Constraints on self-annihilating DM from Reionization and CMB

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GGI – Firenze, 11/05/2010

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)

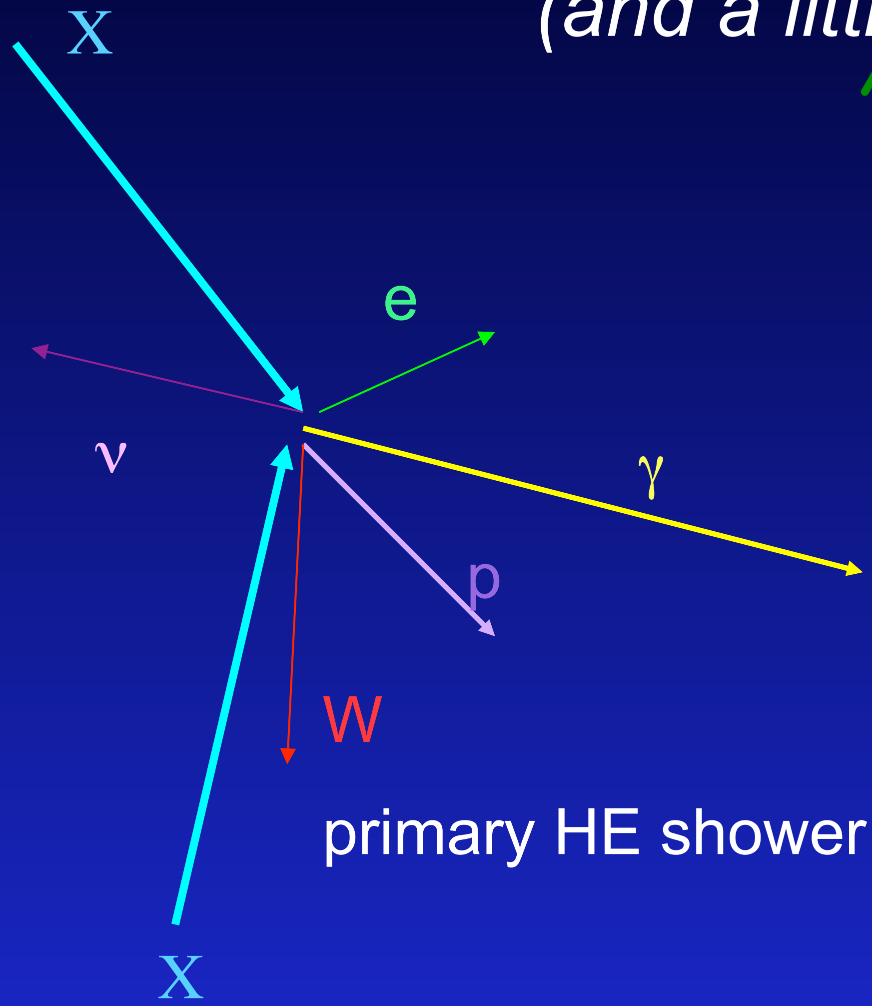
DM density halo profile
Burkert / Einasto / NFW

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

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

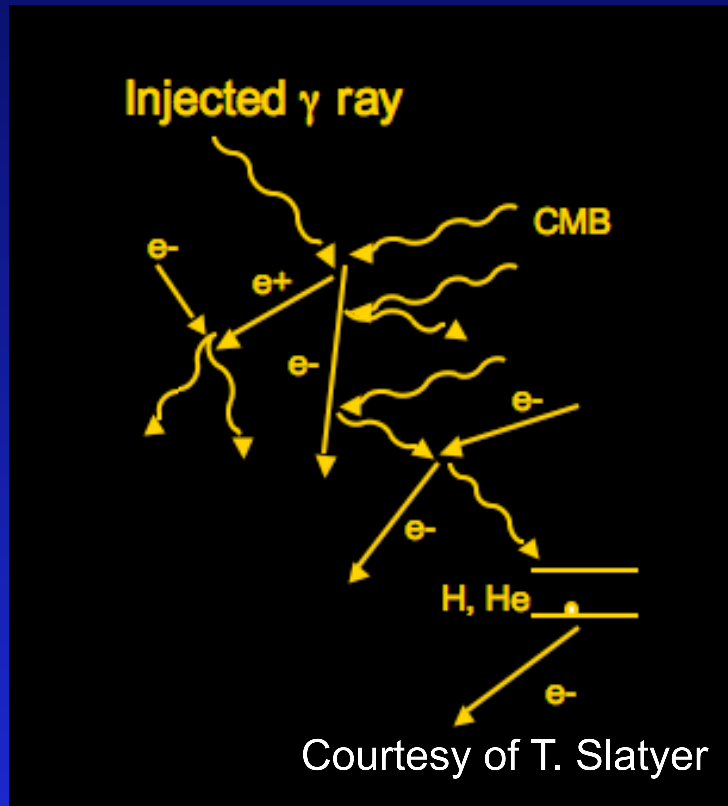
DM annihilation and the *IGM*

(and a little bit of time)



GeV-TeV scale

primary HE shower

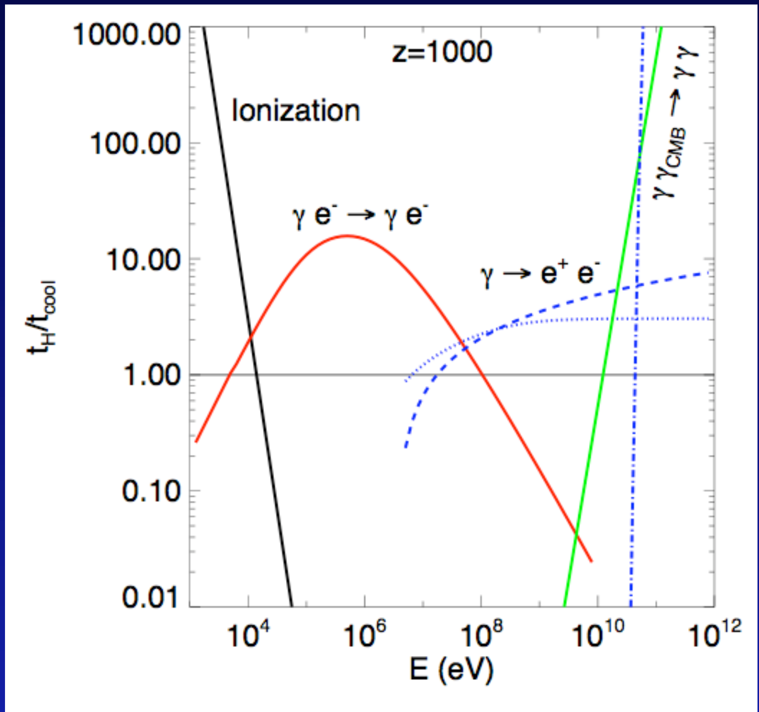


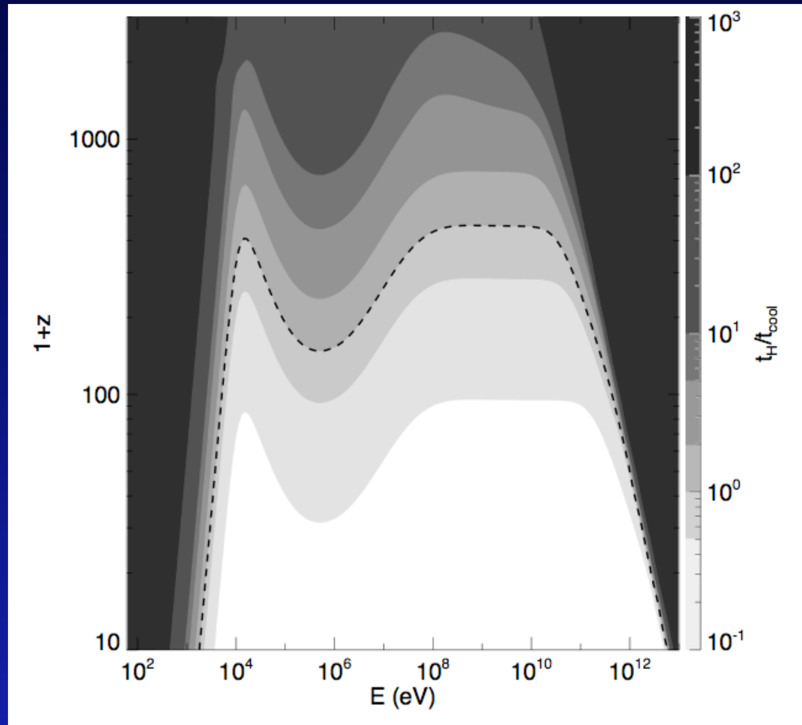
keV scale

heating and ionization

Special guest in the room:
C. Evoli, ask him about details

The IGM opacity
(absorbing the energy – or not)





Photoionization, IC scattering, pair production (on CMB γ and matter), γγ scattering

"Opacity window" of the Universe

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

[Slatyer et al. `09]

The equation to Solve-I

Energy deposition rate

$$\mathcal{E}(z) = \int_0^{m_\chi} dE_\gamma \, \frac{dn}{dE_\gamma}(z) \cdot n_{\rm A}(1+z)^3 \cdot \sigma_{\rm tot}(E_\gamma) \cdot E_\gamma$$

$$\frac{dn}{dE_\gamma}(z) = \int_\infty^z dz' \, \frac{dt}{dz'} \, \frac{dN}{dE'_\gamma}(z') \, \frac{(1+z)^3}{(1+z')^3} \cdot A(z') \cdot \exp\left[\Upsilon(z,z',E'_\gamma)\right]$$

Gas (IGM) Opacity

$$\Upsilon(z,z',E'_\gamma) \simeq -\int_{z'}^z dz'' \frac{dt}{dz''} n_{\rm A}(1+z'')^3 \sigma_{\rm tot}(E''_\gamma)$$

Annihilation rates

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

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

The equation to Solve-II

Evolution of ionization fraction

$$-n_{\mathrm{A}} H_0 \sqrt{\Omega_{\mathrm{M}}}(1+z)^{11/2} \frac{dx_{\mathrm{ion}}(z)}{dz} = I(z) - R(z)$$

Recombination rates

$$R_{\mathrm{H}}(z) = \kappa_{\mathrm{H}}\, n_{\mathrm{H}}\, n_{e^-} = \kappa_{\mathrm{H}} \frac{0.76}{0.82} \left(n_{\mathrm{A}}(1+z)^3 x_{\mathrm{ion}}(z)\right)^2$$

$$R_{\mathrm{He}}(z) = \kappa_{\mathrm{He}} \frac{0.06}{0.82} \left(n_{\mathrm{A}}(1+z)^3 x_{\mathrm{ion}}(z)\right)^2$$

Ionization rates

$$I(z) = \int_{e_{\mathrm{i}}}^{m_\chi} dE_\gamma \frac{dn}{dE_\gamma}(z) \cdot P(E_\gamma, z) \cdot N_{\mathrm{ion}}(E_\gamma)$$

Electron optical depth τ

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

Integrated quantity

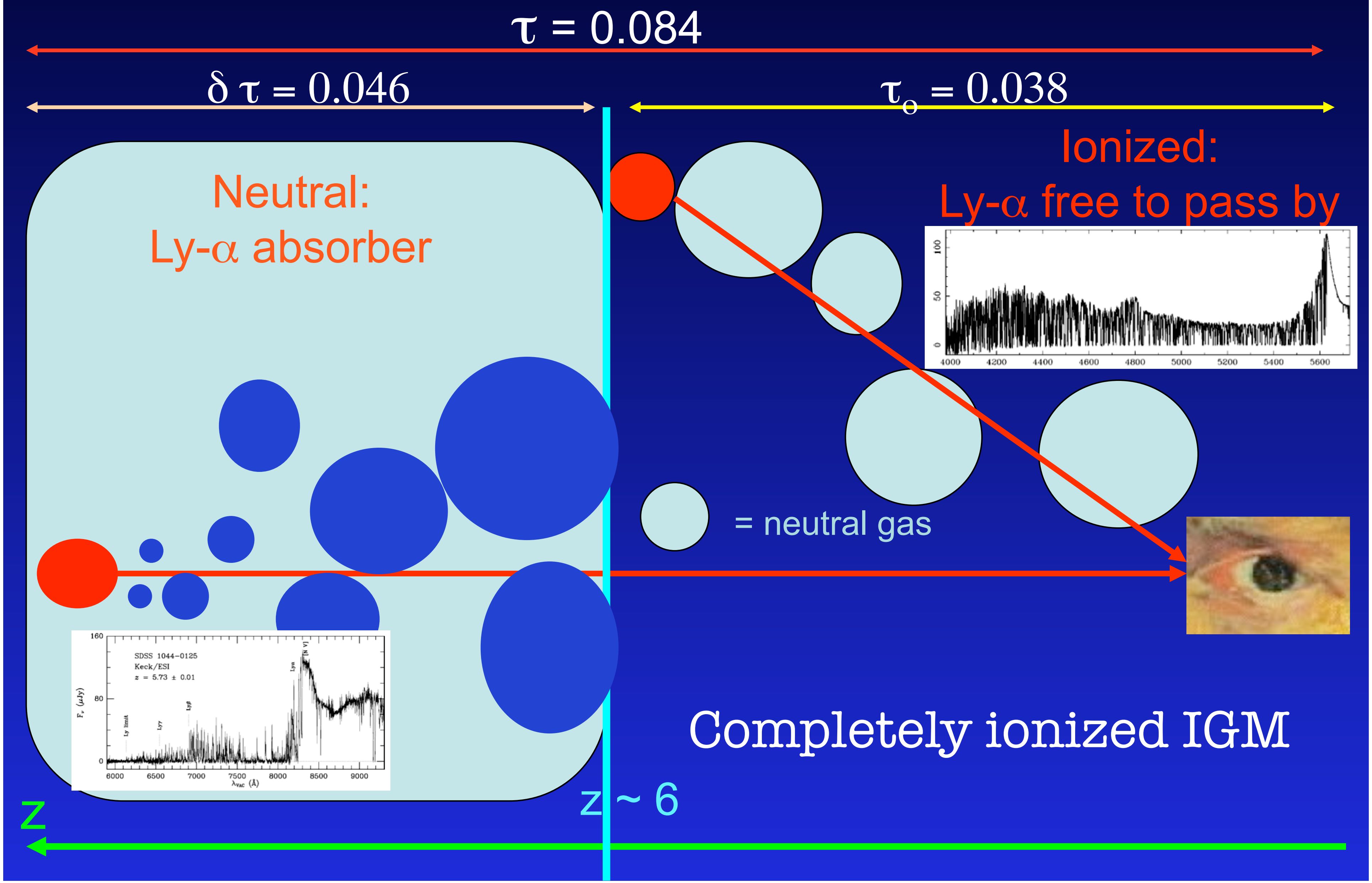
$$\tau = \underbrace{n_{\rm A}\,\sigma_{\rm T}\left[-\frac{0.88}{0.82}\int_0^3 dz\frac{dt}{dz}(1+z)^3 - \int_3^6 dz\frac{dt}{dz}(1+z)^3\right]}_{0.038} +$$

Known contribution

Sources z > 6: known unknowns

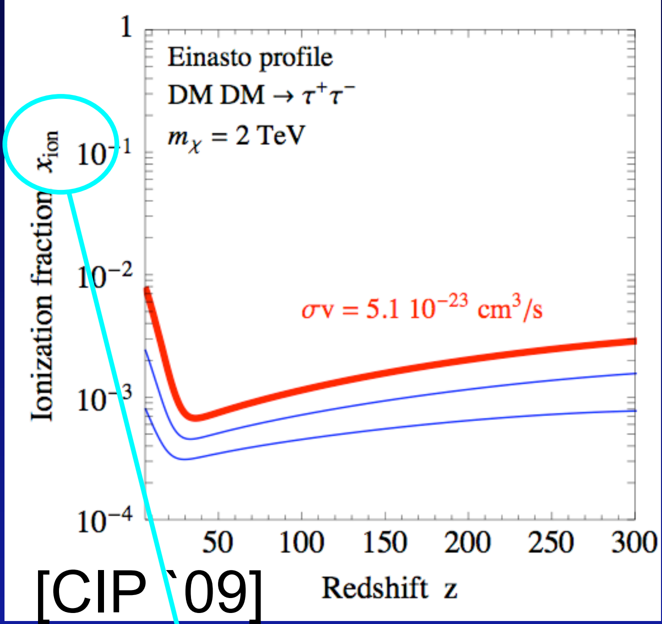
$$\underbrace{n_{\rm A}\,\sigma_{\rm T}\left[-\int_6^\infty dz\frac{dt}{dz}(1+z)^3 x_{\rm ion}(z)\right]}_{\delta\tau}$$

Summarizing “Reionization”



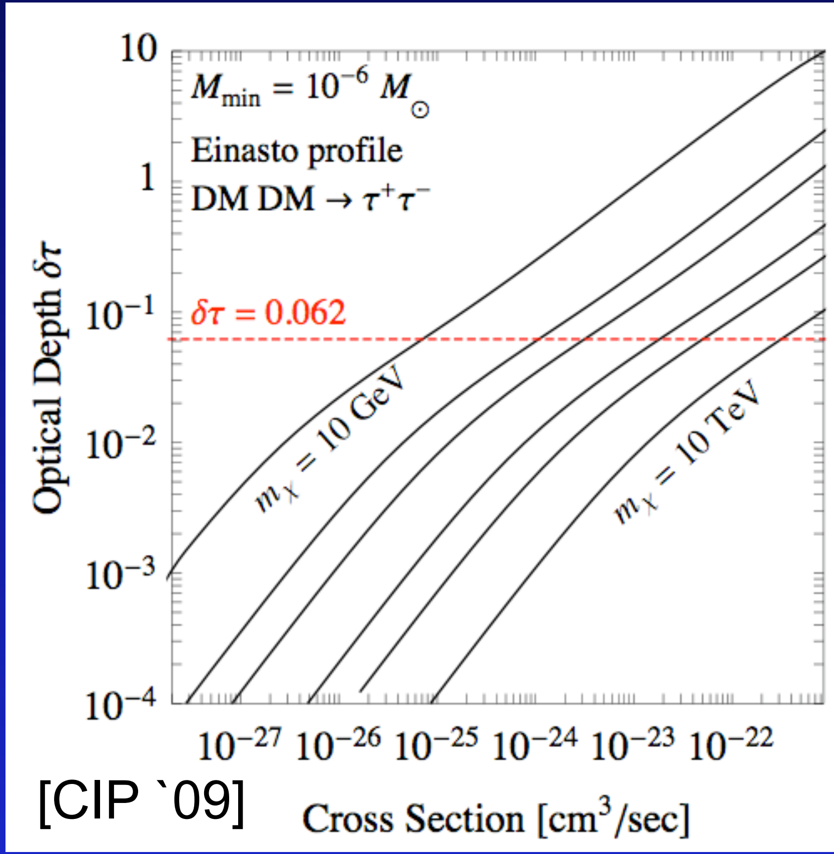
τ constraints

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



[CIP `09]

To be integrated!



[CIP `09]

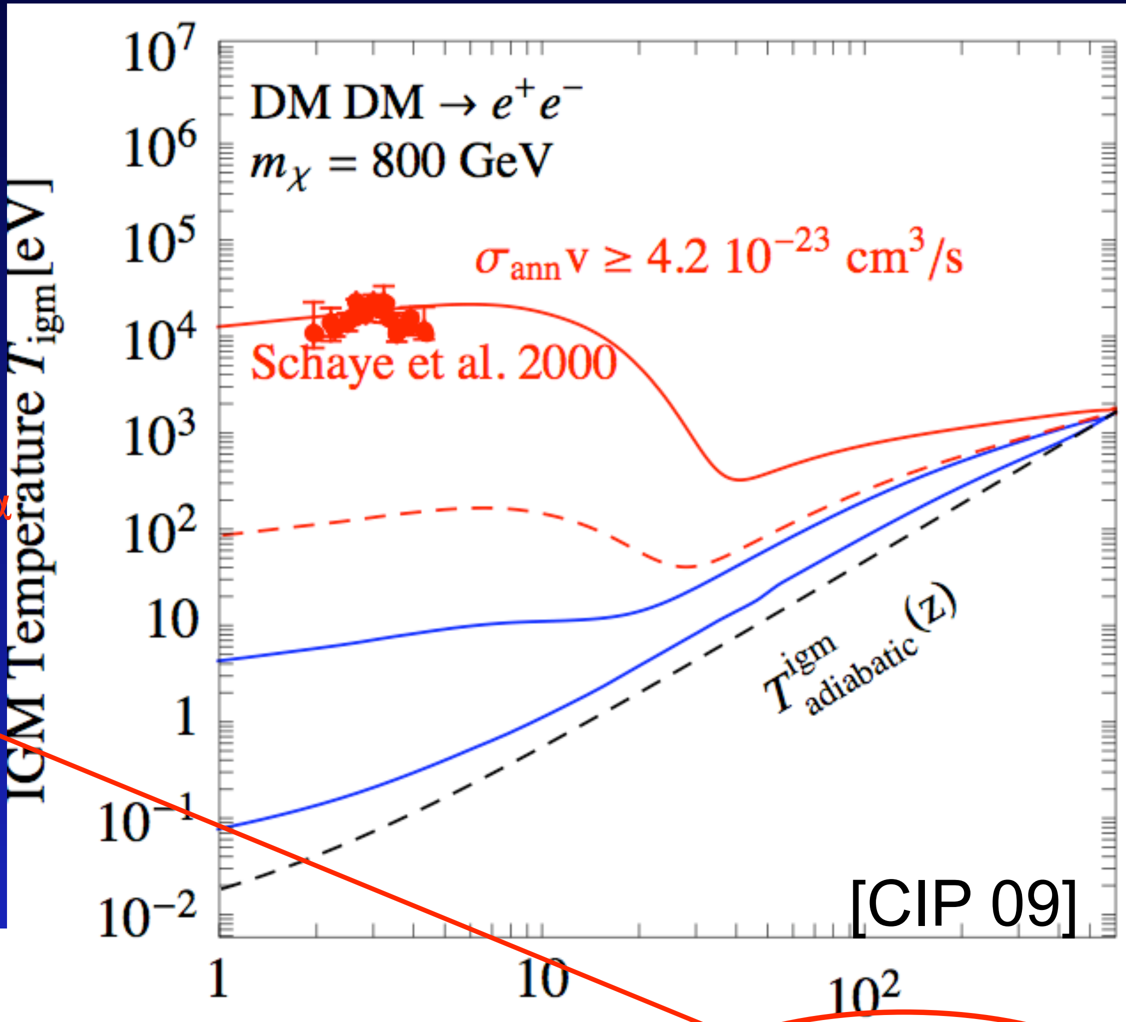
In this models:

no astrophysical sources (z > 6)

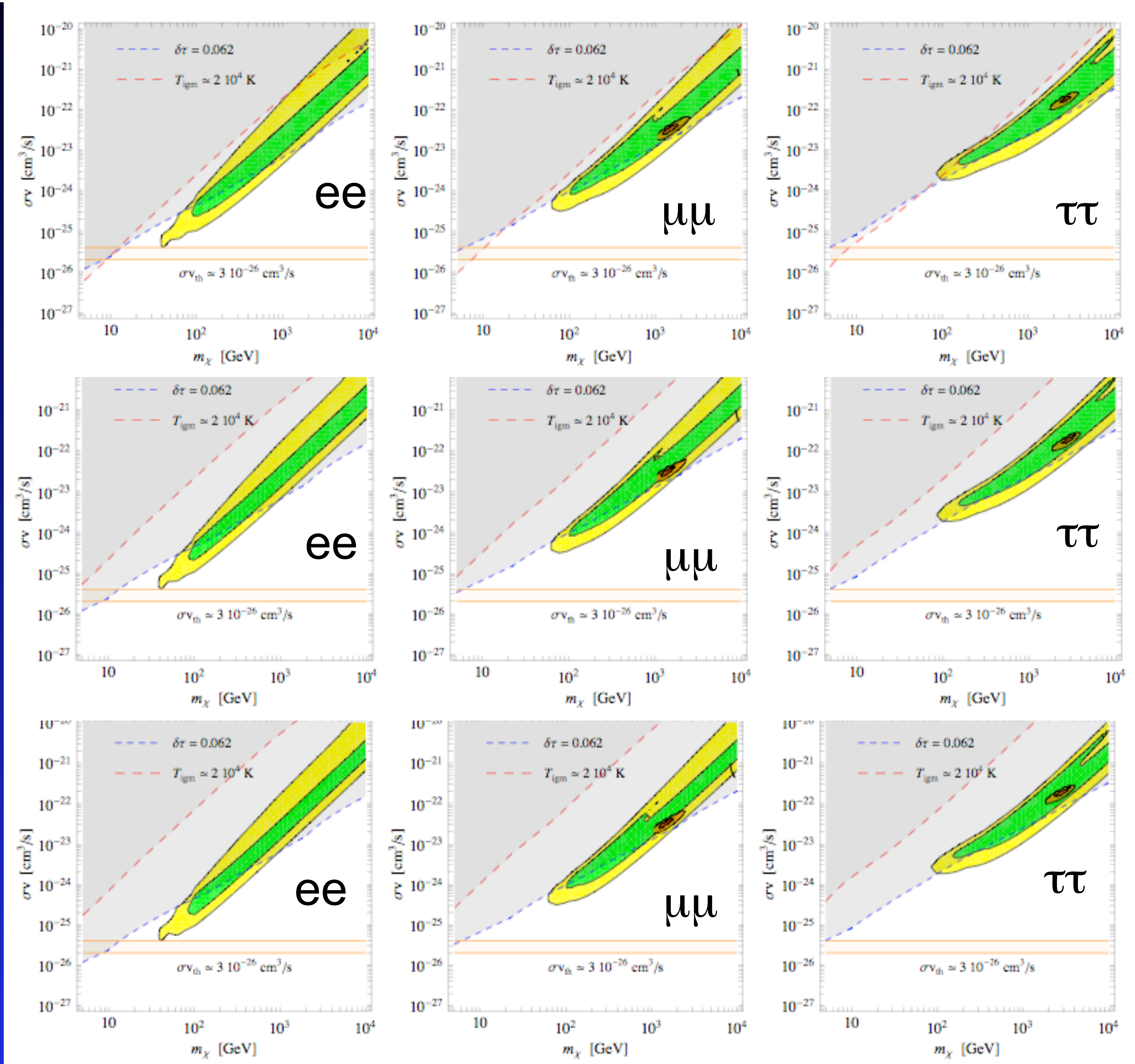
Extra-conservative bounds!

Temperature constraints!

"Exotic heating":
DM, after coupled f
1/3 heat, 1/3 ioniz. 1/3 Ly-α



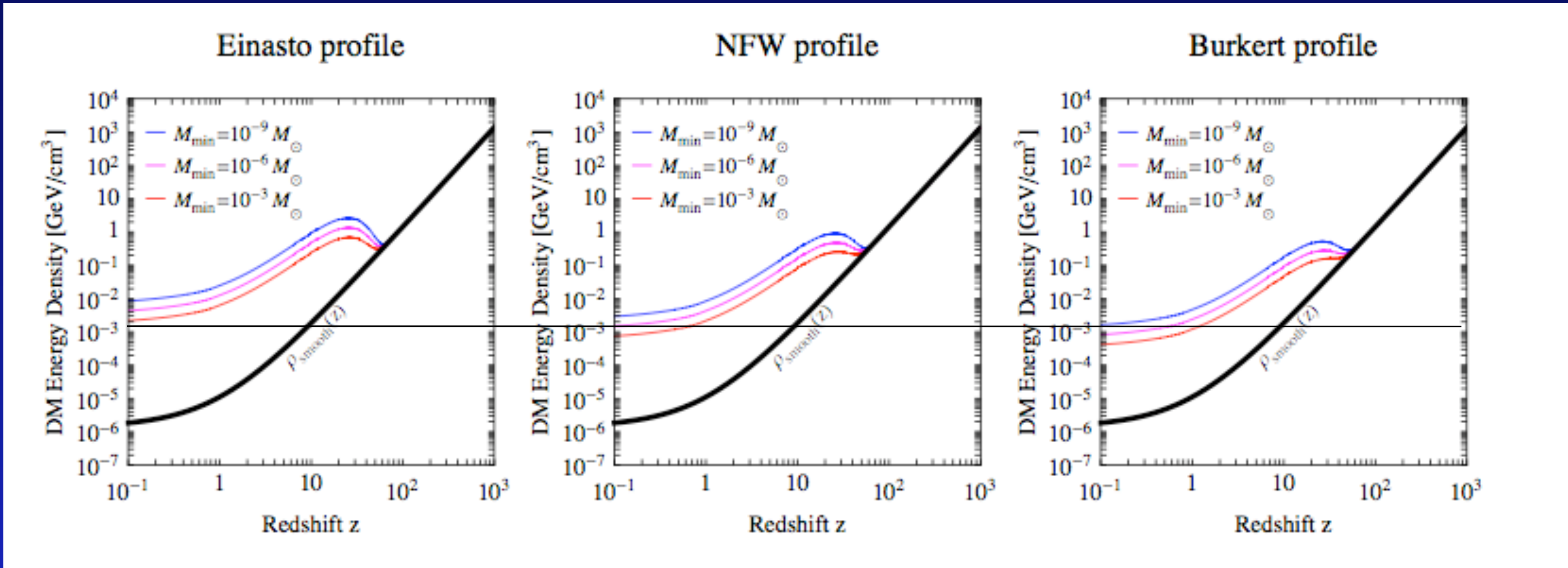
$$\frac{dT_{\rm igm}(z)}{dz} = \frac{2\,T_{\rm igm}(z)}{1+z} - \frac{1}{H_0\sqrt{\Omega_{\rm M}}\,(1+z)^{5/2}}\left(\frac{x_{\rm ion}(z)}{1+x_{\rm ion}(z)+0.073}\,\frac{T_{\rm CMB}(z)-T_{\rm igm}(z)}{t_{\rm c}(z)} + \frac{2\,\eta_{\rm heat}(x_{\rm ion}(z))\,\mathcal{E}(z)}{3\,n_{\rm A}(1+z)^3}\right)$$



$\delta\tau = 0.062$
$T_{igm} \simeq 2\ 10^4$ K
$\sigma v_{th} \simeq 3\ 10^{-26}$ cm^3/s
σv [cm^3/s]
m_χ [GeV]
ee
μμ
ττ
Einasto
NFW
Burkert

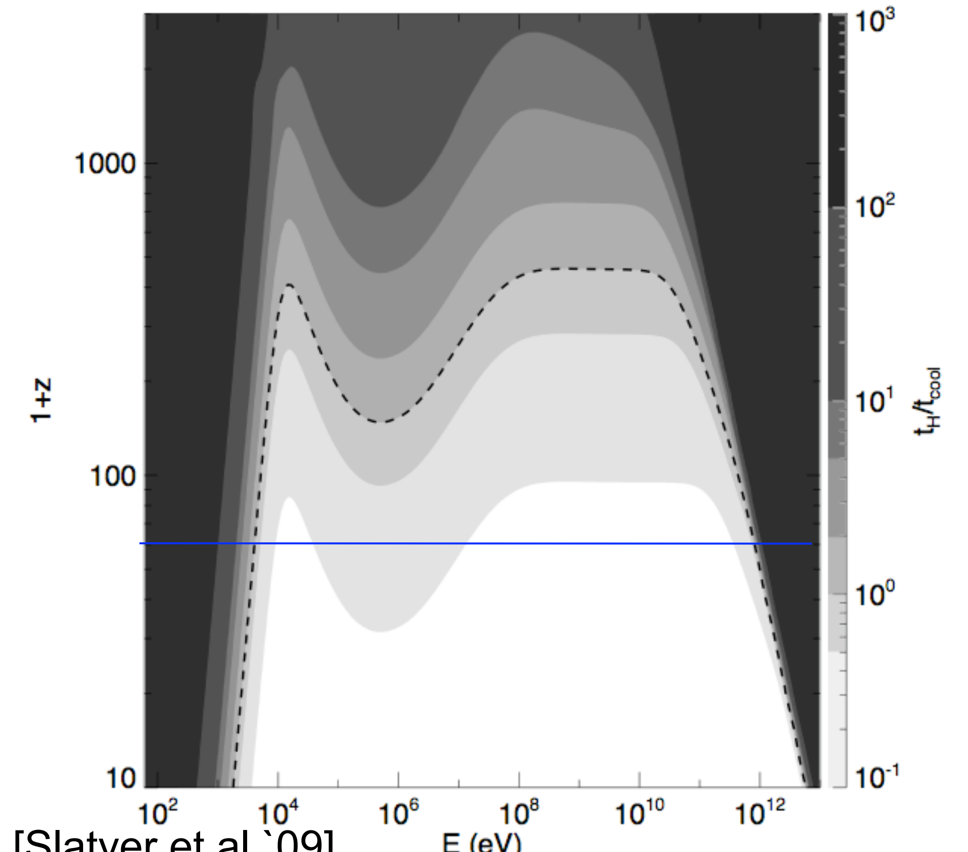
[CIP `09]

Structure boost: parameter dependence



[Cirelli, FI, Panci `09]

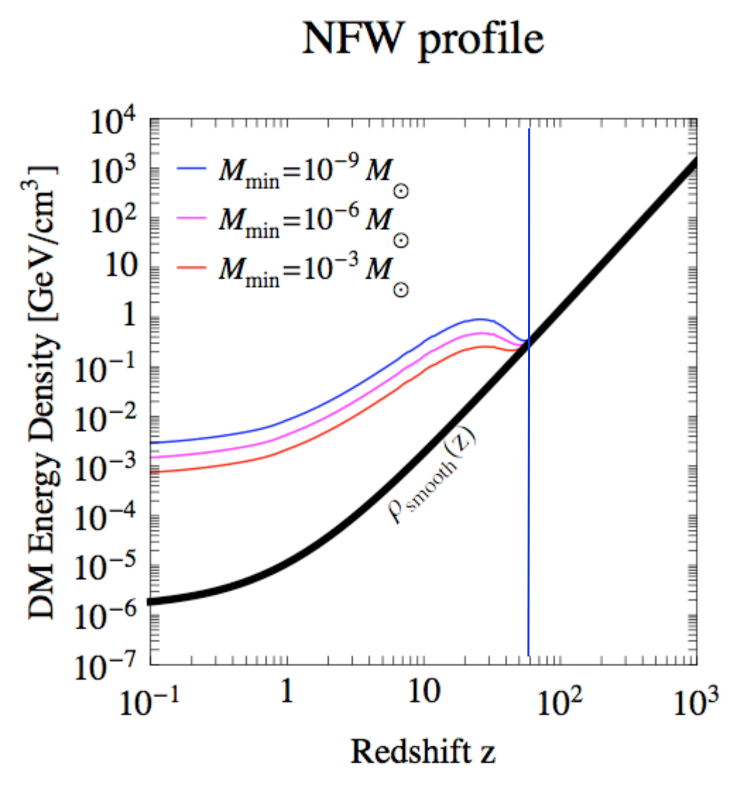
Transparency of the Universe & structure formation



[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]

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

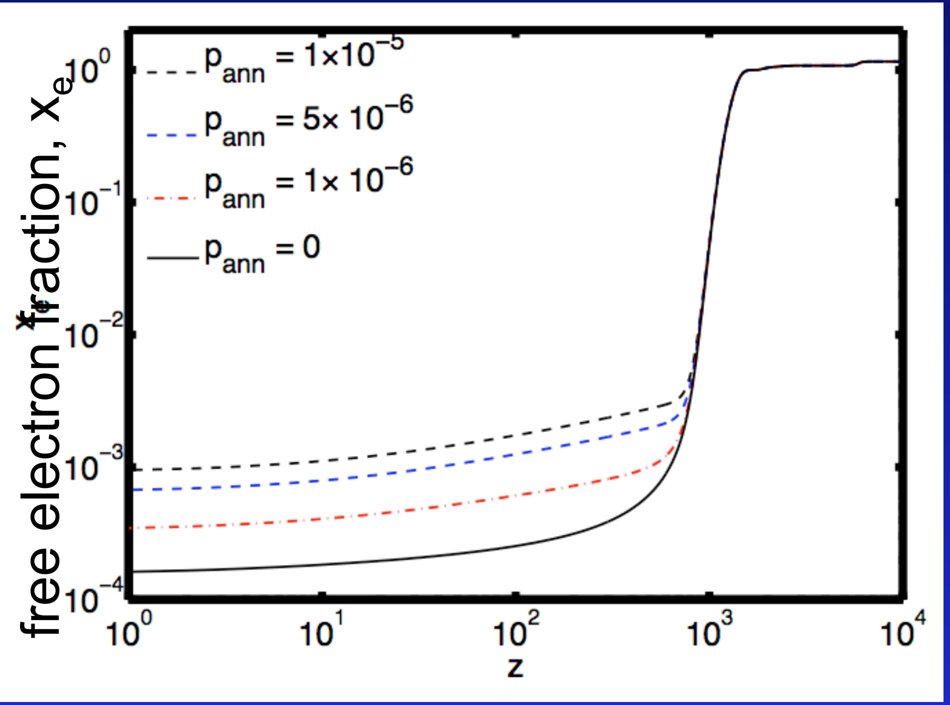
$$\frac{dE}{dt}(z) = \rho_c^2 c^2 \Omega_{DM}^2 (1+z)^6 f \frac{\langle\sigma v\rangle}{m_\chi}$$

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

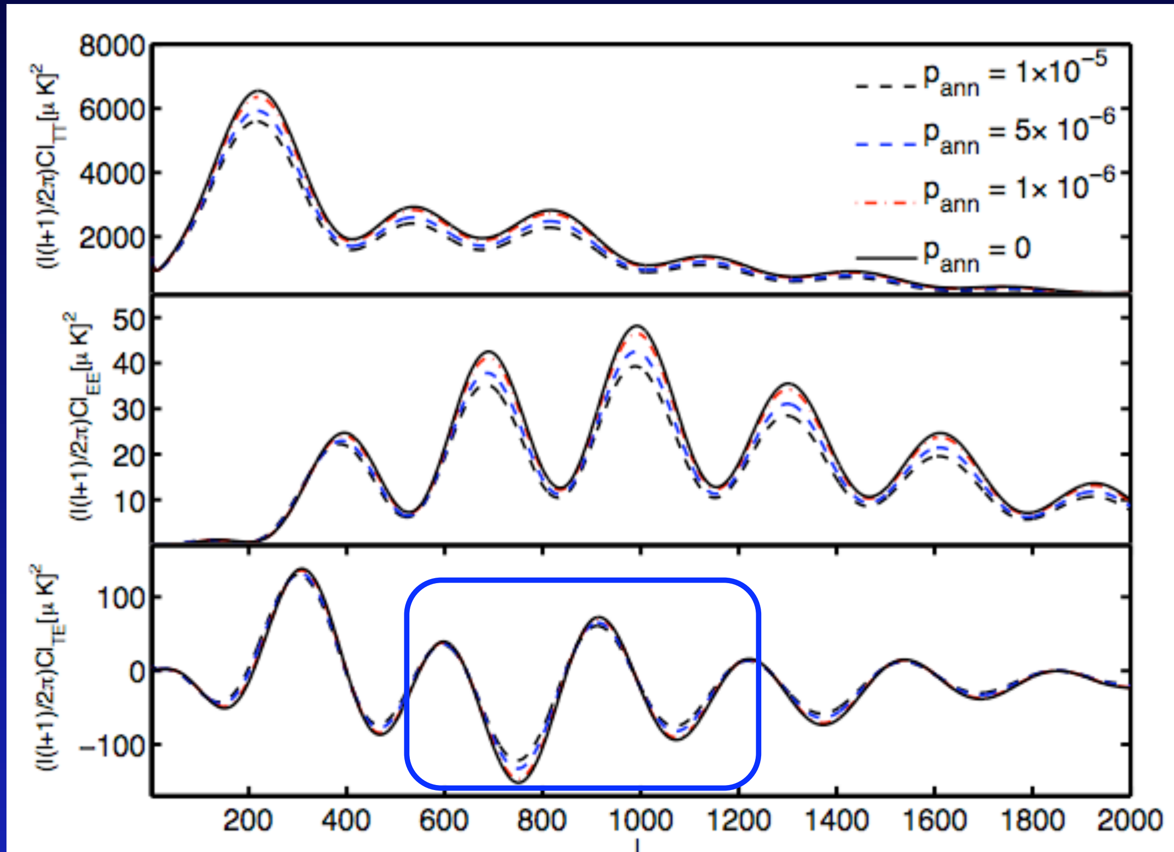


[Galli, FI, Bertone, Melchiorri `09]

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)

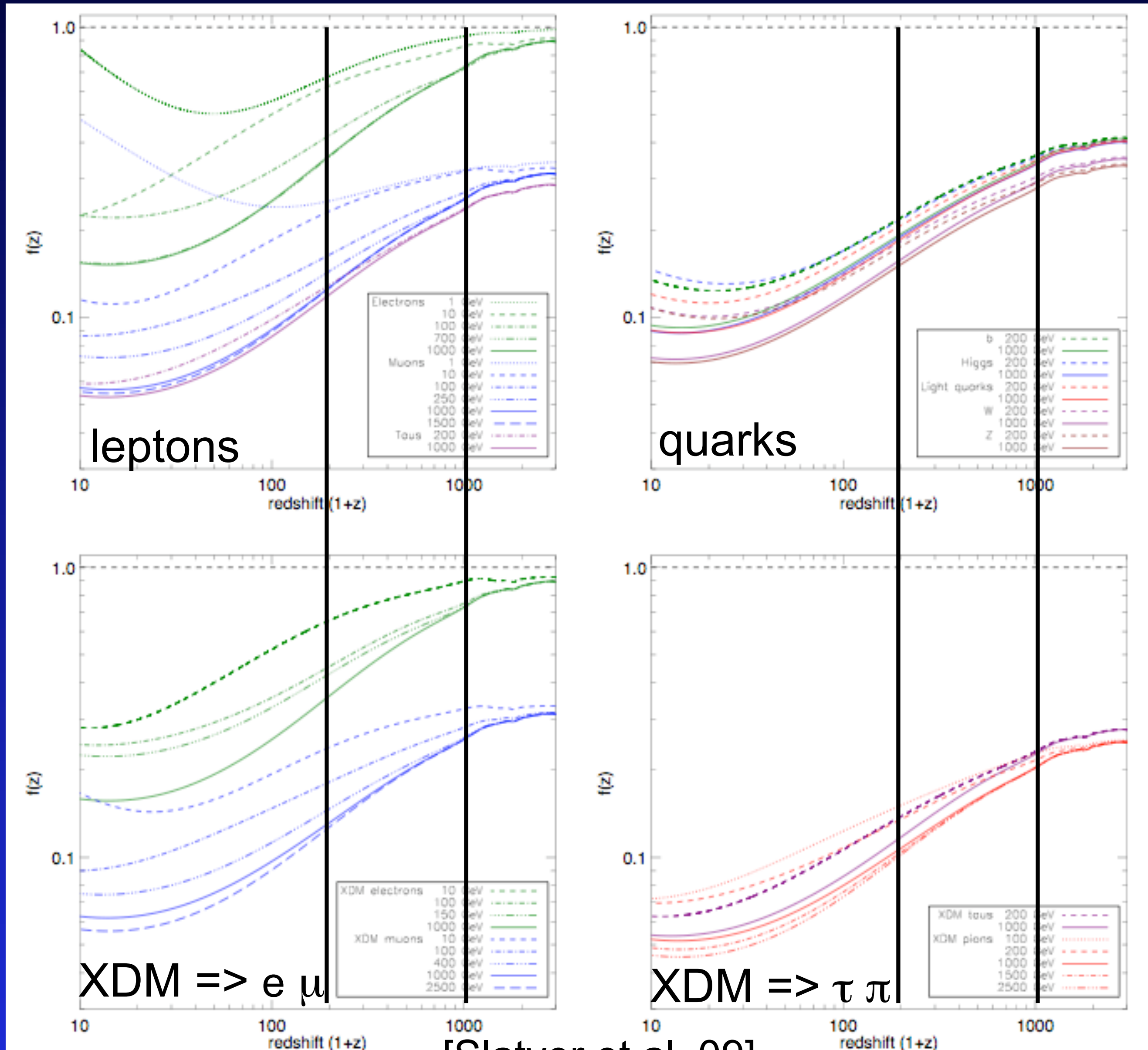
[Galli, Iocco, Bertone, Melchiorri `09]

Evaluating “ f ”

All channels,
all secondaries,
redshift dependence

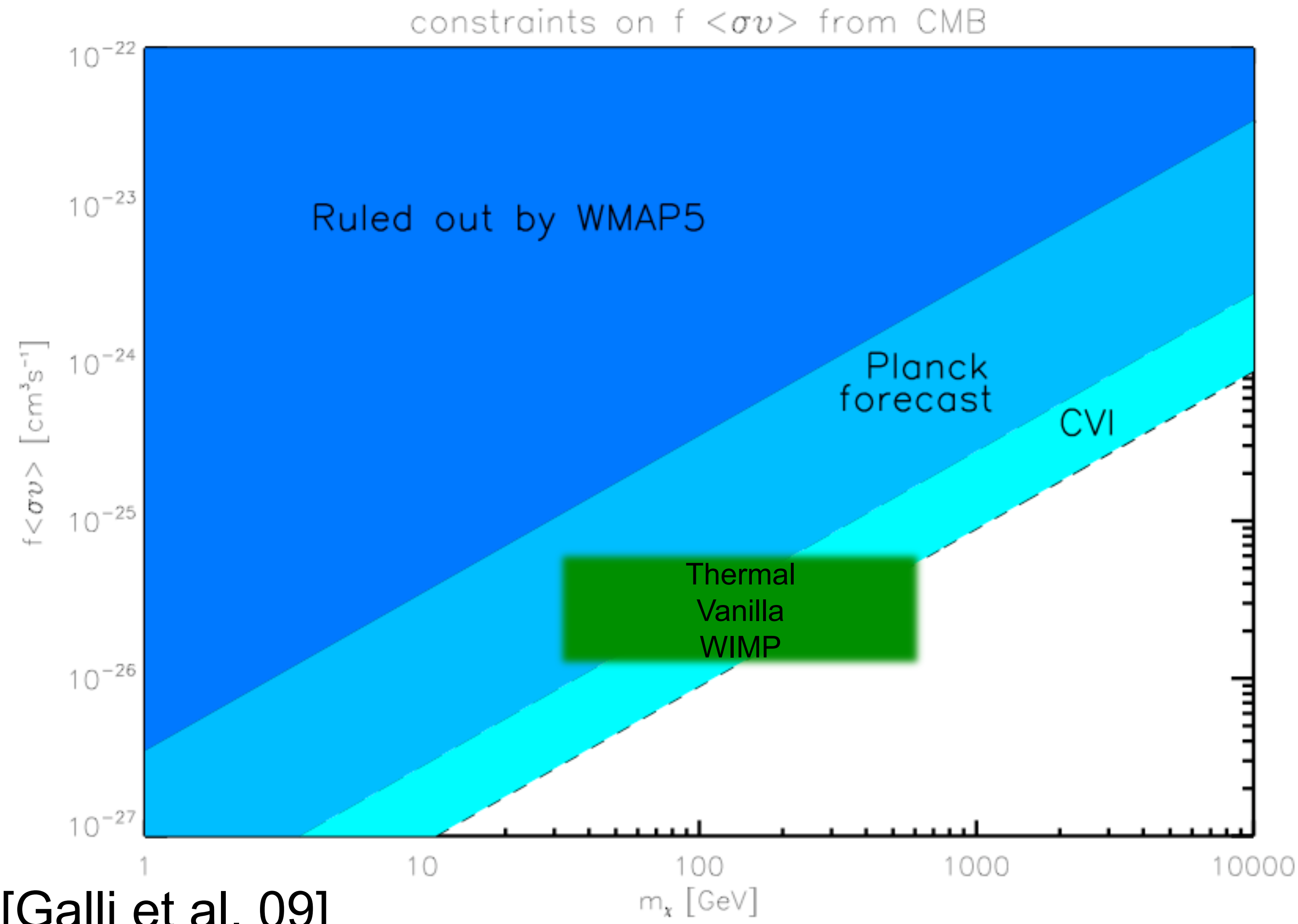
Branching ratio of
DM annihilation
essential for
determining absorption

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



[Slatyer et al. 09]

Constraining DM with CMB



[Galli et al. 09]

Constraining SE with CMB

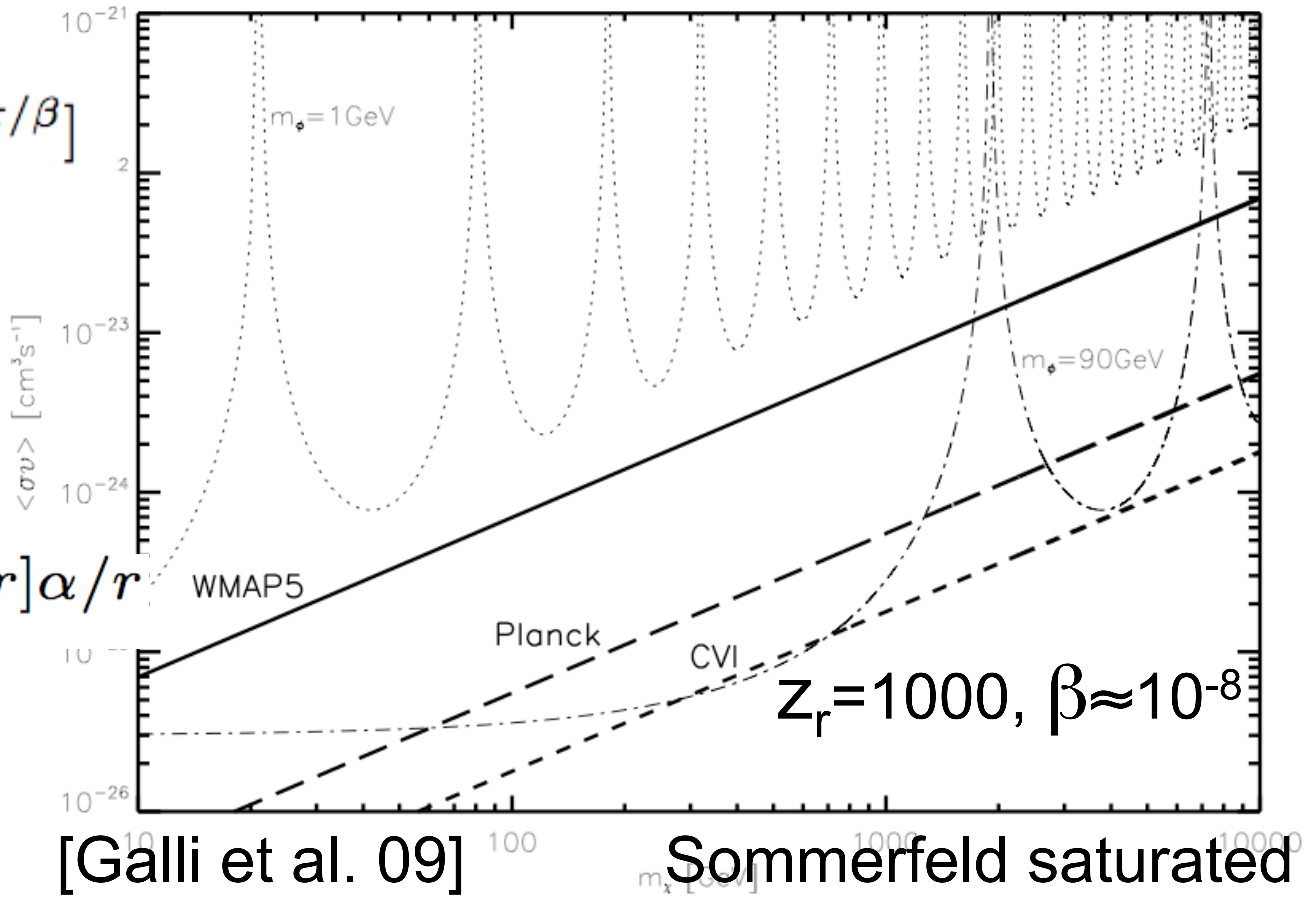
$$\psi''(r) - m_\chi V(r)\psi(r) + m_\chi^2 \beta^2 \psi(r) = 0$$

$$S(\beta) = \frac{\alpha\pi}{\beta}[1 - \exp^{-\alpha\pi/\beta}]$$

Sommerfeld enhancement

$$V(r) = -e^{[-m_\phi r]}\alpha/r$$

Yukawa potential
a benchmark model



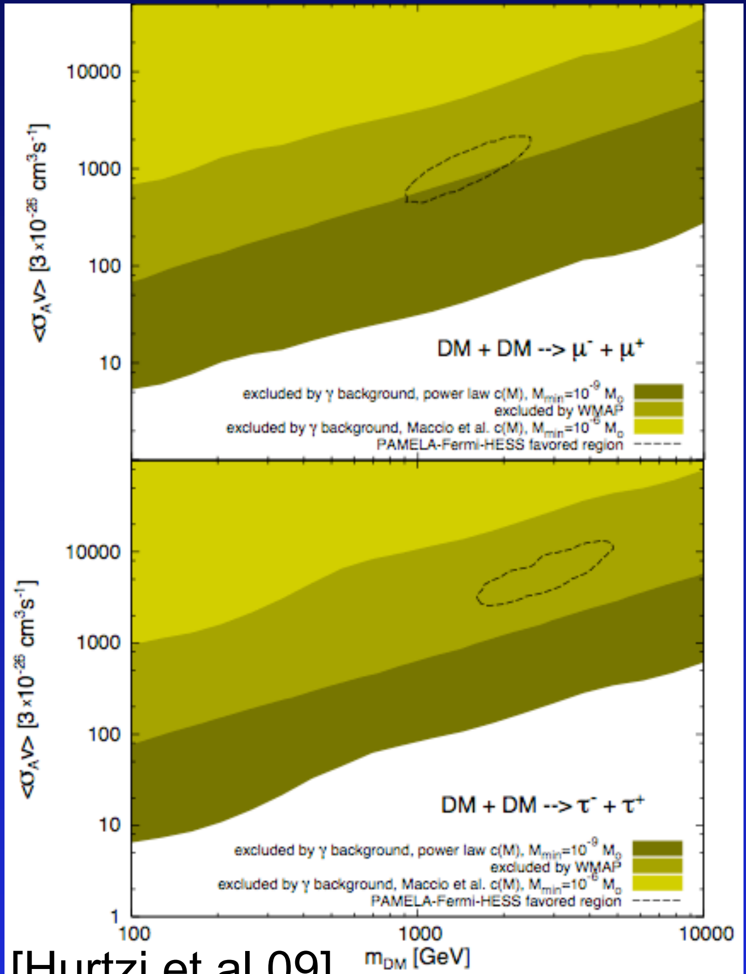
z_r=1000, $\beta \approx 10^{-8}$

[Galli et al. 09]

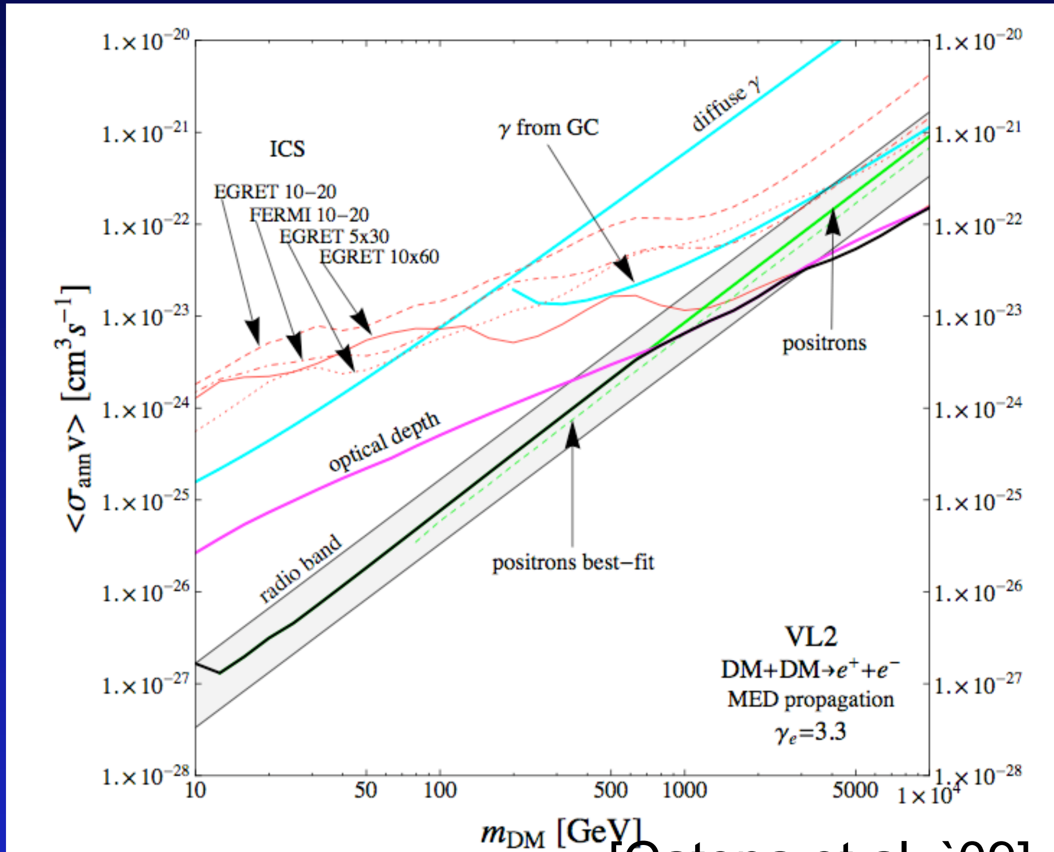
Sommerfeld saturated

Combining the constraints

gammas + τ



[Hurtzi et al 09]



[Catena 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!

FIXSEN ET AL.

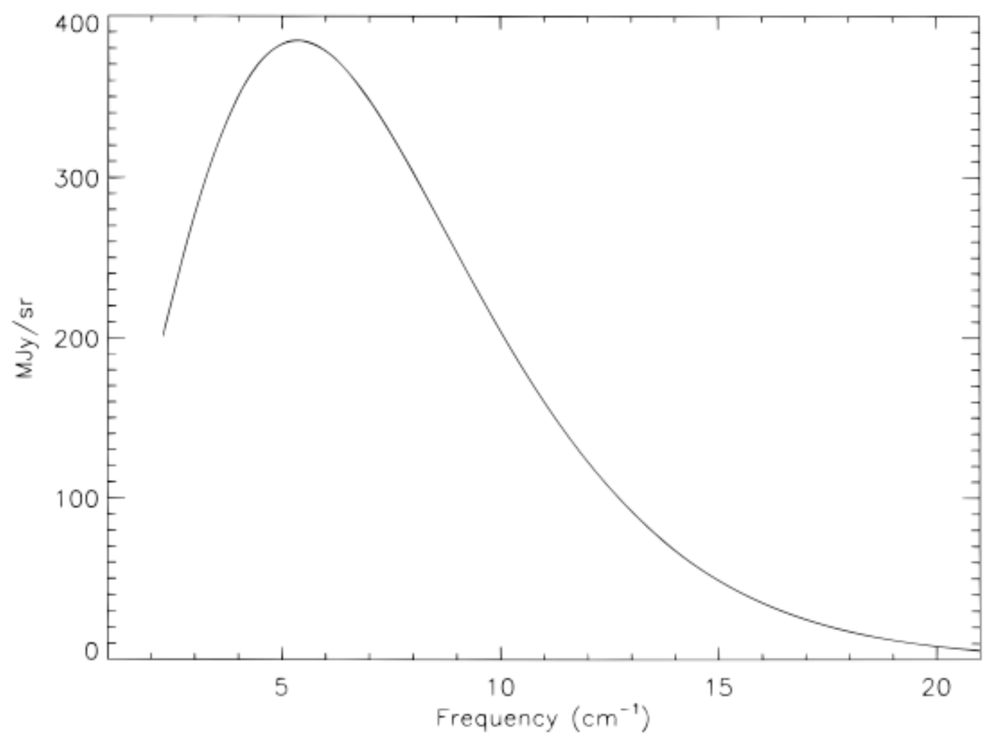


FIG. 4.—Uniform spectrum and fit to Planck blackbody (T). Uncertainties are a small fraction of the line thickness.

$$\mu = 1.4\frac{\delta\rho_\gamma}{\rho_\gamma} = 1.4\int_{t_1}^{t_2}\frac{\dot{\rho}_\gamma}{\rho_\gamma}dt = 1.4\int_{t_1}^{t_2}\frac{f m_\chi \langle\sigma v\rangle n_\chi^2}{\rho_{\gamma,0}a^{-4}}\mathrm{dt} \leq 9.0\times 10^{-5}$$

$5.1\text{x}10^{-4} \leq Z \leq 2\text{x}10^{6}$

<sv> ≤ $10^{-21}\text{cm}^3/\text{s}$

Looser constraint than from anisotropies

[McDonald, Scherrer, Walker ‘02]

[Zavala, Volgersberger, White ‘09]