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| **Science Goals** | **Science Objectives** | **Scientific Measurement Requirements** | | | **Instrument** | | **Mission**  **Functional**  **Requirements** |
| **Model**  **Parameters** | **Physical**  **Parameters** | **Observables** | **Functional Requirements** | **Projected Performance** |
| Explore how the universe began (inflation) | Detect the energy scale at which inflation occurred if it is above xx, or place an upper limit if it is below that level  (see Figure *TBD)* | Tensor-to-scalar ratio *r:* σ(*r*) < *TBD* at *r* = *TBD* ­ | CMB polarization B-mode power spectrum for modes 2<*l*<300  to cosmic variance limits | Linear polarization at frequencies 60 <ν<300 GHz over at least 400 sq. deg  *[over the entire sky?]*  *(can have multiple objectives sharing the same required observables)* | GHz  ΔνFWHM/νc ≤ *TBD*  *TBD* Sensitivity  ≤*TBD* ‘ resolution  @ TBD GHz  *TBD* Field of View  *[what about foregrounds?]* | *TBD*–*TBD* GHz  ΔνFWHM/νc ≤ *TBD*  *TBD* Sensitivity  ≤*TBD* ‘ resolution  @ TBD GHz  ≤*TBD* ‘ resolution  @ TBD GHz  *TBD* Field of View | Sun-Earth L2 halo orbit  Mission life *TBD* yr  Survey *fsky* ≥*TBD*%  Survey efficiency ≥*TBD*%  Downlink *TBD* data  *TBD* Spinning/precessing  *TBD* Pointing accuracy  *TBD* Pointing stability  *TBD* Thermal  *TBD* Sun avoidance  *TBD* Launch vehicle compatibility |
| Reject classes of potentials as the driving force of inflation  (see Figure *TBD)* | Spectral index *ns* and its derivative  σ(*ns*) < *TBD*  (LK/FR insert) < *TBD* |  | CMB intensity and polarization at frequencies 60 <ν<300 GHz over at least ?? sq. deg |  |
| *Discover how the universe works (Neff, dark matter, dark energy)* | Determine the sum of neutrino masses and the neutrino hierarchy (See Figure *TBD*  *similar to Figure 1.5 in EPIC-IM)* | Sum of Neutrino masses: σ(∑*m*ν*)* < *15* meV  Based on measurement of τ combined with forthcoming DESI data |  |  |  |
| Explore how the universe evolved (reionization?) | Distinguish between models of the reionization epoch (see Figure *TBD*) | Depth to reionization τ :  σ(τ*)* < 0.002 | CMB polarization E-mode power spectrum for modes 2<*l*<15  to cosmic variance limits | Intensity and linear polarization at frequencies 60 <ν<300 GHz over the entire sky |  |  |  |

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| **Science Goals** | **Science Objectives** | **Scientific Measurement Requirements** | | | **Instrument** | | **Mission**  **Functional**  **Requirements** |
| **Model**  **Parameters** | **Physical**  **Parameters** | **Observables** | **Functional Requirements** | **Projected Performance** |
| Explore how the universe evolved (magnetic fields) | Determine if rapidly star-forming galaxies at z > 2 are high redshift analogs of low redshift star-forming galaxies |  | CIB power spectra and numbers counts of resolved IR sources | intensity at ν>200 GHz over the entire sky  (why >200 GHz?) |  | *TBD*–*TBD* GHz  ΔνFWHM/νc ≤ *TBD*  *TBD* Sensitivity  ≤*TBD* ‘ resolution  @ TBD GHz  ≤*TBD* ‘ resolution  @ TBD GHz  *TBD* Field of View | Sun-Earth L2 halo orbit  Mission life *TBD* yr  Survey *fsky* ≥*TBD*%  Survey efficiency ≥*TBD*%  Downlink *TBD* data  *TBD* Spinning/precessing  *TBD* Pointing accuracy  *TBD* Pointing stability  *TBD* Thermal  *TBD* Sun avoidance  *TBD* Launch vehicle compatibility |
| Distinguish/discriminate between models of feedback in theory and simulations of galaxy evolution |  | High resolotion Compton-Y map of the Universe | intensity at ν>90 GHz over the entire sky and combined intensity data from CMB-S4 |  |
| Understands how magnetic fields influence star formation |  |  |  |  |  |
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**STM Guidance**

The STM should tell a complete story as it flows (column by column) from Left to Right.  The story starts with the ‘why’ (goals and objectives) and flows to the ‘how’ (science measurement requirements) and then the ‘what’ (instrument and mission requirements).

Science Goals

* Should explicitly reference NASA-driving documents (e.g. NASA Science Plan, NASA Strategic Plan, Decadal surveys)
* This is about showing that CMBpol is within the scope of the priority set that NASA and the Decadal survey have laid out.  The Science Objectives should clearly respond to these Goals (but CMBpol by itself doesn’t need to accomplish the entire stated goal).
* You want multiple quotes, and the more specifically they correlate with your Science Objectives the better.

Science Objectives

* A test of a hypothesis, e.g. “to determine if…” or “to distinguish/discriminate between [models/theories]”  
  “To determine if [hypothesis] or [null/alternative hypothesis] to within an uncertainty TBDsigma”
* One common failure mode: “to measure [model parameter]…” NASA doesn’t fund improved accuracy on numbers, it funds the disposition of important science questions.  In other words, what is it that we learn about the Universe when we improve that number?
* Another common failure mode: vague statements about “characterizing” or advancing the state of knowledge.  In other words, if we are setting our requirement at r=TBD, then there needs to be a theory-based justification for why TBD is interesting/important (not just that its better than what we have, or that it’s a round number in base ten).  For example, it either confirms inflation or tests (to elimination) an important class of models (that you can identify). One good way to communicate this is with a (reference to a) figure that shows where families of models lie in parameter space, and how well the mission will be able to constrain that parameter space (confirming or rejecting models/theories).

Science Measurement Requirements

* These should flow clearly from the Science Objectives
* Columns within this category should flow left to right, column by column
* CMB is very unusual, and sometimes fits awkwardly in this structure.  Most missions are learning about the “Physical Parameters” of *massive objects* using an “Observable” *radiation signature*.  For example, they might be determining the metallicity of exoplanets (physical parameter) by looking at the transmission spectrum as the planet transits in front of the star (observable).  In the case of the CMB, the physical thing we care about is sometimes the CMB radiation itself, which is what we observe.  You can see one suggestion for how to handle this in the attached.

Instrument

* Functional Requirements should flow clearly from the Observables
* These should refer to the Instrument specifically, not the Mission as a whole.  In other words, how sensitive is the Instrument, not how deep are the maps.
* These should allow as much design flexibility as possible.  For example, specify sensitivity and resolution, but don’t specify aperture size.
* An Instrument that meets its Functional Requirements must be sufficient to meet the Scientific Measurement Requirements.
* Projected Performance should show margin against (be better than) the Functional Requirements.
* NB: The above two bullets combine to imply that your Scientific Measurement Requirements must be less ambitious than your Projected Performance.

Mission

* This column covers all the non-instrument aspects of the mission. In a proposal, this column is copied verbatim to form the first column of the MTM (Mission Traceability Matrix), which describes in more detail the implications of these requirements to mission design (launch and orbit), spacecraft (provides things like power, telecom, pointing), ground system (tracking, communications with spacecraft), and mission ops (maneuver scheduling, data management, etc.).
* Most of the STM flows in a simple way from one column to the next.  This column is a little bit different, in that it actually flows mostly from the Science Measurement Requirements (after making the stated assumptions about the Instrument requirements).
* Again, should not unnecessarily dictate design (e.g. say how much data needs to be downlinked, but don’t specify what ground facility will be used or what downlink data rate)