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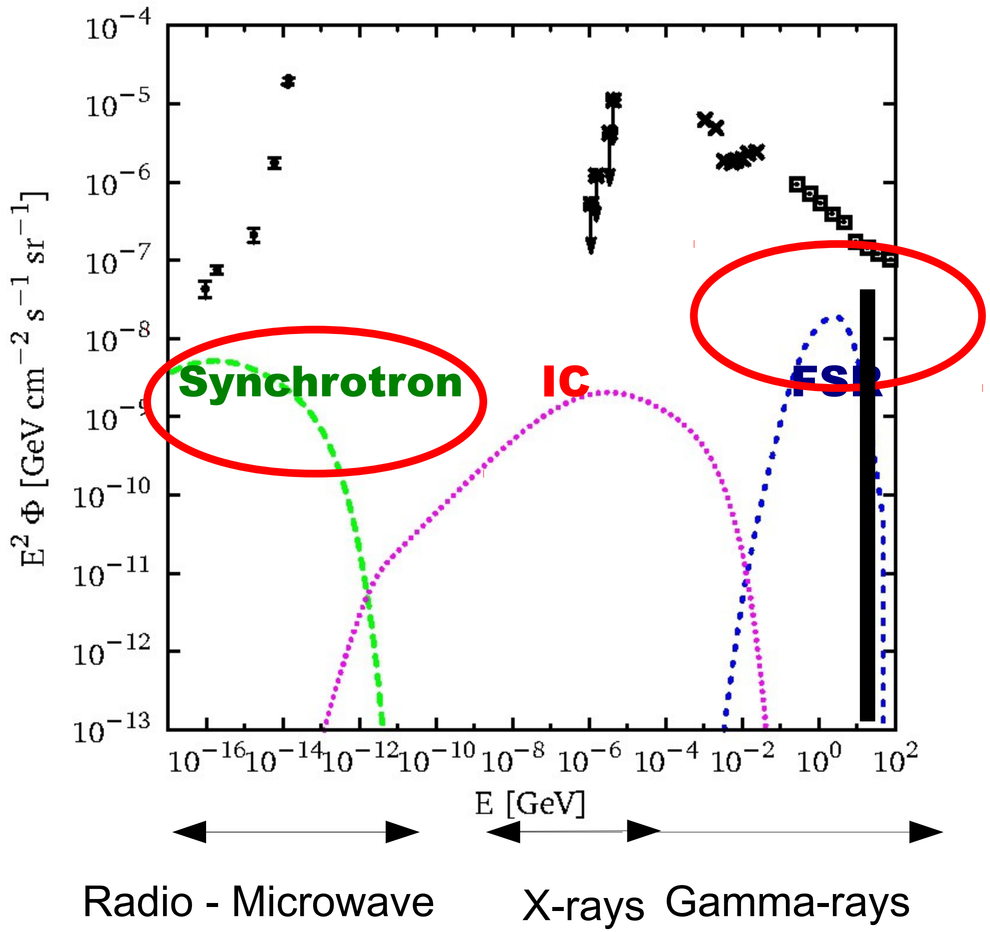
Dark Matter searches with radio and gamma-rays

KITP- Santa Barbara
Identifying and Characterizing Dark Matter via Multiple Probes
13-17 May 2013

Secondary 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

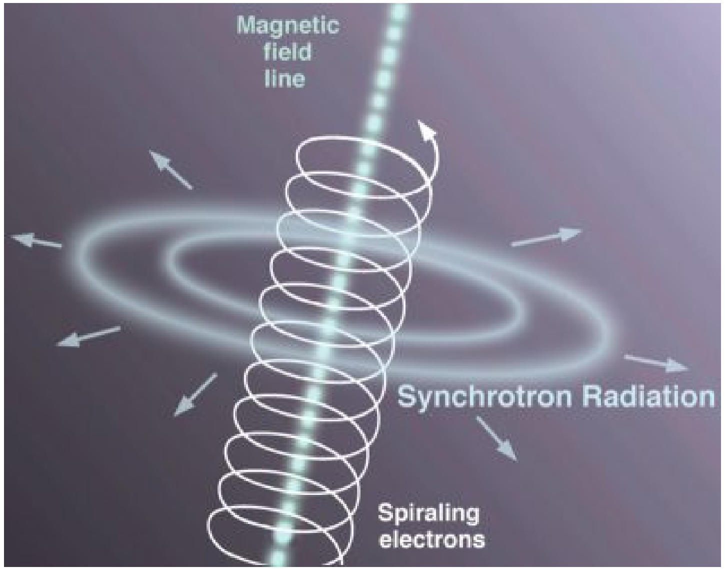
Plan of the talk

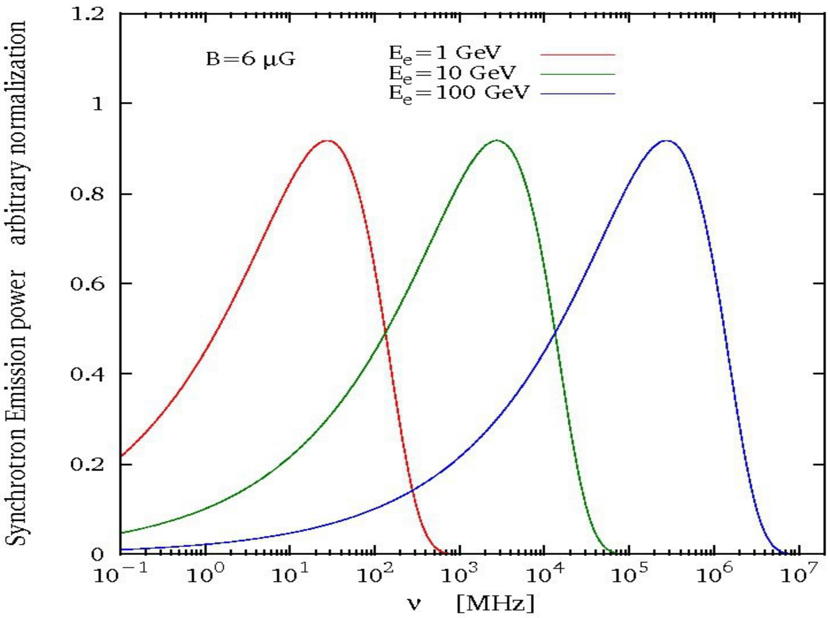
Synchrotron emission and radio observations

- 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

- **DM models for gamma-ray lines**
- Simple recipes for models with prominent gamma-rays lines
- Model with scalar and vector resonance – connection with top physics
- Based on Jackson, Servant, Shaughnessy, Tait, MT 2010, 2013

Synchrotron radiation



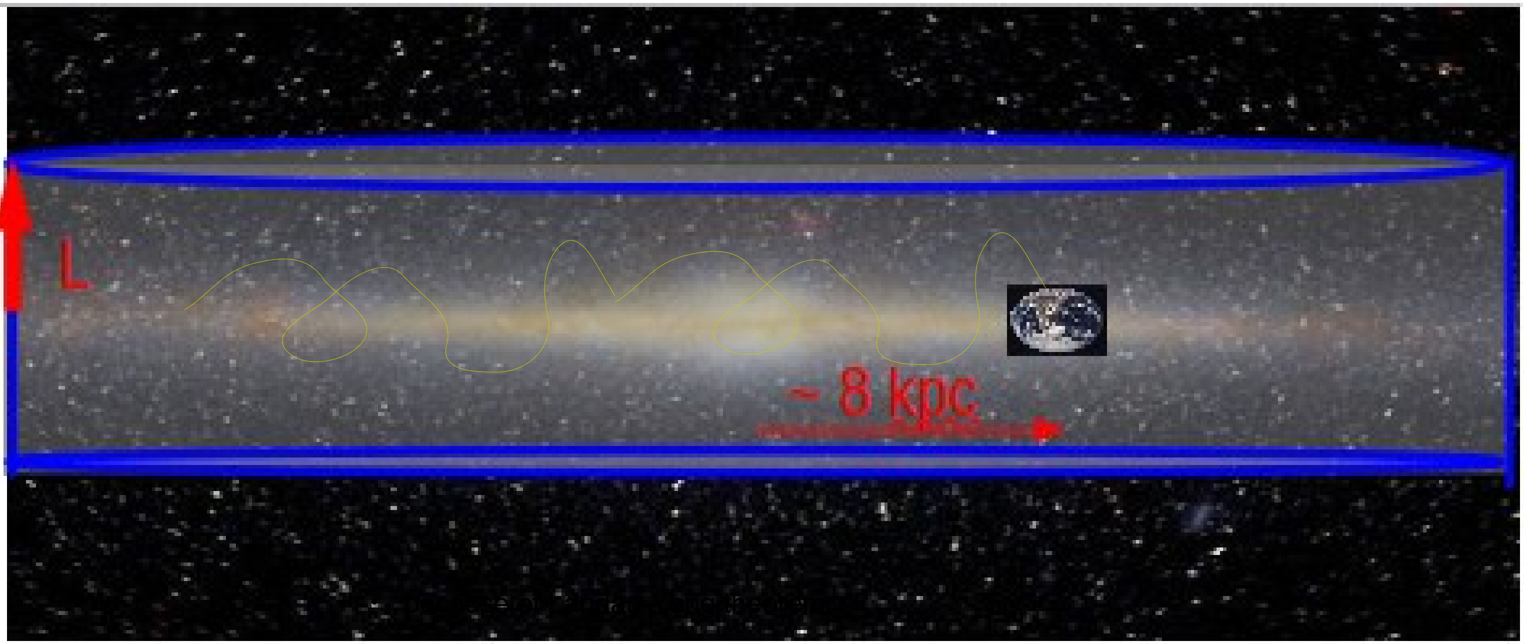


Synchrotron emission from interactions of electrons with magnetic fields

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

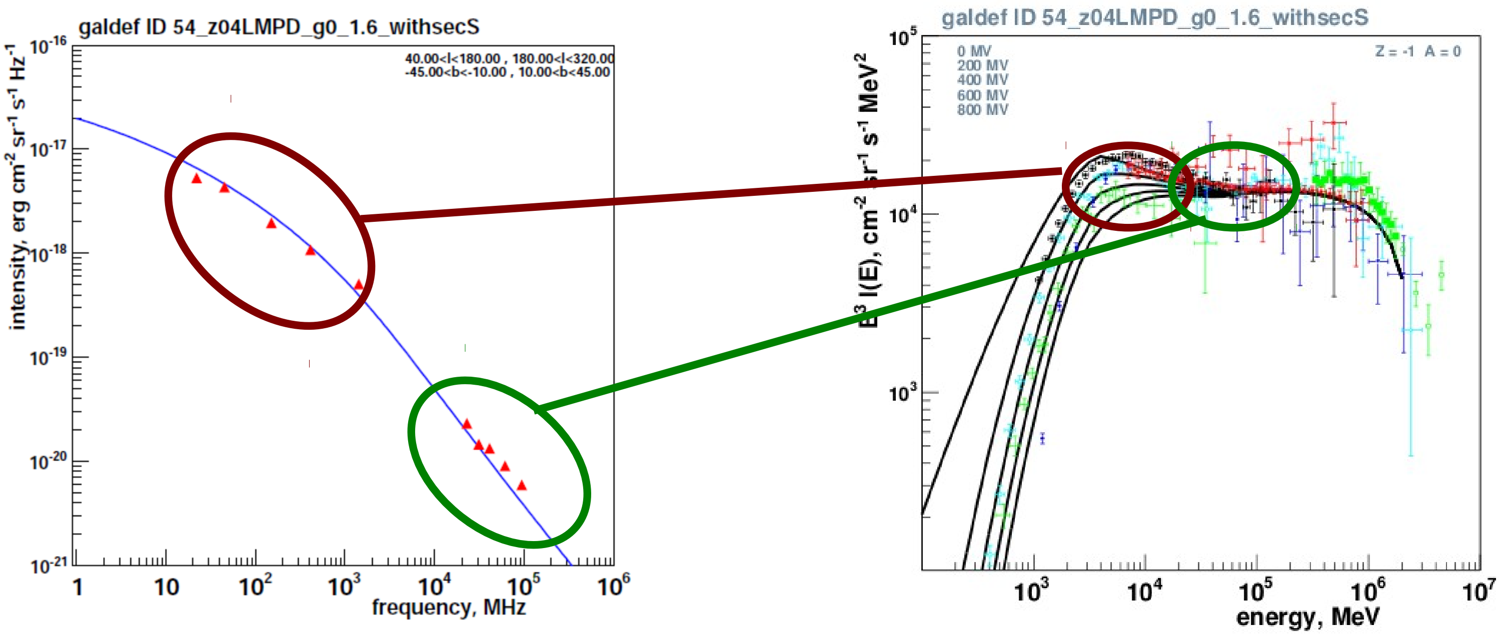


Propagation of charged cosmic-rays described by transport equation which describes energy losses, diffusion accelerations, convection

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

diffusion   energy losses   distribution of sources

Constrain CRs and B with radio



Strong, Orlando, Jaffe 2011

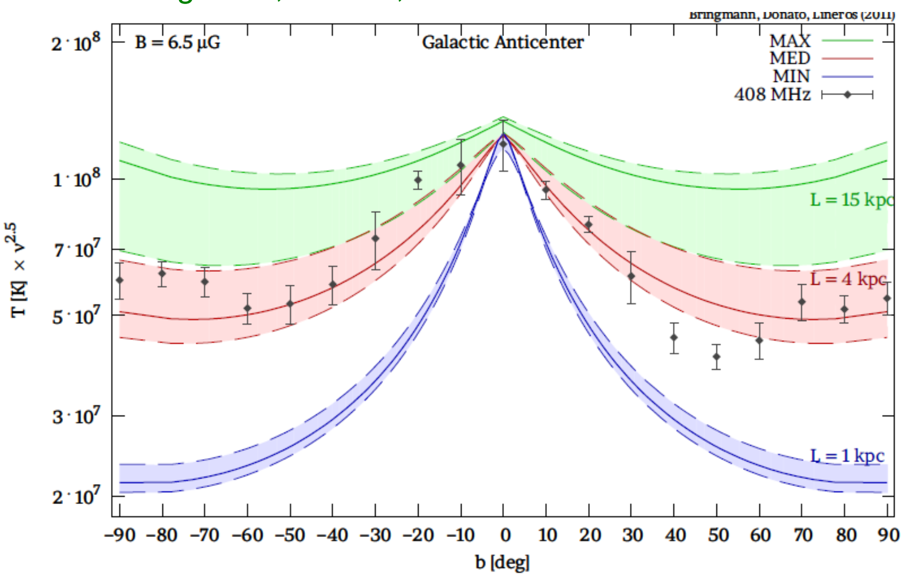
Magnetic fields are constrained by Faraday rotation measurements of sources

Radio surveys constrain the radio emission from CR electrons

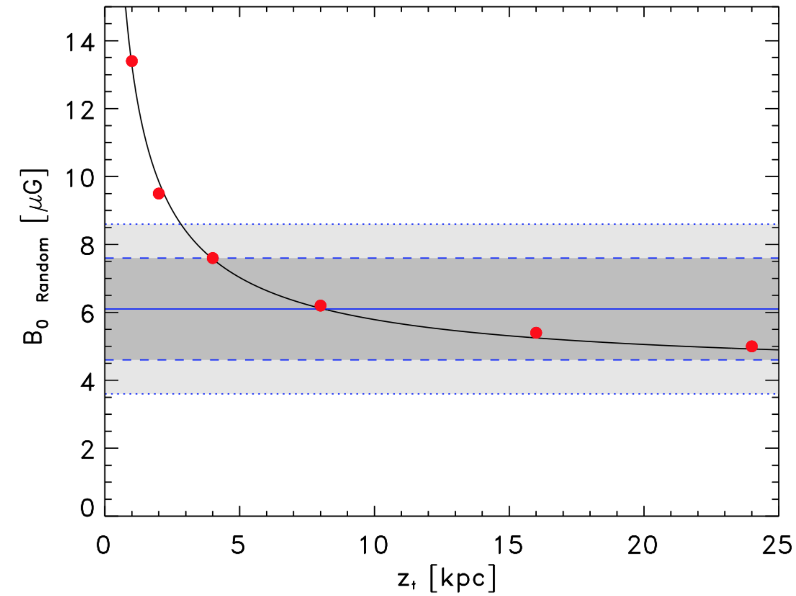
Low/high frequency surveys probe different parts of the interstellar electron spectrum

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)

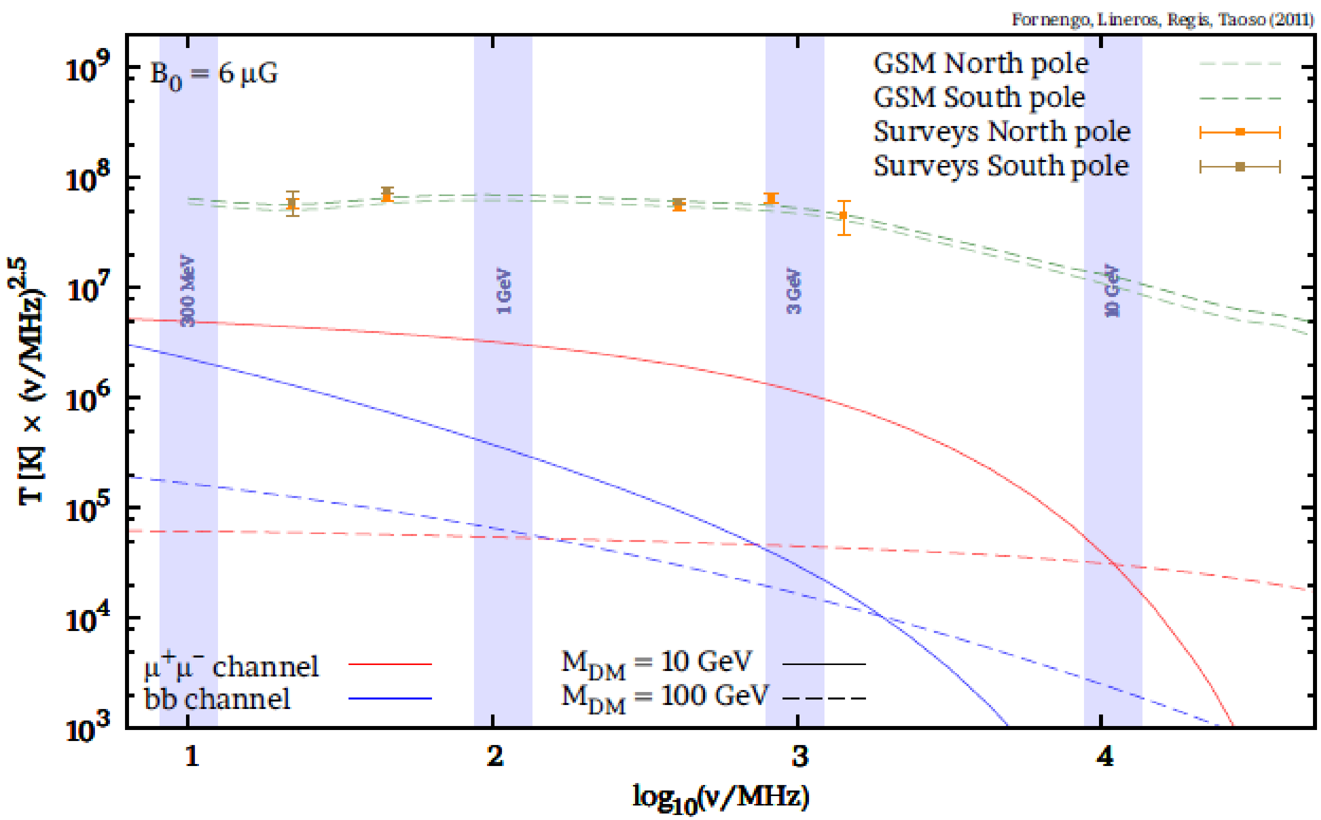
constrain the parameter of propagation models

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

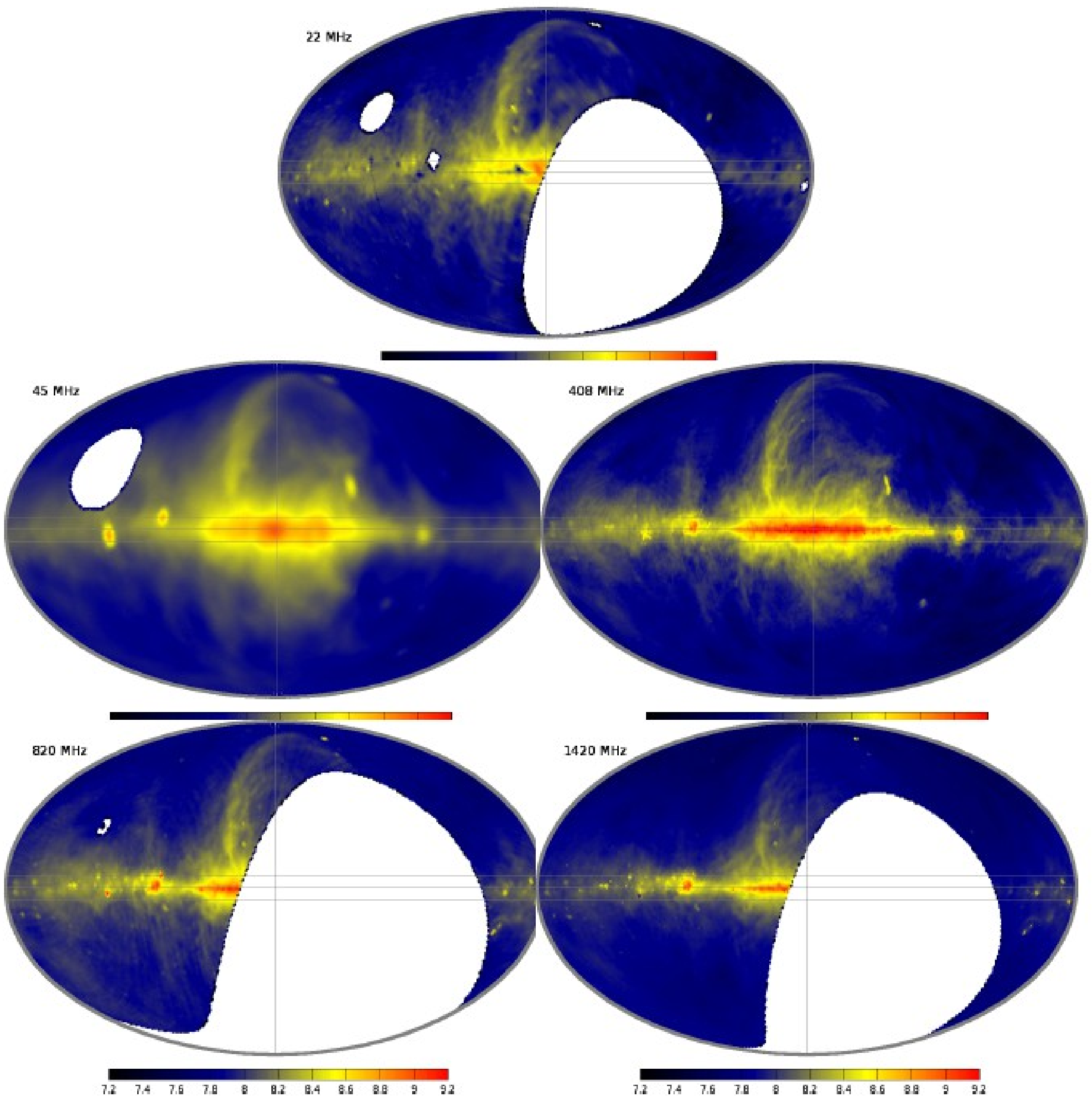
Gamma-ray diffuse from interactions of protons with gas and IC and Brem. of electrons

Synchrotron from DM



Low frequencies particulary suitable to constrain light DM

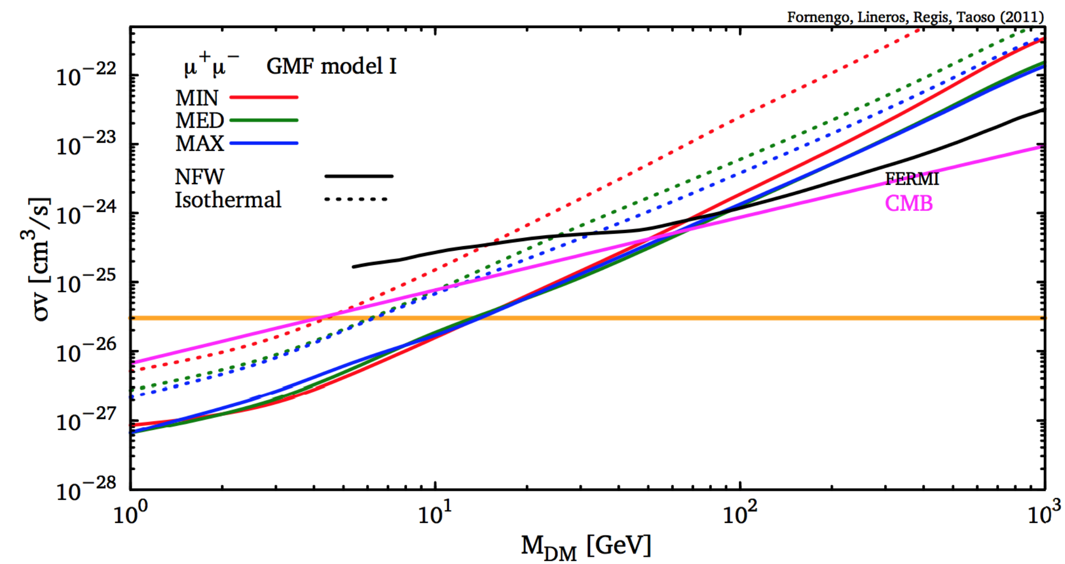
Radio surveys from 22 MHz to 1420 MHz

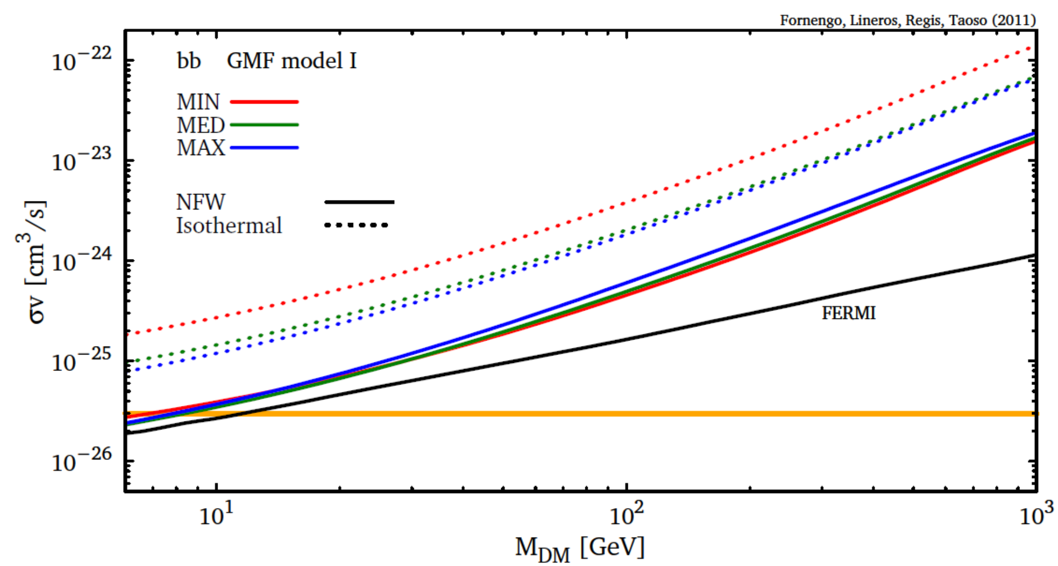


Constraints on DM

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

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





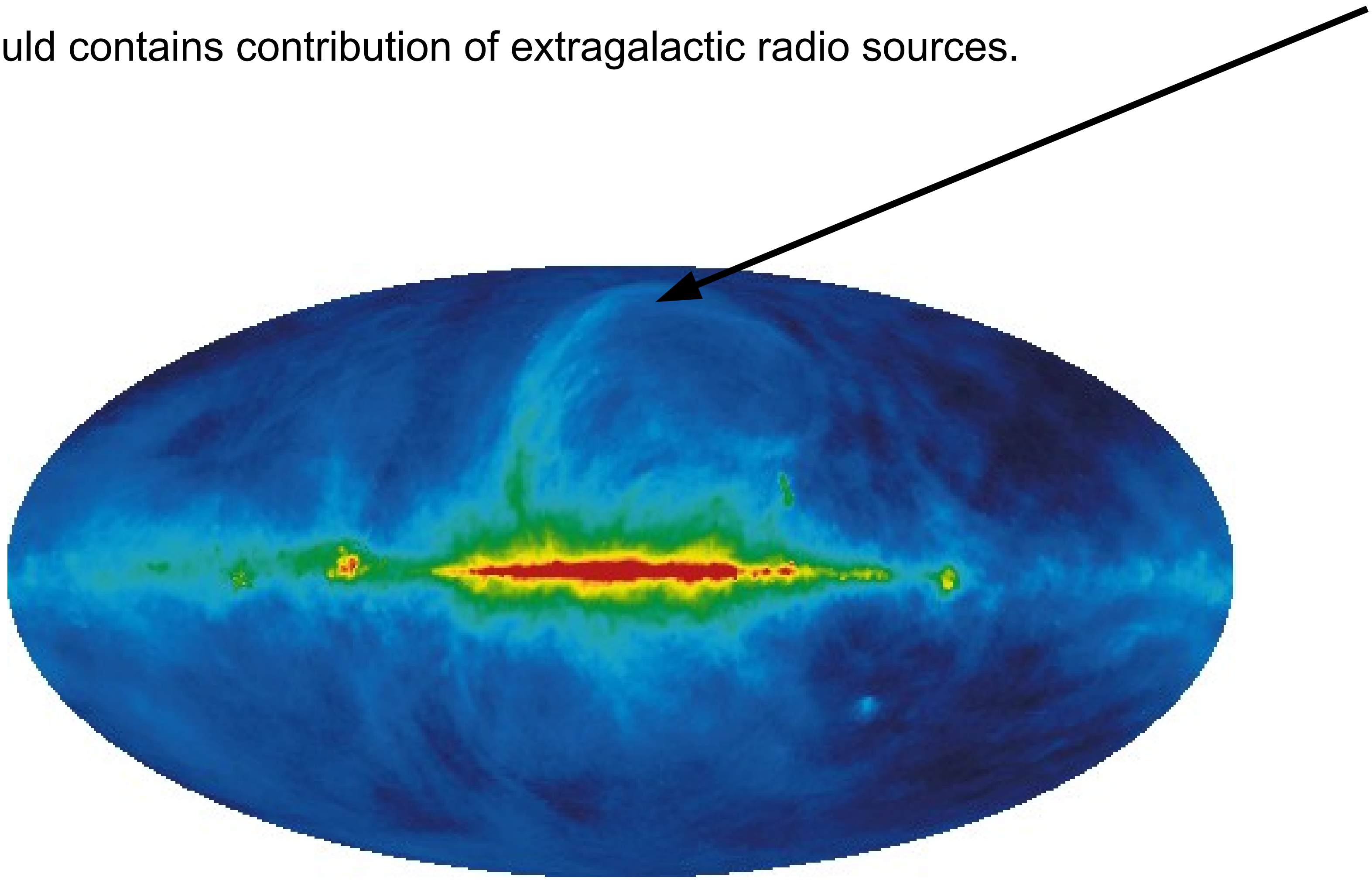
Uncertainties:

- 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.



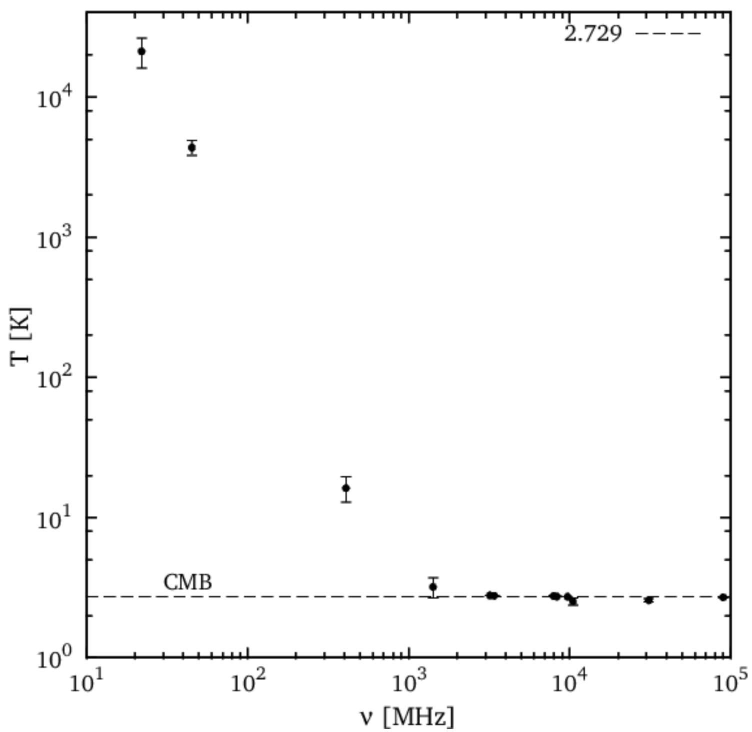
ARCADE-II excess

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

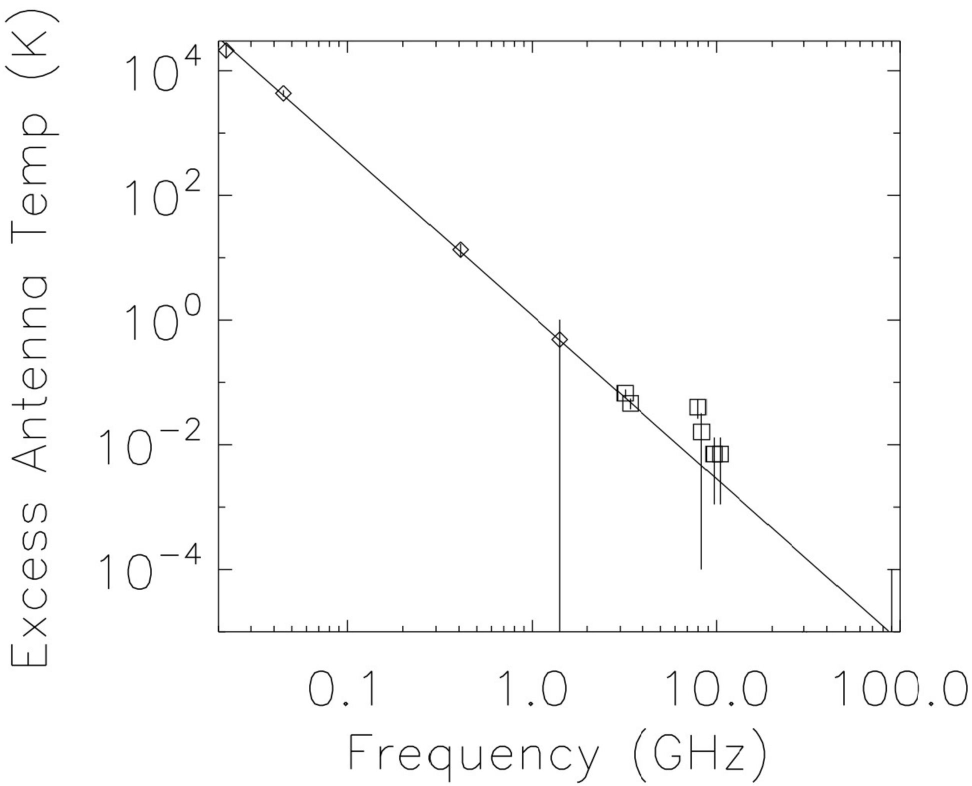
Galactic emission estimated with 2 methods:

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 <10 GHz



Fixen et al. 2009



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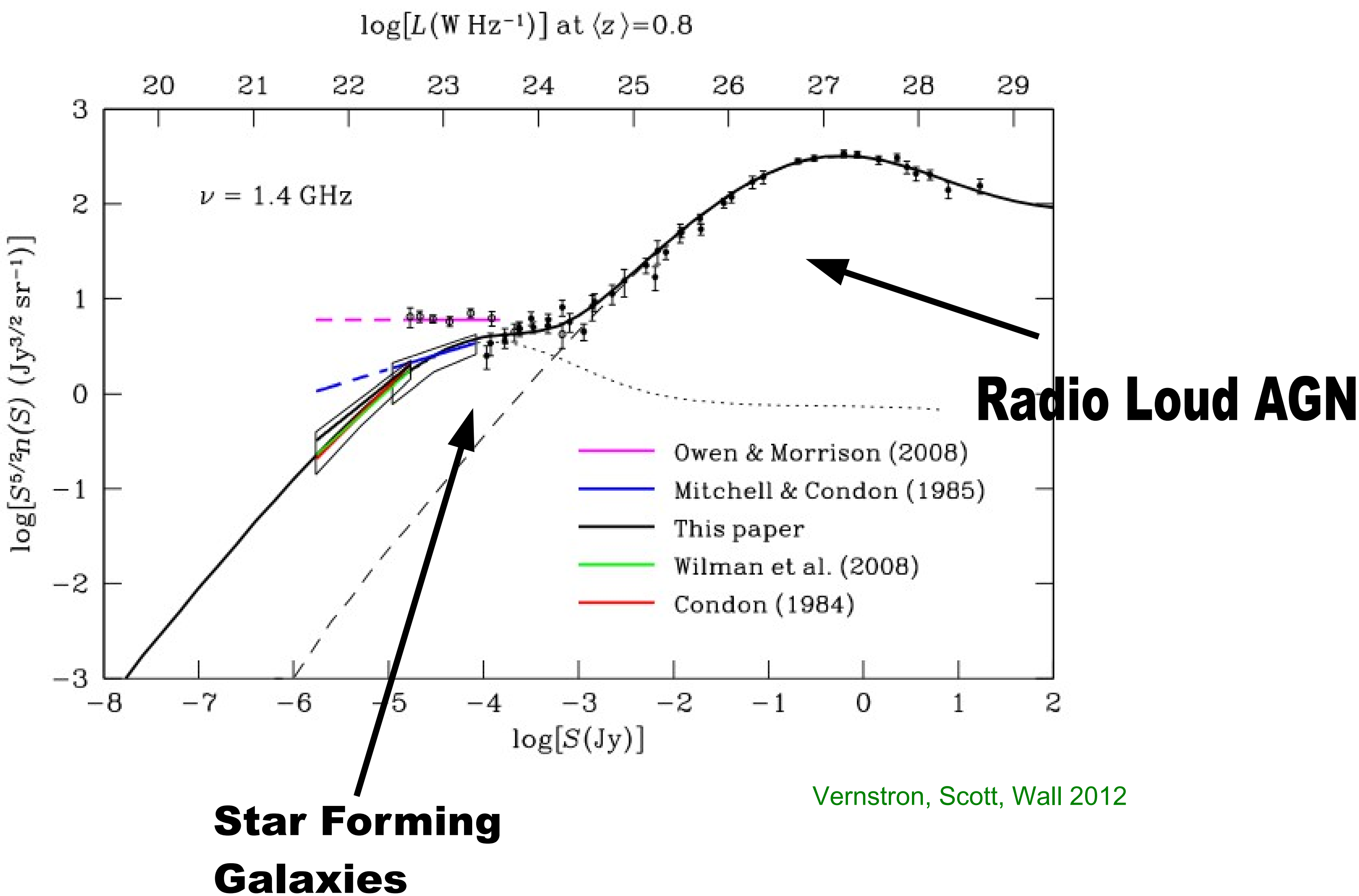
Number counts of sources

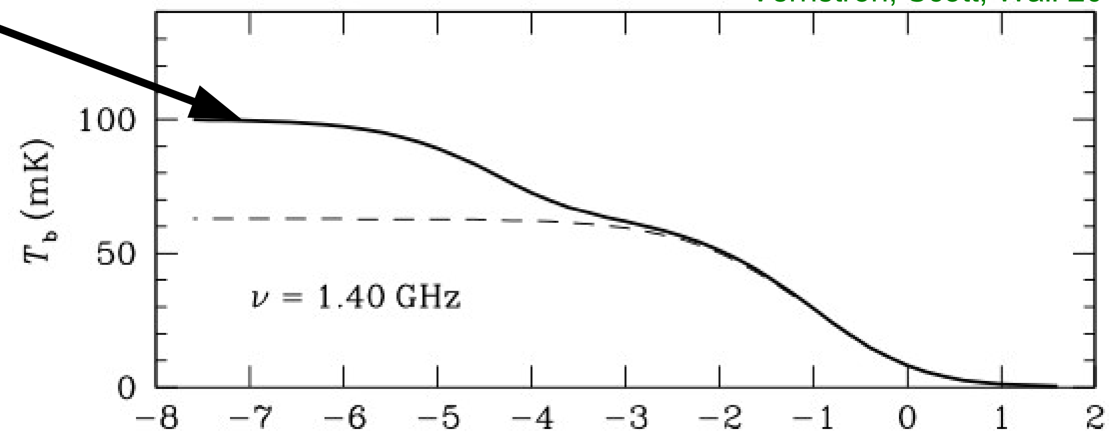


Vernstron, Scott, Wall 2012

ARCADE-II excess

Isotropic radio background inferred by ARCADE is 480 mk!

Vernstron, Scott, Wall 2012



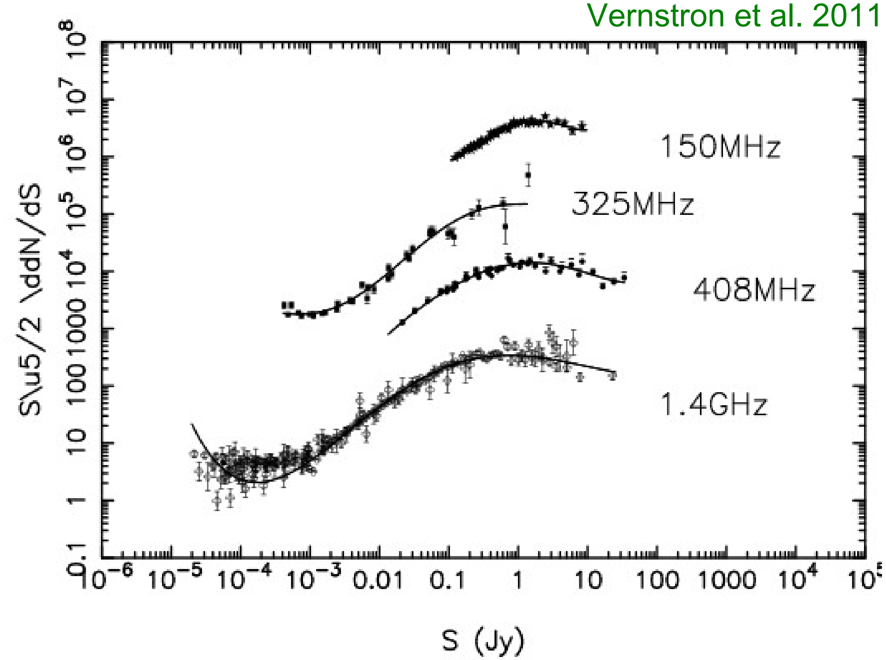
Contribution of radio sources

estimated with number counts:

a factor 4-5 smaller than IRB

obtained by ARCADE

Vernstron et al. 2011



Excess confirmed at other frequencies

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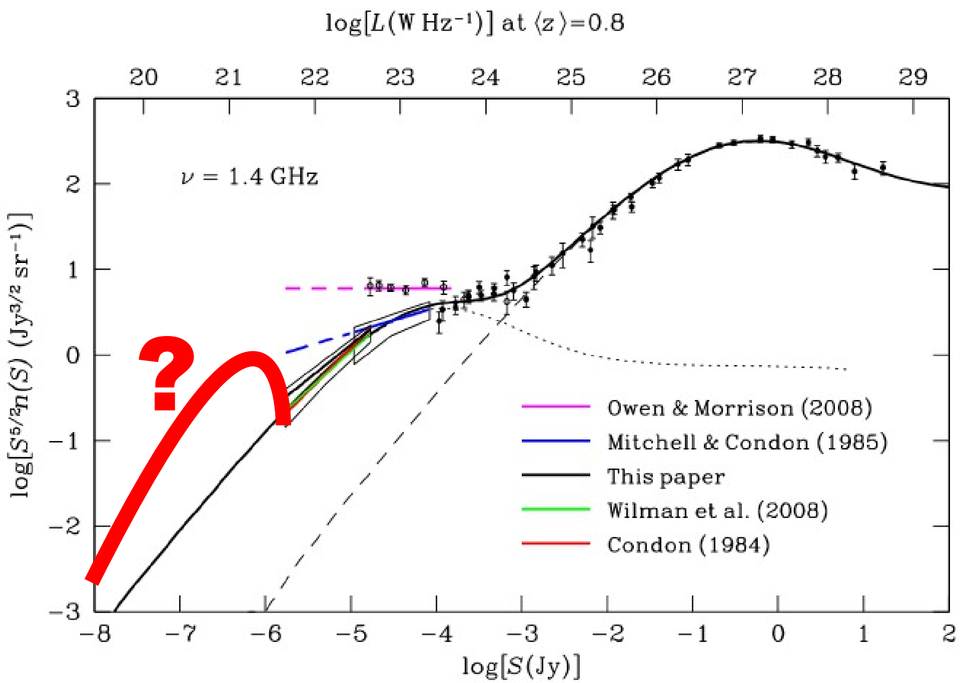
Possible explanations



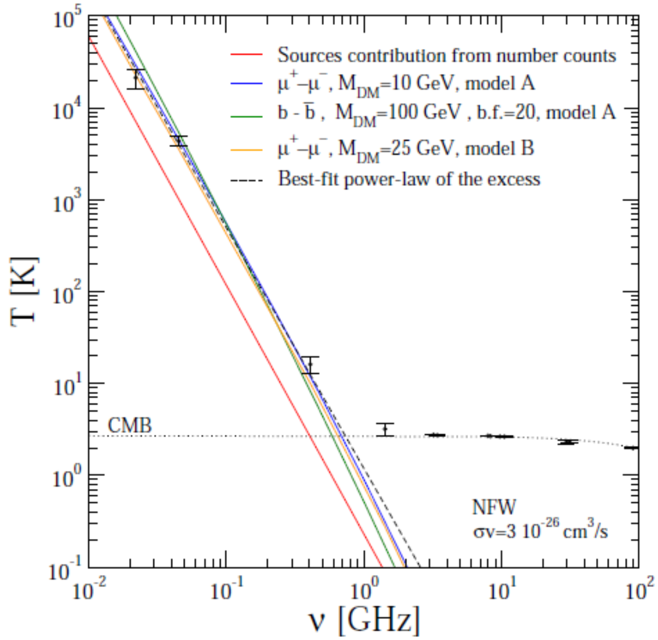
The excess calls for an undetected population of radio sources at fluxes below micro-Jy

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

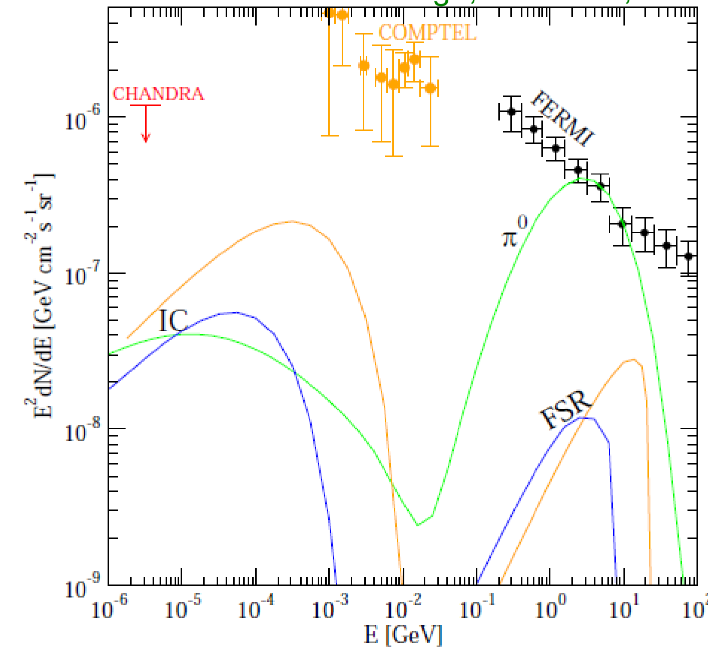
Not yet a viable scenario on the market.

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

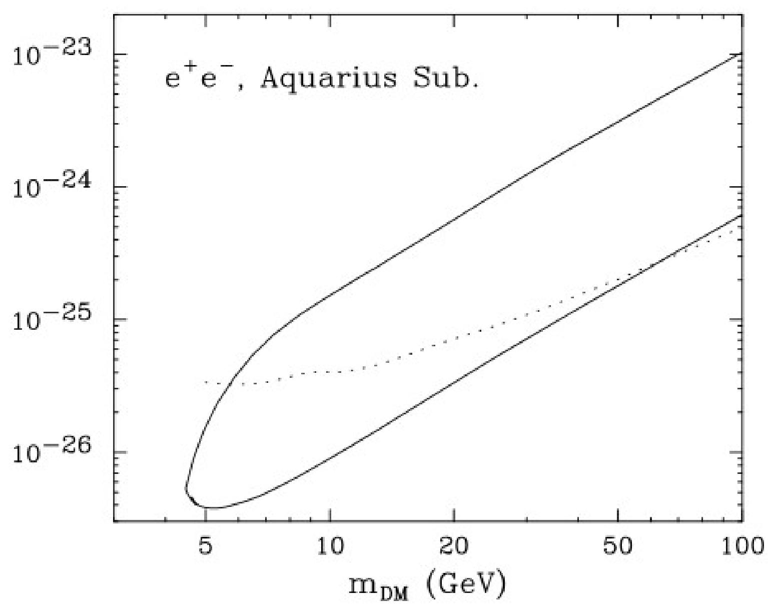
Can DM explain these data?

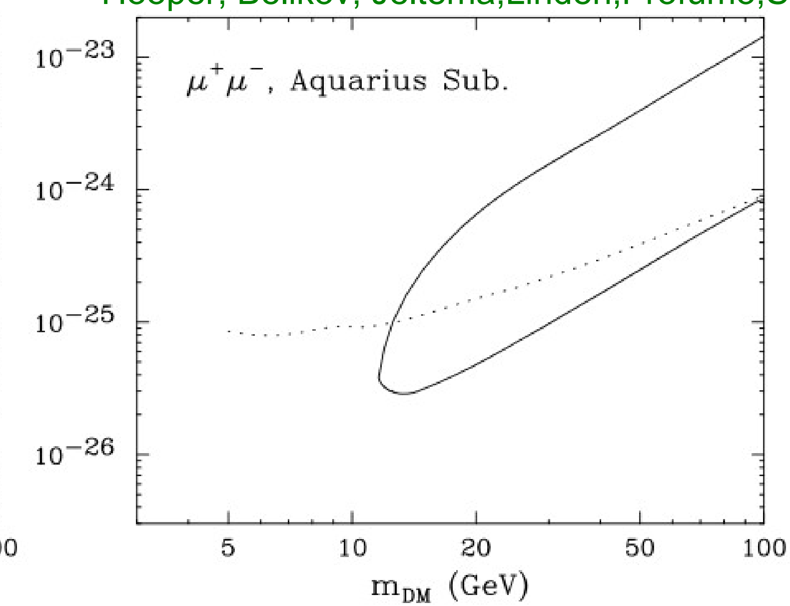


N.Fornengo, R.Lineros, M.Regis, M.T. 2011

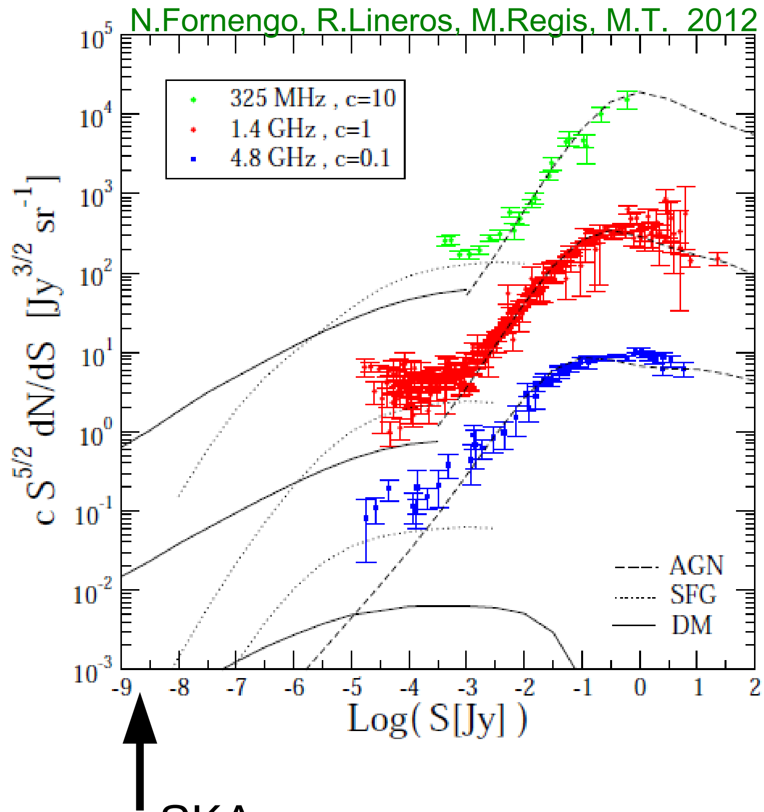


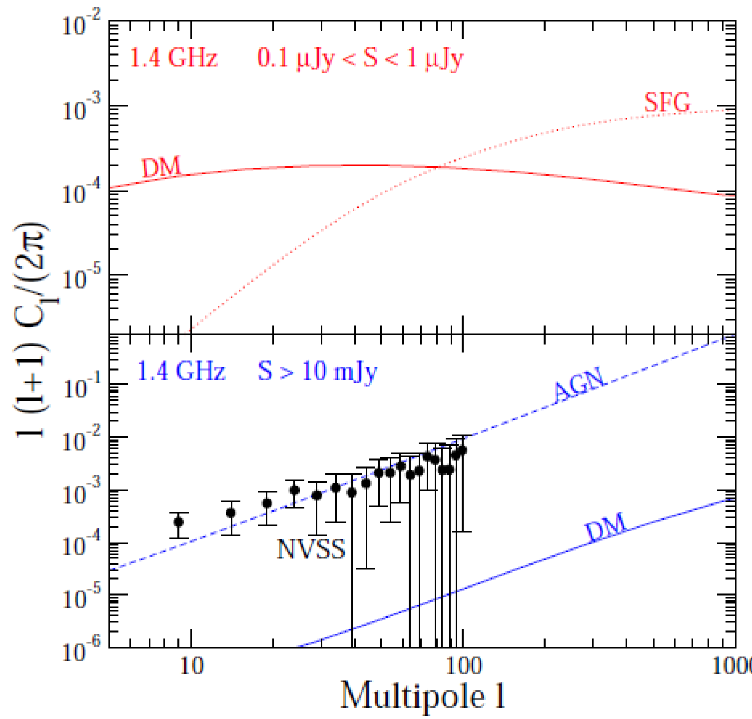
Hooper, Belikov, Jeltema,Linden,Profumo,Slatyer 2012





Forecast for future experiments





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)

Outlook

The determination of the IRB from ARCADE might be contaminated by galactic emission

Alternative methods to estimate the galactic emission?

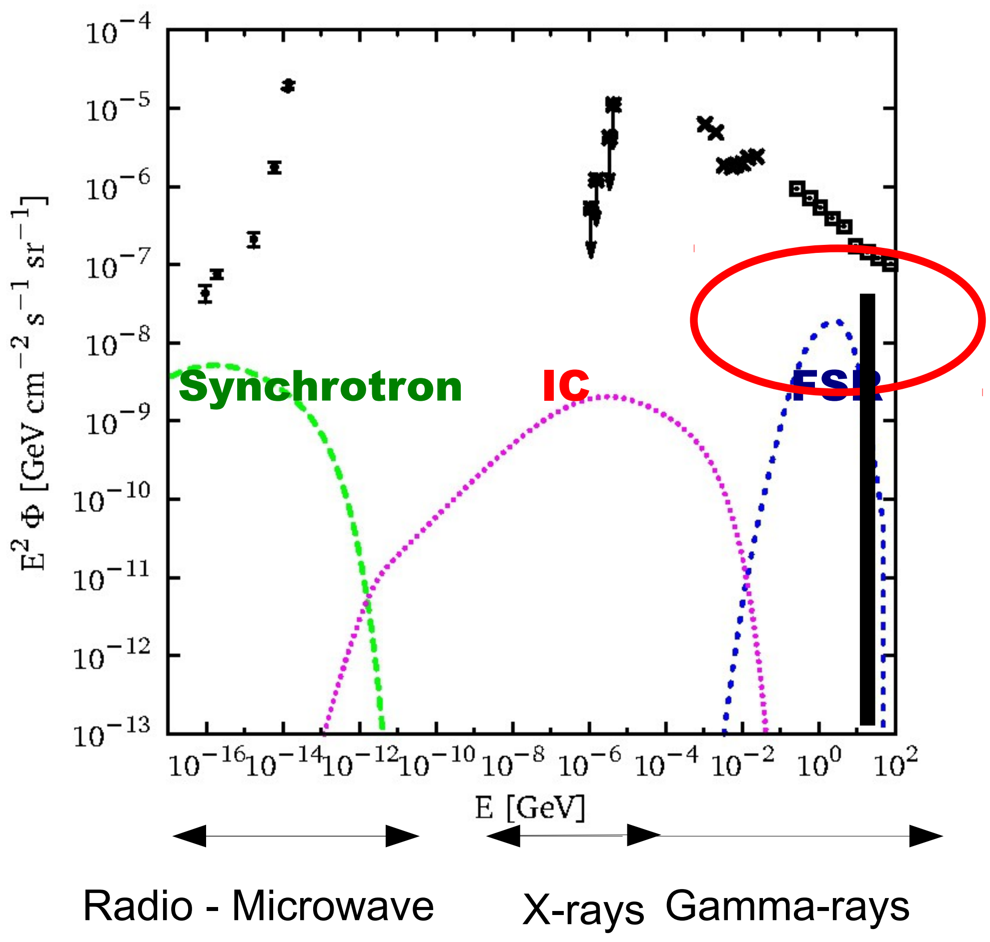
Studying galactic synchrotron we can learn about CRs and magnetic fields.

Better knowledge of galactic foreground is mandatory to look for exotic DM signals and improve the bounds.

If the determination of the IRB is correct is there an exotic population of sources?

They should be very faint and numerous + faint at other frequencies (X, IR, gamma)

Secondary emissions



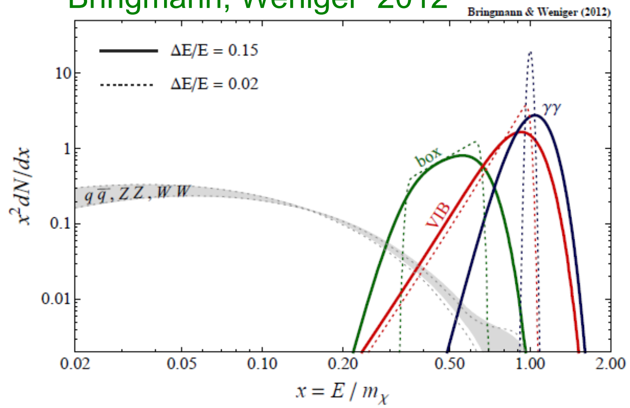
Final state radiation $\chi\chi \to q\bar{q} \to \pi^0 + \ldots \quad \pi^0 \to \gamma\gamma$

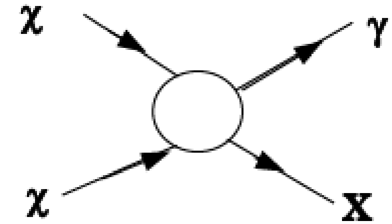
Inverse Compton $e^{\pm}\gamma \to e^{\pm}\gamma'$

Synchrotron emission from interactions of electrons with magnetic fields

Spectral features

Bringmann, Weniger 2012





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

From line(s) position(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

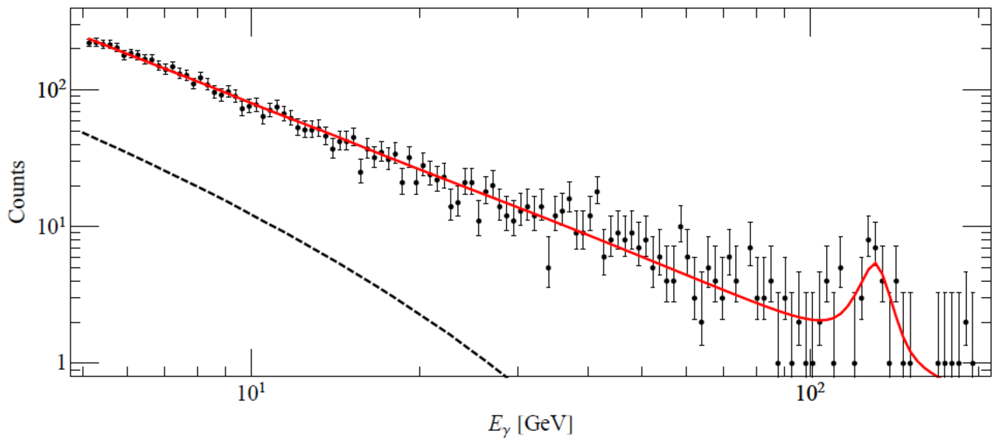
Other spectral features: **internal bremsstrahlung** and **gamma-ray boxes**

DM models & lines

Loop level annihilations are severely suppressed for weak-size interactions

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

Cohen, Lisanti,Slatyer, Wacker 2012



Take the 130 GeV gamma-ray lines:

from the shape of the spectrum bounds

on the continuum

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

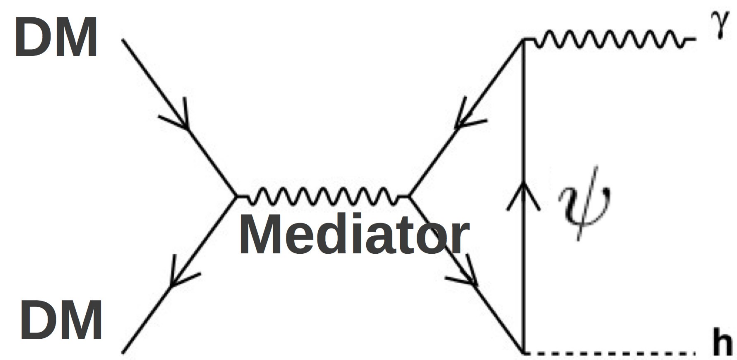
See also Cholis, Tavakoli, Ullio 2012

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

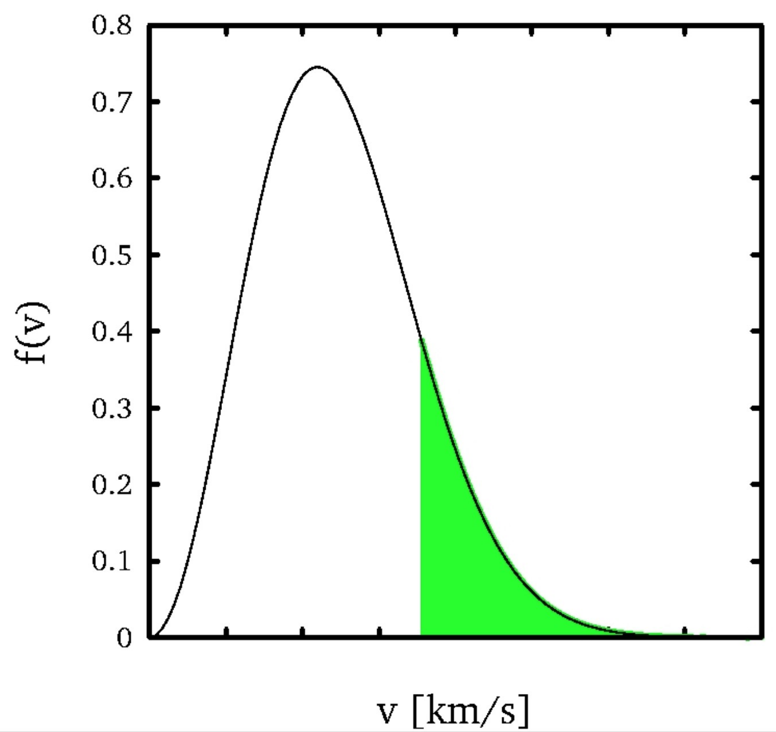
$M_{DM} \lesssim M_{\psi}$ annihilations forbidden today

since DM has small velocities in our galaxy

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

Annihilations occur in the early Universe

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

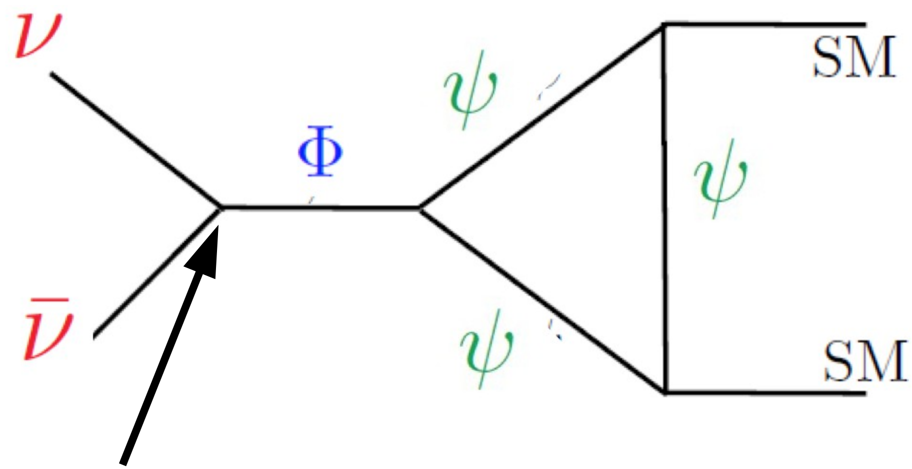


Scalar resonance recipe, example 1

The Dark Sector: DM Dirac fermion ν + real scalar Φ + charged fermion ψ

$$SU(3) \times SU(2) \times U(1): \quad \nu \sim (1,1,0) \quad \Phi \sim (1,1,0) \quad \psi \sim (1,2,1/2)$$

$$\mathcal{L} \supset -\overline{\nu}(y^S_{\nu\Phi} + i y^P_{\nu\Phi}\gamma^5)\nu\Phi - \overline{\psi}(y^S_{\psi\Phi} + i y^P_{\psi\Phi}\gamma^5)\psi\Phi - y_H\,\overline{\psi}H\nu + h.c$$



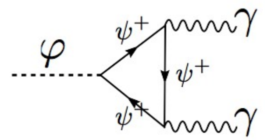
$$\langle \sigma v \rangle \propto \left((y^S_{\nu\Phi})^2 v^2 + 4 (y^P_{\nu\Phi})^2 \right)$$

p -wave suppressed for scalar couplings

Need to consider pseudo-scalar DM coupling

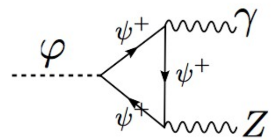
1-loop annihilations

$\gamma\gamma$

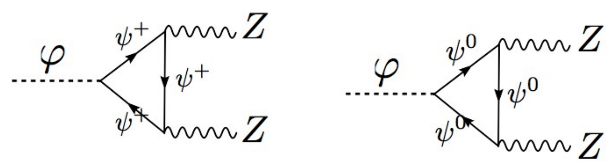


Multiples lines!

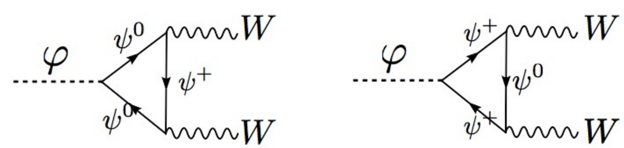
γZ



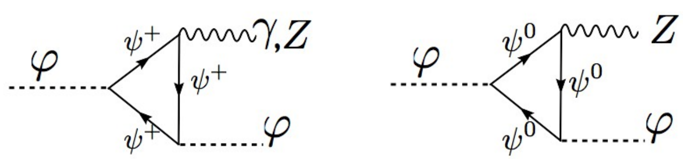
ZZ



WW

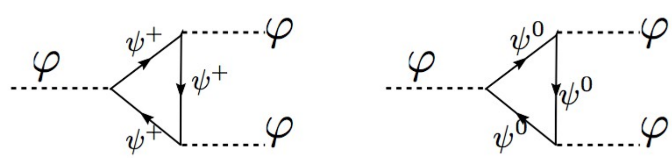


$\gamma\varphi, Z\varphi$



=0

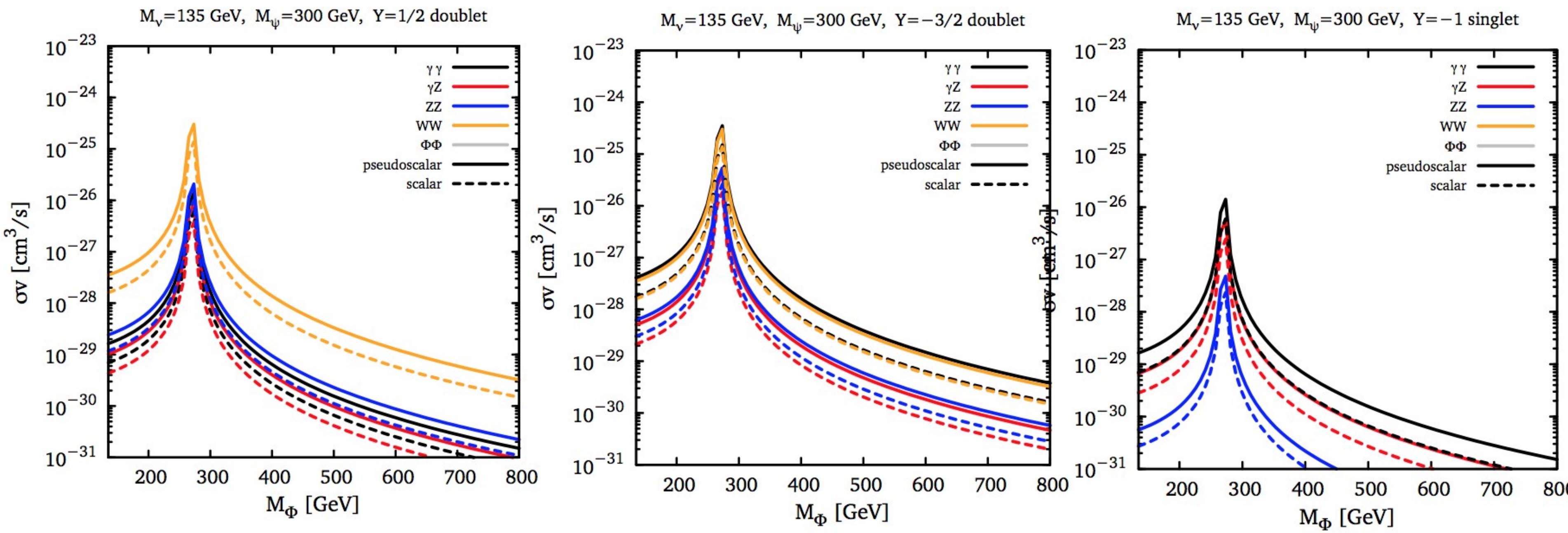
$\varphi\varphi$



Different charge assignments

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

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



	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

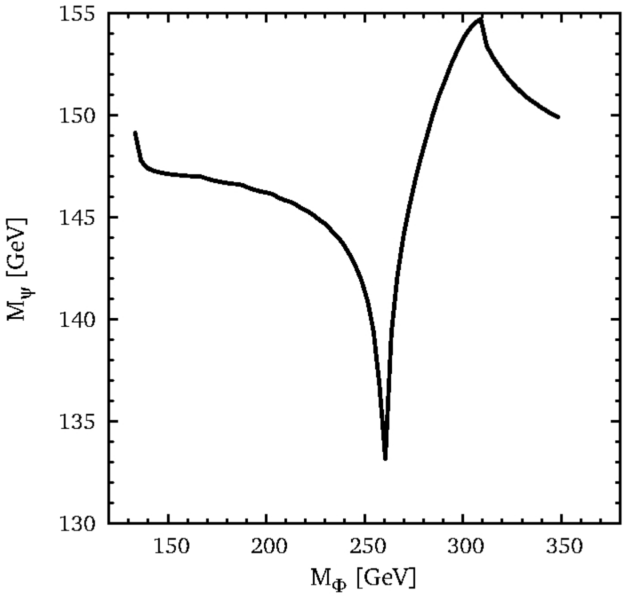
Relic density constraints

If we believe on the 130 GeV gamma-ray line

relic density constraint can be fullfilled

with extra fermions slightly heavier than DM

& annihilations close to the resonance

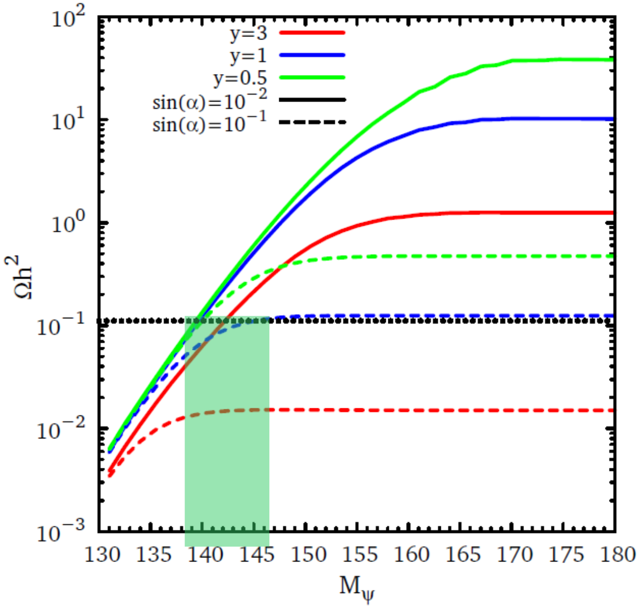


Similar arguments for DM DM → $\Phi\Phi$

Coannihilations present for models with

stable ψ

$$\psi\psi \to Z, W$$

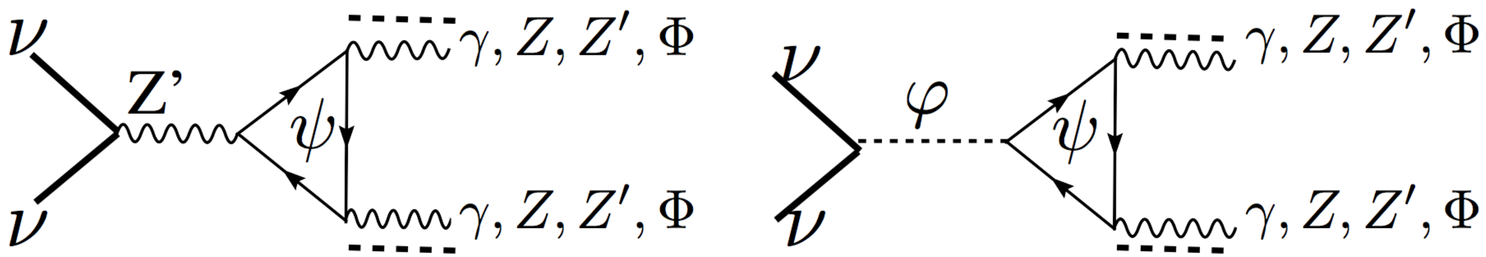


See also Tulin, Yu, Zurek 2012

Vector mediation, ex. 2

Consider a simple model with a U(1)' broken by the VEV of a scalar Φ

DM and an extra fermion ψ are charged under U(1)'



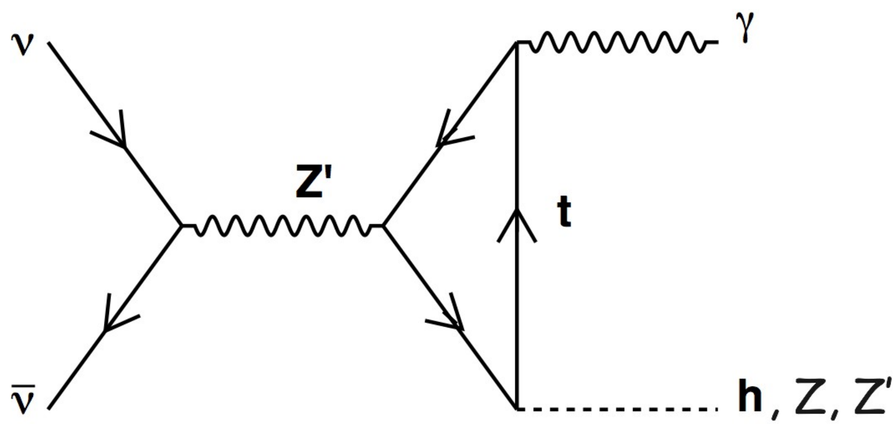
The extra fermions in the loop could mix with the SM fermions, like to quark

Top quark has the mass in the right ballpark to realize the forbidden channel scenario

Dark sectors which preferentially couples to heaviest fermions are motivated

in models of composite fermions and RS extra dimensions

Simple UV completion



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

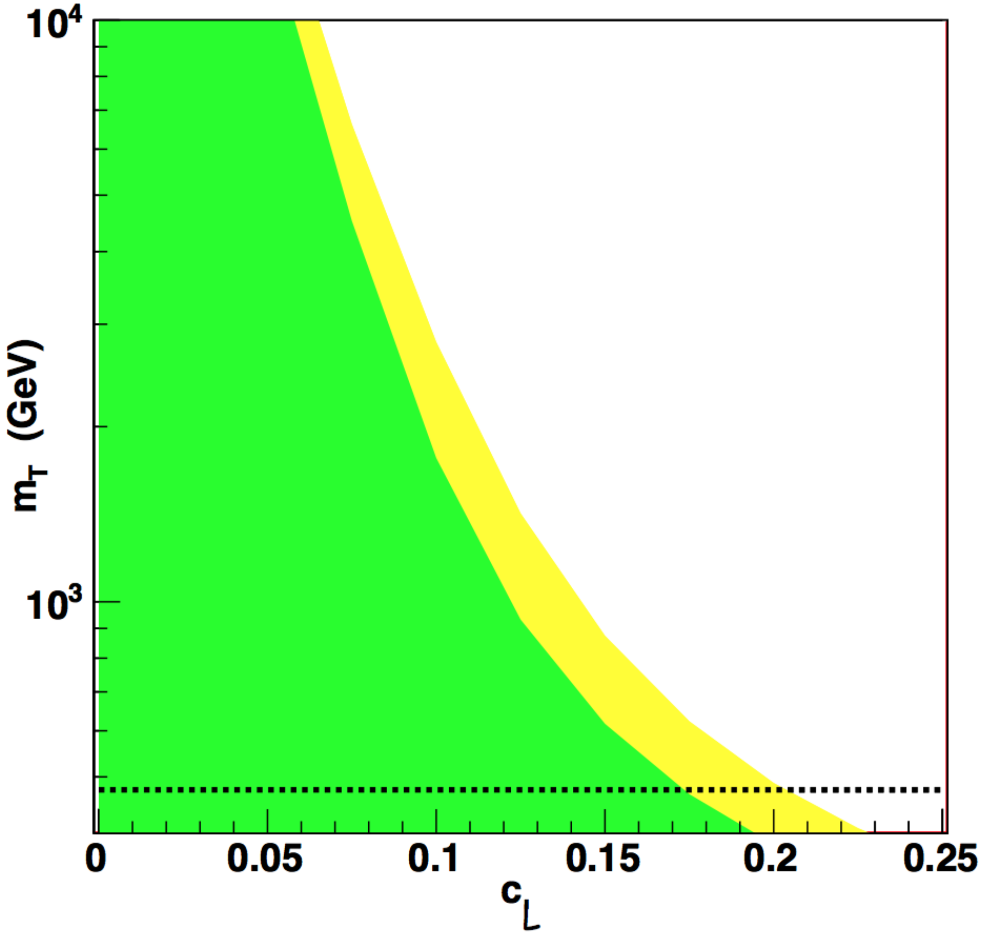
$$yH\bar{\hat{Q}}_3\hat{t}_R + \mu\bar{\psi}_L\psi_R + Y\Phi\bar{\psi}_L\hat{t}_R$$

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

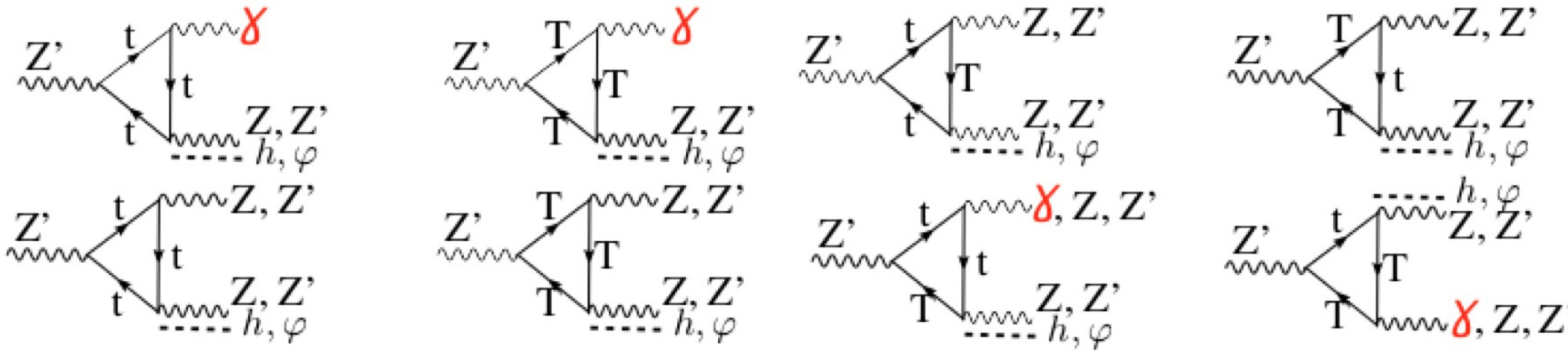
Electroweak precision tests

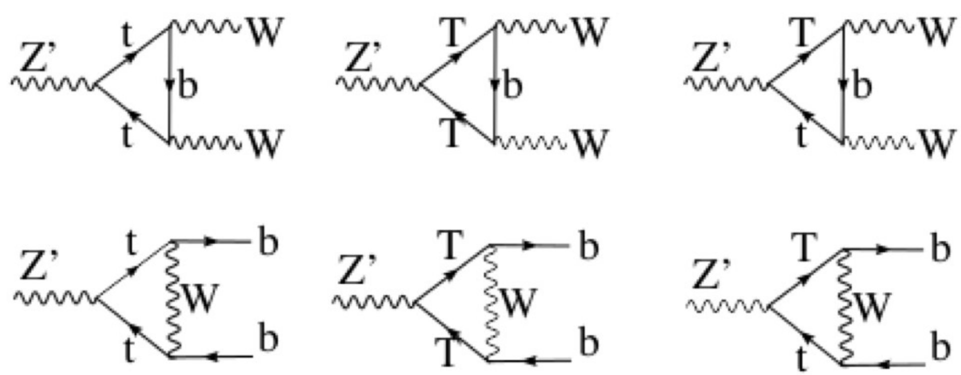
$$\Delta T \;=\; T_{SM} \times c_L^2 \left(-(1+s_L^2) + c_L^2 r + 2 s_L^2 \frac{r}{(r-1)} \log r \right)$$

$$r \equiv \frac{m_T^2}{m_t^2}, \text{ and } \; T_{SM} = \frac{3}{16\pi s_W^2} \frac{m_t^2}{M_W^2} \simeq 1.19 \; .$$

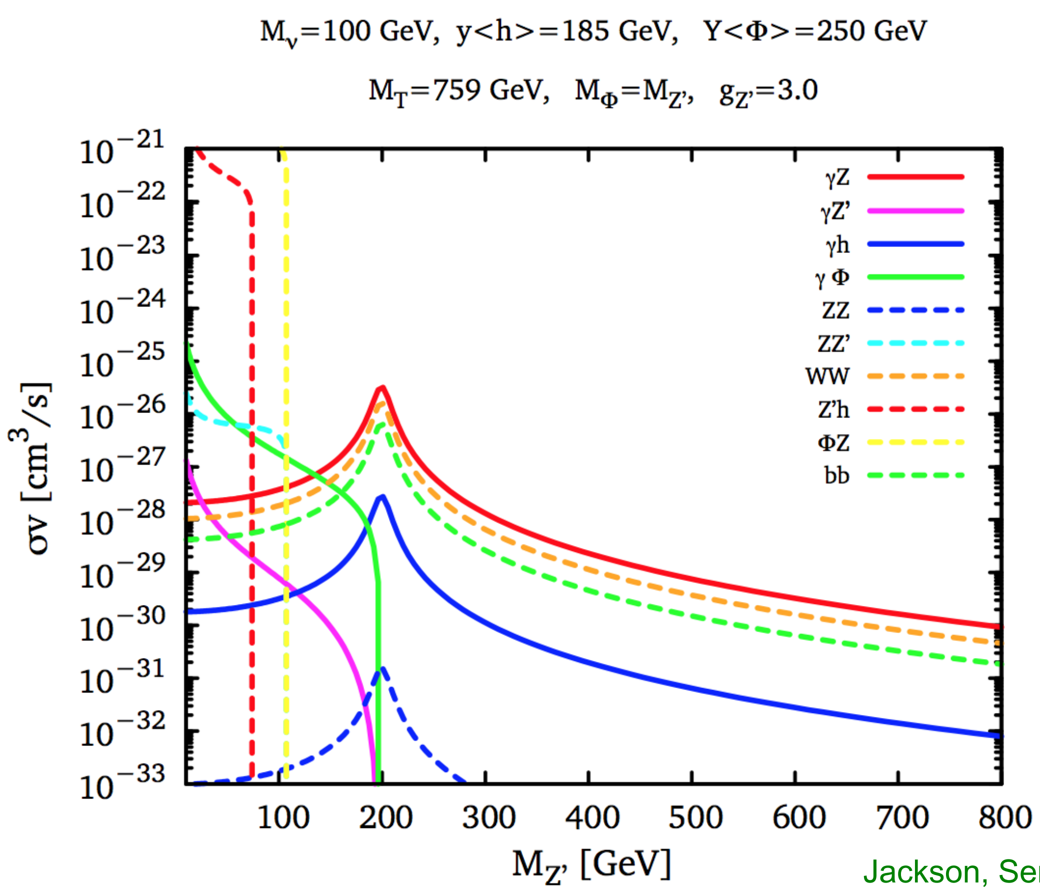


1-loop diagrams





1-loop x-sections



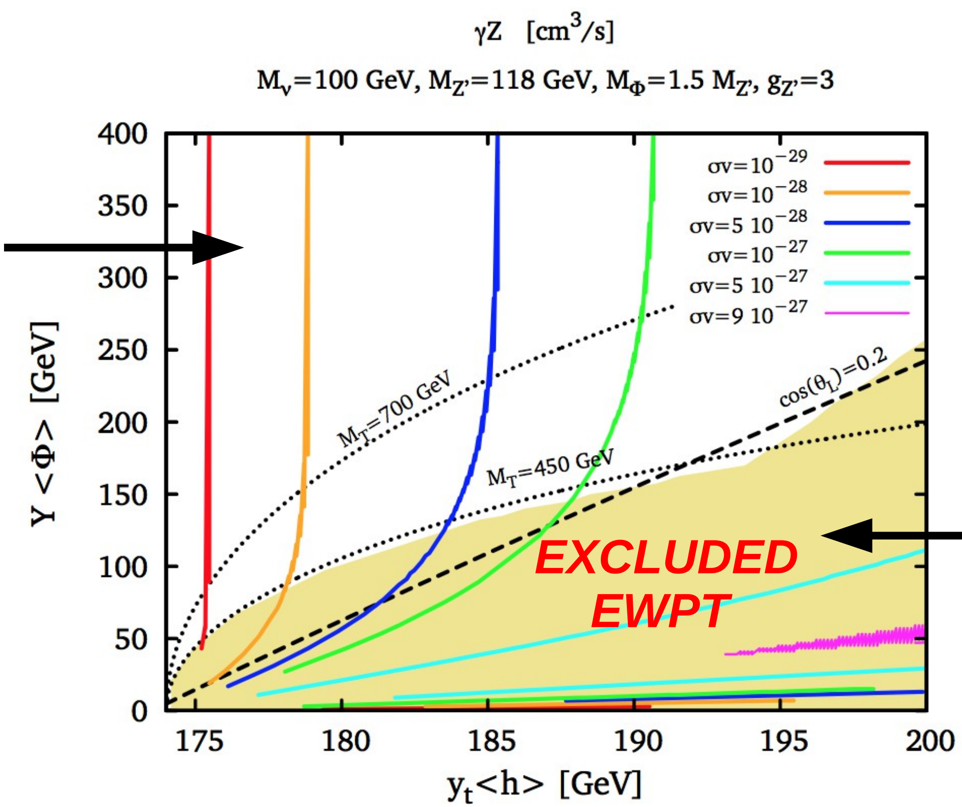
Jackson, Servant, Shaughnessy, Tait, MT 2010, 2013

WW and ZH are the dominant continuum

DM has vector-like couplings to avoid overwhelming 1-loop annihilations into gluons

Signal cross-section

Small top-T mixing



Large top-T mixing

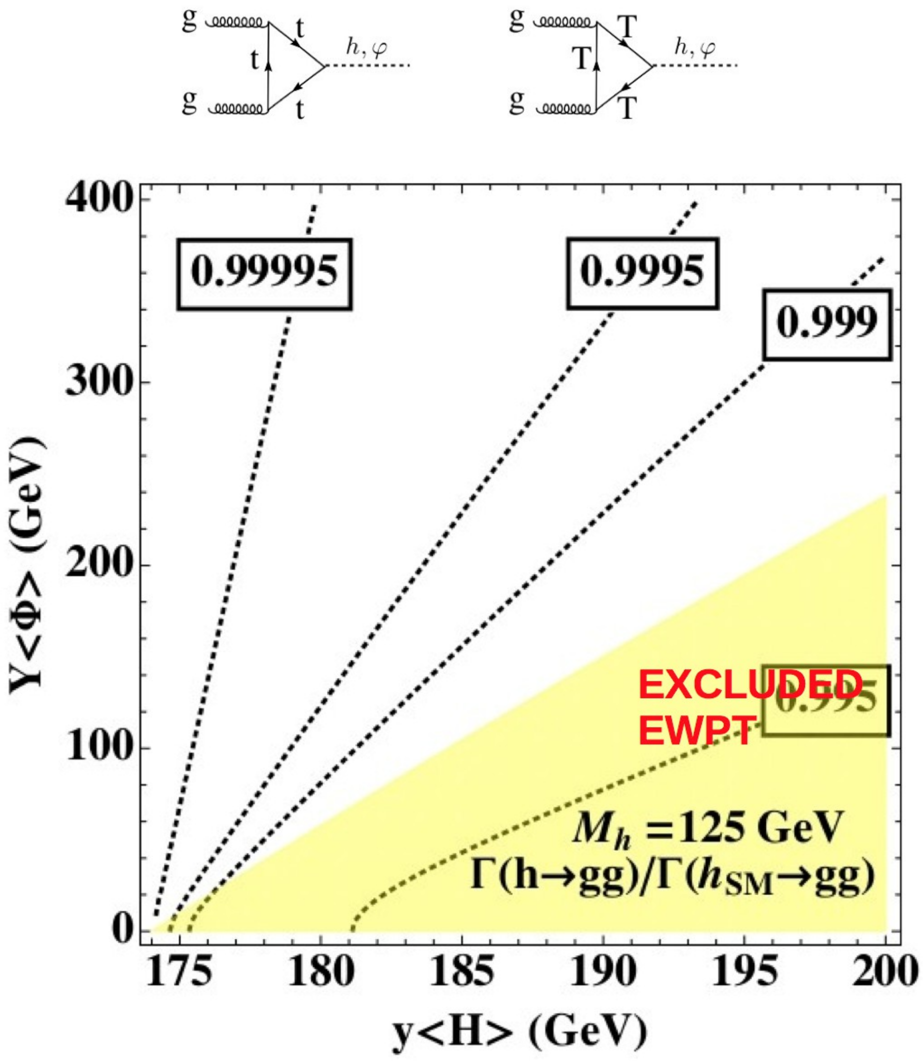
Correct relic density for DM slighlty below the mass of the top or Z '

Mixing of Z – Z' induce SI interactions with protons

Direct detection bounds require a combination of coupling and mixing $g_{\nu}^{Z'} \eta \lesssim 10^{-3}$

This implies that correct relic density can not be obtain through Z – Z' mixing

Higgs Physics



Higgs pheno remains very close to SM

Production rate of Z ' very suppressed

Outlook

WIMPs annihilation into gamma-rays are precious probe of DM

We need to single out which DM theories can be tested

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

These features can be captured in simple models with scalar/vector mediators and possibly with preferential couplings with the top quarks