PBDR

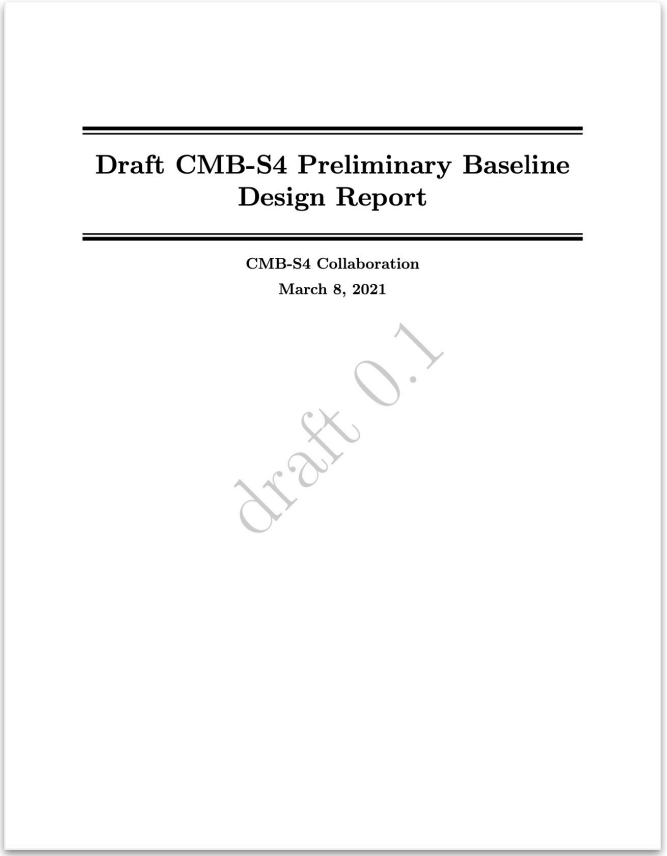
Preliminary Baseline Design Report

John Carlstrom & Kevin Huffenberger

CMB-S4

Outline

- What is the PBDR?
- Why are we preparing the PBDR?
  - History and impact of reports drafted by the collaboration
  - Purpose of the PBDR
- Timeline
- Status & plans for this workshop



What is the PBDR?

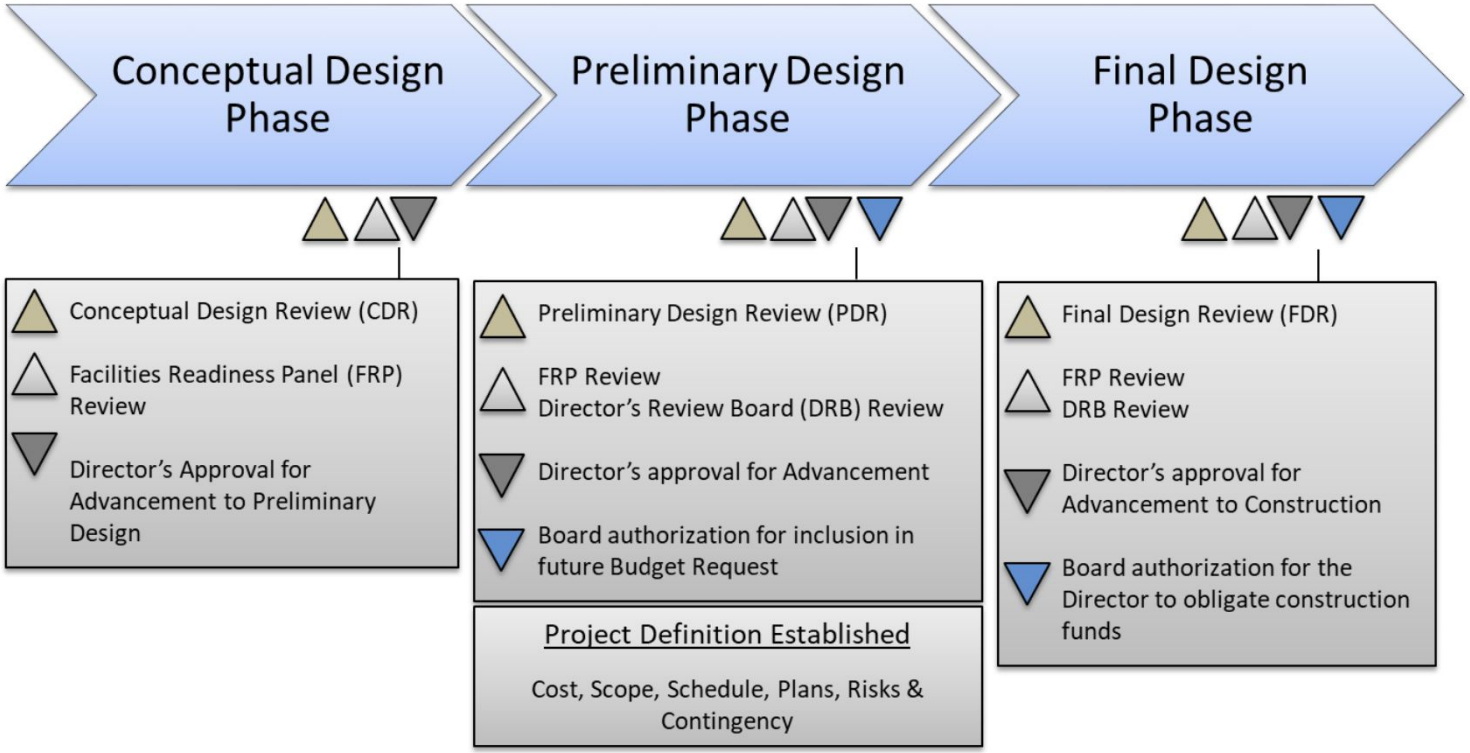
A document that gives the high-level overview of the Science Case, the Technical Design, and the Validation that shows the design will deliver the science.

It should be readable by anyone interested in learning about CMB-S4. It will be posted to the public archive (arXiv).

While it gives the overall design, it is not the authoritative reference for design specifications, nor should it include the detailed specifications. These are covered in the various CMB-S4 project documents.

The PBDR should not have to be continually updated as the detailed specifications of the design are worked out. It should remain a viable and useful overall guide of the design as the detailed specifications and interfaces are evolved.

Preliminary Design Phase for an NSF Major Facility



From Major Facilities Guide: NSF 21-XX (December 2020)
Released for public comment

Preliminary Design Phase for an NSF Major Facility

The Preliminary Design Phase further develops concepts to a level of maturity in which there are: a fully elaborated definition of the motivating research questions; a clearly defined site-specific scope; a PEP and an IMP that address major anticipated risks in the completion of design and development activities and in the undertaking of construction; and a realistic (not too low) cost estimate based on known risks that can be presented with reasonable confidence to the NSF.

PEP - Project Execution Plan
IMP - NSF Internal Management Plan

From Major Facilities Guide: NSF 21-XX (December 2020)
Released for public comment

Overview of the PBDR

Chapters (coordinators)

1. **Science Case** (SC Co-Chairs: Kevin Huffenberger & Joel Meyers)
   Overview of CMB-S4 science themes; background, context and motivation
2. **Science and Measurement Requirements** (Charles Lawrence & John Ruhl)
   Succinct summary of Level 1 science requirements and measurement requirements
3. **Preliminary Baseline Design** (TC Co-Chairs J. McMahon & A. Vieregg; L2 science leads)
   The technical design, organized by WBS elements
4. **Science Analysis** (Science Council)
   Overview of the Analysis from project Data Management products to final scientific results
5. **Project Overview** (Project Director John Corlett)
   Brief overview of the project structure and plan; does not include detailed schedule and costing

Appendices - Design Validation

1. **Technical Design to Measurement Requirements** (Julian Borrill)
   Demonstrate that preliminary baseline design will meet the measurement requirements
2. **Measurement Requirements to Science Requirements** (Science Council)
   Demonstrate that measurement requirements will meet the level 1 science requirements

Why are we preparing the PBDR?

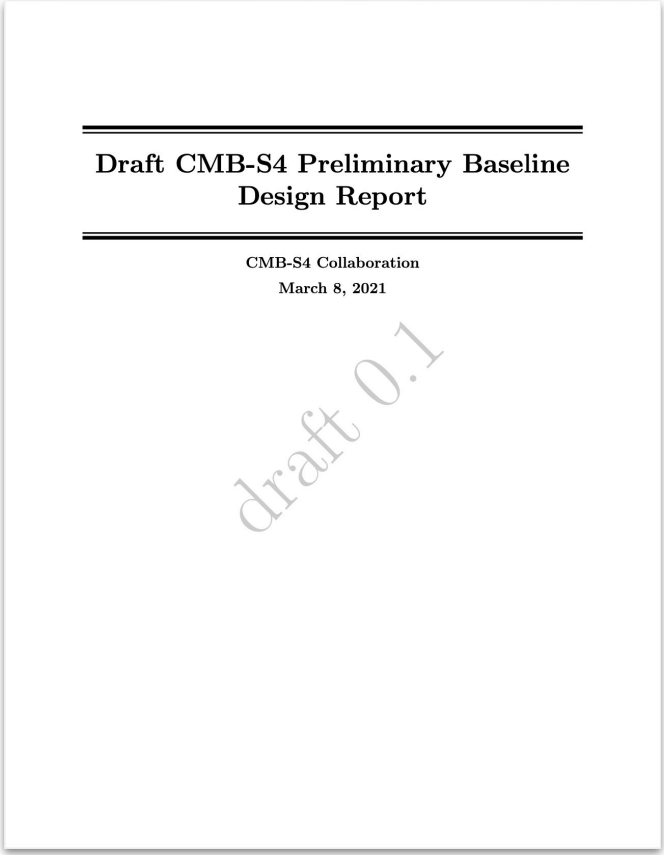
- We have benefited greatly by documenting the case for CMB-S4 as it evolves
  - Snowmass papers provided case for input to P5, and led to P5 recommendation
  - Science Book and Instrumentation Books led to joint agency Concept Definition Task Force, (CDT).
  - The acceptance of the CDT report by the AAAS led to the establishment of the Integrated Project Office and the Science Collaboration
  - The Decadal Survey Report (DSR) with its Reference Design was essential to making our case to the public and the Decadal Survey Committee and it was crucial for preparing the many requests for information from the Decadal Survey
  - We now need to prepare the document that presents the Preliminary Baseline Design
- The PBDR is needed for the upcoming NSF PDR and DOE CD-1 reviews. It will be particularly helpful, by providing the reviewers with a coherent overview of the entire project. It is a much needed guide to CMB-S4.

Timeline for the PBDR

- Now
  - Science Case is ready for collaboration reading and comments
  - Science Goals and Level 1 Science Requirements ready for reading and comments
- At this workshop
  - Collaboration update and input to the Measurement Requirements and the validation that the Measurement Requirements are sufficient to meet the Science Requirements
  - Collaboration update and input to the technical Preliminary Baseline Design
  - Collaboration update and input on the plan to validate the technical design, by showing it will be able to provide the Measurements Requirements
  - All major design decisions that cross WBS elements are identified and made, or a path to their resolution is mapped out and scheduled
- By end of April, for input to the NSF MSRI-1 review to be held in May
  - All sections completed and ready to provide to review panel, except the Technical Design to Measurements Requirements validation section for which we will present its scope and the schedule for its completion.
- By end of Summer
  - PBDR complete in advance of Director's review and posted prior to NSF PDR and DOE CD-1 (tentatively) planned for end of CY 21

PBDR Status

- Lots of recent progress!
- Some sections much more advanced than others.
- The rest of this presentation briefly reviews the PBDR sections and highlights the workshop sessions dedicated to updating the collaboration and, most importantly, working with the collaboration on the remaining issues of the Preliminary Baseline Design Report. This is the work of the workshop.



At 270 pages as of March 8th

Chapter 1: Science Case

Status:

- Ready for collaboration reading and comments; required some updating from DSR
- Related workshop sessions:
  - This session! Next slides review the Science Case
  - Tuesday's plenary/parallel on *Science Case Beyond the Design Drivers* (Joel Meyers & Kevin Huffenberger)

Chapter 1: Science Case

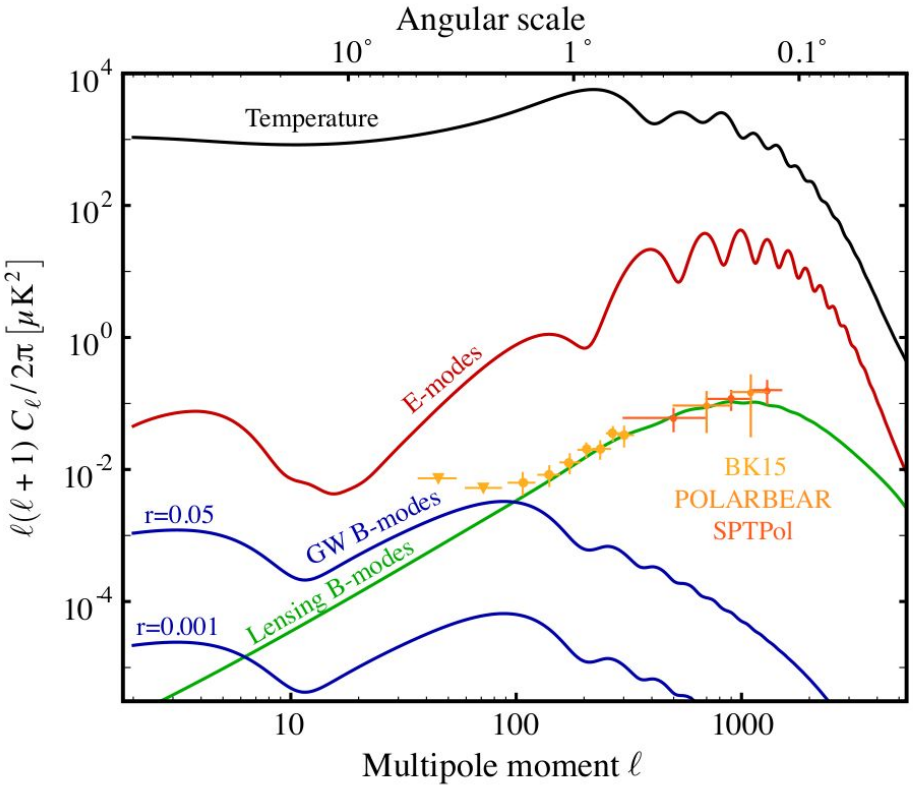
1.2 Summary of Science Themes

Scientific Program of CMB-S4:

1. *Primordial gravitational waves and inflation*
2. *The dark Universe*
3. *Mapping matter in the cosmos*
4. *The time-variable millimeter-wave sky*

Chapter 1.3: Primordial Gravitational Waves and Inflation

- CMB-S4 will reach the sensitivity necessary to detect gravitational waves from a large class of models: those which naturally explain the deviation from scalar spectral invariance



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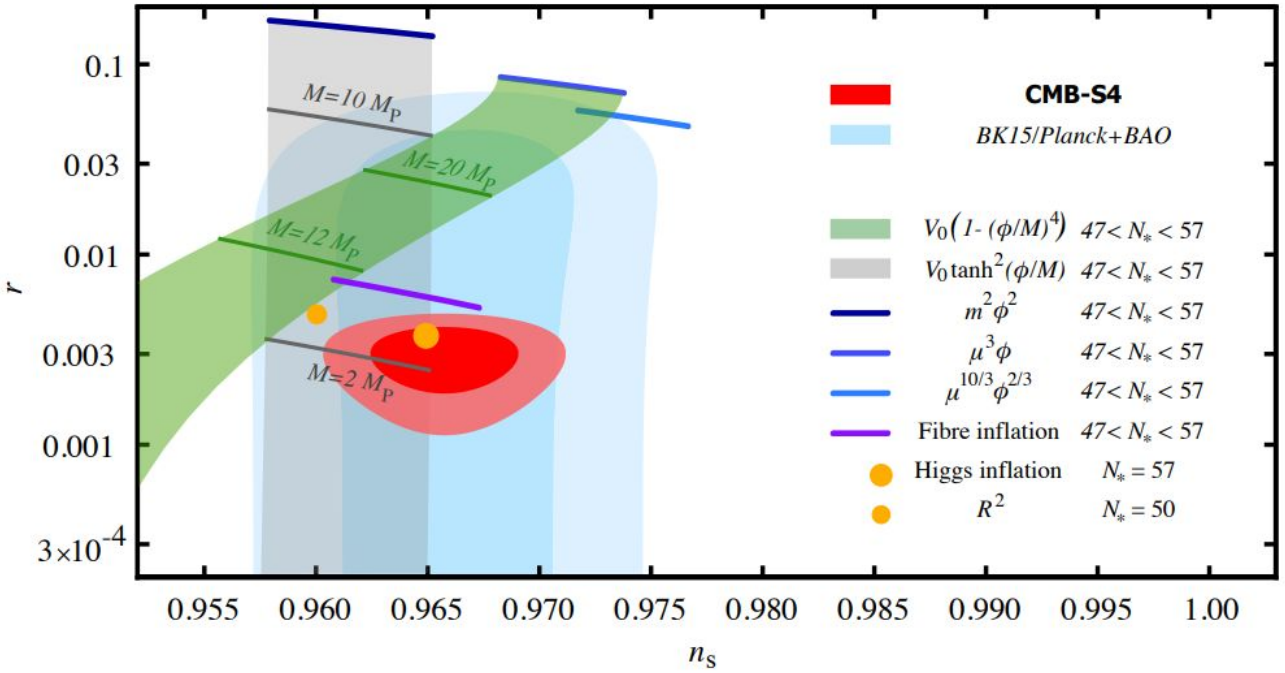
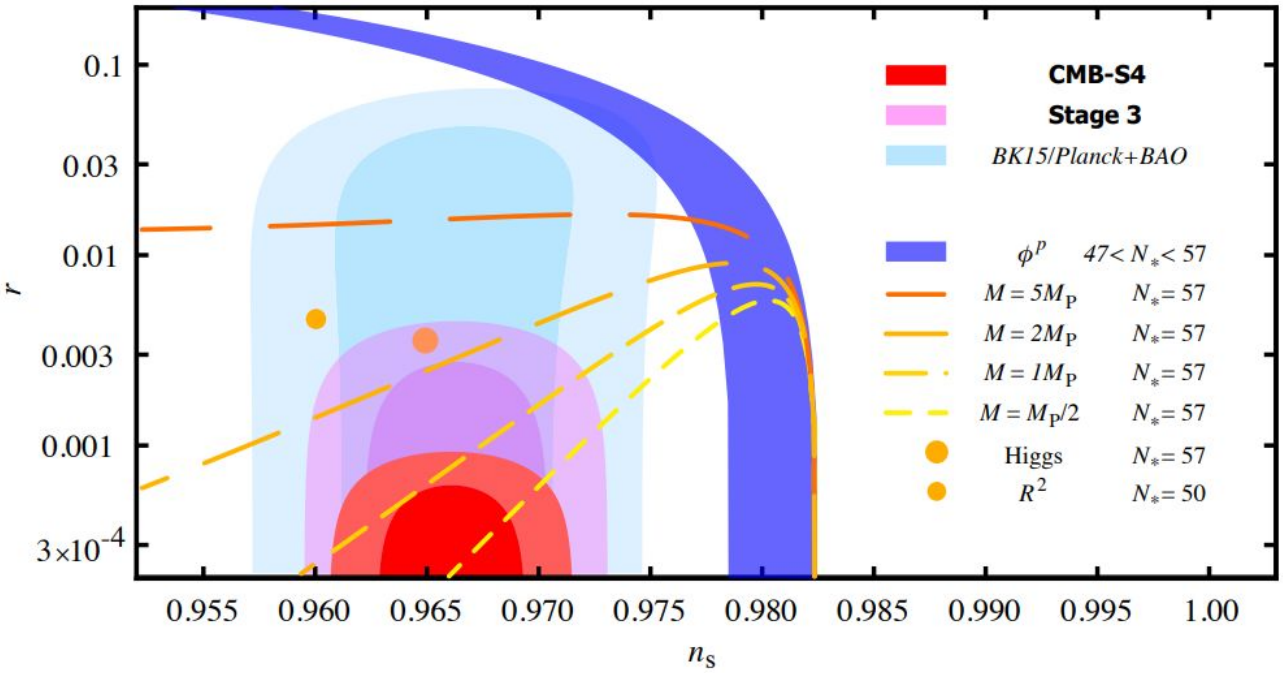


Forecasted constraints in n_s - r plane assuming r = 0.003, compared to predictions from several inflationary models

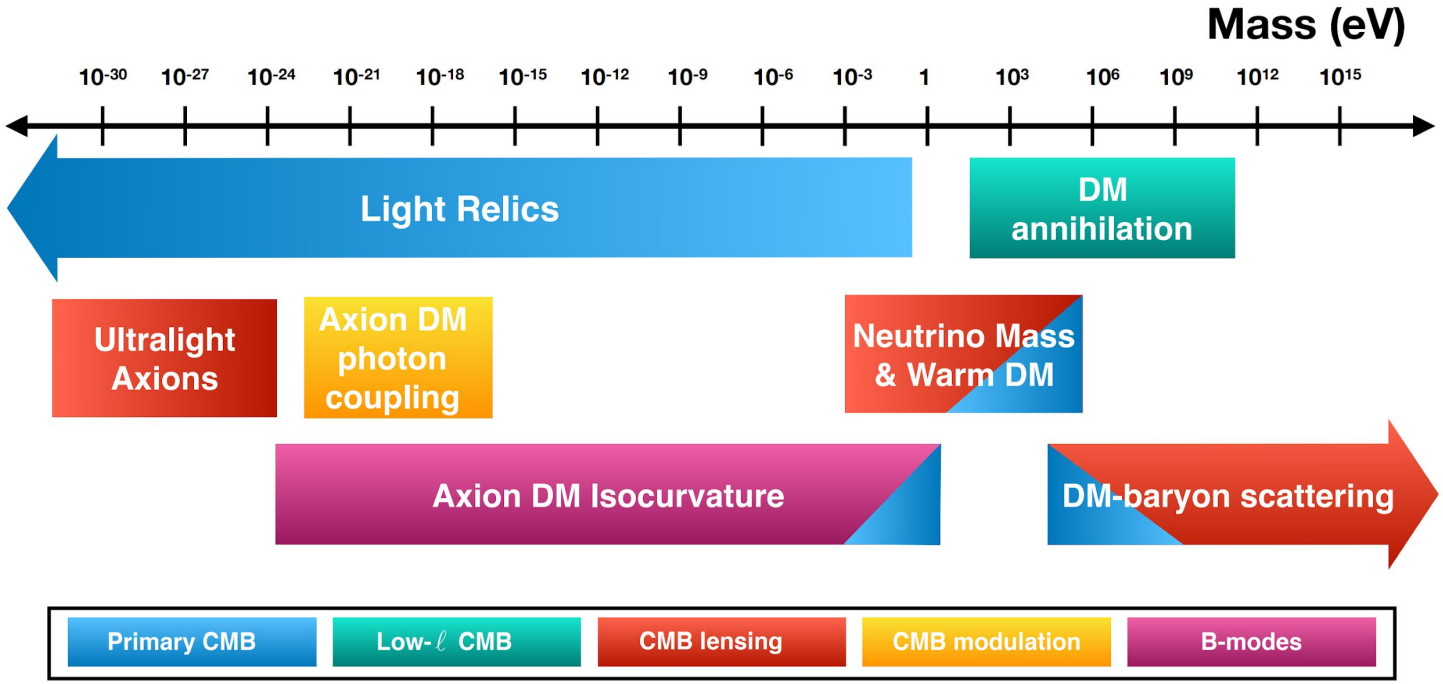
Chapter 1.3: Primordial Gravitational Waves and Inflation

- Even an upper limit on the amplitude of primordial gravitational waves at CMB-S4 sensitivity would also be extremely informative
- A non-detection of primordial gravitational waves would rule out a large class of inflationary models
- Other tests (non-gaussianity, etc.) of inflation picture



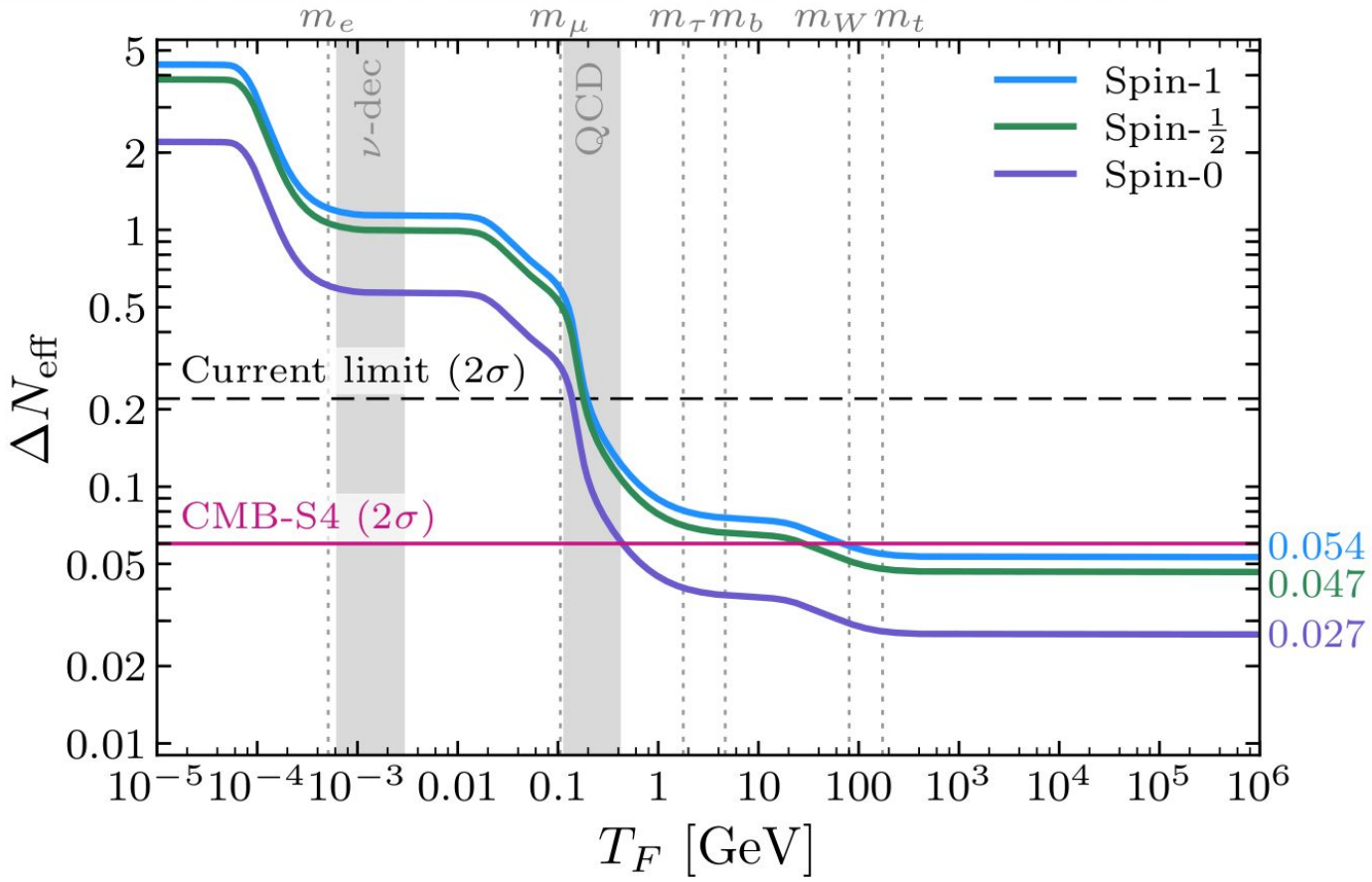
Forecasted constraints in n_s - r plane assuming r = 0

Chapter 1.4: The Dark Universe



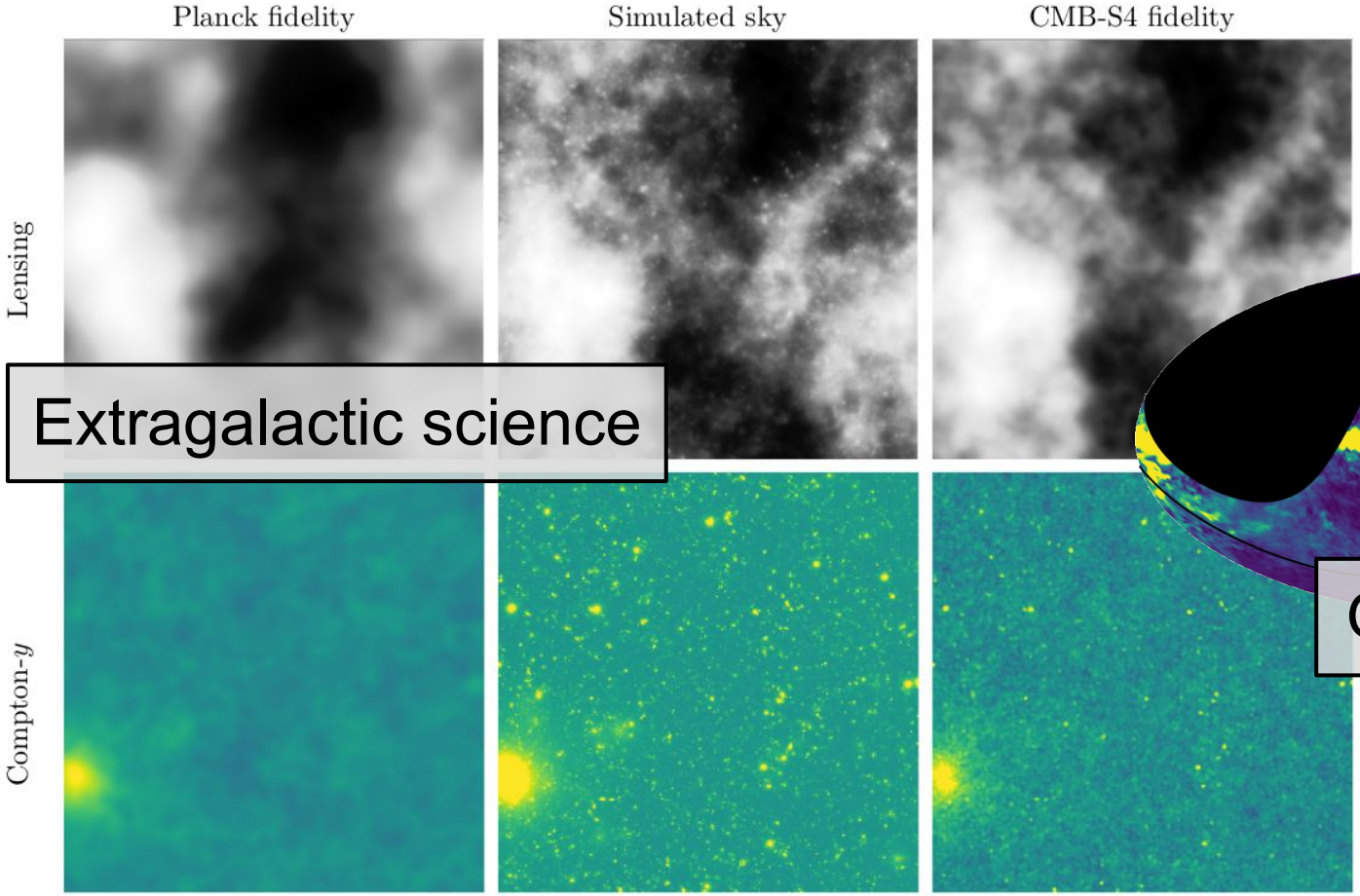
CMB-S4 will probe dark sector physics across a very wide range in mass

Chapter 1.4: The Dark Universe

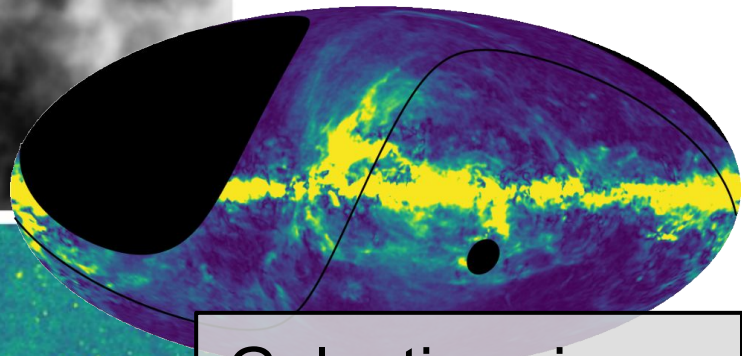


Light relics: limits on $N_{\rm eff}$ and the freeze-out temperature for different particle types

Chapter 1.5: Mapping Matter in the Cosmos



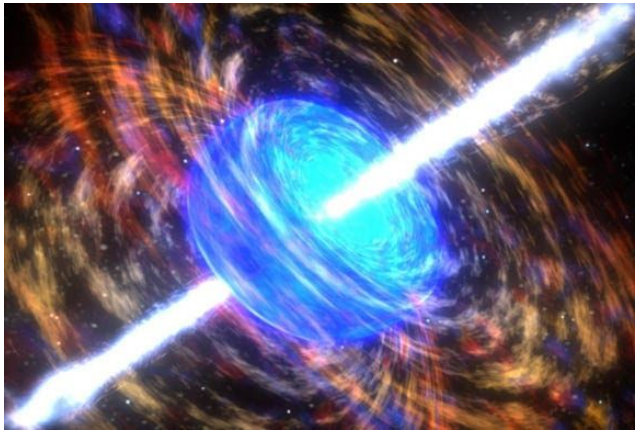
Extragalactic science

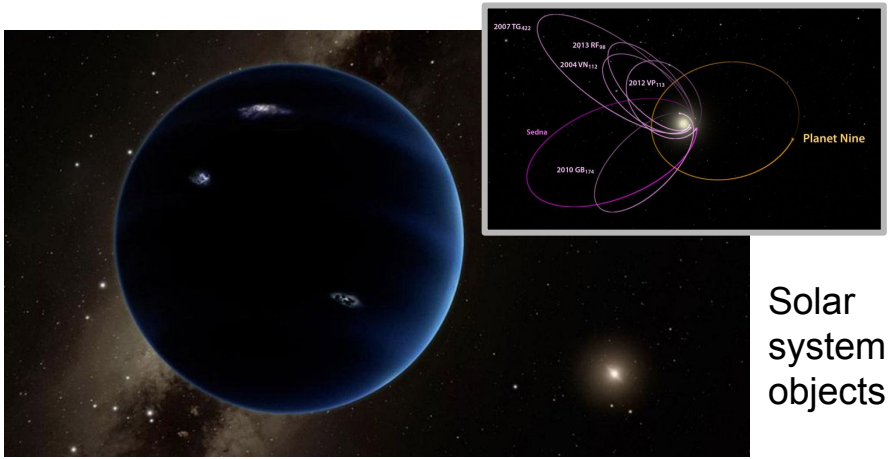


Galactic science

Chapter 1.6: The Time-Variable mm-wave Sky

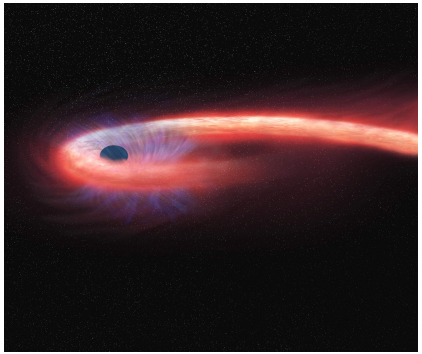
Gamma ray bursts

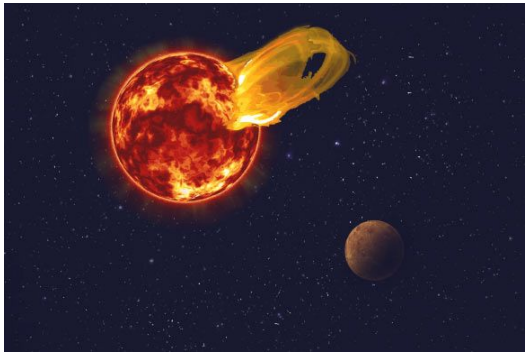




Solar system objects

Tidal disruption events





Stellar flares

Chapter 2: Science and Measurements Requirements

Four **science themes** get condensed into four **science goals**, the most important/challenging. These are **design drivers**.

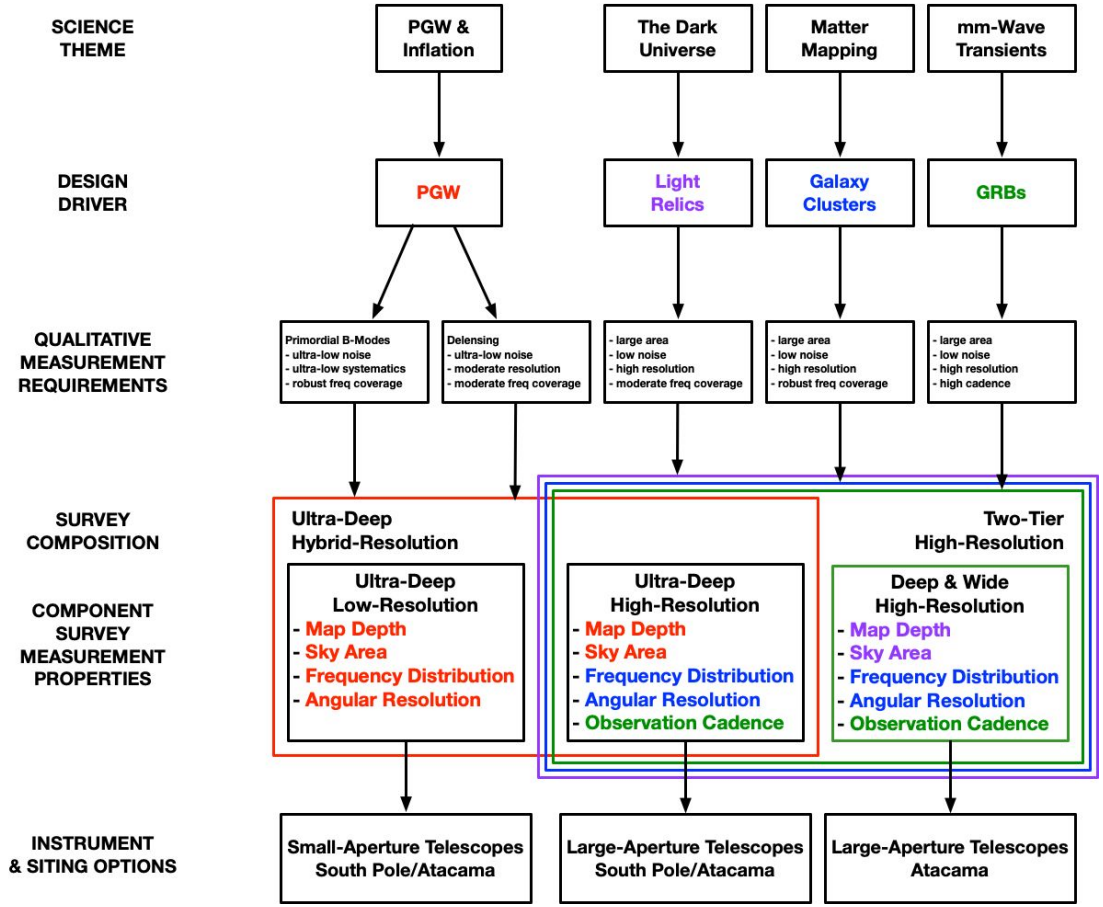
Status:

- Ready for collaboration reading and comments. Largely from Program Level Reqs.

Chapter 2.3: Science Requirements

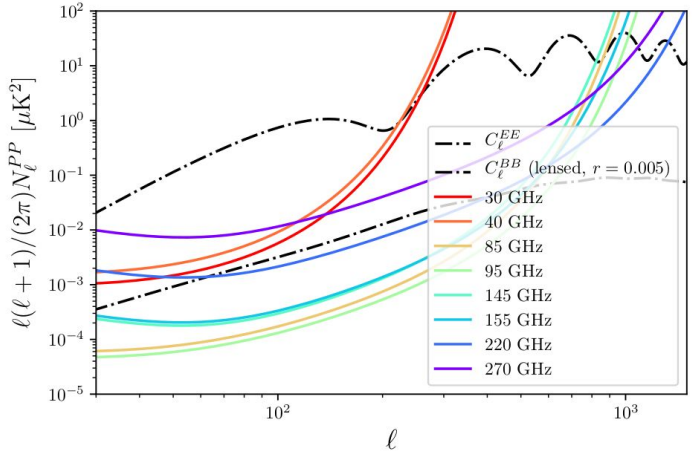
	Formal Science Goal	Science Requirement	Science Theme
PGW	Test models of inflation by measuring or putting upper limits on *r*, the ratio of tensor fluctuations to scalar fluctuations.	Placing upper limit on r of $r \leq 0.001$ at 95% confidence if $r = 0$, or by measuring r at a 5σ level if $r > 0.003$.	PGW & Inflation
Light Relics	Determine the role of light relic particles in fundamental physics, and in the structure and evolution of the Universe.	$\Delta N_{eff} \leq 0.06$, 95% confidence	Dark Universe
Galaxy Clusters	Measure the emergence of galaxy clusters as we know them today. Quantify the formation and evolution of the clusters and intracluster medium during this crucial period in galaxy formation.	(1) Detect at $\geq 5\sigma$ all galaxy clusters at $z \geq 1.5$ with an integrated Compton $Y_{SZ,500} \geq 10^{-12}$ over 50% of the sky. (2) Detect at $\geq 5\sigma$ all galaxy clusters at $z \geq 1.5$ with an integrated Compton $Y_{SZ,500} \geq 5 \times 10^{-13}$ over 2.8% of the sky.	Mapping matter
GRBs	Explore the mm-wave transient sky. Measure the rate of mm-transients for the first time. Use the rate of mm-wave GRBs to constrain GRB mechanisms. Provide mm-wave variability and polarization measurements for stars and AGN.	Detect γ-ray-burst afterglows brighter than 30 mJy at 93 and 145 GHz	Transient sky

Chapter 2.4: Measurement Requirements



Chapter 2.4: Measurement Requirements

Noise curves: e.g.
Ultra-deep, low-res



- Measurement requirement noise curves specified - Chapter 2.
- Logic of PBDR design validation. Need to show:
  - Design exceeds measurement requirements - Chapter 3 and A.1
  - Measurement requirements meet science requirements - A.2

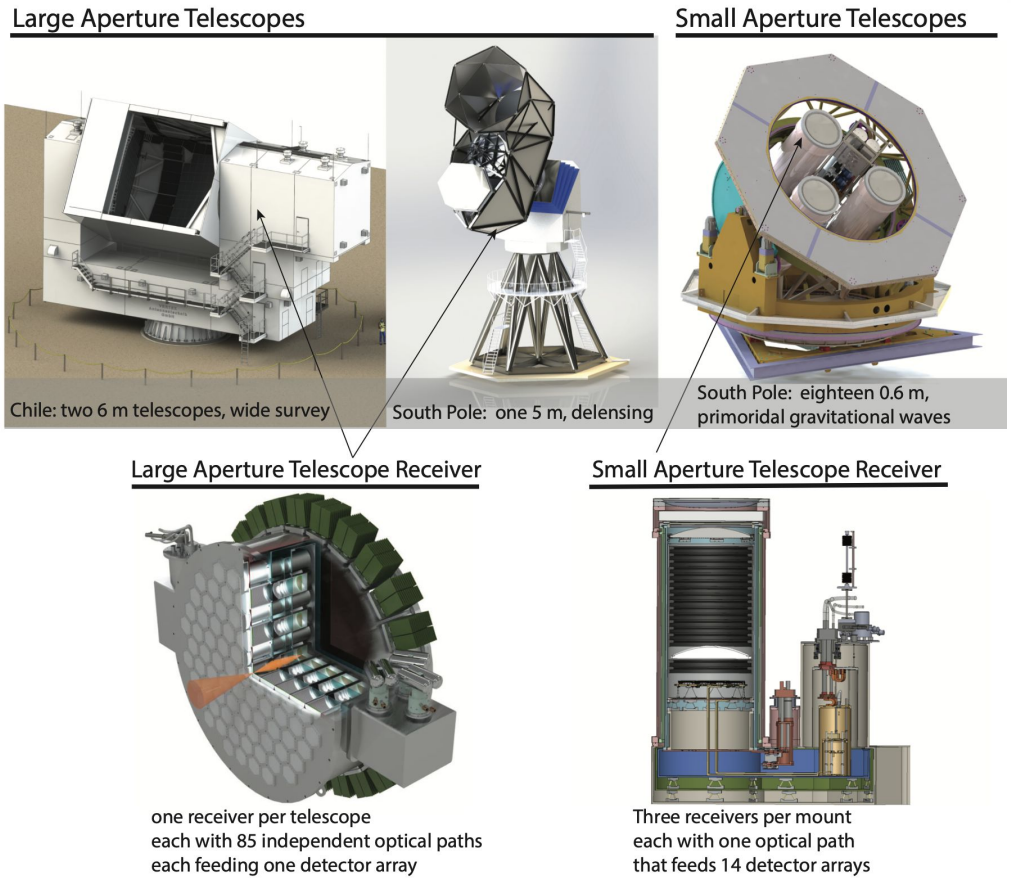
Flowdown plenary 1st session Tuesday:
science ↔ **measurement** ↔ **technical**

Chapter 3: Preliminary Baseline Design

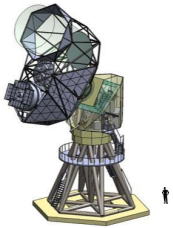
3.1 PBD Overview

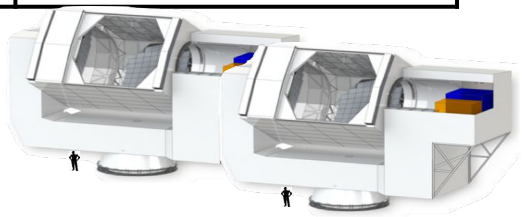
Status:

- Draft is in progress. Being updated from the DSR; defines the overall technical design and *will* define the surveys.
- Related workshop sessions:
  - Essentially all technical sessions!
- For survey definition:
  - Tuesday morning “flowdown” Plenary (J. Ruhl)
  - Thursday Technical to Measurement Plenary/Parallel sessions (Reijo Keskitalo)



Science Requirements \ Measurement Reqts.	Ultra-deep low res survey MR 1.1 • Deg res small aperture telescope telescopes for systematics • 6 bands; ≥3% of sky	Ultra-deep high res survey MR 1.2 • arcminute res & overlap w/ ultra-deep low res for delensing • 7 bands; ≥3% of sky	Deep-wide high res survey MR 2.0, 3.1, 3.2, 4.0 • Arcminute resolution • 6 bands; 70% of sky • daily cadence (for 25% of sky)
SR 1.0 Inflation • Set 95% confidence upper limit at r ≤ 0.001; • If r > 0.003: measure at equivalent 5σ	✓	✓	
SR 2.0 Light Relics • ΔNeff ≤ 0.06, 95% confidence			✓
SR 3.1, 3.2 Emergence of Clusters • z > 1.5 clusters (wide) • z > 1.5 clusters (deep)		✓ (lower mass)	✓ (more sky)
SR 4.0 mm-wave Transients • GRB afterglows > 30 mJy		✓ (higher cadence)	✓ (more sky)





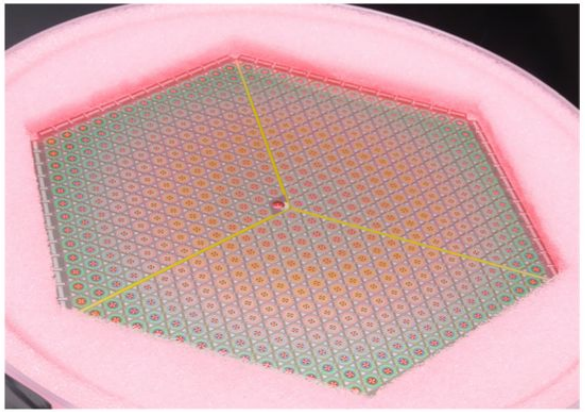
South Pole: fields do not rise-set; provides continuous 24/7 observing (deepest in fixed time frame for limited sky)

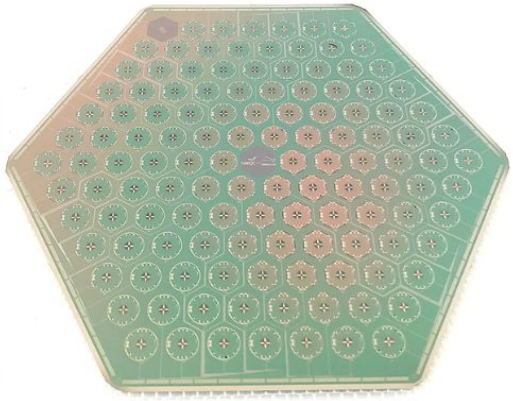
Chile: nearly full sky observable from site; provides deep maps of ~70% of the sky

Chapter 3.2: Detectors

Status:

- Draft is work in progress. The detector PBD is the same as the Reference Design. Most downselects have been made. Several issues remain.
- Related workshop sessions:
  - Wednesday Detector Plenary/Parallel sessions (Brenna Flaugher)





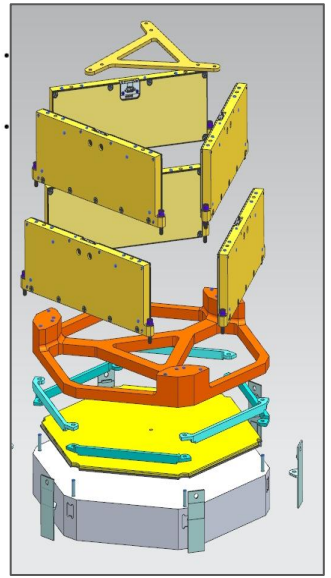
Rhombus and/or Hex pixel layout?

Chapter 3.3: Readout

Status:

- Draft ready for comments; PBD is advanced version of the DSR Reference Design
- Related workshop session:
  - Tuesday Readout Plenary/Parallel (Zeesh Ahmed)

Chapter 3.4: Module Assembly and Testing



Status:

- Draft ready for comments.
  Modules PBD is advanced version of the DSR Reference Design
- Related workshop session:
  - Thursday Module Assembly & Testing Plenary/Parallel (Brad Benson)

Chapter 3.5: Large Aperture Telescopes

Status:

- Nearly ready for comments. LAT PBD has changed significantly from DSR Reference Design; new SP-LAT, LATR, LATCR and I&C equipment added
- Related workshop session:
  - Wednesday Large Aperture Telescopes Plenary/Parallel (Mike Niemack)

Chapter 3.6: Small Aperture Telescopes

Status:

- Ready for comments. SAT PBD basically an advanced version of the DSR Reference Design; I&C equipment added.
- Related workshop session:
  - Tuesday Small Aperture Telescopes Plenary/Parallel (John Kovac)

Chapter 3.7: Data Acquisition and Control

Status:

- Draft ready for comments; DAQ PBD is advanced version of the DSR Reference Design
- Related workshop session:
  - Wednesday Data Acquisition and Control Plenary/Parallel (Laura Newburgh)

Chapter 3.8: Data Management

Status:

- Draft ready for comments; DM PBD is expanded and advanced version of the DSR Reference Design; Added DM for transients
- Related workshop session:
  - Tuesday Data Management Plenary/Parallel (Julian Borrill)

Chapter 3.9: Sites

Status:

- Draft in progress. The Sites PBD is similar to the DSR Reference Design. Commissioning and calibration scope needs to be drafted. I&C equipment moved to LATs and SATs
- Related workshop sessions:
  - Thursday Site Infrastructure, Integration & Commissioning Plenary/Parallel sessions (Amy Bender & Kam Arnold)

Chapter 4: Science Analysis

Status:

- Draft in-progress and needs some updates compared to DSR. Chapter reorganized to call out the design drivers separately from the complementary parts of the scientific program.
- No dedicated workshop session, but sessions on design validation for science and the complementary science case will address analysis.

Chapter 5: Project Plan

Status:

- Compared to the DSR, it will be rewritten to reflect the updated project structure. Will not include detailed cost and schedule information. Not ready for comment at this time.
- No directly related workshop sessions, other than the previous project update plenary.

Appendices: Design Validation

Appendices: Design Validation

A.1 Technical to Measurement Requirements Status:

- Not yet drafted. Path to be drafted by April 30; Completed by end of Summer
- Relevant workshop sessions to advance the validation of the T2M:
  - Tuesday morning “flowdown” Plenary (Instrument parameters, J. Ruhl)
  - Tuesday Data Management Plenary/Parallel sessions (J. Borrill)
  - Thursday Technical to Measurement Plenary/Parallel sessions (Reijo Keskitalo)

A.2 Measurement to Science Requirements Status:

- Partly in place; mainly updating from the DSR; Complete by April 30
- Relevant workshop sessions on the validation of the M2S:
  - Wednesday Plenary/parallels:
    Tensor-to-Scalar Ratio (Colin Bischoff & Kimmy Wu)
    Galaxy Clusters (Nicholas Battaglia)
  - Thursday Plenary/parallels:
    Light relics (Christian Reichardt & Marilena Loverde)
    Transients (Joaquin Vieira)

Questions?

Next step for PBDR is to do the work of the workshop.