Probe of Inflation and Cosmic Origins (PICO)

Julian Borrill, Shaul Hanany

With Many Thanks to all the PICO Collaborators

NASA Prep for 2020

- Set up 8 Probe Mission Studies; Probe= $400M-$1000M
  - Transient Astrophysics Probe (Camp, GSFC)
  - Cosmic Dawn Intensity Mapper (Cooray, UC Irvine)
  - Cosmic Evolution through UV Spectroscopy (Danchi, GSFC)
  - Galaxy Evolution Probe (Glenn, UColorado)
  - Inflation Probe (Hanany, UMinnesota)
  - High Spatial Resolution X-Ray Probe (Mushotzky, UMaryland)
  - Multi-Messenger Astrophysics (Olinto, UChicago)
  - Precise Radial Velocity Observatory (Plavchan, Missouri State)

NASA Prep for 2020

- Set up 8 Probe Mission Studies; Probe= $400M-$1000M
  - **Inflation Probe = Probe of Inflation and Cosmic Origin (PICO)**
- Studies will produce 50 pg. reports + cost estimates that will be submitted to NASA and to the Decadal Panel (12/2018)
- Possible outcomes:
  - Panel recommends a funding wedge. Probes are competed later.
  - Panel recommends specific missions
  - Combination of the above (funding wedge + prioritization)
- Our desired outcome: panel recognizes the promise of a future space mission and gives high ranking

What's at Stake

- NASA only invests in technology development or balloon payloads that lead to a future space mission.

- Over the years NASA has spent significant resources in CMB activities (space, balloons, tech development) because there was a mission in the future.

- NASA invests only in what the decadal panel recommends

- Many of us (most? all?) recognize the strengths of a future CMB space mission, the complementarity with sub-orbital, and the value of keeping NASA engaged with CMB

How to Make the Case

- Communicate breadth and importance of science goals
  - Those we own (r, Neff, tau)
  - Those that also appeal to the broader astrophysics community (structure formation and evolution on all scales)
- Present a *compelling* plan to the agencies, specifically both NSF and NASA
- Present a *coherent* plan - how all components work together, ground, balloons, space
- **Your contributions are important; engage!**

The PICO Collaboration

- **Open to all**
- Steering Committee: Bennett, Dodelson, Page
- Executive Committee: Borrill, Bock, Crill, Devlin, Flauger, Jones, Hanany, Knox, Kogut, Lawrence, McMahon, Pryke, Trangsrud - Weekly Telecons
- 7 working groups:
  - Fundamental physics (Flauger, periodic telecons)
  - Extragalactic science (Battaglia, almost weekly telecons)
  - Galactic science (Chuss+Fissel, periodic telecons)
  - Data challenge (Knox+Borrill)
  - Imager (Hanany, weekly telecons)
  - Spectrometer (Kogut, periodic telecons)
  - Systematics (Crill+Didier, almost weekly telecons)
  - [Technology (McMahon, O'Brient, Hubmayr, Suzuki, …)]
  - [Foregrounds (Flauger, Errard, Remazeilles, Delabrouille, …)]
- Wiki: https://z.umn.edu/cmbprobe
- Mailing list: cmbprobe@lists.physics.umn.edu

The PICO Science

- Broad-band Imagery and Spectrometry
  - Energy scale of inflation (r)
  - Constraints on inflation models (r, n)
  - Optical depth to reionization (tau)

The PICO Science

- Spectrometry
  - The role of AGNs + supernovae in galaxy formation (maps of y-distortion, s/n>100)
  - Constraints on inflation models (mu-distortion from silk damping, s/n>=10?)
  - Detection of recombination lines (s/n<1)
  - Temperature and opacity of galactic dust (spectral information between 30 GHz and few THz)

The PICO Science

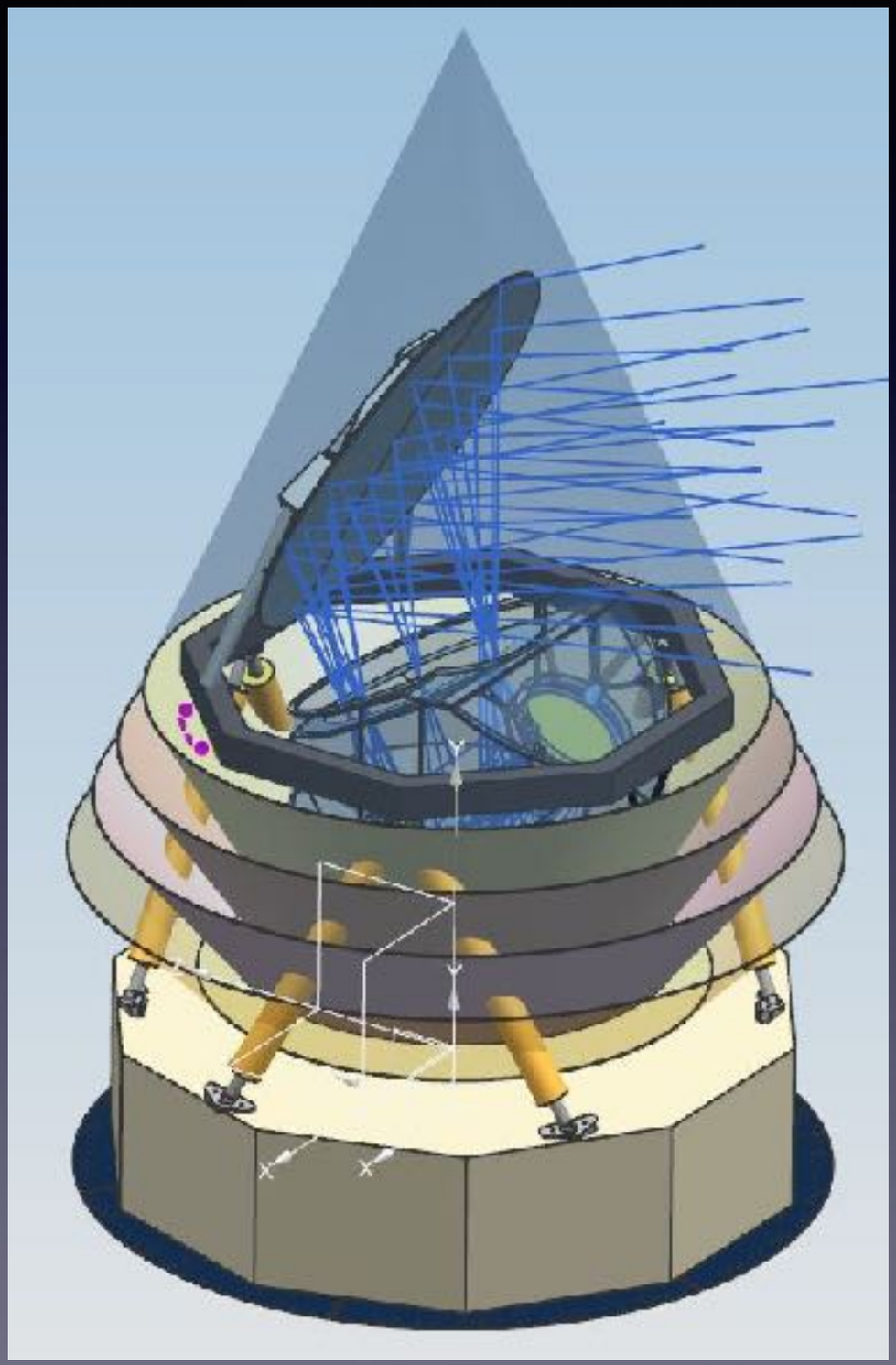
- Broad-band Imagery
  - The number of light species in the early Universe (Neff)
  - Sum of neutrino masses (Lensing, Cluster Counts)
  - Cosmological parameters (Cluster Counts)
  - Galaxy formation and evolution (Low and High z point sources)
  - Star formation process (galactic magnetic fields)
  - Dust and synchrotron characterization

Spectrometer/Imager

- The EC concluded that there is strong case for two Probe scale missions, one devoted to spectroscopy and another to imaging
- The EC considered the case for a combined mission and concluded that it will weaken both instruments
- PICO will be given detailed costing as an imaging mission.

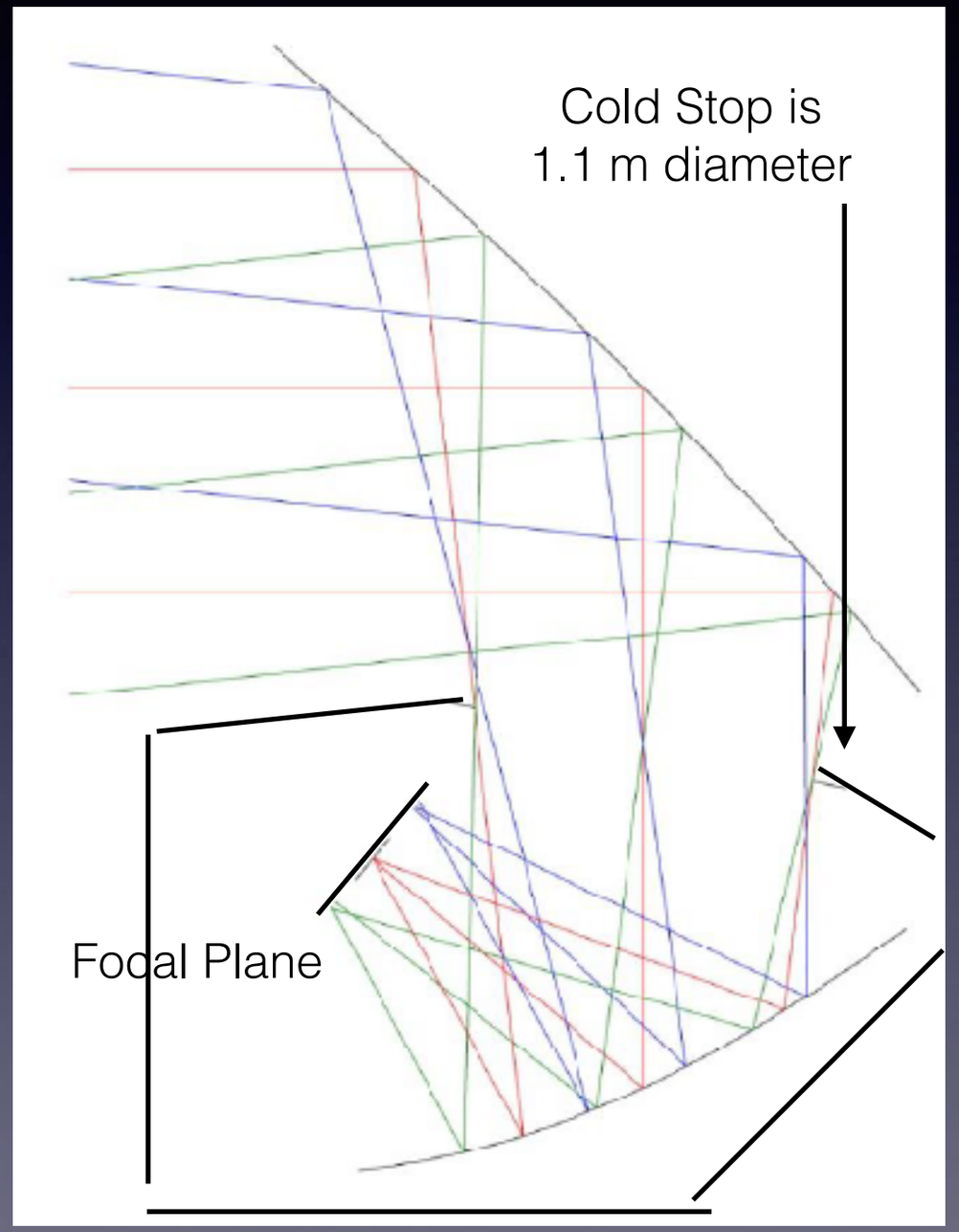
The PICO Imager

- 1.4 m aperture, open Dragone telescope
- 21 frequency bands between 21 and 799 GHz
- 7.6’ resolution at 155 GHz, 1’ at 799 GHz
- 12,060 detectors
  - Three-color TES arrays for 21-462 GHz; Single color PSBs for 555 - 799 GHz
- Multiplexed readouts



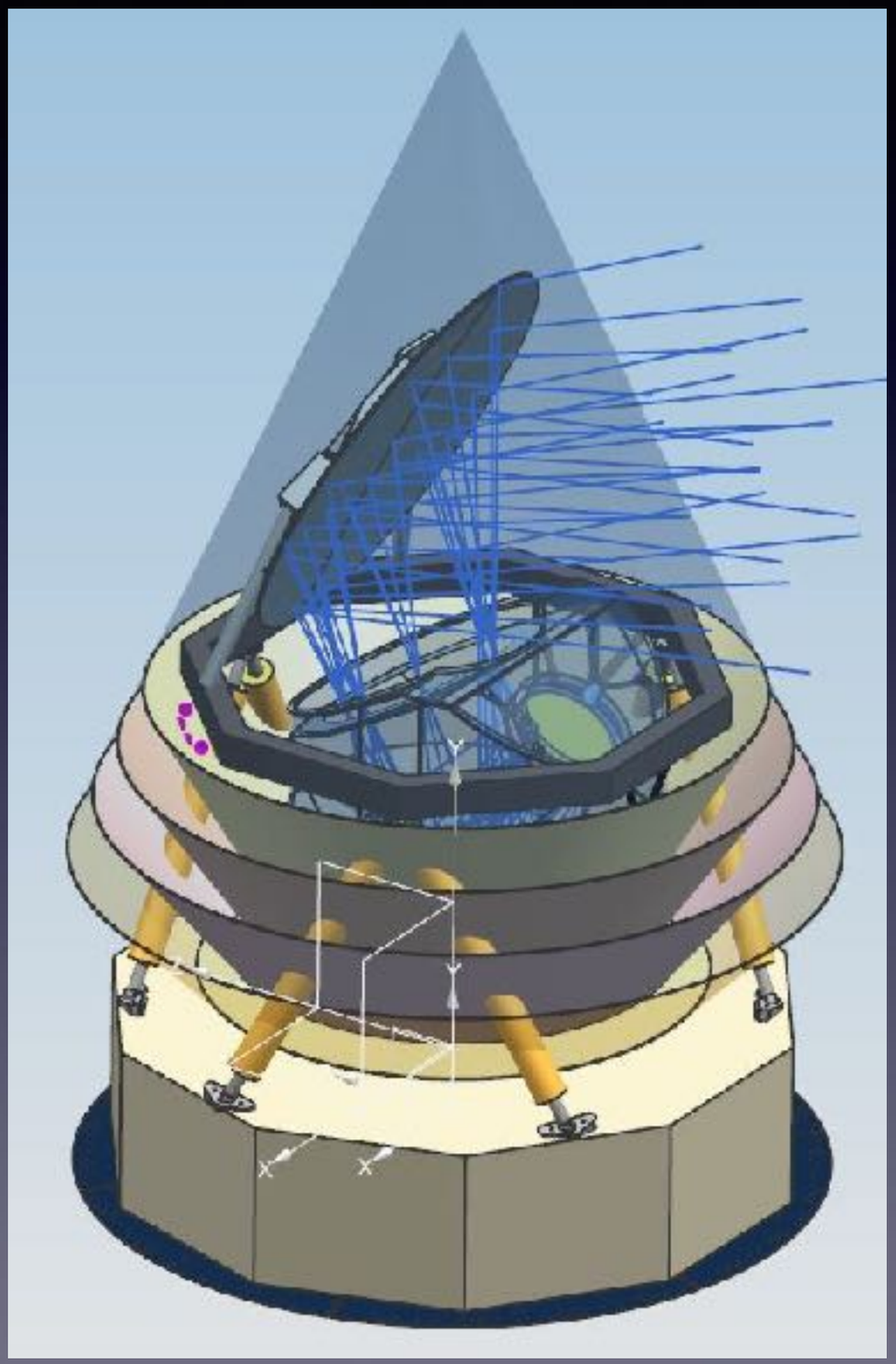
Optics + Cooling

- Open Dragone Telescope
  - No direct view to sky
  - No three-reflection sidelobe
  - Cold stop (without cooling primary mirror)
- Design includes enhancement to DLFOV through coma correction
- Primary mirror at ~40 K;
- Stop + secondary actively cooled to ~6 K;
- Focal plane @ 0.1 K with cADR



Mission

- L2
- 4 years
- Mass, Power - TBD
- alpha/beta: 30, 60
- spin: 1 RPM
- Data: 3.2 TBits/day
- polarization noise = 0.7 uK*arcmin



Science Deliverables: Fundamental Physics

- sigma(r) = $1.5*10^{-5}$ (noise only, no foregrounds, no systematics, includes delensing using self measurement of EB)
- sigma(tau) = 0.0019 (cosmic variance)
- sigma(sum Mnu) = 15 meV
- sigma(Neff) = 0.03

Science Deliverables: Extragalactic Science

- Thousands of new proto-clusters at high redshift (T): discover the process of cluster formation
- 3000 highly magnified dusty sources (T):
  - a probe of dark matter sub-structure in lenses
  - the only way to probe star formation history in high-z dust enshrouded galaxies
- Thousands of IR and radio sources (P): to determine their polarization and its effect on cMB B-mode science
- Tens of thousands of SZ clusters
  - +-5% on w; +-0.27 on w_a
  - sigma(sum Mnu) = 23 meV (independent of lensing measurement)
- s/n=480 on lensing potential power spectrum

Science Deliverables: Galactic Science

- Deep galactic maps to give galactic B-field: determine if magnetic fields are the dominant cause of low star formation efficiency in our galaxy
- First sample of B-field in other galaxies: is the magntic field structure in our galaxy unique or run-of-the-mill?
- All sky maps of dust polarization: are radiative processes responsible for dust alignment? do we understand the dust alignment mechanism?
- Determine dust and synchrotron SED in low, medium, and high, galactic latitudes

Study Status

- First TeamX design and costing session in Dec. 18 (JPL)
- Just concluded 2.5 day Foregrounds workshop in San Diego
- Instrument and mission design will continue through spring 2018.
  - Final TeamX in March2018
- **Planning 2nd Workshop for Late April, Early May (probably Minneapolis)**
  - **Science + Complementarity with Ground + Decadal Preparations**
  - **Stay tuned for announcement soon and keep calendar open**
- Report writing summer + fall 2018.

PICO and You

- PICO is an open collaboration
- wiki: z.umn.edu/cmbprobe
- list: cmbprobe@lists.physics.umn.edu
- You are invited to contribute
- Keeping NASA involved is good for all of us and it is excellent for CMB science.

Additional Slides

Additions

- Decadal: NASA is the third leg
- Coordinated message:
    - AI: real concern is when we're interfacing with S4. Both S4 and Probe concept need to be careful to give the same message, lest NASA HQ decides that only one is needed. Including things ground doesn't get us that space does. Don't want HQ to think that the CMB community thinks a ground mission alone can get the full range of science.
    - AI: It is important that both ground based and NASA side are saying the same thing. Don't want mixed messages. Maybe be best couched in terms of sigmas - sigmar, sigmanf