Marco Taoso

IPhT CEA-Saclay

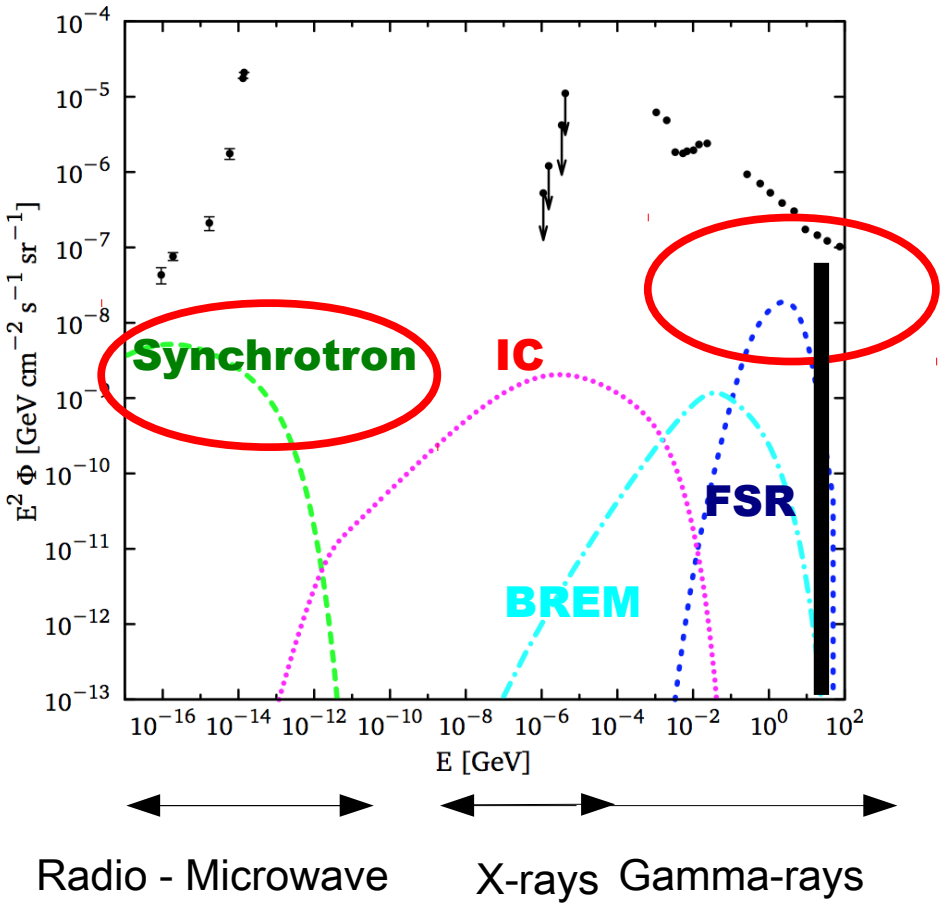
Dark Matter searches with radio and gamma-rays

WIN 2013

Natal

16-21 September 2013

DM emissions



Final state radiation $\chi\chi \to q\bar{q} \to \pi^0 + \ldots \quad \pi^0 \to \gamma\gamma$

Inverse Compton $e^{\pm}\gamma \to e^{\pm}\gamma'$

Synchrotron emission from interactions of electrons with magnetic fields

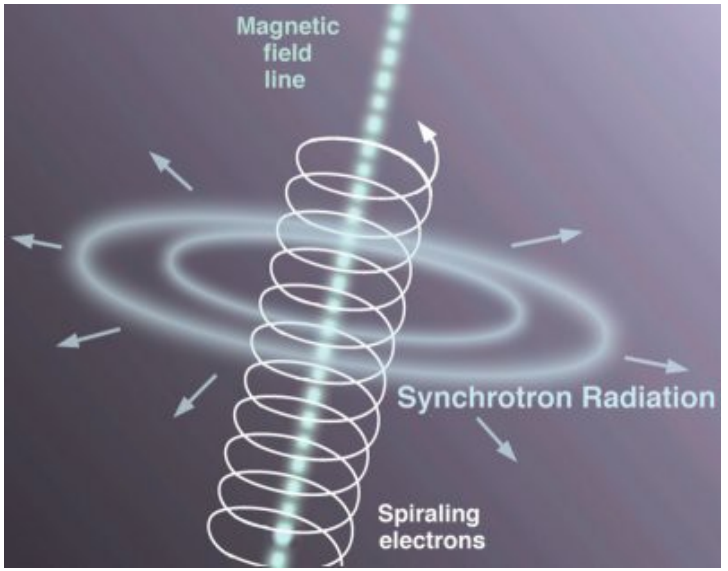
Plan of the talk

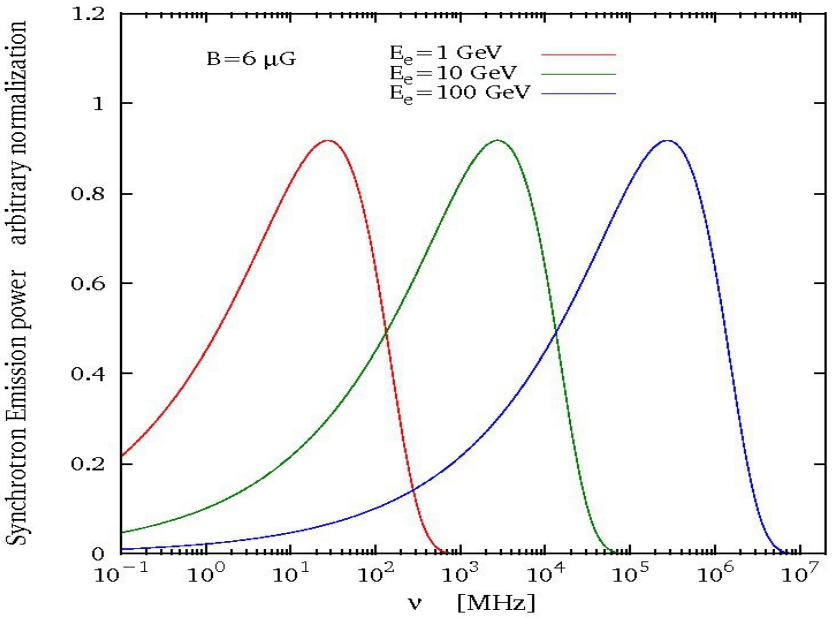
Synchrotron emission and radio observations

- Bounds on DM from present radio surveys
- Extragalactic radio background and searches of extra-galactic DM radio sources
- Based on Fornengo, Lineros, Regis, MT 2011, 2012, 2013 (in progress)

- **DM searches with gamma-ray lines**
- Status of the 130(5) GeV line
- Gamma-ray lines in DM models
- Based on Jackson, Servant, Shaughnessy, Tait, MT 2010, 2013

Synchrotron radiation



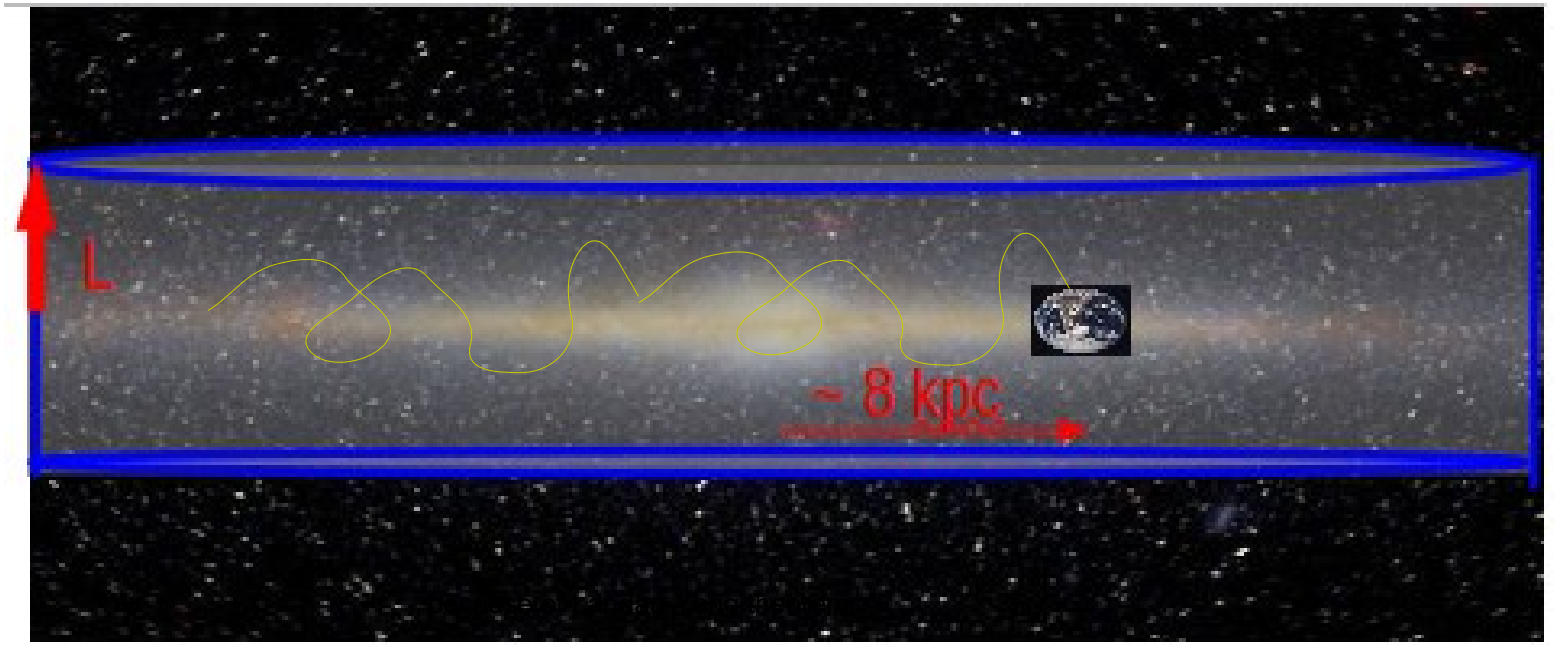


Synchrotron emission from interactions of electrons with magnetic fields

Typical frequency of the synchrotron peak:

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

Propagation of charged particles

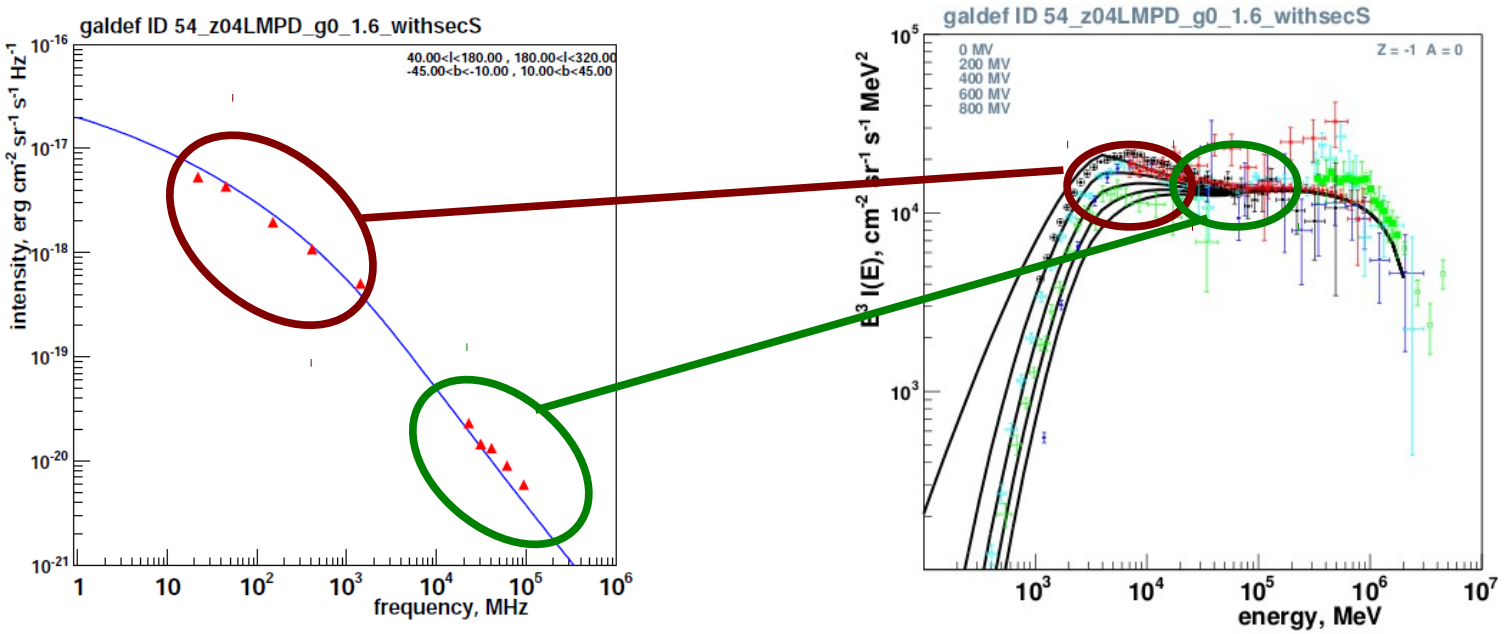


Propagation of charged cosmic-rays described by transport equation which takes into account energy losses, diffusion accelerations, convection

$$\partial_t \mathcal{N} - \boldsymbol{\nabla} \cdot \{K(E)\boldsymbol{\nabla}\mathcal{N}\} + \partial_E \left\{ \frac{dE}{dt}\mathcal{N} \right\} = \mathcal{Q}(E, \boldsymbol{x}, t)$$

diffusion energy losses distribution of sources

Constrain CRs and B with radio



Strong, Orlando, Jaffe 2011

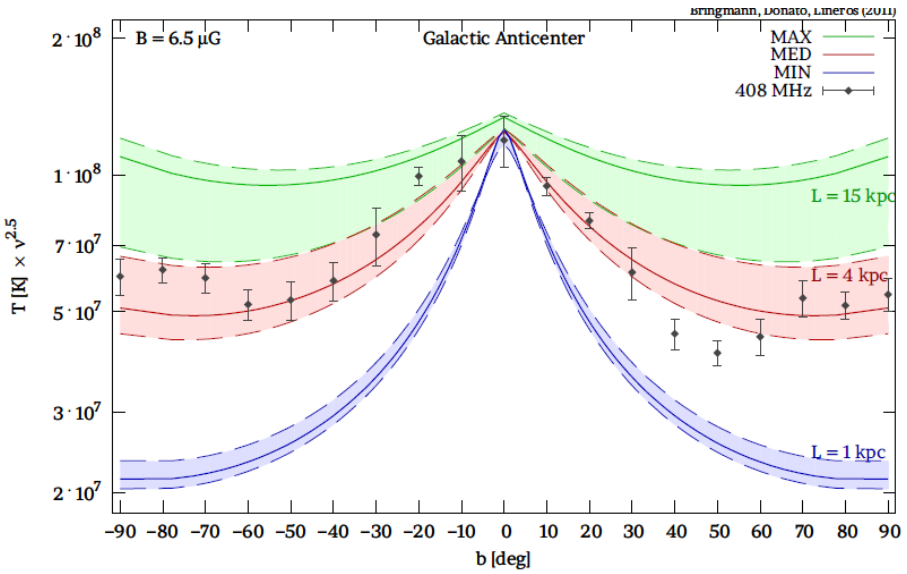
Propagation models tuned against data, notably B/C, radioactive isotopes, protons

This leaves degeneracies among the propagation parameters

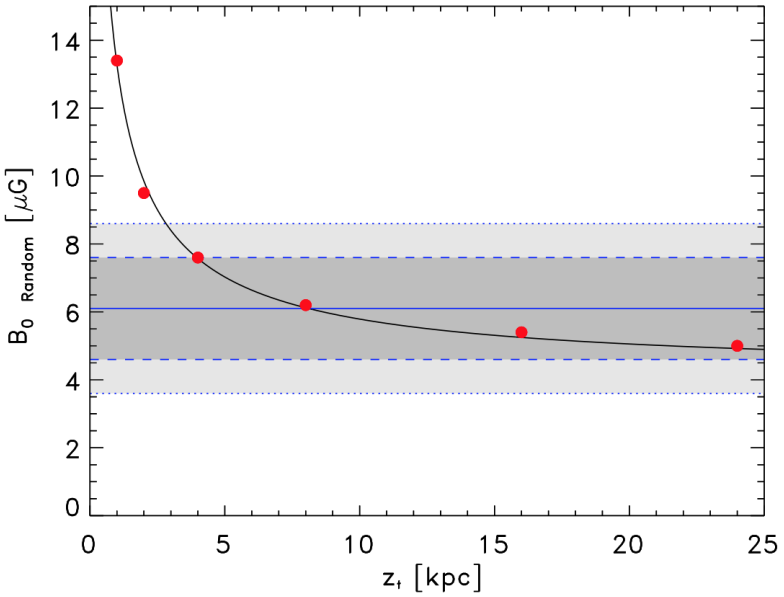
Radio surveys probe the interstellar electron spectrum and further constrain the propagation model / Magnetic fields

Constrain CRs and B with radio

Bringmann, Donato, Lineros 2011



Di Bernardo et al. 2012



Morphology and normalization of synchrotron emission (+ info on Magnetic fields)

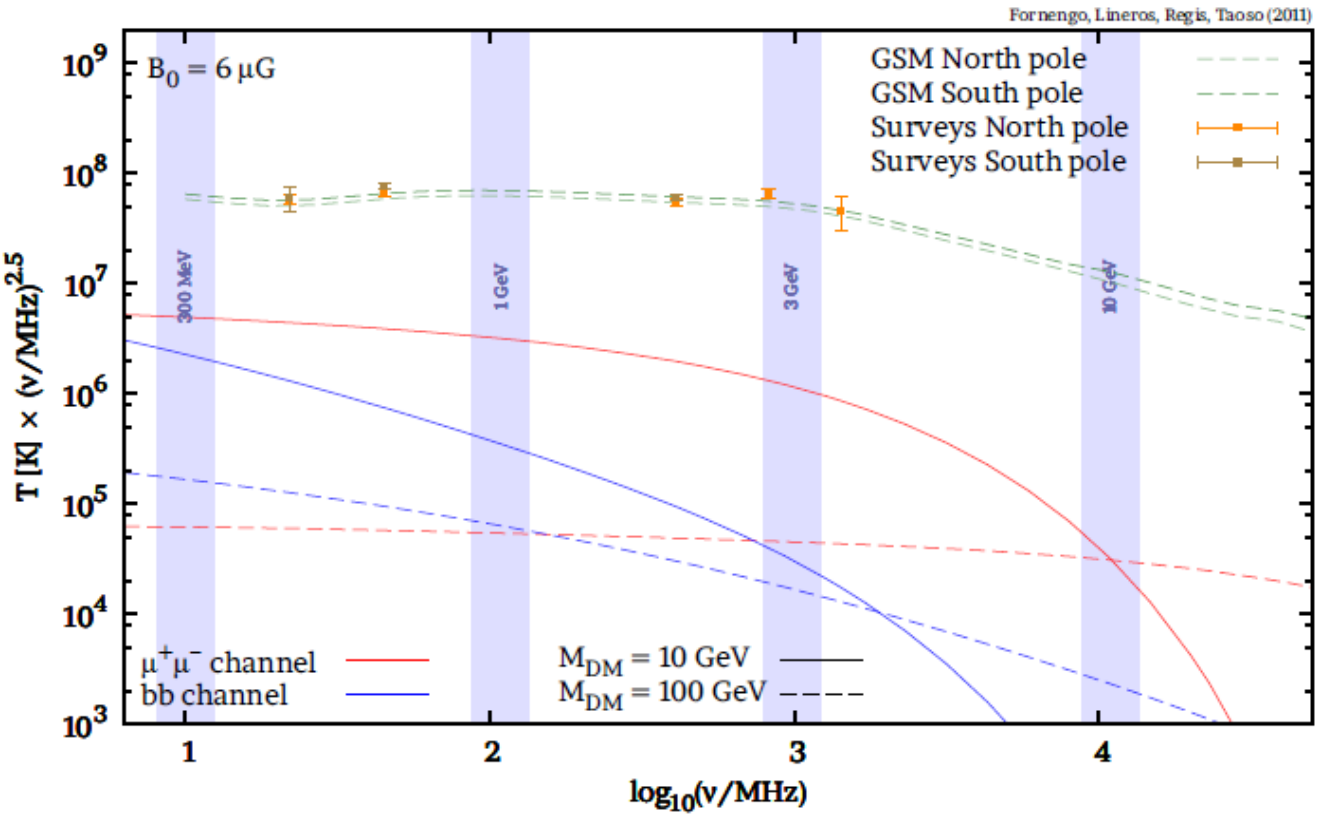
constrain the parameter of propagation models

Models with small scale-height of the diffusion regions are disfavored

Similar conclusions arises from analysis of the diffuse gamma-ray emission from Fermi-LAT

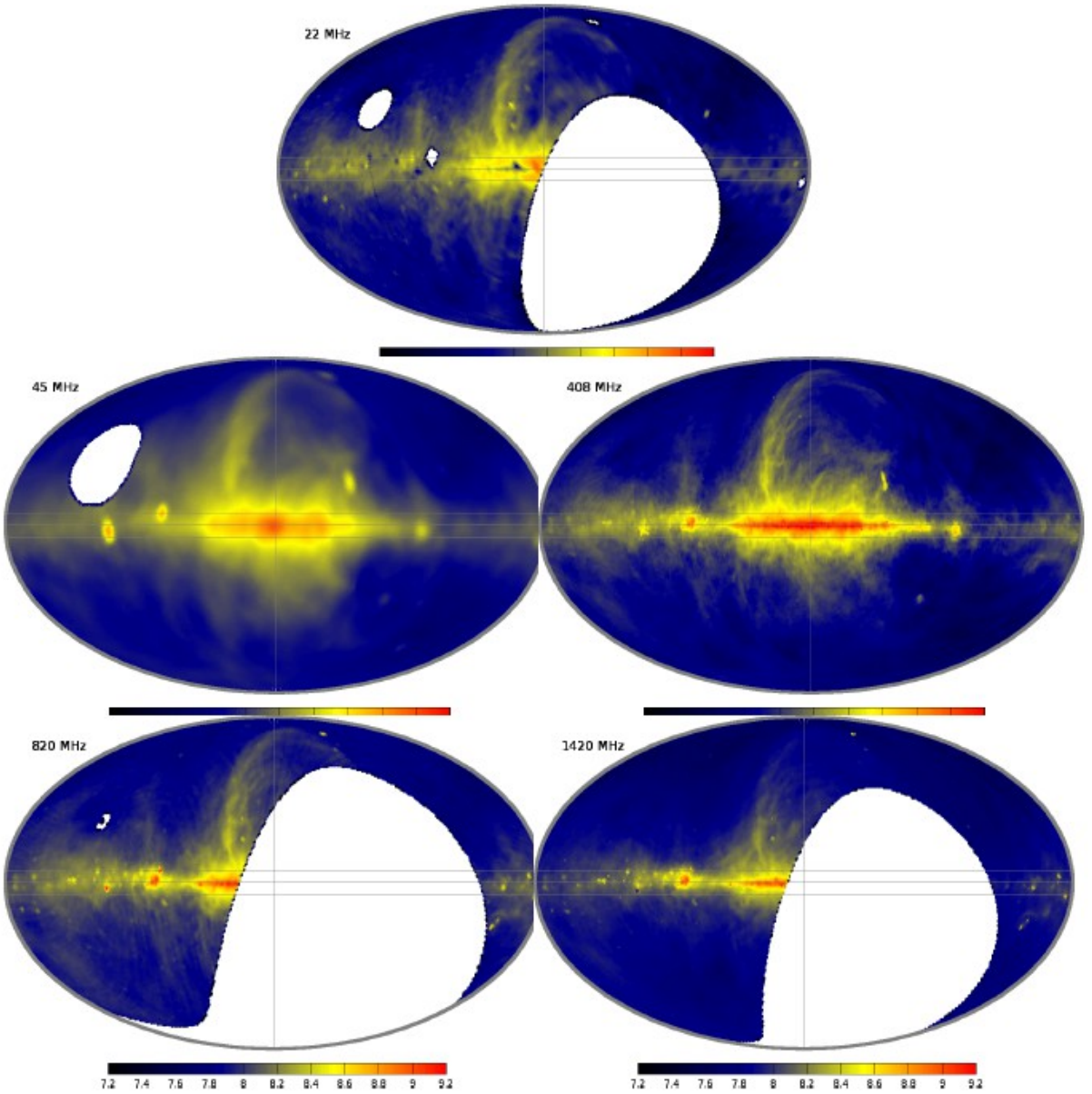
Gamma-ray diffuse from interactions of protons with gas and IC and Brem. of electrons

Synchrotron from DM



Low frequencies are particularly suitable to constrain light DM

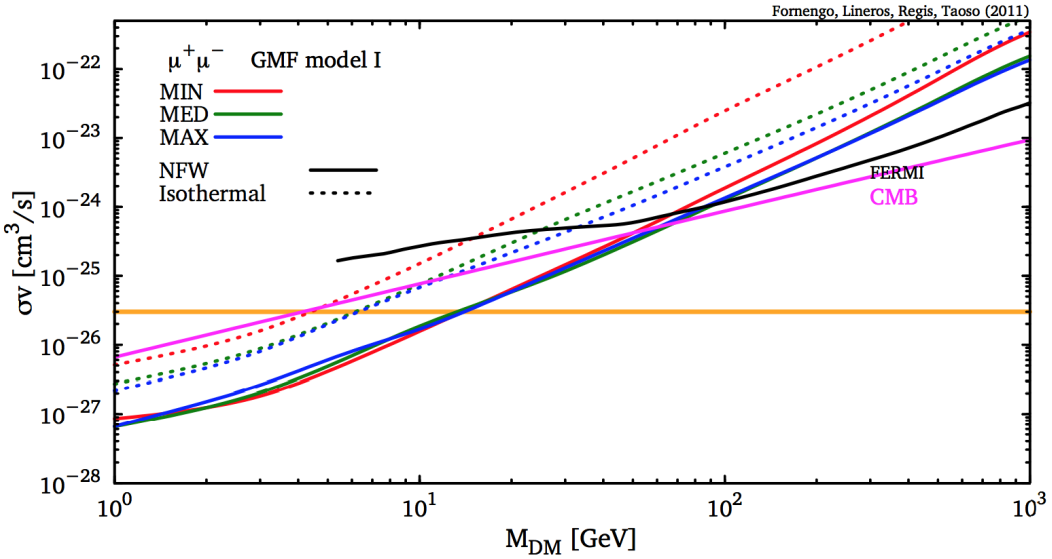
Radio surveys from 22 MHz to 1420 MHz



Constraints on DM

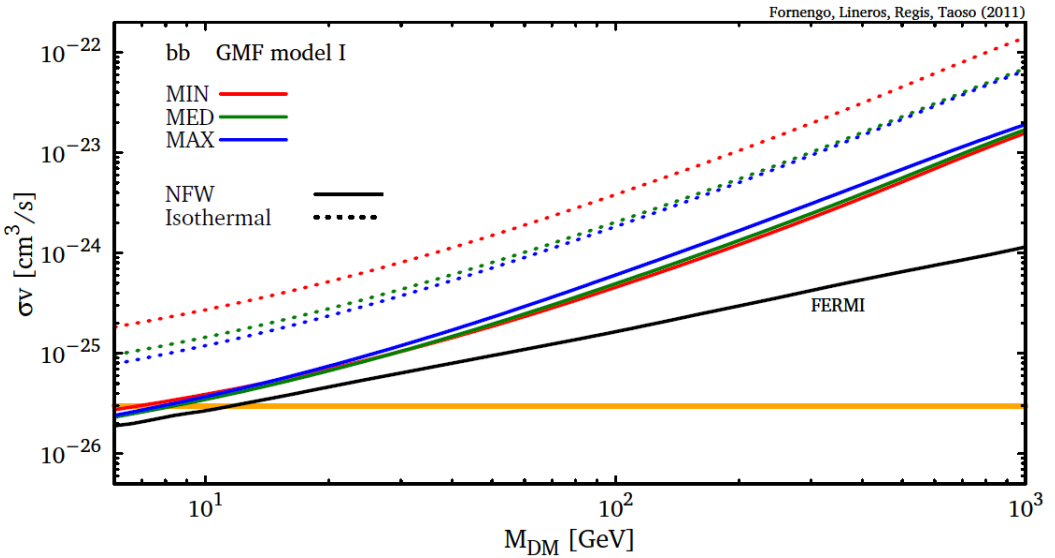
N.Fornengo, R.Lineros, M.Regis, M.T. 2011

Bounds are better/worse than those from Fermi & CMB for leptonic/hadronic channels



Uncertainties:

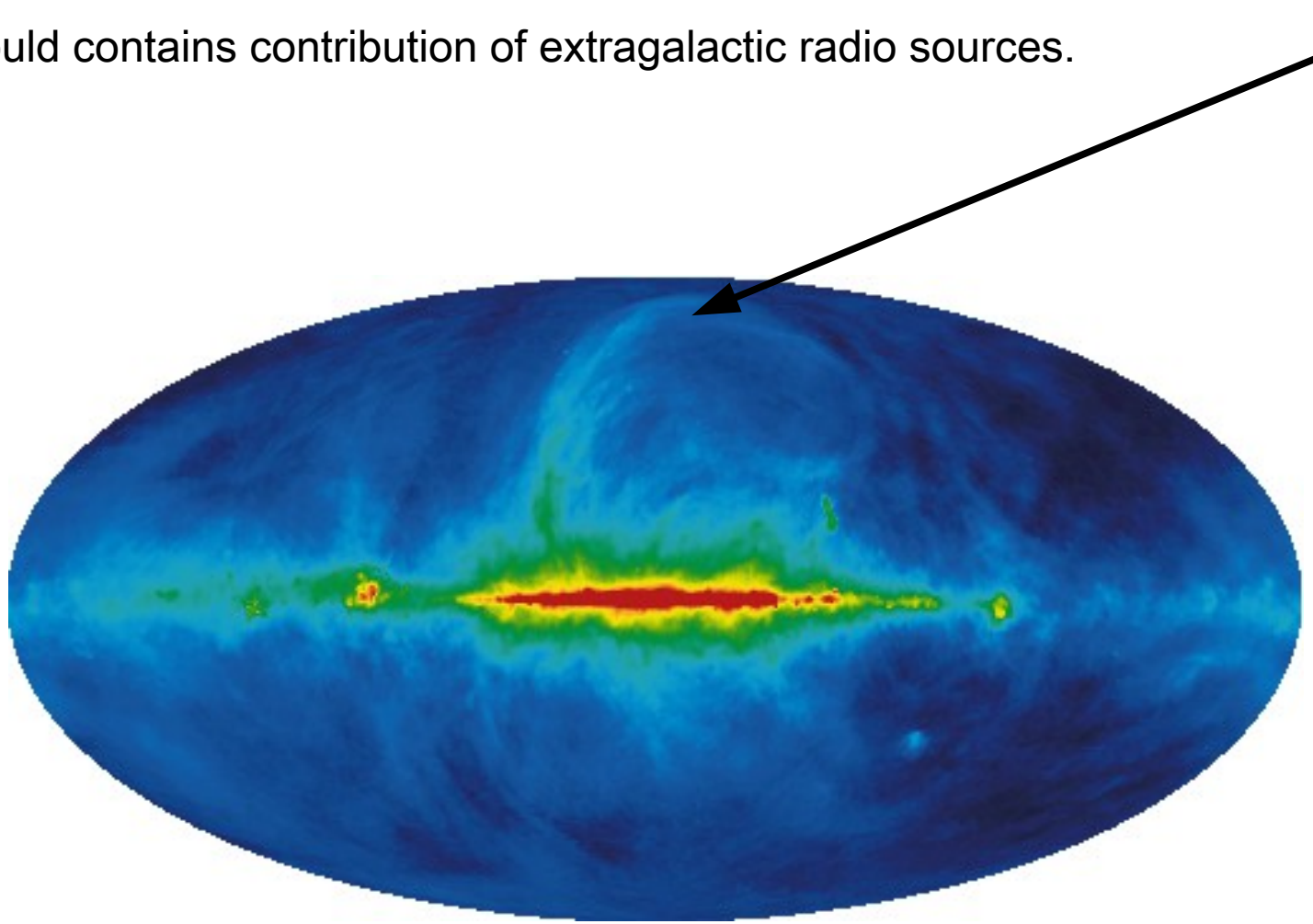
- DM profile
- propagation parameters
- magnetic fields



Isotropic radio background

Isotropic radio background extracted from maps after subtraction of galactic emission

Should contains contribution of extragalactic radio sources.



ARCADE-II excess

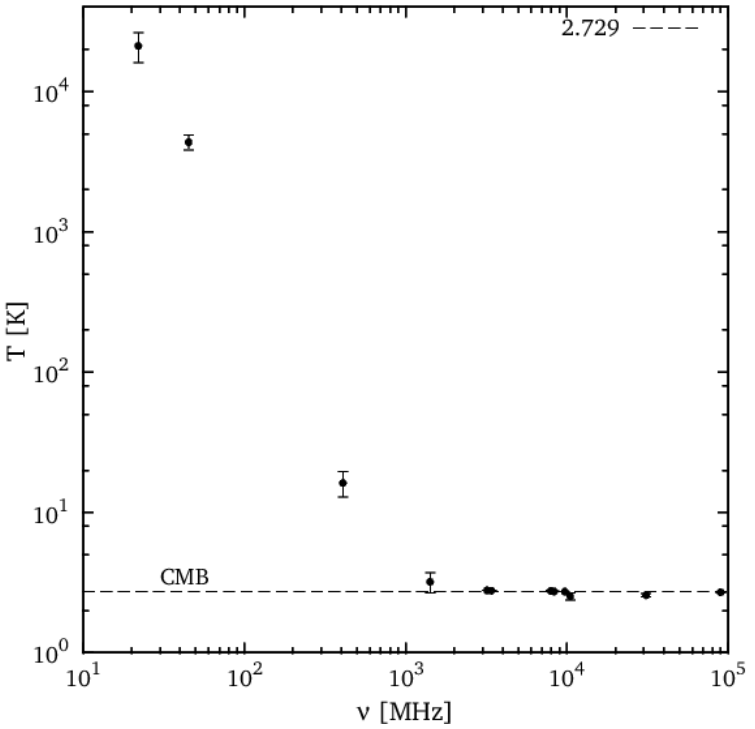
Low frequencies 22 MHz 45 MHz 408 MHz 1420 MHz + ARCADE-2 3.2 GHz-90 GHz

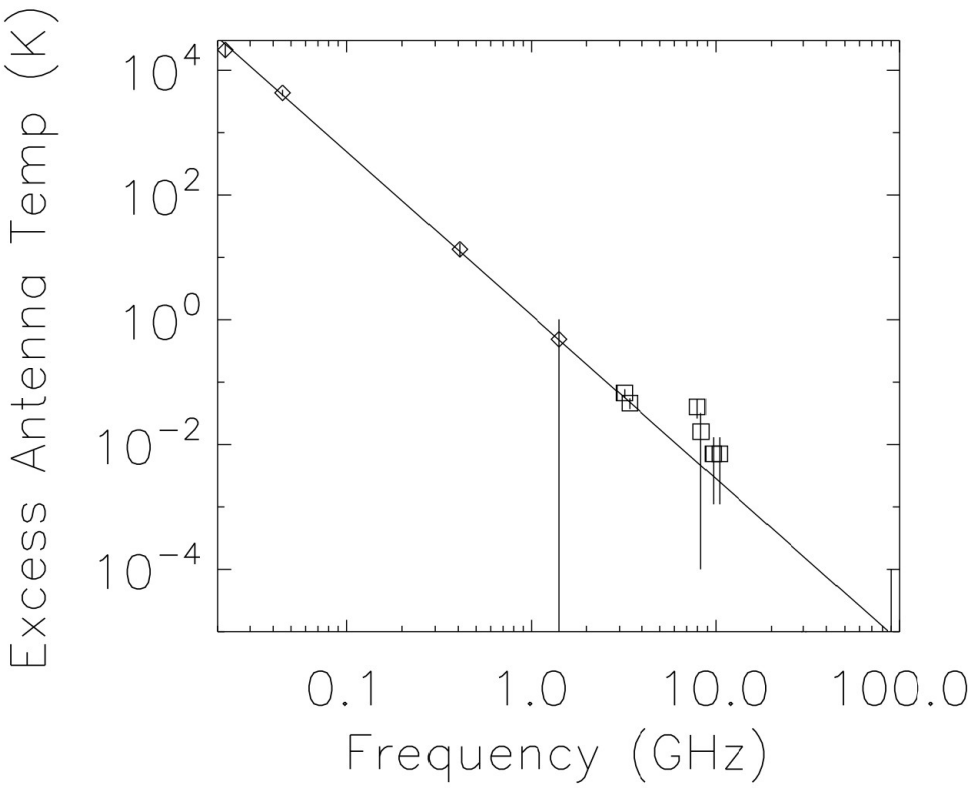
Galactic emission estimated with 2 methods:

plane parallel model & correlation of radio maps with CII map (tracer of galactic emission)

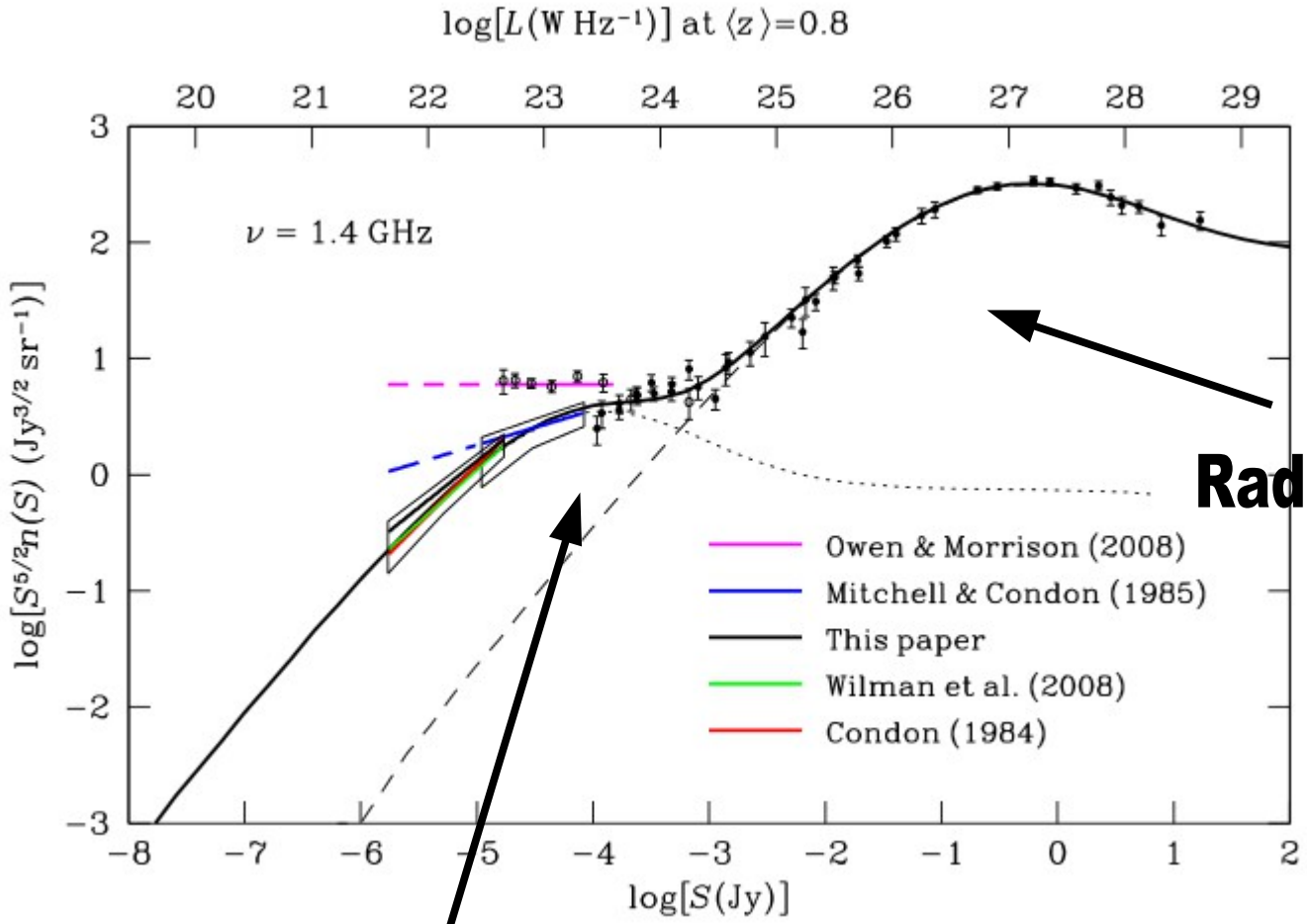
After CMB monopole is removed data an isotropic background is detected below 10 GHz

Fixen et al. 2009





Number counts of sources



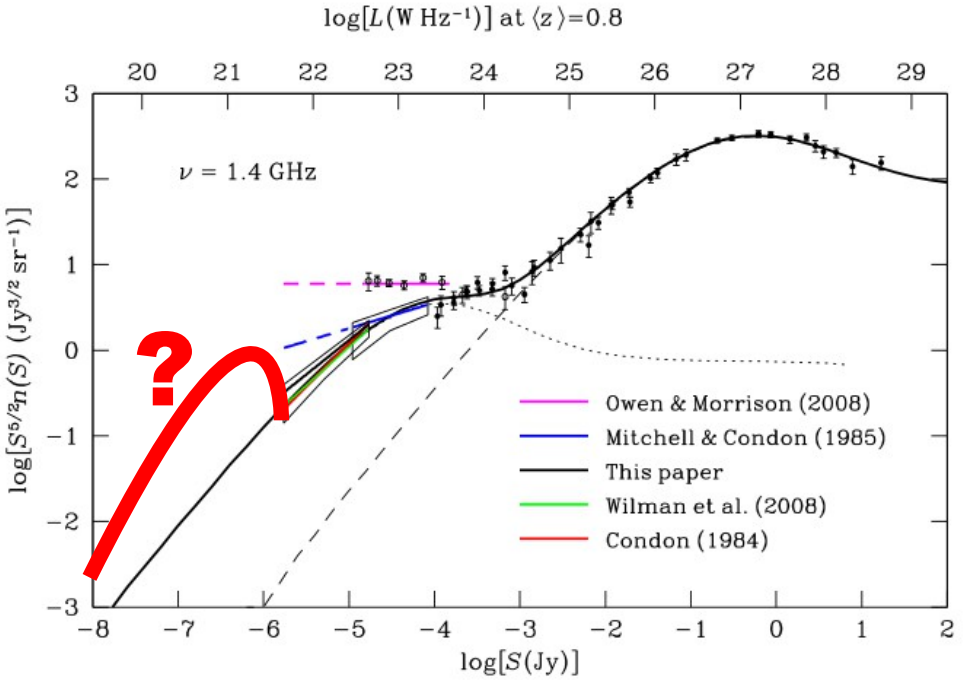
Radio Loud AGN

Star Forming Galaxies

Vernstron, Scott, Wall 2012

Flux from extragalactic radio sources is a factor 4-5 smaller than IRB obtained by ARCADE!!!!!

Possible explanations



The excess calls for an undetected population of radio sources at fluxes below micro-Jy

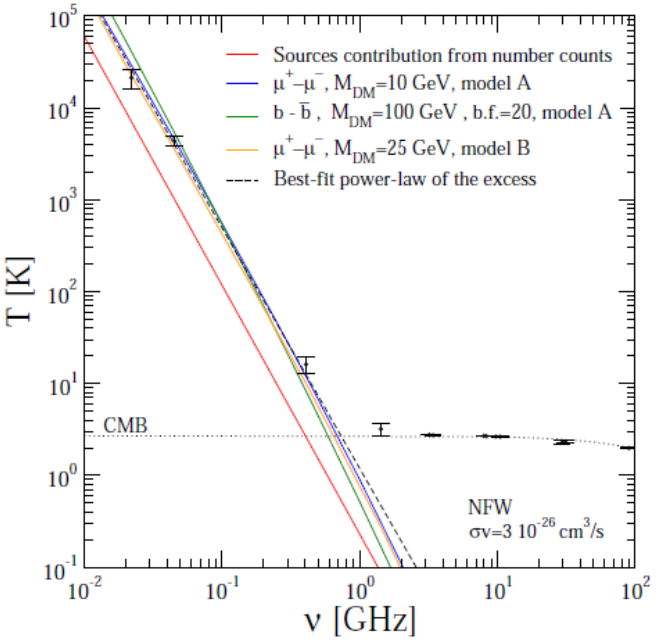
Interpretations in terms of known astro- sources are challenged by multi-wavelength constraints: gamma-rays, X-rays (diffuse intragalactic emission), IR (star forming galaxies).

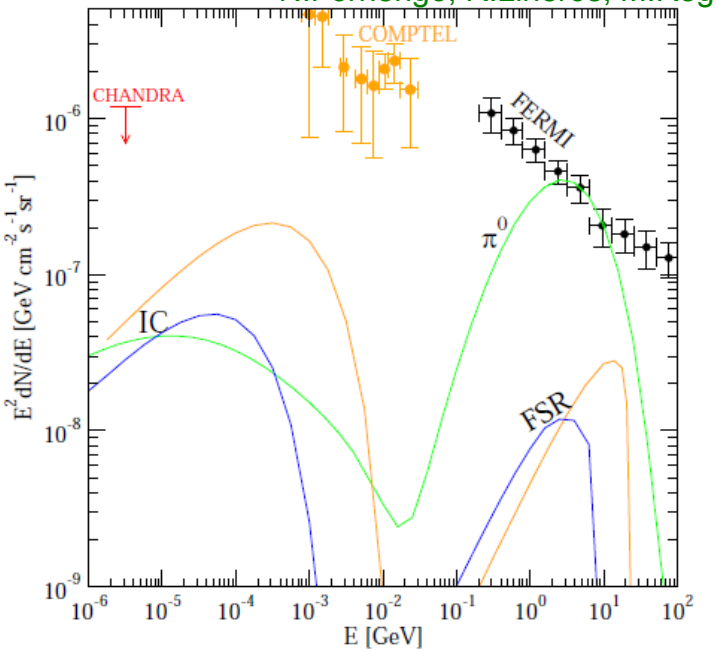
Not yet a viable scenario on the market.

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

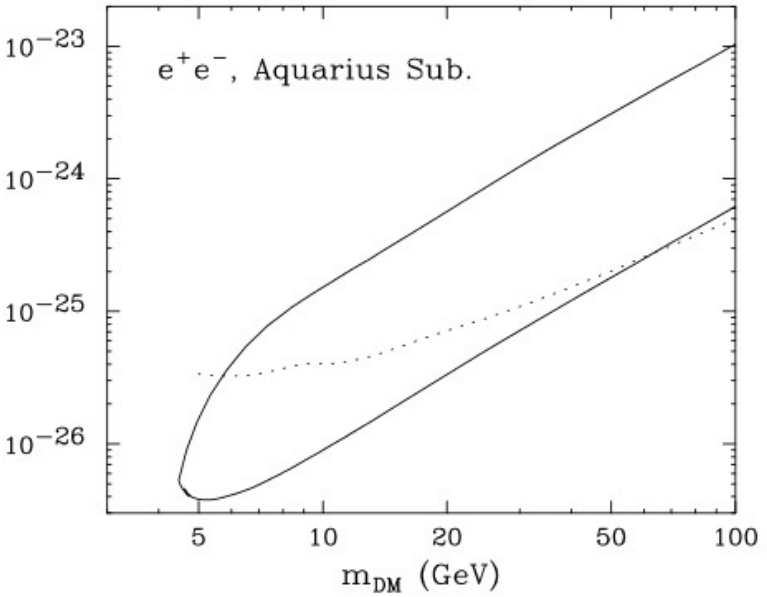
Can DM explain these data?

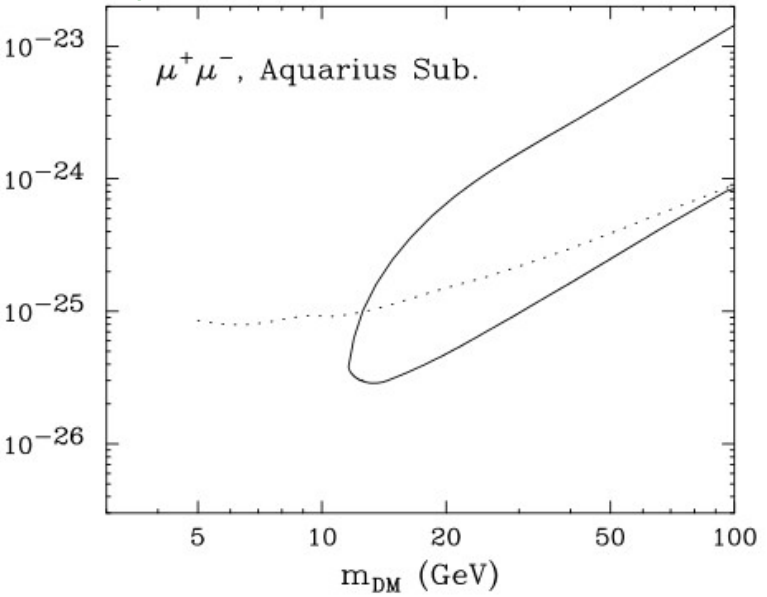
N.Fornengo, R.Lineros, M.Regis, M.T. 2011





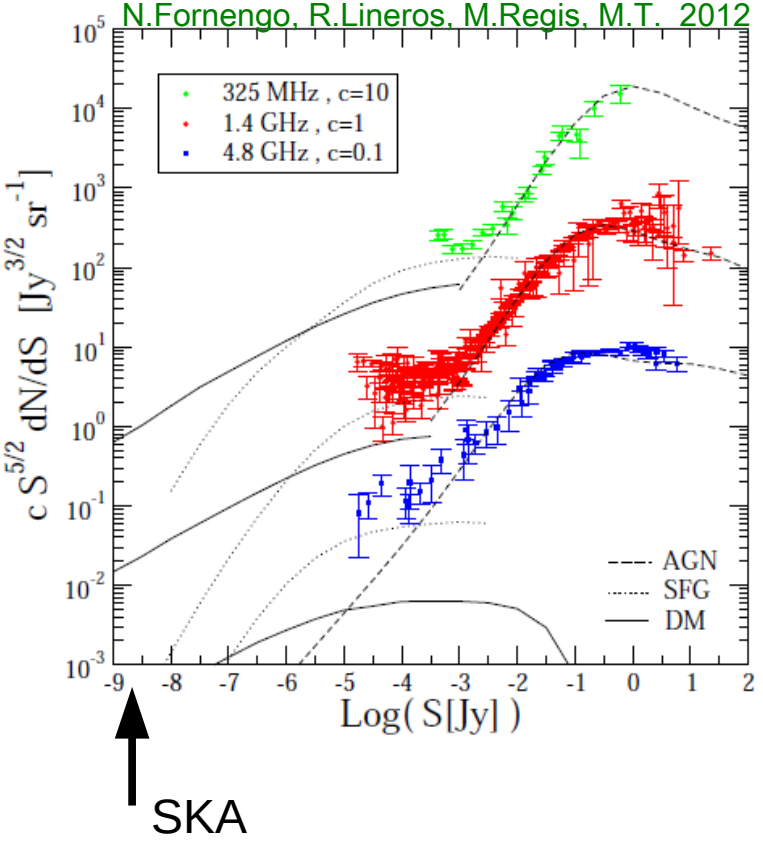
Hooper, Belikov, Jeltema,Linden,Profumo,Slatyer 2012

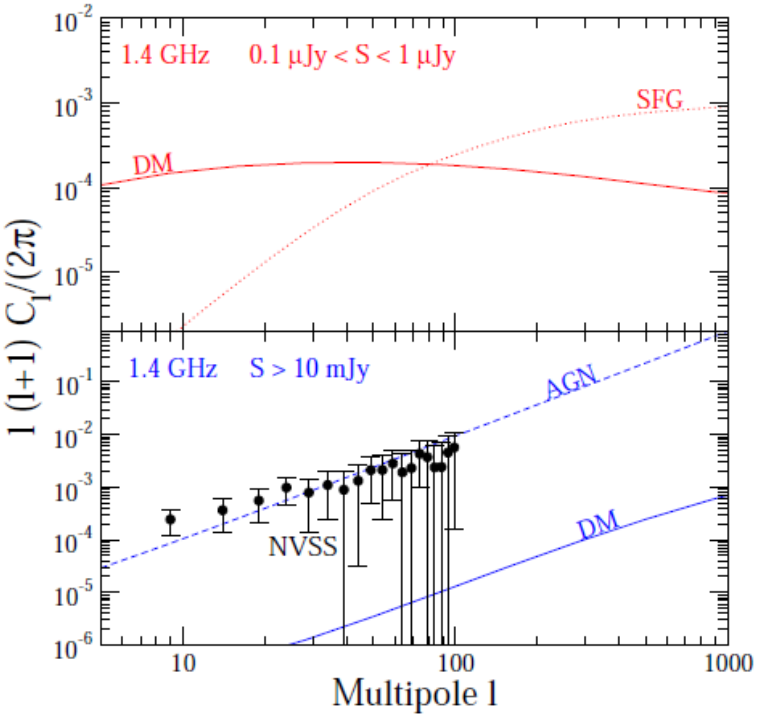




Forecast for future experiments

N.Fornengo, R.Lineros, M.Regis, M.T. 2012



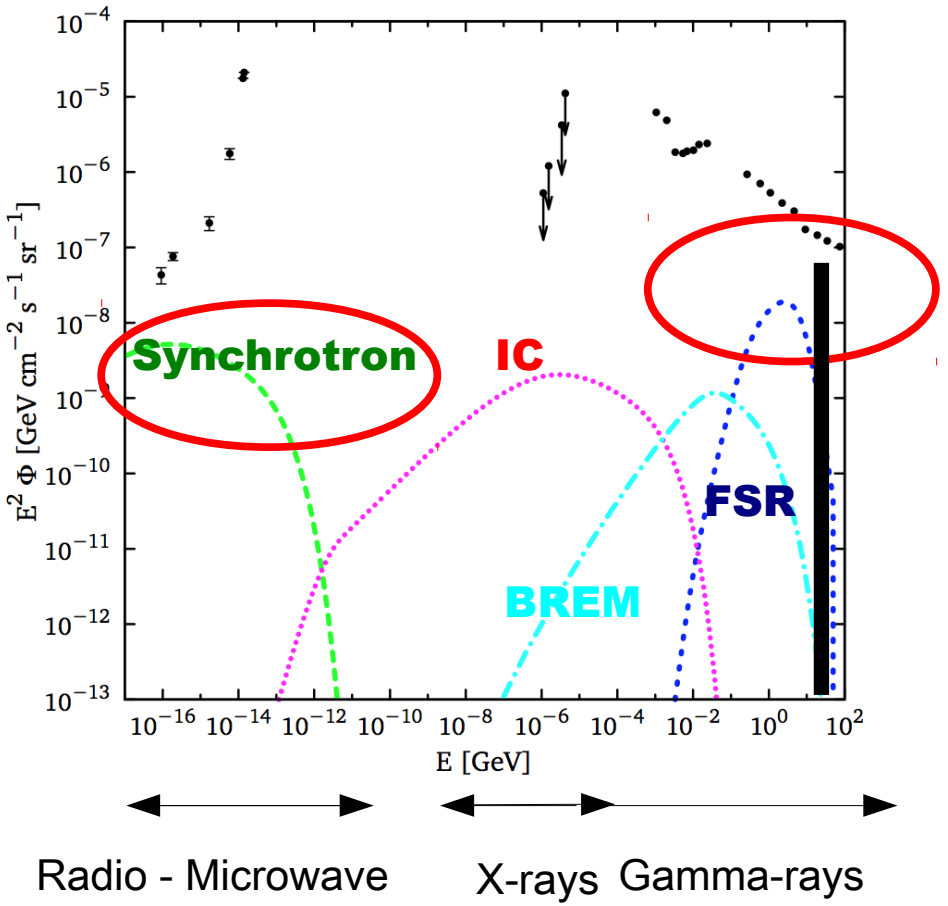


DM sources can dominate the number counts of sources at sub micro-Jy fluxes

These fluxes are at the reach of future radio telescopes:

EVLA and ASKAP soon, SKA (long term project)

DM emissions



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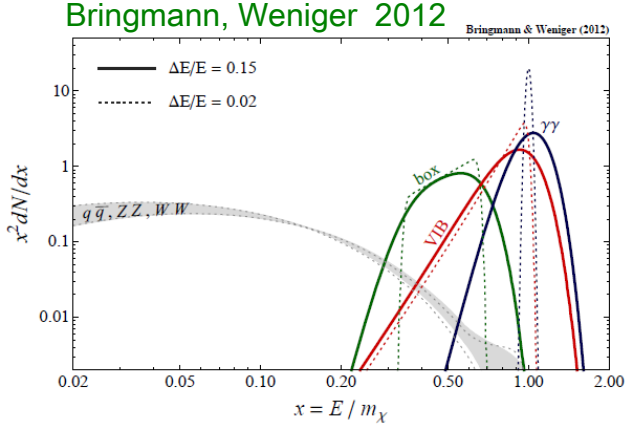
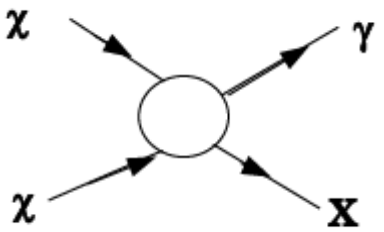
Inverse Compton $e^{\pm}\gamma \to e^{\pm}\gamma'$

Synchrotron emission from interactions of electrons with magnetic fields

Spectral features

Bringmann, Weniger 2012





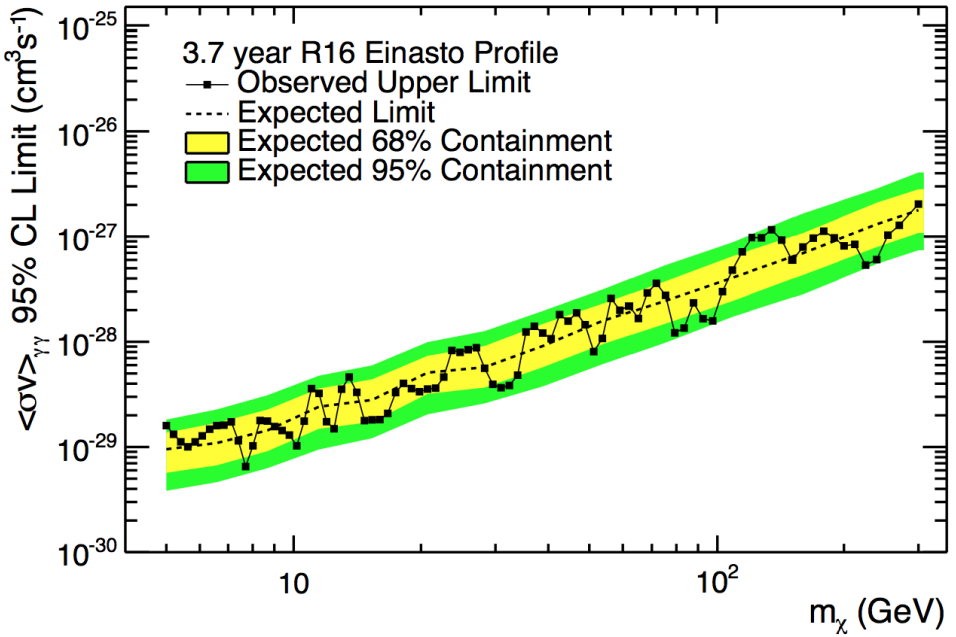
Typically absent in ordinary astro processes: **smoking gun signature for DM**

From line(s) energy(s) information on **masses of DM** $E_\gamma = M_{DM}\left(1 - \frac{M_X^2}{4M_{DM}^2}\right)$

Loop induced process: typically quite suppressed

Other spectral features: **internal bremsstrahlung** and **gamma-ray boxes**

FERMI Line



Bounds on lines from FERMI

Bounds at larger energies from HESS

Fermi-LAT Collaboration 1305.5597

Line at 130 GeV with a global significance > 3-sigma found by several authors

Update from FERMI collaboration:

Smaller statistical significance after data reprocessing + improved energy resolution

Not clear whether systematic effect (why not present outside Galactic center but it appears at smaller significance in the Limb data?)

DM models & lines

Loop level annihilations are severely suppressed for weak-size interactions

$$\mathcal{O}(\alpha^2) \sim 10^{-4}$$

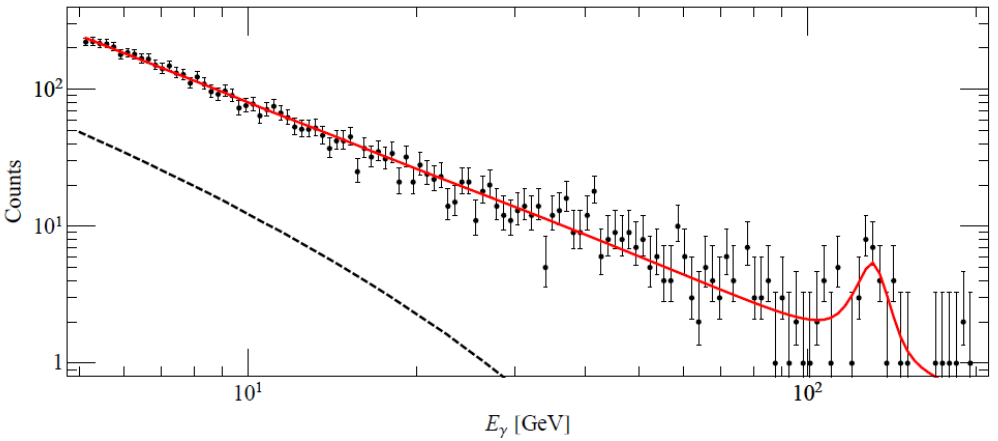
Take the 130 GeV gamma-ray lines:

from the shape of the spectrum bounds

on the continuum

$$\frac{(\sigma v)_{WW,f\bar{f}}}{(\sigma v)_{\gamma\gamma}} \lesssim 10 - 100$$

Cohen, Lisanti,Slatyer, Wacker 2012



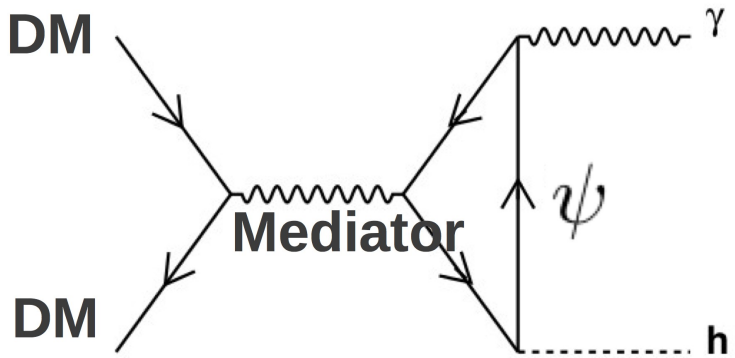
See also Cholis, Tavakoli, Ullio 2012

Continuum should be under control !

Which DM models can we search for with gamma lines?

Forbidden channel scenario

Jackson, Servant, Shaughnessy, Tait, MT 2010



DM has large couplings to new charged particles ψ via a mediator

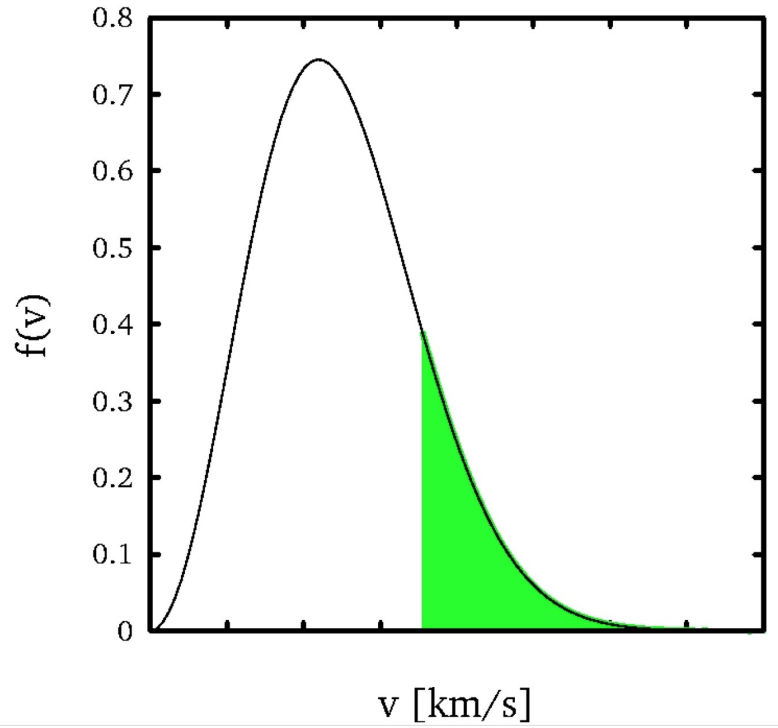
$M_{DM} \lesssim M_\psi$ annihilations forbidden today

since DM has small velocities in our galaxy

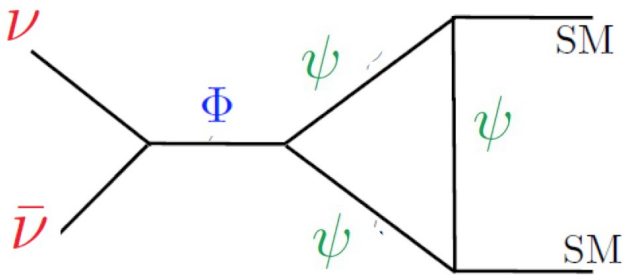
$$v/c \sim 10^{-3}$$

Annihilations occur in the early Universe

$$v/c \sim 10^{-1}$$



Example: scalar resonance



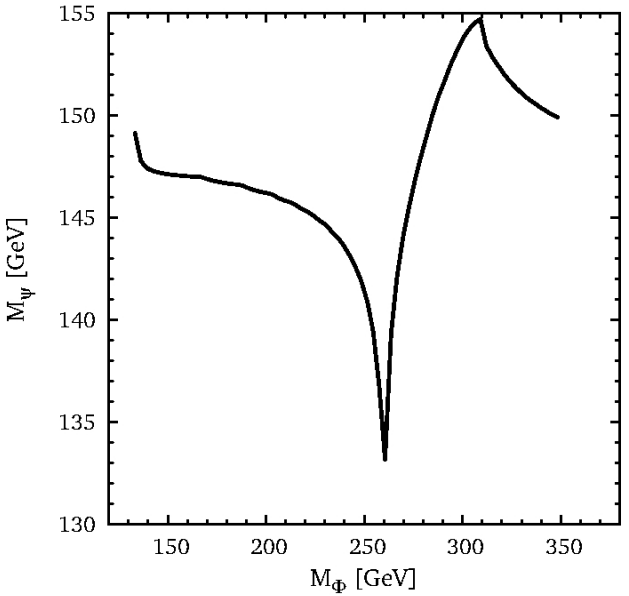
$(SU(3), SU(2), U(1))$

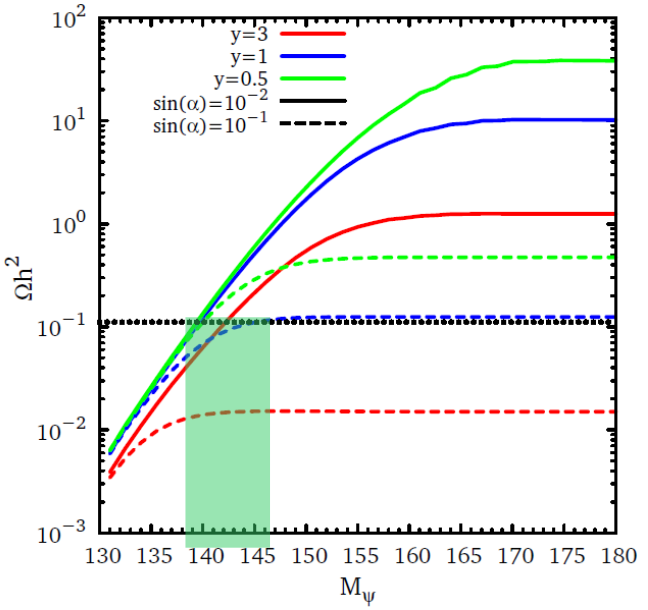
- $(1, 2, 1/2)$: $\psi_{1/2} = (\psi^+, \psi^0)$;
- $(1, 2, -3/2)$: $\psi_{-3/2} = (\psi^-, \psi^{--})$;
- $(1, 1, -1)$: $\psi_{-1} = \psi^-$.

DM relic density and no virtually no continuum today through annihilations into

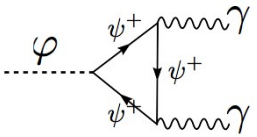
ψ pairs in the early universe of through coannihilations

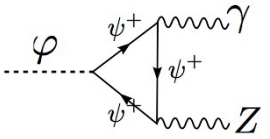
In these examples relic density ok and 130 GeV line is reproduced



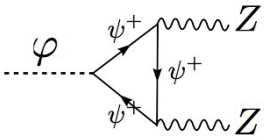
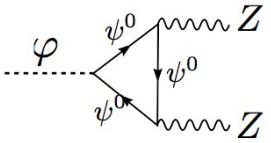


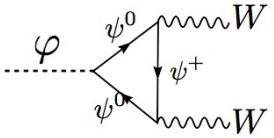
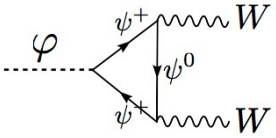
1-loop annihilations

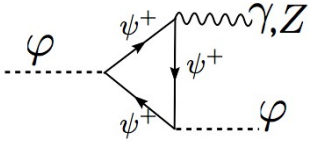
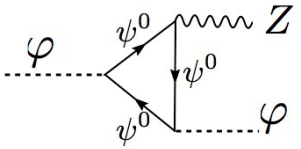
$\gamma\gamma$ 

γZ 

Multiples lines!

ZZ  

WW  

$\gamma\varphi, Z\varphi$  

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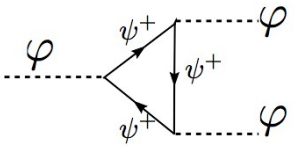
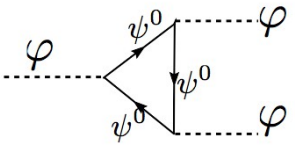
$\varphi\varphi$  

Different charge assignments

Jackson, Servant, Shaughnessy, Tait, MT 2013

$(SU(3), SU(2), U(1))$

- $(1, 2, 1/2)$: $\psi_{1/2} = (\psi^+, \psi^0)$;
- $(1, 2, -3/2)$: $\psi_{-3/2} = (\psi^-, \psi^{--})$;
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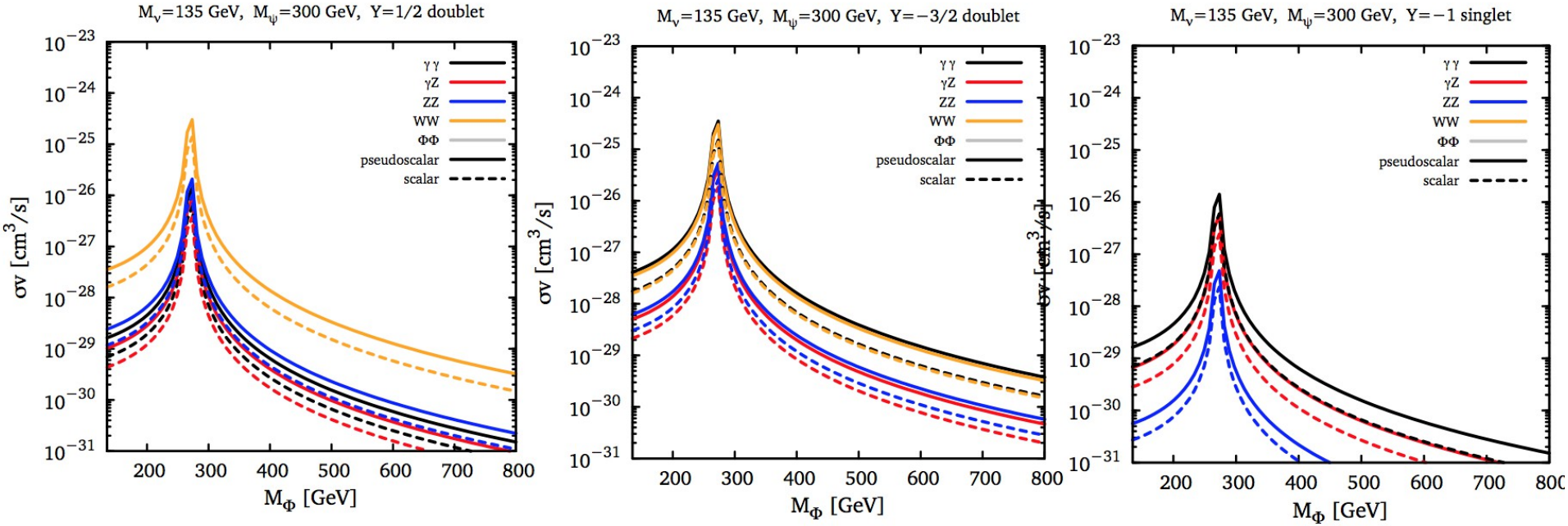
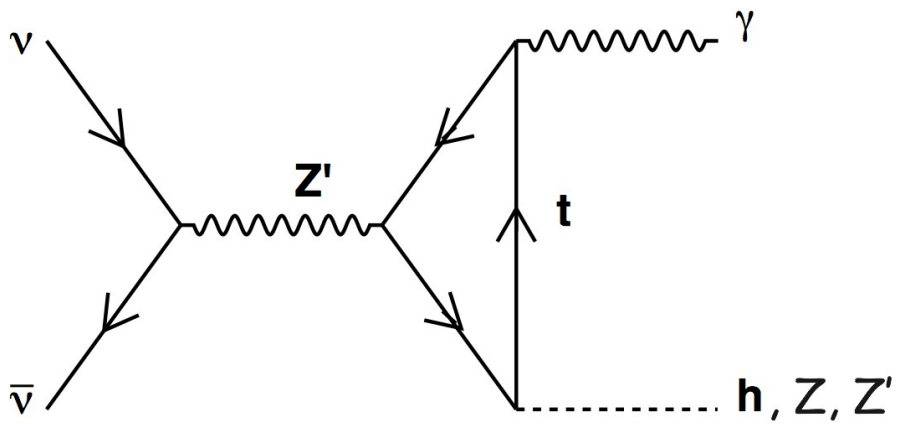


	ψ_{-1}	$\psi_{-3/2}$	$\psi_{1/2}$
$\sigma_{\gamma Z}/\sigma_{cont}$	10	0.5	0.02
$\sigma_{\gamma\gamma}/\sigma_{cont}$	30	1	0.04

Example with top mediation



New vector-like fermion mixes with SM top quark via mass mixing

$$yH\bar{\hat{Q}}_3\hat{t}_R + \mu\bar{\psi}_L\psi_R + Y\Phi\bar{\psi}_L\hat{t}_R$$

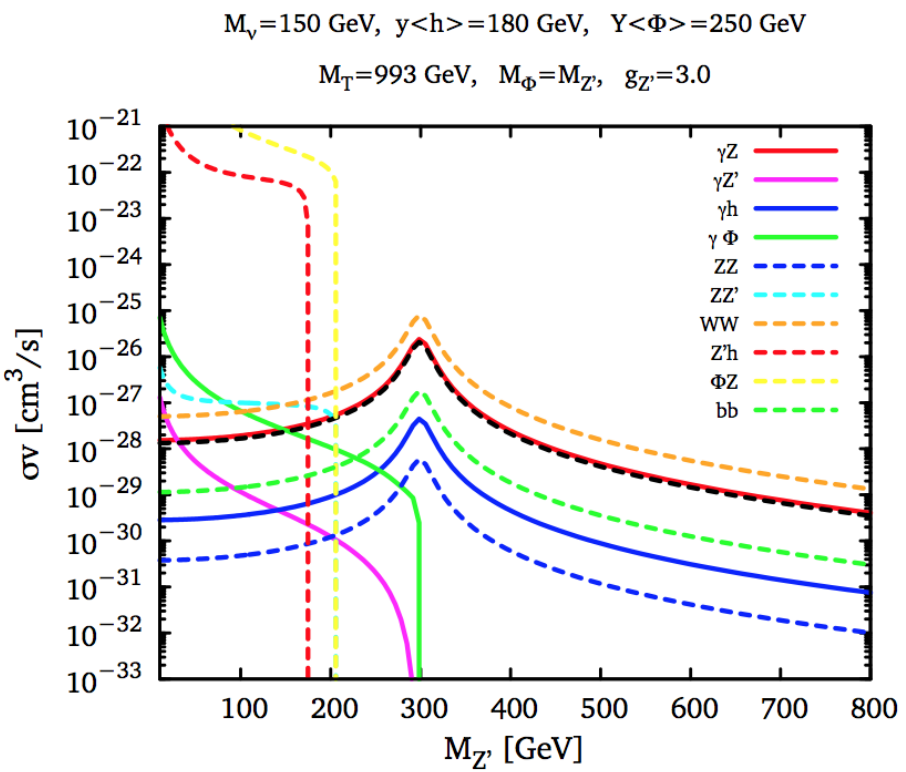
$$\begin{pmatrix} t_{R/L} \\ T_{R/L} \end{pmatrix} = \begin{pmatrix} -\sin\theta_{R/L} & \cos\theta_{R/L} \\ \cos\theta_{R/L} & \sin\theta_{R/L} \end{pmatrix} \begin{pmatrix} \hat{t}_{R/L} \\ \Psi_{R/L} \end{pmatrix} \qquad M_T = m_t \, \frac{\tan\theta_L}{\tan\theta_R}$$

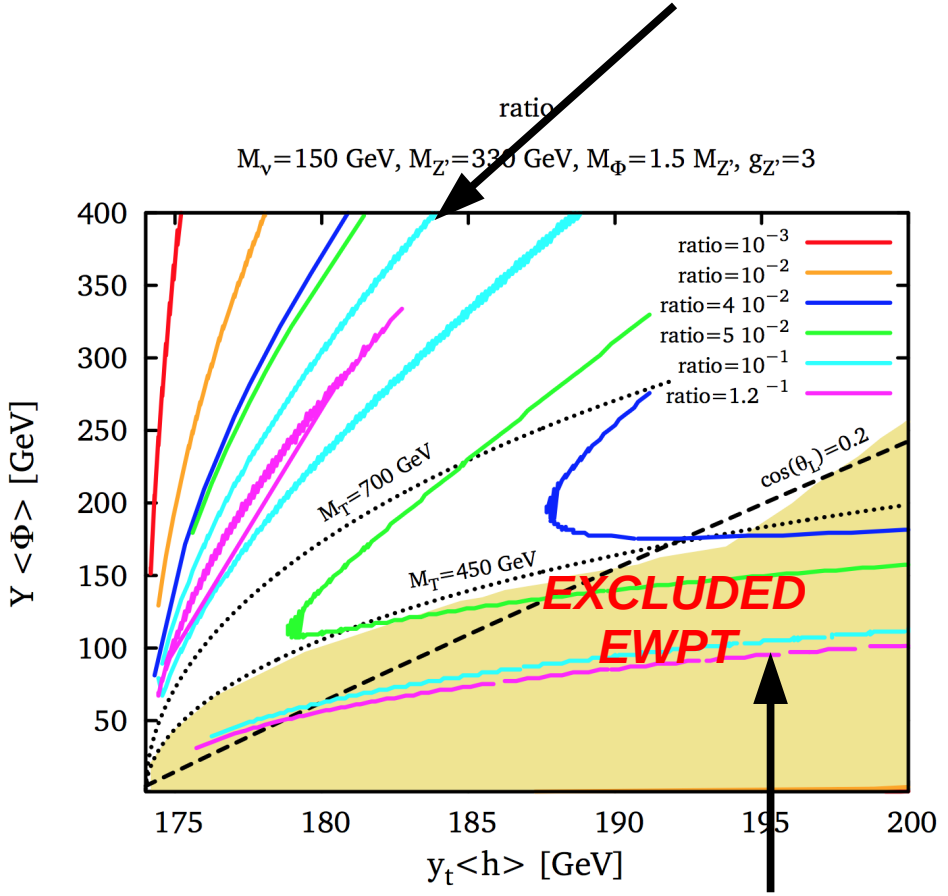
Signal cross sections

Jackson, Servant, Shaughnessy, Tait, MT 2013

Numerous continuum channels are induced at 1-loop.

The ratio line/continuum can be kept under control





Outlook

Radio observations give bound on the WIMPs parameter space complementary to those from gamma-rays

In addition they provide an handle to understand the propagation of charged cosmic-rays in the galaxy, a key ingredient for searches of DM diffuse emissions.

WIMPs annihilation into gamma-rays are precious probe of DM

Large signals can arise in models where annihilations are enhanced by resonance effects and the continuum is forbidden/suppressed

These features are captured in simple models with scalar/vector mediators and new charged particles.