Constraints on primordial magnetic fields coming from *Planck* (arXiv1502.01594)

Beatriz Ruiz-Granados
in collaboration with Planck WG4.1

Instituto de Física de Cantabria
Universidad de Cantabria

Santander, June, 17th, 2015

Outline

Observational probes

- Magnetic fields (MF) are present from smaller (planets) to larger scales
- Recent observations through Faraday rotation have shown strong evidence for MF in clusters of galaxies, low density intracluster regions, voids...
- *Fermi*-LAT data

Mechanisms for primordial origin

- Observational probes points to a primordial origin for MF
- Hydrodynamical proccesses as adiabatic compression and turbulence would amplify the primordial seeds during the structure formation
- Possible mechanisms to produce primordial seeds are:
  - Inflation (Turner & Widrow 1988)
  - Phase transitions (Vachaspati 1991)
  - Other processes as: cosmic strings, cosmic defects...
- Imprints: BBN, LSS, ionization history of the Universe, spectral distortions, CMB

Description of the PMF model

- Stochastic background PMF model with a non-helical and a helical part
- Power spectrum of the magnetic field given by

$$P_B(k) = Ak^{n_B} = \frac{(2\pi)^{n_B+5}}{2k_\lambda^{n_B+3}} \frac{B_\lambda^2}{\Gamma\left(\frac{n_B}{2}+\frac{3}{2}\right)} k^{n_B}, (\text{for } k < k_D), \quad (1)$$

and

$$P_H(k) = A_H k^{n_H} = \frac{(2\pi)^{n_H+8}}{2k_\lambda^{n_H+3}} \frac{H_\lambda^2}{\Gamma\left(\frac{n_H}{2}+2\right)} k^{n_H}, \quad (2)$$

with $k_\lambda = 2\pi/\lambda$, B_λ the strength of the magnetic field smoothed on a comoving scale λ by convolving with a Gaussian kernel ($f_\lambda = Nexp(-x^2/2\lambda^2)$)

- The $\tau_{\mu\nu}^{mag}$ sources scalar, vector and tensor pertubations
- Magnetic-induced perturbations are distinguishable from other sources
- Three different initial conditions can be considered to solve the Einstein-Boltzmann equations: passive, compensated and inflationary
  - Passive-modes: includes the magnetic contribution before neutrino decoupling. No compensation of the anistropic stress due to PMF is produced. It is a logarithmical growing mode.
  - Compensated-modes: includes the magnetic contribution after neutrino decoupling. The magnetic metric perturbations are compensated by the fluid ones to leading order.
- Both are independent of the generation mechanism

CMB data as tool to constrain PMF

Planck 2015 results allow us to establish complementary constraints on a stochastic PMF by quantifying:

- the impact of magnetic-induced perturbations on CMB temperature and polarization power spectra
- the magnetic-induced non-Gaussianities and non-zero bispectrum
- the Faraday rotation of the angular power spectra of CMB polarization
- the magnetic-induced breaking of statistical isotropy (Alfvén waves)

Behaviour of CMB temperature and polarization PS including PMF perturbations.

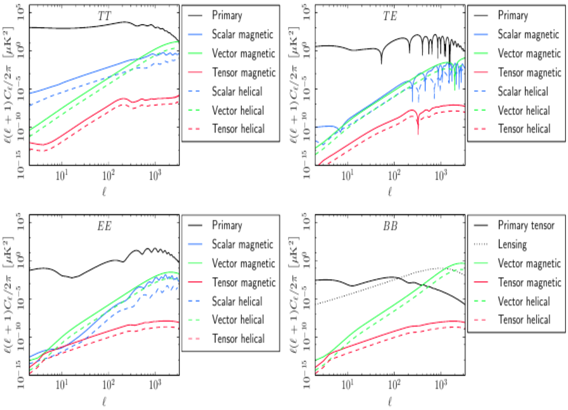

Fig. 5. CMB *TT* (*top left*), *TE* (*top right*), *EE* (*bottom left*), and *BB* (*bottom right*) power spectra due to helical PMFs compared to the ones due to non-helical PMFs. Solid lines are non-helical predictions, while dashed lines are helical predictions. Blue are the scalar modes, green the vector, and red the compensated tensor modes. We consider PMFs with $B_{1\,\mathrm{Mpc}} = 5$ nG and $n_B = -1$.

Constraints on PMF with CMB temperature and polarization power spectra

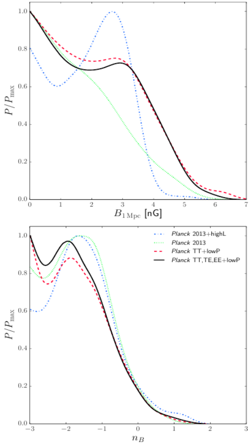

Fig. 7. Comparison of the constraints on the smoothed PMF amplitude (*top*) and the spectral index (*bottom*) from the 2015 temperature and temperature plus polarization data with the 2013 results.

- Constraint on $B_{1\,Mpc} < 4.5$ nG (95% CL) when considering C or C+P modes.

Table 1. Mean parameter values and bounds of the central 68 %-credible intervals from *Planck TT,TE,EE* (left column) and *Planck TT* (right column). When consistent with zero, the upper bound of the 95 %-credible interval is reported. Note that H_0 is a derived parameter.

Parameter	*Planck TT,TE,EE* + lowP	*Planck TT* + lowP
ω_b	0.0222 ± 0.0002	0.0222 ± 0.0002
ω_c	0.1198 ± 0.0015	0.1197 ± 0.0022
θ	1.0408 ± 0.0003	1.0408 ± 0.0005
$\tau_{\rm reion}$	0.078 ± 0.017	0.075 ± 0.019
$\log[A_s 10^{-9}]$	3.09 ± 0.03	3.08 ± 0.04
n_s	0.963 ± 0.005	0.964 ± 0.007
H_0	$67.77^{+0.68}_{-0.67}$	$67.82^{+0.98}_{-1.00}$
$B_{1\,\rm Mpc}/$nG	< 4.4	< 4.4
n_B	< -0.008	< -0.31

BICEP2/*Keck-Planck*

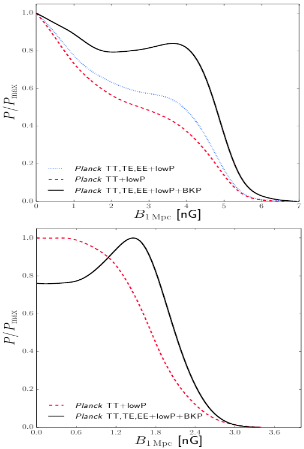

Fig. 11. Probability distributions for the PMF amplitude including the BICEP2/*Keck-Planck* cross-correlation, compared with the one based only on *Planck* data. *Top*: the case in which the spectral index is free to vary, *bottom*: the case with $n_B = -2.9$.

- Constraints on the helical part (i.e. from TB and EB modes).
- PMF strength $B_{1\,Mpc} < 5.6$ nG.

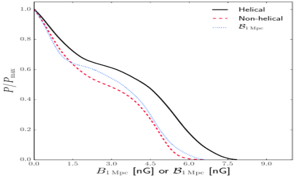

Fig. 12. PMF amplitude constraint for the helical case (solid black) compared with the non-helical case (dashed red). The dotted blue line shows the constraint on the amplitude of the helical component as an alternative interpretation of the constraints on the amplitude of PMFs with a helical component.

Magnetically-induced non-Gaussianities

- They are generated by the perturbations of the quadratic terms MF strength of the energy-momentum tensor
- Allow to provide constraints on PMF by computing the passive-mode bispectrum as well as the compensated-mode bispectrum
- Three results are presented by fixing $n_B = -2.9$:
  1. Magnetically-induced passive tensor bispectrum: $B_{1\,Mpc} < 2.8$ nG (95% CL).
  2. Magnetically-induced directional bispectrum: $B_{1\,Mpc} < 4.5$ nG (95% CL).
  3. Magnetically-induced compensated scalar bispectrum: $B_{1\,Mpc} < 2.97$ nG (95% CL).

FR of CMB polarization

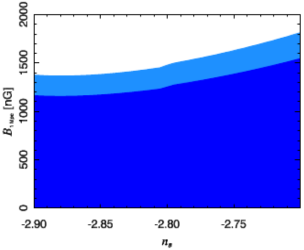

Fig. 13. Probability contours of PMF strength vs. spectral index of the PMF power spectrum as constrained by the 70 GHz observations.

- FR convert B-modes into E-modes and vice versa.
- Characterization with the λ^4-dependece of B-modes and E-modes.
- Constraints on $B_{1\,Mpc} < 1380$ nG (95% CL) for $\ell < 30$ at 70 GHz.

Magnetically-induced breaking statistical isotropy

- Assumption: stochastic PMF as source of primordial vector perturbations.
- Alfvèn waves produces observables imprints on CMB via Doppler and the ISW effects.
- Constraints are provided on the amplitude of the Alfvèn velocity: $B^2_{1\,Mpc} v_A^4/\bar{B}^2 < 1.7 \times 10^{-5}$ (95% CL) $\rightarrow$ no evidence of Alfvèn waves.

Summary

- Magnetically-induced modes do not modified the cosmological parameters of the standard ΛCDM model
- Magnetically-induced modes produce non-Gaussinity
- PMF present at Recombination induce a Faraday rotation of the CMB polarization plane
- All complementary methods favours $B_{1\,Mpc} < 5$ nG (with the exception FR)

Thank you very much!