KIDs for Next-Generation CMB Experiments

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CMB and the Cosmic Timeline

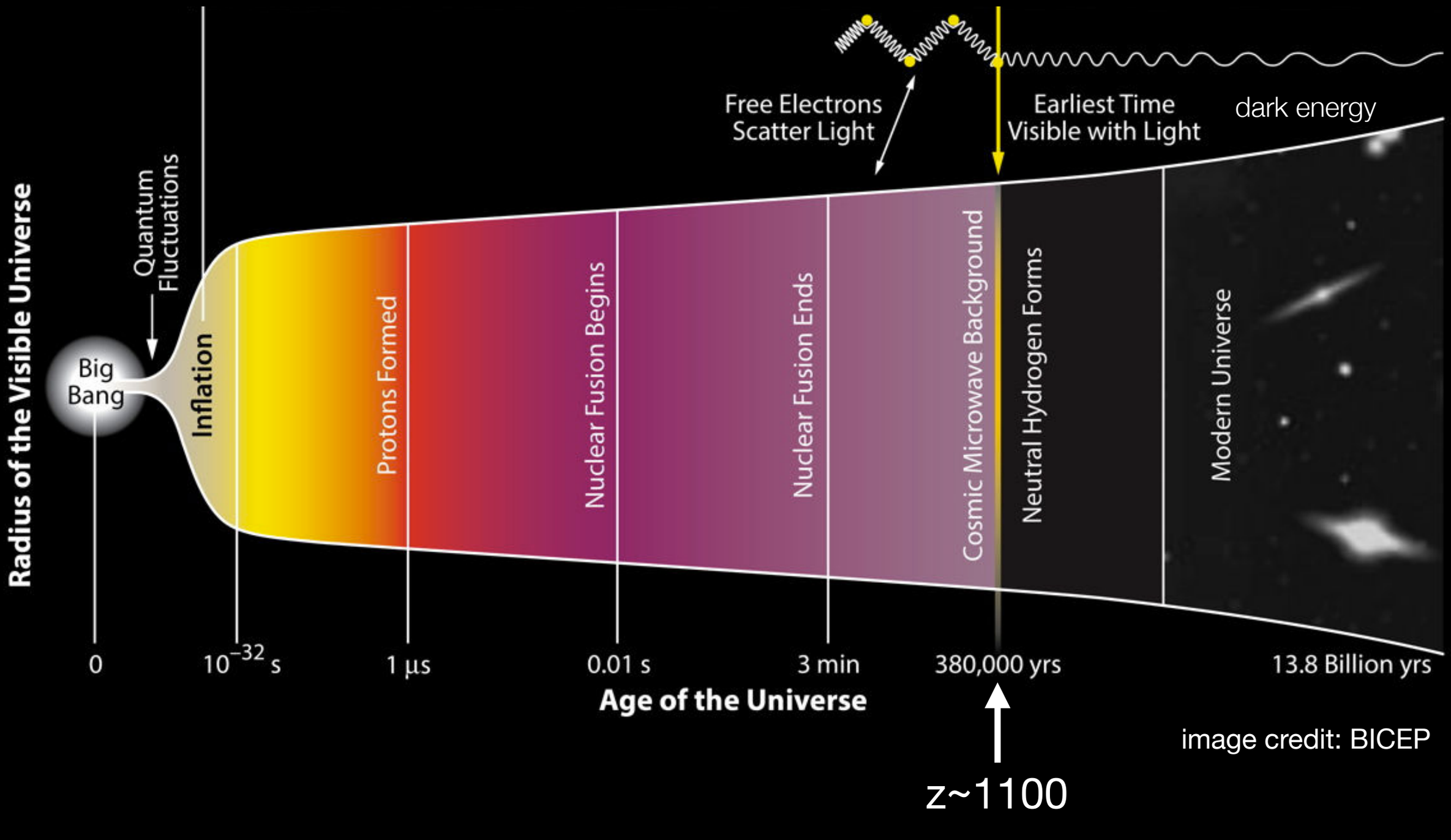


image credit: BICEP

CMB and the Cosmic Timeline

I. Recombination

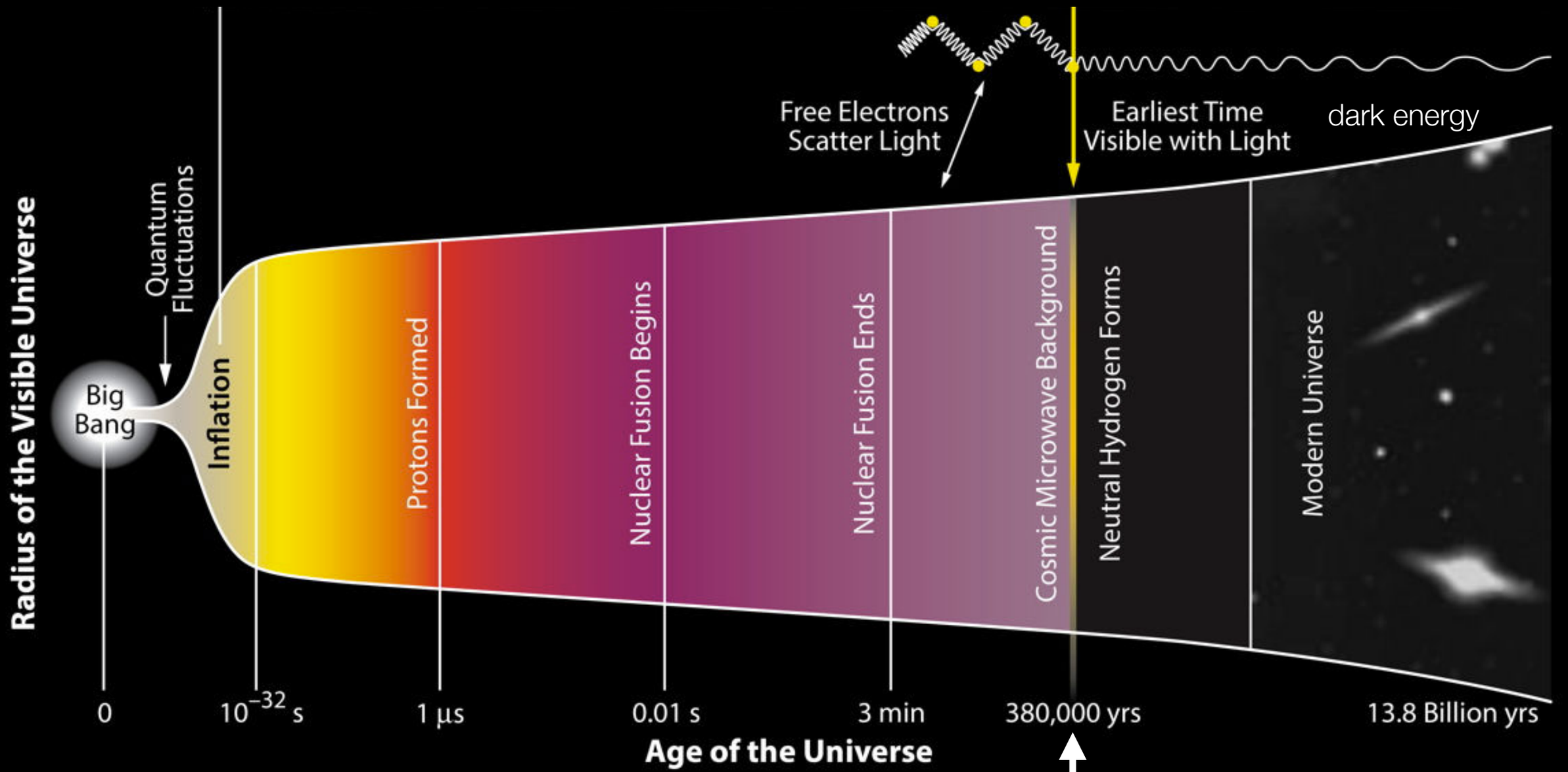
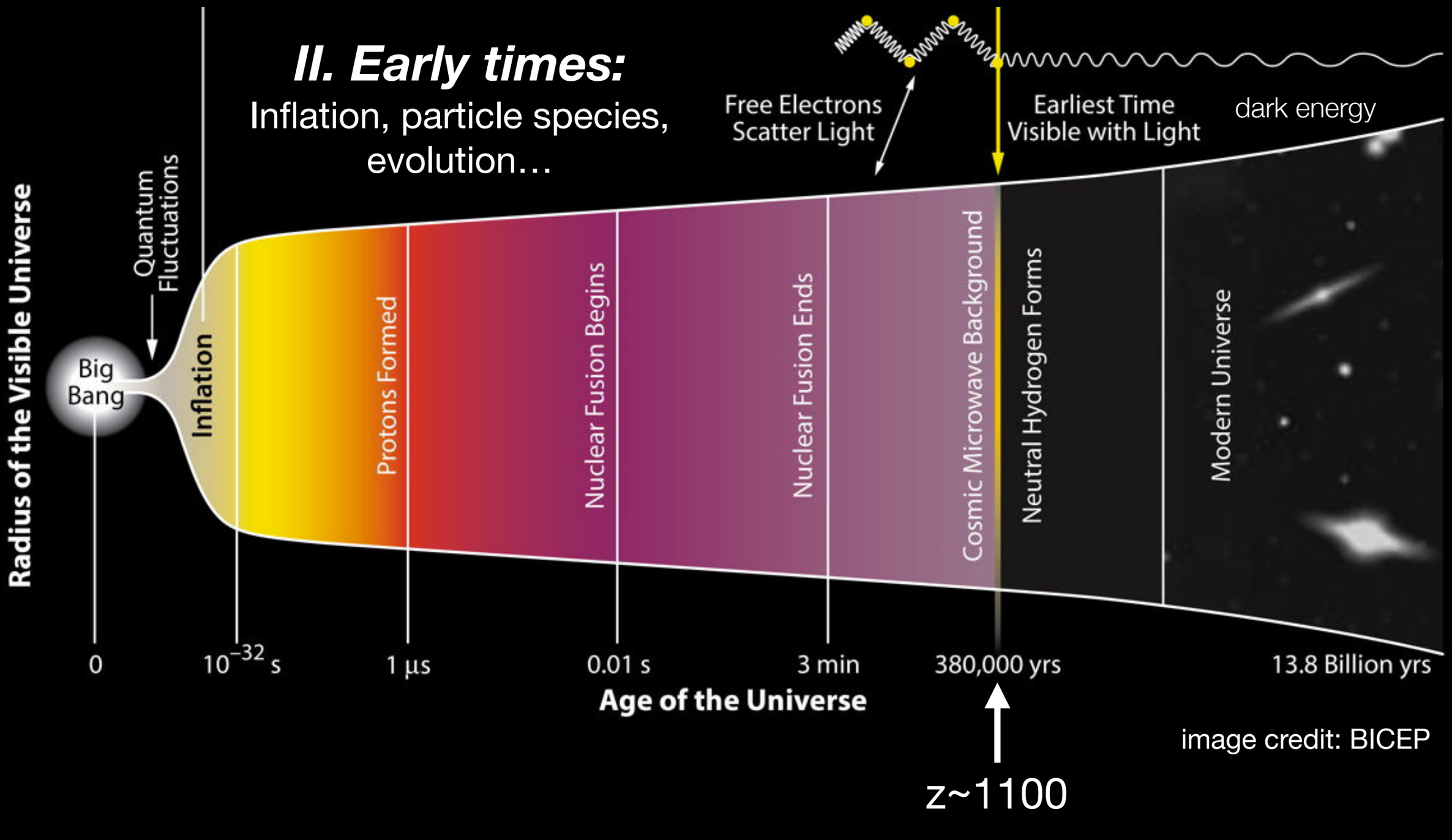


image credit: BICEP

z~1100

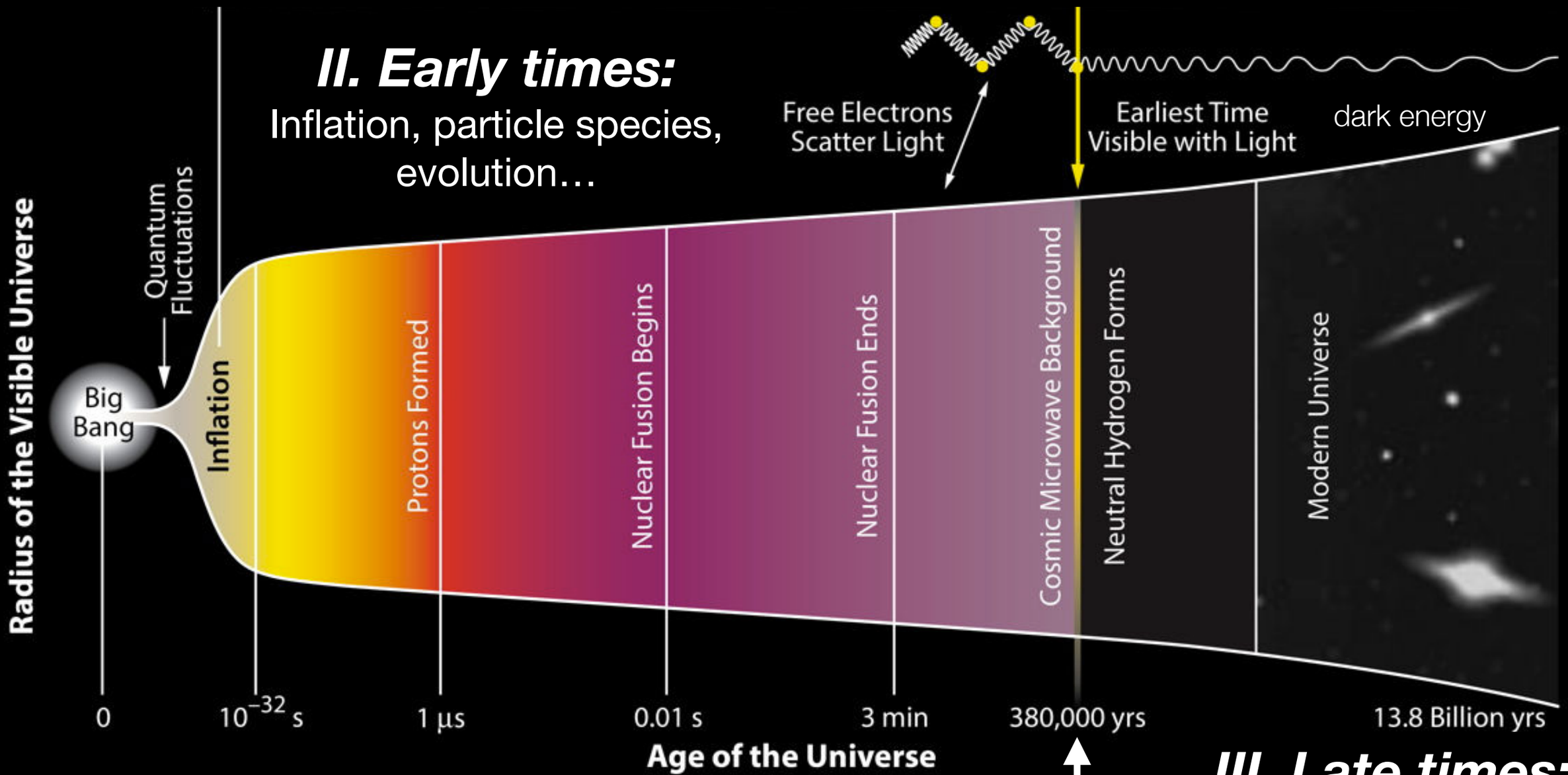
CMB and the Cosmic Timeline



CMB and the Cosmic Timeline

I. Recombination

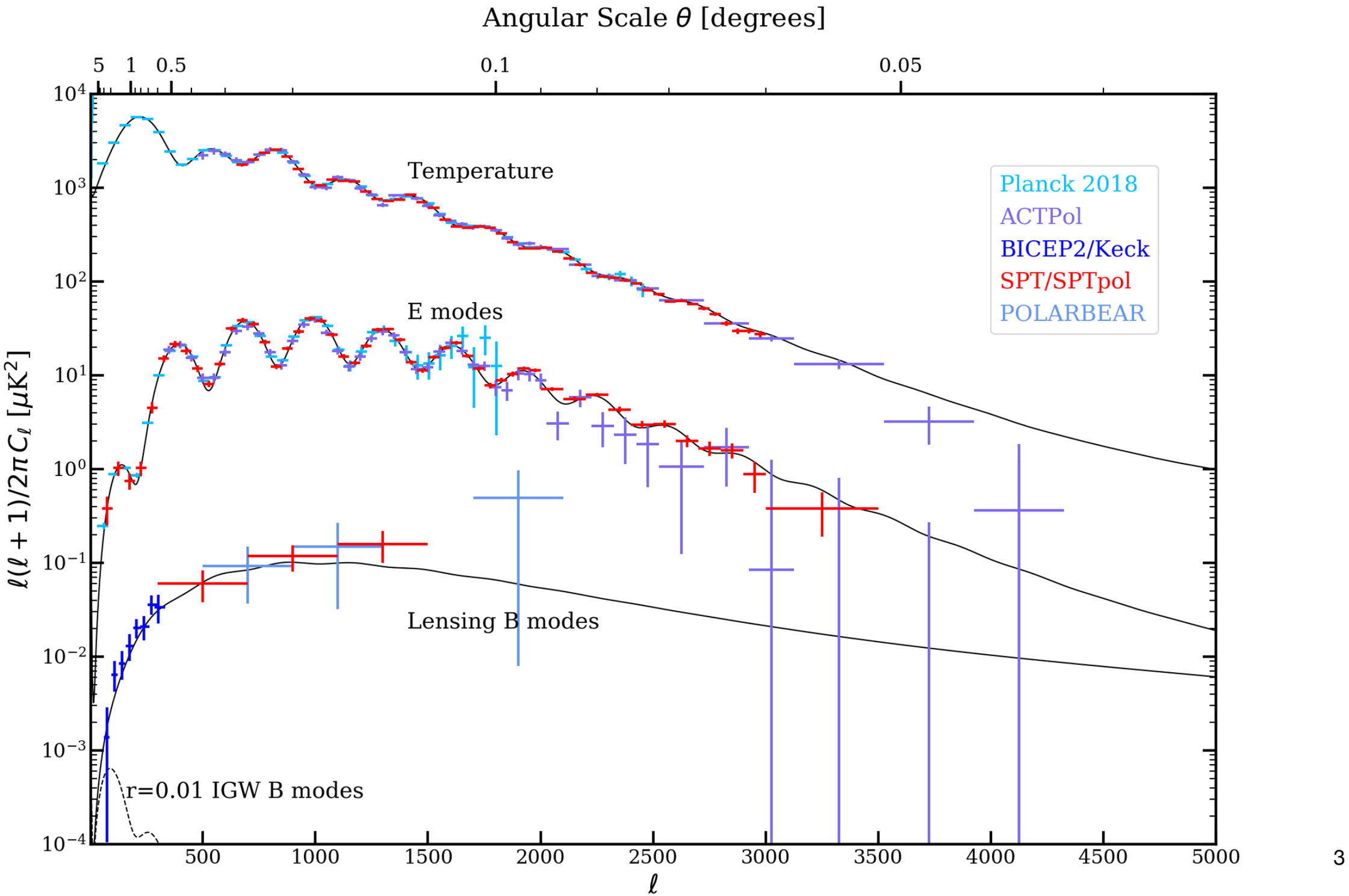
II. Early times:
Inflation, particle species, evolution…



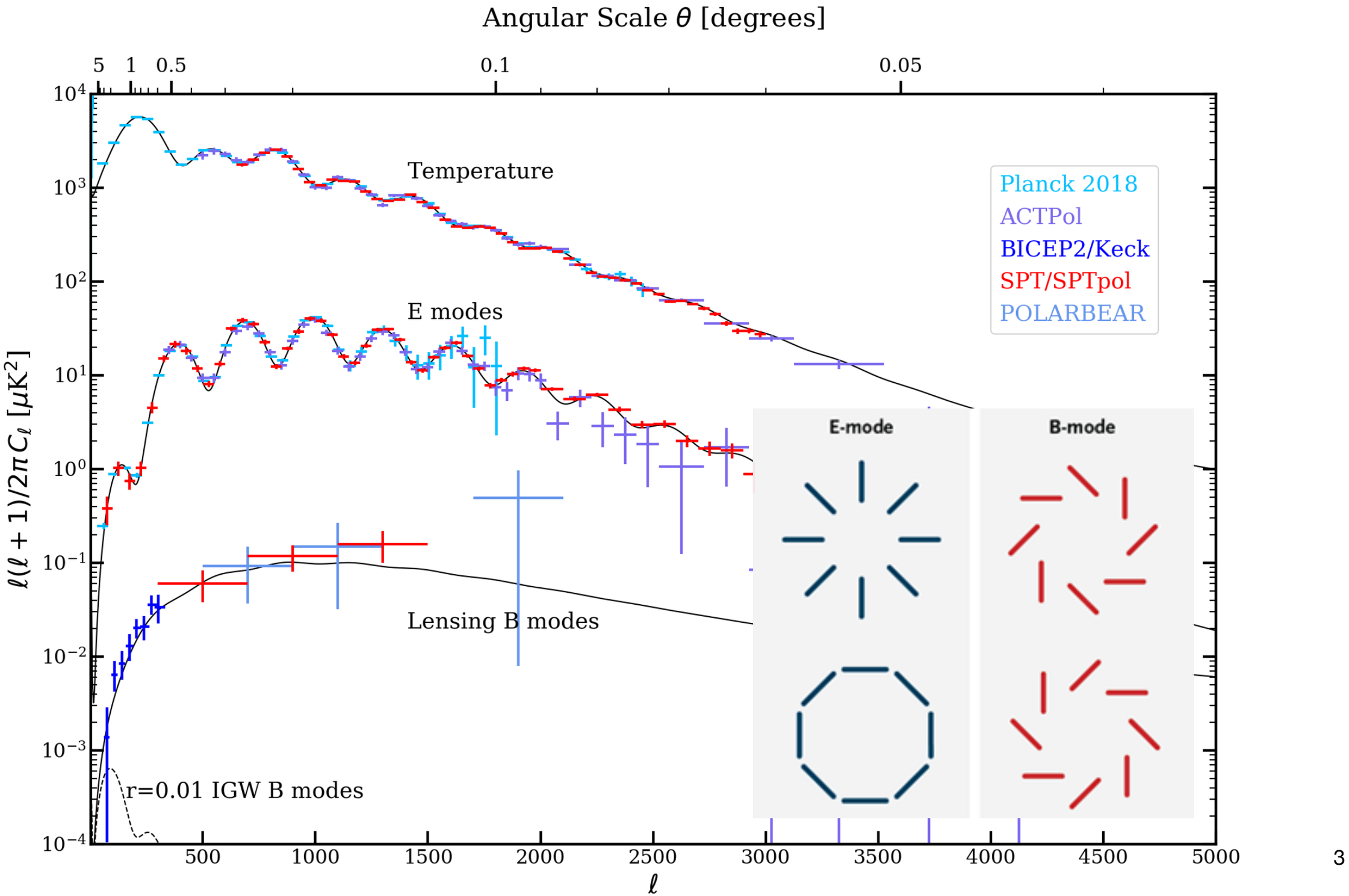
z~1100

III. Late times:
Gravitational lensing, structure formation…

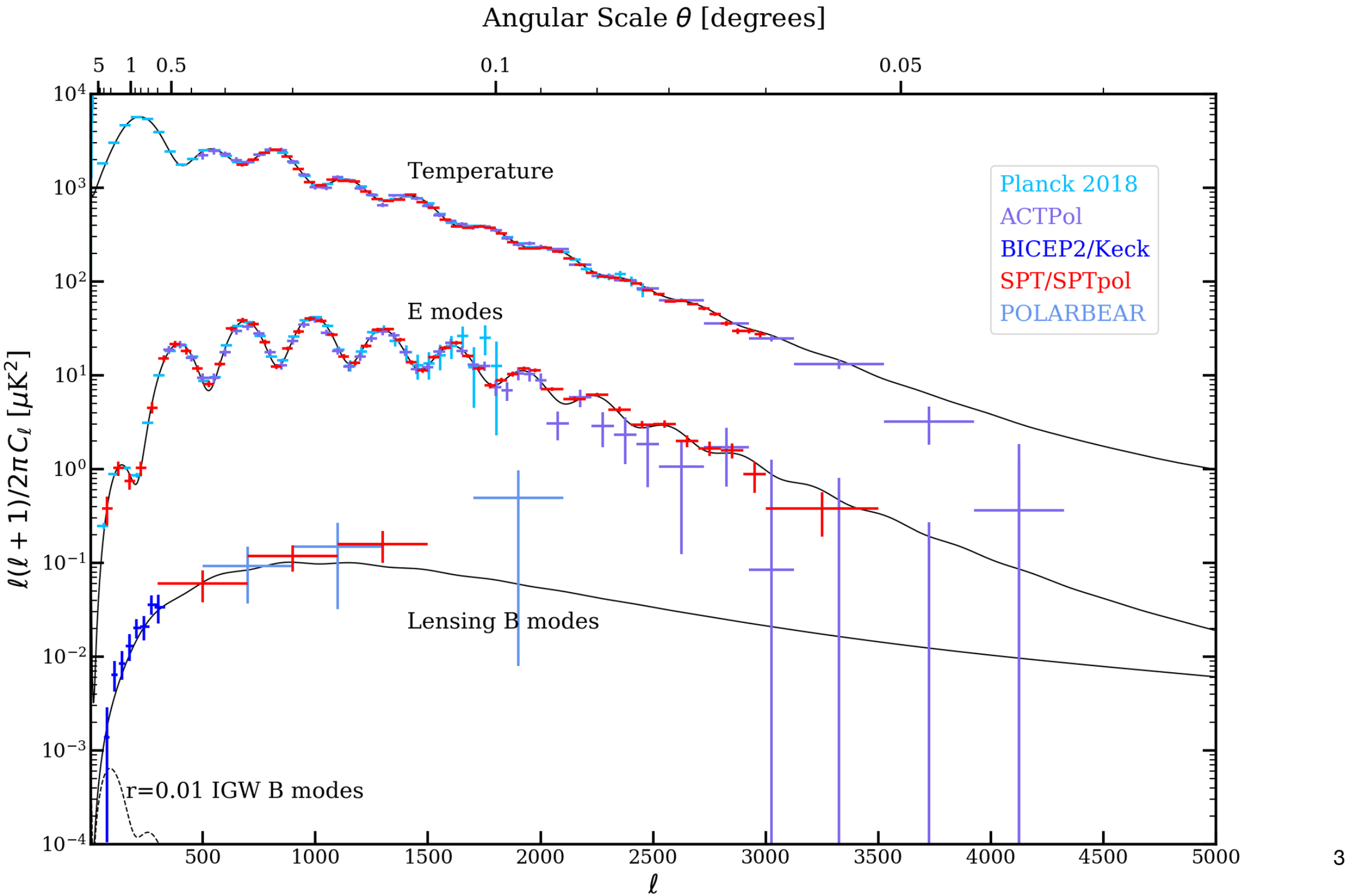
Power Spectra



Power Spectra



Power Spectra



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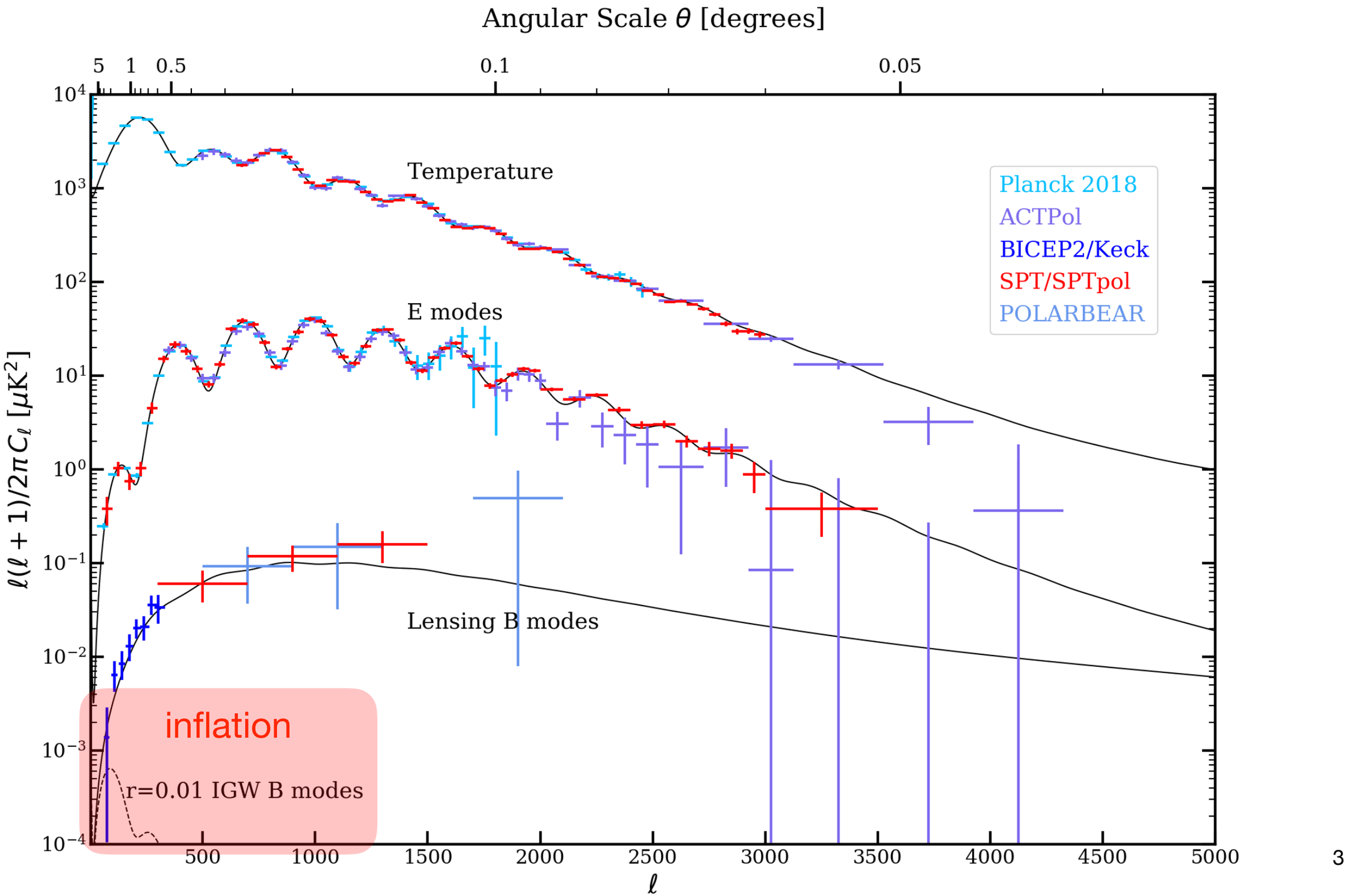
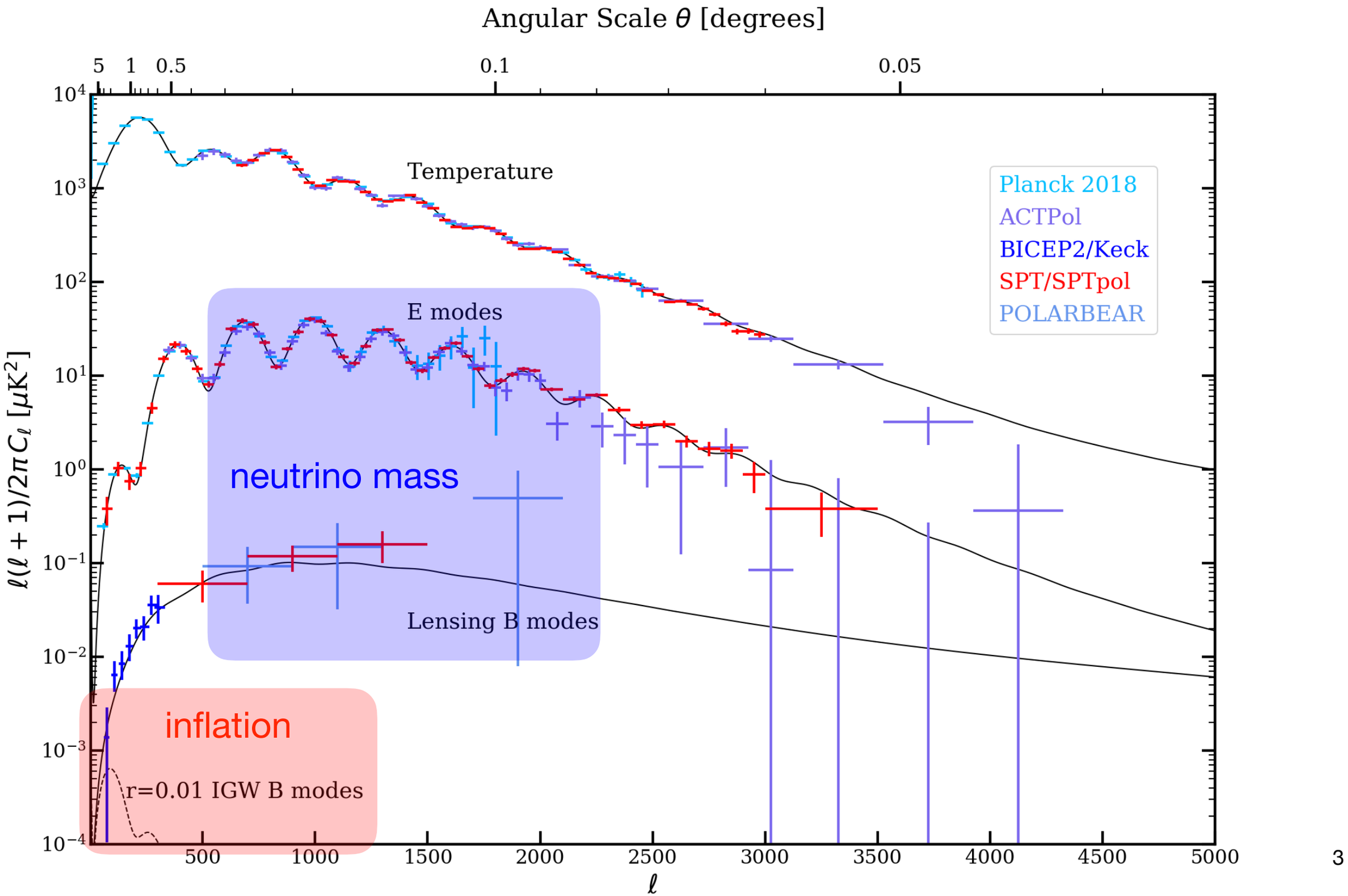
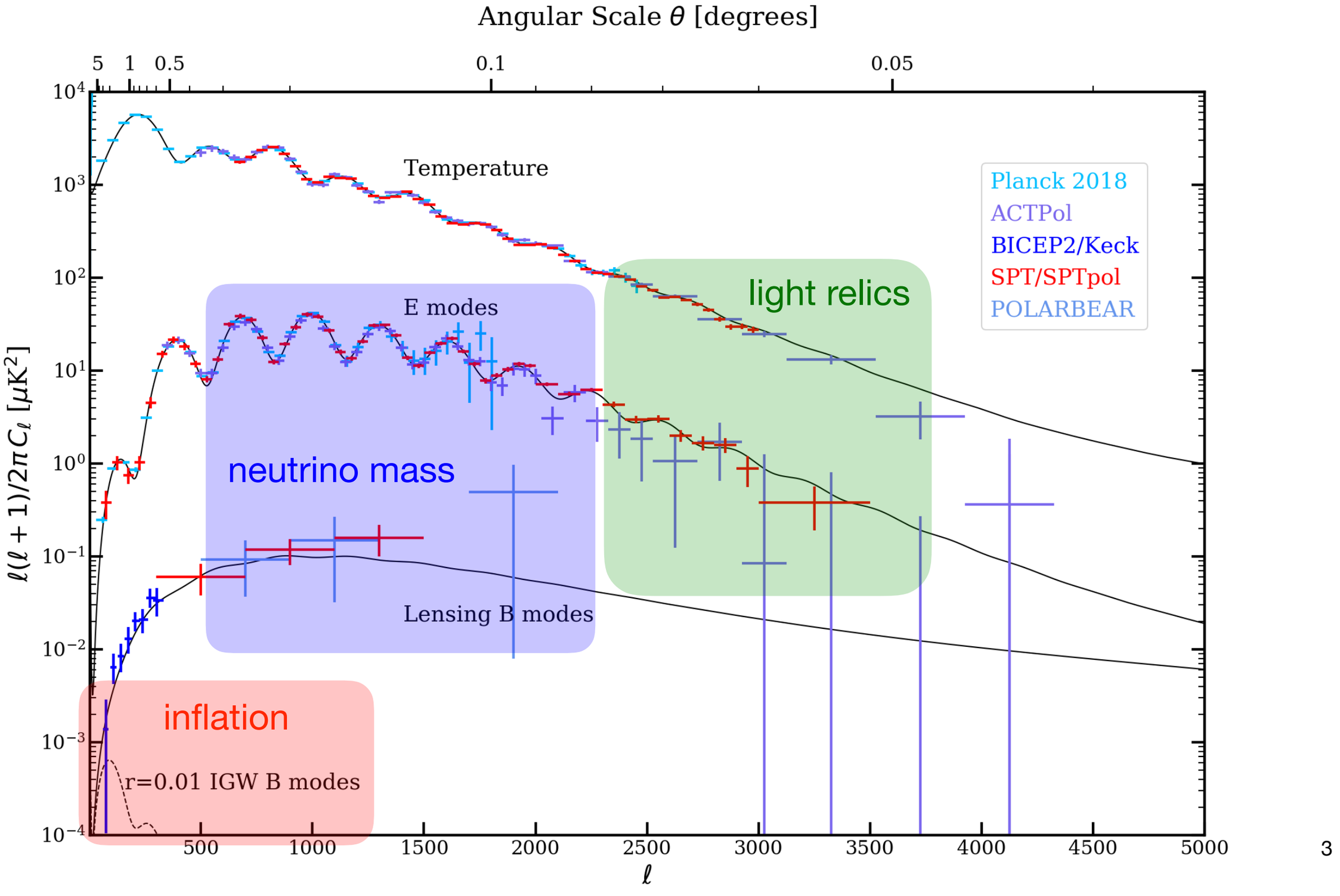


Power Spectra



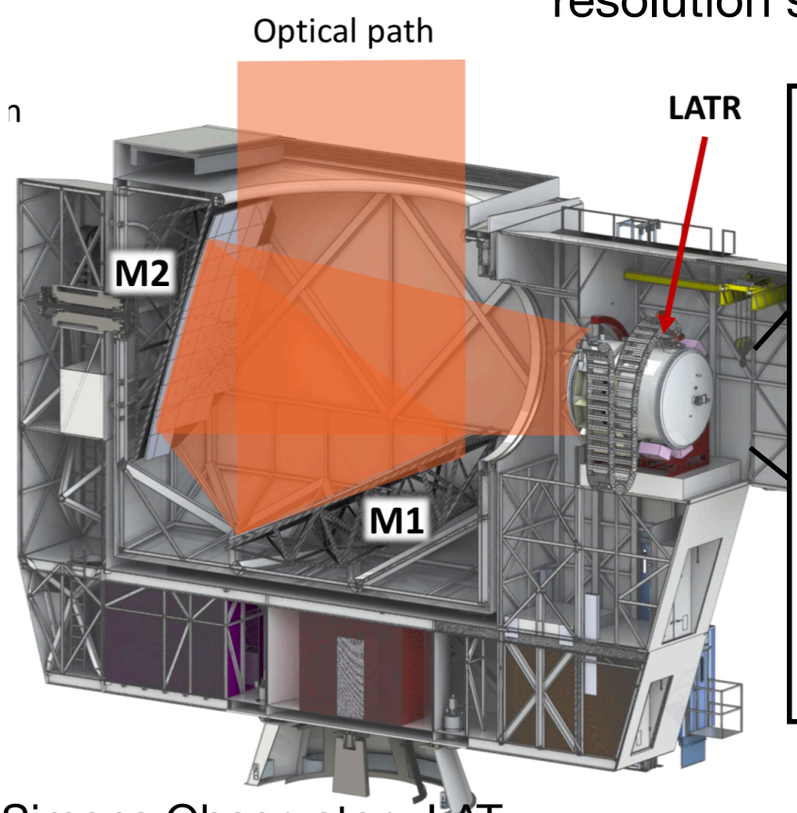
Power Spectra



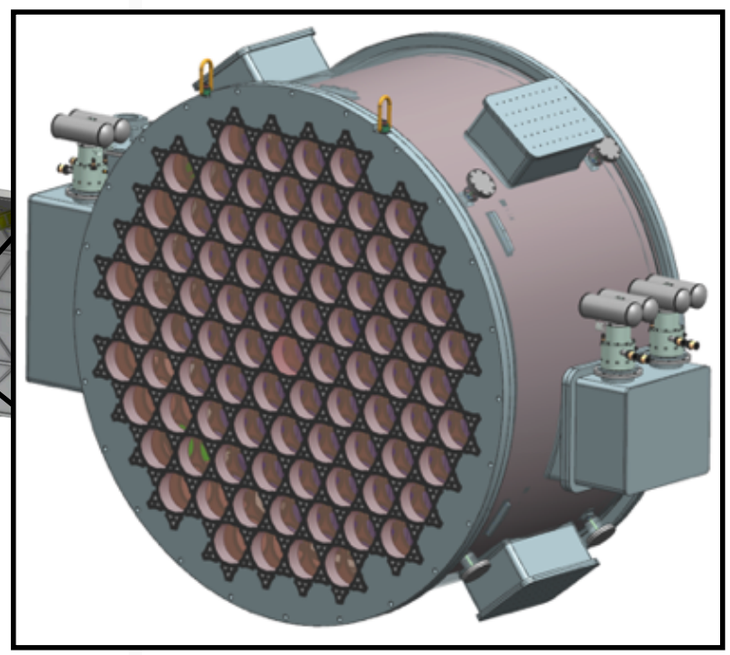
The CMB-S4 Concept

- Achieved DOE CD-0 in 2019! First light in 2026-2027.
- **Concept:**
  - **~500,000 detectors** split between 3x 6m-aperture, ~18x 0.5m-aperture telescopes
  - **Two sites:** Split between South Pole and Atacama in Chile
  - **Two surveys:** Inflation survey on 3-8% sky, neutrinos and cross-correlation on 40% sky
  - **~7 frequency bands:** 20, 30, 40, 95, 150, 220, 270 GHz for foreground characterization

Large aperture: delensing, neutrinos, high-resolution science

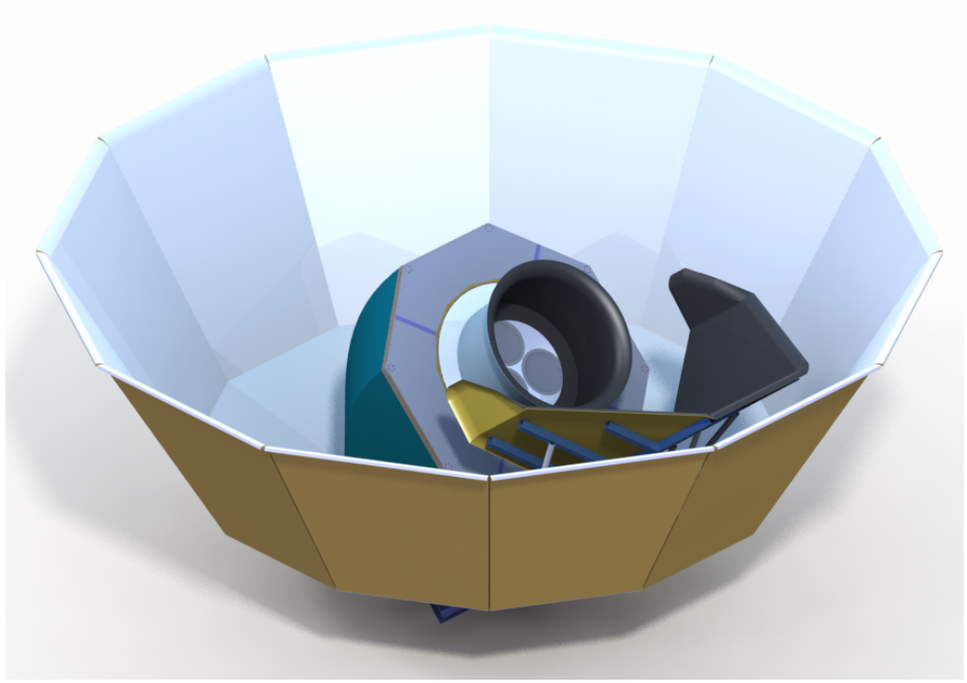


Simons Observatory LAT



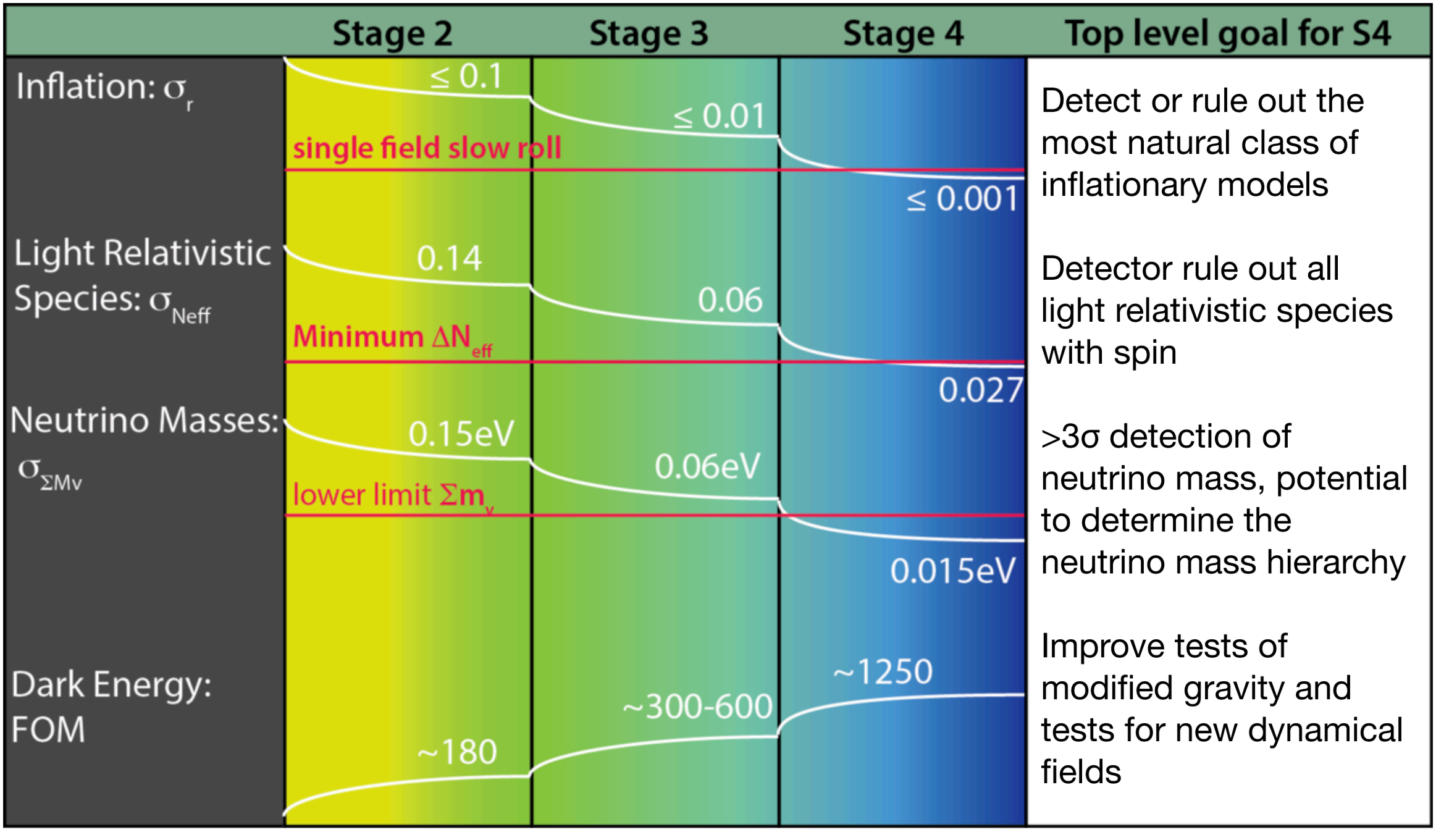
85-tube cryostat concept

Small aperture: inflationary B modes



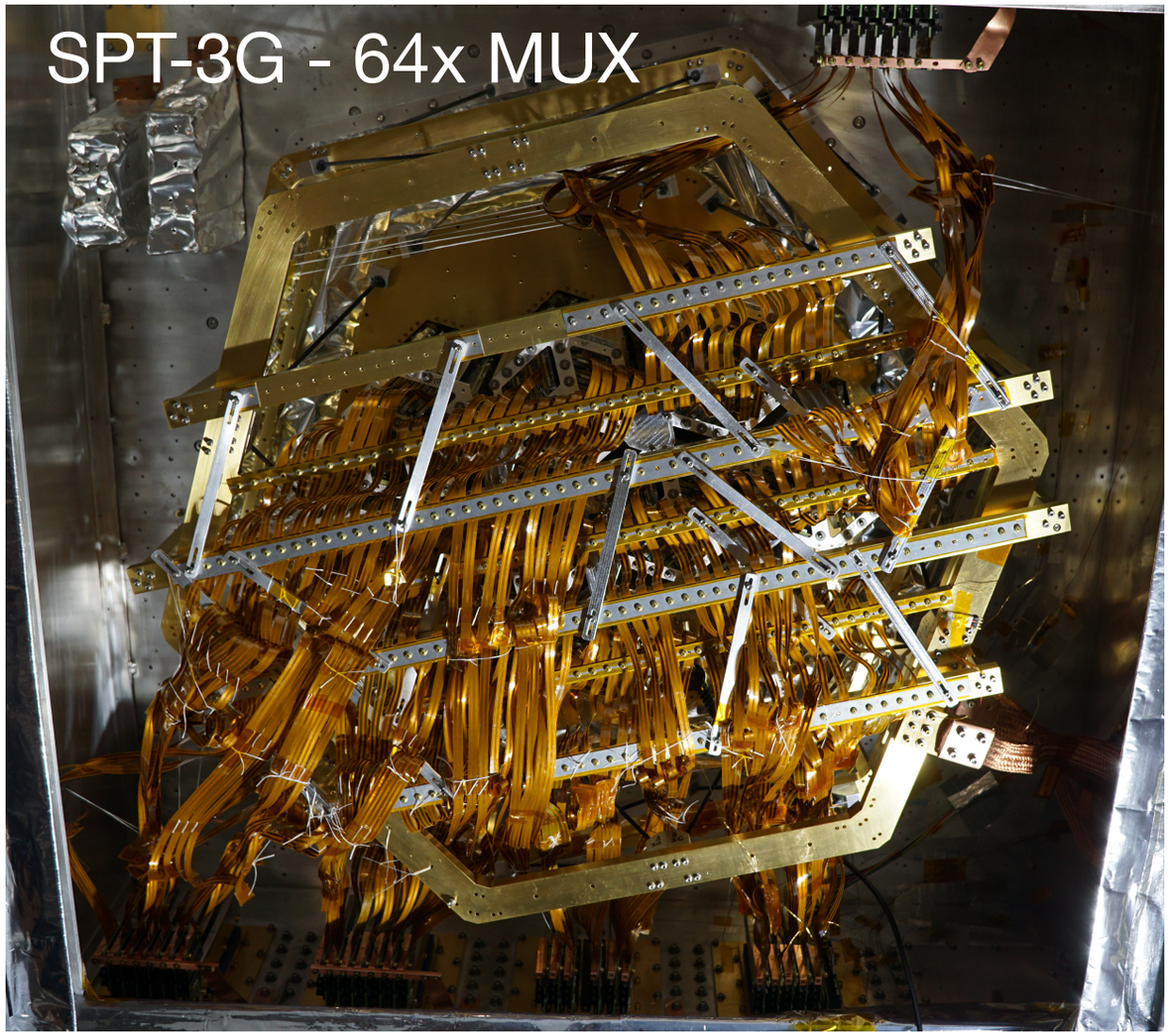
BICEP Array

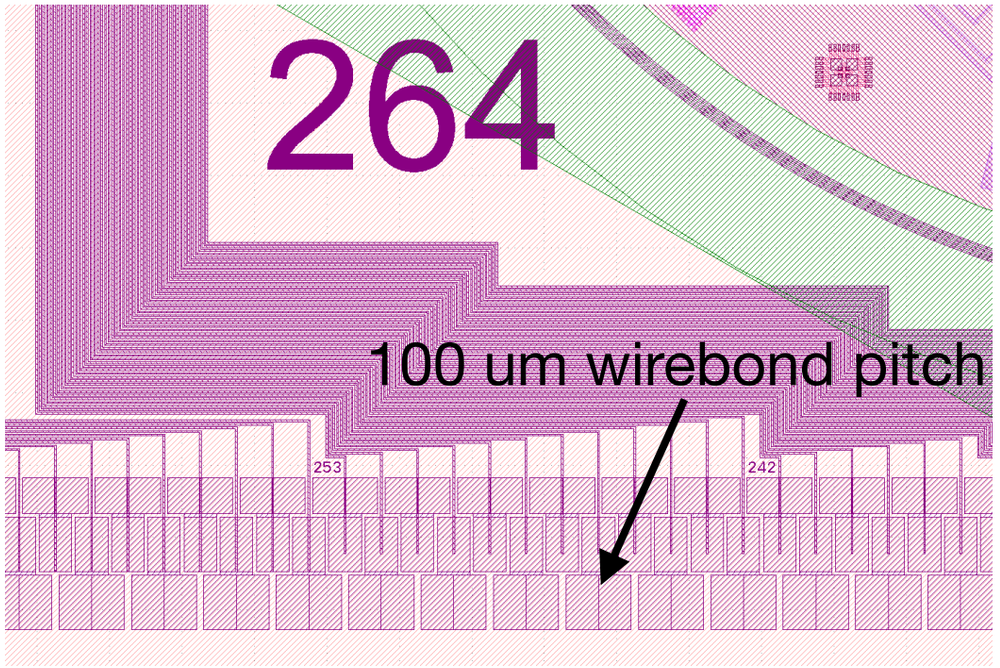
CMB-S4 Science



+ *much more ancillary science!*

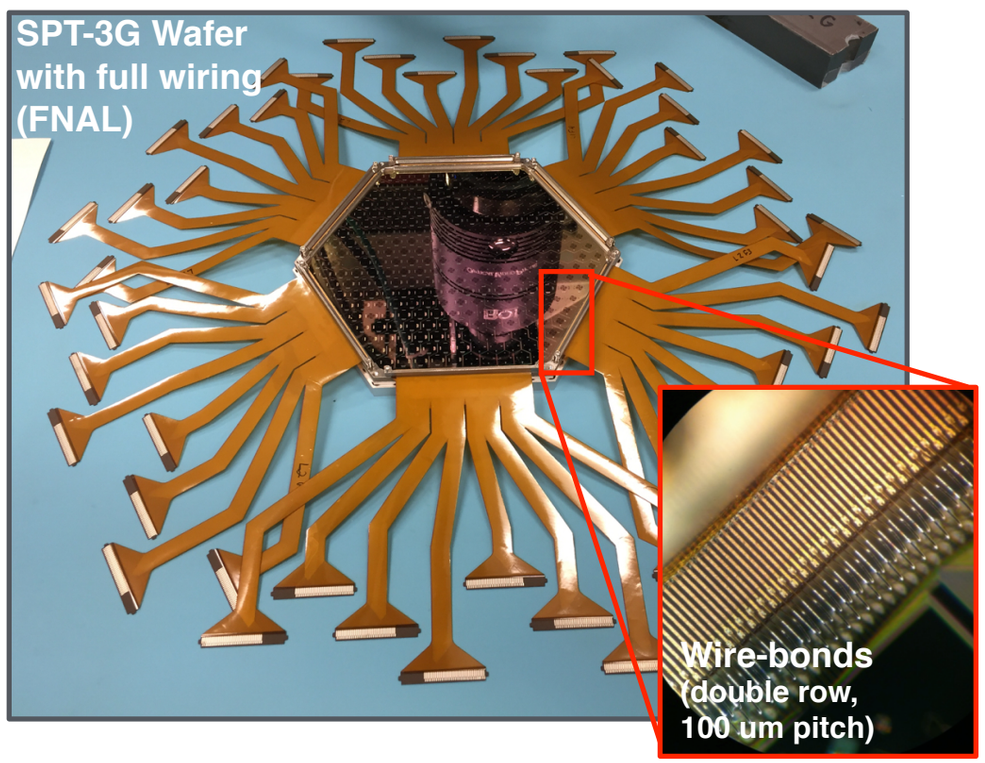
Wiring Constraints in CMB Experiments





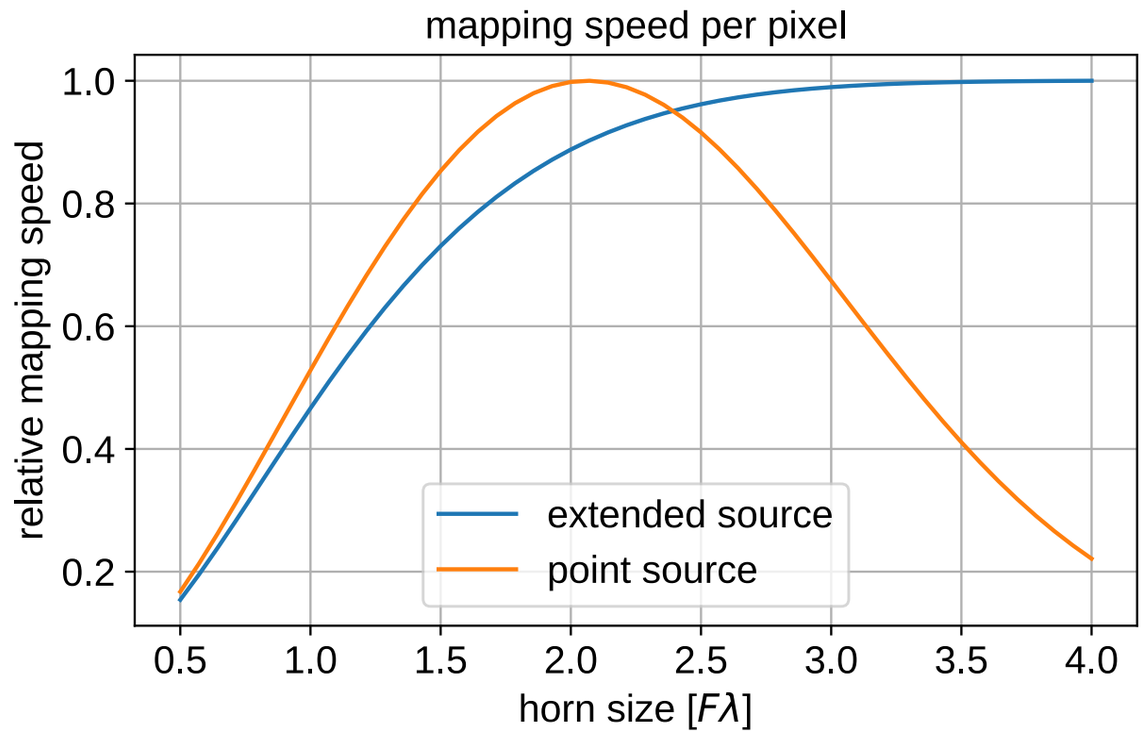
1. Many wires after multiplexing

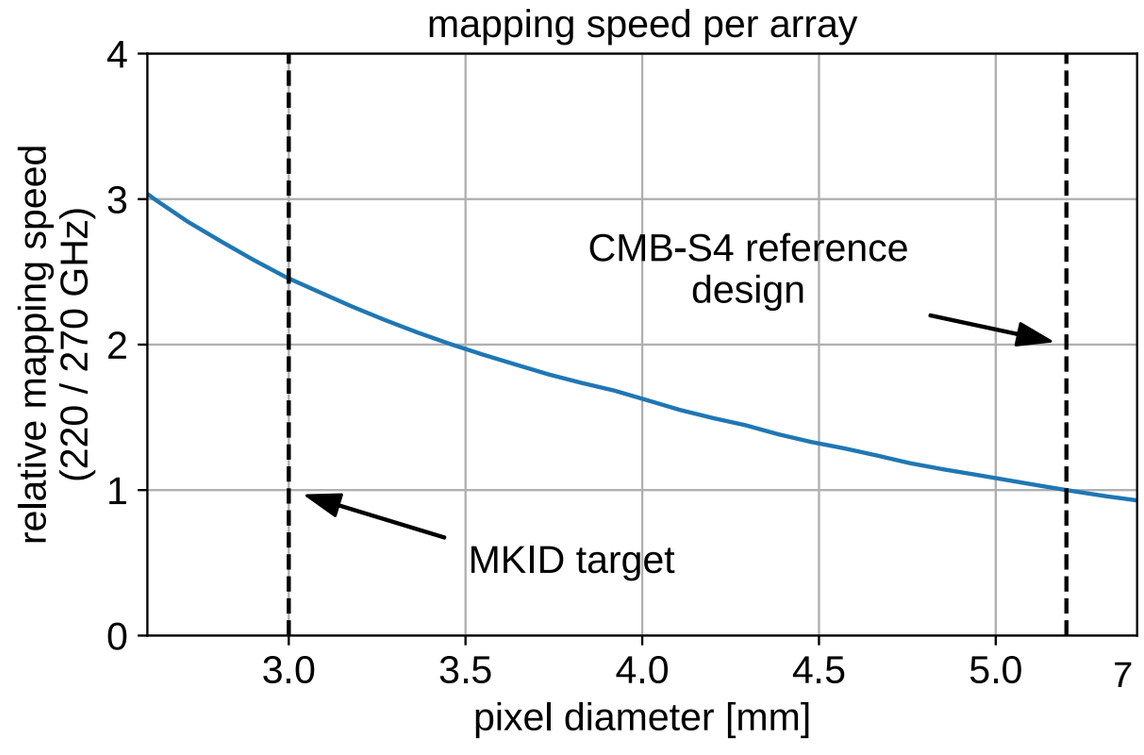
2. Only room for ~2000 detector wirebonds on perimeter of 6-inch wafer



Pixel Size Optimization

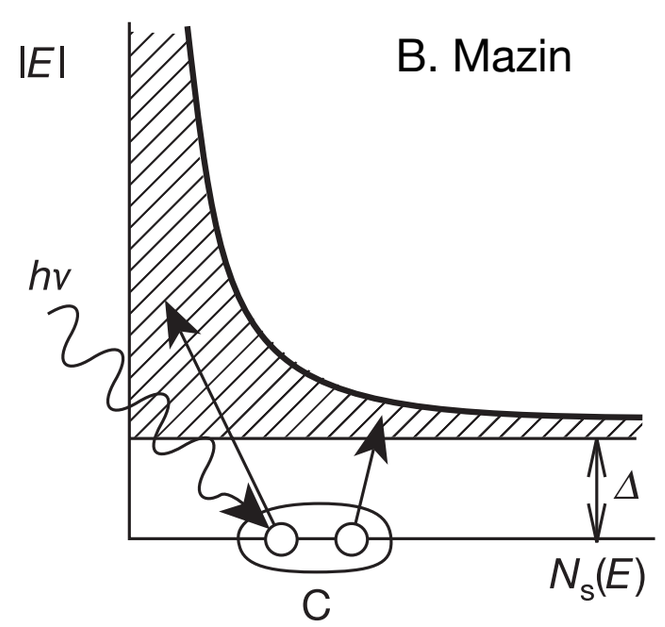
- Mapping speed ***per pixel*** optimized for ≥ 2 *Fλ*
- But smaller pixels enable more detectors per array, so mapping speed ***per array*** maximized for small pixels
- CMB-S4 220/270 GHz dichroic band is limited to ~2000 detectors / wafer
- 2-3x increase in sensitivity possible by moving to smaller pixels

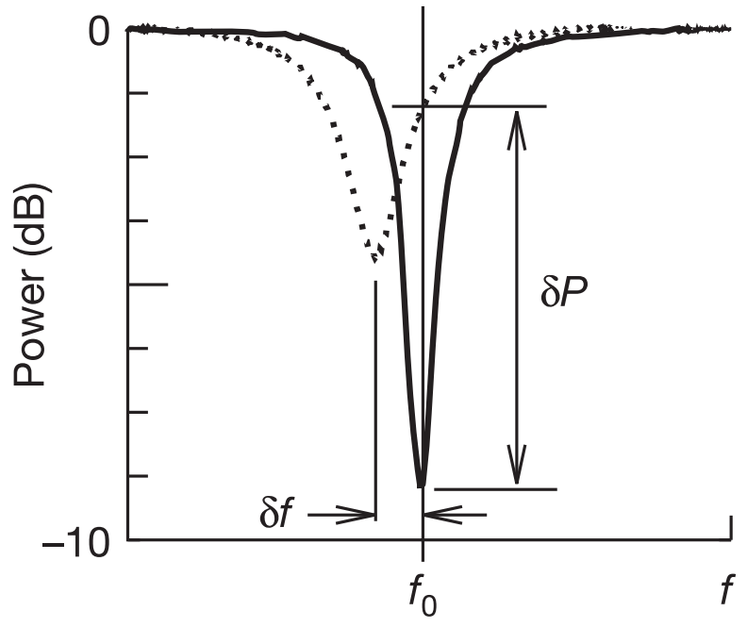


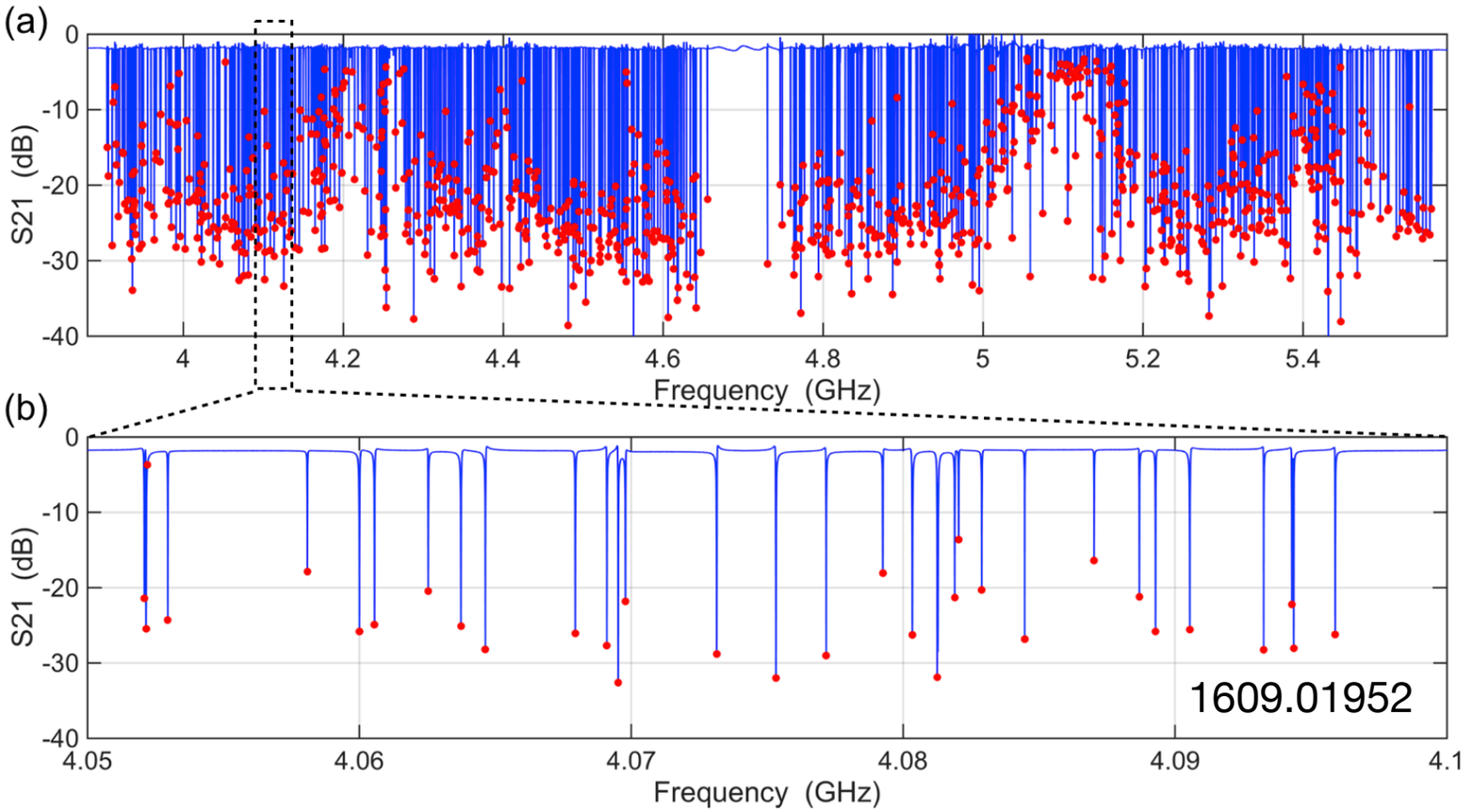


KIDs Enable Higher Density

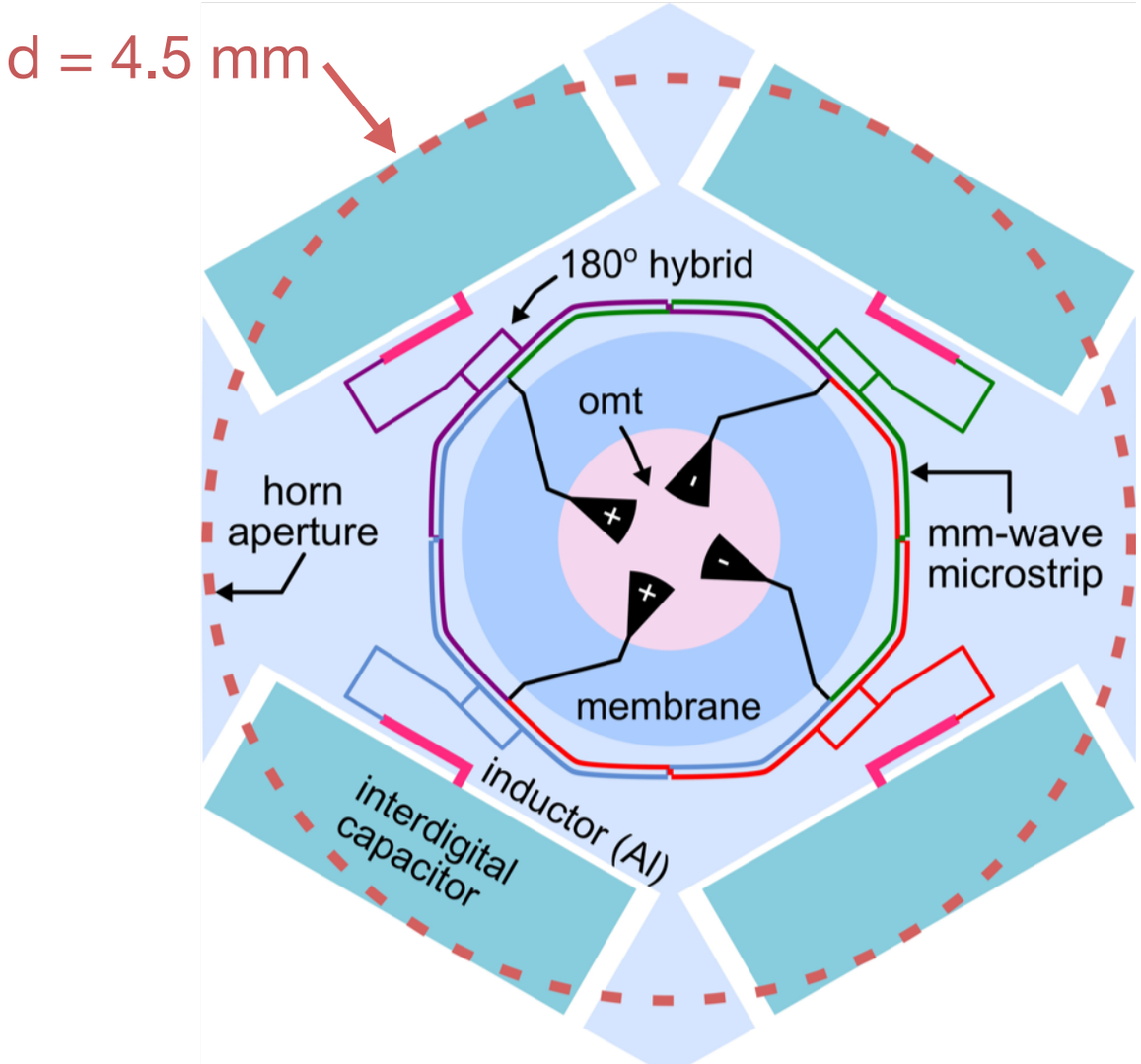
- At $T < T_c$ electrons condense into Cooper pairs
- Photons with $E = h\nu > 2E_{gap}$ break Cooper pairs into quasiparticles
- Cooper pairs' inertial mass gives rise to kinetic inductance in an AC field
- Kinetic inductance changes with the number of quasiparticles
  - Use a resonance circuit to see phase change under optical load

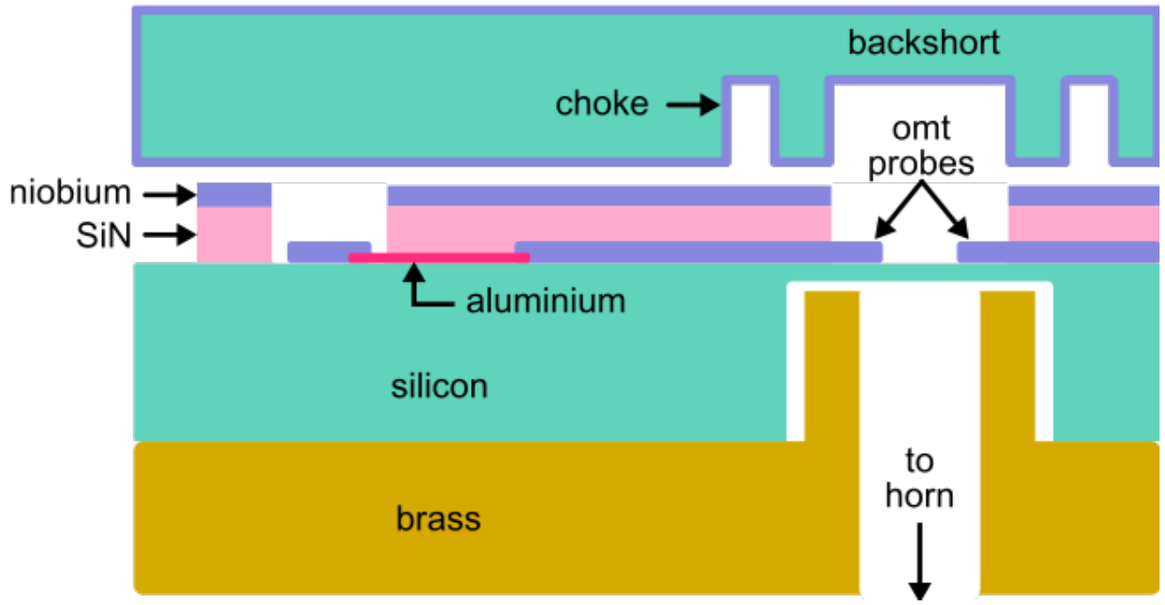


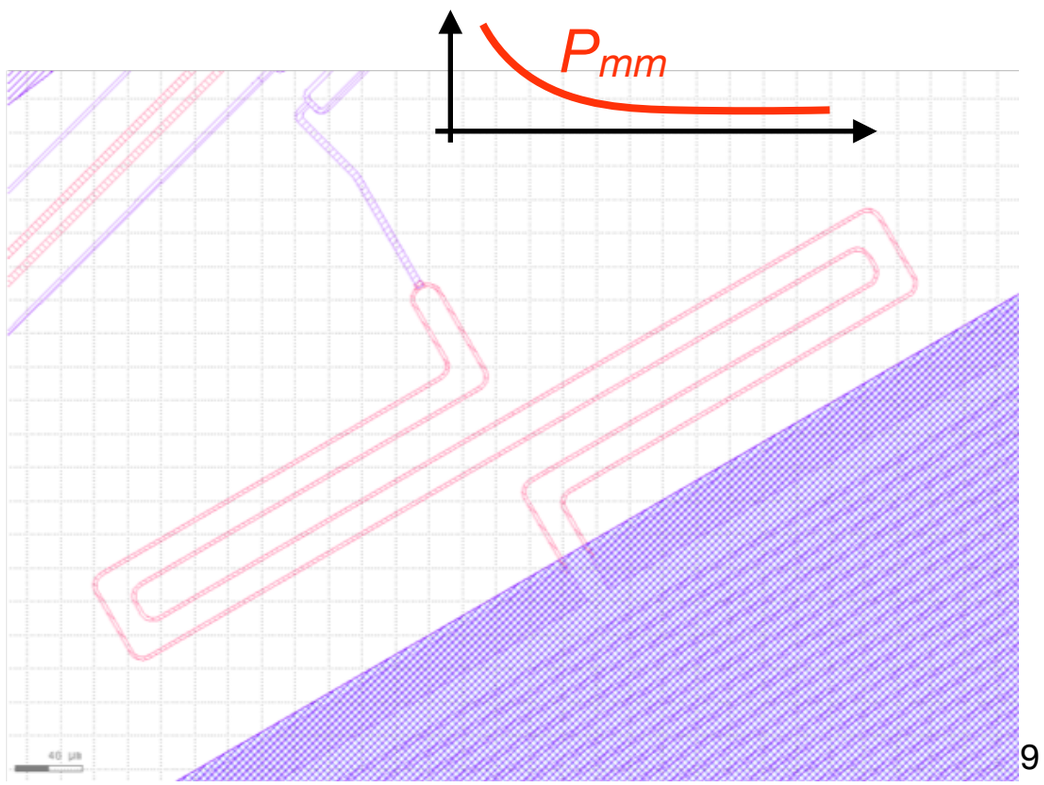




Horn-Coupled OMT Design



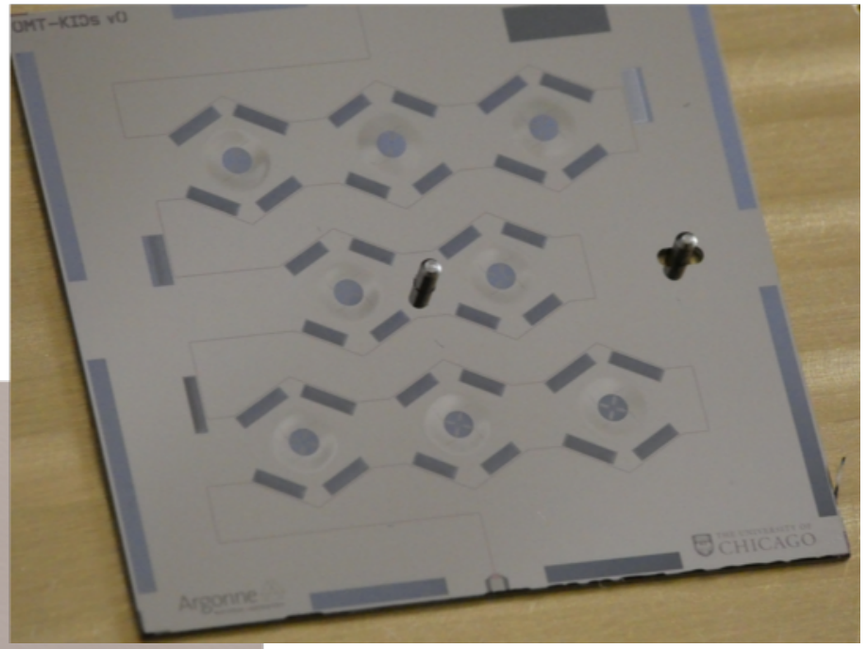


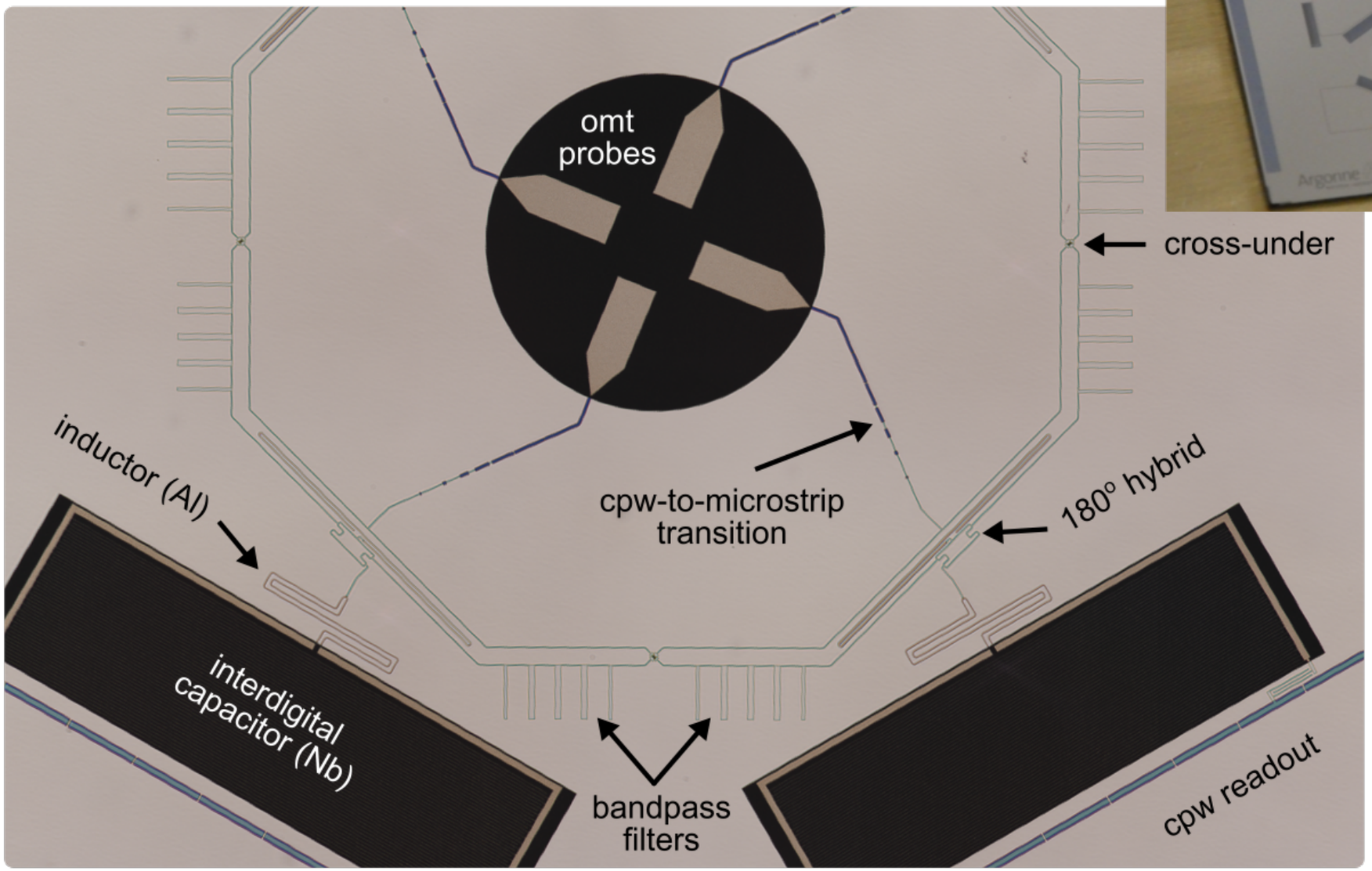


- Lumped-element KID design (P. Barry, E. Shirokoff, Q. Tang)
- Should be possible to scale to 3 mm horn diameter
- ***Drop-in replacement for CMB-S4 - 220/270 GHz dichroic at S4 baseline parameters***

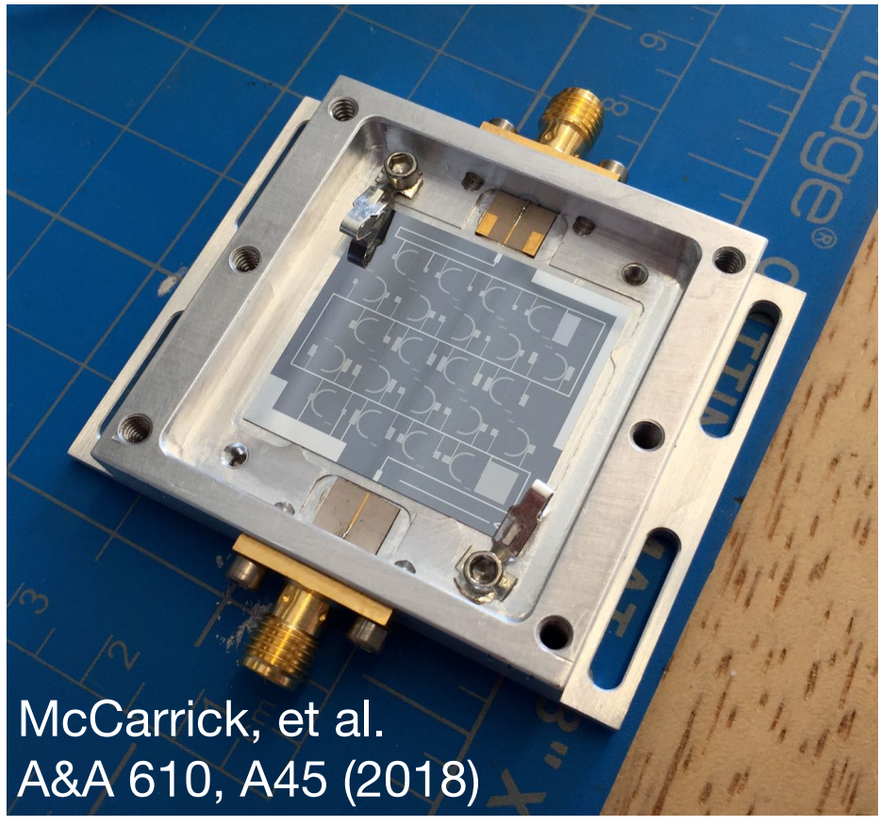
Prototype Devices

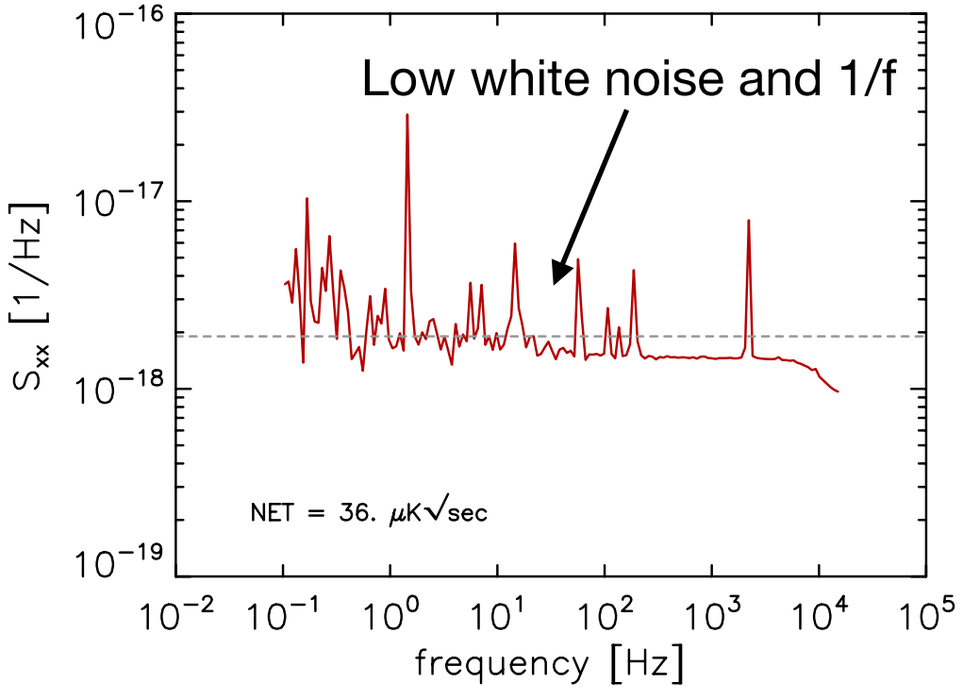
- Prototype pixels fabricated at Chicago
- ***Optical tests ongoing***
- Porting process to 6-inch wafers at Argonne (Cecil, Barry)

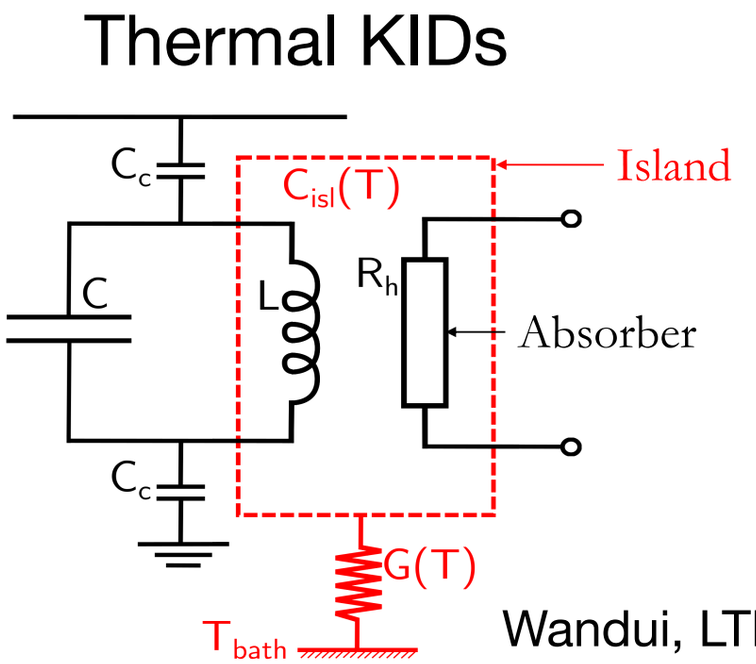




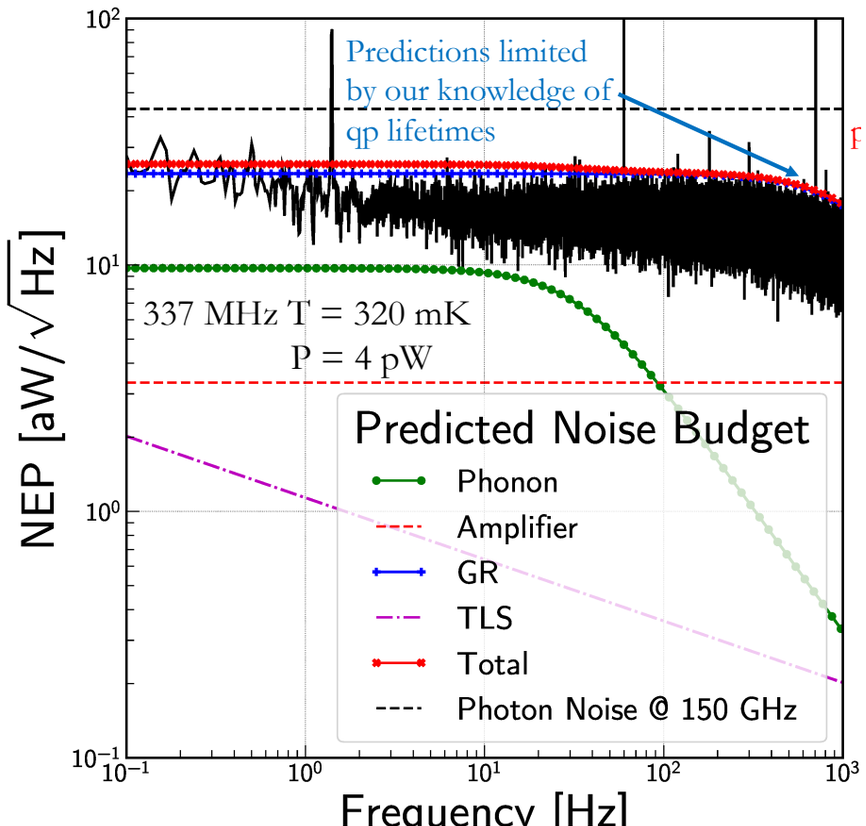
Other Examples







Wandui, LTD 2019



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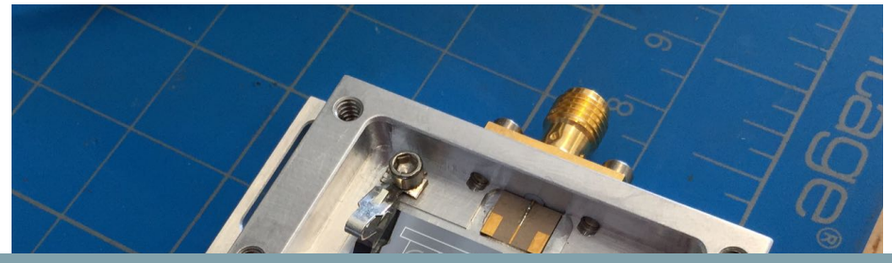
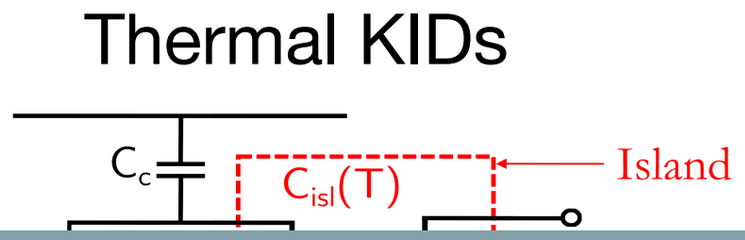




+ *Many More*

AMKID: APEX 2015, 350um + 850um

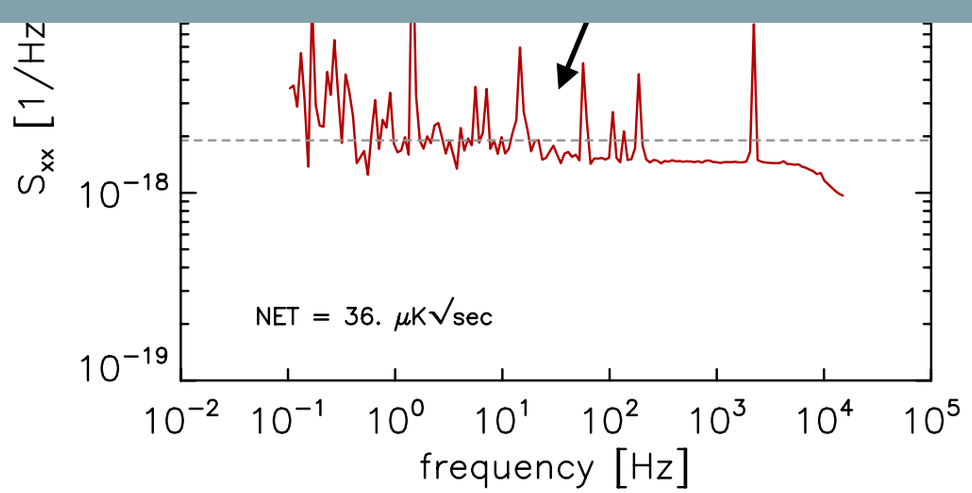
BLAST-TNG: balloon 2020, 250um + 350um + 500um

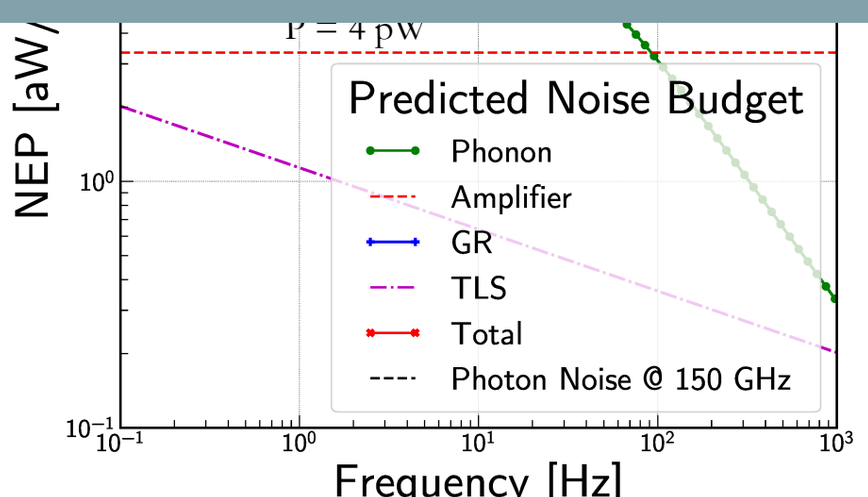
MAKO: CSO 2015, 350um + 850um

MUSIC: CSO 2012-2015, 850um to 2mm

NIKA/NIKA-2: IRAM 2011-present, 1mm + 2mm

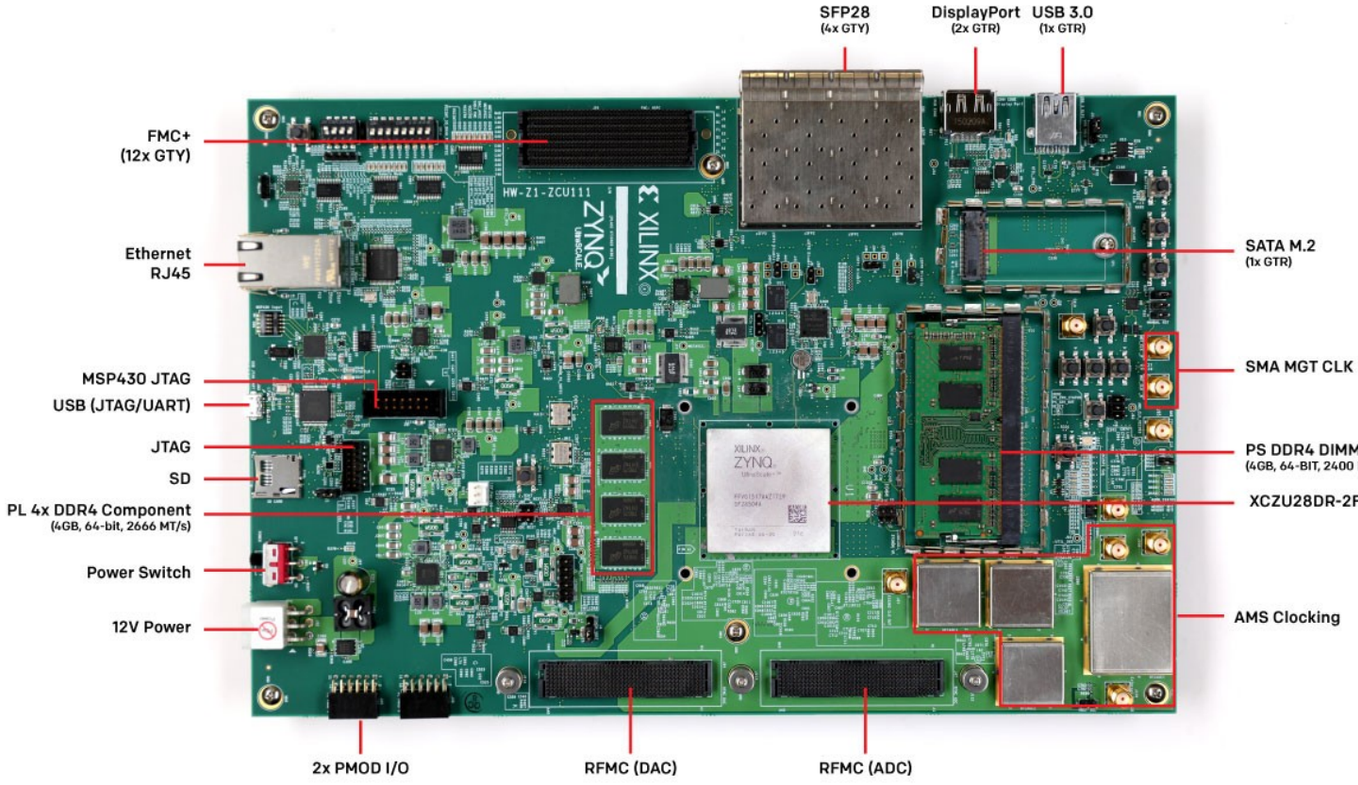
…

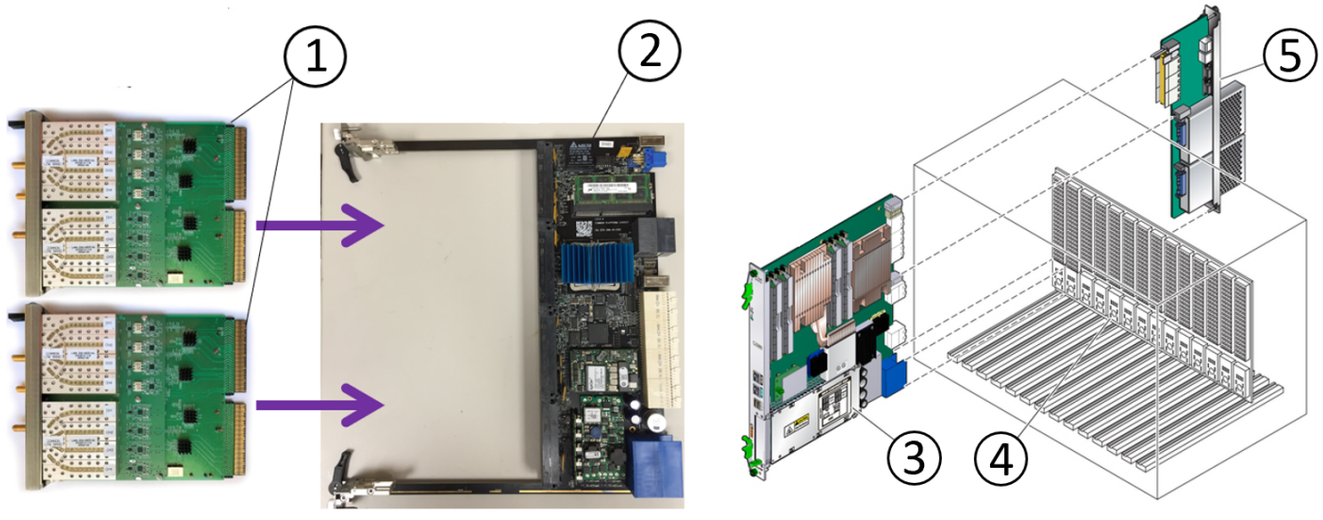




Readout Electronics

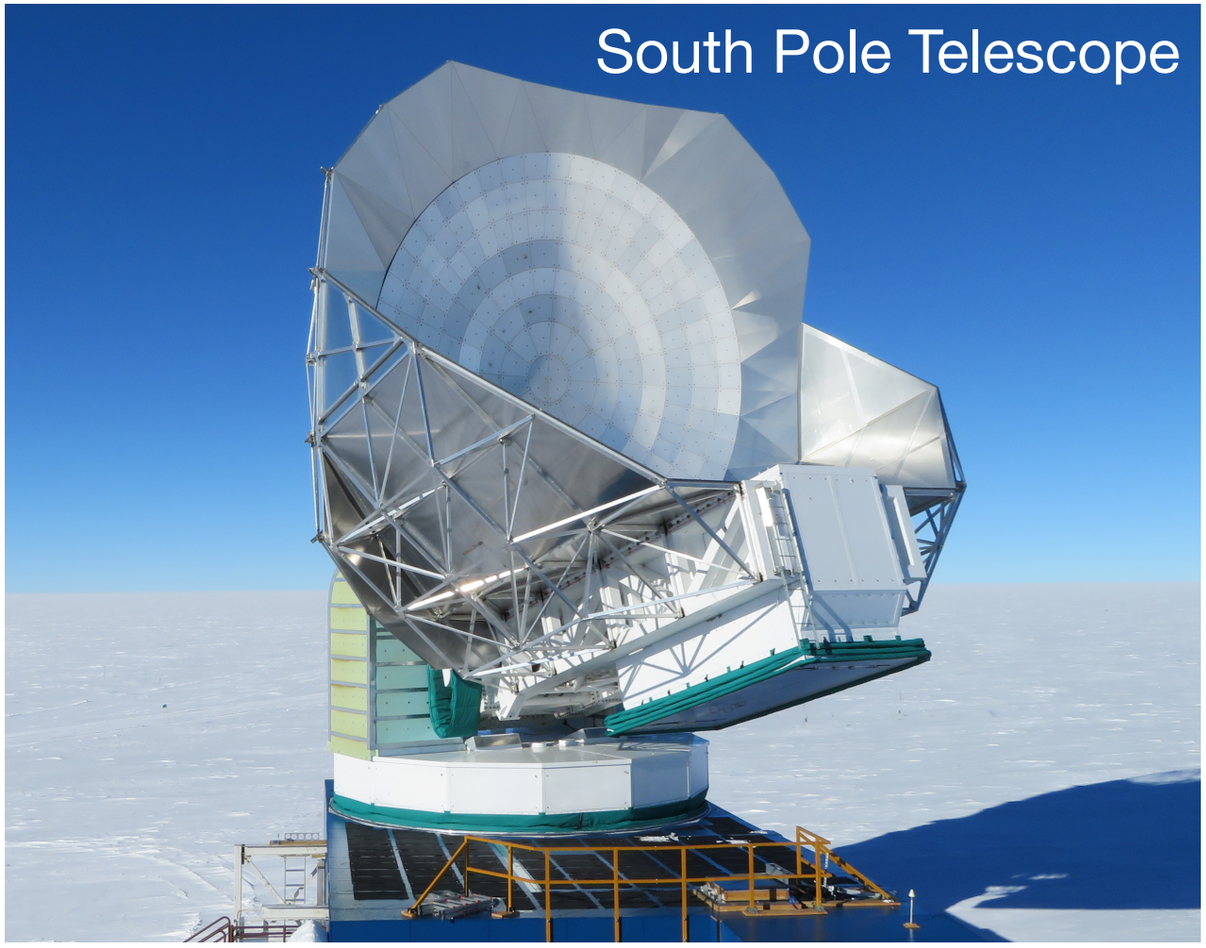
- Lower cost readout based on RFSoC under development (Fermilab / UCSB)
  - ***~$10 -> $1-2 / channel***
  - Xilinx ZCU111 with 8x ADC/ DACs per FPGA
    - See G. Cancelo talk, this session
- SLAC SMuRF electronics
  - Designed for uMUX readout of TESs, but could work with MKIDs
  - 2 ADC/DACs per card, 4-6 or 6-8 GHz
  - Joint SLAC / Argonne / Fermilab demo planned: SMuRF + CMB MKIDs + tested @ Fermilab

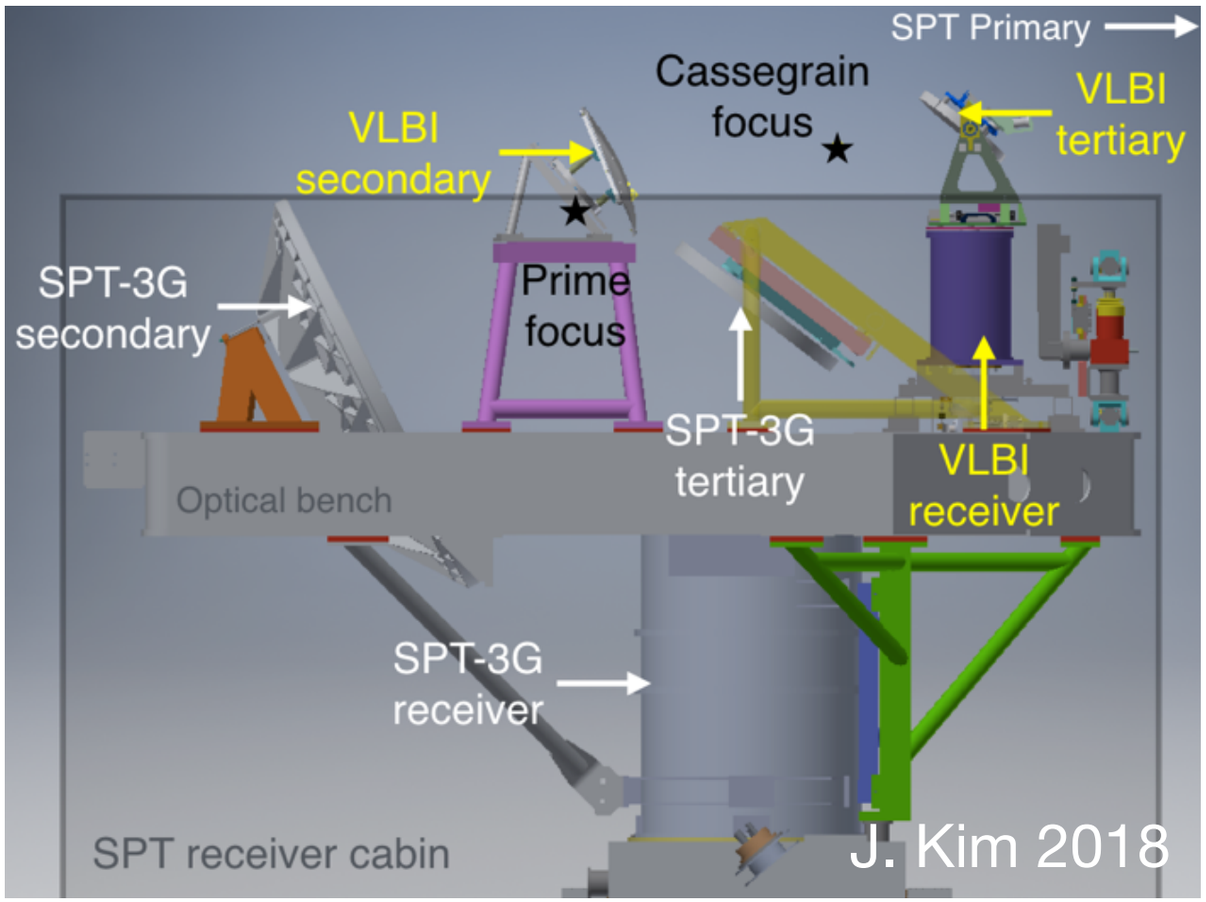




Deployment Options

- SPT-3G completes operations in 2023…
- ***SPT-Spec:*** Proposed camera with 7 optics tubes to replace SPT-3G, could contain 1 tube of CMB KIDs
- ***SPT Summer:*** Small receiver cryostat (e.g. EHT) can be installed with 3G optics for summer-only observations (cf. SPT-SLIM / Shirokoff)
- ***CMB-S4:*** TES uMUX readout proposed for S4, could be cross-compatible with MKIDs





Conclusions

- CMB-S4 requires enormous detector counts with background limited performance over 20-270 GHz
- MKIDs solve practical wiring problems but may also realize greater sensitivity than TESs for 220/270 GHz
- Chicago/Argonne horn-coupled leKID prototype being developed specifically to exploit this advantage
- Potential deployment scenarios exist using SPT demo followed by CMB-S4