The Design of The CCAT-prime Epoch of Reionization Spectrometer Instrument

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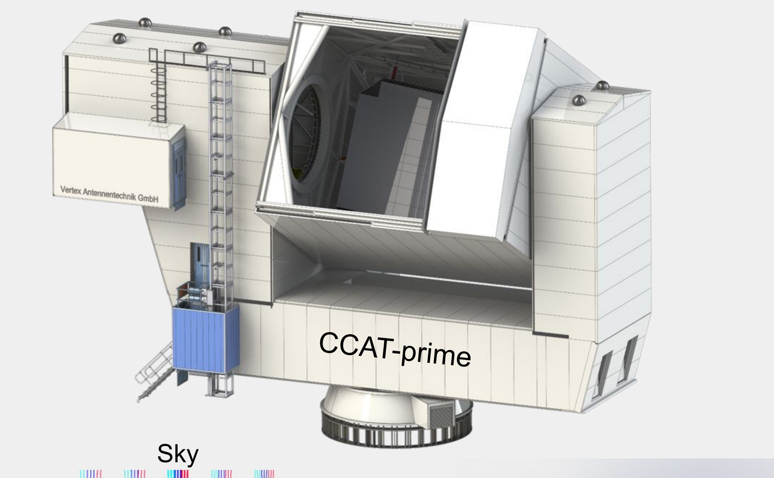
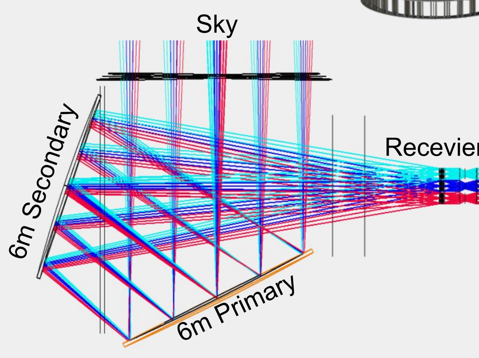
Introduction: EoR-spec

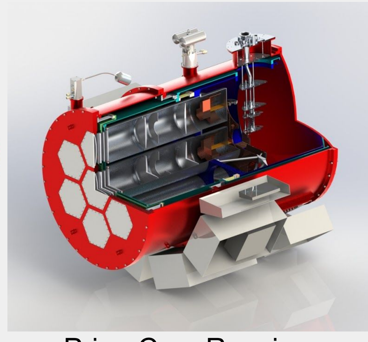
- **EoR-Spec is a 210-420 GHz intensity mapping spectrometer** for the CCAT-prime telescope.
- Cryogenic scanning FPI & dichroic superconducting detector arrays.
- Tomographic maps of **[CII] line emission at redshifts 3.5 - 8**.
- Lower redshifts, observe galaxies during the period of peak star formation - when most stars in today's universe were formed.
- Higher redshifts, trace formation of large-scale clustering of early star-forming galaxies, and the late stages of reionization.
- Combining CCAT-prime's location and large field of view with EoR-Spec enables efficient mapping of the epoch of reionization. [1]

CCAT-prime Telescope





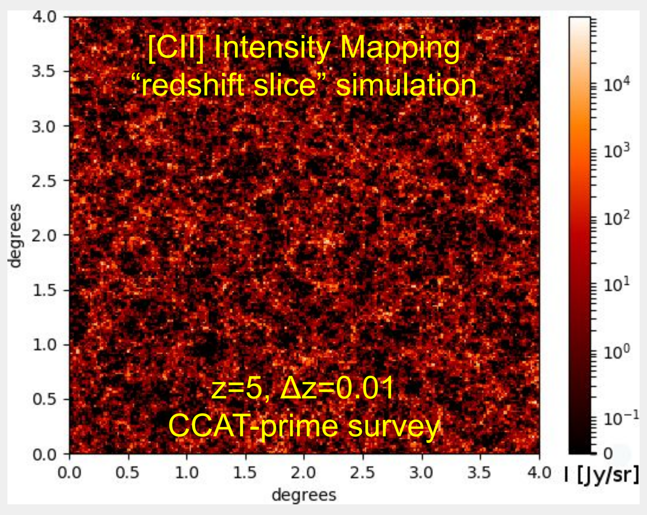
Ray trace of CCAT-prime

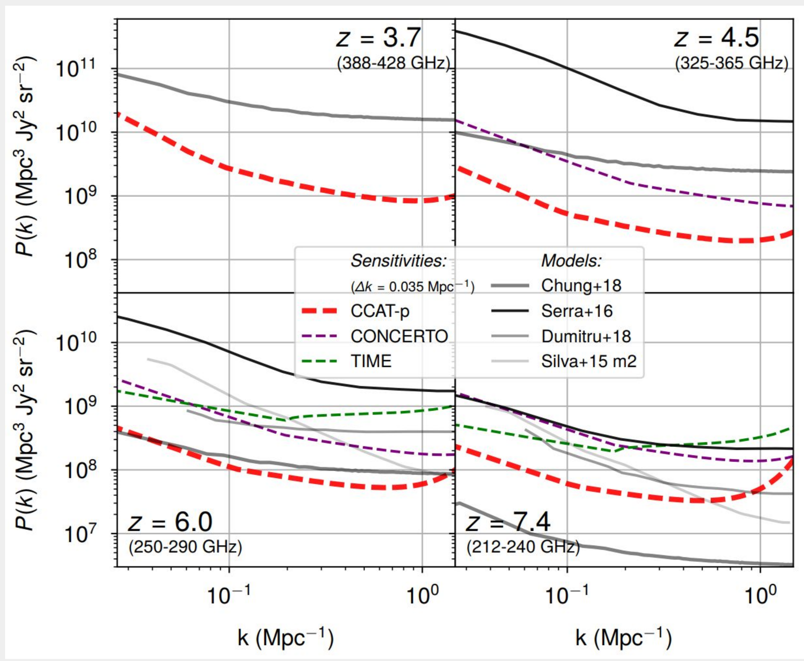


PrimeCam Receiver

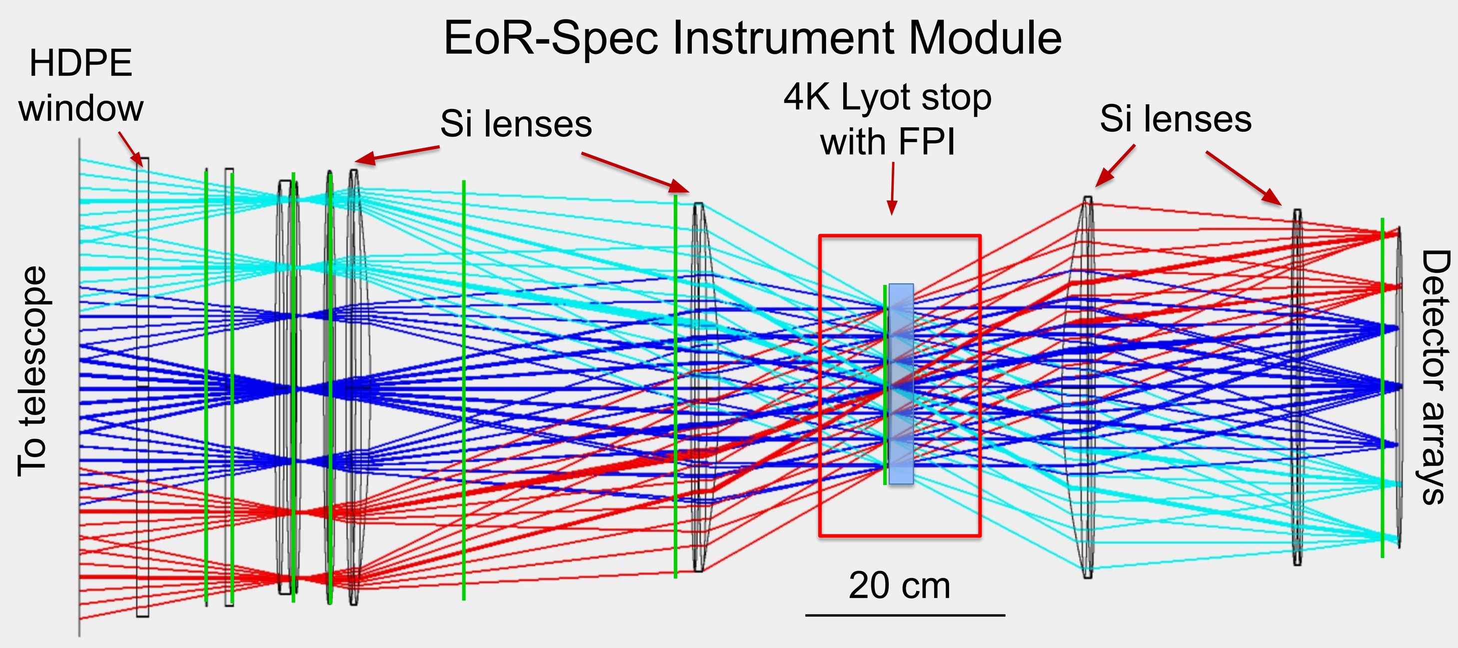
- 5600m, Atacama Desert, Chile [2]
  - Extremely low water vapor
- 6m Crossed Dragone
  - High throughput
  - Wide field of view
- PrimeCam Receiver
  - Up to seven instrument modules
  - 1.4° field of view per module
- EoR-Spec module
  - 4K FPI at Lyot stop
  - 100mK superconducting detectors

Intensity Mapping of [CII] from EoR





[CII] emission sensitivity estimates of EoR-Spec over 16deg^2 survey

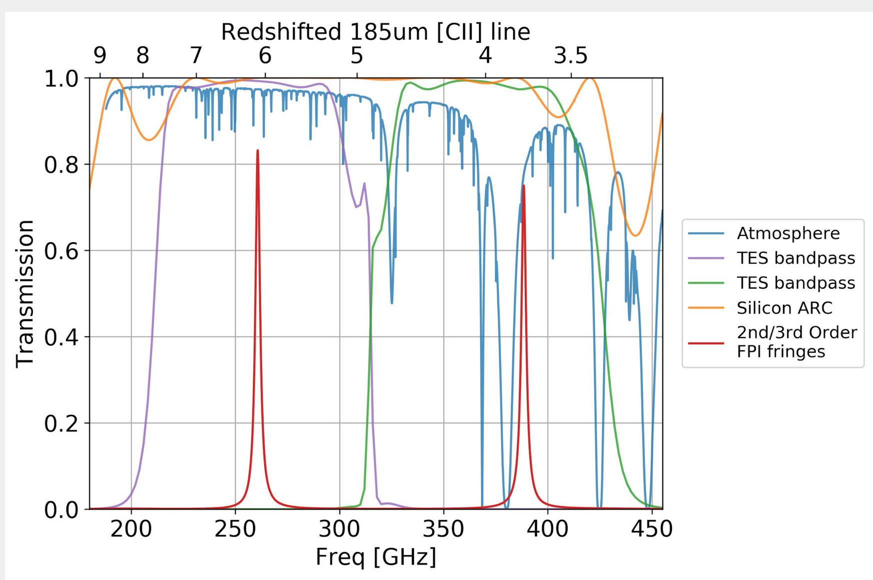


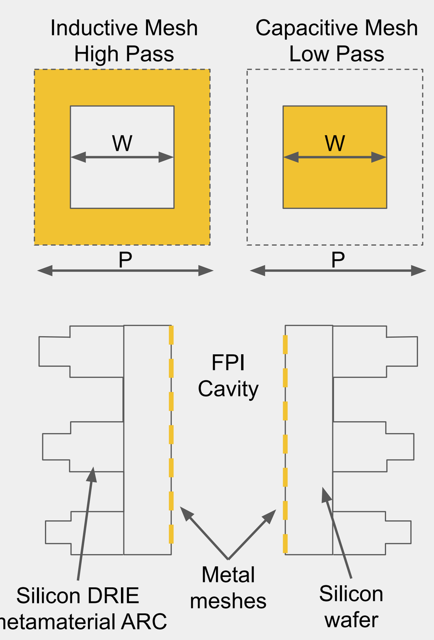
- Sources of reionization numerous but very faint
  - Direct observations of individual sources difficult
- Line intensity mapping [3] overcomes this challenge
  - Measure spatial fluctuations of aggregate emission from galaxies
  - Diffraction limited beams (~60"/30" for 210/420 GHz) well matched to EoR clustering
- **The 158 µm [CII] line traces star formation**
  - When cross correlated with the 21-cm HI line, it tracks reionization from EoR forward
  - [CII] probes the formation and growth of the first galaxies
  - [CII] provides maps of gravitational overdensities, revealing the growth of large-scale structure

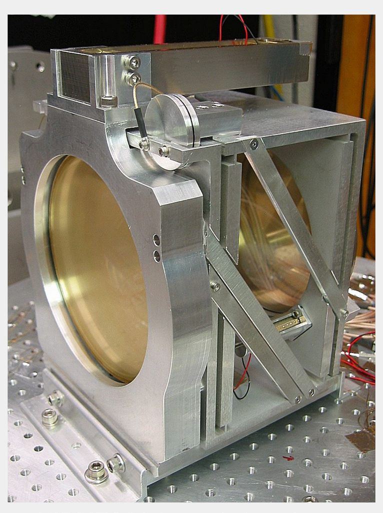
- EoR-Spec will:
  - Map [CII] emission at redshifts 3.5 - 8
    - 210 - 420 GHz
    - Spectral resolution R=100
  - Survey of 16 deg^2 patch of the sky
    - 1-30 Mpc spatial scales

Silicon Substrate Fabry-Perot Interferometer

- Silicon substrate mirrors [4]
  - Minimize ohmic losses
  - Improve thermal performance
  - Mechanically stable substrate
- Metal mesh reflectors [5]
  - Lithographically patterned meshes
  - Combine inductive and capacitive geometries to improve bandwidth
  - 2nd order, resolving power ~100
- Metamaterial ARC
  - Minimize reflections from substrate
  - Micromachined with deep reactive ion etching (DRIE) [6]
  - Thermally matched to substrate
- Cryogenic scanning FPI
  - Stepper motor actuated

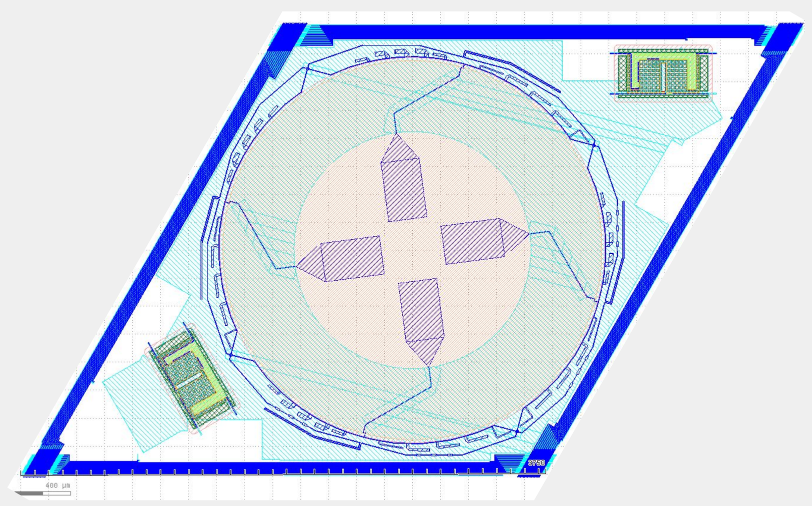




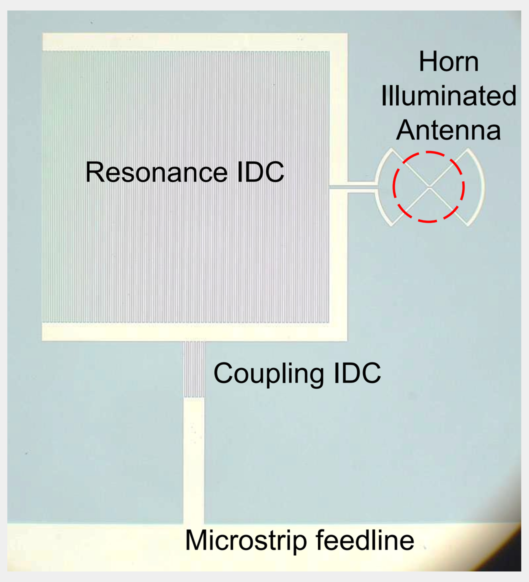


HIRMES high resolution, long wave FPI, R=100,000

Detectors and Readout



Dichroic TES



Unpolarized KID

- Focal plane of 3x 6-inch arrays
- Transition Edge Sensors (TESes)
  - N_{dets}~2000 detectors per array
  - Dichroic pixels, polarizations lumped [7]
  - Aluminum feedhorn + OMT coupling
  - On-chip bandpass filtering
  - Strong heritage from fielded arrays [8]
  - Proven low background devices
  - Baseline detector architecture
- Kinetic Inductance Detectors (KIDs)
  - N_{dets}~4000 detectors per array
  - N_{dets} linearly increases mapping speed
  - Bandpasses from horns and mesh filters
  - Proposal in review to investigate low-background KIDs
- FDM Readout
  - TES multiplexed by uMUX+SMuRF [9]
  - MKIDS readout using ROACH2

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Acknowledgements

- NFC supported by a NASA Space Technology Research Fellowship.
- MDN acknowledges support from NSF award AST-1454881.
- FPI development at CNF supported by NASA Grant NNX16AC72G.
- Cornell NanoScale Facility under NSF Grant ECCS-1542081.