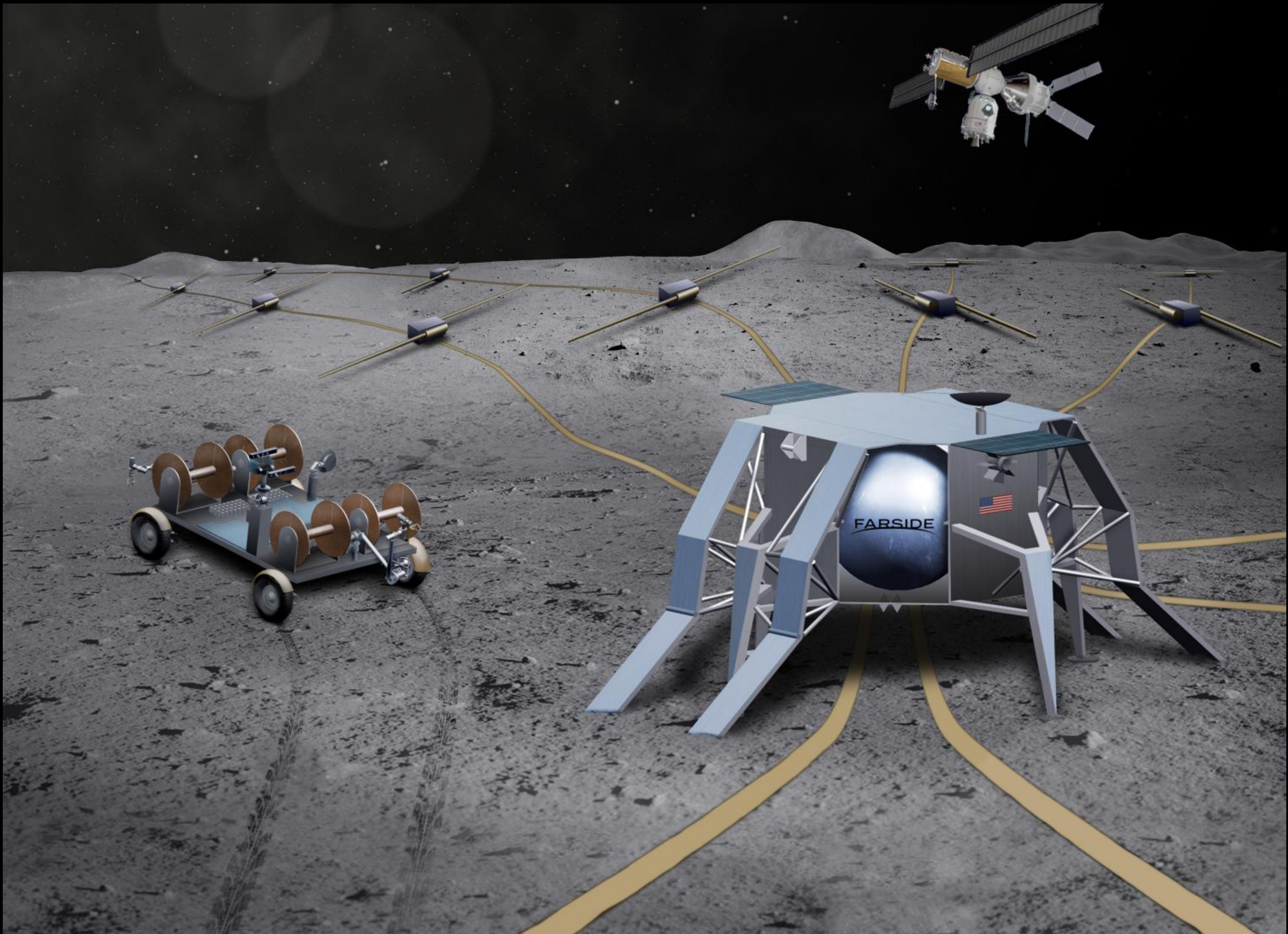
FARSIDE: A Low Radio Frequency Interferometric Array on the Lunar Farside



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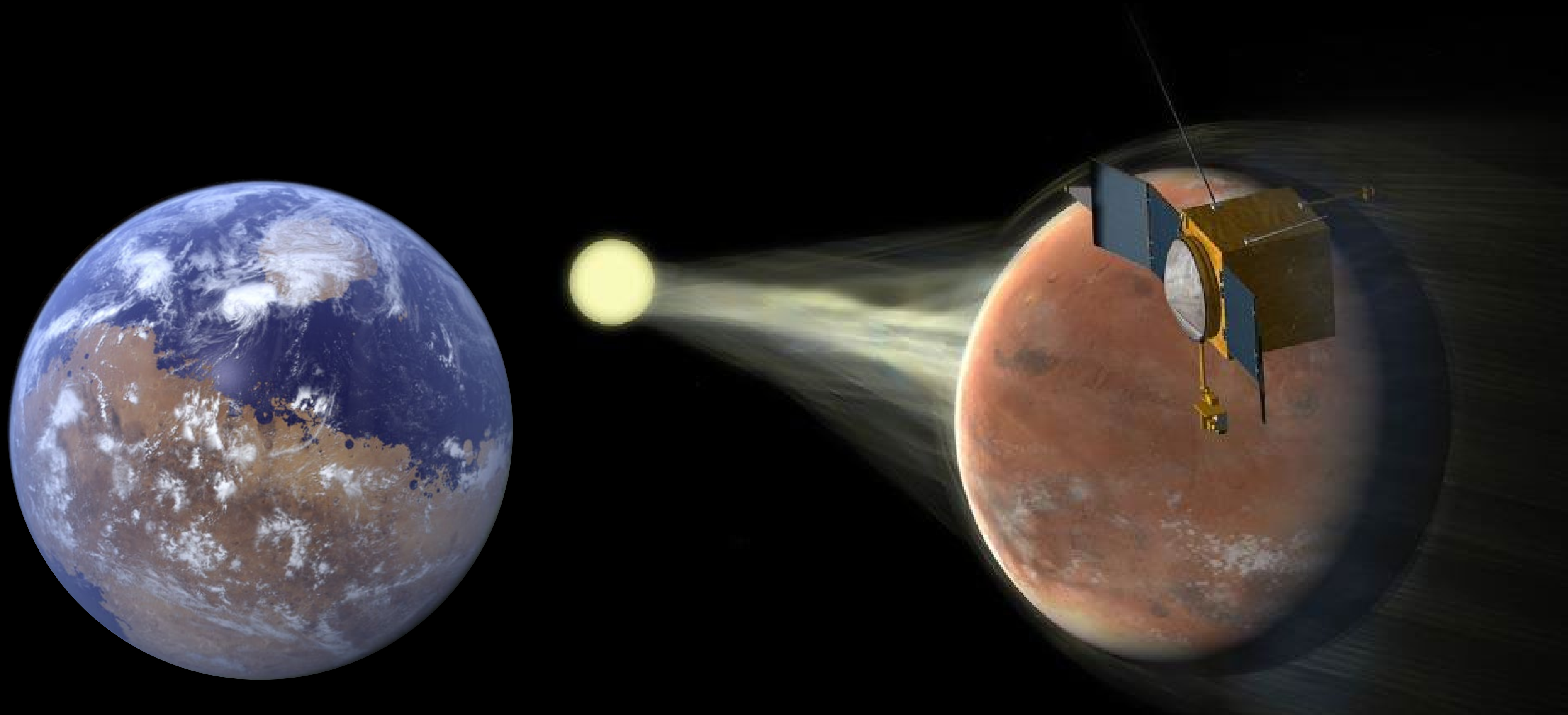
The Dark Ages and Cosmic Dawn

Magnetospheres and Space Environments of Habitable Planets

Simulation: Marcelo Alvarez

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

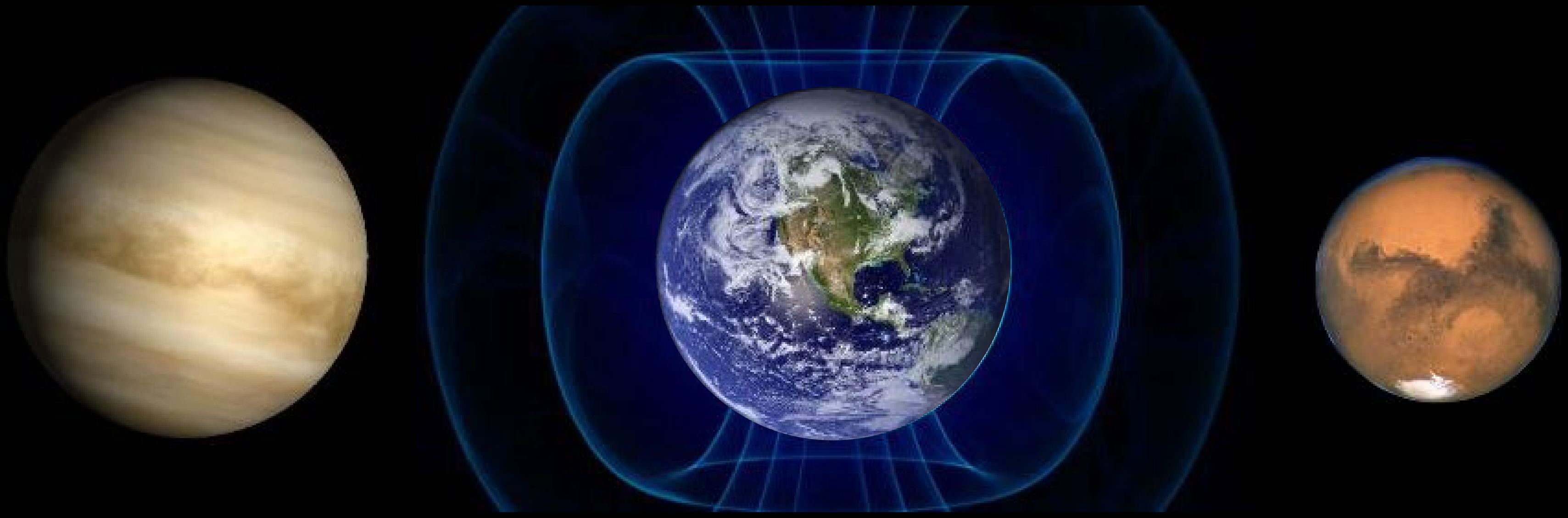


Young Mars was warmer and wetter

Mars atmosphere removed by coronal mass ejections from the young Sun (Jakosky et al. 2015)

Flares – higher X-ray and ultraviolet radiation flux –>
heating results in extended thermospheres (Lammer et al. 2003)

Coronal mass ejections (CMEs) – higher stellar wind flux –>
can erode atmosphere – eg. ion pick-up erosion (Kulikov 2007)

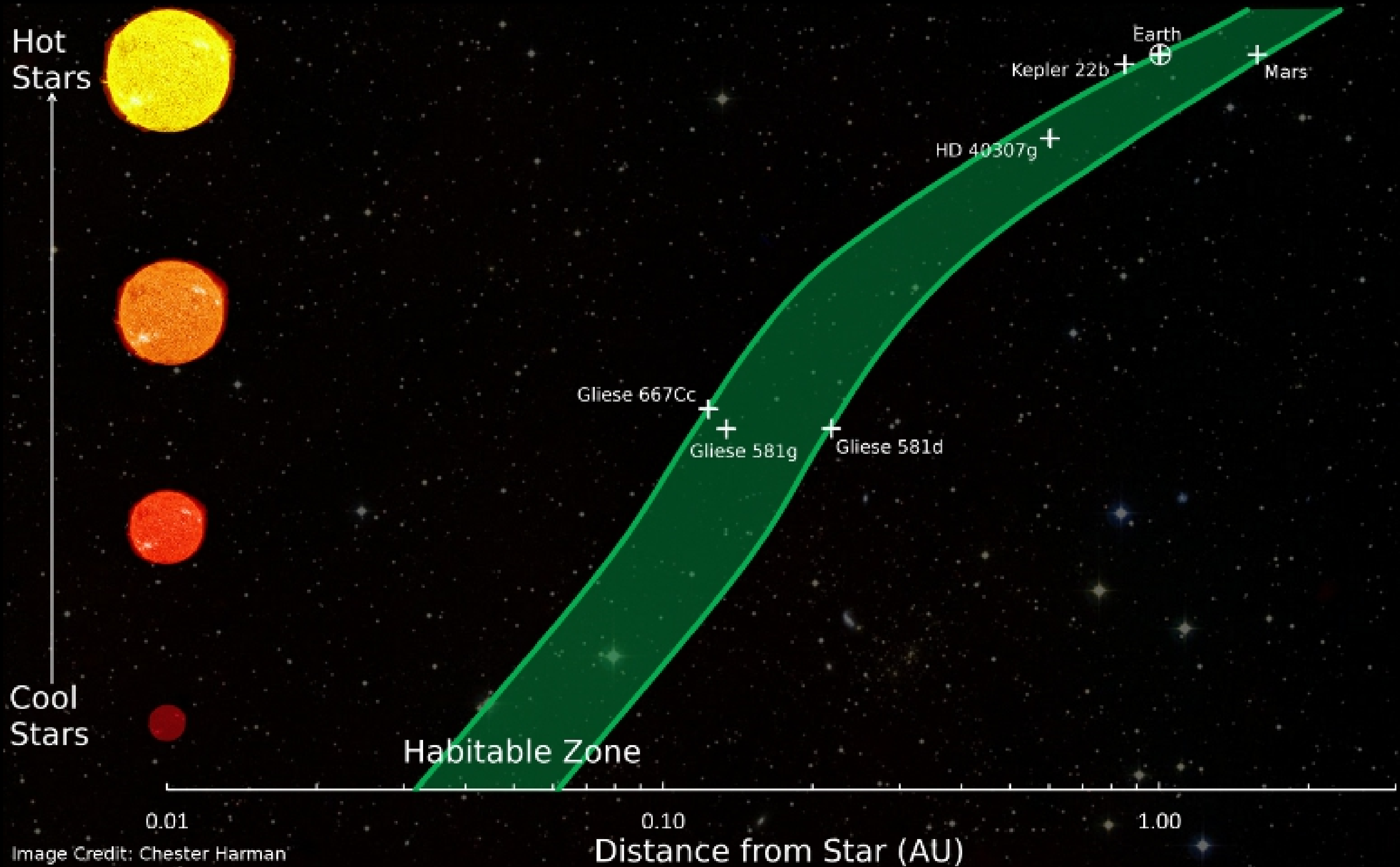


Magnetic activity can redefine habitability!

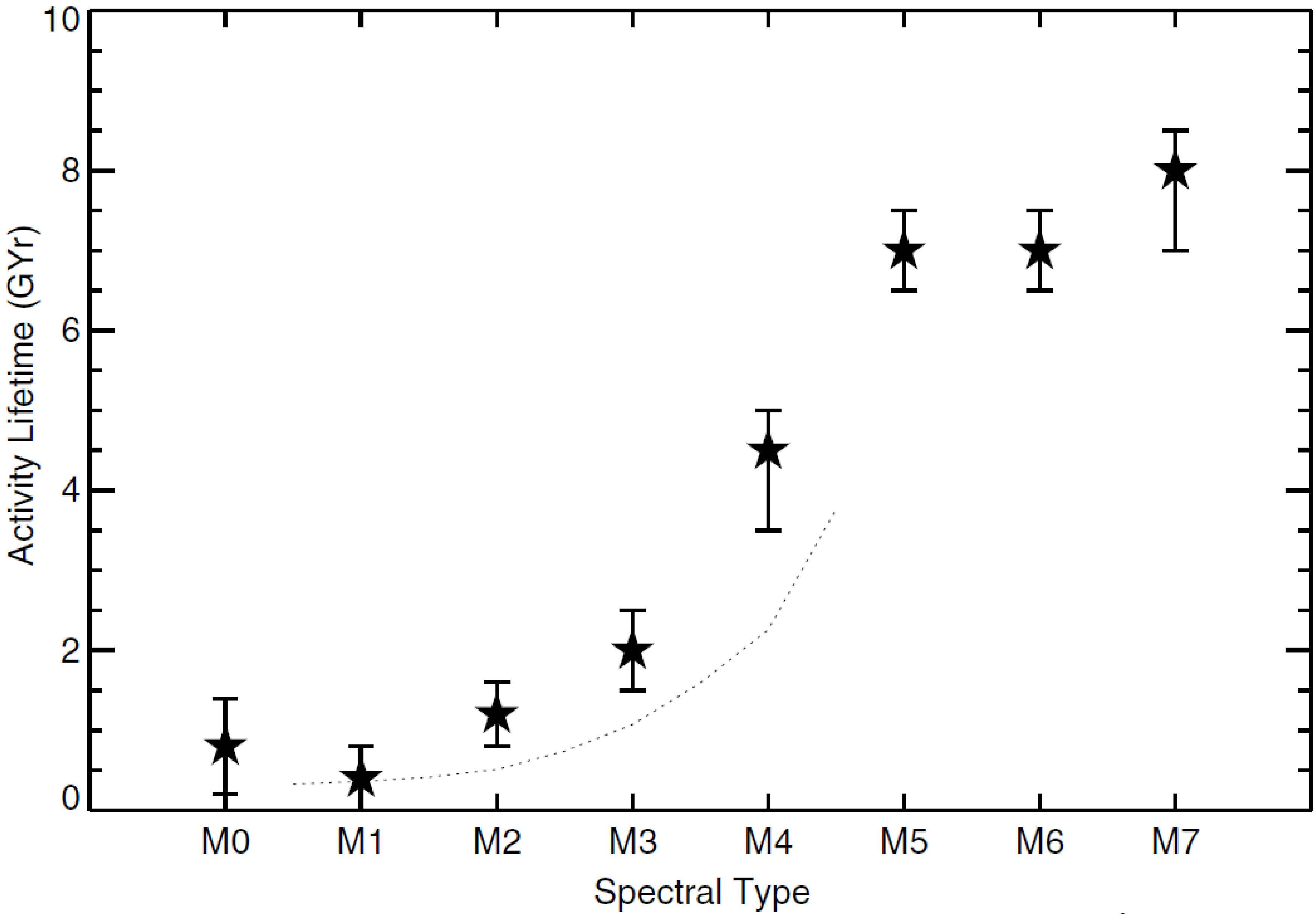
The M Dwarf Opportunity

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

The nearest "habitable" planet likely orbits an M dwarf within a few pc

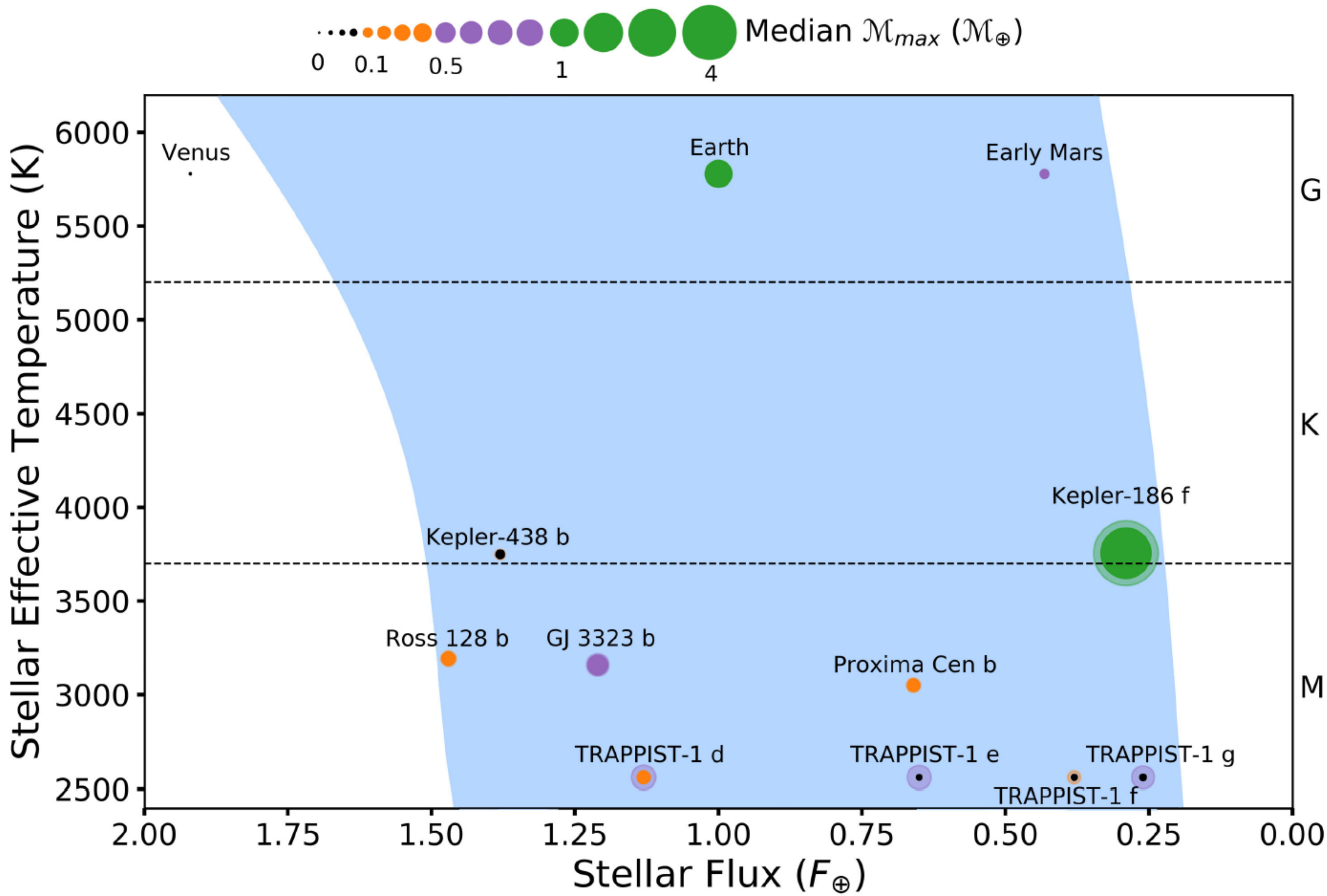


Hot Stars
Cool Stars
Earth
Kepler 22b
Mars
HD 40307g
Gliese 667Cc
Gliese 581g
Gliese 581d
Habitable Zone
0.01
0.10
1.00
Distance from Star (AU)
Image Credit: Chester Harman



West et al. 2008

The Magnetic Fields of Candidate Habitable Planets



McIntyre et al. 2019

Credit: Chuck Carter / Caltech