Fundamental physics from Planck

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On behalf of the Planck collaboration

TAUP 2015, Torino, 7 September 2015

Outline

- The ΛCDM model: understanding the differences between WMAP and Planck, e.g.:

Hubble parameter

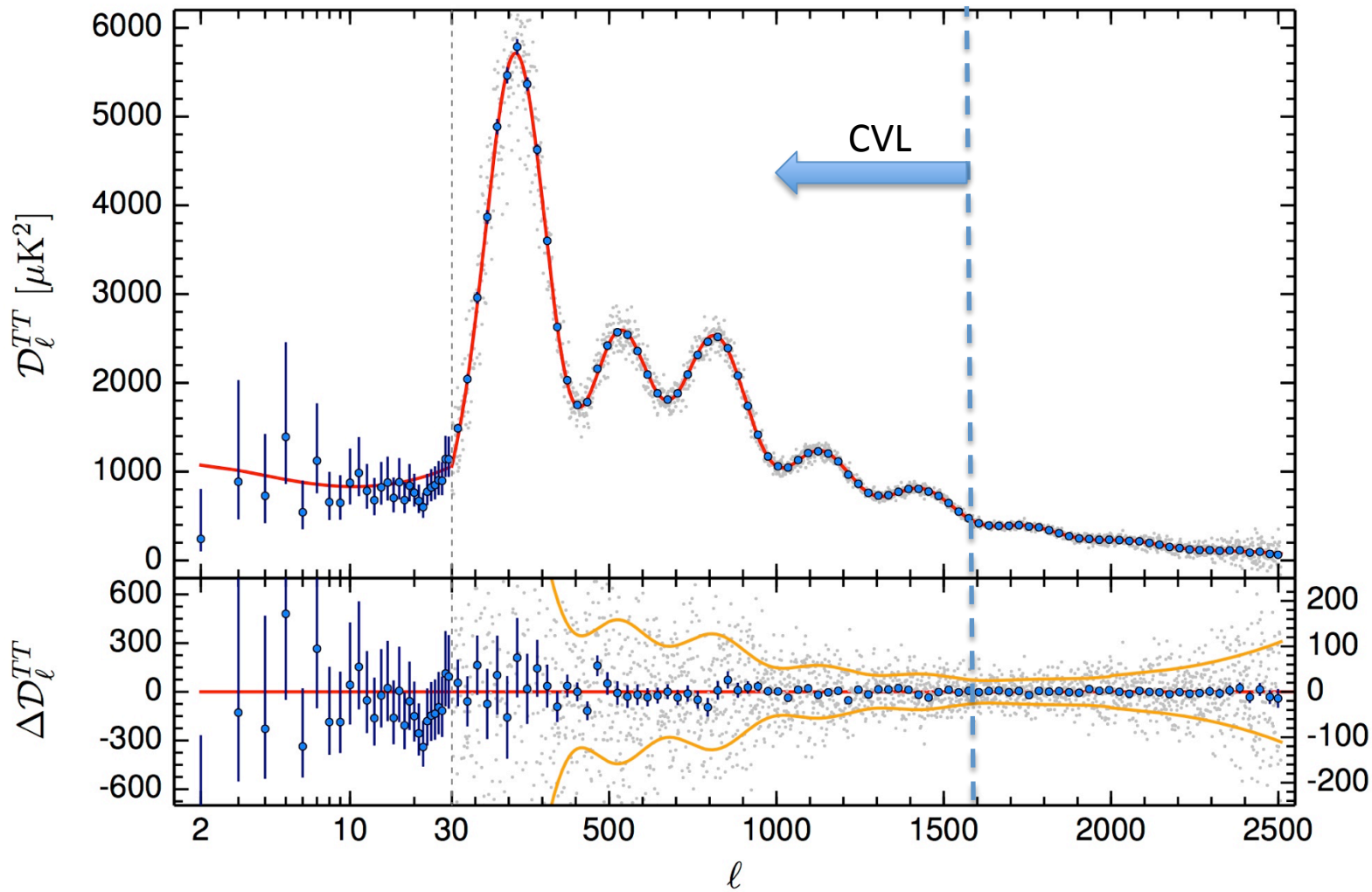
Planck 67.31 ± 0.96

WMAP 69.7 ± 2.1

- Extensions of ΛCDM: results on dark matter annihilation.

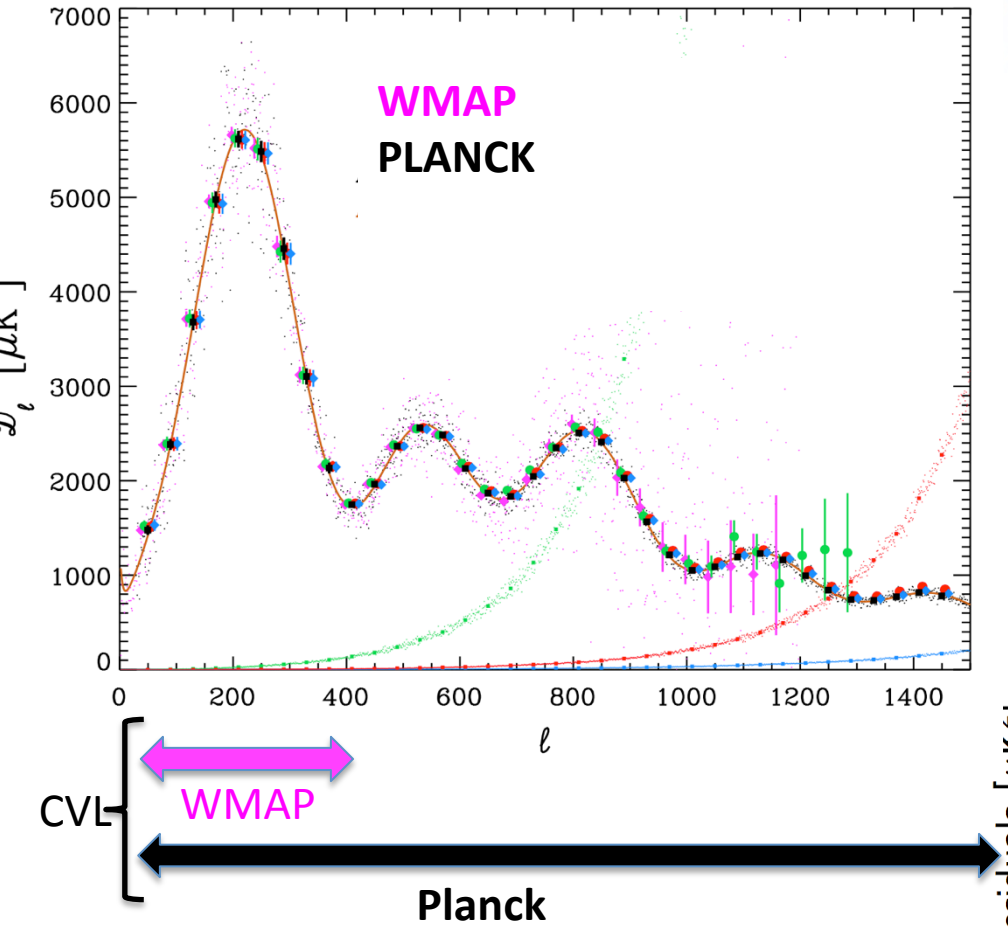
This talk will cover only a very small part of the Planck 2015 results, mostly in the Cosmological Parameters and Likelihood papers (Planck 2015 results XI, XIII).

Planck TT power spectrum

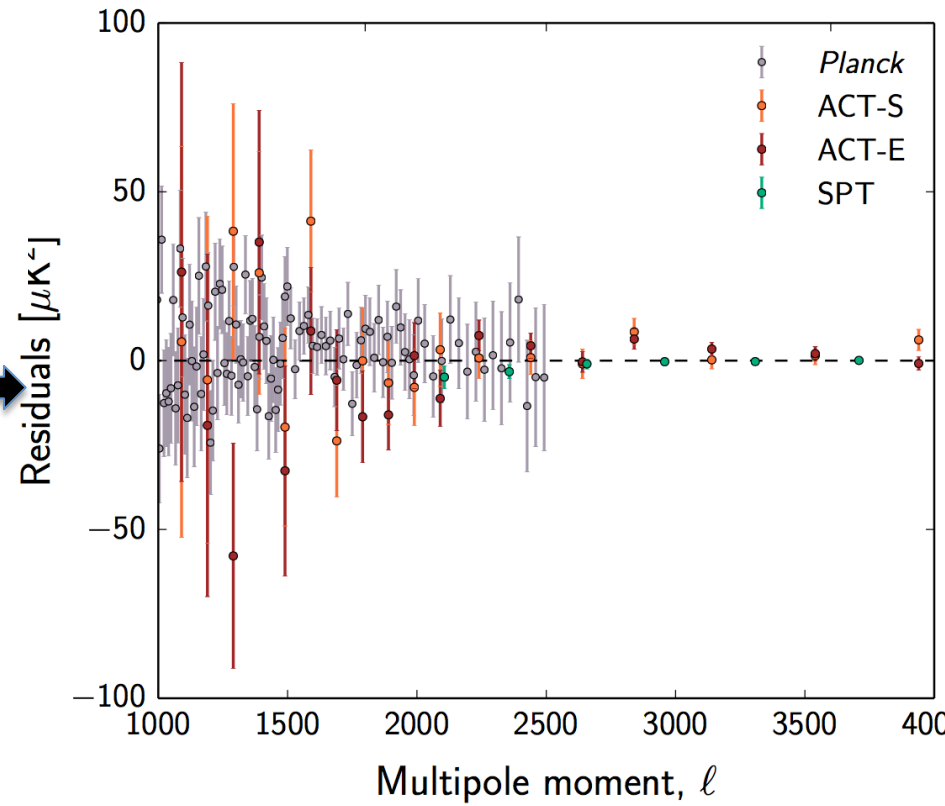


Temperature power spectrum **cosmic variance limited till l~1600**, on 40-70% of the sky.

Other experiments

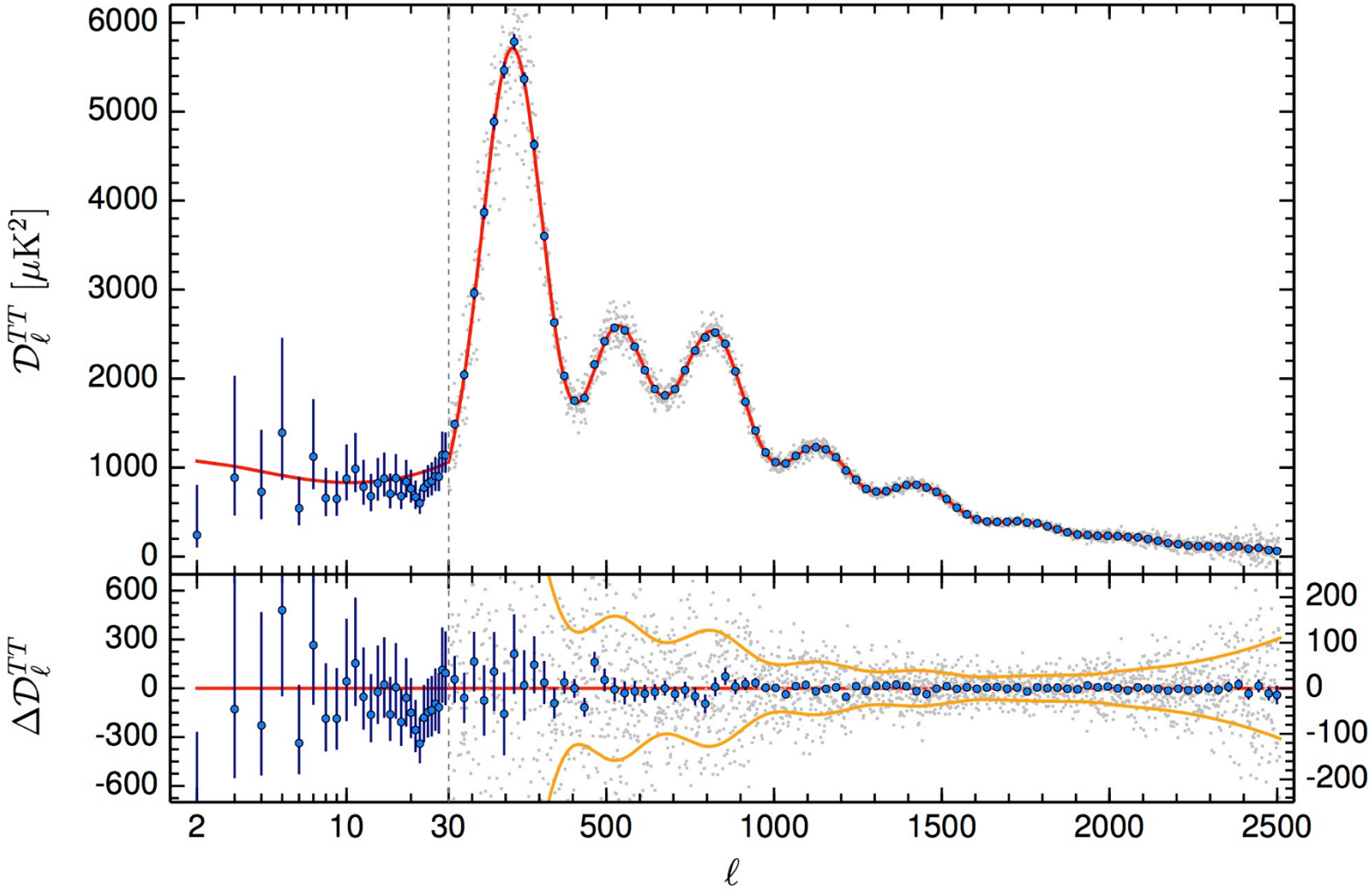


WMAP cosmic variance limited till l~400 (data points till l~1200)

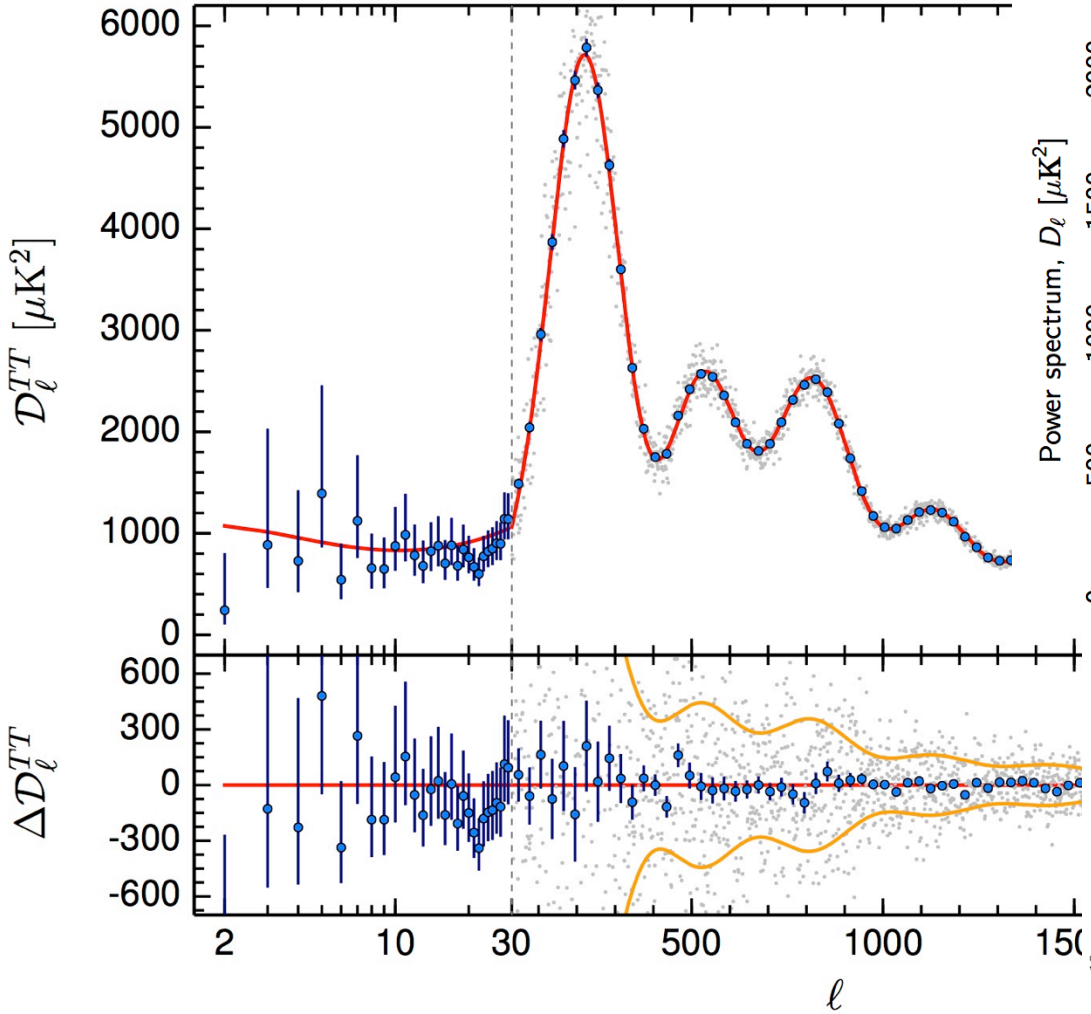


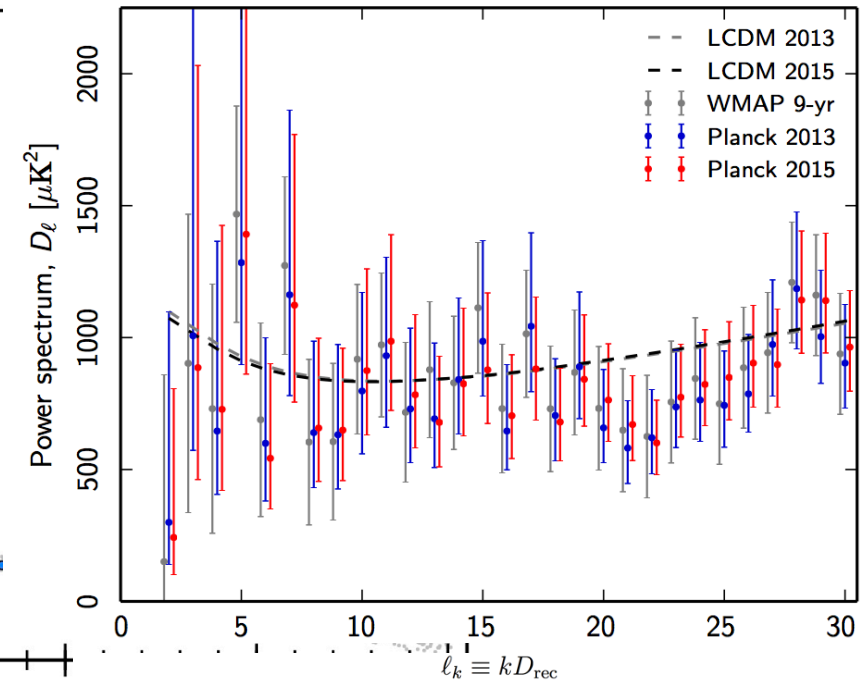
ACT and SPT use < 5% of the sky VS 40-70% in Planck. Sample variance more than 3 times larger than Planck!

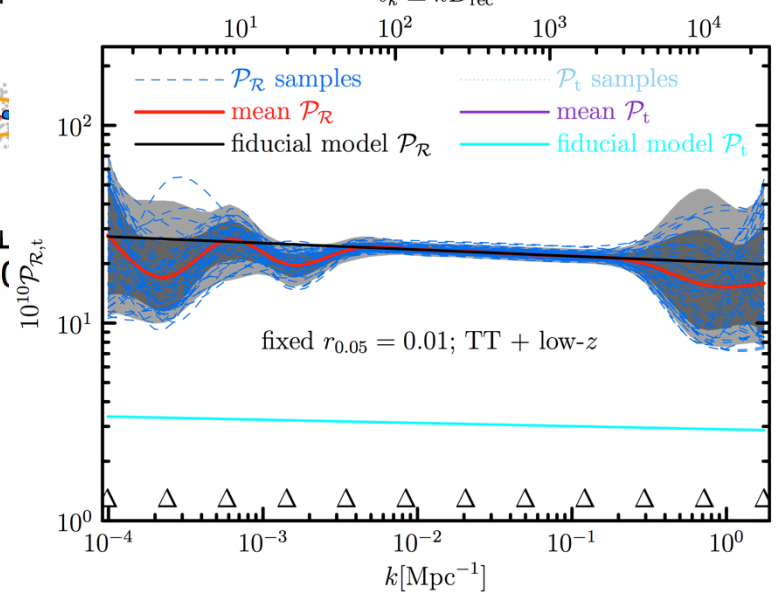
Planck TT power spectrum



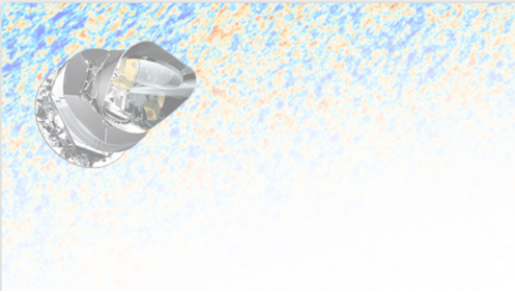
Planck TT power spectrum







See also Hannestad 03, Shafieloo 03,
Bennet et al. 2011, Mortonson et al. 2009 and many others



Scalar spectral index ns

Planck 0.9655 ± 0.0062

WMAP 0.974 ± 0.013

Dark Matter density

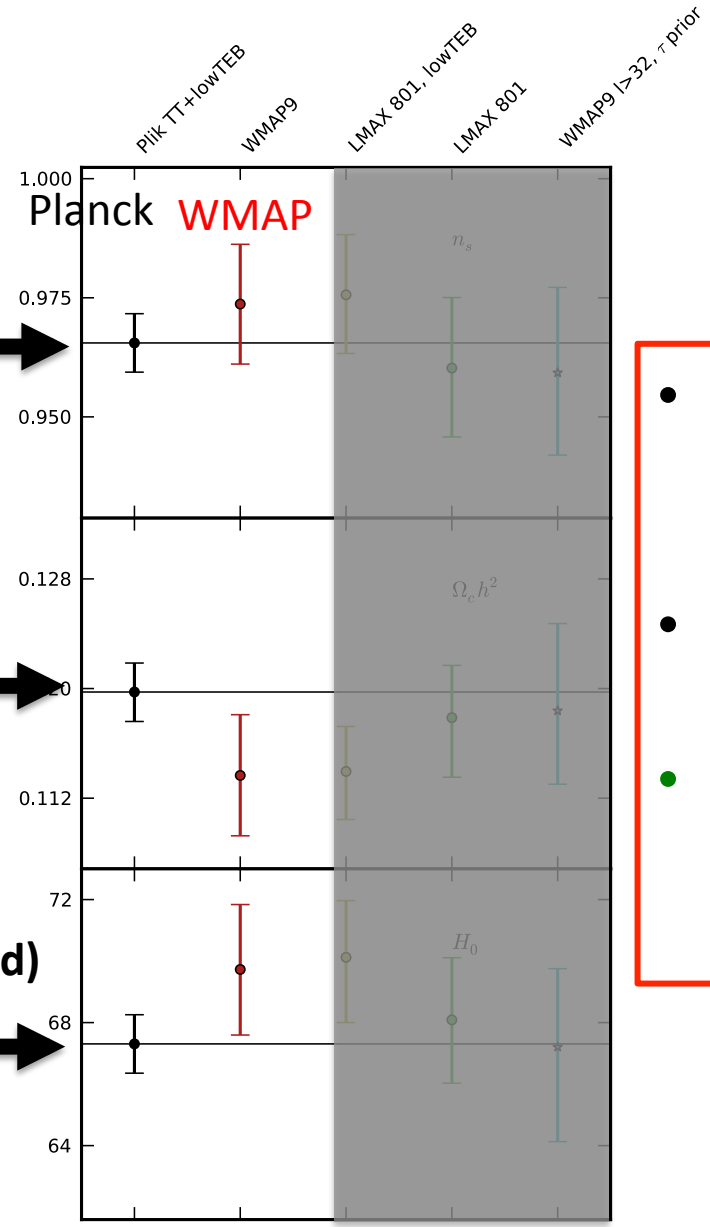
Planck 0.1197 ± 0.0022

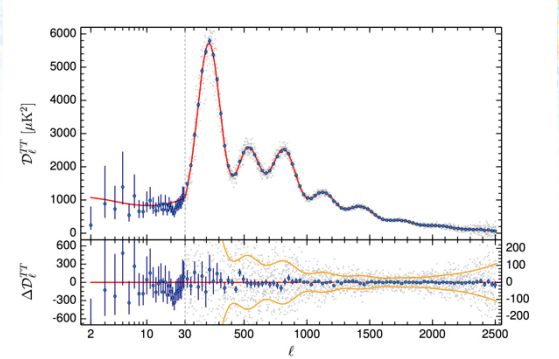
WMAP 0.1137 ± 0.0045

Hubble parameter (derived)

Planck 67.31 ± 0.96

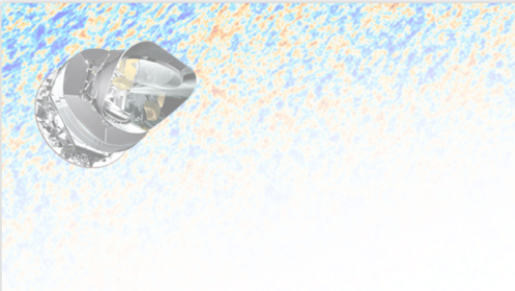
WMAP 69.7 ± 2.1





- WMAP and Planck parameters differ by ~1 sigma.
- WMAP errors factor 2 larger than Planck.
- n_s and H_0 are larger in WMAP, while $\Omega_c h^2$ is smaller.

(NB: For Planck, we use TT only at high-l and TT and pol at low-l. For WMAP, we use all the TT and pol data available)



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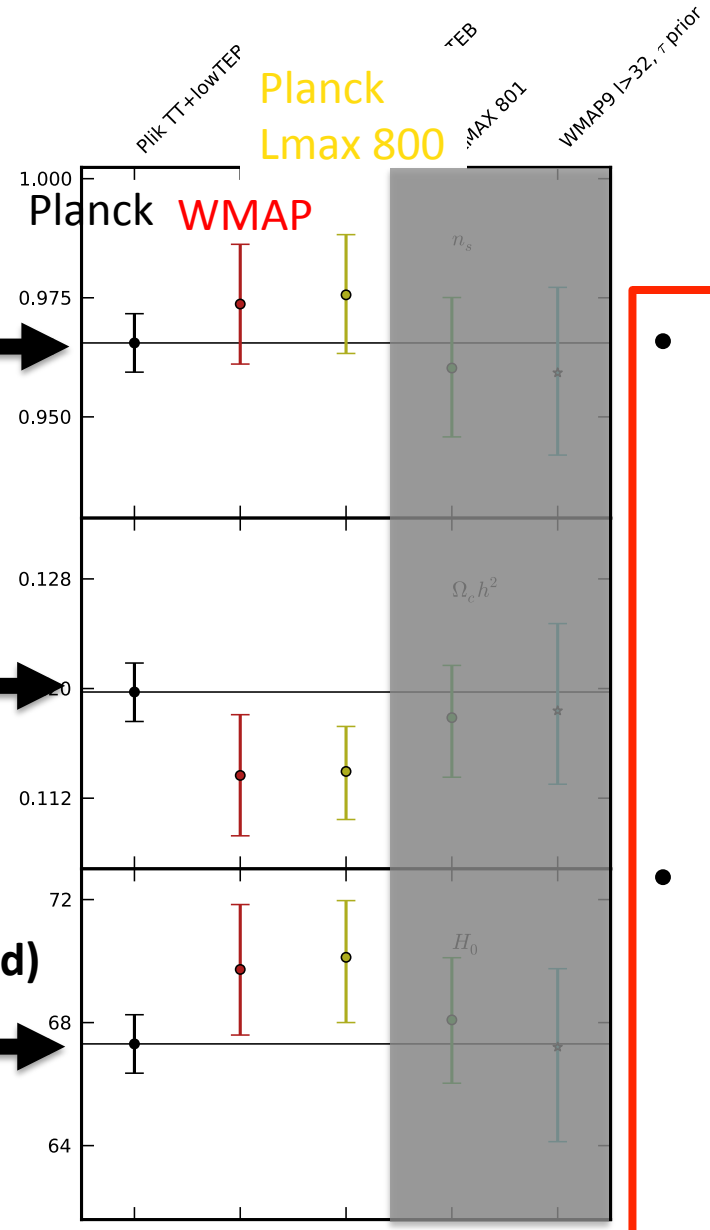
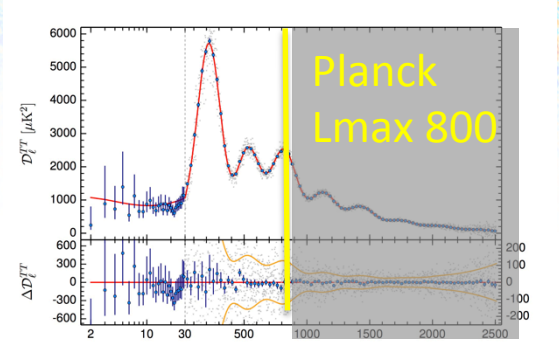
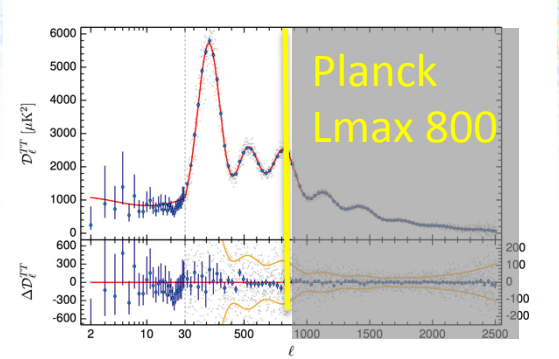




- If we cut Planck data at lmax=800, n_s and H_0 increase and $\Omega_c h^2$ decreases, in good agreement with WMAP.
- Cutting lmax=800 makes Planck more sensitive to the l~20 deficit, similarly to what happens with WMAP.

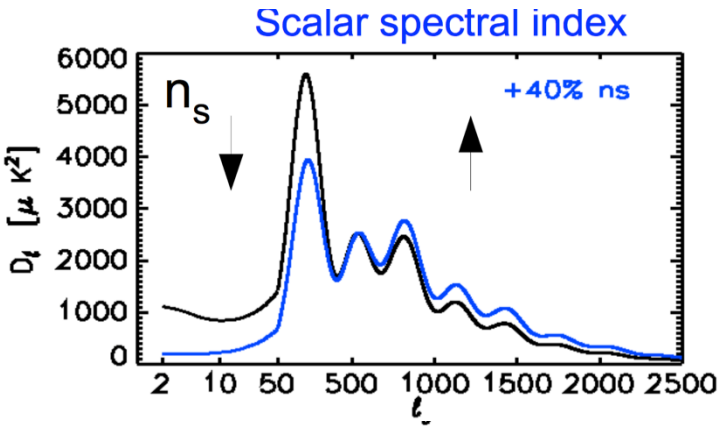


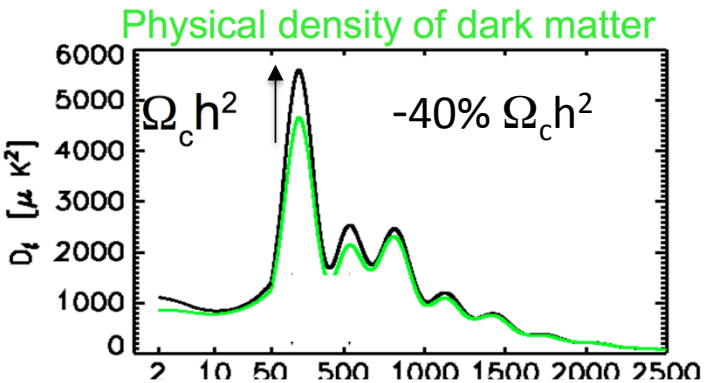
- When we cut at lmax=800, degeneracies in parameters are large. One can increase n_s to better fit the l=20 deficit

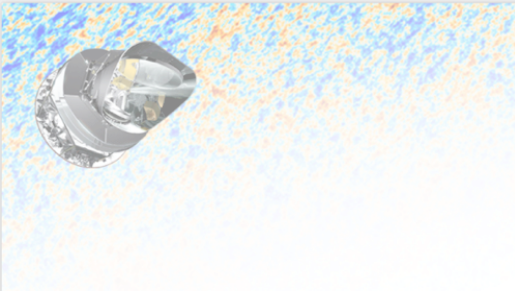
$$\mathcal{P}_{\mathcal{R}}(k) = A_s \left(\frac{k}{k_0}\right)^{n_s - 1}$$

- Since a larger n_s decreases the first peak, one can compensate by decreasing the value of $\Omega_c h^2$.

- A smaller $\Omega_c h^2$ requires a larger H0 in order to keep the position of the peaks (e.g. the angular distance to last scattering) fixed.







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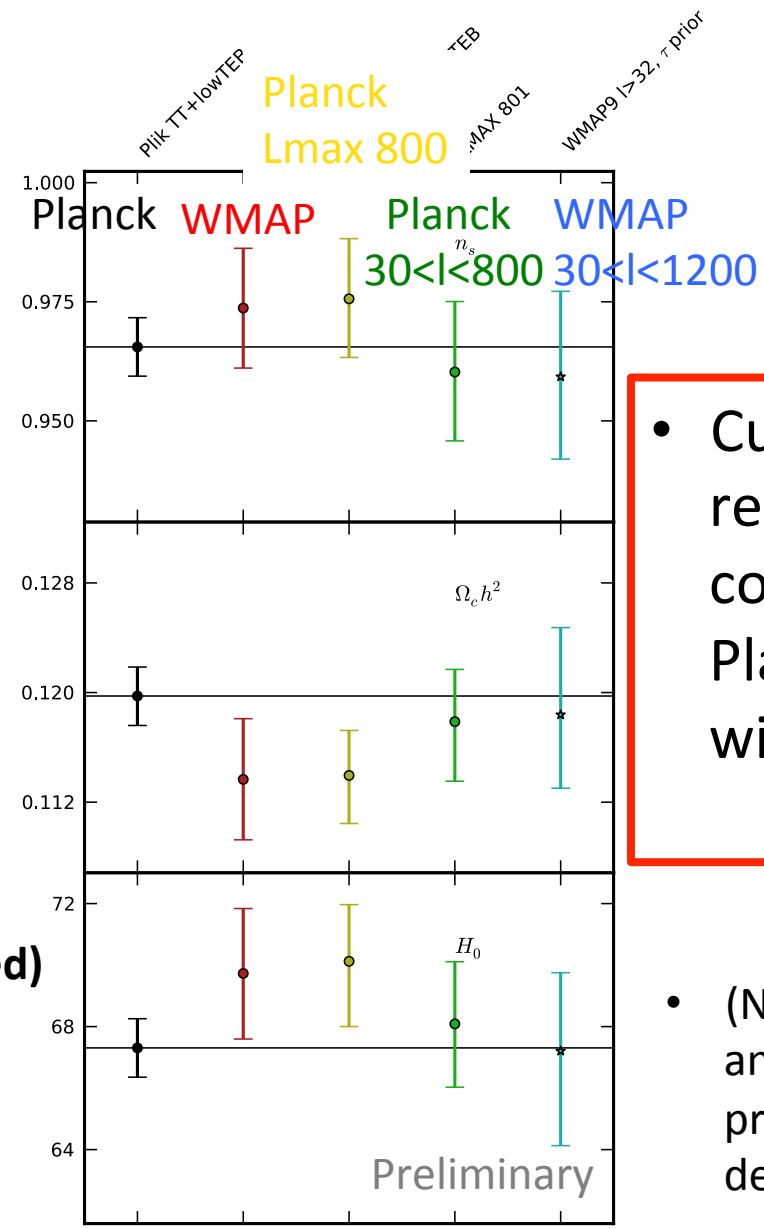
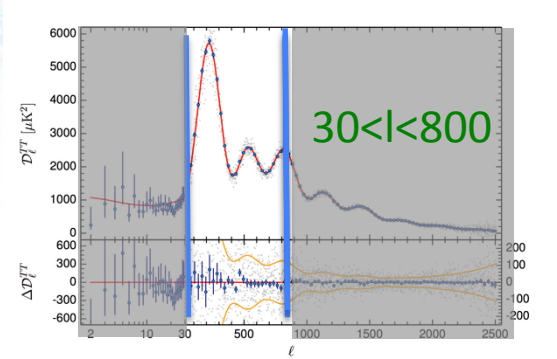




- Cutting the TT l<30, we recover the full Planck cosmology both with Planck lmax=800 and with WMAP.

- (NB: we cut here both the TT and pol data at low-l. We use a prior on tau to break degeneracies)

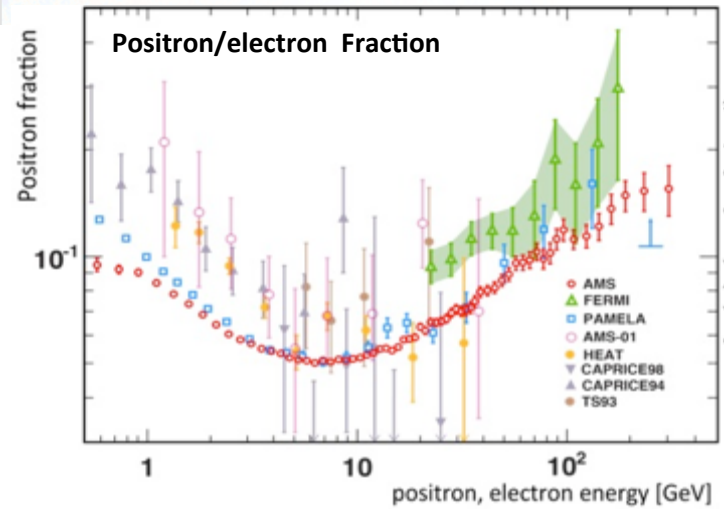
Summary

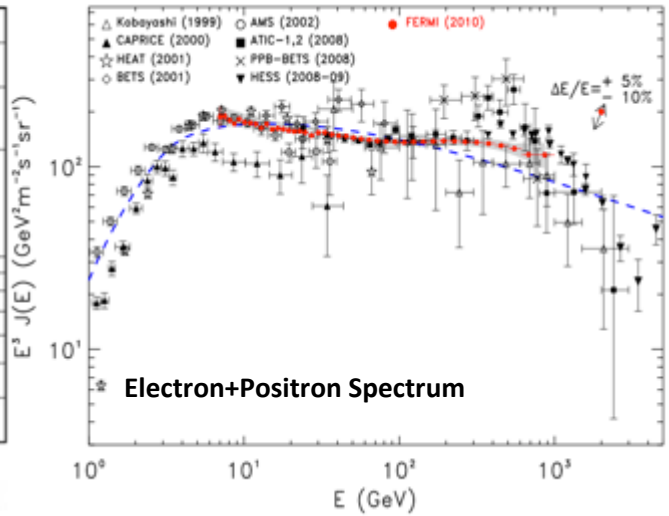
- Planck and WMAP cosmologies are in very good agreement, in particular when cutting Planck at lmax=800.
- The WMAP and Planck lmax=800 cosmologies are affected by the l~20 feature: n_s is large to better fit the low-l, $\Omega_c h^2$ is low to compensate for large n_s on the first peak, H_0 increases to keep the position of the peaks (angular diameter distance to last scattering surface) fixed.
- If we cut the l<30, the WMAP and Planck lmax=800 cosmologies are in very good agreement with the full Planck one.
- The full Planck cosmology is less affected by the l~20 deficit thanks to the longer lever arm. However, this deficit still impacts parameters at some level (e.g. Neff, Alens)

Constraints on dark matter annihilation

Indirect search anomalies:

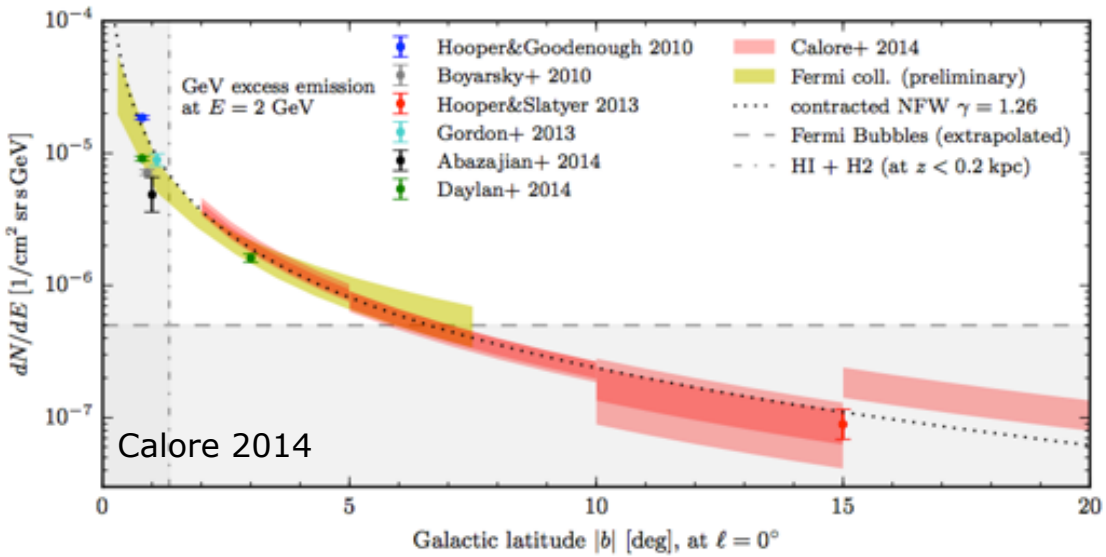
Dark matter annihilation?





Cosmic rays excesses in PAMELA/FERMI/AMS-02

- Leptonic ann.chan.,
- Mass ~ TeV,
- Large cross-section required (~10^{-23}cm^3/s).
- Need broken power law in electrons.

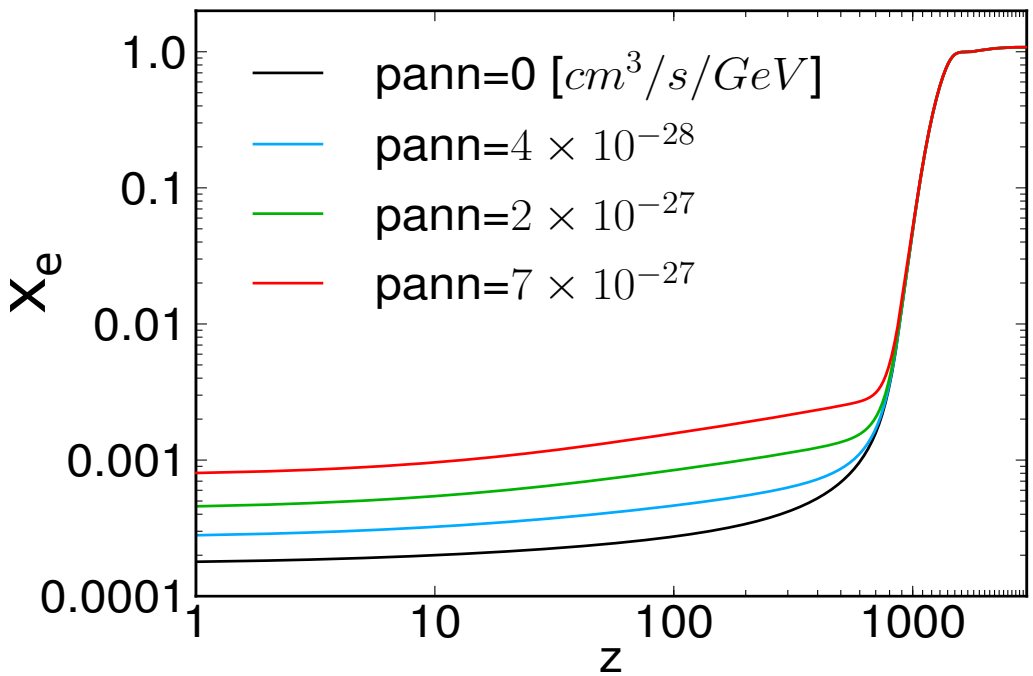


Fermi Galactic Center excess

- Many ann. chan. allowed.
- Mass ~ few tens GeV,
- Thermal relic cross section (~10^{-26}cm^3/s)

DM annihilation at the epoch of recombination

$$\frac{dE}{dt} = \rho_c^2 c^2 \Omega_{DM}^2 (1+z)^6 \underbrace{f_{eff} \frac{<\sigma v>}{m_\chi}}_{p_{ann}}$$



The injected energy ionizes, excites and heats the medium. This affects the evolution of the free electron fraction.

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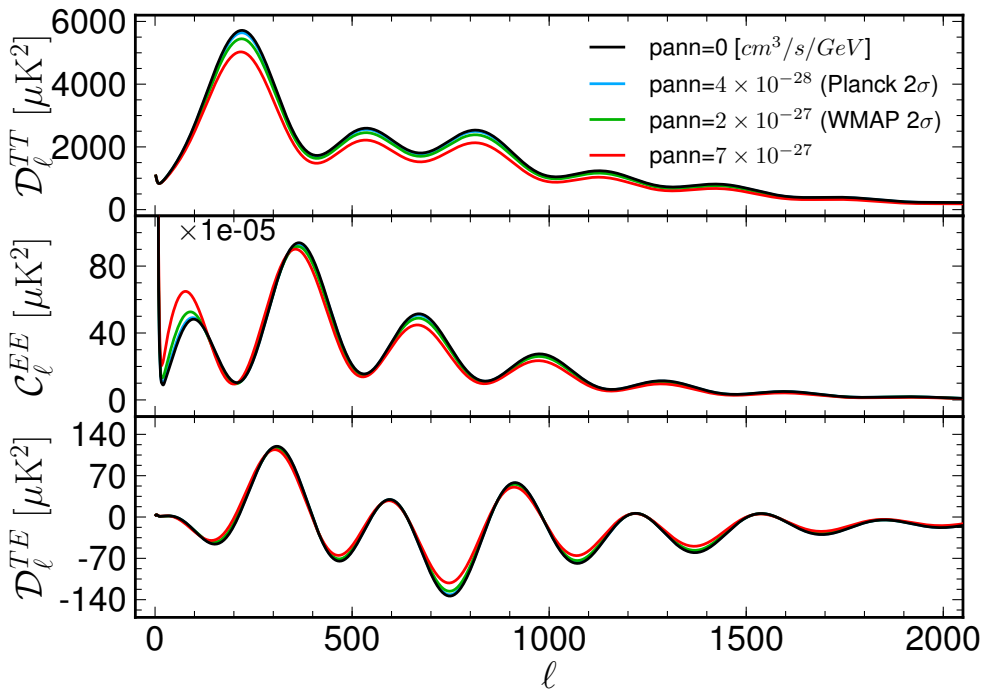
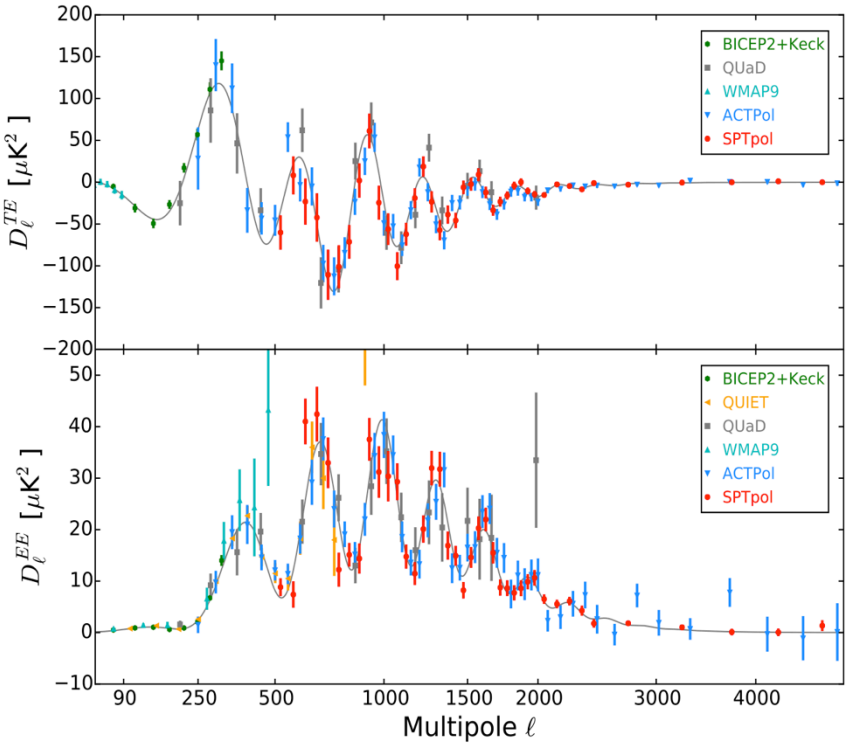
$$\frac{dE}{dt} = \rho_c^2 c^2 \Omega_{DM}^2 (1+z)^6 \underbrace{f_{eff} \frac{<\sigma v>}{m_\chi}}_{p_{ann}}$$



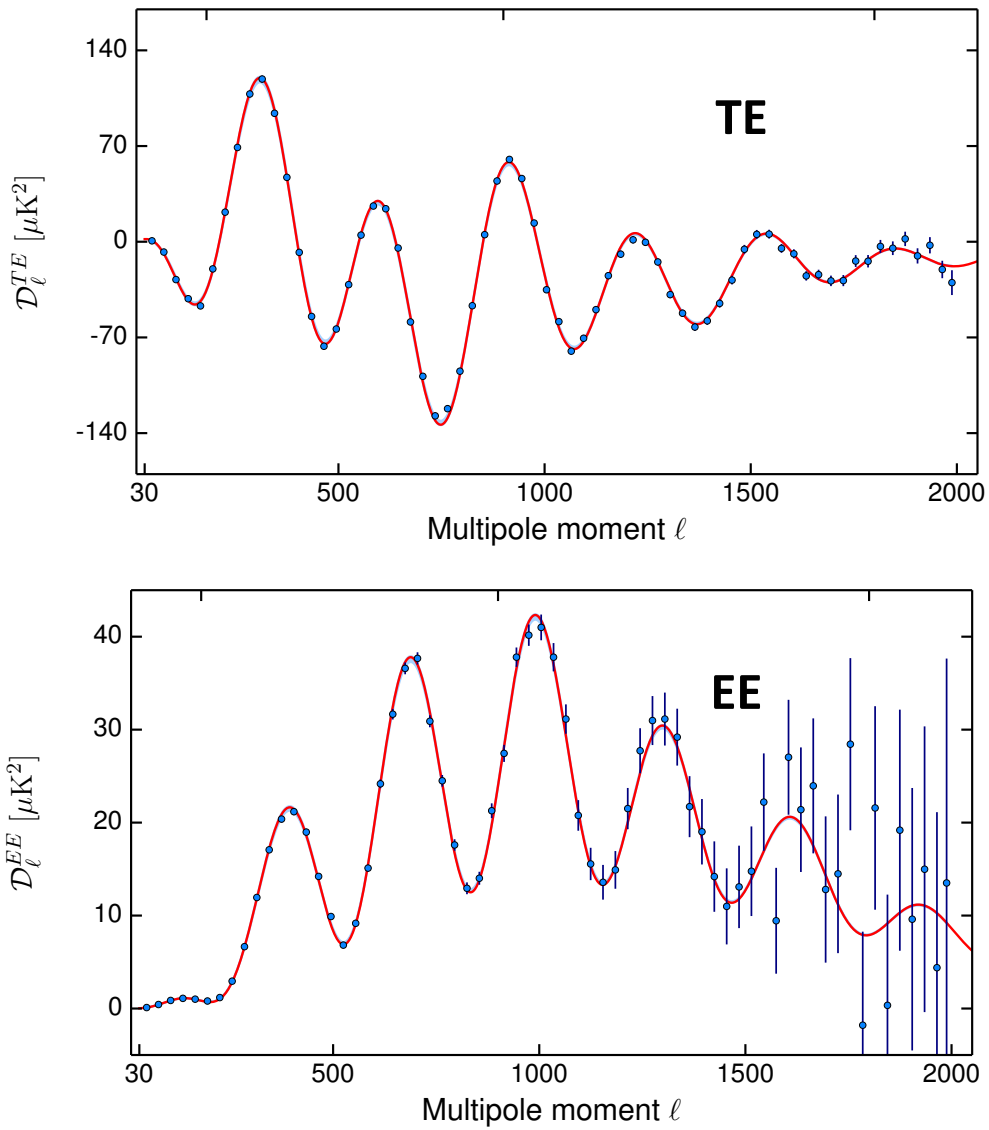
- The injected energy ionizes, excites and heats the medium. This affects the evolution of the free electron fraction.
- Suppresses the peaks, but enhances polarization at large scales!

2015 Polarization power spectra

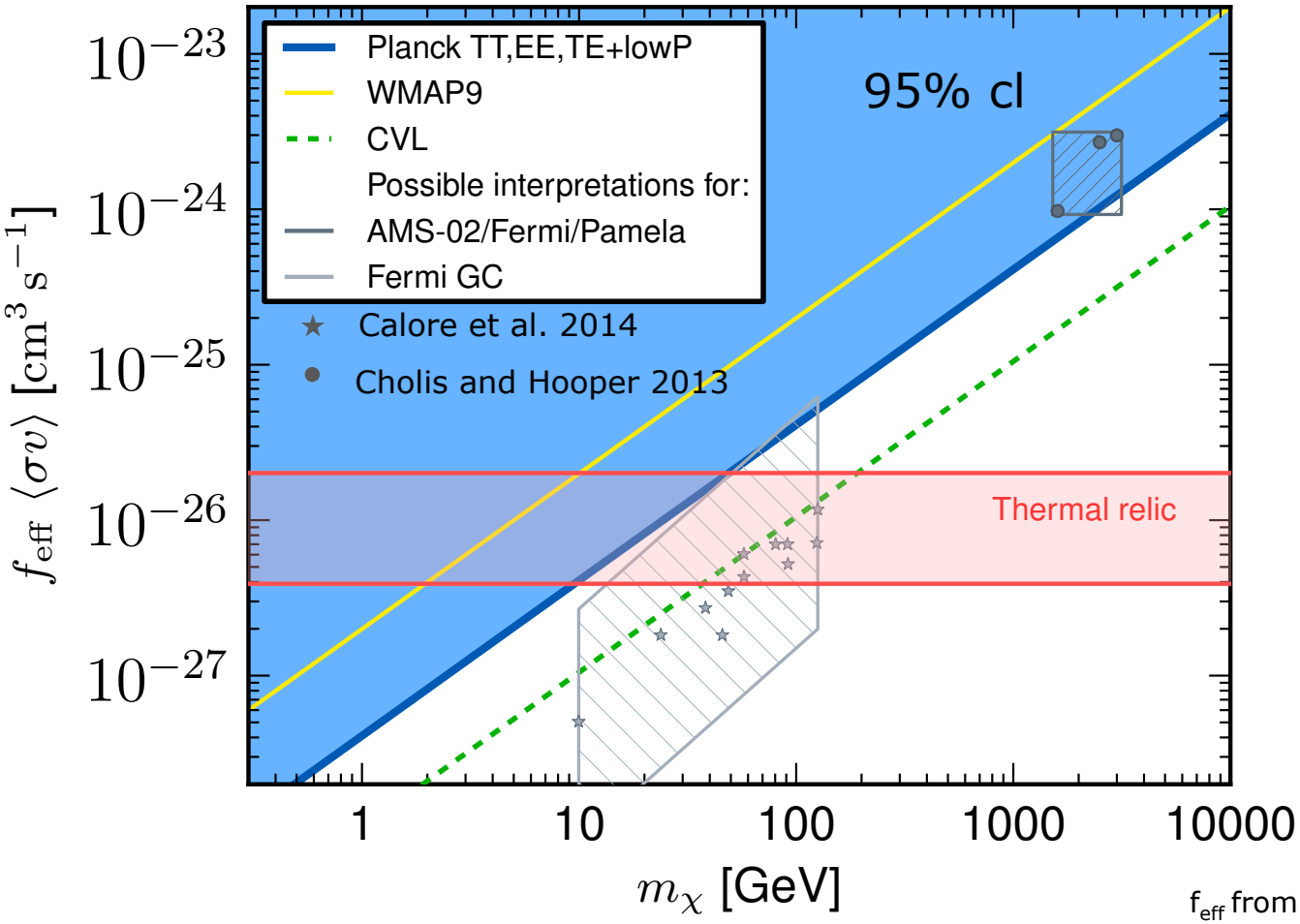
Pre-Planck measurements



Planck 2015



Constraints on Dark Matter Annihilation



Most of parameter space preferred by AMS-02/ Pamela/Fermi ruled out at 95%, under the assumption $\langle\sigma v\rangle(z=1000)=\langle\sigma v\rangle(z=0)$

Thermal Relic cross sections at z~1000 ruled out for:

m~<40 GeV (e^-e^+)
m~<16 GeV ($\mu^+\mu^-$)
m~<10 GeV ($\tau^+\tau^-$).

Only a small part of the parameter space preferred by Fermi GC is excluded

f_{eff} from T. Slatyer (Madhavacheril et al. 2013)

Conclusions

- Planck 2015 data is powerful to constrain LCDM and extensions.
- Planck polarization improves spectacularly constraints on DM annihilation.
- Thermal Relic cross sections at z~1000 ruled out for:

$m \sim < 40$ GeV $(e^- e^+)$
$m \sim < 16$ GeV $(\mu^+ \mu^-)$
$m \sim < 10$ GeV $(\tau^+ \tau^-)$.

The scientific results that we present today are a product of the Planck Collaboration, including individuals from more than 100 scientific institutes in Europe, the USA and Canada.

Planck is a project of the European Space Agency, with instruments provided by two scientific Consortia funded by ESA member states (in particular the lead countries: France and Italy) with contributions from NASA (USA), and telescope reflectors provided in a collaboration between ESA and a scientific Consortium led and funded by Denmark.

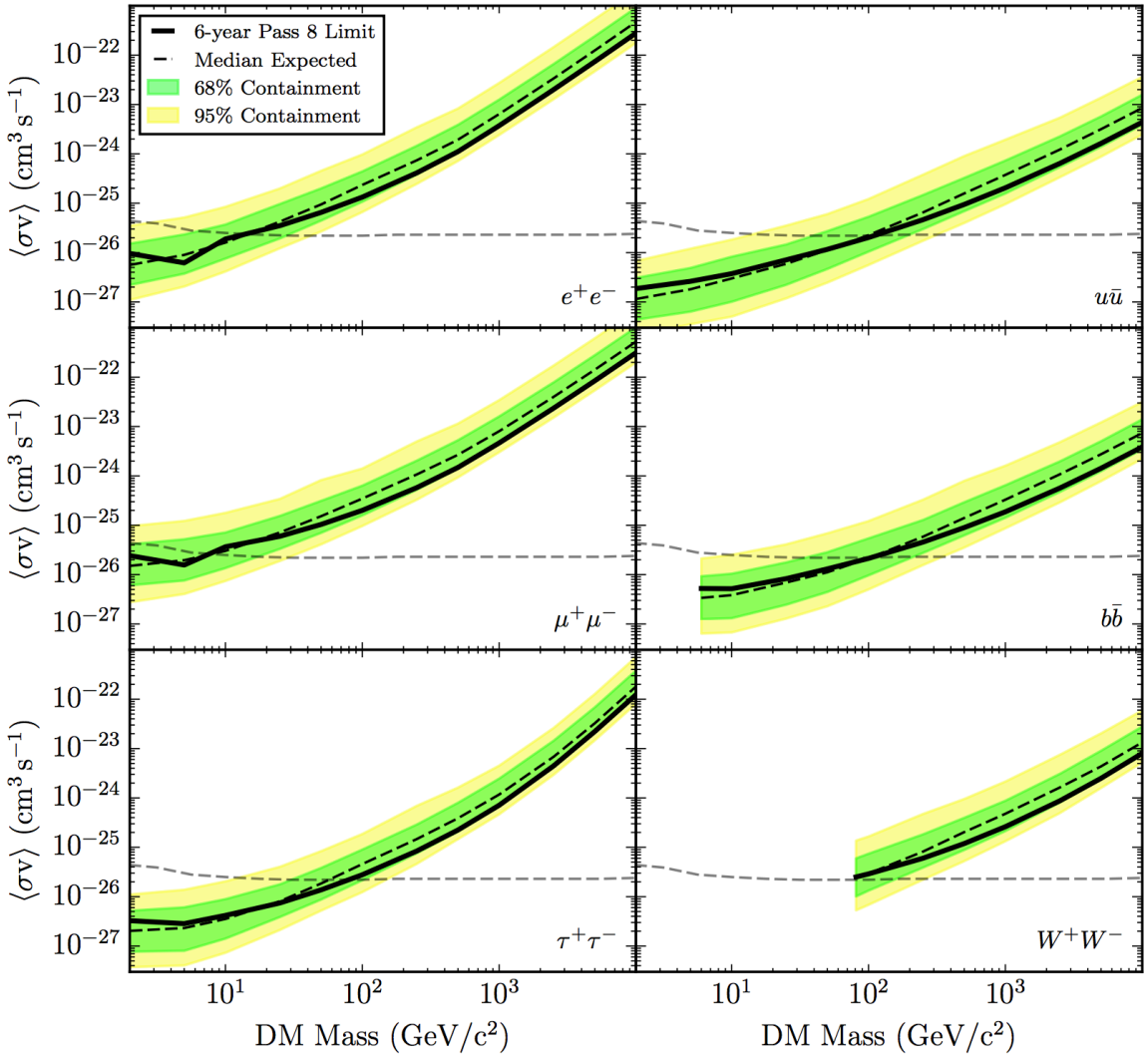


FIG. 8. DM annihilation cross-section constraints derived from the combined 15-dSph analysis for various channels.

Thermal relic cross section excluded at:

ee ~15 GeV

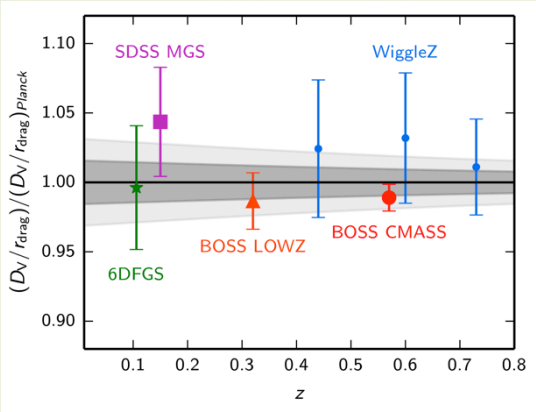
μμ ~10 GeV

ττ ~80 GeV

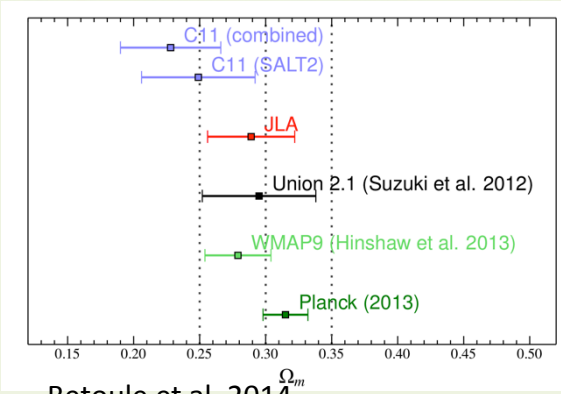
Fermi-lat collaboration
arXiv:1503.02641

Comparison with other datasets:

BAO

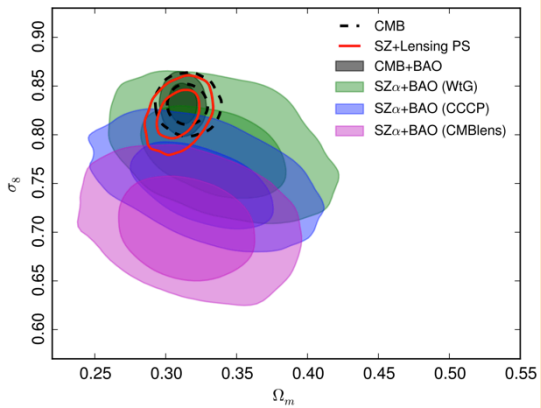


Supernovae (Ω_m)



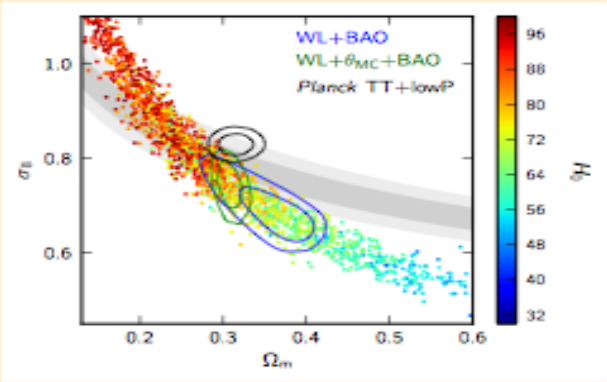
Betoule et al. 2014

Cluster counts (σ_8-Ω_m)



Planck collaboration XXIV

Weak Lensing (σ_8-Ω_m)



Direct measurements H_0

H_0=67.8±0.96
(PlanckTT+lowP+lensing)

VS

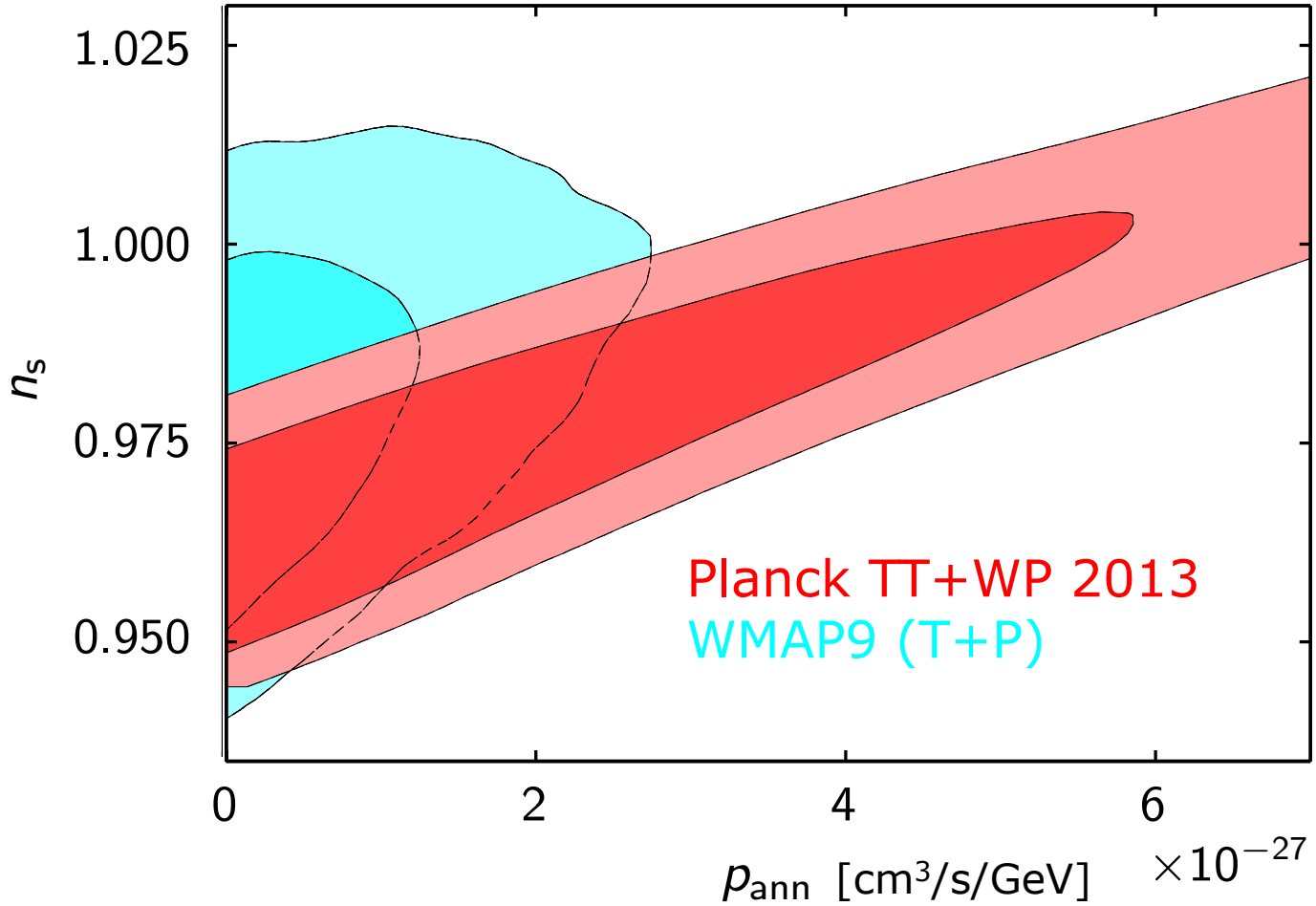
H_0=72.8±2.4 **[2σ tension]**
(Riess+11)

H_0=70.6 ± 3.3 **[1σ tension]**
(Efstathiou+14)

H_0=74.3 ± 2.6 **[2.5σ tension]**
(Freedman+12)

[in Km/s/Mpc]

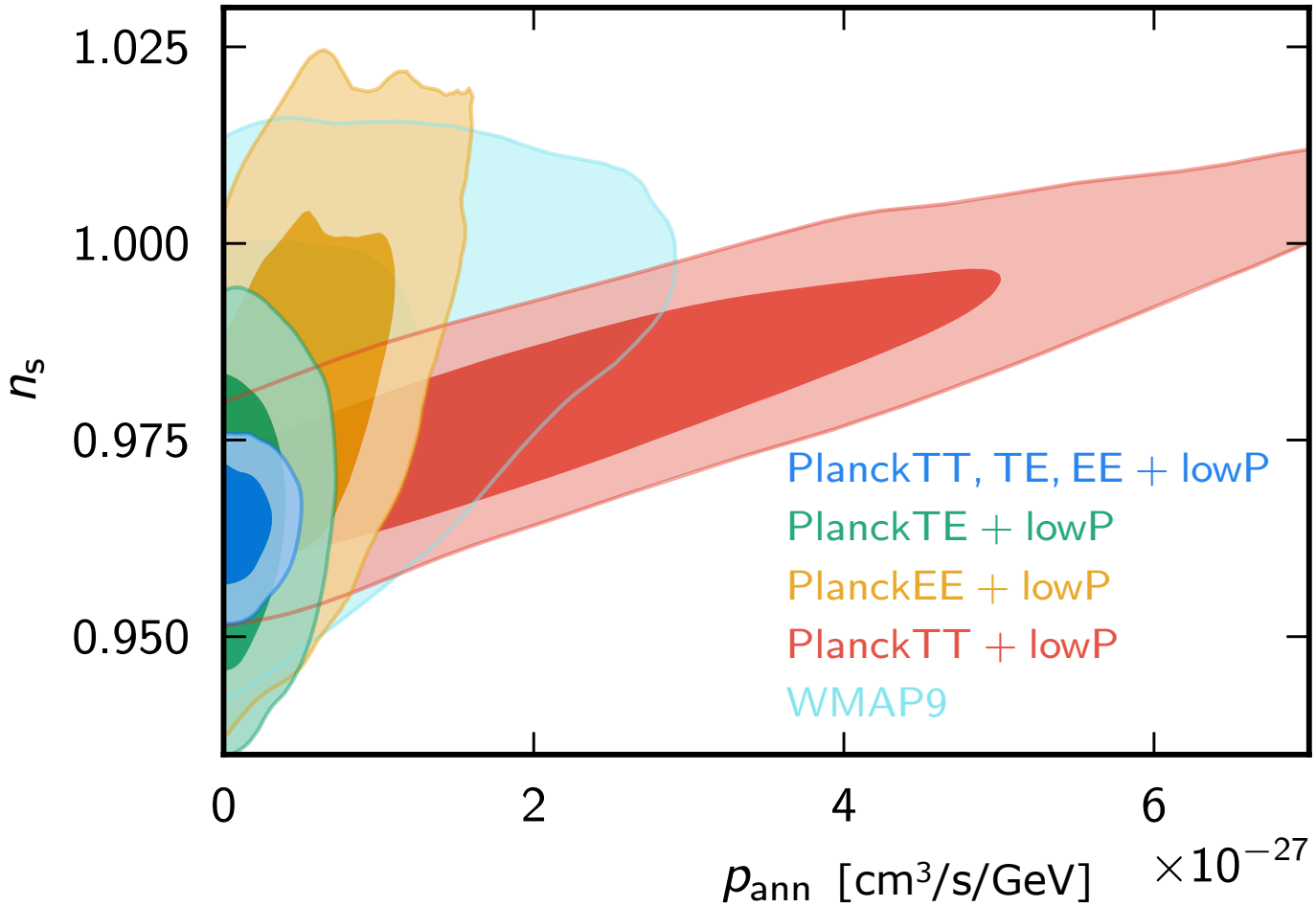
Previous Constraints



Large degeneracies in TT only data.

$$p_{ann} = f_{eff} \frac{<\sigma v>}{m_\chi}$$

Planck 2015 Constraints



Polarization breaks degeneracies!

Planck TT,TE,EE set a constraint 5 times stronger than WMAP9, 4 times stronger than WMAP9+SPT

$$p_{ann} = f_{eff} \frac{<\sigma v>}{m_\chi}$$

Dataset

- **Planck TT**: Planck **TT 2 < ell < 2500**.
- **lowP**: low-l Planck **polarization 2 < ell < 30** (For 2013 results, this will indicate low-l WMAP polarization).
- **Planck TE, EE**: Planck TE and EE high-ell, 30 < ell < 2000
  Small systematics in polarization might still be affecting the results.
- **Lensing**: Planck lensing potential 40 < ell <400 from 4-point correlation function
- **Ext,** external datasets:
  - **BAO** (6dFGS, SDSS-MGS, BOSS-LOWZ, CMASS DR11)
  - **JLA**: Type Ia Supernovae (SNLS +SDSS+low z Sne)
  - **H0**: Hubble constant (Efstathiou 2014 reanalysis of Riess et al. 2011)

➢ Whenever not specified, we assume
Neff=3.046, Σm_ν=0.06eV (1 massive, two massless).