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SSERVI EC Meeting, 25 June 2018

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AAS 232nd MEETING
AMERICAN ASTRONOMICAL SOCIETY
DENVER, COLORADO • 3-7 JUNE 2018

Meeting-in-a-Meeting

Low Radio Frequency Observations from Space

June 5 – 6, 2018 · Denver, Colorado

The space environment, particularly the farside of the Moon, will further open a window to the low radio frequency universe. Join us to learn more.

SESSION 1:
Low Radio Frequency Heliophysics from Space

SESSION 2:
Magnetospheres & Space Weather Environments of Extrasolar Planets

SESSION 3:
Redshifted 21-cm Hydrogen Cosmology from Space

Invited Speakers

Session 1:
- Robert MacDowall (NASA GSFC)
- Heino Falcke (Radboud U.)
- Sofia Moschou (SAO)
- Thejappa Golla (U. Maryland at NASA GSFC)
- Justin Kasper (U. Michigan)

Session 2:
- Gregg Hallinan (Caltech)
- Peter Williams (CfA)
- Joseph Lazio (NASA JPL)
- Rachel Osten (STScI)
- Jake Turner (U. Virginia)

Session 3:
- Judd Bowman (ASU)
- Jonathan Pober (Brown U.)
- Anastasia Fialkov (CfA)
- Jack Burns (U. Colorado)
- David Rapetti (U. Colorado & NASA Ames)

Radio cubesats and space-based arrays will investigate the impacts of the Sun's activity, interplanetary plasmas, and interstellar inputs on the energetic particle and dust environment in the inner solar system.

Low frequency radio arrays will probe extrasolar space weather and detect magnetospheres of potentially habitable exoplanets.

Hydrogen cosmology with single antennas (monopole) and arrays (power spectrum) will open a new window into Cosmic Dawn.

Low Latency Surface Telerobotics

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Co-Investigators:
Jack Burns, U. Colorado
Terry Fong, NASA ARC
Dan Szafir (Comp. Sci), U. Colorado

Collaborators:
Jennifer Heldmann, NASA GSFC
David Kring, LPI
Chris Norman, Lockheed Martin
Tim Cichun, Lockheed Martin

NPP SSERVI Postdoc:
Midhun Sreekumar Menon, U. Colorado

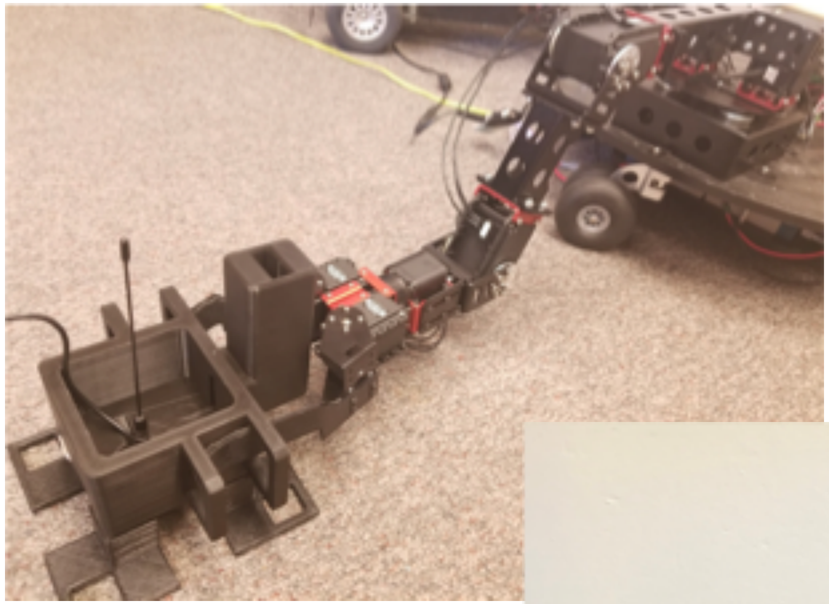
Graduate Student:
Michael Walker (Comp. Sci), U. Colorado

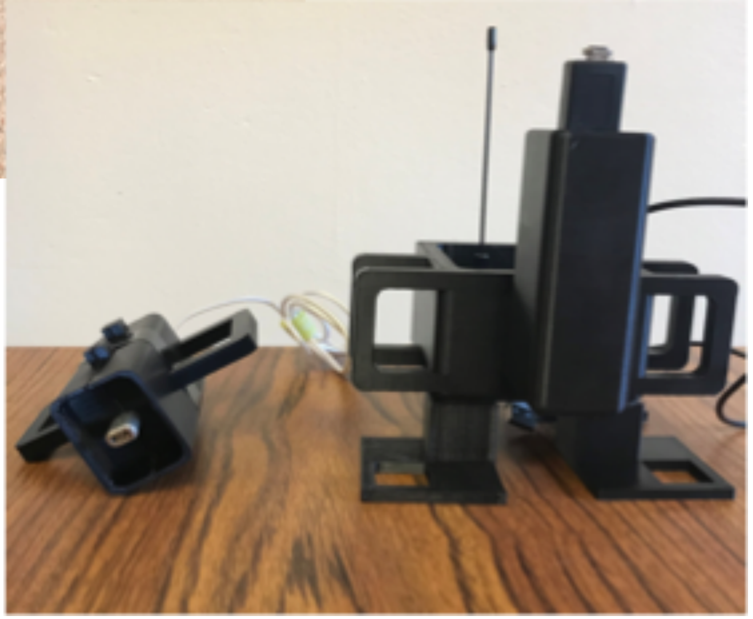
Undergraduate Students:
Benjamin Mellinkoff
Alex Sandoval
Arun Kumar

Robotic Arm and Rover for Future Low-Latency Telerobotic Assembly Experiments

Arun Kumar
Alexander Sandoval

Assembly of Radio Telescope Elements





- Radio Telescope Assembly
  - Construct a simple radio array telescope
  - Receive radio frequencies for data processing
  - Maximize situational awareness from video feedback
  - Robotic arm motion capabilities
- Connect magnetic micro USB to power and transmit data from antenna
- Using 3D printed case and gripper to aid the robotic arm
- Demonstration of how a radio telescope could be assembled on the lunar farside

Initial Results

University of Colorado
Boulder

VIRTUAL REALITY SIMULATION TESTBED: *IMPROVING SURFACE TELEROBOTICS FOR THE DEEP SPACE GATEWAY*

ATLAS INSTITUTE

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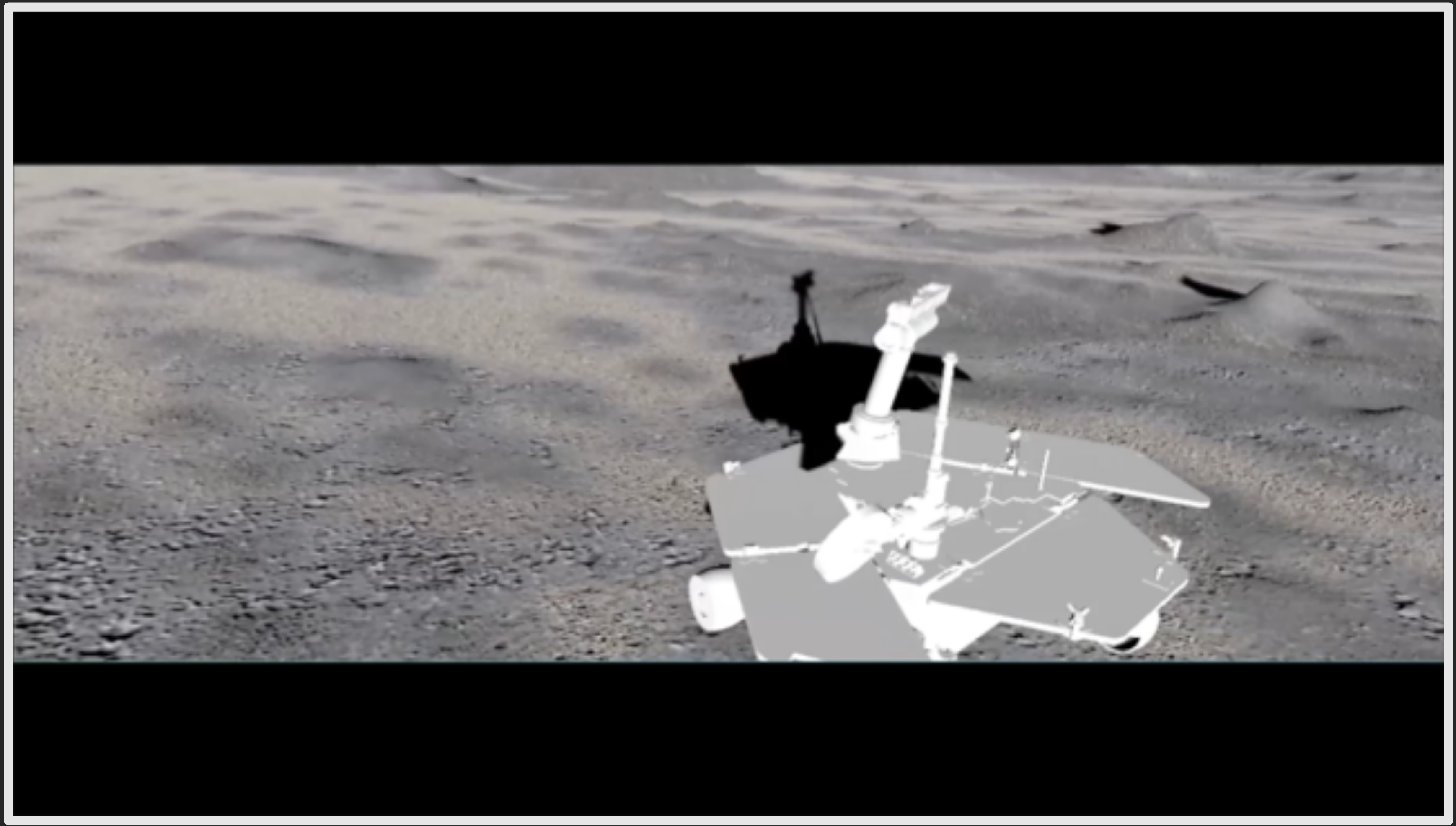
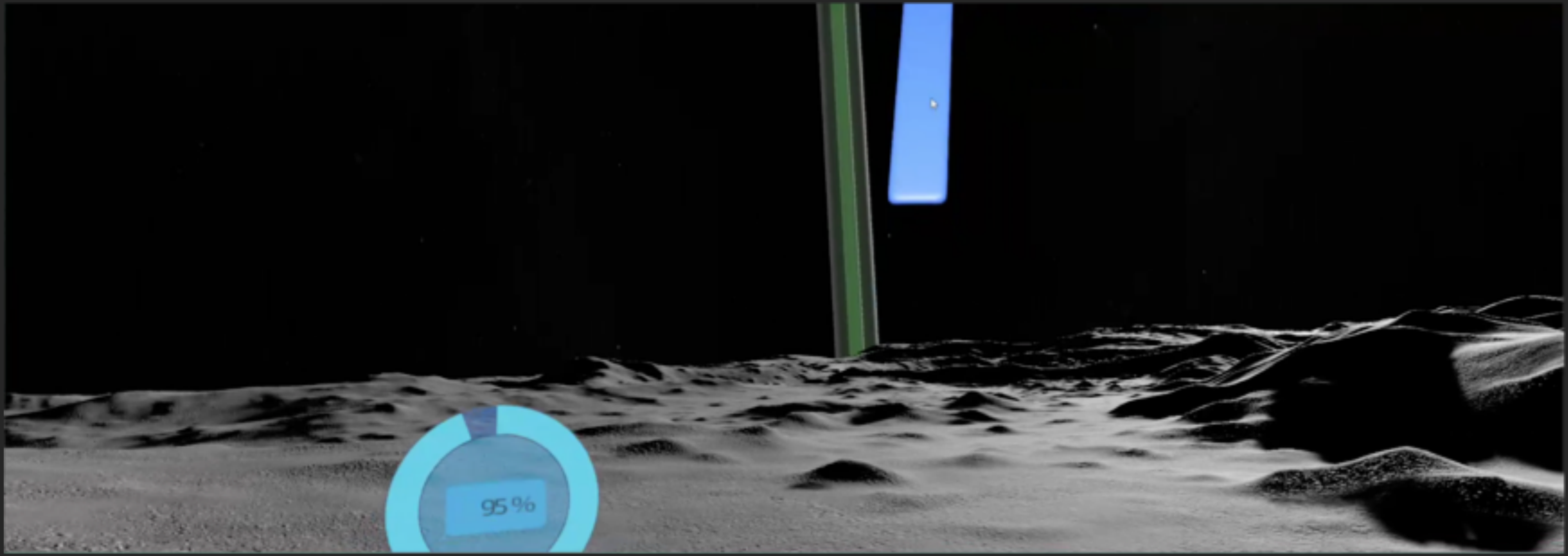
Michael Walker, Jack Burns, & Daniel Szafir

3rd PERSON ROVER TELEOPERATION



AUTONOMOUS ADVISOR TRUST FOR ROVER TELEOPERATION



Low Frequency Radio Heliophysics

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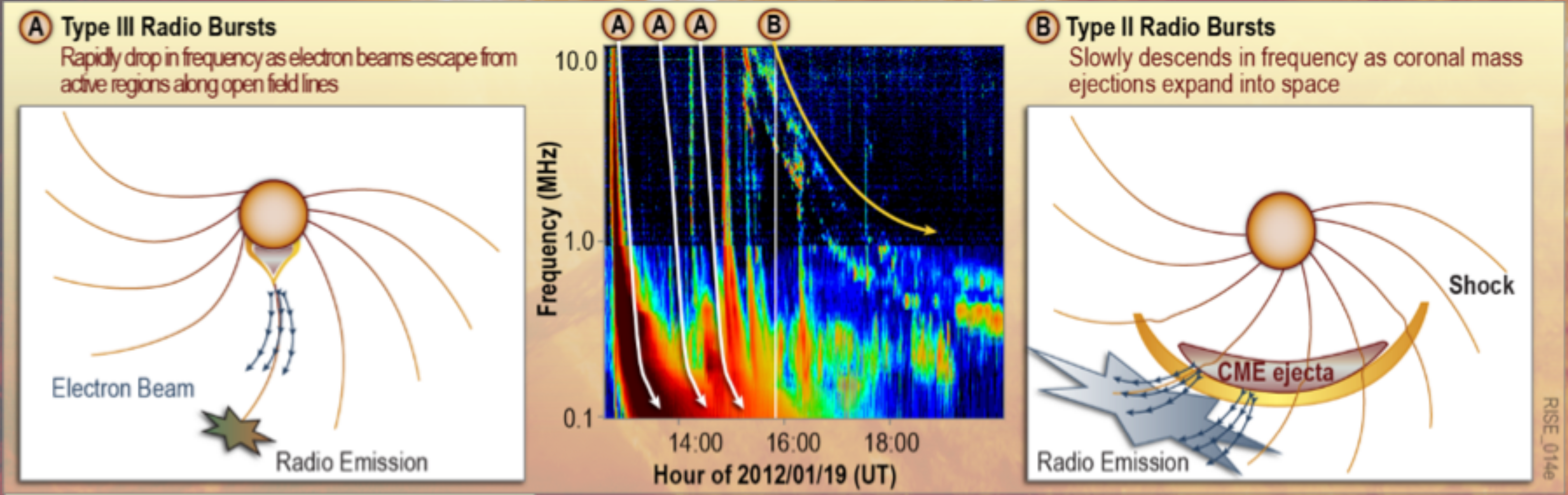
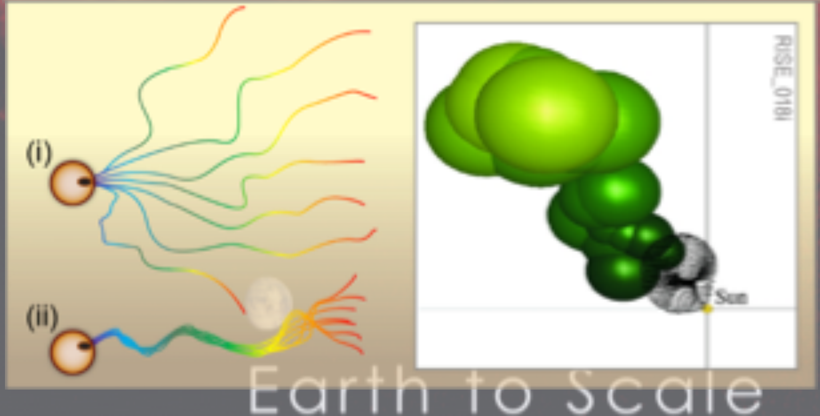
Co-Investigators:
Robert MacDowall, NASA GSFC
Justin Kaspar, U. Michigan
Michael Reiner, NASA GSFC

Collaborators:
Bill Farrell, NASA GSFC
Dan Baker, U. Colorado
Milan Maksimovic, Observatoire de Paris

Solar Type II & III Bursts



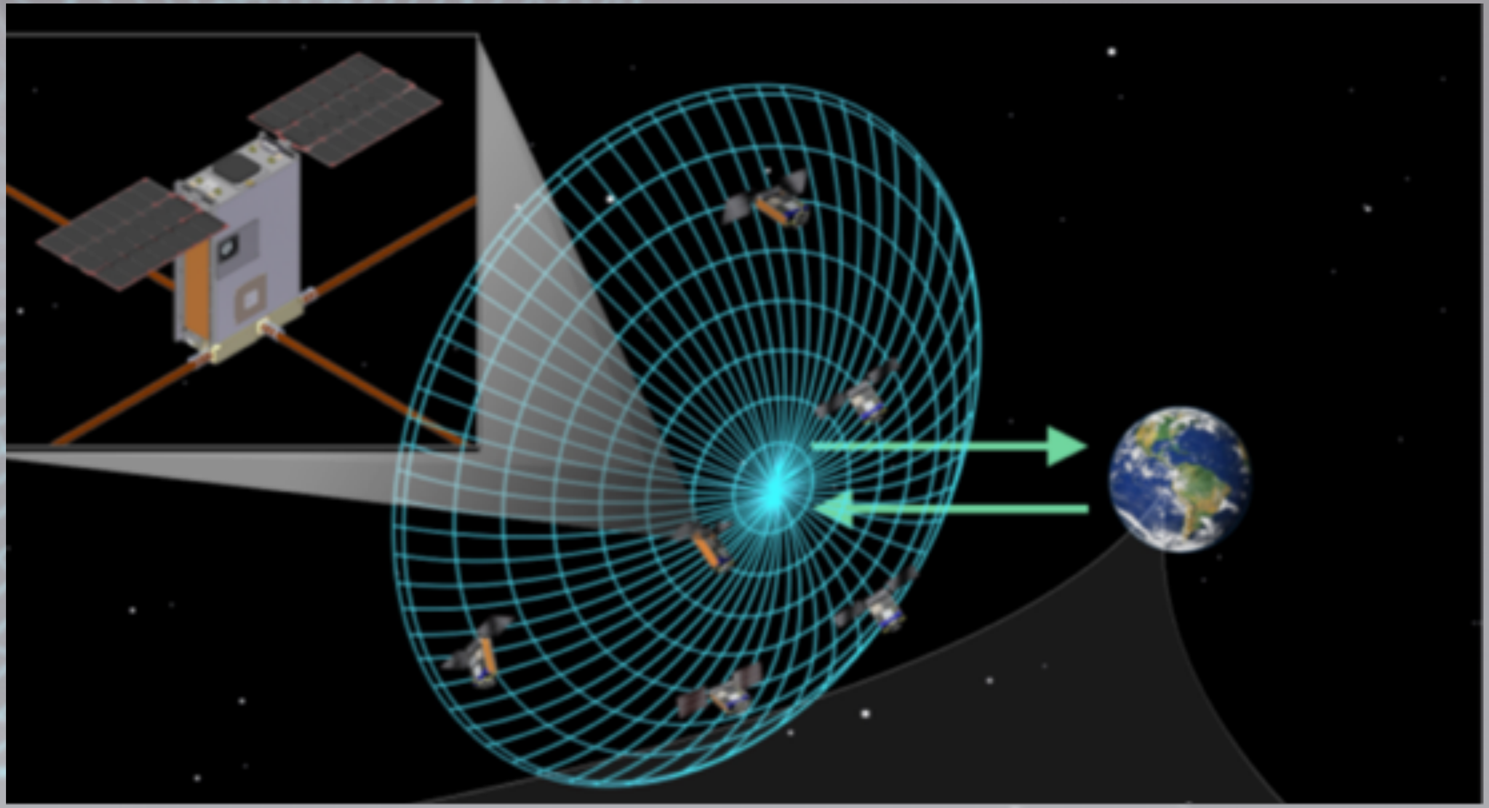


Figures from SunRISE Concept Study

Bougeret, J.-L., M. L. Kaiser, P.J. Kellogg, et al., "WAVES: The Radio and Plasma Wave Investigation on the WIND Spacecraft", *Space Sci Rev*, 71, 5, 1995.

SunRISE – Earth Orbiting Array

- SunRISE – Sun Radio Interferometer Space Experiment
- Heliophysics Explorers Mission of Opportunity
- Currently in Phase A
- Will launch 2022 if funded
- 6 CubeSats in GEO Graveyard Orbit
- Track Bursts to 20 Rs



Legend

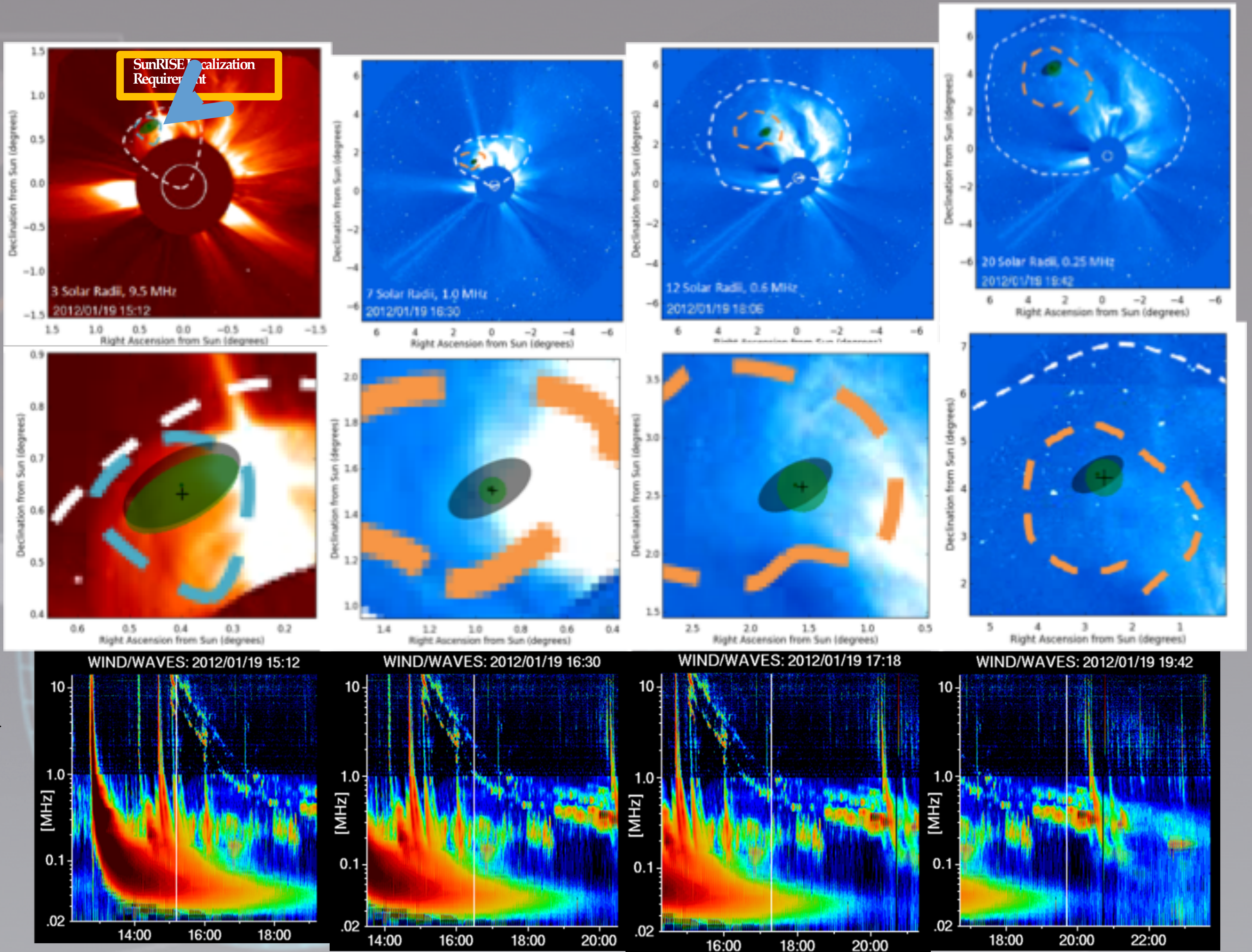
Big Dashed Line:
All Disturbed

Small Dashed Line:
1/3 Size of CME
Base Requirement

Black Ellipse:
Truth Input

Green Ellipse:
Array Reconstruction

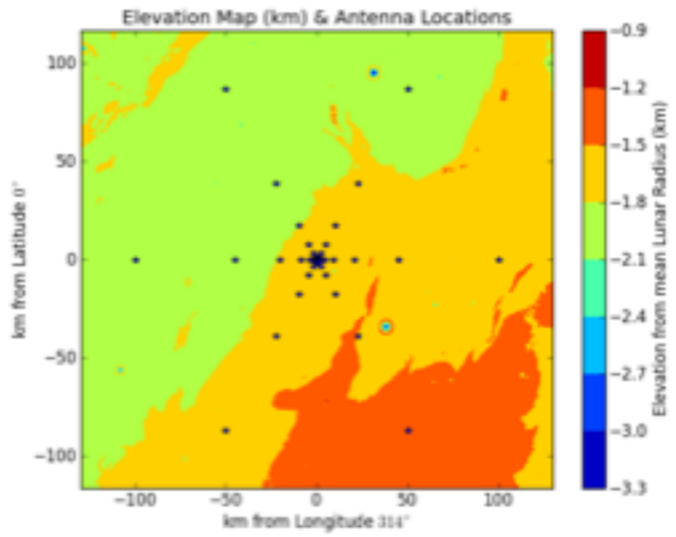
Error Bars:
1 sigma 5 S/C error
Over 80 Trials



Requirements for imaging these radio sources from the lunar surface

Table 3.4.1. Summary of ROLSS parameters

Parameter	Value	Comment
Wavelength (Frequency)	30–300 m (1–10 MHz)	• Matched to radio emission generated by particle acceleration in the inner heliosphere • Provide context for observations during Solar Probe Plus perihelion passes • Detect lunar ionosphere • Operate at frequencies below the terrestrial ionospheric cutoff
Angular Resolution	2° (at 10 MHz)	• Localize particle acceleration sites of CME shocks and Type III solar bursts • Order of magnitude improvement from present
Bandwidth	≥ 100 kHz	Track time-evolution of particle acceleration
Minimum Lifetime	~1 year	Obtain measurements during several solar rotations; avoid solar minimum



Radio Heliophysics Summary

- Solar radio bursts at frequencies < 20 MHz have never been imaged.
- The timing and location of the bursts provides an indication of energetic particle acceleration, and therefore, the potential of space weather alerts.
- Imaging the bursts will also provide data on the locations of electron acceleration, answering magnetic field configuration and other questions.
- Radio observatory antennas on the lunar surface will also be large dust detectors, especially if the unrolled-polyimide antenna substrate is used.
- We realized during the proposal development that a near side radio array might be able to observe synchrotron radio emissions from the Earth's radiation belts. This emission is also controlled by space weather events.
- Requirements for the pathfinder lunar surface radio telescope are modest, except for surviving the thermal environment, which includes surviving 14 days of lunar night. OK, maybe getting to the surface is still an issue…

Magnetospheres & Space Weather Environments of Extrasolar Planets

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Co-Investigators:
Gregg Hallinan, Caltech

Collaborators:
Robert MacDowall, GSFC
Judd Bowman, ASU
Justin Kasper, U. Michigan

Graduate Student:
Marin Anderson, Caltech

Credit: KISS/Caltech

Is magnetic activity important for defining habitability?

Can we directly detect CMEs and planetary magnetic fields?

<u>Yes – with radio observations</u>

Low Frequency Radio Emission

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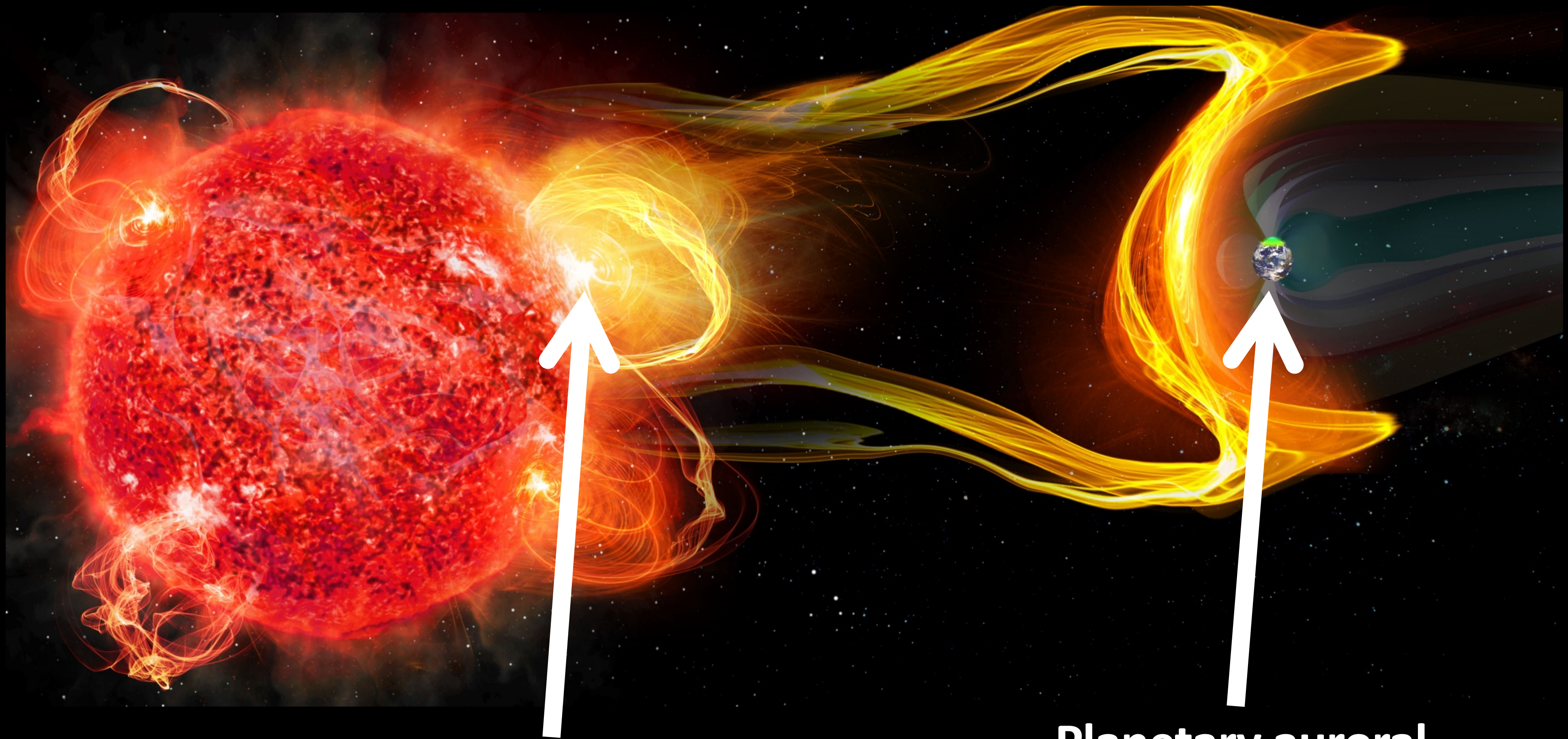


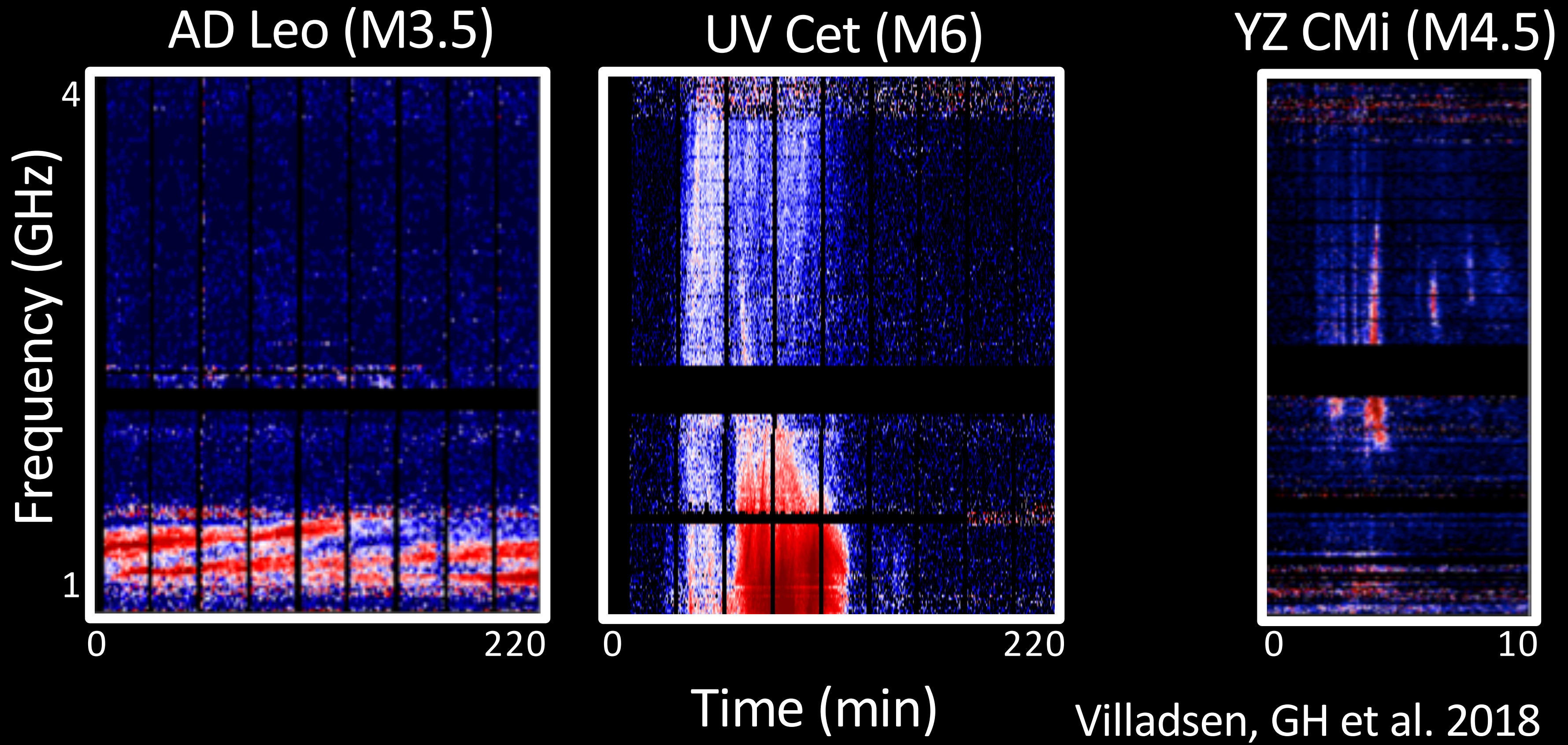
Type II radio emission associated with CMEs

Planetary auroral radio emission

Ongoing Searches for Stellar CMEs

Long bursts (>~1 hour)
Requires ongoing electron acceleration

Short bursts (sec - min)
Powered by individual flares?

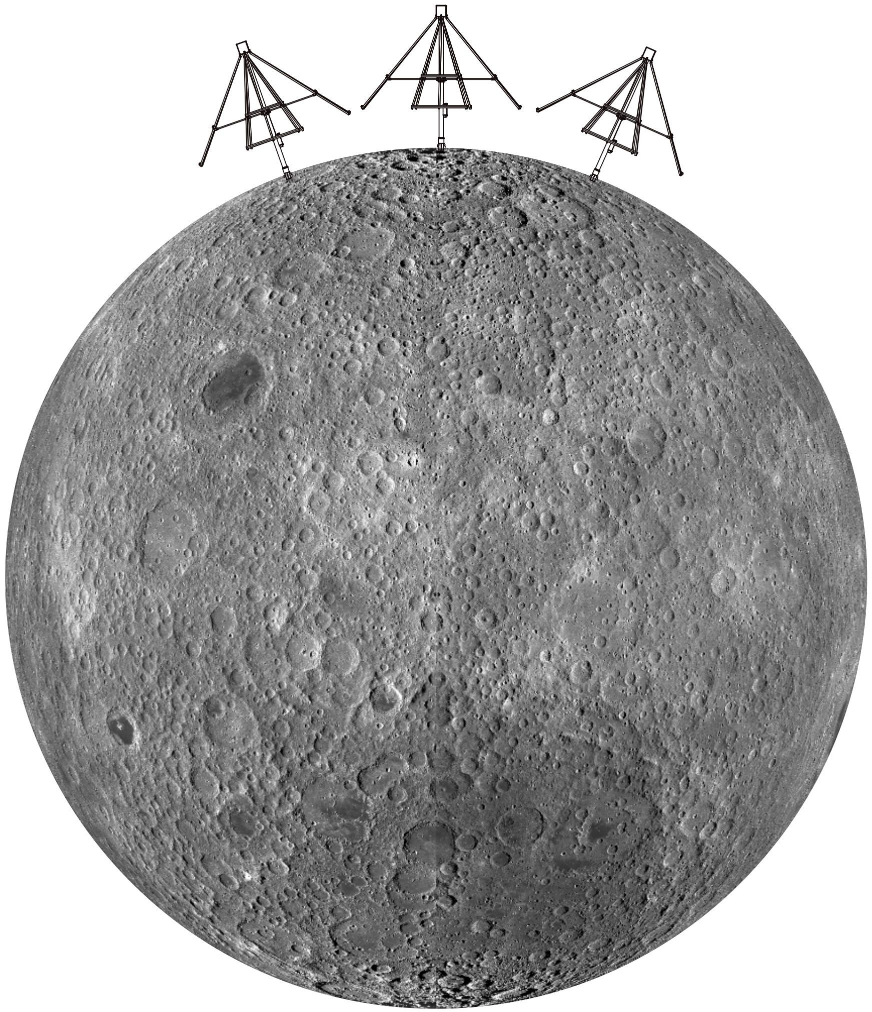


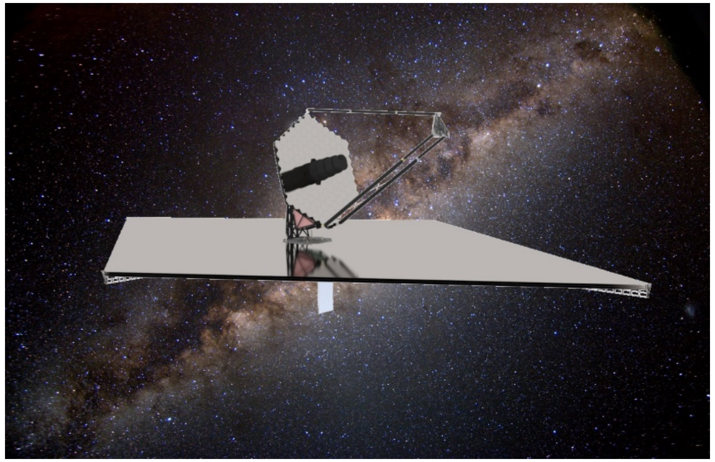
Villadsen, GH et al. 2018

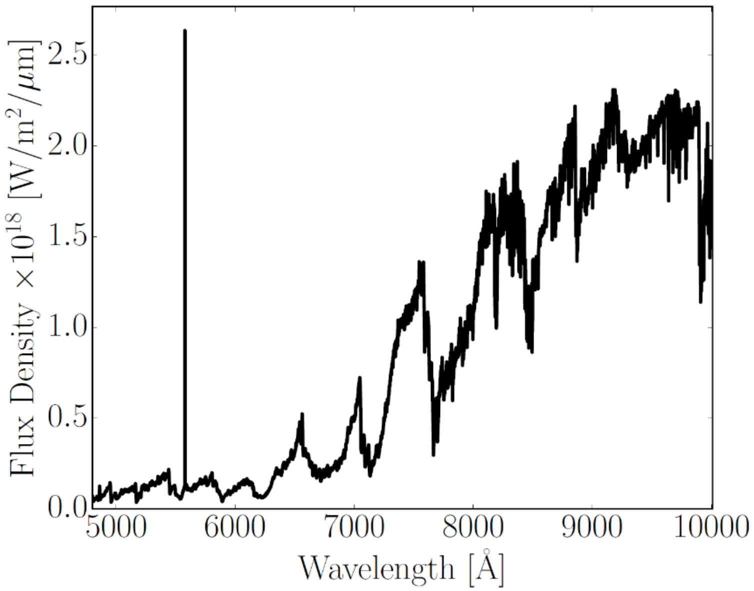
- *Stellar dynamic spectroscopy a mature field (Bastian & Bookbinder 1987, Osten & Bastian 2006)*
- *Recent study – 21 bursts with ultra-wide bandwidth, no Type II bursts (Villadsen, GH et al. 2018)*

- Need more sensitivity at lower frequencies!

Triggered Alerts from a Lunar Array







Simulated high-resolution spectrum of Proxima Cen b with 0.1 TW auroral emission at 5577 Å (Luger et al. 2017)

Hydrogen Cosmology

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Co-Investigators:
Jack Burns, U. Colorado
Judd Bowman, ASU
Richard Bradley, NRAO
Steve Furlanetto, UCLA

Collaborators:
Heino Falcke, Radboud U., Netherlands
Marc Klein Wolt, Radboud U., Netherlands
Dayton Jones, Space Science Institute
Leon Koopmans, U. Groningen, Netherlands
Jonathan Poper, Brown U.

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Jordan Mirocha, UCLA
Raul Monsalve, U. Colorado

Graduate Students:
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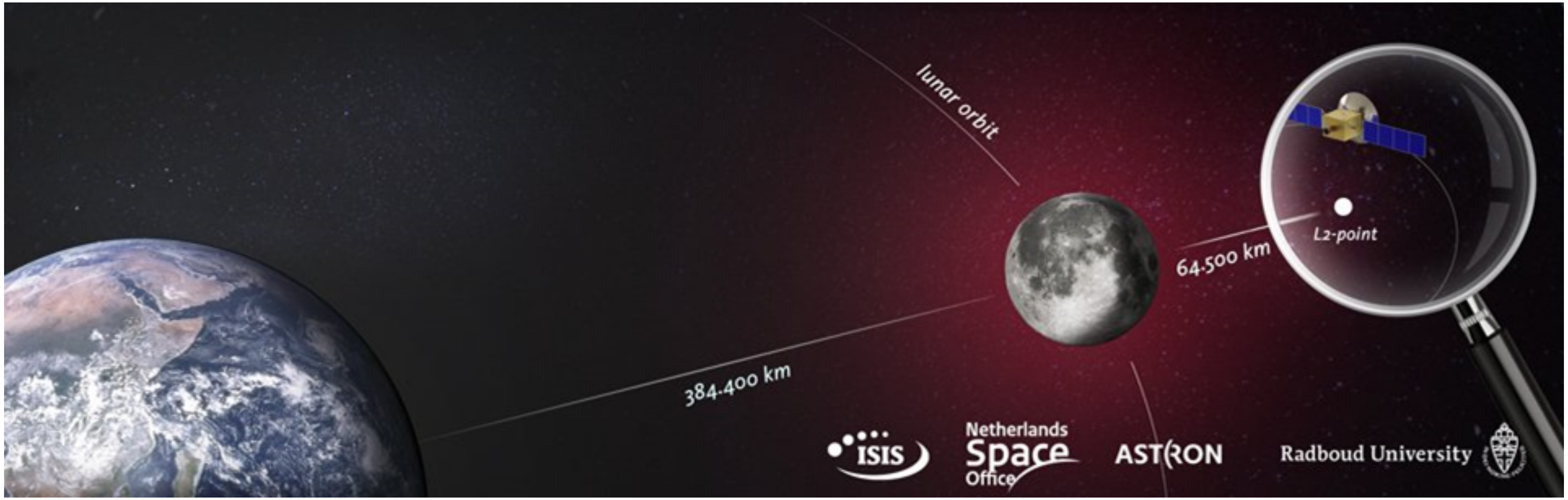
David Bordenave, U. Virginia
Bang Nhan, U. Colorado
Nivedita Mahesh, ASU
Richard Mebane, UCLA

NETHERLANDS-CHINA LOW-FREQUENCY EXPLORER (NCLE)

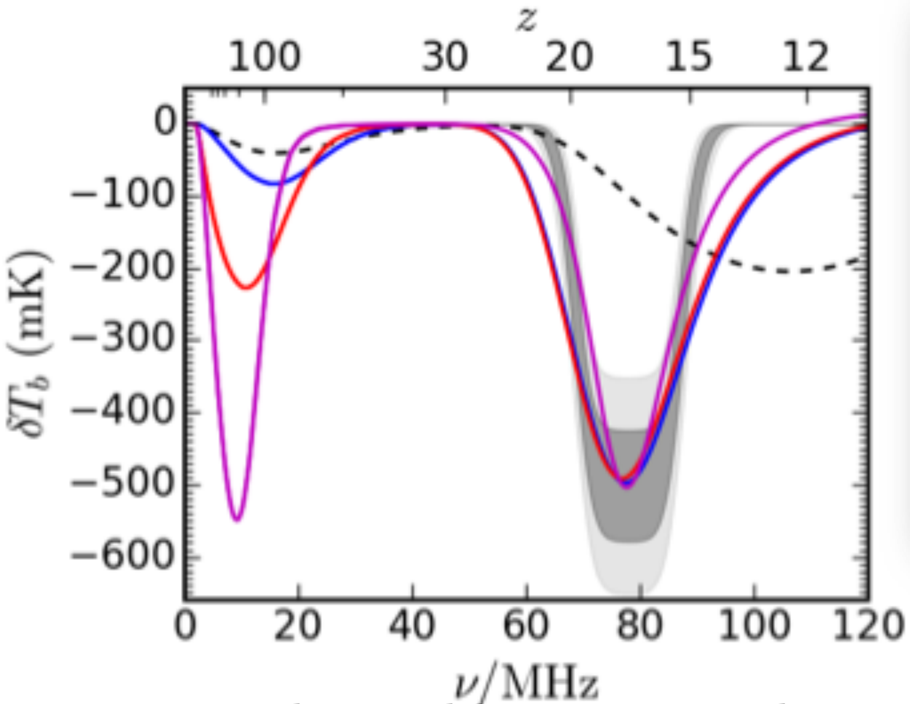


- Will characterize the RFI environment in deep space at Earth-Moon L2.
- Will serve as precursor for future Hydrogen Cosmology missions and radio interferometry.
- Will attempt to detect CMEs from the Sun.
- 3 orthogonal, monopoles of 5-m length. Frequencies: 1-80 MHz.
- Heino Falcke is P.I.

The Dark Ages Polarimetry PathfindER (DAPPER): Probing Dark Matter in the Dark Ages – P.I. Jack Burns, U. Colorado

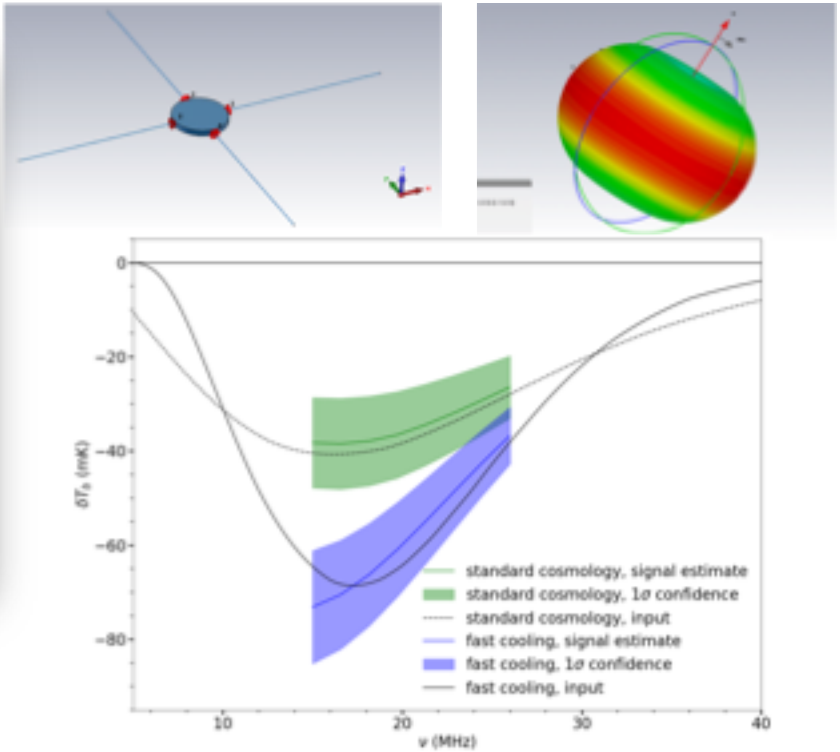
Science Objective: Search for deviations from the standard model of cosmology, possibly produced by dark matter, via measurements of the low radio frequency absorption trough at ~15-30 MHz (93≥z≥46) in proximity to the Lunar Gateway.

Technical Implementation: 7-m diameter cross-dipole antenna on SmallSat to measure polarization of galactic foreground (heritage: WIND/WAVES); low noise amplifiers & dual channel receiver to measure all 4 Stokes parameters. (Based on Parker Solar Probe FIELDS instrument).



Parametric cooling models consistent with new EDGES results (grey bands) predict deep absorption troughs at <20 MHz which we will observed by DAPPER.

3 locations for DAPPER will be studied: (1) on the Gateway, (2) released from the Gateway, (3) delivered to low lunar orbit by Gateway tug.



Top left: cross-dipole wire antennas with central S/C. *Top right:* modeled antenna beam. *Bottom:* estimated uncertainties for DAPPER observations using Machine Learning, Pattern Recognition, & Training Sets.

21-cm Dark Ages Science

<table>
<tr><th colspan="4">Science Traceability Matrix</th></tr>
<tr><th>Decadal Science Goals</th><th>Science Objectives</th><th>Science Measurements</th><th>Instrument Requirements</th></tr>
<tr><td rowspan="2">1) What is the nature of inflation?</td><td>1) Are primordial matter density perturbations non-Gaussian? What is the value of f_{NL}?</td><td rowspan="3">1) Power spectrum of redshifted 21cm absorption fluctuations before stars

2) Frequency range approx. 10-40 MHz (50<z<100)

3) Angular modes between 1 and 10 degrees

4) Spectral modes between 0.05 to 4 MHz</td><td rowspan="3">1) Full Stokes aperture synthesis array on lunar farside (to avoid ionosphere and RFI) with:
* 400,000 m^2 area
* 1 km baselines
* Full-sky imaging

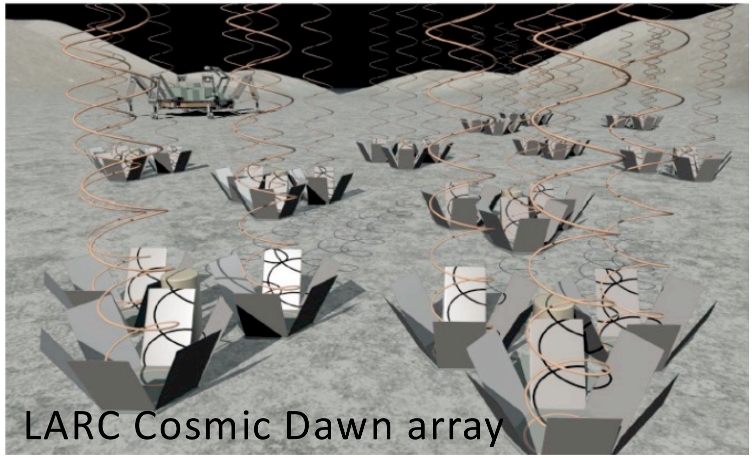
2) High-precision bandpass and beam calibration for foreground removal

3) Hardware that is radiation and thermally tolerant to survive the lunar environment

4) Deployer for chosen antenna design</td></tr>
<tr><td>2) What are the cosmological parameter values?</td></tr>
<tr><td>2) What is the nature of dark matter?</td><td>3) What is the temperature evolution of baryons after recombination?</td></tr>
</table>

Notional pathfinder array – 1%

- Lunar farside
- Frequency band:
  - 1-20 MHz
- 1 Jy sensitivity:
  - 100 dipole-like antennas
- 1 degree resolution:
  - 1 km baselines
- Data rate:
  - 4 GB/s (raw)
- Power estimate:
  - Analog 100 elements: <20 W
  - Digital processing: 10-100 W
- Lifetime:
  - 1-5 years
- Mass and volume target/estimate:
  - 10^4 cm^3 per antenna = 1 m^3 total
  - 10 kg per antenna = 1000 kg total



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