PICO -
Probe of Inflation and Cosmic Origins

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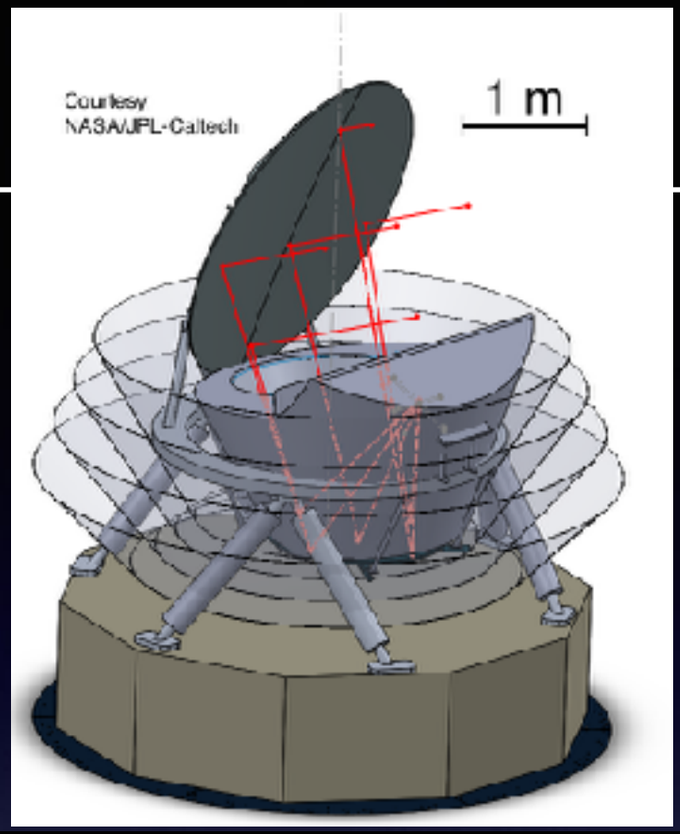
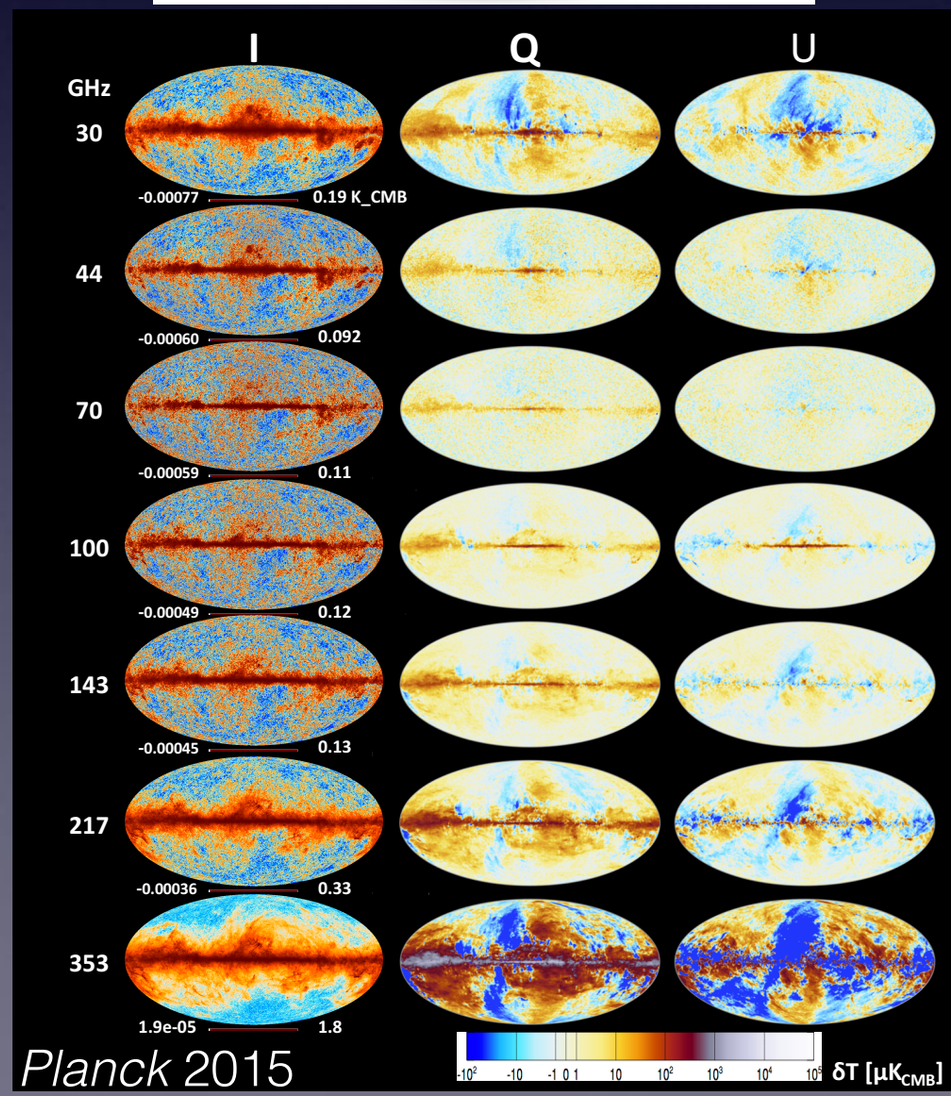
Executive Committee
Bock, Borrill, Crill, Devlin, Flauger, Hanany, Jones, Knox,
Kogut, Lawrence, McMahon, Pryke, Trangsrud

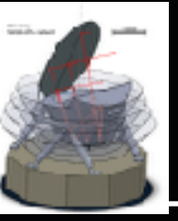
Steering Committee
Bennett, Dodelson, Page

PICO in Brief

- Millimeter/submillimeter-wave, polarimetric survey of the entire sky
- 21 bands (25% bandwidth) between 20 GHz (15 mm) and 800 GHz (0.375 mm)
- 1.4 m aperture telescope
- Diffraction limited resolution: 38’ to 1’
- 12,400 transition edge sensor bolometers + multiplexed readouts
- 4 year survey from L2
- 70 times the sensitivity of *Planck*
- Open collaboration, led by Executive and Steering Committees



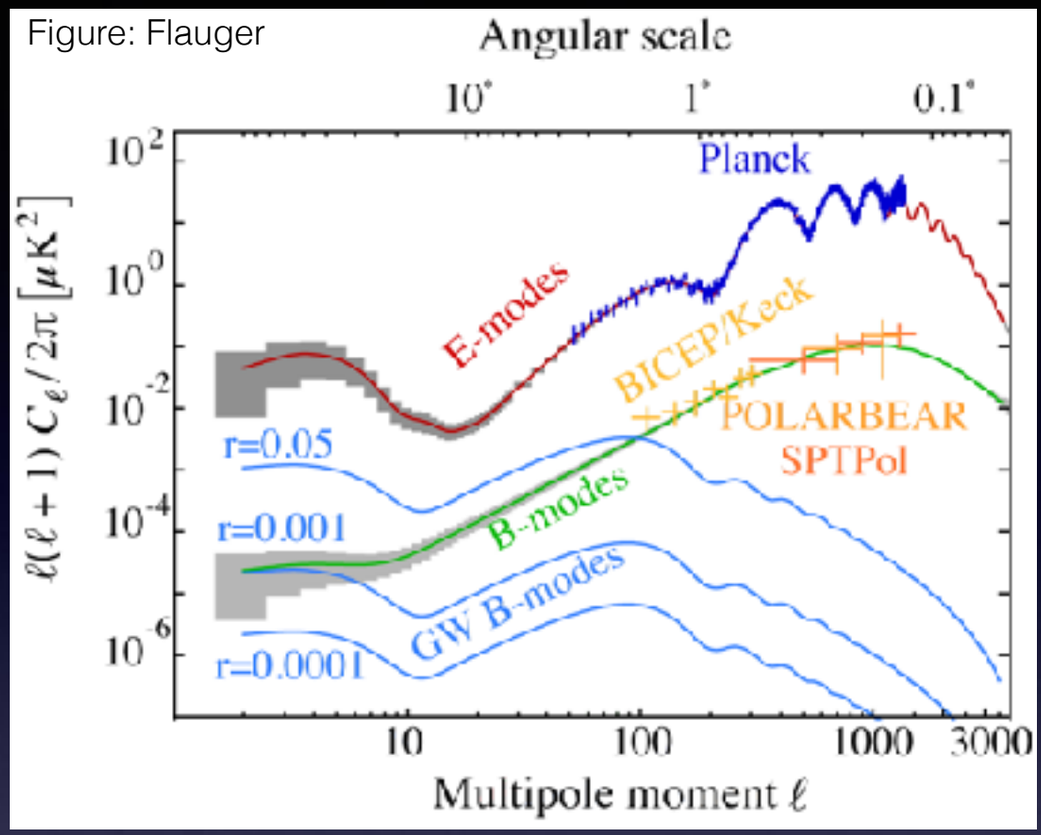




Explore How the Universe Began

- Detect or set upper bound on the energy scale of inflation
  - $E = 3.7 \cdot 10^{16} r^{1/4}$ GeV
  - Currently $r < 0.07$ (95%)
  - PICO: $r < 10^{-4}$ (95%)
  - 700 times lower than current constraint
  - $\sigma(r) = 5 \cdot 10^{-5}$
  - r, $\sigma(r)$ quoted constraints already include x2.5 margin
  - Includes internal delensing, removal of a simple foregrounds model; excludes systematic uncertainties

Figure: Flauger



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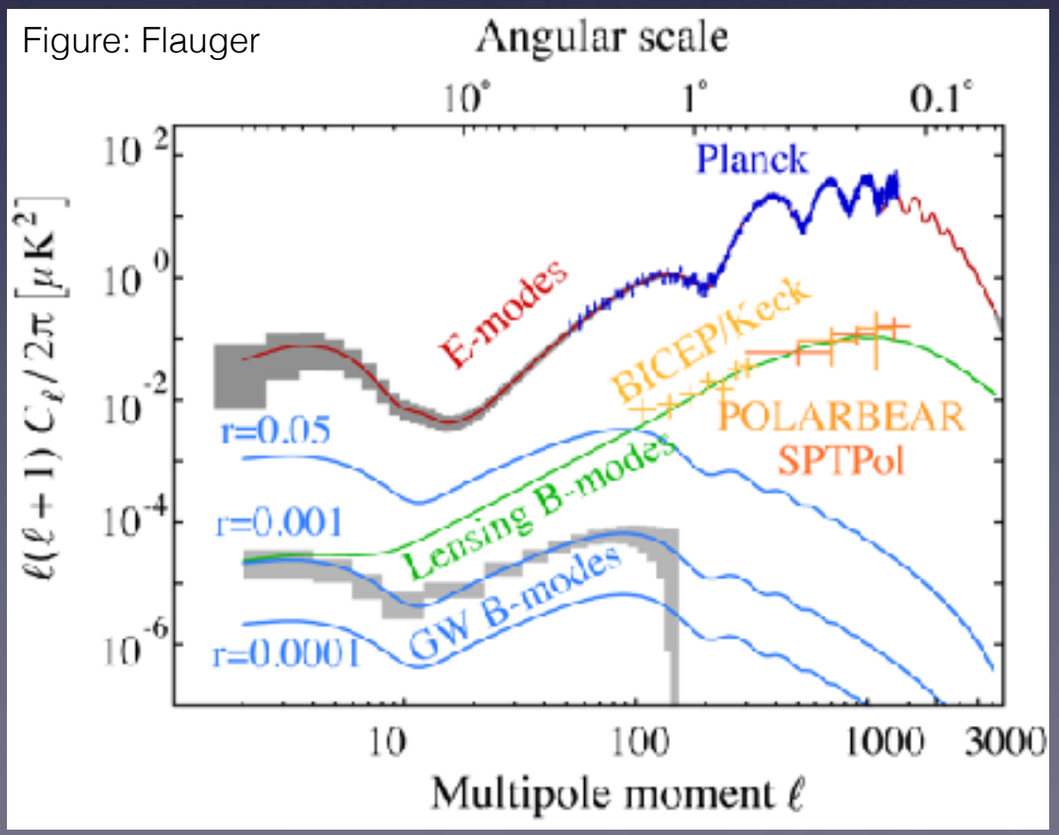
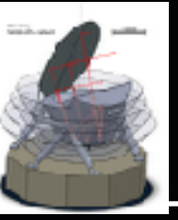
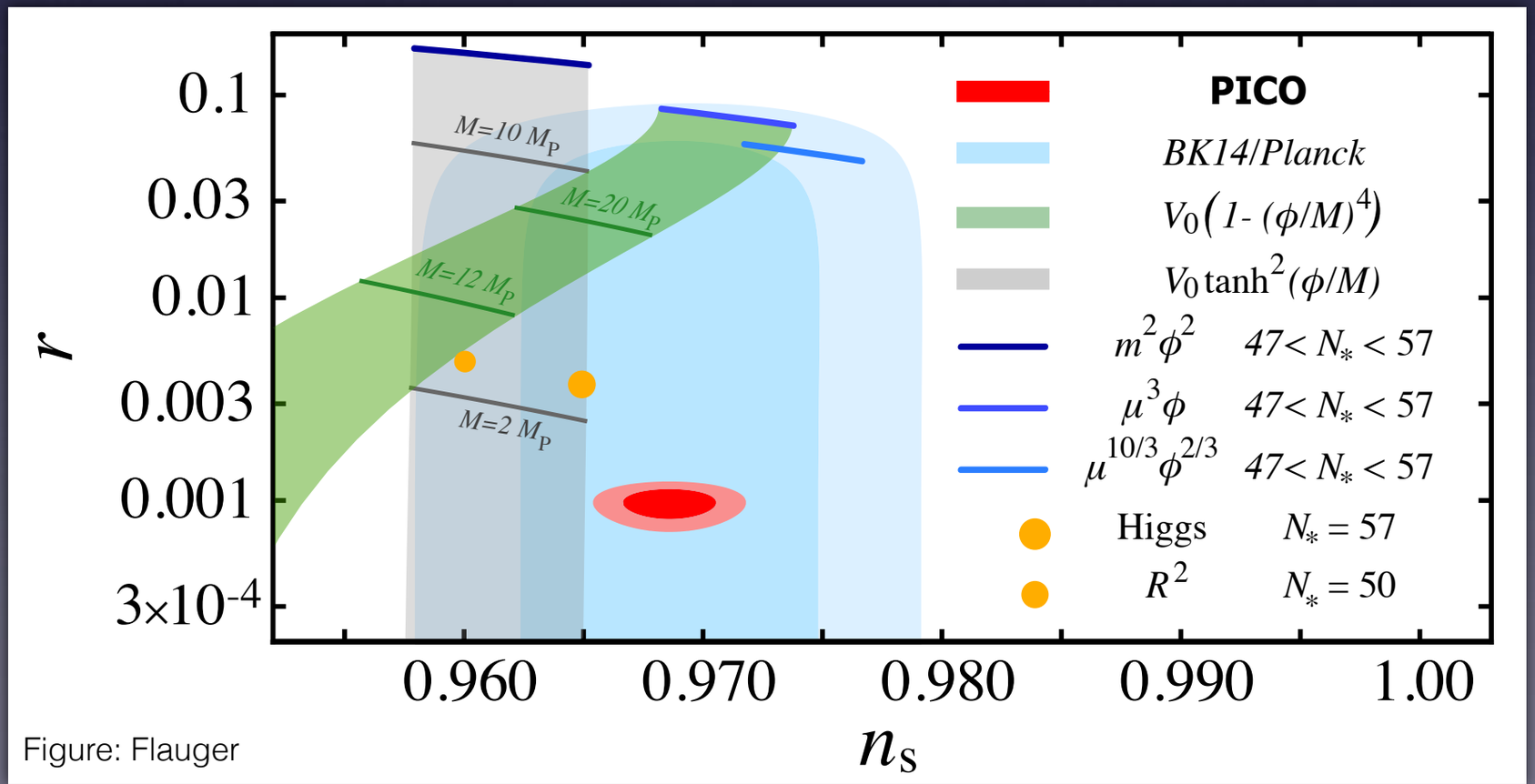




Explore How The Universe Began

- Detection would point to specific large field inflation models as the drivers for inflation, and would motivate their connection to string theory

- An upper limit will exclude classes of inflation potentials



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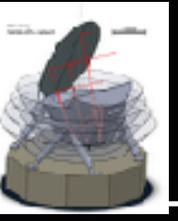


Explore how the Universe Evolved

- Determine the reionization history of the Universe
  - Through measurement of the EE power spectrum on the largest angular scales

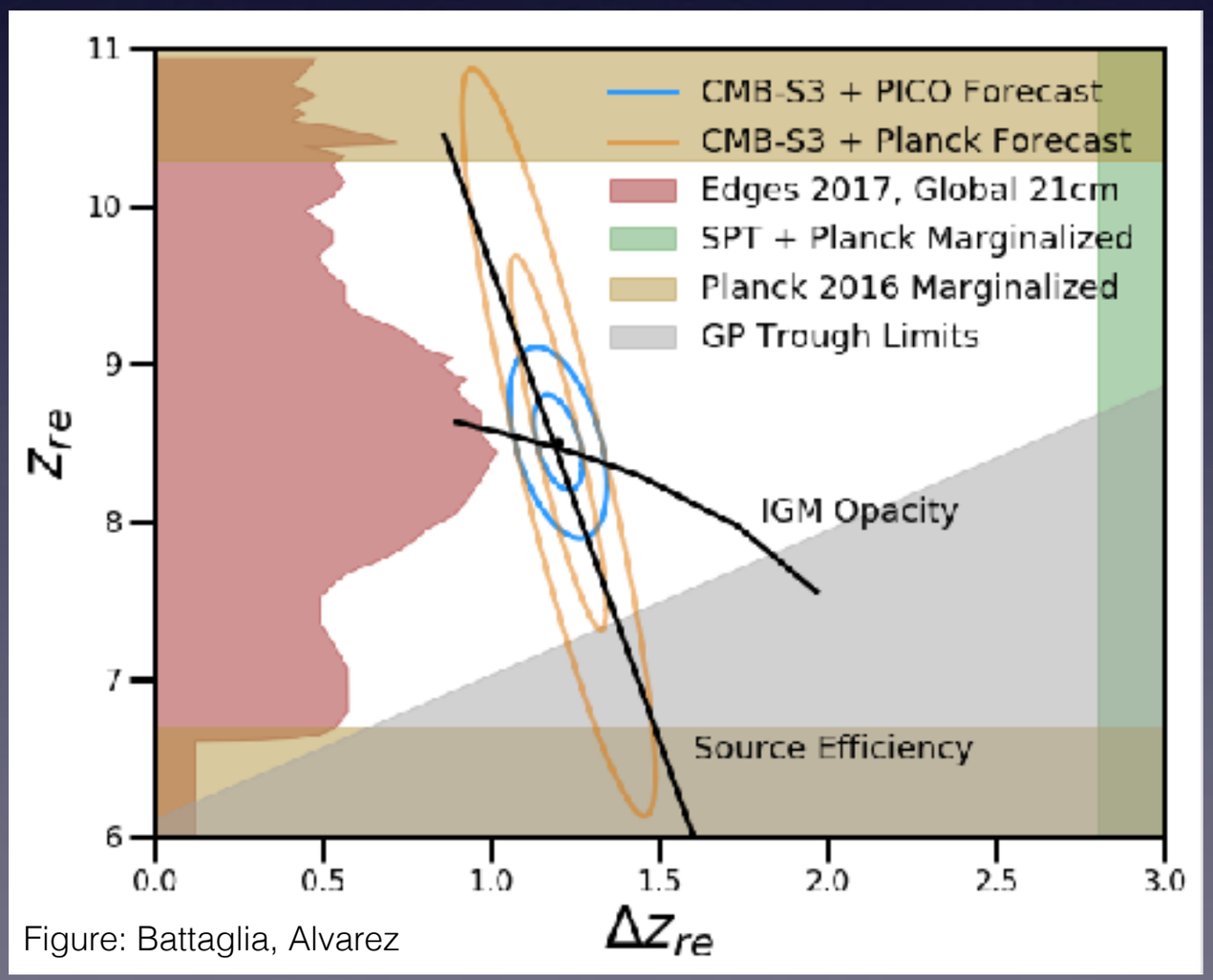
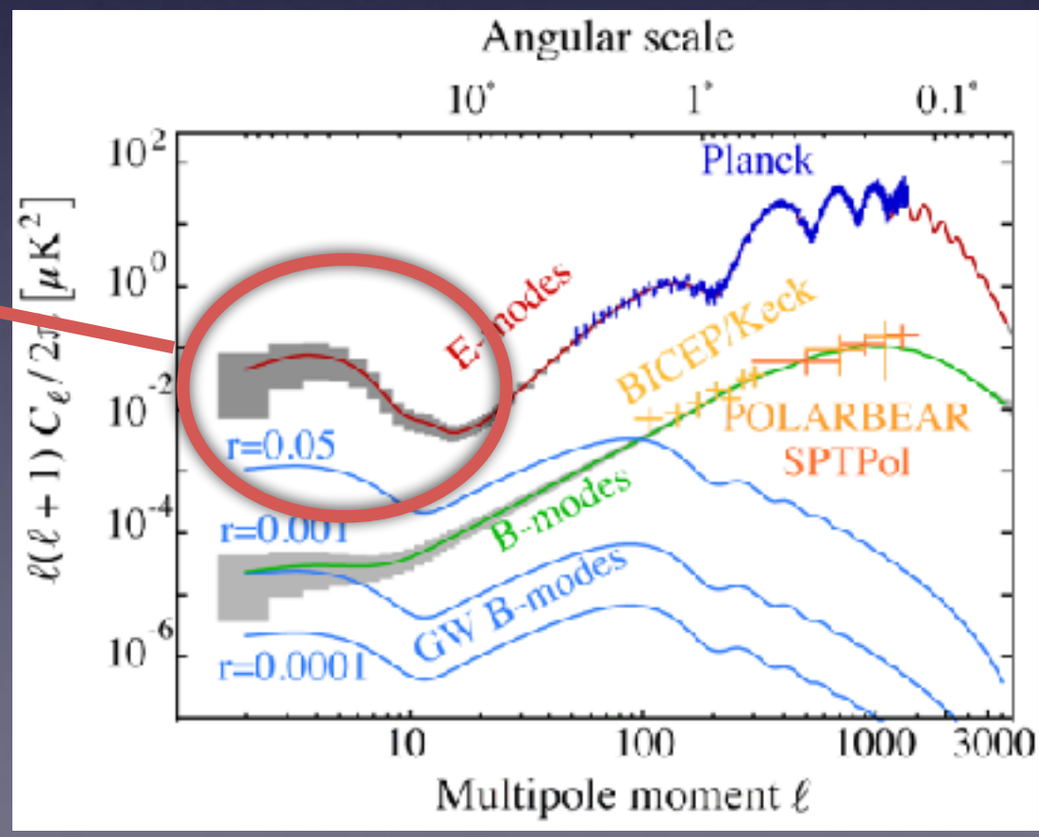


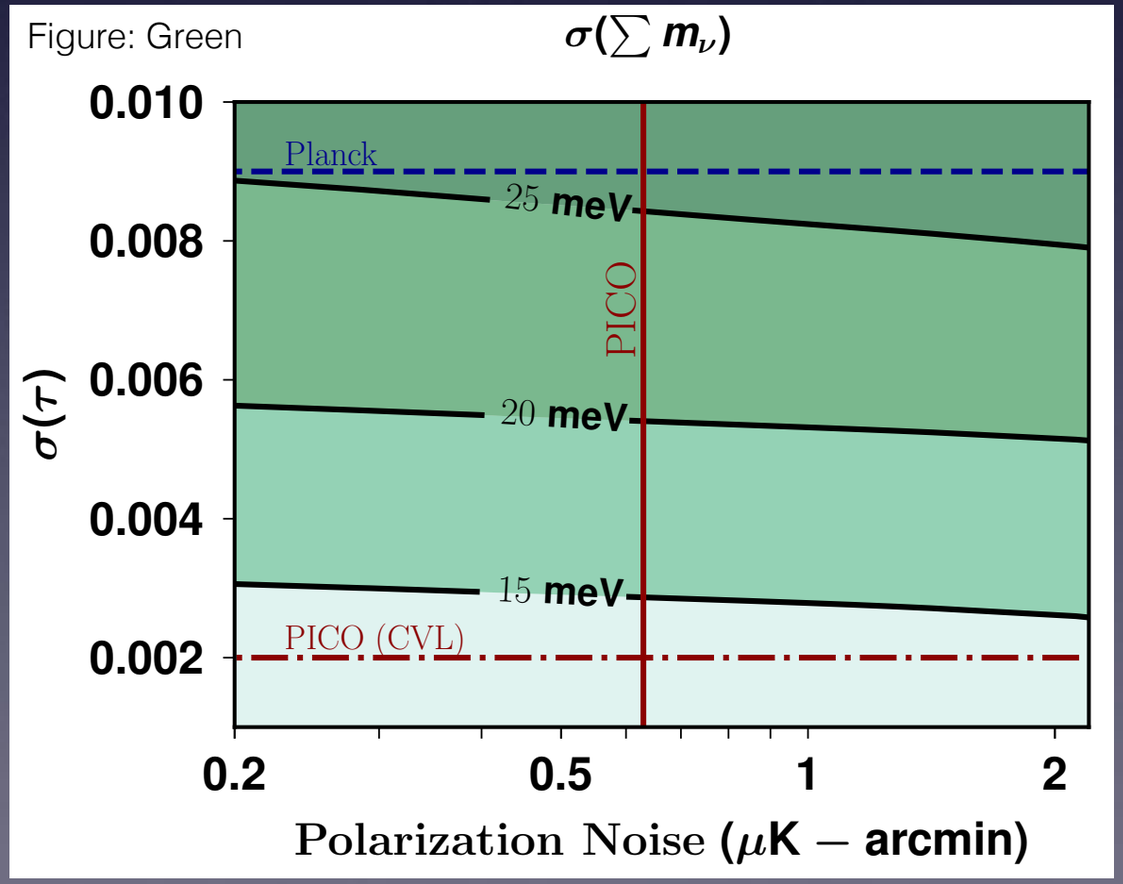
Figure: Battaglia, Alvarez



Discover How The Universe Works

- Determine the sum of neutrino masses $\sigma(\Sigma m_\nu) = 14\ \ \mathrm{meV}$
- Determine mass hierarchy, or mass of the lightest neutrino (if mass hierarchy known)

Figure: Green



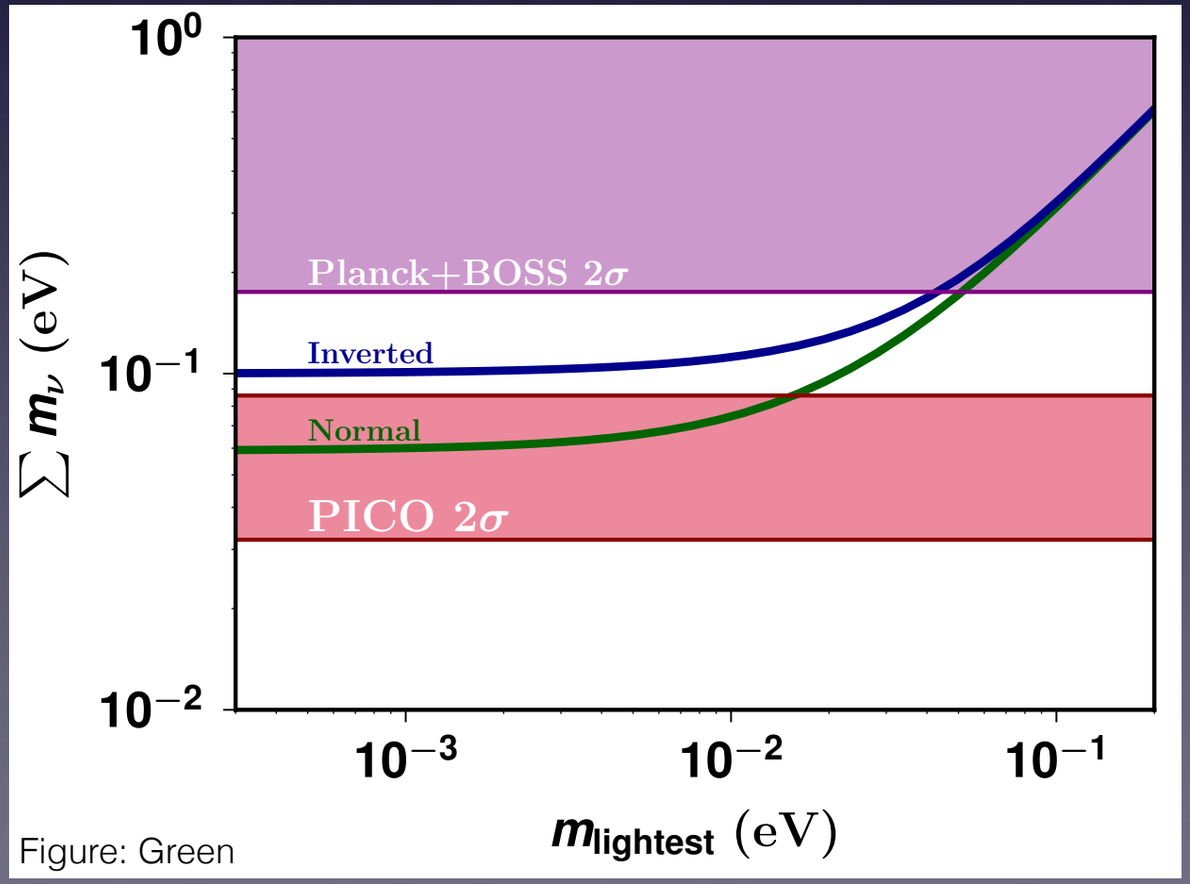
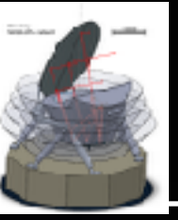


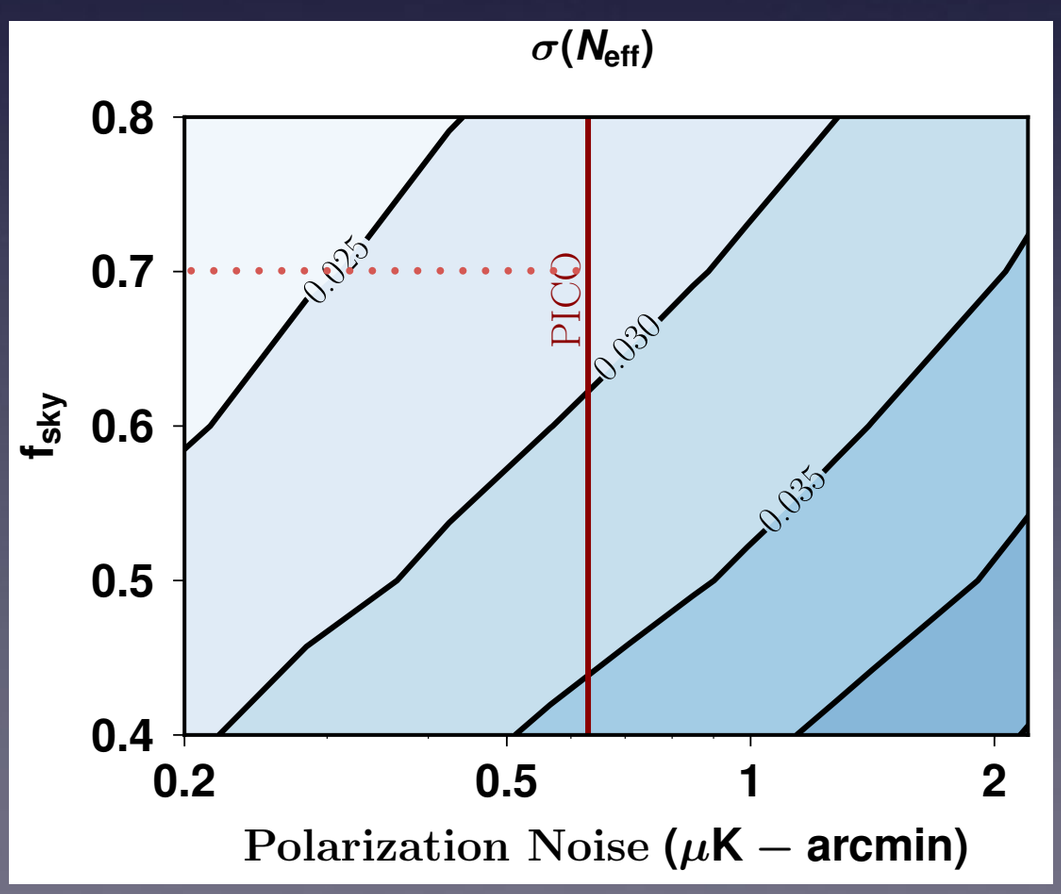
Figure: Green

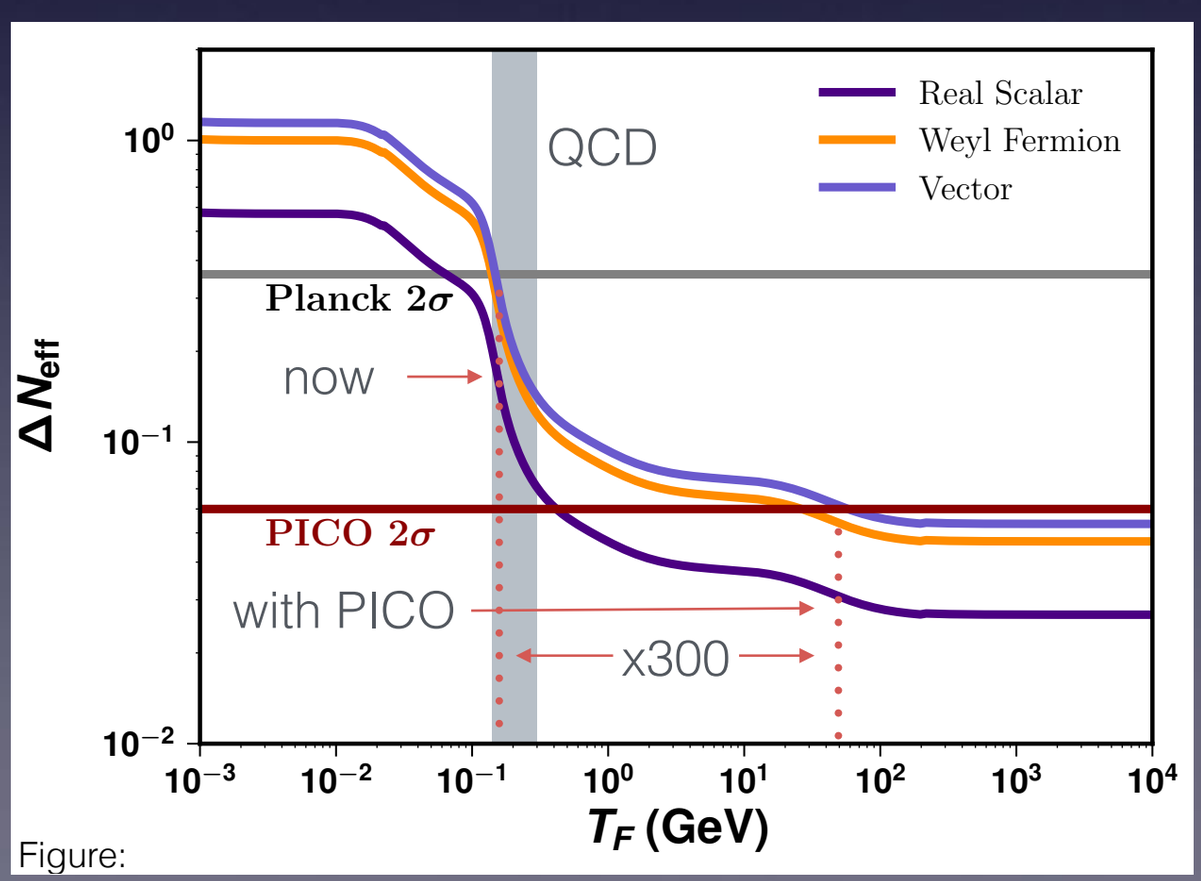


Discover How The Universe Works

- Determine the number of relativistic species of particles
  - Standard model: $N_{eff} = 3.046$
  - *Planck*: $N_{eff} = 3.04 \pm 0.18$
  - PICO: $\sigma(N_{eff}) = 0.03$

Figure: Green





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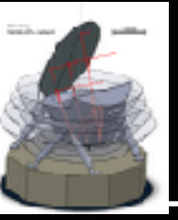


Explore how the Universe Evolved

- Determine the relative roles of turbulence and magnetic field in Milky Way dynamics and star formation efficiency

- Map sub-mm emission from the ISM in nearly 100 nearby galaxies: is the Milky Way typical?

- Constrain the shape and composition of interstellar dust grains

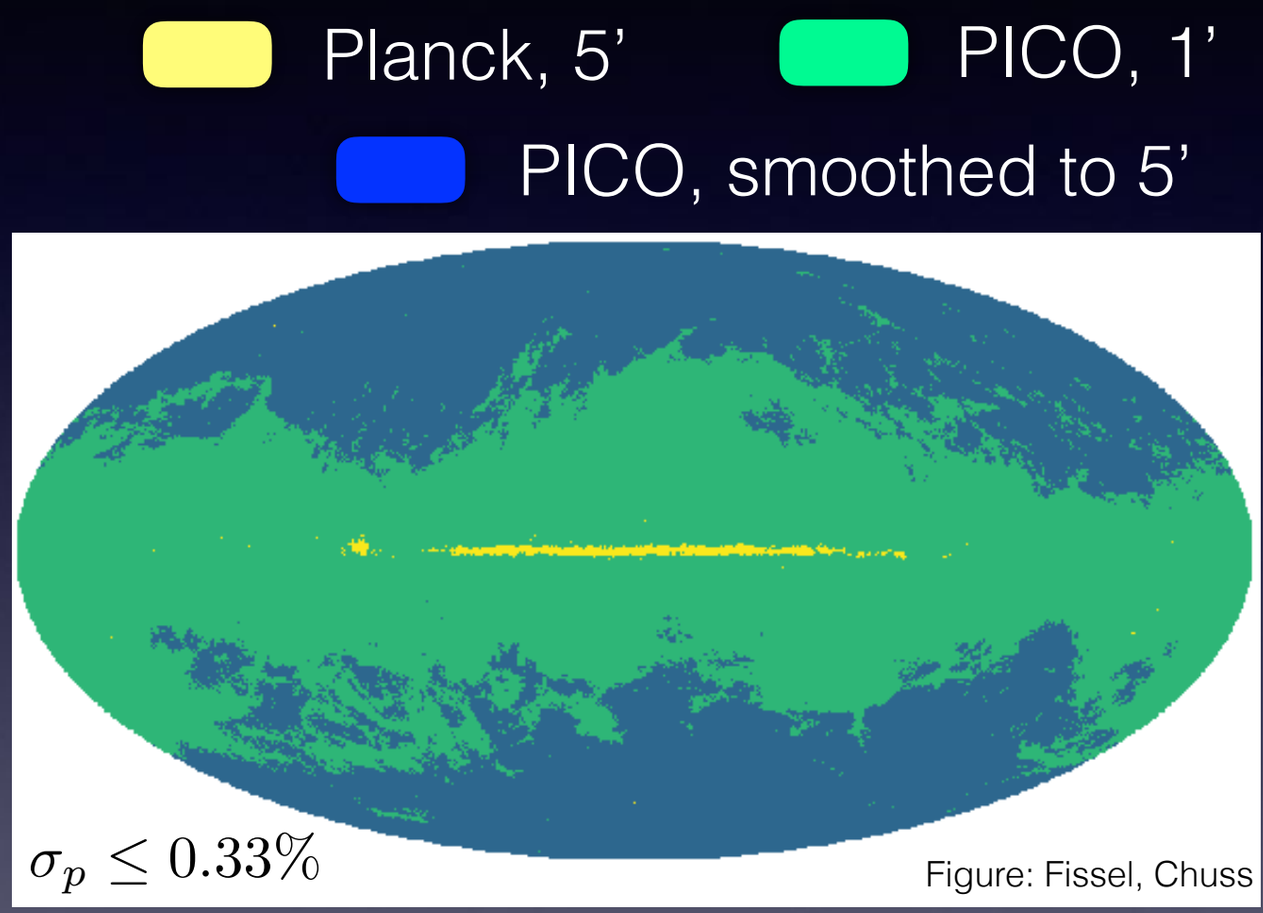


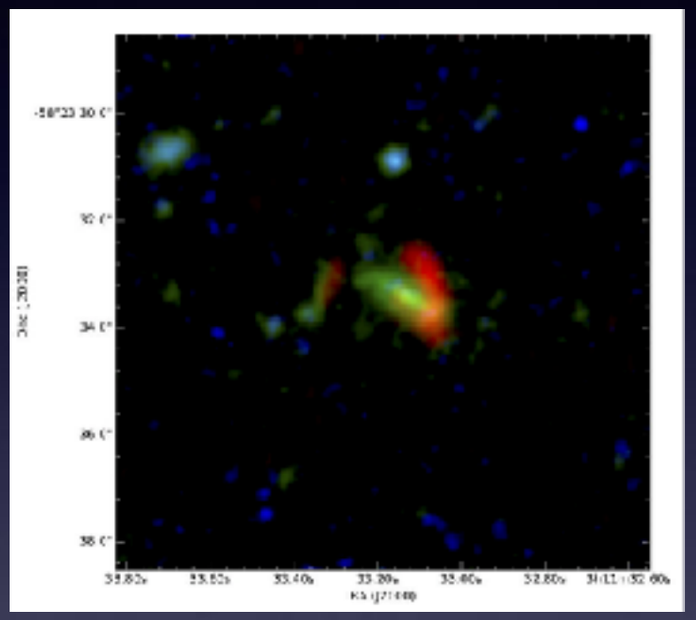
Figure: Fissel, Chuss

Legacy Science

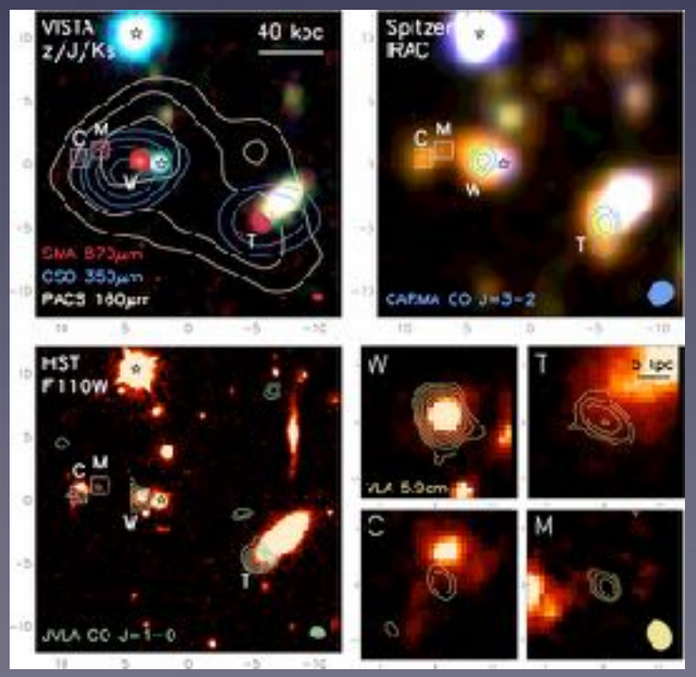
- Discover 3000 highly magnified dusty galaxies at z up to ~4.5;
- Discover 3000 proto-clusters over the sky and extending to high redshift;
- Detect polarization of 4000 radio and FIR-emitting galaxies;
- x10-100 more than known today
- Probe star formation history; determine galaxy and cluster formation and evolution; learn about dark matter substructure; and measure properties of jets in radio-loud sources.

NSF News Release Dec. 6, 2017

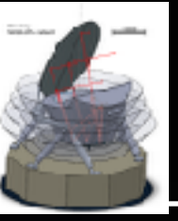
Massive primordial galaxies found in 'halo' of dark matter



Marrone et al. 2017; two strongly lensed massive galaxies, z=6.9 (SPT initial detection)



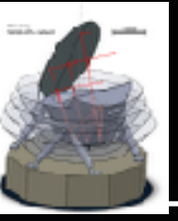
Ivison et al. 2013; proto-cluster core, z=2.4 (Herschel initial detection)



PICO Summary

- Inflation, quantum gravity, particle physics, extragalactic and galactic structure and evolution:
  - All unique goals for the measurements proposed,
  - PICO is the only instrument with the combination of sky coverage, resolution, frequency bands, and sensitivity to achieve all of this science with one platform.
- Initial engineering + costing study complete:
  - Technology implementation is a simple extension of today's technologies; no technological breakthroughs required
  - Mission is a good fit to the cost window

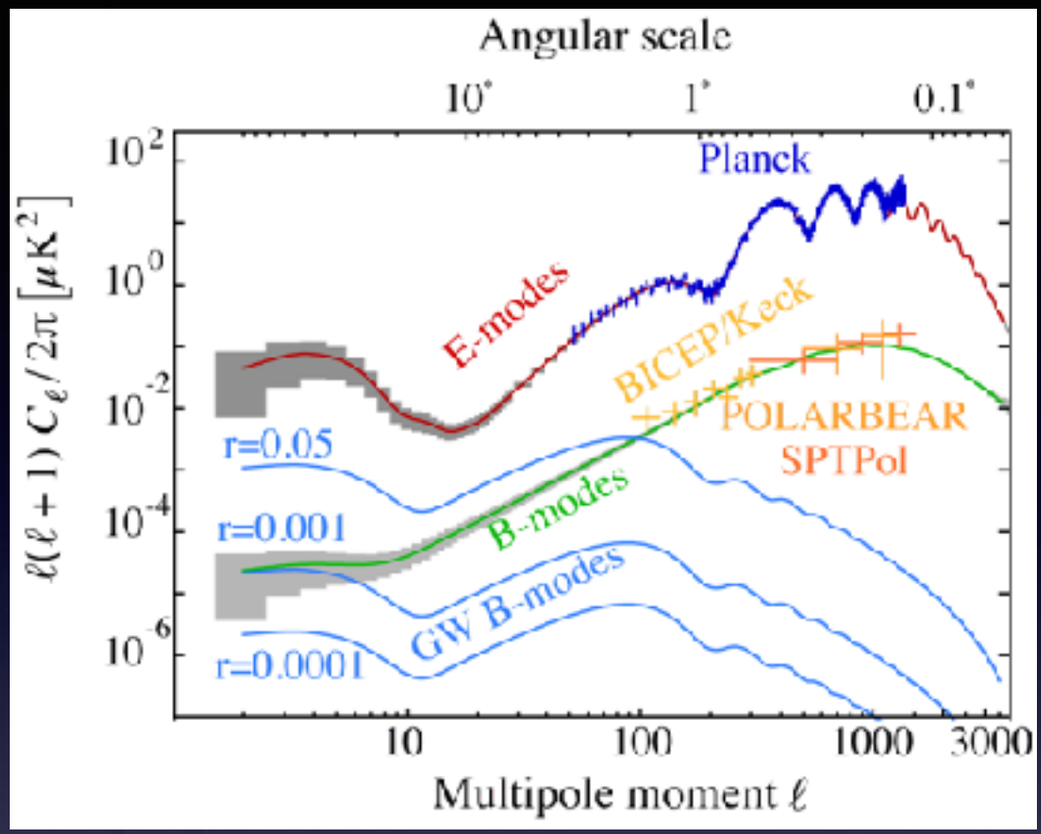
Additional Slides



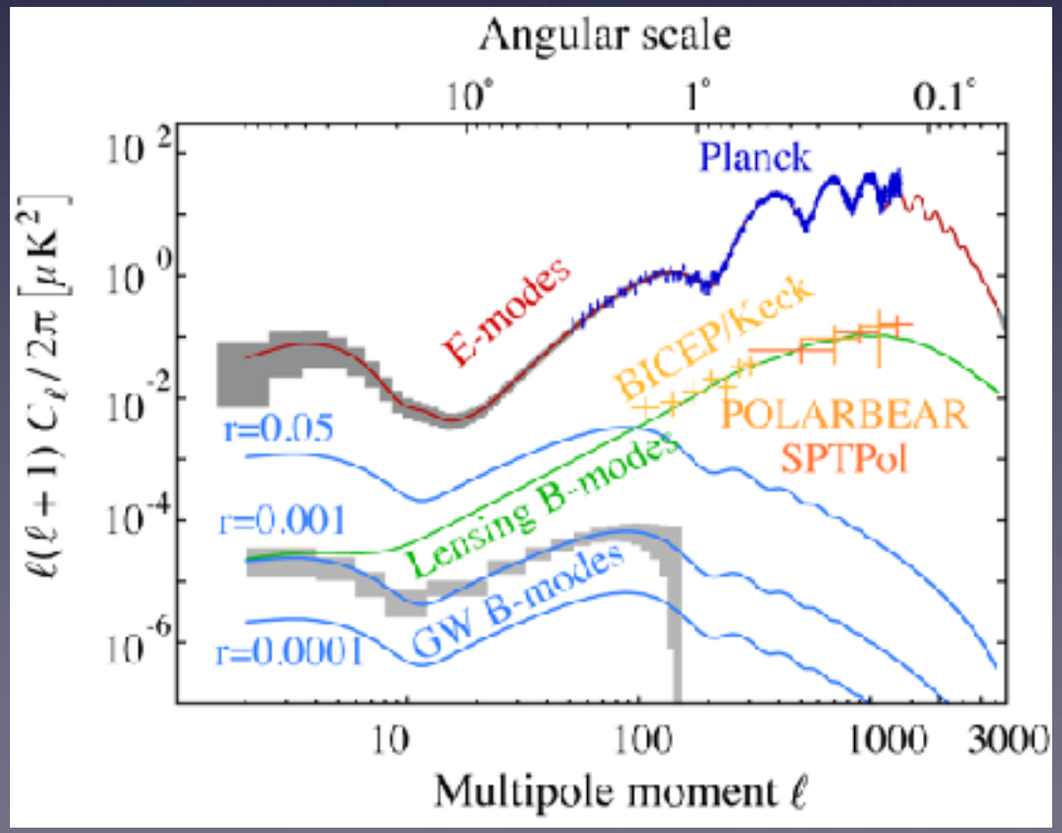
PICO and Sub-Orbital CMB Efforts

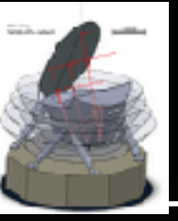
PICO's capabilities are not matched by any other foreseeable experiment

- Full sky coverage with ~4' resolution (and the same depth S4 has on 5% of the sky)



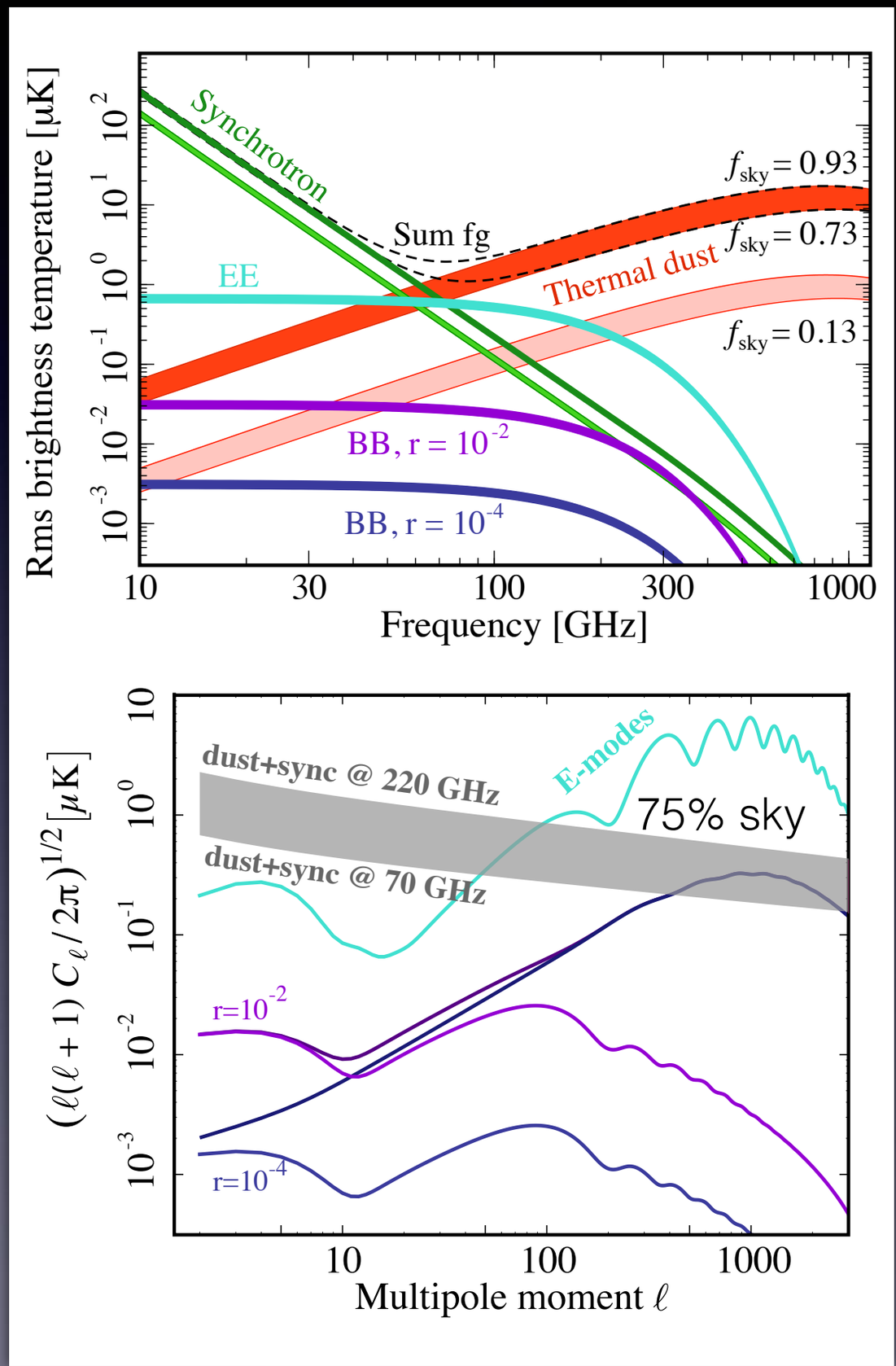
- Access to the entire range of angular scales of the B-mode signal, including the largest, while maintaining the capability to delens

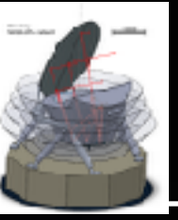




PICO and Sub-Orbital CMB Efforts

- Unmatched/unmatcheable frequency coverage
  - Galactic foregrounds are known to overwhelm the cosmological B-mode signal
  - Signals are at the nano-K level: even low level of residual foregrounds can bias the measurement
- Space gives the most systematic-error-robust platform
  - Signals are at the nano-K level





PICO Summary

- Extraordinarily compelling science goals, extraordinarily broad range of science deliverables:
  - Inflation, quantum gravity, particle physics, extragalactic, and galactic astrophysics
- PICO had initial engineering study at JPL in mid-December:
- Technology implementation is simple extension of today's technologies; no technological breakthroughs required
- Mission is an excellent fit to the cost window