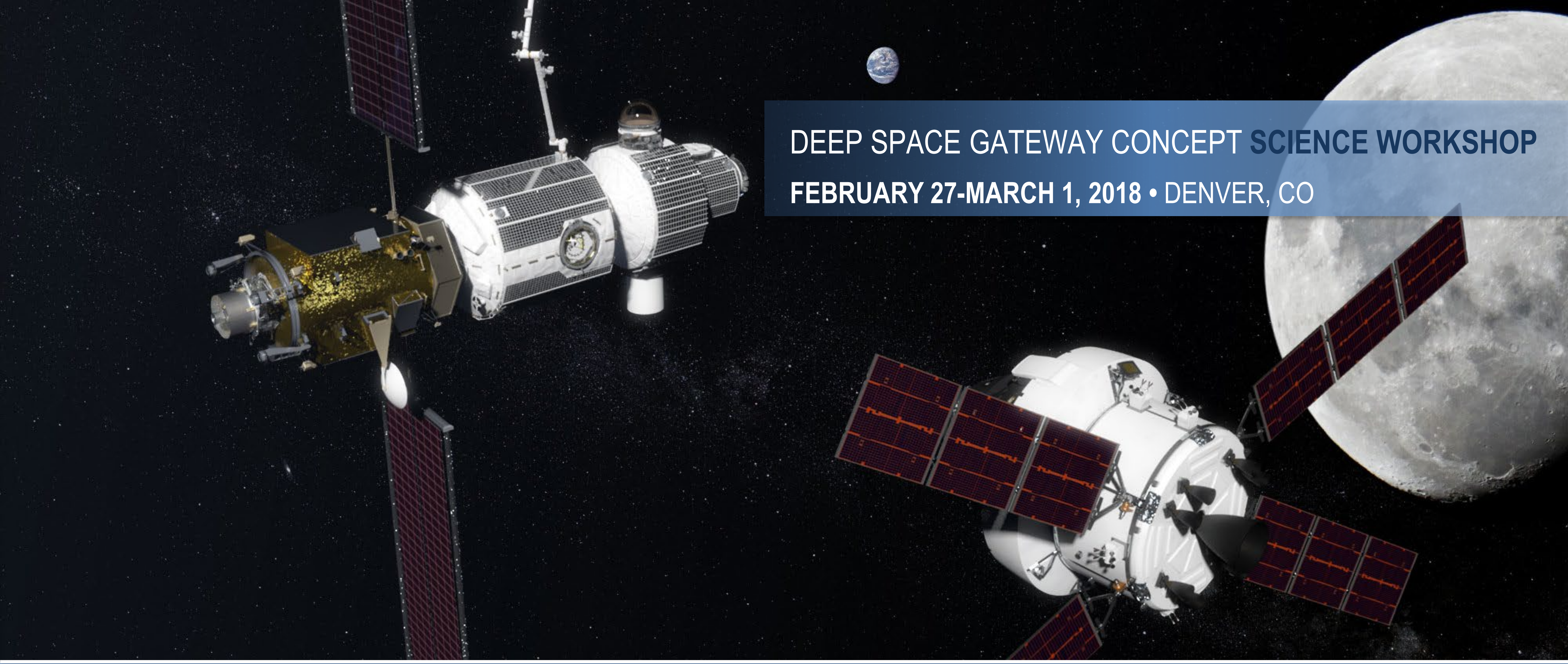

DEEP SPACE GATEWAY CONCEPT **SCIENCE WORKSHOP**

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IMPORTANCE OF A LOW RADIO FREQUENCY INTERFERENCE ENVIRONMENT FOR THE DSG

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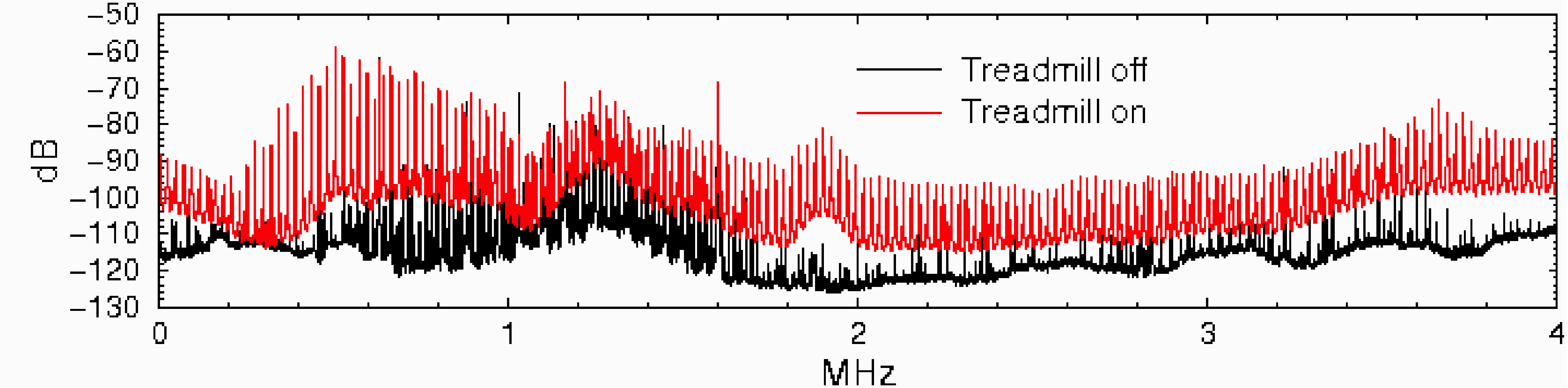
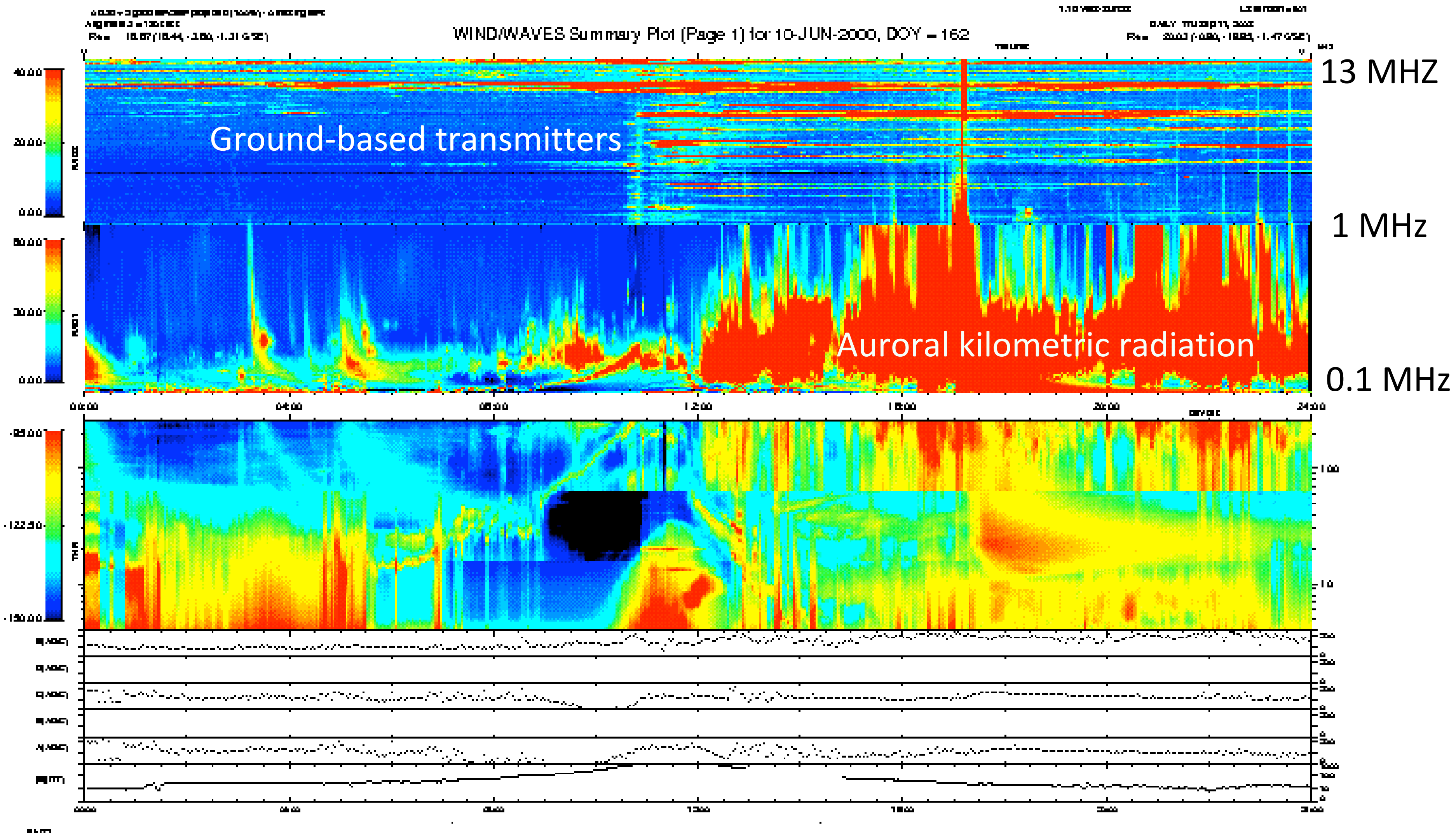
Introduction to Lunar Radio Frequency Interference (RFI) Environment

- The terrestrial ionospheric cutoff (at frequencies that vary from ~10 – 30 MHz, depending on the electron density) blocks electromagnetic waves from space. Therefore, radio astronomy observations below ~ 20 MHz must be done from space.
- These include studies of solar radio bursts, planetary and galactic radio emission, and potentially more distant and less intense radio emissions from exoplanet magnetospheres and cosmological sources.
- Lunar orbit or the lunar surface represent unique environments for the study of these radio sources, as well as higher frequencies, because of the option of being on the far-side of the Moon relative to Earth, thereby blocking the radio frequency interference from ground-based transmitters and other sources.



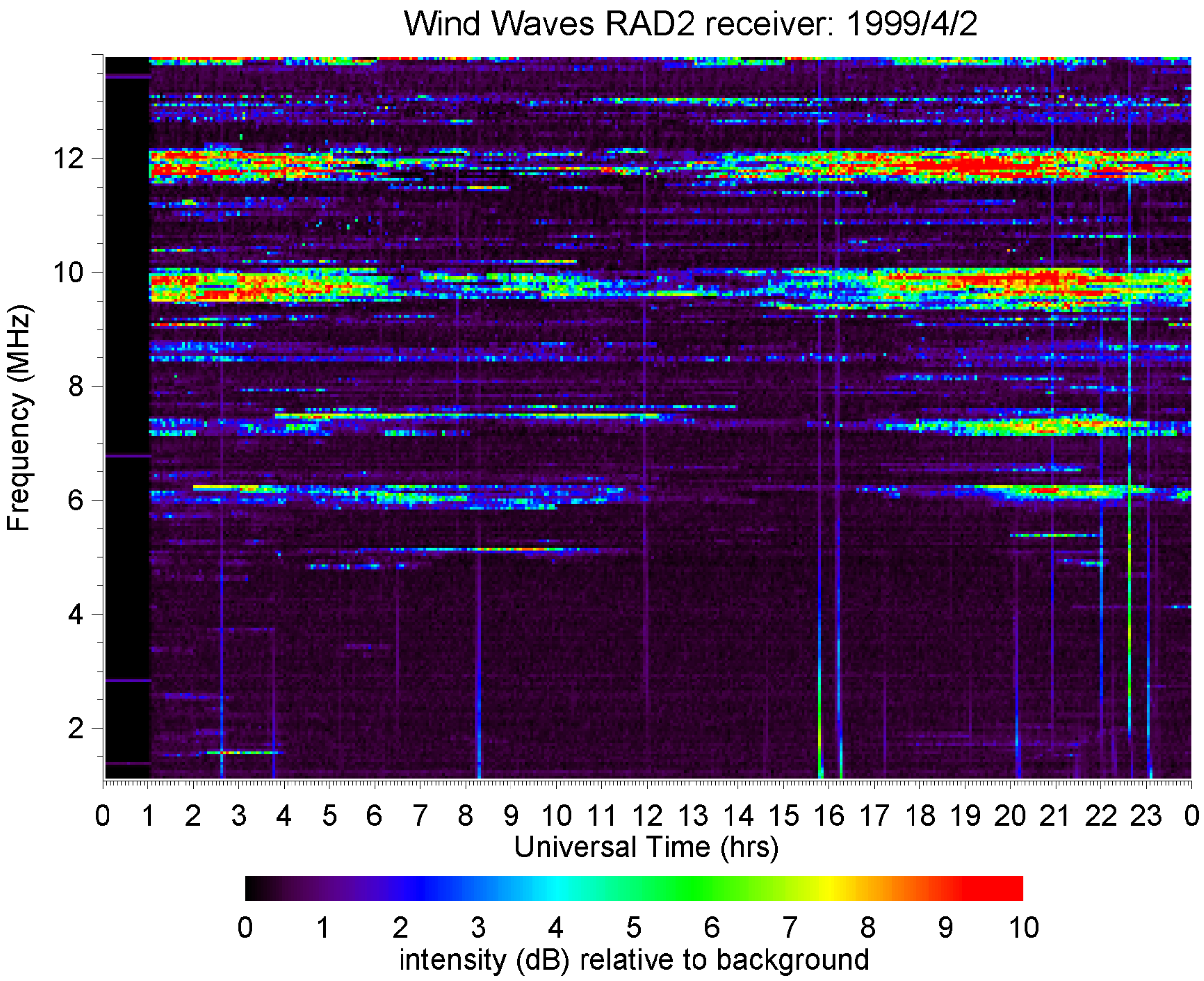
The Radio Interference Environment near Earth (< 20 R_E)

- The plot at right shows 24 hrs of data from the Wind spacecraft Waves instrument.
- At ~11:00 the Wind spacecraft altitude is ~19.5 R_E as it enters the night-time terrestrial hemisphere
- The horizontal lines represent all the emissions from ground-based transmitters.
- The intense (red) terrestrial auroral kilometric emissions are also very intense.



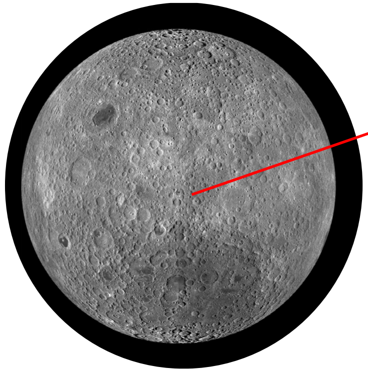
The Radio Interference Environment of the Moon (Near-Side)

- On 1999/04/02, the Wind spacecraft's trajectory took it near the moon. The plot shows that RFI from Earth-based transmitters is still significant.
- The peak RFI values are more than 10 dB above the galactic background (0 dB in the dynamic spectrum).
- This RFI is a serious problem for wide-band receivers trying to detect weak signals from distant sources.
- Consequently, taking data on the far side of the Moon with Earth occulted is a compelling idea.



The Radio Interference Environment of the Moon (Far-Side)

- The Radio Astronomy Explorer-2 (RAE-2) was a lunar-orbiting Explorer spacecraft launched in June 10, 1973.
- The plot at right shows the expected disappearance of terrestrial RFI when RAE-2 passes behind the moon.
- These data extend up to 13.1 MHz, but the occultation of the Earth emissions is also of value for higher frequencies.



RAE-2 1973

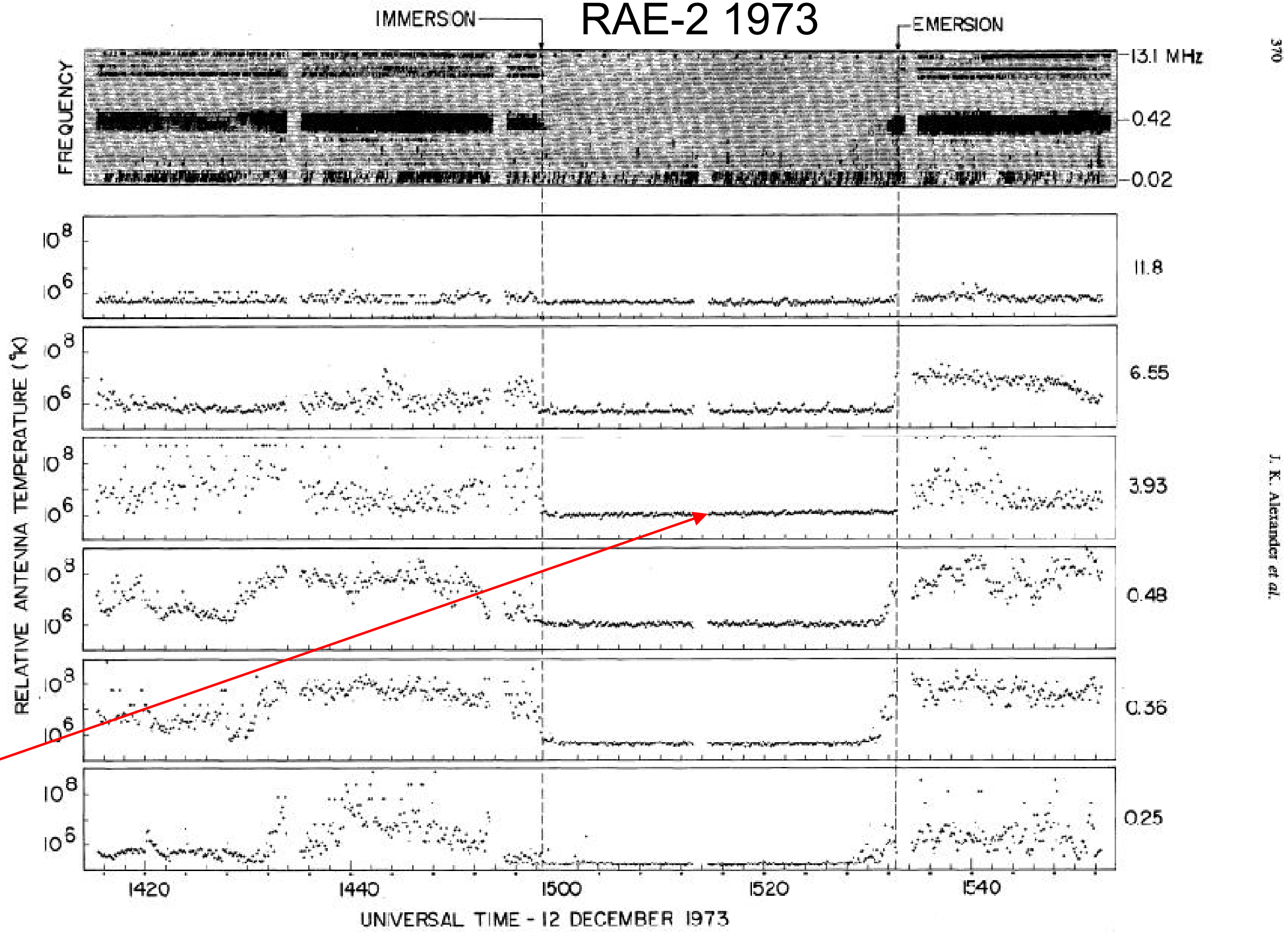


Fig. 5. Example of a lunar occultation of the Earth as observed with the upper-V burst receiver. The top frame is a computer-generated dynamic spectrum; the other plots display intensity vs. time variations at frequencies where terrestrial noise levels are often observed. The 80-s data gaps which occur 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

Missions affected by RFI in the Lunar Environment

Talk #	Topic	Presenter	Hardware	RFI requirement in abstract
3087	Hydrogen Cosmology: Data analysis pipeline	Rapetti	Not the topic	-
3096	Low Frequency Radio Telescope for the DSG	Tauscher	Pair of orthogonal wideband bicone antennas, etc.	50 dB better than the MIL-STD461F standard (20-100 MHz)
3109	Lunar Farside Low Frequency Cosmology Radio Telescope	Monsalve	Pair of orthogonal wideband bicone antennas, etc.	low self-generated EMI from DSG
3129	Lunar Farside Radio Array Pathfinder	Bowman	~100 low-gain antennas tuned to 1-20 MHz + receiver system, etc.	-
3163	Heliophysics radio observations enabled by the DSG	Kasper	Cubesats with antennas and radio receivers like SunRISE	-
3185	Radio imaging spectroscopy of inner heliosphere physics	Kontar	16-32 element sun-pointed radio telescope array	-

Potential DSG sources of RFI

Electromagnetic noise is produced in the source due to rapid current and voltage changes, and spread via the coupling mechanisms (conductive, inductive, capacitive, radiative).

For a radio astronomy instrument mounted on the Deep Space Gateway, likely RFI sources are:

- Power supplies and other noisy equipment
- Other science instruments
- DSG internal and external communication signals

For lunar surface radio observatories, the distance from the Deep Space Gateway is a major factor in reducing RFI. This means that its distance from the moon and observatory are relevant.

If the DSG is in a halo orbit around the Earth-Moon L2 point, then its distance from the lunar far-side is ~65,000 km, less than 20% of the distance to Earth (356,500 km – 406,700 km). It is still desirable to avoid excessive EMI since the lunar radio observatory will be very sensitive at frequencies ~ < 100 MHz, and a bright source in the field of view is undesirable.

The DSG communication connection to Earth will not be a direct factor since the HGA beam is not directed at the moon. However, there may be some DSG locations where a side lobe of the HGA beam (~ -20 dB) could be pointed at the lunar observatory. Such possibilities should be minimized, especially because of the time variability and possible periodicity.

Acceptable RFI levels

- Radio astronomy receivers on the DSG, like the concept (Figure 1) presented by K. Tauscher (#3096) would have a ground plane and a sun shade, like the example shown at right.
- A preliminary determination is that “In the 20-100 MHz range being measured, the instrument must be shielded from EMI at a level 50 dB better than the MIL-STD461F standard.”
- One element of MIL-STD461F that would apply would be the RE102 limit for radiated emissions, shown at right. 50 dB better would be a challenge to systems not designed from the start to meet this requirement.
- A similar system on the far side lunar surface (Figure 2), presented by R. Monsalve (#3109) would not have the same challenging radiated emissions requirements, but it would have all the problems of an instrument on the lunar surface.
- To avoid the DSG appearing as a bright source in the sky, attention to limits like RE102 would be reasonable.

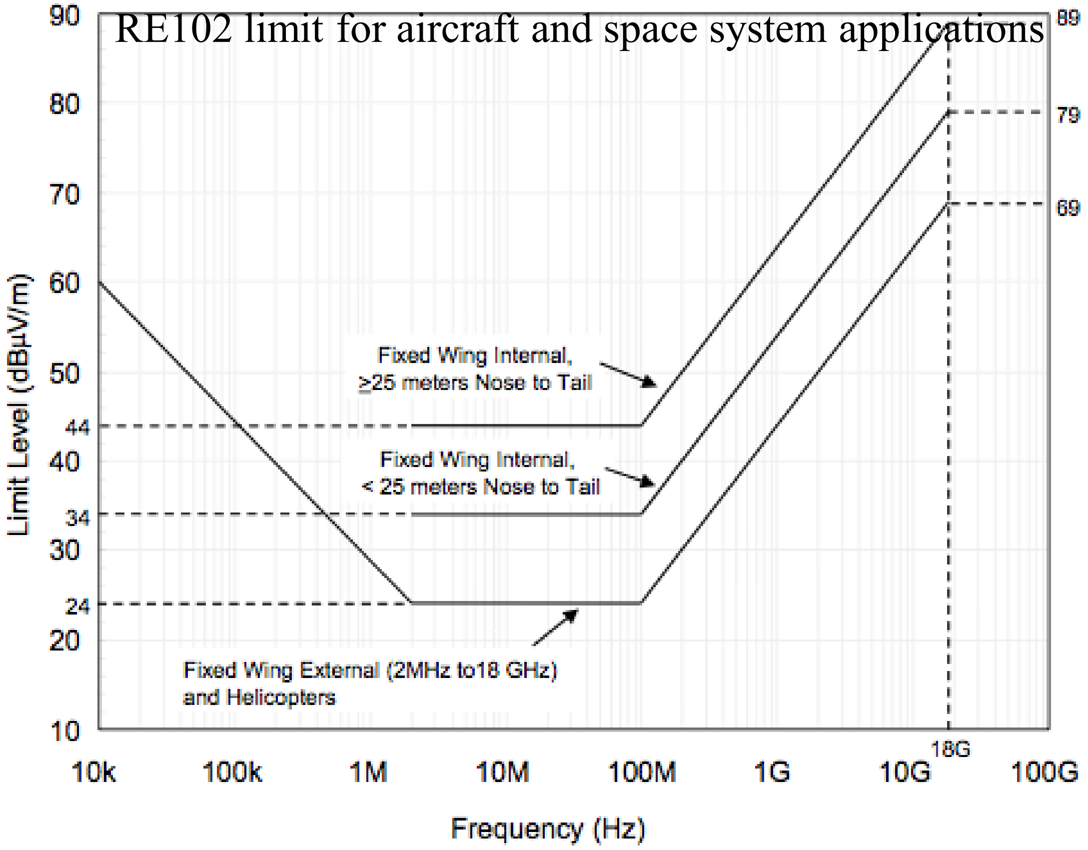


Figure 1

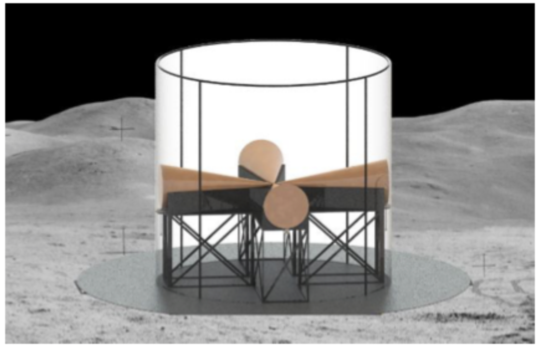


Figure 2. Global 21-cm experiment conception, observing from the surface of the Lunar Farside. For reference, the dipole antenna length is < 10 m.

Techniques to reduce Electromagnetic Interference

Electromagnetic noise is produced in the source due to rapid current and voltage changes, and spread via the coupling mechanisms (conductive, inductive, capacitive, radiative). For remote sources, only “radiative” applies.

Grounding and shielding aim to reduce emissions or divert EMI away from the victim by providing an alternative, low-impedance path. Techniques include:

- Grounding or earthing schemes such as star earthing for audio equipment or ground planes for RF. The scheme must also satisfy safety regulations.
- Shielded cables, where the signal wires are surrounded by an outer conductive layer that is grounded at one or both ends.
- Shielded housings. A conductive metal housing will act as an interference shield. In order to access the components, such a housing is typically made in sections (such as a box and lid); an RF gasket may be used at the joints to reduce the amount of interference that leaks through the joint.

Other general measures include:

- Decoupling or filtering at critical points such as cable entries and high-speed switches, using RF chokes and/or RC elements. A line filter implements these measures between a device and a line.
- Transmission line techniques for cables and wiring, such as balanced differential signal and return paths, and impedance matching.
- Avoidance of antenna structures such as loops of circulating current, resonant mechanical structures, unbalanced cable impedances or poorly grounded shielding.

Techniques to reduce Electromagnetic Interference (2)

Perhaps the most valuable technique is to require that all devices that function by switching or chopping electrical current, causing them to create RFI, make use of crystal-controlled circuits.

As an example, for Parker Solar Probe (as is the case for STEREO, and other spacecraft with radio astronomy instruments), "a fundamental requirement of the PSP EMC program is that all DC–DC power converters be operated at fixed frequencies in 50 kHz intervals, beginning at 150 kHz (i.e. 150 kHz, 200 kHz, 250 kHz, etc.) and that these chopping frequencies be crystal-controlled. This "picket fence" approach concentrates power-supply noise and harmonics into well known and narrow frequency bands providing 'clean' regions of spectral density in which to make sensitive measurements." (Bale et al, 2016)

A detailed description of the EMI mitigation techniques for the STEREO spacecraft is described by Bougeret et al (2007).

The crystal-controlled oscillator requirement needs to be implemented early so that everyone whose hardware is affected has time to make the needed changes.

J.L. Bougeret et al.

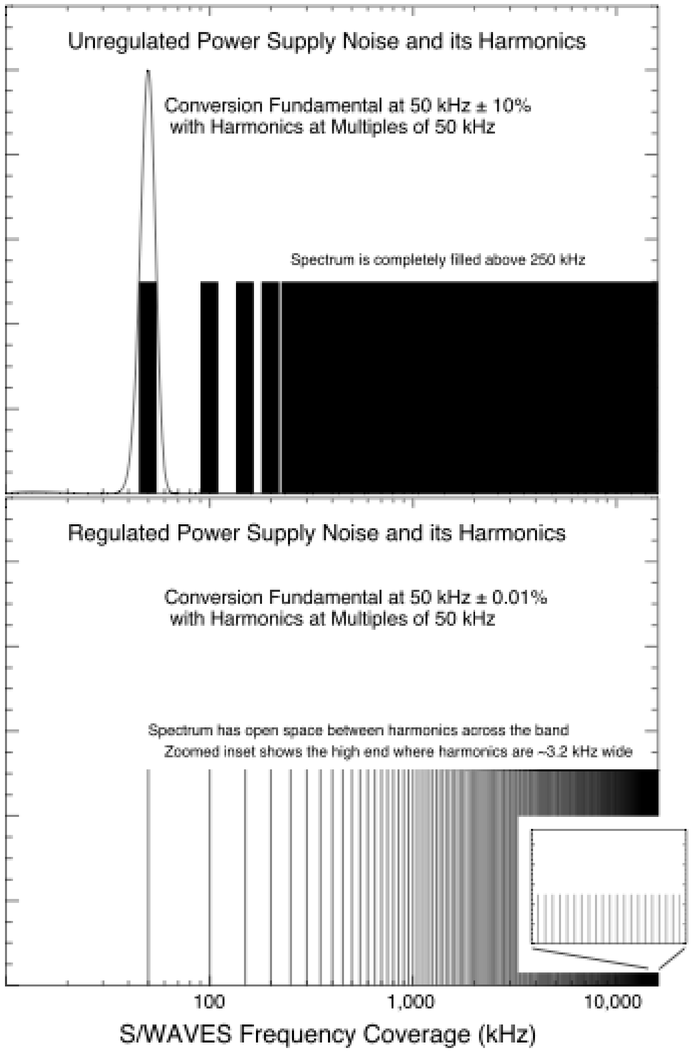


Fig. 17 The "picket fence" made possible by strict control of power supply switching transients. The *top panel* shows an unregulated spectrum of power supply noise, covering the entire band above 200 kHz. The *bottom panel* shows the quiet gaps in the band made possible when power supplies have good frequency control

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Lunar RFI Environment - Summary

- The far-side of the moon provides an environment free of RFI from terrestrial transmitters.
- The most demanding electromagnetic compatibility would be for a high sensitivity radio receiver instrument installed as an external instrument on the Deep Space Gateway.
- The combination of all the components of the Deep Space Gateway and all of the potential science instruments creates a long list of items to be checked for RFI. From the radio perspective they could be required to meet the RE102 limit.
- Application of the complete list of RFI mitigation strategies will keep the Deep Space Gateway from impacting lunar-based radio astronomy. The “picket fence” technique for DC-DC converters and other switching components is very important.
- It is important to develop and operate the lunar surface radio observatory before the lunar surface environment becomes impacted by RFI.