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1 Summary

This is a proposal to formulate a program of technology and instrument development for a future definition of a Beyond Einstein Inflation Probe using the polarization of the cosmic microwave background anisotropy signal (CMBPol).

Inflation explains the apparent flatness of the universe, the small amplitude of CMB anisotropy on large scales, and provides a natural explanation for the seeds of structure. The CMB polarization anisotropy has imprinted on it a signal predicted to be sourced by these same inflationary era seed fluctuations. This signal is one of the few direct observational handles on the physics of inflation.

Detection of inflation with CMB polarization is difficult because 1) The signal is at most 100 nanoKelvin so high sensitivity is needed. 2) Other polarization and temperature anisotropy is many times bigger. Current instruments do not have the required level of rejection. 3) Astrophysical and local foregrounds are large and their properties are poorly known making rejection difficult.

It is not known what is needed to make a definitive, high signal-to-noise B-mode measurement. The proposed work will develop a plan to implement the program called for in the "Task Force on Cosmic Microwave Background Research" report. We will summarize systematics mitigation and foreground rejection methods in current experiments. We will develop estimates for the cost of two template missions and the cost and schedule of maturing promising detector and optics technologies. We will summarize today's scan strategies, foreground models and rejection methods, and identify the most promising directions for further advances. We will summarize the theoretical underpinnings, the lensing signal and other sceondary anisotropy. We will show the richness of the ancillary science that would result from a CMBPol mission. The resulting report will be delivered to NASA and the Decadal Survey of the National Research Council.

2 Science Justification

The past three decades have seen several revolutions in our thinking about how the Universe evolved. Inflation, Dark Matter, Dark Energy are concepts which did not exist 30 years ago and each is a major upheaval in our thinking. Yet out of those decades, a robust, quantitative model for the early evolution of the Universe has emerged.

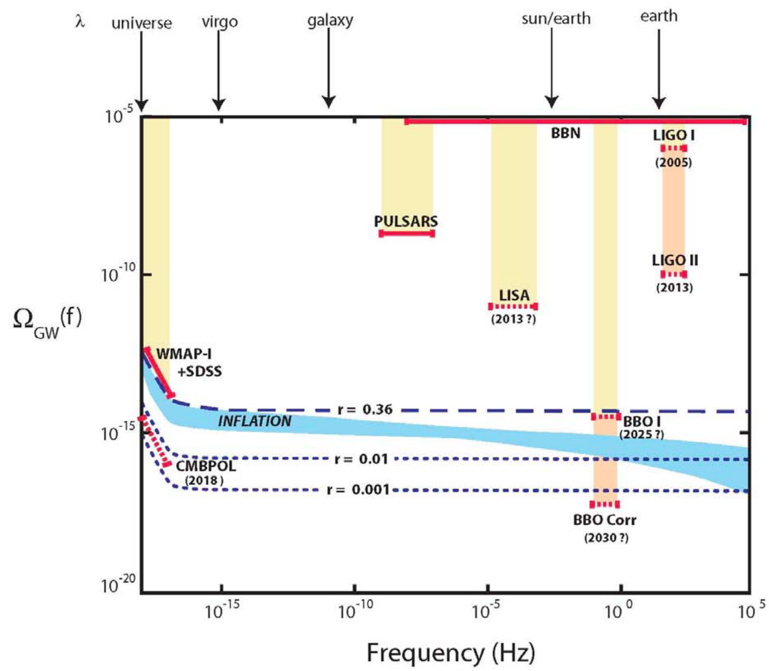

Figure 1: The plot shows the expected amplitude of gravitational waves as a function of frequency for several values r, the tensor-to-scalar ratio. WMAP constrains $r < 0.36$. The CMBPol mission sensitivity is for the Weiss Report sensitivity of 10 times more sensitive than the Planck mission. Also shown are the sensitivities of other measurements and their expected completion data. Only the Big Bang Observer, a distant future direct gravitational wave detector, has the sensitivity to see primordial gravity waves at the same level as the CMBPol mission. (Figure taken from the Weiss Report)

A remarkable interplay between new, ever more sensitive measurements, and an evolving theoretical understanding of their consequences has left us with a picture of an expanding Universe, its dynamics driven by forms of matter and energy which we have yet to discover directly, and large-scale structure thought to be the consequence the of gravitational collapse from initial seeds formed during an inflationary period. The period of inflation is one of exponential expansion with a constant density during which the size of the Universe grew by many orders of magnitude and left us with the matter, energy and expansion we see today.

Inflation itself is the first of these revolutions in thinking and is an extremely attractive model of what happened in the earliest times because it explains so much of what we see.

- Inflation solves the "flatness problem." Space grows more flat during inflation and less flat afterwards, so that without inflation, generic initial conditions would predict curvature growing over time and the density rapidly approaching either zero or infinity. The universe today is measured to be very close to flat.

- Inflation solves the "horizon problem". Regions we see in two opposing directions in a CMB map would never have been in causal contact without an inflationary era and we would have no explanation for their nearly identical temperatures as measured by the CMB anisotropy experiments.
- Inflation solves the "monopole problem" by diluting away unobserved relics from phase transitions in the early Universe.
- Inflation provides a natural way to generate the initial seeds of later structure formation by predicting that quantum fluctuations with nearly constant fluctuation power per decade of scale will be produced.

These explanations for the classic problems of cosmology of the 1960's are compelling and make it extremely important that the idea be explored by direct measurement.

Quite aside from the cosmological interest, inflation, if correct, has enormous consequences for fundamental physics. Inflation is modeled as being caused by a scalar field rolling slowly down a potential with a kinetic energy that acts as a "cosmological constant" which causes the exponential expansion. The dynamics of the field ends inflation and gives a prediction for the spectrum of fluctuations departing slightly from scale invariant.

Unfortunately, there are very few direct inflationary observables with which to test the physics of inflation. One of the most powerful observational handles would the detection of the gravitational radiation predicted because of the quantum fluctuations occurring during inflation. Measuring the gravitational wave power spectrum would provide a direct measurement of the cosmic density history while it remains relatively constant during inflation. The measurement would not only demonstrate that something akin to inflation actually happened, but would also give tantalizing information about physics on energy scales vastly exceeding those accessible in laboratories.

The inflationary gravitational waves are expected to be produced in a scale invariant spectrum from at least the size of our Hubble length and below. As illustrated in Figure 1, current and currently planned gravitational wave detectors are 5 to 10 orders of magnitude too insensitive to measure this signal directly. In the very distant future, the Big Bang Observer may have sufficient sensitivity for a direct detection.

The Cosmic Microwave Background (CMB) Radiation provides an independent way to detect the gravitational waves from inflation because of the effect they have on the polarization pattern of the anisotropy of the CMB. As seen in Figure 1 the fiducial CMBPol mission of the Weiss Report (a factor of 10 more sensitive than the Planck mission) has the ability to detect primordial gravity waves to a level of $r < 0.01$ where r is the ratio of tensor-to-scalar perturbations.

Figure 2 illustrates how close WMAP has already come in sensitivity to constraining models of inflation. Indeed, there is a hint of departure from scale invariance which would be an indicator of inflation physics being probed (Spergel et al., 2007). The Planck mission which launches in 2008 is to be able to set a constraint of $r = 0.1$. Models with zero or one degree of fine tuning are within the black curve of Figure 2 and would be detected by the fiducial Weiss Report mission, whose sensitivity is shown by the red horizontal line at $r = 0.01$ (Boyle et al., 2006).

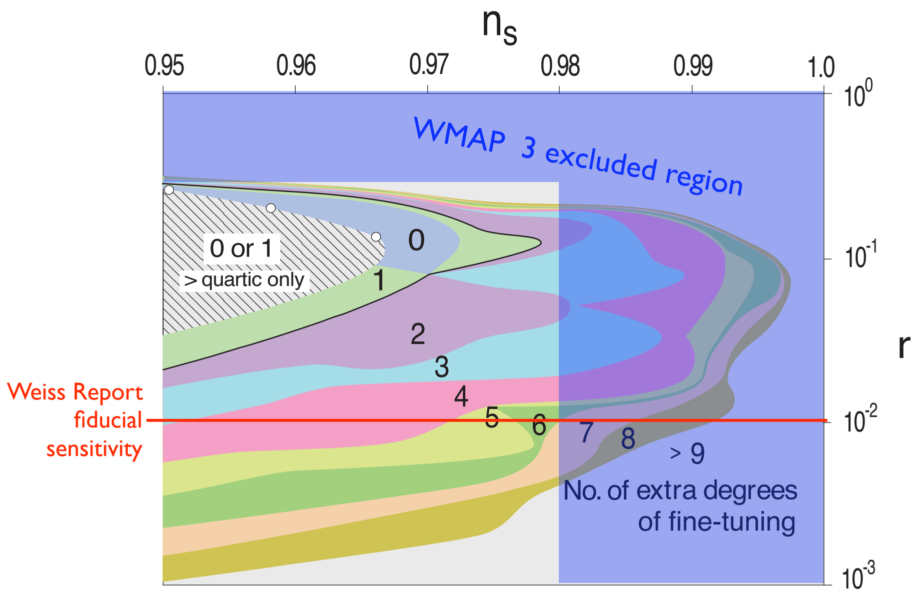

Figure 2: Predictions for the fluctuation power law slope, n_s, and tensor-to-scalar ratio, r, for minimally tuned inflation models. Over plotted are the excluded regions from WMAP three year data in purple (Spergel et al., 2007), and the red sensitivity line for the fiducial Weiss Report mission at $r = 0.01$. Figure is modified from Boyle et al. (2006).

This is a proposal to carry out a Mission Concept Study and develop a program for the study of technology and instrumentation leading to the definition of a Beyond Einstein Inflation Probe. The Probe would use the CMB B-Mode anisotropy to determine the amplitude of primordial gravitation waves. This measurement will provide unique insight to the existence and nature of an inflationary era in the early universe. The measurement addresses question 1 in the astrophysics science area of the NASA 2007 Science Plan: "Understand the origin and destiny of the universe, phenomena near black holes and the nature of gravity" (NASA, 2007).

3 Proposal Context

The roadmap "Beyond Einstein: From the Big Bang to Black Holes" recommended that an Inflation Probe be launched to "Detect the imprints left by quantum effects and gravitational waves at the beginning of the Big Bang" (Structure and Evolution of the Universe Roadmap Team, 2003). Three mission concepts based on CMB B-Mode polarization measurements were developed (Bock et al., 2006b). Several members of this proposal team were part of those mission studies. This proposed work builds on those studies.

The four national agencies, NASA, NSF, DoE and NIST involved in CMB research, combined to charge an interagency "Task Force on Cosmic Microwave Background Research" to published a report in 2005 (Weiss Report) (Bock et al., 2006a). The report emphasized the importance and fundamental nature of the CMB B-Mode research and presented a program of technology and instrument development, data analysis work and theory.

This last summer, the Beyond Einstein Program Assessment Committee (BEPAC) has made it clear that the Inflation Probe is not likely to be started in the next several years (Kennel, 2007). However, the importance of carrying out the mission was reaffirmed by the BEPAC for the reasons outlined in Section 2. As pointed out in the Weiss Report, the mission will require a number of new developments beyond the current state of the art in technology, instrument characterization, knowledge of foregrounds, and analysis. The BEPAC also reaffirmed that ongoing funding for research and technology development was a requirement for the success of the missions after the first two. The needed research to arrive at a point where an optimal mission can be started must start now.

The NASA Primordial Polarization Program Definition Team (PPPDT) (Hanany et al., 2007) was formed to shepherd the activities called out in the Weiss Report . Their recommendation was that the entire CMB community should combine to submit a single response to the Astrophysics Mission Concept Study Program. The study should carry out an Inflation Probe mission costing exercise. In addition to a report for NASA, a goal is to make the results available for the 2010 Astrophysics Decadal Survey committees.

This proposal team has found that there are sufficient questions about the nature of a future B-Mode experiment that a more in-depth review of the current technology, techniques and experiments, of our understanding of foregrounds and systematics is necessary. In addition there are several major mission design questions which are not yet answered. For example, should the Inflation Probe be aimed at only angular scales above one degree be built which permits a smaller and probably cheaper mission? Or should a mission with much higher resolution enabling the study of weak lensing of the CMB (a possible foreground) in addition to the primordial signal be the goal? Questions of foregrounds, systematics, instrument and spacecraft cost and ancillary science are all tied up in this fundamental question. These questions should be examined carefully before proposing a final mission design.

4 Proposed Work

This proposed study is designed to gather input from a broad sector of the scientific community doing research related to studying the CMB. In addition to fully costing two template mission for a CMB polarization probe of the physics of inflation, it will summarize the current state of experimental and theoretical research and outline the current technologies. The structure of the proposed work and the management is designed to permit a broad range of community input with a range of time commitment levels.

Part of the proposed work is to carry out two complete but interrelated costing exercises for two“Template Missions.” The studies will examine the characteristics and costs of a satellite with angular resolution of one degree or greater and a small beam telescope satellite with resolution of a few arcminutes. It will also study the two main focal plane detector technologies, bolometers and amplifiers. These studies will develop complete mission against which the other theoretical, systematic, and data analysis study elements of this proposed work will be tested. It is likely that the cost of the small beam mission which will require a 3m telescope would exceed $800M. It is however also possible that the outcome of this study will be that the smaller mission, with one degree beams or larger is the correct approach. It may be that the best approach is a mission in combination with larger ground-based telescopes. The answer to this question will depend on a careful balancing of cost, capability, science and risk. We propose to carry out that analysis.

Because of the BEPAC recommendation to start JDEM and LISA before the Inflation Probe, it may be that the technology detailed in our template costing studies for this proposal will not be the best possible solution by the time the actual mission is developed. We will therefore also examine in detail the current state of promising detector, optics and cooling technology for CMB research. We will assess the Technology Readiness Level (TRL) of and the cost and schedule to develop that technology to the point where a mission can be confidently defined.

Since the time of the Weiss Report, advances have been made in the techniques for analyzing foregrounds together with primordial signal. Other advances in the characterization of systematics have occurred. A numerical simulation of the template missions with primordial signal, foreground and systematics will be run. A detailed study of what is known about millimeter foregrounds and what is still needed in terms of foreground emission characteristics will be part of the report. We will carry out a survey of the primary science papers in the literature and how they couple to measurement sensitivity as a function of angular scale. The template missions will also be measured against the primary science goals.

An additional study we plan to carry out is an overview of current CMB experiments, both polarization and temperature measurements. We will look carefully at the methods each of these experiments use to reduce foregrounds and systematics in an effort to gather together the information about where the tchnology and instrumentation is now and what direction will be most promising for the future.

The report written for NASA and the Decadal Survey will develop what is learned from these studies to make a concrete costing estimate for the Inflation Probe mission. It will also present a plan with schedule and estimated costs for the research needed to enable the final definition of a mission concept within the next decade.

As shown in Figure 7 and listed below, eight detailed studies will be carried out. Two are the mission costing studies. The other studies carry out investigations of key questions experimental or technical nature that span the issues to be investigated to come to a complete understanding of the CMBPol mission. These studies will be organized to provide input to the Workshops which are described below.

The key to the success of the work outlined in this proposal is a great deal of carefully channeled input from a broad cross-section of the CMB community. This input will come from two sources: individual contributions to the workshops from investigators in the community whose research overlaps CMBPol questions, and from the detailed studies. All workshop contributions will have an oral and written component and contributers will be considered proposal collaborators.

4.a Workshops

Three workshops, all meeting in the summer of 2009 are planned. The workshop topics are

1. Theory, ancillary science and foregrounds

2. Systematic errors, observing strategies and template missions

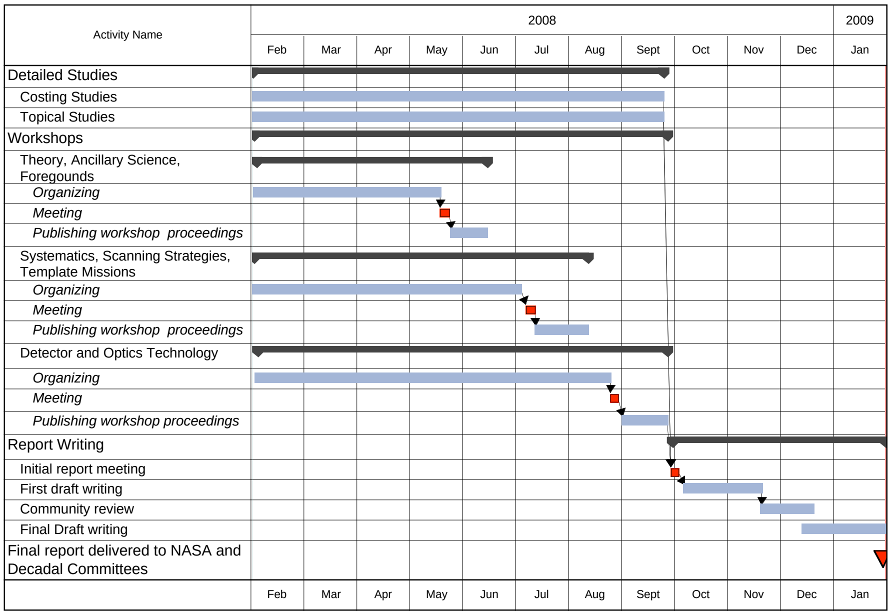

Figure 3: The CMBPol Mission Concept Study centers on the workshops. The topical and costing studies will provide major input to the workshops. Members of the community will be asked to contribute to the workshops and will be study collaborators. Each workshop generates a proceedings which includes not only written versions of the presentations, but also an analysis of the topics covered in the workshops. These are then gathered for an initial report writing meeting in early October 2008. The last quarter is devoted to writing the report and obtaining community review.

3. Focal plane and optics technology definition and costs

The first of these will be at the end of May 2008 at Fermilab. The second in June or July of 2008 near Goddard Space Flight Center. The third will be in August 2008 at NIST in Boulder. Each workshop will be led by a proposal Co-Investigator. They will be 4 to 5 days long with each day consisting of presentations in the morning followed by afternoon and evening subgroup meetings. Each subgroup will explore one of the topics or a set of topics covered in the presentation. The sub-group develops a report which summarizes the topic.

Much of the effort of the workshop organizers will be in the planning of the workshops. This planning is essential for success and is organized by the by the workshop lead. Choosing the topics for the presentations and subgroups is the first step. Choosing the presenters and formulating the make up of the subgroups and their topics will determine the productivity of the meeting. It is likely that many of the presenters will also be members of the subgroup summarizing the topic of the presentation. The presenters will be made up of co-investigators who have lead detailed studies, members of the CMB community who have been asked to present at the workshop, and also members of the community who volunteer to contribute and are willing to contribute a written part to their presentation.

Once the subgroups have met they will be responsible for writing the topical summary. The goal of the summary is to capture the consensus of the presentations and the subgroup participants. This consensus may be just a summary of what has been agreed upon. On the other hand it may be an outline of points of disagreement among the presenters or subgroup members. In this case, a synthesis of the main points of disagreement will be formulated.

Following the workshop, a proceedings, which includes the presentations, the written version of each presentation, the subgroup written findings, and a workshop summary outlining the final findings and results will be compiled. These proceedings will be published on the study website.

All presenters in workshops are considered collaborators (or are co-investigators) and are responsible for a written version of their presentation (not just the slides). The subgroups are responsible for developing the topical summary. The workshop lead will write the overall workshop summary and compile the proceedings.

All travel and room and board for the summer workshops will be supported for contributing participants. The workshop lead will have control of a workshop budget which can include relevant support staff salaries and a month of summer support for the study lead or collaborator. The workshops are open to all. Non-contributers must support their travel with other funds.

4.b Detailed Studies

A number of detailed studies will be undertaken. Each is lead by a co-investigator and results in a presentation in at one of more of the workshops. Ideally, most of the study work would be complete by the time the workshop meets. Figure 3 shows the approximate timing of the studies and workshops. The study will result in a report written by the study lead which may be the written contribution to the workshop. There will be no restriction to otherwise publishing the results of these studies in journals and the authors retain the intellectual property rights. The only requirement for this work is that a document appropriate for this study is written. The topics of the detailed studies is as follows. Additional topics may be required as the study develops.

1. A costing and template missions study for an amplifier focal plane based mission. This study will include the complete spacecraft, optics, cooling system, pointing system, control and telemetry.
2. A costing and template mission study for a bolometer focal plane based mission. This study will include the complete spacecraft, optics, cooling system, pointing system, control and telemetry.
3. Foreground removal methods study .
4. Scanning strategy study.
5. Horn optics study.
6. Weak lensing study.
7. Optical system study.
8. Systematics study.

The first two items are mission costing studies. They are to be carried out by a co-investigators lead. Because these studies are difficult and must be carried out in a rather short time, the lead will be supported by engineers and other co-investigators of this proposal. In the case of the amplifier focal plane study, some initial work has already been done on a similar study. In the case of the bolometer focal plane, this study is an amplification and continuation of a previous CMBPol mission concept study.

The other studies are on particular topics that proposal co-investigators will undertake. In all cases these studies will work in close consultation with the workshop leads, the mission costing studies, each other, and the PI. Of particular interest is that these other studies provide the needed input for the mission costing studies and support them when needed.

4.c Two Mission Costing Studies

Two mission costing studies will be carried out. Because this proposal incorporates input from the whole community, these can be carefully coordinated so that a number of possible mission architectures and capabilities may be evaluated together. Taken together, they will explore the two major detection methods, amplifiers and bolometers, and two types of experiments, a low-resolution mission aimed at seeing the B-Mode signal at angles above 1 degree, and a high-resolution mission which covers both the large and the small angular scales.

The mission studies will be coordinated in their goals but carried out independently. Their characteristics will be used to make the two "Template Missions" against which all the detailed studies will be investigated. The templates will also provide the test cases for all three workshops. This will permit the strengths of each mission to be tested against the scientific goals and the difficulties introduced by foregrounds, non-ideal experimental characteristics, and systematics.

4.c.1 Bolometer Mission Concept

Requirements for Bolometers and Technological Readiness For future space-borne polarization measurements, bolometers offer the highest sensitivity and the possibility of covering all frequency bands of interest, from 30 Ð 300 GHz. The sensitivities achievable per detector with a cryogenic space-borne telescope are clearly within reach. As shown in Table 4.1, these sensitivities are a modest factor of 2.5 lower than the goal sensitivities of Planck. In fact, laboratory instrument tests of the Planck HFI bolometric focal plane demonstrate sensitivities significantly better than the Planck goals (Bock et al., 2006a), though the in-flight sensitivities will only be demonstrated after the launch of Planck, expected in late 2008. We anticipate that CMBPol will need a raw sensitivity advantage of a factor of greater than 10 over Planck, and that most of this advantage will come from operating large arrays of order 2000 detectors. Covering the required spectral bands in a single technology provides technical simplification, avoiding the systems difficulties in combining HEMTs and bolometer technologies into a single focal plane.

In order to achieve readiness for CMBPol, the two main technical hurdles for bolometers will be developing large-format arrays, and extending the frequency coverage to low frequencies. Instruments using SQUID-multiplexed TES bolometer arrays (SCUBA2,

Freq (GHz)	NET[1]				NEP[2]	
	CMBPol[3]		Planck/HFI[4]		CMBPol	Planck/HFI
	Req'd	Goal	Goal	Meas.	Goal	Goal
30	80	57	-		4	
40	71	50	-		5	
60	60	42	-		5	
90	52	37	102	67	6	14
135	49	35	83	48	7	16
200	54	38	135	68	7	17
300	92	65	400	224	7	20

[1]Noise Equivalent Temperature per polarized detector in $\mu K_{CMB}\sqrt{s}$
[2]Noise Equivalent Power at the detector detector in $aW/\sqrt{Hz}$
[3]Assumes TES bolometers with single-mode linear polarization, 40% optical eficiency, 30% fractional badnwidth, 10mK base temperature, 2K optics, and a 40K baffle with 0.3% coupling.
[4]Planck bands are shifted slightly to match the closest CMBPol band. Measured data taken from ground-based instrument-level tests, channel average.

Table 4.1: Detector Sensitivities for CMBPol Bolometer and Planck/HFI

Frequency Bands	30-300 GHz	**Orbit**	L2 Halo
Resolution	0.9° at 90 GHz	**Inflow Data Rate**	1260kbps
Detectors	2366 TES bolometers	**Total Mass (CBE)**	1320 kg
Design Lifetime	2 years	**Total Power (CBE)**	875 W
Optics	Six 30 cm refractors	**Delta-V**	215 m/s

Table 4.2: Summary of EPIC low-resolution mission configuration

ACT, and SPT) are now coming to into the field, with formats as large as 10,000 bolometers. While further development may be required on key aspects, e.g. array uniformity, low-frequency noise stability, and magnetic field susceptibility, the pace of development indicates that large arrays will be at TRL = 6 prior to the start of CMBPol. Bolometers to date have operated at frequencies greater than 90 GHz, due limits on suspended absorber size in classical bolometers. New antenna-coupled bolometers, currently being developed by several groups in the US, avoid this limitation and can be naturally extended to operate at lower frequencies. Individual antenna-coupled bolometers have been fully demonstrated, sub-orbital experiments are now in development based on arrays of these devices, and on track to demonstrate technological readiness in a matter of a few years.

Scan-Imaging Bolometric Polarimeters We plan to further develop point bolometric mission configurations based on a previous NASA study, the Experimental Probe of Inflationary Cosmology. EPIC developed two instrument concepts based on drift-scanned bolometric polarimeters, the approach successfully demonstrated by several sub-orbital experiments and planned for the upcoming Planck mission. Scan-imaging

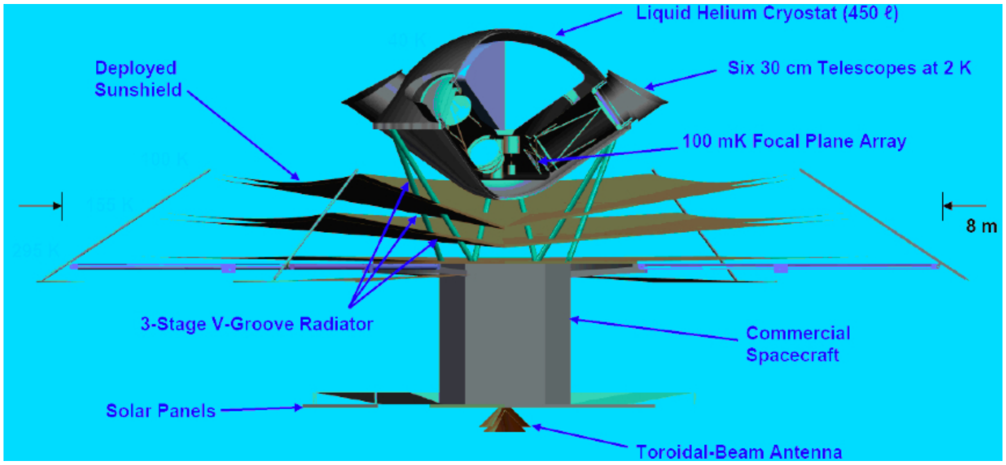

Figure 4: Low-resolution EPIC mission configuration, using multiple 30 cm cryogenic refracting telescopes operating arrays of 100 mK bolometers in bands between 30 Ð 300 GHz. The instrument is cooled to 2 K by a long-duration liquid helium cryostat, the outer shell of which is passively cooled to 40 K. The experiment scans the sky with a spinning and precessing scan strategy covering more than half the sky in a 24 hour period with a high degree of uniformity and angular coverage. A deployed shield keeps radiation from the sun, earth, and moon from entering the optics or causing thermal disturbances.

polarimeters are now producing maps with sensitivity $< 1\ \mu K_{RMS}$ in 1 degree^2 pixels on small regions of sky, demonstrating the basic technique but at 20 times lower sensitivity than will ultimately be required over the entire sky. The EPIC study developed a low-resolution mission configuration, based on multiple 30-cm refracting telescopes similar to the optics used in the BICEP experiment, and a high-resolution mission configuration, based on a 3-m Gregorian-Dragone reflecting telescope similar to the optics developed for the EBEX and Polarbear experiments.

We propose to expand the work of the EPIC study to assess the scientific tradeoffs in the choice of frequency bands and aperture diameter(s). The understanding of systematic error control is critical, and we propose to extend the current analysis to quantify in particular the impact of 1/f noise, scan strategy, and control of main beam mismatches. The large 3-m mission option opens the possibility for strong ancillary science, and we will investigate alternate optical configurations that could reduce the mass and cost of this configuration.

4.c.2 Amplifier Mission Concept

Amplifier focal planes provide a number of advantages for a CMBPol mission. Among these is the possibility of obtaining all Stokes parameters for each pixel of the focal plane continuously, the fact that the focal plane can be run at 20K rather than at sub-Kelvin temperatures, the ability of using of a correlation receiver which permits differencing inputs before the detection process. The disadvantages are the lower sensitivity due to the "amplification noise" which is a fundamental noise introduced with amplification, and higher power operation of the focal plane.

As with the bolometer mission study, the amplifier mission concept study will expand on an earlier study, in this case an Explorer Class mission. The challenges unique to the amplifier focal plane are the cooler and the sensitivity. In the previous study, three

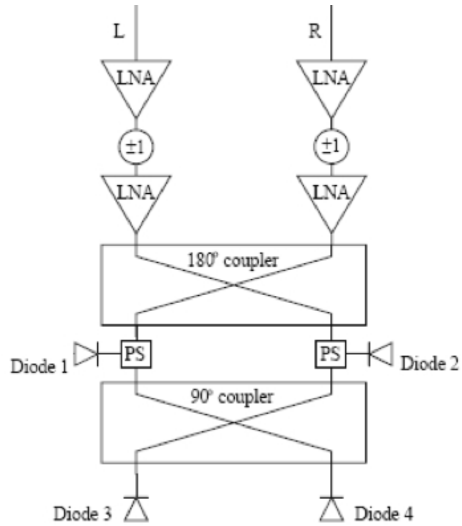

Figure 5: An schematic of the polarimeter components on the integrated circuit module of QUIET. Left- and rightcircularly-polarized radiowaves enter from the top, both fed from the same input horn which is one pixel in the focal plane. Phase switches in each arm (indicated by ±1) are operated one at a time and provide the Dicke-switching which separates the polarized signal from the total power. The signals pass through low noise amplifiers (LNA) , and then enter a series of hybrid couplers, detailed in the text. PS indicates power splitters. The demodulated outputs of detector diodes 1 and 2 are proportional to the Stokes parameter Q while diodes 3 and 4 encode U after demodulation. Filters have been omitted for clarity.

cooler options were appraised, a staged pulse tube cooler, a two stage Stirling cooler, and a Sorption Cooler. These will each be reevaluated in the light of this mission.

The amplifier sensitivity and power requirements are another element of this study. The current generation use InP amplifiers, which achieve the lowest system temperatures available for these large bandwidths at frequencies below 100 GHz. Low noise amplifiers at 40 GHz and 90 GHz with greater than 20% bandwidth and state of-the-art noise performance have been demonstrated by members of this team. A 90-GHz four-stage amplifier was developed for radio astronomy applications and has been used in CAPMAP, SZA, SEQUOIA, AMiBA, JPL's Deep Space Network and at the Effelsberg Telescope. The noise measured for this design is between 40 and 50 K when cooled to 20 K as shown in Figure 6.

4.d Final Report

After the three summer workshops, the core team of investigators (the co-investigators and the PI) will meet at Chicago to organize the writing of the final report. During the meeting the leads of the workshops and the detailed reports will present their summaries. This information will be used to formulate the report.

Figure 3 shows the schedule of the final report activity. After a first version of the report is completed, we will solicit comment from the community on the report and its conclusions. This input will be used to make any necessary modifications. The final report will be ready at the end of January 2009. The report will be delivered to the NASA

Starting September 2008, with the reports from the studies and the workshops in hand, the final writing of the report would begin. The PI and the CoIs would be responsible for the final report. Everything in the study including the final report and

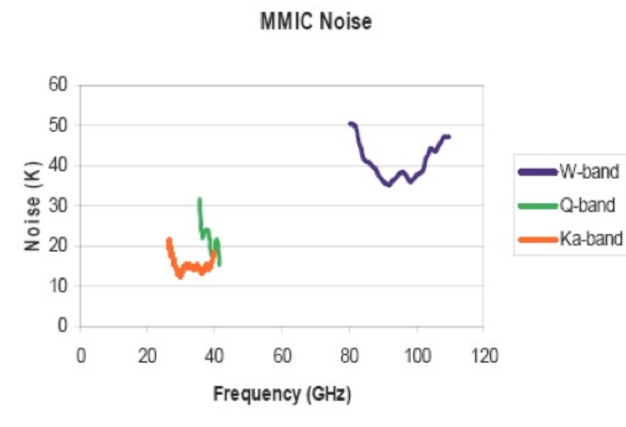

Figure 6: noise curves of one of our MMIC amplifiers. Two dozen of the 90 GHz amplifiers are currently operating in CAPMAP with a typical receiver noise of 50 K. The 40 GHz amplifiers have 20 K typical noise and are also operating in CAPMAP. We have demonstrated similar band-average performance in the QUIET modules.

the workshop and detailed study report will be public. The final report, the study and workshop reports and the workshop presentations will be a useful resource to the community following the completion of the report.

4.e Webpage

Throughout the proposed period of activity and for a period thereafter a study webpage will be maintained. The webpage will announce study activities and workshops. It will be an open repository for the detailed studies, the workshop proceedings, study conclusions and final report. The webpage will be accessible to all and a mechanism for sending comments will be provided. In addition we will maintain a small outreach webpage explaining the activity of the study and the relevant science at a level aimed at the gerneral public.

We plan to organize the material on the webpage so that it will be useful as a reference for the community in addition to being aimed at the decadal survey committees and other NASA committees. The final report and all the underlying reports and materials will be in a single, organized location.

5 Management

The CMBPol study will bring input from as wide a group as possible. It also must converge within the one year study period. This requires a carefully constructed management structure.

The PI has overall responsibility for the timely completion of the study and writing of the report. In this he is assisted by the Co-Investigators who each have responsibility for one of two activities: a workshop or a detailed study.

The workshops are the mechanism which brings collaboration from a large part of the interested community into the study. Careful planning before the workshops will be needed and is the responsibility of the co-investigator in charge of the workshop. The workshop, consisting of presentations followed by analysis of specific topics by subgroups will result in a proceedings which is the responsibility of the workshop lead. The workshop title and leads are shown in Figure 7. The workshop lead will also organize

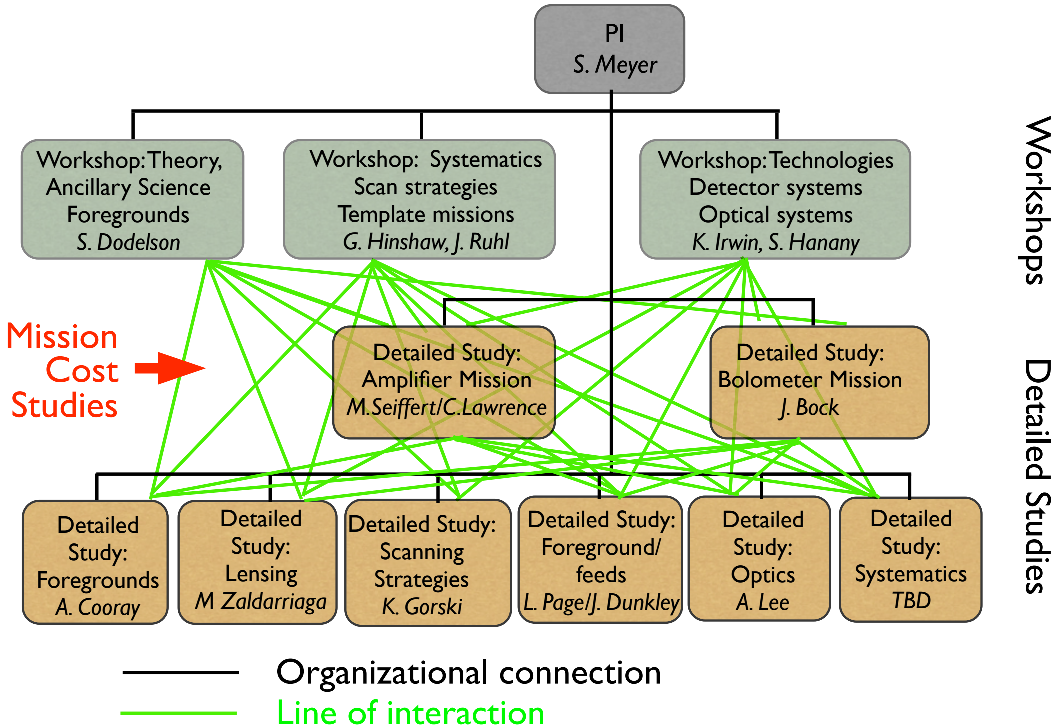

Figure 7: The CMBPol Mission Concept Study is organized around two activities. Workshops which bring in the opinions and ideas of the community and detailed studies which look at specific issues for a CMBPol mission. The detailed studies are a major input to the workshops themselves. As the chart indicates, interactions between nearly all studies with each other and the workshops will tie the study together. Two mission cost studies will be carried out and the results will be presented in two of the three workshops.

the topics, designate a subgroup chair and ensure that each topic is fully developed within the subgroup. The subgroups will be responsible for a summary of their topic and the generation of a written set of conclusions. Anyone contributing a presentation and written contribution to one of the workshops will be considered a collaborator. The subgroups will consist of both collaborators and CoIs.

Another set of co-investigators will carry out detailed studies on particular topics. These include costing studies as well as the studies on scanning, foregrounds, and instrumentation. The study results will be presentated at one of more of the workshops and a written report will be folded into the final proposed report.

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