The Magnetospheres and Space Weather Environments of Extrasolar Planets

Optimized Strategies for Detecting Extrasolar Space Weather

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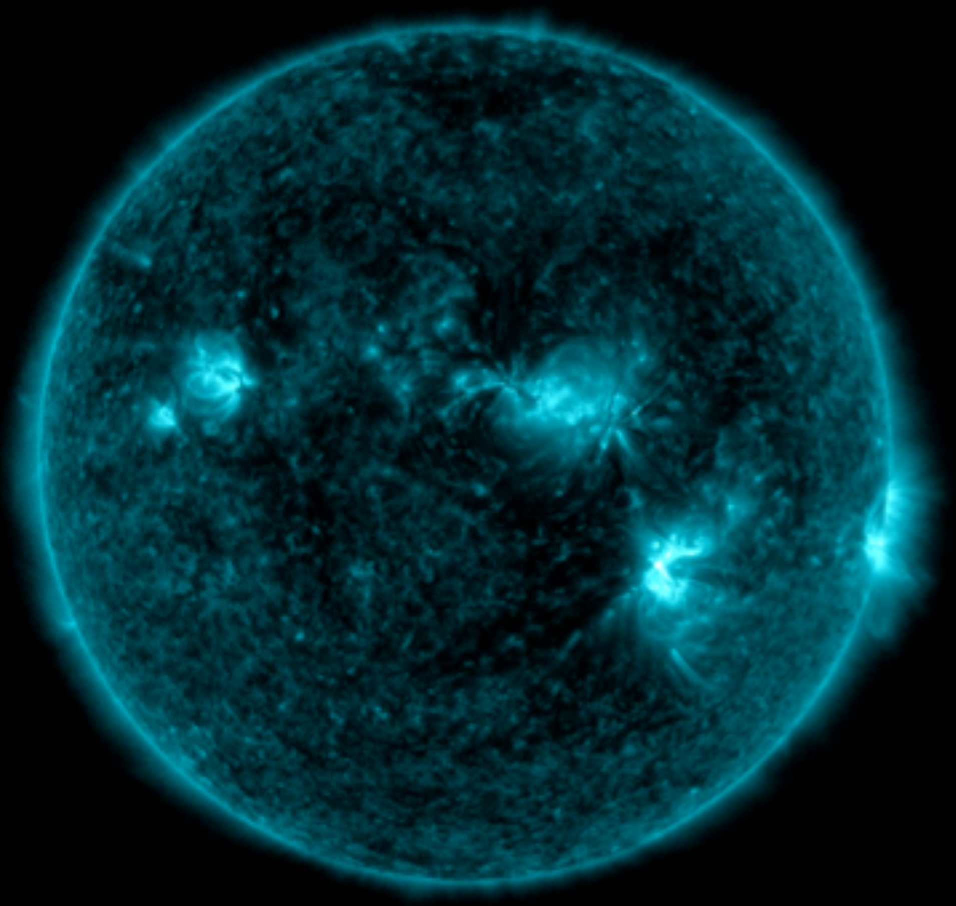
Caltech

NESS

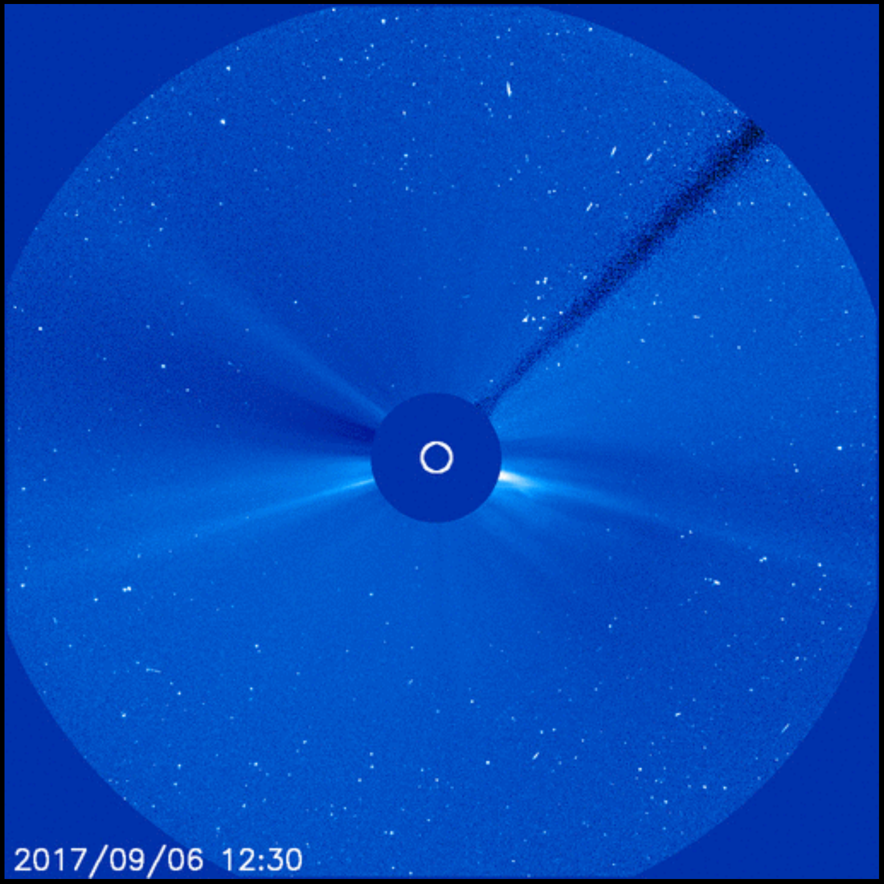
Network for Exploration and Space Science

Sept 6th, 2017

Sunspot AR2673



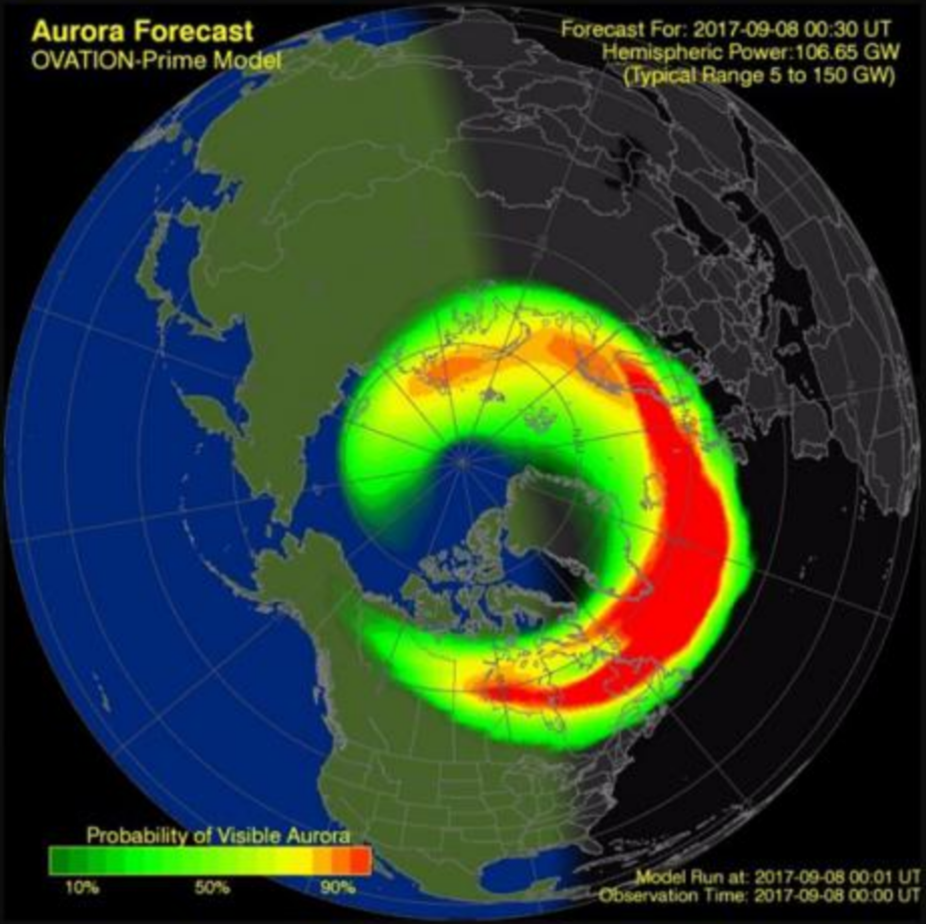
SDO/AIA 131 2017-09-06 00:12:56 UT



2017/09/06 12:30

Severe storm conditions met at: 07/2350 UTC

G4



G4

A fertility company that defies the textbooks

Multigenerational effects on development

Microbial ecology and evolution

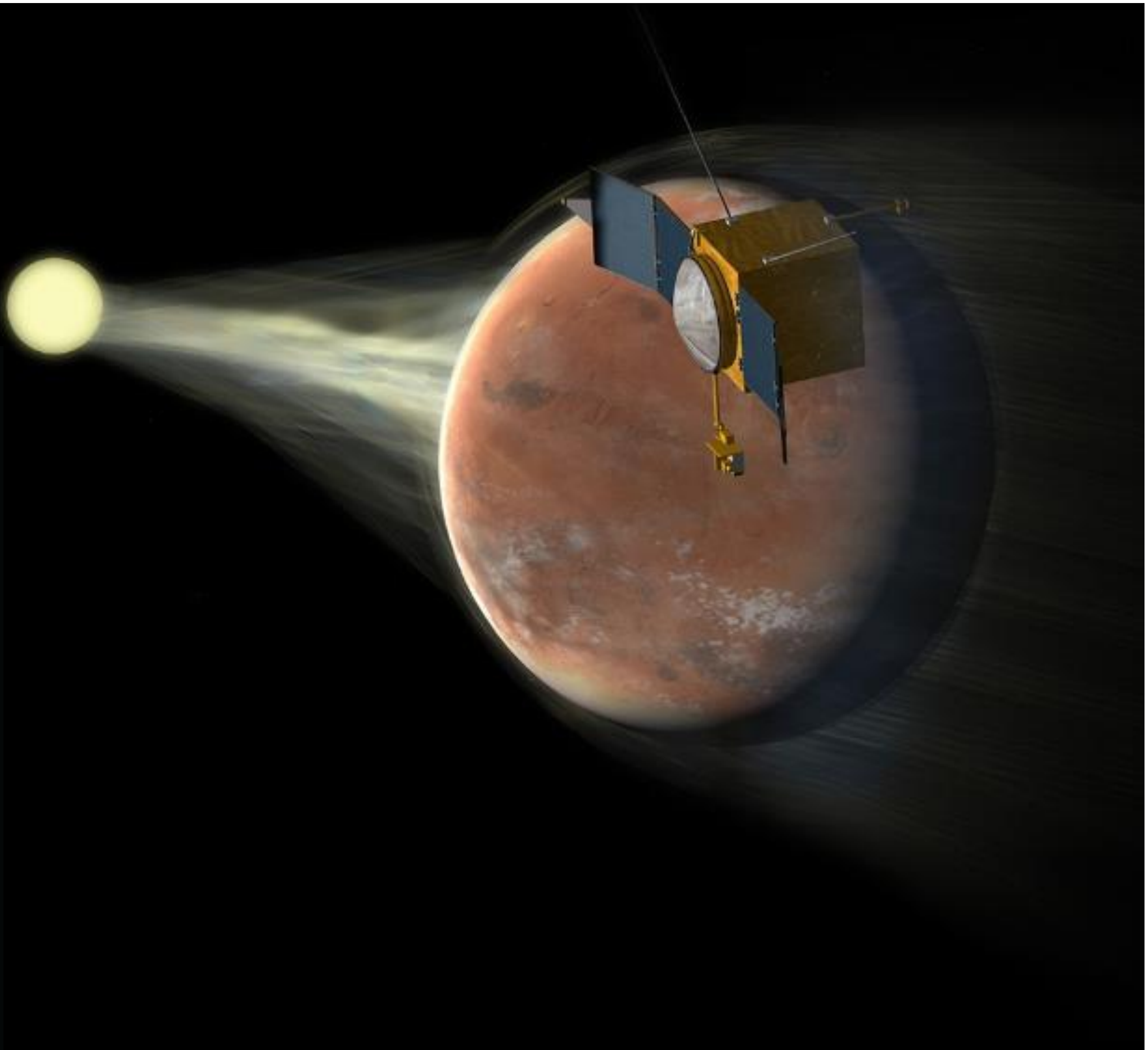
Science

$10
6 NOVEMBER 2015
sciencemag.org

AAAS

MAVEN at Mars

Probing a dynamic upper atmosphere *p. 643*

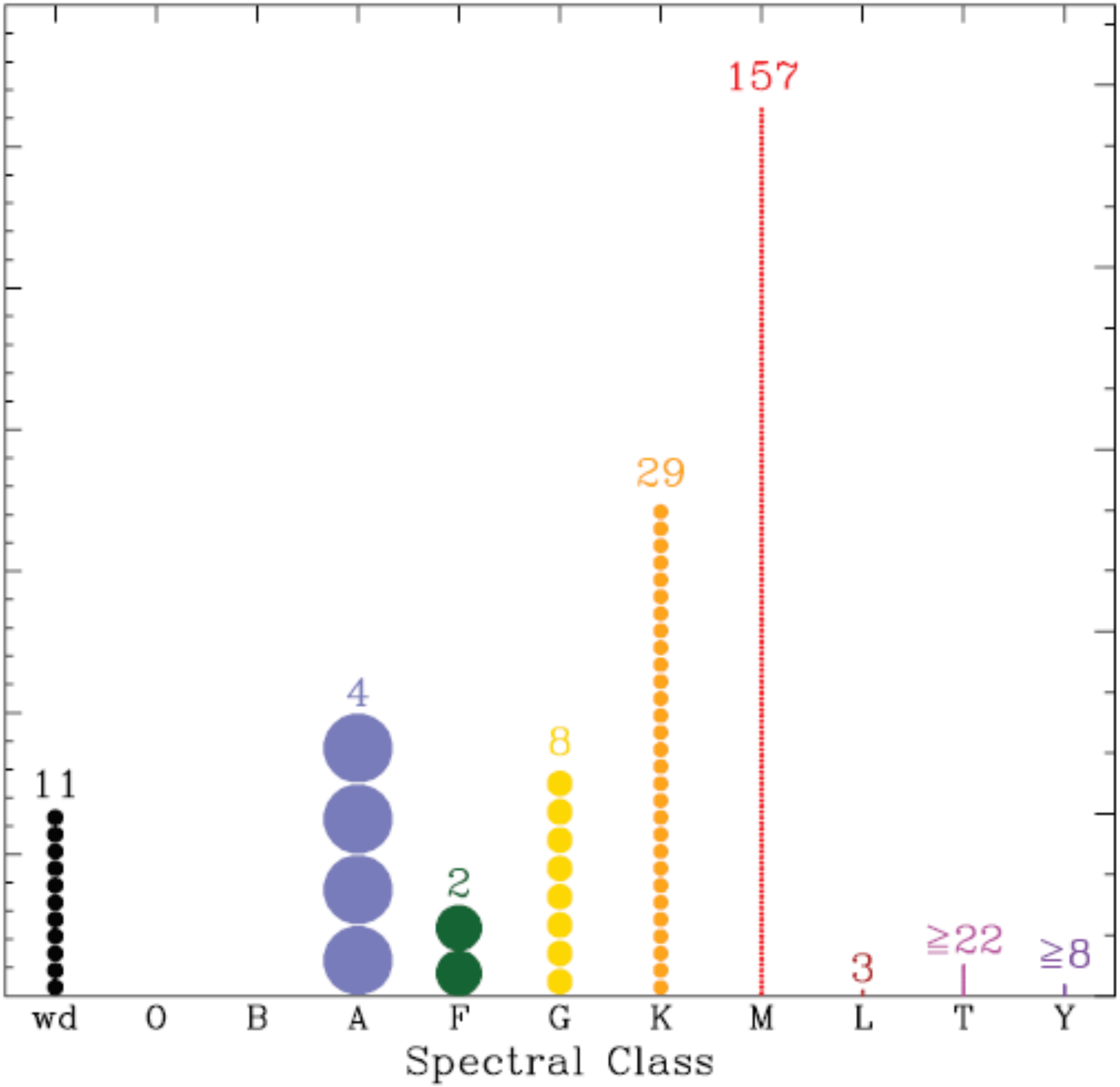


- Flares – higher X-ray and ultraviolet radiation flux –> photochemical reactions leading to significant atmospheric loss

- Coronal mass ejections (CMEs) – higher stellar wind flux –> can erode atmosphere – eg. ion pick-up of a CO^2-rich atmosphere

Magnetic activity can redefine habitability!

Stars out to 8 pc



Kirkpatrick et al. 2012

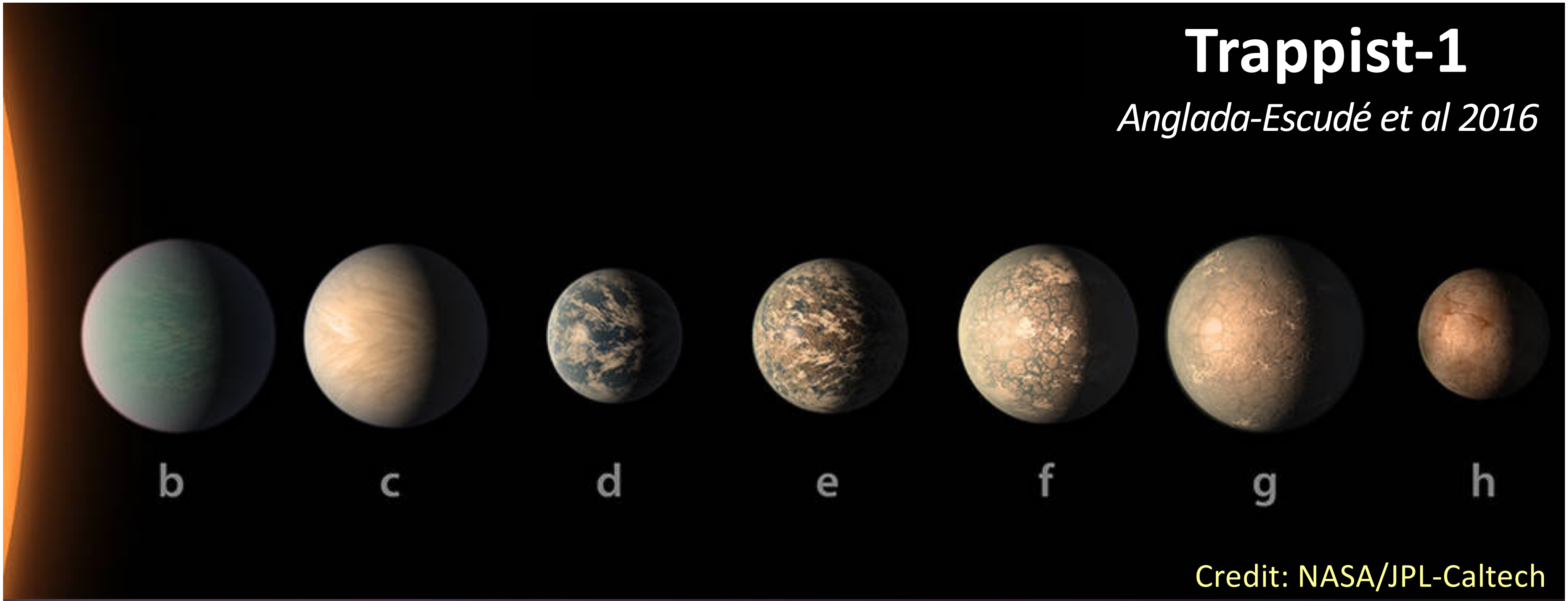
Small planets dominate planetary demographics and favor smaller stars (Howard et al. 2012)

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

The nearest habitable planet likely orbits an M dwarf at 2.6 +/- 0.4 pc

Trappist-1

Anglada-Escudé et al 2016



Credit: NASA/JPL-Caltech

Proxima b

Gillon et al 2016

Credit: ESO/M. Kornmesser

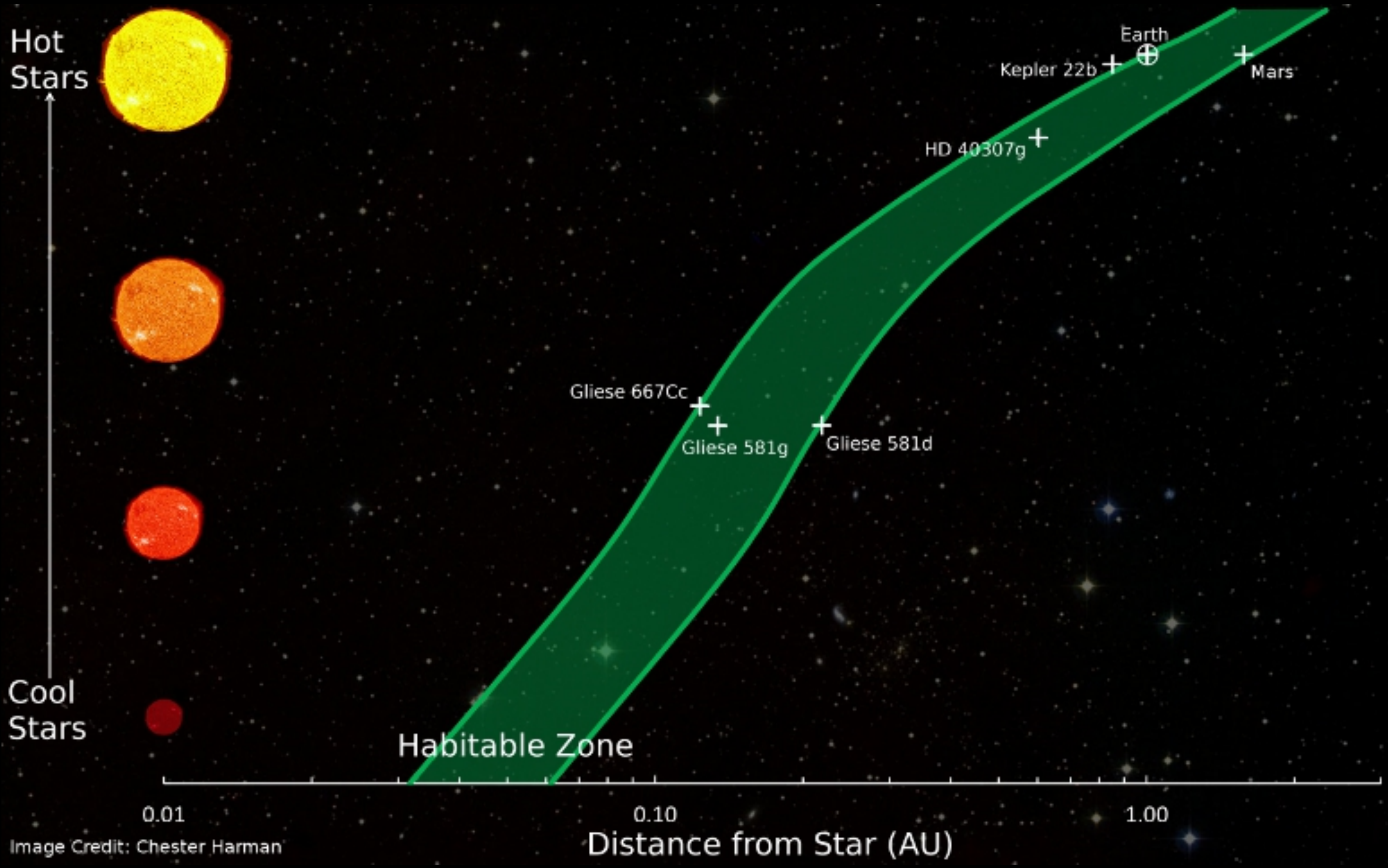
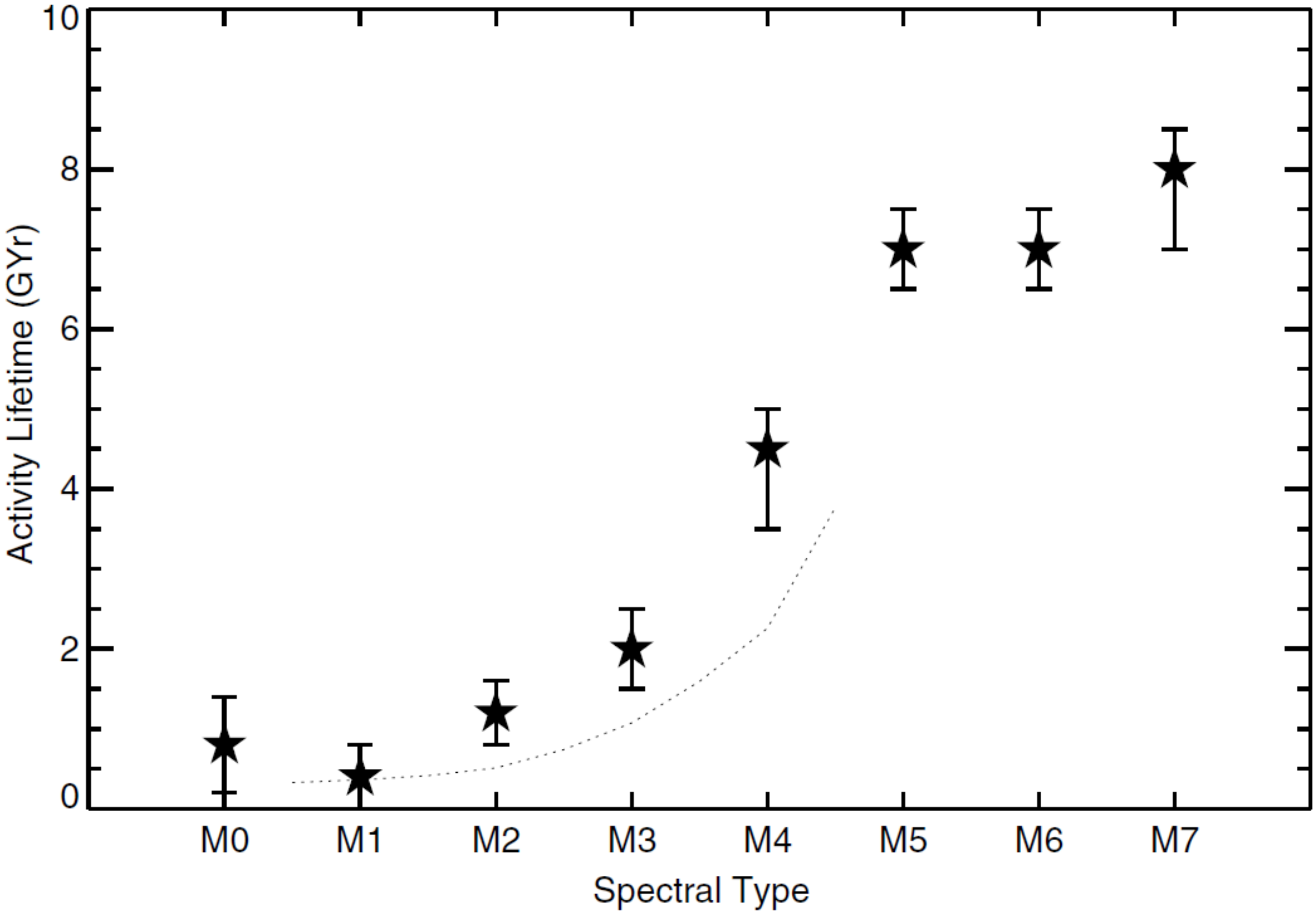


Image Credit: Chester Harman

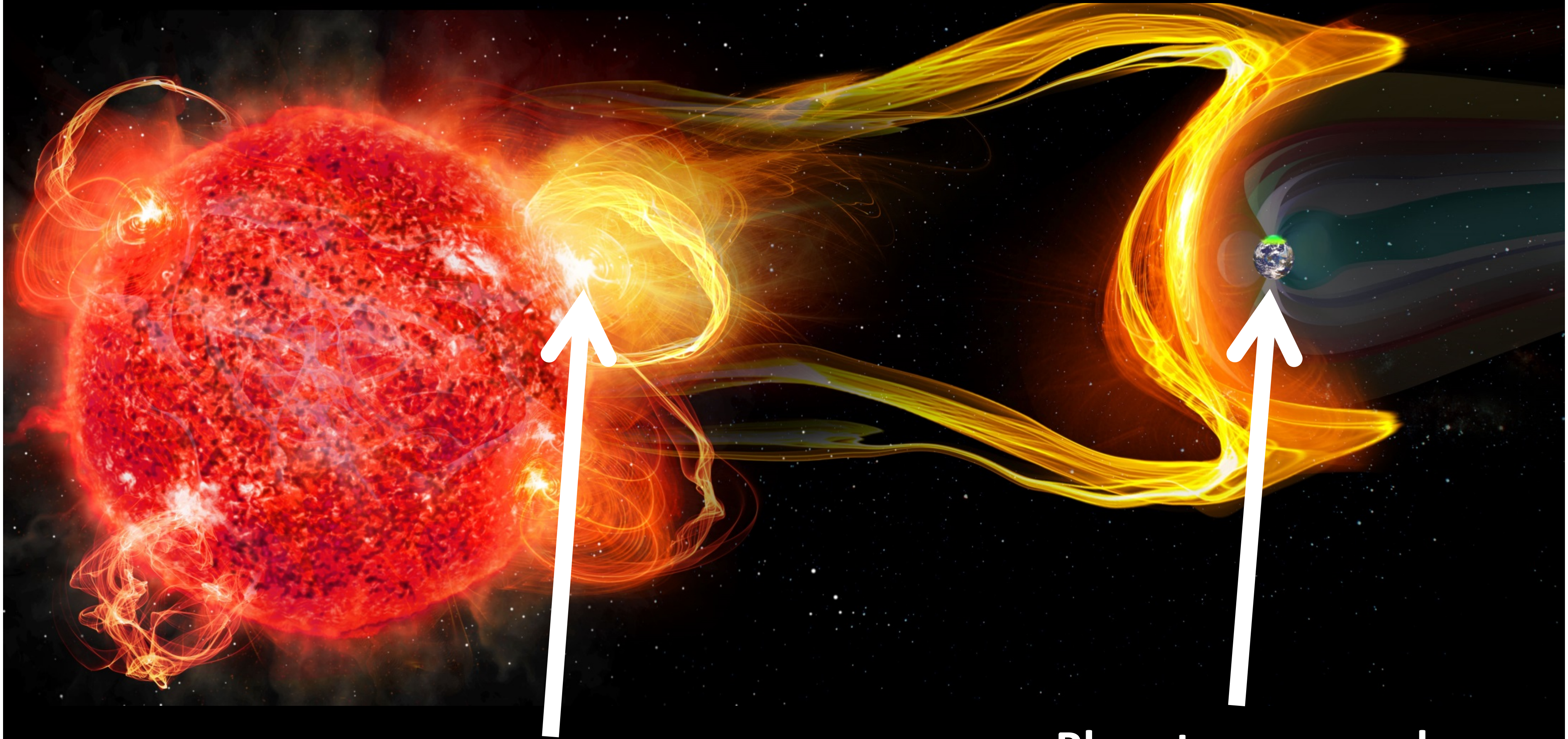


West et al. 2008

Credit: KISS/Caltech

Is magnetic activity important for defining habitability?
Can we directly detect CMEs and planetary magnetic fields?
Yes – with radio observations

Low Frequency Radio Emission



Type II radio emission associated with CMEs

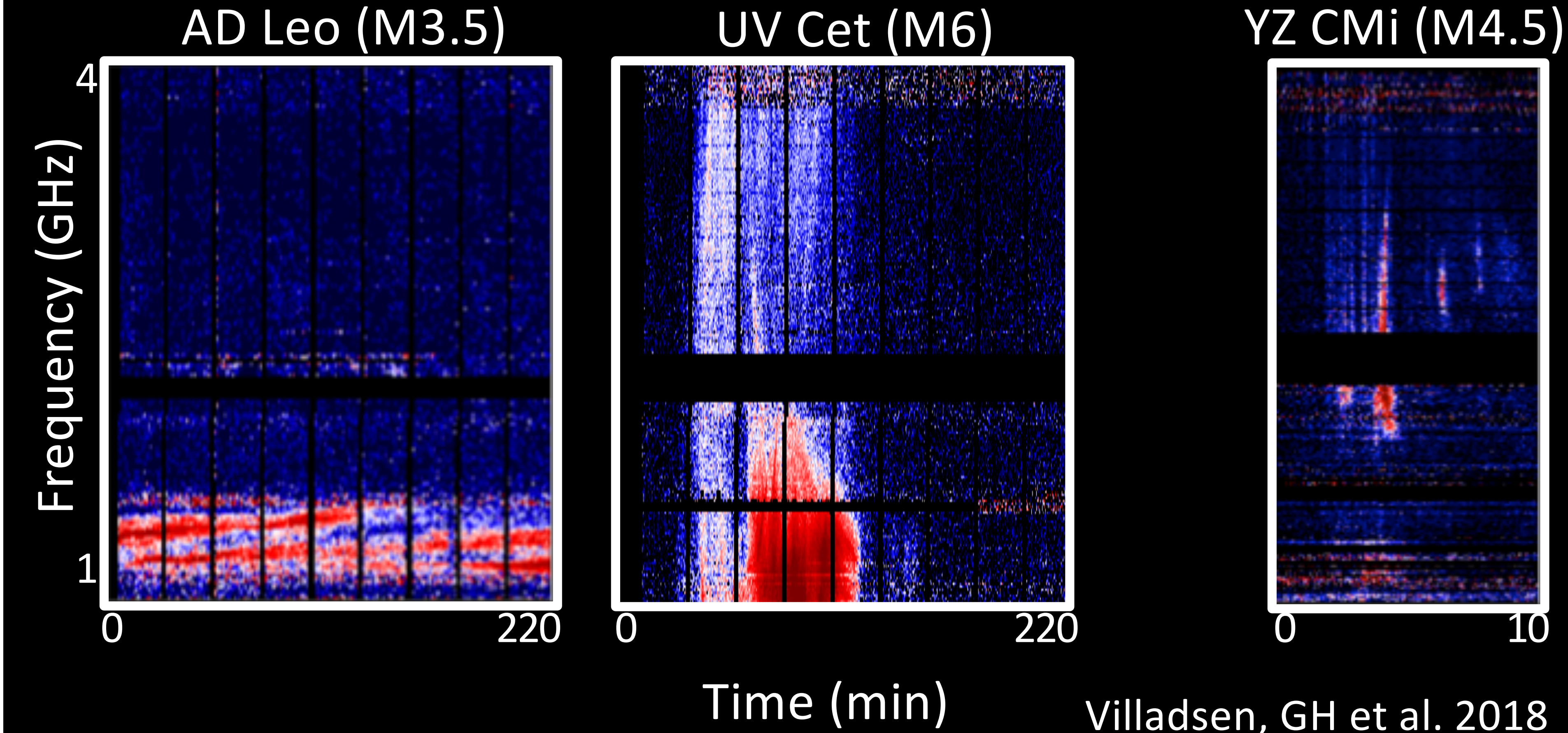
Planetary auroral radio emission

Strategy 1: Targeted Searches

Ongoing Searches for Stellar CMEs

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

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



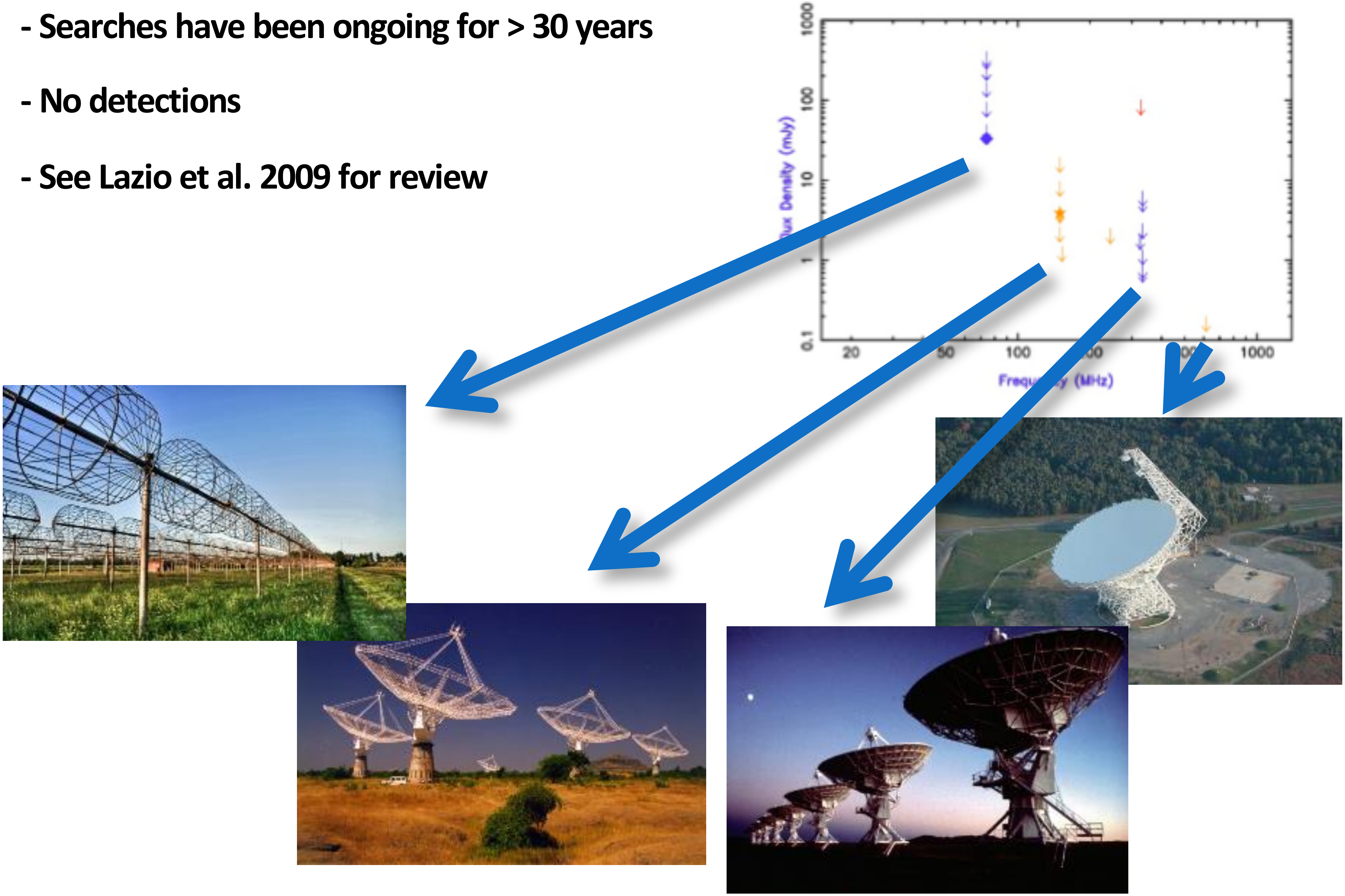
Villadsen, GH et al. 2018

- *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)*

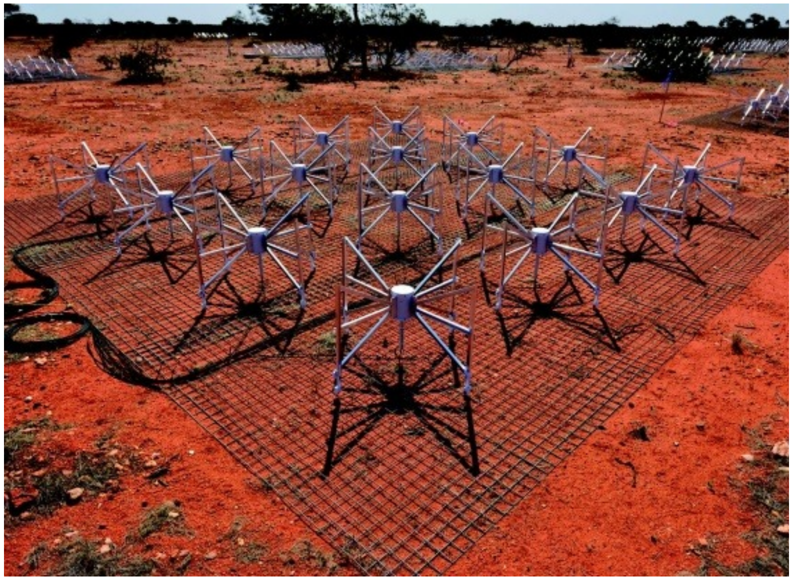
- Need more sensitivity at lower frequencies!

Exoplanet Searches

- Searches have been ongoing for > 30 years
- No detections
- See Lazio et al. 2009 for review



New Kids on the Block



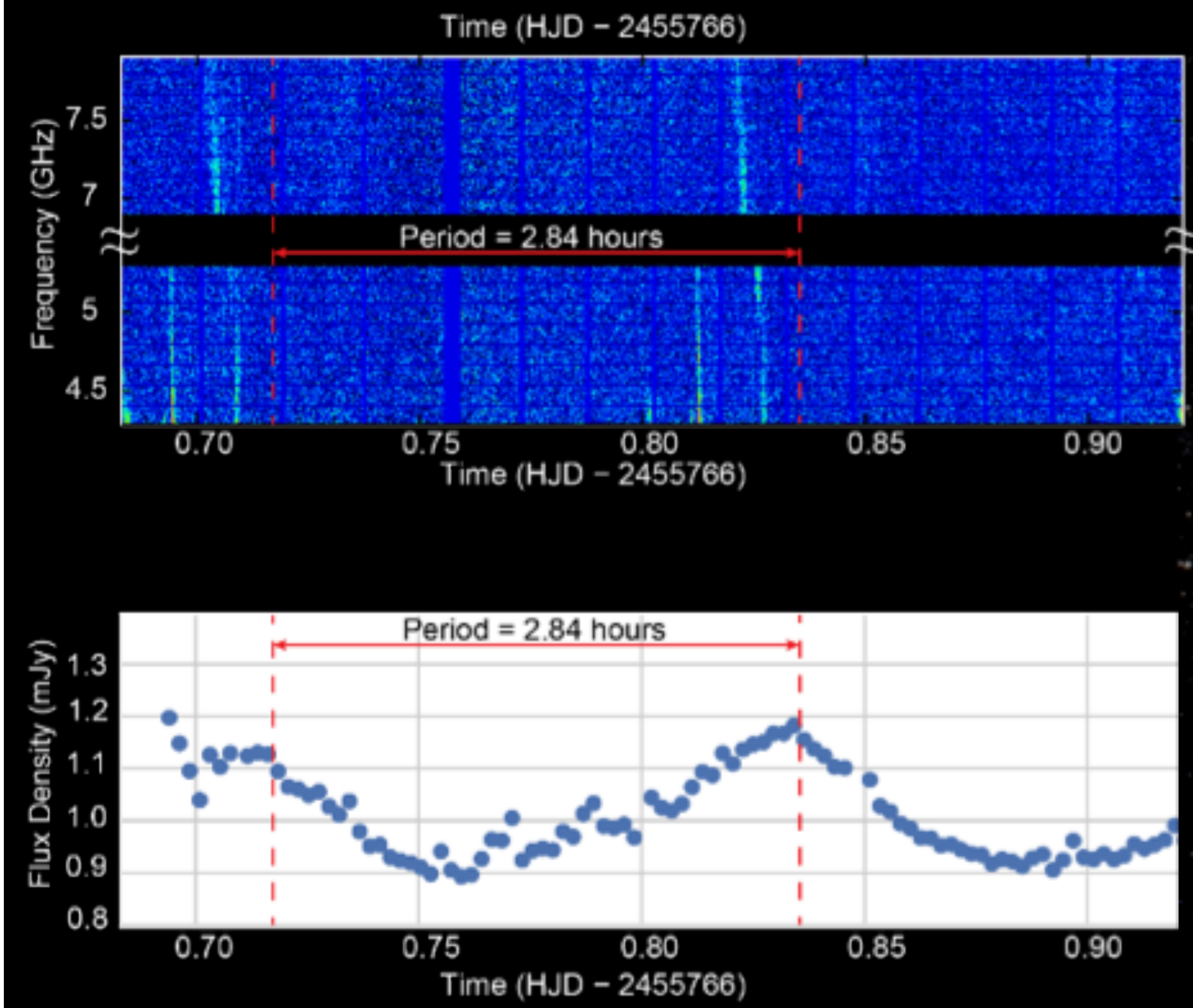
MWA: 80-300 MHz

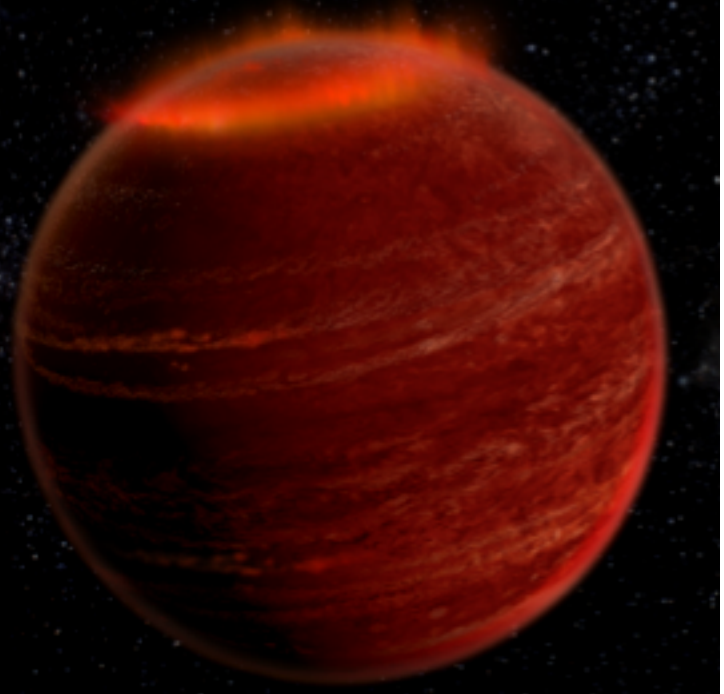
HERA: 50-250 MHz

LOFAR: 10-240 MHz

LWA: 10-90 MHz

Brown Dwarf Radio and Optical Aurorae

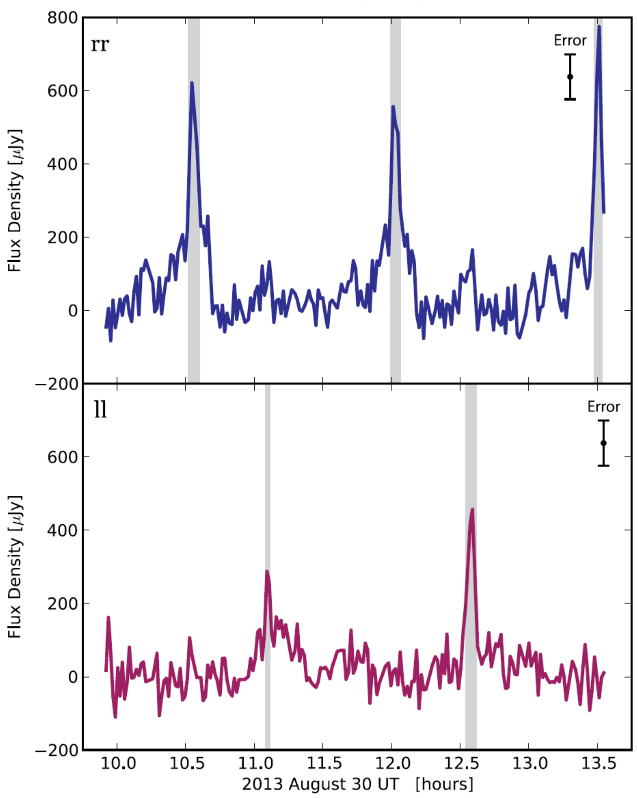


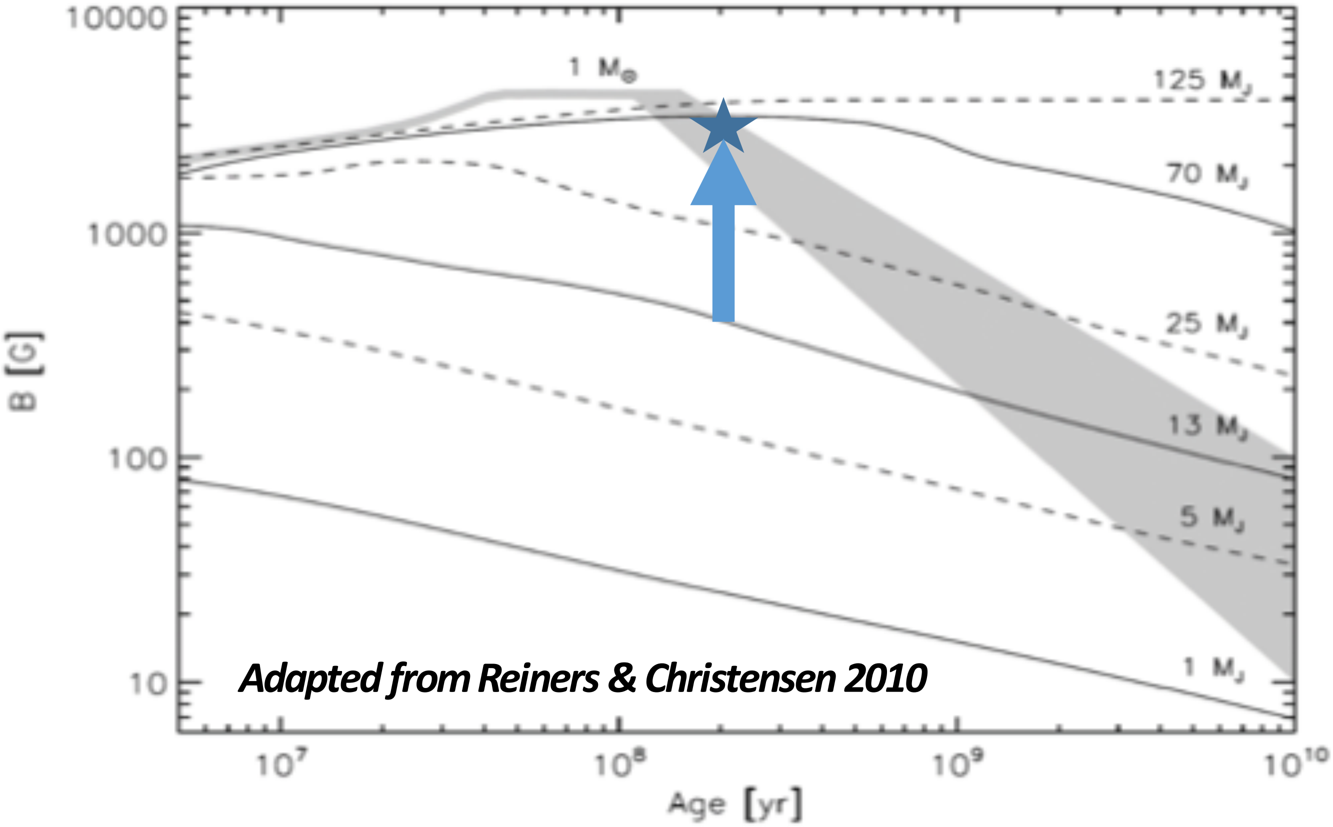


Hallinan et al. 2015, *Nature*, 523, 568

- *Mostly detected with the VLA at GHz frequencies →kG magnetic fields*
- *see recent reviews by Pineda, GH and Kao 2017; Williams 2017*

Radio Emission from a Candidate Free Floating Planet – SIMP0136





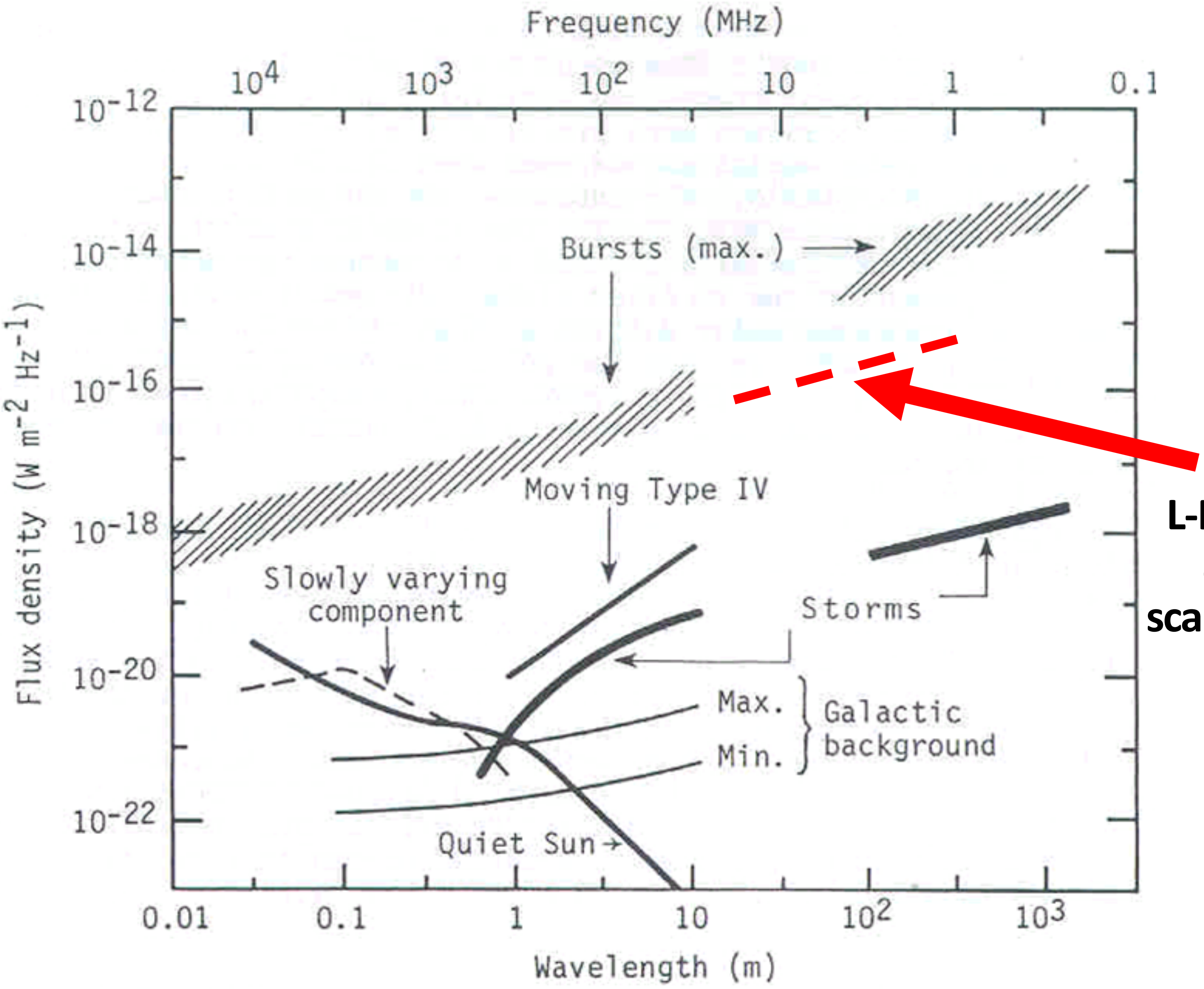
Adapted from Reiners & Christensen 2010

Kao, GH et al. 2016, 2018

- Brightest T dwarf in the northern hemisphere (Artigau et al. 2006)
- Carina Near moving group association - age of 200 Myr (Gagne et al. 2017)

Estimated mass of 12.7 ± 1.0 Jupiter masses – first radio exoplanet?
Magnetic fields ~ 3 kG
Gaia will find many more candidates for the VLA…

Targeted Searches from Space

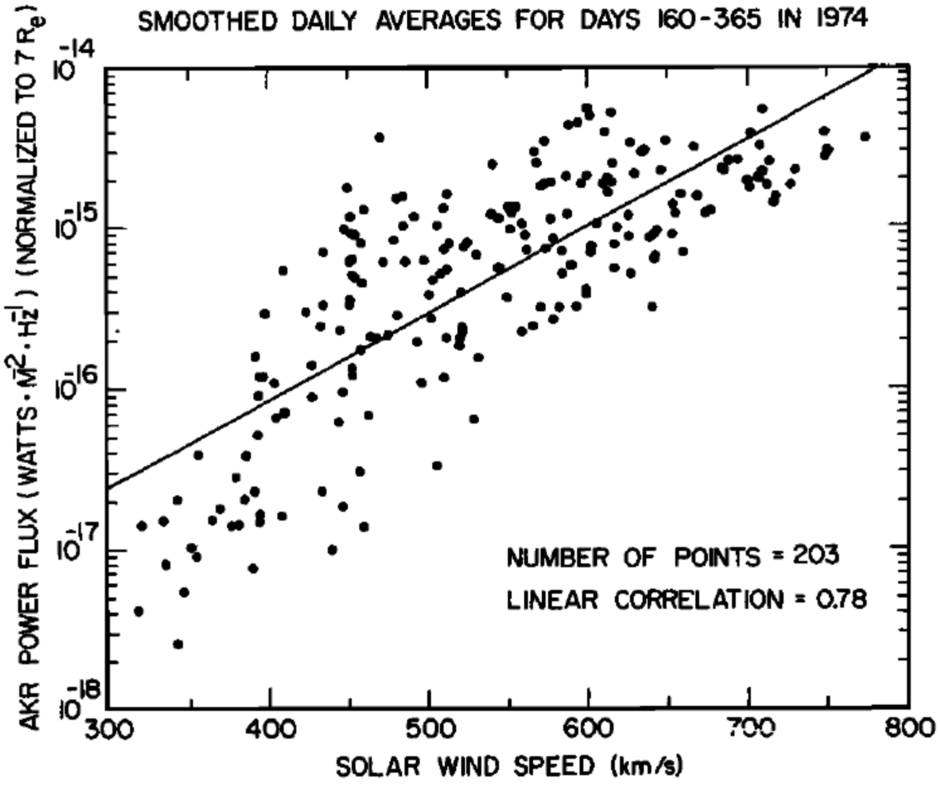


L-ROLS - 100 lunar-based dipoles (Bob's talk) – scaled to Alpha Cen system

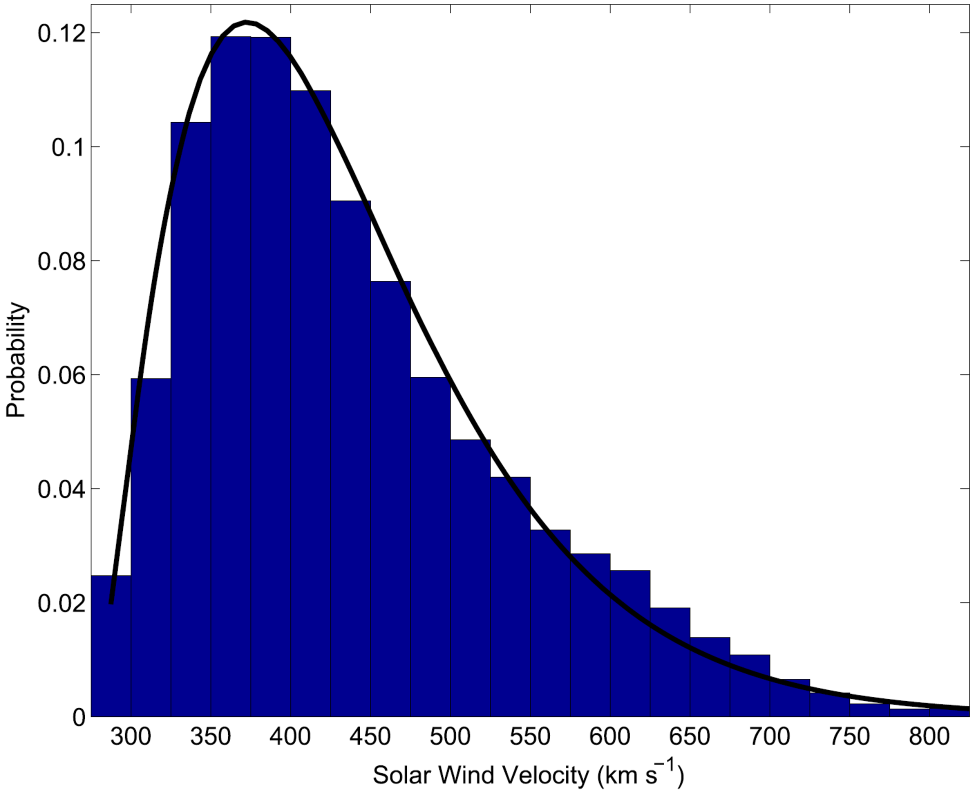
- Long-term monitoring of nearest candidate habitable exoplanet hosts (e.g. Alpha Cen system)
- **Can we detect solar-like CMEs on Alpha Cen AB and Proxima Centauri?**
- ***Do M dwarfs produce radio bursts (and CMEs) as energetic as the Sun?***
- ***Exoplanets detection via this method likely requires >10^4 dipoles***

Strategy 2: Multiplexed Searches

Space Weather Is highly Variable

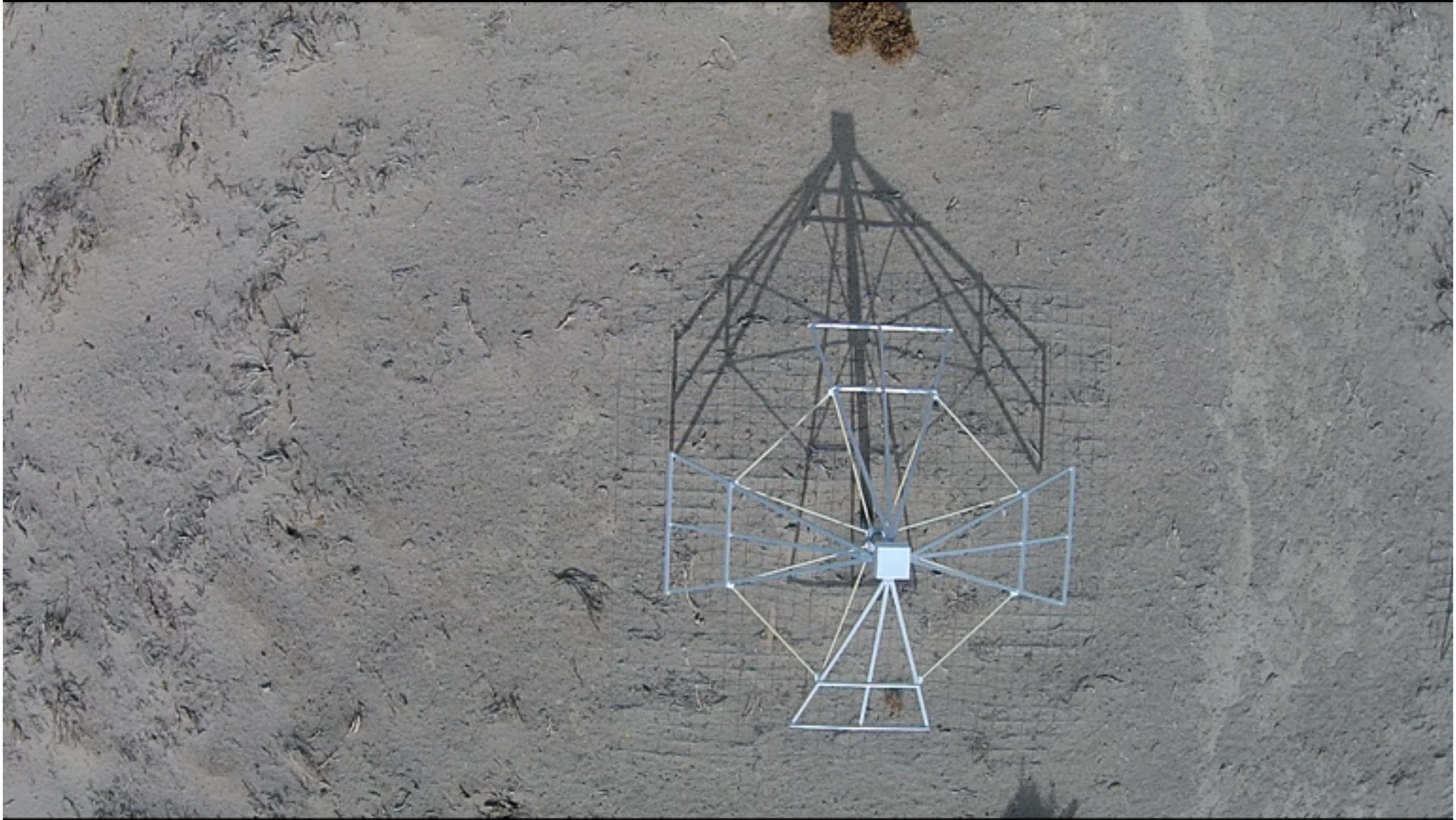


Gallagher & D'Angelo 1981

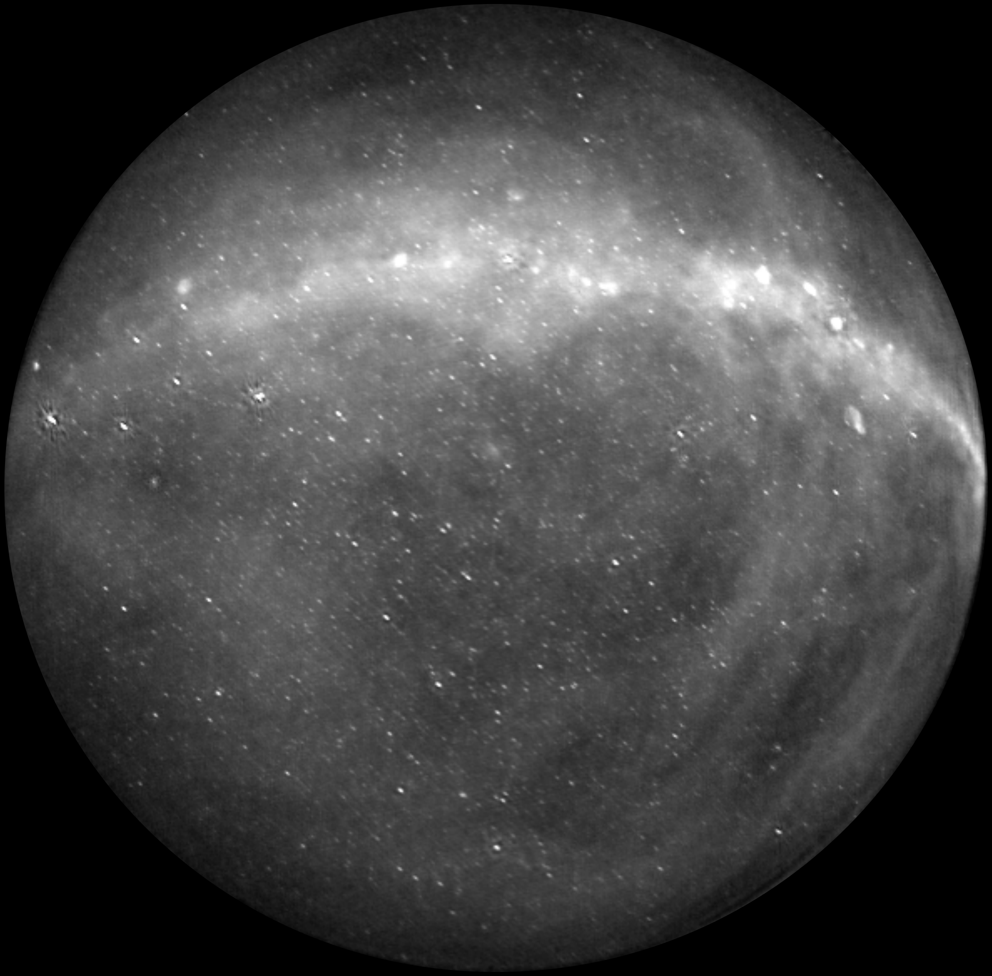


Li, Zhang & Feng 2016

The OVRO-LWA:
An Extrasolar Space Weather Telescope

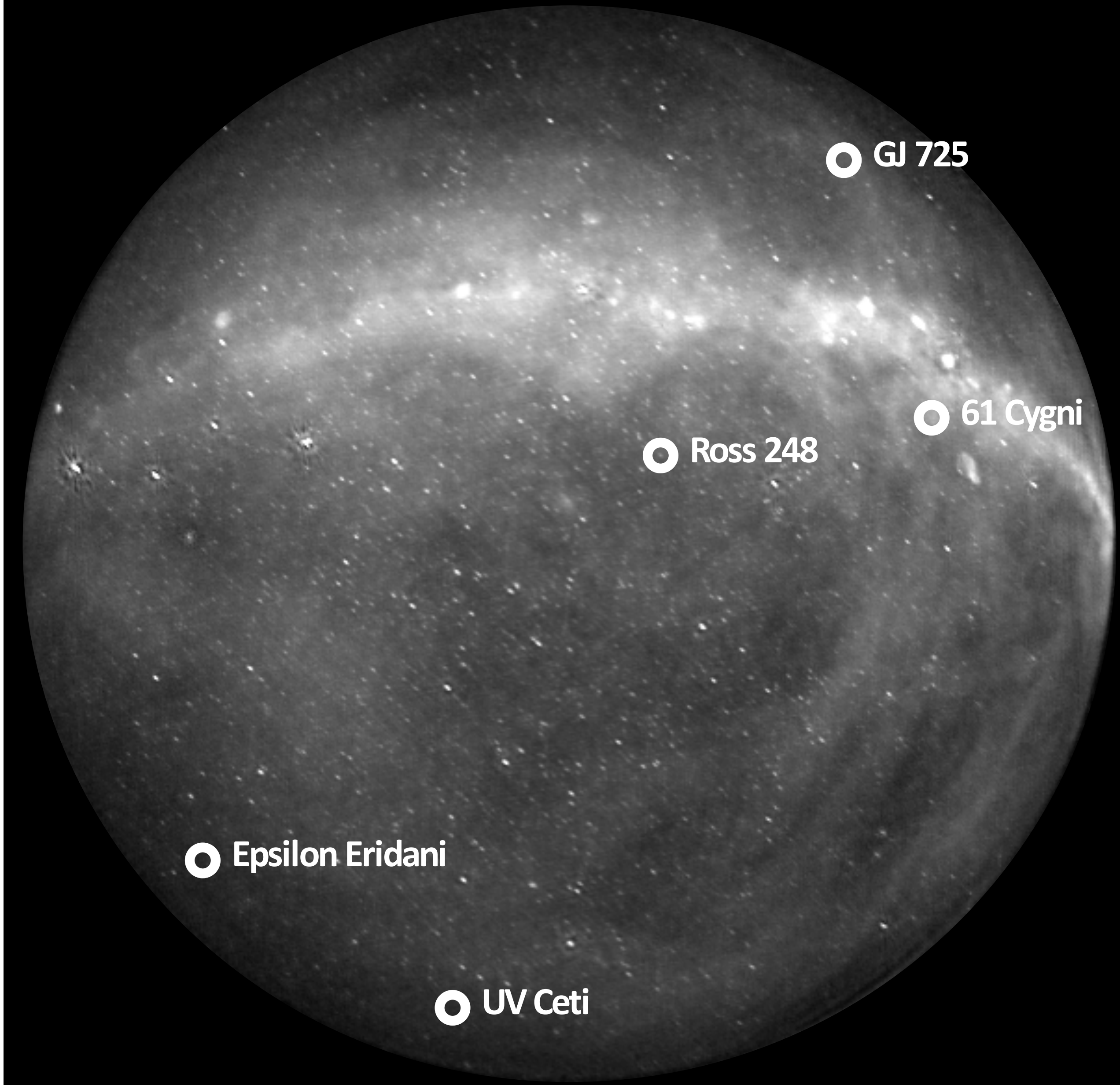


Stokes I

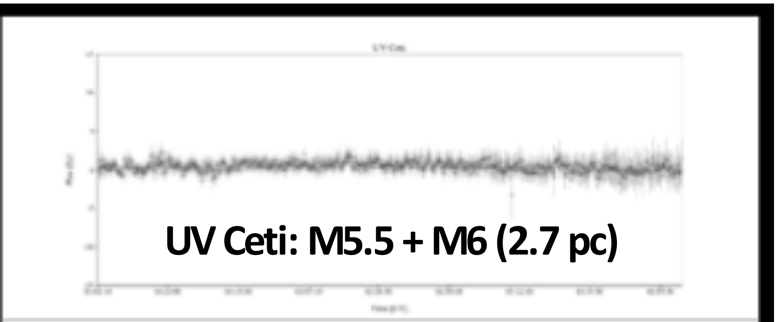


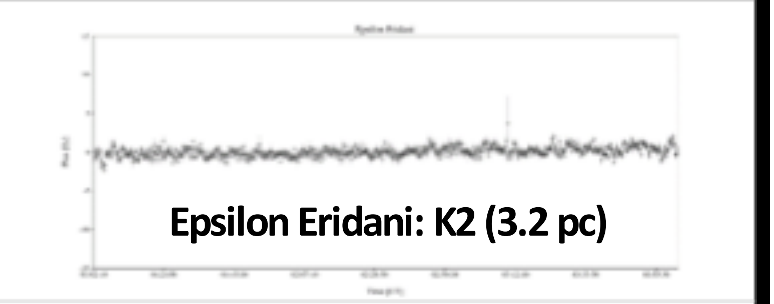
Stokes V

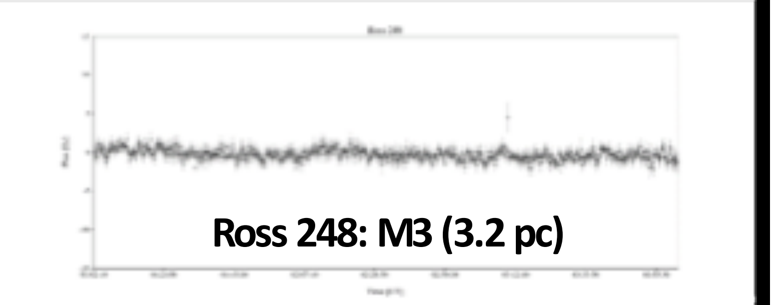
Anderson, GH et al. 2017

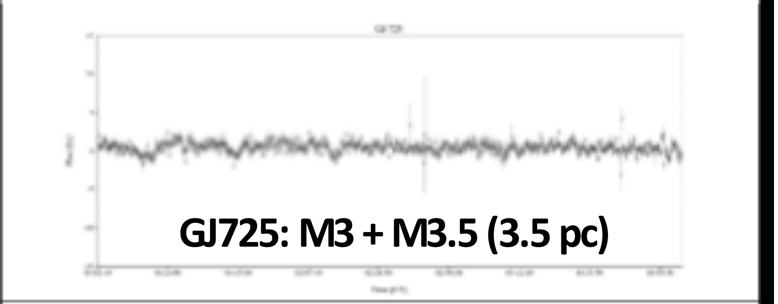


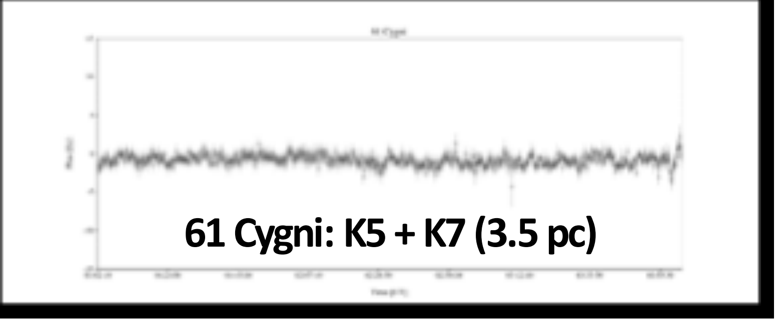
288-antenna performance: 500 mJy (10 s); 50 mJy (1 hr)
352-antenna performance: 100 mJy (10s); 5 mJy (1 hr); 1 mJy (1 day)

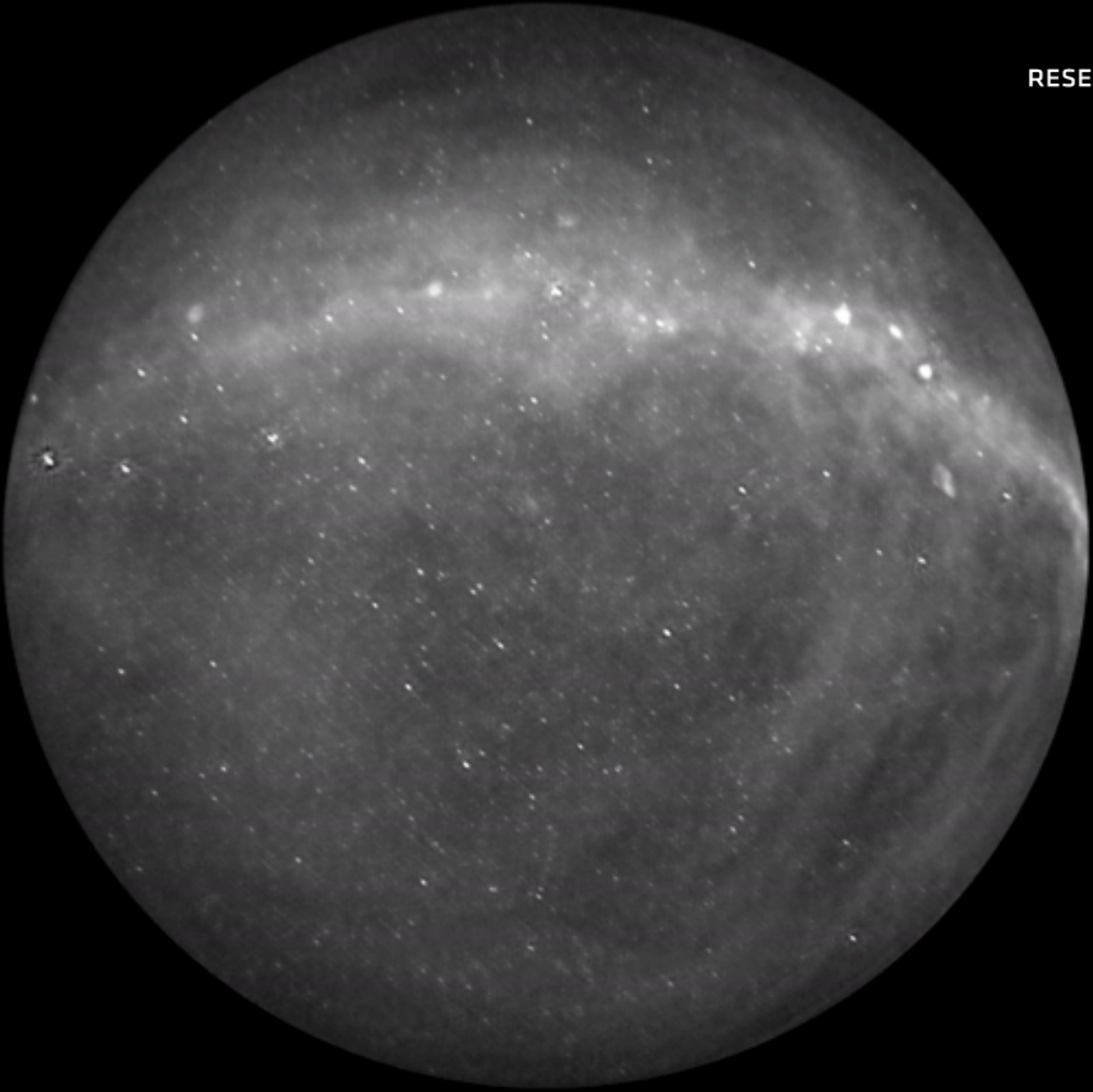

UV Ceti: M5.5 + M6 (2.7 pc)


Epsilon Eridani: K2 (3.2 pc)


Ross 248: M3 (3.2 pc)


GJ725: M3 + M3.5 (3.5 pc)


61 Cygni: K5 + K7 (3.5 pc)

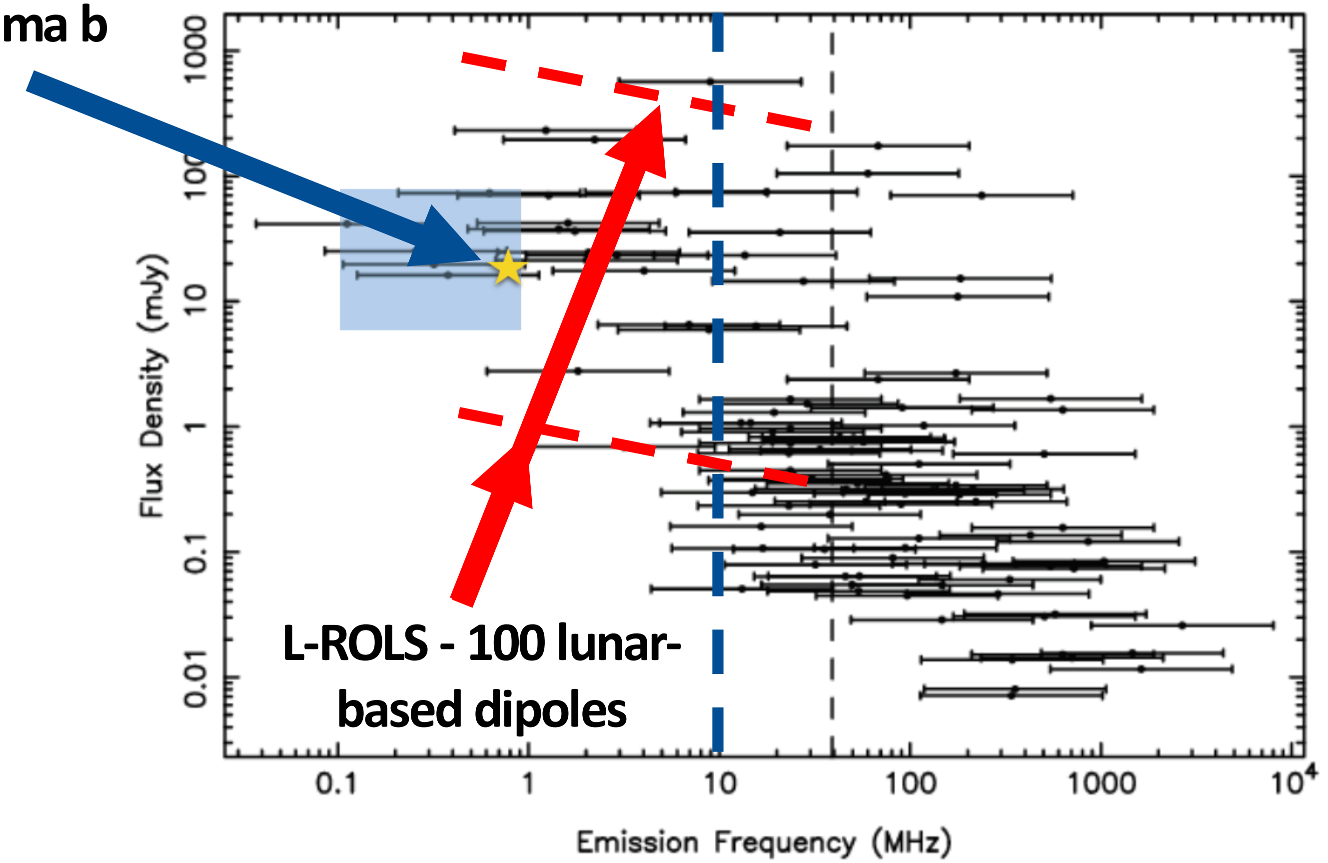


Monitors ~4,000 stellar/planetary systems out to 25pc

Anderson, GH et al. 2017

Multiplexed Searches from Space

Planetary radio emission subject to scaling laws for magnetic field strength and input solar wind power (e.g. see Farrell et al. 1999)

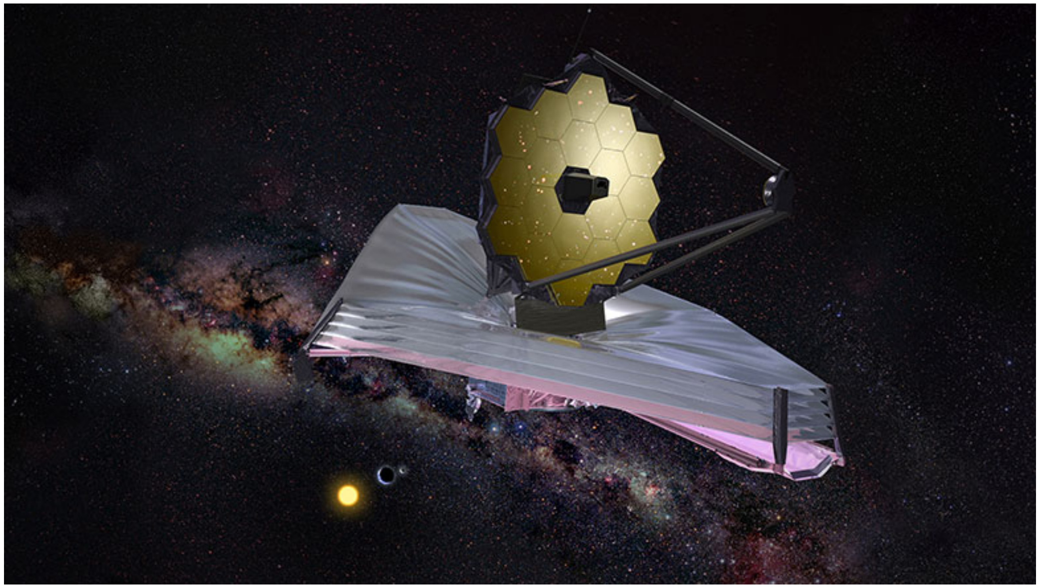


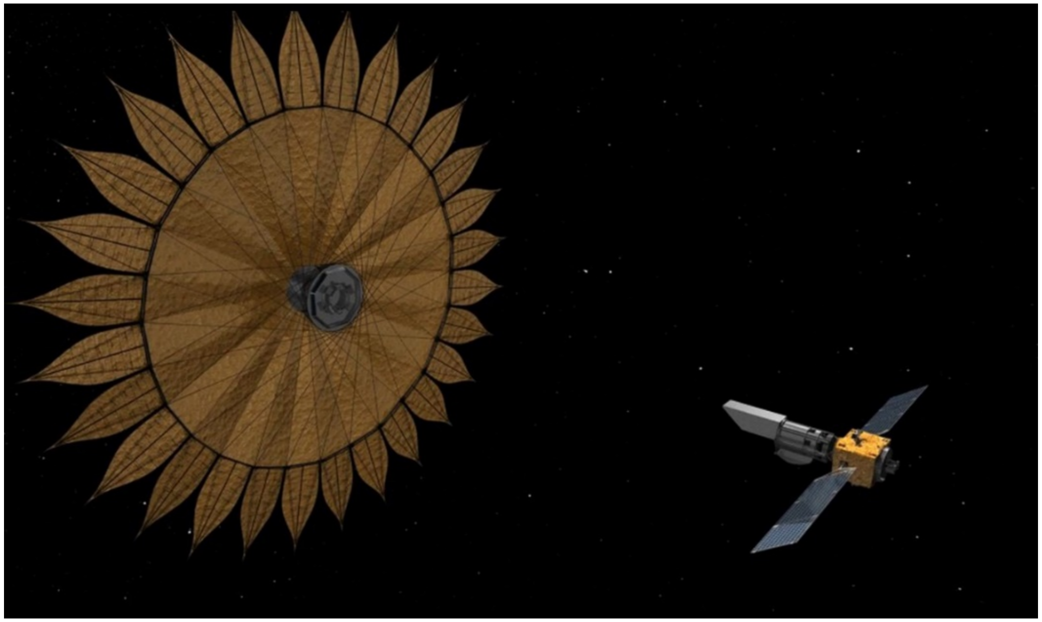
Proxima b

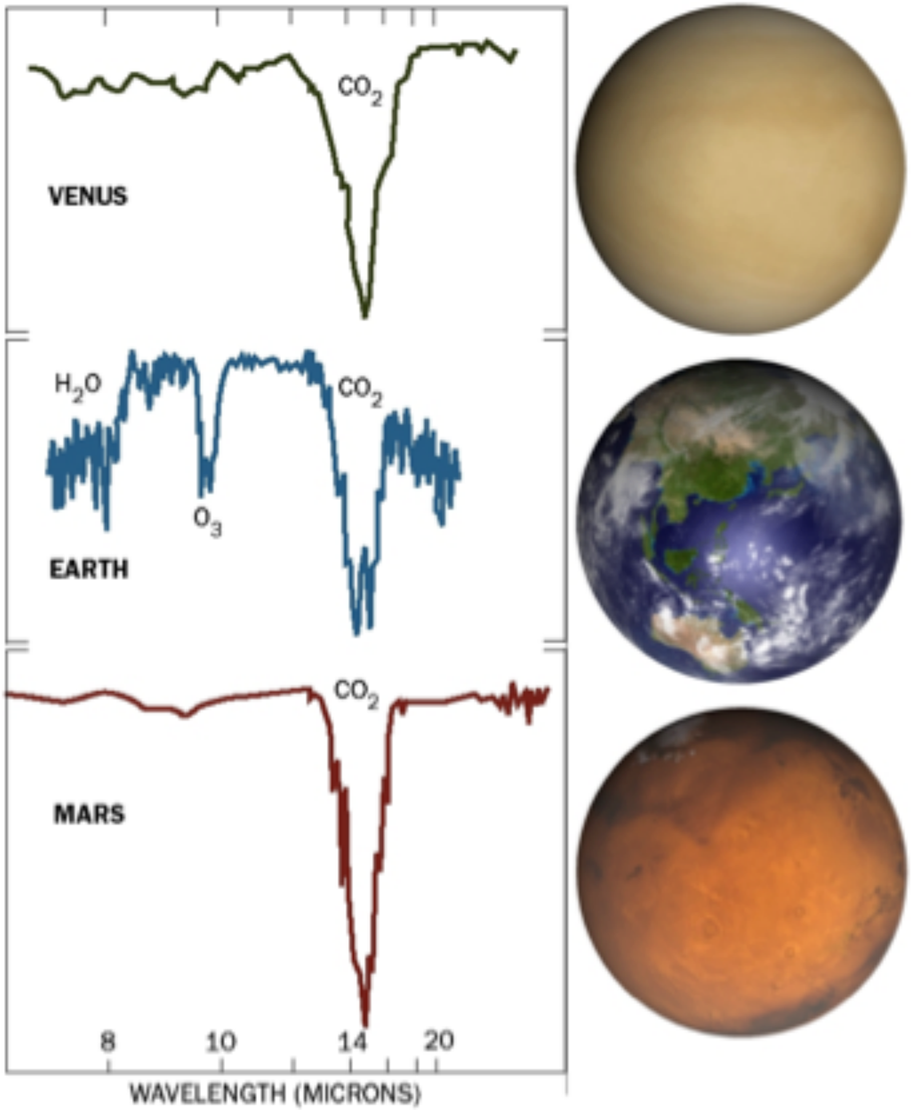
L-ROLS - 100 lunar-based dipoles

Adapted from
Burkhart & Loeb 2017

Contextual Data in the Search for Biosignatures

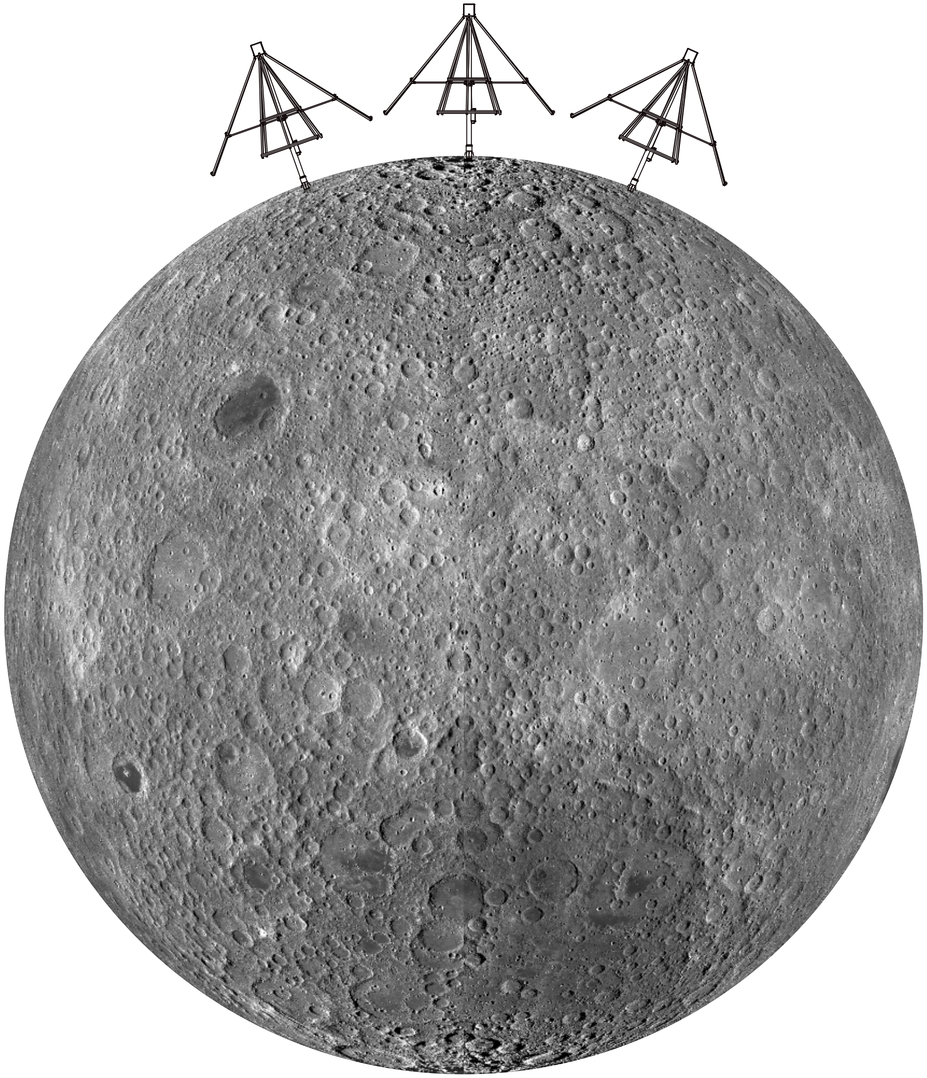


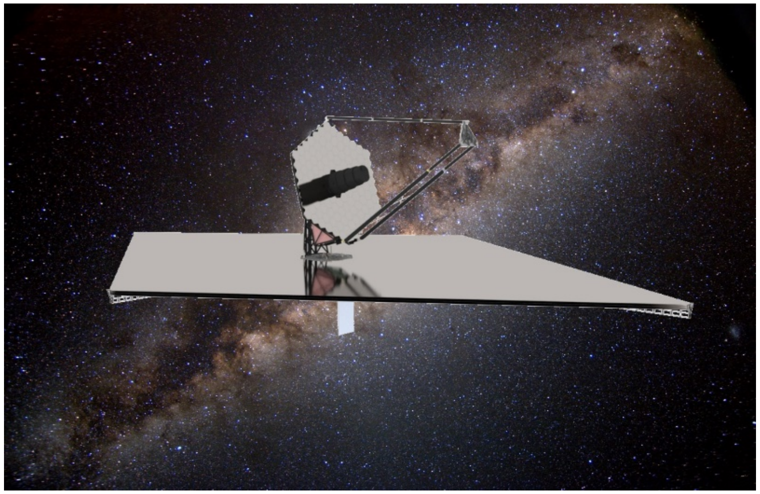


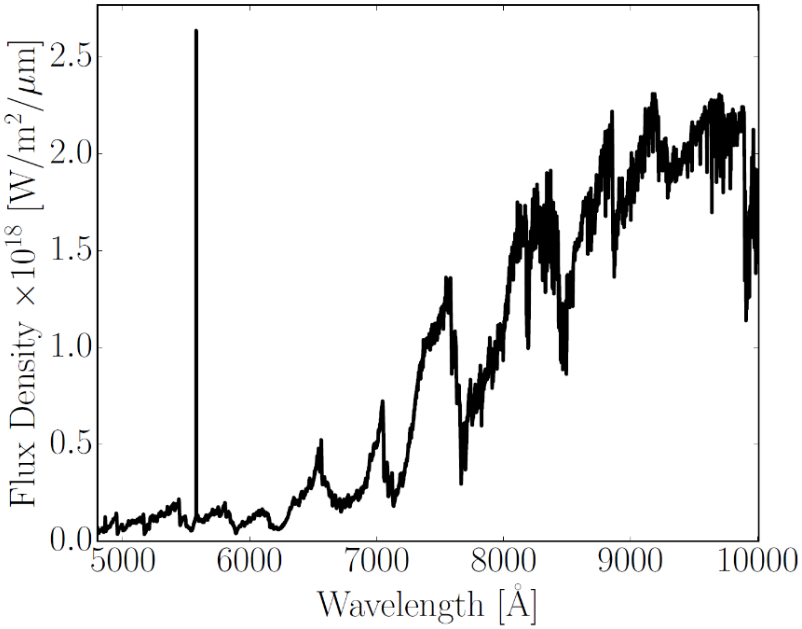


Strategy 3: Triggered Searches for Biosignatures

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)

Summary

Understanding the impact of stellar activity and the presence of planetary magnetic fields is becoming increasingly important for defining planetary habitability

Low frequency radio observations are key

The long-term future is from the lunar far-side

Targeted searches are computationally low-cost but limited

Multiplexed searches require significant in-situ computational resources

Triggered searches for biosignatures present an exciting possibility