Moon as an Astrophysics Platform

Nivedita Mahesh
On Behalf of the AMMB STIG

Ad ASTRA Workshop, Pasadena, Sept 2nd 2026

Inputs from: Marin Anderson, Martijn Oei, Karan Jani, Tabetha Boyajian, Paul Goldsmith, Kim Weaver, Anish Roshi, Richard Miller, Ken Carpenter

Why the Moon?

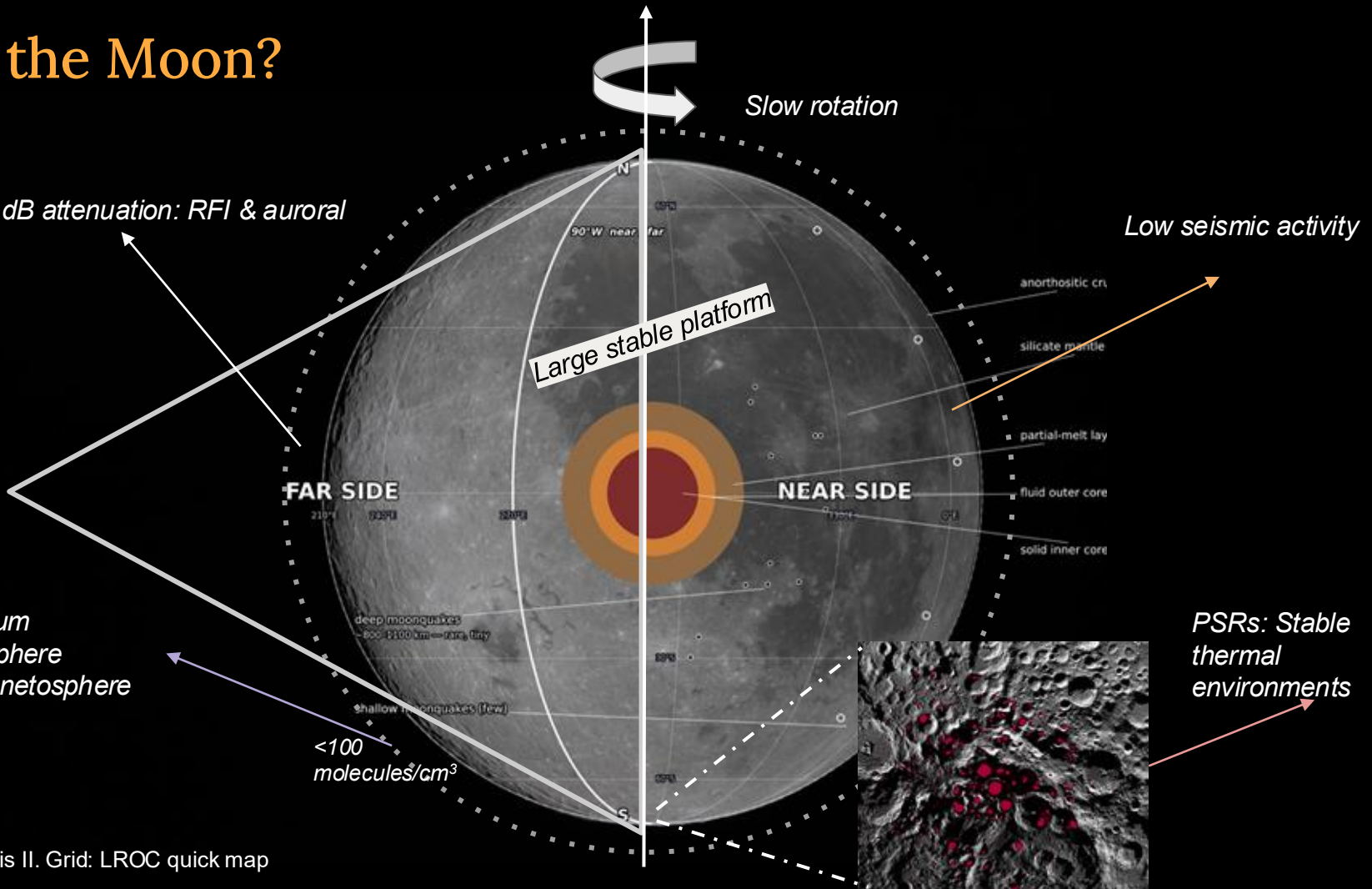


Image: Artemis II. Grid: LROC quick map

Why the Moon?

Low-frequency radio
(ν < 30MHz)

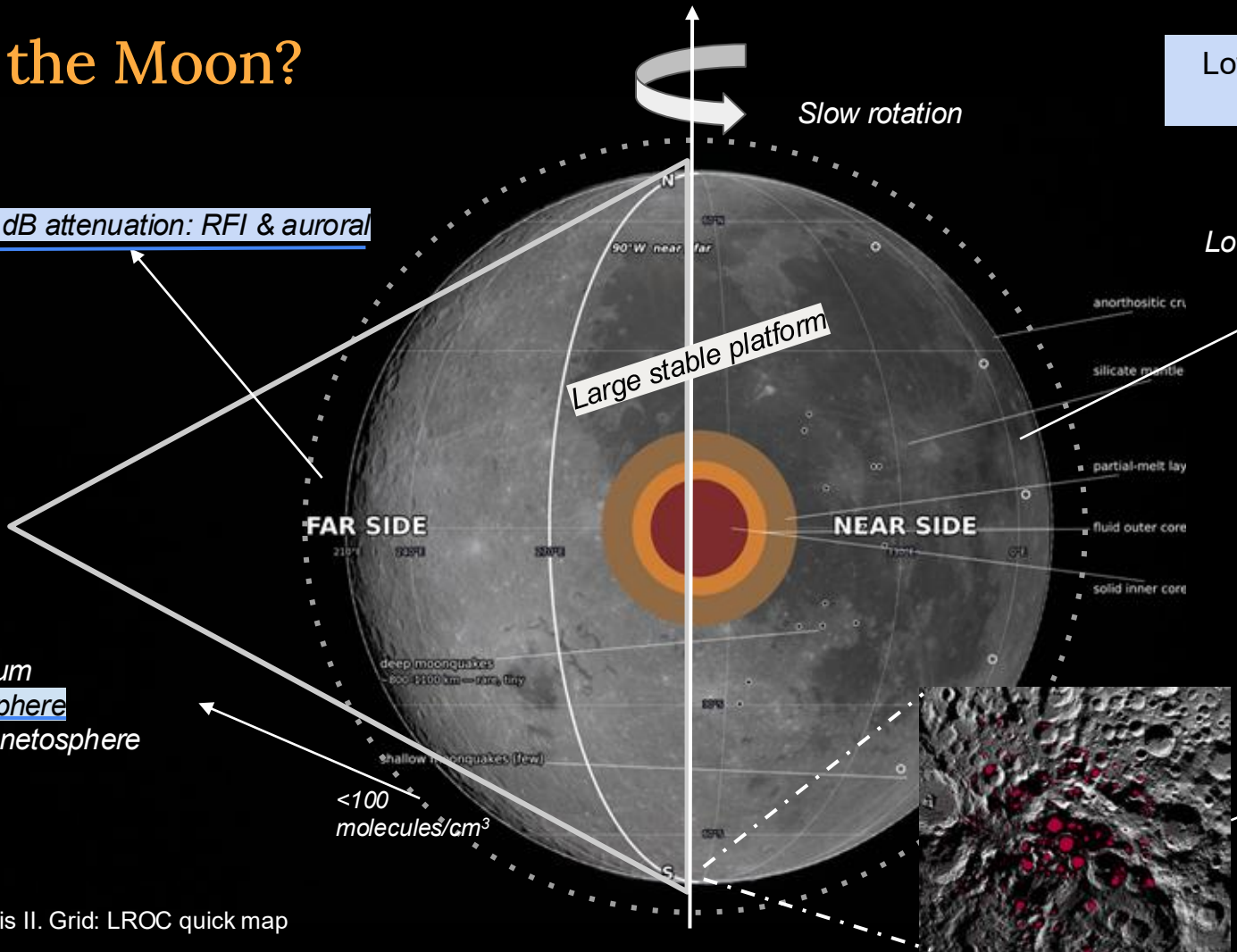


Image: Artemis II. Grid: LROC quick map

Why the Moon?

deci-Hz Gravitational waves

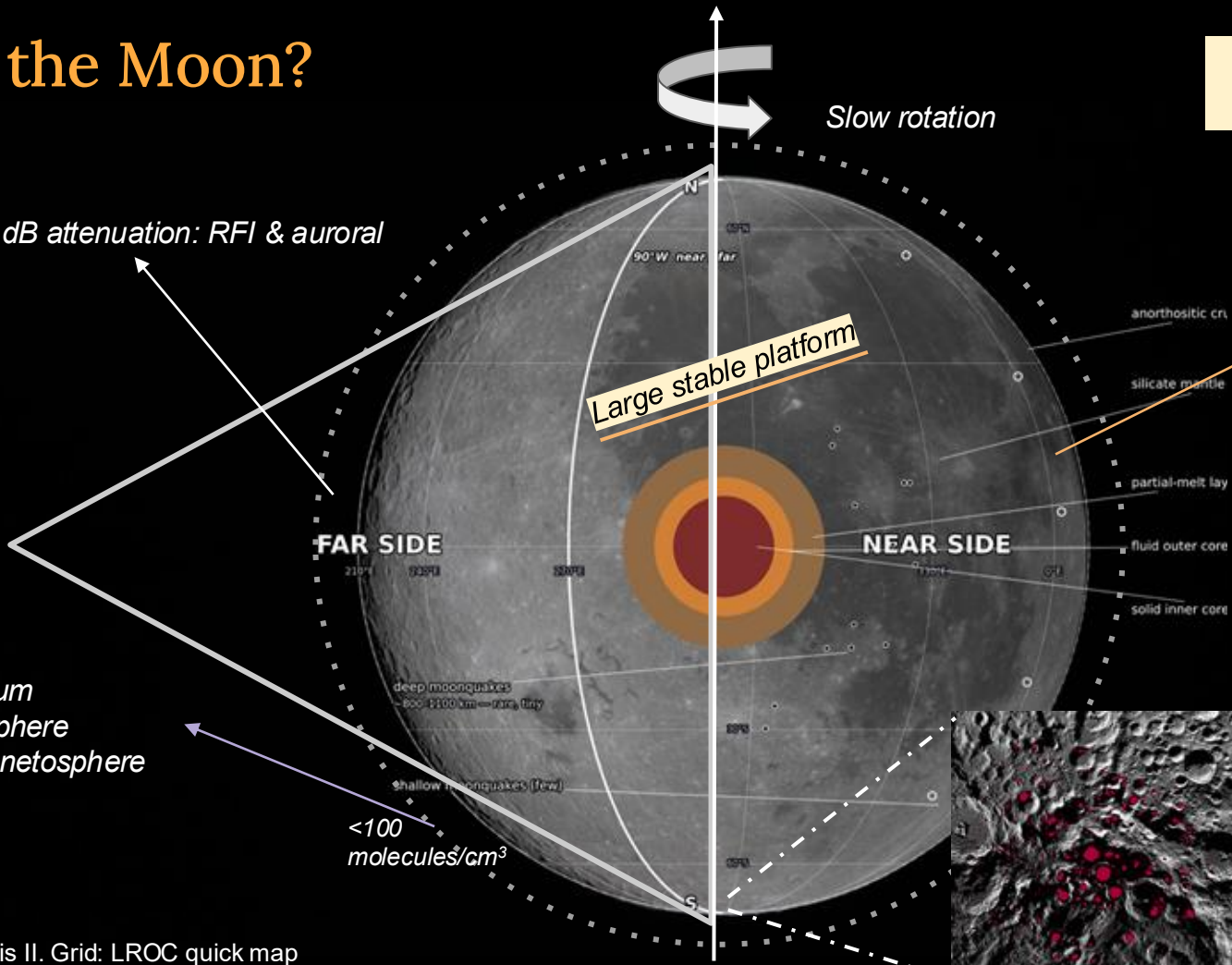


Image: Artemis II. Grid: LROC quick map

Why the Moon?

UV / Optical

Slow rotation

> 80 dB attenuation: RFI & auroral

Low seismic activity

Large stable platform

FAR SIDE

NEAR SIDE

N

S

anorthositic cr

silicate mantle

partial-melt lay

fluid outer core

solid inner core

deep moonquakes

Near vacuum
Thin ionosphere
Weak magnetosphere

<100 molecules/cm^3

PSRs: Stable thermal environments

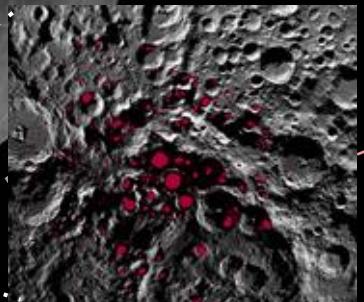


Image: Artemis II. Grid: LROC quick map

Why the Moon?

Sub-mm/ Far-IR

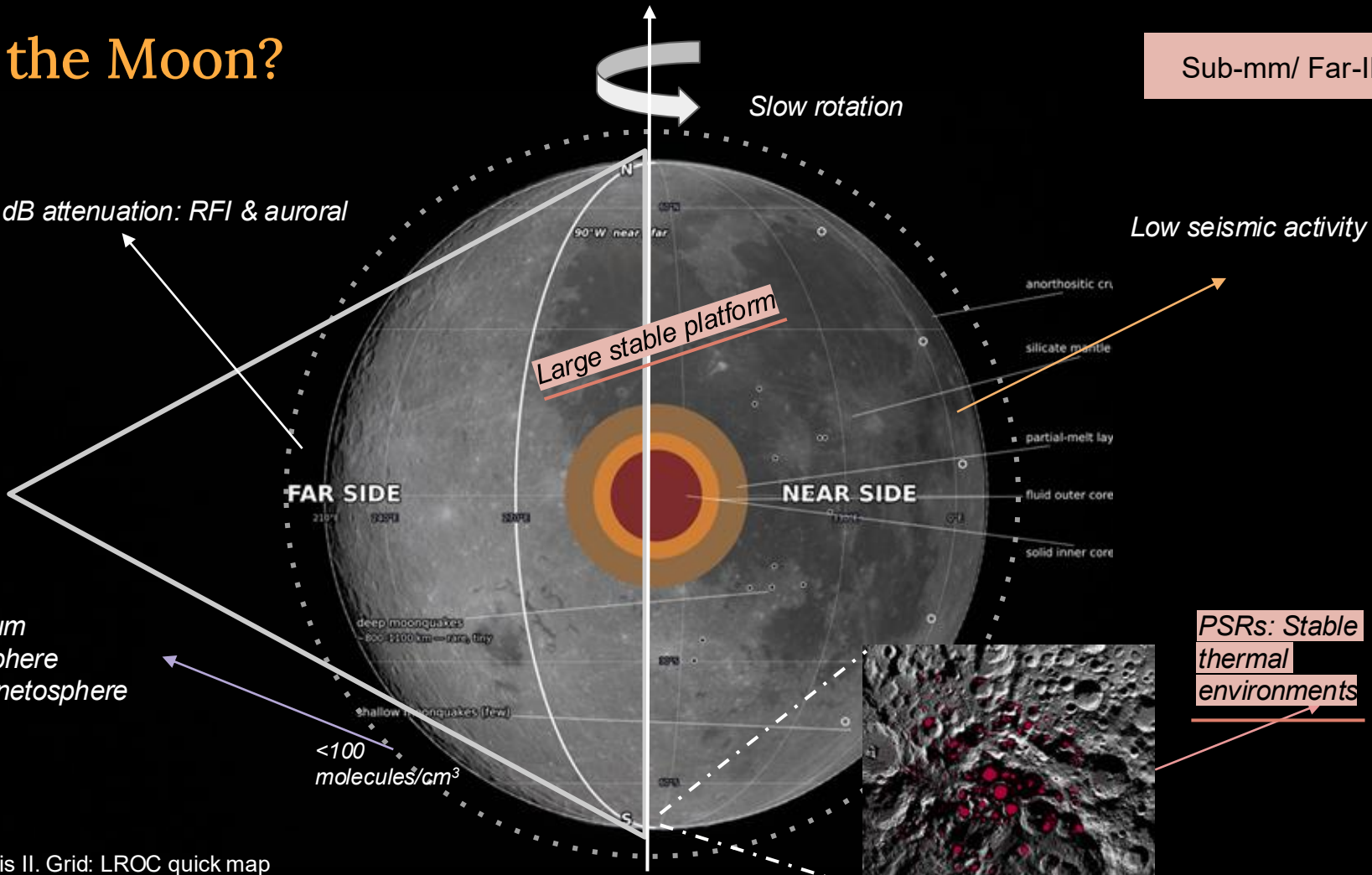
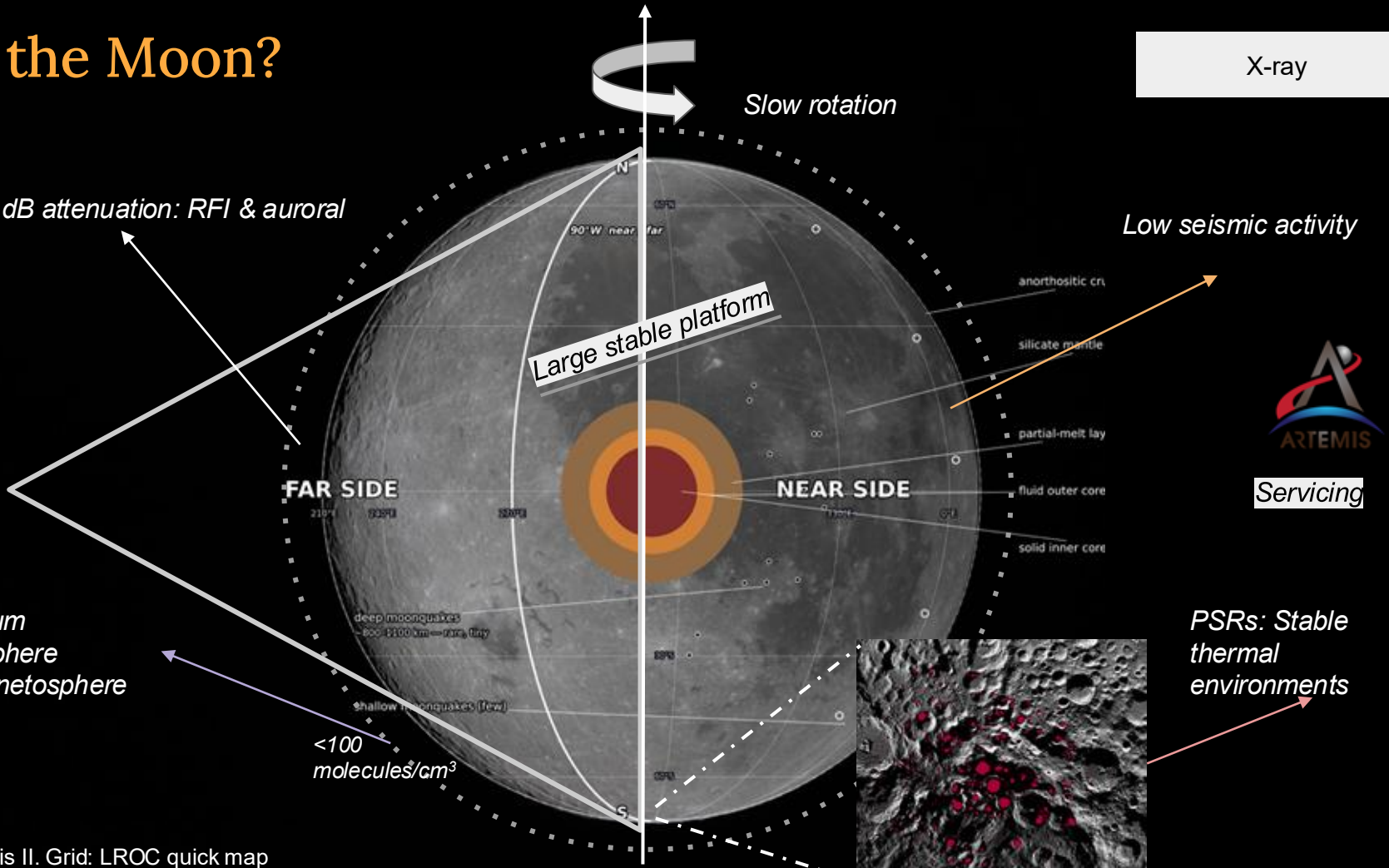


Image: Artemis II. Grid: LROC quick map

Why the Moon?

X-ray



ARTEMIS

Servicing

Image: Artemis II. Grid: LROC quick map

Why the Moon?

Gamma-ray

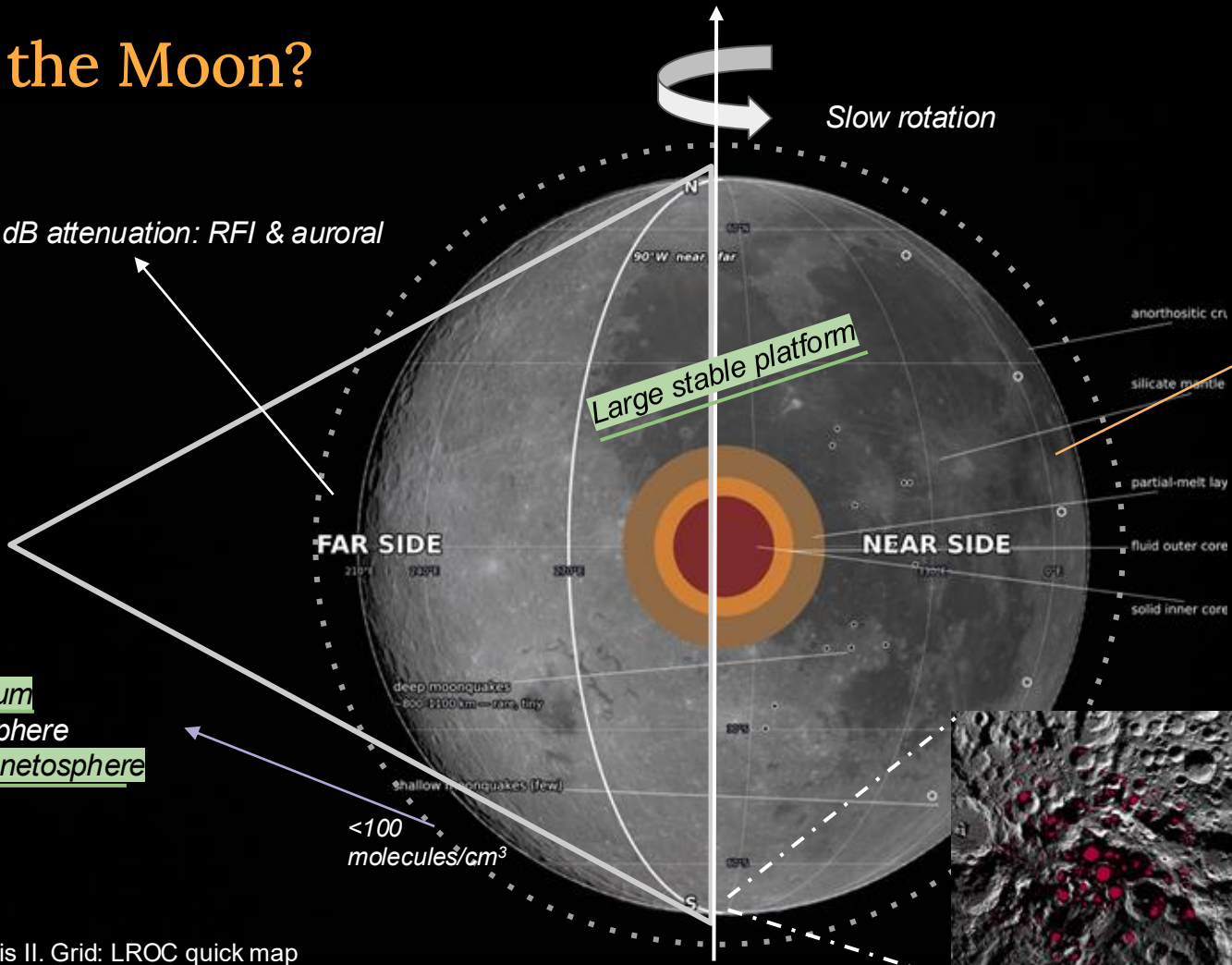


Image: Artemis II. Grid: LROC quick map

Why the Moon?

Direct Cosmic Rays

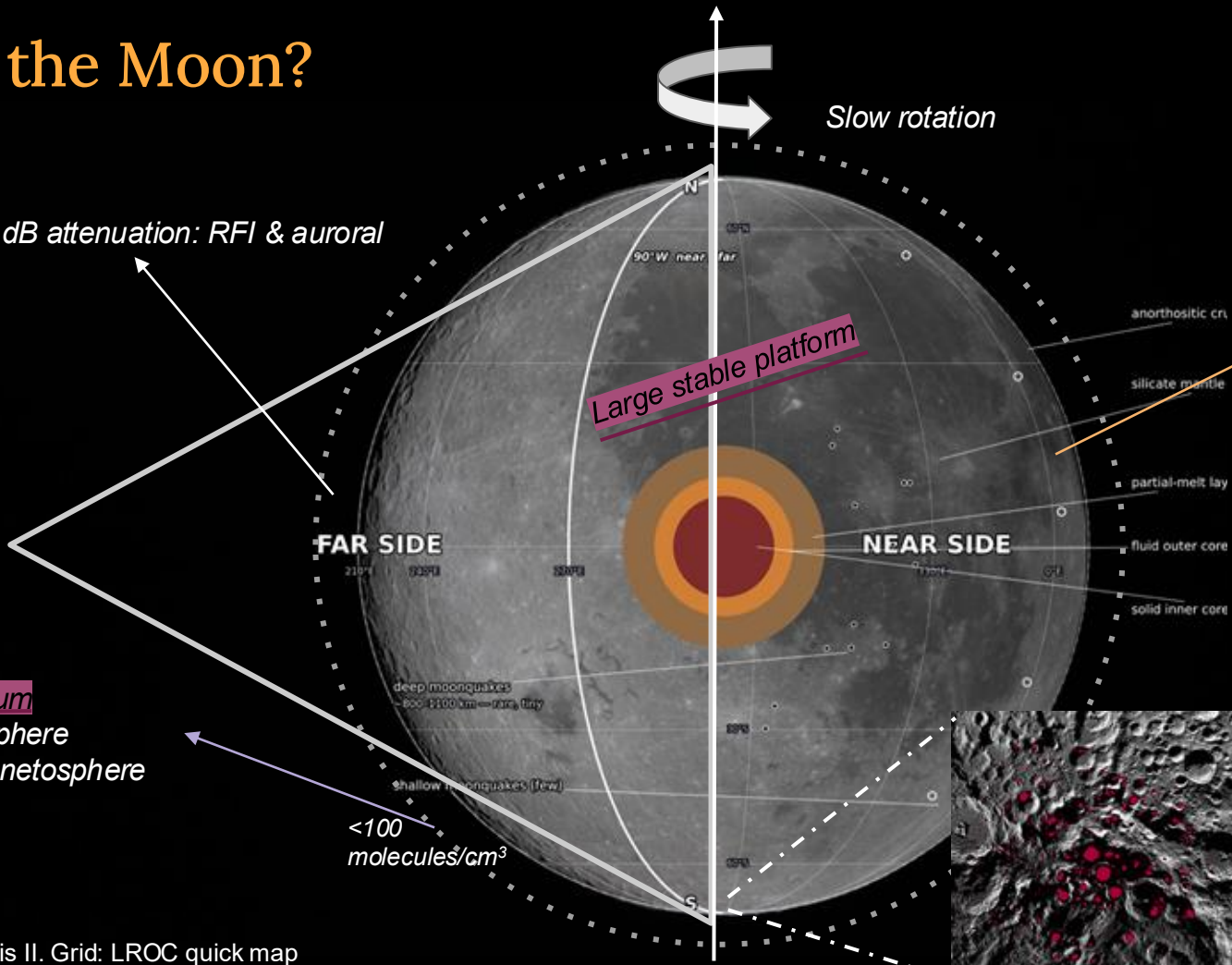
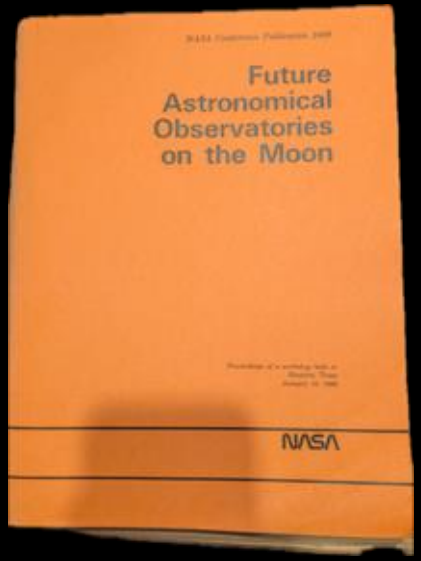


Image: Artemis II. Grid: LROC quick map

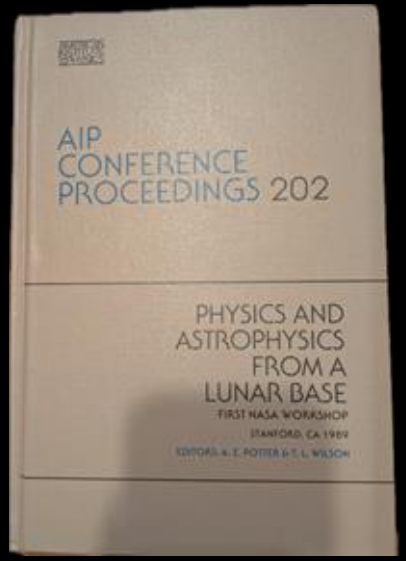
Why Now?

"Moon is a unique and extremely valuable opportunity for Space Science ... the overall justification for a lunar base would not be scientific in nature" Michel



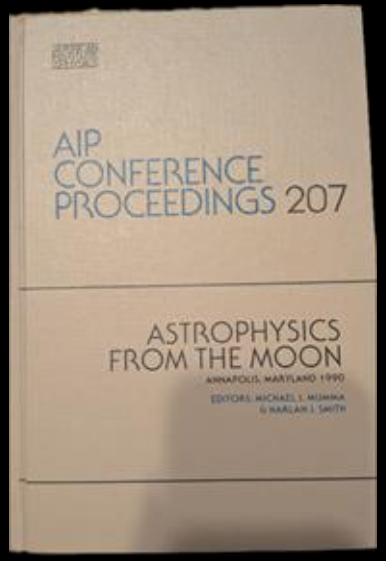
1986

"the Moon is very possibly the best location within the inner solar system ... astronomy will not be the prime mover ... piggybacking on a facility constructed with national funds" Burns & Mendell

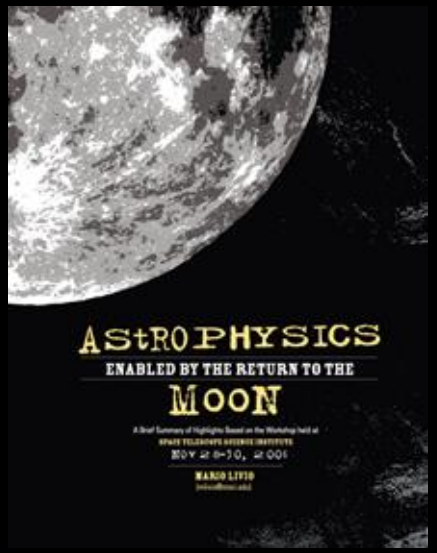


1989

"The moon offers many advantages. Astronomy-independent motives may underwrite most of the costs of a human-infrastructure on the moon" Mumma & Smith



1990



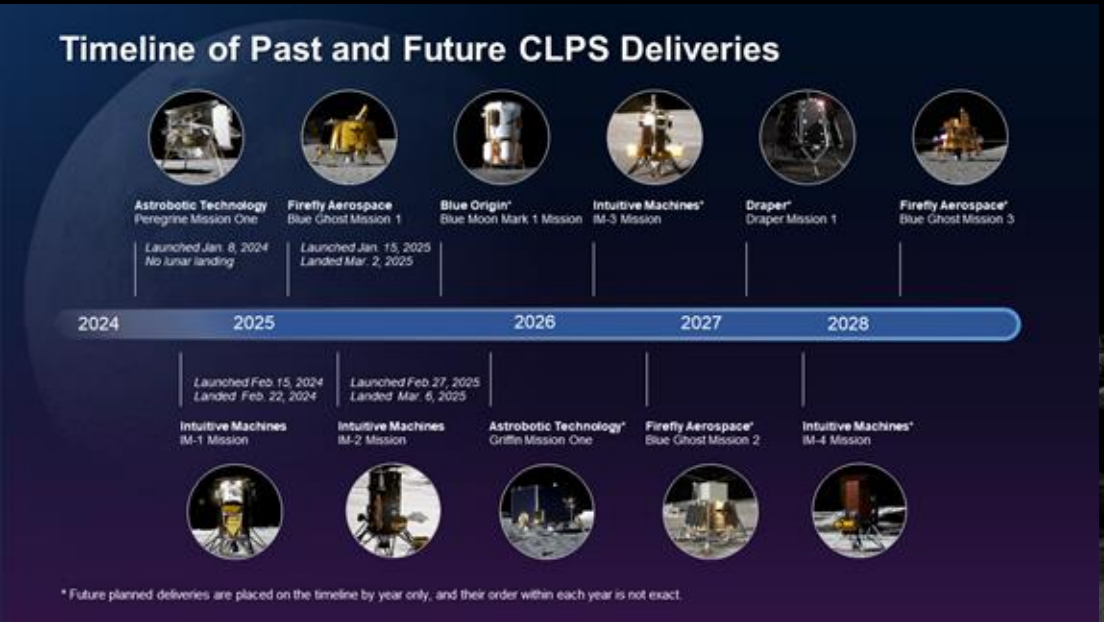
2006

"a few important astrophysical observations.. There are challenges to be addressed" Livio

Why Now?

Getting there: Commercial Lunar Payload Services

Regular transport and landing cadence, at costs that make payloads viable



Staying there: NASA Moon Base

(Communication, Power, Thermal control, Night survivability)

Astrophysics from the Moon across the Astro2020 landscape

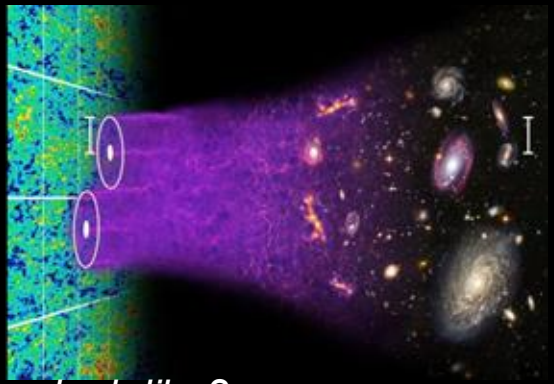
Astro 2020 Panel	Radio	GW	UV/ optical	sub-mm/ Far-IR	X-ray	γ-ray	CR
Compact Objects and Energetic Phenomena		◆	◆		◇	◆	◆
Cosmology	◆	◆		◇		◆	◆
Galaxies		◆		◆	◇		
Exoplanets, Astrobiology, and the Solar System	◆		◆		◇		
Interstellar Medium and Star and Planet Formation	◆		◆	◆		◇	
Stars, the Sun, and Stellar Populations	◆		◆		◇		

Case I: Radio Waves

Low-Frequency from the Moon can answer some profound questions

What do stars do to their planets?
Can other planets support life?

How did the first structures of our Universe form?



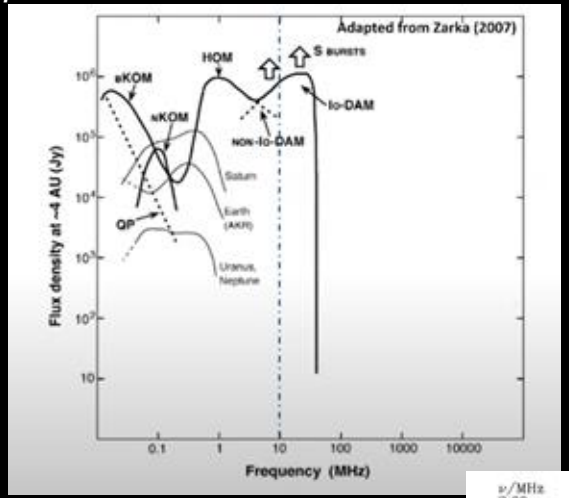
What does the Galaxy's interstellar medium look like?
How does stellar death affect stellar birth?

Case I: Radio Waves

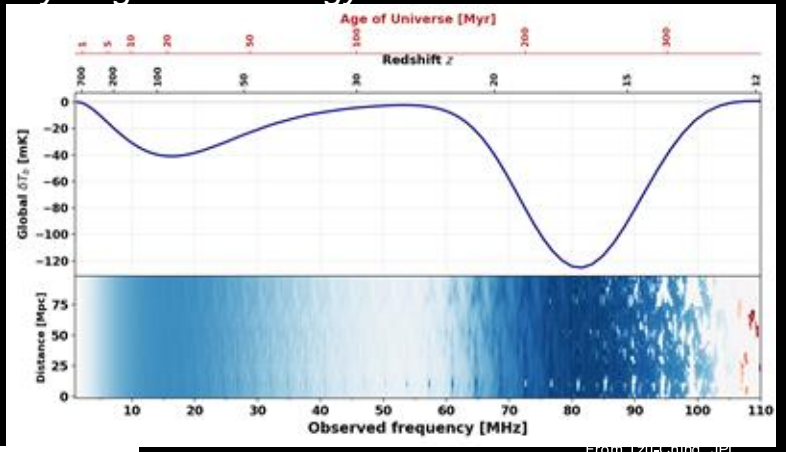
Low-Frequency from the Moon can answer some profound questions

All of these questions require low-frequency observations ⇒ $\nu < 30$ MHz

Space weather & radio auroral emissions

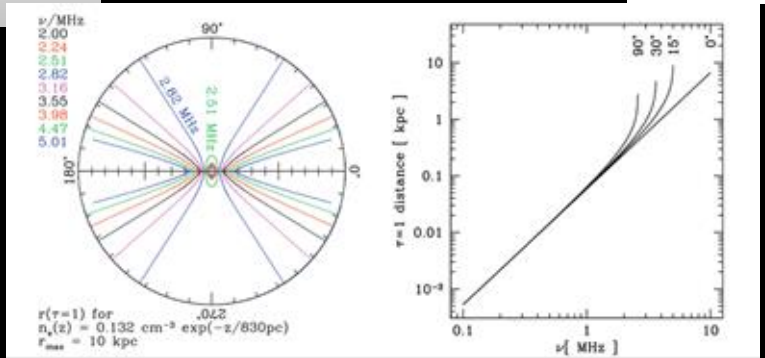


Probing Dark ages & Cosmic Dawn with Hydrogen cosmology



From Tzu-Ching, JPL

All-sky tomography of the local warm ionized medium



From Jester & Falcke (2009)

Case I: Radio Waves

Progress made in answering open questions w.r.t challenges

- How does the antenna behave over the regolith?
  - *500x more sensitivity laying it on surface*
- How do you deploy a large array on the surface?
- How do you power the electronics?
- Can you maximize the science return given a robotic array deployment? [Mahesh et al.(2025)]
- What is the correlator and digitiser architecture?
  - *Digital Signal Processing Trade Space for Space-based Radio Telescopes (K.Plant)*

LuSEE-Night CLPS mission (Bale et al. 2023)

ULW Farside observatory (Anderson & Mahesh et al., ASTRA)

MegaWave Radio Surveyor (Lazio et al. 2026)

FARSIDE Probe study (Burns & Hallinan et al. 2019)

Lunar Crater Radio Telescope (Bandyopadhyay et al. 2021)

FarView Lunar Array (Pollidan & Burns et al. 2025)

FARSIDE continuation study (McGarey et al. 2022)

MoonRISE PRISM proposal (Bandyopadhyay & Anderson et al. 2026)

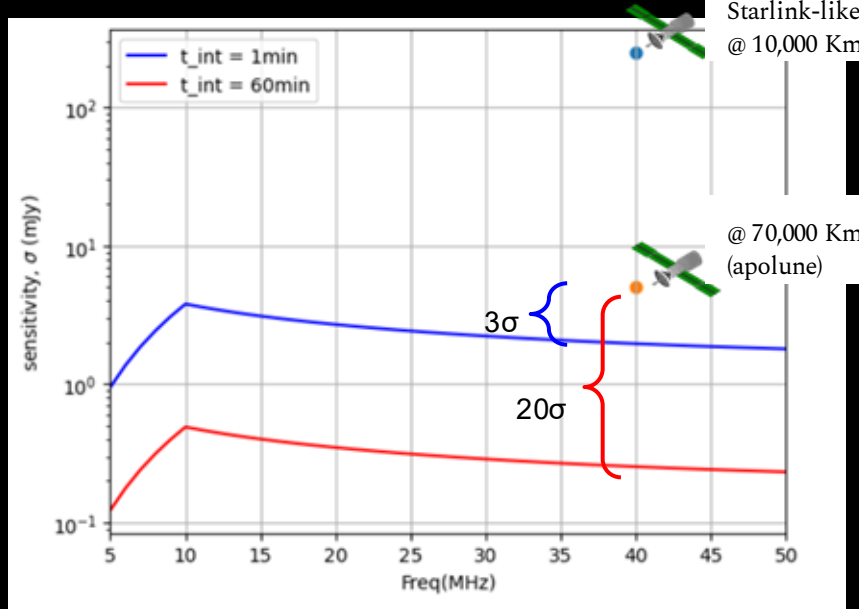
Lunar Farside Transients & Technology Telescope (DeBoer et al. 2026)

Case I: Radio Waves

Urgency: unintended EM Radiation

Radio telescopes on Earth have begun to detect leakages from Starlink Satellites!
Substantial

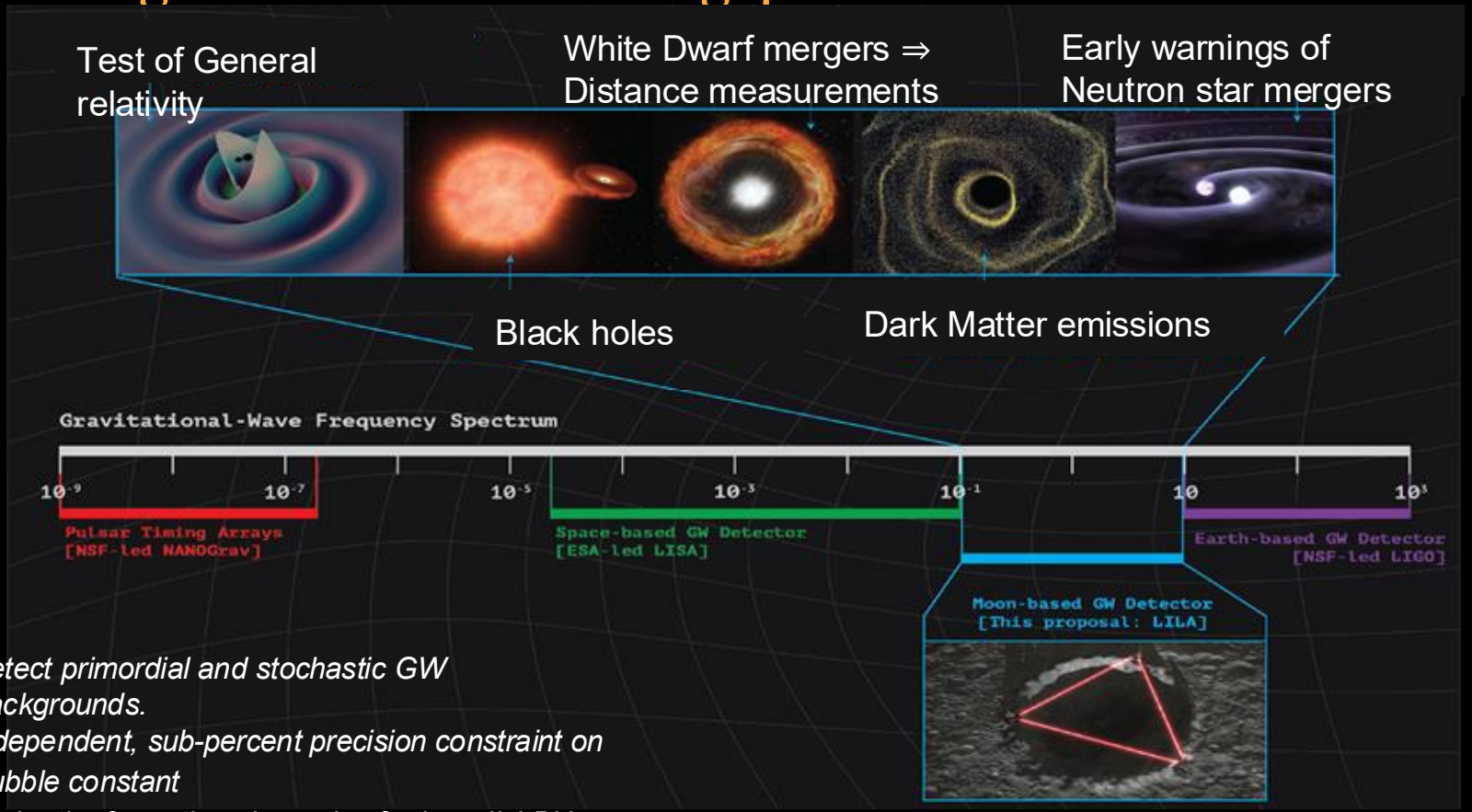
LOFAR:
•"varies from 15 to 1300 Jy, between 56 and 66 MHz **[Bassa et al. 2024]"**
•**[Zhang et al. 2025]** report the detection of broadband radio emissions from Starlink satellites below 100 MHz using NenuFAR...with flux densities ranging from 2 Jy to 261 Jy.



If there are satellites like Starlink placed in lunar orbit, the farside radio-quiet zone is in great danger!
⇒ Important to build a lunar farside observatory as quickly as possible while the Moon has minimal UEMR

Case II: Gravitational Waves

Filling in the observational gap in deci-Hz GW



- *Detect primordial and stochastic GW Backgrounds.*
- *Independent, sub-percent precision constraint on Hubble constant*
- *Probe the formation channels of primordial BHs*

Jani et .al. 2025 (NAS white paper)

Case II: Gravitational Waves

Progress made in answering open questions w.r.t challenges

- Can a surface laser strainmeter actually measure lunar normal modes?
- How do lunar normal modes couple to a gravitational wave?
- What are the fundamental noise limits on the lunar surface?
  - *Coating thermal + shot noise, not seismic — the lunar background sits ~6 orders of magnitude below Earth's*[Creighton et al. 2025]
- How much seismic isolation does a lunar GW detector need?
- Which lunar sites work, and do they fit Artemis surface operations?
- How do we mitigate dust on exposed laser optics?
- What do GCR and solar particles do to GW sensitivity?

Laser Interferometer Lunar Antenna (Jani et al. 2025)

LILA site selection (Trippe et al. 2025)

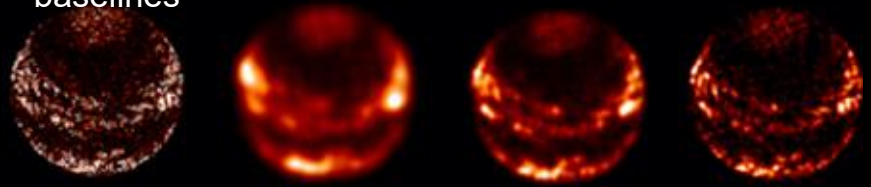
Lunar Gravitational-wave Antenna (Harms et al. 2021)

Case III: UV

UV Universe from the Moon: High resolution & continuous time domain.

What do other stars actually look like?

Resolve Magnetic Stellar activity at long baselines

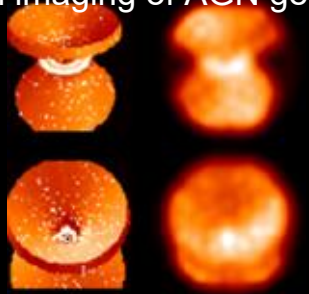


Model Baseline: 125m 250m 500m

Ref: AeSI, Ken Carpenter

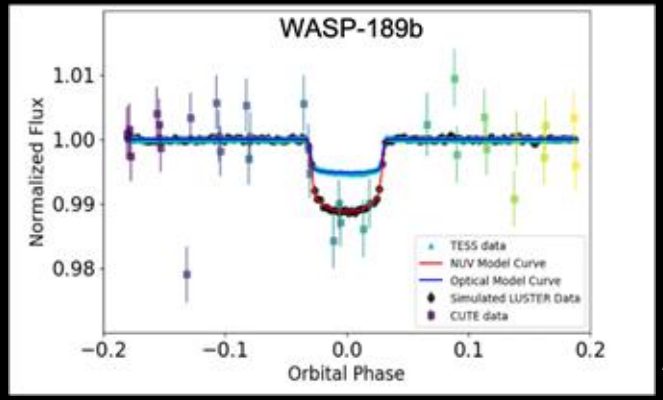
What lies at the heart of a galaxy?

High resolution imaging of AGN geometries



Model Baseline: 500m; 0.1mas

What are other worlds made of?



Ref: LUSTER-Net, T. Boyajian

Case III: UV

Progress made in answering open questions w.r.t challenges

- Deploying and phasing many mirrors on the surface

- Dust and thermal cycling on exposed optics
  - Chang'e-3 LUT ran stably on the surface for 1.5+ years, no dust degradation of optics or pointing (Wang et al. 2015)
  - Active dust removal now demonstrated: Electrodynamic Dust Shield on Firefly Blue Ghost Mission 1 (2025)

Artemis enabled Stellar Imager (Carpenter et. al. 2025)

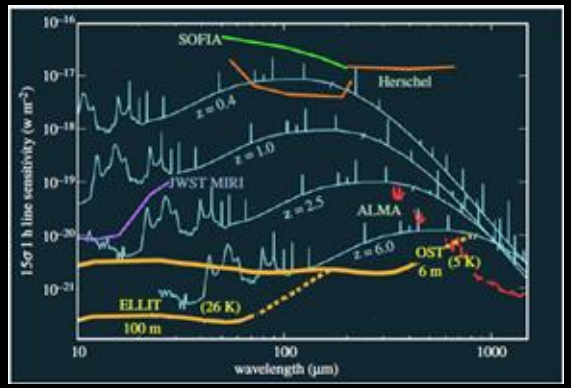
LUSTER PRISM Proposal (*T. Boyajian et al. 2026*)

MoonLITE (*Van Belle et. al. 2024*)

Case IV: Sub-mm & Far-IR

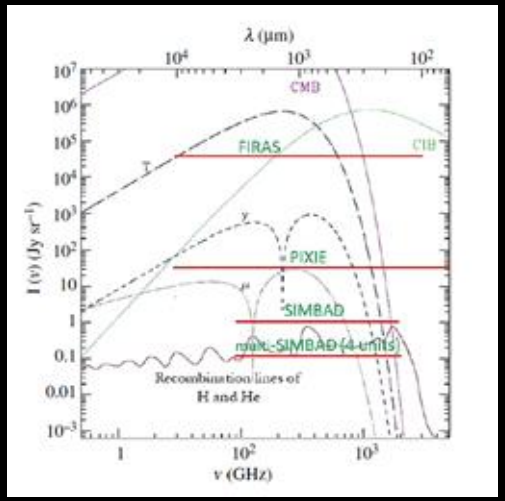
Deepening far-infrared sensitivity from the Moon

How do galaxies form and grow?



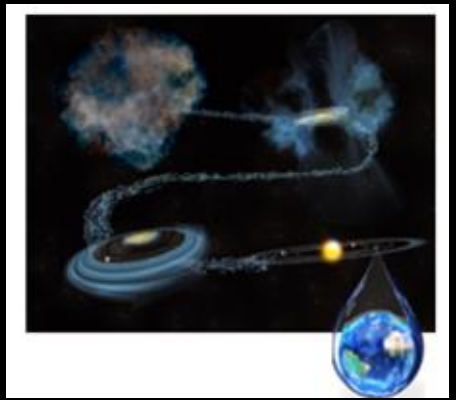
Ref: Maillard et al. 2020, Trans R. Soc

What hides in the Big Bang's afterglow?



Ref: Maillard et al. 2020, Trans R. Soc

How do planets get their water?



Ref: LASSO (Goldsmith)

Case IV: Sub-mm & Far-IR

Progress made in answering open questions w.r.t challenges

- Delivering a large dishes in a single launch (7m - 10m)
  - Possible via New Glenn launch vehicle & Blue Moon-Mark 2 class landers

- Power and sitting in a permanently shadowed crater
  - Crater sitting concept: Near-continuous solar on the Shackleton rim (Stoica 2019)

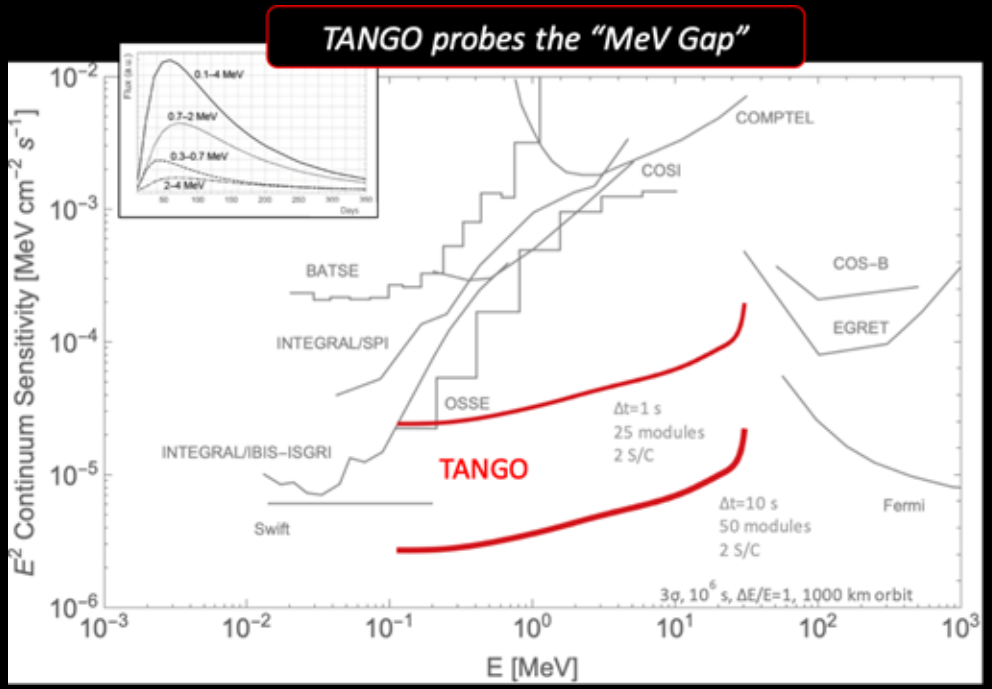
Extremely Large Lunar Infrared Telescope
(Maillard et. al. 2021, 2024)

PHOENIX
(Roshi et al., ASTRA)

LASSO
(Goldsmith et. al., ASTRA)

Case V: γ-rays

The unexplored MeV range of γ-rays



From: Richard Miller

Where do elements come from?

How fast is the Universe expanding?

Case V: γ-rays

Progress made in answering open questions w.r.t challenges

- Confusion from the lunar gamma-ray background
  - Faint, stable, well-characterized cis-lunar background

- Proving the occultation method works at all
  - Validated on 1.5 years of Lunar Prospector data, recovering real time-variable sources

TANGO
(Miller et. al., ASTRA)

Lunar Prospector: Occultation validation
(Miller & Peplowski 2026)

Detector Heritage
(Prettyman et al. 2011)

MITHRA
(Singer et al. ASTRA)

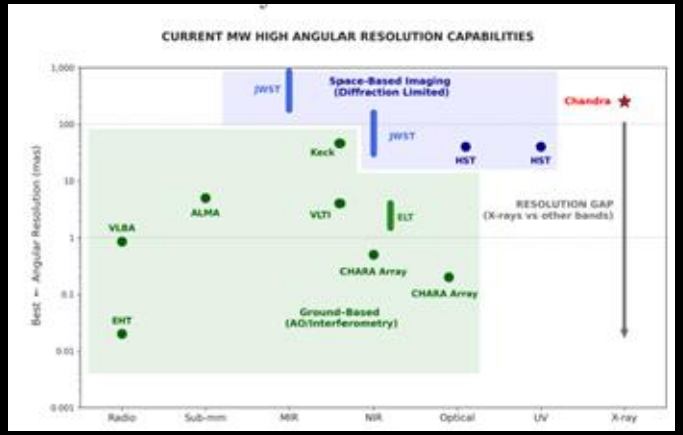
Case VI: X-Rays

Bridging the science gap due to lack of high resolution X-*ray* observations

Kim Weaver, Jenna Cann, +

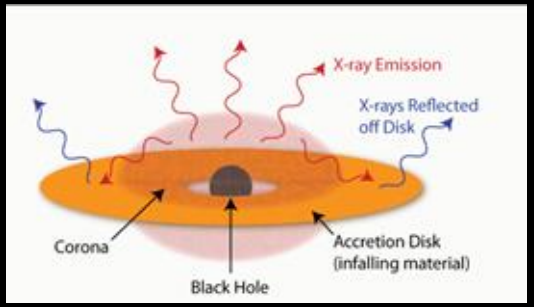
milliarcsec to micro-arcsec imaging!

Astrophysical jets

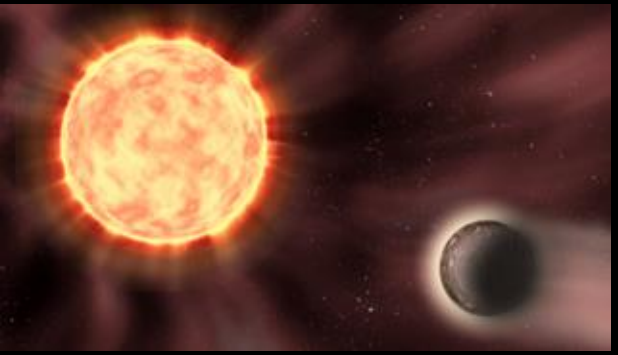


H.L. Marshal, k. Weaver ++ 2026

AGN accretion and feedback



Exoplanet habitability



H.L. Marshal , 2026

Supermassive black holes

Artist rendering of SMBH in MCG-6-30-15

Case VI: X-Rays

Progress made in answering open questions w.r.t challenges

- Slow lunar rotation makes tracking hard
  - Site near a pole; drift-scan observing strategy
- Seismic, thermal, dust, and lunar X-ray background
  - Calibration, a dedicated background monitor, and mounting above the surface with baffles
- Aligning the optics
  - On-surface human servicing near Artemis Base Camp

X-ray interferometry from the Moon
(Gandhi et al. 2024)

Accretion Explorer Interferometer
(Weaver et al., NIAC)

Lunar X-ray Interferometer concept
(Weaver et al., ASTRA)

Where does the Moon actually help?

Messenger	Science Questions	The Moon's advantage
Low Frequency	• Dark Ages and Cosmic Dawn • exoplanet magnetospheres • Galactic Cosmic Rays	• Farside provides 80dB attenuation to RFI & auroral emissions • No ionosphere cut off ~30 MHz
deci-Hz Gravitational waves	• IMBHs • early binaries • Stochastic background [illegible]ation	• Seismically quieter than the Earth • Stable solid platform for a long-baseline detector
UV/Optical	• High-resolution imaging a[illegible] (stellar surfaces, AGN) • Time-domain (exoplanets[illegible] TDAMM counterparts)	[illegible] ⇒ long coherence times [illegible]e baselines without formation flying [illegible]tion ⇒ Long observation window
Sub-mm/ Far-IR	• The cold universe • star and planet formation[illegible] • CMB spectral distortions	[illegible]ers give passive cryogenic cooling [illegible]meter platform
X-ray	• μarcsec imaging of black-hole environments and AGN	• Stable km baselines on solid ground • servicing
Gamma-ray	• The MeV sensitivity gap • TDAMM counterparts	• Low Magnetosphere • Regolith for shielding and background veto

The Lunar Program at Ad ASTRA

Radio

SCIENCE

Cosmology from the FARSIDE J. Burns · #21

Dark Ages cosmology S. Furnaletto · #25

Exoplanet magnetospheres G. Hallinan · #38

Galactic cosmic rays M. Oei & K. Plant · #46

Stellar space weather I. Davis · #54

CONCEPTS

LCRT S. Bandyopadhyay · #57

LFT3 J. Turner · #155

ULW Farside Observatory M. Anderson · #97

FarView J. Burns · #162

MegaWave (cislunar) J. Lazio · #70

Cosmic Ray

CONCEPTS

LCRO N. Cannady · #77

Gravitational Waves

SCIENCE

CHRONOS D. Leibrandt · #147

DISA J. Slutsky · #141

Beyond LISA A. Buonanno · #117

CONCEPTS

LILA V. Quetschke · #71

UV / Optical

CONCEPTS

AeSI K. Carpenter · #142

LUSTER-net A. Sohani · #94

X-ray

CONCEPTS

AEI K. Weaver· #142

γ-ray

SCIENCE

GRB science E. Burns · #8

Antinuclei probe von Doetinchem · #27

CONCEPTS

MITHRA L. Singer · #178

TANGO R. Miller · #73

Sub-mm / Far-IR

SCIENCE

Star formation R. Paladini · #55

CONCEPTS

LASSO P. Goldsmith · #39

PHOENIX A. Roshi · #90

The right momentum, but there are some key gaps

Define the science:
goals & probe-class, flagship concepts

PhysCOS · AMMB · Ad ASTRA

Mature the Design, hardware:
Eg: system design, detectors, pipelines, simulations

ROSES-26 APRA · SSERVI-CAN-5

?

THE MISSING MIDDLE

› No clear path for intermediate-scale astrophysics missions ⇒ PRISM sits under Planetary (PSD)

› Parameters of the ride & infrastructure? It sets the instrument boundary conditions

› Cis-lunar architecture undefined: own propulsion, or drop in orbit?

› Interface with Human Exploration (ESDMD)? It sets the instrument boundary conditions

THE RIDE

Commercial launch & lander contracts

Private launches, CLPS landers

Surface infrastructure: comms, power, thermal

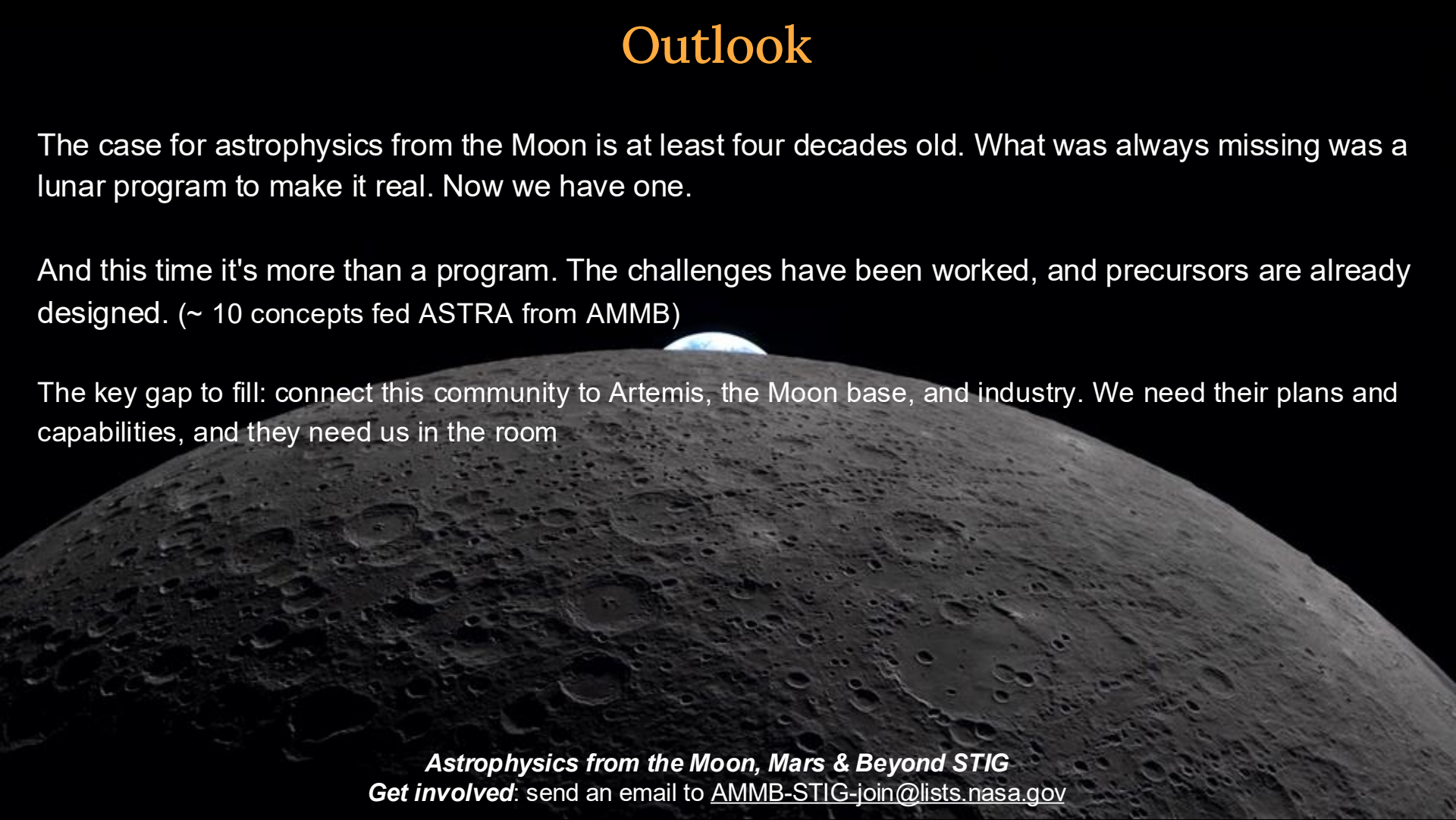
Artemis, Moon Base

Outlook

The case for astrophysics from the Moon is at least four decades old. What was always missing was a lunar program to make it real. Now we have one.

And this time it's more than a program. The challenges have been worked, and precursors are already designed. (~ 10 concepts fed ASTRA from AMMB)

The key gap to fill: connect this community to Artemis, the Moon base, and industry. We need their plans and capabilities, and they need us in the room



Astrophysics from the Moon, Mars & Beyond STIG
Get involved: send an email to AMMB-STIG-join@lists.nasa.gov

EXTRAS

Case II: Gravitational Waves

Progress made in answering open questions w.r.t challenges

- **Can a surface laser strainmeter actually measure lunar normal modes?**
  - *Yes — SNR 10–1000 for modes < 10 mHz with a single 5 km arm; even the Slichter inner-core mode may be in reach* [Panning et al. 2026]
- **How do lunar normal modes couple to a gravitational wave?**
  - *GWs resonantly drive the ℓ=2 quadrupole modes; amplification 25 $L^2 eff Q^2/R^2 Moon$, with Q ~10^2 at 1 Hz rising to ~10^4 at 1 mHz* [Majstorović et al. 2025]
- **What are the fundamental noise limits on the lunar surface?**
  - *Coating thermal + shot noise, not seismic — the lunar background sits ~6 orders of magnitude below Earth's*[Creighton et al. 2025]
- **How much seismic isolation does a lunar GW detector need?**
  - *1 stage if the background is quiet* [Shapiro 2025]
- **Which lunar sites work, and do they fit Artemis surface operations?**
  - *Site-agnostic science; 7 sites identified from LRO/LROC and Lunar Prospector data* [Trippe et al. 2026]
- **How do we mitigate dust on exposed laser optics?**
  - *LADEE/LDEX densities put dust-scattering noise far below shot noise; EDS flight-demonstrated on Blue Ghost Mission 1 [Publication in-prep]*
- **What do GCR and solar particles do to GW sensitivity?**
  - *No free-falling test mass in the strainmeter channel → a lifetime/TID problem, not a sensitivity floor; charge control demonstrated by LISA Pathfinder [Publication in-prep]*

Telescopes on the moon isn't a new idea!

Telescopes on the moon were envisioned even before the Apollo 11 landing.

Here is an interview with Arthur C. Clarke in 1963 on British Television

"In a few generations, all serious astronomy will be with telescopes on the Moon or in space."

It has now been a few generations and we have incredible space telescopes.

....leaving only the Moon part left to do!!

What is AMMB?

Science and Technology Interest group within the PhysPAG (& open all):
Astrophysics from the Moon, Mars & Beyond

Get involved: send an email to AMMB-STIG-join@lists.nasa.gov with Subject="subscribe"

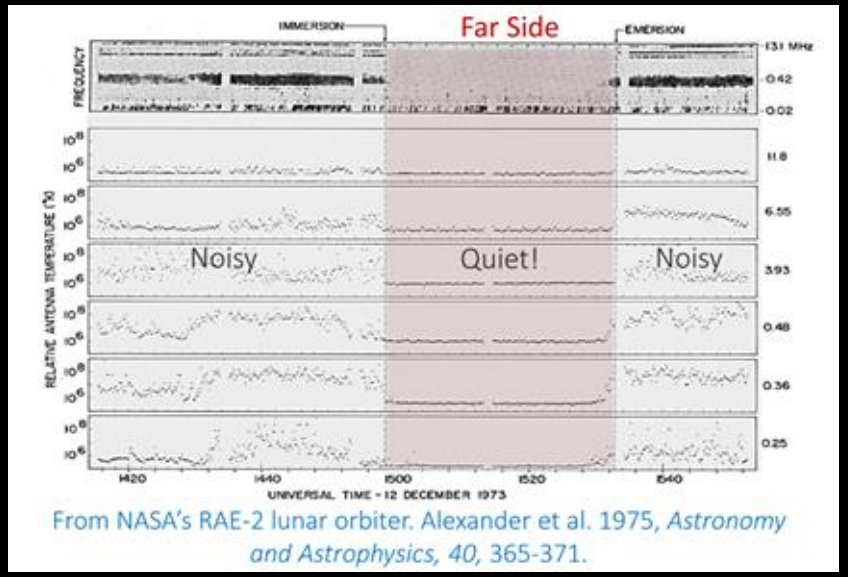
Co-Chairs

Nivedita Mahesh

Marin Anderson

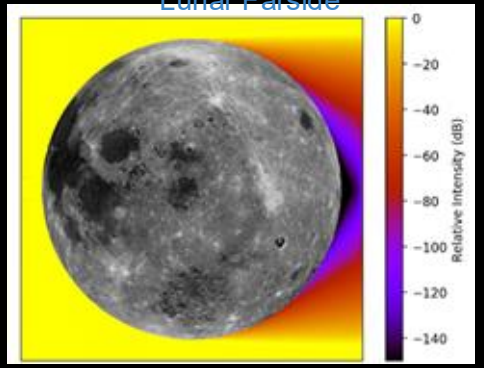
Case I: Radio Waves

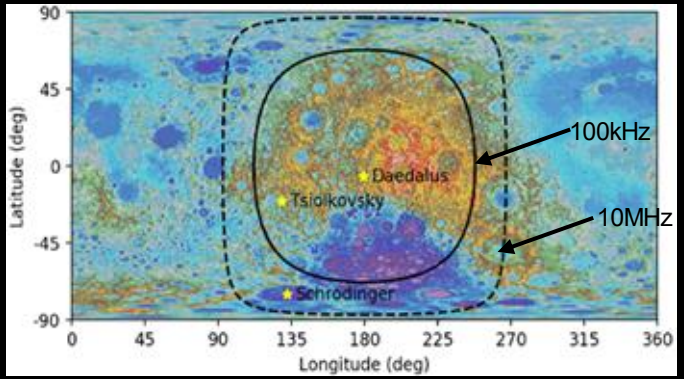
Why Moon and the Farside



From NASA's RAE-2 lunar orbiter. Alexander et al. 1975, *Astronomy and Astrophysics, 40,* 365-371.

Numerical modeling of the Radio quiet zone on the Lunar Farside



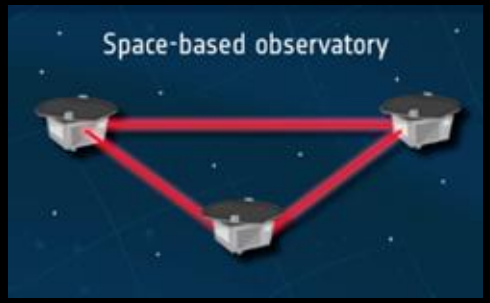


≥ 80 dB attenuation plotted over a map of the lunar surface. *(Basset et.al. 2020)*

- **Lunar farside provides isolation from radio frequency interference**

Gravitational Waves

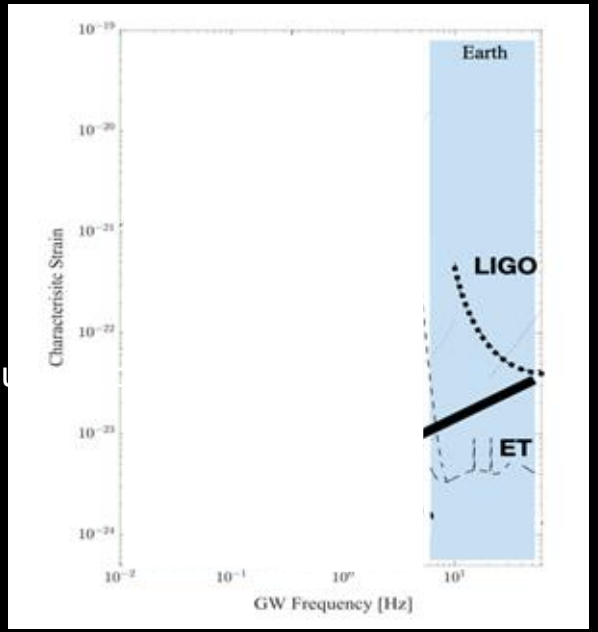
Filling in a critical observational gap in deci-Hz Gravitational Waves



Cannot measure small fluctuations

- Low seismic activity
- Can measure small fl

Earth's seismic activity ⇒ limited sensitivity



Gravitational Waves

Where on the Moon for LILA *Jani et .al. 2025 (NAS white paper)*

- For GW, Near or Farside both works
- But, preferably away from any Artemis activities: launching & landing
- Very sensitive to seismic activity ⇒
  - Away from possible mining activities!

Site selection constraints and options for LILA-Pioneer and LILA-Horizon *(https://arxiv.org/abs/2604.02405)*

Case III: UV

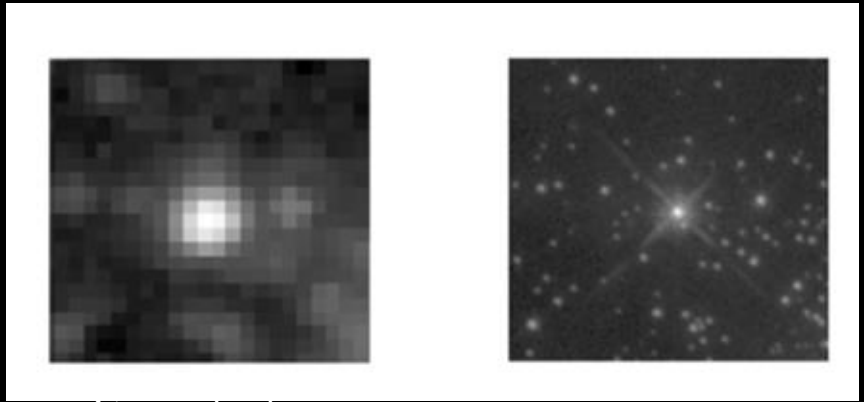
Why the Moon?

On earth:

- Turbulence due to the atmosphere
- Attenuation

Why not space?

- Difficult: mm accuracy while free flying
- Not easy: To make long baselines (>500m)



Atmospheric Turbulence

No Atmospheric Turbulence

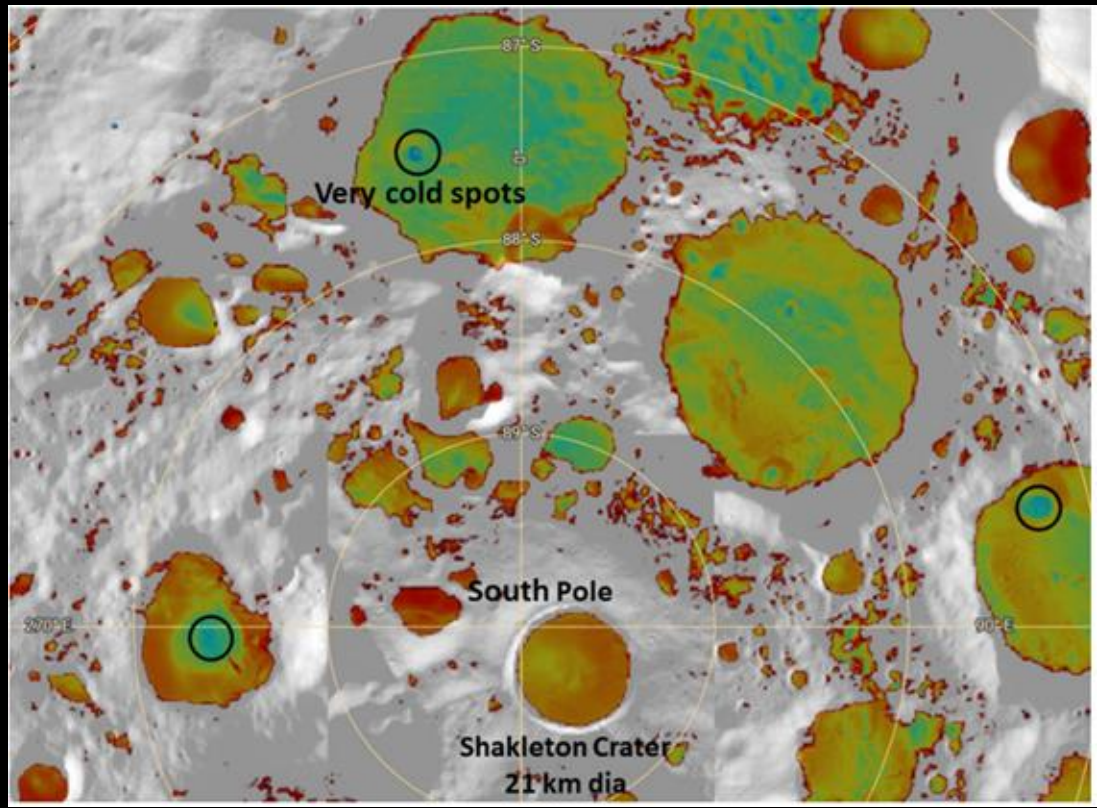
On the Moon

- Longer coherence time: 10 - 1000 secs Vs 0.001 secs ⇒ sharper images
- No attenuation
- Easy equipment: Natural vacuum
- lunar gravity ⇒ free sub-micron stationkeeping & pointing

Case IV: Sub-mm & Far-IR

So, where on the Moon?

- Permanently Shadowed regions
- Temperatures of < 5K during all seasons



Open questions and Where we need answers

- We are interested in forming dedicated Science Analysis Groups (SAGs)
- Reliant on Artemis, CLPS and Moon Base
  - Power, comms, infrastructure
- “Assume the capabilities announced by commercial partners are available for free” - where do we find these?
- Outcomes of the Innovation workshop
  - Available tech & products we can take advantage of.
- Promising: Interest in lunar and cis-lunar payloads for ROSES-26 & PIONEERs
- What about Explorer calls? What about PRISM calls?
  - Great that the SIG has been initiated.
  - APD involvement into PRISM that has traditionally been funded by PSD?

What have we done so far?

- Formed in March of this year
- We are about ~ 60 people in our group
- Identified sub-focus areas based on messenger:
  - Low-frequency Radio
  - Gravitational waves
  - Ultra-violet
  - Sub-mm & Far-IR
  - X-Rays
  - Gamma-Rays

AMMB community gave talks at the recent AAS ExoPAG session:

- MoonLITE (UV, Lunar)
- MegaWave (Radio, cis-Lunar)
- Farside observatory (Radio, Lunar)

Bi-weekly Community meetings: *Tuesdays at 9am PDT*

Progress Prior to AMMB: Various papers from our community

since 2025

Radio

Mar 2025: "Results from NASA's First Radio Telescope on the Moon (ROLSES-1): technosignatures & low-freq Galactic background" *Hibbard, J.O. Burns et al. · Published, AJ*
Apr 2025: "The Dark Ages Explorer (DEX): filled-aperture ULW interferometer on the lunar far side" *Koopmans et al. · arXiv:2504.03418*
May 2025: "Detecting the 21 cm Signal of the Cosmic Dark Ages" *W. Smith & J. Pober · ApJ 984, 116*
Oct 2025: "Polarisation Performance of Offset Phase Antennas: A Study for FARSIDE" *Mahesh, Bowman, Gehlot & Jacobs · Published, PASA*
Dec 2025: "Lunar topography & the 21-cm power spectrum for grid-based arrays (DEX)" *Ghosh, Koopmans et al. · MNRAS 546, 3 (2026)*
Mar 2026: "The ROLSES instrument onboard the IM-1 mission" *Burns / MacDowall group · arXiv:2603.22600*
May 2026: "A Designer's Guide to Lunar Far-Side Interferometer Arrays (Dark Ages)" *Wen et al. · arXiv:2605.29276*

GRAVITATIONAL WAVES

Mar 2025: "Massive Double White Dwarf Binary Mergers from the Moon" *Marcano, Yelijar, Jani · ApJ (in review)*
Aug 2025: "Laser Interferometer Lunar Antenna (LILA): advancing U.S. GW & lunar science" *Jani et al. · arXiv:2508.11631*
Sep 2025: "Potential for Lunar Interior Science by the GW Detector LILA" *Panning et al. · arXiv:2509.15452*
Dec 2025: "New-generation lunar GW detectors: sky-map resolution & joint analysis" *arXiv:2512.23556*
Jan 2026: "The Moon as a Gateway to Discovery (lunar GW, cross-disciplinary review)" *X. Chen · npj Space Explor. 2, 1*
Jun 2026: "The Geometry of Lunar Gravitational-Wave Detection" *Tissino et al. · arXiv:2606.04918*

UV / OPTICAL

Aug 2024: "MoonLITE: CLPS-delivered lunar optical/UV interferometer (100 m baseline; Astrophysics Pioneers)" *van Belle et al. · SPIE / arXiv:2408.01392*
Mar 2025: "Artemis-enabled Stellar Imager (AeSI): lunar long-baseline UV/optical interferometer — NIAC Phase I" *Carpenter et al. · arXiv:2503.02105*
2025: "LUSTER: lunar NUV+visible time-domain survey (exoplanet atmospheres, comets & NEAs; PRISM/SALSA)" *LUSTER team · AAS 246 / EPSC 2025 abstr.*

Progress Prior to AMMB:

NATIONAL ACADEMIES Sciences Engineering Medicine

Key Non-Polar Destinations Across the Moon to Address Decadal-level Science Objectives with Human Explorers: Panel on Heliophysics, Physics, and Physical Science

Objectives of the Panel

- Identify key science objectives within solar physics, space weather, astronomy, and fundamental physics that must be done by human explorers;
- Specify the key measurements,needed to achieve these key science objectives and why human explorers;
- Detail any pre-placed assets that would be either necessary or enabling of these key measurements;
- Prioritize potential non-polar landing sites or characteristics of landing sites that would be most enabling of these key science objectives

Committee

Maura E. Hagan

Adrienne R. Dove

Heather Elliott

Karan Jani

Justin C. Kasper

Ronald S. Polidan

Joseph Silk

Shasha Zou

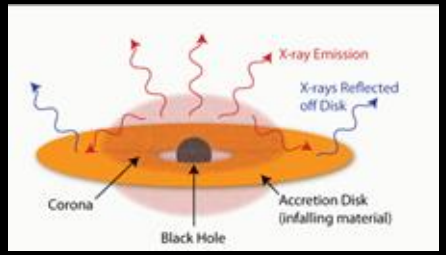
Case V: X-Rays

Bridging the tremendous science gap due to lack of high & ultra-high resolution *X-ray* observations

Kim Weaver, Jenna Cann, +

Science Investigations:

- Supermassive black holes
- Exoplanet habitability
- Astrophysical jets
- Galaxy evolution; AGN accretion and feedback



Need milliarcsec to micro-arcsec imaging!

Why the Moon?

- Can translate a milliarcsecond X-ray interferometer as a single telescope on the lunar surface (small baselines).
- permanence and serviceability.
- Micro-arcsec needs stable km-length distances or longer.
- no formation flying or advanced thruster technology needed.

Astro Decadal priorities and/or Moon to Mars objectives

MtM: LPS-4: Advance understanding of the origin of life in the solar system by identifying where and when potentially habitable environments exist(ed), what processes led to their formation, how planetary environments and habitable conditions have co-evolved over time, and whether there is evidence of past or present life in the solar system beyond Earth.

Astro2020: Priority science areas: Unveiling the Hidden drivers of galaxy growth and opening New Windows on the Dynamic Universe through the goal of Understanding black hole accretion and feedback.

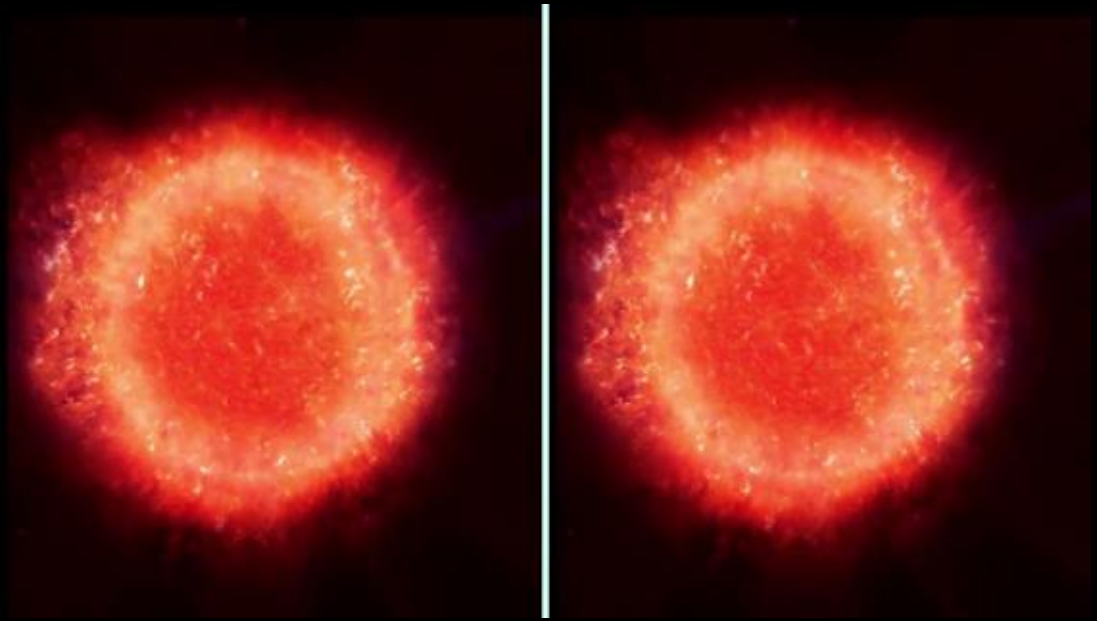
•Questions: (1) How do gas, metals, and dust flow into, through, and out of galaxies?, (2) How do supermassive black holes form?, and (3) ***How is [supermassive black hole] growth coupled to the evolution of their host galaxies?***

•Habitable Worlds objectives require: ***A high spatial and spectral resolution X-ray space observatory*** *to probe stellar activity across the entire range of stellar types, including host stars of potentially life-sustaining exoplanets.*

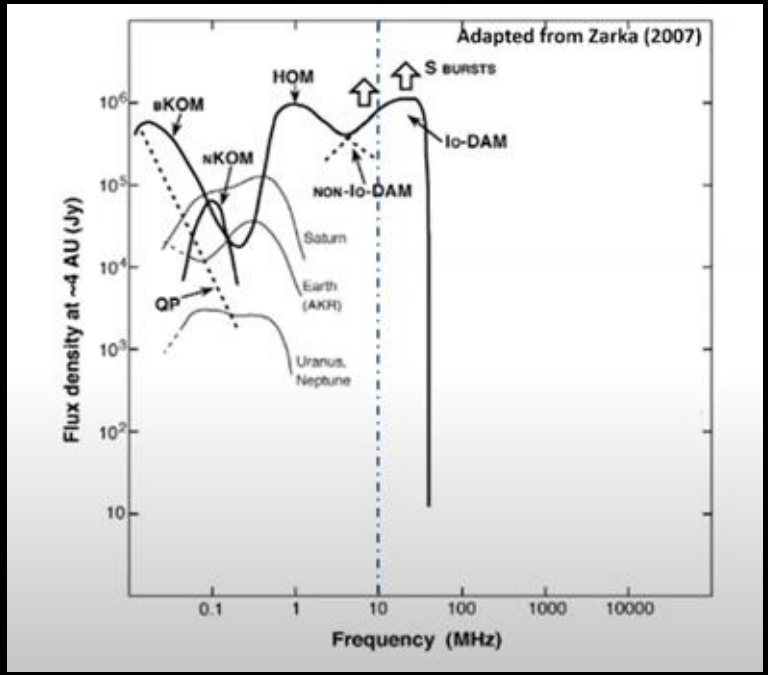
Case I: Radio Waves

Can other planets support life?

To protect the atmosphere ⇒ Need: Magnetic fields ⇒ produces Radio auroral emission



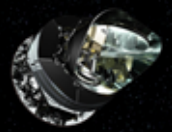
Bonus: Magnetic field estimates → shed light on the exoplanet's interior structures (PSD/ ESMD)

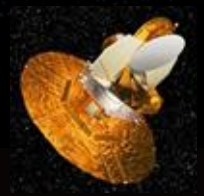


Observed radio auroral emissions <10 MHz

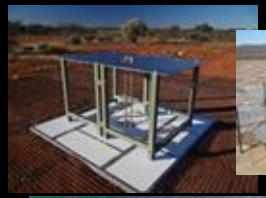
Case I: Radio Waves

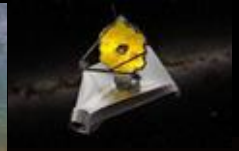
Where did we come from?

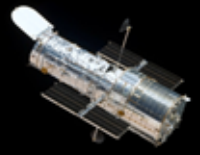




No Observations/
Planned Instruments







rs after the Big Bang

400 thousand | 0.1 billion | 1 billion | 4 billion | 8 billion | 13.8 billion

The Big Bang

Recombination

Fully ionized

Neut

Formation of first

Reionization

Fully ionized

Present day

10

1+Redshift

1

Why observe the Dark Ages?

- Ideal playground to test the ΛCDM
- Deviations ⇒ Test exotic physics (eg:non-gravitational interaction of DM)

Fit into: NRC's connecting Quarks to Cosmos
Moon to Mars objective: "Advance understanding of physical systems and fundamental physics."

Case I: Radio Waves

Opening up the low-frequency window opens up..

Science Objective (§)	Tier	Relevant PAG	Frequency
Dark Ages Cosmology: exotic physics / excess cooling, dark matter microphysics & inflationary signatures (§1.1)	Compelling	PhysPAG	10–40 MHz
Exoplanet Magnetospheres& Space Weather: stellar coronal mass ejections, exoplanet magnetic fields, habitability (§1.2)	Compelling	ExoPAG	0.1–40 MHz
Galactic Cosmic Rays: cosmic ray transport, ISM magnetic fields, baryon feedback from stars (§1.3)	Enabling	COPAG	0.1–40 MHz

- The same Farside array delivers a Milky Way / ISM science case
- *Why the farside is essential:* below ~10 MHz, free-free absorption by the warm ionized medium blocks extragalactic sources, so the low-frequency sky becomes a clean Milky Way view — enabling confident source subtraction and confusion-free imaging.
- Galactic hectometric synchrotron emission (0.3 to 3 MHz) offers the best possibility to study the physics of relativistic electrons in galaxies with Γ ~ 100 to 1000!
- Synchrotron emission from CR electrons (CRe) is a key diagnostic of ***star formation activity, magnetic fields, and the still-uncertain pl***

$$\nu_c \approx 3.3\ \mathrm{Hz} \times \gamma^2 \left(\frac{B}{1\,\mu\mathrm{G}}\right) \xrightarrow{B=3\,\mu\mathrm{G}} 0.1\ \mathrm{MHz} \left(\frac{\gamma}{100}\right)^2 .$$

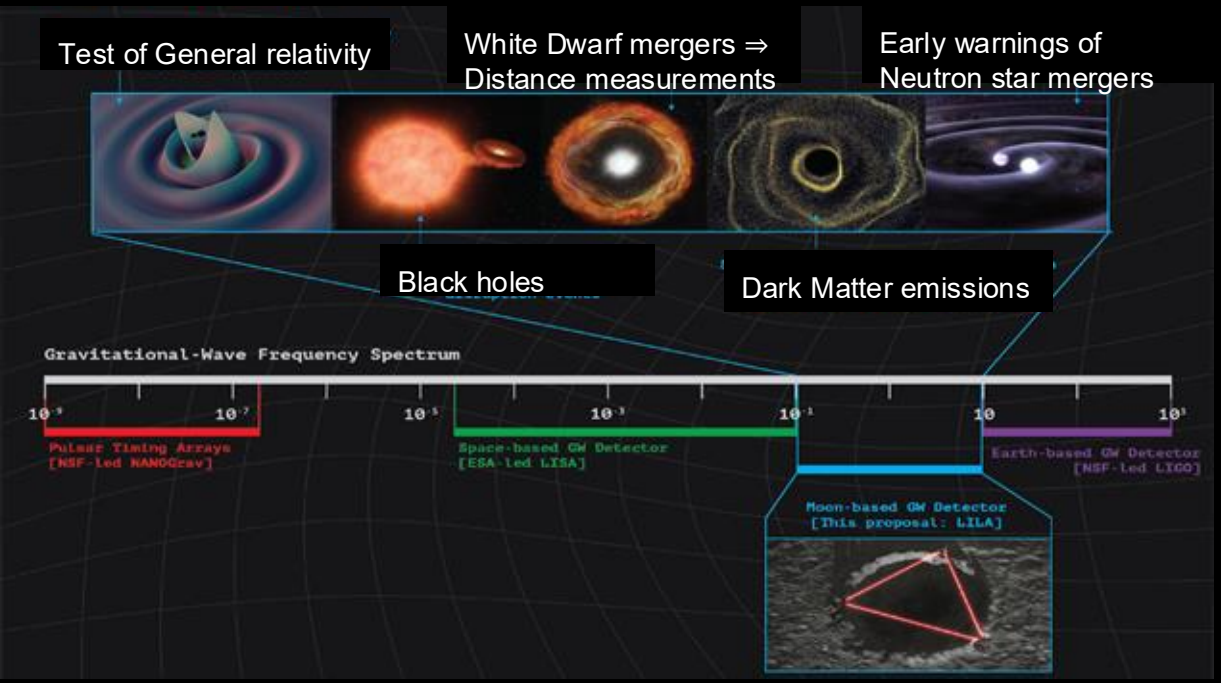
Martijn Oei, Kathryn Plant

Case I: Radio Waves

Science Objective (§)	Tier	Relevant PAG	Frequency
Dark Ages Cosmology: exotic physics / excess cooling, dark matter microphysics & inflationary signatures (§1.1)	Compelling	PhysPAG	10–40 MHz
Exoplanet Magnetospheres& Space Weather: stellar coronal mass ejections, exoplanet magnetic fields, habitability (§1.2)	Compelling	ExoPAG	0.1–40 MHz
Galactic Cosmic Rays: cosmic ray transport, ISM magnetic fields, baryon feedback from stars (§1.3)	Enabling	COPAG	0.1–40 MHz
Solar System & Heliophysics: ice-giant magnetospheres, solar wind & particle acceleration, Planet 9 (§1.4)	Bonus	Planetary (OPAG)	0.1–40 MHz
Lunar Science: ionosphere, seismic activity (§1.4)	Bonus	LEAG	0.1–30 MHz

Gravitational Waves

Filling in a critical observational gap in deci-Hz Gravitational Waves *Jani et .al. 2025 (NAS white paper)*



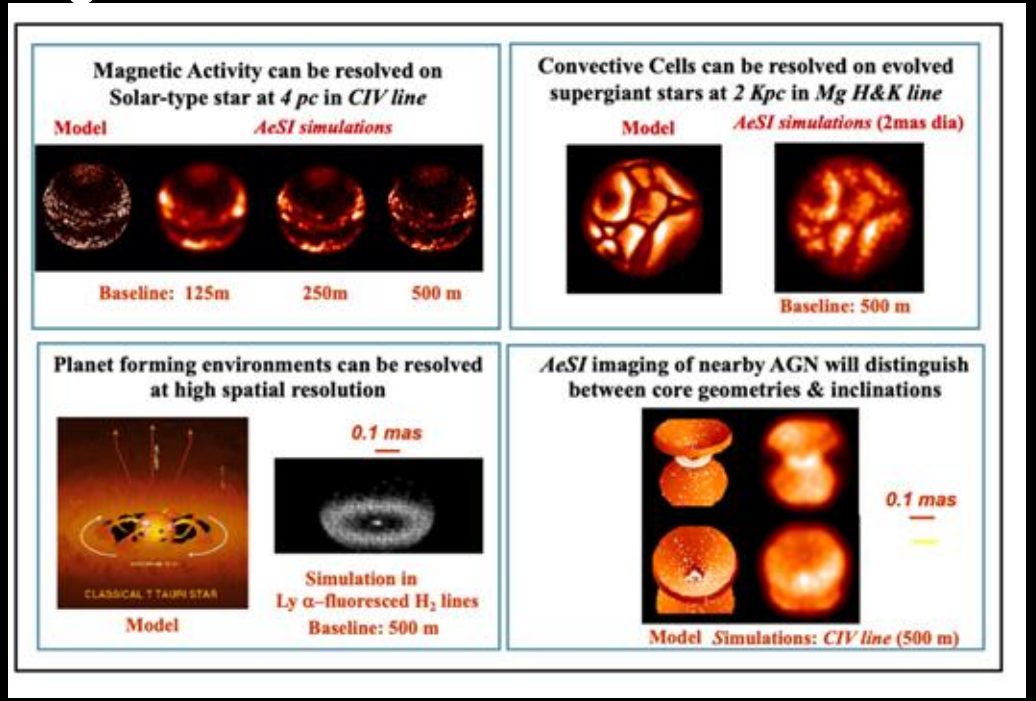
Moon to Mars objective: “Advance understanding of physical systems and fundamental physics.”

Case III: UV

Unparalleled insights with high-resolution UV observations

Study the role of magnetism in the Universe and revolutionize our understanding of:

- Solar/stellar dynamos and magnetic activity and their roles in the formation and evolution of stars and in the habitability of planets
- Mass transport processes and their roles in the formation, structure, and evolution of stars and stellar systems
- Active Galactic Nuclei (AGN), Black Hole environments, and accretion flows and jet



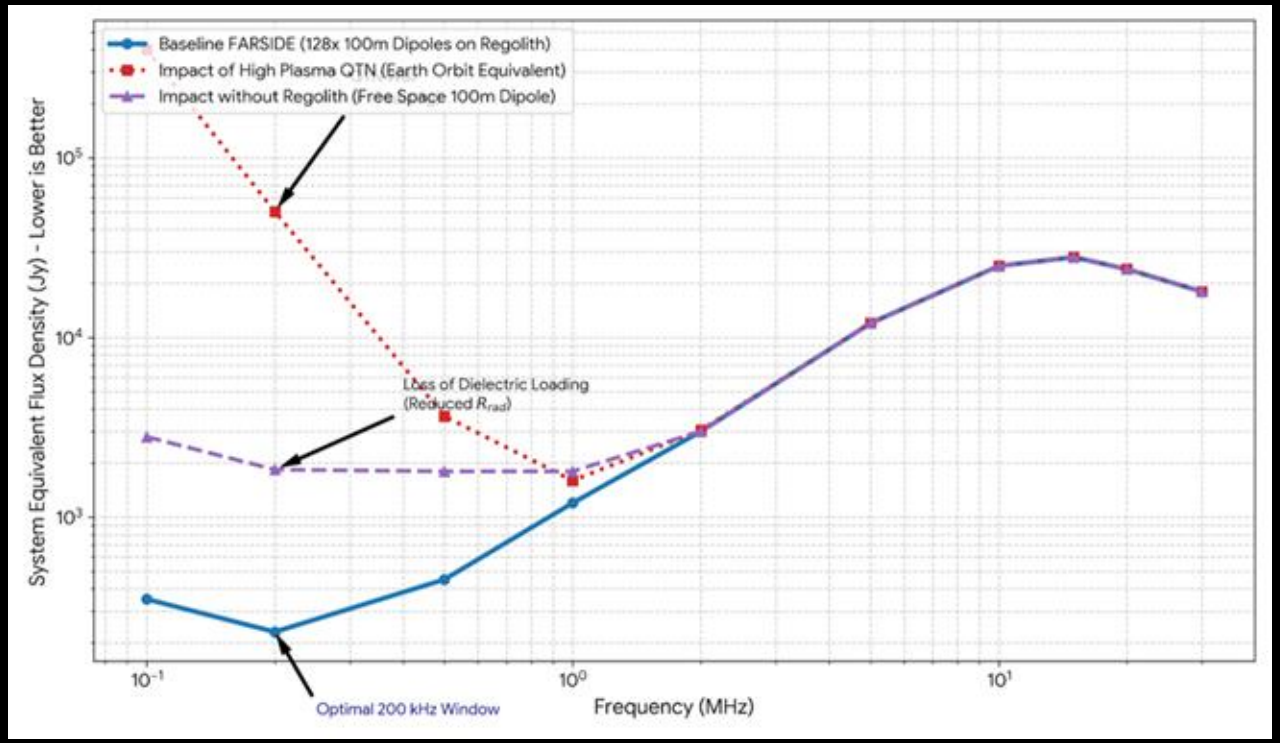
Ref: AeSI, Ken Carpenter

Focus areas & white papers to ASTRA

Band	White paper	AMMB relevance	Relevant PAGs	Corresponding authors
Radio	MegaWave Radio Surveyor	includes cis lunar orbit	PhysPAG, ExoPAG	Joseph Lazio, Evgenya Shkolnik
Radio	Ultra-Long Wavelength Lunar Farside Observatory	Lunar Farside	PhysPAG, ExoPAG CoPAG	Marin Anderson, Nivedita Mahesh
GW	LILA Observatory: A Lunar-Surface Mid-Band Gravitational-Wave Observatory	Lunar Surface	PhysPAG, CoPAG	Karan Jani
UV	Artemis enabled Stellar Imager	Lunar Surface & Artemis	CoPAG, ExoPAG	Ken Carpenter
UV	MoonLITE	Lunar Surface	ExoPAG	Gerard van Belle
UV	Lunar network of UVOIR telescopes for time domain astronomy (LUSTER-net)	Lunar surface	Cross-PAG	Tabby Boyajian
X-Ray	Lunar X-ray Telescope (LXT)	Lunar Surface	PhysPAG ExoPAG	Kimberly Weaver
Sub-mm	Submillimeter and Far-IR photonic interferometer for Lunar and Space based astronomy	PSRs	PhysPAG ExoPAG	Anish Damodaran
CR	Lunar Cosmic Ray Observatory (LCRO)	Lunar Surface	PhysPAG	Eun-Suk Seo
Gamma-Ray	The Time-domain All-sky Nuclear Gamma-ray Observatory (TANGO) for Cis-lunar nuclear astrophysics	Cis-lunar		Richard Miller

Case I: Radio Waves

Why Moon and the Farside



Sensing elements: Dipoles

- Isolation from Quasi-thermal Noise (QTN)
- Placing the antenna directly on the lunar regolith also greatly improves sensitivity

Progress prior to AMMB: Talks, conferences & workshops

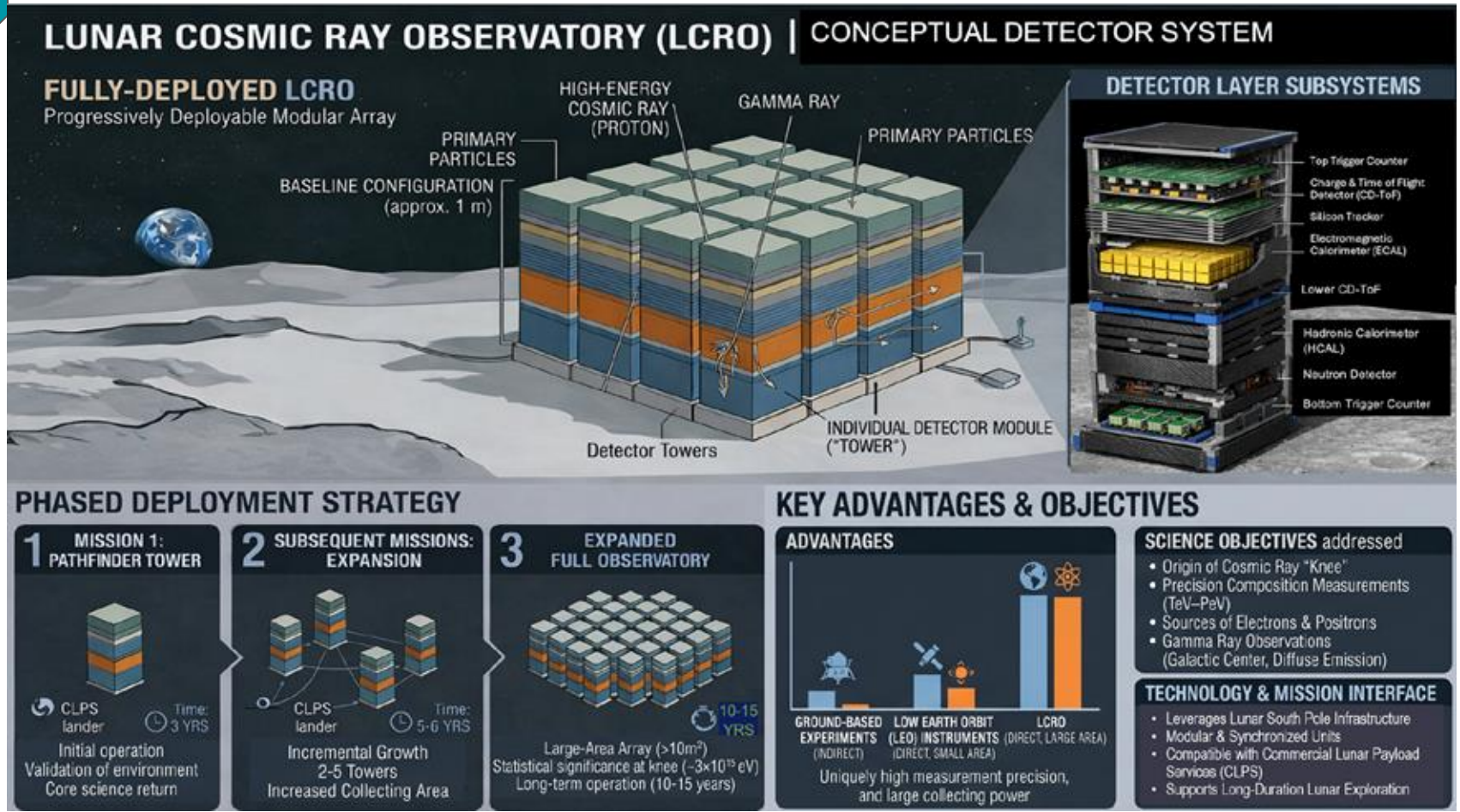
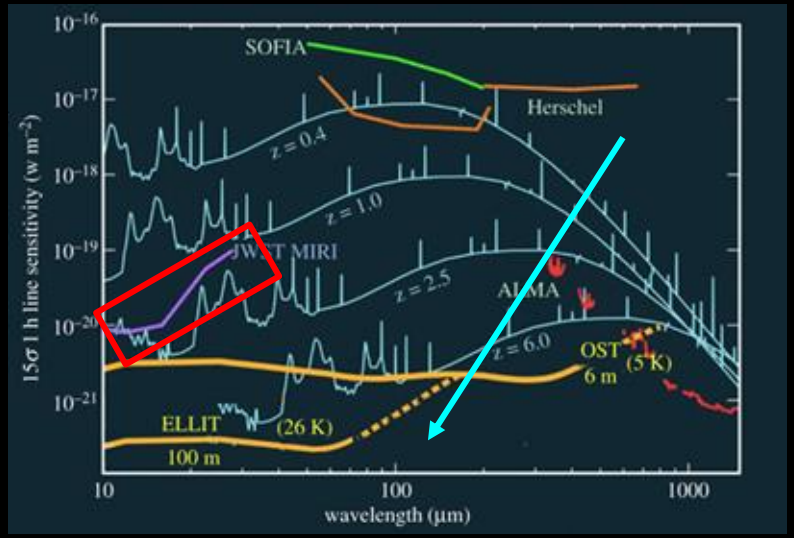
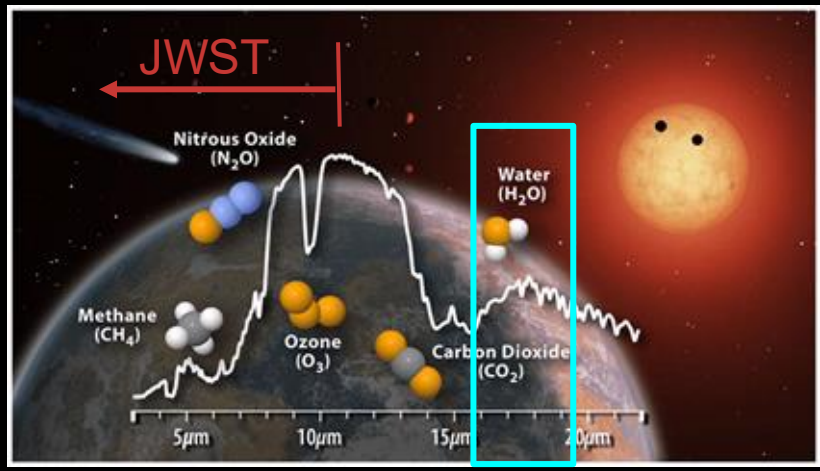
This past academic year

- **AAS 246** — Anchorage, AK · 8–12 Jun 2025
  Summer AAS — lunar & multi-messenger contributions
- **NASA Exploration Science Forum (NESF)** — Albuquerque, NM · 22–24 Jul 2025
  SSERVI — the Moon as a science platform
- **deci-Hz GW Observations on the Moon & Beyond** — JHU · 1–3 Sep 2025
  Deci-Hz detectors & sources; LGWA / LILA / LISA / atom interfer.
- **VIII Global 21-cm Workshop** — Caltech, Pasadena · 22–25 Sep 2025
  Global 21-cm (Dark Ages/Cosmic Dawn/EoR); ground + lunar farside
- **LEAG Annual Meeting** — JHU/APL, MD · 28–30 Oct 2025
  Lunar Exploration Analysis Group — astrophysics from the Moon
- **AAS 247** — Phoenix, AZ · 4–8 Jan 2026
  Special Session "The Moon and Beyond, Now"; Joint-PAG session
- **Lunar GW Workshop (Intl. LILA Meeting)** — JHU/APL, MD · 13–14 Nov 2025
  5th annual lunar-GW workshop; LILA science, instrument & consortium
- **AAS 248** — Pasadena, CA · 14–18 Jun 2026
  Summer AAS — lunar / AMMB contributions

Upcoming

- **SPIE Astronomical Telescopes + Instrum.** — Copenhagen · 5–10 Jul 2026
  "Radio Telescopes, Technologies & Methods" — farside, LuSEE, interferometry
- **NASA Exploration Science Forum 2026** — NASA Ames, CA · 21–23 Jul 2026
  SSERVI annual lunar science forum

Case VI:
γ-Rays



Profound Astrophysics questions answered