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Report on my one-month visit to the Yukawa Institute for theoretical physics in February 2018

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Abstract. A short report on what I did and the great scientific time I had while at the Institute.

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1. Overview

Contrary to our expectation when this visit was planned, the final legacy release of the Planck satellite mission[1] was not completed at the time of the visit. I thus unavoidably spent substantial amount of my time on that topics, since I am a Planck science team member, and the HFI (High Frequency Instrument) science coordinator, Data Processing manager and co-PI. There is thus no escape from E-mail and teleconference. Nevertheless, during one-month stay at Yukawa Institute for Theoretical Physics, I completed several works and successfully initiated a new project. Below, I describe a part of the scientific activities at Yukawa Institute.

2. Main activities

2.1 Presentations

I prepared two presentations, one for the general colloquium of the Yukawa Institute[2], which I delivered on 7th February, and another one as an invited speaker at the YKIS2018 symposium "General Relativity - The Next Generation" on 22nd February. The first one, entitled "Cosmic Microwave Background & Cosmology: then and now", was geared to a general audience. I thus prepared an overview of the developments and results over the last 25 years of the experimental field of CMB (Cosmic Microwave Background) anisotropies, which is currently culminating with our Planck results; I then described some of our most significant results for all of physics and astrophysics.

The second one-hour presentation was geared to a more specialised audience, since many of the world leaders had been invited during that intensive workshop of one week. There, I delivered a more in-depth view of what we accomplished with the Planck data, how that was done, what we are currently doing, and I also gave my point of view on how we might address some of the profound questions

[1] https://www.cosmos.esa.int/web/planck
[2] also held as a lecture presentation organized by the International Research Unit of Advanced Future Studies.

currently still open. Among those, we shall aim at detecting a deviation of the primordial power spectrum from a pure power-law, at measuring primordial gravity waves or primordial non-gaussianity. We shall also try elucidating some existing anomalies in the context of the LCDM (Lambda Cold Dark Matter) cosmological model, which is otherwise so amazingly successful at describing consistently a gigantic set of diverse cosmological data accumulated by means of many different survey, probing many scales and epochs.

2.2 Research developments: *CMB lensing bi-spectrum as a new cosmological probe of gravity*

The so-called cosmological dark energy initially revealed by the study of type Ia Supernovae is a complete mystery, with no obvious theoretical explanation, or only extremely fine tunes ones. One possibility currently considered is that the observational evidences of this mysterious dark energy are actually traces of the breakdown of General relativity (GR) at large scales, and have nothing to do with another component of the Universe. Figuratively speaking, one may consider modifying the left-hand side of Einstein equation, $G_{\mu\nu}=(8\pi G/c^4)T_{\mu\nu}$, rather than the right-hand side.

In order to accrue further experimental clues, many astronomical experiments are currently being conducted or prepared in order to constrain the growth rate of large-scale structures of the Universe (DESI, DES, EUCLID, etc.). One difficulty is that one wants to confront the dynamics of the dark matter with various theoretical possibilities, while visible objects -- galaxies, clusters of galaxies -- that are biased tracers of the dark matter distribution delineate large-scale structures. Of course, many bias models exist in order to relate the light and mass distributions, and a simple linear term at large scales, which we know how to tame, dominate them.

Nevertheless, deviations from GR are bound to be very small, and controlling the accuracy of these models at the level of precision needed for a relevant test is a challenge, which will be hard to meet convincingly. It is therefore all too natural to try finding observables that rather rely on a solid understanding of their physics, and gravitational lensing effects are obvious candidates. The lensing bi-spectrum (i.e., three-point statistics in harmonic space) from weak-lensing observations has recently been examined to that effect. This is a promising avenue, but not devoid of pitfalls. Indeed, analyst will have to cope with uncertainties in the redshift distribution of the lensed sources (i.e., galaxies), and they can realistically be used in the near future only for GR modification which are substantial at redshifts around half that of the most distant sources, i.e., not that long ago.

Prof. Atsushi Taruya and I spend much time discussing the situation and ways to address it. In the end, it seemed to us that the lensing effect of the CMB is very worth investigating. Indeed its physical and temporal origin are very well known and the lensing effect originates from a large redshift range centered at redshift z~2, which therefore allows probing a redshift range unattainable by direct lensing measurements of sources. Even better, we noticed that Toshiya Namikawa at National Taiwan University, had already developed software to compute the CMB lensing bi-spectrum, which could easily be modified to include the effect of modification to gravity, and we agreed to join force to address together this problem.

The results we obtained during my visit were still preliminary, but were already quite promising. Further work through remote contacts since then is ongoing to actually write the paper, with a number of interesting conclusions. In particular, this new probe will allow constraining, in a way we quantify, an extremely broad class of beyond GR theories. We also found that some of the tightest constraints arise when considering small enough scales (that CMB experiments will surely measure), where correction from the non-linear part of the growth of structures is relevant. We did show that different approximations considered in the literature lead to substantially different results. This is likely to provide further impetus to the search of new, better, approximations. One should note that the results are also suggesting that this avenue of research is rather promising with many extensions (with related observational probes) worth exploring. This might be ideal to explore in another visit.