Stage M2, 2018

The Sunyaev-Zel'dovich effect: measurement of the distortion of primordial radiation by galaxy clusters

The Cosmic Microwave Background and galaxy clusters

The cosmic microwave background (CMB) is the oldest existing radiation; it was imprinted by the same physical processes which determined the creation, structure and early evolution of the Universe. Measurements of the CMB have enabled the cosmological community to encapsulate their understanding of the Universe simply using six main parameters [Planck Collaboration et al., 2016a]. Extracting information from the CMB, however, is a more complex affair as certain late-time features, such as galaxies, can distort the CMB signal. CMB photons which travel through galaxy clusters undergo inverse Compton scattering by the energetic electrons in these hot clusters; this distortion is known as the Sunyaev-Zel'dovich (S-Z) effect.

The S-Z effect is an excellent probe of cluster astrophysics, the formation of structure within the Universe and additionally it serves as an independent check of several of the cosmological parameters determined from the CMB. Accurately mapping this effect relies on a good understanding of not only the CMB itself but also the astrophysical emissions within our Galaxy (foregrounds) which stand between us and any cosmological information.

Production of a map of the S-Z effect

Our group has primarily been working on mapping the astrophysical foregrounds which obscure the view of the CMB from the Milky Way. At high frequencies (over 100 GHz) radiation from interstellar dust irradiated by starlight provides the dominant astrophysical foreground. This thermal dust emission must be precisely modelled and then removed from any high frequency observations before the CMB and the SZ-effect can be studied. Over the last year we have coupled traditional astrophysical model fitting with statistical methods at the forefront of signal processing, such as sparsity and non-linear optimisation, to produce thermal dust maps from the latest satellite observations of the CMB.

The goal of this stage M2 is to use observational data from the *Planck* satellite [1] alongside our thermal dust emission map and estimate of the CMB [Bobin *et al.*, 2016] to produce a map of the S-Z effect. Maps of the S-Z effect already exist [Planck Collaboration et al., 2016b] and are available to the community, but the goal of this stage M2 is unrivalled accuracy. From the discovery of the CMB to date the field has seen two Nobel prizes, three groundbreaking satellite missions and thousands of science publications. The emphasis is no longer on 'first light' detections but on precision cosmology. This leading S-Z map will be used to verify the CMB measurement of the matter density within the Universe as well as its fluctuation over time.

[1] http://www.esa.int/Our_Activities/Space_Science/Planck

Methods
During their stage, the student will work on astronomical maps of the CMB as seen through the Galaxy, so featuring astrophysical emissions. They will learn how to interpret such maps in pixel space as well as in the spherical harmonic domain. They will utilise signal processing techniques such as sparsity and the wavelet transform and optimisation techniques such as gradient descent and least squared minimisation.

The student will develop an understanding of the astrophysics at play within our Galaxy, both diffuse and compact emission mechanisms, as well as the overall cosmology accompanying the 'Big Bang' theory and the dark energy dominated model of the Universe.

The new methods the student develops will be tested on *Planck* data and compared to existing publications within the field. The existing codes utilised for this project are written in python; an opportunity for the student to either refine their existing skills or to learn this widely applicable programming language.

Scientific environment
The stage will be carried out in the CosmoStat[2] laboratory at the Departement d'Astrophysique (DAp)[3] at CEA Saclay, under the supervision of Melis Irfan. CosmoStat hosts a multidisciplinary team whose research includes statistics, signal processing, astrophysics and cosmology.

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References
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Planck Collaboration et al. Planck 2015 results. XXII. A map of the thermal Sunyaev-Zeldovich effect. *Astronomy and Astrophysics*, 594:A22, September 2016.

[2] `http://www.cosmostat.org`
[3] `http://irfu.cea.fr/Dap/`