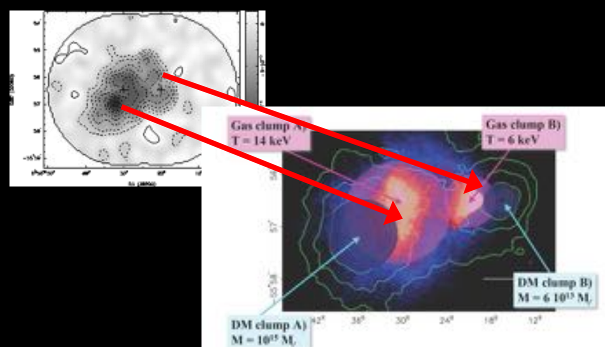
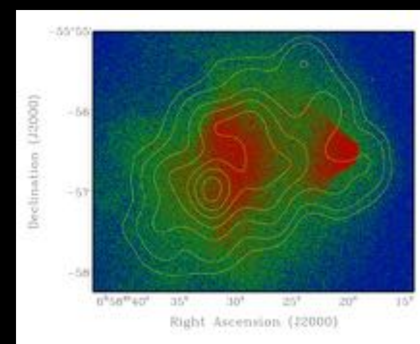
SZE-Radio Halo composite: Disentangling diffuse emission & pressure sub-structures in galaxy cluster mergers





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November 5, 2016, *SKA / SPARCS 2016*

Outline

SZ Effect

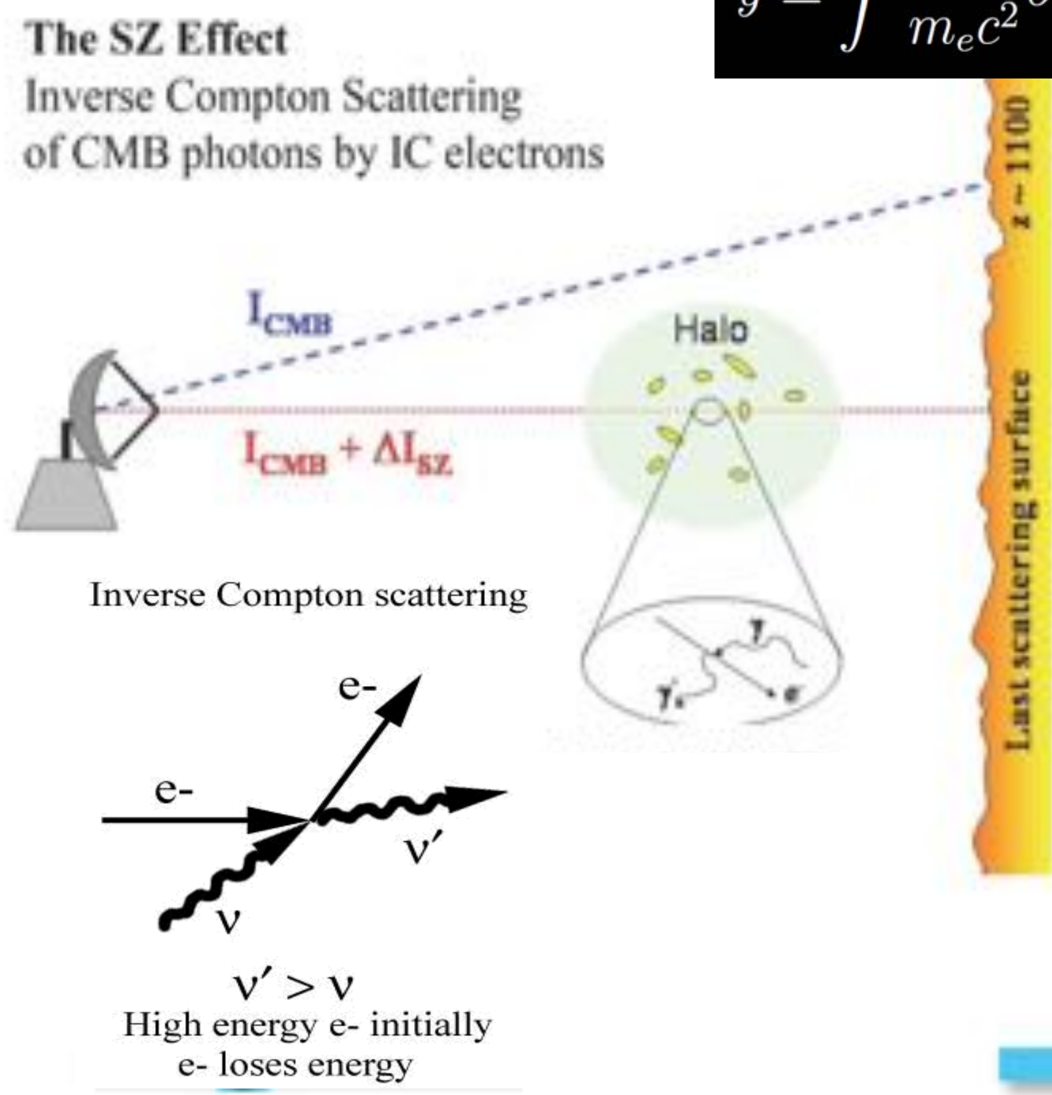
Motivation for observing clusters at 18 GHz – complex astrophysics of mergers

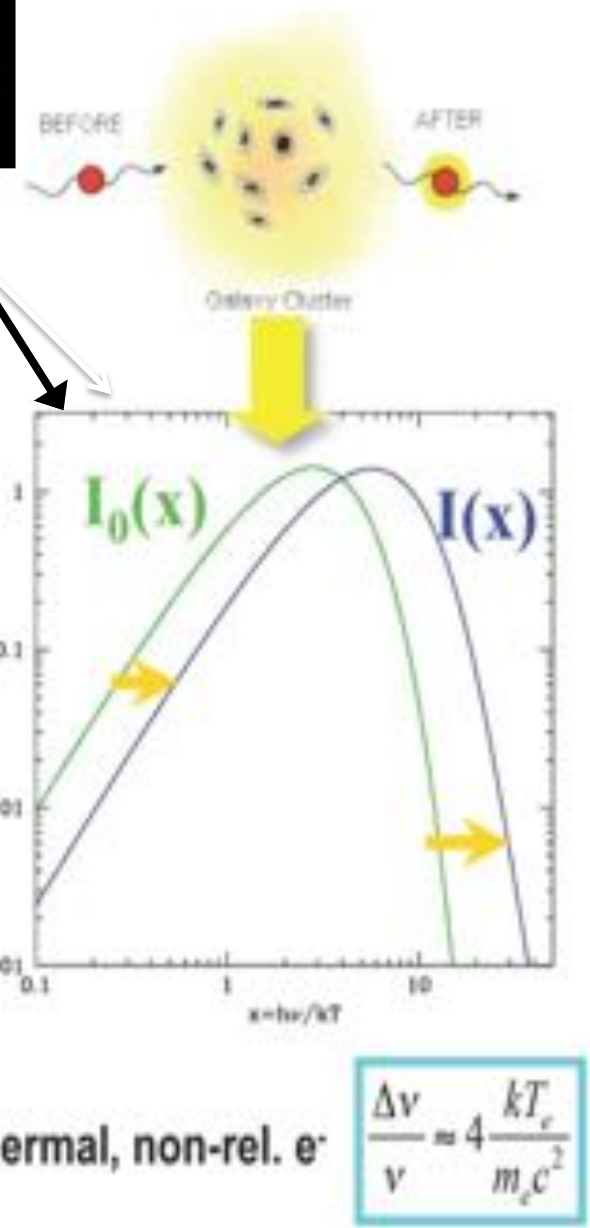
Results from 18 GHz obs. of the Bullet cluster

Separating Diffuse emission & SZ effect at cm-wavelengths

SZ Effect: The Standard Lore

$$y \equiv \int \frac{k_B T}{m_e c^2} \sigma_T n_e c dt$$





Slide courtesy S. Colafrancesco

Carlstrom et al. 2002 (AR&A)

Clusters of Galaxies:

Largest gravitationally bound objects

Size ~ few Mpc $= 10^{22}$ -10^{23} m

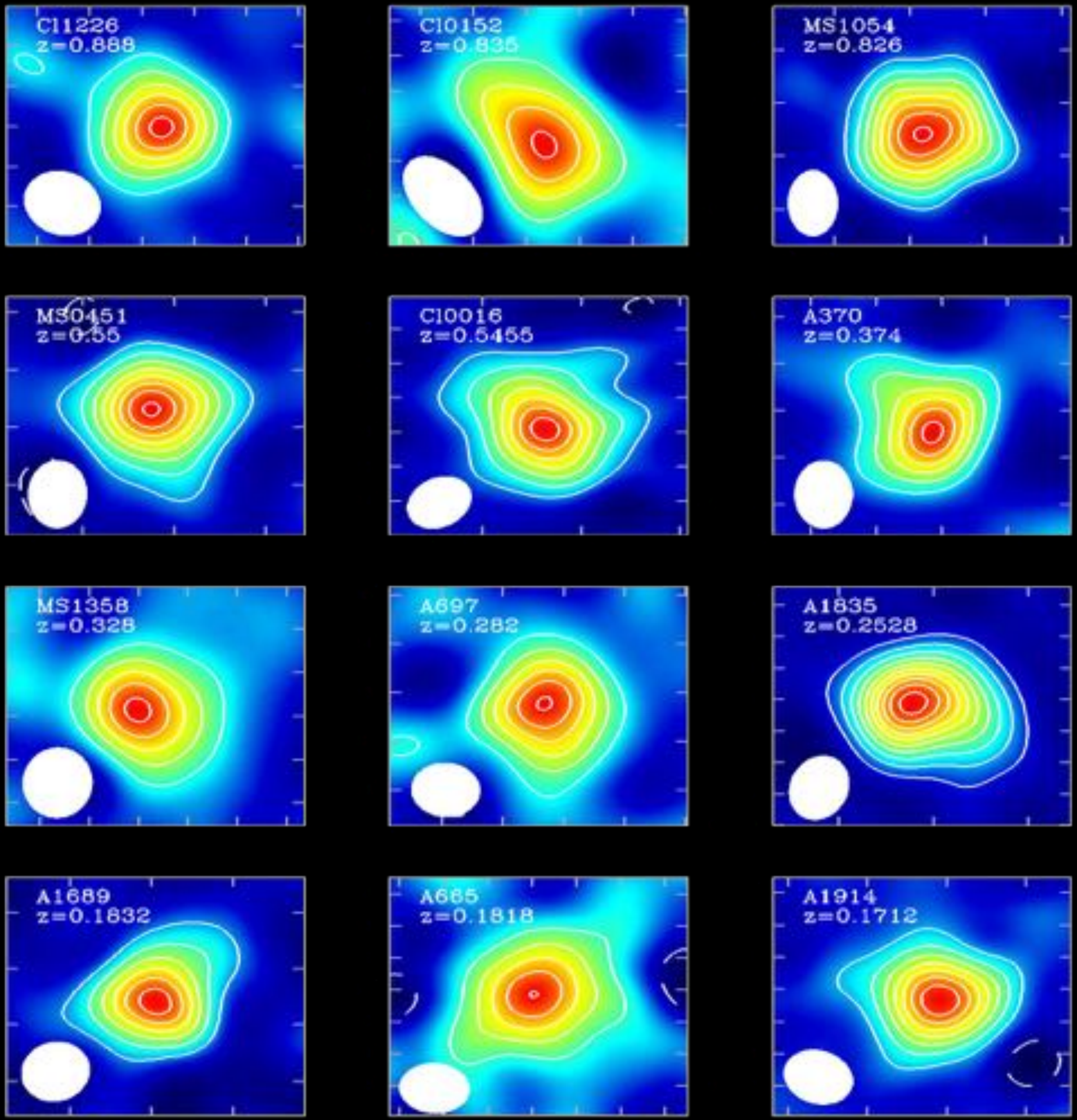
Largest collections of hot gas

$M_{galaxies} \sim 10^{13}\ M_{sun}$

$M_{gas} \sim 10^{15}\ M_{sun}$

$T_e \sim 10^7$-10^8 K

$n_e \sim 10^{-4} - 10^{-2}\ cm^{-3}$



Galaxy cluster mass:

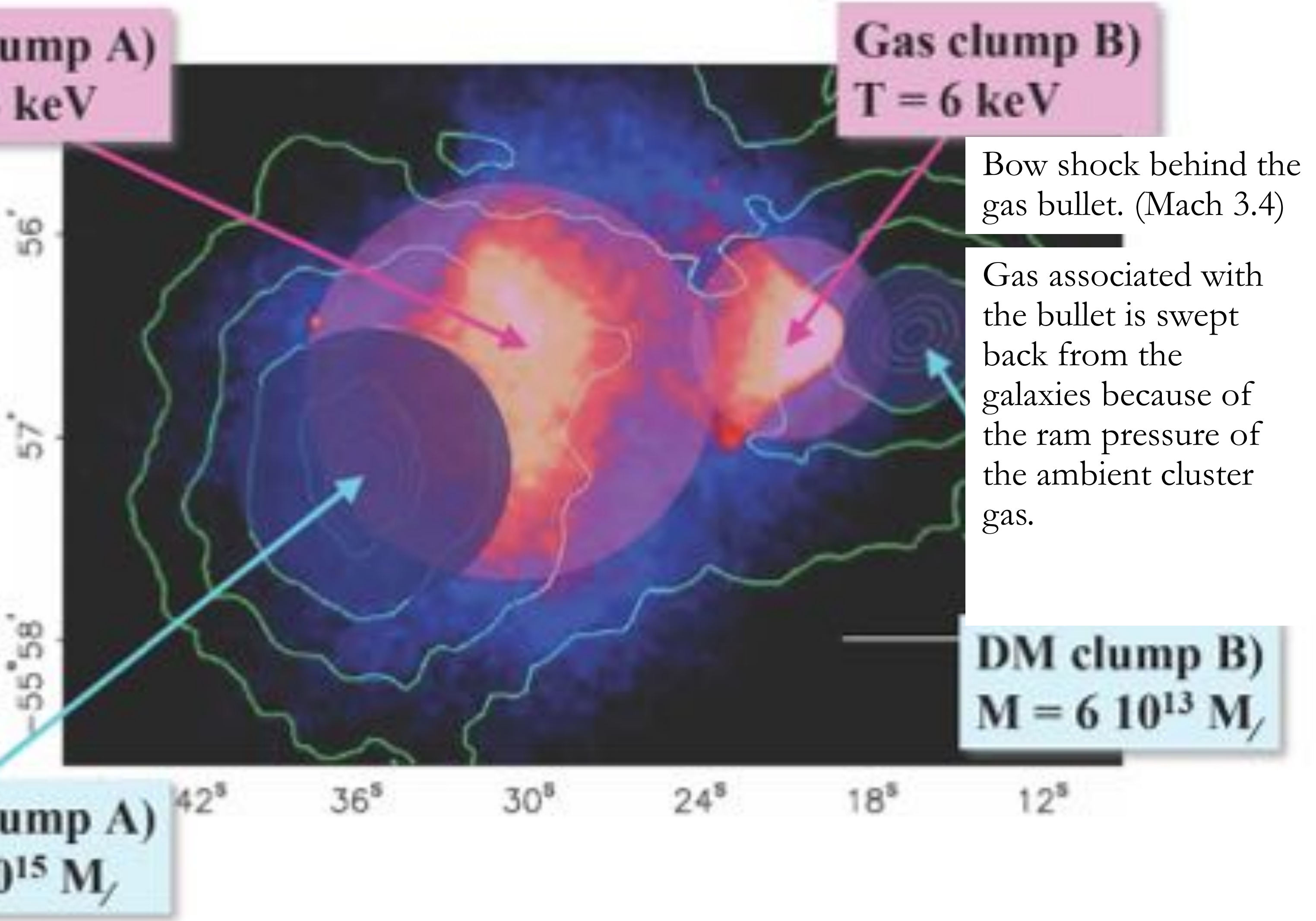
Baryons 10% stars/galaxies
15-20% hot gas

Dark Matter 70%

Carlstrom et al. 2003

The Bullet Cluster: a merging system

The Bullet Cluster



Redshift z=0.296, or 10.3 Gyr after the Big Bang

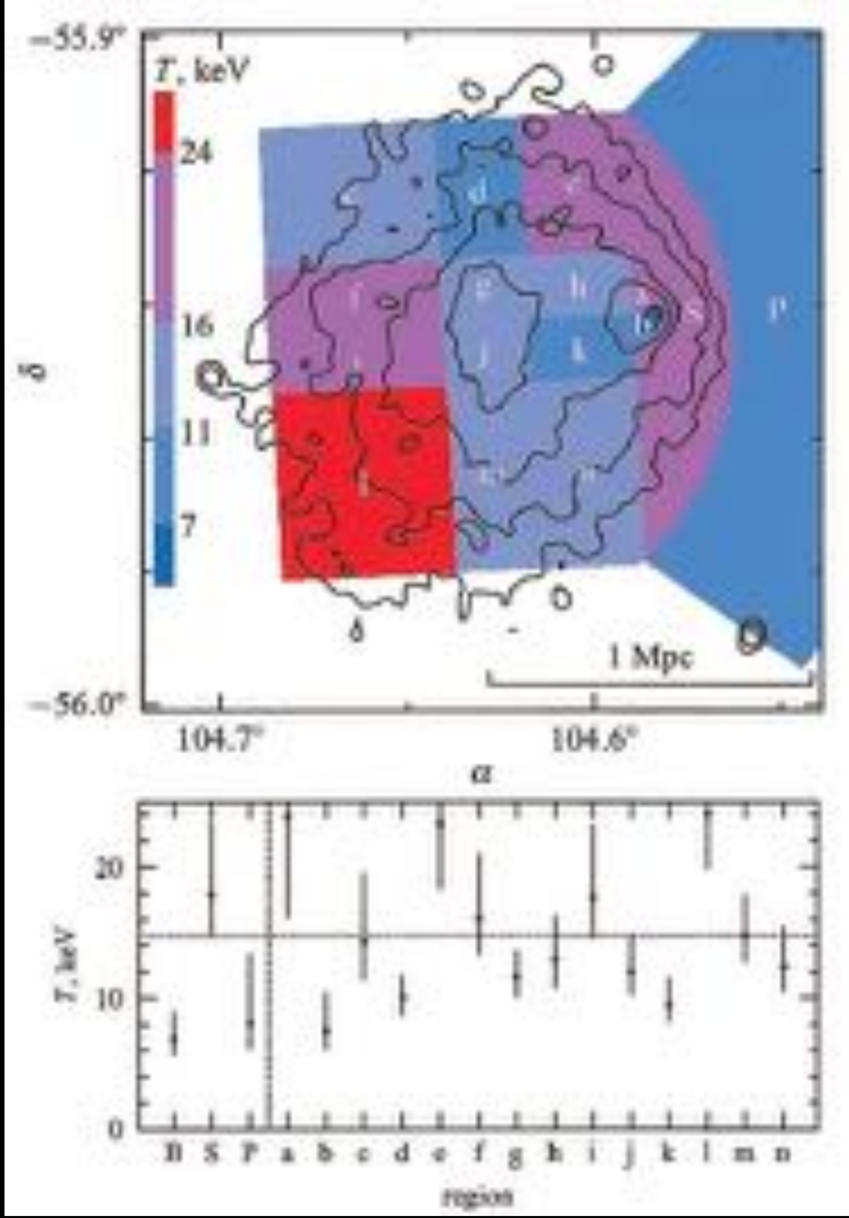
(4 arcmin = 1 Mpc; 1 arcsec = 4 kpc)

Slide courtesy Colafrancesco

Temperature from Chandra ACIS spectral energy in 0.9-9.5 keV band

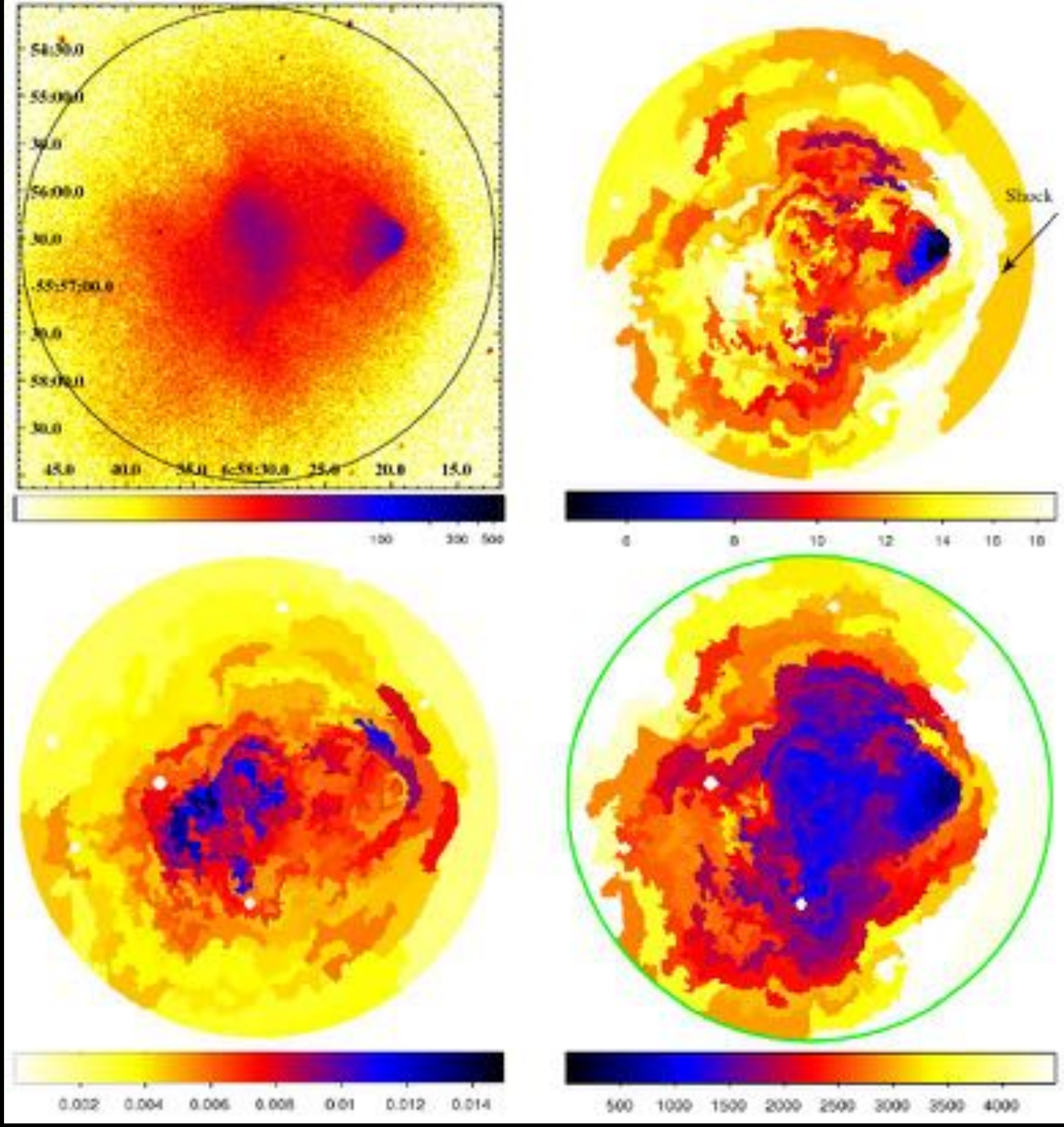
- Coolest part is the gas in the bullet – 7 keV
- There is a temperature and density jump (3-4) at the shock and at the contact discontinuity between the bullet and ambient gas
- Bullet Mach number 2-3 (4700 km/s): collision 100 Myr ago.
- **Hottest part is to SE →24 keV where there are several bright galaxies**

→ Should SZ offset from X-ray have been expected?



Markevitch et al. 2002

XMM data



→ (From top left, clockwise): X-ray emission, Temperature, Entropy and Pressure maps

→ Shock position consistent with observed SZ effect at the same location

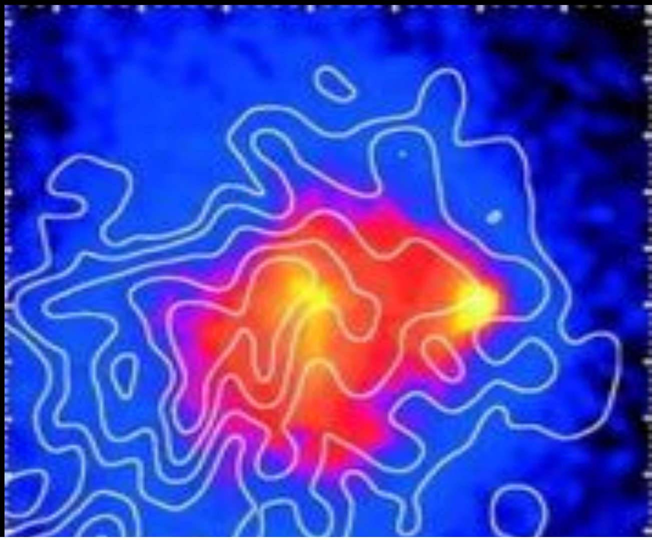
Boehringer et al 2009

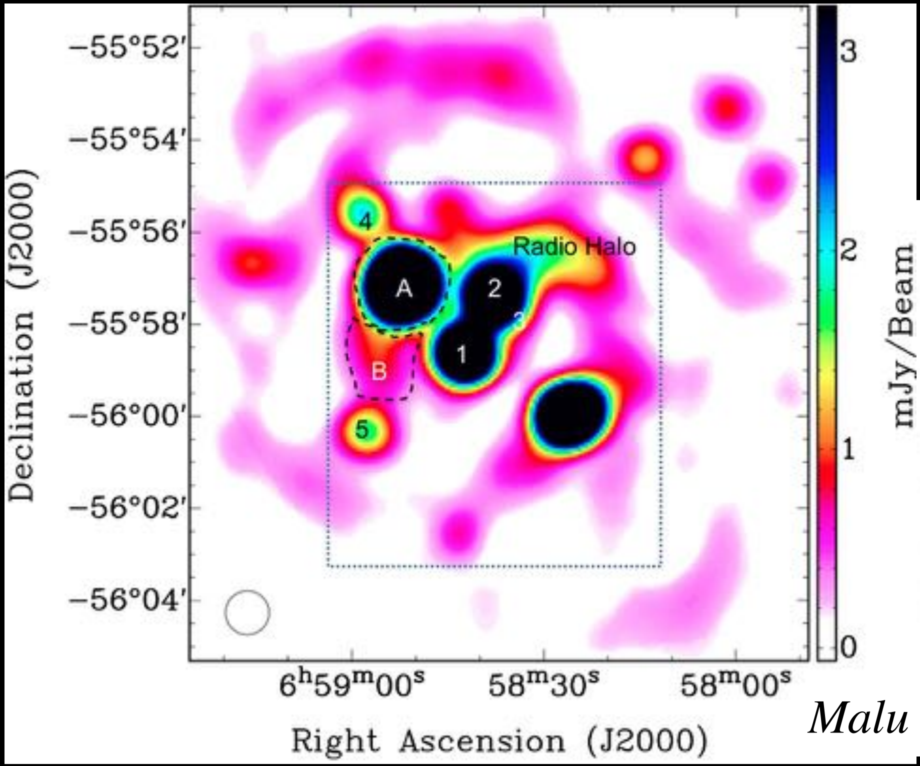
Radio Halo in the bullet cluster

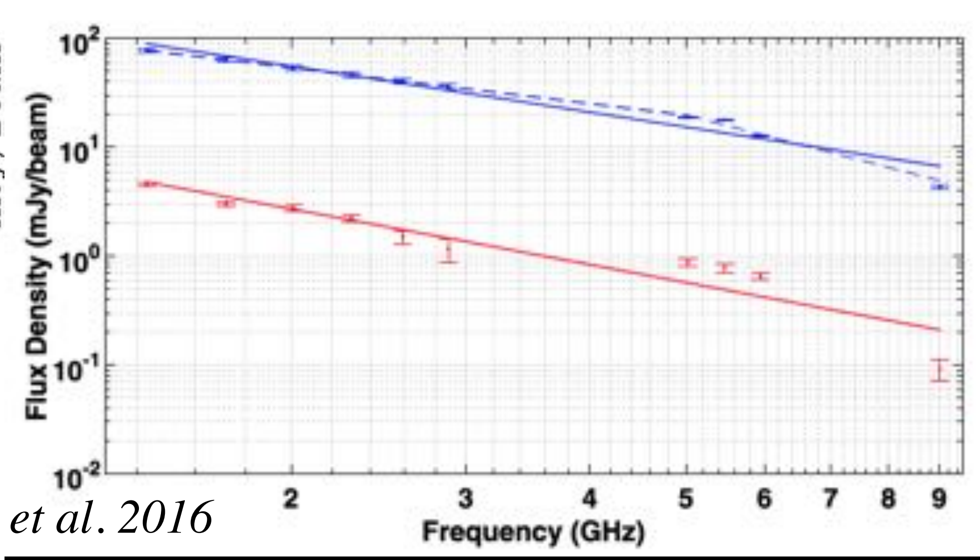
Govoni et al. 2004

…but didn't expect to see any diffuse emission at 18 GHz or higher…

→ Because spectrum of diffuse emission is expected to steepen beyond 5 GHz…



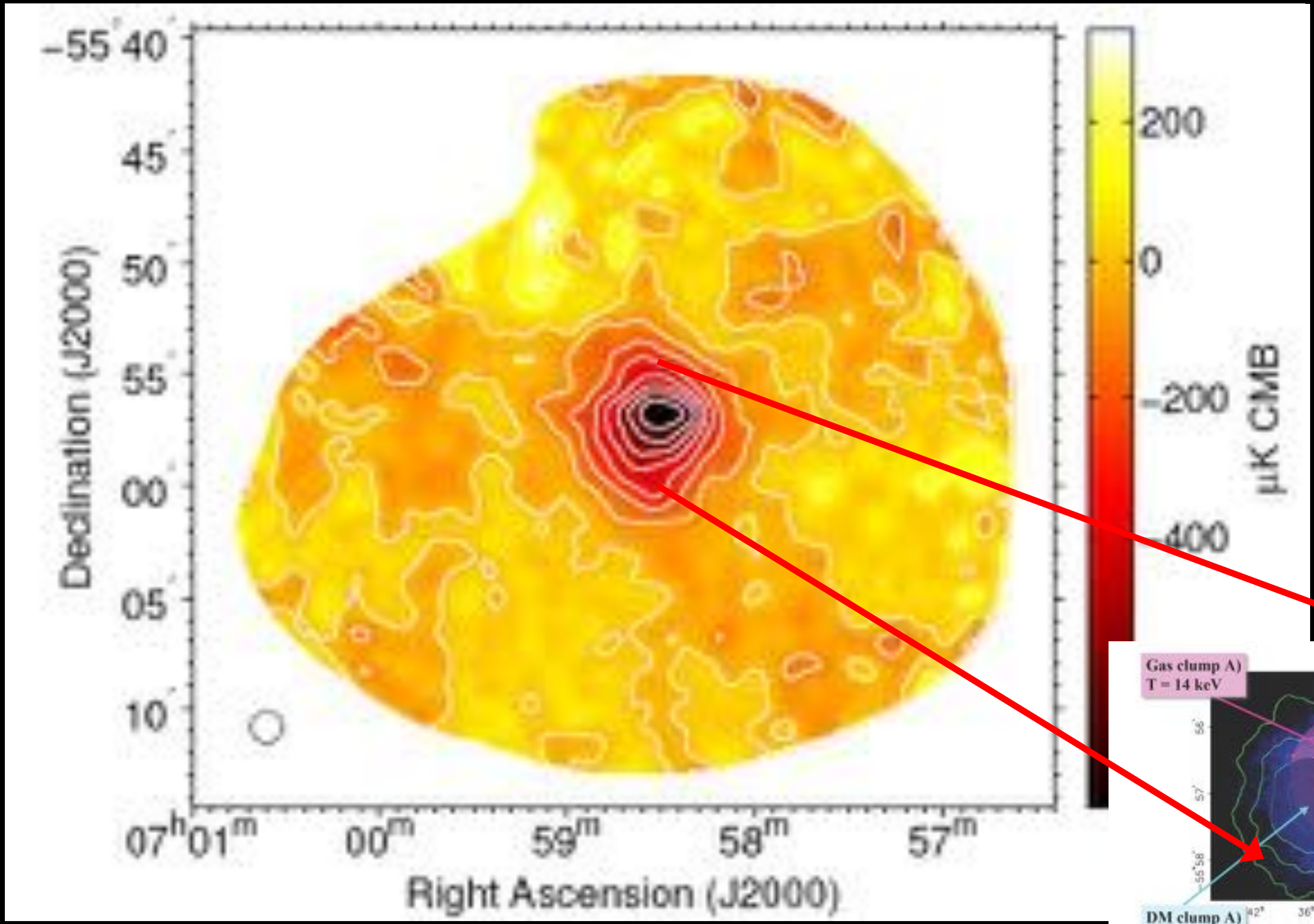


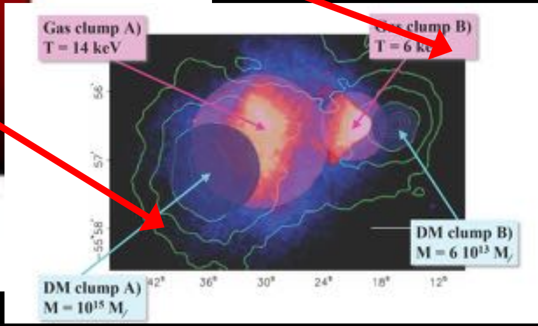


Malu et al. 2016

→ Main aim: probe sub-structure in SZ effect in Bullet cluster at 18 GHz

→ Demonstrate usefulness of cm-wave observations for SZE





Halverson et al. 2009

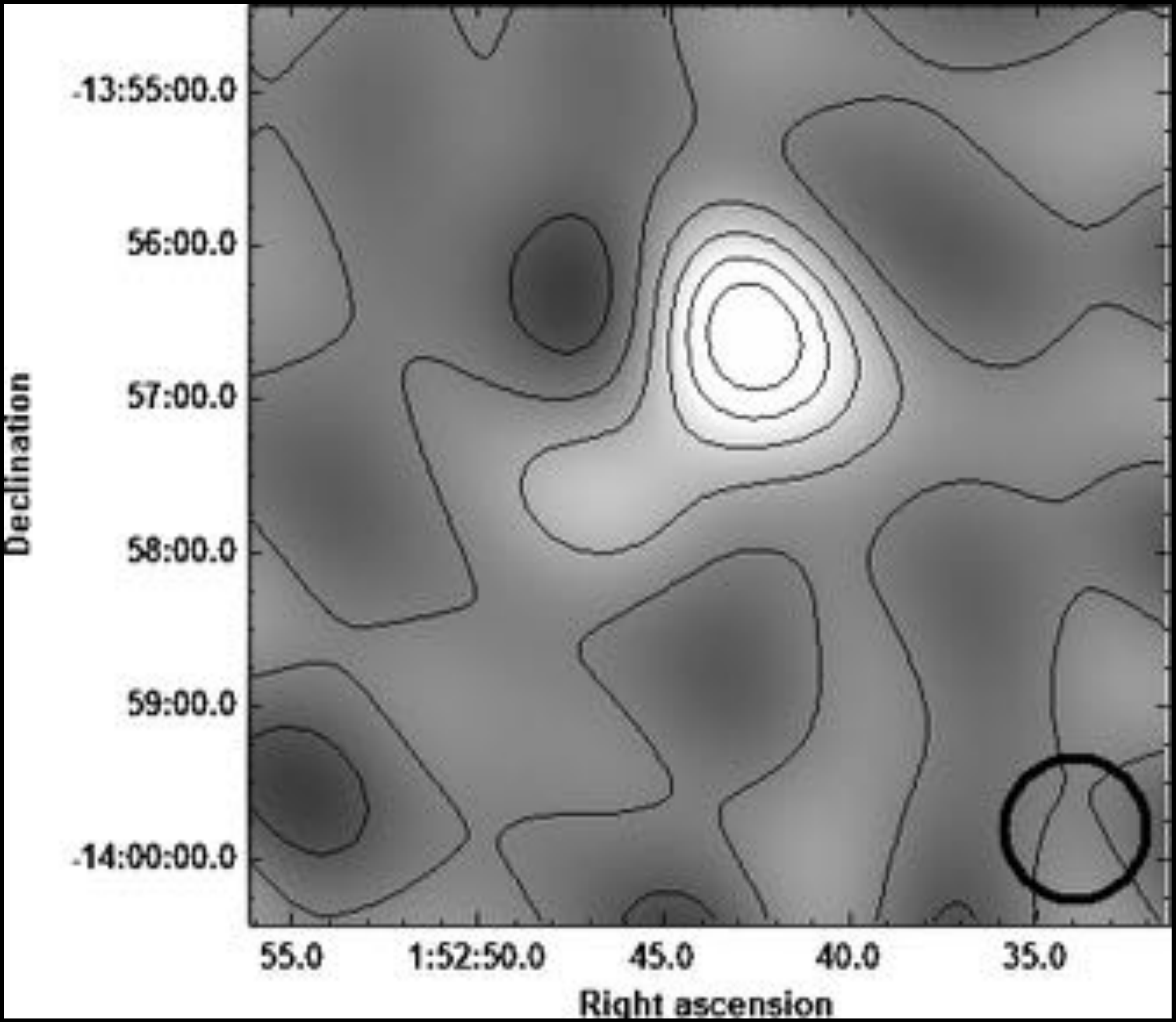
150 GHz APEX SZ Effect map of the Bullet cluster

85 arcsec beam

0.88 mK decrement , contours 0.1mK

Merger activity is expected to affect the SZE,

…but this single-dish image does not show any structure in SZE…



Massardi et al. 2010

→ SZ Effect Detection using the ATCA

→ Robust detection

→ Luckily, no diffuse emission in this cluster

ClJ0152-1357

SZ Effect at 18 GHz from interferometric observations

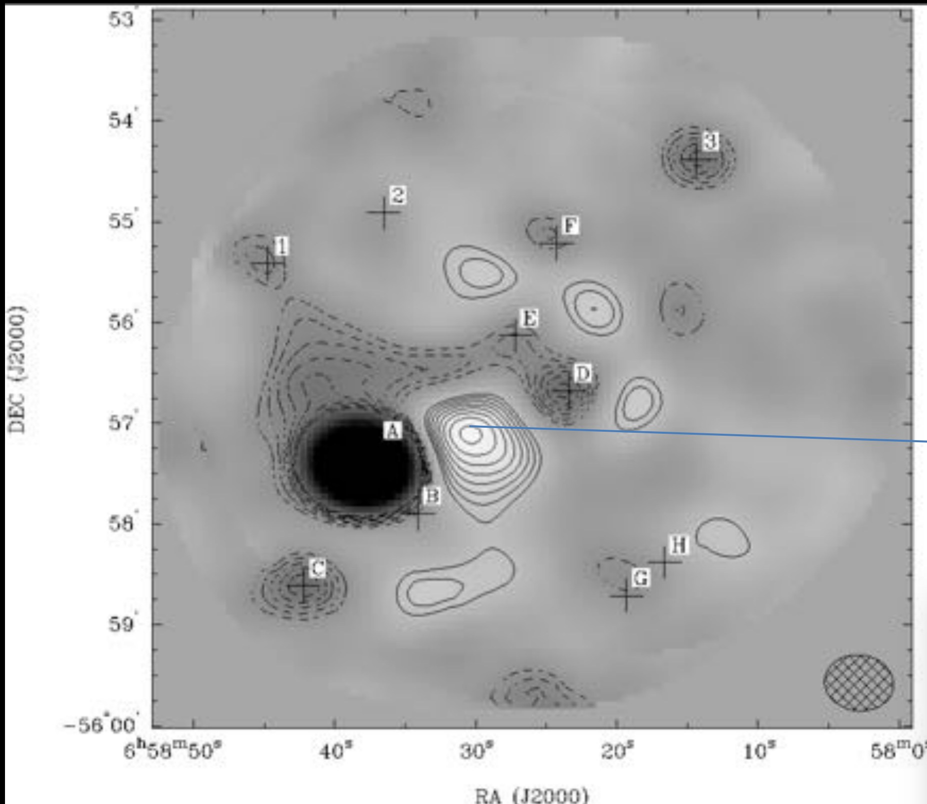
Bullet cluster at 18 GHz

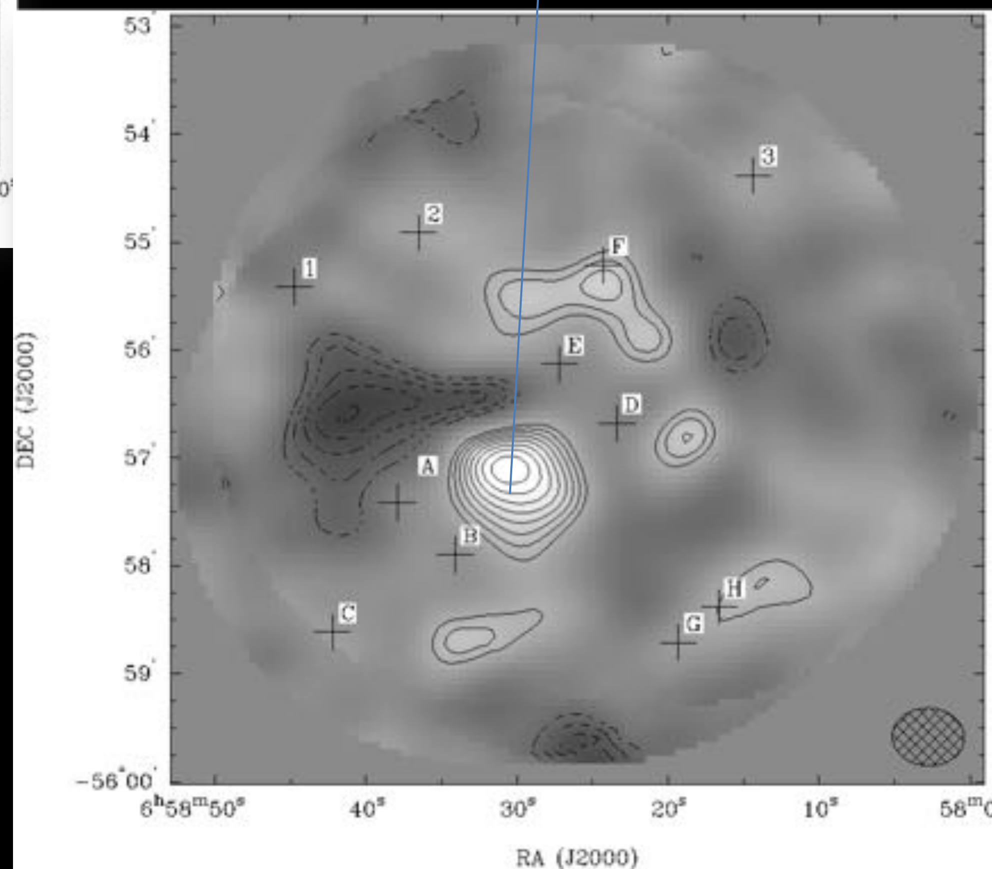
7 μJy/beam rms noise

Dark = +ve

Light = -ve

Radio Halo Location





38x32 arcsec beam

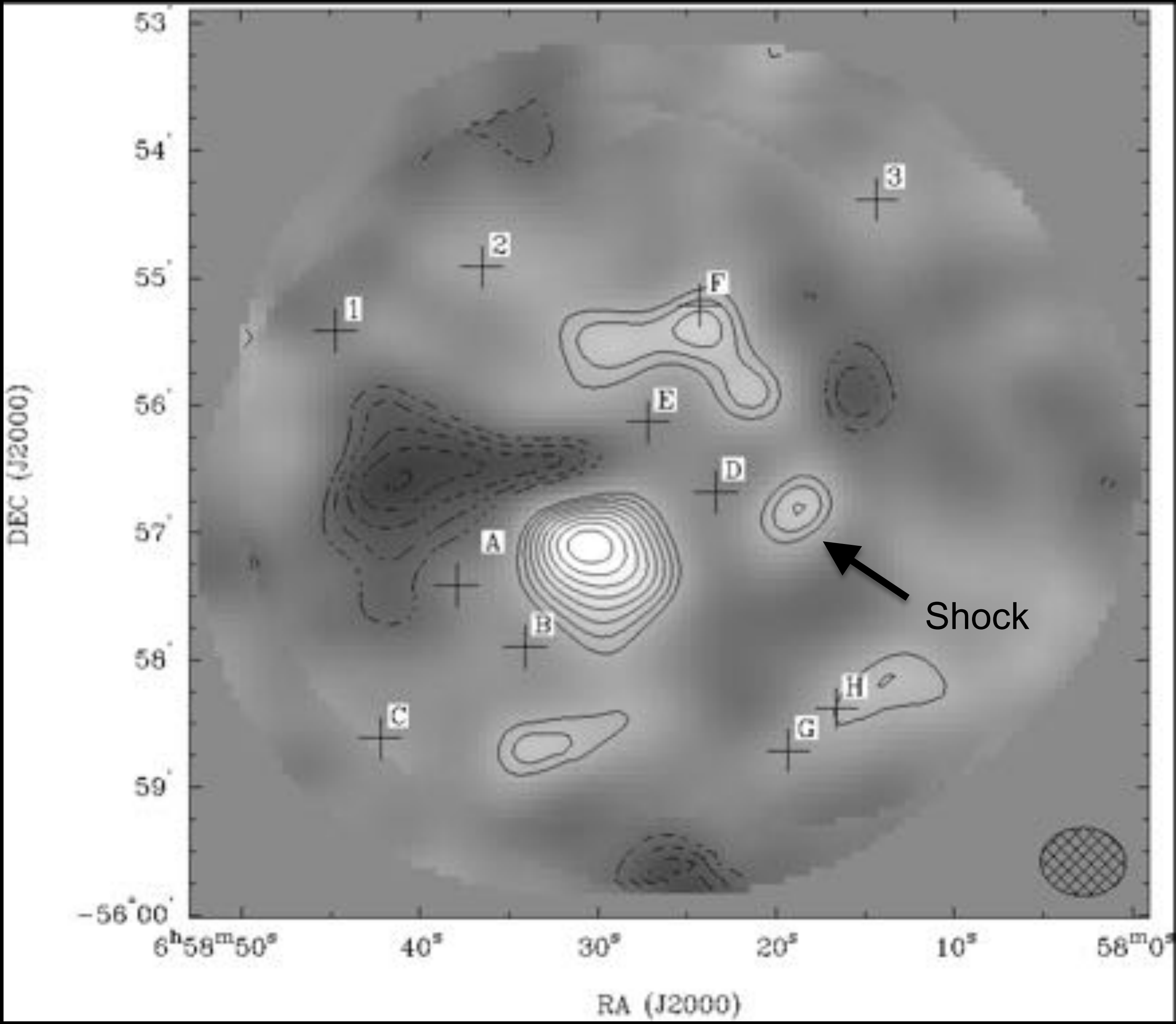
7 μJy/beam rms noise

Peak +ve feature: 60μJy/beam

Deepest -ve feature: -83μJy/beam

$\pm(3,4,5,6,7,8,9,10)\sigma$

The Bullet cluster at 18 GHz



38x32 arcsec beam

Dark = +ve
Light = -ve

Noise RMS
7 μJy/beam

±(3,4,5,6,7,8,9,10)σ

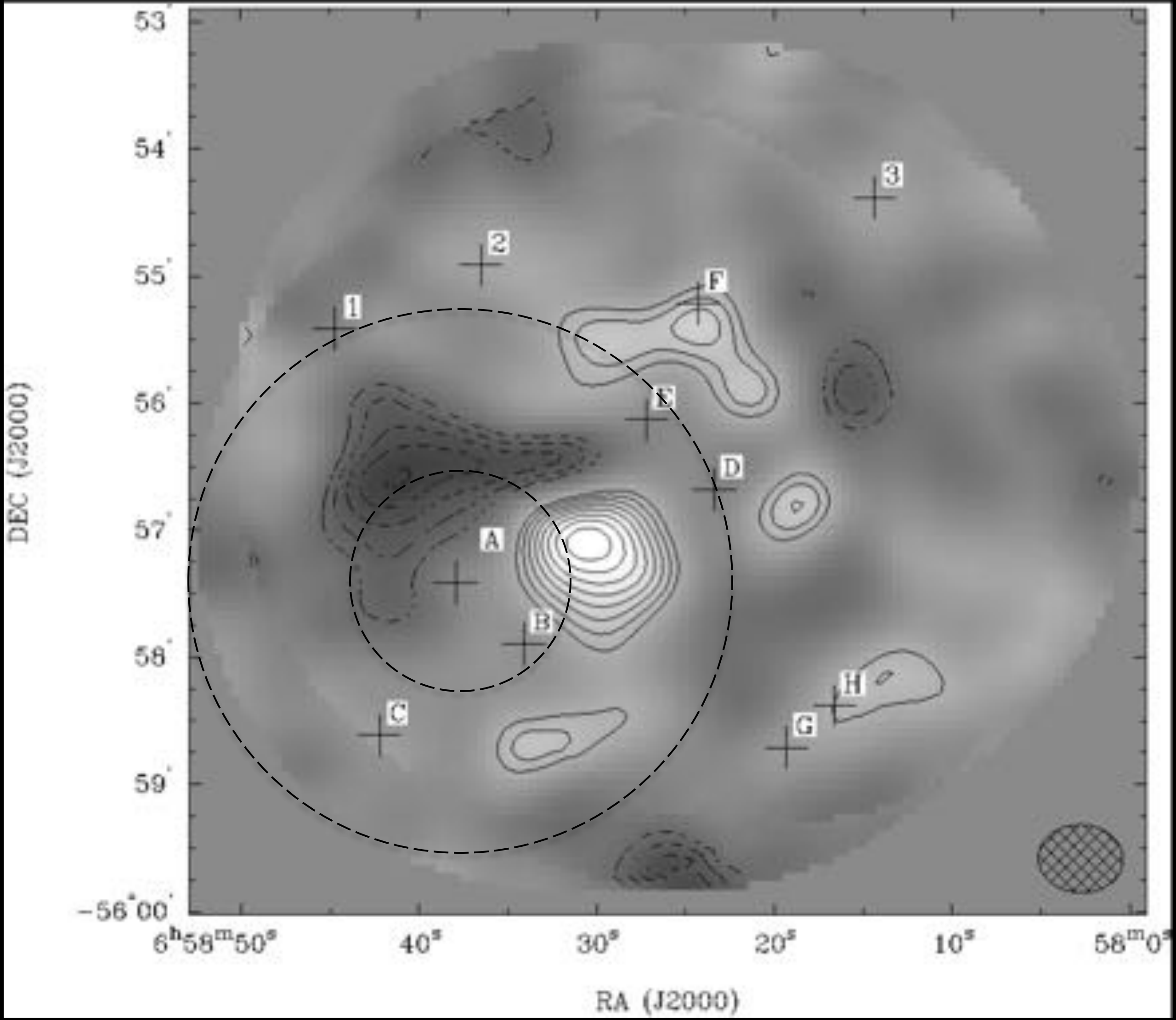
Peak +ve feature: 60μJy/beam
Deepest -ve feature: 83μJy/beam

A consistency test:

Compare the data in the ring with the data in the same ring in Stokes-V map, using a non-parametric test

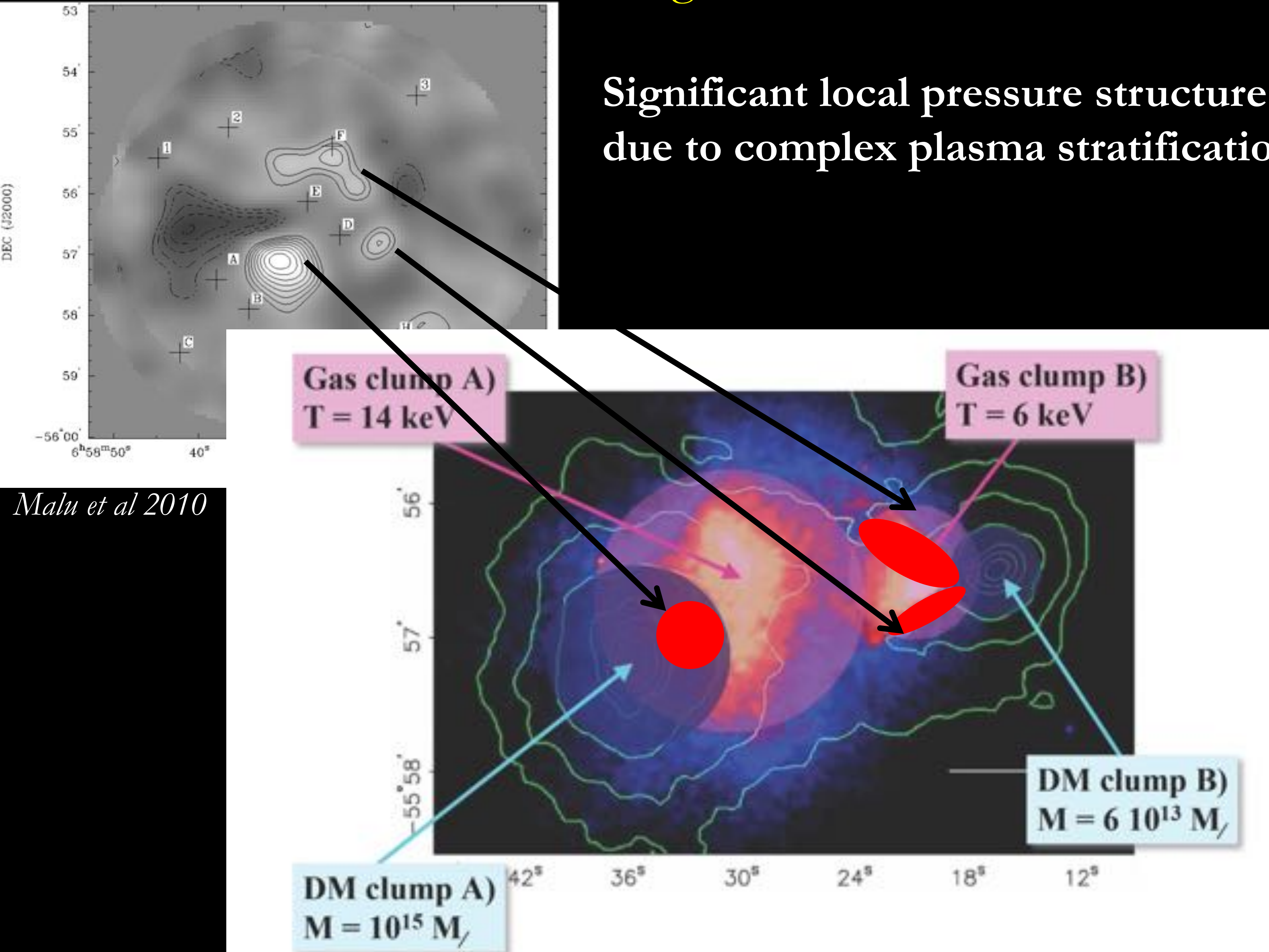
Result: p-value<0.0001, i.e. inconsistent with noise at high significance

z-value~-14



The 18 GHz interferometric image shows several features…

Significant local pressure structures due to complex plasma stratification



Malu et al 2010

Some surprises …

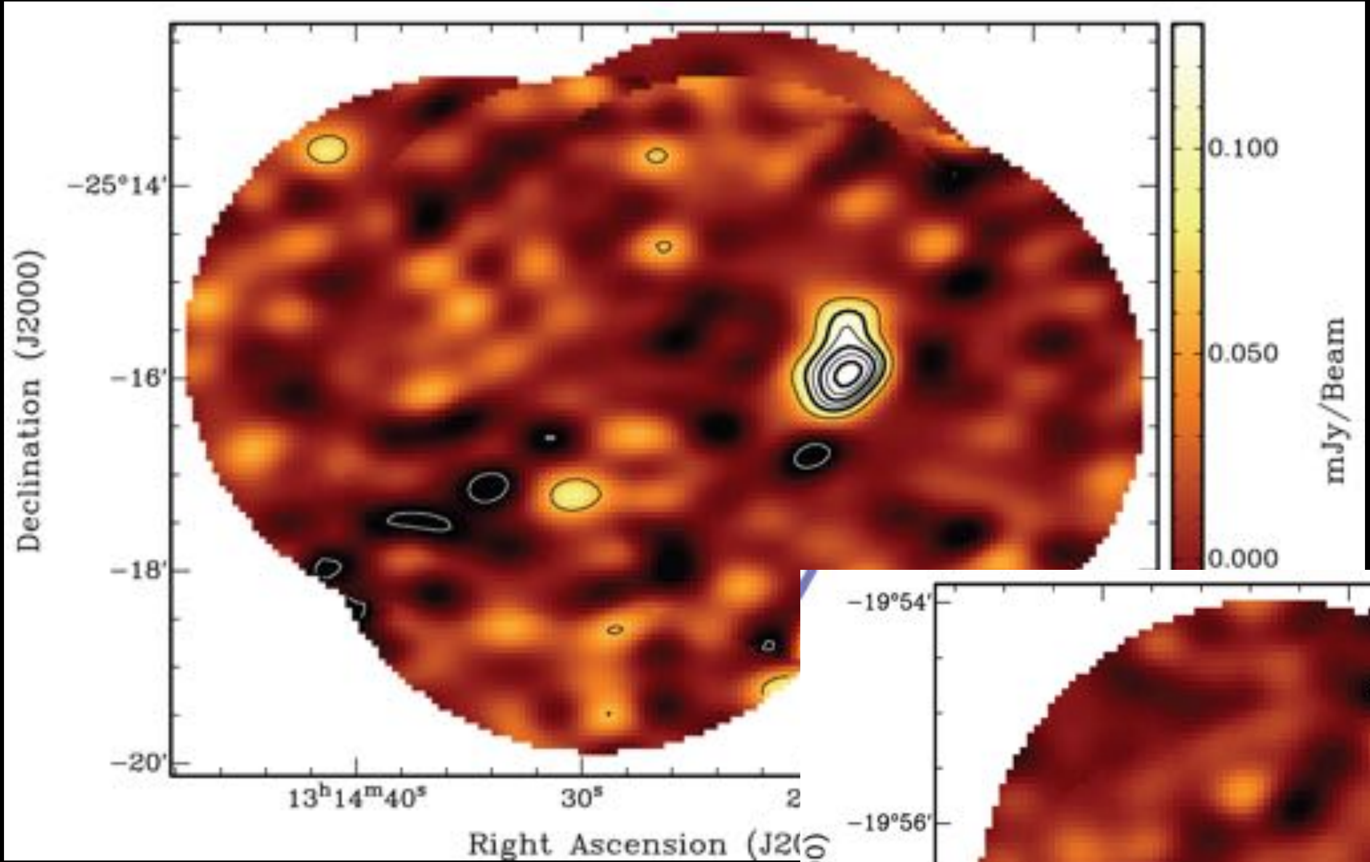
→ Diffuse emission at 18 GHz

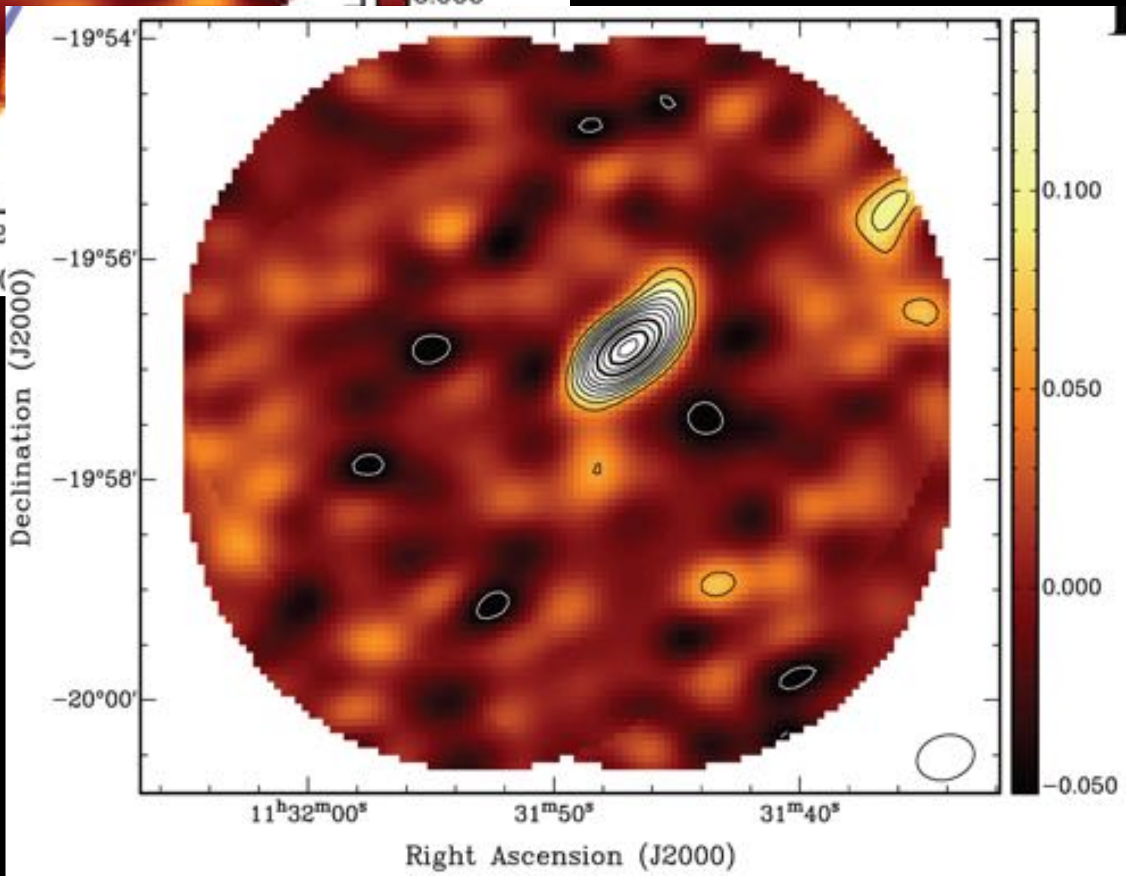
With spectral steepening at ~ 6 GHz, expected a peak of ~ 10 μJy/beam (i.e. < 2σ); get ~ 60 μJy/beam

→ SZ Effect displaced from X-ray brightness centre

Significant displacement of SZE from X-ray is observed in other merger clusters as well

-- Similar to Massardi et al. 2010





Radio relics
at 18 GHz
from ATCA

Conclusions

- First detection of diffuse emission in a cluster at 18 GHz
- Merging clusters great for studying complex dynamics and physics
- Integrated Compton parameter (SZE) is a good tool for probing dynamics, BUT SZE and diffuse emission 'contaminate' each other
- Need to figure out how to model or estimate either SZE or diffuse emission exactly with the same uv-coverage. Right now, high-frequency SZE observations @ very low resolution only → complete uv-coverage mismatch!