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

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GGI

17/05/2010

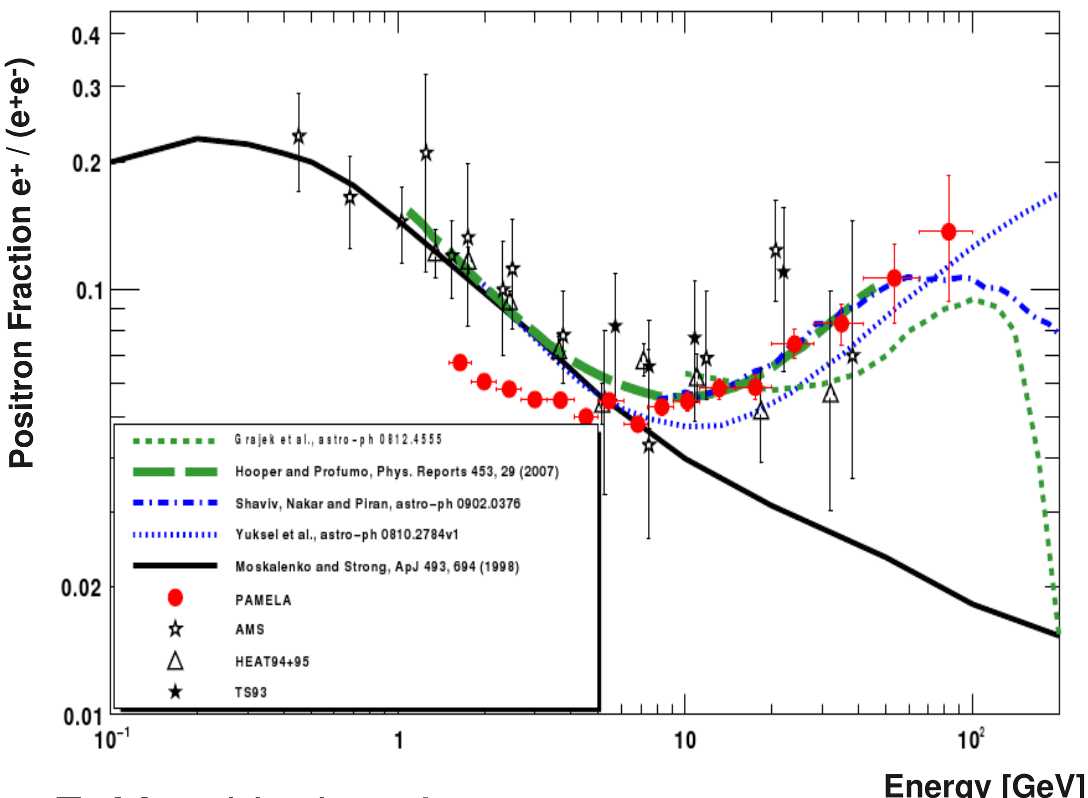
Outline

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

Motivations

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

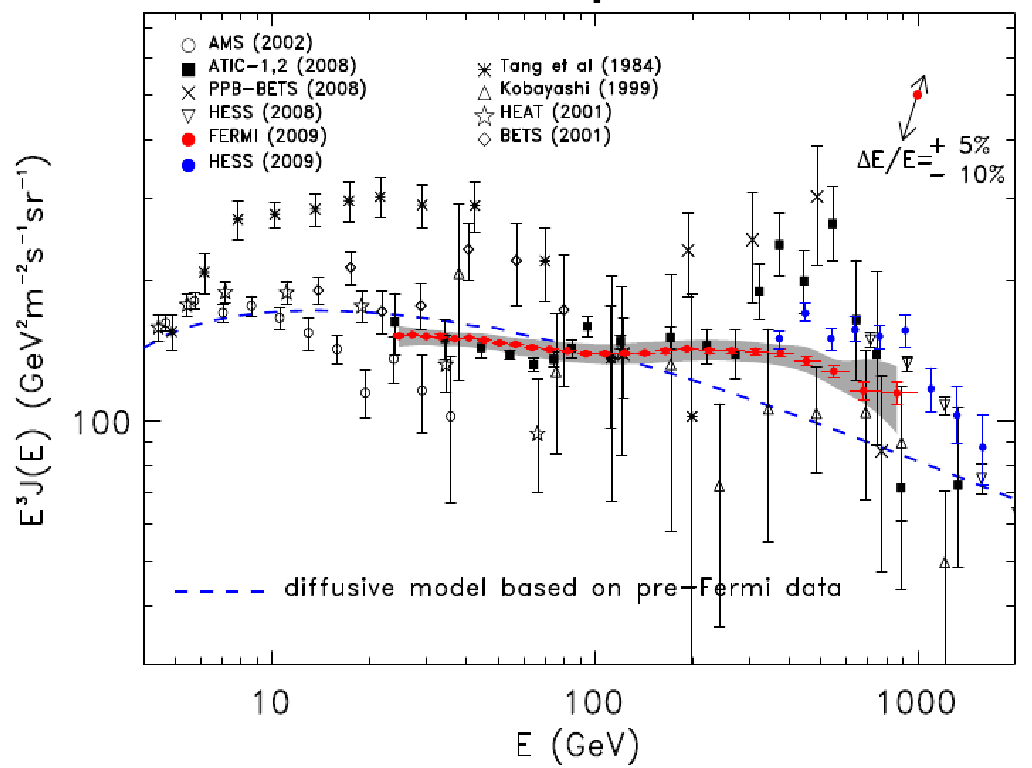
Positron Electron Fraction



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:**

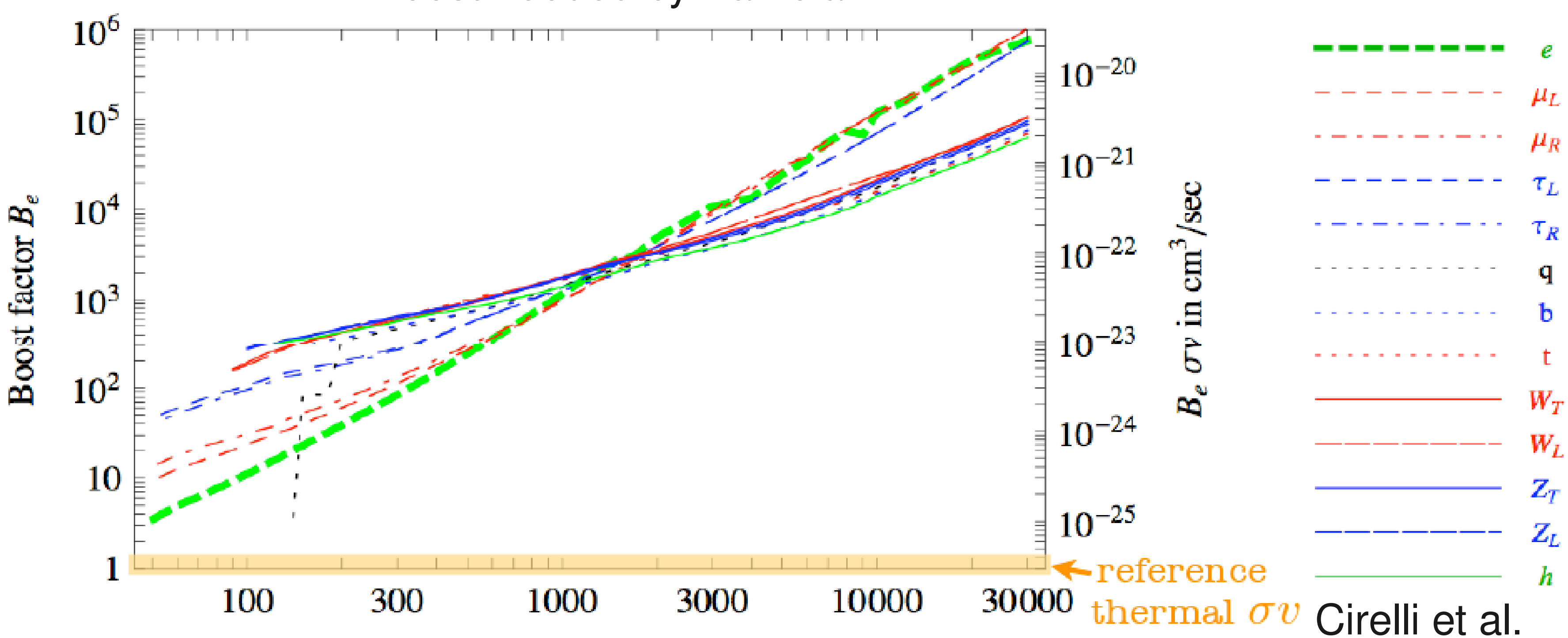
$<\sigma v> \sim 10^{-26}$ cm^3/s. **(WIMP)**

→ **Annihilation rate:**

$\Gamma \propto n^2 <\sigma v>$. n from dm simulations, models, observations

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

Boost needed by Pamela



Cirelli et al.
Nucl.Phys.B813:1-21,2009

Motivations

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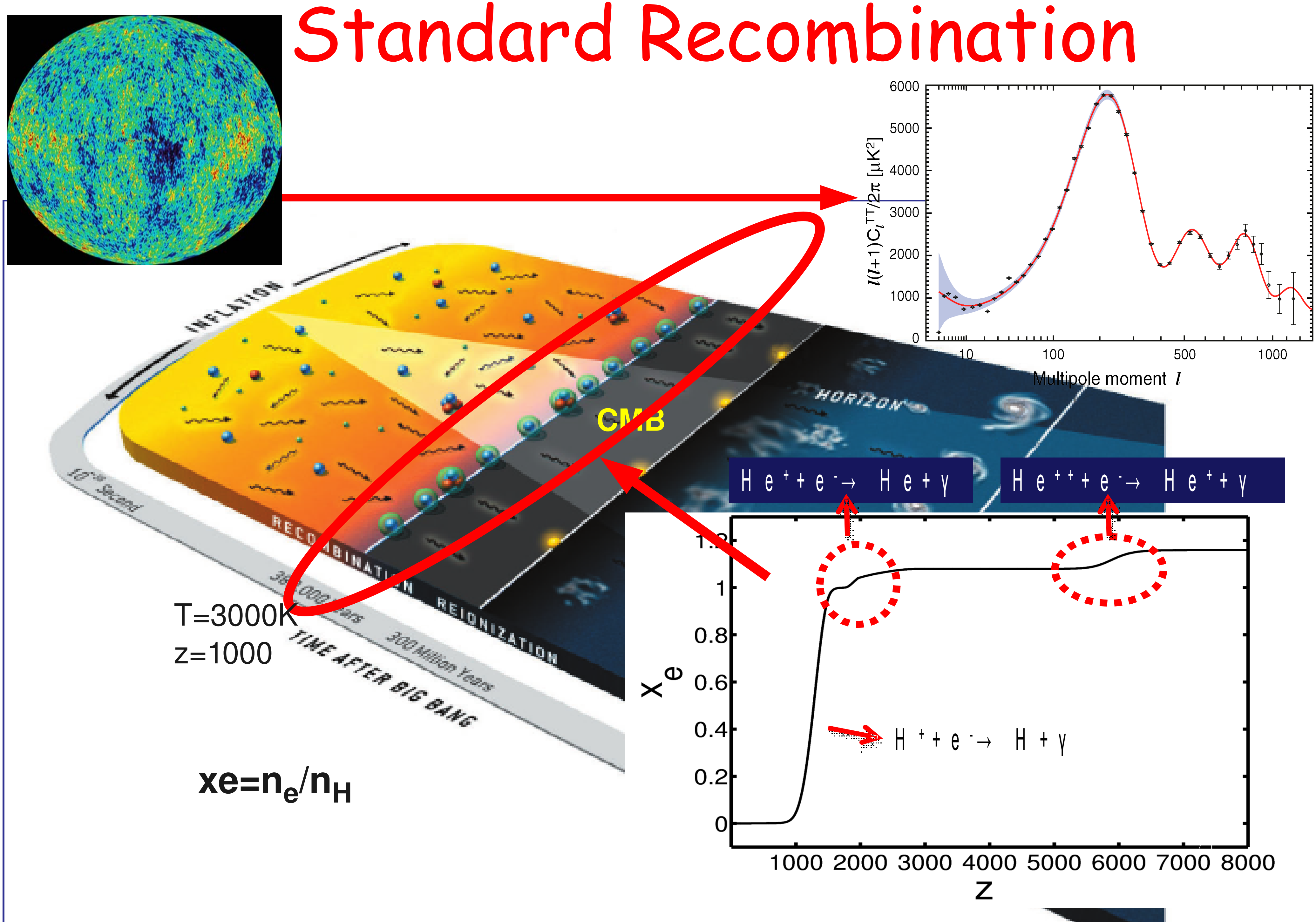
BOOST of the cross section to explain the data, depends on mass of DM and annihilation channel.

Dark Matter annihilation should leave a signature in CMB:

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

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

Standard Recombination



Hu & White (2004); artist: B. Christie/SciAm; available at http://background.uchicago.edu

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

Direct Recombination but NO NET recombination

$$H_{1s} + \gamma \leftrightarrow H^{+} + e^{-}$$

2-photon decay from metastable 2s states

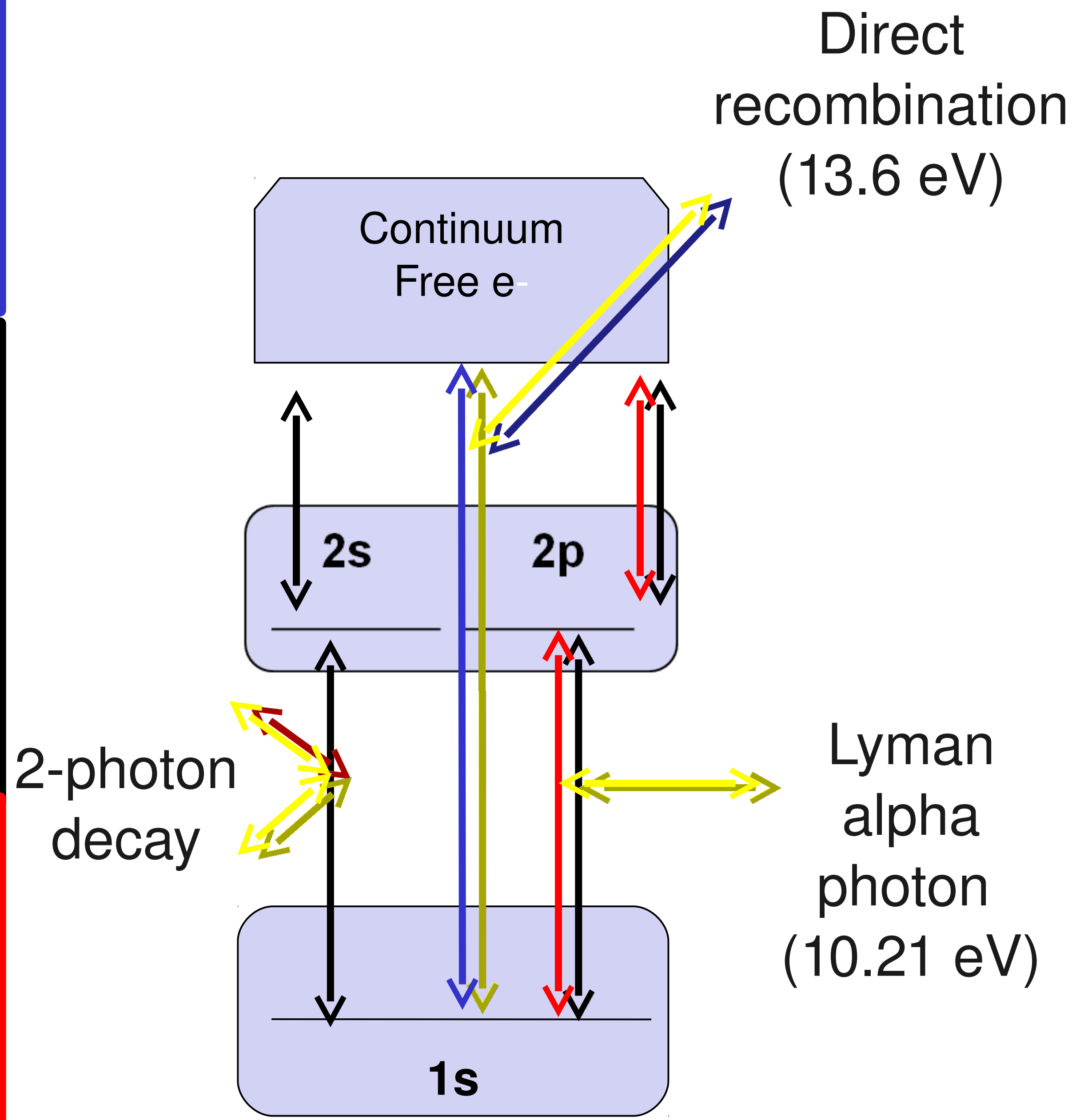
$$H^{+} + e^{-} \leftrightarrow H_{2s} + \gamma$$

$$H_{2s} \leftrightarrow H_{1s} + 2\gamma$$

Cosmological redshift of the **Lyman alpha** photons

$$H^{+} + e^{-} \leftrightarrow H_{2p} + \gamma$$

$$H_{2p} \leftrightarrow H_{1s} + \gamma$$



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].)

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

Cosmic string decays,magnetic monopoles etc...

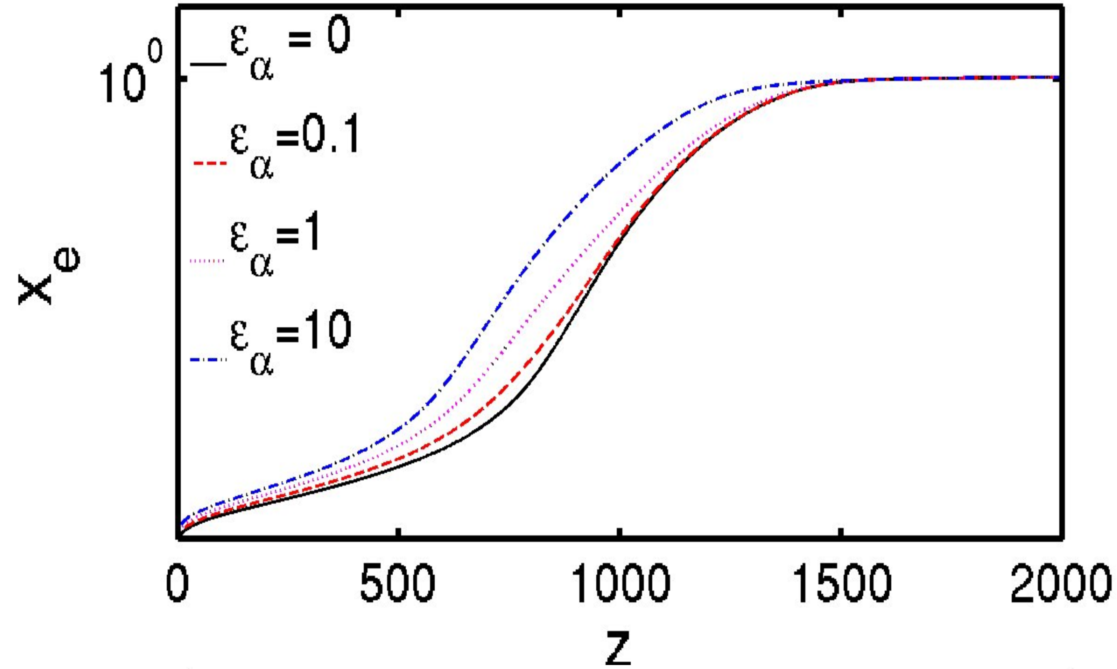
Extra Ionizing and Lyman-alpha photons

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

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

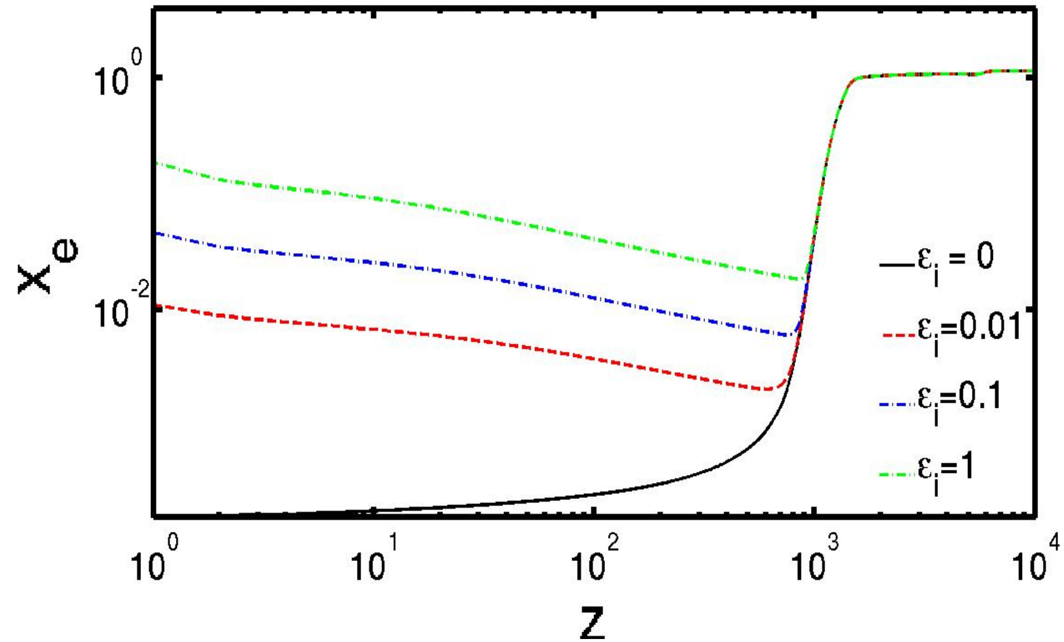
Extra Lyman-alpha photons

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



Extra ionizing photons

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



Results

WMAP05:

εα	<	0.39	at 95% c.l.
εi	<	0.058	at 95% c.l.

WMAP 05+ACBAR :

εα	<	0.31	at 95% c.l.
εi	<	0.053	at 95% c.l.

PLANCK

εα	<	0.01	at 95% c.l.
εi	<	0.0005	at 95% c.l.

1)There is still room to believe in non standard recombination!

2) Results for Planck are valid if recombination is known less than percent level.

S. Galli, R. Bean, A. Melchiorri, J. Silk
Phys. Rev. D 78, 063532 (2008)

Testing a specific Model: Dark Matter annihilation

- Lyman alpha and ionizing photons affects xe 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

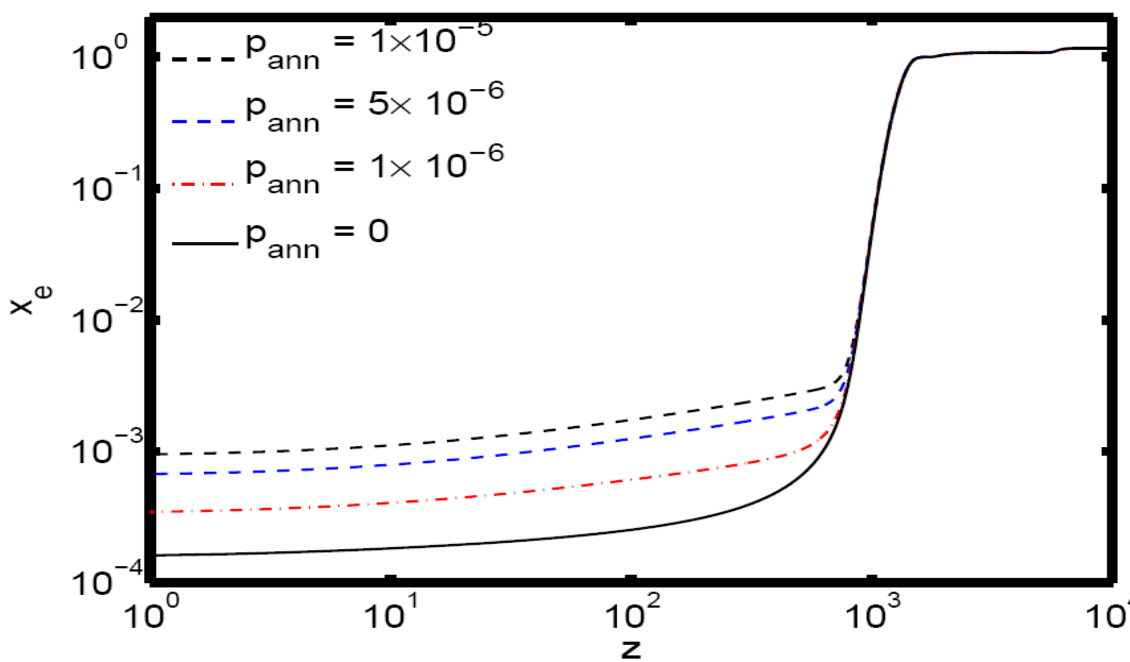
One new parameter that contain:
f = energy fraction to plasma
<σv> = cross section
m_χ = mass of the annihilating particle

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

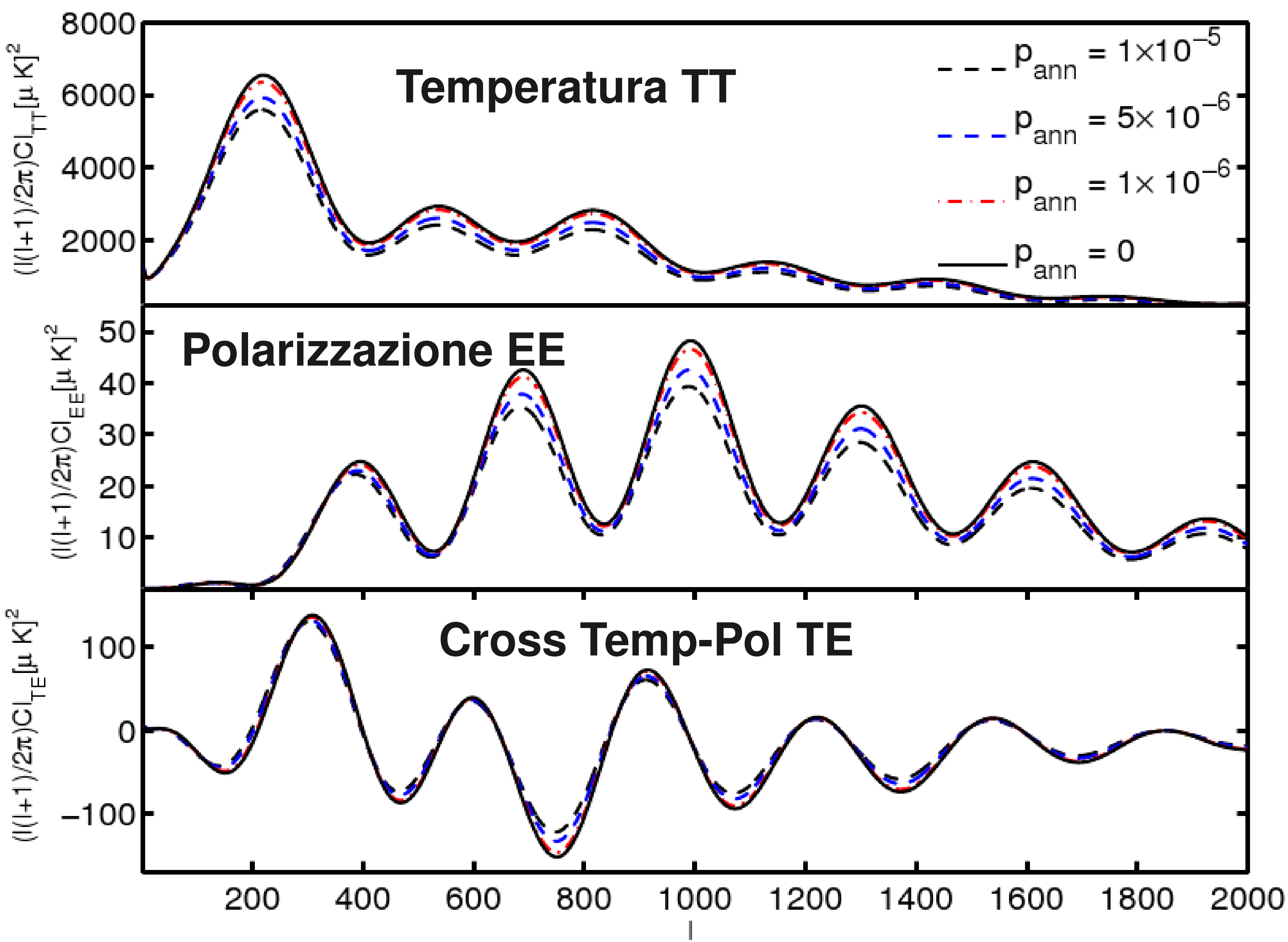
$$\varepsilon_\alpha(z) = C \chi_\alpha \frac{dE/dt}{n_H(z) E_\alpha H(z)}$$

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

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



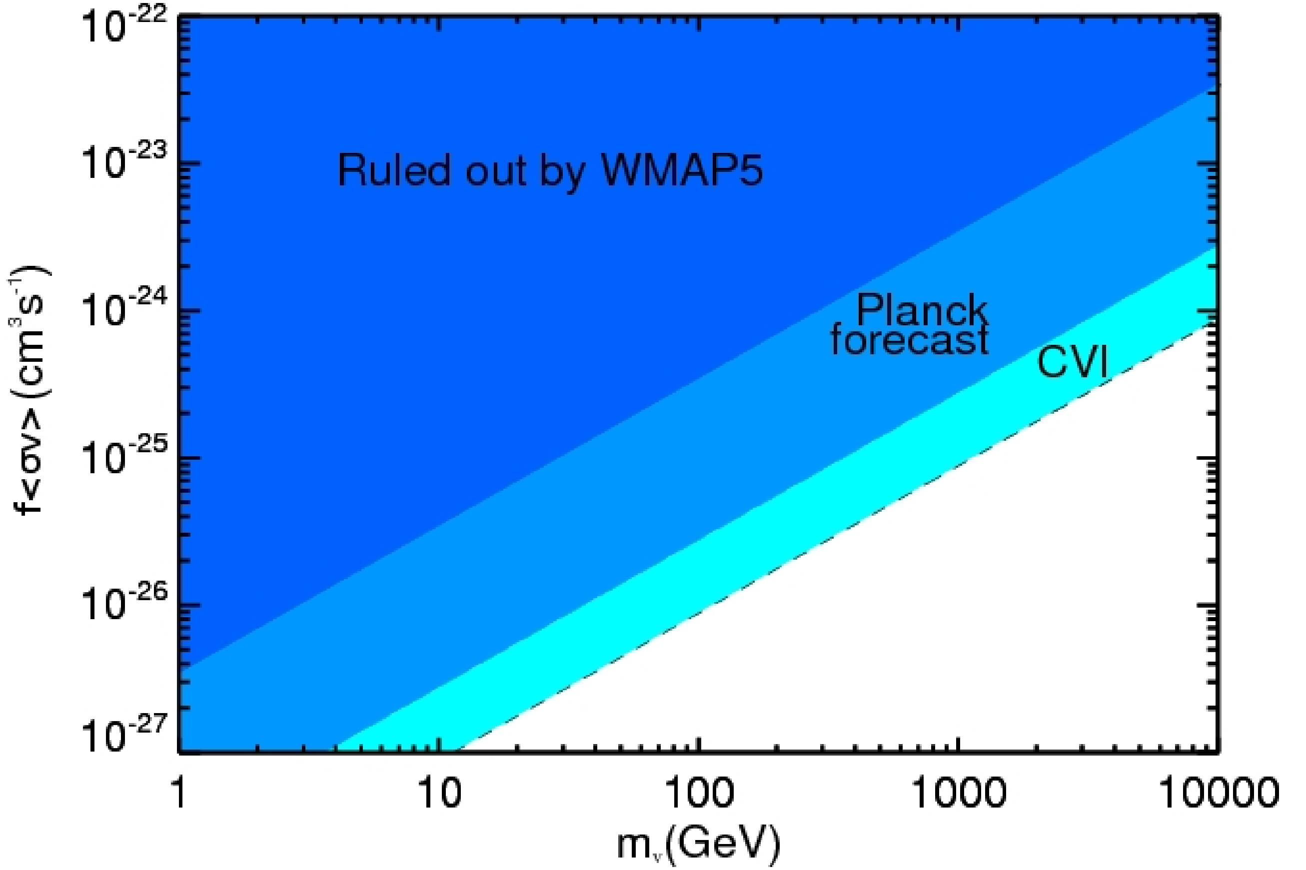
CMB Angular Power Spectra



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 hypotetical Cosmic Variance limited experiment

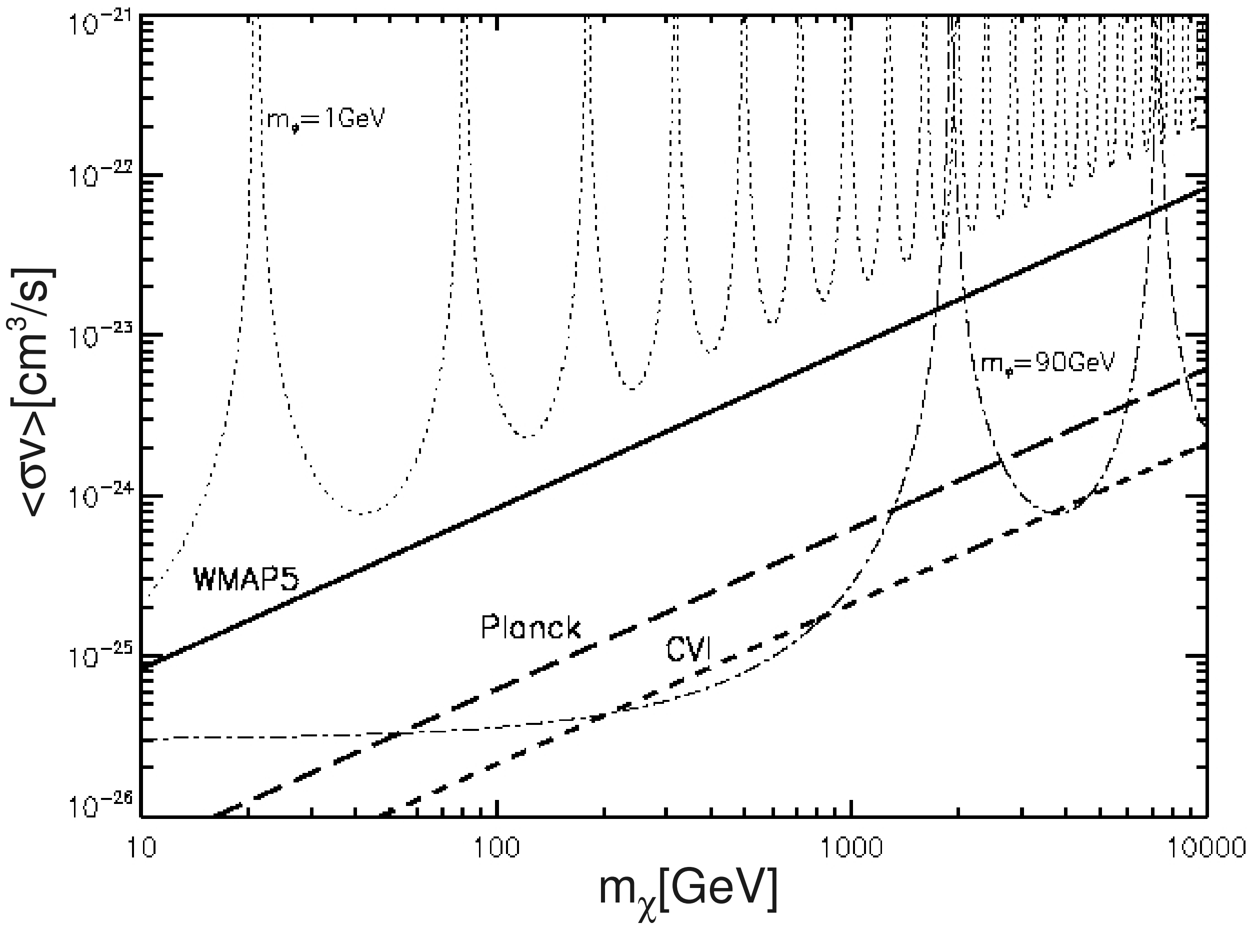
$$p_{ann} = f \frac{\langle \sigma v \rangle}{m_\chi}$$



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

S. Galli, F. Iocco, G. Bertone, A. Melchiorri, Phys. Rev. D, vol. 80, Issue 2, (arXiv:0905.0003), 2009.

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)

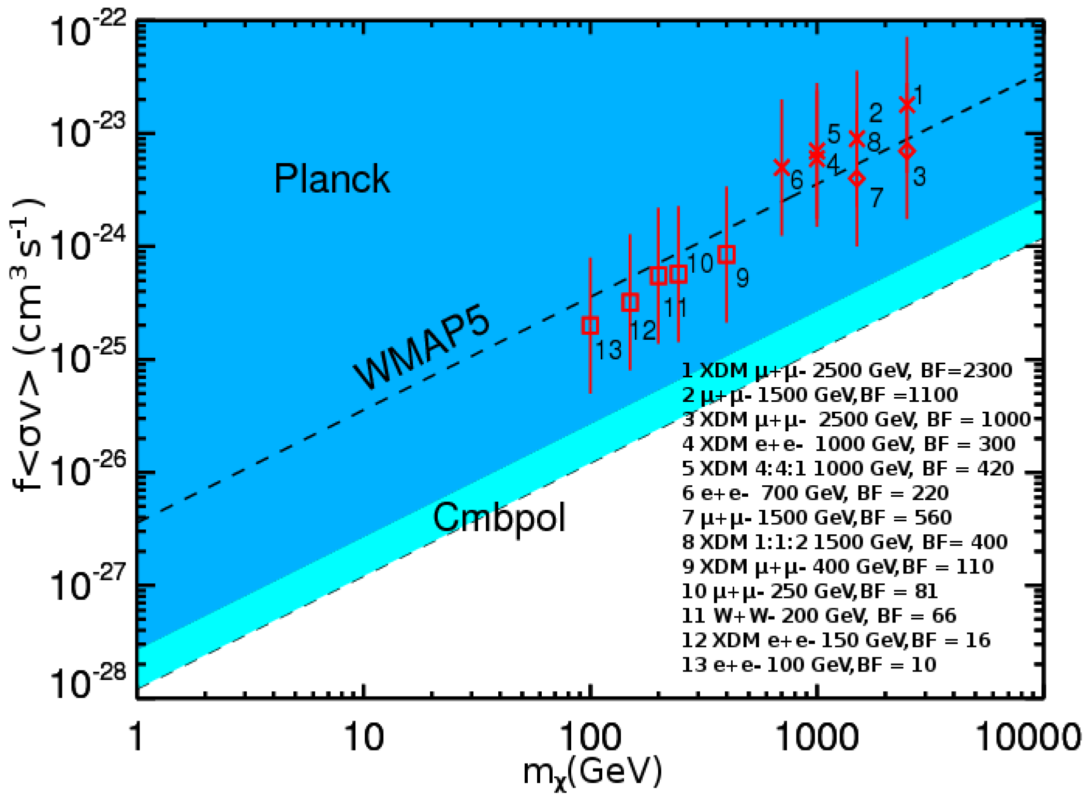
Future constraints (preliminary results)

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

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

•ACT will measure TT till lmax~2500 and EE~till lmax~3500 due to foregrounds. ACT will improve Planck Data by 20%.

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



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

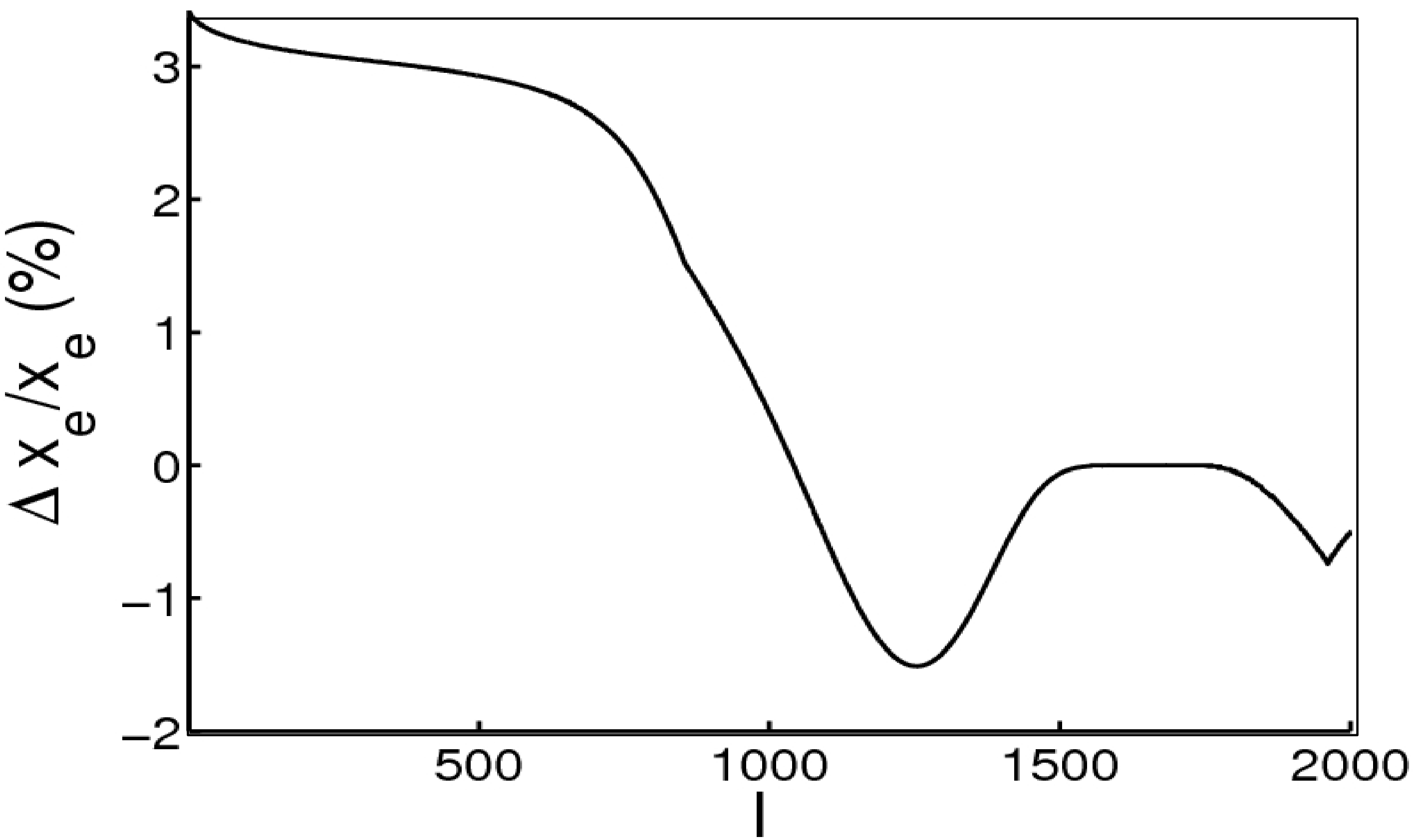
Squares: PAMELA only. Diamonds: PAMELA and Fermi. Crosses: PAMELA and ATIC

Red data points taken from:
P. Grajek, et al.(2008), 0812.4555.
I. Cholis,et al. (2008), 0811.36
Slatyer, T.~R.et al.(2009),PRD, 80, 043526

Galli S., Martinelli M., Melchiorri A., Pagano L., Sherwin B., Spergel D., in preparation

Dependence on the Recombination knowledge

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



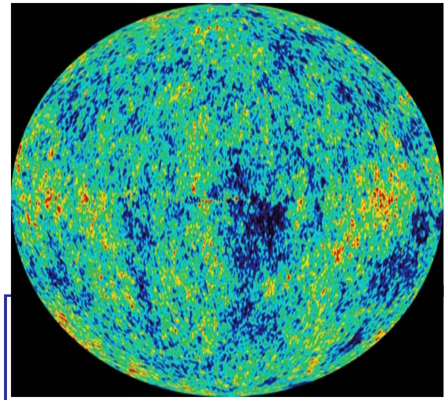
Difference between recfast 1.4 and 1.5

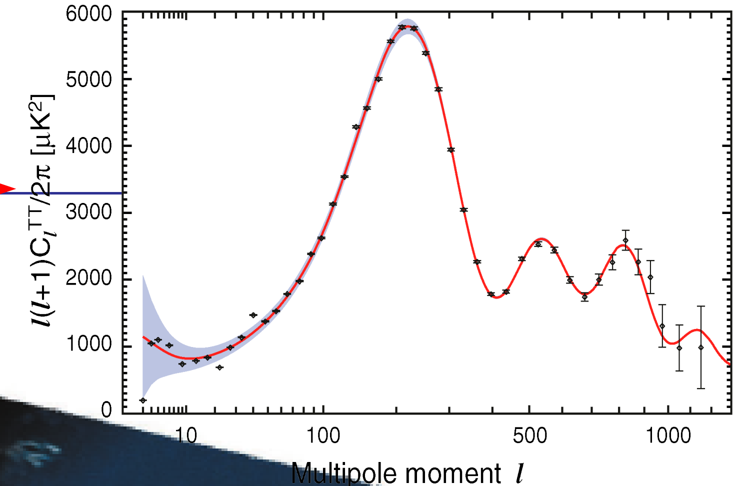
Rubiño-Martin J. A. et al., arxiv:0910.4383v1

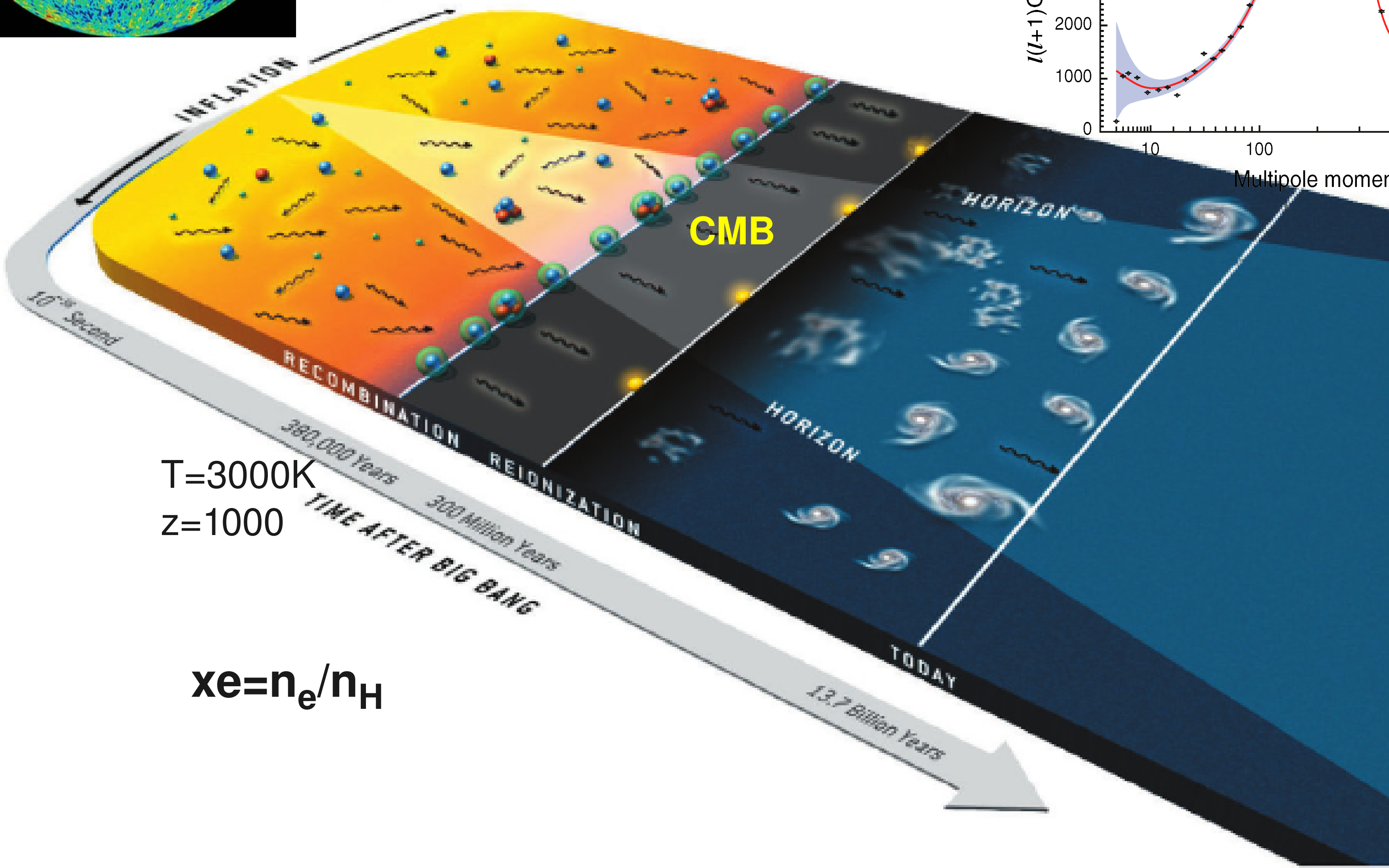
Conclusions

- 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!

Standard Recombination







T=3000K
z=1000

xe=n_e/n_H

Hu & White (2004); artist: B. Christie/SciAm; available at http://background.uchicago.edu

Extra Ionizing and Lyman-alpha photons

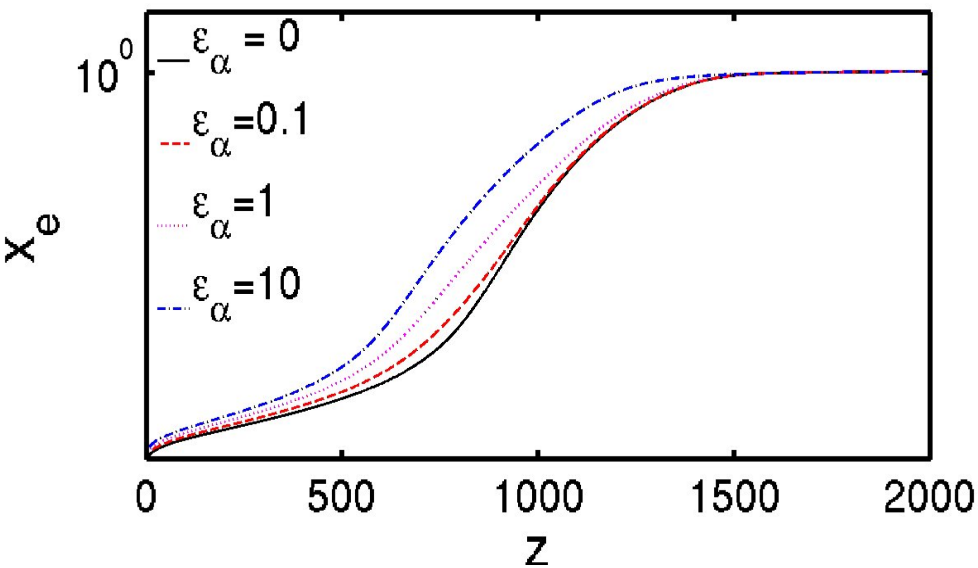
- First approximation: constant injection of photons.
- Two parameters added to Standard Model

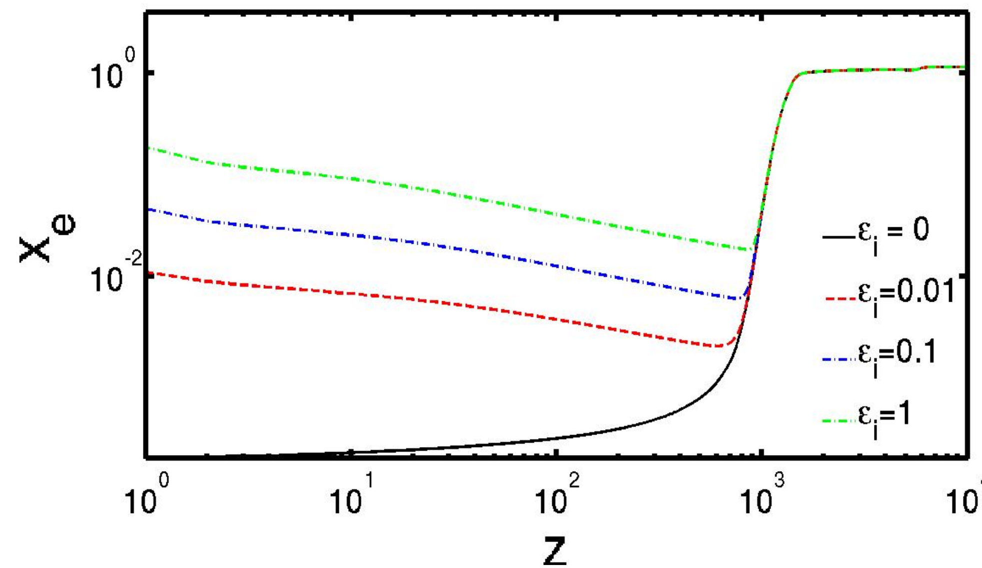
$$\frac{dn_\alpha}{dt} = \varepsilon_\alpha n_H H(z)$$

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

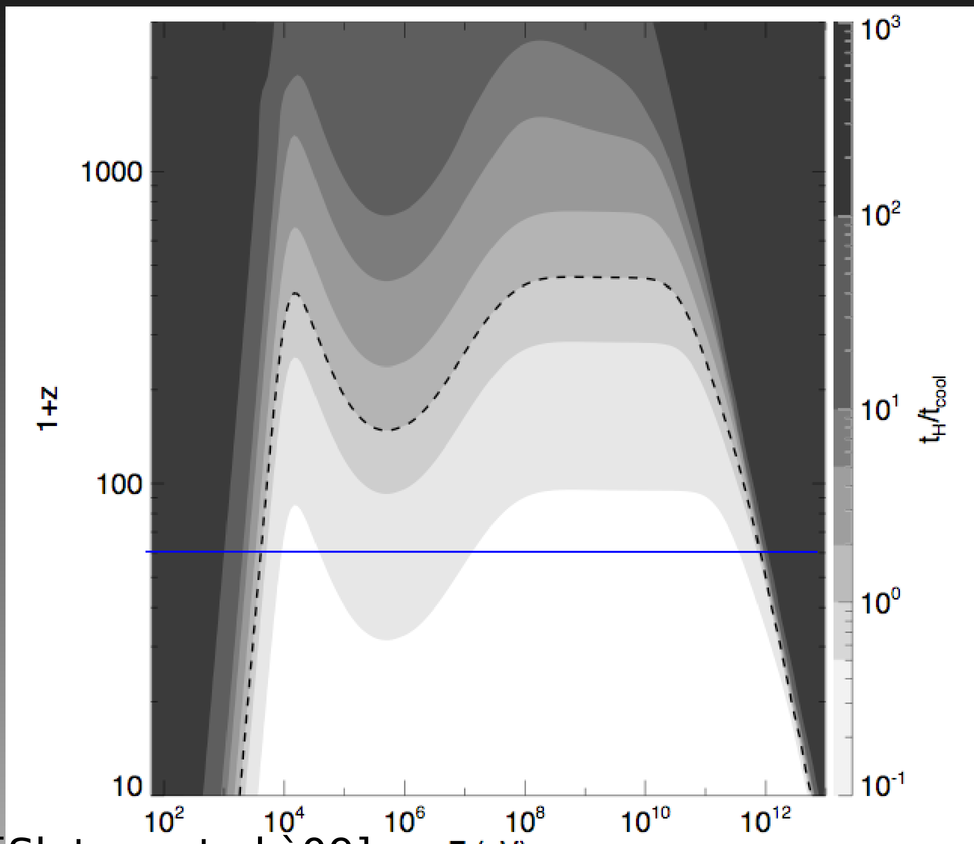
P.J.E. Peebles, S. Seager, W.Hu, Astrophys.J.539:L1-L4,2000

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





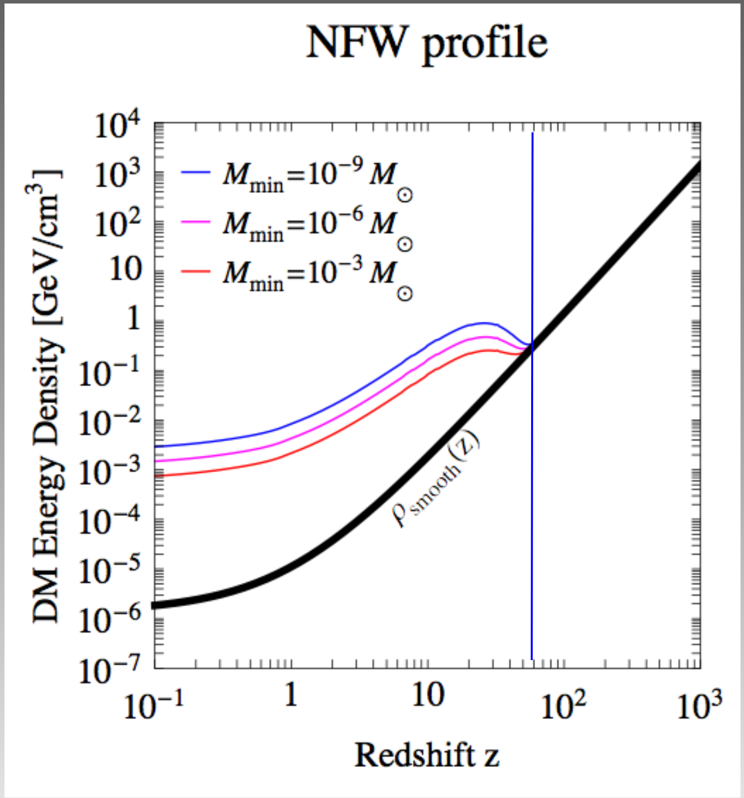
Transparency of the Universe & structure formation



[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]

Credit: Fabio Iocco