# ECHO: Exploring Cosmic History and Origin

*Next generation comprehensive CMB space mission*


- L. Sriramkumar (IIT Madras)
- Rishi Khatri (TIFR Mumbai)
- Subha Majumdar (TIFR, Mumbai)
- Tuhin Ghosh (NISER, Bhub'war.)
- Dhiraj Hazra (INFN-> NISER )
- Suvodip Mukherjee (IAP→ ?)
- Jasjeet Bagla (IISER Mohali)
- Zeeshan Ahmed (SLAC, Stanford)
- Mayuri Rao (UC Berkeley & RRI)
- Tirthankar Roy Chowdhury (NCRA)
- Ranajoy Banerjee (U Olso → ?)
- Aditya Rotti (U Manchester → ?)


**Cosmology- The Next Decade**
*(CMB- The next Decade session)*

**ICTS Bangalore**

**Jan. 24, 2019**


**Tarun Souradeep**
IUCAA

On behalf of CMB-Bharat

(An Indian Cosmology consortium)

# Next CMB space mission: Why ?

- **CMB measurements have been transformational for Cosmology**
- Planck mission (ESA) extracted ≈100% of CMB temperature information
  But only a small fraction (10%) of the rich **CMB polarisation information**

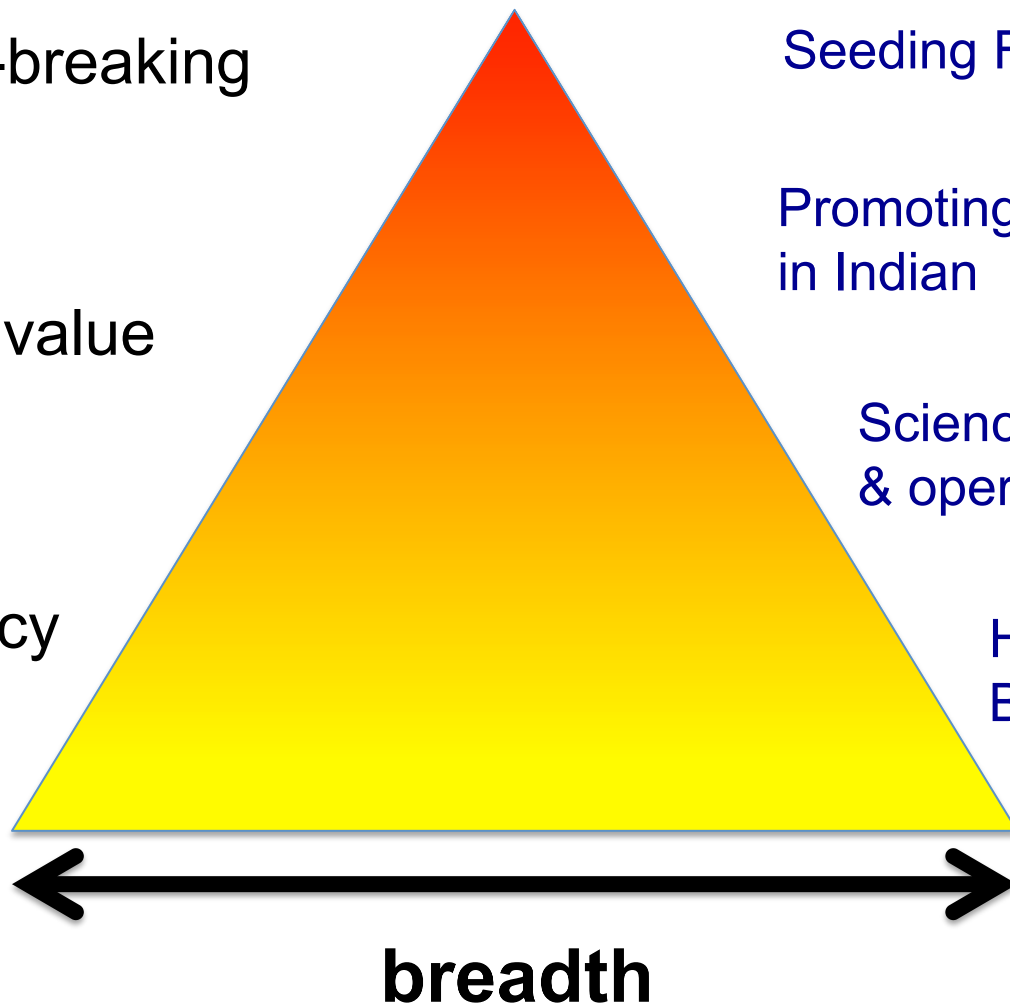
## Scientific promise:

- **ULTRA- HIGH: Reveal first clear signature of quantum gravity and ultra-HEP in the very early universe**
  ***(GW of Quantum Origin. Note, LIGO detected classical GW)***
- **HIGH Goals: Neutrino physics: number of species, total mass and hierarchy; Map all dark matter and most baryons in the observable universe**
- **Legacy : Improve probe of cosmological model by a factor of > 10 million; Rich Galactic and extra Galactic Astrophysics datasets**
- **Unexpected Discovery space: Unique probe of 'entire'($z<2\ x10^6$) thermal history of the universe**

# Balanced Impact-Returns profile

**Science**

**Technology**




| Science | Technology |
| --- | --- |
| Path-breaking | Seeding Frontier programs |
| | Promoting nascent technology in Indian Labs & Industry |
| High value | Science mission planning & operation at L2 |
| Legacy | HPC, IT and Big-data |

# CMB-Bharat

- ***A "near-ultimate" CMB polarisation survey*** *(2μK.arcmin sensitivity, ~20 bands in 60-900 GHz)*

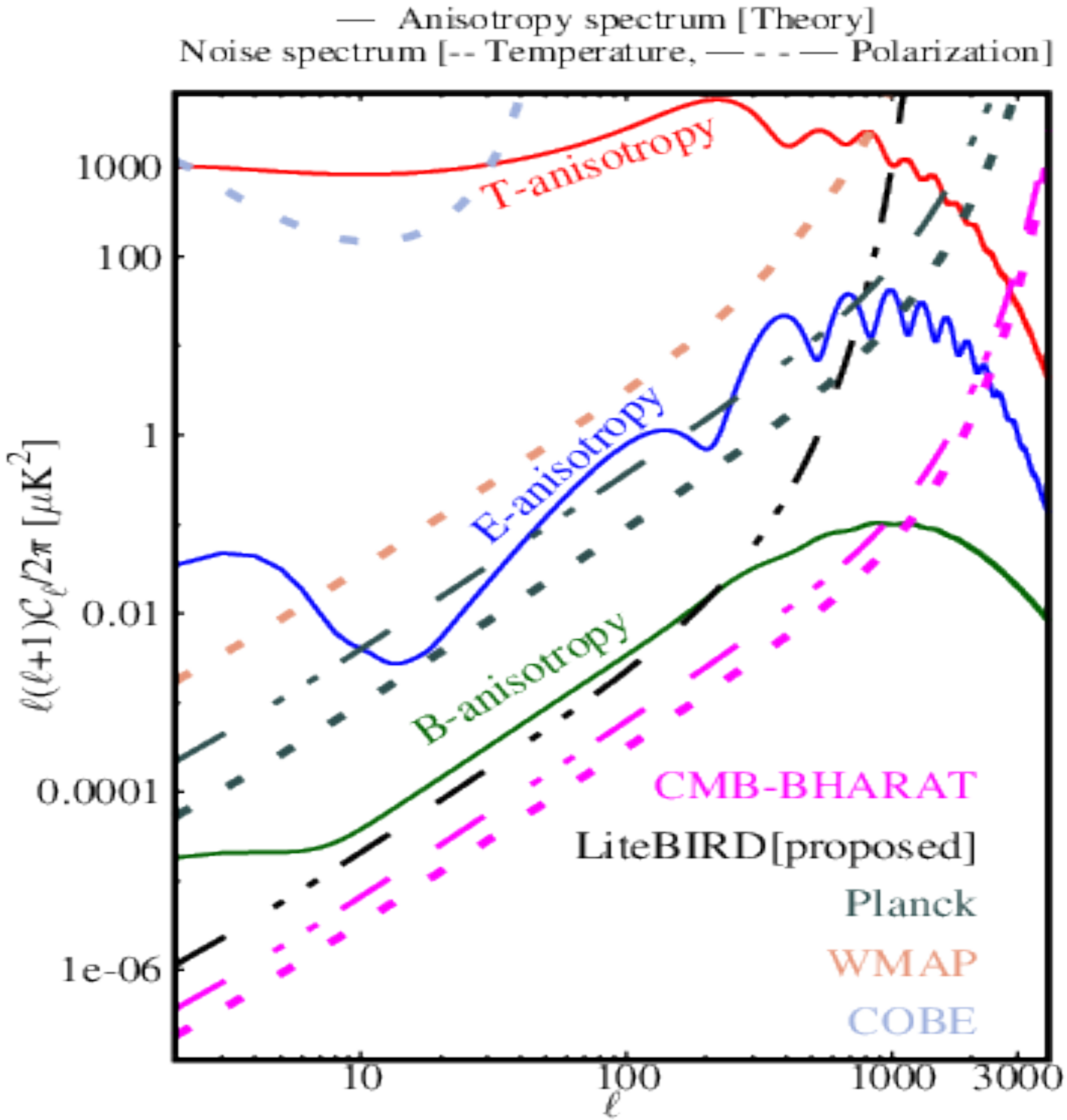
\+ possibly

- ***spectral capability--On-board absolute BB calibrator, Spectrometer***
- ***Observatory mode (2 years) after survey (4 years)***

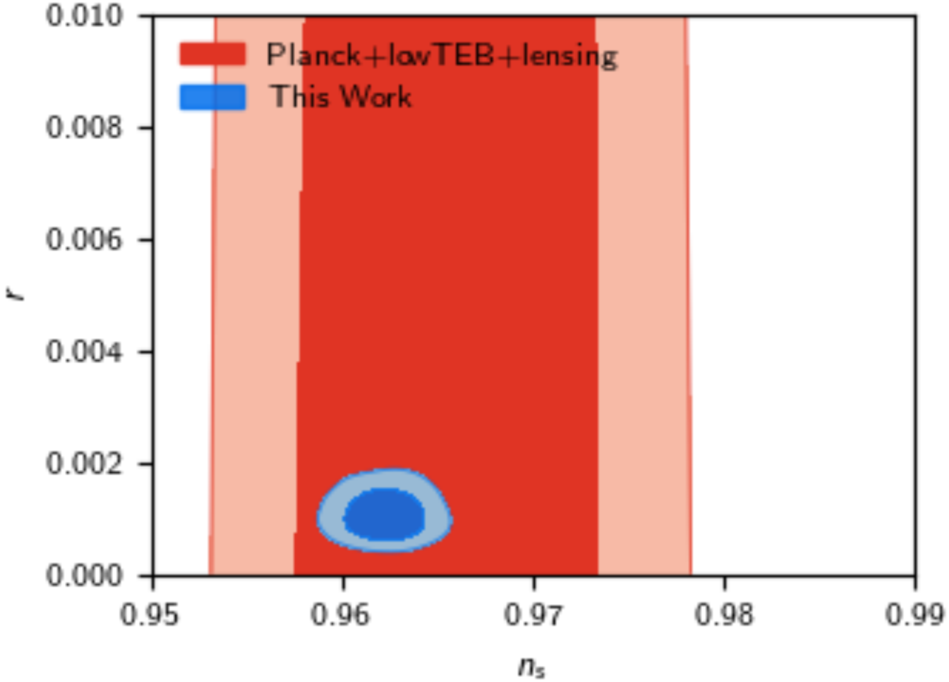
| | |
|---|---|
| . New Science | • Primordial gravitational waves **~ Quantum gravitation**<br>• Dark matter distribution<br>• Neutrino mass, hierarchy and species **Tighest limits**<br>• Reionization history<br>• Cosmic thermal history |
| i. Extension/ Improvisation to the previous findings | • Highly precise standard model parameters<br>• Dark matter annihilation<br>• Galaxy clusters<br>• Nature of dark energy<br>• Cosmic anomalies |
| ii. Supplementary / complementary science | • Cosmic Infrared Background<br>• Magnetic field and dust in the Milky Way<br>• Magnetic dipolar emission |

**HUGE DISCOVERY SPACE**

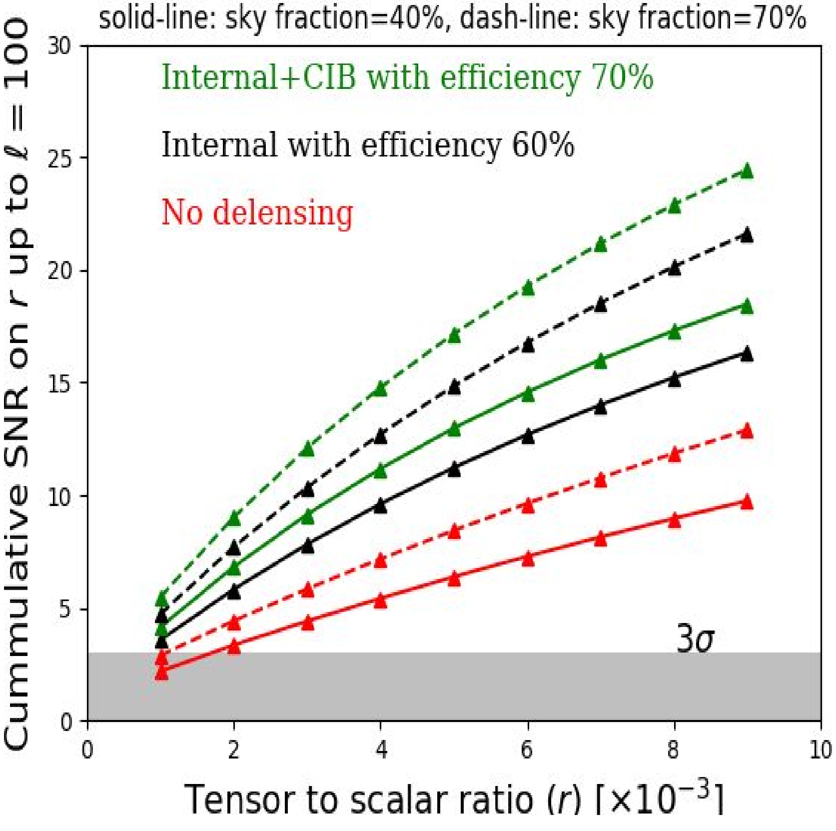
# CMB Polarization



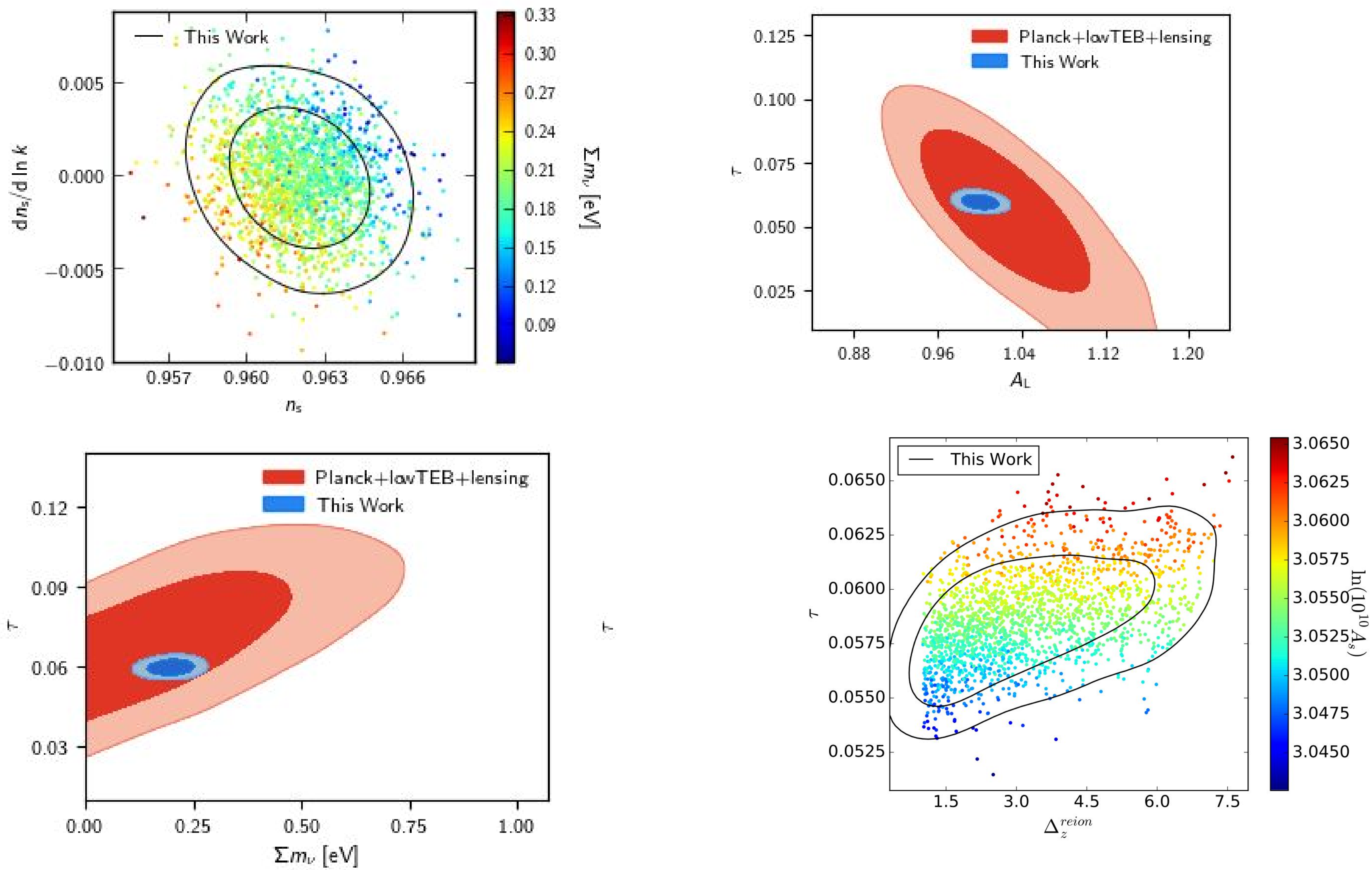
# CMB Polarization: ultra-high dividend



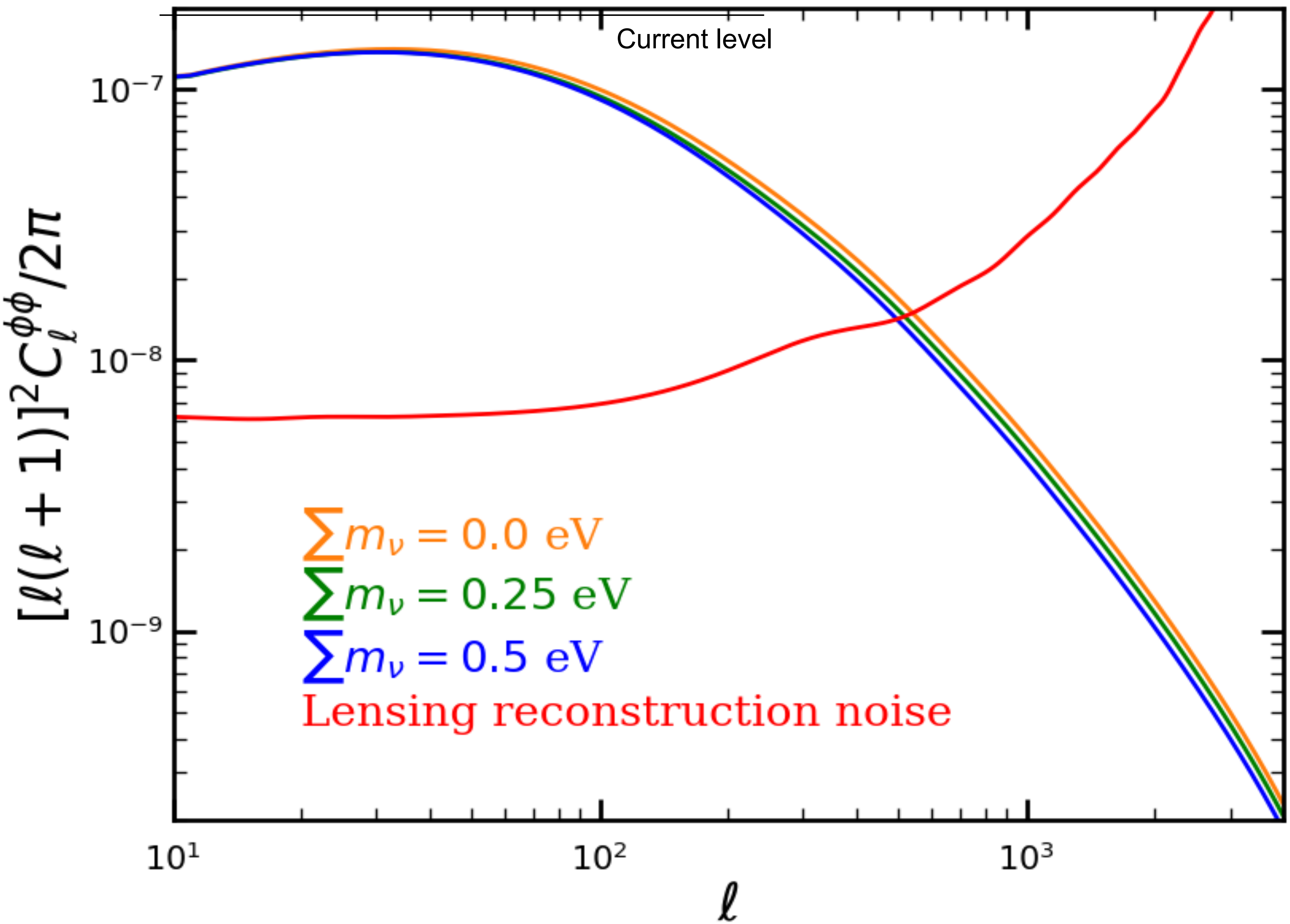

Primordial GW from Inflation
Tensor/Scalar ratio



# CMB Polarization: high dividend

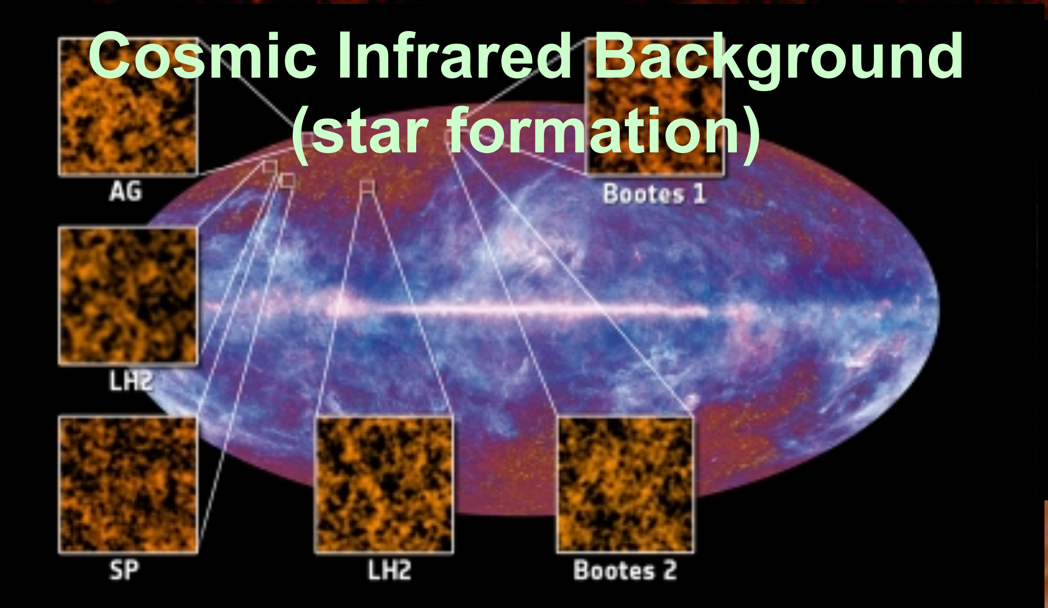


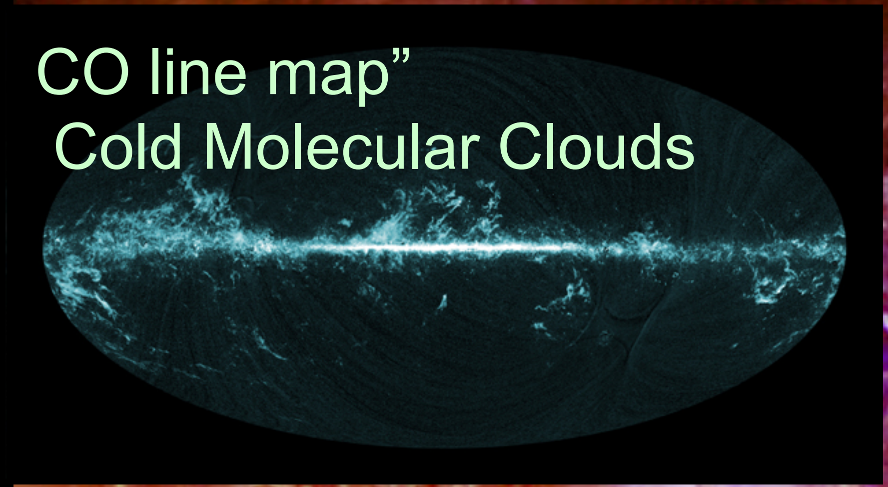
# Projected Lensing potential from Planck

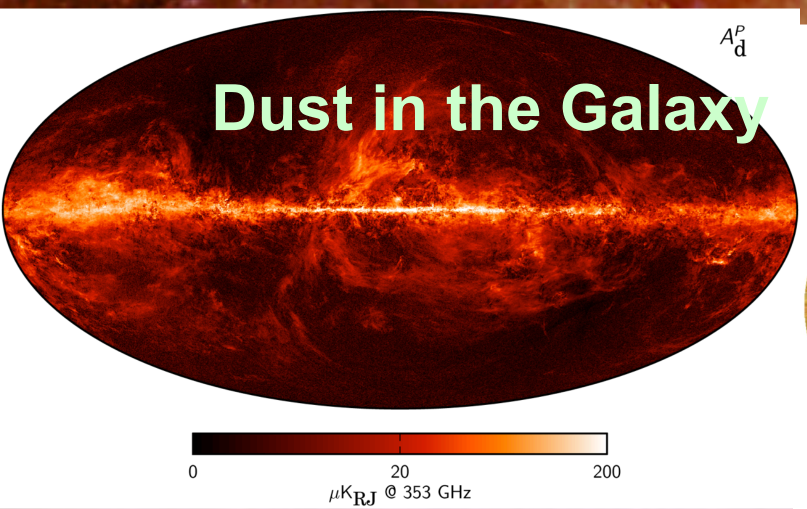


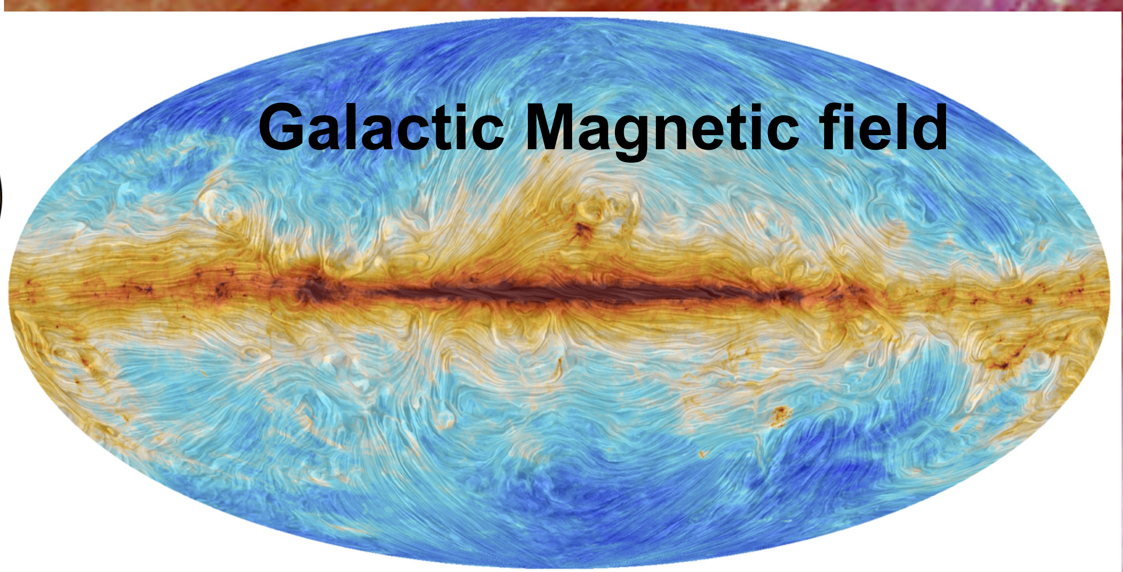

- C

# CMB Foregrounds : Rich A&A science
## (600-900GHz )

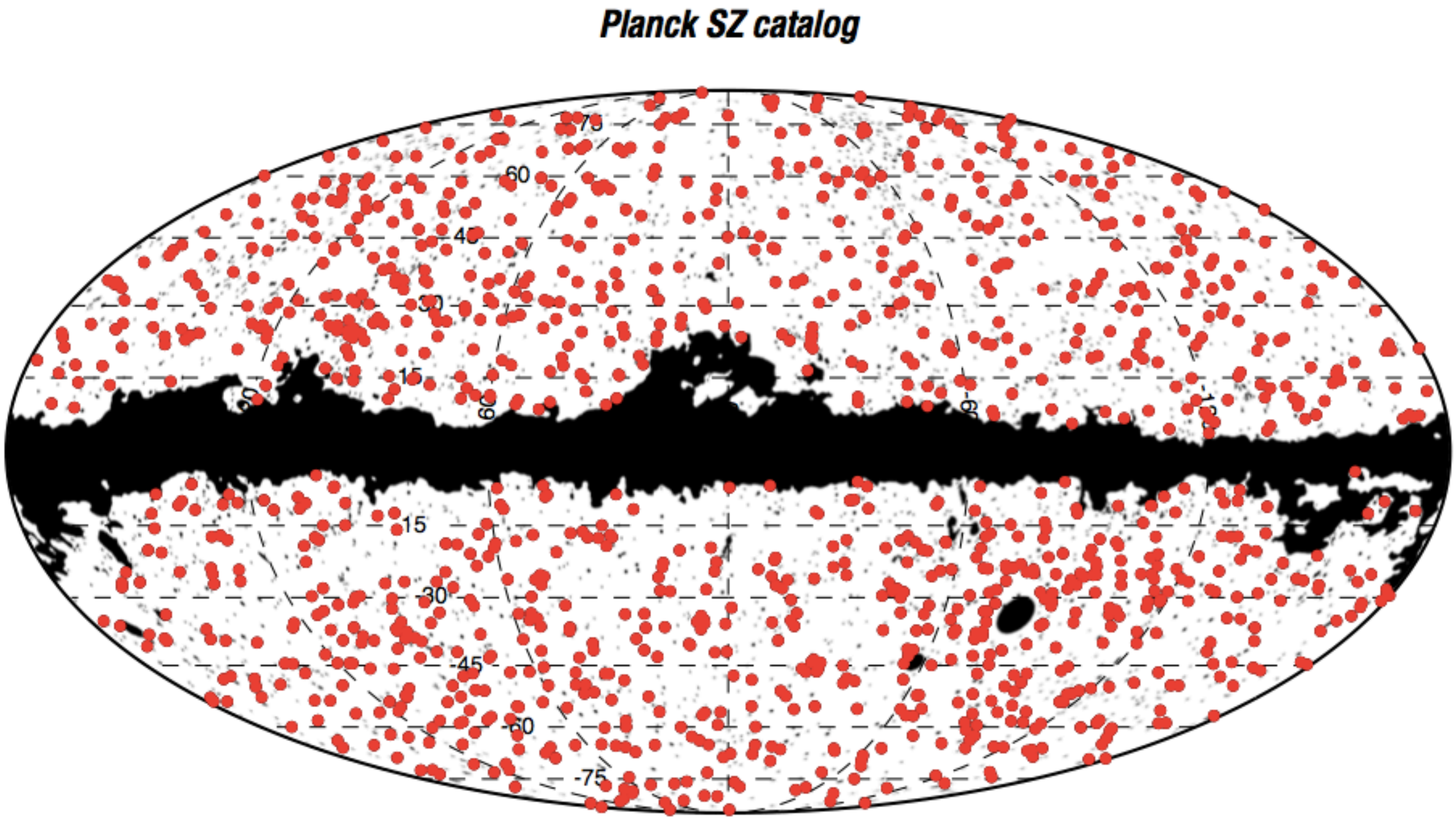


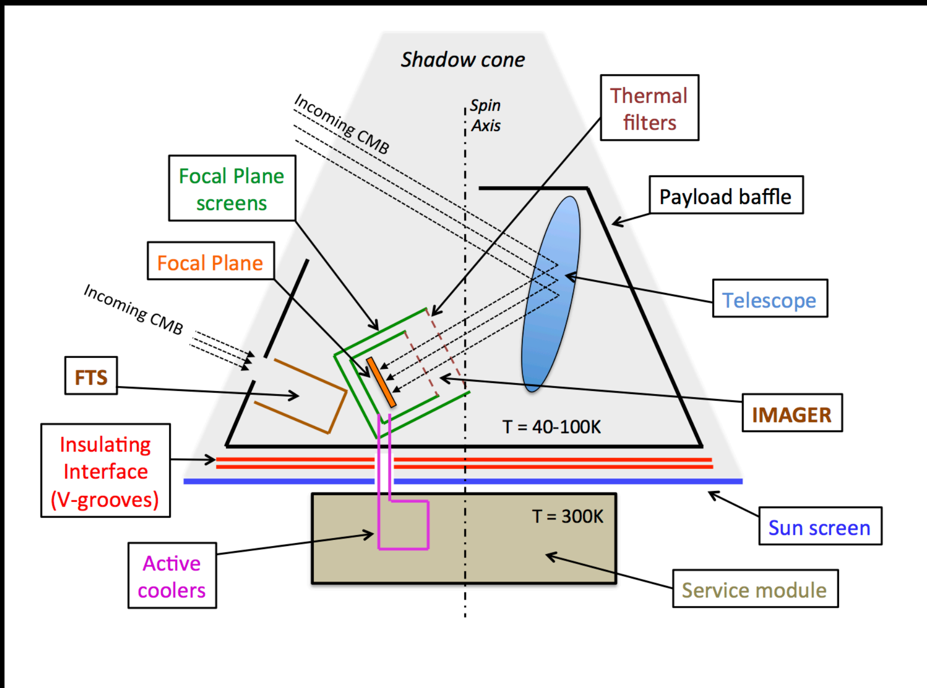



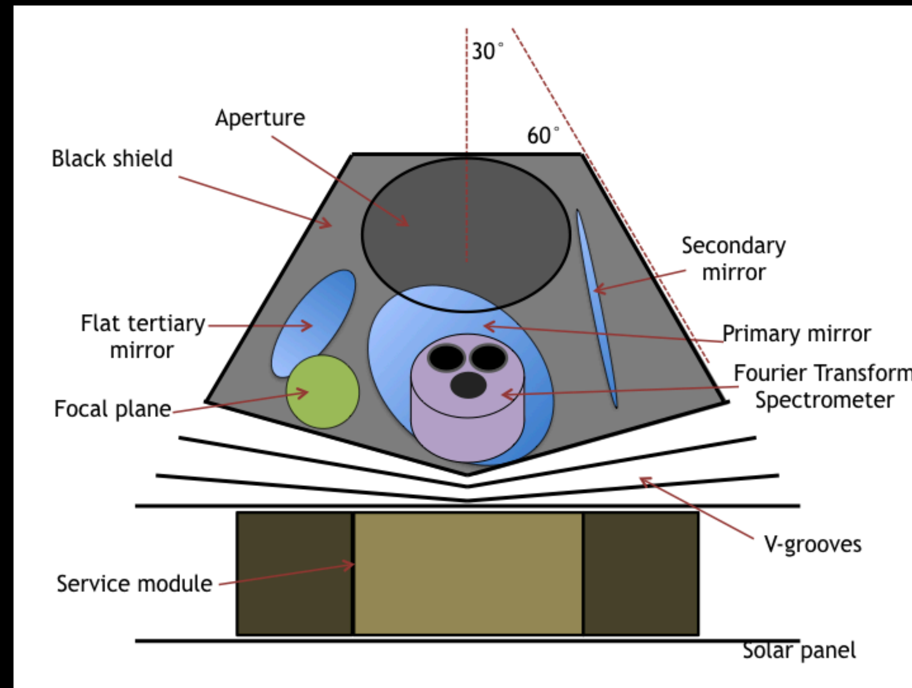
# SZ clusters from Planck




50,000 clusters of mass above $10^{14} M_{sol}$ up to a redshift $z \sim 2.5$

# CMB-Bharat  Payload schematic




A multifaceted frontier science and astronomy mission

- map sky  temperature, linear polarization (~60-1000 GHz),
- Multi-frequency (20+) → Spectral science
- unprecedented sensitivity, accuracy and angular resolution.

# CMB-Bharat S/c Specs.

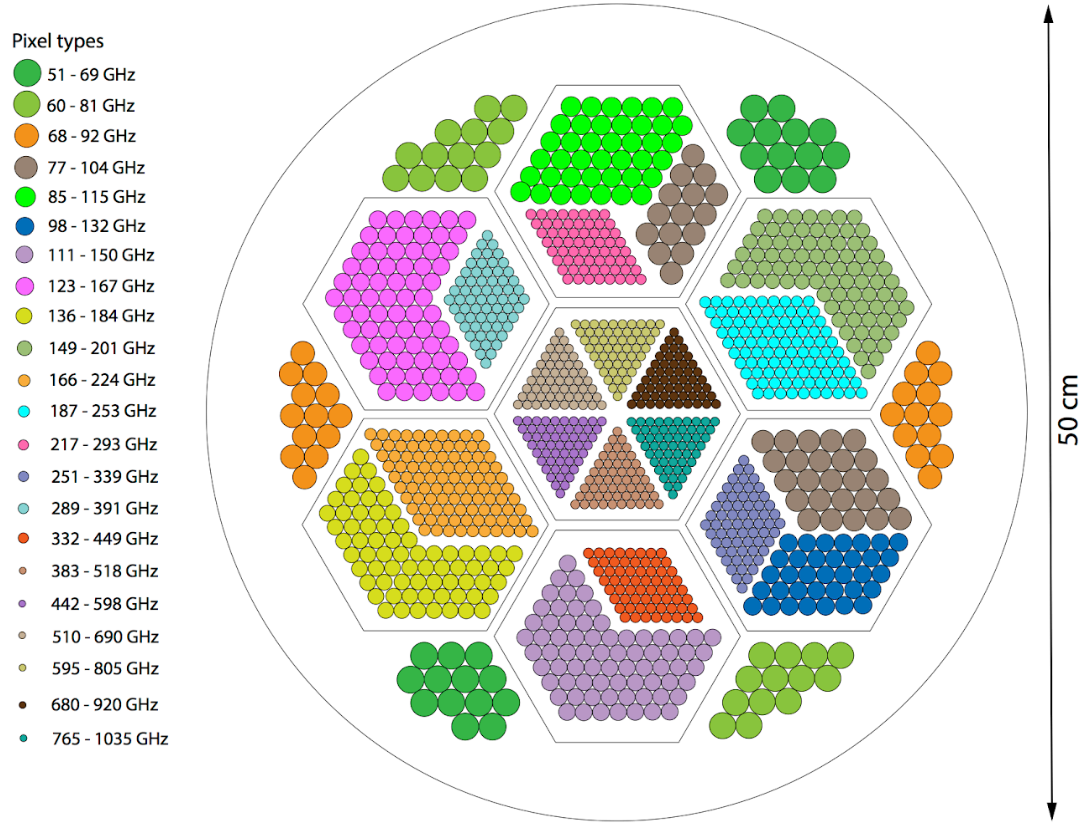
| Subsystem | Mass (kg) | Margin (%) | Allocated (kg) |
|---|---|---|---|
| **Telescope Optics** | | | |
| Primary mirror | 50 | 20 | 60 |
| Secondary mirror | 45 | 20 | 54 |
| Tertiary mirror | 18 | 20 | 22 |
| Telescope structure | 75 | 20 | 90 |
| **Subtotal Telescope Optics** | 188 | 20 | 226 |
| **Passive Cooling and Shielding** | | | |
| Sunshield with supports | 180 | 20 | 216 |
| Telescope baffles/shields | 50 | 20 | 60 |
| V-grooves | 90 | 20 | 108 |
| **Subtotal Passive Cooling and Shielding** | 320 | 20 | 384 |
| **Active Cooling** | | | |
| Pulse tube coolers | 85 | 20 | 102 |
| Joule Thomson coolers | 90 | 20 | 108 |
| Closed cycle dilution refrigerator | 30 | 20 | 36 |
| Aluminum shells | 40 | 20 | 48 |
| Thermal/IR filters and supports | 20 | 20 | 24 |
| **Subtotal Active Cooling Subsystem** | 265 | 20 | 318 |
| **Focal Plane Array** | | | |
| Feed-horn coupled detector array | 20 | 20 | 24 |
| Cryogenic readout and harnesses | 10 | 20 | 12 |
| Support structure | 10 | 20 | 12 |
| **Subtotal Focal Plane Array** | 42 | 20 | 48 |
| Cabling | 50 | 20 | 60 |
| Warm readout electronics | 30 | 20 | 36 |
| **Subtotal Payload** | 910 | 20 | 1100 |
| Attitude Control System | 80 | 30 | 104 |
| Command and Data Handling | 30 | 20 | 36 |
| Power units | 60 | 20 | 72 |
| Cabling | 50 | 20 | 60 |
| Spacecraft Antenna with amplifier | 15 | 20 | 18 |
| Miscellaneous structures and mechanisms | 200 | 20 | 240 |
| **Total dry mass** | 1340 | | 1610 |
| Propellant | 150 | 100 | 300 |
| **Total spacecraft wet mass** | 1500 | | 1900 |

| Item | Power (Watt) | Margin (%) | Allocated (Watt) |
|---|---|---|---|
| Detectors and readout | 150 | 20 | 180 |
| Data processing | 75 | 20 | 90 |
| Cooling chain | 1300 | 20 | 1560 |
| Subtotal Payload | 1525 | 20 | 1830 |
| Attitude control | 100 | 20 | 120 |
| Command and data handling | 80 | 20 | 96 |
| Communication | 40 | 20 | 48 |
| Other mechanisms | 30 | 20 | 36 |
| Total Power | 1775 | 20 | 2130 |

| | |
|---|---|
| Mirror diameter | 1.5m |
| Focal plane radius | 26 cm |
| Total # of detectors | 2388 |
| CMB detectors 130 to 220 GHz | 956 (40%) |
| CMB Pol. Sensitivity (130 to 220 GHz) | 2.0 $\mu K_{CMB}$ |
| Total CMB Pol. Sensitivity (full array) | 1.7 $\mu K_{CMB}$ |
| Data rate of FPU | 2050 kbit/s |

# Focal plane-1A

| FREQ. (GHz) | BEAM. (arc-min) | $N_{DET.}$ | $\Delta T$ $\mu K_{CMB}$ | $\Delta P$ $\mu K_{CMB}$ |
|---|---|---|---|---|
| 60 | 14.3 | 48 | 7.5 | 10.6 |
| 70 | 12.31 | 48 | 7.1 | 10 |
| 80 | 10.82 | 48 | 6.8 | 9.6 |
| 90 | 9.66 | 78 | 5.1 | 7.3 |
| 100 | 8.73 | 78 | 5 | 7.1 |
| 115 | 7.65 | 76 | 5 | 7 |
| 130 | 6.81 | 124 | 3.9 | 5.5 |
| 145 | 6.15 | 144 | 3.6 | 5.1 |
| 160 | 5.61 | 144 | 3.7 | 5.2 |
| 175 | 5.16 | 160 | 3.6 | 5.1 |
| 195 | 4.67 | 192 | 3.5 | 4.9 |
| 220 | 4.18 | 192 | 3.8 | 5.4 |
| 255 | 3.65 | 128 | 5.6 | 7.9 |
| 295 | 3.19 | 128 | 7.4 | 10.5 |
| 340 | 2.79 | 128 | 11.1 | 15.7 |
| 390 | 2.45 | 96 | 22 | 31.1 |
| 450 | 2.12 | 96 | 45.8 | 64.8 |
| 520 | 1.84 | 96 | 116.4 | 164.6 |
| 600 | 1.59 | 96 | 357.8 | 506 |
| 700 | 1.36 | 96 | 1532 | 2166.6 |
| 800 | 1.18 | 96 | 6811.4 | 9632.8 |
| 900 | 1.05 | 96 | 31127.1 | 44020.3 |

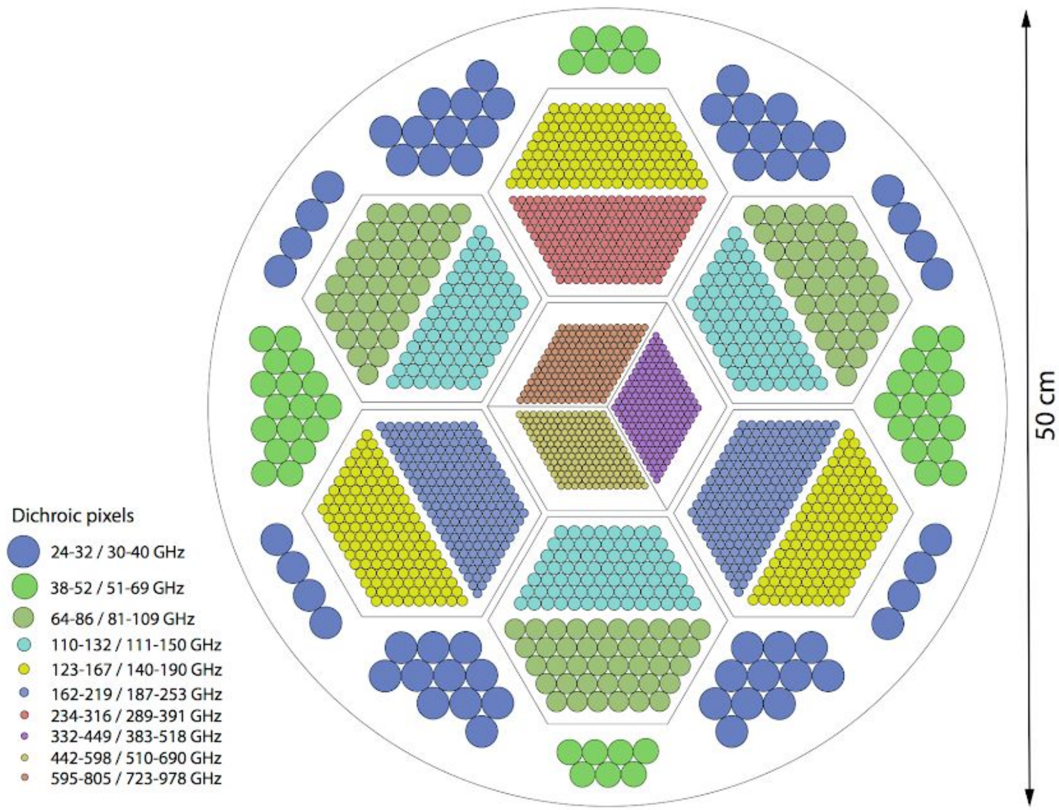



Extended CORE
700, 800, 900GHz

~2400 detectors
Sensitivity in CMB band: 2μK.arcmin

# Focal plane-1B

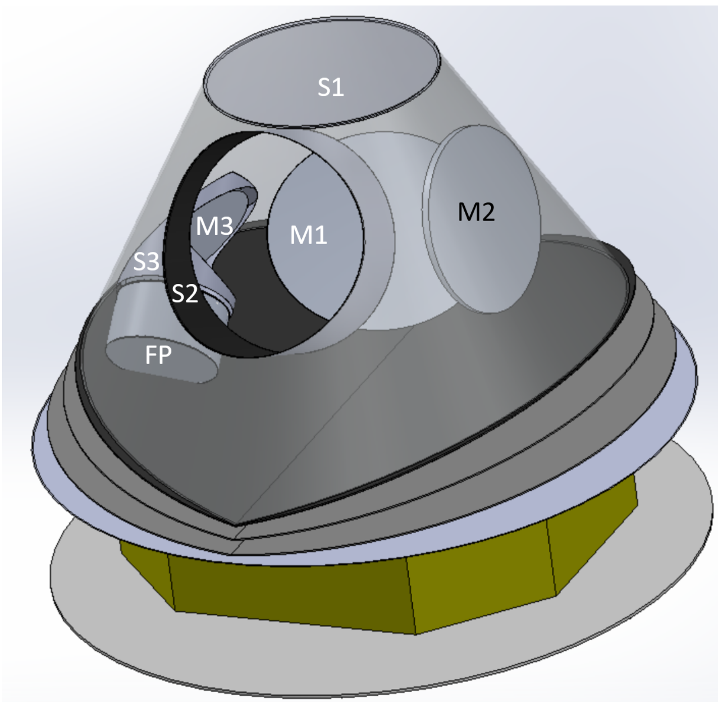
| $\nu_o$ GHz | Beam size arcmin (′) | $N_{det}$ | $\Delta T$ $\mu K'_{CMB}$ | $\Delta P$ $\mu K'_{CMB}$ |
|---|---|---|---|---|
| 28 | 39.9 | 120 | 11.7 | 16.5 |
| 35 | 31.9 | 120 | 9.4 | 13.3 |
| 45 | 24.8 | 96 | 8.4 | 11.9 |
| 65 | 17.1 | 96 | 6.3 | 8.9 |
| 75 | 14.9 | 240 | 3.6 | 5.1 |
| 95 | 11.7 | 240 | 3.2 | 4.6 |
| 115 | 9.72 | 462 | 2.2 | 3.1 |
| 130 | 8.59 | 462 | 2.2 | 3.1 |
| 145 | 7.70 | 810 | 1.7 | 2.4 |
| 165 | 6.77 | 810 | 1.7 | 2.5 |
| 190 | 5.88 | 752 | 2.0 | 2.8 |
| 220 | 5.08 | 752 | 2.3 | 3.3 |
| 275 | 4.06 | 444 | 4.5 | 6.3 |
| 340 | 3.28 | 444 | 8.1 | 11.4 |
| 390 | 2.86 | 338 | 15.6 | 21.9 |
| 450 | 2.48 | 338 | 30.7 | 43.4 |
| 520 | 2.14 | 338 | 72.2 | 102 |
| 600 | 1.86 | 338 | 204 | 288 |
| 700 | 1.59 | 338 | 794 | 1122 |
| 850 | 1.31 | 338 | 6752 | 9550 |




Ground expt inspired
Readout challenging

~6800 detectors/polarisation
Sensitivity in CMB band: 1μK.arcmin

# CMB-Bharat S/c Specs.




≈ 4.0 m

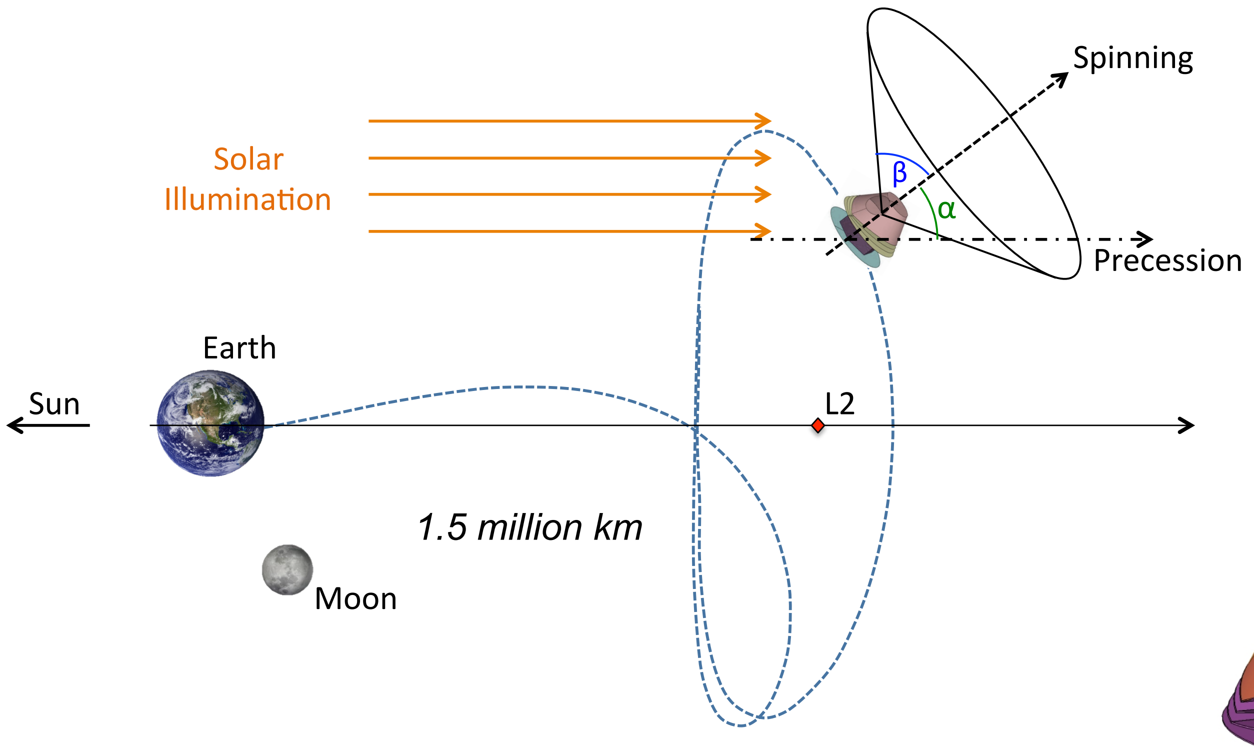
≈ 4.4 m

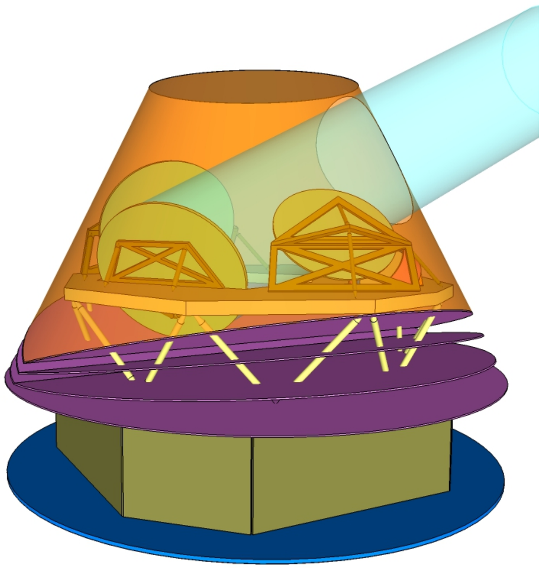
- Total wet mass ≈ 2.0 tons
- Diameter ≈ 4.4 meter
- Height ≈ 4.0 meter
- Power ≈ 2 KW

Adjustments are possible.

**Max. Launch capacity: Well suited for a GSLV Mk-III launch towards a Sun-Earth L2 orbit**

# CMB-Bharat: Orbit and scanning



**Challenges :**

- orbitography
- pointing accuracy ≈ 10'
- pointing reconstruction ≈ 10''
- Data flow : ≈ 1 to 8 Mb/s (100 Gb/day)

# Indian technical contribution

Capabilities that are challenging, but nevertheless, may be readily achieved in India include:

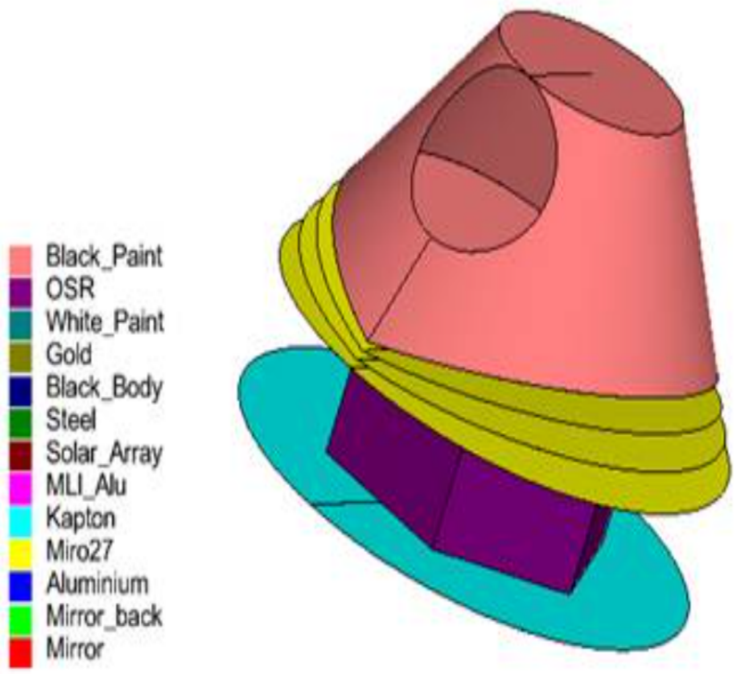
- Mission planning and operations;
- Launch to L2, tracking and control, orbit maintenance, science data downlink;
- Thermal infrastructure: design and fabrication of solar shield, hot-cold stage V-groove separator;
- Service module: design, fabrication, assembly and testing;
- Extensive modelling of instrument for calibrating systematic effects;
- Data products, analysis and science.

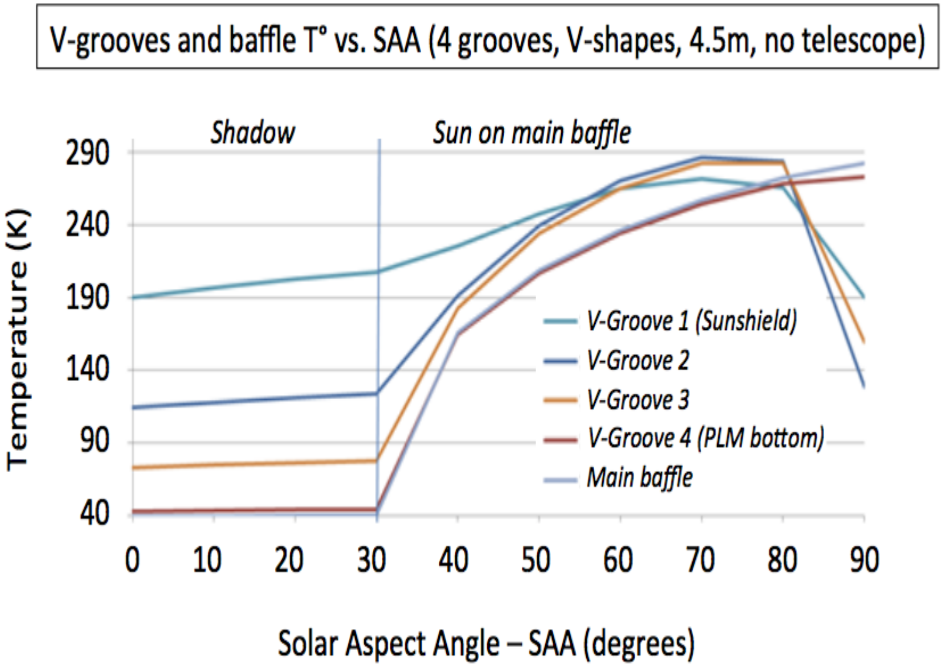
# Indian technical contribution

**Capabilities achieved with modest planned investments**

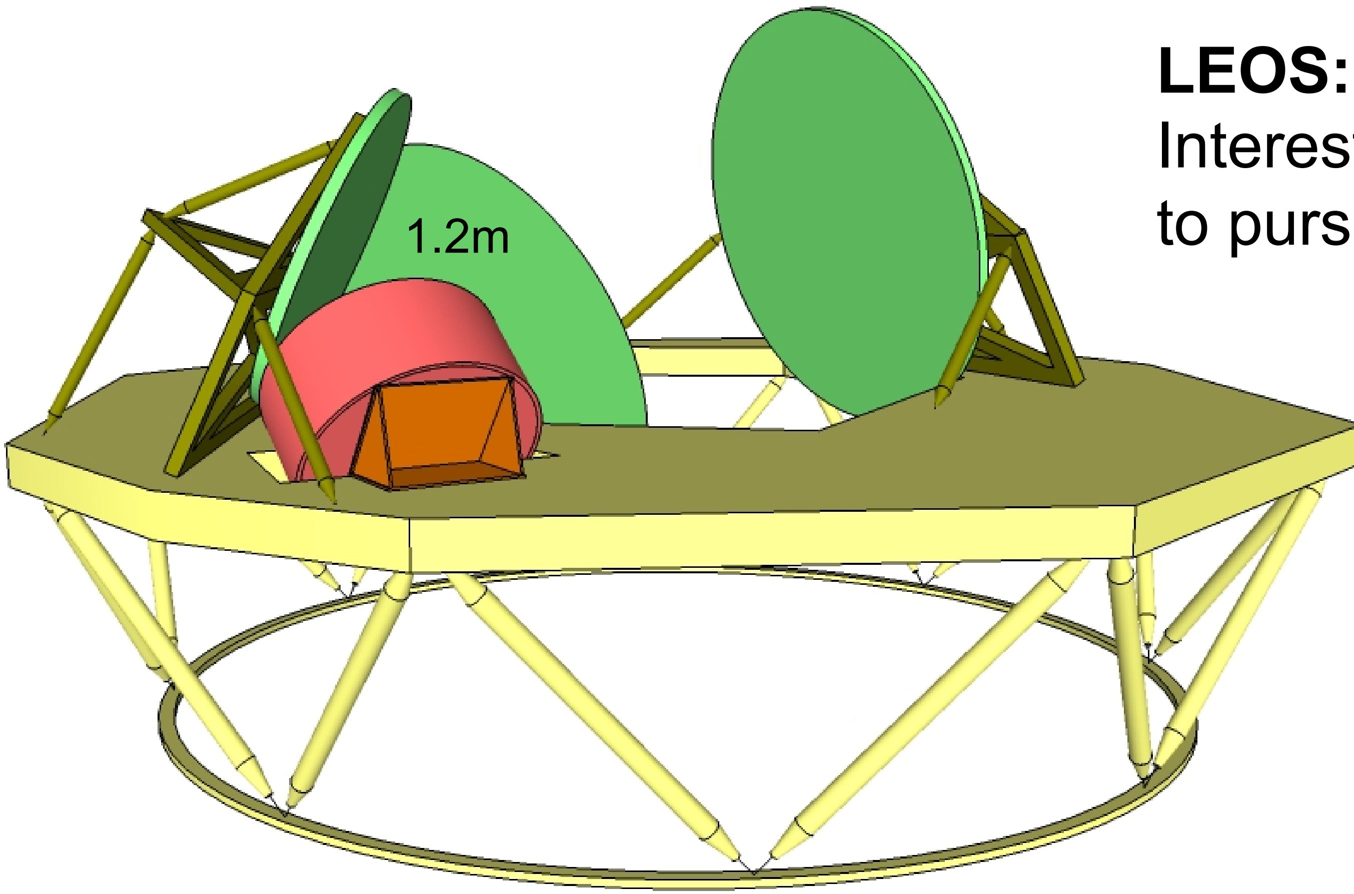
- Telescope and Optics **LEOS**
  - Design, fabrication, assembly, testing
  - Reflectors, baffling
  - Reimaging optics, filters
- Science Payload
  - Design, assembly, testing
- Thermal system: first stage coolers in the cryogenic cooling chain;

# Passive Thermal isolation s/c design

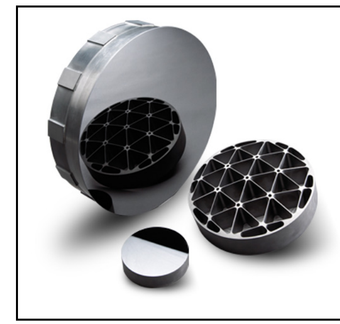


# SiC Telescope optics




**LEOS:**
Interest & expertise to pursue with TDP



The telescope is made of silicon carbide, a technology that has been space proven with the *Herschel*

# Indian technical contribution

**Capabilities achieved with long-term planned investments**

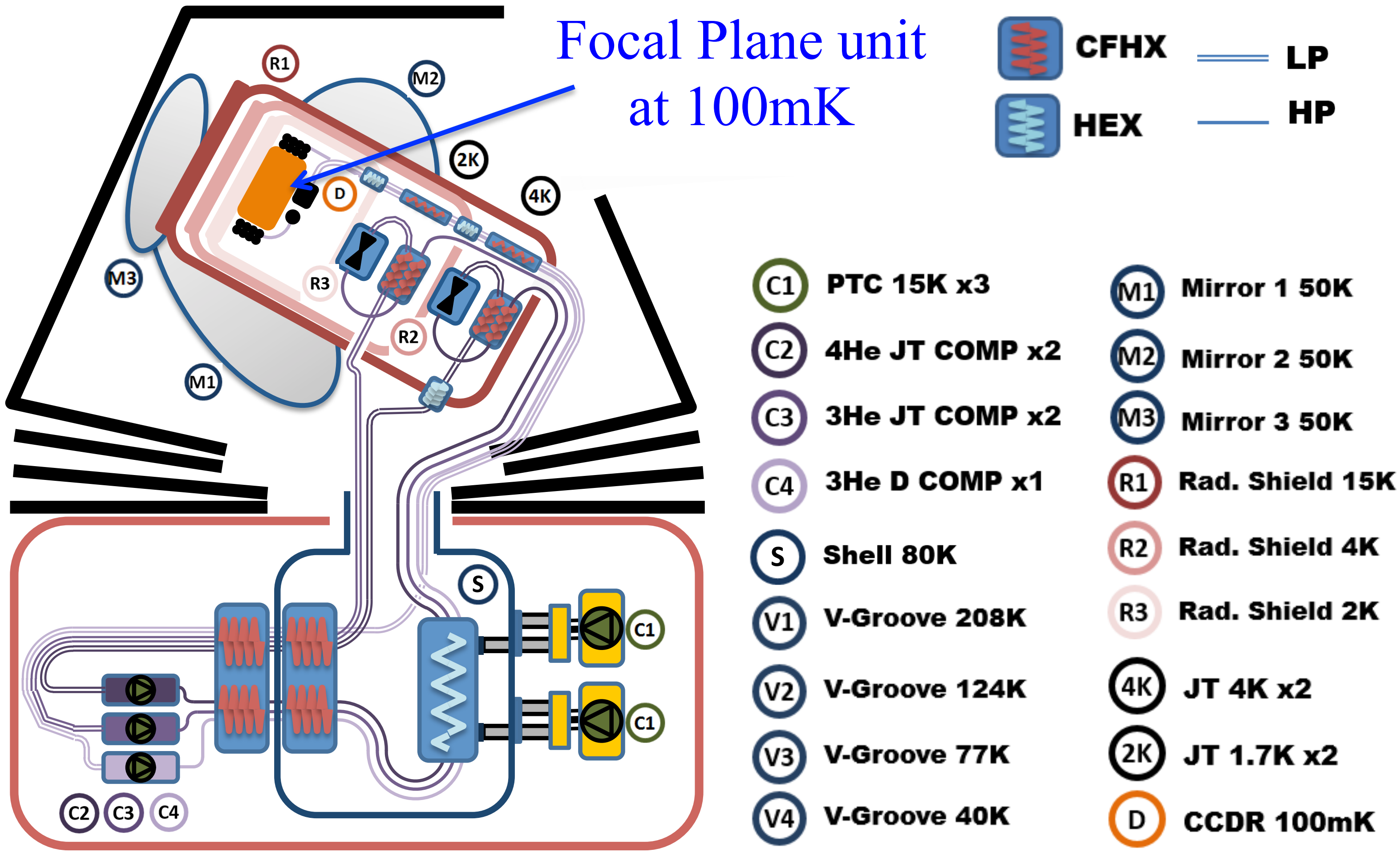
- Broadband photon-noise-limited sensors & readout for CMB frequency bands
- Cryogenic coolers at 100mK in space

**Jan 21-22: fruitful meeting with SAC THz group on a aligned and concurrent Tech. Dev. Programme**

**Preferable route is to seek from international partner**

However, time and manpower intensive **Detector testing & calibration facility** can be set up in one of many institutions coupled with faculty hiring of advanced Indian postdocs in CMB-Bharat (now working with top groups)

# Cryogenic Cooling chain



# Indian technical contribution

**Benefits of making medium- and long-term strategic investments**

- Build upon capabilities in ISRO, and enhance experimental physics efforts at academic institutions in India.
- Expand nanofabrication, MEMS and cryogenics capabilities as well as people trained to use and exploit these resources, which can have very wide applications in Indian science community.
- Quantum sensor technologies developed for CMB frequency bands can be extended to other bands in astronomy (X-ray, gamma ray), spectroscopy in various bands, particle physics applications and even to quantum computing.
- Developing Labs and Test Infrastructure will be useful in the long term for training young scientists and engineers.

# Possible implementation schemes

- A space mission such as CORE, PICO or CMB-Bharat requires an international collaboration. No single agency has the resources and capability to do it alone

- The consortium is open to investigate all options, e.g.
  - **ISRO led with substantial ESA participation could be envisaged.**
  - **ESA-led mission with substantial ISRO (& NASA) participation could be envisaged for M7 call**;
  - US primary mission if US Astro Decadal survey 2020 ranks PICO high
  - ISRO, ESA, NASA …???

- **Any such collaboration model needs to be preparatory through a joint study phase with appropriate international partner**

# Proposed Project timeline

| Phase | | Period (months) | Milestone achieved |
|---|---|---|---|
| 1 year | Pre-Mission: Joint study 1&2<br>TRL assessment/increase | 12 | Mission selection |
| 9 years | Phase B1: TRL enhancement | 14 | Mission adoption |
| | Detailed design-1 | 12 | |
| | Detailed design-2 | 18 | Critical design review |
| | Qualification model<br>procurement (24)<br>assembly & test (7) | 31 | Qualification review |
| | Flight model procurement, (24)<br>assembly (6) & test (6) | 36 | Flight readiness review |
| | Launch campaign | 6 | Launch |
| 6 years | Science operation - Survey mode | 48 | Primary science |
| | - Observatory mode | 24 | TAC/TOO science |

Suggestive and preliminary

# CMB-Bharat: multi-faceted science

## Indian Working groups

- ***Cosmological parameters:*** *Lead: Dhiraj Hazra (APC, Paris→ NISER?,…)*
- ***Wea***
- ***For***
- ***Inst***
- ***Infl***
- **Sta** … er)
- ***Spe***
- ***Cluster Physics from CMB:*** *Lead: Subhabrata Majumdar (TIFR)*
- **End to end Modeling & Systematics:** Lead: Ranajoy Banerji (U. Oslo)
- ***Simulations and Data Pipelines:*** *Lead: Jasjeet Singh Bagla (IISER Mohali)*

CMB-Bharat mission design and technical specification builds upon several mature designs proposed elsewhere (in particular, CORE and PiXiE)

PI’s of CORE and PiXIE are listed as international POC in the Proposal

# CMB-Bharat Working groups

***Cluster Physics from CMB:***
*Lead: Subhabrata Majumdar (TIFR)*
*Members: Suvodip Mukherjee, Dhiraj Hazra, K.P. Singh, Siddharth Savyasachi Malu, Abhirup Datta, Priyanka Singh*

***Foregrounds and CIB:***
*Lead: Tuhin Ghosh (NISER)*
*Members: Rajib Saha, Soumen Basak, Pavan K. Aluri, Moumita Aich, Ranajoy Banerji, Aditya Rotti, Abhirup Datta, Pravabati Chingangbam, Sandeep Rana (List Here)*

***Instrument science:***
*Lead: Zeeshan Ahmed (Stanford Univ)*
*Members: Aafaque R Khan, Rahul Datta, Mayuri S.Rao, Ritoban Thakur*

***Inflation:***
*Lead: L. Sriramkumar (IIT Madras)*
*Members: Dhiraj Hazra, Anshuman Maharana, Urjit Yajnik, Raghu Rangarajan, Supratik Pal, Anjan Ananda Sen, Subodh Patil, Rajeev Kumar Jain, Gaurav Goswami, V. Sreenath, Debika Chowdhury, Pravabati Chingangbam, Moumita Aich (List here)*

# CMB-Bharat Working groups

***Cosmological parameters:***

*Lead: Dhiraj Hazra (APC, Paris→ NISER?,…)*

*Members: Suvodip Mukherjee, Rajib Saha, Urjit Yajnik, Supratik Pal, Anjan Ananda Sen, Rajeev Kumar Jain, Ujjaini Alam, Barun Kumar Pal, Arindam Chatterjee, H K Jassal, Priyanka Singh*

***Lensing:***

*Lead: Suvodip Mukherjee (CCA, NY)*

*Members: Dhiraj Hazra, Anjan Ananda Sen, Supratik Pal, Aditya Rotti, Shabbir Shaikh, Rajorshi Sushovan Chandra, Barun Kumar Pal, Ashish Meena, Priyanka Singh*

***Simulations and Data Pipelines:***

*Lead: Jasjeet Singh Bagla (IISER Mohali)*

*Members: Soumen Basak, Tuhin Ghosh, Shamik Ghosh, Ranajoy Banerji, Rahul Kothari, Aditya Rotti, Abhirup Datta, Nishikanta Khandai*

***Spectral Distortions:***

*Lead: Rishi Khatri (TIFR)*

*Members: Suvodip Mukherjee, Anjan Ananda Sen, Aditya Rotti, Subodh Patil, Rajeev Kumar Jain, Biman Nath*

# CMB-Bharat Working groups

**Statistics: Isotropy and Gaussianity:**
Lead: Aditya Rotti (U Manchester)
Members: Suvodip Mukherjee, Dhiraj Hazra, Rajib Saha, Urjit Yajnik, Shamik Ghosh, Pavan K. Aluri, Subodh Patil, Rahul Kothari, Nidhi Pant, Shabbir Shaikh, Rajorshi Sushovan Chandra, Pravabati Chingangbam, Moumita Aich, Sandeep Rana

**Systematics:**
Lead: Ranajoy Banerji (U. Oslo)
Members: Abhirup Datta, (List Here)

**Synergy with Astrophysics:**
Dust in ICM/IGM, science at ~1.3 TeraHz
Members: K. P. Singh, Jasjeet Singh Bagla, Priyanka Singh

**Synergy with ground experiments:**
Lead: Mayuri Sathyanarayana Rao
Members: Abhirup Datta, Siddharth Malu

**Planck launch 2009**

**Next Generation CMB mission ?**


**CMB-BHARAT mission presents an unique opportunity for India to take the lead on prized quests in fundamental science in a field that has proved to be a spectacular success, while simultaneously gaining valuable expertise in cutting-edge technology for space capability through global cooperation.**

# Thank you !!!

# TRL levels

| Subsystem | Has Space heritage (Y/N) | Needs demonstration thru Lab Model (Y/N) | Needs space qualification (Y/N) | TRL level (use enclosed def. table) |
|---|---|---|---|---|
| **Detector system** | N | N | Y | 5 |
| Detector (chip-level) | N | N | Y | 5-6 |
| Detector (array-level) | N | N | Y | 5-6 |
| Detector Readout electronics | N | N | Y | 6 |
| | | | | |
| **Optics** | | | | Delivering agency |
| Optics design | Y | N | N | 8 |
| Optical coating (if any) | Y | N | N | 9 |
| Opto-mechanical design (if any) | Y | N | N | 6 |
| Special optics material (if any) | Y | N | N | 9 |

# TRL levels

| | | | | |
|---|---|---|---|---|
| **Mechanical systems** | | | | |
| Mechanical structure design | Y | N | N | 8 |
| Special material requirement (if any) | | | | |
| | | | | |
| **Thermal** | | | | |
| Thermal design | Y | N | N | 7 |
| If active cooling is required | Y (ADR+PT+JT4K)<br>N (CCDR+PT+JT4K+JT2K) | N | N (ADR+PT+JT4K)<br>Y (CCDR+PT+JT4K+JT2K) - ongoing | 7-8<br>5 |
| | | | | |
| **Mechanisms** | | | | |
| Mechanism 1 – FTS | Y | N | N | 8 |
| Mechanism 2 – (name) | | | | |
| **Electronics systems** | | | | |
| Electronics design | N | Y | Y | 5-6 |
| Use of any non-std devices (if any) | | | | |
| | | | | |