Meeting MacroArea 1, Bologna, 16 June 2016

Astrophysical Tests of Fundamental Physical Principles and Constants

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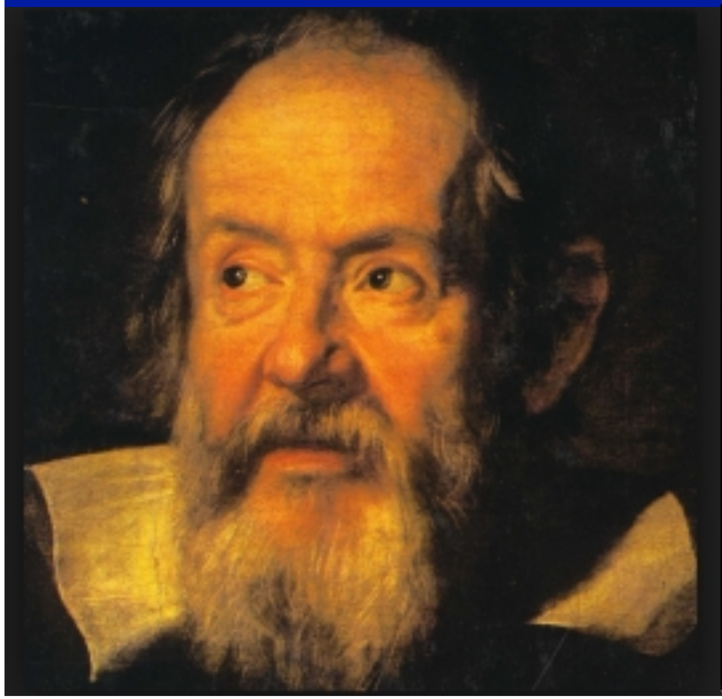
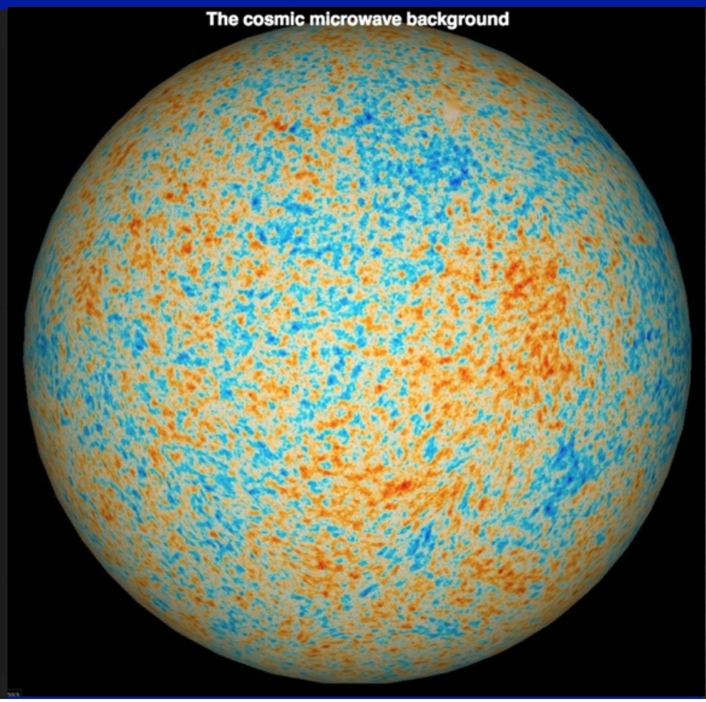
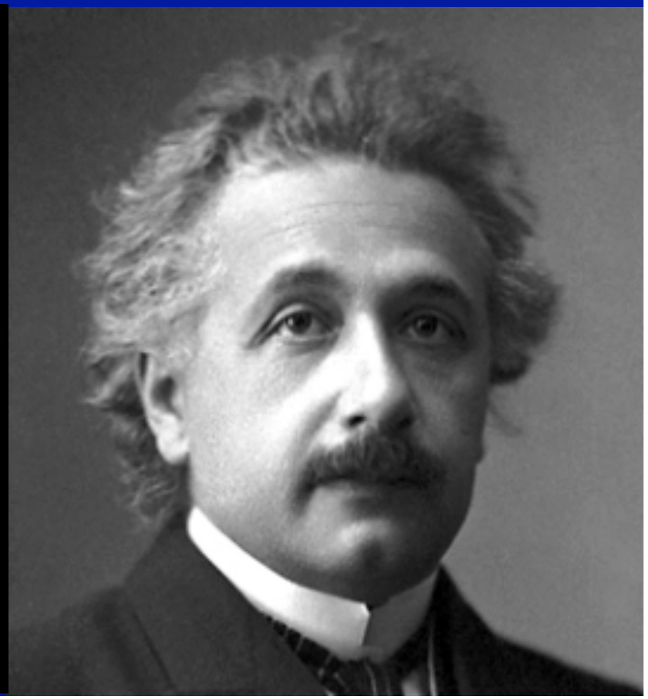
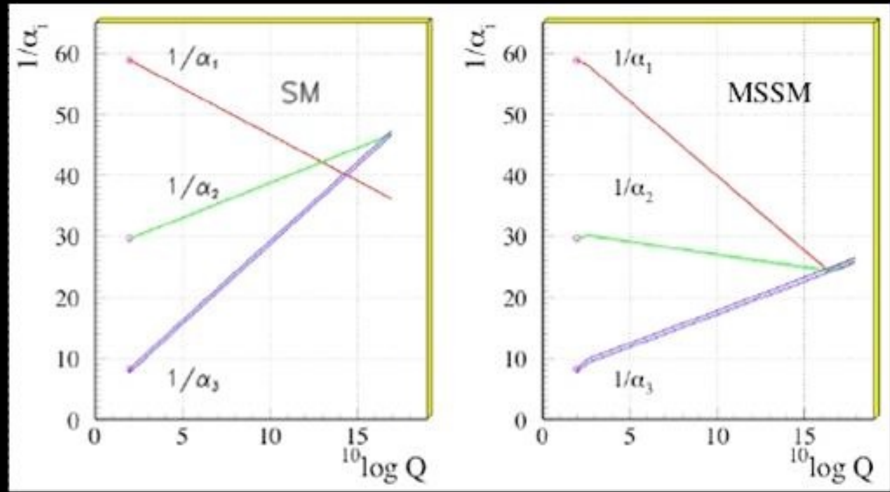
Internat. J. Mod. Phys. D 24, 1530016 (2015)



Are the fundamental constants constant? Paolo Molaro

GUTs



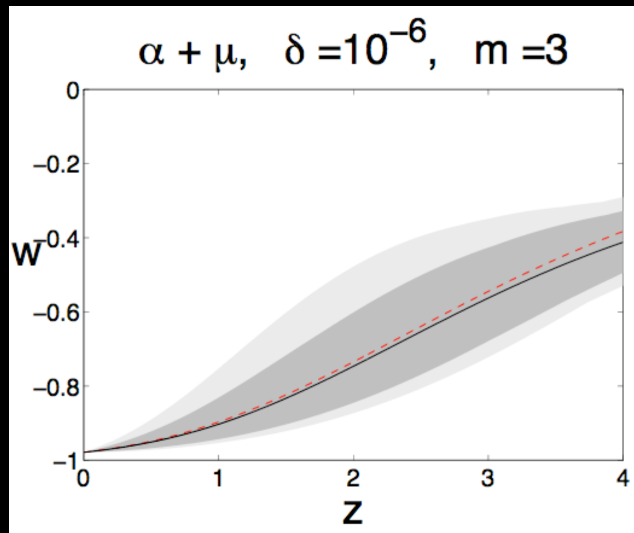
Which Constants?

- Fine structure constant α
- Me/Mp
- G (dimensional)

Which physics?

- GUTs
- DARK ENERGY: QUINTESSENCE
- STRINGS, M-Theories
- INFLATION (for space-variations)

Dark Energy



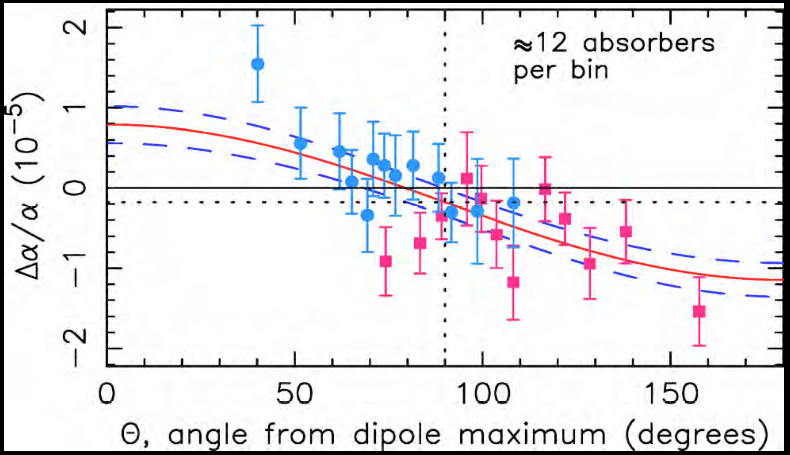
Alonso et al 2013

Probes:

- QSO-absorption systems:
  - Alkaline-doublets,
  - MM method:
  - atomic (FeII, MgII, SiII etc)
  - Molecular gas (H_2,NH_3, methanol)

Are the fundamental constants constant? Paolo Molaro

Webb et al 2011



Status

no variation of α with time ~ 5 ppm (10 Gyrs)

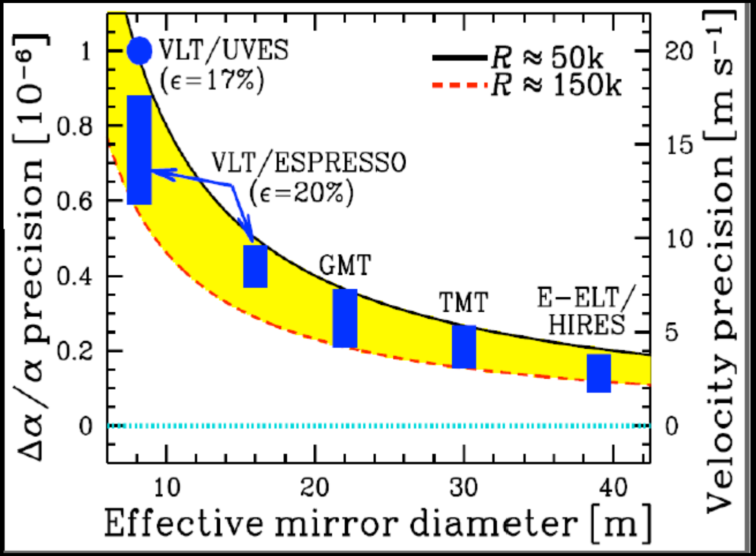
consistent with spatial variation (at 4.1 σ) but systematics

Future facilities

ESPRESSO first HR spectrographs designed for this science

Precision expected of < 1 ppm

Gain with ESPRESSO and HIRES



Should we push in some direction? E.g. HIRES

HIRES ~ one order of mag gain in sensitivity

Wait for the ESPRESSO's results..

Role of Italian community?

with ESPRESSO & HIRES Italy could play a leading role

Searches for Cosmic Polarization Rotation

CPR is the rotation of the plane of polarization for photons traveling in *vacuum* across the Universe (not Faraday rotation).

We search for CPR for two main reasons:

1. To see if one of the 3 basic informations carried by photons (direction, energy and polarization) is changed while they travel to us.

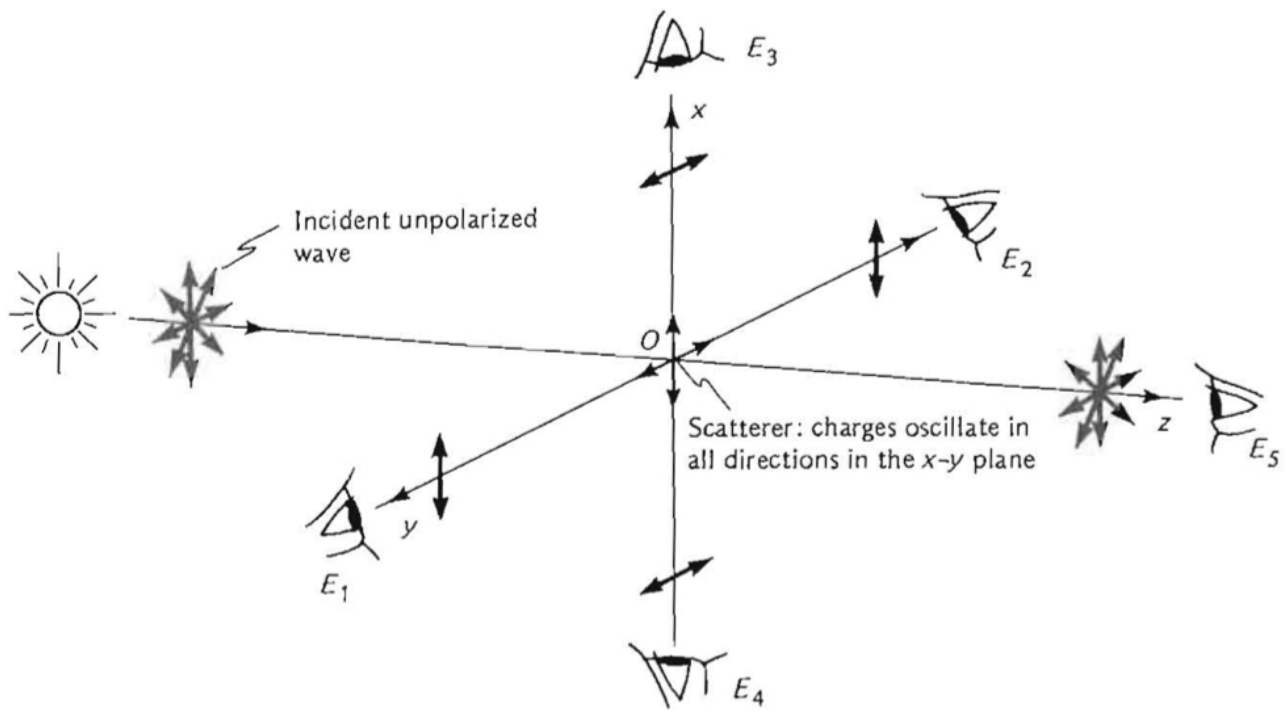
2. Because eventual violations of fundamental physical principles (Lorentz invariance violation, CPT violation, neutrino number asymmetry, and violation of the Einstein Equivalence Principle) would cause CPR. Therefore our confidence in these principles would increase, if we can put stringent constraints on CPR being zero.

We advise to use the term CPR, not birefringence (rotation, no splitting).

How to test for CPR

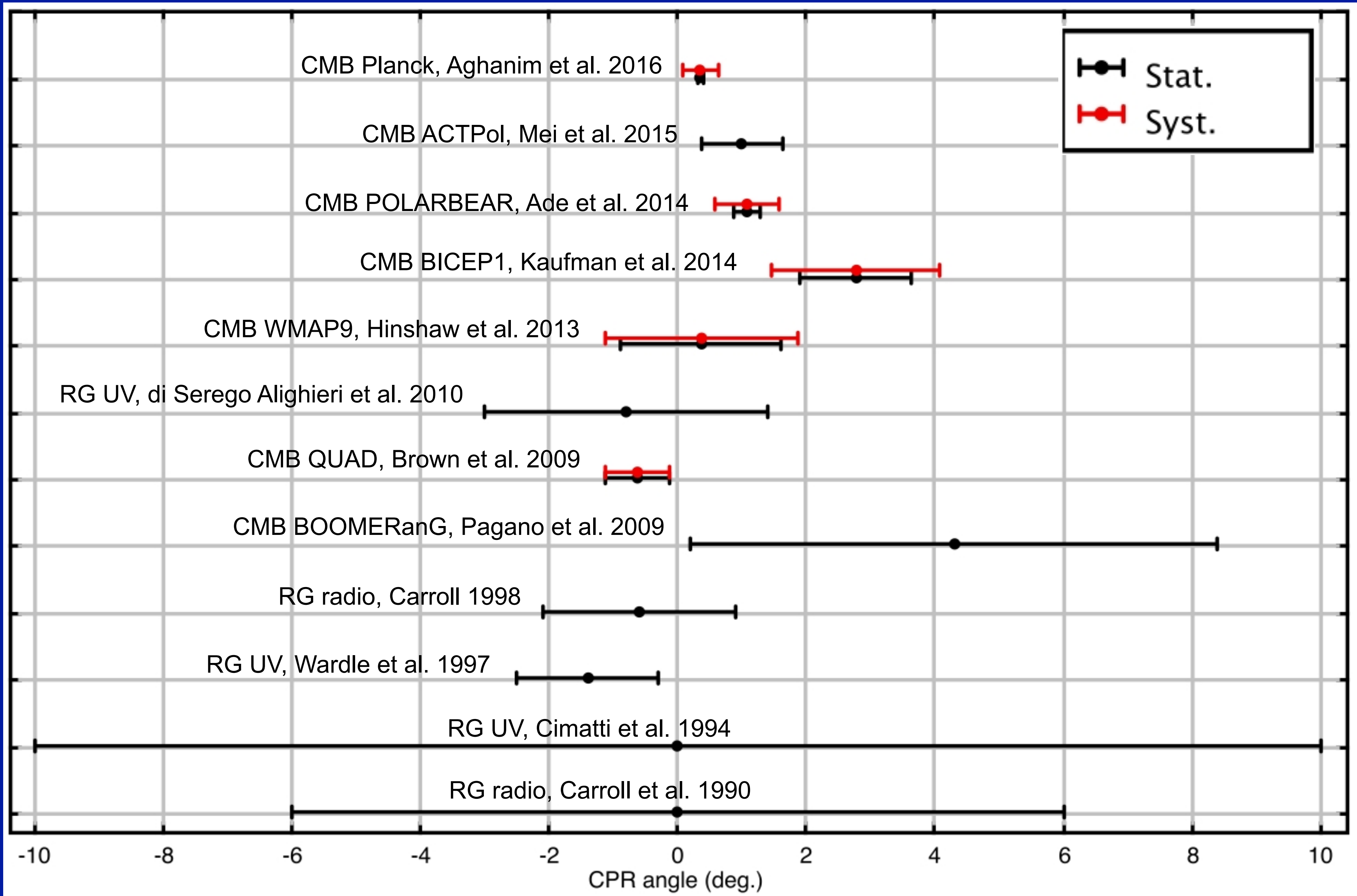
Testing for CPR is simple in principle: it requires **a distant source of linearly polarized radiation, for which the orientation PA_{em} of the polarization at the emission can be established**. Then CPR is tested by comparing the observed orientation PA_{obs} with PA_{em}:
$\alpha = PA_{obs} - PA_{em}$.
In practice, it is not easy to know a priori the orientation of the polarization for a distant source: in this respect the fact that **scattered radiation is polarized perpendicularly** to the plane containing the incident and scattered rays has been of great help, applied both to radio galaxies (RGs) and to the cosmic microwave background (CMB) radiation.
For those cases in which CPR depends on wavelength, one can also test for CPR by simply searching for variation of PA with wavelength, even without knowing PA_{em}.

I will summarize the results on CPR obtained with the astrophysical methods which have been used to test it, discuss some of the problems of the various methods and suggest future prospects for these tests.



A summary of CPR tests with different methods

di Serego Alighieri 2015 (IJMPD 24, 1530016) updated



Problems in testing the CPR with the CMB

1. CMB Polarization PA calibration problem

One problem is the calibration of the polarization PA for the **lack of sources with precisely known PA at CMB frequencies**. This introduces a systematic error, which is similar (if not bigger) than the statistical measurement error β, of the order of 1°. Recently the polarization PA of the Crab Nebula (α Tau) has been measured with an accuracy of 0.2° at 89.2 GHz (Aumont et al. 2010). However most CMB polarization measurements are made at higher frequencies (100 – 150 GHz) and the Crab is not visible from the South Pole. In order to overcome this problem, some CMB polarization experiments have used a TB and EB nulling procedure (Keating et al. 2013). However this procedure actually gives a measurement of α-β and can hardly be used for CPR tests.

Recent measurement by Planck: $\alpha = 0°.35 \pm 0°.05$ (stat.) $\pm\ 0°.28$ (syst.)

Problems in testing the CPR with the CMB

2. CMB Polarization PA convention problem

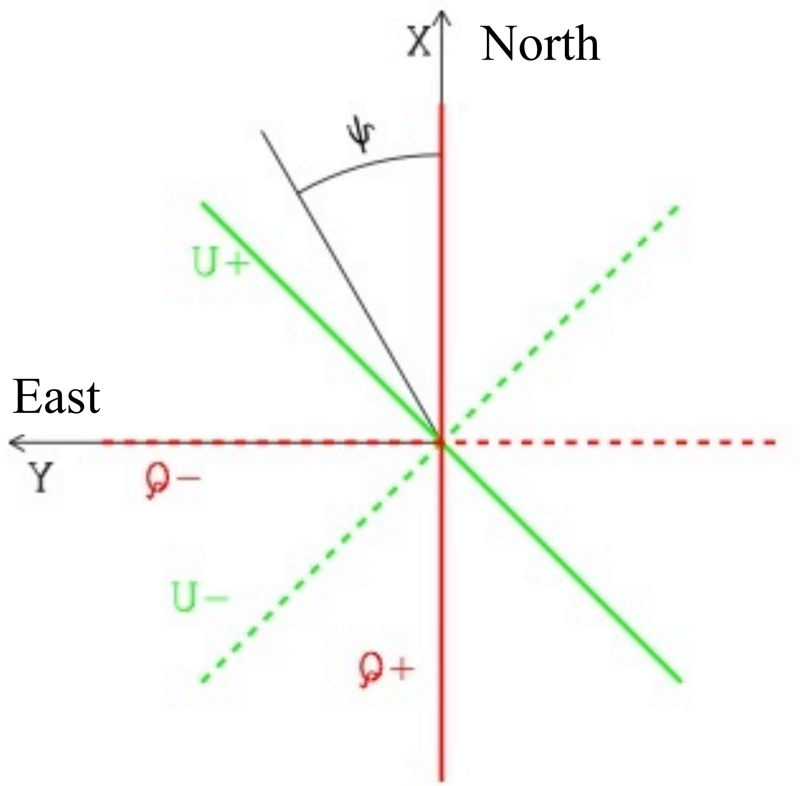
A second problem is that unfortunately the CMB polarimetrists have adopted the convention that the polarization PA increases clockwise (looking at the source), which is **opposite to the standard convention** adopted by all other polarimetrists for centuries and enforced by the IAU (PA increses counter-clockwise). This is obvioulsy producing problems when comparing measurements with different methods, like for CPR tests, also because the "CMB convention" has not been well documented in the CMB polarization papers.

Two opposite conventions for the polarization PA

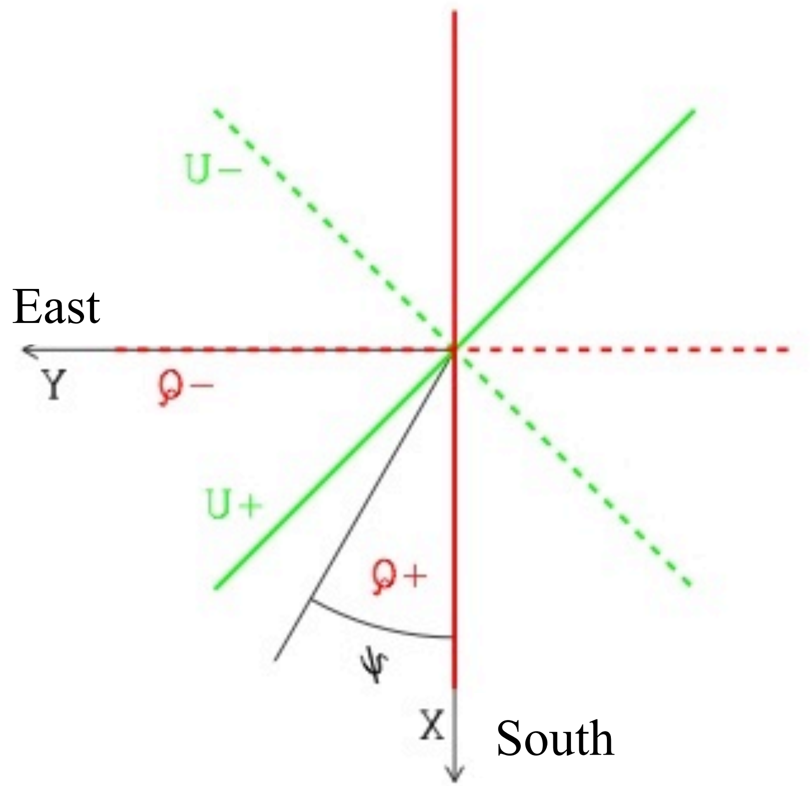
1. IAU convention: looking at the source, the polarization PA increases counter-clockwise.

2. "CMB" convention: looking at the source, the polarization PA increases clockwise.

IAU coordinates



"CMB" coordinates



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To Whom It May Concern

The issue

Scientists working on the polarization of the Cosmic Microwave Background (CMB) use a convention for the polarization angle (PA) which is opposite to the IAU approved standard. This may cause confusion and misunderstandings.

Background

The convention astronomers follow for the PA (Polarization Angle) goes back to the 19th century and it has been in use for observations going from radio to gamma rays: the PA increases counter-clockwise when looking at the source. This convention is consistent with the one used for the Position Angle and it has been enforced by the IAU with a Resolution by Commissions 25 and 40 at the IAU XVth General Assembly in Sydney in 1973 (see Transactions of the IAU, Vol. XVB, pg. 166).

Recently, the scientists investigating the polarization of the CMB (the CMB polarization has been discovered in 2002), have unfortunately adopted the opposite convention (PA increasing clockwise when looking at the source). This corresponds to a change of sign of the U Stokes parameter and is causing confusion and misunderstandings, in particular in the case of polarization data coming from experiments and satellites which are used by the CMB community and by other astronomers.

Recommendation

The IAU recommends that all astronomers, including those working on the CMB, follow the IAU Resolution for the Polarization Angle in all their publications.

Paris, December 8th, 2015

Piero Benvenuti	Pietro Ubertini	Saul J. Adelman
IAU General Secretary	President, Division B	President, Commission B6

A rotation of linear polarization produces a coupling between T, E-mode and B-mode polarization of CMB

$$C_\ell^{TE} = \cos(2\Delta\psi)\tilde{C}_\ell^{TE}$$

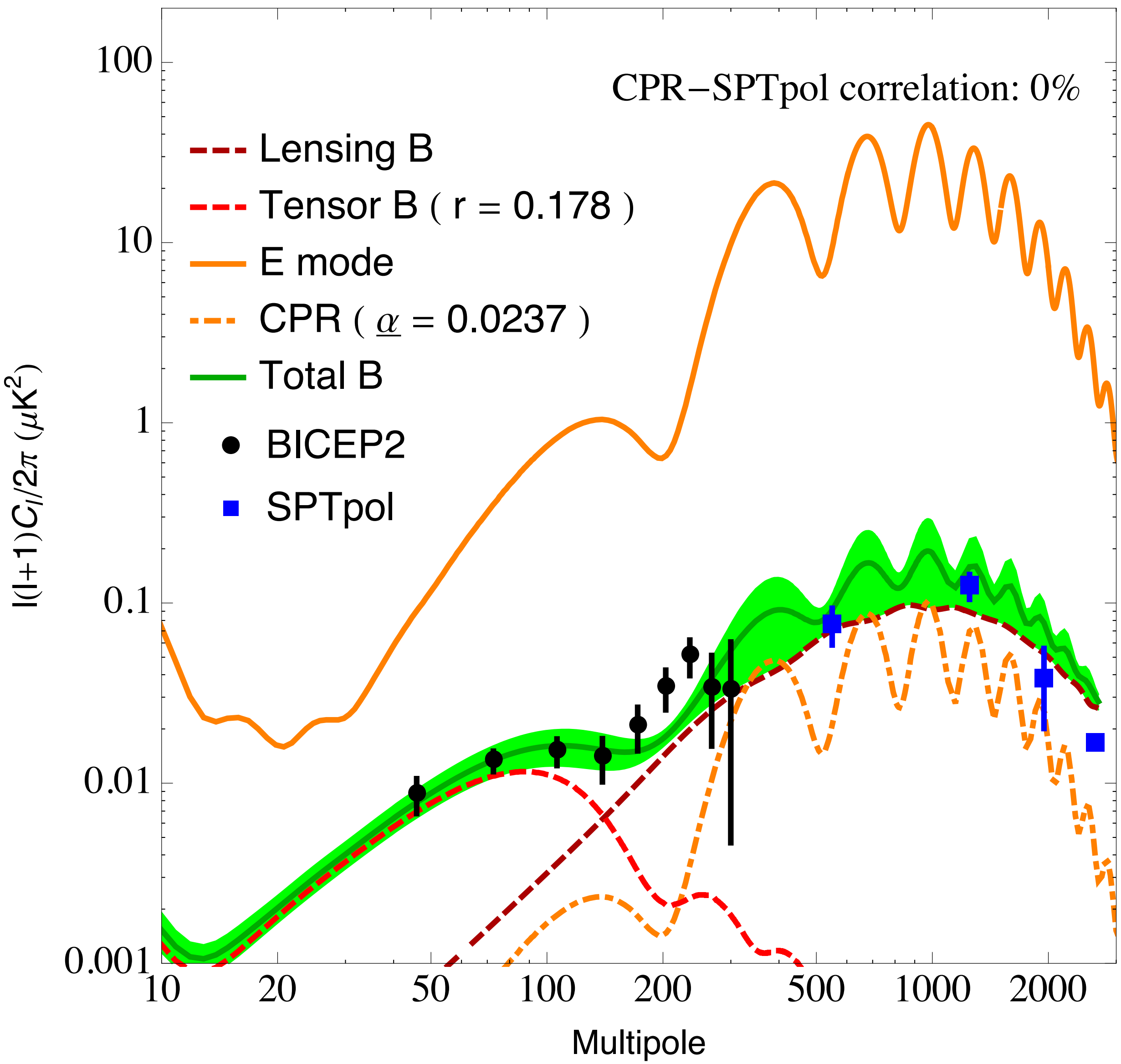
$$C_\ell^{EE} = \sin^2(2\Delta\psi)\tilde{C}_\ell^{BB} + \cos^2(2\Delta\psi)\tilde{C}_\ell^{EE}$$

$$C_\ell^{EB} = \frac{1}{2}\sin(4\Delta\psi)\left(\tilde{C}_\ell^{BB} - \tilde{C}_\ell^{EE}\right)$$

$$C_\ell^{TB} = -\sin(2\Delta\psi)\tilde{C}_\ell^{TE}$$

$$C_\ell^{BB} = \cos^2(2\Delta\psi)\tilde{C}_\ell^{BB} + \sin^2(2\Delta\psi)\tilde{C}_\ell^{EE}$$

A new test of CPR using B-mode polarization of CMB



$\langle \delta\alpha^2 \rangle \leq (1.56°)^2$ di Serego Alighieri et al. (2014) ApJ 792, 35

Summary and outlook

1. All results are consistent with a null CPR. All CPR test methods have reached so far an accuracy of the order of 1° and 3σ upper limits to any rotation of a few degrees. This excludes violations of the EEP, improves our confidence on GR, and makes polarization as the most constant property of photons.

2. They are complementary in many ways. They cover different wavelength ranges and the methods at shorter wavelength have an advantage, if CPR effects grow with photon energy. They also reach different distances, and the CMB method reaches furthest.

3. Improvements can be expected by better targeted high resolution radio polarization measurements of RGs and quasars, by more accurate UV polarization measurements of RGs with the coming generation of giant optical telescopes, and by future CMB polarimeters such as BICEP3. These will have to reduce accordingly also the systematic error in the calibration of the polarization angle, which at the moment is of the order of 1° for CMB polarization experiments. The best prospects to achieve this improvement are likely to be more precise measurements of the polarization angle of celestial sources at CMB frequencies with the ATCA and ALMA and a calibration source on a satellite (CalSat, Kaufman et al. 2014).

Summary and outlook

4. The CMB experimental requirements to improve constraints on the CPR are the same as those for detecting primordial B-modes (de Bernardis & Masi 2016).

5. If CPR will be detected, it would be interesting to study its dependence on photon energy, distance, and position in the sky (Galaverni et al. 2015).