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The COrE+ (Cosmic Origins Explorer) mission

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Abstract

COrE+ has been proposed to ESA as a medium-class mission for investigating, within the framework of the ESA Cosmic Vision program, a set of important scientific questions that require high sensitivity, full-sky observations of the sky emission at wavelengths ranging from millimeter-wave to the far-infrared. Its main scientific objective is to explore the physics of inflation and the distant universe, probing cosmic history from very early times until now as well as the structures, distribution of matter, and velocity flows throughout our Hubble volume. *COrE+* will survey the full sky in 19 frequency bands in both intensity and polarization, from 60 to 600 GHz.

1 Introduction

The aim of this talk is to describe to the Spanish Astrophysical Community the *COrE+* (Cosmic Origins Explorer) space mission, which has been recently proposed in response to the M4 call for a Medium-size mission opportunity in ESA's Science Programme[1].

COrE+ will investigate Cosmic Origins through high sensitivity, full sky observations of the polarized microwave and sub-millimeter sky between 60 and 600 GHz. Its primary science goal is to investigate the physics of the very early Universe, which is the source of the entire cosmic structures that we observe today, by means of an exquisite characterization of the B-modes in the cosmic microwave background (CMB) polarization. But *COrE+* also addresses a broad range of other questions of prime scientific importance that cannot be answered by any other means.

The proposed mission builds on the success of *Planck* [8] and *Herschel* [7], re-using many of the subsystems and methods developed by the mm/sub-mm community. Previous proposed missions were *COrE* [14] and *PRISM* [2].

[1] M4 ESA Call: http://sci.esa.int/2014_M4_Call

2 Science case

COrE+ will map the full sky in about 20 frequency bands to measure the temperature and polarization of the CMB. The primary science goals are:

- Mapping inflation
- Mapping all the mass in the Universe
- Mapping all the hot gas in the Universe
- Mapping star formation
- Mapping the Milky Way

2.1 Mapping inflation

The primary motivation is understanding the physics of inflation and how our Universe begin. There is compelling evidence that the early universe underwent a period of accelerated expansion, called inflation [12, 11, 4, 6]. The energy scales involved in this epoch ($E \sim 10^{16}$ GeV) are more than 12 orders of magnitude beyond the energy scales accessible to particle accelerators. These are also the energy scales where quantum gravity effects start to become relevant.

The inflationary paradigm also provides the mechanism to produce the seeds to all cosmic structures. Those primordial seeds or fluctuations can be classified in two categories: scalar (gravitational potentials) and tensor (gravitational waves). The tensor perturbations would imprint a very particular pattern in the CMB polarization named B-mode polarization [10, 5, 15]. The scalar fluctuations have been measured and characterized very precisely by the Planck mission [9]. *COrE+* aims to detect and characterize the tensor fluctuations.

However, cosmic inflation does not provide a unique prediction for the amplitude of the primordial tensor mode, parameterized by the tensor-to-scalar ratio, r. In the simplest inflationary models, inflation is powered by a single scalar field ϕ (the inflaton) with a certain potential energy density $V(\phi)$, which can be related to the r value as $V^{1/4} = 1.1 \times 10^{16}(r/0.01)^{1/4}$ GeV. Thus, the knowledge of r will substantially restrict the field of inflationary models allowed by current observations.

Present constraints on inflationary models ($r < 0.12$) rely mainly on measurements of the primordial scalar mode power spectrum, which is well measured by Planck [9] and ground-based CMB experiments and unlikely to improve substantially in the future. Thus, an improvement on this requires specific observations of the B-mode polarization.

A generic class of inflationary models known as large-field models predicts $r \sim 0.1$. Such a large r value is detectable by ground-based experiments [1] but is already disfavored by the current Planck data. If confirmed, COrE+ observations will provide the best possible full-sky, signal-dominated maps of CMB E and B mode polarization anisotropy, which will serve to provide precision constraints on the shape of the B mode power spectrum, testing also the expected near scale invariance of the primordial tensor modes. In case of a more plausible value of $r \sim 2 \times 10^{-3}$, these signals will be very challenging to detect convincingly from the ground or stratospheric balloons, and thus a space mission like *COrE+* will be needed for an ultimate measurement.

2.2 Mapping all the mass in the universe

COrE+ will probe the distribution of clustered mass in the Universe through the observation of the lensing of CMB polarization due to all the structures between us and the last scattering surface. The reconstruction of the CMB lensing potential will provide highly accurate maps of the distribution of dark matter at redshifts $z = 1$–3. The power spectrum of this signal constraints cosmological parameters such as the curvature, neutrino masses at sub-eV scales, and the dark energy equation of state. In addition, by combining this lensing map with other tracers of the large scale structure, stringent constraints will be achieved. For example, the combination with EUCLID will constrain the sum of the three light neutrino masses with a statistical error of 3 meV, five times better than any single cosmological probe alone and sufficient to distinguish unambiguously between the standard or inverted neutrino hierarchies.

2.3 Mapping the hot gas in the Universe

Inverse Compton scattering of CMB photons off hot thermal electrons introduces a distortion to the CMB spectrum named the Sunyaev-Zeldovich (SZ) effect [13]. As the surface brightness of the thermal SZ (tSZ) effect is redshift independent, it can be used to detect galaxy clusters at large distances. *COrE+* will use the tSZ effect to measure all the hot gas in the observable universe. It will detect $\sim 100,000$ galaxy clusters up to redshifts $z = 2$–3, and part of the hot baryons in the cosmic web (WHIM). Combined with high resolution (2-3') ground-based CMB data in atmospheric windows between 90 and 250 GHz, *COrE+* will also detect the individual peculiar motions of $\sim 30,000$ galaxy clusters, thus directly measuring the cosmic velocity field at various redshifts, a measurement that cannot be performed by any other means.

2.4 Mapping star formation

Unlike *Planck*, *COrE+* will be confusion limited up to its highest frequencies, and thus deeper point source detection limits will be achieved. *COrE+* will discover and characterize a large number of new galactic and extragalactic point sources and also measure their polarization properties. Its sub-mm surveys will provide unique information for galaxy evolution models, covering the gaps between *Planck* and *SPT* or *Herschel*. Among other things, *COrE+* will allow us: a) to carry out unbiased studies of proto-clusters at $z = 1$–3 whose intergalactic gas has not yet reached the virial temperatures; b) to measure the CIB power spectrum over a wide range of angular scales, breaking the degeneracy between Poisson contributions and non-linear effects; c) to extend the counts of radio sources (intensity and polarization), specially at high frequencies.

2.5 Mapping the Milky way

COrE+ will map the polarized emission from our Galaxy with unprecedented sensitivity and angular resolution. These observations of the dust polarization will provide a unique tool to understand the role of magnetic fields in star formation, and the interplay between turbulence, gravity and magnetic fields. The combination of the spectral and spatial information provided by *COrE+* will open a new window to study the interstellar dust.

3 Scientific requirements and proposed mission

The *COrE+* mission is designed with the aim of gathering almost all the cosmological information encoded in the CMB polarization. To this end, the detailed study of the polarized emissions of the interstellar medium is mandatory for producing clean maps of the primary CMB signals. The target sensitivity of the mission corresponds to $r = 0.001$. This requires detecting both the reionization ($\ell < 10$) and the recombination ($\ell \sim 80$) peaks. For the second one, it is necessary to reduce the "contamination" of primordial CMB B modes by gravitational lensing by a factor of 2–3. In practice, this translates into a sensitivity better than $2.5\,\mu$K per square arcminute pixel, and an angular resolution better than 6'. Moreover, observations in almost all sky ($f_{\rm sky} > 75\%$) are needed in order to have near complete statistics at large scales. Galactic and extragalactic foregrounds need to be removed with high precision in all the sky area.

The proposed *COrE+* baseline mission reaches the required CMB sensitivity with an array of 2410 cryogenically cooled, linearly polarized detectors at the focus of a 1.5 meter aperture Gregorian telescope (see Table 1). The entire sky will be surveyed with 19 frequency bands spanning the range 60 to 600 GHz. As previous CMB satellites, the spacecraft will be located in an orbit around the Sun-Earth L2 Lagrange point to avoid far sidelobe contamination. The scanning strategy includes a combination of three rotations of the spacecraft to mitigate the systematic effects. Note that at frequencies above 350 GHz, *COrE+* will for the first time provide full sky, high quality polarization maps.

Achieving the *COrE+* cosmological science programme will require accurate separation of the many astrophysical foregrounds as well as exquisite control and assessment of systematic errors. We have tested, using detailed simulations, that the proposed design includes all the needed spectral bands for this purpose

In addition to the aforementioned primary science goals, the *COrE+* high sensitivity maps of the three Stokes parameters I, Q, and U in 19 frequency bands will constitute a long standing legacy and a reference dataset for the microwave and submillimeter emissions over the full sky.

4 Conclusions

The proposal with the *COrE+* mission was submitted in January 2015 to the Call for a Medium-size mission opportunity in ESAs Science Programme for a launch in 2025 (M4). A

Table 1: Proposed *COrE+* frequency channels. The sensitivity is calculated assuming $\Delta\nu/\nu = 25\%$ bandwidth, 50% optical efficiency, total noise of twice the expected photon noise from the sky and the optics of the instrument at 60 K temperature. The aggregated CMB sensitivity is 2 μK.arcmin in polarization. This is the *COrE+* baseline configuration, based on single-frequency, dual polarization detectors.

Channel (GHz)	Beam (arcmin)	$N_{\rm det}$	ΔT (μK.arcmin)	ΔP (μK.arcmin)	$\Delta y \times 10^6$ ($y_{\rm SZ}$.arcmin)	PS flux (5σ) (mJy)
60	14	28	11.3	16	-2.3	6
70	12	30	10.5	14.9	-2.2	6.3
80	10.5	38	9.1	12.9	-2.0	6
90	9.33	72	6.5	9.2	-1.5	4.6
100	8.4	84	6.0	8.5	-1.5	4.5
115	7.3	124	5.0	7.0	-1.3	4
130	6.46	180	4.2	5.9	-1.3	3.5
145	5.79	264	3.6	5.0	-1.3	3
160	5.25	254	3.8	5.4	-1.7	3.1
175	4.8	290	3.8	5.3	-2.2	3.0
195	4.31	346	3.8	5.3	-4.1	2.9
220	3.82	200	5.8	8.1	-	4.0
255	3.29	140	8.9	12.6	5.5	5.1
295	2.85	60	19.4	27.4	5.7	8.4
340	2.47	60	30.9	43.7	5.6	9.2
390	2.15	60	55.0	77.8	7.0	10.2
450	1.87	60	116.6	164.8	10.9	11.5
520	1.62	60	295.7	418.2	21.0	13.2
600	1.4	60	899.7	1272.4	50.3	15.0

complete description of the mission, including the final proposal submitted to ESA, can be found in the following web page: https://hangar.iasfbo.inaf.it/core/ [3]. This web page also contains a list of supporters, and it is open to any scientists interested in the *COrE+* mission. The Spanish community is deeply interested and involved in the *COrE+* proposal, including scientists from the Instituto de Astrofísica de Canarias, Instituto de Física de Cantabria, Institut de Ciencies del Cosmos at the Universitat de Barcelona, Universidad de Oviedo, Centro de Estudios de Física del Cosmos de Aragón, Instituto de Física Teórica de Madrid and Universidad de Granada.

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