Does the Low CMB Quadrupole Provide a New Cosmic Coincidence Problem?

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We point out that the recent WMAP findings of a suppressed large scale power in the Cosmic Microwave Background anisotropy power spectrum, if of cosmological origin, make the case for a new cosmic coincidence problem. The observed suppression of anisotropies at large angles requires an explanation for why this suppression is occurring only for perturbation wavelengths of the order of our present Hubble horizon. This is a very challenging task since a consistent model for the emerging picture of the universe has to address both cosmic coincidences and thus may reveal a deeper inter-relation with the dark energy problem.

Recent developments in precision cosmology have presented theoretical physicists with a tantalizing picture of the universe. By a combination of all data, there is indisputable evidence that our universe is accelerating[1]. This means that about 70% of the energy density in the universe is made up by a mysterious component, coined dark energy, with an equation of state \( -1.38 \leq w_X \leq -0.82 \) at 95% confidence level (see e.g. [2]).

Cosmic microwave background (CMB) measurements have provided valuable data that have proven a powerful tool in lending support to a concordance \( \Lambda CDM \) picture in cosmology. Nevertheless we still lack an understanding of the origin and nature of DE and dark matter which together make for about 95% of the energy density in the universe’s budget.

It is well known that the dark energy (DE) mystery is a notoriously difficult problem, mainly due to the following two fundamental questions which need to be addressed simultaneously: why is DE magnitude \( \rho_X \simeq 10^{-122}M^3_\odot \) 122 orders less than the expected value \( M^3_\odot \). This is known as the fine-tuning problem; why is DE domination over matter energy density in driving the expansion of the universe occurring around redshifts \( z \simeq 0-1 \) i.e at scales of the order the present value of the Hubble radius \( H_0 \simeq 10^{-33}eV \). The latter is known as the coincidence problem of DE and hereafter we refer to it as the first cosmic coincidence.

In this work we discuss the possibility that the CMB data accumulated recently, reveals a second cosmic coincidence stemming from the suppressed perturbation modes crossing the horizon only recently, and at the same energy scale as the DE coincidence. The recent results from the WMAP satellite experiment on the Cosmic Microwave Background anisotropy power spectrum have been an extraordinary success for the standard model of structure formation based on dark matter, inflation and dark energy (see e.g. [3]). These results have not only confirmed (with a sensible reduction of the error bars!) the previous cosmological picture as defined by several ground-based and balloon-borne experiments (see e.g. [4]) but also presented indications for several intriguing discrepancies. Between the most surprising findings, WMAP measured a suppression of power at large angles, (low multipoles \( l \)), for temperature auto-correlations \( C^{TT}_l \) in the CMB anisotropy spectrum [4]. The indication for a quadrupole suppression was already reported a decade ago by the COBE/DMR experiment but with much lower signal-to-noise and frequency coverage. The higher frequency coverage of the WMAP experiment has, for example, excluded an explanation of the effect as a systematic related to known galactic foregrounds.

Moreover, recent analysis [7] of the WMAP maps have reported that the cosmic quadrupole (\( l = 2 \)) on its own is anomalous at the 1-in-20 level by being low, the cosmic octopole (\( l = 3 \)) on its own is anomalous at the 1-in-20 level by being very planar and that the alignment between the quadrupole and octopole is anomalous at the 1-in-60 level. While the large scale temperature power spectrum clearly shows discrepancies, other large scale CMB measurements are providing interesting clues. For example, the measured level of large angle cross temperature-polarization \( C^{TE}_l \) is higher than what expected in the most common scenario of reionized intergalactic medium (see e.g. [8]). Furthermore, recent works [9] have presented evidence for large scale non gaussian-signals in the WMAP maps which again, if of cosmological origin, would present a problem for the standard scenario.

These findings cannot be considered as conclusive evidence yet because of the limitations set by cosmic variance or by possible systematics (see e.g. [10]). Statistical “flukes” are indeed present at several multipoles. Furthermore, the correlations with the local dipole and ecliptic may suggest presence of systematics due, for example, to unknown foregrounds or
FIG. 1: The CMB power spectra from the 1st year WMAP data release for temperature (top panel) and cross temperature-polarization (bottom panel) compared with the expectations of a standard Λ-CDM model. The lack of power at large scales (small ℓ) in the temperature maps can be interpreted as a signature for new physics. The high power at large scale in the $T_E$ spectrum is in tension with the expected values (based on numerical simulations) of $\tau \sim 0.05 - 0.10$. It might suggest an higher value for the optical depth of the universe ($\tau \sim 0.2$).

These modes carry the pristine information of the history of the universe. Thus they have not been contaminated by the internal evolution and non-linearities of the cosmic fluid inside the Hubble radius. Recall that in an inflationary universe perturbations produced near the end of inflation leave the horizon whenever their wavelength becomes larger than the inflationary horizon $H_i$ due to 'superluminal' propagation. These modes re-enter the horizon at later times when the Hubble parameter once again becomes equal to their wavelength. This is known as the horizon crossing condition $k = \alpha(t)H(t)$. Thus the largest wavelengths are the first ones to leave the horizon and the last ones to re-enter. Modes currently re-entering $k_0 = a_0H_0$ have wavelengths horizon size, which means they have been outside of the Hubble horizon for most of the history of the universe. Thus they have not been contaminated by the internal evolution and non-linearities of the cosmic fluid inside the Hubble radius. These modes carry the pristine information of the unknown physics which sets the Initial Conditions of the universe.

The possibility of a late-time effect that DE may have on the suppression of large angle anisotropies still remains open although it does not look like a promising direction at the moment. So far there has been no successful attempt that can accomodate and relate both coincidences within the framework of low energy or late time physics. Perhaps this is because, based on the inflationary paradigm, we expect a vacuum energy component to enhance power of long wavelengths due to the integrated Sachs Wolfe effect (ISW).

What kind of physics could give rise to a consis-
tent picture? Two coincidences in our present universe cannot be accidental. Perhaps this bizarre picture of the present universe emerging from precision cosmology is providing clues of new physics. String theory and quantum gravity are possible candidates of the unknown physics of the early universe. There are current models in literature that offer an explanation for the CMB power suppression, by having the Initial Conditions set within the framework of string theory [15, 16], loop quantum gravity [17], or an unknown hard cut-off [19]. However none of these models can address the issue as to why the suppression of anisotropies in the visible spectrum should occur at exactly only those wavelengths of order our present Hubble radius and not for any other modes that crossed the horizon earlier (shorter wavelengths), although we have an infinite range of shorter wavelength modes.

There is also an ongoing search for a possible UV/IR mixing of gravitational scales [20]. The motivation comes from the fact that both observed cosmic coincidences occurring at present low energy scales, namely the DE coincidence and CMB coincidence, independently suggest constraints imposed on the number of efoldings, (about 60 efoldings for GUT scale inflation), during the early times when the universe underwent an inflationary episode [12, 20]. However a theoretical model that can successfully accommodate all observed cosmic coincidences around the scale $H_0 \simeq 10^{-33}$ eV is yet to be found.

A single solution to the DE and low CMB quadrupole problems will have to address both cosmic coincidences and also reveal a deeper inter-relation between the two, a very challenging task.

It is worth mentioning that recent works have presented evidence for correlations between the large-scale WMAP data and radio sources distributions which certainly provide hints that the suppressed power may be connected to the recent DE domination.

An important implication of having two cosmic coincidences at the same scale is the possibility that this energy scale is special, possibly indicating that our present Hubble parameter may turn out to be a new scale of physics at very low energies. Or perhaps a new scale of low energies derived from a fundamental scale of high energy physics through a possible UV/IR mixing. This radical possibility, although very intriguing, is not yet realized in a concrete model.

At the moment, our theoretical knowledge of the relation between the low CMB quadrupole and the dark energy lies in the realm of speculations while pushing forward the discovery of new physics. Future investigation of the new cosmic coincidence puzzle discussed here, may independently aid us to a better understanding of the emerging picture of the present universe.

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