Predicting radio emission from the newborn hot Jupiter V830 Tau b and its host star

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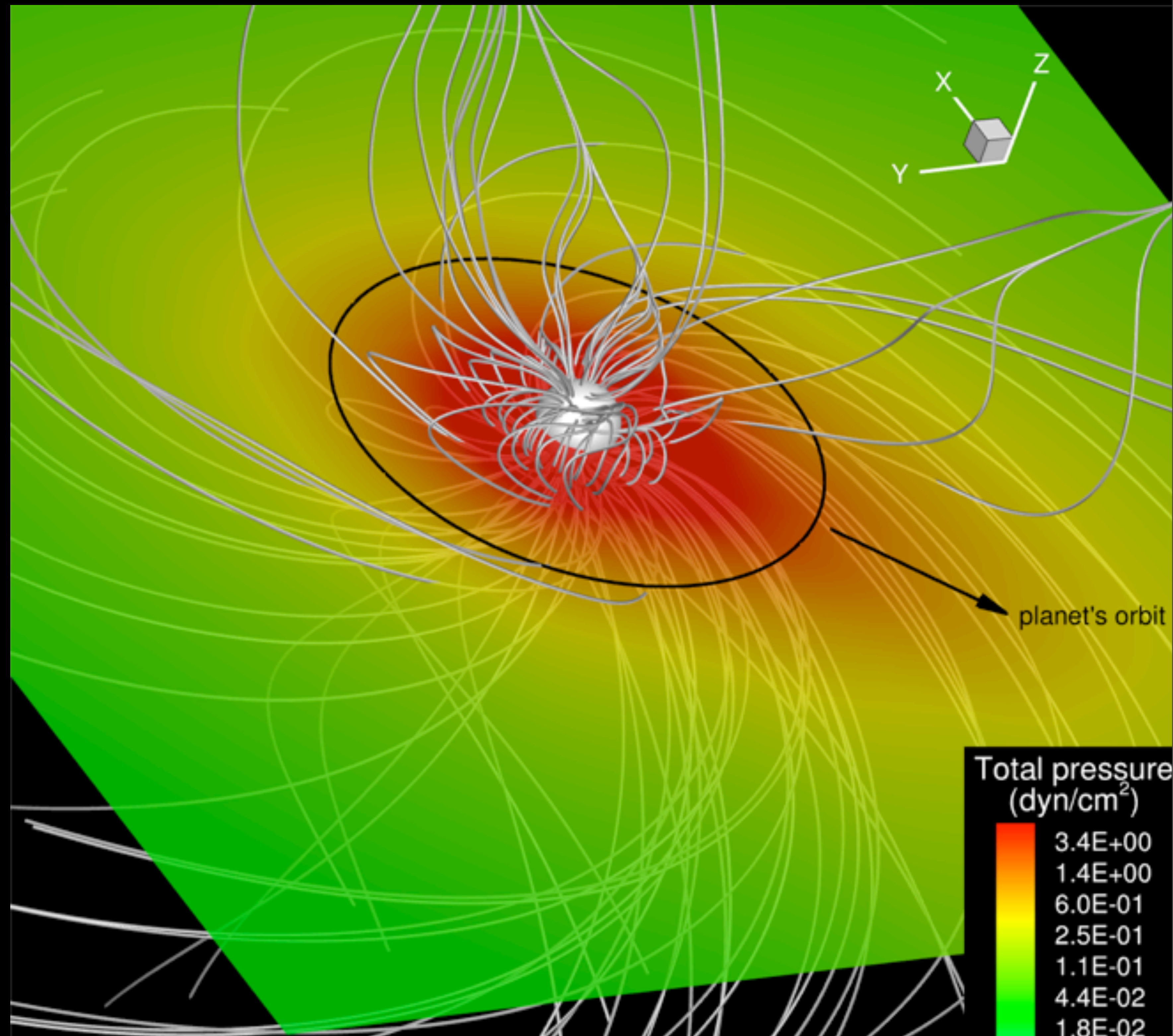
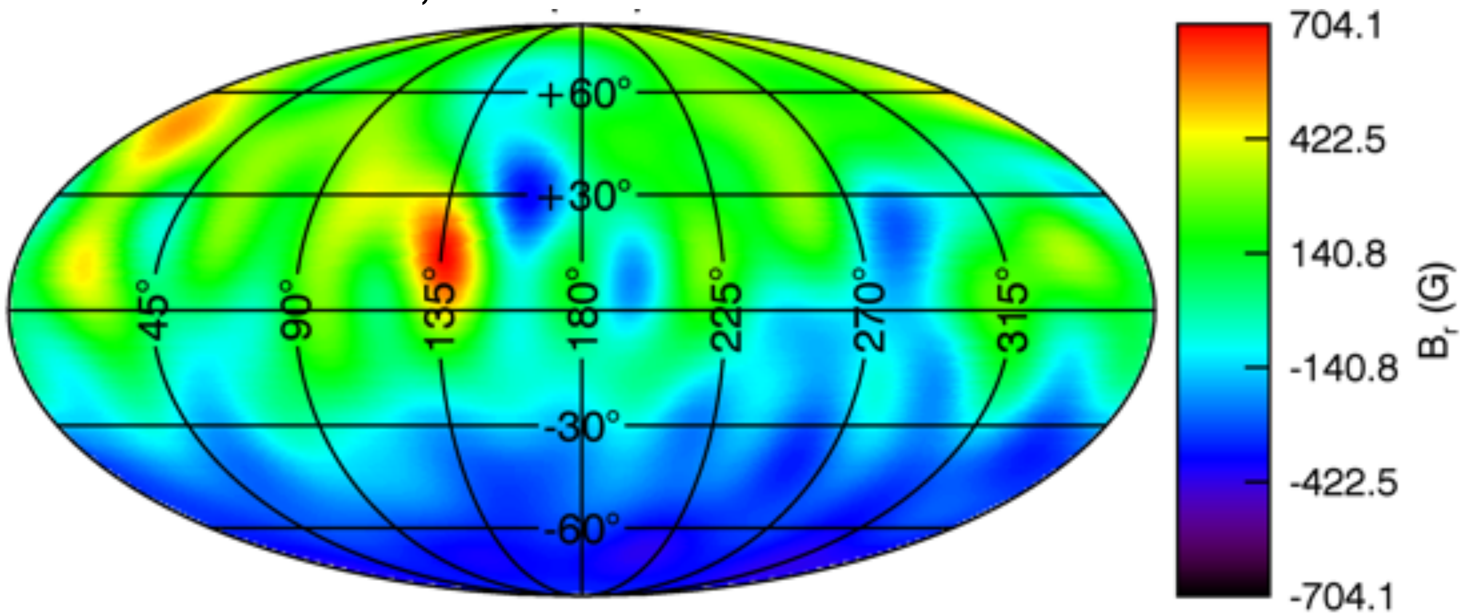


Vidotto & Donati (2017, A&A, 602, 39)

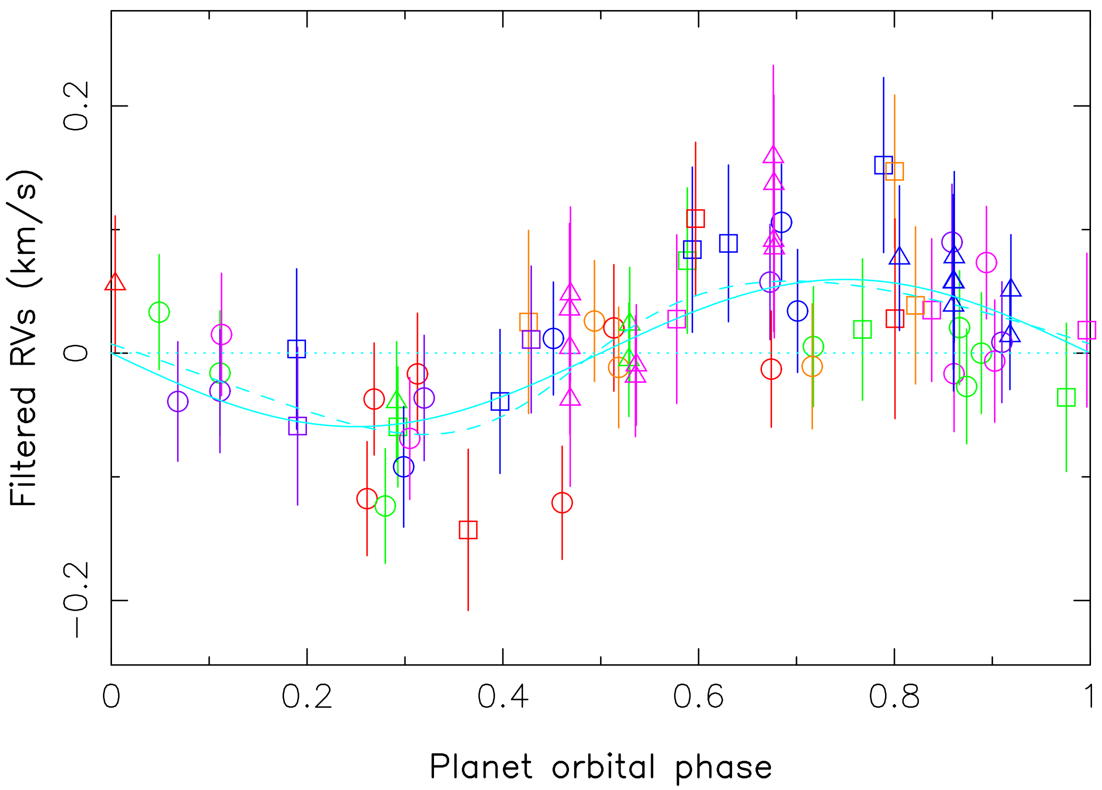
The newborn Sun: V830 Tau

Donati+2015, 2017



Why so special?

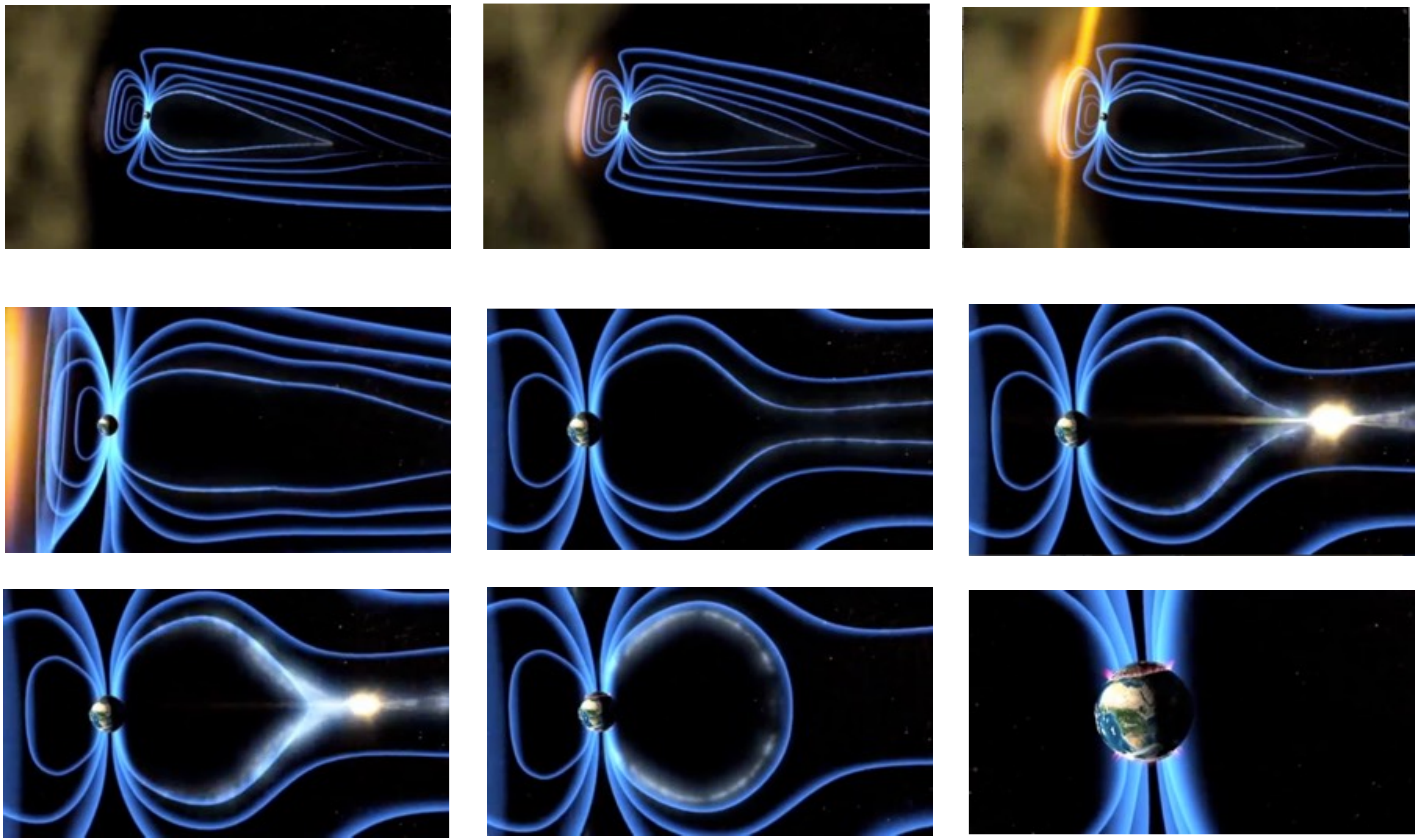
- star young & active: 2Myr-old, B~1kG
- youngest-detected hot Jupiter (Donati+ 15,16)
- star detected with VLA&VLBA (Bower+16)



P_{orb}≈5 days
M_p=0.7 Mjup
a=0.057au = 6Rstar

Prediction: planets orbiting young stars should emit larger radio fluxes

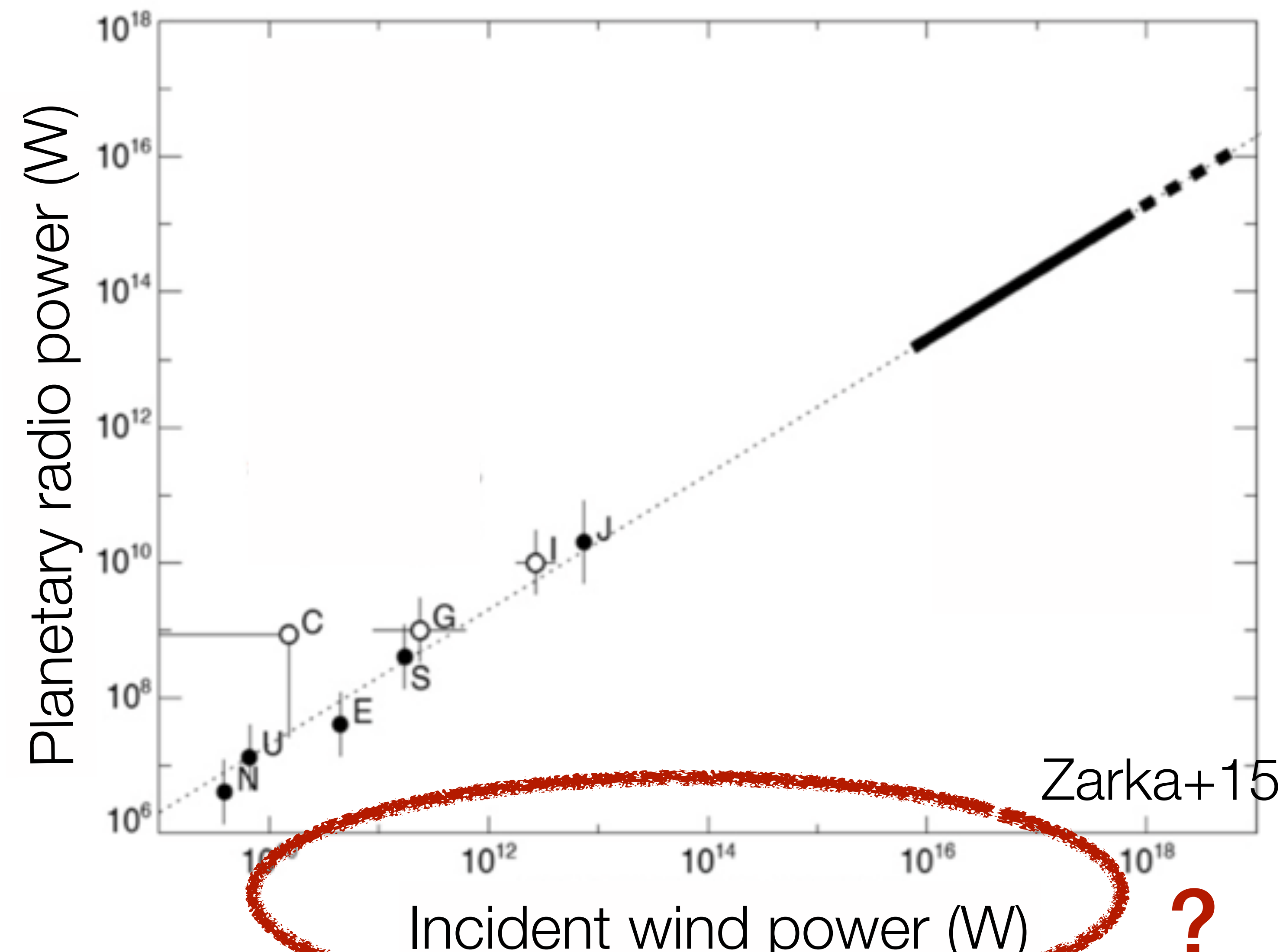
(Exo)planetary radio emission from stellar wind-planet interactions



Credit: NASA

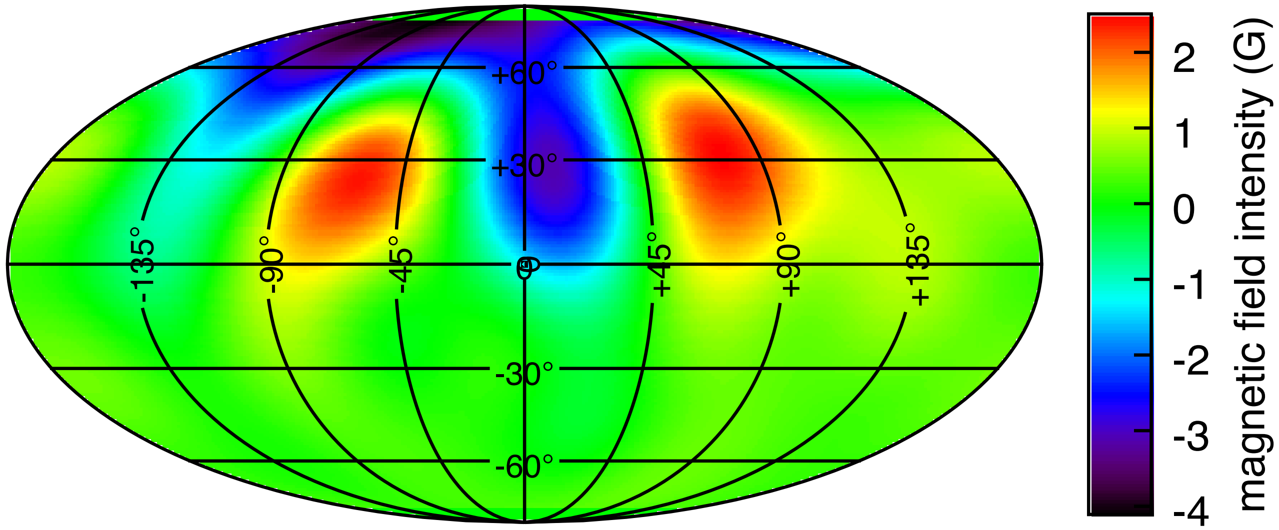
(Exo)planetary radio emission from stellar wind-planet interactions

scaling law seems to apply more generally to
any plasma flow-obstacle interaction



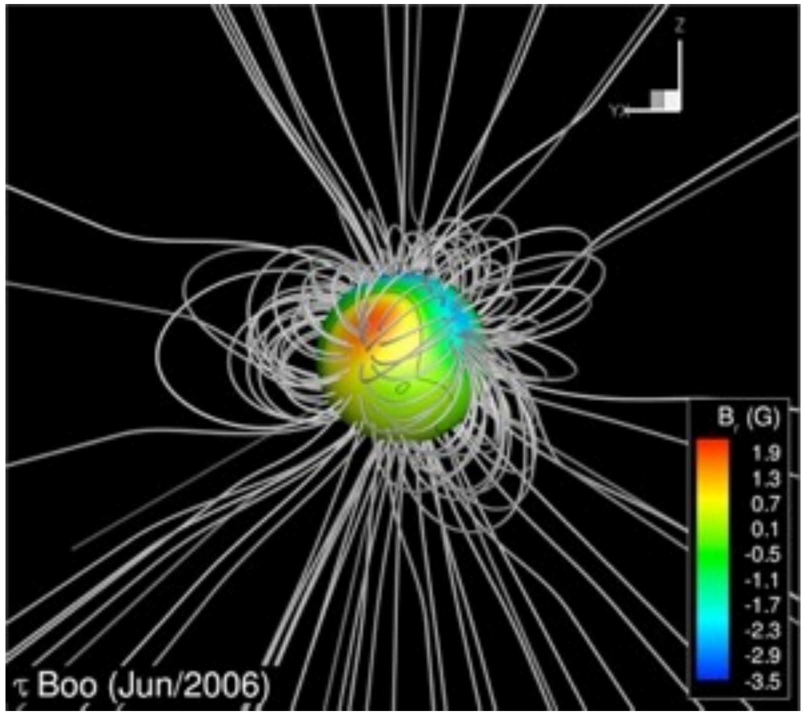
How do we characterise stellar winds?

Magnetic field from observations

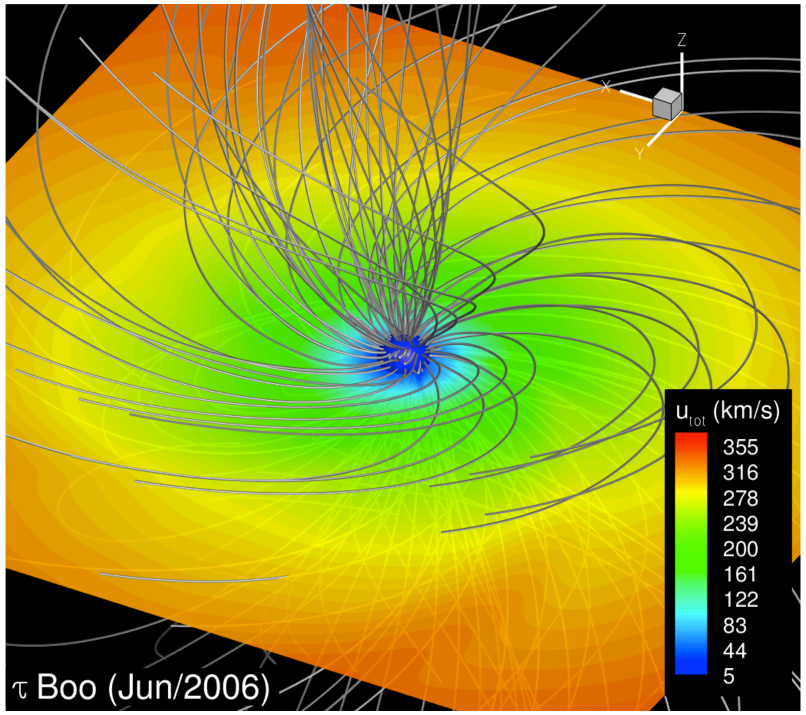


→ more on the technique & other objects: Vidotto+09a, 10ab,11a,12,14a,15; etc

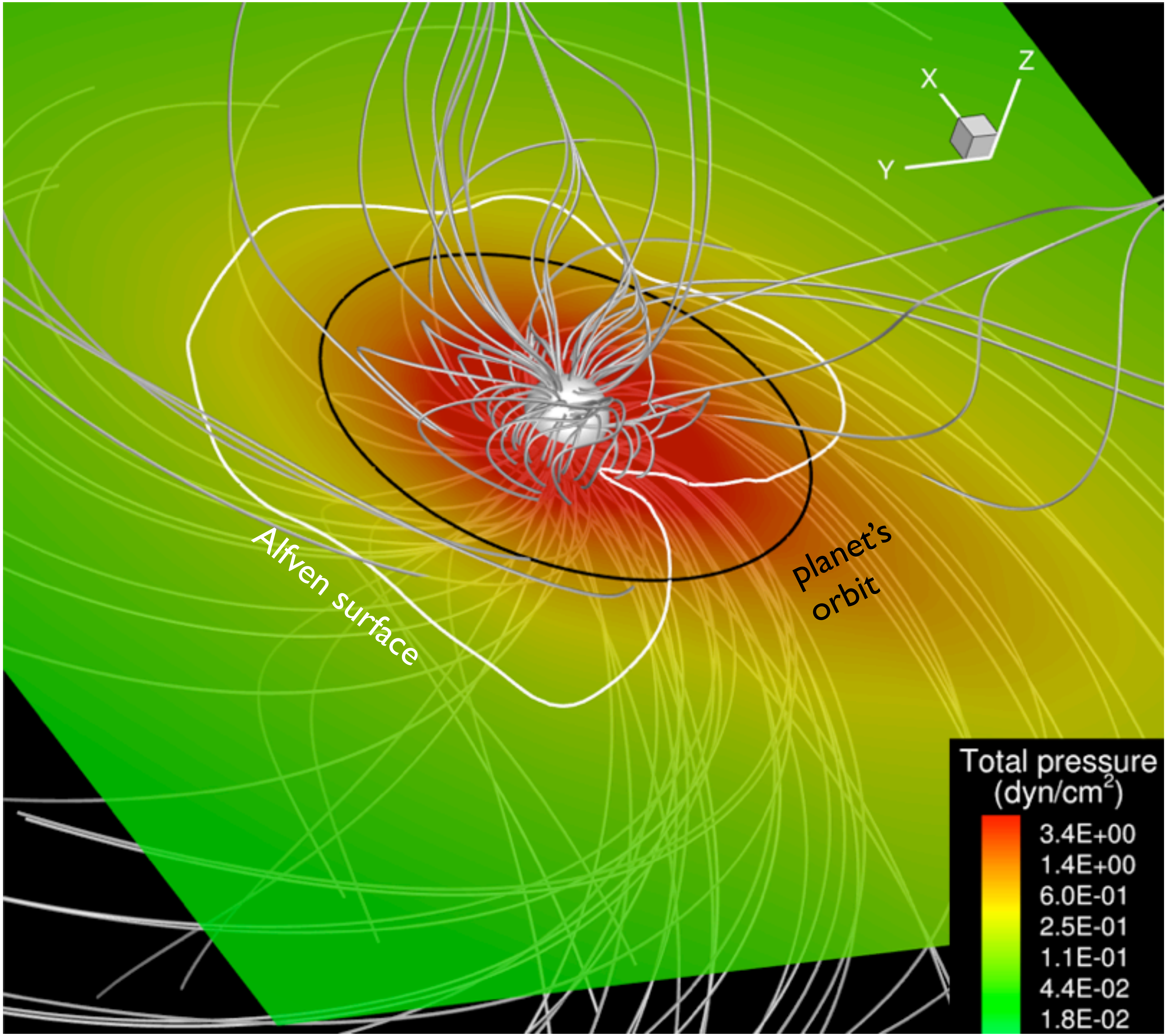
Initial state: potential field incorporated in MHD simulations



Final state: self-consistent MHD wind solution



(BATS-R-US)



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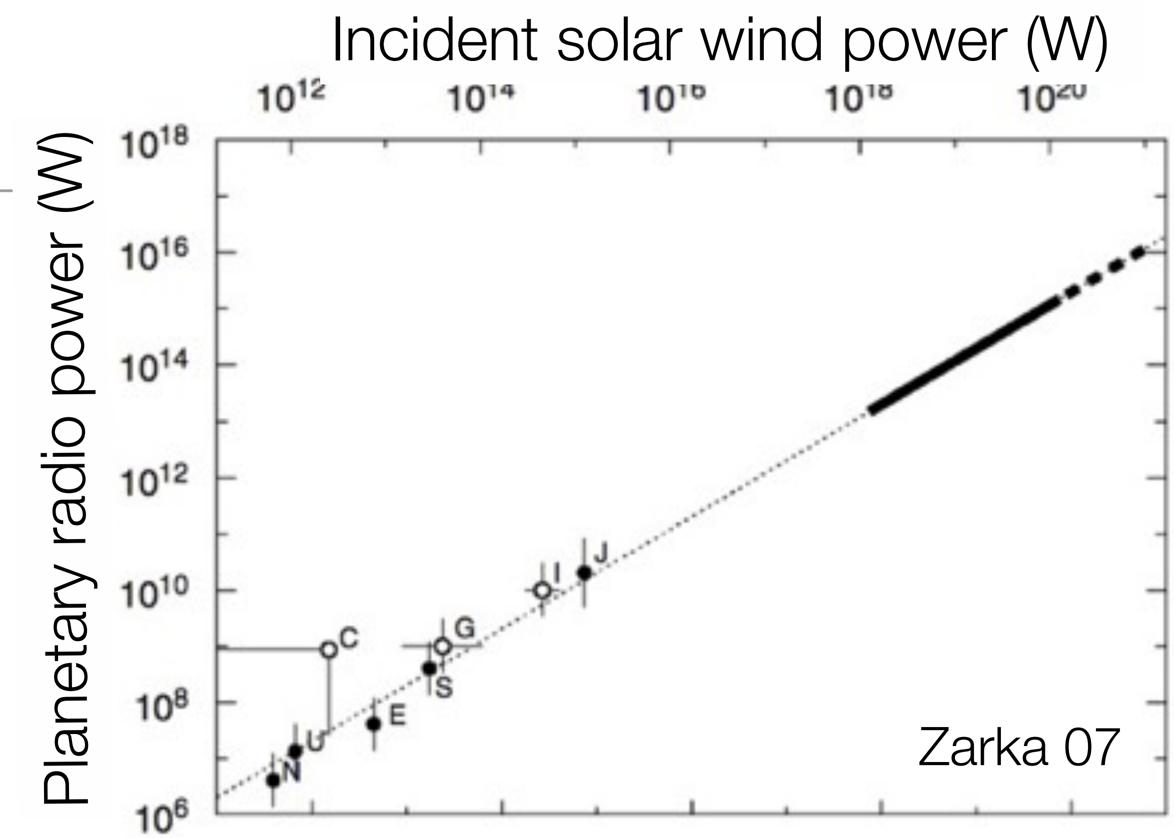
How to estimate exoplanetary radio emission

- From wind simulations → calculate the strengths of the physical interactions between the wind of the star and the hot Jupiter

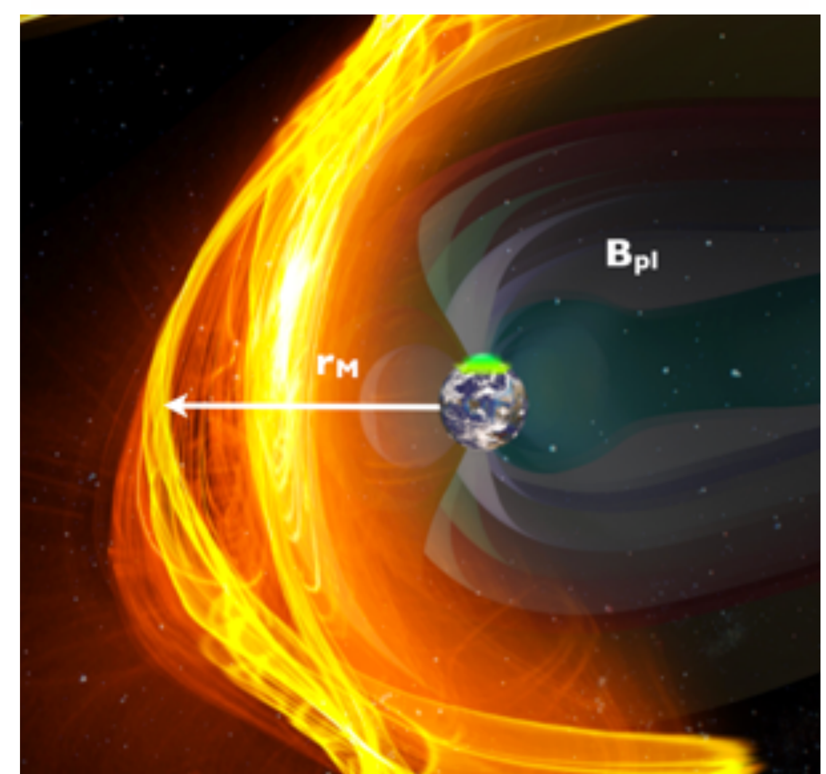
$$\text{incident stellar wind power} \simeq \frac{B_\perp^2}{4\pi}(\Delta u)\pi r_M^2 \,,$$

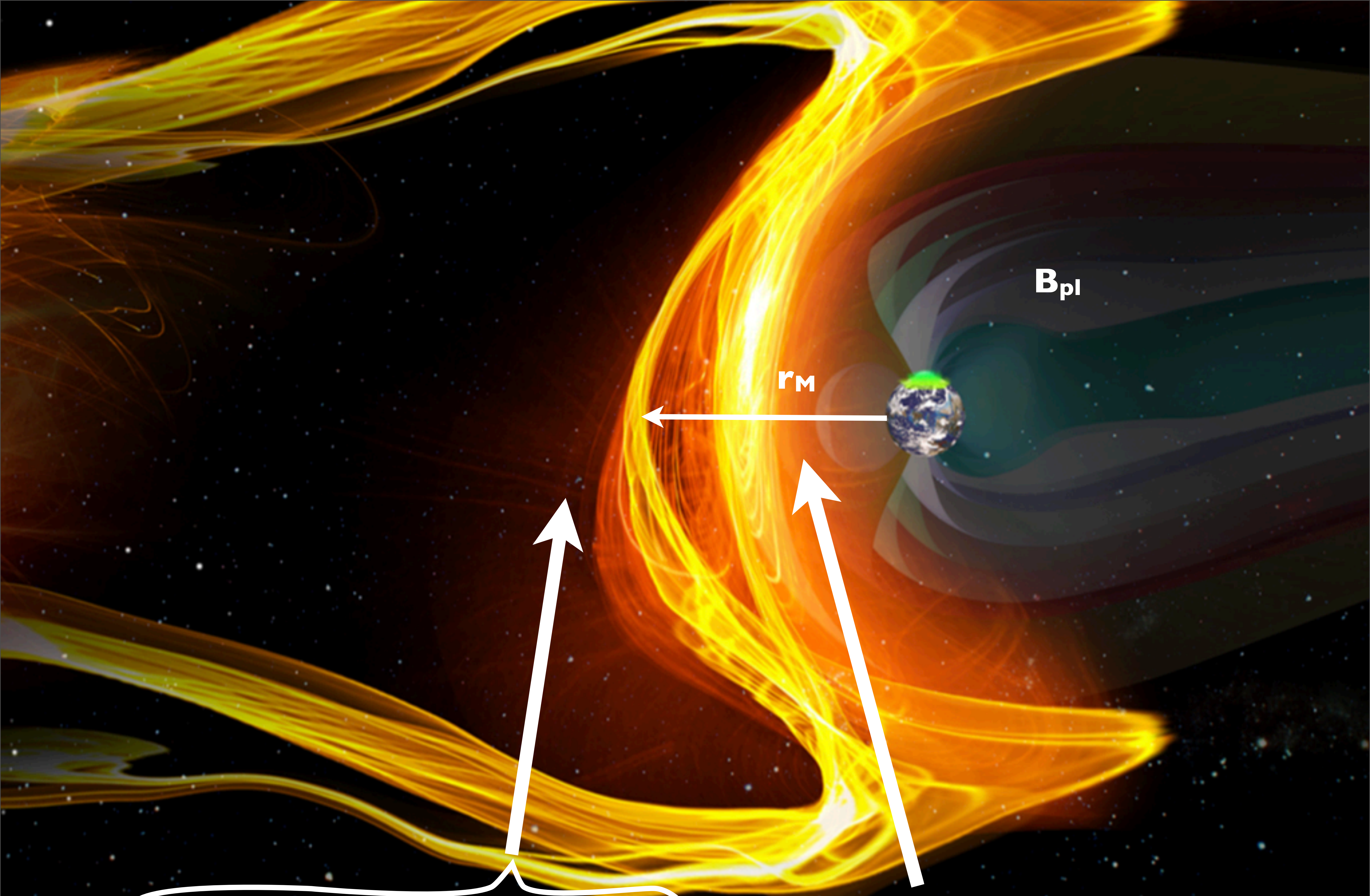
- Then, we compute the radio flux:

$$\phi_{\rm radio} \propto P_{\rm radio}/{\rm distance}^2$$



r_M: Planet's magnetosphere





$$p_{\rm ram}^{\rm wind} + \frac{[B_\star(R_{\rm orb})]^2}{8\pi} + p_{\rm th}^{\rm wind} \simeq \frac{[B_{\rm pl}(r_M)]^2}{8\pi}$$

Characteristics of the planet's magnetosphere

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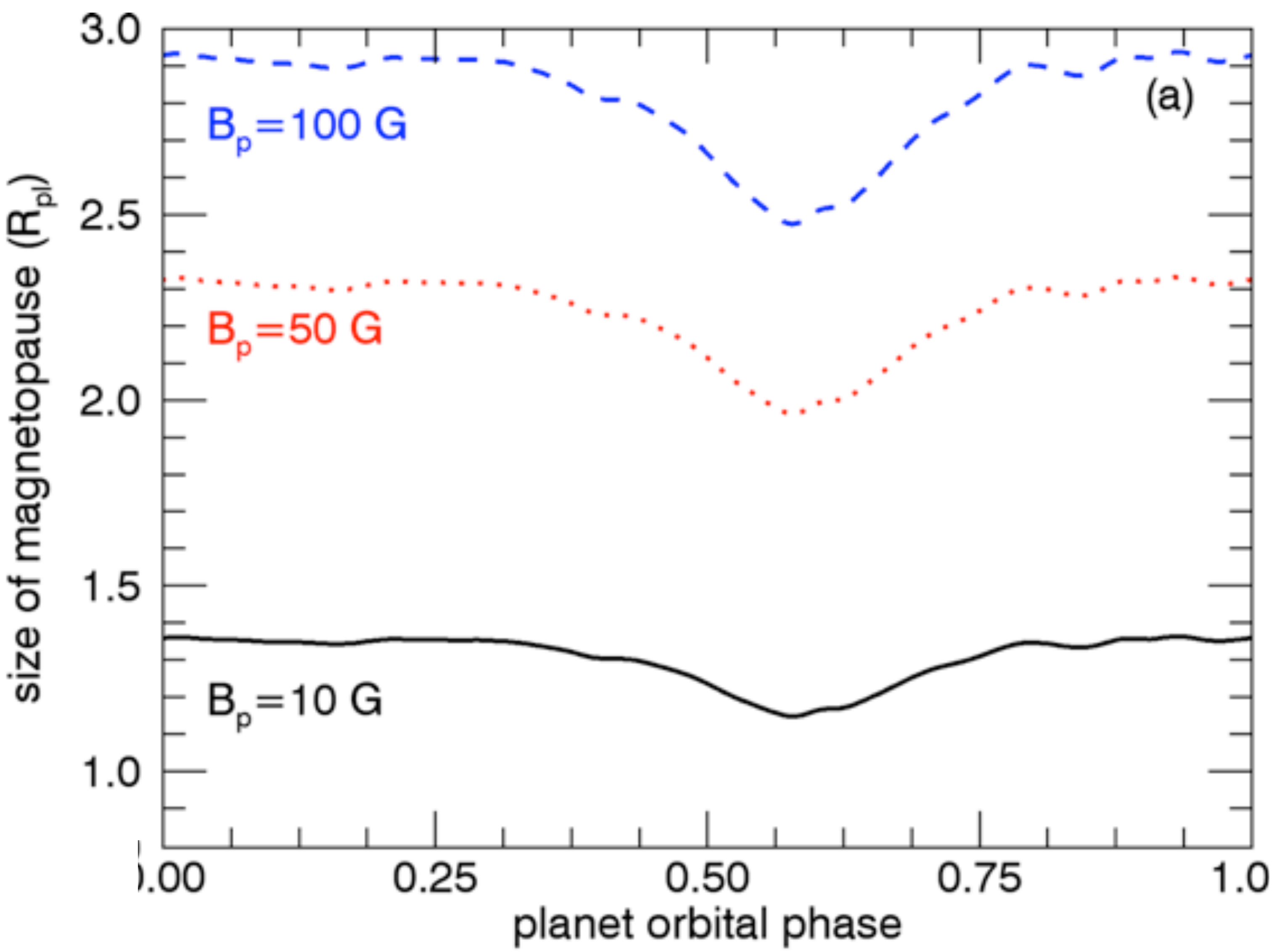

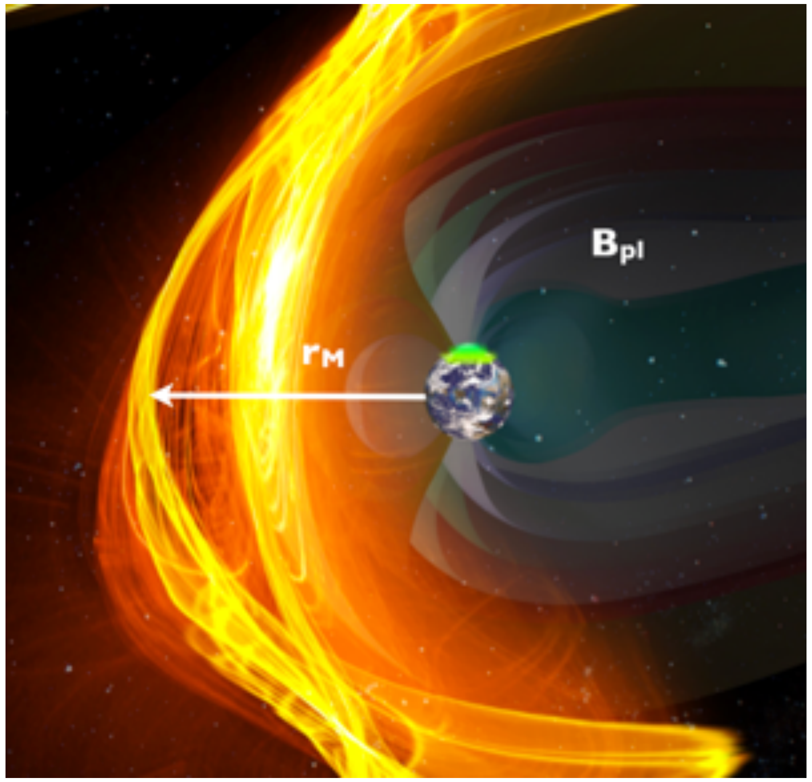

- Compare to Earth's magnetospheric size: ~10-15 R_{earth}
- Compare to Jupiter's magnetospheric size: ~70-90 R_{jup}

Radio emission from V830 Tau b

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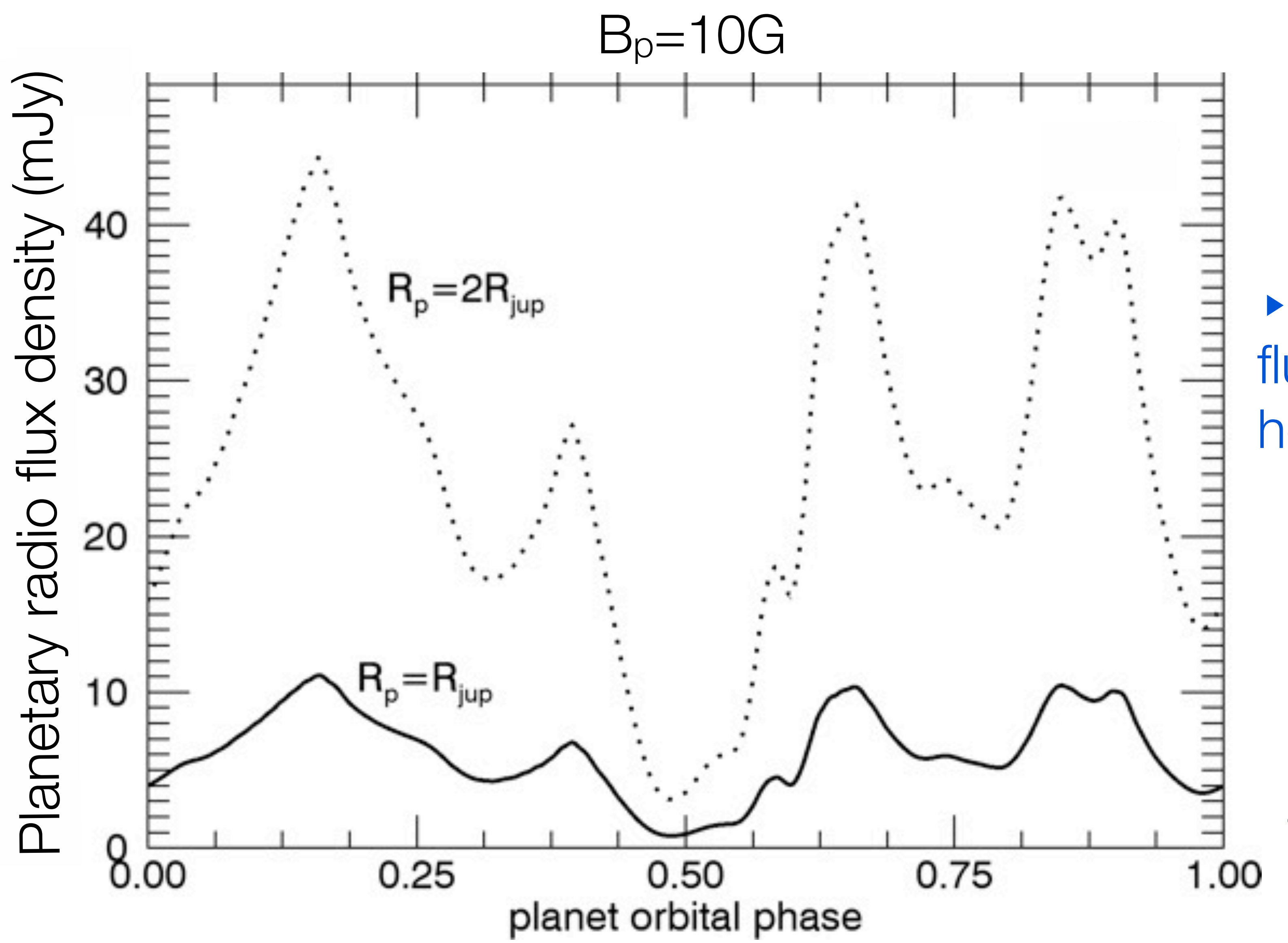
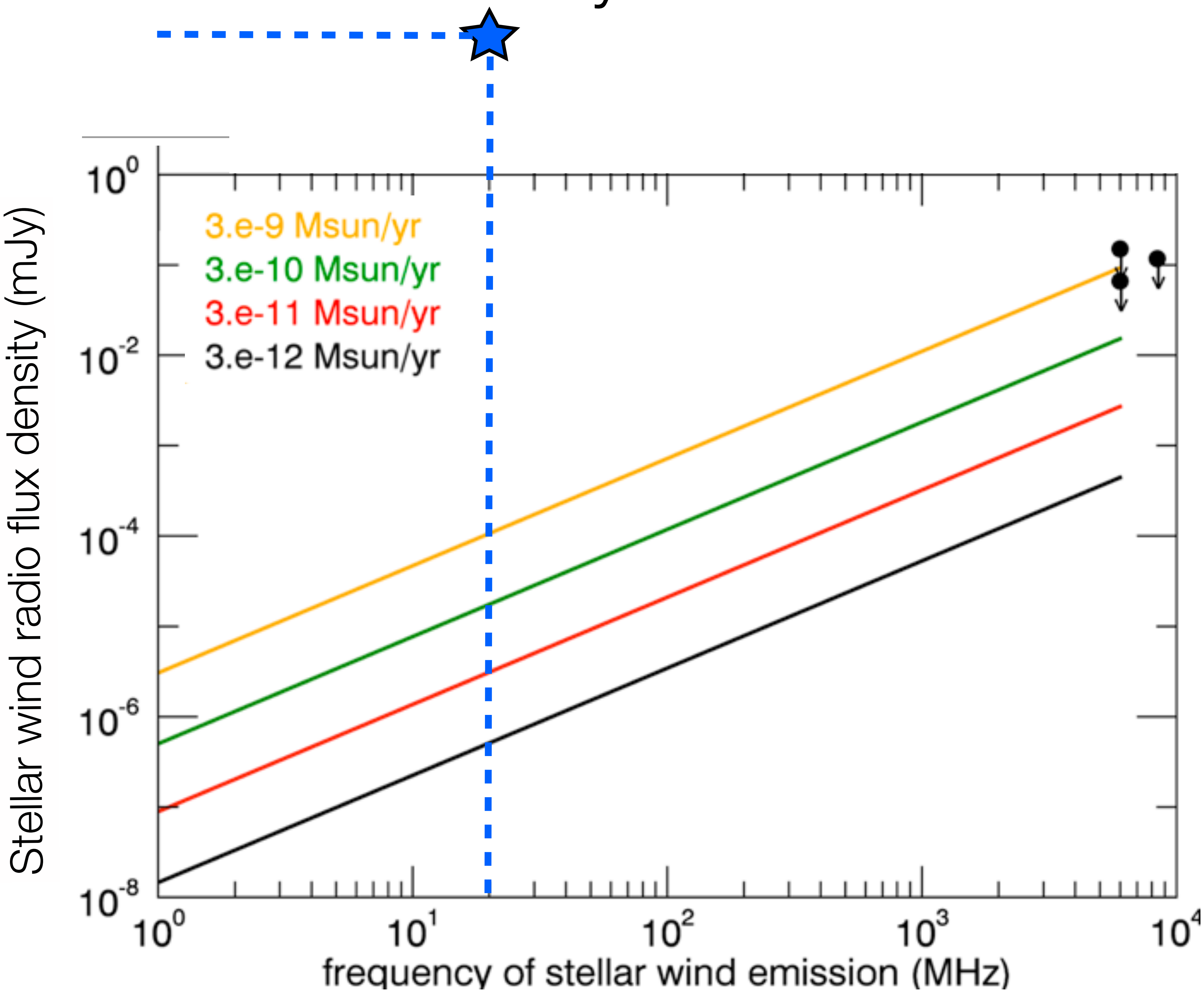


- Average flux: 24mJy with peak fluxes of ~44 mJy (versus 1mJy for hot-Jupiters around MS stars)
- Average flux: 6mJy with peak fluxes of ~11 mJy

Radio flux not strongly dependent on B_p (good news)

Cyclotron frequency of emission depends on B_p:
10G: 18 MHz
50G: 114 MHz
100G: 240 MHz

Radio flux density of the stellar wind



- Observations (even if only non-detections) allow us to place an upper limit in mass-loss rates: $\dot{M}<3\times10^{-9}\ M_\odot/yr$
- Best estimates: the wind of V830Tau should have $\dot{M} \sim [10^{-12},10^{-10}]\ M_\odot/yr$

▸ Note: Wind emission is a lot smaller than exoplanet's emission: ~44 mJy at ~18MHz (B_p=10G)

Panagia & Felli 75, Guedel 02,

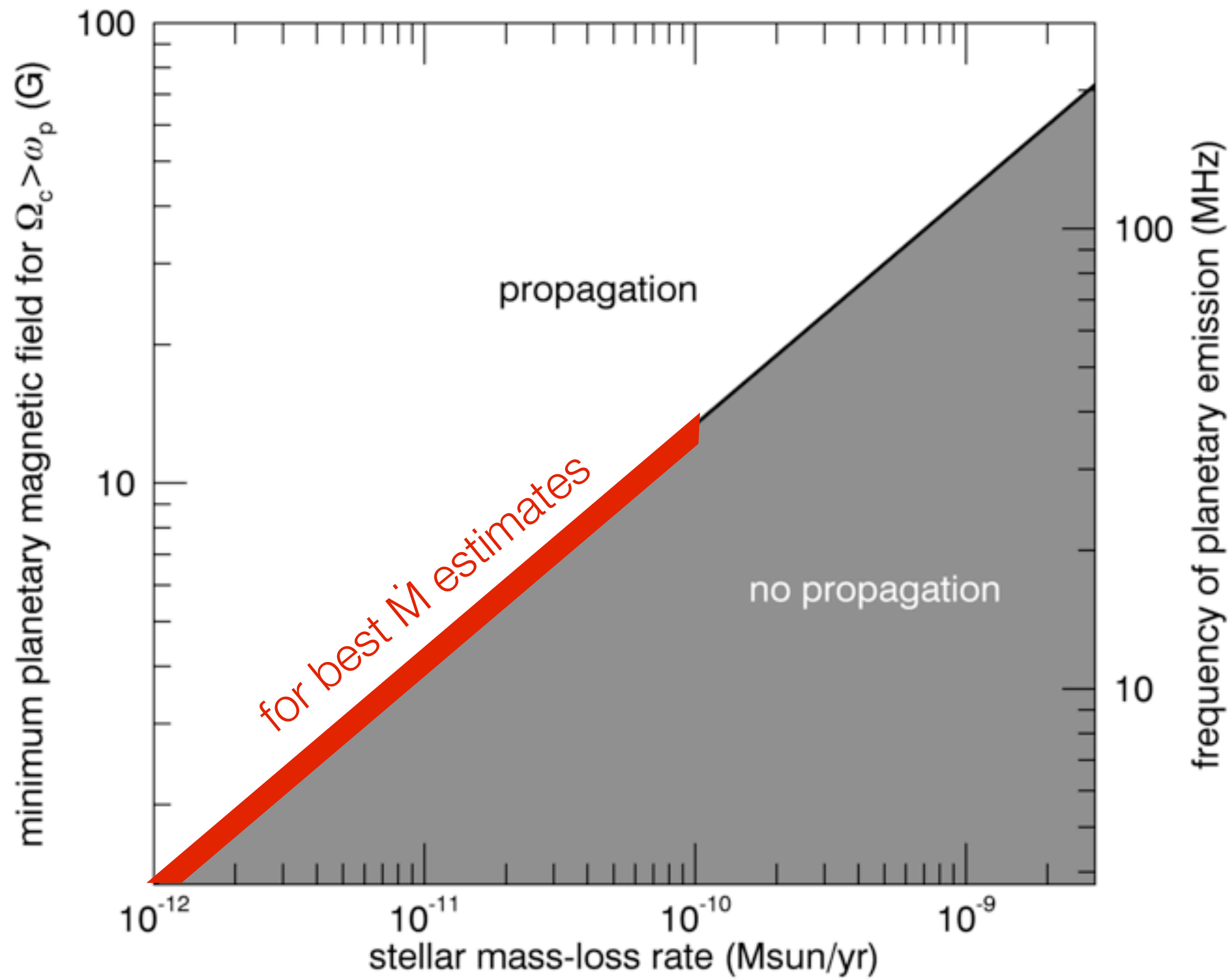
Villadsen+14, Fichtinger+17

Can planetary emission “escape” the stellar wind?

- The planetary radio emission can only propagate in the stellar wind plasma if the frequency of emission Ω_c is larger than the stellar wind plasma frequency ω_p.

$$B(\alpha_0) > \left(\frac{n_e}{10^5\ \mathrm{cm}^{-3}}\right)^{1/2} \mathrm{G},$$

▸ planetary radio emission can propagate through the stellar wind if the planetary magnetic field strength is <1.3 – 13 G .



Summary and Conclusions

- 3D MHD simulations+ZDI maps used to describe the wind of V830Tau
- Wind-planet interaction: radio emission from the planet (if magnetised)
  - Predicted radio emission:
    - ➡6mJy for $R_p=R_{jup}$ (peaks at ~11mJy)
    - ➡24mJy for $R_p=2R_{jup}$ (peaks at ~44mJy)
    - ➡frequency of emission $\propto B_p$: from 18 to 240 MHz for B_p=[10,100] G
- Dense winds can produce free-free emission at radio wavelengths. Wind emission (<μJy) is much smaller than planet emission though.
  - Important upper limit on wind mass-loss rates: $\dot{M}<3\times10^{-9}\ M_\odot/yr$
  - Best estimates: **$\dot{M} \sim [10^{-12},10^{-10}]\ M_\odot/yr$**
- Planet orbit is at $6R_{star}$ → even after attenuation, a significant fraction of the planetary radio flux can escape (note thought that $B_p > 1.3$ -- 13 G)