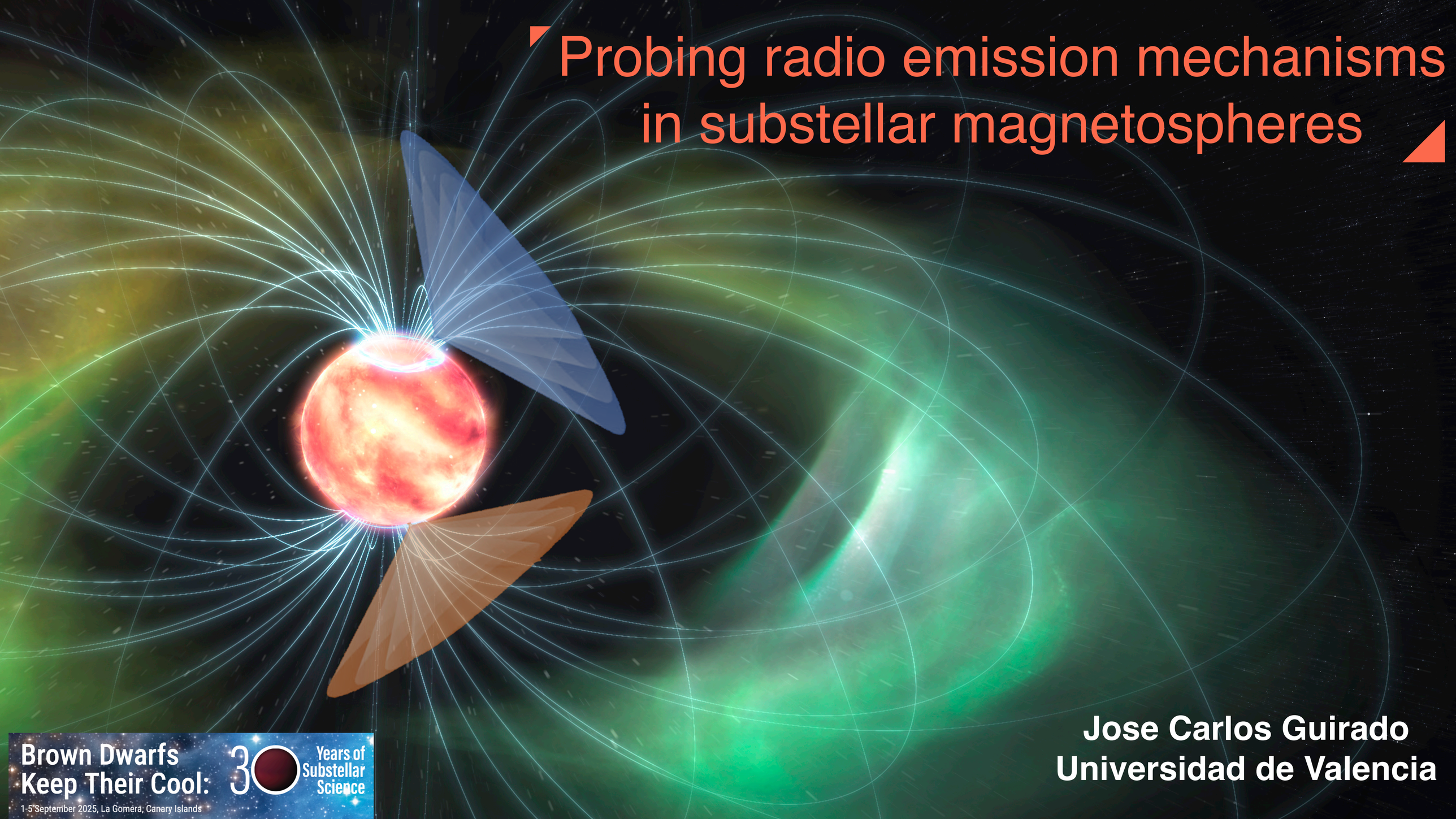
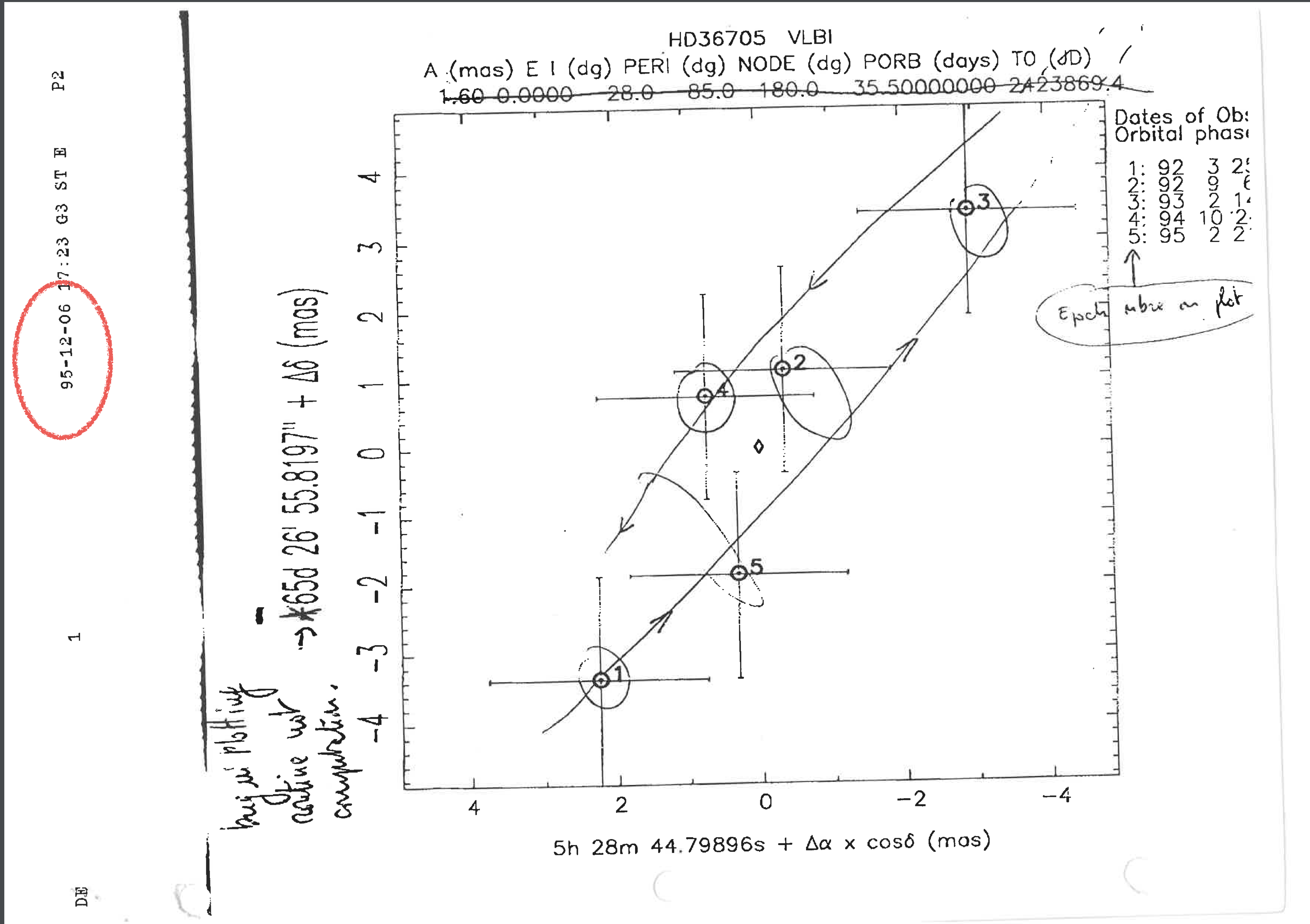
Probing radio emission mechanisms in substellar magnetospheres



Jose Carlos Guirado
Universidad de Valencia

Brown Dwarfs Keep Their Cool: 30 Years of Substellar Science
1-5 September 2025, La Gomera, Canary Islands

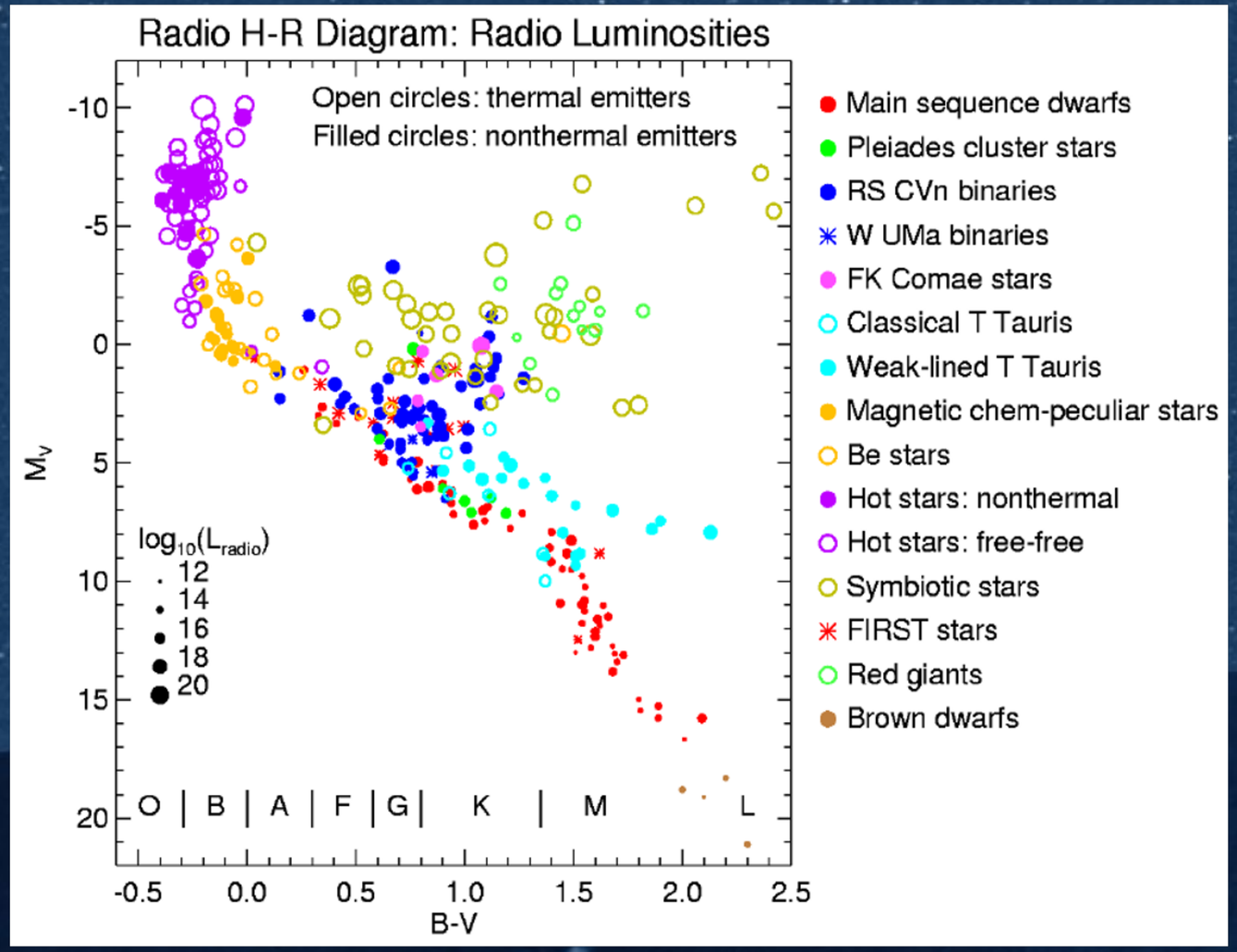


Personal story (apologies):
my beginnings in BDs…

- VLBI astrometric “fit” of a possible brown dwarf around ABDor
- Quite an excitement at JPL!!
- Not a BD after all (90 Mjup), but…

Radio Stars

- Detected throughout the complete H-R diagram
- Few detections but large outcome: stellar flares, magnetic coronae structures, colliding-wind binaries, proper motions, parallaxes, orbital motions...
- Radio emission comes basically from the presence of high energy electrons and magnetic fields, but there are MANY mechanisms...

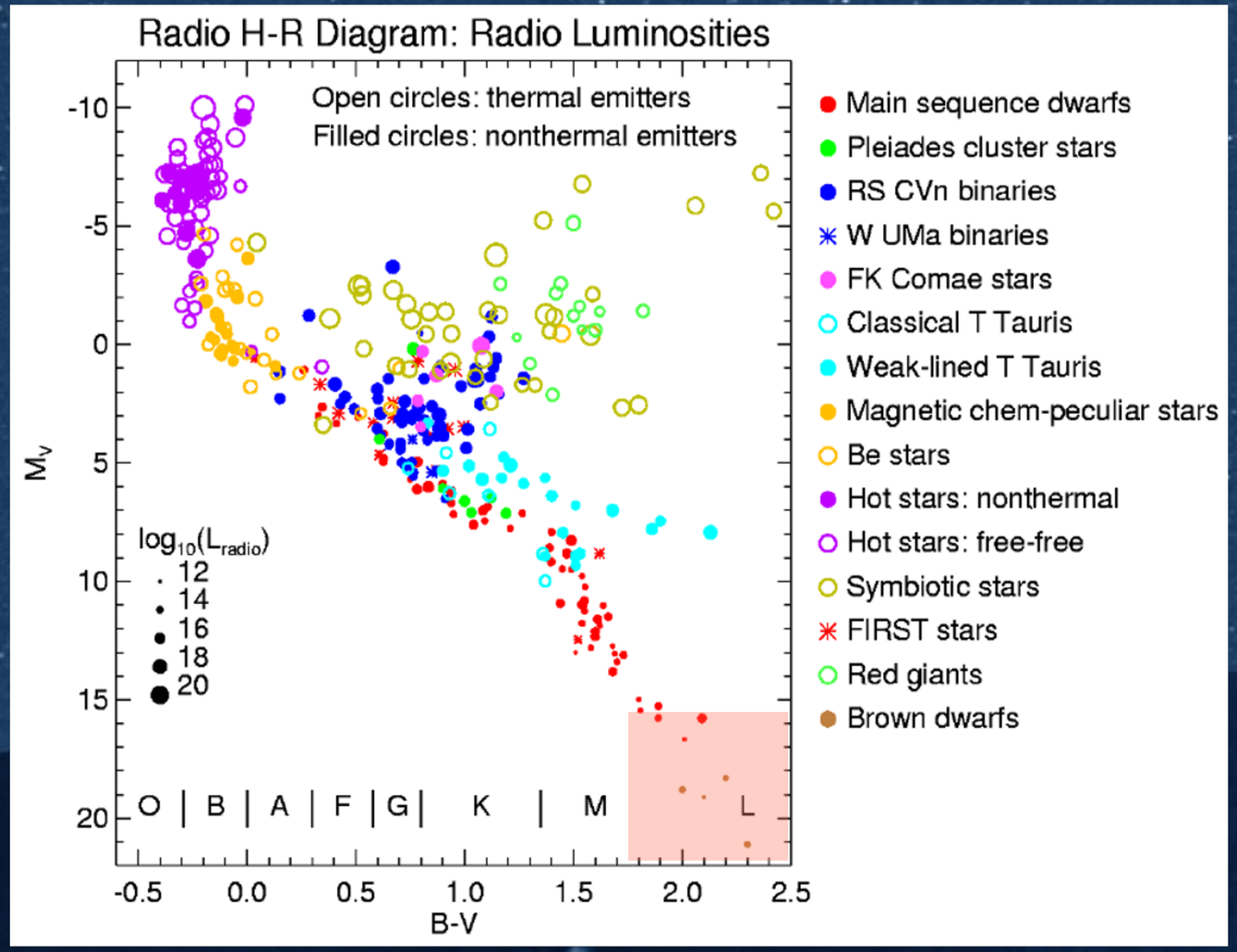


Brown dwarfs

- Detected throughout the complete H-R diagram
- Few detections but large outcome: stellar flares, magnetic coronae structures, colliding-wind binaries, proper motions, parallaxes, orbital motions...
- Radio e[illegible]omes basi[illegible] from the p[illegible]r high en[illegible] electrons a[illegible]tic fields. h[illegible]here are m[illegible]echanism[illegible]

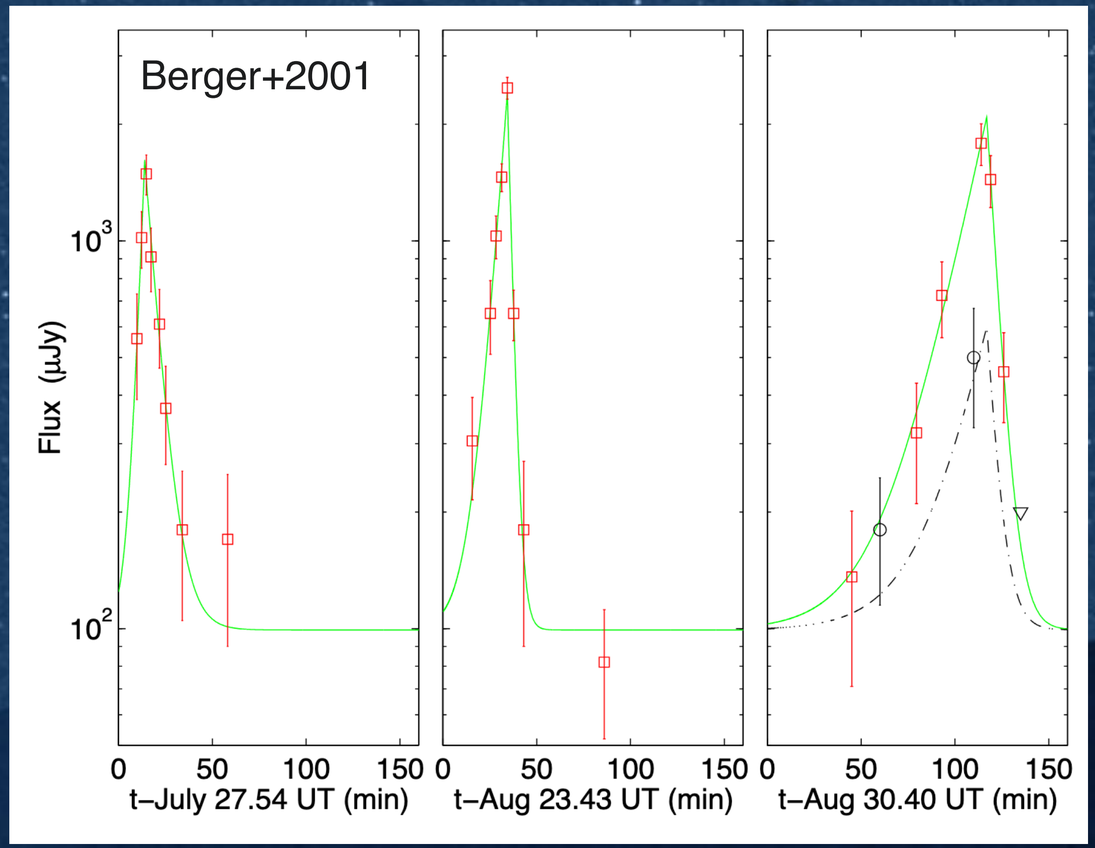
DIFFICULT TO DISCRIMINATE!!!!

and ... very weak!!

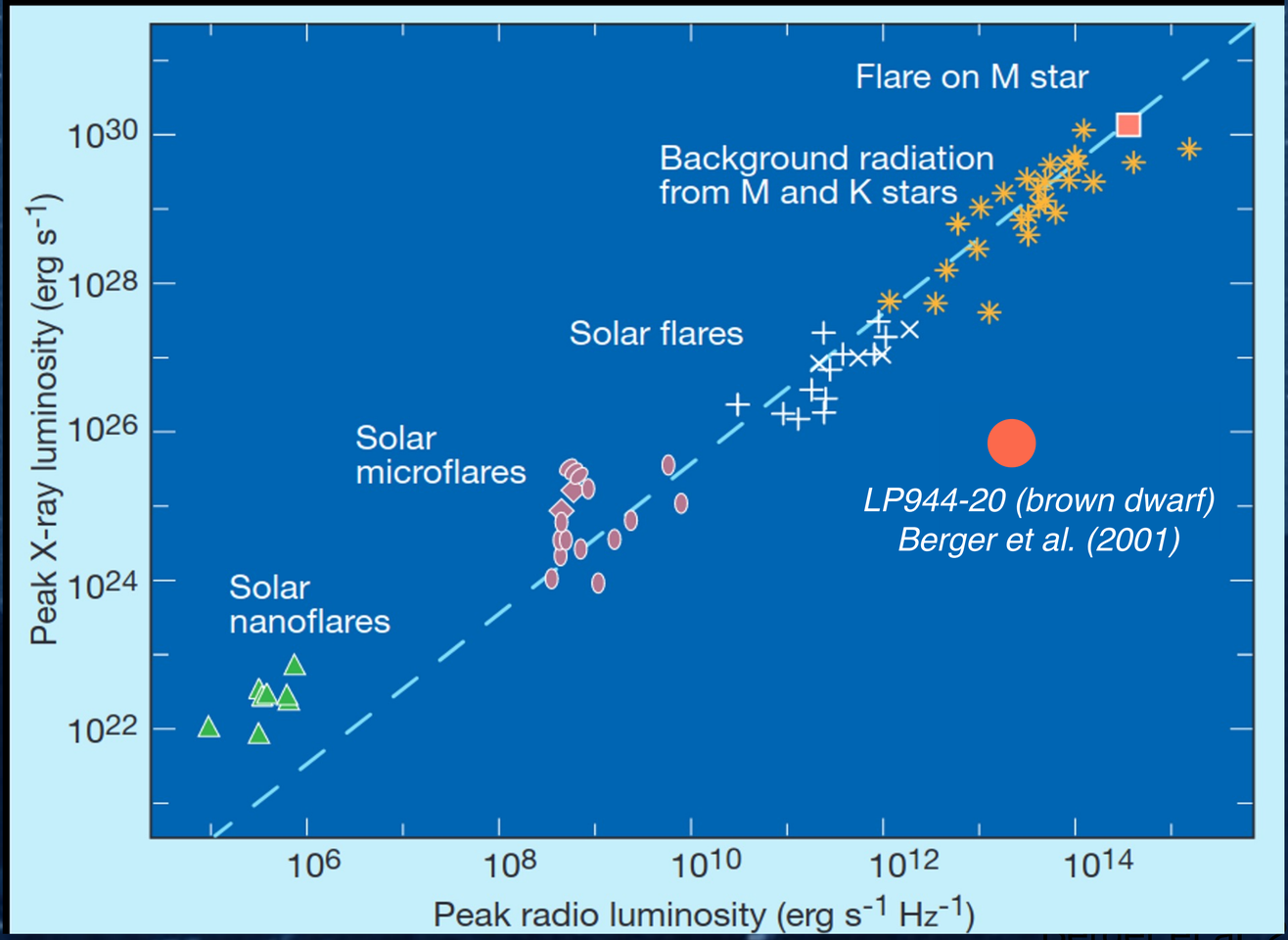


Brown dwarfs in radio

Hallinan+2008



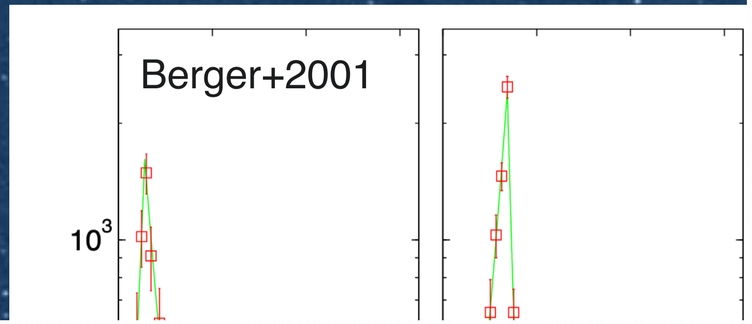
Güdel-Benz X-ray/radio relation (Benz et al. 2001)

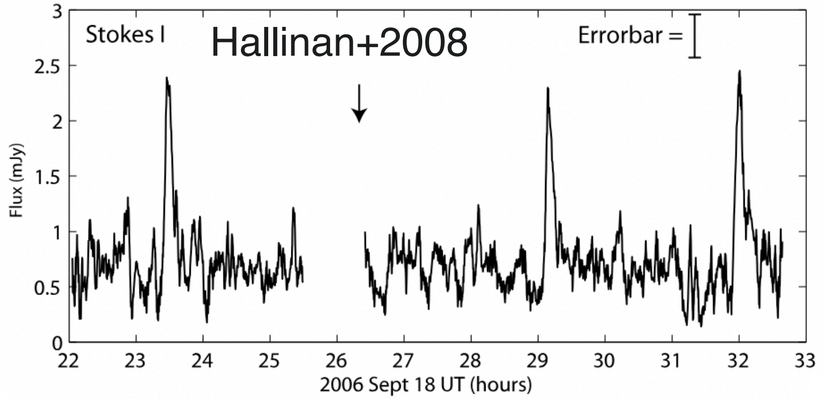


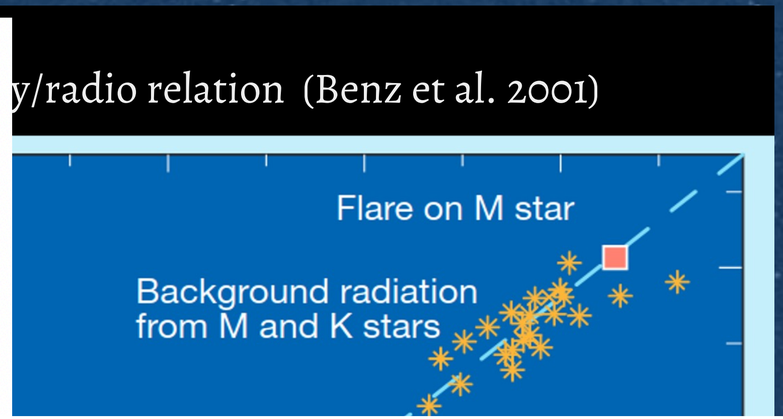
Berger et al. 2008

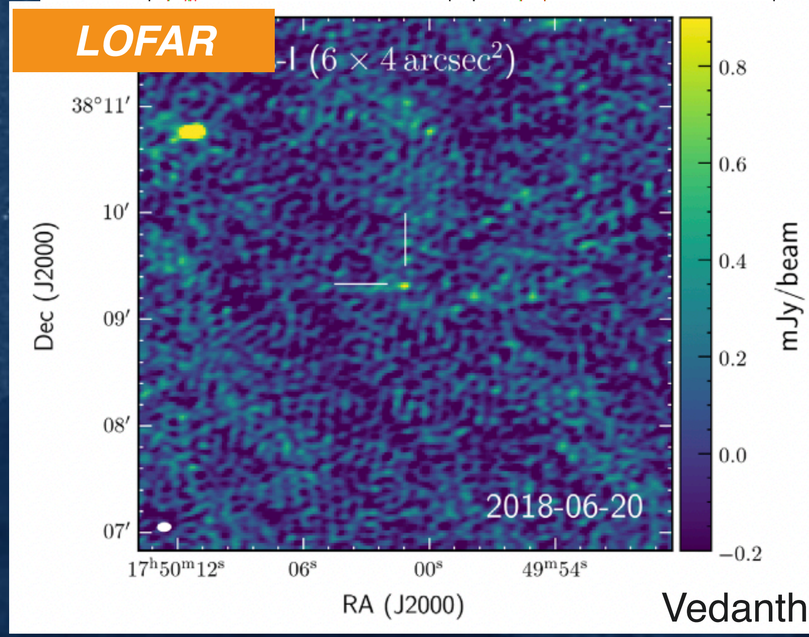
Brown dwarfs in radio

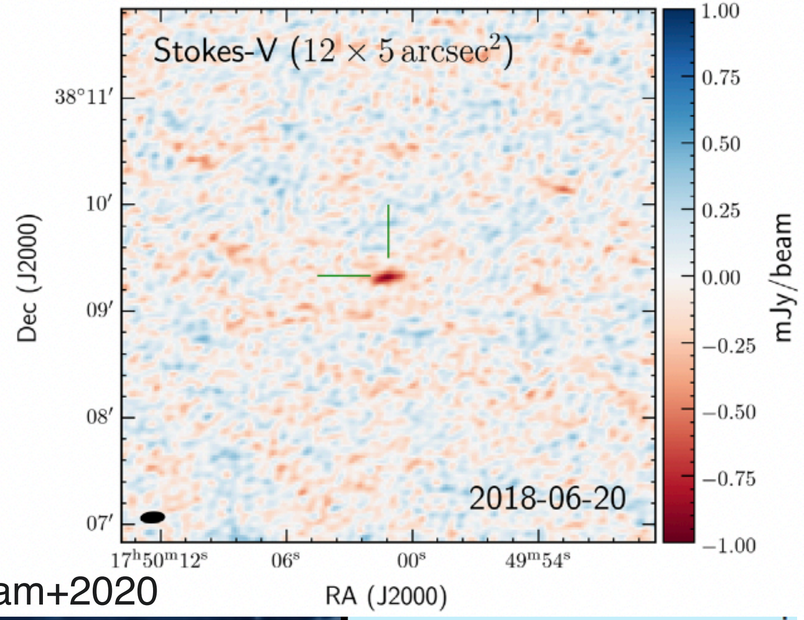
~10% of ultra cool dwarfs are active in radio



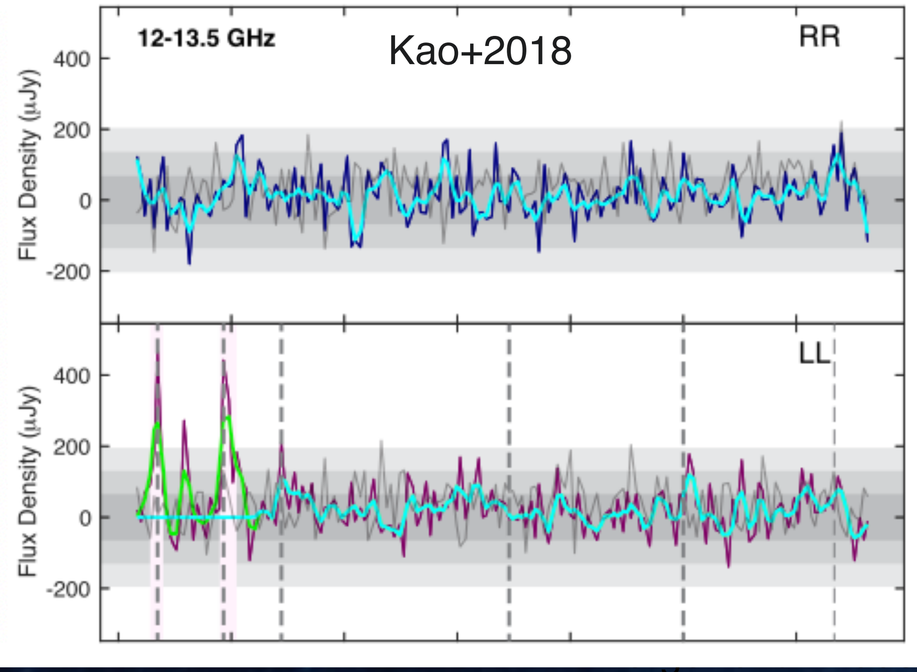




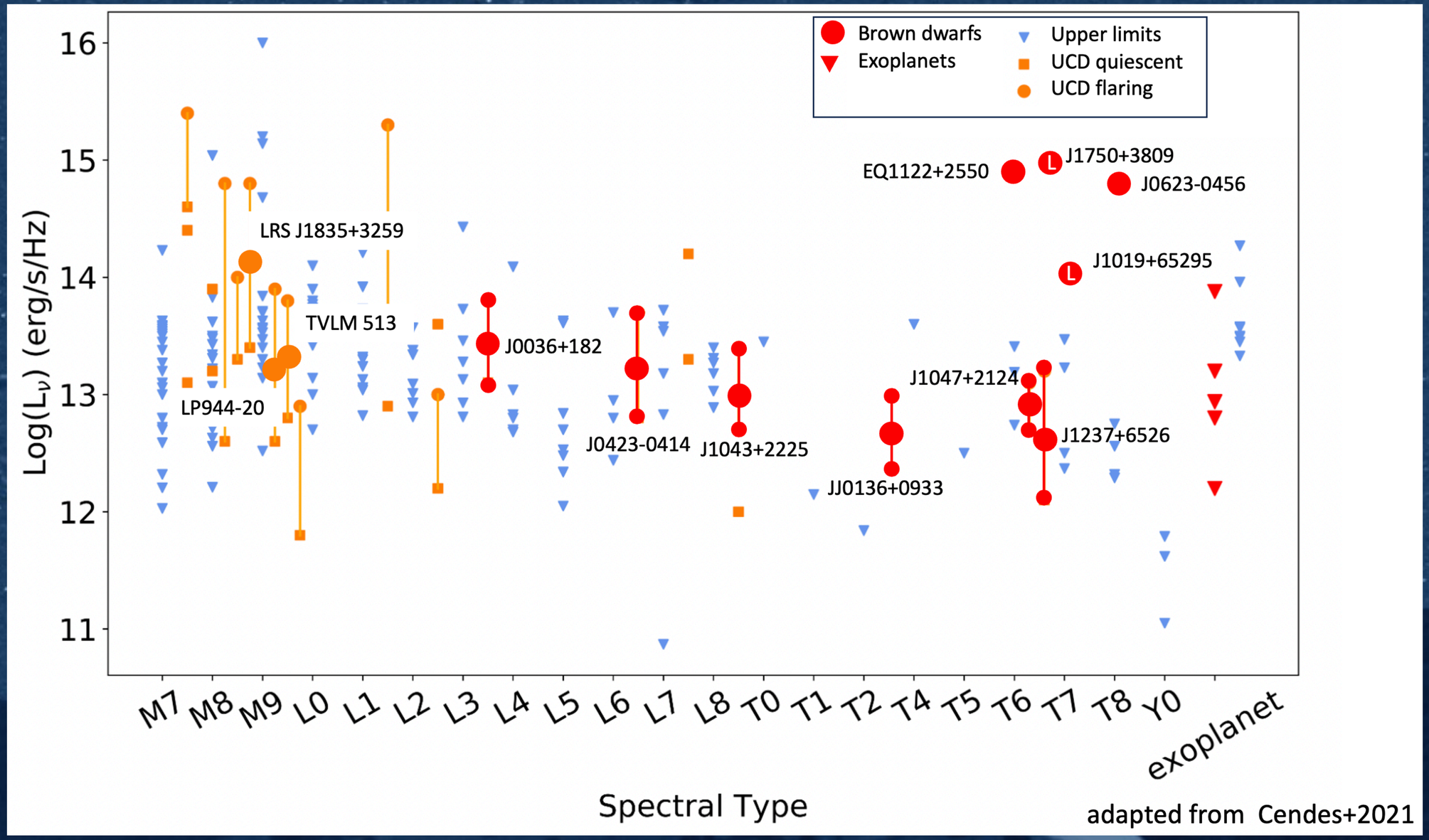




Vedantham+2020

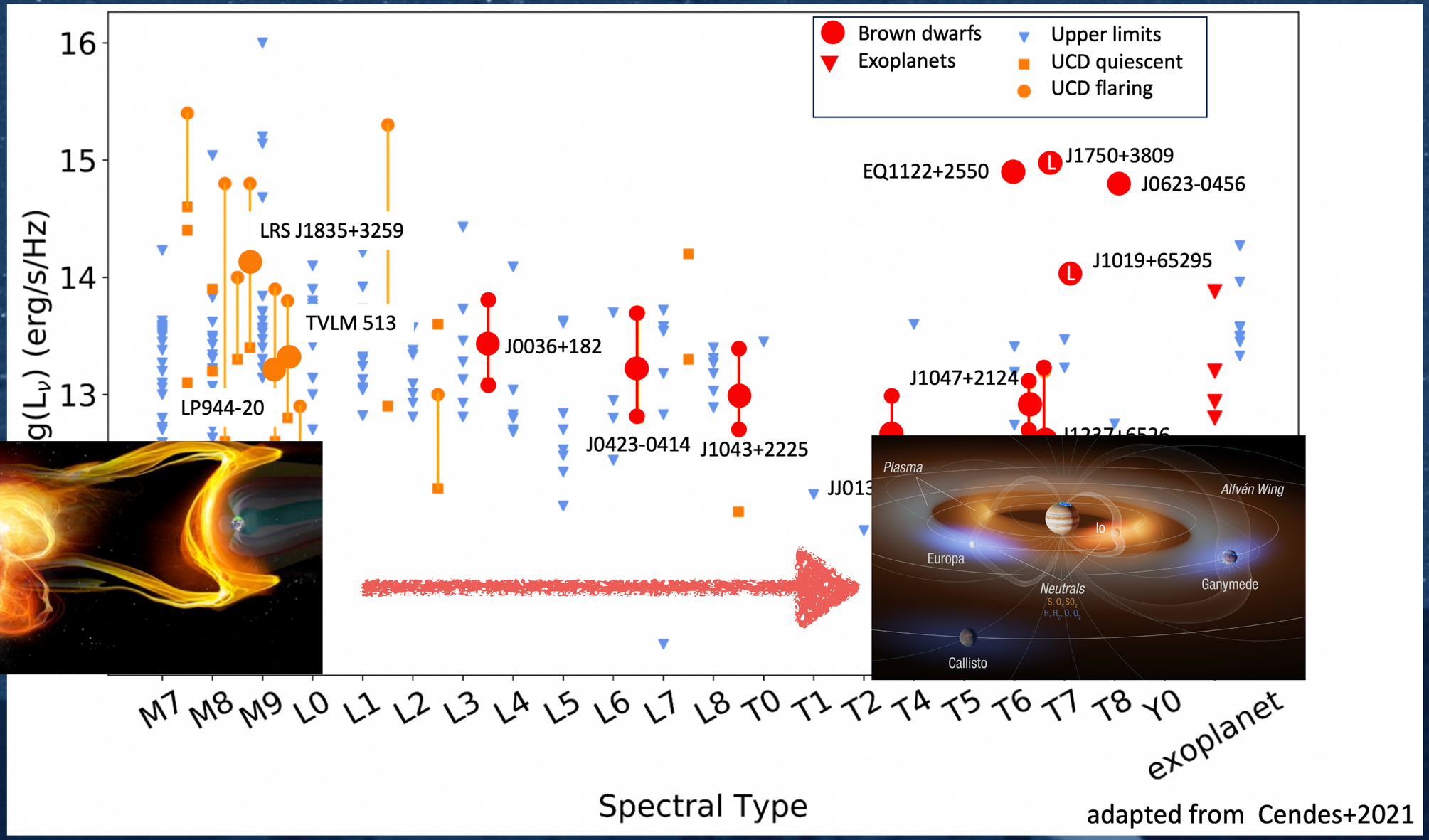


Brown dwarfs in radio

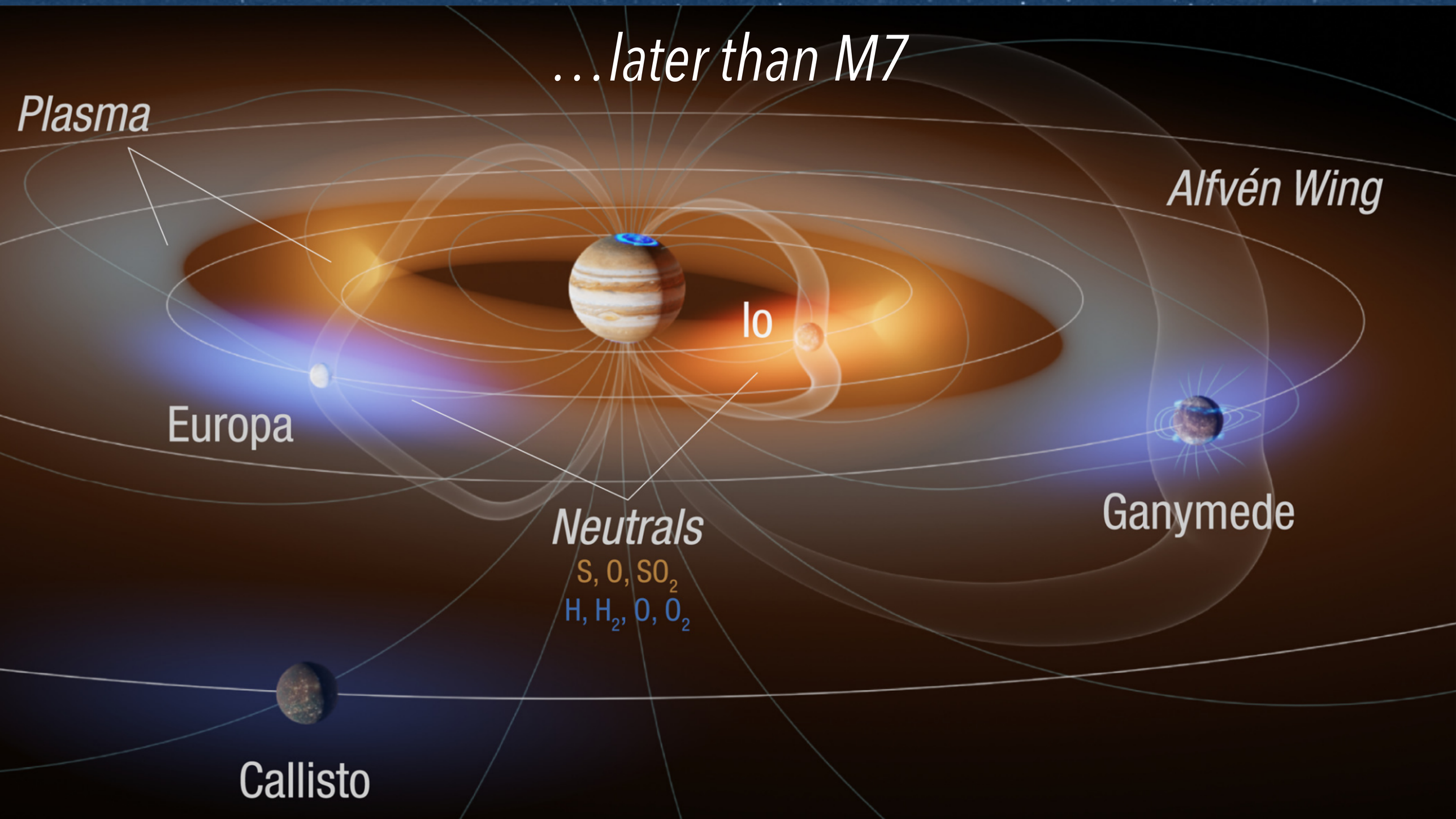


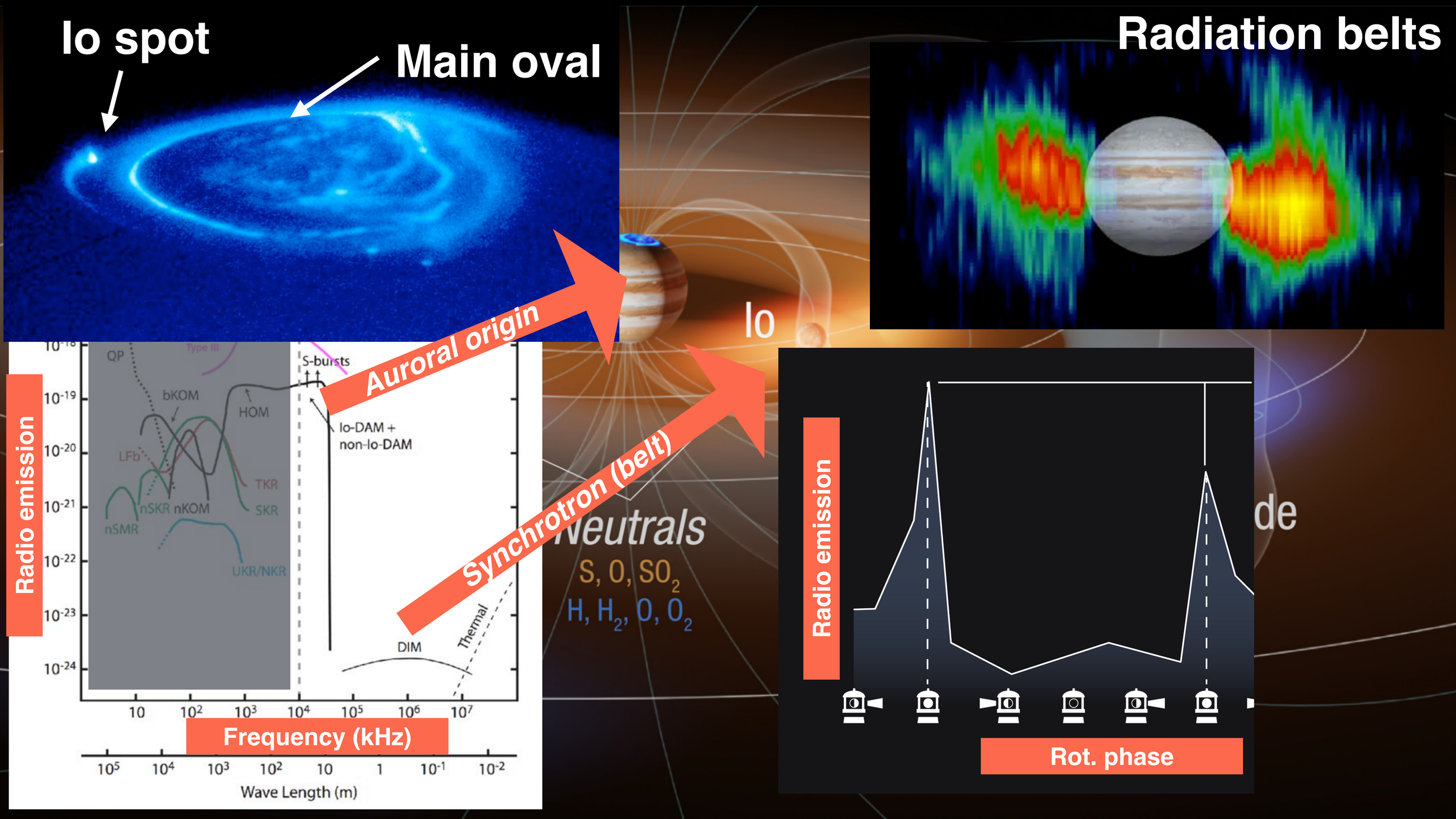
adapted from Cendes+2021

Brown dwarfs in radio

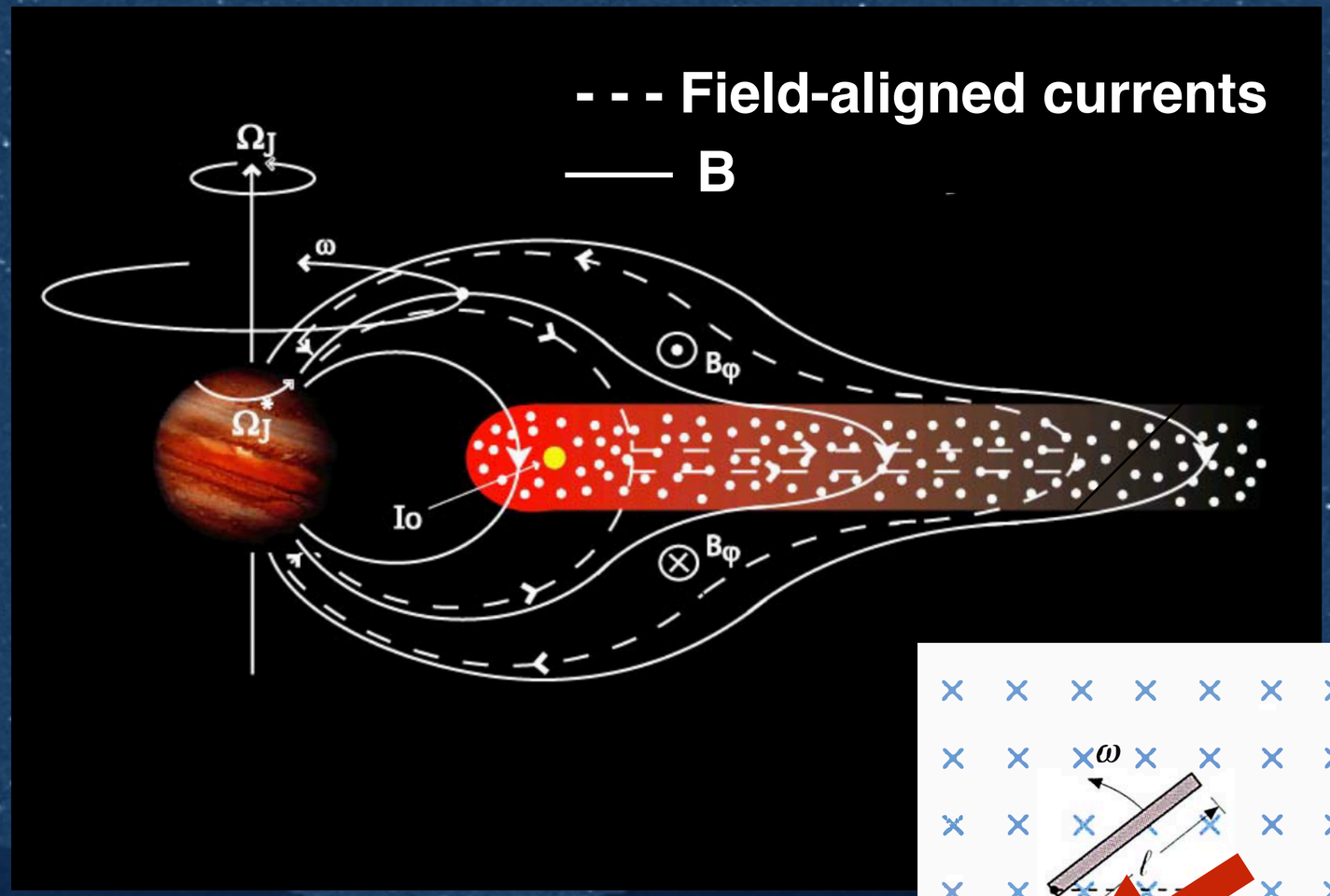


adapted from Cendes+2021

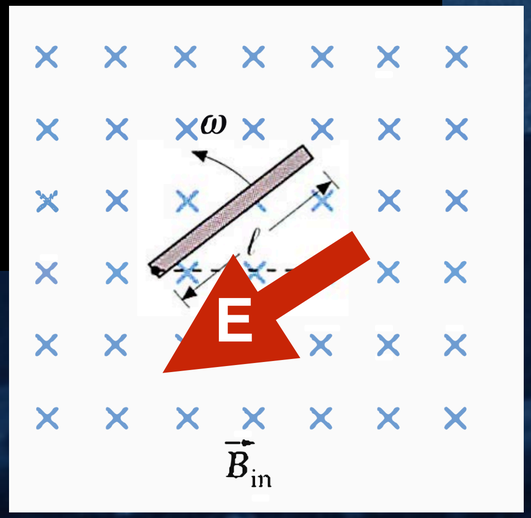

. . . later than M7
Plasma
Alfvén Wing
Io
Europa
Neutrals
S, O, SO_2
H, H_2, O, O_2
Ganymede
Callisto

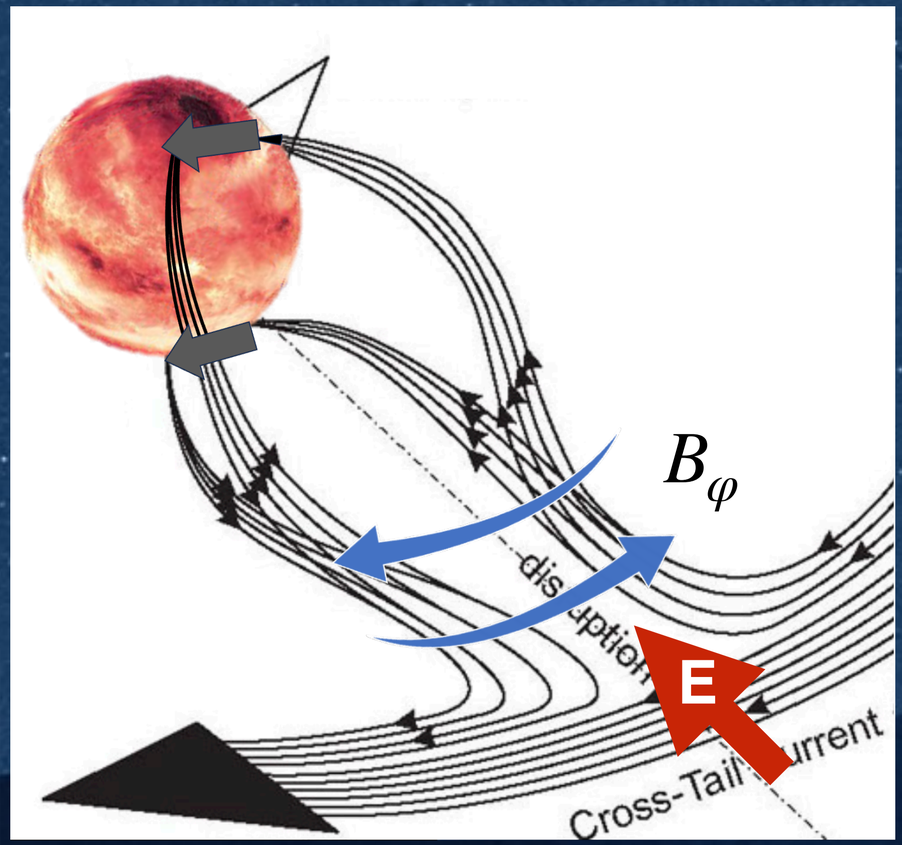

Io spot
Main oval
Radiation belts
Auroral origin
Synchrotron (belt)
Io
Neutrals
S, O, SO2
H, H2, O, O2
de
Radio emission
QP
Type III
S-bursts
bKOM
HOM
Io-DAM +
non-Io-DAM
LFb
TKR
nSKR
nKOM
SKR
nSMR
UKR/NKR
DIM
Thermal
Frequency (kHz)
Wave Length (m)
Radio emission
Rot. phase

Auroral emission (radio)



Turnpenney+2017

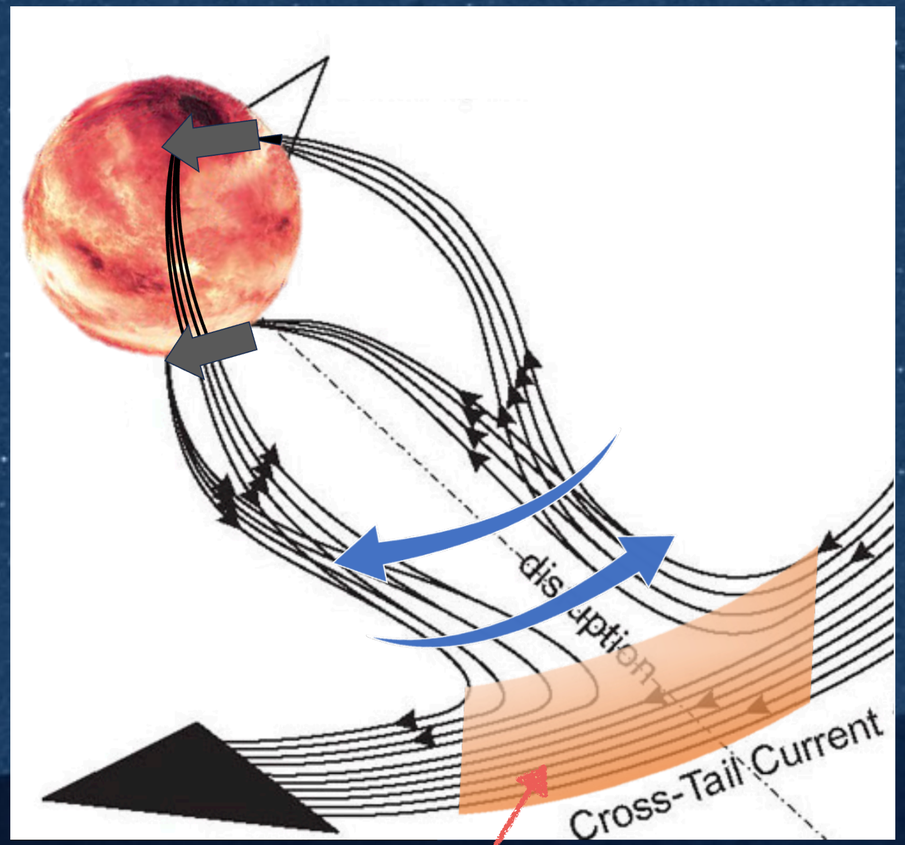




Auroral emission

“Generator region” (co-rotation breakdown, reconnection, presence of exoplanets/ exomoons…).

This generator region could extend from preferred magnetic longitudes to the complete disk



“Generator region”

Auroral emission

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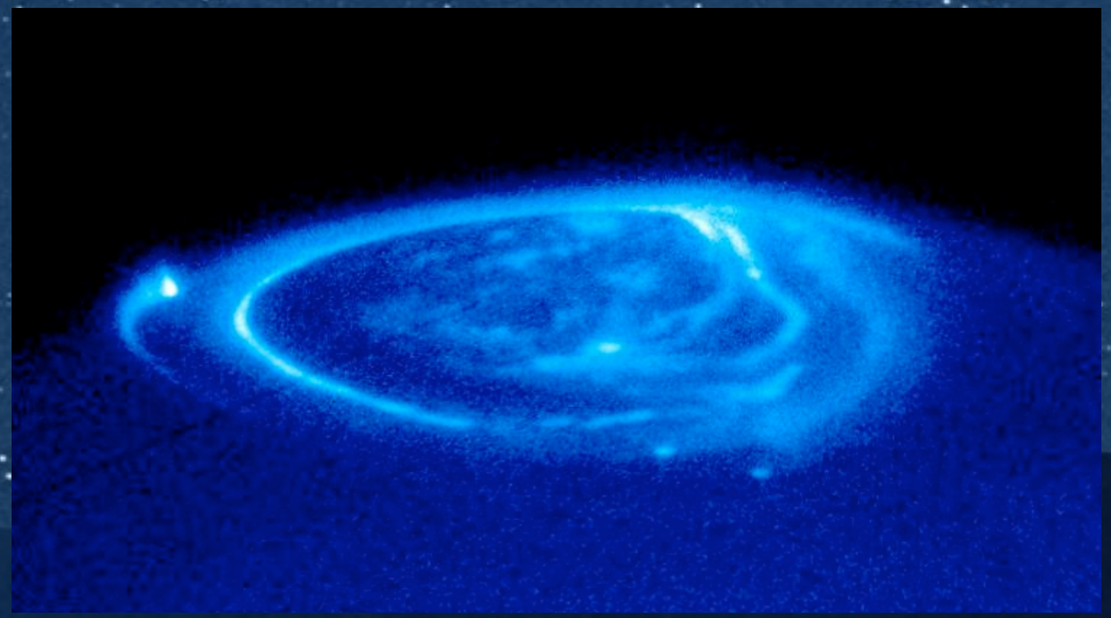
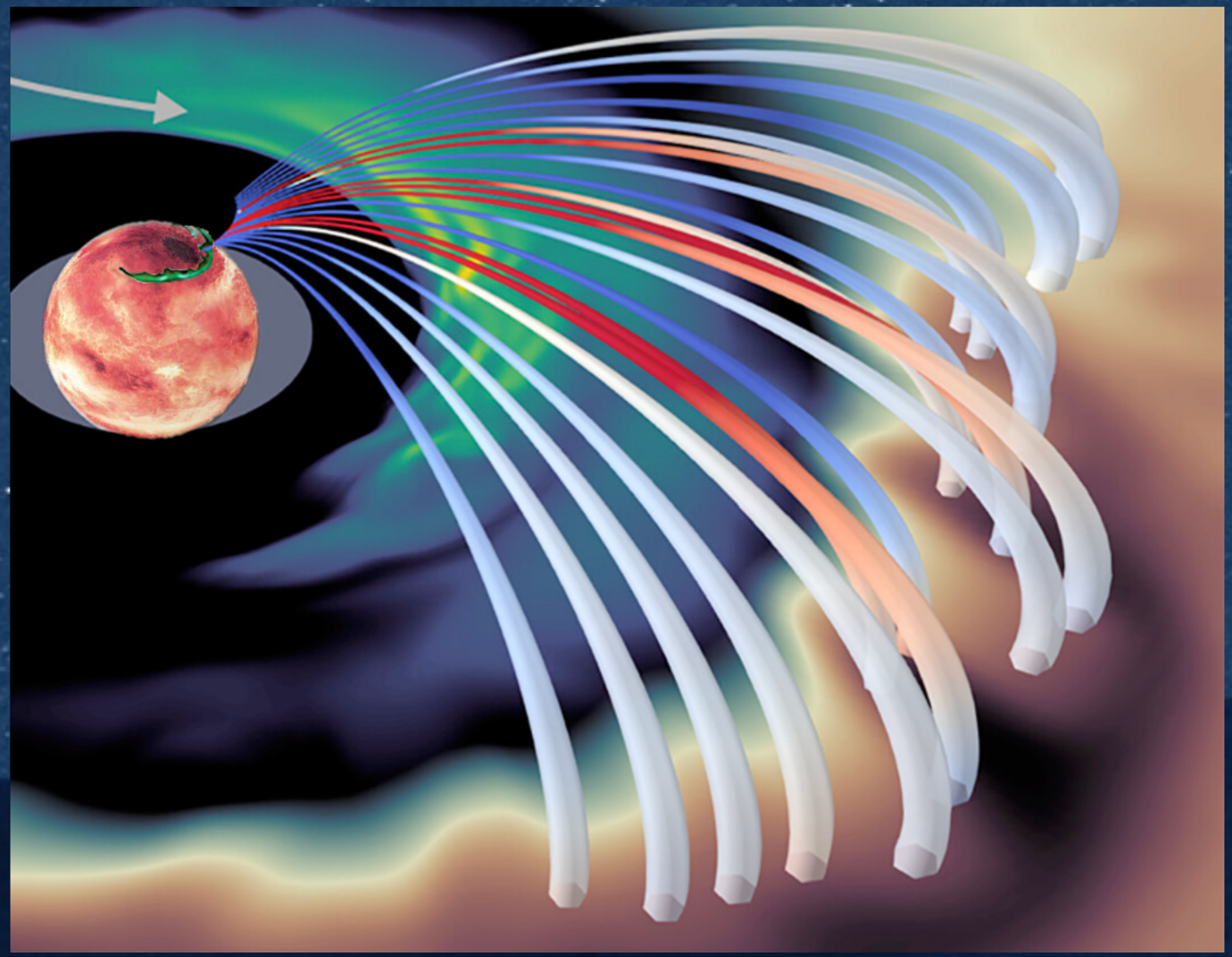
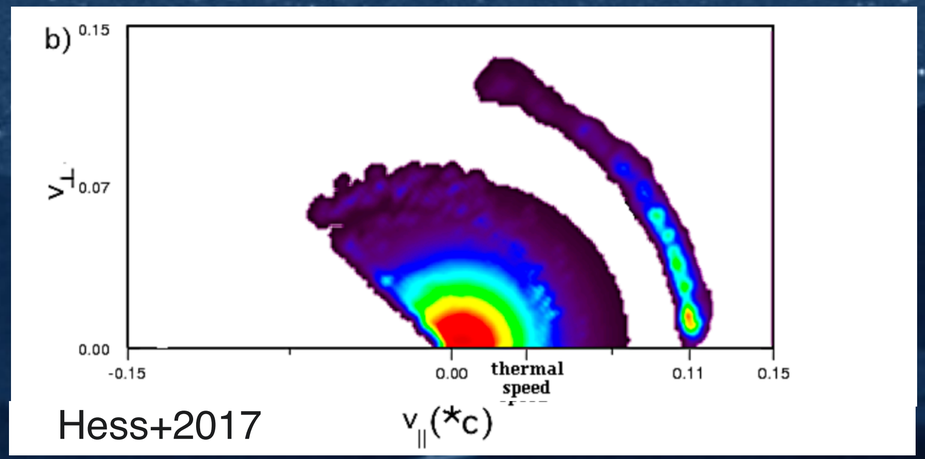




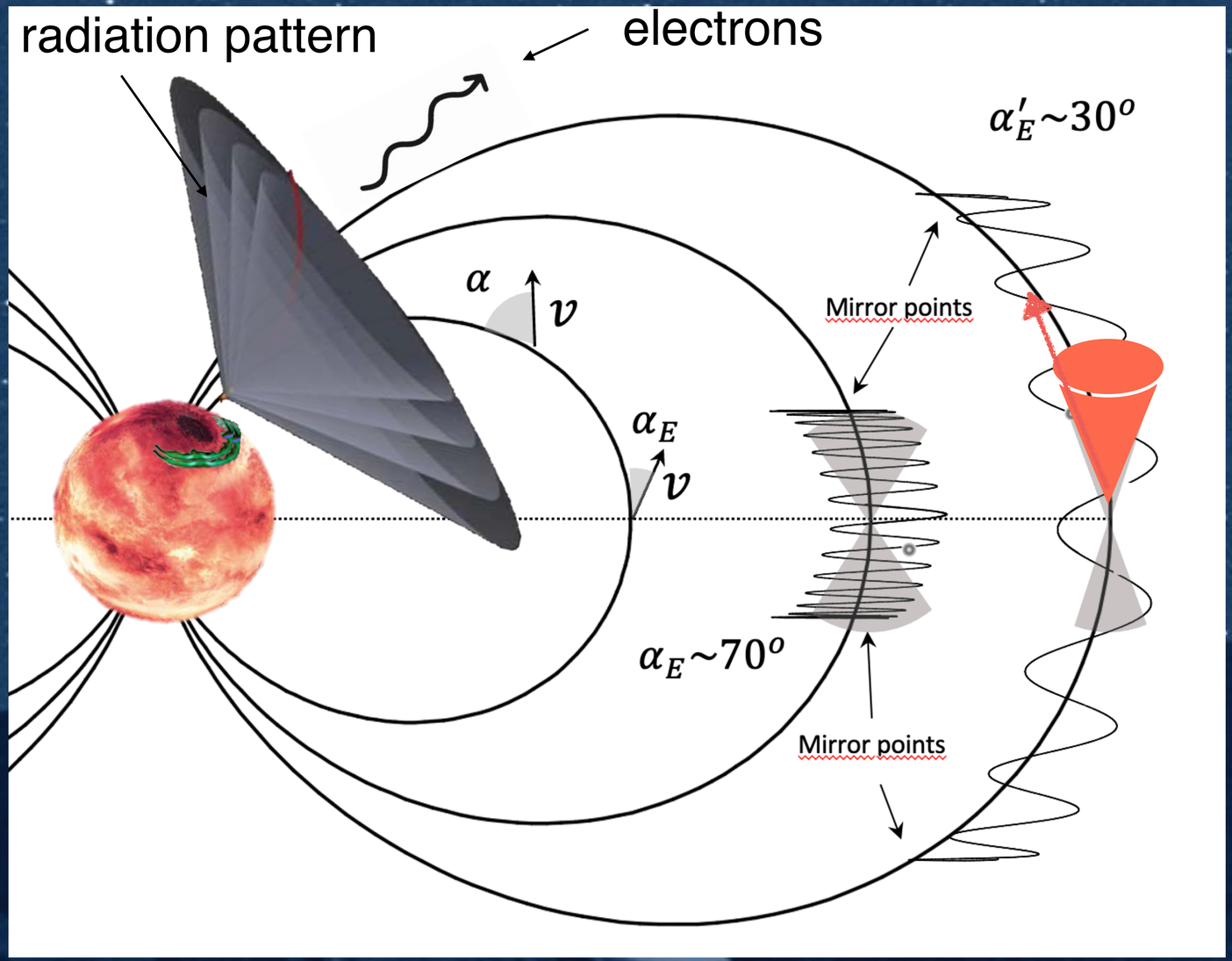
Auroral radio emission

Radio emission: ECMI (electron ciclotron maser instabilty):

- Strong magnetic field
- Low plasma density
- Loss-cone (non-thermal) electron distribution
- Acceleration mechanism



Hess+2017

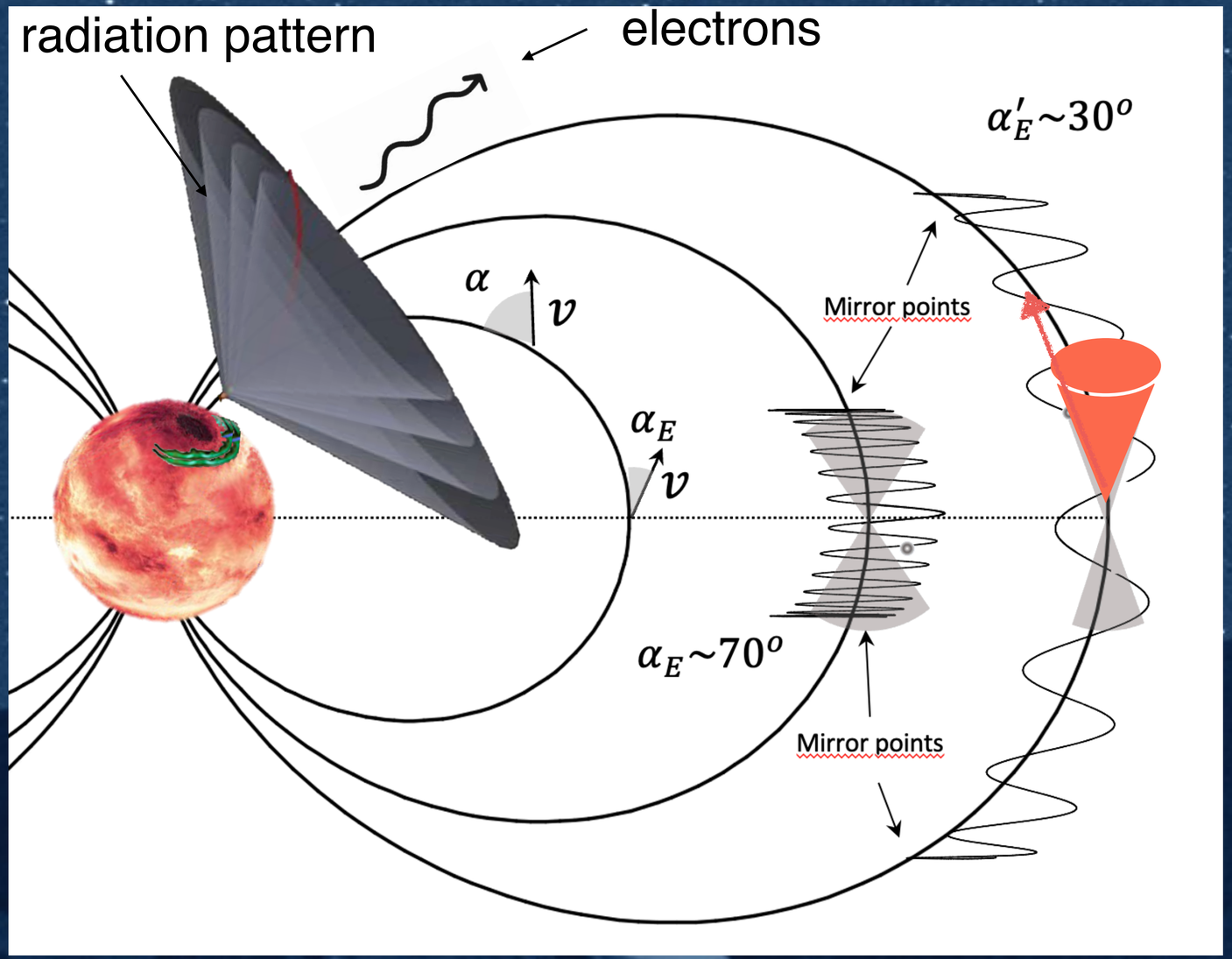


Auroral radio emission

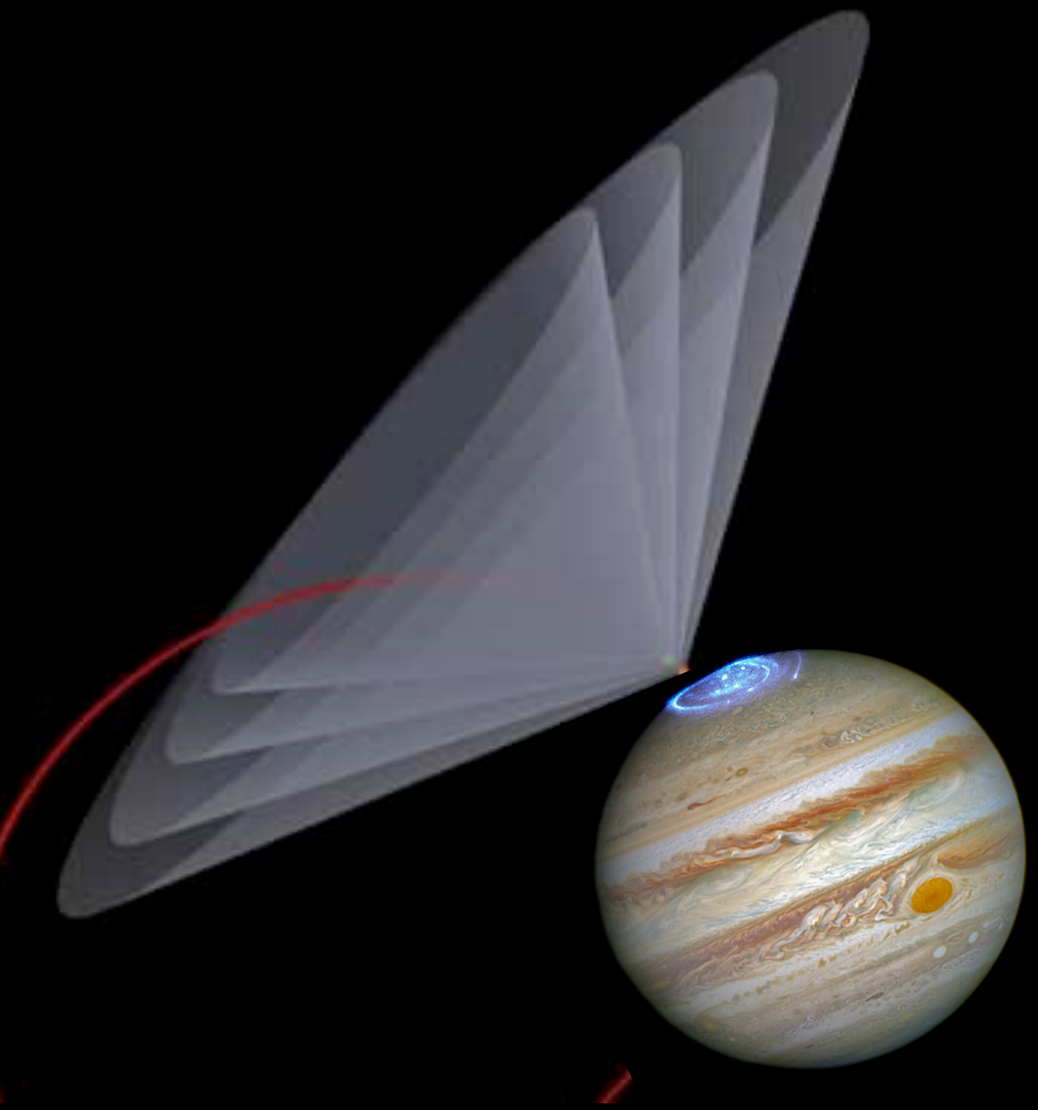
Radio emission: ECMI (electron ciclotron maser instabilty):

- Strong magnetic field
- Low plasma density
- Loss-cone (non-thermal) electron distribution
- Acceleration mechanism

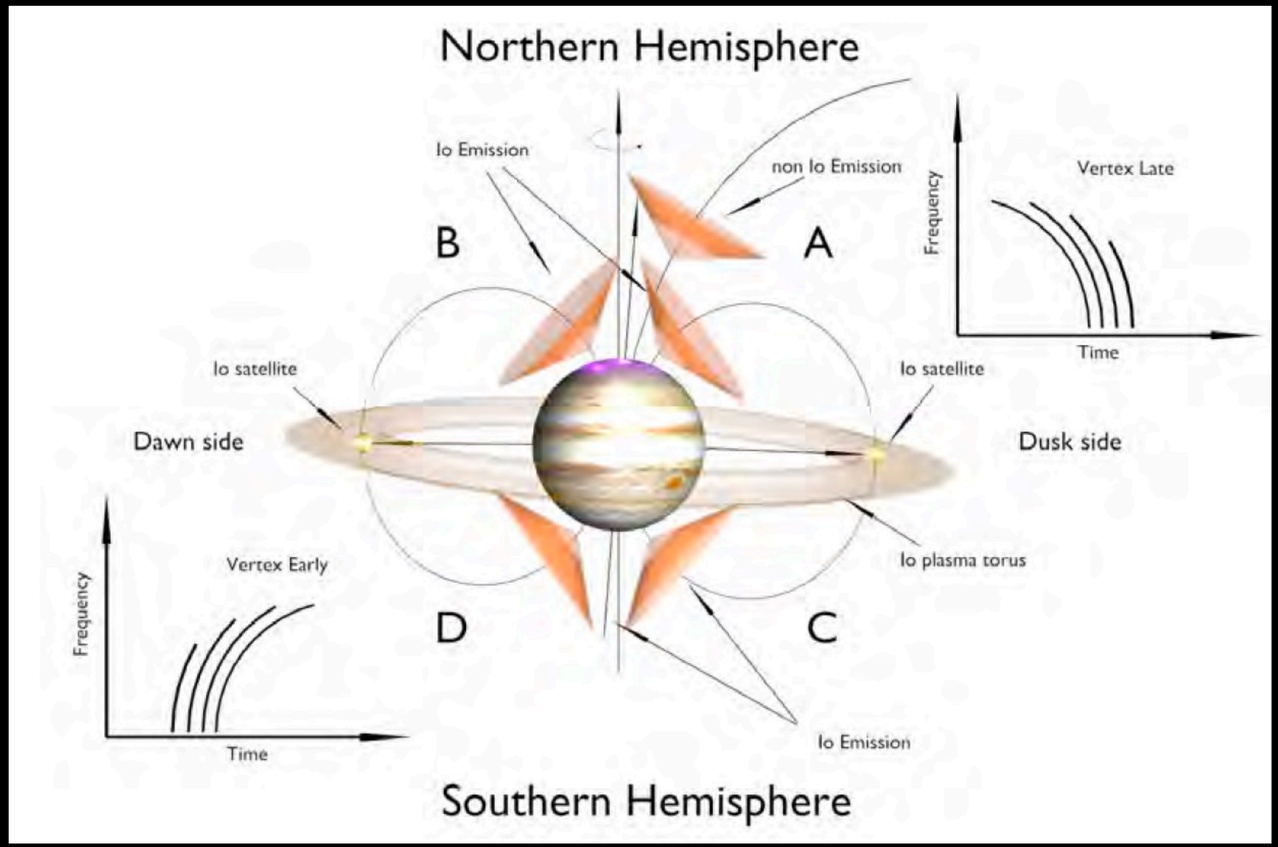
$$\left(\frac{\nu_c}{MHz}\right) = 2.8 \times 10^6 \left(\frac{B}{\text{Gauss}}\right)$$



Auroral radio emission —Jupiter



The case of Jupiter is well known but different geometries for UCD / brown dwarfs !!

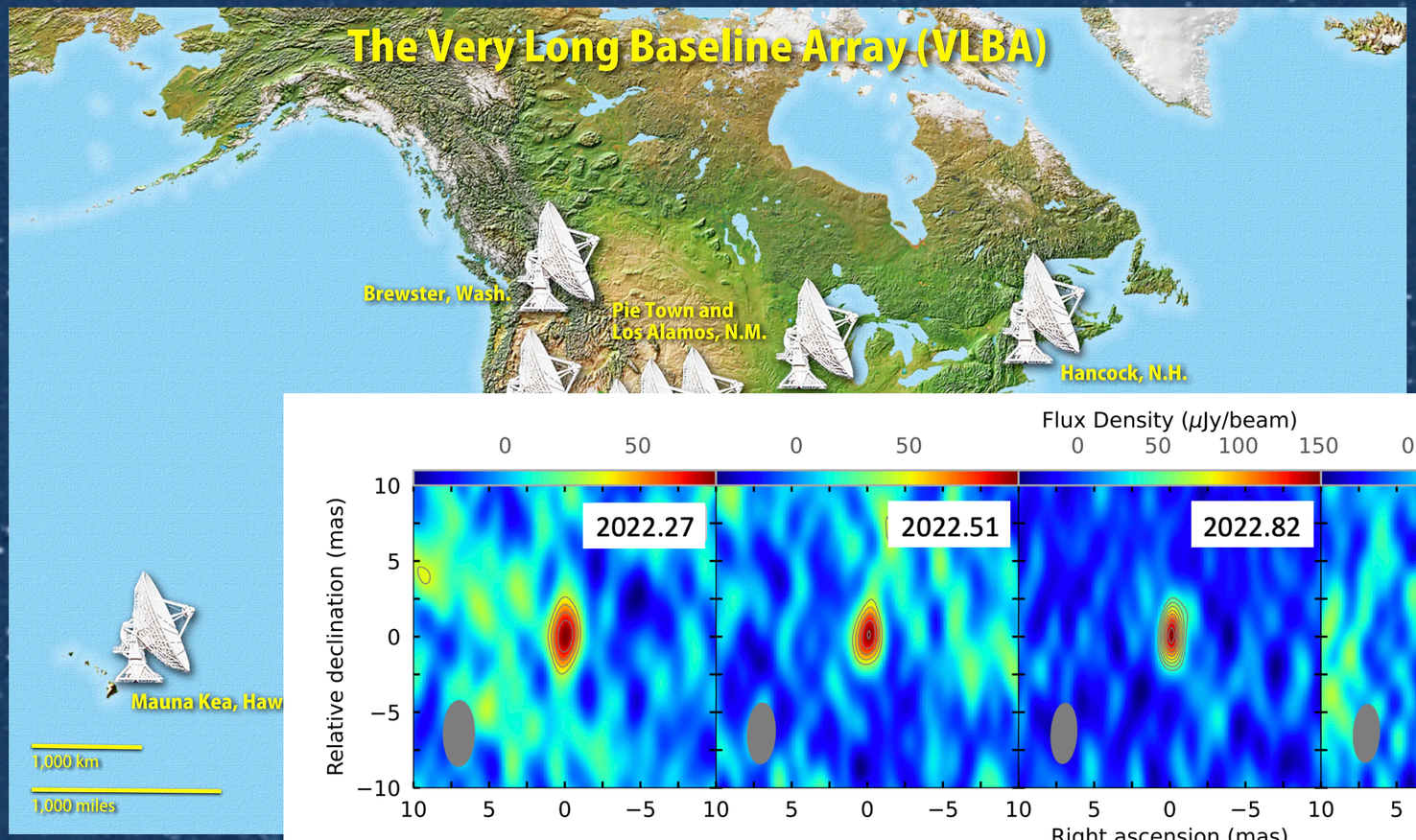


WISE J112254.72+255022.2

- T6 BD object at only 15.9 pc
- Rotation period ~2 hr
- Detected with VLA and
- Arecibo @ GHz-freqs
- B on surface ~kG

(Williams+2018, Route+2016)

WISE J112254.72+255022.2

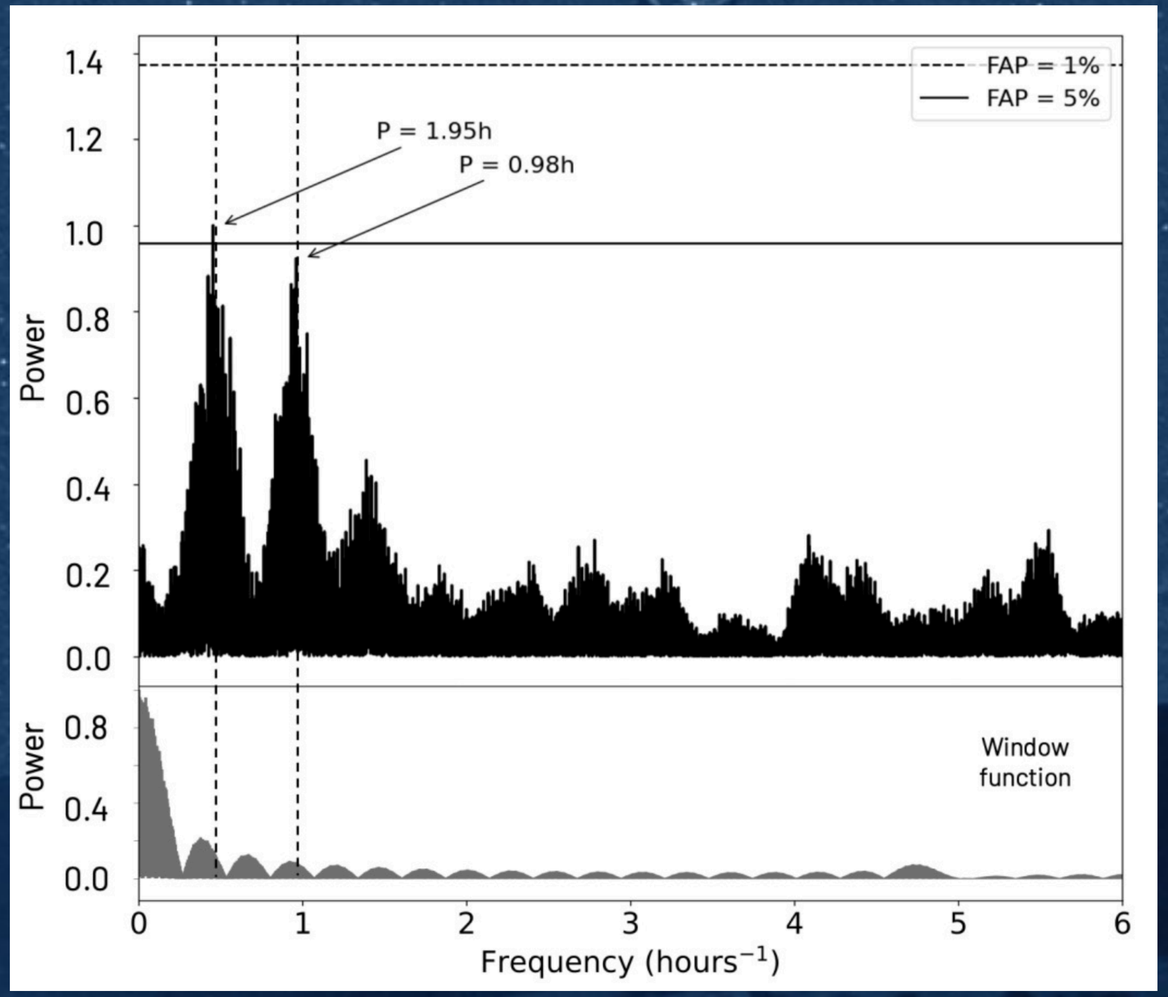


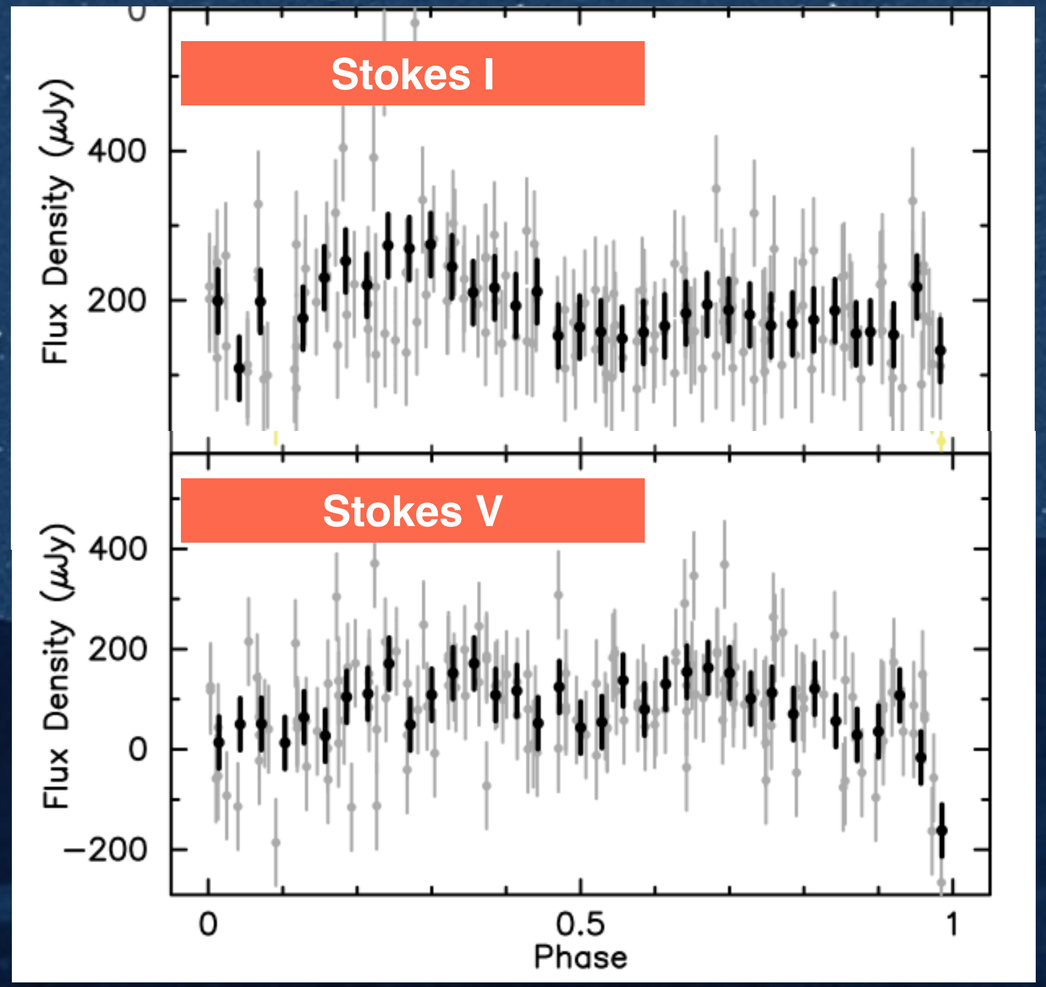
- T6 BD object at only 15.9 pc
- Rotation period ∼2 hr
- Detected with VLA and
  lz-freqs
- ∼kG
- 3, Route+2016)

$$L_R \sim 10^{14.5}\ \mathrm{erg\ s^{-1}\ Hz^{-1}}$$

Guirado+2025

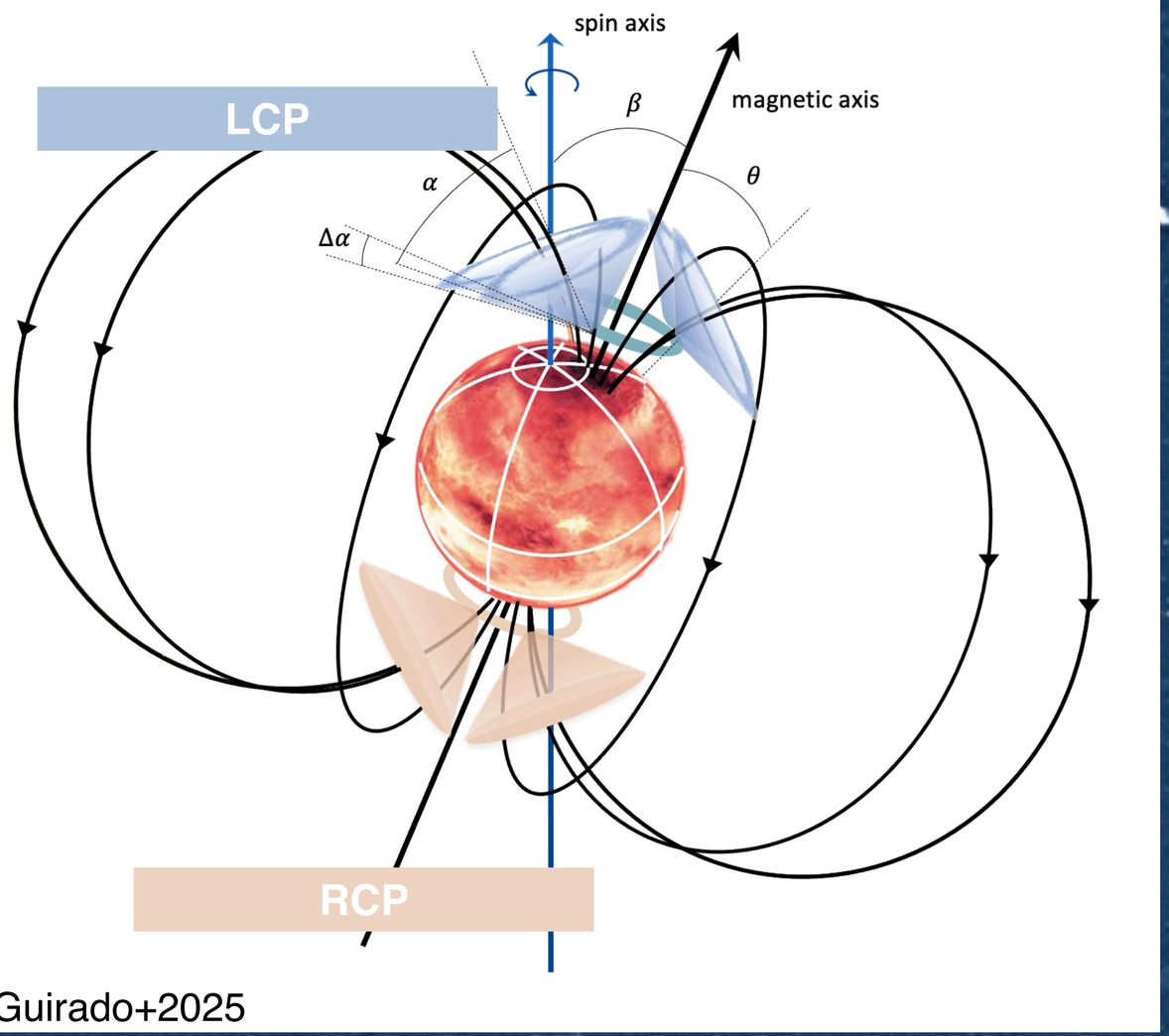
WISE J112254.72+255022.2
main oval radio emission





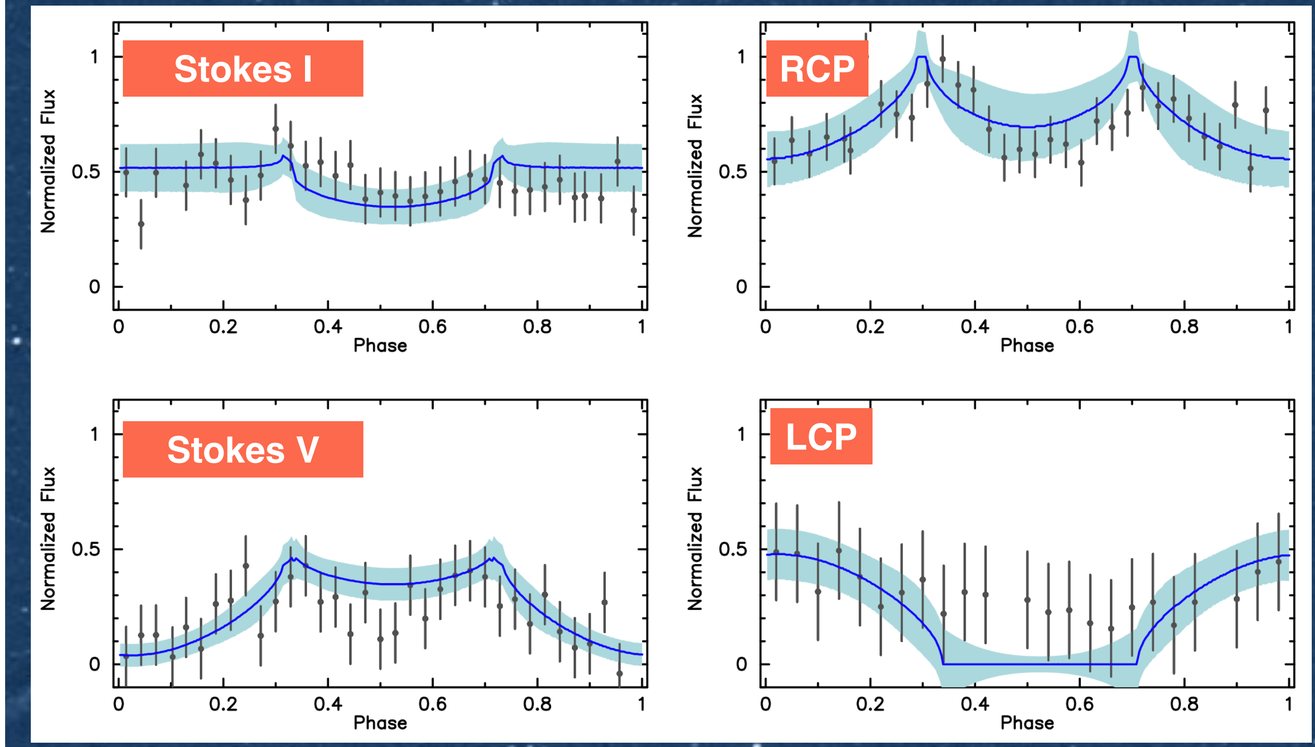
Guirado+2025

WISE J112254.72+255022.2
main oval radio emission



Guirado+2025

The auroral emission originates in circumpolar rings around the magnetic poles —which may remind the main oval in Jupiter



WISE J112254.72+255022.2 main oval radio emission

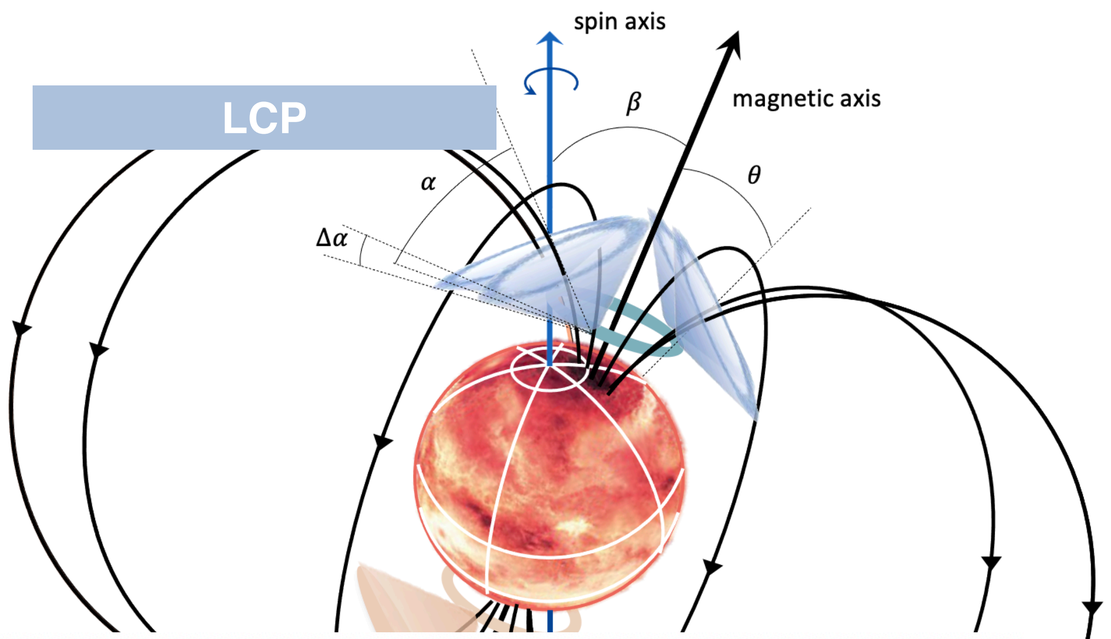
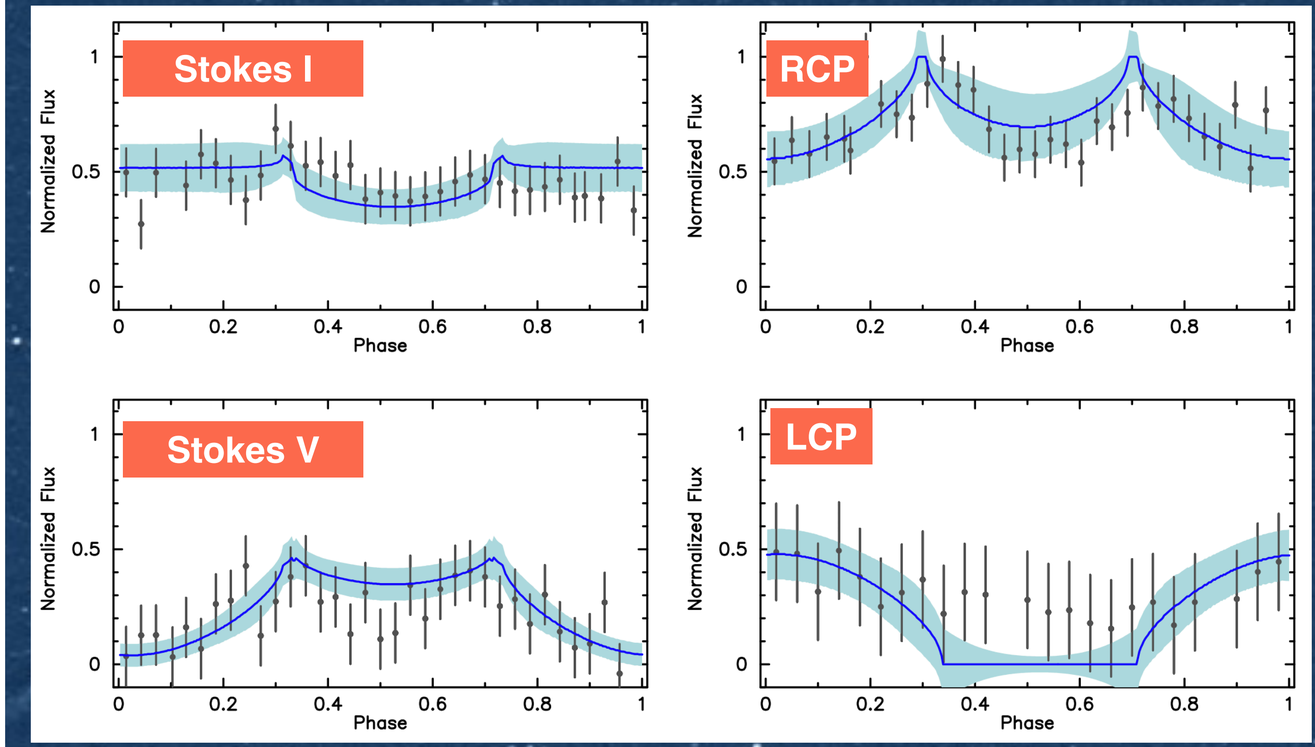


Table 3. Inferred geometric parameters of the auroral for WISE J1122

Parameter	Posterior
Spin axis inclination (i):	$86.8^{\circ} \pm 0.6^{\circ}$
Magnetic axis obliquity (β):	$2.6^{\circ} \pm 0.5^{\circ}$
Magnetic colatitude of the auroral ring (θ_B):	$2.7^{\circ} \pm 0.6^{\circ}$
Hollow cone half-opening angle (α):	$86.0^{\circ} \pm 0.7^{\circ}$
Hollow cone thickness ($\Delta\alpha$):	$8.4^{\circ} \pm 1.4^{\circ}$

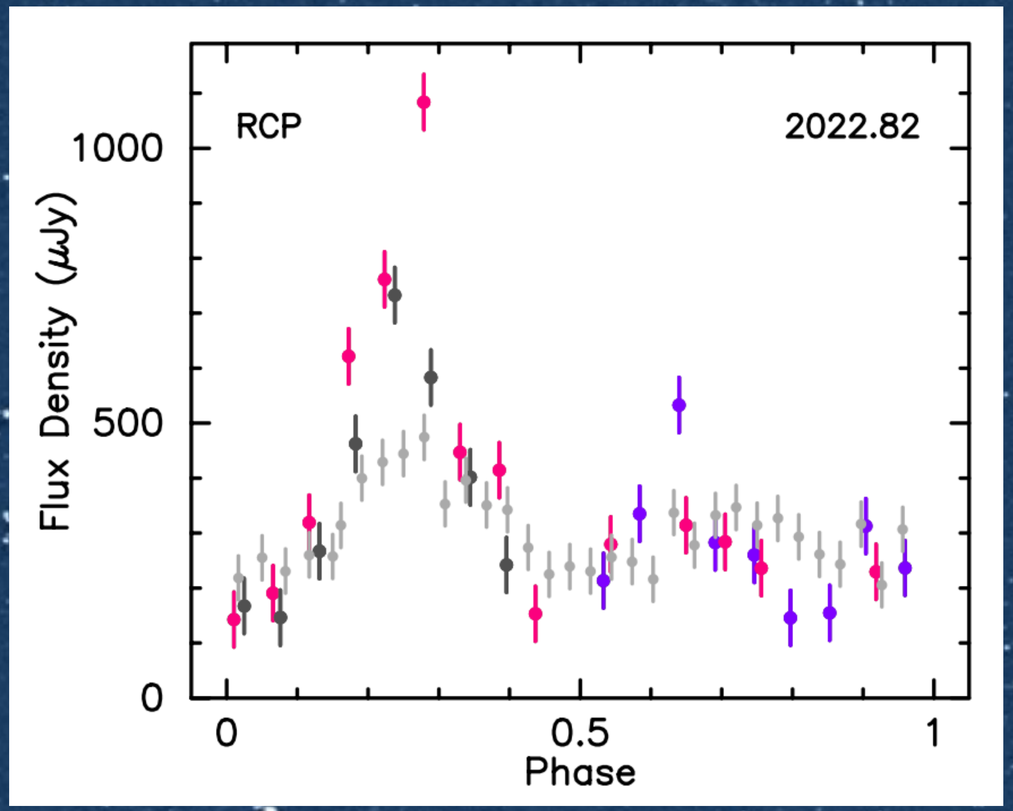
Guirado+2025

The auroral emission originates in circumpolar rings around the magnetic poles —which may remind the main oval in Jupiter

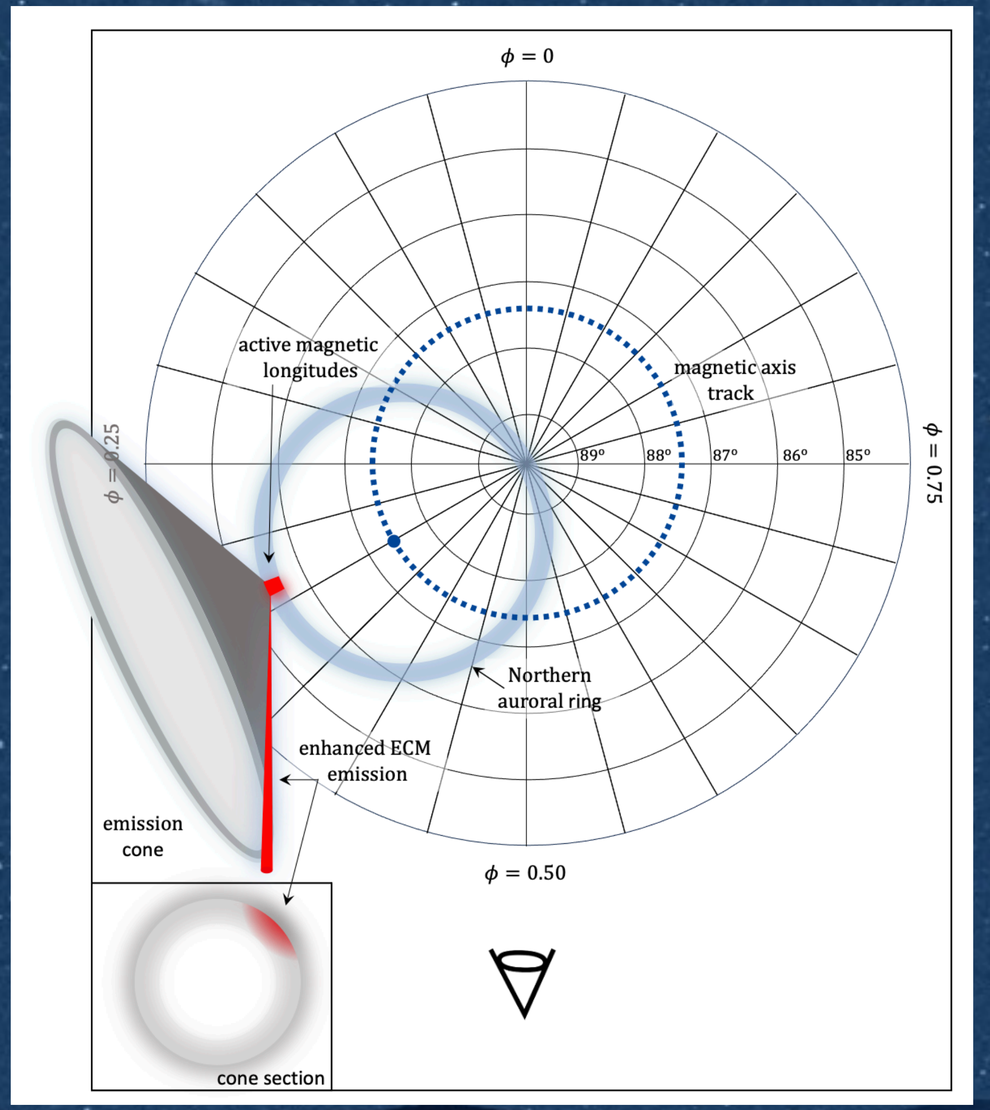


WISE J112254.72+255022.2
main oval radio emission

Flares may be simulated with inhomogeneities in the emission pattern (just like in Jupiter's non-Io DAM).



Guirado+2025



WISE J112254.72+255022.2
sub-milliarcsecond astrometry

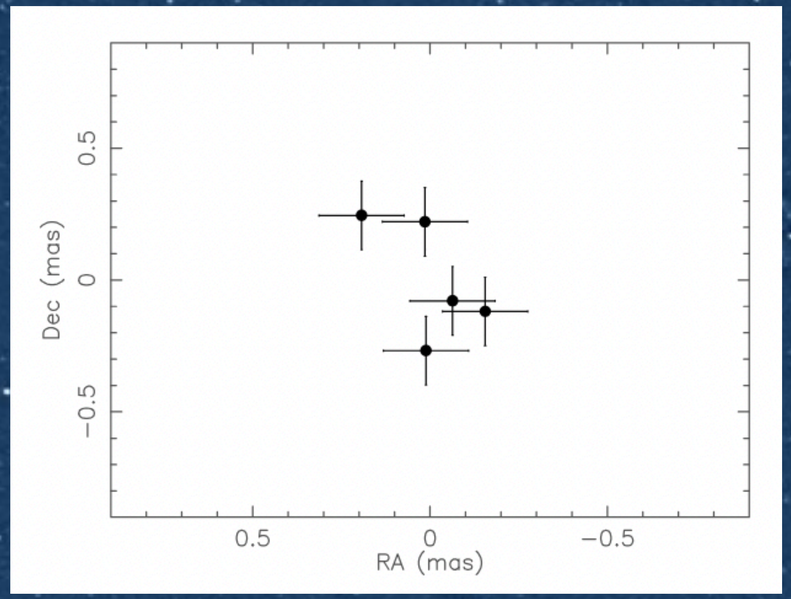
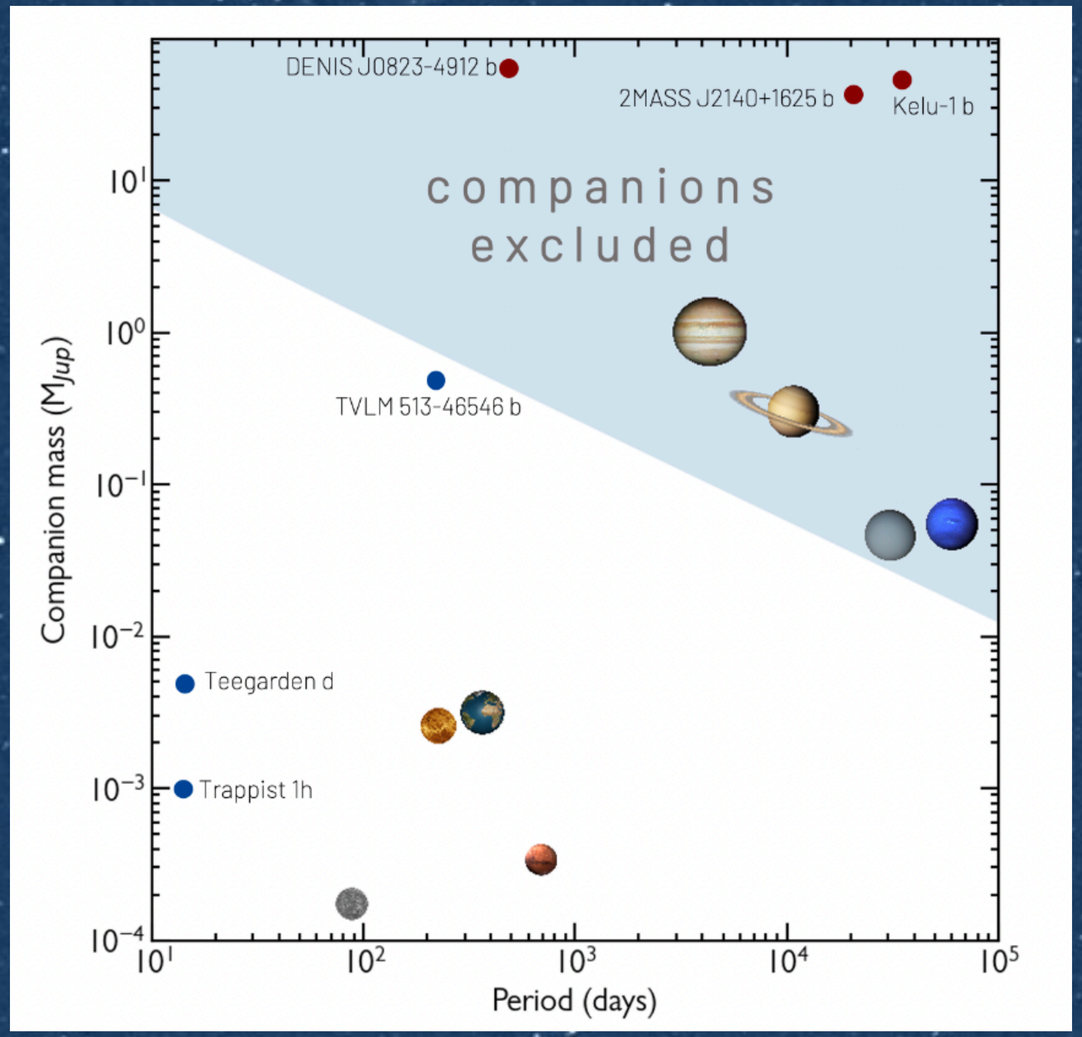


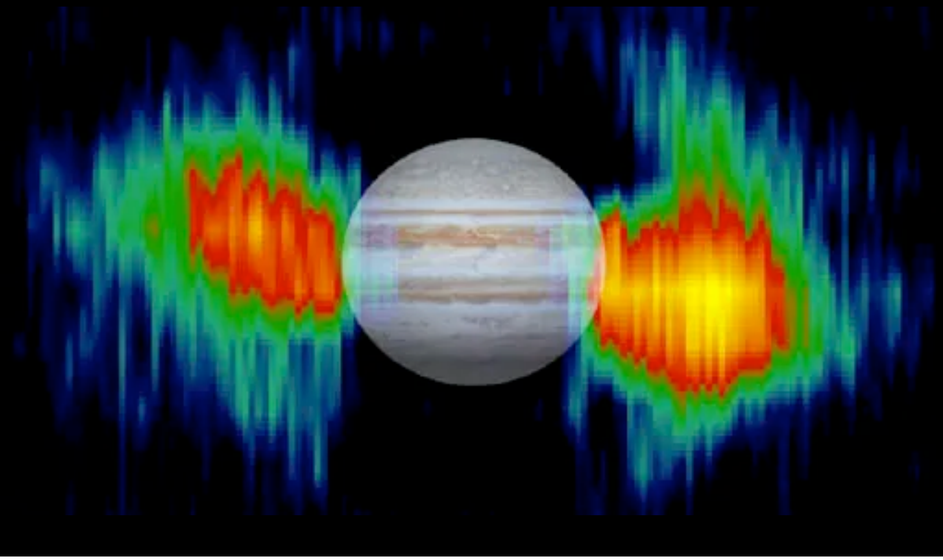
Table 5. Astrometric parameters of WISE J1122 and its wide companion LHS 302

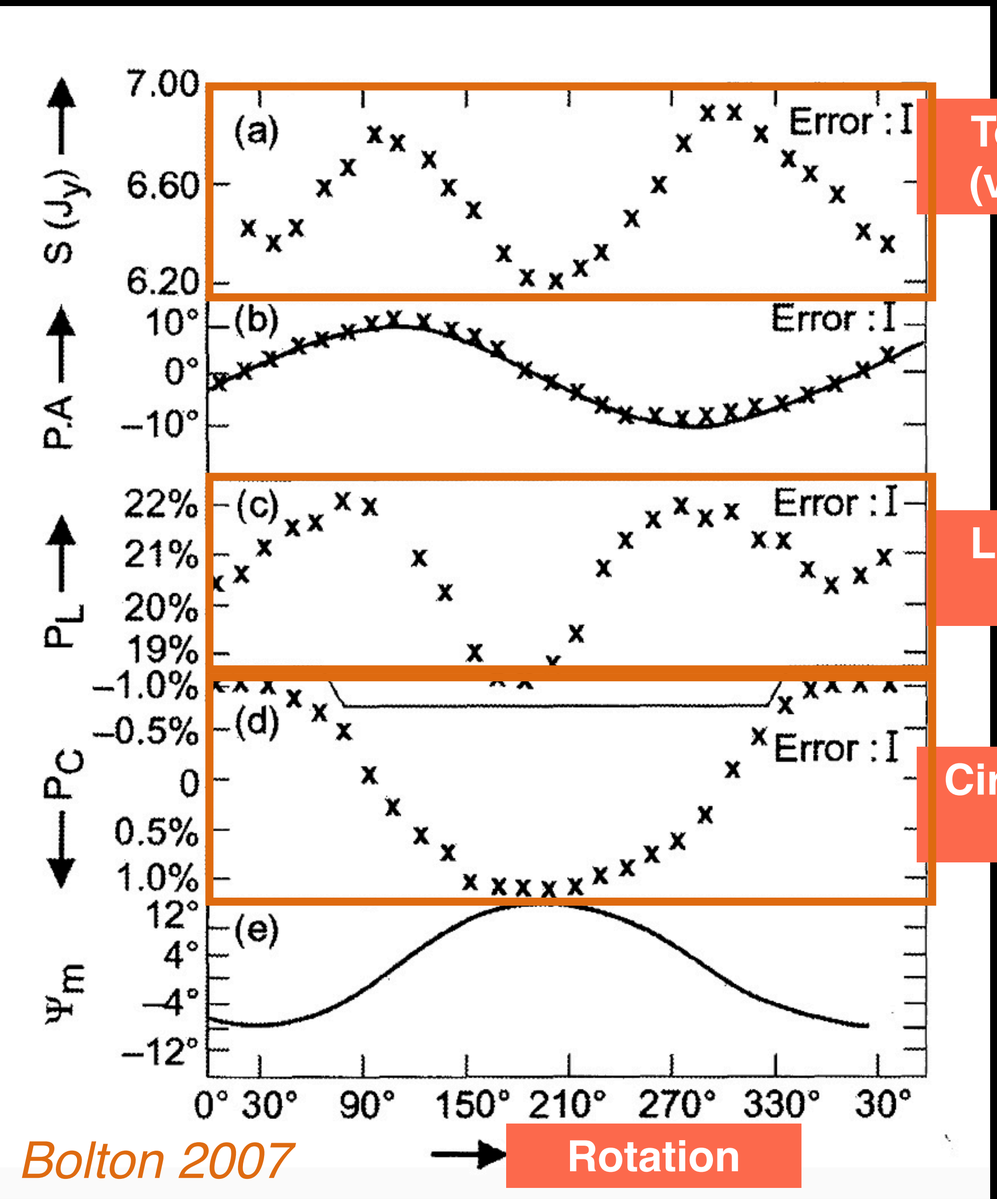
	VLBI	Gaia
	WISE J1122$^{(a)}$	LHS 302$^{(b)}$
μ_α (mas yr^{-1})	-1015.62 ± 0.14	-1010.9189 ± 0.0734
μ_δ (mas yr^{-1})	-322.08 ± 0.20	-323.1270 ± 0.0684
Parallax (mas)	61.68 ± 0.10	61.6520 ± 0.0644



Guirado+2025

Radiation belts (synchrotron)



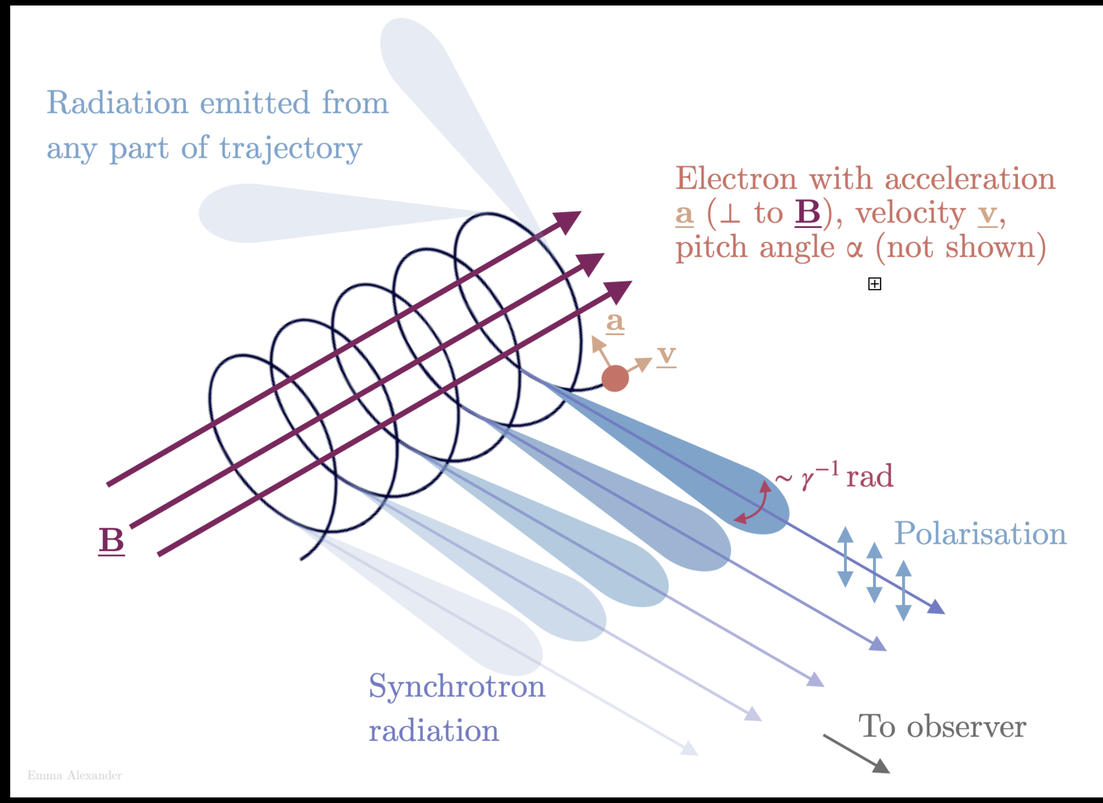


Total flux (variable)

Linear Pol (high!)

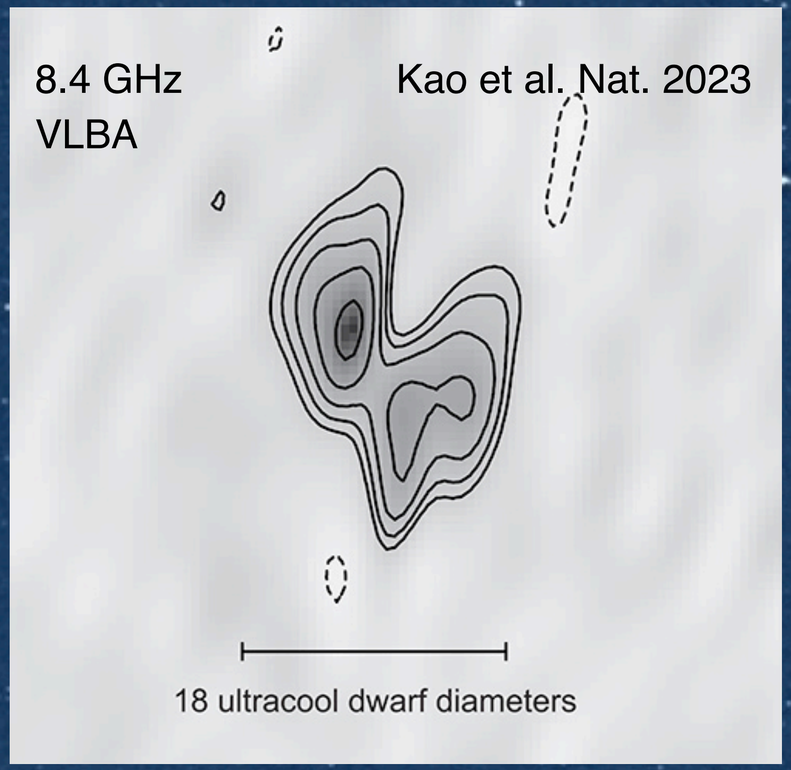
Circular Pol (low!)

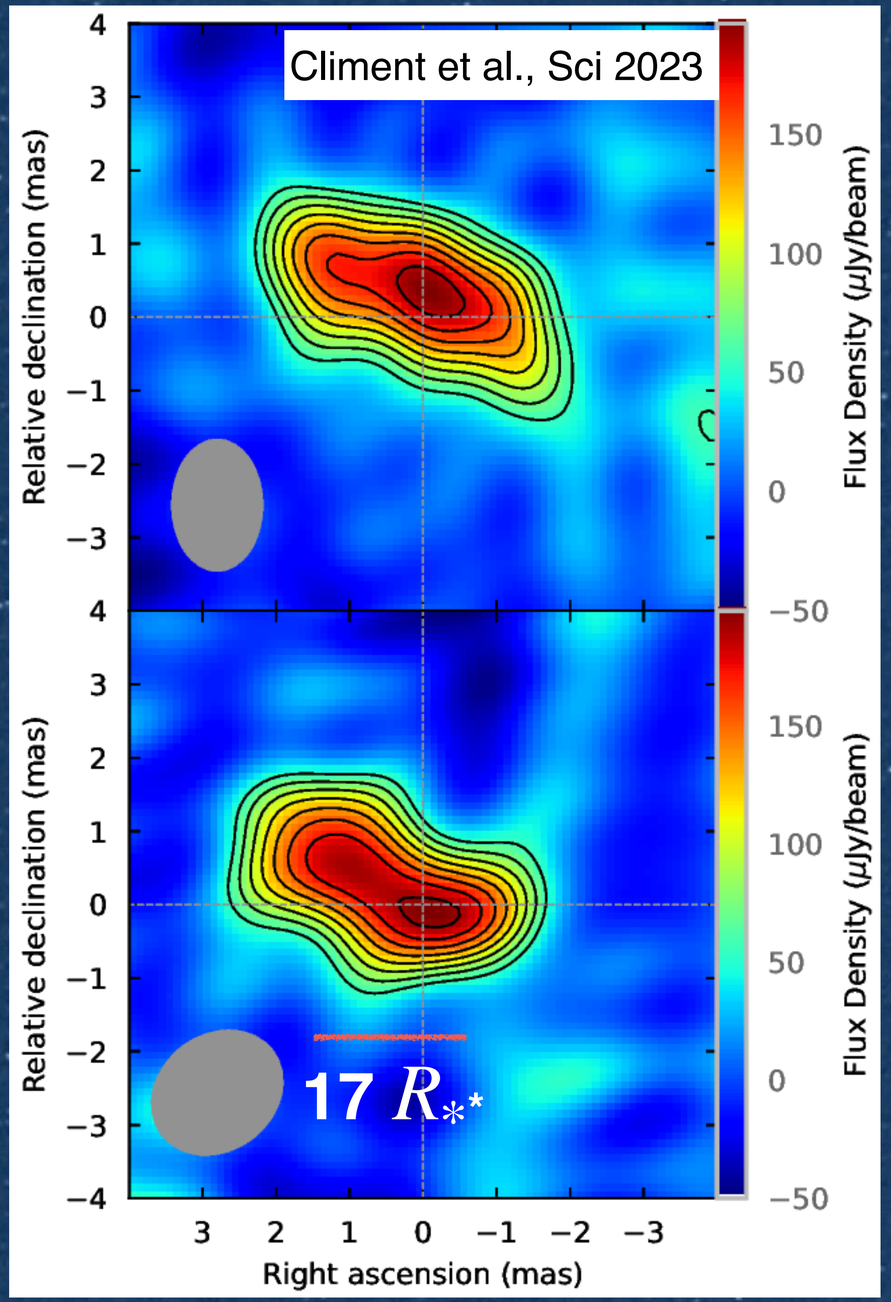
Bolton 2007



LSR J1835+3259 (EVN, 5 GHz)

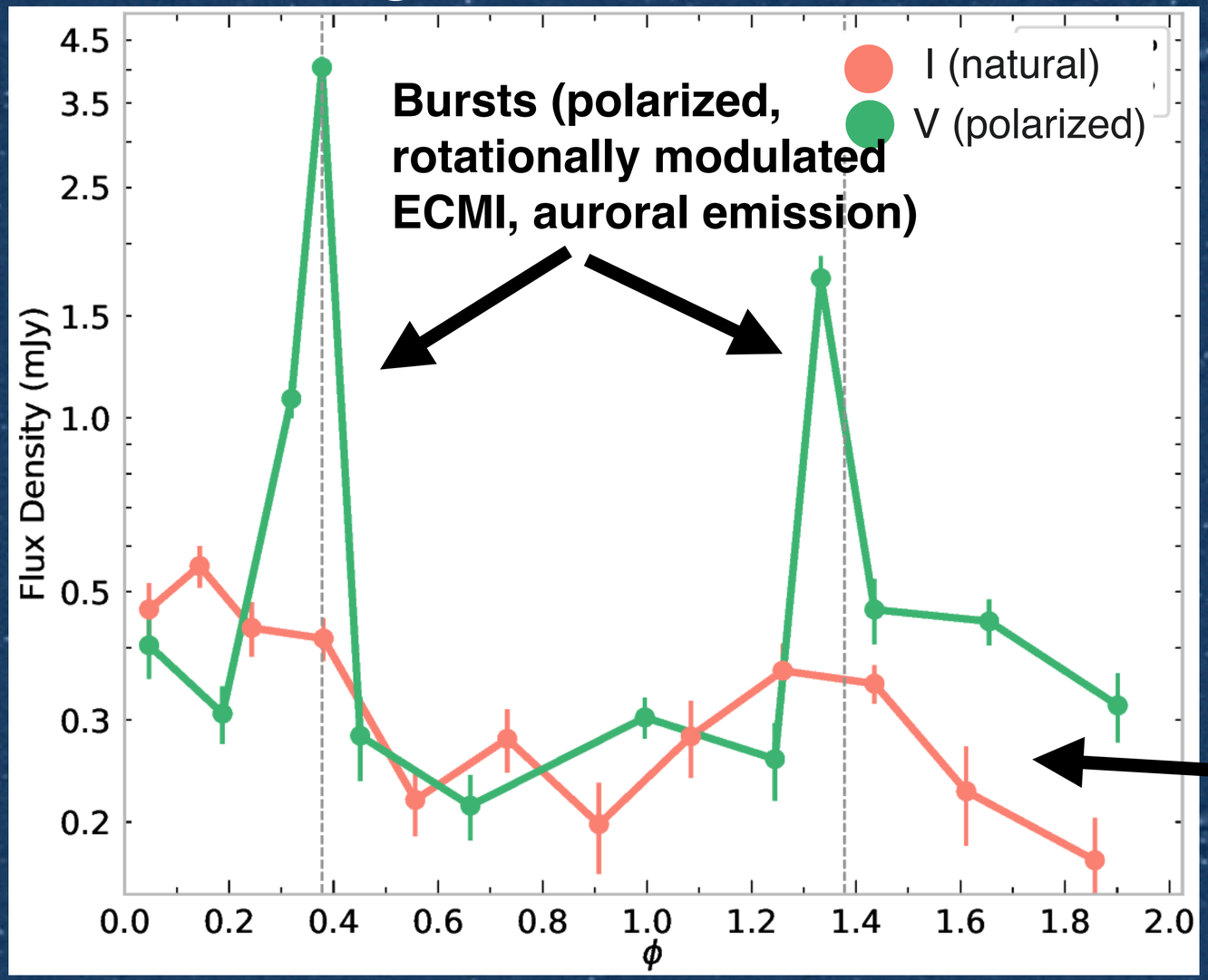
- **Observed during 6 hr = 2 full rotations**
- **The maps show an average of the magnetosphere after 1 (or 2) rotations**





LSR J1835+3259 (EVN, 5GHz)

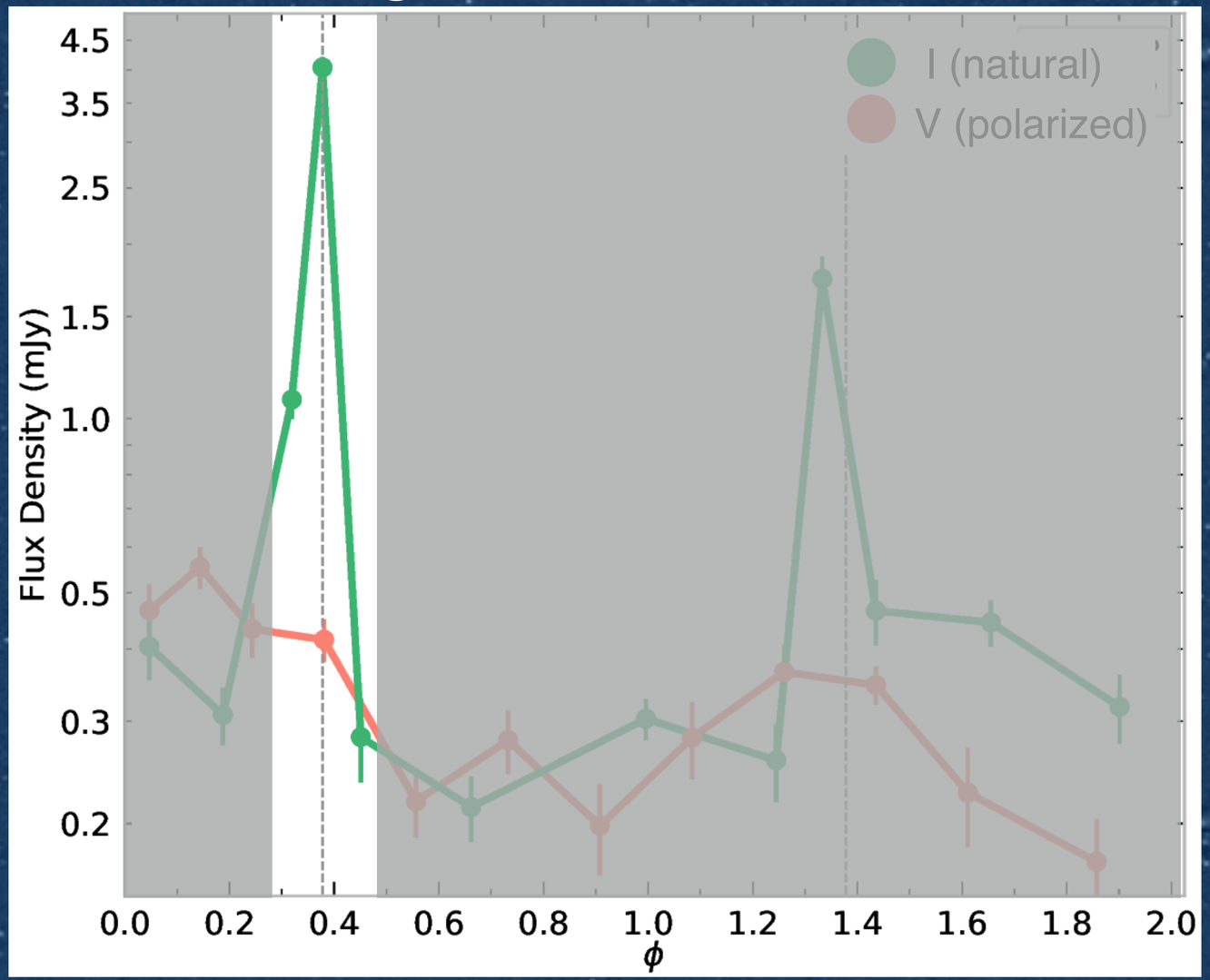
- **VLBI light curve**



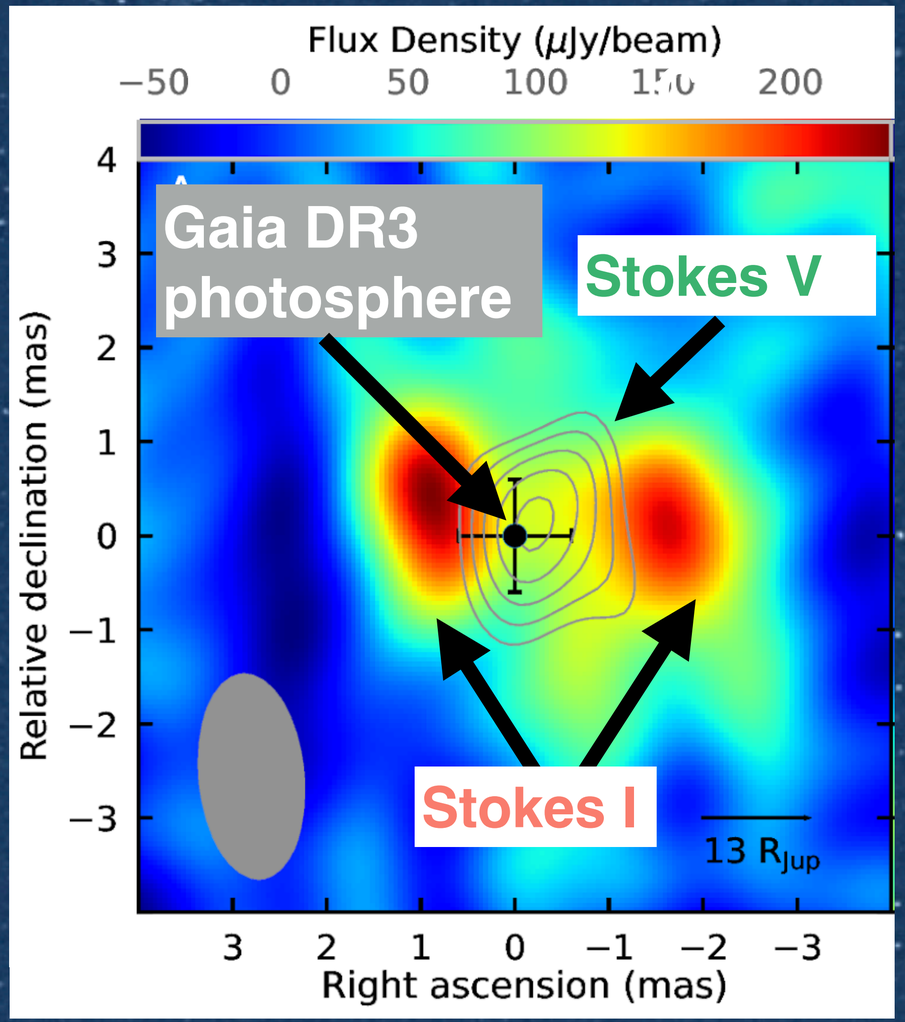
Quiescent (slowly varying, low polarization, (gyro)synchrotron?)

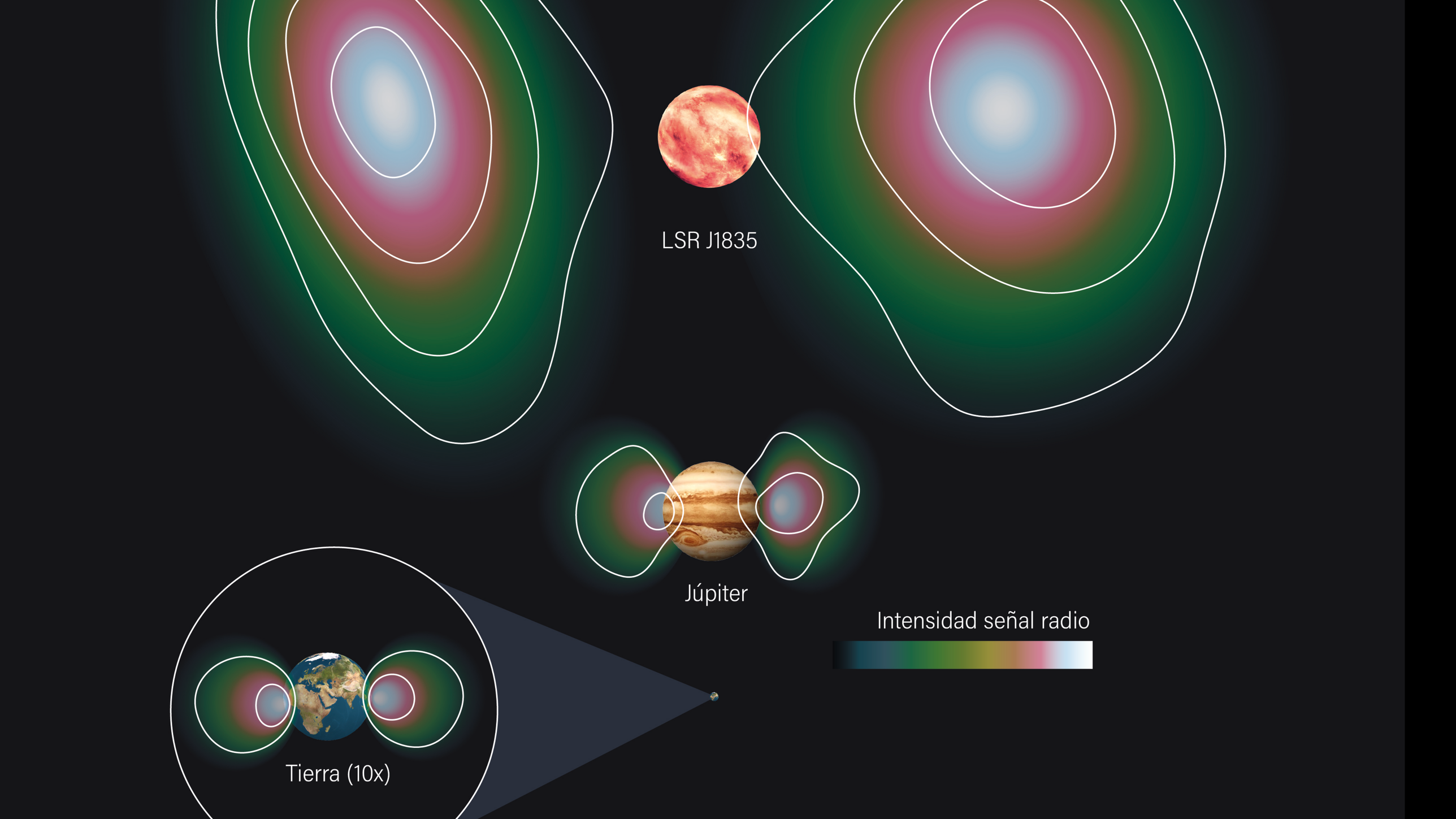
LSR J1835+3259 (EVN, 5GHz)

- VLBI light curve



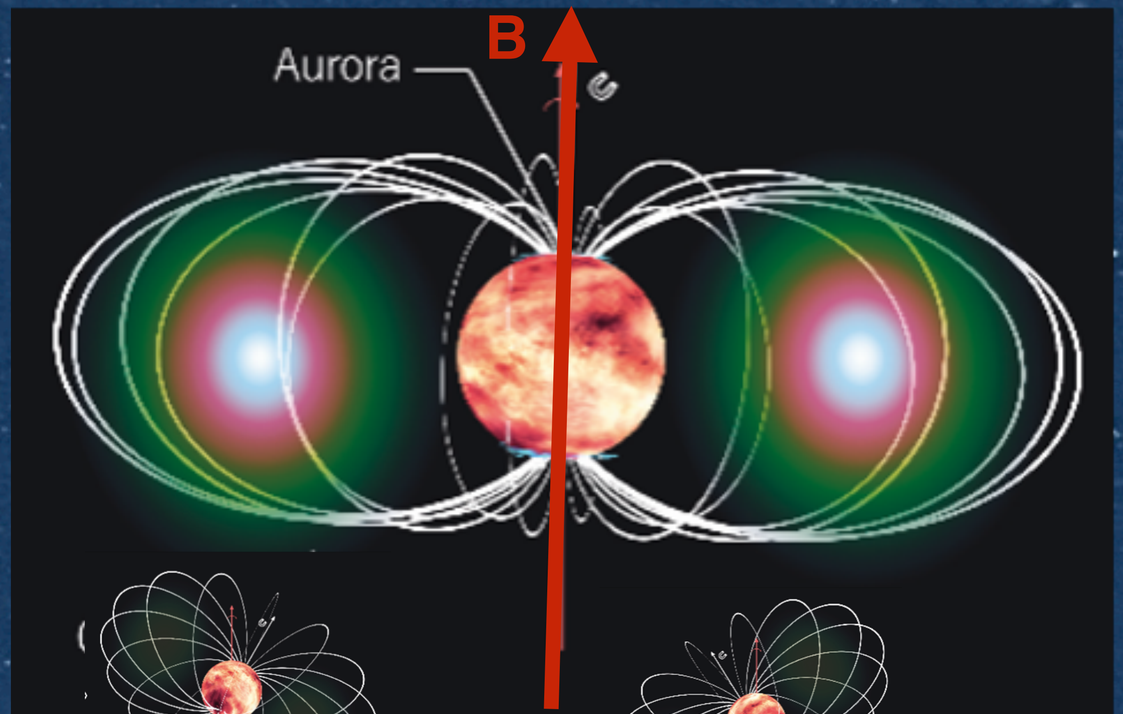
30min maps (during aurora)

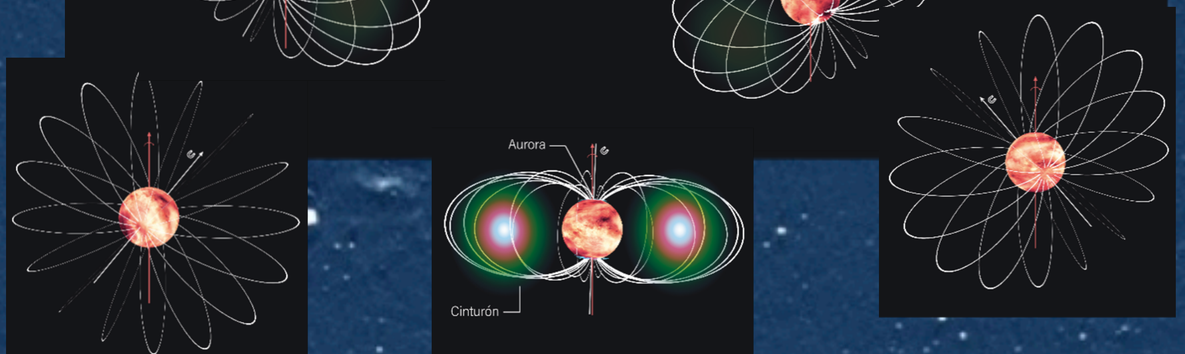


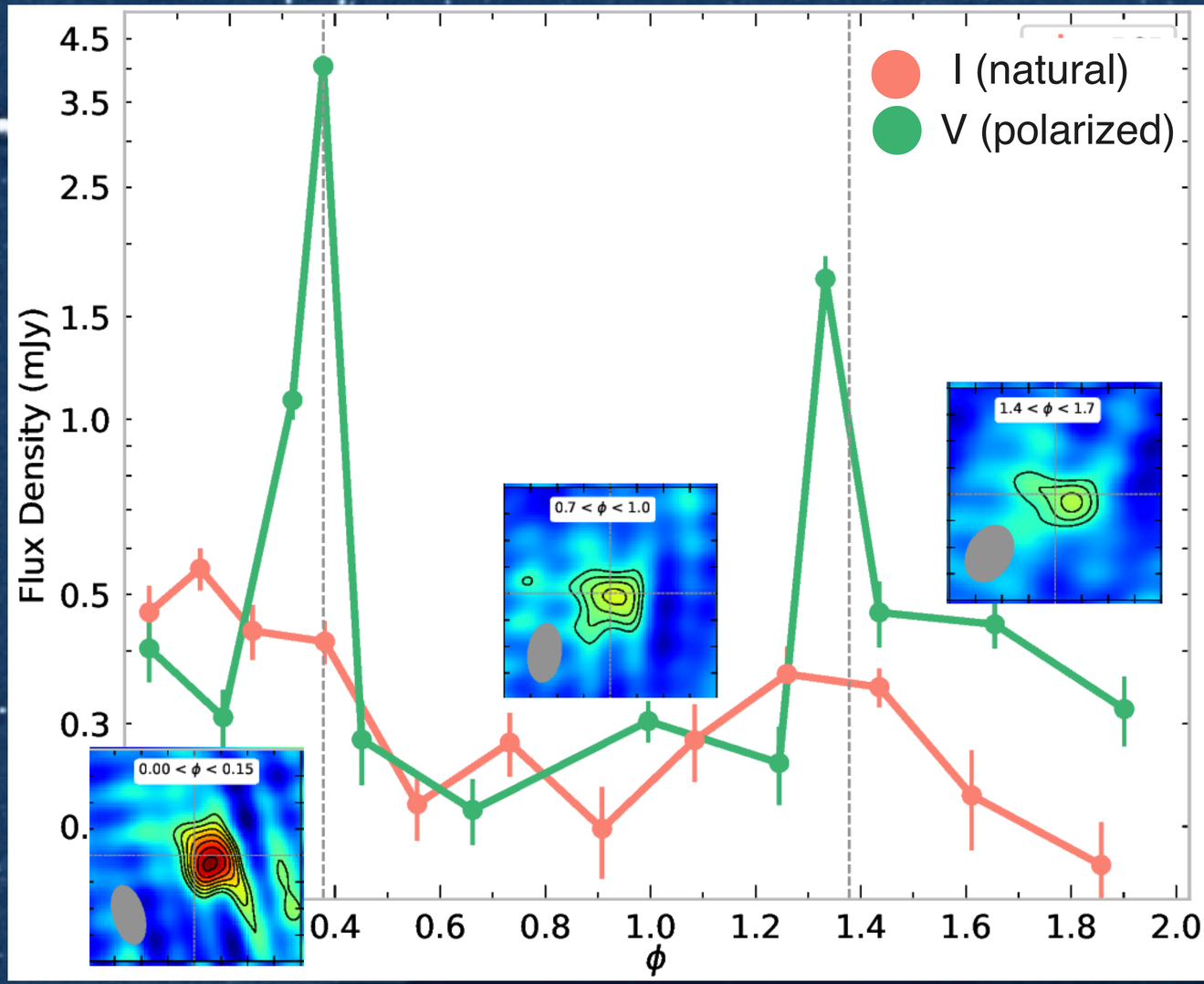

LSR J1835
Júpiter
Intensidad señal radio
Tierra (10x)

LSR J1835+3259 (EVN, 5GHz)

Snapshot maps show that double structure (belt) is only seen at the times of the auroral peaks.



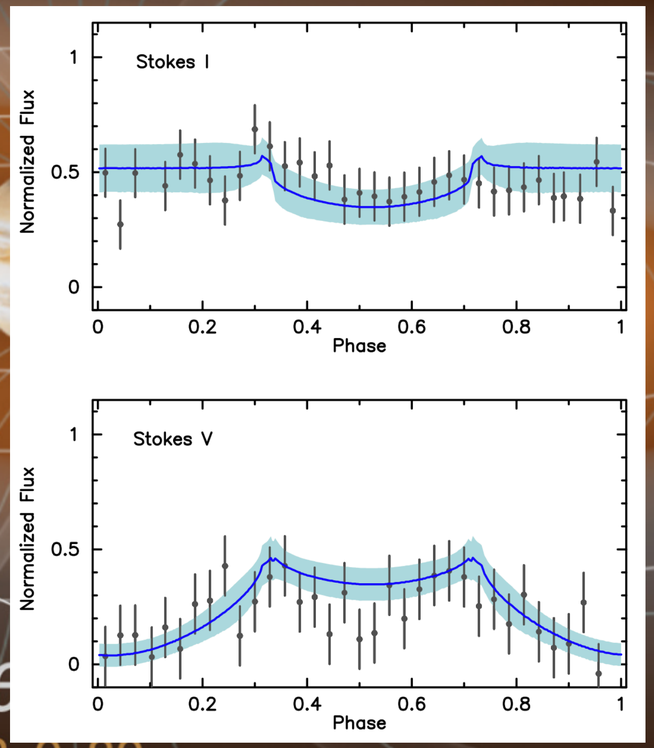


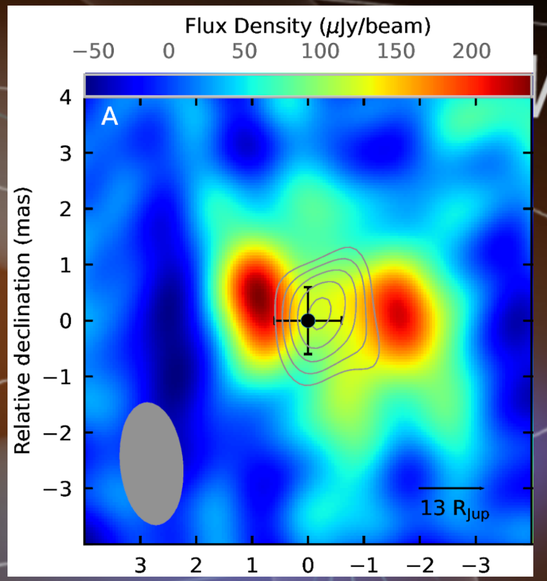


A word about SPI

BD's check list

- Main oval? ✓
- Radiation belts? ✓
- Io-like storms? ☐

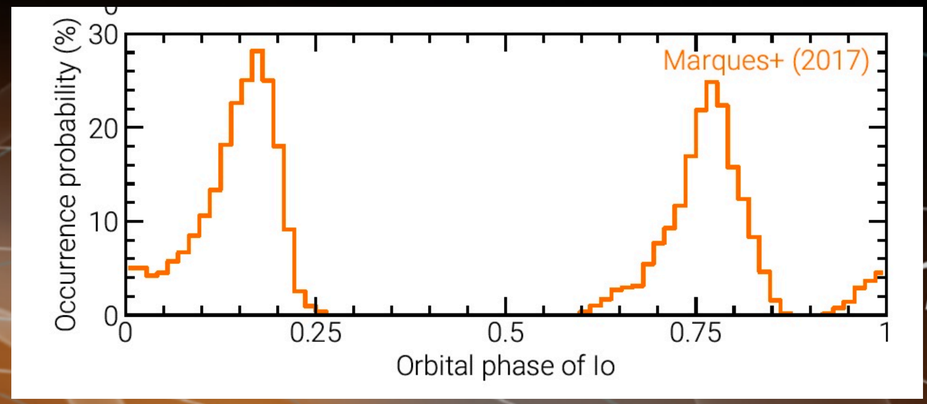


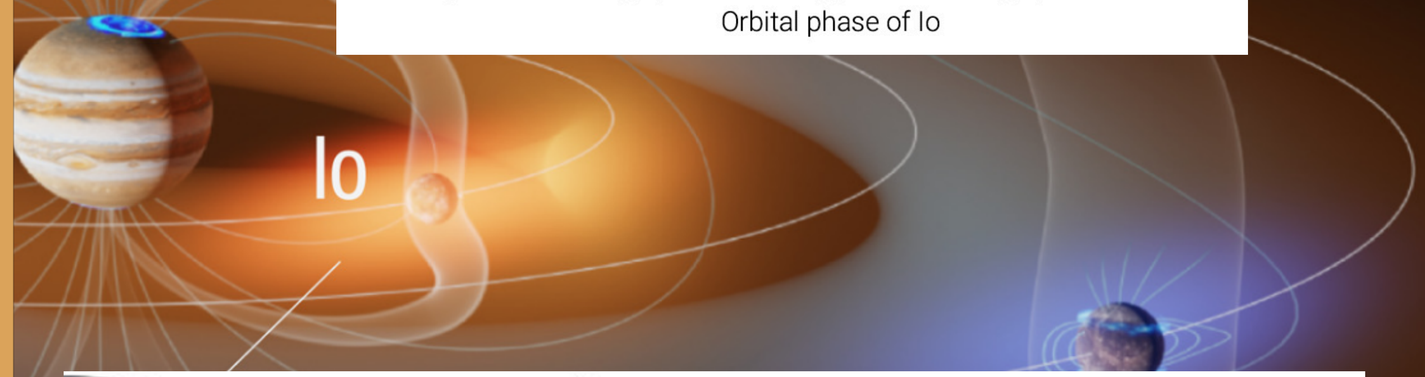


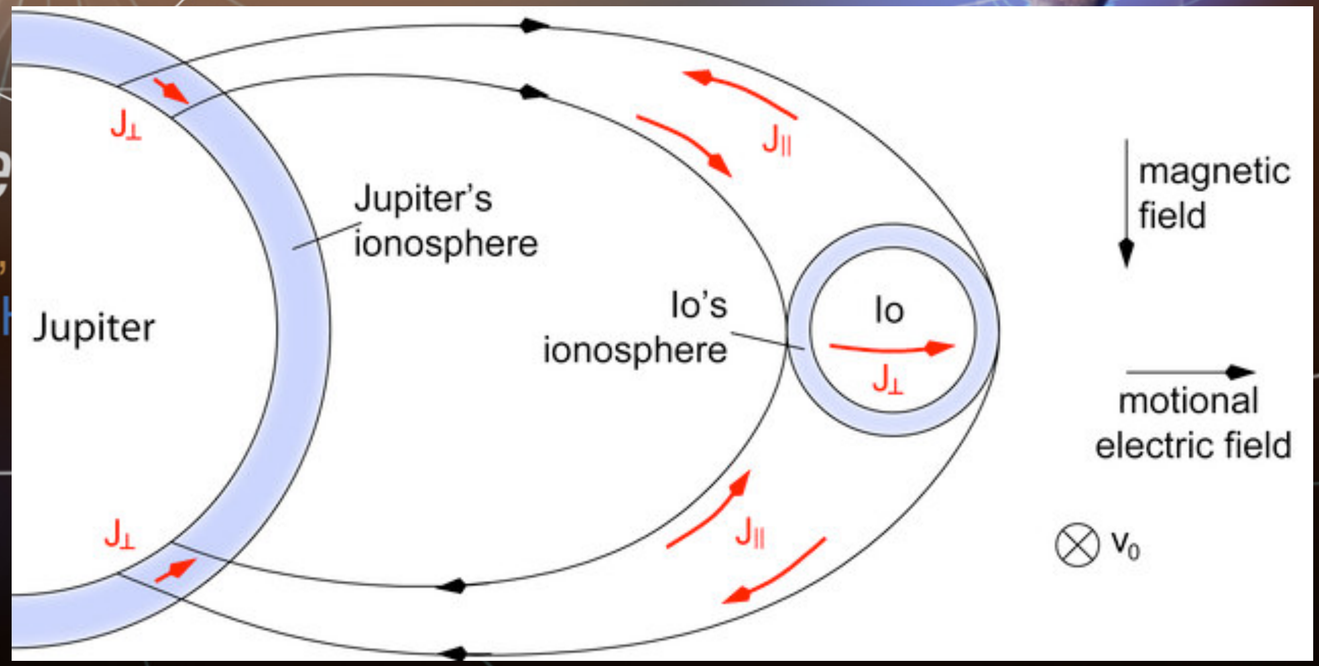
Ganymede

BD's check list

- Main oval? ✓
- Radiation belts? ✓
- Io-like storms? ✓





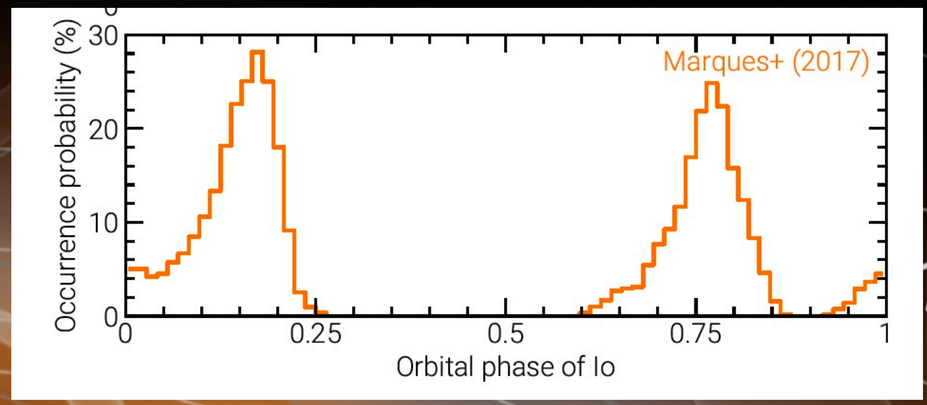


BD's check list

Main oval? ✓

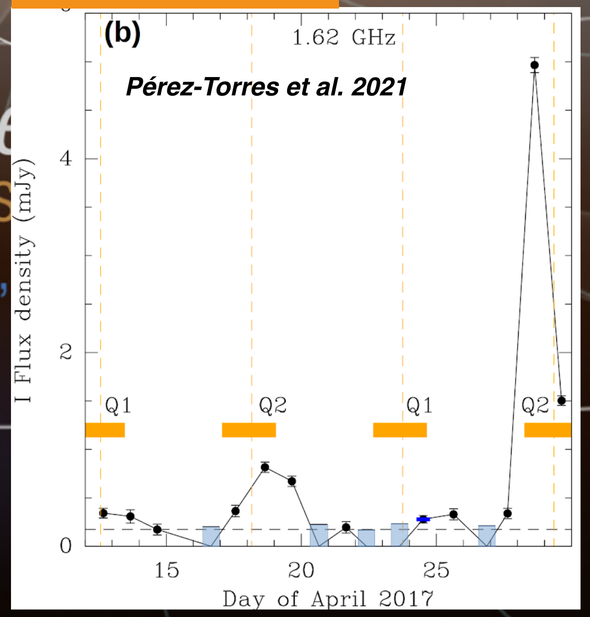
Radiation belts? ✓

Io-like storms? ✓

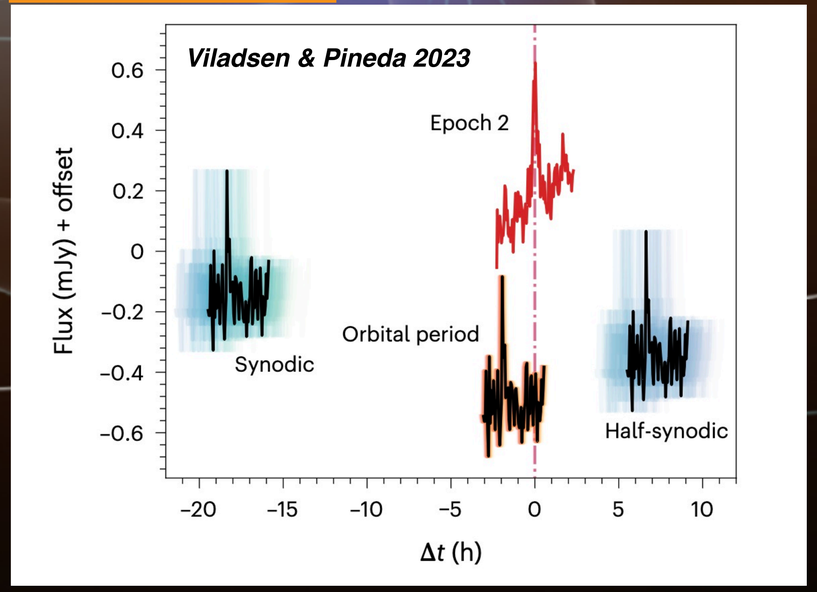


Io

Proxima Cen

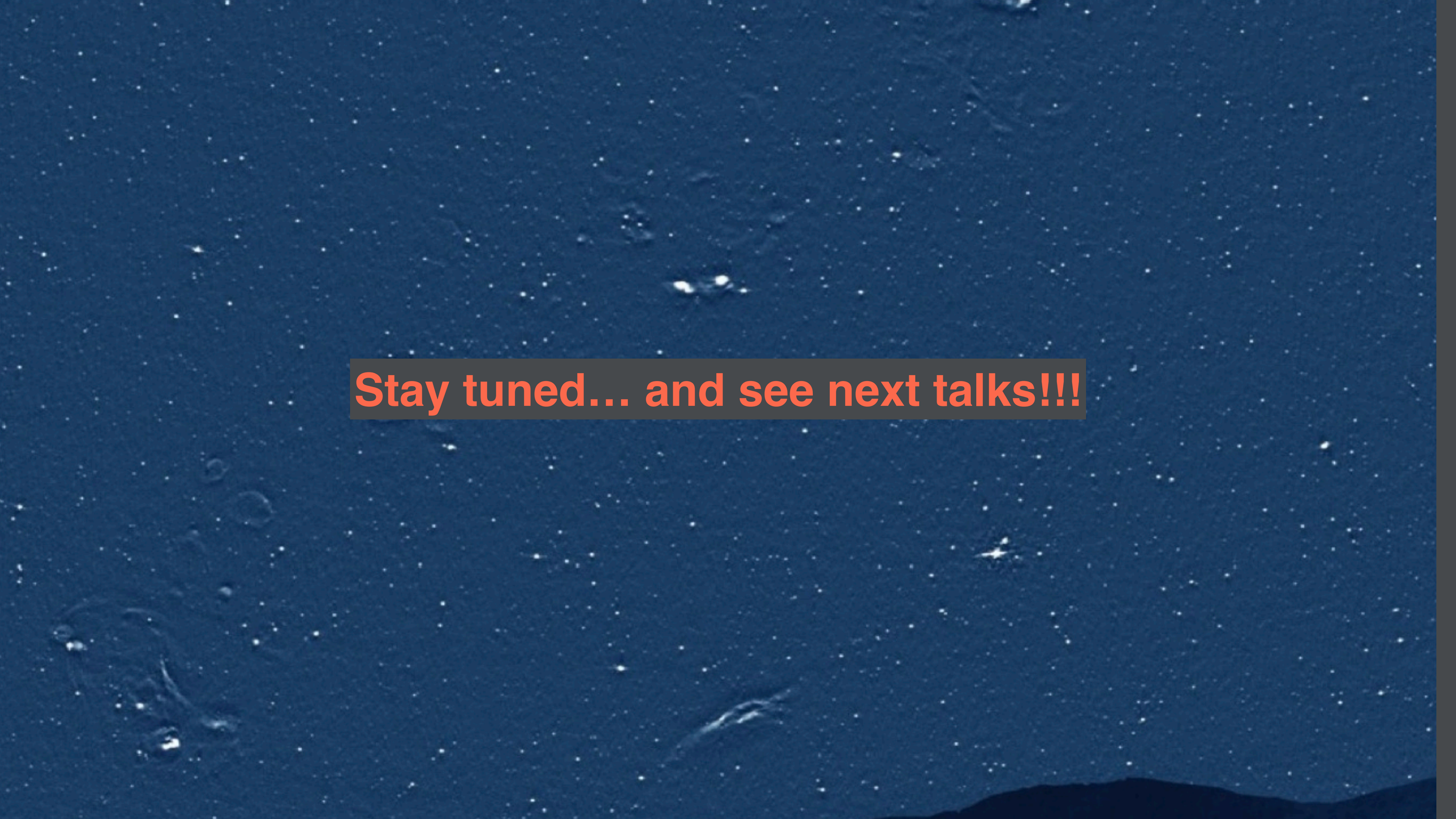


YZ Cet



Final messages…

- 10% ultracool dwarf / brown dwarfs are radio emitters. Radio emission consists on “bursty” ECMI and (gyro)synchrotron.
- Both fast rotation and dipolar magnetic field morphology are essential
- A system of (Jupiter-like) auroral currents predict the observed radio auroras. “Main oval” emission seems to be present in some brown dwarfs
- Radiation belt in a low-mass object proofs the presence of magnetic confinement.
- Possible satellites/exoplanets are essential as plasma source


Stay tuned… and see next talks!!!