Radio Signal of Dark Matter

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Collaborators

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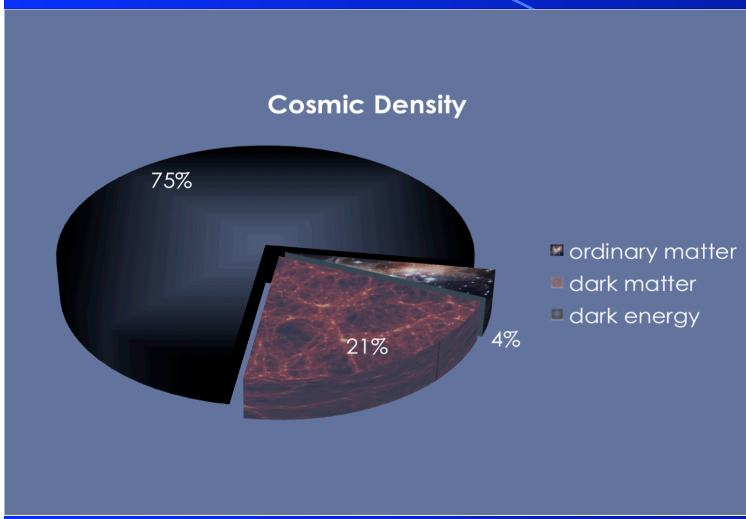
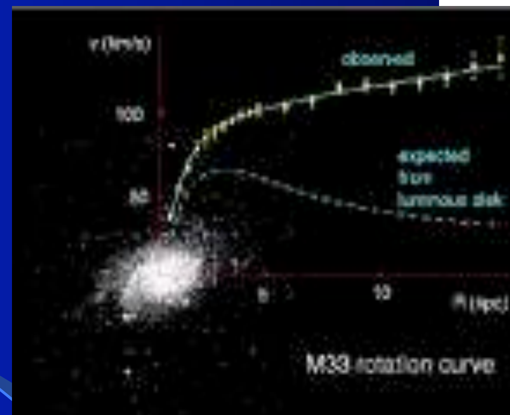
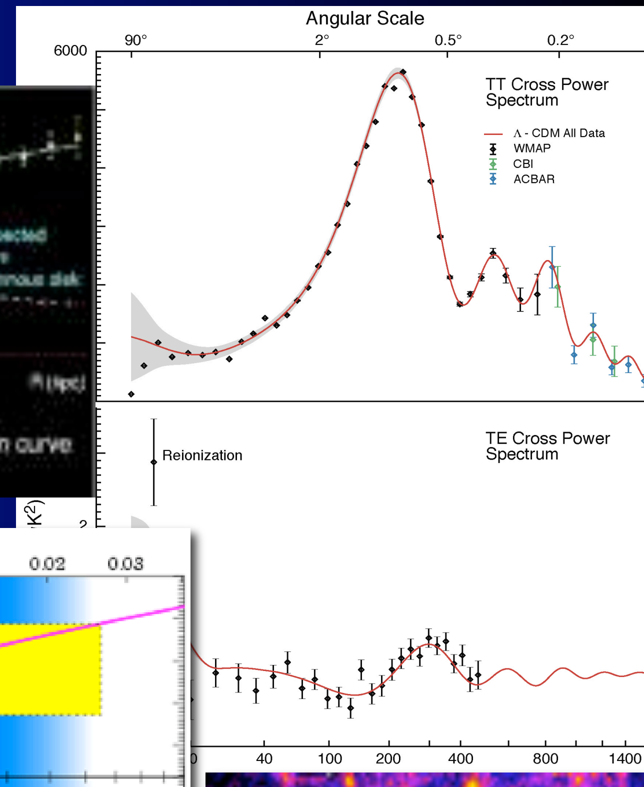
- Qiang Yuan (袁强）, Xiaojun Bi （毕效军） IHEP

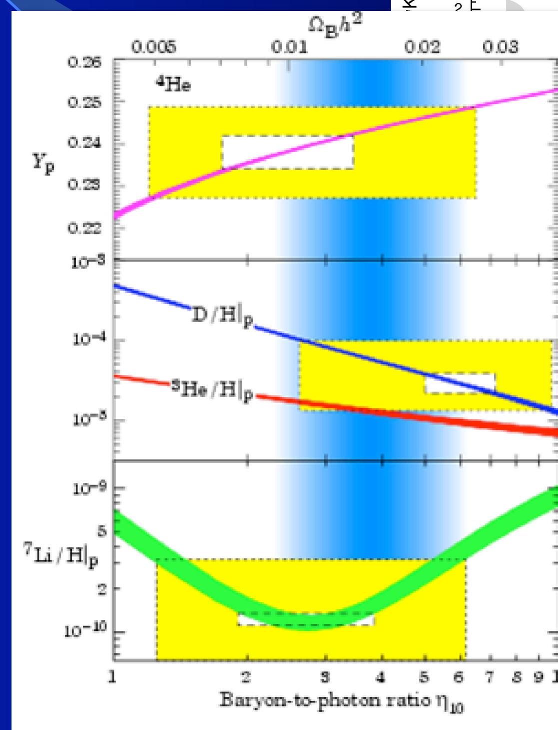
Introduction

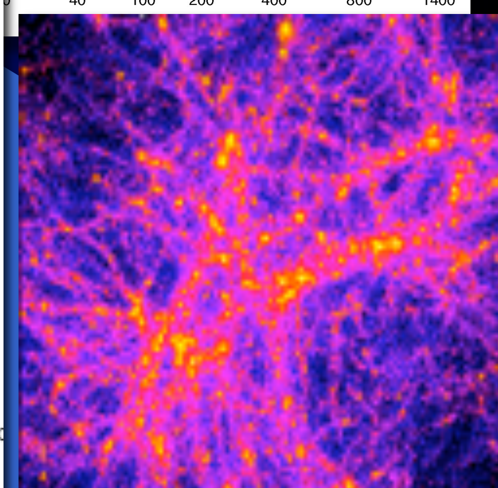
Dominant matter component :
non-baryonic matter









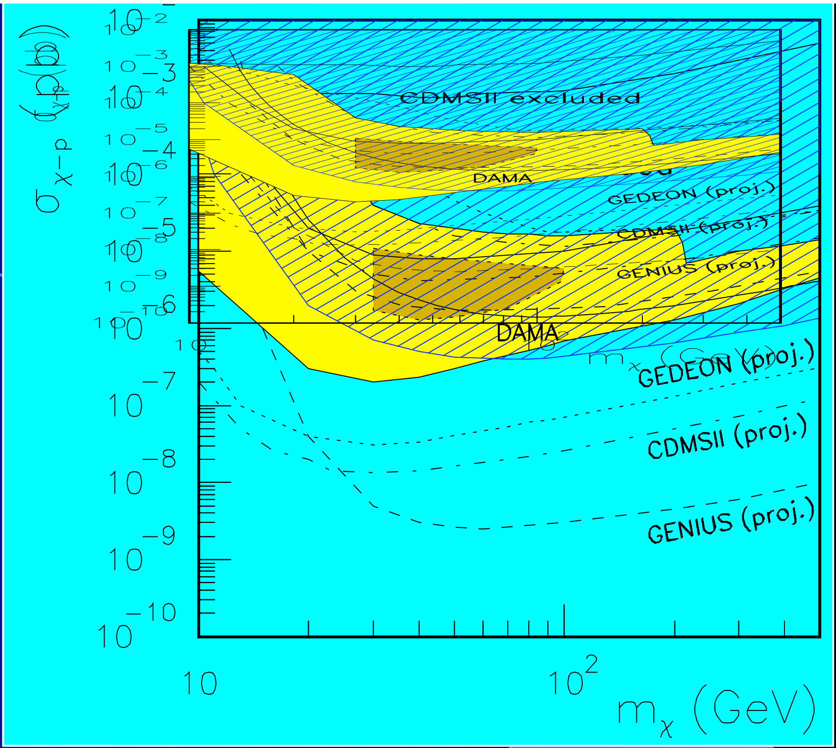


Evidence: Rotation Curves, CMB, BBN, LSS …(gravitational effects)

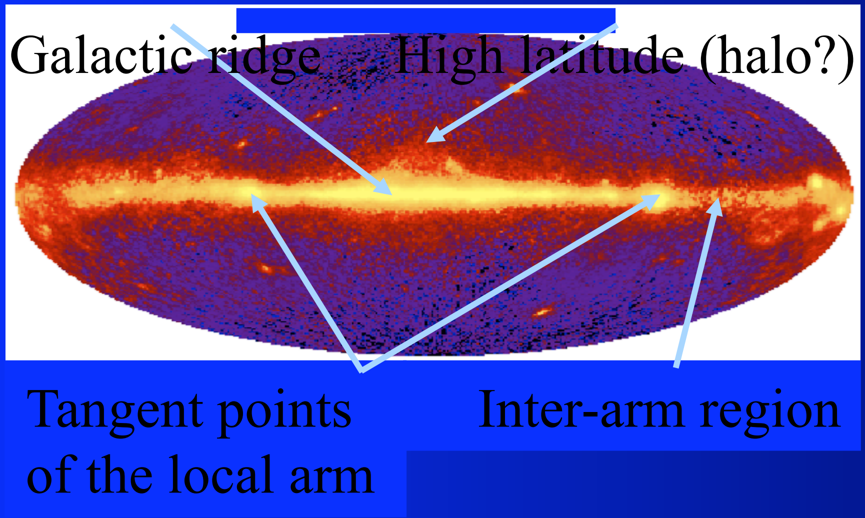
What's the particle nature?
—remain a puzzle

What is Dark Matter?

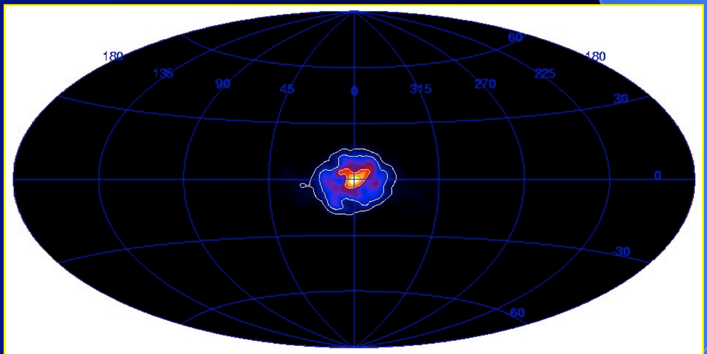
1. Colliders
2. Direct detection
3. Indirect detection



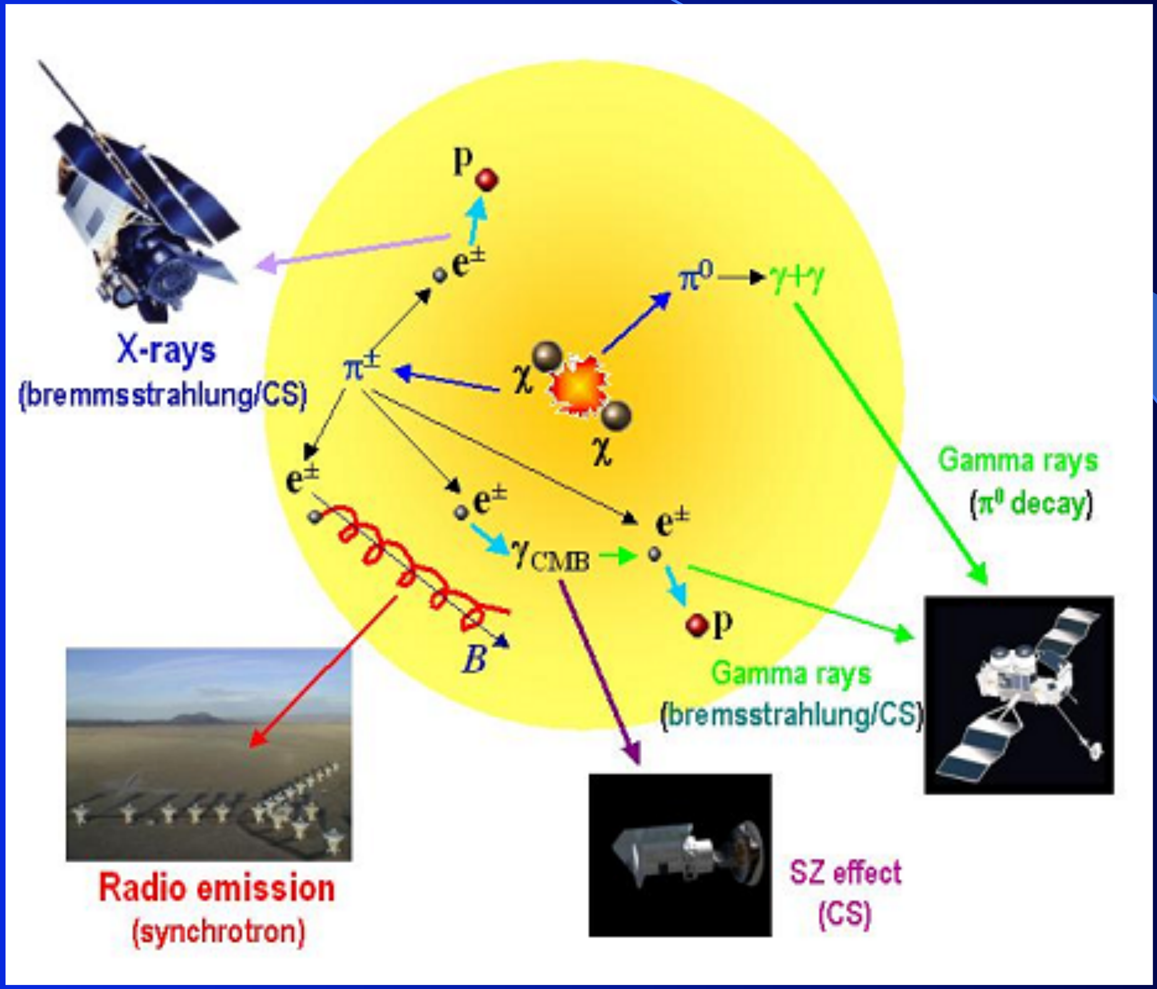
WIMP: Neutralino (10GeV-TeV)
Kaluza-Klein (TeV)



Light dark matter (MeV)



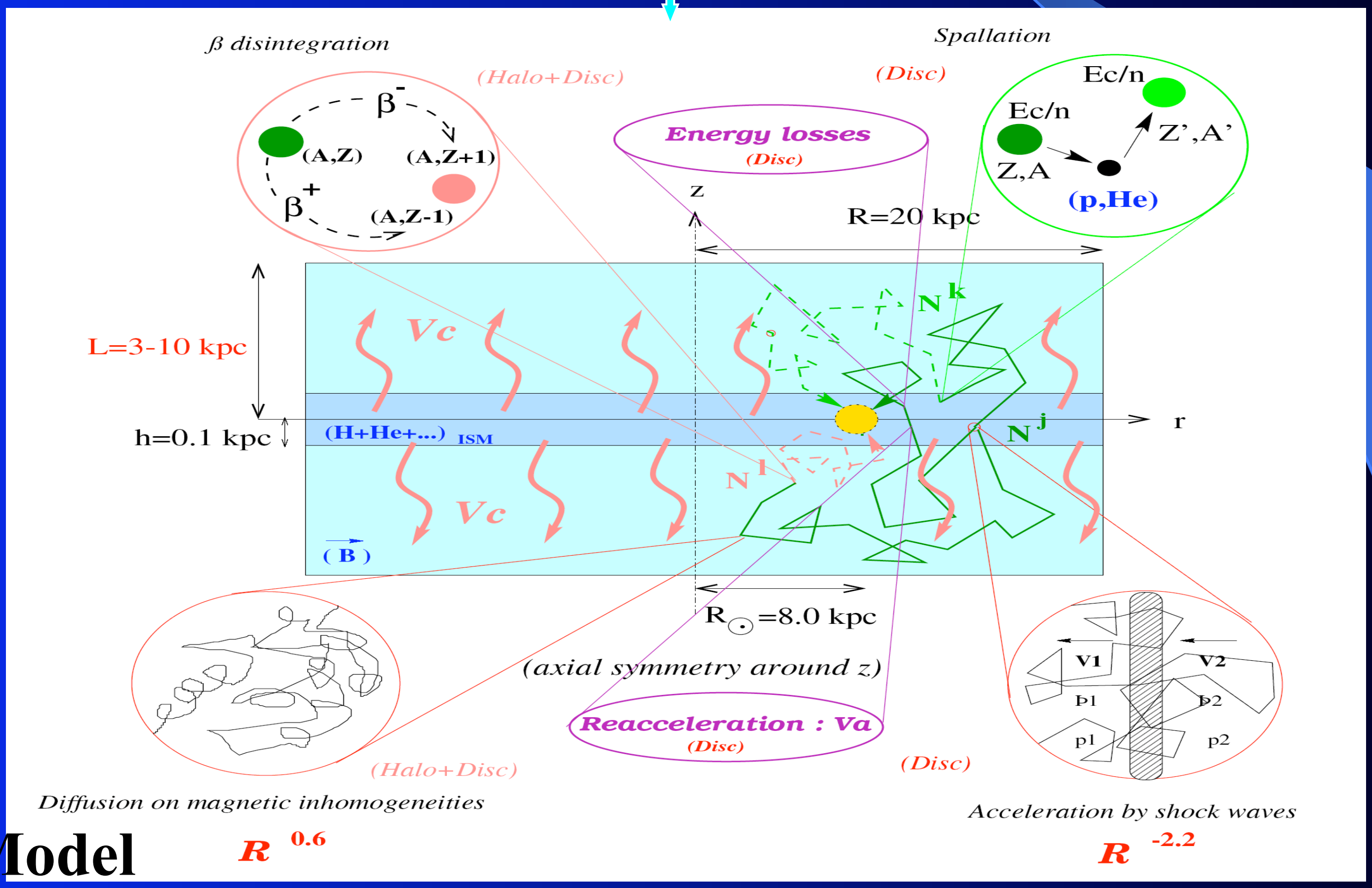
Products from DM annihilation



Colafrancesco, IoP/RAS Meeting 2007

Electrons and positrons detection

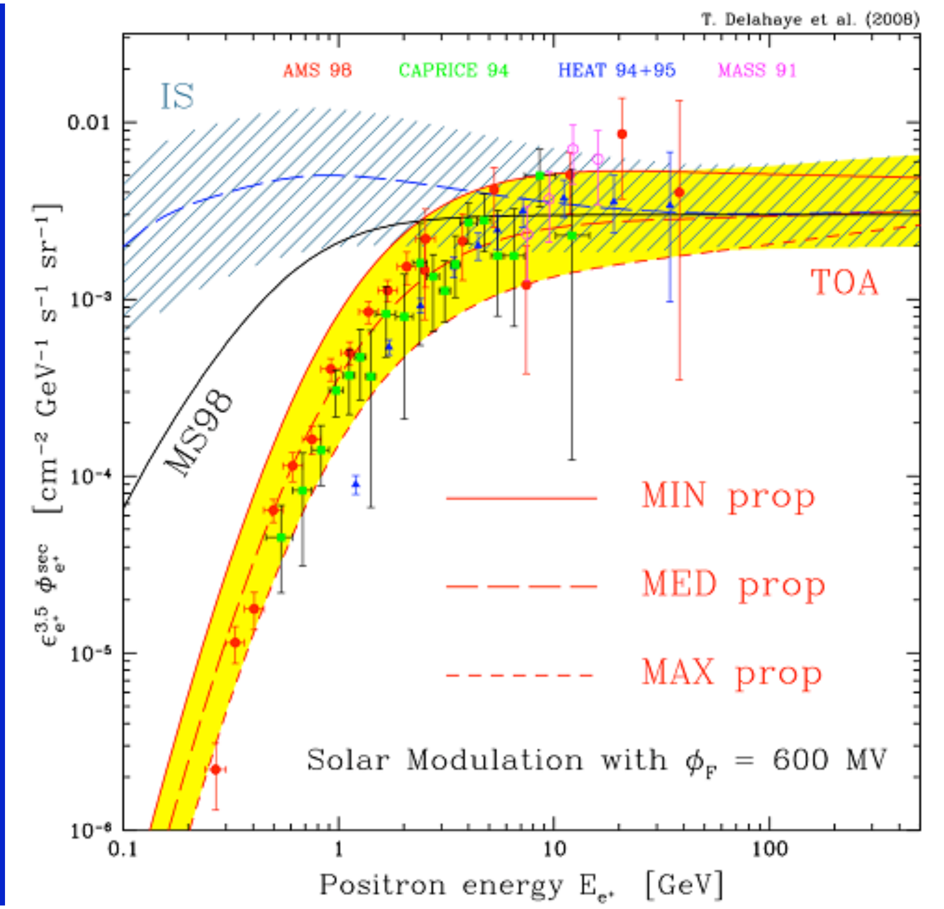
Nearby Sources (~1kpc) → propagation → Earth Detector



P. Salati
Glactic Model

Uncertainties of the diffusion model

Model	δ	K_0 [kpc^2/Myr]	L [kpc]	V_c [km/s]	V_a [km/s]
MIN	0.85	0.0016	1	13.5	22.4
MED	0.70	0.0112	4	12	52.9
MAX	0.46	0.0765	15	5	117.6



Possible Collaboration

Student: Wei Liu

French advisor: Pierre Salati (**LAPTH & Université de Savoie**)

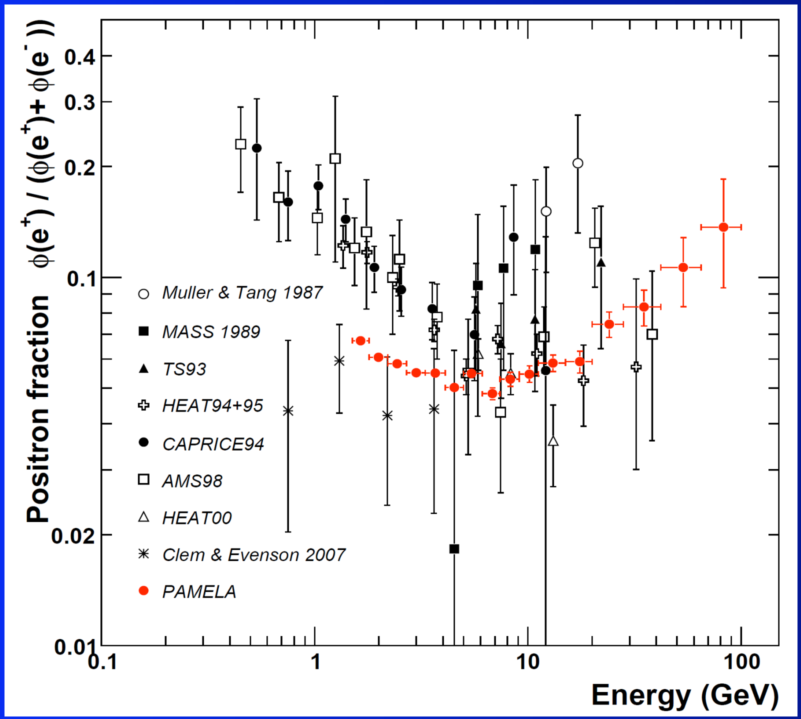
Chinese advisor: Xuelei Chen (National Astronomical Observatory of China)

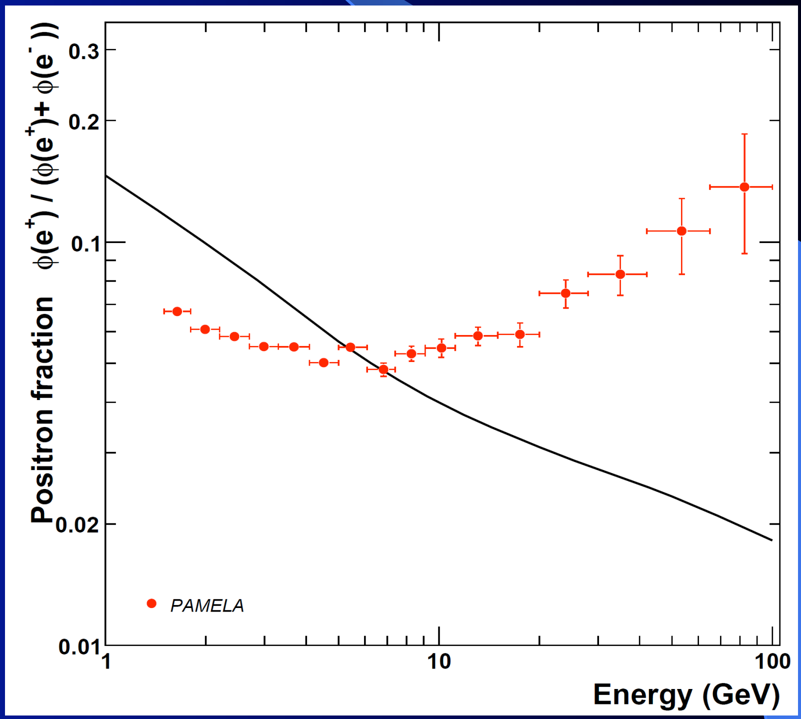
Duration: one year

We propose to carry out research on modeling the propagation of the cosmic ray particles, especially positrons and electrons, and use such model to investigate the signature of dark matter and other possible astrophysical sources. This is one of the major research area of P. Salati. We believe that this could be a very fruitful area of collaboration supported by the FCPPL_CSC program.

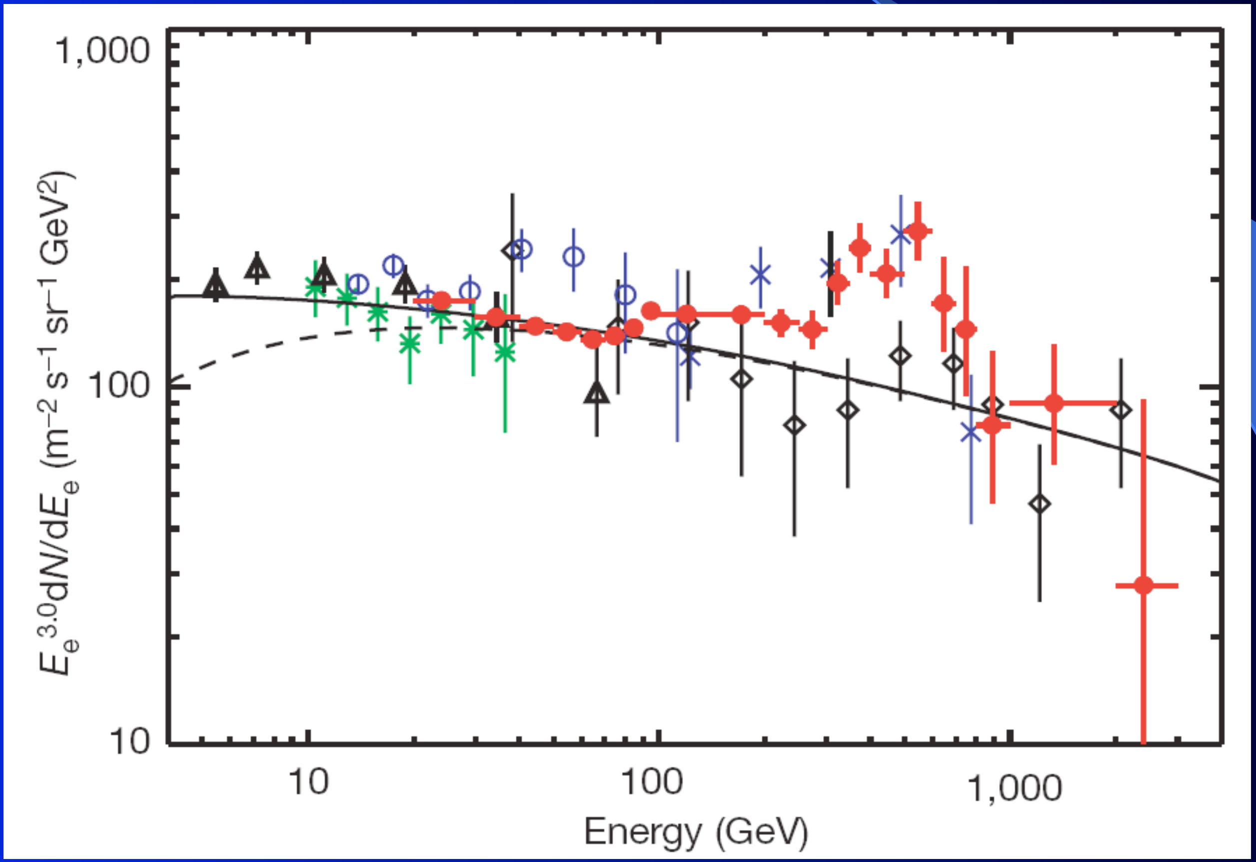
Recent Observation results

PAMELA: positron fraction

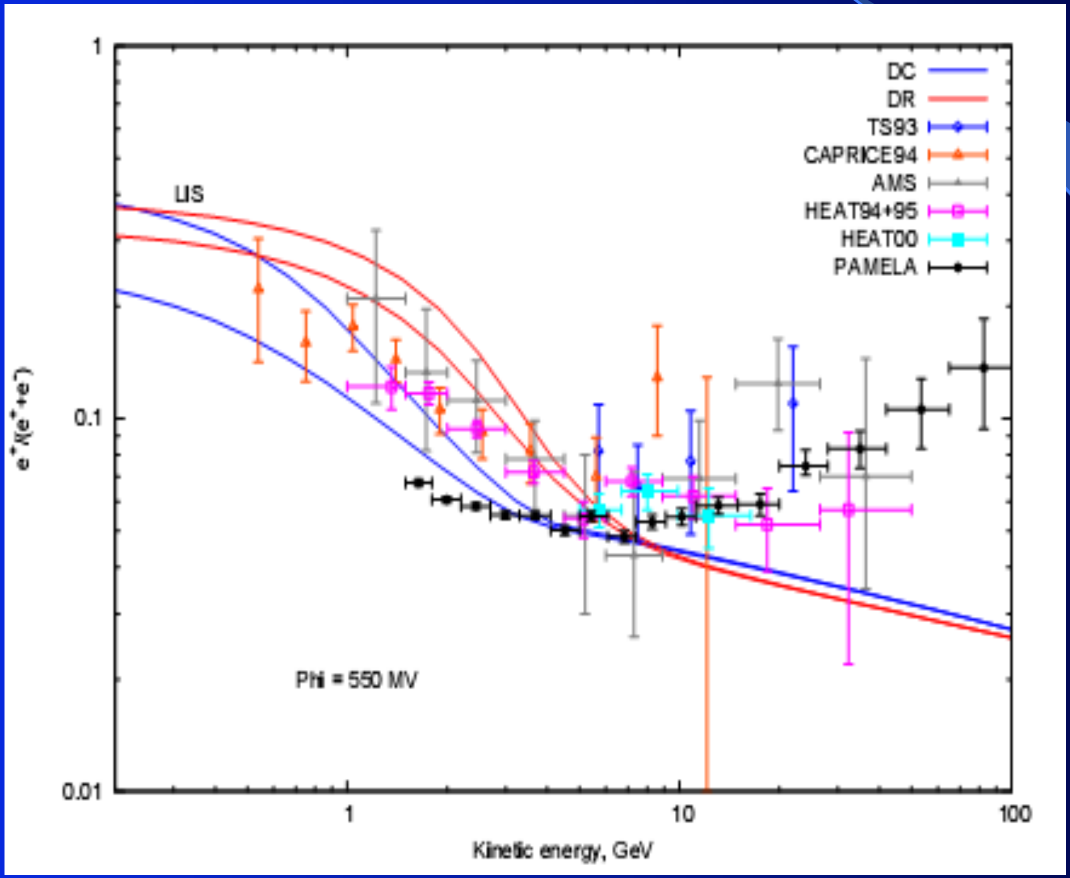




ATIC: electron + positron flux

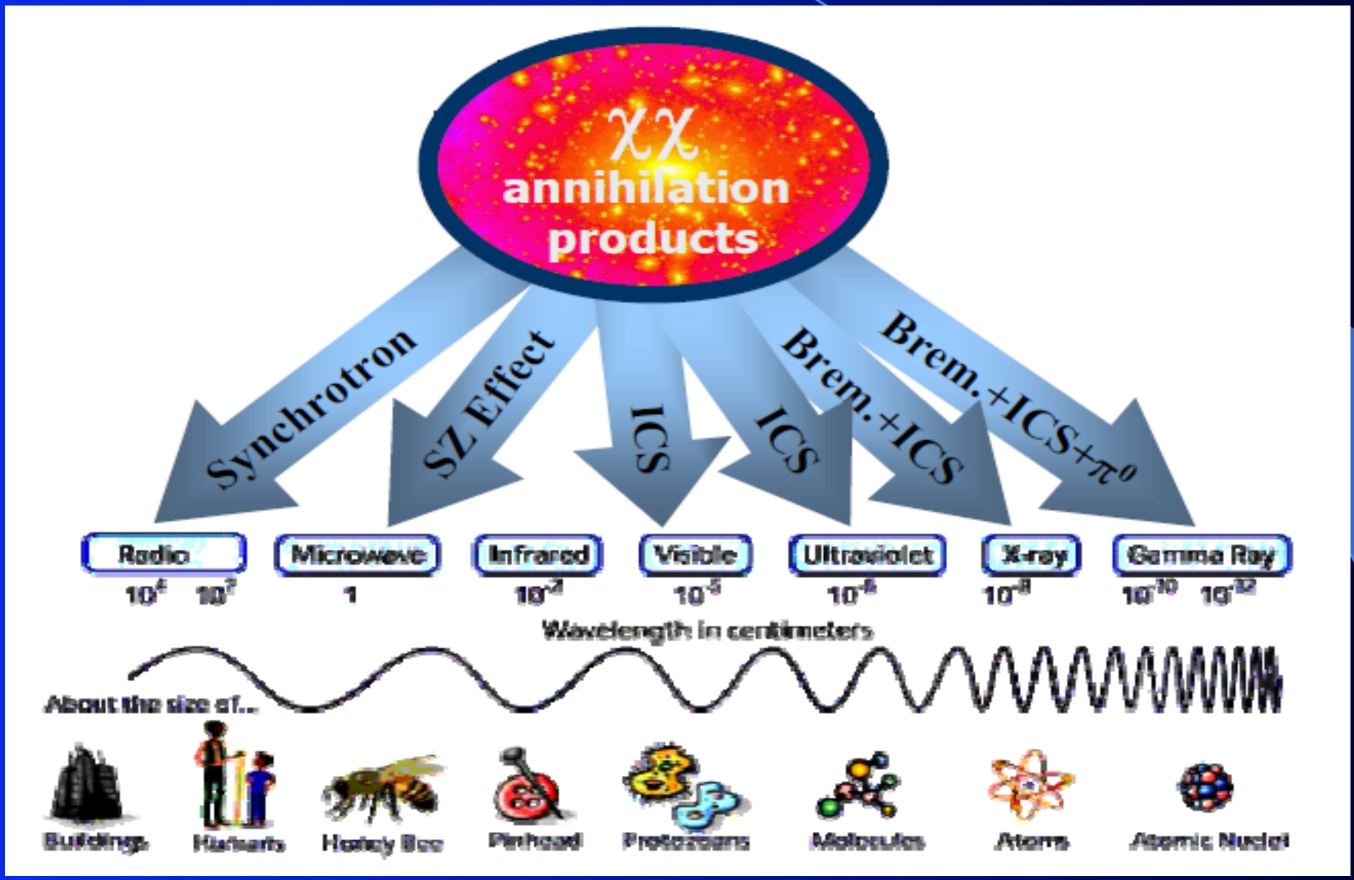


Excess still exists with the diffusion uncertainties considered



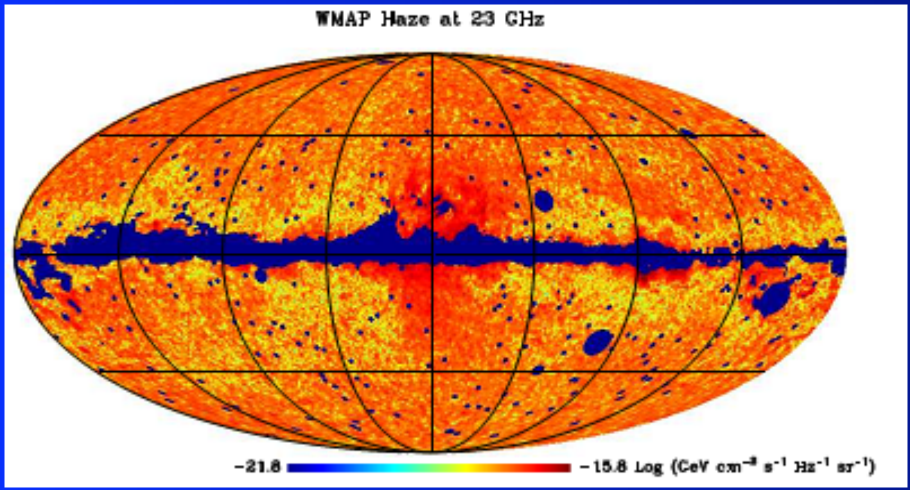
Yin, *et al.* 0811.0176

Other ways to reveal electrons and positrons

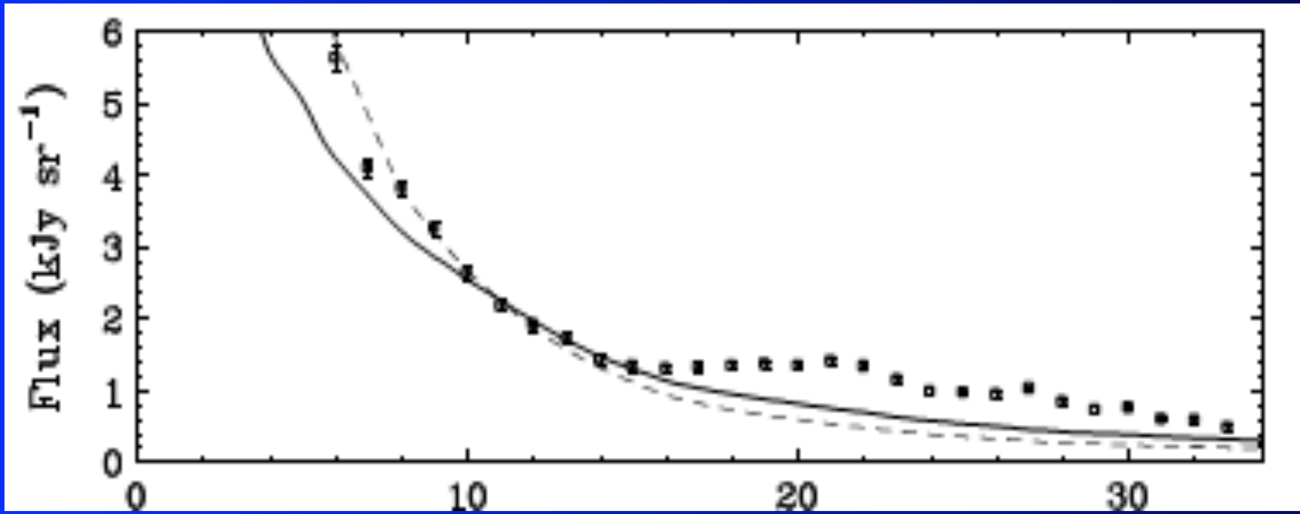


Synchrotron emission @ Galactic Center

WMAP Haze ← **DM annihilation**



B=10mGs @ Galactic center

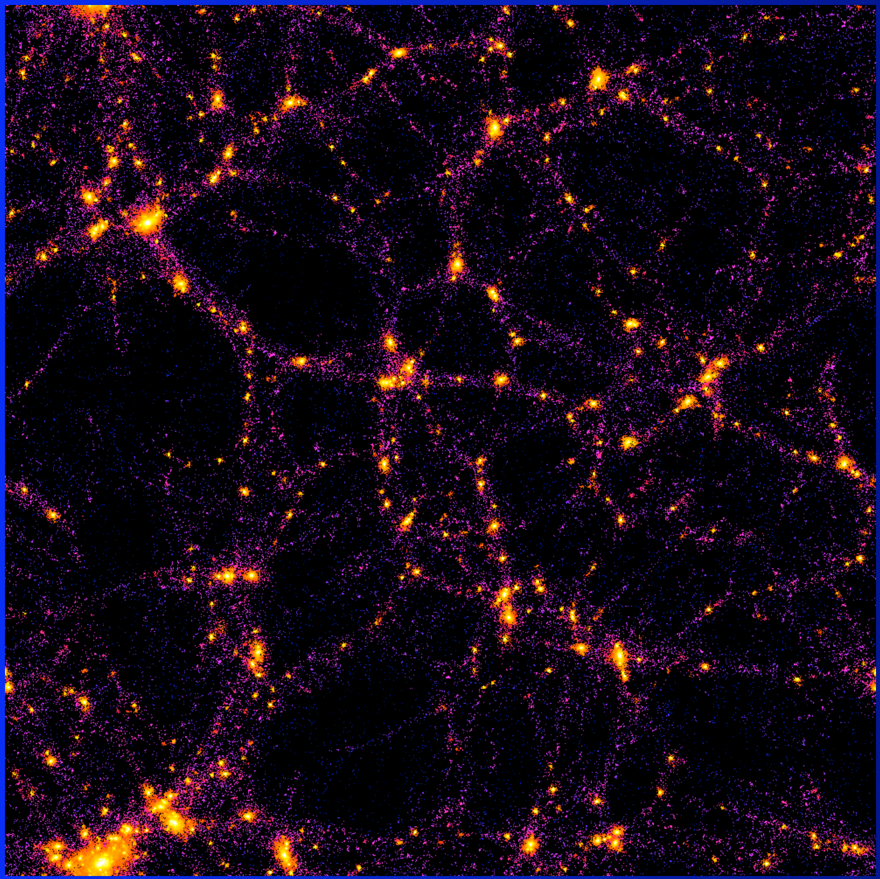


Dashed----Moore
Solid -------NFW

D. Hooper astro-ph/0705.3655

Other places to probe the signals

Annihilation rate ∝ ρ^2



Density profile of dark halo

$$\rho_{NFW}(r) = \frac{\rho_s}{(r/r_s)(1+r/r_s)^2}$$

$$\rho_{Moore}(r) = \frac{\rho_s}{(r/r_s)^{1.5}(1+(r/r_s)^{1.5})}$$

$$\rho_{cored} = \frac{v_a^2}{4\pi G}\frac{3r_c^2+r^2}{(r_c^2+r^2)^2}$$

Where to probe?

Possible local DM annihilation sources

Annihilation rate $\propto \rho^2$

- Nearby galaxies clusters:

  cluster as the largest bound containers of DM

- Dwarf galaxies:

  dominated by DM both in central regions and outskirts

  close to be a *pure* dark halo

  local group satellites

Energy spectrum of $e^{\pm}$ produced by DM annihilation

Diffuse transport equation of electrons (positrons) produced by DM annihilation

$$\frac{\partial}{\partial t}\frac{dn_e}{dE_e} = \nabla\left[D(E,r)\nabla\frac{dn_e}{dE_e}\right] + \frac{\partial}{\partial E}\left[b(E,r)\frac{dn_e}{dE_e}\right] + q_e(E,r)$$

Diffusion coefficient: $D(E) = D_0(E/B)^{\delta}$

Energy loss term: $b(E) = b_{Syn} + b_{ICS} + b_{Coul}$

Source spectrum: $q_e(E,r) = \frac{1}{2\,M_\chi^2}\sum_f \frac{dN_e^f}{dE_e}(E)B_f\,\rho^2(r)$

Basic Formulas

Stationary transport equation:

$$\cancel{\frac{\partial}{\partial t}\frac{dn_e}{dE_e}} = \nabla\left[D(E,r)\nabla\frac{dn_e}{dE_e}\right] + \frac{\partial}{\partial E}\left[b(E,r)\frac{dn_e}{dE_e}\right] + q_e(E,r)$$

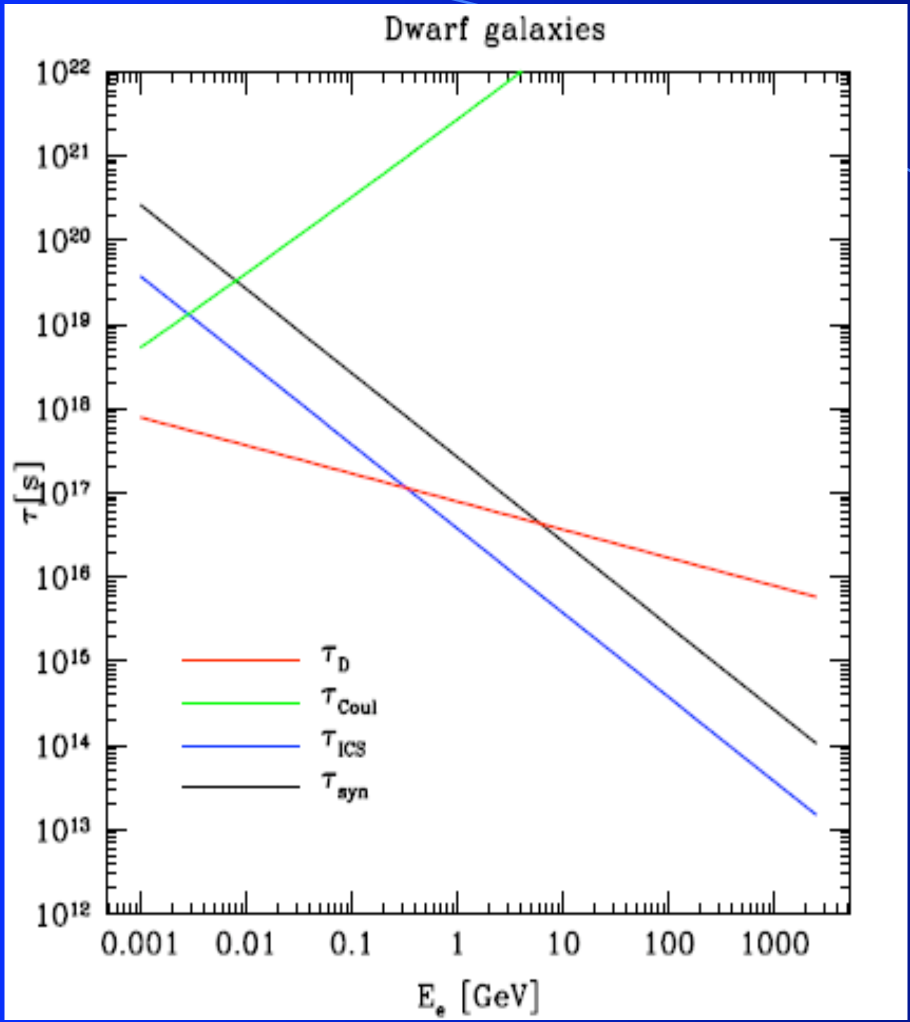
Qualitative Electrons equilibrium spectrum

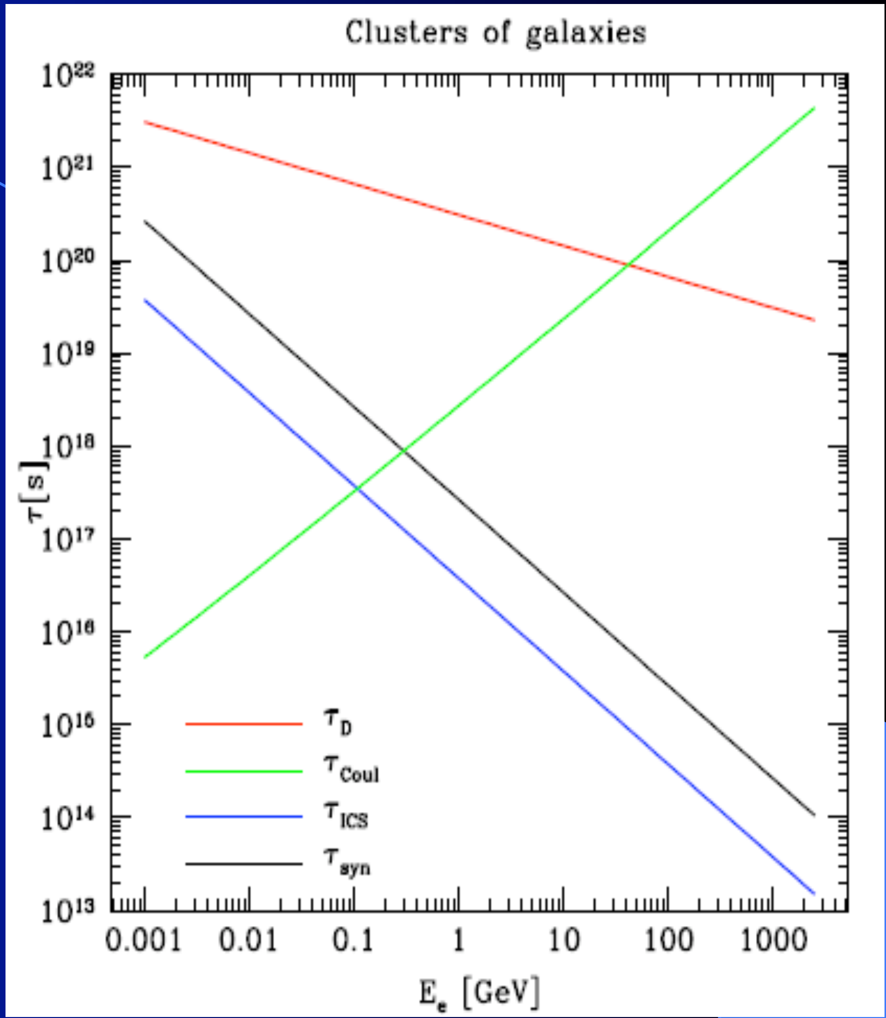
$$\frac{dn_e(E,r)}{dE_e} \approx [q_e(E,r)\tau_{loss}] \times \frac{V_s}{V_s + V_o} \times \frac{\tau_D}{\tau_D + \tau_{loss}}$$

time scales:

$$\tau_D = R_{halo}{}^2 / D(E)$$

$$\tau_{loss} = E / b(E)$$

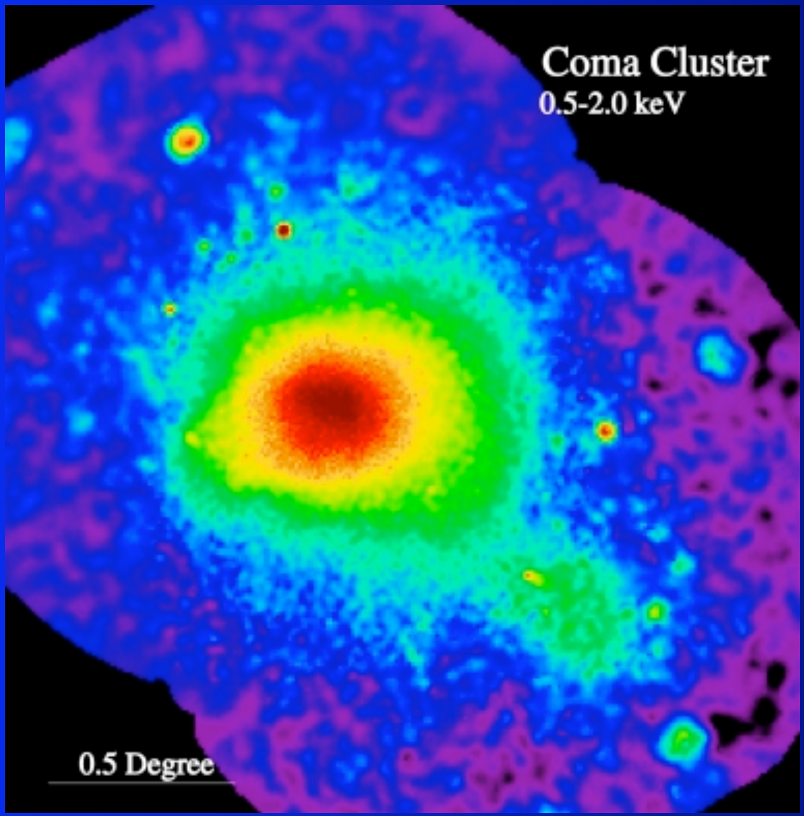




$$\frac{dn_e(E,r)}{dE_e} = q_e(E,r) \cdot \tau_D \cdot \frac{V_s}{V_D}$$

$$\frac{dn_e(E,r)}{dE_e} = q_e(E,r) \cdot \tau_{loss}$$

Clusters *v.s.* Dwarf galaxies

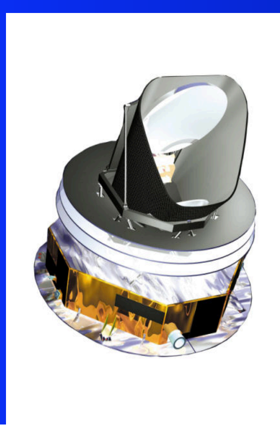


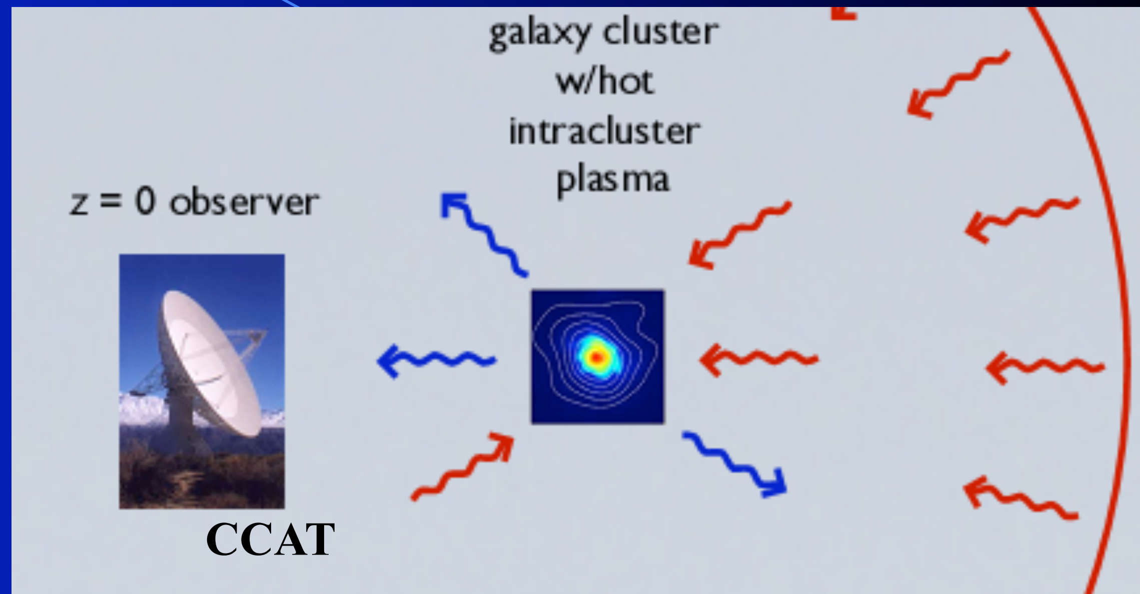
Large Scale
Hot gas
Diffusion irrelevant

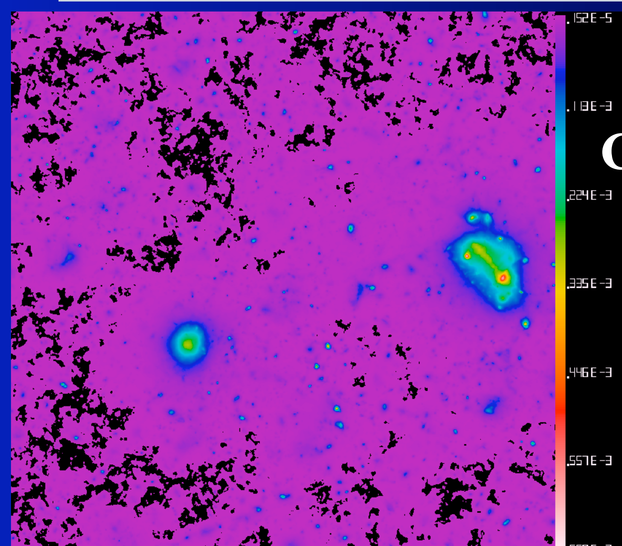
Small scale
Lack of gas
Diffusion dominant

Clusters

Thermal SZ effect







Clusters with hot/warm gas

DSphs?

Non-thermal SZ effect induced by electrons & positrons from DM annihilation

$$\Delta T \propto y_{DM} \cdot \tilde{g}(x)$$

$$y_{DM} = \frac{\sigma_T}{m_e c^2} \int P_{DM} d\ell$$

Compton parameter

Spectral shape

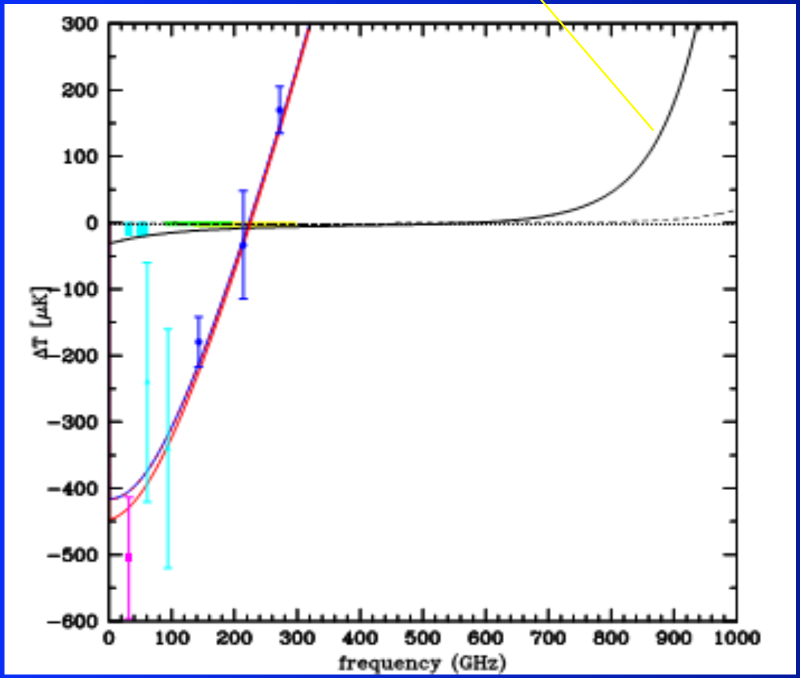
$$\tilde{g}(x) = \frac{m_e c^2}{\langle k_B T_e \rangle} \left\{ \frac{1}{\tau} \left[\int_{-\infty}^{+\infty} i_0(xe^{-s}) P(s) ds - i_0(x) \right] \right\}$$

$$\langle k_B T_e \rangle \equiv \frac{\sigma_T}{\tau} \int P d\ell = \frac{\int P d\ell}{\int n_e d\ell} = \int_0^{\infty} dp f_e(p) \frac{1}{3} p v(p) m_e c$$

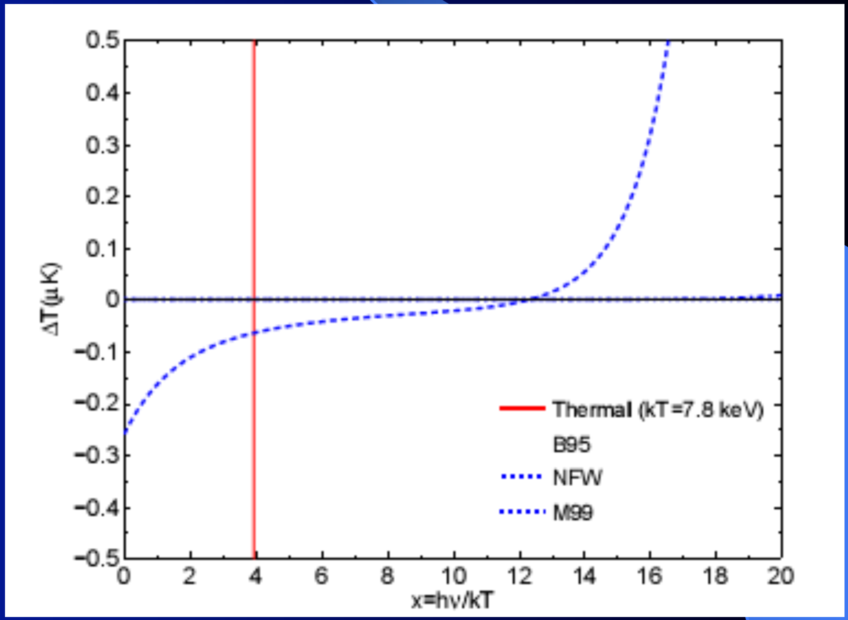
(Ensslin&Kaiser: astro-ph/0001429 Colafrancesco: astro-ph/0211649……)

SZ effect induced by WIMP in Coma Cluster

m=40GeV



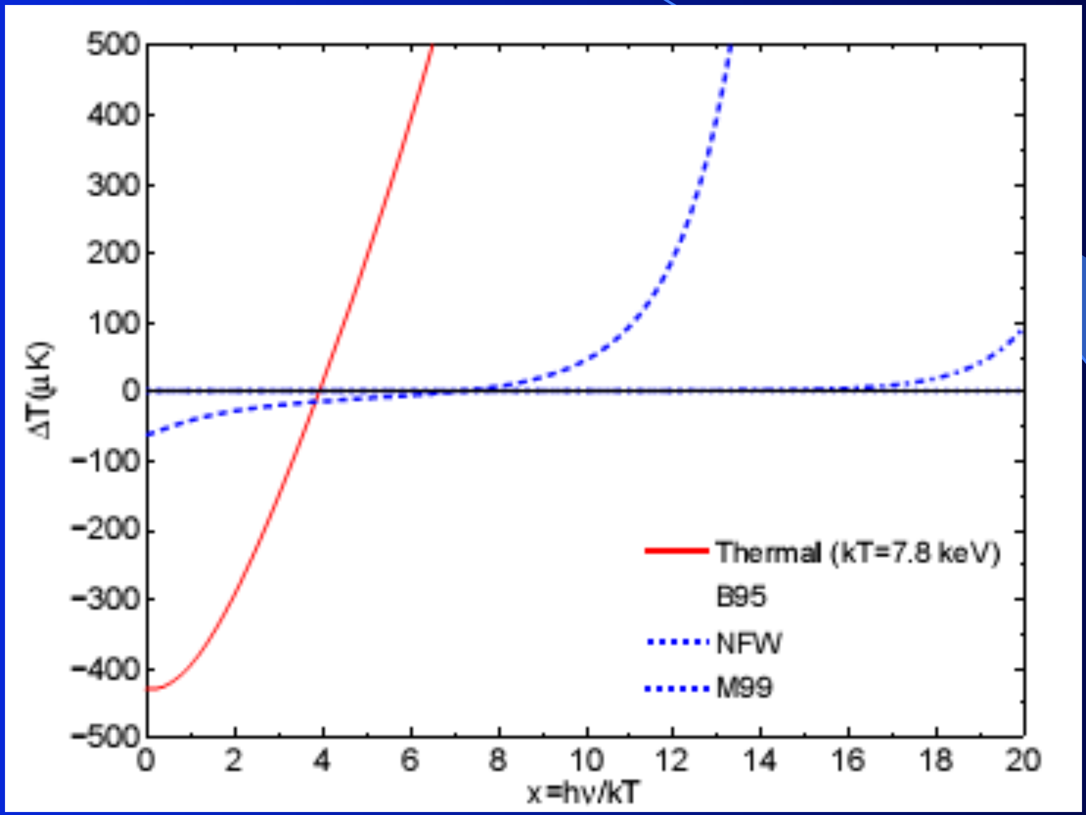
m=100GeV



S. Colafrancesco *et al.*
astro-ph/0507575

Q. Yuan *et al.*
arxiv:0902.4294

SZ effect induced by LDM in Coma Cluster

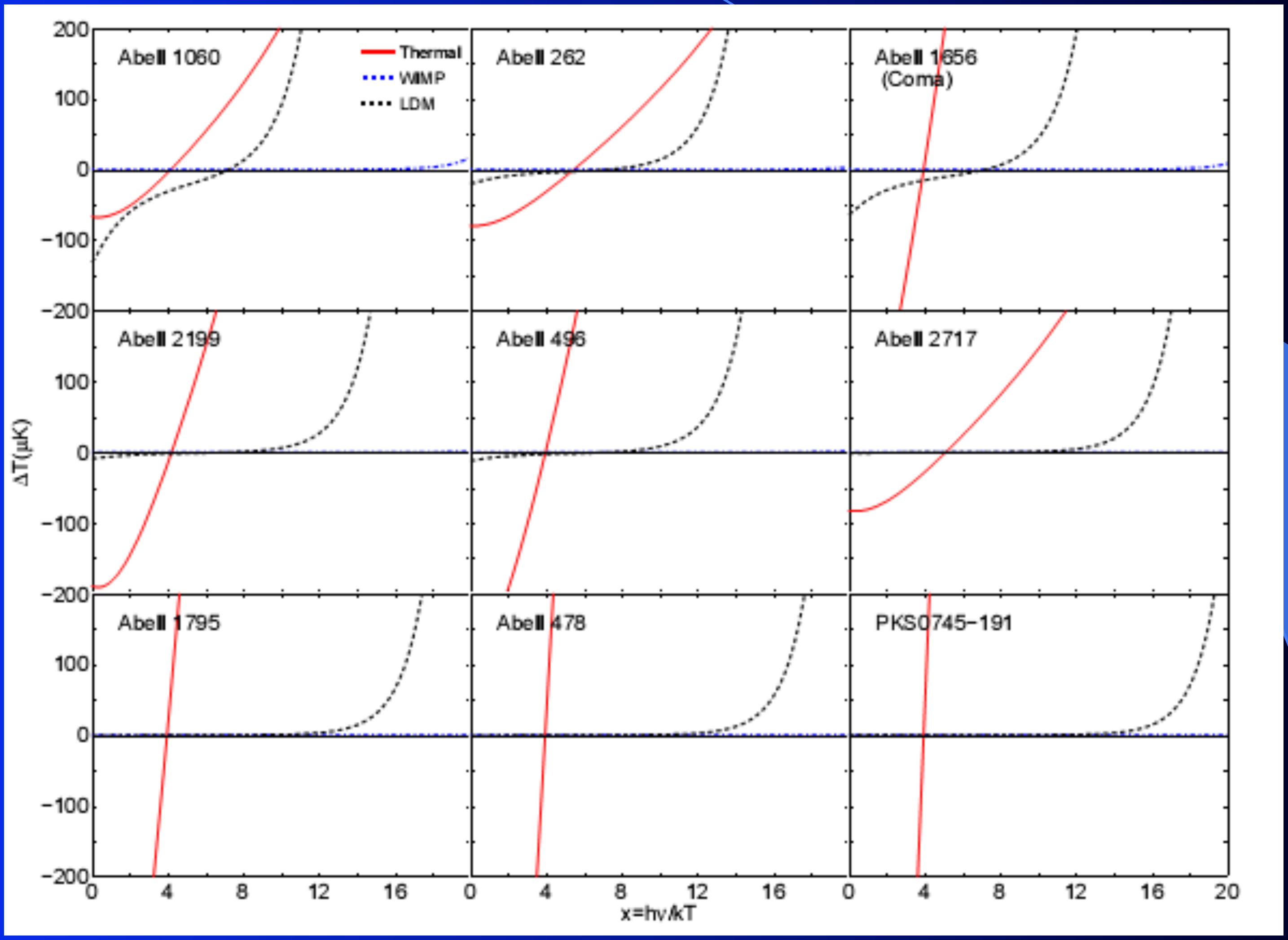


$<\sigma v>(1\text{MeV}/m)^2 \sim 10^{-30} \text{cm}^3/\text{s}$

(PRL, 2004, 92, 101301)

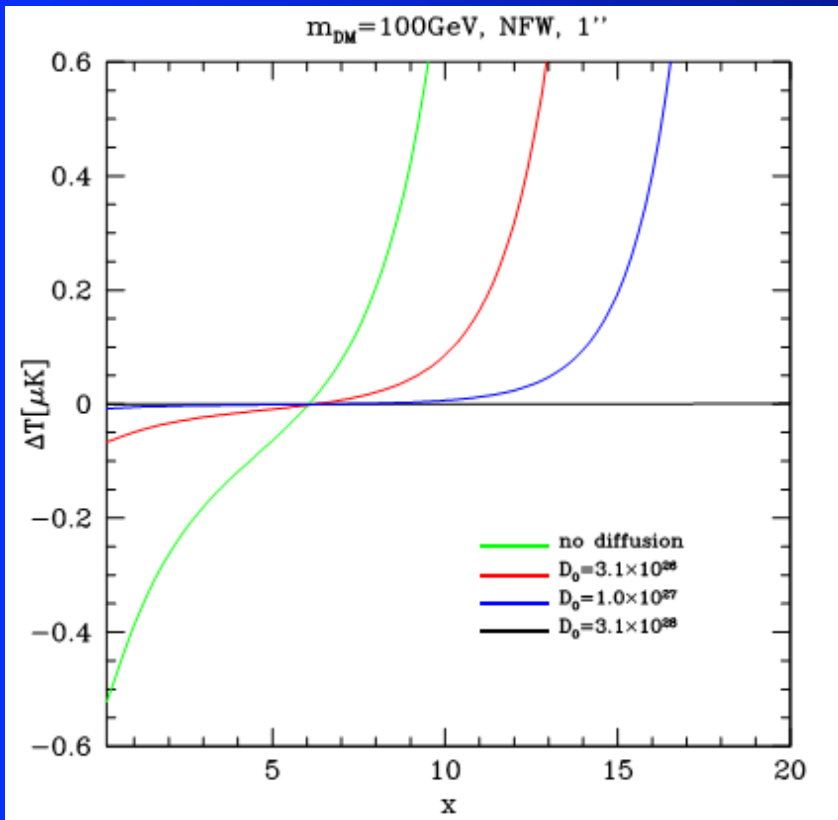
511keV emission @GC

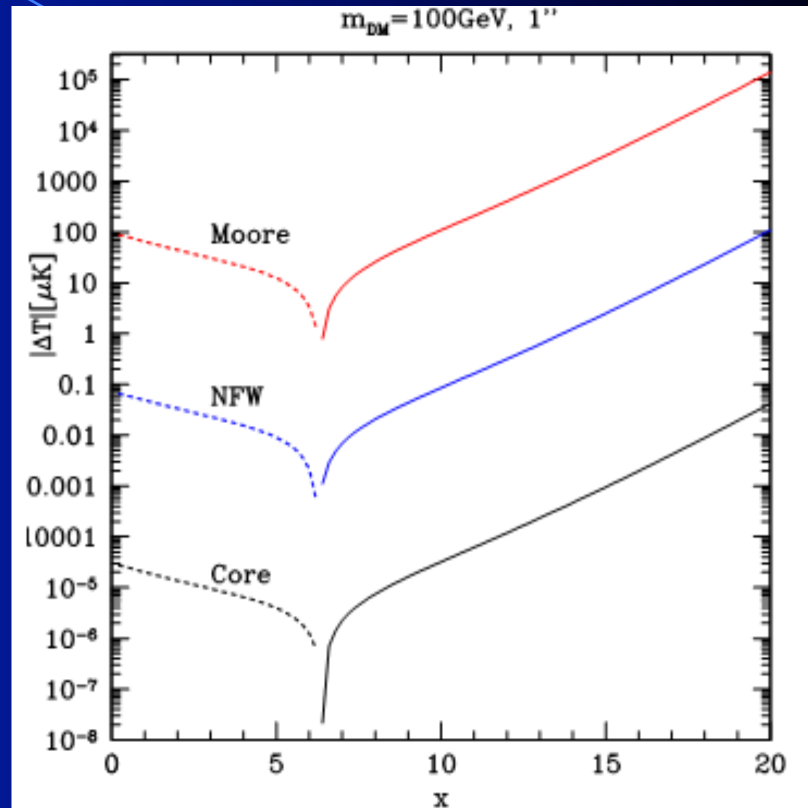
Other Clusters



Dwarf Galaxies

SZ effect induced by neutralino annihilation

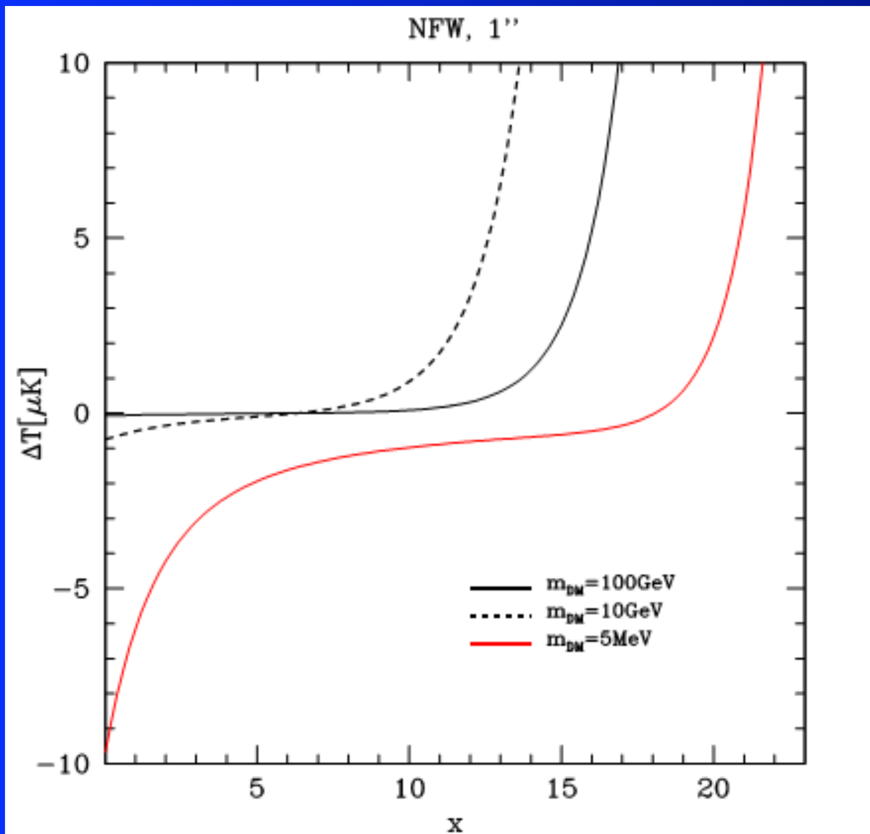


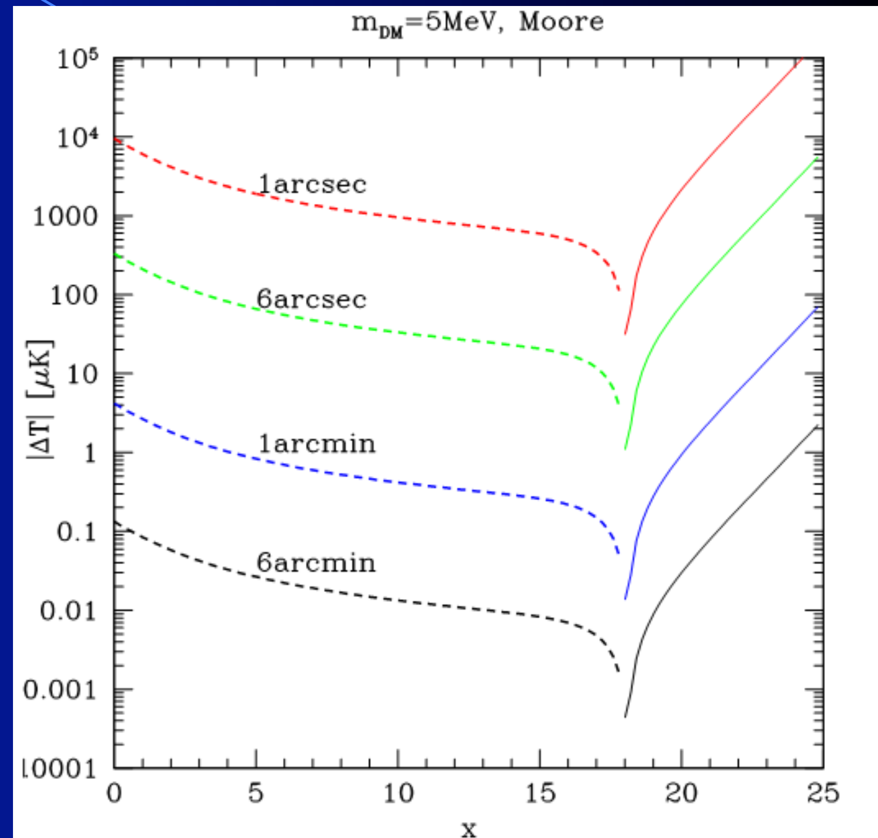


Only highly cusped dark halos produce **mK signal**

Larger distortion expected in the case of Light Dark Matter

SZ effect induced by Light DM annihilation





$<\sigma v>(1\mathrm{MeV}/m)^2 \sim 10^{-30}\mathrm{cm}^3/\mathrm{s}$

(PRL, 2004, 92, 101301)

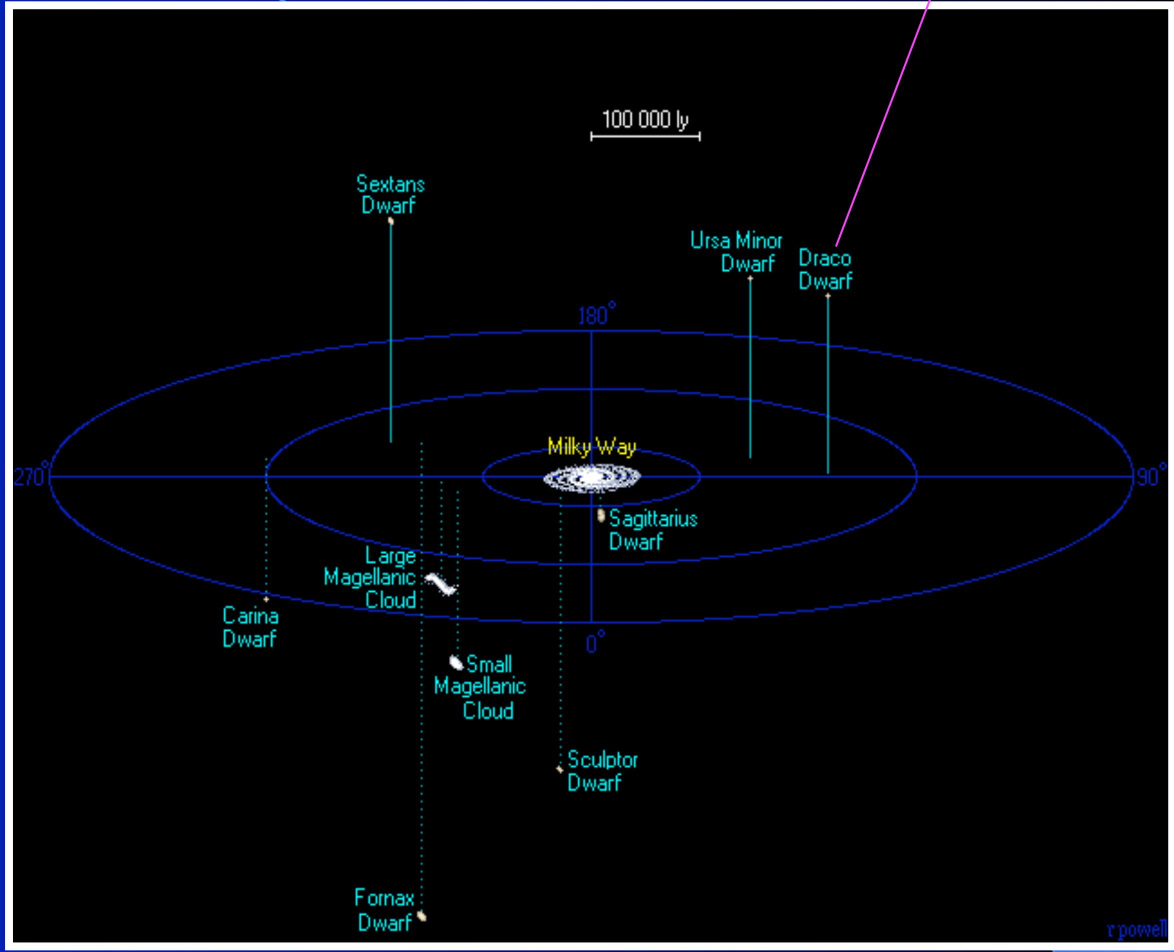
511keV emission @GC

Nearby dSphs: satellites of Milky Way

High latitude
Highest mass/light

Name	Year Discovered
LMC	1519
SMC	1519
Sculptor	1937
Fornax	1938
Leo II	1950
Leo I	1950
Ursa Minor	1954
Draco	1954
Carina	1977
Sextans	1990
Sagittarius	1994
Canis Major	2003
Ursa Major I	2005
Willman I	2005
Ursa Major II	2006
Bootes	2006
Canes Venatici I	2006
Canes Venatici II	2006
Coma	2006
Leo IV	2006
Hercules	2006
Leo T	2007

Census of Milky Way Satellites (Circa 2007)



Dark Halo of these DSphs

Parameters of the halo profile is determined by M_vir

Name	D [kpc]	M_{vir} [$10^8 M_\odot$]	ρ_s [$10^8 M_\odot/kpc^3$]	r_s [kpc]	r_t [kpc]
Draco	80	40	0.82	1.2	9.9
LeoI	250	10	1.2	0.64	16.7
Fornax	138	10	1.2	0.64	10.3
LeoII	205	4	1.5	0.43	10.6
Carina	101	2	1.8	0.32	4.8
Sculptor	79	10	1.2	0.64	6.5
Sextans	86	3	1.6	0.38	4.8
Ursa MajorII	29	0.049	4.8	0.064	0.57
LeoT	27	0.082	4.2	0.080	0.63
Ursa MajorI	29	0.15	3.6	0.10	0.81
LeoIV	28	0.014	6.8	0.037	0.38
Coma Berenice	44	0.012	7.1	0.50	0.035
Canes VenatII	151	0.024	5.9	0.047	1.6
Canes VenatI	224	0.27	3.1	0.13	4.8
Hercules	138	0.071	4.4	0.076	2.1

$$(\rho_s, r_s) \rightleftharpoons (\mathrm{M_{vir}, c})$$

$$c(\mathrm{M_{vir}}) = 9.6 \times \left(\frac{\mathrm{M_{vir}}}{10^{14}\mathrm{h^{-1}M_\odot}}\right)^{-0.1}$$

Halo size is assumed to be the tidal radius which determined by

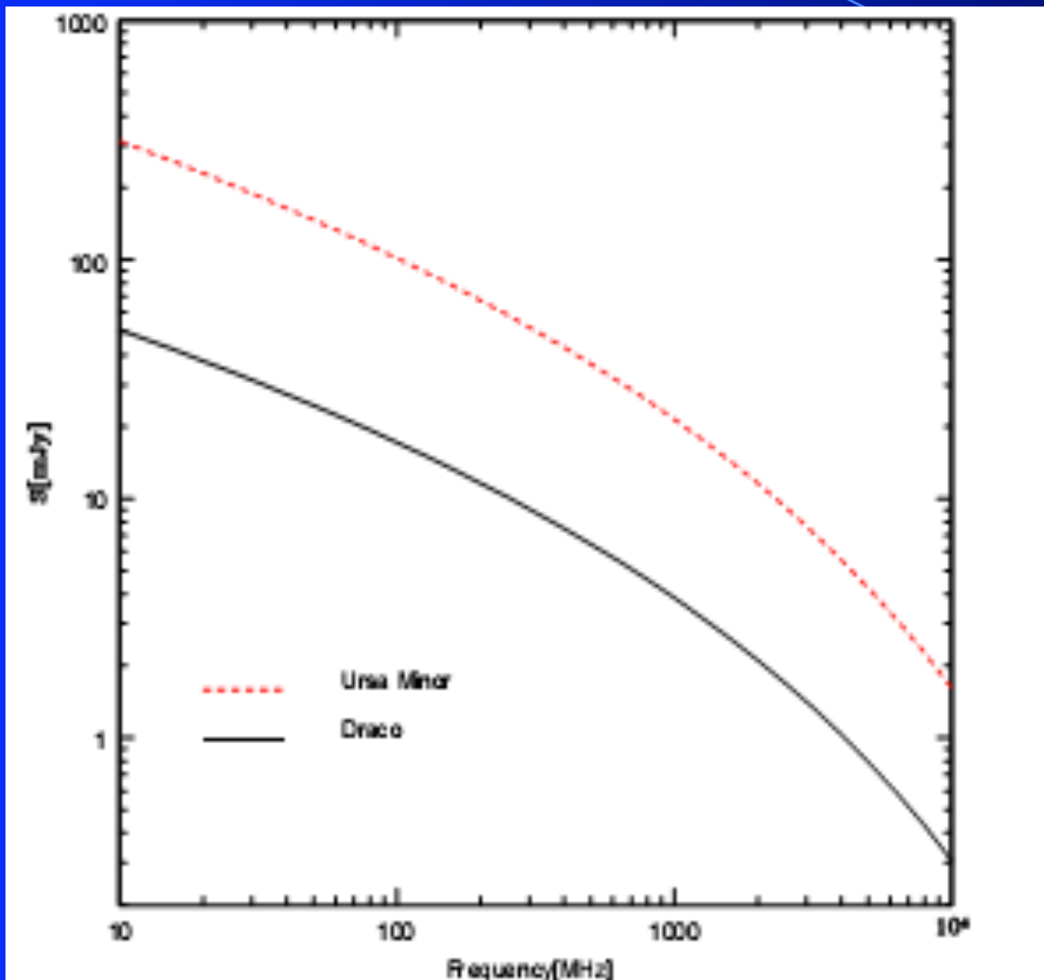
$$\frac{M_{\mathrm{dSph}}(r_t)}{r_t^3} = \frac{2M_{\mathrm{MW}}(\mathrm{D}-\mathrm{r_t})}{(\mathrm{D}-\mathrm{r_t})^3}$$

SZ from DSphs

Table 4: The DM induced SZ effect (in units of K) for Local Group dwarfs. We assume m_χ = 100 GeV, $\langle\sigma v\rangle = 3.0 \times 10^{-26}\text{cm}^3\text{s}^{-1}$, NFW profile, and beamwidth 1 arcsec.

dSph	$D_\odot$(kpc)	$M_{vir}(M_\odot)$	35GHz ($x = 0.616$)	1000GHz ($x = 17.46$)
Draco	80	4×10^9	-2.08×10^{-6}	6.53×10^{-4}
LeoI	250	1×10^9	-5.77×10^{-7}	1.75×10^{-4}
Fornax	138	1×10^9	-7.67×10^{-7}	2.41×10^{-4}
LeoII	205	4×10^8	-3.84×10^{-7}	1.20×10^{-4}
Carina	101	2×10^8	-1.43×10^{-7}	4.88×10^{-5}
Sculptor	79	1×10^9	-6.69×10^{-7}	2.22×10^{-4}
Sextans	86	3×10^8	-1.91×10^{-7}	6.54×10^{-5}
Ursa MajorII	29	4.9×10^6	-1.29×10^{-11}	3.26×10^{-9}
LeoT	27	8.2×10^6	-2.80×10^{-11}	7.18×10^{-9}
Ursa MajorI	29	1.5×10^7	-1.02×10^{-10}	2.74×10^{-8}
LeoIV	28	1.4×10^6	-1.18×10^{-12}	2.82×10^{-10}
Coma Berenice	44	1.2×10^6	-2.88×10^{-12}	7.13×10^{-10}
Canes VenaticiII	151	2.4×10^6	-2.63×10^{-10}	8.11×10^{-8}
Canes VenaticiI	224	2.7×10^7	-2.98×10^{-8}	1.02×10^{-5}
Hercules	138	7.1×10^6	-1.51×10^{-9}	4.89×10^{-7}

Synchrotron emission in DSphs



B=1mGs

NFW

Typical neutralino:

Mc=100GeV

Flux increases with frequency decreasing

Radio emission in dSphs: diffuse and weak

Table 2. Related results (θ: half of the angular diameter)

	Flux(mJy) from Draco			Flux(mJy) from Ursa Minor		
	4.89GHz	1.42GHz	0.7GHz	4.89GHz	1.42GHz	0.7GHz
$\theta = 6'$	0.2	0.7	1.1	0.4	1.5	2.7
$\theta = 30'$	0.8	2.9	5.1	4.4	15.9	28.6
$\theta = 60'$	0.9	3.2	5.7	6.2	22.8	40.9

~90% of the total flux is from the central region of 2 degree
~50% is within central 50 arcmin region.

What's the implication for observation?

Radio Observation Requirement

Fomalont *et. al*. with VLA at 4.885GHz in 1979

very center region (within 4arcmin)
no detectable radio emission (<2mJy)

Updated observation required

Diffuse emission -------- large field view
weak emission -------- high sensitivity

Proposed ATA observation

Figure 2: Rendering of the completed ATA-350 at the Hat Creek Radio Observatory.

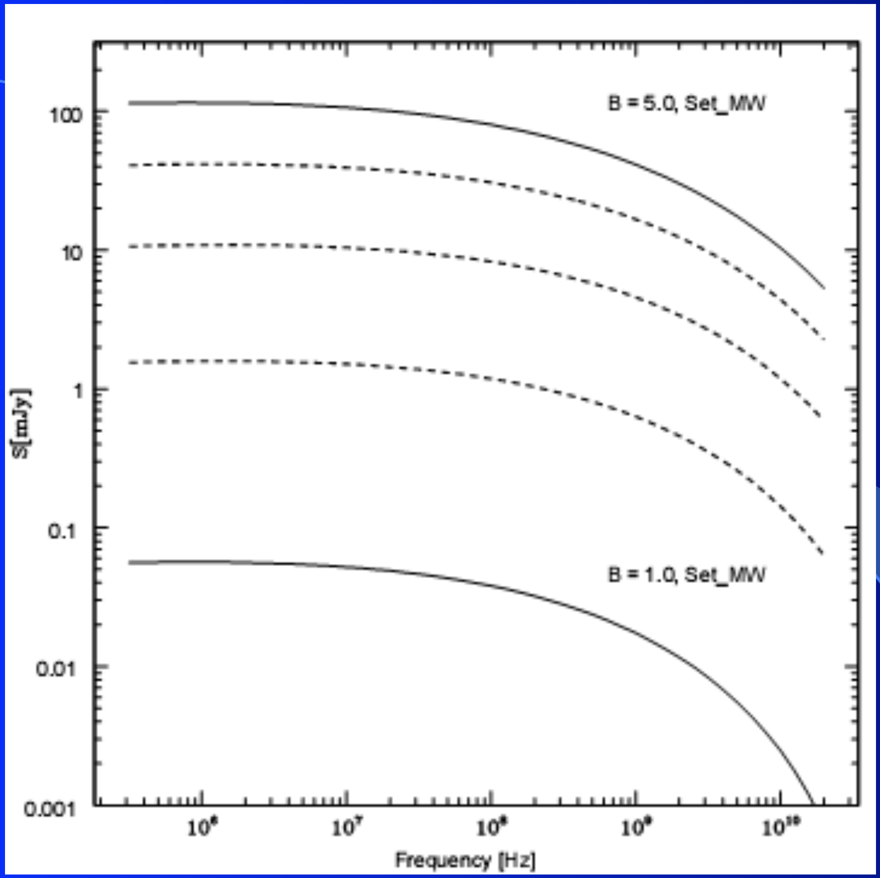
F.o.V at 1.4GHz: 2.5 degree
42 working antennas
Effective bandwidth :103MHz
6hrs on-source time.

↓

rms: 0.1mJy/beam @ 1.4GHz

peak/rms >10

Crucial factor: local magnetic field B



Non-detection

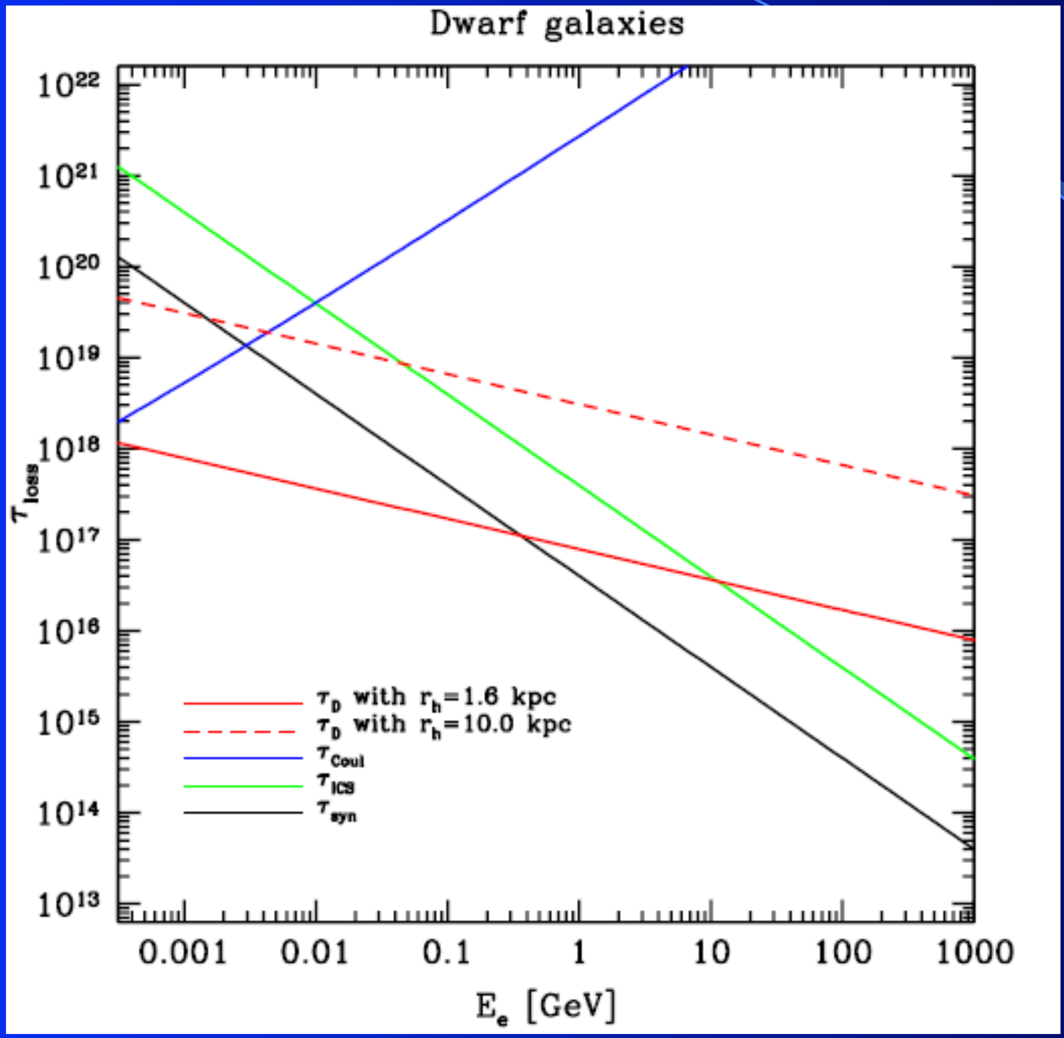
B is smaller

Dark matter

GLAST: gamma ray

$$S[mJy] \approx 11.25 < \sigma v >_{26} B^{4.5}(1 - 0.3B + 0.022B^2)$$

Thank You!



Dwarf galaxies
10^{22}
10^{21}
10^{20}
10^{19}
10^{18}
10^{17}
10^{16}
10^{15}
10^{14}
10^{13}
τ_{loss}
0.001
0.01
0.1
1
10
100
1000
E_e [GeV]
τ_D with r_h=1.6 kpc
τ_D with r_h=10.0 kpc
τ_{Coul}
τ_{ICS}
τ_{syn}

Synchrotron radio emission from nearby dIrrs:

B_dIrr > B_dSph → Stronger radio flux_DM from dIrrs

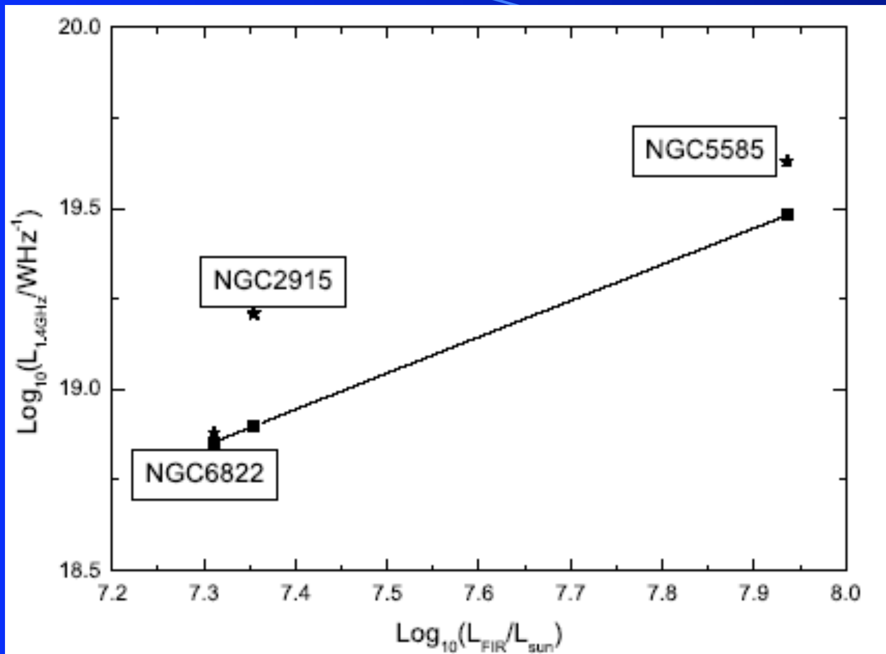
Contaminated by

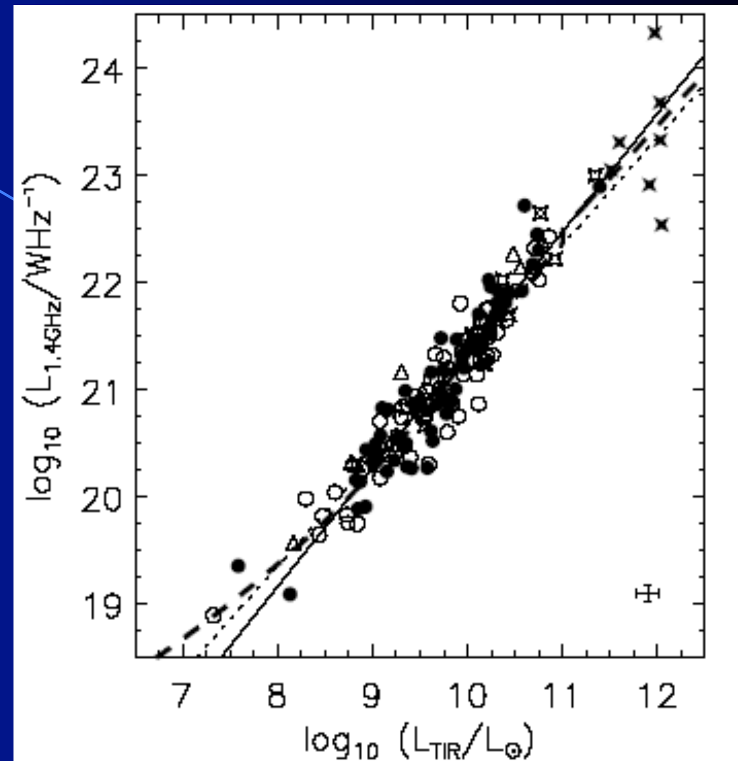
Radio: Cosmic Ray e^- accelerated by SNe from massive star

Star formation rate

FIR: UV radiation from young star re-emitted in the surrounding dust

Tight and universal FIR-radio correlation in normal galaxies





ID	Name	D(Mpc)	Flux at 20 cm(mJy)		
			$FIR-20cm$	$DM-20cm$	$data-20cm$
1	DDO161	7.60	2.07	0.91	4.60
2	ESO444-G84	4.61	5.20	0.30	9.25
3	ESO325-G11	3.40	2.39	5.12	8.0
5	NGC2915	3.63	5.02	4.54	11.56
7	DDO10	10.15	0.52	0.069	11.60
8	DDO34	8.17	1.12	0.51	10.00
9	IC1613	0.70	8.41		3.30

Possible explanation for such a trend is that either the FIR are overestimated in low luminosity galaxies or another kind of non-thermal contribution should be considered.