Multi-frequency analysis of Dark Matter signals

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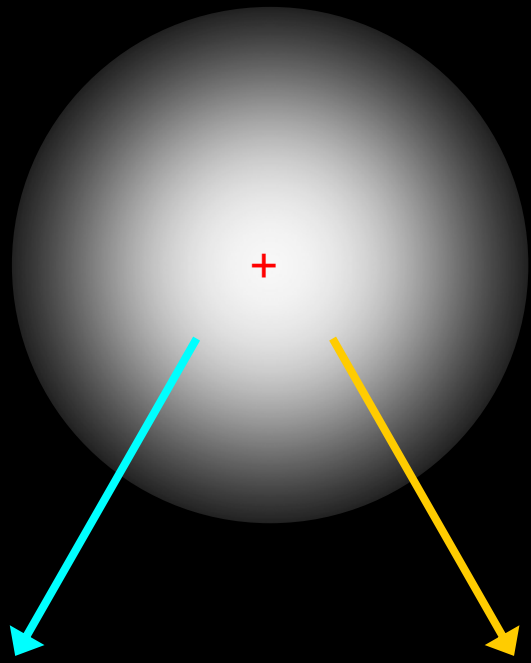
INFERENCE

PHYSICAL



Virial Theorem

Hydro Equilibrium

Gravitational lensing

Annihilation

$$X + X \rightarrow \pi^{0,\pm}, p, \ldots$$

$$X + X \rightarrow e^{\pm}, \mu^{\pm}, \tau^{\pm}, \nu_i$$

Decay

$$X \rightarrow x_i + \gamma$$

Astrophysical search for DM

DM and LSS

- Cosmology
- DM candidates

Search for DM

- Signals
- Targets
- Detectability

Optimal laboratories

- Dark galaxies (dwarfs)
- DM–baryon offset clusters

Coma - 1ES0657-556

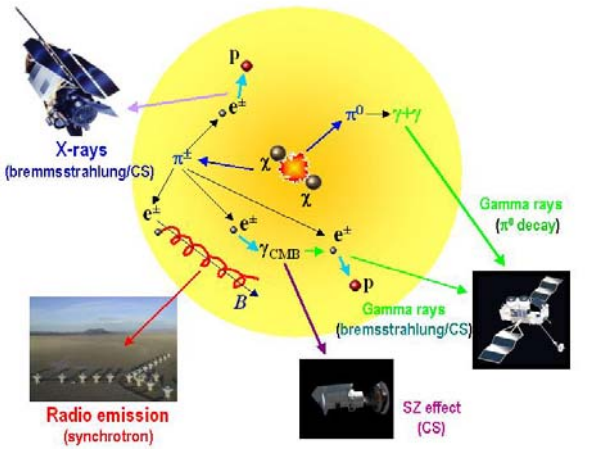
MW Dwarf Sph. galaxies

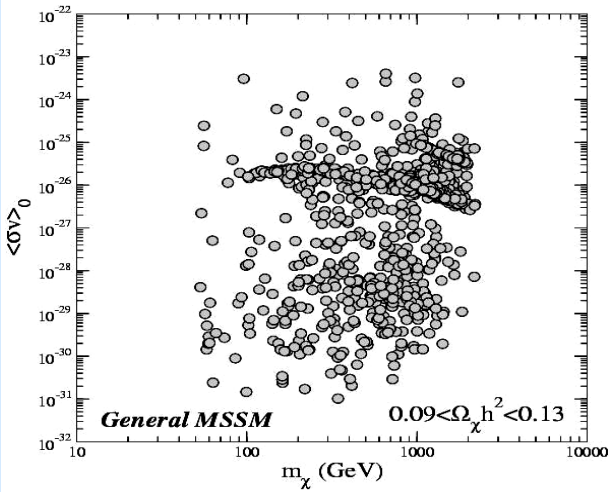
- Constraints
- Experimental outline

Viable DM candidates

Neutralinos

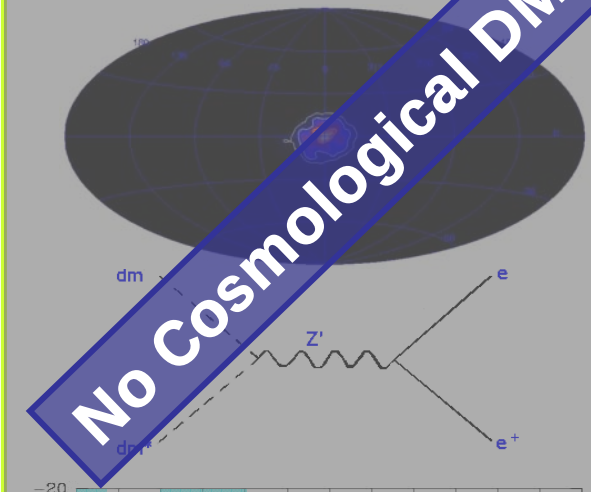
$$\tilde{\chi}_1^0 = N_{11}\tilde{B} + N_{12}\tilde{W}^3 + N_{13}\tilde{H}_1^0 + N_{14}\tilde{H}_2^0$$

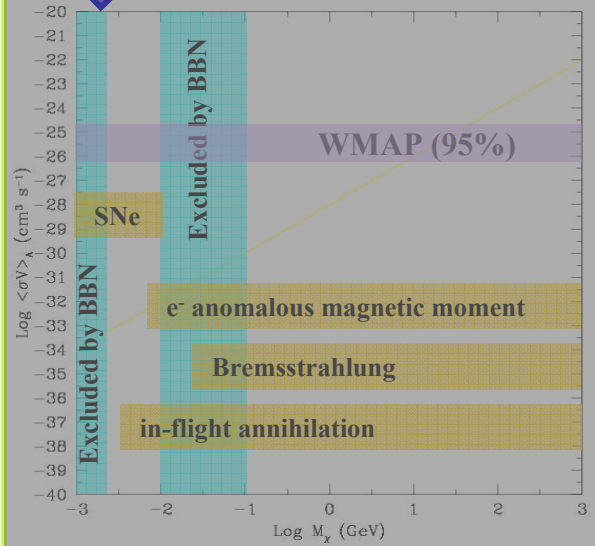




Light (MeV) DM

No Cosmological DM



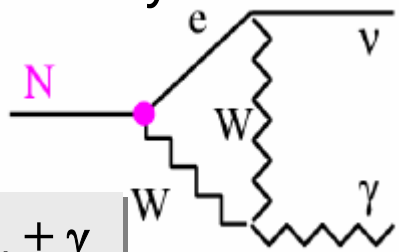


Sterile ν's

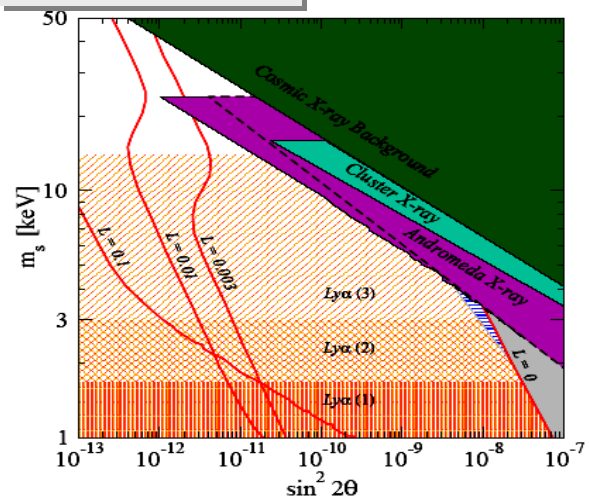
Unstable

$$\tau \simeq 5\times10^{23}\ \mathrm{sec}\left(\frac{10\mathrm{keV}}{M_I}\right)^5\left(\frac{10^{-10}}{|\Theta|^2}\right)$$

Radiative decay: line

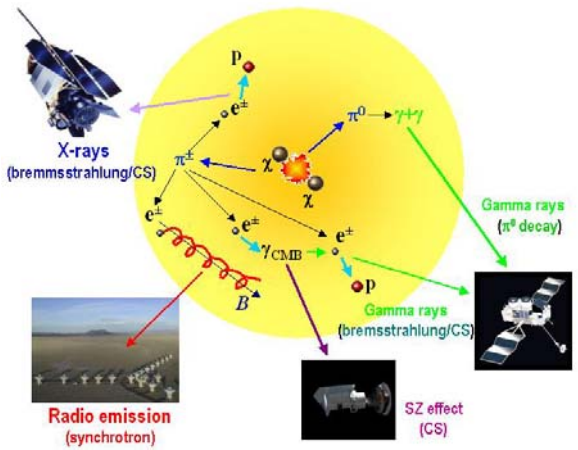


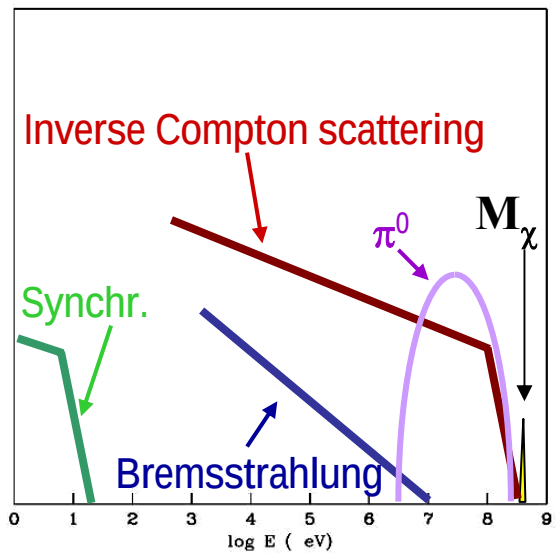
$$\nu_s \rightarrow \nu_\alpha + \gamma$$



DM candidates: signals

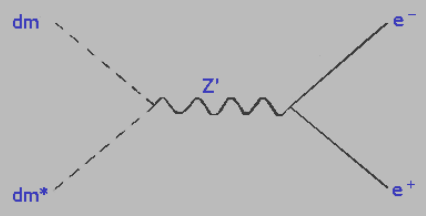
Neutralinos

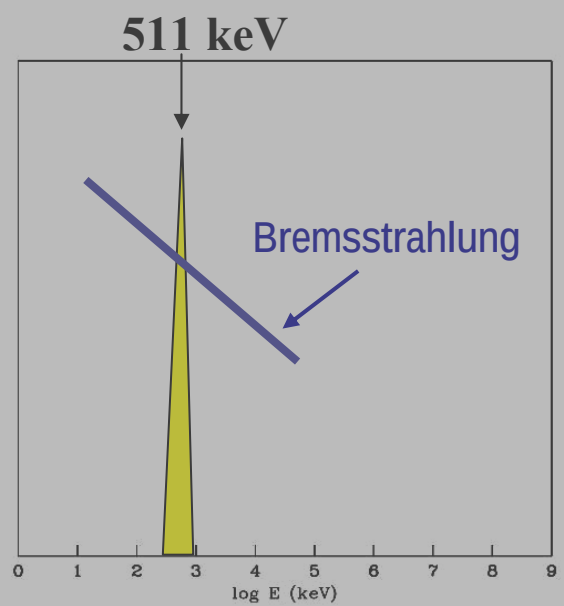




Light (MeV) DM

Annihilating MeV DM
- Continuum: HXR/γ-rays
- Line: $e^\pm$ annihilation



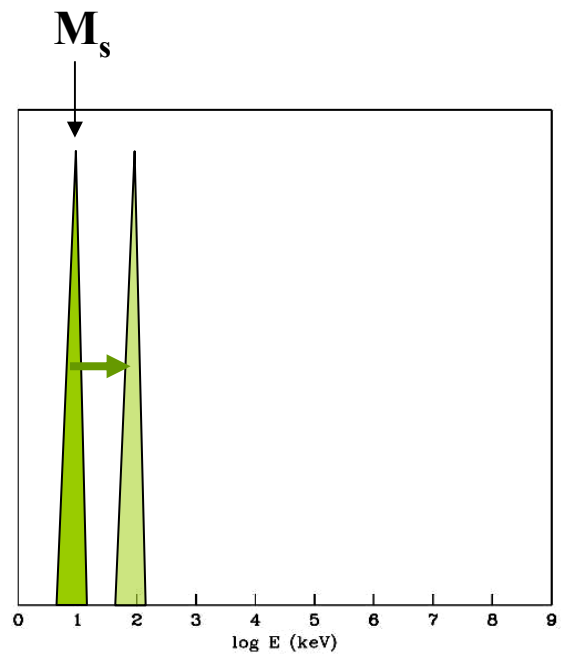


Sterile ν's

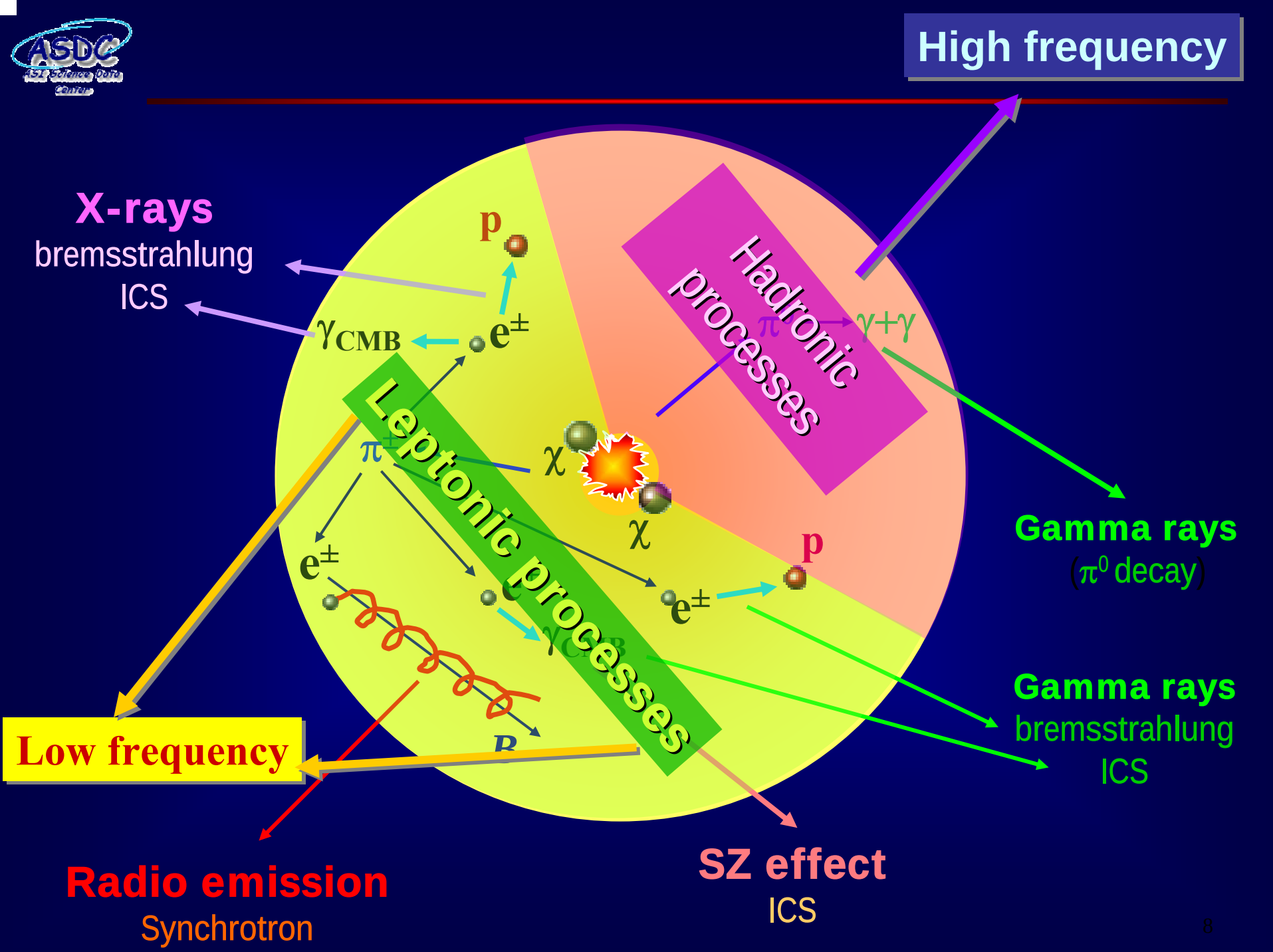
Radiative decay: line

$$\nu_s \rightarrow \nu_\alpha + \gamma$$

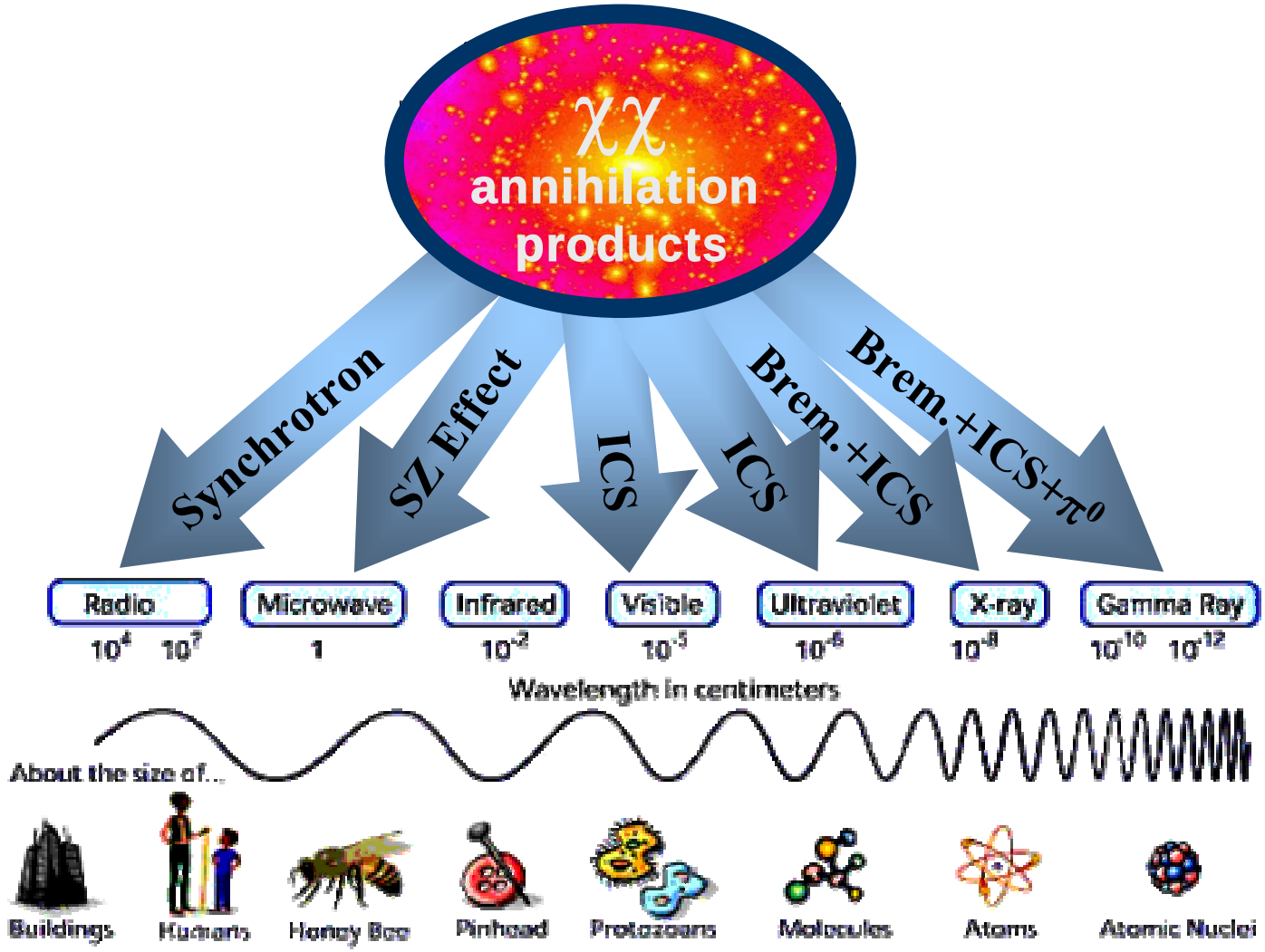
$$\Gamma_s \simeq 6.8 \times 10^{-33} \mathrm{s}^{-1} \left(\frac{\sin^2 2\theta}{10^{-10}}\right) \left(\frac{\mathrm{m_s}}{\mathrm{keV}}\right)^5$$



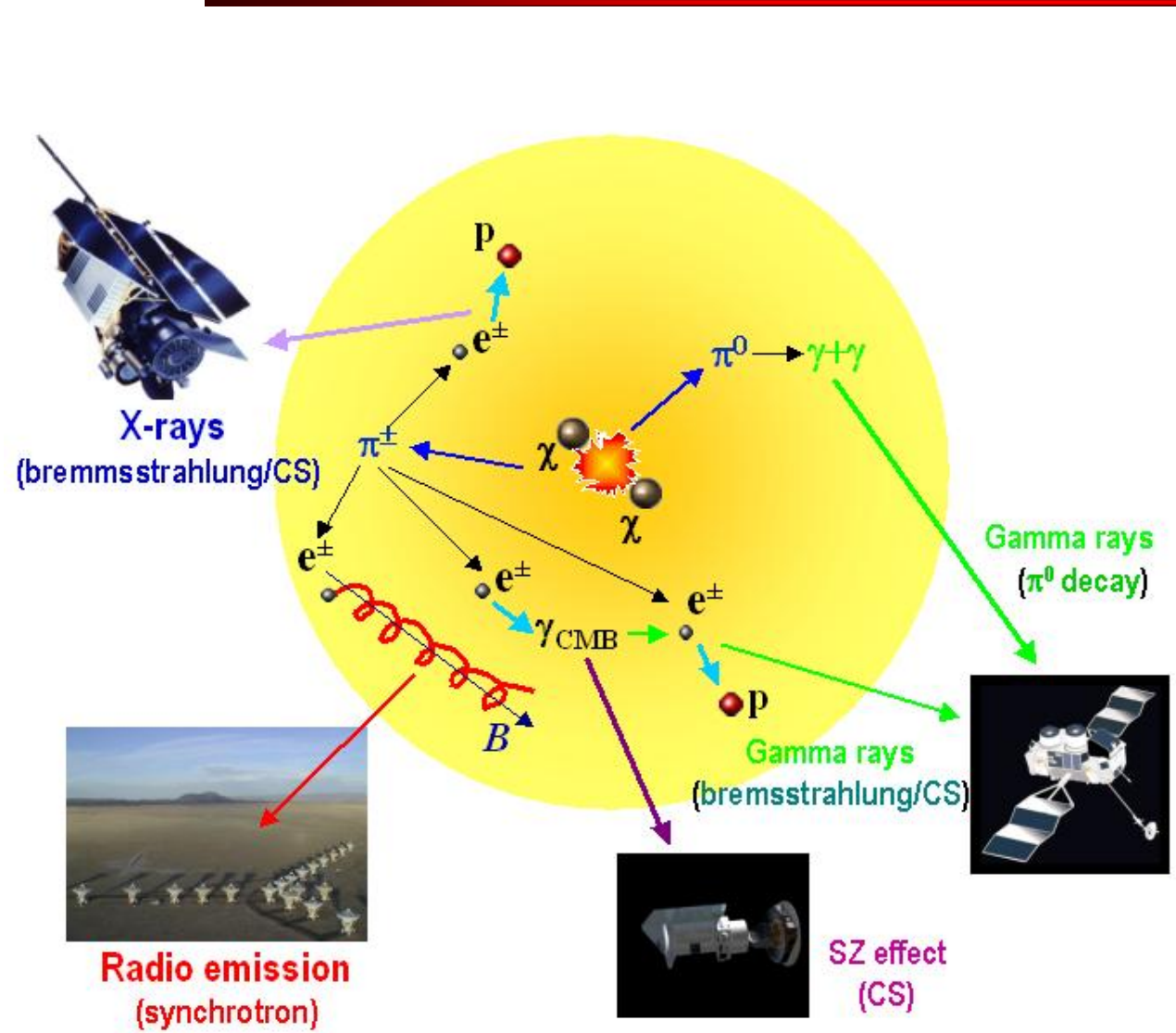
SUSY neutralino DM

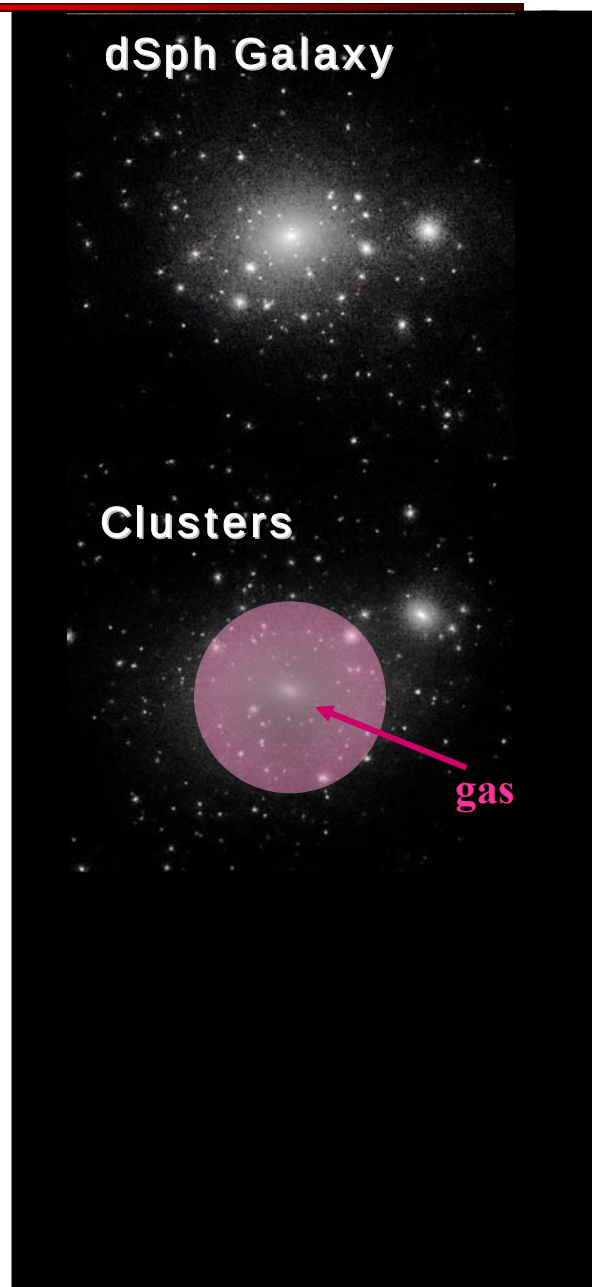

High frequency
X-rays
bremsstrahlung
ICS
p
γ_{CMB}
$e^{\pm}$
Hadronic processes
π
$\gamma+\gamma$
Leptonic processes
$\pi^{\pm}$
χ
χ
$e^{\pm}$
$e^{\pm}$
p
γ_{CMB}
Gamma rays
(π^0 decay)
Gamma rays
bremsstrahlung
ICS
Low frequency
Radio emission
Synchrotron
SZ effect
ICS

Covering the whole e.m. spectrum



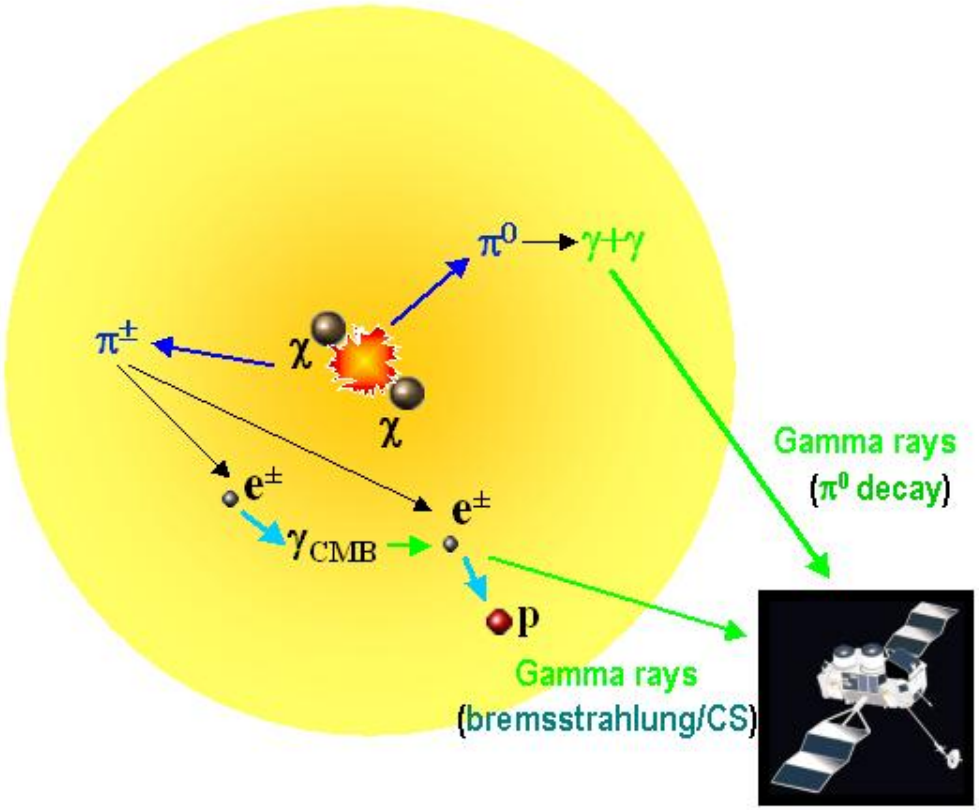
DM signals: multi-ν Best Labs.





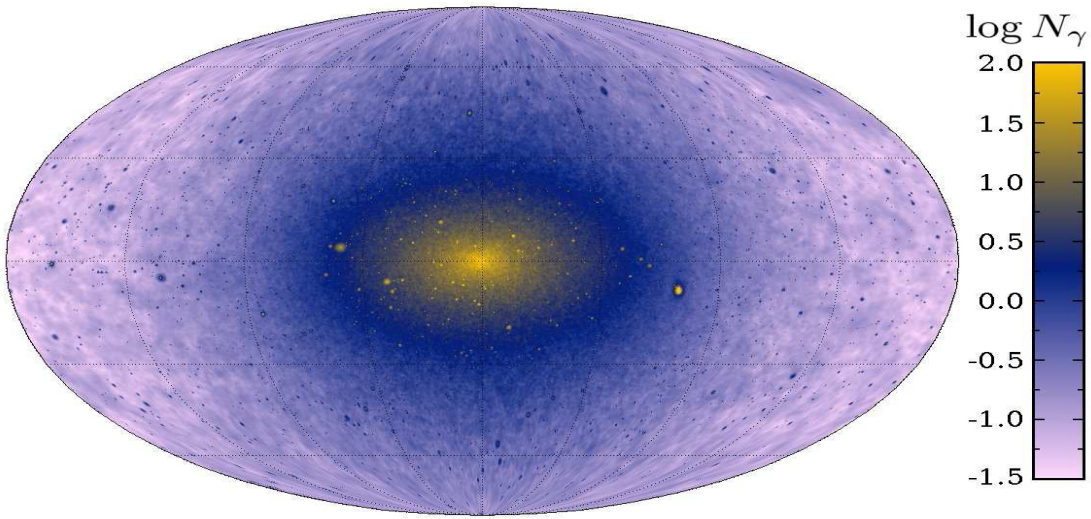
[Colafrancesco 2005, 2007]

Neutralino DM: γ-rays



The γ-ray DM sky

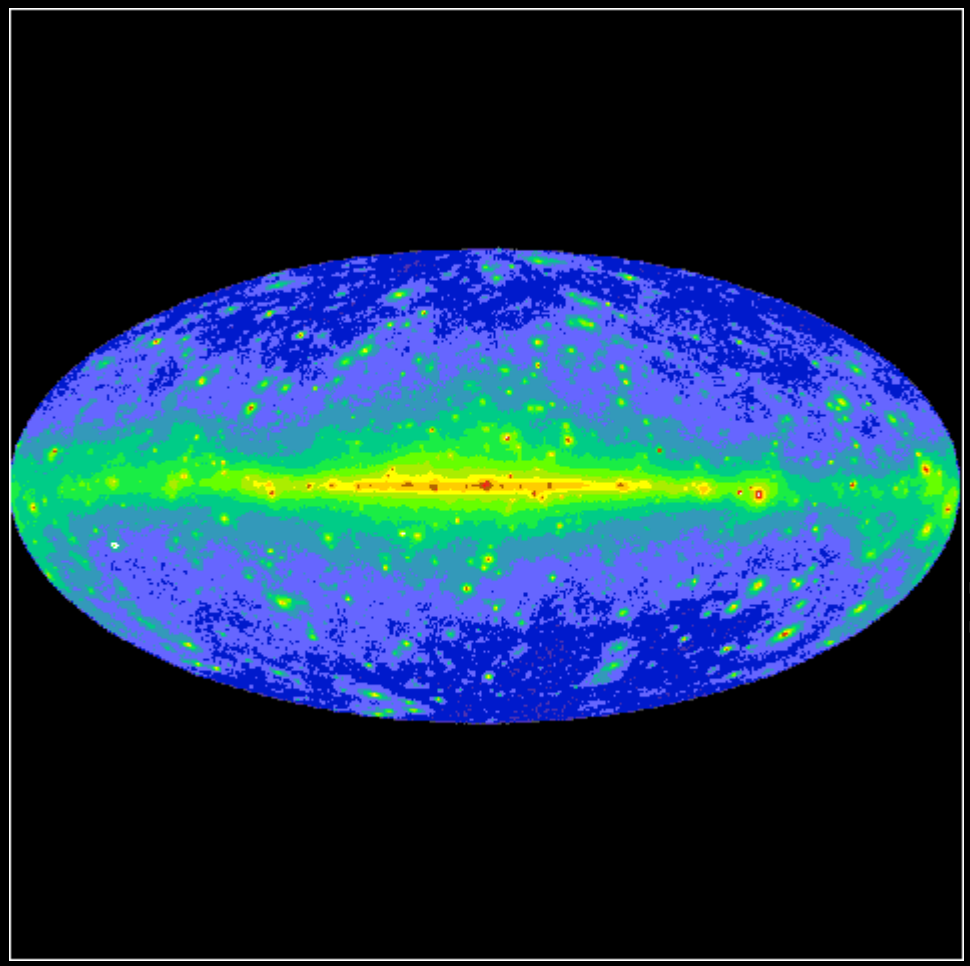
$$M_\chi = 46\ \text{GeV},\ \langle \sigma v \rangle = 5 \times 10^{-26}\ \text{cm}^3\ \text{s}^{-1}$$



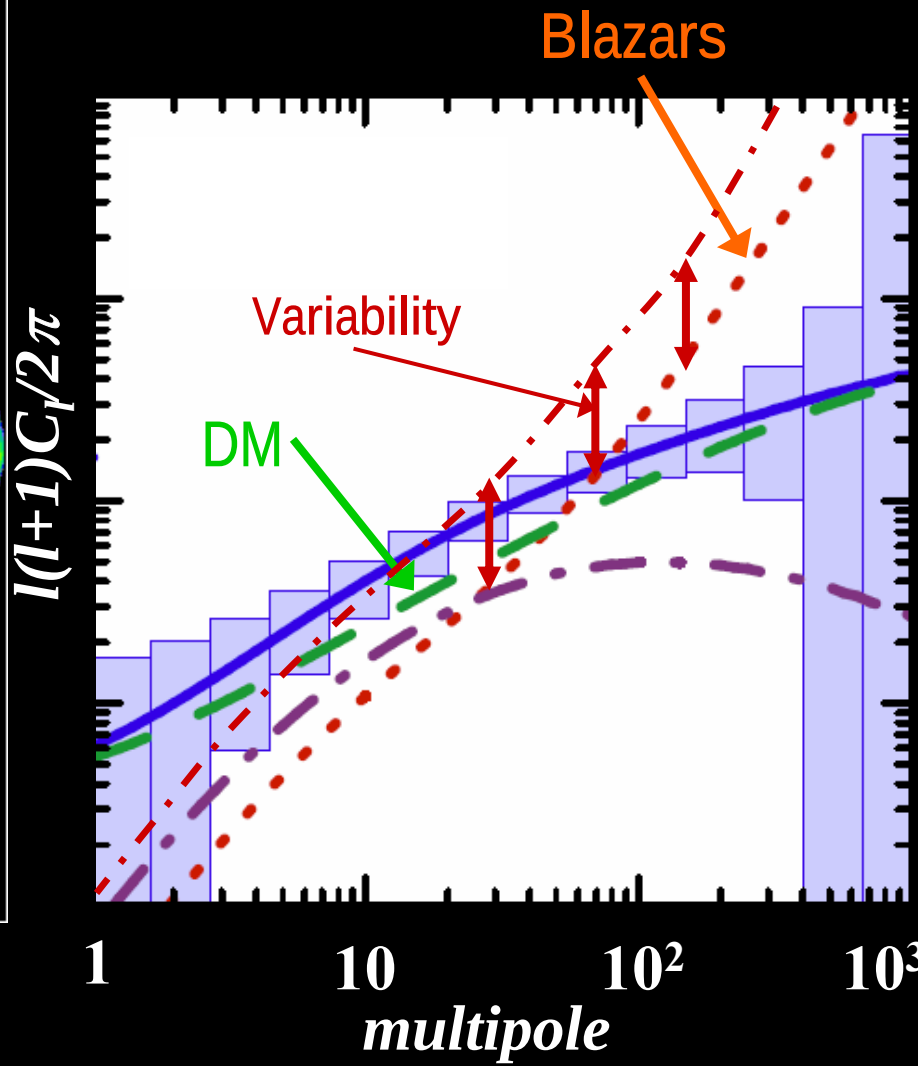
[Kuhlen et al. arXiv:0704.0944]

The GLAST sky

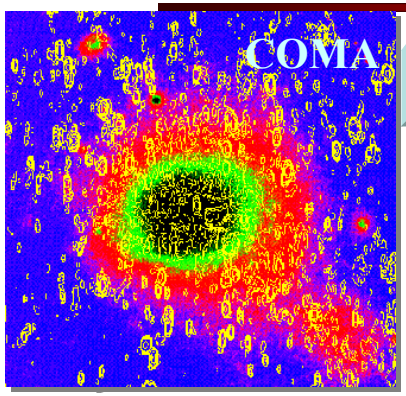
SC2 simulation (55 days)



Angular power spectrum

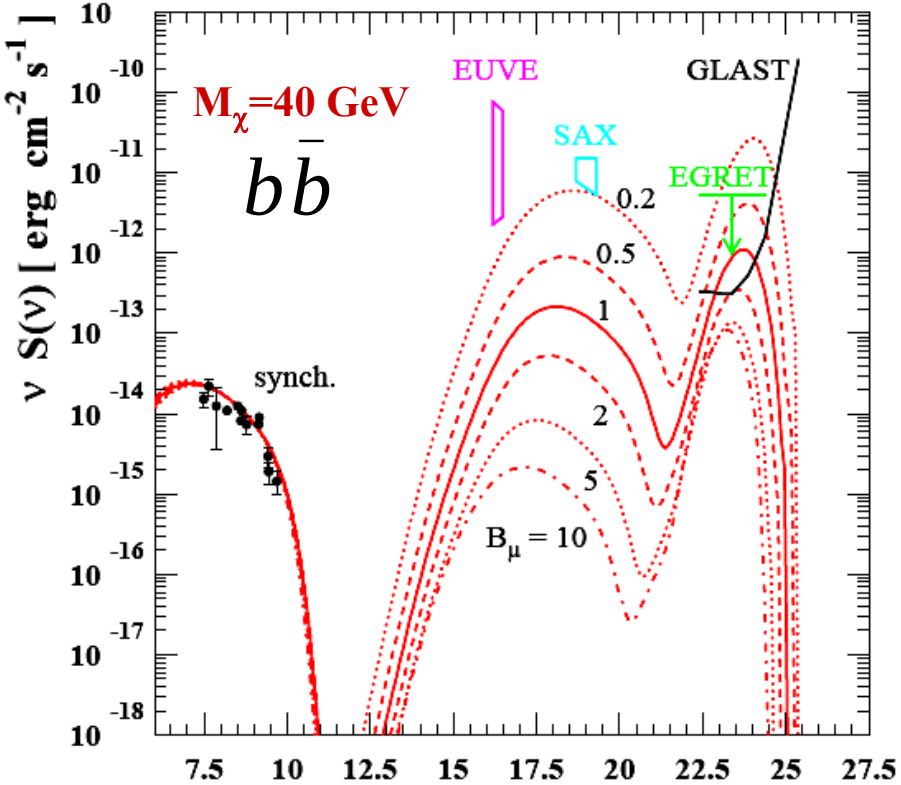


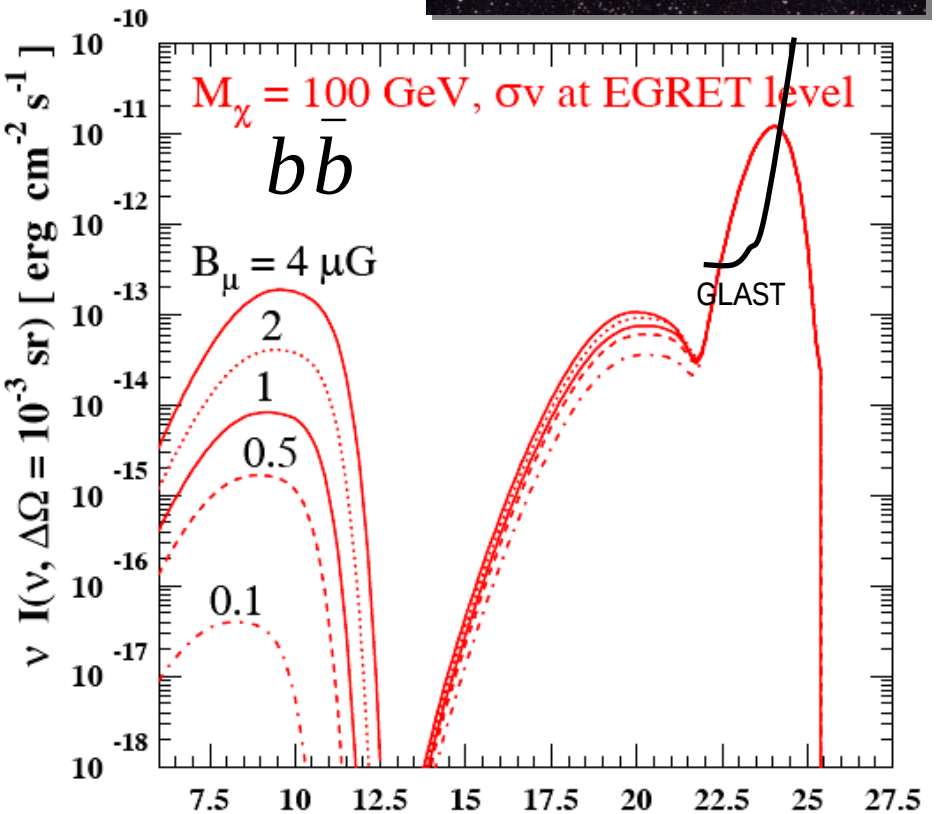
DM halos: multi–ν messengers



Galaxy clusters

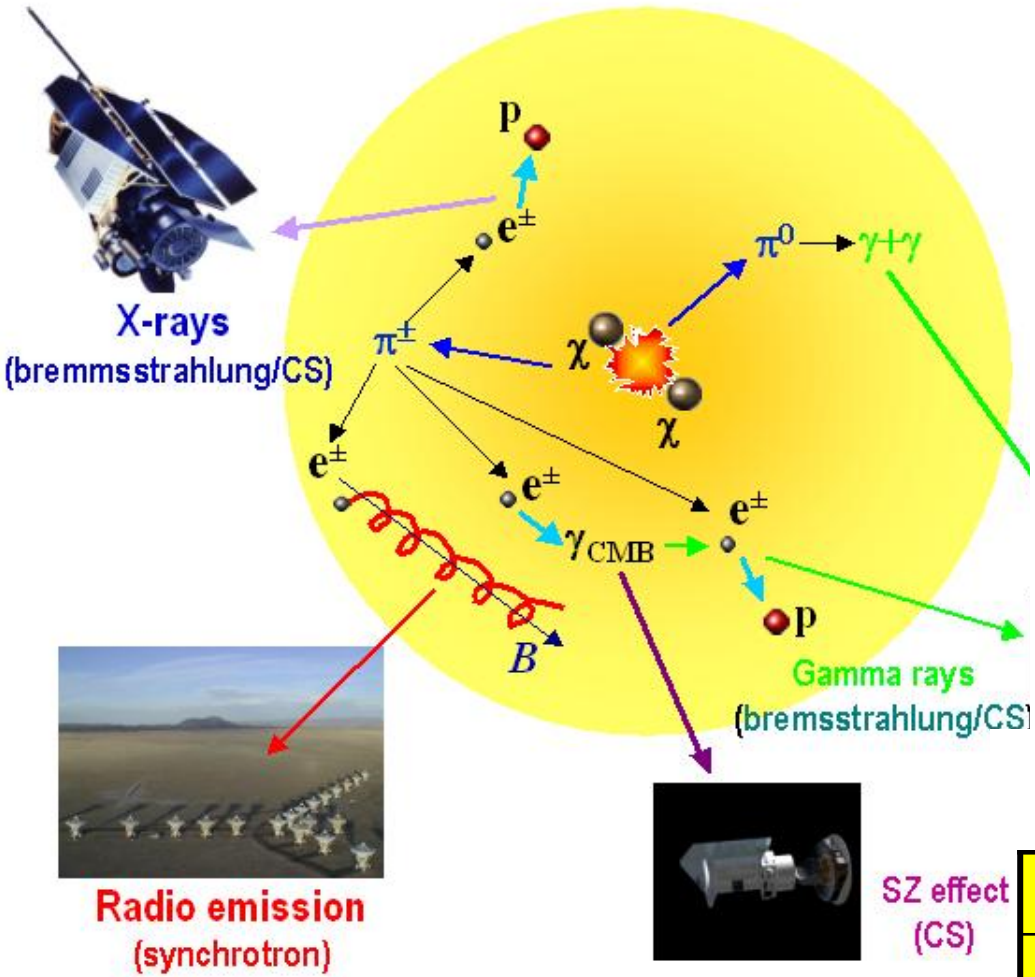
Dwarf galaxies

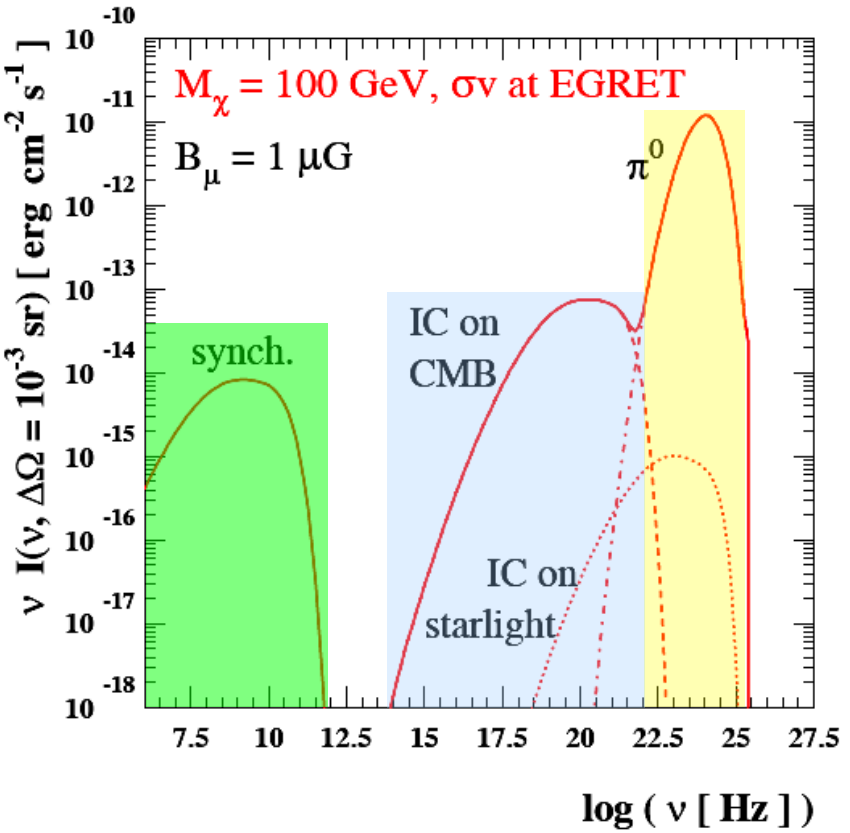




[Colafrancesco, Profumo & Ullio 2006, 2007]

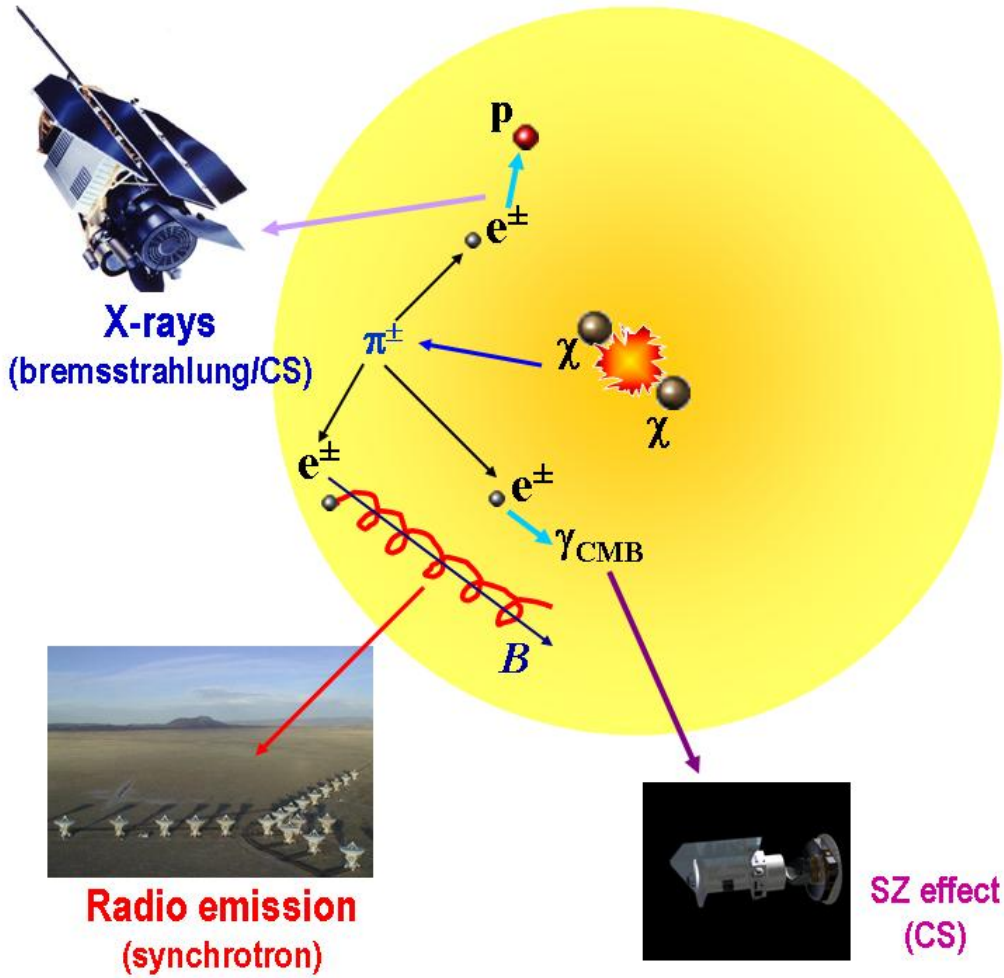
DM signals: multi-frequency





	F (erg/s cm^2)	counts	S/N
$\pi^0 \rightarrow \gamma\gamma$	~ 10^{-11}	10^2	~ 6
ICS	~ 10^{-13}	10^6	≥ 10^3
Synchrotron	~ 10^{-14}	10^{16}	≥ 10^4

Neutralino DM: low-ν

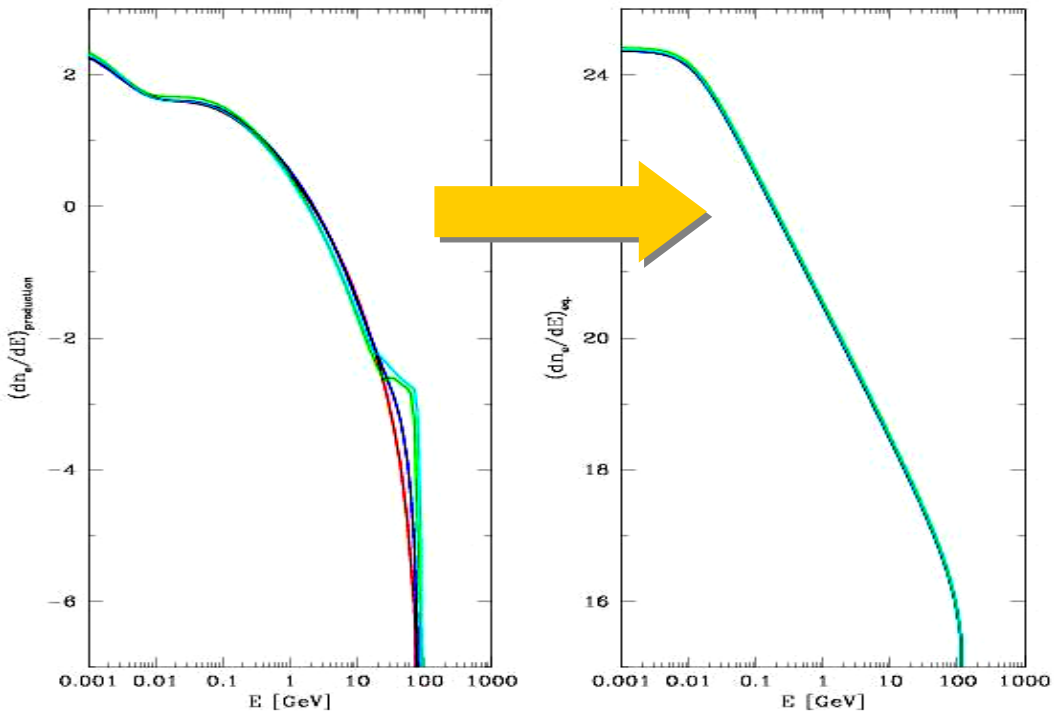


Leptons: $e^{\pm}$ equilibrium spectrum

$$\cancel{\frac{\partial n_e(E,r)}{\partial t}} - \nabla\left[D(E)\nabla n_e(E,r)\right] - \frac{\partial}{\partial E}\left[b_e(E)n_e(E,r)\right] = Q_e(E,r)$$

Production

$Q_e(E,r)$



Equilibrium

$n_e(E,r)$

Diffusion

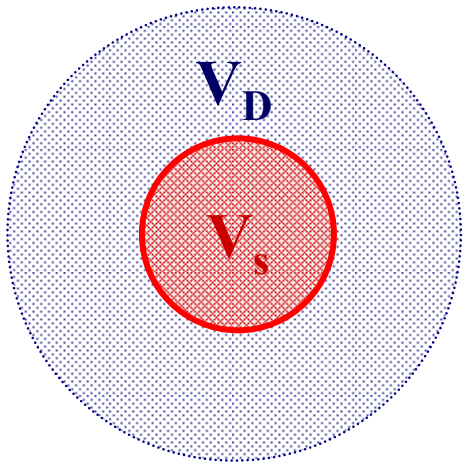
$$D(E) = D_0 E^{\gamma} B^{-\gamma}$$

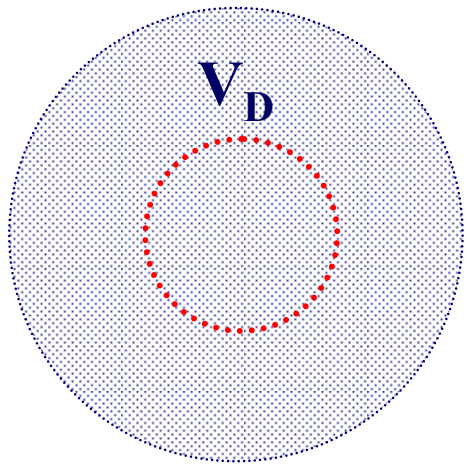
E losses

$$b_e(E) = b_{IC} + b_{sync} + b_{Coul} + b_{brem}$$

Solution: qualitative

$$n_e(E,r) = \left[Q_e(E,r)\tau_{loss}\right] \cdot \frac{V_{source}}{V_{source} + V_{diffusion}} \cdot \frac{\tau_D}{\tau_D + \tau_{loss}}$$





$\tau_{loss} \ll \tau_D$

$\tau_{loss} \gg \tau_D$

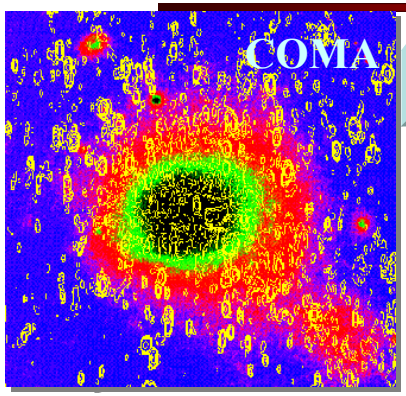
$$n_e(E,r) = \left[Q_e(E,r)\tau_{loss}\right]$$

$$n_e(E,r) = \left[Q_e(E,r)\tau_{loss}\right] \cdot \frac{V_{source}}{V_{diffusion}} \cdot \frac{\tau_D}{\tau_{loss}}$$

Galaxy clusters (~Mpc)

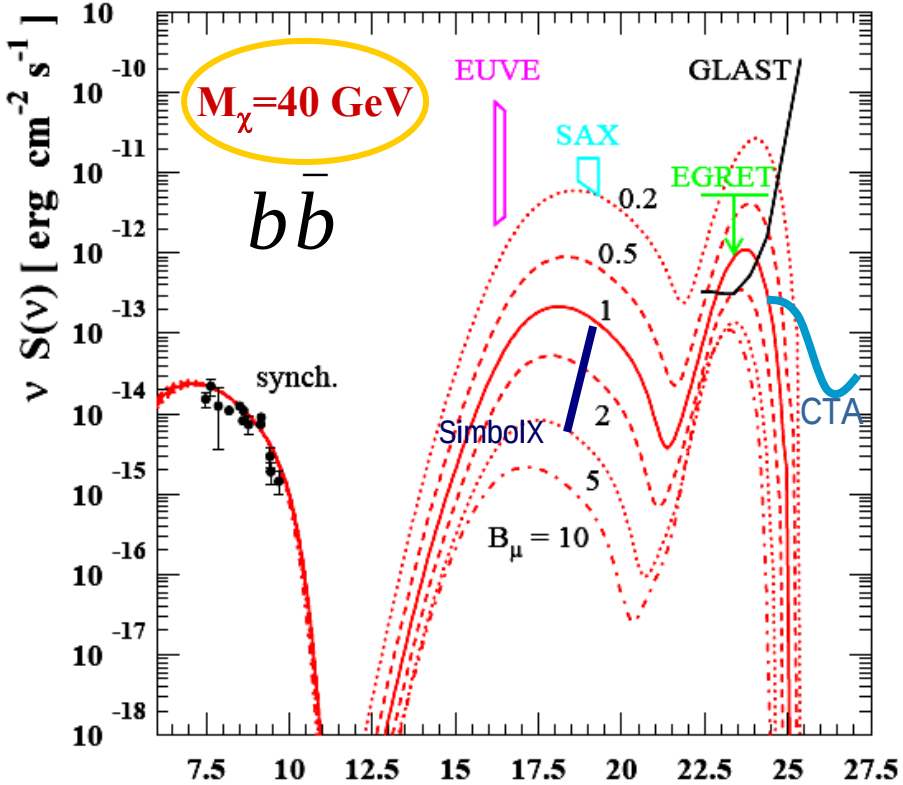
Galaxies (~kpc)

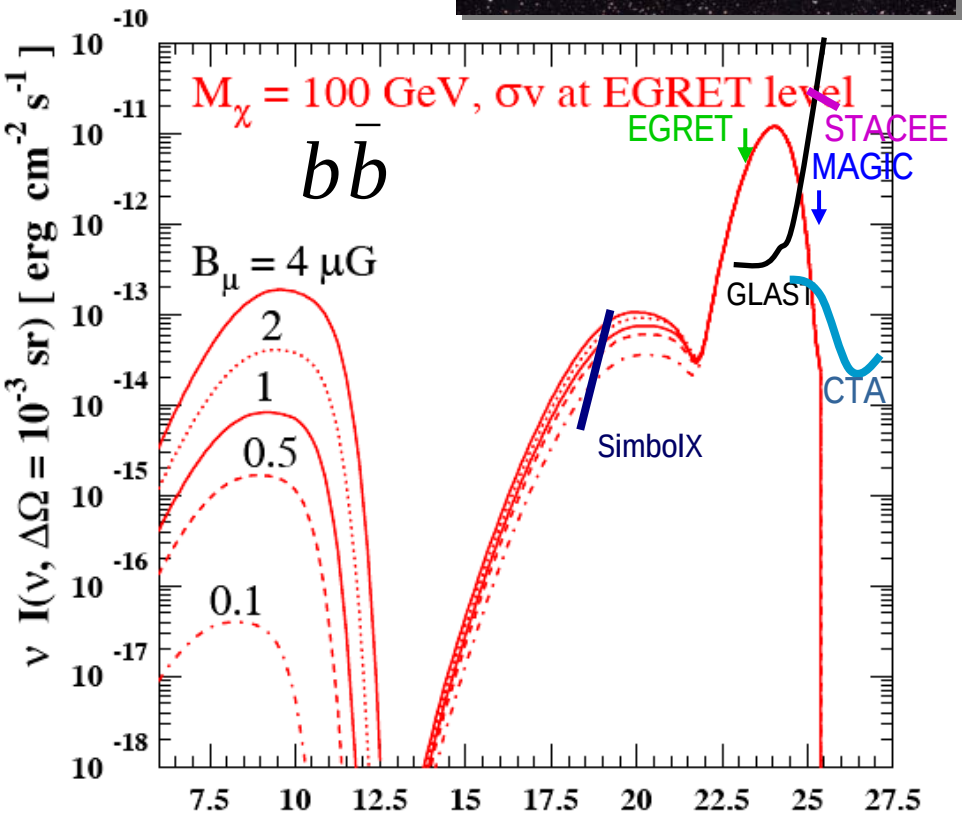
DM halos: multi–ν messengers



Galaxy clusters

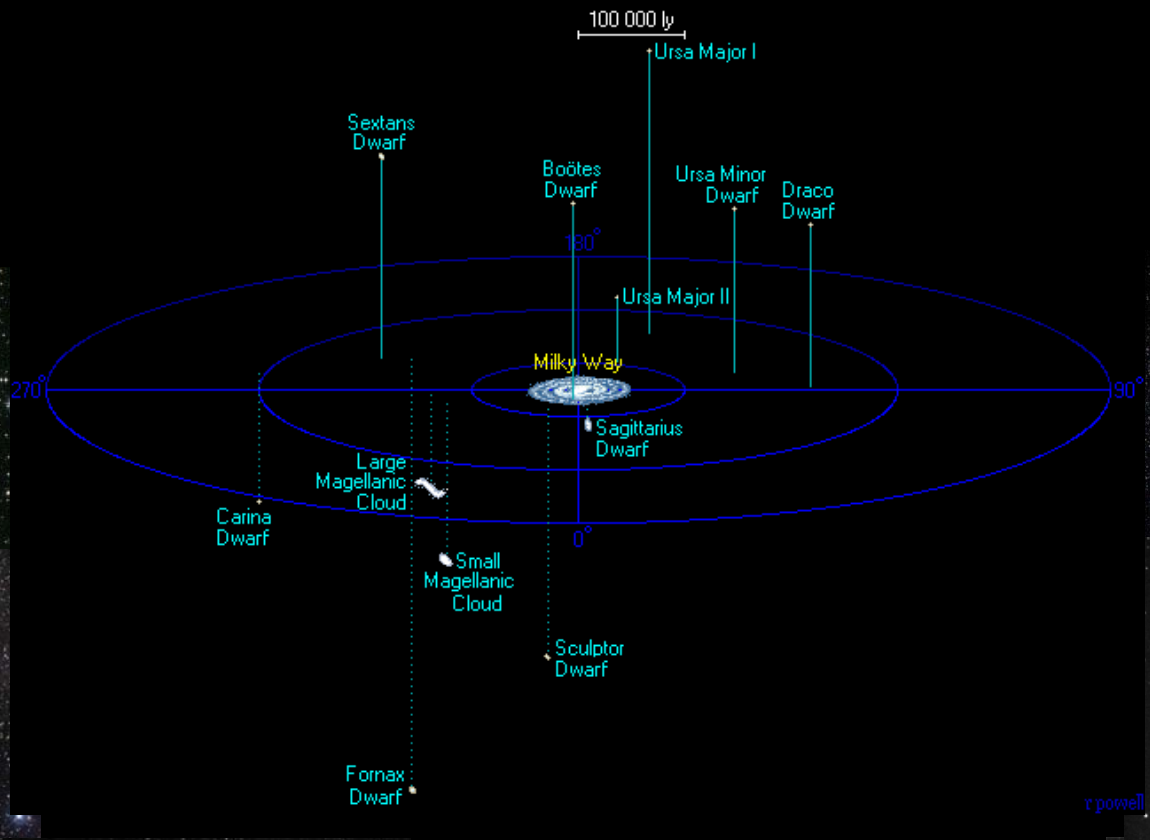
Dwarf galaxies



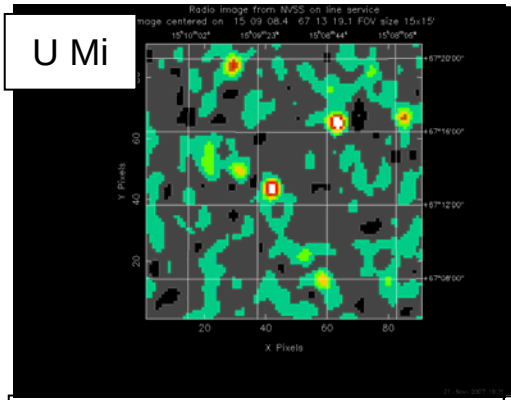


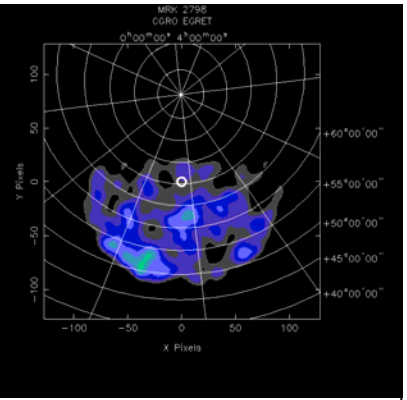
[Colafrancesco, Profumo & Ullio 2006, 2007]

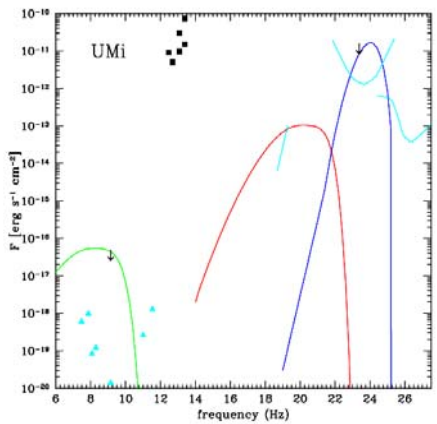
Dwarf Galaxies at multi-ν: a DM survey



U Mi





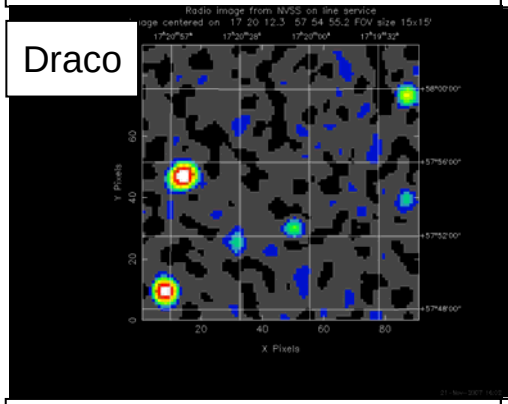


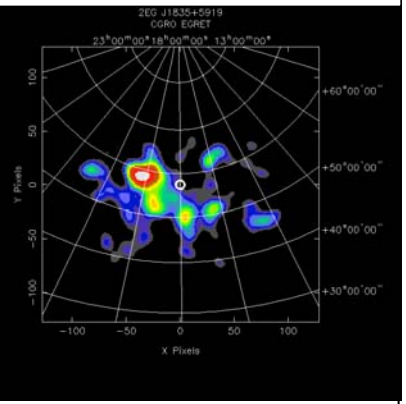
$F_{1.4}$ < 3.5 mJy

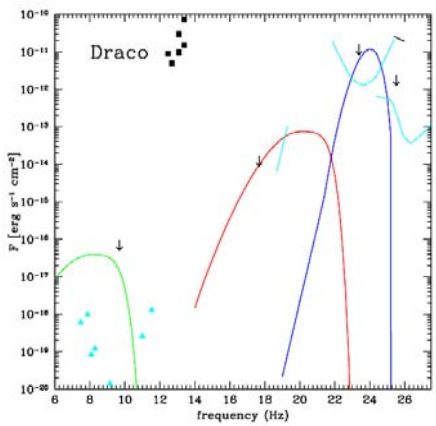
F_{2keV} <

S=13 pho; bkg=11 pho

Draco





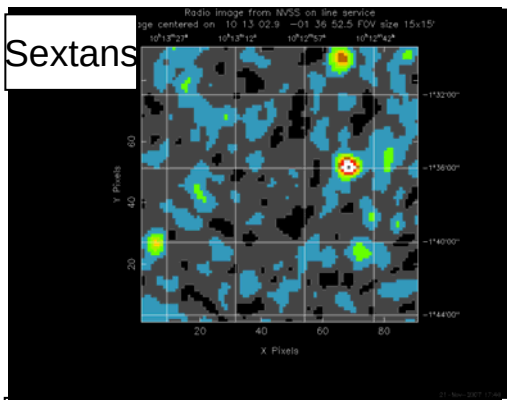


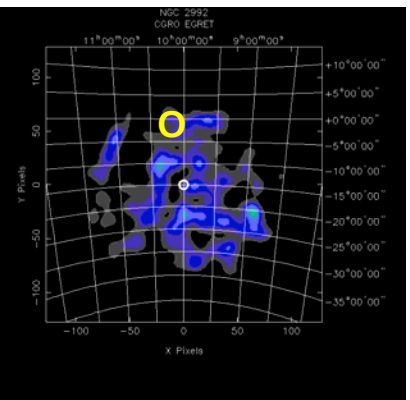
$F_{4.9}$ < 2 mJy

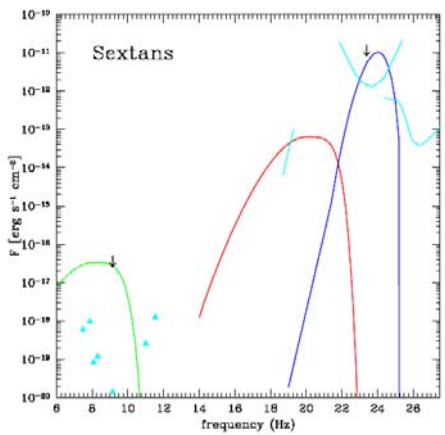
F_{2keV}<1.7e-14 erg/scm^2

S=1 pho; bkg=1 pho

Sextans







$F_{1.4}$ < 3.5 mJy

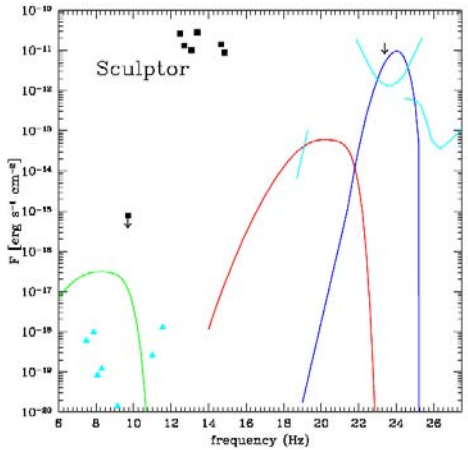
F_{2keV} <

S=4 pho: bkg=2 pho

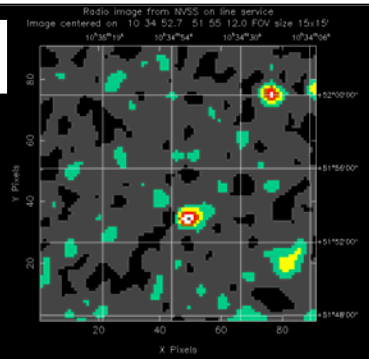
Scl.

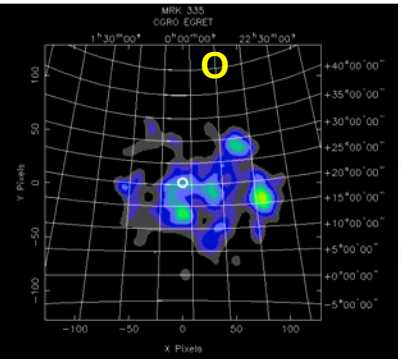
$F_5 < 15.2$ mJy

$F_{2keV} <$



UMa

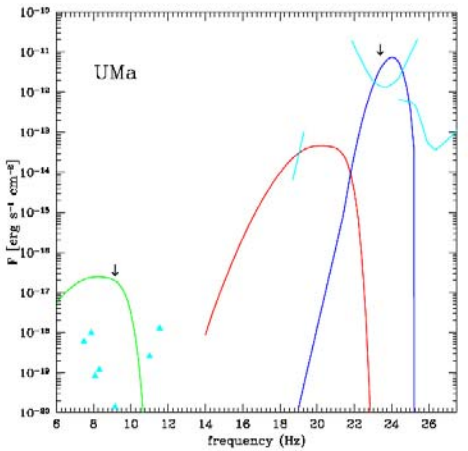




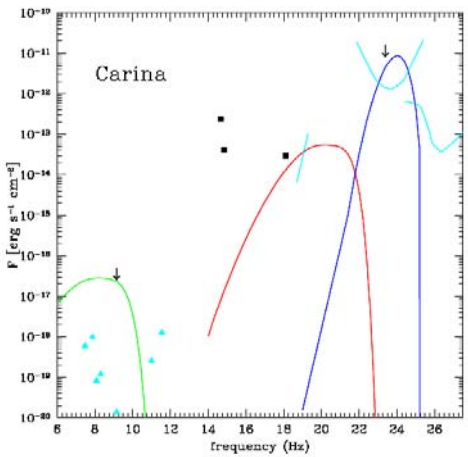
$F_{1.4} <$ 3.5 mJy

$F_{2keV} <$

S=2 pho; bkg=3 pho



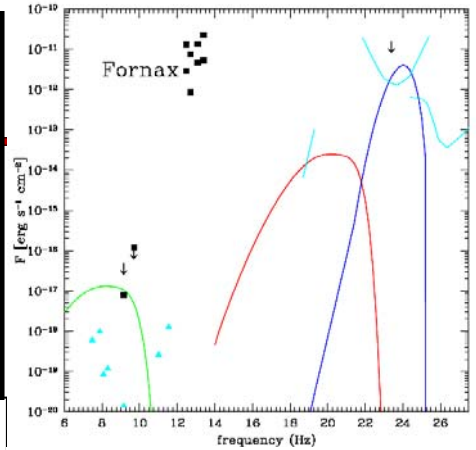
Carina



No NVSS coverage

$F_{0.1\text{-}10}$=2.9° 14erg/scm^2

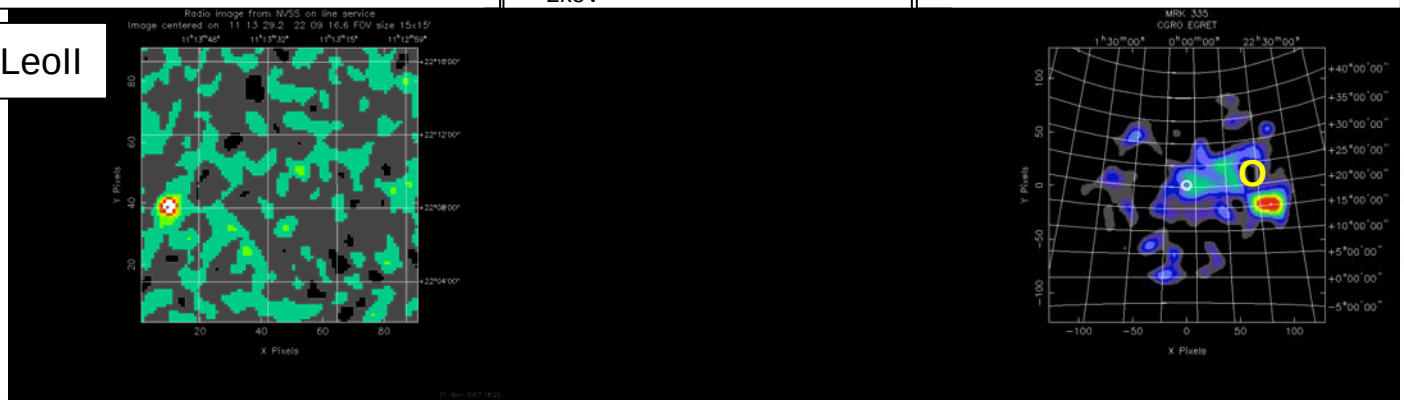
Fornax

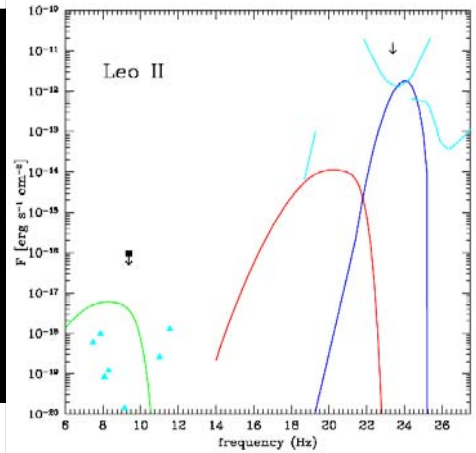


$F_{1.4}$ = 0.54 mJy (HI line)

F_{2keV} <

LeoII



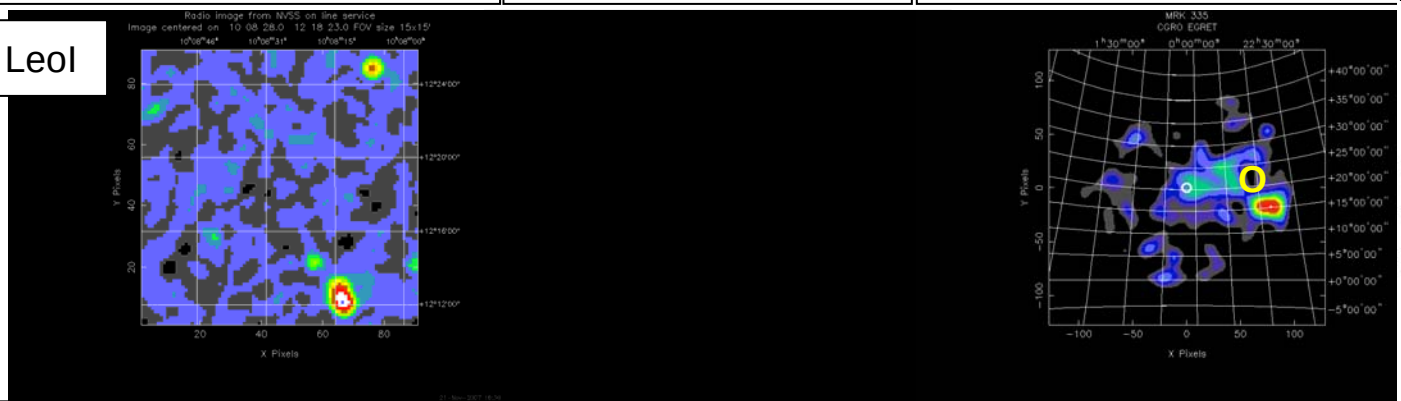


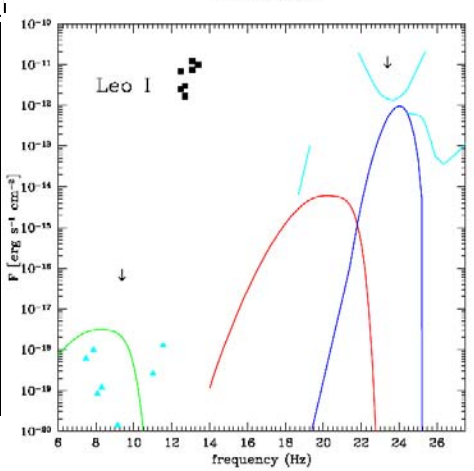
$F_{2\text{-}38}$ < 4 mJy

F_{2keV} <

S=2 pho; bkg=3 pho

LeoI



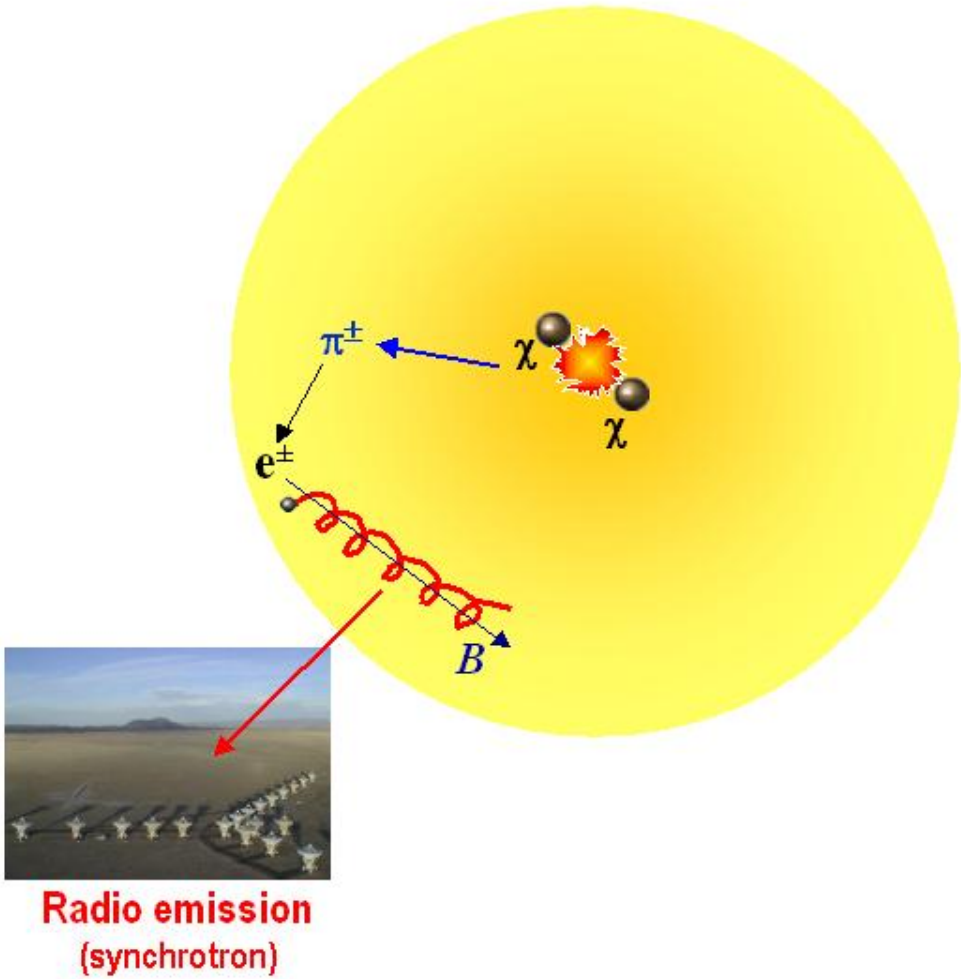


$F_{1.4}$ < 3.5 mJy

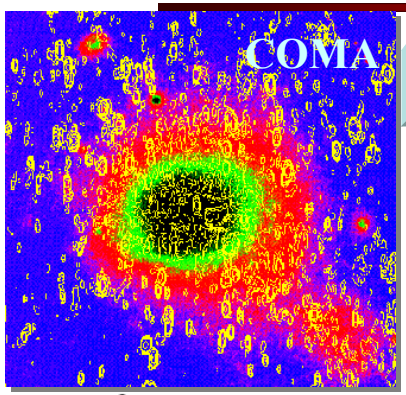
F_{2keV} <

S=2 pho; bkg=3 pho

Neutralino DM: radio emission



DM halos: Synchrotron radio emission

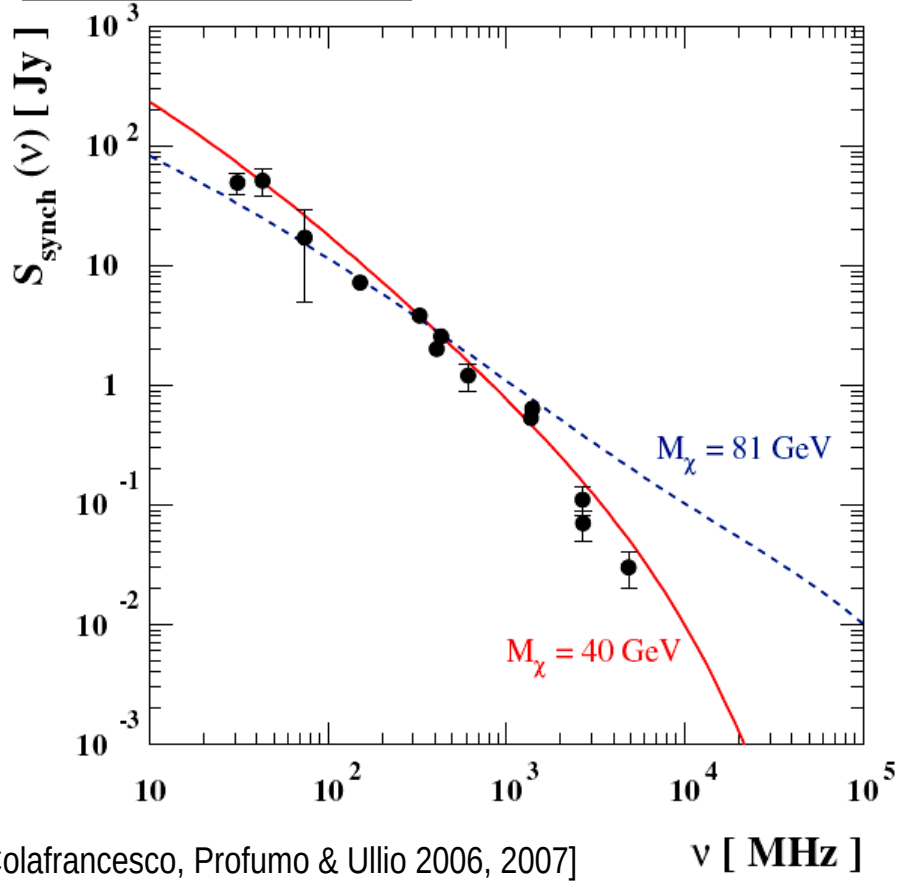


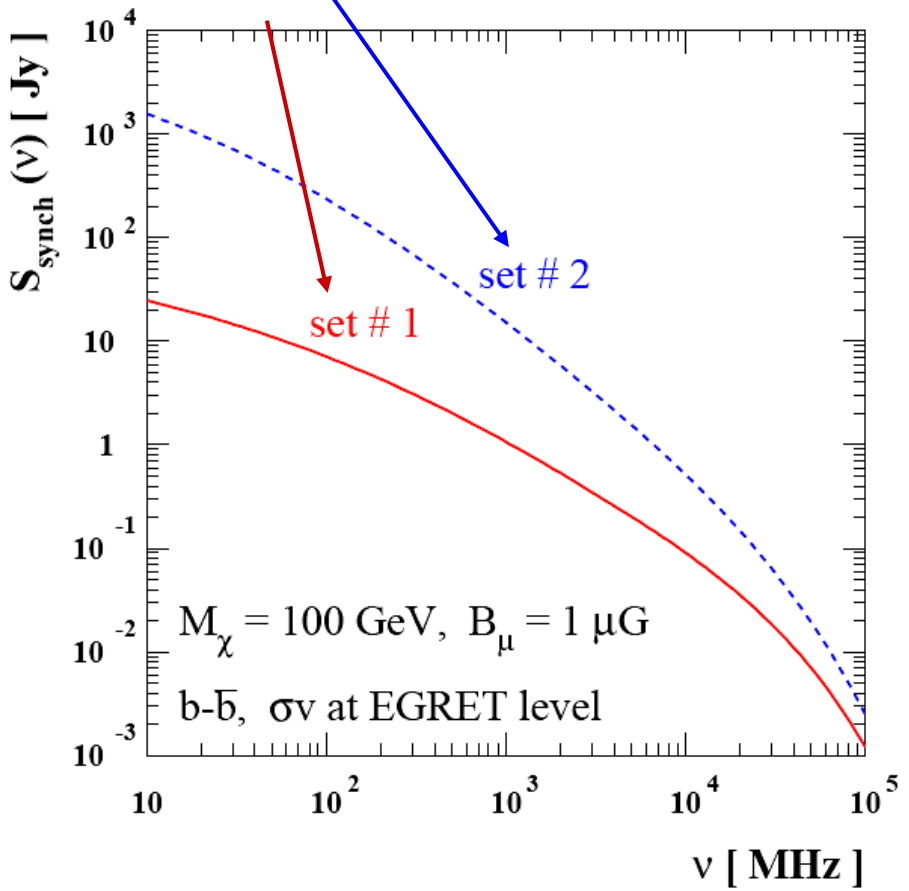
Galaxy clusters

Diffusion irrelevant

Dwarf galaxies

Diffusion dominant



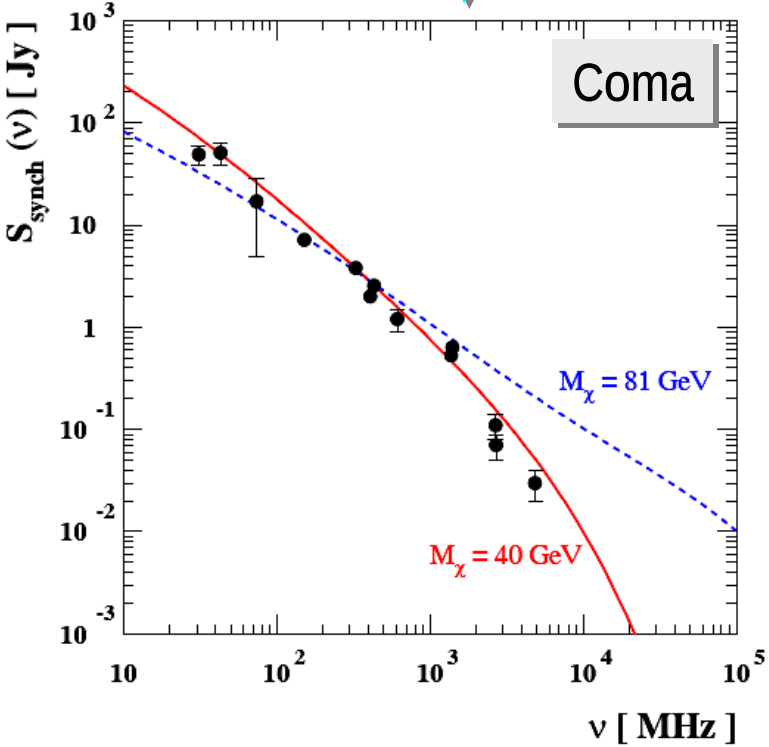


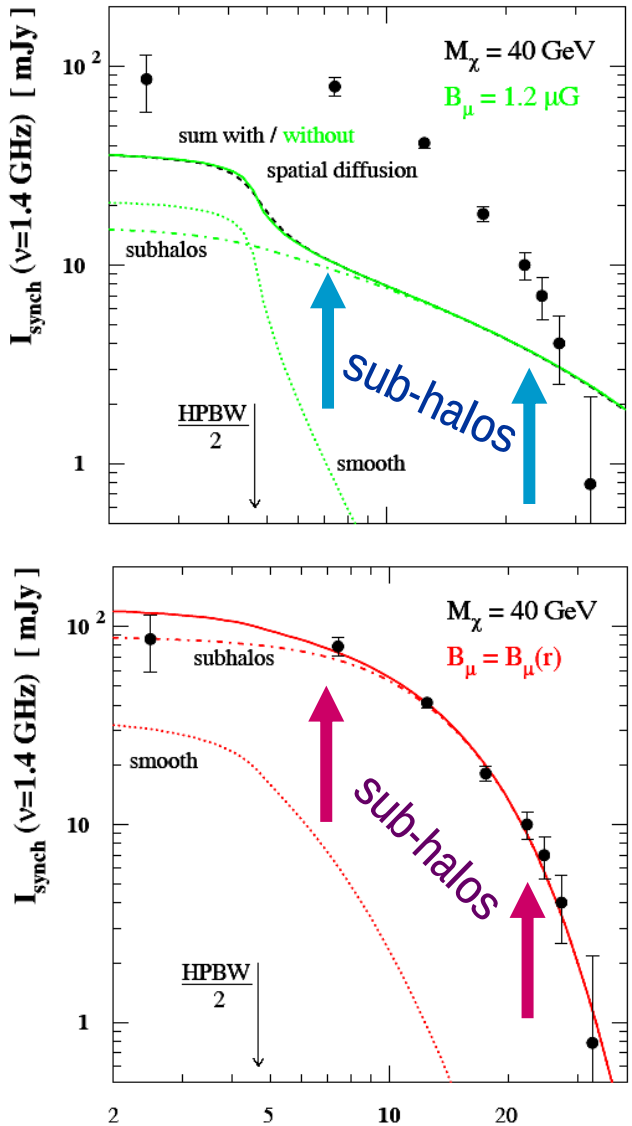
[Colafrancesco, Profumo & Ullio 2006, 2007]

Clusters of galaxies: χ properties

Radio halo

- brightness distribution (@ 1.4 GHz)
- integrated spectrum (30 MHz-5 GHz)





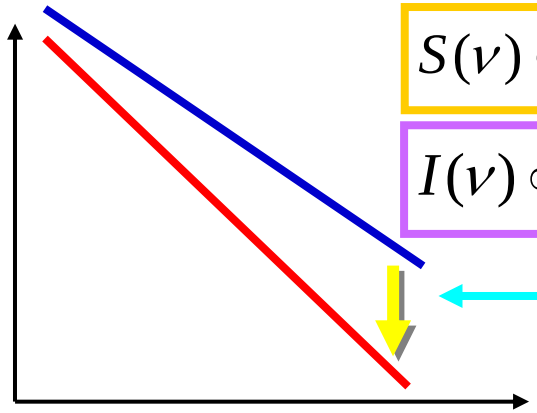
[Colafrancesco, Profumo & Ullio 2006]

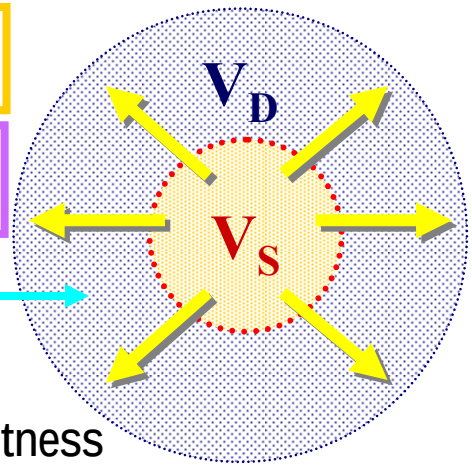
Dwarf galaxies: avoiding the B-trap

$$S(\nu) \propto B \otimes D_e \otimes n_e^2(E_e, \nu, r)\langle\sigma v\rangle$$

$$I(\nu) \propto B \otimes D_e \otimes n_e^2(E_e, \nu, r)\langle\sigma v\rangle$$

$$D_e = D_0 (E_e / B)^{\gamma}$$

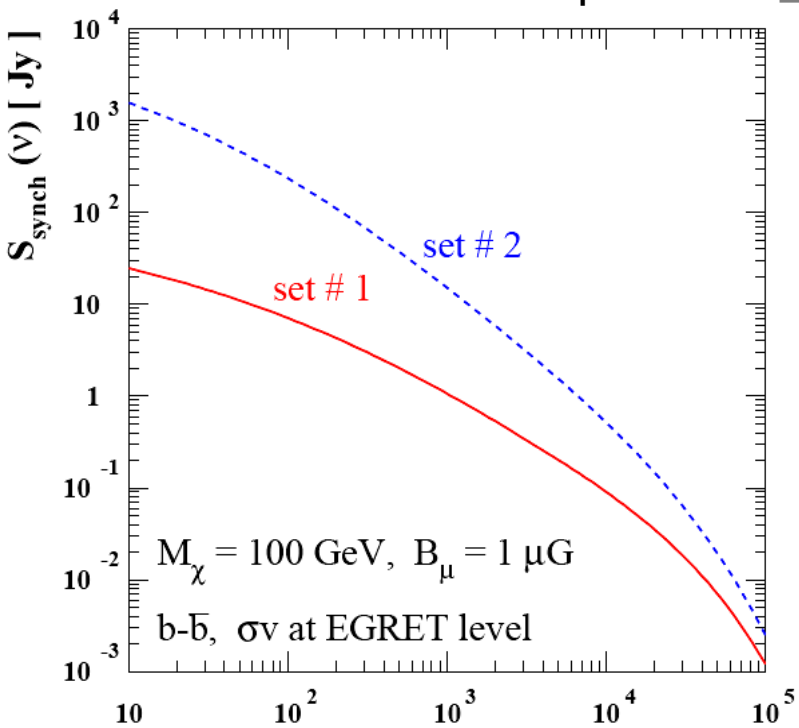


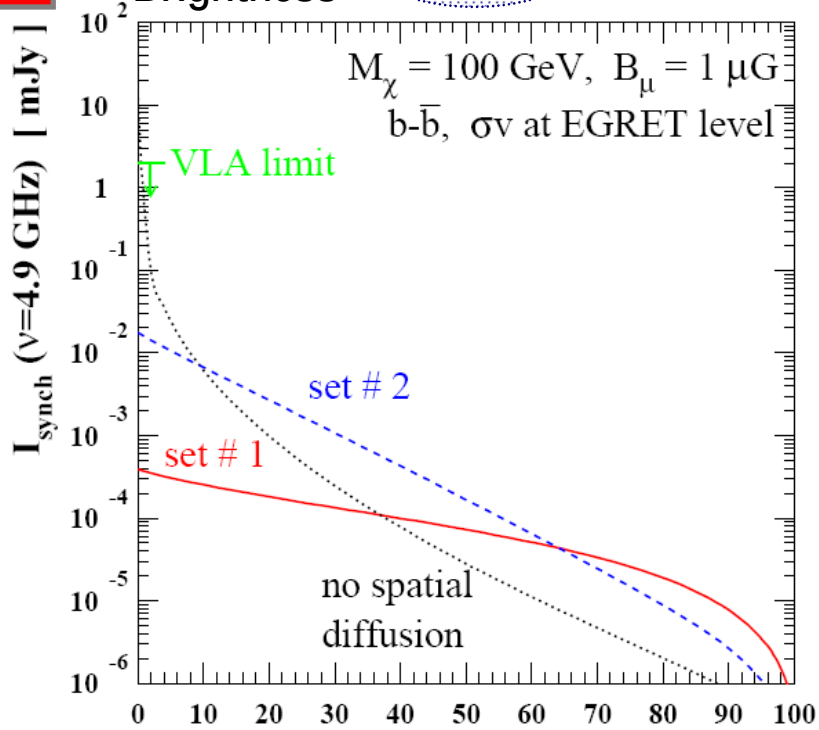


Spectrum

B

Brightness

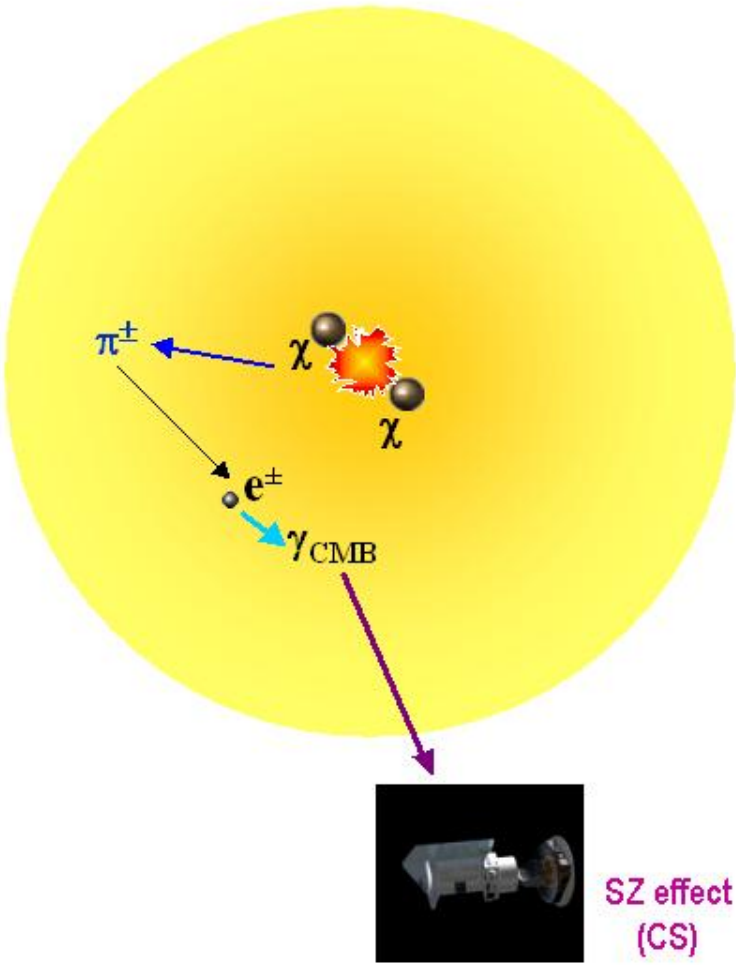




χ

[Colafrancesco 2007, Colafrancesco & Pieri 2007]

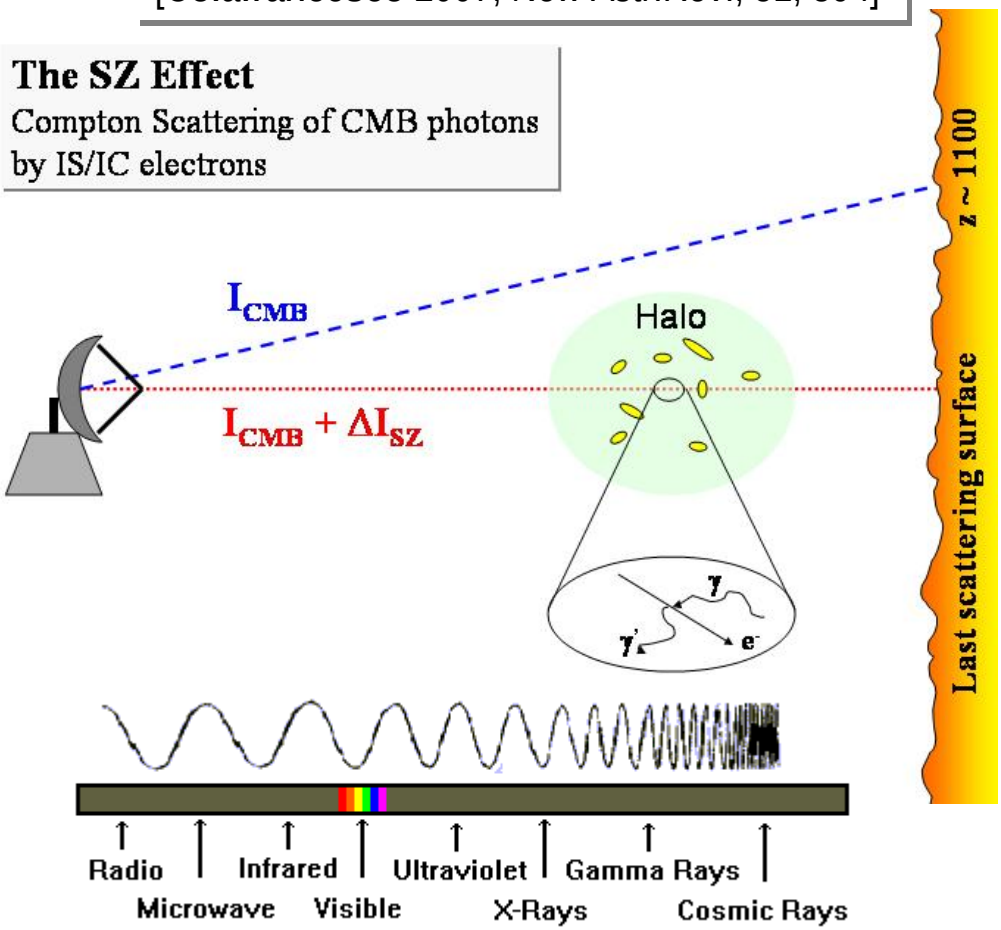
Neutralino DM: ICS of CMB (SZE)

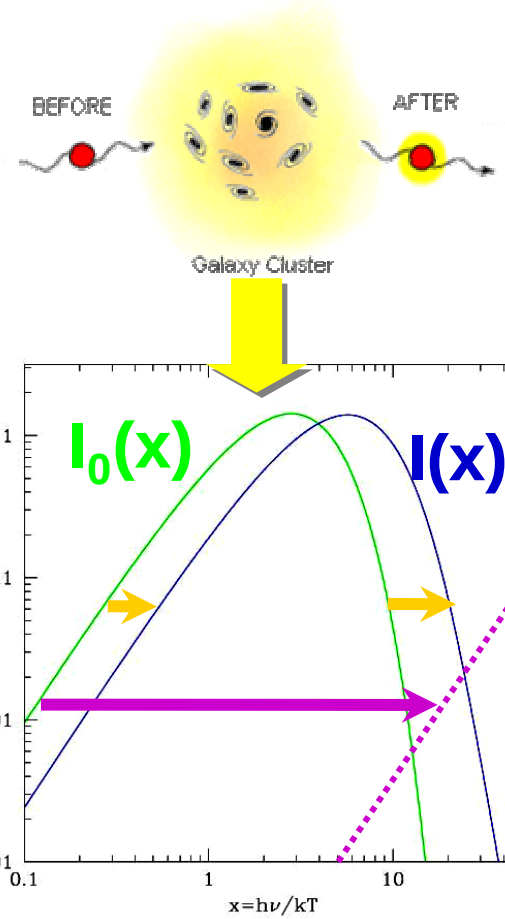


SZE: probe of leptonic atmospheres

[Colafrancesco 2007, New Astr.Rev., 51, 394]

The SZ Effect
Compton Scattering of CMB photons by IS/IC electrons





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 & 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

$$P_{rel} = n_e \int_0^\infty dp f_e(p) \frac{1}{3} pv(p) m_e c$$

Spectral shape

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

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

Redistribution function

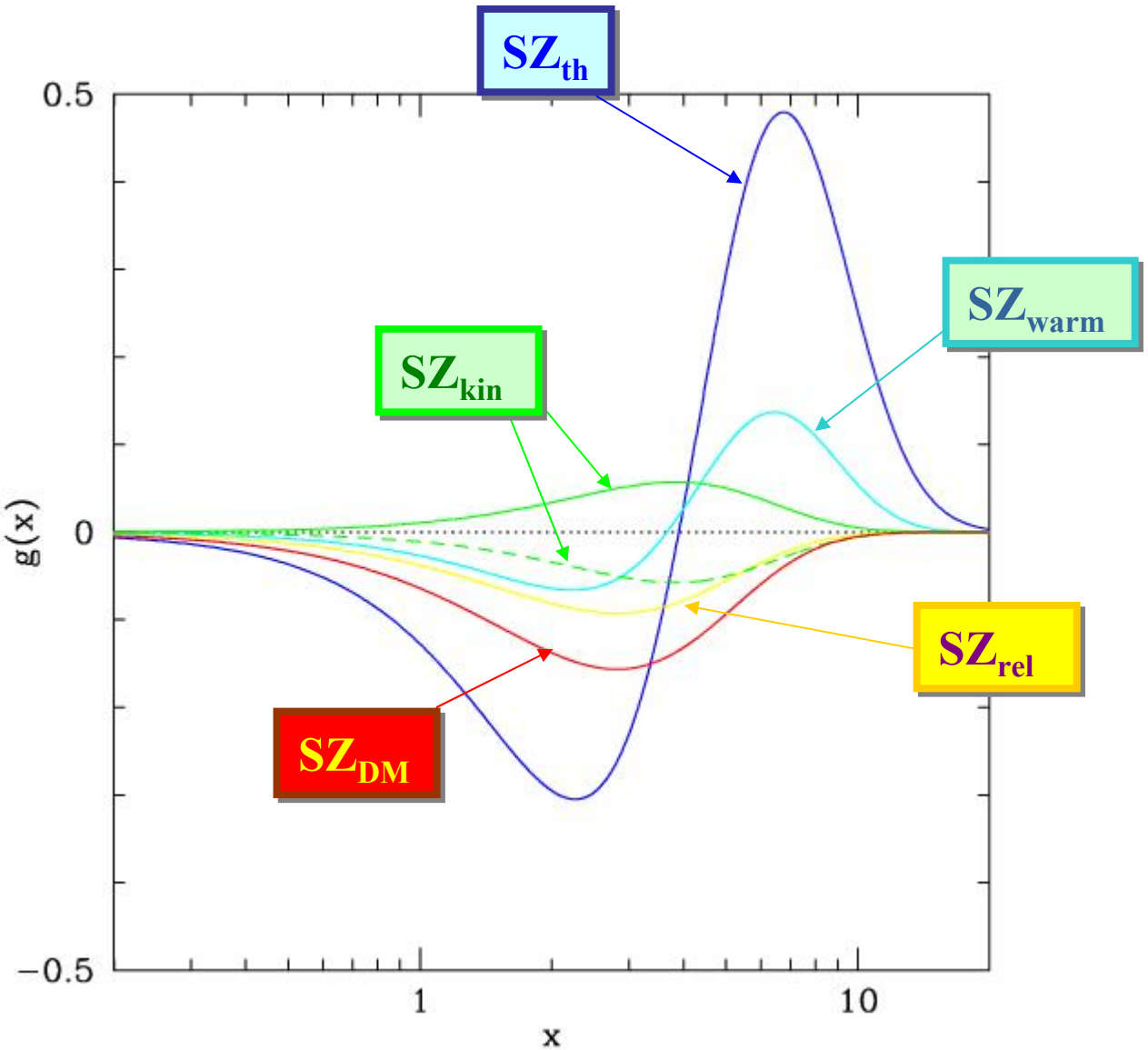
$$P(s) = \int_0^\infty dp f_e(p) P_s(s;p)$$

SZE in DM halos

[Colafrancesco 2007, New Astr.Rev., 51, 394]

A structure with:

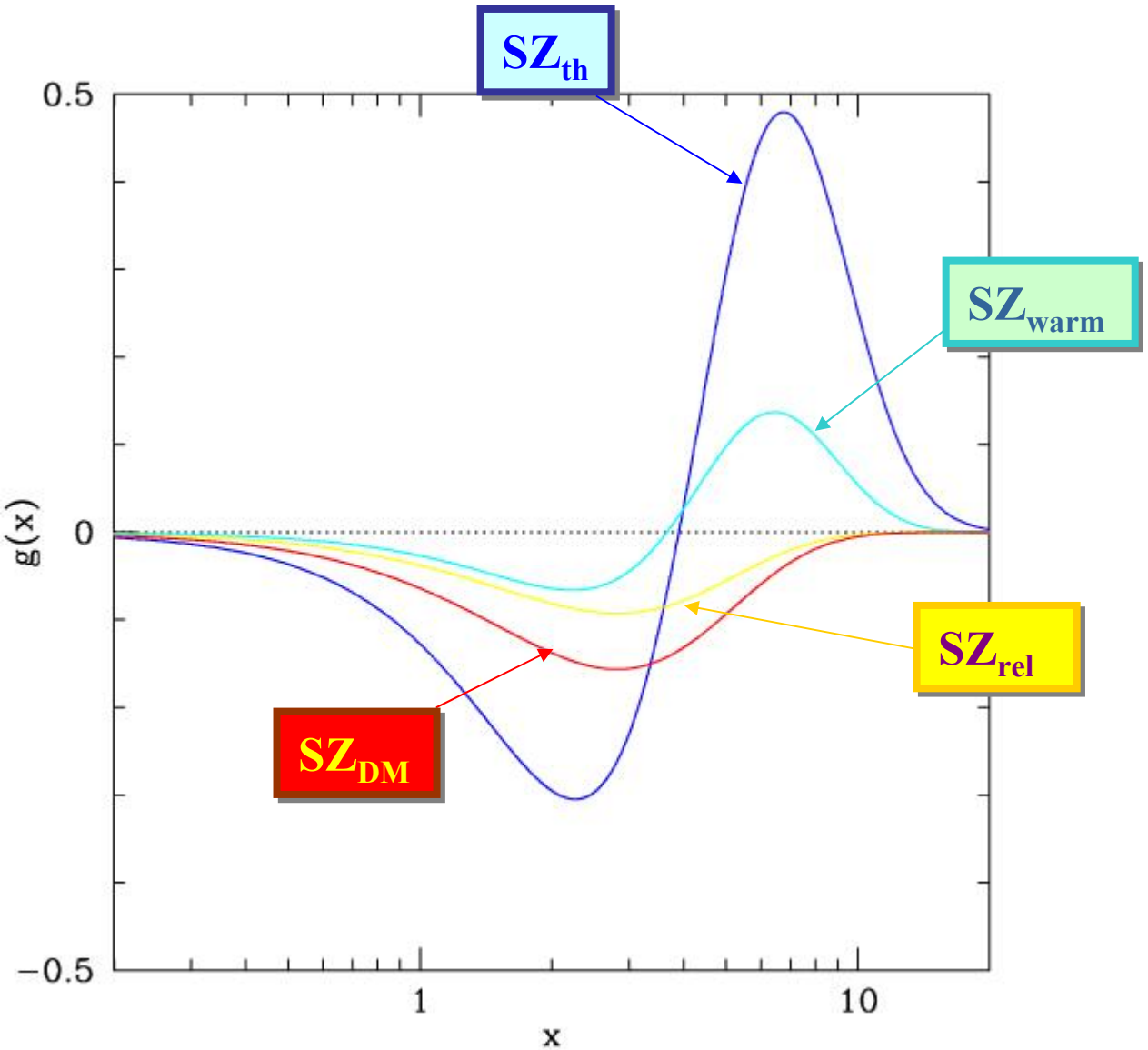
- **Hot gas**
- **Warm gas**
- **Rel. Plasma**
- **DM**
- **$V_r > 0$**



SZE in DM halos

A structure with:

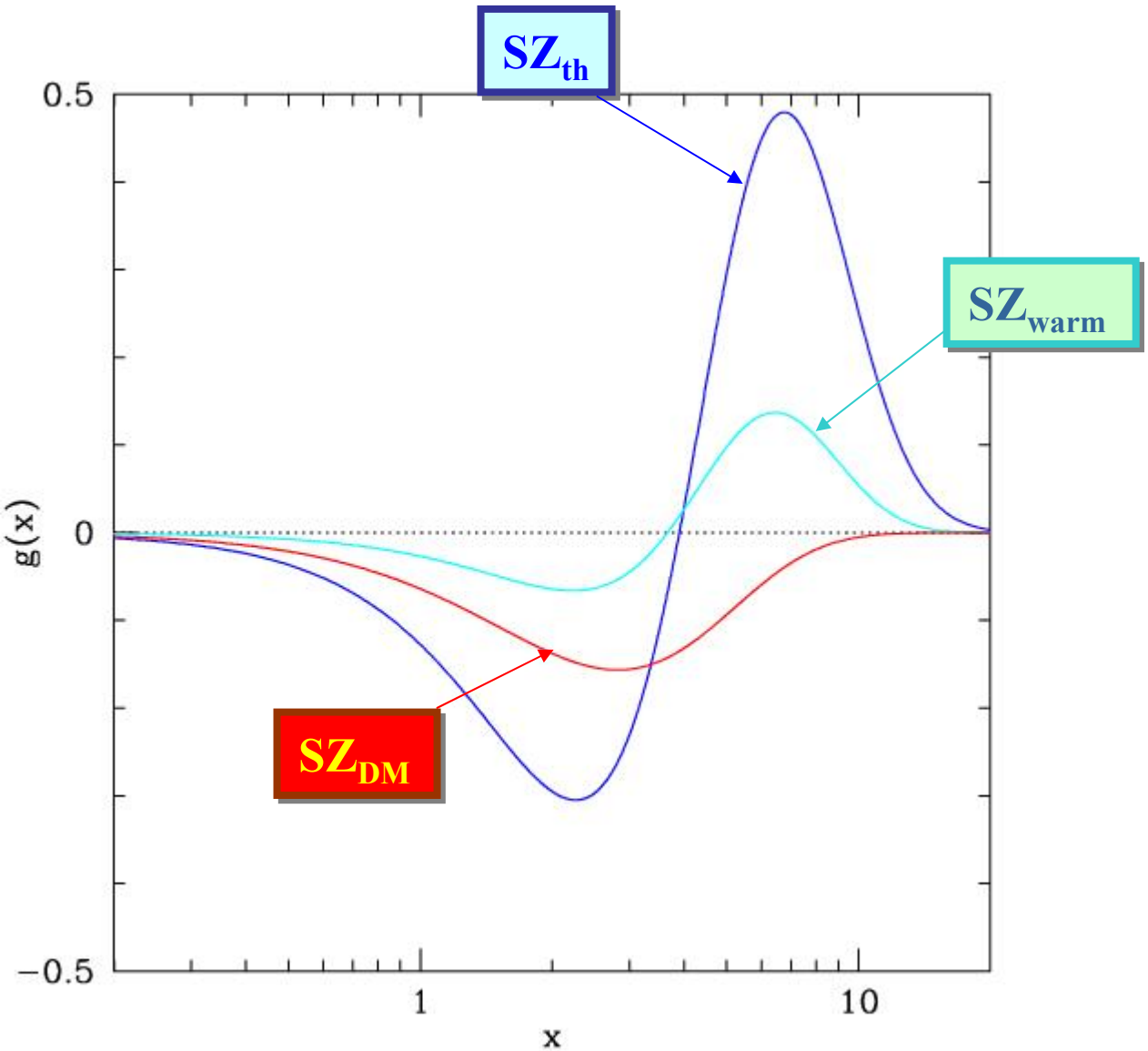
- **Hot gas**
- **Warm gas**
- **Rel. Plasma**
- **DM**
- **($V_r \approx 0$)**



SZE in DM halos

A structure with:

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



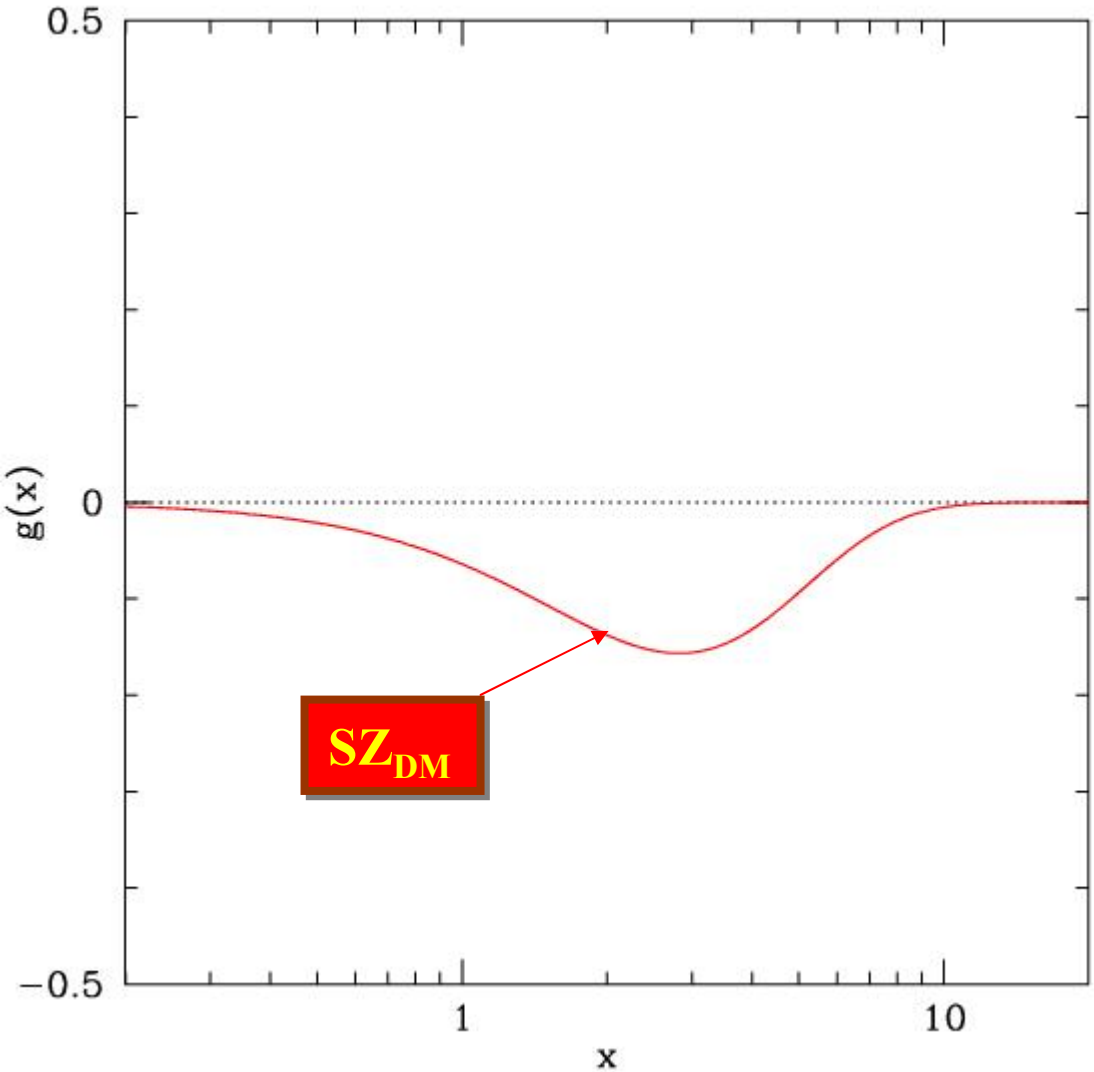
SZE in DM halos

[Colafrancesco 2004, A&A, 422, L23]

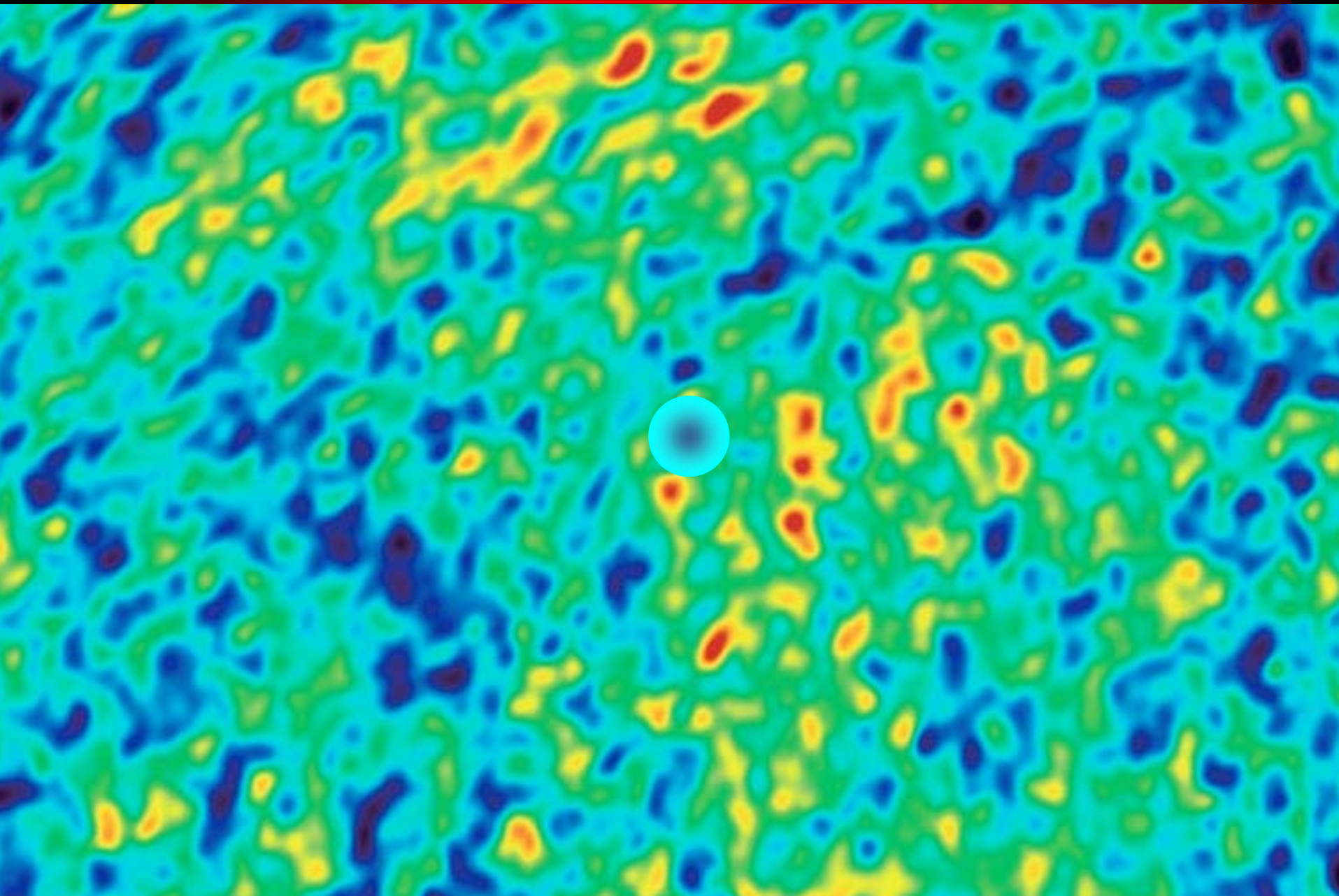
A structure with:

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

Pure DM halo



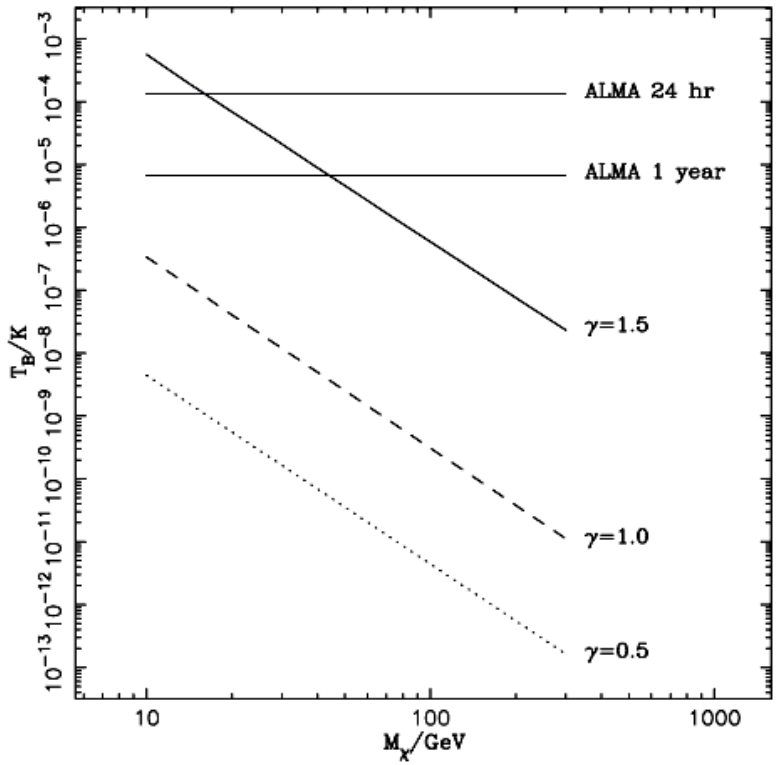
Draco dSph.



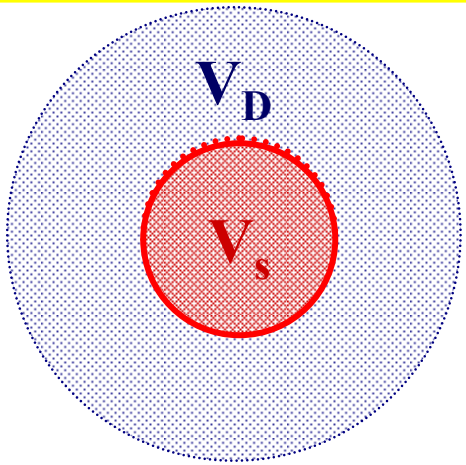
SZ_{DM} in Draco

Diffusion effects

$$n_e(E,r) = \left[Q_e(E,r)\tau_{loss}\right] \cdot \frac{V_{source}}{V_{source} + V_{diffusion}} \cdot \frac{\tau_D}{\tau_D + \tau_{loss}}$$

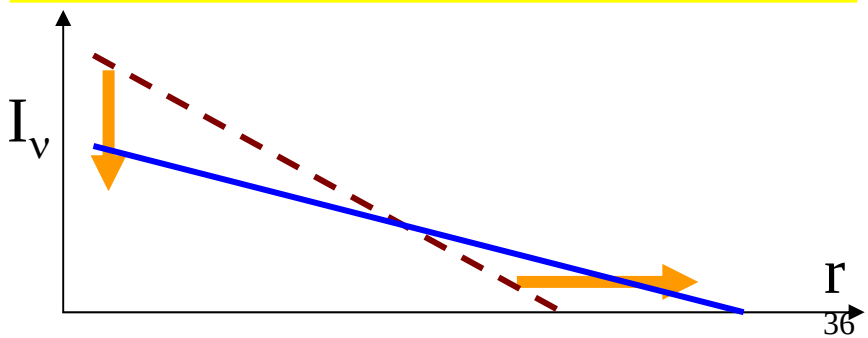


[Culverhouse, Evans & Colafrancesco 2006]



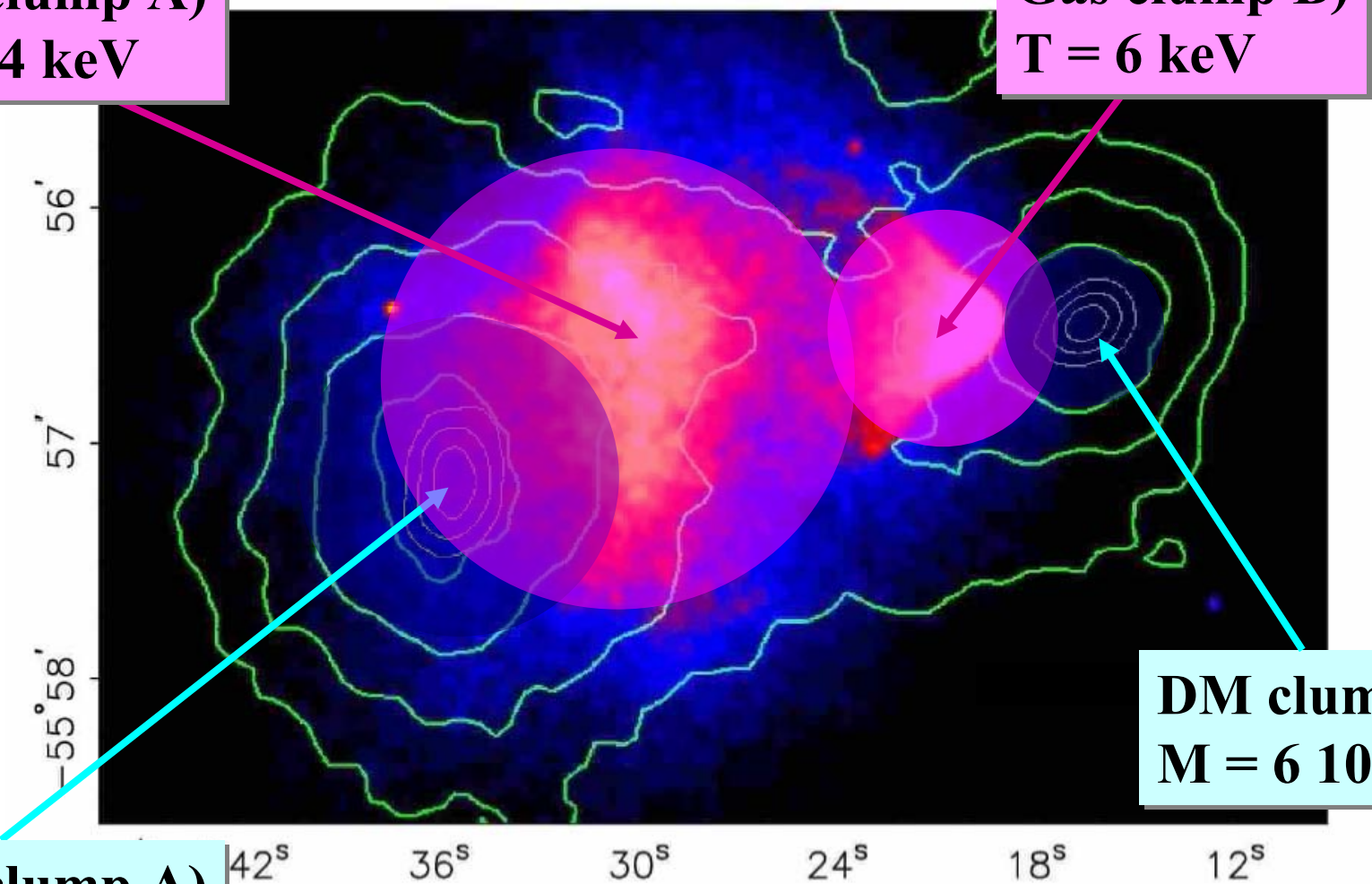
$\tau_{loss} \gg \tau_D$

$$n_e(E,r) = \left[Q_e(E,r)\tau_{loss}\right] \cdot \frac{V_{source}}{V_{diffusion}} \cdot \frac{\tau_D}{\tau_{loss}}$$

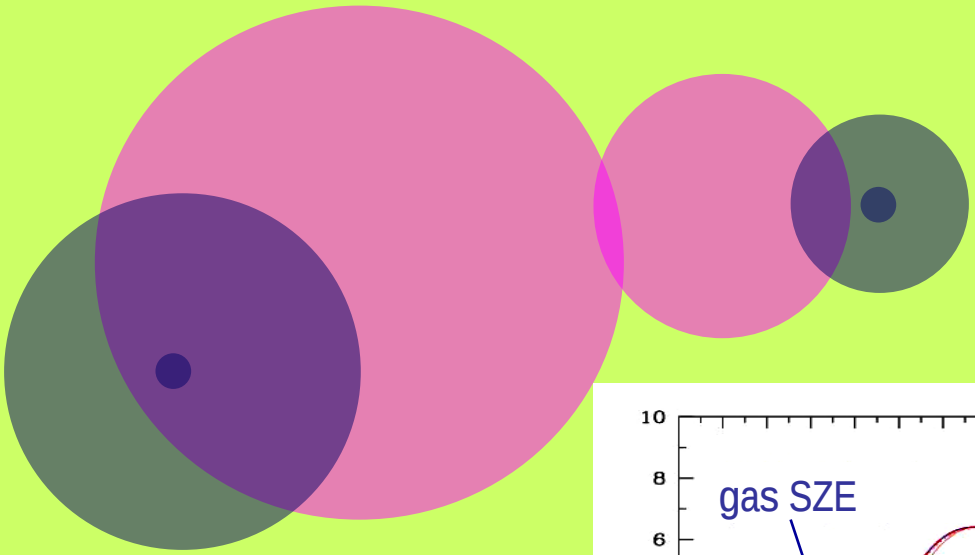


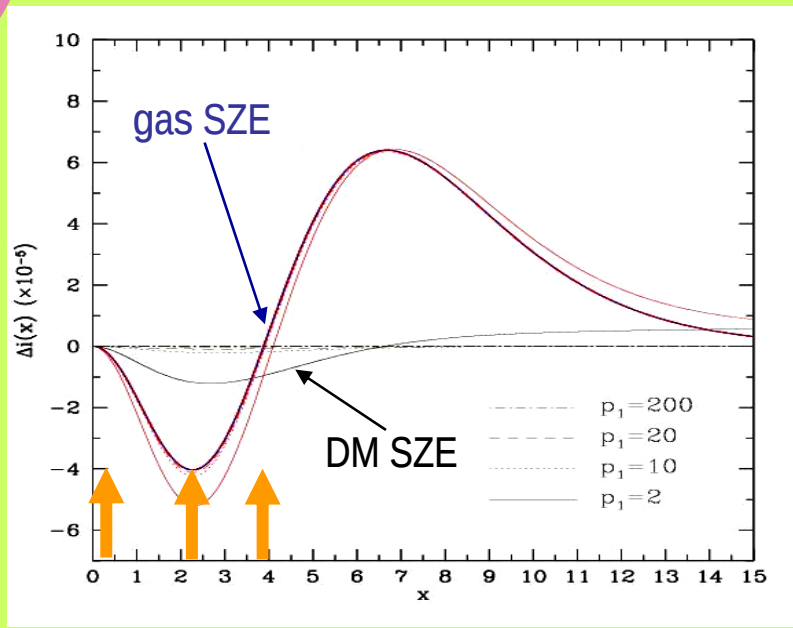
[Colafrancesco, Profumo & Ullio 2007]

The cluster 1ES0657-556



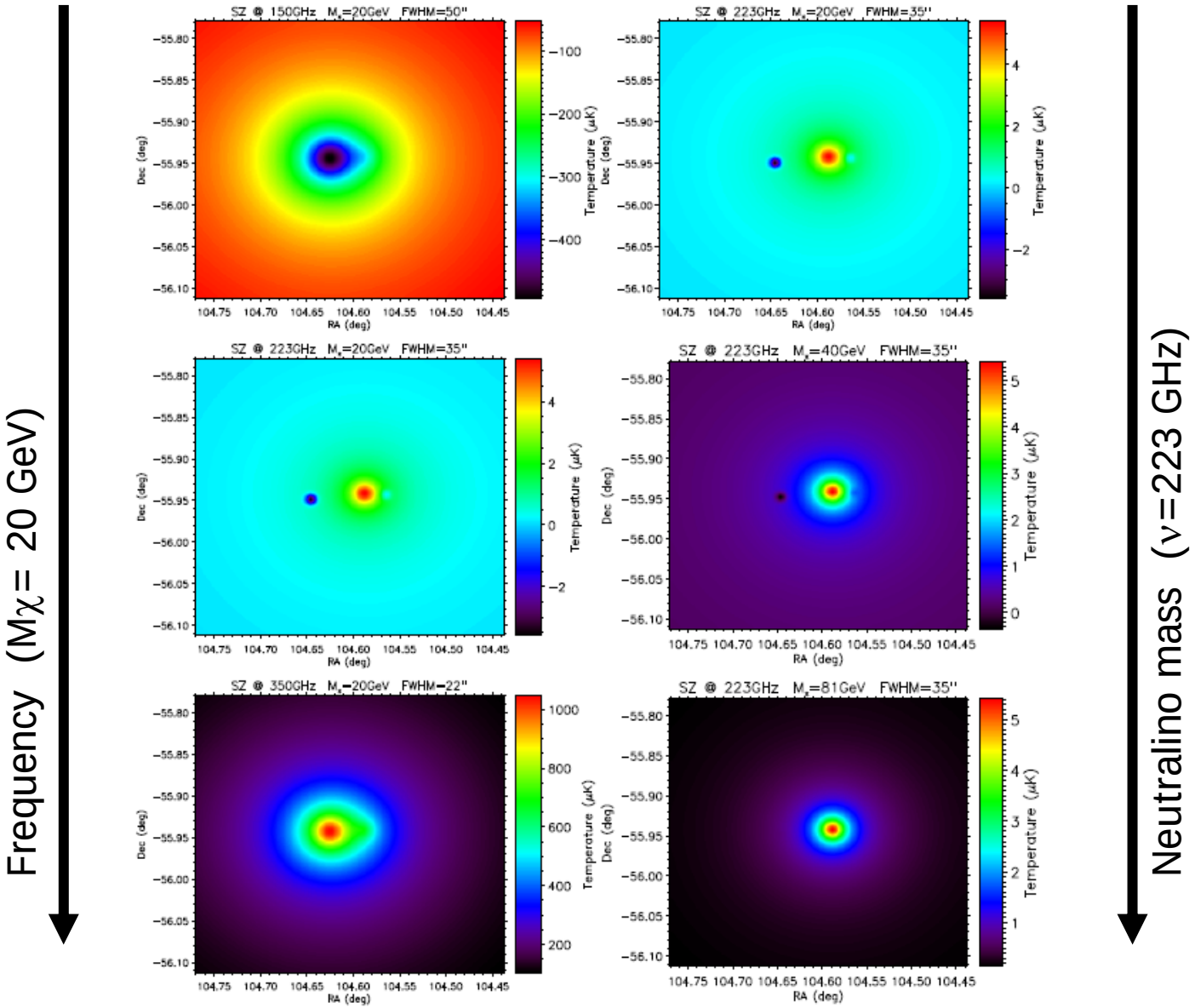
SZE in 1ES0657-556: avoiding the θ-trap





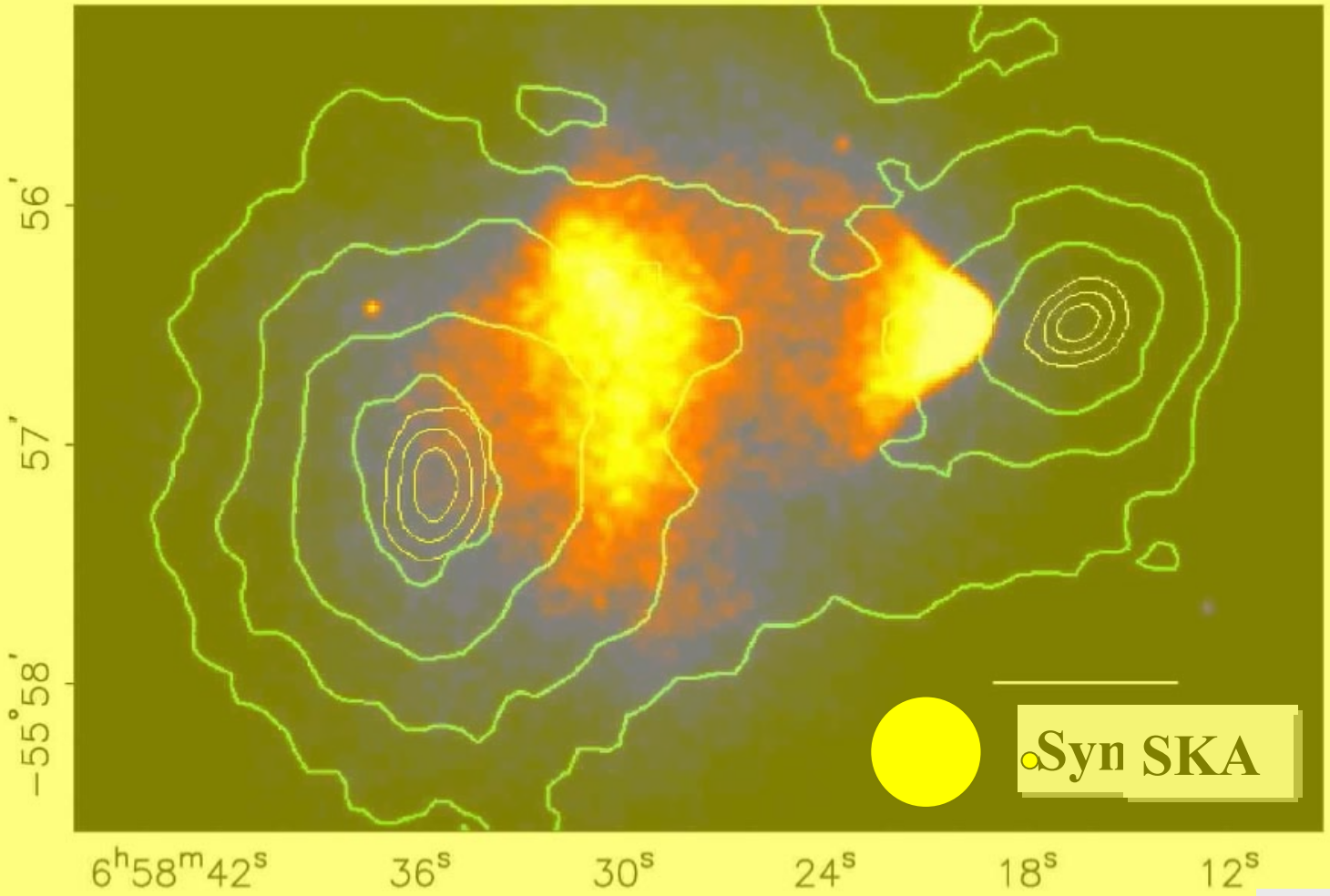
Isolating SZ_{DM} at ~223 GHz

[Colafrancesco et al. 2007]



1ES0657-556 @ various frequencies

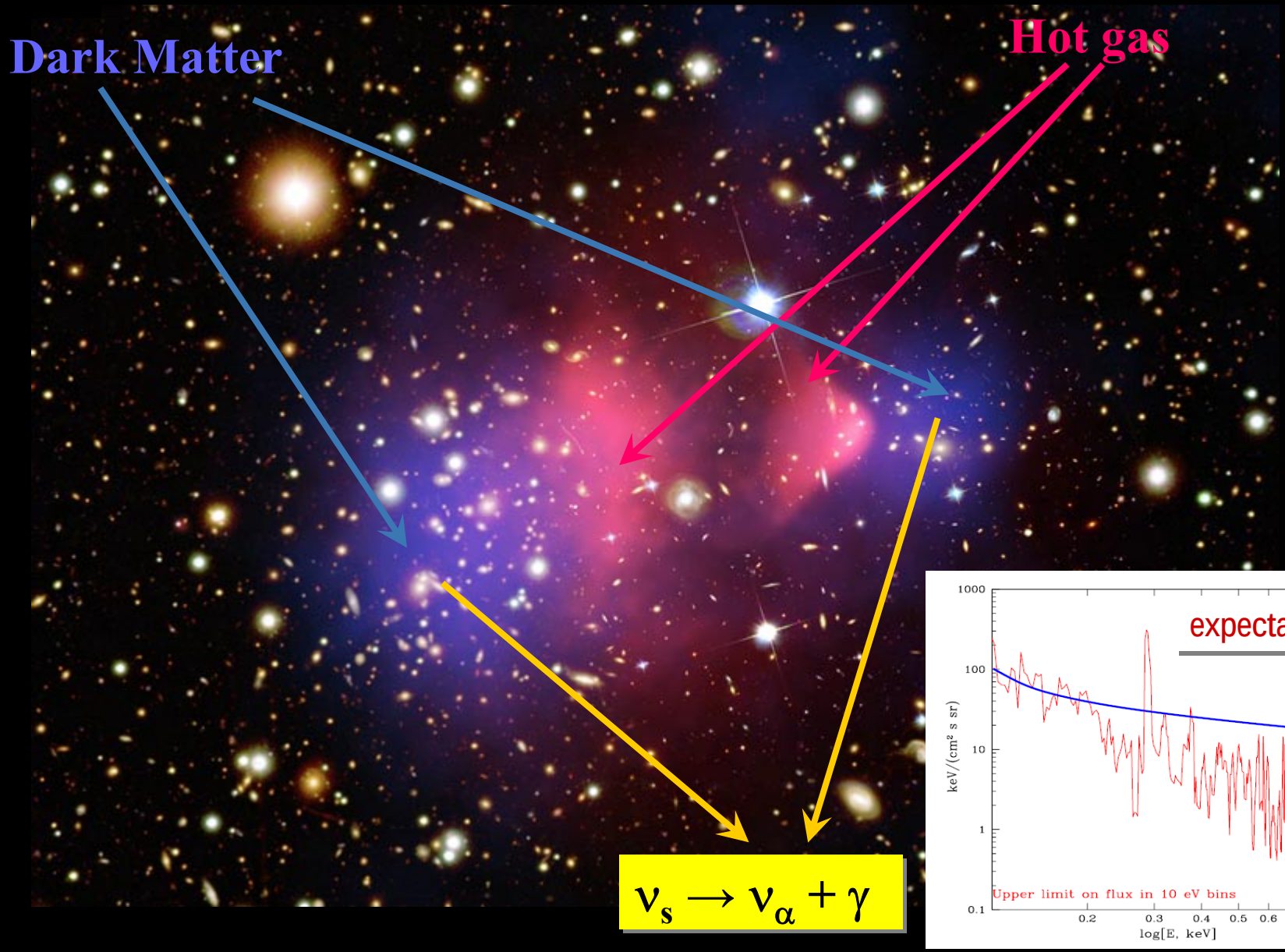
[Colafrancesco & Ullio 2006]



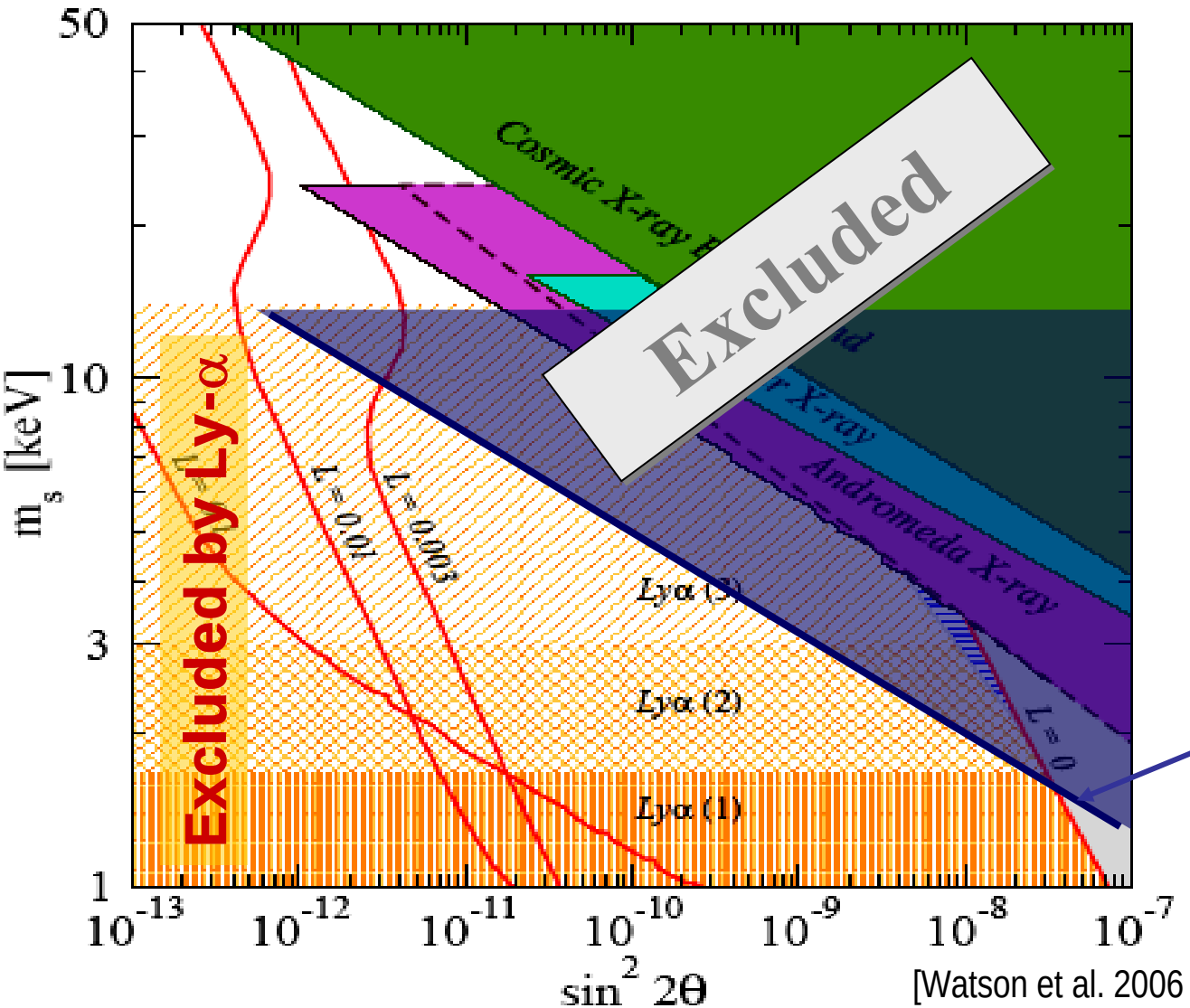
GLAST

Sterile neutrino DM

Sterile neutrino DM: line



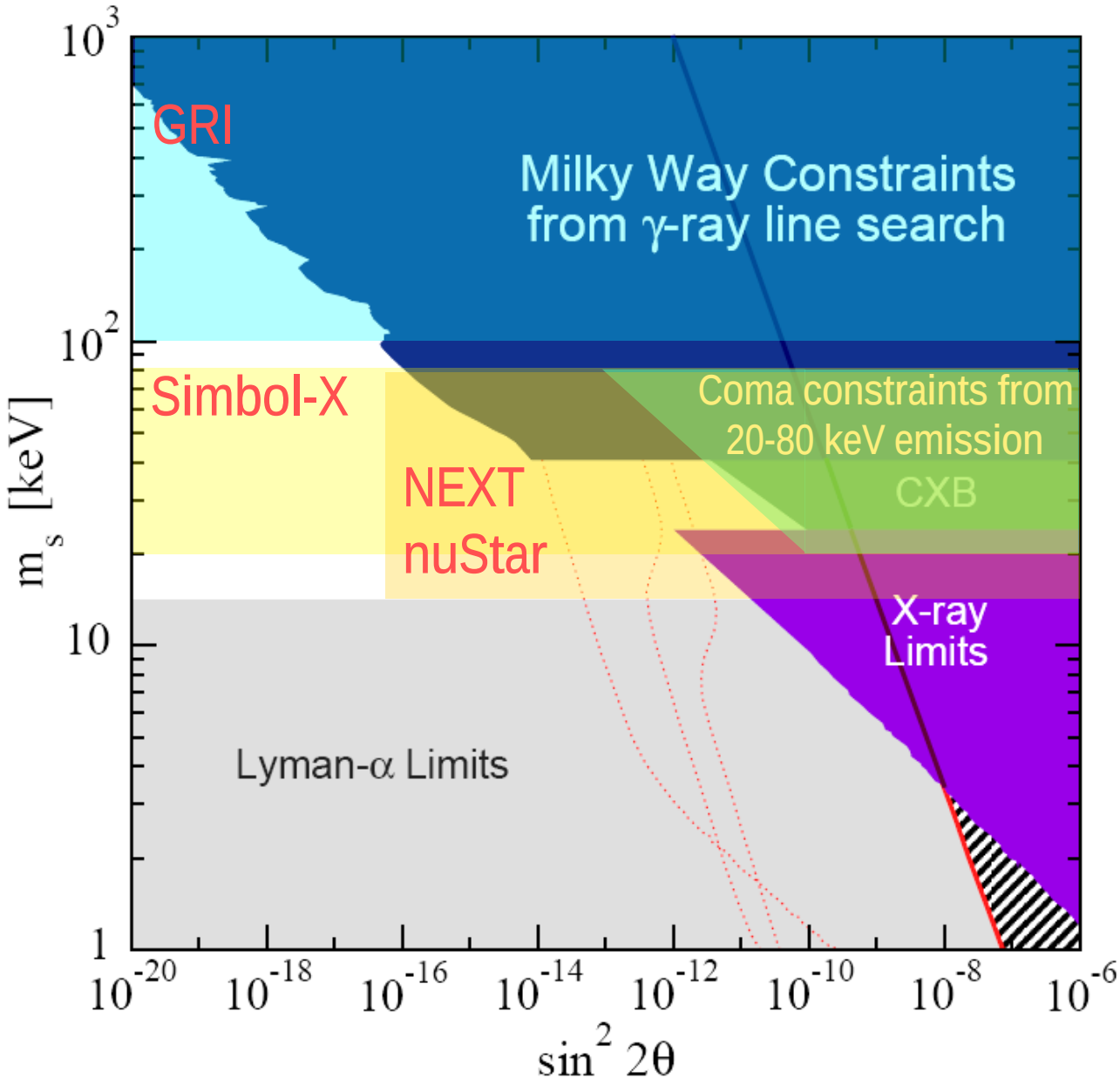
Sterile neutrinos: limits



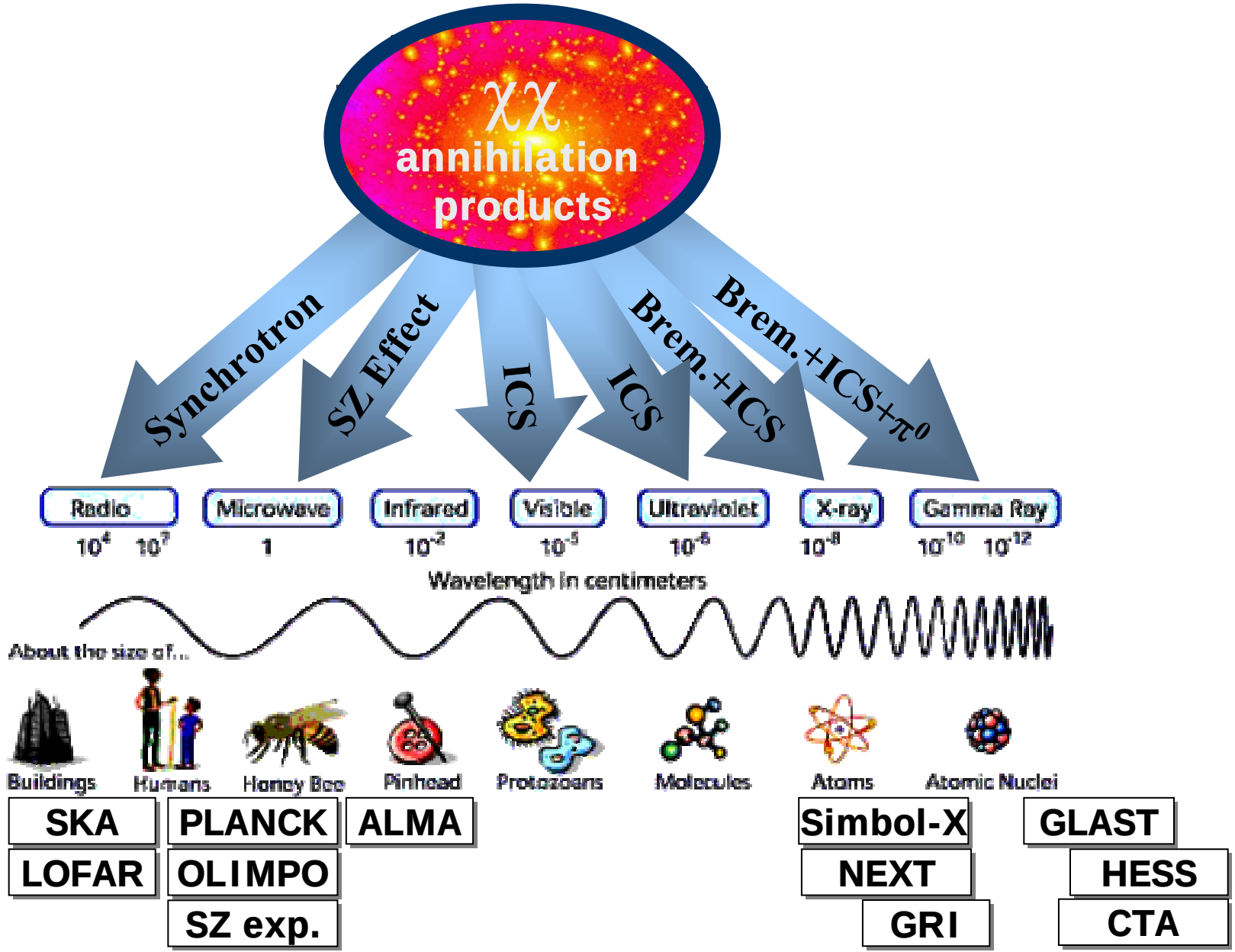
Bullet cluster

[Watson et al. 2006 (astro-ph/0605424)]
[Colafrancesco 2007]

[Yuksel et al. 2007]
[Colafrancesco 2007]



DM search thru the e.m. spectrum



THANKS

for your attention !