# “Modified gravity: constraints and tools after PLANCK”

Valentina Salvatelli

“Dark Energy: beyond the 6 parameters”
Workshop , CPPM, 3 March 2015

# My research topic

- Constraining cosmological models with dataset combinations (bayesian approach)
- Focus on extensions in the Dark Energy sector.
- Particular interest in modified gravity and interactions between dark matter and dark energy.
- Expertise in constraints from Cosmic Microwave Background (and from its combinations with other measurements).

# Outline

- Current constraints on modified gravity: the PLANCK perspective.
- Available tools for testing MG models and datasets already included.
- Possible projects for the next years.

# Why is the CMB relevant for MG?

Most evident: pin down theory at early times

+

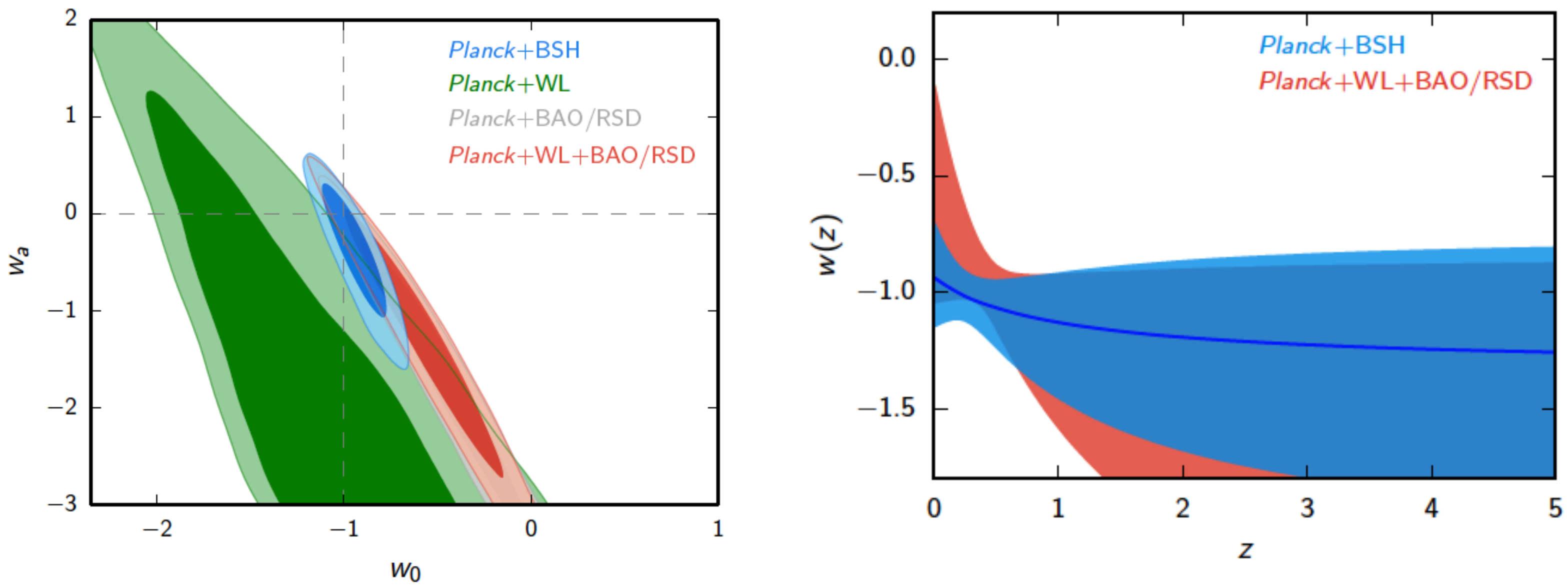
Source of several other probes:

- Position of the peaks ⟷ background history
- ISW effect ⟷ gravitational potential
- Lensing ⟷ gravitational potential / perturbations
- Amplitude of perturbations ⟷ growth of structure
- Ratio between peaks ⟷ baryons/DM couplings

# Main outcomes of PLANCK

## Scientific perspective:

- No evidence for significant deviation from LCDM at the background level.



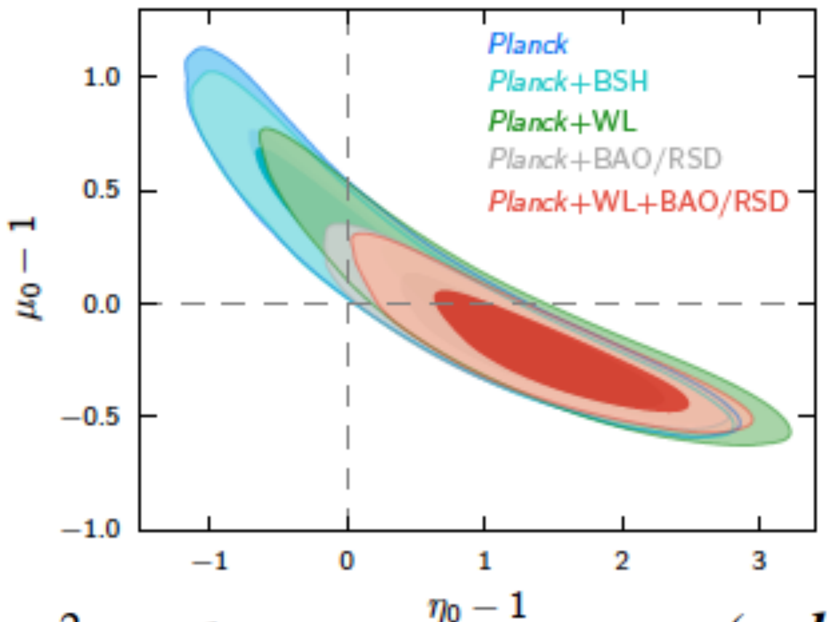

$$w(a) = w_0 + (1-a)w_a$$

*Planck 2015 results. XIV. Dark energy and modified gravity*

# Main outcomes of PLANCK

## Scientific perspective:

- Some tensions emerge when changes in perturbations are considered (if we combine PLANCK with weak lensing/ redshift surveys and we consider phenomenological parametrizations).



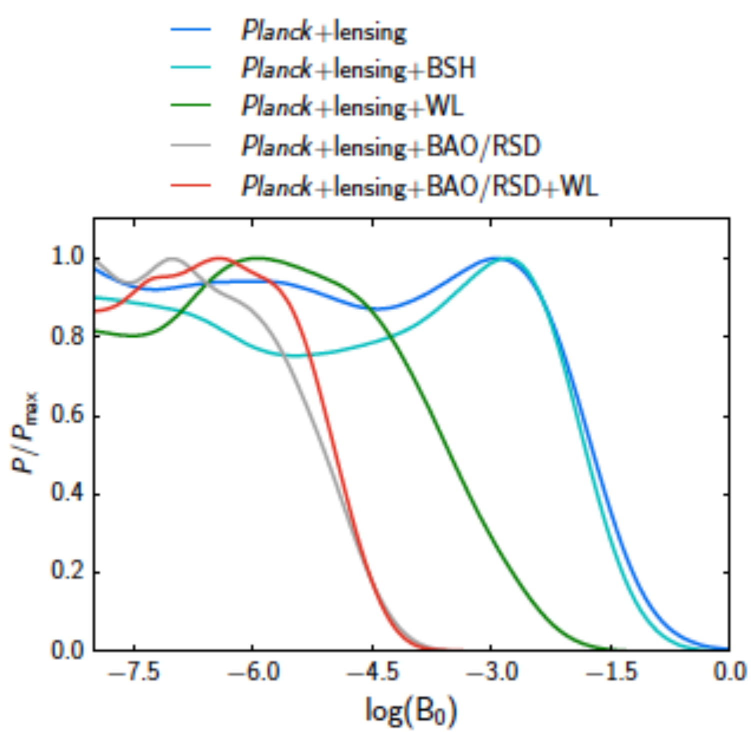

$$-k^2\Psi \equiv 4\pi G a^2 \mu(a,\boldsymbol{k})\rho\Delta; \qquad \eta(a,\boldsymbol{k}) \equiv \Phi/\Psi$$

*Planck 2015 results. XIV. Dark energy and modified gravity*

# Main outcomes of PLANCK

## Scientific perspective:

- No evidence for deviations when considering specific models i.e. f(R) theories.

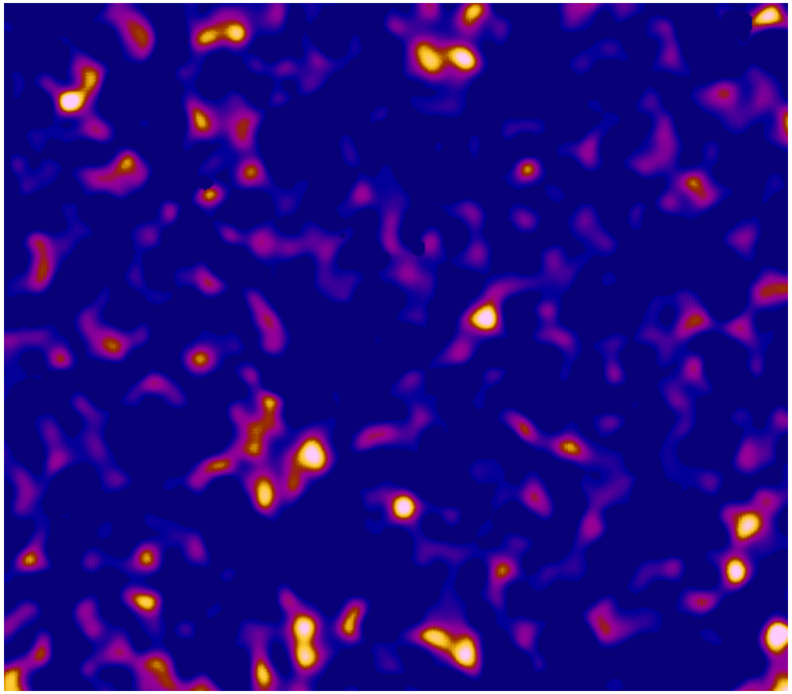



*Planck 2015 results. XIV. Dark energy and modified gravity*

# Main outcomes of PLANCK

## Scientific perspective:

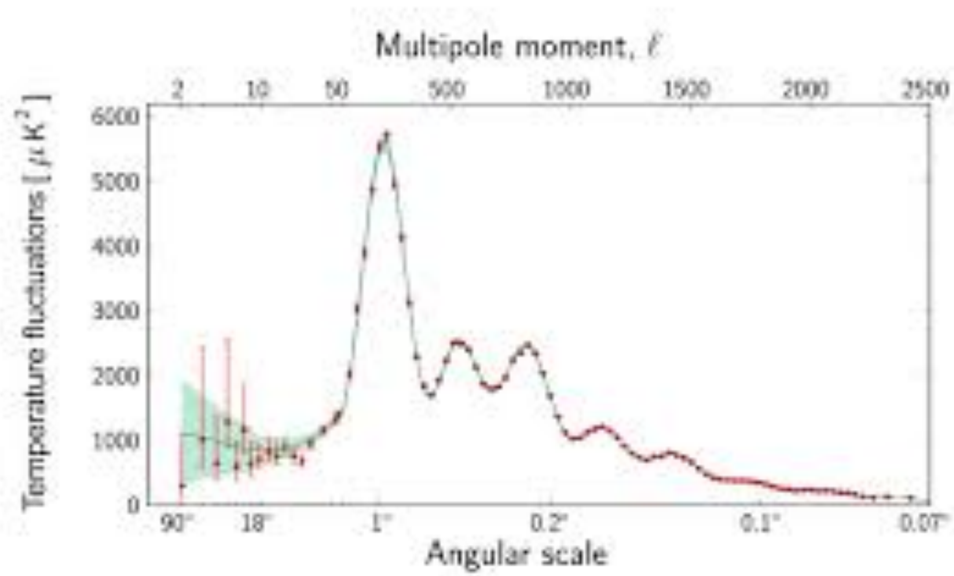
- Combination with large scale structure probes, like weak lensing and galaxy redshift surveys, are powerful.



# Main outcomes of PLANCK

## Scientific perspective:

- Still not in the era of precision cosmology for dark energy.
  - Effects of DE on CMB show up in multipole ranges where measurements are less powerful



# Main outcomes of PLANCK

## Technical perspective:

- Background evolution well-tested but still early days for testing the perturbations.

- Parametrization linked to the observables, that is able to recover a large set of physical models and to avoid unphysical cases, still not determined.

- Few, not very-well tested and sporadically updated codes are available for testing MG.

# Review of existing tools

## MGCAMB (Modification of Growth with CAMB)

arXiv:1106.4543, arXiv:0809.3791

- Modified version of CAMB in which some changes in the linearized Einstein equations of General Relativity can be implemented .
- Changes introduced with two time and scale-dependent functions, that, in the quasi-static limit can also recovers specific theories (i.e. f(R), scalar-tensor theories).
- Different parametrizations of these functions included in the code, plus the Linder's parametrization for the growth rate.
- Background fixed to LCDM. Only the changes in the growth of perturbations are computed.

# Review of existing tools

## EFTCAMB (Effective Field Theory with CAMB)

arXiv:1312.5742, arXiv:1405.1022

- Modified version of CAMB that implements the effective field theory approach for dark energy (see Federico's talk later).
- The code can be used to investigate the effect of different EFT operators on linear perturbations as well as to study perturbations in any specific DE/MG model that can be cast into EFT framework.
- Background evolution can be varied as well.
- Full perturbative equations are evolved, any quasi-static approximation is assumed.

# Review of existing tools

## CosmoMC (Cosmological Monte Carlo)

arXiv:0205436

- Markov-Chain Monte-Carlo (MCMC) engine for exploring cosmological parameter space plus code for analysing samples.
- It uses CAMB for computing CMB and matter power spectra.
- Code in quick evolution (12 releases in the last 2 years).
- Patches for using MGCAMB and EFTCAMB with CosmoMC exist. Not updated to the last version.

# Review of existing tools

## CosmoMC: included datasets

- PLANCK-2013 (Planck-TT 2015 expected in next weeks)
- Baryon Acoustic Oscillation from: 6DFGS, SDSS-DR11/DR9/DR8/lrgDR4/DR7MGS, WiggleZ
- JLA compilation of SN (SDSS-II+SNLS) arXiv:1401.4064 , SNLS, Union 2.1
- Weak lensing from CFHTLENS arXiv:1303.1808
- Redshift Space Distortions from BOSS arXiv:1312.4899 and 6dFGS arXiv:1204.4725
- Yp and D/H abundance measurement arXiv:1308.3240
- BICEP2 and BICEP-Keck-Planck

# Steps towards the future:

- Improvements in the MG parametrizations:
  - Frameworks able to cover many class of models
  - Choice of parameters connected to the measured quantities and to the theories

➢ **Interesting possibility: Effective Field Theory approach**

- in principle lots of parameters are needed to characterise the temporal functions
- Investigation needed to optimise the parameter space and understand which priors we can set from theory and current measurements.

# Steps towards the future:

- Identifying powerful combination of probes:
  - Current datasets show that combination of growth rate and weak lensing measurements with CMB temperature spectrum are powerful
  - What about cross-correlating the LSS measurements with higher-order CMB statistics? ( i.e. ISW-weak lensing correlation)
  - And with polarization modes? And with lensing spectrum?

➢ Tests of combinations will be possible with Planck 2015 likelihoods.

# Steps towards the future:

- Improvements in the statistical tools:
  - We search for "smoking guns" of LCDM extensions.
  - This means we need to estimate how much the extended model is preferred with respect to a fewer-parameter model -> Model selection
  - In bayesian approach this can be done computing the Bayes factor. Easy if we are dealing with one parameter extensions, hard in the other cases.

➢ One project exists called Cosmonest for dealing with model selection: can we integrate it with the MG codes?

# Thank you !