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Is the large-scale magnetic field of τ Boötis A too weak to explain LOFAR radio observations?

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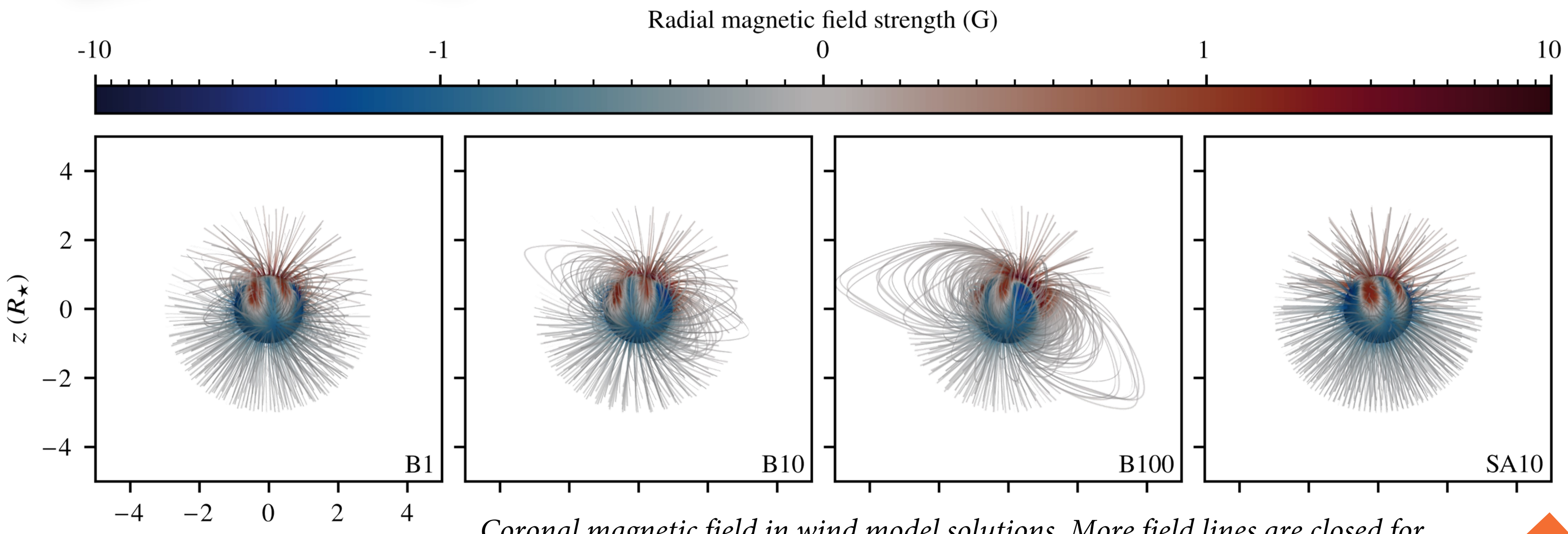
Introduction

In 2021, LOFAR **radio observations** found a signal of strength 890^{+690}_{-500} mJy in the direction of the τ Boötis system (Turner et al. 2021). The signal was posited to arise from **interactions between τ Boötis A and its exoplanet** τ Boötis Ab.

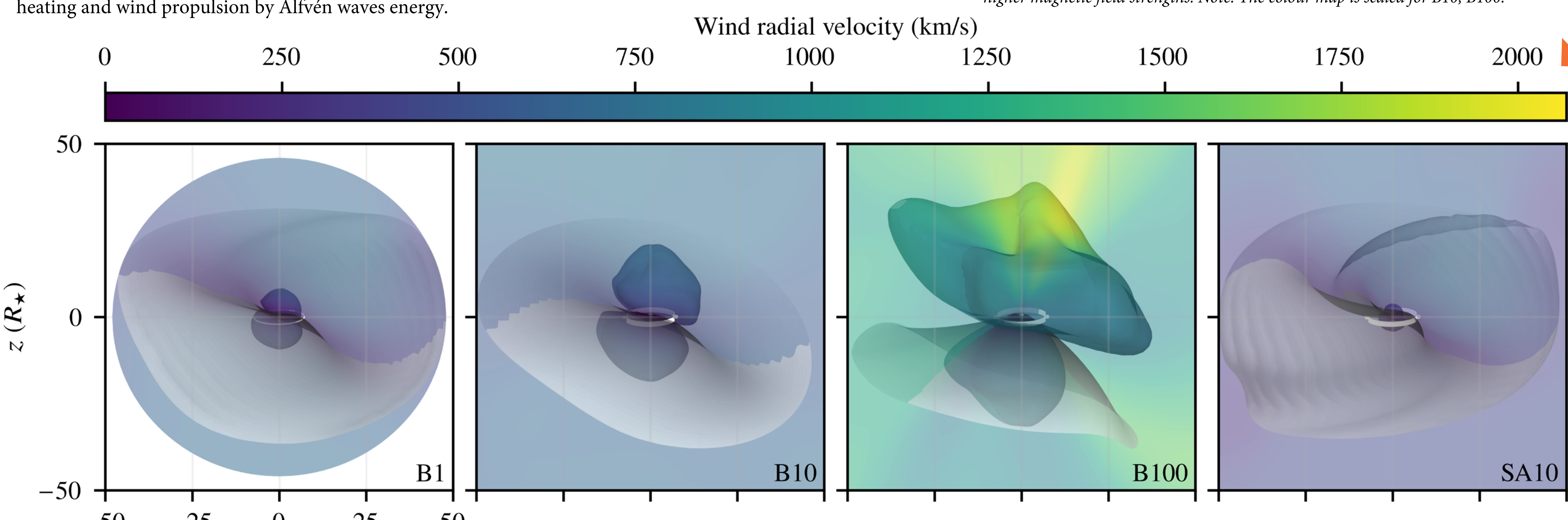
We investigate the star-planet interaction theory with a **contemporaneous magnetic map** of τ Boötis A, obtained via **Zeeman-Doppler imaging.** The map shows the **stellar magnetic field at the time of the signal emission.**

Recognizing the influence of magnetic field geometry and the resulting stellar wind power on exoplanet radio emission profiles, we have constructed four **three-dimensional magnetohydrodynamic models** of the system.

The models are driven by the magnetic map data and incorporates coronal heating and wind propulsion by Alfvén waves energy.



Coronal magnetic field in wind model solutions. More field lines are closed for higher magnetic field strengths. Note: The colour map is scaled for B10, B100.



x (R⋆)

Alfvén surface (two-lobed structure) and current sheet (grey). The plane of sky and Alfvén surface are coloured by the local wind velocity. The orbit of the planet τ Boötis Ab is shown in white.

Method and results

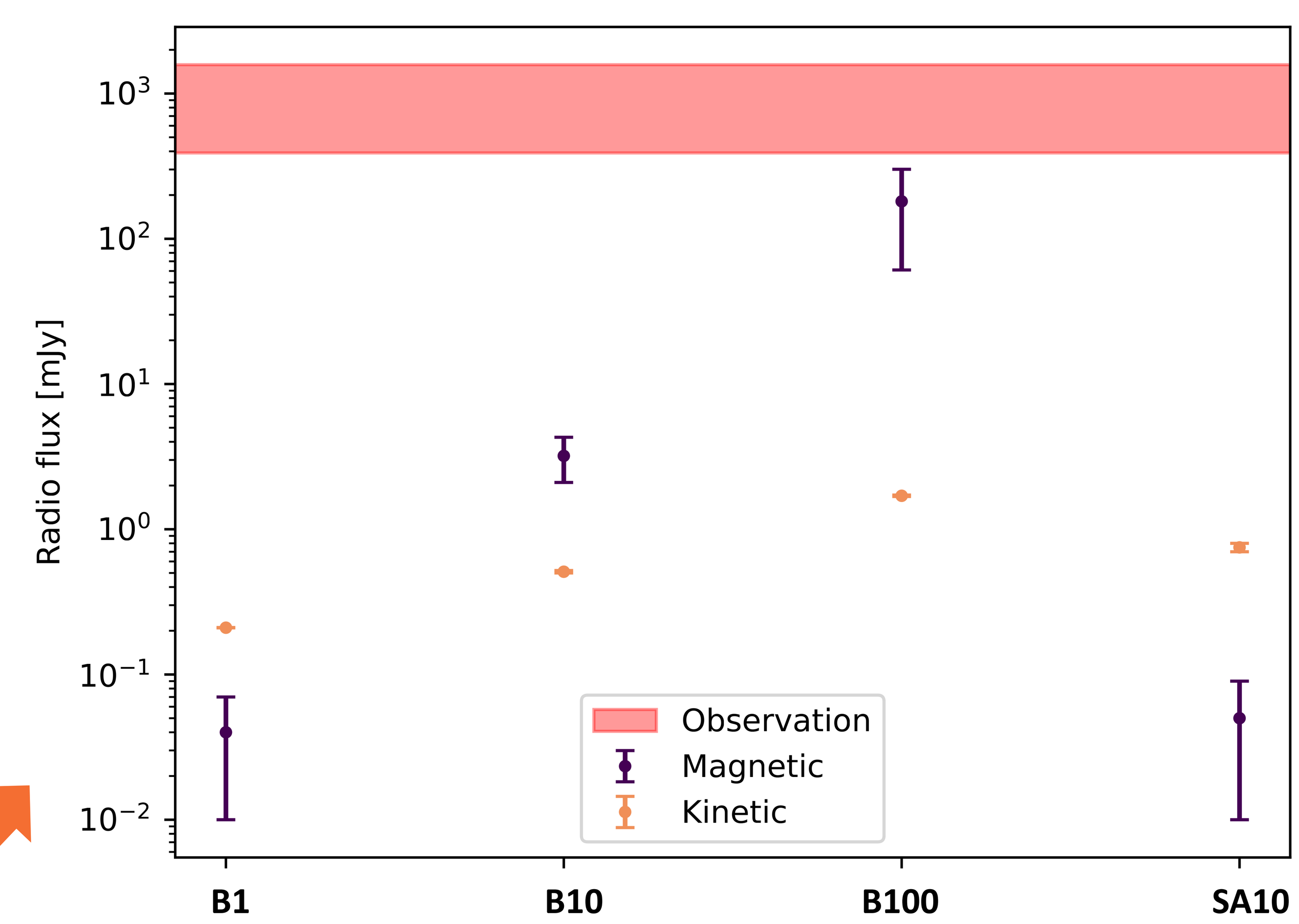
We consider **four models**: the default (B1), two with enhanced magnetic field strength (B10 and B100), and one with an enhanced Alfvén flux (SA10).

We calculate the flux of **wind magnetic energy entering the magnetosphere** of the planet τ Boötis Ab, accounting for its orbital inclination and phase.

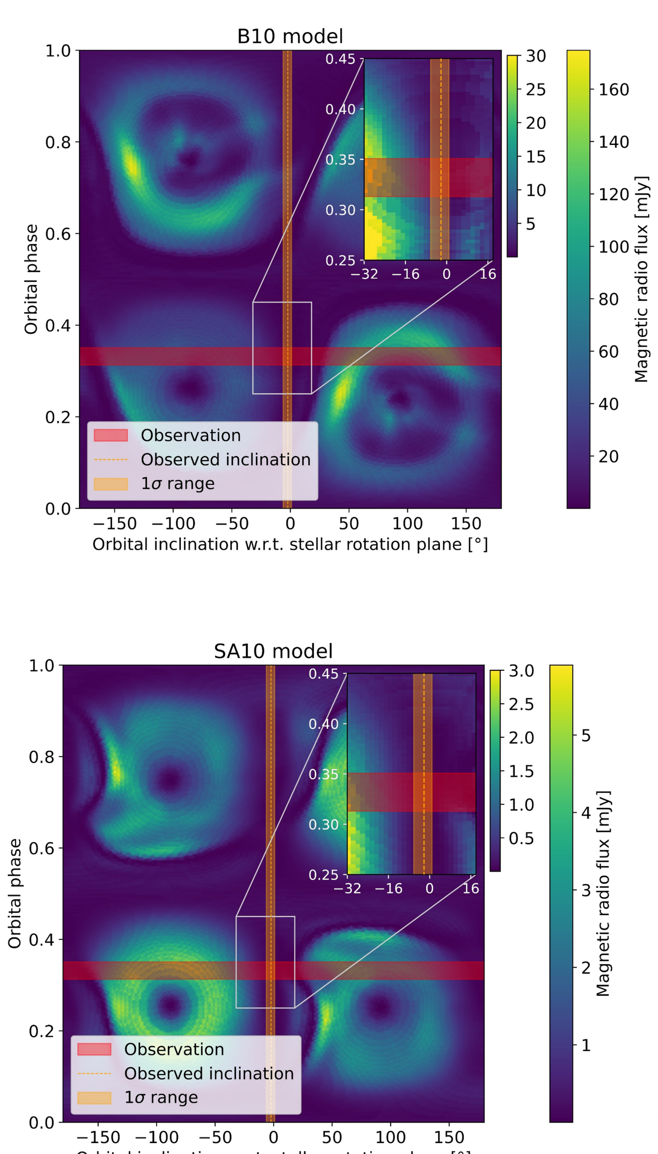
Based on solar system observations, we assume that **0.2% of the incident magnetic energy** (Zarka et al. 2007, Vidotto & Donati 2017) eventually produces radio waves in the LOFAR band, and that this flux is beamed in a narrow (1-2 sr) double cone.

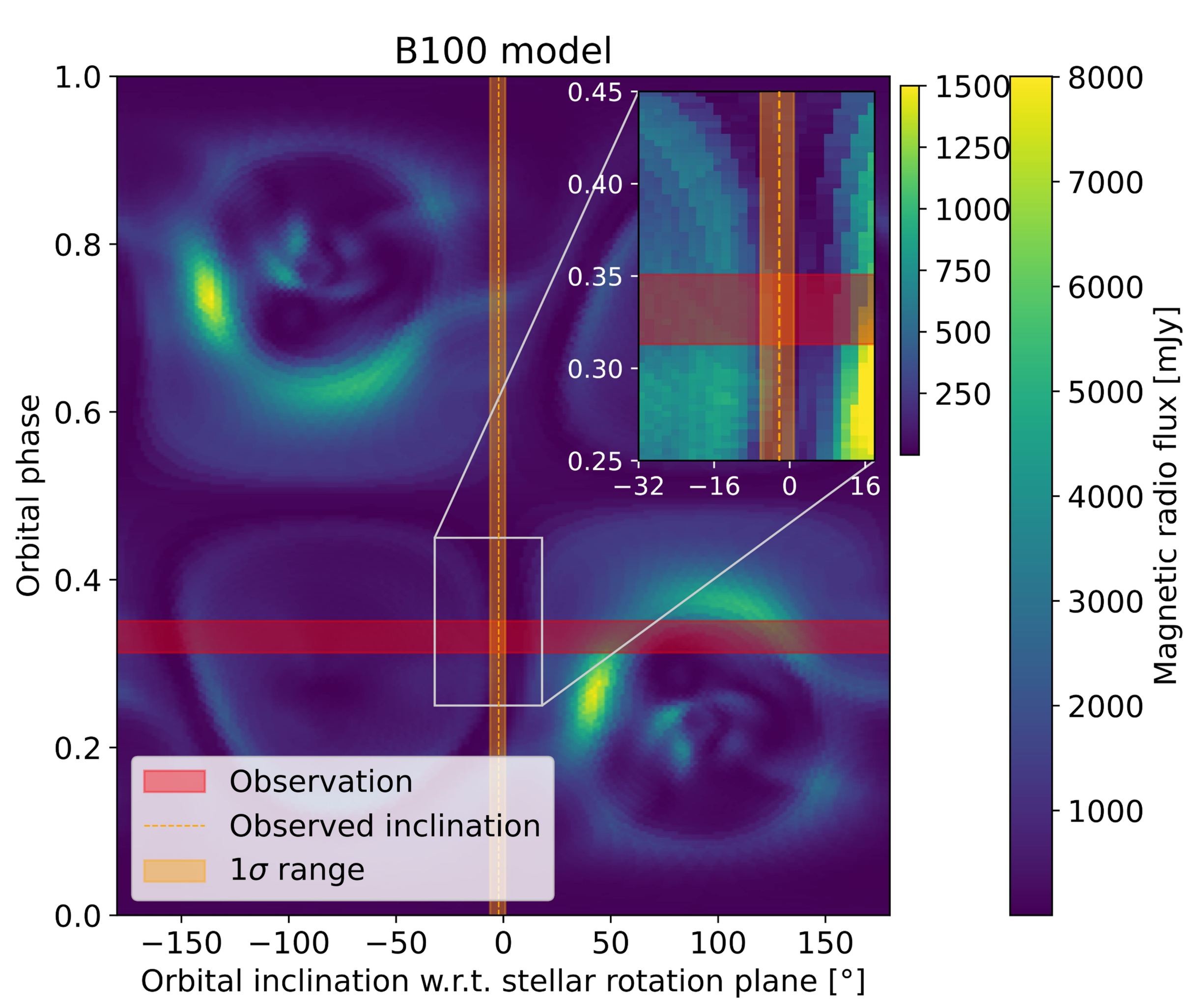
In our models, we find that **only the B100 model** (stellar magnetic field scaled by a factor of 100) yields a radio flux comparable to the LOFAR signal.

While the ZDI map may underestimate the stellar magnetic field strength, we consider a scaling factor of 2-10 to be reasonable, and **a scaling factor of 100 to be unreasonable.**



*Maximal computed **radio flux**. Only the B100 model, where the magnetic field is increased hundredfold, approaches the intensity of the observations by Turner et al. (2021).*





*Computed maximal **radio flux from magnetic interactions** as a function of planetary phase and orbital inclination with respect to stellar rotational inclination.*

Conclusion

Our analysis concludes that **the observed magnetic field of τ Boötis A is too weak to account for the LOFAR-detected radio emission intensities.** However, episodic events like coronal mass ejections may temporarily enhance the wind-planet interaction signal's strength.

References

Turner J. D., et al., 2021, A&A, 645, A59
Vidotto, A.A., Donati, J.F., 2017, A&A, 602, A39
Zarka, P., 2007, Planet. Space Sci., 55, 598