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BISOU: A balloon project for spectral observations of the early Universe.

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ABSTRACT

The BISOU (Balloon Interferometer for Spectral Observations of the Universe) project studies the viability and prospects of a balloon-borne spectrometer, pathfinder of a future space mission dedicated to the measurements of the CMB spectral distortions, while consolidating the instrumental concept and improving the readiness of some of its key sub-systems. A balloon concept based on a Fourier Transform Spectrometer, covering a spectral range from about 90 GHz to 2 THz, adapted from previous mission proposals such as PIXIE and FOSSIL, is being studied and modelled. Taking into account the requirements and conditions of balloon flights (i.e. residual atmosphere, observation strategy for instance), we present here the instrument concept together with the results

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of the CNES phase 0 study, evaluating the sensitivity to some of its potential observables. For instance, we forecast a detection of the CMB Compton y-distortion monopole with a signal-to-noise ratio of at least 5.

Keywords: Balloon, Cosmic Microwave Background, CMB Spectral distortions, Cosmic Infrared Background

1. INTRODUCTION

With the success of the ESA Planck mission, the concordance cosmological model is established as the reference framework. However, outstanding questions about this model are still unanswered. In particular the simplest inflationary model proposed as the origin of the initial matter perturbations is favoured by Planck measurement of the spectral index and low non-Gaussianity. Nevertheless, it still needs to be confirmed through the measurement of its smoking gun signature: the relic background of primordial gravitational waves. The latter can only be observed through the Cosmic Microwave Background (CMB) polarisation: namely B-modes, for which several dedicated instruments have been or are being developed, with notably the future space mission LiteBIRD.[1] The CMB frequency spectrum is another key observable to probe the cosmological model. Its intensity was precisely measured by COBE/FIRAS almost three decades ago,[2,3] with deviations limited to $\Delta I/I \approx 10^{-5}$. Since then, not much progress has been achieved in measuring its deviation from a true blackbody. However, while the space mission proposals PIXIE[4,5] (NASA), PRISTINE (to ESA F1 mission call) and FOSSIL (to ESA M7-mission call) have not been successful, following two white papers,[6,7] the ESA Voyage 2050 programme has selected this topic amongst its three upmost priority themes.

The BISOU (Balloon Interferometer for Spectral Observations of the Universe) project aims to study the viability and prospects of a balloon-borne spectrometer, pathfinder of a future space mission dedicated to the absolute measurement of the CMB spectrum. While PIXIE and PRISTINE were targeting both the measurement of the CMB polarisation, namely a first detection of the CMB B-mode polarisation, and the absolute measurement of the CMB spectral distortions, BISOU's main goal is to perform a first measurement of the later. However, secondary science will also include a better measurement of the Cosmic Infrared Background (CIB) emission, a better determination of the CMB average temperature, together with Galactic emission lines such as CI, CII, NII and OI. In a second phase, BISOU could also measure the polarisation of the dust up to 2 THz (see Sec. 3).

Taking into account the specificity of a balloon flight in term of requirements and conditions (i.e. residual atmosphere, observation strategy for instance), this CNES Phase 0 study evaluates if such a spectrometer is sensitive enough to measure at least the Compton y-distortion while consolidating the instrument concept and improving the readiness of some of its key sub-systems.

2. SCIENCE GOALS

While the CMB has a nearly perfect blackbody emission spectrum, deviations from it, referred to as spectral distortions, are expected. These distortions encode information about the full thermal history of the Universe from the early stages (primordial distortions from inflation and cosmological recombination lines) until today (star formation and galaxy clusters). Many of these processes are part of our standard cosmological model and are detailed in several publications[6,8] .

Spectral distortions result from processes that affect the thermal equilibrium between matter and radiation. One of the standard distortions, known as the Compton y-distortion, is created in the regime of inefficient energy transfer (optically thin scattering) between electrons and photons, relevant at redshifts $z < 5 \times 10^4$. Processes creating this type of distortion are dominated by the inverse-Compton scattering of CMB photons off hot electrons during the epoch of reionization and structure formation, also known as the thermal Sunyaev-Zeldovich (tSZ) effect.

Chemical potential or μ-type distortions, on the other hand, are generated by energy release at earlier stages ($z > 5 \times 10^4$), when interactions are still extremely efficient (optically thick scattering) and able to establish kinetic equilibrium between electrons and photons under repeated Compton scattering and photon emission processes.

The COBE-FIRAS limit, $|\mathrm{y}| < 1.5 \times 10^{-5}$ (95% C.L.), is roughly one order of magnitude larger than the expected signal,[9] $\mathrm{y} \approx 2 \times 10^{-6}$. Signal from μ-type distortions will be even fainter. It is therefore crucial to have

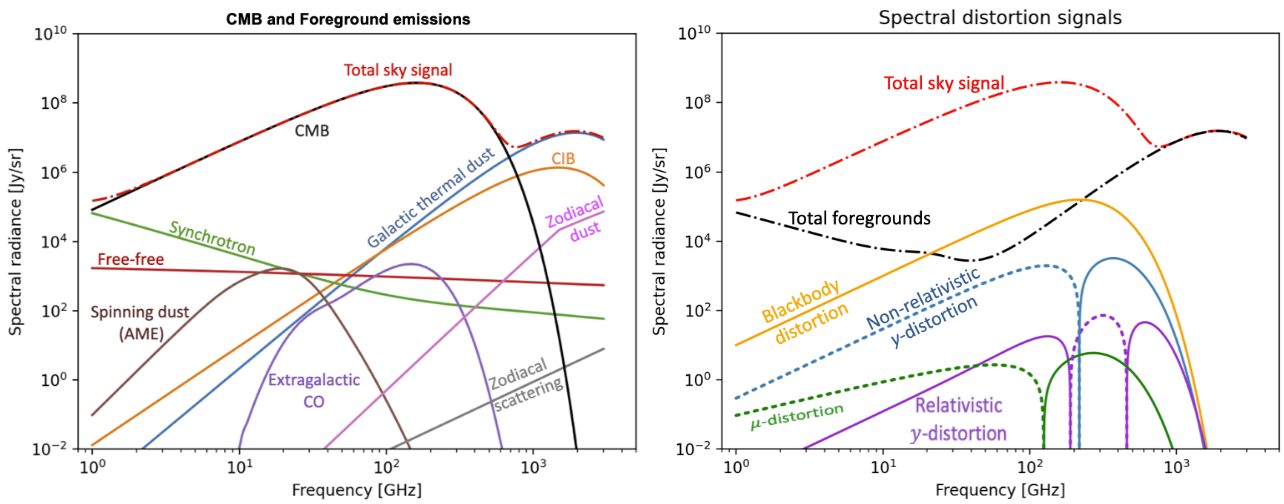

Figure 1. (a) Right: CMB and Foreground emission contributions, together with the sum of all astrophysical signals. (b) Left: Models of the spectral distortions. Black body distortion ΔT_{CMB} (orange), non-relativistic y-distortion (blue), relativistic y-distortion (purple) and μ-distortion (green). This is compared to the total foreground signal (dashed black) and the total sky signal - Foregrounds + CMB (dashed red).

reliable models of all the emissions that will be much stronger than these signals in order to properly subtract them.

2.1 Modeling the signals

Several astrophysical foregrounds contribute meaningfully to the sky signal at frequencies relevant to CMB spectral distortions. In addition to the ones already modeled[8] from Planck data[10] , additional components from the zodiacal dust have been included[11] . Figure 1a shows the individual contributions together with the sum of all sky signals, including the CMB. At low frequencies (below 70 GHz), the brightest foregrounds are from the synchrotron, the free-free and the so-called anomalous microwave emissions. High frequencies foregrounds (above 100 GHz) are mainly due to the emission of the Galactic thermal dust, the cumulative redshifted emission from thermal dust in distant galaxies, called the cosmic infrared background (CIB), and the zodiacal thermal dust emission. Additional foregrounds contributing to the total sky signal are the cumulative CO emission from distant galaxies at intermediate frequencies and the zodiacal scattering at high frequencies.

2.2 CMB spectral distortions modeling

Following the same assumptions and processes as the ones presented in Abitbol et al.[8] , our model[11] led to Fig. 1b showing the signals associated with the various distortions of the spectrum, with respect to the total emission of the foregrounds and the total sky signal (including the CMB emission).

Four contributions are considered and modeled. First a blackbody distortion that represents a first order temperature deviation ΔT_{CMB} to the true CMB blackbody spectrum. Then a cumulative thermal SZ y-distortion, including both standard non-relativistic and relativistic contributions (from Hill et al.[9]). The intracluster medium (ICM), the intergalactic medium and reionization contributions are included in the Compton-y signal. A relativistic correction to thermal SZ distortion[9,8] is modeled using the moment-based approach. Finally the chemical potential μ-distortion is generated assuming only signals from acoustic damping and adiabatic cooling. The r-type distortion, sometimes called "residual" distortion, is expected to have a contribution smaller than the μ-type distortion and is not represented in Fig. 1b.

3. INSTRUMENT CONCEPT

The starting point is based on the concept that had been proposed by the PIXIE team[4] (shown in Fig. 2 left) which then evolved[5] and has also been used for the PRISTINE F-class ESA mission proposal and then further

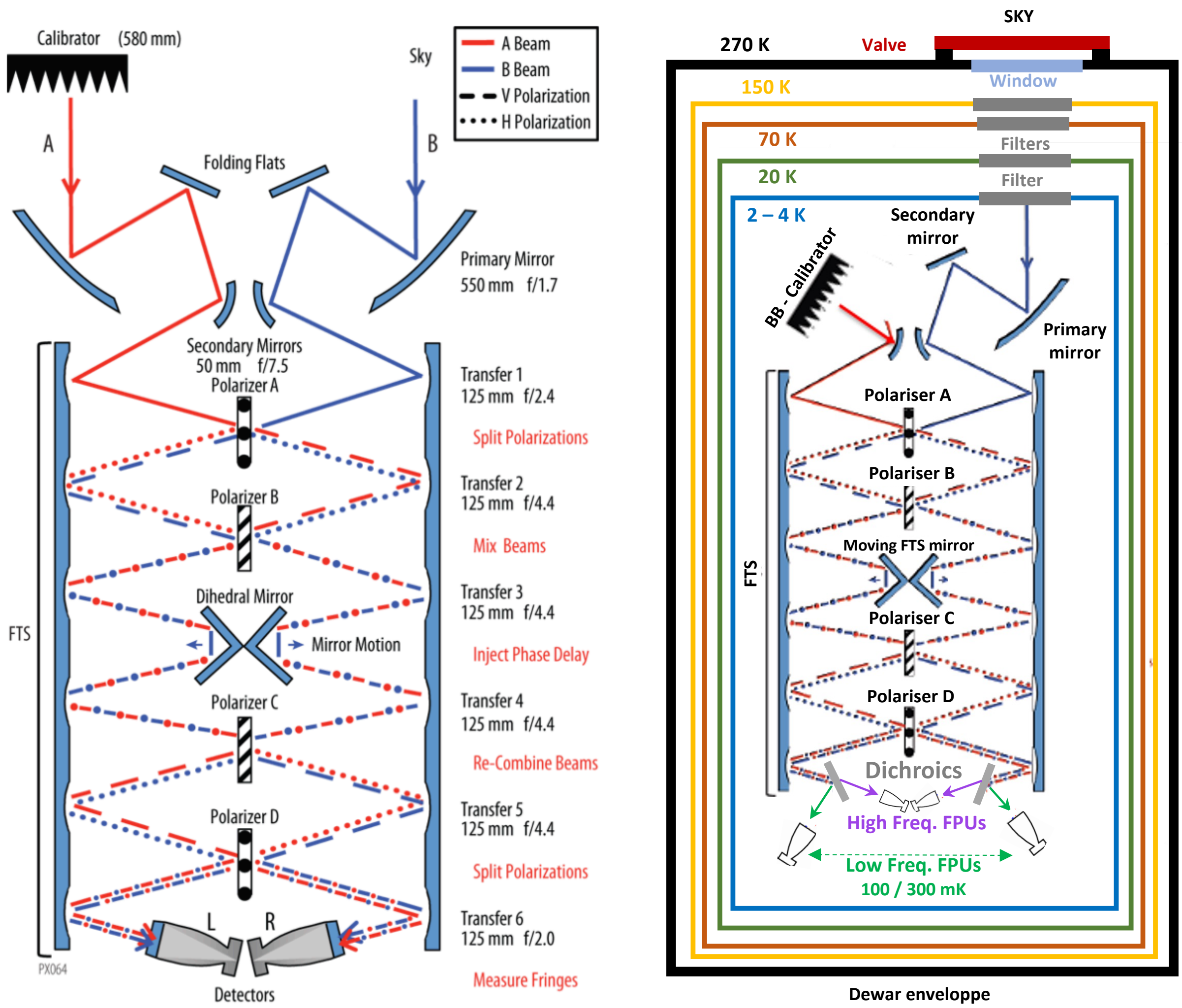

Figure 2. (a) Left: Original instrument concept from the PIXIE space mission proposal[4] . (b) Right: BISOU instrument concept adapted for a balloon platform.

modified for the M7 proposal FOSSIL. The instrument is based on a Fourier Transform Spectrometer (FTS) with two inputs and two outputs. Both inputs are going through a separate telescope, both sets of optics being identical in order to minimise the systematics. Because PIXIE has several observation modes, an external calibrator (cooled blackbody) could be located in front of one of the apertures at any one time.

In the “spectral distortion” mode, for which the absolute spectrum needs to be measured, one input is directed towards the sky, the second towards the blackbody calibrator whose temperature is set to the CMB one, 2.726 K. After going through a set of polarisers, each of the two outputs is focused on a dual-polarisation multimoded bolometric detector (L and R on Fig. 2a). Each of the four detectors measures an interference fringe pattern between orthogonal linear polarisations from the two input beams. Therefore the variable part of the interferogram signal will be the difference between the signal from the sky and the one from the calibrator at 2.726 K[4,5] thus a differential measurement.

In order to limit the photon noise, the whole instrument is cooled to about 3 K, the detectors being at sub-K temperature.

3.1 Balloon specificity

The previous studies for the instrument concept were performed on the basis of a space mission. For the case of a balloon project, the conditions, the requirements and therefore the instrument concept will be different. Stratospheric balloon projects might be considered to be in near-space conditions, but there are still many differences, some of these being the potential flight time, access to the sky, thermal environment, etc...

A few will have strong impacts on the payload concept. First the residual atmosphere at an altitude of about 40 km will be at a pressure of about 3 mbar with a temperature of the order of 250-270 K. This will not only lead to an additional photon noise contribution, but also to the necessity of hosting the overall instrument inside a dewar in order to maintain it under vacuum and at a temperature of about 2 to 4 K depending on the outside pressure when using liquid helium. Even with a small pressure difference, the dewar will then need to have a window through which the telescope will point towards the sky (see Fig. 2 right). The outside dewar shell being at ambient temperature, intermediate thermal stages will be necessary with thermal filters in order to limit the thermal background load and potential straylight.

This is also preventing the calibrator to be outside the dewar and will then have to be located inside in order to keep it at a very steady temperature of about 2.7 K.

The balloon being located above the gondola, the payload will not be able to point at the zenith. Avoiding emissions from the ground or from the Sun has a direct impact on the observation strategy. We will have to limit the elevation span to 20 - 40 deg with respect to the zenith and have the line of sight direction opposite to the Sun location.

3.1.1 Gondola

Assuming that the balloon flight will be provided by CNES, our study is based on the use of the CARMEN gondola[12,13] design (Fig. 3a) that has been used lately for the PILOT balloon project[14] for instance, allowing for a maximum mass of 1750 kg, 610 kg being dedicated to the payload and associated equipment (including the supply of power for the payload - batteries and/or solar panels). The maximum footprint allocated for the payload in this gondola is 0.9 m×1.8 m as it is shown in Fig. 3. The **payload** will need to include our science **instrument**, the elevation mechanism, the start tracker for the attitude control and reconstruction.

While CNES has so far flown these types of payload for a typical 35-hour flight duration, it is planned that a first 5-day test-flight between Kiruna (north of Sweden) and Canada will happen in 2024. We will therefore base our sensitivity calculations on the assumption that this type of flight will be available in the future.

3.2 The instrument

New highly sensitive technologies able to perform spectroscopy in the millimetre / sub-mm regime are being developed (such as spectroscopy on a chip with bolometric detectors[15,16]). They might well be technologies that will be used for a distant space mission, but due to their present lack of maturity, the obvious choice for a broad spectral range spectrometer is a FTS, which has also the benefit for its spectral resolution and frequency coverage to be optimised even during the flight if necessary. Its major drawback is that for a null path difference the entire spectrum of the signal of interest, but also of any other emissions (foregrounds, instrument, etc..) are reaching the detectors, therefore leading to a large photon noise. Thus any instrument emission will have to be limited (Sec. 4.1) by either decreasing the temperature or/and the emissivity. BISOU instrument concept is shown in Fig. 2b.

3.2.1 Preliminary choices

The main science goal of BISOU is to perform the first detection of the Compton y-parameter distortion. With respect to a space mission that might even aim at detecting the μ-parameter, BISOU sensitivity will be lower and the requirements for systematics control somehow relaxed. Therefore, due to mass and dimension constrains, knowing that the whole instrument has to be kept cold, as well as limiting the risks and complexity:

- Only one set of telescope aiming at the sky will be used, the second FTS input looking at a fixed Black Body calibrator. Unlike PIXIE which could alternate the position of the calibrator over either telescope in order to cancel any asymmetry between both optical systems, for BISOU, the systematics arising from this asymmetry will have to be carefully studied, traded off by a thorough ground calibration campaign, the inclusion of a calibration source and a highly accurate monitoring of the temperature of the optical components;
- The lowest frequency driving the size of the optics, we converged towards a minimum frequency of 90 GHz;
- The study started with a telescope primary diameter of 40 cm but could be reduced to 30 cm as the spatial resolution is not a driver for the targeted science;
- A fixed spectral resolution of 15 GHz across the frequency range is sufficient.

3.2.2 Residual Atmosphere

A 3 mbar residual atmosphere at 40 km altitude will still create a large photon noise contribution with respect to the extremely faint signal that we are trying to observe. For instance, atmospheric effects at ground level and even at balloon altitudes are shown in Masi et al.[17] with respect to spectral distortion signals. The signal level due to the atmosphere is 2 to 3 orders of magnitude higher that the non-relativistic y-distortion signal depending on the frequency. In theory, assuming a perfectly reliable model, this contribution could be removed.

More important, will be the variations of the atmosphere with altitude, observation elevation and time. This cannot be modelled and will therefore need a way to modulate/monitor the atmosphere at a high enough frequency to be compatible with the variation timescale. Such a modulator is already used for COSMO[17] . However this would be too big and heavy for BISOU. Therefore another type of modulator, such as a cold internal beam stirrer is being considered. On the other hand, this emission being larger at higher frequency, a study is being conducted in order to assess how the high frequency detector array could allow the atmosphere emission subtraction.

For the time being, at that stage of the study, the atmosphere is not yet considered in our sensitivity and systematic effects calculations.

3.2.3 Optics

The optical system (telescope, FTS and feedhorn) is being modeled[18] with Zemax and GRASP. This system is multi-moded from the lowest frequency (about 10 modes), the number of modes increasing with frequency and therefore keeping a beam width almost constant across the whole spectrum. With a 40 cm diameter primary telescope, the equivalent FWHM is of the order of 1.5 deg. The size of the optics dictating the overall dimensions of the payload, a schematic view of what could look like the instrument is shown in Fig. 3b.

3.2.4 Dewar and cooling chain

Models are showing that even the telescope will need to be cold. Therefore the whole instrument needs to be cooled to about 3 K, where the detectors only will be cooled to a sub-K temperature.

Due to mass and power limitations, mechanical coolers for balloon platforms are not yet mature enough, even if some developments are being investigated, most notably by NASA. We chose a proven cooling solution using liquid helium to cool the overall instrument, between 4 and 2 K depending on the bath pressure, using the natural low pressure at high altitude. Several intermediate thermal stages and shields cooled with the helium vapour retrieved from the bath will allow for heat load reduction on the 3 K stage. Typical intermediate temperature stages are 150 K, 70 K and 20 K, where spectral filters will be located at the optical input of each shield to decrease the photon load on the detectors and avoid out-of-band spectral leakages.

With the help of an instrument model being developed[11] , and assuming some initial parameters such as telescope diameter, flight duration and observation efficiency, or again spectral resolution, calculations presented in Sec. 4 are showing that the sensitivity is strongly dependant on three key parameters: the temperature and emissivity of the window, and the maximum frequency of observation as the photon noise is increasing with frequency. The implications of these issues will be discussed in the following sections. However, we see straight

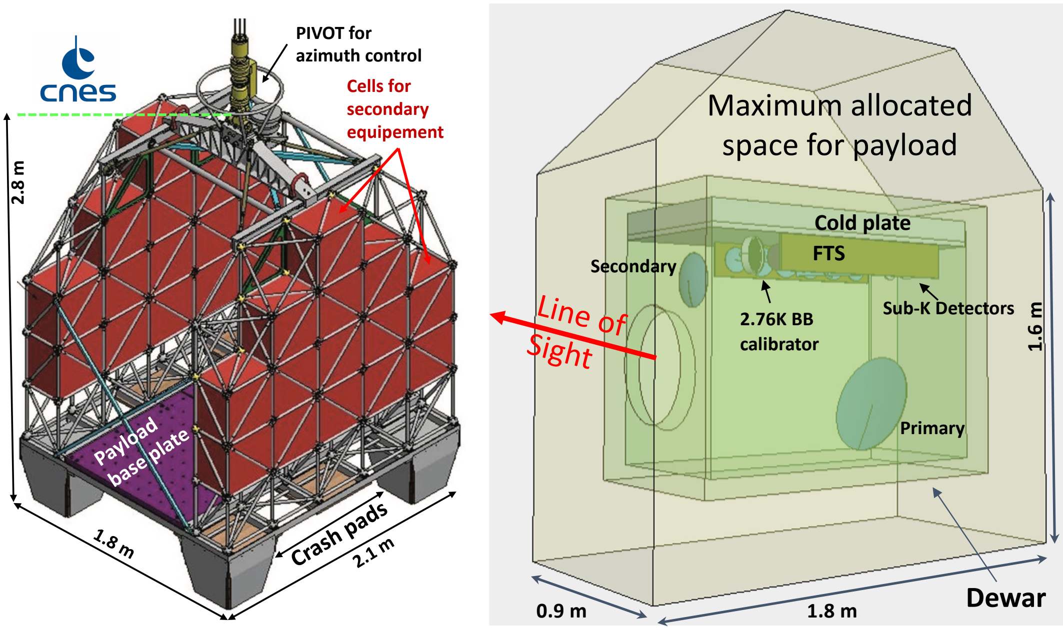

Figure 3. (a) Left: CARMEN gondola from CNES[4] . (b) Right: BISOU preliminary instrument scheme.

away that the dewar window, the warmest optical element, needs to have a very low emissivity and a stable temperature, therefore be as thin as possible to minimise the systematics.

In order to use a very thin window, a valve at the entrance of the dewar, opening only when the pressure difference is small (at a certain altitude), could be used. Such a technique was used for the Archeops[19] balloon project for instance.

The emissivity of the window could be reduced by the application of a copper/gold grid as was done on the ArTéMiS[20] ground based camera. While the dewar will be at a temperature ranging from 300 to 270 K, the window could have a mount thermally isolated from the structure and actively cooled with the vapour coming from the helium bath. Such a development will be studied with a dedicated R&D programme. This should bring the window temperature below 200 K. However, that being said, we will see below that by splitting the detection over two sub-bands (low and high frequencies) using a dichroic, makes this option less necessary and therefore attractive taking into account the risks and complications associated to cooling actively the window.

Depending of the operating temperature of the detectors (see afterwards) two sub-K technologies could be considered. Above 260 mK typically, a ^{3}He sorption cooler is a very mature technology, having been used by several balloon projects (PRONAOS, BOOMERanG, PILOT). If even cooler temperatures are required, ADR technology being most probably incompatible (mass, current/power necessary), a ^{4}He-^{3}He dilution refrigerator would seem most suited. While such a system has been already used on Archeops,[19] a new closed-cycle version is being developed for space applications[21] .

3.2.5 Focal planes and detectors

Our instrument model seems to show that splitting the focal planes in two spectral bands with a frequency split around 500 GHz, using a dichroic would improve dramatically the sensitivity of our instrument. We would therefore have four focal planes (Fig. 2b), two at each output of the FTS, one for the low frequencies (90 - 500 GHz), one for the high frequencies (500 GHz - ν_{max}). The maximum frequency ν_{max} still needs to be optimised using our model for the scientific parameters retrieval from the observations (Sec. 4).

Depending on the assumptions and instrument parameters, our photometric model shows that a detector NEP of the order of a few 10^{-15} W Hz$^{-1/2}$ is enough to be photon noise limited. Therefore various detector technologies could be available. On the one hand, resistive detectors developed by NASA-GSFC for PIXIE could be adapted and optimised for BISOU. On the other hand, BISOU could also serve as a pathfinder for new technologies such as Kinetic Inductance Detectors (KIDs) with high potential or even Thermal KIDs (TKIDs). Each of these technologies would be best optimised for different frequency ranges, and would require further development within the time frame of BISOU, but the use of two different spectral bands could allow for a mix of technologies.

The detectors will be coupled to the optics through the use of multi-moded feedhorns defining the beam shape and allowing for a control of straylight without the use of a cold stop. The instrument sensitivity has been computed assuming the use of only one detector. However the focal planes will contain several pixels (trade off under study still) in order to improve the sensitivity and the redundancy. The advantage of having two bands will allow us to increase the number of the smaller high frequency detectors, therefore giving us an information of the atmosphere emission variation across a larger field of view.

The selection of the detector technology will also drive the operating temperature (and therefore the choice of sub-K cooler technology) and the polarisation properties of the instrument. Dual polarisation KIDs being at very low TRL, the rest of the instrument being the same, we will proceed with a step approach. Indeed, the main science goal not relying on the measurement of the polarisation, depending on the technology choice, we might have a first flight with the spectral intensity measurement of the sky only to move towards polarisation measurement of the dust emission mainly at a later stage (other flights).

4. PRELIMINARY SENSITIVITY ESTIMATES

4.1 Photometric model

Based on previous models, a preliminary photometric model[11] has been adapted and developed for BISOU. It did confirm that the sensitivity will be highly dependant on some parameters such as:

- The emissivity and temperature of the optical components, and mainly the warmest being the dewar window;
- The maximum observable frequency ν_{max};
- The number of modes that are allowed to go through the optics and therefore the throughput;

As a starting point, we took into account only the dewar window (the warmest element in the optical path) and a minimum of two spectral filters on the lowest temperature stages (supposed to be at 20 and 3 K and with a top-hat transmission profile) for the optical input. The emission of all the components in the optical path is modeled as blackbody emission (at the temperature of the component) multiplied by the emissivity of that component at the specified temperature. The load on the detector is estimated by adding the power contributions of the optical components as well as the contribution from the sky, using for each:

$$P(\nu, T) = \int_{\nu_{min}}^{\nu_{max}} eff(\nu) A\Omega(\nu) \epsilon(\nu, T) B(\nu, T) d\nu$$

where $A\Omega$ is the throughput of the multi-moded optics, eff the transmission/efficiency of the optical system, B the blackbody function, and for this first version of our model, the emissivity ϵ is taken as a constant for each component.

We integrate the power received by the detector over the full range of frequencies. In order to assume the worst case scenario for the detector load, when the optical path difference of the Fourier Transform Spectrometer is null, the power is integrated over the full frequency range that we will observe.

The total Noise Equivalent Power (NEP$_{total}$) is then calculated by adding in quadrature the photon NEP from the signal arriving on the detector and the detector NEP which is assumed to be about four times lower than the photon NEP. For the time being, we assume that the other contributions to the total NEP are small in comparison to the photon one. Depending on the assumptions made, for the temperature and emissivity of the optical components for instance, NEP_{total} is of the order of a few 10^{-16} W $Hz^{-1/2}$ for a space mission to about 10^{-14} W $Hz^{-1/2}$ for a balloon configuration.

From classic calculations[4] , the detected noise for a fixed integration time τ is given by:

$$\delta P = \frac{NEP_{total}}{\sqrt{\tau/2}}$$

where τ is taken to be 90 hours, corresponding to a flight duration of 5 days with 75% observation efficiency. From this, the noise at the detector may in turn be referred to the specific intensity, leading to an equivalent instrumental sensitivity that can be compared to spectral emissions.

4.2 Forecasting method

This forecasting method uses a sky emission model and a sensitivity estimate previously detailed, to predict the Signal-to-Noise ratio (S/N) of the sky model parameters. Fisher formalism is used to determine the parameter uncertainties (S/N) assuming Gaussian posteriors, allowing for the exploration of the effects when modifying the instrument concept. The Fisher information matrix is calculated as:

$$F_{ij} = \sum_{a,b} \frac{\partial(\Delta I_\nu)_a}{\partial\theta_i} C_{ab}^{-1} \frac{\partial(\Delta I_\nu)_b}{\partial\theta_j}$$

where the sum is computed over the frequency bins, C_{ab} is the BISOU noise covariance matrix, which is assumed to be diagonal, θ_i the i^{th} sky model parameter , and ΔI_ν the sky-averaged spectral radiance relative to the assumed CMB blackbody.

4.3 Results

Results on four instrument configurations are presented in Fig. 4 in order to assess the sensitivity evolution following the values of some key instrument parameters.

A parameter which is crucial, is the maximum observation frequency ν_{max}. The photon contributions being higher with increasing frequency, the overall sensitivity will decrease with increasing ν_{max}. On the other hand, in order to retrieve the "easy" science goals, such as the y-parameter spectral distortions, ΔT_{CMB} and T_{CIB} for the measurement of the Cosmic Infrared Background, observations have to go towards high frequencies. Therefore a trade-off needs to be reached in order to optimise the S/N for each parameter. Previous results from this model[11] have shown that the sensitivity would be optimised for $1200 \leq \nu_{max} \leq 2000$ GHz, depending in the instrument assumptions.

For all these configurations we assume:

- FTS spectral resolution $\Delta\nu = 15$ GHz across the whole spectral range;
- Lowest frequency ν_{min}=90 GHz;
- Highest frequency ν_{min}=2000 GHz;
- Filters on the different temperature stages have an emissivity of 0.1%;
- Calculations are performed assuming only one detector.

The emission of the atmosphere, and therefore its removal, are not taken into account. Only the astrophysical and instrument signals are.

The four cases are:

- Case 1: this represent the best case scenario for which the temperature of the window would be 180 K, its emissivity $\epsilon = 3 \times 10^{-4}$, and two spectral bands separated by a dichroic with a split frequency at 500 GHz;

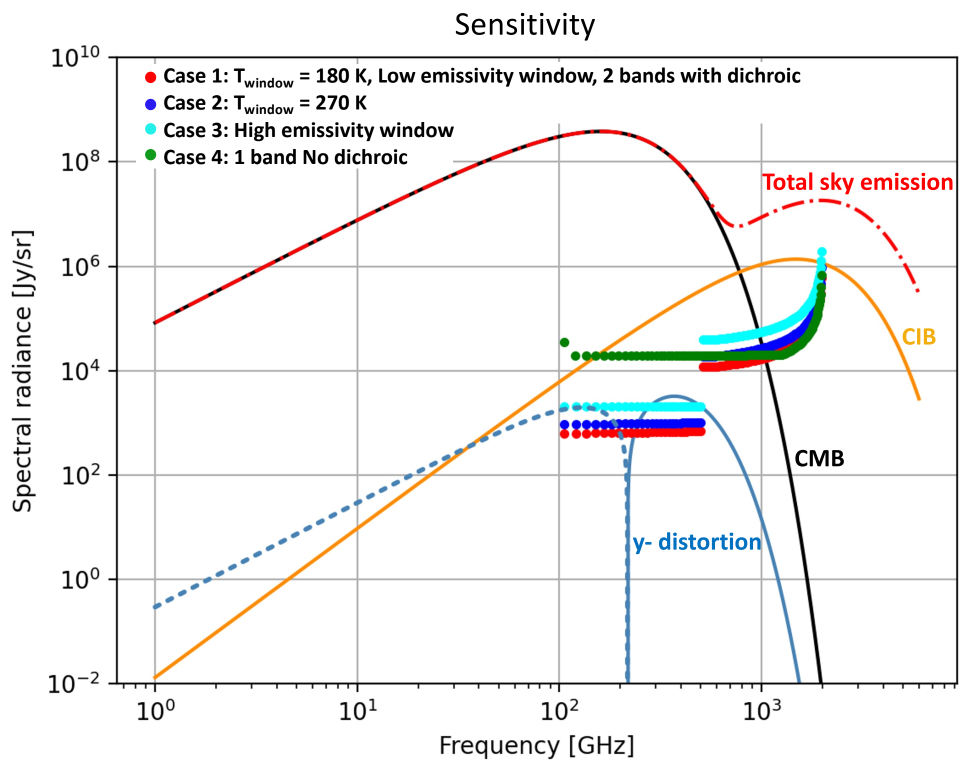

Figure 4. Estimated instrument sensitivity for different instrument configurations (cases), compared to astrophysical signals of interest for BISOU. All calculations are assuming a 5-day flight assuming only one detector.

	Δ T_{CMB}	Compton y-parameter	A_{CIB}
S/N ratio (σ)	428	5.6	2.8
Improvement factor vs COBE-FIRAS	1070	24	N/A

Table 1. Sensitivities to the three main parameters targeted by BISOU. Δ T_{CMB}, the y-parameter and A_{CIB}. These are for the best case 1 scenario. Sensitivity quoted in S/N ratio and in improvement versus COBE-FIRAS determination.

- Case 2: the difference with case 1 is that the temperature of the window is at 270 K;
- Case 3: the difference with case 1 is that the emissivity of the window is $\epsilon = 10^{-3}$;
- Case 4: the difference with case 1 is there are no dichroic, thus only one band detecting the full power.

Figure 4 shows clearly that a major increase of sensitivity can be reached by splitting the full spectral band over 2 sub-bands. The split frequency still needs tweaking, but 500 GHz is a good starting point. Then the window emissivity and temperature have a relatively lesser effect. We can see that if the window emissivity can be as low as 0.03%, something we hope could be reached from prior measurements, the temperature of the window will then have a small effect. A R&D programme due to start by autumn 2022 should answer these questions.

From Tab. 1, not taking into account the atmosphere, and **assuming only one detector**, we see that **S/N ratios of 5.6 for the y-distortion monopole, about 430 for ΔT_{CMB}, the error in T_{CMB} determination, and about 3 for A_{CIB}, the amplitude of the CIB monopole**, could be reached.

5. ON-GOING AND FUTURE WORK

Aside from more detailed model of the instrument and sensitivity calculations, several points need to be addressed, some by the end of the Phase 0 study, some during a potential Phase A follow up.

5.1 Observation strategy and flights

The effect of various observation strategies have started to be implemented as these will have a direct impact on the mission concept. The major decision which had to be made was on the type of scanning in order to optimise for the main science goals: spinning the payload for a partial survey of the sky (25 to 30 % typically) or a raster scan on some pre-determined zones. Taking into account that the Sun has to remain as far as possible from the line of sight for a flight during daylight, observation time being equal, a raster scan strategy leads to an improved sensitivity on the parameters determination. We will therefore identify at least two patches of the sky to focus our observations. One patch where the foregrounds are minimal, another one where the foregrounds are high, mainly with dust contamination, so that the foregrounds contaminations can be properly subtracted.

5.2 Atmosphere subtraction

The next important hurdle to cross is understanding how to deal with the atmosphere. More accurate models, expertise and data for high altitude are being gathered within the consortium but this work will go over the timescale of this phase 0 study. Therefore an active subtraction method seems inevitable and will need to be implemented. Concept work and the study of the associated effects have started.

5.3 Calibration and systematics

Unlike imager projects aiming at measuring B-mode polarisation of the CMB that have been studied for many years, systematics of a spectrometer for spectral distortions detection, mainly from a balloon platform, are not well-known. In parallel to any detailed systematic effect study that will be started if this project is selected, it is clear that a thorough ground-calibration, together with the implementation of an in-flight calibration strategy (additional source that could be included in the optical path) need to be considered.

With respect to this, major advantages of a balloon project are (1) that we can perform a ground calibration in nearly-operationnal conditions (closer than for a space mission), (2) providing that the payload is recovered in good conditions after the first flight, optimisation / upgrade can be implemented for following flights if necessary.

6. CONCLUSION

So far, assuming that the atmospheric problem can be solved, it seems that according to our preliminary estimates, such a balloon borne instrument will be able to have valid scientific outputs, and not be limited to a technological demonstrator for future space missions. Namely, a measurement of the CIB, a better constraint on ΔT_{CMB}, and more importantly a first 5-σ measurement of the y-distortion monopole, if not better.

If these results are confirmed by the end of Phase 0, a proposal will be submitted to start a more detailed one-year Phase A study by spring 2023. By then, assuming that the project pass a final selection, an optimistic schedule could be:

- 2 years of development and sub-system tests $\longrightarrow$ spring 2026
- one year of integration, validation and calibration $\longrightarrow$ spring 2027
- First test (short) flight from Kiruna in summer 2027
- First long science flight - Intensity only - (5 days) Kiruna - Canada in summer 2028.
- Second long flight - Polarisation / or Southern hemisphere flight if necessary - TBD - summer 2029.

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