

The Recombination epoch of the Universe with dark matter: constraints on self-annihilation cross sections

Silvia Galli

Laboratoire APC, Paris
University of Rome La Sapienza



SAPIENZA
UNIVERSITÀ DI ROMA

TeVpa 2010

22/07/2010

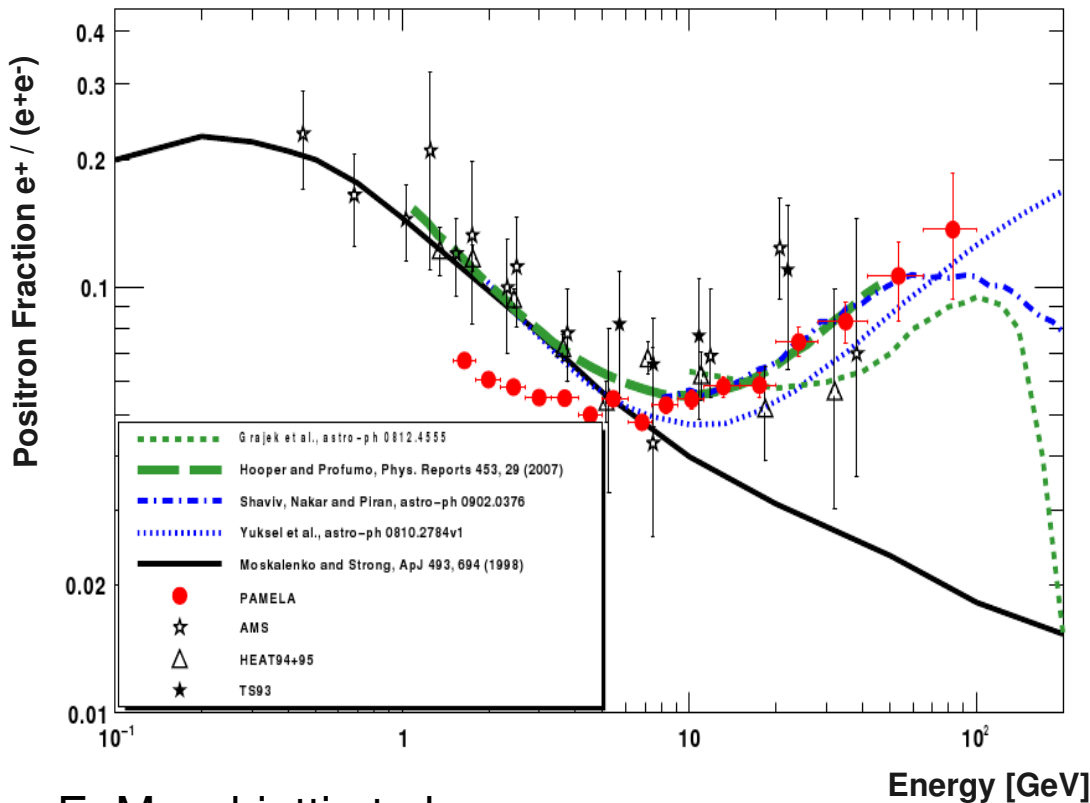
Outline

- Motivations:
 - Pamela, Atic, Fermi + study of recombination model
- Theory:
 - Standard Recombination
 - Recombination with DM annihilation
- Results
 - Constraints from WMAP5
 - Constraints from future experiments.
- Conclusions

Motivations

- **Anomalies:** excess in the **positron** electron fraction and in the energy spectrum of **electrons**.
- Several explanations: pulsar emission, dark matter decay, **dark matter annihilation** etc...

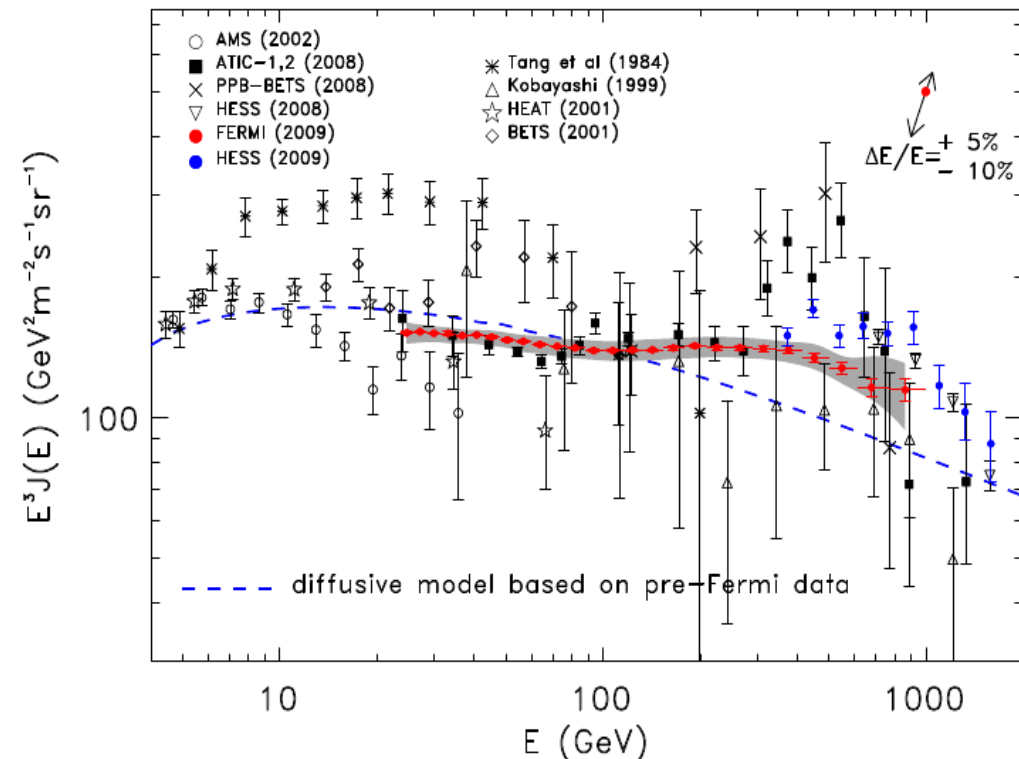
Positron Electron Fraction



E. Mocchiutti et al.
arXiv:0905.2551v1

Pamela

Electron Spectrum



Latronico et al.(Fermi Lat-collaboration)
arXiv:0907.0452v 1

Atic, Fermi

Motivations

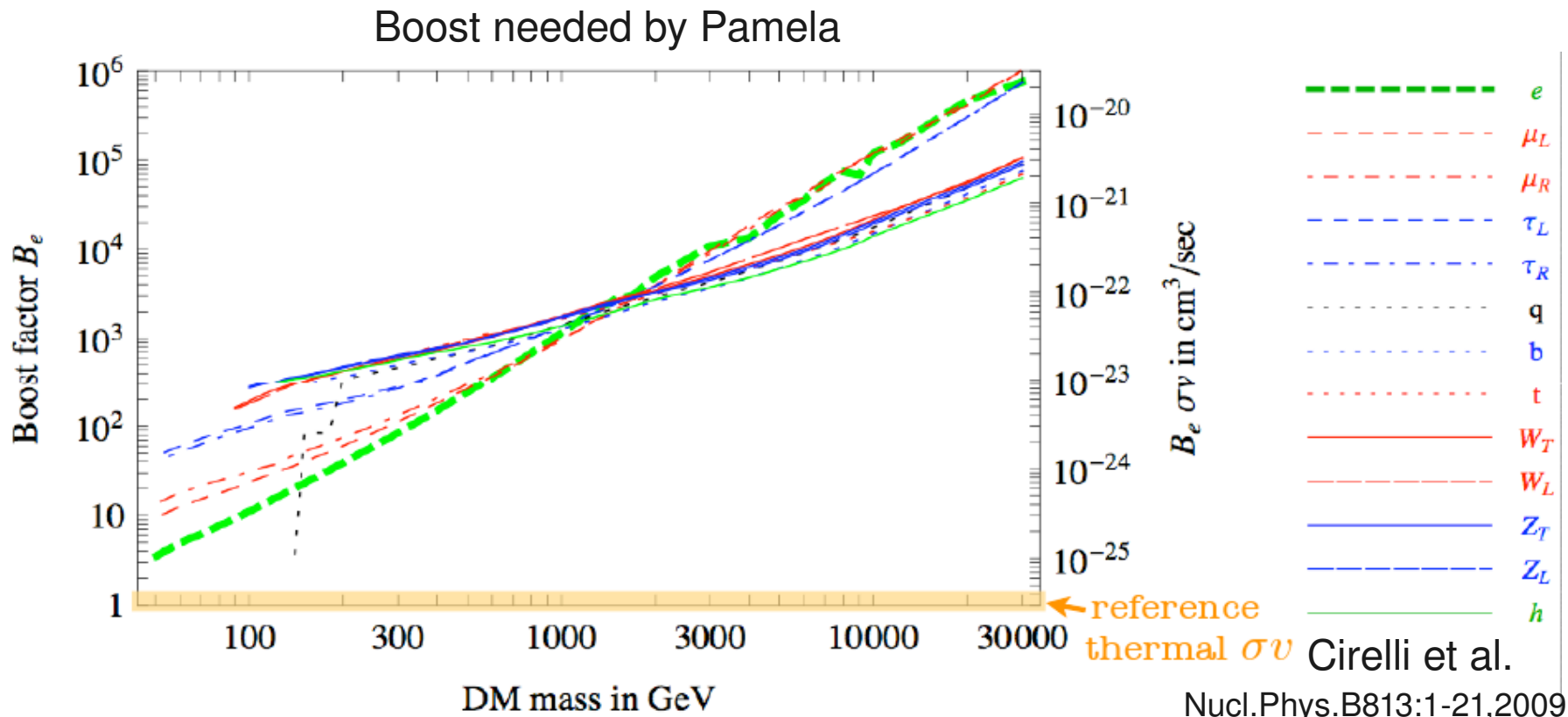
→ Thermal production of DM:

$$\langle \sigma v \rangle \sim 10^{-26} \text{ cm}^3/\text{s. (WIMP)}$$

→ Annihilation rate:

$$\Gamma \propto n^2 \langle \sigma v \rangle. \text{ n from dm simulations, models, observations}$$

Astrophysical or Particle Physics **BOOST** to explain the data.



Motivations

→ Thermal production of DM:

$$\langle\sigma v\rangle \sim 10^{-26} \text{ cm}^3/\text{s. (WIMP)}$$

→ Annihilation rate:

$$\Gamma \propto n^2 \langle\sigma v\rangle. \text{ n from dm simulations, models, observations}$$

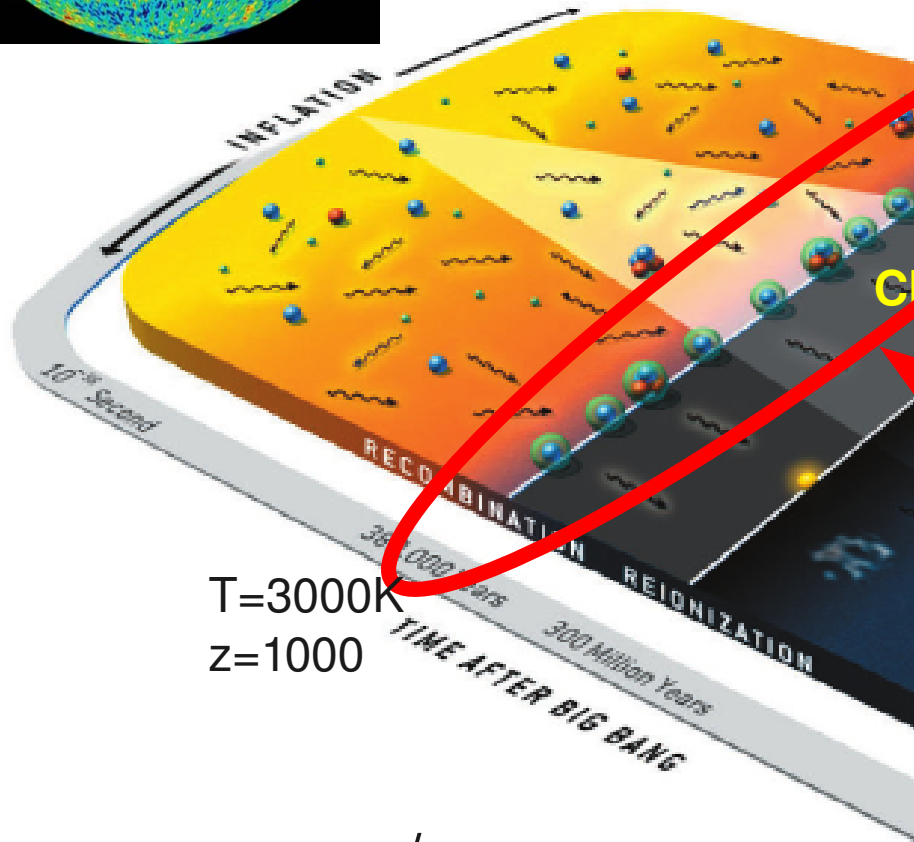
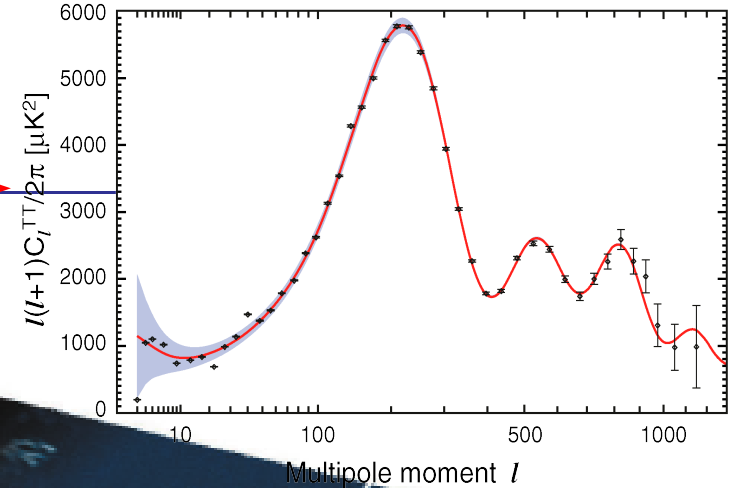
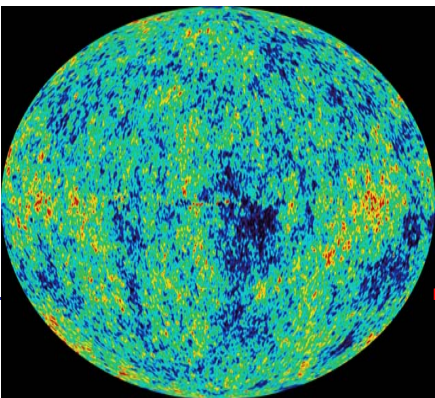
BOOST of the cross section to explain the data, depends on mass of DM and annihilation channel.

Dark Matter annihilation should leave a signature in CMB:

→ At ($z \sim 1000$), when CMB forms, the homogenous dark matter density is $n(z=1000) = n_{\text{today}} (1+z)^3 \sim n_{\text{today}} \times 10^9$

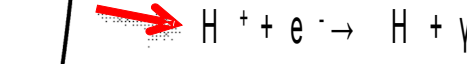
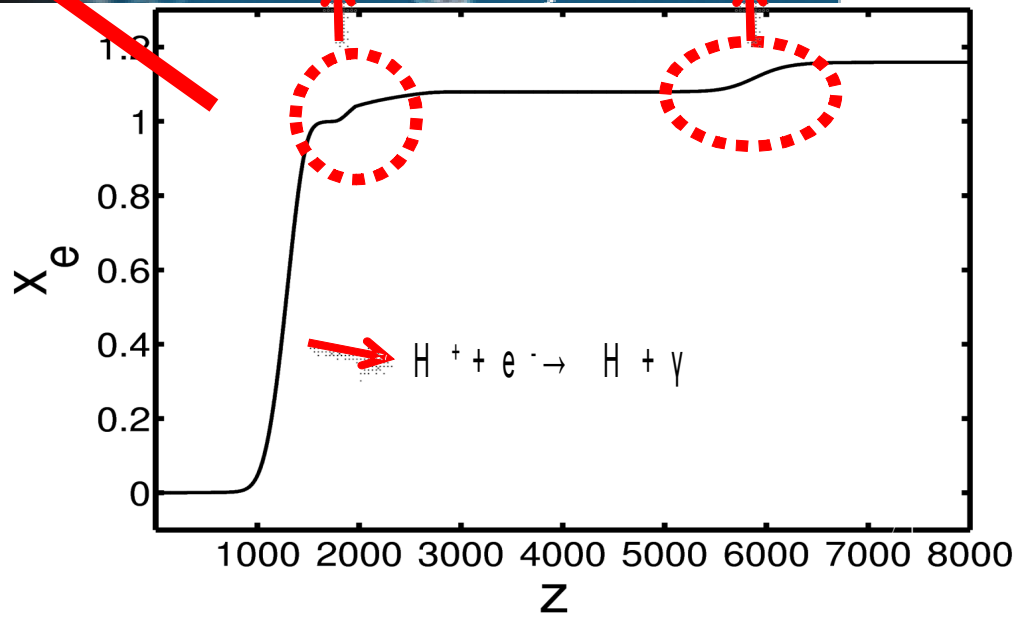
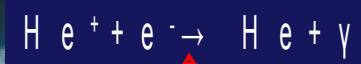
→ DM mean velocity $\beta \sim 10^{-8}$. Favours Sommerfeld Enhancement.

Standard Recombination



$T=3000\text{K}$
 $z=1000$

$$x_e = n_e / n_H$$



Extra Lyman Alpha and ionizing photons in recombination: not only from dark matter

- Lyman alpha and ionizing photons are the most important in changing recombination
- Several possible Sources of extra ionizing and Lyman Alpha photons:

Dark Matter Decay and annihilation (A.G.Doroshkevich and P.D. Naselsky.

Phys.Rev. D, 65(12), 2002, J. Kim and P. Naselsky, arXiv:0802.4005 [astro-ph]. A. Lewis, J. Weller, and R. Battye, *Mon. Not. Roy. Astron., Soc.* 373, 561 (2006) [arXiv:astro-ph/0606552]. A. G. Doroshkevich and P. D. Naselsky, *Phys. Rev. D* 65, 123517 (2002) [arXiv:astro-ph/0201212]; P. D. Naselsky and L. Y. Chiang, *Phys. Rev. D* 69, 123518 (2004) [arXiv:astro-ph/0312168]; E. Pierpaoli, *Phys.Rev. Lett.* 92, 031301 (2004) [arXiv:astro-ph/0310375]; X. L. Chen and M. Kamionkowski, *Phys. Rev. D* 70, 043502 (2004) [arXiv:astro-ph/0310473]; N. Padmanabhan and D. P. Finkbeiner, *Phys. Rev. D* 72, 023508 (2005) [arXiv:astro-ph/0503486]; M. Mapelli, A. Ferrara and E. Pierpaoli, *Mon. Not. Roy. Astron. Soc.* 369, 1719 (2006) [arXiv:astro-ph/0603237] and many others.....

Evaporating Black Holes (P.D. Naselsky A.G. Polnarev. *Sov.Astron.Lett.*, 13:67, 1987.)

Cosmic string decays, magnetic monopoles etc...

Testing a specific Model:

Dark Matter annihilation

- Lyman alpha and ionizing photons affects x_e and

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

Energy injection rate

One new parameter that contain:

f = energy fraction to plasma

$\langle \sigma v \rangle$ = cross section

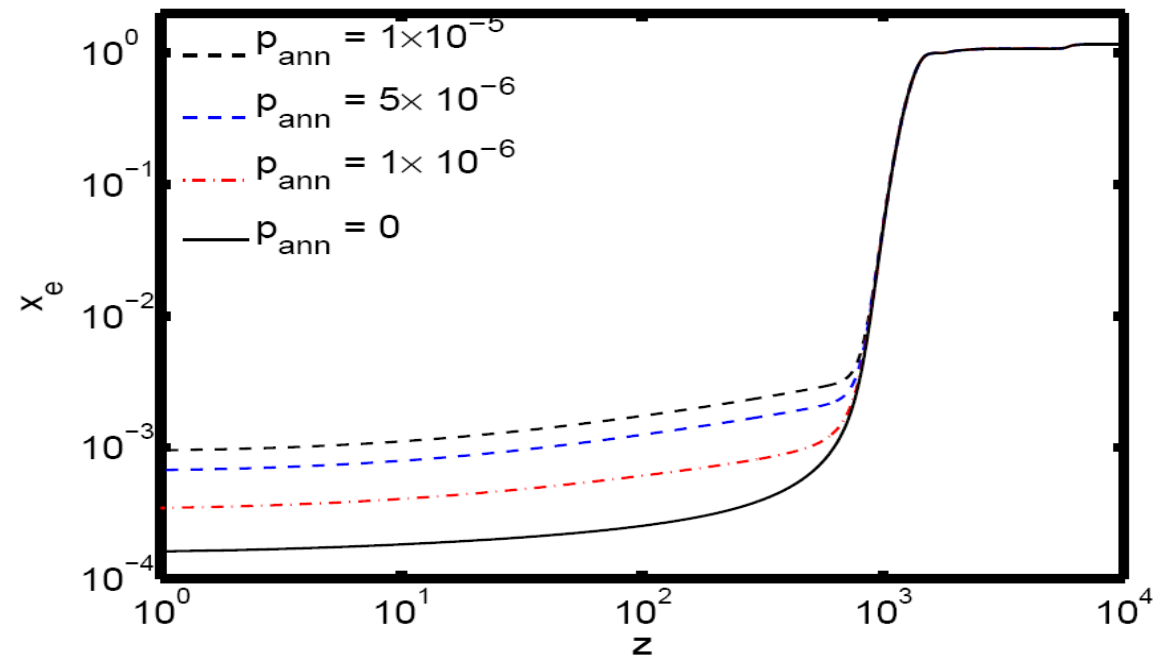
m_χ = mass of the annihilating particle

Redshift dependence of the injection rate of Lyman alpha (ϵ_α), ionizing (ϵ_i) photons and heating term that changes matter temperature

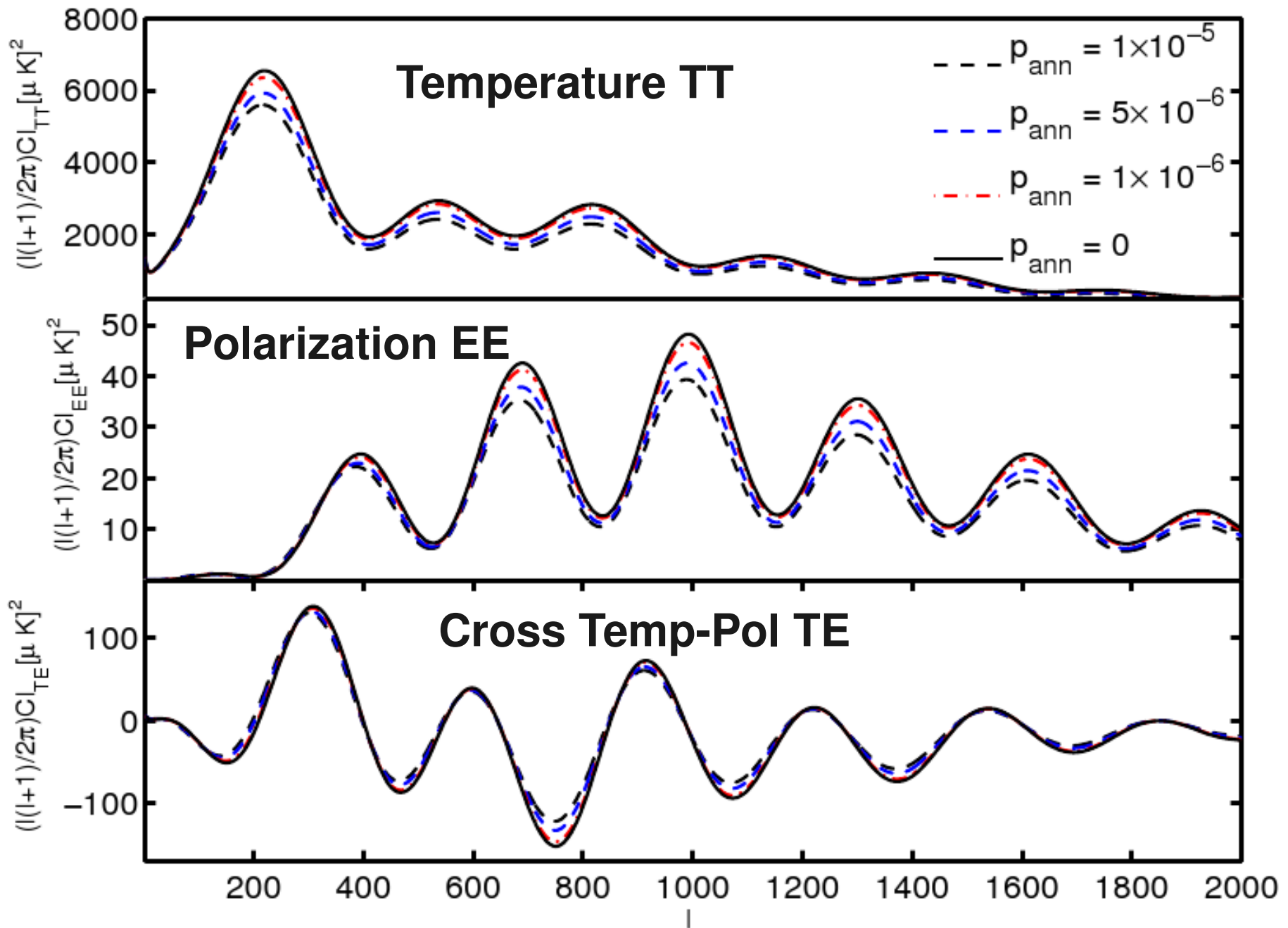
$$\epsilon_\alpha(z) = C \chi_\alpha \frac{dE/dt}{n_H(z) E_\alpha H(z)}$$

$$\epsilon_i(z) = C \chi_i \frac{dE/dt}{n_H(z) E_i H(z)}$$

$$\kappa_h = \chi_h \frac{dE/dt}{n_H(z)}$$



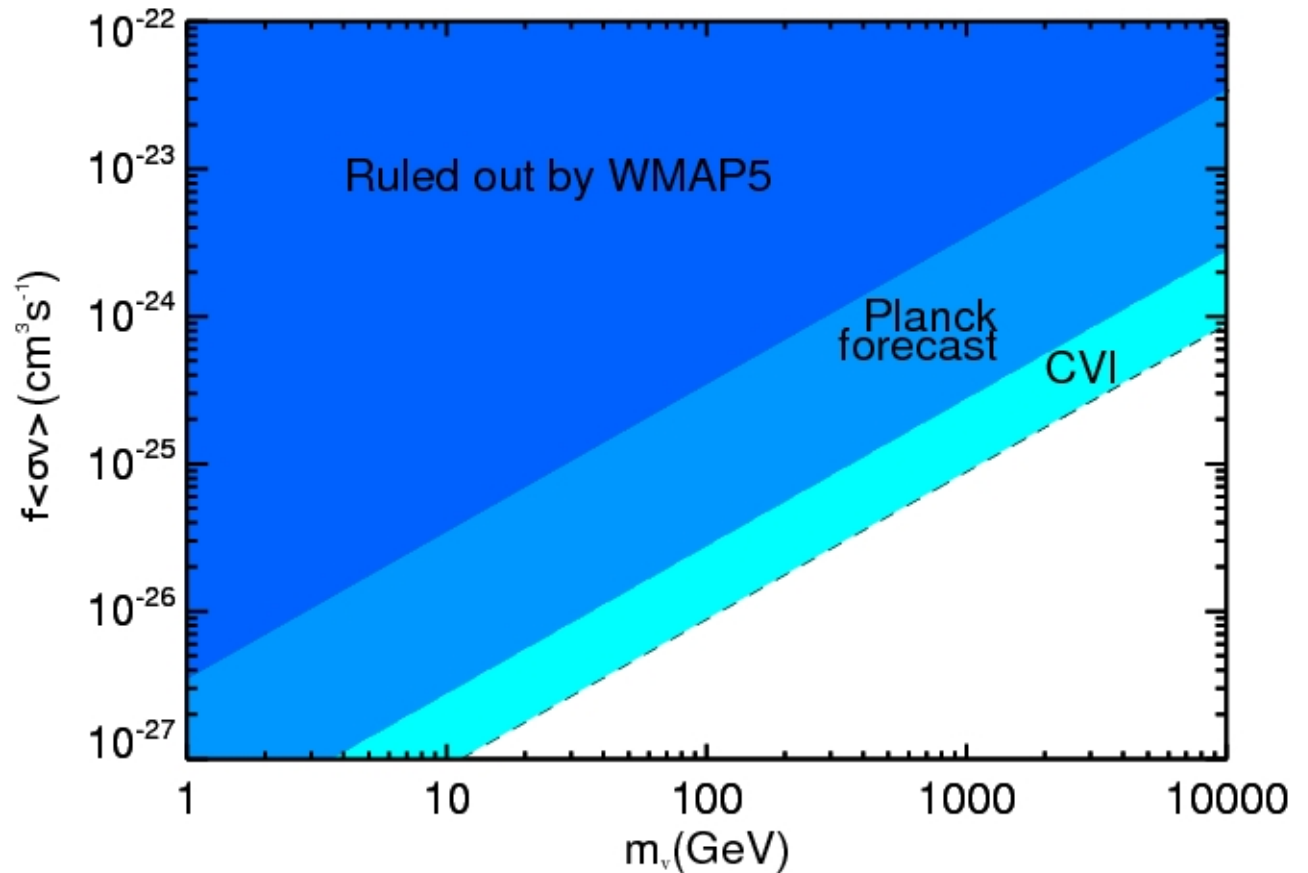
CMB Angular Power Spectra



Results on dark matter annihilation

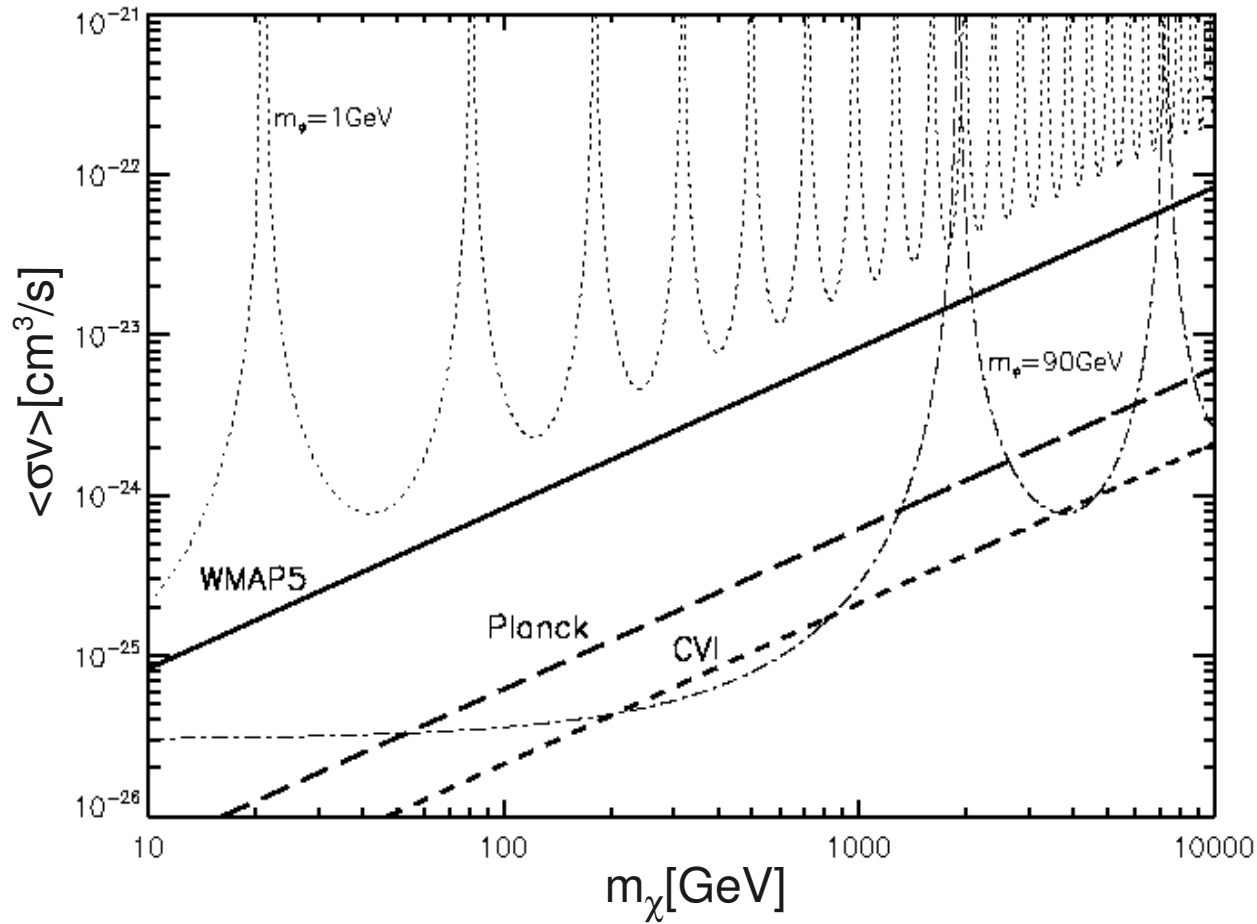
Constraints on the p_{ann} parameter = fraction of DM annihilation energy that goes into the plasma times DM cross section divided by DM mass using Wmap5 data, Planck mock and a hypothetical Cosmic Variance limited experiment

$$p_{ann} = f \frac{\langle \sigma v \rangle}{m_\chi}$$



Experiment	p_{ann} 95% c.l.
WMAP	$< 2.4 \times 10^{-6} \text{ m}^3/\text{s}/\text{kg}$
Planck	$< 1.7 \times 10^{-7} \text{ m}^3/\text{s}/\text{kg}$
CVI	$< 5.9 \times 10^{-8} \text{ m}^3/\text{s}/\text{kg}$

Coupling with gas: constant f



- Assuming constants $f=0.5$
- Runs with a more proper redshift-variable coupling with the plasma are on going.
- Depends on annihilation channel, mass of the particle (Based on T.R. Slatyer, N. Padmanabhan, P. D. Finkbeiner, arXiv:0906.1197)

Future constraints

- Constraints improvable by extracting the lensing signal with the Hu and Okamoto quadratic estimator. (Okamoto, T., & Hu, W. 2003, Phys. Rev. D, 67)

• Adding lensing extraction will improve Planck data by 10%.

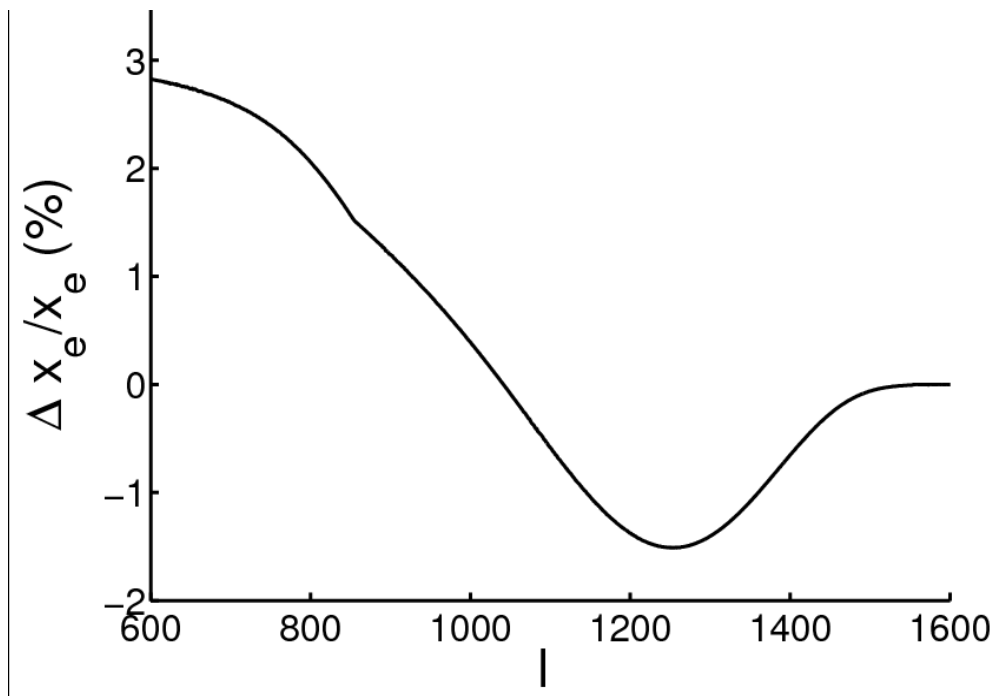
• ACT will measure TT till $l_{\text{max}} \sim 2500$ and EE till $l_{\text{max}} \sim 3500$ due to foregrounds. ACT will improve Planck Data by 20%.

Experiment	p_{ann} 95% c.l.
Planck	$< 1.5 \times 10^{-7} \text{ m}^3/\text{s}/\text{kg}$
Planck+ACT	$< 1.2 \times 10^{-7} \text{ m}^3/\text{s}/\text{kg}$
CMBpol	$< 6.3 \times 10^{-8} \text{ m}^3/\text{s}/\text{kg}$

• CMBpol with lensing extraction will constrain DM annihilation to a level comparable to the CVI case.

Dependence on the Recombination knowledge

- All the constraints presented assumes a perfect knowledge of recombination.



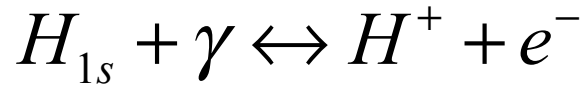
Difference between
recast 1.4 and 1.5

Conclusions

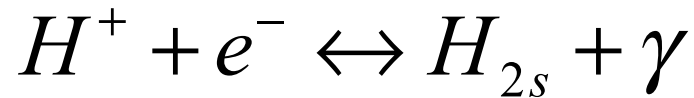
- CMB is a very interesting probe for dark matter annihilation.
- The interpretation of the Pamela, Atic and (Fermi) anomalies seems to be disfavoured by CMB data.
- The Planck Forecast suggests that there will be an improvement of 1 order of magnitude on the constraints.
- All the results are based on the assumption that we perfectly know standard recombination. This is not completely true!

Physics of recombination (Peebles (1968) and Zeldovich, Kurt & Sunyaev (1968))

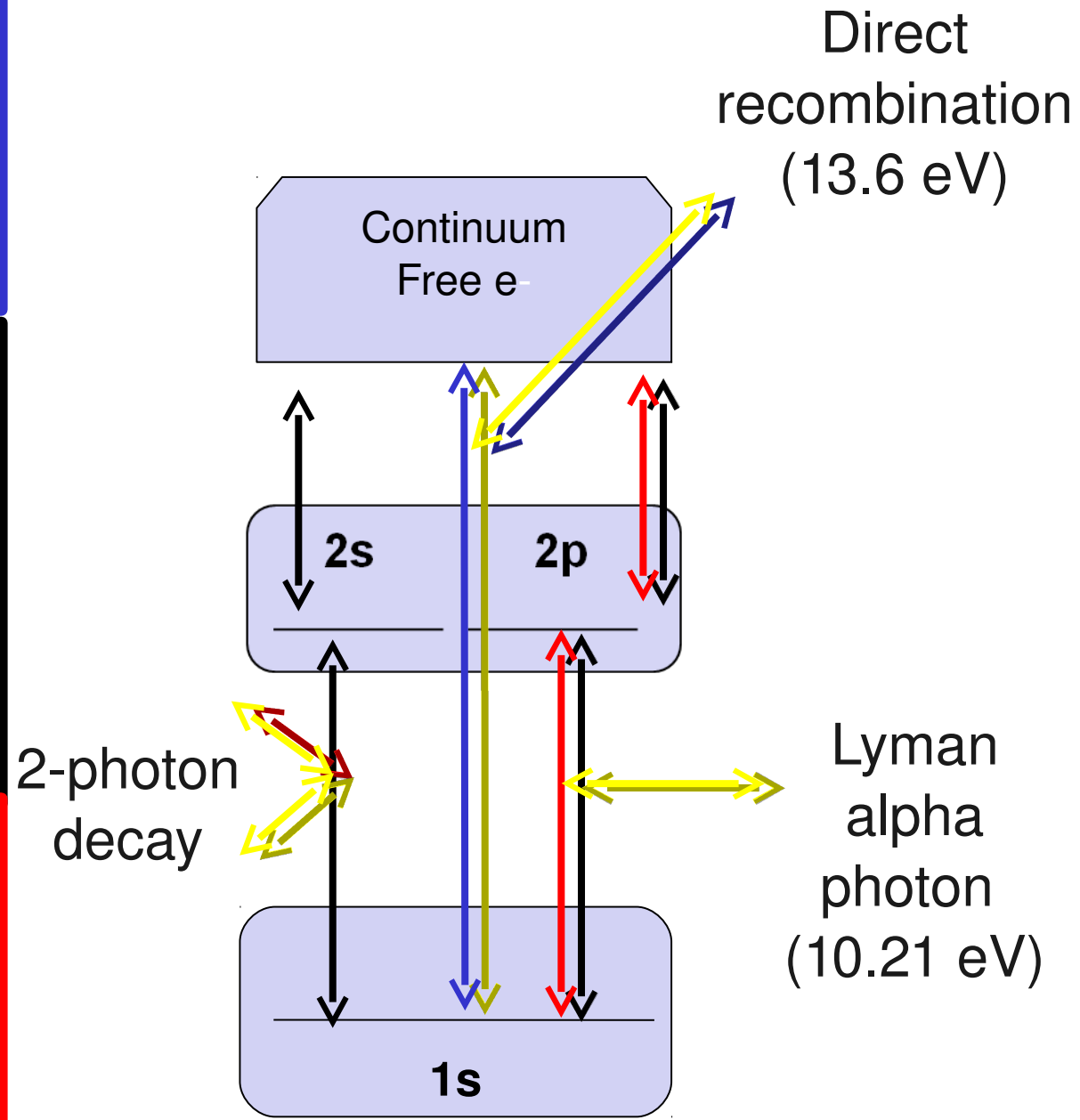
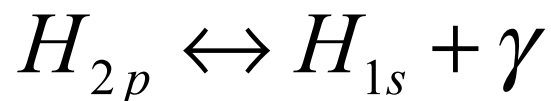
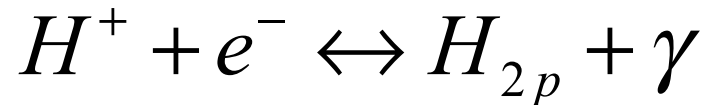
Direct Recombination but
NO NET recombination



2-photon decay from
metastable 2s states



Cosmological redshift of the
Lyman alpha photons



Extra Ionizing and Lyman-alpha photons

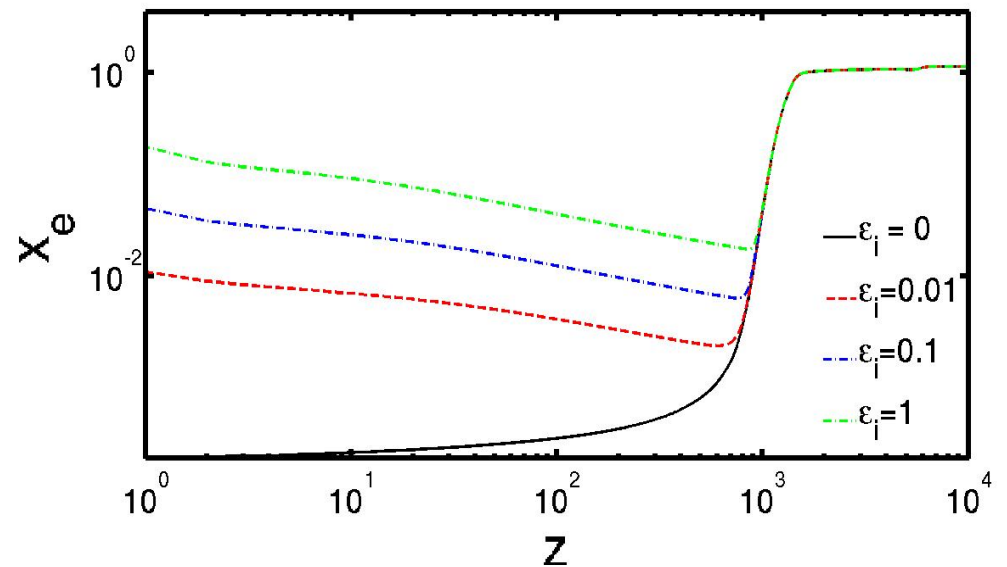
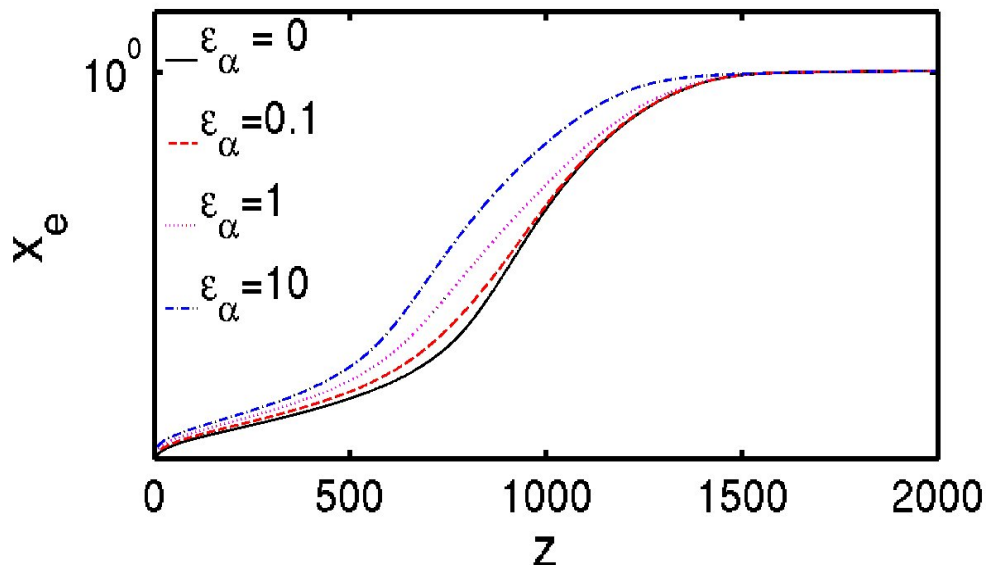
- First approximation: constant injection of photons.
- Two parameters added to Standard Model

$$\frac{dn_{\alpha}}{dt} = \varepsilon_{\alpha} n_H H(z)$$

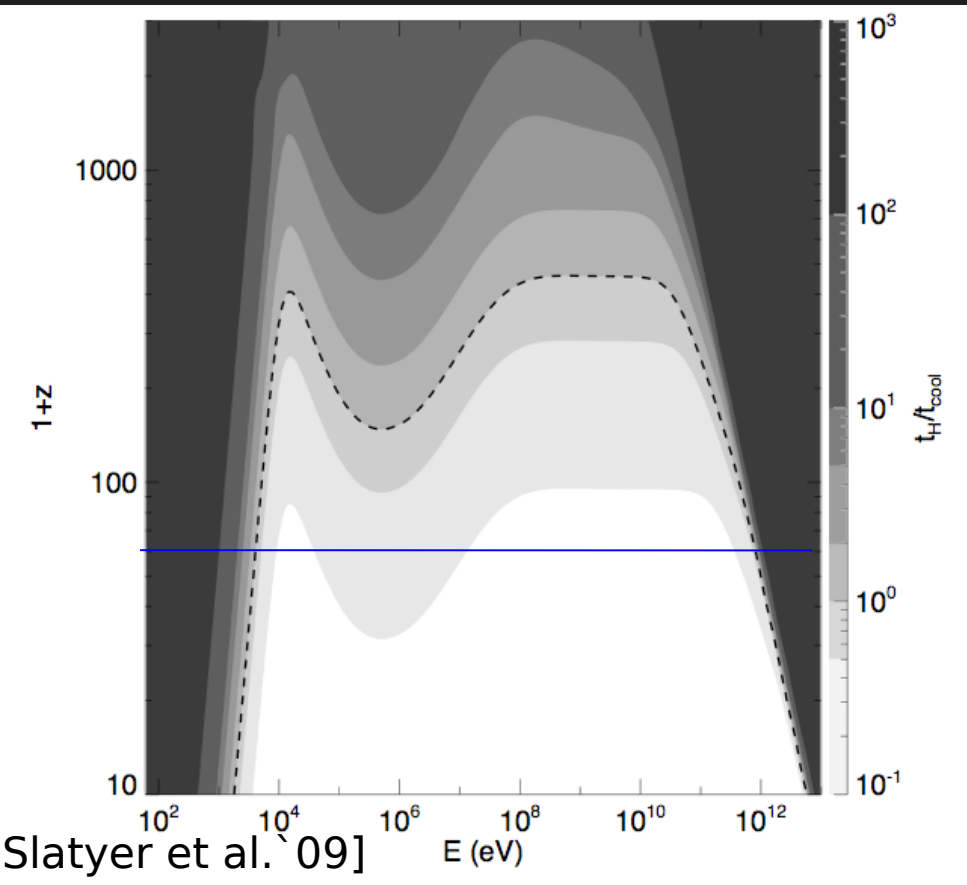
$$\frac{dn_i}{dt} = \varepsilon_i n_H H(z)$$

P.J.E. Peebles, S. Seager, W.Hu,
Astrophys.J.539:L1-L4,2000

$$\frac{-dx_e}{dt} = \frac{-dx_e}{dt} \Big|_{std} - C \varepsilon_i H - (1 - C) \varepsilon_{\alpha} H$$



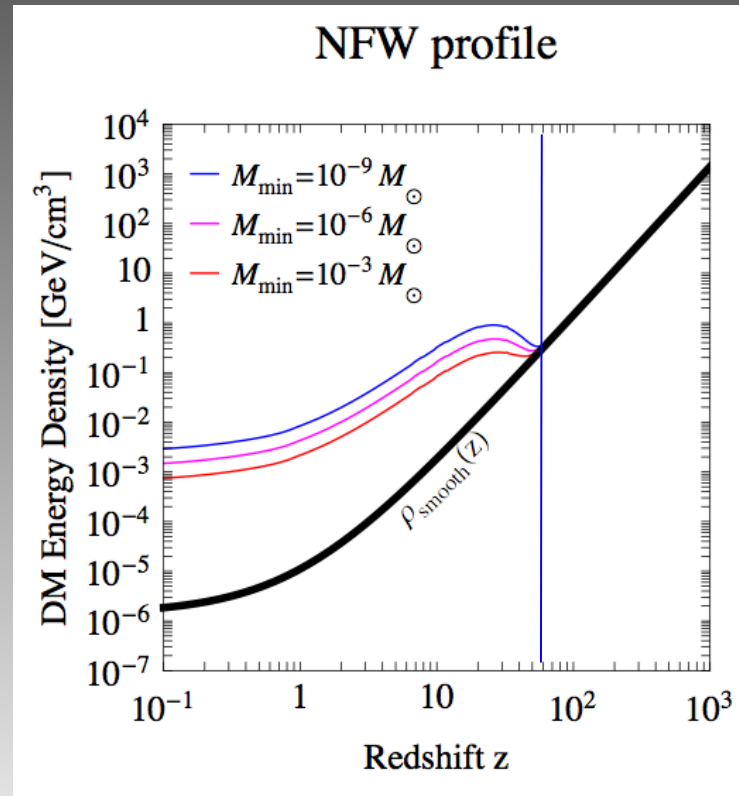
Transparency of the Universe & structure formation



[Cirelli, FI, Panci '09]

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

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



Credit: Fabio Iocco