Pressure from Dark Matter Annihilation and The Rotation Curve of Spiral Galaxies

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DESY THEORY WORKSHOP: 28th Sep. 2011

Outline

- Introduction to Dark Matter (DM)
- Propagation of $e^{\pm}$ from DM annihilation
- Pressure from DM annihilation
- Effect of the DM pressure on the rotation curve of galaxies
- Conclusions

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Cosmological evidences for DM

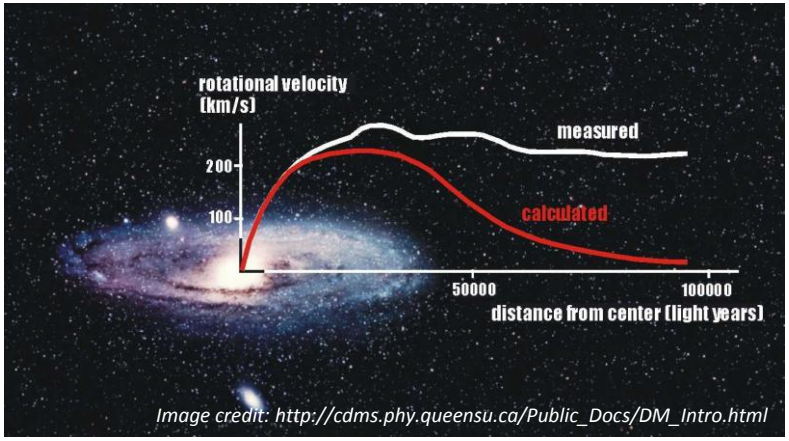


Image credit: http://cdms.phy.queensu.ca/Public_Docs/DM_Intro.html

Rotation curve of galaxies

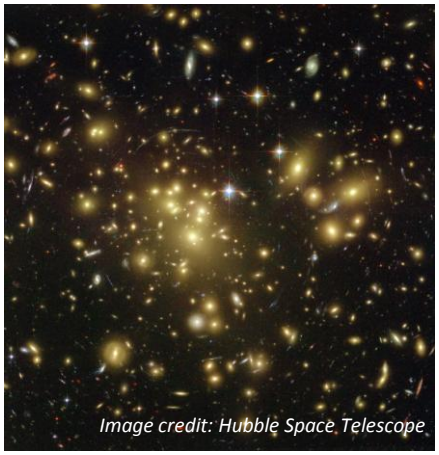


Image credit: Hubble Space Telescope

Gravitational lensing

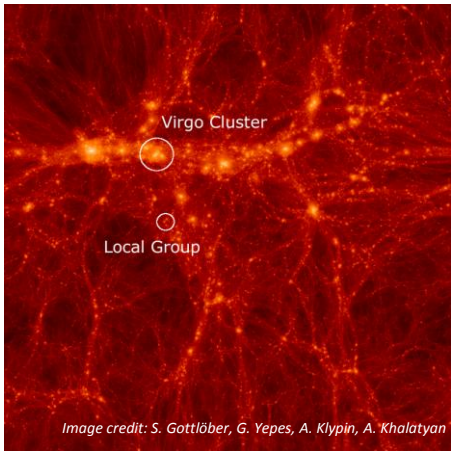
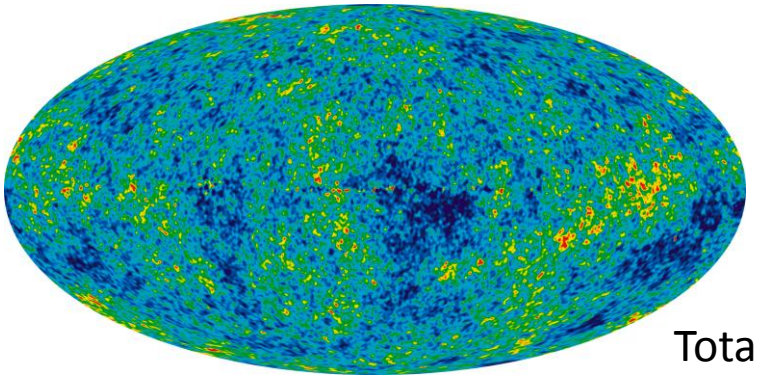
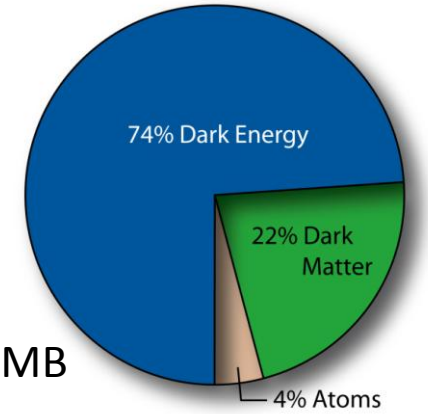


Image credit: S. Gottlöber, G. Yepes, A. Klypin, A. Khalatyan

Structure formation

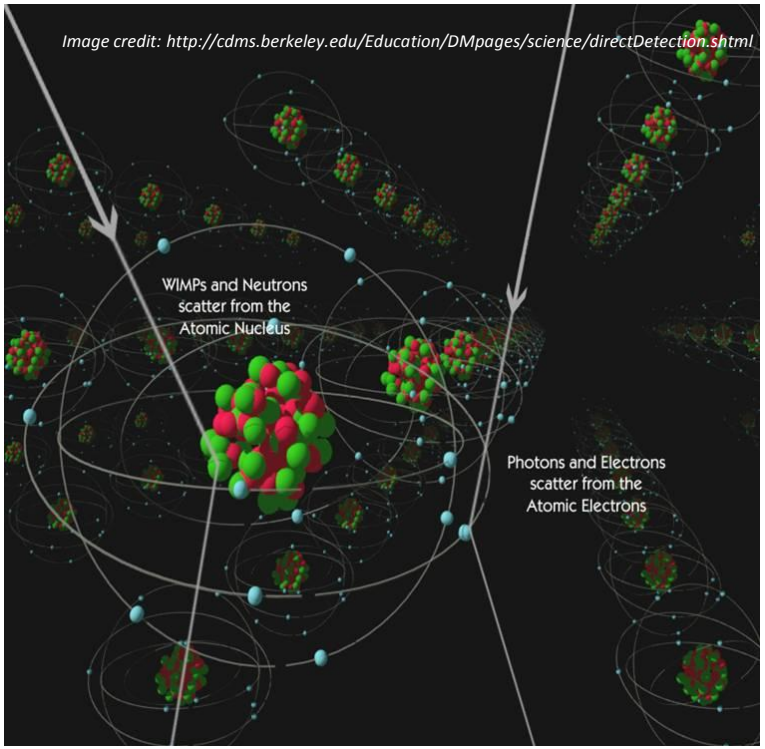


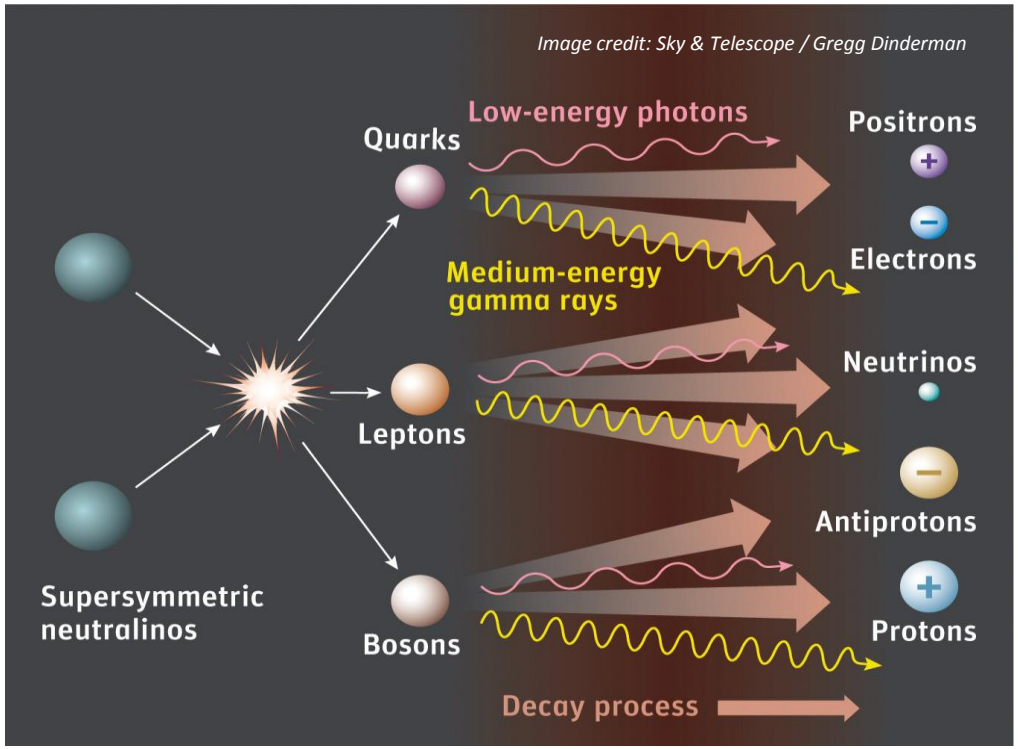


Total amount of DM from CMB

Image credit: NASA / WMAP Science Team

How to detect dark matter?





Direct detection

Indirect detection

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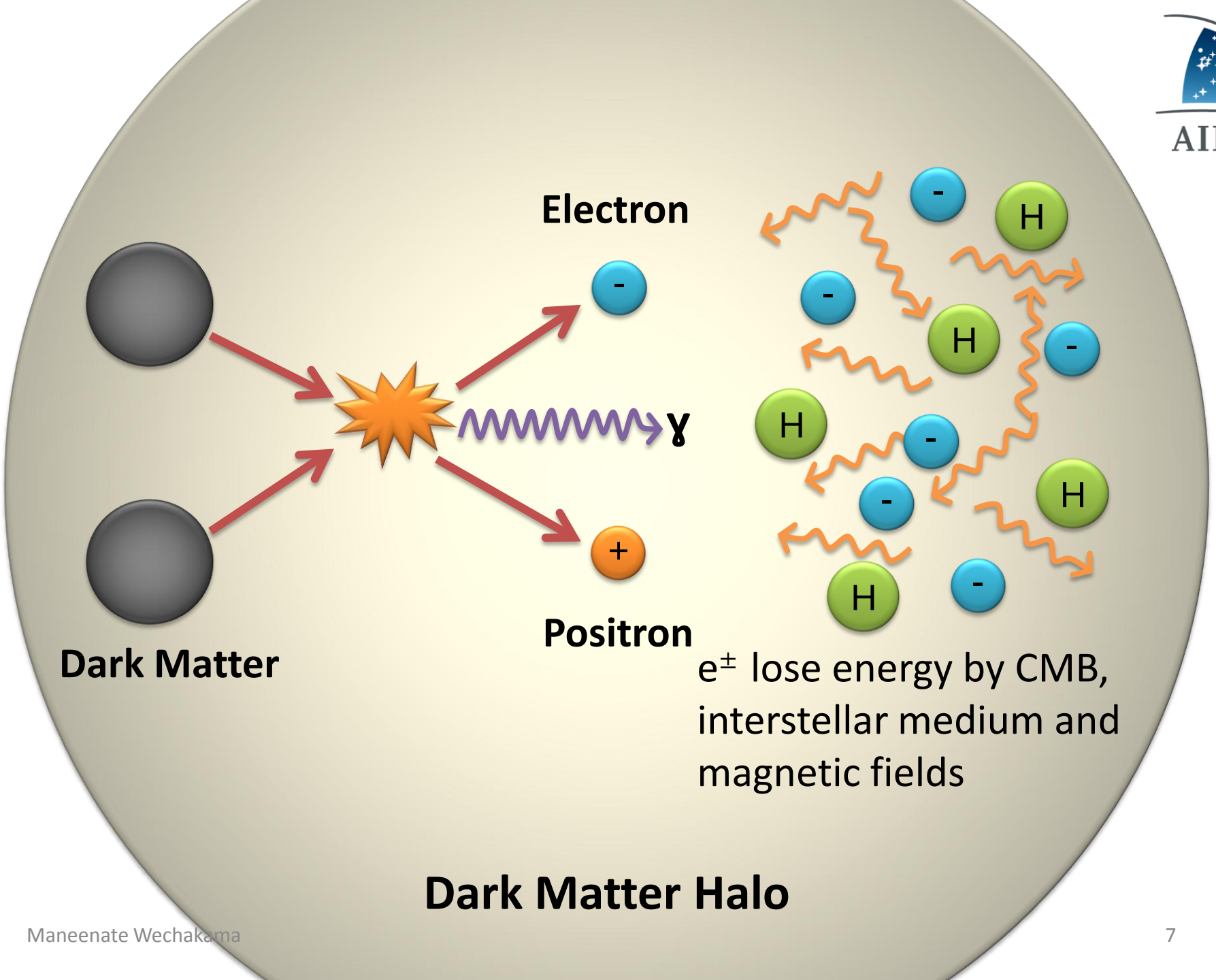

Electron
γ
Positron
Dark Matter
H
e± lose energy by CMB, interstellar medium and magnetic fields
Dark Matter Halo

Model of $e^{\pm}$ Propagation

AIP

Diffusion-Loss Equation

$$\frac{\partial}{\partial t}\frac{dn}{d\gamma}(x,\gamma) = \nabla\left[K(x,\gamma)\nabla\frac{dn}{d\gamma}(x,\gamma)\right] + \frac{\partial}{\partial\gamma}\left[b(x,\gamma)\frac{dn}{d\gamma}(x,\gamma)\right] + Q(x,\gamma)$$

- $e^{\pm}$ Spectrum
- Diffusion
- Energy Losses
- Source Term

γ is Lorentz factor

Source Term

$$\frac{\partial}{\partial t}\frac{\mathrm{d}n}{\mathrm{d}\gamma}(x,\gamma) = \nabla\left[K(x,\gamma)\nabla\frac{\mathrm{d}n}{\mathrm{d}\gamma}(x,\gamma)\right] + \frac{\partial}{\partial\gamma}\left[b(x,\gamma)\frac{\mathrm{d}n}{\mathrm{d}\gamma}(x,\gamma)\right] + Q(x,\gamma)$$

$$Q(r,\gamma) = n_{dm}(r)n_{dm^*}(r)\langle\sigma v\rangle_{e^\pm}\frac{dN_{e^\pm}}{d\gamma}$$

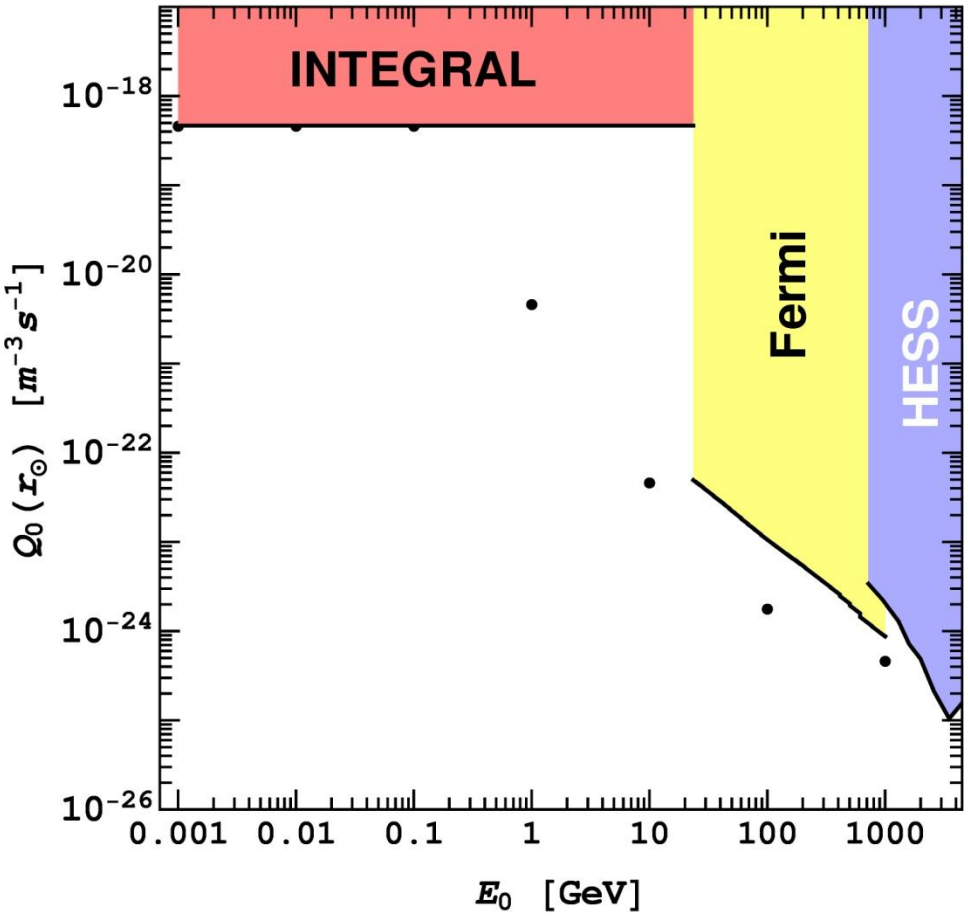
Assuming all electrons and positron are injected with the same energy $\gamma_0 \sim m_{dm}/m_e$

$$Q(r,\gamma) = Q_0(r)\delta(\gamma-\gamma_0)$$

$$Q_0(r) = 2\left[\frac{\rho_{dm}(r)}{m_{dm}}\right]^2\langle\sigma v\rangle_{e^\pm}$$

DM Density Profile

Constraints of the Source Term



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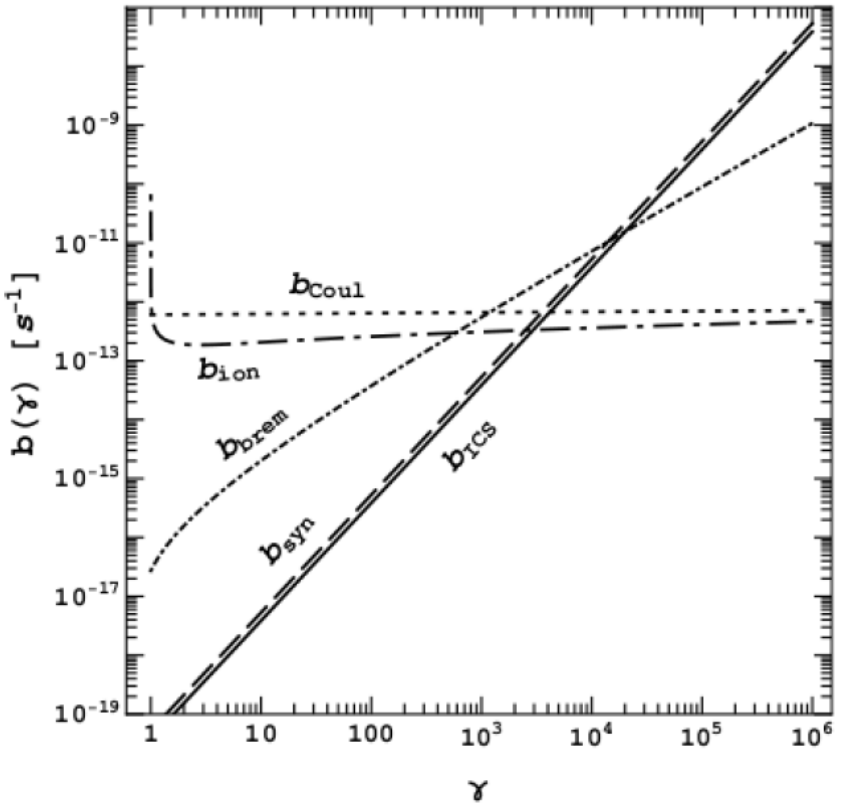
Energy Losses

$$\frac{\partial}{\partial t}\frac{\mathrm{d}n}{\mathrm{d}\gamma}(x,\gamma) = \nabla\left[K(x,\gamma)\nabla\frac{\mathrm{d}n}{\mathrm{d}\gamma}(x,\gamma)\right] + \frac{\partial}{\partial\gamma}\left[b(x,\gamma)\frac{\mathrm{d}n}{\mathrm{d}\gamma}(x,\gamma)\right] + Q(x,\gamma)$$

- $e^{\pm}$ - photon
  - Inverse Compton
  - Synchrotron
- $e^{\pm}$ - thermal electron
  - Coulomb collisions
  - Bremsstrahlung
- $e^{\pm}$ - atom/ion
  - Coulomb collisions
  - Bremsstrahlung
  - Ionization



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Diffusion

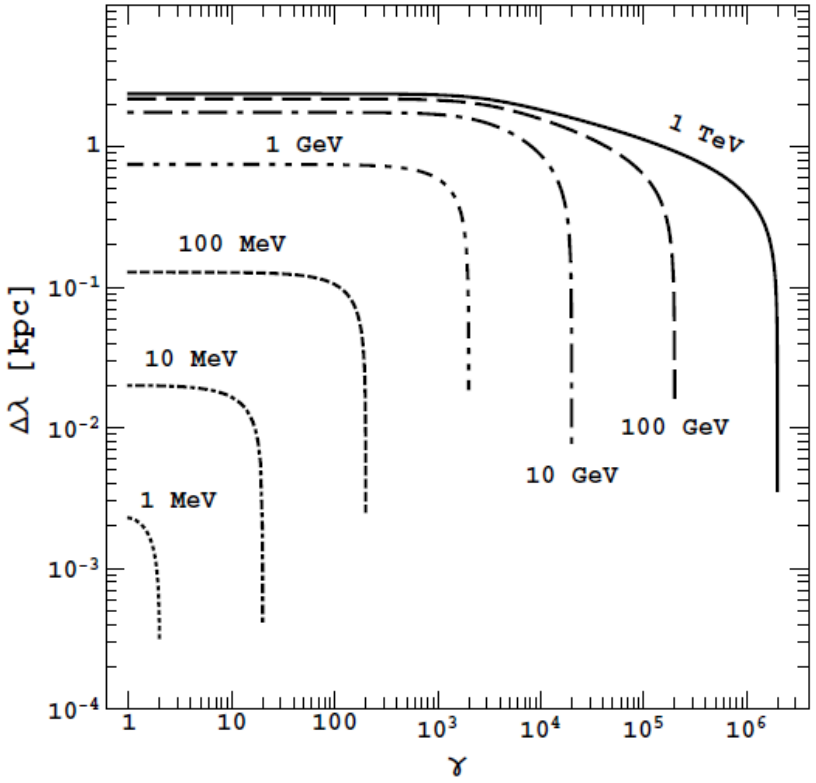
$$\frac{\partial}{\partial t}\frac{dn}{d\gamma}(x,\gamma) = \nabla\left[K(x,\gamma)\nabla\frac{dn}{d\gamma}(x,\gamma)\right] + \frac{\partial}{\partial\gamma}\left[b(x,\gamma)\frac{dn}{d\gamma}(x,\gamma)\right] + Q(x,\gamma)$$

We use a constant diffusion coefficient from median model in Donato et al. 2004

$$K(\gamma) = K_0\gamma^{\delta}$$

$$K_0 = 1.67\times10^{25}\ \mathrm{cm^2 s^{-1}}, \quad \delta = 0.7$$

$$\lambda^2(\gamma) = \int_{\gamma}^{\infty}\frac{2K(\gamma)}{b(\gamma)}d\gamma$$ diffusion length



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Model of $e^{\pm}$ Propagation

Steady-State

$$0 = \nabla\left[K(x,\gamma)\nabla\frac{\mathrm{d}n}{\mathrm{d}\gamma}(x,\gamma)\right] + \frac{\partial}{\partial\gamma}\left[b(x,\gamma)\frac{\mathrm{d}n}{\mathrm{d}\gamma}(x,\gamma)\right] + Q(x,\gamma)$$

$e^{\pm}$ Spectrum

$$\frac{\mathrm{d}n}{\mathrm{d}\gamma}(r,\gamma) = \frac{1}{b(\gamma)}\frac{\exp\left(-\frac{r^2}{2\Delta\lambda^2}\right)}{(2\pi r^2\Delta\lambda^2)^2} \times\int_{\gamma}^{\infty} d\gamma_s\int_{0}^{\infty} dr_s \exp\left(-\frac{r_s^2}{2\Delta\lambda^2}\right) \times\left[\exp\left(\frac{rr_s}{\Delta\lambda^2}\right)-\exp\left(-\frac{rr_s}{\Delta\lambda^2}\right)\right]Q(x_s,\gamma_s)$$

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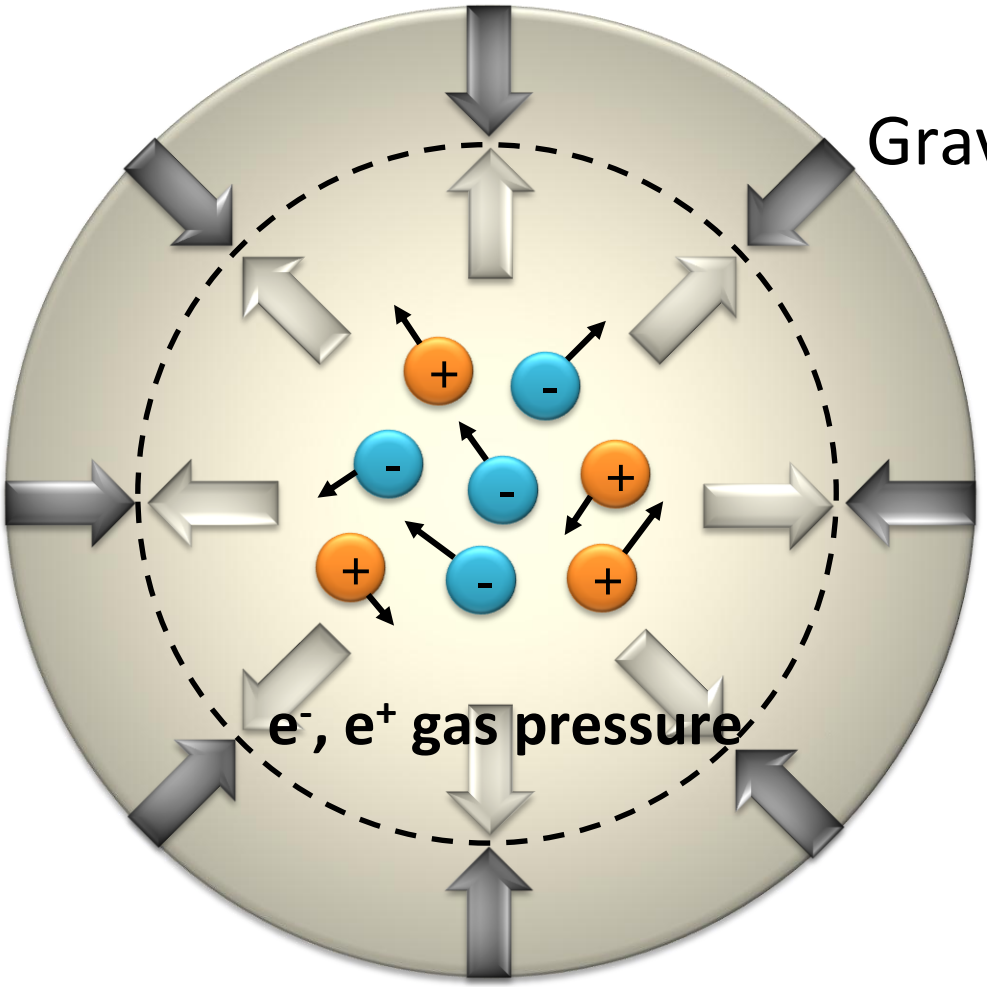
DM Pressure ≡ Pressure of $e^{\pm}$ gas from DM annihilation



AIP

Dark Matter Pressure $\propto$ $e^{\pm}$ spectrum

$$P_{\mathrm{dm}}(r) = \frac{m_e c^2}{3} \int_1^{\infty} \frac{\mathrm{d}n}{\mathrm{d}\gamma}(r,\gamma) \left(\frac{\gamma^2 - 1}{\gamma} \right) \mathrm{d}\gamma$$

Model Parameters

Galactic properties (energy losses)

- Gas density: ρ_g
- Ionization fraction: X_{ion}
- Magnetic fields: B

DM properties (Source term)

- Dark matter density profile: ρ_{dm}
- Cross-sectiom: $\langle\sigma v\rangle$, Q_0
- DM Mass : $E_0 = m_{dm}\, c^2$

Canonical Model

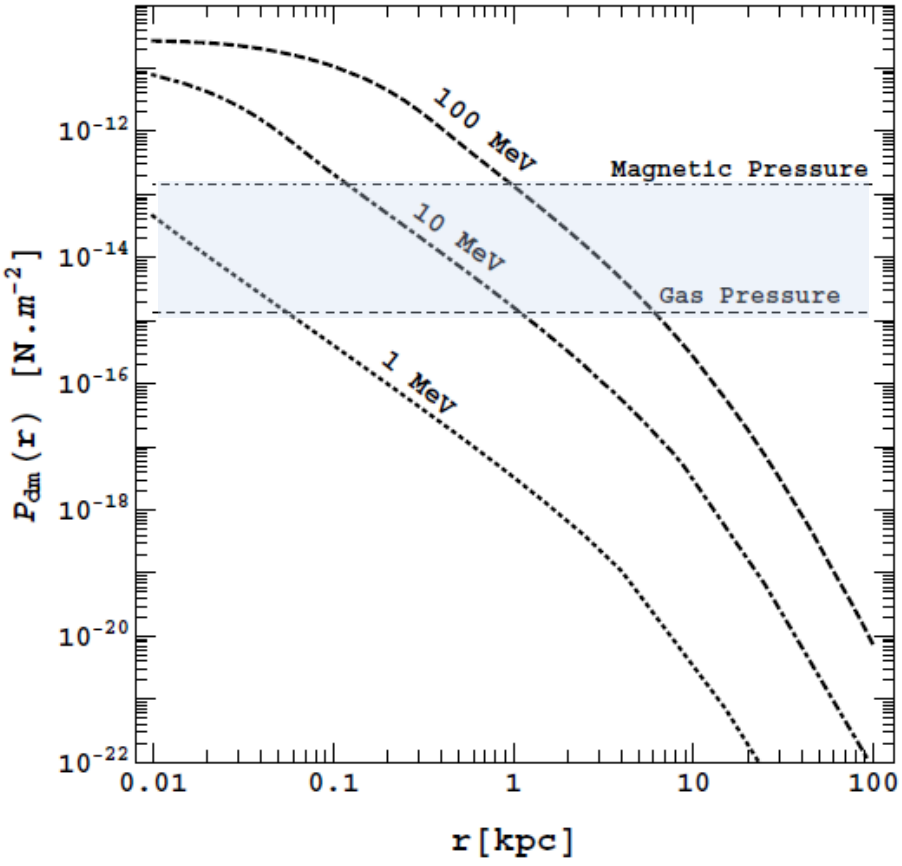
- $1\ cm^{-3}$ (ref 1.)
- 0 (ref 1.)
- $6\ \mu G$ (ref 2.)
- NFW (ref 3.)
- Constraint by Integral, Fermi and HESS

1. Dehnen & Binney 1998, Ferrière 2001, Robin et al. 2003
2. Ferrière 2001, Beck 2001, Ascasibar & Díaz 2010
3. Dehnen & Binney 1998, Klypin et al. 2002

Dark Matter Pressure

as a function of

- DM particles (m_{dm}, Q_0)
- Magnetic fields
- Gas density
- Ionization fraction
- Dark matter density profile



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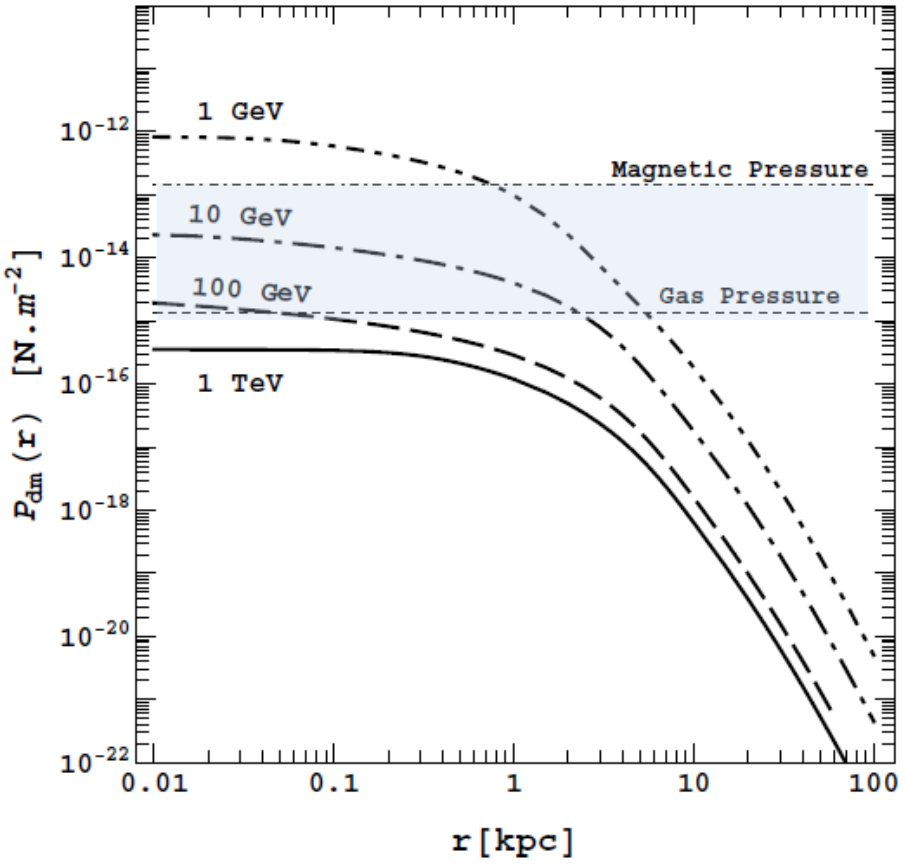

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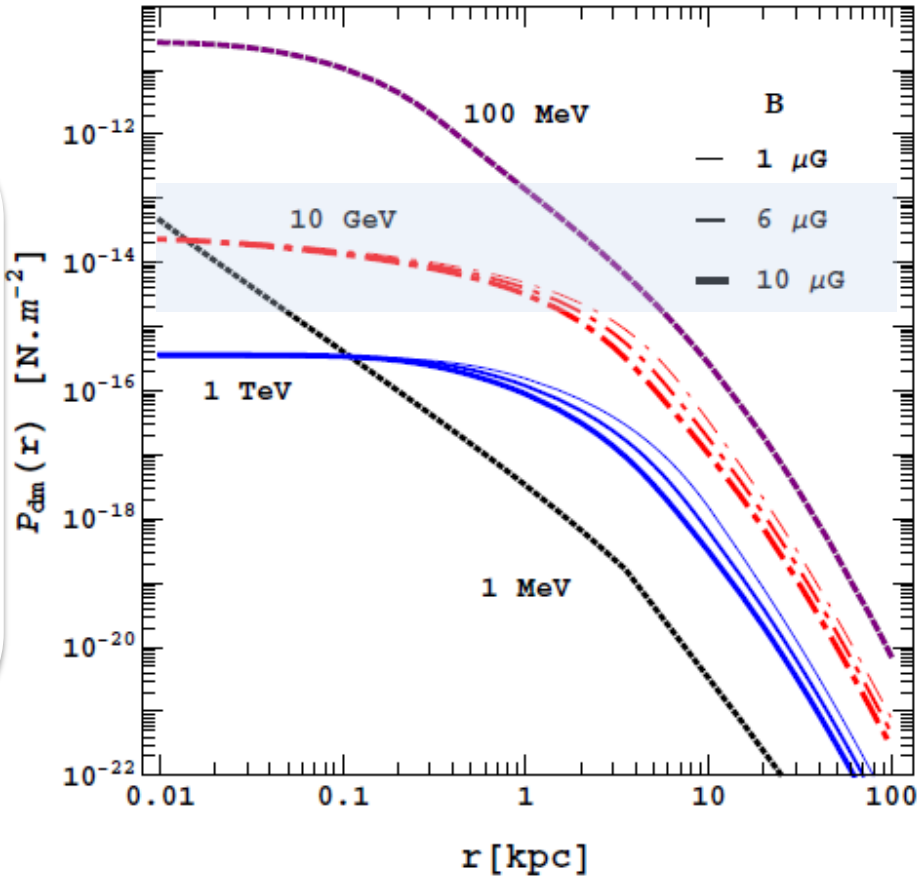

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Dark Matter Pressure

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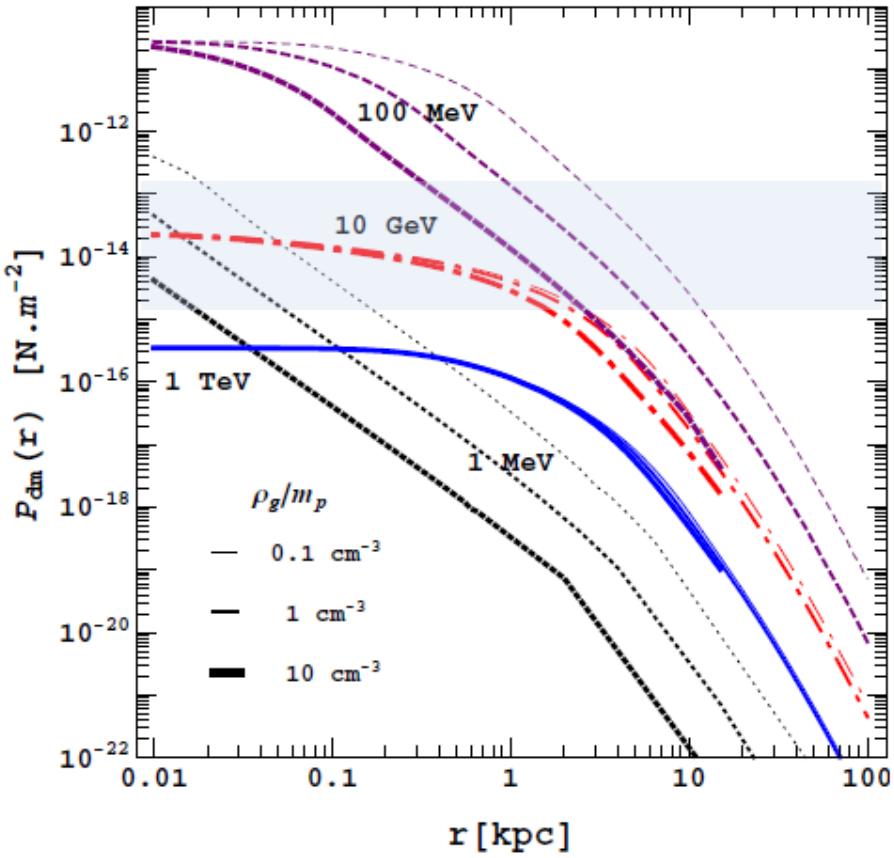

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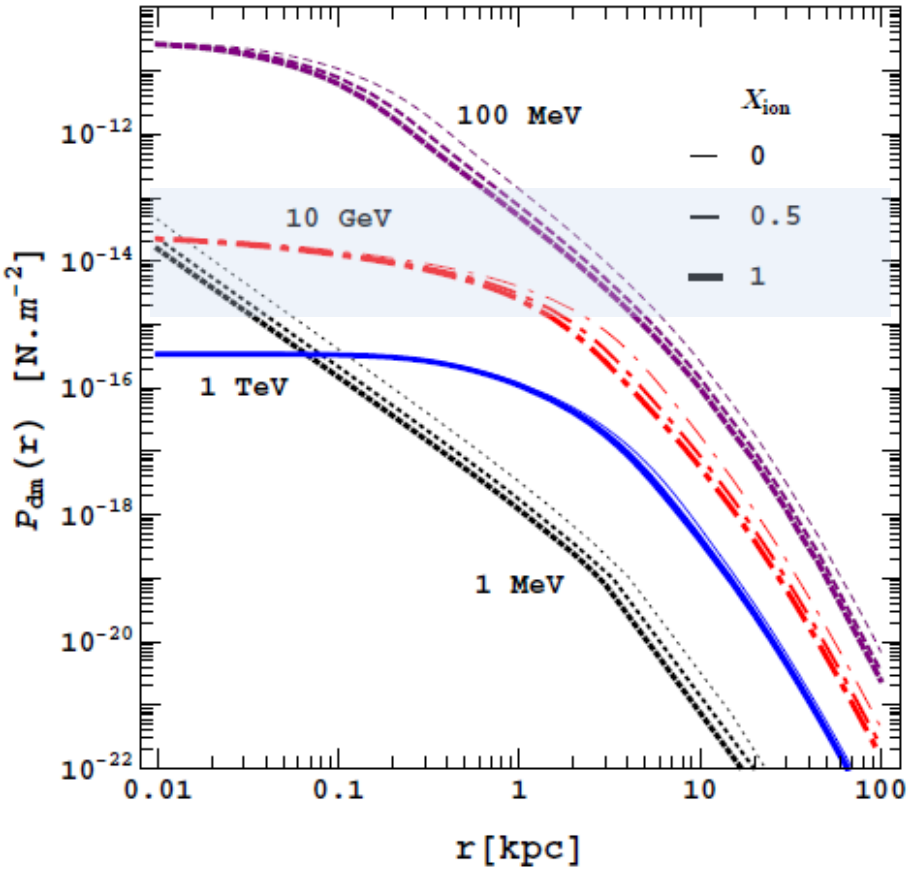

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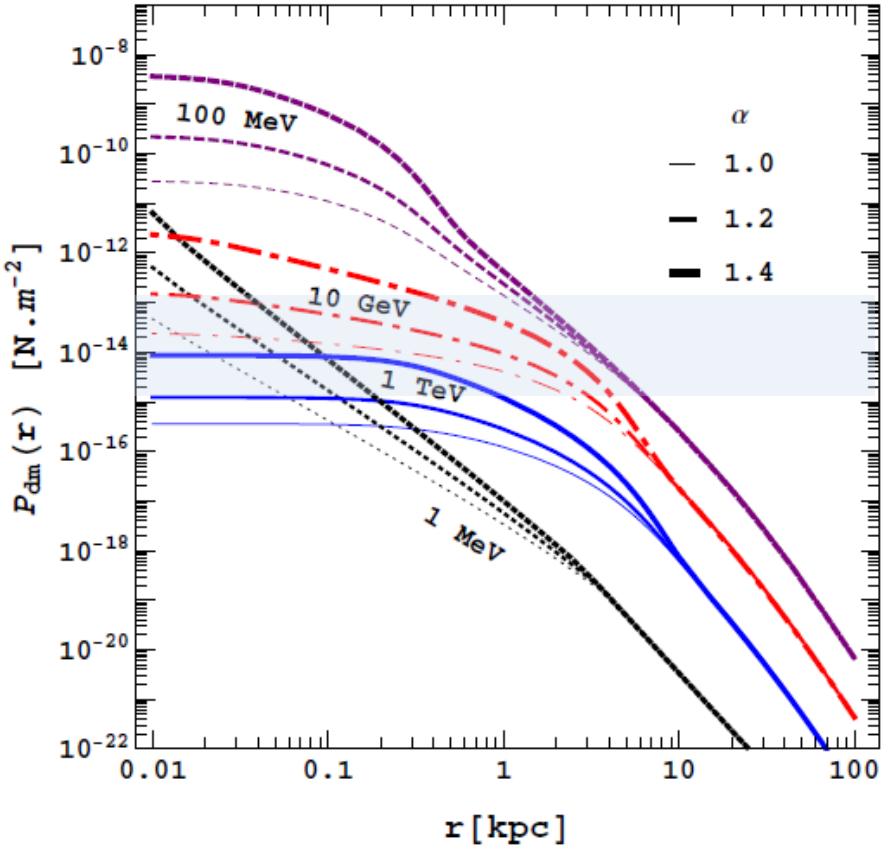

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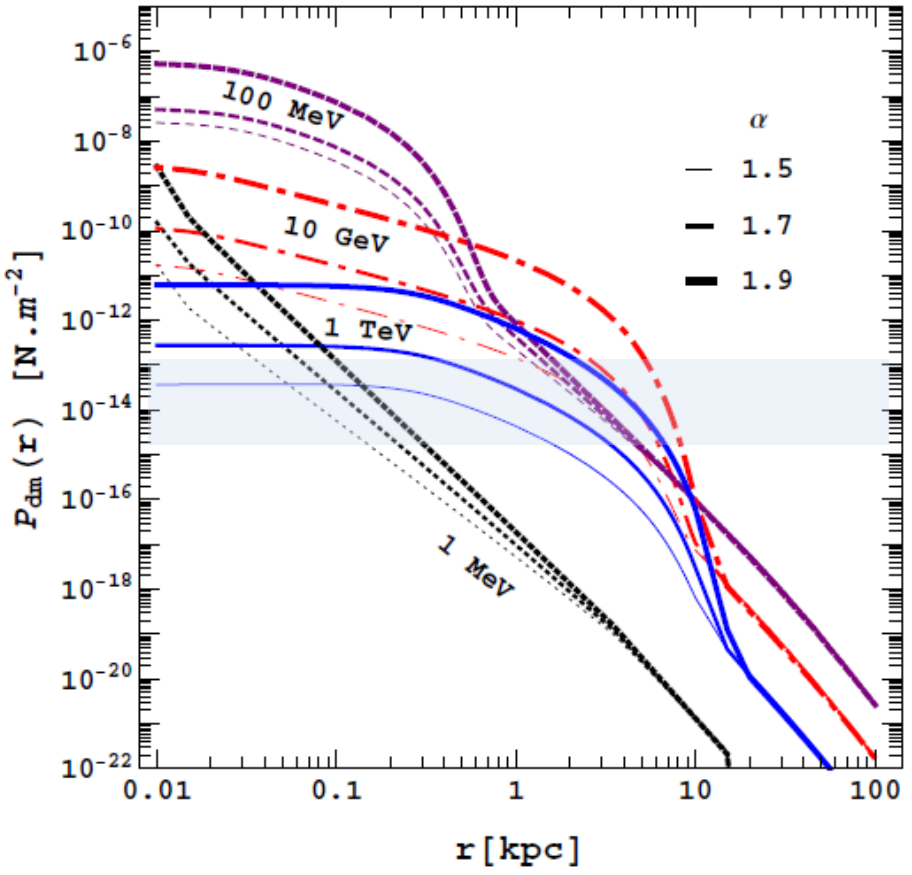

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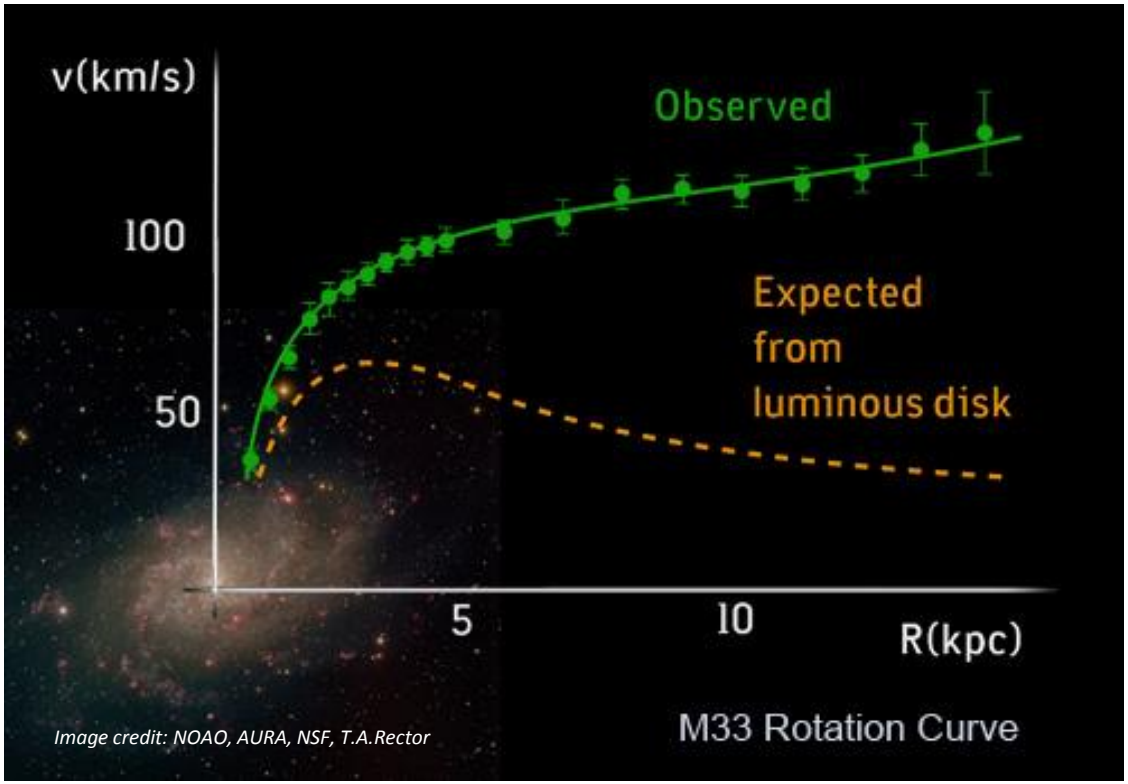
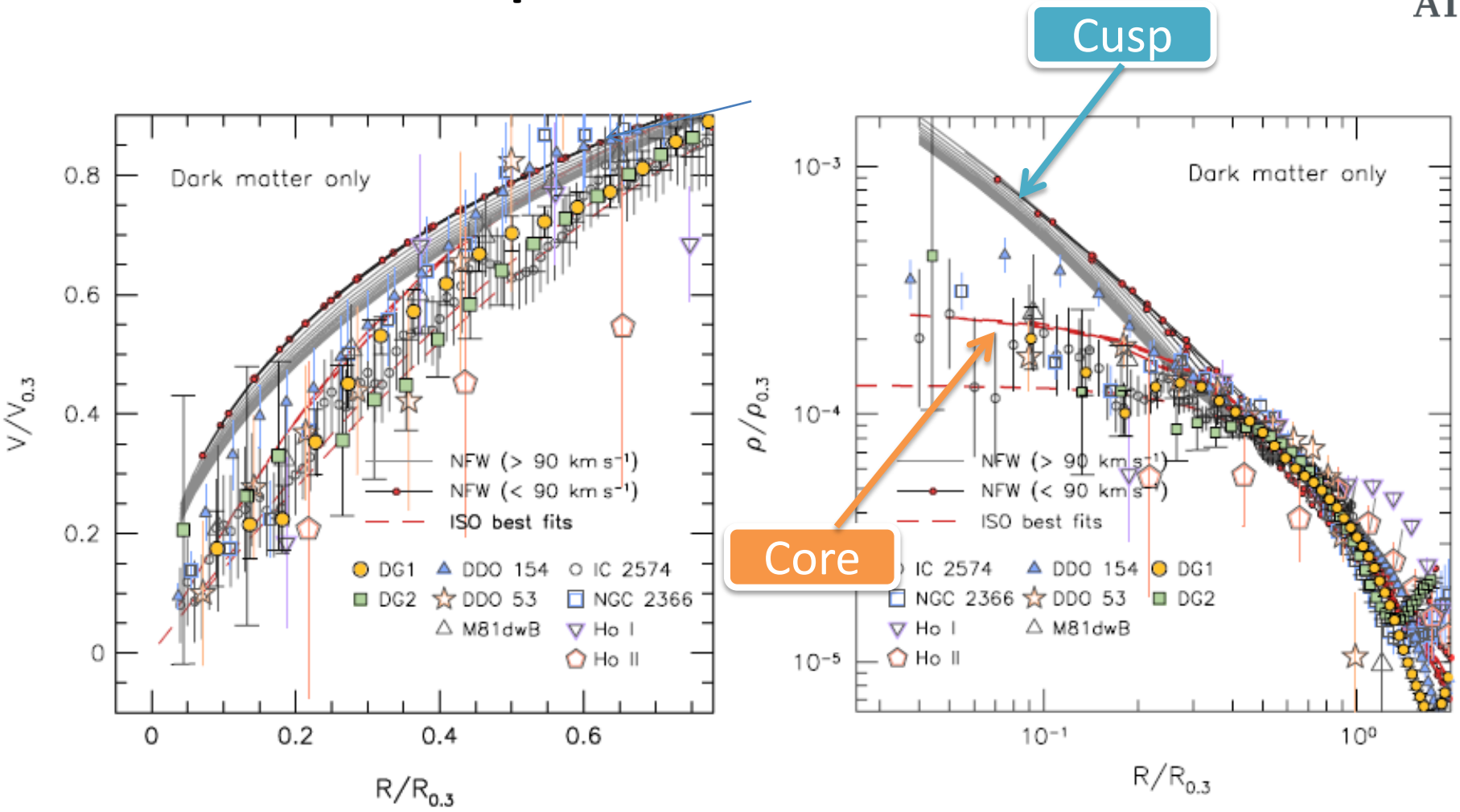
Rotation Curve of Galaxies



$$\frac{v_{rot}^2(r)}{r} = g_{star}(r) + g_{gas}(r) + g_{dm}(r)$$

Cusp-Core Problem



Oh et al. (2011)

Pressure Support

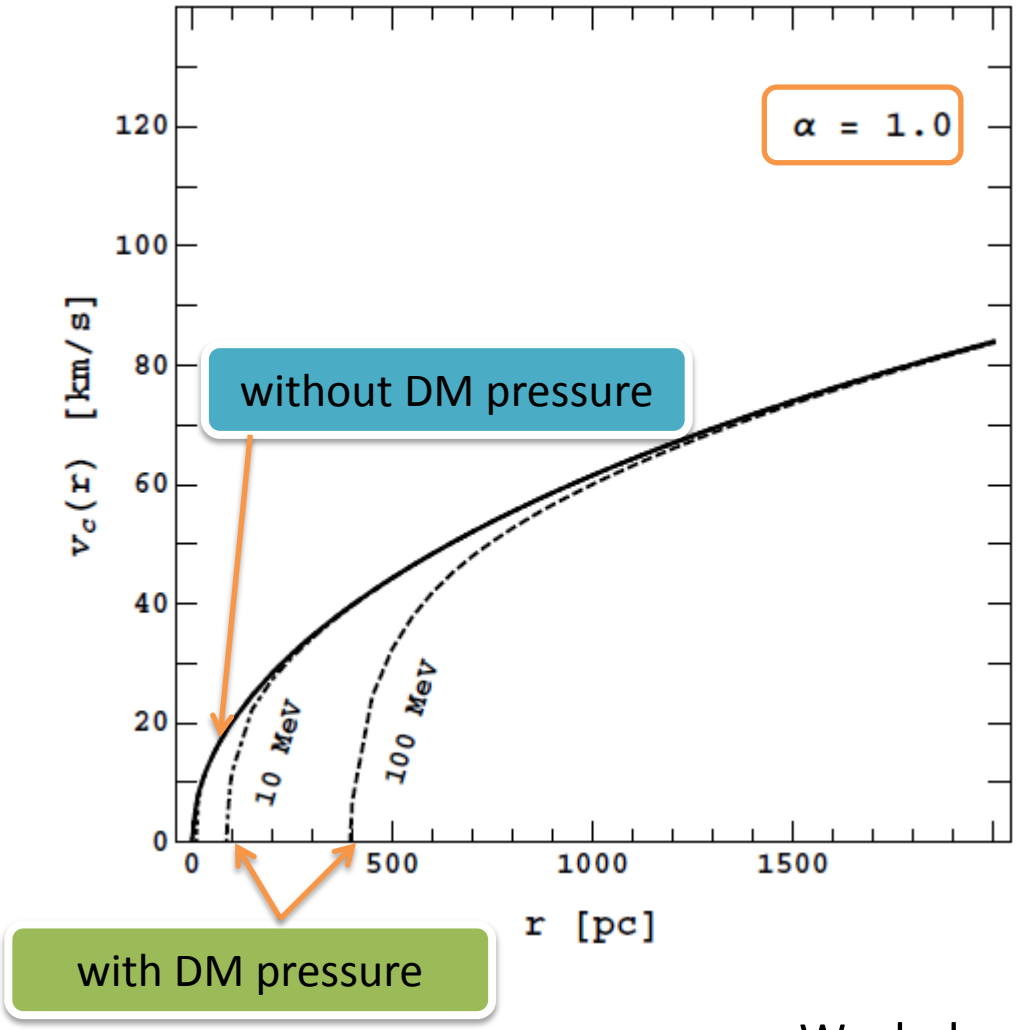
- Pressure

$$P_{\mathrm{dm}}(r) = \frac{m_{\mathrm{e}} c^2}{3} \int_1^{\infty} \frac{\mathrm{d}n}{\mathrm{d}\gamma}(r,\gamma) \left(\frac{\gamma^2 - 1}{\gamma} \right) \mathrm{d}\gamma$$

- Circular velocity + DM pressure gradient

$$v_{rot}(r) = \sqrt{r g_*(r) + r g_{gas}(r) + \frac{G M_{dm}(r)}{r} + \frac{r}{\rho_{\mathrm{g}}(r)} \frac{\mathrm{d}P_{dm}(r)}{\mathrm{d}r}}$$

Canonical Milky Way Model



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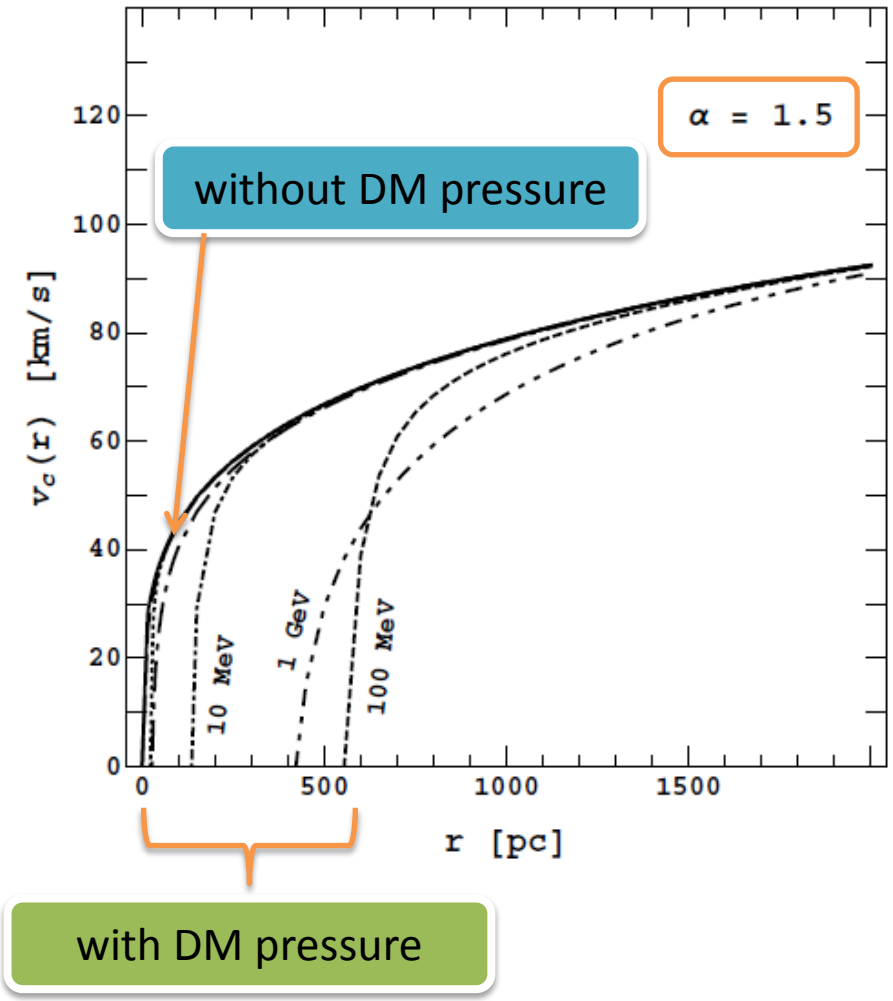

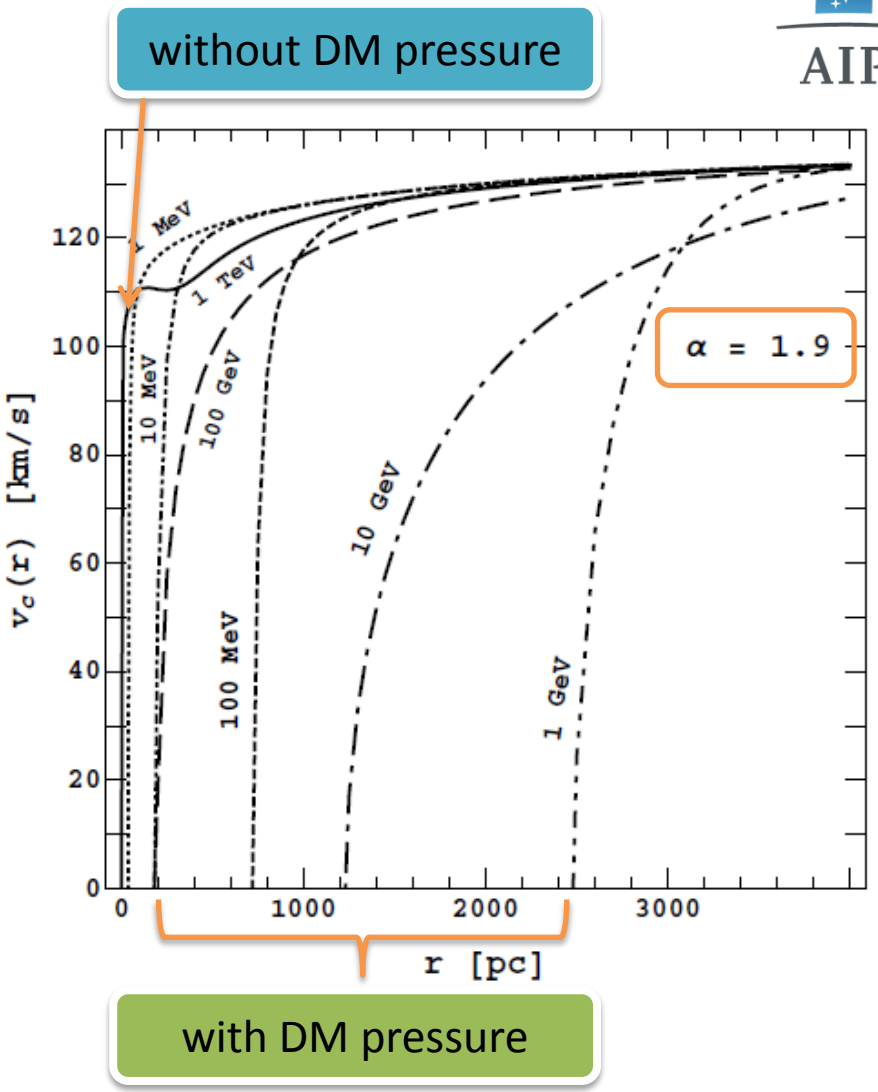

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Conclusion

DM pressure and rotation curves

- Effect on $\sim$ kpc scales
- Significant if
  - $\alpha \geq 1.5$
  - $m_{\mathrm{dm}} \leq 1$ GeV and $\alpha \sim 1$
- Implications for the cusp-core problem
- Probably, this effect is useful as a constraint on the annihilation cross-section

Thank You!!