# Testing Fundamental Physics with the Cosmic Microwave Background

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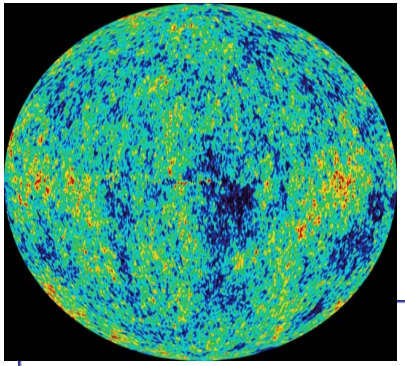
Cosmology on the beach
Puerto Vallarta
11/01/2011

# Outline

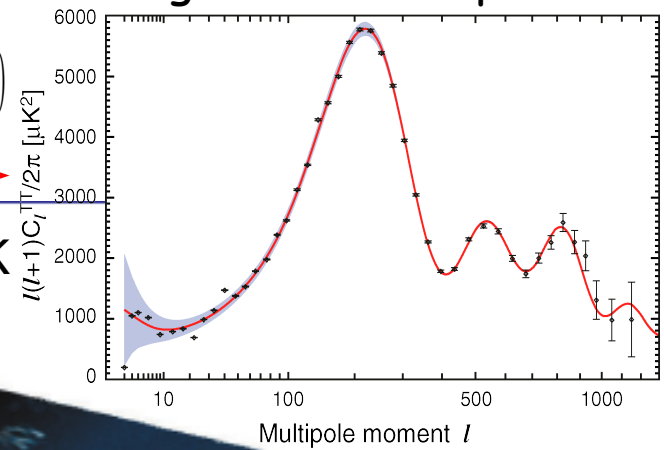
- CMB and standard recombination
- Changing std. Recombination: Energy injection from Dark Matter Annihilation
  - Motivation
  - Effects on Spectra
  - Constraints from Wmap
  - Forecasts for future experiments
- Conclusions

# CMB

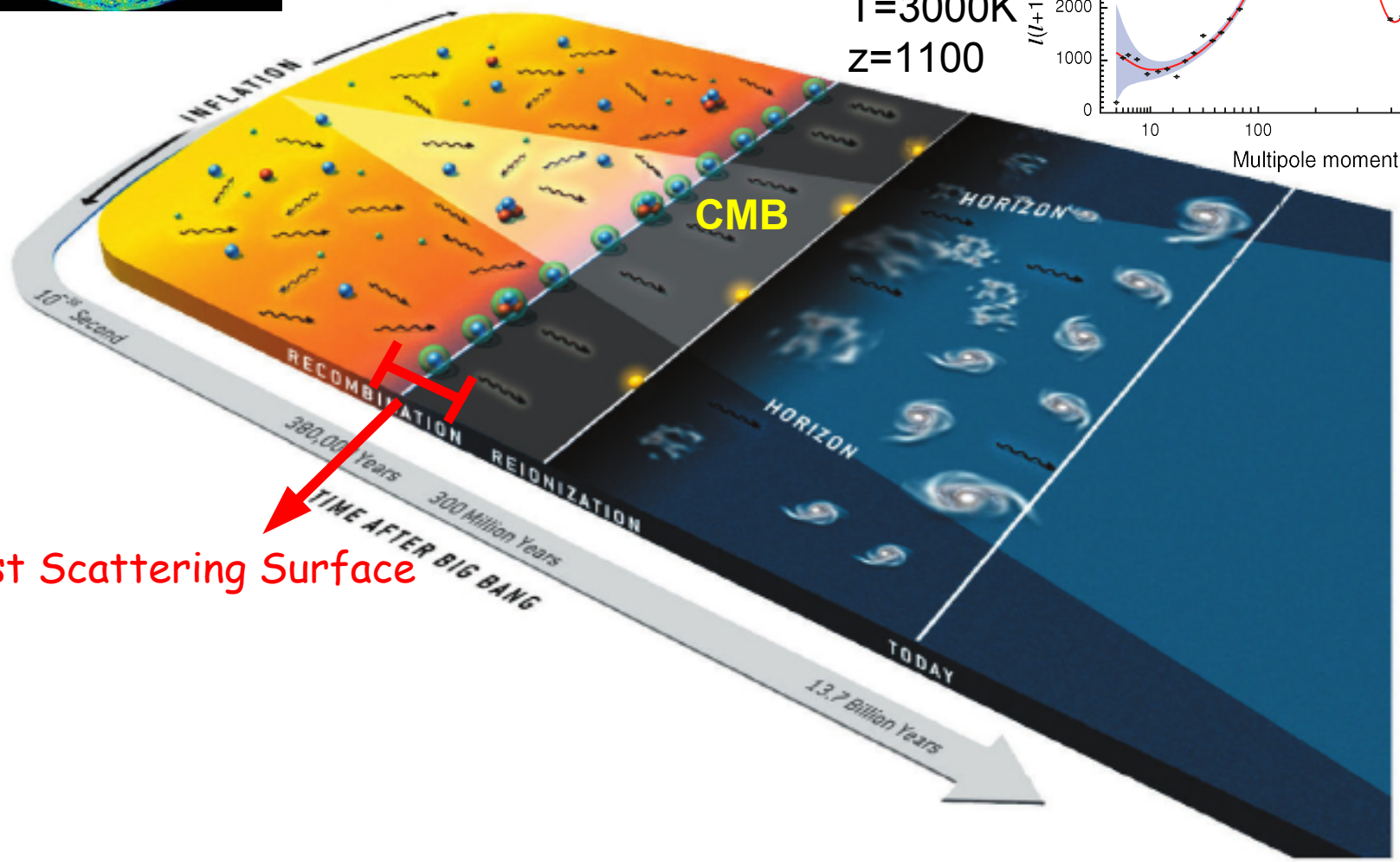


$$\left\langle \frac{\Delta T}{T}(\vec{\gamma}_1)\frac{\Delta T}{T}(\vec{\gamma}_2)\right\rangle = \frac{1}{2\pi}\sum_{\ell}(2\ell+1)C_\ell P_\ell(\vec{\gamma}_1\cdot\vec{\gamma}_2)$$

Angular Power Spectra




T=3000K
z=1100




Last Scattering Surface

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

# CMB and the Visibility Function

$$\frac{\Delta T}{T}(\vec{n}) = \int_0^\infty \left[ g(\eta) \left( \Psi + \Theta_0 + \vec{n}\cdot\vec{v}_b \right) \right] d\eta$$

Gravity Adiabatic Doppler

η= conformal time

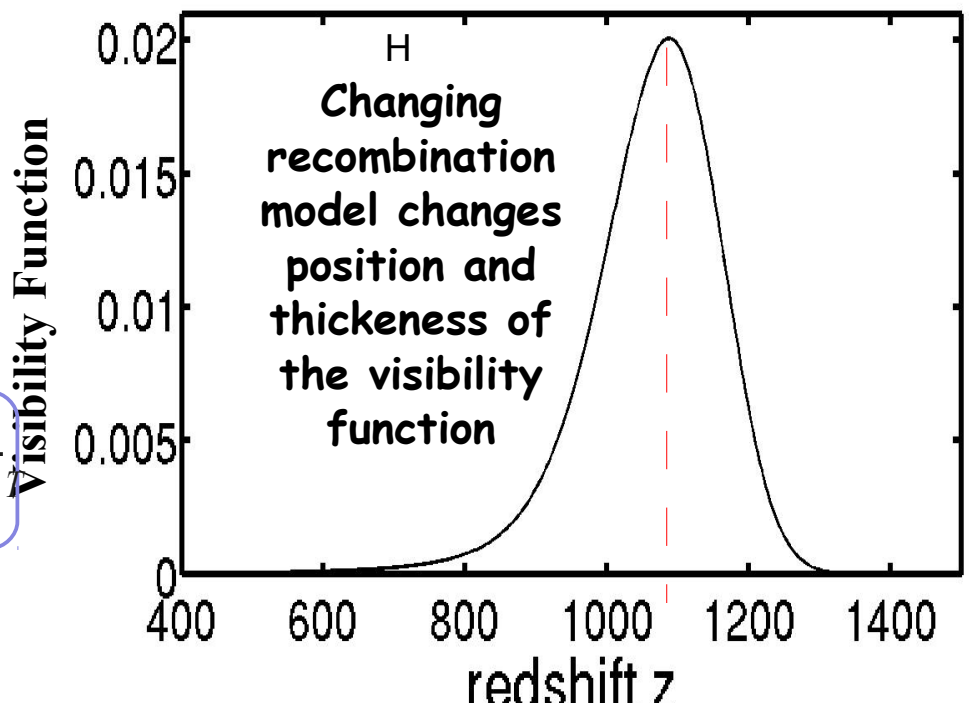
The **visibility function** is defined as the probability density that a photon is last scattered at redshift z:

**xe=$n_e/n_H$**

$$g(\eta) = \dot{\tau} e^{-\tau}$$

Scattering rate Optical Depth

$$\dot{\tau}(\eta) = n x_e a \sigma_T \qquad \tau(\eta) \int_\eta^{\eta_0} d\eta\, n x_e a \sigma_T$$



# 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

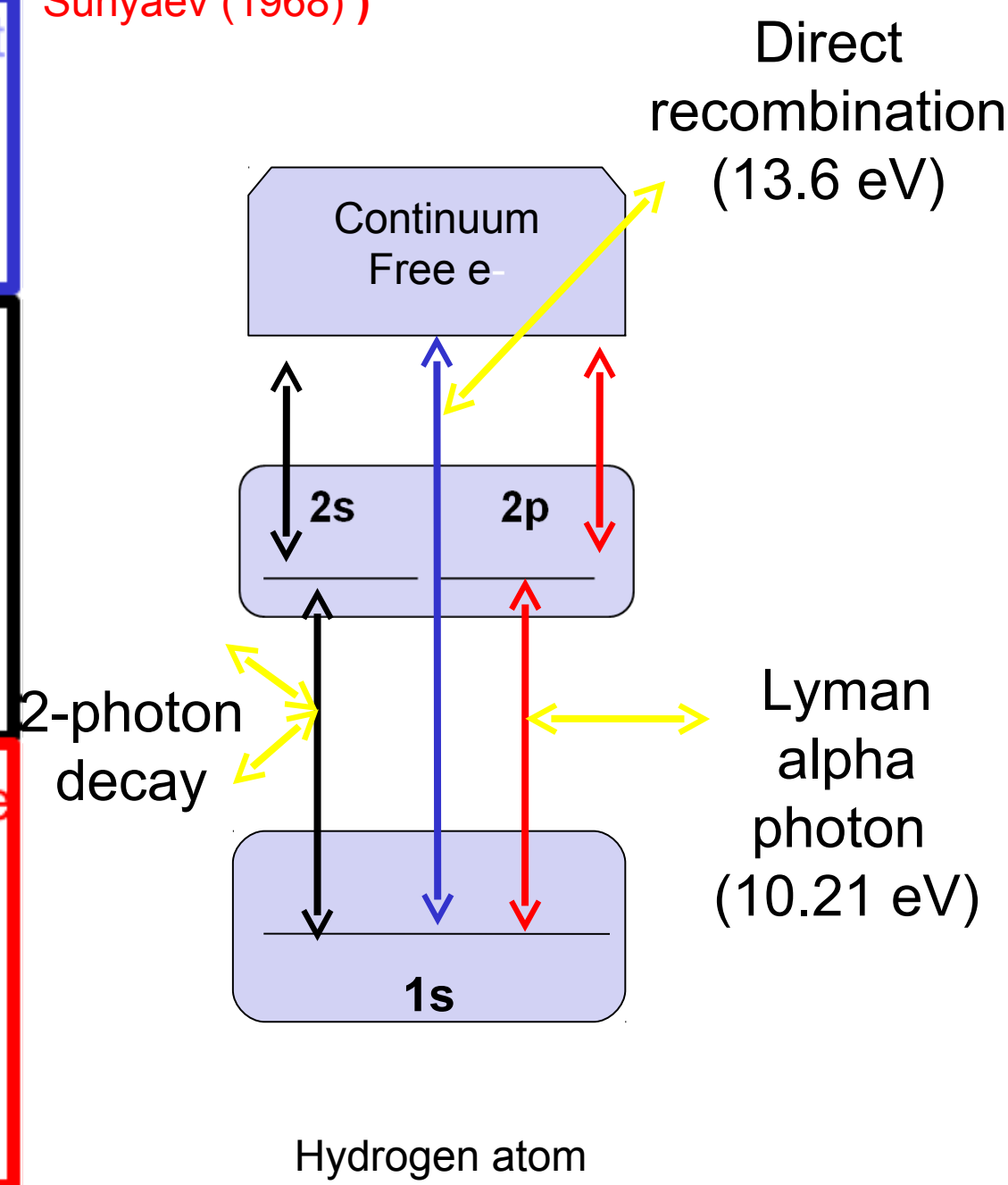
$$H^{+} + e^{-} \leftrightarrow H_{2s} + \gamma$$

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

Cosmological redshift of the **Lyman alpha** photons

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

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

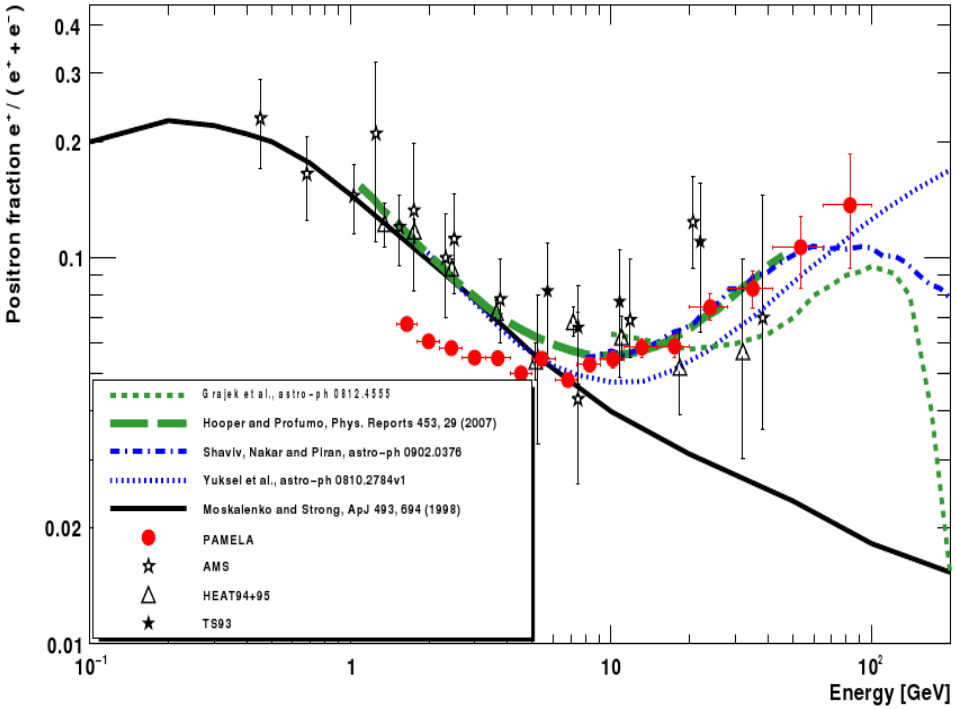


# Dark Matter Annihilation

# 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**

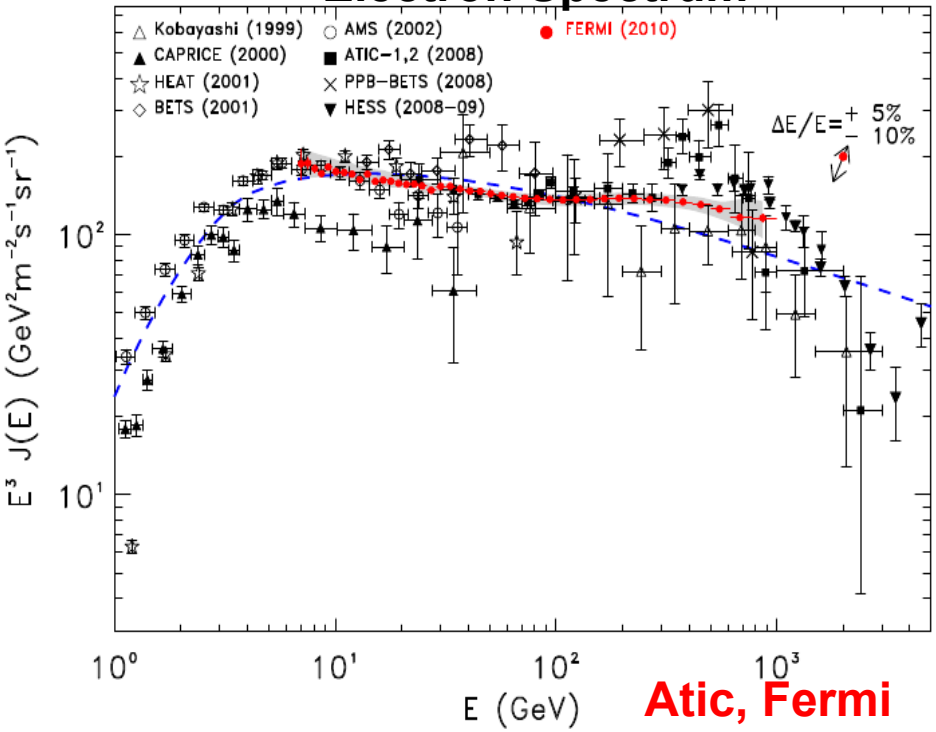



Adriani, O., et al.2009, Nature, 458, 607

**Pamela**

Mocchiutti, E., et al.\ 2009, arXiv:0905.2551

**Electron Spectrum**




**Atic, Fermi**

Fermi Lat-collaboration arXiv:1008.3999

# Motivations

→ **Thermal production of DM:**

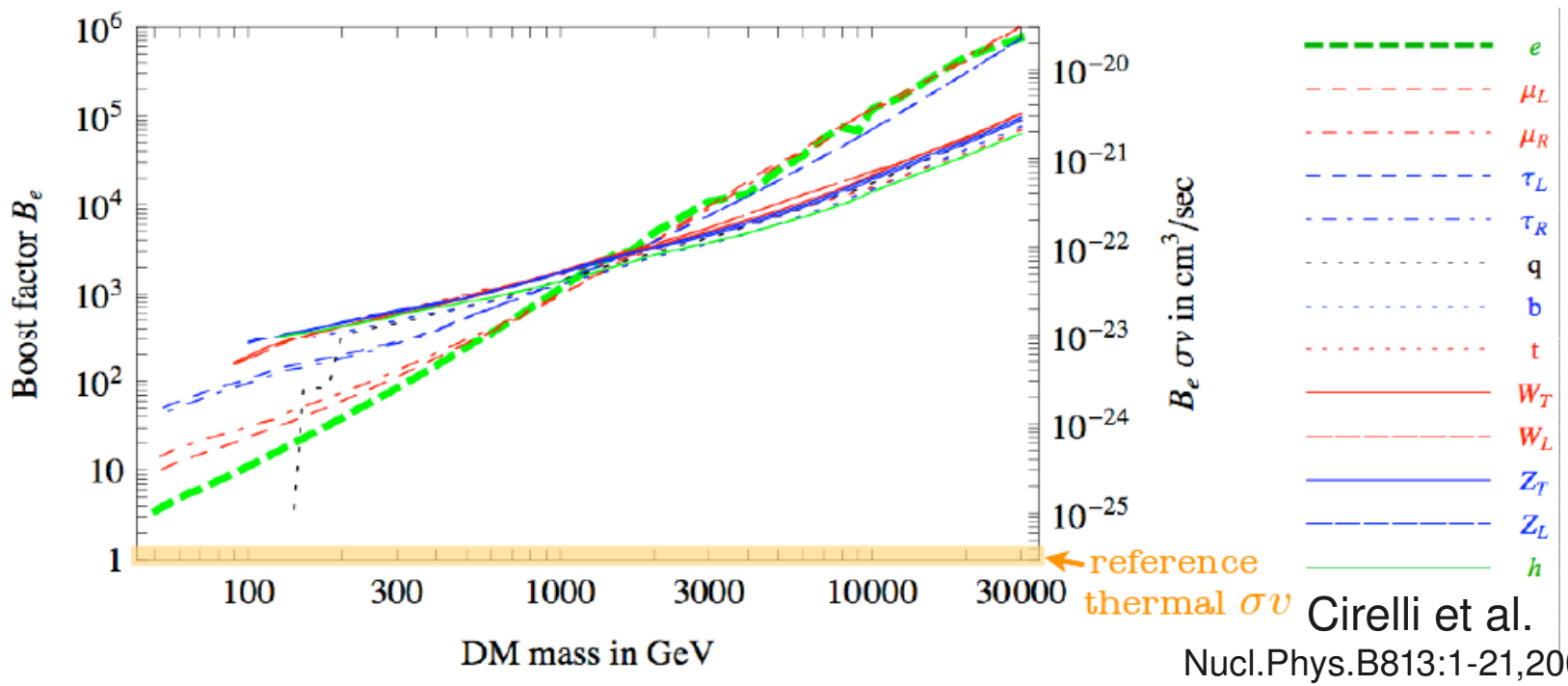
$\langle\sigma v\rangle \sim 10^{-26}\ cm^3/s.$ **(WIMP)**

→ **Annihilation rate:**

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

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

Profumo, S. 2005, PRD, 72, 103521




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

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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.

# Testing a specific Model: Dark Matter annihilation

- Lyman alpha and ionizing photons affects xe and temperature

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

Energy injection rate

$p_{ann}$

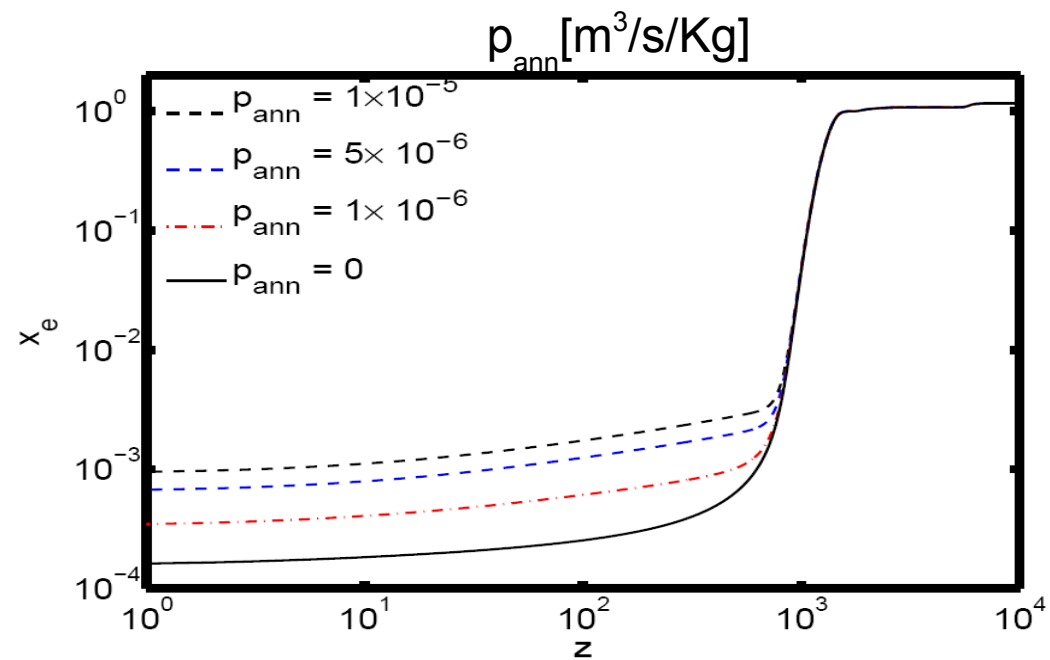
Redshift dependence of the injection rate of Lyman alpha (εα), ionizing (εi) photons and
heating term that changes matter temperature

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

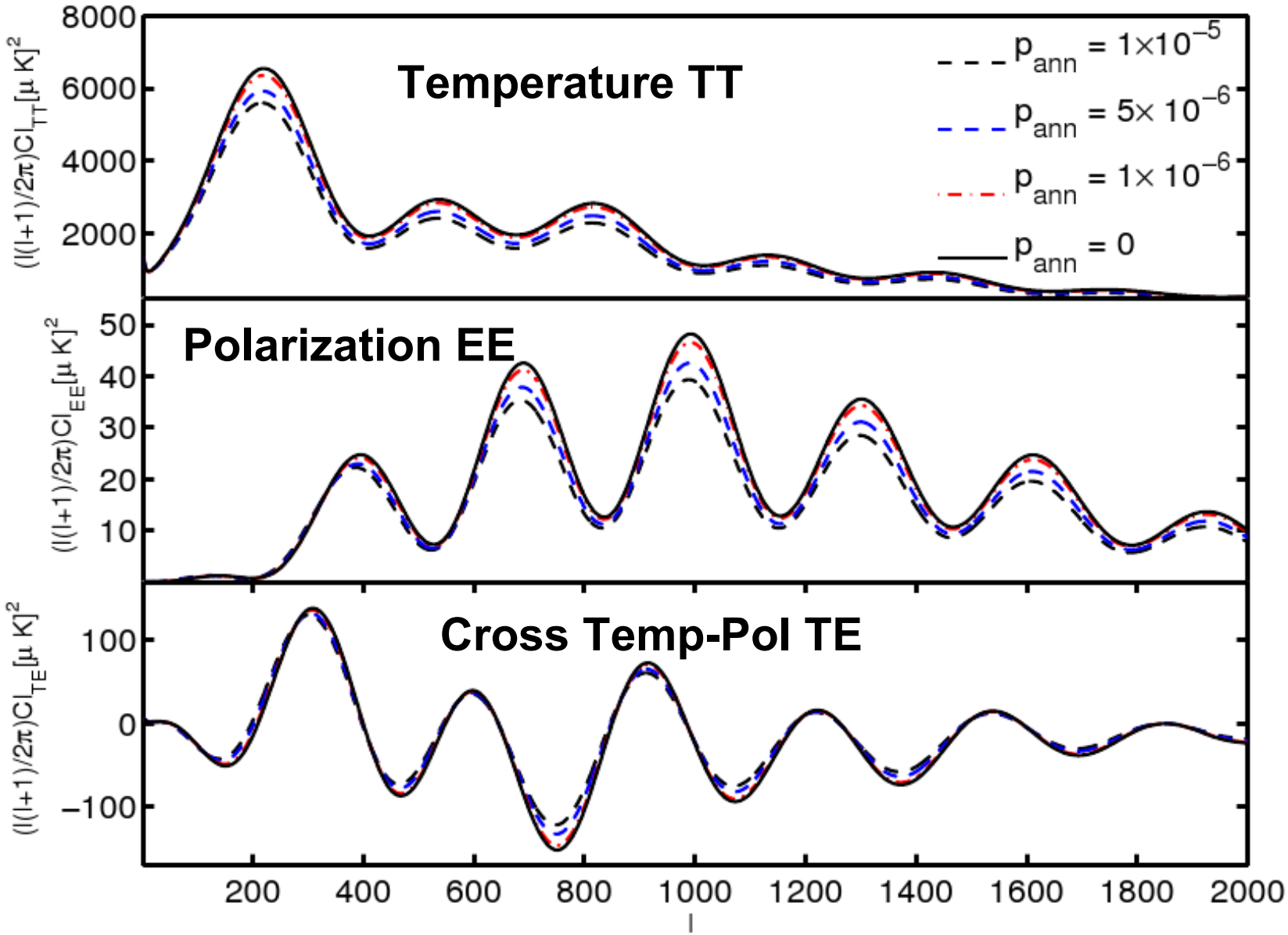
$$\varepsilon_\alpha(z) = C \chi_\alpha \frac{dE/dt}{n_H(z) E_\alpha H(z)}$$

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

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



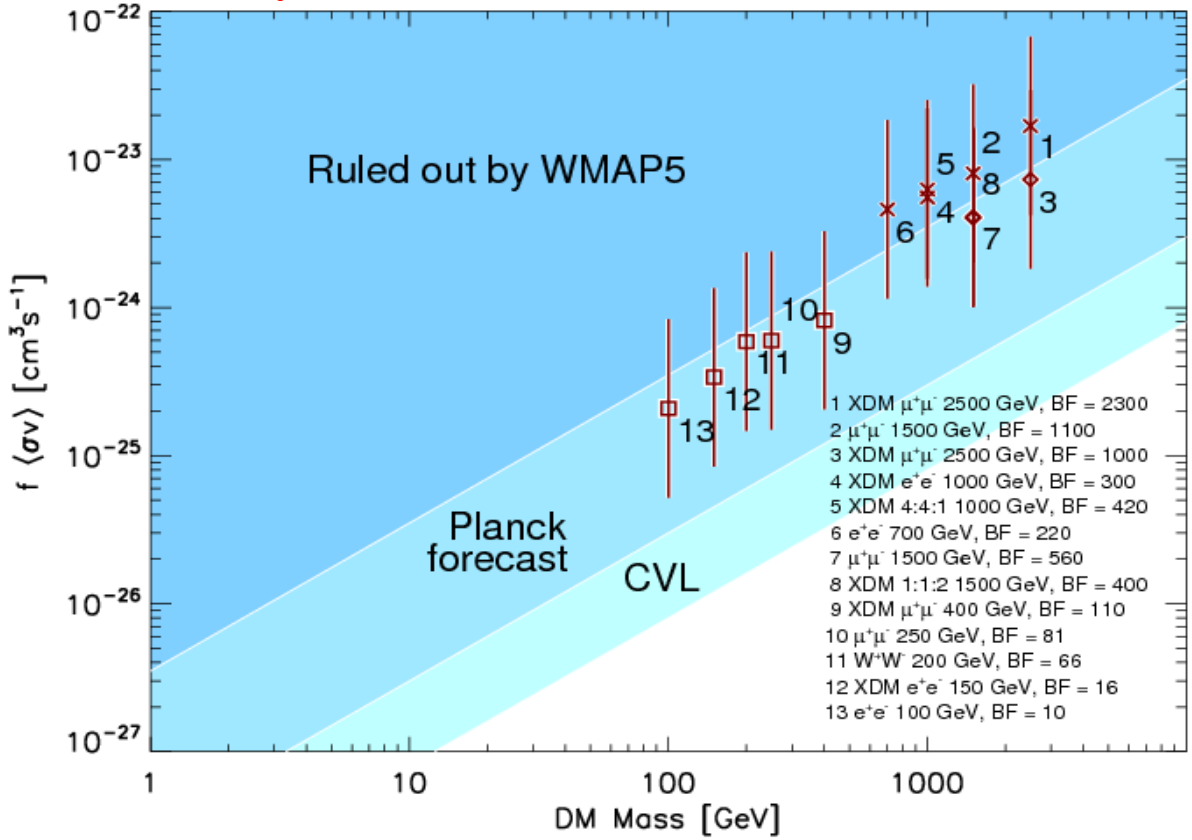
# CMB Angular Power Spectra



# 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

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

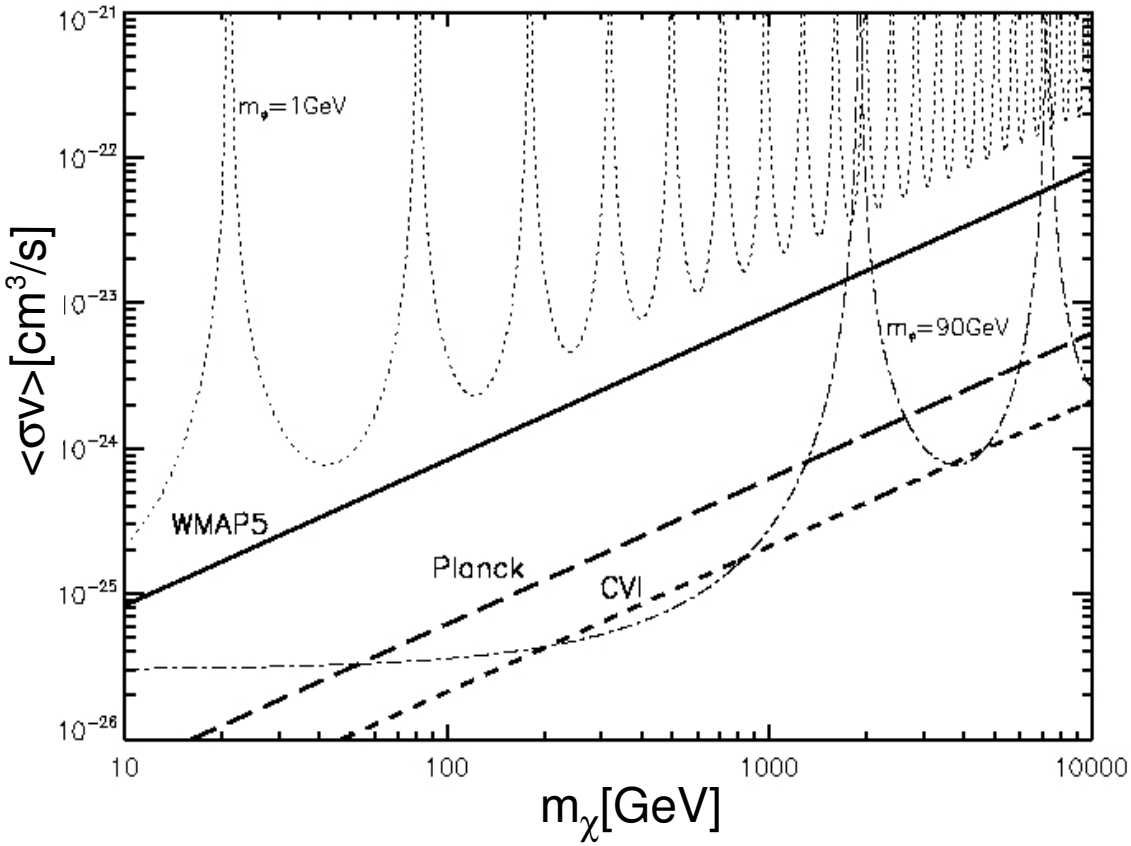



| Experiment | $p_{ann}$ 95% c.l. |
|---|---|
| WMAP | $< 2.4 \times 10^{-6} \mathrm{m}^3/\mathrm{s}/\mathrm{kg}$ |
| Planck | $< 1.7 \times 10^{-7} \mathrm{m}^3/\mathrm{s}/\mathrm{kg}$ |
| CVl | $< 5.9 \times 10^{-8}\ \mathrm{m}^3/\mathrm{s}/\mathrm{kg}$ |

Points from Slatyer et al. arXiv:0906.1197

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

- 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%.

**ACTpol** will provide info useful for CMB science till **TT lmax~2500** and **EE lmax~3500** (foregrounds limited). 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 | $< 1.5 \times 10^{-7} \mathrm{m}^3/\mathrm{s}/\mathrm{kg}$ |
| Planck+ACT | $< 1.2 \times 10^{-7} \mathrm{m}^3/\mathrm{s}/\mathrm{kg}$ |
| CMBpol | $< 6.3 \times 10^{-8}\ \mathrm{m}^3/\mathrm{s}/\mathrm{kg}$ |

Galli S., Martinelli M., Melchiorri A., Pagano L., Sherwin B., Spergel D., arXiv:1005.3808

# Conclusions on Dark Matter annihilation

- CMB = very good DM annihilation probe as indipendent from the knowledge of DM distribution
- WMAP already puts strong constraints
- More accurate model needed to improve constraints
- Planck will improve constraints by one order of magnitude.