PROJECT: Studi di Cosmologia		WP…
WP TITLE: Next Generation of Space Missions **CONTRACTOR: INAF –IASF Bologna** **START EVENT**: KO **END EVENT**: RF **WP MANAGER: Reno Mandolesi**		**Sheet**: 1 **of** 1 **Issue Ref**: 1 **Issue Date**:01/09/2016

1. RATIONAL OF THE PROJECT

The current cosmological models and the state-of-the-art of CMB temperature and polarization observations (mainly based on *Planck* and BICEP/Keck results) point towards the need of a complementary approach of space projects, focused on CMB analysis, and of sub-orbital observations for precise, multi-frequency (including the lowest and highest – experimentally feasible frequencies) foreground treatment and very high resolution mapping. The latter is crucial to be able to e.g. detect and characterize primordial B-mode polarization from a stochastic background of gravitational waves with a primordial perturbation tensor-to-scalar ratio r around 10^{-3}.

In parallel we will investigate also the observability of CMB spectral distortions specially those deriving from the re-ionization epoch.

As a third goal we will investigate the feasibility of a micro/mini space mission to be used as a calibrator for all CMB experiments on ground (and eventually space).

The main object of this WP is aimed at:

I. Definition and design implementation of a next CMB oriented space mission.
II. Definition and road-map implementation of sub-orbital (ground and balloon) experiments/projects/ facilities to complement space mission.

2. RESULTS EXPECTED AFTER SIX MONTHS FROM THE KO-MEETING

The main goals planned for this period are: 1. Ingesting of available tools and data sets; 2. Design and simulation planning; 3. Outline of future CMB space missions in the orbital & sub-orbital frameworks.

In the analyses described below (Sect. 3) we largely ingested and used the *Planck* legacy for what concerns both data analysis tools and component maps to characterize astrophysical foreground emissions and CMB anisotropies (item 1). We mainly focused the study on anisotropy missions under different configurations (item 2). Finally, we started also the investigation (item 3) of implications of spectrum oriented missions (Sect. 4), a topic that still relies mainly on COBE/FIRAS data of about 20 years ago.

A CMB space calibrator to be used as a large use facility will also be examined.

3. RESULTS OBTAINED AFTER SIX MONTH FROM THE KO-MEETING

In the first six months we concentrated our efforts mainly in a CMB polarization mission and started studying a spectral space mission.

We have studied the capabilities of different concepts for the next space CMB mission dedicated to polarization to improve on the current cosmological constraints, largely based on *Planck* for temperature, E-mode polarization and lensing, and on BICEP 2/Keck Array/*Planck* joint cross-correlation for primordial B-mode polarization.

As a first step, we have concentrated on the impact of the telescope size and noise sensitivity on the science results. This comparison is important since the size of the primary aperture, and therefore of the instrument, and the number of detectors determine the cost of a CMB polarization mission.

We have studied the CORE-like specifications of the proposal for a CMB space satellite submitted in October 2016 in response to the ESA fifth call for a medium-size mission (Burigana et al. 2017; de Bernardis et al. 2017; de Zotti et al. 2016; Di Valentino et al. 2016; Finelli et al. 2016); these specifications correspond to an aggregate noise sensitivity of 1.7 μK arcmin obtained by 19 frequency channels spanning the range 60-600 GHz with an angular resolution of 5' at 200 GHz determined by a 120 cm mirror. We have compared these CORE-like forecasts to those obtained with experimental specifications from other concepts for the next space missions dedicated to CMB polarization, with telescope sizse from 60 cm to 150 cm.

These concepts include (a) the LiteBIRD-ext configuration (Errard et al. 2015) for JAXA LiteBIRD mission (Matsumura et al. 2014) with an aperture around 60 cm, (b) three configurations with the same noise sensitivity per arcmin as LiteBIRD-ext, but with higher angular resolution thanks to a larger telescope of 80 cm (LiteCORE-80) or 120 cm (LiteCORE-120) or 150 cm (LiteCORE-150), and (c) the COrE+ proposal previously submitted to ESA in response to the M4 mission call and its version optCOrE+ with an extended mission duration.

3.1. Cosmological Parameters

The precision of the determination of cosmological parameters will be greatly improved by a CORE-like experiment. With the inclusion of the CMB lensing, whose information will be exploited up to the scales where linear theory is reliable, the improvement with respect to Planck is extremely significant: a CORE-like experiment can simultaneously improve constraints on the cosmological parameters of the concordance cosmological model by a factor 7.3 (A_s), 5.5 (H_0, $\Omega_{cdm}h^2$), 4.5 ($\Omega_b h^2$, τ), and 3.4 (n_s). The reionization optical depth tau is measured down to the cosmic variance limit by all different configurations studied because of the high signal-to-noise measurement of the reionization bump in the EE power spectrum. For the other five parameters, the telescope size is important: the improvement in the ratio of uncertainty expected from a CORE-like over a LiteBIRD-like experiment ranges between a factor 3.4 for n_s and 4.3 for H_0, respectively.

For important one-parameter extensions of the concordance cosmological model the figure of merit are the following:
a. A CORE-like experiment alone could detect neutrino masses with an uncertainty on the neutrino mass around 0.043 eV, enough to rule out the inverted mass hierarchy at more than 95 c.l..

b. A CORE-like experiment could also provide extremely stringent constraints on the neutrino effective number N_{eff} with en uncertainty around 0.041.

c. The primordial Helium abundance Y_p can be measured by CORE-like with an uncertainty of 0.0029 that is almost a factor two better than current constraints from direct measurements from metal-poor extragalactic H II regions.

d. By measuring the intermediate angular scale CMB polarization with unprecedented accuracy, a CORE-like will scrutinize with the highest possible detail the process of recombination, improving current constraints on the amplitude of the recombination two photons rate by a factor 5.

Also for these one-parameter extensions a CORE-like experiment constrains the neutrino effective number and the primordial helium abundance with a precision about 5 and 3 times better than LiteBIRD alone, respectively. It is important to stress that the differences between different versions of a CORE-like experiment as CORE-M5 and COrE+ are of the order of 10 % demonstrating the optimization of the design for the proposal submitted to the M5 call with a telescope size 20 % smaller. See Di Valentino et al. (2016) for more details.

3.2. Inflation

The precision on key inflationary parameters such as dn_s /d ln k and Ω_k will improve with respect to the Planck 2015 release by approximatively factors of 2.9, and 4, respectively. By providing a cosmic variance limited measurement of the EE power spectrum up to high multipoles, any of the proposed CORE-like configurations will increase the amount of information available on the scalar primordial power spectrum by an order of magnitude with respect to current data, and will be able to probe the primordial origin of features in the Planck temperature power spectrum at high statistical significance. CORE will determine the nature of the initial conditions of primordial fluctuations 2--5 times better than Planck by providing nearly cosmic variance limited upper bounds on the allowed isocurvature fraction up to l=3000. As a figure of merit for primordial non-Gaussianities, the direct bispectrum measurements by CORE will shrink the allowed f_{NL} volume in the three-dimensional Local-Equilateral-Orthogonal (LEO) shape-function space by a factor of approximately 20 with respect to the current Planck results.

We have throughly demonstrated how the telescope size is important for improving the knowledge on the statistics and initial conditions for primordial fluctuations. LiteBIRD alone does not bring significant improvement to the running of the spectral index and to the constraints on isocurvature perturbations with respect to Planck; it can bring some limited improvement for the LEO bispectrum shapes due to the much better measurement of polarization, in particular on large angular scales.

Concerning B-mode polarization, a first comparison of the different configurations has been done by assuming that the lower and higher frequency channels are sufficient to remove completely the foreground residuals of the central cosmological channels. Whereas this is probably a good approximation for E-mode polarization, it is an optimistic assumption for primordial B-mode for all the configurations considered. Since all the different concepts considered target the white noise part of the B-mode signal from lensing, all the configurations lead to very similar uncertainties for the tensor-to-scalar r, in the ballpark of 4 $10^{-4,}$ when considering detector sensitivities only. The various concepts of the CMB space mission considered are however different in the capability of partially removing the B-mode lensing signal, i.e. internal delensing. In this case, the angular resolution is important and a CORE-like experiment can indeed reach a sensitivity to r which is roughly half of the one obtainable by LiteBIRD, i.e. 4 10^{-4}, always in absence of foreground residuals. See F. Finelli et al. (2016) for more details.

Parameter	Results from Planck 2015 release	CORE-like expected uncertainties	Improvement factor
ΛCDM model			
A_s	$A_s = (2.130 \pm 0.053) \times 10^{-9}$ (68% CL)	$\sigma(A_s) = 0.0073$	7.3
n_s	$n_s = 0.9653 \pm 0.0048$ (68% CL)	$\sigma(n_s) = 0.0014$	3.4
$\Omega_b h^2$	$\Omega_b h^2 = 0.02226 \pm 0.00016$ (68% CL)	$\sigma(\Omega_b h^2) = 0.000037$	4.3
$\Omega_c h^2$	$\Omega_c h^2 = 0.1193 \pm 0.0014$ (68% CL)	$\sigma(\Omega_c h^2) = 0.00026$	5.4
τ	$\tau = 0.063 \pm 0.014$ (68% CL)	$\sigma(\tau) = 0.002$	7.0
H_0 [km/s/Mpc]	$H_0 = 67.51 \pm 0.64$ (68% CL)	$\sigma(H_0) = 0.11$	5.8
Ω_k	$\Omega_k = -0.0037^{+0.0083}_{-0.0069}$ (68% CL)	$\sigma(\Omega_k) = 0.0019$	4
$N_{\rm eff}$	$N_{\rm eff} = 2.94 \pm 0.20$ (68 % CL)	$\sigma(N_{\rm eff}) = 0.041$	4.9
M_ν	$M_\nu < 0.315\,\mathrm{eV}$ (68 % CL)	$\sigma(M_\nu) = 0.043$ eV	7.3
(m_s^{eff}, N_s)	$(m_s^{eff} < 0.33eV, N_s < 3.24)$ (68 % CL)	$\sigma(m_s^{eff}, N_s) = (0.037eV, 0.053)$	8.9, 4.5
Y_p	$Y_p = 0.247 \pm 0.014$ (68 % CL)	$\sigma(Y_p) = 0.0029$	4.8
τ_n [s]	$\tau_n = 908 \pm 69$ (68 % CL)	$\sigma(\tau_n) = 13$	5.3
w	$w = -1.42^{+0.25}_{-0.47}$ (68 % CL)	$\sigma(w) = 0.12$	3
T_0	Unconstrained	$\sigma(T_0) = 0.018$ K	
p_{ann}	$p_{ann} < 3.4 \times 10^{-28}\ cm^3/GeV/s$ (68 % CL)	$\sigma(p_{ann}) = 5.3 \times 10^{-29}\ cm^3/GeV/s$	6.4
$g^4_{\rm eff}$	$g^4_{\rm eff} < 0.22 \times 10^{-27}$	$\sigma(g^4_{\rm eff}) = 0.34 \times 10^{-28}$	6.4
α/α_0	$\alpha/\alpha_0 = 0.9990 \pm 0.0034$ (68 % CL)	$\sigma(\alpha/\alpha_0) = 0.0007$	4.8
$\Sigma_0 - 1$	$\Sigma_0 - 1 = 0.10 \pm 0.11$ (68 % CL)	$\sigma(\Sigma_0 - 1) = 0.044$	2.5
$A_{2s1s}/8.2206$	$A_{2s1s}/8.2206 = 0.94 \pm 0.07$ (68 % CL)	$\sigma(A_{2s1s}/8.2206) = 0.015$	4.7
$\Delta(z_{reio})$	$\Delta(z_{reio}) < 2.26$ (68 % CL)	$\sigma(\Delta z_{reio}) = 0.58$	3.9
$\mathrm{d}n_s/\mathrm{d}\ln k$	$\mathrm{d}n_s/\mathrm{d}\ln k = -0.0023 \pm 0.0067$ (68% CL)	$\sigma(\mathrm{d}n_s/\mathrm{d}\ln k) = 0.0023$	2.9
$\mathrm{d}^2n_s/\mathrm{d}\ln k^2$	$\mathrm{d}^2n_s/\mathrm{d}\ln k^2 = 0.025 \pm 0.013$ (68% CL)	$\sigma(\mathrm{d}^2n_s/\mathrm{d}\ln k^2) = 0.0046$	2.8
r	$r < 0.08$ (95% CL)	$\sigma(r) = 4 \cdot 10^{-4}$ ($r_{\rm fid} = 0.01$)	10^2
n_t	$-0.38 < n_t < 2.6$ (95% CL)	$\sigma(n_t) = 0.08$ ($r_{\rm fid} = 0.01, n_{\rm fid\,t} = -r_{\rm fid}/8$)	10
$\beta_{\rm iso}$	$\beta^{\rm curvaton}_{\rm iso} < 0.0013$ (95% CL)	$\beta^{\rm curvaton}_{\rm iso} < 0.00026$ (95% CL)	5.0
	$\beta^{\rm axion}_{\rm iso} < 0.038$ (95% CL)	$\beta^{\rm axion}_{\rm iso} < 0.018$ (95% CL)	2.1
$f_{\rm NL}$	$f^{\rm local}_{\rm NL} = 0.8 \pm 5.0$ (68% CL)	$\sigma(f^{\rm local}_{\rm NL}) = 2.1$	2.4
	$f^{\rm equil}_{\rm NL} = -4 \pm 43$ (68% CL)	$\sigma(f^{\rm equil}_{\rm NL}) = 21$	2.0
	$f^{\rm ortho}_{\rm NL} = -26 \pm 21$ (68% CL)	$\sigma\left(f^{\rm ortho}_{\rm NL}\right) = 9.6$	2.2
	$f^{\rm ISW-lens}_{\rm NL} = 0.79 \pm 0.28$ (68% CL)	$\sigma\left(f^{\rm ISW-lens}_{\rm NL}\right) = 0.045$	6.2
c_s	$c_s > 0.023$ (95% CL)	$c_s > 0.045$ (95% CL)	2.0
$G\mu$	$G\mu < 2.0 \times 10^{-7}$ (95% CL)	$G\mu < 2.1 \times 10^{-8}$ (95 % CL)	9.5

Table 2: Summary of the current results based on the latest Planck 2015 release and CORE-like forecasts presented in [2, 3]. The third column gives the figure of merit of the improvement expected with CORE.

3.3. Effects of observer peculiar motion: science outcome and cosmological tests

We carried out a detailed and original study (Burigana et al. 2017) of the effects of our peculiar motion with respect to the CMB rest frame and of the possibility of using it to extract valuable cosmological information from anisotropy missions. The analysis have been performed considering different specifications.

The main effect is the observed dipole pattern, that on the other hand could be in principle contributed also by intrinsic signal.

We focussed on three specific topics: i) analysis of possible improvements on dipole determination at each frequency, carried out in real space, since sky masking is typically essential in these types of analyses; ii) extension of boosting effects to polarization and cross-correlations will enable a more robust determination of purely velocity-driven effects that are not degenerate with the intrinsic CMB dipole; an observer moving with respect to the CMB rest frame will also see boosting imprints on the CMB at l > 1, due to Doppler and aberration effects, which can be measured in harmonic space as correlations between l and l + 1 modes (assuming that the CMB is statistically isotropic in its rest frame). iii) analysis of the frequency dependence of dipole spectrum to extract information on CMB spectral distortions and on CIB spectrum.

About point i) the main conclusion is that sky sampling quality is critical not only for dipole direction estimation but also for dipole amplitude estimation, an aspect crucial in particular for point iii). Sky sampling is clearly related to beam resolution, but not the only parameter, since, in principle, it is possible to sample the sky very accurately independently of the beam size, but, of course, this has to be properly planned in CMB projects and has design and mission implication. The main result is summarized in Fig. 1 where the almost linear scaling of uncertainty in dipole parameter retrival with sky sampling is evident and the dominant factor also in the presence of systematics.

About point ii) we found that an experiment like CORE can measure this signal independently in temperature and polarization, which constitutes a new consistency check, with a signal-to-noise ratio of about 8 for TT , 7 for TE + ET and 7 for EE. Overall, CORE can achieve a signal-to-noise ratio of almost 13, which improves on the capabilities of Planck (about S/N $\simeq$ 4, only in TT) and is essentially that of an ideal cosmic-variance-limited experiment up to $l \simeq 2000$. Note the importance of performing high-sensitivity measurements at close to arcminute resolution in order to be sensitive to the correlations at high multipoles that yield most of the signal. The main result and comparison between different configurations is shown in Fig. 2.

Comparing analyses of this type carried out in a wide set of frequency domains, where dipole signals come from sources at different shells in redshifts, allows us to carry out utimate tests about the fundamental principles of cosmological model.

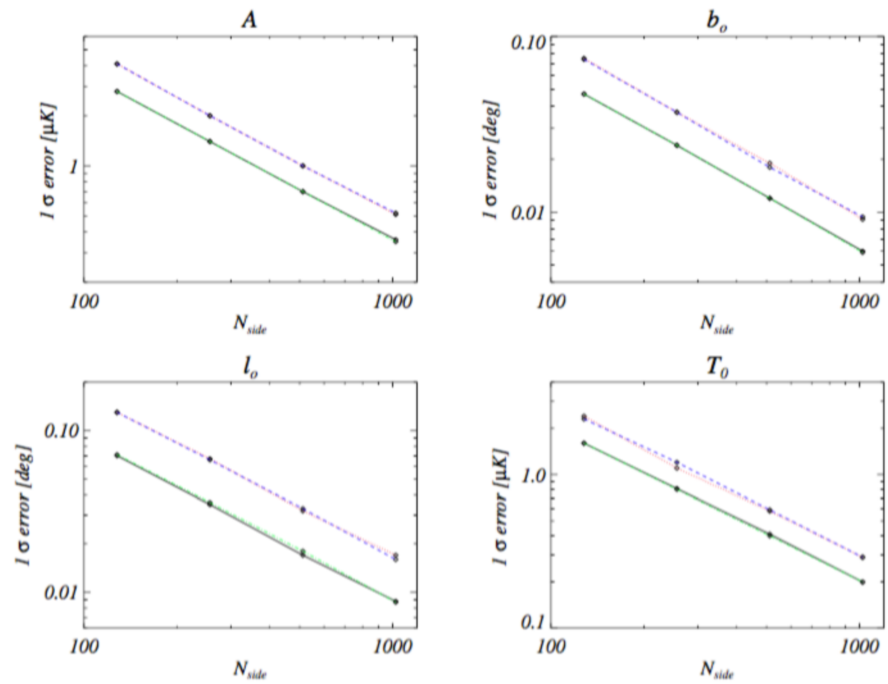


Fig. 1: 1 σ errors as function of HEALPix N_{side} values for the parameters A, b_0, l_0, and T_0: dipole- only (solid black line); dipole+noise (green dot-dashed line); dipole+noise+mask (red dotted line); and dipole+noise+mask+systematics (blue dashed line). The chosen frequency channel is 60 GHz and the noise map corresponds to 7.5 μK.arcmin. The adopted mask is the Planck Galactic mask extended to cut out ±30◦ of the Galactic plane. The systematics correspond to the pessimistic expectation of calibration errors and sky (foreground, etc.) residuals. Notice that the pixelization error, due to the finite map resolution, is dominant over the noise for any N_{side}. While the impact of noise and systematics is negligible, we find that the effect of reducing the effective sky fraction is important.

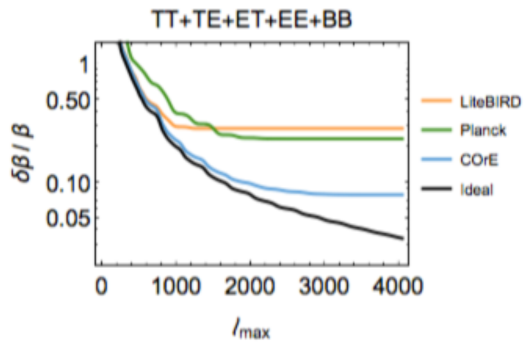


Fig. 2: Achievable precision in estimating the velocity through aberration and Doppler effects for the different configurations of CMB temperature and polarization anisotropy experiments reported in the figure legend on the right.

We dedicate a bit more space to the discussion of point iii), aimed to the scientific objectives in Sect. 4, but through the differential observational approach. Note that absolute and differential approaches can be obviously combined together to provide the most reliable results.

Precise inter-frequency calibration will offer the opportunity to constrain or even detect CMB spectral distortions, particularly from the cosmological reionization epoch, because of the frequency dependence of the dipole spectrum, without resorting to precise absolute calibration.

Fig. 3 compares the ideal sensitivity to dipole (and quadrupole, in some cases) signal for various types of spectra in the case of space missions with CORE and LiteBIRD specifications (note that only the temperature sensitivity is exploited here).

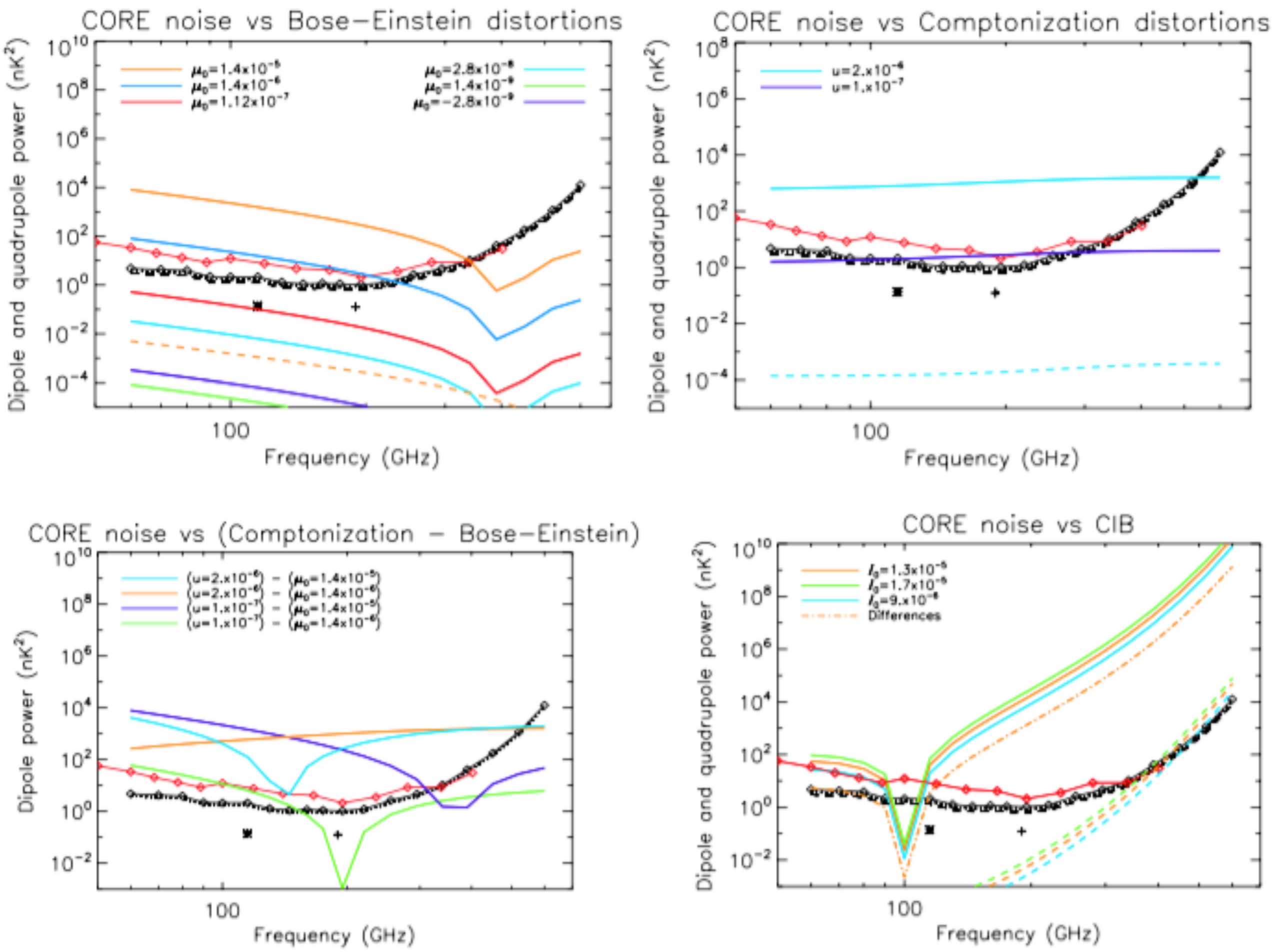


Fig. 3: *Top:* Angular power spectrum of the dipole map, derived from the difference between distorted spectra and the current blackbody spectrum versus CORE sensitivity. The CORE white noise power

spectrum (independent of multipole, shown as the black upper solid curve and with diamonds for different frequency channels) and its rms uncertainty (for l = 1, using dots, and for l = 2, using dashes) are plotted in black. The cross (asterisk) displays aggregated CORE noise from all channels (up to 220 GHz). We shown also for comparison the LiteBIRD white noise power spectrum (red solid curve and diamonds for different frequency channels). Left: BE distortions for $\mu_0 = -2.8 \times 10^{-9}$ (representative of adiabatic cooling), $\mu_0 = 1.4 \times 10^{-5}$, 1.4×10^{-6} (representative of improvements with respect to FIRAS upper limits), $\mu_0 = 1.12 \times 10^{-7}$, 2.8×10^{-8}, and 1.4×10^{-9} (representative of primordial adiabatic perturbation dissipation). For $\mu_0 = 1.4 \times 10^{-5}$ we show also the angular power spectrum of the quadrupole map. Right: Comptonization distortions for $u = 2 \times 10^{-6}$ (upper solid curve for the dipole map and bottom dashed curve for the quadrupole map) and $u = 10^{-7}$ (lower solid curve for the dipole map), representative of imprints by astrophysical and minimal reionization models, respectively. *Bottom:* Left: The same as in Top, but comparing of the two above cases of Comptonization distortions with the two above cases of BE distortions with the largest values of μ_0; Right: The same as in the Top, but for the CIB (assuming the model from Fixsen et al. 1998, ApJ 508, 123). Also shown is the quadrupole signal (dashes). The different values of I_0 refer to the best-fit value and deviations by $\pm 1\ \sigma$.

We may expect that the main limitation to CMB spectral distortion parameters and CIB amplitude do not come from sensitivity, but from foreground residuals and calibration uncertainty. To quantify their relevance for the differential approach we performed dedicated simulations assuming the CORE frequency coverage and sensitivity (the latter resulting not so relevant, with respect to systematics), indeed frequency coverage beyond 400 GHz is critical to separate CIB from CMB distortions (other than Galactic foregrounds), as shown in Fig. 3, and assuming different level of foreground removal and calibration accuracy.

Table 1 summarizes the results in terms of improvement with respect to FIRAS.

	$E_{\rm cal}$ (%)	$E_{\rm for}$ (%)	CIB amplitude	Bose-Einstein	Comptonization
Ideal case, all sky	-	-	$\simeq 4.4 \times 10^3$	$\simeq 10^3$	$\simeq 6.0 \times 10^2$
All sky	10^{-4}	10^{-2}	$\simeq 15$	$\simeq 42$	$\simeq 18$
P76	10^{-4}	10^{-2}	$\simeq 19$	$\simeq 42$	$\simeq 18$
P76ext	10^{-2}	10^{-2}	$\simeq 17$	~ 4	~ 2
P76ext	10^{-4}	10^{-2}	$\simeq 22$	$\simeq 47$	$\simeq 21$
P76ext	10^{-4}	10^{-3}	$\simeq 2.1 \times 10^2$	$\simeq 2.4 \times 10^2$	$\simeq 1.1 \times 10^2$
P76ext	$10^{-3}_{(\leq 295)}-10^{-2}_{(\geq 340)}$	10^{-2}	$\simeq 19$	$\simeq 26$	$\simeq 11$
P76ext	$10^{-3}_{(\leq 295)}-10^{-2}_{(\geq 340)}$	10^{-3}	$\simeq 48$	$\simeq 35$	$\simeq 15$
P76ext, $N_{\rm side} = 128$	$10^{-3}_{(\leq 295)}-10^{-2}_{(\geq 340)}$	10^{-2}	$\simeq 38$	$\simeq 51$	$\simeq 23$
P76ext, $N_{\rm side} = 128$	$10^{-3}_{(\leq 295)}-10^{-2}_{(\geq 340)}$	10^{-3}	$\simeq 43$	$\simeq 87$	$\simeq 39$
P76ext, $N_{\rm side} = 256$	$10^{-3}_{(\leq 295)}-10^{-2}_{(\geq 340)}$	10^{-2}	$\simeq 76$	$\simeq 98$	$\simeq 44$
P76ext, $N_{\rm side} = 256$	$10^{-3}_{(\leq 295)}-10^{-2}_{(\geq 340)}$	10^{-3}	$\simeq 85$	$\simeq 1.6 \times 10^2$	$\simeq 73$

Table 1: Predicted improvement in the recovery of the distortion parameters discussed in the text with respect to FIRAS for different calibration and foreground residual assumptions. "P06" stands for the Planck common mask, while "P06ext" is the extended P06 mask. When not explicitly stated, all values refer to E_{cal} and E_{for} at Nside = 64.

The expected improvement with respect to COBE-FIRAS in the recovery of distortion parameters (which could in principle be a factor of several hundred for an ideal experiment with the CORE configuration) ranges from a factor of several up to about 50, depending on the quality of foreground removal and relative calibration. Even in the case of ≃ 1% accuracy in both foreground removal and relative calibration at an angular scale of 1°, we find that dipole analyses for a mission like CORE will be able to improve the recovery of the CIB spectrum amplitude by a factor ≃ 17 in comparison with current results based on COBE-FIRAS. While these results are very encouraging and clearly show the potentially good complementarity between absolute and differential approaches, they put our attention to the real impact of foreground and calibration accuracy relevance, likely much stronger that ideal sensitivity (with the obvious caveat that better sensitivity could help, at least in part, the achievement of good systematic mitigation during data analysis).

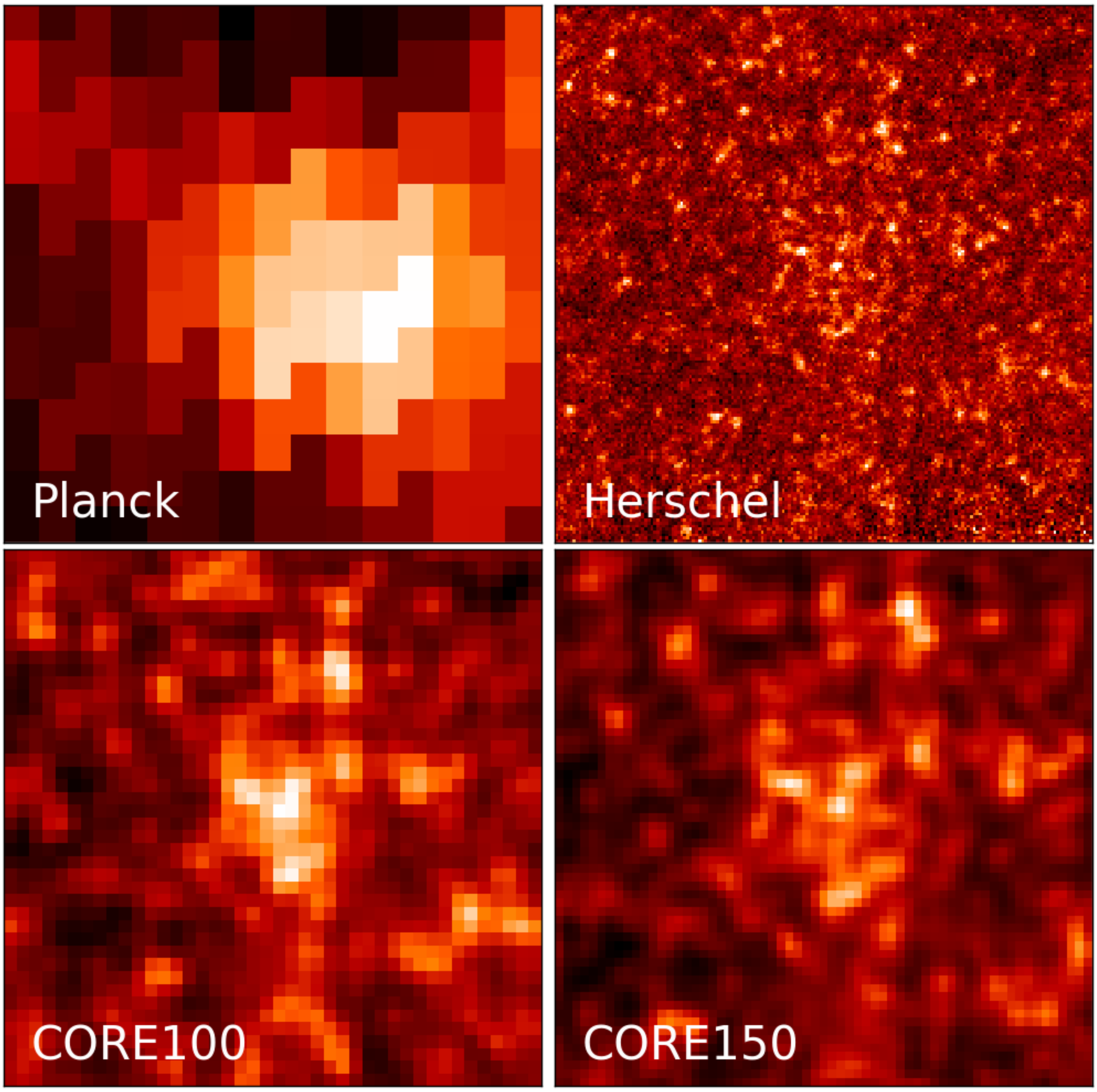
3.4. Extragalactic sources

A direct consequence of the extreme sensitivity, close to fundamental limits, of modern space-borne CMB missions is that their surveys of extragalactic sources are confusion limited. This was already the case for the *Planck* High Frequency Instrument (HFI) which however reached the diffraction limit only up to 217 GHz. Since the confusion limit scales roughly as the beam solid angle, i.e. as the square of the full width at half maximum (FWHM) of the instrument, an instrument like CORE, diffraction limited up to the highest frequencies, will substantially improve over *Planck*-HFI, even in the case of a somewhat smaller telescope. For example, at 545 GHz (550 μm) the *Planck* beam has an effective FWHM=4.83', while the diffraction limit for its 1.5-m telescope is 1.5'.

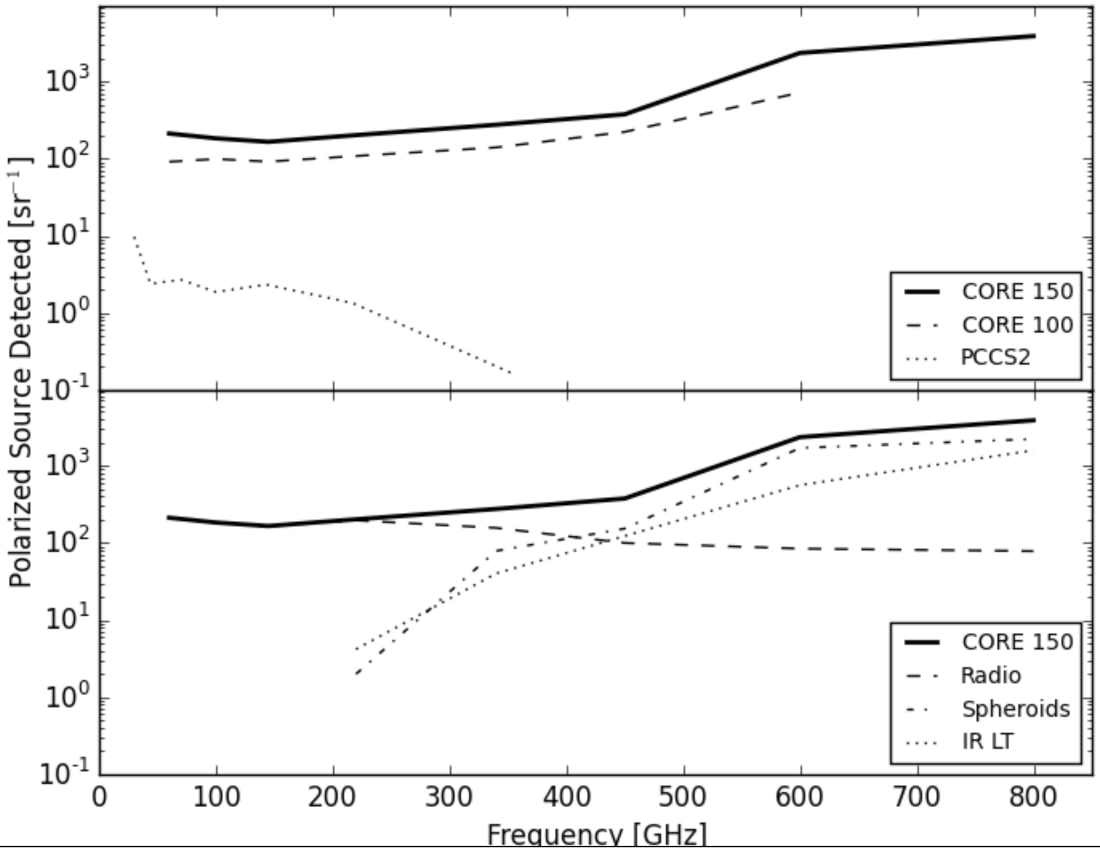
The above Table gives the 4σ completeness limits for 4 effective sizes of the CORE telescope obtained by means of realistic simulations. The last column shows, for comparison, the 90% completeness limits of the second Planck Catalogue of Compact Sources (PCCS2) in the "extragalactic zone" ($|b|> 30°$) for the Planck channel nearest to a CORE channel. Even in the case of a smaller telescope size, CORE performs substantially better than *Planck*. Especially at the highest frequencies, the substantially better resolution of the diffraction-limited CORE telescope offers a large advantage in terms of survey depth.

The advantage is further boosted in terms of the number of detected sources by the steepness of the source counts at mm/sub-mm wavelengths. *Planck* has already vividly demonstrated the power of all-sky surveys at these wavelengths in detecting rare sources with extreme properties. In particular, *Planck has* detected several of the most extreme, strongly-lensed, high-z galaxies, with estimated gravitational amplifications, μ, of up to 50; CORE will detect thousands of strongly lensed galaxies. Strong lensing offers the opportunity of detailed follow-up studies of high-z galaxies with otherwise unattainable sensitivity: the exposure time to reach a given flux density limit varies as μ^{-2} and, since lensing conserves surface brightness, it stretches the image, thus effectively increasing the angular resolution by a substantial factor (at least in one dimension).

Also *Planck* photometry proved to be crucially important to characterize the synchrotron peak of blazars. Surveys at mm wavelengths are the most effective way to select this class of sources, which, among other things, constitute the overwhelming majority of the identified extragalactic γ–ray sources detected by the Fermi-LAT. Planck data have also provided key information on the energy spectrum of relativistic electrons responsible for the synchrotron emission with interesting implications for their acceleration mechanisms. The larger samples provided by the deeper surveys of a mission like CORE will allow us to make substantial progress on these subjects.



Beyond strongly expanding the samples of source populations detected by *Planck*, CORE will open new windows. In particular, it will provide unbiased, flux limited samples of dense proto-cluster cores of star-forming galaxies. Although *Planck* has already provided a sample of over 2,000 sub-mm selected proto-cluster candidates, the real nature of these objects is difficult to assess and it is quite likely that most of them are actually positive fluctuations in the number of physically unrelated proto-clusters within the *Planck* beam. Again, the problem is related to the limited *Planck* resolution at sub-mm wavelengths: it is about 4′ to 5′ while the characteristic angular size of proto-clusters at z=1-3 indicated by *Herschel* and *Spitzer* ranges from ⁀1ℤ to ⁀0.5ℤ. The above figure shows *Planck* (upper left panel) and *Herschel* (upper right panel) images at 857 and 600GHz, respectively, of a candidate z = 2.3 proto-cluster in the Bootes field of the HerMES survey, compared with the appearance it may take for the diffraction limited beams of CORE with a 1m (CORE100) and 1.5m (CORE150) telescope at 600GHz. The proto-cluster candidate stands out more clearly in the low resolution *Planck* and CORE maps than in the higher resolution *Herschel* map. But *Planck* resolution is not ideal since unrelated objects contribute to the observed signal.



Upper panel: predicted numbers of extragalactic sources detected in polarized flux density as a function of frequency for the two CORE configurations (solid and dashed lines) compared to the numbers of sources detected in polarization by Planck (PCCS2, dotted line). Lower panel: contributions of the different source populations to the counts in polarized flux density as a function of frequency for the CORE150 configuration. The dashed, dot-dashed and dotted lines refer to radio sources ("radio"), proto-spheroidal galaxies ("spheroids") and late-type galaxies "IR LT"), respectively,

Unlike those in total intensity, surveys in polarization are limited by instrumental sensitivity. A spectacular progress in this field is expected thanks to the much higher sensitivity of future CMB missions, like CORE. As illustrated by the above figure, in the "extragalactic zone", *Planck* detected only a few tens of extragalactic objects in polarization, all of them being radio sources, while the CORE sensitivity will allow thousands of detections. The number counts in polarization at several frequencies and the CORE detection limits for different sizes of the telescope are shown in the figure below. The detection limits at these frequencies and the surface densities of sources brighter than such limits are given in the Tables below, for the 1m and 1.5m options for the CORE telescope. Objects detected by CORE in polarization are essentially only radio sources for frequencies up to around 200GHz. The number of detected dusty galaxies increases with increasing frequency. CORE is expected to detect similar numbers of radio sources and of dusty galaxies at 500 GHz. At 600GHz the latter population will dominate, reaching an integral count of 660 sr^{-1} (1 m option) to 2300 sr^{-1} (1.5 m option) for sources detected with $S/N > 4$. Thus CORE can provide the first blind high frequency census of the polarization properties of radio sources and of star-forming galaxies. Note that, at present, the global polarization degree has been measured for only one star-forming galaxy (M82). See De Zotti et al. (2016) for more details.

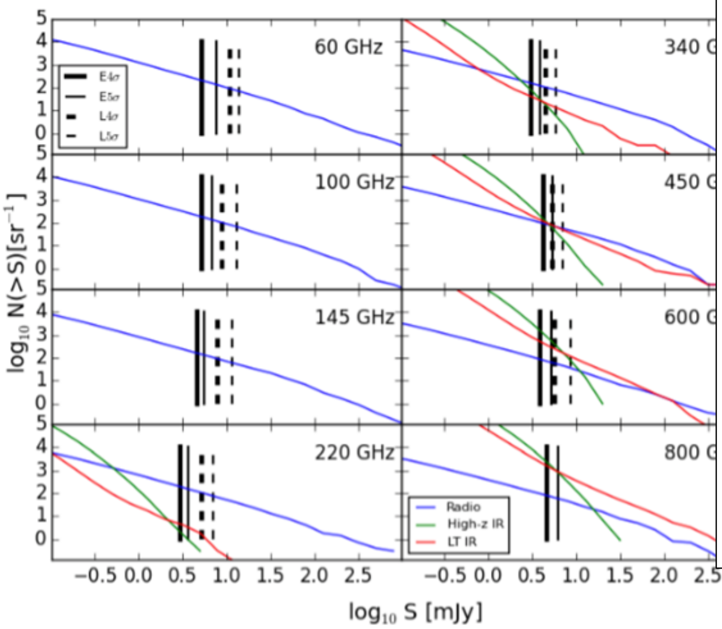


Fig. 4: Estimated source number counts in polarization for a selection of CORE channels and different source populations: radio sources (solid blue line); two populations of dusty galaxies (proto-spheroids and late-type; spiral and starburst, galaxies). Proto-spheroids, labelled "High-z IR" (solid green line) dominate at faint flux densities. Late-types (LT IR, solid red lines) dominate at the brighter flux densities. The vertical lines show the 4σ and 5σ detection limits obtained from the simulations for the 1-m (dashed) telescope 1.5-m (solid) telescope. From de Zotti et al.

Table 4. Estimated detection limits in polarized flux density and surface densities of sources brighter than such limits for the CORE configuration with a 1-m telescope.

			Radio		Proto-sph		Late-type	
Freq. [GHz]	$P_{4\sigma}$ [mJy]	$P_{5\sigma}$ [mJy]	$N_{4\sigma}$ [sr^{-1}]	$N_{5\sigma}$ [sr^{-1}]	$N_{4\sigma}$ [sr^{-1}]	$N_{5\sigma}$ [sr^{-1}]	$N_{4\sigma}$ [sr^{-1}]	$N_{5\sigma}$ [sr^{-1}]
60	11.0	13.9	91	69	...	...	...	...
100	9.0	13.2	99	65	...	...	...	...
145	8.0	11.7	92	61	...	...	...	...
220	5.2	7.0	106	77	0.3	0.1	1.7	1.1
340	4.5	5.8	103	78	17.0	6.1	20.3	13.3
450	5.3	7.0	79	59	62.2	19.6	81.1	49.7
600	5.7	8.7	55	34	403.4	69.7	260.5	116.9

Table 5. Estimated detection limits in polarized flux density and surface densities of sources brighter than such limits for the CORE configuration with a 1.5-m telescope.

			Radio		Proto-sph		Late-type	
Freq. [GHz]	$P_{4\sigma}$ [mJy]	$P_{5\sigma}$ [mJy]	$N_{4\sigma}$ [sr^{-1}]	$N_{5\sigma}$ [sr^{-1}]	$N_{4\sigma}$ [sr^{-1}]	$N_{5\sigma}$ [sr^{-1}]	$N_{4\sigma}$ [sr^{-1}]	$N_{5\sigma}$ [sr^{-1}]
60	5.2	7.7	212	137	...	...	...	...
100	5.2	6.9	184	134	...	...	...	...
145	4.6	5.6	165	134	...	...	...	...
220	3.0	3.7	196	154	2	1	4	3
340	3.1	3.9	156	122	79	32	40	27
450	4.2	5.3	100	78	153	60	123	80
600	3.9	5.2	84	61	1699	596	560	317
800	4.7	6.2	78	58	2215	817	1581	891

Table 2: detection limits in polarization and number of expected sources for a 1m vs 1.5 m telescope. From de Zotti et al., arXiv:1609.07263.

4. Spectral Distortions: goals and overall mission view

A CORE-like mission has been recognized as the most promising project to analyse CMB anisotropy in temperature and, particularly, in polarization in the view of the maximum outcome for B-mode, inflation and parameters. On the other hand, the budget quoted by ESA for CORE exceeds that of a medium-size mission, requiring substantial parternships, likely also for next calls, or a large-size mission. Similar projects (led by e.g. S. Hanany) are on-going in the context of NASA mission studies, while a less ambitiuos mission like LiteBIRD is approaching the end of JAXA phase-A.

As anticipated in Sect. 2, a spectrum oriented mission can fill a crucial gap in CMB cosmology. Such a mission does not require extreme sensitivity, nor polarization, but a clear improvement in absolute calibration or, at least, in frequency relative cross-calibration for differential approaches (see Sect. 3.3). Note that the Comptonization-like signal expected by cosmological reionization in realistic astrophysical scenarios does not require a NASA PIXIE-like sensitivity, but only an improvement of a factor 10-50 with respect to FIRAS, that would be able to set also stronger contraints (or, possibly, to detect) early-type distortions. Various types of astrophysical and physical processes can be studied through spectral distortions. Absolute and differential methods could be jointly adopted. Long wavelengths are important for both early (Bose-Einstein like) and late (free-free) distortions: sinergies with ground-based and radio (e.g. SKA) projects are crucial in this spectral domain, and, in general, for a better understanding of foreground signals. (TBC)

5. PERSPECTIVES FOR A CMB SPECTRUM ORIENTED MISSION

A CORE-like mission has been recognized as the most promising project to analyse CMB anisotropy in temperature and, particularly, in polarization in the view of the maximum outcome for B-mode, inflation and parameters. On the other hand, the budget quoted by ESA for CORE exceeds that of a medium-size mission, requiring substantial parternships, likely also for next calls, or a large-size mission. Similar projects (leaded by e.g. S. Hanany) are on-going in the context of NASA mission studies, while a less ambitiuos mission like LiteBIRD is approaching the end of JAXA phase-A.

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6. PEOPLE INVOLVED

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