

III

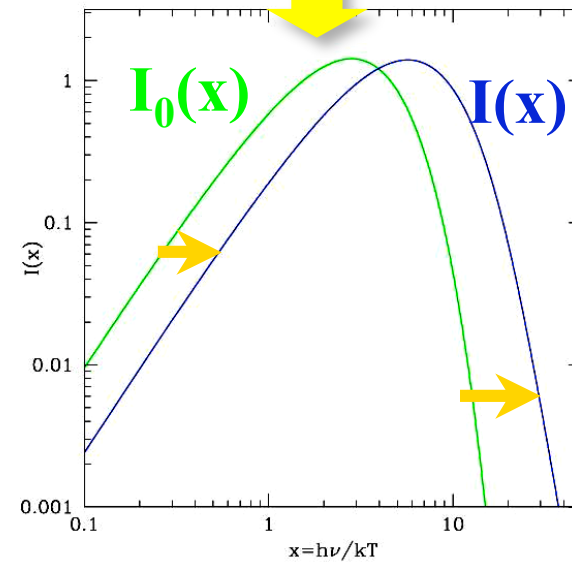
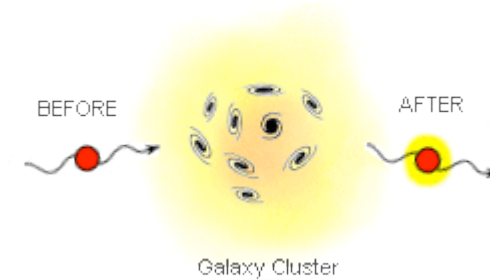
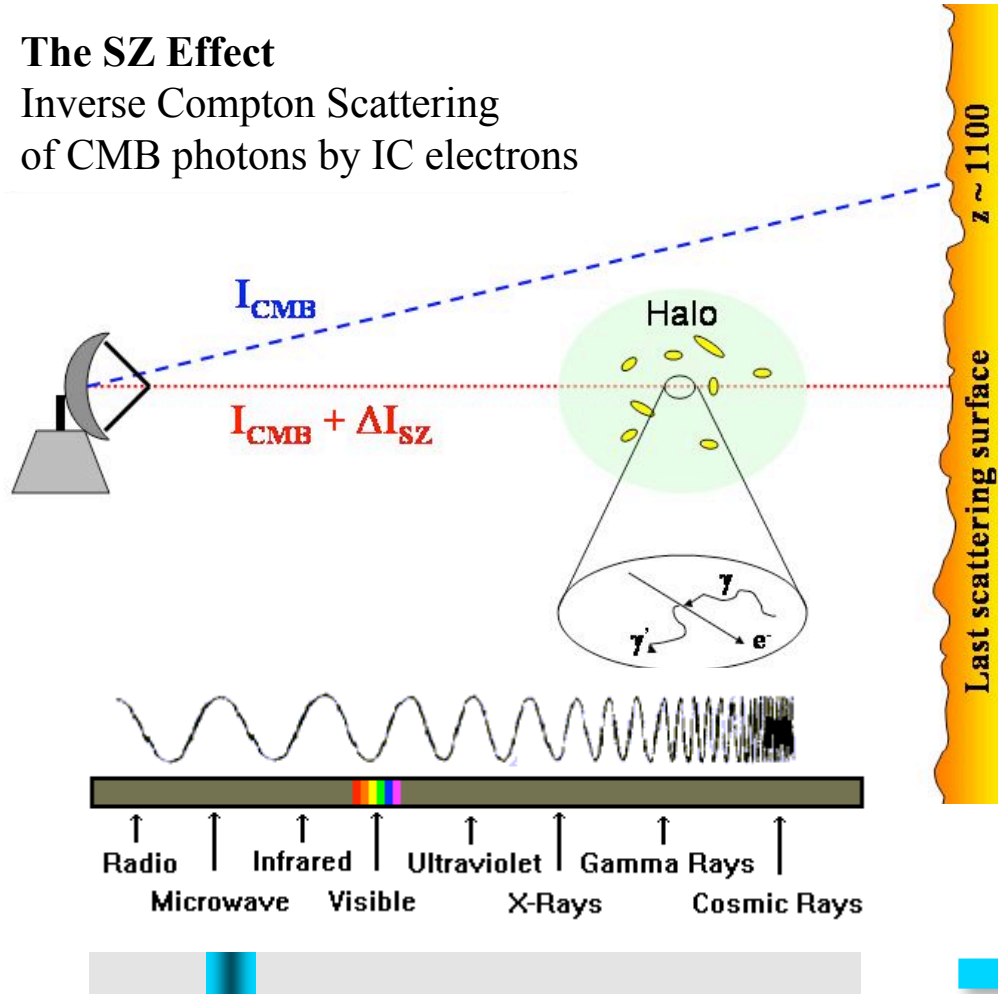
SZ effects with ALMA

Credit: S. Colafrancesco

SZ effect: the standard lore

The SZ Effect

Inverse Compton Scattering
of CMB photons by IC electrons



thermal, non-rel. e⁻

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

The origin of the SZ effect

Non-coherent Compton Scattering

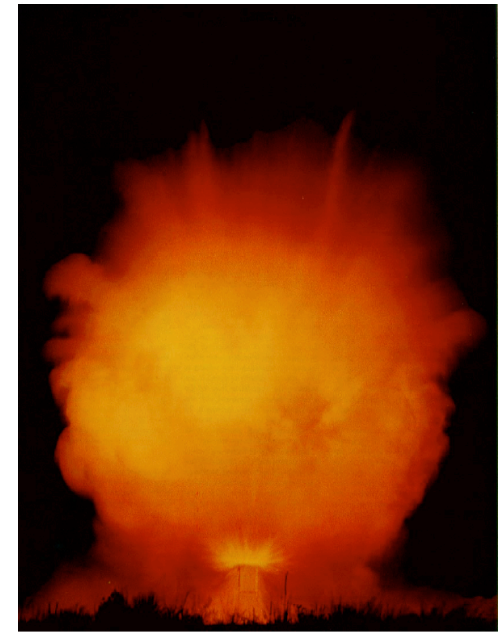
Fall-out effect of the Cold War

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

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



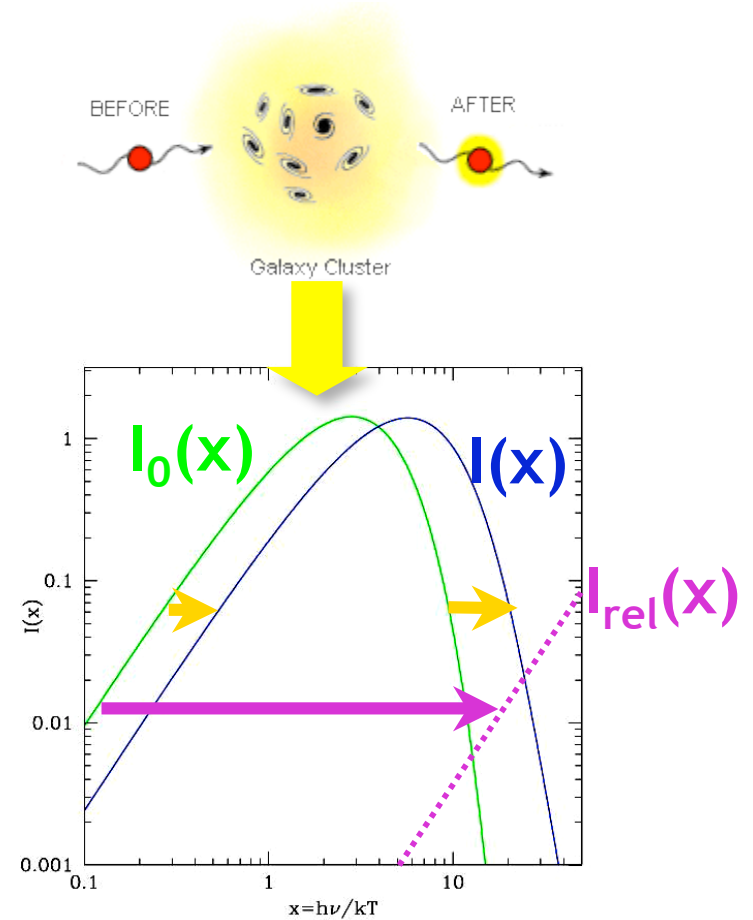
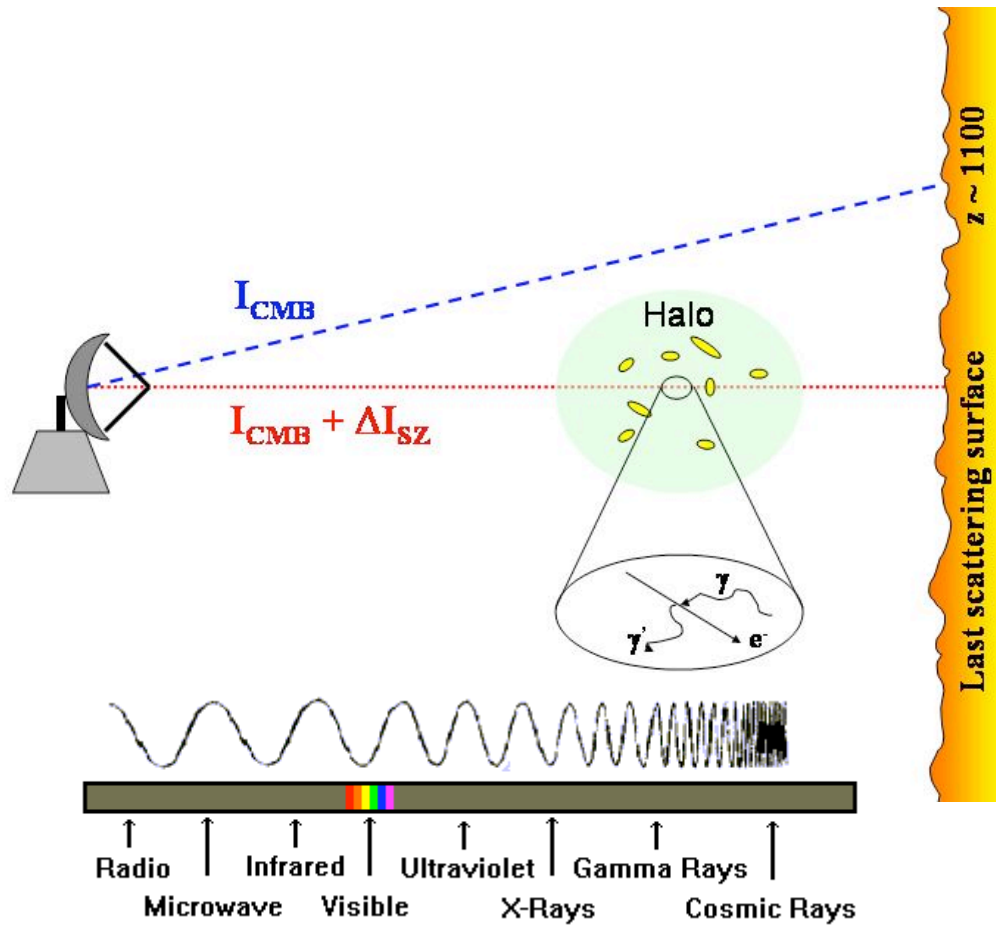
(derived by A.S. Kompaneets in Soviet Union ~1950
but was classified due to bomb research until 1956)



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



SZ effect: ...more than basics



thermal NR e^-

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



relativistic e^-

$$\frac{\Delta v}{v} \approx \frac{4}{3} \gamma^2$$

SZE: general derivation

Intensity change

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

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

electron "Pressure"

in thermal case

$$P_{th} = n_e k_B T_e \longrightarrow \text{Mass}$$

spectral shape

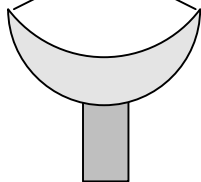
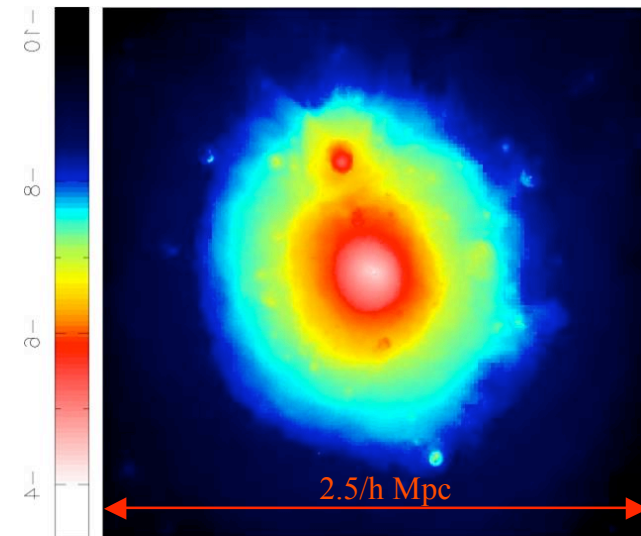
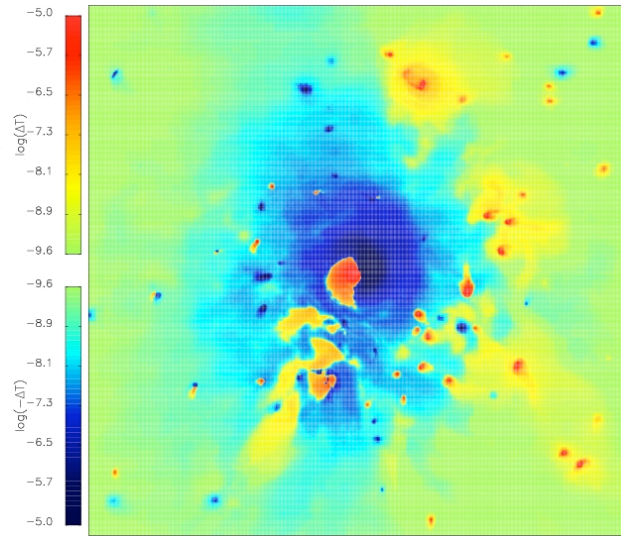
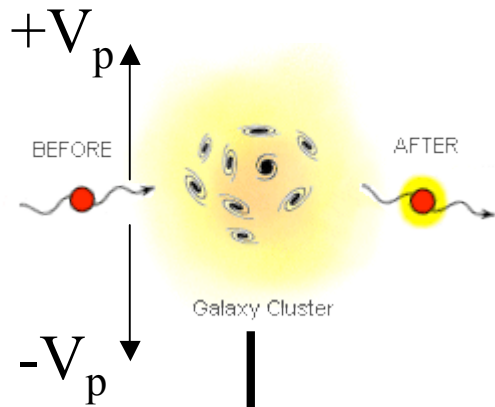
depends on electrons
energy distribution

Note: **redshift not involved** \Rightarrow detectability independent of redshift
(provided that the angular resolution is appropriate)

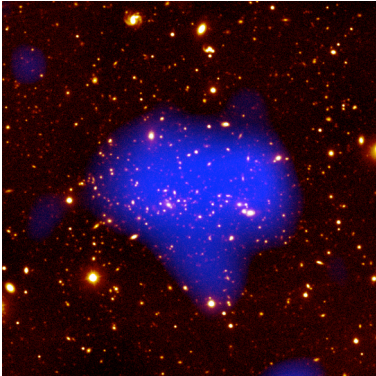
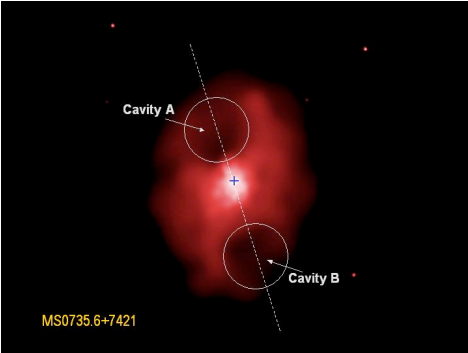
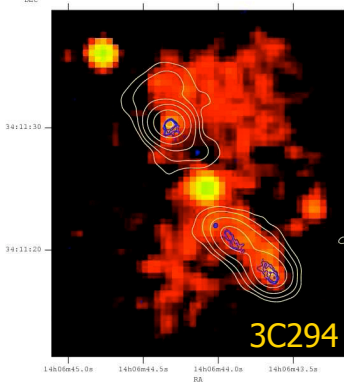
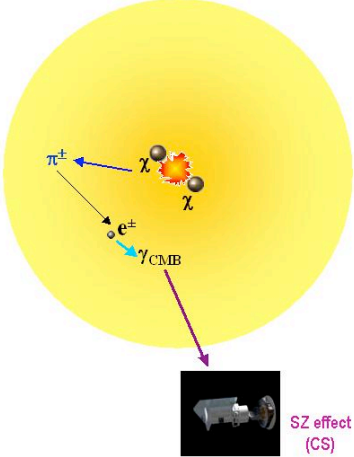
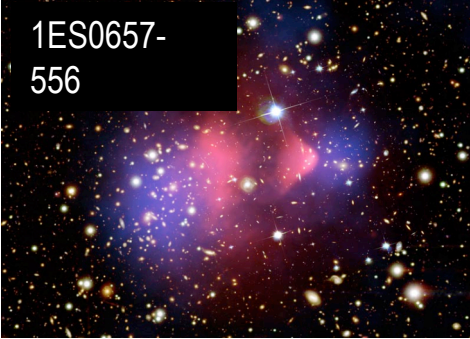
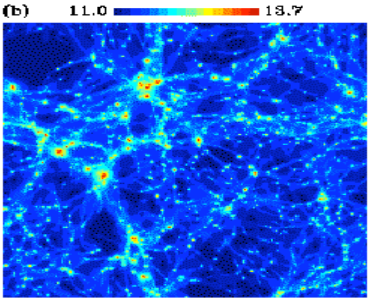
SZE: other sources

Kinematic SZE

$$\frac{\Delta T}{T} = \frac{\pm V_p}{c} \tau$$



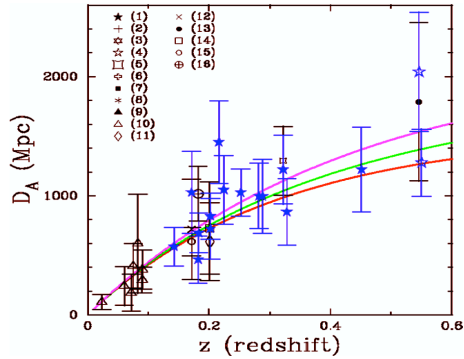
Sources of SZ

Galaxy clusters	AGN jets/cavities	Dark Matter	WHIM
 <p>A multi-wavelength image of a galaxy cluster showing a dense field of stars and galaxies in the foreground, with a prominent blue emission region in the center.</p>	 <p>Diagram of an AGN jet/cavity system. A central black hole (marked with a '+') is surrounded by two cavities, labeled 'Cavity A' and 'Cavity B', which are shown as red regions. The system is identified as MS0735.6+7421.</p>  <p>Radio map of the galaxy cluster 3C294, showing two bright radio lobes. The map includes axes for Right Ascension (RA) and Declination (DEC).</p>	 <p>Diagram illustrating the SZ effect. A yellow circle represents the dark matter halo. A central black hole emits particles (π^\pm, χ, e^\pm) and γ_{CMB} rays. A small inset shows a radio telescope dish labeled 'SZ effect (CS)'.</p>  <p>Image of the galaxy cluster 1ES0657-556, showing a multi-wavelength view with various colors representing different energy bands.</p>	 <p>Image of the Warm-Hot Intergalactic Medium (WHIM), showing a network of filaments and nodes. A color bar at the top indicates intensity from 11.0 to 13.7. The image is labeled (b).</p> <p>$M > 10^{11} M_{\odot} \text{Mpc}^{-2}$</p>

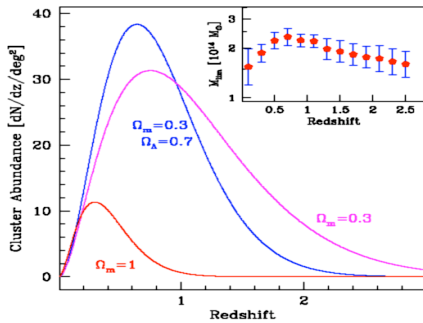
Astrophysical relevance

Galaxy clusters

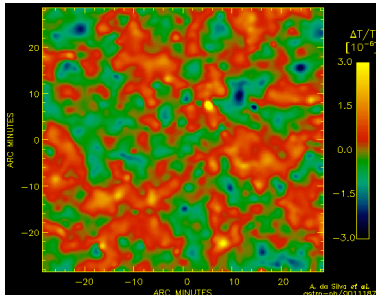
Hubble diagram



Cluster counts/masses

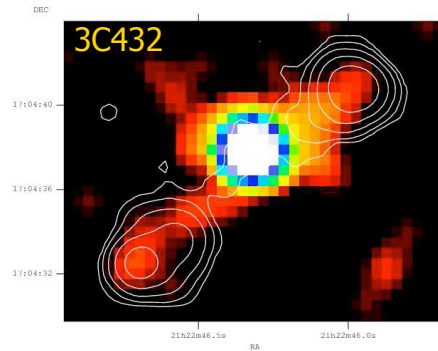


Cluster velocities



AGN jets/cavities

T_CMB(z)

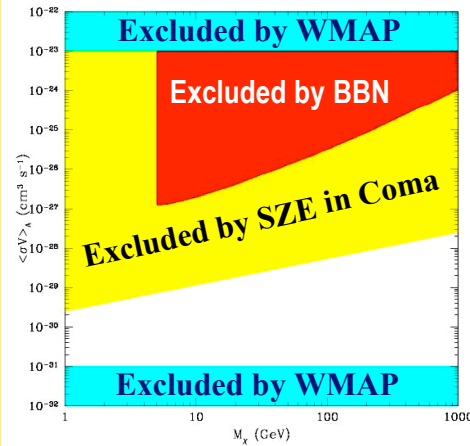


$$\frac{\Delta T}{F_{IC}} \propto (kT_{CMB})^{-3}$$

$$\times \gamma_{\min}^{-(\alpha-1)} \cdot E_{X \min}^{-(\alpha-1)/2}$$

DM nature

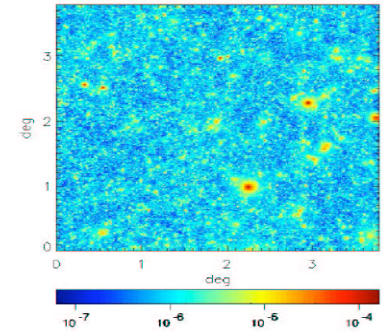
SUSY DM



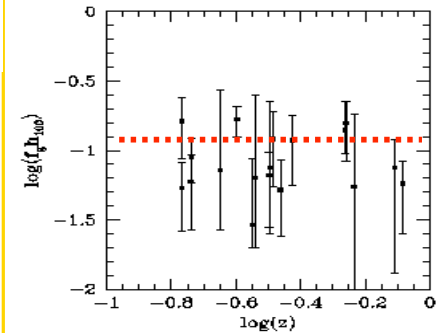
Non-SUSY DM

- MeV DM
- sterile ν
- ...

WHIM

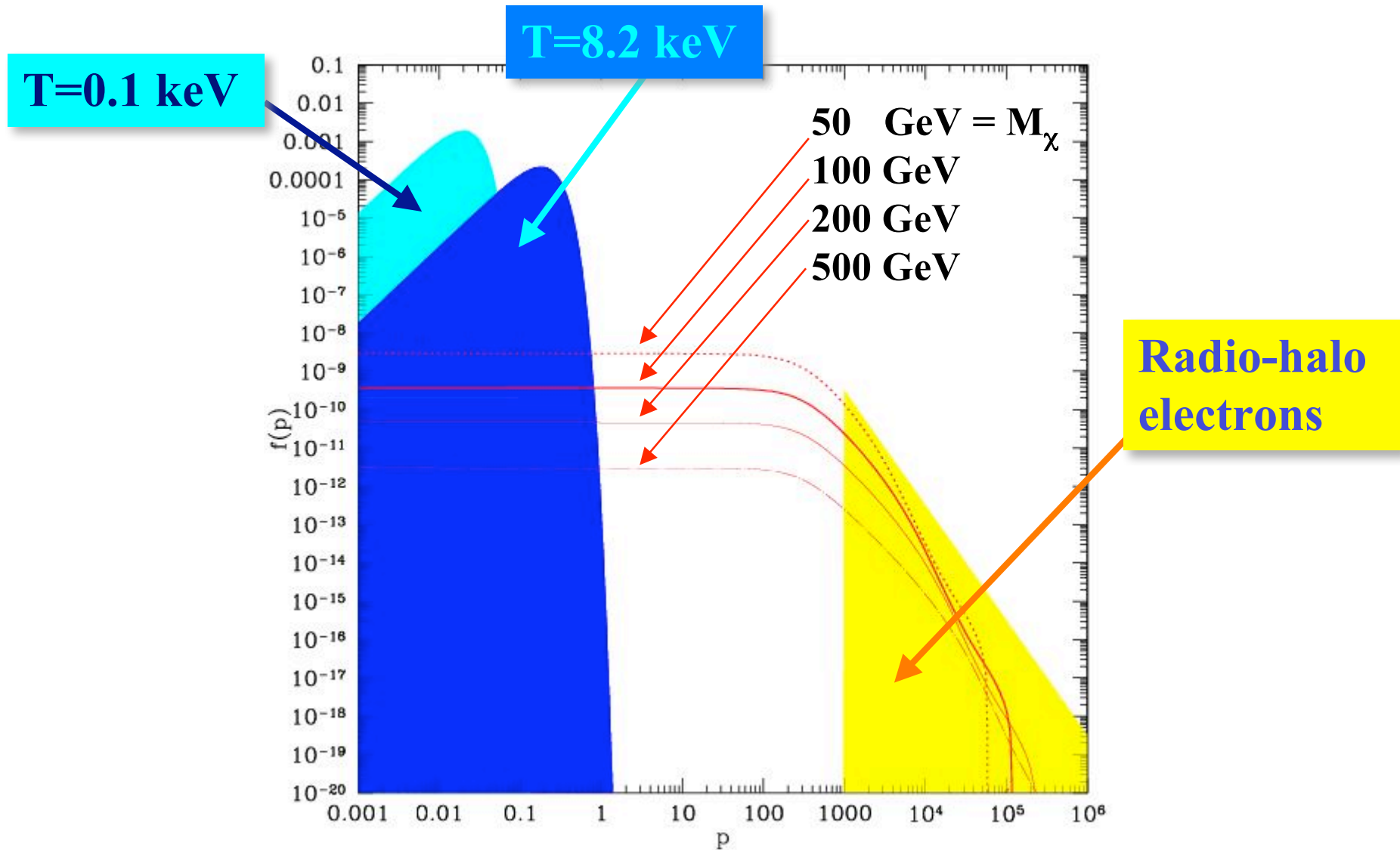


Baryon fraction



The e^\pm distribution in clusters

COMA: warm gas + hot gas + radio halo + DM halo

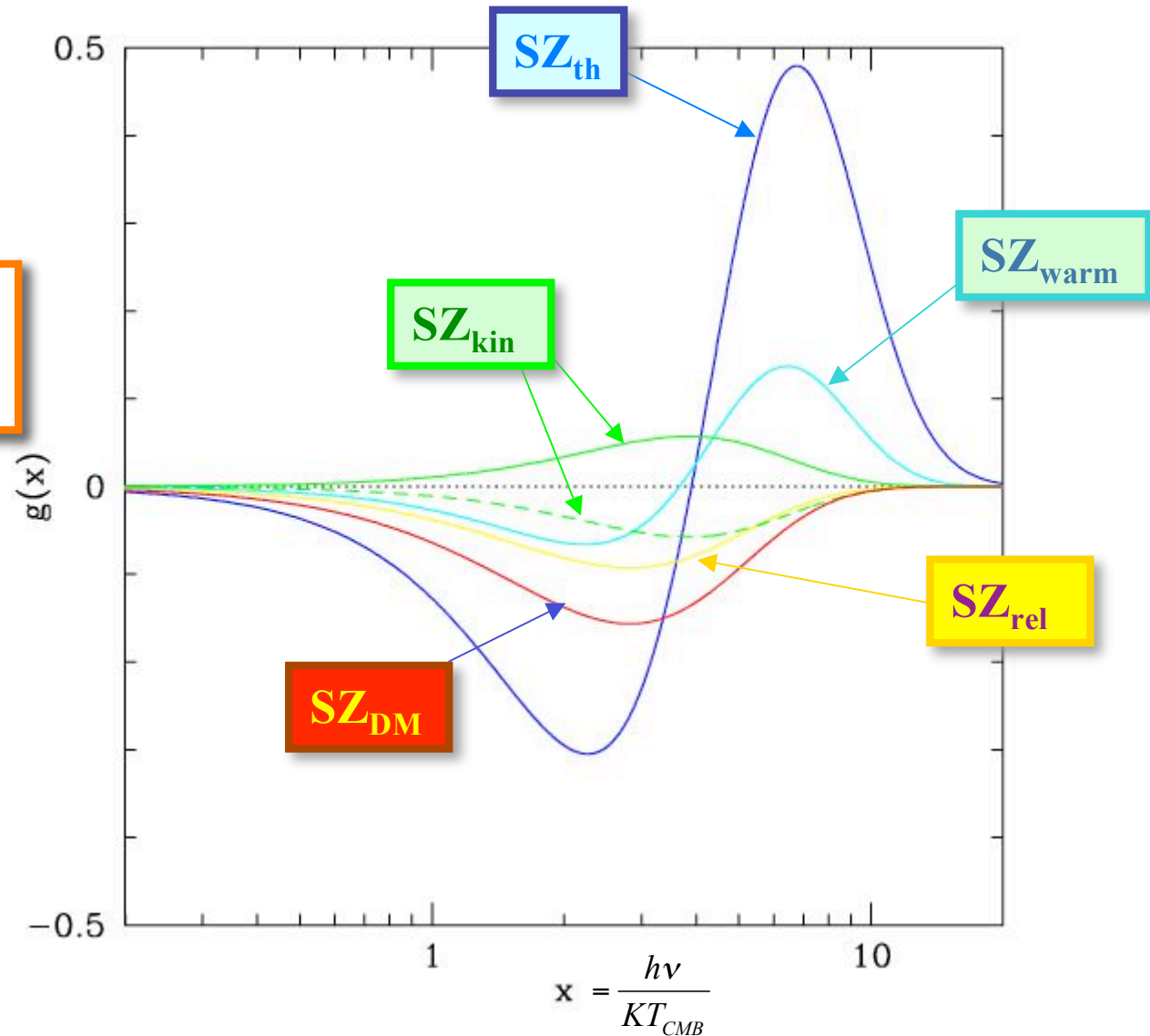


The SZE from various e^\pm pops.

Colafrancesco 2007

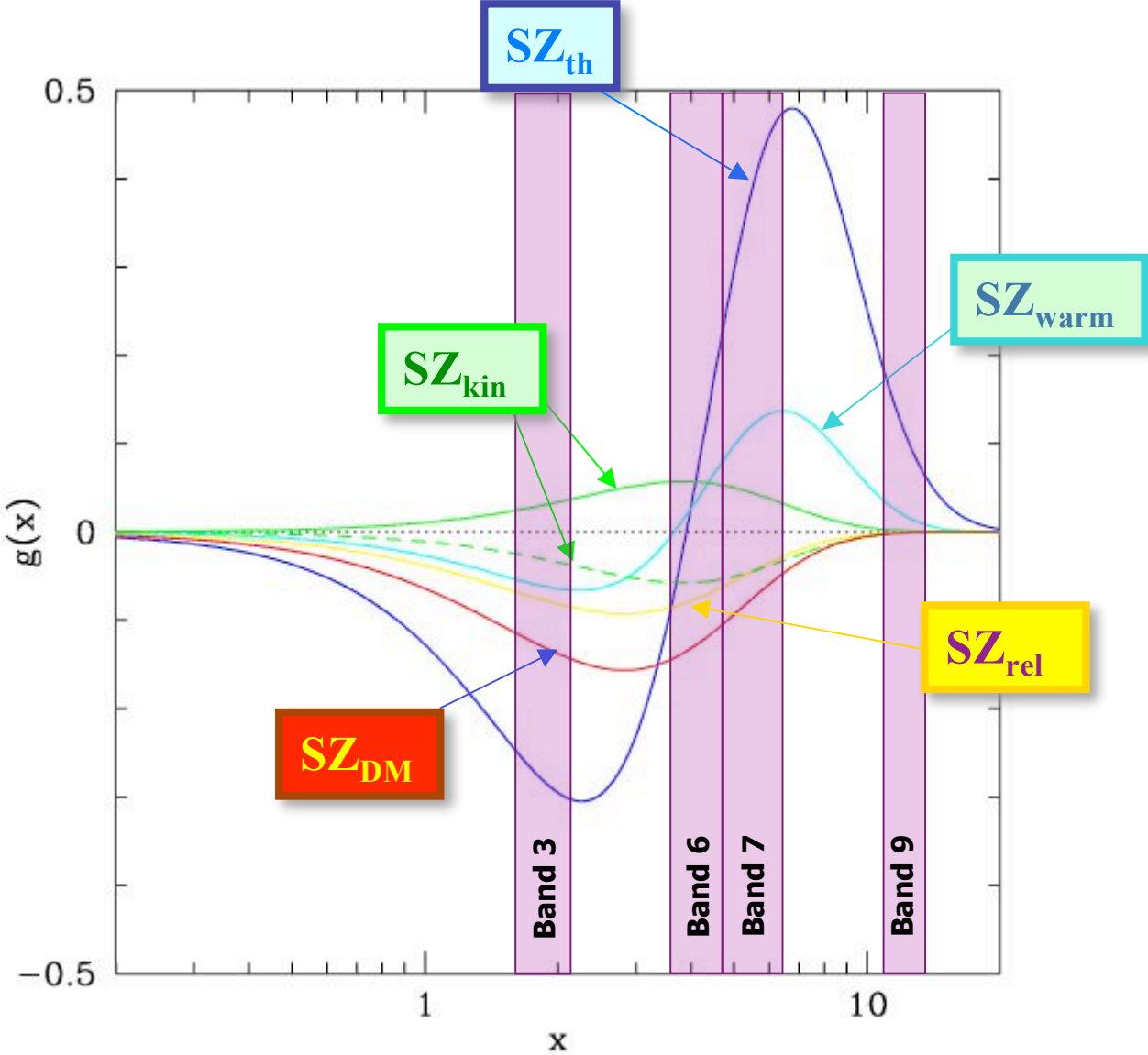
$$\Delta I(x) = 2 \frac{(k_B T_0)^3}{(hc)^2} y \tilde{g}(x)$$

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

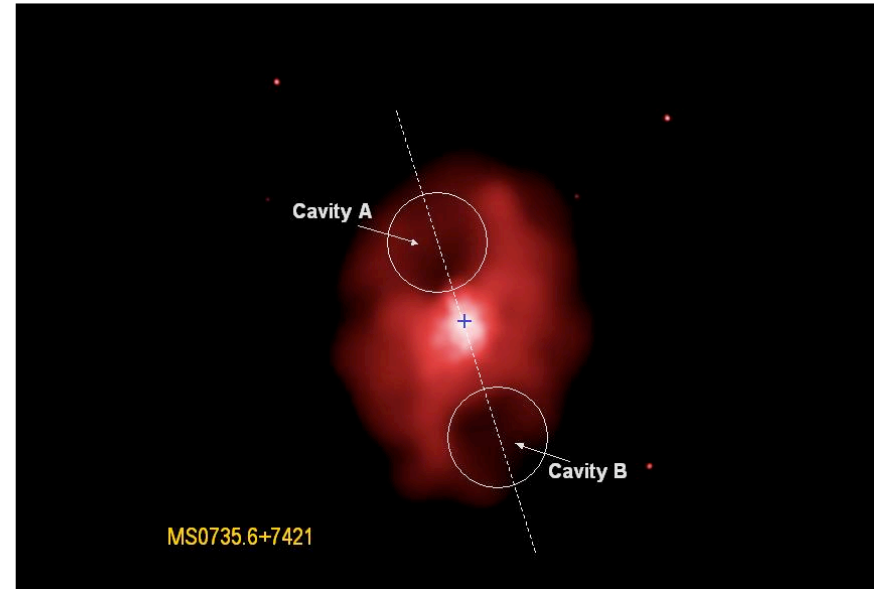
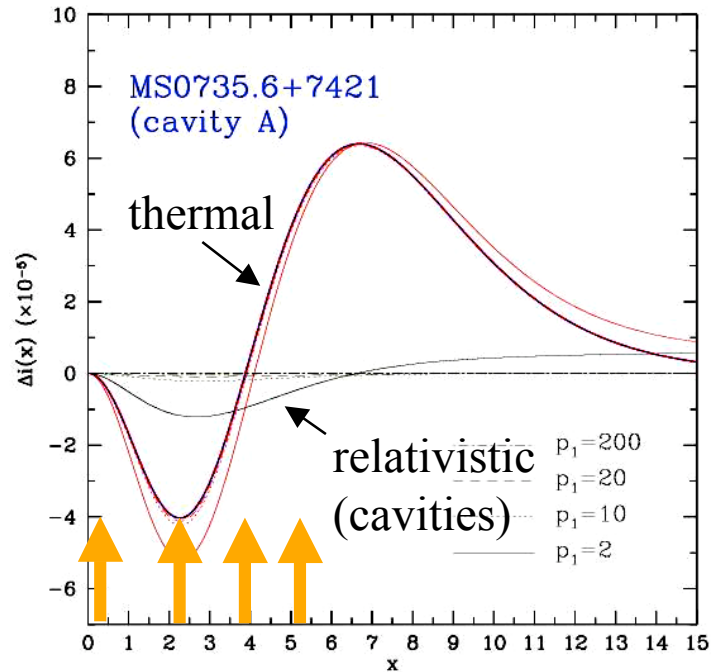


SZE: ALMA ν -coverage

ALMA reference ν -bands	
Band 3	86 – 116 GHz
Band 6	211 – 275 GHz
Band 7	275 – 370 GHz
Band 9	602 – 720 GHz



SZE & cavities in clusters

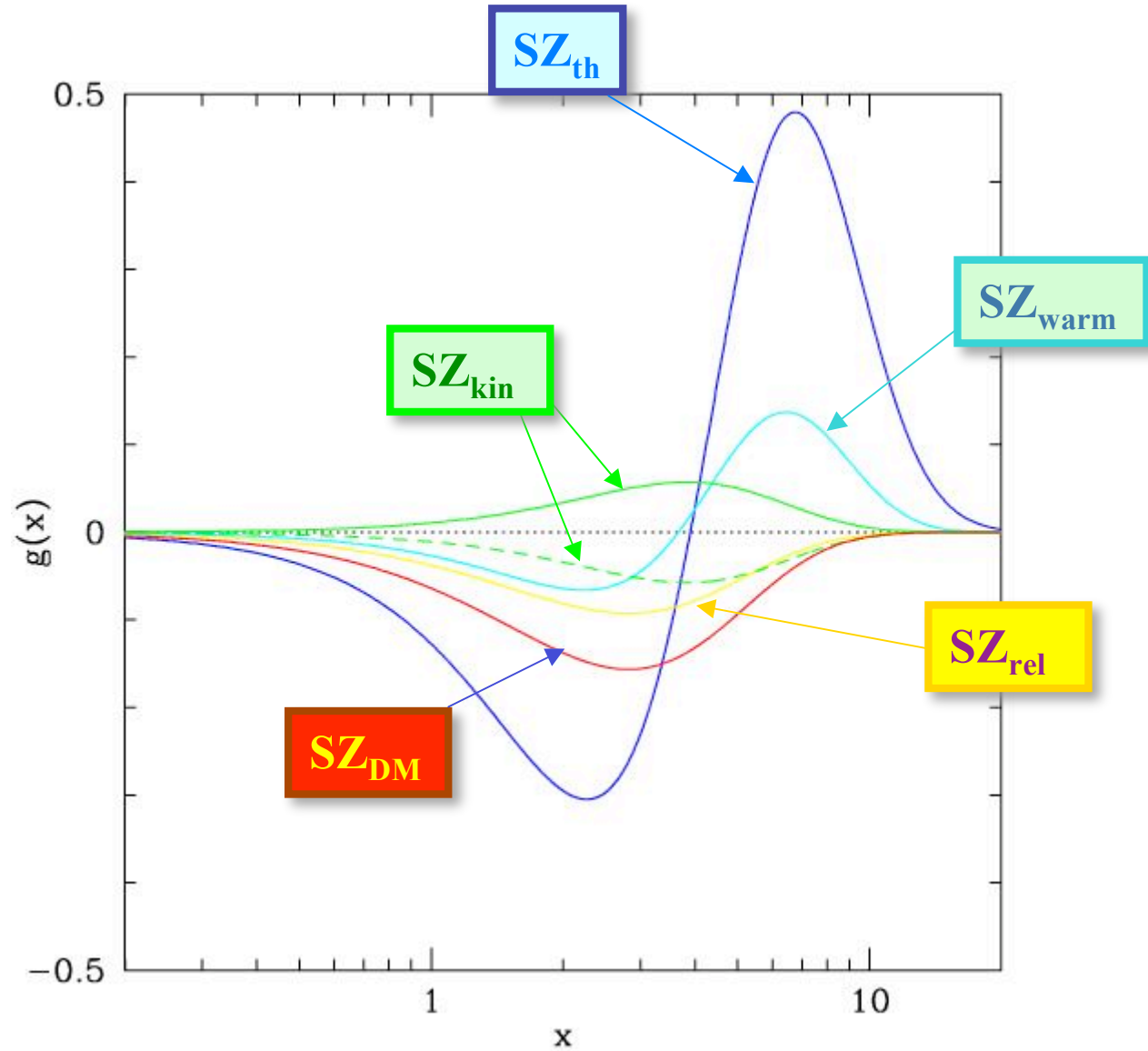


Colafrancesco+05

SZE in DM halos

A structure with:

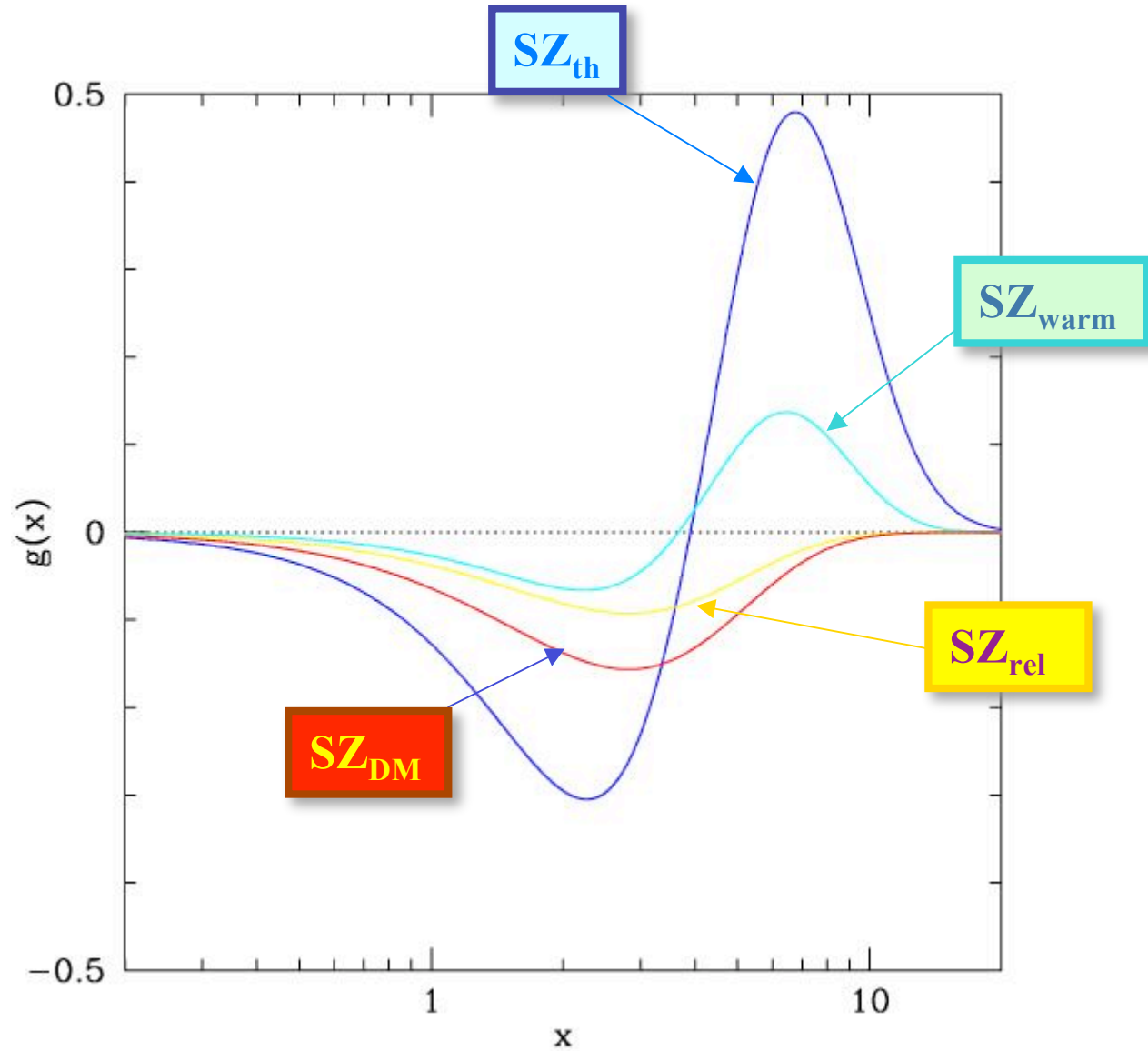
- Hot gas
- Warm gas
- Rel. Plasma
- DM
- Distant & V_r



SZE in DM halos

A structure with:

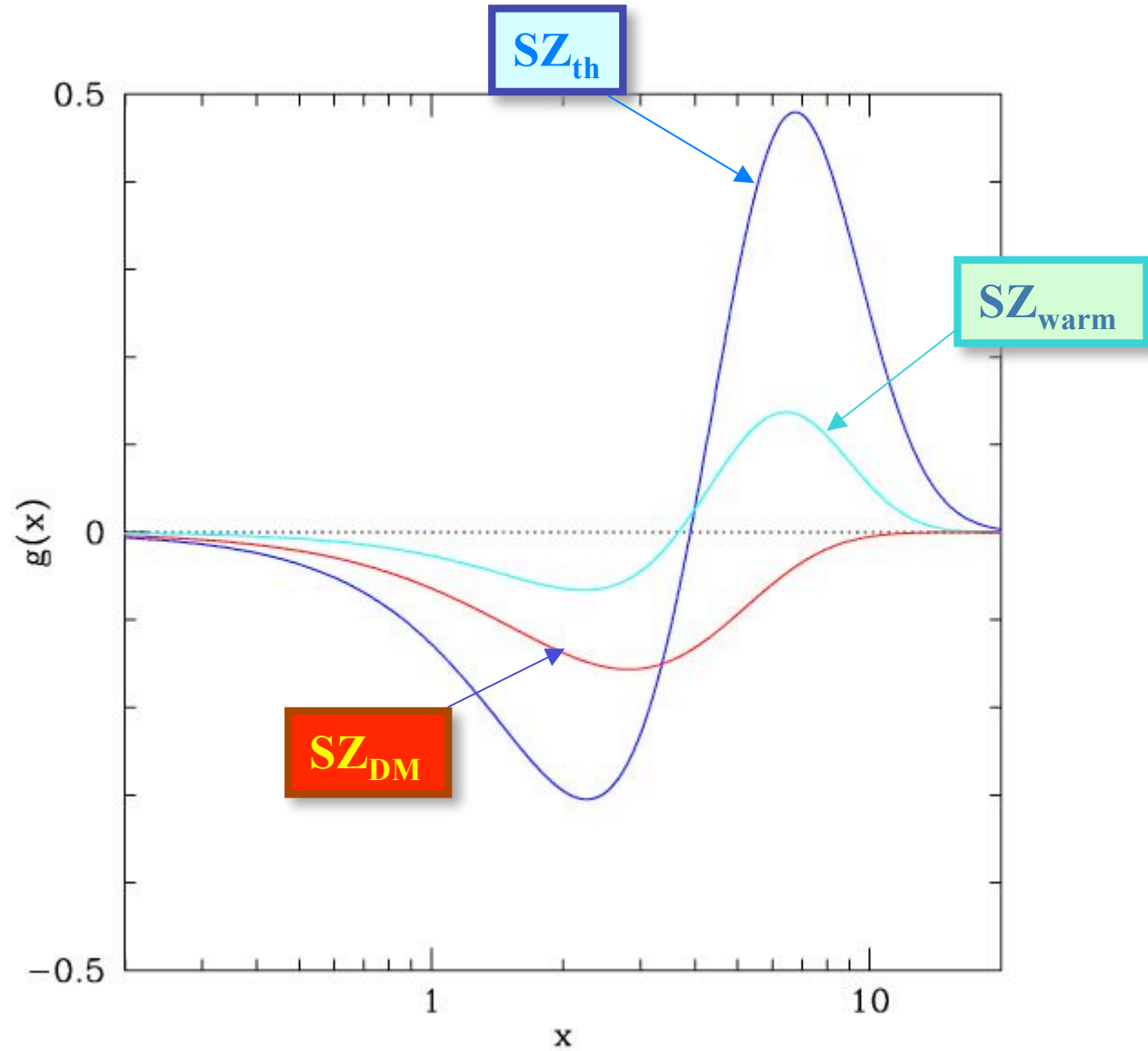
- Hot gas
- Warm gas
- Rel. Plasma
- DM
- Nearby ($V_r \approx 0$)



SZE in DM halos

A structure with:

- Hot gas
- Warm gas
- DM
- Nearby ($V_r \approx 0$)



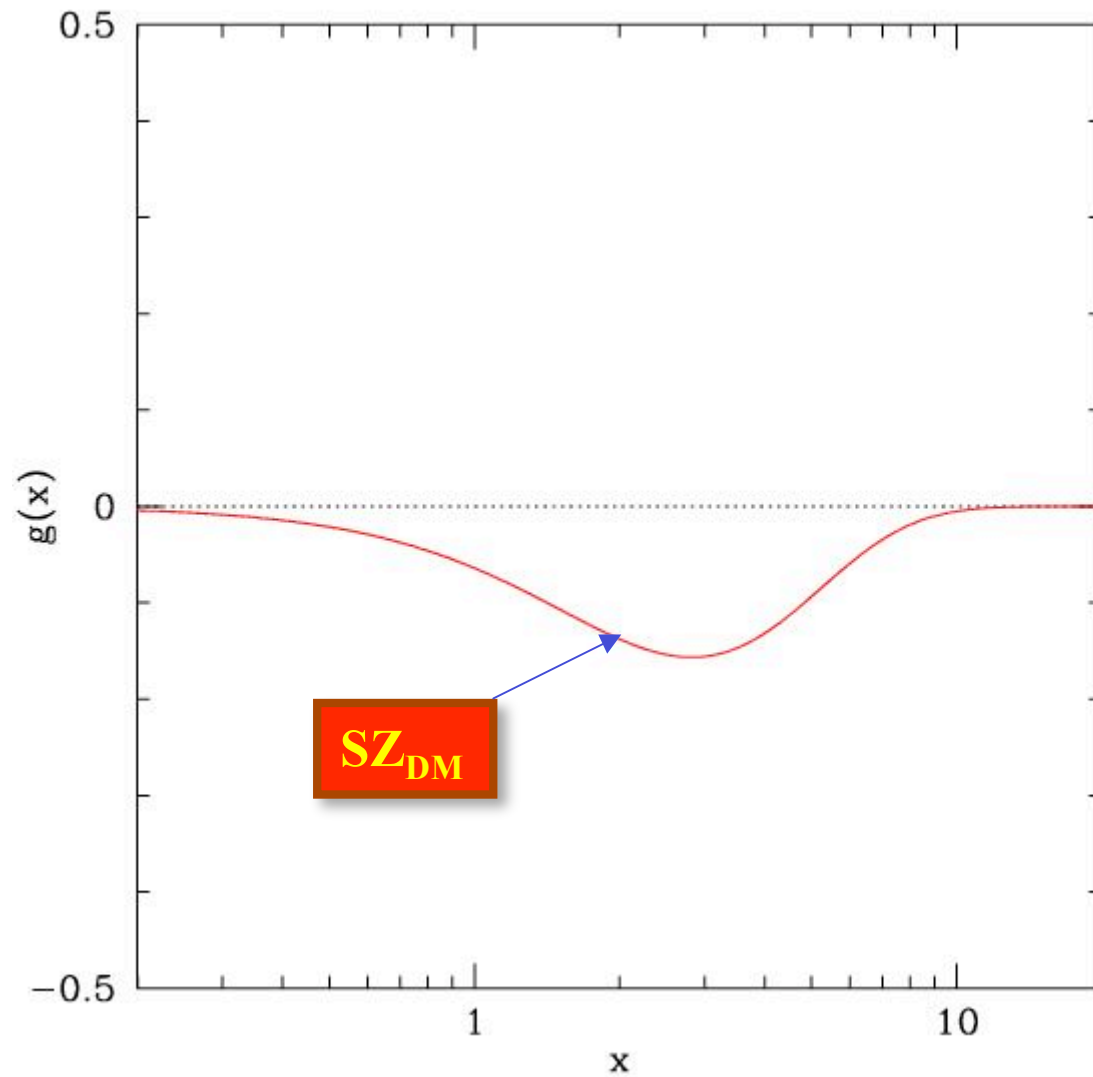
SZE in DM halos

A structure with:

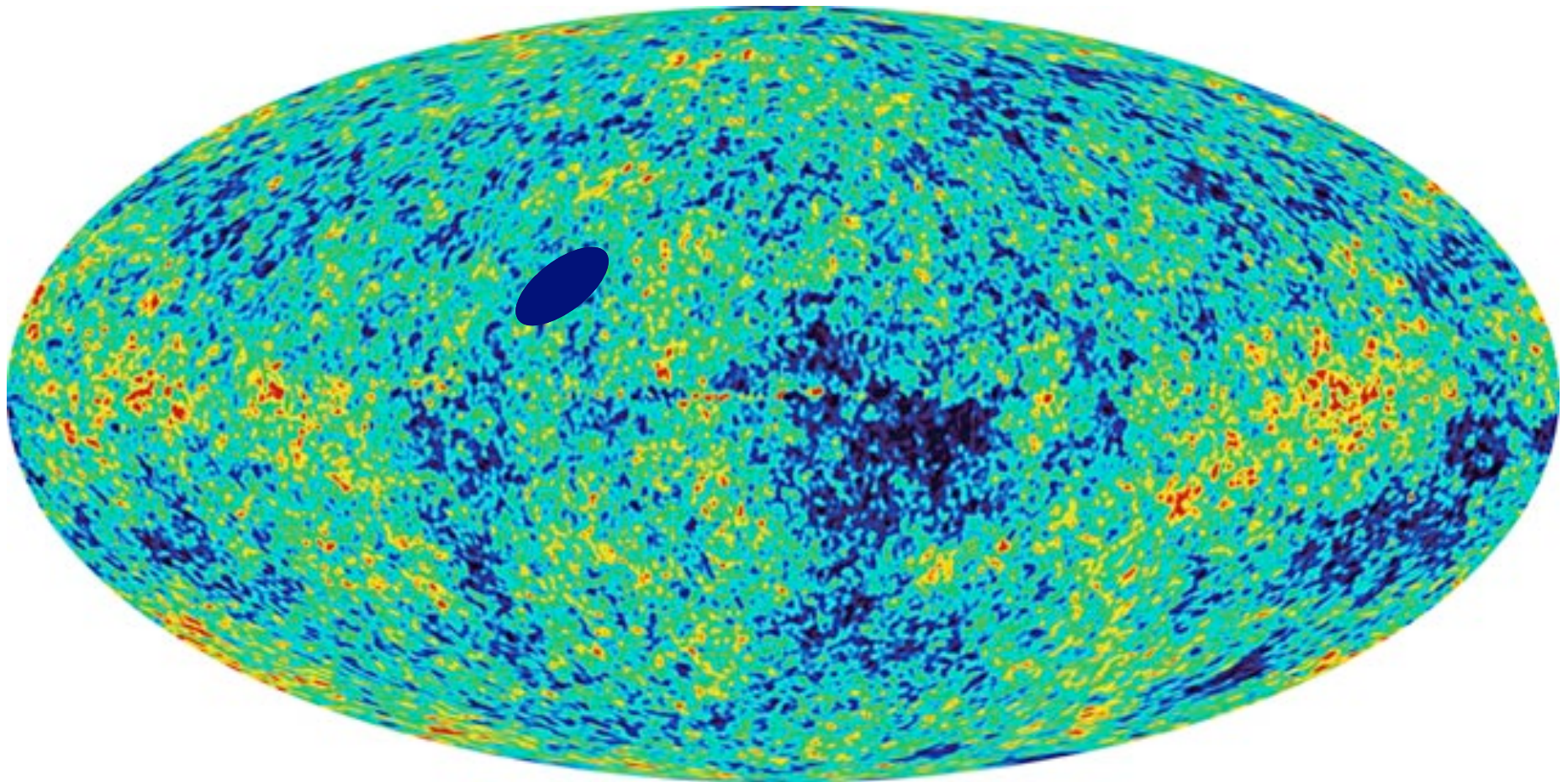
-
-
-
- DM
- Nearby ($V_r \approx 0$)



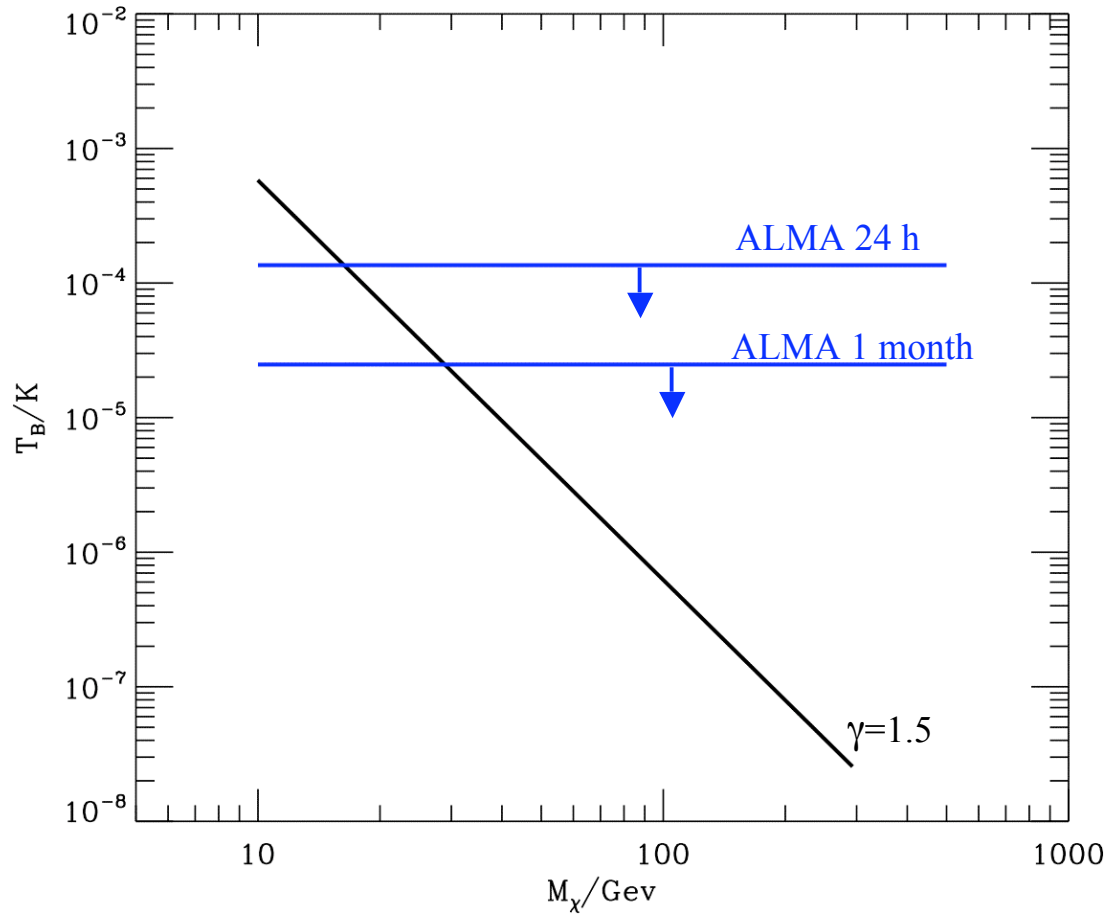
low surface
brightness galaxies



CMB maps & DRACO



SZ_{DM} in Draco



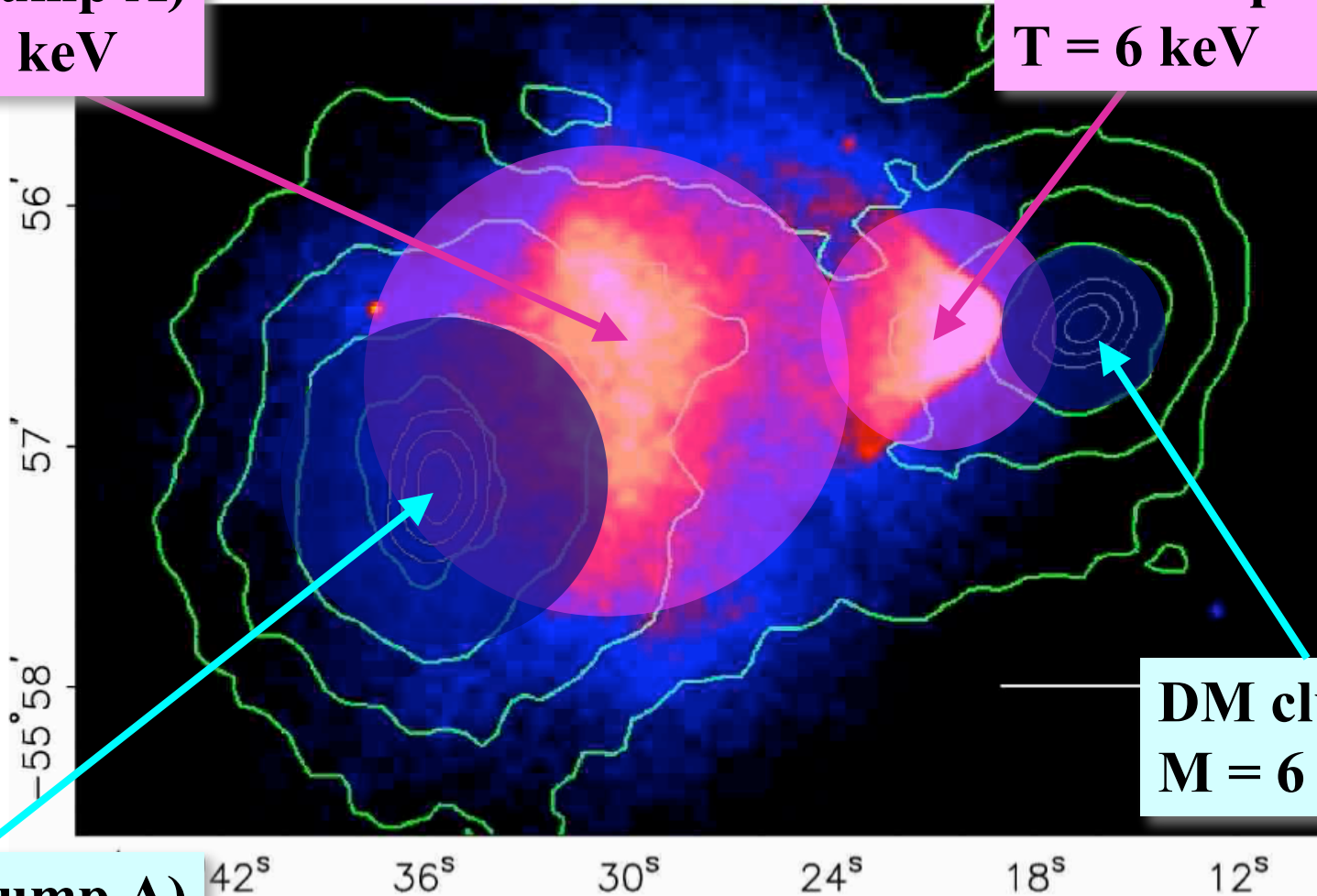
limits without
ACA

adapted from Culverhouse+06

The cluster 1ES0657-556

Gas clump A)
T = 14 keV

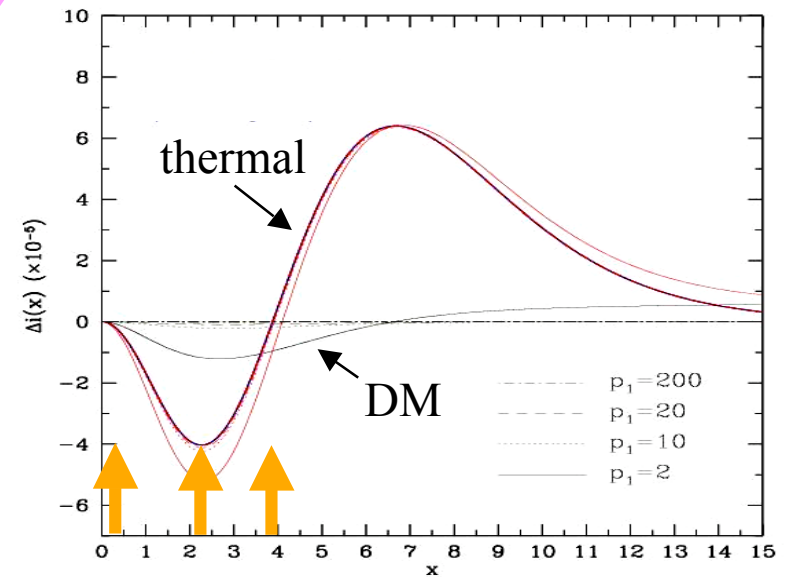
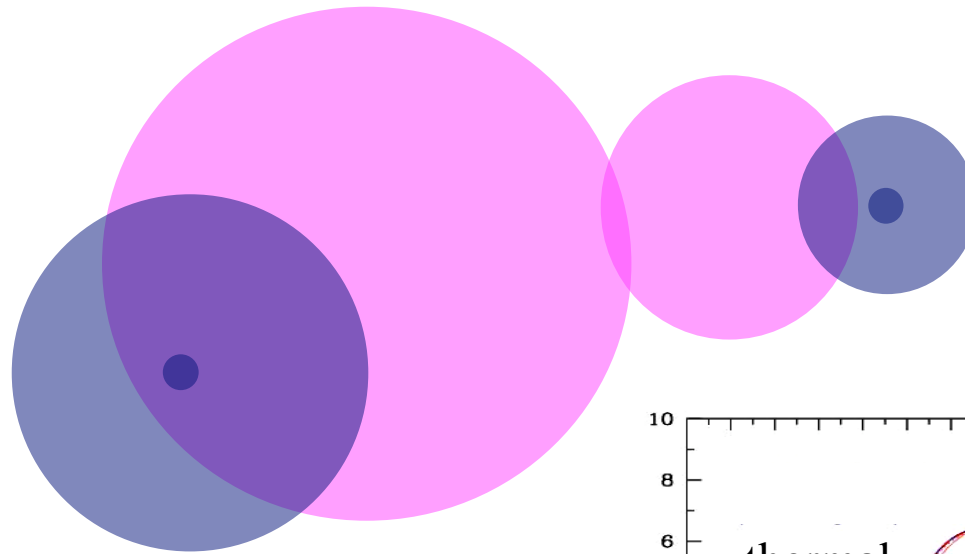
Gas clump B)
T = 6 keV



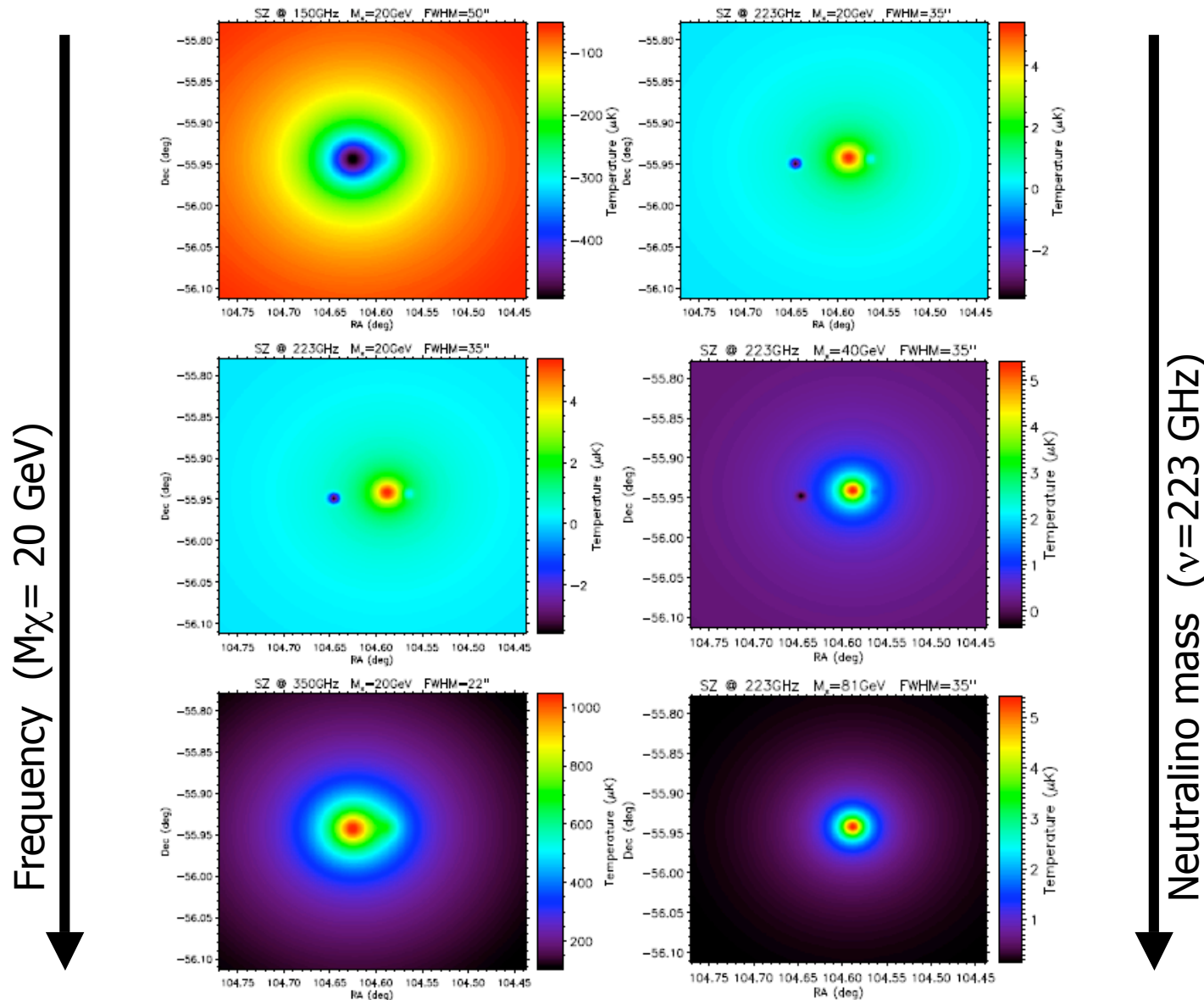
DM clump A)
M = 10¹⁵ M_⊙

DM clump B)
M = 6 10¹³ M_⊙

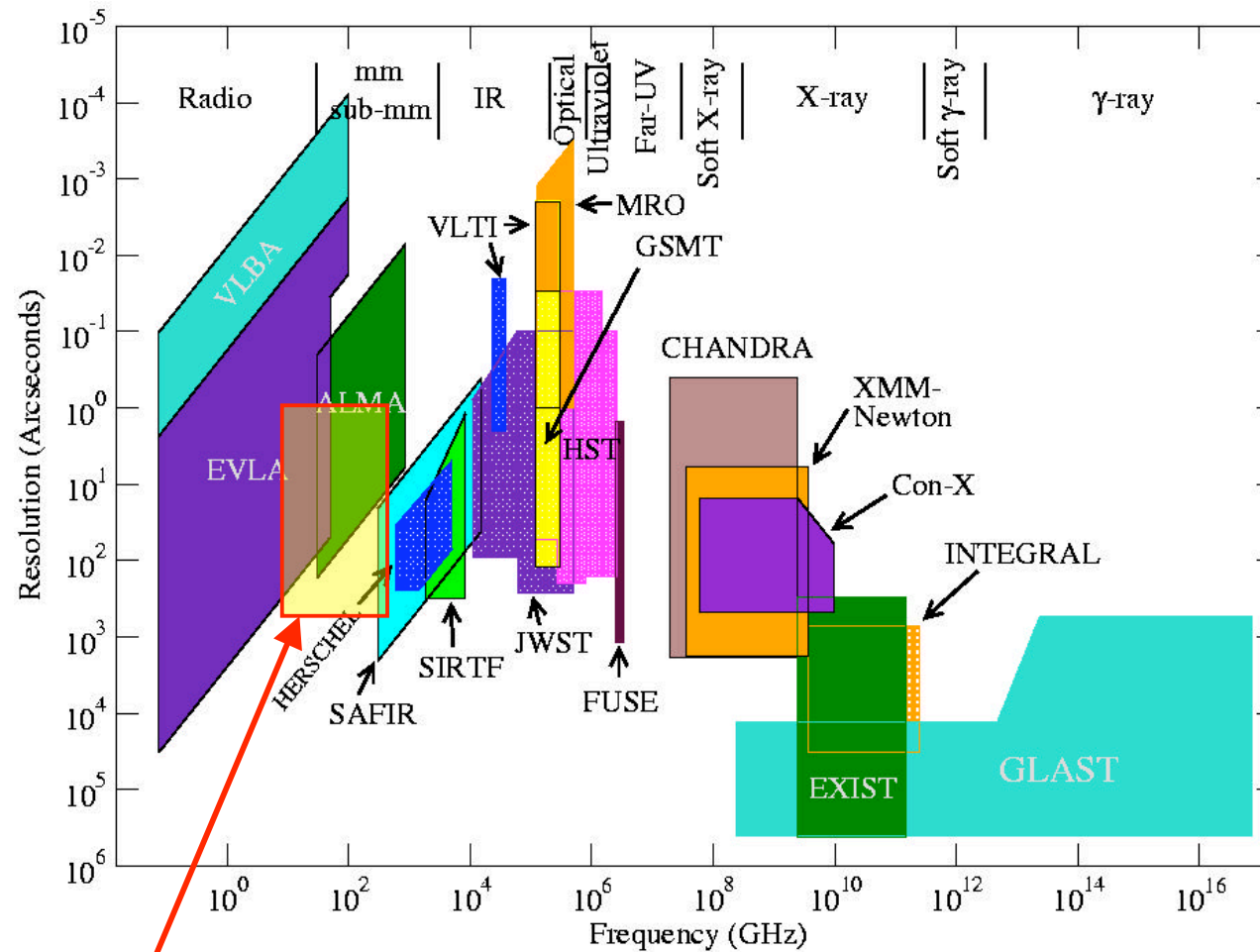
The SZ_{DM} from 1ES0657-556



Isolating SZ_{DM} at ~ 223 GHz



SZE science: requirements



SZE

Resolution: 1'' – 10'

$\Delta\nu = 10 - 500$ GHz