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GT05 - Physique de l'inflation et énergie noire

ESA Voyage 2050 white papers for cosmology with a spectro-polarimetric survey of the microwave sky

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1 Introduction

The twentieth century witnessed the spectacular transformation of physical cosmology into a quantitative branch of science and has ushered the era of "precision cosmology".

During the past two decades a standard cosmological model, inflationary ΛCDM, has emerged. However, in spite of the success of the model in providing a good phenomenological fit to most cosmological observations, very fundamental questions remain unanswered: we do not know what the dark matter and dark energy are, whether dark matter interacts, or if extra light particles exist. We are unsure whether inflation did indeed take place and exactly what physics was at work in the very early Universe. We still have to reconcile the laws of gravitation with the standard model of particle interactions – both of which are known to be incomplete and require extensions to explain existing observations. We do not know the topology of the Universe, or whether it is finite or infinite. We do not fully understand how structure forms, or why some structures on small scales appear to be incompatible with ΛCDM predictions. We do not have a convincing explanation for anomalies in the large-scale statistics of cosmic microwave background (CMB) anisotropies, except invoking chance multipole alignments and excursions in tails of the realization of a Gaussian random field.

2 The proposal

The distribution of matter and energy in the Universe encodes answers to these questions. In the context of the ESA Voyage-2050 consultation of the scientific community,[1] we submitted four coordinated white papers which propose to conduct an unprecedented full census of this distribution, over angular scales from one arcminute to the entire sky, and over 99% of cosmic history. The census will be carried out using a high-angular-resolution, high-sensitivity spectro-polarimetric survey of the microwave sky, which will track faint signatures of matter and radiation interactions across cosmic time, exploit the CMB as a multi-faceted cosmology probe, and construct a three-dimensional picture of the various components of the cosmic web, across space and time, using five main observables:

1. tracers of the interaction of the CMB with ionized electron gas (Sunyaev-Zeldovich effects), to map the distribution and temperature of hot gas, and large-scale velocity flows;
2. CMB deflections by gravitational lensing, used to track mass in the entire Hubble volume;
3. high-redshift dust and line emission, to map atoms in structures across cosmic time;
4. primary CMB anisotropies at the cosmic-variance limit, to constrain parameters of ΛCDM and its extensions or alternatives;
5. distortions of the CMB blackbody spectrum, to probe the thermal history of the Universe and all processes that can impact it up to redshifts of a few million.

[1] https://www.cosmos.esa.int/web/voyage-2050

None of these signals can be observed with high accuracy in full isolation from the others. Most of them probe inter-connected phenomena, and also generate superimposed signatures in the microwave sky emission. The combined survey will offer the means to identify each of them to provide a comprehensive and detailed view of the history of the Universe, and a tomographic and dynamic census of the three-dimensional distribution of hot gas, velocity flows, early metals, dust, and mass distribution. In addition to its exceptional capability for cosmology, this survey will be extremely valuable for many other branches of astrophysics.

3 An L-class space mission

The proposed survey requires an L-class space mission, featuring three instruments that observe within the 10–2000 GHz frequency range, at varying spectral and angular resolutions. Two of these instruments (a broad-band imager and a spectrometer) will be located at the focus of a large (~ 3.5 m) cold (~ 8 K) telescope providing arcminute-scale angular resolution at 300 GHz. The third instrument will be an independent Fourier-transform spectrometer that will perform absolute spectroscopy across the entire frequency range at moderate angular resolution:

Instrument 1: A broad-band, multifrequency, polarimetric imager in the main telescope's focal plane will provide sensitive observations of the CMB and of SZ effects at ~1 arcminute angular resolution. Examples of that instrument's capability for probing cosmic structure include: the detection of all massive bound structures ($M > 5 \times 10^{13}$ solar masses) in the observable Universe (i.e. ~ one million galaxy clusters); routine measurement of CMB halo lensing and the kinetic Sunyaev-Zeldovich (SZ) effect; measurement of the relativistic SZ effect in individual halos; the first detection of the polarized SZ effects; investigation of non-thermal SZ effects and resonant scattering of CMB photons; a full sky map of the projected dark matter distribution, signal-dominated down to 10 arcminute angular scales.

Instrument 2: At the focus of the same telescope, a moderate spectral resolution ($R \simeq 300$) filter-bank spectrometer will map the IR background and atomic and molecular lines out to high redshift, to detect hundreds of thousands of high redshift lensed galaxies and galaxy protoclusters, and produce hundreds of maps of line emission from CII, OI, OIII, CO, at various redshifts up to z=7-8, for a tomographic view of structures in the Hubble volume.

Instrument 3: The absolute spectrophotometer will consist of one or a few independent FTS modules, covering the full 10–2000 GHz band, with spectral resolution ranging from 2.5 to 60 GHz, angular resolution ranging from a fraction of a degree to a few degrees, and overall sensitivity $< 1\,\mathrm{Jy\,sr^{-1}}$, 4 to 5 orders of magnitude better than that of *COBE*-FIRAS.

Through its spectroscopic capability with two of its three instruments, the space mission is designed to map the entire sky in hundreds of channels, most of which are inaccessible to ground-based observatories. This is key in enabling the observation of the time-evolution of structures and of energy exchanges of matter with the photon background across cosmic times – including processes that generate spectral distortions in the background photon distribution before recombination, up to a redshift $z \simeq 2,000,000$.

We envision 6 years of observation from an orbit around the L2 Sun-Earth point, with two different observing modes: a survey for about half the mission time, to map the entire sky as well as a few selected wide fields of specific interest (e.g. mapped with complementary experiments, at other wavelengths or with large ground-based telescopes); and an observatory mode, during which the rest of the time will be made available to the wider scientific community for an opportunity to observe regions of specific interest.

Although ambitious, the proposed survey builds upon previous space mission concepts already studied at the pre-phase-A or phase-A levels and should be well feasible in the 2035-2050 timeframe. By systematically probing the Universe using many approaches, and with an unprecedented capability to observe faint signals coming from the largest cosmological distances, the proposed mission will be key in pushing back the frontiers of our understanding of the Universe that we live in. It will be transformational in many areas of physics, astrophysics, and cosmology at the most fundamental level, in a way that is unmatched by any other existing or proposed experiment – and can only be achieved from space.

4 References

The four white papers are available on arXiv:

- Mapping Large-Scale-Structure Evolution over Cosmic Times (arXiv:1908.07533)
- Microwave Spectro-Polarimetry of Matter and Radiation Across Space and Time (arXiv:1909.01591)
- A Space Mission to Map the Entire Observable Universe using the CMB as a Backlight (arXiv:1909.01592)
- New Horizons in Cosmology with Spectral Distortions of the Cosmic Microwave Background (arXiv 1909.01593)