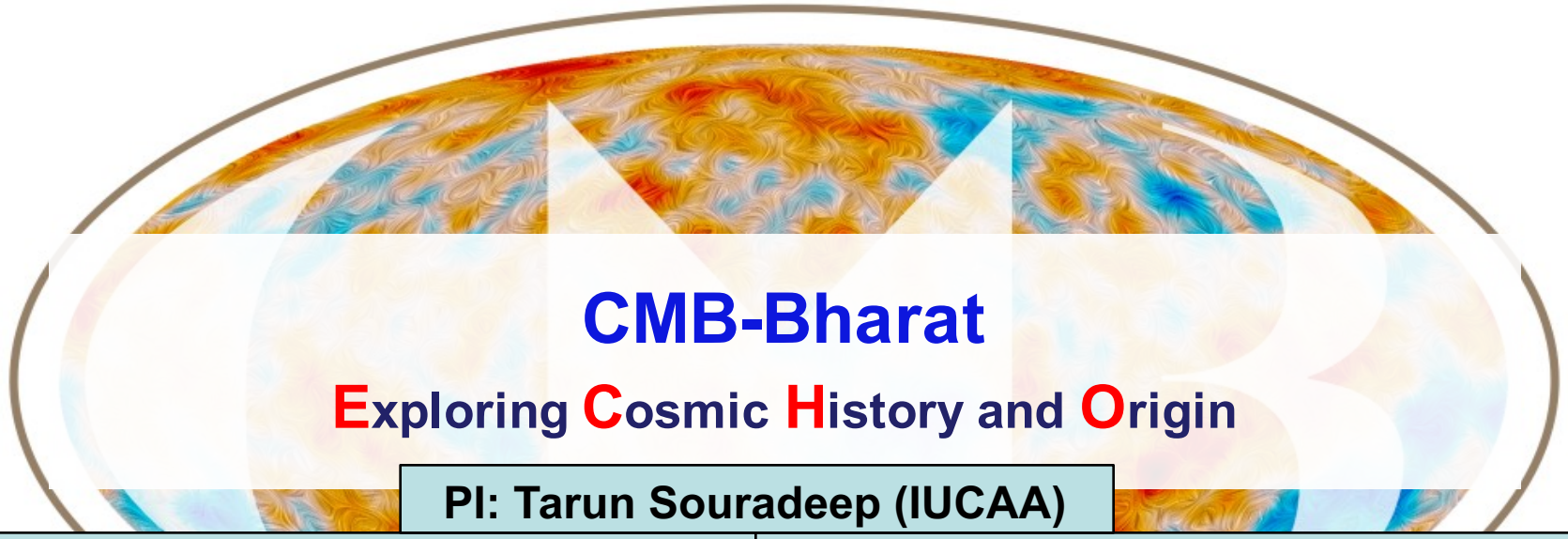


CMB-Bharat

Exploring Cosmic History and Origin

PI: Tarun Souradeep (IUCAA)

- L. Sriramkumar (IIT Madras)
- Rishi Khatri (TIFR Mumbai)
- Subha Majumdar (TIFR, Mumbai)
- Tuhin Ghosh (NISER, Bhub'war.)
- Dhiraj Hazra (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)

Rishi Khatri

TIFR

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'($z<2 \times 10^6$) thermal history of the universe**

CMB space mission proposals

Spectral distortions
(Absolute Calibration)

B-modes

Low resolution

PRISTINE (ESA)

LITEBIRD (JAXA)

PIXIE (NASA)

ECHO (ISRO)?

CORE (ESA)
PICO (NASA)
ECHO (ISRO)

High resolution

PRISM (ESA)

Indian response: Context

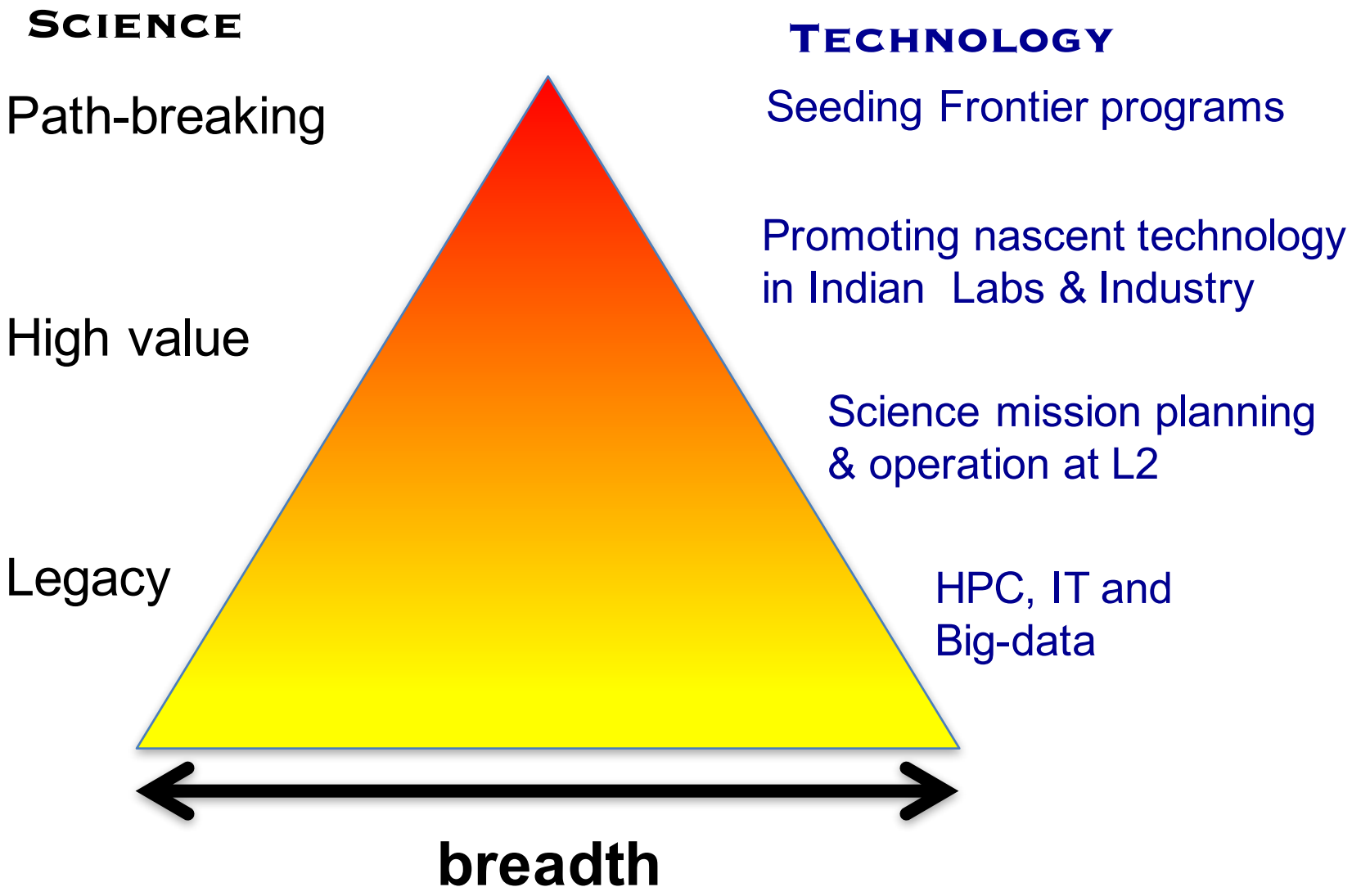
- European CMB proposal CORE (Cosmic Origins Explorer)
  Did not pass the initial programmatic screening by ESA in Jan 2017.
  High science rating (APPEC, CNES prospective) & support from member states, **but cost did not fit within an M-class envelope**.
  Suggested to seek international partners

- First discussions of Indian participation June 2017, mentioned at ISRO-Astrosat panel discussion in Sep 2017
- Meeting of CORE proposal PI & co-PI with SSPO, ISRO in Oct 2017 to explore joint collaboration prospects .

- Meeting at ISRO-HQ on Jan 8-9, 2018 to demonstrate an Indian community capable of taking on the science.
  - Possibility of launching ISRO-ESA joint study
  - **CMB-Bharat:** Cross-institutional Indian cosmology consortium

  Set up formally on Jan 9th at ISRO HQ meet ~ 90 members from ~15 institutions/laboratories & growing
- **Suggested to respond to AO as next step**
- **Proposal by CMB-Bharat consortium to ISRO on Apr 16, 2018.**

Balanced Impact-Returns profile



CMB-Bharat

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

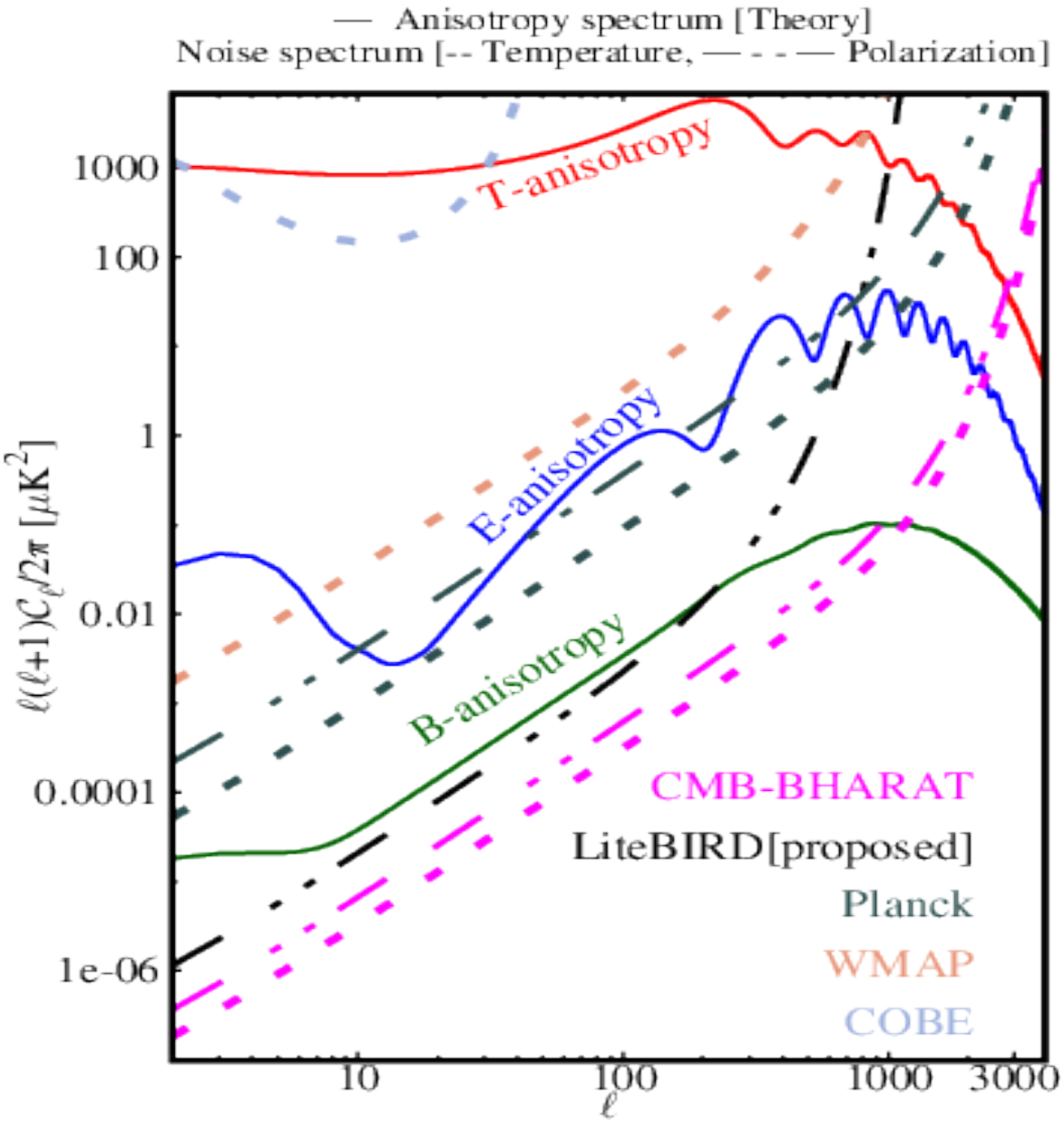
+ possibly

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

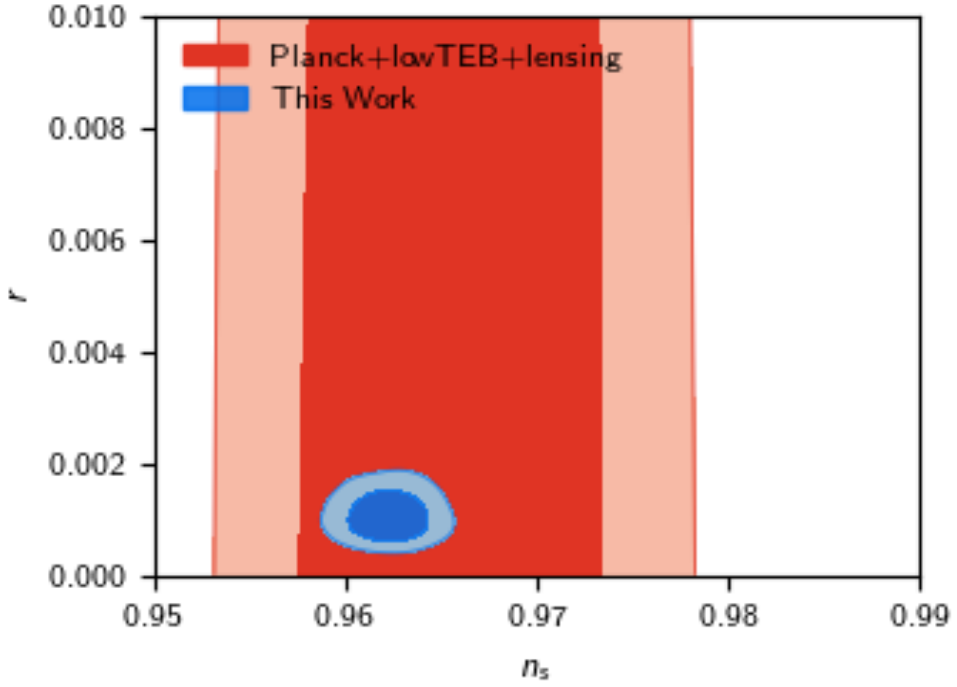
. New Science	• Primordial gravitational waves **~ Quantum gravitation** • Dark matter distribution • Neutrino mass, hierarchy and species **Tighest limits** • Reionization history • Cosmic thermal history
i. Extension/ Improvisation to the previous findings	• Highly precise standard model parameters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

HUGE DISCOVERY SPACE

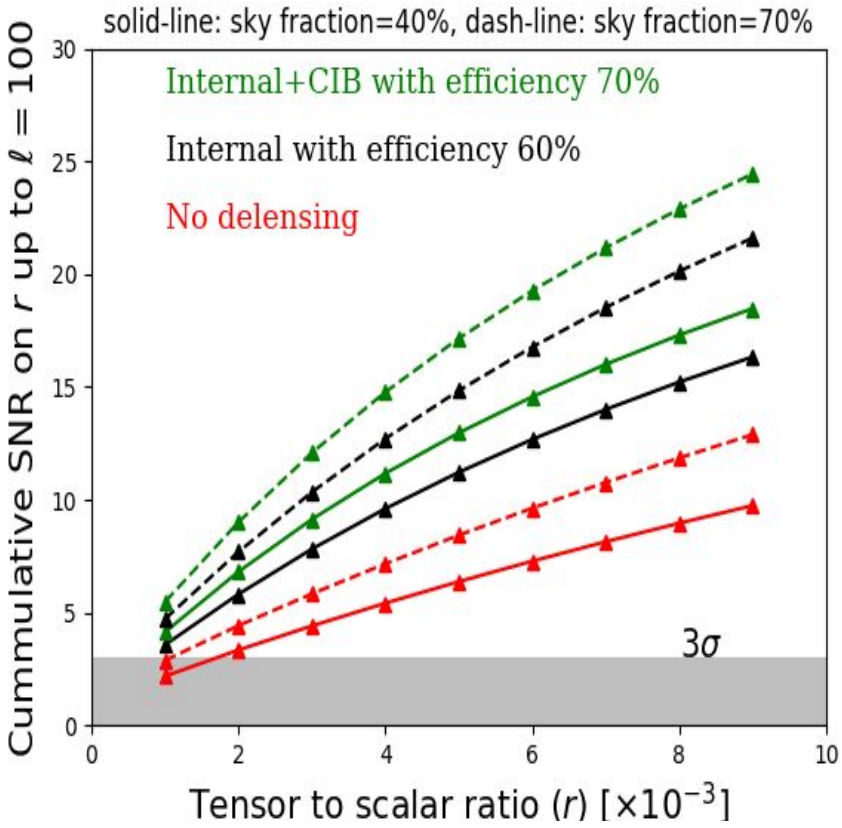
CMB Polarization



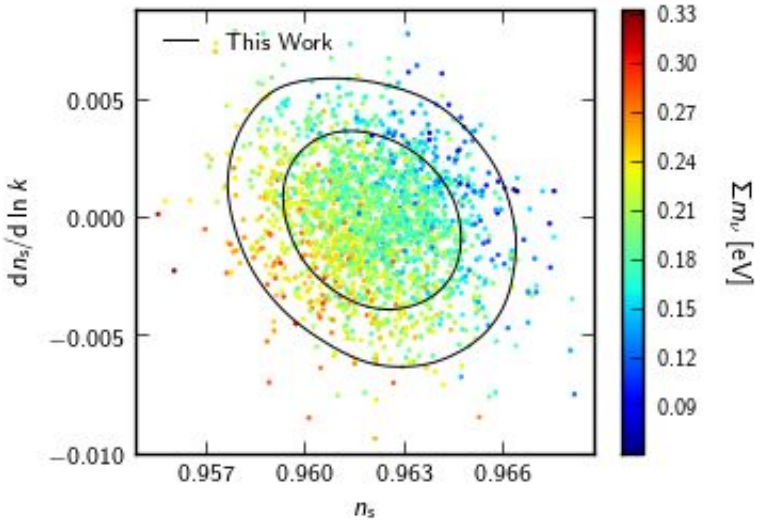
CMB Polarization: ultra-high dividend

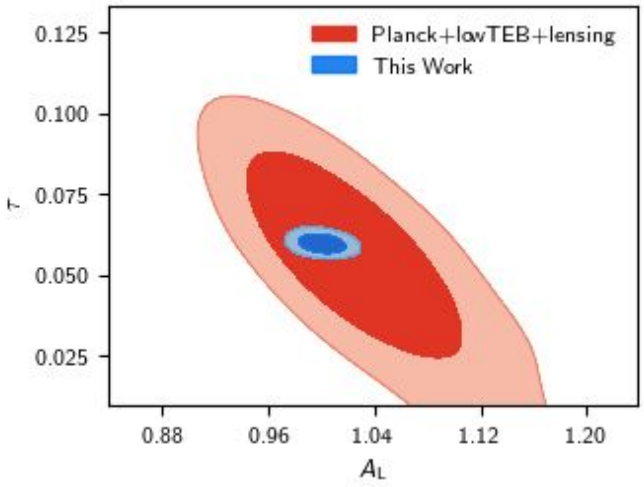


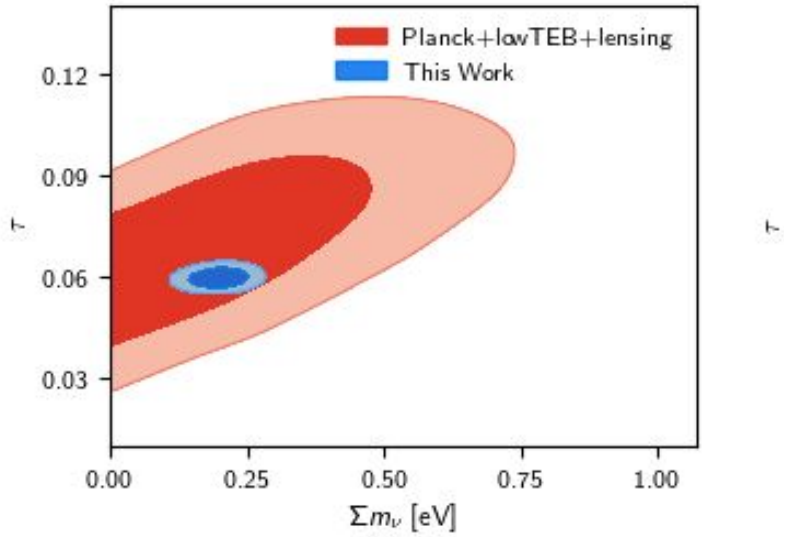
Primordial GW from Inflation
Tensor/Scalar ratio

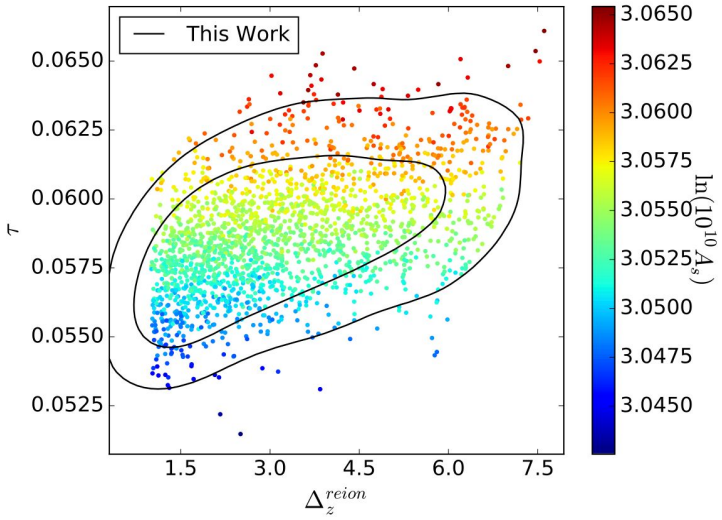


CMB Polarization: high dividend

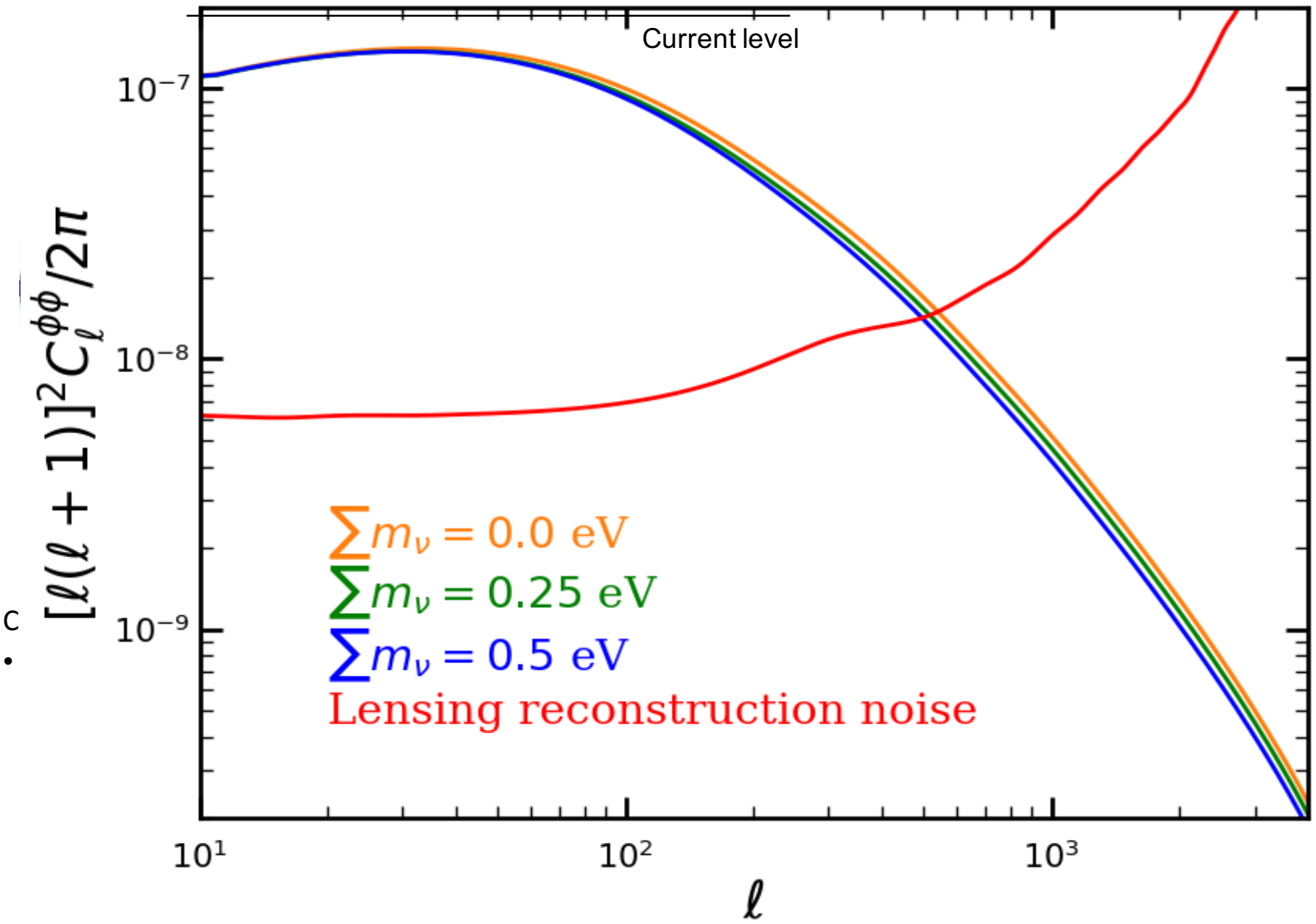








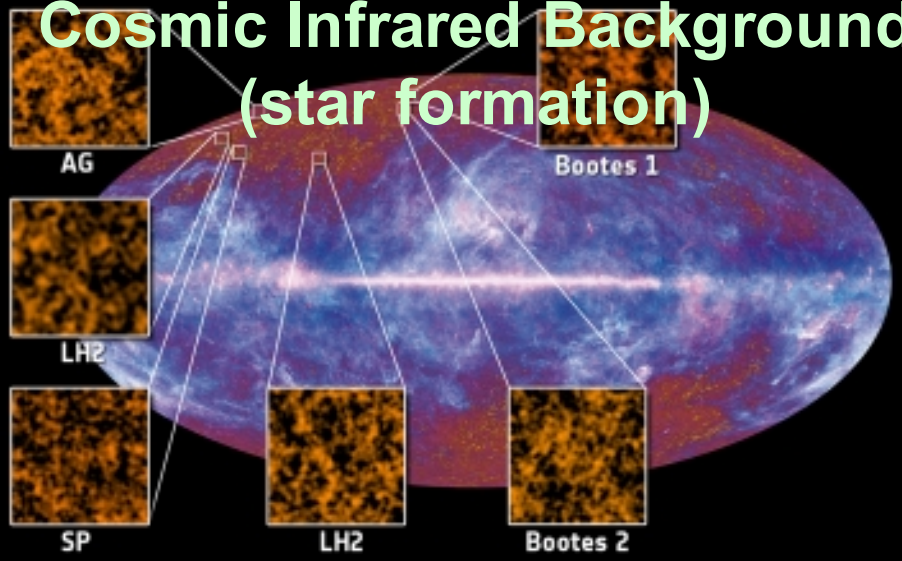
Projected Lensing potential from Planck



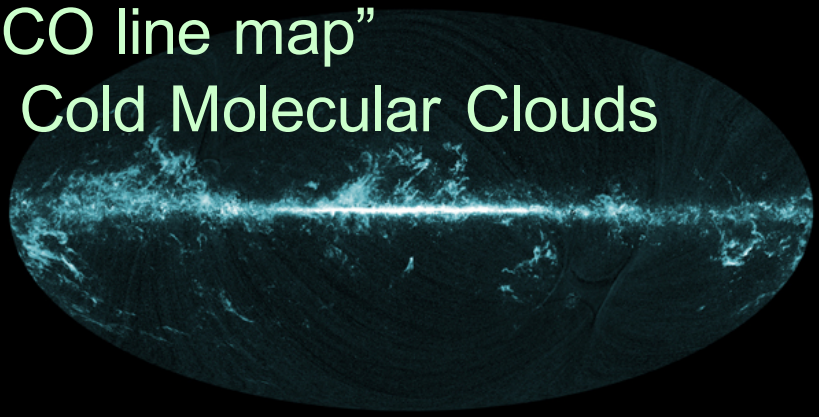
- C

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

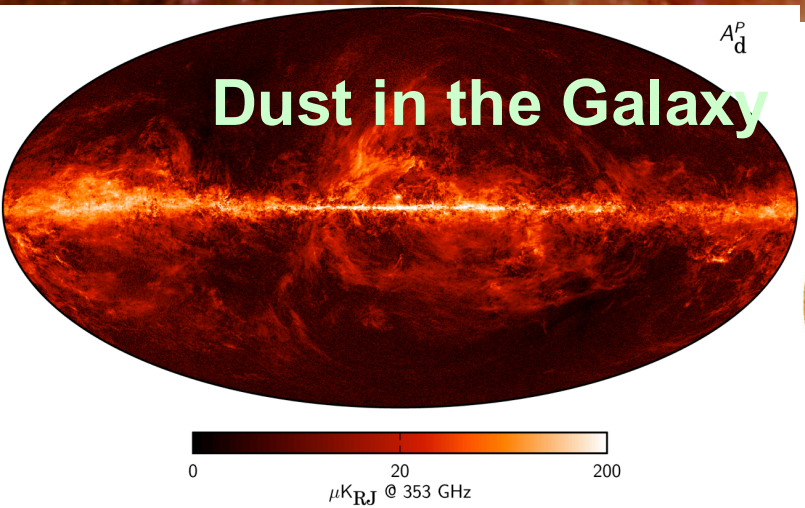
Cosmic Infrared Background (star formation)



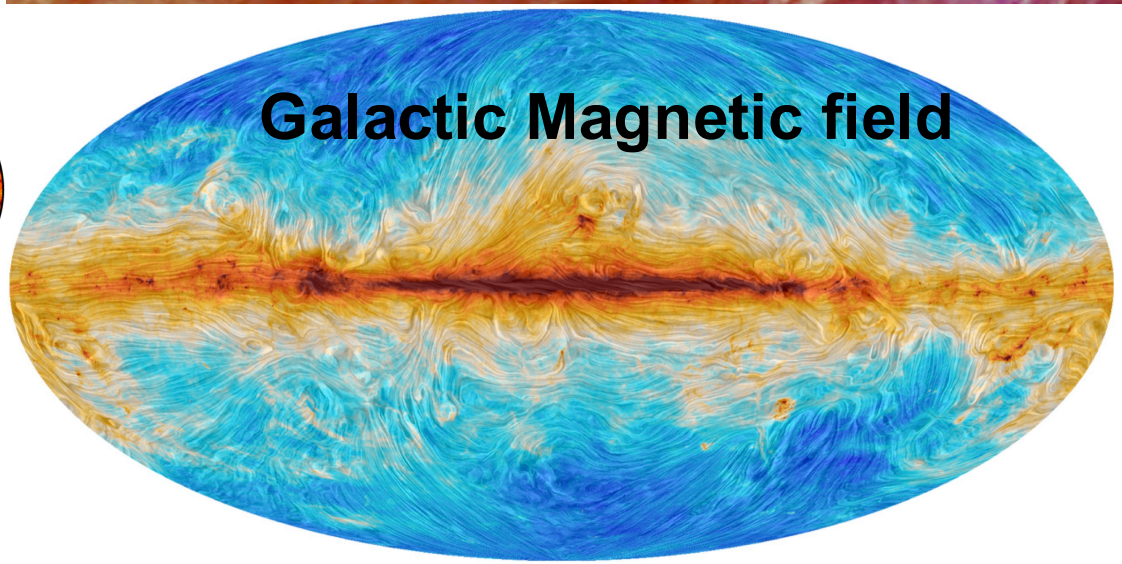
CO line map" Cold Molecular Clouds



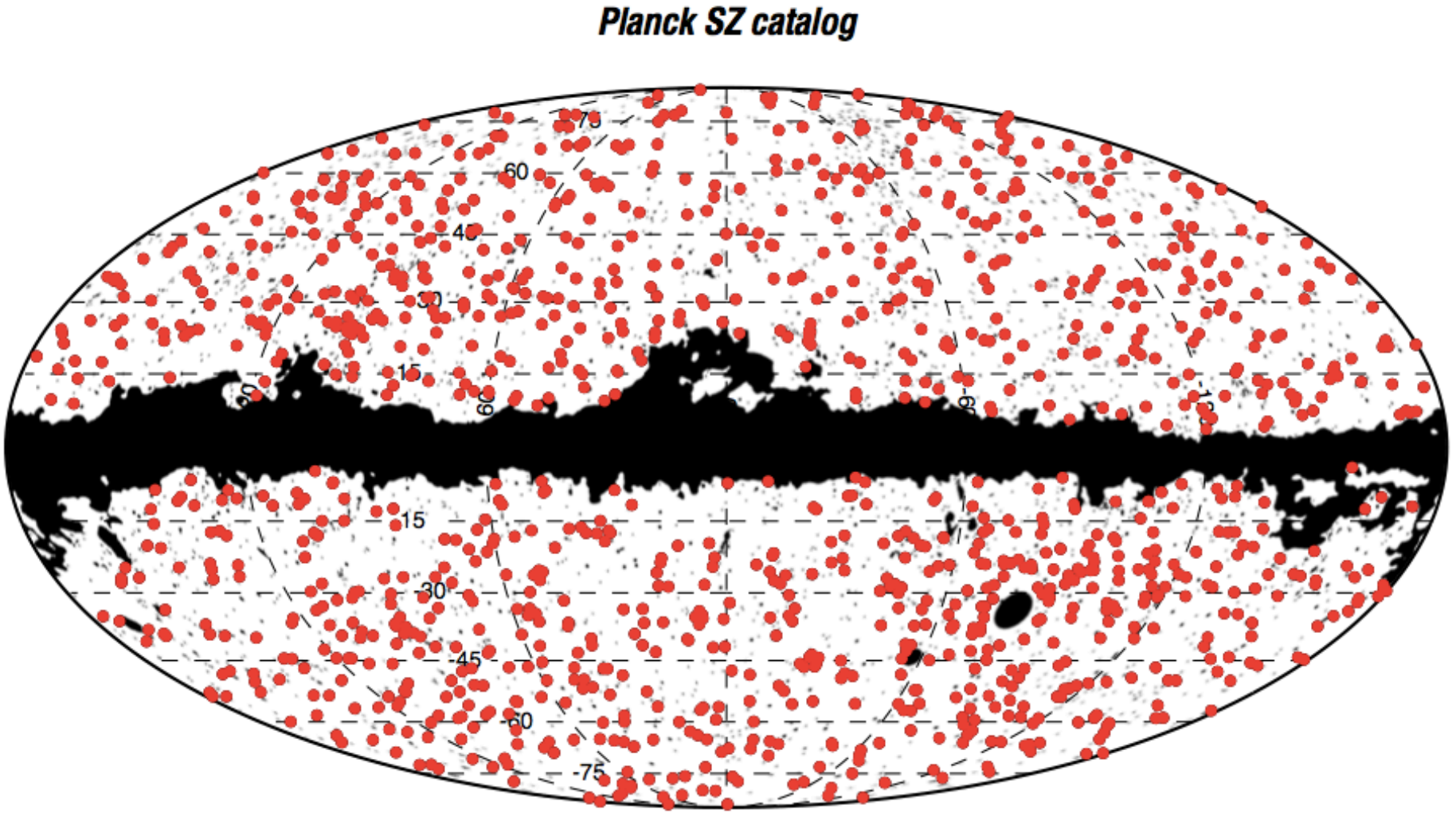
Dust in the Galaxy



Galactic Magnetic field

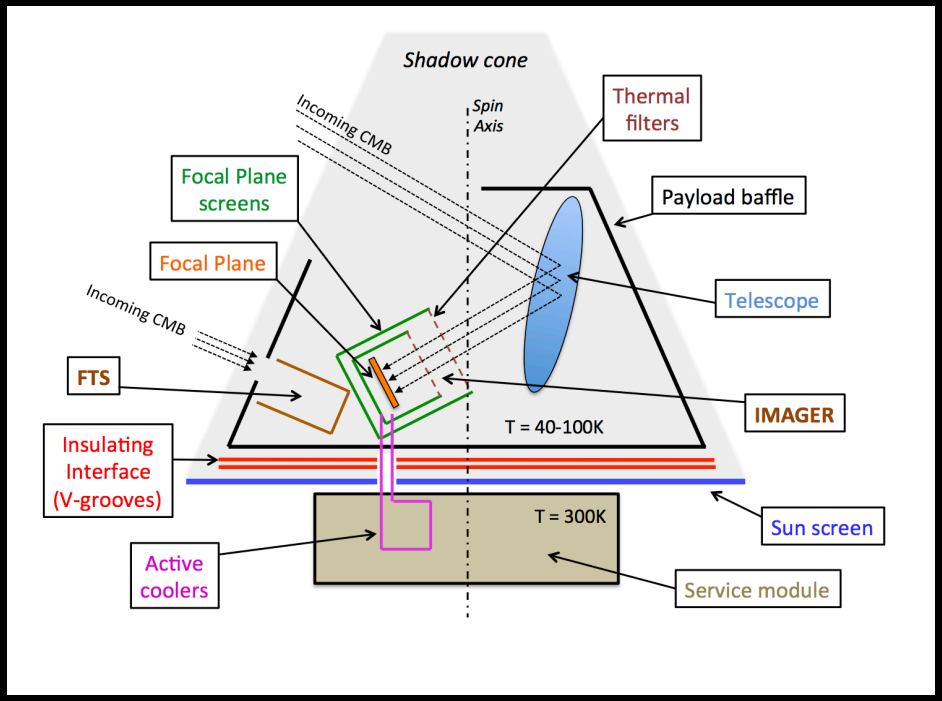


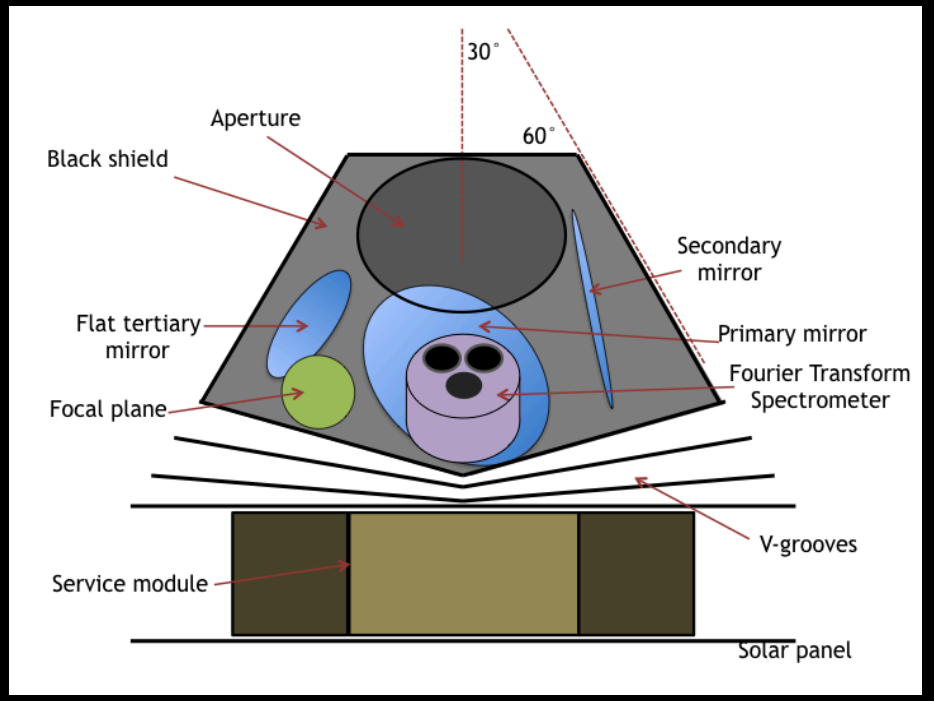
SZ clusters from Planck



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

CMB-Bharat Payload schematic



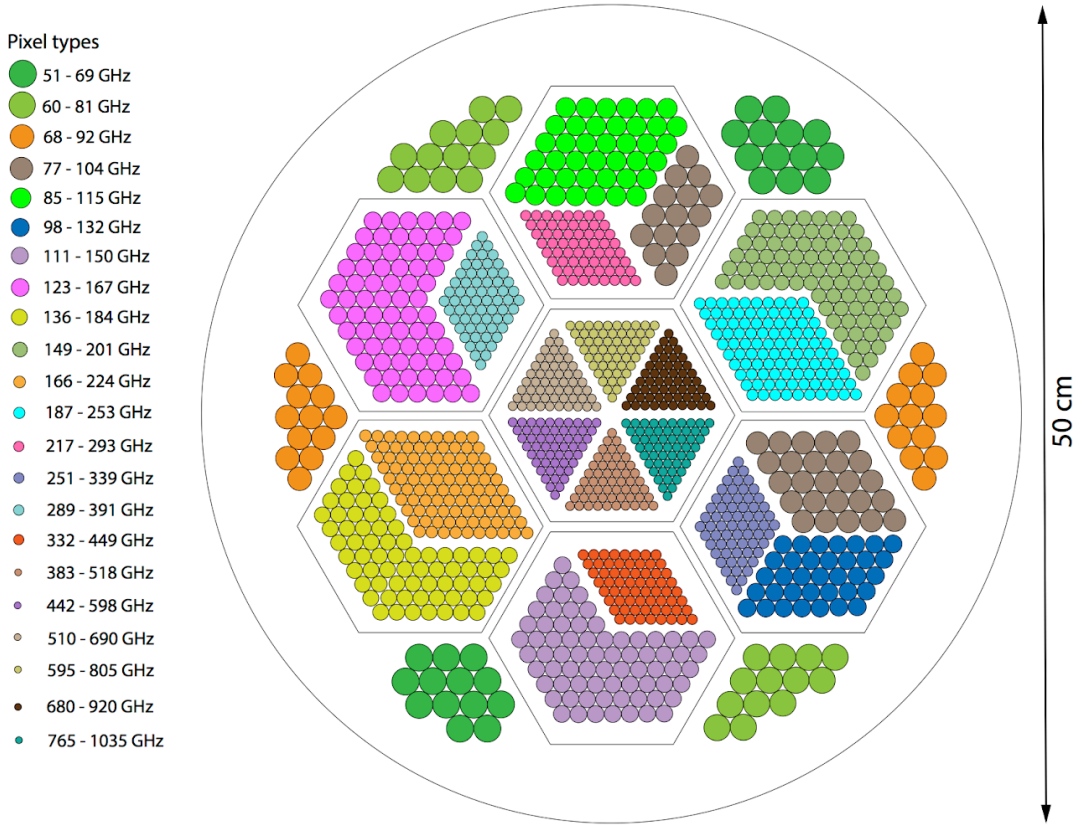


A multifaceted frontier science and astronomy mission

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

Focal plane-1A

FREQ. (GHz)	BEAM. (arc-min)	$N_{DET.}$	ΔT μK_{CMB}	ΔP μK_{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

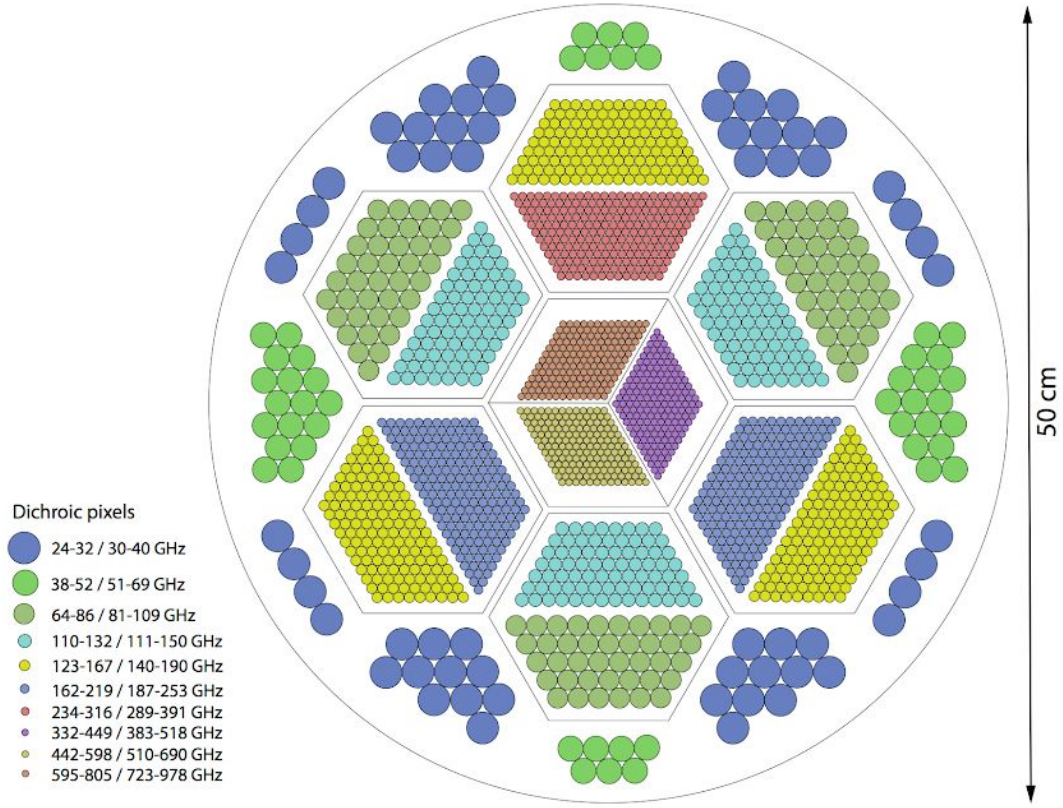


Extended CORE
700, 800, 900GHz

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

Focal plane-1B

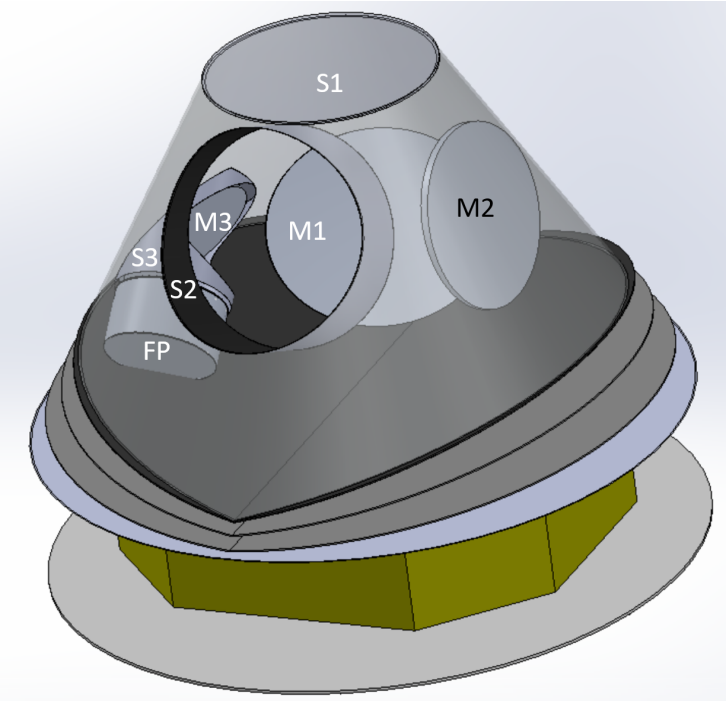
ν_o GHz	Beam size arcmin ($'$)	N_{det}	ΔT $\mu K'_{CMB}$	ΔP $\mu K'_{CMB}$
28	39.9	120	11.7	16.5
35	31.9	120	9.4	13.3
45	24.8	96	8.4	11.9
65	17.1	96	6.3	8.9
75	14.9	240	3.6	5.1
95	11.7	240	3.2	4.6
115	9.72	462	2.2	3.1
130	8.59	462	2.2	3.1
145	7.70	810	1.7	2.4
165	6.77	810	1.7	2.5
190	5.88	752	2.0	2.8
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 ~6800 detectors/polarisation

Readout challenging Sensitivity in CMB band: 1μK.arcmin

CMB-Bharat S/c Specs.



≈ 4.4 m

≈ 4.0 m

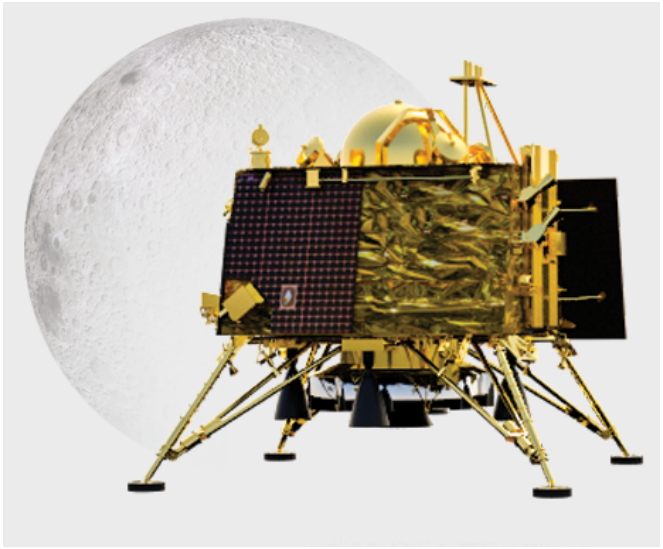
- Total wet mass ≈ 2.0 tons
- Diameter ≈ 4.4 meter
- Height ≈ 4.0 meter
- Power ≈ 2 KW

Adjustments are possible.

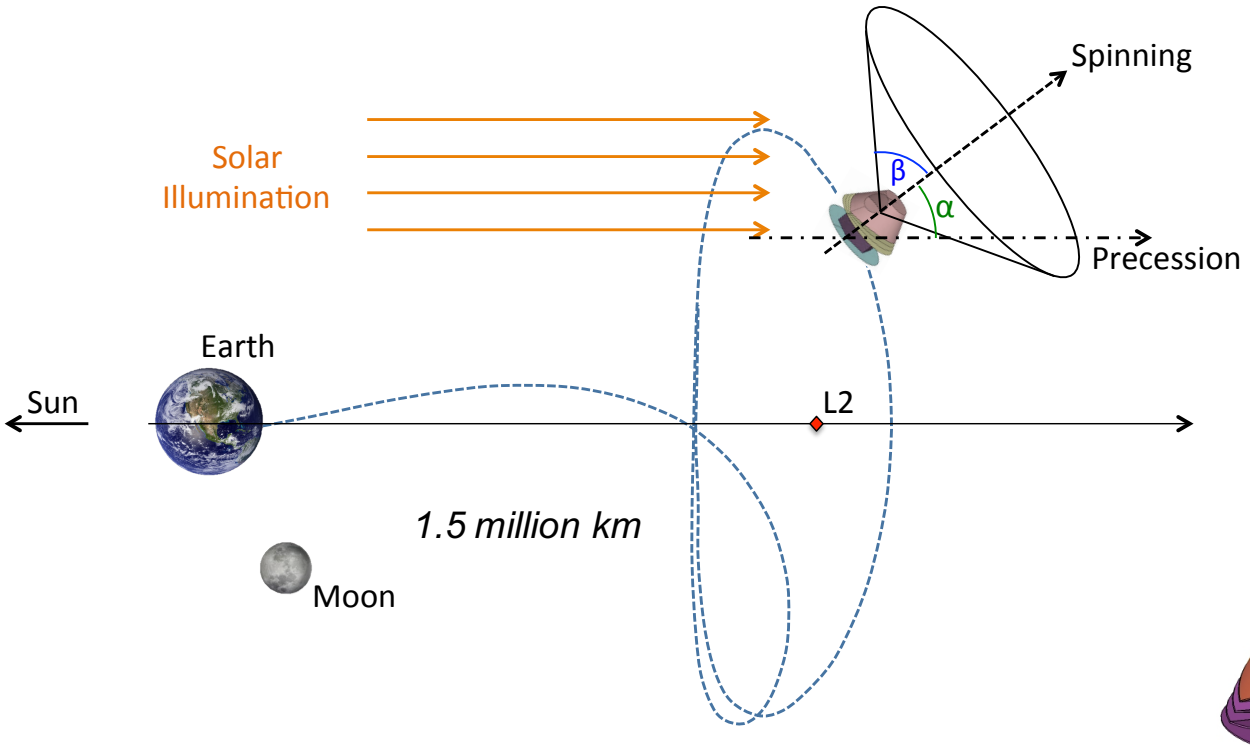
Max. Launch capacity: Well suited for a GSLV Mk-III launch towards a Sun-Earth L2 orbit

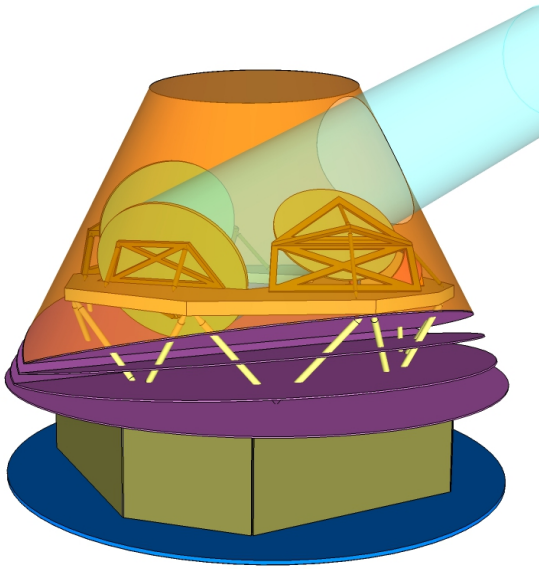
Chandrayaan-2 successful launch with GSLV-III July 22,2019

Orbiter – Lander - Rover



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:

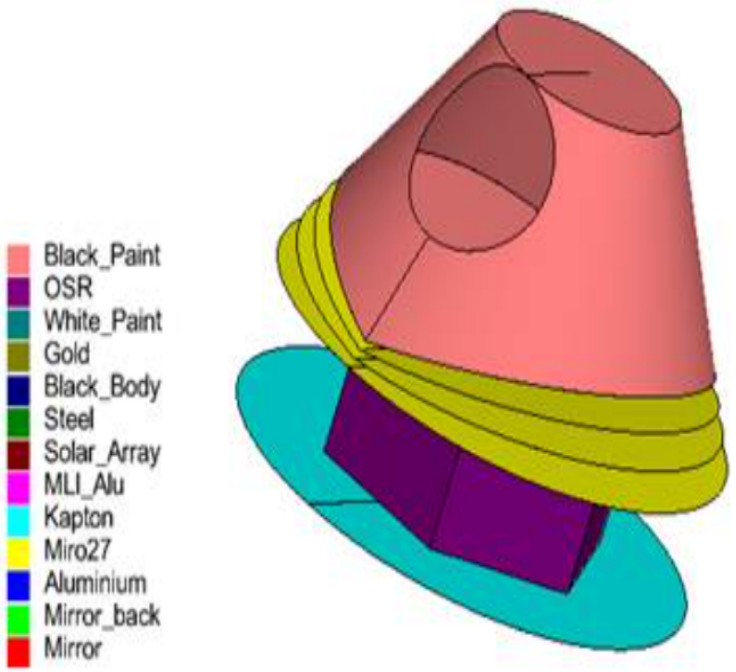
- Mission planning and operations;
- Launch to L2, tracking and control, orbit maintenance, science data downlink;
- Thermal infrastructure: design and fabrication of solar shield, hot-cold stage V-groove separator;
- Service module: design, fabrication, assembly and testing;
- Extensive modelling of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

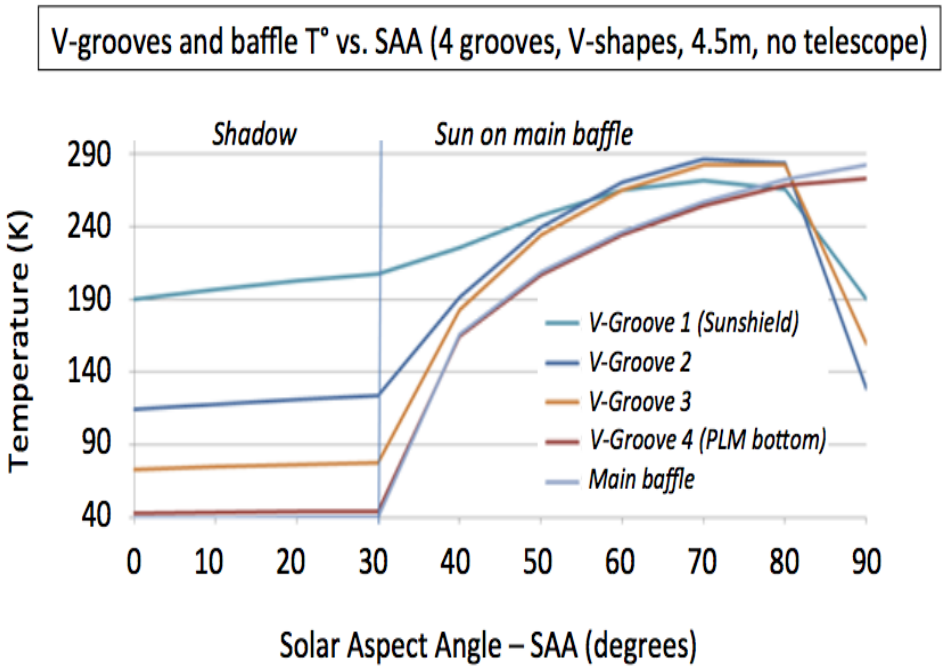
Indian technical contribution

Capabilities achieved with modest planned investments

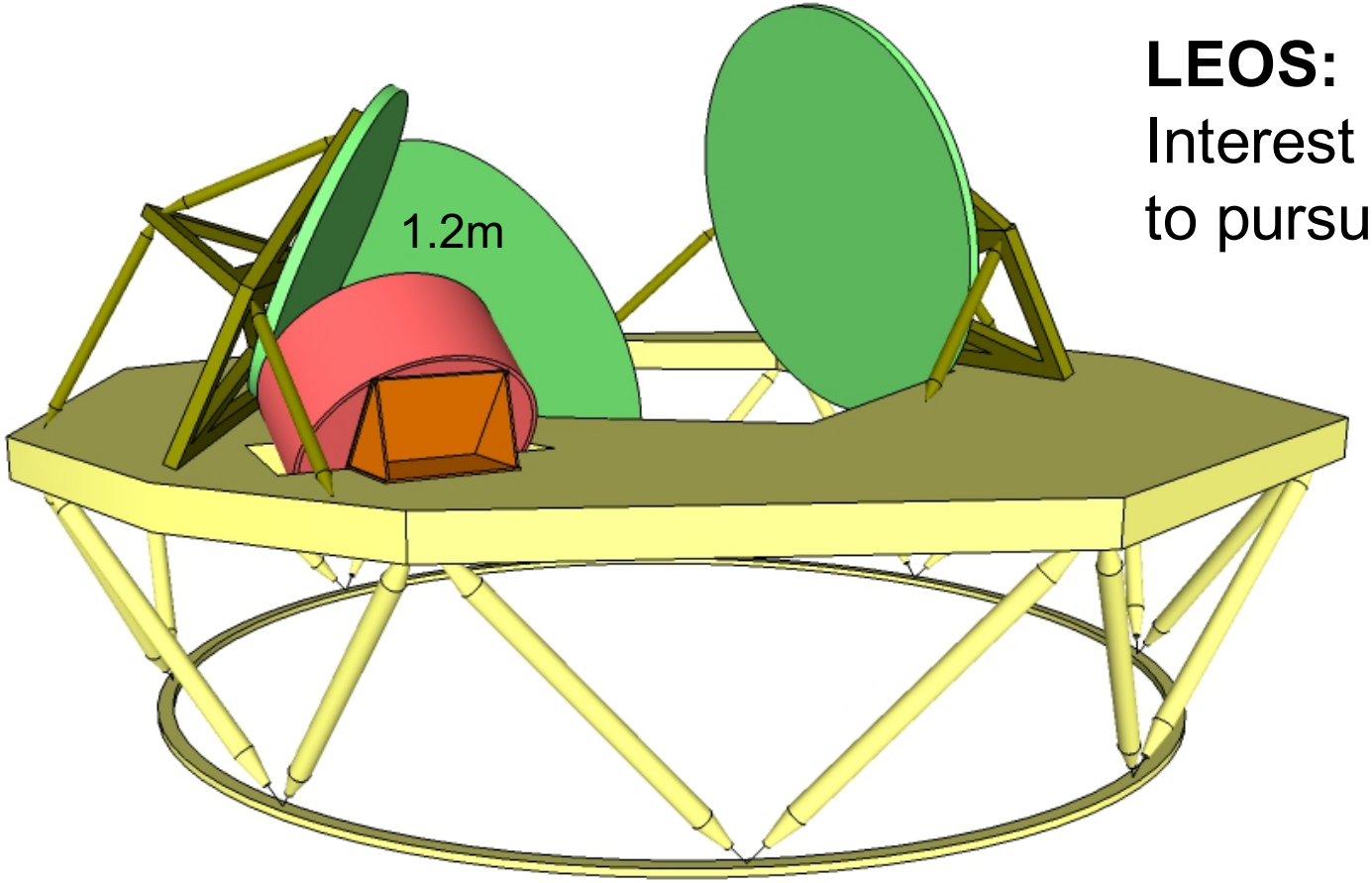
- Telescope and Optics **LEOS**
  - Design, fabrication, assembly, testing
  - Reflectors, baffling
  - Reimaging optics, filters
- Science Payload
  - Design, assembly, testing
- Thermal system: first stage coolers in the cryogenic cooling chain;

Passive Thermal isolation s/c design

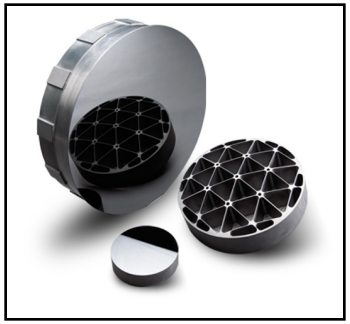




SiC Telescope optics



LEOS:
Interest & expertise
to pursue with TDP



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

TDP: Technology Development Program
LEOS: Laboratory for Electro-Optics Systems

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)

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 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 procurement (24) assembly & test (7)	31	Qualification review
	Flight model procurement, (24) 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

CMB-Bharat: multi-faceted science

Indian Working groups

- ***Cosmological parameters:*** *Lead: Dhiraj Hazra (APC, Paris→ NISER?,…)*
- ***We***
- ***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

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 !!!