**STM V4.6:**

**History:**

Includes galactic science updates from Dave/Laura, Dec. 7.

**Comments:**

Currently based on BandsV2.7 (Fundamental Physics is based on V2.4)

No need to touch Column 1,8;

Science WGs fill columns 2-5;

SH fills columns 6,7;

Red highlight means – needs to be completed

Fundamental Physics (Raphael)

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| **1. Science Goals** | **2. Science Objectives** | **Scientific Measurement Requirements** | | | **Instrument** | | **8. Mission Functional Requirements** |
| **3. Model Parameters** | **4. Physical Parameters** | **5. Observables** | **6. Functional Requirements** | **7. Projected Performance** |
| Explore how the universe began (Inflation) | 1. Probe the physics of the big bang by detecting the energy scale at which inflation occurred if it is above 4x1015 GeV, or place an upper limit if it is below  (see Figure *TBD)* | Tensor-to-scalar ratio *r:*  σ(*r*) < 5x10-5 at *r* = *0*­  r<10-4 at 95% CL (1) | CMB polarization B-mode power spectrum for modes 2<*l*<300 to cosmic variance limit, and CMB lensing power spectrum  for modes 2<*l*<1000 to cosmic variance limit | Linear polarization at frequencies 60<ν<300 GHz over the entire sky | 21 frequency bands between 20 and 800 GHz; fractional bandwidth of 25% (2)  FWHM of 6.2’ at 155 GHz and remaining single mode resolution to higher frequencies (3)  Combined instrument noise weight of 0.7 uK\*arcmin | 21 frequency bands between 20 and 800 GHz; fractional bandwidth of 25%  7.6’ resolution at 150 GHz  Combined instrument weight of 0.7 uK\*arcmin | Sun-Earth L2 halo orbit  Mission life *4* yr  Full sky survey  Survey efficiency ≥*95*%  Downlink *150 Mbits/hour; 6 hour/day*  *TBD* Spinning/precessing  *TBD* Pointing accuracy  *TBD* Pointing stability  *TBD* Thermal  *TBD* Sun avoidance  *TBD* Launch vehicle compatibility |
| 2. Probe the physics of the big bang by excluding classes of potentials as the driving force of inflation  (see Figure *TBD)* | Spectral index *ns* and its derivative  σ(*ns*) < *0.0015*  σ(*nrun*) < *0.002* | CMB polarization B-mode power spectrum for modes 2<*l*<1000 to cosmic variance limit | Intensity and linear polarization at frequencies 60<ν<400 GHz over the entire sky |

(1) The values include internal delensing and an ILC foreground separation using the 21 frequency bands. The foreground sky had no spatial decorrelations.

(2) Broad frequency for foreground separation

(3) Resolution required for delensing and foreground characterization

Fundamental Physics (Raphael) + reionization (Nick)

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| Discover how the universe works (Neutrino Mass and Neff) | 3. Determine the sum of neutrino masses, and distinguish between inverted and normal neutrino mass hierarchies (See Figure TBD) | Sum of Neutrino masses: σ(∑*m*ν*)* < *15* meV (4) | CMB polarization B-mode power spectrum for modes 2<*l*<4000 to cosmic variance limit;  CMB intensity maps (to give Compton Y map from which we extract clusters) | Intensity and linear polarization at frequencies 60<ν<400 GHz over the entire sky | As above | As above | As above |
| 4. Detect departures from or tightly constrain the thermal history of the universe | Number of effective relativistic degrees of freedom  σ(Neff*)* < *0.03* | CMB temperature and E-mode polarization power spectra  2<*l*<4000  to cosmic variance limit | Intensity and linear polarization at frequencies 60 <ν<300 GHz over the entire sky |
| Explore how the universe evolved (reionization) | 5. Distinguish between models that describe the formation of the earliest stars in the universe. (see Figure *TBD*) | Optical depth to reionization τ:  σ(τ*)* < 0.002 | CMB polarization E-mode power spectrum for modes 2<*l*<20 to cosmic variance limit; T power spectrum and Compton Y maps. | Intensity and linear polarization at frequencies 60 <ν<300 GHz over the entire sky (role of intensity maps at high \ell to be clarified) | Frequency bands as above  Resolution of 1 deg; (role of intensity maps at high \ell to be clarified)  Combined instrument weight of 0.7 uK\*arcmin  *(Perhaps can survive with less sensitivity)* |

(4) Using the PICO BB lensing power spectrum and τ, and BAO information (what specifically?) from DESI; or independently using our cluster counts and LSST data

Extragalactic Science (Nick)

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| **3. Model Parameters** | **4. Physical Parameters** | **5. Observables** | **6. Functional Requirements** | **7. Projected Performance** |
| Explore how the universe evolved (galaxy formation, & feedback) | 6. Determine the role of energy injection due to feedback processes on galaxy formation and evolution | The baryon density and electron pressure radial profile of galaxy halos of mass  M>1013.5 Msun/h | All sky CMB temperature and Compton Y maps | Temperature at frequencies 60<ν<400 GHz over the entire sky | Beam size of 2.5 arcmin at 385 GHz and increasing with single mode dependence to lower frequencies | As above | As above |

Galactic Science (Laura + Dave)

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| **1. Science Goals** | **2. Science Objectives** | **Scientific Measurement Requirements** | | | **Instrument** | | **8. Mission Functional Requirements** |
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| Explore how the universe evolved (magnetic fields) | 7. Determine if magnetic fields are the dominant cause of low star formation efficiency in our Galaxy. | B - Magnetic Field strength as a function of spatial scale and density; Μa - Alfven Mach number (ratio of turbulent energy to magnetic energy); βp, Plasma beta (ratio of thermal energy to magnetic energy). | The turbulence power spectrum on scales 0.05 – 100 pc (from cores to diffuse cloud envelopes); Fractional polarization level p; Correlations of fractional polarization and direction with hydrogen column density and temperature. | Linear polarization at the highest resolution, ν = 799 GHz for galactic latitudes -20 <b<20  (to obtain maps of thousands of molecular clouds with <1pc resolution and <0.05 pc for the 10 nearest MCs.) | Frequency band at 799 GHz;  Angular resolution of 1 arcmin.  Sensitivity of 27.4 KJy/Sr (check new specification V3.0) | Frequency band at 799 GHz;  Angular resolution of 1 arcmin.  Sensitivity of 27.4 KJy/Sr  (check new specification V3.0) | Same as above |
| 8. Determine whether the interstellar medium of our galaxy is unique by comparing the ratio of energy in magnetic field to turbulence to that in nearby galaxies. | B - Magnetic Field strength; Μa - Alfven Mach number | Magnetic field maps of ~100 nearby external galaxies with at least 10 measurements across each; Maps of fractional polarization | Linear polarization at the highest resolution, ν = 799 GHz  (to obtain maps of a statistically-significant set of external galaxies.) |
| 9. Determine whether radiative torque is responsible for the alignment of dust grains with magnetic fields | Grain alignment efficiency b vs extinction where polarization fraction p ∝A\_V-b, maximum size of the dust grain distribution a\_max. (first part of sentence is not clear) | Polarization spectrum as a function of wavelength p(λ); polarization vs extinction p(AV); polarization vs angle between radiation source and magnetic field p(ψ). | Linear polarization maps in (10?) several frequency bands between 150 and 799 GHz for regions with high and low radiative flux (how many is several?) | 10 frequency bands between 150 and 799 GHz;  To be completed |  |
| 10. Determine the influence of the magnetic field on Galactic dynamics within the Milky Way. | Galactic magnetic field geometry and strength. Distribution and temperature within the diffuse ISM.  B - Magnetic Field strength; Μa - Alfven Mach number | Column density, spectral index, and magnetic field direction maps | Polarized intensity maps at multiple frequencies for low density regions. | Sensitivity: A\_v <0.1 (need to convert to Jy/sr), < 4 arcmin resolution |  |

Galactic Science Cont. (Laura + Dave)

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| Explore how the universe evolved (magnetic fields) | 11. Determine the level of magnetized turbulence in the Milky way, and use this knowledge to constrain models of cosmic ray propagation to understand the physics of the sources responsible for accelerating these high energy particles.  (Need to shorten this; first need to understand better) | B - Magnetic Field strength as a function of spatial scale; Μa - Alfven Mach number | Magnetic field maps of the diffuse ISM.  The turbulent power spectrum in regions of low intensity. | Linear polarization at frequencies > 300GHz over the entire sky, with <0.1 pc resolution for the edge of the local bubble (d~100pc). | Sensitivity: A\_v <0.1(need to convert to Jy/sr), < 4 arcmin resolution  (is this the same as item 10?) |  |  |

Legacy Science (Nick, Gianfranco)

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| Catalog | Impact | Science |
| 1. Proto-Clusters | Discover 3000(a) mm/sub-mm proto-clusters distributed over the sky and across redshift.    Current Planck data expected to yield few tens. | Explore how the universe evolved: Probe the earliest observable dust-enshrouded galaxy clusters to determine the initial stages of their formation and evolution |
| 2. Strongly Lensed Galaxies | Discover 3,000(a) highly magnified dusty galaxies across redshift.  13 sources confirmed in current Planck data; there are few hundred candidates in Herschel, SPT and ACT data(c) | Explore how the universe evolved: Learn about dark matter sub-structure in the lensing galaxies; probe star formation history in high-z dust enshrouded galaxies, a population in which star formation history can not be probed in any other way |
| 3. High-z Galaxy Clusters | Find 1000(a) mm/submm emitting clusters at 1 < z < 1.5 and ~20 at z>2.  Planck and Herschel identified mm/sub-mm emission of ~100 known sources | Explore how the universe evolved: Probe star formation history at high z and in dust-enshrouded environments. |
| 4. Polarized Point Sources | Detect 4000(a,b) radio and dusty galaxies in polarization | Explore how the universe works: Determine the structure of magnetic fields in dusty galaxies, and the mechanism for relativistic jet formation in radio-loud galaxies; Determine the importance of polarized sources as foreground for CMB polarization science. |

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Comments:

(a) Confusion (not noise) limited

(b) Noise and confusion limited

(c) Many Planck candidates are not expected to be real because of confusion. Because the beam size of Herschel, SPT, ACT is much smaller most of their candidates are expected to be real sources. The same – candidates will mostly be true sources - will hold for PICO.