THE COSMIC MICROWAVE BACKGROUND RADIATION AND ITS POLARIZATION

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CMB: Past and Present…
Inflation Paradigm: Quantum fluctuations in the metric and inflaton expand to astronomical scales.

Scalar perturbations create density perturbations.

Tensor perturbations create gravity waves that propagate from early to late times.

Cosmic Microwave Background: Thomson scattering → CMB Polarization
- Density perturbations (scalar) – E mode only
- Gravity waves (tensor) – E and B modes
CMB Status: Temperature & Polarization

- Planck – full sky maps with 4’ resolution available…
- Rich cosmological and galactic data sets…
- Consistency with 6 parameter cosmological model…
- Consistency among numerous experiments…
CMB Status: Temperature & Polarization

![Graph showing CMB power spectrum with multipole \( \ell \) on the x-axis and \( \ell(\ell+1)C_\ell/2\pi \) on the y-axis. The graph includes data from various experiments: Planck (2013), ACTPol (2014, ~650 hours), SPTPol (2013/14), BICEP2 (2014), and PBear (2014). The graph also highlights the region of interest for lensing B plus tensors, with constraints on the tensor-to-scalar ratio \( r \). The graph covers multipole values from 20 to 5000.]
CMB Status: Temperature & Polarization

\[ \ell (\ell + 1)C_\ell / 2\pi \] (\(\mu K^2\))

Multipole \(\ell\)

Planck (2015)
ACTPol (2016)
SPTPol (2013/14/15)
BICEP/Keck (2015)
PBear (2014)

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CMB Status: Temperature & Polarization

• Temperature power spectra characterized over ~ four decades by a variety of experiments…

• No surprises with $E$-mode power spectra…

• Indirect detections of $B$-mode via lensing…

• Joint BICEP2/Keck analysis with Planck data yields $r = 0.028 \pm 0.026$ and $r < 0.09$ at 95% confidence


CMB Coming Soon...

Analyzing available Polarization Data:
- Planck (space, intermediate ell)
- BICEP2/BICEP3/Keck (ground, low ell)
- SPTPol (ground, high ell)
- ACTPol (ground, high ell)
- POLARBEAR (ground, high ell)
- ABS (ground, low ell)
- EBEX (balloon, intermediate ell)
- SPIDER (balloon, low ell)

Launch/Deployment
- PIPER (balloon, low ell)
- CLASS (ground, low ell)

Funded extensions to ~20,000 detectors
- SPT3G, Advanced ACTPol, Simons Array
CMB Polarization Mission Planning

• NASA Inflation Probe to provide high-sensitivity measurements over entire sky enabling extraction of all cosmological information from CMB in polarization.
• B-mode polarization tests the physics behind the process of inflation plus tests of neutrino mass, mapping large-scale structure with gravitational lensing, and epoch of reionization science.
• Space provides access to the largest spatial angular scales and entire spectral range of interest – a combination of capabilities which far surpasses that achievable from other observational platforms.
Inflation Probe Mission Landscape

**NASA**

- Probe-Scale Mission Study: $400M - $1000M
  - Proposal submitted (11/2016) – awaiting NASA response
  - Part of NASA preparations for 2020 Decadal Panel
  - Single proposal representing entire CMB community
  - Science: *Inflation/Quantum Gravity, Particle Physics, Dark matter, Dark energy, Galactic Astrophysics*

- PIXIE - submitted as Explorer class mission (2016)
  - Low Resolution (~1.6 deg@150GHz), LEO, FTS
  - Science: *Inflation, Spectral Distortions, Galactic*

**ESA M5, COrE+**

- Submitted in 10/2016; Response expected in Spring 2017; Launch = 2028
  - E550M ESA + E50-100M Members = E600-650M
  - Medium resolution (5.5 arcmin @150 GHz), L2
  - Intense European interest for US contribution; Strong community backing
  - Science: *Inflation, Lensing/Clusters, Neutrinos, Galactic*
Inflation Probe Mission Landscape

**JAXA, LiteBIRD**

- Low Angular Resolution
- Includes US contribution (Focal Plane)
- Phase A studies funded in Japan (conclusion in 2017, SRR early 2018) and in the US (concluded in summer 2016 – awaiting NASA decision)
- Launch (if approved): 2025+
- **Science: Inflation, Galactic**

**ESA/JAXA Collaboration**

Discussions ongoing between ESA/JAXA and science teams regarding possible collaboration as part of M5: Main discussion point is targeted angular resolution
CMB Community Meetings and Inputs

• Probe-Scale Mission Study proposal submitted
  • Part of NASA preparations for 2020 Decadal Panel
  • Single proposal representing entire CMB community
  • Complementarity of Inflation Probe and CMB-S4 science as well as measurement foreground challenges to be studied

• AAS Special Session, "The Polarization of the Cosmic Microwave Background", San Diego, June 15, 2016.

• Workshop Series, “Cosmology with CMB-S4”:
  • Lawrence Berkeley National Laboratory, March 7-8, 2016
  • University of Chicago, September 19-20, 2016
  • SLAC, February 27-28, 2017 → save the date
Inflation Probe Science Interest Group:

• Goal: Develop a US community response which articulates a consensus for a Inflation Probe mission priorities. Inputs from all members of the community are welcomed.

• Inflation Probe SIG website and mailing list:
  http://pcos.gsfc.nasa.gov/sigs/ipsig.php

• Physics of the Cosmos Program Analysis Group (PhysPAG) Inflation Probe Science Interest Group (IPSIG) Community Representatives: Amber Miller & Edward Wollack