Radio Astronomy on and around the Moon

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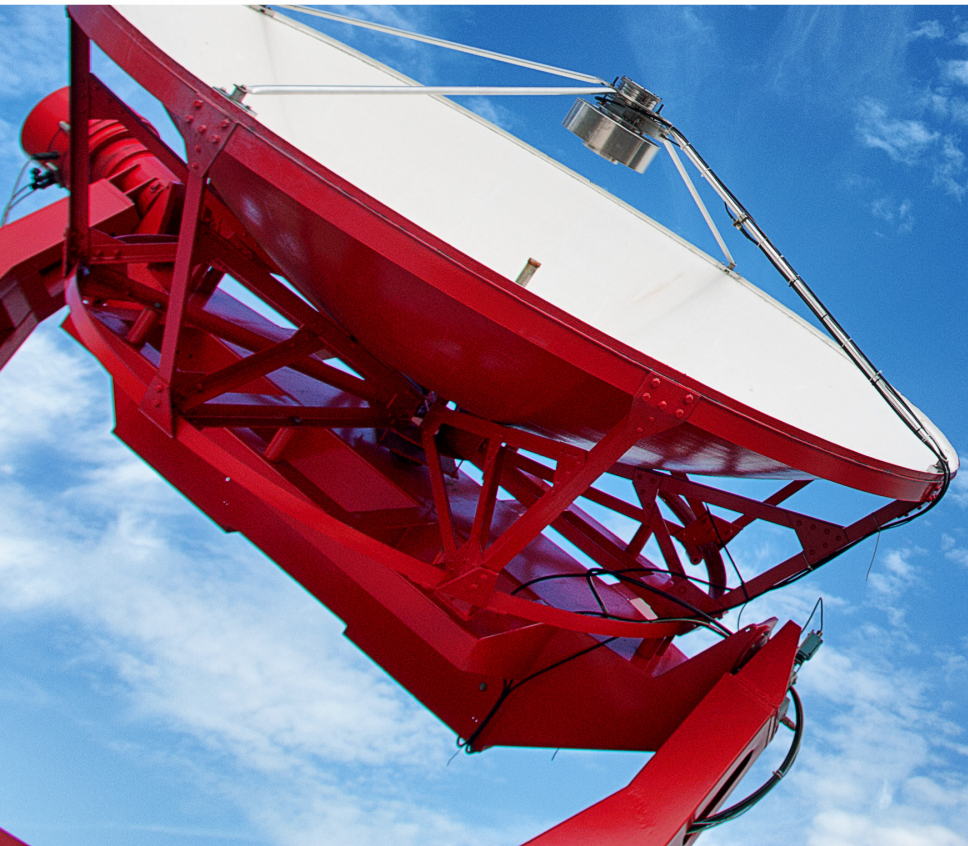
ChangE 4 NCLE PI



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Astronomy across the electromagnetic spectrum

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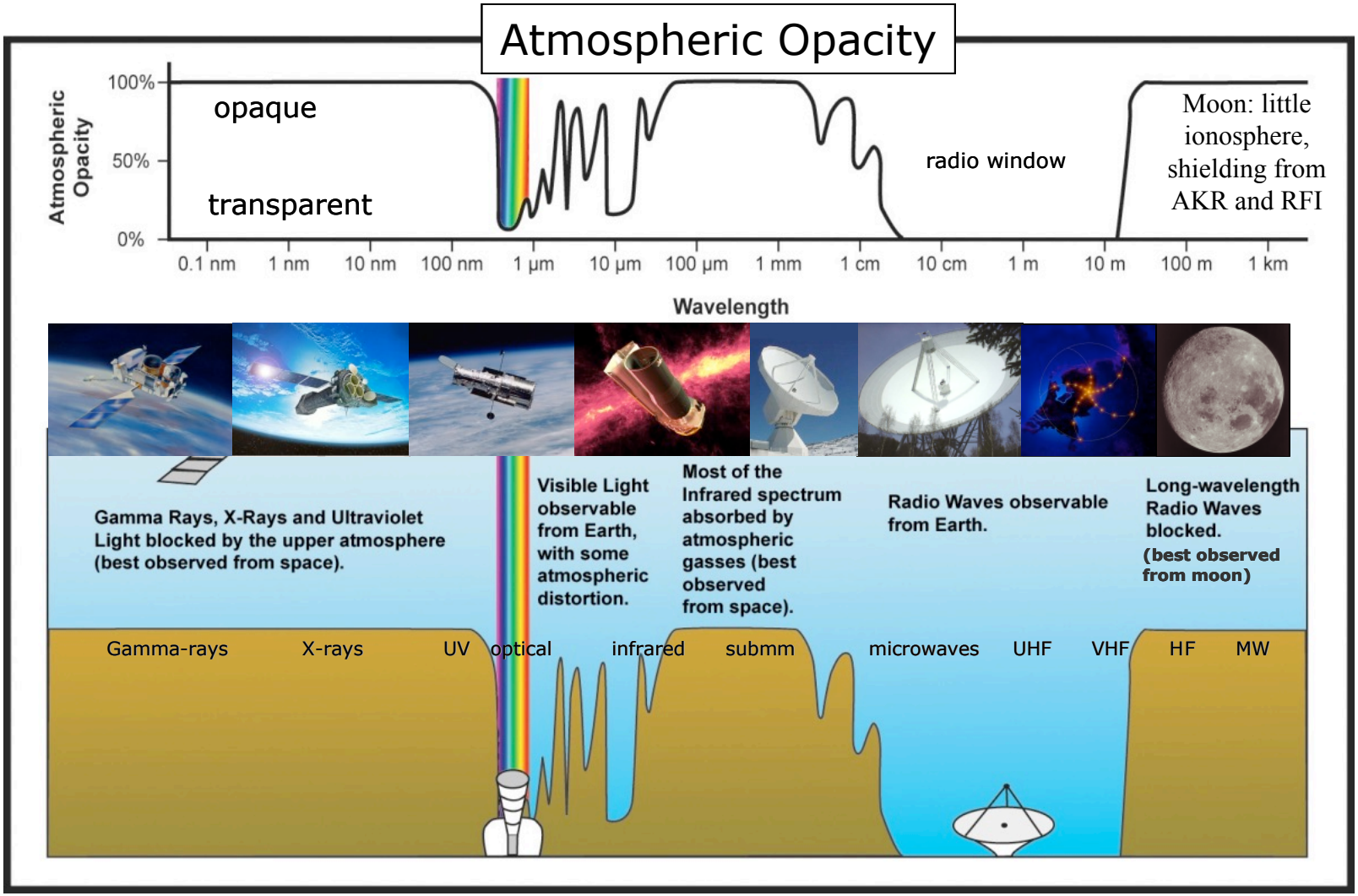


Shielding of Terrestrial Radio Emission

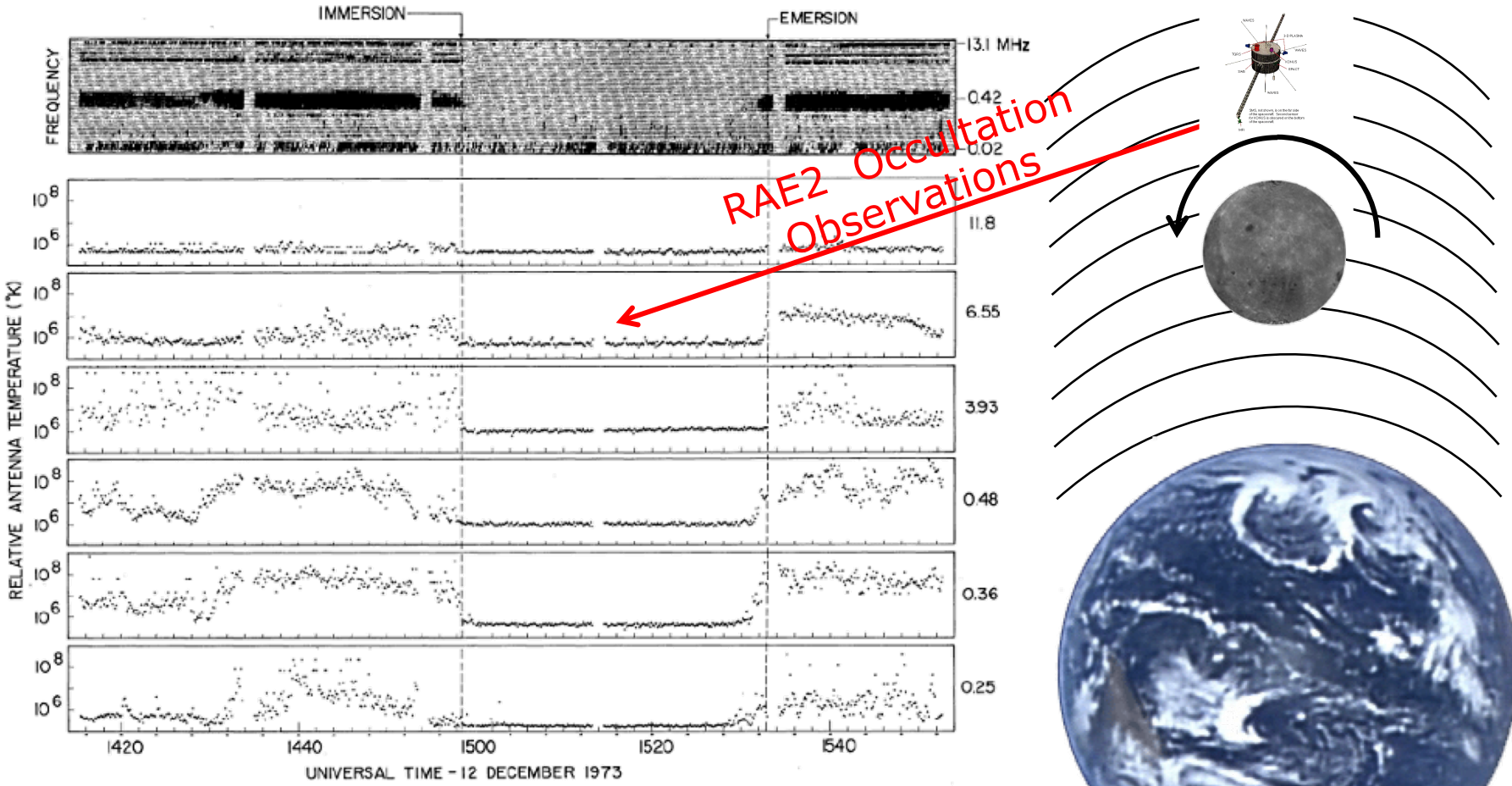


Fig. 5. Example of a lunar occultation of the Earth as observed with the upper-V burst receiver. The top frame is a computer-generated dynamic spectrum; the other plots display intensity vs. time variations at frequencies where terrestrial noise levels are often observed. The 80-s data gaps which occur every 20 m are at times when in-flight calibrations occur. The short noise pulses observed every 144 s at the highest frequencies during the occultation period are due to weak interference from the Ryle-Vonberg receiver local oscillator on occasions when both that receiver and the burst receiver are tuned to the same frequency

G. Woan et al. from ESA study SCI(97)2

Lunar Far Side is radio-protected zone for astronomy!

- The back side of the moon is declared as a radio protected site within the ITU Radio Regulations
  - The IT Radio Regulations are an international treaty within the UN.
  - Details are specified in a published ITU Recommendation (this is a non-mandatory recommendation, but is typically adhered to).

⇒ Radio astronomy on the moon has been a long-standing goal, protected by international treaties!

⇒ Steps need to be taken to protect the pristine and clean nature of the moon.

⇒ Lunar communication on the far side needs to be radio quiet.

ARTICLE 22
(ITU Radio Regulations)
Space services
Section V – Radio astronomy in the shielded zone of the Moon

22.22 § 8 1) In the shielded zone of the Moon[31] emissions causing harmful interference to radio astronomy observations[32] and to other users of passive services shall be prohibited in the entire frequency spectrum except in the following bands:

22.23 *a)* the frequency bands allocated to the space research service using active sensors;

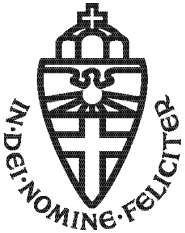
22.24 *b)* the frequency bands allocated to the space operation service, the Earth exploration-satellite service using active sensors, and the radiolocation service using stations on spaceborne platforms, which are required for the support of space research, as well as for radiocommunications and space research transmissions within the lunar shielded zone.

22.25 2) In frequency bands in which emissions are not prohibited by Nos. **22.22** to **22.24**, radio astronomy observations and passive space research in the shielded zone of the Moon may be protected from harmful interference by agreement between administrations concerned.

22.22.1 The shielded zone of the Moon comprises the area of the Moon's surface and an adjacent volume of space which are shielded from emissions originating within a distance of 100 000 km from the centre of the Earth.

22.22.2 The level of harmful interference is determined by agreement between the administrations concerned, with the guidance of the relevant ITU-R Recommendations.

Moon Advantages/Disadvantages



Pros:

- No atmosphere
- Shielding against earth and sun (e.g. radio interference)
- Big stable platform for large instruments (interferometers)
- Ground based - no satellite needed to build around it
- Synergy with human and robotic exploration space program
  - Big launchers
  - Assembly of very large structures
  - Maintenance & infrastructure

Cons:

- Free-flyers well advanced in astronomy
- Science community very skeptical about moon
- dust, moonquakes, tiny exosphere (all overrated …)
- The moon always blocks half the sky
- Power supply during lunar night (14 days)
- Extra overhead for soft landing

Dark Ages & Cosmic Dawn Detection?

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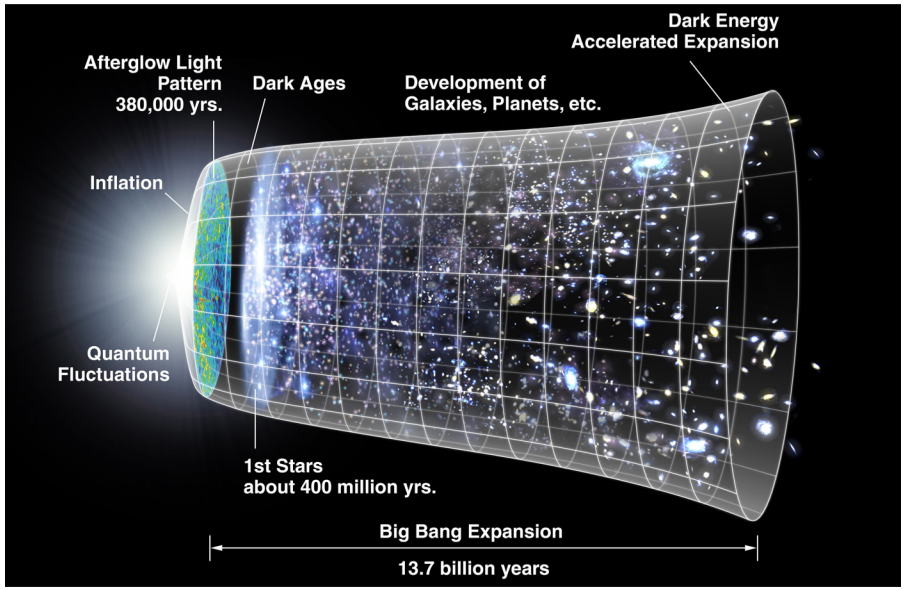
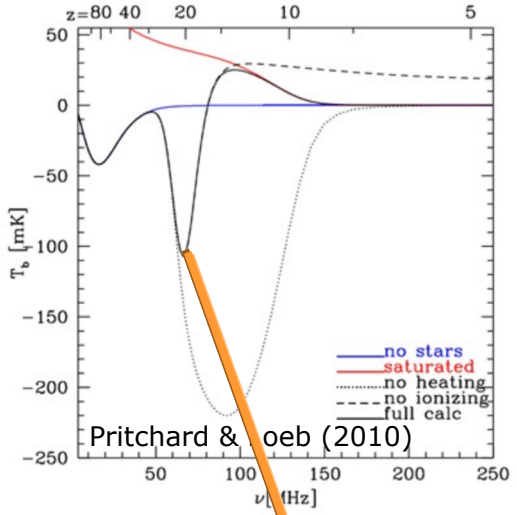
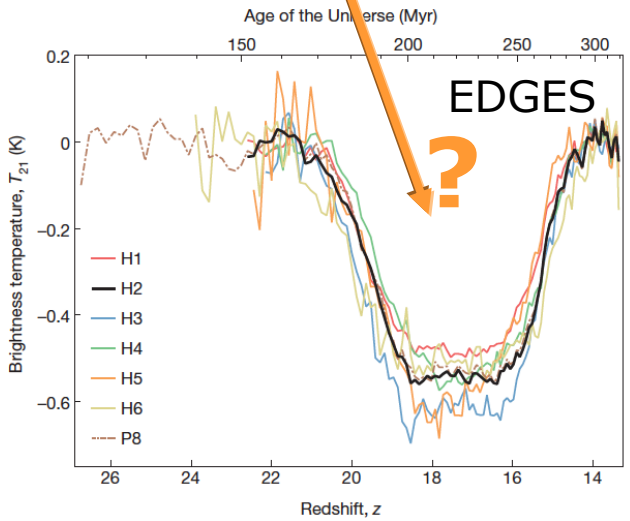




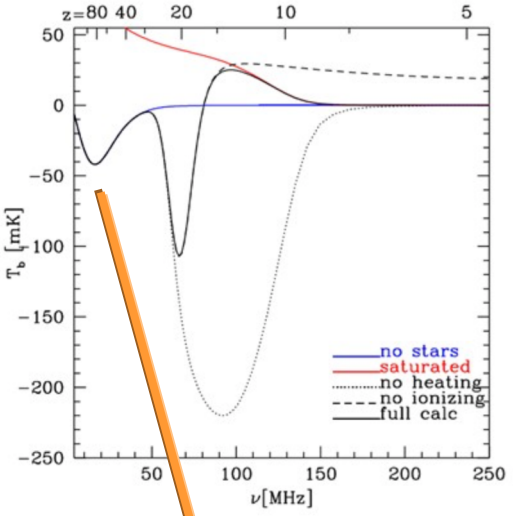
Pritchard & Loeb (2010)



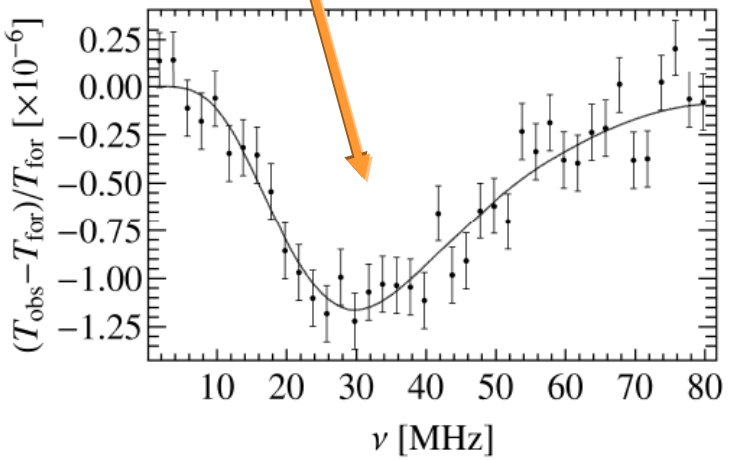
Bowman et al. (2018, Nature)

Global Dark Ages Signal

- HI global dark ages signal could be seen with one antenna.
- Integration time < 1 year at 37 MHz (i.e. z=37).
- Huge problem is the unknown foreground contamination and spectral „roughness“
- Signal is only 10^{-6} of foreground!

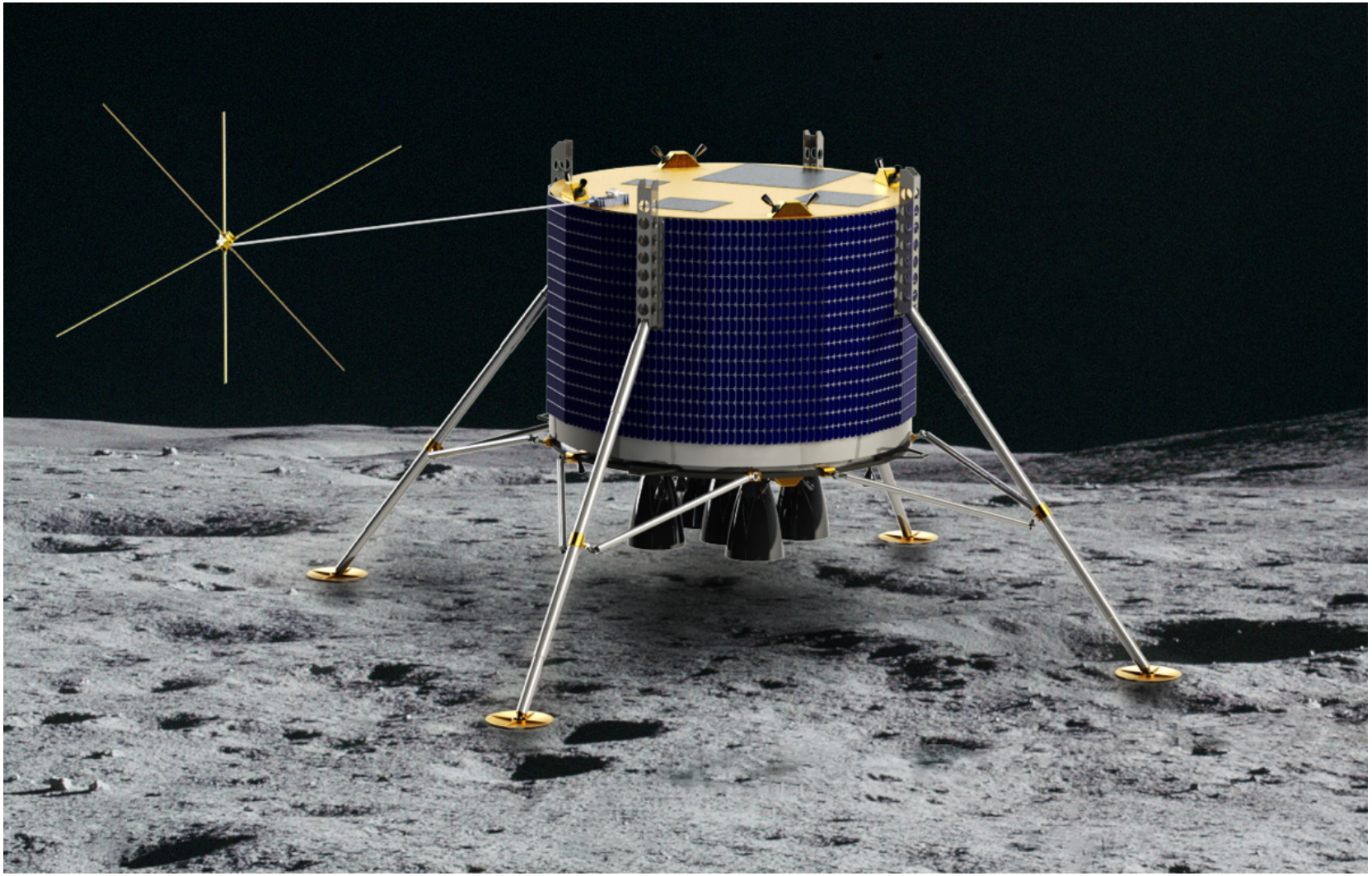


1 year integration, 1 dipole



Jester & Falcke (2008, New Astronomy Rev.)

LRX – Lunar Radio Explorer (ESA Lunar Lander)



South Pole – peak of (almost) eternal light

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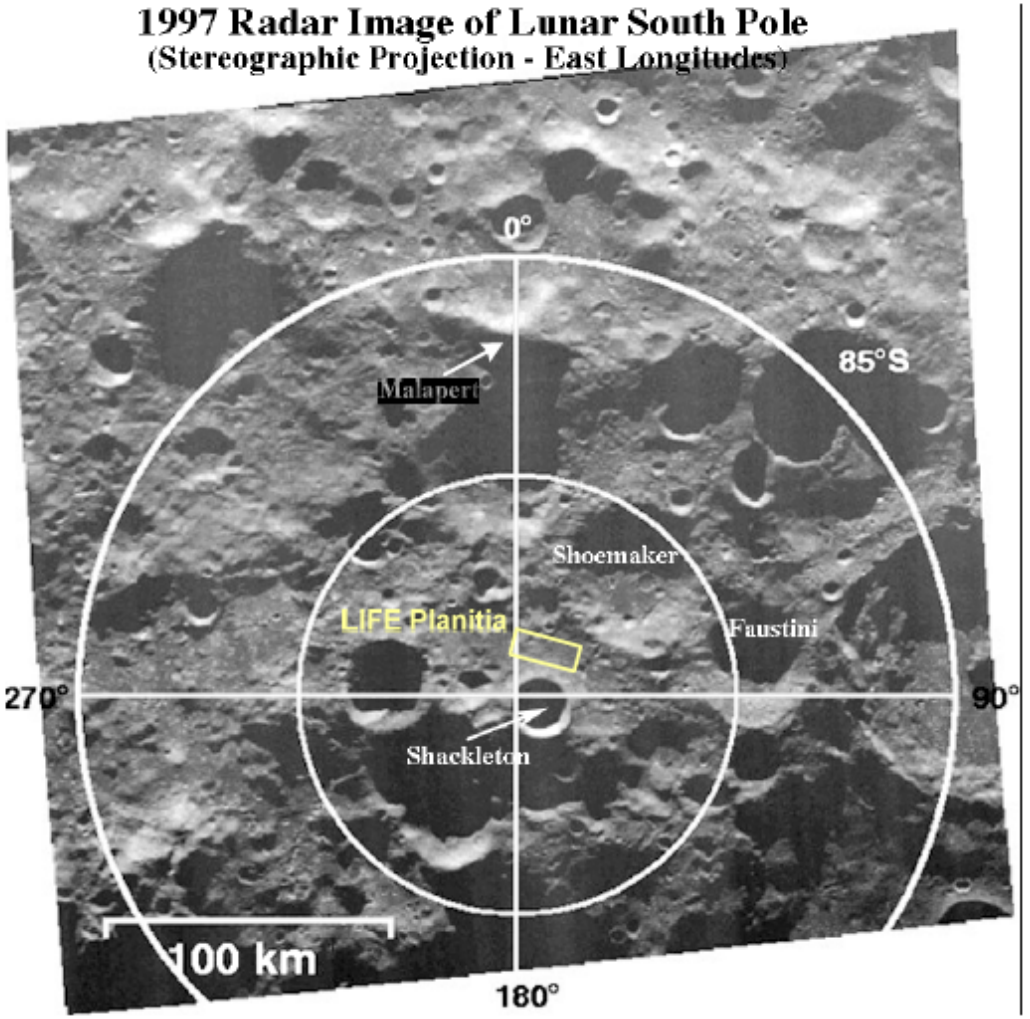
- **Shackleton Crater**
- **Malapert Mountain**
- **LIFE Planitia** *

*"LIFE" = Lunar Infrastructure for Exploration (EADS study)



ESA Lunar Lander canceled …

DSL – "cubesat train" Interferometer around moon

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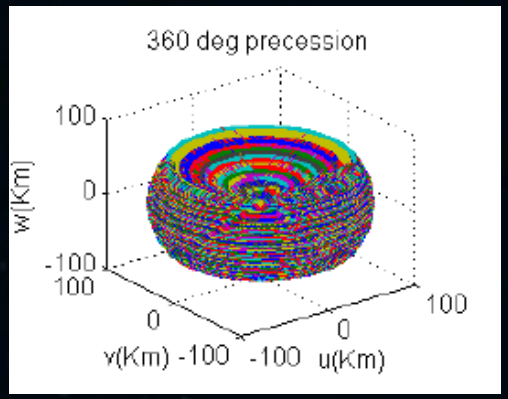
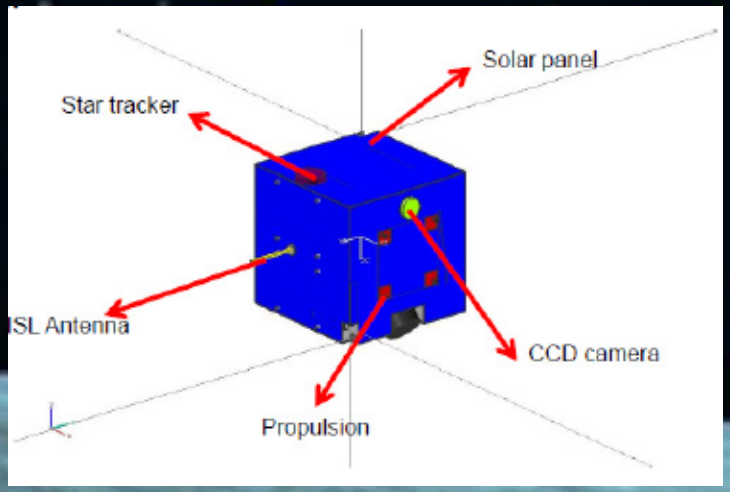
Fill 3D UVW-plane by precessing orbit at 300 km

Pass thru moon shadow

Relative attitude/range optically





China/NL proposal

"LUNAR LOFAR" Movie

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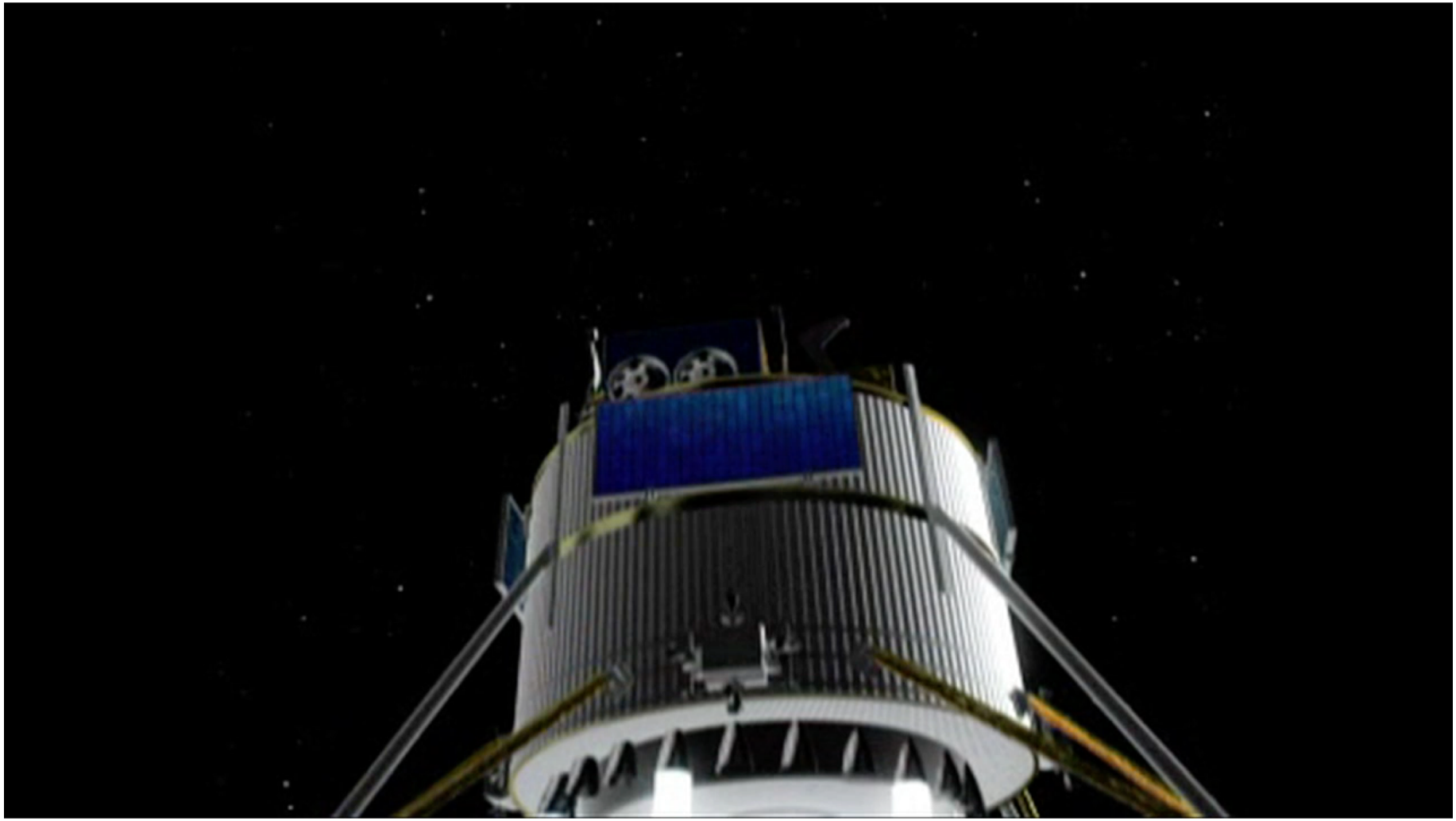
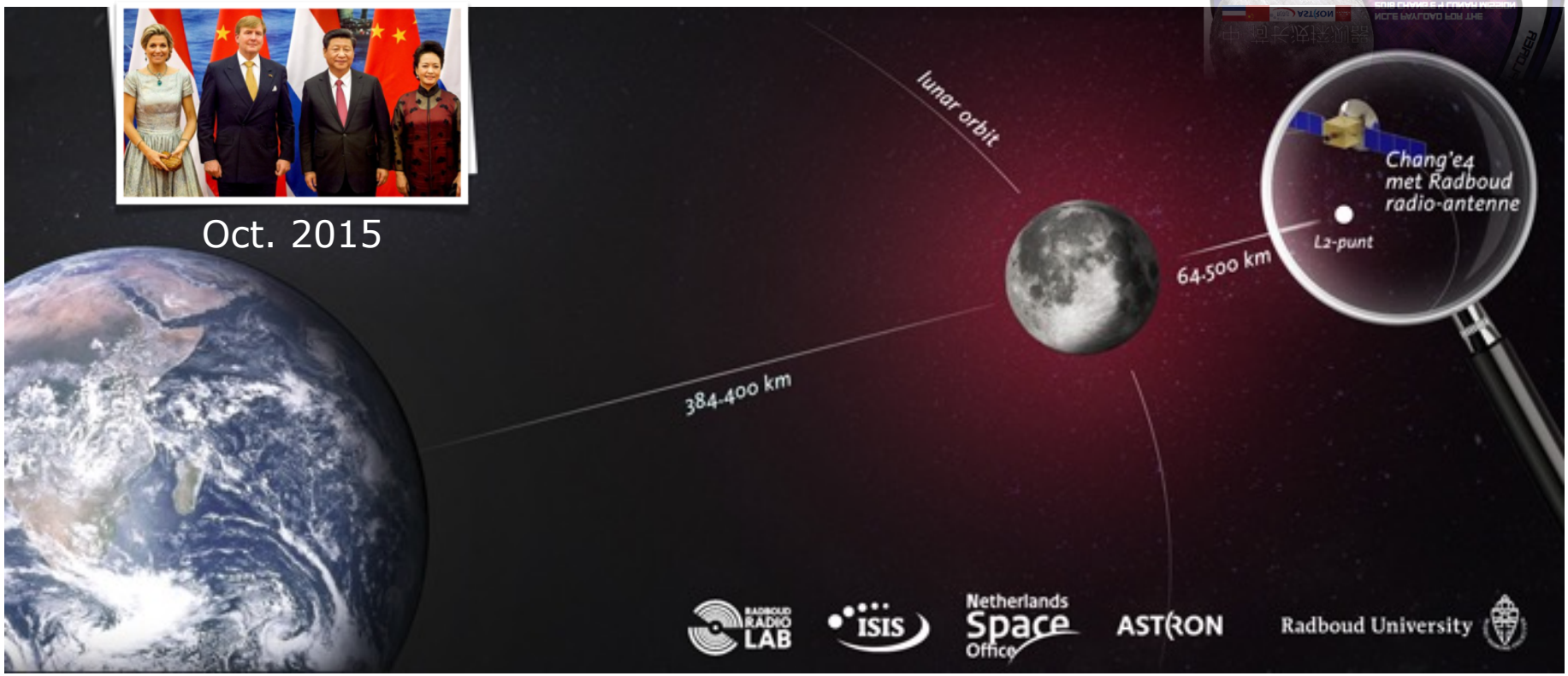


ASTRON/EADS Astrium (Bremen)

NCLE – NL/China Low-Frequency Explorer

Onboard Chang'E4 Queqiao relay satellite at Earth-Moon L2
(first part of Chinese lunar far-side lander mission)



NCLE – Low-Frequency Explorer

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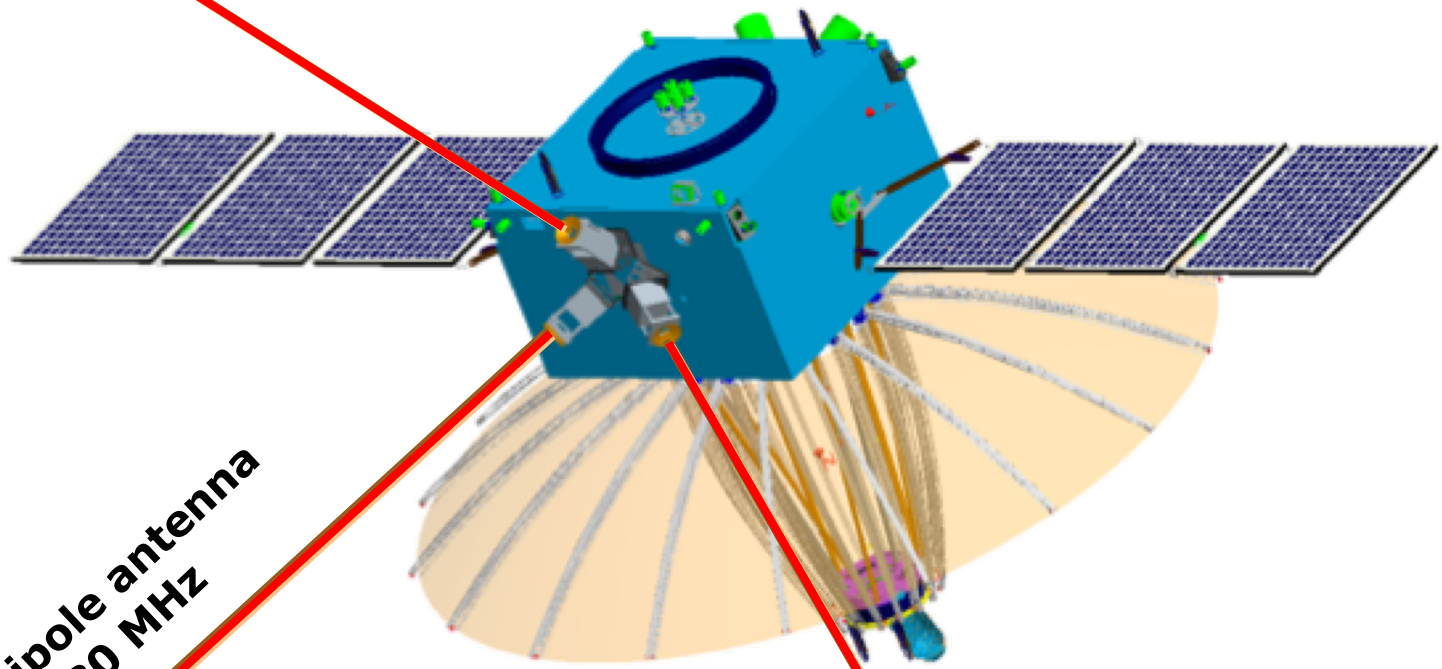
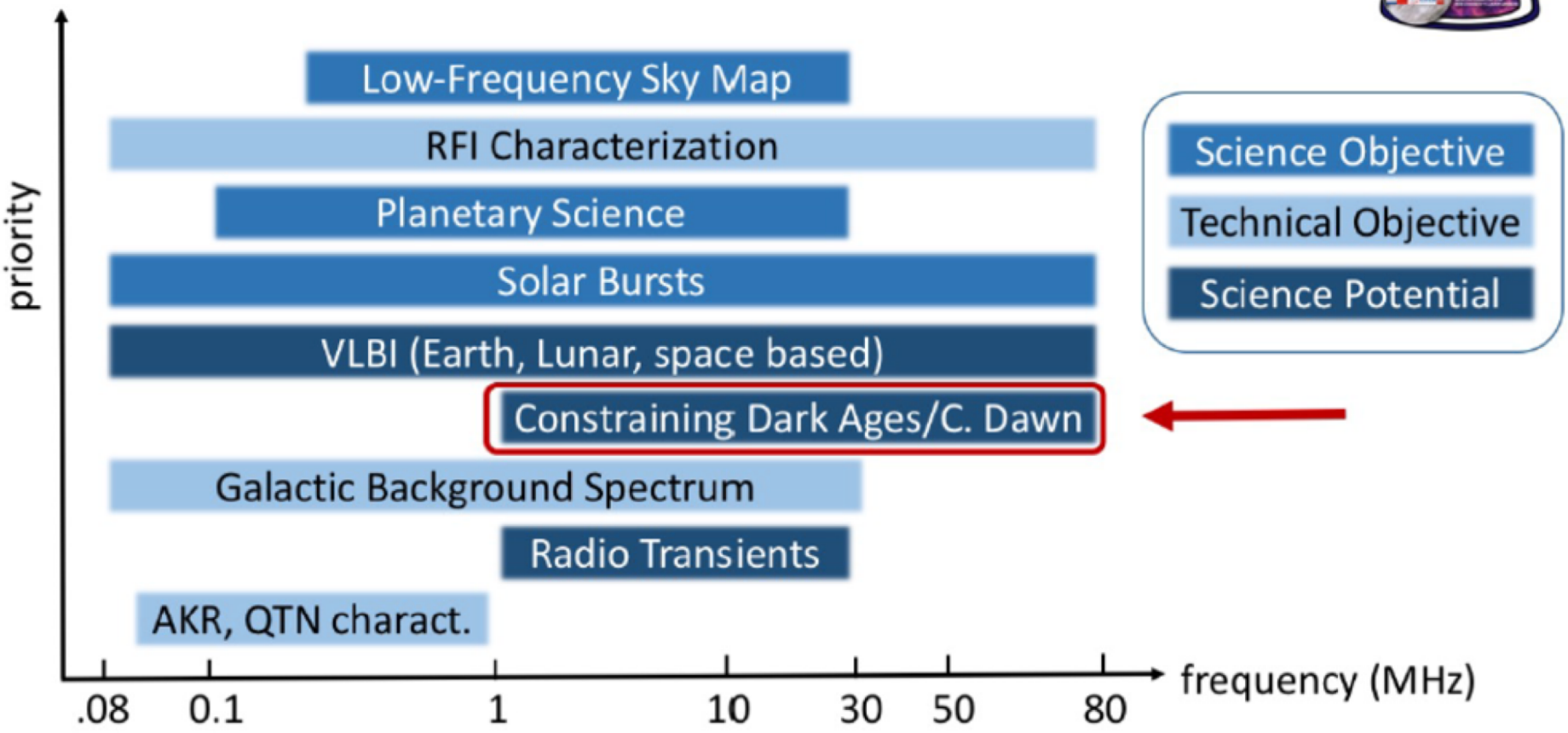


5m Tripole antenna
80kHz-80 MHz

NCLE Science Objectives



NCLE Sensitivity (3 bands)

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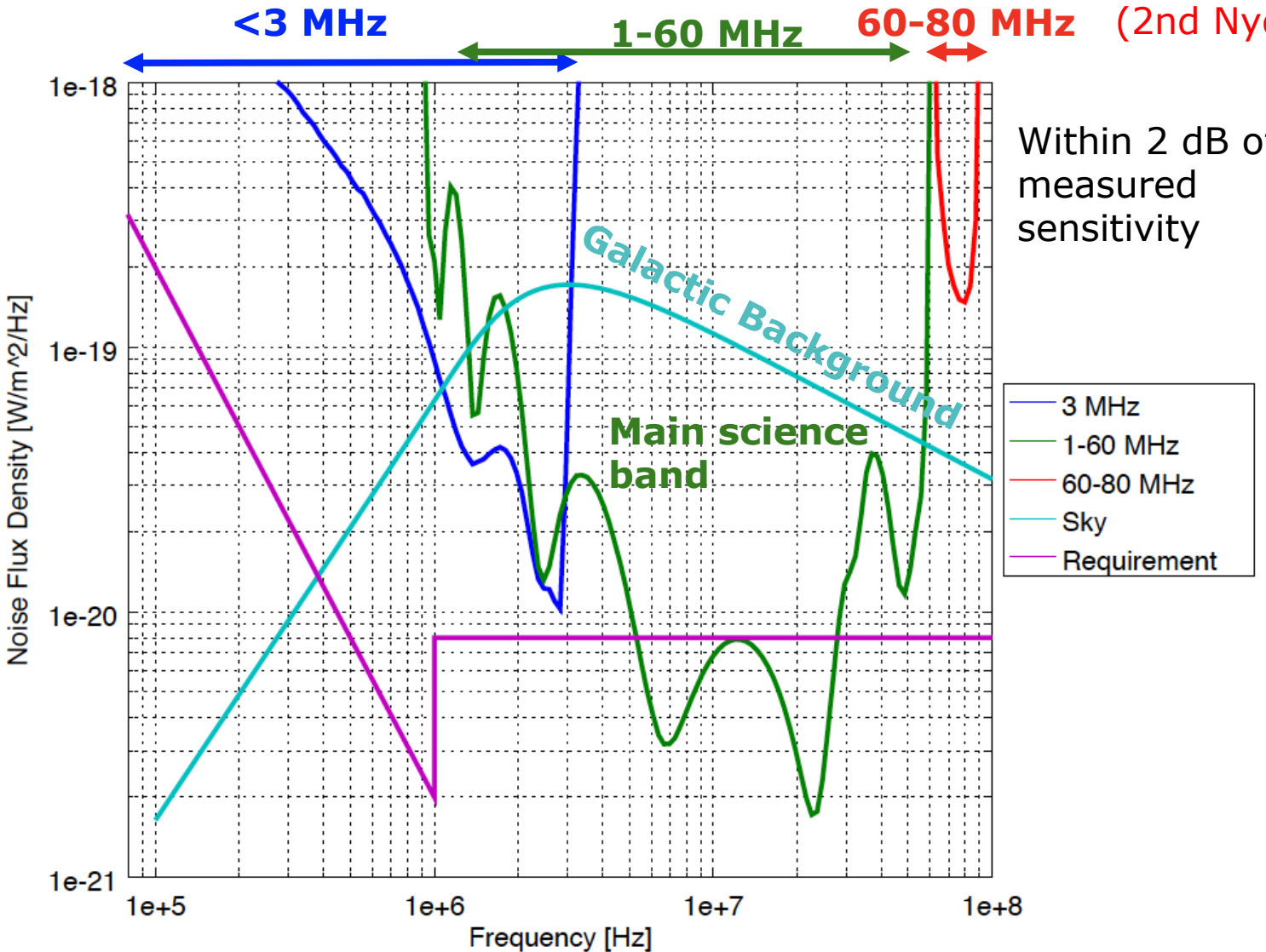
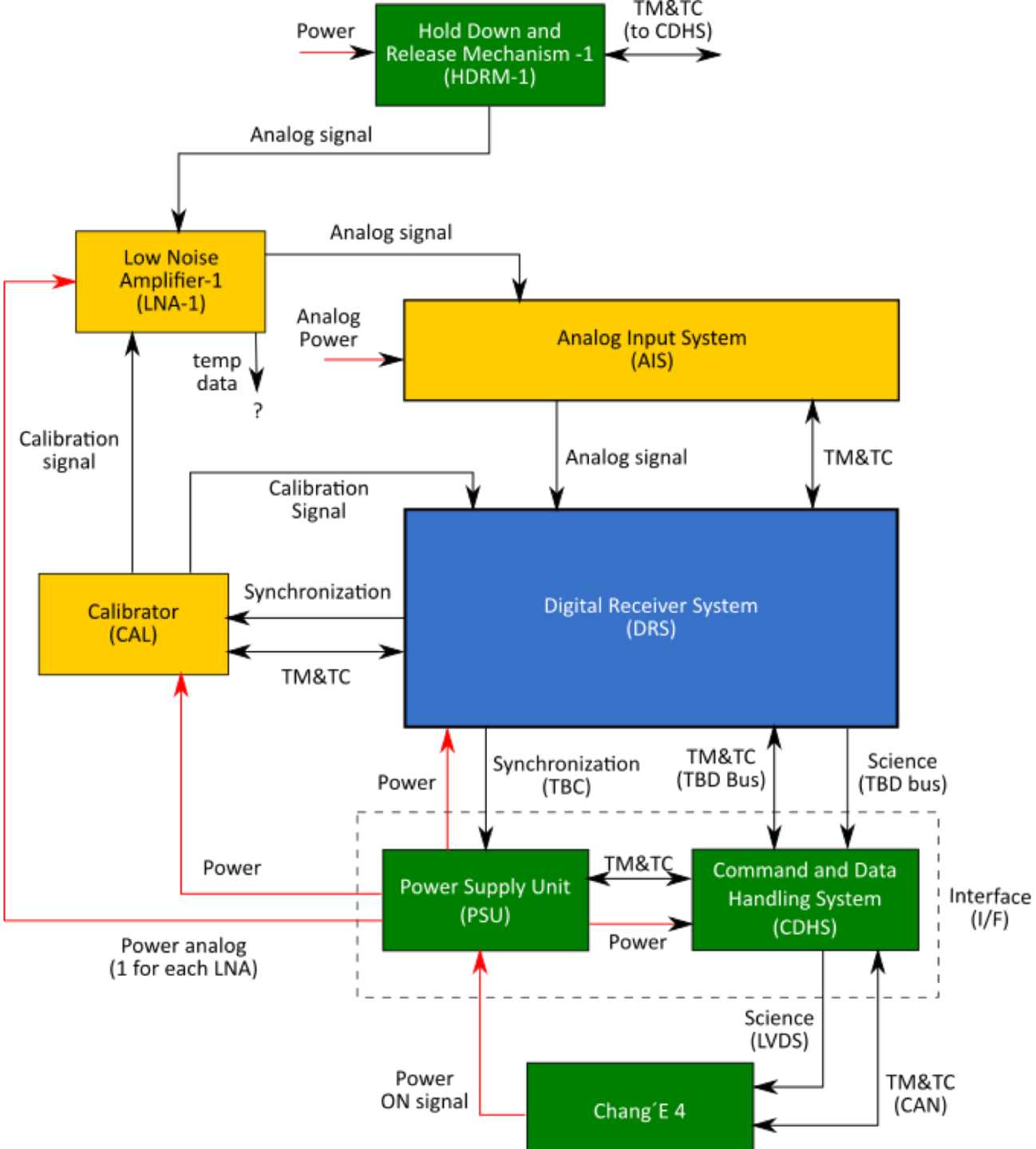


Within 2 dB of measured sensitivity


Power
Hold Down and Release Mechanism -1 (HDRM-1)
TM&TC (to CDHS)
Analog signal
Low Noise Amplifier-1 (LNA-1)
Analog signal
Analog Power
Analog Input System (AIS)
temp data
?
Calibration signal
Analog signal
TM&TC
Calibration Signal
Calibrator (CAL)
Synchronization
TM&TC
Digital Receiver System (DRS)
Power
Synchronization (TBC)
TM&TC (TBD Bus)
Science (TBD bus)
Power
Power Supply Unit (PSU)
TM&TC
Command and Data Handling System (CDHS)
Interface (I/F)
Power
Power analog (1 for each LNA)
Science (LVDS)
Power ON signal
Chang´E 4
TM&TC (CAN)

NCLE components

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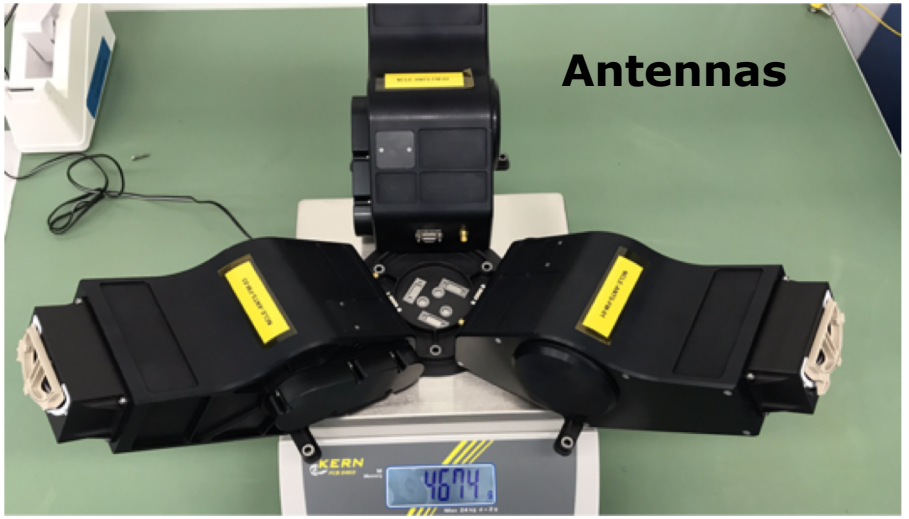
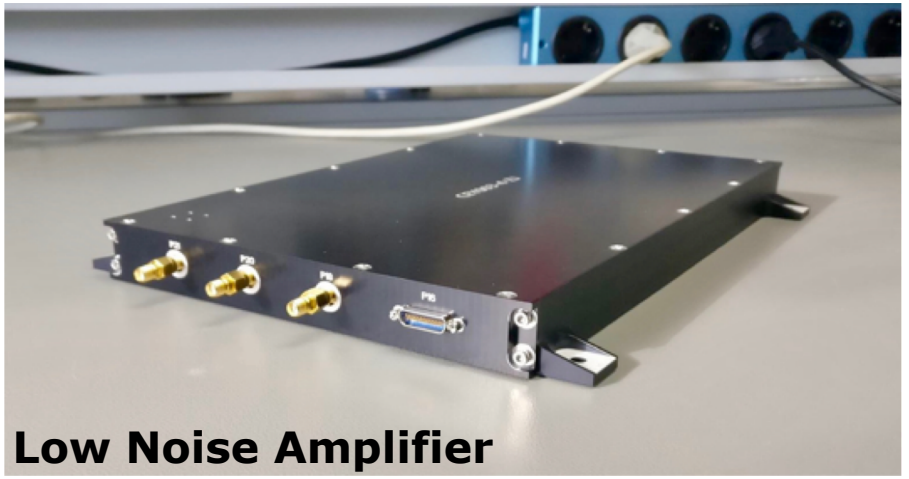
- **Three Monopoles**, 5m each
- **3 bands**: <3 MHz, 1-60 MHz, 60-80 MHz
- **16k chan**, 7.5-0.9kHz, 100 ms dump time
- **Sky noise limited** for 2-50 MHz
- **Full polarization**: XX, YY, ZZ, XY,XZ,YZ
- **14 bit ADC**: 4x, 120 MHz
- on-board memory: **250 GB**
- Downlink: < **10Mbps**
- Power: < **25W**
- Mass: < **10Kg**
- mission life time: **3 years**
- Antenna deployment: **March 2019**





Ground Testing

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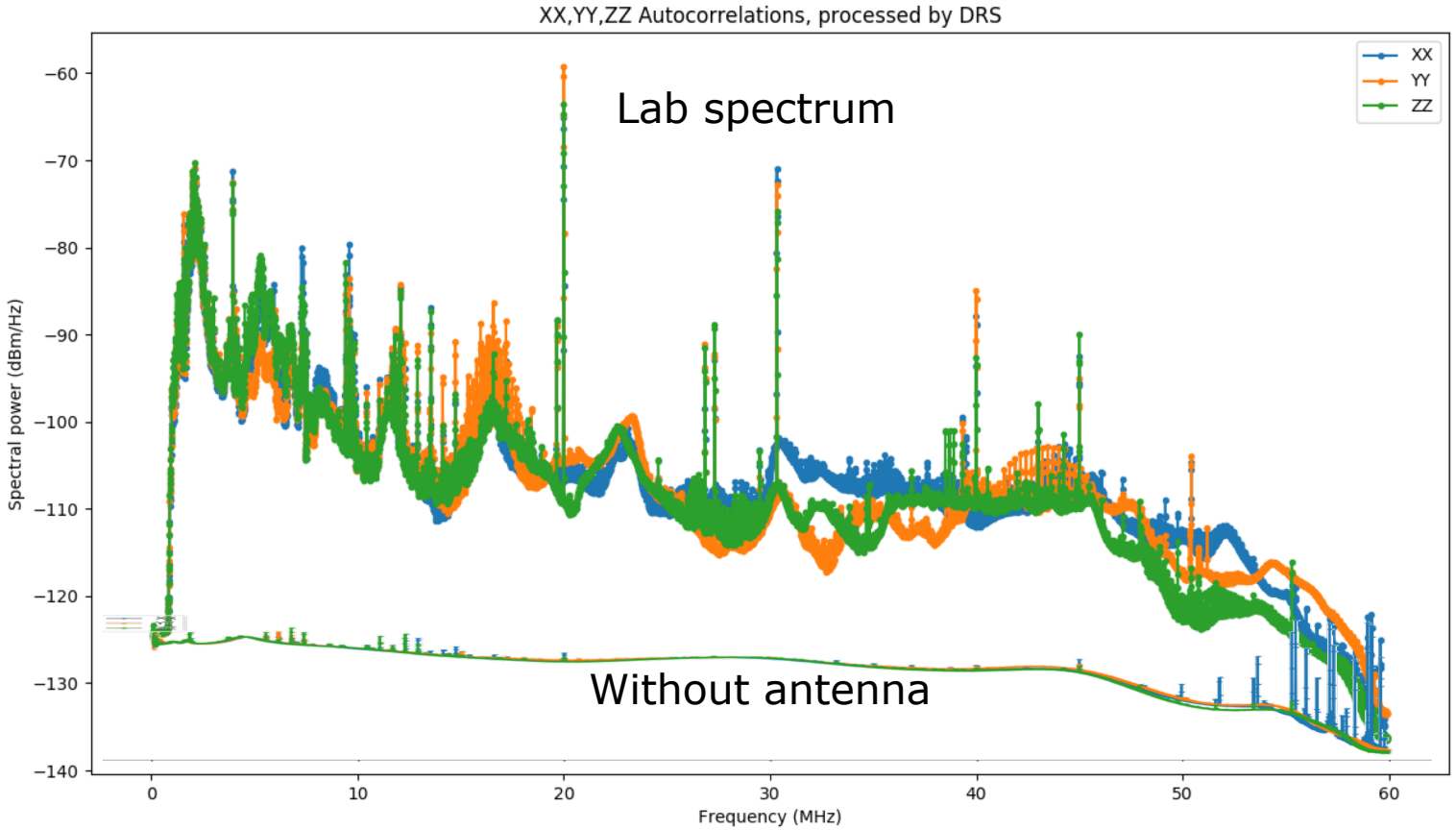

NCLE QM Deployment Test

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Queqiao/NCLE Launch

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Queqiao

Long March 4C

Queqiao/NCLE Launch

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Queqiao

Long March 4C

NCLE Launch May 20, 2018

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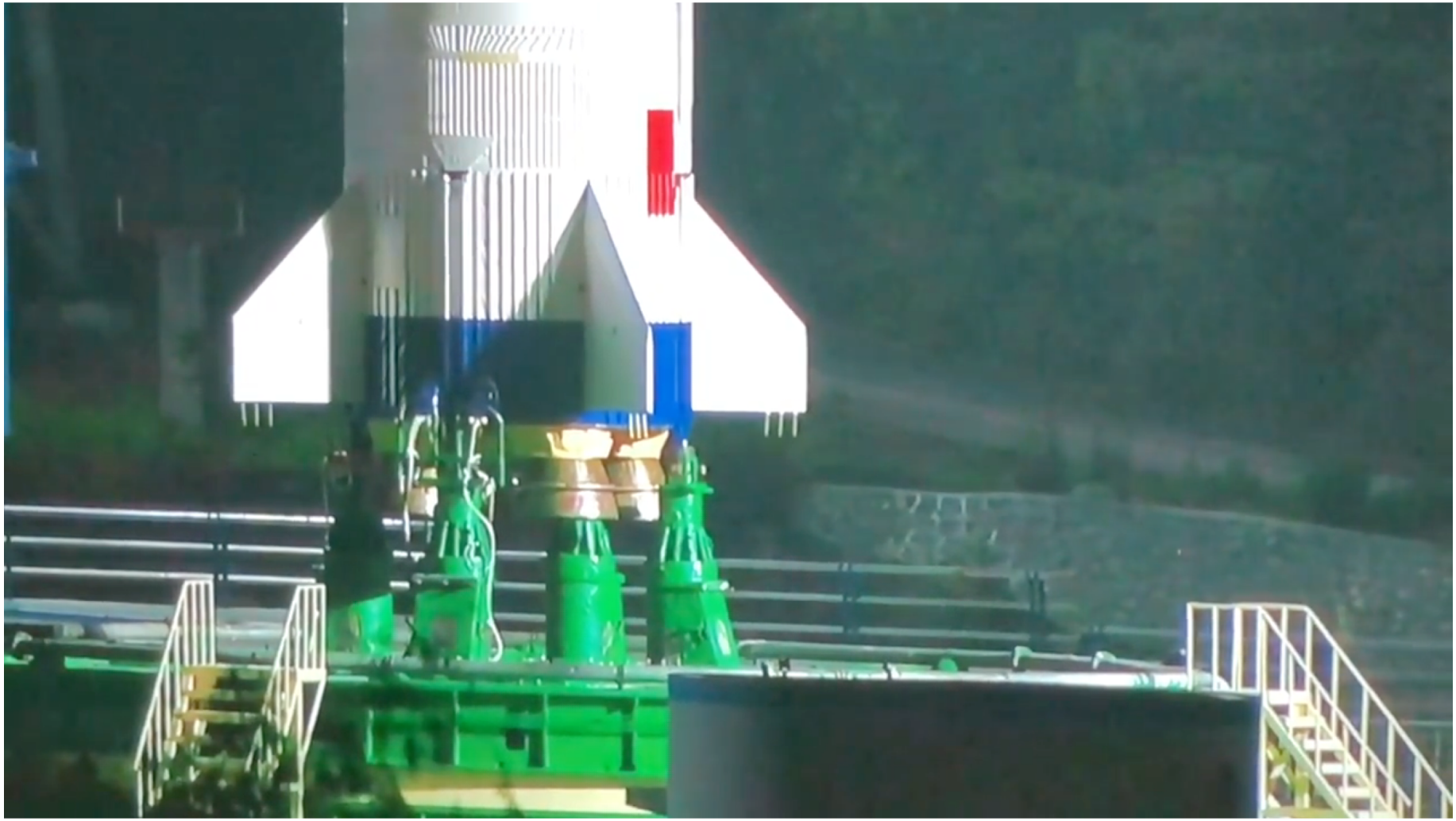

NCLE Launch May 20, 2018

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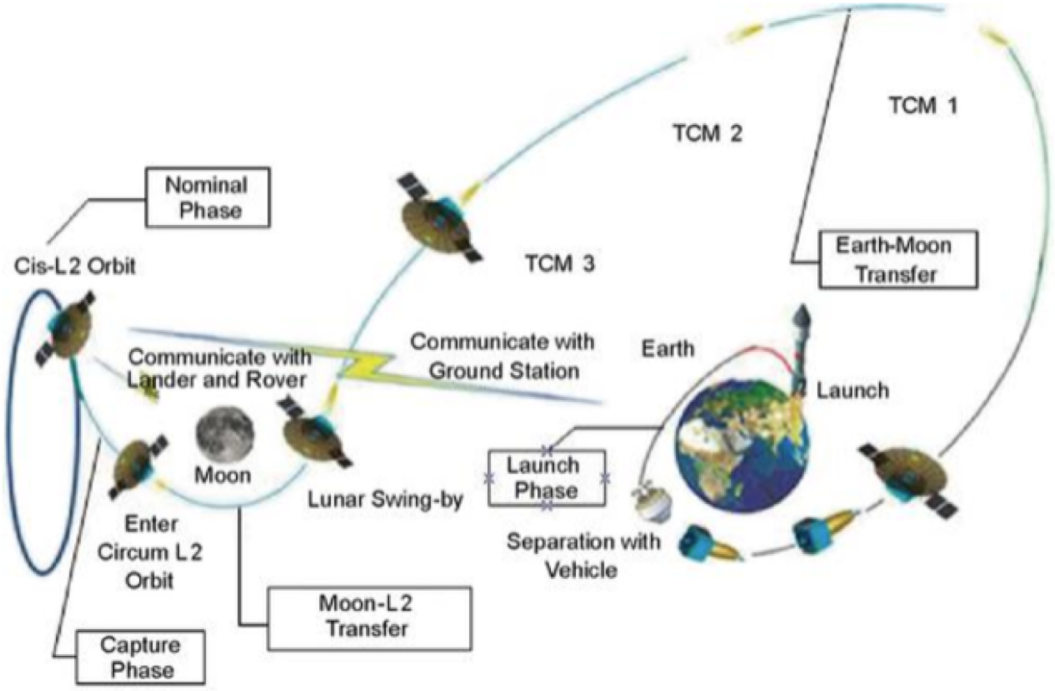
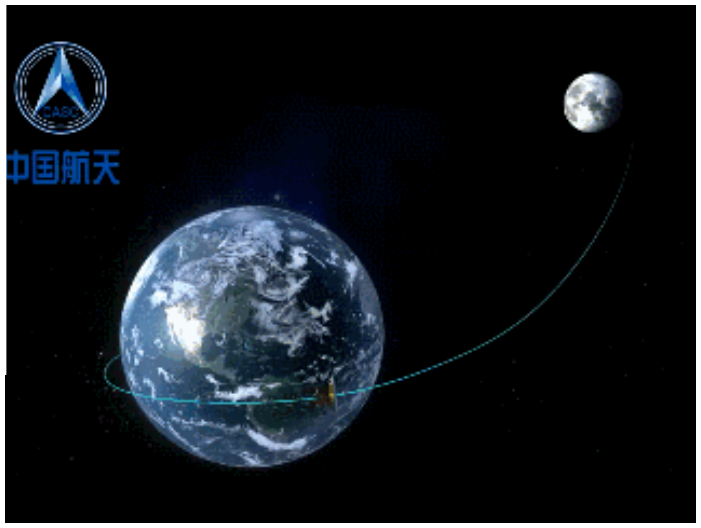


Launch profile for the Chang'e-4 communications relay satellite. *Chinese Academy of Sciences*



Conclusions

- Return to the moon offers unique opportunities for astronomy
- The lunar environment is an ideal location for radio astronomy
  - infrastructure, shielding, stable ground for simple dipole arrays
- Very low-frequency radio astronomy addresses beginning of space time: dark ages and cosmic dawn of universe
  - high-precision cosmology <50 MHz needs to be done from space
  - Steps: small, regular, large, extra-large (N=3,100,10^4,10^5).
- NCLE is a first path finder for lunar far-side orbits
  - Pioneering Chinese-EU space cooperation
  - optimized for dark ages, plus solar bursts, Jupiter, AKR, Galactic spectrum
  - downsides: little shielding, satellite not RFI optimized, rapid development
  - upsides: we are in orbit, will get real data 😎🚀
  - Possibility to form international science teams … (tbd.)