**STM V4.6.7:**

**History:**

Put back SO9, although it isn’t completely cooked.

Includes galactic science updates from Dave/Laura, Aug 21, 2018.

**Comments:**

* All forecasts need to be updated to version 4.1 = final required noise levels
* Red highlight = needs to be completed
* Amy’s comments:
  + Consider prioritizing PICO objectives, describing all the science in the text body of the 50-page report, but reducing the number of objectives in the STM. Survey of smaller astrophysics missions (MIDEX ($0.25B), Discovery ($0.5B), and smaller Missions of Opportunity) gives the number of Science Objectives to be (2,2,3,5,5,10,10). Of the other JPL Probes, 2 have ~4 objectives, and 1 has more (I’m not sure how many – their STM is immature). It’s OK to have 11 – just worth thinking about.
  + Column2 should be based on Column 5, not 6.

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| 1.  Science Goals  (from NASA Science Plan) | 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) | SO1. 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 (§2.2.1, Figure TBD) | Tensor-to-scalar ratio r (1):  σ(r) < 5x10-5 at r = 0­  r<10-4 at 95% confidence level | 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 across 60<ν<300 GHz over entire sky | *Frequency resolution:*  Δν/ν*c* = 25%  *Frequency coverage*  *[for foreground separation]:*  ν*c* from 30 GHz to 500 GHz  *Angular resolution**[for delensing and foreground separation]:*  ( 6.2’ ) \* ( 155 GHz / ν*c* )  *Sampling rate:*  ( 3 / Beam FWHM ) \* ( 336’ / sec )  *Sensitivity:* See Table TBD  Combined instrument weight of < 0.7 uKCMB √s  Polarization systematics? | Frequency coverage:  See Table TBD  21 bands with ν*c* from 21 GHz to 799 GHz  *Frequency resolution:*  Δν/νc = 25%  *Angular resolution:*  See Table TBD  ( 6.2’ ) \* ( 155 GHz / ν*c* )  1.1’ for ν*c* = 799 GHz  *Sampling rate:*  See Table TBD  ( 3 / Beam FWHM ) \* ( 336’ / sec )  *Sensitivity:*  See Table TBD  Combined instrument weight of 0.46 uKCMB √s | Class B  EELV launch vehicle  Sun-Earth L2 orbit with  Sun-Probe-Earth < XX°  5 yr survey with  ≥95% survey efficiency  Full sky survey:  Spin instrument @ 1 rpm; Boresight 69” TBD off spin axis;  Spin axis 26” TBD off anti-Sun line, precessing 360” / 10hr  Pointing control:  Spin axis 60’ (3σ, radial)  Spin @ 1 rpm ± 0.1rpm (3σ)  Pointing stability  Drift of spin axis < 1’ / 1min (3σ, radial)  Jitter < 20” / 20 msec (3σ, radial)  Pointing knowledge (telescope boresight):  10” (3σ, each axis) from spacecraft attitude  1” (3σ, each axis) final reconstructed  Thermally isolate instrument from solar radiation and from spacecraft bus  Return and process instrument data:  1.5 Tbits/day after 4x compression |
| SO2. Probe the physics of the big bang by excluding classes of potentials as the driving force of inflation (§2.2.1, Figure TBD) | Spectral index (ns) and its derivative (nrun):  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 across 60<ν<400 GHz over entire sky |
| Discover how the universe works (Neutrino Mass and Neff) | SO3. Determine the sum of neutrino masses, and distinguish between inverted and normal neutrino mass hierarchies (§2.2.1, Figure TBD) | Sum of neutrino masses (4) (∑mν):  σ(∑mν) < 15 meV with DESI or Euclid  σ(∑mν) < XX meV alone | 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) |
| SO4. Tightly constrain the thermalized fundamental particle content of the early Universe (§2.2.1, Figure TBD) | Number of neutrino effective relativistic degrees of freedom (Neff): σ(Neff) < 0.03 | CMB temperature and E-mode polarization power spectra 2<l<4000 to cosmic variance limit | Intensity and linear polarization across 60<ν<300 GHz over entire sky |
| Explore how the universe evolved (reionization) | SO5. Distinguish between models that describe the formation of the earliest stars in the universe (§2.2.2, 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 across 60 <ν<300 GHz over entire sky (role of intensity maps at high \ell to be clarified) | *Like SO1-4, except:*  *Angular resolution*  < 1 deg at XX GHz (role of intensity maps at high \ell to be clarified)  Combined instrument weight of <0.86 uK\*arcmin |
| Explore how the universe evolved (cluster and galaxy formation) | SO6. Determine the role of energy injection due to feedback processes on galaxy formation and evolution (§2.2.2, Figure TBD) | 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 | Intensity across 60<ν<400 GHz over entire sky | Beam size of 2.5’ at 385 GHz and increasing with single mode dependence to lower frequencies |
| Explore how the universe evolved (Galactic structure and dynamics) | SO7. Determine if magnetic fields are the dominant cause of low star formation efficiency in our Galaxy. (§2.2.3, Figure TBD) | Plasma ratio of thermal energy to magnetic energy (βp)  Ratio of turbulent energy to magnetic energy (Alfven Mach number Μa) on scales 0.05 – 100 pc | The turbulence power spectrum on scales 0.05 – 100 pc (from cores to diffuse cloud envelopes)  Magnetic field strength (*B*) as a function of spatial scale and density  Hydrogen column density  Gas velocity dispersion5 | Linear polarization with <1 pc resolution for thousands of molecular clouds and <0.05 pc for the 10 nearest molecular clouds. | *Enveloped by SO1-4, except:*  *Angular resolution:*  ≤ 1.1’ (at highest frequency)  *Sensitivity:*  27.4 KJy/Sr (check new specification V3.0)  Are there Saturation/Dynamic range reqts? |
| SO8. Test the validity and determine the parameters of the two-component model for the interstellar diffuse dust. (§2.2.3, Figure TBD) | Intrinsic polarization fractions of the warm and cold components of the diffuse ISM to accuracy better than 2% when averaged over 10 arcmin pixels.  Temperature and spectral indices of the two components to an accuracy better than ??% | Fractional polarization and intensity as a function of frequency | Intensity and linear polarization maps in (10) frequency bands between 150 and 800 GHz. |
| SO9. Understand the relationship between magnetized turbulence in the diffuse ISM and structure formation. Confirm TB correlation observed by Planck (more sensitivity and larger ell range). Is temperature-polarization relation parity non-conserving?  (§2.2.3, Figure TBD) | Alignment of diffuse density structures with the magnetic field as a function of e.g. hydrogen column density and environment. | TE, TB, EB, EE, BB power spectra correlations  Hydrogen column density (*comes from other data sets)* | Maps of polarization 1-5’ resolution over the entire sky. |
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(1) The values include internal delensing and an ILC foreground separation using the 21 frequency bands.

(2) Broad frequency for foreground separation

(3) Resolution required for delensing and foreground characterization

(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

(5) Using data from (these available surveys)

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. |

Top of Form

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.