(Dark matter) Bremsstrahlung gamma ray signatures

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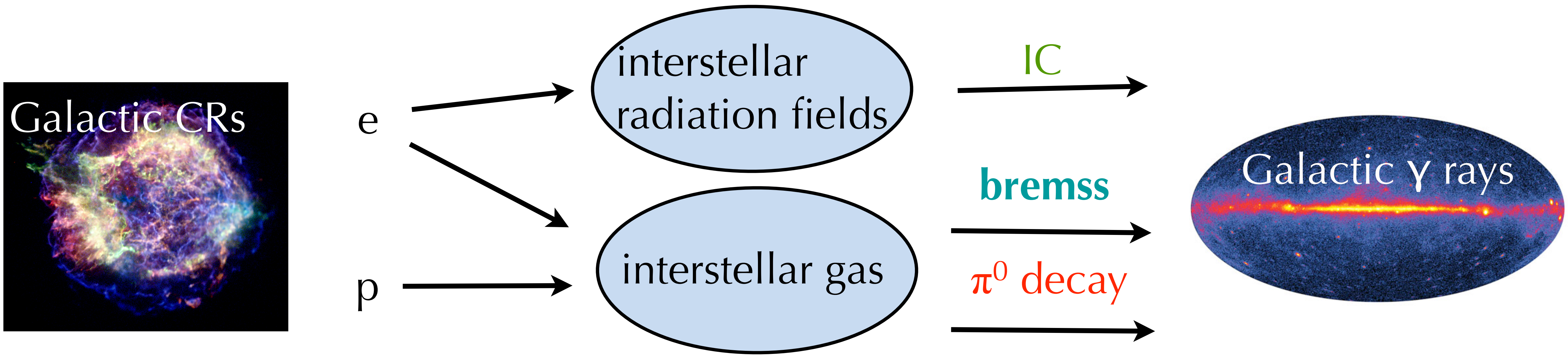
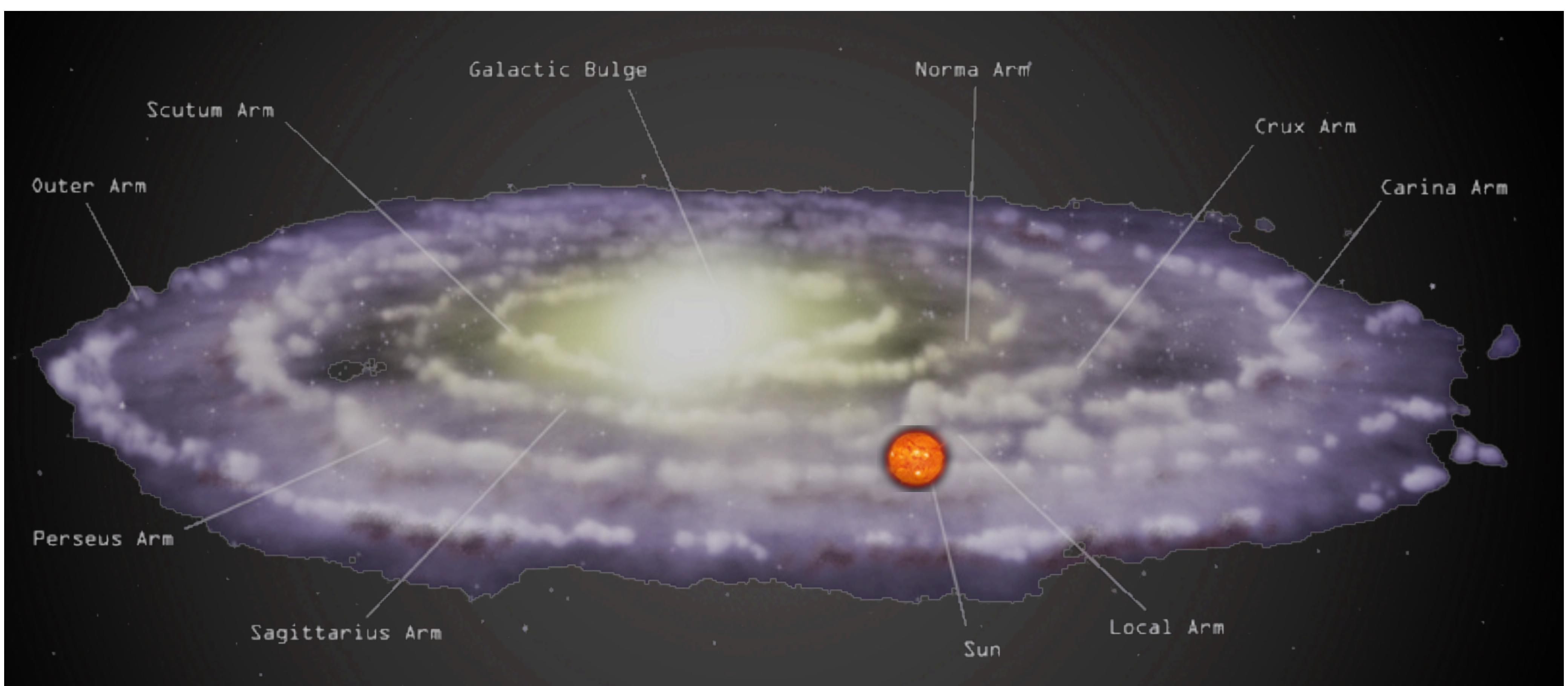
w P. Serpico and M. Cirelli

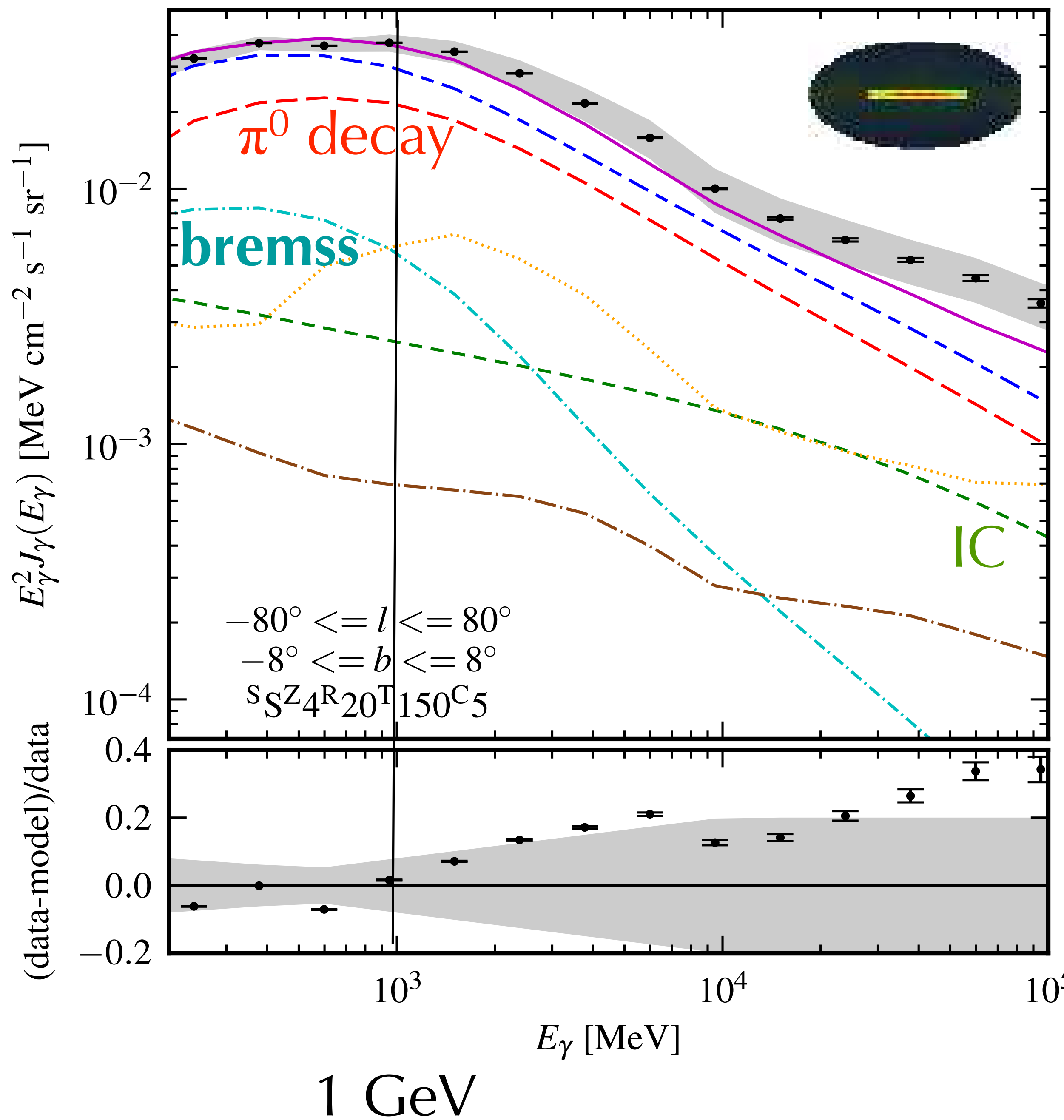
Bremsstrahlung emission





Bremsstrahlung emission

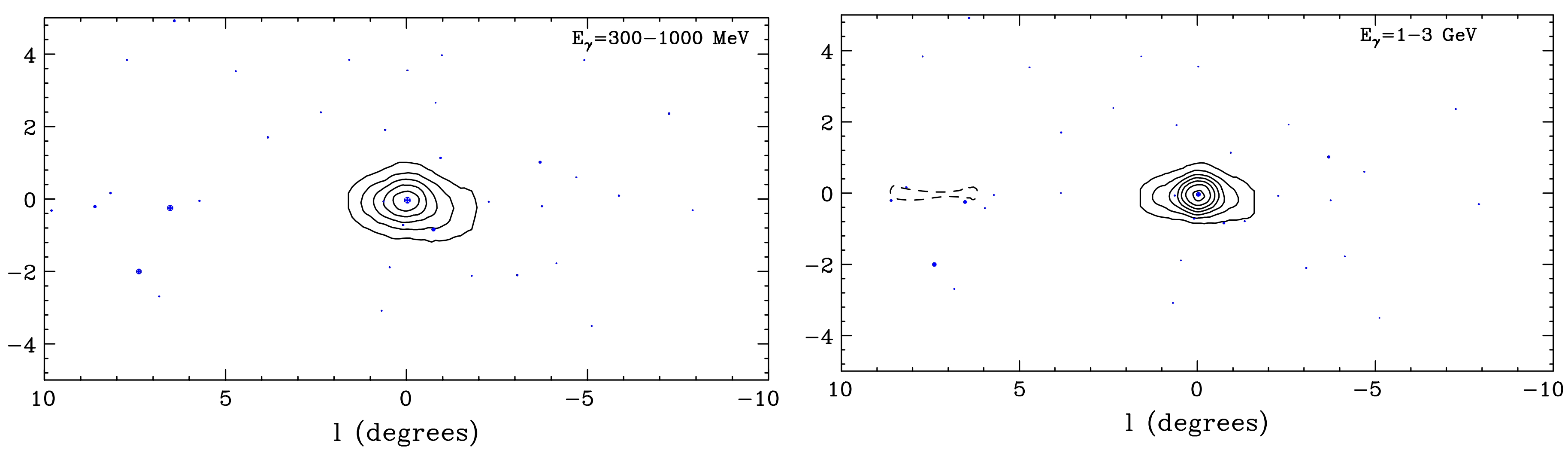
- Three component of astrophysical and DM emission.
- Bremss (and related uncertainties) often neglected: general argument being that it is subdominant below 1 GeV.
- Analyses of γ rays more challenging at <1 GeV (PSF larger).



[Ackermann, M.+, ApJ. 750 (2012)]

Goals

- Given the precision of the current CR and γ ray data and importance of including <1 GeV data in the gamma ray analysis it is timely to **explore the relevance and associated uncertainties of the bremss component**.
- This specially holds in the regions **where gas density determinations are plagued with uncertainties**, as in the GC region.



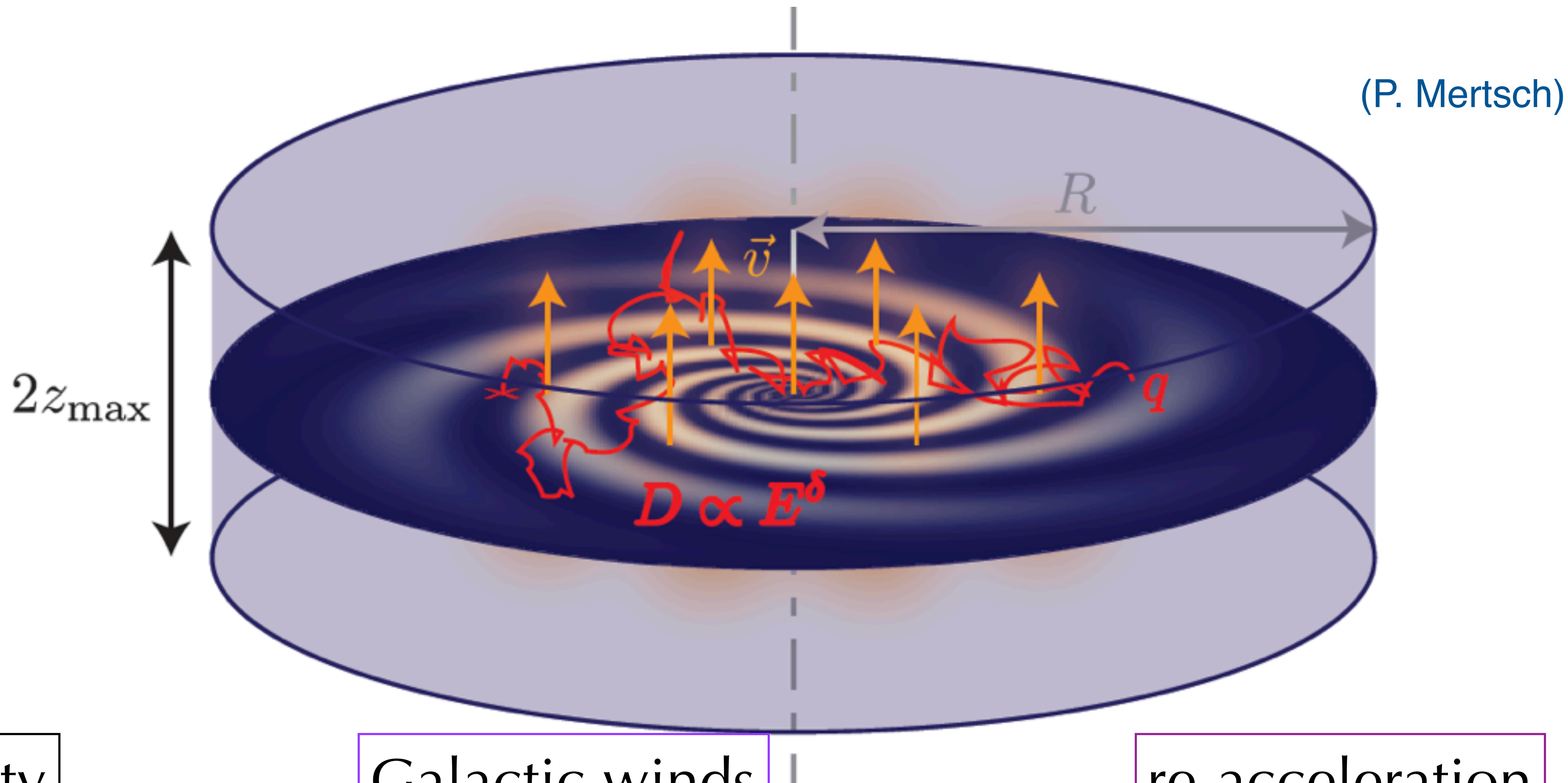
Residuals in the GC region, [Hooper&Goodenough, 1010.2752; Hooper&Linden, 1110.000; Abazajian&Kaplinghat, 1207.6047]

Procedure:

- As a **source of electrons** we take **dark matter annihilations**, for definiteness and relative simplicity but *main conclusions hold also for CRe of conventional astrophysical origin*.
- we do not explore the full range of astro uncertainties -> **use a well motivated set of benchmark parameters and focus on (some of) uncertainties related to bremss emission**.

Calculation of the electron spectrum

- electron spectra at a given position in the Galaxy is governed by the diffusion and energy loss processes.



CR density

Diffusion

Galactic winds

energy losses

re-acceleration

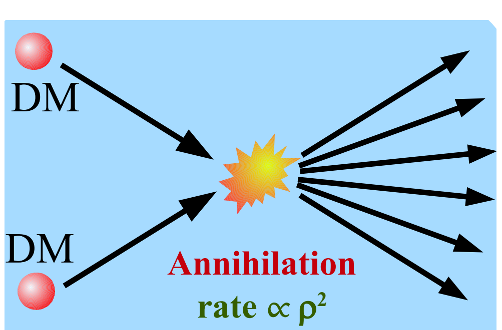
primary and secondary sources

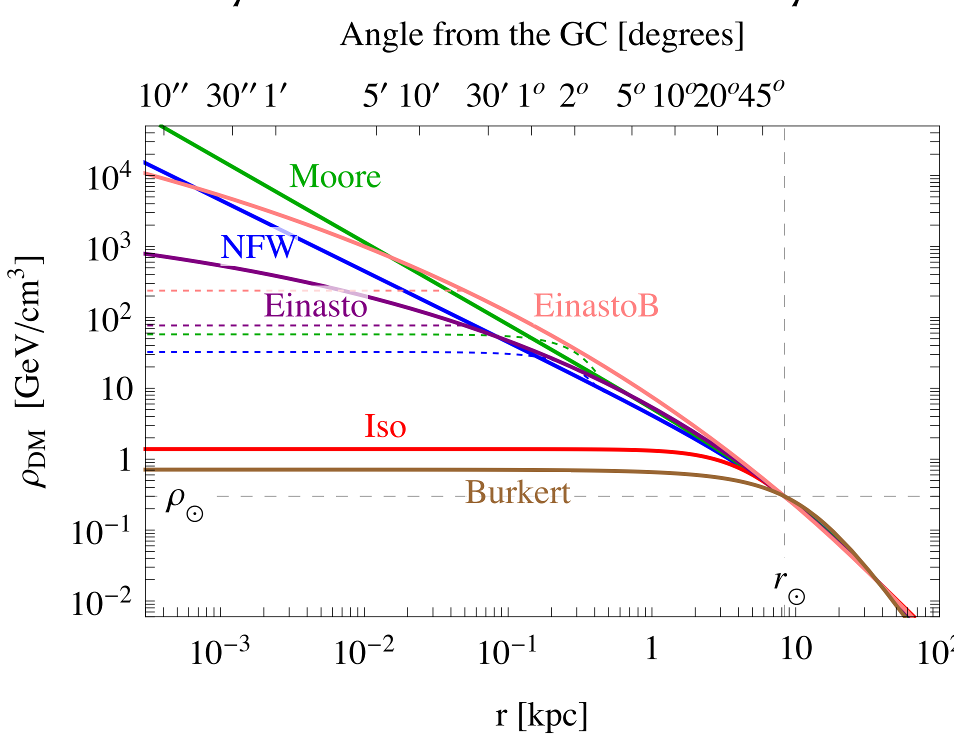
$$\frac{\partial \psi}{\partial t} - \nabla \cdot (D\nabla - v_c)\psi + \frac{\partial}{\partial p} b_{\mathrm{loss}} \psi - \frac{\partial}{\partial p} K \frac{\partial}{\partial p} \psi = q_{\mathrm{source}}$$

Calculation of the electron spectrum

- Calculations done with two codes: PPPC4DMID and GALPROP
  - **PPPC4DMID**: Propagation performed with an improved semi-analytic method that takes into account position-dependent energy losses (www.marcocirelli.net/PPPC4DMID.html)
  - **GALPROP**: fully numerical calculation (http://galprop.stanford.edu/webrun.php)

- **diffusion parameters** we take the 'MED' model and B fields of 4 μG.
- **source**: DM annihilations
  - to μ, τ, b channels
  - distributed in a Galaxy with NFW density distribution.

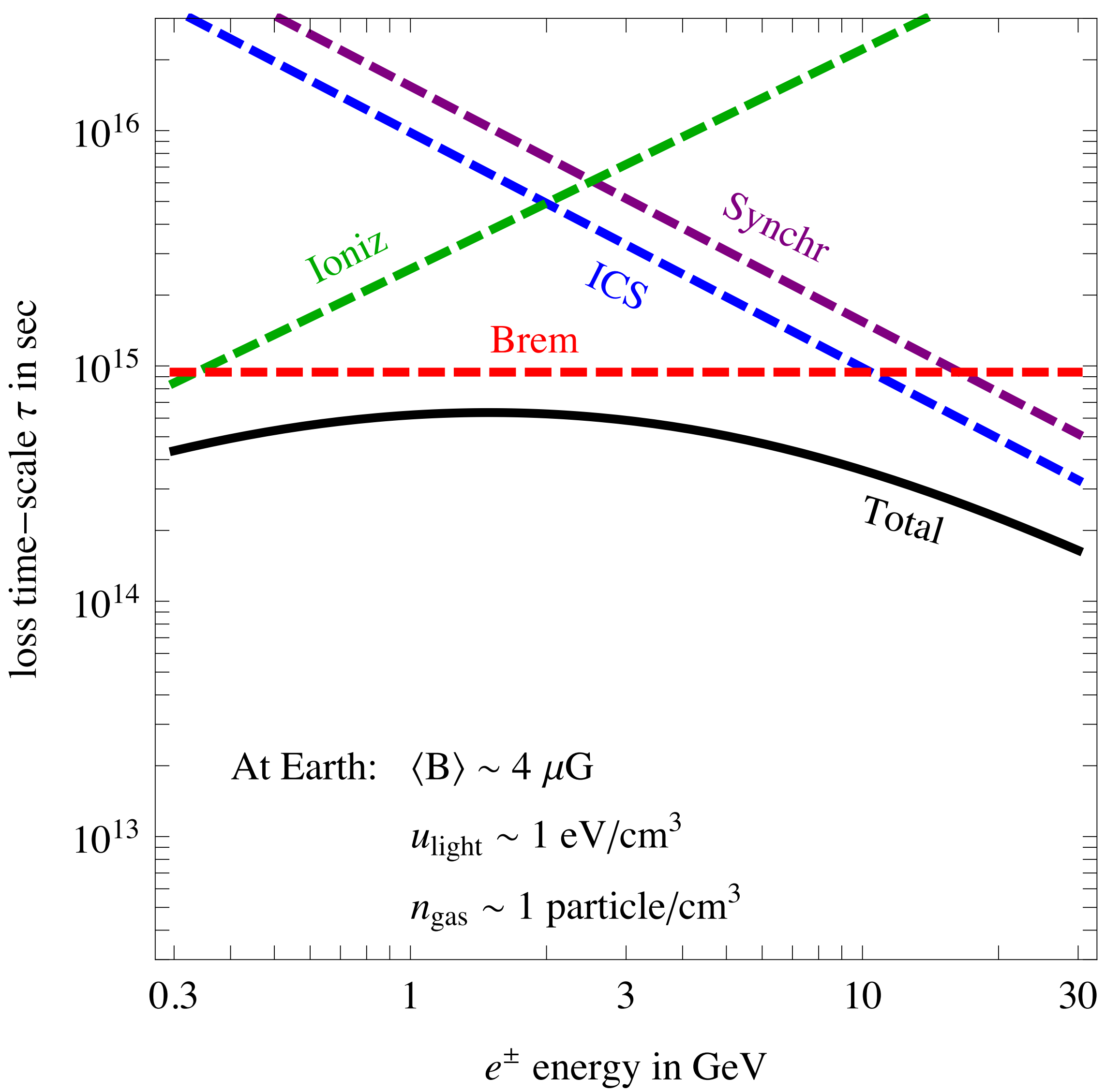


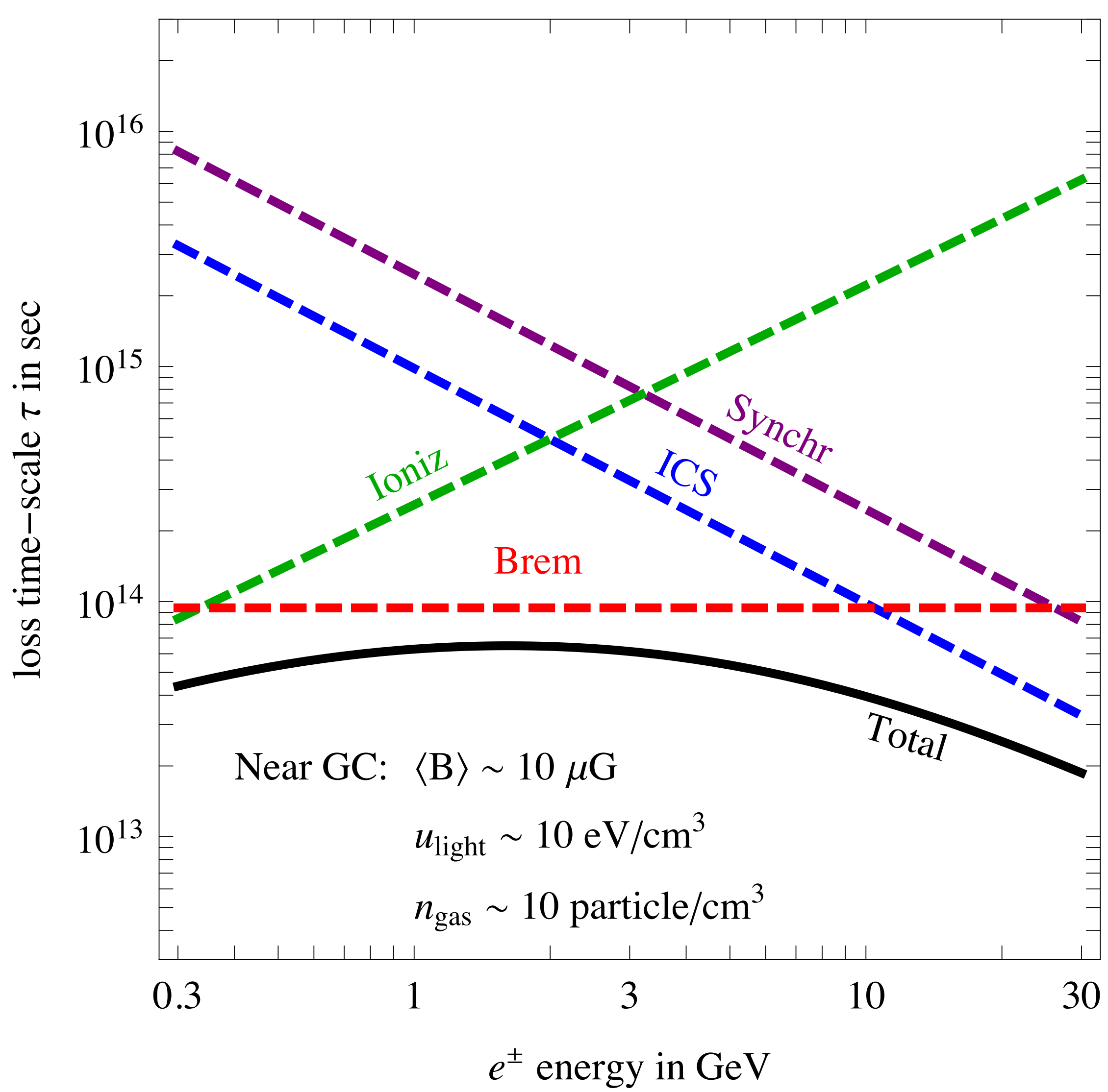


Model	Electrons or positrons δ	Electrons or positrons $\mathcal{K}_0$ [kpc²/Myr]	L [kpc]
MIN	0.55	0.00595	1
MED	0.70	0.0112	4
MAX	0.46	0.0765	15

Calculation of the electron spectrum

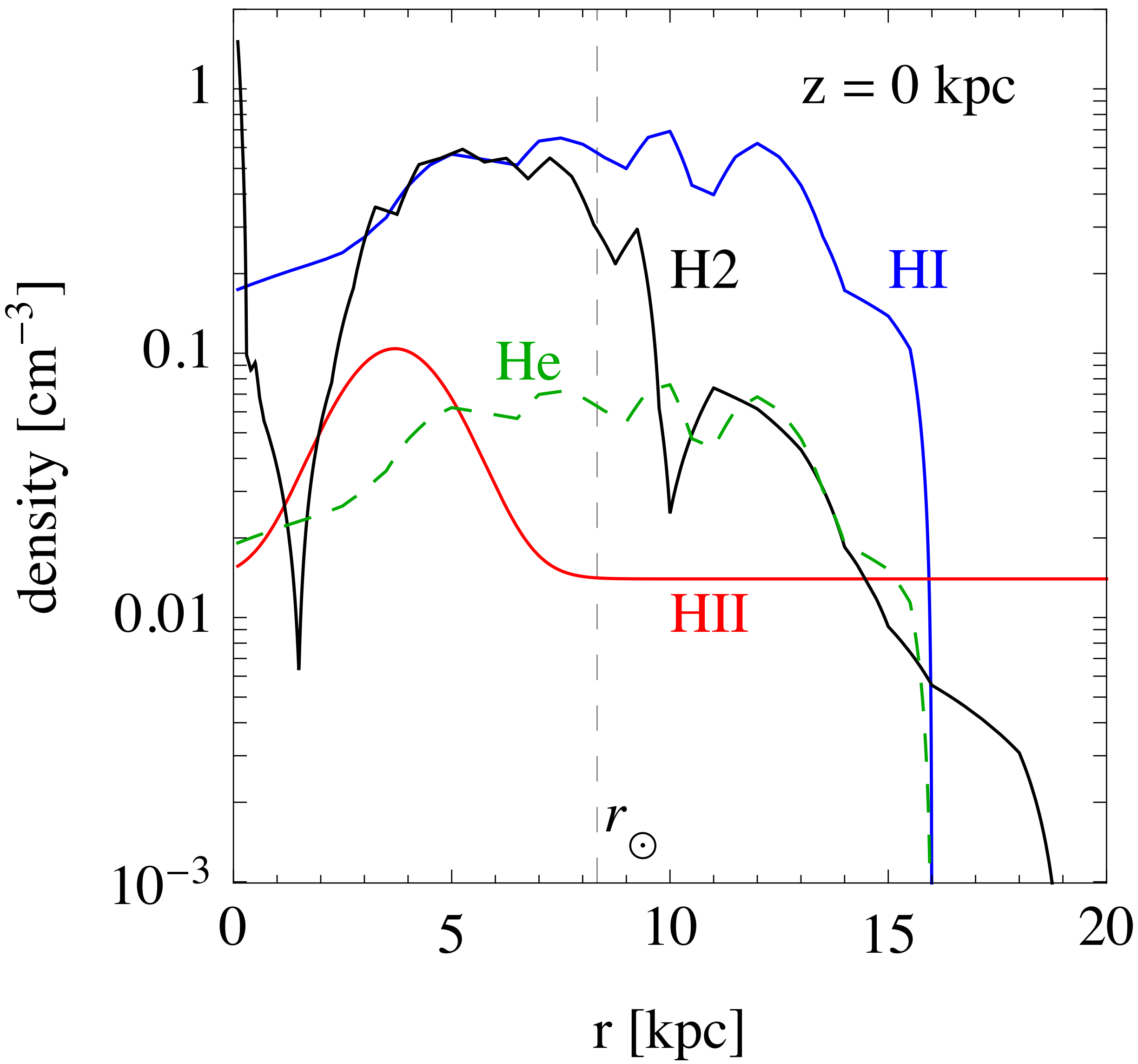
- main energy losses in the few GeV range: **IC, bremss and synchrotron** (Galactic mag fields).
- below ~10 GeV (electron energy!), bremsstrahlung is the dominant process for typical environmental conditions.

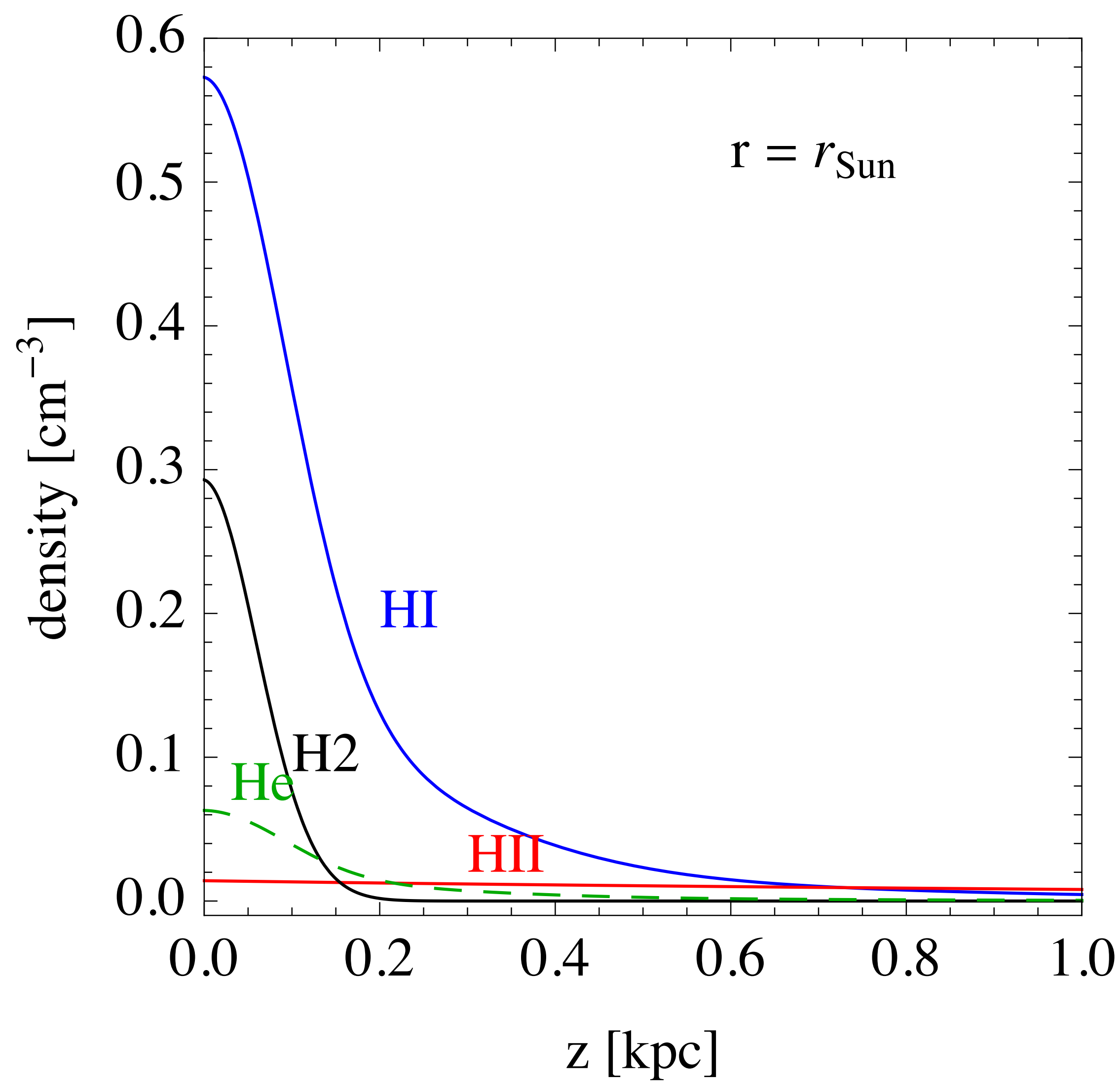




Interstellar gas maps

- use gas maps as in the GALPROP code (http://galprop.stanford.edu/webrun.php)



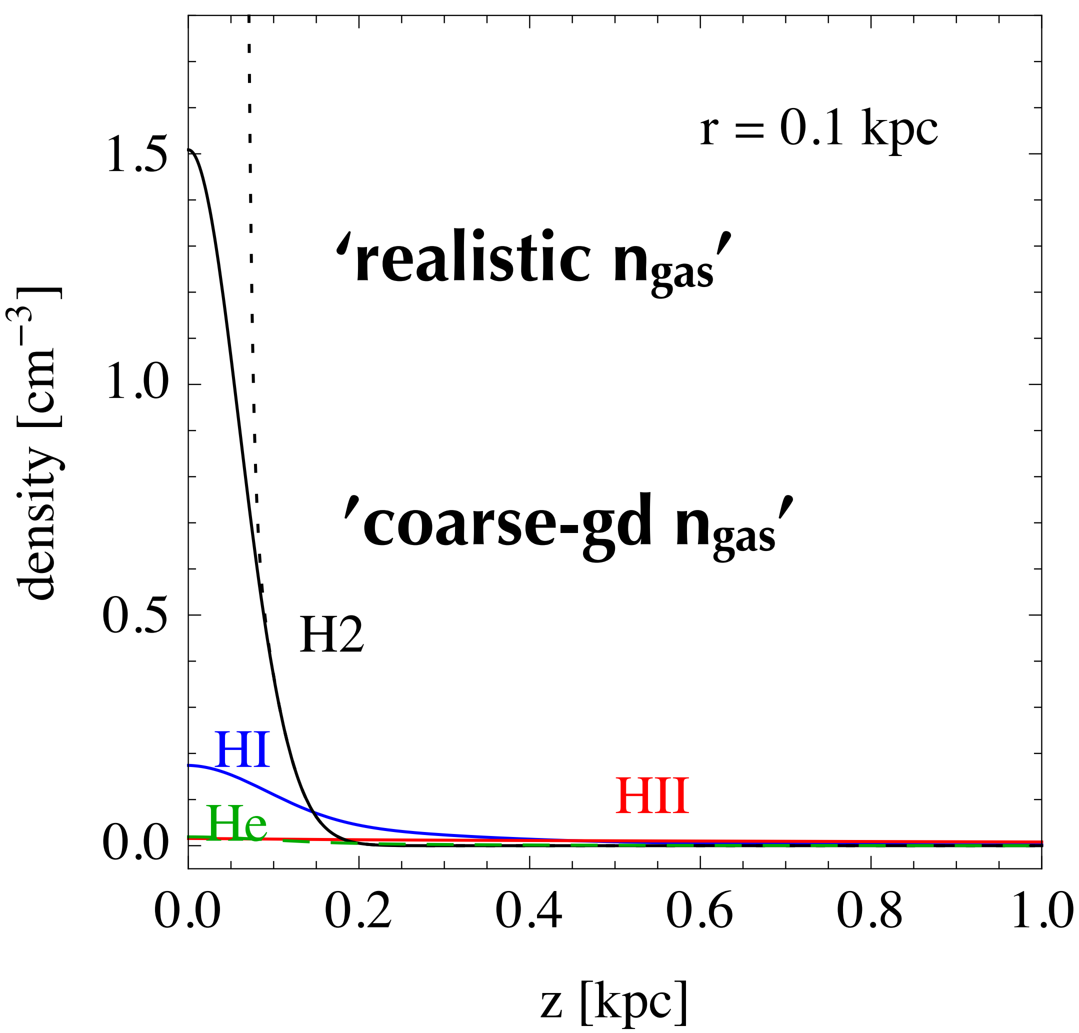


[Gordon & Burton, ApJ 208 (1976); Dickey & Lockman, Ann. Rev. Astron. Astrophys. 28 (1990); Cox+, A&A, 155 (1986); Bronfman+, Astrophys. J. 324 (1988); Wouterloot+, A&A 230 (1990); Gaensler+, Publ. Astron. Soc. of Australia 25 (2008)]

Interstellar gas maps

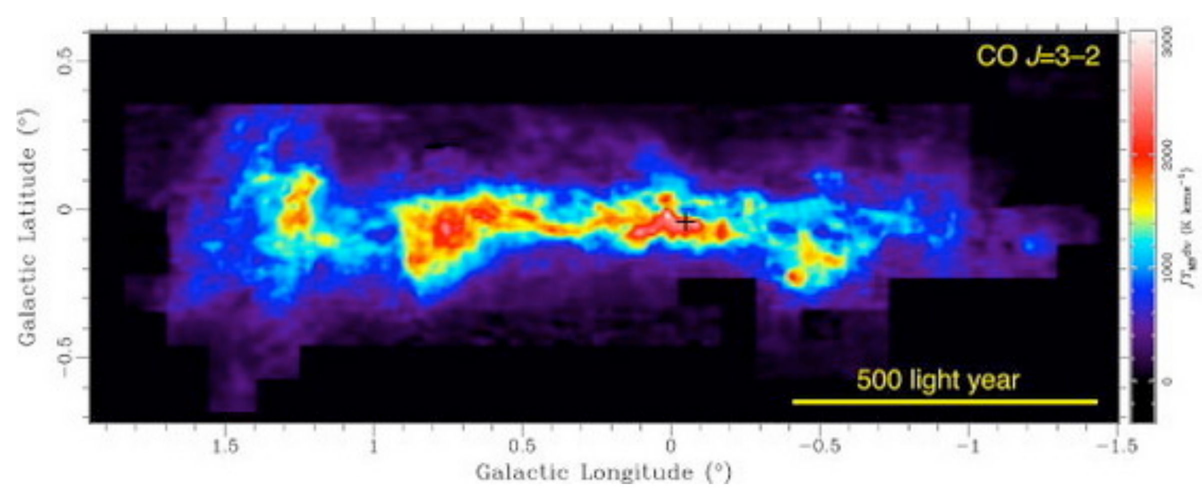
R. Crocker's talk

- In the **inner Galaxy** uncertainties are bigger:
- region at $\lesssim 2^\circ \sim 200$ pc scales hosts several structures of dense gas:
  - The Central Molecular Zone: Ferriere+ (2007) estimate that densities reach $\langle \mathbf{n_{H2}} \rangle_{\mathbf{CMZ}} \approx \mathbf{150\ cm^{-3}}$
  - The Circum-Nuclear Ring: inner 1 to 3 pc $\langle n_{H2} \rangle_{CNR} = 2.2 \times 10^5\ cm^{-3}$.



To explore uncertainty in this region we use:

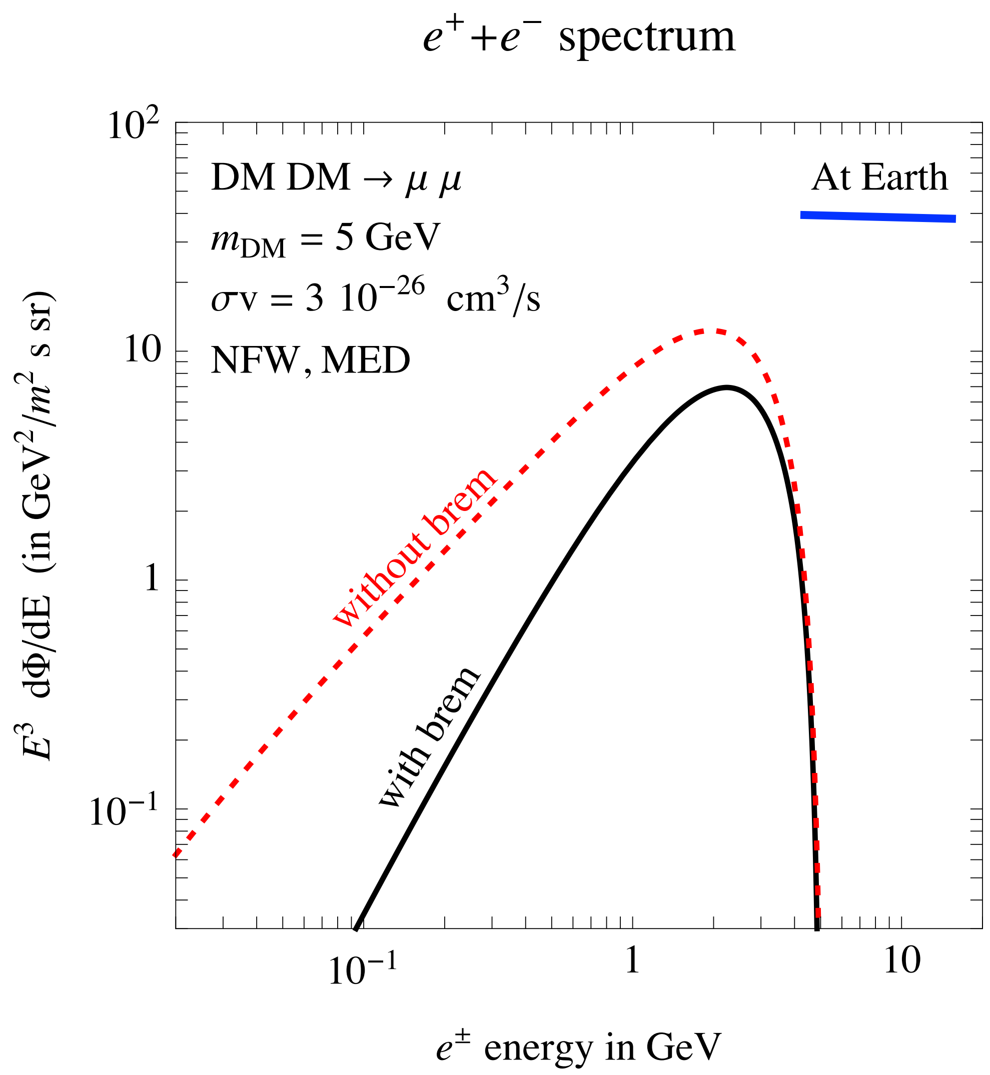
- 'coarse-gd n_{gas}'
- 'realistic n_{gas}': constructed to have $\langle n_{H2} \rangle_{CMZ}$ $\approx$**$100\ cm^{-3}$** while **z height is kept the same** as for the usual gas maps.

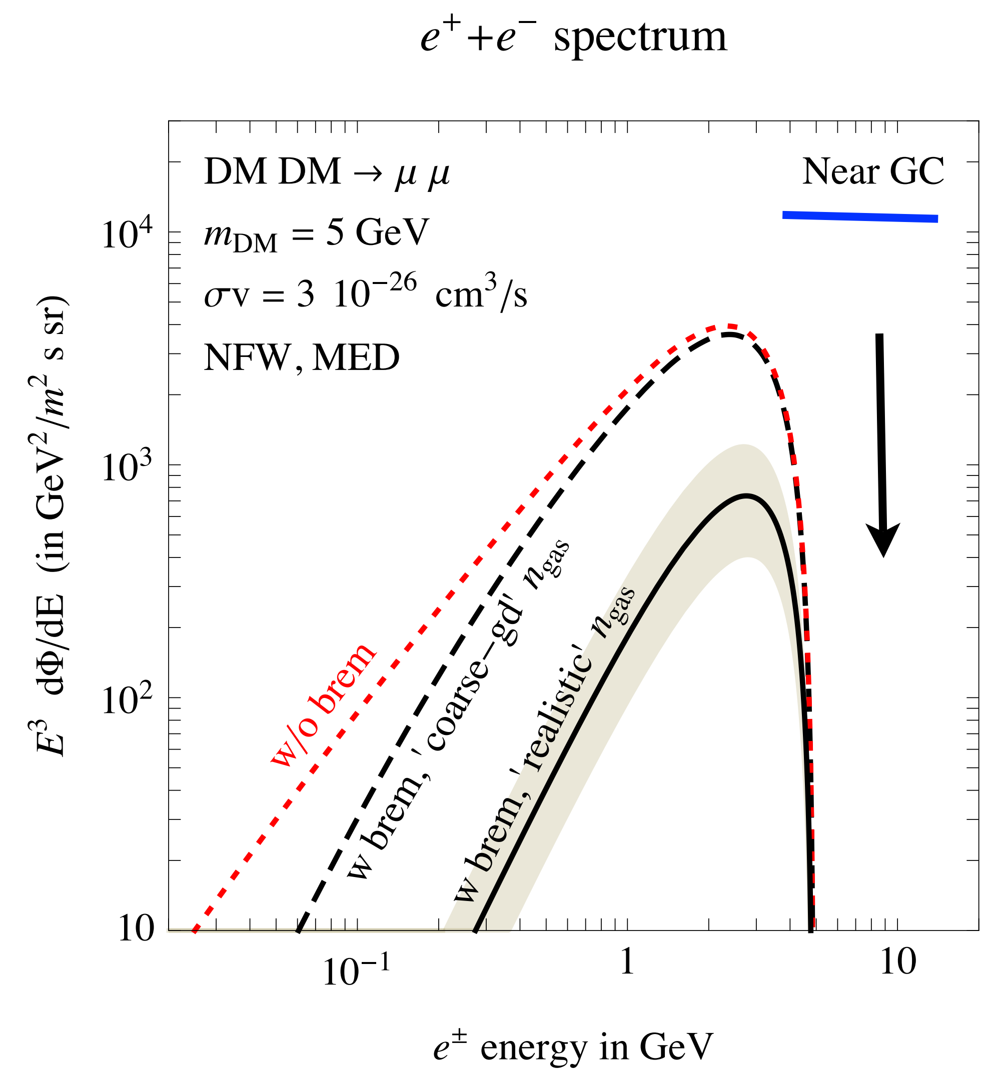


Electron Spectra

We calculate relevant spectra assuming i) no bremss losses, or ii) bremss for realistic and coarse-grained case of the gas density.

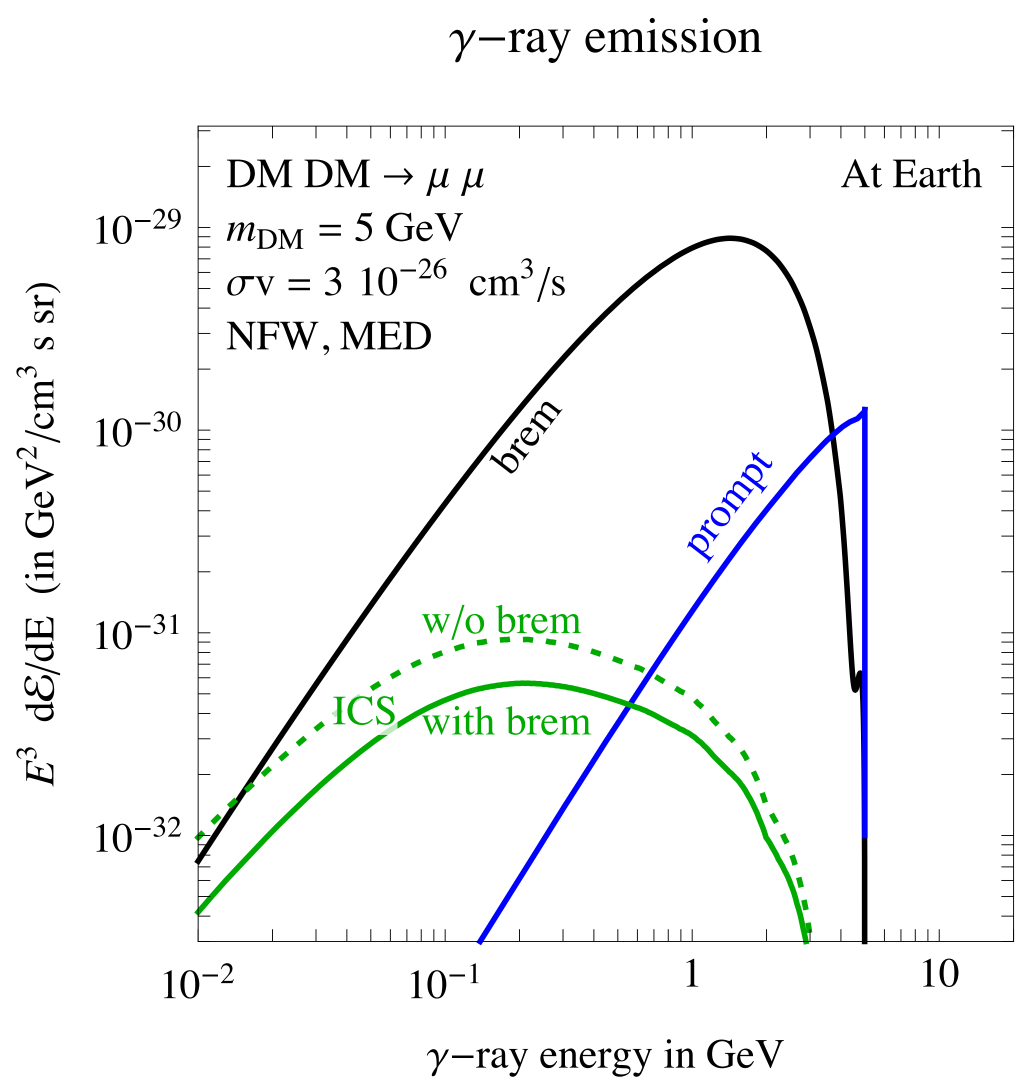
$$\frac{\mathrm{d}\Phi_{e^\pm}}{\mathrm{d}E}(E,\vec{x}) = \frac{c}{4\pi\, b(E,\vec{x})}\frac{1}{2}\left(\frac{\rho(\vec{x})}{m_{\rm DM}}\right)^2 \sum_f \langle\sigma v\rangle_f \int_E^{M_{\rm DM}} \mathrm{d}E_{\rm s}\, \frac{\mathrm{d}N^f_{e^\pm}}{\mathrm{d}E}(E_{\rm s})\, I(E,E_{\rm s},\vec{x})$$

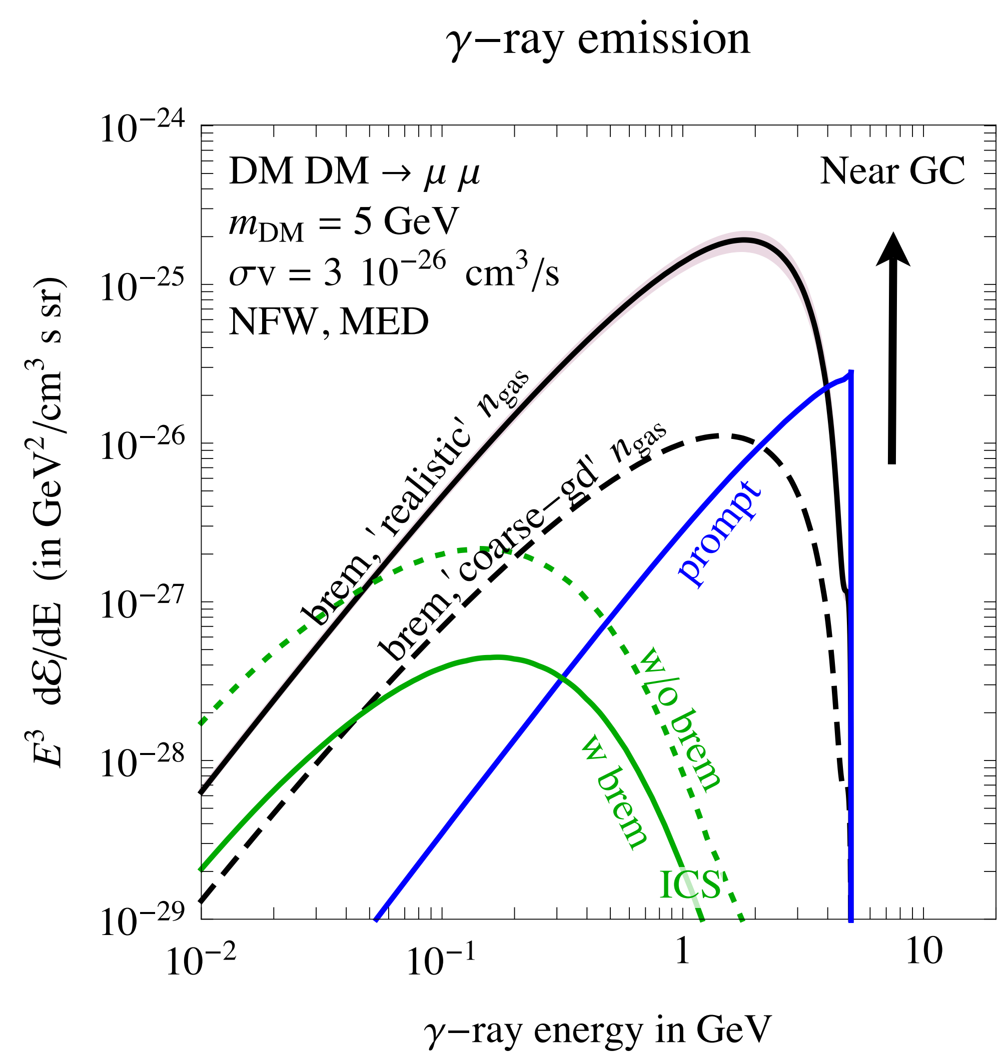




γ ray emission

$$\frac{\mathrm{d}\mathcal{E}_{\gamma,\mathrm{brem}}(\vec{x})}{\mathrm{d}E_\gamma} = \sum_i n_i(\vec{x}) \int_{E_L} \mathrm{d}E_{e^\pm}\ 2\frac{\mathrm{d}\Phi_{e^\pm}(\vec{x})}{\mathrm{d}E_{e^\pm}} \cdot \frac{\mathrm{d}\sigma_i}{\mathrm{d}E_\gamma}$$



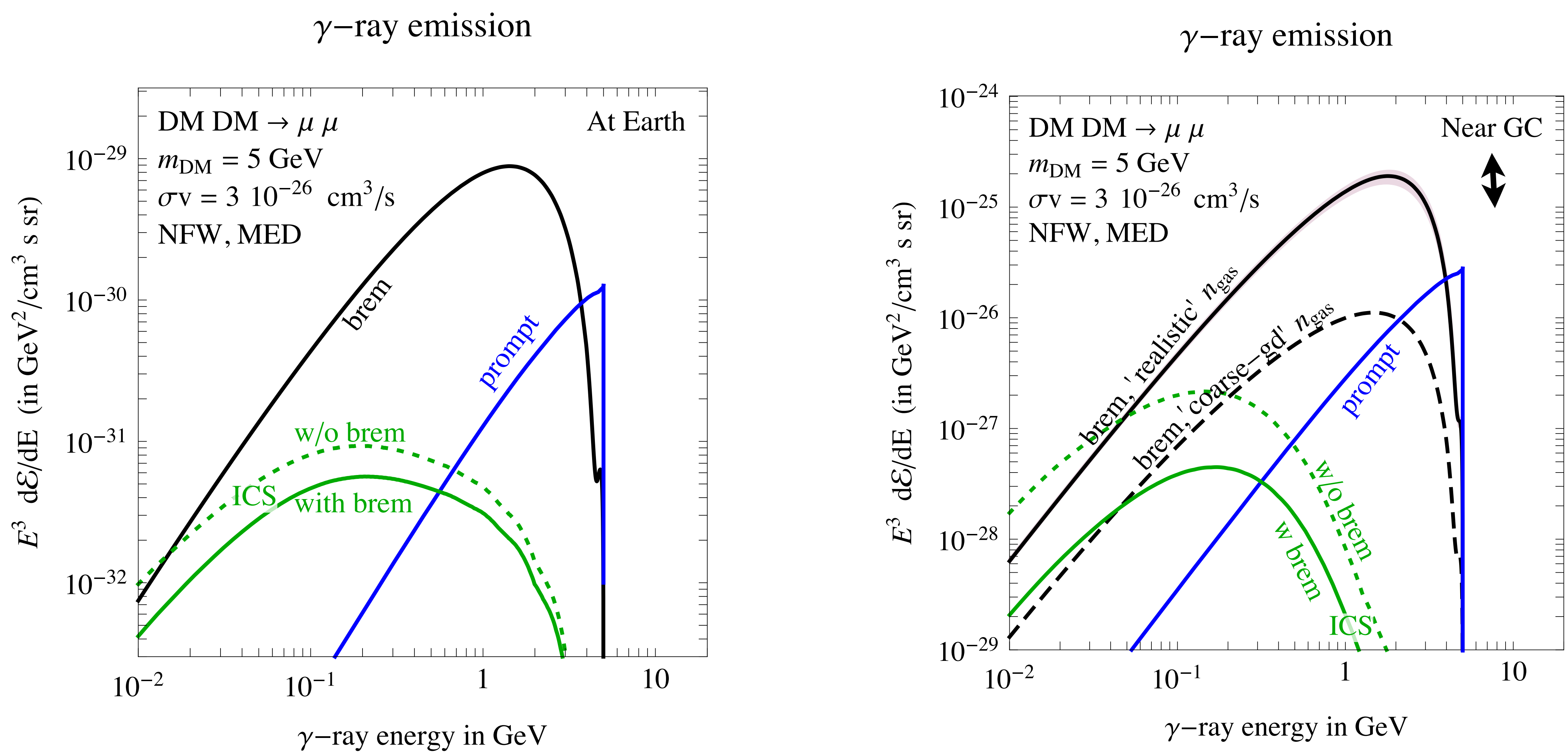


Two competing effects in which the γ-ray signal is affected by bremsstrahlung:

- via the impact that the additional energy loss has on electron steady state spectrum (-> **lowers the e spectrum** -> lowers the ICS);
- via the additional emission process -> higher gas density -> **higher bremss**.

γ ray emission

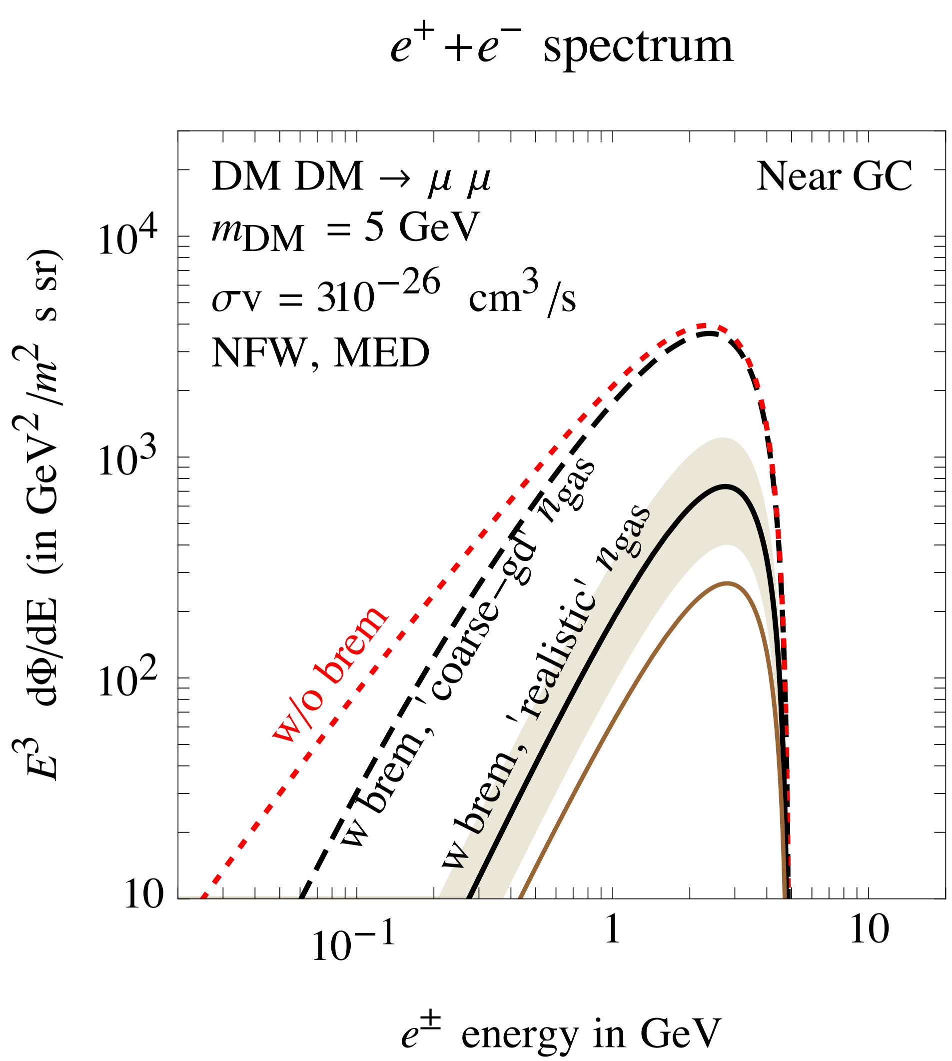
$$\frac{d\mathcal{E}_{\gamma,\mathrm{brem}}(\vec{x})}{dE_\gamma} = \sum_i n_i(\vec{x}) \int_{E_L} dE_{e^\pm}\ 2\frac{d\Phi_{e^\pm}(\vec{x})}{dE_{e^\pm}} \cdot \frac{d\sigma_i}{dE_\gamma}$$

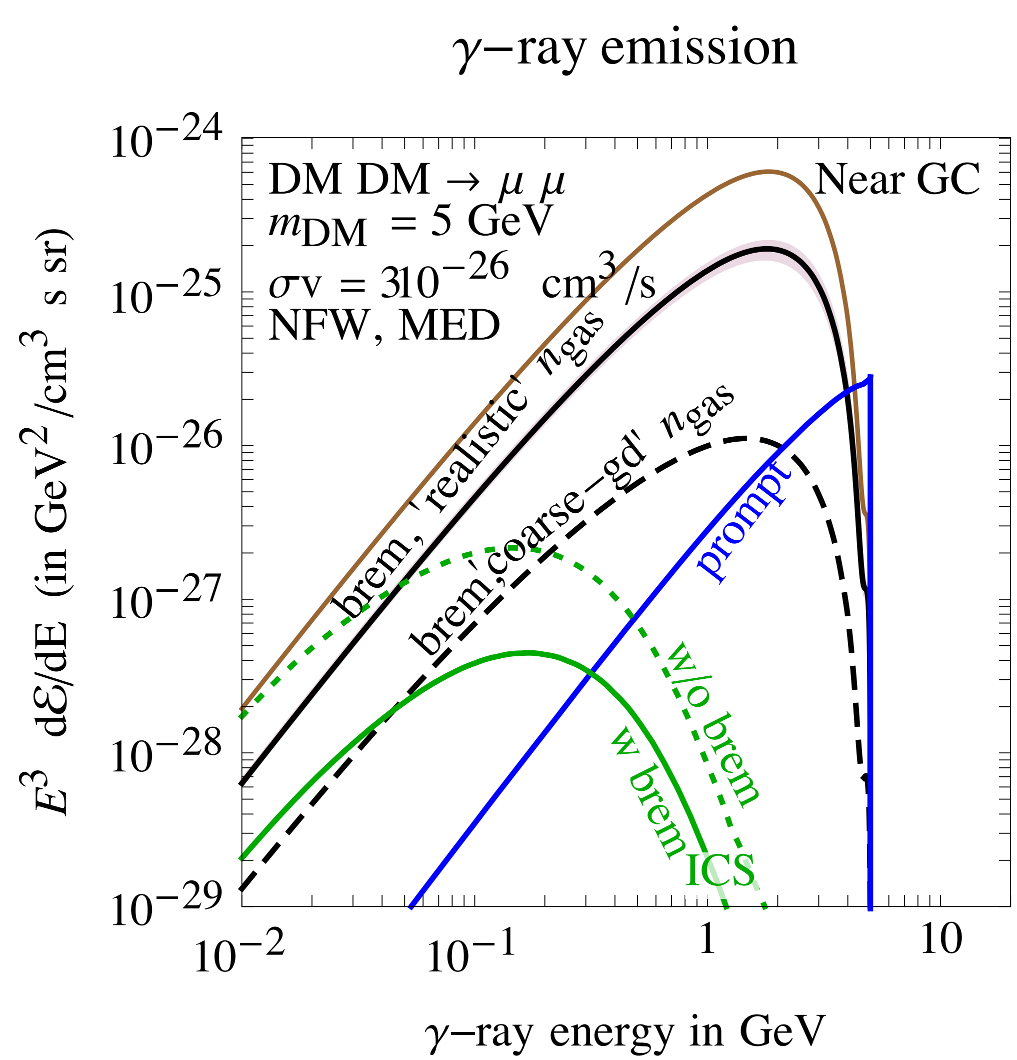


➡ for a fixed gas density distribution and in the case when bremss losses dominate, uncertainty on the emission is moderate (two competing effects!)

γ ray emission

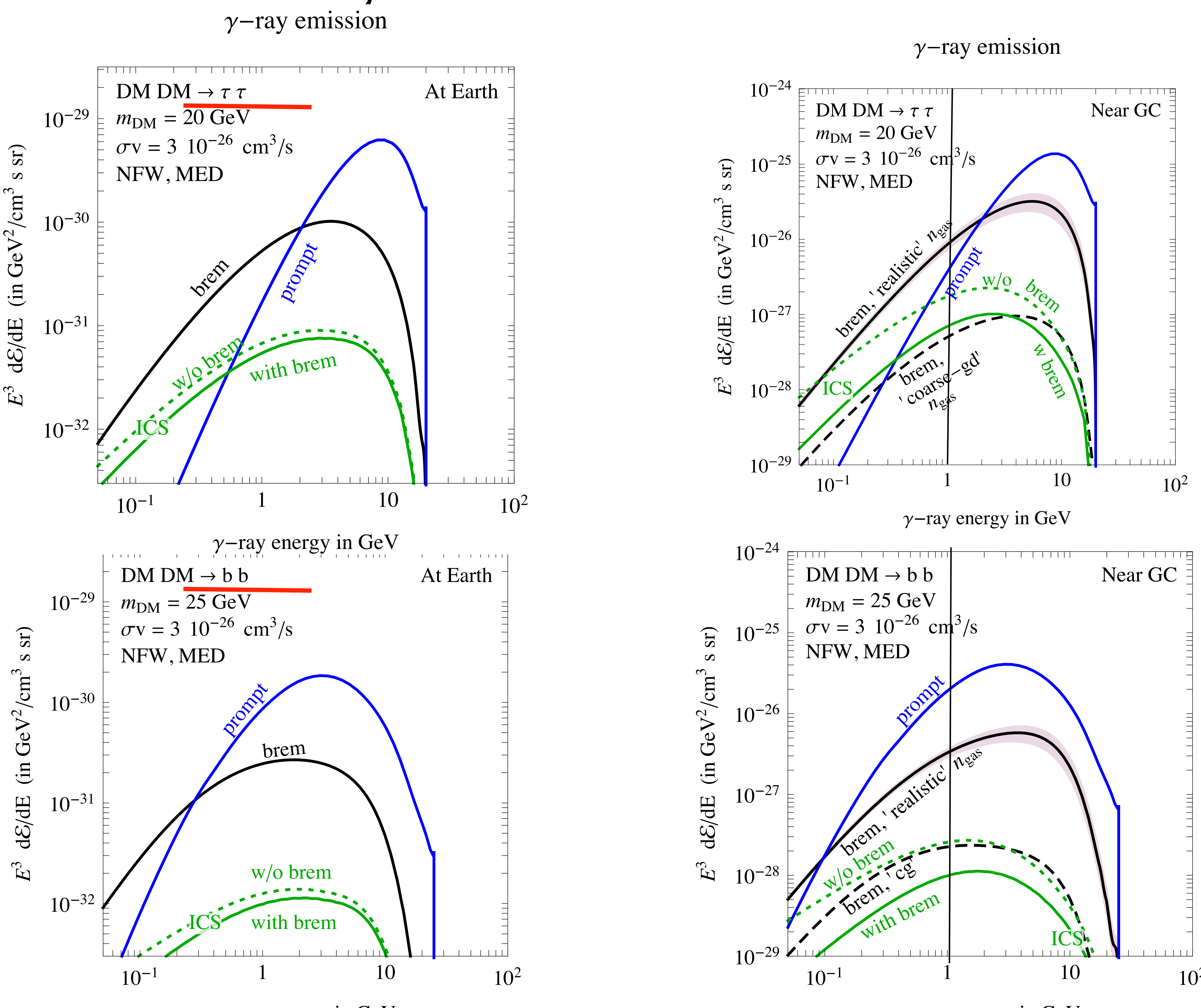
- ➡ in first approx.: bremss gamma ray signal sensitive to $n_{H2}(R)$ z scale of CMZ and
- (& diffusion and environment related uncertainties! (R. Crocker))



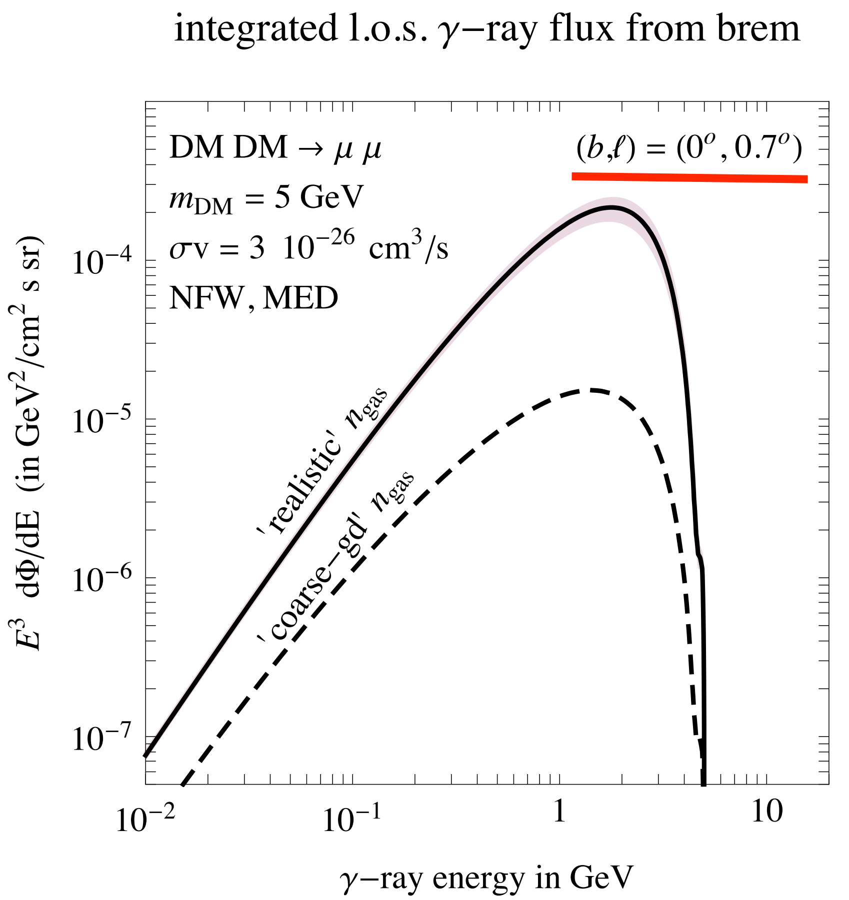


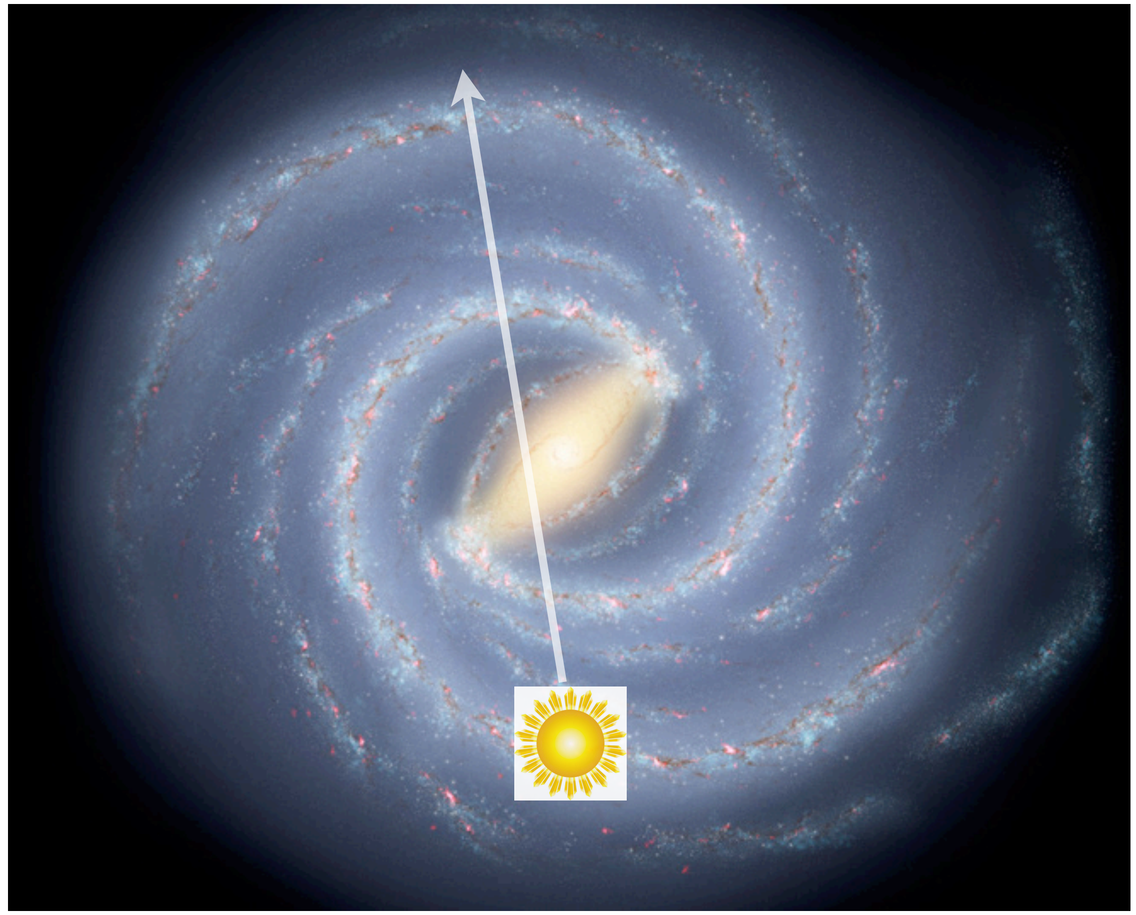
– If following more closely Ferriere+ (2007) in R and z dependence.

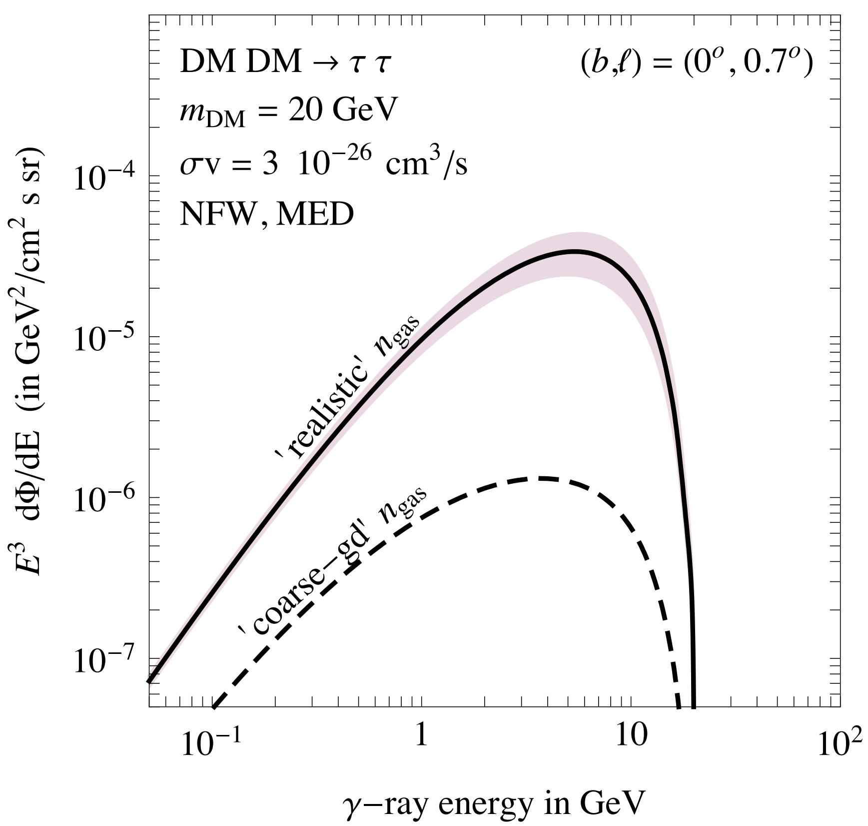
γ ray emission: other channels

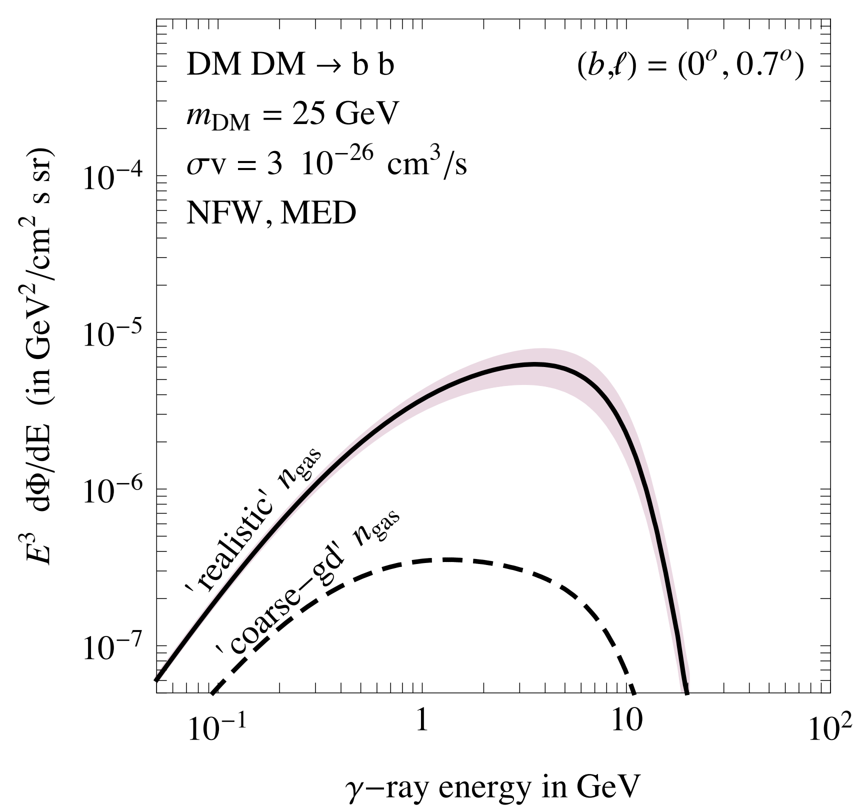


γ line-of-sight integrals



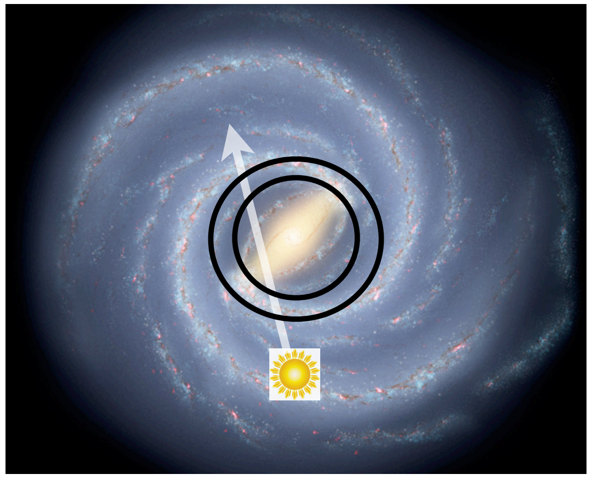






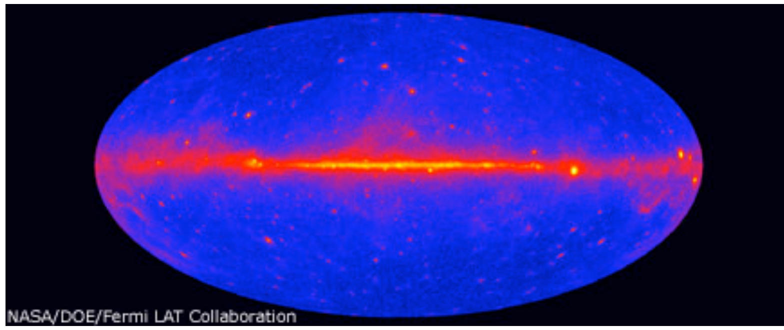
- los integrals at ~. 0.5deg sensitive to the assumption on the gas density in the inner 100 pc.

γ line-of-sight integrals



- Note:
- routinely in numerical codes (GALPROP, DRAGON, etc):
  - electron energy losses calculated assuming *one set of maps* **(R,z)**
  - for the bremss emission and los integrals a **(l,b) hi res** set of maps is used (match for good angular resolution of Fermi LAT).
  - ➡ emissivities rescaled within Galactocentric rings i:

$$\frac{\mathrm{d}\Phi_{\gamma,\mathrm{brem}}}{\mathrm{d}E_\gamma} = \Sigma_i \frac{N_{\mathrm{HI},i} + 2\ X_{\mathrm{CO},i} W_{\mathrm{CO},i}}{\int n_{\mathrm{HI}} + 2 n_{\mathrm{H}_2}\ ds} \times \int_i \frac{\mathrm{d}\mathcal{E}_{\gamma,\mathrm{brem}}}{\mathrm{d}E_\gamma}\ ds$$

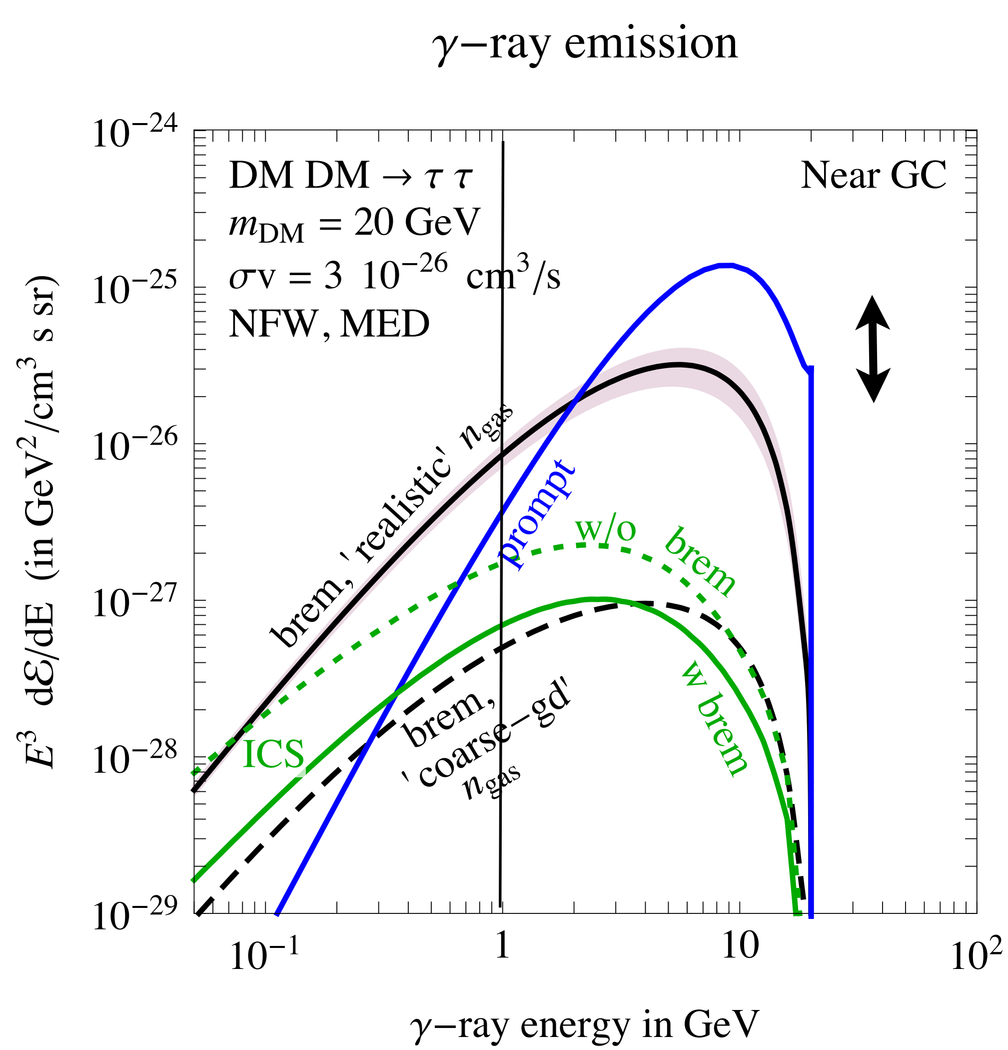


- Potential issues:
  - electron energy losses and bremss emission not treated self consistently (+X_{CO} a posteriori adjusted).
  - Degeneracy with source distribution.

- (here we use a self-consistent approach, i.e. one set of maps to check the impact on the spectrum.)

Bremsstrahlung emission

- In the case of DM: prompt spectra **universal throught the Galaxy.**
- however, **secondary radiation spectra**: bremss and IC are **position dependent** -> important to take into account when comparing DM searches between different channels and targets.



Summary

- Uncertainties in gas density alter gamma-ray spectrum via two effects: **indirectly**, (electron steady state spectrum->inverse Compton, synchrotron etc) **directly**, higher bremss emission (two opposite effects).

- in regions in which bremsstrahlung dominates energy losses, the related γ-ray emission is only **moderately sensitive to possible large variations in the magnitude of the gas density**.

- For computing precise spectra in the (sub-)GeV range, it is important to obtain a **reliable description of the inner Galaxy gas distribution** as well as to **compute self-consistently** the gamma emission and the solution to the diffusion-loss equation.