Two observables for indirect DM searches

Fabio Iocco
fabio.iocco .AT. iap.fr
Marie Curie fellow at
Institut d'Astrophysique de Paris

LAPTH-28/10/2010
Annecy-le-Vieux

Chapter I:

Annihilating DM and CMB

Fabio Iocco
MC fellow at IAP

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Isotropically averaged cosmological DM annihilation

Smooth component

$$A^{\mathrm{sm}}(z) = \frac{\langle \sigma v \rangle}{2\, m_\chi^2} \rho_{\mathrm{DM},0}^2 (1+z)^6$$

Structure component

$$A^{\mathrm{struct}}(z) = \frac{\langle \sigma v \rangle}{2\, m_\chi^2} \int \int dM \frac{dn}{dM}(z, M) (1+z)^3 4\pi r^2 \rho_i^2(r, M(z)) dr$$

Structure formation history
(Press-Schechter / Sheth-Tormen)

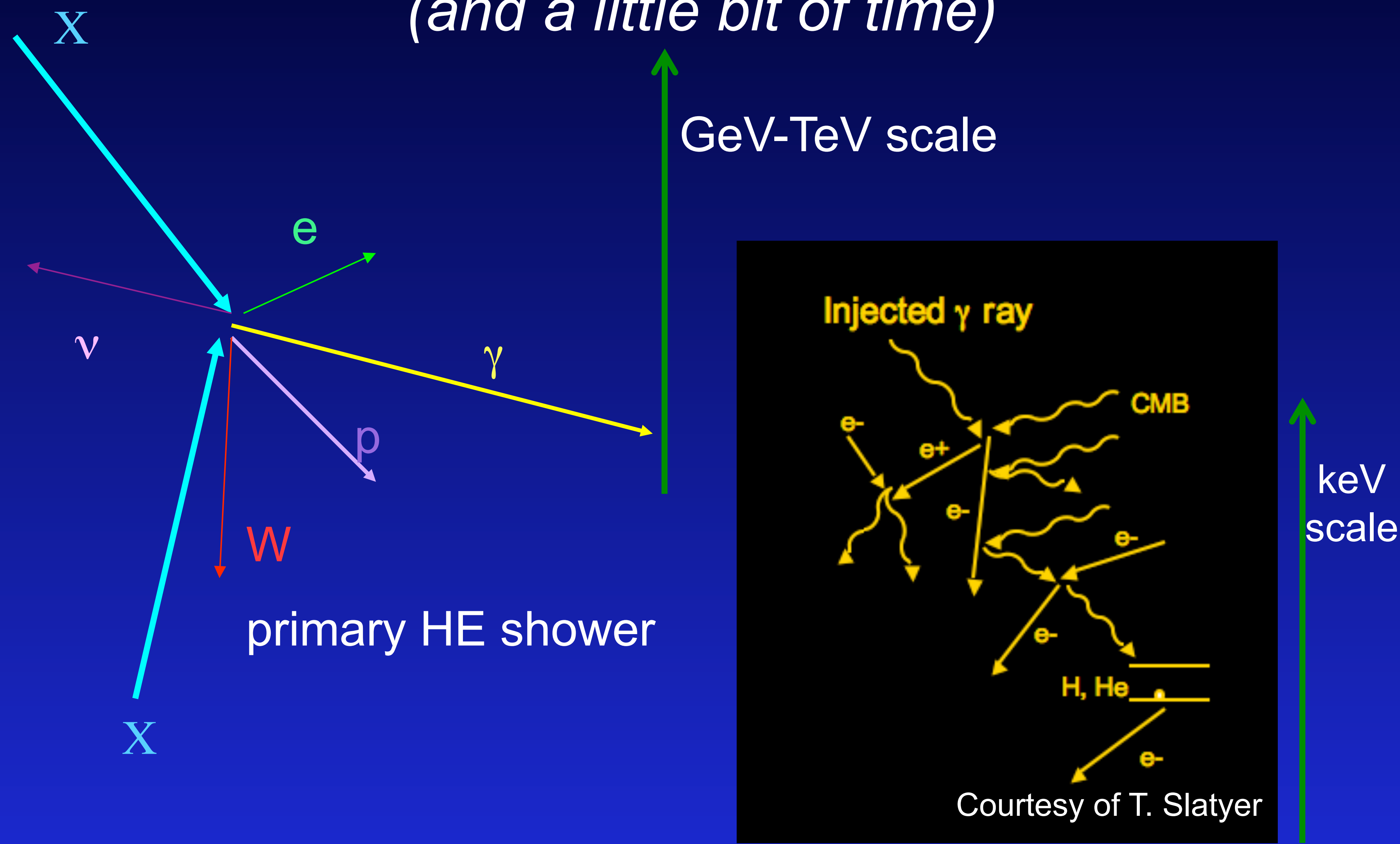
DM density halo profile
Burkert / Einasto / NFW

$$A(z) = \frac{\langle \sigma v \rangle}{2\, m_\chi^2} \rho_{\mathrm{DM},0}^2 (1+z)^6 \left(1 + \mathcal{B}_{\mathrm{M}}(z)\right)$$

Only after structure formation $z \leq \approx 100$

DM annihilation and the *IGM*

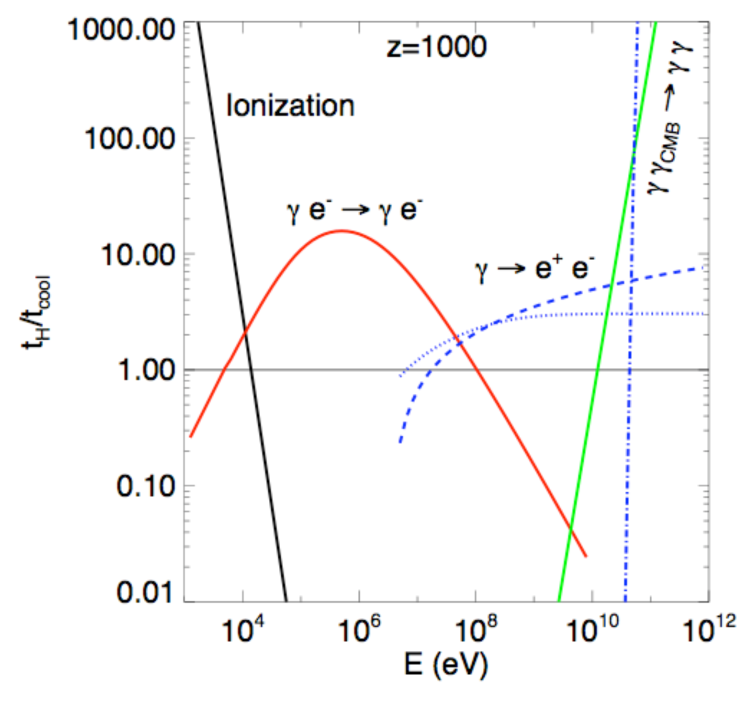
(and a little bit of time)

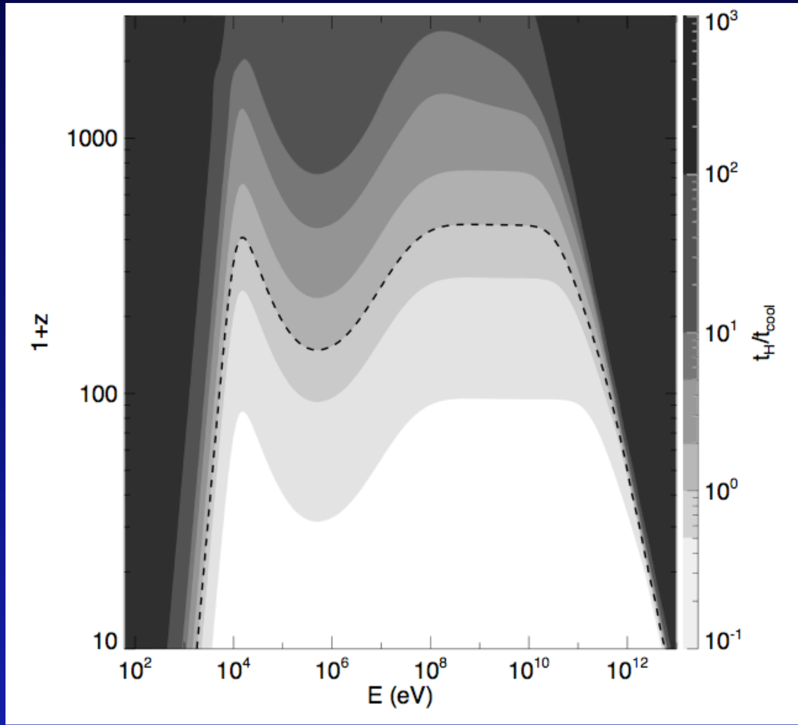


heating and ionization

The IGM opacity

(absorbing the energy – or not)





Photoionization, IC scattering, pair production (on CMB γ and matter), $\gamma\gamma$ scattering

"Opacity window" of the Universe

absorption is DM model-dependent: type of secondaries is important!

[Slatyer et al. `09]

Electron optical depth τ

$$\tau = -\int n_e(z)\,\sigma_{\mathrm{T}}\,\frac{dt}{dz}$$

Integrated quantity

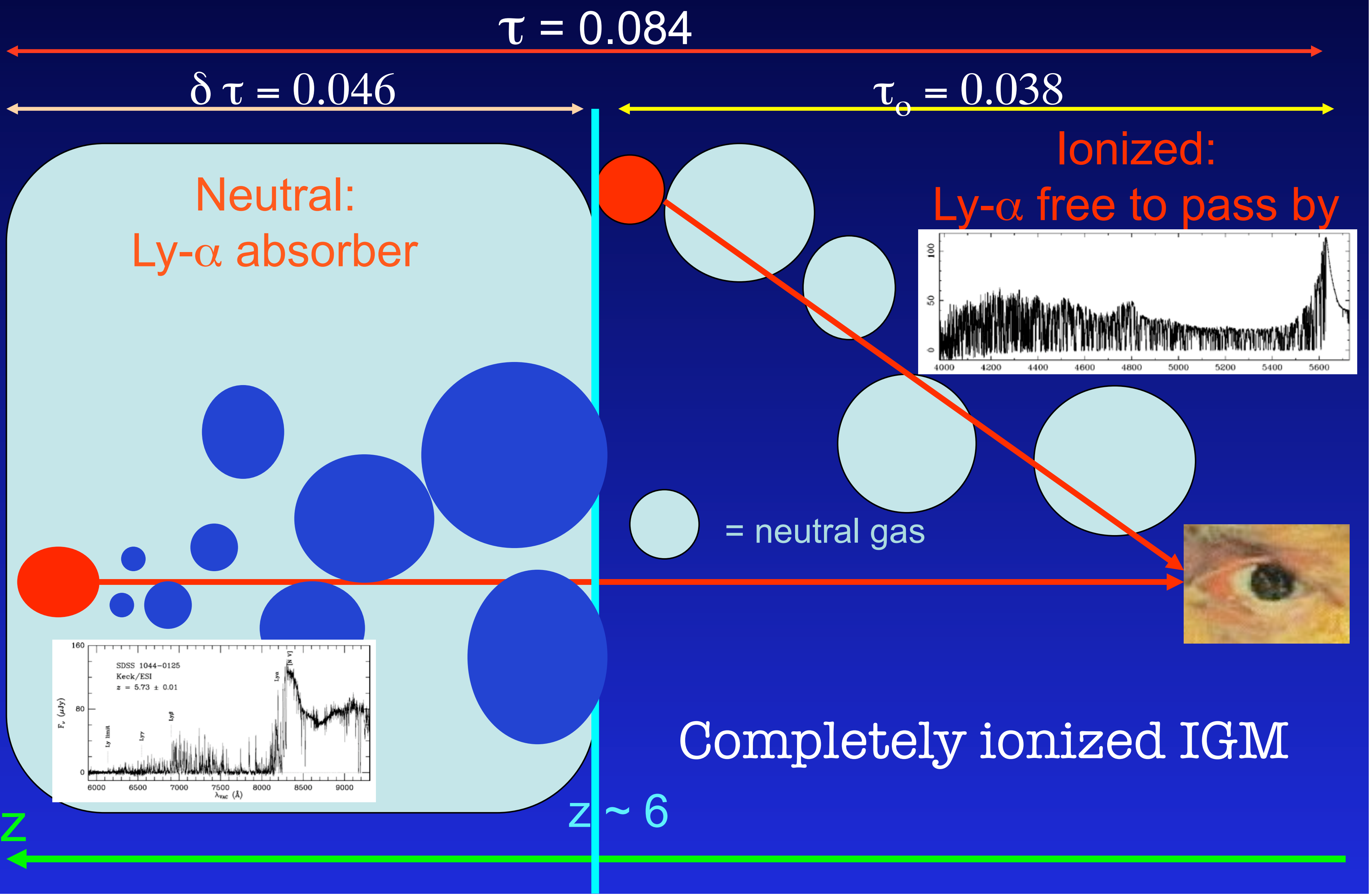
$$\tau = \underbrace{n_{\mathrm{A}}\,\sigma_{\mathrm{T}}\left[-\frac{0.88}{0.82}\int_0^3 dz\frac{dt}{dz}(1+z)^3 - \int_3^6 dz\frac{dt}{dz}(1+z)^3\right]}_{0.038} +$$

Known contribution

Sources z > 6: known unknowns

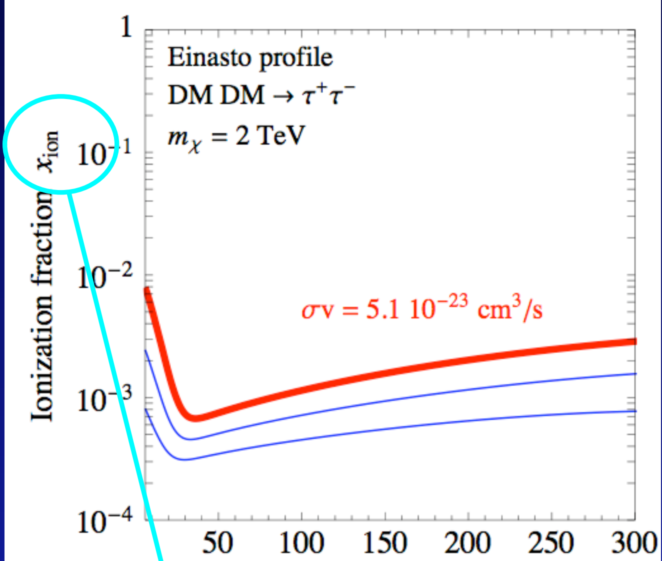
$$\underbrace{n_{\mathrm{A}}\,\sigma_{\mathrm{T}}\left[-\int_6^\infty dz\frac{dt}{dz}(1+z)^3 x_{\mathrm{ion}}(z)\right]}_{\delta\tau}$$

Summarizing “Reionization”



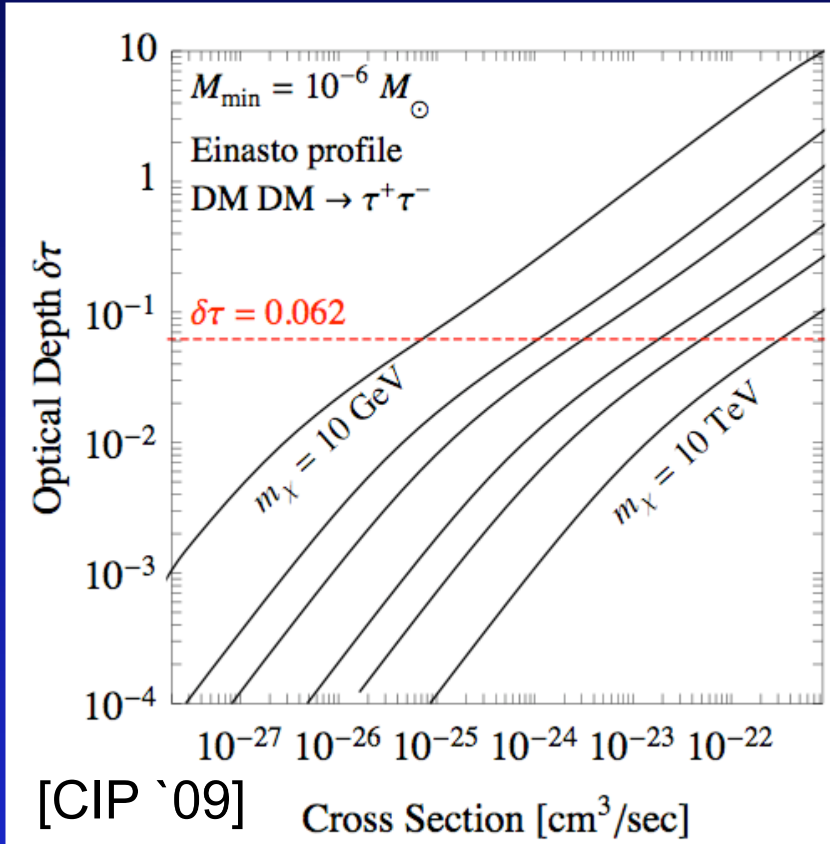
τ constraints

(DM annihilations <u>can</u> overproduce free e⁻)



[CIP `09]

To be integrated!



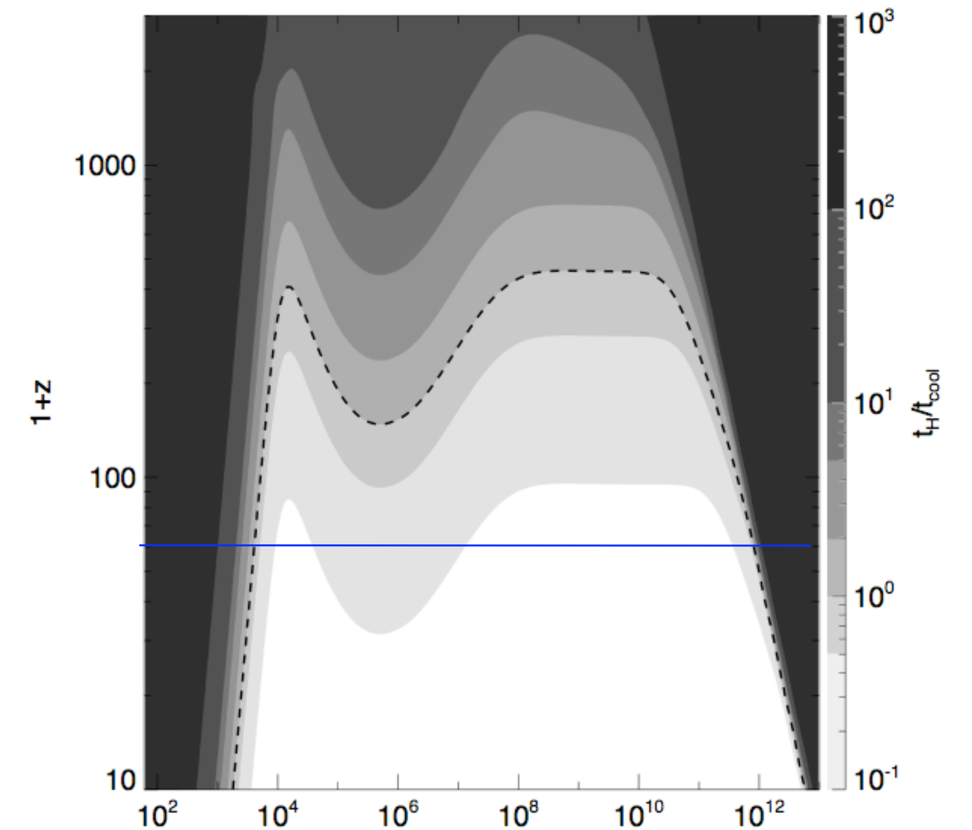
[CIP `09]

In this models:

no astrophysical sources (z > 6)

Extra-conservative bounds!

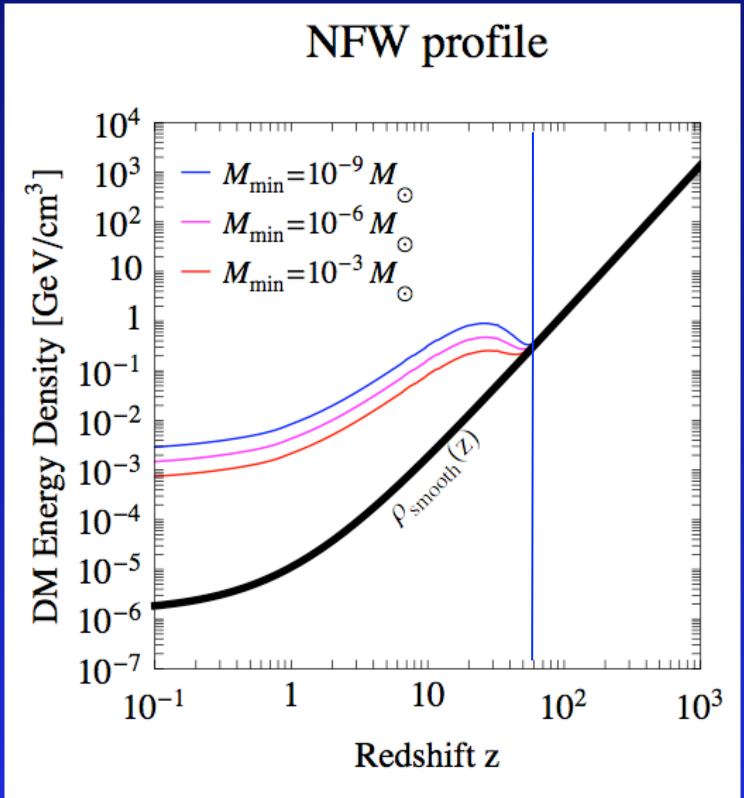
Transparency of the Universe & structure formation



[Slatyer et al.`09]

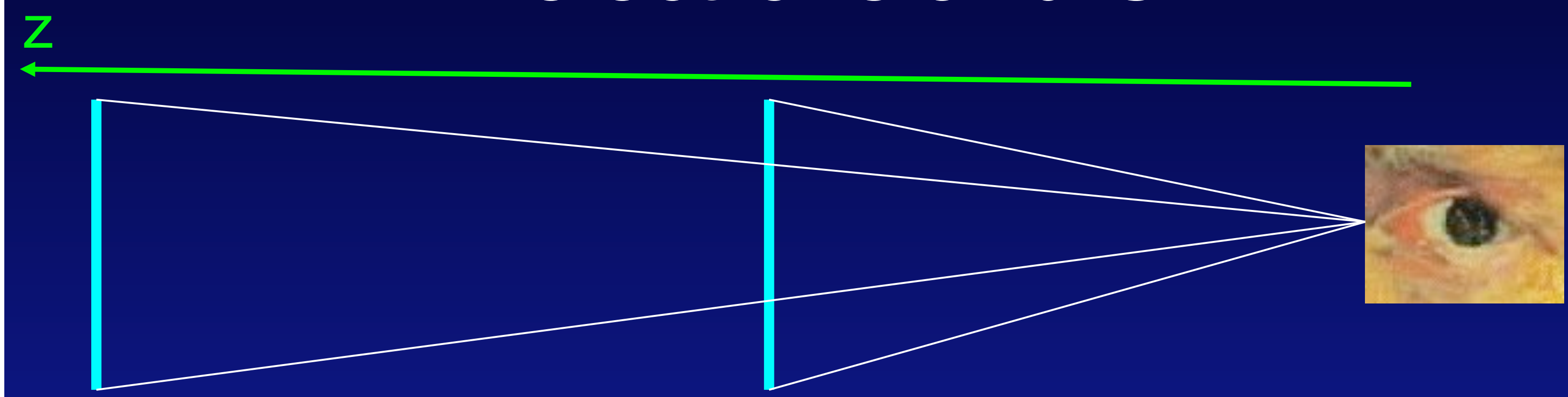
HE shower gets efficiently absorbed ***only*** at high z

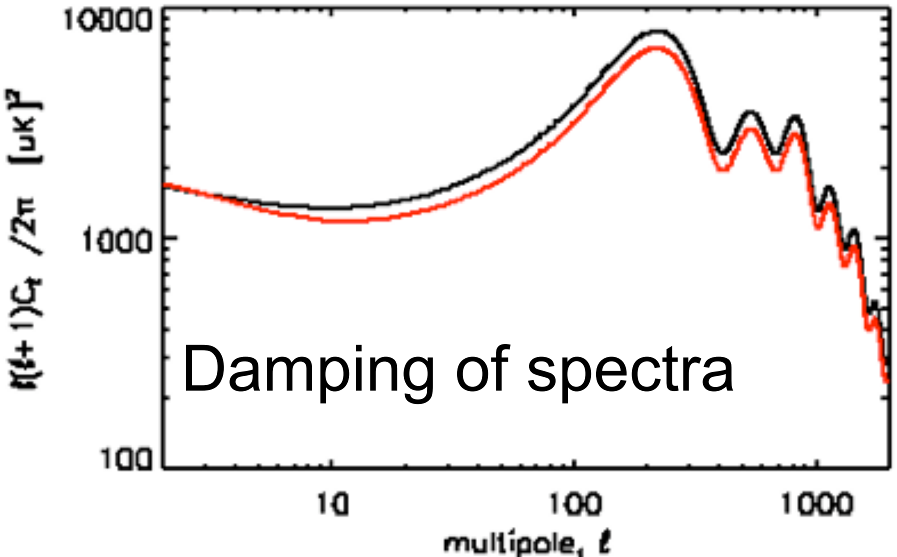
Structure formation takes place in a late Universe (z < 60)

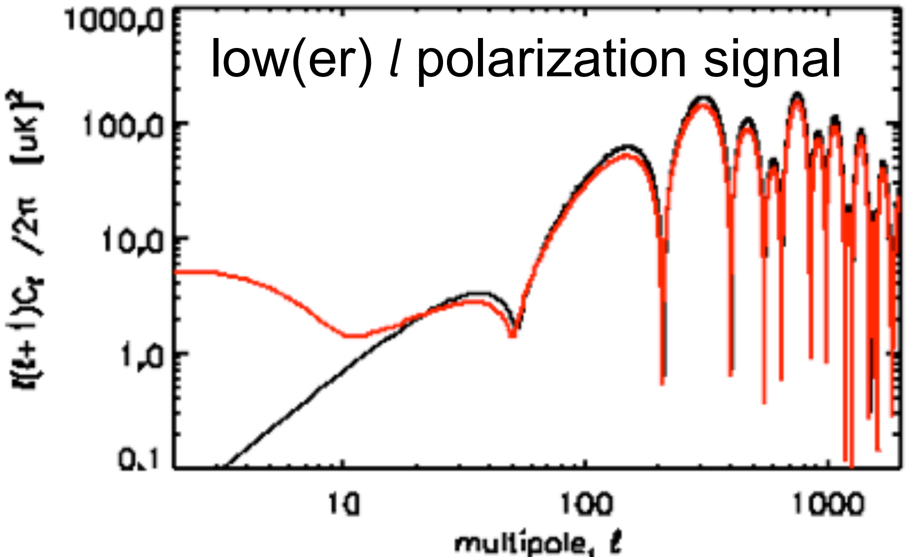


[Cirelli, FI, Panci `09]

Observing Reionization: electrons and CMB







Self-annihilating DM: on-the-spot approximation

Annihilation rate

$$\frac{dI}{dt}(z) = n_{DM}^2(z)\langle\sigma v\rangle m_\chi c^2$$

Energy deposition rate

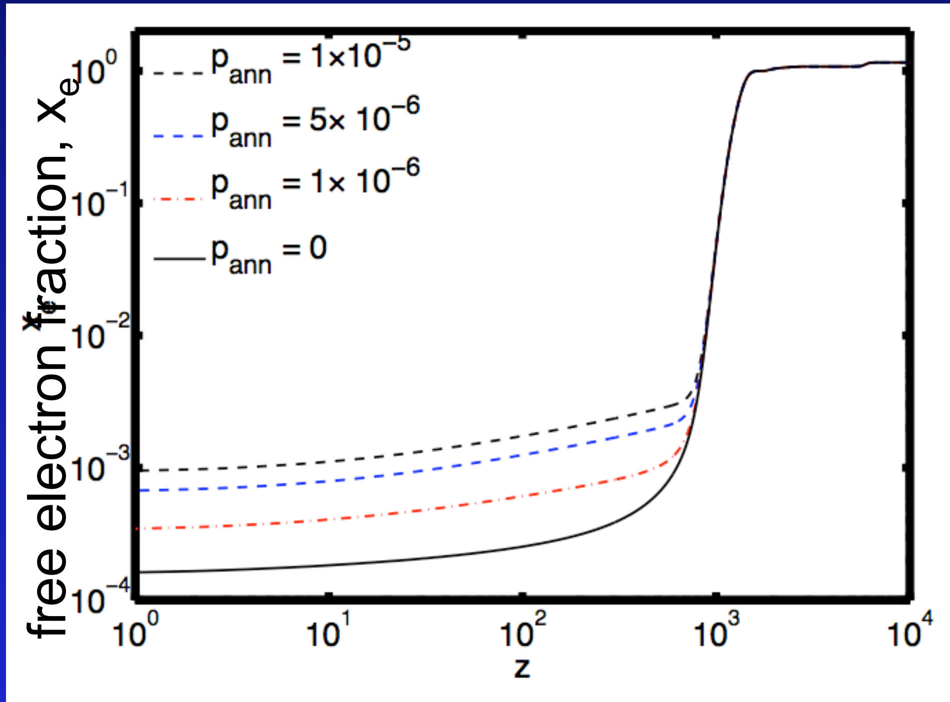
$$\frac{dE}{dt}(z) = \rho_c^2 c^2 \Omega_{DM}^2 (1+z)^6 f \frac{\langle\sigma v\rangle}{m_\chi}$$

The only DM parameter is

$$f \frac{<\sigma v>}{m_\chi} \equiv p_{ann}$$

more about " f " later

Main effect of injected energy: heating and ionization of the IGM

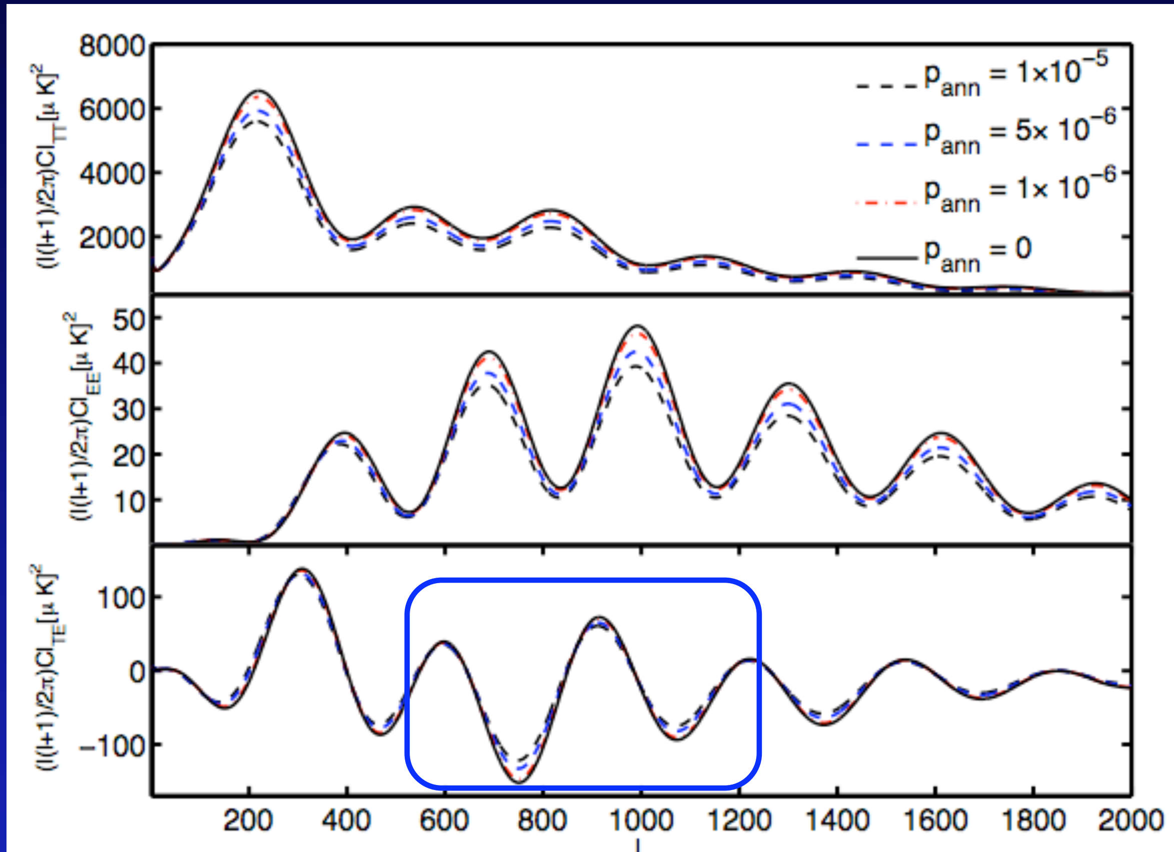


[Galli, FI, Bertone, Melchiorri `09]

Self-annihilating DM and the CMB

DM annihilation
indirect,
SZ by “additional” e^-

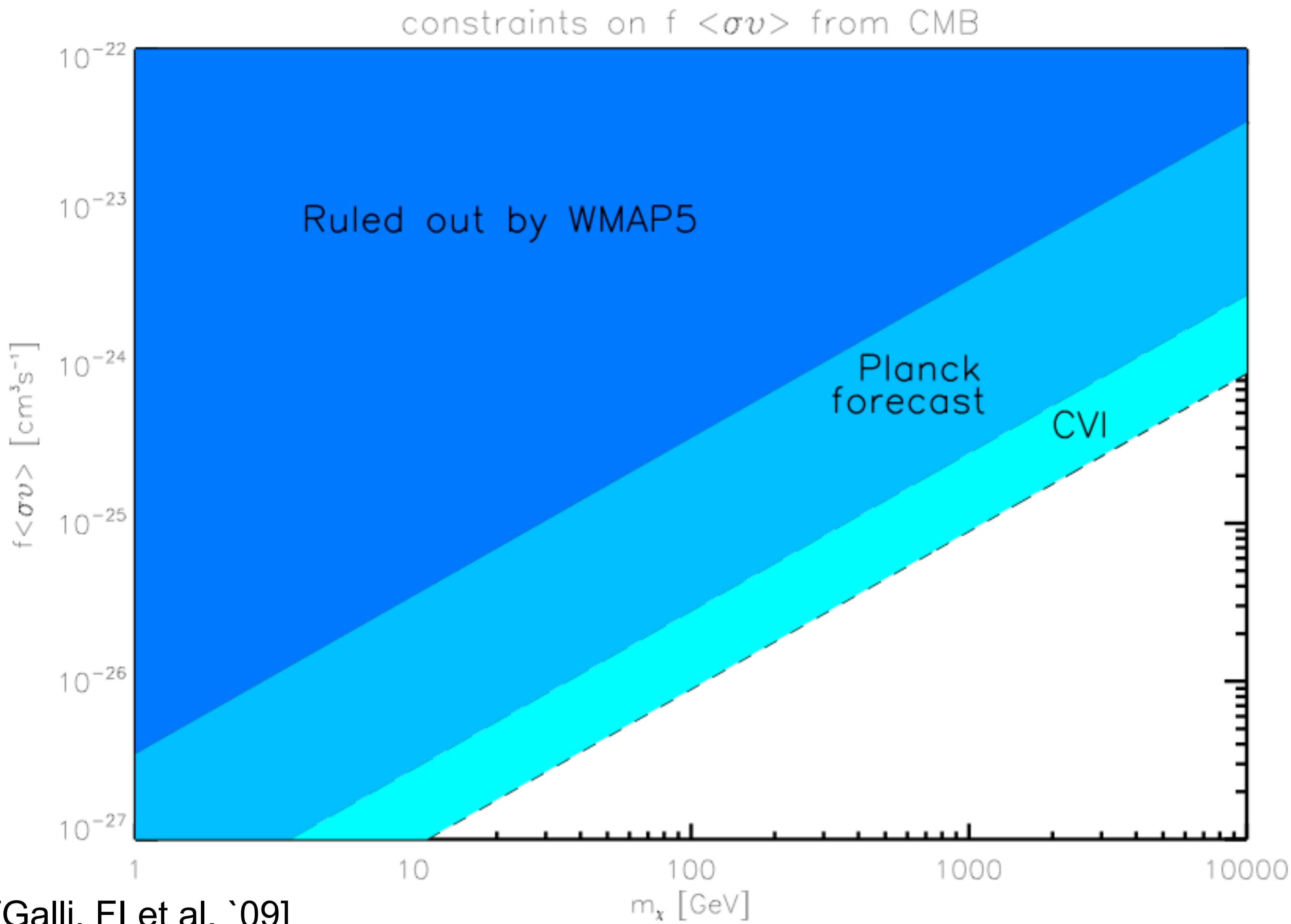
z>1000 there are many e^-
energy injection is small
no effects on CMB blackbody



Modifying TT, TE, EE with
additional e^- (by DM annih)

[Galli, Iocco, Bertone, Melchiorri `09]

Constraining DM with CMB



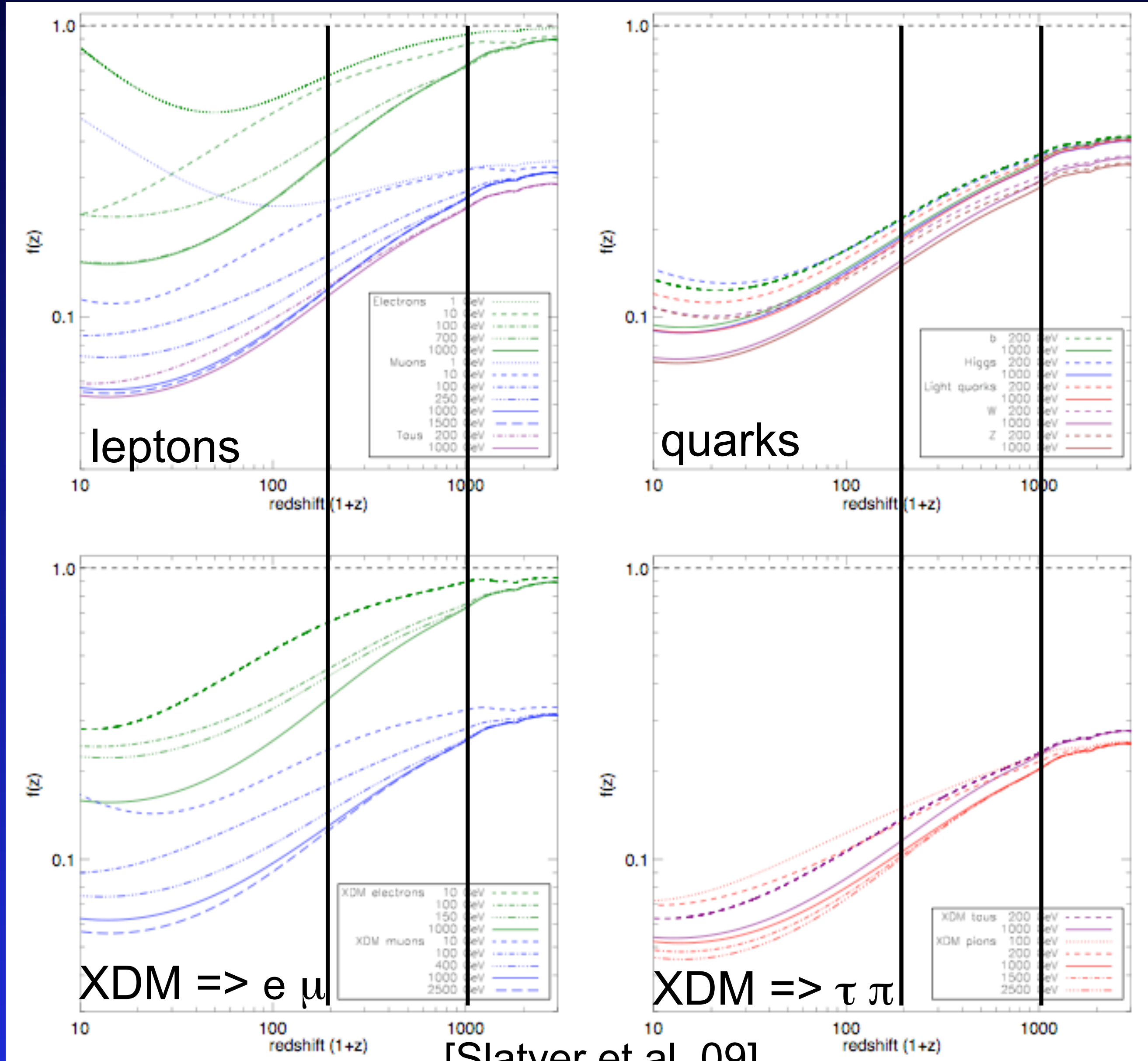
[Galli, FI et al. `09]

Evaluating “ f ”

All channels,
all secondaries,
redshift dependence

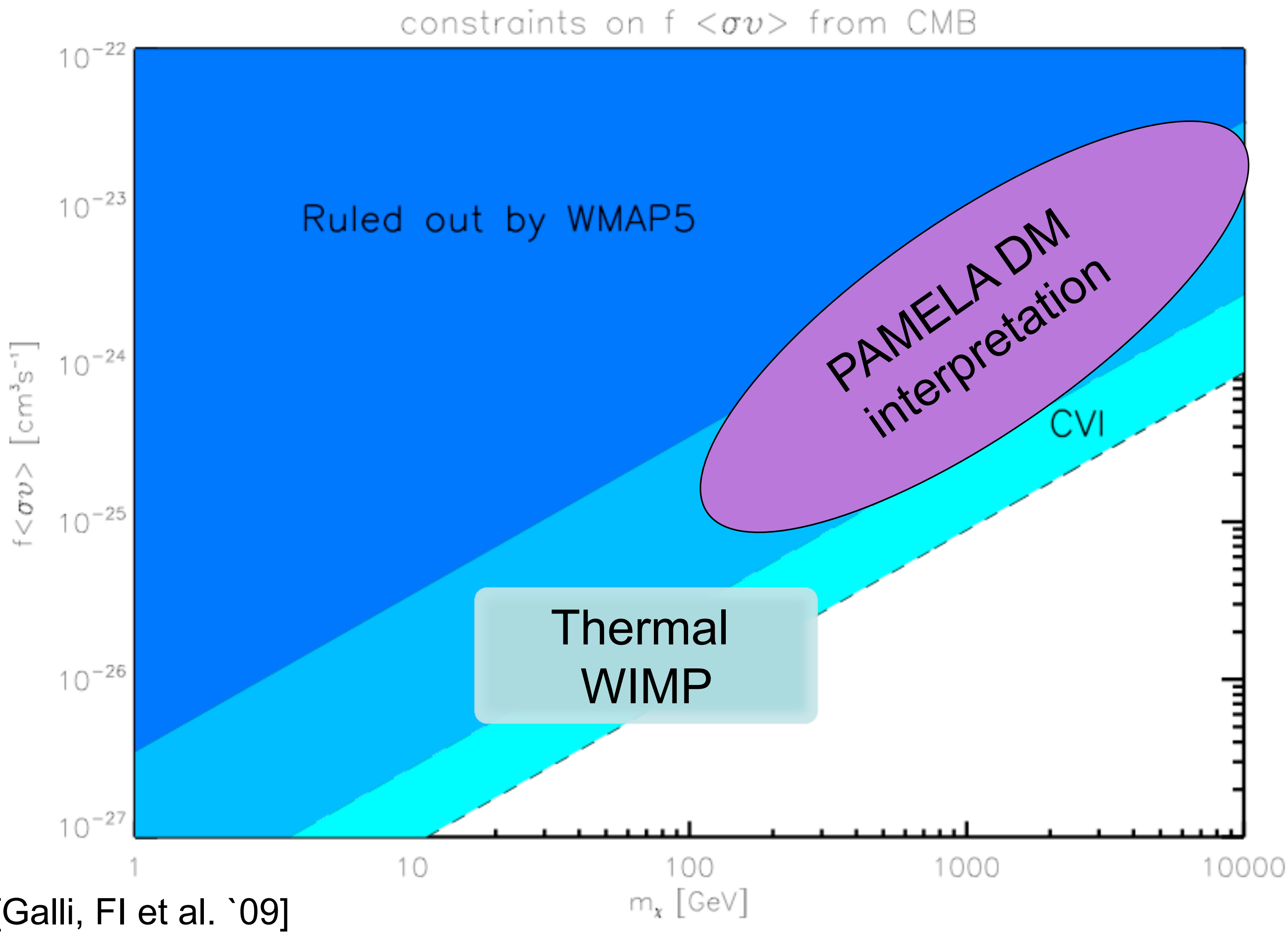
Branching ratio of DM annihilation essential for determining absorption

Little reminder:
Pamela is leptophilic
(from greek: “*likes it thin*”)



[Slatyer et al. 09]

Constraining DM with CMB



[Galli, FI et al. `09]

Concluding

Cosmological DM annihilation provides strong constraints on <sv>

Annihilation “signal” comes from smooth DM density field (can get rid of structure formation uncertainties!)

Self-annihilating DM can inject enough energy (free electrons) to sizably modify the CMB spectra

Ideal to test Sommerfeld enhancement

Own it now: your kids will love it!

Chapter II:

Thermal neutrinos from the Sun

Fabio Iocco
MC fellow at IAP

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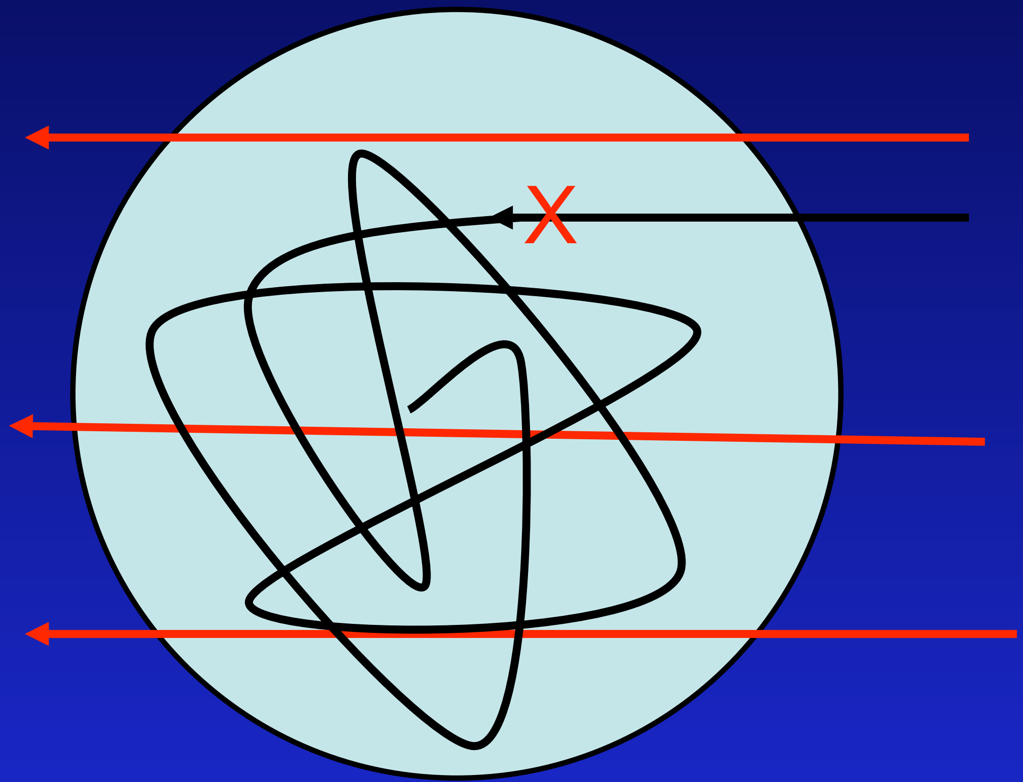
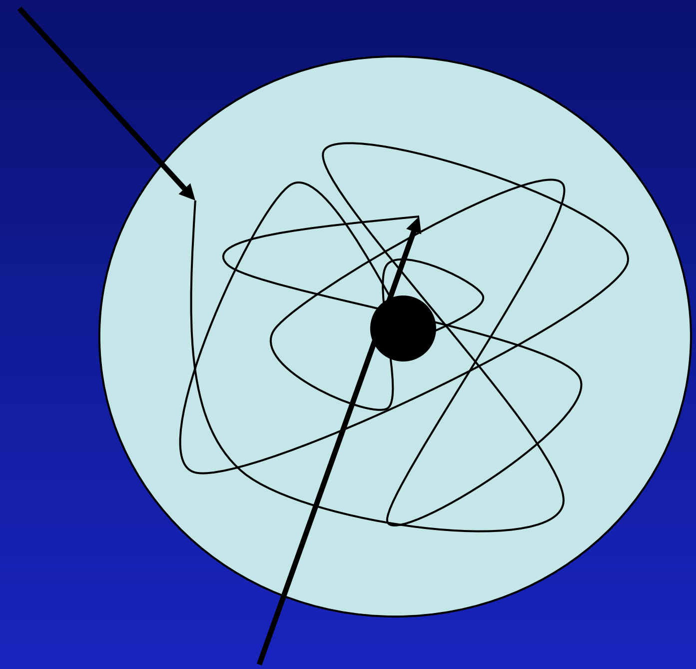
Scattering and capture

Halo WIMPs are captured



by scattering off the gas of the star

Captured WIMPs accumulate inside the star, thermalize



and "sink" to the center

DM Capture

(for the “vanilla” WIMP)

$$\dot{N}_\chi = C - 2AN_\chi^2 - EN_\chi$$

Capture rate C

$$C \propto \frac{\boxed{\sigma_0 \rho}}{\bar{v}} \frac{M_*^2}{R_*} \frac{1}{m_\chi}$$

WIMPs thermally relaxed within the star:
Distribution

$$n_\chi(R) = n_\chi^c \exp(-R^2/R_\chi^2)$$

WIMP resilience volume
≈ point-source
$R_\chi \approx 10^9$cm<<R_c

Equilibrium timescales are short

$$\tau_{\rm th} = \frac{4\pi}{3\sqrt{2G}} \frac{m_\chi}{\sigma_0} \frac{R_*^{7/2}}{M_*^{3/2}}$$

$$\tau_\chi = \left(\frac{\pi^{3/2} R_\chi^3}{C \langle \sigma v \rangle} \right)^{1/2}$$

“Dark Luminosity” inside the star

$$L_{DM} = 4\pi \langle \sigma v \rangle m_\chi \int n_\chi^2(r) r^2 dr$$

At equilibrium

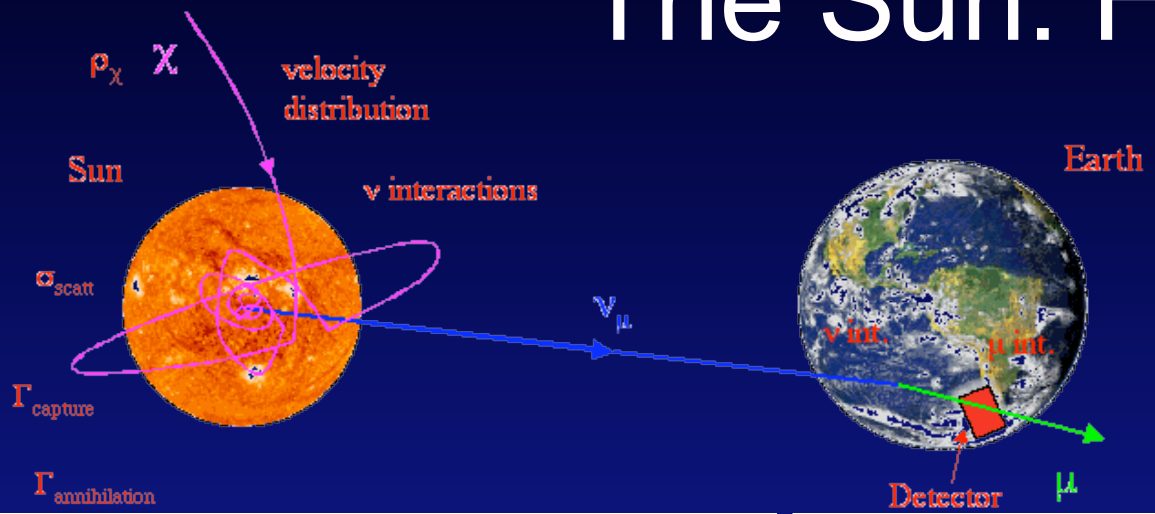
$$L_{\rm DM} = C m_\chi$$

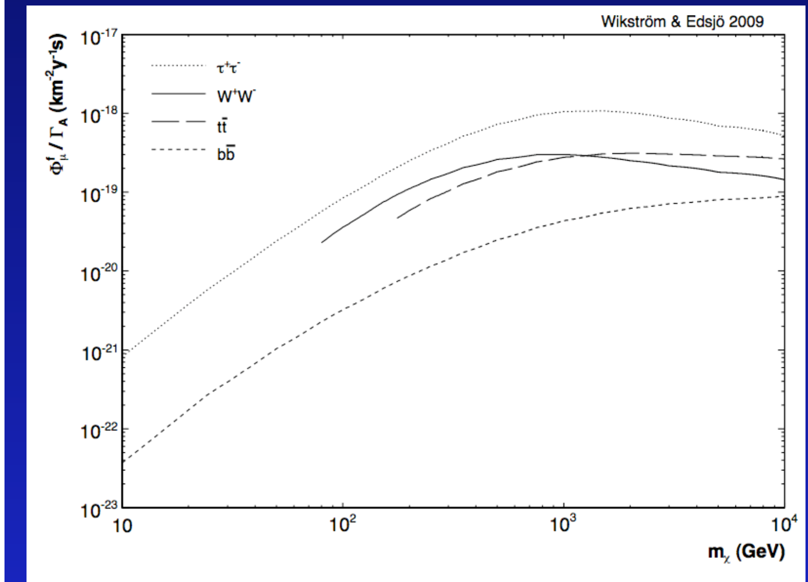
Energy transport effects:
scatter of orbiting DM

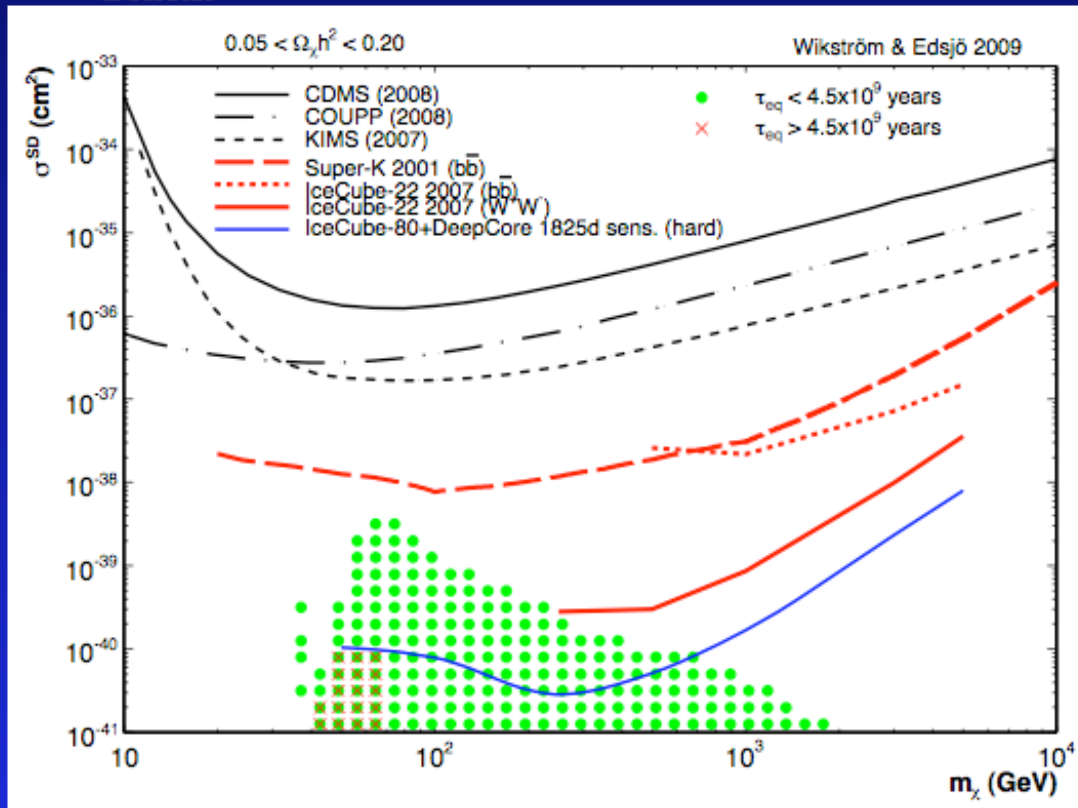
$$\frac{1}{l_\chi(r)} = \sum_i \sigma_i X_i(r) \frac{\rho(r)}{m_i}$$

Seminal literature by:
Gould, Griest, Press,
Raffelt,Salati, Seckel,
Spergel ...

The Sun: HE νs from DM



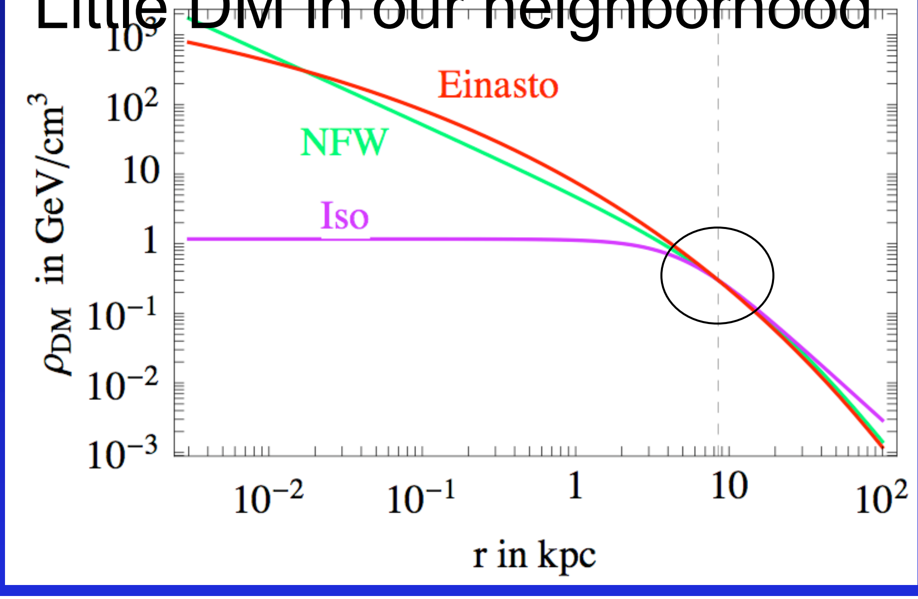




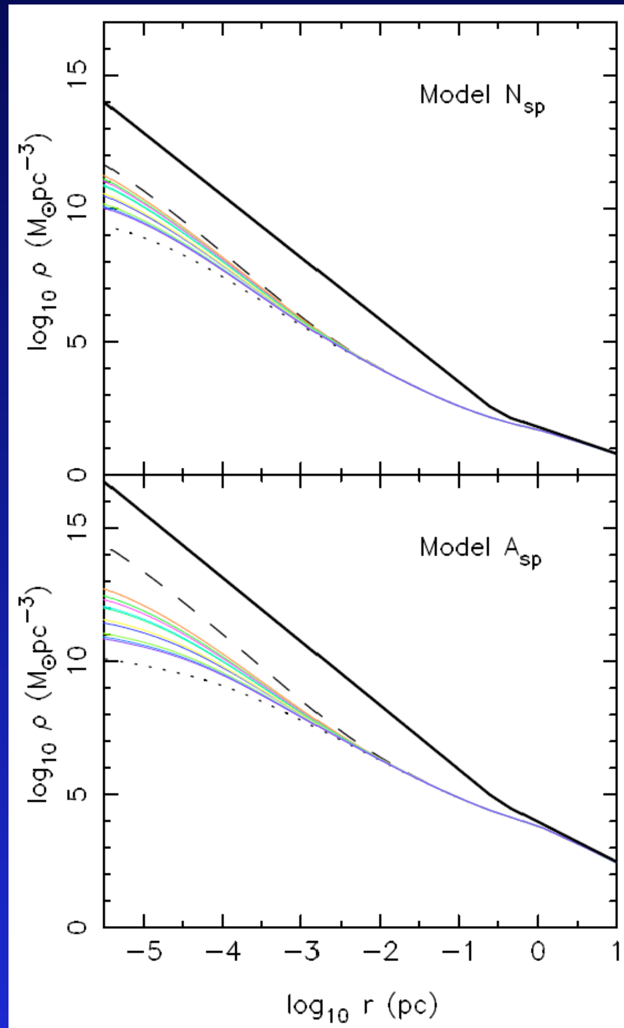
[Wikstrom & Edsjo `09]
JCAP; arXiv:0903.2986

Where does this take place (efficiently)?

Little DM in our neighborhood



Galactic Center
is dense in DM



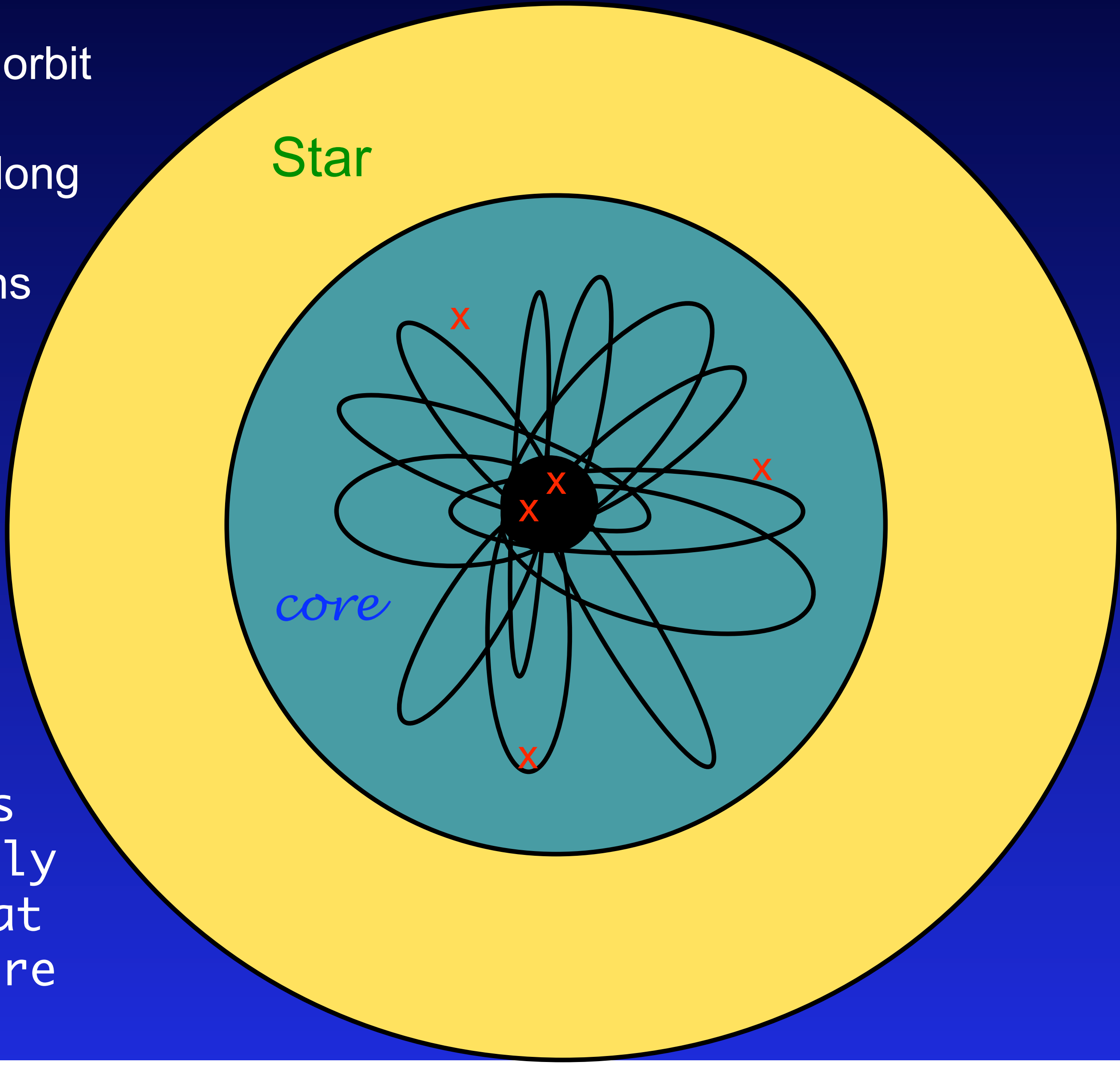
[Ullio et al. `01, Bertone & Merritt `05]

Scattering and transport

Captured WIMPs orbit

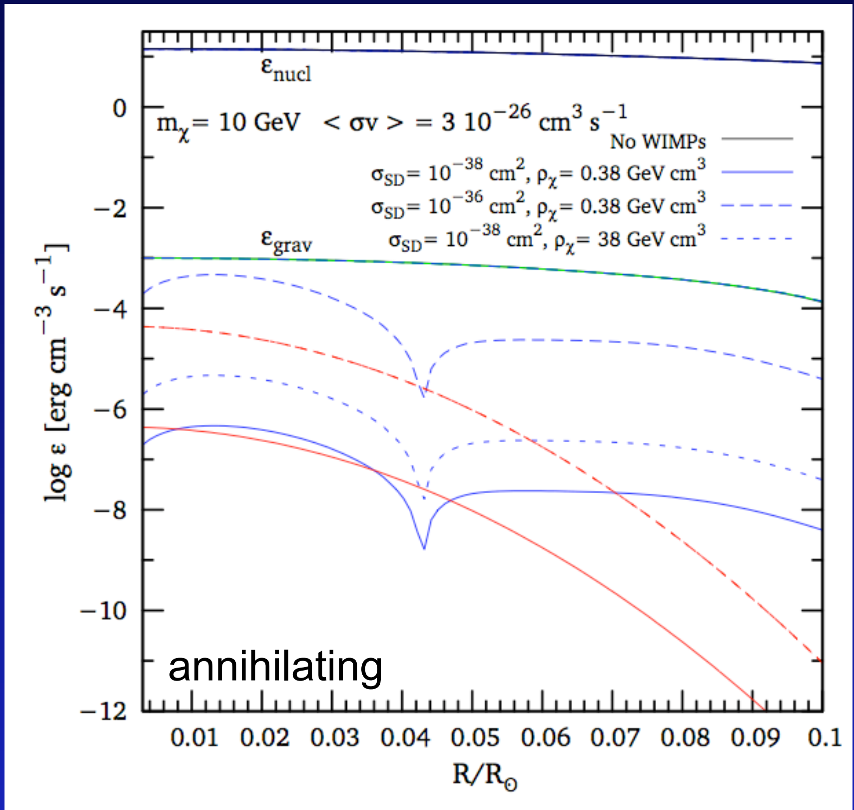
and scatter over long

mean free paths

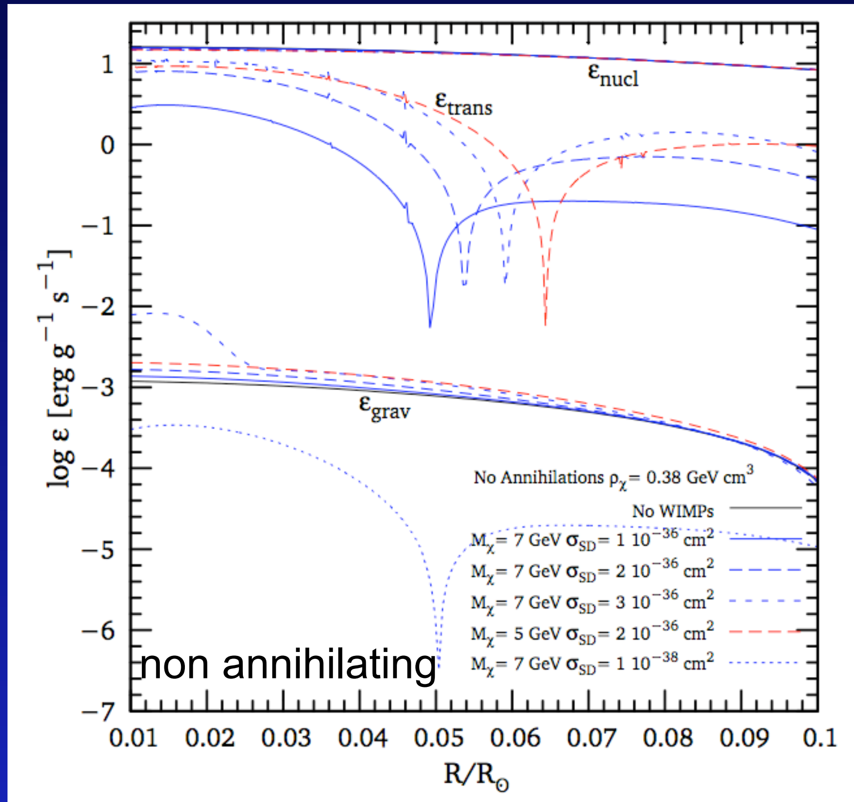


DM particles can efficiently transport heat inside the core

WIMPs and the SUN:
energy transport



DM annihil & DM transp
o.o.m. smaller nuclear



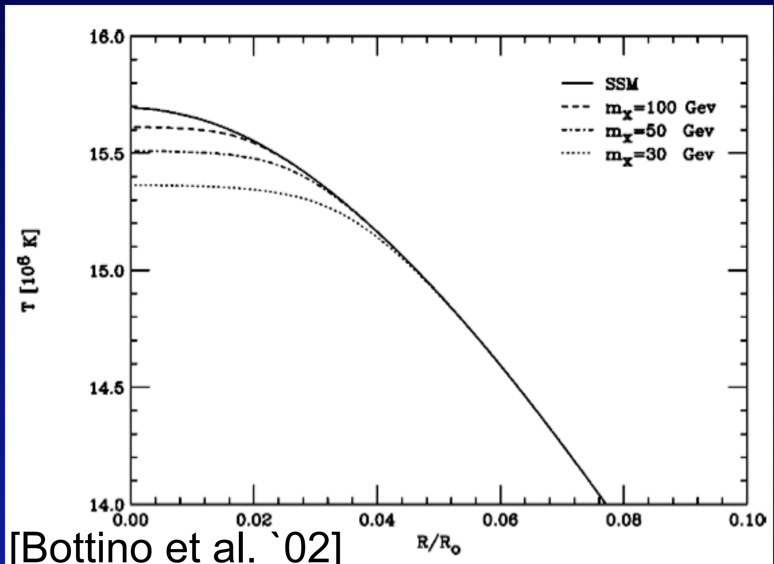
DM transp
o.o.m. nuclear

$$\frac{1}{l_\chi(r)} = \sum_i \sigma_i X_i(r) \frac{\rho(r)}{m_i}$$

$\lambda_\chi \approx 10^{10}$ cm, $\sigma = 10^{-36}$ cm^2

[Taoso, FI, 2010]

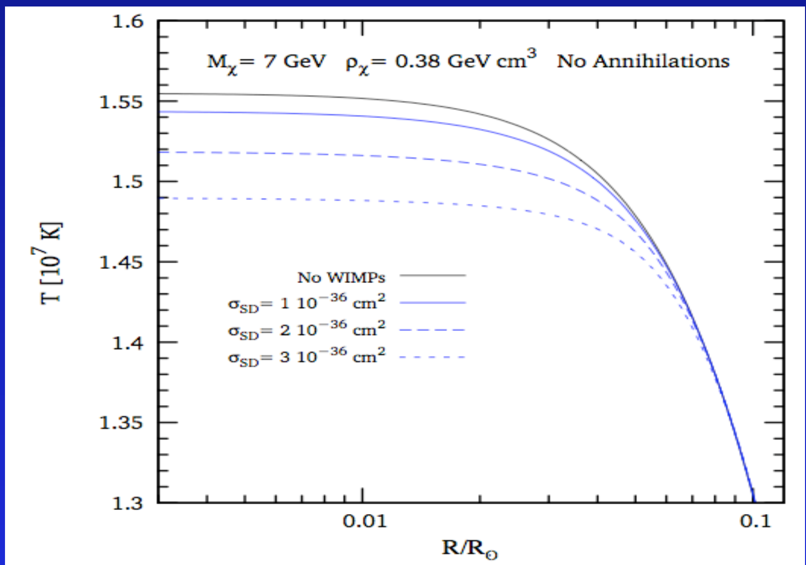
Asymmetric DM and the SUN: energy transport effects

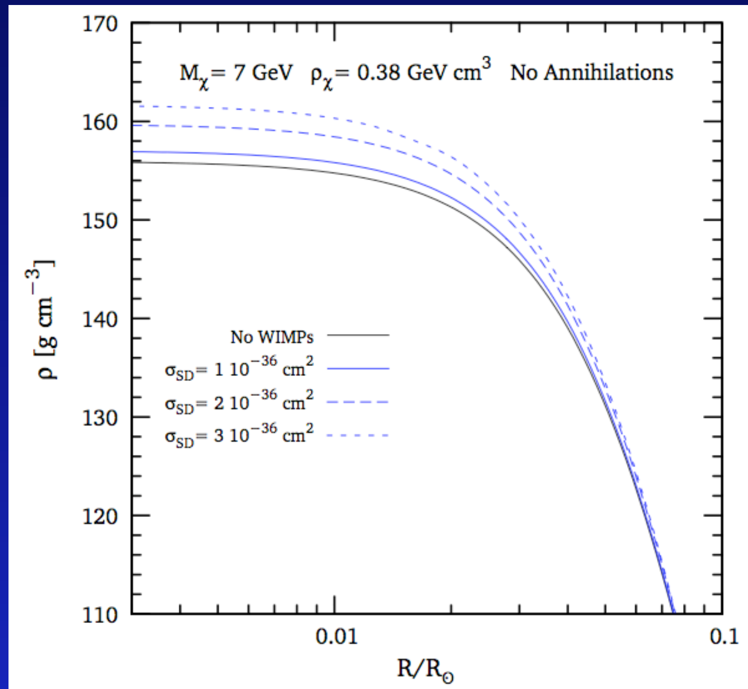


[Bottino et al. `02]

$$\dot{N}_\chi = C$$

<sv> ≤ 10^{-33} cm^3/s

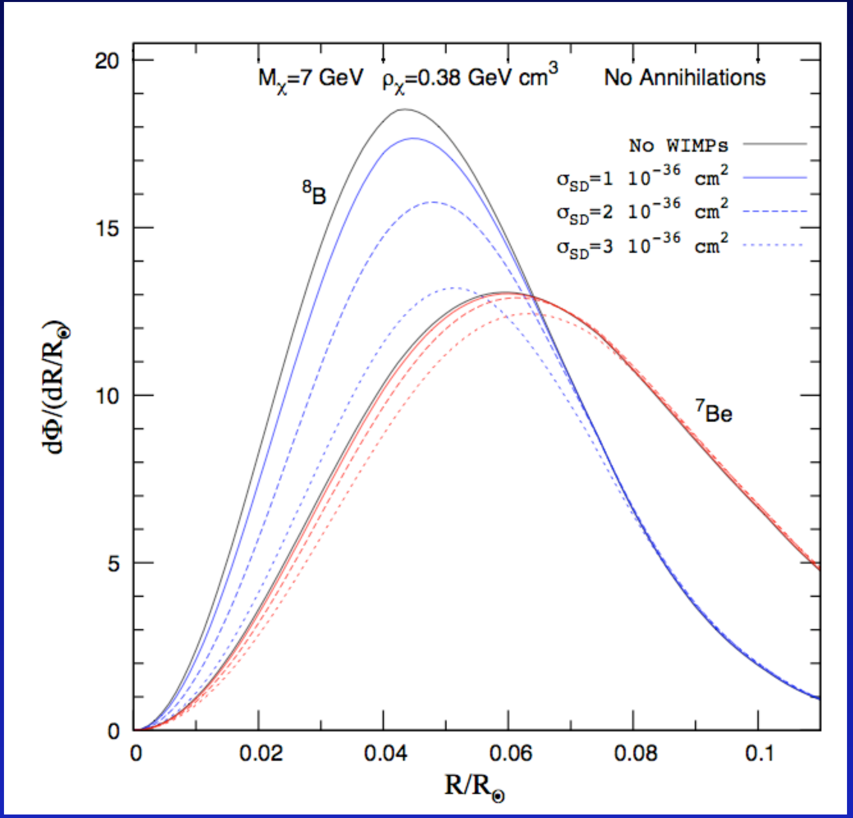


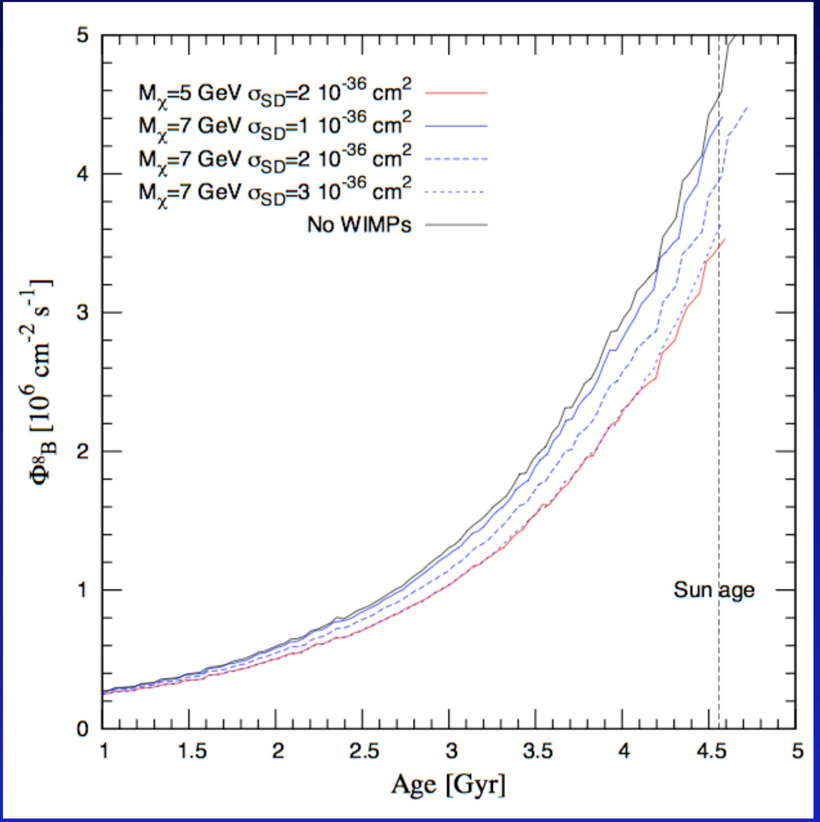


asymmetric DM can modify
solar structure at > % level in the core

[Taoso, FI et al. `10]

NA DM and Sun: modifying thermal neutrinos





^{8}B ν produced innermost than ^{7}Be ν

modified by asymmetric DM

[Taoso, FI et al. `10]

Exclusion power using ^{8}B neutrinos

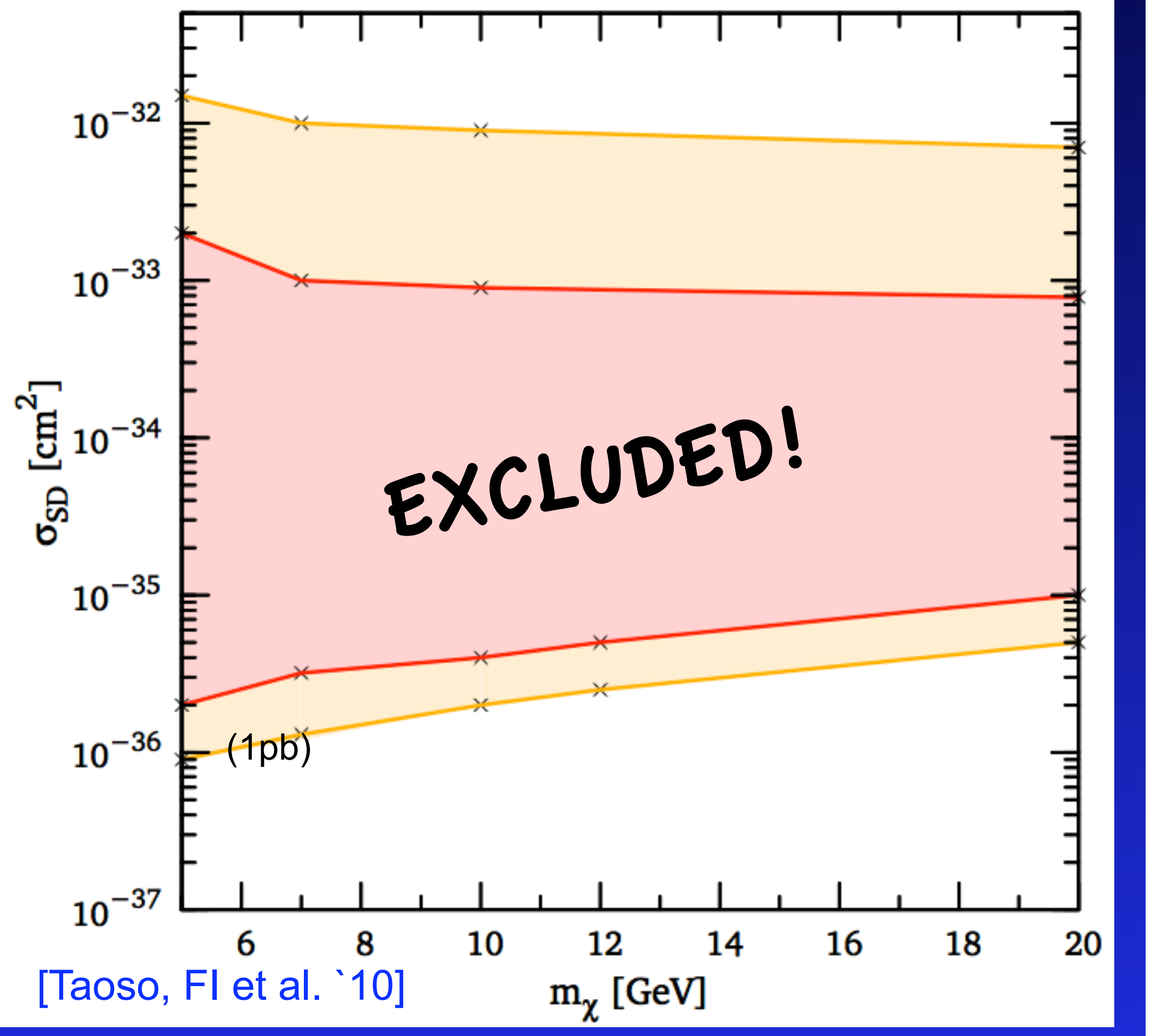
Benchmark ν flux [SNO]

$\phi_B = 5.046 \times 10^6\ \mathrm{cm^{-2}s^{-1}}$

$^{+0.159}_{-0.152}(\mathrm{stat})^{+0.107}_{-0.123}(\mathrm{syst})$

$\Delta\phi_B = 5\%$

$\Delta\phi_B = 25\%$

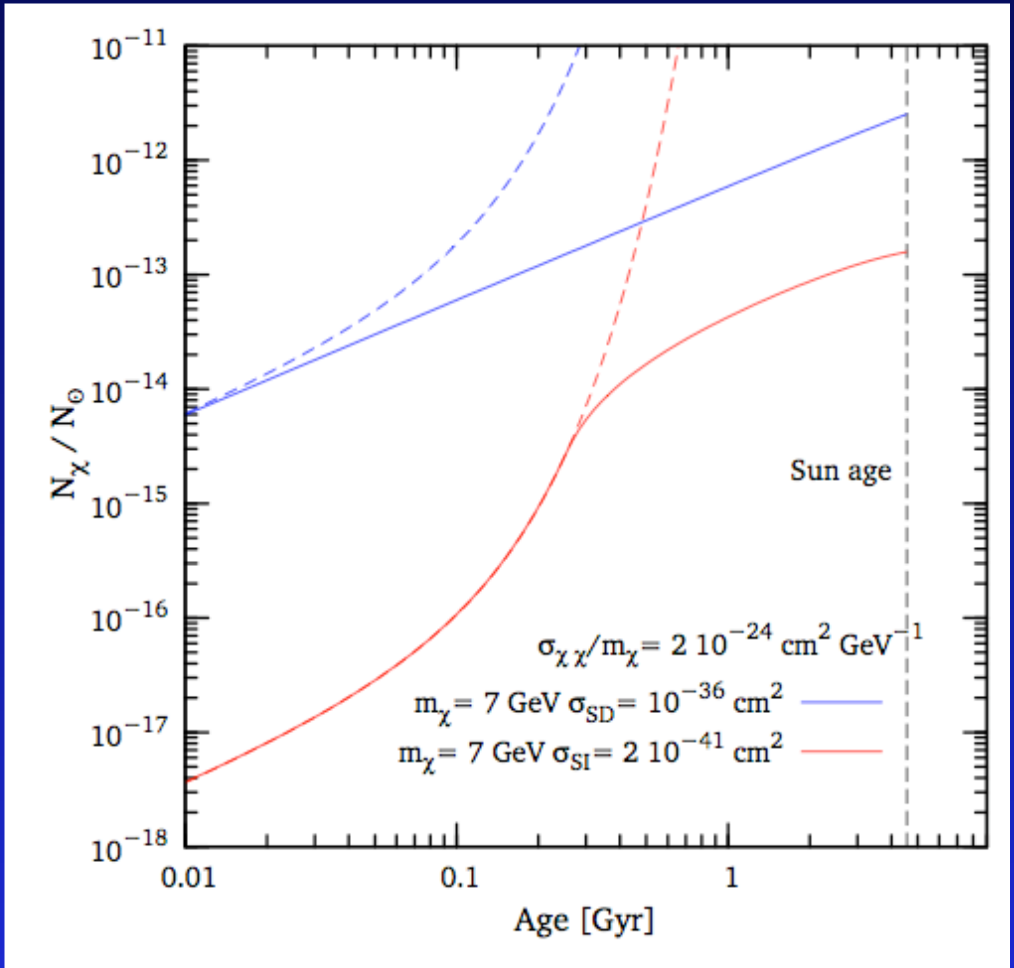


[Taoso, FI et al. `10]

See also [Cumberbatch et al. `10]
(helioseismology, weaker diagnostic)

Self-Interacting DM in the Sun

$$\dot{N}_\chi = C + C_{\chi\chi} N_\chi$$



Capture of SI-DM
Limited by geometrical
cross section of DM region
(optical limit)
πr^2_χ

No sizable effect
on solar composition
disagreement with
[Frandsen & Sarkar `10]

[Taoso, FI, et al. `10]

Conclusions

- Annihilating DM can <u>not</u> modify the structure of the Sun
- <u>Non</u> annihilating DM <u>**can**</u> modify the structure of the Sun
- Non annihilating DM induces variation on ^{8}B neutrino flux
- Competitive constraints on SD cross section (low masses)
- More to be addressesd with other type of stars in other environs