Metre-wave emission from stars and planets

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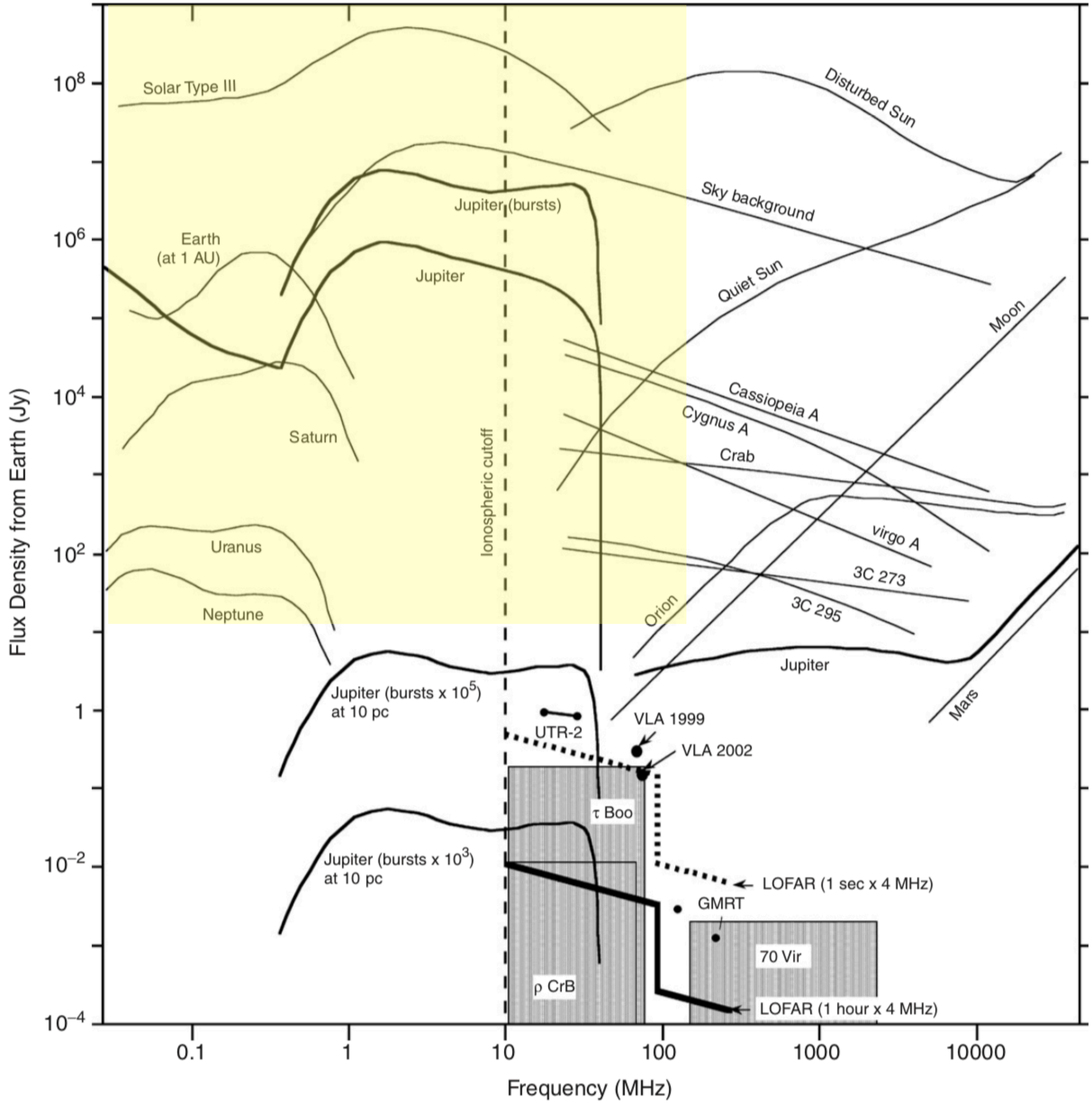
Solar system at low frequencies



Zarka++2007

This talk

What are we seeing in the radio band?

What is the unique to low radio frequencies?

First results from LOFAR (more in Joe’s talk)

The plasma regime

Magnetic field : $B \sim 10^{-1} - 10^{3}$ Gauss

Thermal electrons : $T \sim 10^{6} - 10^{7}\,\mathrm{K},\ n \sim 10^{6} - 10^{10}\,\mathrm{cm}^{-3}$

Accelerated electrons : $T \sim 10^{1} - 10^{3}\,\mathrm{keV}$

Lengthscales : $l \sim 10^{9} - 10^{11}\,\mathrm{cm};\quad \theta \sim 10\,\mu\mathrm{as} - 1\,\mathrm{mas}$

$S_{\mathrm{thermal}} \sim 10 - 100\,\mathrm{nJy}$ @ $150\,\mathrm{MHz}$

$S_{\mathrm{synchrotron}} \sim 1 - 100\,\mu\mathrm{Jy}$ @ $150\,\mathrm{MHz}$

Coherent emission dominates at low freq

Plasma emission (harmonic oscillations)

$$\nu_{\mathrm{P}} \approx 0.3 \left(\frac{n_e}{10^9} \right)^{1/2} \mathrm{GHz}$$

Cyclotron emission (gyration)

$$\nu_{\mathrm{C}} \approx 2.8 \left(\frac{B}{10^3\,\mathrm{G}} \right) \mathrm{GHz}$$

Coherent emission dominates at low freq

Plasma emission (harmonic oscillations)

$$\nu_{\mathrm{P}} \approx 0.3 \left(\frac{n_e}{10^9} \right)^{1/2} \mathrm{GHz}$$

$$T_b^{\mathrm{sat}} \sim 10^{11} \left(\frac{\nu}{0.5\,\mathrm{GHz}} \right)^{-1} \left(\frac{T}{10^6\,\mathrm{K}} \right)^{2.5}$$

$$T_b \sim 10^{11} \left(\frac{\nu}{0.5\,\mathrm{GHz}} \right) \left(\frac{h_p}{10^{10}\,\mathrm{cm}} \right)$$

circularly polarised

Cyclotron emission (gyration)

$$\nu_{\mathrm{C}} \approx 2.8 \left(\frac{B}{10^3\,\mathrm{G}} \right) \mathrm{GHz}$$

$$T_b^{\mathrm{sat}} \sim 10^{18}\,\mathrm{K}$$

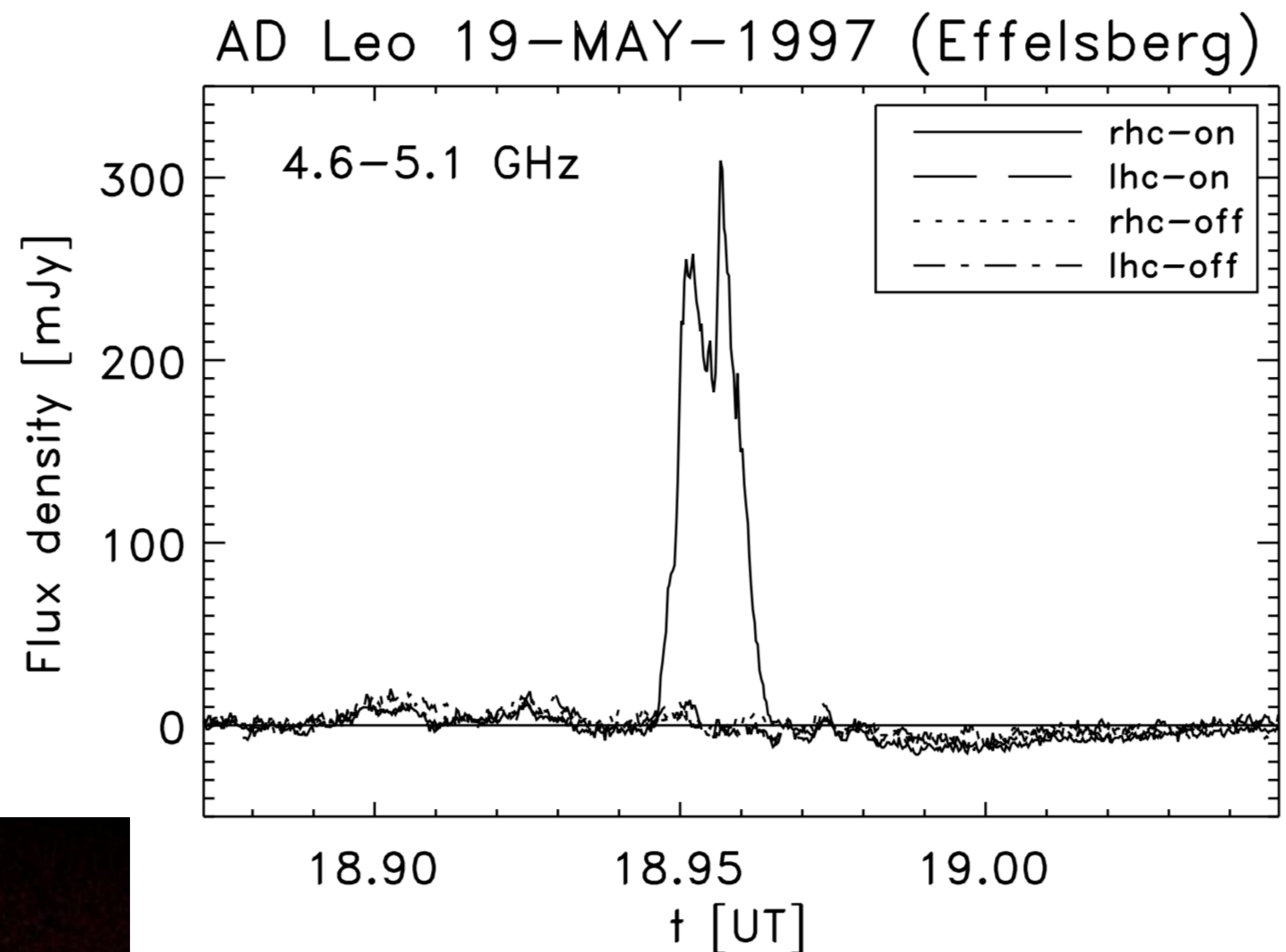
$$T_b \sim 10^{13} \left(\frac{\nu}{0.5\,\mathrm{GHz}} \right)^{-2} \mathrm{K}$$

circularly polarised

Plasma emission - coronal loops

Plasma emission - closed field

$$\nu_{\mathrm{P}} \approx 0.3 \left(\frac{n_e}{10^9} \right)^{1/2} \mathrm{GHz}$$

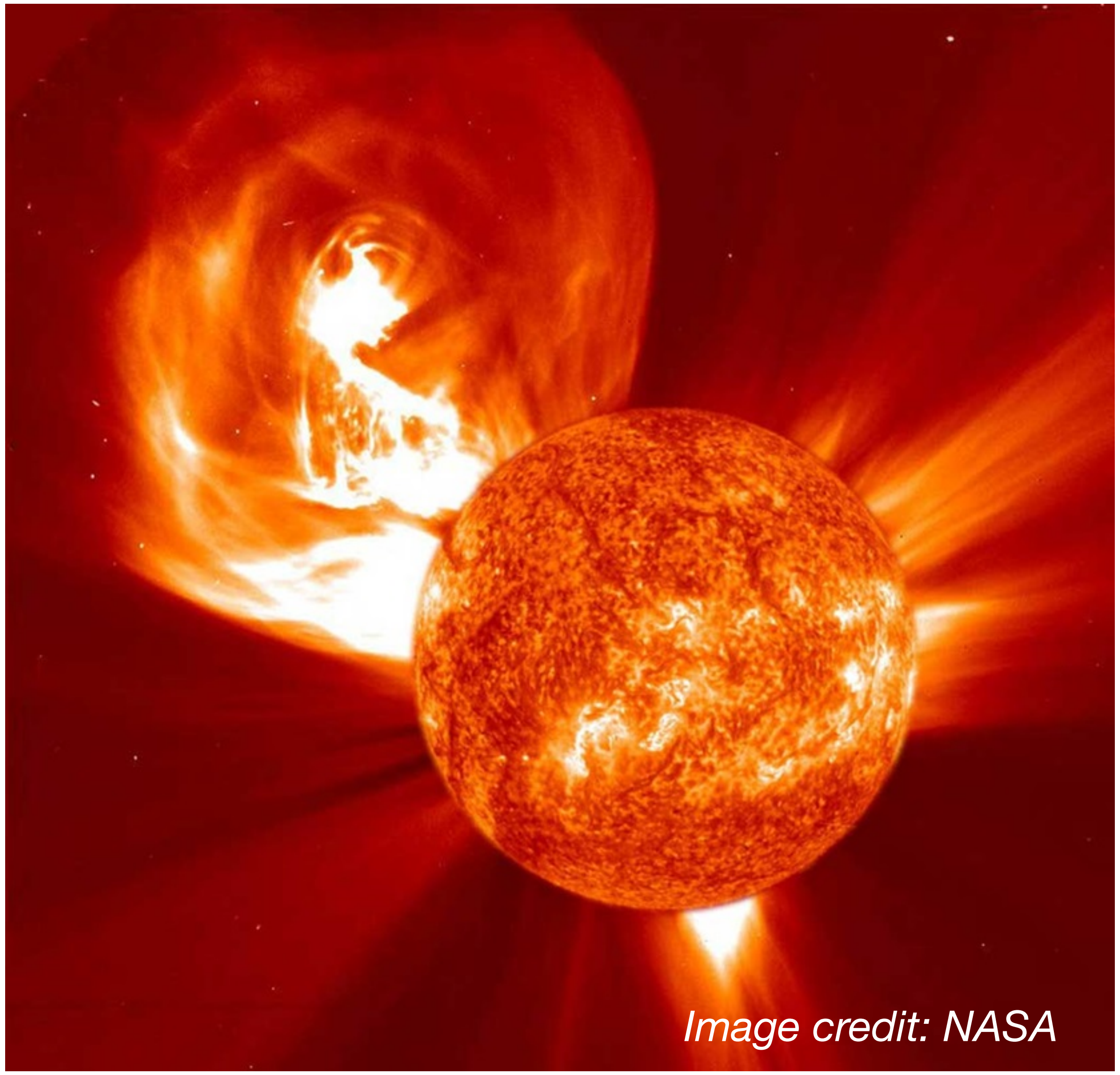


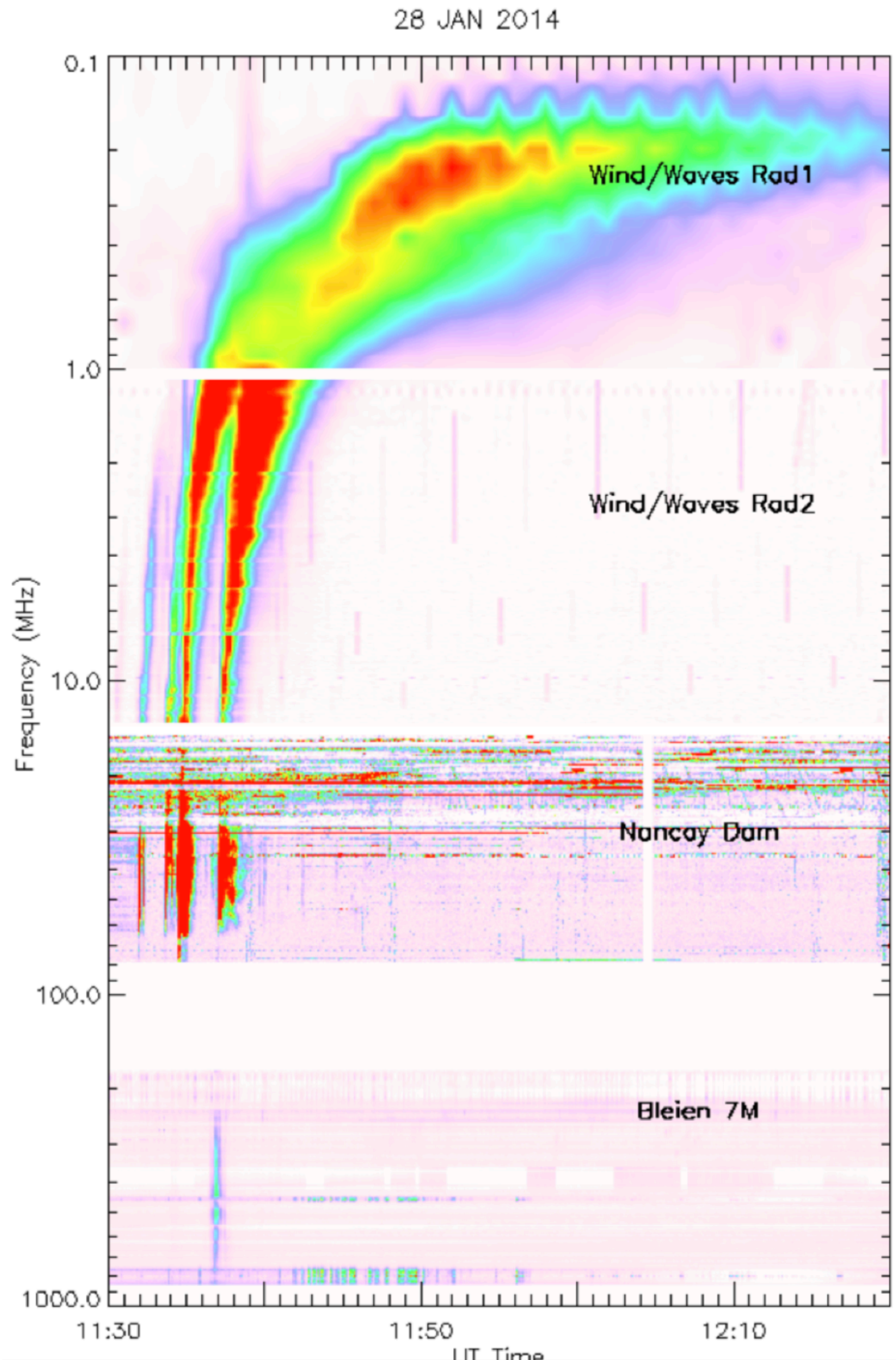
Stepanov++ (2001)

Quasi-isotropic emission

Needs high plasma density
(low corona; coronal loops)

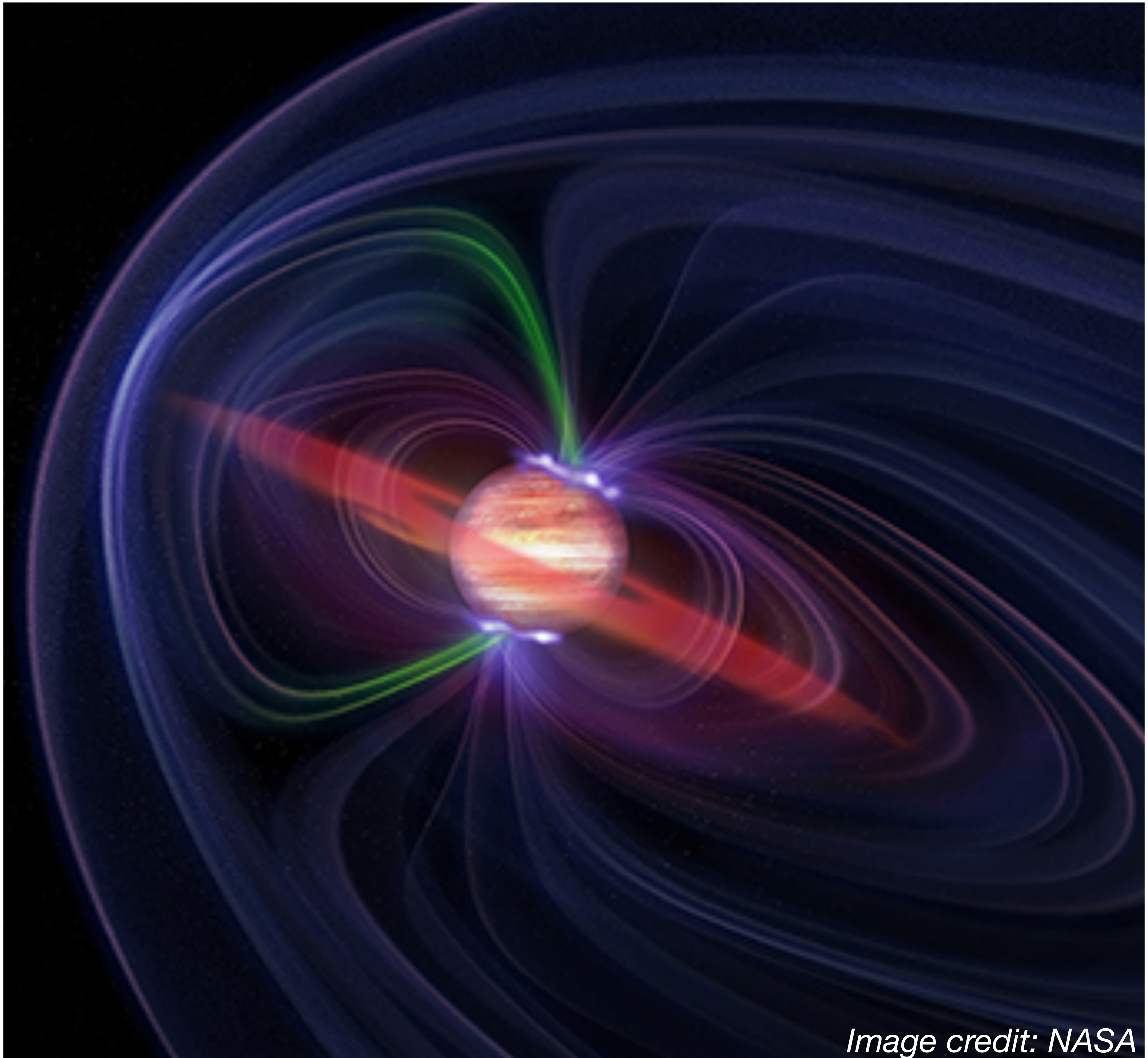
Plasma emission - open field



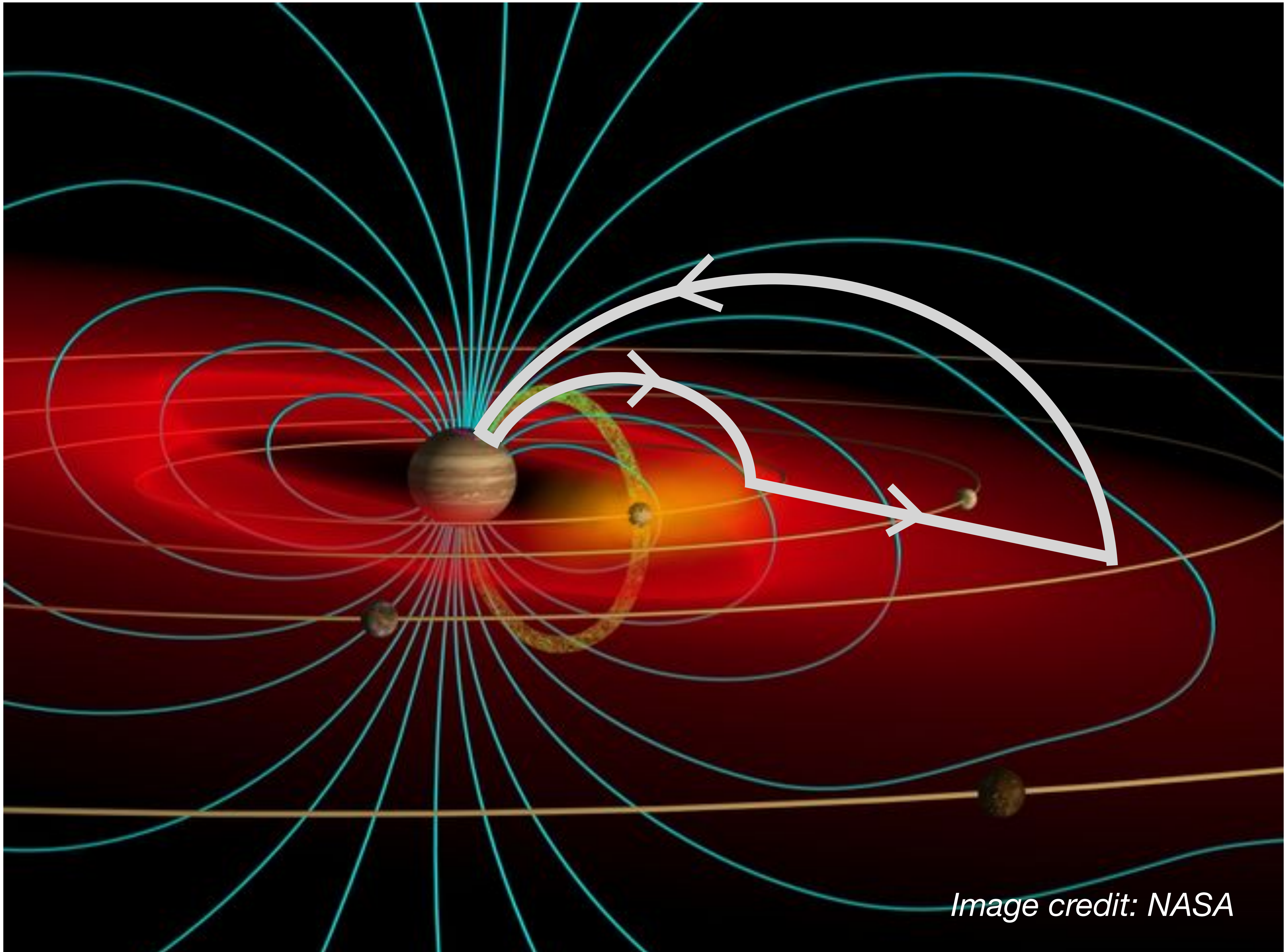


Winds data

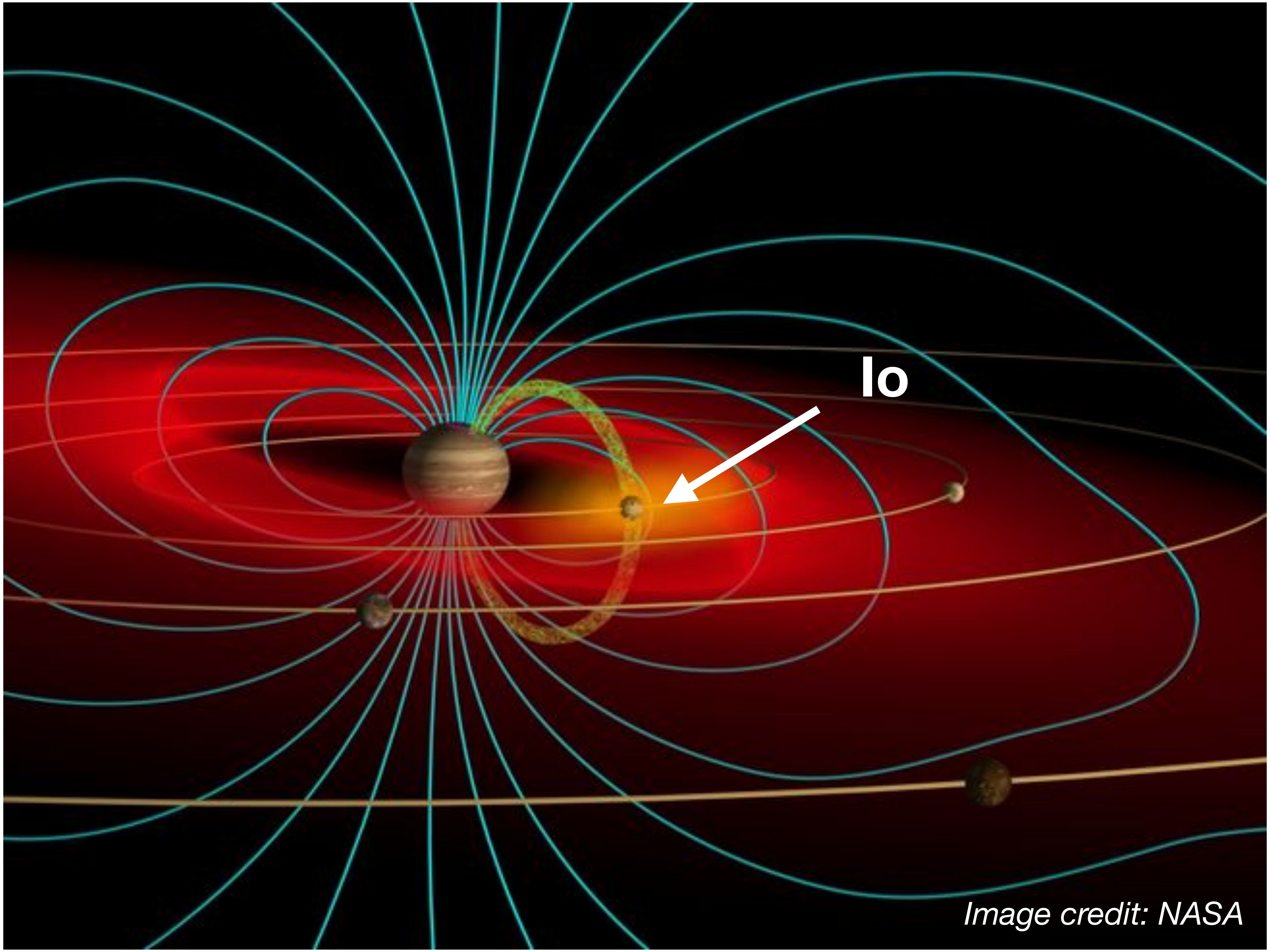
Cyclotron emission - aurorae



Cyclotron emission : sub co-rotation



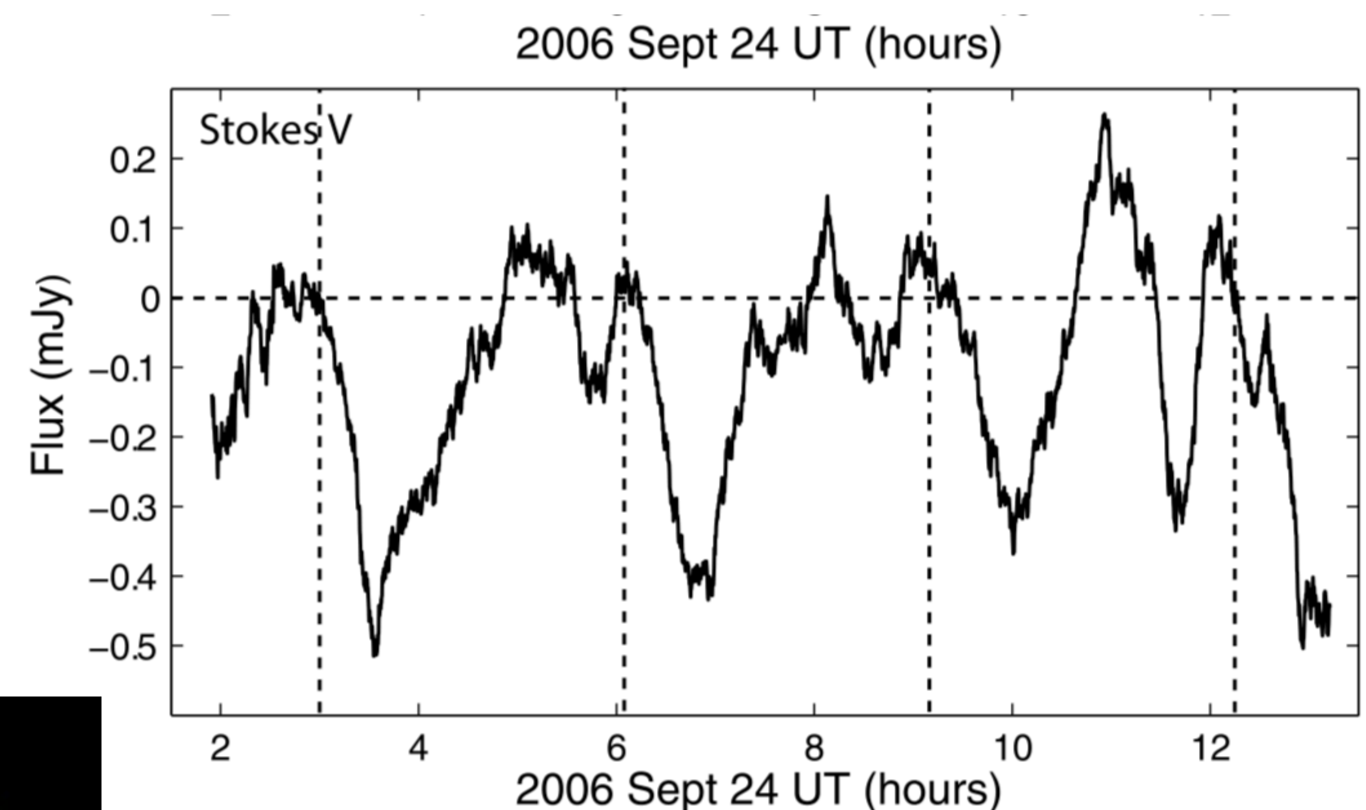
Cyclotron emission : obstruction



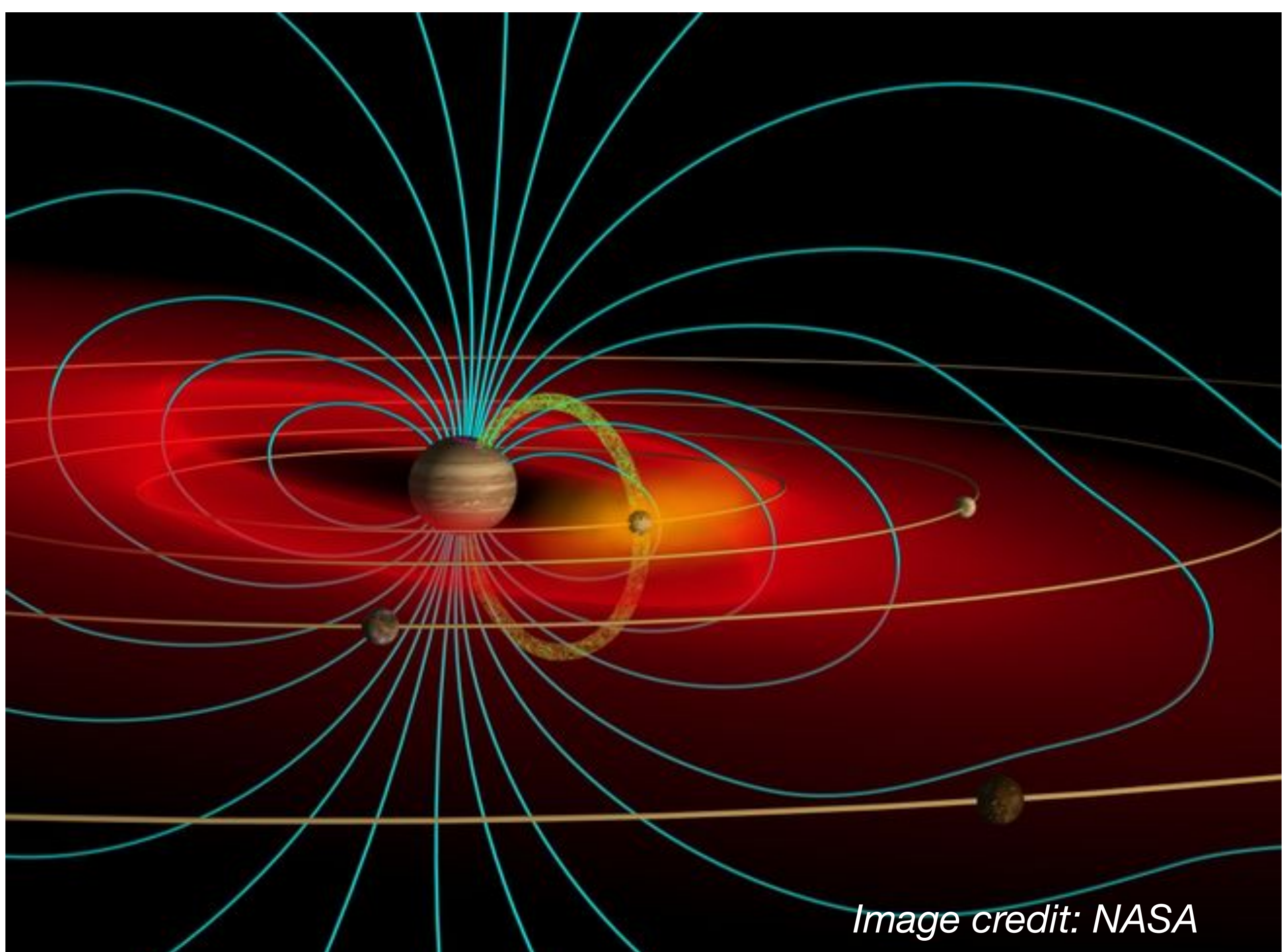
Auroral cyclotron emission

$$\nu_C \approx 2.8 \left(\frac{B}{10^3\,\mathrm{G}} \right) \mathrm{GHz}$$

$$\nu_C \gg \nu_P$$



Hallinan++ (2008)



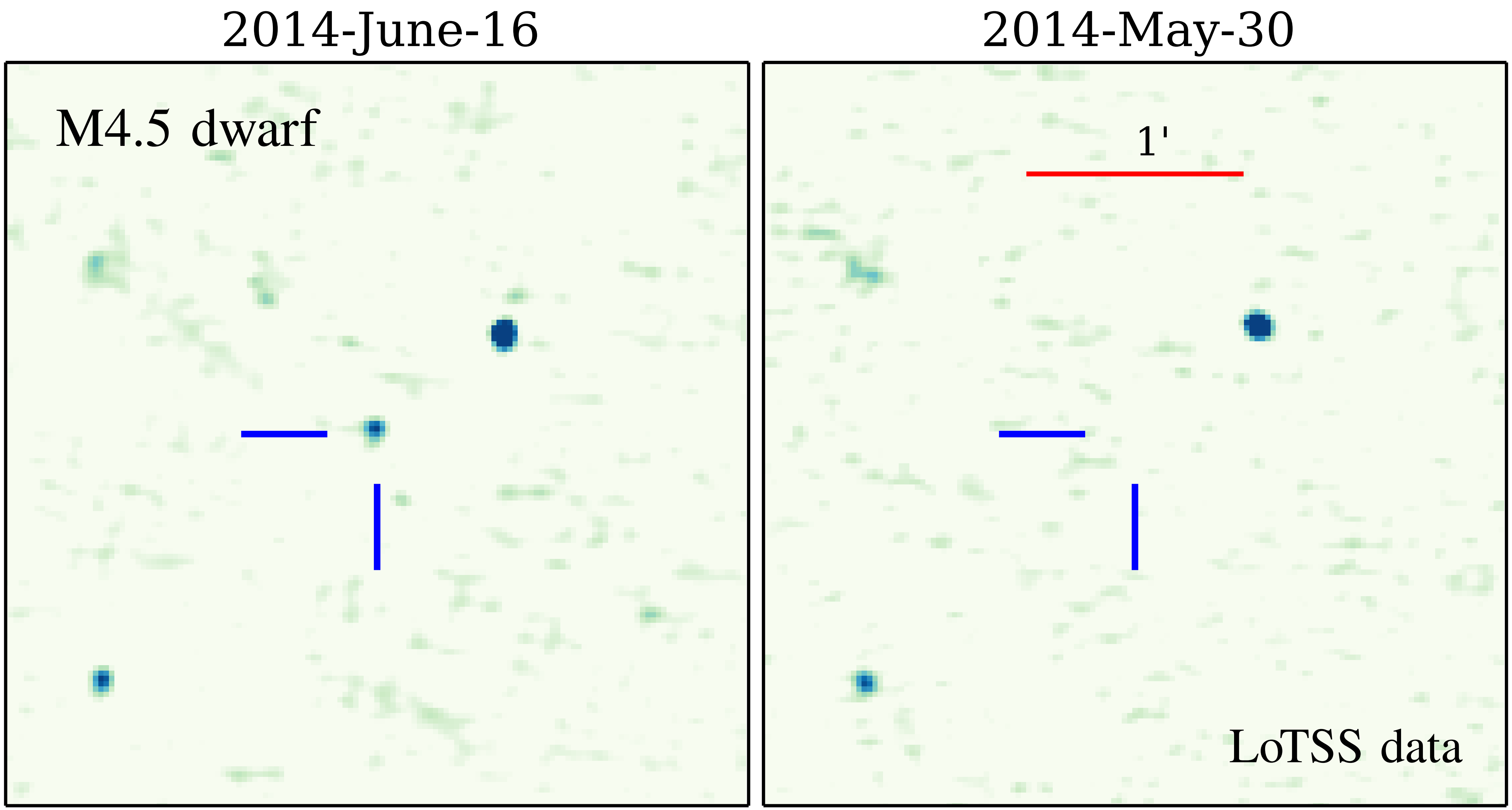
Emission beamed along cone

Low plasma density regions
(e.g. planets, brown/UC dwarfs)

Low-frequency: a unique probe

- Outer coronal structure and mass ejections (space weather)
- Diffuse high-energy plasma in radiation belts (~10keV-1Mev)
- Star planet interaction (atmospheric retention, Joule heating)
- Exoplanet magnetic fields, dipole tilt, rotation period

First low-freq detection of quiescent star

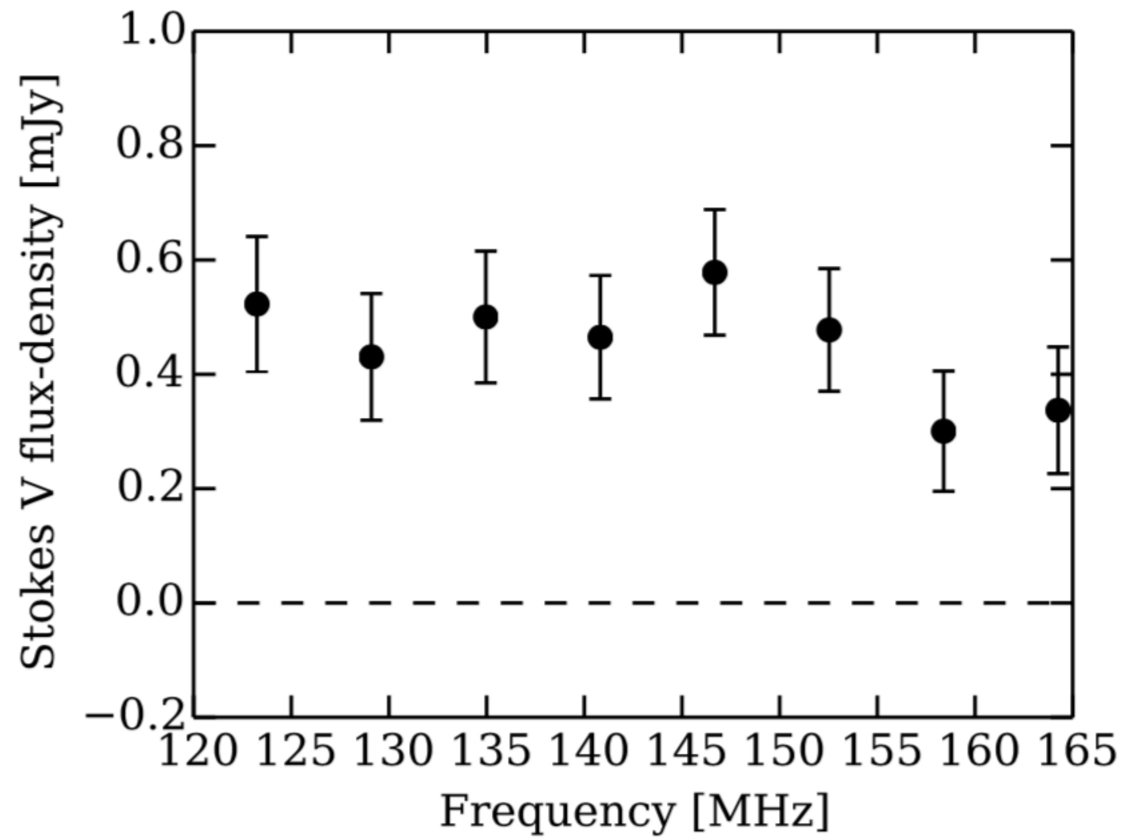


Vedantham++ (under review)

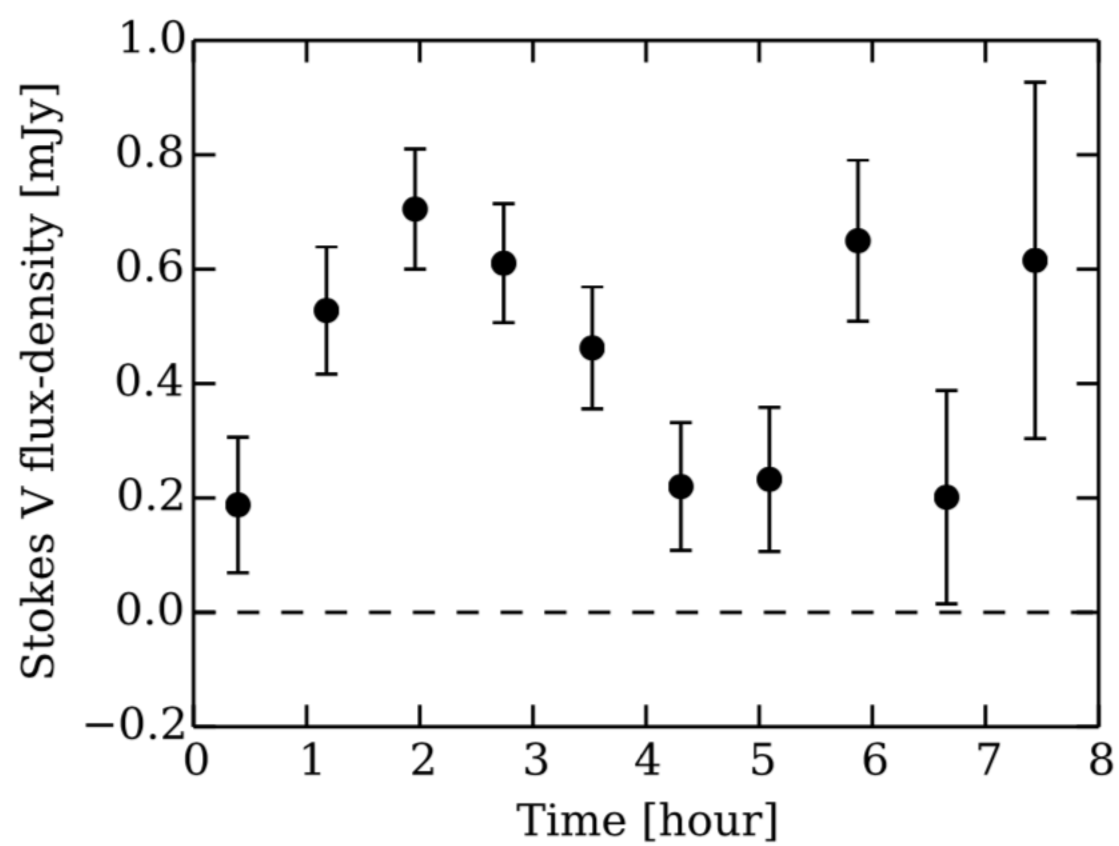
$S_I = 800\,\mu\text{Jy}$ $\tau > 8^{\text{h}}$

$S_V = 500\,\mu\text{Jy}$ $\Delta\nu/\nu \sim 1$

First low-freq detection of quiescent star



LoTSS data



Vedantham++ (under review)

First low-freq detection of quiescent star

	GJ1151	AD Leo
Sp. type	M4.5	M3
Distance	8pc	5pc
Halpha eq. width	0.034(41) Ang	-3.3
Chandra X-ray lum (1E28 ergs/s)	<0.01	2.3
Rot period (days)	130(30)	2.2

Origin of emission

Plasma emission ruled out by Tb and pol. fraction

Cyclotron emission is the only viable option

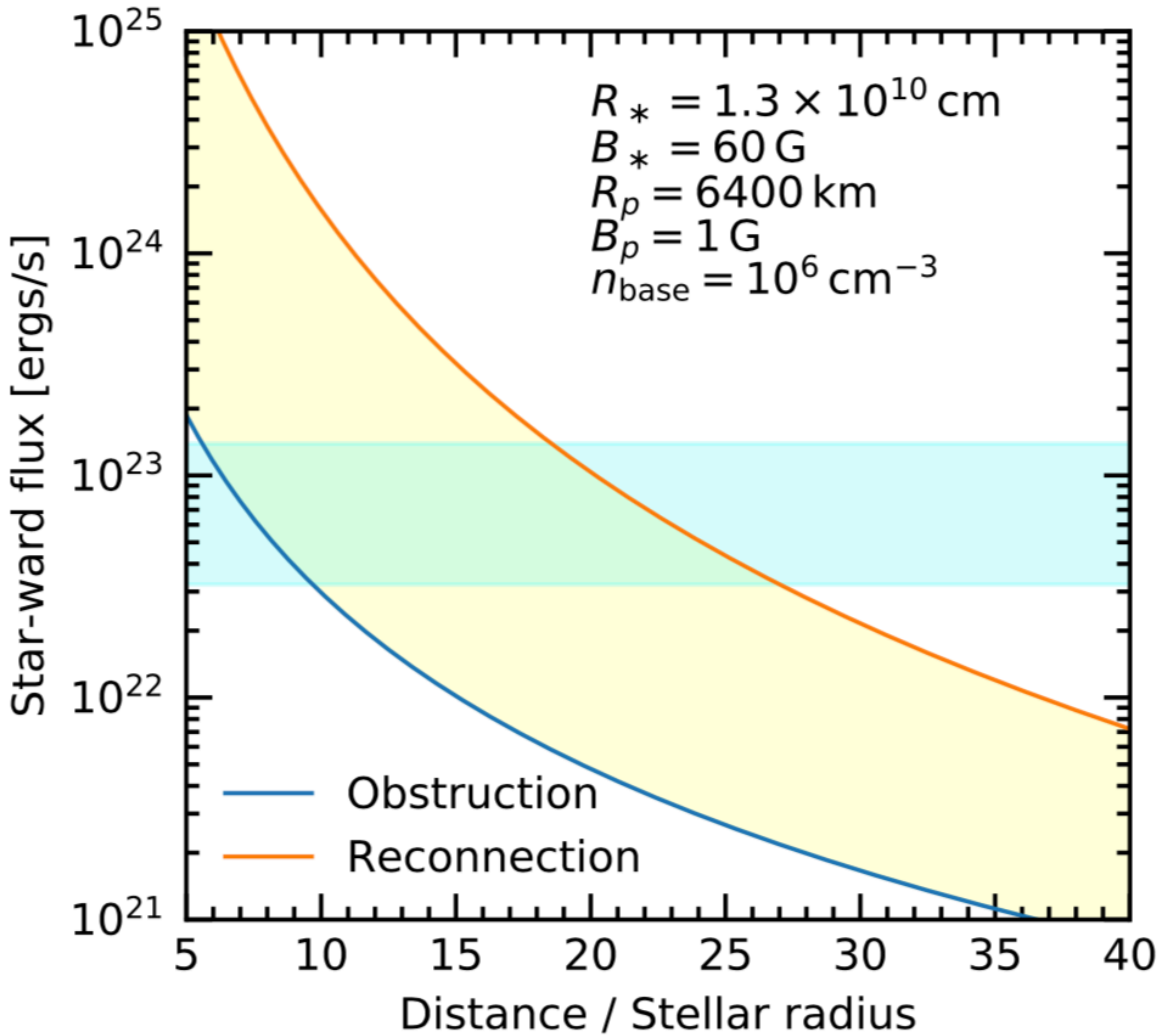
Low plasma density $n_e < 10^6\,\mathrm{cm}^{-3}$

Slow rotation make sub co-rotation model problematic

Induction by an obstacle (planet) is only known viable engine

Earth-size planet in few day orbit will do (difficult to detect in RV)

Energetic / beaming constraints



Conclusions

Low freq. frontier (outer coronae, magnetosphere, star-planet interaction)

LoFAR HBA detections now “routine” (Joe’s talk) thanks to LoTSS team

Discoveries: (1) Aurorae are ubiquitous in M-dwarfs (not just planets, BD)

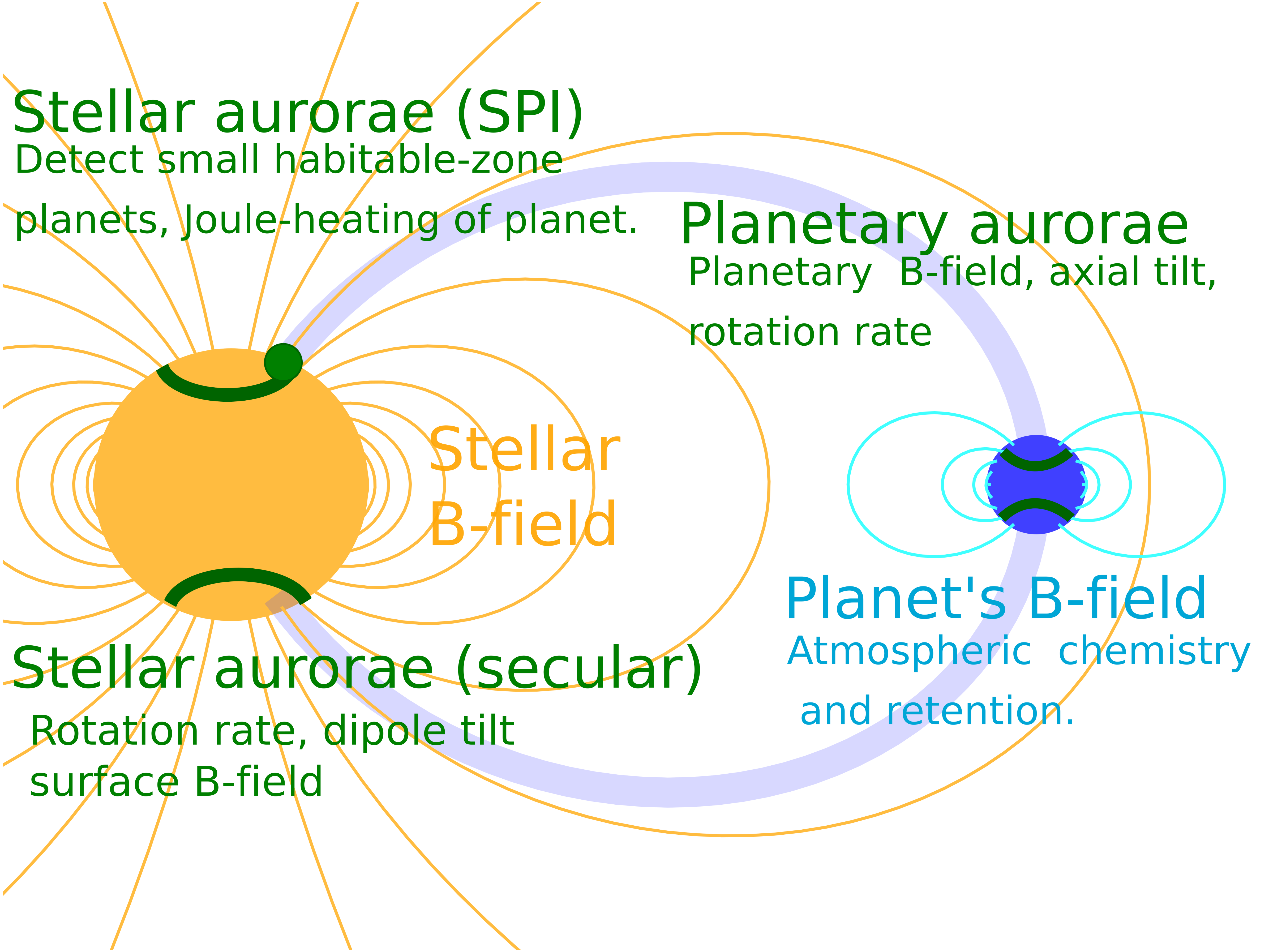
(2) Radio-bright quiescent stars - exoplanet induced

Next steps

Search for radio periodicity (conclusively prove exoplanet interaction)

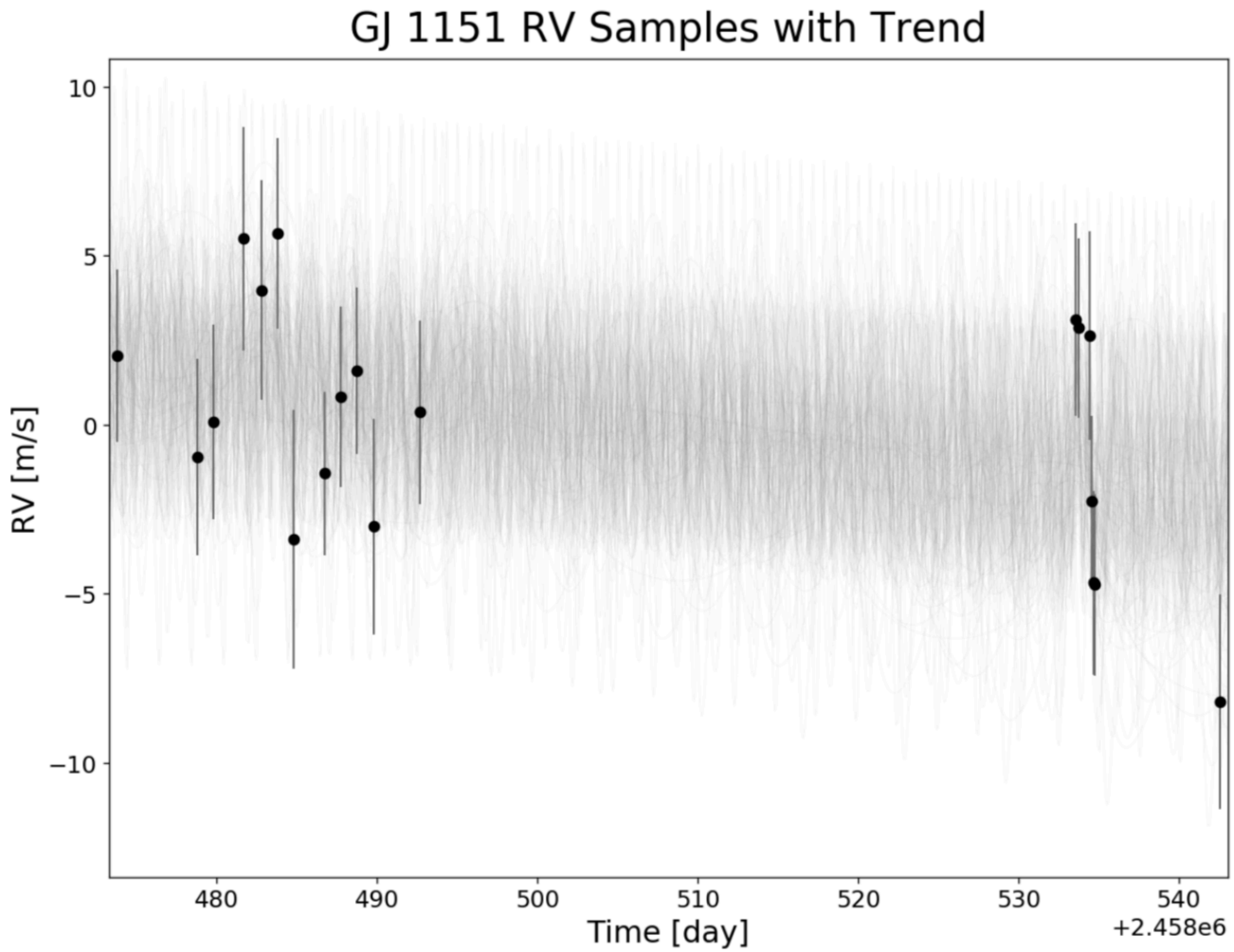
Move to lower frequencies (exoplanet aurorae at similar flux-densities)

The End


Stellar aurorae (SPI)
Detect small habitable-zone
planets, Joule-heating of planet.
Planetary aurorae
Planetary B-field, axial tilt,
rotation rate
Stellar
B-field
Planet's B-field
Atmospheric chemistry
and retention.
Stellar aurorae (secular)
Rotation rate, dipole tilt
surface B-field

EXTRAS

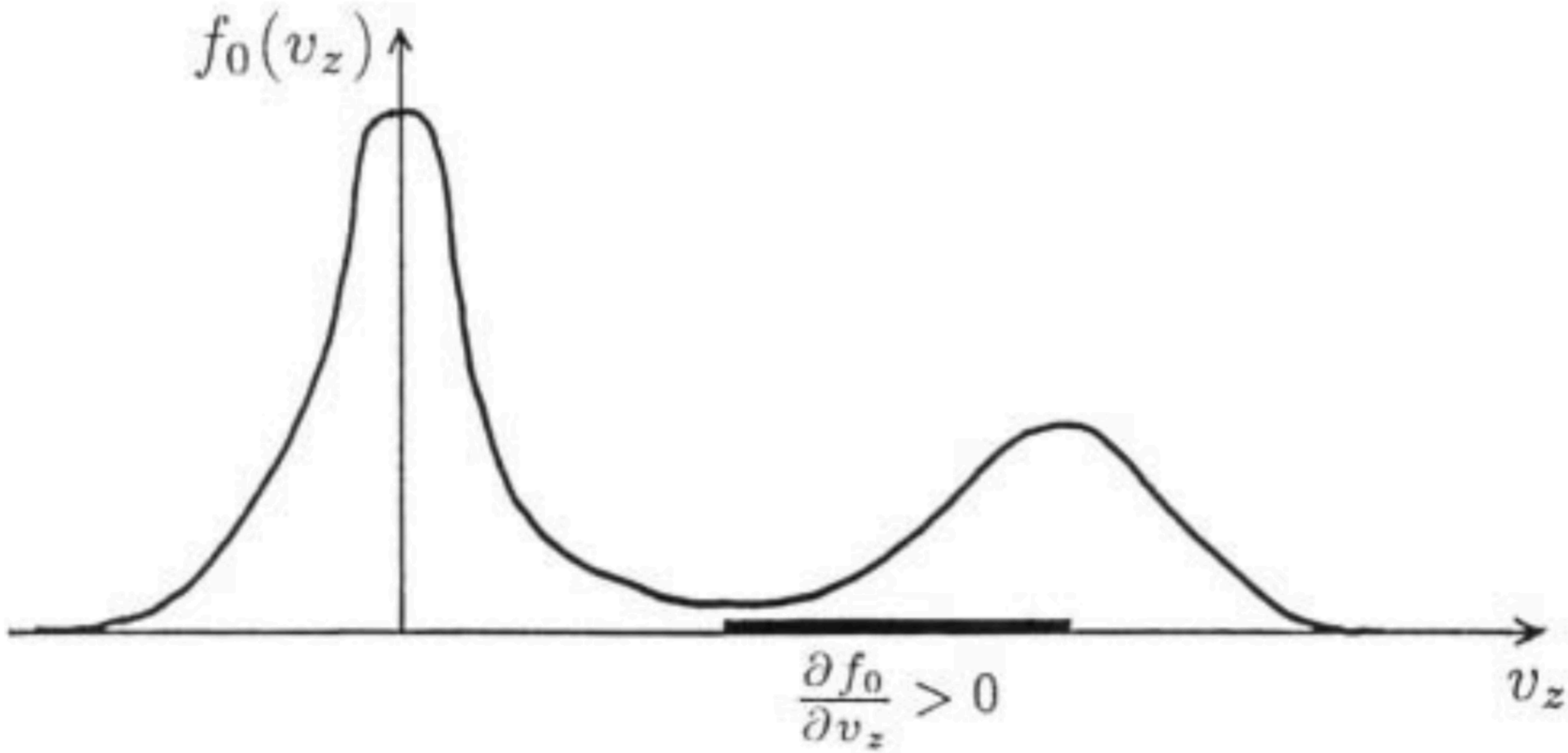
A pilot RV search with HARPS-N



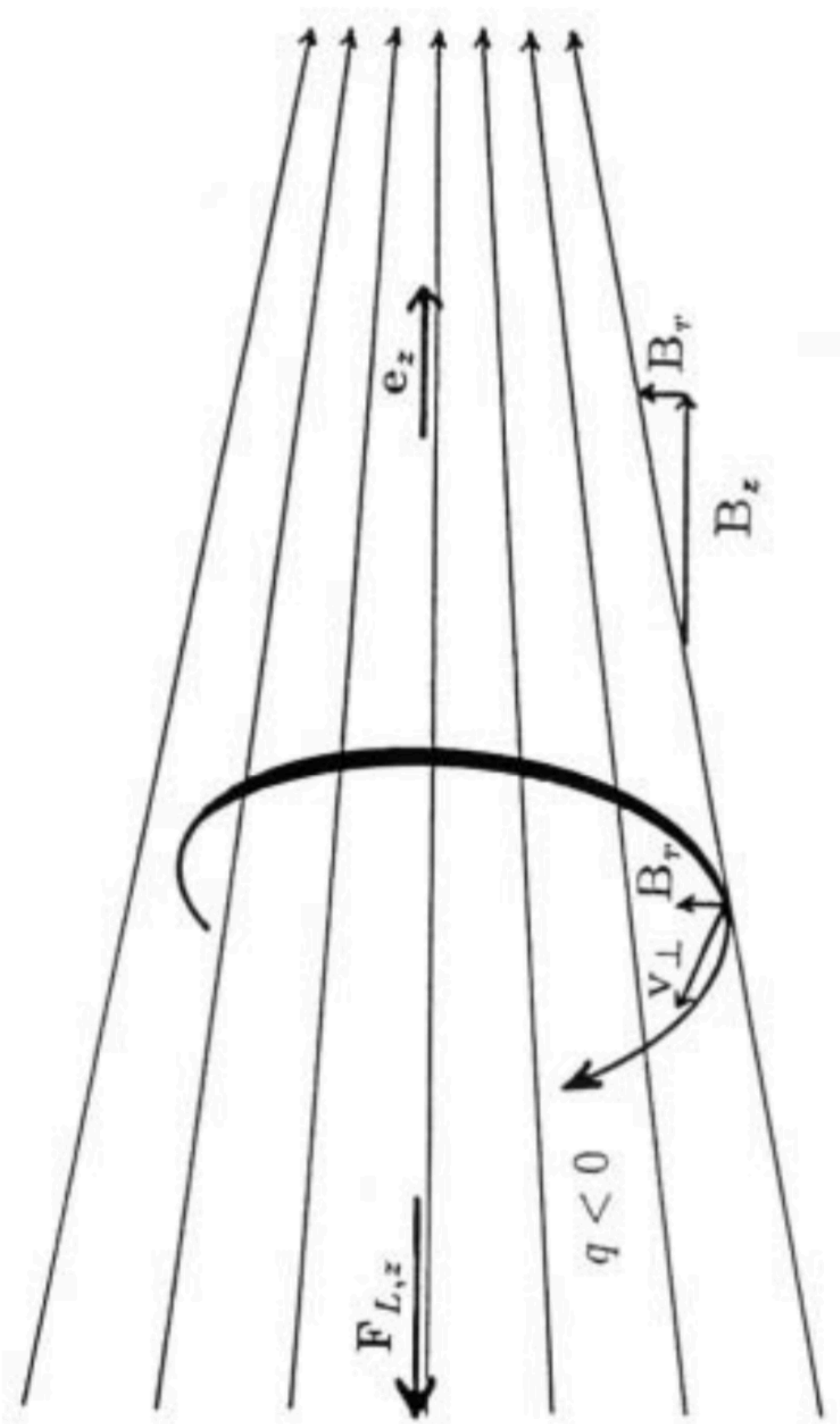
M > few Earth masses ruled out.

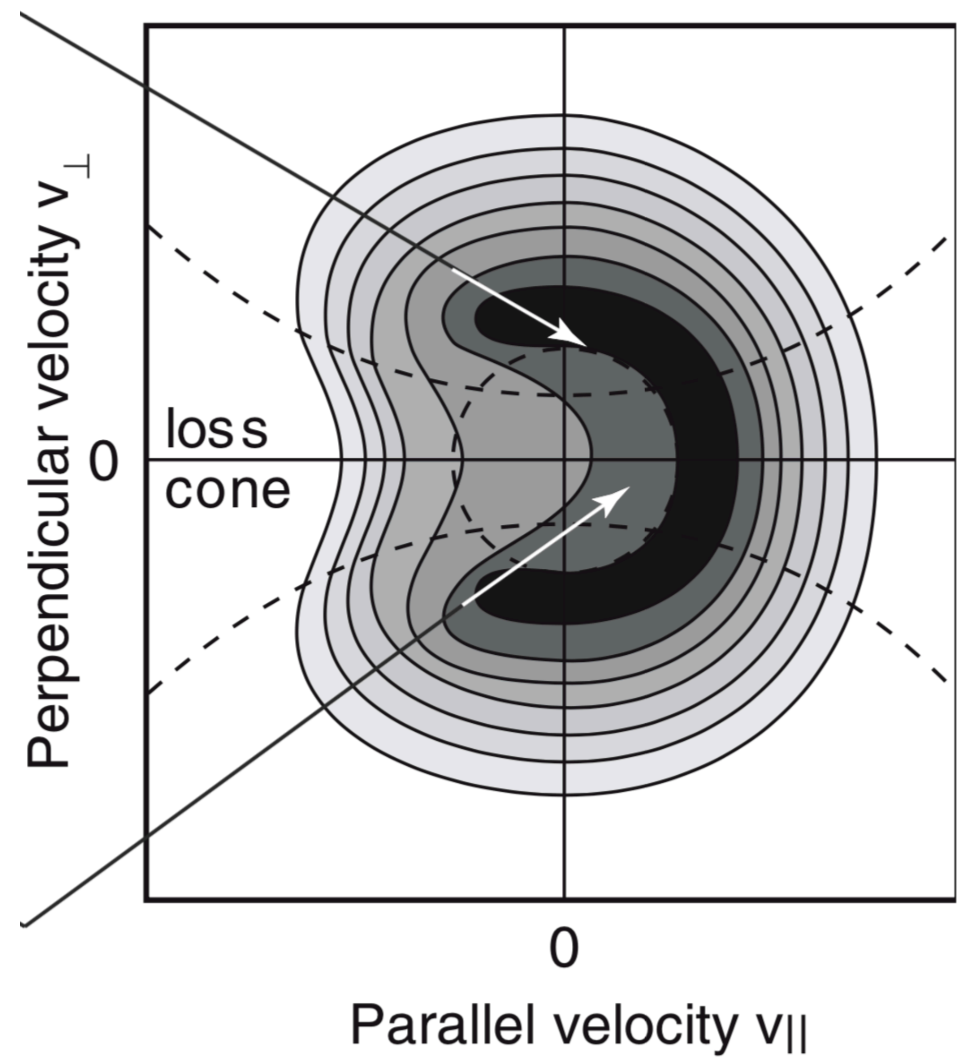
Pope++ (in perp)

Plasma emission - two stream instability



Cyclotron maser emission - loss cone instability





A LOFAR wish list

Find the low-frequency population (so far only UV Ceti)

Star-planet magnetic interaction (in habitable zone for mid-late M-dwarfs)

Coronal mass ejections on other stars - exoplanet habitability

Radio emission from an exoplanet (LBA?)

Determine surface B-field, orbital period, axial tilt, stellar wind flux