Multi-wavelength Approach to Indirect Dark Matter Searches with RX-DMFIT

Based on arXiv:1705.09384

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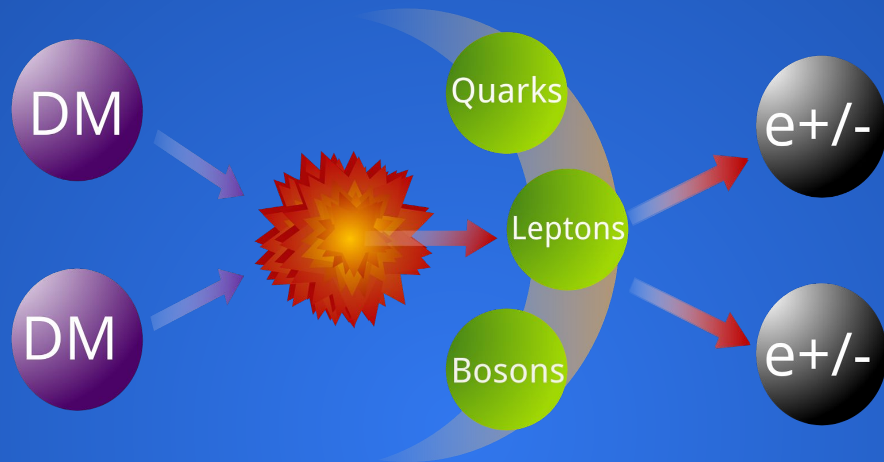
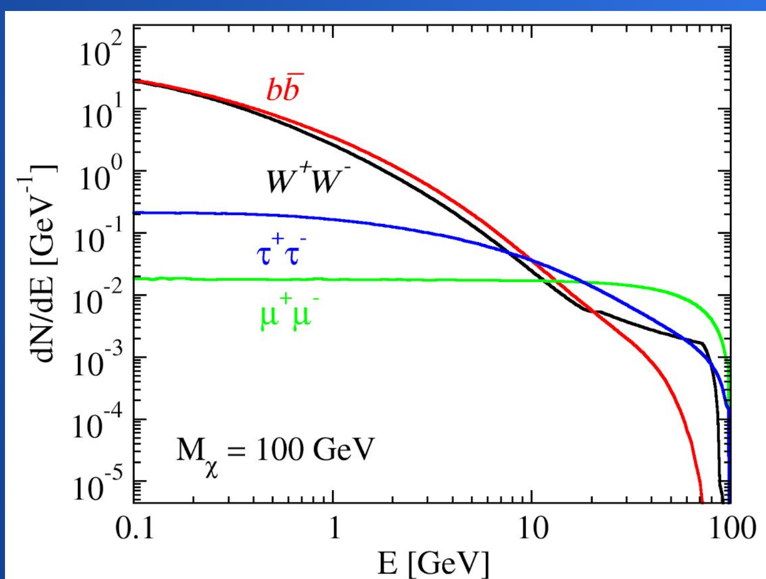
TeVPA, Ohio State University, Columbus, OH - Aug 7-11, 2017

DM Annihilation

Annihilating Dark Matter ⇒ Production of SM particles ⇒ electrons/positrons

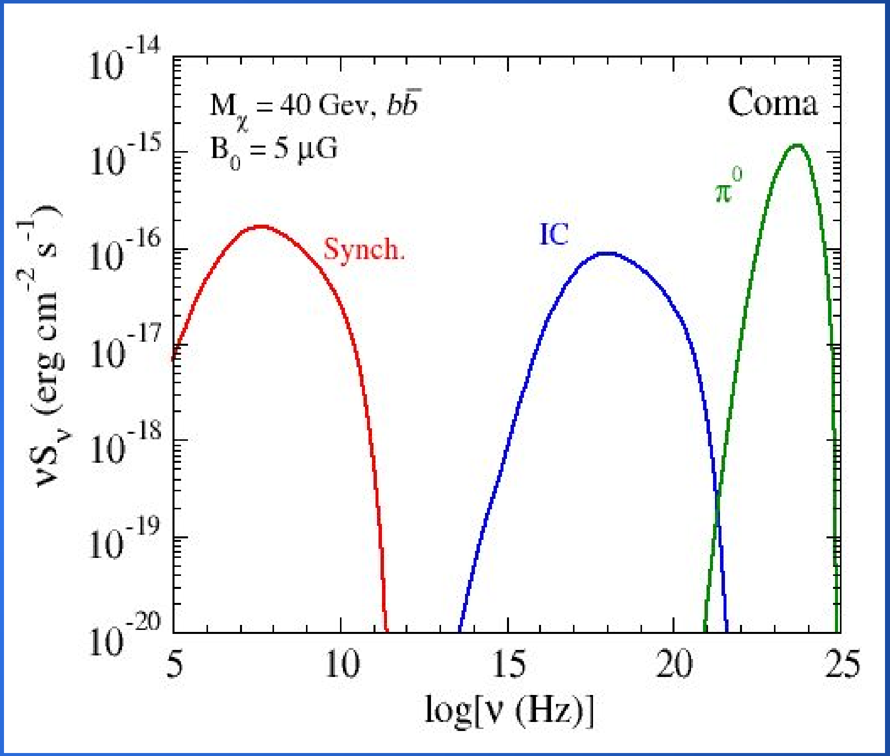




$$Q(E,r) = \frac{\langle \sigma v \rangle \rho_\chi^2}{2M_\chi^2} \sum \frac{dN_i^f}{dE} BR_f$$

The Multi-wavelength Signal

- Prompt Emission of Gamma-rays
  - Fermi, HAWC, CTA, HESS etc...
- Synchrotron
  - $\sim \mu G$ Magnetic fields
- Inverse Compton
  - CMB, Starlight, IR components



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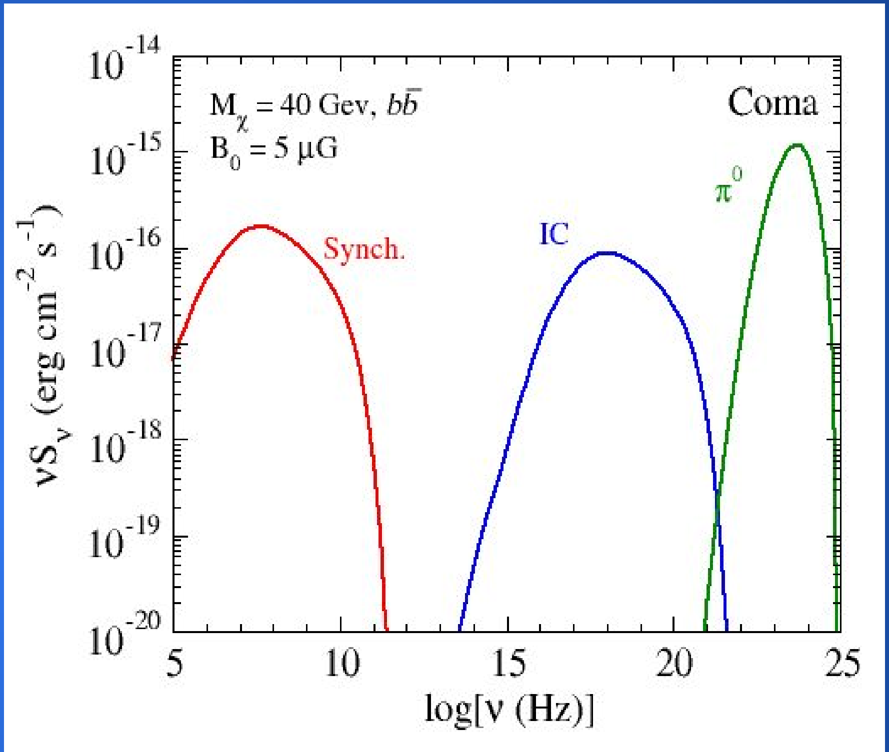
Diffusion



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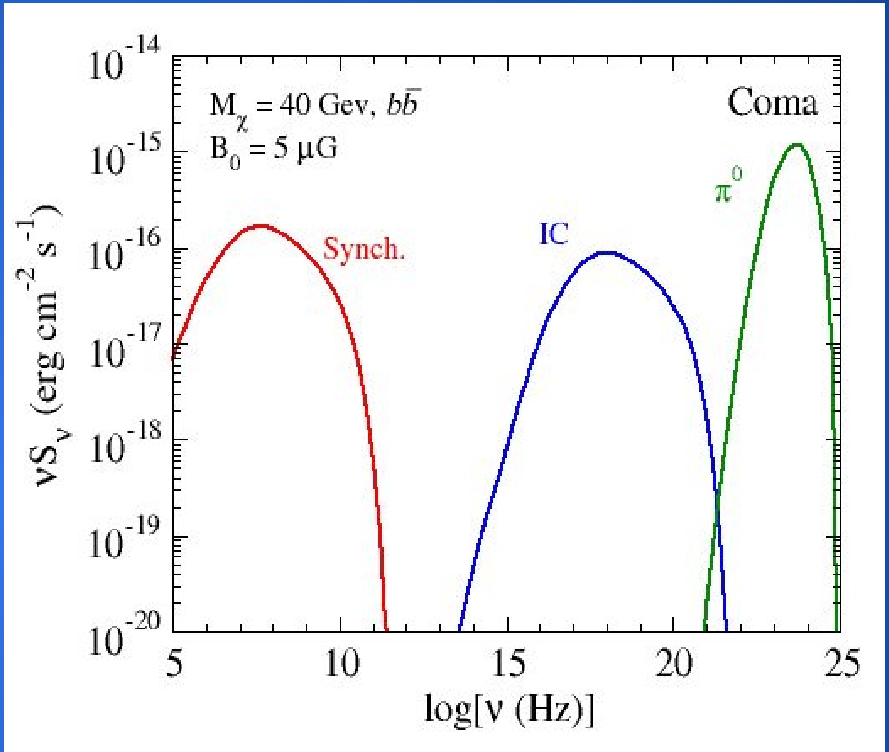


Diffusion

RX-DMFIT

Radio and **X**-ray - **DMFIT**

Good targets for multi-wavelength searches?

Targets

Dwarfs

Contain a lot of Dark Matter

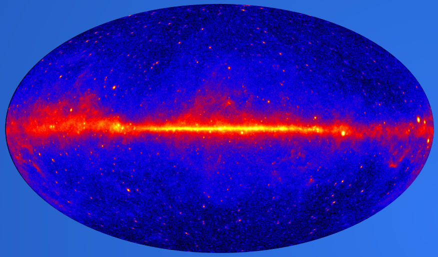
Low background

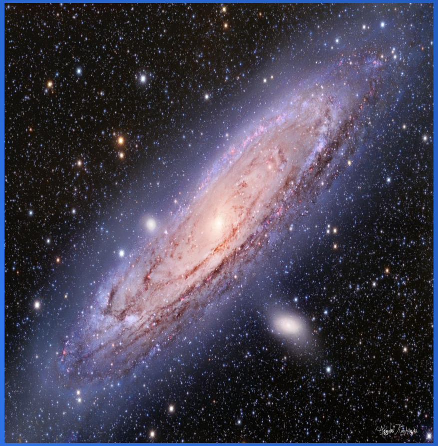
Nearby

Targets

Dwarfs

Galaxies (e.g GC, M31)





Contain a lot of Dark Matter

Low background

Nearby

Bright DM Signal

High astrophysical background

Complex Astrophysics

Targets

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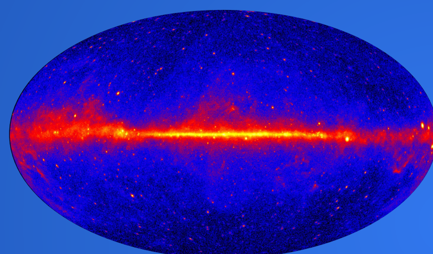
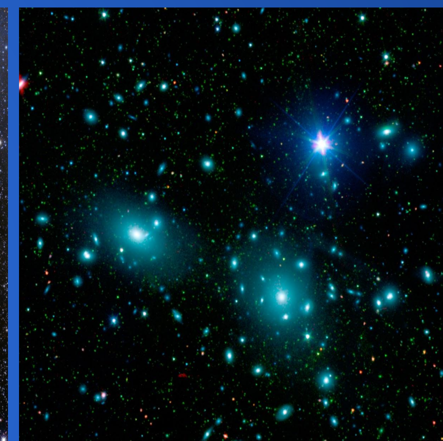


Bright DM Signal

High astrophysical background

Complex Astrophysics

Clusters



Contain a lot of Dark Matter

Low background

~~ μG Magnetic fields

Astrophysical Ingredients

- Dark Matter Profile

$$\rho_\chi(r) \quad \text{e.g.,} \quad \frac{\rho_s}{\left(\frac{r}{r_s}\right)\left(1+\frac{r}{r_s}\right)^2},\ \rho_s \exp\left\{-\frac{2}{\alpha}\left[\left(\frac{r}{r_s}\right)^\alpha - 1\right]\right\}$$

- Magnetic field

$$B(r) \quad \text{e.g.,} \quad B_0 e^{-r/r_c},\ B_0\left[1+\left(\frac{r}{r_c}\right)^2\right]^{-1.5\beta\eta}$$

- Radiative Energy Losses

$$b(E,\mathbf{r}) = b_{synch}(E,\mathbf{r}) + b_{IC}(E) + b_{Coul.}(E) + b_{brem.}(E)$$

- Diffusion

$$\frac{\partial}{\partial t}\frac{\partial n_e}{\partial E} = D(E)\nabla^2\frac{\partial n_e}{\partial E} + \frac{\partial}{\partial E}\left[b(E,\mathbf{r})\frac{\partial n_e}{\partial E}\right] + Q(E,\mathbf{r})$$

RX-DMFIT - github.com/alex-mcdaniel/RX-DMFIT

Astrophysics

$D(E)$ $B(r)$

$b(E, r)$

$\rho_\chi(r)$ r_h z

Particle Physics

BR_i

$\langle \sigma v \rangle$ M_χ

RX DMFIT

Diff Eq. $\Rightarrow$ $\dfrac{\partial n_e}{\partial E}$

$$j_i = 2 \int_{m_e}^{M_\chi} dE \frac{dn_e}{dE} P_i$$

$$S_i = \int dr \frac{r^2 j_i(r)}{4\pi d^2}$$

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RX DMFIT

Dark SUSY

http://www.darksusy.org/

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BR_i M_χ

$\langle \sigma v \rangle$

RX-DMFIT

DarkSUSY

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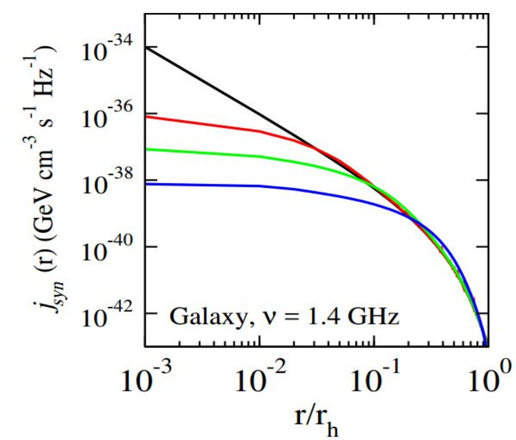
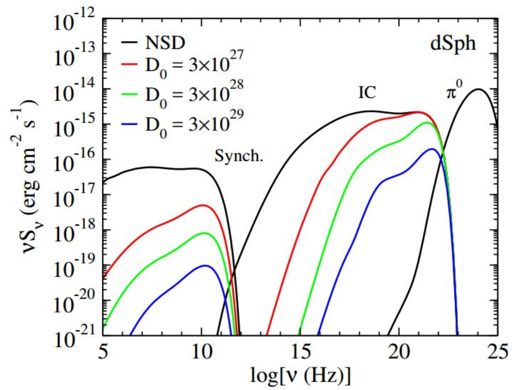
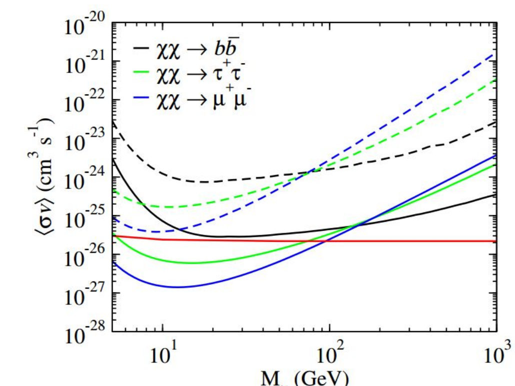






Astrophysical Ingredients

Dominate at ≳ GeV energies

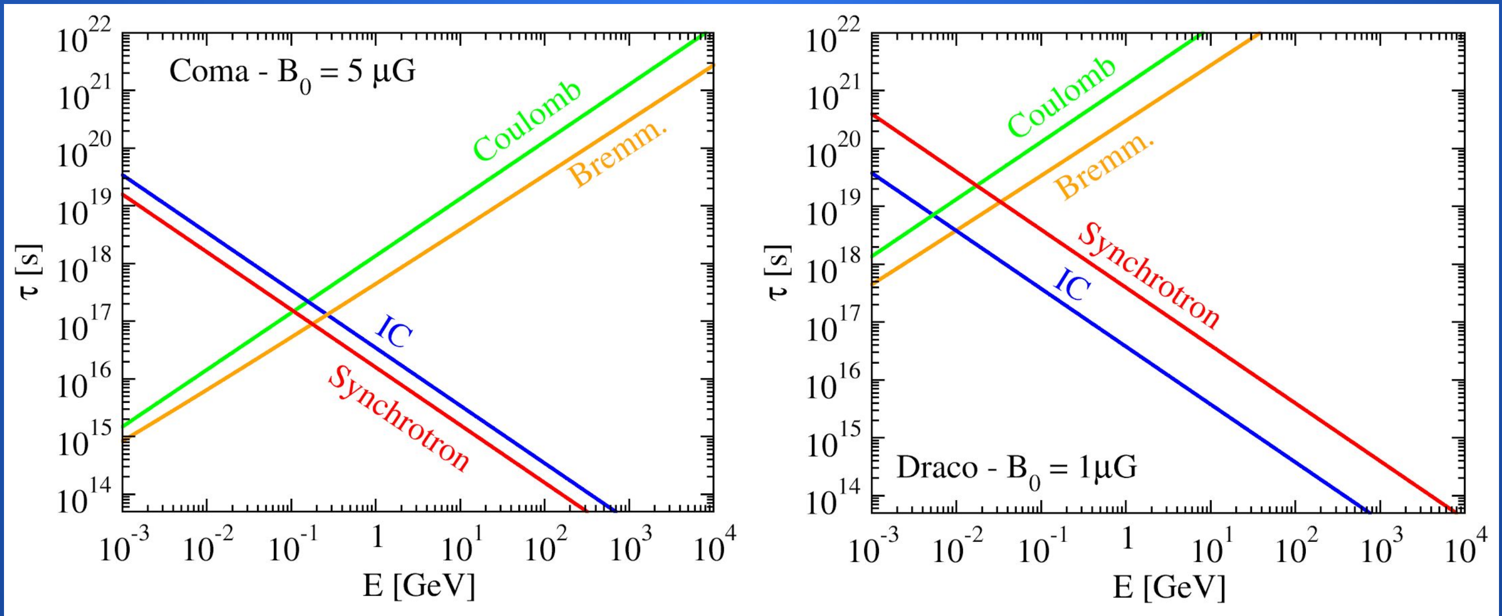
- Radiative Energy Losses

$$b(E,\mathbf{r}) = b_{synch}(E,\mathbf{r}) + b_{IC}(E) + b_{Coul.}(E) + b_{brem.}(E)$$

$$b_{synch}(E,\mathbf{r}) \sim B^2(\mathbf{r})E^2$$

$$b_{IC}(E) \sim E^2$$

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



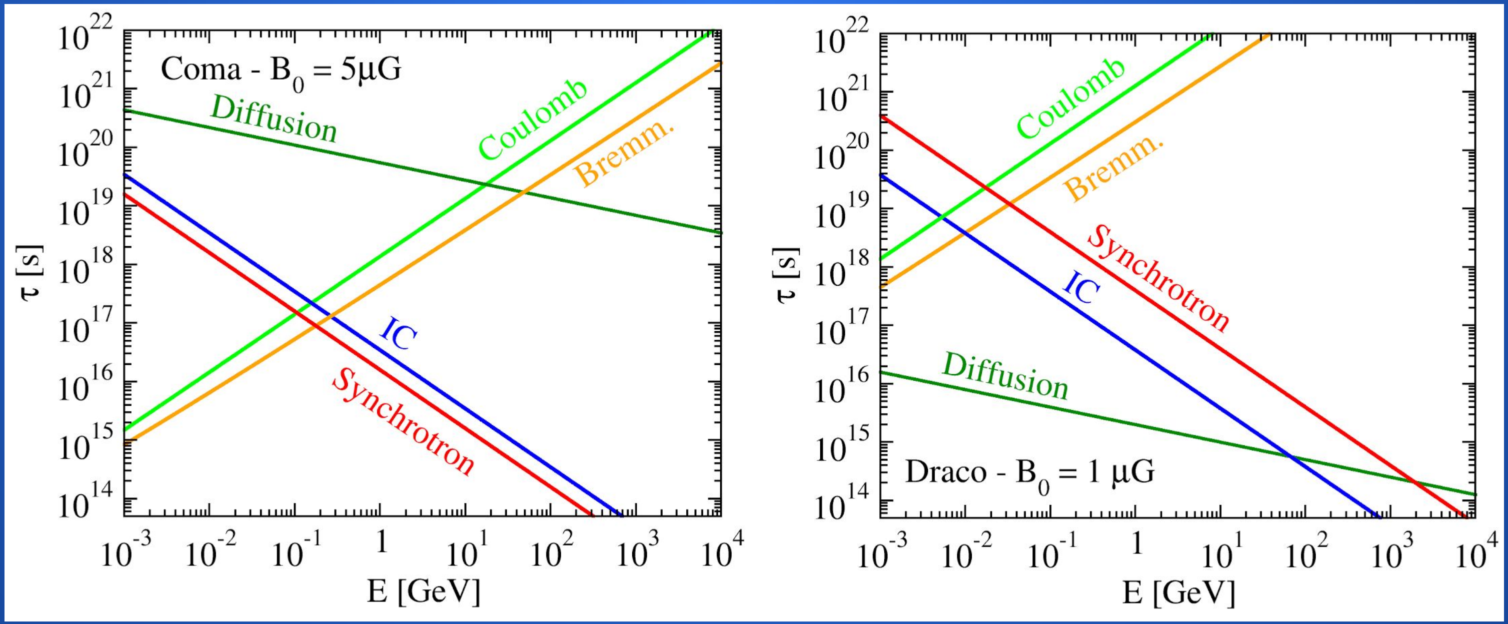
Astrophysical Ingredients

- Diffusion

$$\frac{\partial}{\partial t}\frac{n_e}{\partial E} = D(E)\nabla^2\frac{n_e}{\partial E} + \frac{\partial}{\partial E}\left[b(E,\mathbf{r})\frac{n_e}{\partial E}\right] + Q(E,\mathbf{r})$$

Milky Way ~3×10^{28} cm^{2}s^{-1}

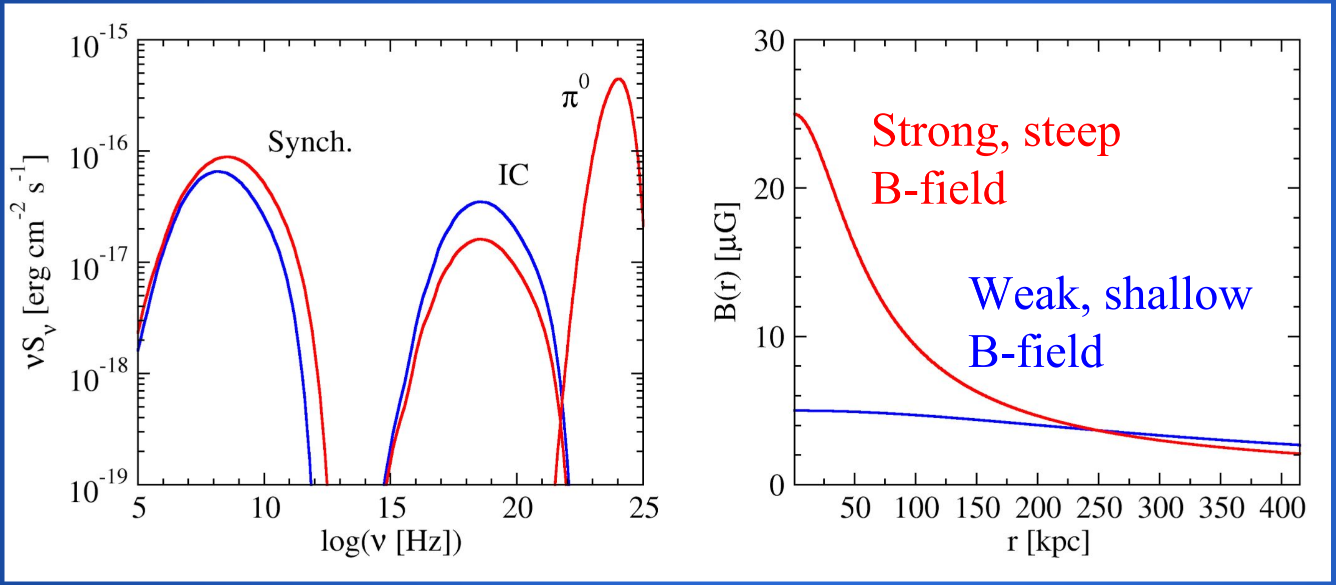
$$D(E) = D_0 E^{\gamma} \qquad \tau_{Diff} \approx r_h^2/D(E)$$

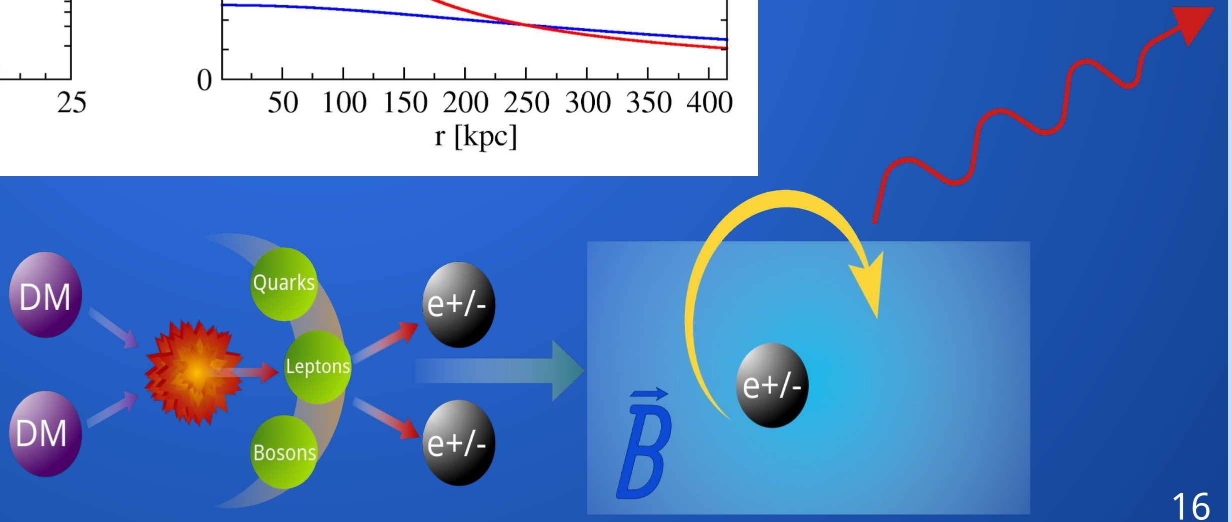


Synchrotron Emission

$$\nu_0 = \frac{eB}{2\pi m_e c}$$

$$P_{synch}(\nu, E, r) = \int_0^\pi d\theta \frac{\sin\theta}{2} 2\pi\sqrt{3} r_0 m_e c \nu_0 \sin\theta F\left(\frac{x}{\sin\theta}\right)$$





Synchrotron Emission - Prospects

- Archival Radio Data
- New Data & Upcoming Facilities

LOFAR

Image Credit: LOFAR/ASTRON

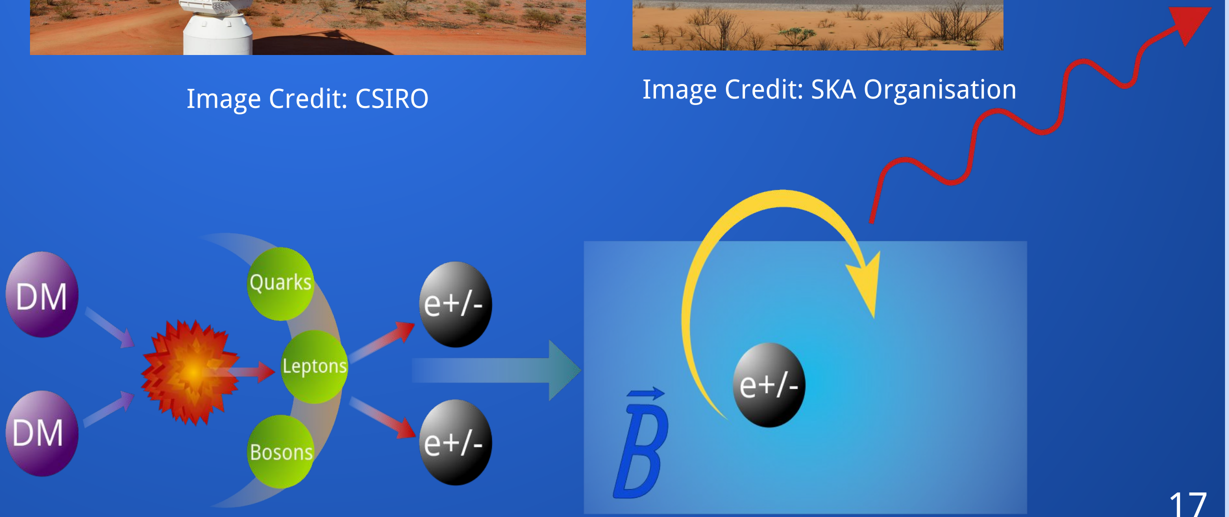
ASKAP

Image Credit: CSIRO

SKA

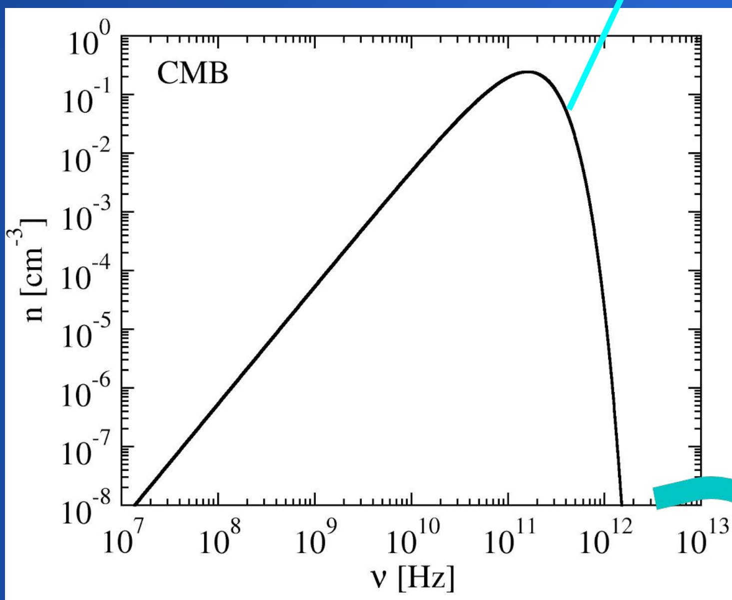
Image Credit: SKA Organisation

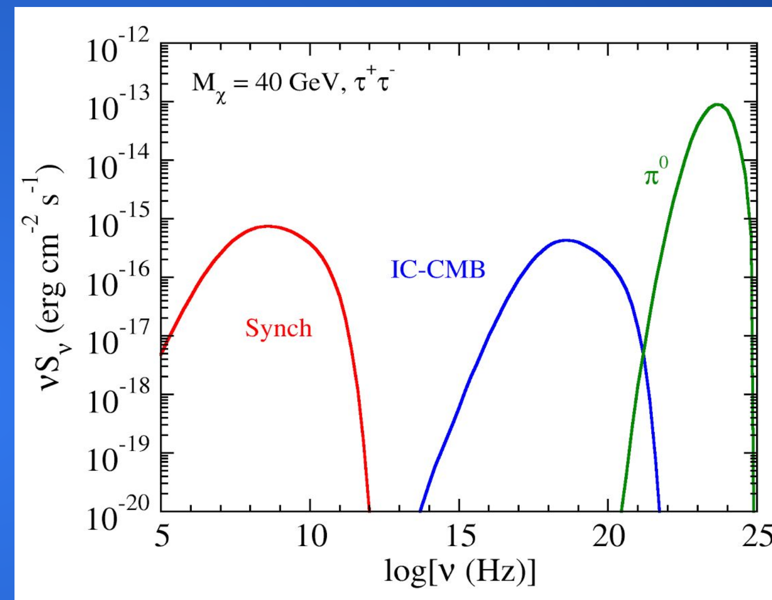
See also
[Storm et. al (2017)]
(arXiv:1607.01049v2)

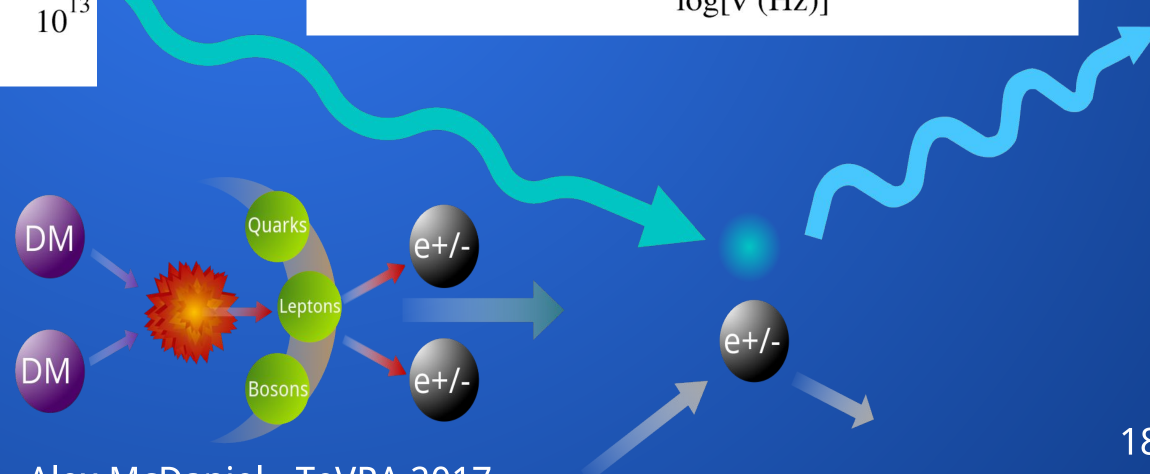


Inverse Compton Scattering

$$P_{IC}(E_\gamma, E) = cE_\gamma \int d\epsilon \, n(\epsilon) \, \sigma(E_\gamma, \epsilon, E)$$



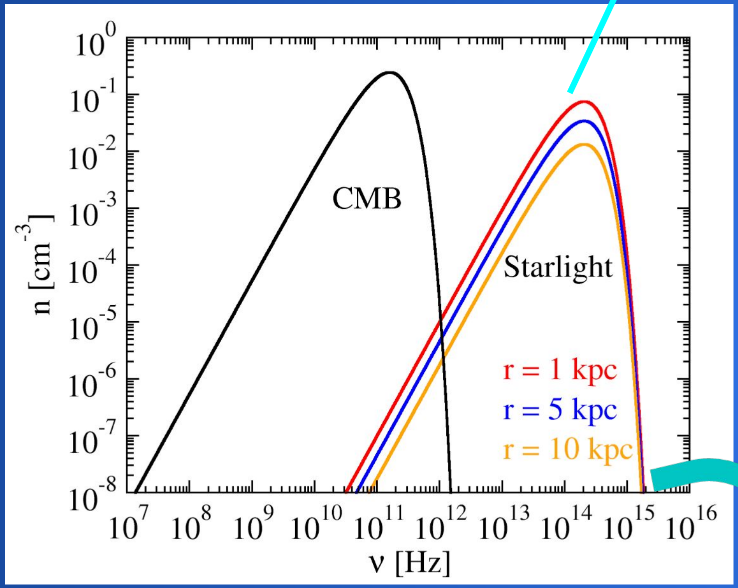


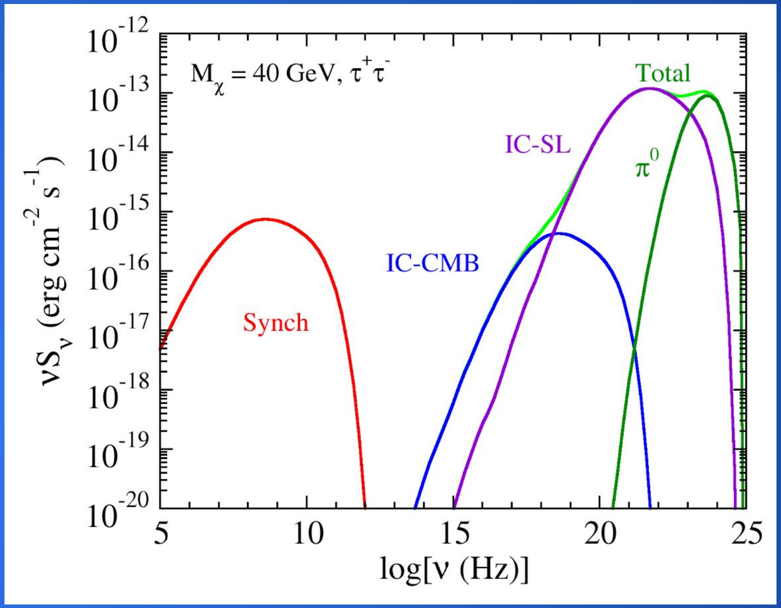


Inverse Compton Scattering - Starlight

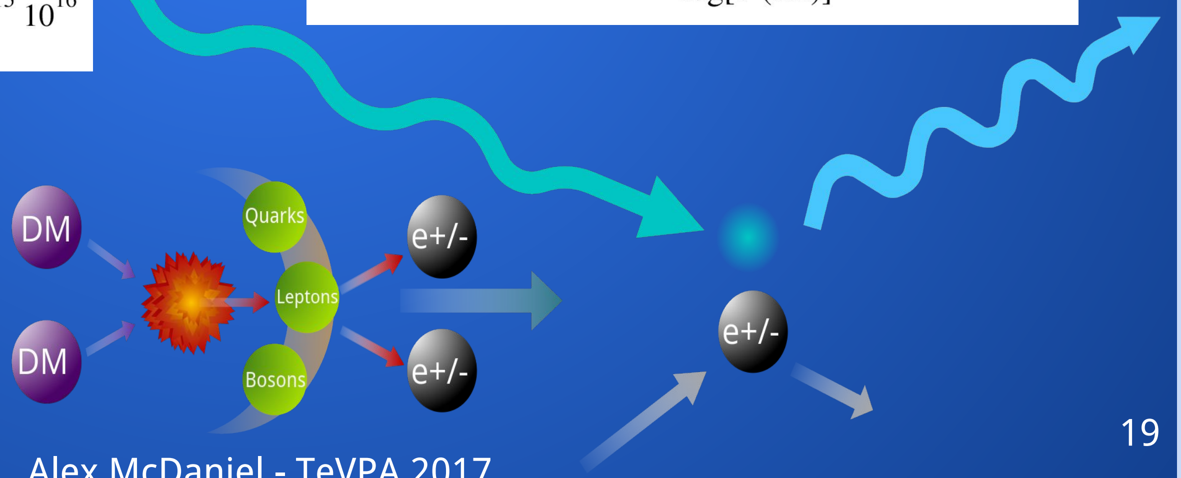
Work in Progress

$$P_{IC}(E_\gamma, E) = cE_\gamma \int d\epsilon\, n(\epsilon, r)\, \sigma(E_\gamma, \epsilon, E)$$



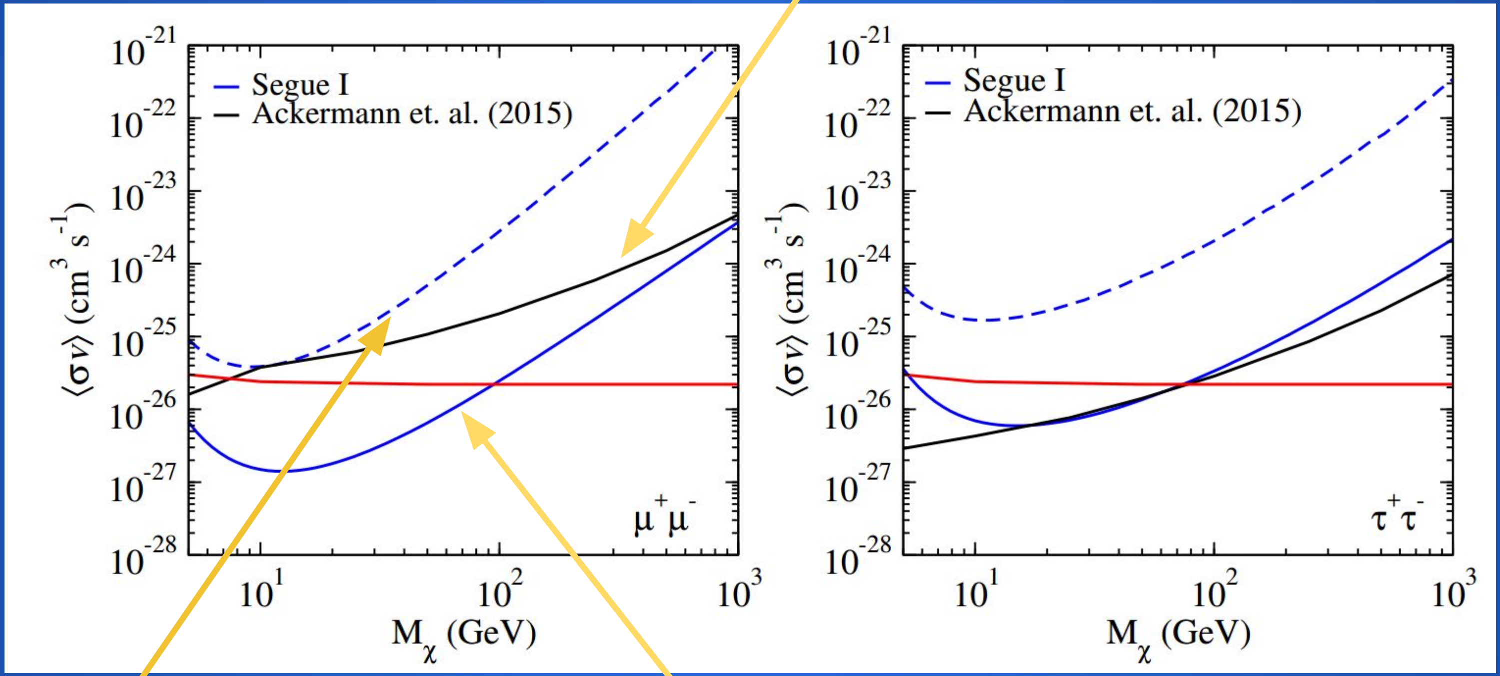


$$b_{SL}(E) \sim u_{SL} E^2$$



Constraints from Synchrotron Emission

Fermi stacked dSphs



Strong Diffusion
3×10^{28} cm^{2}s^{-1}

Weak Diffusion
3×10^{26} cm^{2}s^{-1}

Wrap-up

- RX-DMFIT makes predicting radio and X-ray fluxes easy
  - github.com/alex-mcdaniel/RX-DMFIT
- Includes important astrophysics, (Diffusion, energy losses, magnetic fields)
- Can be used for many different systems
- Untapped potential for competitive constraints.

Thank you!

Bonus Slides

Full Diffusion Solution

$$\frac{\partial}{\partial t}\frac{\partial n_e}{\partial E} = D(E)\nabla^2 \frac{\partial n_e}{\partial E} + \frac{\partial}{\partial E}\left[b(E,\mathbf{r})\frac{\partial n_e}{\partial E}\right] + Q(E,\mathbf{r})$$

$$\frac{\partial n_e}{\partial E} = \frac{1}{b(E,\mathbf{r})}\int_E^{M_\chi} dE' G\left(r, v(E) - v(E')\right) Q(E,\mathbf{r})$$

$$r_n = (-1)^n r + 2nr_h$$

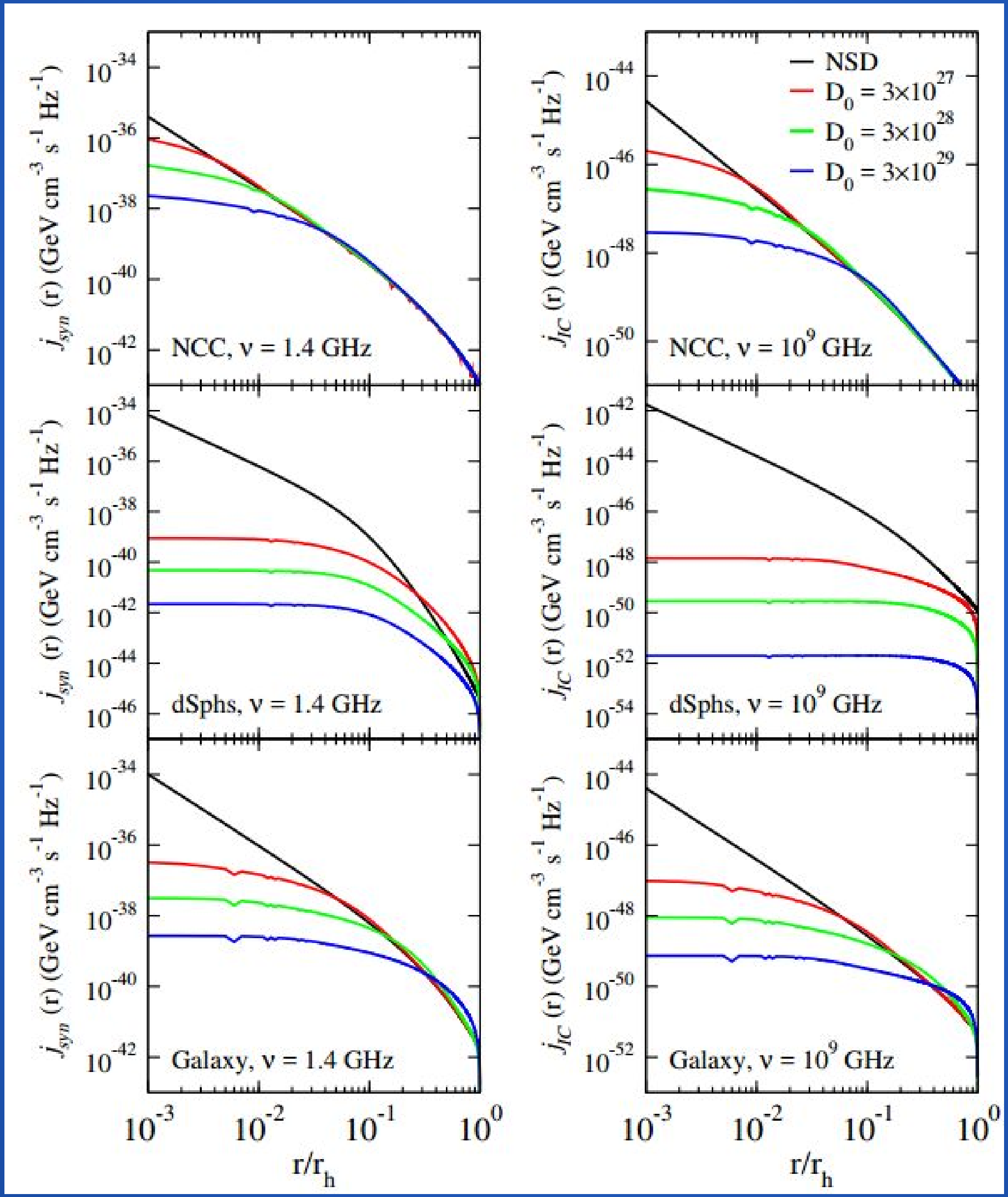
$$G(r,\Delta v) = \frac{1}{\sqrt{4\pi\Delta v}}\sum_{n=-\infty}^{\infty}(-1)^n \int_0^{r_h} dr' \frac{r'}{r_n}\left(\frac{\rho_\chi(r')}{\rho_\chi(r)}\right)^2 \times \left[\exp\left(-\frac{(r'-r_n)^2}{4\Delta v}\right) - \exp\left(-\frac{(r'+r_n)^2}{4\Delta v}\right)\right]$$

$$\Delta v = v(E) - v(E')$$

$$v(E) = \int_E^{M_\chi} d\tilde{E}\frac{D(\tilde{E})}{b(\tilde{E})}$$

See Colafrancesco et al (2006)
arXiv:astro-ph/0507575v2

Emissivity Profiles



Diffusion effects on SED