The Cosmic Microwave Background Radiation and its Polarization

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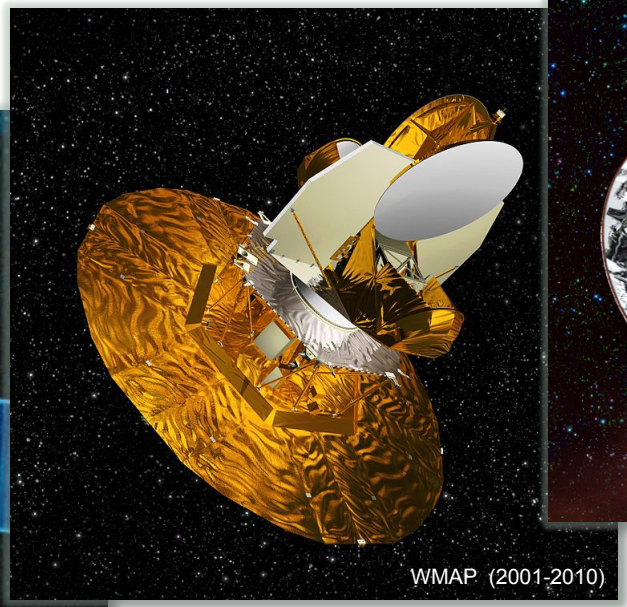
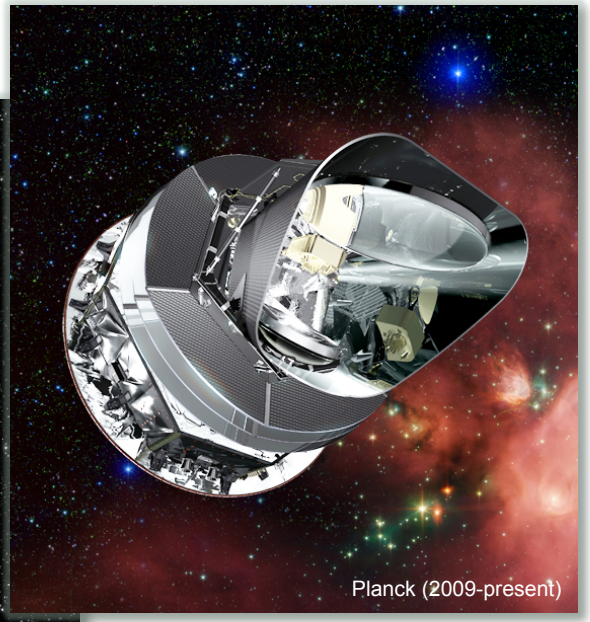
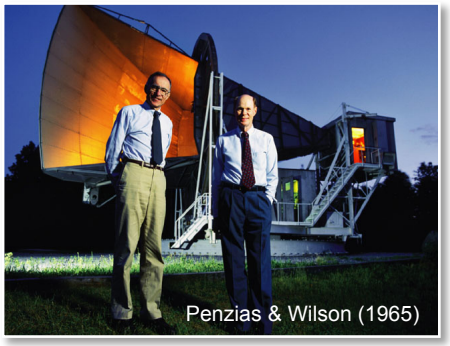
CMB: Past and Present…





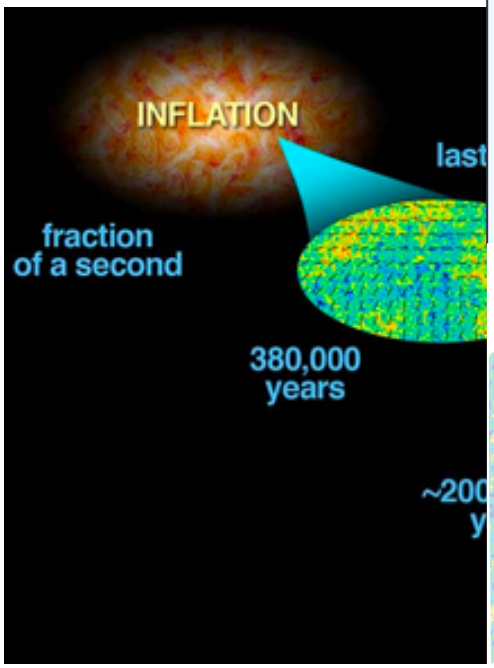


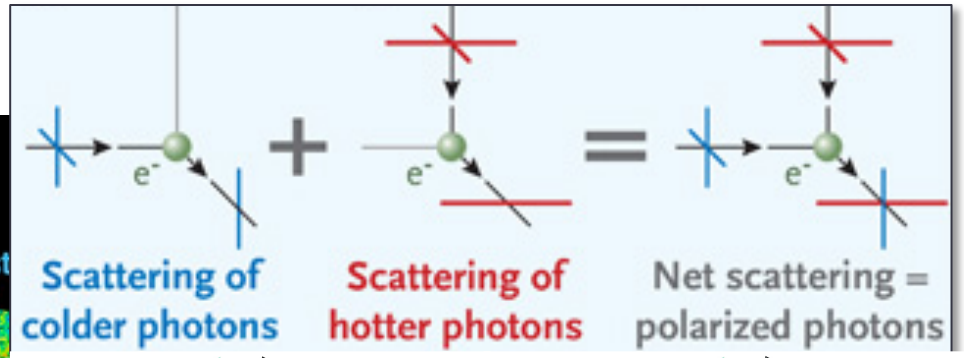
Cosmic Microwave Background:
Polarization Anisotropies

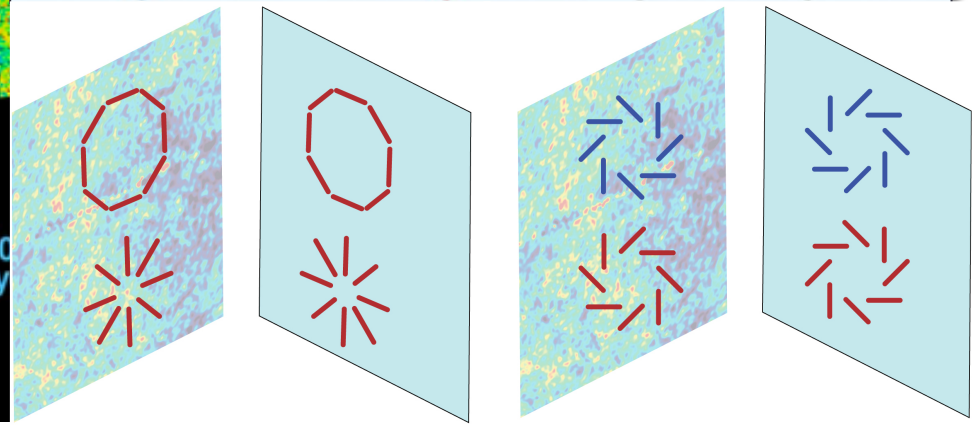
Inflation Paradigm: Quantum fluctuations in the metric and inflaton expand to astronomical scales.

Scalar perturbations create density perturbations.

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





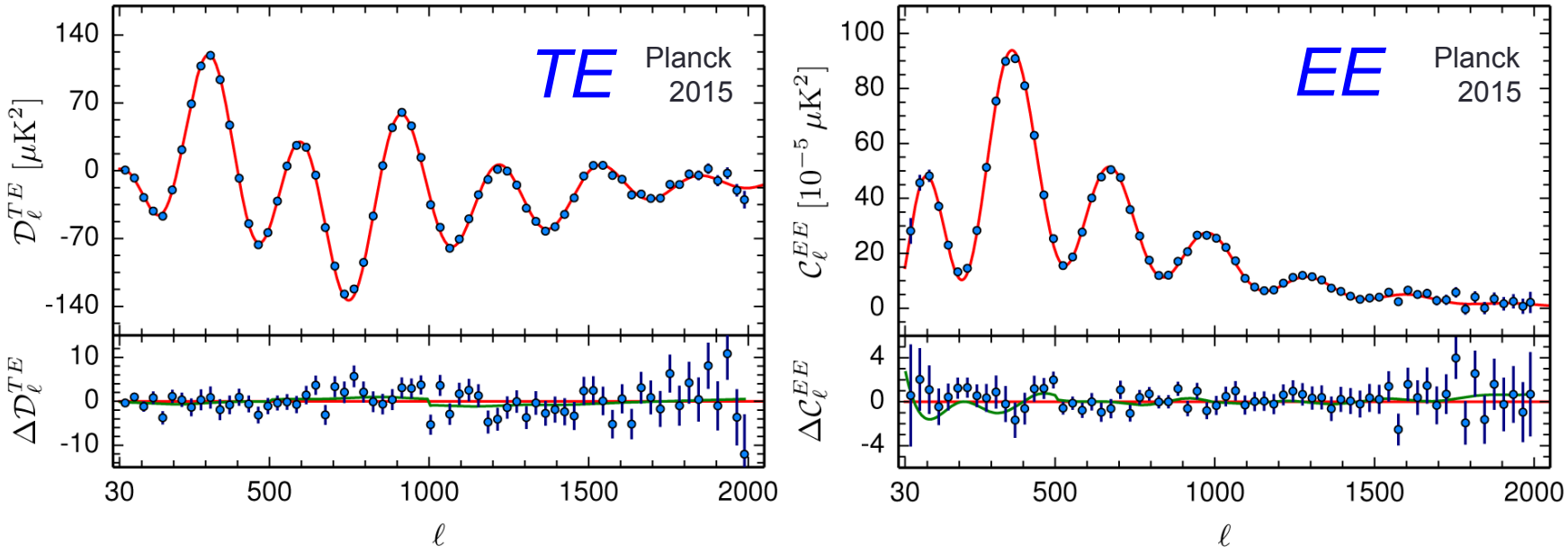


Comic Microwave Background:
Thomson scattering ➞ CMB Polarization

- 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…



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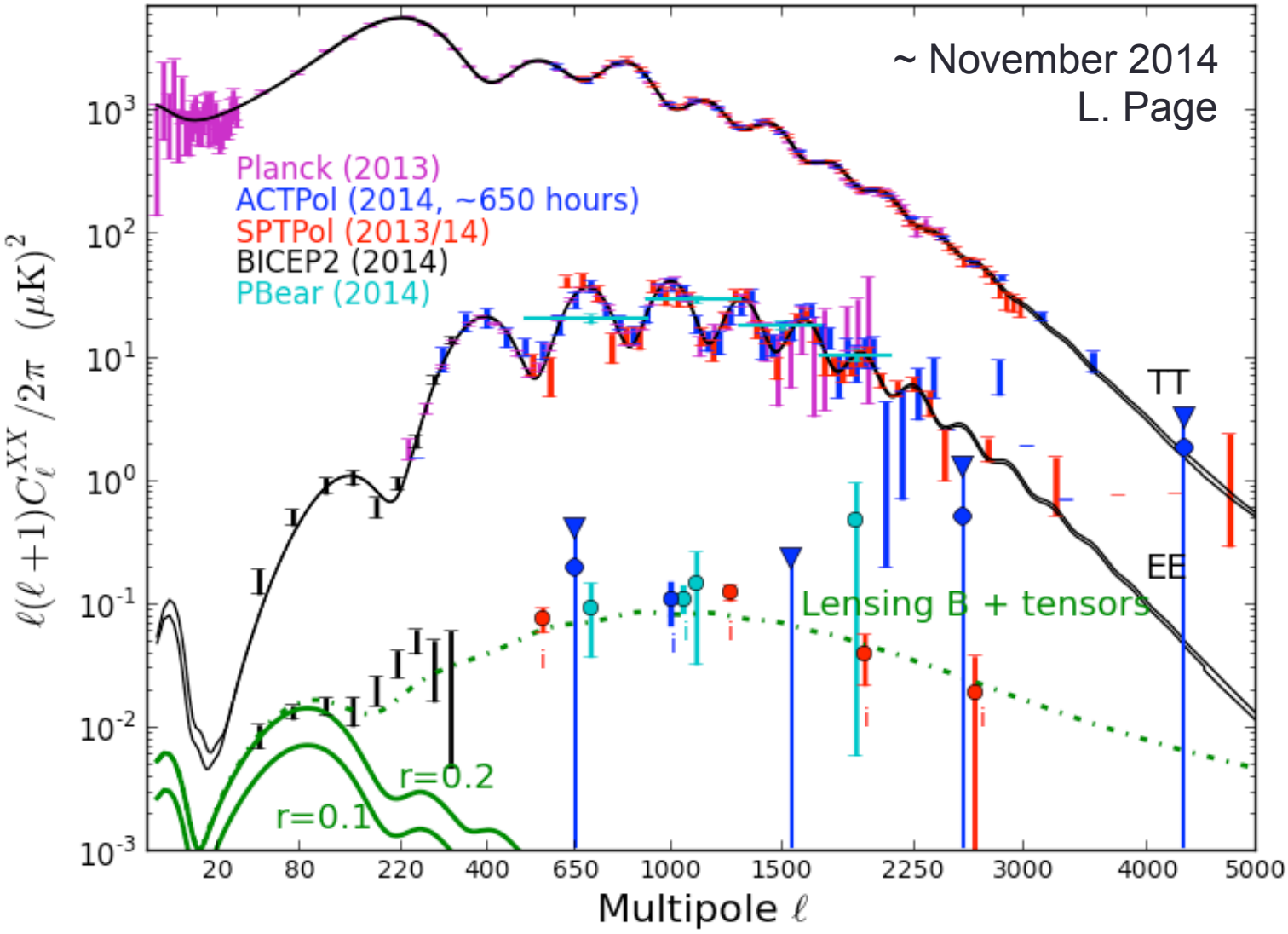
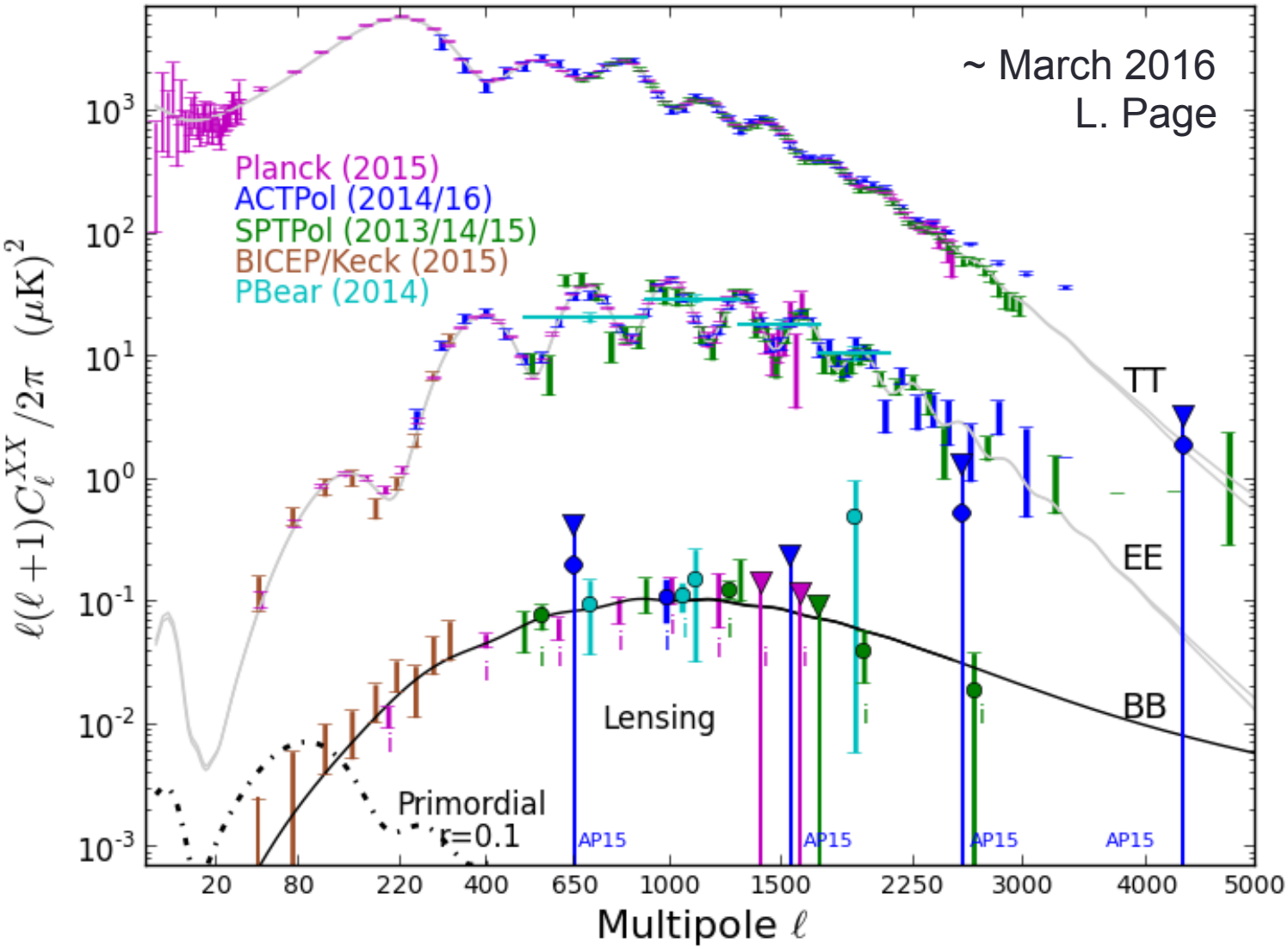


CMB Status: Temperature & Polarization



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…
- BICEP2/Keck analysis yields r = 0.028 +/- 0.026 and r < 0.09 at 95% confidence

P.A.R. Ade et al., "Joint Analysis of BICEP2/Keck Array and Planck Data" PRL (2015) 114, 101301.

P.A.R. Ade et al., "Improved Constraints on Cosmology and Foregrounds from BICEP2 and Keck Array Cosmic Microwave Background Data with Inclusion of 95 GHz Band" (2016) Phys. Rev. Lett. 116, 031302

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)
- EBEX (balloon, intermediate ell)
- ABS (ground, low ell)
- SPIDER (balloon, low ell)

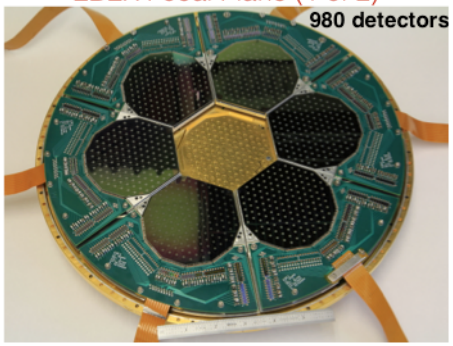
Launch/Deploy in 2015/2016

- PIPER (balloon, low ell)
- CLASS (ground, low ell)

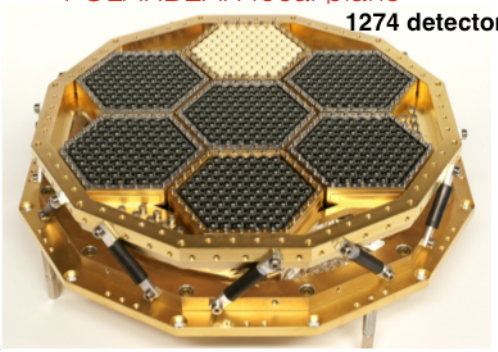
Funded extensions to ~20,000 detectors

- SPT3G
- Advanced ACTPol
- POLARBER/Simons Array

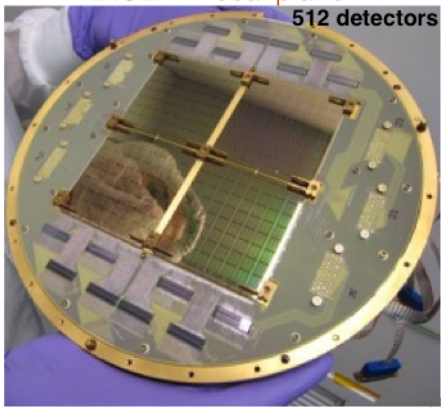
EBEX Focal Plane (1 of 2)



POLARBEAR focal plane

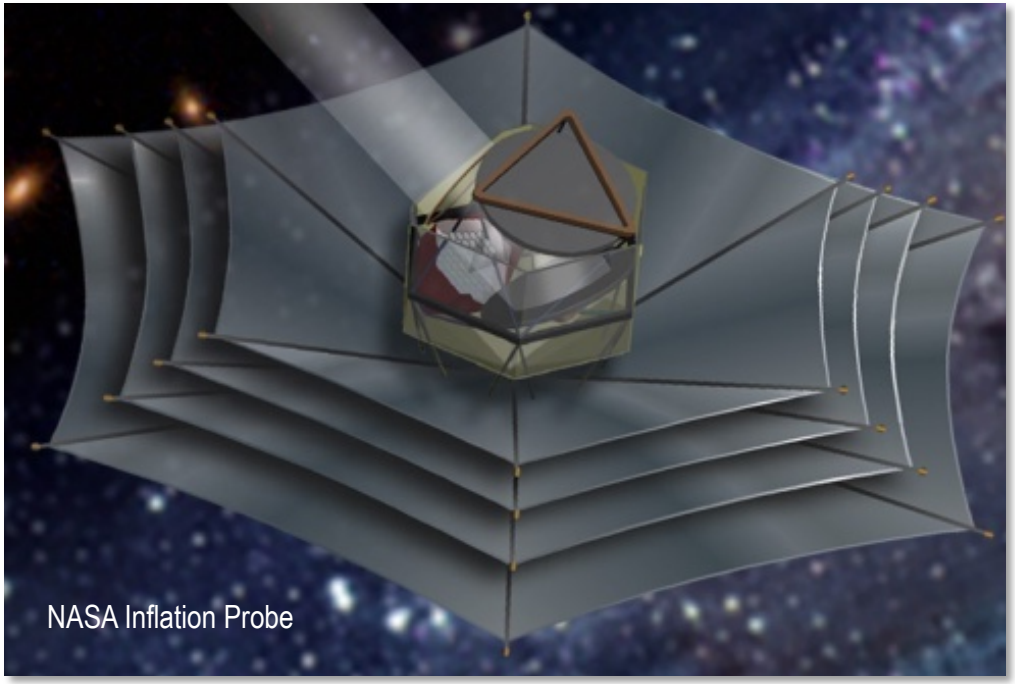


BICEP-II focal plane



CMB Polarization Mission Planning

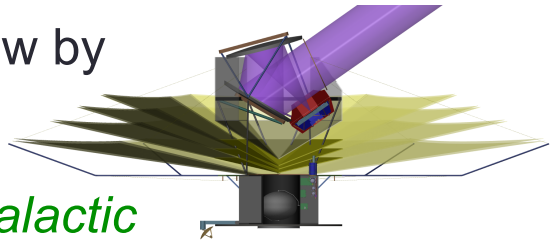
- NASA Inflation Probe to provide high-sensitivity measurements over entire sky enabling extraction of all cosmological information from CMB in polarization.
- B-mode polarization tests the physics behind the process of inflation plus tests of neutrino mass, mapping large-scale structure with gravitational lensing, and epoch of reionization science.
- Space provides access to the *largest spatial scales* and *entire spectral range* of interest – naturally complementing ground- and balloon-based capabilities...


NASA Inflation Probe

Inflation Probe Mission Landscape

NASA

EPIC-IM



- NWNH: Case for Inflation Probe mission under review by Mid-Decadal Panel
  - Cost (BEPAC, ~2008): ~ 1.2 - 1.3B$
  - Science *Inflation, Lensing, Clusters, Neutrinos, Galactic*
- PIXIE - submitted as Explorer class mission (2011)
  - Low Resolution (~1.6 deg@150GHz), LEO, FTS
  - Science*: Inflation, Spectral Distortions, Galactic*
  - Resubmission in late 2016

COrE+

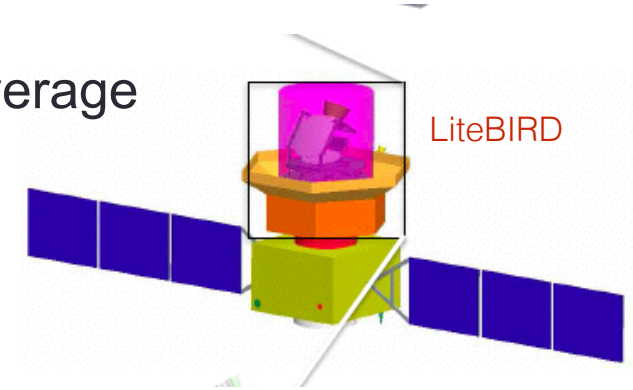
ESA M5, COrE+

- E550M ESA + E150M Members = E700M
- Submission expected in Spring 2016; Launch = 2028
- Medium resolution (5.5 arcmin @150 GHz), L2
  Science*: Inflation, Lensing/Clusters, Neutrinos, Galactic*
- Intense interest in Europe for US contribution
- Strong European/US community backing

Inflation Probe Mission Landscape

JAXA, LiteBIRD

- Low Angular Resolution, Wide Spectral Coverage
  Science: *Inflation, Galactic*
- Includes US contribution (Focal Plane)
- Phase A studies funded in Japan (to be concluded in 2017) and in the US (part of MO2014, to be concluded in summer 2016)
- Launch (if approved): 2025



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

- Responses to NASA's PhysPAG Charges:
  - Flagship Mission Concepts Study for the 2020 Decadal Survey
  - Whitepaper: "The Inflation Probe: A Probe-Class Astrophysics Mission"
- Meeting, "Towards the European Coordination of the CMB Programme", held August 31-1 September 2015, Villa Finaly.
- Report to the Mid-Decadal Review Panel, "CMB Polarization in 2015", AMiller for IPSIG, December 9, 2015.
- AAS Special Session, "The Polarization of the Cosmic Microwave Background", San Diego, June 15, 2016.
- Workshop Series, "Cosmology with CMB-S4":
  - University of Michigan, September 21-22, 2015
  - Lawrence Berkeley National Laboratory, March 7-8, 2016
  - University of Chicago, September 19-20, 2016 → *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
  http://pcos.gsfc.nasa.gov/sags/ipsag/ipsag-maillist.php

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