Constraints on large DM annihilation cross sections from the early Universe

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Self-annihilating DM and the IGM

The smooth DM component annihilates with a rate (per volume)

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

depositing energy in the gas (IGM) at a rate

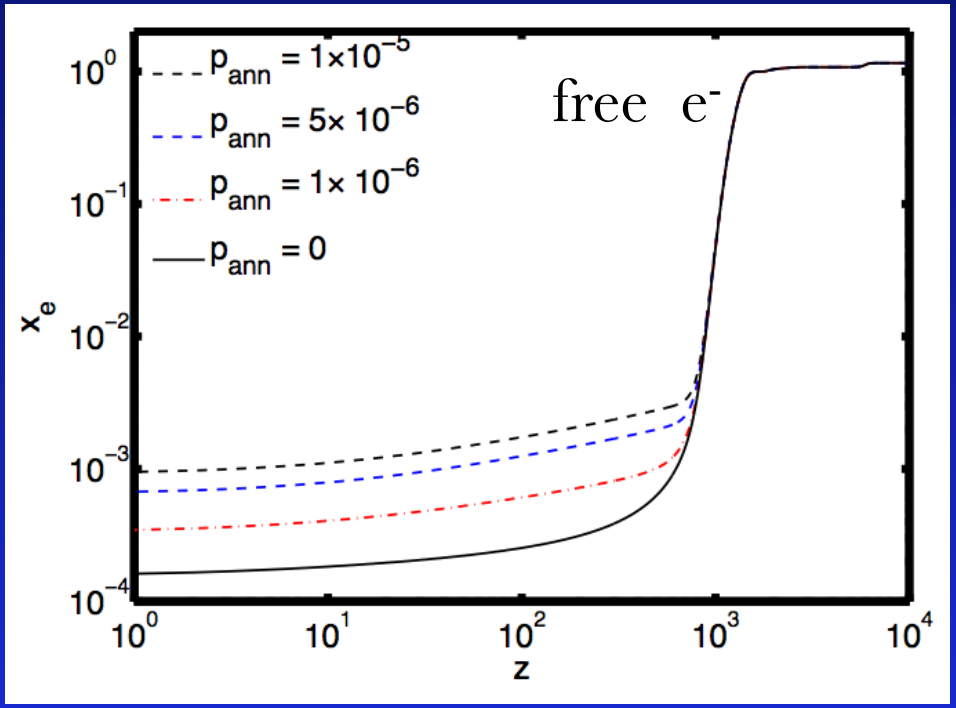
$$\frac{dE}{dt}(z) = \rho_c^2 c^2 \Omega_{DM}^2 (1+z)^6 f \frac{\langle\sigma v\rangle}{m_\chi}$$

The only DM parameter is

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

About "f", in Satyer's talk

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



[Galli et al. 09]

Structure formation "boosts" DM annihilation

Smooth component

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

Structure component

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

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

DM density halo profile
Burkert / Einasto / NFW

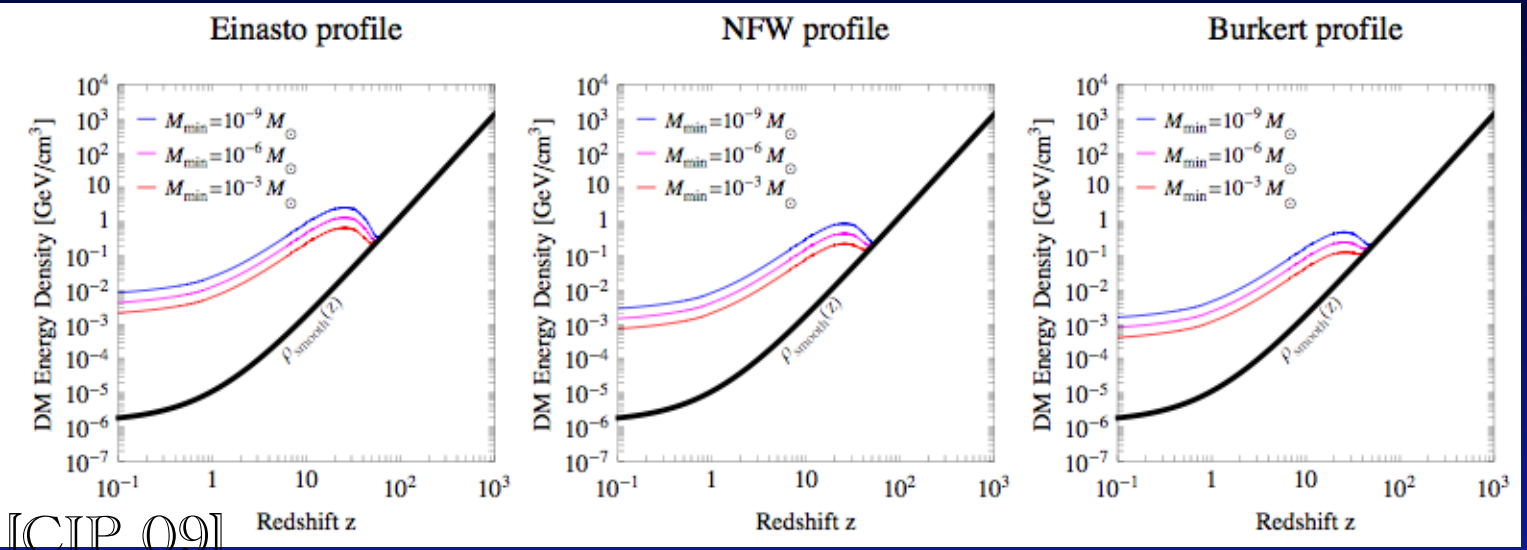
$$A(z) = \frac{\langle\sigma v\rangle}{2\,m_\chi^2}\rho^2_{\rm DM,0}(1+z)^6\,(1+\mathcal{B}_{\rm M}(z))$$

Structure formation starts at z ~ 150
with minihalos of Earth mass 10^{-6} Msun

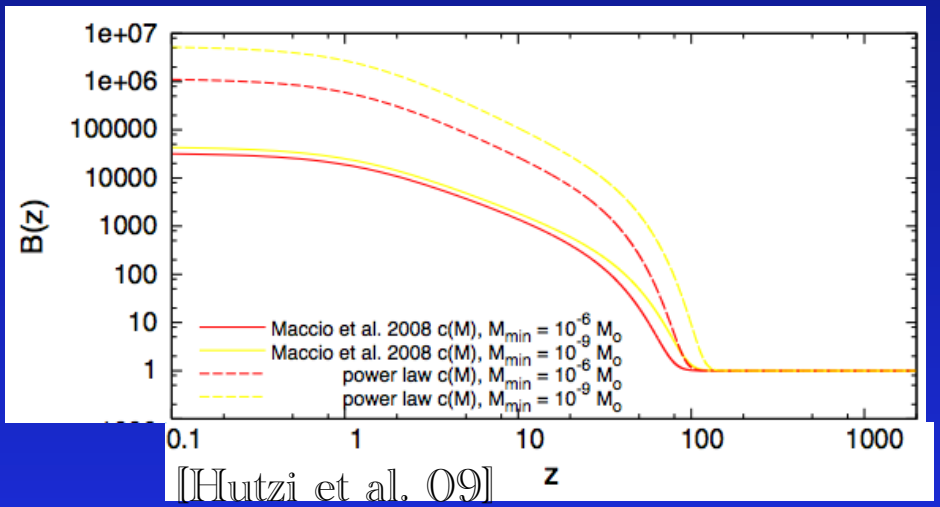
Structure boost: parameter dependence

$M_{min}=M_{fs}(?)$

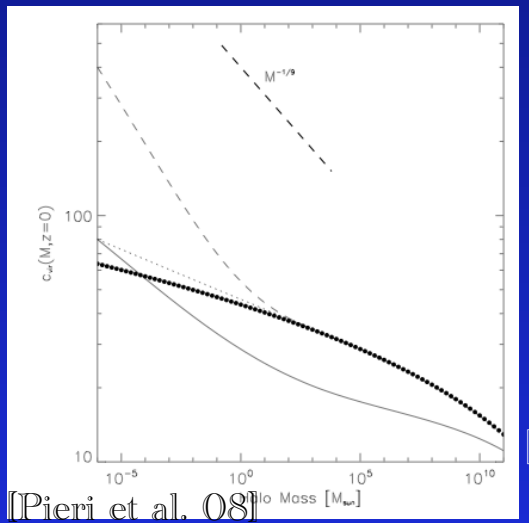
$C_{vir}(M) = ?$



[CIP 09]



[Hutzi et al. 09]



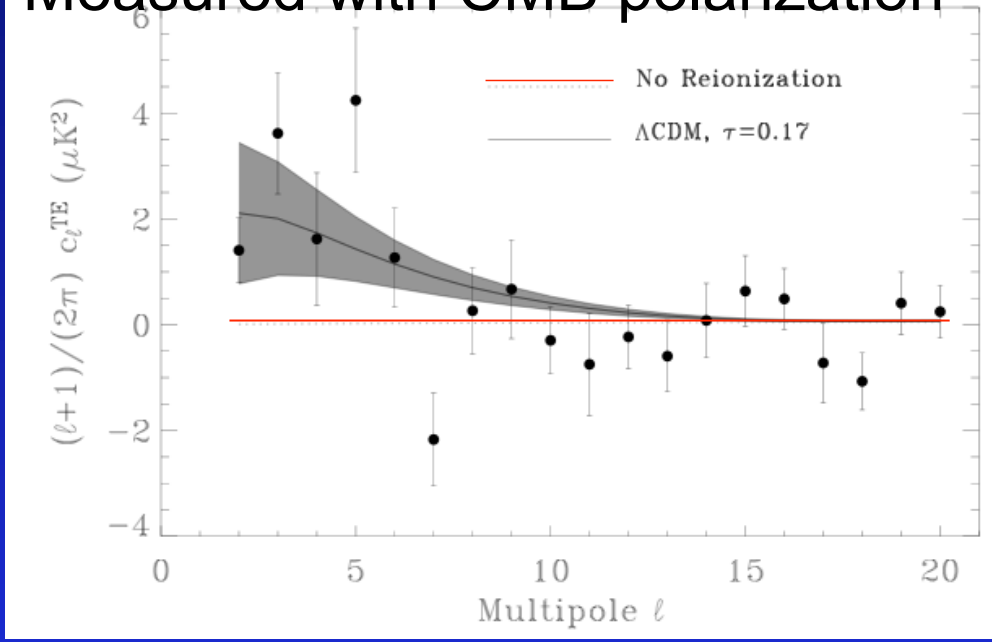
[Pieri et al. 08]

[Maccio' et al 08]
and others

Electron optical depth τ

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

Measured with CMB polarization



Integrated quantity!

WMAP 5 value

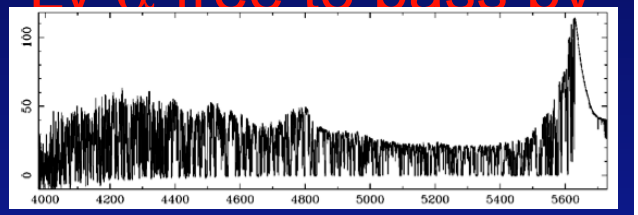
$$\tau = 0.084 \pm 0.016$$

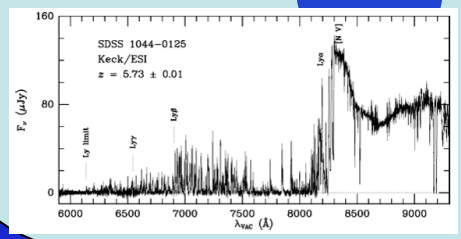
A quick view on “Reionization”

$\delta\tau = 0.038$

Neutral:
Ly-α absorber

Ionized:
Ly-α free to pass by





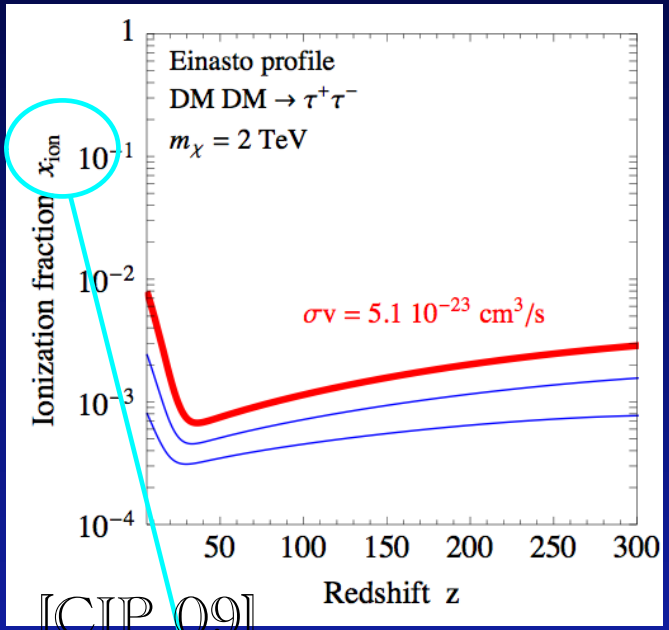
Completely ionized IGM

z ~ 6

z

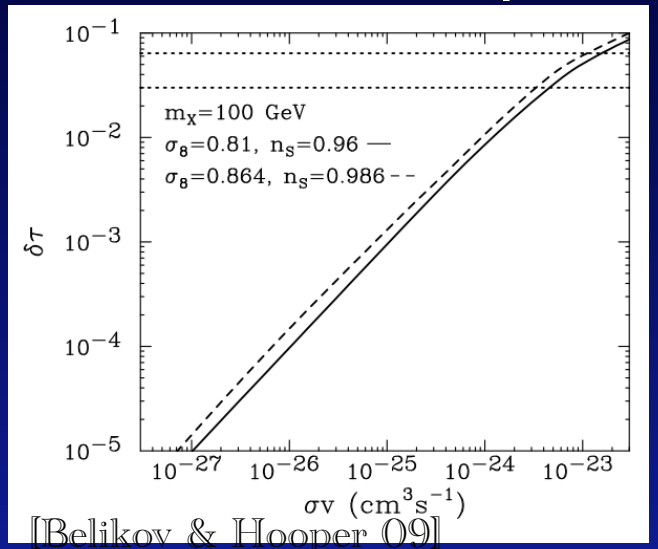
τ constraints

(annihilation from structures can overproduce free e^-)



[CIP 09]

To be integrated!

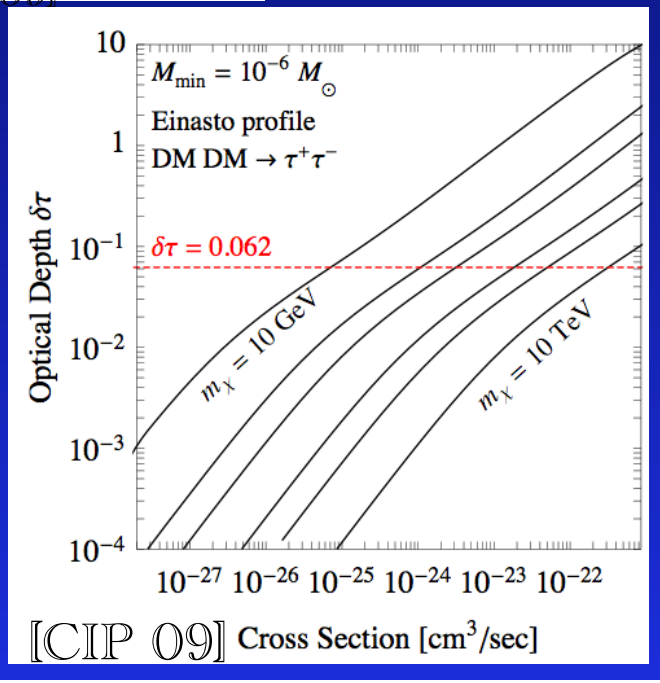


[Belikov & Hooper 09]

In this models:

no astrophysical sources

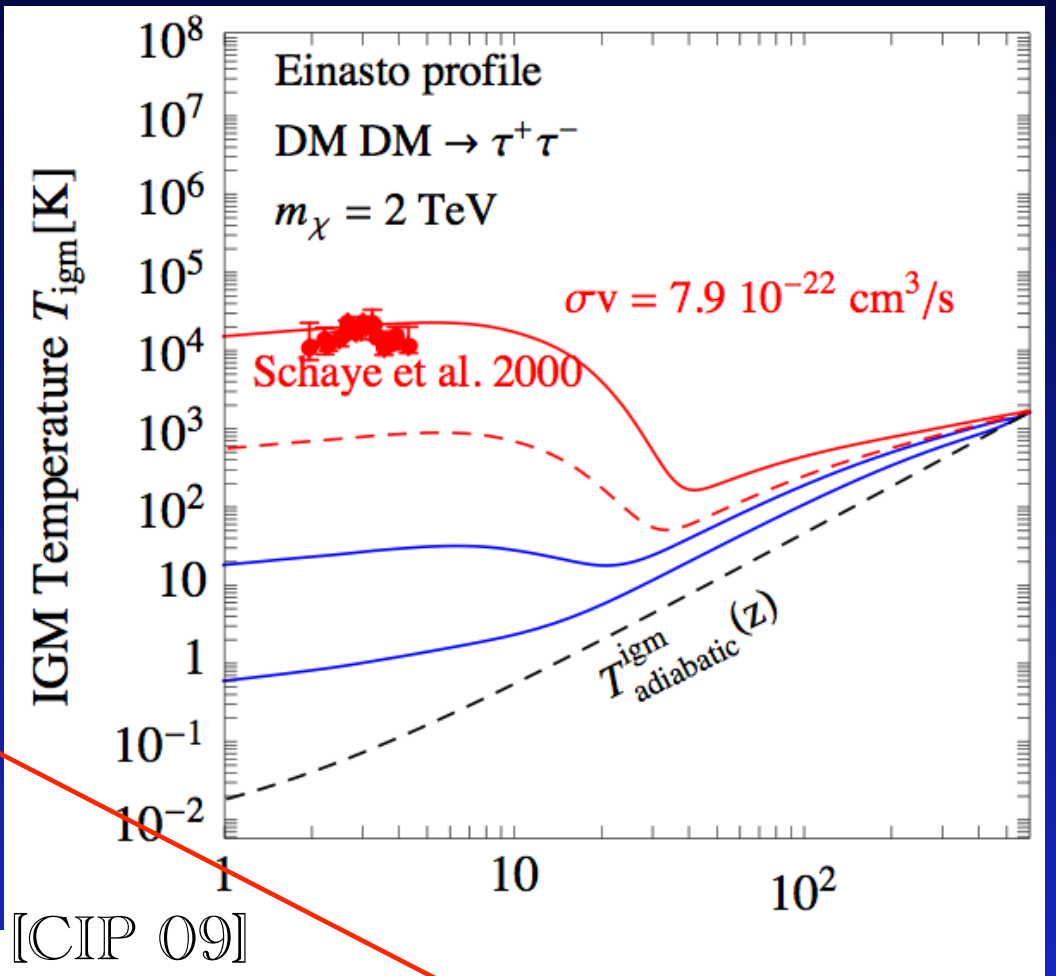
Extra-conservative bounds!



[CIP 09]

Temperature constraints!

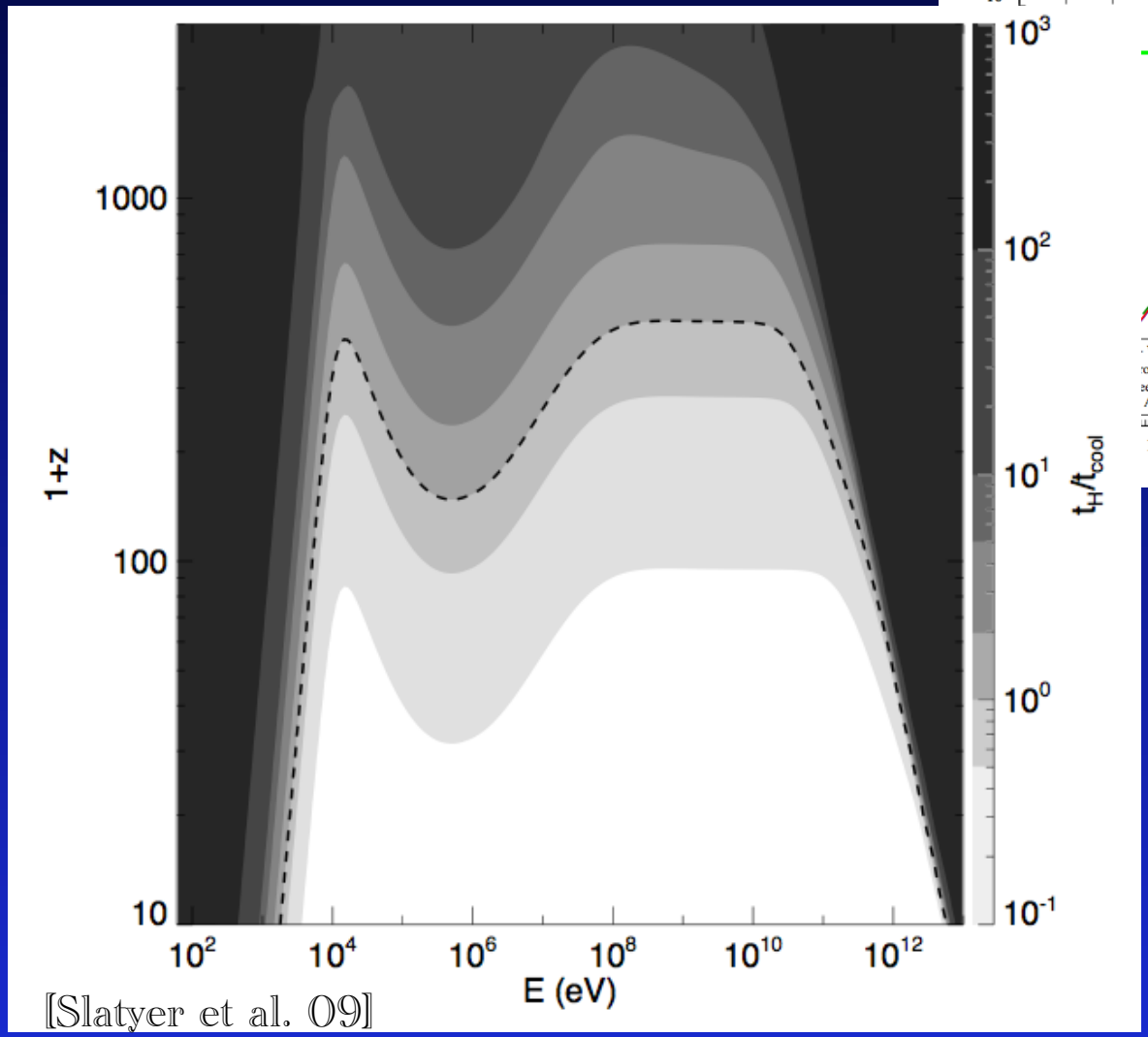
"Exotic heating":
DM, after coupled f
1/3 heat, 1/3 ioniz. 1/3 Ly-α



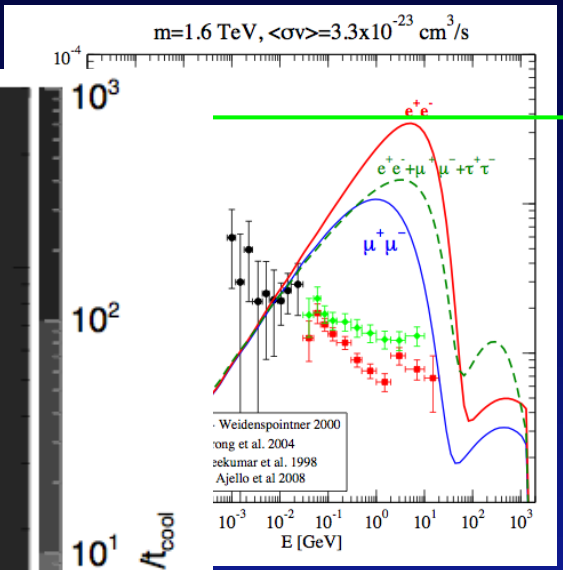
[CIP 09]

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

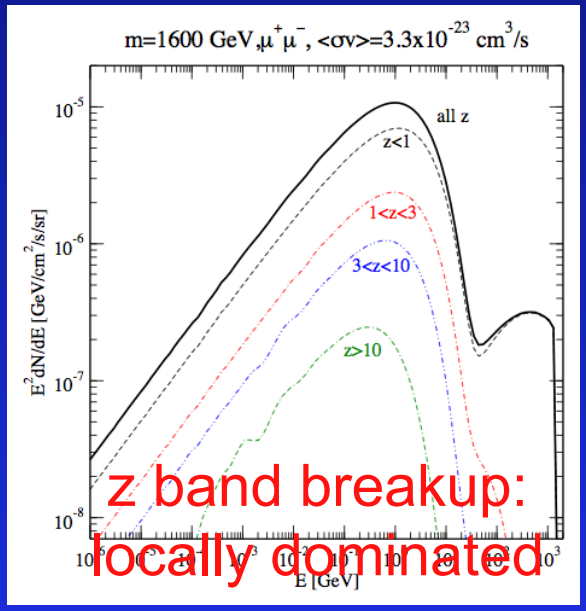
Watching negative: gammas



[Slatyer et al. 09]



e^+ e^- boost IC

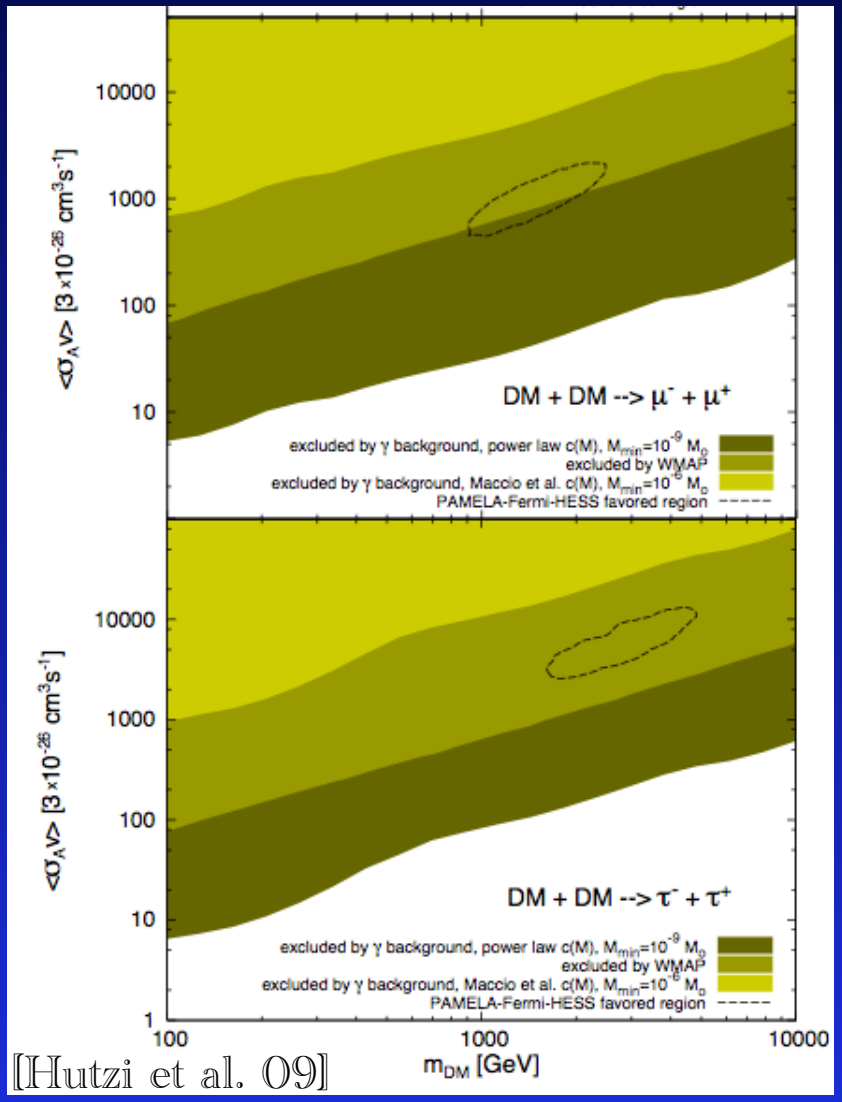


z band breakup: locally dominated

[Profumo & Jeltema 09]

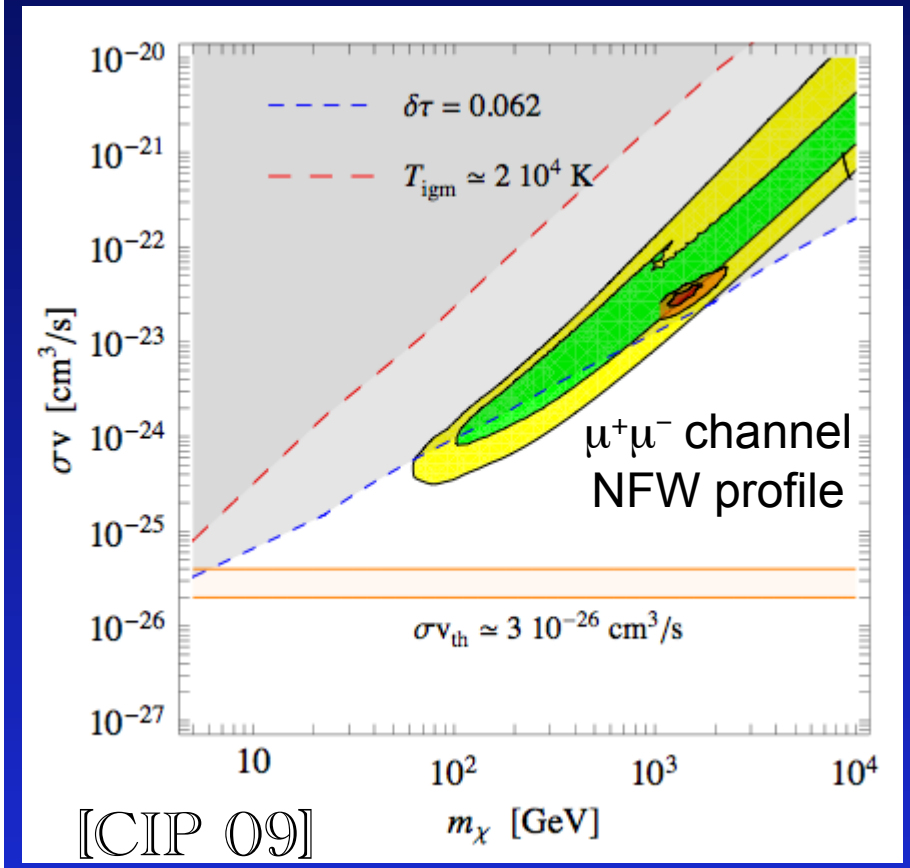
Combining the constraints

gammas + τ



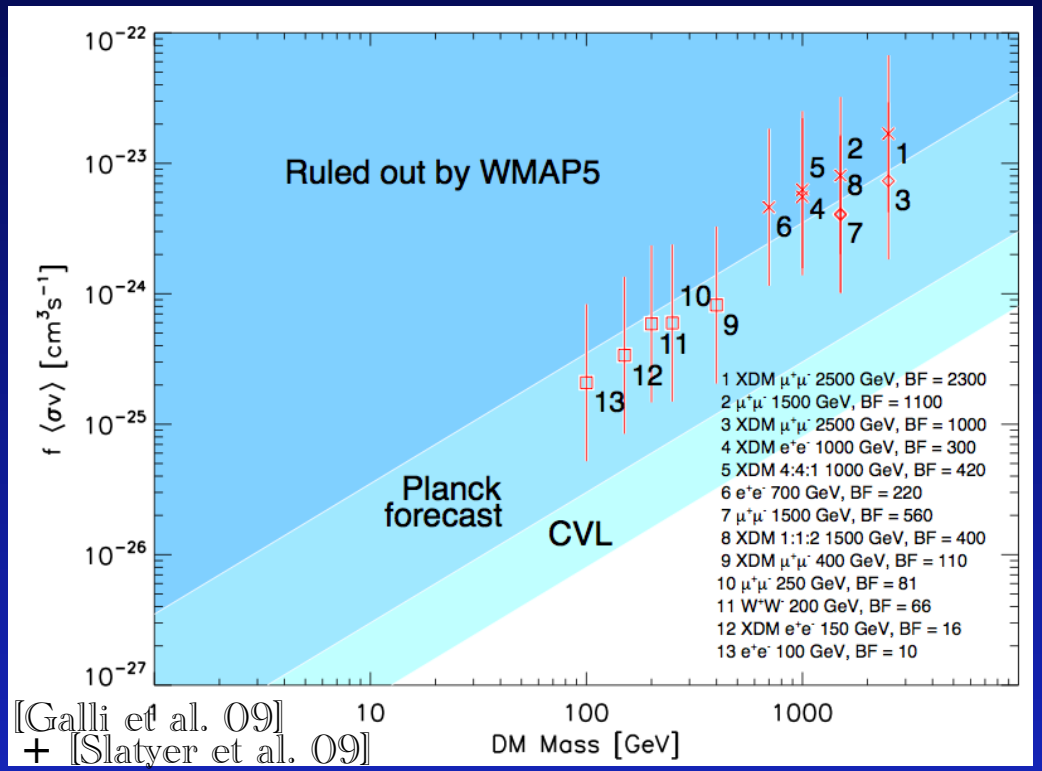
[Hutzi et al. 09]

τ + IGM temperature

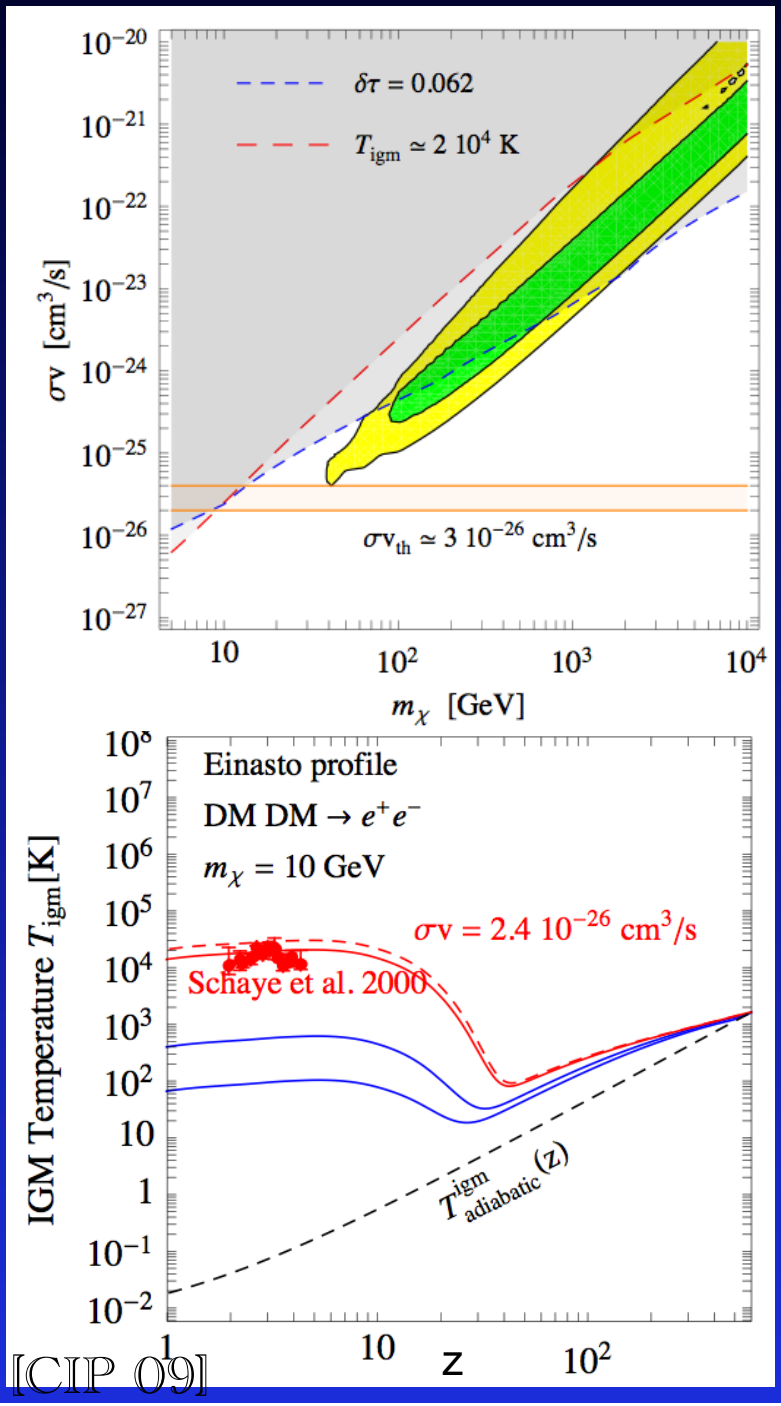


[CIP 09]

Down to thermal cross-section!



[Galli et al. 09] + [Slatyer et al. 09]



[CIP 09]

Concluding

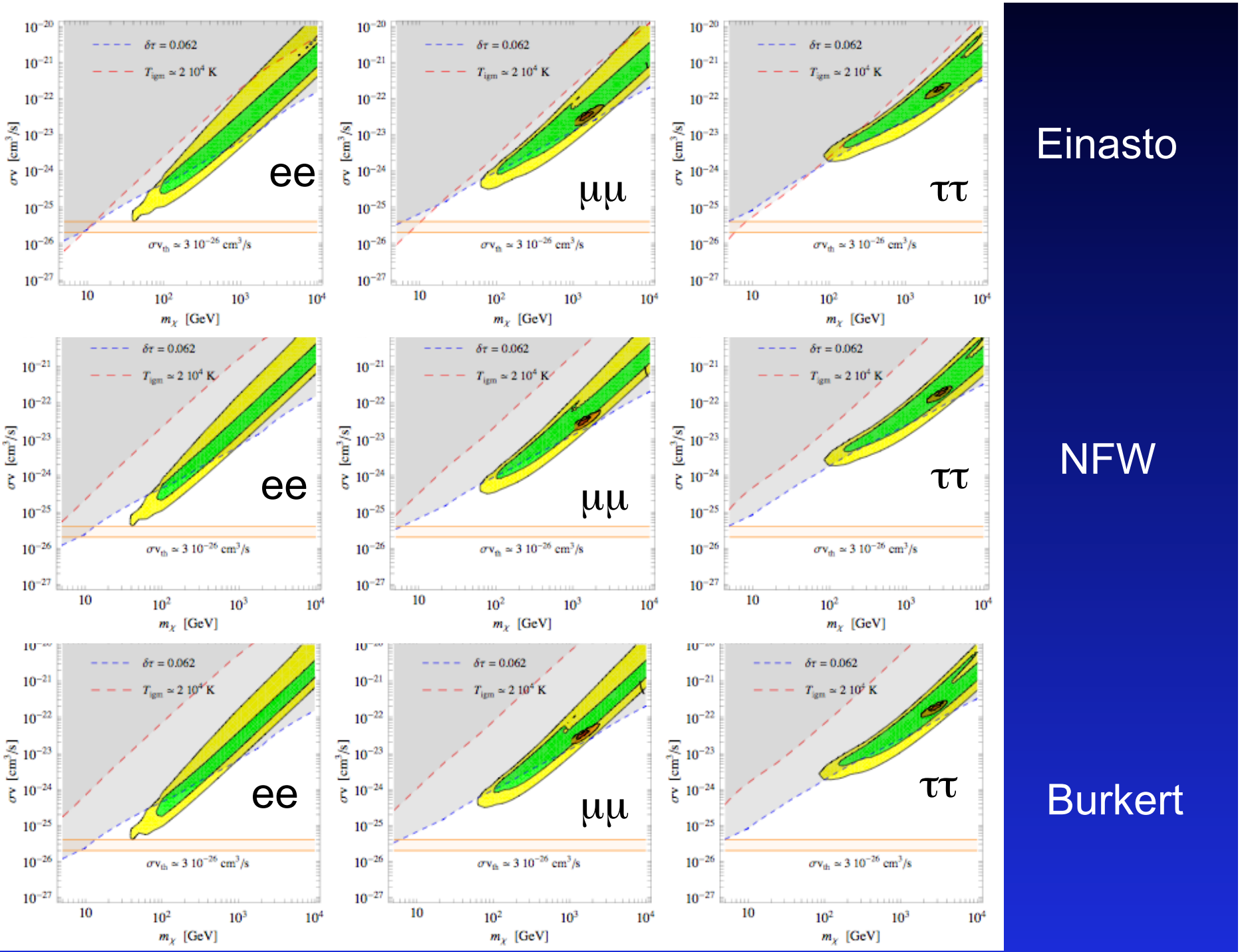
Early Universe astrophysical observables
can constrain DM properties

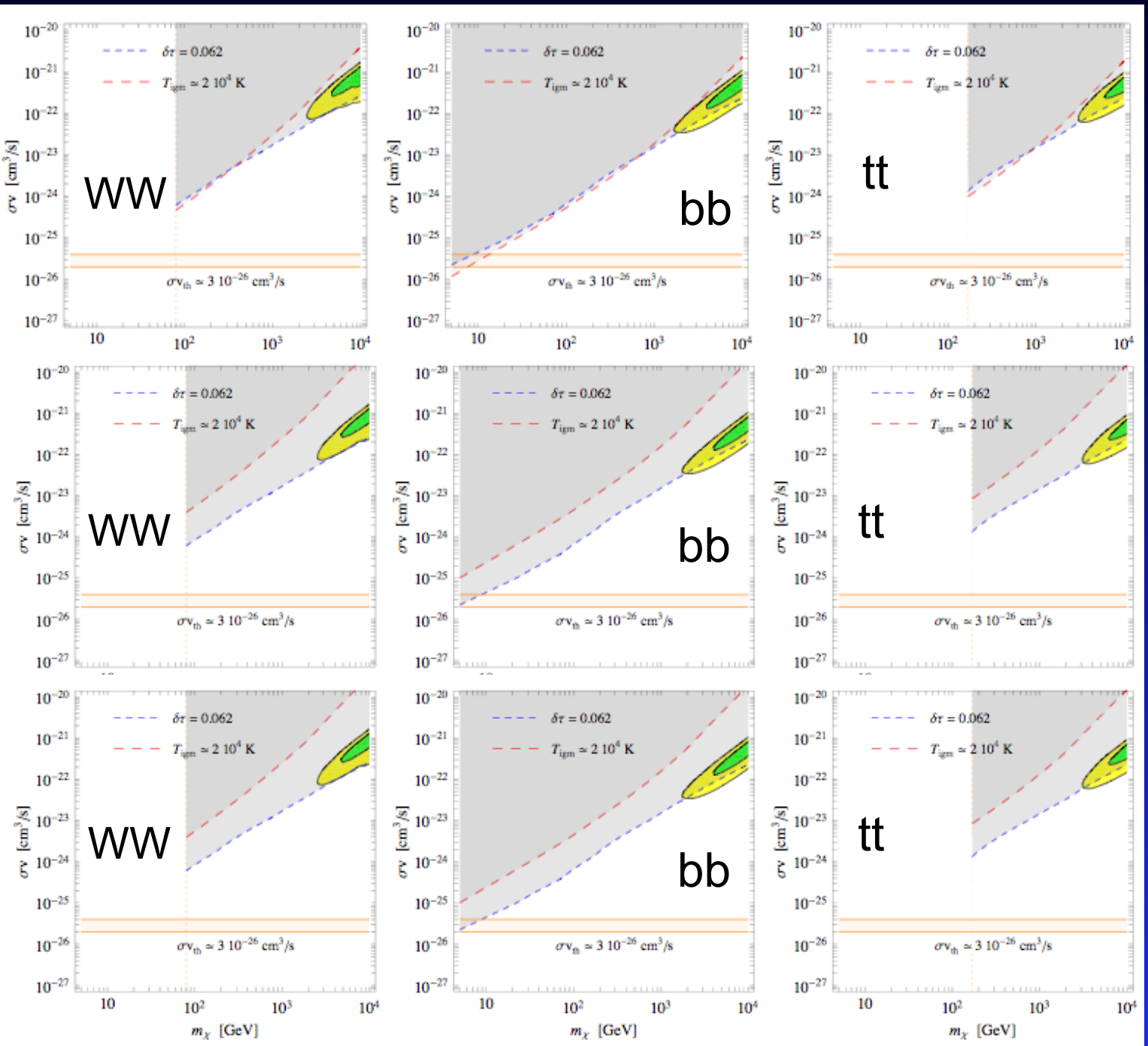
The constraints are strong, competitive
with local Universe ones (astroph. uncertainties)
(getting to thermal value of $<\sigma v>$!!!)

Going technical

Can we reionize the Universe with DM?
Yes we can!

AND it is not structures to do it: smooth, cold component
(getting rid of astro-simulation uncertainties, too)


Einasto
NFW
Burkert
ee
μμ
ττ
δτ = 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]


ww
bb
tt
Einasto
NFW
Burkert
$\delta\tau = 0.062$
$T_{igm} \simeq 2\ 10^4$ K
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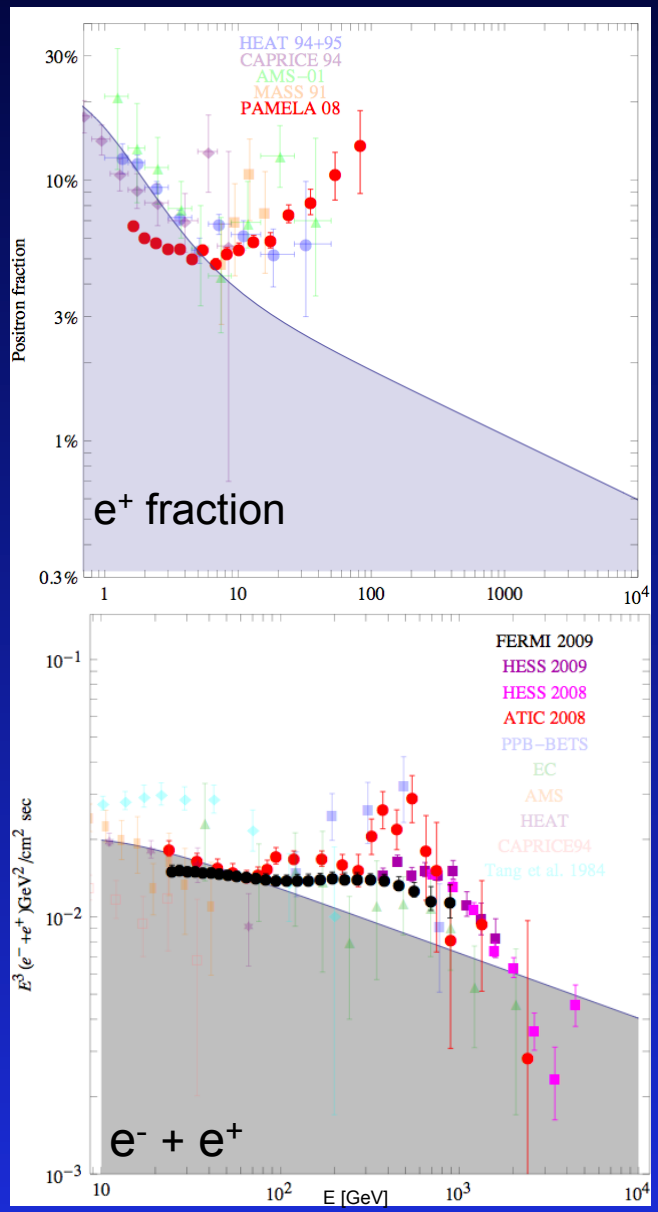
σv [cm^3/s]
m_χ [GeV]

The Pamela(/Fermi/ATIC) saga



By courtesy of M. Cirelli

IF intepreted as DM:

High annih cross-section
$\langle\sigma v\rangle \sim 10^{-24}$-$10^{-21}$ cm^3/s
Forget about
thermal decoupling
WIMP miracle

Unless

$\langle\sigma v\rangle = \langle\sigma v\rangle(v)$

DM decoupling: $\beta \sim 1$

Recombination: $\beta \sim 10^{-8}$

Small halos: $\beta \leq 10^{-4}$

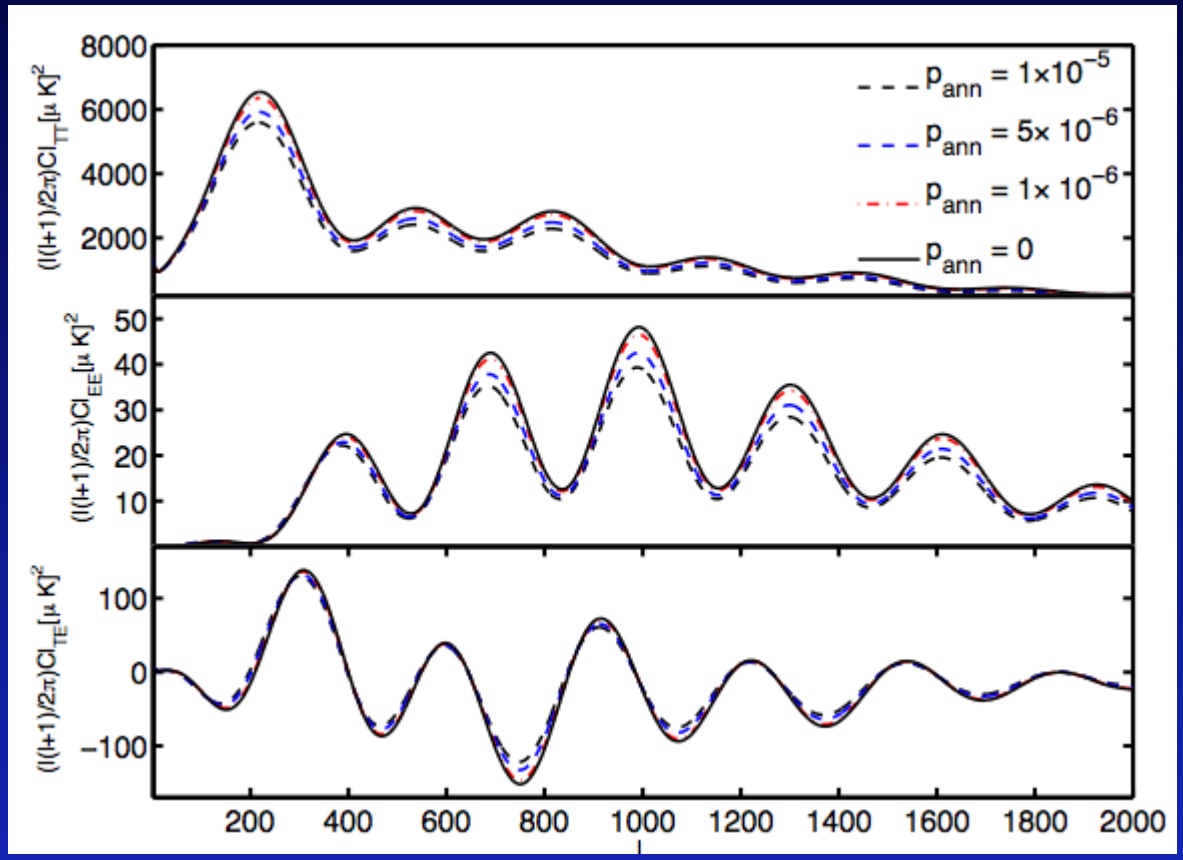
Milky Way: $\beta \sim 10^{-4}$

"Sommerfeld" enhancement
fulfills the requirements
(higher masses preferred)

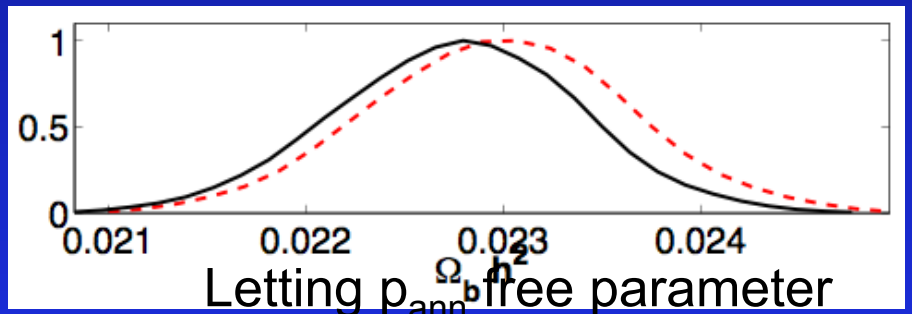
Self-annihilating DM and the CMB

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

$z>1000$ there are many e^-
no effects
Energy injection is small



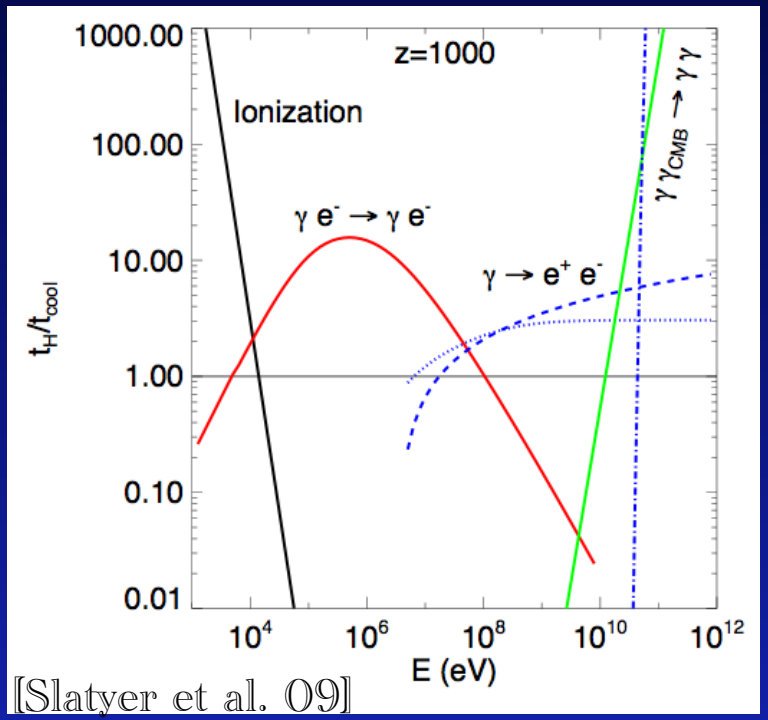
Modifying TT, TE, EE with additional e^- (by DM annih)



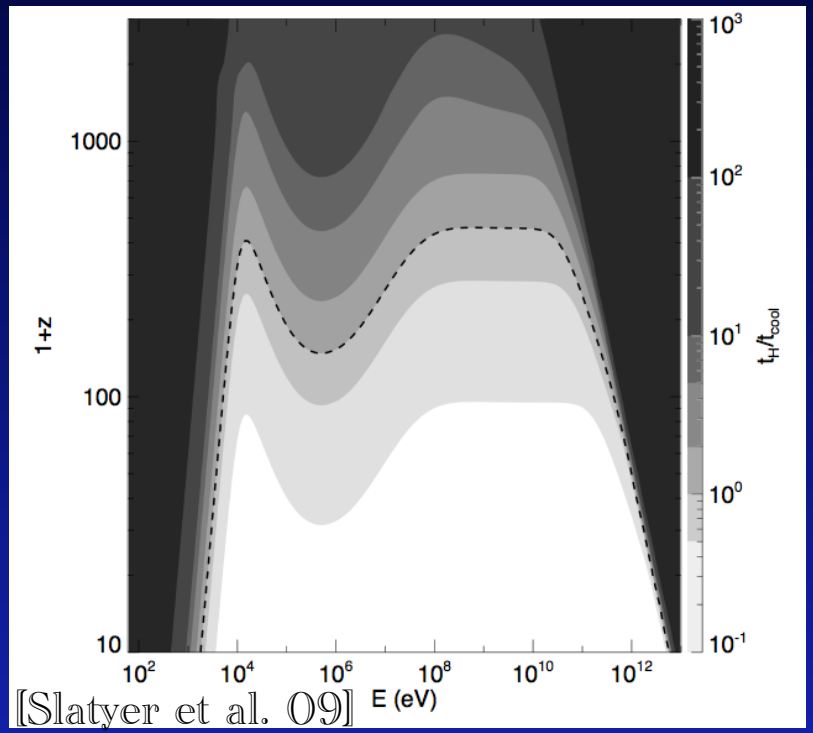
Letting p_{ann} free parameter

[Galli et al. 09]

A little more about "f"
(coupling DM induced shower to IGM)



[Slatyer et al. 09]



[Slatyer et al. 09]

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

"Opacity window"
of the Universe

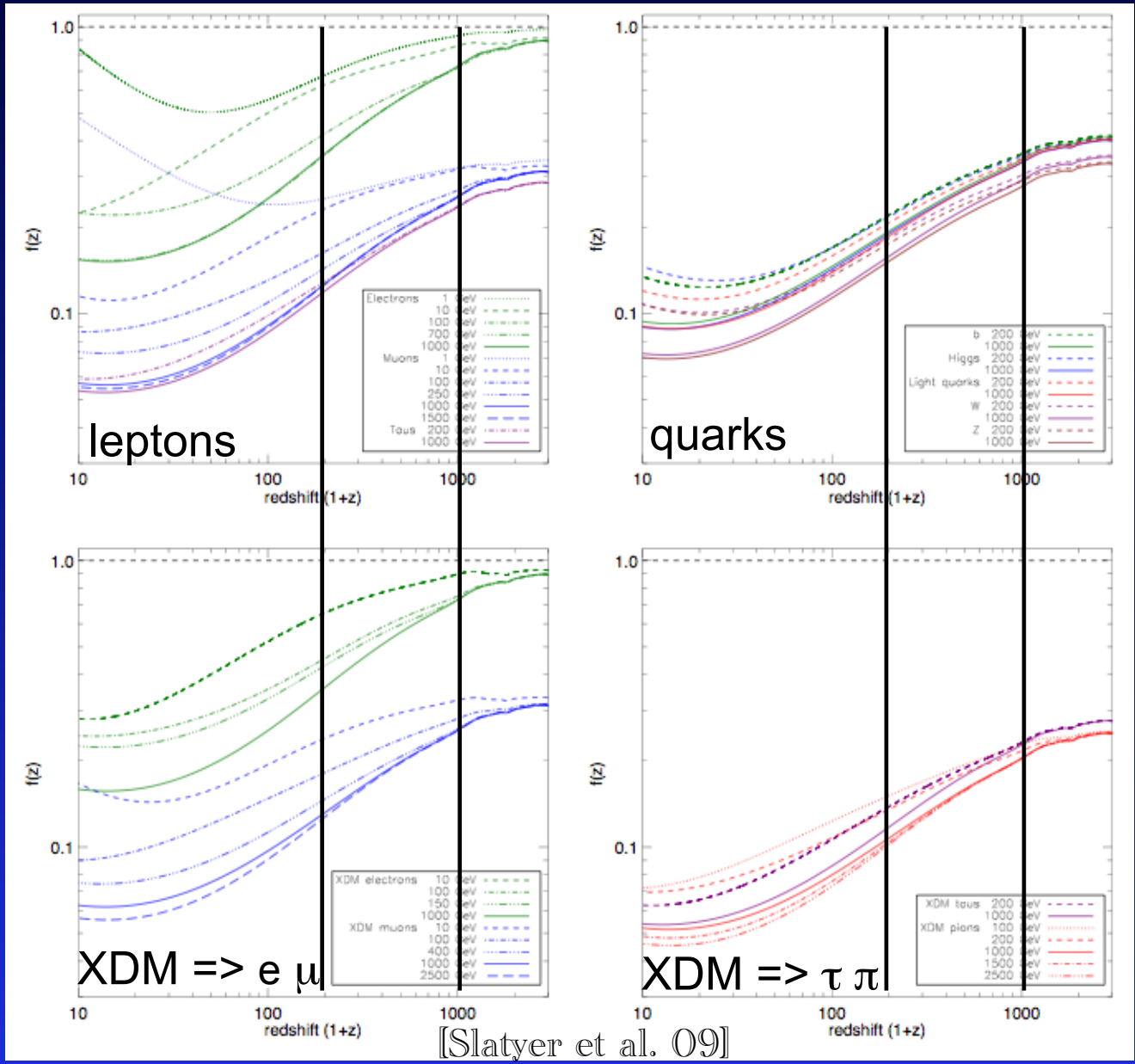
"f" is DM model-dependent:
type of secondaries is important!

Evaluating "f"

All channels,
all secondaries,
redshift dependence

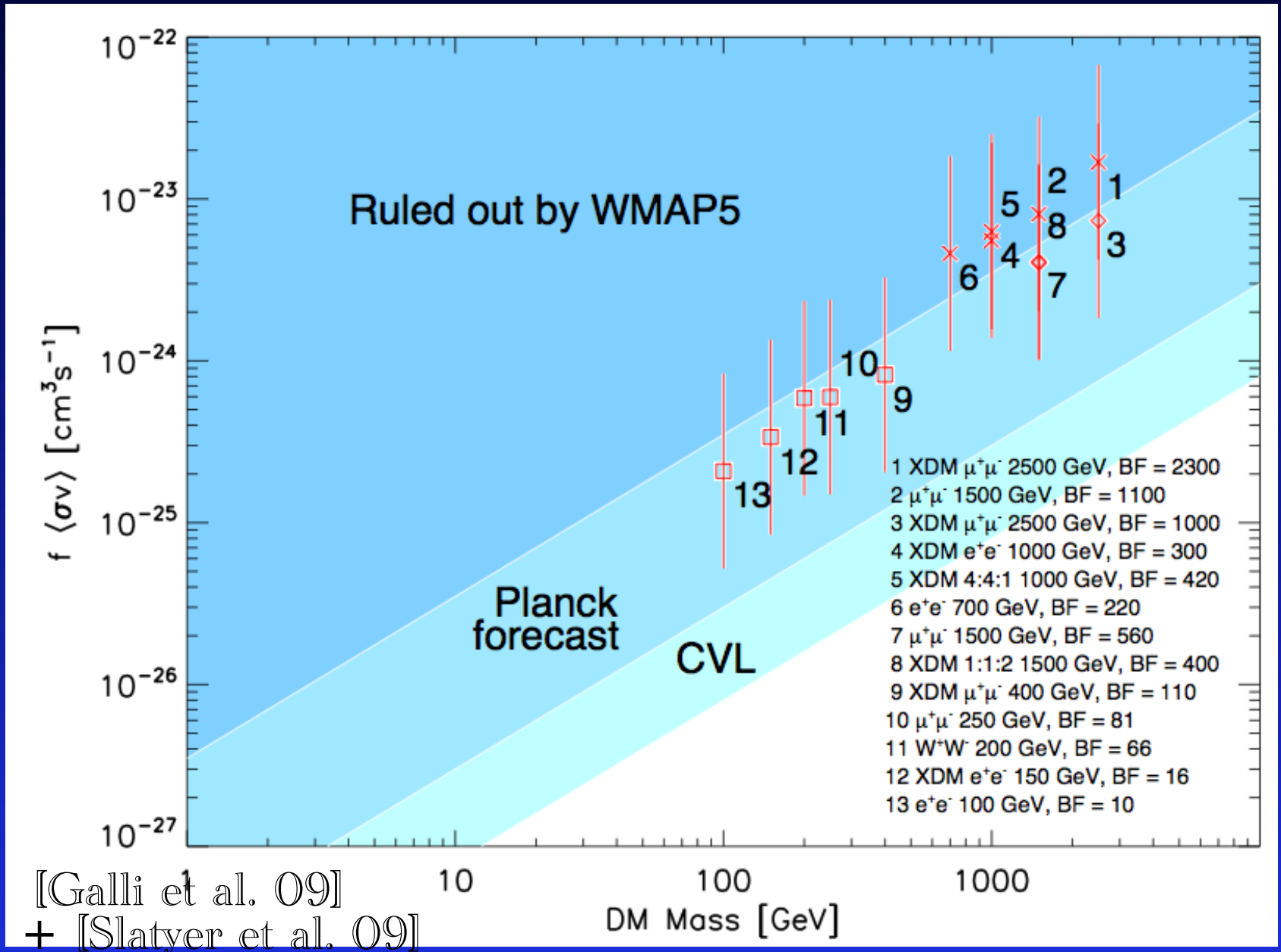
Branching ratio of
DM annihilation
essential for
determining absorption

Little reminder:
Pamela is leptophilic
from greek:
"it likes it small"



[Slatyer et al. 09]

Constraining DM with CMB



[Galli et al. 09]
+ [Slatyer et al. 09]

Constraining SE with CMB

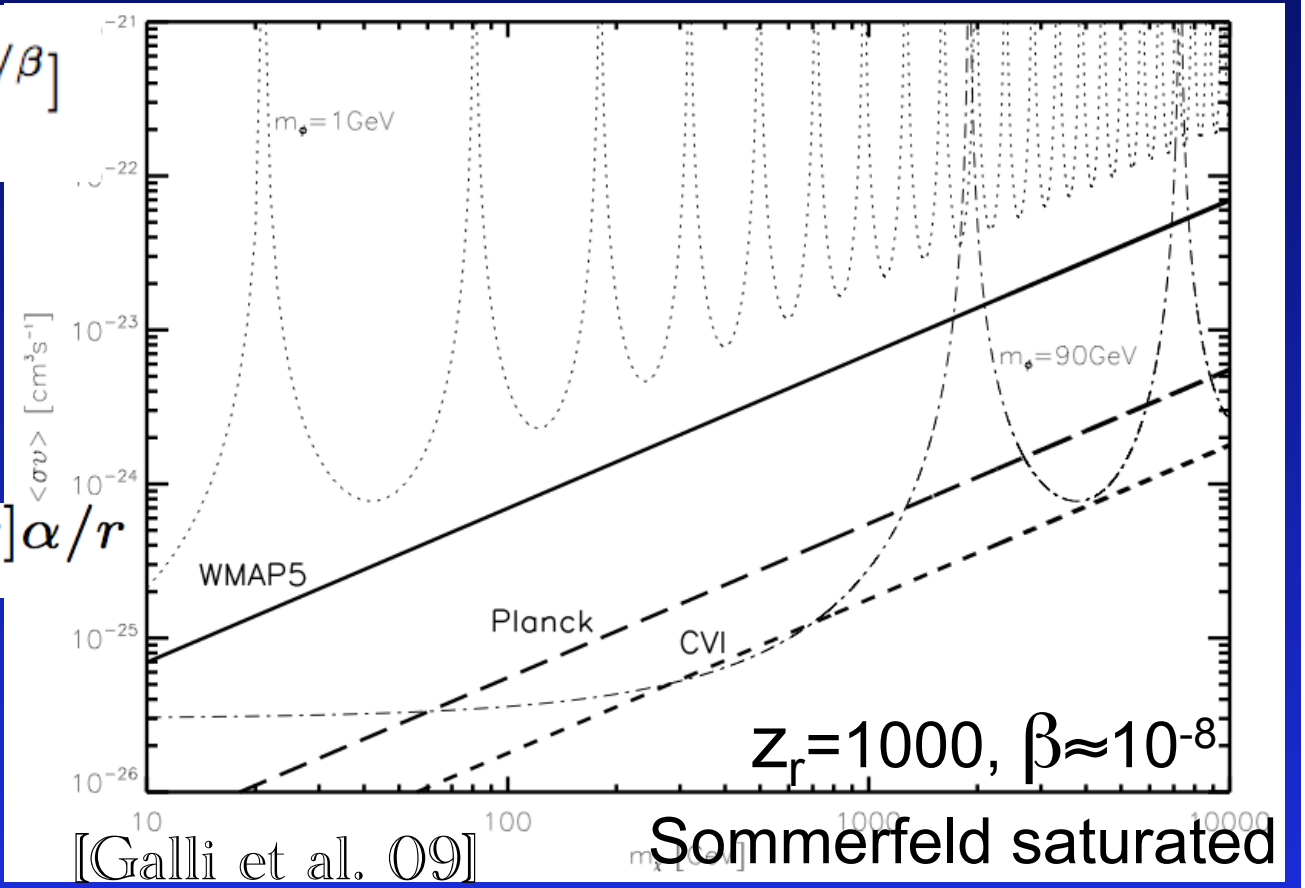
$$\psi''(r) - m_\chi V(r)\psi(r) + m_\chi^2\beta^2\psi(r) = 0$$

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

Sommerfeld enhancement

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

Yukawa potential a benchmark model



[Galli et al. 09]

Sommerfeld saturated