IPhT CEA-Saclay

Marco Taoso

Modeling the galactic and extragalactic radio emission

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LAPTh , Annecy

03 April 2014

Outline

Determination of extragalactic radio bkg from maps

- motivation
- modeling of galactic emission, cosmic-rays, magnetic fields
- results

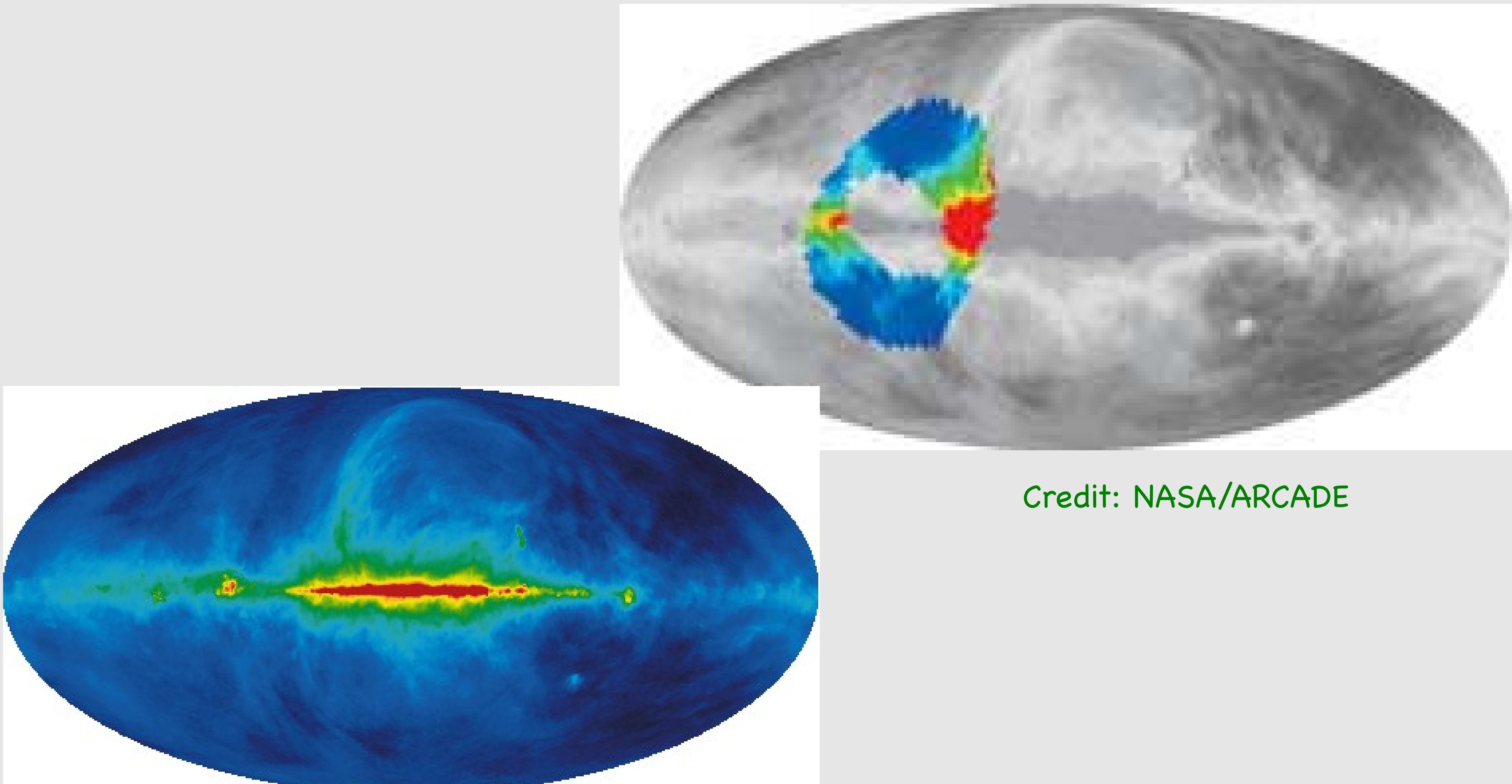
Radio emission from Dark Matter annihilations

- bounds on galactic DM
- signals from extragalactic halos

Based on: Phys. Rev. Lett.107 (2011) 271302, JCAP 1201 (2012) 005,
JCAP 1203 (2012) 033, JCAP xxxx (2014) xxx

ARCADE-2 estimation of ERB

ARCADE-2 baloon: 6 frequencies from 3-90 GHz.
Analysis performed on ARCADE data + low frequencies surveys



Credit: NASA/ARCADE

ARCADE-2 estimation of ERB

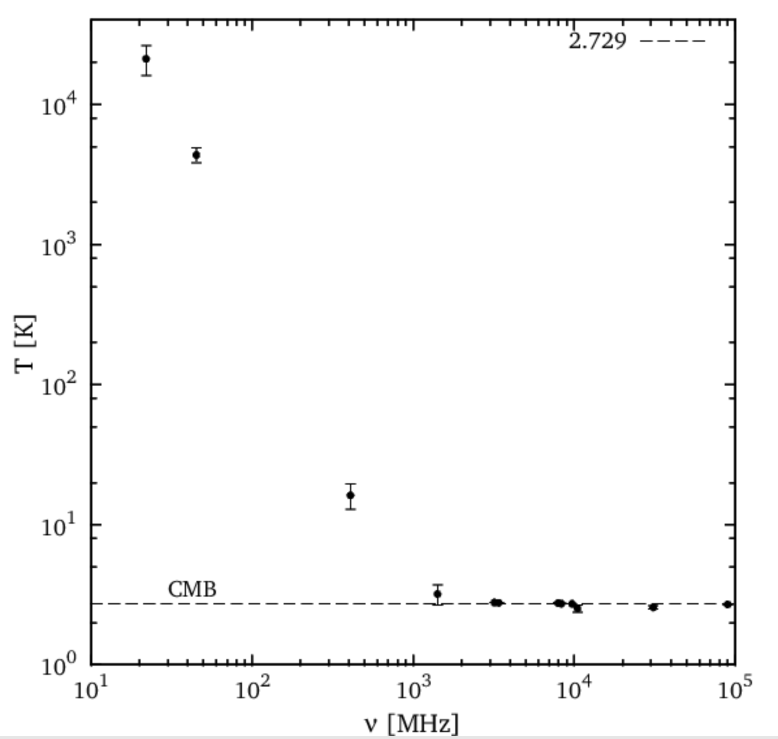
Galactic emission estimated with two methods

- Plane parallel model $$T(b) = T_E + T_G \ \mathrm{cosec}(|b|)$$

- Correlation with C II line

Isotropic emission detected at frequencies below 10 GHz

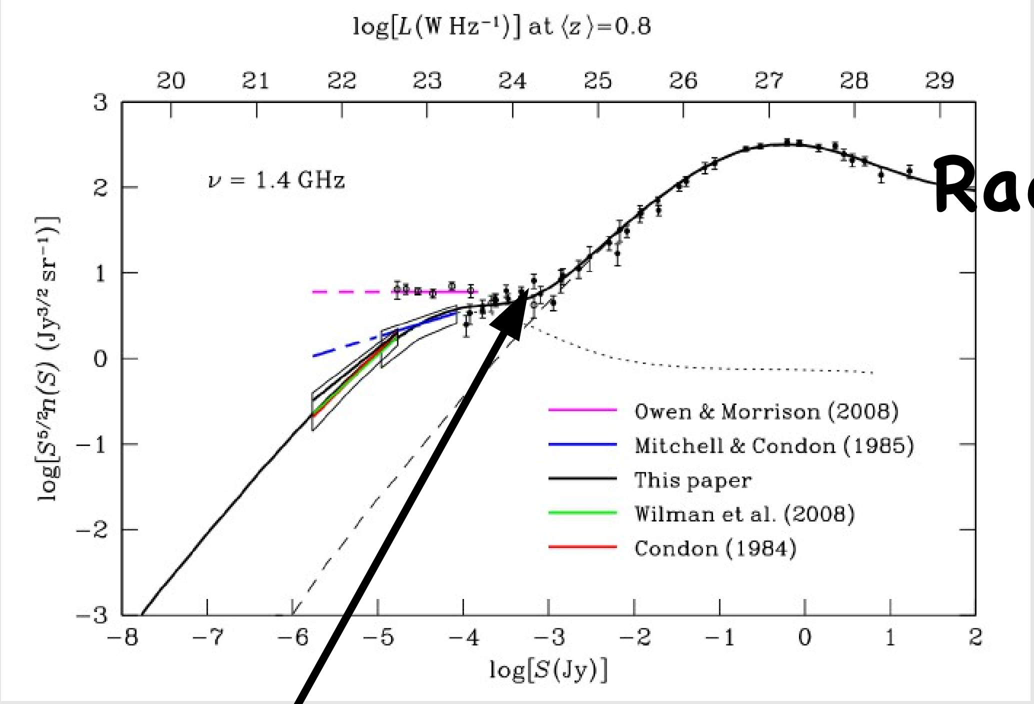
Fixen et al. 2009



IRB from number counts of sources

Comparison with expectation from counts: slope ok but normalization too small
IRB a factor 5-6 larger than expected

$$T_E = \int dT = \frac{c^2}{2\,k_B\,\nu_{obs}^2} \int_0^{S_{\max}} dS\, \frac{dN}{dS}(S)\, S$$



Radio Loud AGN

Vernstron, Scott, Wall 2012

Star Forming Galaxies

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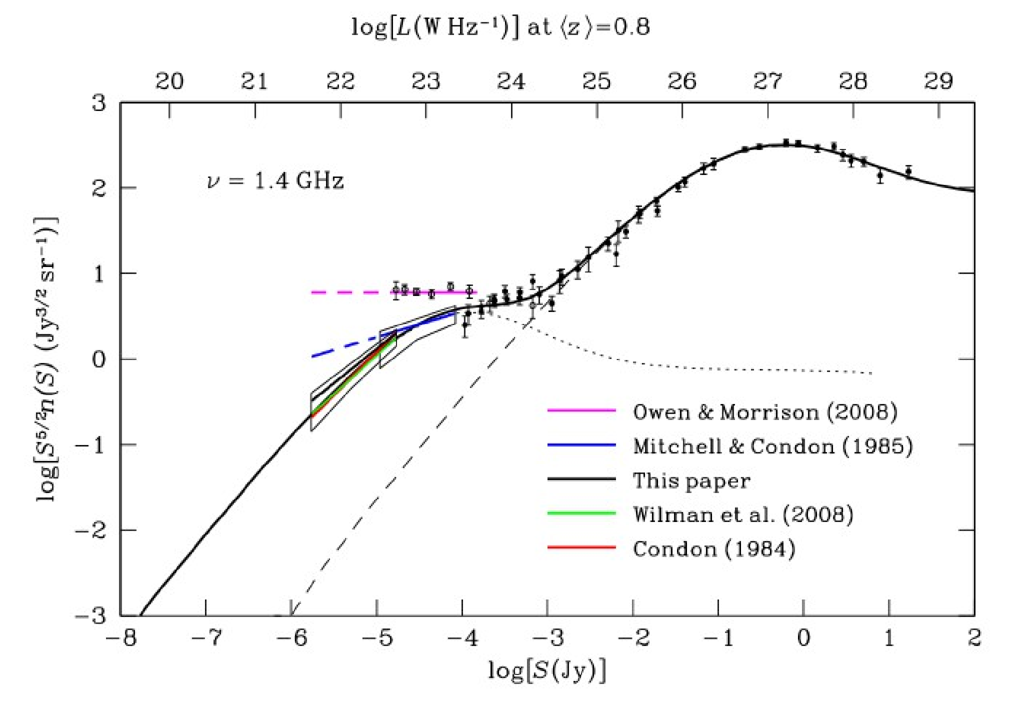
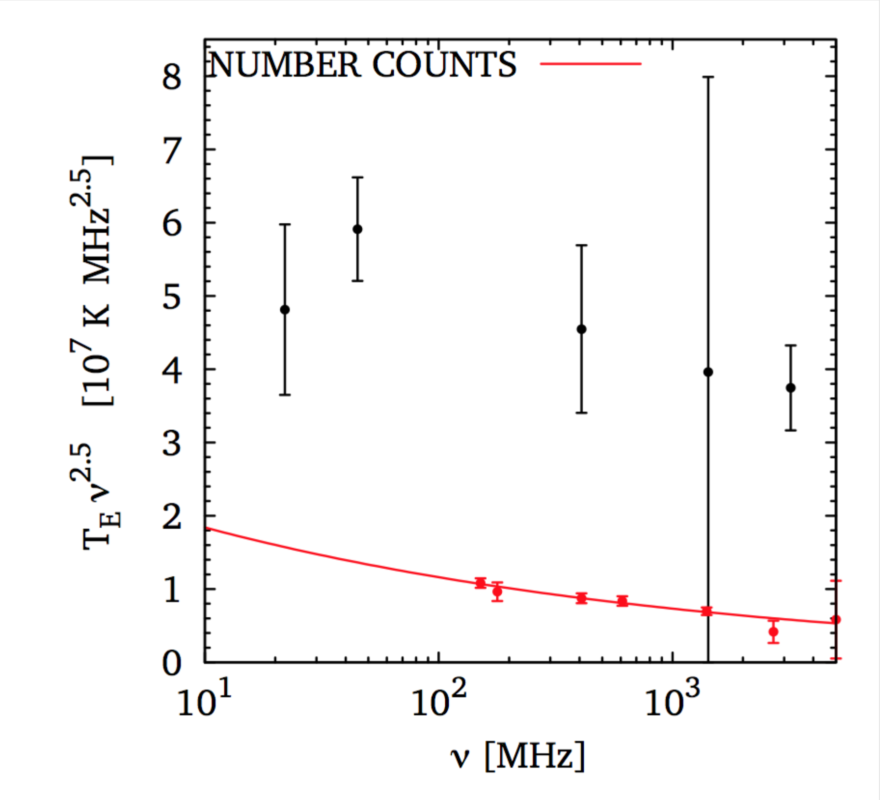
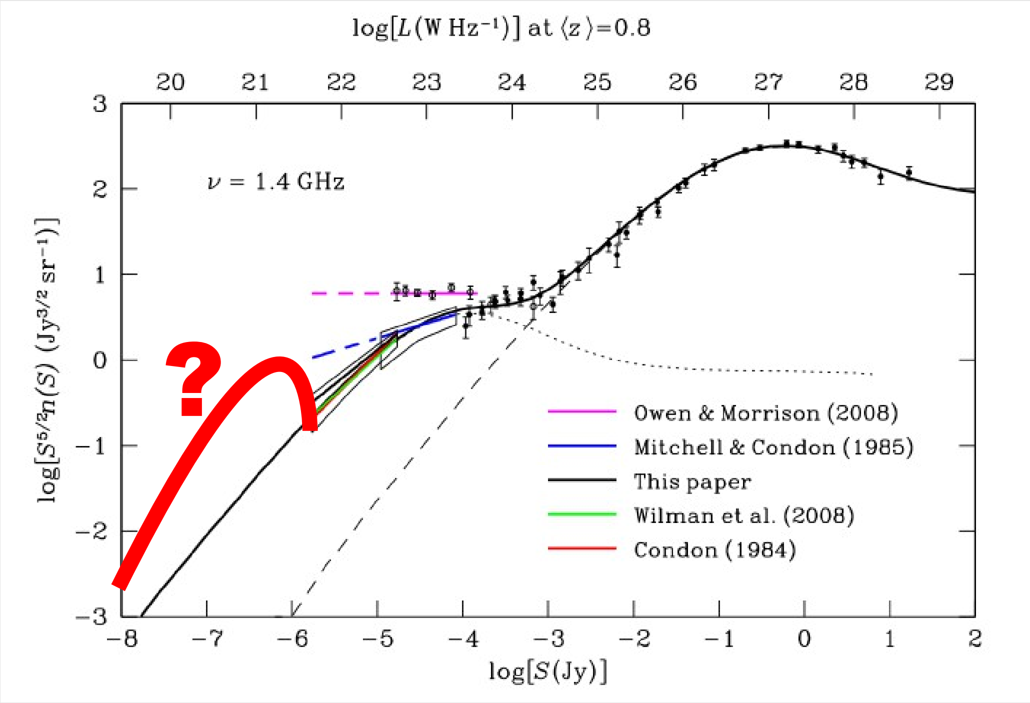


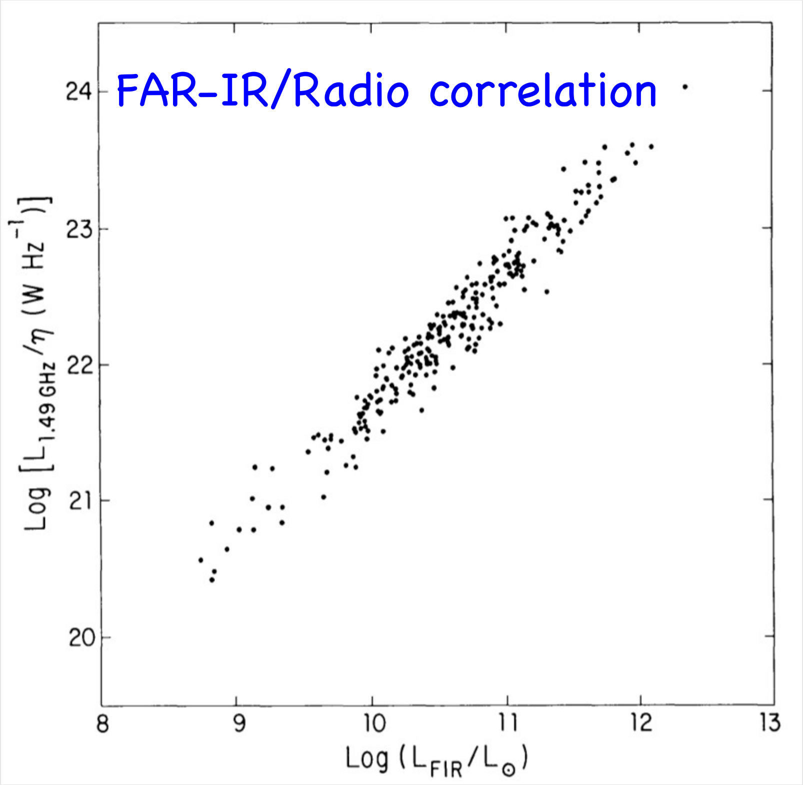


Possible explanations

The excess call for an undetected population of radio sources. Interpretations in terms of standard radio sources challenged by multi-wavelength constraints. E.g. Infrared emission (star-forming galaxies), Gamma-rays (diffuse intra-galactic emission).

See Singal et al. 2010, Lacki 2010, Ponente 2010, ...

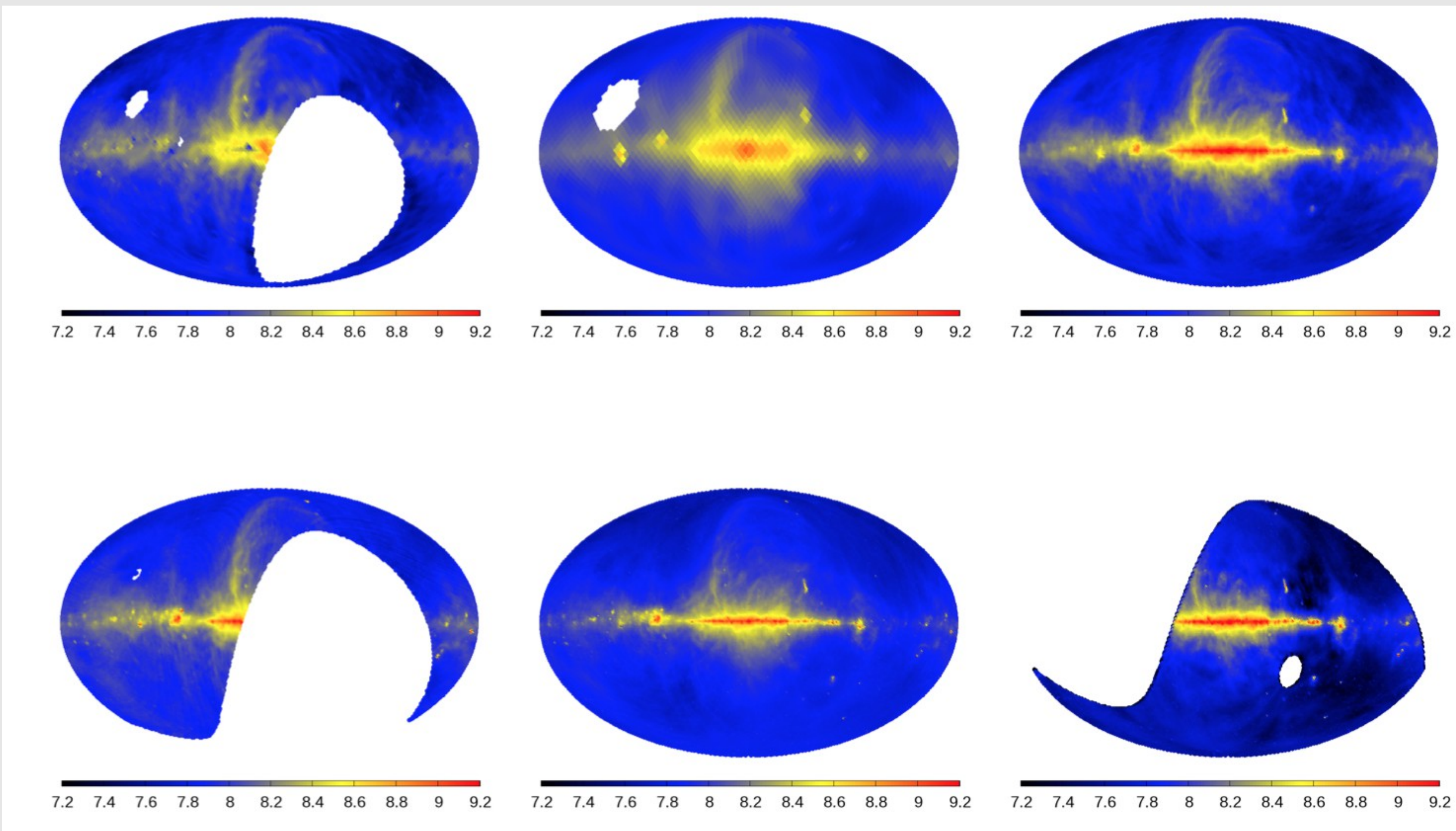




Ordinary Star-Forming galaxies have to break the Radio/IR correlation
More efficient cosmic-rays formation at high z?
Larger magnetic fields?

New evaluation of IRB

Select only radio maps with good sky coverage.
22MHz - 45MHz – 408 MHz – 820 MHz - 1420 MHz - 2326 MHz



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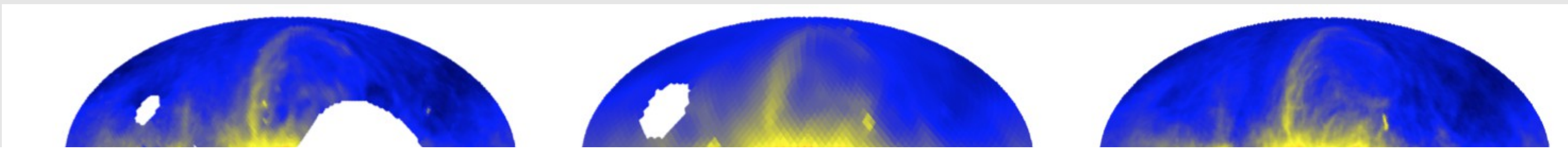
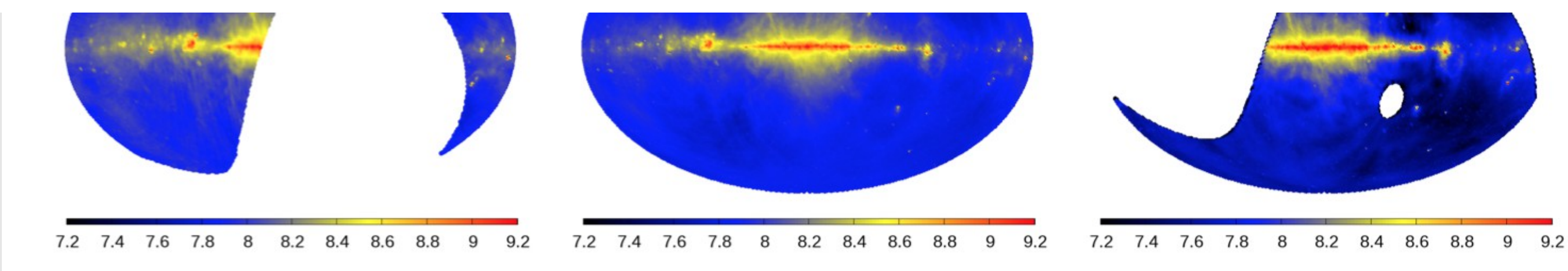


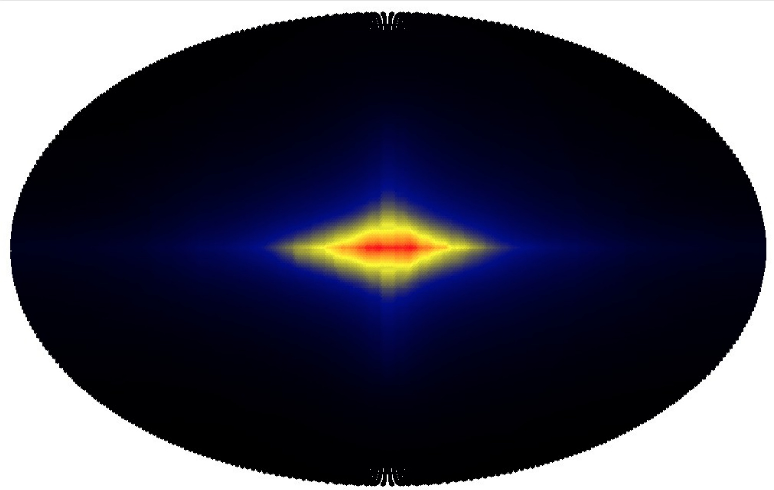
Frequency [MHz]	Angular resolution	rms Noise [K]	Calibration error	Zero-level [K]	Fraction of Sky	Survey reference
22	$1.1^\circ \times 1.7^\circ / \cos Z$	3000	5%	5000	73%	Roger et al. [24]
45	5°	2300/300	10%	544	96%	Guzman et al. [25]
408	0.85°	1.2	10%	3	100%	Haslam et al. [26]
820	1.2°	0.5	6%	0.6	51%	Berkhuijsen [27]
1420	0.6°	0.017	5%	0.2 (0.5)	100%	Reich et al. [29–31]
2326	0.33°	0.03	5%	0.08	67%	Jonas et al. [33]



Galactic emission

3 main components

Diffuse synchrotron emission from cosmic-rays



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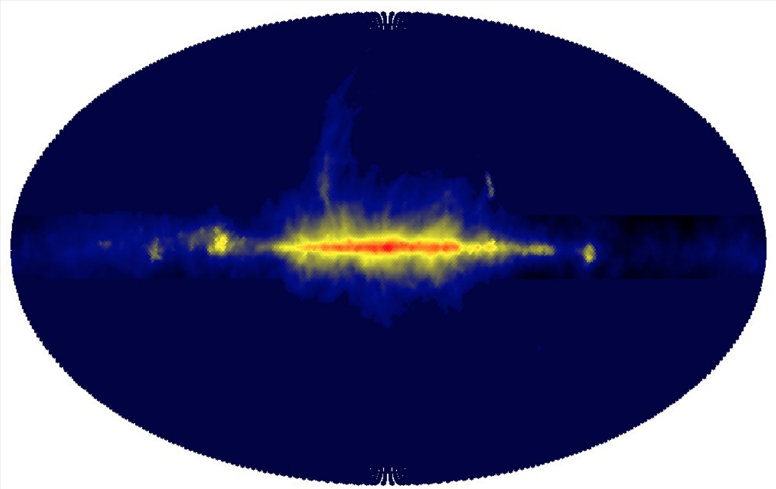
Radio Sources (SNRs)



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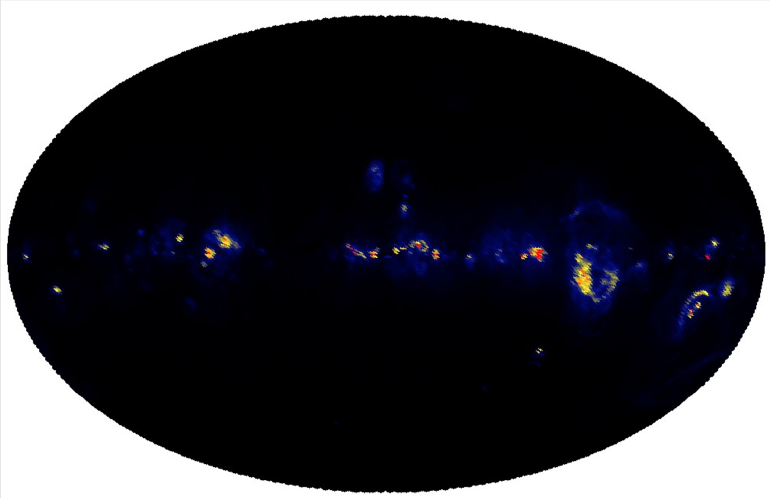
Free-free



Galactic emission

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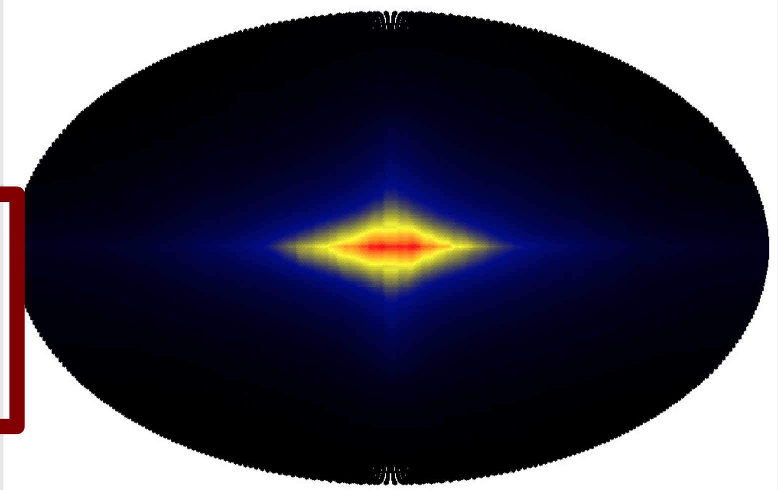

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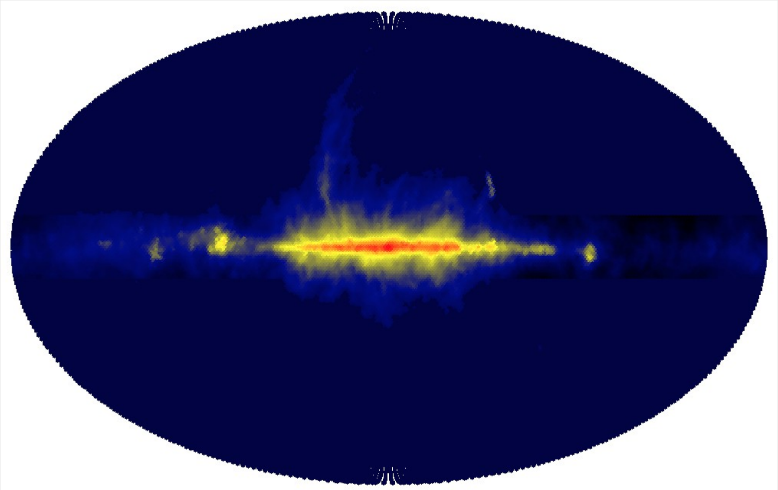
Radio Sources (SNRs)



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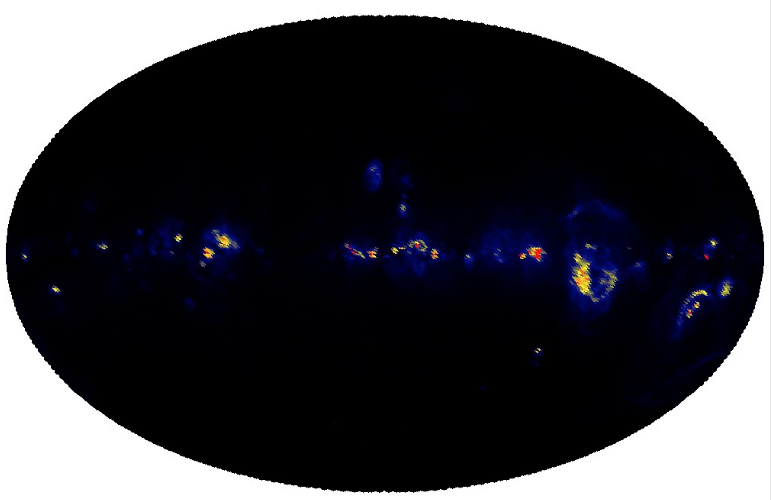
Free-free

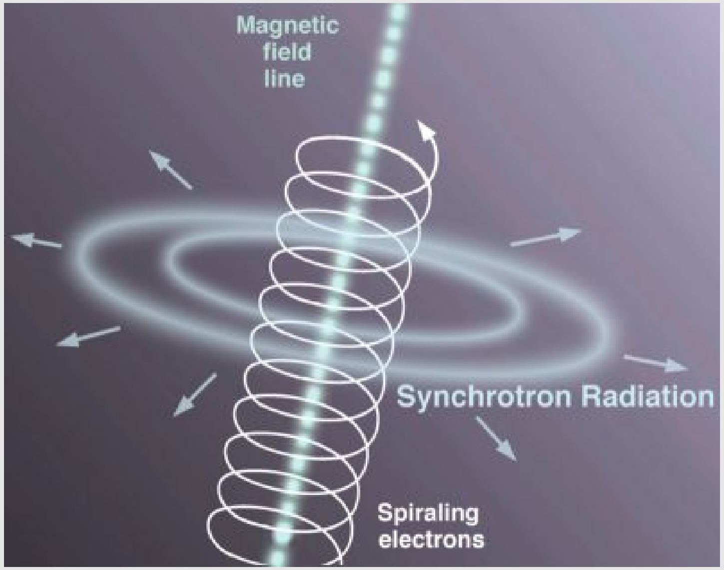


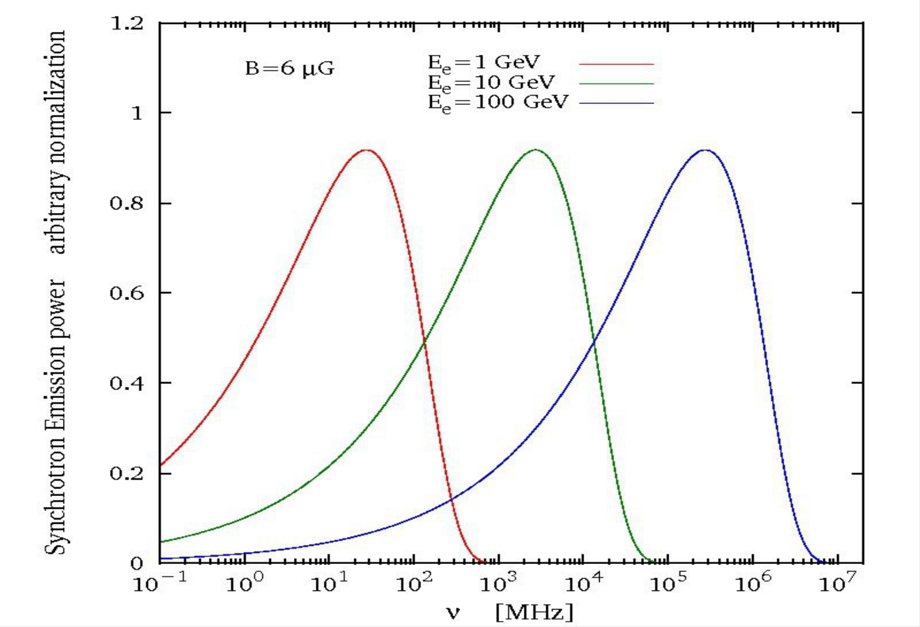
Synchrotron radiation

Large scale synchrotron emission from interaction of cosmic-rays with magnetic fields peaks frequency at

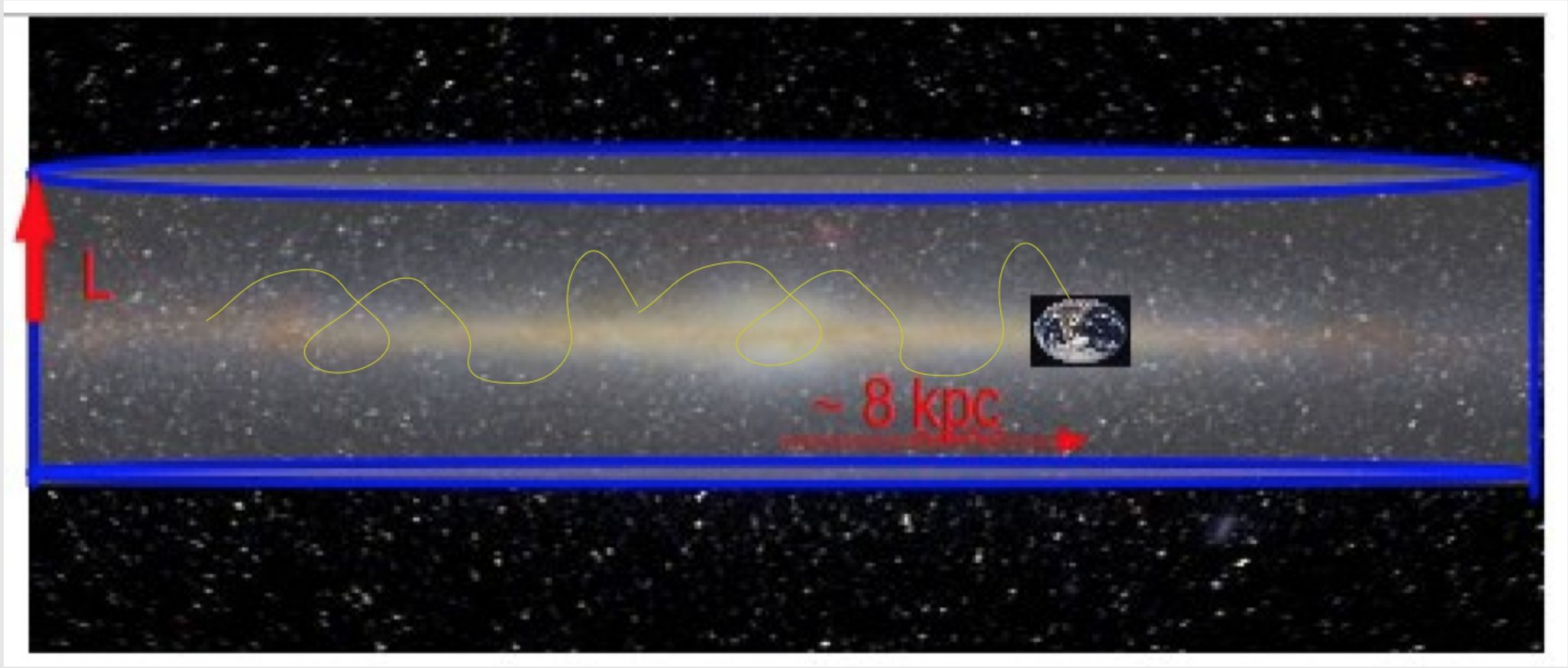
$$\nu \sim 30 \text{ MHz} \, \frac{B}{6\mu G} \left(\frac{E_e}{1GeV} \right)^2$$

Emission in the range of frequencies of our interest from low energy electrons





CR propagation model



$$\frac{\partial n_i(\vec{r},p,t)}{\partial t} = \vec{\nabla}\cdot\left(D_{xx}\vec{\nabla}n_i - \vec{v}_c\, n_i\right) + \frac{\partial}{\partial p}\, p^2 D_{pp}\frac{\partial}{\partial p}\,\frac{1}{p^2}\, n_i - \frac{\partial}{\partial p}\left[\dot{p}\, n_i - \frac{p}{3}\,(\vec{\nabla}\cdot\vec{v}_c)\, n_i\right] + q(\vec{r},p,t) + \frac{n_i}{\tau_f} + \frac{n_i}{\tau_r}$$

Diffusion

Reacceleration

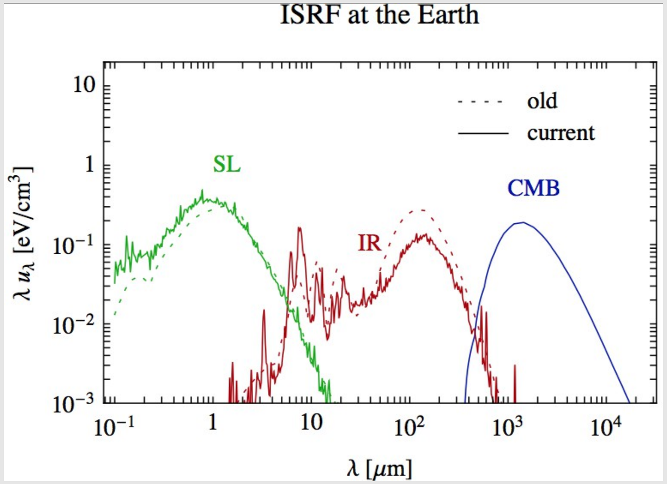
Energy losses

Sources distribution &
Injection spectrum

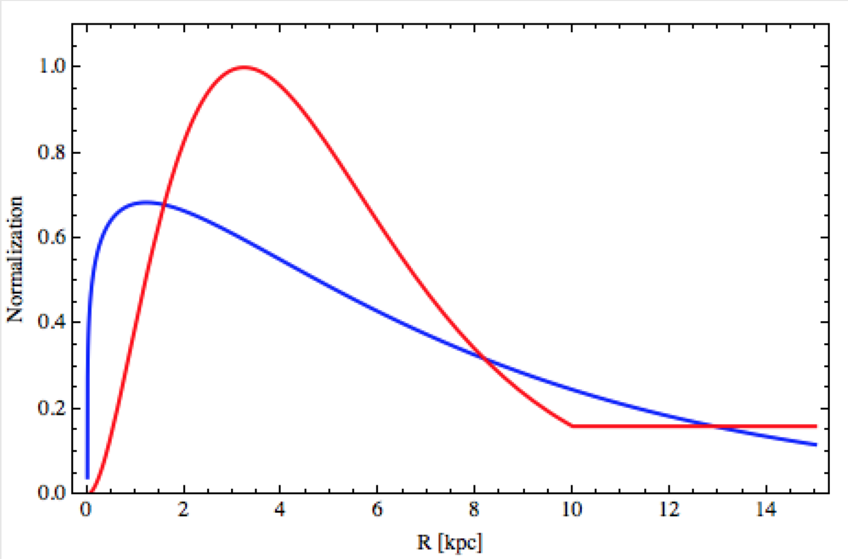
CR propagation model

Interstellar Radiation Field and Gas determine (with Bfield) electrons energy losses
ISRF models from dust-IR observations and Stellar population synthesys

HI maps from 21cm surveys

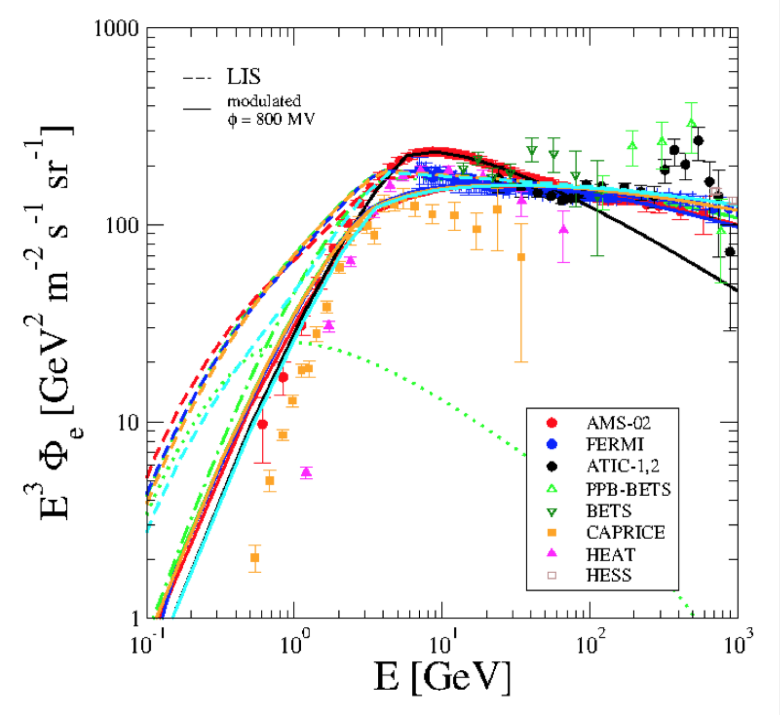


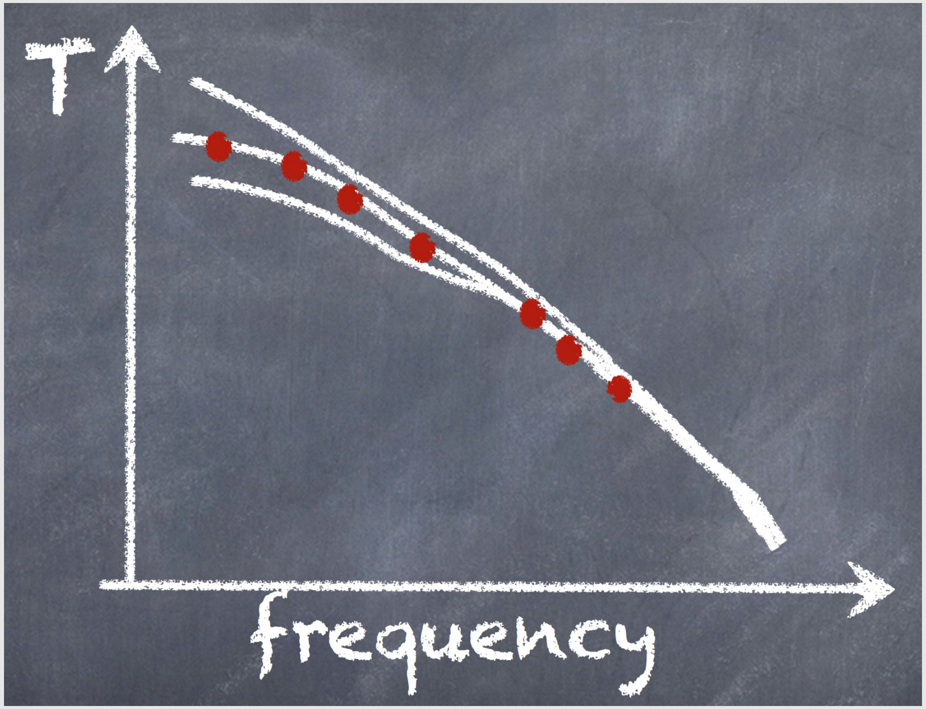
SNRs radial distribution from surveys
We used two models
Distribution in z-direction is exponentially falling with a scale z_s =200 pc
Impact of z_s quite modest since equilibrium density of CRs depends mostly on L & diffusion



Source injection spectrum

Synchrotron emission below GHz is produced by electrons of energies around few GeVs
Solar modulation matters!
Electron spectrum >10 GeV from CRs observations in agreement with microwave surveys at tens of GHz
Need to adjust the low energy electrons injection spectrum to match low frequencies
Radio maps





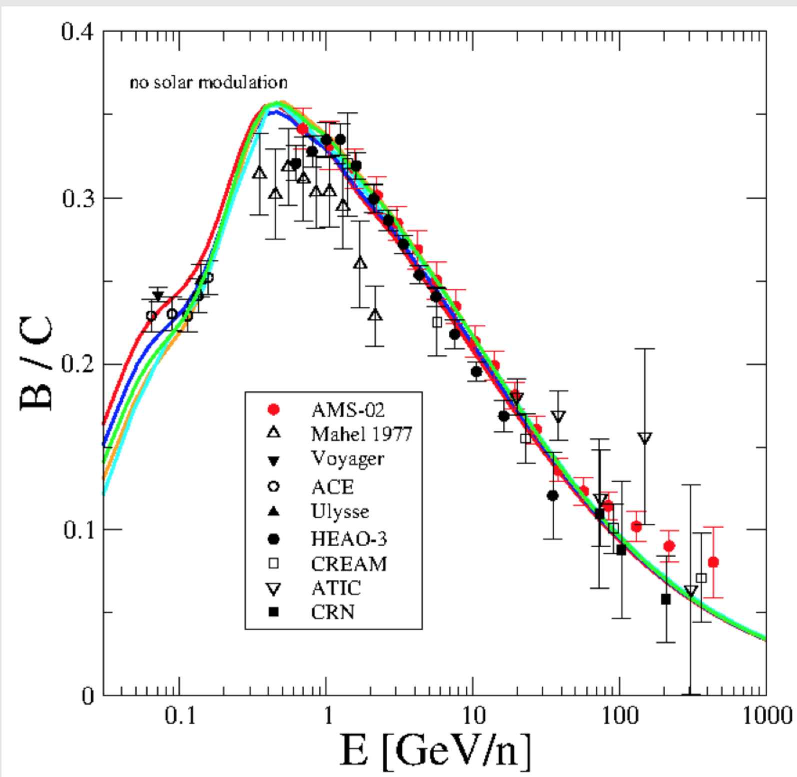
Propagation setup

Not full scan of parameter space but set of benchmark models to study the impact of relevant parameters on synchrotron maps

Size of box L has large impact on radio emission at large latitudes, where IRB is detected

Plain diffusion models constructed to agree with CRs and gamma-ray data

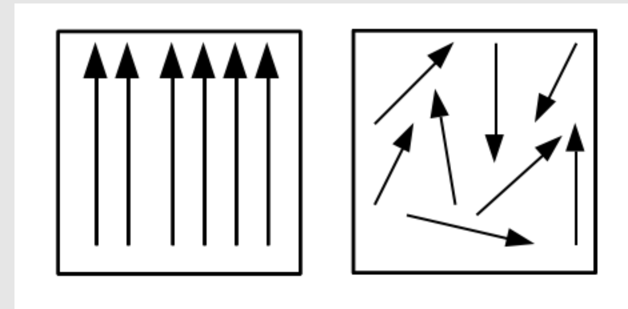
Consider also large values of L, extreme values probably not realistic



code name	L [kpc]	D_0 [10^{28} cm^{2}s^{-1}]	$\beta_{inj,nuc}$	$\beta_{inj,e}$	B_0 [μG]	color coding
L1	1	0.75	1.80/2.3	1.20/2.3	12	red
L2	2	1.7	1.80/2.3	1.20/2.35	8.0	blue
L4	4	3.4	1.80/2.3	1.20/2.35	6.0/7.0	green
L8	8	5.8	1.80/2.3	1.20/2.35	4.6/4.7	orange
L16	16	8.0	1.80/2.3	0.5/2.35	4.0/4.7	cyan
L25	25	8.1	1.80/2.3	0.5/2.35	3.9	maroon
L40	40	8.3	1.80/2.3	0.5/2.35	3.8	brown

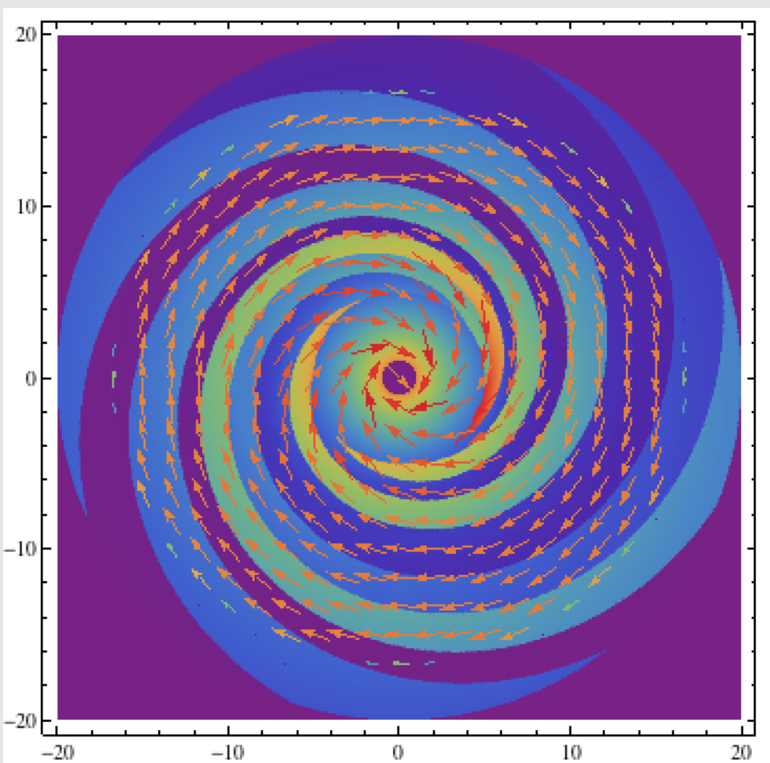
Magnetic fields

The galactic magnetic field contains a large-scale **regular component** + a **random component**



Regular B is trace by Faraday Rotation Measurements of extragalactic sources and polarization synchrotron
We use model containing disk spirals + X halo + Toroidal halo
Obtained from fit of 40000 FRMs + 22GHz WMAP pol. data

Jansson, Farrar 20012



X-Y section at z=0 of B regular

Magnetic fields

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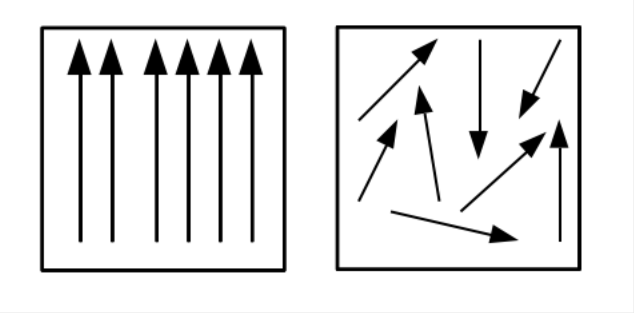

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Simple parametrization for **Random B**

$$B(R, z) = B_0 \exp[-(R - R_T)/R_B] \exp(-|z|/z_B),$$

Two prescriptions for zB

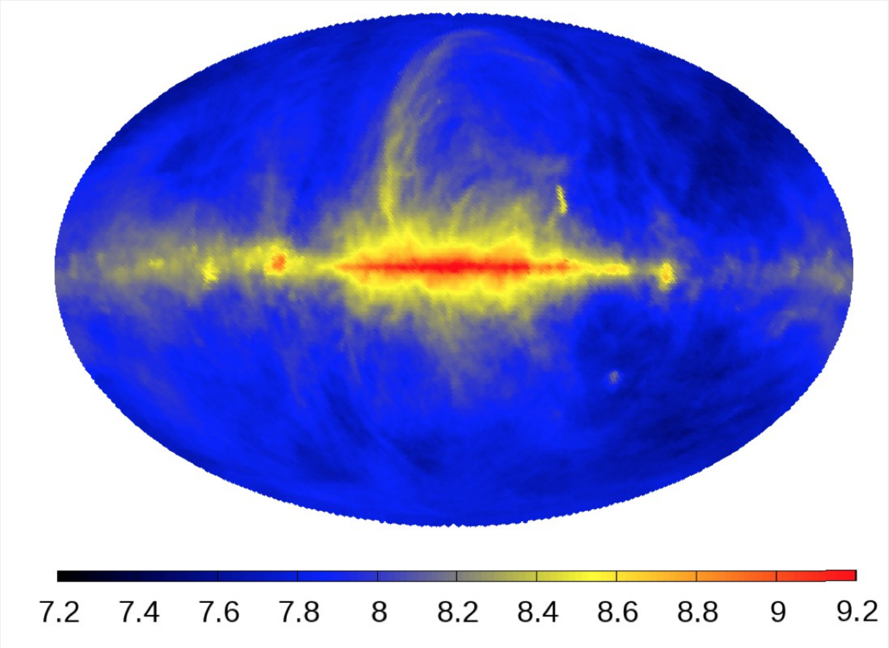
- zB = L, B dies at the boundaries of diffusion box
- zB < L, we fix zB=2 kpc.

Radio sources

Galactic sources are mostly located on galactic plane.
Cut on |b|<10 degrees to reduce contamination

Free-free emission traced by H-alpha recombination line. Since we cut low b emission we found that this template has no impact on our analysis

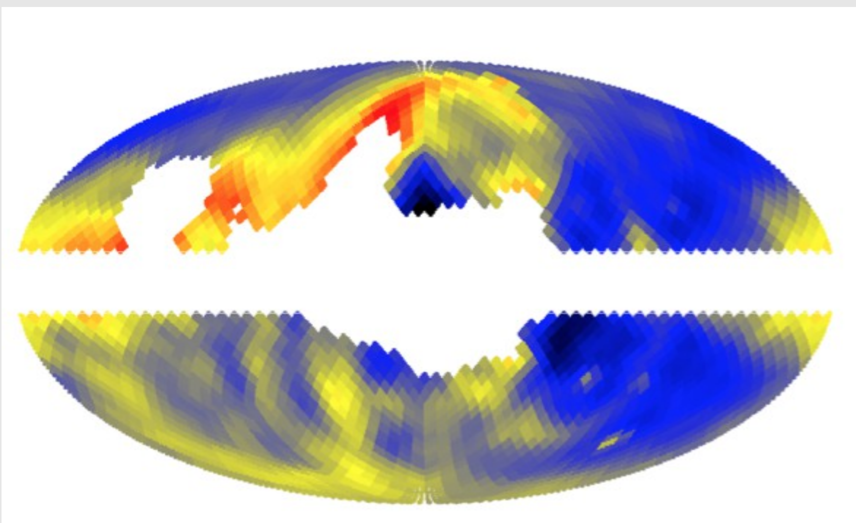
Large extended emissions present in radio maps. Radio-Loops, shell of local SNRs.
Two prescriptions for them : **1) mask or 2) model with a template**



Masks

I) Mask obtained with iterative fit of the radio maps using synchrotron maps +free-free+ isotropic emission
Thresholding applied to residuals to identify pixels with largest deviations.
Threshold imposed combining experimental uncertainties of maps + variance of residuals

Example of mask at 408 MHz for a given galactic model



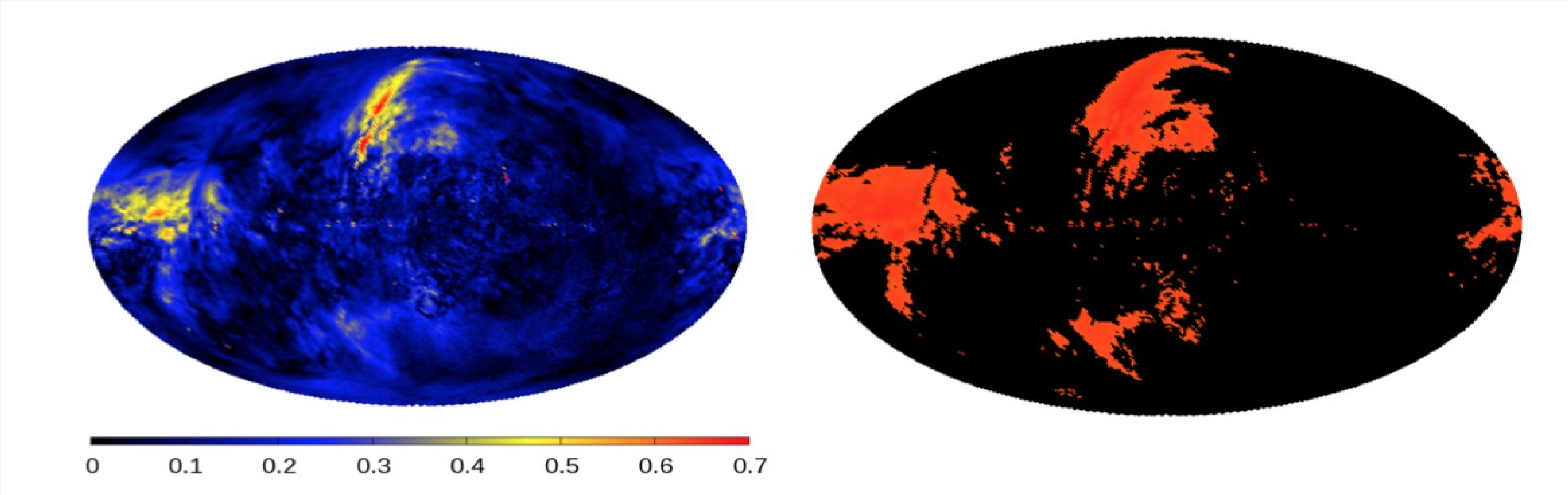
Mask employed by WMAP 7

II) Similar method employed by SExtractor software to mask sources

III) Mask used by WMAP 7 collaboration

Polarization template

Template of the most intense synchrotron sources from Polarization map at 1420 MHz
Select only the most bright pixels.



Fitting procedure

Turbolent nature of magnetic field induces a variance in the intensity of sync. emission at scales larger than coherent scale. We have modeled B random with its RMS value!
Models are not expected to reproduce observations at small scales.
Perform a course-graining of radio maps before comparing models and surveys

We use HEALPix scheme with a resolution of approx 15 degrees

$$T_i^{\mathrm{model}} = T_E + c_{\mathrm{gal}} T_i^{\mathrm{gal,synch}} + c_{\mathrm{brem}} T_i^{\mathrm{gal,brem}} + c_{\mathrm{PI}} T_i^{\mathrm{PI}}$$

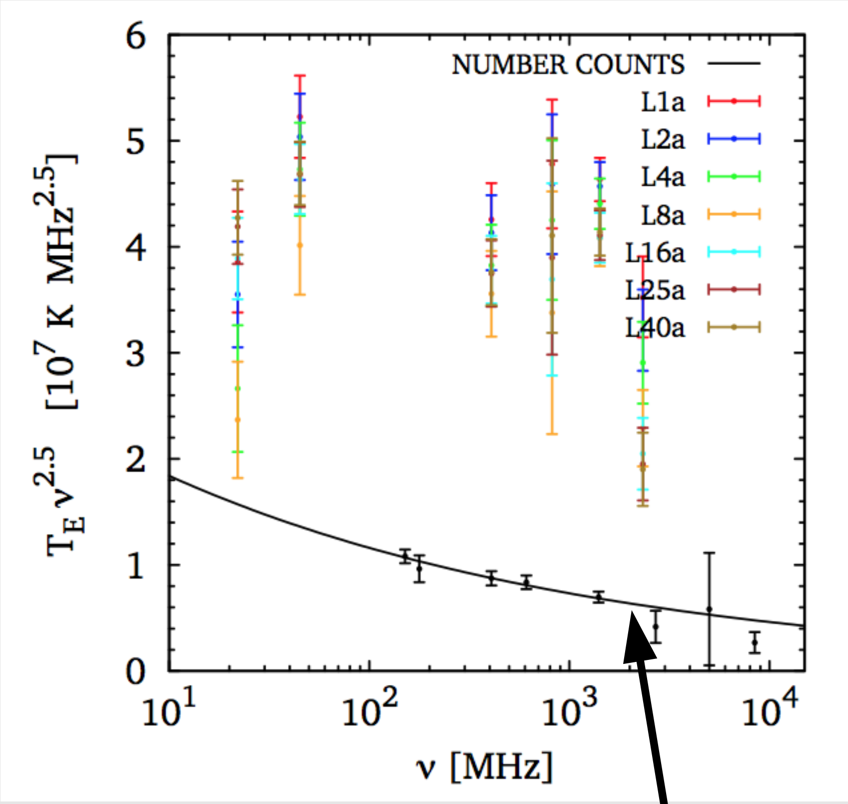
$$\chi^2 = \sum_i \frac{(T_i^{\mathrm{data}} - T_i^{\mathrm{model}})^2}{\sigma_i^2}$$

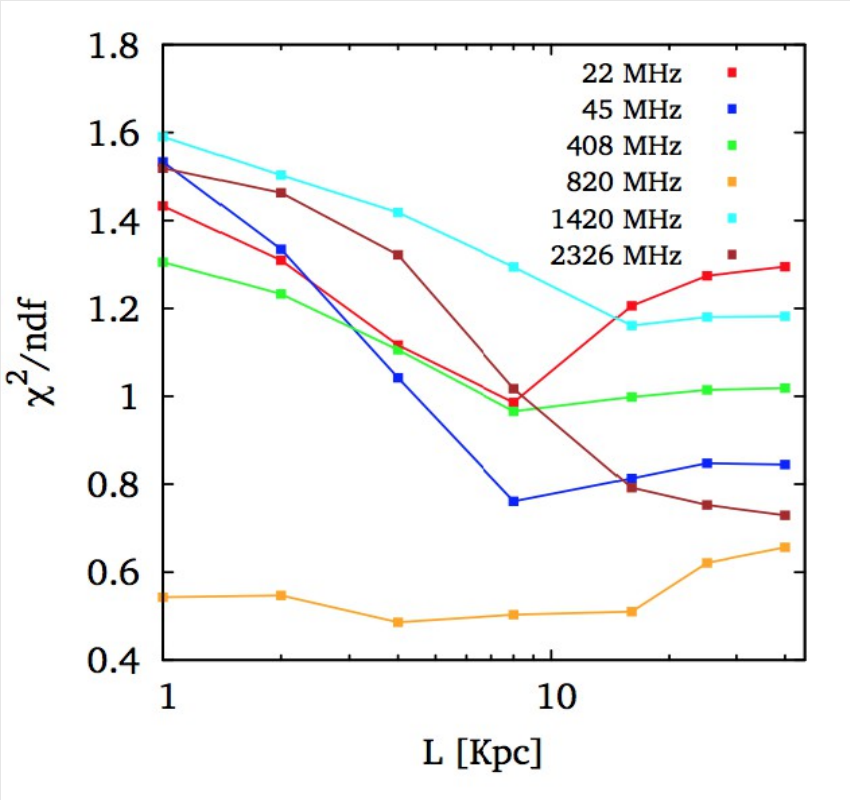
Fluctuations due to B random estimated from maps and combined with experimental uncertainties

Analysis repeated with filtering maps on smaller pixels, around 4 degrees

Example of fits

Estimate the uncertainty on IRB from modeling of the synchrotron galactic emission
Radio maps prefer models with intermediate-large L



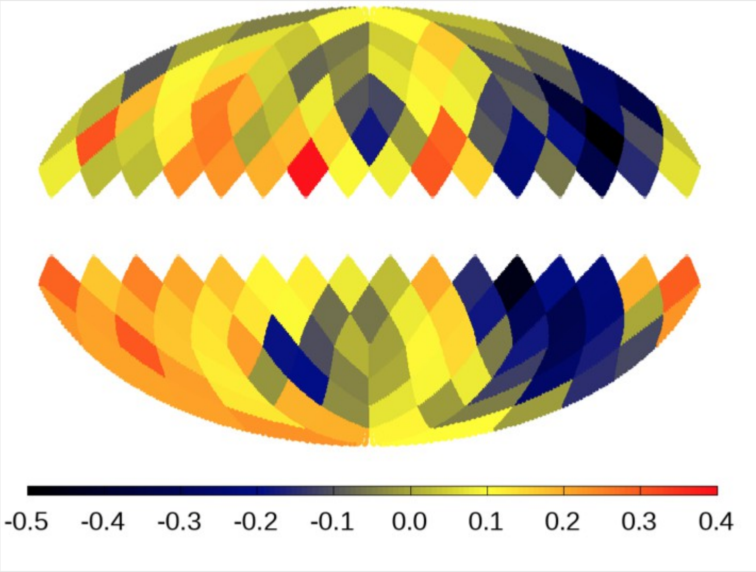


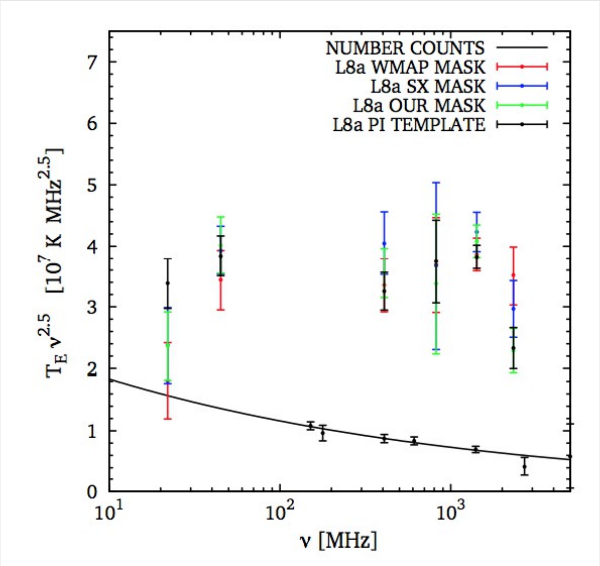
IRB from Number Counts

Example of fits

Residuals are in average (taking the absolute values) around 10-20 %, depending of the frequency and the model

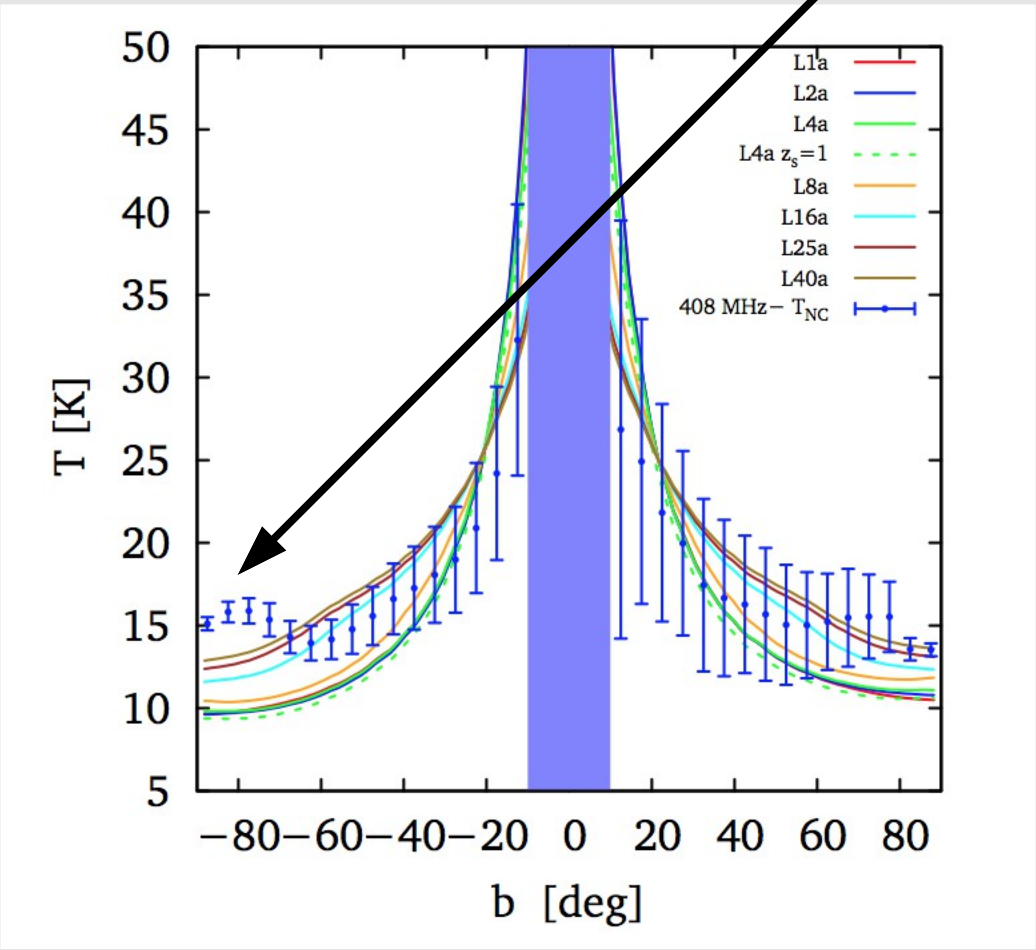
Results obtained with different methods (masks or PI template) agree





Latitude profiles

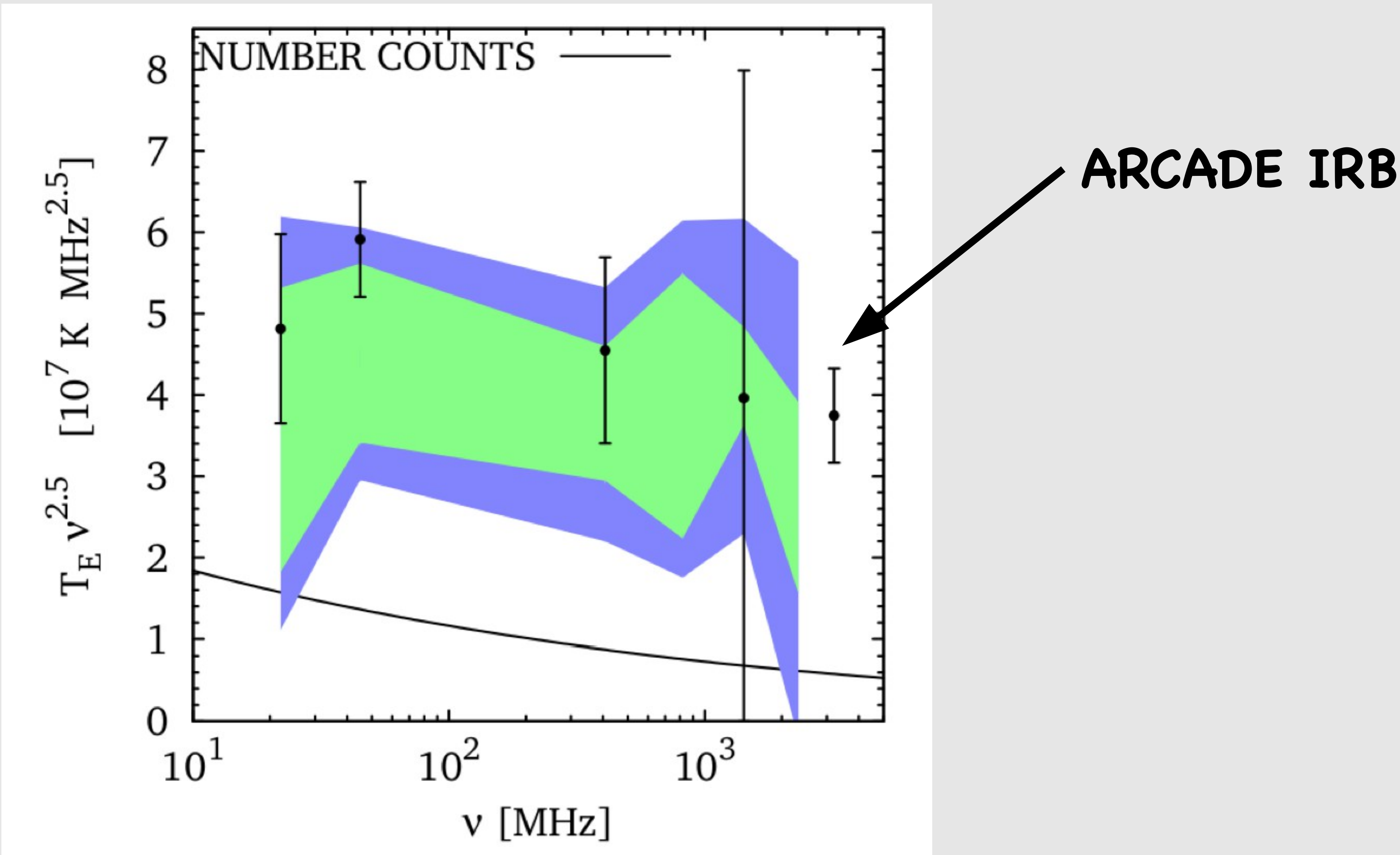
Isotropic Radio Background mostly relevant at large latitudes.
Synchrotron models + IRB from number counts not enough!



Colored lines:
Models + IRB from counts

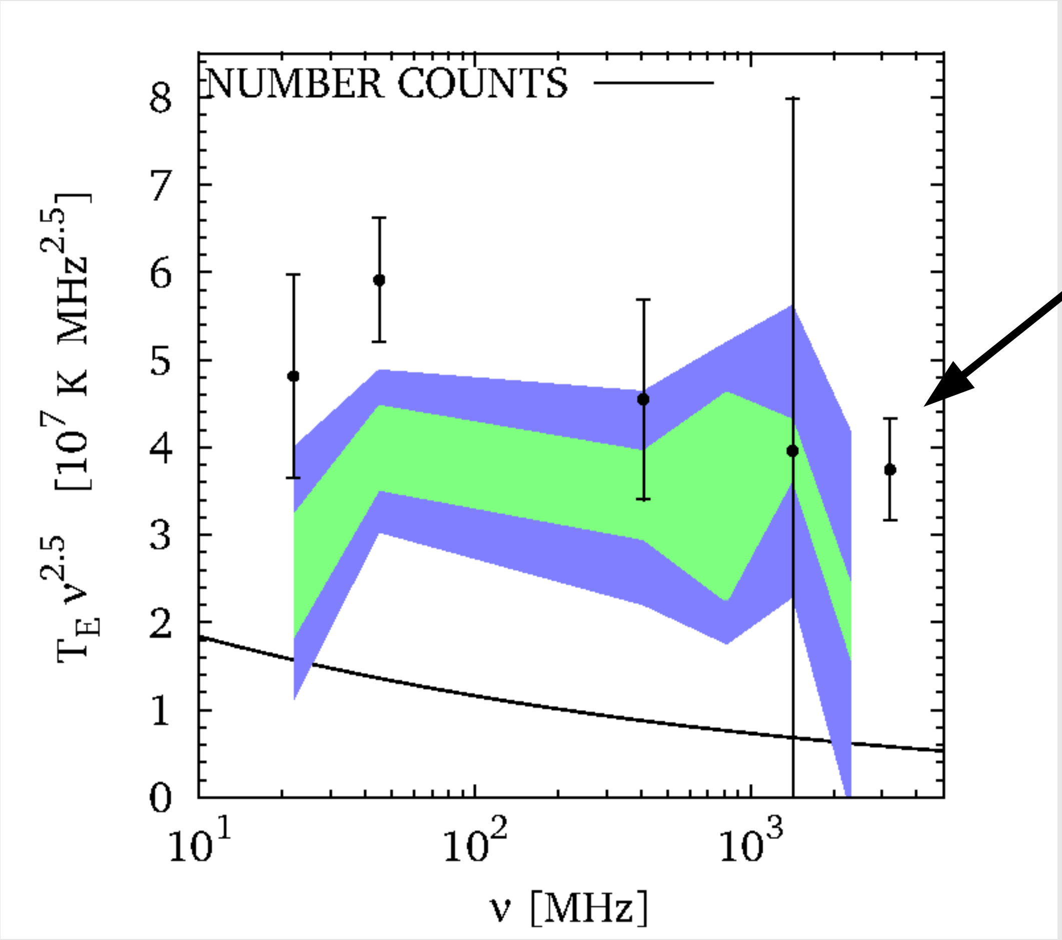
Isotropic bkg

Estimate of the IRB from the fits with all methods and galactic models employed
Zero-level uncertainty of maps is large.



Isotropic bkg

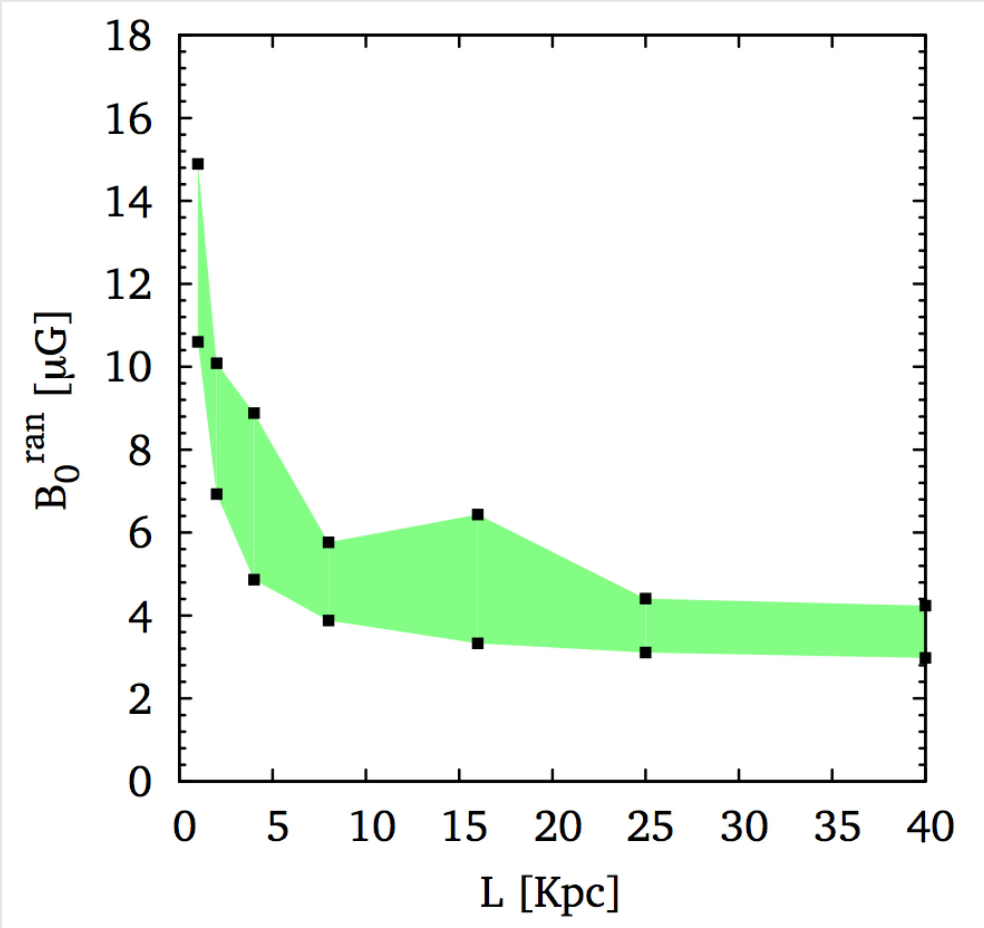
Marginalize over galactic models



ARCADE IRB

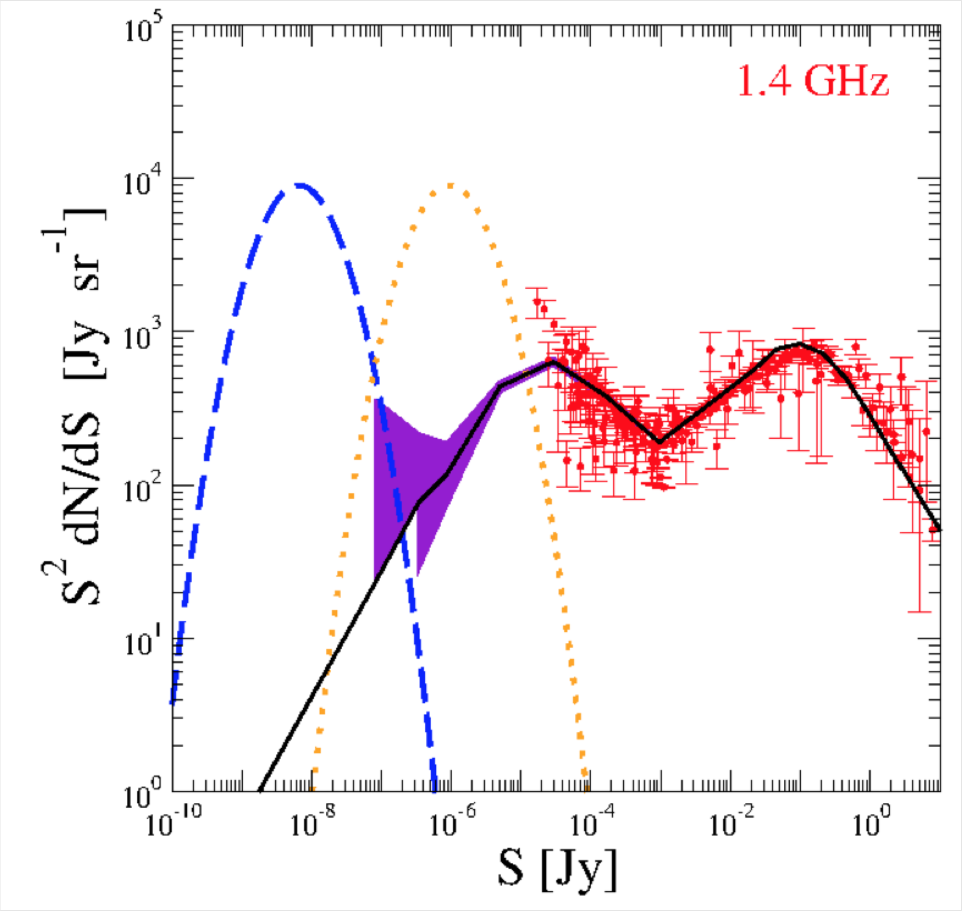
Normalization of magnetic field

Fits of radio maps constrain the parameters of cosmic-rays propagation model and galactic magnetic field. Constraints on normalization of B from the fits.



What one would expect from NC?

Example of gaussian bumps of number counts needed to account for the IRB excess



Summary

The high latitude emission of radio maps is too flat to be explained by the galactic models we are using. The question is:

1) Galactic models are not enough accurate ?

2) Systematic offset of several surveys, all in the same directions?

3) Additional population of extragalactic sources below present sensitivity ?

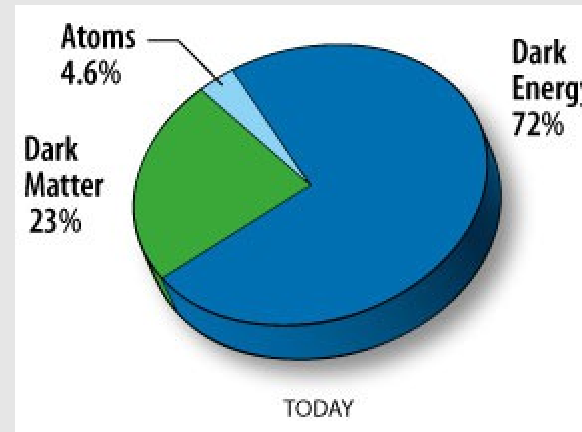
Can we use these data to learn about Dark Matter?

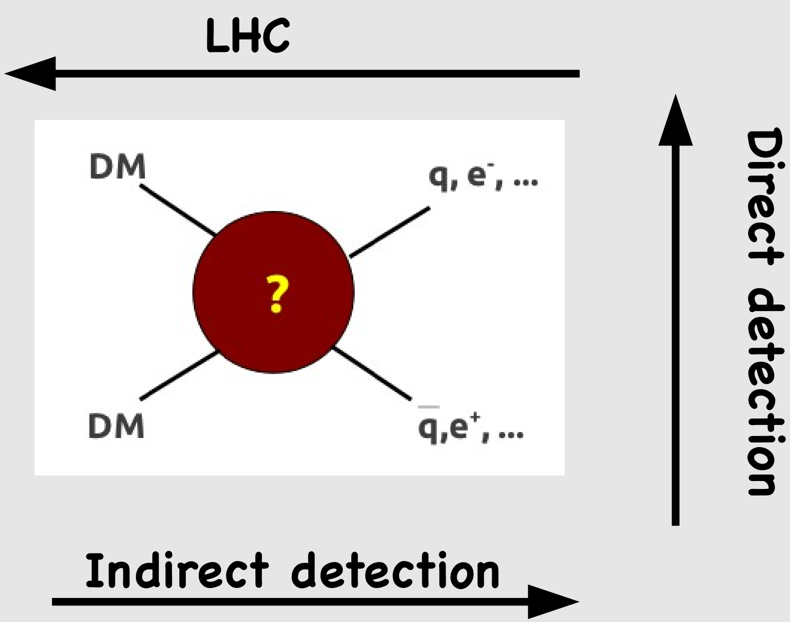
What Dark Matter do we consider?

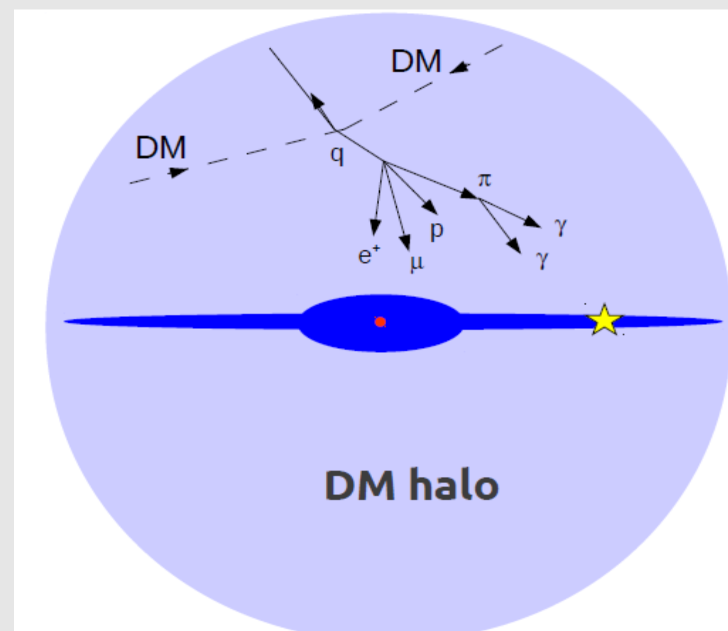
There are solid gravitational evidences for non-baryonic Dark Matter

What are the properties of particles.
Which is theory of the Dark Matter sector?

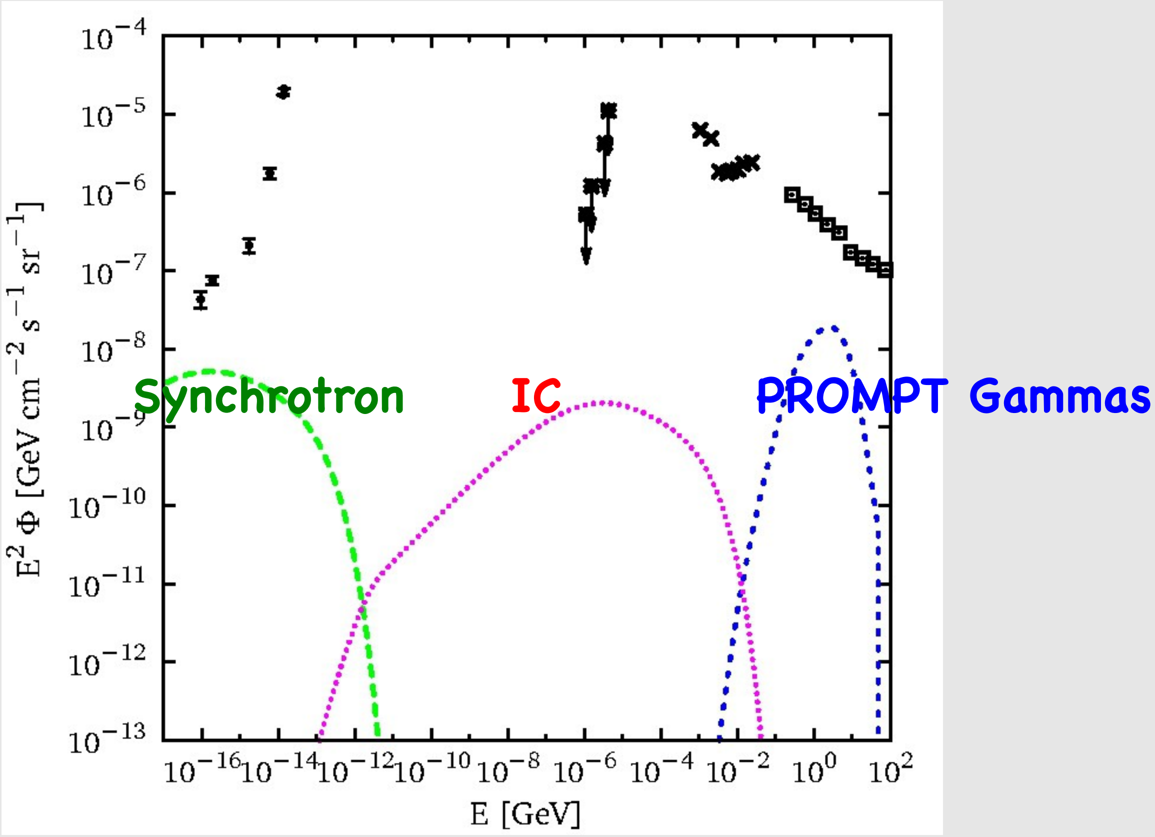
Weakly Interacting Massive Particles the most studied DM candidates because
- rich phenomenology
- theoretical reasons







Astro Dark Matter signals

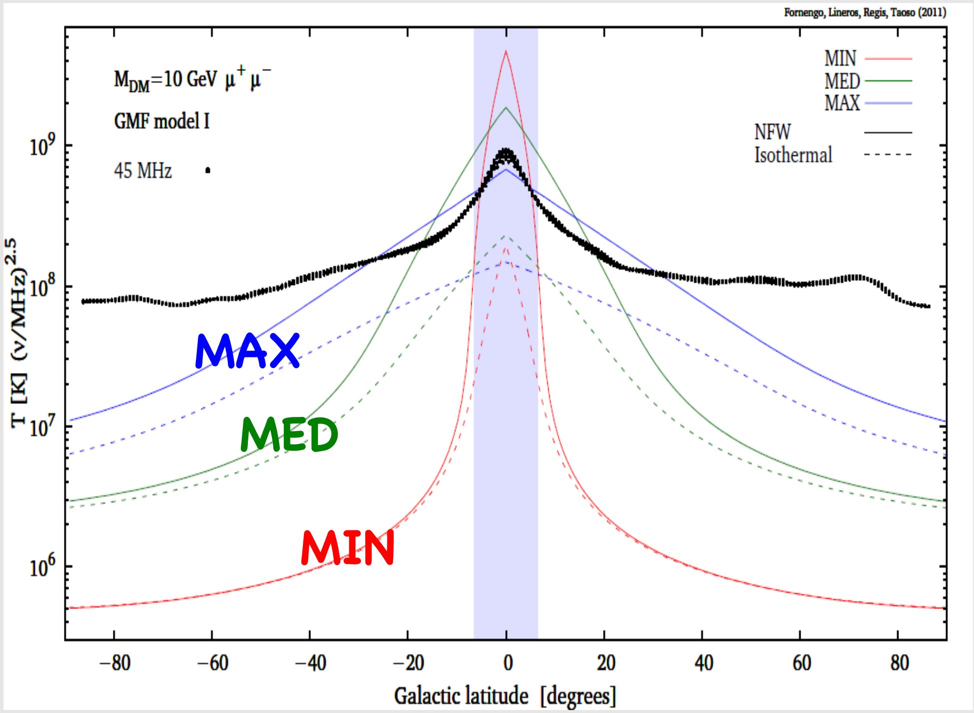


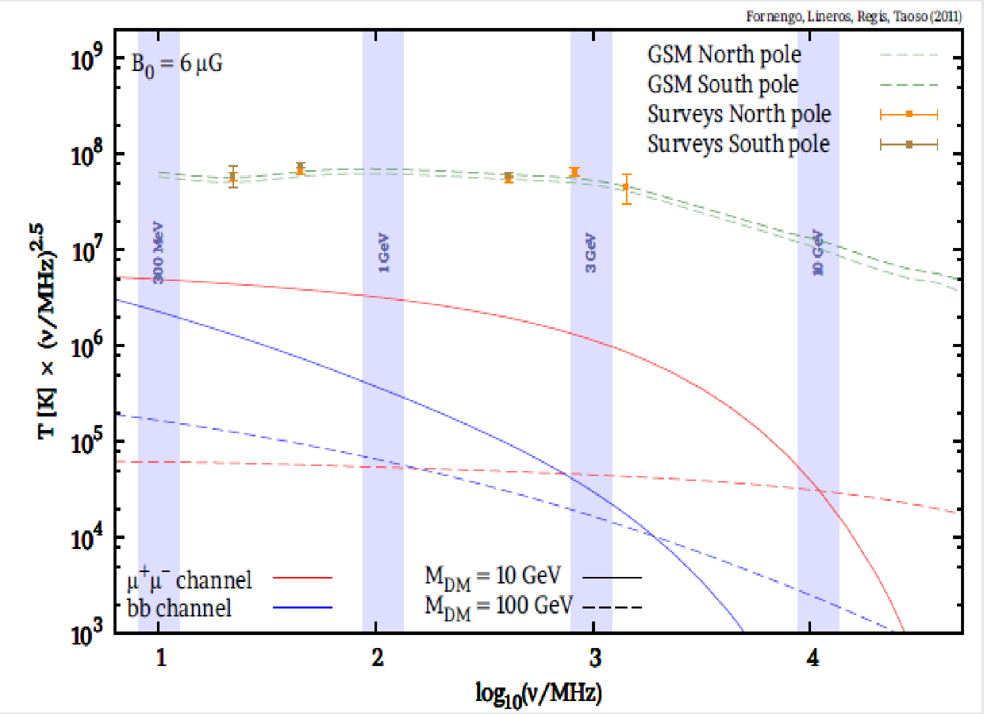
Gamma-rays produced as prompt photons. FERMI-LAT and ACTs

Secondary emissions: **Inverse Compton & Brehmstrahlung** → Gammas, X-rays

Synchrotron → Radio & Micro-wave

Synchrotron from DM

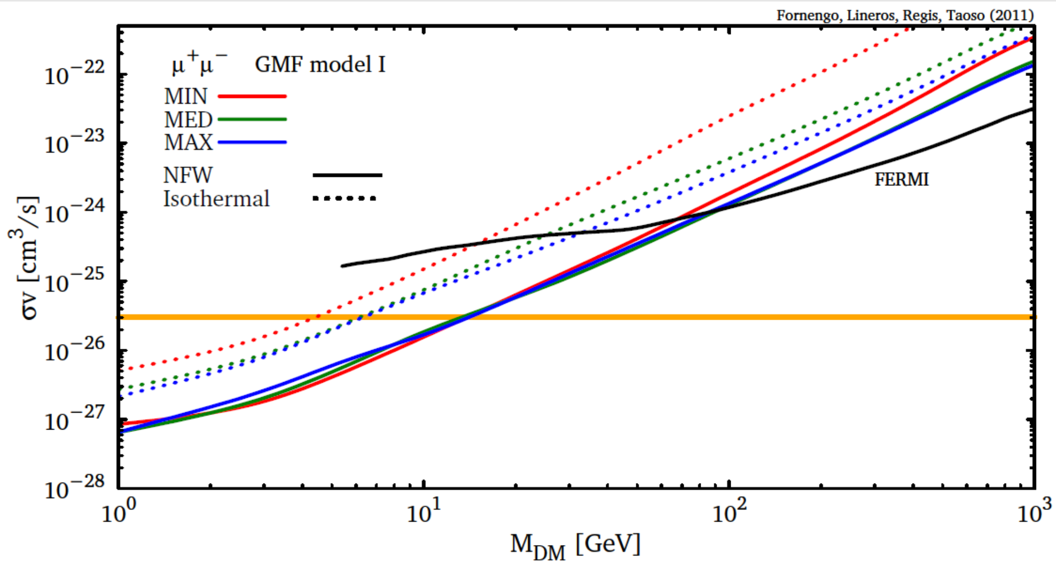


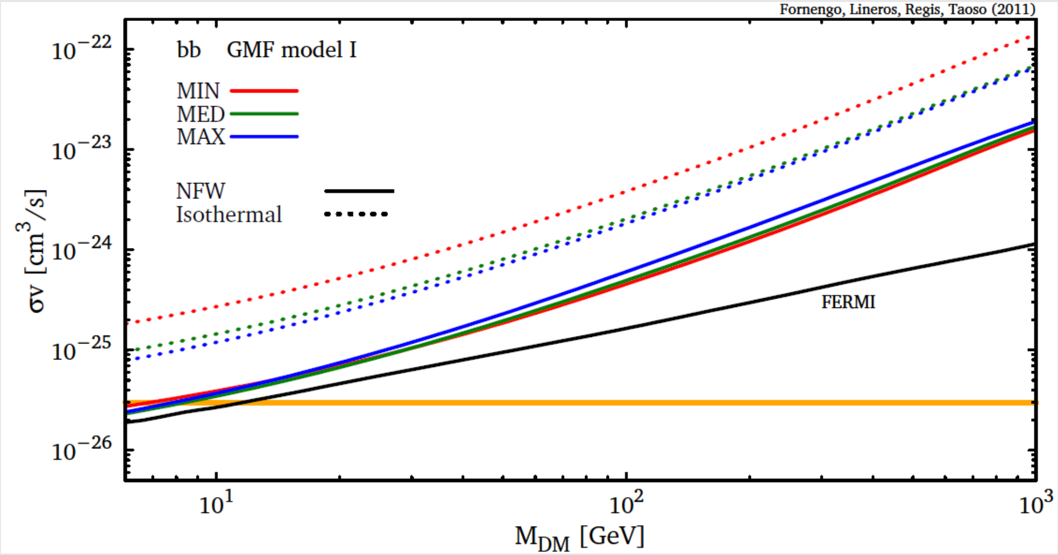


MIN MED MAX sets of propagation parameters

Constraints

Significant bounds from radio for light DM and in particular for leptonic channels



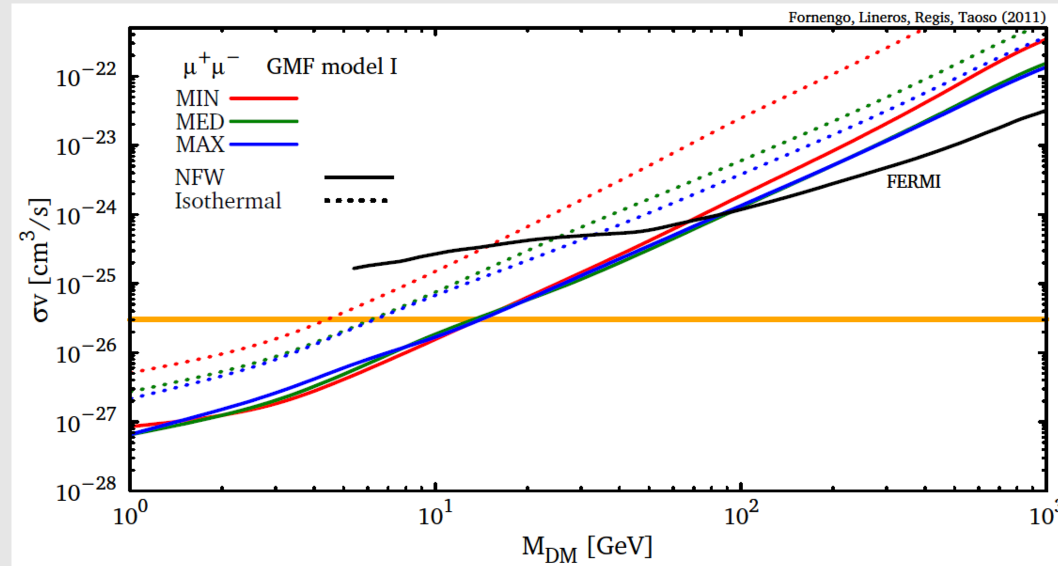


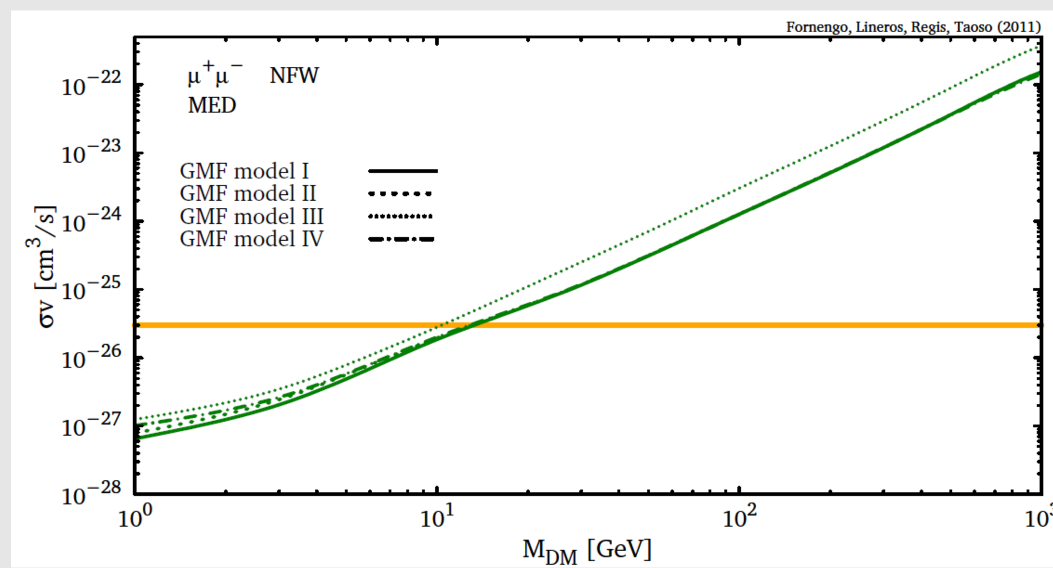
Constraints

Significant bounds from radio for light DM and in particular for leptonic channels

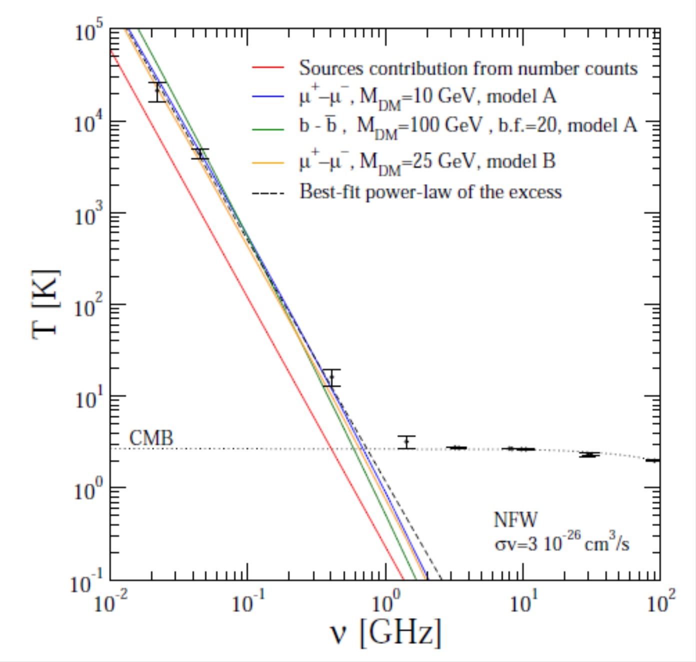
Dependence on propagation and on magnetic fields (under reasonable assumptions) not dramatic.

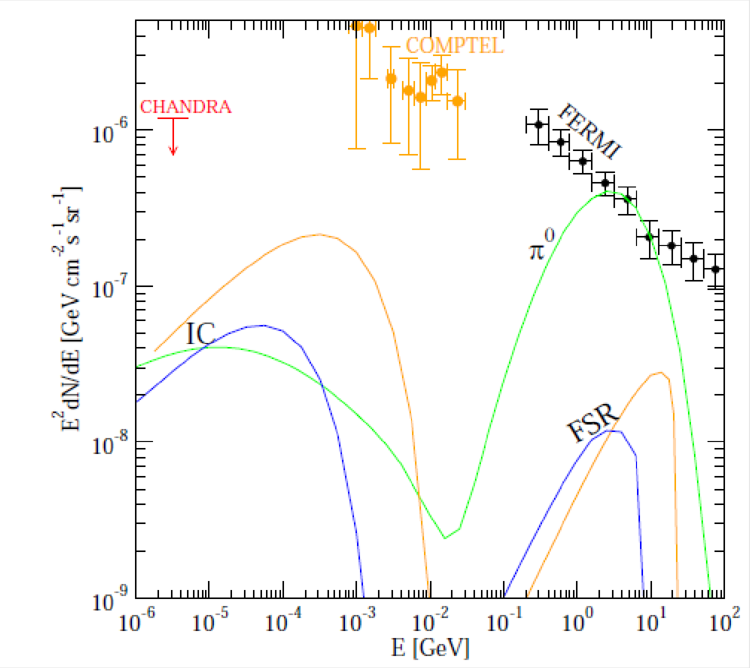
Usual critical dependence on DM profile





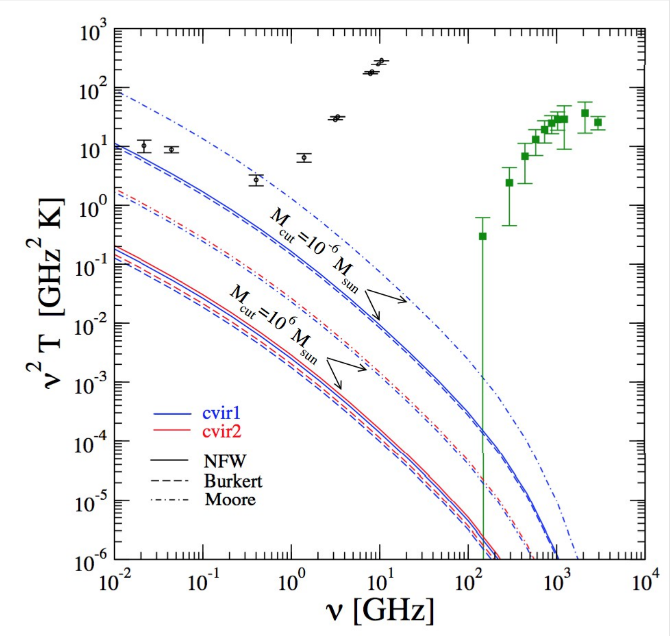
Radio signals from extragalactic halos

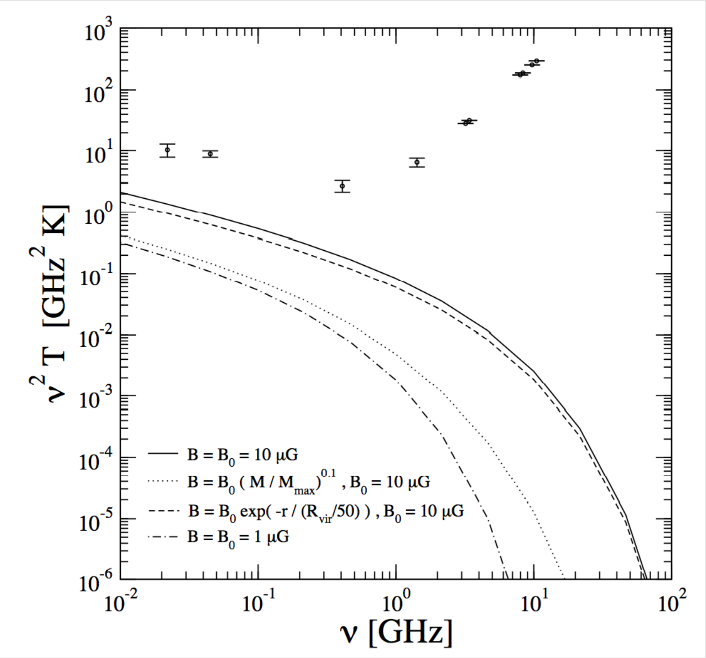




DM signals contribution to extragalactic emission can be large for leptonic channels
Bounds from gammas evaded

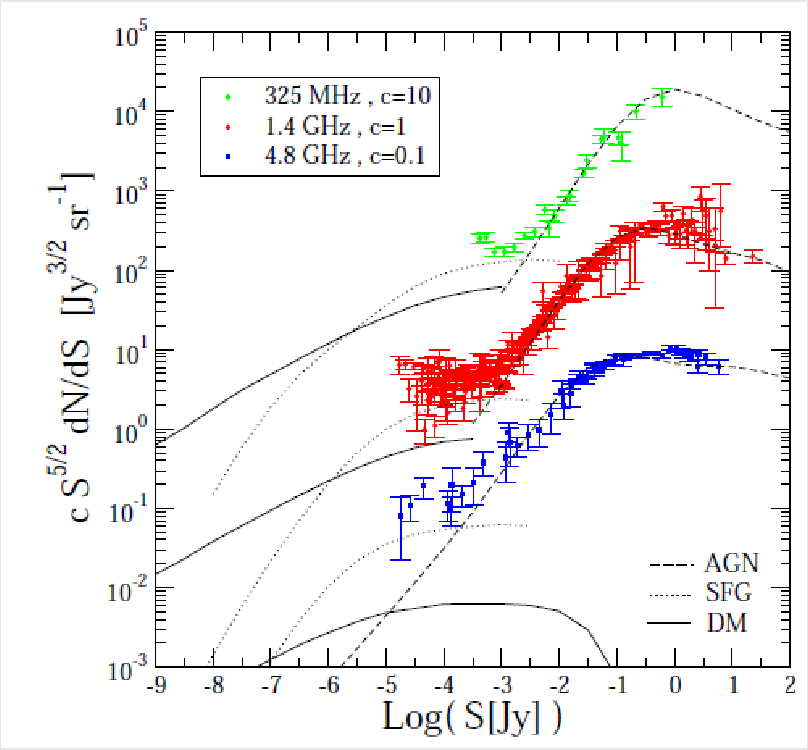
Radio signals from extragalactic halos

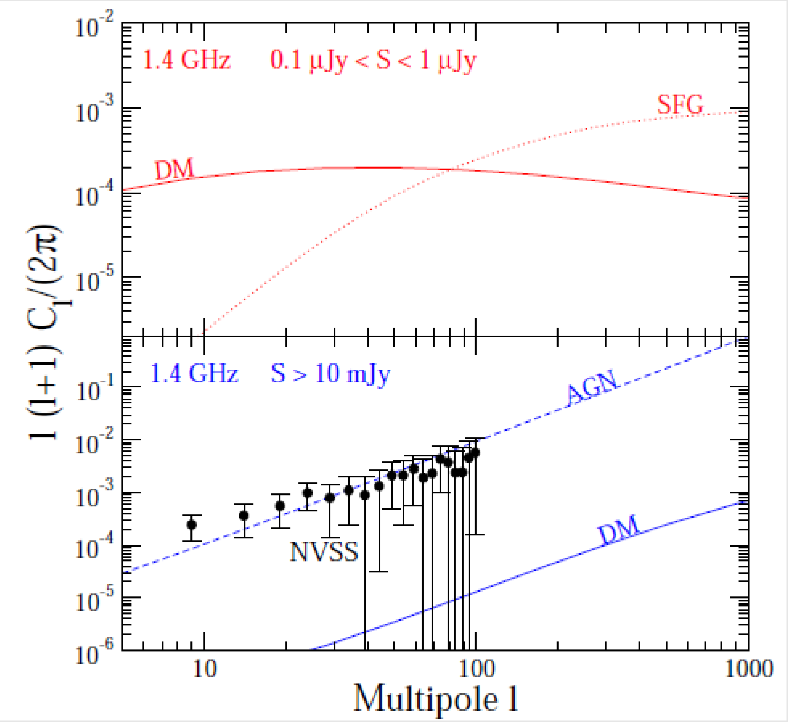




Uncertainties in the calculations are large!
- DM clustering: profile, concentration, role os substructures
- Magnetic fields
- electrons transport: diffusion, confinement...

Forecast for future experiments





Possibly DM signals at reach of future telescopes (EVLA, ASKAP, SKA...)

Not really a smoking-gun signature for DM
Angular anisotropies + correlations with other measurements (gamma, lensing...)
can help to distinguish DM from astro

THANKS