Science Task List

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This document is put together by the Science Council with input from the Analysis Working Groups. It seeks to enumerate tasks that need to be completed as we design, construct, and field the CMB-S4 instruments. This is a living document and will change as our understanding evolves.

NOTE: For the upcoming DOE FOA the tasks listed below that are project-enabling, that is, activities that are important for advancing the design of the Project, are more likely to be considered for funding. In a similar vein, tasks which are expected to be funded by the Project and are included in the WBS are not likely to receive funding separately from the Project.

I. **Generic tasks:**
   A. Advancing theory/prediction codes to the necessary accuracy
   B. Building forecasting software for the science cases
   C. Building analysis pipeline software components
   D. Running pipelines on data management data challenge outputs
   E. Cosmological simulation efforts, especially those that support CMB-S4 cross-correlation studies (with external collaborations)
   F. Studies of systematics robustness for science goals
   G. Foreground modeling

II. **Low-ell BB:**
   A. Improving/exploring foreground models (for both SATs and LAT)
      1. Studying impact of high-ell non-Gaussianity on lensing reconstruction and delensing
   B. Improving and refining Fisher forecasting:
      1. Incorporating more realism on LAT/delensing from existing experiments
   C. Generating improved high realization count simulations (for both SATs and LAT)
      1. Including the effects of timestream filtering
      2. Establishing the ability to re-analyze these more realistic simulations which have missing modes due to filtering
   D. Quantification of systematic effects
      1. SAT: Adding pickup/sidelobe systematics to the simulations and exploring the residuals when filtered and re-analyzed
      2. SAT + LAT: Exploring the effects of bandpass related systematics
      3. LAT: effects of beam shape variation on delensing
   E. Developing alternate re-analysis algorithms and pipelines
   F. Refining the extrapolation of sensitivity from existing experiments
   G. Testing the developing CMB-S4 pipelines on existing datasets
   H. Improvements and further development of iterative lensing reconstruction algorithm

1. Algorithmic improvements to iterative lensing reconstruction
2. Analyses on simulations with foreground correlated with lensing potential
3. Improvement on lensing reconstruction using both temperature and polarization maps

III. Clusters:

A. Study mass calibration
   1. Study self calibration for cluster masses
   2. Study of using stacked lensing analysis from DESC/Rubin
   3. Study extended cosmologies beyond LCDM for the halo mass function, for example neutrino masses, dark energy, and modified gravity
   4. Building hydrodynamical simulations with multiple parameters that govern the relation between gas, galaxies, and dark matter, or a baryon pasting scheme calibrated to hydro sims
   5. Develop methods to combine CMB-halo lensing with galaxy lensing.
      a) Study the improvements in the signal-to-noise.
      b) Explore the shared systematics and develop methods to mitigate them.

B. Understanding the selection function
   1. Study detection methods
   2. Studying evolution effects on the selection function
   3. Studying impacts of dust/foreground residuals

C. Explore polarization-based science cases for clusters

D. Building a combined likelihood for cluster counts, cluster clustering, and external probes such as 3x2pt

E. Develop methods for cluster candidate counterpart identification, especially the high-z objects that are unique to S4

IV. Maps To Power Spectra:

A. Pipeline work on simulations, increasing realism with each generation

B. Building power spectra pipeline tools

C. Exploring strategies for handling systematics in beams, gains

D. Studying of the above for delensing

E. Combining data for different statistics, combined likelihoods, joint analysis

V. Maps To Other Statistics:

A. Lensing / Neutrino Mass
   1. Optimal lensing autospectrum pipeline development and detailed testing
   2. Characterization of galactic dust and synchrotron-induced biases for optimal polarization lensing pipelines (and potential development of mitigation strategies); application and further development of non-Gaussian small scale foreground simulations
   3. Likelihoods for joint neutrino mass constraints from lensing + other probes
   4. Study improvements to lensing reconstruction using external tracers such as CIB
   5. Explore shear only estimators
   6. Explore systematics and mitigation techniques for lensing reconstruction

B. SZ constraints on baryon distribution
    1. Develop + test component separation pipelines to mitigate, e.g., CIB contributions
    2. Develop stacking and cross-correlation analysis pipelines to extract information about electron density and pressure profiles
    3. Develop models for the joint distribution of baryons and galaxies from LSS surveys + further work to connect to weak lensing observables
C. Reionization and Optical Depth (tau)
    1. Develop kSZ 4pt pipeline; find strategies to mitigate lensing, CIB, SZ... “foregrounds”
    2. Develop modeling and likelihood codes to combine kSZ power and 4pt; connect with neutrino mass constraints
    3. Forecast + develop case for synergies of different reionization observables: patchy tau/B, kSZ power, Compton-y, kSZ-4pt...
D. Broader cross-correlation science
    1. Growth of structure from lensing-galaxy cross correlations:
        a) Develop cross-correlation pipelines
        b) Investigate polarization lensing x galaxy biases due to dust extinction?
        c) Develop higher-order bias modeling infrastructure to go from kg, gg -> s8
        d) Joint-probes Nx2 likelihood development
    2. Study primordial large scale density fluctuations with lensing, kSZ, and polarized SZ
    3. Primordial non-Gaussianity (f_NL) from cross-correlations:
        a) Develop cross-correlation pipelines and investigate systematics for lensing x galaxies and kSZ velocity reconstruction
E. Develop simulations for all of above

VI. Sources and Transients:

A. Theoretical modeling and forecasting for protoclusters
B. New techniques for cross matching external catalogs and source classification and characterization
C. Theoretical predictions for transients
D. Optimal source finding