Extrasolar Space Weather Monitoring from the Ground:
Paving the Way for FARSIDE

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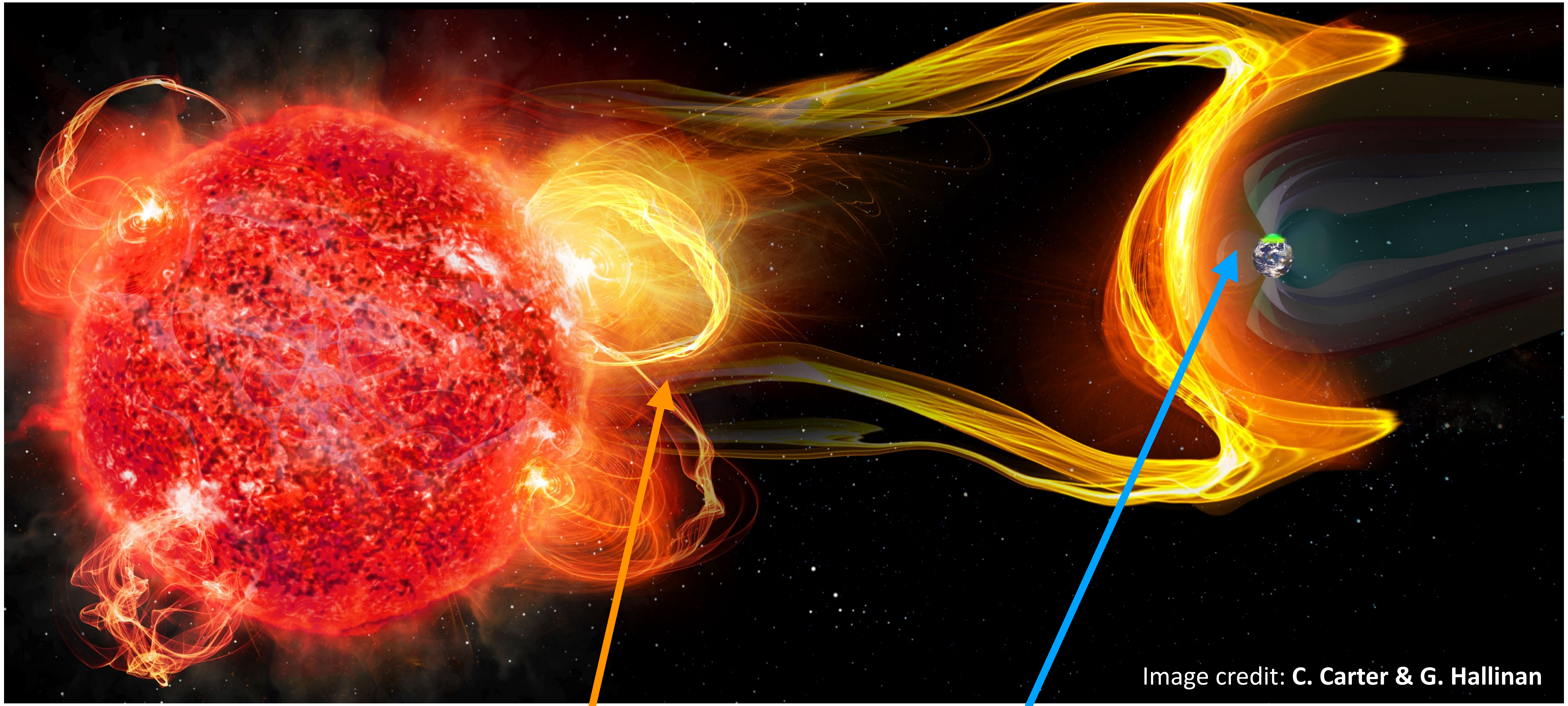
Measuring exoplanetary and stellar radio emission is critical for understanding how both the exoplanetary magnetosphere and the surrounding space weather environment influences habitability.



Coronal mass ejections (CMEs)

Earth's Auroral Kilometric Radiation (AKR)

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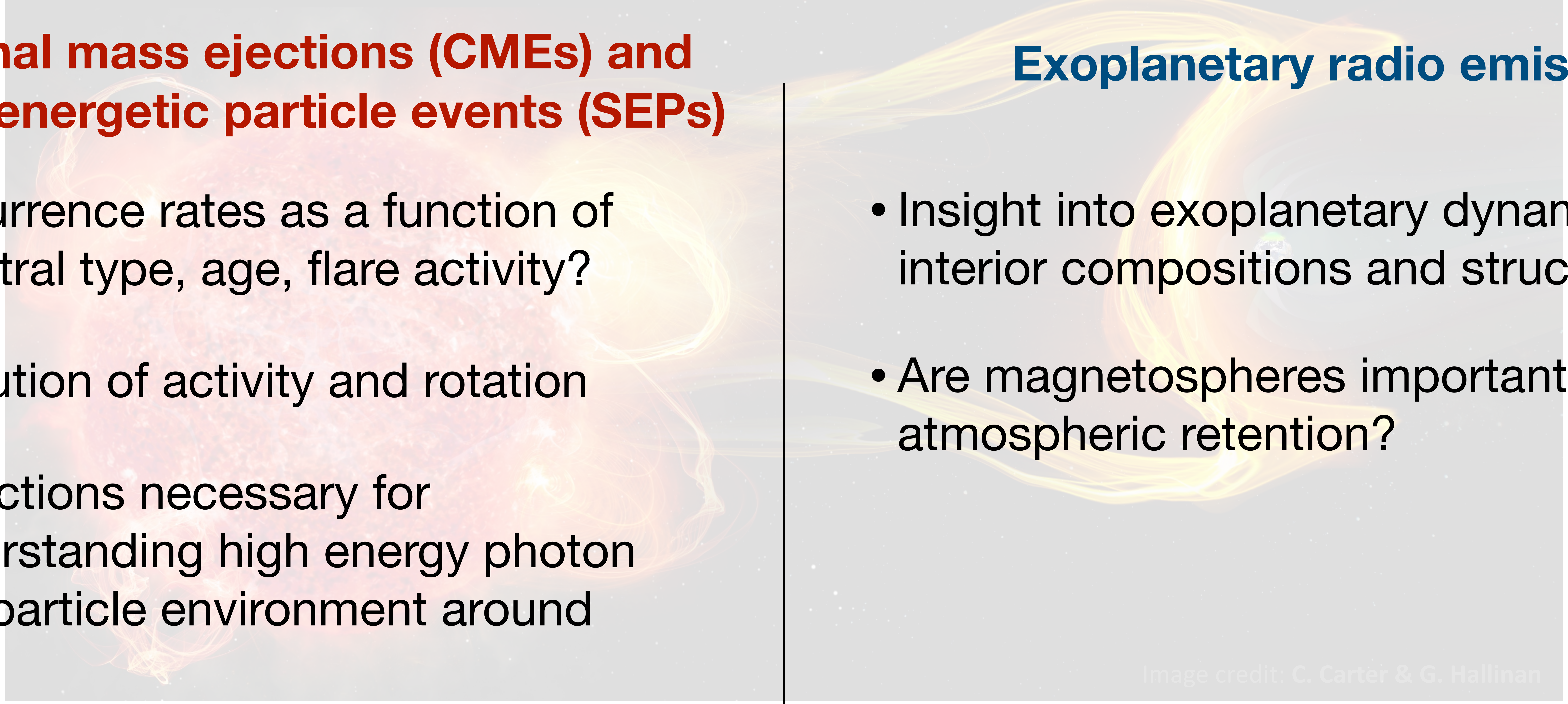


Coronal mass ejections (CMEs) and stellar energetic particle events (SEPs)

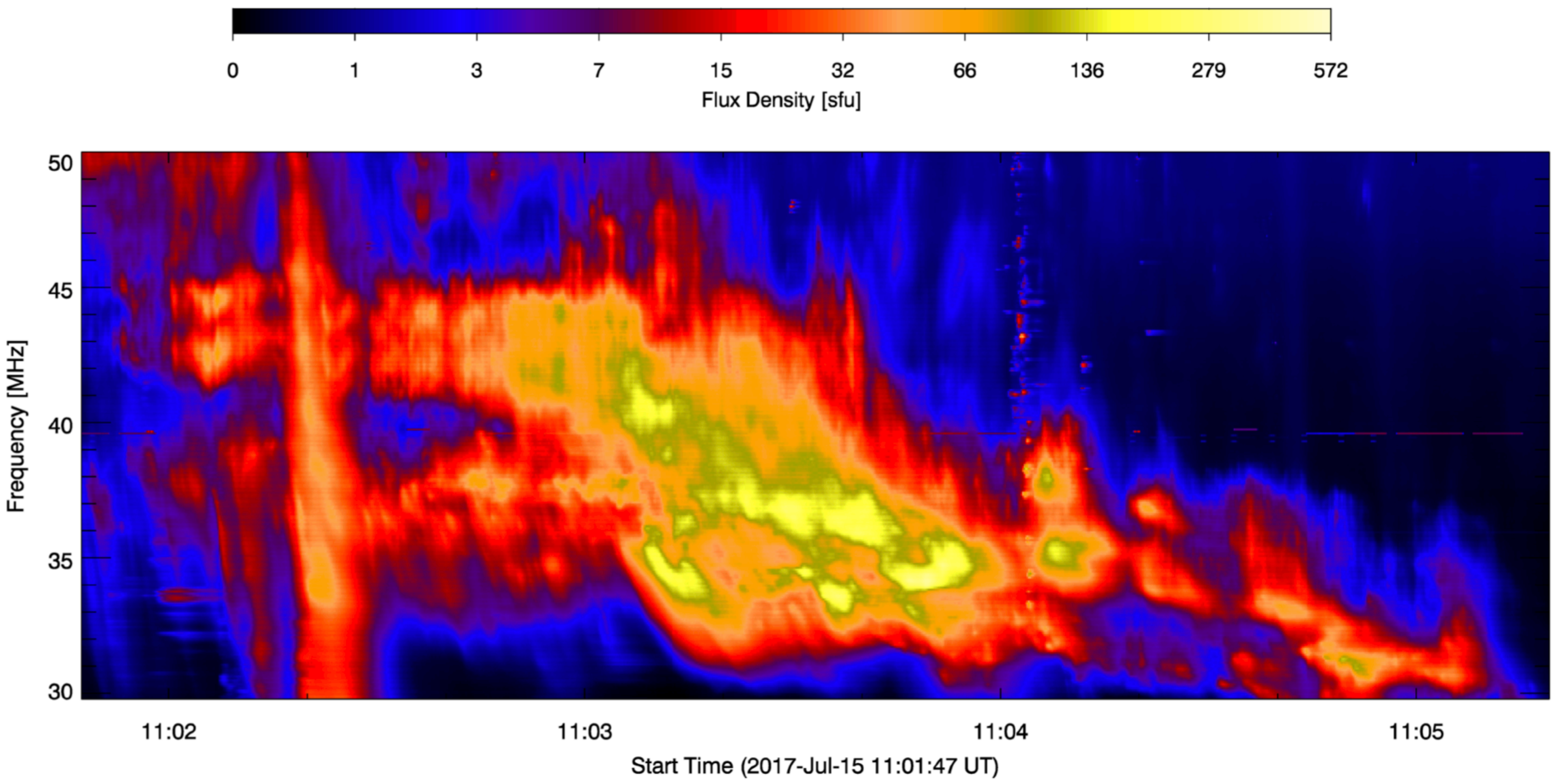
- Occurrence rates as a function of spectral type, age, flare activity?
- Evolution of activity and rotation
- Detections necessary for understanding high energy photon *and* particle environment around stars

Exoplanetary radio emission

- Insight into exoplanetary dynamos, interior compositions and structure
- Are magnetospheres important for atmospheric retention?

Coronal mass ejections (CMEs) and Solar energetic particle events (SEPs)

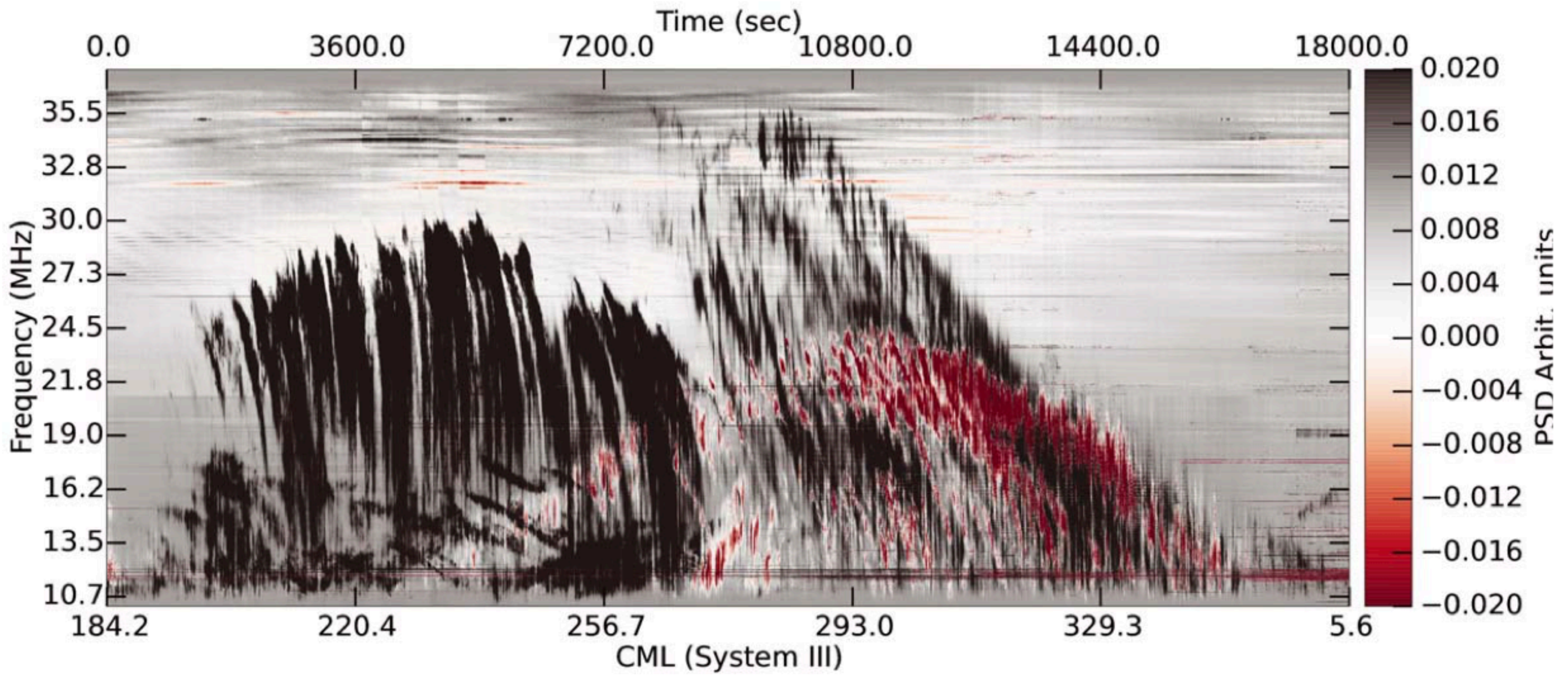
- Solar CMEs / SEPs are associated with Type II / III radio bursts
- Langmuir waves —> plasma emission
- $\nu_p \propto \sqrt{n_e}$



Chrysaphi et al. 2020

Exoplanetary radio emission

- Electron cyclotron maser emission (ECME)
- $\nu_{\mathrm{cyc}} \propto B$
- Emission is circularly polarized and beamed in a hollow cone with large opening angle along magnetic field



Clarke et al. 2017

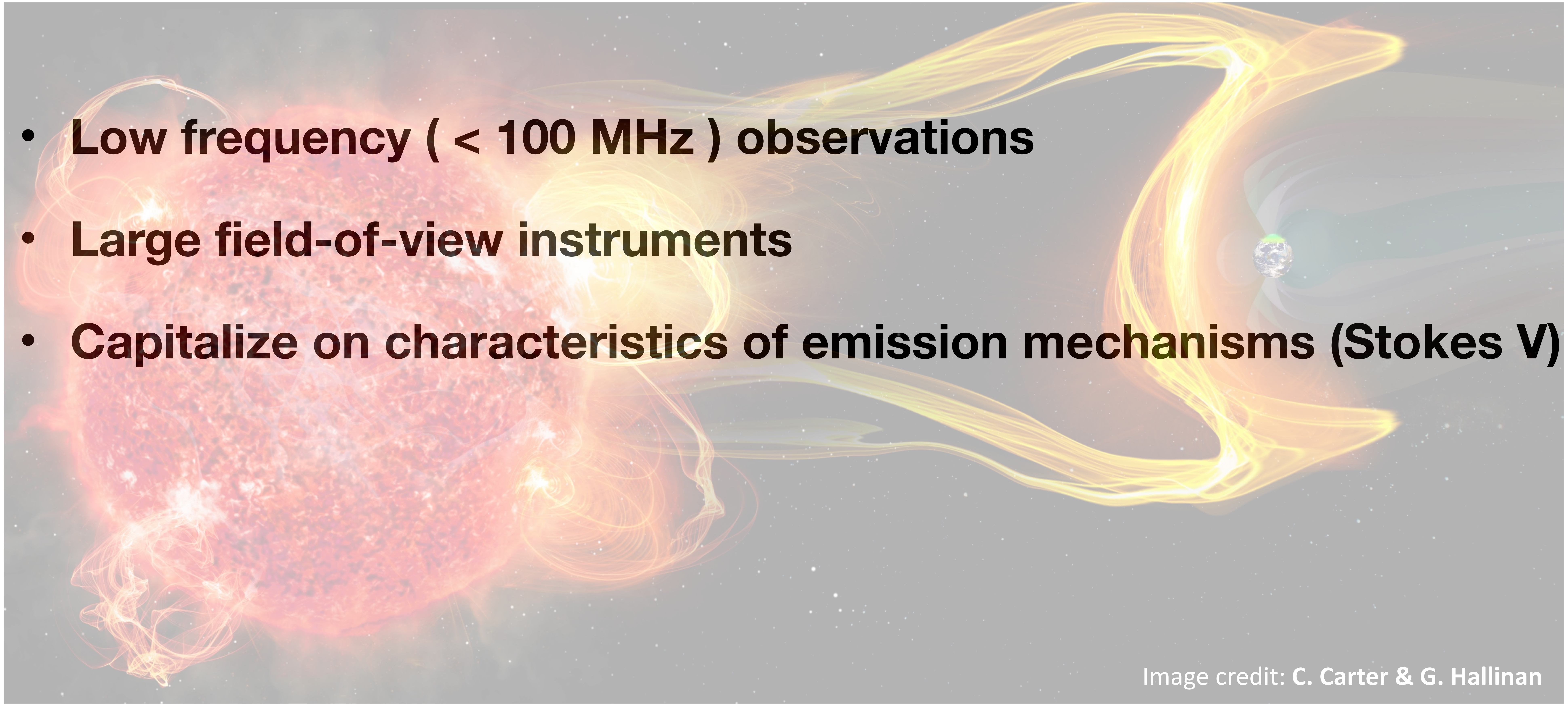
Neither exoplanetary radio emission nor Type II / III stellar radio bursts have been detected to date.

M dwarfs

- Active flare stars are emitters of coherent radio bursts indicative of auroral processes (e.g., **Lynch+2017**, **Villadsen+2019**).
- Detection of solar Type IV-like emission from Proxima Cen (**Zic+2020)**.
- Detection of auroral radio emission from the inactive, slowly rotating M4.5 dwarf GJ1151 evidence of a sub-Alfvénic interaction of the stellar magnetic field with a close-in planet (**Vedantham+2020a**).
- Radio aurorae have been detected on in ultracool dwarfs (across a range of spectral types, from M9 to T6, e.g. **Hallinan+2015**, **Kao+2018**) at GHz frequencies, and most recently at 144 MHz (**Vedantham+2020b**).
- Detection of radio emission associated with the τ Boötis planetary system (**Turner+2020)**.

Exoplanets

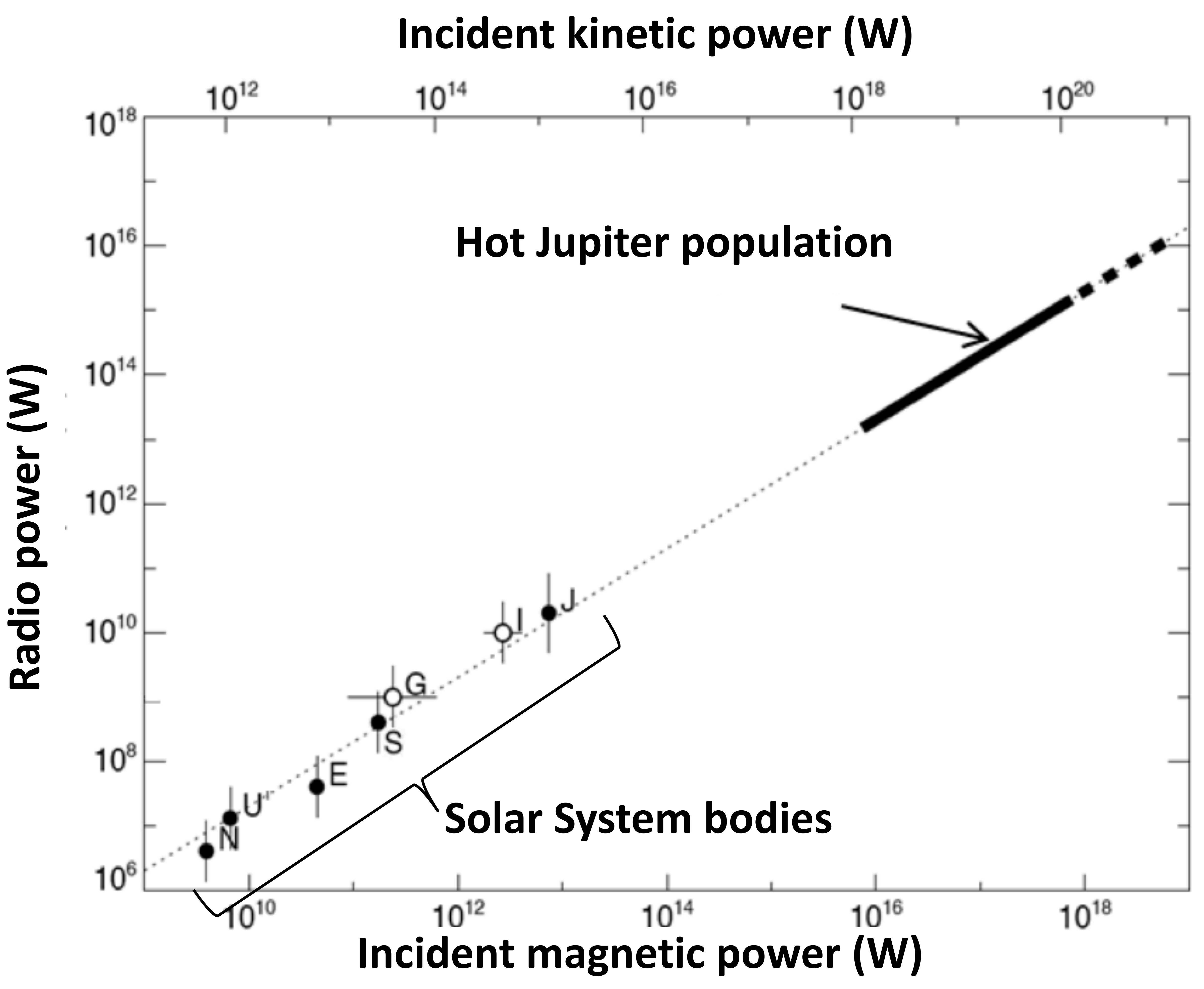
How can we optimize the search for extrasolar space weather, and begin detecting and characterizing a wide range of systems en masse?



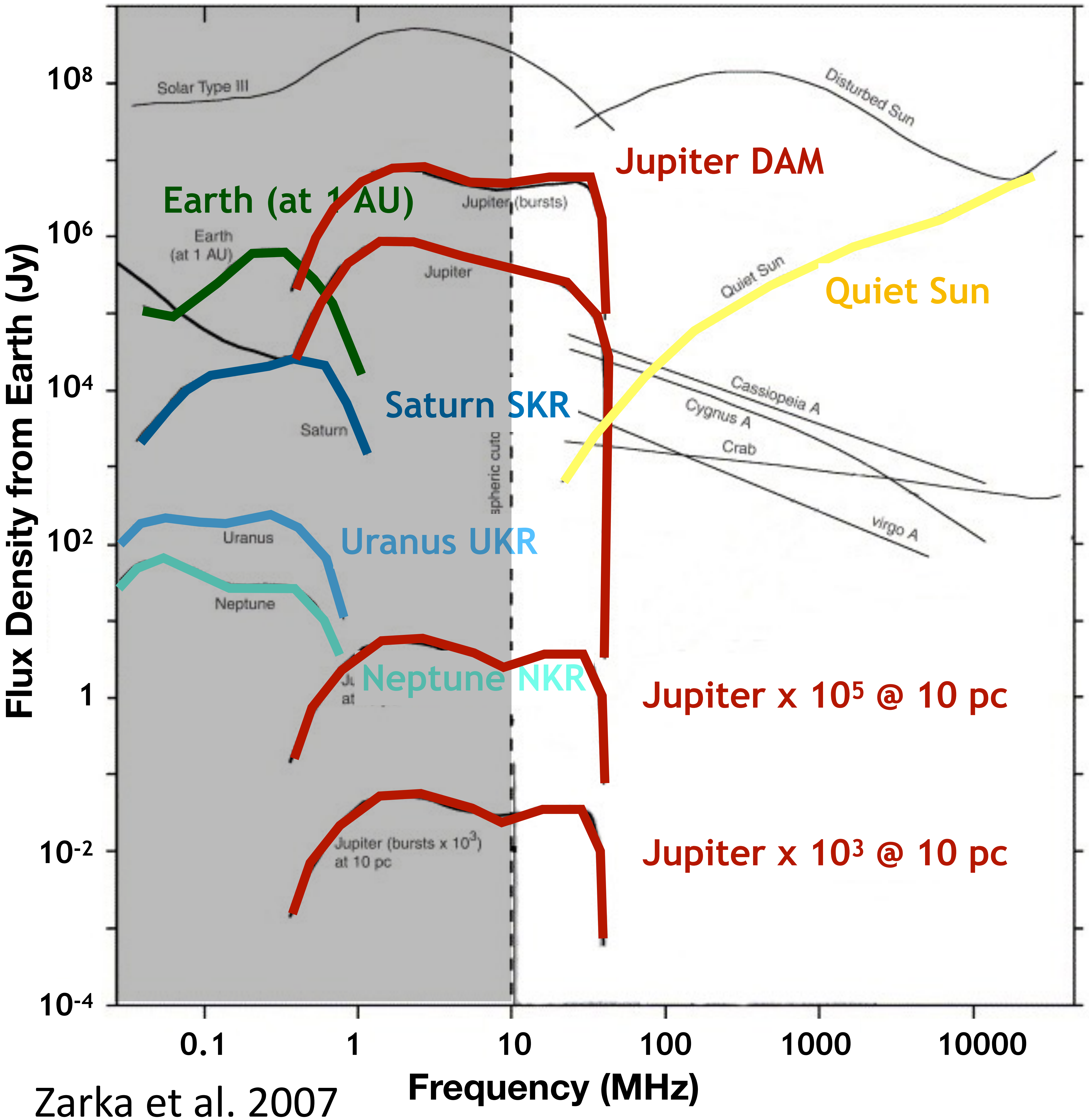
- Low frequency (< 100 MHz) observations
- Large field-of-view instruments
- Capitalize on characteristics of emission mechanisms (Stokes V)

Image credit: **C. Carter & G. Hallinan**

Extrapolation from our own solar system suggests it is necessary to go below 100 MHz to directly detect exoplanetary radio emission.



Zarka 2001

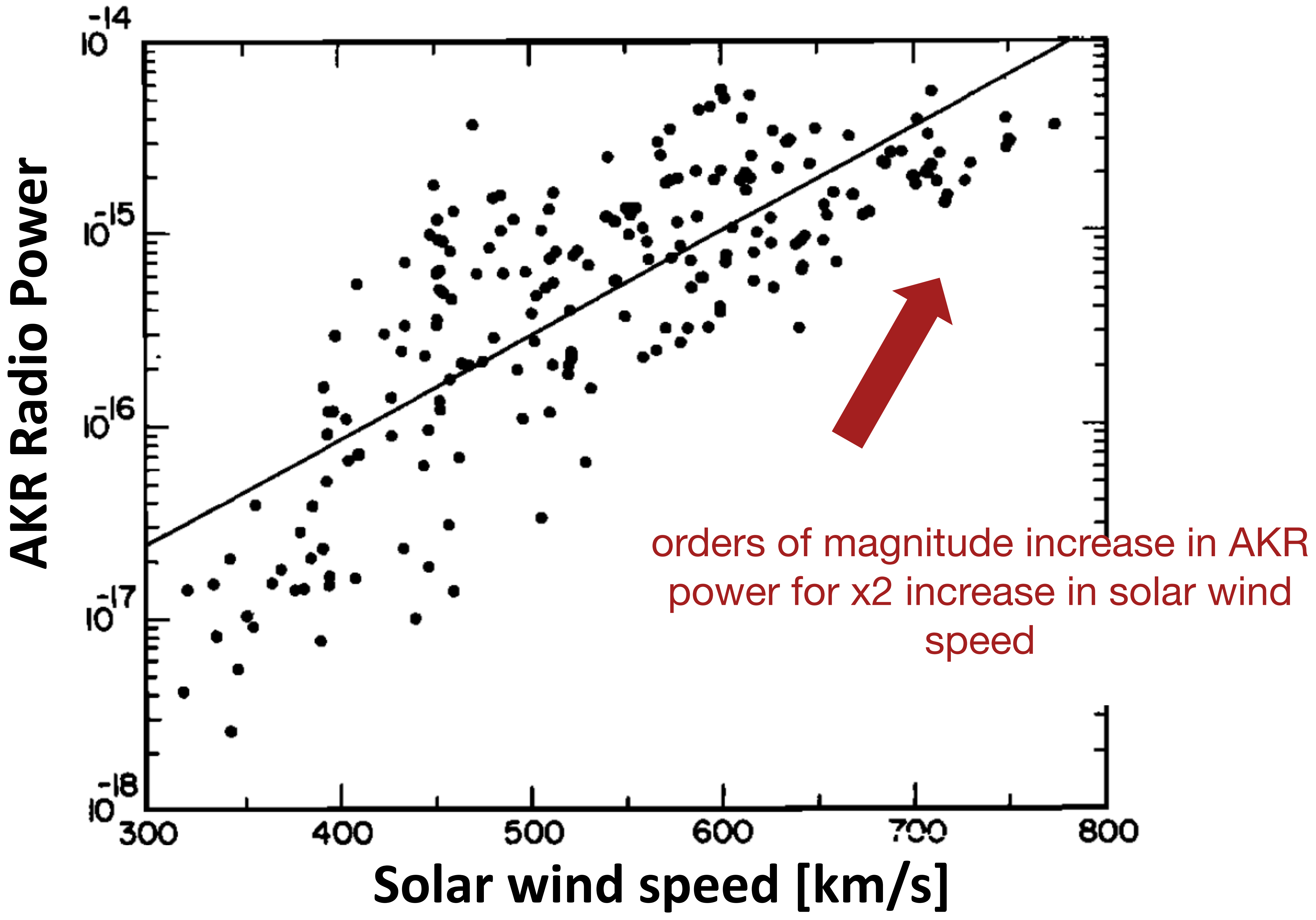


Zarka et al. 2007

Capture a large fraction of the sky in order to simultaneously monitor a large sample of objects.

- Sensitive to rare CME-driven events that can increase the output power in exoplanetary radio emission by orders of magnitude.

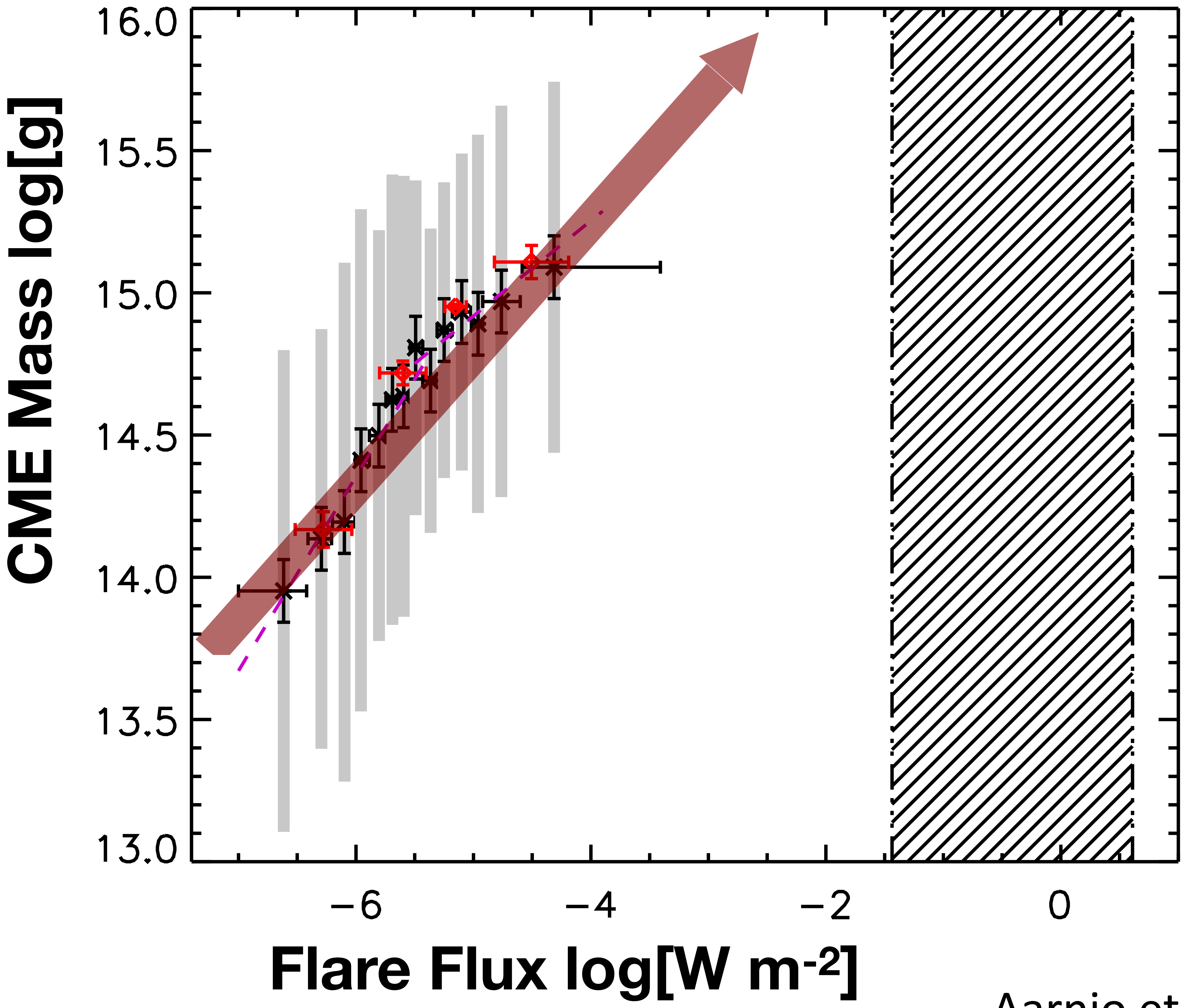
Earth's Auroral Emission



Gallagher & D'Angelo 1981

It remains an open question whether the Solar flare–CME relation can be extrapolated to higher flare energies and more magnetically active stars.

Relationship between CME mass and flare flux for the Sun



Aarnio et al. 2010

Owens Valley Radio Observatory Long Wavelength Array (OVRO-LWA)

Stage I OVRO-LWA (2013-2014)

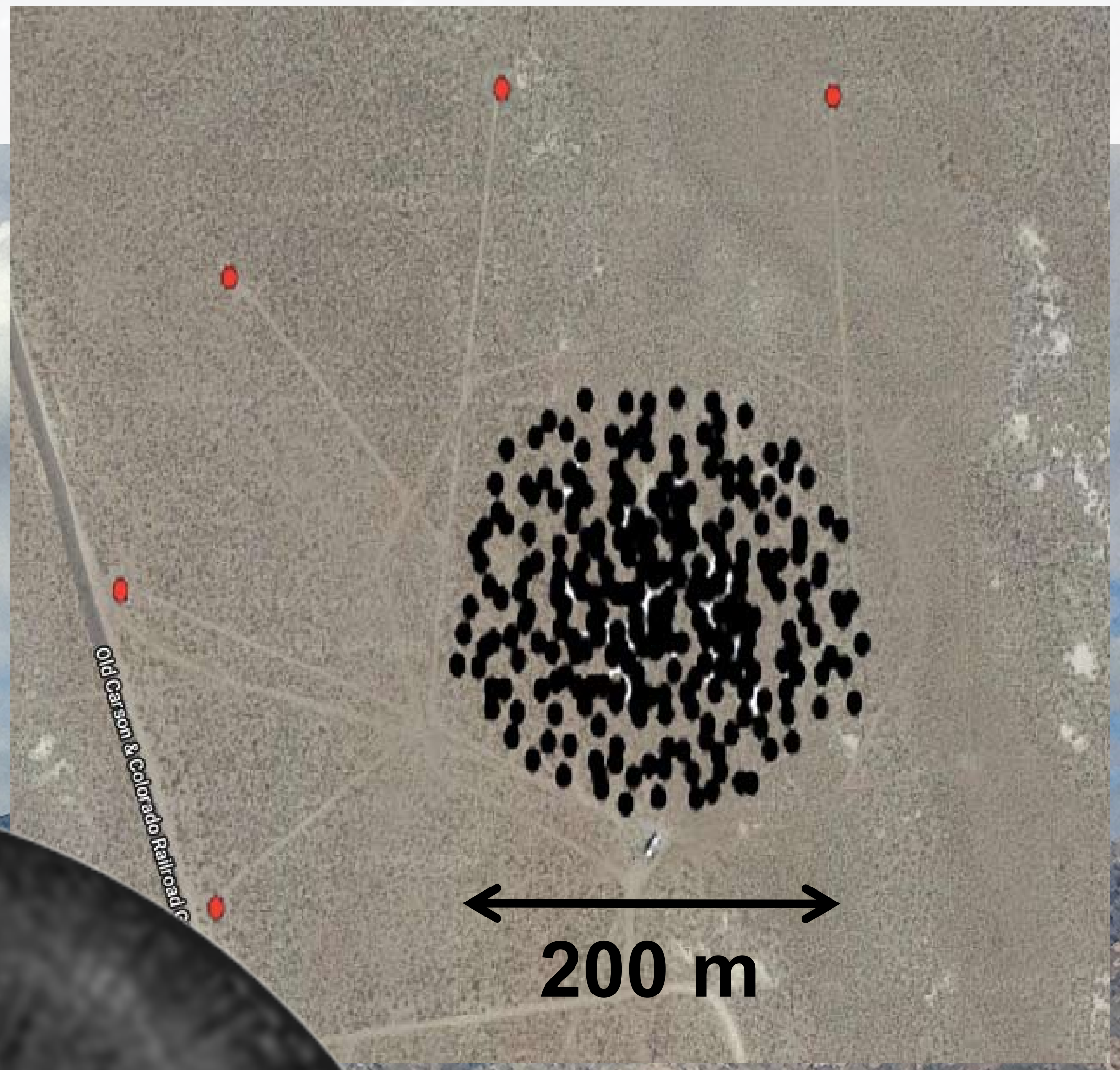
Stage II OVRO-LWA (2015-2016)

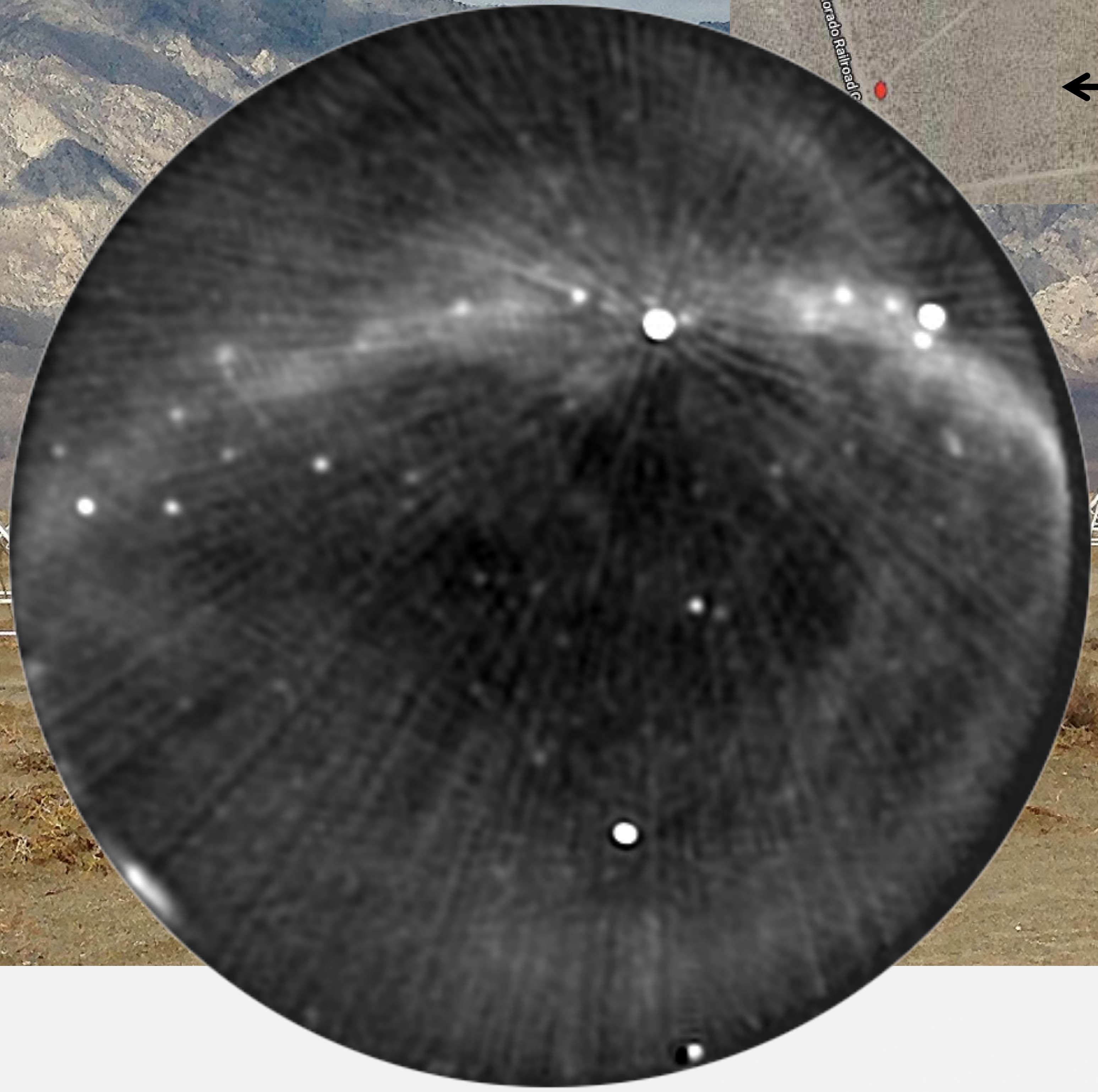
Stage III OVRO-LWA-352 (2019-)

OVRO-LWA Stage I (2013–2014)

- 251 LWA crossed-dipole antennas, in 200 m diameter core
- 5 LEDA antennas — total power measurements (**Price+2018**)
- 28-84 MHz band, 24 kHz resolution
- full cross-correlation with 512-input LEDA correlator (**Kocz+2015**)
- 1 deg resolution

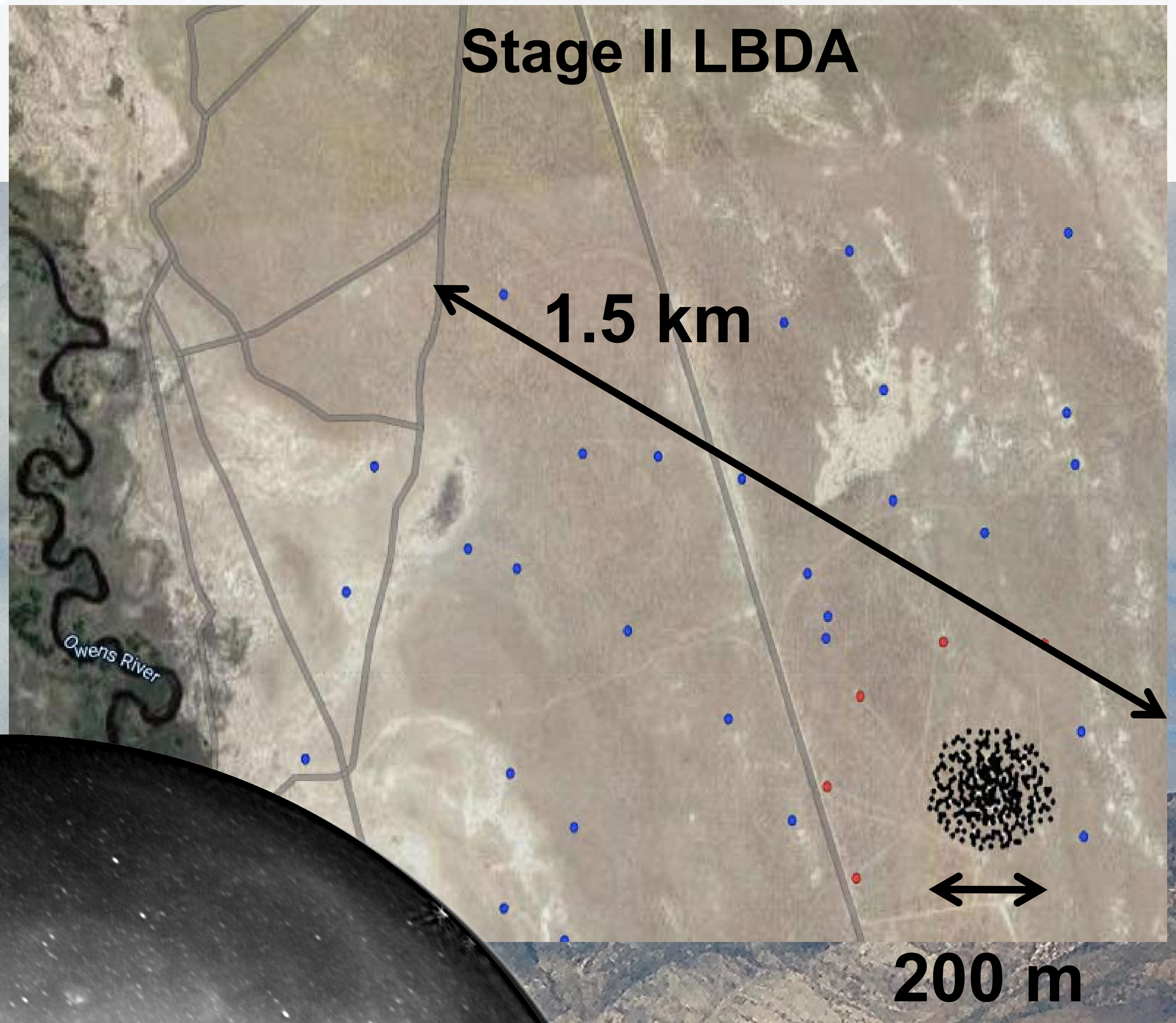
Stage I Core Array

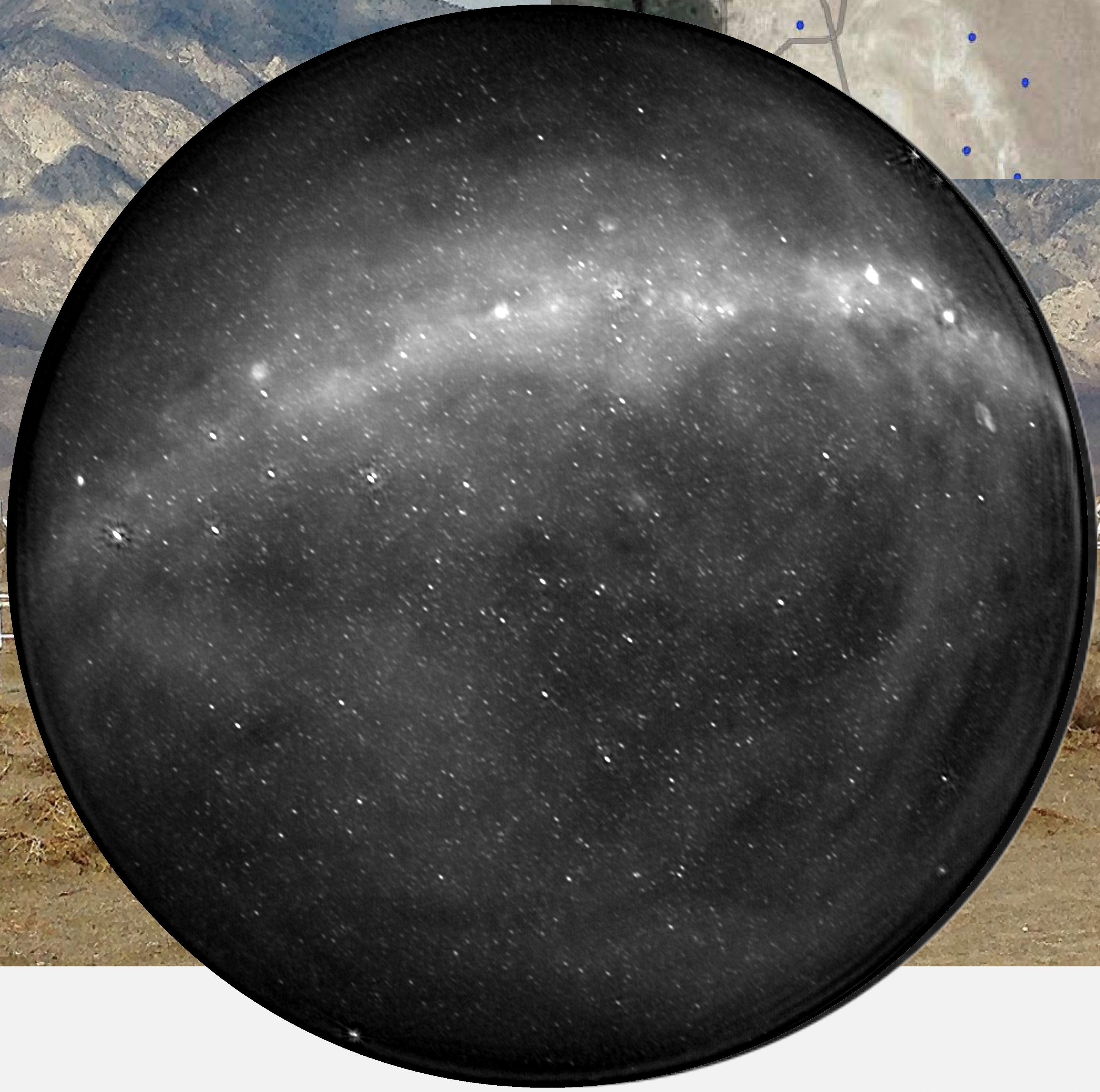




OVRO-LWA Stage II (2015–2016)

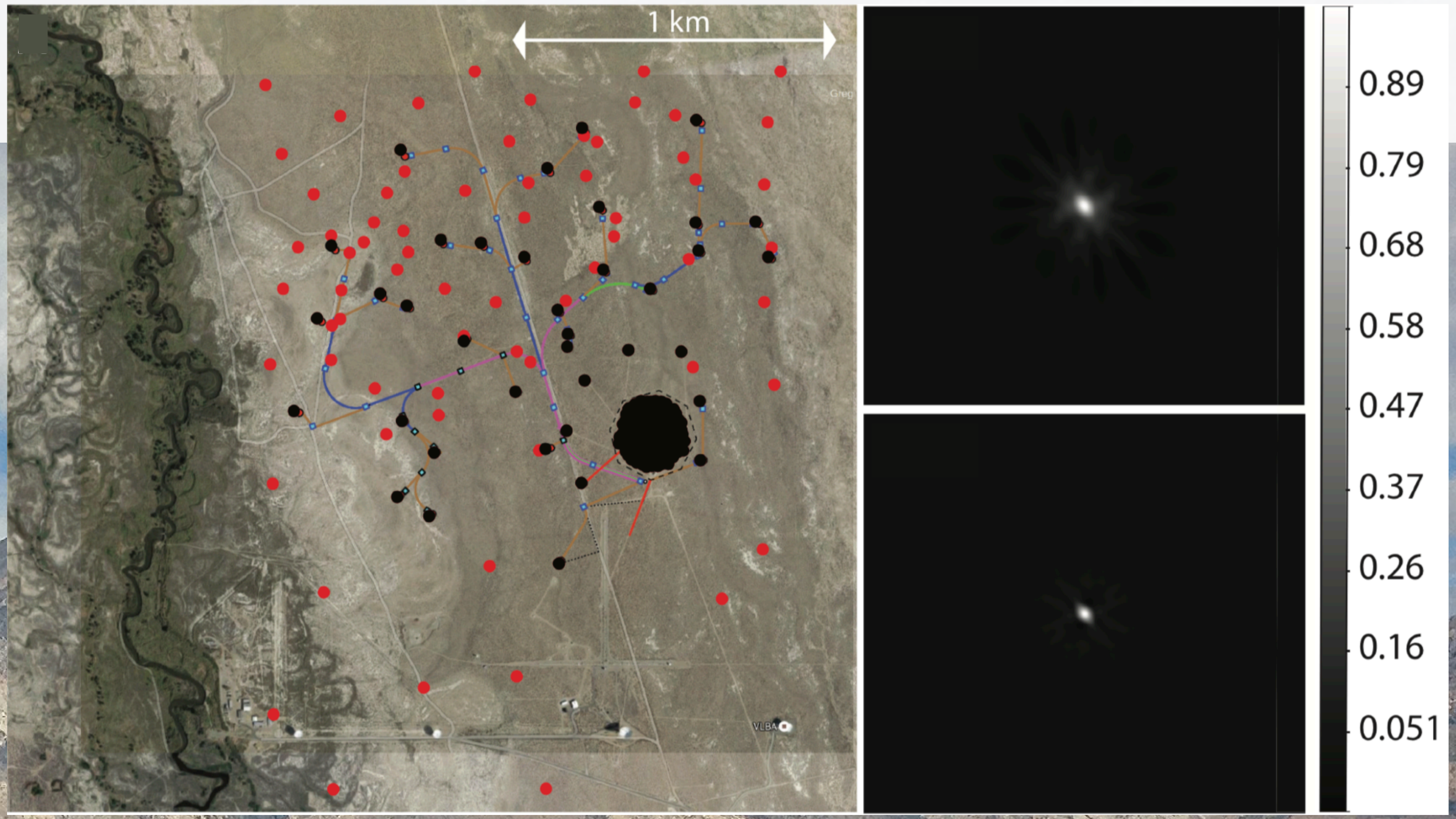
- 32 additional antennas out to 1.5 km (Long Baseline Demonstrator Array)
- RF signal transport over optical fiber
- 7 arcmin resolution at top of band
- >10,000 point sources in single 13 s snapshot
- ~800 mJy snapshot sensitivity





OVRO-LWA-352 (2019–)

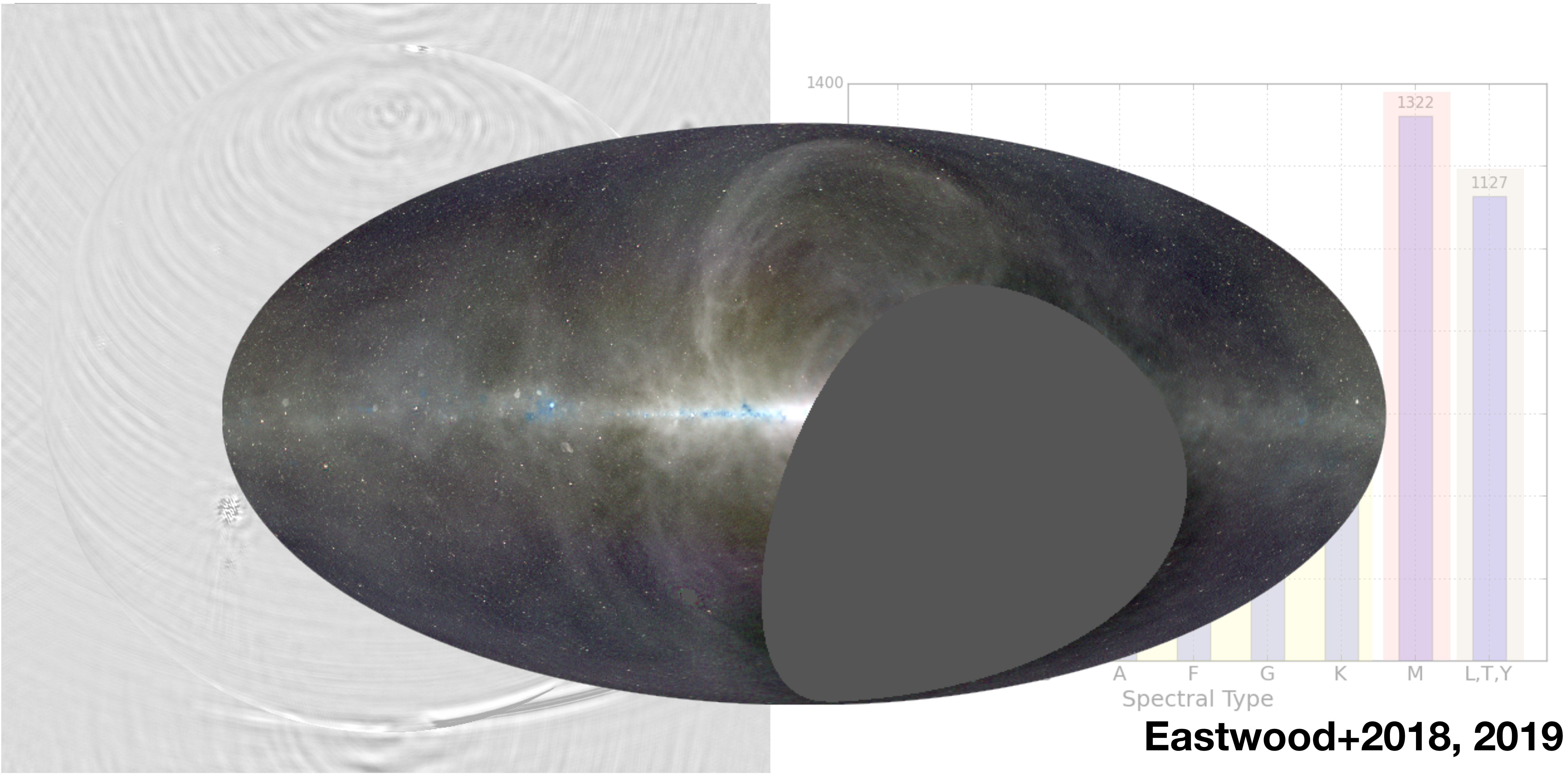
- Additional 64 antennas **out to 2.6 km**, for a **total of 352**
- Complete redesign of the analog receiver boards
- Digital backend redesign, next-gen correlator (maintaining the FPGA/GPU architecture of the existing 512-input LEDA), with **704 inputs and 70 MHz BW**
- Upgraded calibration and imaging cluster, **3 PB usable storage and 4 TB RAM**



Simultaneous!

standard correlation mode
beamforming mode (12 beams)
cosmic ray detection

Extrasolar space weather monitoring with the OVRO-LWA



Eastwood+2018, 2019

- Volume-limited sample of nearly 4000 systems.
- Search for signatures of space weather across a broad range of stellar ages and spectral types.

Questions?