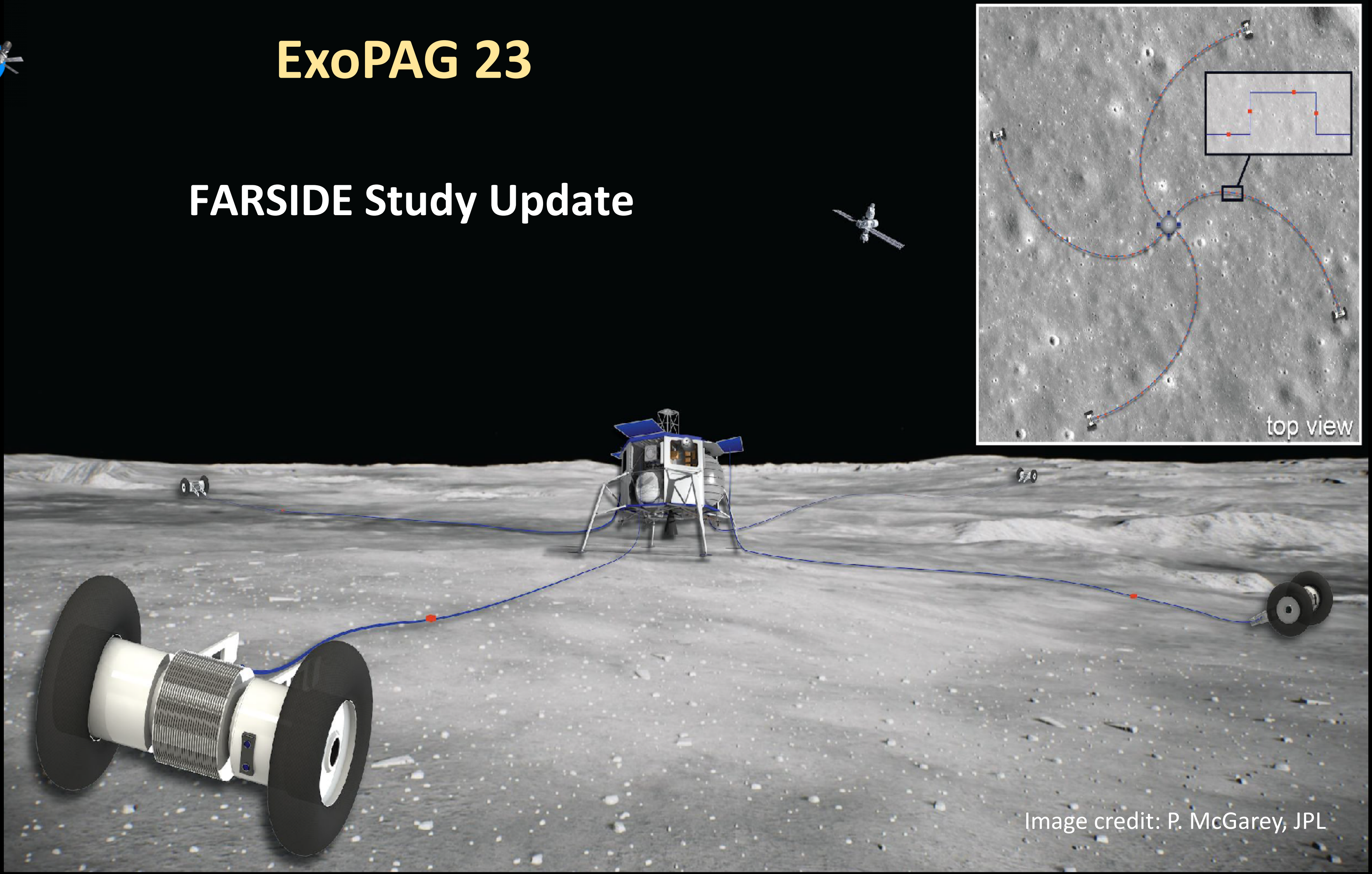
ExoPAG 23

FARSIDE Study Update



Gregg Hallinan
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Caltech

Collaboration

NESS – Network for Exploration and Space Science

PI: Jack Burns (University of Colorado Boulder); co-PI: Gregg Hallinan (Caltech)
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NASA Jet Propulsion Laboratory, California Institute of Technology

Lawrence Teitelbaum, Jim Lux, Andres Romero-Wolf, Tzu-Ching Chang, Marin Anderson, Issa Nesnas, Mark Panning, Andrew Klesh, Alex Austin, Patrick McGarey, Adarsh Rajguru, Matthew Bezkrovny, Varhaz Jamnejad , Eric Sunada, Jeff Booth

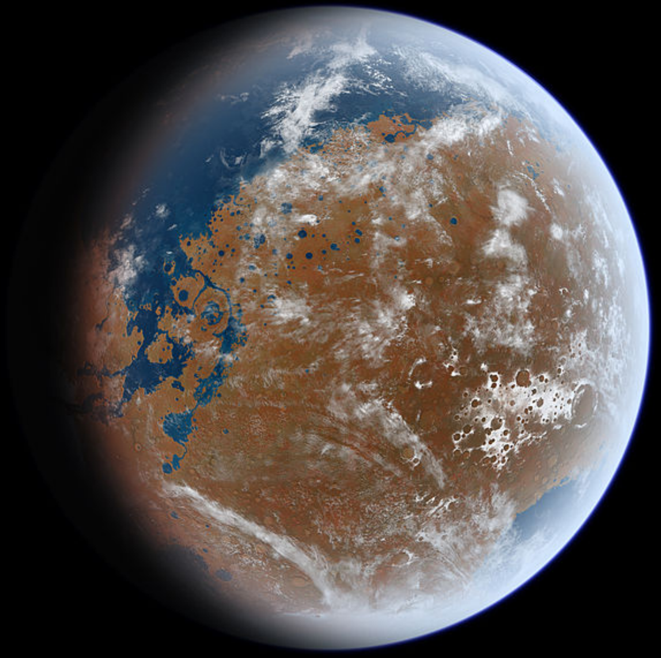
BLUE ORIGIN

Steve Squyres, Alex Miller and the Blue Origin Team

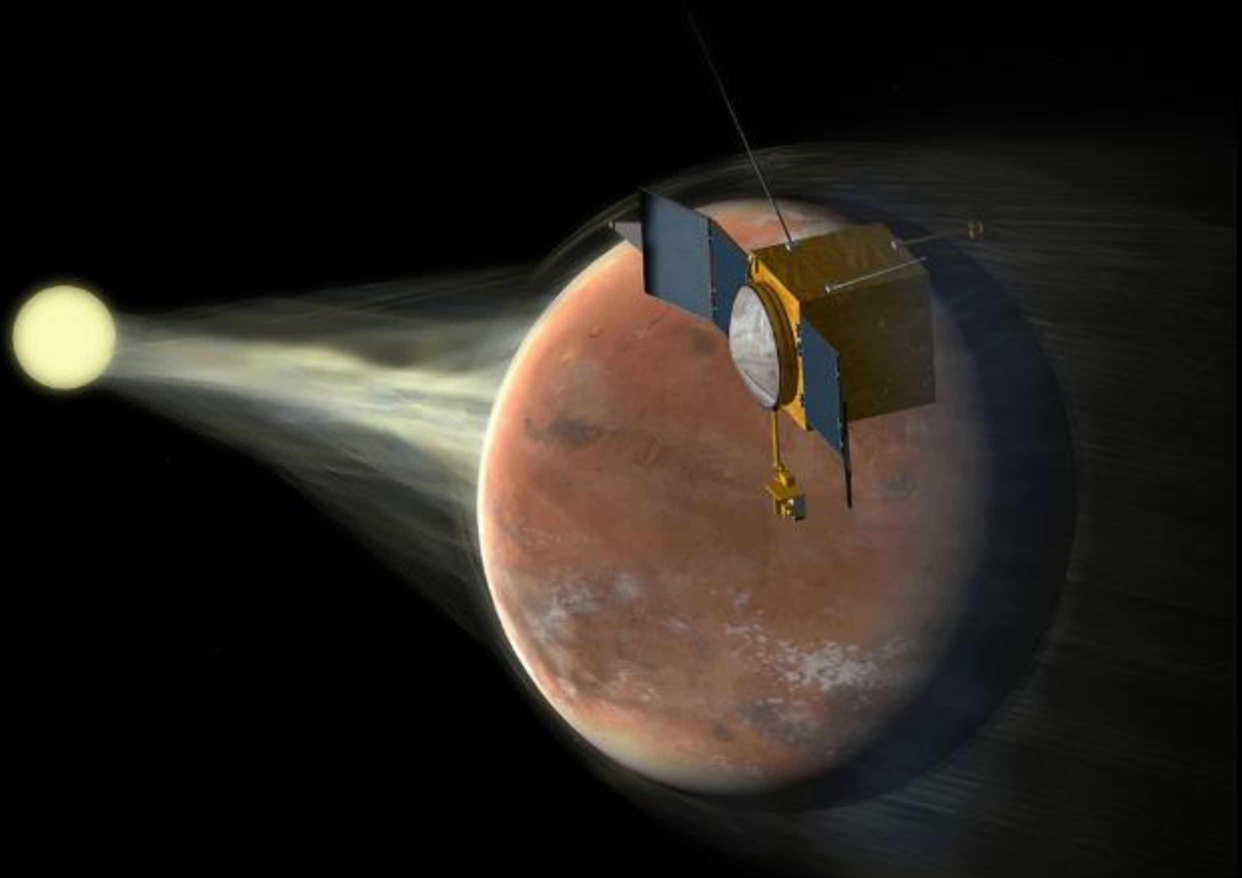
1.1 Science Traceability Matrix

Investigation	Goals	Objectives	Scientific Measurement Requirements: Physical Parameters	Scientific Measurement Requirements: Observables	Instrument Functional Requirements	Instrument Predicted Performance	Mission Functional Requirements Common to all Investigations	Mission Functional Requirements Specific to Each Investigation
Exoplanets and Space Weather	NASA Science Plan 2014 • Discover and study planets around other stars, and explore whether they could harbor life. New Worlds, New Horizons (2010 Decadal Survey) • Do habitable worlds exist around other stars, and can we identify the telltale signs of life on an exoplanet? • Discovery area: Identification and characterization of nearby habitable exoplanets. Exoplanet Science Strategy (National Academies of Sciences 2018) Goal 2: to learn enough about the properties of exoplanets to identify potentially habitable environments and their frequency, and connect these environments to the planetary systems in which they reside. • The presence and strength of a global-scale magnetic field is a key ingredient for planetary habitability.	E1: Determine the prevalence and strength of large-scale magnetic fields on rocky planets orbiting M dwarfs and assess the role of planetary magnetospheres in the retention and composition of planetary atmospheres and planetary habitability.	Planetary magnetic field strength (proportional to frequency). Local stellar wind velocity. Planetary rotation period and assessment of the presence of a convective interior for a sample of rocky planets orbiting M dwarfs out to 10 pc.	Planetary radio flux: < 250 μJy (in the 150 kHz–250 kHz band). Frequency range: 150 kHz–1 MHz band. Polarization (IQUV stokes parameters)	**Noise Equivalent Flux** (for 60 second integration): 40 mJy @ 200 kHz \ 0.5 Jy @ 10 MHz **Pointing Resolution (FWHM):** 10 deg @ 200 kHz \ 10 arcmin @ 10 MHz **Spectral Resolution:** < 25 kHz **Temporal Resolution:** < 60 seconds **Minimum Frequency:** < 150 kHz **Maxmimum Frequency:** > 20 MHz **Number of Frequency Channels in band:** > 1000 **Polarization:** Full Stokes radio telescope or array on lunar farside with < 5% uncertainty **Sky Coverage:** > 5,000 sq. degrees Any other driving requirements with sidelobes? UV coverage? Confusion?	**Noise Equivalent Flux:** 40 mJy @ 200 kHz \ 0.5 Jy @ 10 MHz **Pointing Resolution (FWHM):** 10 deg @ 200 kHz \ 10 arcmin @ 10 MHz **Spectral Resolution:** 25 kHz **Temporal Resolution:** 60 seconds **Minimum Frequency:** 100 kHz **Maxmimum Frequency:** 40 MHz **Number of Frequency Channels in band:** 1400 **Polarization:** Full Stokes radio telescope or array on lunar farside (to avoid ionosphere and RFI), operational from 300 kHz to 10 MHz. [5% uncertainty] **Sky Coverage:** 10,000 sq. degrees	**Location:** Latitude and longitudes within 65 degrees of the anti-Earth point (required to suppress RFI from Earth by −80dB).	**Observation time:** > 1000 hours
		E2: Determine whether the largest stellar flares are accompanied by comparably large CMEs that can escape the corona of the star to impact the space environment of orbiting exoplanets. E3: Determine the space weather environment of rocky planets orbiting M dwarfs during extreme space weather events and assess whether such events play a decisive role in atmospheric retention and planetary habitability. E4: Determine the impact of extreme space weather events on exoplanets orbiting Solar type (FGK) stars and assess whether such events play a decisive role in atmospheric retention and planetary habitability.	Stellar radio bursts from particles accelerated in magnetic fields that vary with frequency due to their local plasma environment.	Radio burst dynamic spectrum: sensitivity 40 mJy @ 200 kHz \ 0.5 Jy @ 10 MHz over 60 seconds. Frequency range: 150 kHz–35 MHz band.	**Noise Equivalent Flux** (for 60 second integration): 40 mJy @ 200 kHz \ 0.5 Jy @ 10 MHz **Pointing Resolution (FWHM):** 10 deg @ 200 kHz \ 10 arcmin @ 10 MHz **Spectral Resolution:** < 25 kHz **Temporal Resolution:** < 60 seconds **Minimum Frequency:** <= 100 kHz **Maxmimum Frequency:** > 35 MHz **Number of Frequency Channels in band:** > 1000 **Sky Coverage:** > 5,000 sq. degrees			
Cosmology	"Explore how (the Universe) began and evolved" NASA Science Plan (2014) "What is the nature of dark matter?" Astro2010 "Resolve the structure present during the dark ages and the reionization epoch" NASA Astrophysics Roadmap	C1: Determine if excess cooling beyond adiabatic expansion in standard cosmology and exotic physics (e.g., baryon-dark matter interactions) are present in the Dark Ages with > 5σ confidence.	Redshift-dependent *mean* brightness temperature variation of the cosmic radio background at the level of −100 mK due to the spin-flip transition of neutral hydrogen. Redshift range approx. (50 < z < 130)	Brightness temperature: a −40 mK absorption feature between 11–28 MHz against the cosmic radio background, globally averaged over > 10 deg^2. Frequency range approx. 11–28 MHz (corresponding to 50 < z < 130). Frequency resolution of 50 kHz to resolve the absorption feature and allow foreground & RFI mitigation and systematic checks. Astrophysical foreground mitigation to better than 10^5 level in spectral domain.	**Noise Equivalent Brightness Temperature Sensitivity:** < 20 mK **Antenna Beam Size:** field-of-view > 10 deg^2 (non-driving) **Antenna Beam Pattern Knowledge:** To a level of < 50 dB.	**Noise Equivalent Brightness Temperature Sensitivity:** 15 mK **Antenna Beam Size:** field-of-view > 10,000 deg^2 **Antenna Beam Pattern Knowledge:** 50 dB		**Observation time:** > 5000 hours

From the Probe Study Report: https://arxiv.org/abs/1911.08649



Young Mars was warmer
and wetter



MAVEN
Jakosky et al. 2015

- **Flares – higher X-ray and ultraviolet radiation flux –>**
  drives photochemistry and thermal escape

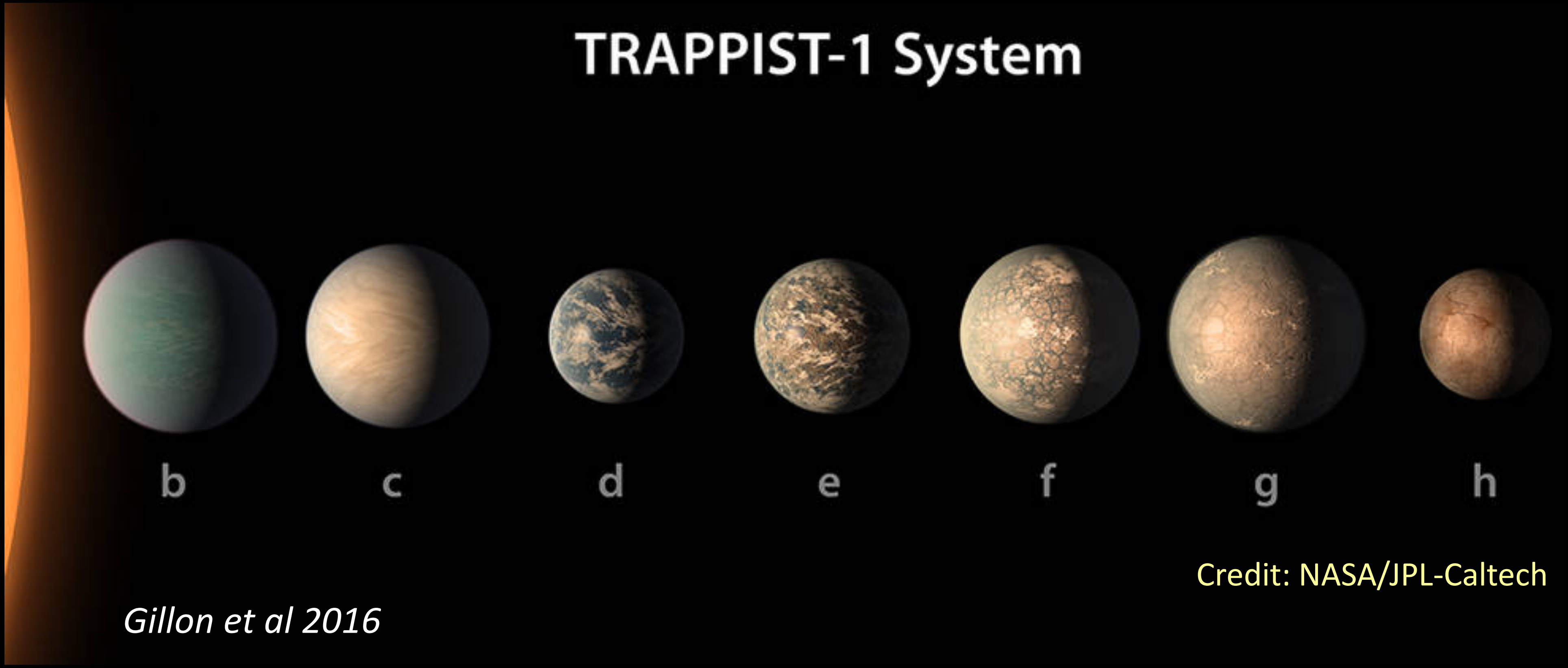
- **Particle flux – Coronal Mass Ejections and Solar Energetic Particles –>**
  can erode atmosphere – e.g. ion pick-up erosion (Kulikov 2007)

Does magnetic activity redefine habitability?

Are magnetospheres an important ingredient for habitability?

The jury is still out - Barabash (2010), Ehlmann et al. 2016

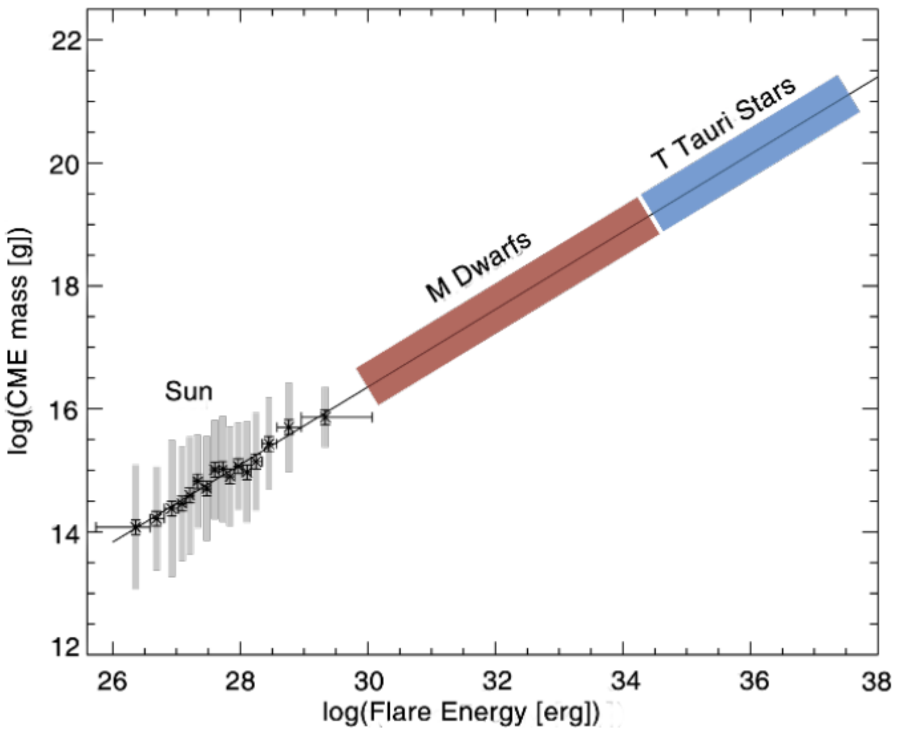
The M Dwarf Opportunity



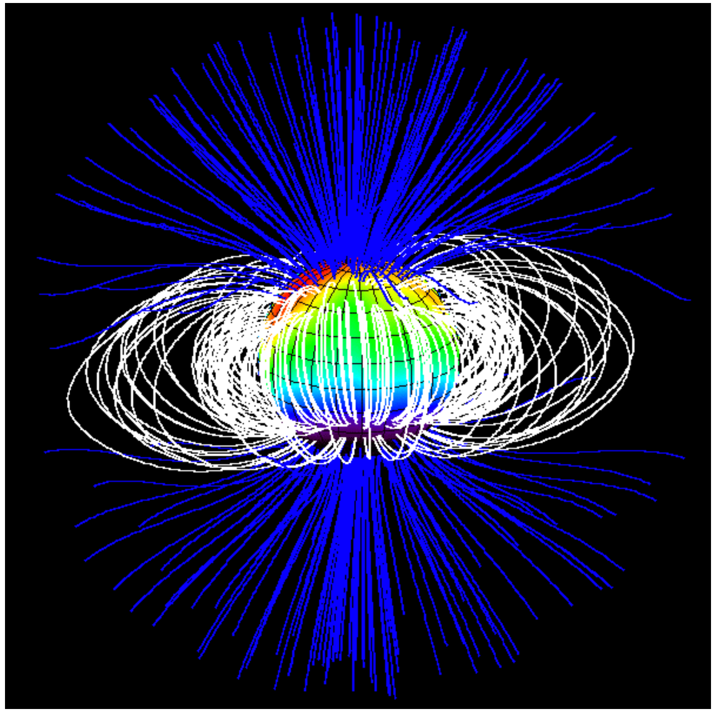
Rocky planets are particularly frequent around M dwarfs (Dressing & Charbonneau 2013, 2015)

- **Flares up to 10^4 times the largest solar flares (Osten et al. 2016)**
- **Habitable zone much closer to the parent star**
- **Active for much longer (West et al. 2008)**

Stellar Coronal Mass Ejections



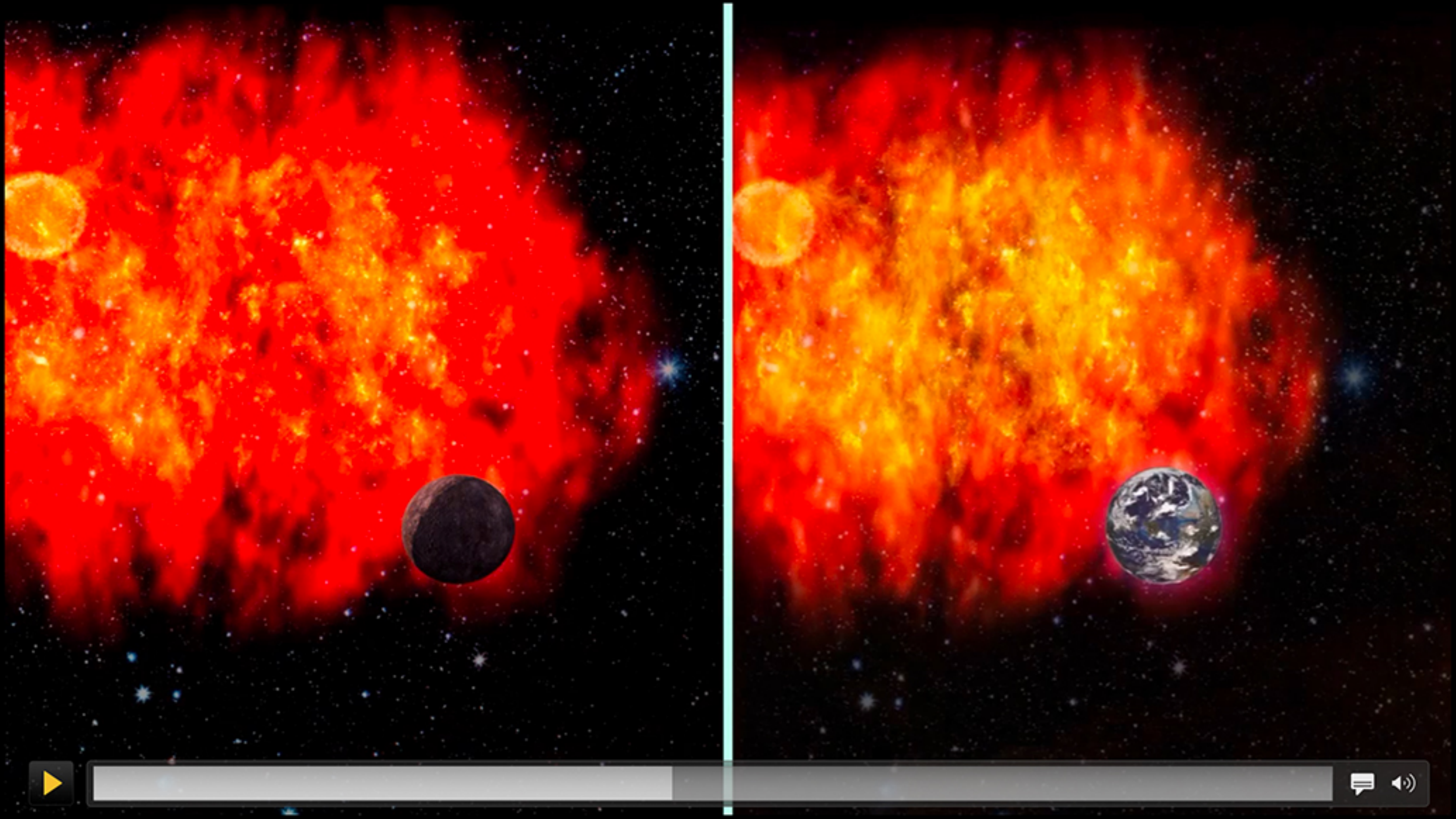
Adapted from Aarnio et al. 2012



Donati et al. 2006

No direct evidence of CMEs on any main sequence star other than the Sun to date

Magnetic field configuration may play an important role (Alvarado-Gómez et al. 2018, Villadsen & Hallinan 2019)



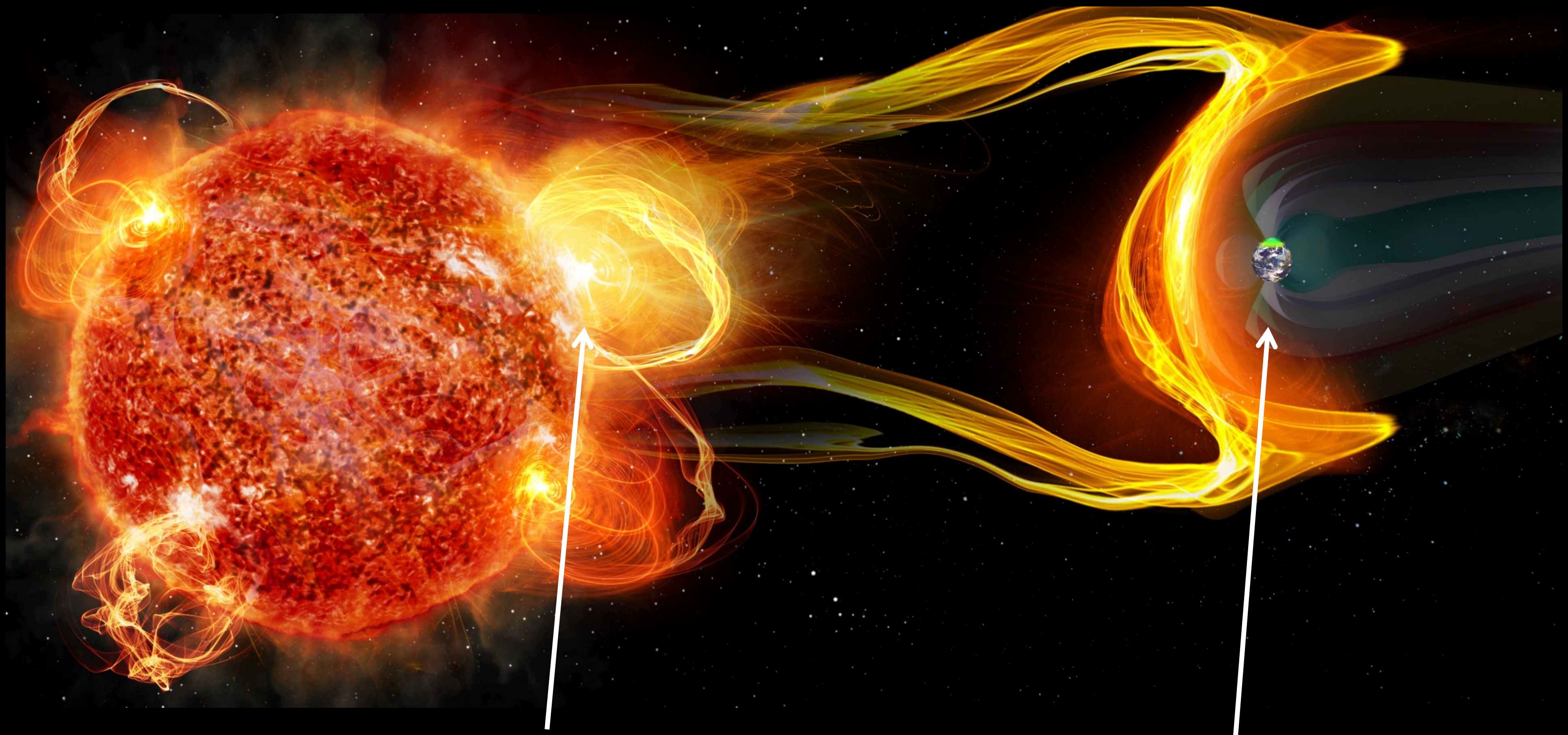
Credit: Chuck Carter and Caltech/KISS

Do M dwarfs produce super-CMEs?

Can the magnetospheres of orbiting exoplanets support an atmosphere and biosphere?

Magnetospheres and Space Environments of Candidate Habitable Planets

Credit: Chuck Carter & Caltech/KISS

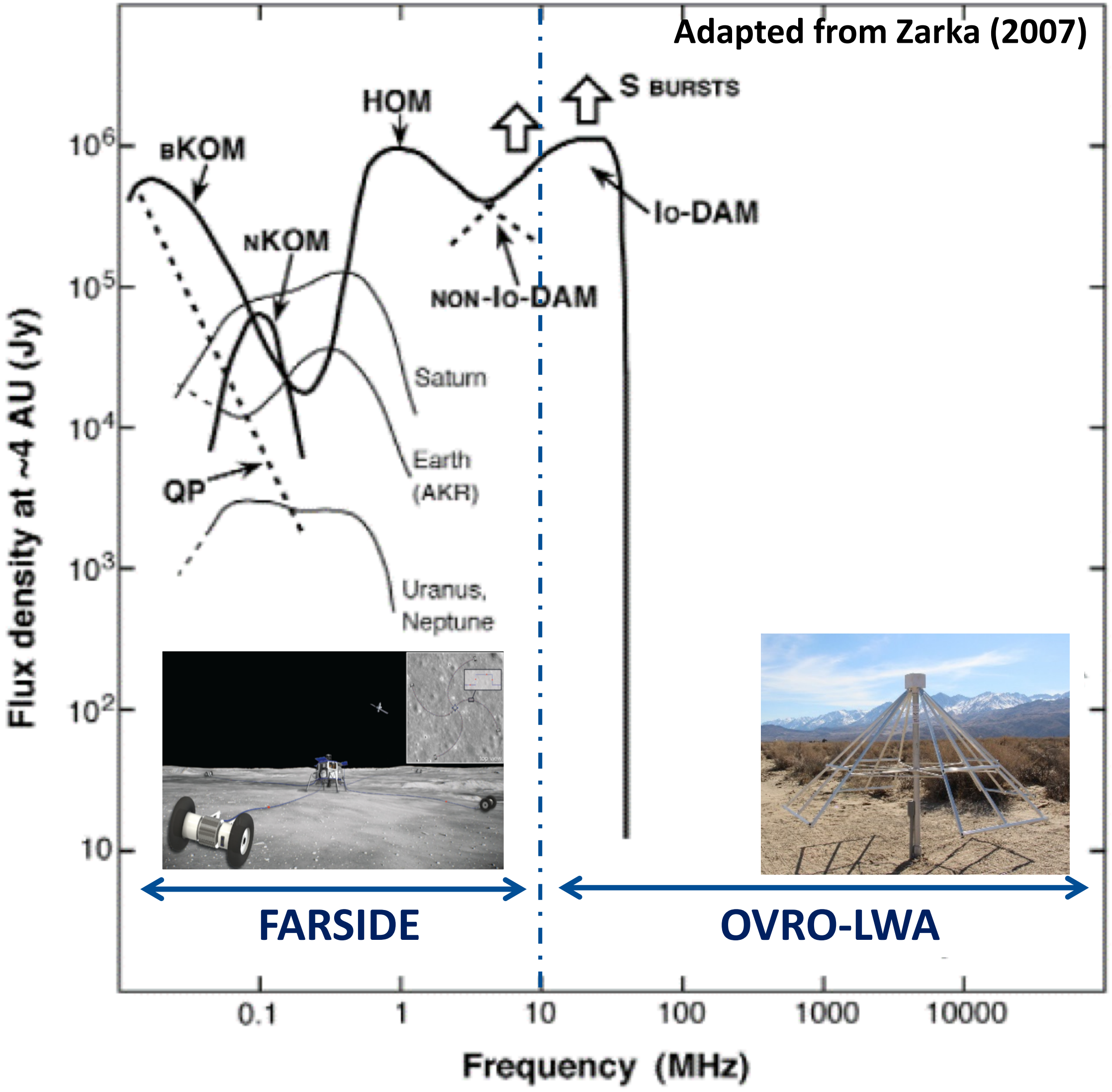


Type II radio bursts
traces density at CME shock

Auroral radio emission
measures magnetic fields

Radio Emission from Planets

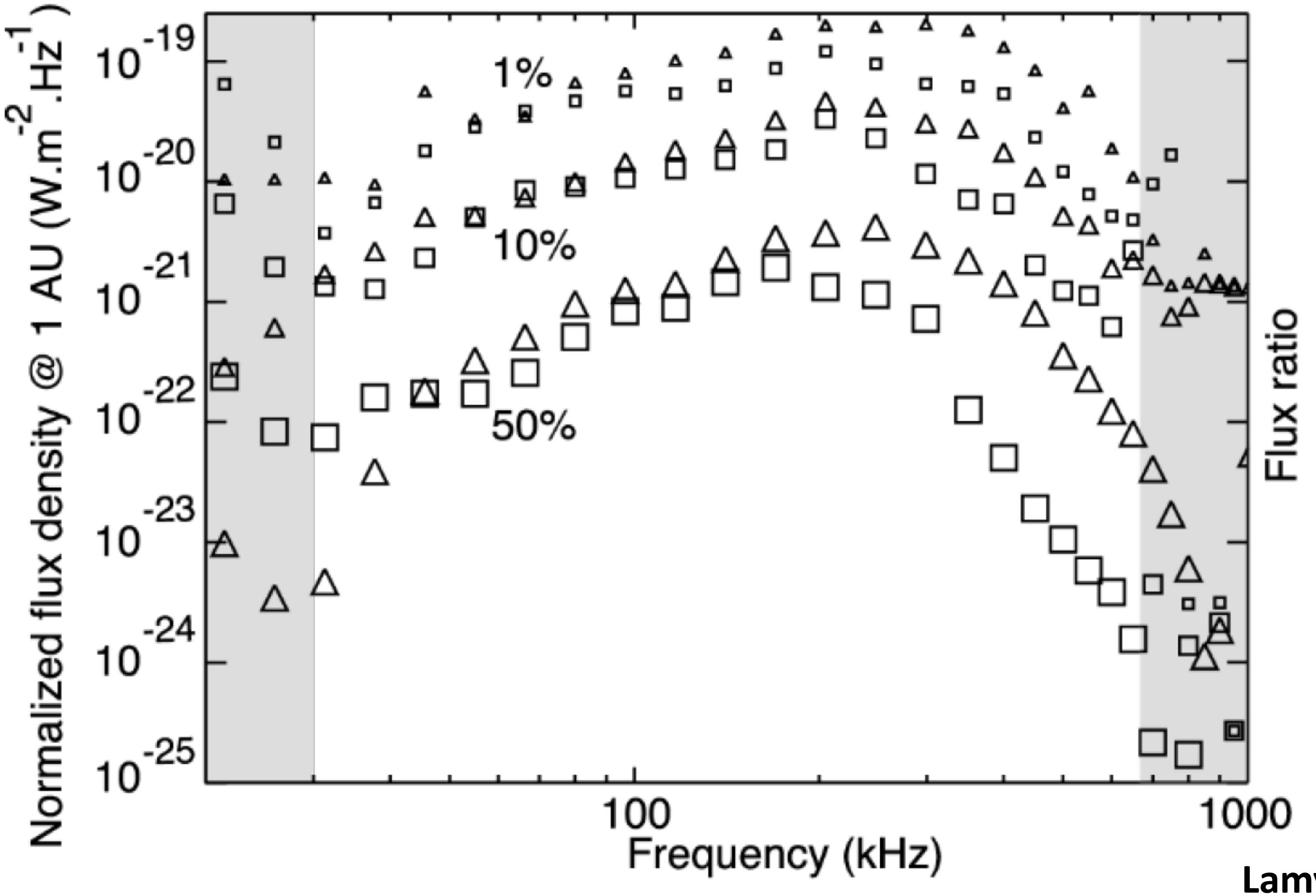
- **Electron cyclotron maser emission - coherent, highly circularly polarized**
- **Frequency (MHz) = B_{Gauss} x 2.8**



Lots of exciting results from the ground…

Kao et al. 2018
Turner et al. 2020
Hallinan et al. 2015
Vedantham et al. 2019

Earth's AKR is Highly Variable



Lamy et al. 2010

- **Need to monitor systems for 1000s of hours**

Requirements

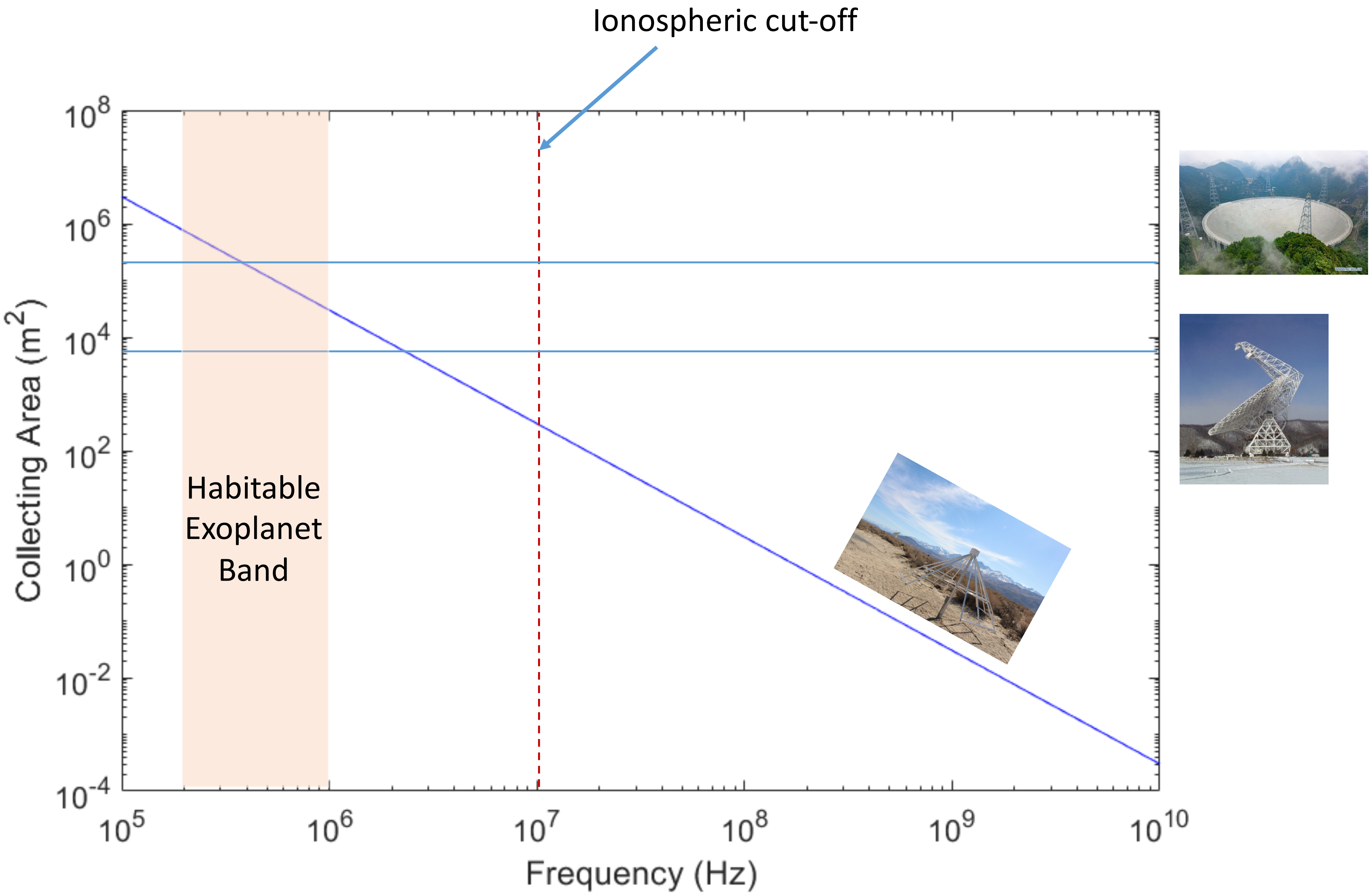
Need many km^2 of collecting area…

in space…

that can monitor 1000s of stellar systems simultaneously

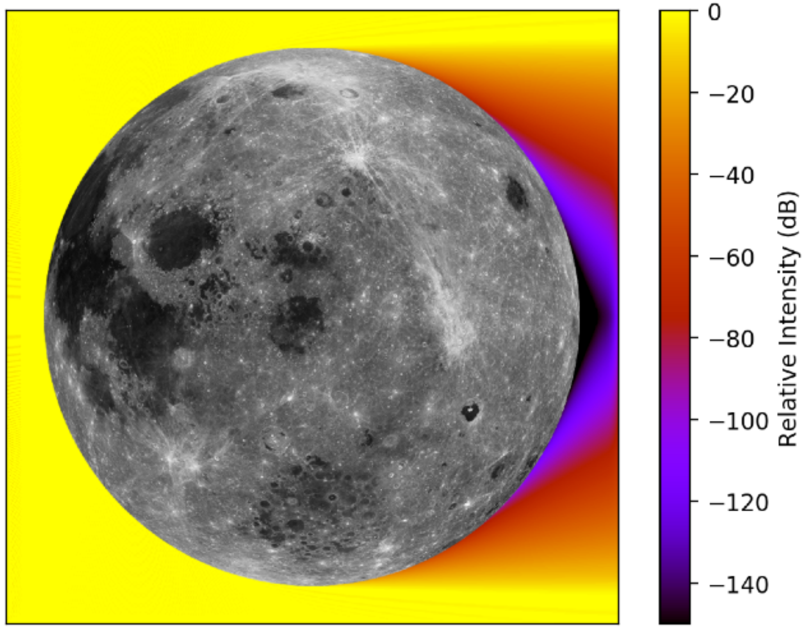
EASY!

What kind of Antenna?

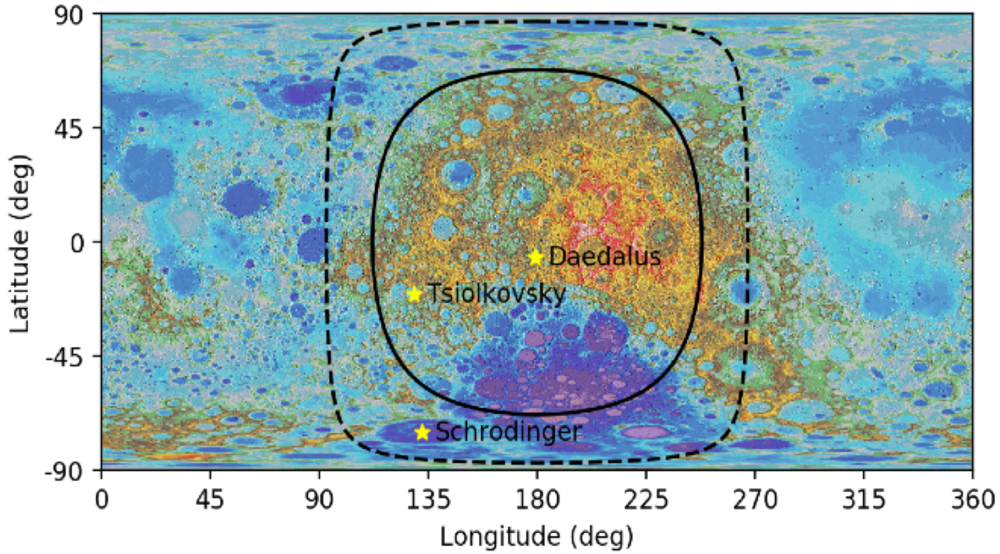


Simulations of the Radio Environment of the Moon

Bassett, Burns, et al. 2020, *Advances in Space Research*



Two-dimensional numerical electrodynamics simulations show that the relative intensity of terrestrial radio waves incident on the Moon is highly attenuated behind the farside.

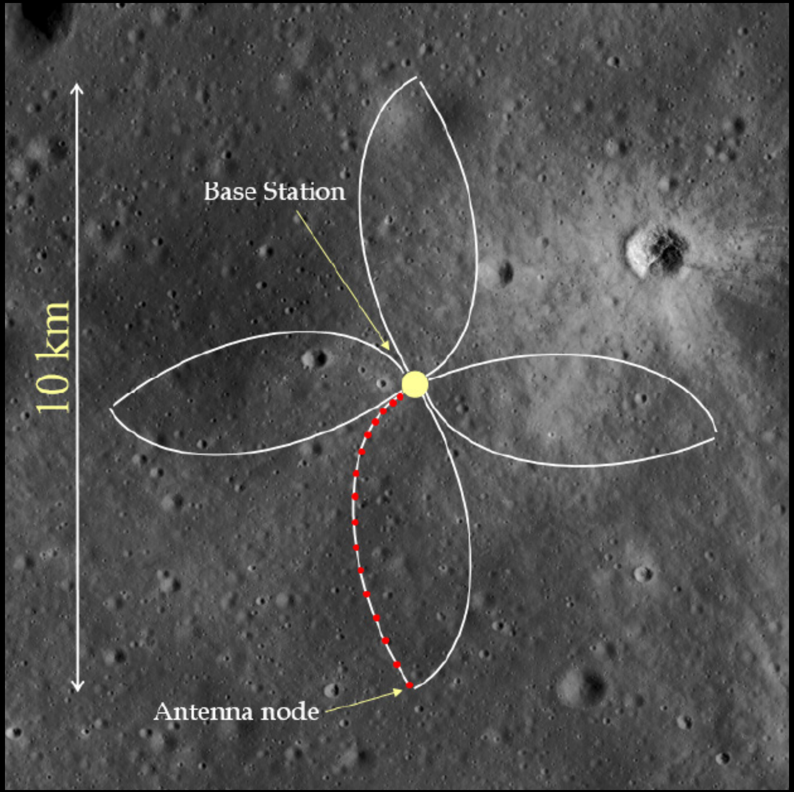


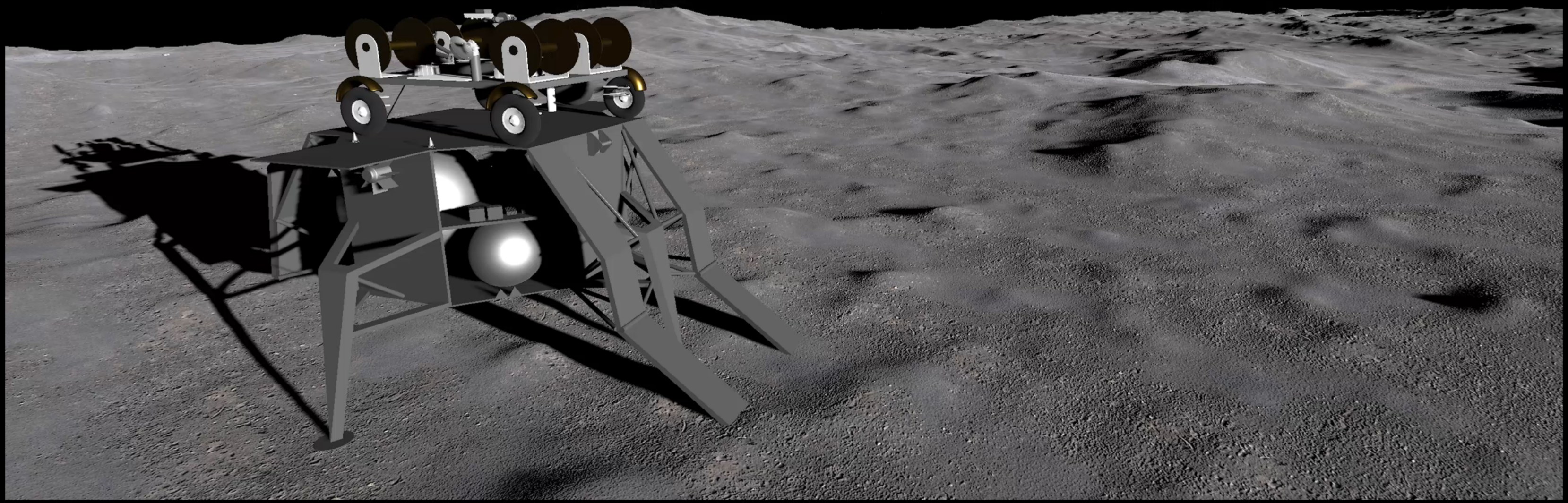
The "radio quiet" region at 100 kHz (solid) and 10 MHz (dashed) defined by ≥ 80 dB attenuation plotted over a map of the lunar surface.

FARSIDE Timeline to Date

- Nov 2018: Directed probe study commenced – JPL selected as NASA Center
- Mar 2019: Overall architecture selected [JPL Team X]
- Apr 2019: Follow up Rover, Base Station and Instrument studies [JPL Team X]
- July 2019: Astro2020 APC White paper [https://arxiv.org/abs/1907.05407]
- Nov 2019: Final Probe Study Report submitted [https://arxiv.org/abs/1911.08649]
- April 2020: Commencement of JPL / Blue Origin Partnership
- Aug 2020: Planetary Science Decadal Review White Paper

FARSIDE Initial Design





video credit: M. Walker, J. Burns,
University of Colorado Boulder

Blue Moon Lander

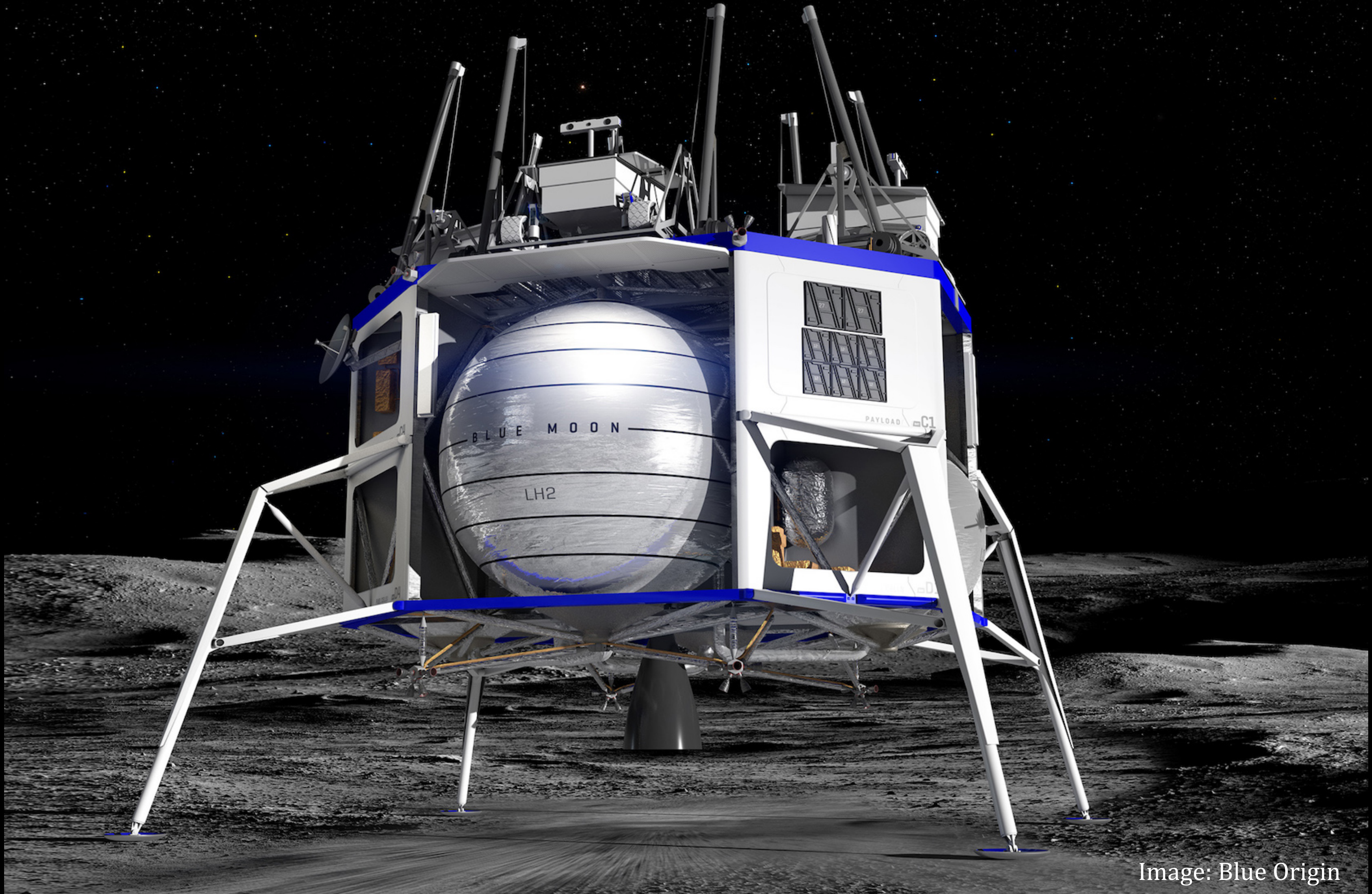
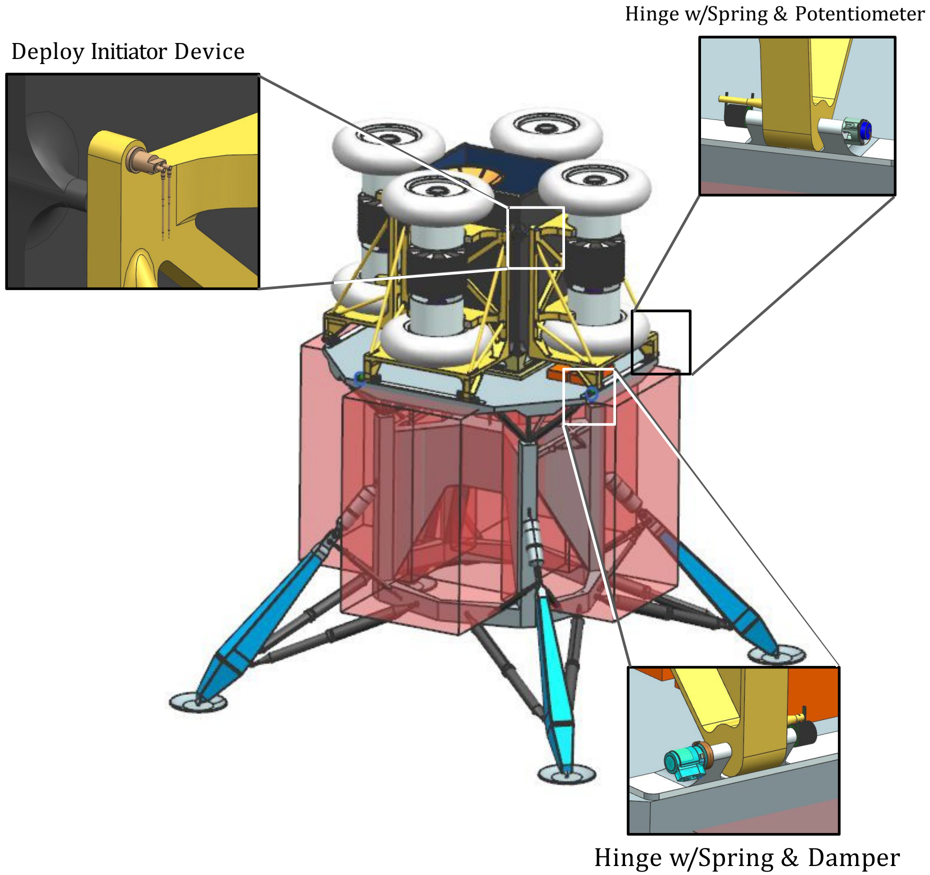


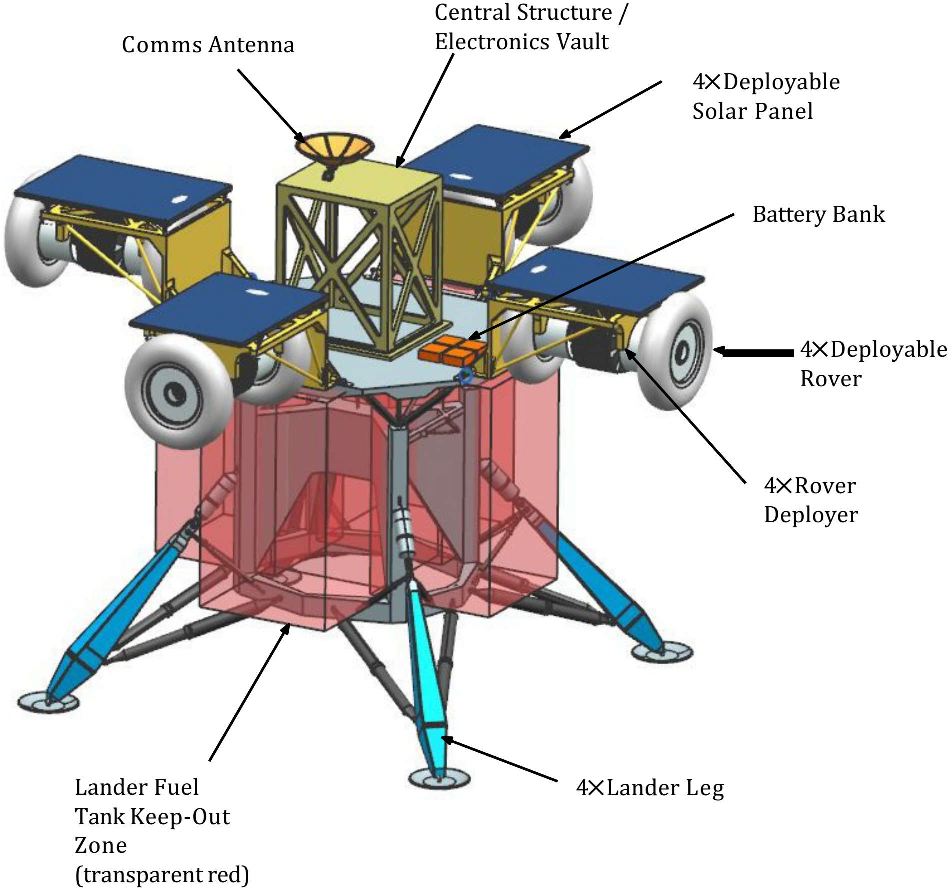
Image: Blue Origin

Lander/Rover Configuration Overview

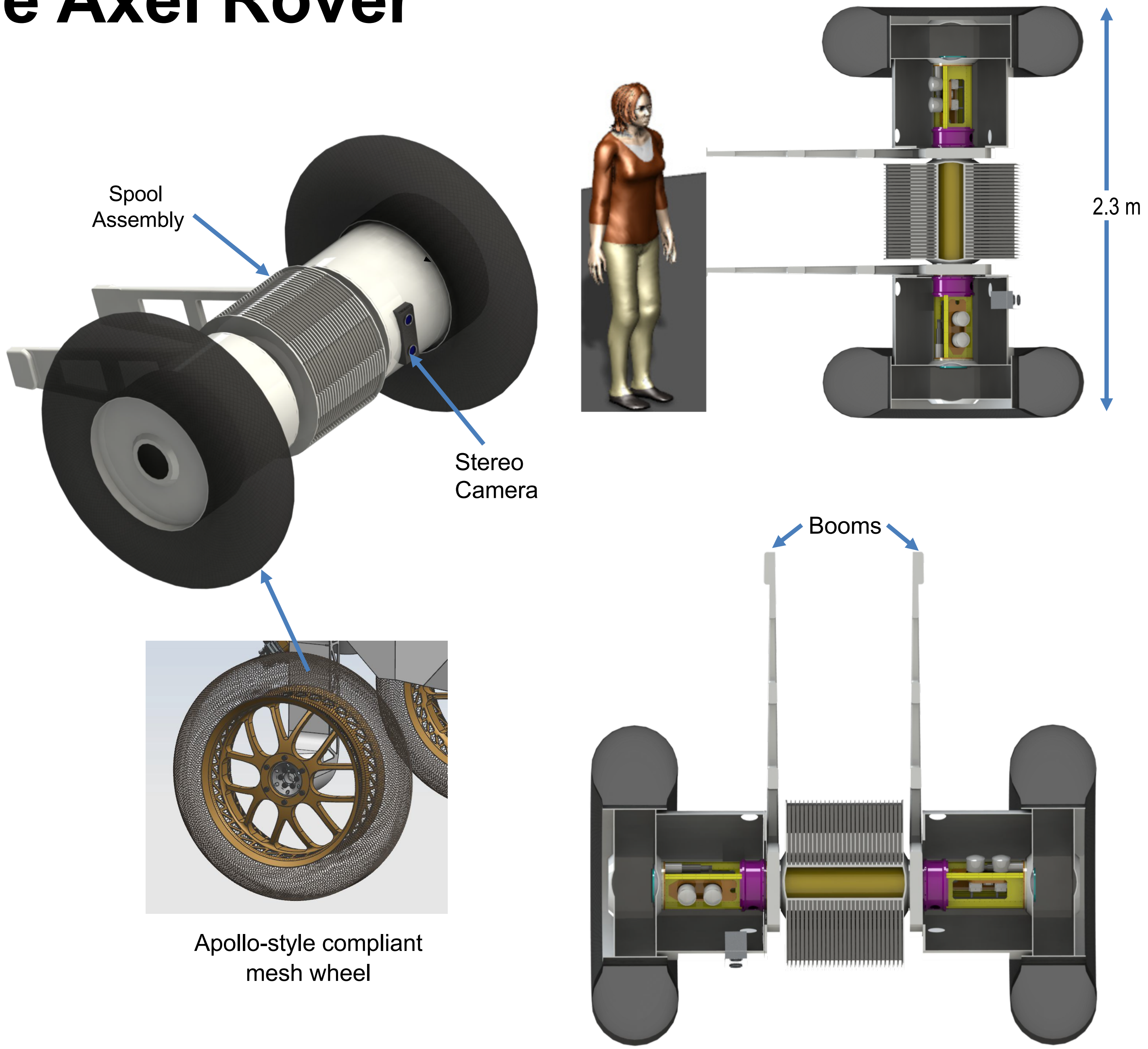
Stowed/Landing Configuration



Mid-Deploy Configuration



The Axel Rover



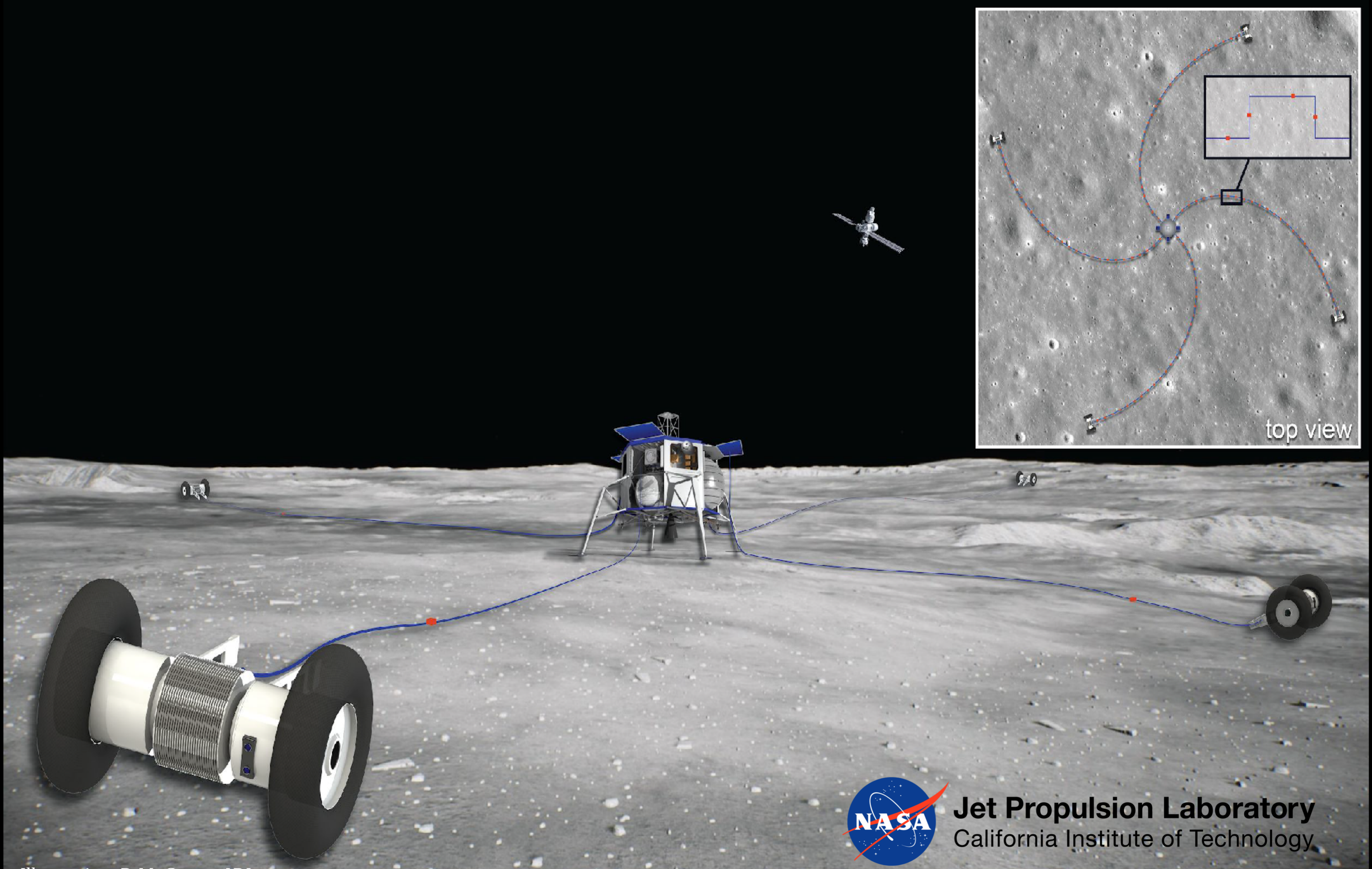
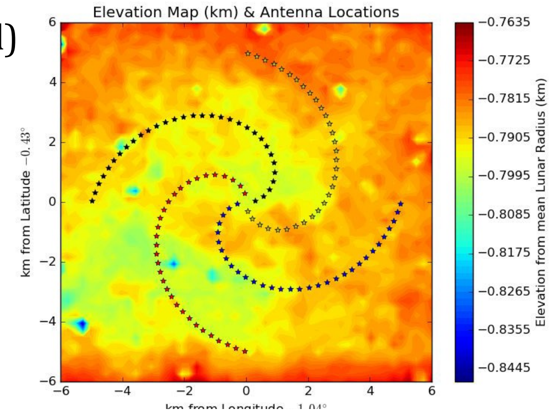


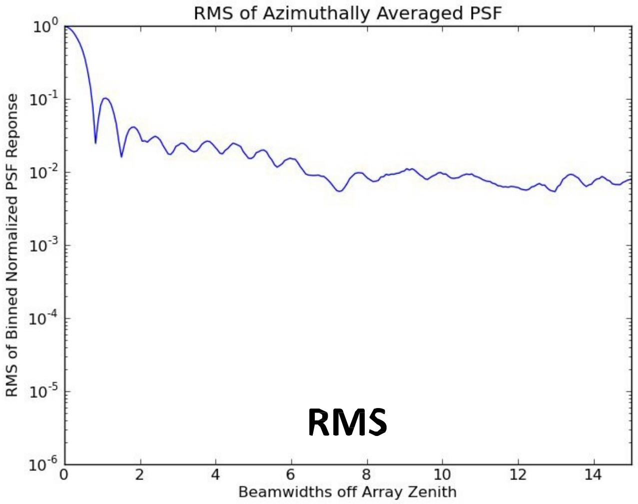
Illustration: P. McGarey, JPL

Tether/Antenna Response (Nominal)

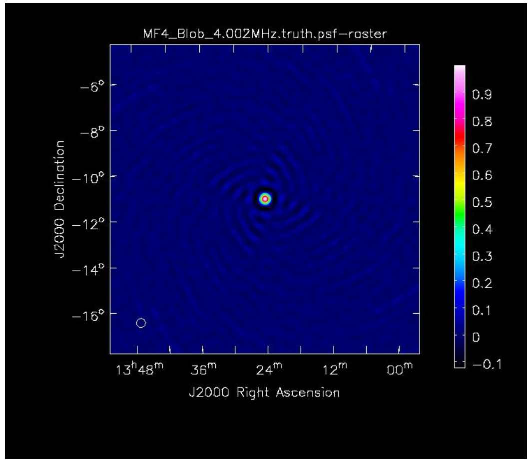
8.9 km arm length
4 spiral configuration (4 operational)

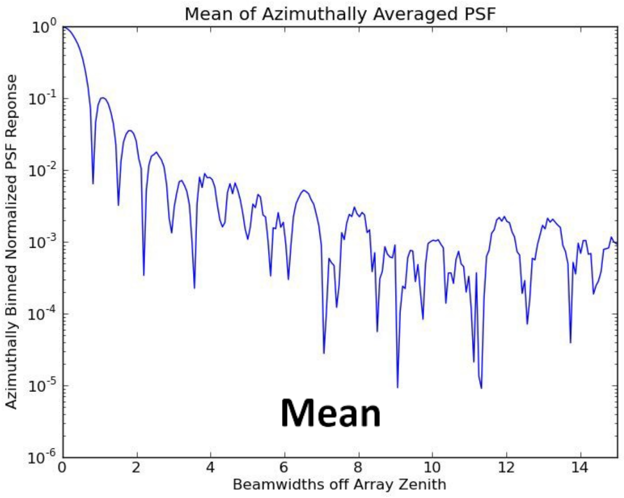
Frequency	Beam Width, arcsec
100 kHz	55,255.2
10 MHz	552.552
40 MHz	138.138
80 MHz	69.069

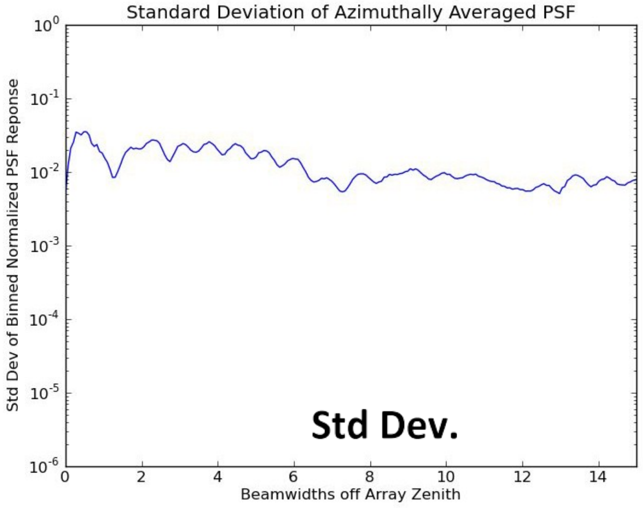




Point Spread Function

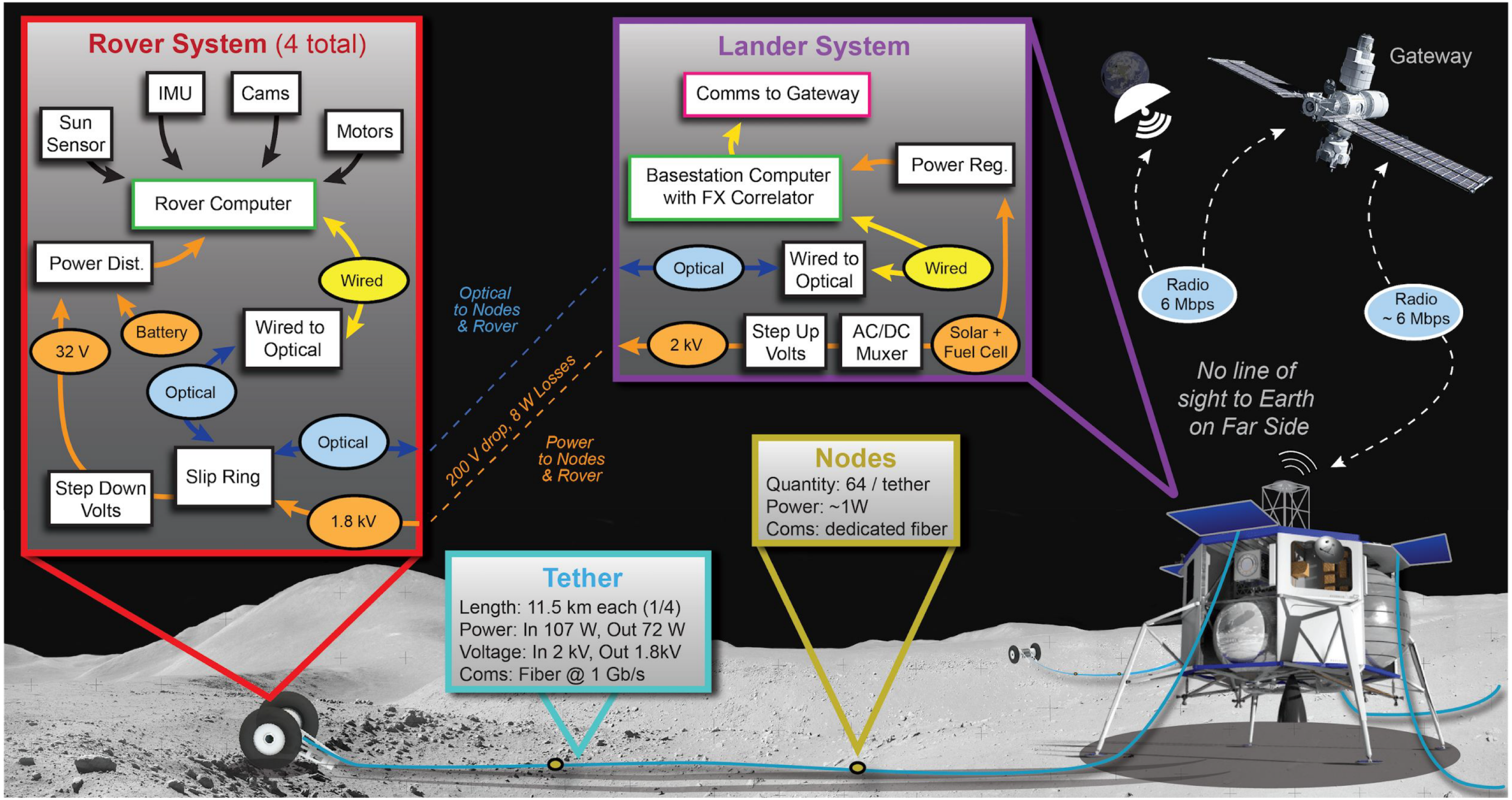




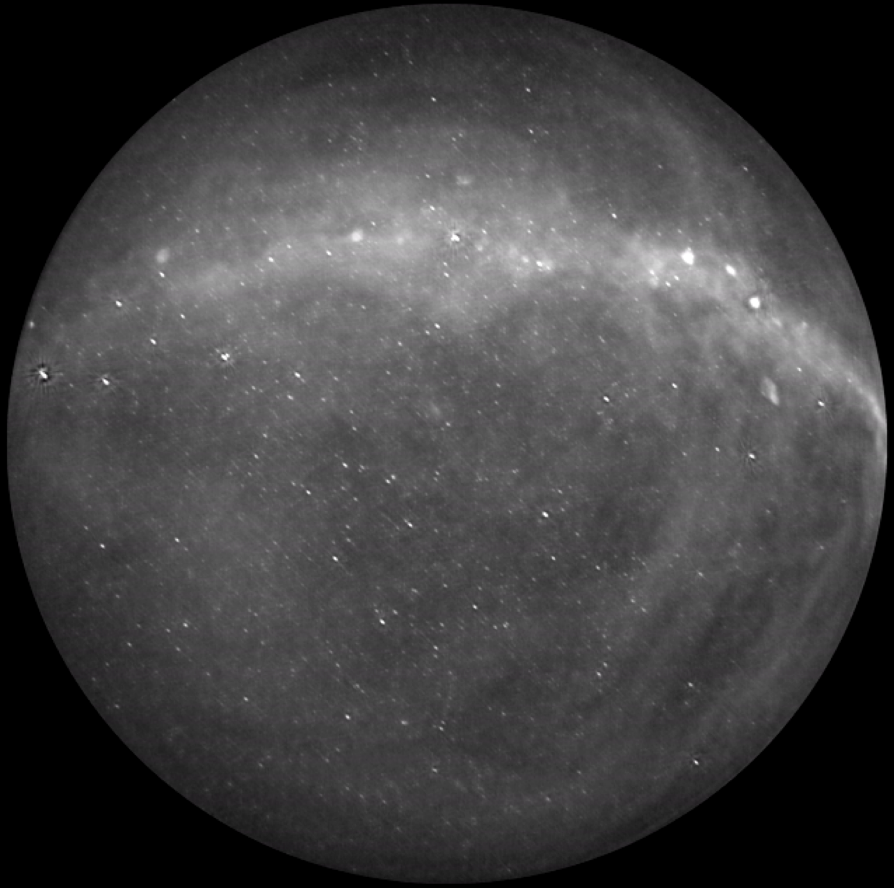


FARSIDE Mission Architecture

Frequencies: 100 kHz to 40 MHz



Data Products

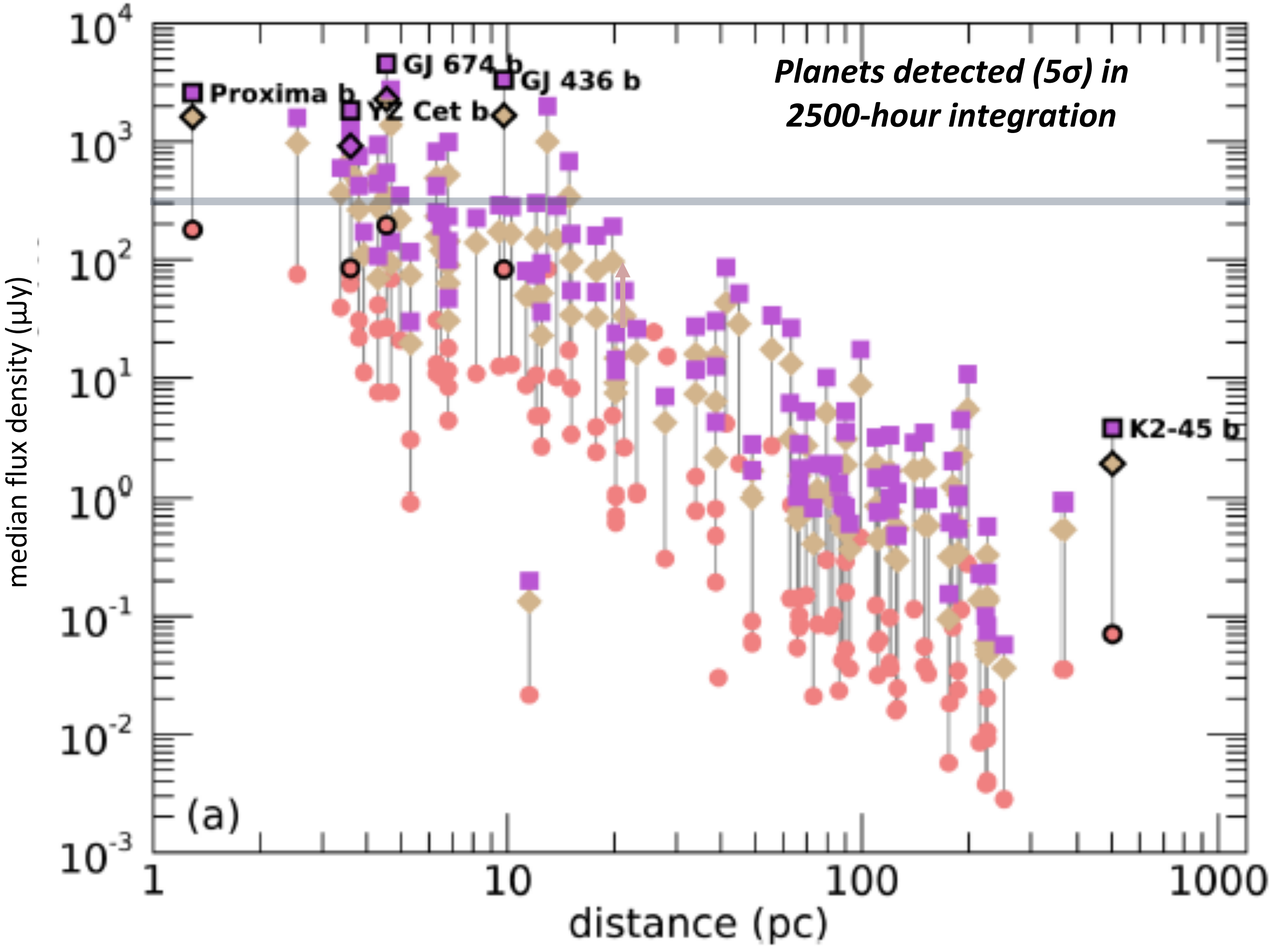


Marin Anderson and the OVRO-LWA team

Data products are identical to OVRO-LWA, but 100x lower in frequency

Frequency range: 0 – 40 MHz (1400 channels)
Integration time: 60 s
All visibilities: 65 GB/day
All-sky imaging every 60 seconds (Stokes I and V)
Deep all-sky imaging every lunar day (no confusion noise!)

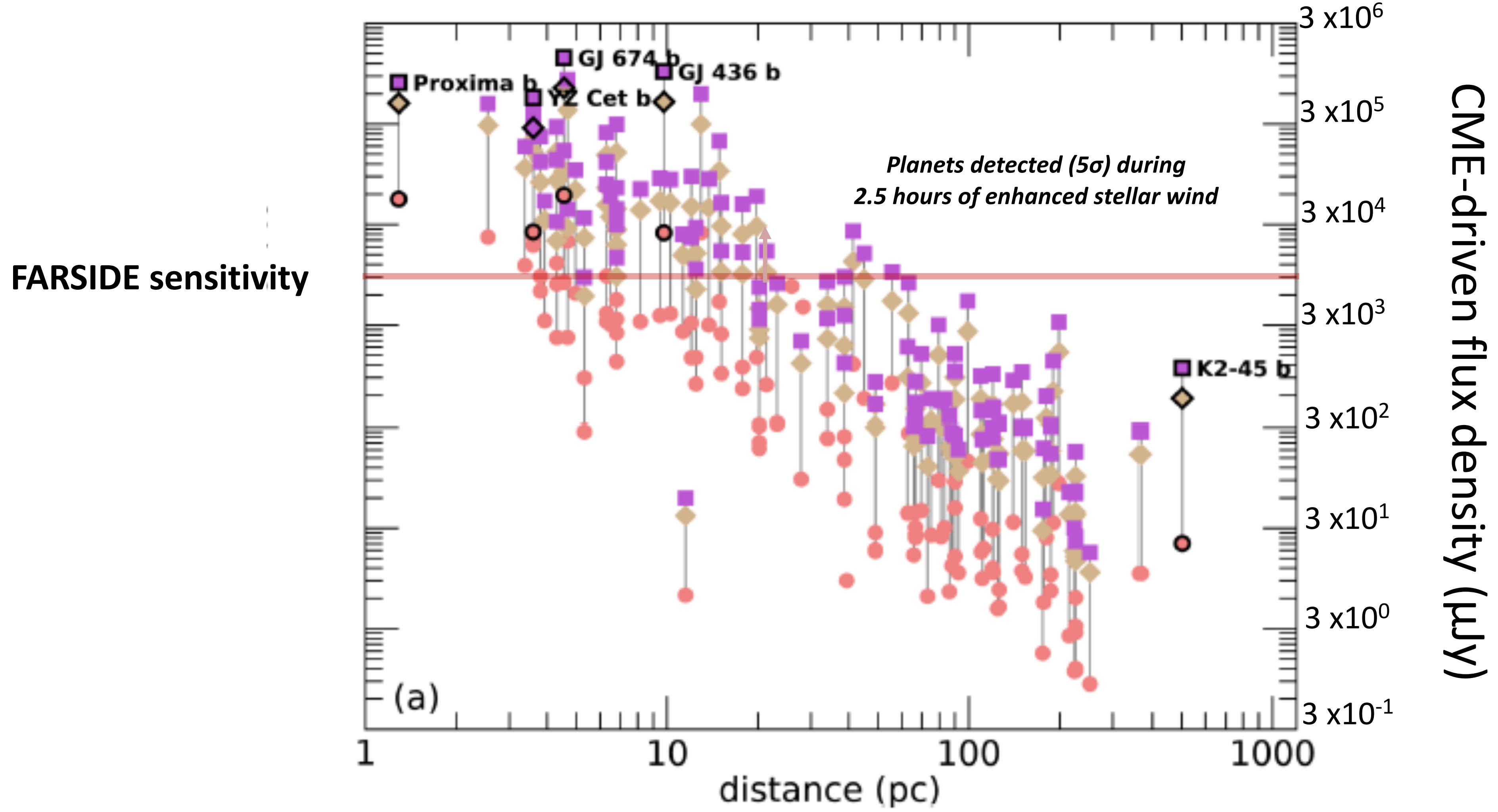
Median Exoplanet Radio Emission



FARSIDE sensitivity

Adapted from Vidotto et al. 2019

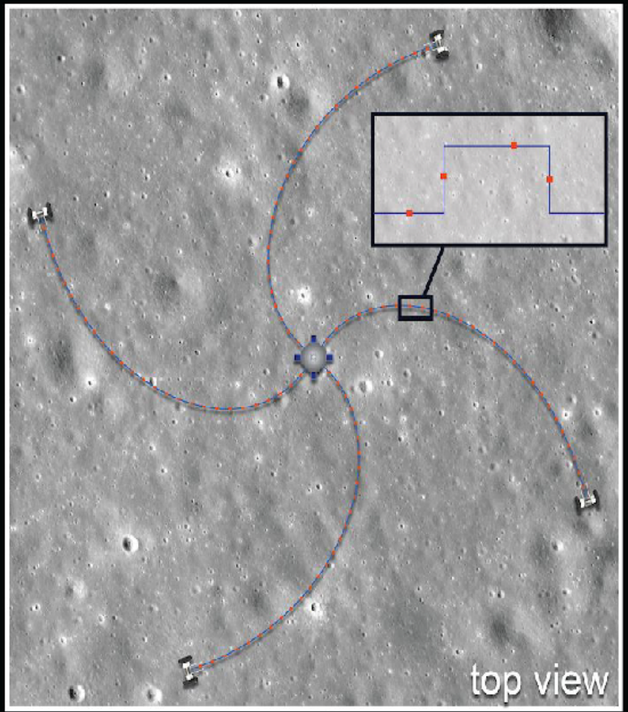
CME-driven Exoplanet Radio Emission



Adapted from Vidotto et al. 2019

Summary

- FARSIDE is proposed to consist of 128 dipole antennas on the lunar far side
- NASA-funded study to define architecture and feasibility
- Recent collaboration between JPL and Blue Origin has greatly improved the design
- FARSIDE will detect CMEs and SEP-like events from solar-type stars and M dwarfs
- FARSIDE will measure the magnetospheres of the nearest candidate habitable planets



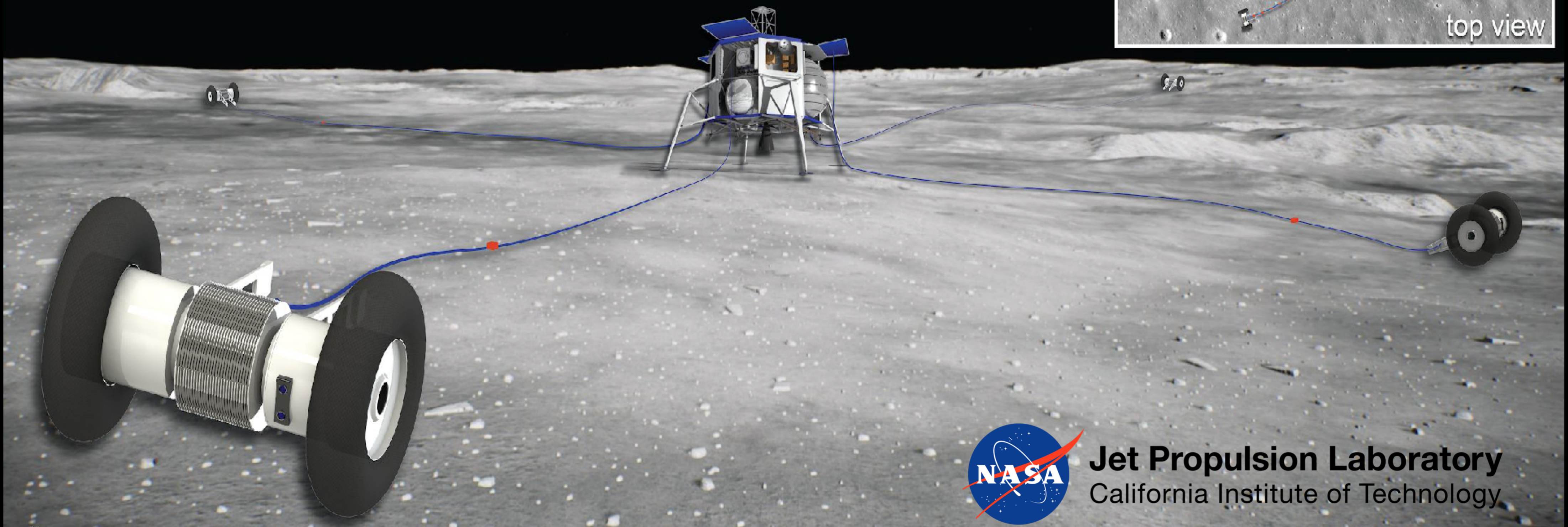


Illustration: P. McGarey, JPL