0717+3745 | MACS 0744+3927 | MACS 1115+0129 | MACS 1149+2223 | MACS 1206-0847



RXJ 0647+7015 | RXJ 1347-1145 | RXJ 1423+2404 | MS-2137 core | RXJ 1702+3536 | RXJ 2129+0005

Cutouts of Chandra images of 18 of the 25 CLASH clusters from ACCESS database

CLASH: An HST Multi-Cycle Treasury Program



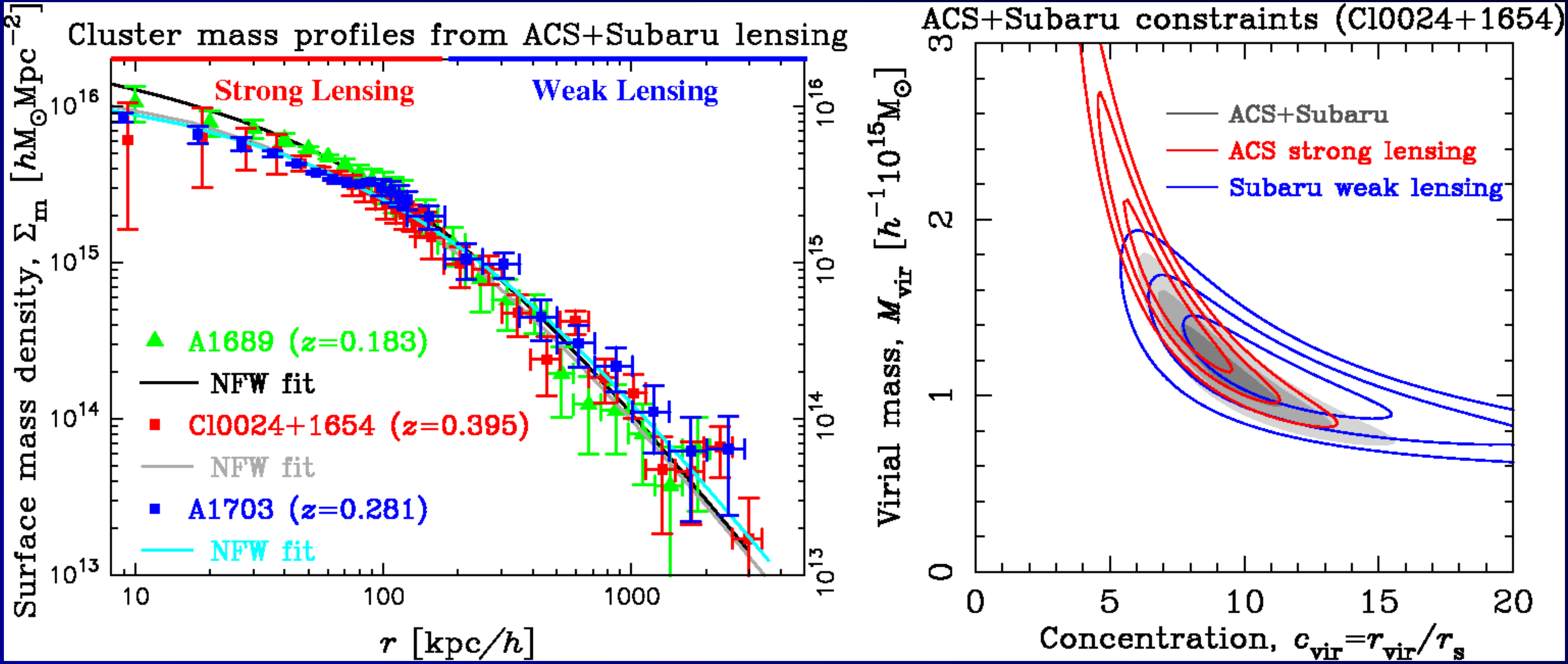
Simulation of dark matter around a forming cluster (Springel et al. 2005)

Deep HST image of massive cluster

$$R \propto \frac{\theta_{Einstein}}{\sqrt{N_{Arcs}}}$$

WHERE R IS THE RESULTING SPATIAL RESOLUTION OF THE DARK MATTER MAP

Both Strong & Weak Lensing Measurements Needed for Good Costraints



Umetsu et al. 2010

Both strong AND weak lensing measurements are needed to make accurate constraints on the DM profile.

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

Summary

— AMiBA is one of few SZE instruments that operate on ~1-10 arcmin scales at 90GHz.

- SPT bolometer in the southern hemisphere
- SZA interferometer (CARMA) on <1 arcmin scales at 90GHz

— AMiBA helped to establish active observational cosmology groups in Taiwan.

— AMiBA trained a number of students, postdocs, engineers, and junior faculty as well as industorial companies in Taiwan.

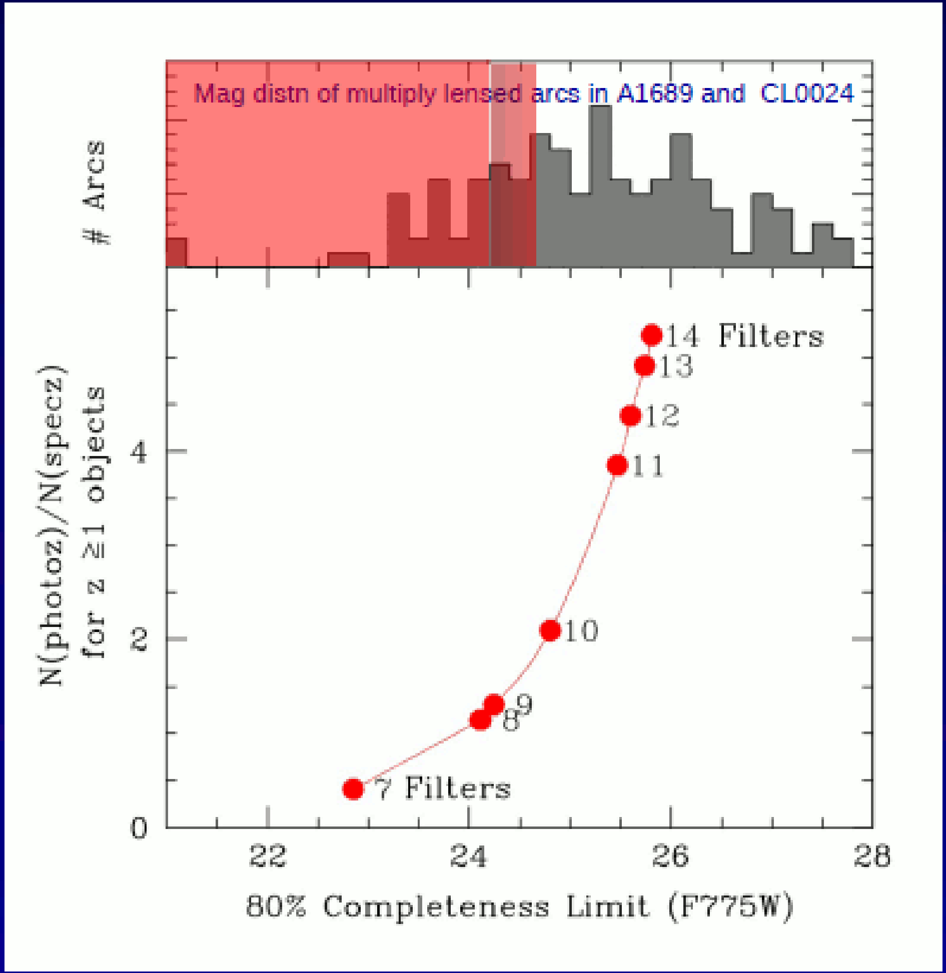
— A total of 10 papers on published in ApJ as of May 2010.

— AMiBA-13 will focus on tSZE observations of the CLASH clusters (<z>=0.39) for measuring the DM mass profile shapes (DM = total – baryons).

CLASH: An HST Multi-Cycle Treasury Program

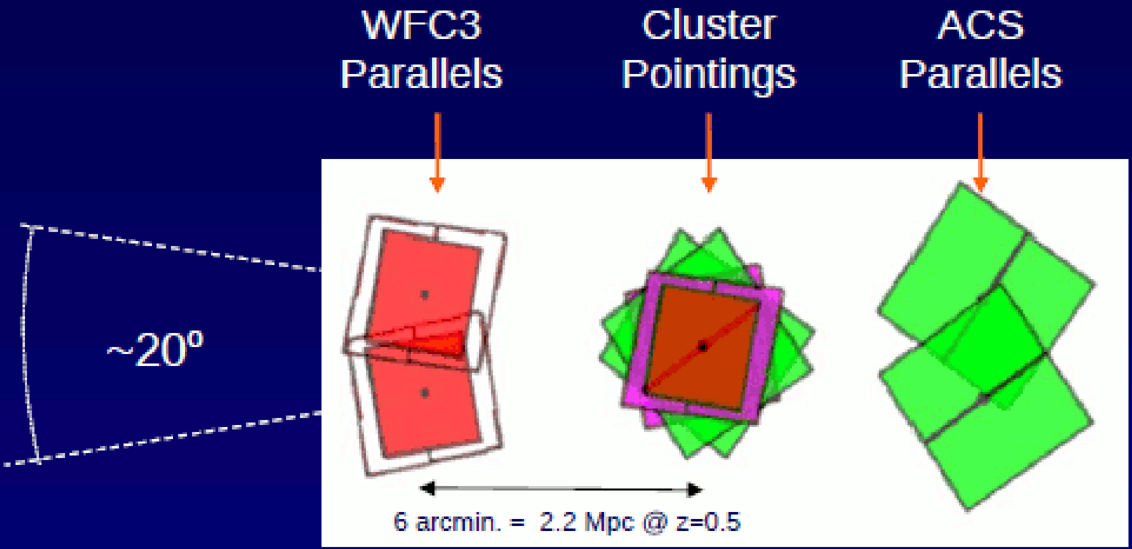
Why 14 filters?

Will yield photometric redshifts with rms error of ~2% x (1 + z) for sources down to ~26 AB mag.

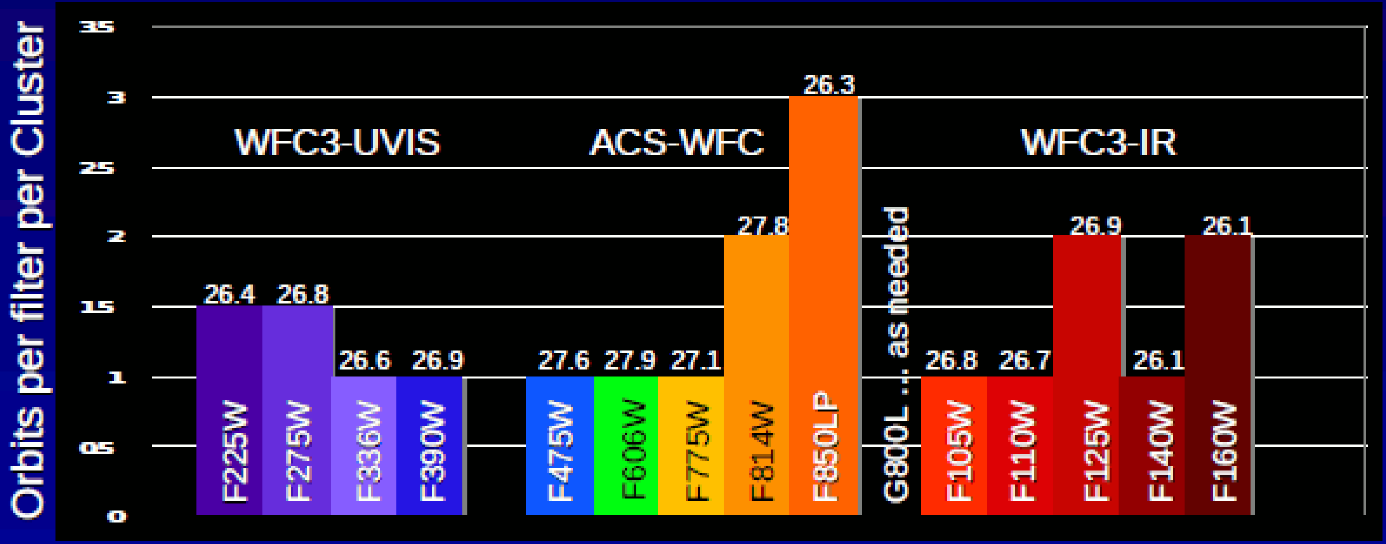


With 14 filters, 80% photo-z completeness is reached at AB ~26 mag and useful redshift information is available for ~5 times as many lensed objects than would be possible solely from spectroscopically acquired redshifts.

CLASH: An HST Multi-Cycle Treasury Program



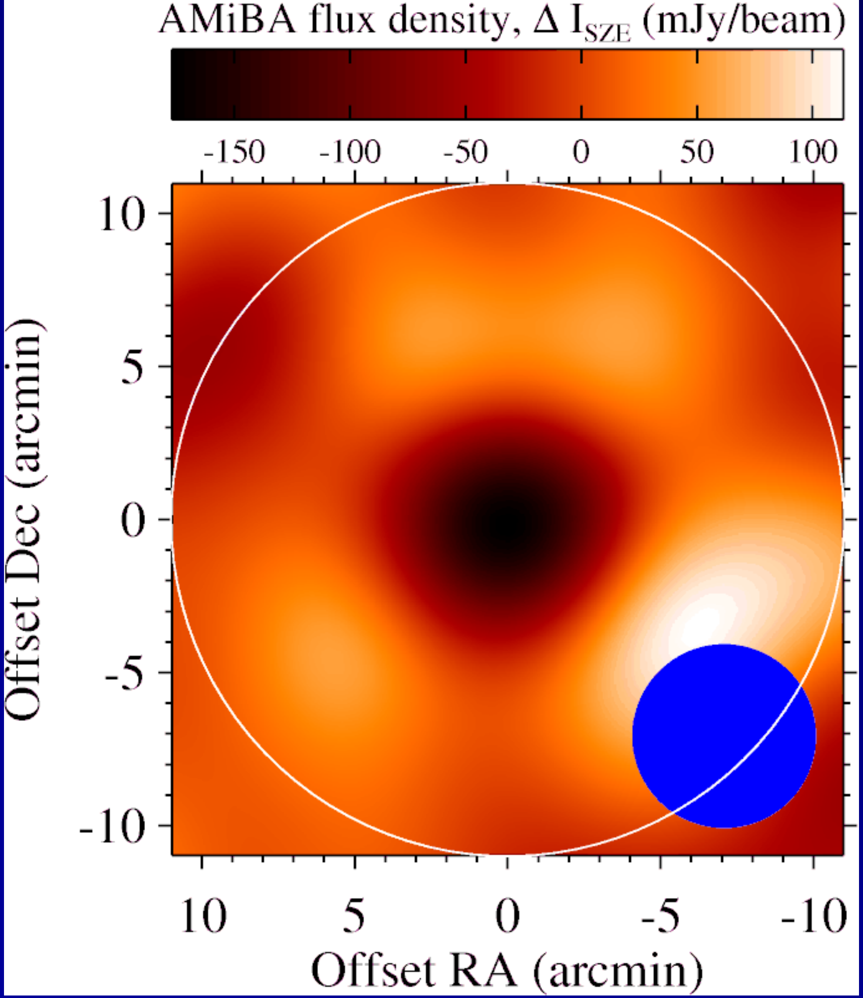
Footprint of our 2 ORIENT survey. ACS FOV in green, WFC3/IR FOV in red, WFC3/UVIS in magenta. The area of the complete 14-band coverage in the cluster center is 4.07 square arcminutes (88% of the WFC3/IR FOV).



Limiting SNR=5 AB magnitudes (for flat spectrum point source) for each passband shown above

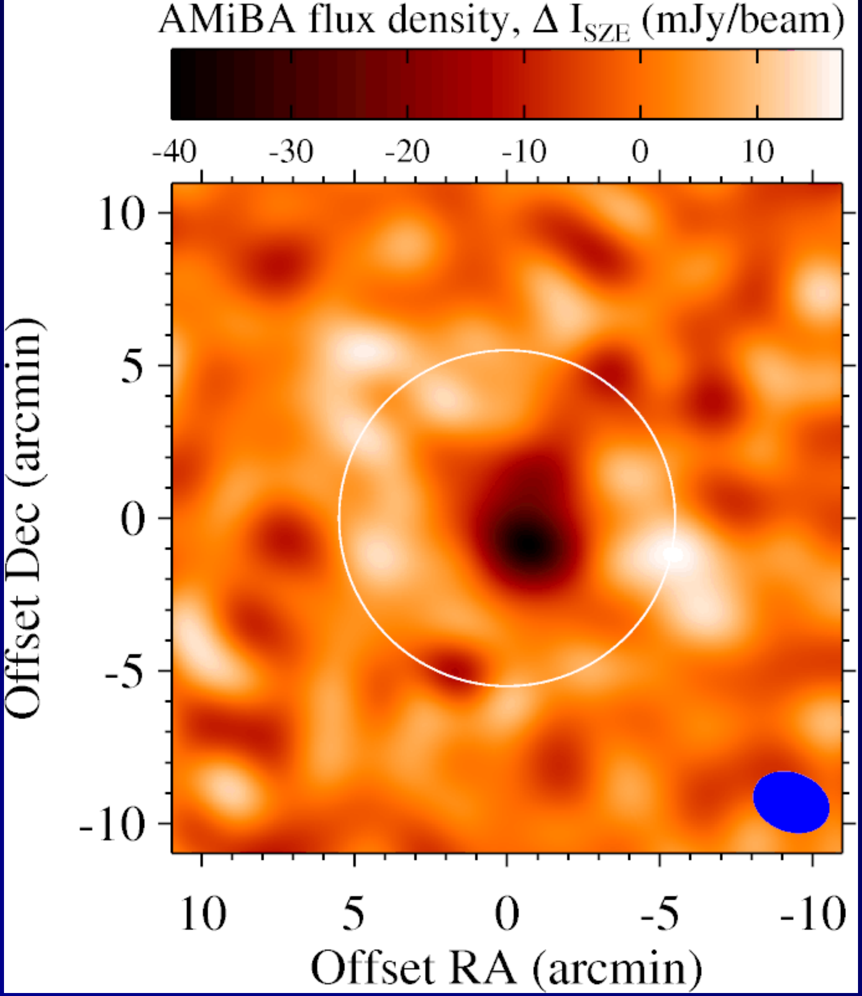
AMiBA tSZE Maps of A1689

AMiBA-7 (60cm, Wu et al. 09)



7.1hr on-source integration (6σ)

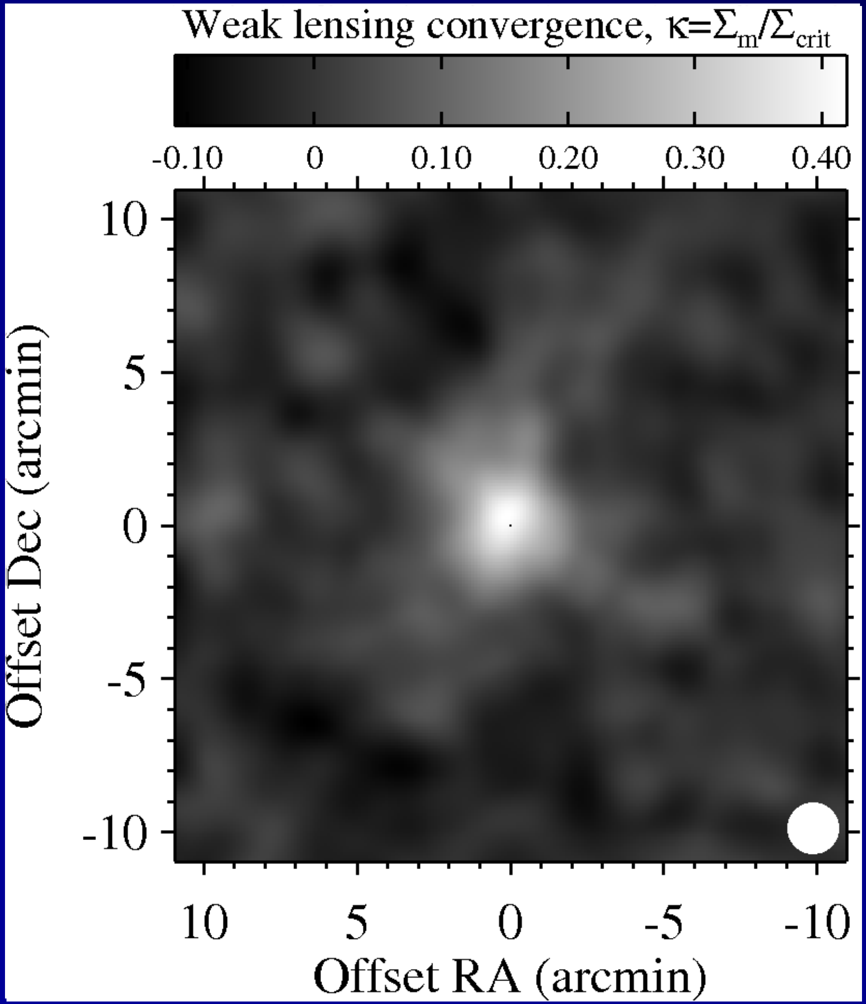
AMiBA-13 (120cm)



3.4hr on-source integration (10σ)

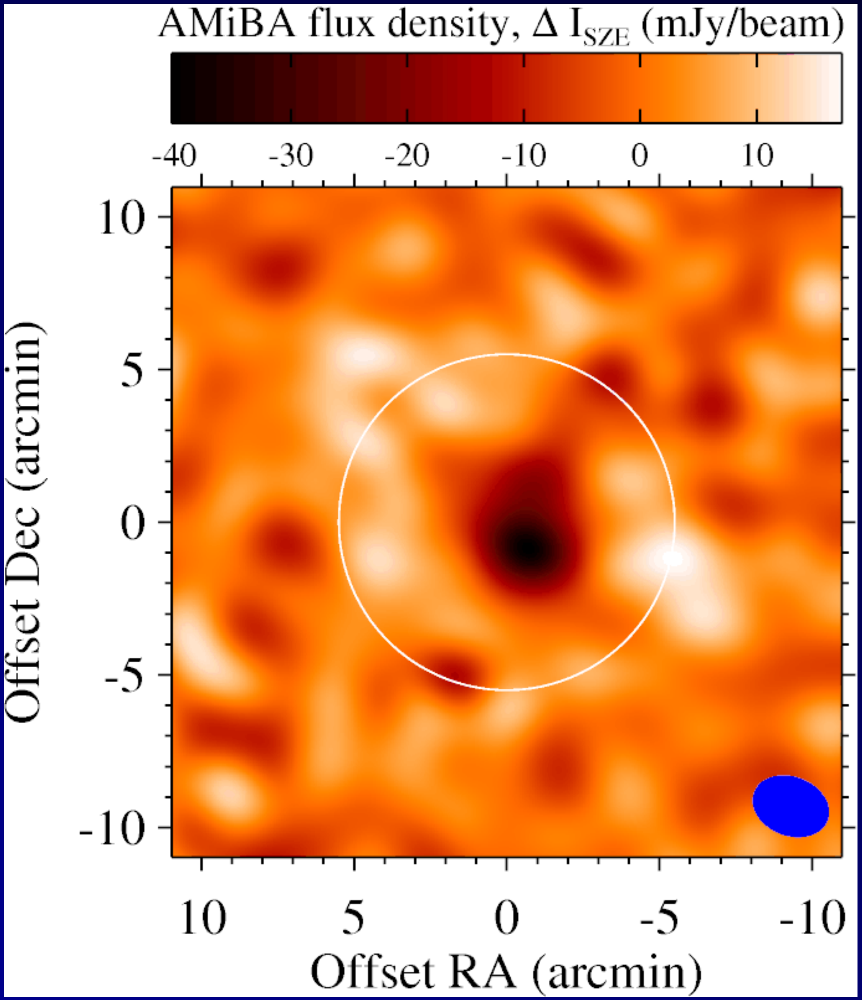
Mass (DM) vs. Pressure (ICM) Maps

Subaru WL (Umetsu & Broadhurst '08)



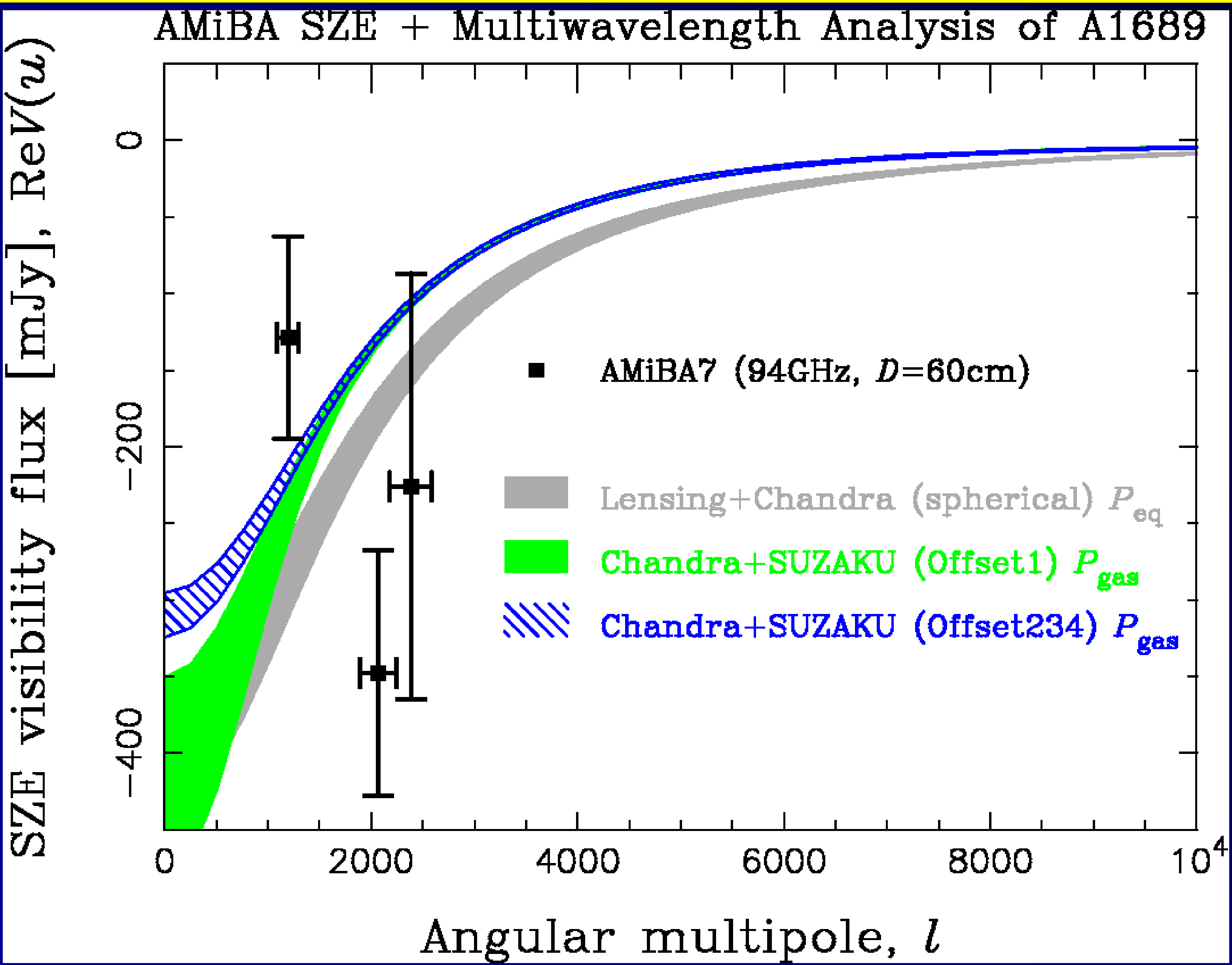
M_{vir}= (1.3 ± 0.3) x 10^{15} M_{sun}/h

AMiBA-13 (120cm, by K.Y. Lin)



S_{tSZE} = -40mJy/beam

Lensing/X-ray Discrepancy



AMiBA-13 Constraints