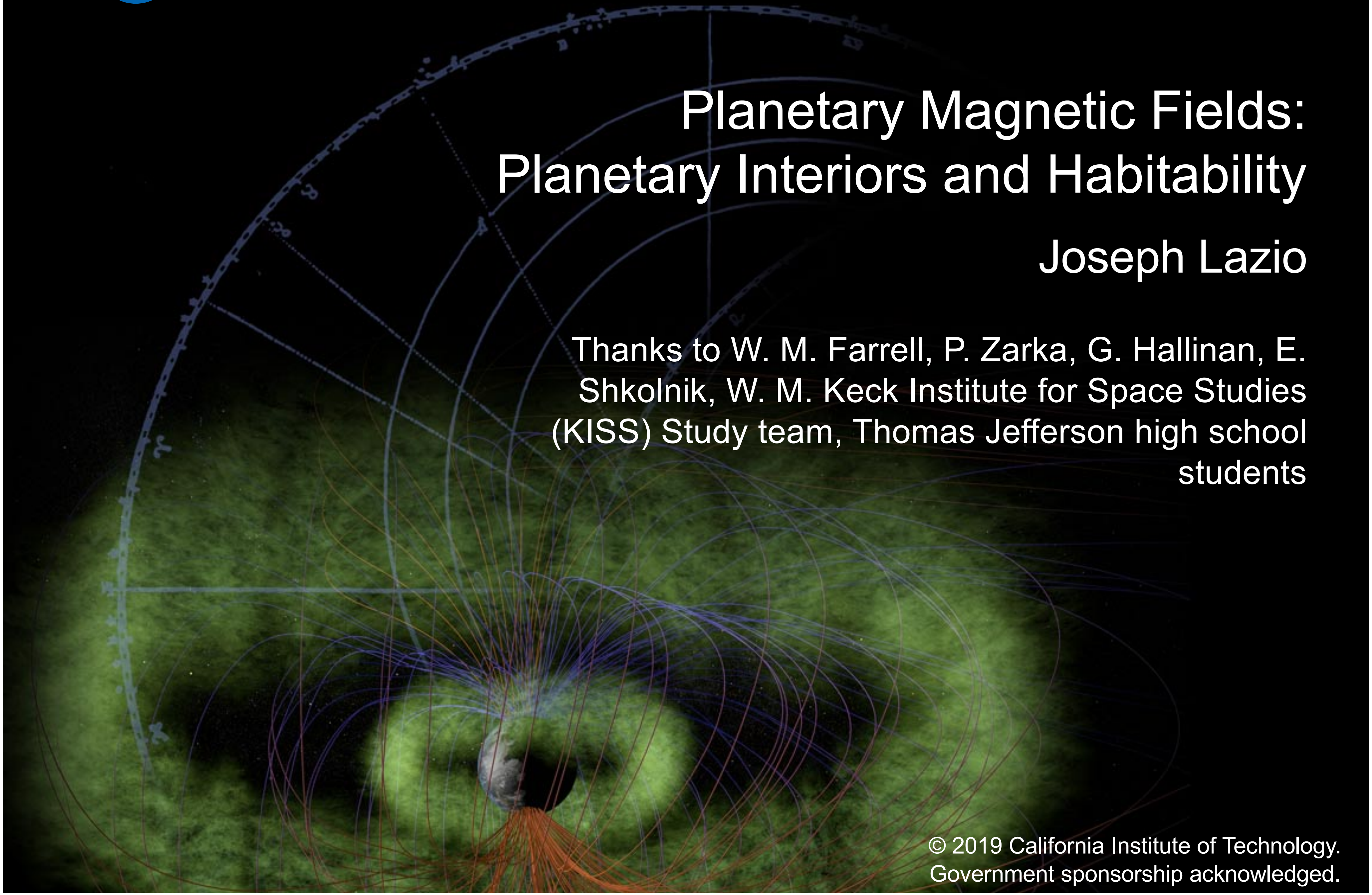

Jet Propulsion Laboratory
California Institute of Technology

Planetary Magnetic Fields: Planetary Interiors and Habitability

Joseph Lazio

Thanks to W. M. Farrell, P. Zarka, G. Hallinan, E. Shkolnik, W. M. Keck Institute for Space Studies (KISS) Study team, Thomas Jefferson high school students

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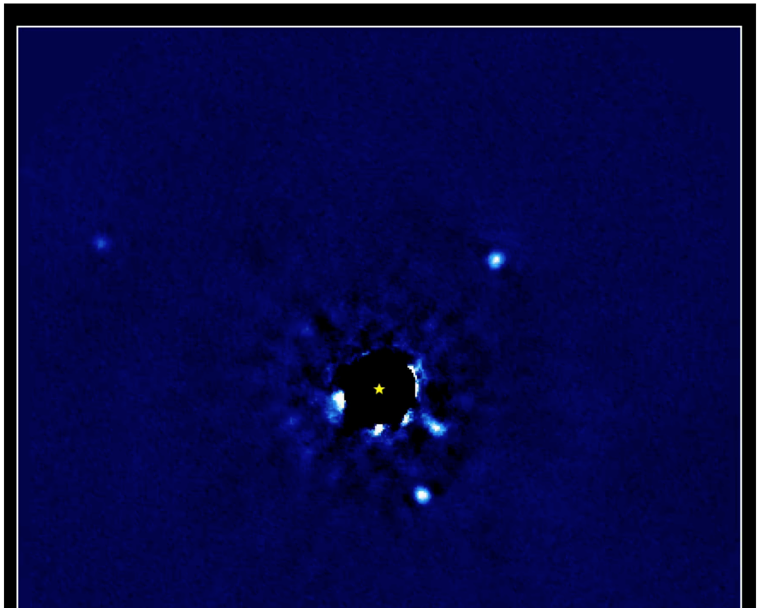
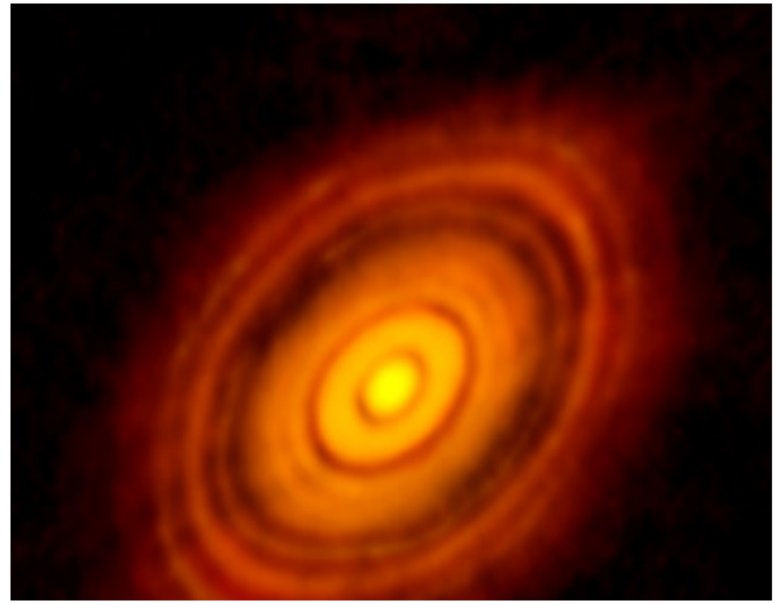
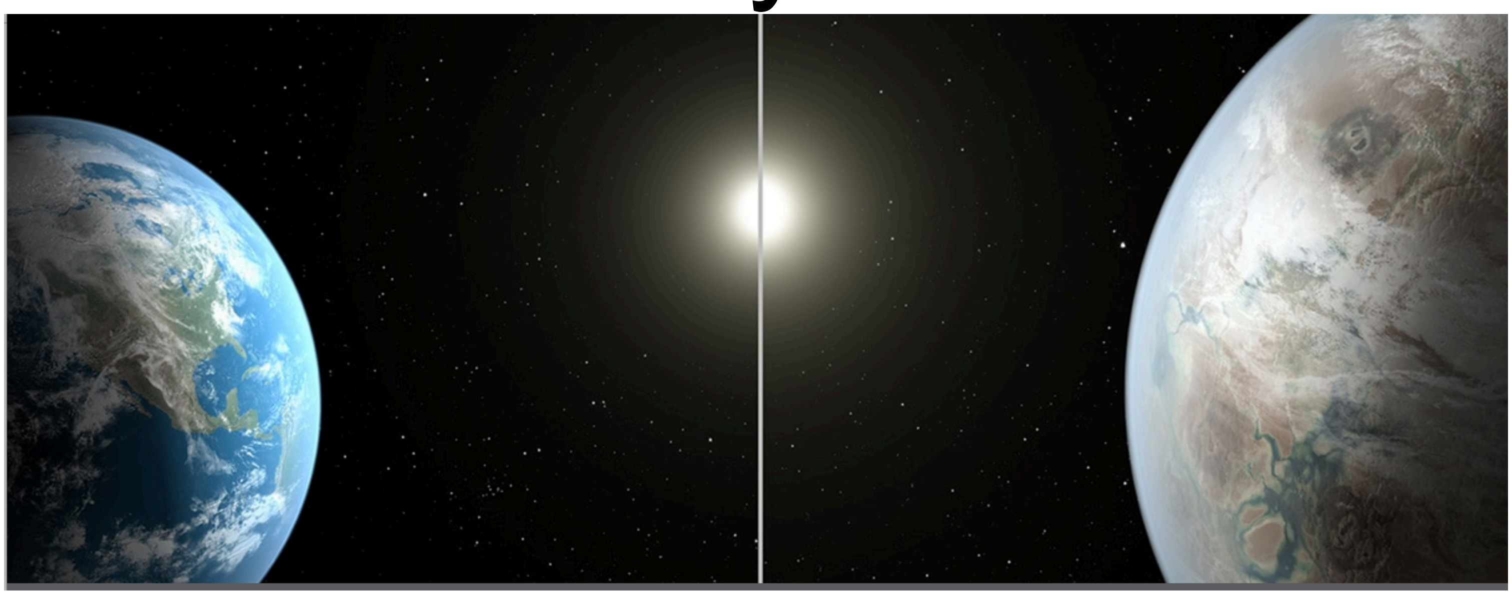
Government sponsorship acknowledged.





Act I: Magnetic Fields

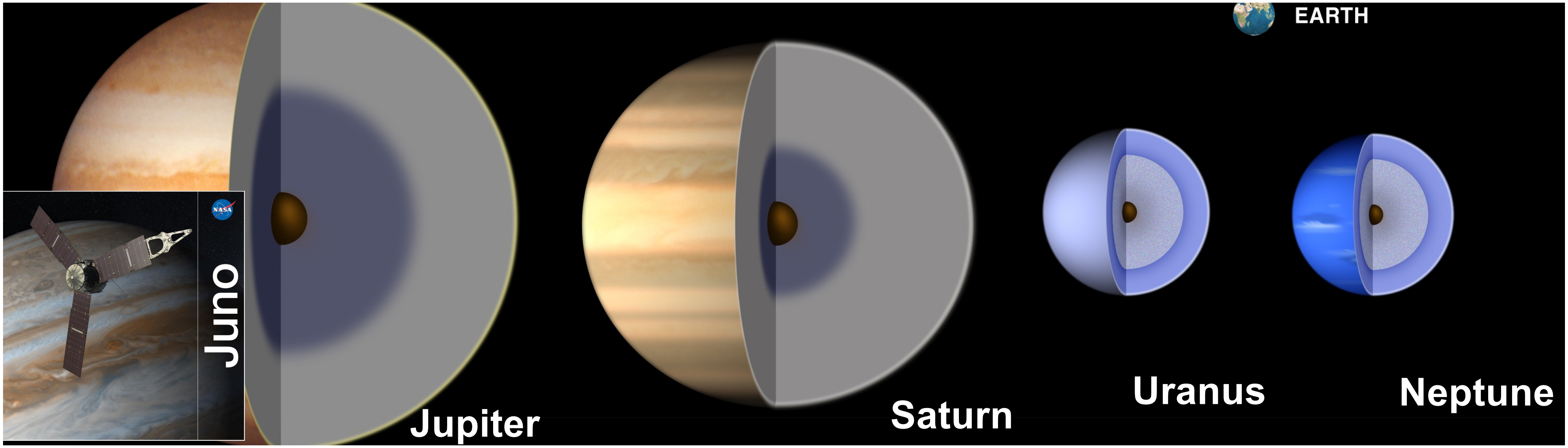
a.k.a. Why Do We Care?

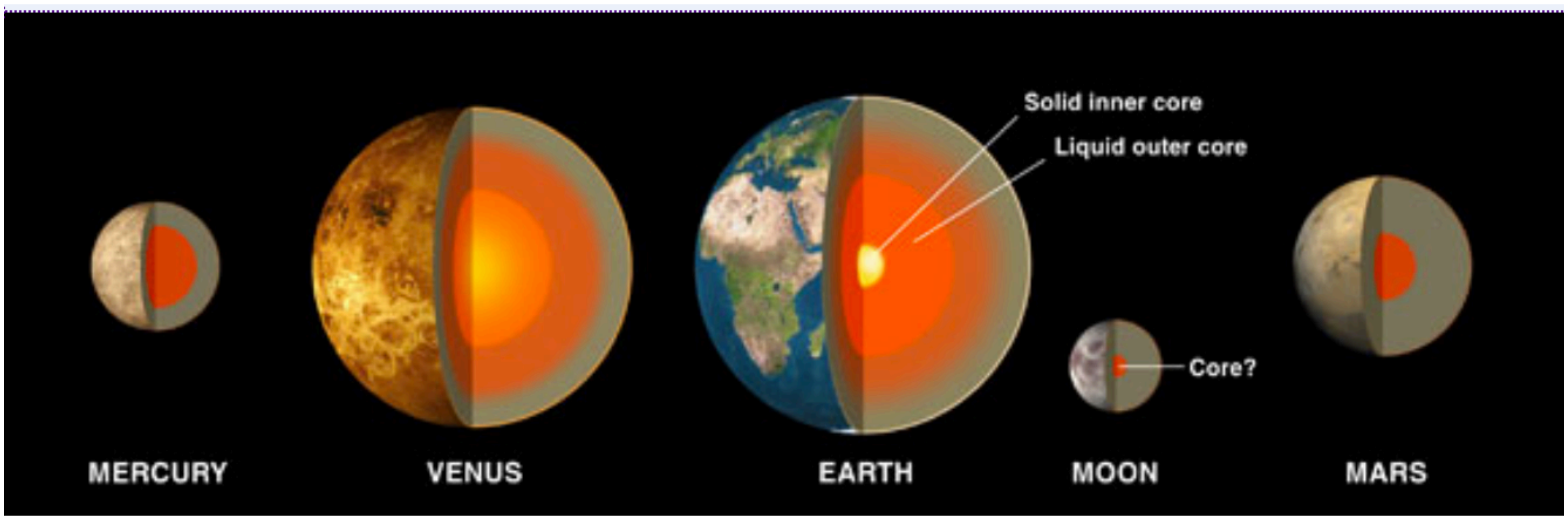


Credits: J. Wang & C. Marois; ALMA (NRAO/ESO/NAOJ); C. Brogan, B. Saxton (NRAO/AUI/NSF);JPL, CIT

Planetary Interiors and Magnetic Fields

Solar System Guidance



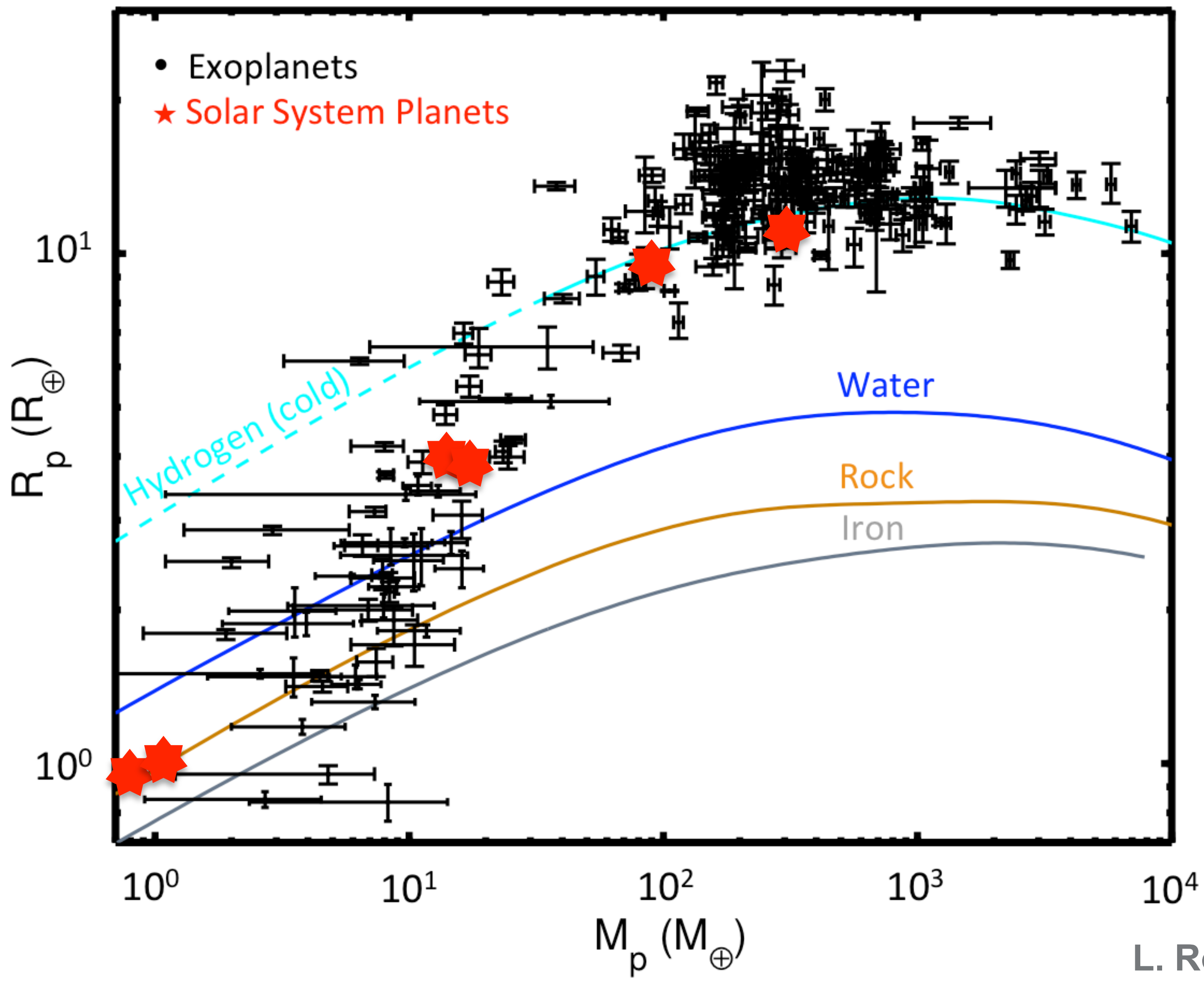


Planetary Interiors

Mass-Radius Relation ➔ Mass-Radius-Magnetic Field Relation?

Mass from radial velocity

Radius from transit



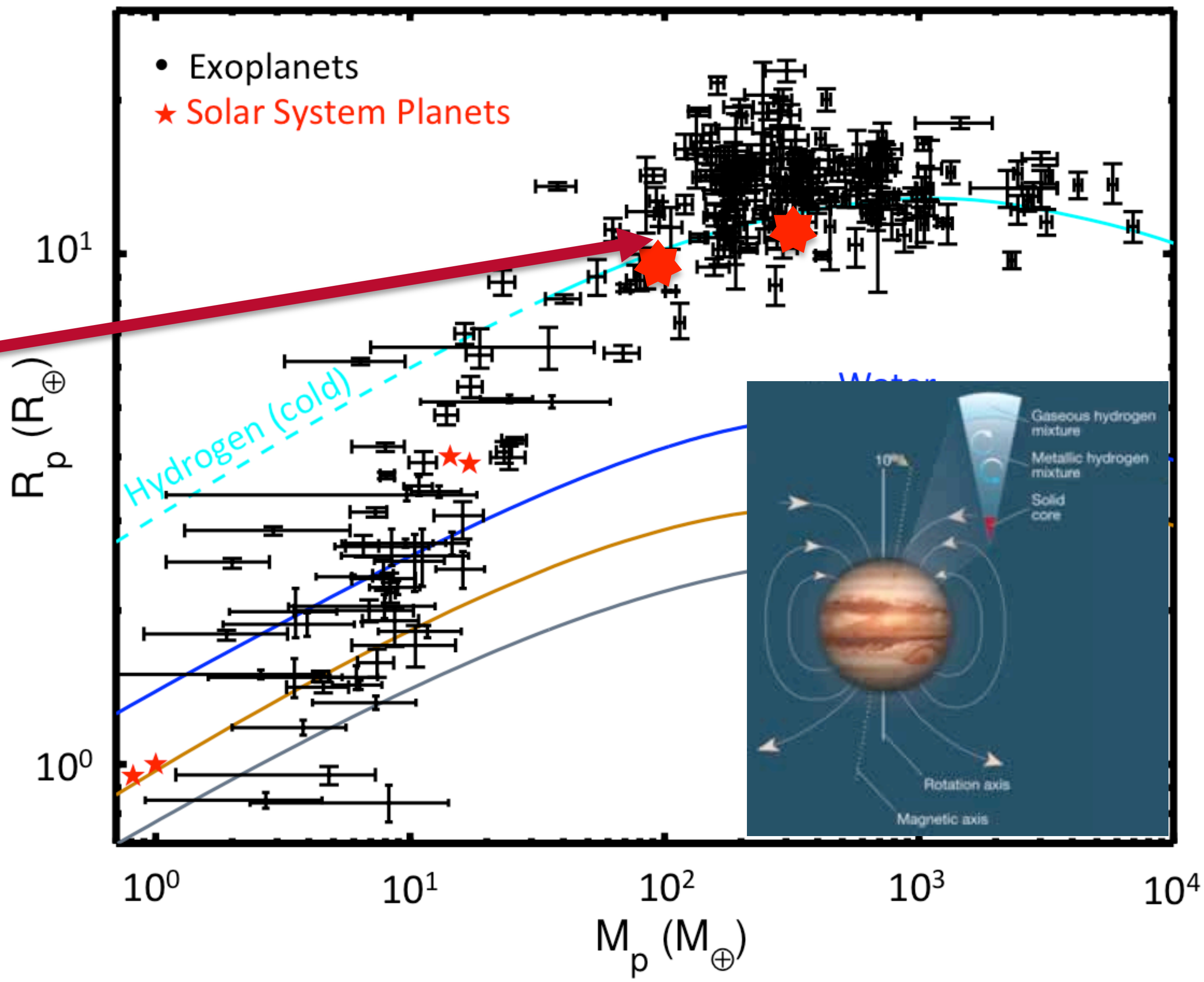
L. Rogers

Planetary Interiors

Jovian Planets

- **Hydrogen is metallic at P >~ 25 GPa**
- **Convective at depth**

➢ ***Should* have magnetic fields; wrong if absent**

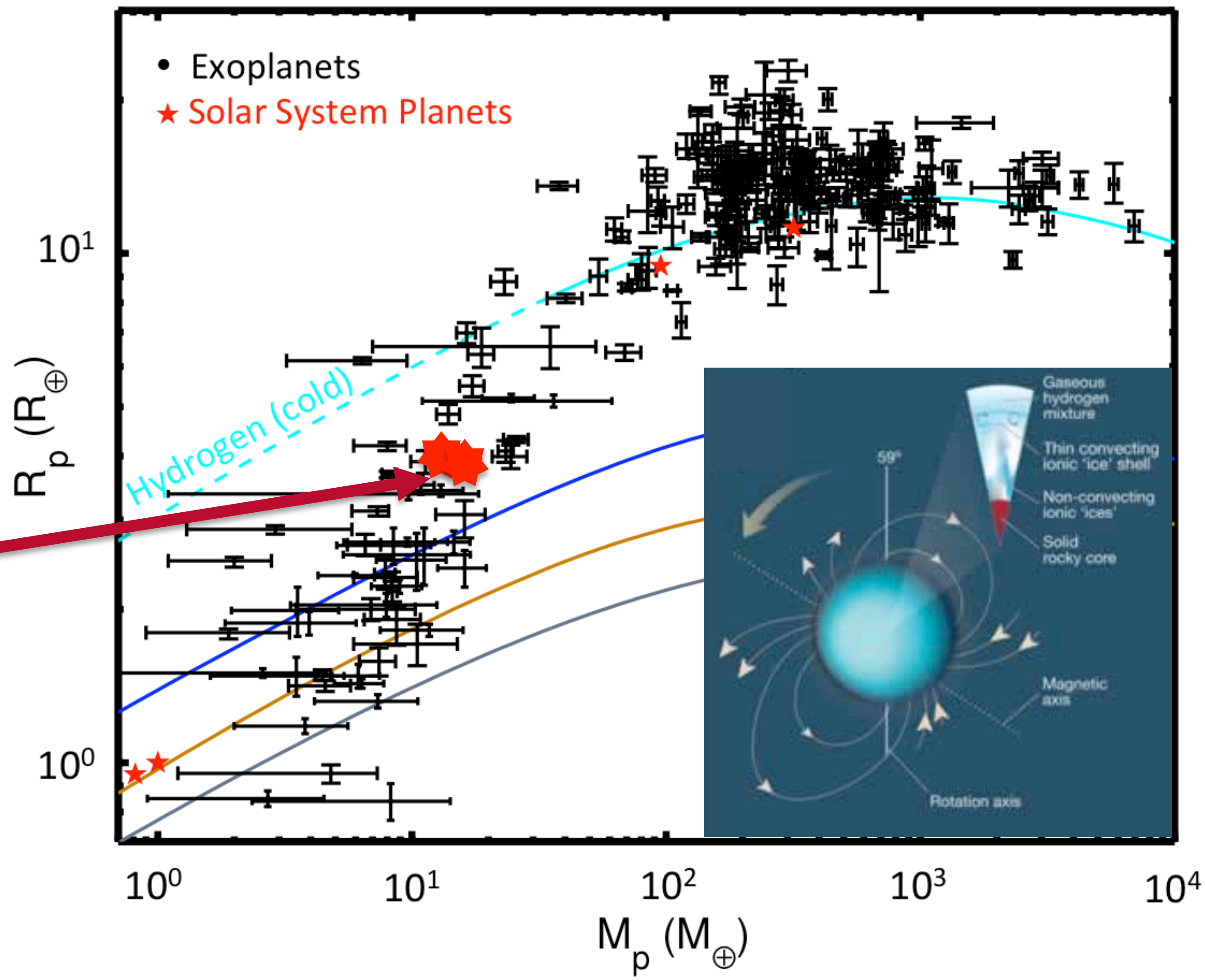


Planetary Interiors

Ice Giants

Water electrically conducting >~ 1000 K

- ➢ **Neptune-like planets *should* sustain planetary-scale dynamos**
- ∴ **Detection of magnetic field would confirm composition as substantially water**



Planetary Interiors

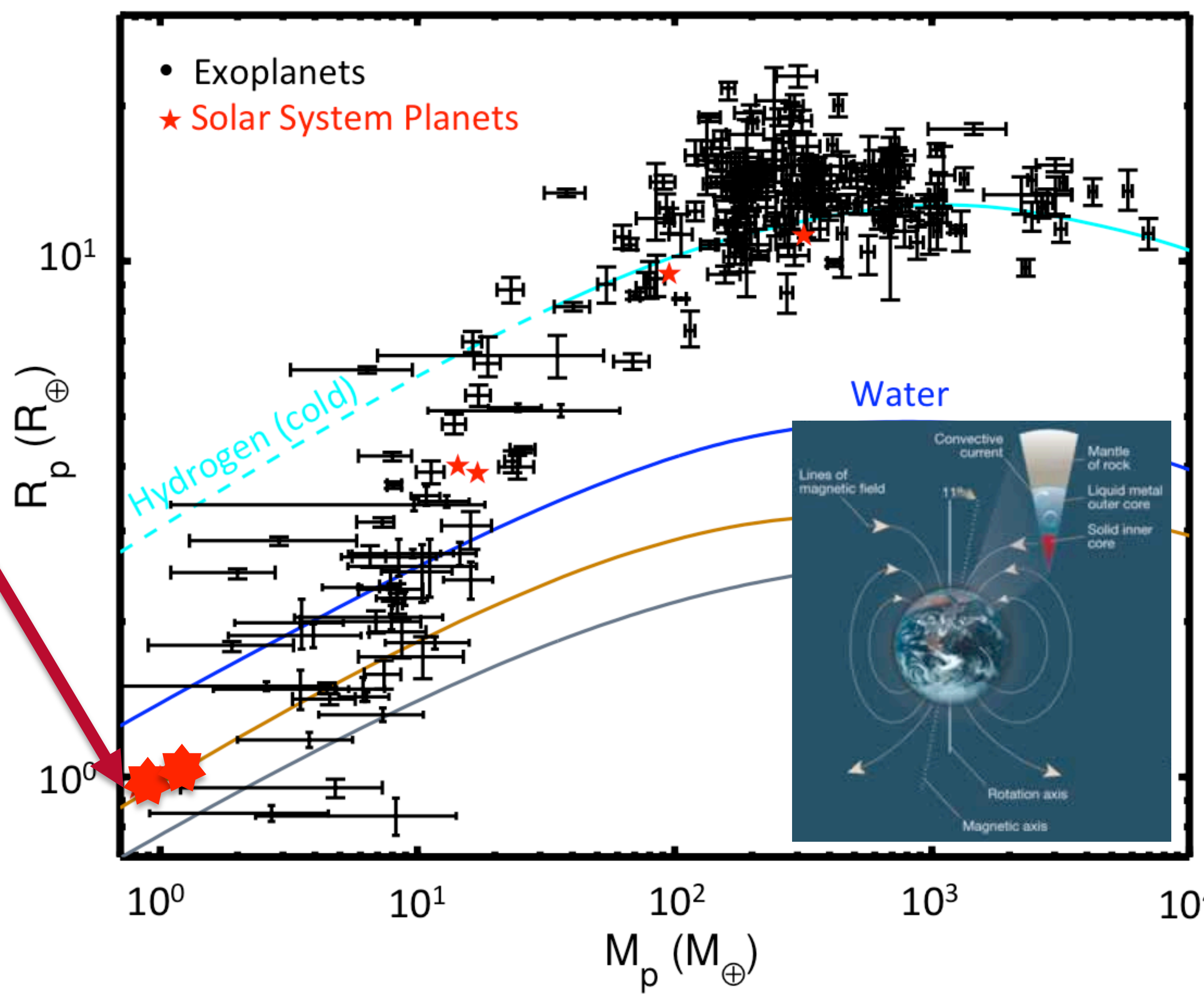
Terrestrial-Mass Planets

Not **guaranteed to have convecting, conductive Fe-liquid cores**

- **SiO mantle+Fe core *or* Si-Fe-O mantle?**
- **Core (partially) solid? (volatile concentration)**

❖ **Marginal convective energy budget in Earth's core**

- **T > 1500 K**
- **Stronger tidal heating**
- **Higher concentration of radio nuclei**
- **Thick H/He envelope or stagnant lid tectonics**



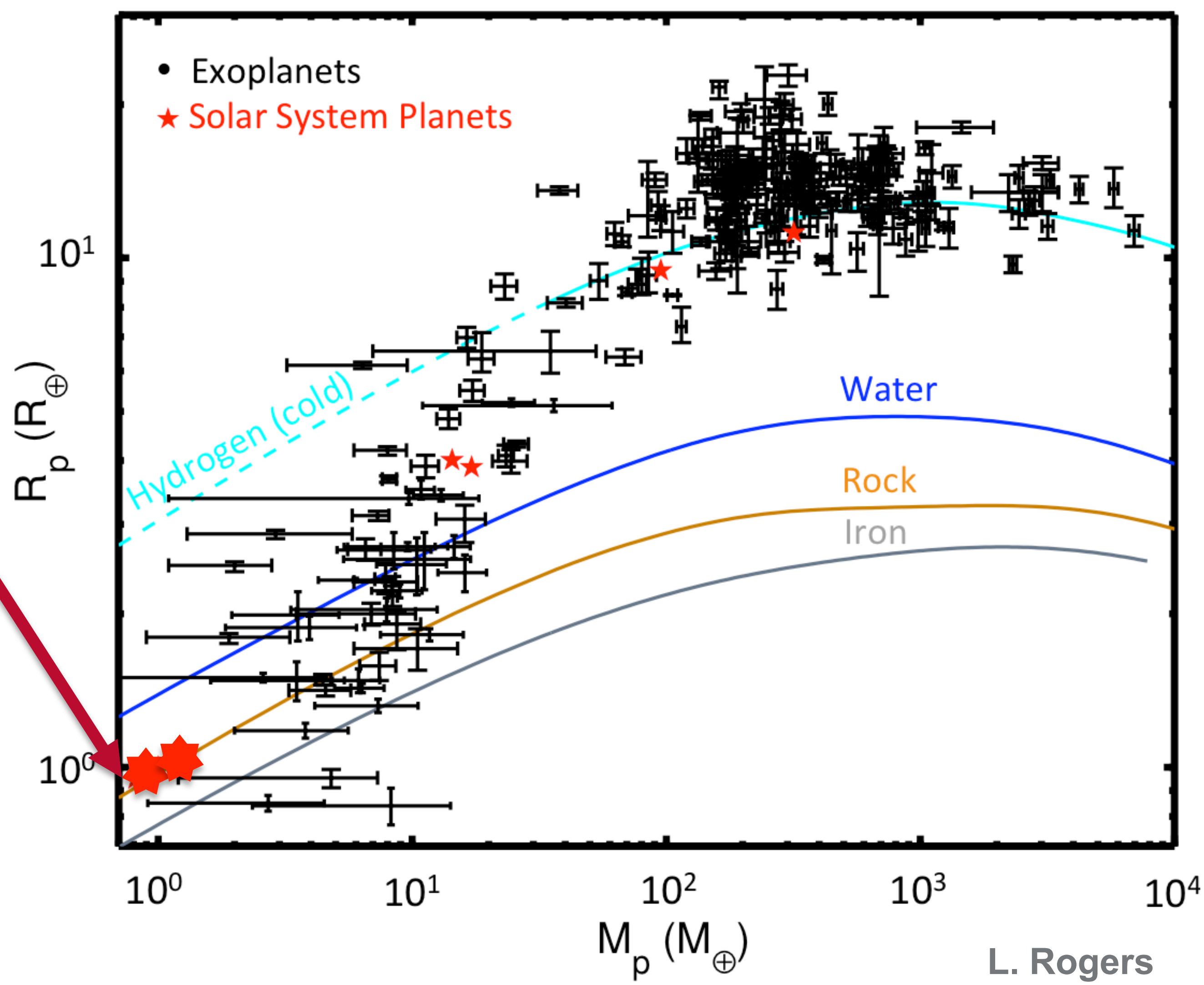
Planetary Interiors

Terrestrial-Mass Planets

***Not* guaranteed to have convecting, conductive Fe-liquid cores**

- **SiO mantle+Fe core *or* Si-Fe-O mantle?**
- **Core (partial) solidification?**
- **Marginal convective energy budget in Earth's core**

- **Magnetic field measurement constrains planet's thermal evolution, energy budget, may indicate plate tectonics**



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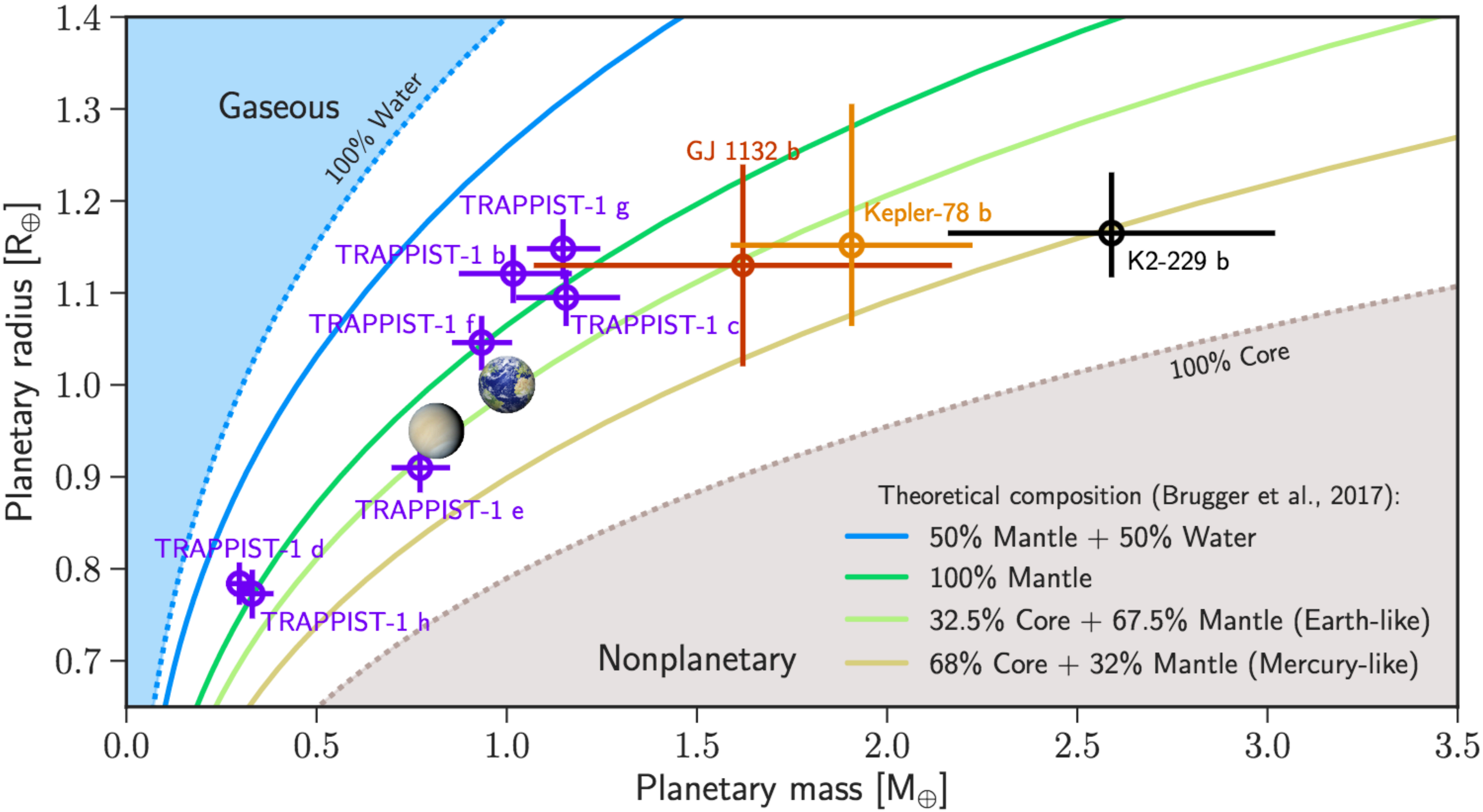
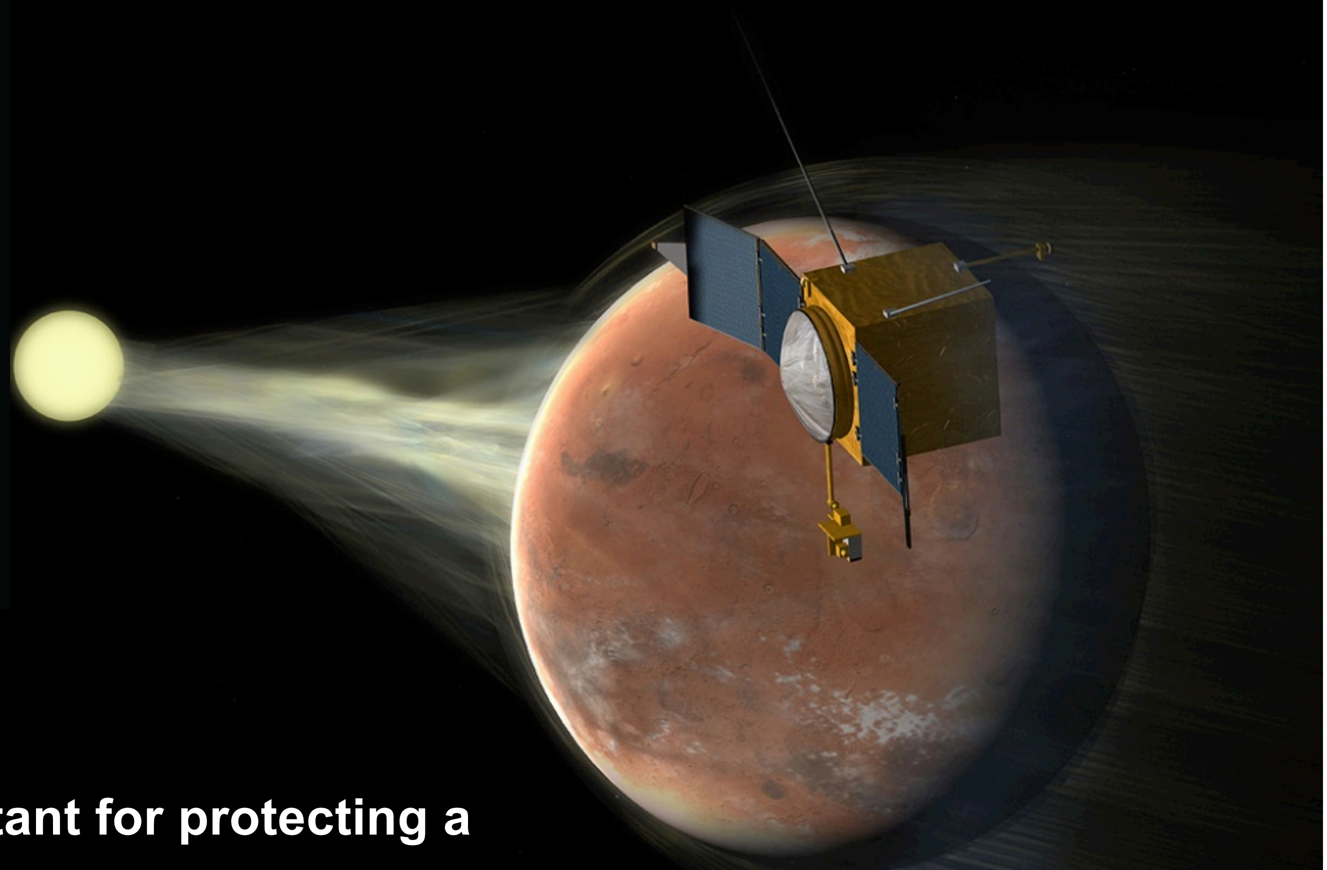
An Earth-sized exoplanet with a Mercury-like composition

Santerne et al.; arXiv:1805.08405





Magnetic fields are important for protecting a planet's atmosphere.

Yes?

… but atmospheric loss in solar system planets?

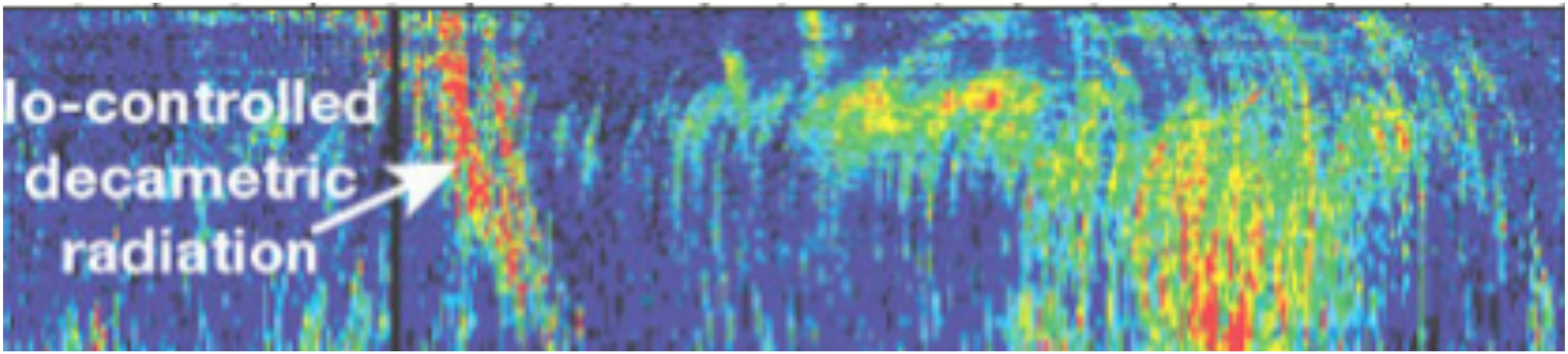
[From *Science* (2015 November 6). Reprinted with permission from AAAS.]

What Makes a Planet Habitable?

In parallel with the advances in observations, the exoplanet, Solar System, and astrobiology communities have generated a more comprehensive picture of planetary habitability. … Many factors and interactions are now expected to impact planetary habitability. These include the following:

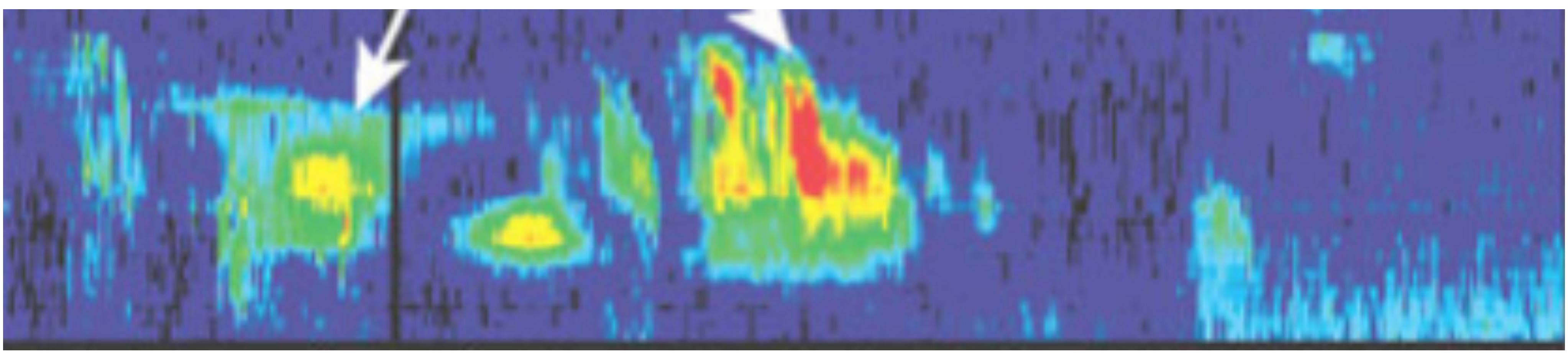
- The presence and distribution of liquid water oceans on the planetary surface ….
- The presence of a stable secondary atmosphere. …
- The presence of tectonic or volcanic activity and weathering processes to replenish atmospheric loss (…), and buffer climate (…).
- The internal energy budget of a planet ….
- The presence and strength of a **global-scale magnetic field**, which depends on interior composition and thermal evolution (Driscoll and Bercovici, 2013).

There are important feedbacks identified between the processes listed above …. For example, the persistence of a secondary atmosphere over billion-year time scales requires low atmospheric loss rates, which in turn can be aided by the presence of a **planetary magnetic field** (Driscoll and Bercovici, 2013; Garcia-Sage et al., 2017; Dong et al., 2018).

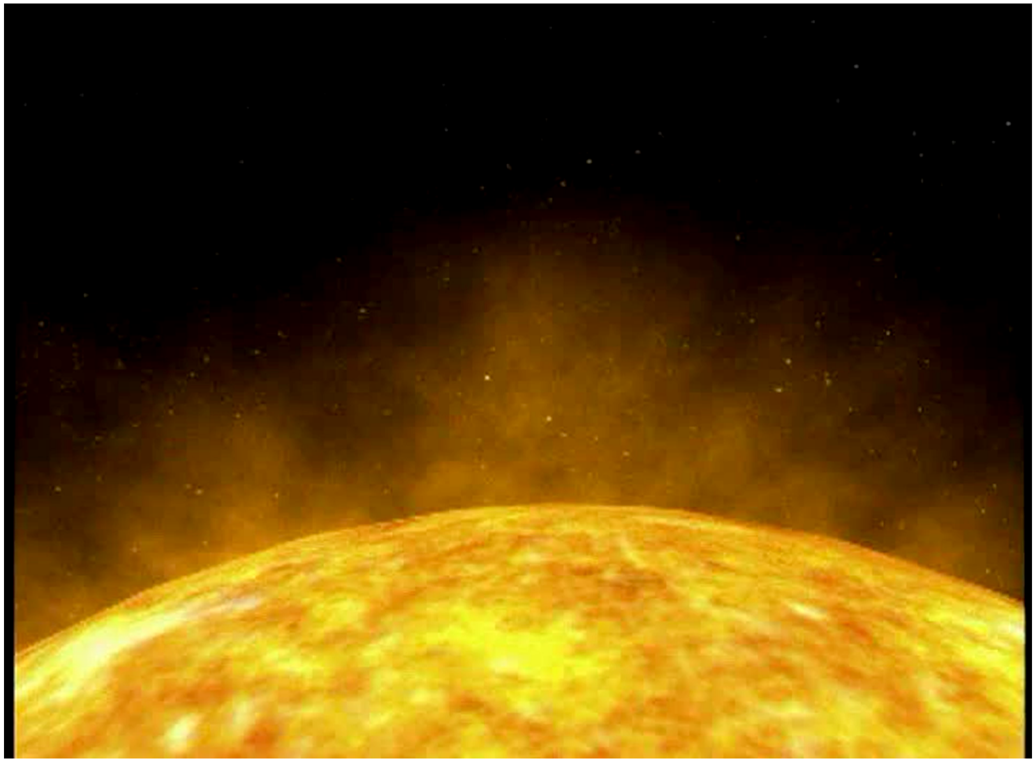


Act II

Magnetic Fields and Radio Emission



Electron Cyclotron Maser Radio Emission

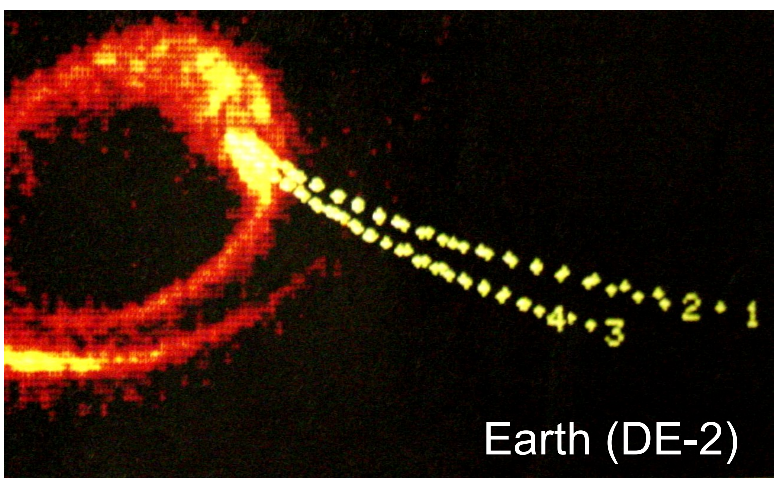


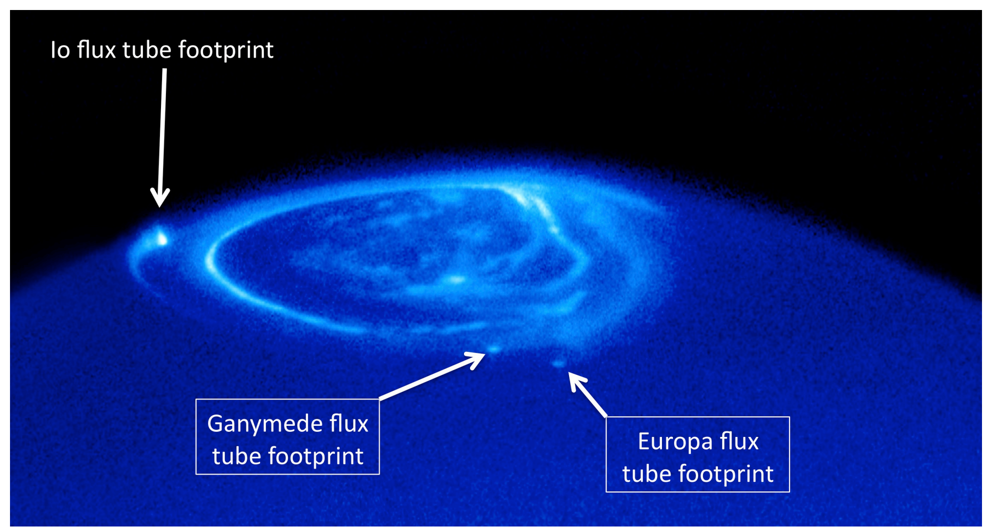
Stellar wind provides energy source to magnetosphere

~ 1% of input energy to auroral region emitted in UV

~ 1% of auroral input energy into electron cyclotron maser radio emission

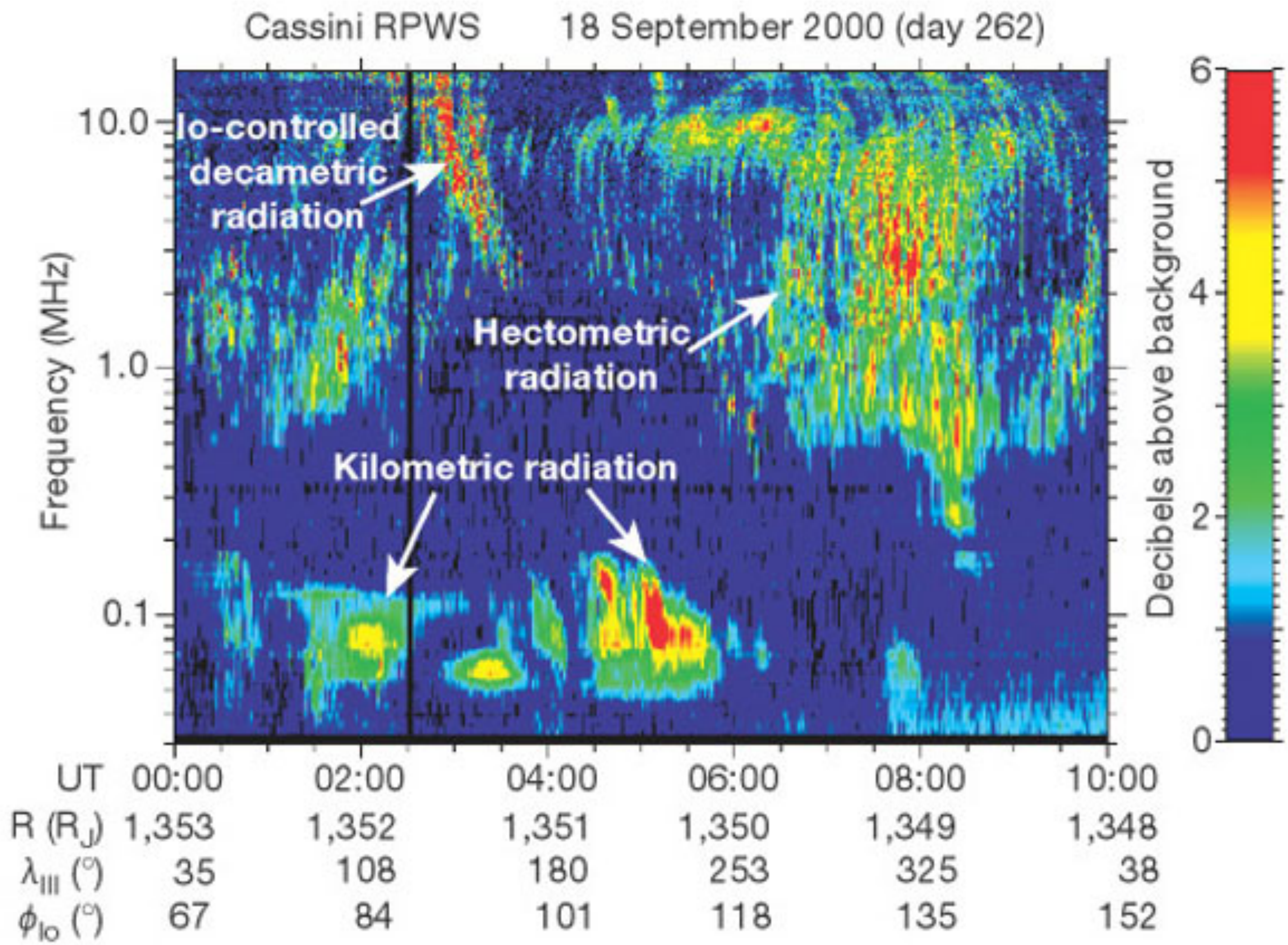
- Can also be driven by magnetosphere-moon interactions





Planetary Radio Emission

Jupiter

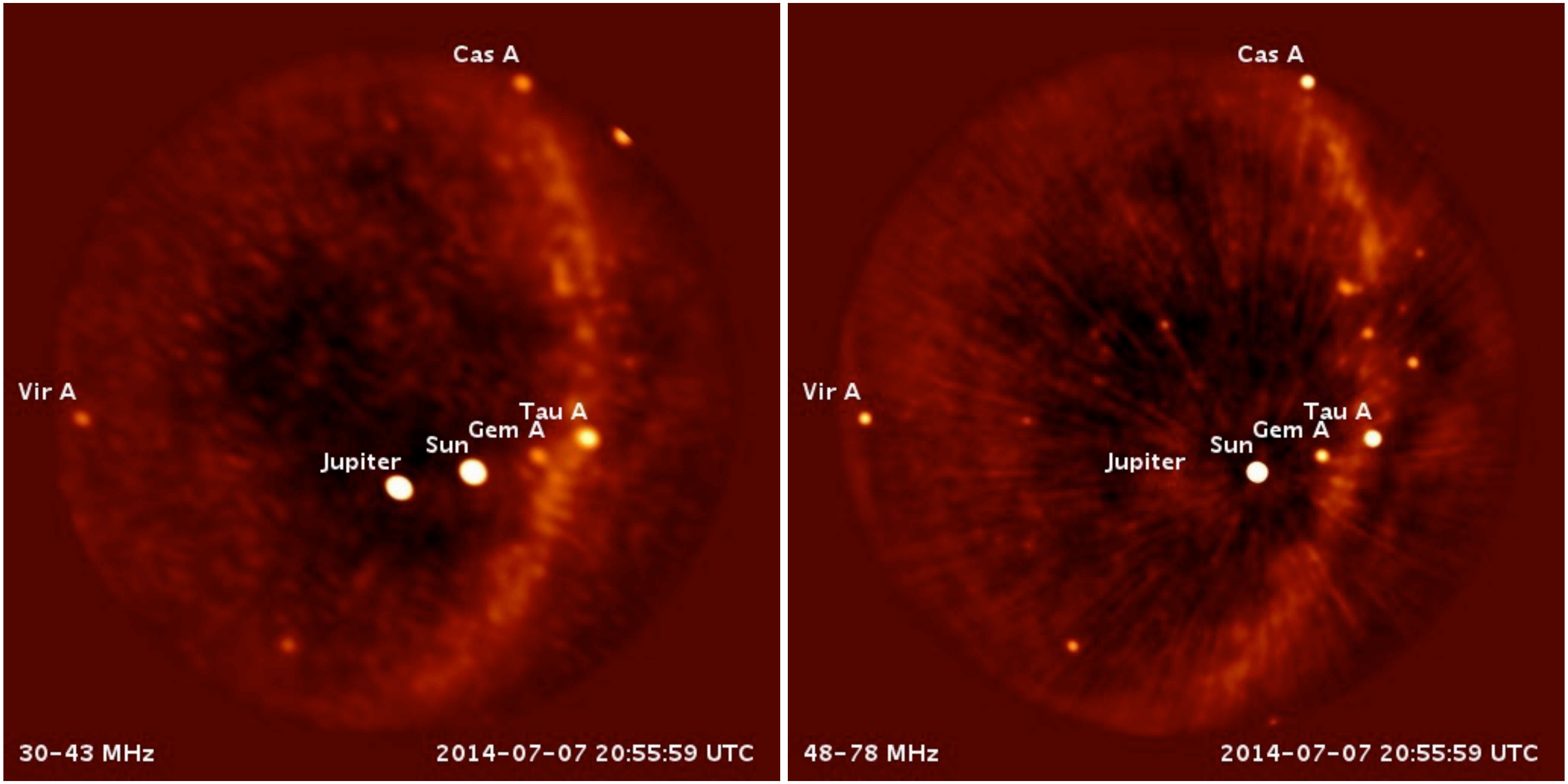


- **All gas giants and Earth have strong planetary magnetic fields and auroral / polar cyclotron emission.**

Jupiter: Strongest at 10^{12} W

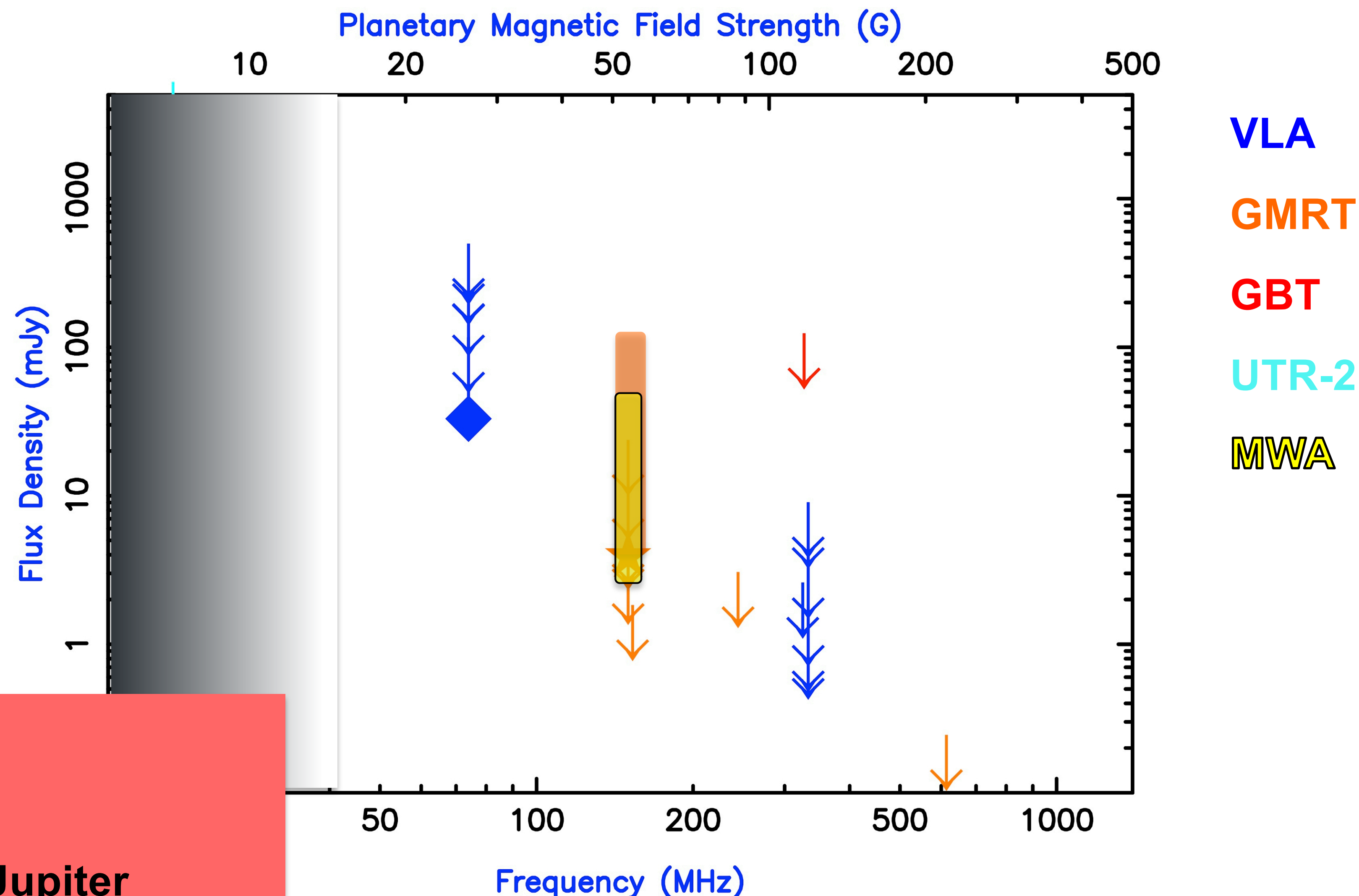
Planetary Radio Emission

Jupiter – and What We Want To See for an Extrasolar Planet!



Credit: M. Anderson

Radio Searches – State of the Field



Jupiter

Blind Search of the Solar Neighborhood

Sample	Flux Density (3σ, mJy)	Luminosity (erg/s)	Stellar Wind Amplification Factors					K.E. * Jupiter	M.E. * Jupiter
			v	n	B	nv^3	vB^2		
NStars	17	9×10^{23}	1.7	9.8	2.4	48	9.5	4.8×10^{20}	9.5×10^{19}
SPOCS-age	33	1.1×10^{24}	1.4	4.9	1.8	15	4.8	1.5×10^{20}	4.8×10^{19}
SPOCS-eage	28	5.1×10^{23}	1.6	8.6	2.2	38	8.3	3.8×10^{20}	8.3×10^{19}
GCS-age	18	7.3×10^{23}	1.6	6.7	2.0	25	6.5	2.5×10^{20}	6.5×10^{19}
GCS-eage	14	5.8×10^{23}	2.2	30	3.6	319	28	3.2×10^{21}	2.8×10^{20}

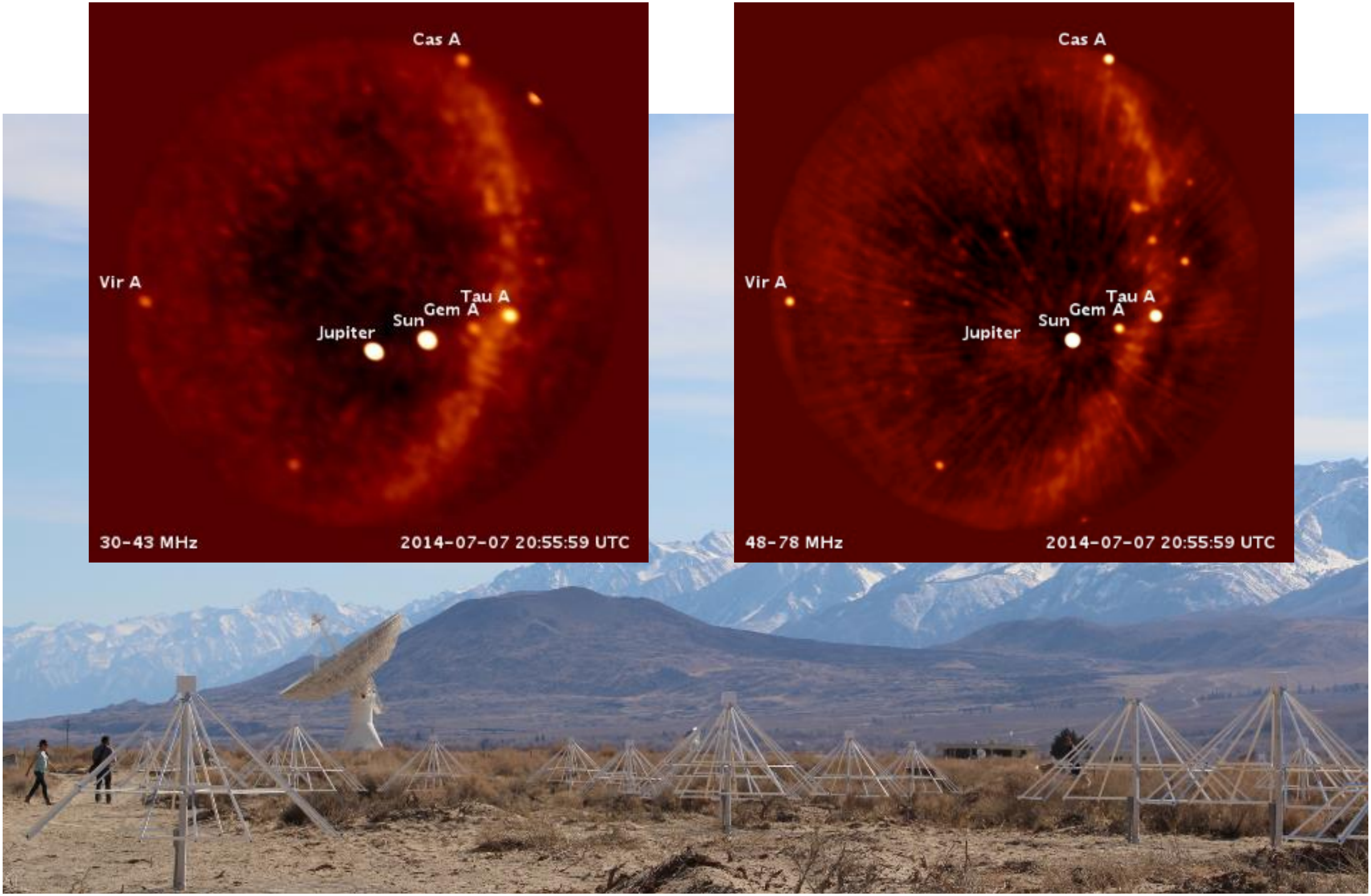
From nearby catalogs, select
- **F, G, K stars**
- **Age < 3 Gyr**
- **D <~ 40 pc**

Required for detection

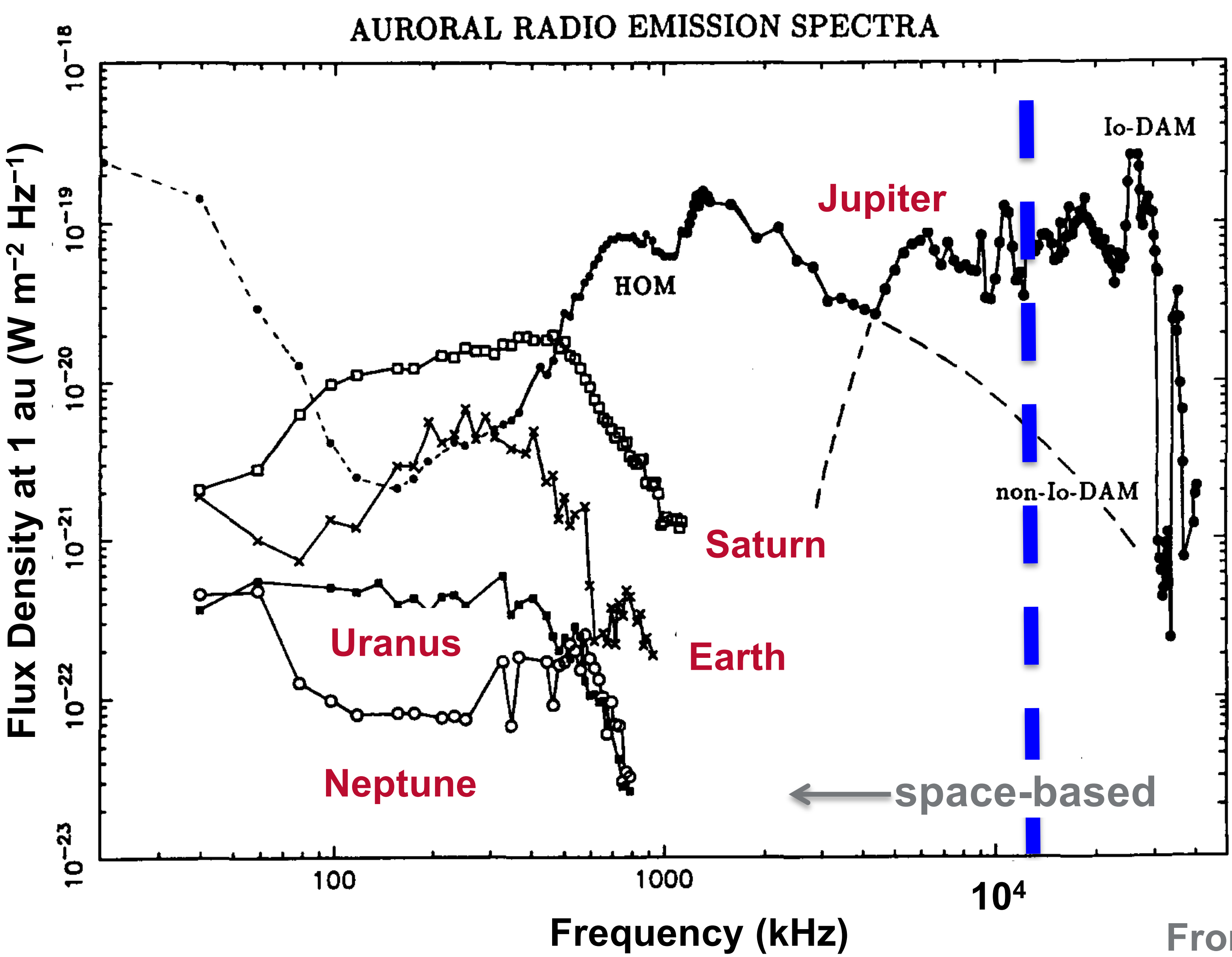
Jupiter's scaled luminosity

Act III: Future

Today: LWA-OVRO

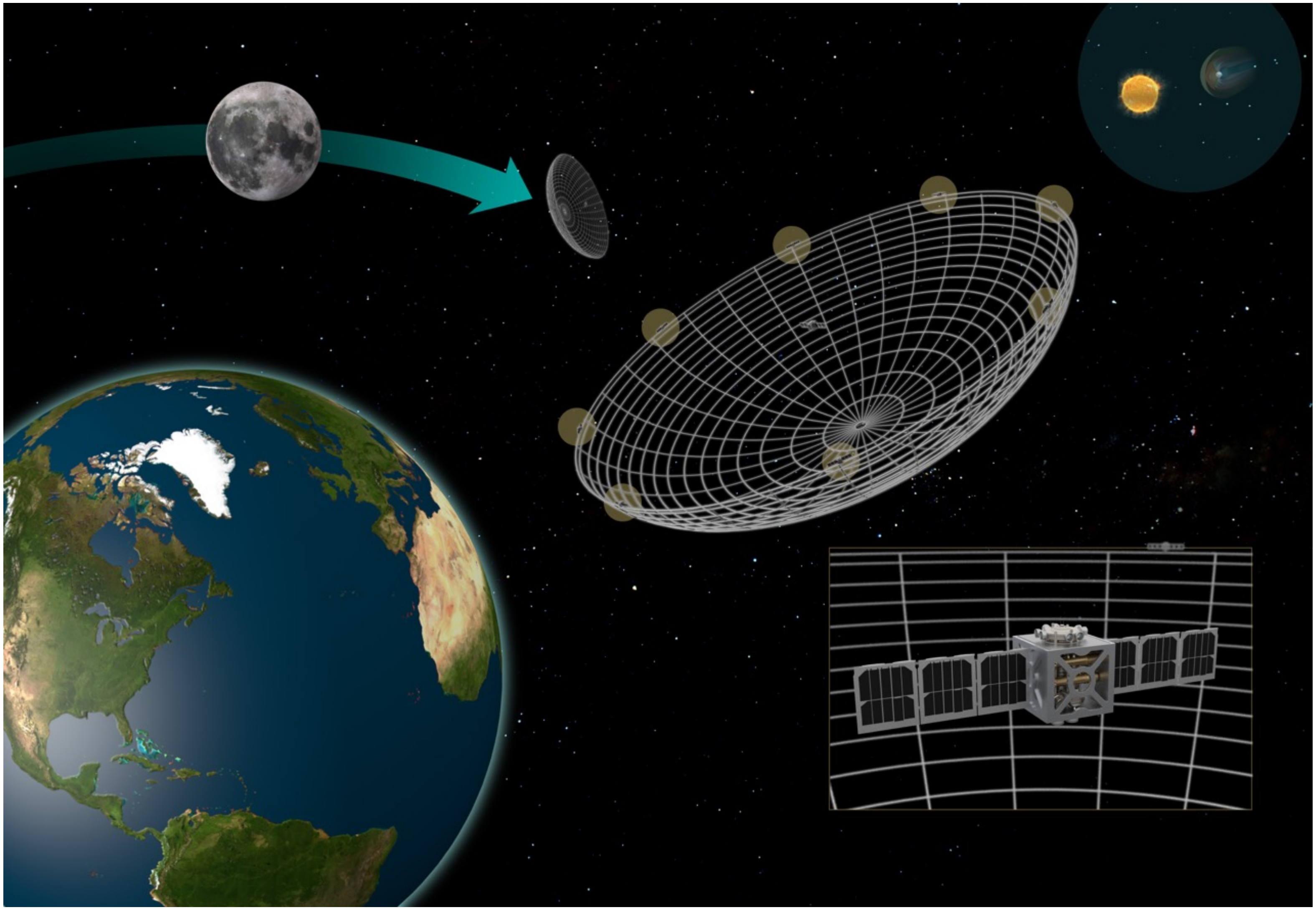


Magnetic Emissions from Solar System Planets

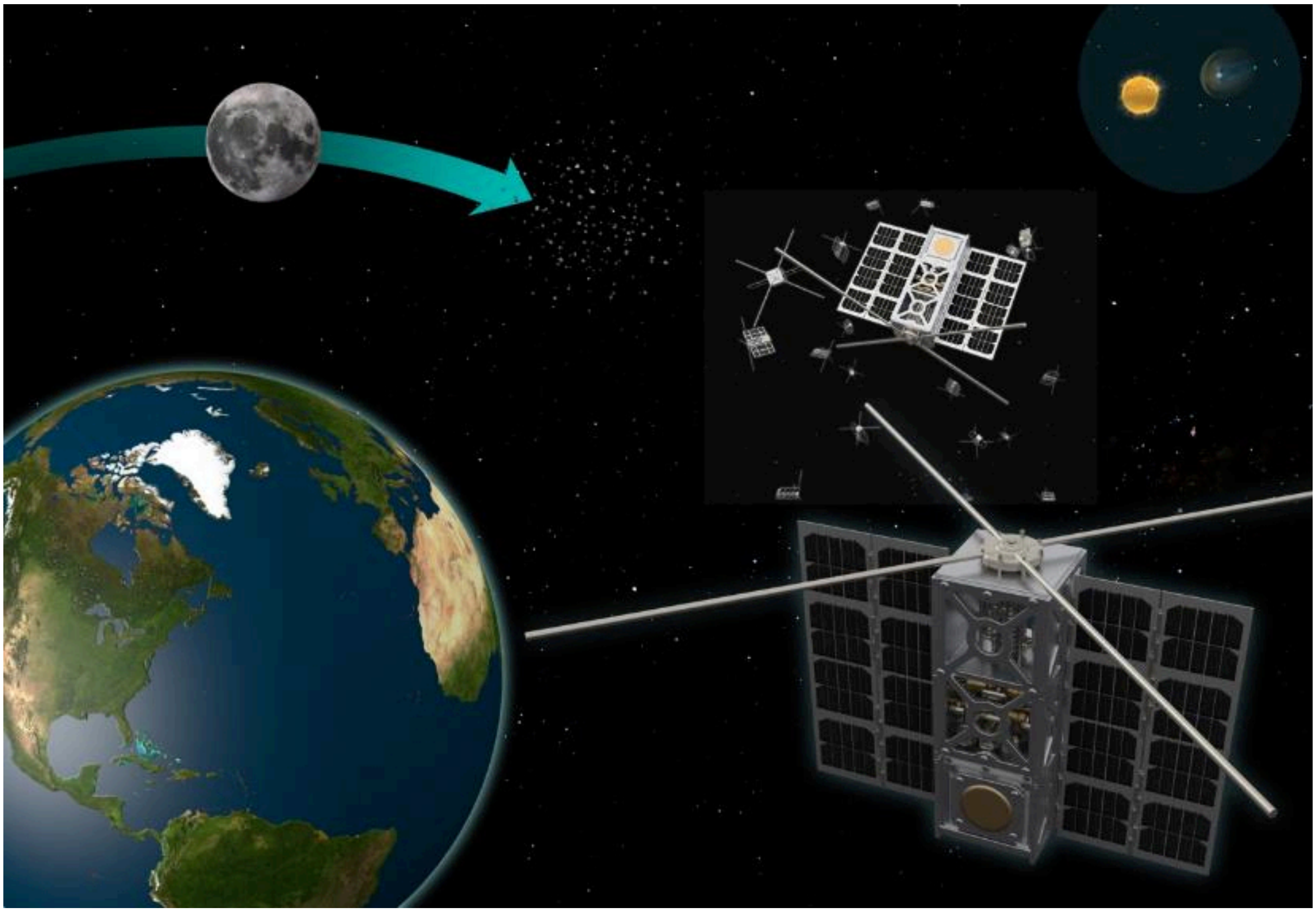


From Zarka (1992)

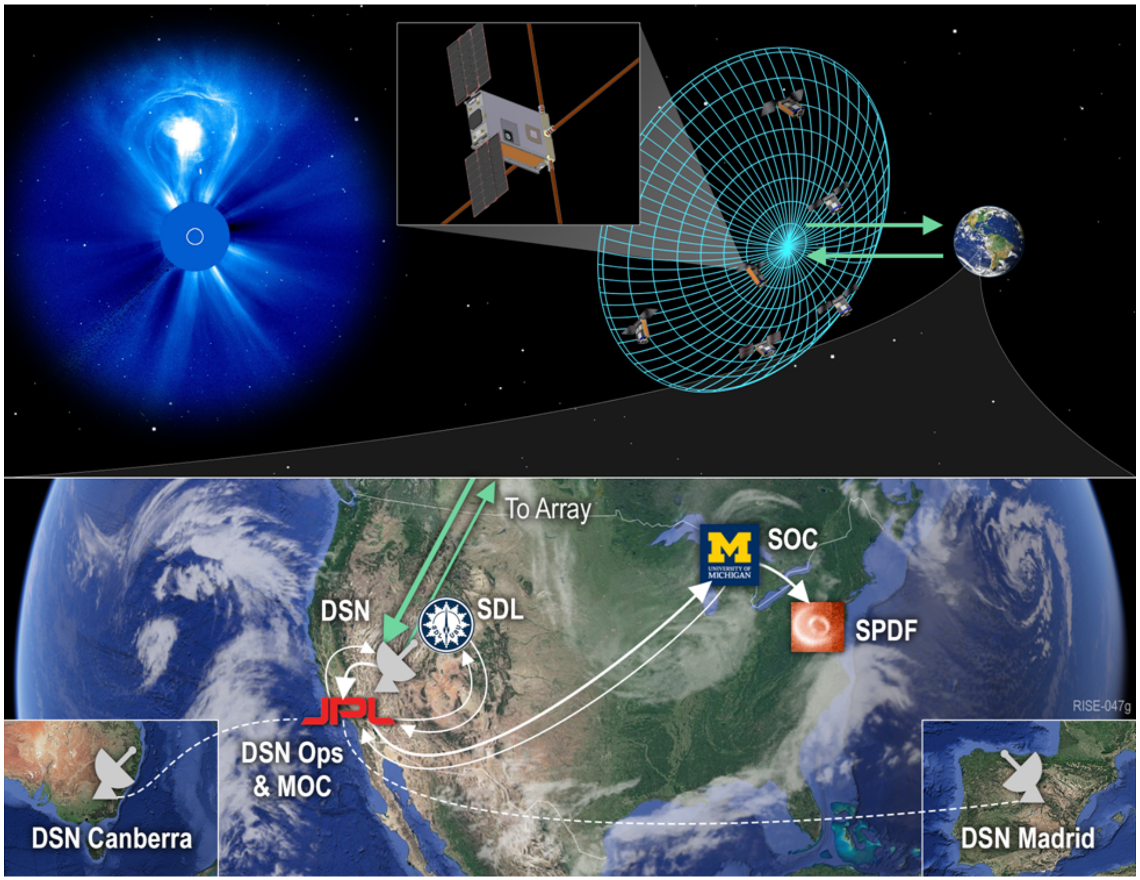
Tomorrow: Big Aperture Radio Telescope?



Tomorrow: Radio Array in Space?

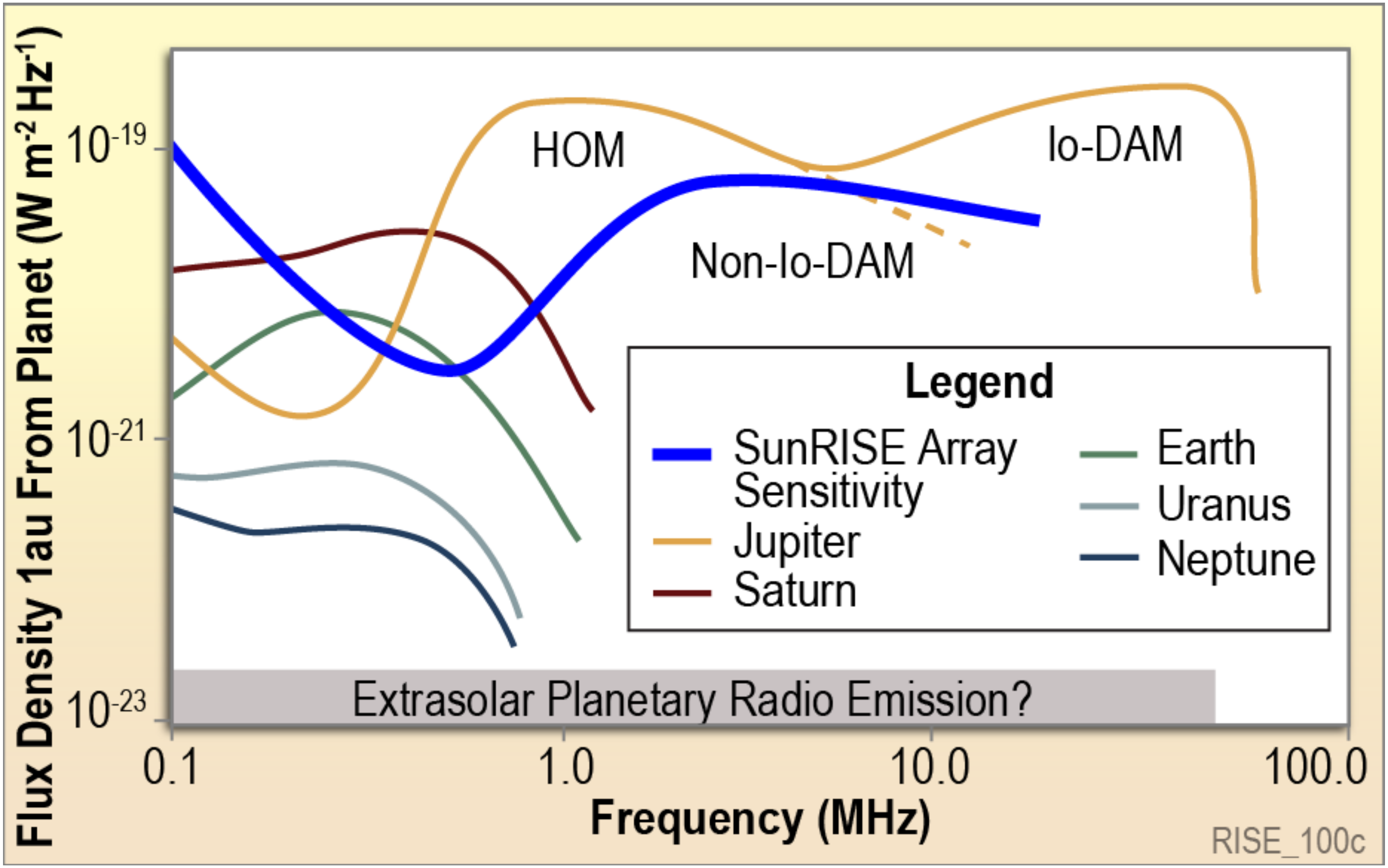


Sun Radio Interferometer Space Experiment



Launch	2024 March (TBC)
Selected for Extended Phase A study	**2019 February 25**
Phase A Concept Study report	2018 July 30
Selected for Phase A study	2017 July 28
SunRISE proposal submitted (NASA/Heliophysics SALMON-2 PEA Q/MOO SCM)	2016 October 14
NASA/Heliophysics Announcement of Opportunity	ca. 2016 July

SunRISE – The Planet Hunter



"Nothing New Under the Sun"

035-5 A Search for Extra-Solar Jovian Planets by Radio Techniques. W.F. YANTIS, U. Wash. and Goldendale Observatory, W.T. SULLIVAN, III, U. Wash. & W.C. ERICKSON, U. Maryland. – We propose to search for the presence of planets associated with nearby stars through detection of Jovian like decametric radio bursts. Planetary bursts would be distinguished from possible stellar bursts by the presence of a high-frequency cut-off and possibly a modulation associated with the rotation of the planet. A search for such planetary radio bursts at 26.3 MHz is presently being conducted at The Clark Lake Radio Observatory. The sample includes 22 stars within 5 parsecs. The sensitivity limit is 10^{-26} watts m^{-2} Hz^{-1}, about 1,000 times the signal expected from a strong Jovian burst. However, it is expected that the strength of any bursts will depend strongly on the planetary magnetic field and also possibly on the presence of a stellar wind. Initial observations exhibit several non-instrumental features which are under current study. Further results will be reported and monitoring observations are continuing.

"A Search for Extra-Solar Jovian Planets by Radio Techniques" (Yantis, Sullivan, & Erickson 1977)

- **Soon after recognition that Saturn also intense radio source**
- **Earth, Jupiter, Saturn**

"A Search for Cyclotron Maser Radiation from Substellar and Planet-like Companions of Nearby Stars (Winglee, Dulk, & Bastian 1986)

Extrasolar Planetary Magnetic Fields

- Magnetic fields provide probe of planetary interiors
  - Both solar system and extrasolar!
- Atmospheric retention (and habitability) influenced by presence of magnetic fields
  - Other confounding factors?
- Magnetospheric radio emissions are unique probe
  - Will require ground-based experience to inform future space missions

Extrasolar Planetary Magnetic Fields

BACKUP