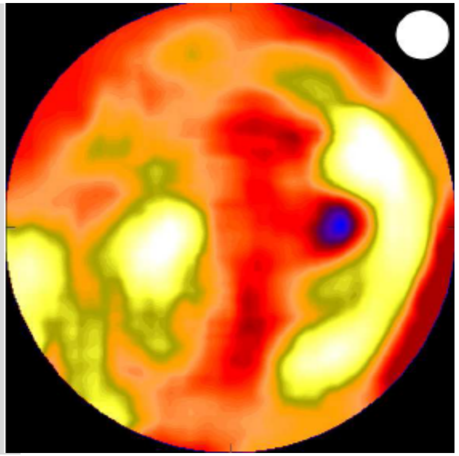
# The SZ Effect in the PLANCK & HERSCHEL Era



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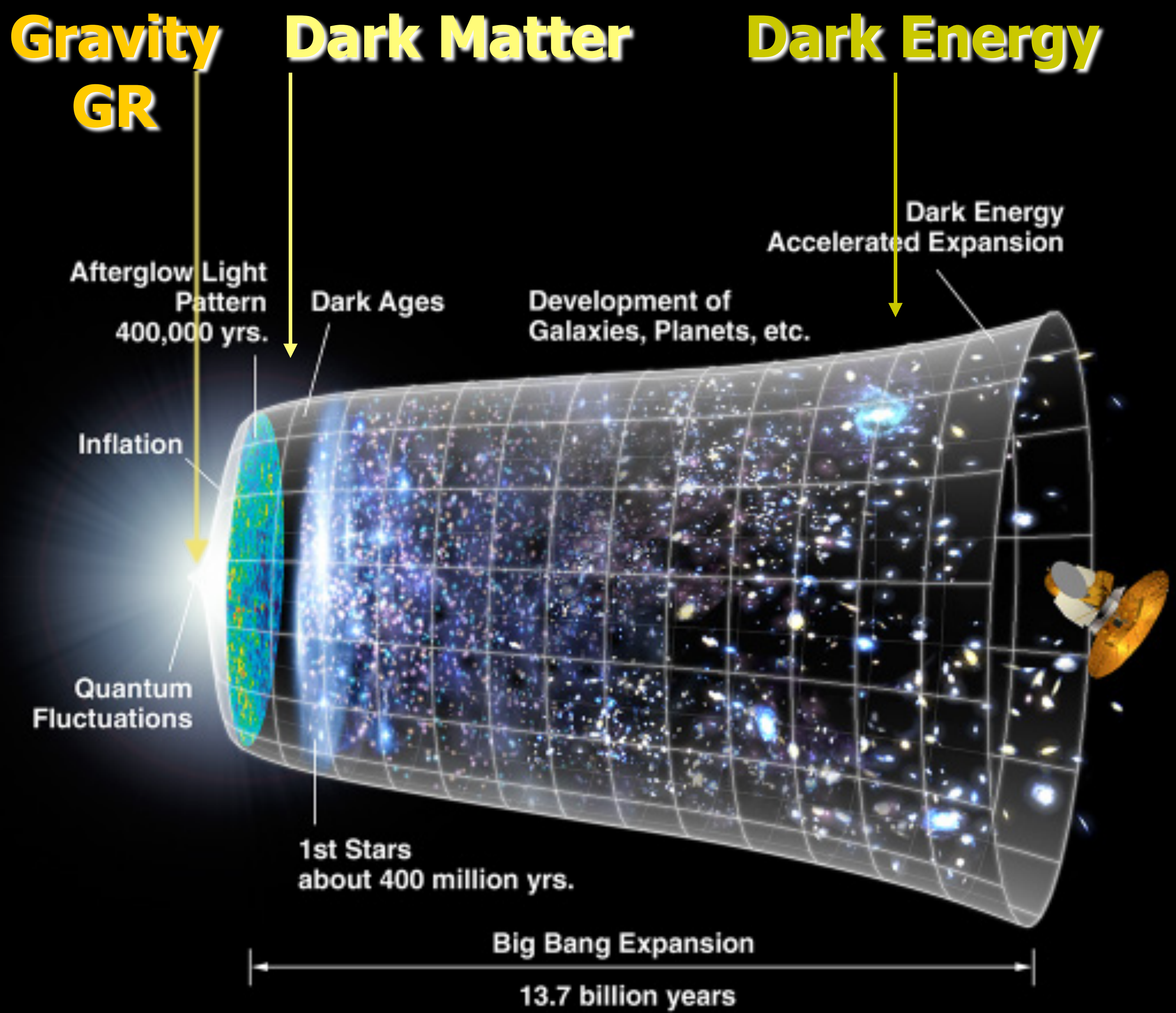
Email: Sergio.Colafrancesco@wits.ac.za

# The Cosmic History



# Cosmology with Cosmic Structures

UNIVERSE **Probes** **Tools** **Utensils**


DM-meter

DE-meter

G-meter

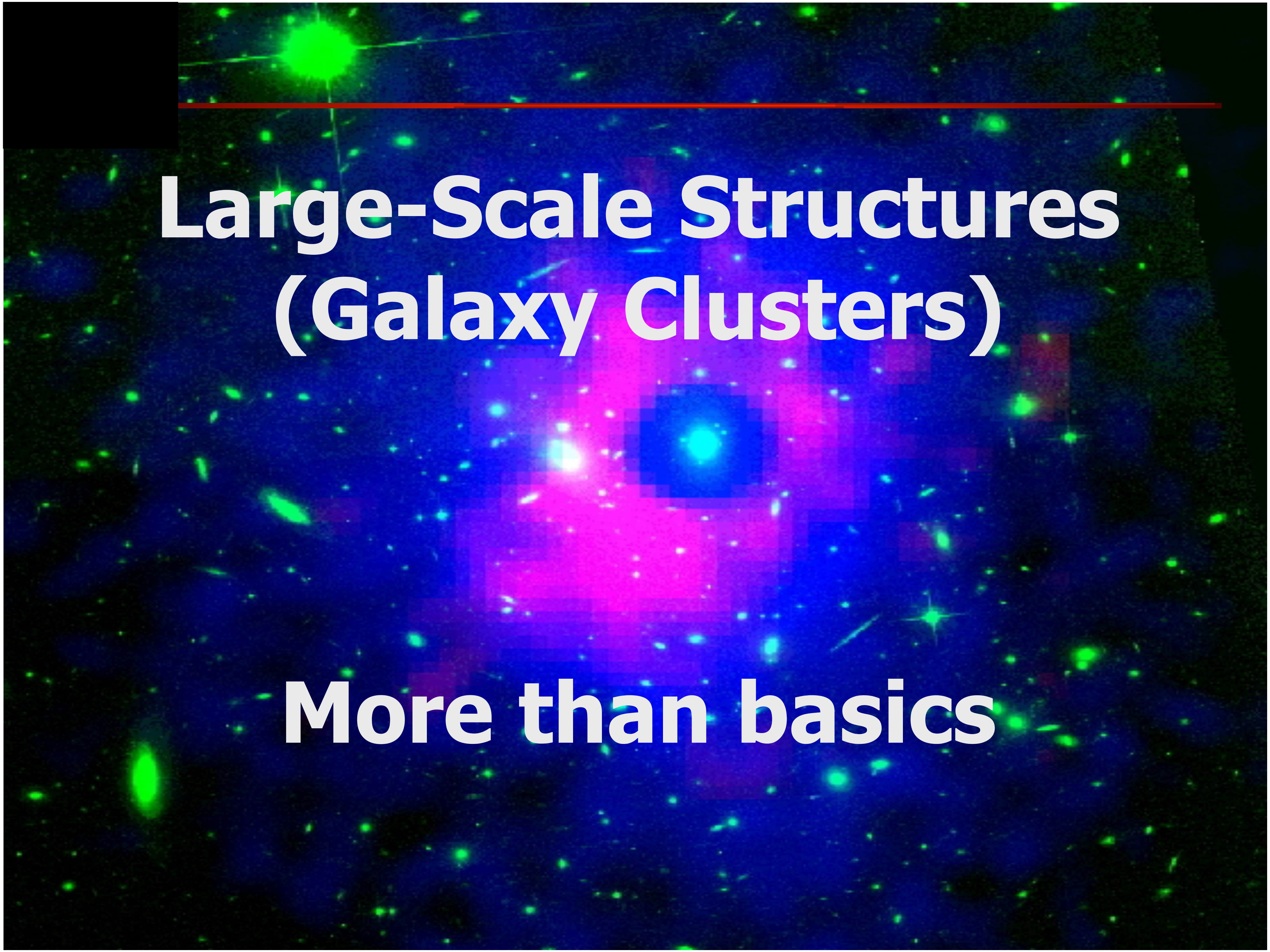

Jet-feedback

BHs

**Baryons**

B-field

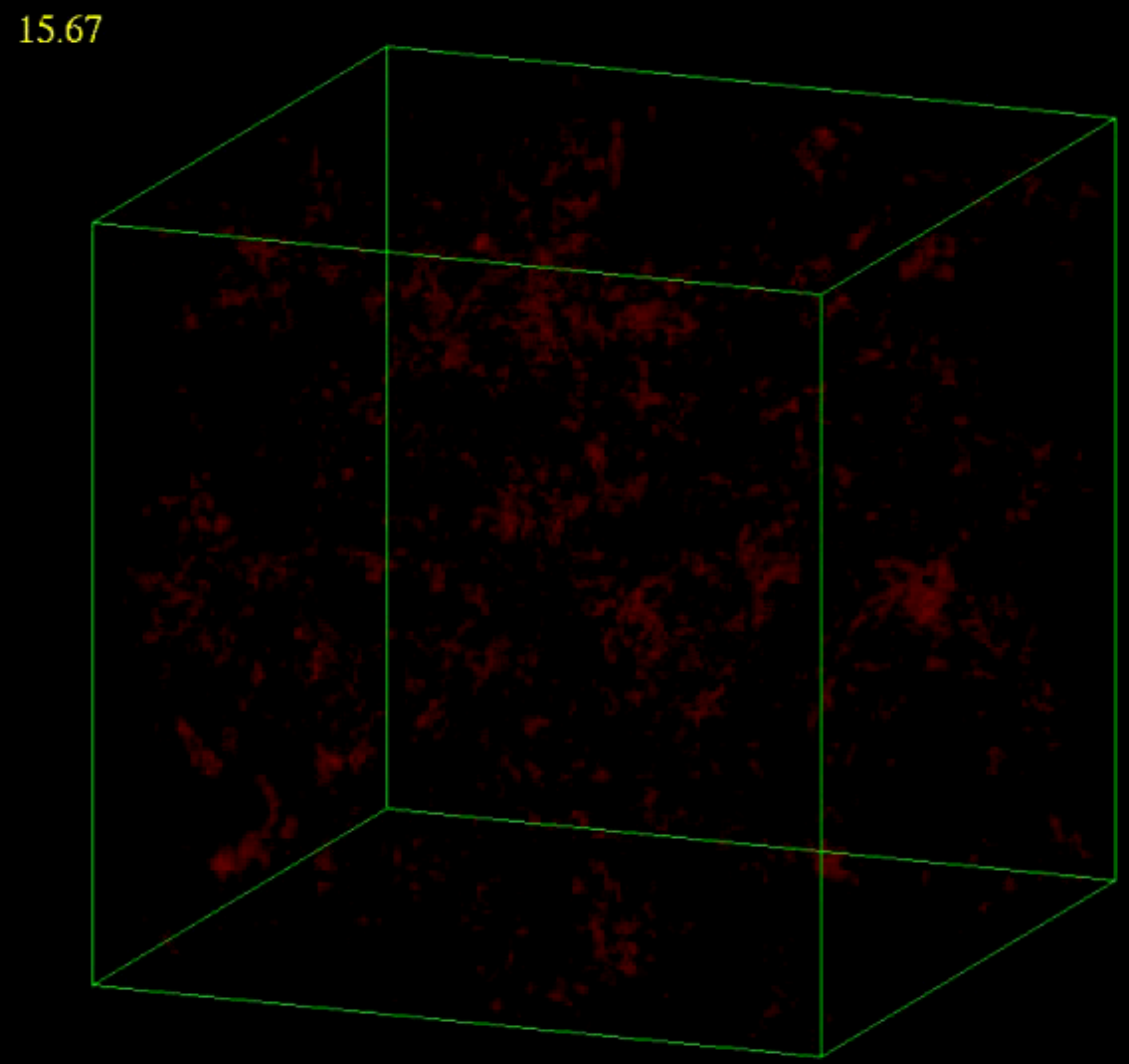
Cosmic Rays



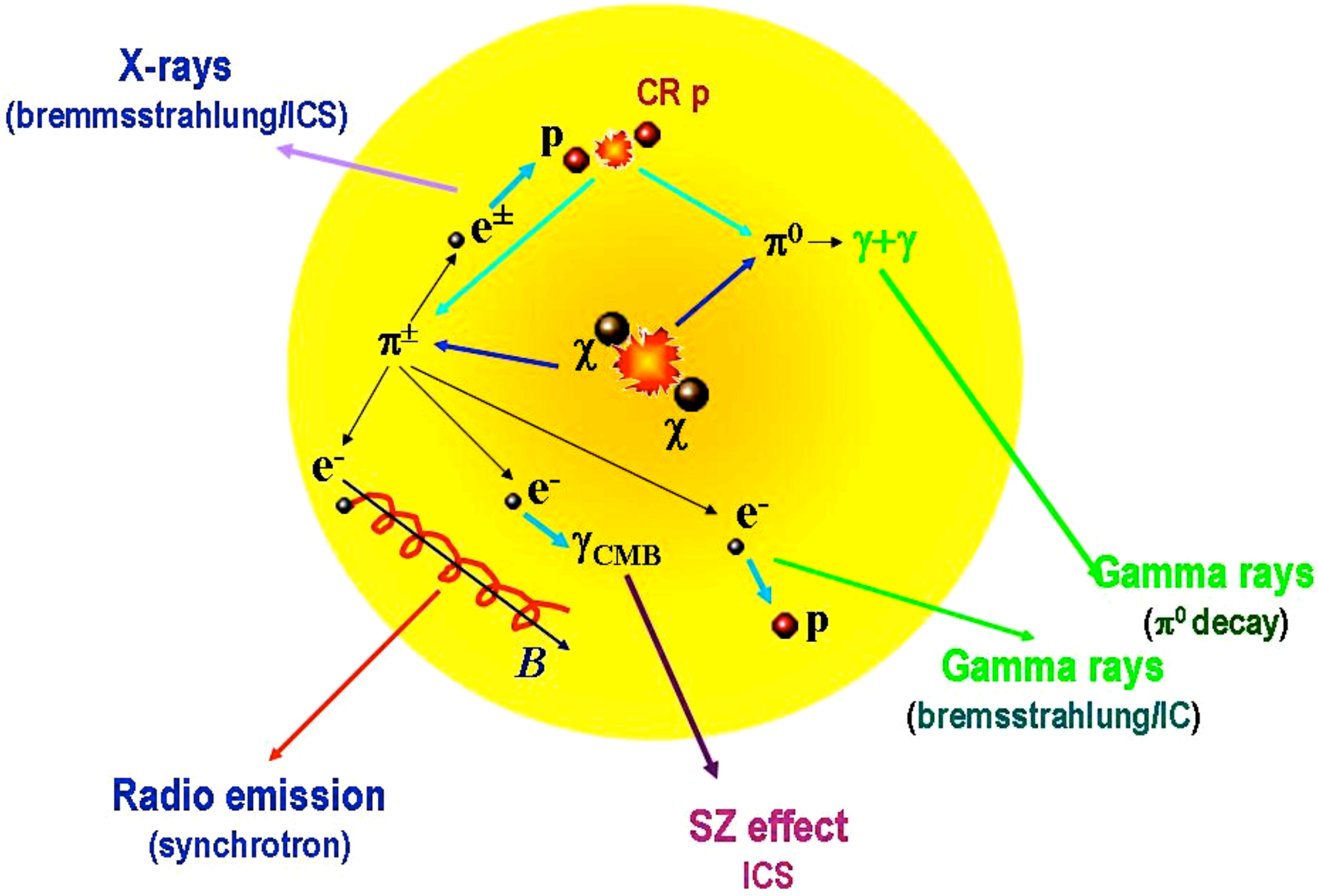
# Large-Scale Structures (Galaxy Clusters)

## More than basics

# LSS and Dark Matter



# Dark Matter nature



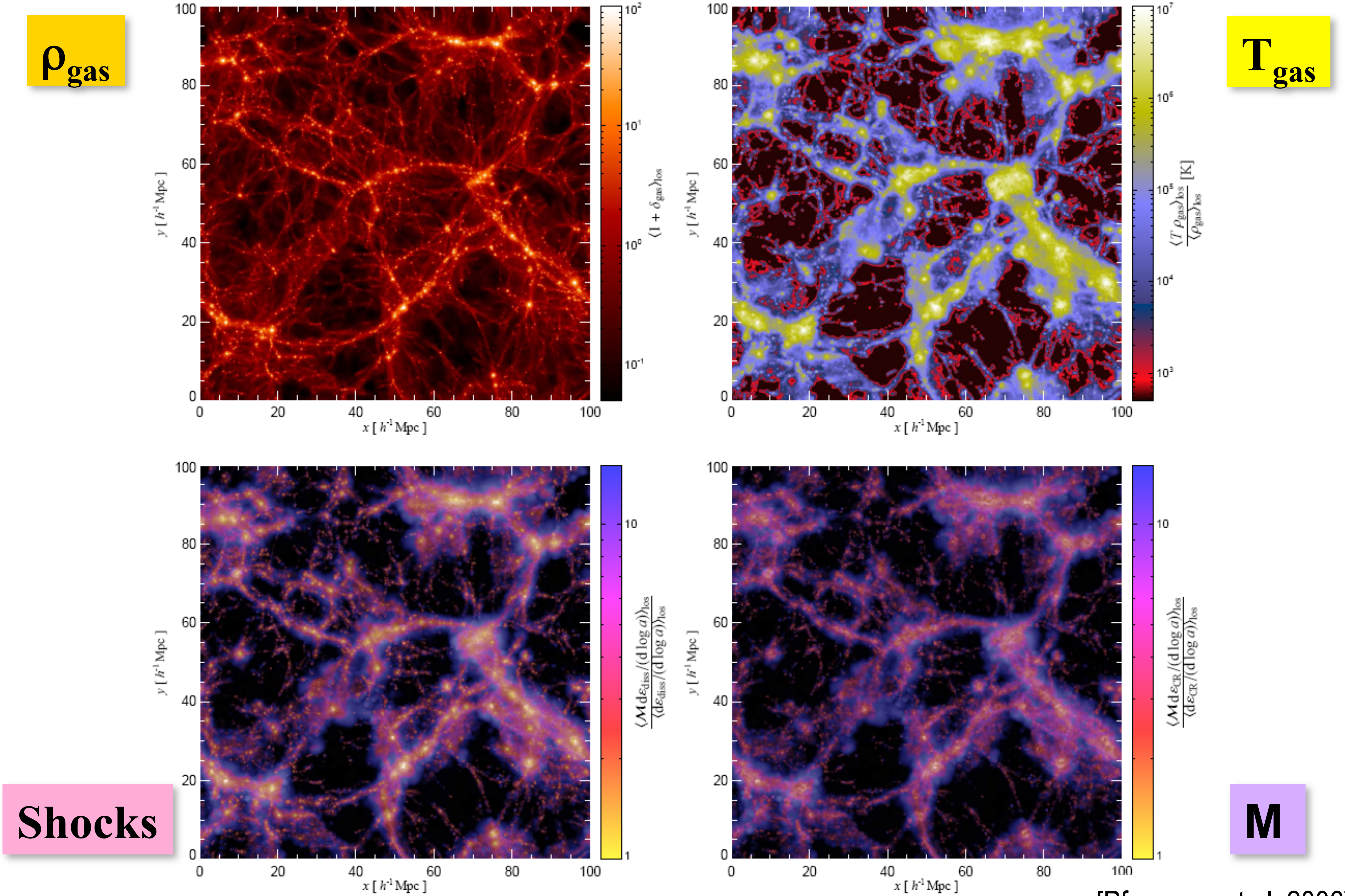

Bullet cluster

MACS J0025.4-1222

ZwCl0024+1652

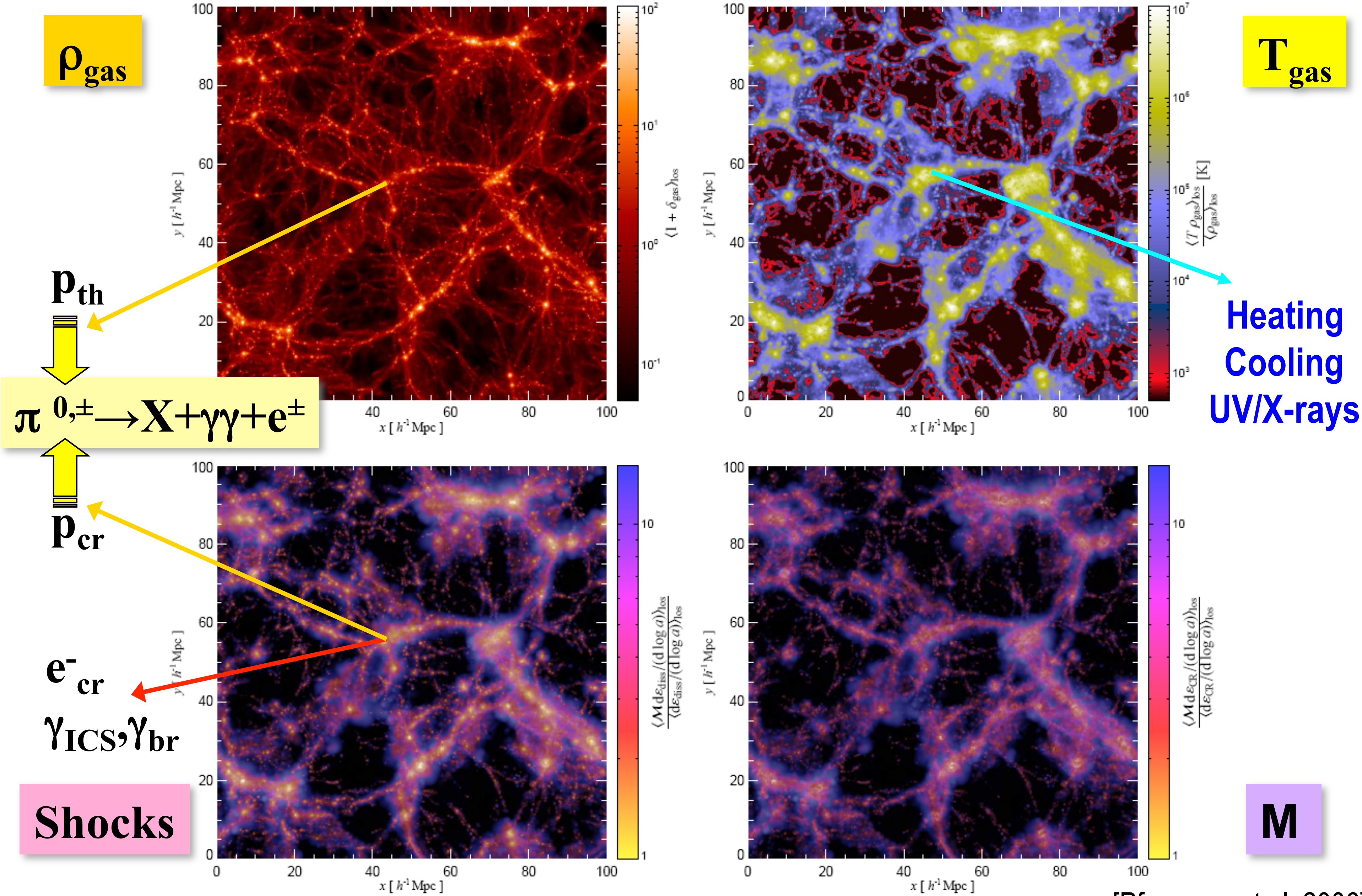
[Colafrancesco 2006, 2007]

# LSS shock waves




[Pfrommer et al. 2006]

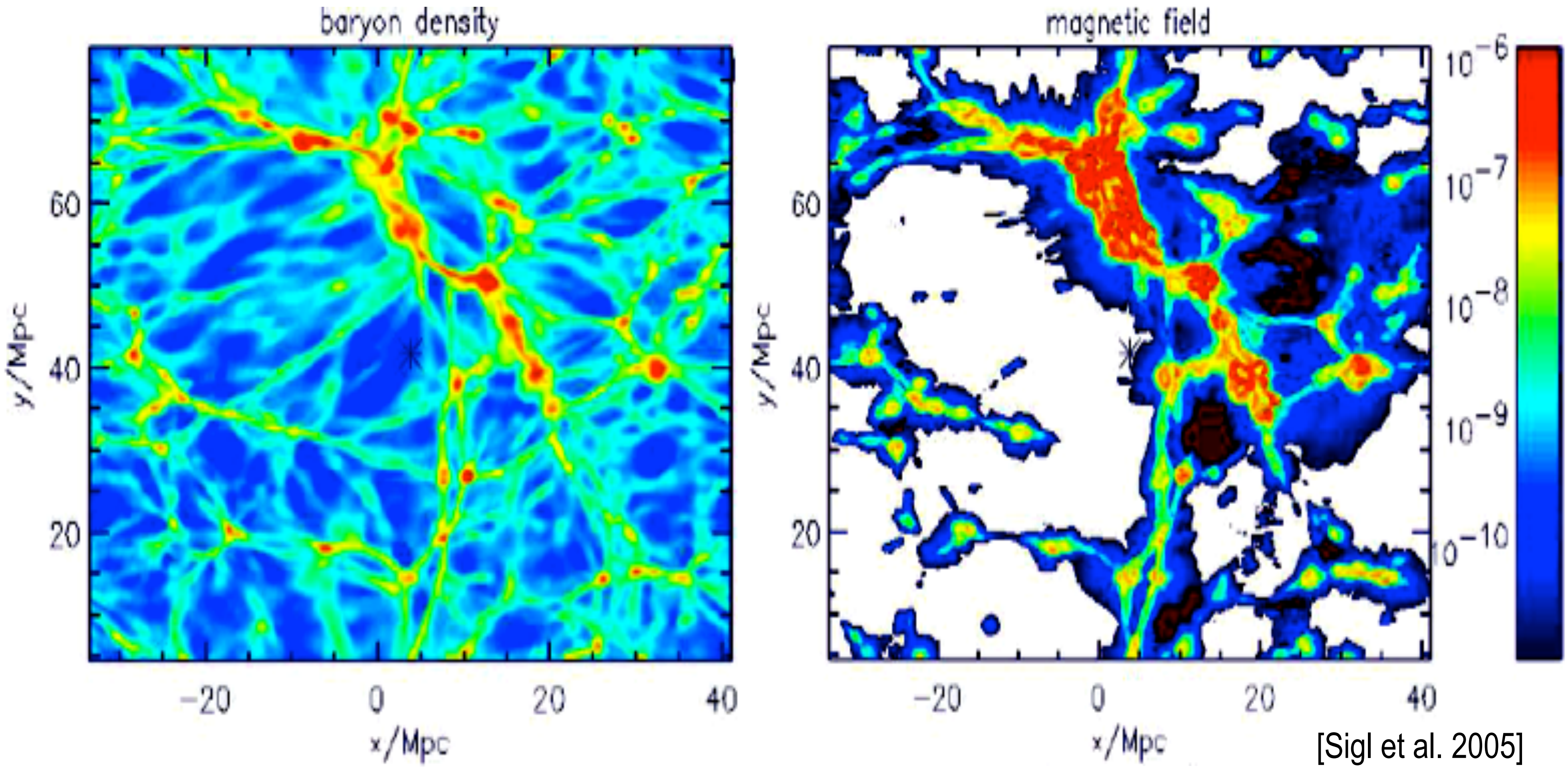
# LSS shock waves




[Pfrommer et al. 2006]

# Magnetic fields in LSS

**Origin** → Primordial / Post-recombination → G + MHD → $\mathbf{B}(\delta\rho, z; P_k)$




[Sigl et al. 2005]

# B-field in clusters: evidence

## Synchrotron radiation

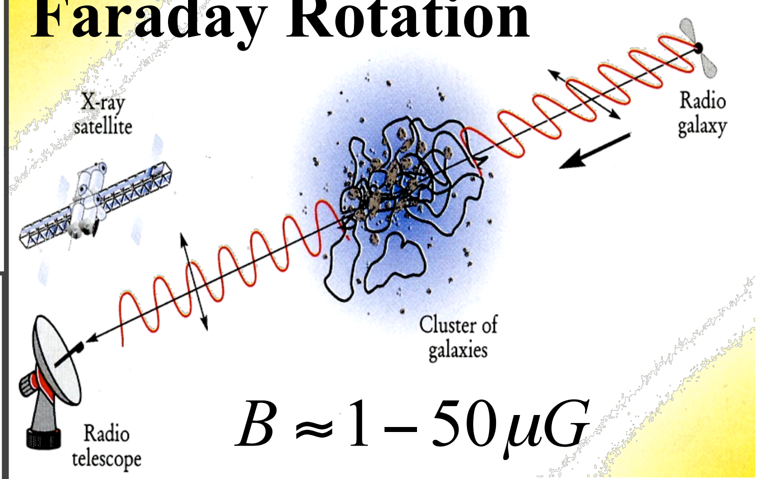

### Radio Halos

$$B \approx 0.1 - 5\mu G$$

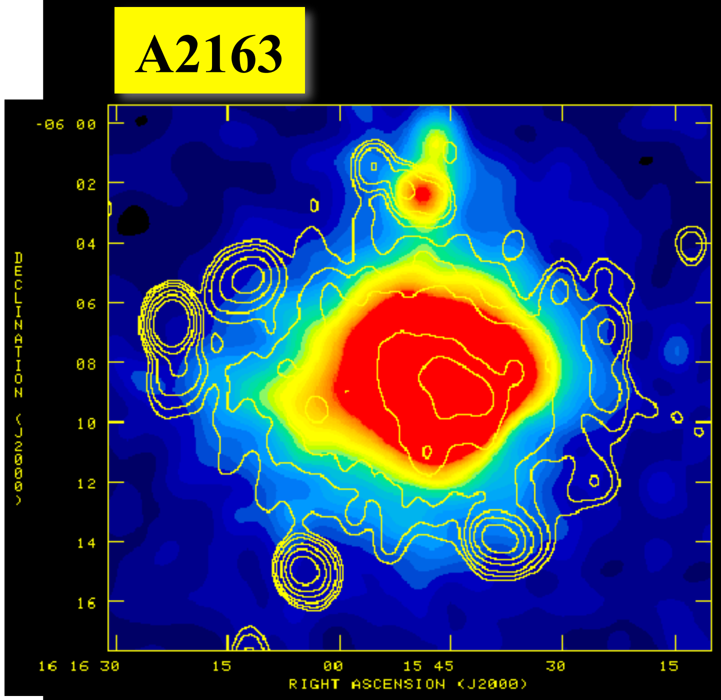
### Radio Relics

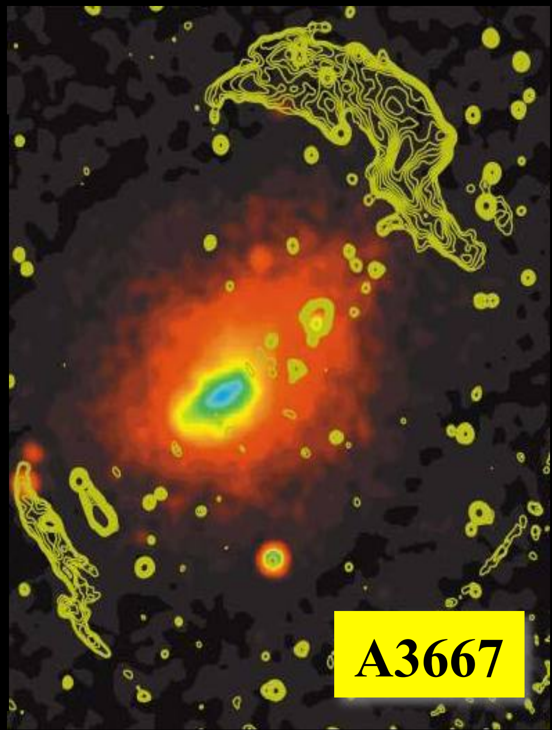
$$B \approx 0.2 - 8\mu G$$

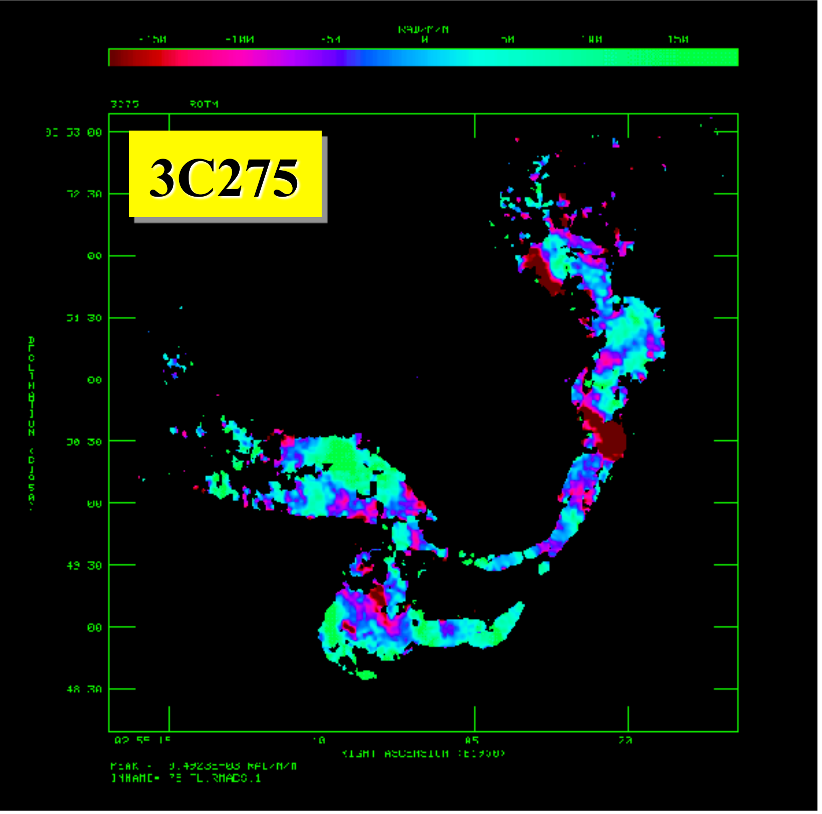
## Faraday Rotation



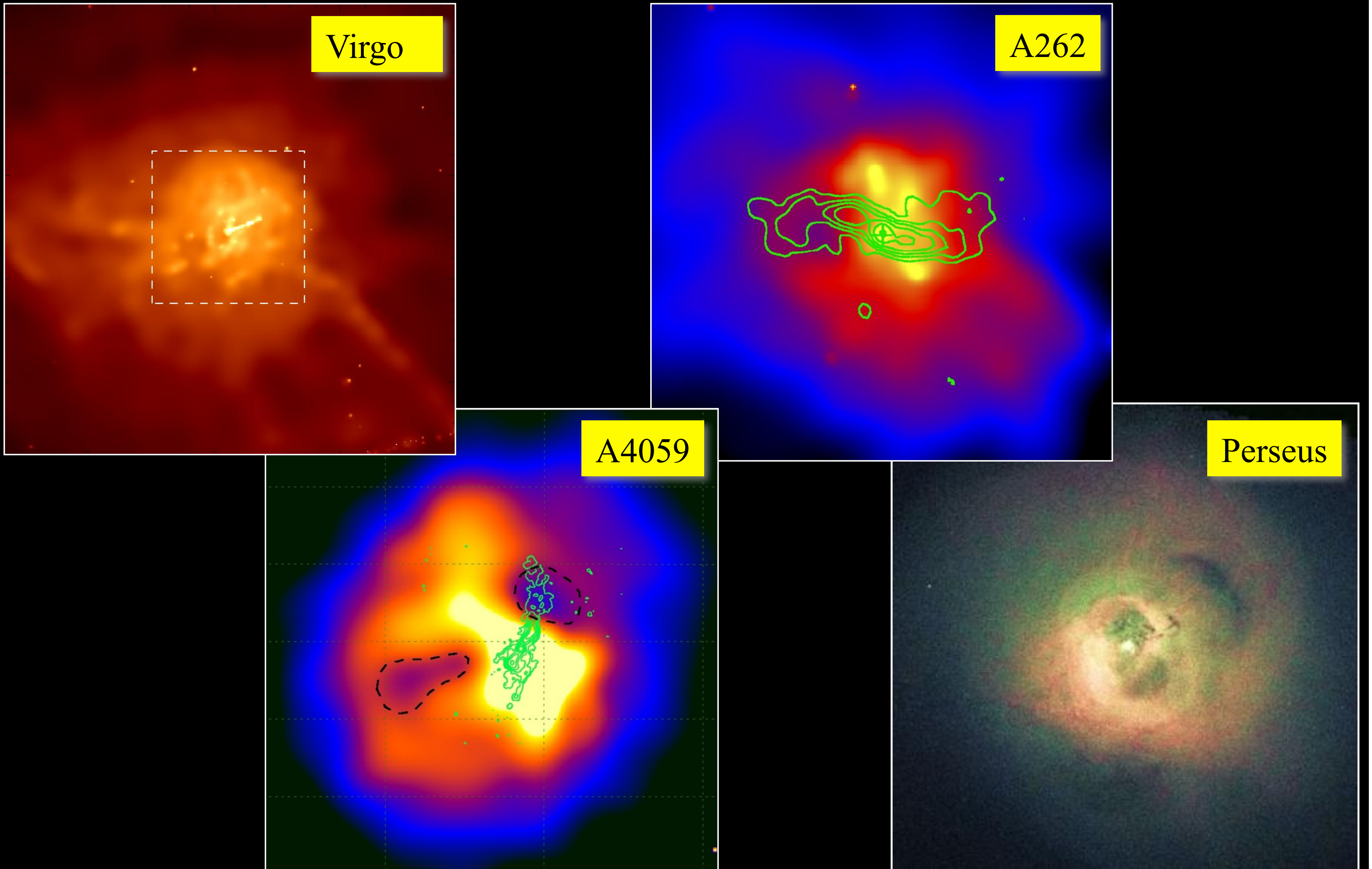

$$B \approx 1 - 50\mu G$$



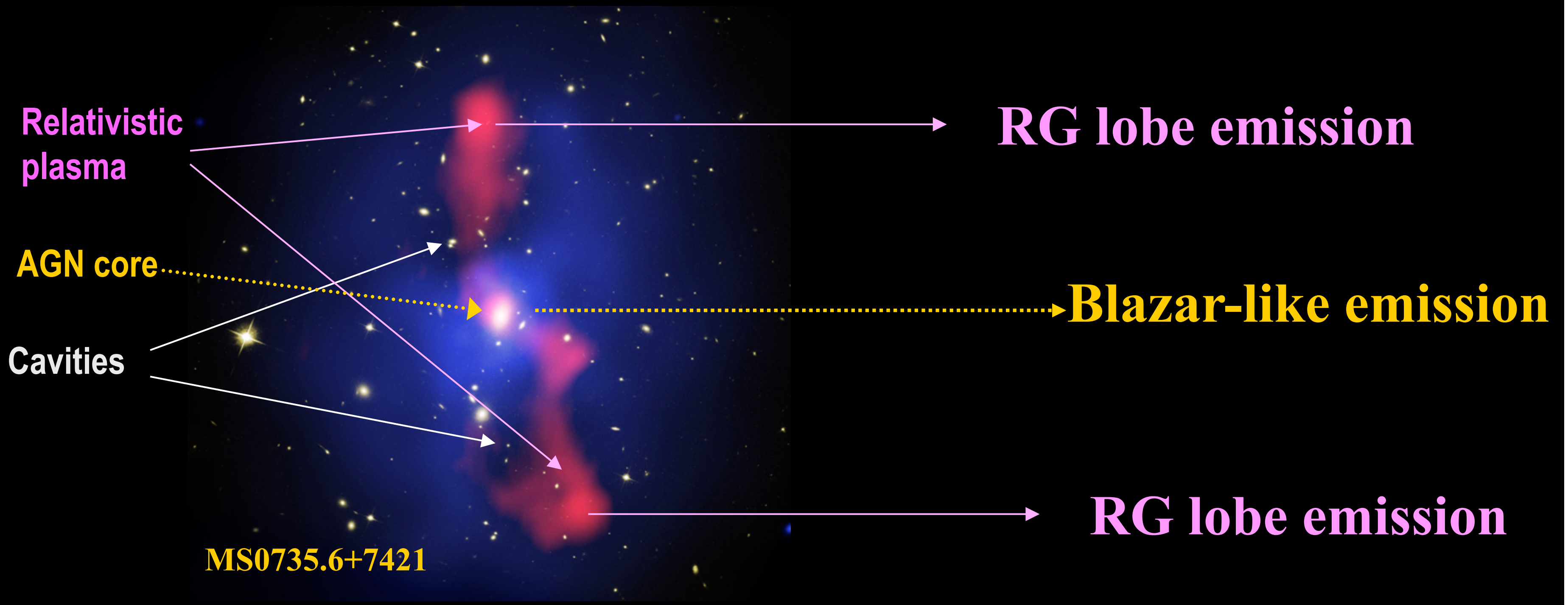



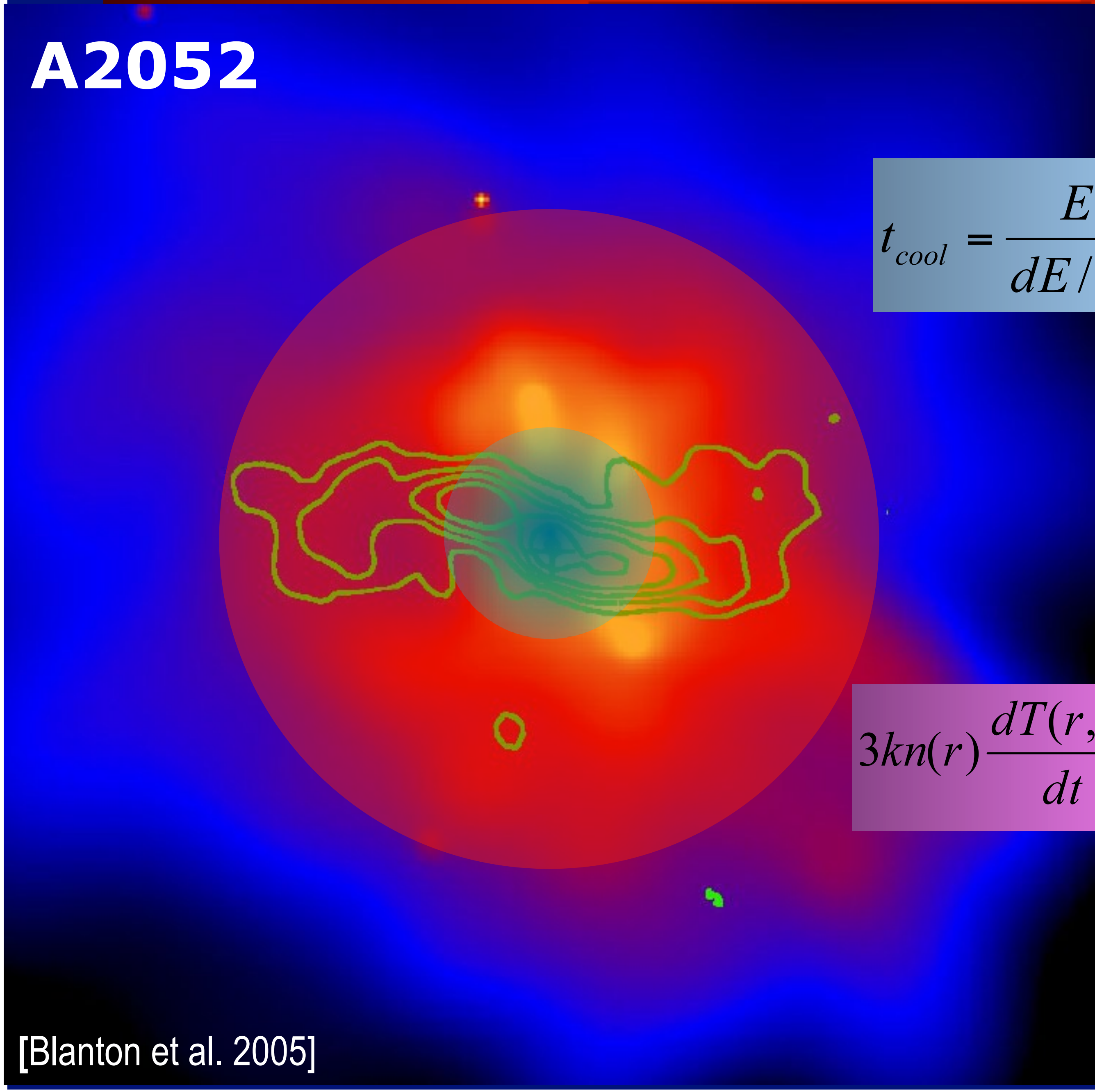
# BHs in galaxy clusters: evidence



# BHs in galaxy clusters: ejecta



# Cooling or not cooling ?



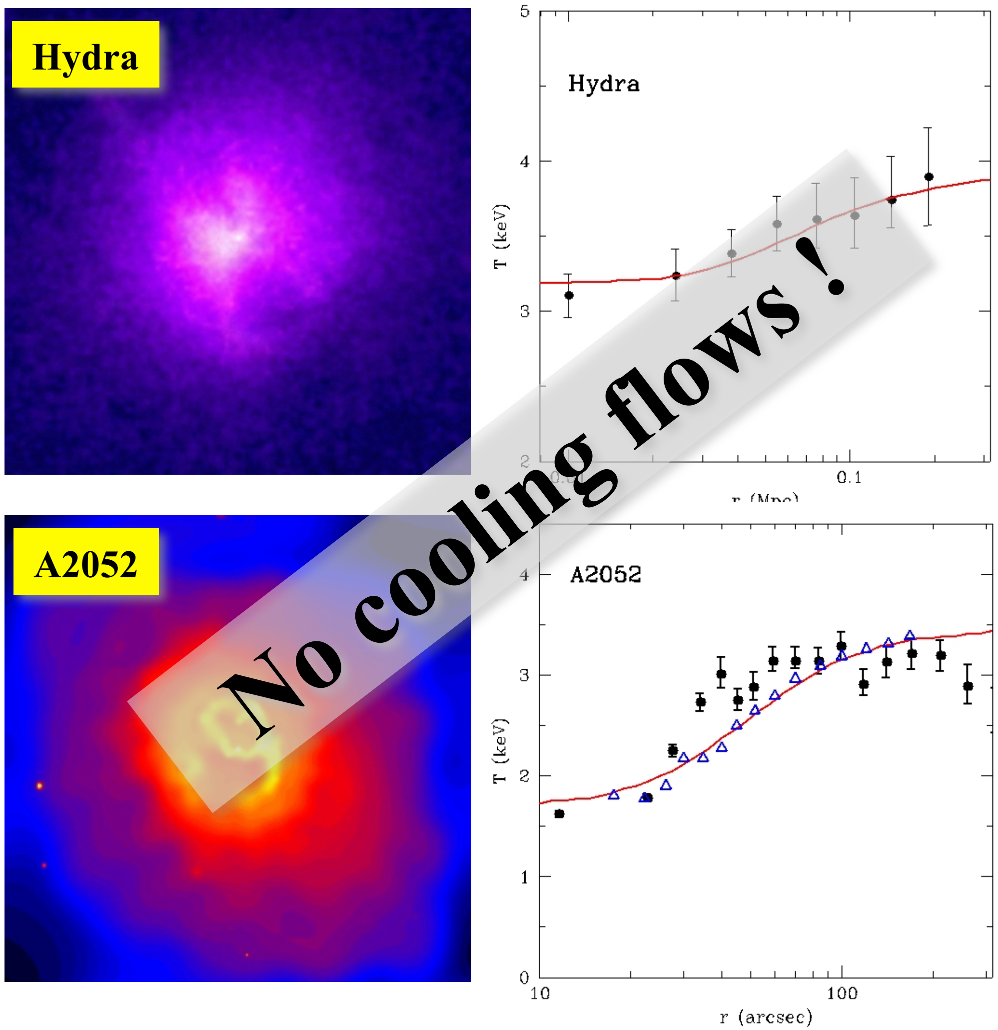

$$t_{cool} = \frac{E}{dE/dt} = \frac{E}{L} \approx \frac{nkT}{n^2\sqrt{kT}} = \frac{\sqrt{kT}}{n}$$

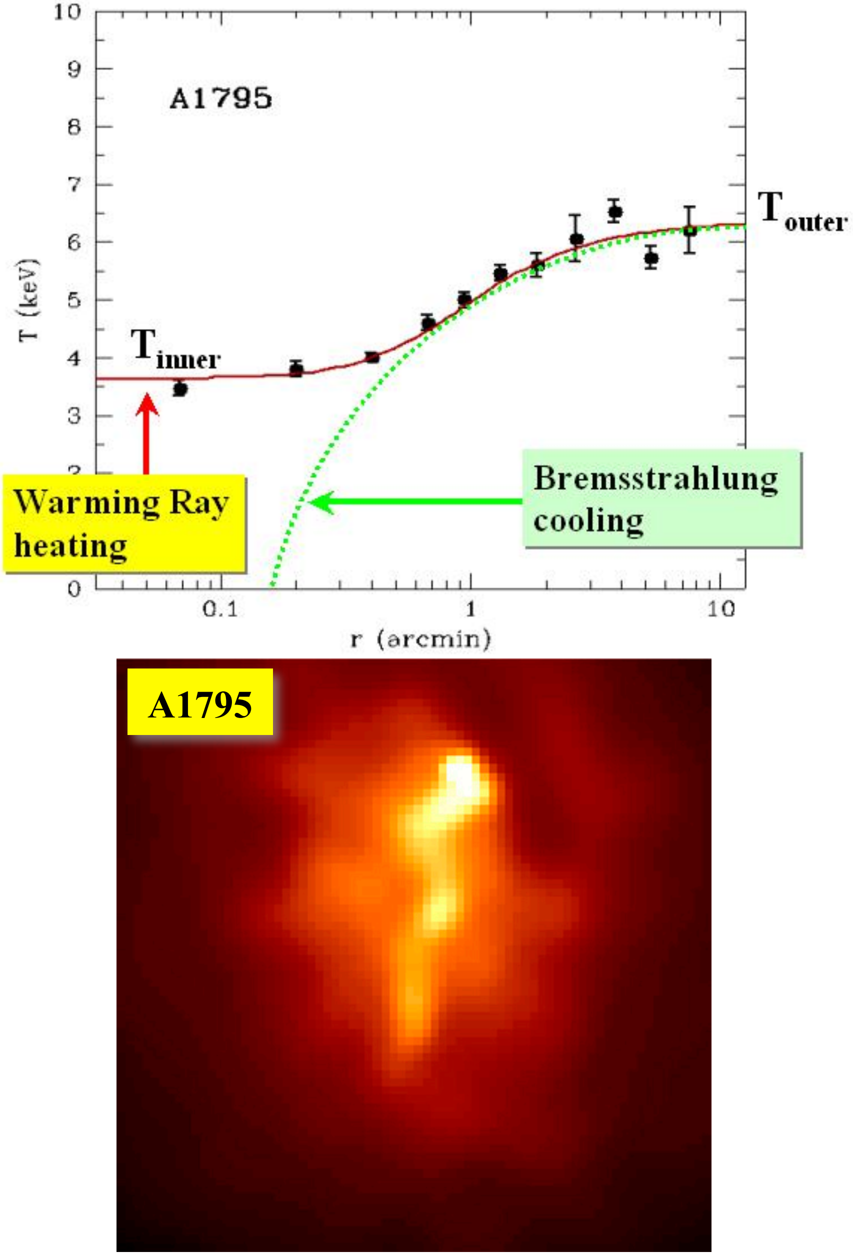
**cooling**

$$3kn(r)\frac{dT(r,t)}{dt} = \qquad - \left(\frac{dE}{dt}\right)_{cooling}$$

**heating**

# Cluster cool cores

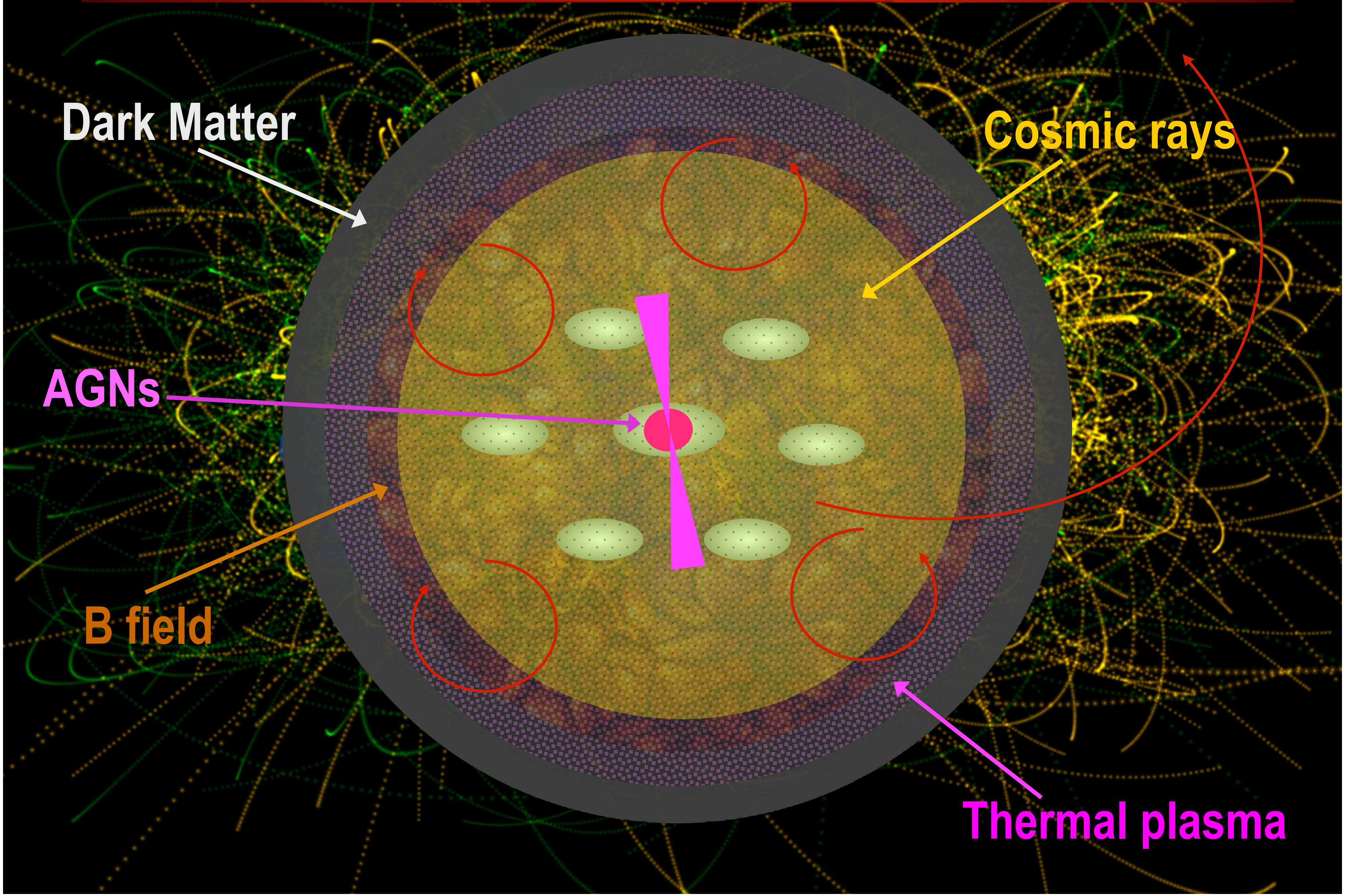



[**S.C.** Dar & DeRujula (2004)]

[**S.C.** (2005)] [**S.C.** & Marchegiani (2008)]

# Clusters: crossroads of cosmic physics



# Challenge

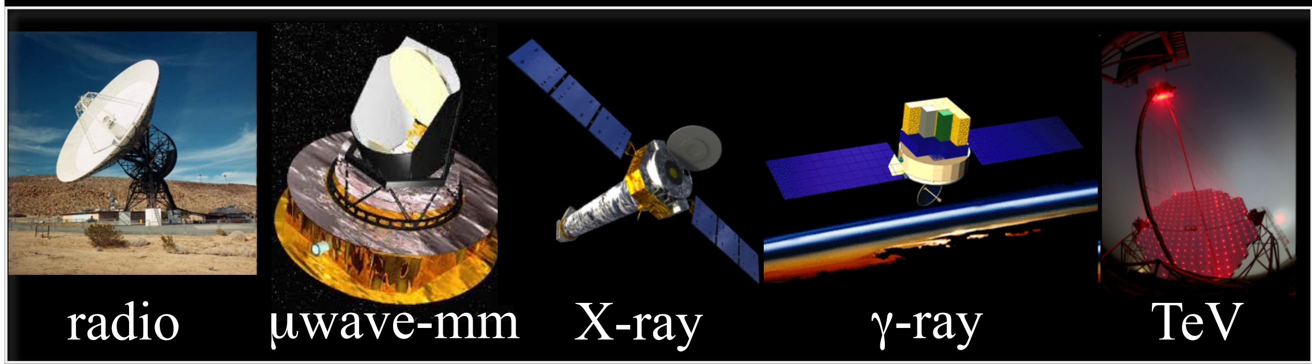
**Multi-D tomography**
**(disentangle cluster atmospheres)**

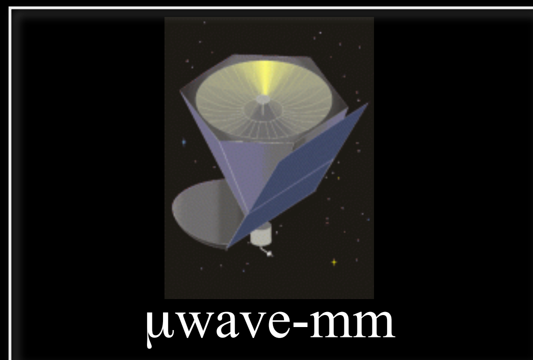
**Multi-technique single-purpose (Radio to TeV)**

**Single-technique multi-purpose (SZE)**

**Multi telescopes**
Multi techniques

**Single telescope**
Single technique



# A single-technique approach: SZE

- **A single-technique and powerful tool for multi-D tomography**
  - **Particle-AstroPhysics**
  - **Cosmology**

- **Opportunities**
  - **PLANCK**
  - **HERSCHEL**
  - **ALMA**
  - **SKA**
  - **Wide-band Spectro-Polarimetry @ $\mu$wave – mm offering a complete approach to study SZE in cosmic structures**

[SZE image of the Bullet cluster : Herschel-Spire]

# The Physics of the SZ Effect

**The SZ effect is a specific form of Radiation-Matter interaction**

**Photon fields**

~~Internal~~ External

↓ ↓

CMB

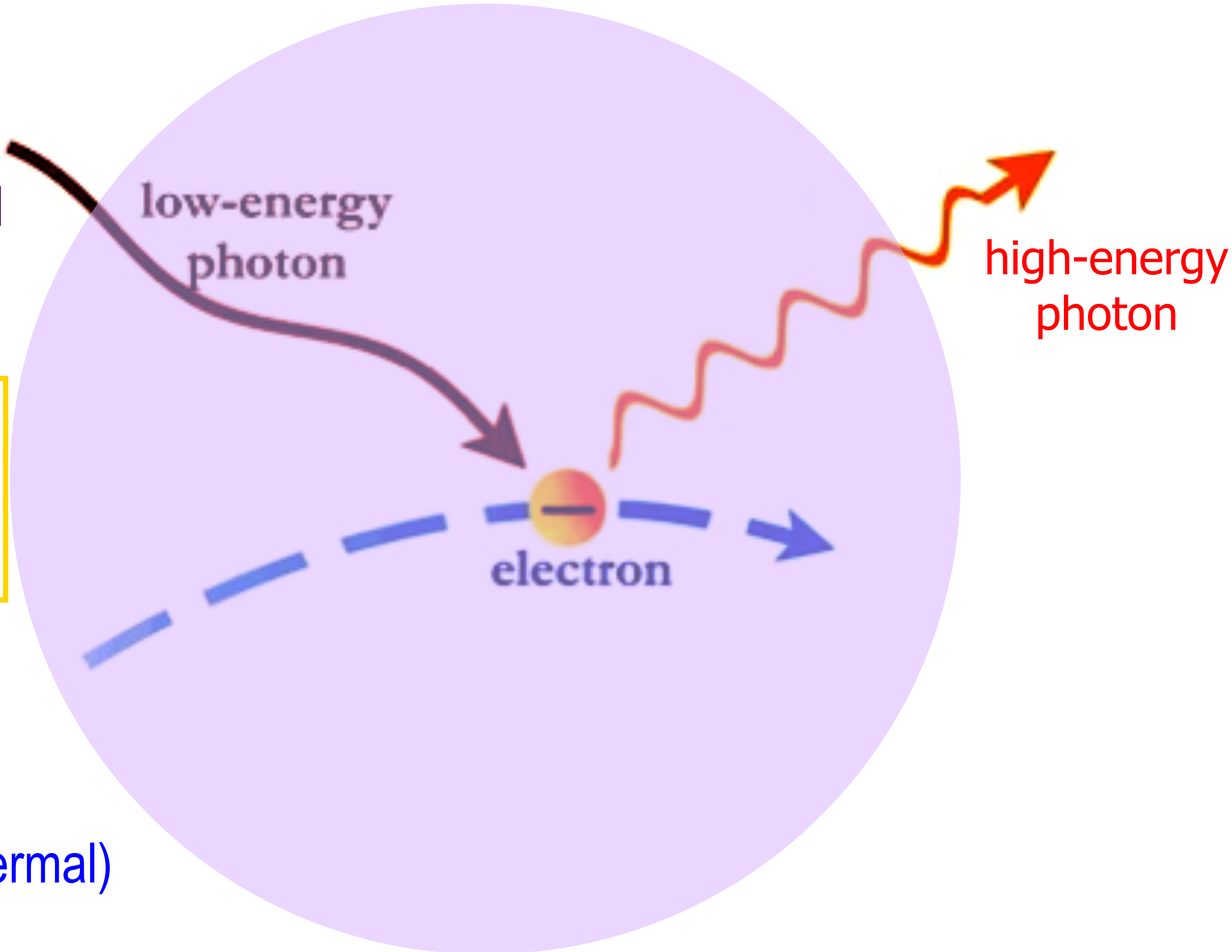
Use CMB photons to extract plasma information

↑

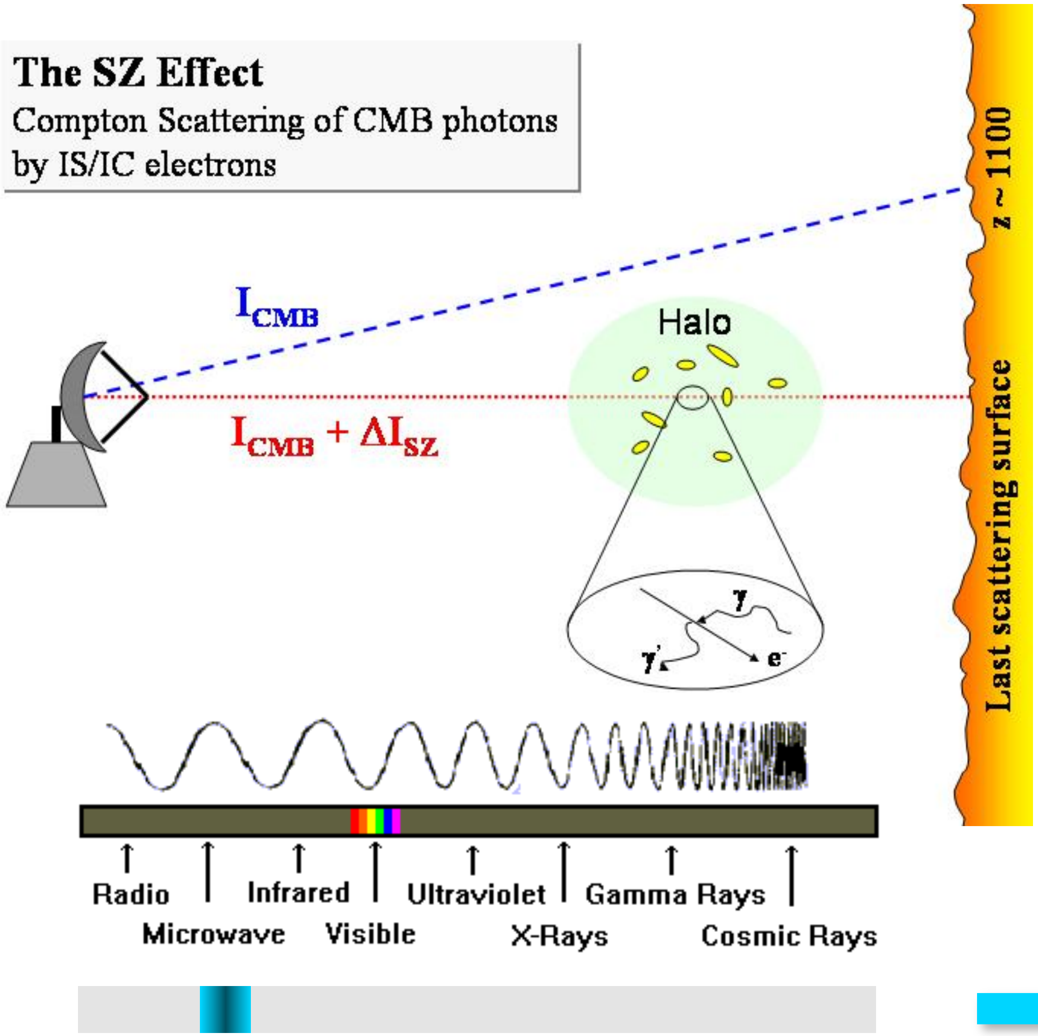
Internal

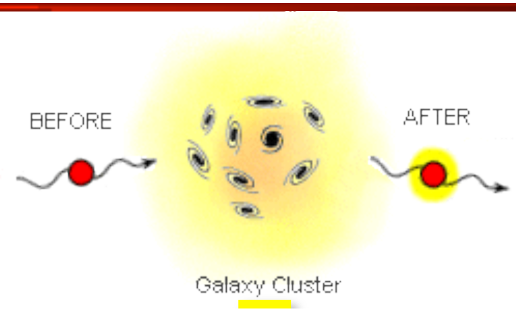
**High-E electrons**

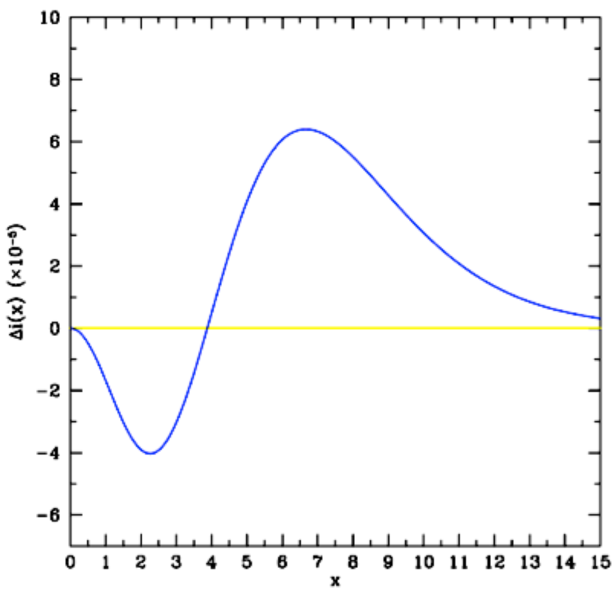
- thermal (supra-thermal)
- relativistic



# SZ effect: the Standard Lore



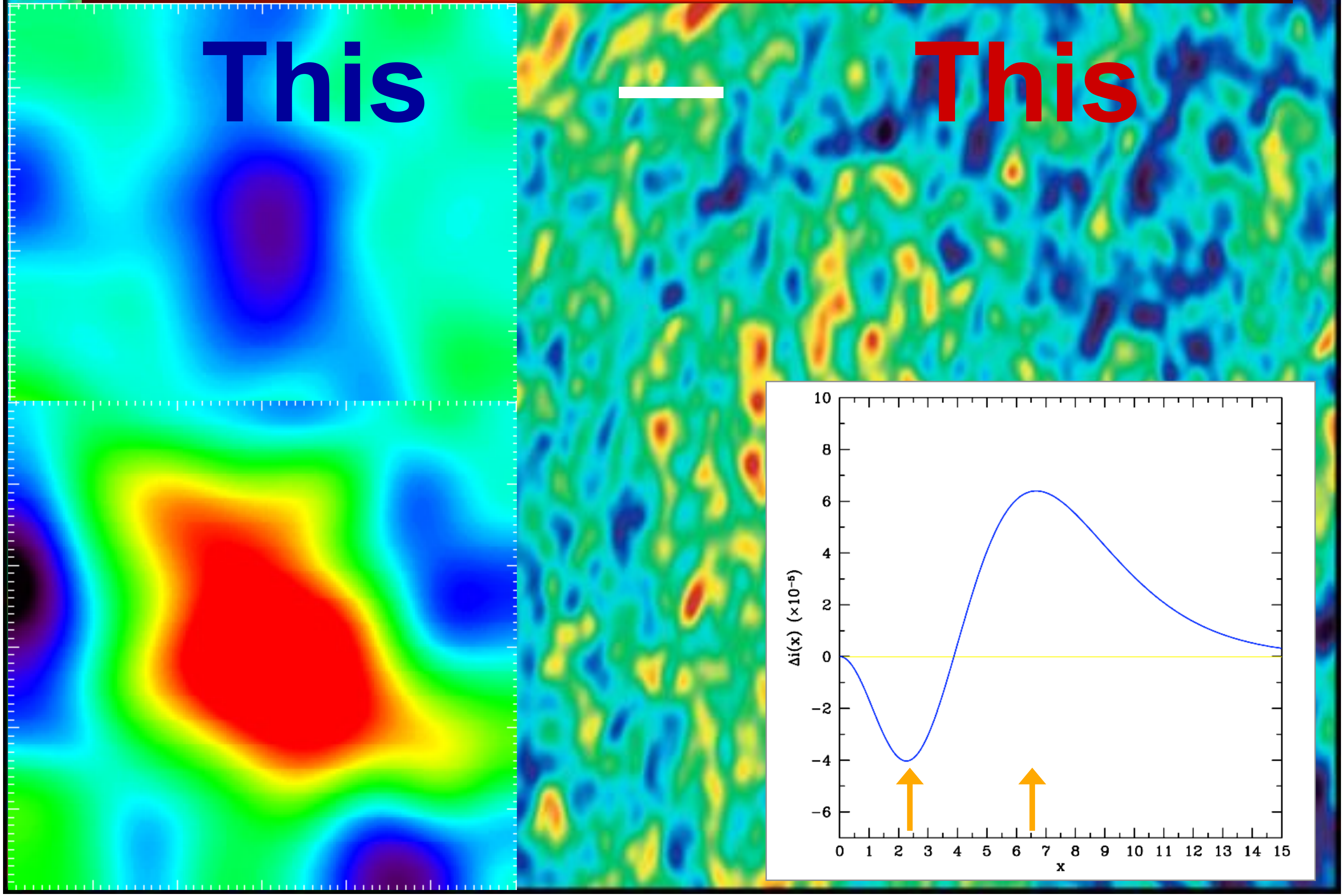




thermal NR e-

$$\frac{\Delta\nu}{\nu} \approx 4\frac{kT_e}{m_e c^2}$$

# SZE: Observational fact



# The origin of the SZ effect

## Non-coherent Compton Scattering

Fall-out effect of the Cold War

**1957 A.S. Kompaneets publishes his Compton scattering Fokker-Planck equation**

$$\frac{\partial n}{\partial y} = \frac{1}{x^2}\frac{\partial}{\partial x}x^4\left(\frac{\partial n}{\partial x} + n + n^2\right)$$

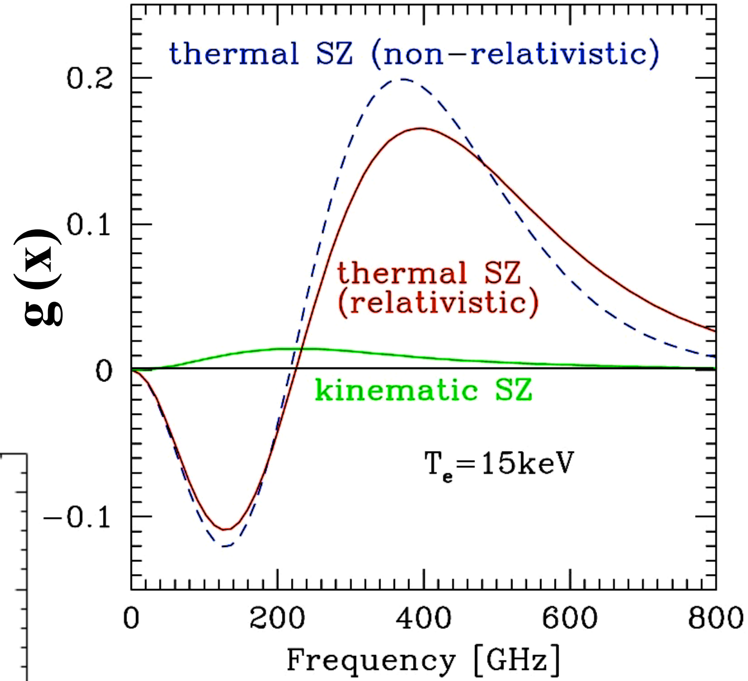
(derived by A.S. Kompaneets in Soviet Union ~ 1950 but was classified due to nuclear bomb research until 1956)

**1969 Ya. B. Zel' dovich & R. Sunyaev derive the thermal SZ effect (i.e., applied the Kompaneets eq.)**

# SZE: working approximations

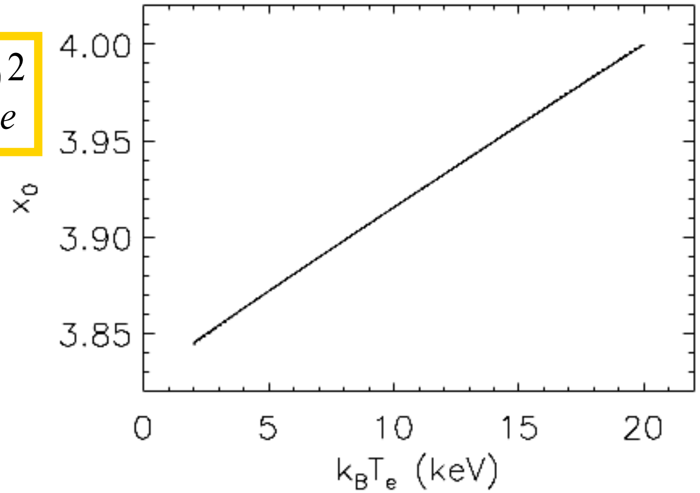
$$\Delta I_{th} = 2\frac{(kT_0)^3}{(hc)^2} y_{th} g(x)$$

$$y_{th} = \sigma_T \int d\ell\, n_e \frac{kT_e}{m_e c^2}$$




$$X_{0,th} \approx a + b\theta_e + c\theta_e^2$$

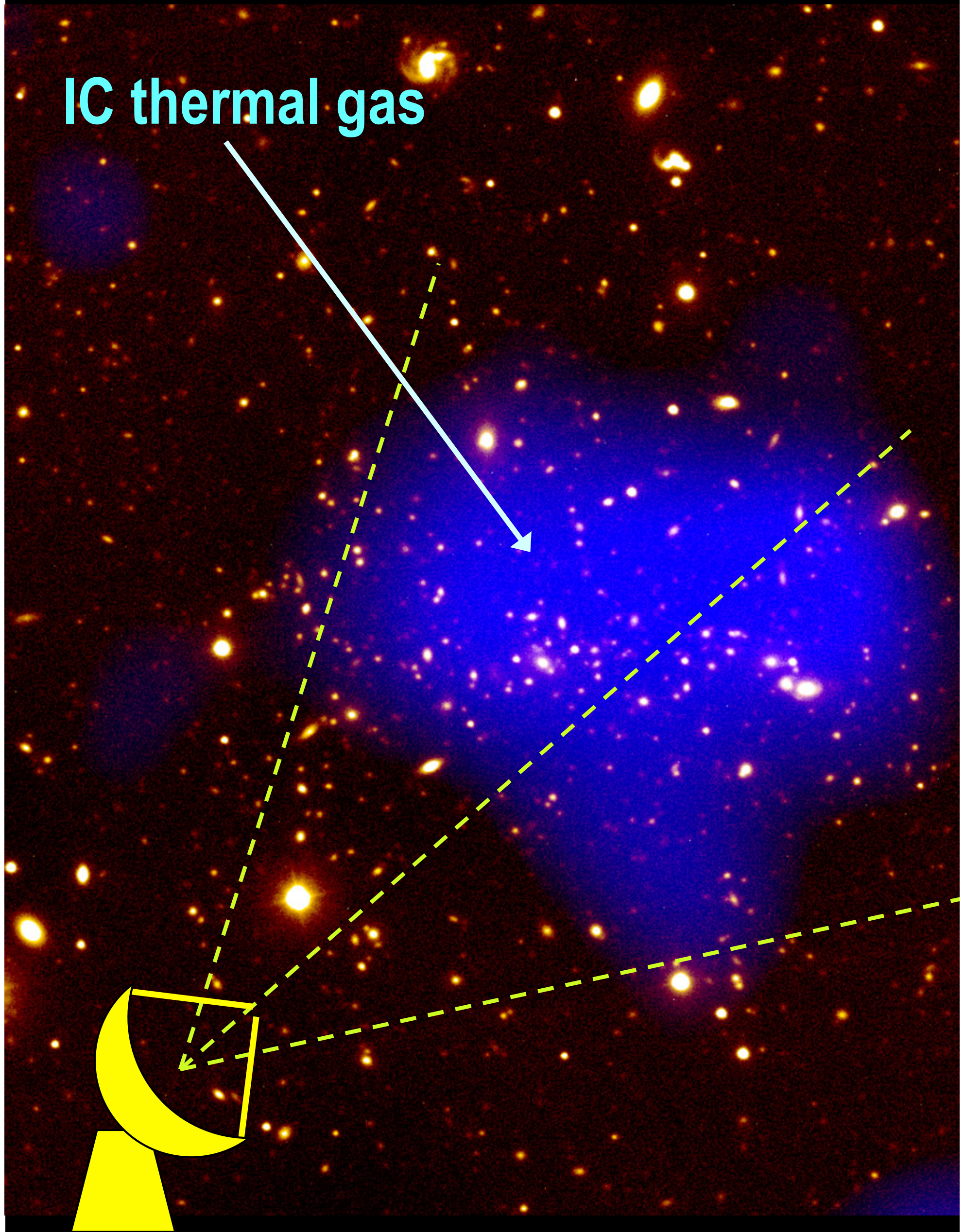
$$\theta_e \equiv \left(\frac{k_B T_e}{m_e c^2}\right)$$

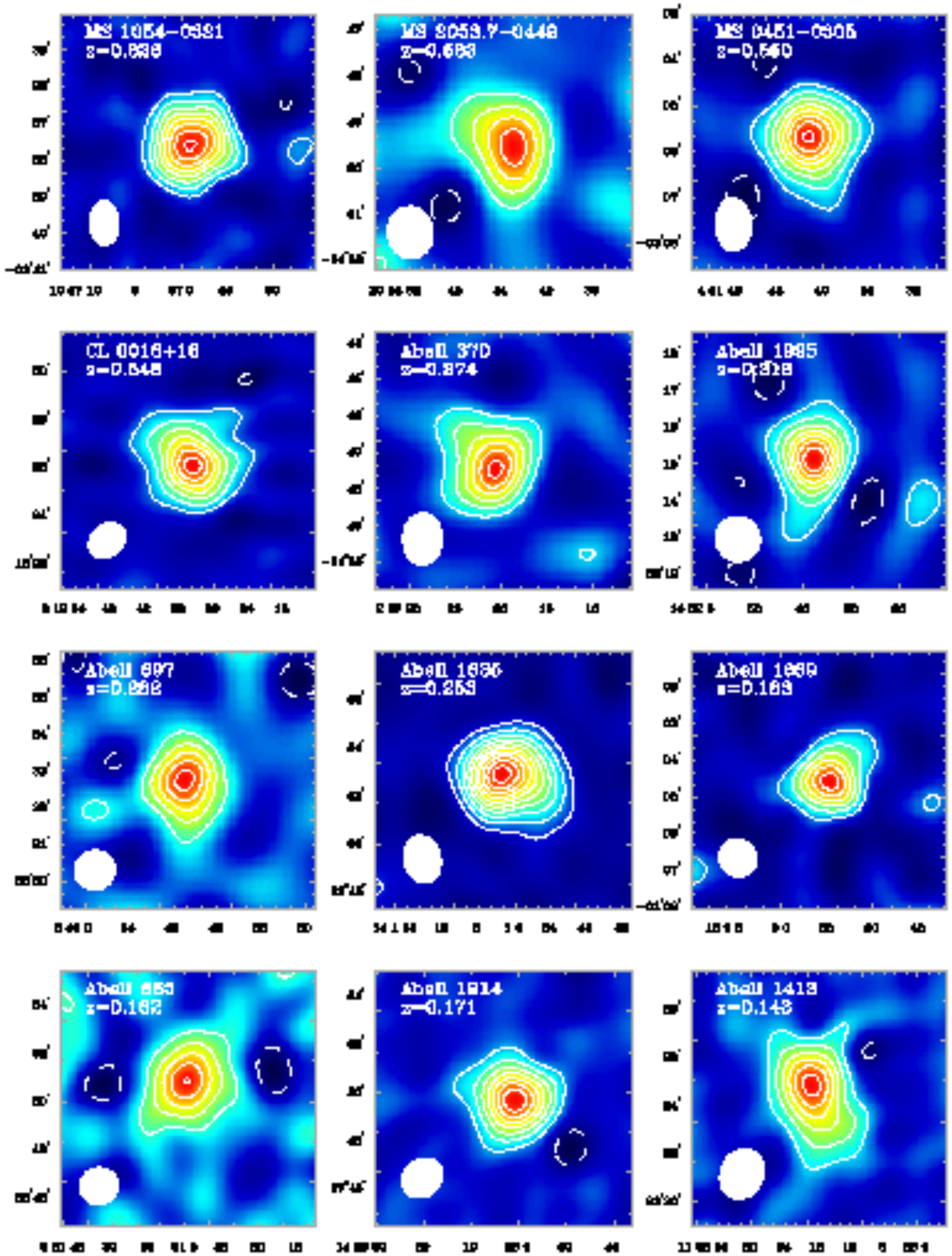



**Diffusion limit** → Single scattering ($\tau \ll 1$)

**Single thermal population** → Thermal electrons (X-ray)

# Blob-ology


IC thermal gas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MS 2053.7-0449
z=0.583
MS 0451-0305
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CL 0016+16
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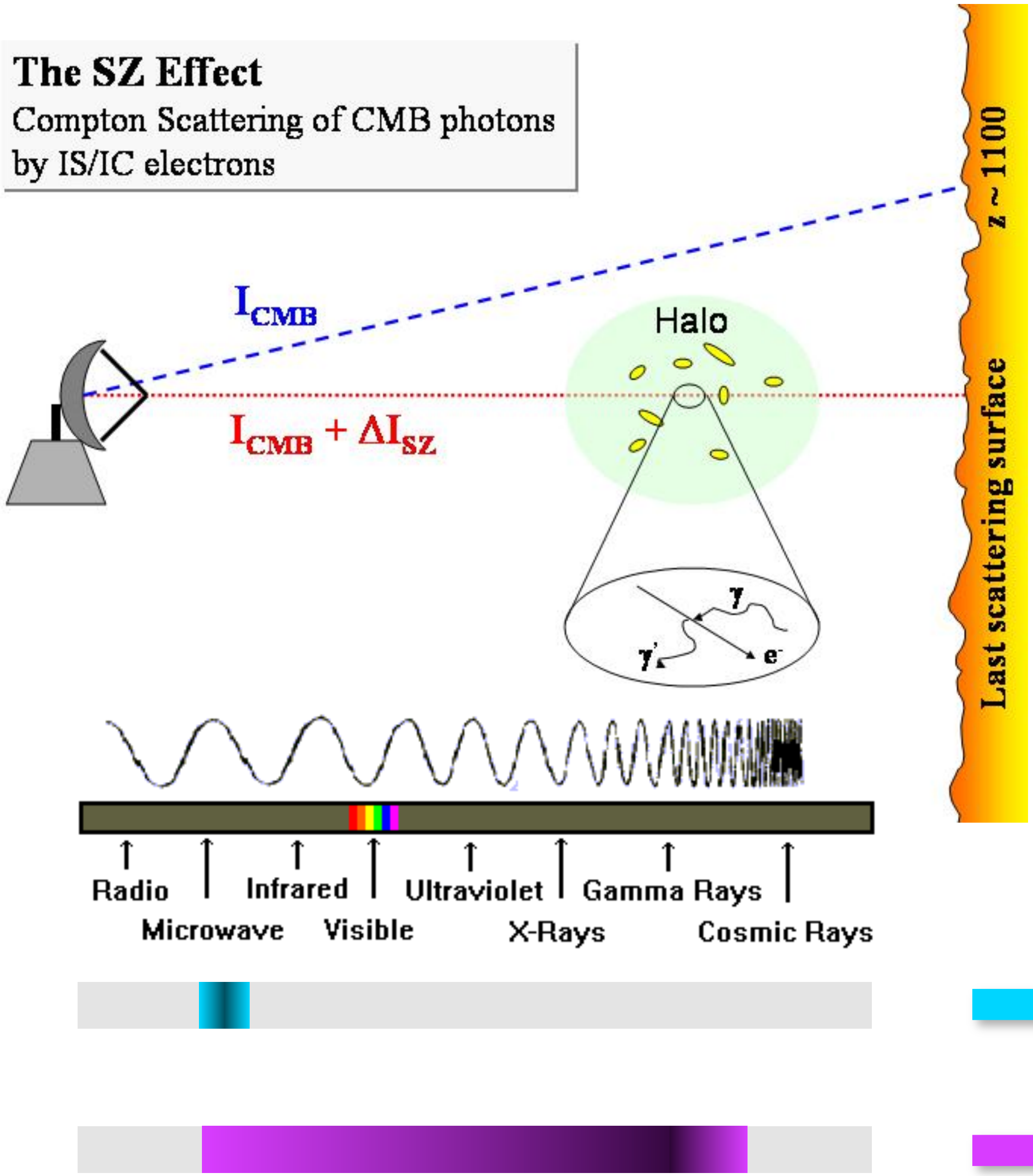
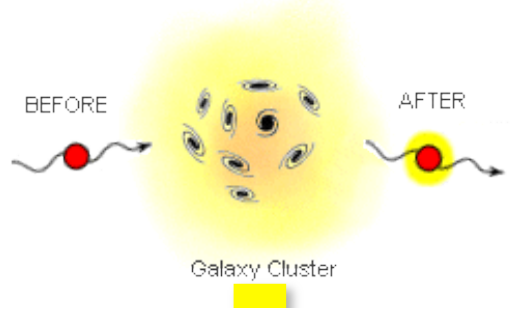
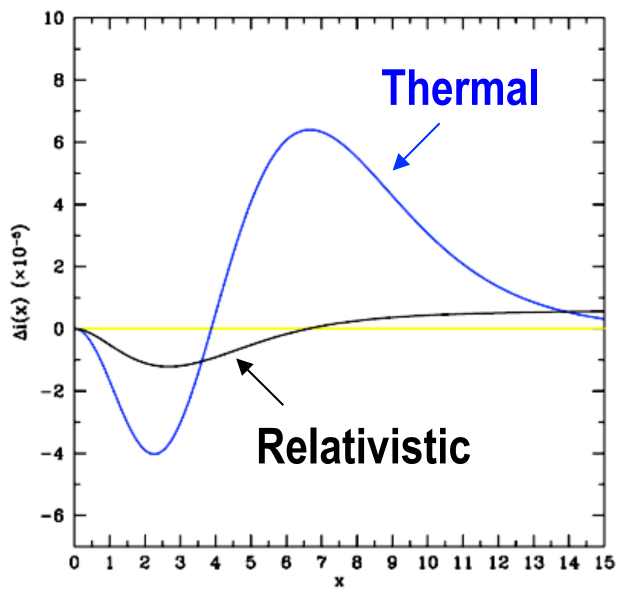
Abell 370
z=0.374
Abell 1995
z=0.322
Abell 697
z=0.282
Abell 1835
z=0.252
Abell 1689
z=0.183
Abell 665
z=0.182
Abell 1914
z=0.171
Abell 1413
z=0.143

# SZ effect: …more than basics




(x)

thermal NR e⁻ $\frac{\Delta \nu}{\nu} \approx 4 \frac{kT_e}{m_e c^2}$

relativistic e⁻ $\frac{\Delta \nu}{\nu} \approx \frac{4}{3} \gamma^2$

# SZE: general derivation

[Colafrancesco et al.  2003, A&A, 397, 27]

**Intensity change**

$$\Delta I(x) = 2\frac{(k_B T_0)^3}{(hc)^2} y \tilde{g}(x)$$

$$y = \frac{\sigma_T}{m_e c^2} \int P d\ell.$$

**Pressure**

- Thermal: $$P_{th} = n_e k_B T_e$$
- Relativistic: $$P_{rel} = n_e \int_0^{\infty} dp f_e(p) \frac{1}{3} p v(p) m_e c$$

**Spectral shape**

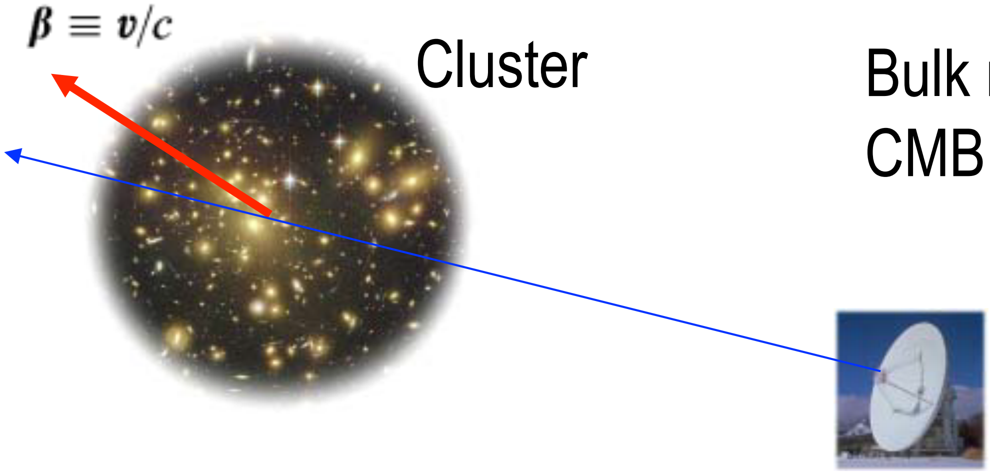
$$\tilde{g}(x) = \frac{m_e c^2}{\langle k_B T_e \rangle} \left\{ \frac{1}{\tau} \left[ \int_{-\infty}^{+\infty} i_0(x e^{-s}) P(s) ds - i_0(x) \right] \right\}.$$

$$\langle k_B T_e \rangle = \frac{\sigma_T}{\tau} \int P d\ell = \frac{\int P d\ell}{\int n_e d\ell}.$$

**Redistribution function**

$$P(s) = \int_0^{\infty} dp f_e(p) P_s(s;p)$$

# SZE-kinematic: general derivation




Bulk motion effect of a gas cloud in the CMB photon field

**Intensity change**

$$\left.\frac{\Delta T}{T_0}\right|_{kin} = h(x)\cdot\frac{1}{m_e c}\int d\ell\,\sigma_T n_e p_p = h(x)\cdot\frac{p_e}{m_e c}\cdot\tau$$

**Momentum**

$$p_e = \gamma \cdot m_e v$$

Relativistic generalization

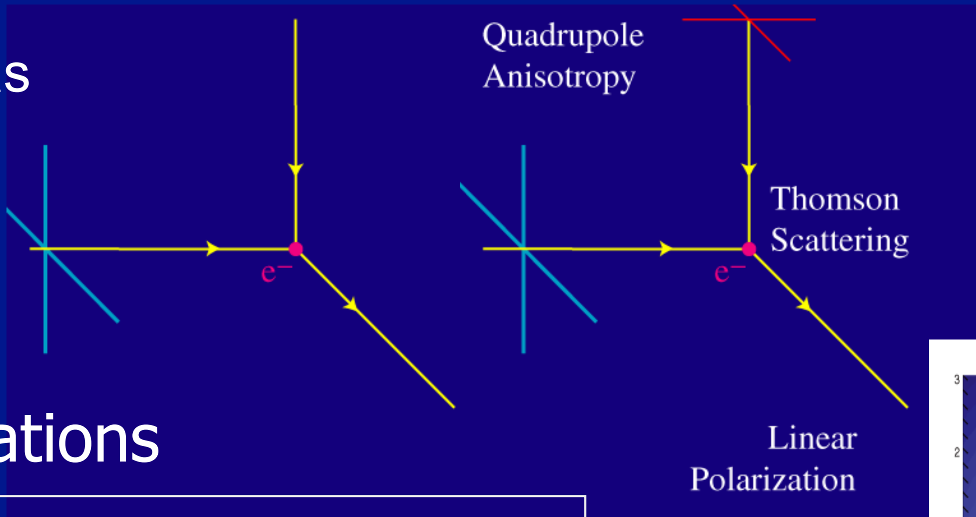
**Spectral shape**

$$h(x) = \frac{x^4 e^x}{\left(e^x - 1\right)^2}\left[1 + \kappa_{rel}(x)\right]$$

CMB spectrum

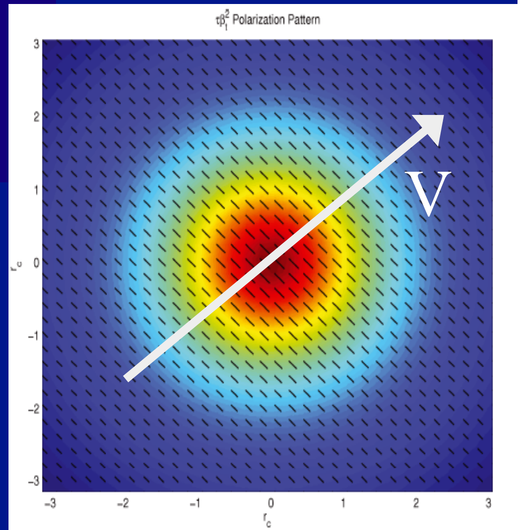
# SZE: polarization

Polarizations arises as a natural outcome of γ-e scattering



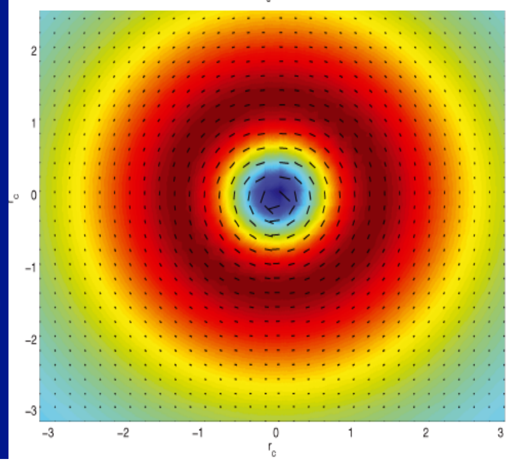

→ various polarizations

Polarization due to peculiar motion of clusters $\Pi_t \approx \beta_t^2 \tau$




Polarization due to transverse motions of plasma within the cluster $\Pi_V \approx \beta_t \tau^2$

Polarization due to multiple scattering γ-e within the cluster $\Pi_T \approx \left( \frac{kT}{m_e c^2} \right) \tau^2$



# SZE polarization: general formalism

Relativistic covariant formulation [Colafrancesco & Tullio 2010-11]

Polarization matrix $Q_{ij} = \langle E_i E_j^* \rangle_T$

Stokes parameters

$$Q_{ij} = \begin{pmatrix} I+Q & U+iV \\ U-iV & I-Q \end{pmatrix}$$

General derivation (single scattering, Thomson limit)

$$Q'(p_1) = \frac{3}{16\pi} \int_{\hat{z}} d\tau \int \frac{d^3\beta_e}{\gamma_e} f_e(\beta_e) \int d\Omega_2 \frac{n_{22} + \alpha_1 r_{12}}{(n_{12} n_{22})^2} I(\alpha_2; \vec{n}_2) \times$$
$$\times \left[ \sin^2(\theta_2)\cos(2\phi_2) + 2\gamma_e\beta_e \frac{r_{12}}{n_{12}} \sin(\theta_2)\sin(\theta_e)\cos(\phi_2+\phi_e) + \left(\gamma_e\beta_e \frac{r_{12}}{n_{12}}\right)^2 \sin^2(\theta_e)\cos(2\phi_e) \right]$$

$$U'(p_1) = \frac{3}{16\pi} \int_{\hat{z}} d\tau \int \frac{d^3\beta_e}{\gamma_e} f_e(\beta_e) \int d\Omega_2 \frac{n_{22} + \alpha_1 r_{12}}{(n_{12} n_{22})^2} I(\alpha_2; \vec{n}_2) \times$$
$$\times \left[ \sin^2(\theta_2)\sin(2\phi_2) + 2\gamma_e\beta_e \frac{r_{12}}{n_{12}} \sin(\theta_2)\sin(\theta_e)\sin(\phi_2+\phi_e) + \left(\gamma_e\beta_e \frac{r_{12}}{n_{12}}\right)^2 \sin^2(\theta_e)\sin(2\phi_e) \right]$$

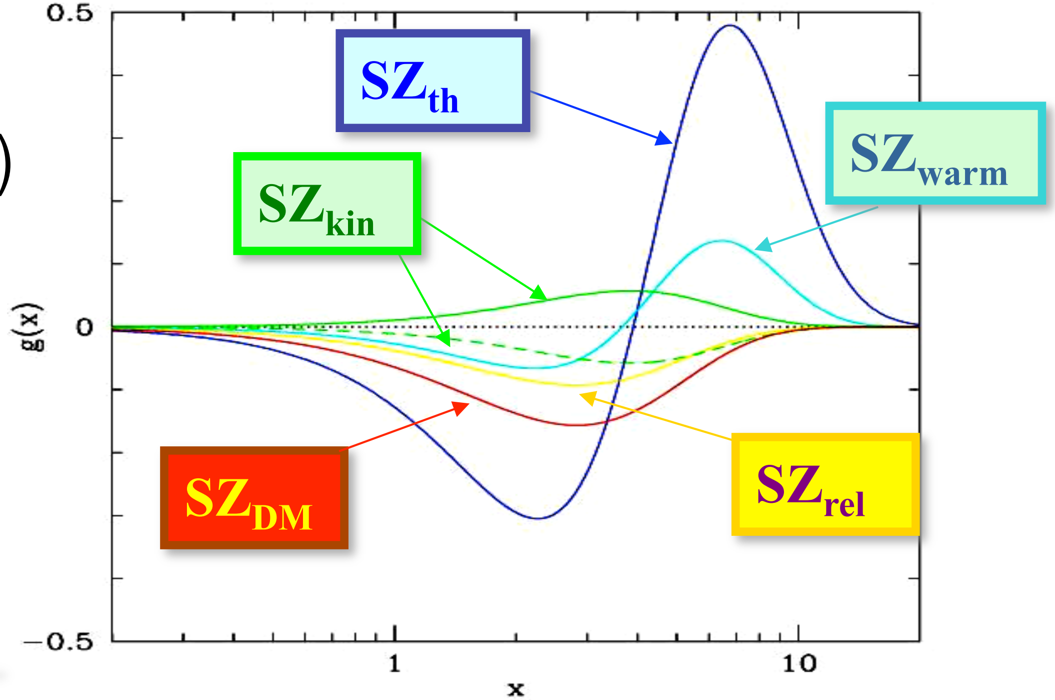
General derivation (multiple scattering, Thomson limit)

$$\tilde{I}(\vec{p}; \vec{v}_L) = I(\vec{p}; \vec{v}_L) + \int_{\hat{n}} d\tau \int_{-\infty}^{\infty} P_1(s) \left[ e^{3s} I_0(pe^{-s}) - I_0(p) \right] ds$$

# SZE spectro-polarimetry

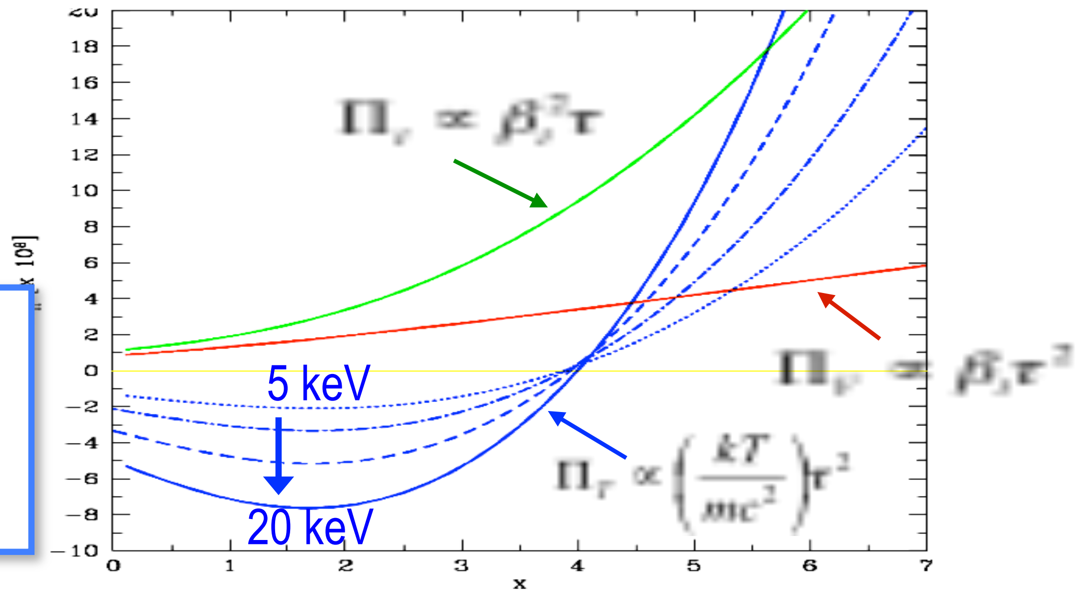
**SZE Intensity**:
sensitivity to projected (along the l) physical parameters

$\tau$, $kT_e$ , $P_e$, $E_e$, $M_\chi$, $V_t$




**SZE polarization**:
sensitivity to m-D distribution of physical parameters

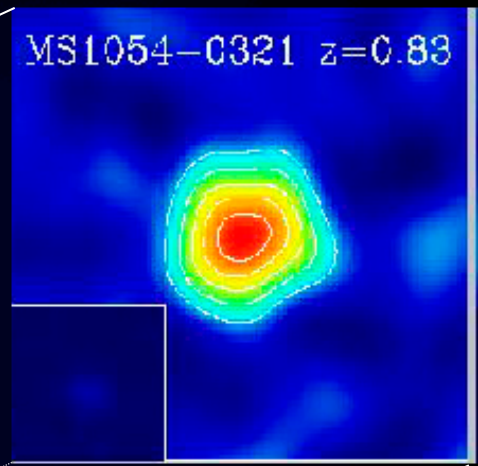
For a thermal plasma:
- Velocity sub-structure ($\beta\ \tau^2$)
- Temperature sub-structure ($T_e\tau^2$)



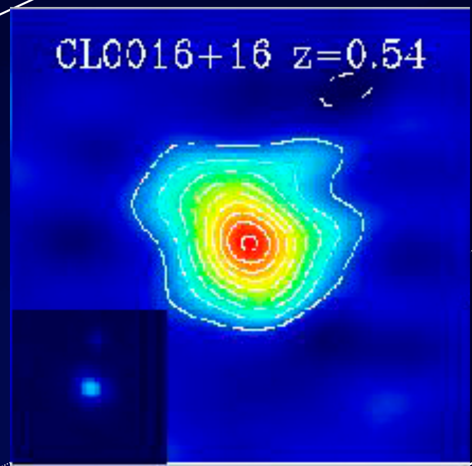
# Astrophysics & Cosmology

The SZE is independent of redshift and therefore it is an optimal tool for Cosmological applications

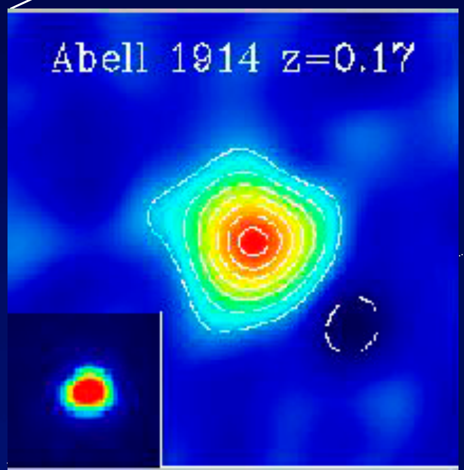
**Standard-rod "physical" effect**




X-rays




X-rays




X-rays

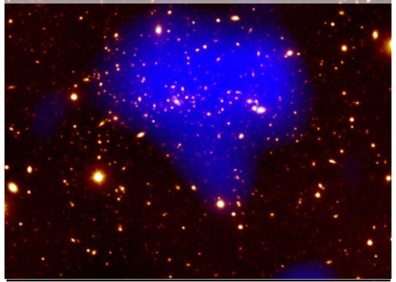
The SZE depends directly on the electron distribution in the atmospheres of cosmic structures and therefore it is an optimal tool for Astrophysical applications

**Cosmic Lepto-meter, speedo-meter**

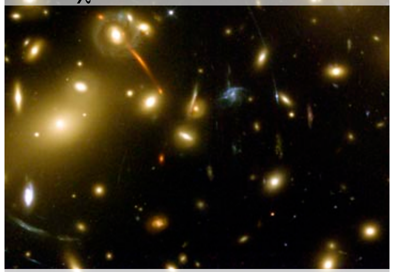
# Astrophysical relevance

## Galaxy clusters

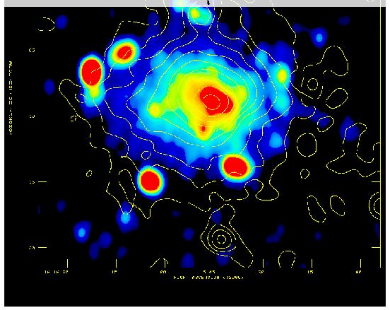
**Thermal particles**
$E_e \sim 0.1 - 10$ keV



**WIMPs**
$M_\chi \sim 10–500$ GeV

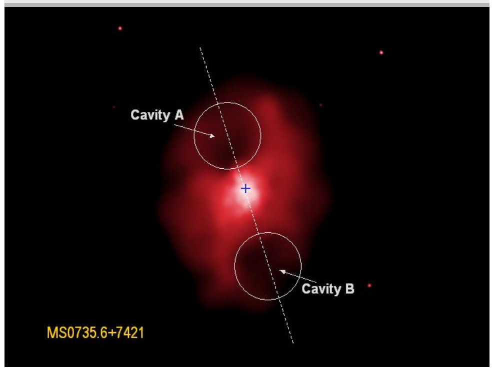


**Cosmic rays**
$E_e \sim 16 GeV\ B_\mu^{1/2} (\nu_{GHz})^{1/2}$

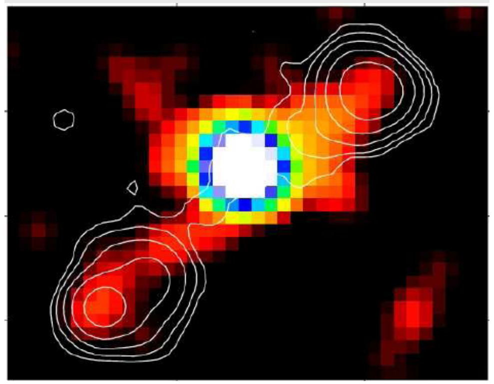


## AGN jets/cavities

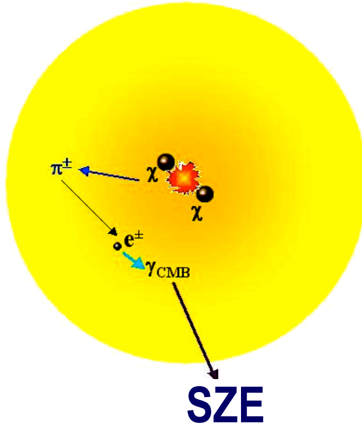
**Cluster Cavities**
MS0735+7421 (Chandra)

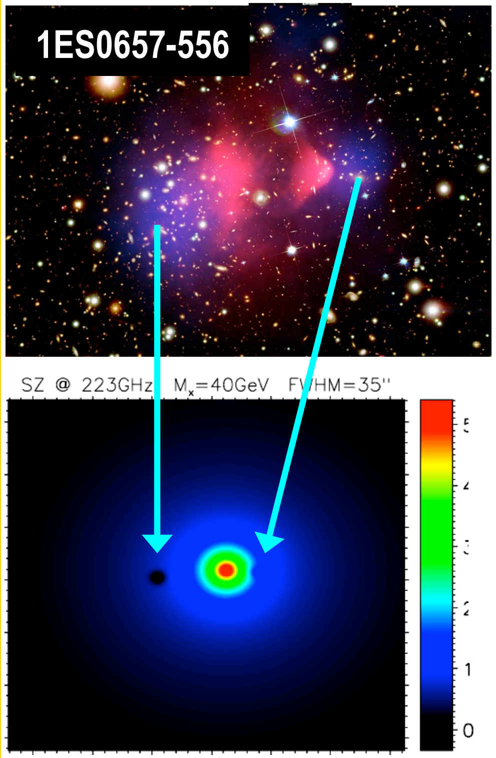



**Radio Galaxy Lobes**
3C432 (Chandra)



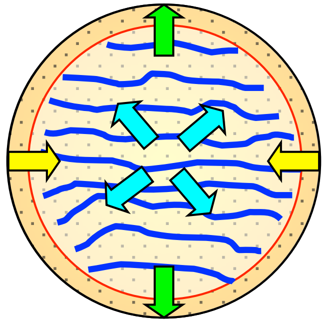
## DM nature



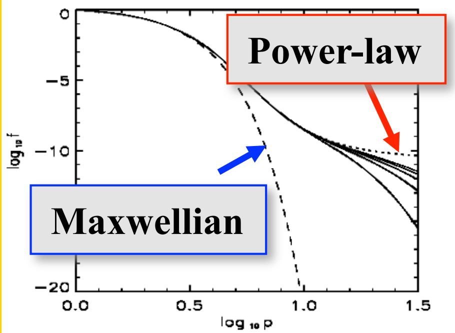




## Plasma physics

**B-fields**



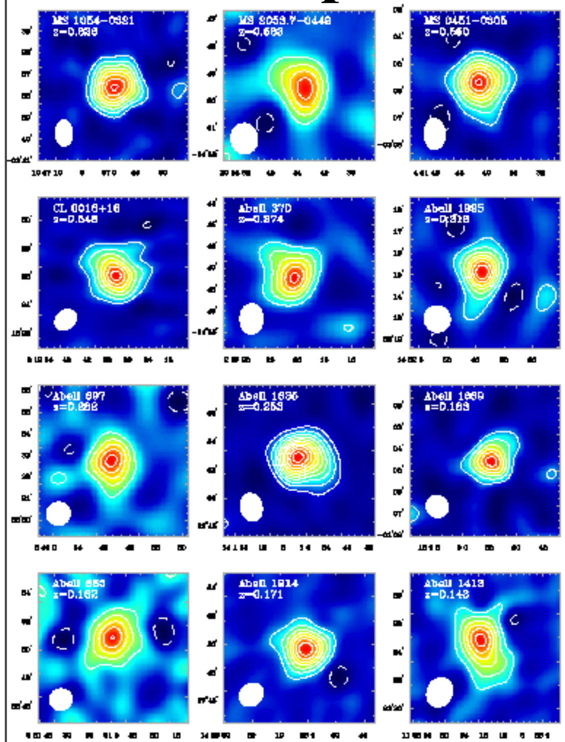
**Acceleration proc.**



# Pre-PLANCK Era

## Simple Observables

### Shape



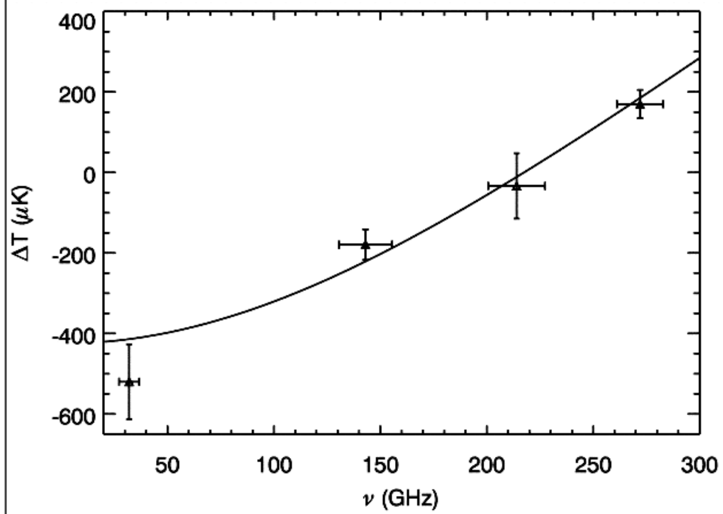
OVRO (30 GHz)

**SZE has larger angular size than X-ray image**

$L_X \sim n^2(r)\ T^{1/2}$

$Y_{SZ} \sim n(r)\ T$

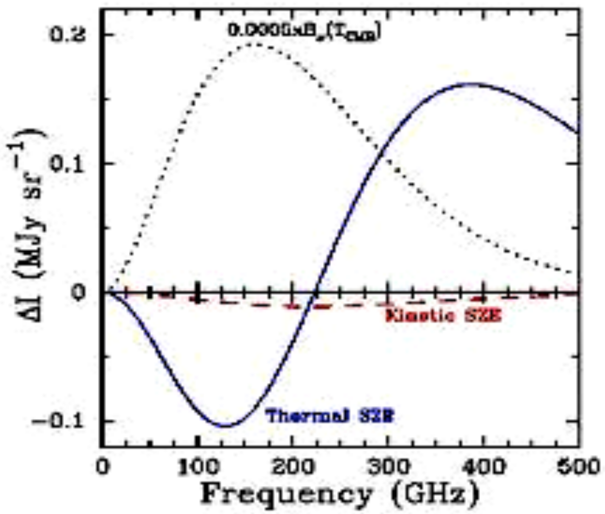
### Spectrum




First SZE spectrum Coma cluster (MITO exp.) (DePetris et al. 2002)

- **Spectrum observed in a few bands (30, 150, 220, 275 GHz)**
- **The zero near the peak of CMB spectrum (~ 220 GHz)**

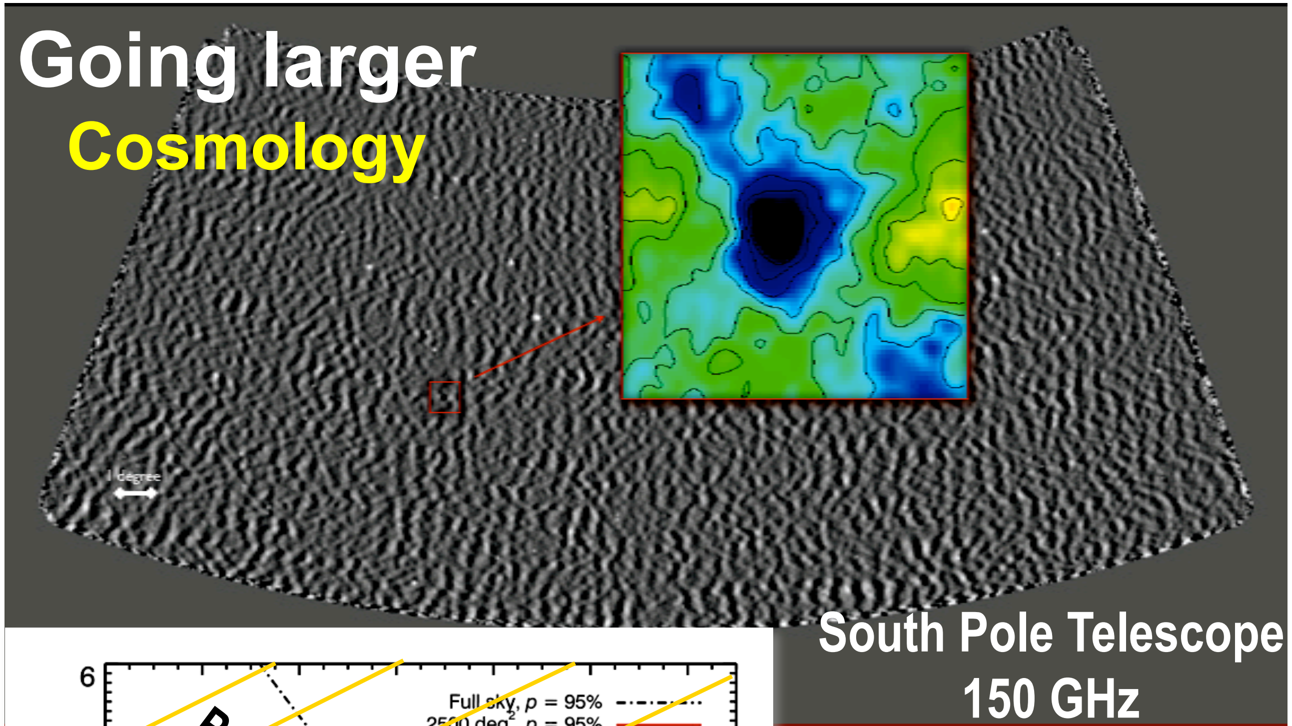
### Kinematic

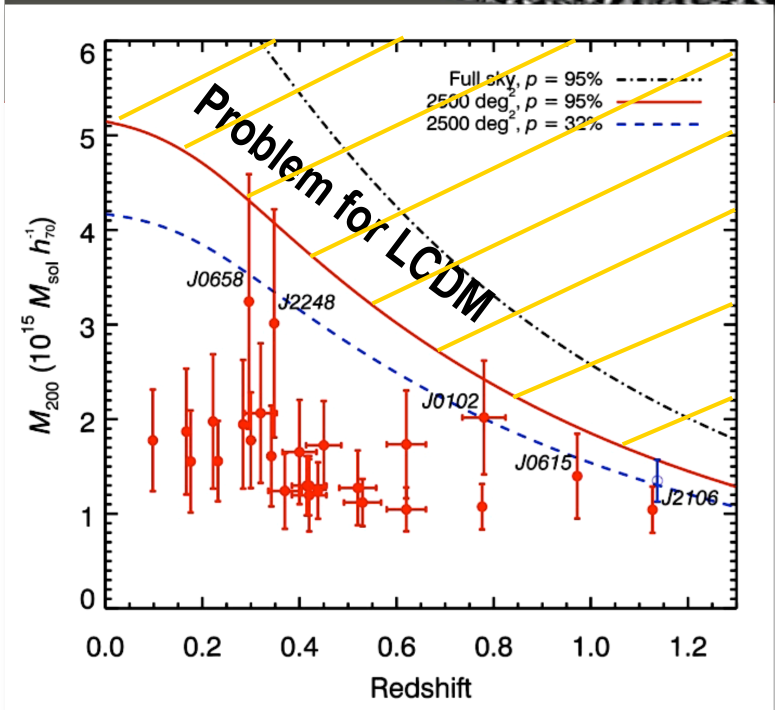



- **Small compared to thermal SZE at low ν**
- **No zero (CMB spectrum)**
- **Confused by primordial CMB structure**
- **No detection**

# Pre-PLANCK Era

## Going larger
### Cosmology

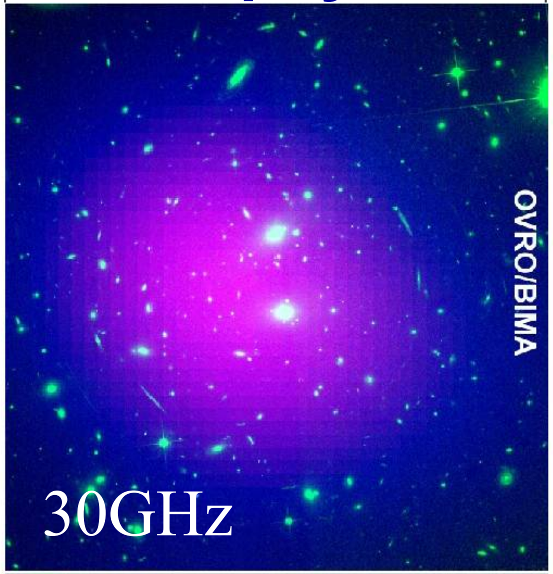


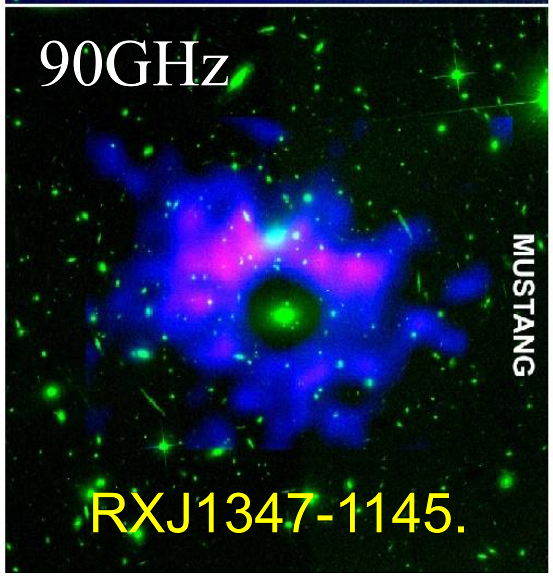




**SZE-selected samples dominated by disturbed clusters**

**Contaminating point sources (AGN, star forming galaxies)**

## Going deeper
### Astrophysics



# Pre-PLANCK Era

$$\Delta I_{th} = 2\frac{(kT_0)^3}{(hc)^2} y_{th} g(x)$$

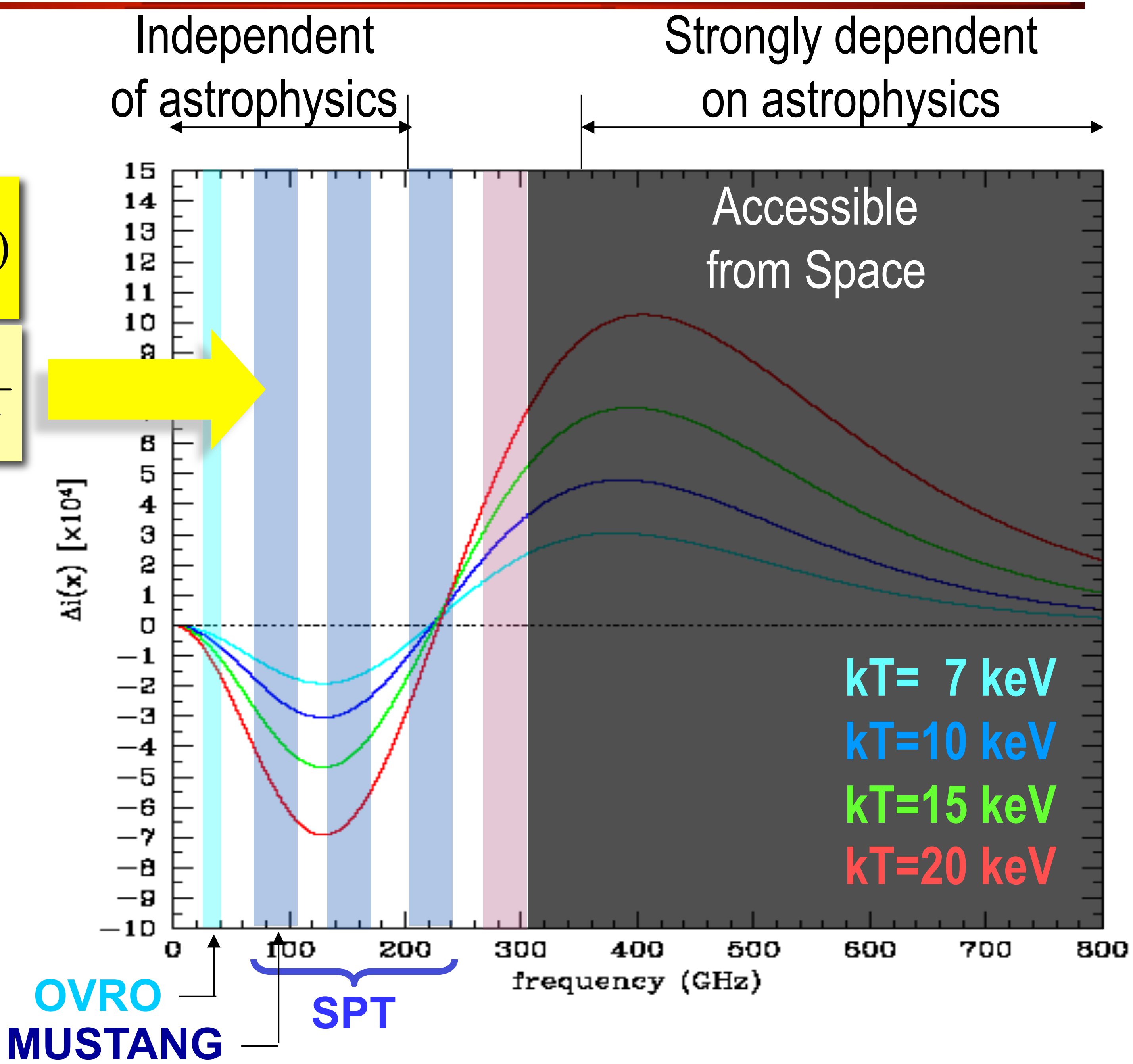
$$y_{th} = \sigma_T \int d\ell n_e \frac{kT_e}{m_e c^2}$$

Need external priors

- X-ray → kT
- WL → M
- O → z

for a proper use in

- Cosmology
- Astrophysics



# PLANCK-Era

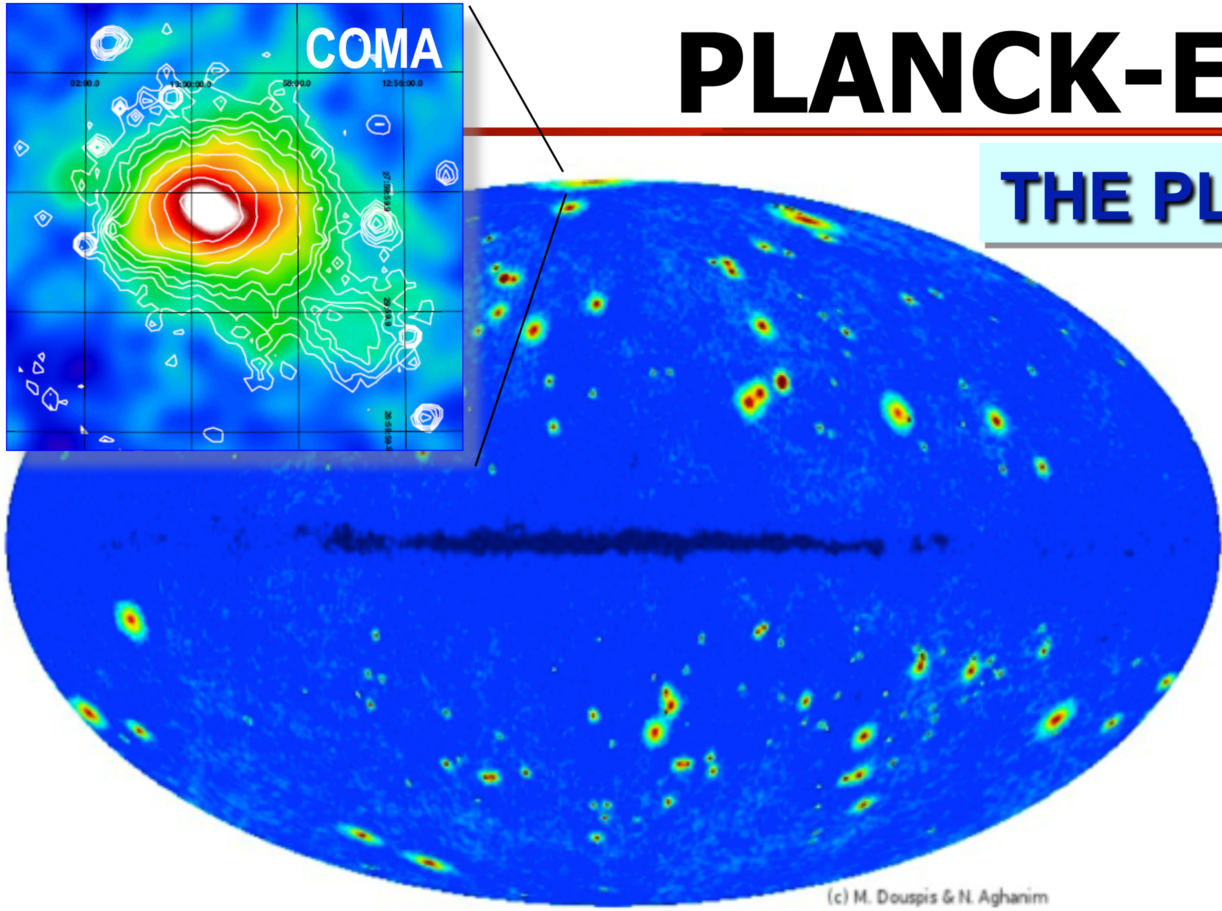
## THE PLANCK MISSION

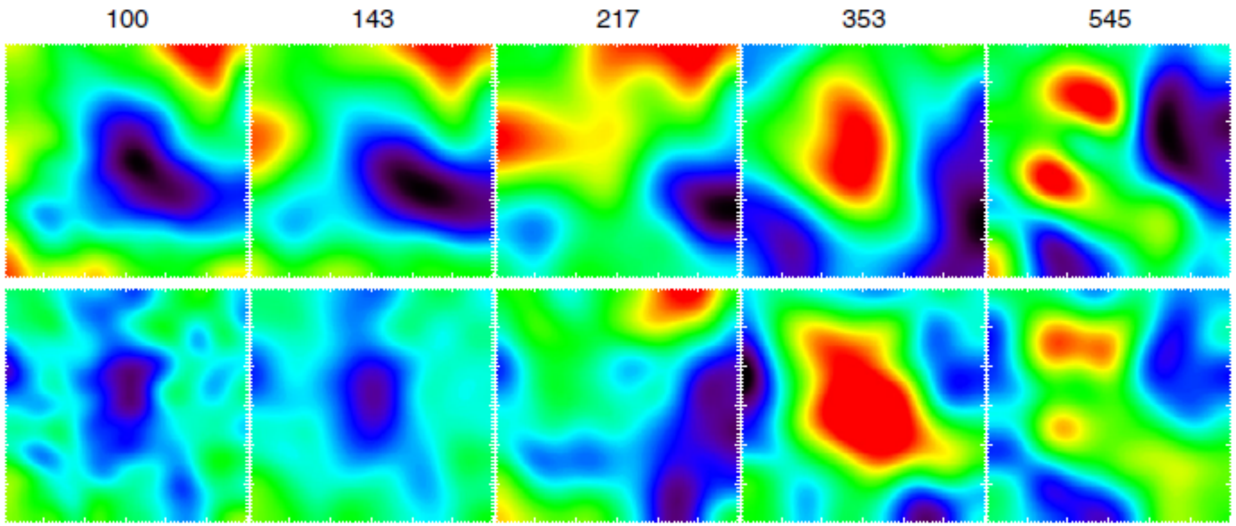
- Launch in May 2009 ; L2 orbit
- 1.5 m gregorian telescope
- 9 frequency bands 30-857GHz
- $\sim$ 5-30 arcmin resolution
- LFI 22 radiometers, 3 frequencies
- HFI 72 bolometers+thermometers cooled down to 0.1 K, 6 frequencies
- nominal mission = 2 full sky surveys
- extended mission = 4 surveys+

## THE HERSCHEL MISSION

- 3.5 m telescope
- HIFI: high-resolution spectrometer
- PACS Camera & Spectrometer
- SPIRE: FTS spectro-photometer

# PLANCK-Era



Coma. S/N=21.93

## THE PLANCK EARLY SZ SKY

**189 SZ sources (S/N > 6)**

- First SZE measure for ~ 80% of known clusters
- 37 new clusters

**Detection of SZ clusters**

- Multi-matched filter
- Internal validation
- Ancillary data
- Follow-ups
  - X-rays (XMM-Newton)
  - SZ (AMI)
  - Optical (ESO, NOAO,...)
  - Confirmation
  - Redshift estimation
  - Global physical parameters

# PLANCK-Era

## NEW DETECTED CLUSTERS

**8 unconfirmed ESZ candidates**

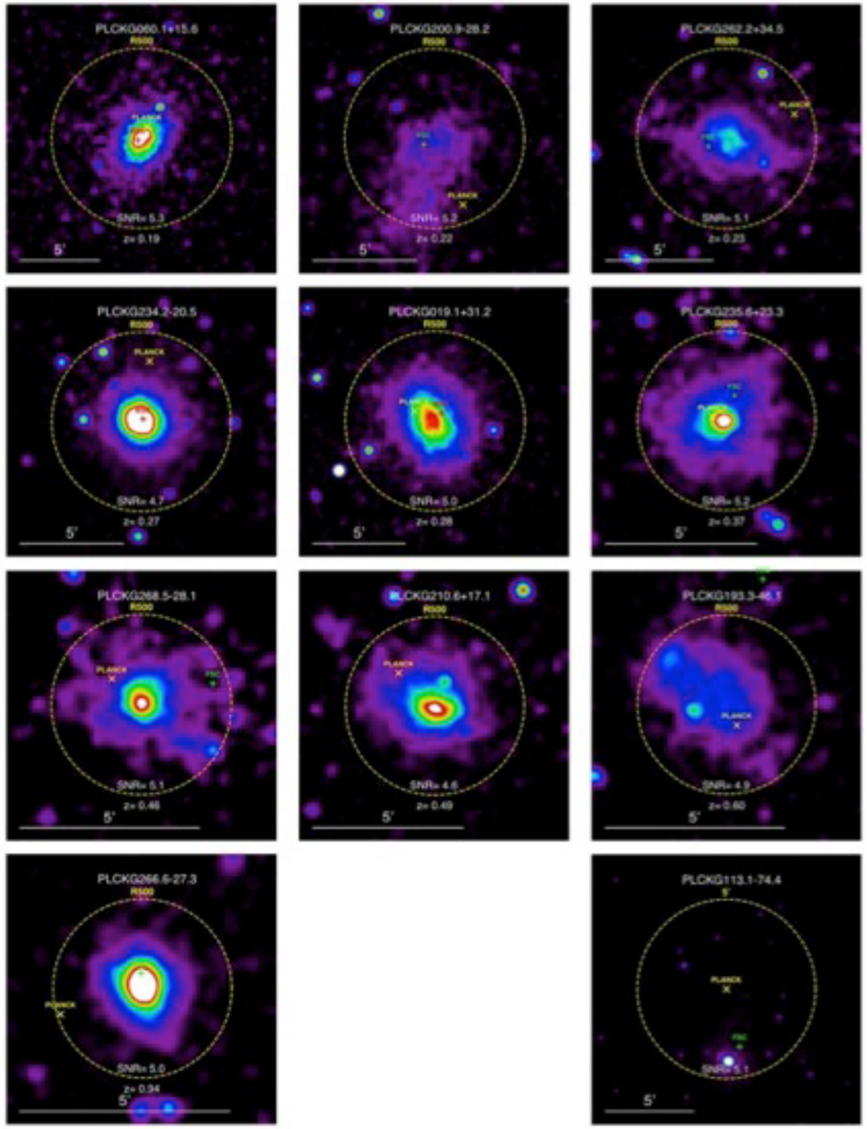
- 7 confirmed by third party (SPT, AMI)

**XMM-Newton DDT program**

- maximize the synergy between the two ESA missions
- short snapshot exposures (10ksec )
- high success rate (>85%)
- 27 single clusters
- 2 double systems
- 2 triple systems

- 37 new clusters with XMM-Newton

+ 15 SZ targets for validation run 4



(Validation run 3)
[Pointecouteau 2012]

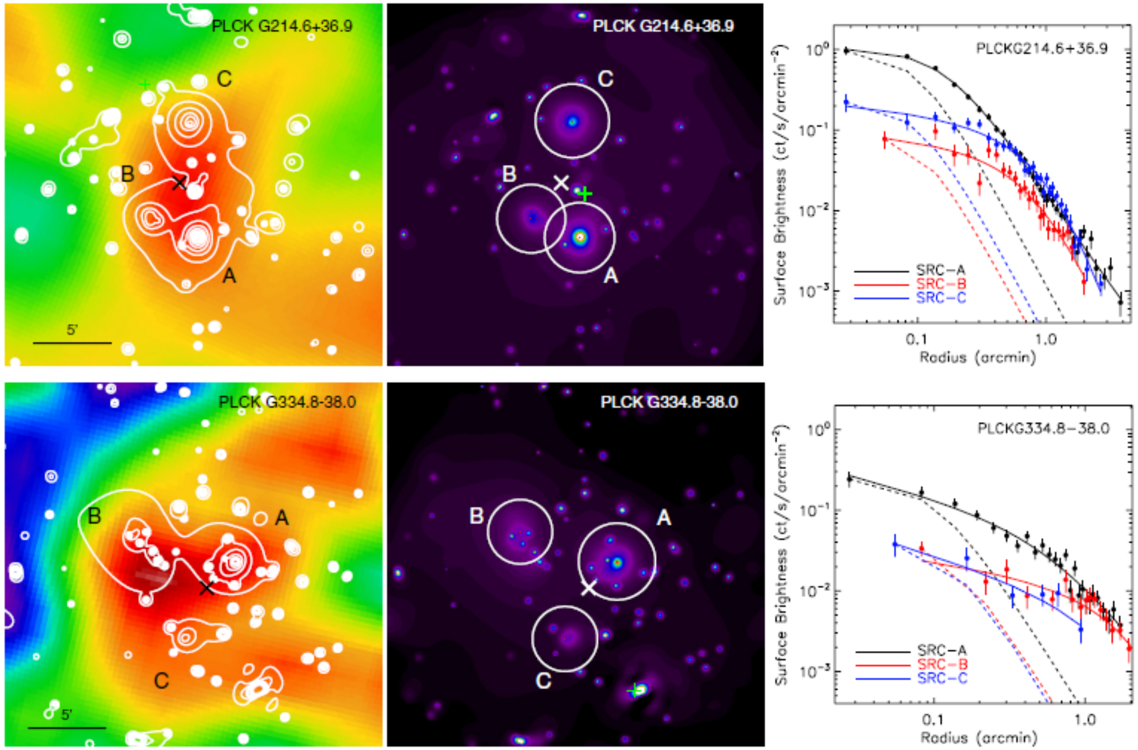
# PLANCK-Era

## Multiple SZE systems

SZE-selected samples are dominated by disturbed clusters

Question:

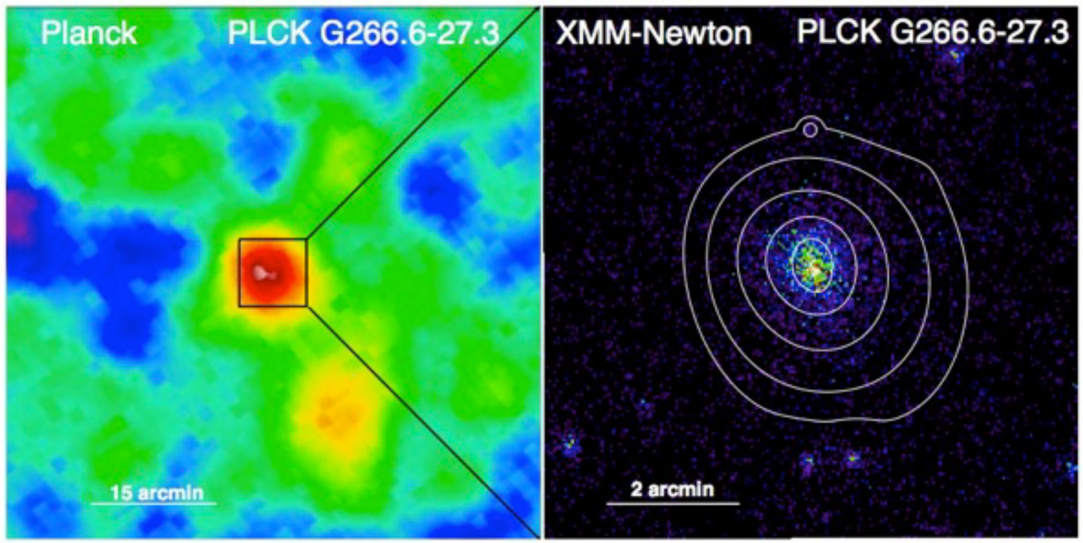
*How much does merger activity bias (scatter) the SZE cluster samples, as a function of M , z ? i.e. affects Cosmological use?*




## Distant clusters via SZE

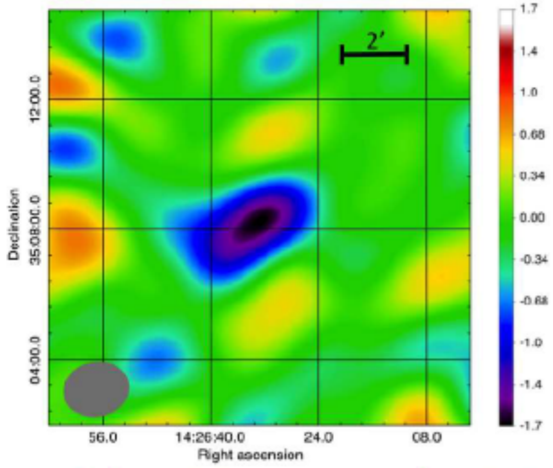
**PLCK G266.6-27.3**

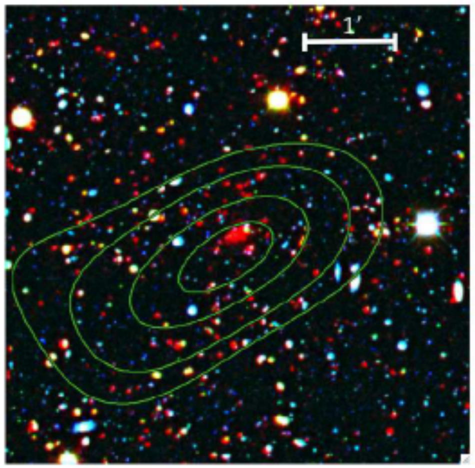
- SNR = 5
- $z_{FeK}$=0.94
- $L_X$[0.5-2keV]=$(1.4\pm0.5)\times10^{45}$ erg/s
- $M_{500}=(7.8\pm0.8)\times10^{14}\ M_\odot$
- Highly relaxed

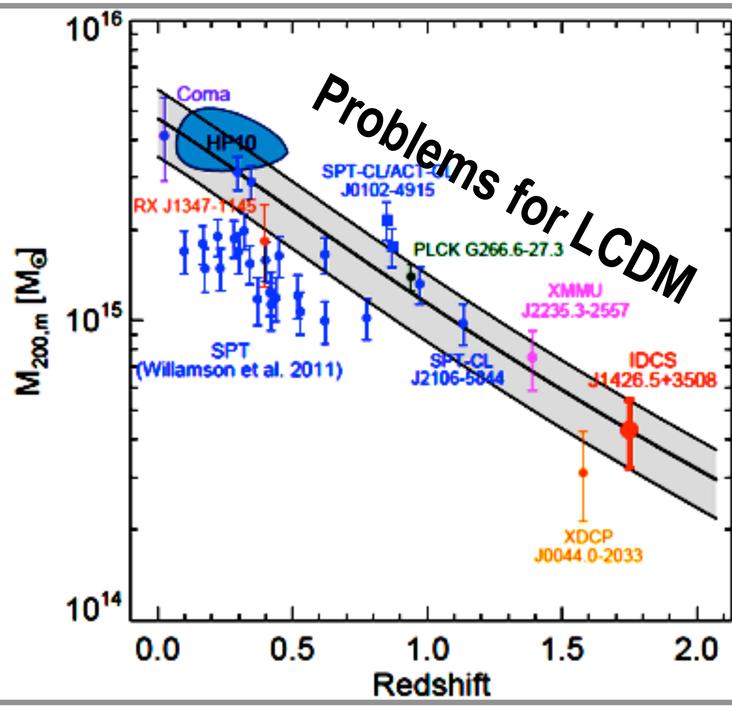


# SZE: other results in the PLANCK-Era

Very distant clusters with CARMA (31 GHz)
IDCSJ1426.5+3508 (z=1.75)

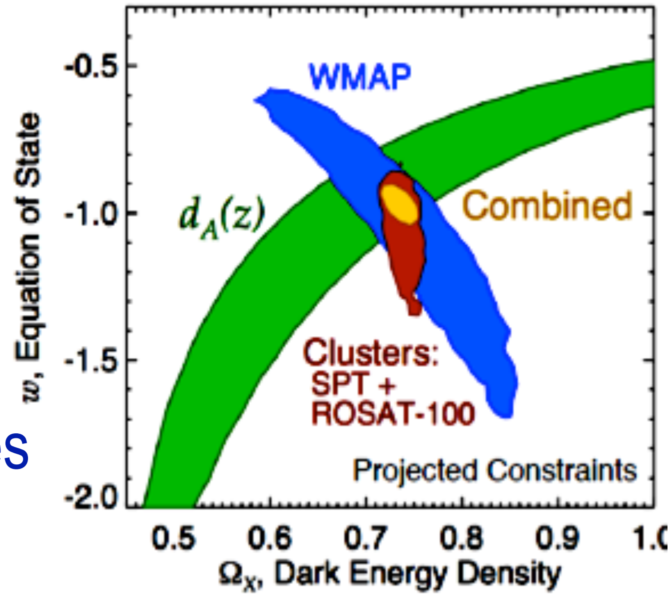


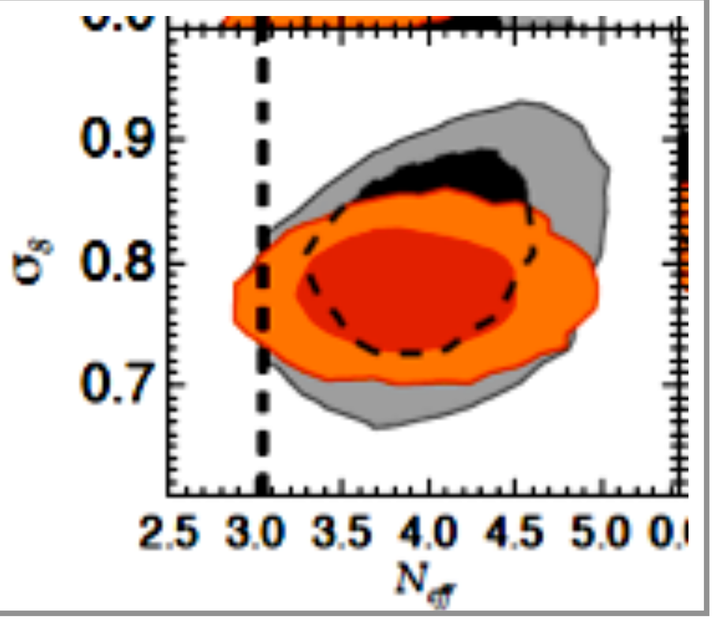



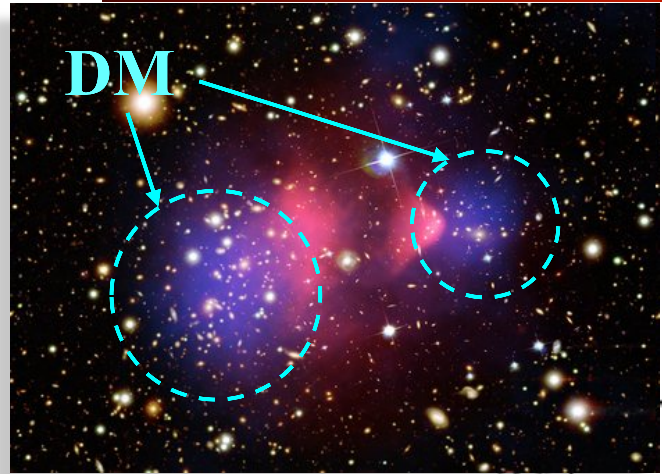

**SPT: 450 clusters**

- $\Delta w \sim 5\%$
- 2-$\sigma$ preference for non-zero $m_\nu$
  $\Sigma m = 0.34 \pm 0.17$eV
  and an extra $\nu$ species
  Neff=3.91±0.42

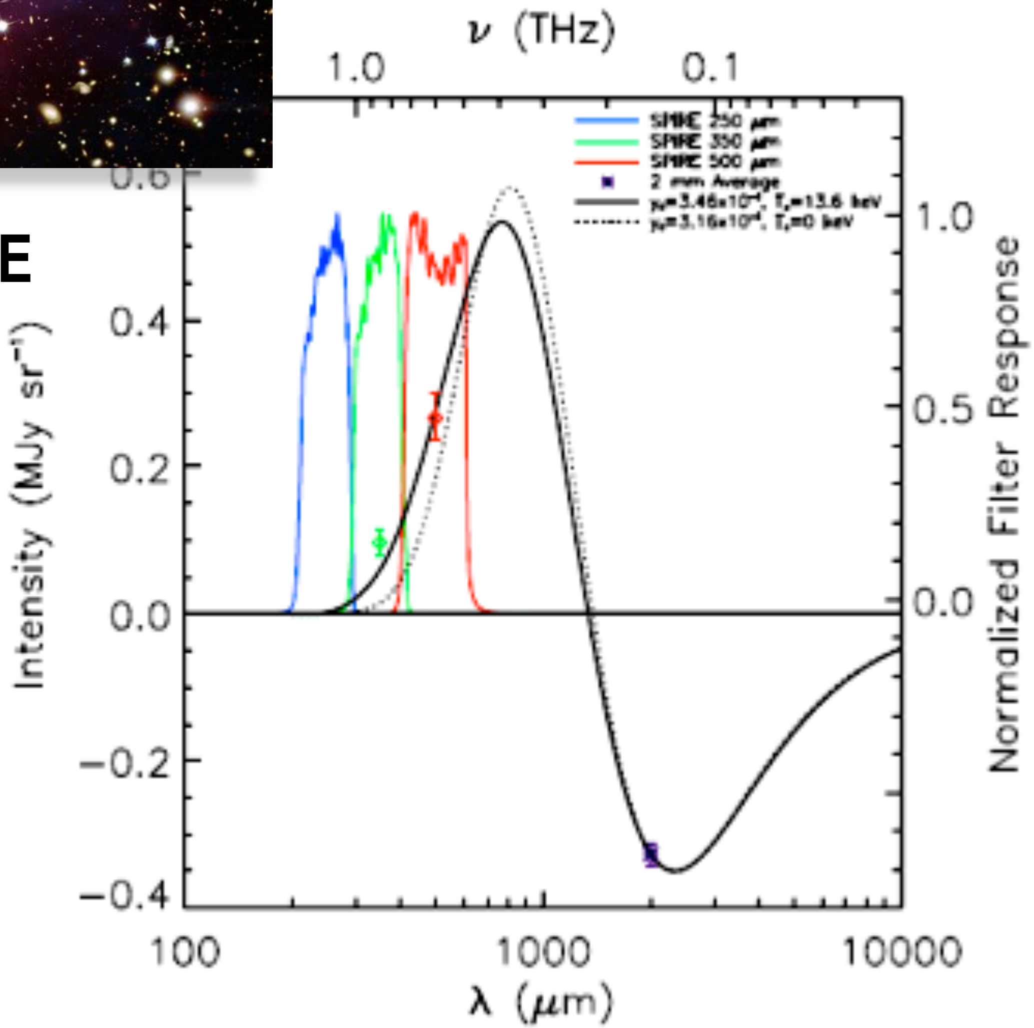


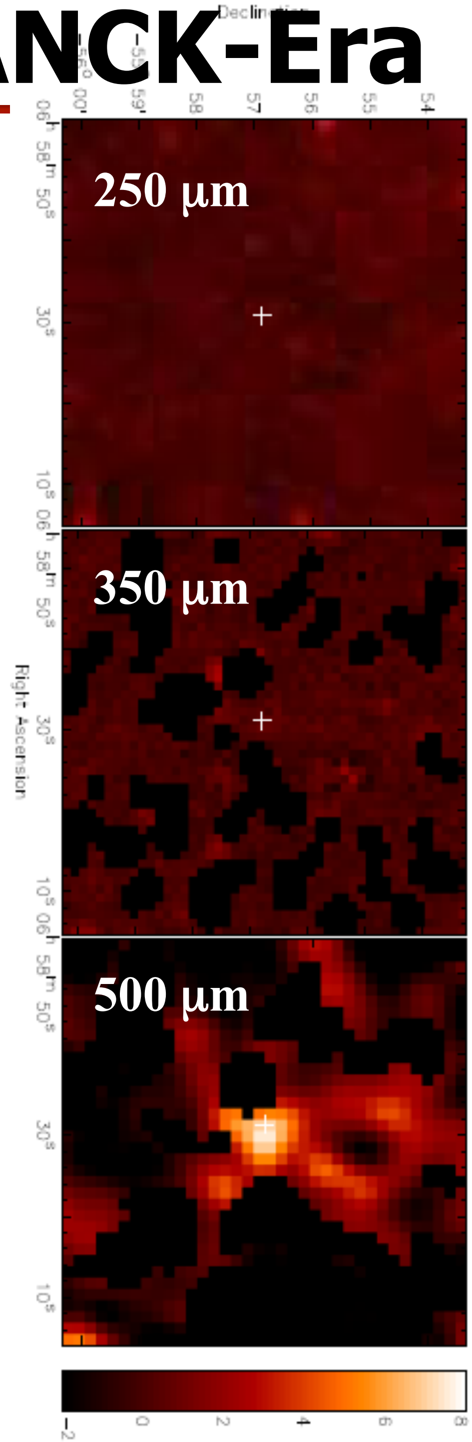



# SZE: other results in the PLANCK-Era

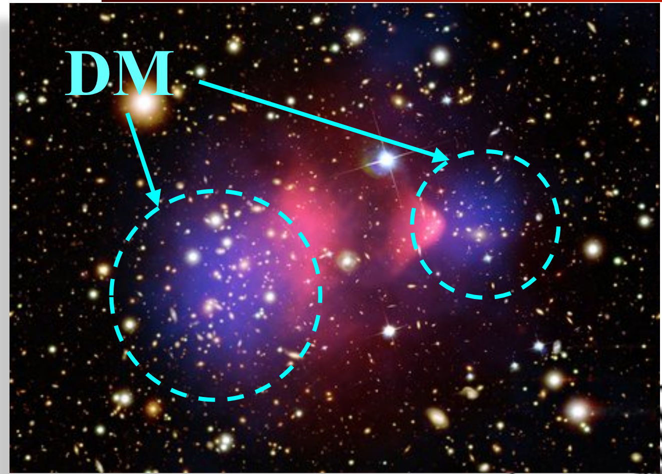



Herschel SPIRE view of the Bullet cluster



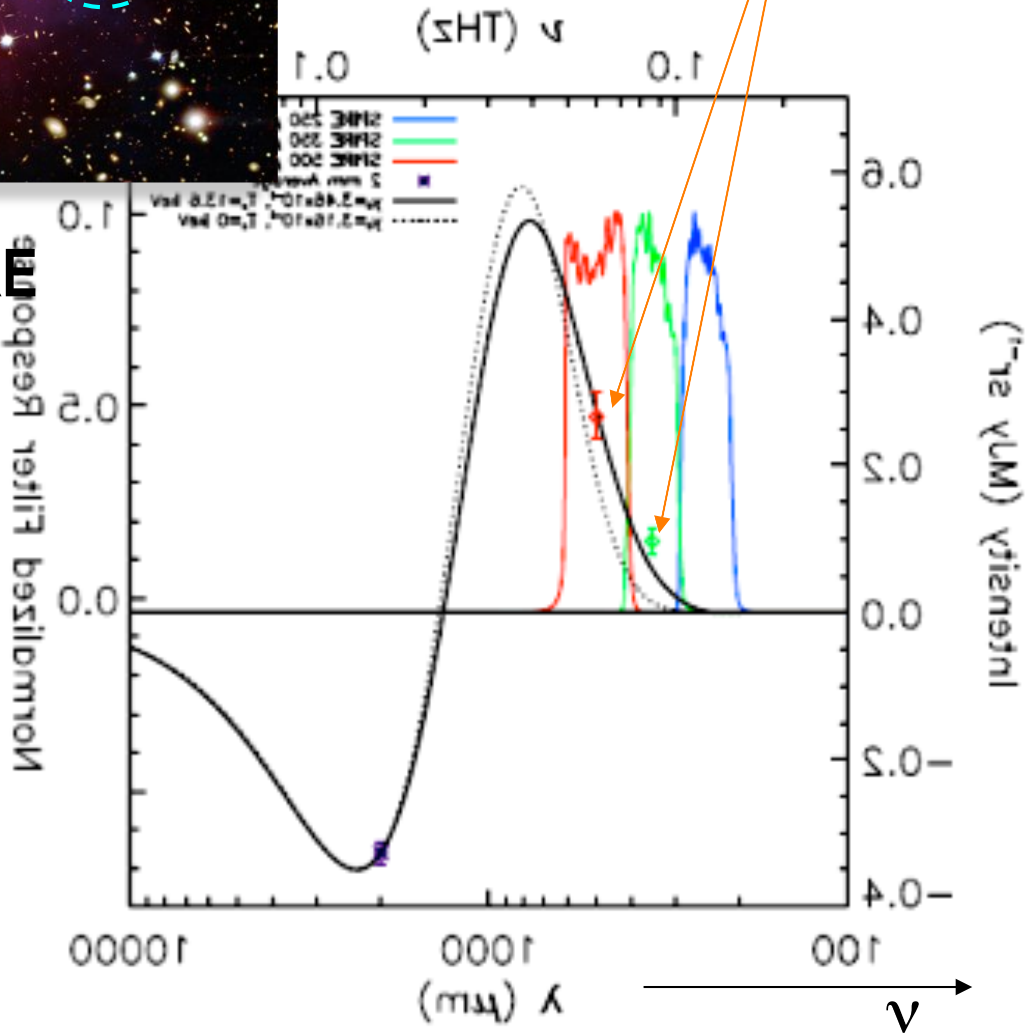



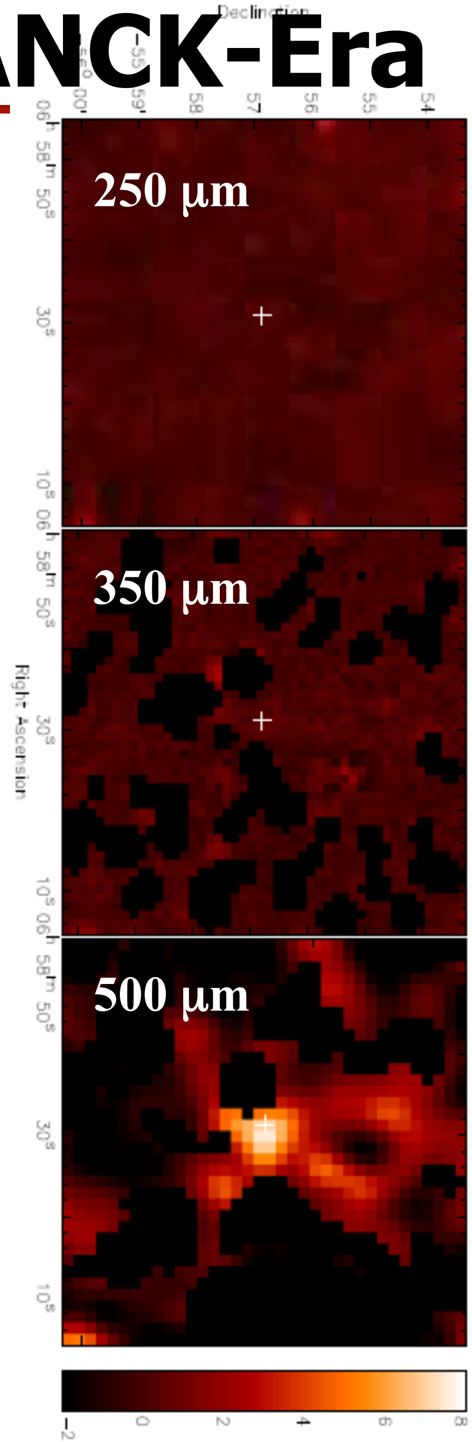
# SZE: other results in the PLANCK-Era




First evidence of relativistic / non-thermal effects

Herschel SPIRE view of the Bullet cluster

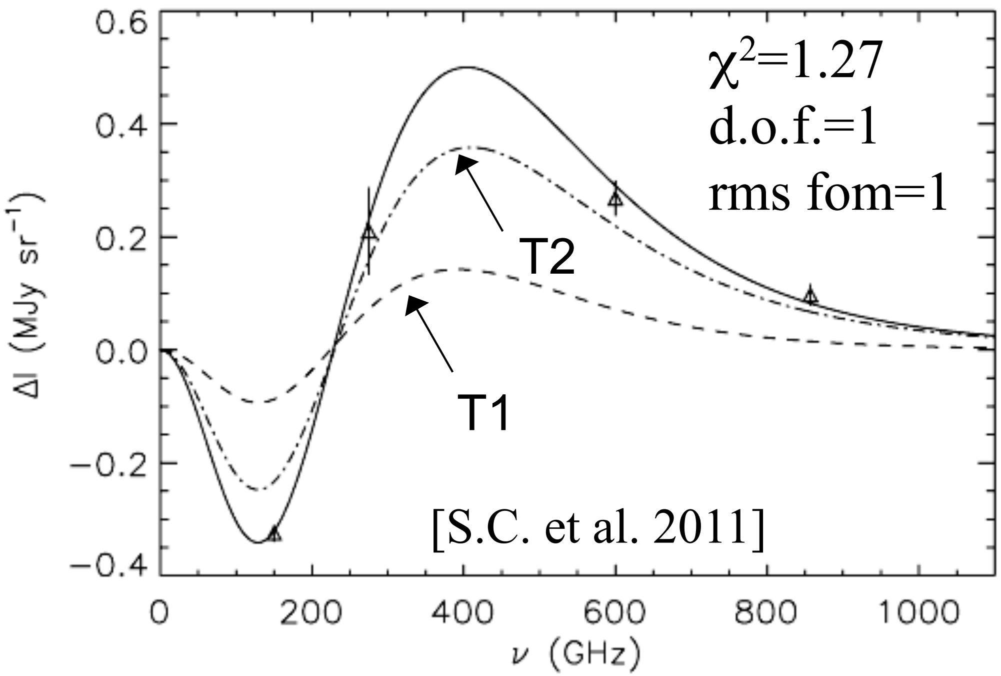


# SZE: probes of astrophysics

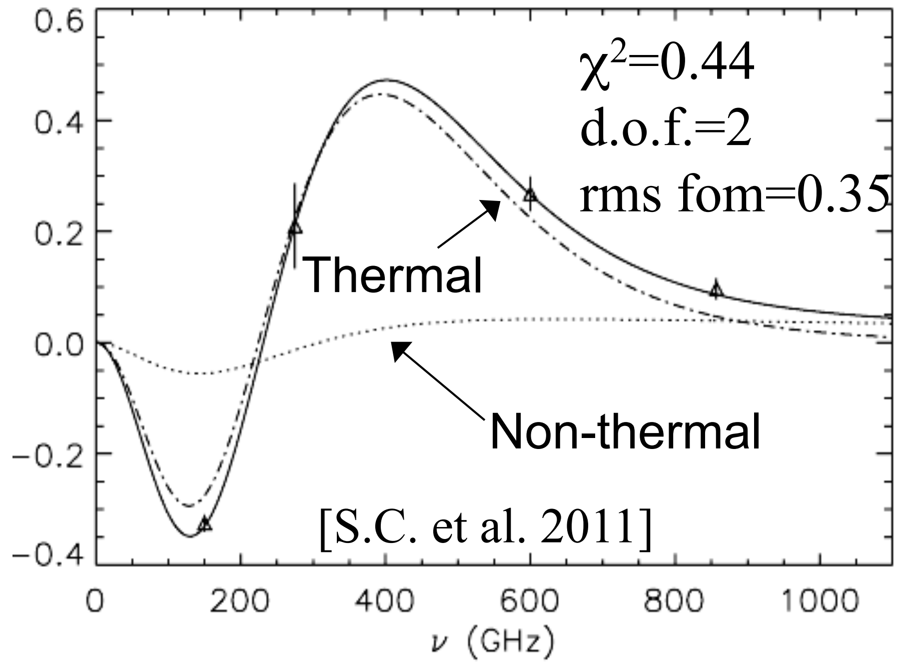
**Multi - Temperature**

$kT_1$= 13.9 keV $\tau$=3.5e-3
$kT_2$= 25 keV, $\tau$=5.5e-3




**Thermal + non-thermal**

kT = 13.9 keV $\tau$=1.1e-2
$n_e \sim E^{-2.7}$, $p_1$=1, $\tau$=2.4e-4




Evidence of non-gravitational activity in the cluster merging

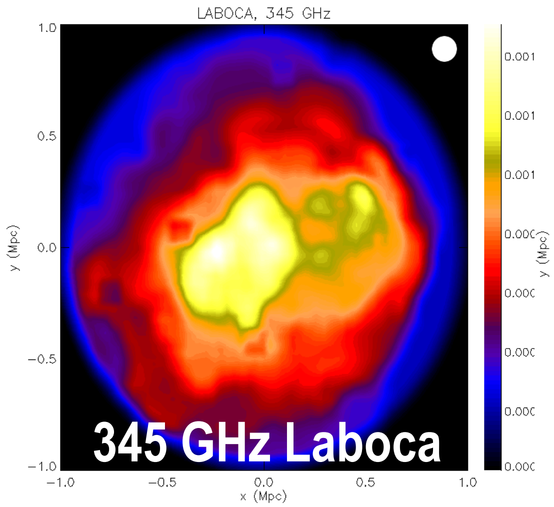
Shock acceleration or MHD acceleration

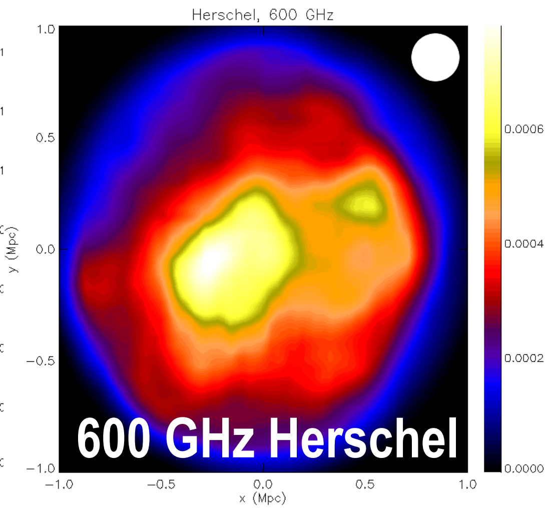
Stochastic electron acceleration

Continuous hadron acceleration

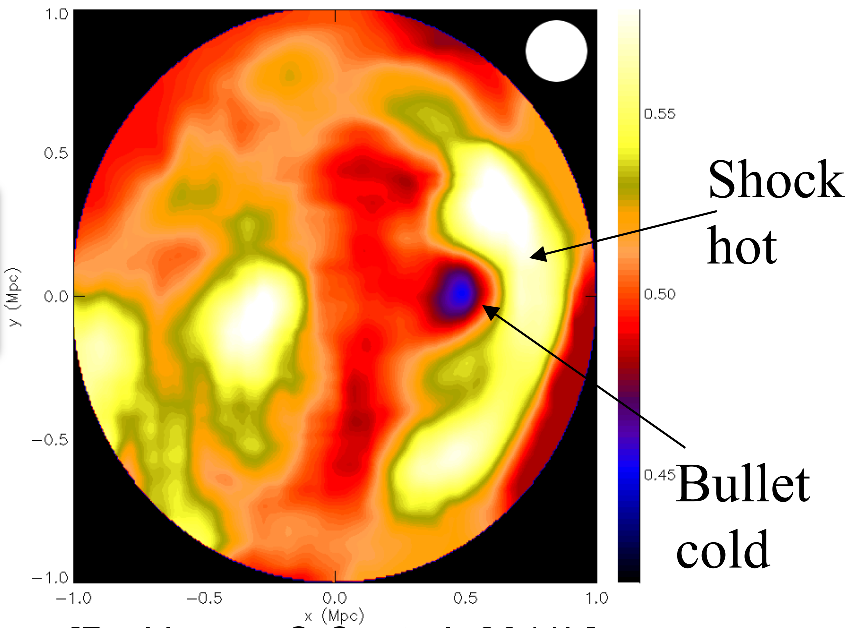
# SZE: 3-d tomography

## Morphological SZE




$$\frac{\Delta I_{600GHz}}{\Delta I_{345GHz}}$$




[Prokhorov, S.C. et al. 2011b]

## T standard deviation

First measurement of the temperature standard deviation in galaxy clusters: using the SZE
[Prokhorov & Colafrancesco 2012]

$$\sigma = \sqrt{\langle (k_{\mathrm{b}} T_{\mathrm{e}})^2 \rangle - (\langle k_{\mathrm{b}} T_{\mathrm{e}} \rangle)^2}$$

**Bullet Cluster**

**<T> ~ 13.9 keV**

**σ = 10.6 ± 3.8 keV**

- Measure of the temperature stratification in clusters
- Measure of plasma in-homogeneity along the line-of-sight

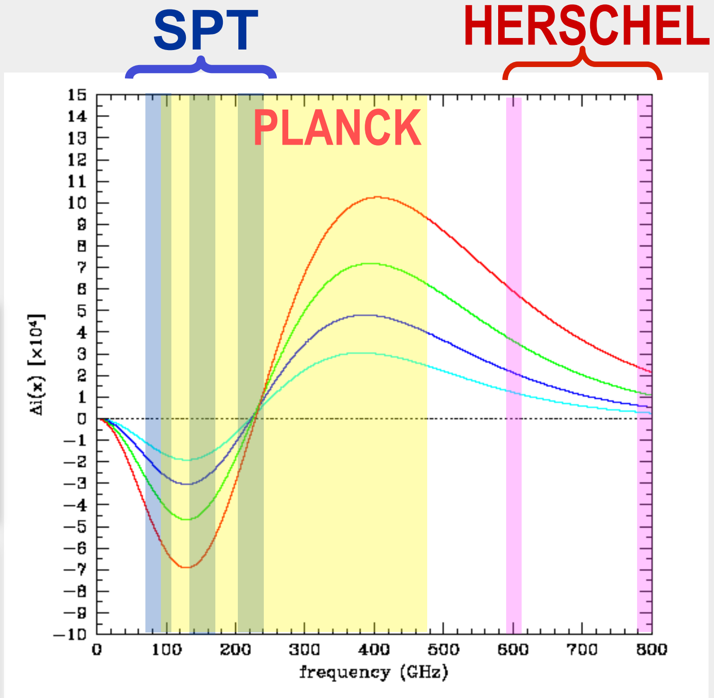
# From PLANCK onward



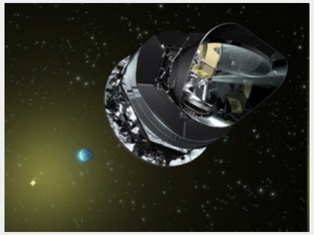
Deep integrations, high resolution, ~$10^3$ $deg^2$ survey.
- No access to positive peak of SZE ($\nu$>300 GHz)
- No spectroscopy.

APEX - SZ + LABOCA
150-215 345 GHz

- No spectroscopy
- Different instruments




**PLANCK**



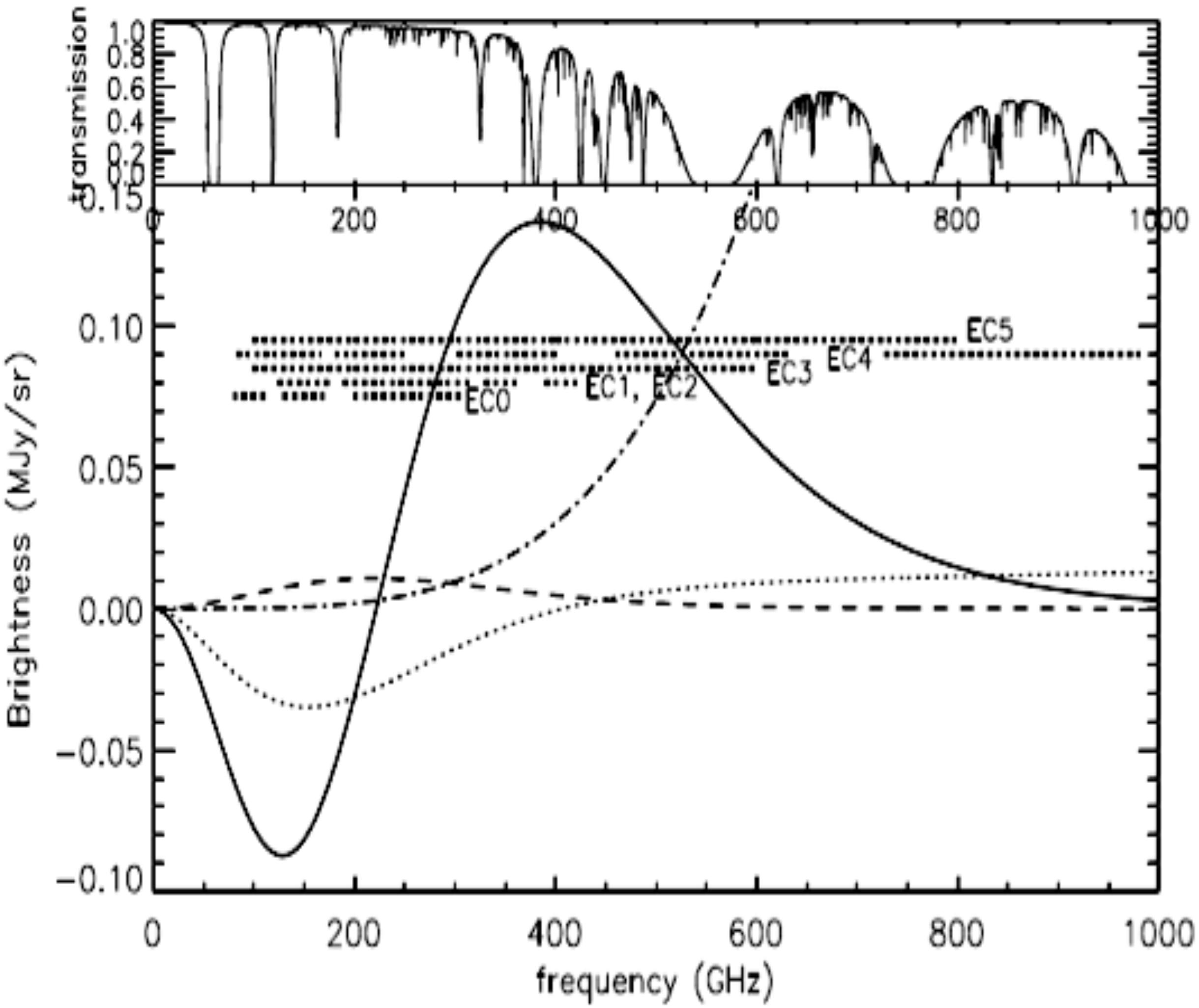
Full sky, but shallow survey
A few thousand clusters with low-moderate S/N ratio.
Low-moderate spatial resolution & spectroscopy in bands

To fully exploit the SZE info. we would need

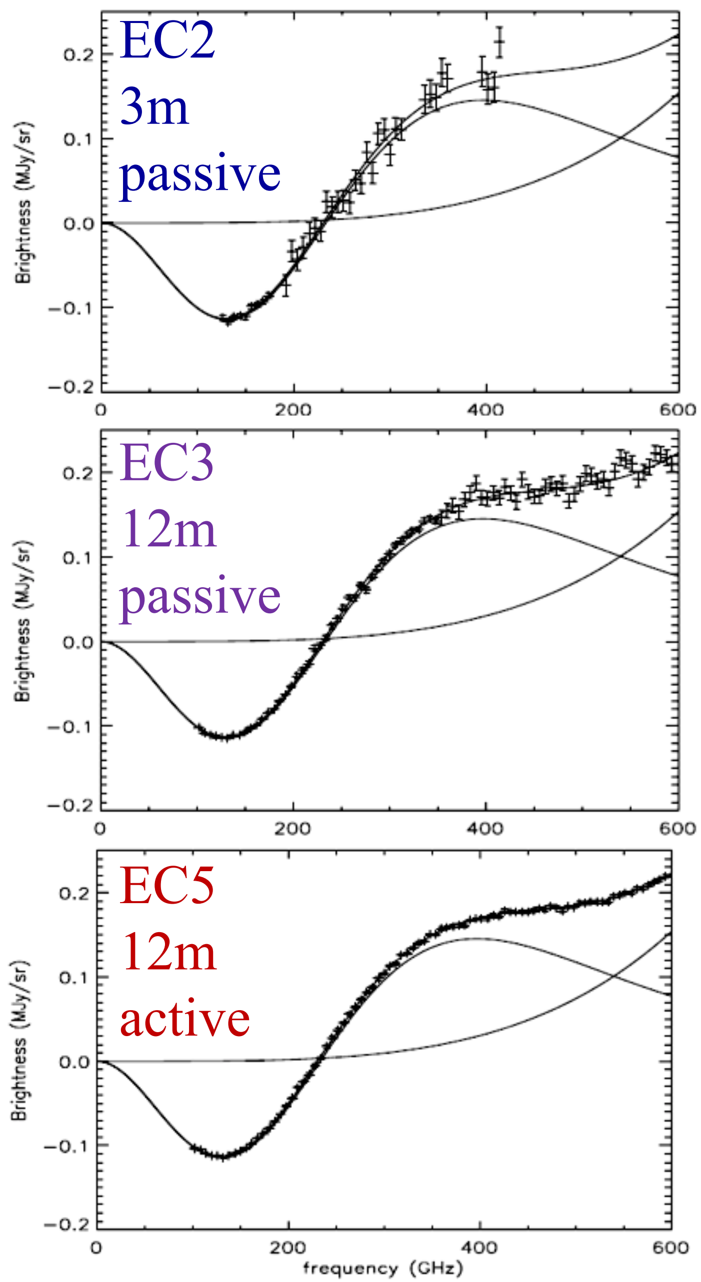
- Spectroscopic capabilities — wide-band
- Wider & continuous frequency coverage — FTS-like
- Better calibration — (no multi-band, no atmosphere)
- Better knowledge of foregrounds — PS separation
- Deep integrations on selected targets/fields — Astro+Cosmo

# Expectations: spectra

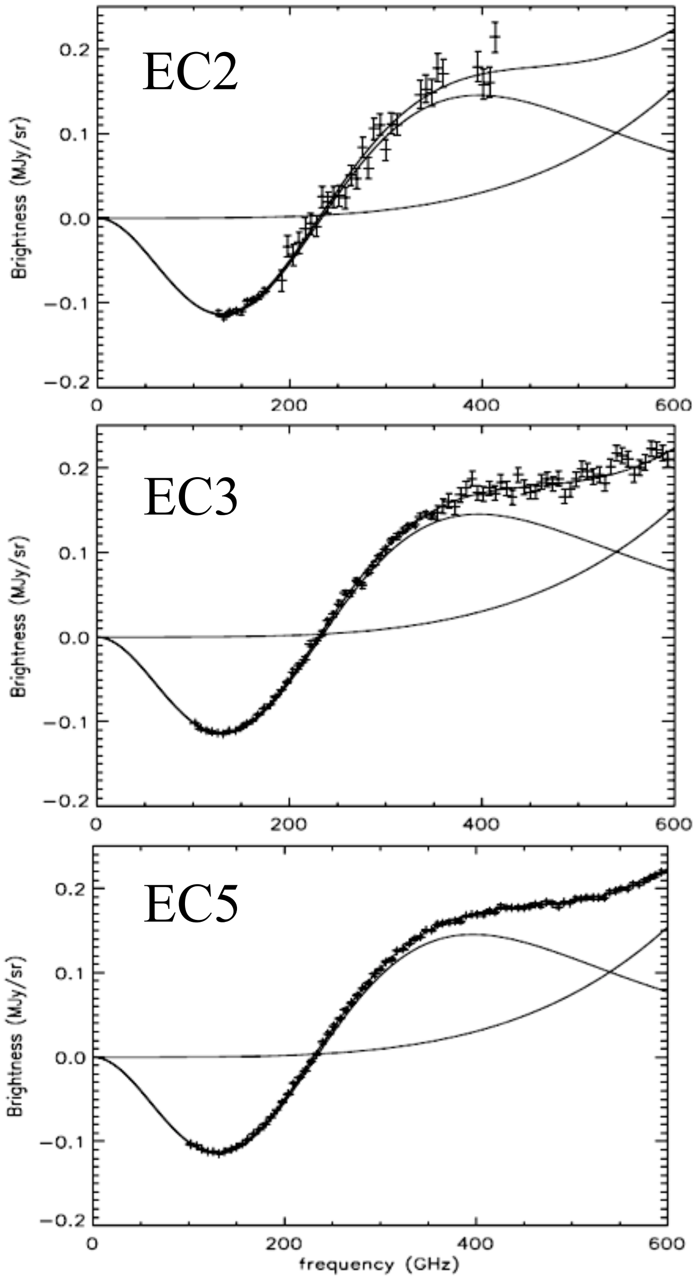
Different spectroscopic configurations for studying the SZE in cosmic structures

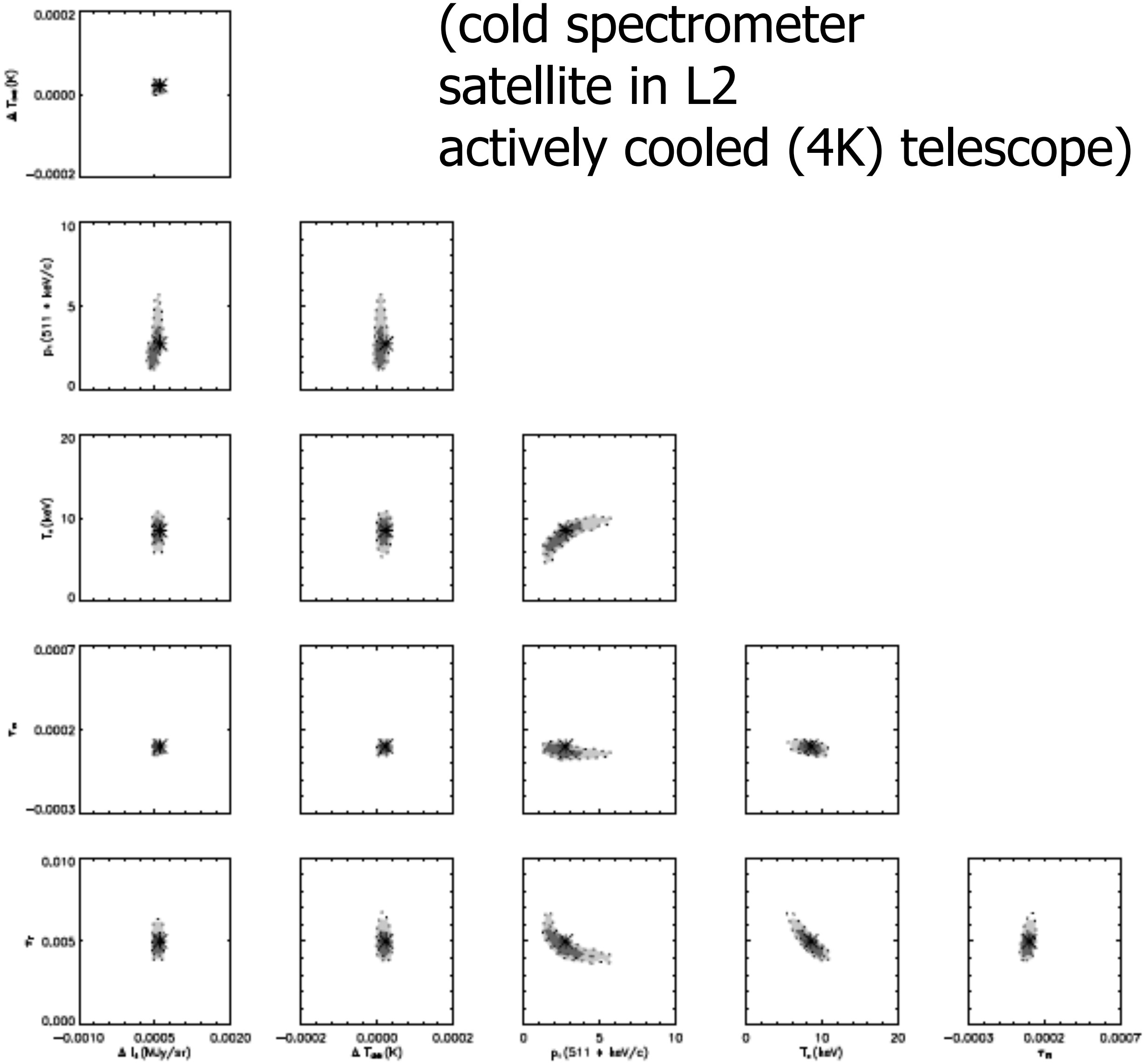



[DeBernardis, Colafrancesco et al. 2011]



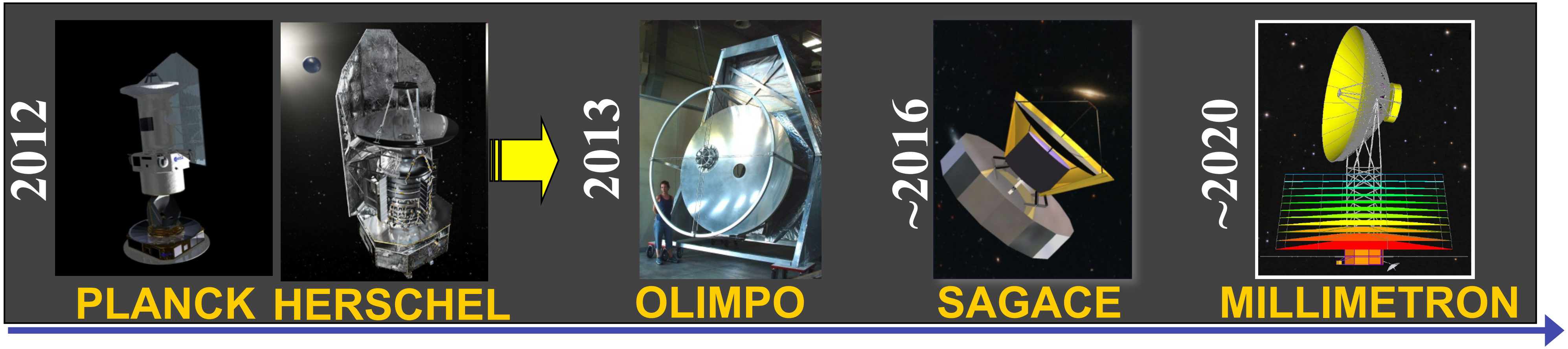
# Requirements




EC5
(cold spectrometer
satellite in L2
actively cooled (4K) telescope)

# SZE in Space: a future outline

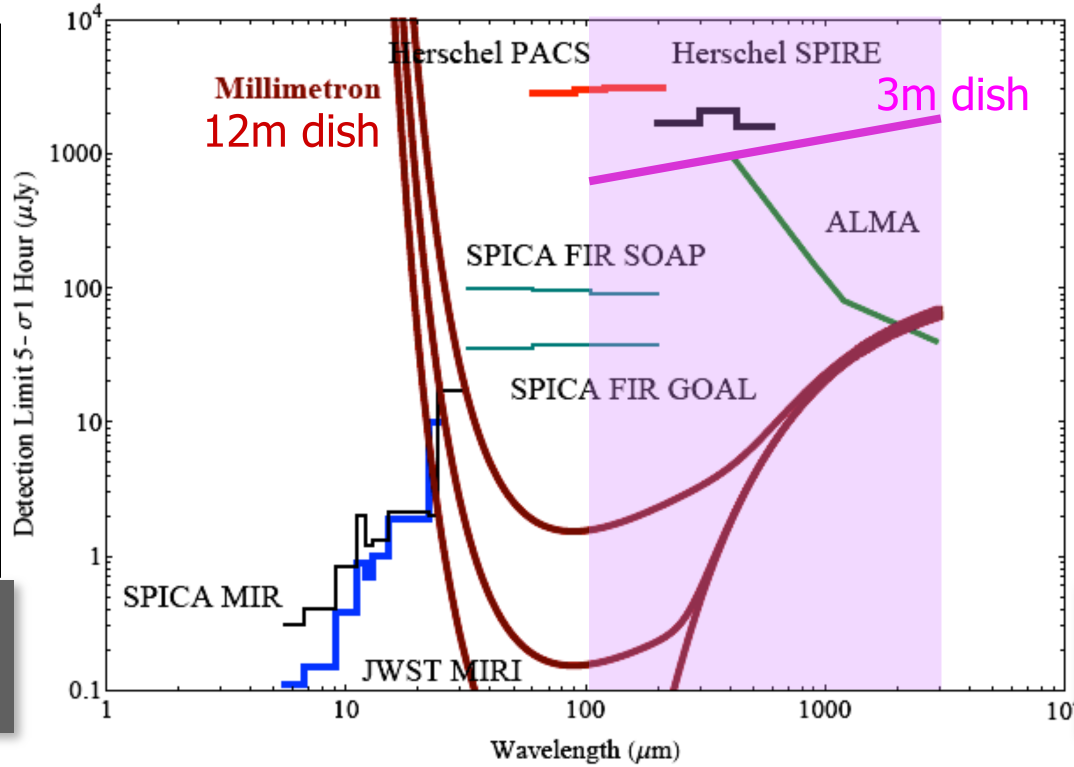



**SAGACE 3m**

**MILLIMETRON 12m**

**3 m dish**
**Passive cooling**
**(50 K)**
**Θ= 0.7-4.2 arcmin**
**Noise=18 mJy/√Hz**
**FTS spectroscopy**

**Large-survey mode**
**Pointed mode**



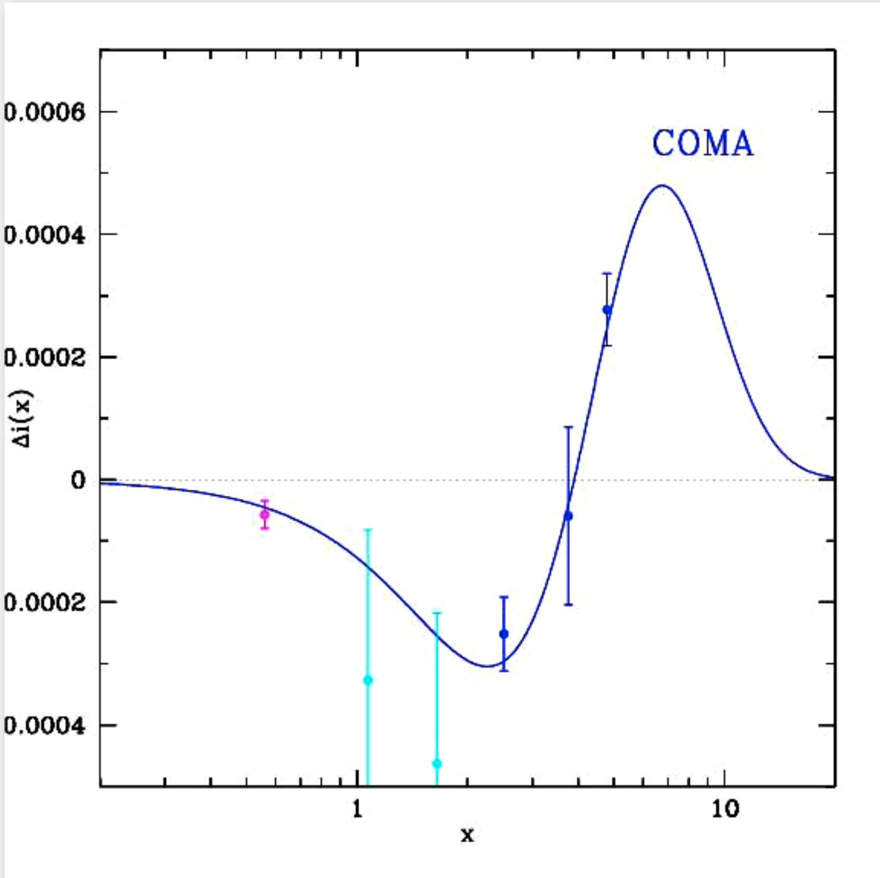

**12 m dish**
**Active cooling**
**(4 K)**
**Θ< 0.1-1.0 arcmin**
**Noise<0.1 mJy/√Hz**
**FTS spectroscopy**
**Polarimetry**
**Super VLBI**

**Observatory mode**
**Small-survey mode**

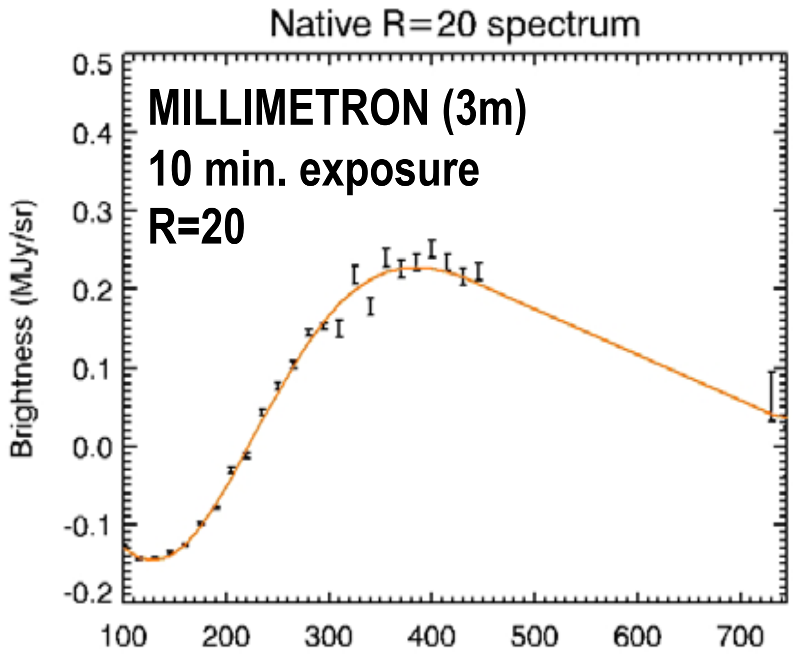
# SZE spectroscopy: precision

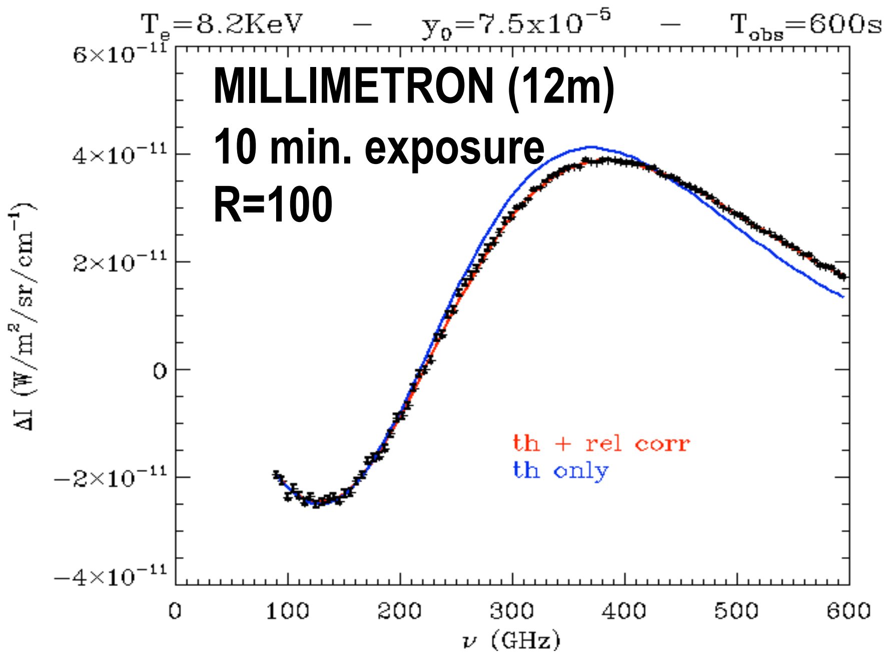
**COMA in SZE: Current data**

(Battistelli et al. 2003, ApJ 598, L75)

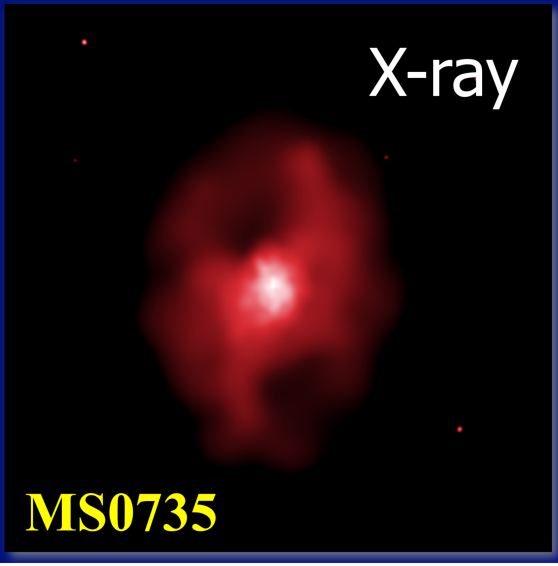


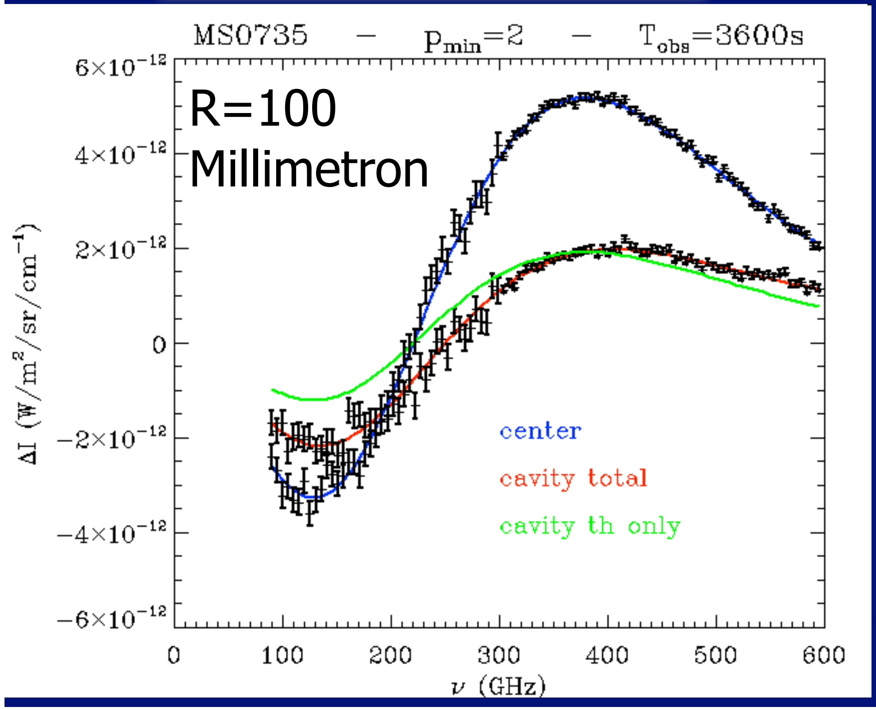

[Colafrancesco 2004-2010]

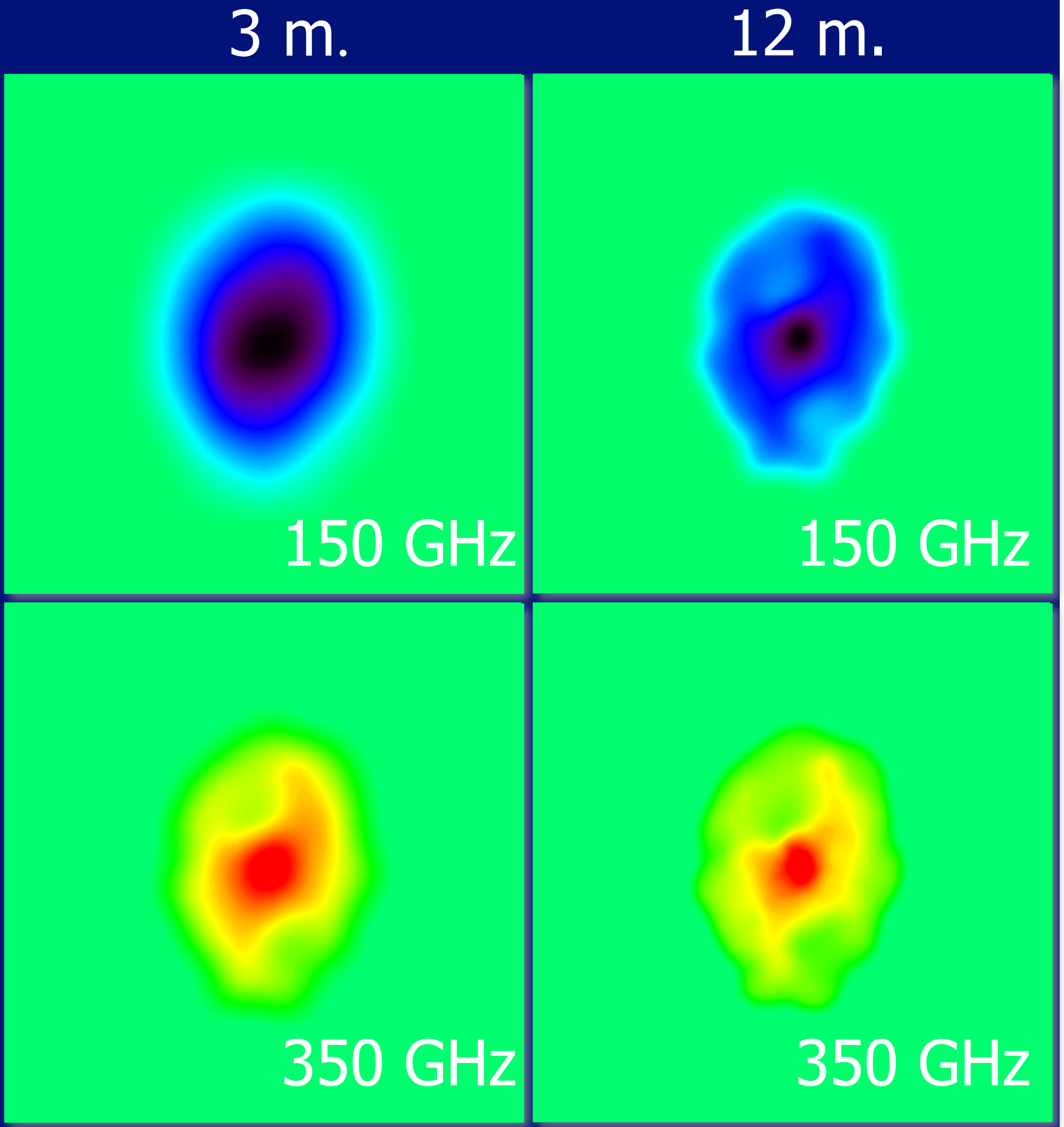


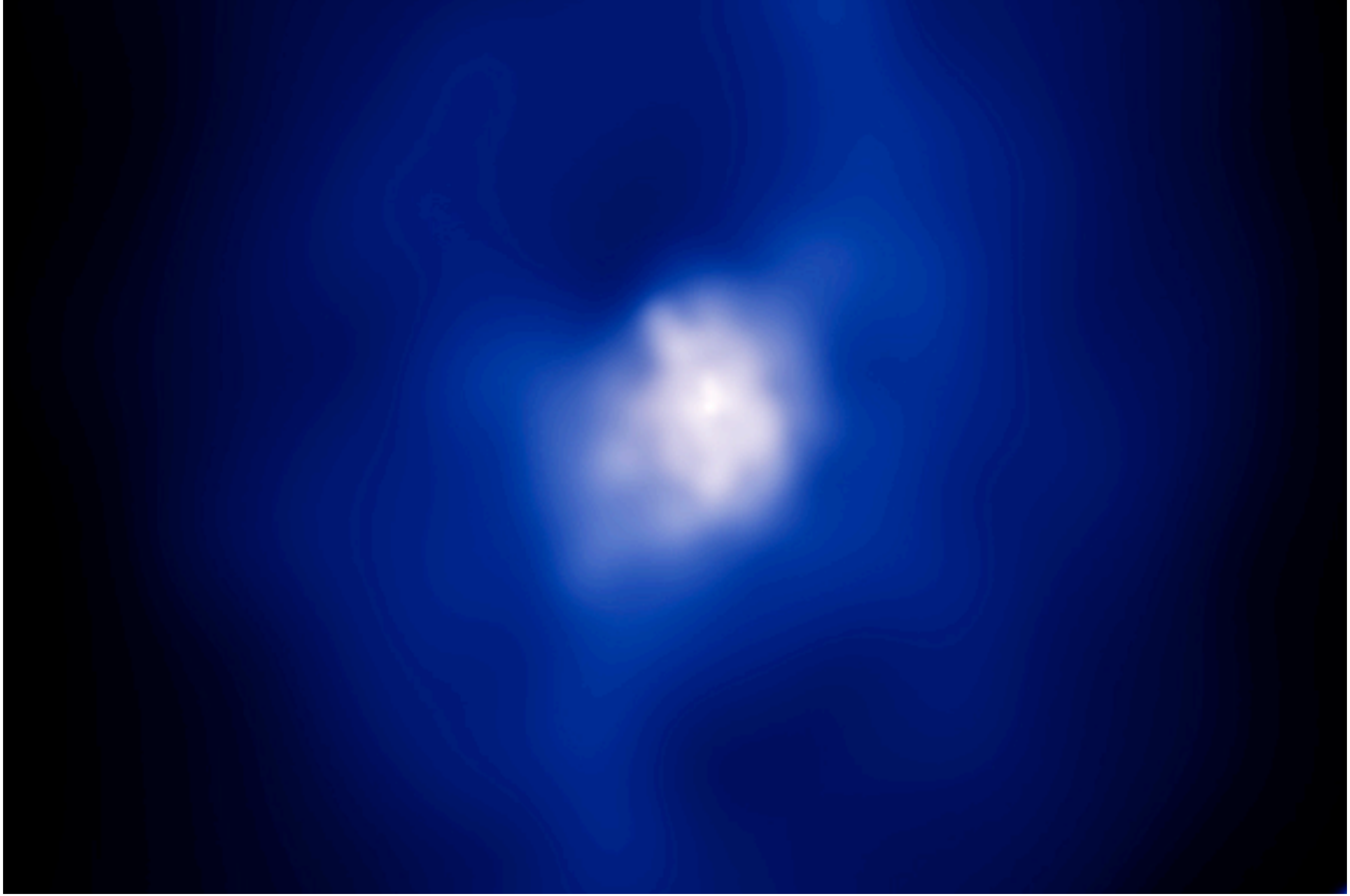
# SZE: resolving cluster atmospheres



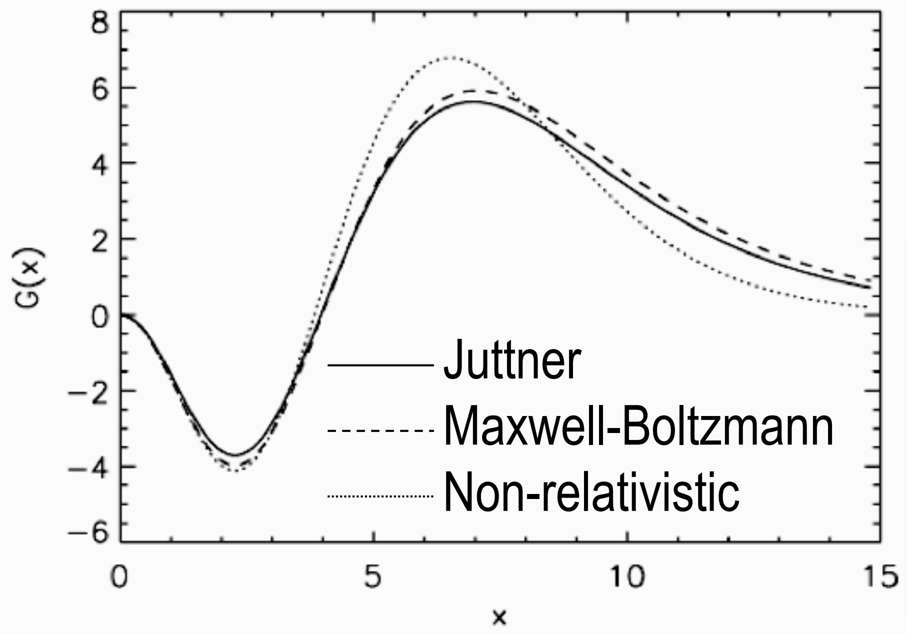



# SZE and thermal plasma



# SZE spectroscopy: thermal plasma




The relativistic kinetic theory (DF derivation) of astrophysical plasma is still unknown !

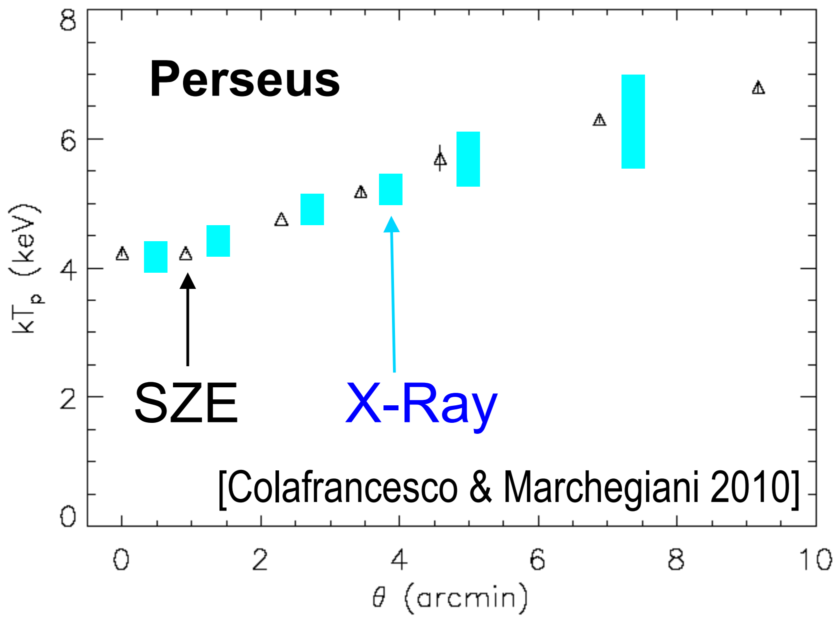
A method based on Fourier analysis to derive the velocity DF of electrons by using SZE observations at ≥ 4 frequencies.
[Prokhorov, Colafrancesco, et al. 20011a]

**SZE spectroscopy will allow to derive spatially resolved T-profiles for nearby clusters out to large radii:**

**Inversion Technique SZE → $T, \tau, V_p, T_{CMB}$**

**T profile with uncertainties similar to those of X-ray observations**

**T profile uniquely sampled in the outer parts of the cluster**



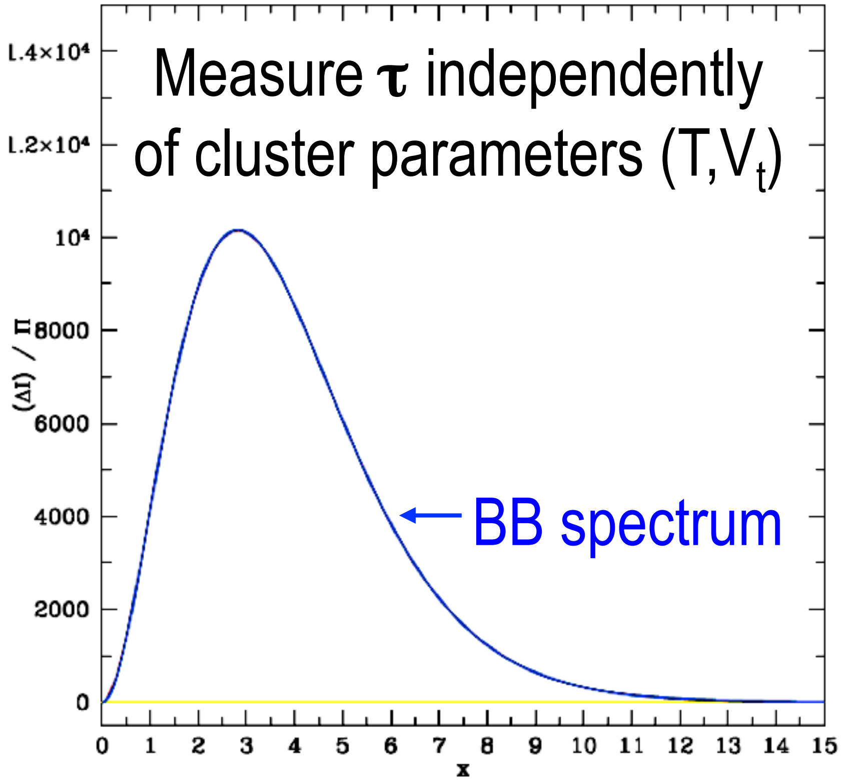
# SZE spectro-polarimetry: 6-d

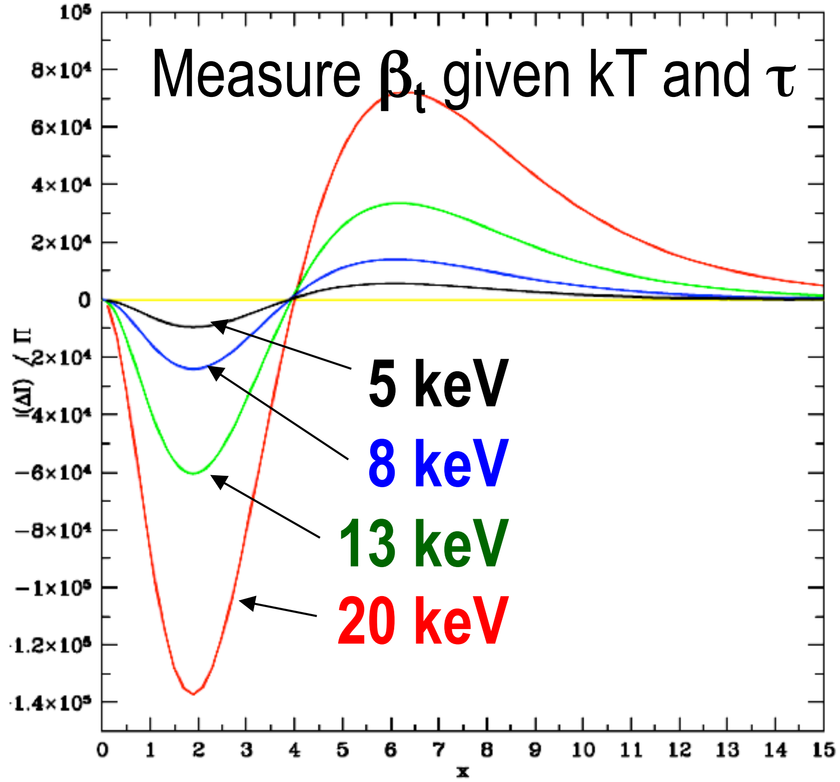
SZE intensity spectrum allow to measure the plasma temperature kT

Polarization due to finite optical depth **τ** allow to measure the density and velocity distribution of the electron plasma → 6-d phase-space

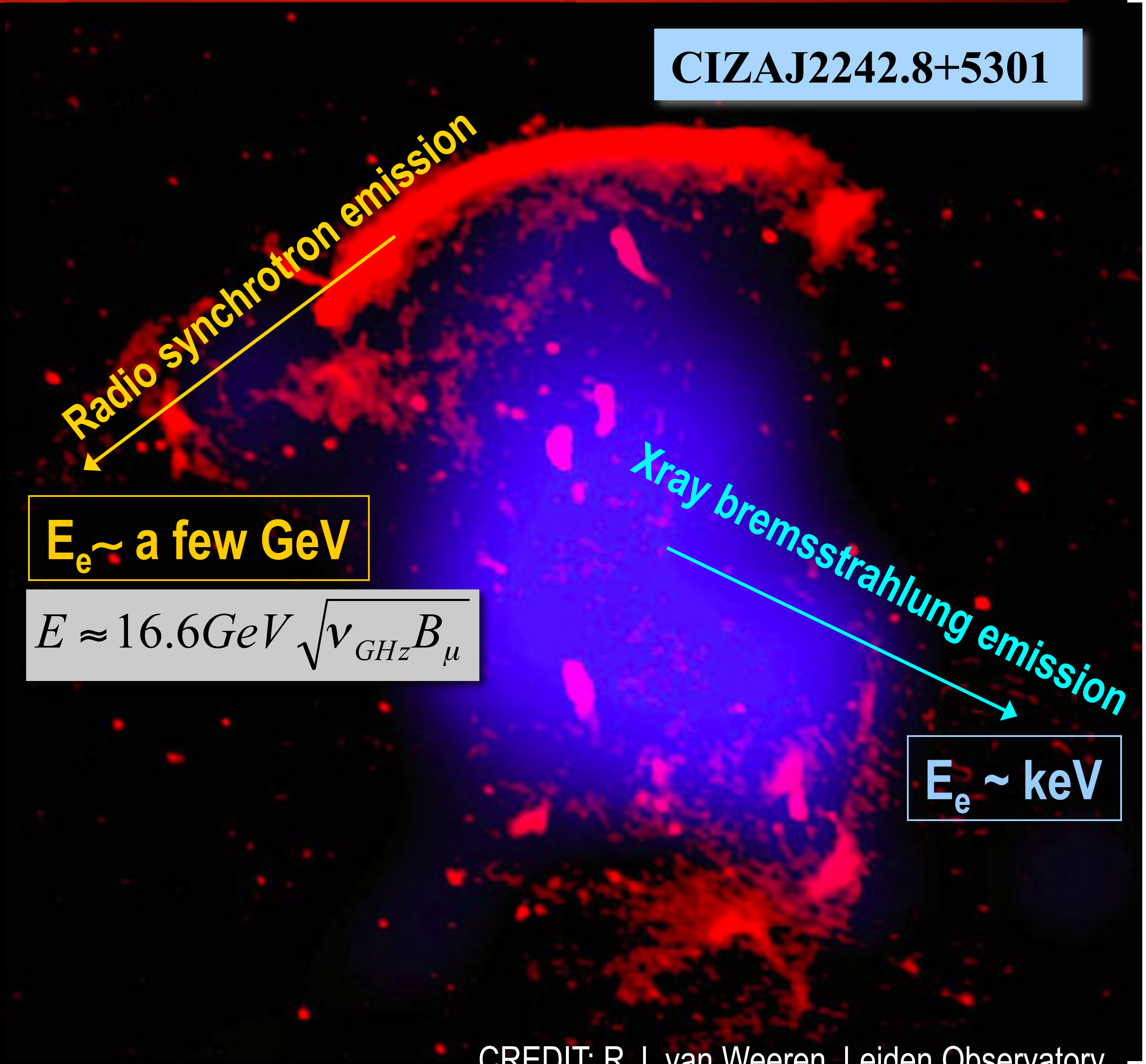
$$\frac{\Delta I}{\Pi_T} = 71.43 \frac{g(x)}{f_T(x)} \frac{1}{\tau}$$

$$\frac{\Delta I}{\Pi_V} = 40 \frac{g(x)}{f(x)} \frac{1}{\tau} \frac{1}{\beta_t} \frac{kT}{m_e c^2}$$

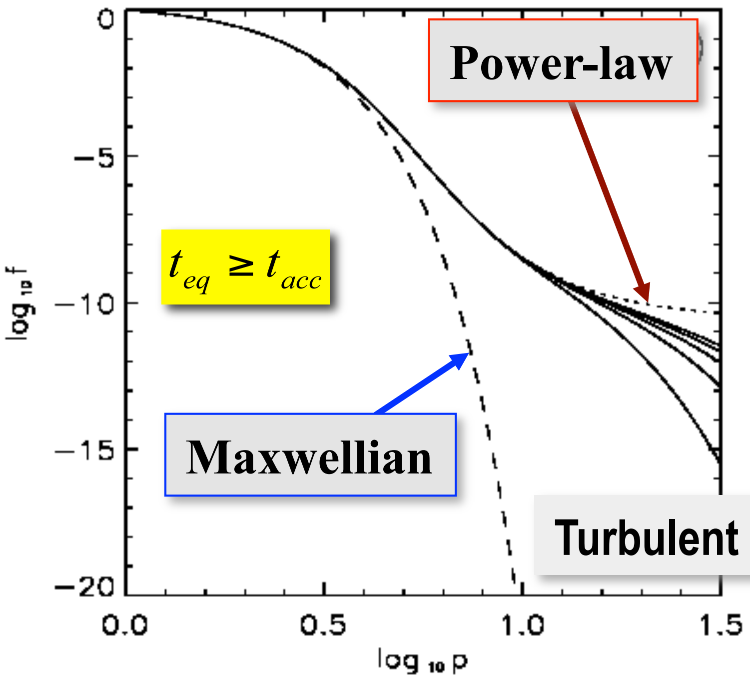


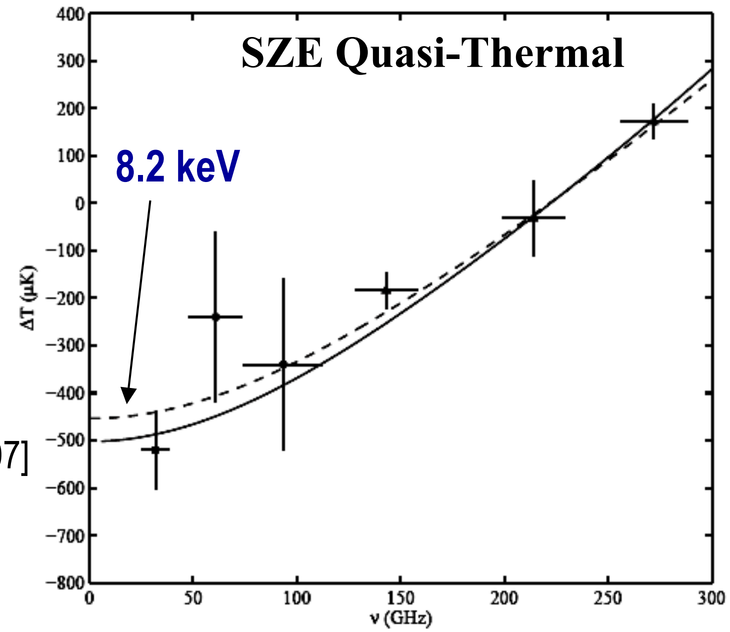



# Particle acceleration



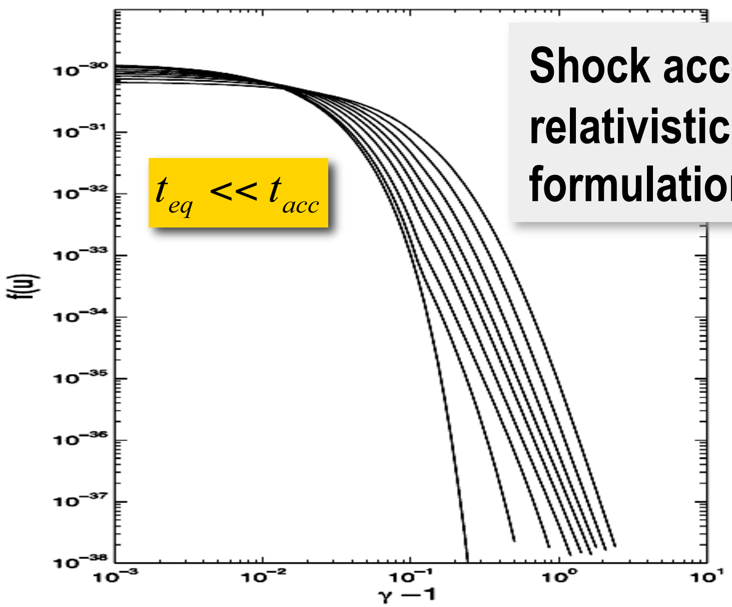
# SZE: high-E particles (CRs)



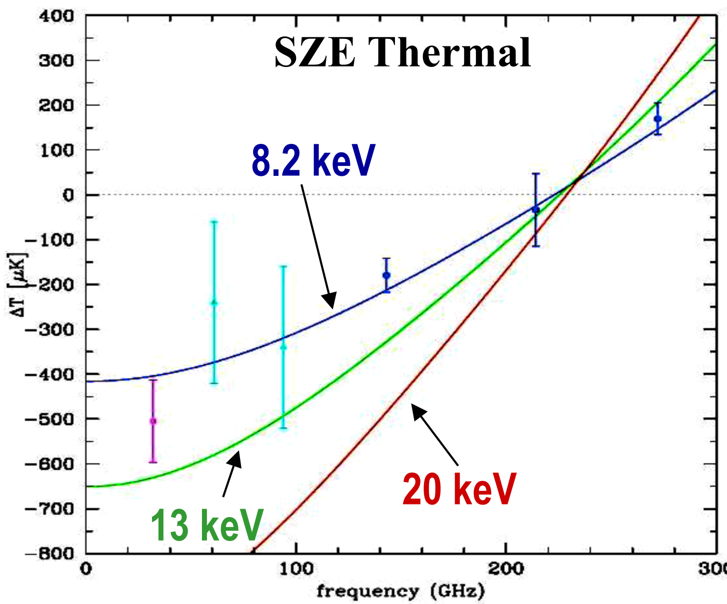




[Dogiel, **S.C.**, et al. 2007]

Turbulent acceleration

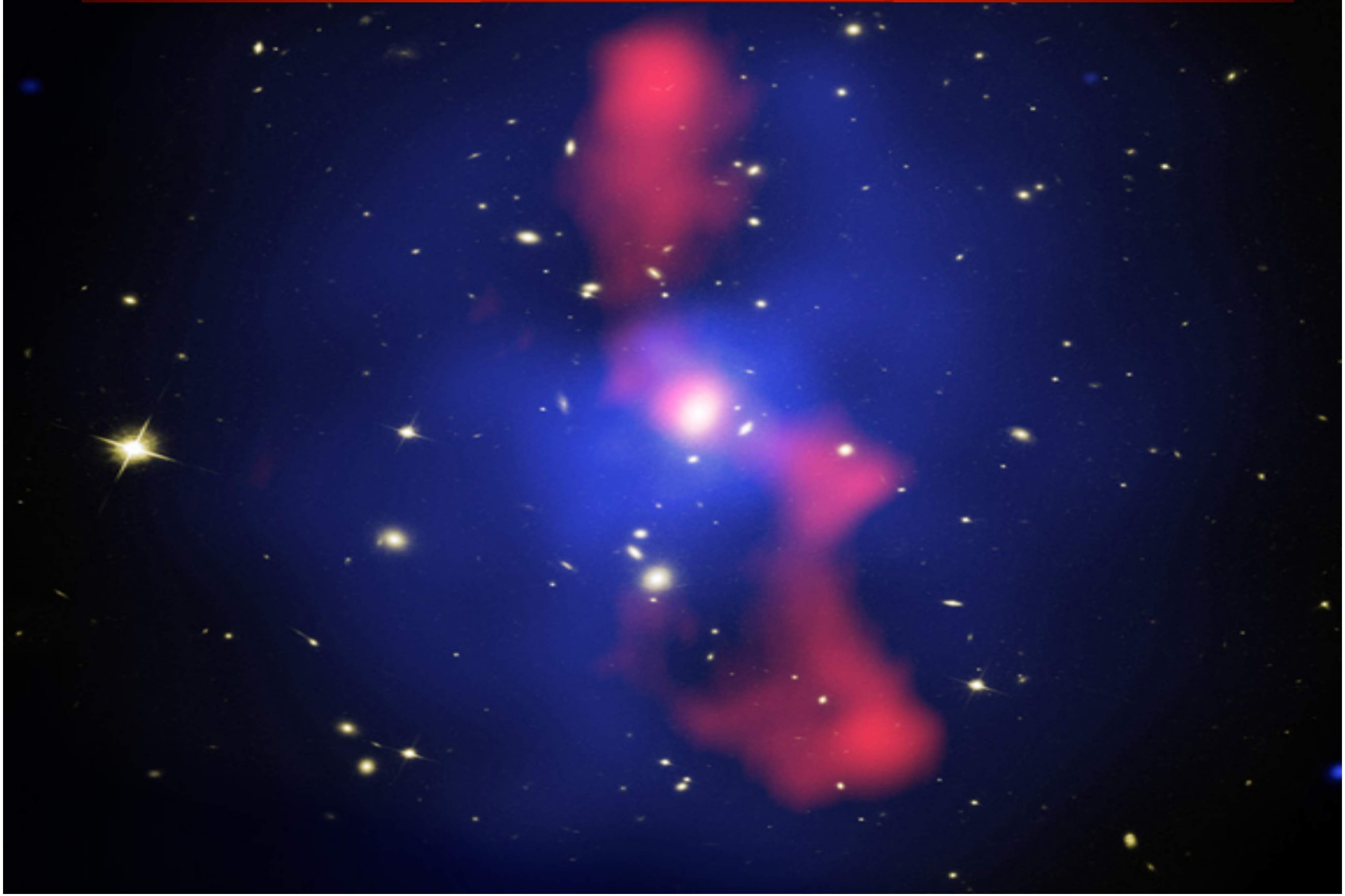



**Shock acceleration: relativistic covariant formulation**

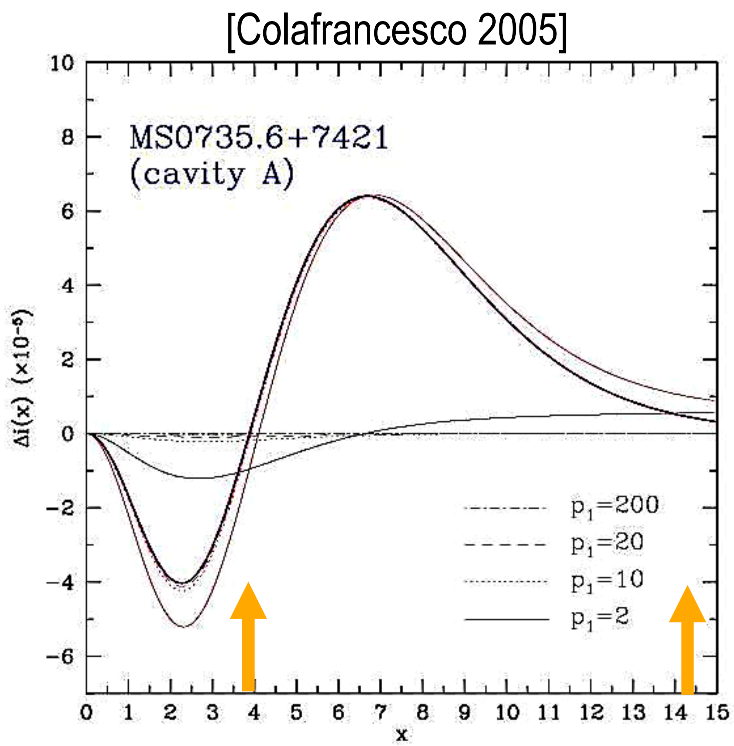


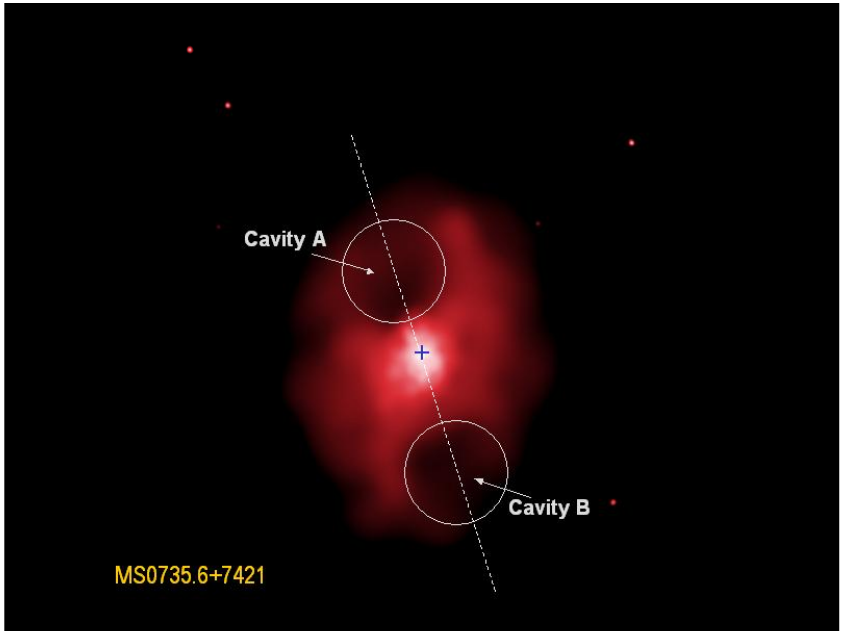

[Wolfe & Melia 2006]

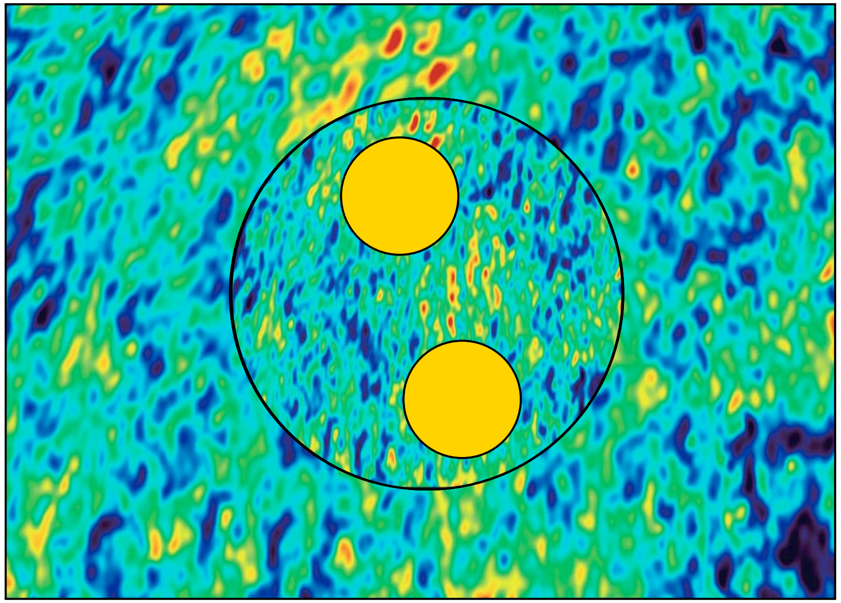
# SZE and cluster cavities



# SZE: cavities in Clusters



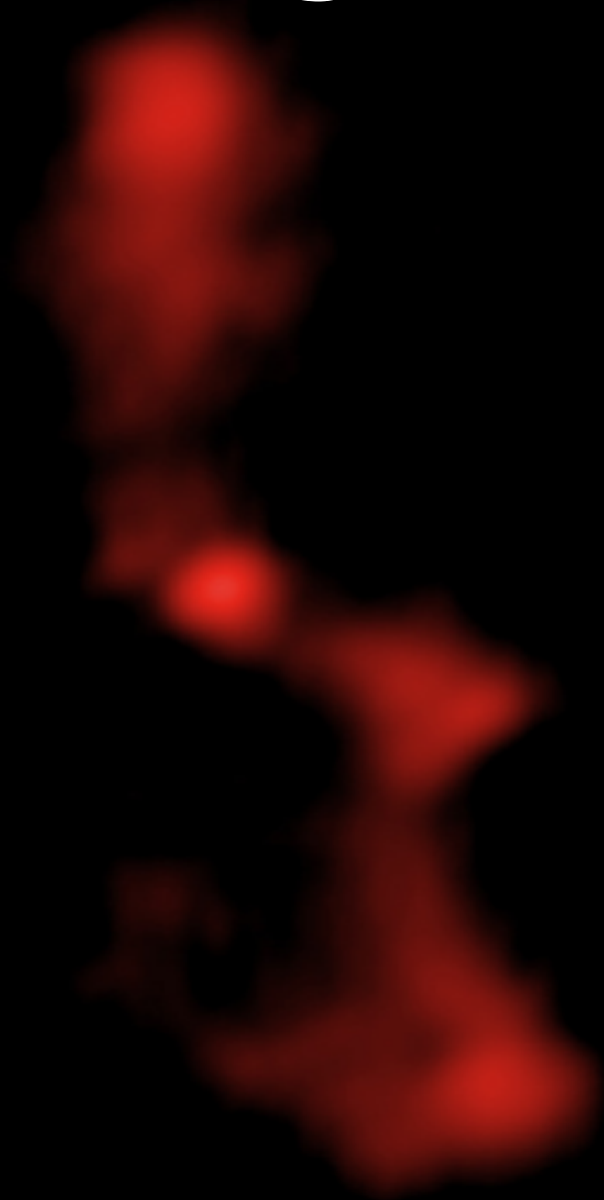



**Cavities are isolated from the surrounding cluster atmosphere at**

- **$\nu \sim 220$ GHz**
- **$\nu > 800$ GHz**

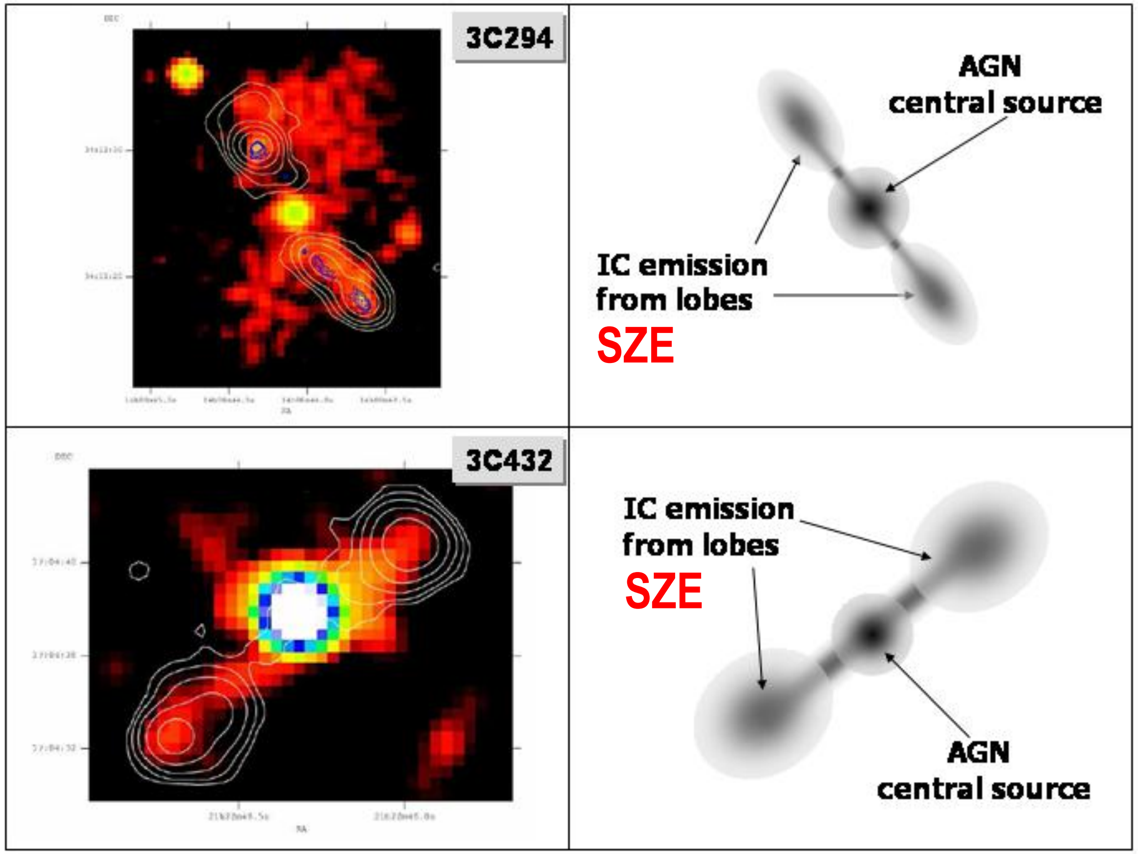
$\Delta I \sim \int dl \cdot U_{e,tot}$ : advantage w.r.t. X-rays

# SZE and radio-galaxy lobes

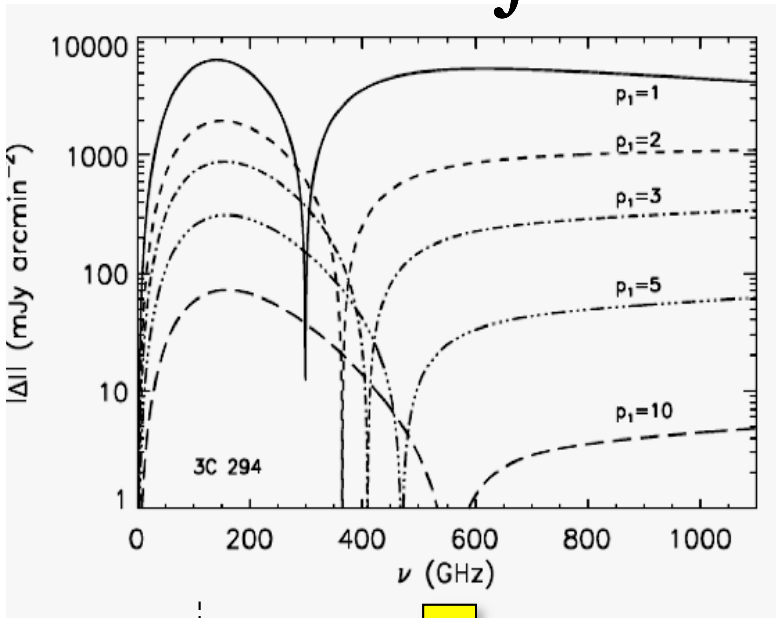


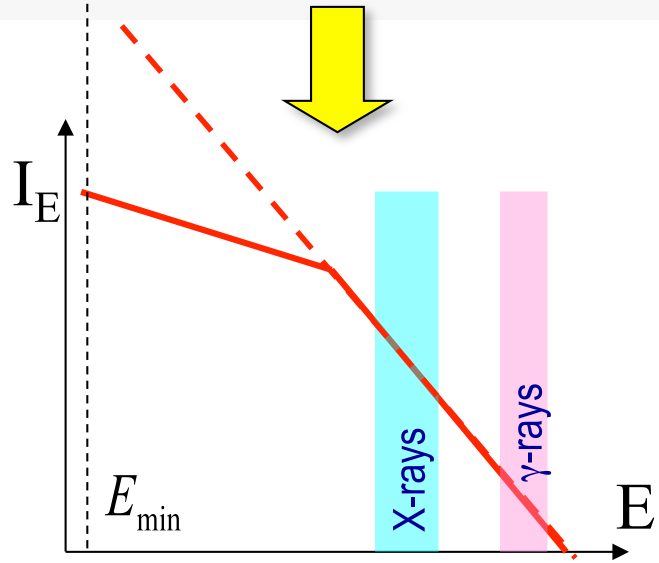
# SZE: radio-galaxy lobes

**X-rays** **SZE**




$$\Delta I(x) \propto g(x) \cdot \int d\ell \cdot U_{e,rel}$$



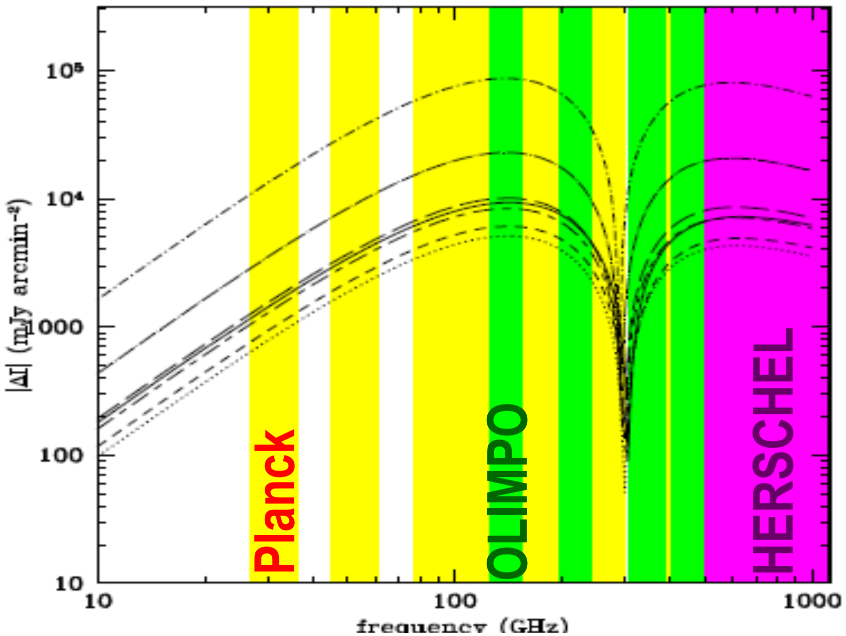



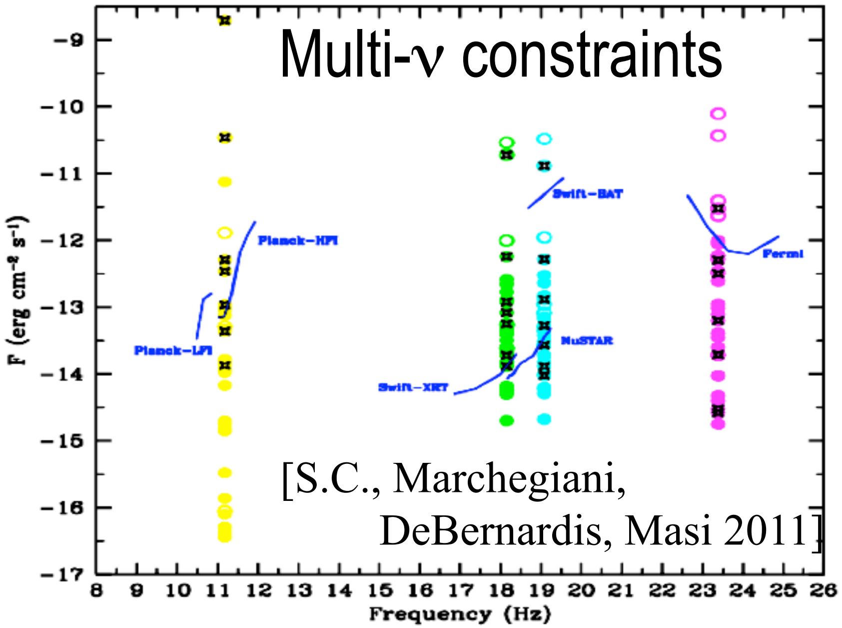

Total leptonic spectrum of RG lobes $\quad P_{tot}; E_{\min}$

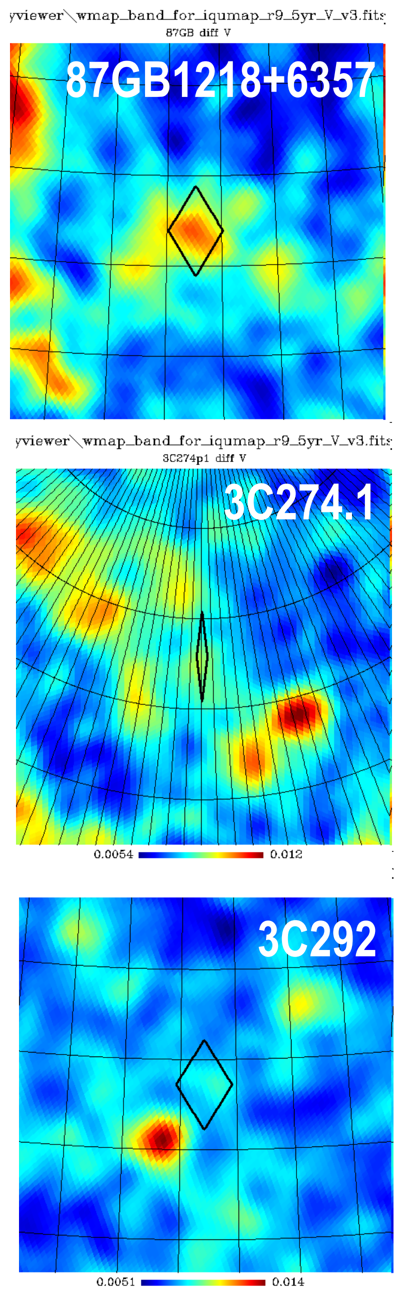
B-field structure in RG lobes $\quad \dfrac{F_{radio}}{F_{ICS}} = \dfrac{U_B}{U_{rad}}$

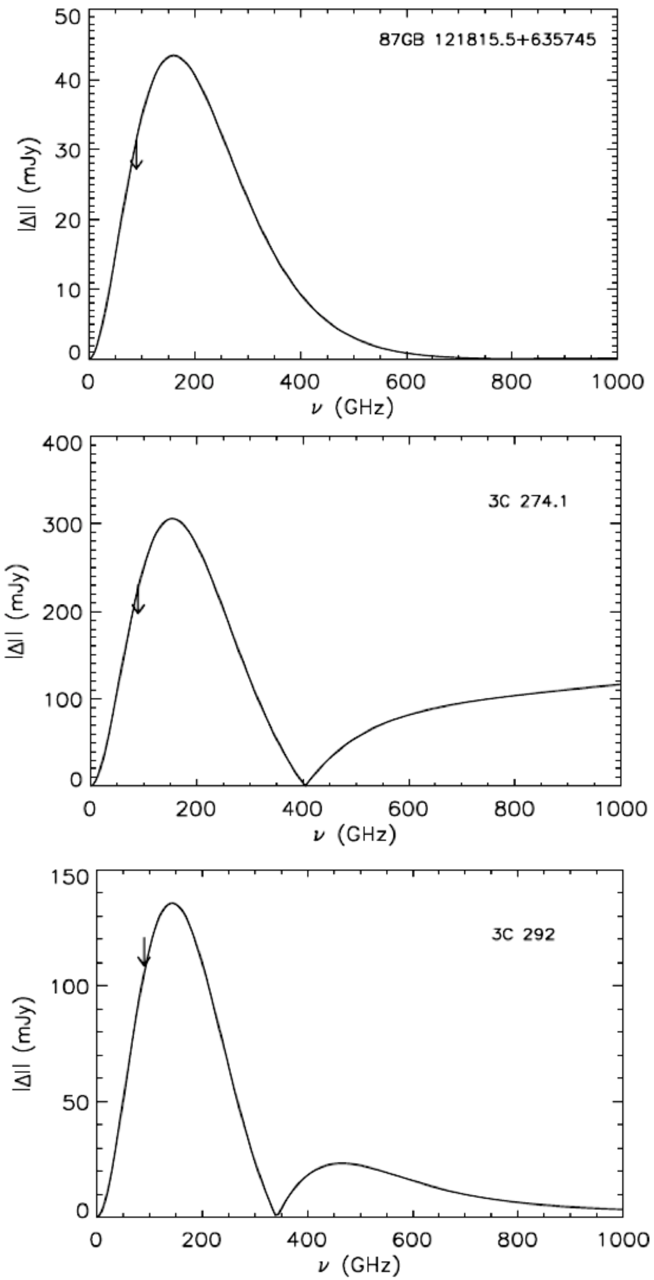
$T_{CMB}(z)$ $\quad \dfrac{\Delta T_{SZ}}{F_{IC}} \propto (kT_{CMB})^{-3} \times f(\gamma_{\min}, E_{X\min})$

# Theory WMAP Expectation

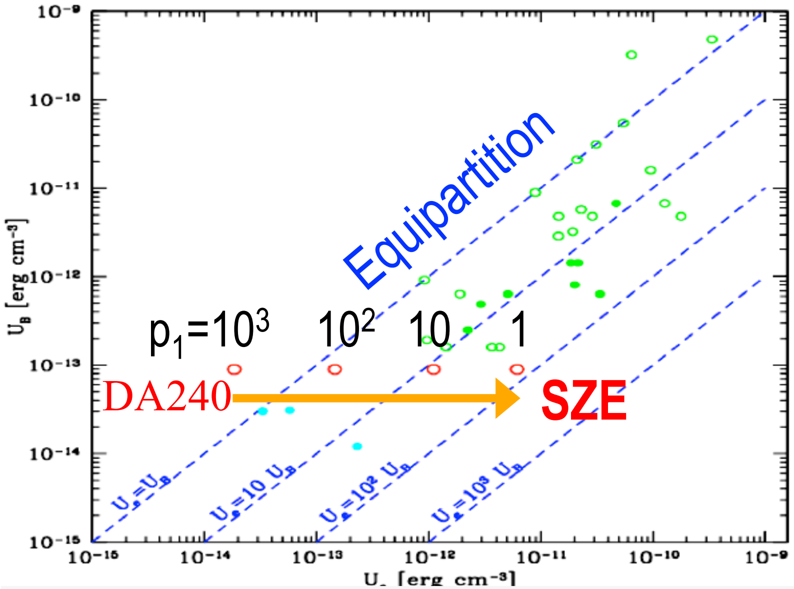


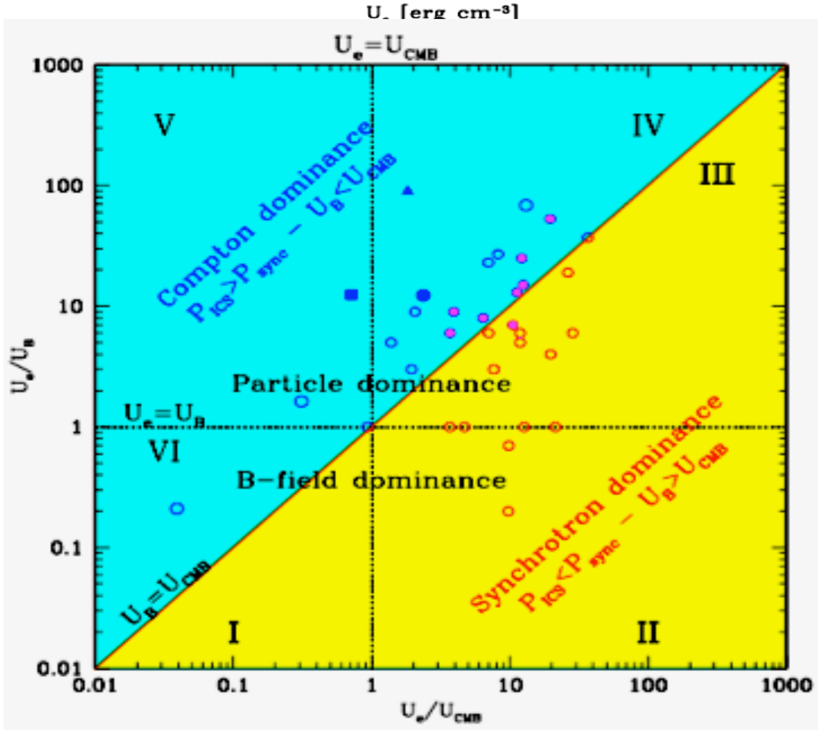
# SZE: RG lobe energetics revisited




$$U_e = \int_{p_1}^{\infty} dp N(p) (\sqrt{1+p^2} - 1) m_e c^2$$

**X-ray** → **rough misleading measure of Ue**

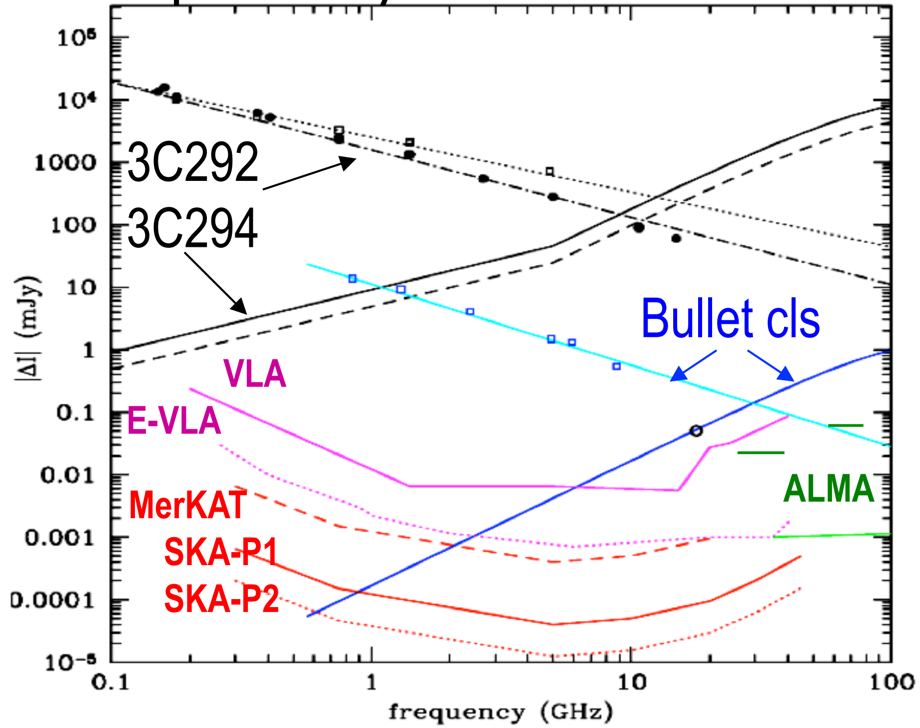
**SZE** → **reliable unbiased measure of Ue**



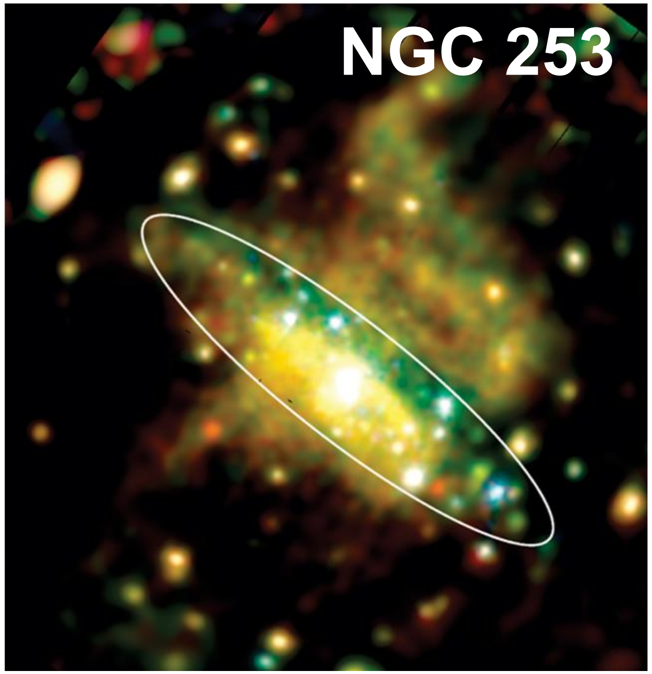

**SKA, MeerKAT, E-VLA**

$\Delta\nu$ = 0.1 - 45 GHz

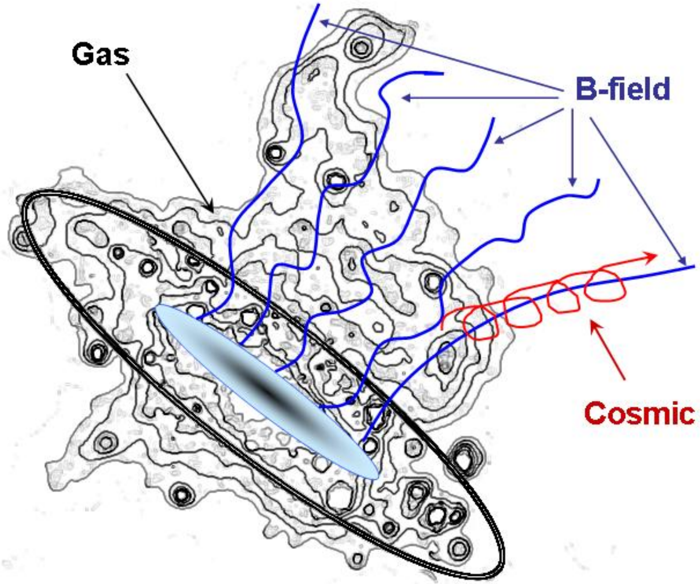
Separate Synchrotron & SZE



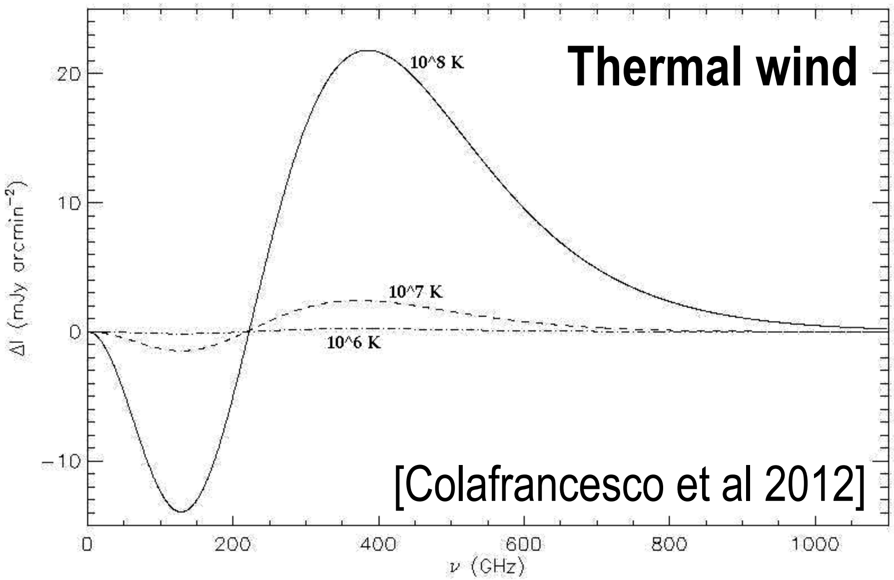
# SZE: galaxy winds and SF

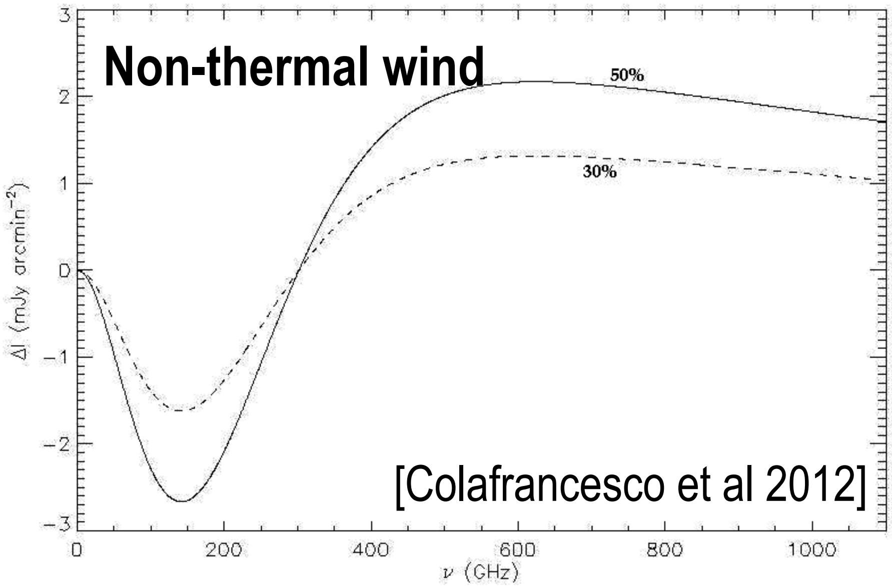



**Combine MILLIMETRON and SKA**




**to study the wind composition & energetic**



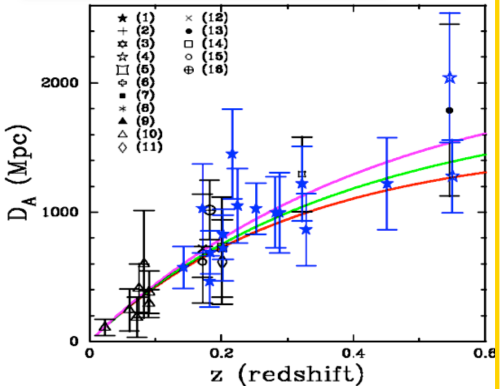



# Cosmological relevance

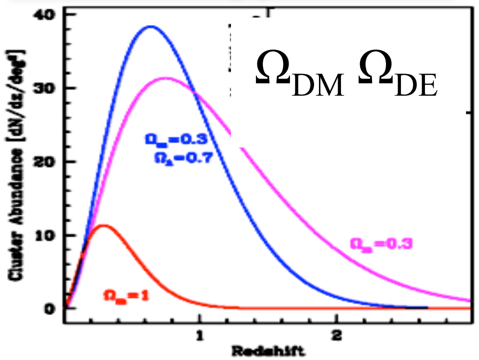
| Galaxy clusters | AGN jets/cavities | DM nature | Plasma physics |
|---|---|---|---|

## Galaxy clusters

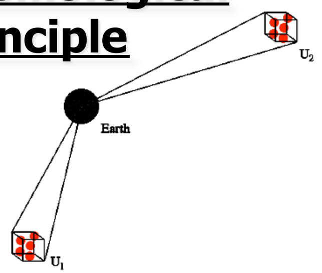
### Hubble constant




### Dark Energy - ModG

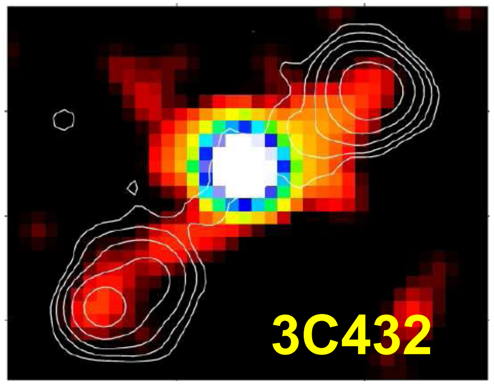



### Cosmological Principle

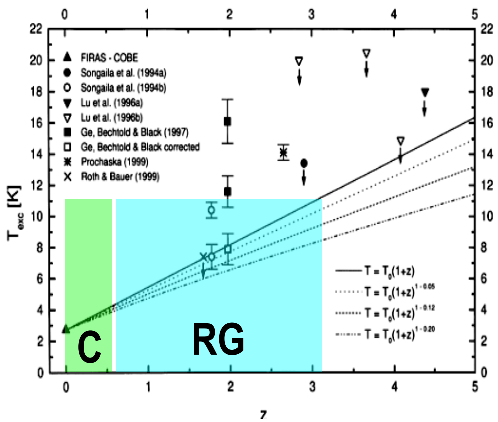



## AGN jets/cavities

### $T_{CMB}(z)$

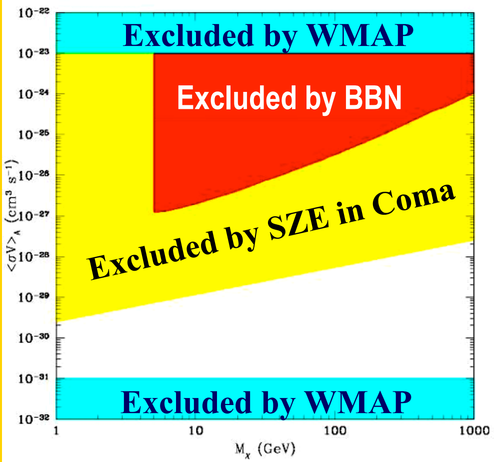



$$\frac{\Delta T}{F_{IC}} \propto (kT_{CMB})^{-3} \times \gamma_{\min}^{-(\alpha-1)} \cdot E_{X\min}^{-(\alpha-1)/2}$$

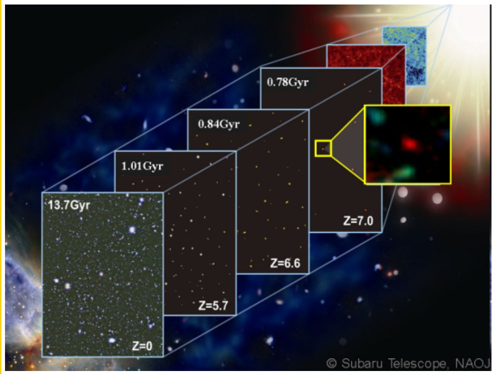



## DM nature

### SUSY DM

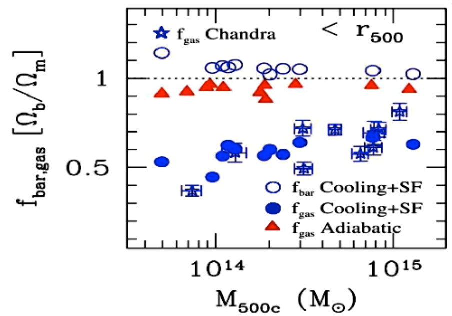



### Early DM-galaxies

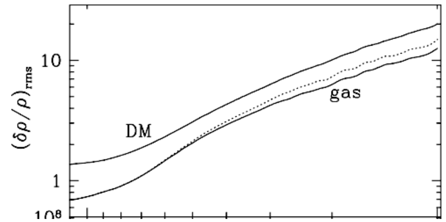



## Plasma physics

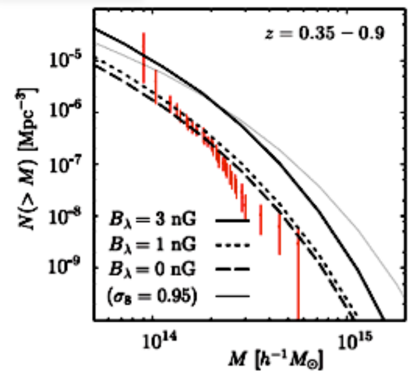
### Baryon fraction




### CR history



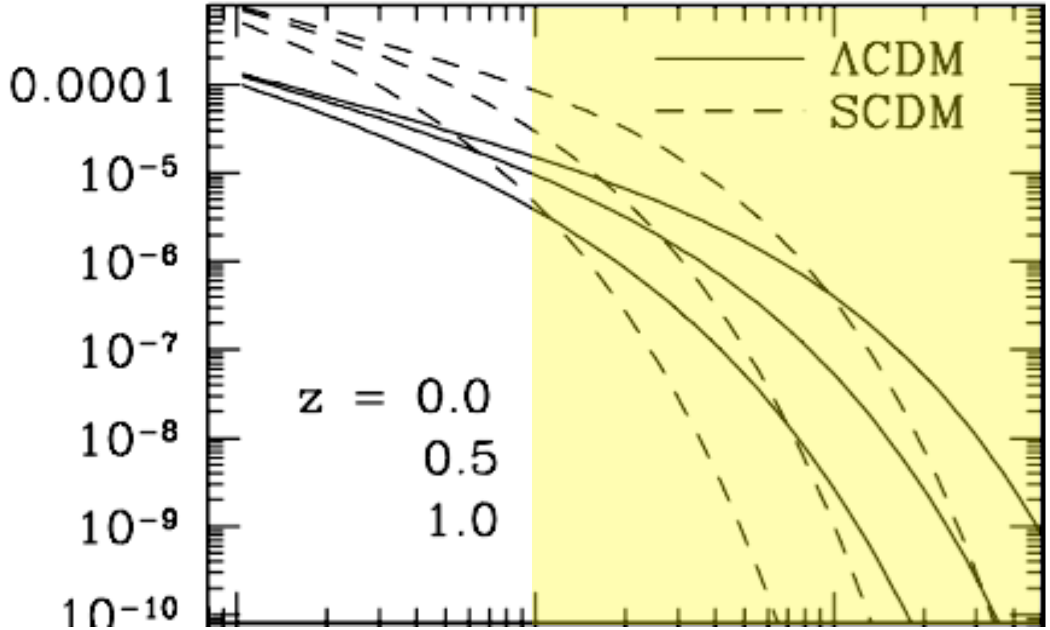

### B-field

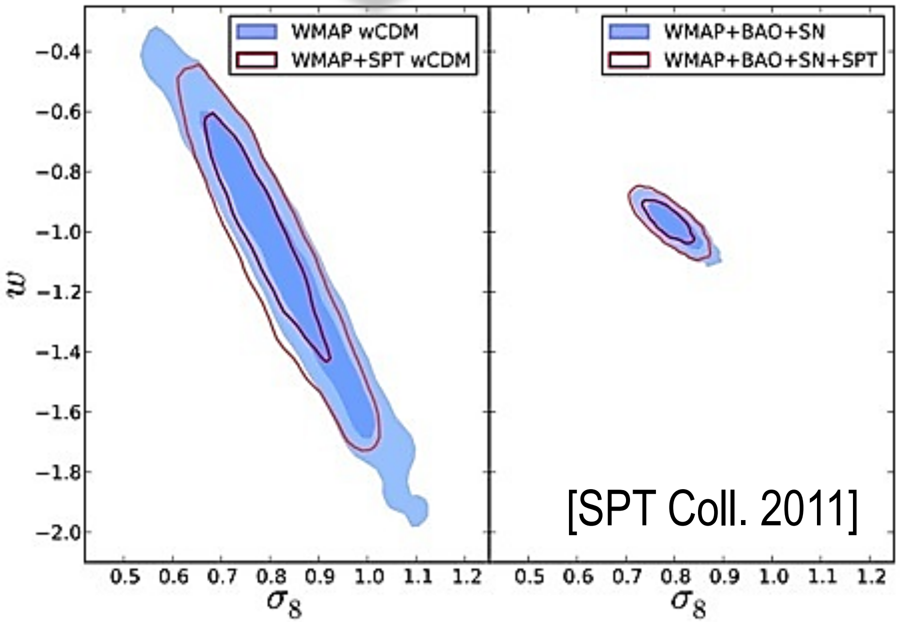


# SZE: clusters cosmology

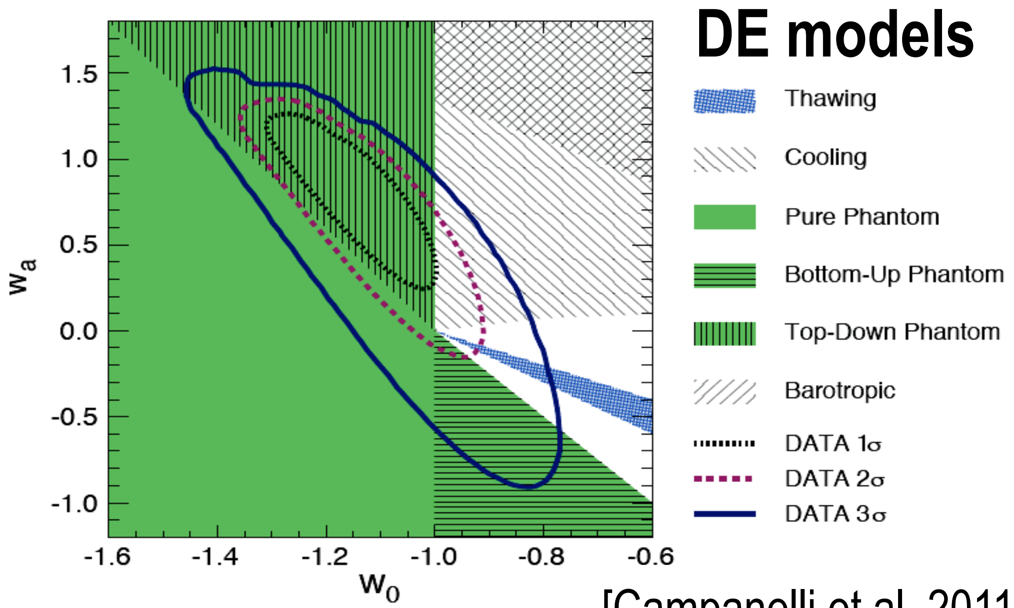
**SZE will allow to derive an unbiased measure of cluster DM mass**

$$N(M) = \frac{\rho}{M} f(\nu) \frac{d\nu}{dM}$$




[SPT Coll. 2011]




[Campanelli et al. 2011]

# SZE and primordial B-field

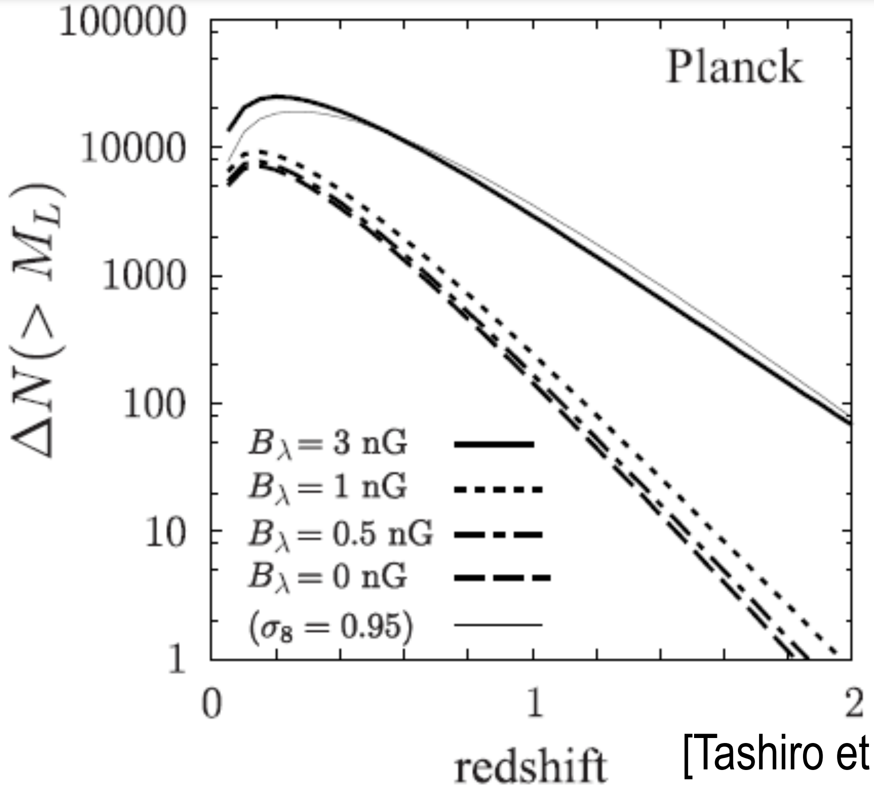
After the epoch of recombination, a primordial B-field generates additional density fluctuations forming additional cosmic structures. Such density fluctuations enhance the number of galaxy clusters.

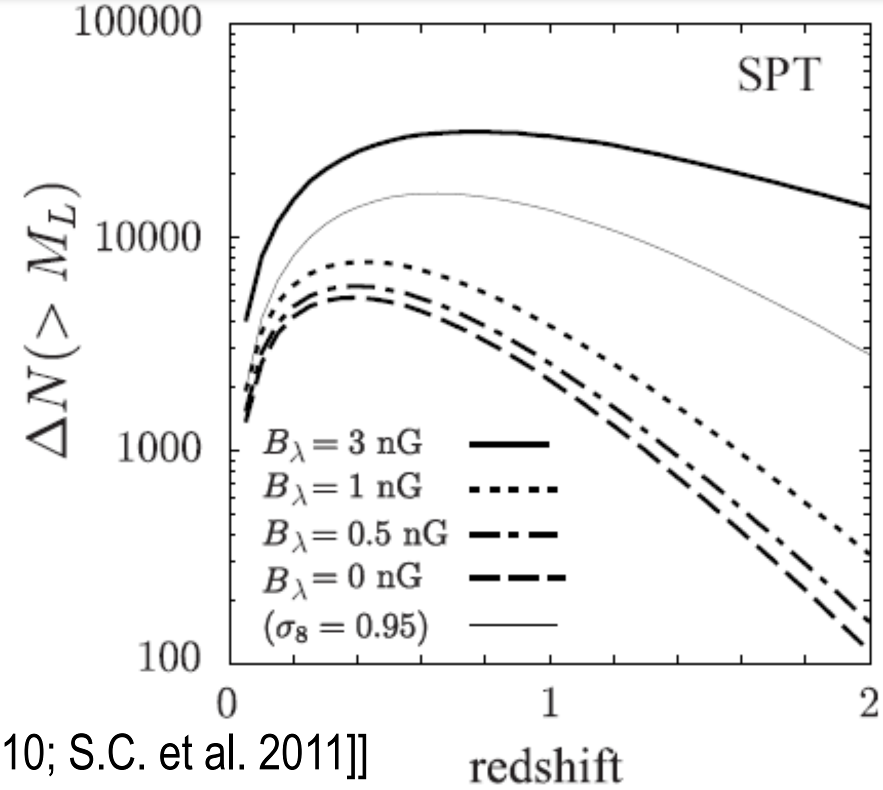
Primordial density fluctuations → $P_P$; Primordial-B density fluctuations → $P_M$

$$P(k,t) = P_{\mathrm{P}}(k,t) + P_{\mathrm{M}}(k,t)$$

$$P_P \propto D_M^2(t) \cdot k^n$$

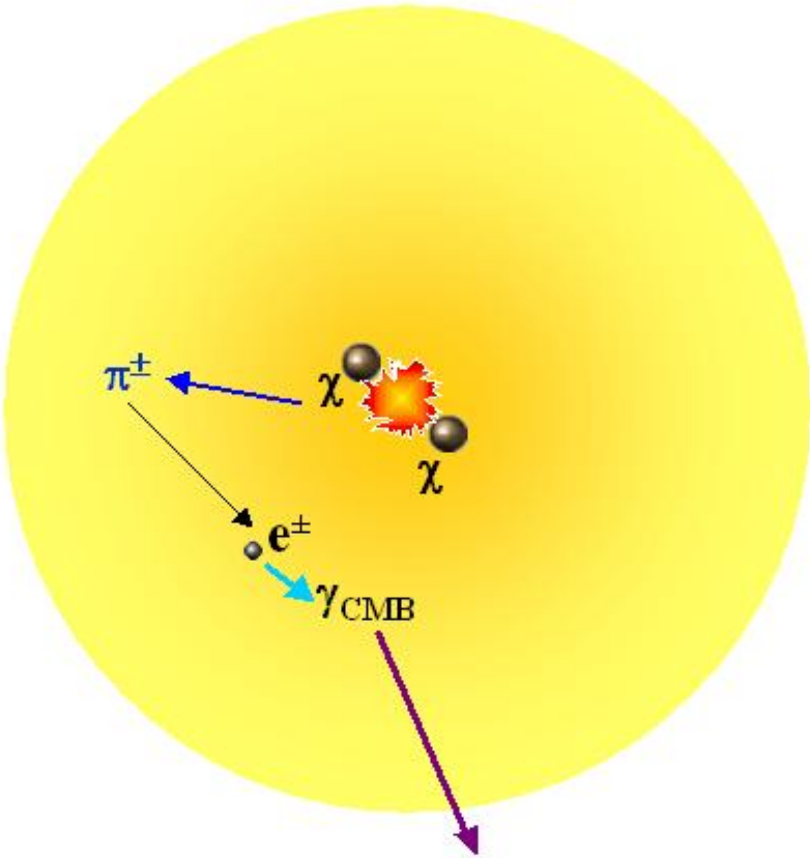
$$P_M \propto D_M^2(t) \cdot I_k^2$$



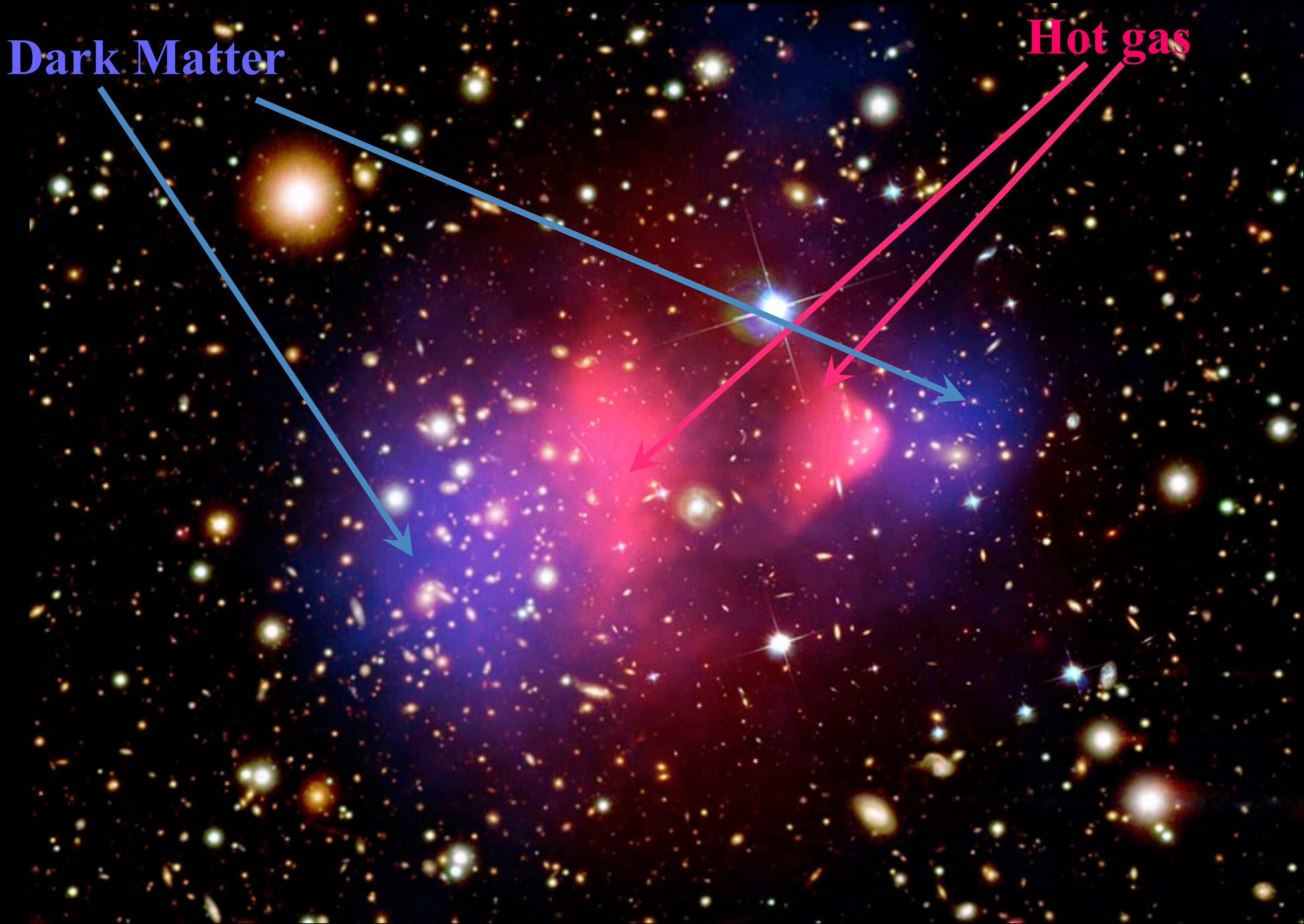

[Tashiro et al. 2010; S.C. et al. 2011]]

# SZE and Dark Matter nature

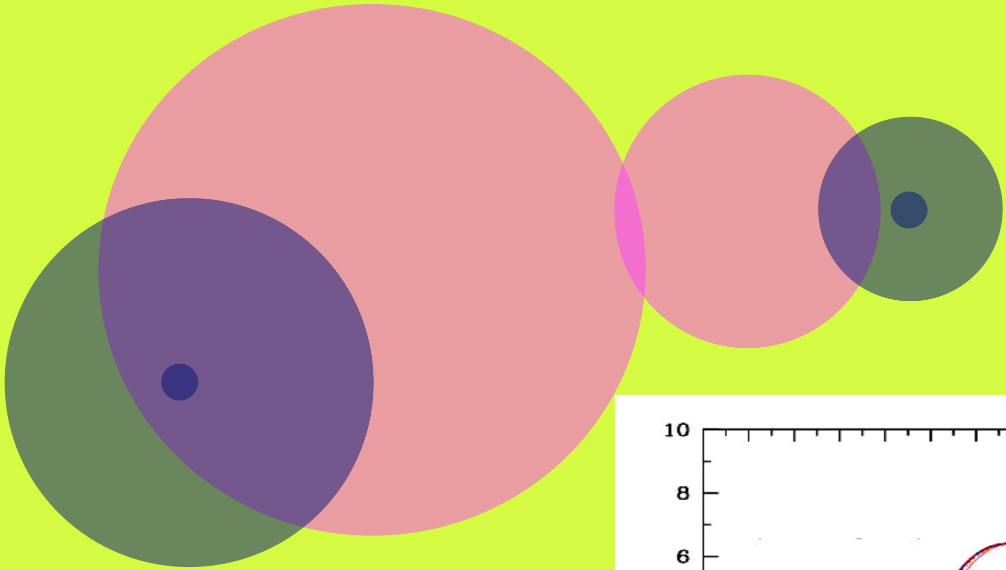


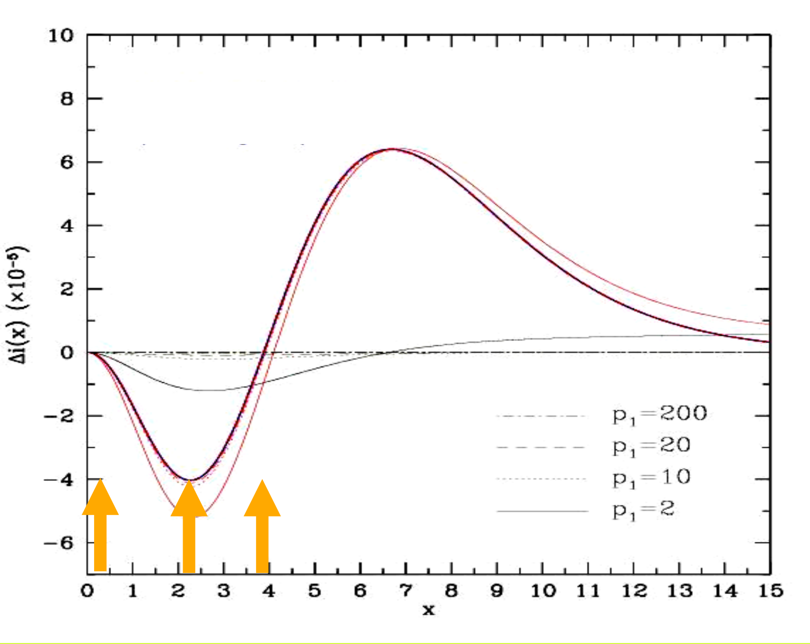

SZE
ICS on CMB

# 1ES0657-556

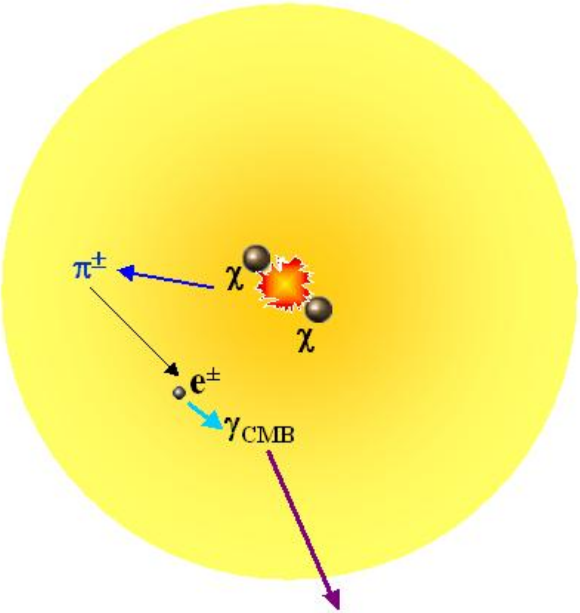


# $SZ_{DM}$ from 1ES0657-556

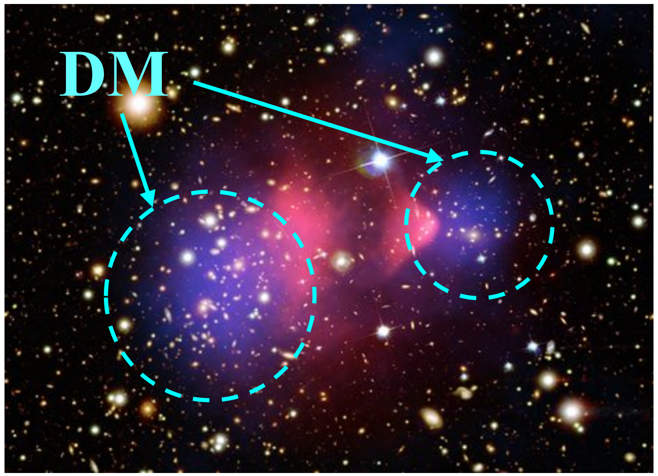


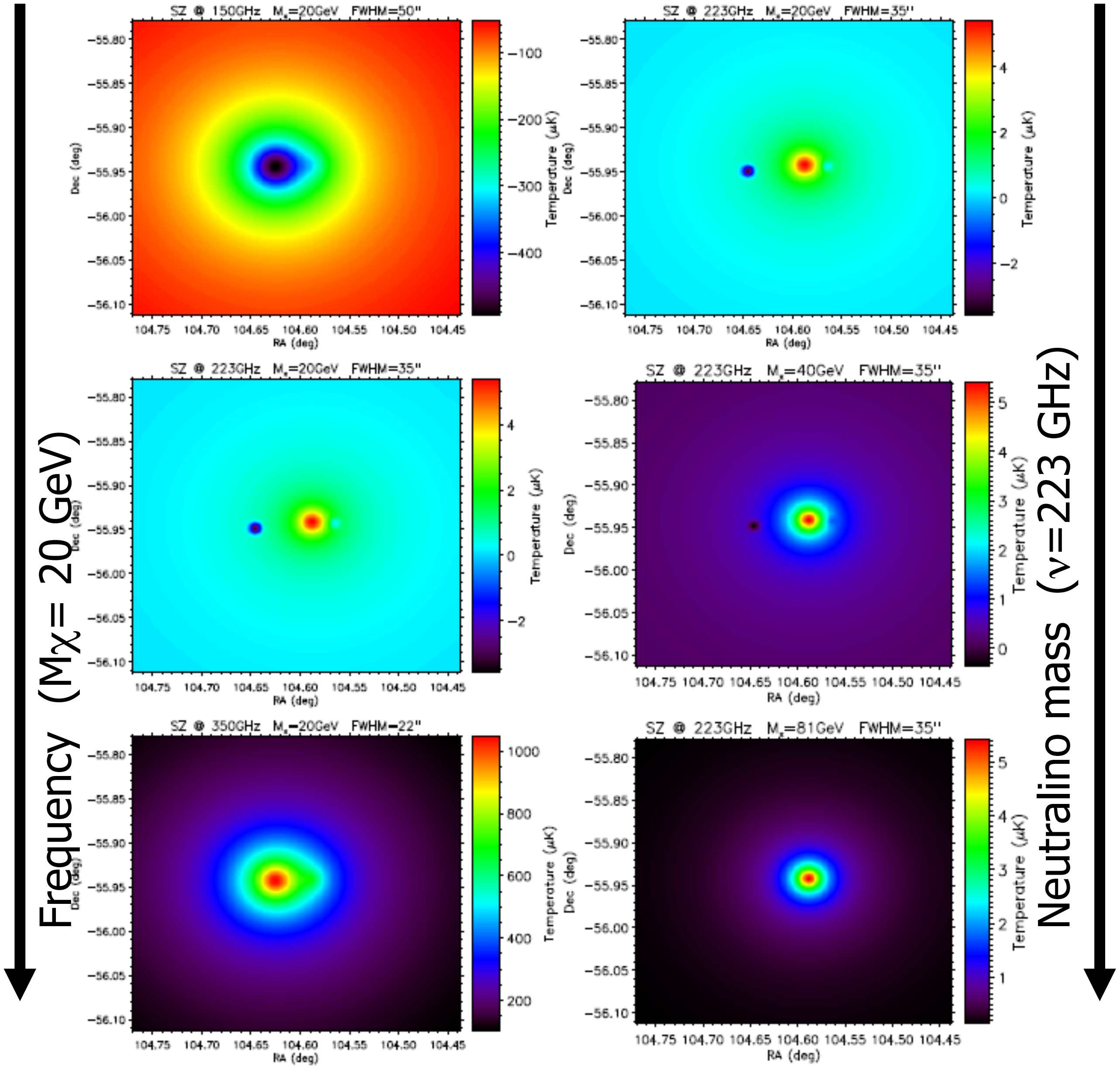


# SZE and Dark Matter



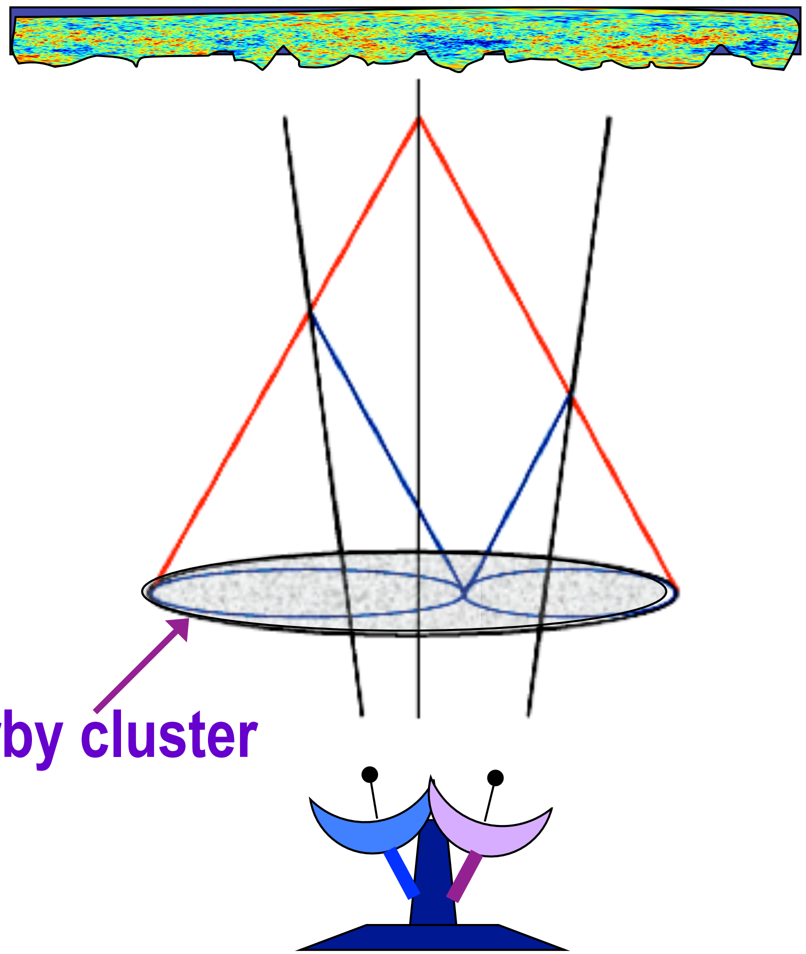

**SZE**



# SZE: the Cosmological Principle

Although we cannot directly observe Homogeneity, we can test the **Cosmological Principle** at the foundation of **Homogeneity**, using observations that carry information from inside our past lightcone.
[R. Marteens 2011]




Large (non-perturbative) th. or kin. SZE

non-FLRW universe

Large (non-perturbative) SZE polarization

non-FLRW universe

# THANKS

## for your attention