Plasma interaction between extrasolar planets and their stars

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Outline

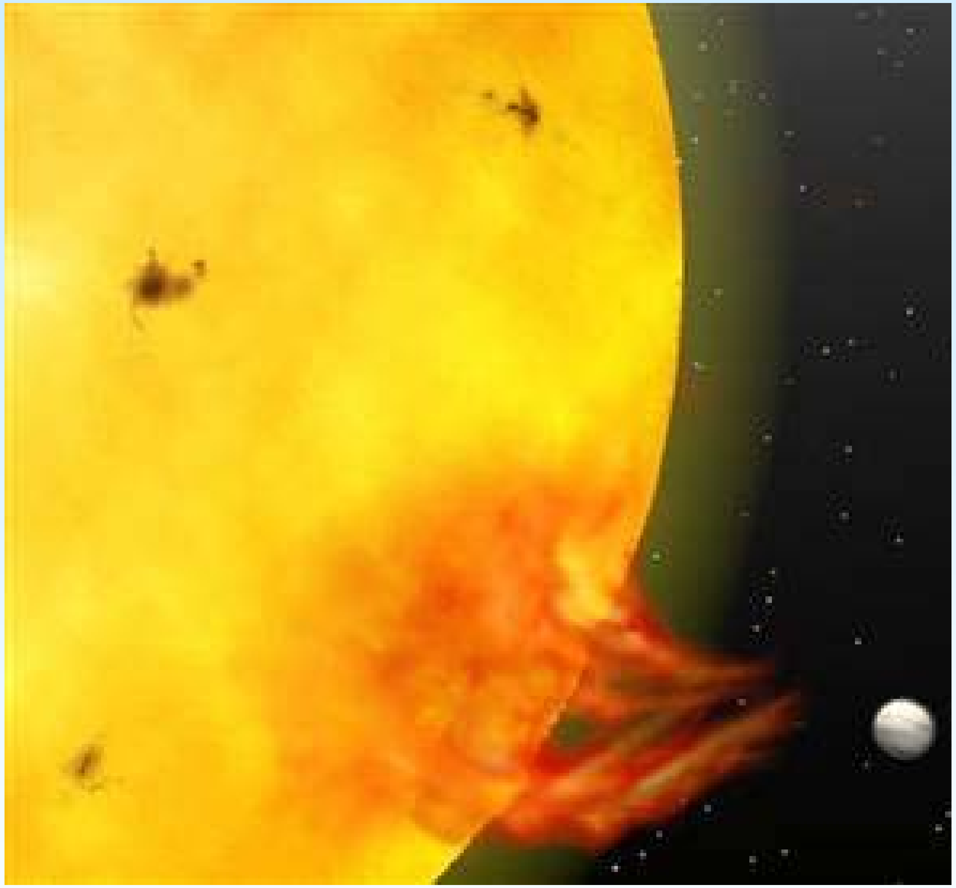
- Unlike our solar system approx. 20 % of extrasolar planets are within 0.06 AU
- Hence: many extrasolar planets are located inside the Alfven-radius
- Which phenomena can be expected?
- Obervations 2003-05 of chromospheric activity, synchronized with planetary motion
- Our hypothesis: this activity can be due to an electrodynamical coupling via currents
- Magnetohydrodynamic (MHD) simulation
- Alfvén – wing model
- Similarity to the Io – Jupiter interaction

Chromospheric observations

[Shkolnik et al., 2003, 2005]

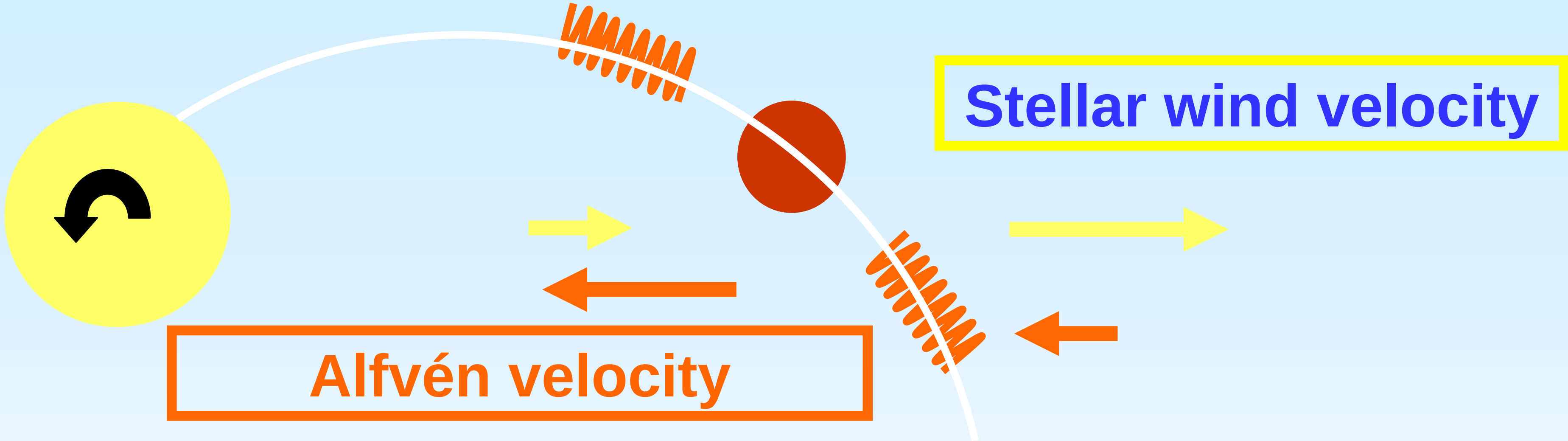
... observed chromospheric Ca II H- and K-emissions, localized activity called „hot spots“

- The „hot spots“ rotate with the same period as the close-in ESP (planet), i.e. no (bimodal) gravitational interaction
- The „hot spots“ last longer than the life-time of the usual stellar spots (cf. magnetically driven sunspots)
- „hot spot“ leads the planetary motion:
  - by 60° (HD179949) and
  - by 169° (ups And)



(Artist‘s impression by Shane Erno‘s, UBC – NRC, Canada) but what could explain such interaction?

Consequence of close-in position



Many extrasolar planets (ESPs) are close enough to the star that an electromagnetic perturbation of the stellar- wind flow can travel back to the star

Compare:

for planets in the solar system electromagnetic perturbations are carried away by the solar wind

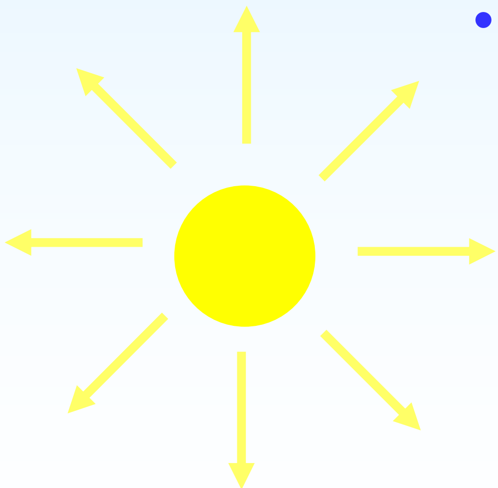
Parameters to be considered

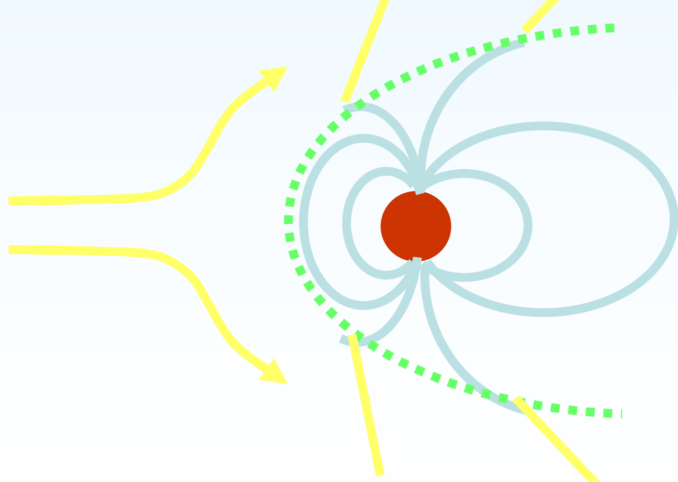
Star:
- Mass
- Radius
- Rotation period
- Corona temperature
- Magnetic field
- Mass loss

Stellar wind (SW):
- velocity
- density
- magnetic field

Planet:
- orbital parameters
- Radius
- Necessary for superflares:
- Extended Magnetic fields -> ???

Planetary magnetosphere:
- Extension (magnetopause stand-off distance) ???
- open or closed to the stellar wind

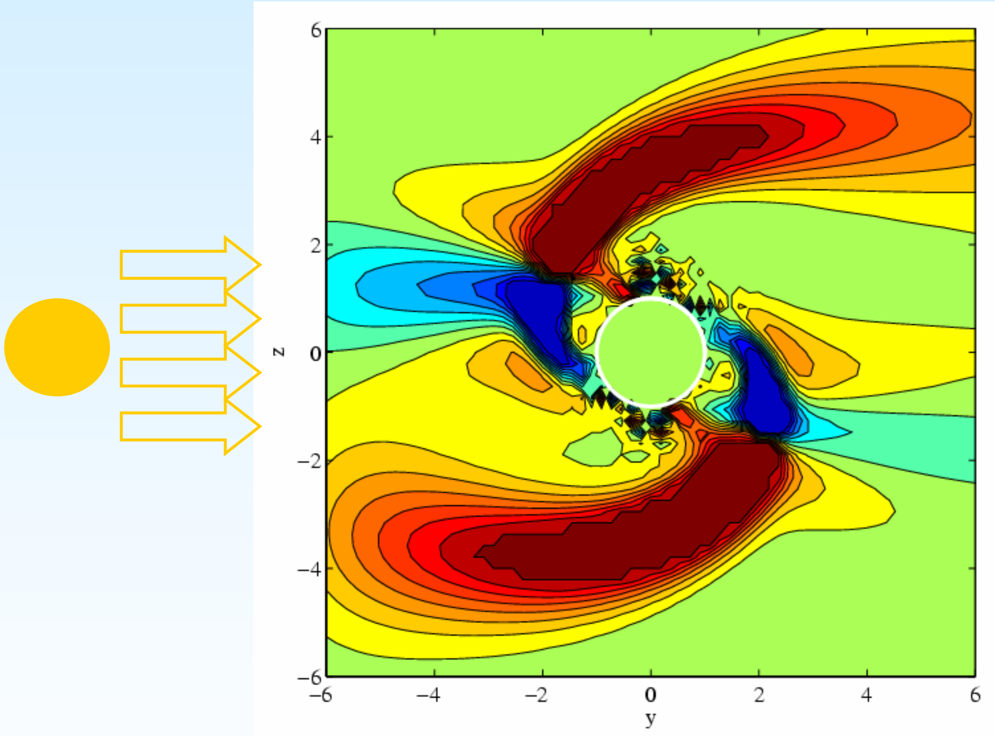


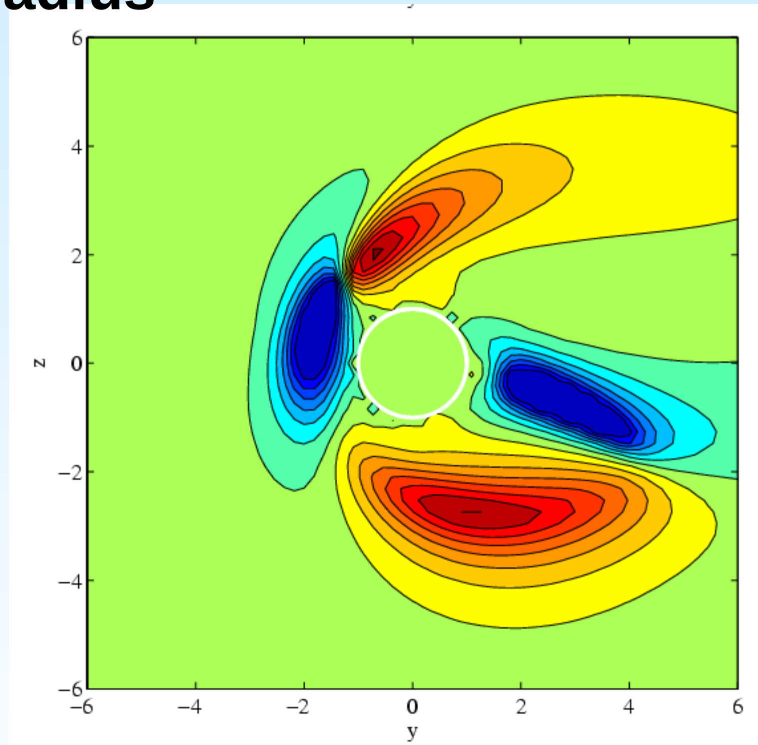


Consequence of close-in ESPs: field-aligned currents toward the star

Field-aligned currents

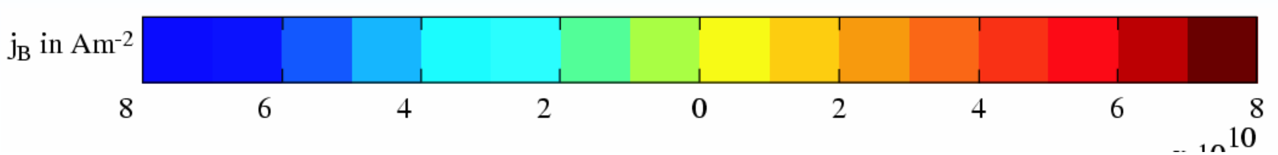
Alfvén radius



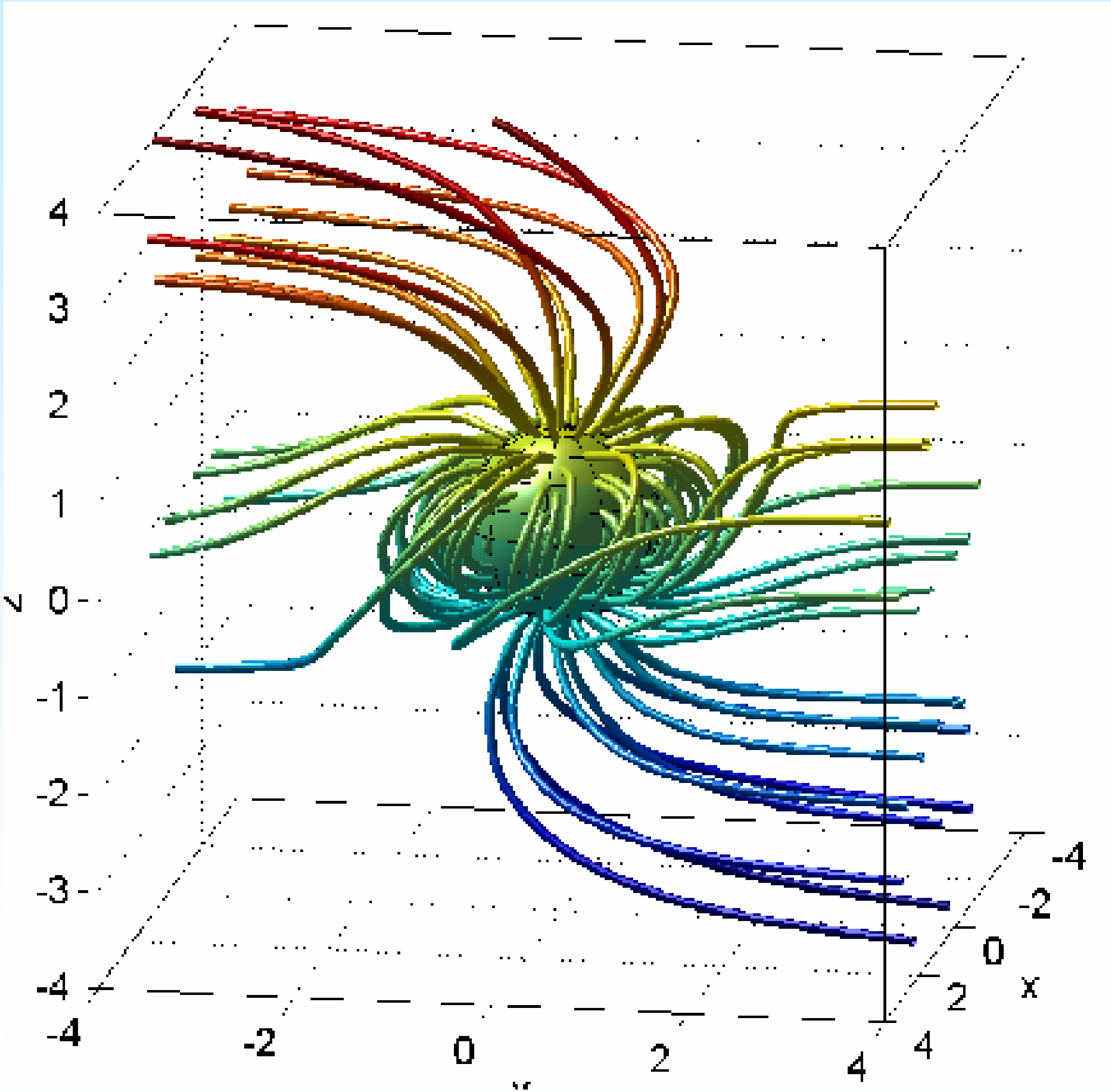


0.025 AU **0.086 AU** **0.150 AU**

-8 -6 -4 -2 0 2 4 6 8 x 10^{-10}



Simulation result



<- Simulations for ups And show extended wings of open field lines along which field-aligned currents can flow.

[Preusse et al. 2005]

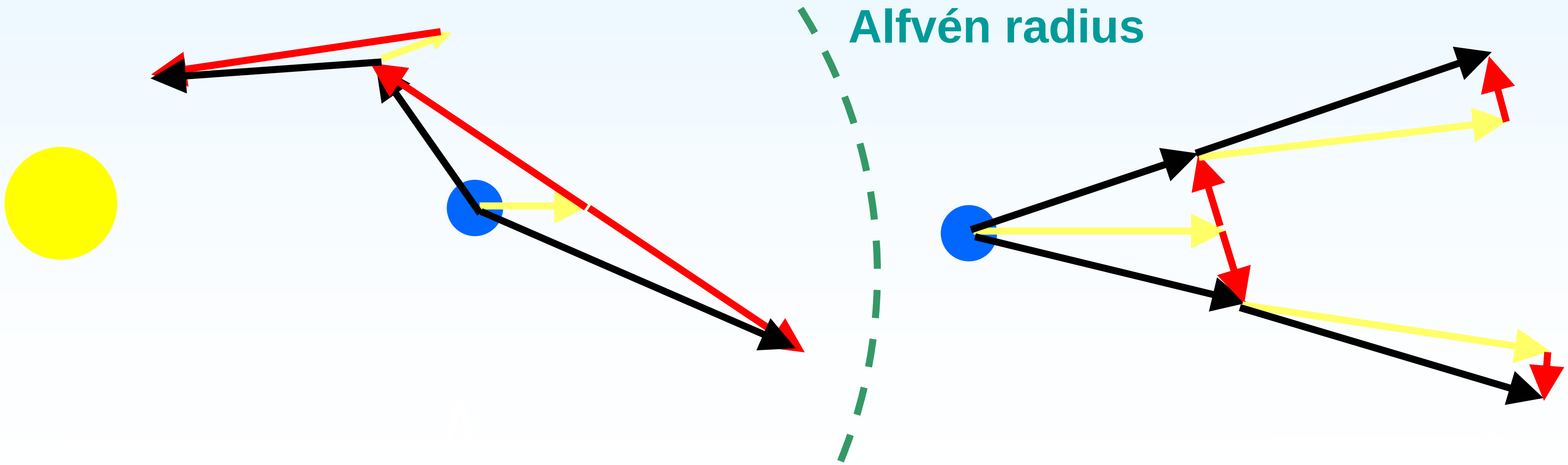
An internal planetary magnetic field is, however, not a necessary model ingredient – just a conducting layer.

Alfven wave propagation model

- **Field aligned currents create Alfvén waves [Neubauer, 1980]**
- **The perturbation travels along the characteristics:**

$$\boxed{\mathbf{c}_A^{\pm}} = \boxed{\mathbf{v}} \pm \frac{\mathbf{B}}{\sqrt{\mu_0 \rho}}$$

Alfvén velocity

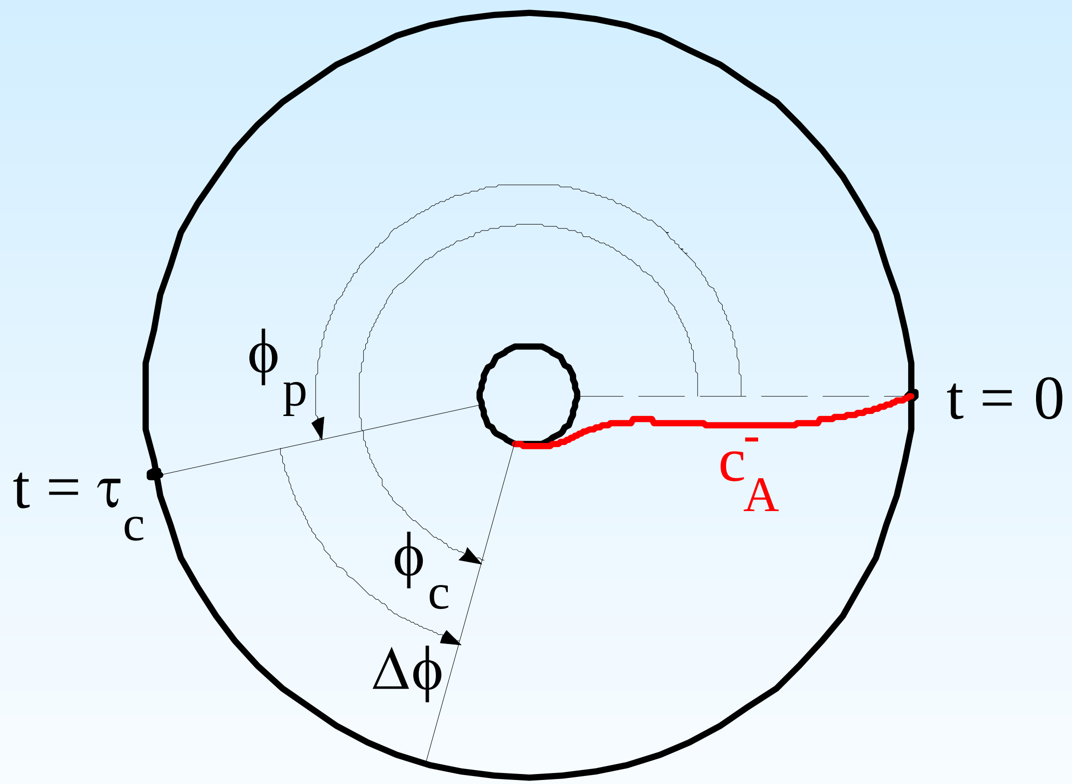


Modeling the characteristics

- The [Weber and Davis 1967] stellar wind model (see Münster 2004 talk by Preusse et al.] reveals for the two ESP cases:
  - Slower and denser than for planets in the solar system
  - Super-sonic but sub-Alfvénic velocities
- Neglect of the out-of ecliptic plane B-component
- A conducting planetary surface layer, mving in the stellar wind causes B-perturbations and current flows
- The planetary motion around the star adds to the relative velocity
- The wave propagation time from planet to star may not be neglected
- During this propagation time the planet moves on along its orbit
- As a result the magnetic field lines, suggested by [Shkolnik et al., 2005] do not correctly map

-> Only wave characteristics, considering these aspects may explain the observable phase angles

Example 1: HD 179949



Star:

$$M = 1.24\,\mathrm{M_{sol}}$$
$$R = 1.24\,\mathrm{R_{sol}}$$
$$F_m = 1.6 \cdot 10^8\ \mathrm{kgs^{-1}}$$
$$P = 9\,\mathrm{d}$$
$$T = 0.6 \cdot 10^6\ \mathrm{K}$$
$$B = 1.0 \cdot 10^{-4}\ \mathrm{T}$$

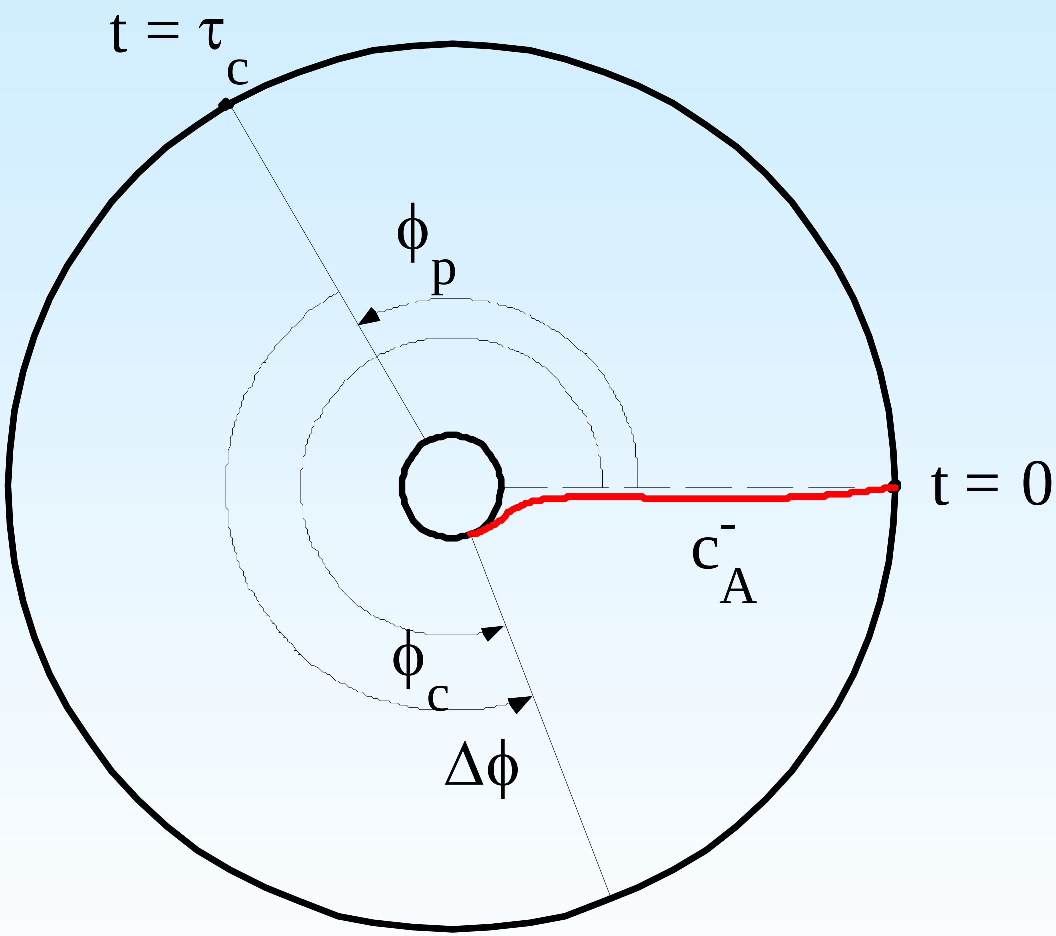
Planet:

$$a = 0.045\,\mathrm{AU}$$
$$P_{orb} = 3.1\,\mathrm{d}$$

$$\boxed{\tau_c = 1.6\,\mathrm{d} \qquad \Delta\phi = 62°}$$

Good agreement with the observed 60° [Shkolnik et al. 2005]

Example 2: ups And



Star:

$$M = 1.37\,\mathrm{M_{sol}}$$

$$R = 1.45\,\mathrm{R_{sol}}$$

$$F_m = 2.2 \cdot 10^8\ \mathrm{kgs^{-1}}$$

$$P = 9\,\mathrm{d}$$

$$T = 0.5 \cdot 10^6\ \mathrm{K}$$

$$B = 1.5 \cdot 10^{-4}\ \mathrm{T}$$

Planet:

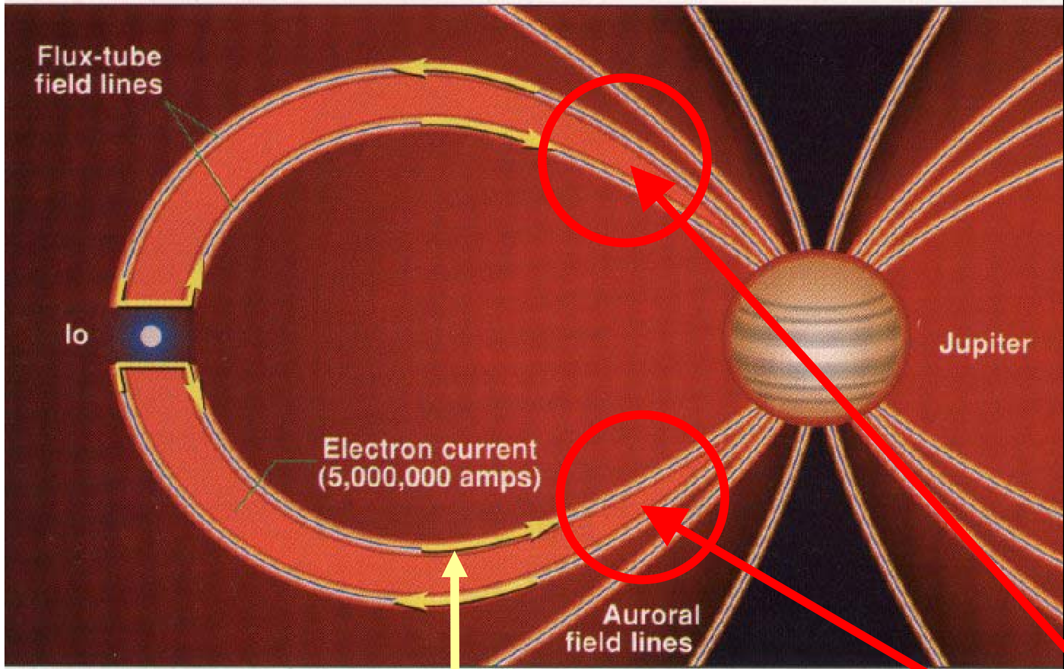
$$a = 0.057\ \mathrm{AU}$$

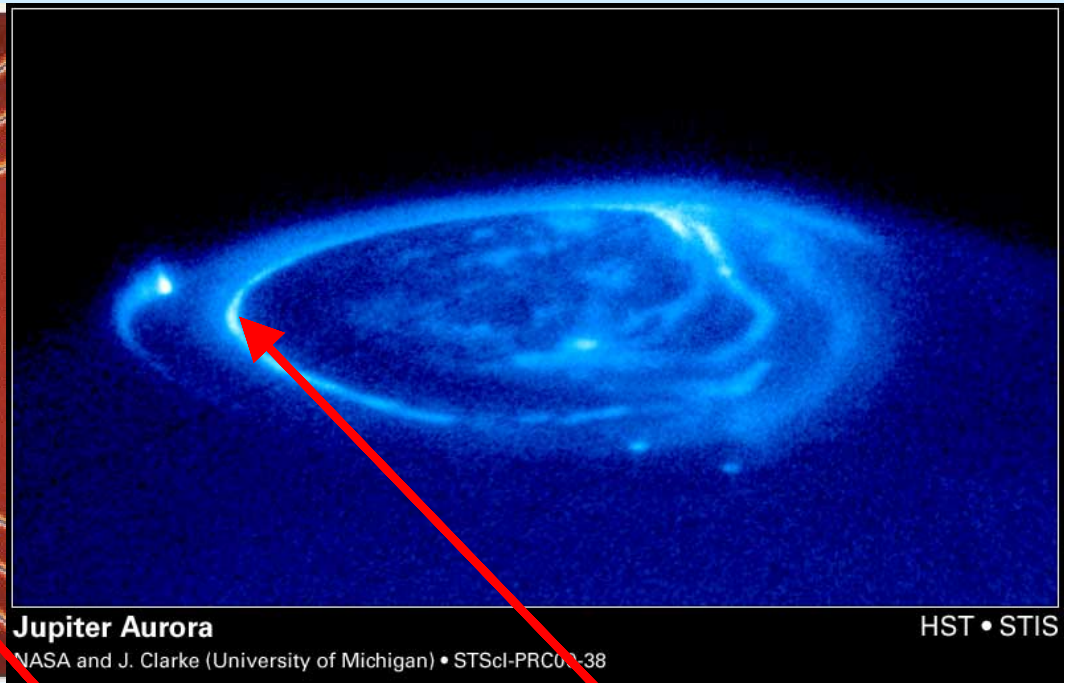
$$P_{orb} = 4.6\,\mathrm{d}$$

$$\boxed{\begin{aligned} \tau_c &= 1.5\,\mathrm{d} \\ \Delta\phi &= 171^\circ \end{aligned}}$$

Good agreement with the observed 169° [Shkolnik et al. 2005]

Analogy to Io-Jupiter system





Current system, set up by Alfvén waves

Observed consequences:
Decametric radiation & aurora

Does the interaction of extrasolar planets and their stars cause decametric radiation and planetary aurorae?

Summary

- The stellar chromospheric activity (“hot spots”), observed in extrasolar planetary (ESP) systems, could indeed, be explained by an interaction between close-in planets and their stars, since the observed planets are within the Alfvén radius
- Our current-interactíon model reveals the correct phase angles, seen at HD 179949 and ups And
- Our model does not require a planetary magnetic field which would be necessary for unrealistic and not yet observed in ESP systems superflares
- In analogy to the similar, well established Io-Jupiter interaction, our model predicts extrasolar planetary decametric radiation and aurorae, which are, unfortunately, not yet observable