Indirect Dark Matter constraints with radio observations

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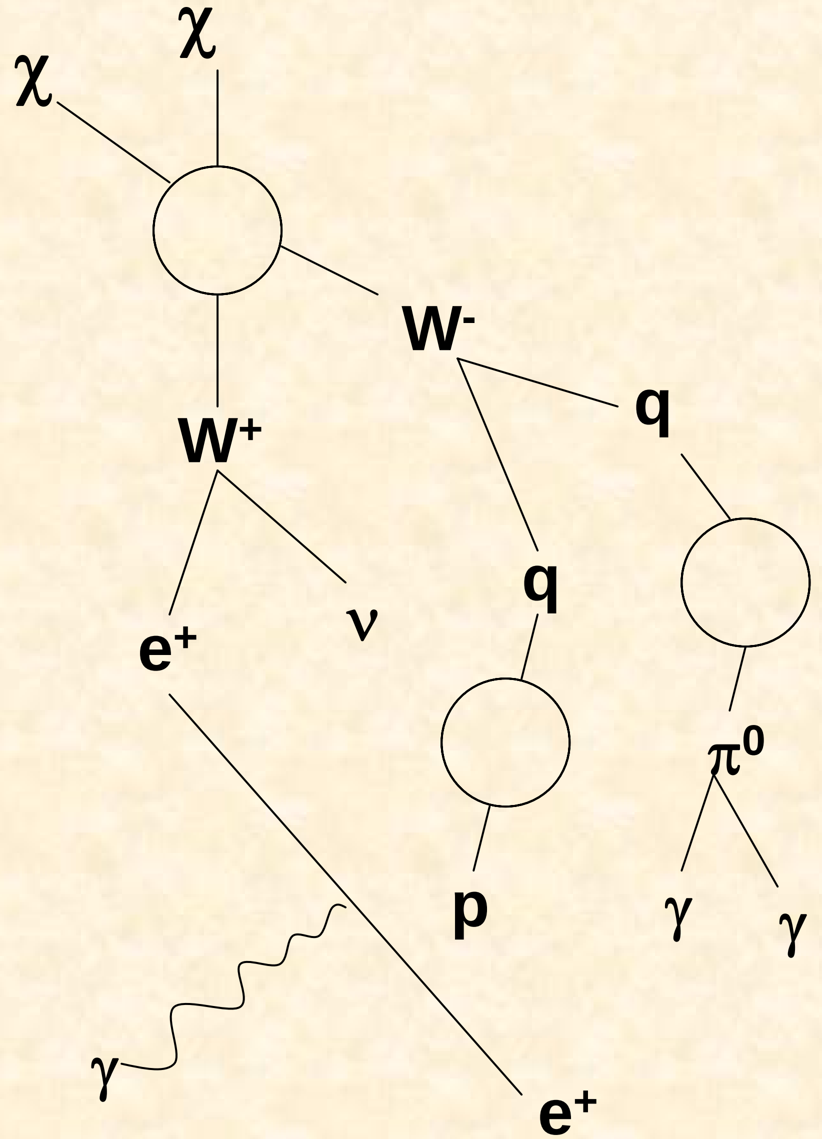
Indirect Detection of Dark Matter: the General Framework

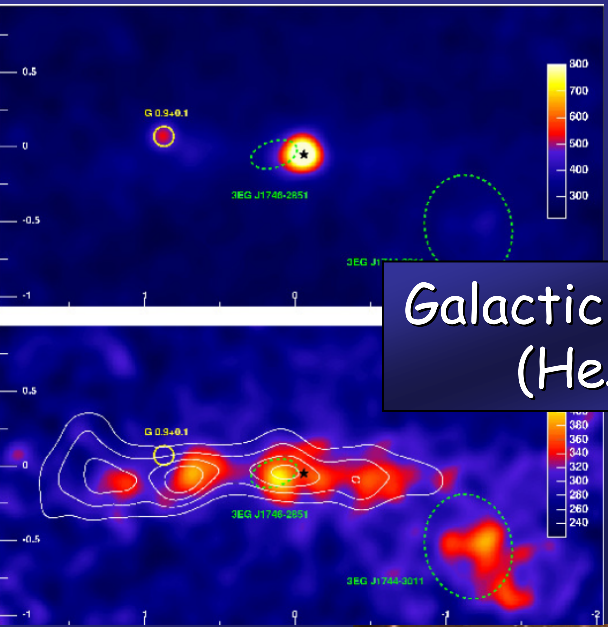
1) **WIMP Annihilation**
   Typical final states include heavy fermions, gauge or Higgs bosons

2) **Fragmentation/Decay**
   Annihilation products decay and/or fragment into some combination of electrons, protons, deuterium, neutrinos and gamma rays

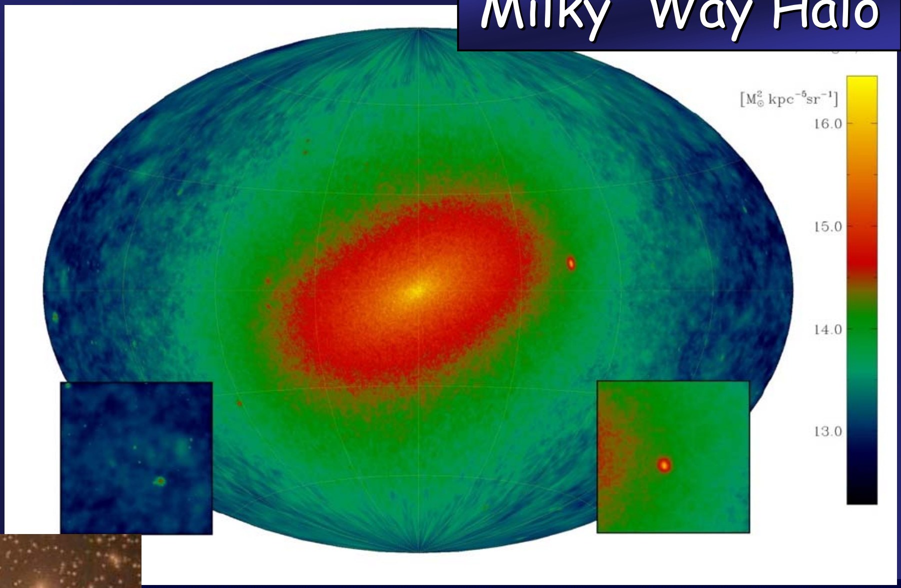
3) **Synchrotron and Inverse Compton**
   Relativistic electrons up-scatter starlight to MeV-GeV energies, and emit synchrotron photons via interactions with magnetic fields



Where to look

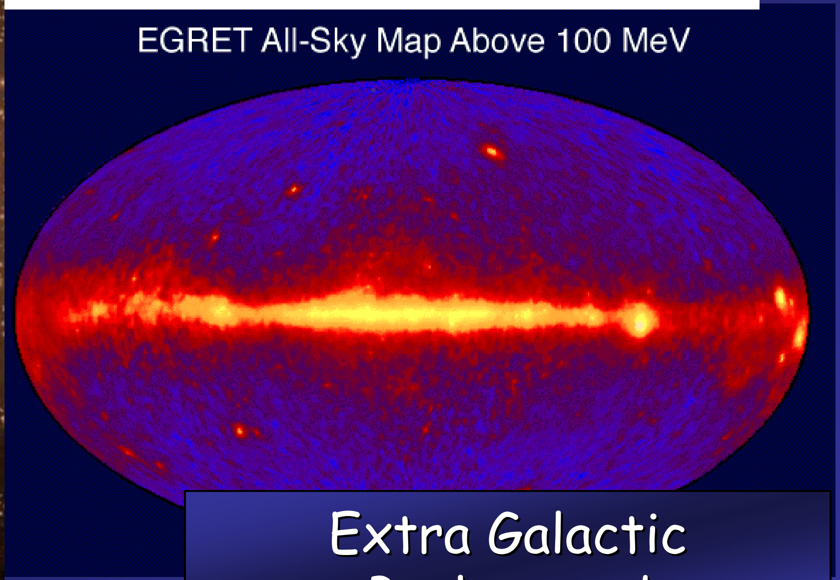


Galactic Center (Hess)



Milky Way Halo

DM Clumps: Via Lactea Simulation Diemand et al.

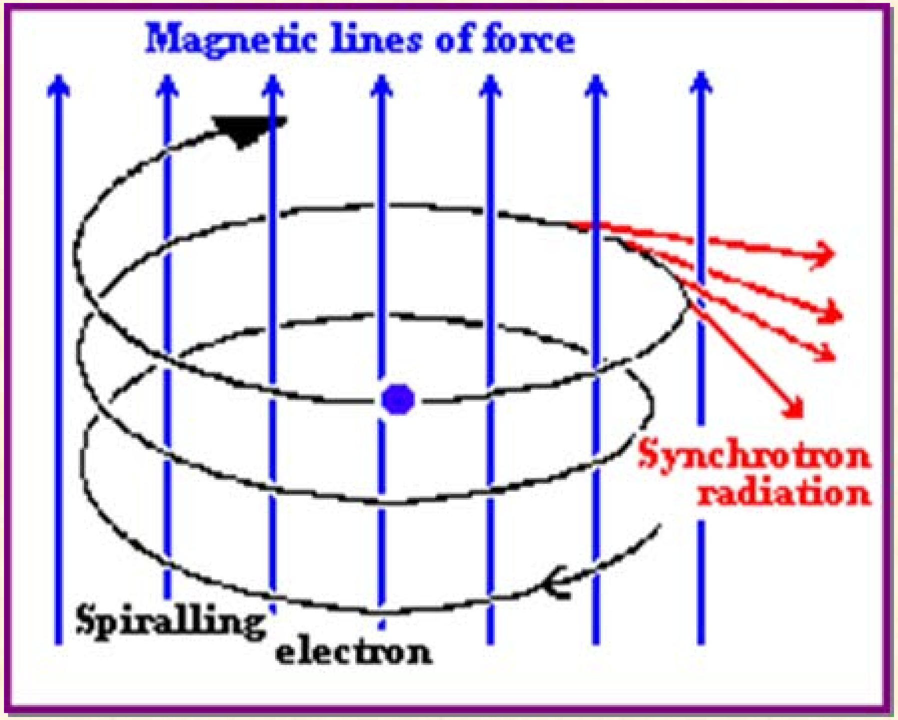


Extra Galactic Background

Indirect Detection With Synchrotron

- Charged leptons and nuclei strongly interact with gas, radiation and Galactic Magnetic Field.

- During the process of thermalization HE e+e− release secondary low energy radiation, in particular in the radio and X-ray band.

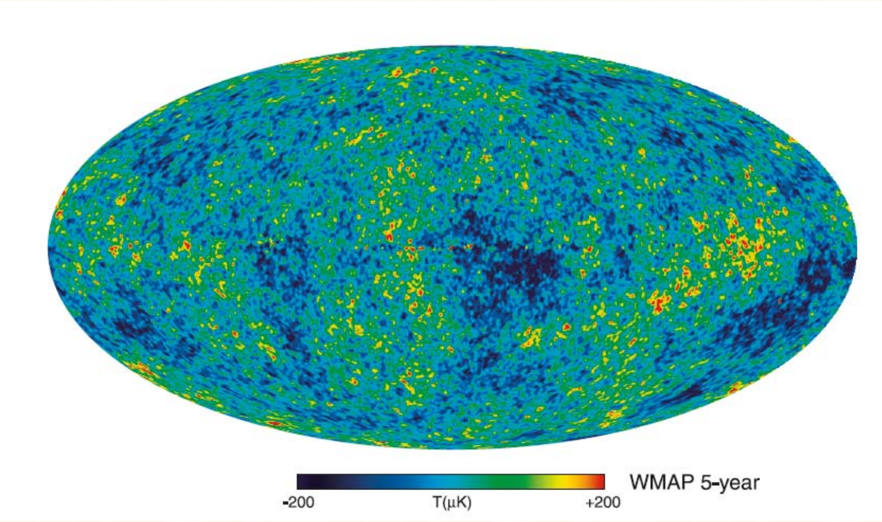


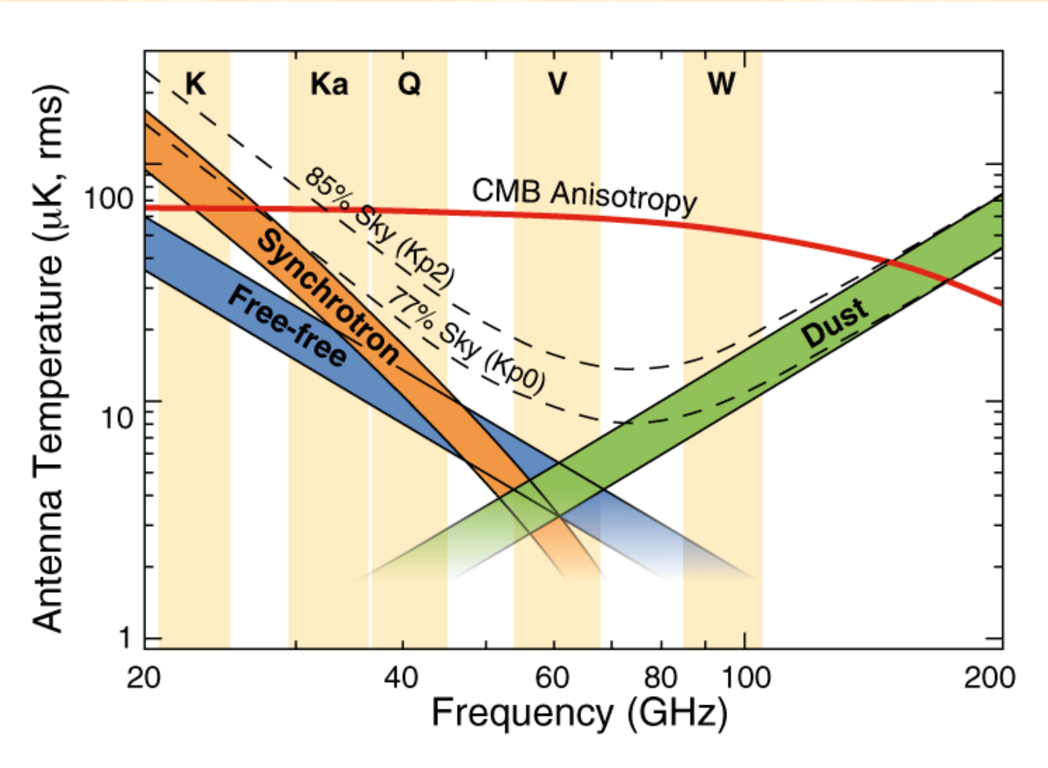
The astrophysical uncertainties need to be accurately characterized. However, radio observations are very sensitive and allow the discrimination of tiny signals against backgrounds many order of magnitudes more intense

Interestingly, for Electroweak-Scale DM, the resulting synchrotron radiation falls within the frequency range of WMAP.

L. Bergstrom, M. Fairbairn and L. Pieri, Phys. Rev. D 74, 123515 (2006)
M. Regis and P. Ullio, Phys. Rev. D 78 (2008) 043505.
T. E. Jeltema and S. Profumo, arXiv:0805.1054 [astro- ph].
P. Blasi, A. V. Olinto and C. Tyler, Astropart. Phys. 18 (2003) 649.
R. Aloisio, P. Blasi and A. V. Olinto, JCAP 0405 (2004) 007.
A. Tasitsiomi, J. M. Siegal-Gaskins and A. V. Olinto, Astropart. Phys. 21 (2004) 637.
L. Zhang and G. Sigl, arXiv:0807.3429 [astro-ph].
S. Colafrancesco, S. Profumo and P. Ullio, Astron. Astrophys. 455 (2006) 21
S. Colafrancesco, S. Profumo and P. Ullio, Phys. Rev. D75 (2007) 023513.
E. A. Baltz and L. Wai, Phys. Rev. D 70 (2004) 023512.

The Microwave sky

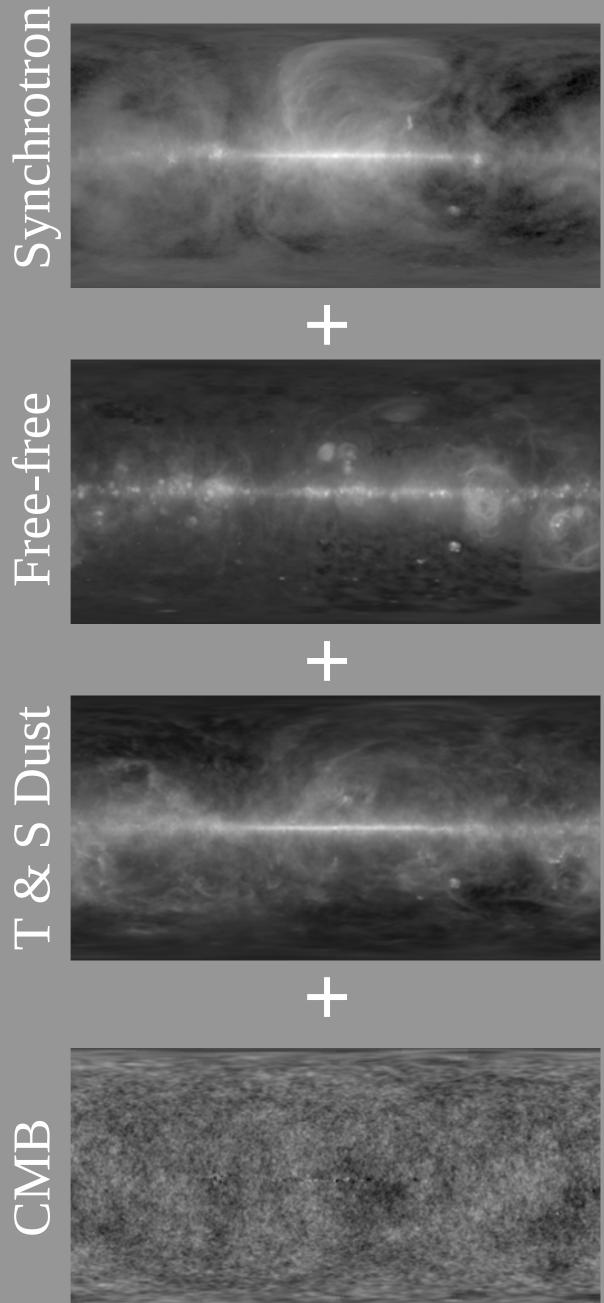




•In addition to CMB photons, WMAP data is "contaminated" by a number of galactic foregrounds that must be accurately subtracted

•The WMAP frequency range is well suited to minimize the impact of foregrounds

•Substantial challenges are involved in identifying and removing foregrounds



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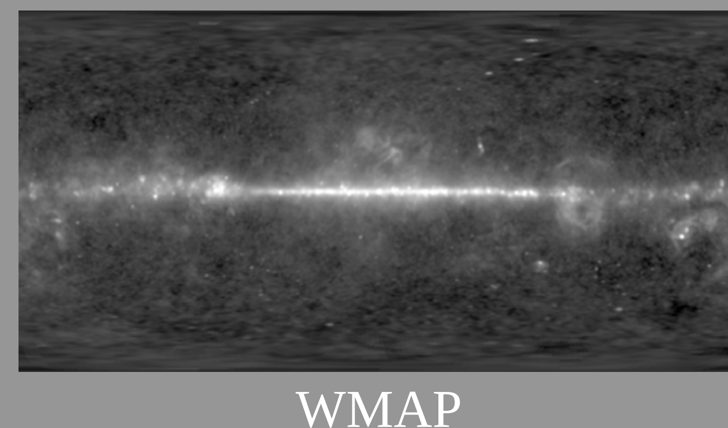
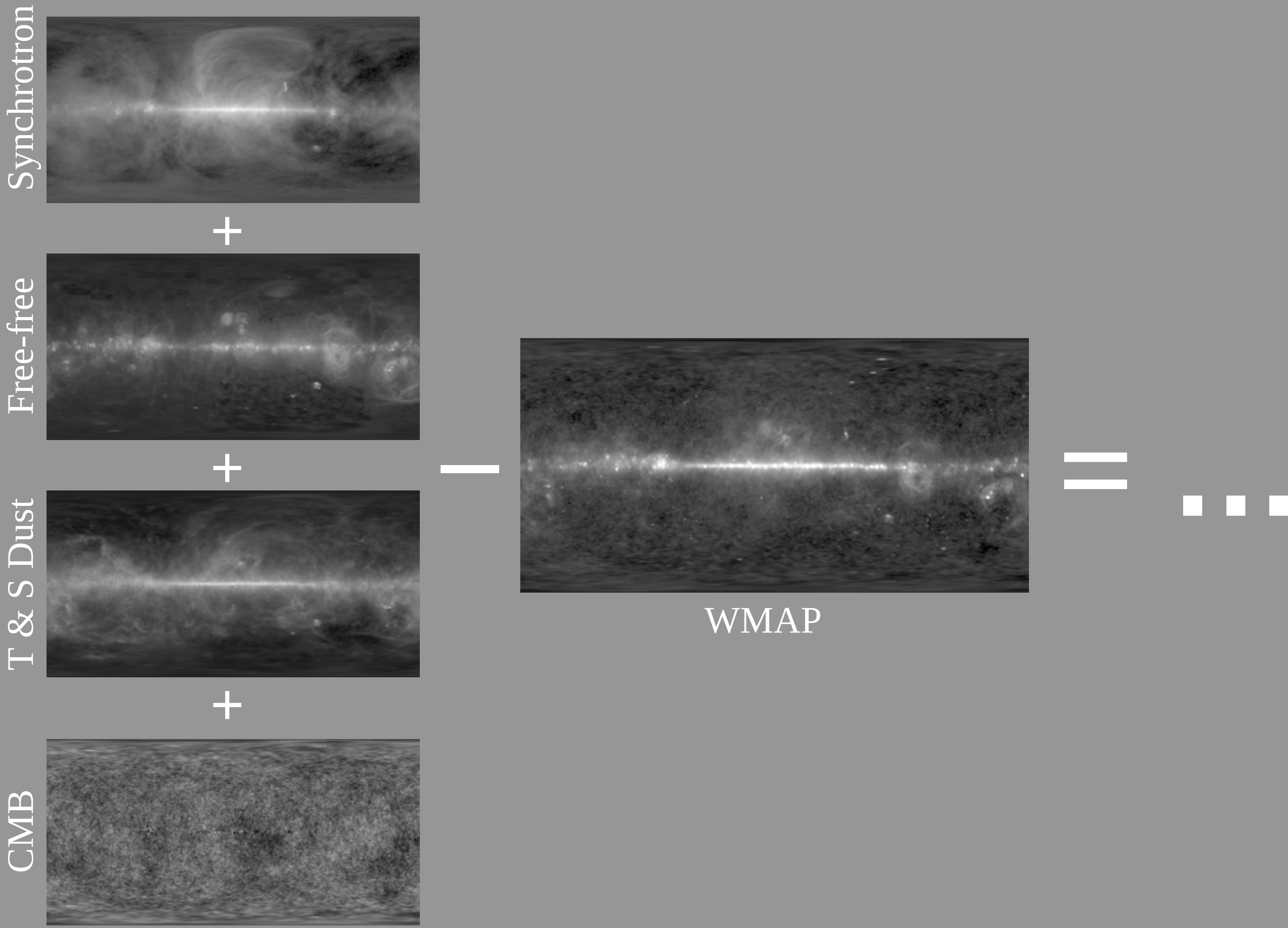
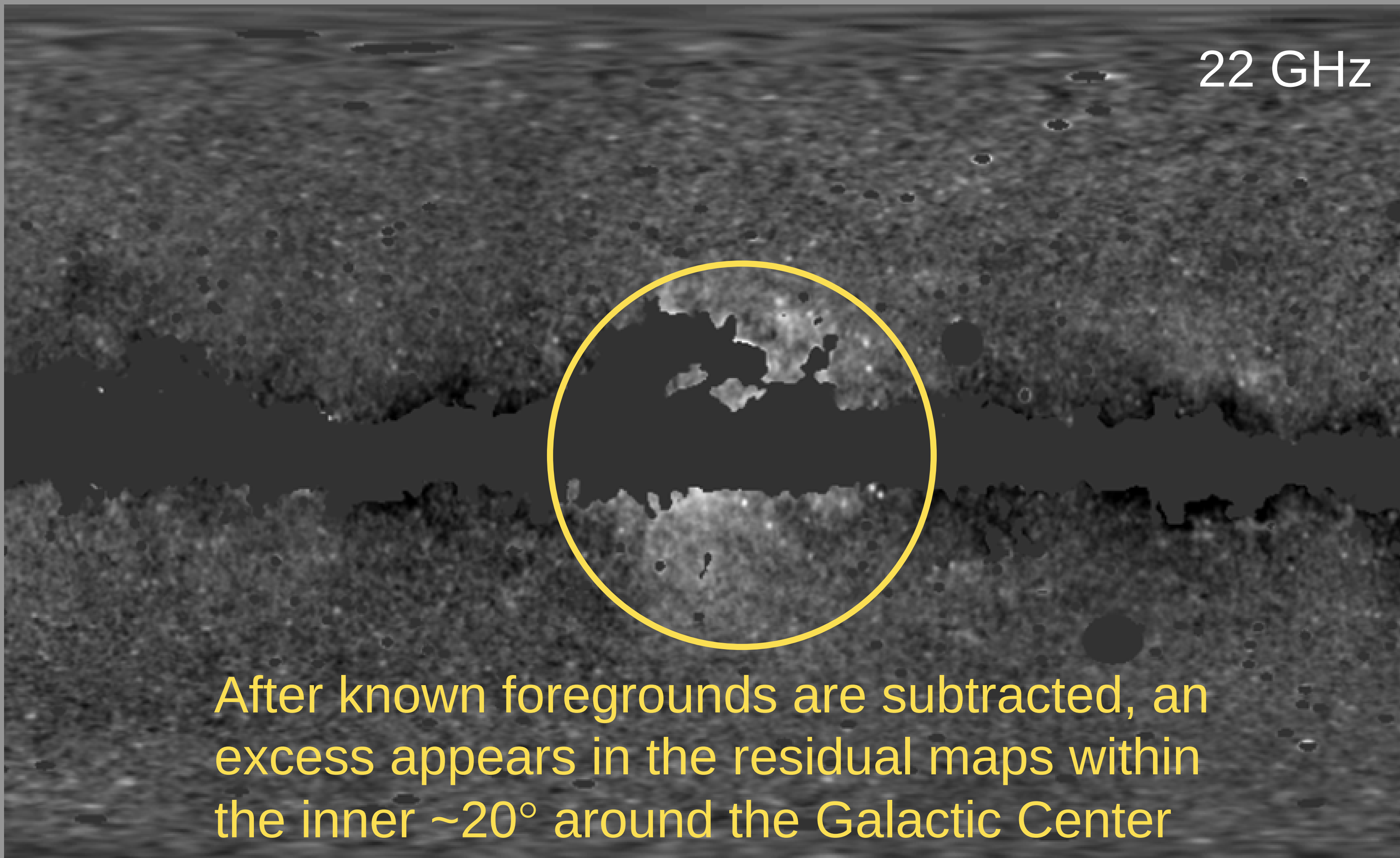


Well, actually… No


Synchrotron
+
Free-free
+
T & S Dust
+
CMB
−
WMAP
=
. . .

The “WMAP Haze”



After known foregrounds are subtracted, an excess appears in the residual maps within the inner ~20° around the Galactic Center

D. P. Finkbeiner, Astrophys. J. 614 (2004) 186 [arXiv:astro-ph/0311547].
G. Dobler and D. P. Finkbeiner, arXiv:0712.1038 [astro-ph].

The “WMAP Haze” ?

The fit procedure used for the haze extraction is quite important, and using more degrees of freedom to model the foregrounds as performed by the WMAP team fails in finding the feature.
The Haze residual should then be interpreted with some caution, given that the significance of the feature is at the moment still debated.

Map of the synchrotron spectral indexes in a pixel by pixel fit procedure by WMAP

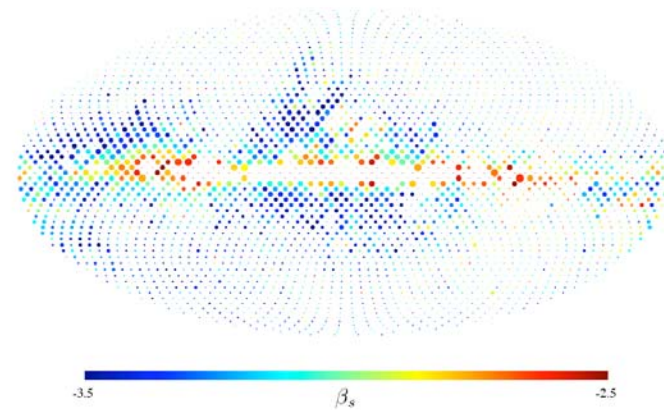
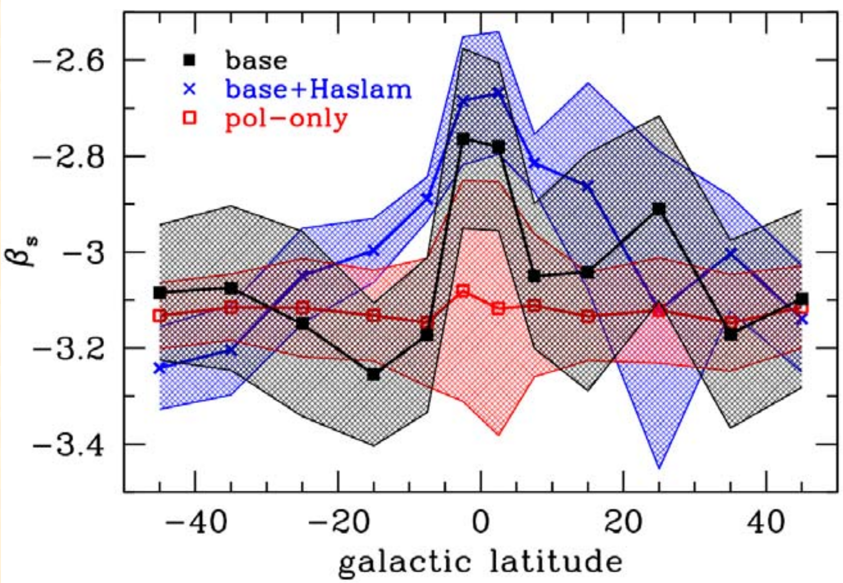


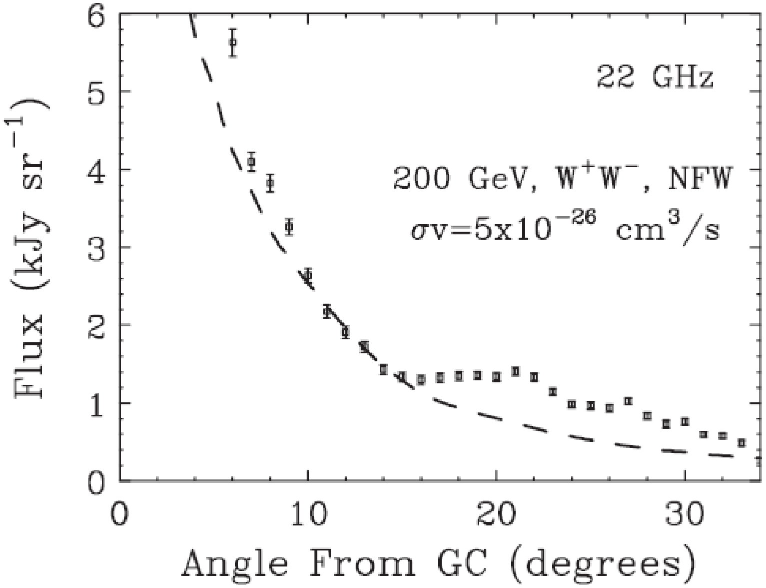
Fig. 11.— Map of synchrotron spectral index for the “base” fit, binned to $N_{side} = 16$. Color shows the value of the spectral index, and circle area indicates the weight $\sigma_\beta{}^{-2}$ given by the fit. Pixels with $\chi^2_\nu > 2$ were explicitly de-weighted.

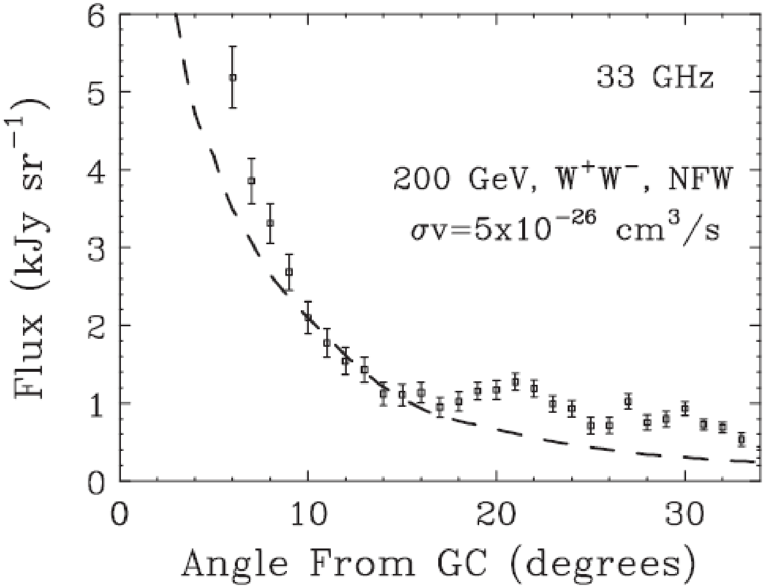
Synchrotron spectral indexes averaged along constant longitudes stripes by WMAP



WMAP Collaboration (B. Gold et al.) 2008 [arXiv:astro-ph/0803.0715].
D.T. Cumberbatch,, arXiv:0902.0039 [astro-ph].

Haze Fit vs Conservative Approach





Haze Fit: Hooper,2007, Hooper et al. 2008

Averaged Haze Profile at 22 and 33 GHz bands, as a function of the angle from the Galactic Center and flux of synchrotron emission from the annihilation products of a 200 GeV neutralino annihilating to WW. A constant ratio Ub/(Ub+Urad) = 0,26 is employed.

Conservative approach:

We assume that the current radio observations are entirely astrophysical in origin, and we derive constraints on the possible DM signal. We use further radio observations besides the WMAP ones, in the wide frequency range 100 MHz-100 GHz

Details of the Calculations

Propagation equation for e+e-

$$\frac{\partial}{\partial t}\frac{dn_e}{dE_e} = \vec{\nabla}\cdot\left[K(E_e,\vec{r})\vec{\nabla}\frac{dn_e}{dE_e}\right] + \frac{\partial}{\partial E_e}\left[b(E_e,\vec{r})\frac{dn_e}{dE_e}\right] + Q(E_e,\vec{r}), \quad (13)$$

=0 Steady State Solution

Source Term: Injection Spectrum

Diffusion

Energy Losses: ICS and Synchrotron

Complementary and full numerical: **Galprop**, Moskalenko & Strong 98-08

e+e- energy losses: synchrotron vs ICS

$$\frac{dn_e}{dE_e}(E_e,\vec{r}) = \frac{\tau}{E_e}\int_{E_e}^{m_\chi c^2} dE\, Q(E,\vec{r})$$

$$\frac{1}{\tau} = -\frac{1}{E_e}\left(\frac{dE_e}{dt}\right) = \left(\frac{1}{\tau_{syn}} + \frac{1}{\tau_{ICS}}\right)$$

$$\tau_{syn} \cong 4\cdot 10^{17}\left(\frac{B}{\mu G}\right)^{-2}\left(\frac{E_e}{GeV}\right)^{-1} \sec$$

$$\tau_{ICS} \cong 10^{16}\left(\frac{U_{rad}}{eV/cm^3}\right)^{-1}\left(\frac{E_e}{GeV}\right)^{-1} \sec$$

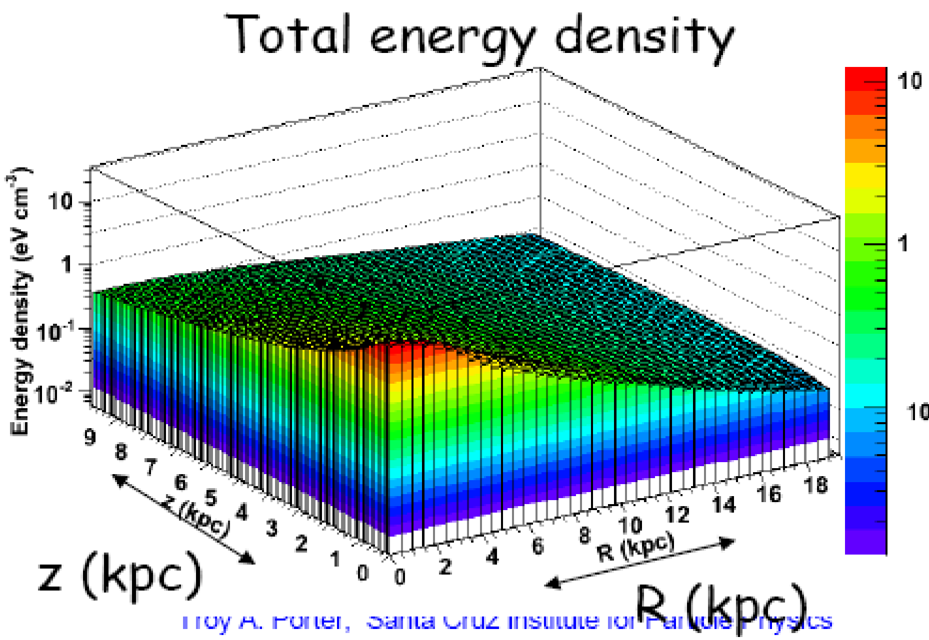
Synchrotron emission and Inverse Compton Scattering (ICS) on the background photons (CMB and starlight) are the faster processes and thus the ones really driving the electrons equilibrium.

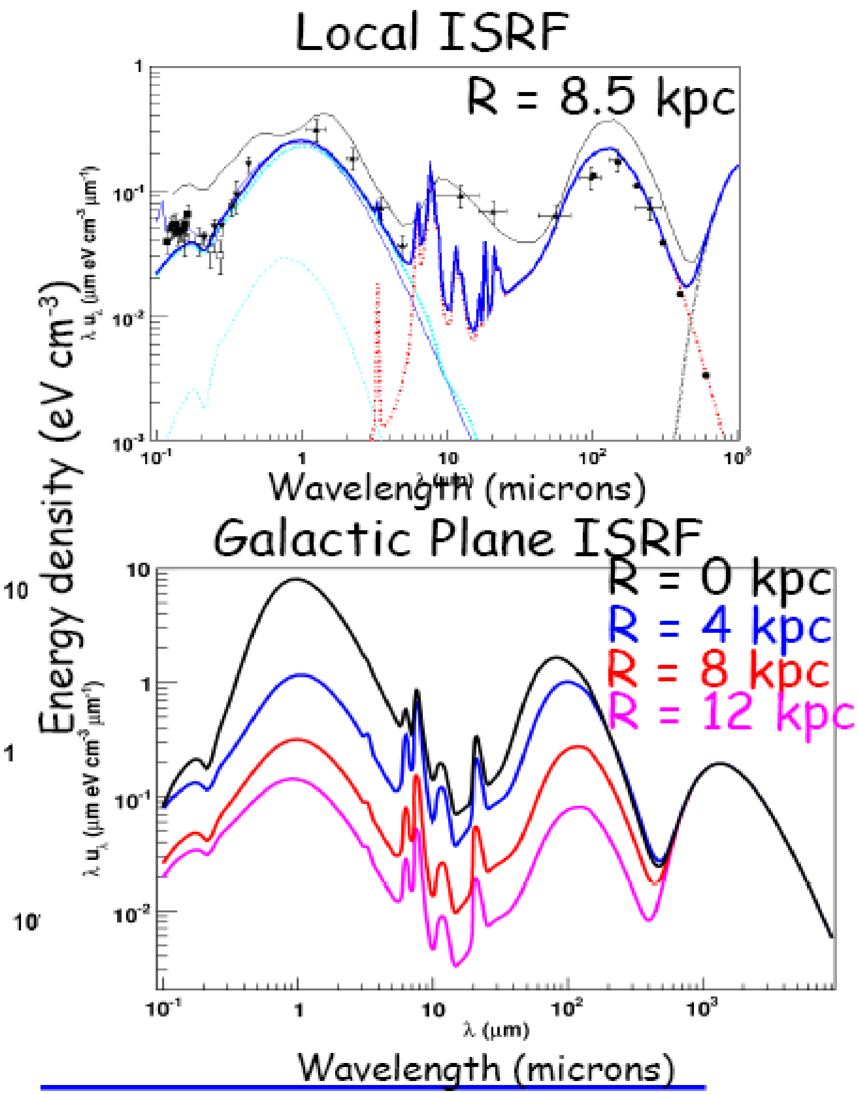
Other processes, like synchrotron self absorption, ICS on the synchrotron photons, *e+e-* annihilation, Coulomb scattering over the galactic gas and bremsstrahlung are generally slower.

Further, ICS is generally dominating over the synchrotron losses.

Interstellar Radiation Field

- Emission by stars and reprocessing by dust
- MC radiative transfer calculation ⇒ self-consistent treatment
- Scale height ~10 kpc → ICS γs by CR $e^{\pm}$ in halo major component





T. A. Porter and A. W. Strong, arXiv:astro-ph/0507119.

Galactic Magnetic Field

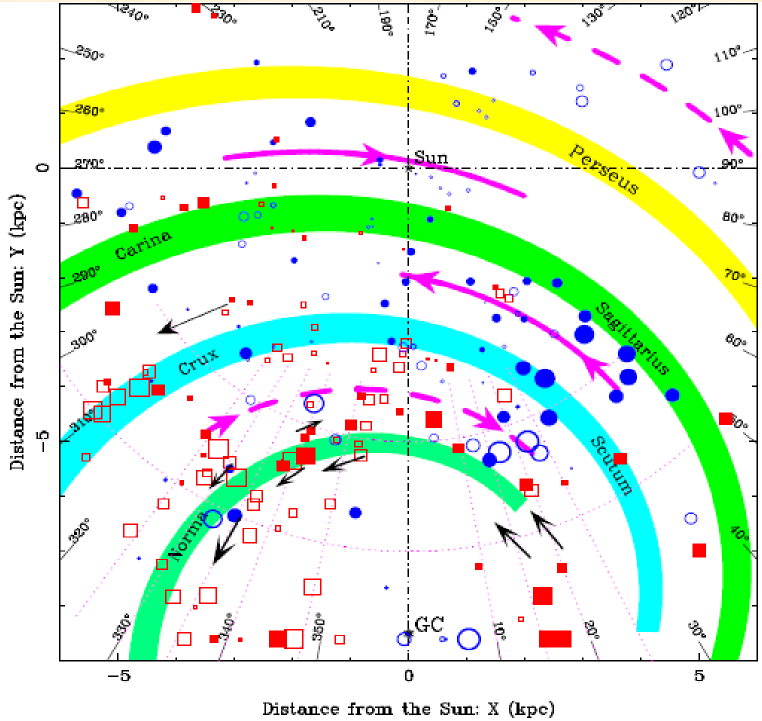
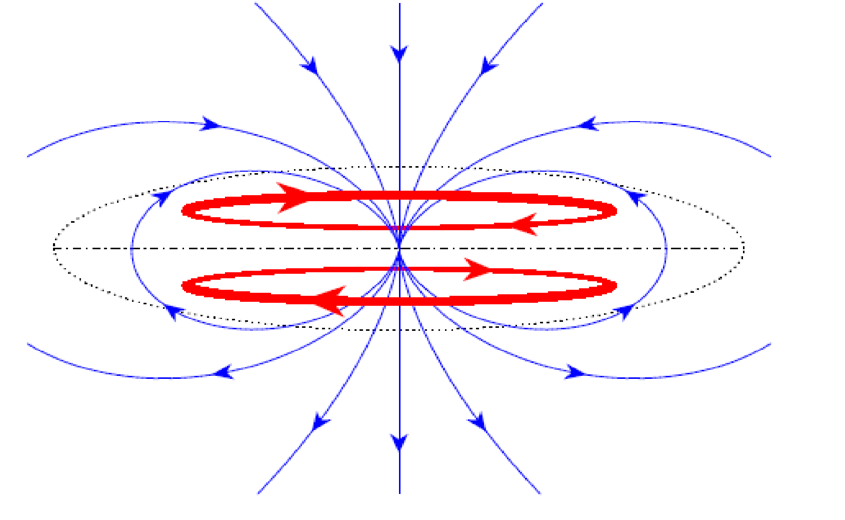


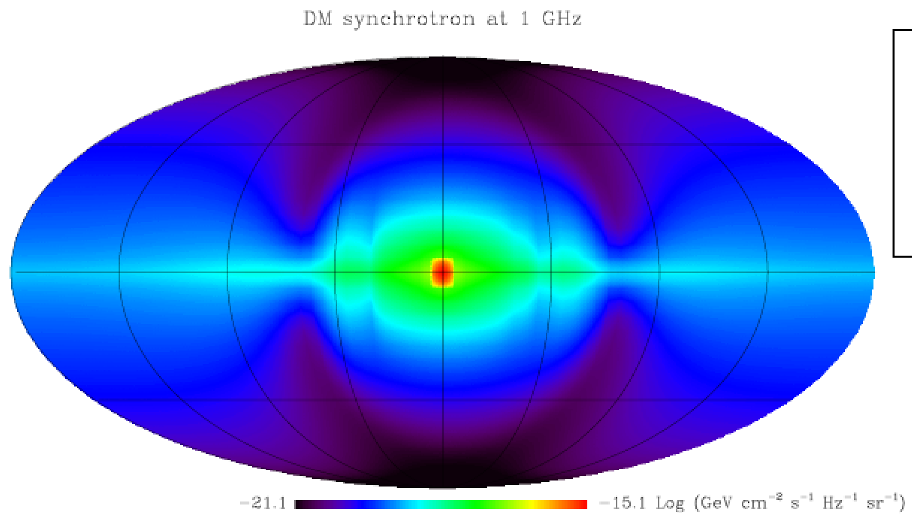
Fig. 4 RMs of pulsars in the Galactic disk reveal the large-scale magnetic fields and the field reversals from arm to arm (after Han et al. 2002).

- The MW magnetic field is still quite uncertain especially near the galactic center.
- The overall structure is generally believed to follow the spiral pattern of the galaxy itself with a normalization of about ~ 1 μG near the solar system.
- *A toroidal or a dipole component is considered in some model.*

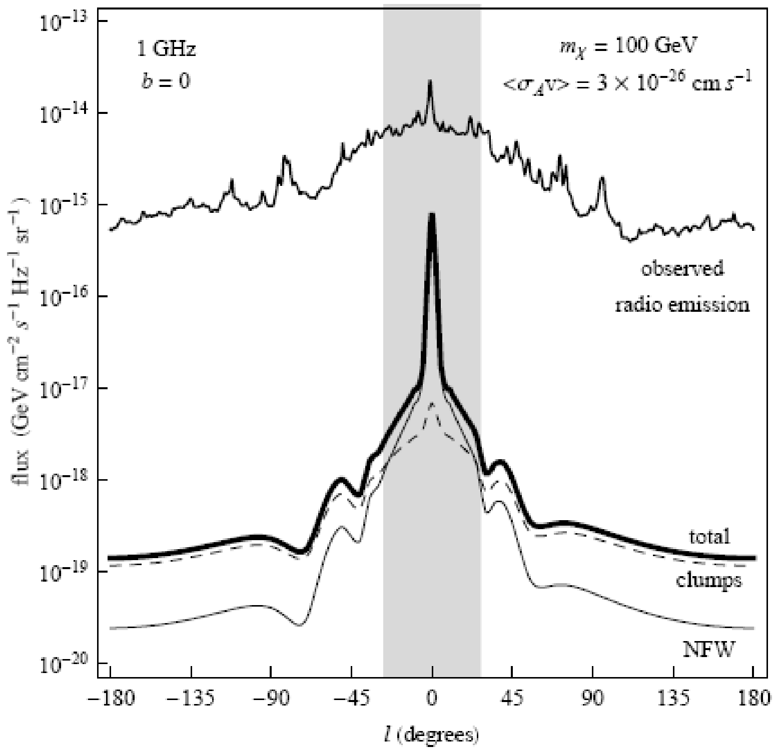


We use a typical spiral pattern, with an exponential decreasing along the z axis and a $1/r$ behavior in the galactic plane.
The field intensity in the inner kpc's is constant to about 7 μG.
P. G.Tinyakov and I. I. Tkachev, Astropart. Phys. 18(2002) 165 [astro-ph/0111305]. M.Kachelriess, M.Teshima, P.D.Serpico Astropart. Phys. 26(2006) 378 [astro-ph/0510444].

DM diffuse signal



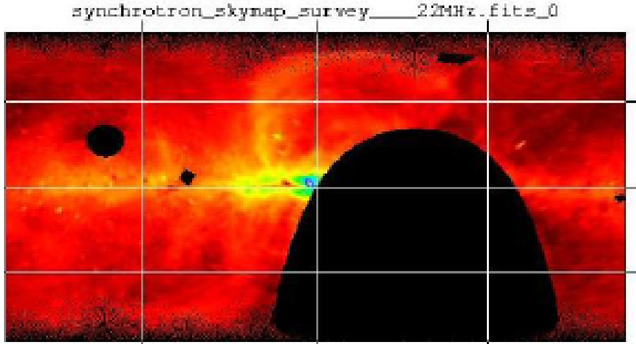
Pattern of the DM synchrotron emission at 1 GHz. The characteristic pattern is given by the line of sight projection of the galactic magnetic field.



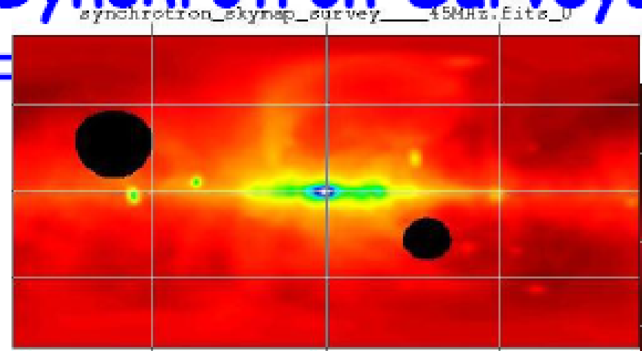
Requiring that the DM signal does not exceed the observed radio emission (CMB cleaned, but not foreground cleaned) DM constraints in the m_χ - $<\sigma Av>$ plane can be derived. The region around the GC (15°x15°) is excluded from the analysis.

DM synchrotron profile for the halo and unresolved substructures and their sum at 1 GHz. The astrophysical observed emission at the same frequency is also shown. The gray band indicates the angular region within which the DM signal from the host halo dominates over the signal from substructures

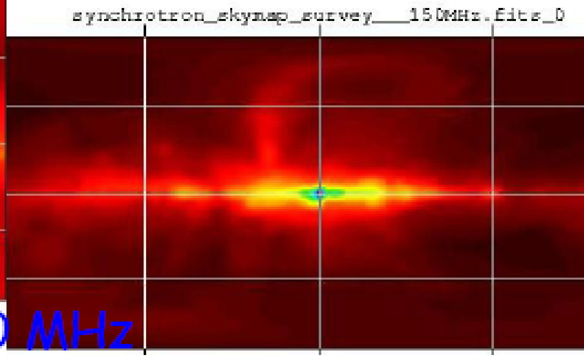
Synchrotron Surveys



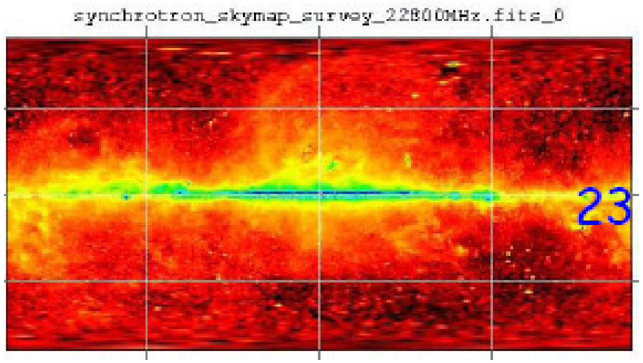
22 MHz



45 MHz



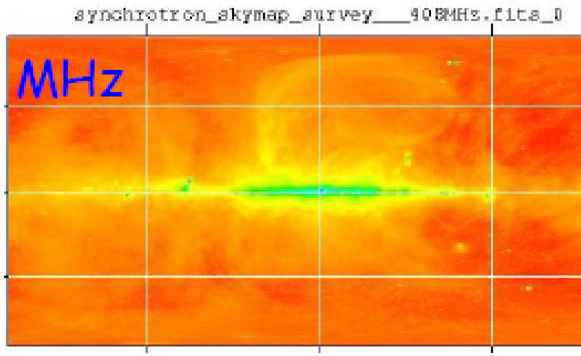
150 MHz

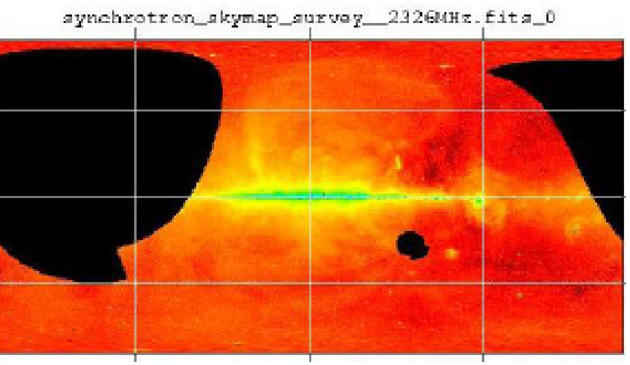


23 GHz

Continuum sky surveys

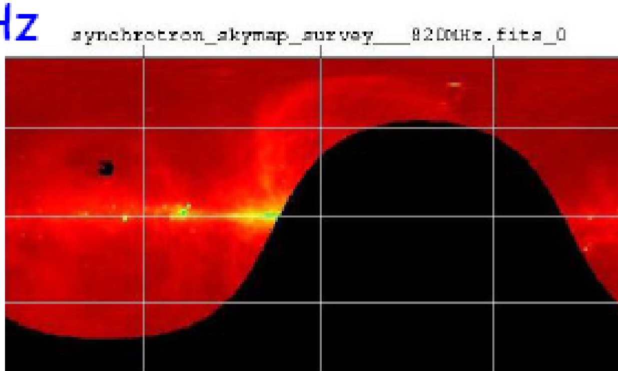
408 MHz



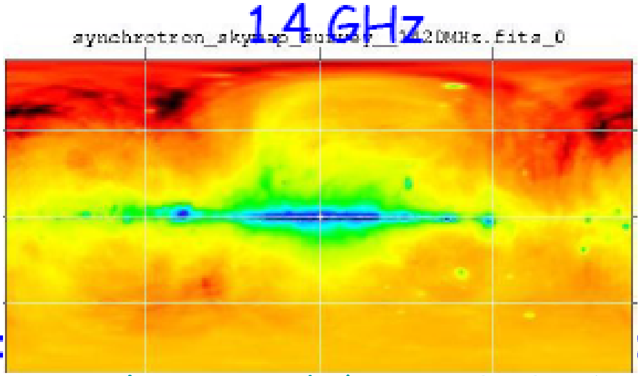


2.3 GHz

820 MHz

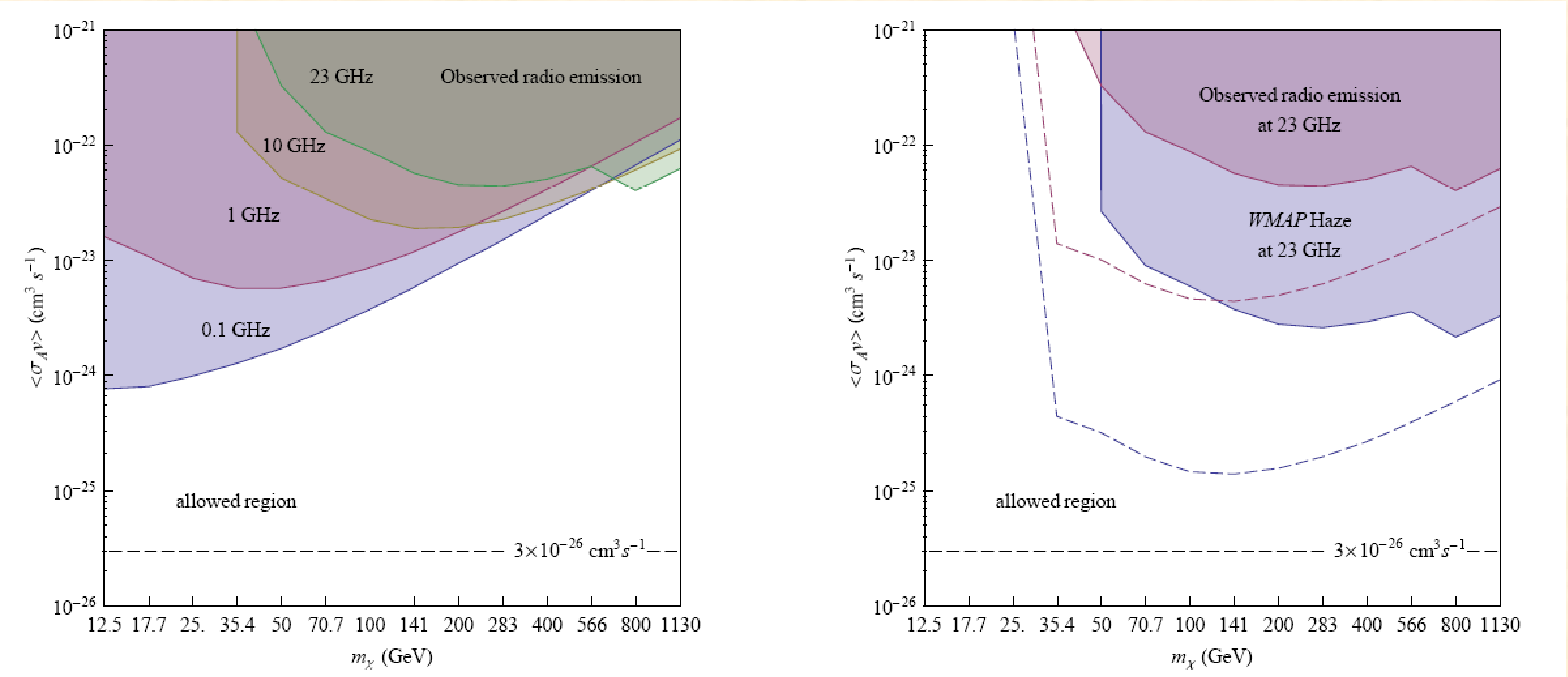


1.4 GHz



See the review De Oliveira-Costa et al. astro-ph/arXiv:0802.1525

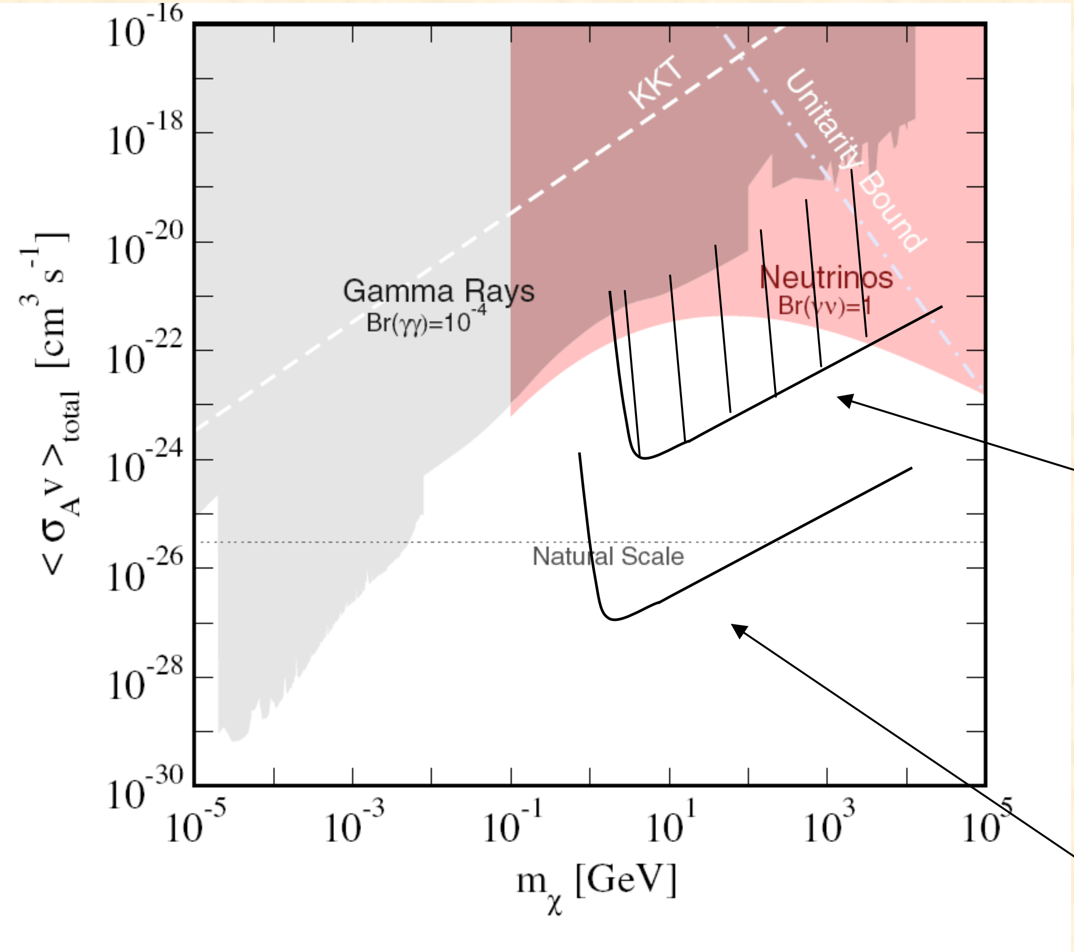
DM constraints in the m_χ-<σ_Av> plane



- Constraints in the m_χ - <σ_Av> plane for various frequencies, without assuming synchrotron foreground removal.
- DM spectrum is harder than background, thus constraints are better at lower frequencies.

- Constraints from the WMAP 23 GHz foreground map and 23 GHz foreground cleaned residual map (the WMAP Haze) for the TT model of magnetic field (filled regions) and for a uniform 10 μG field (dashed lines).
- With a fine tuning of the MF is possible to adjust the DM signal so that to match the Haze, like in Hooper et al.

Complementary Constraints



Conservative Gamma and neutrino Constraints from
H. Yuksel et al. P.R.D76:123506,2007,
G.D. Mack et al. P.R.D78:063542,2008,
M.Kachelriess and P.D.Serpico P.R.D76:063516,2007

Conservative Synchrotron Constraints from the halo
E.Borriello, A.Cuoco, G.Miele P.R.D79:023518,2009

Expected from Fermi-Glast from observation of the halo
E.A.Baltz et al. JCAP 0807:013,2008

e+e- direct mesurements: Pamela/ATIC

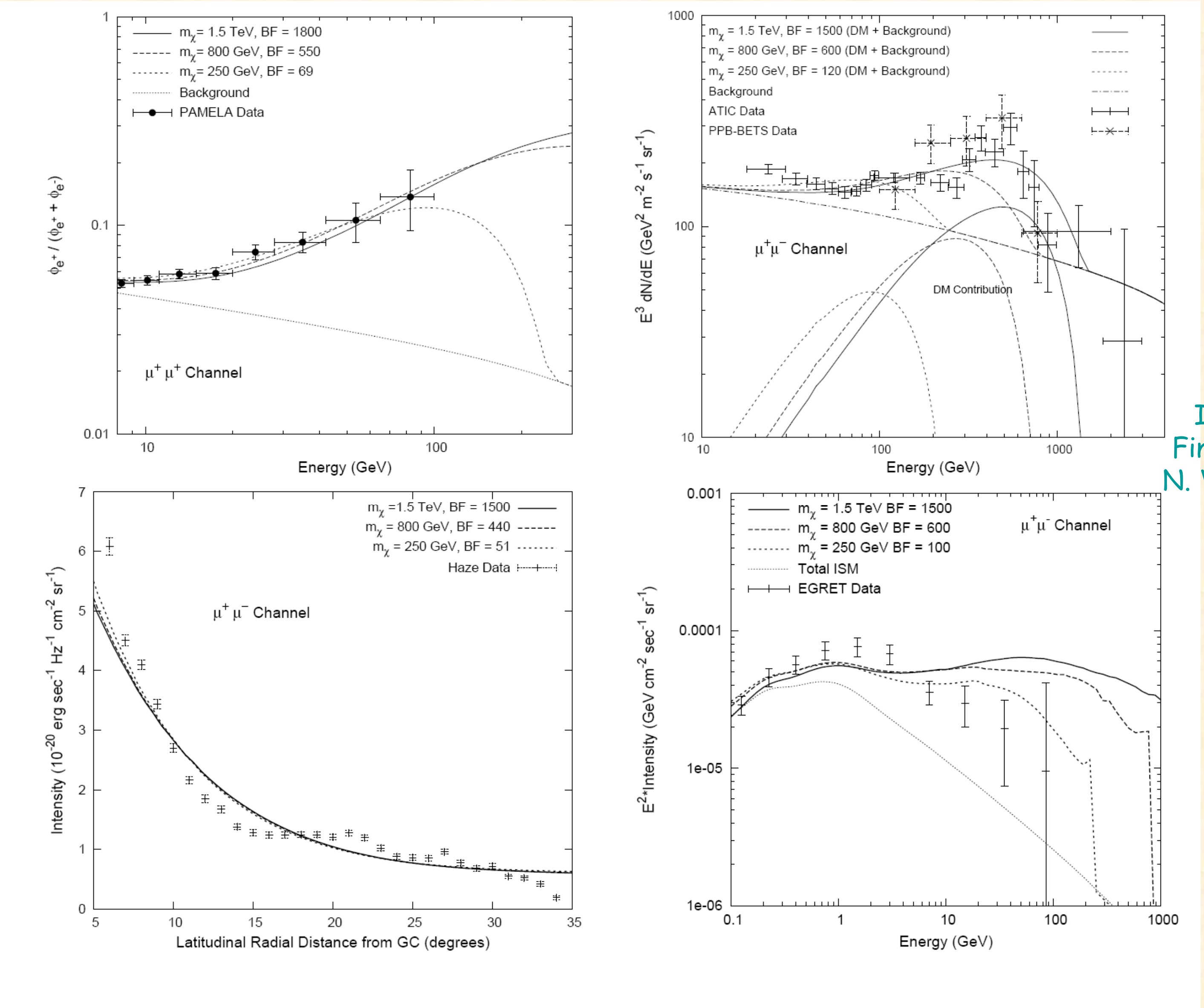
Anomalies in the positron fraction and e+e- total flux seen Pamela and ATIC

O.Adriani et al. arXiv:0810.4995 [astro-ph] , arXiv:0810.4994 [astro-ph], J.Chang et al. Nature 456, 362 (2008)

Both the signals seems to have the same origin:

- A nearby pulsar(s)?
- A DM clump?
- Relation with the WMAP Haze?

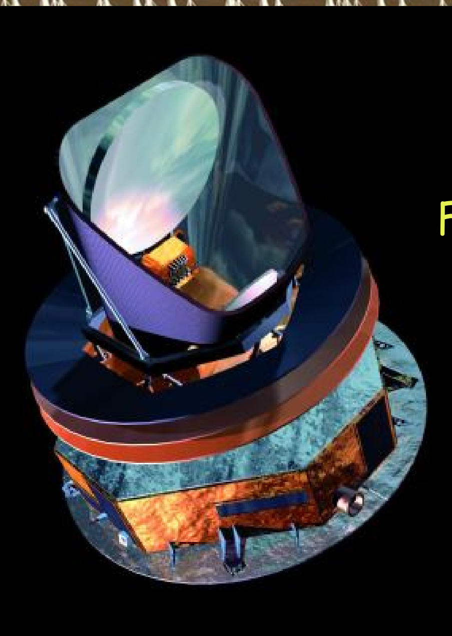
The e+e-/Synchrotron-ICS connection



I.Cholis, G.Dobler, D.P. Finkbeiner, L.Goodenough, N. Weiner, arXiv:0811.3641 [astro-ph]

Other multi-wavelenght studies: E.Nardi, F.Sannino, A.Strumia, arXiv:0811.4153 [astro-ph], G.Bertone, M.Cirelli, A.Strumia, M.Taoso , arXiv:0811.3744 [astro-ph], L.Bergstrom, G.Bertone, T.Bringmann, J.Edsjo, M.Taoso, arXiv:0812.3895 [astro-ph] K.Ishiwata, S.Matsumoto, T.Moroi, arXiv:0811.4492 [astro-ph], J.Zhang et al., arXiv:0812.0522 [astro-ph]

The Future: SKA and PLANCK



PLANCK
Launch: April 2009
Frequencies: 30-1000 GHz

Square Kilometer Array(SKA)
Location: South-Africa or Australia
Start: 2015-2020
Frequencies: 0.1-10 GHz

LOFAR
Location: Netherlands
Completion: 2009
Frequencies: 40-200 MHz