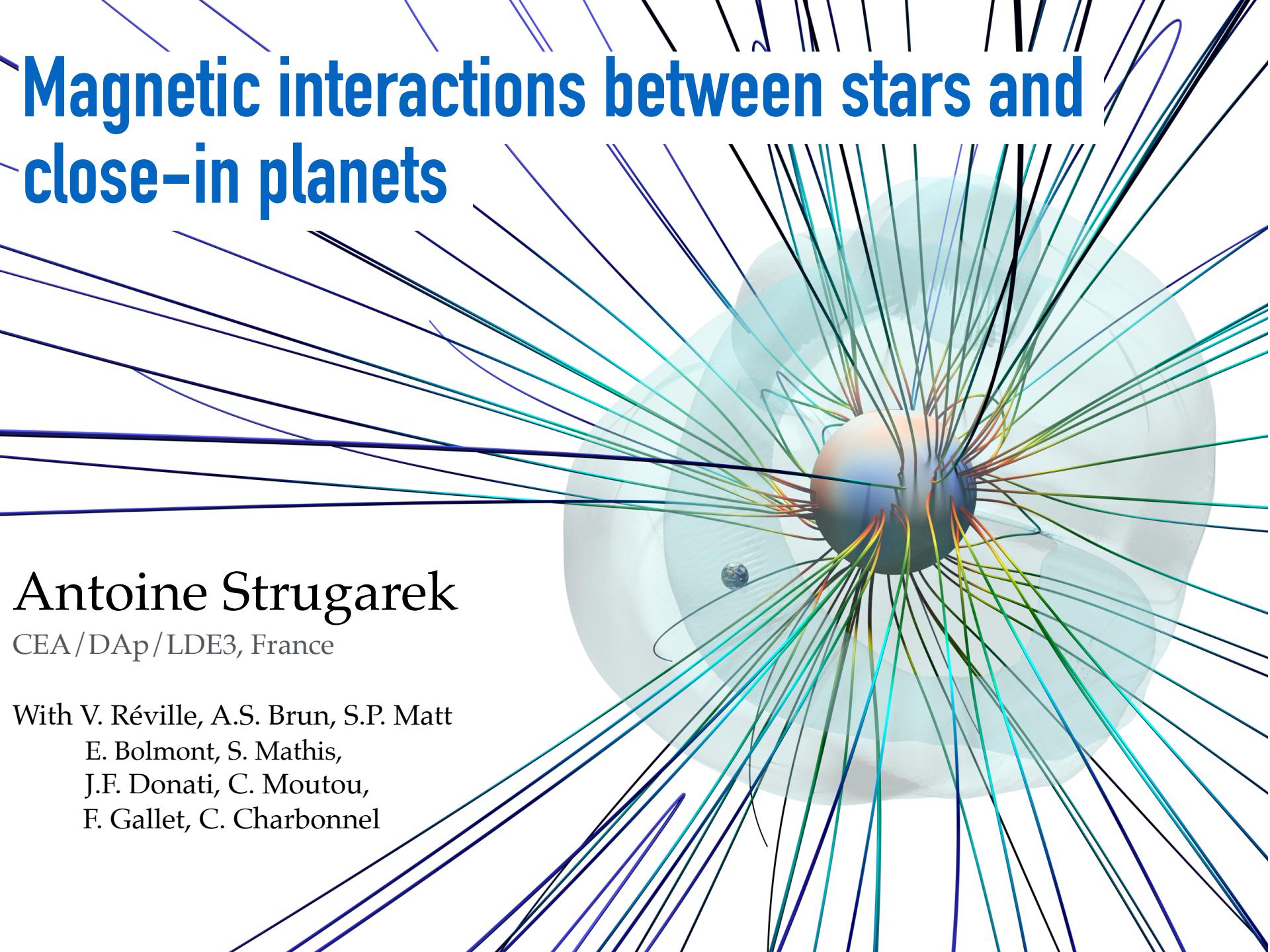


Magnetic interactions between stars and close-in planets



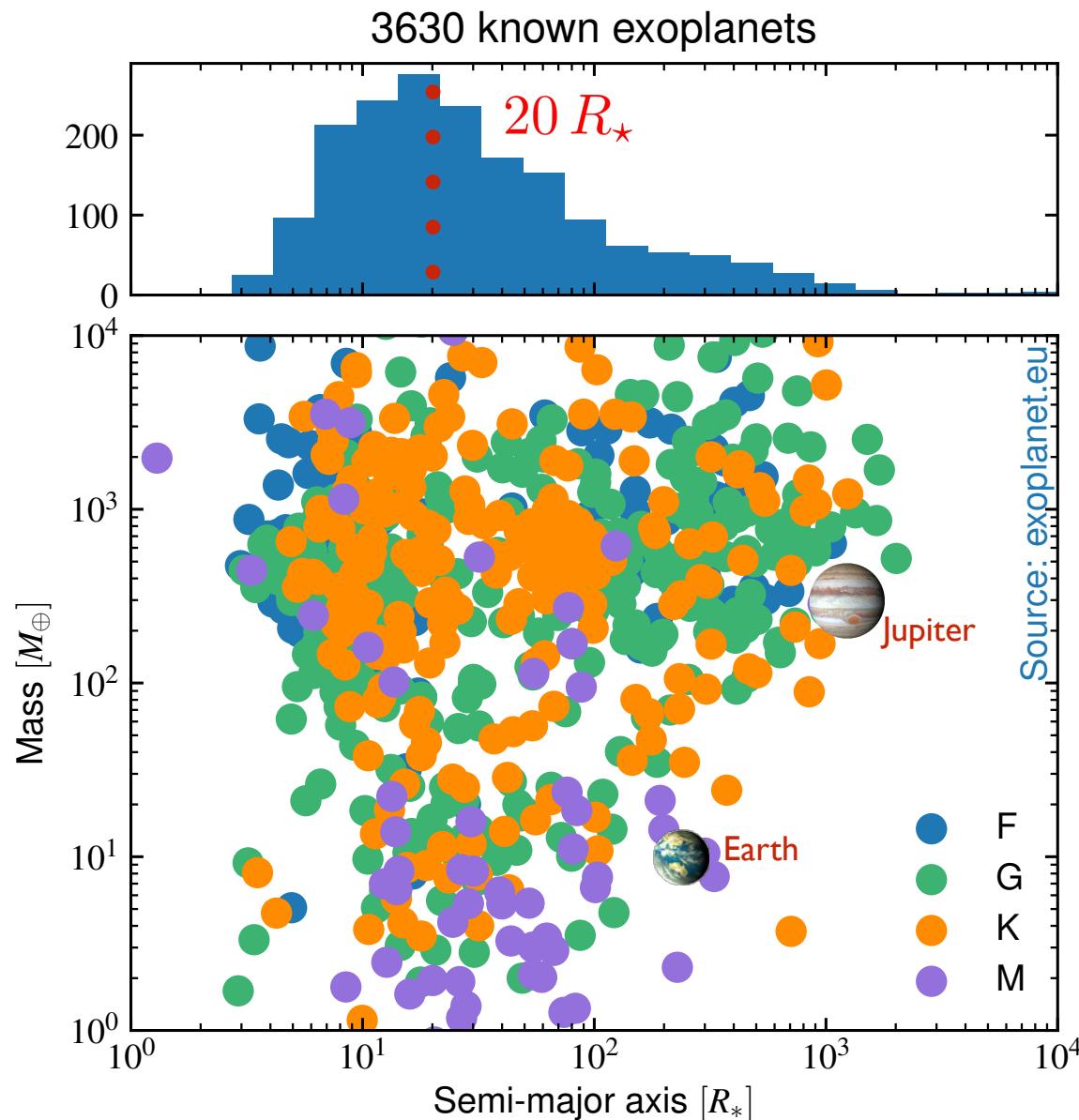
Antoine Strugarek

CEA/DAp/LDE3, France

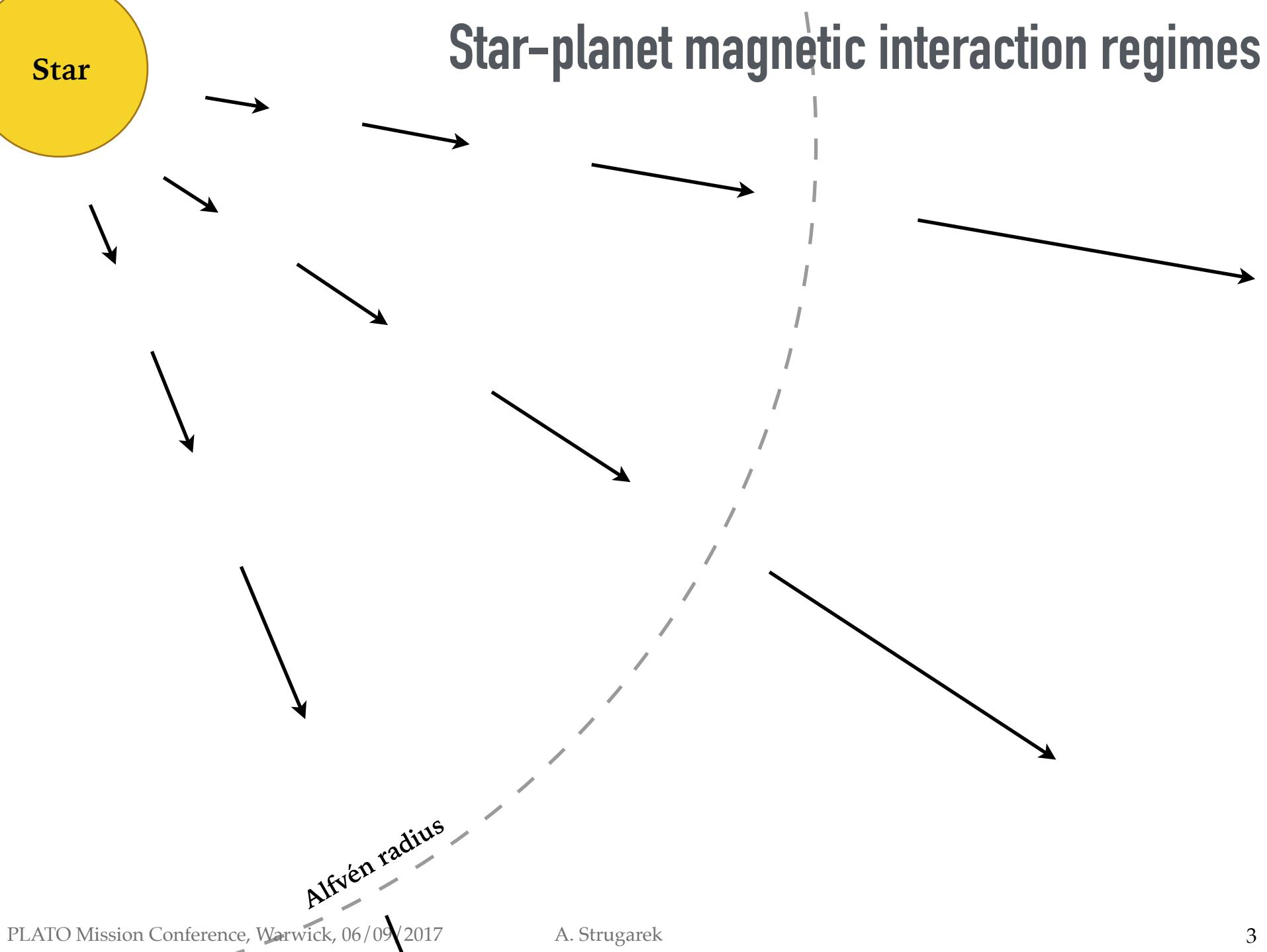
With V. Réville, A.S. Brun, S.P. Matt

E. Bolmont, S. Mathis,
J.F. Donati, C. Moutou,
F. Gallet, C. Charbonnel

We know a lot of very close exoplanets



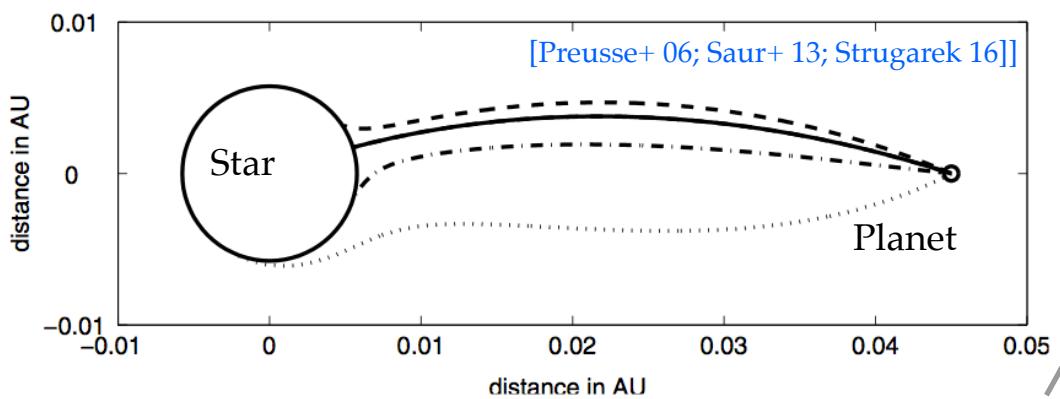
Star-planet magnetic interaction regimes



Star-planet magnetic interaction regimes



**Sub-Alfvénic interaction:
star-planet connection**

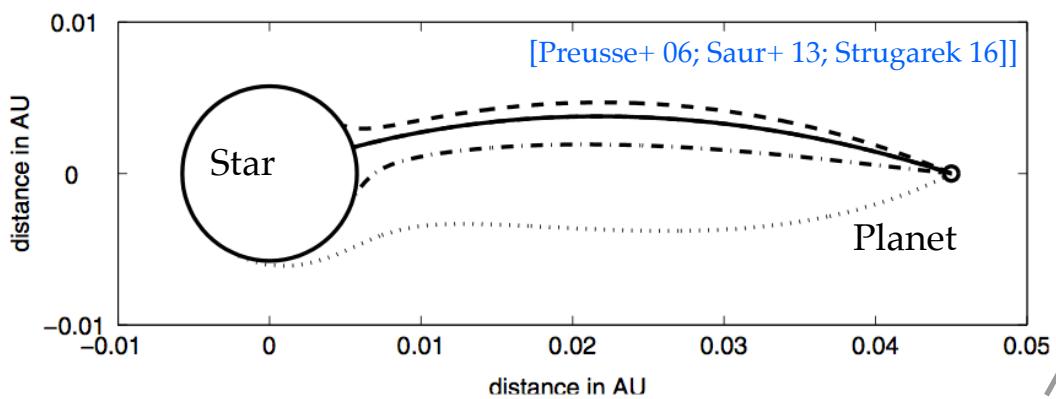


Alfvén radius

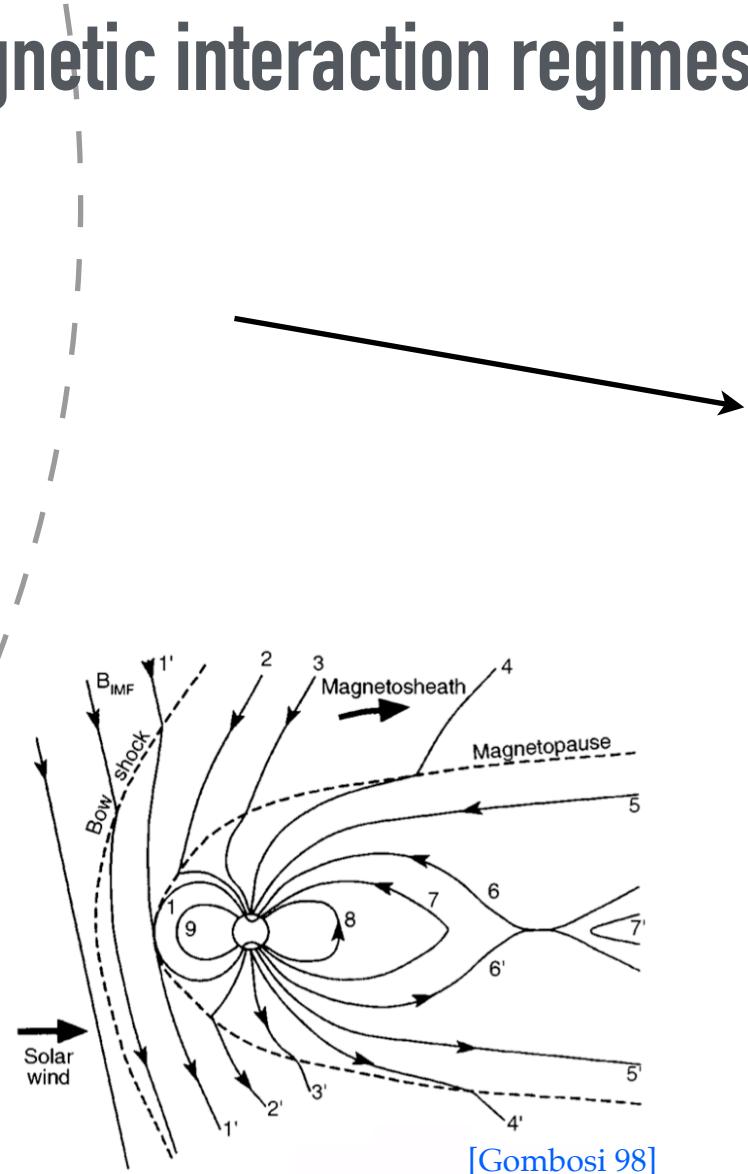
Star-planet magnetic interaction regimes



**Sub-Alfvénic interaction:
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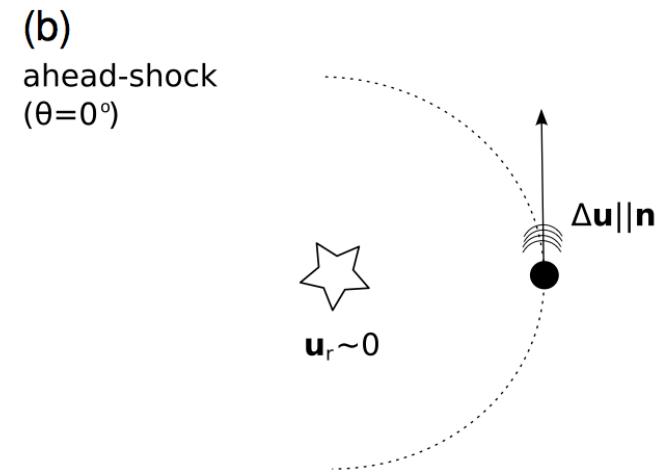
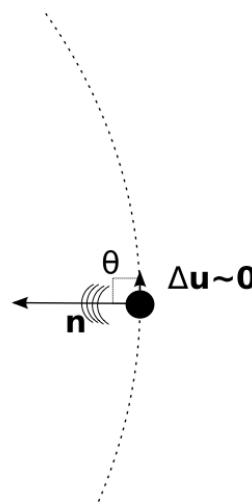
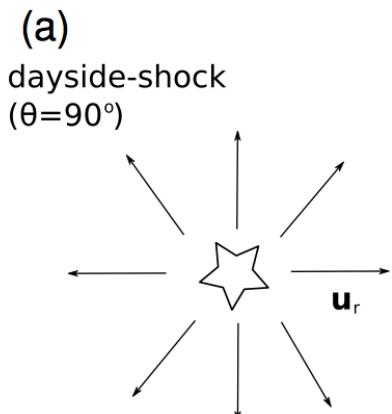


Alfvén radius

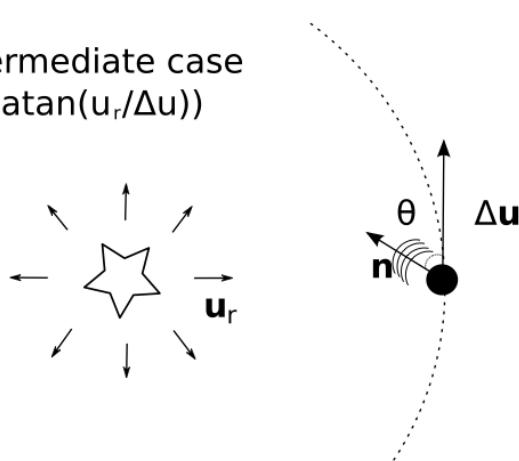


**Super-Alfvénic interaction:
shock formation**

Alfvénic regimes and shock geometry



(c)
intermediate case
($\theta=\text{atan}(u_r/\Delta u)$)



(d)
No shock is formed

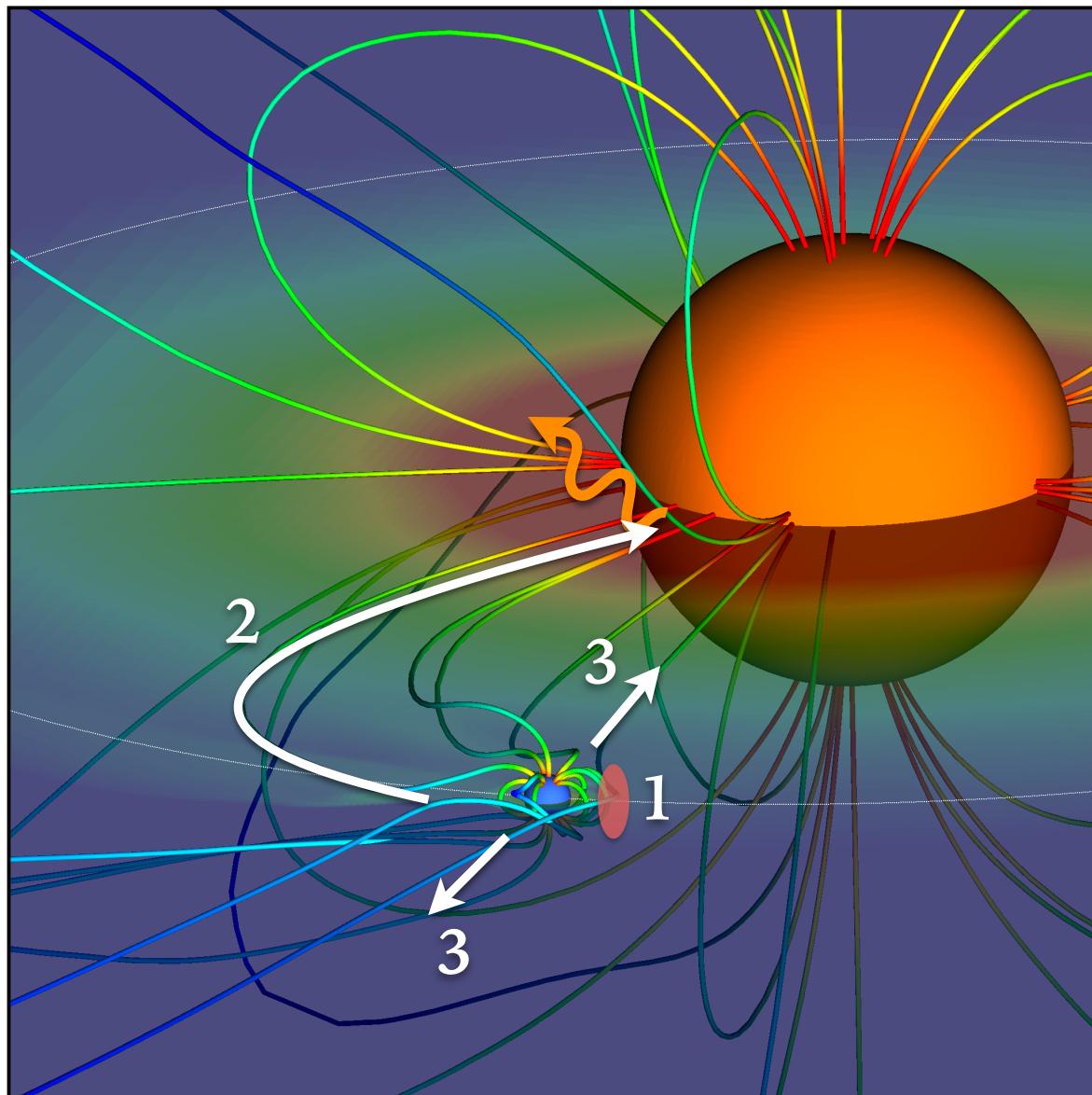
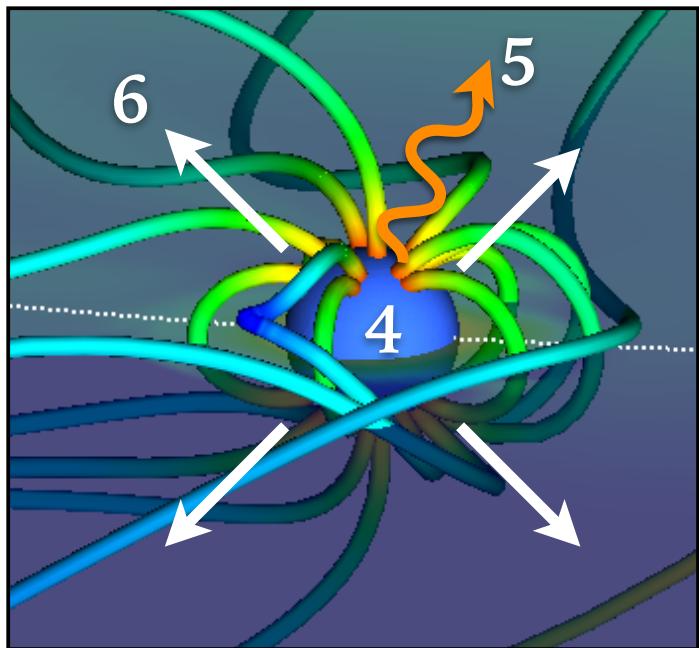
$$f = R_\star \Omega_\star (GM_\star/R_\star)^{-1/2}$$

$$v = v_{A\star} (GM_\star/R_\star)^{-1/2}$$

$$R_{\text{orb}} < R_{\text{crit}} = R_\star (f + v)^{-1/2}$$

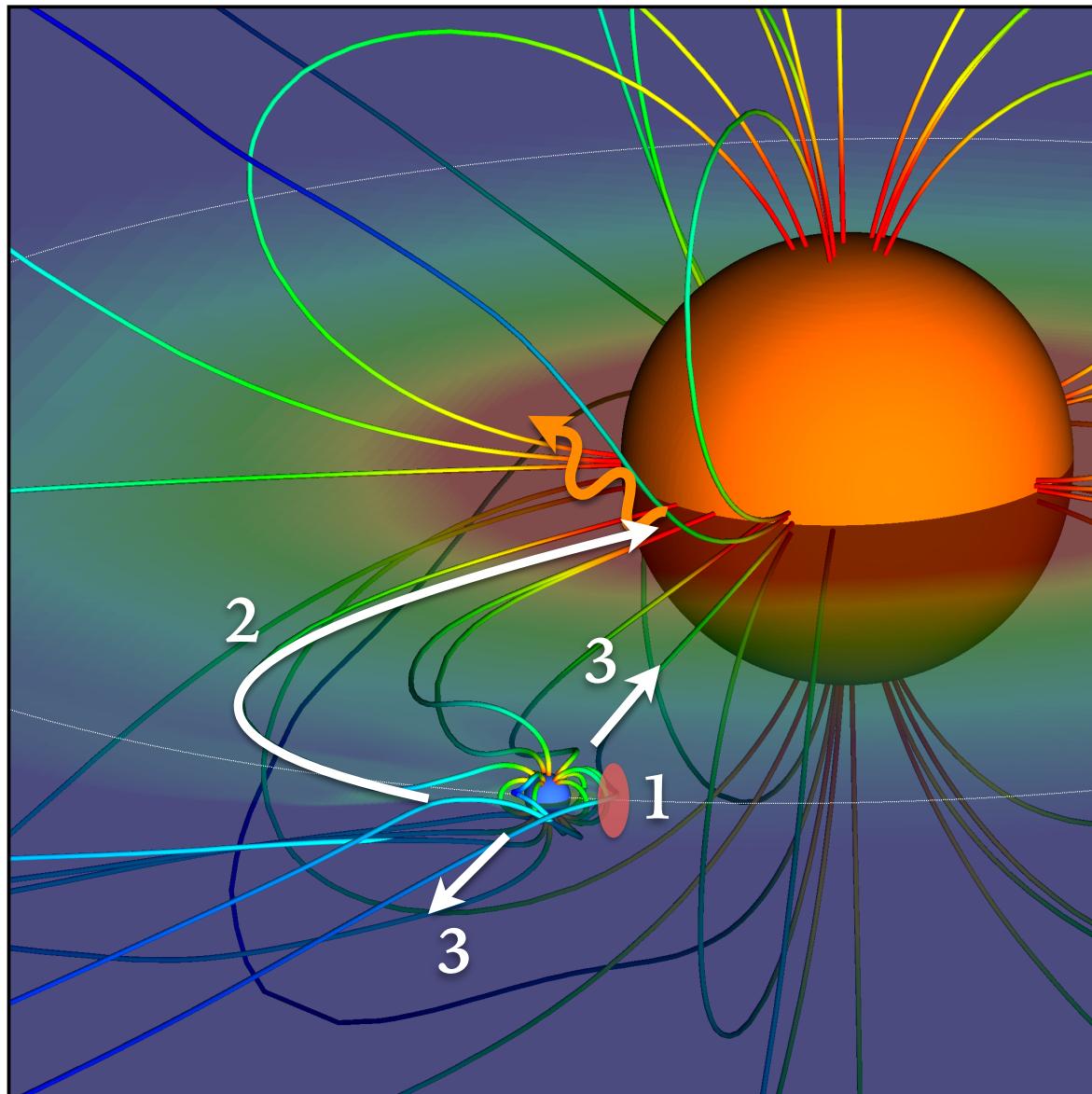
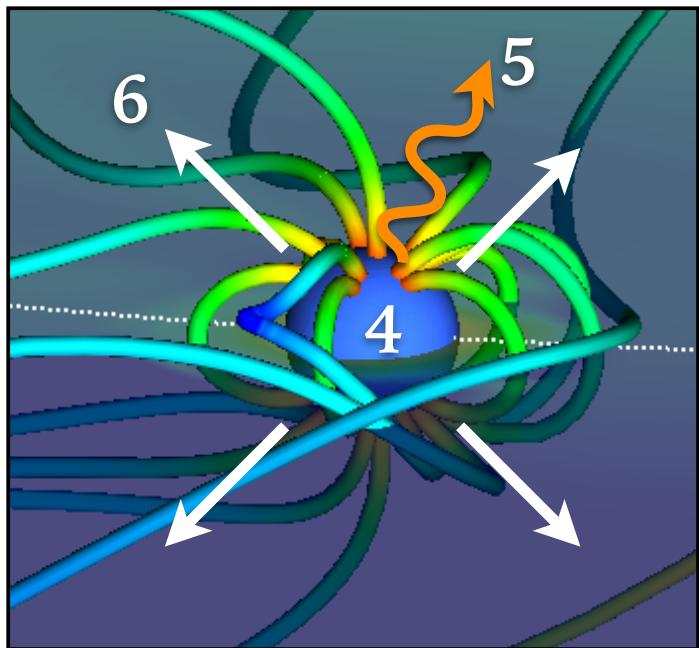
Main effects of magnetic star-planet interactions

1. MHD shock
2. Energy channeling
3. Planet migration
4. Planet heating
5. Planet emissions
6. Atmospheric escape



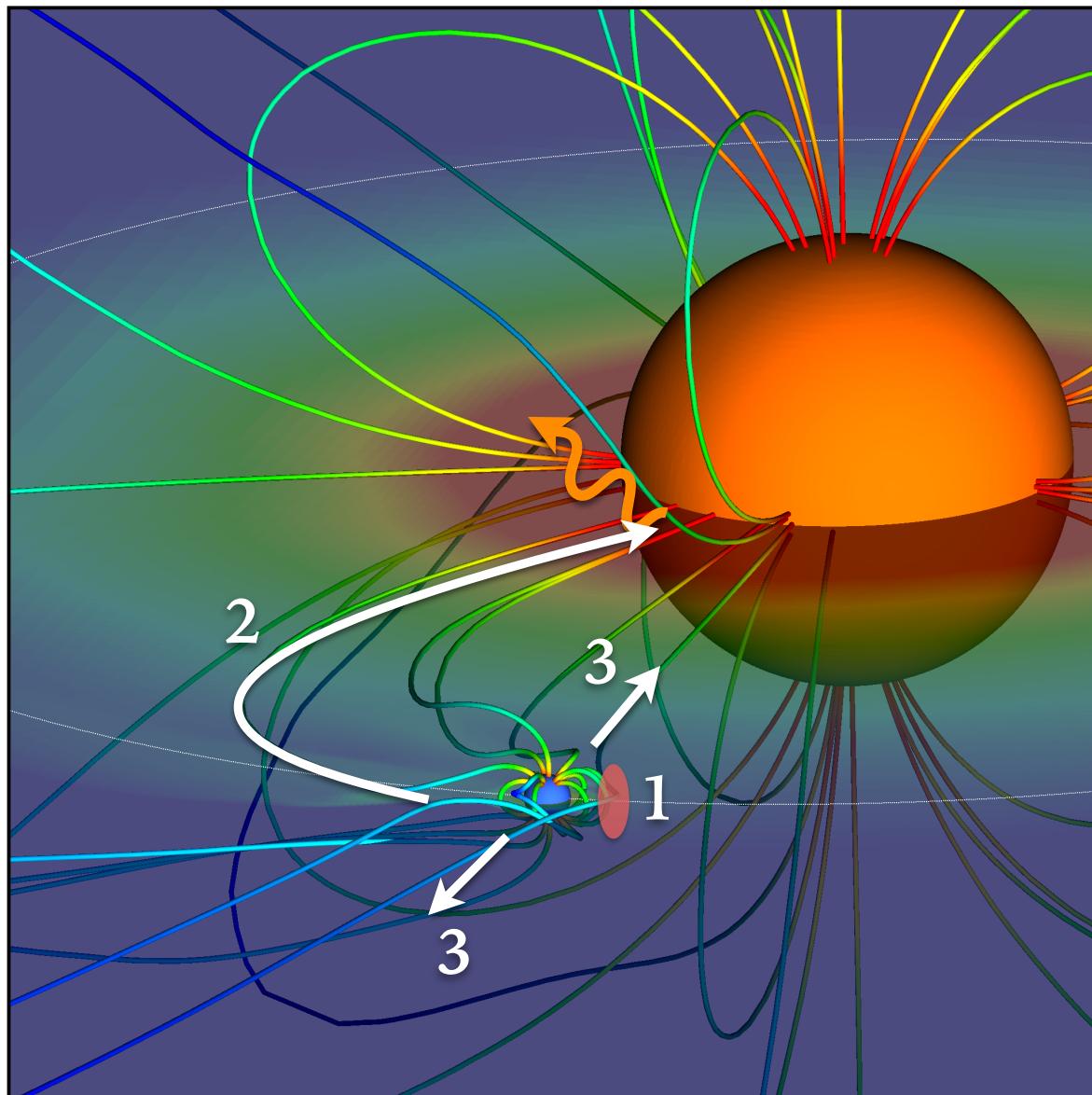
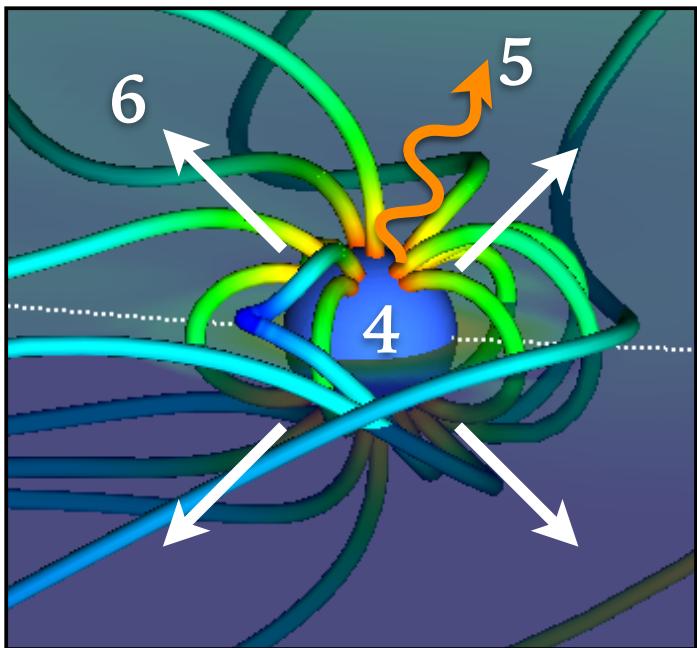
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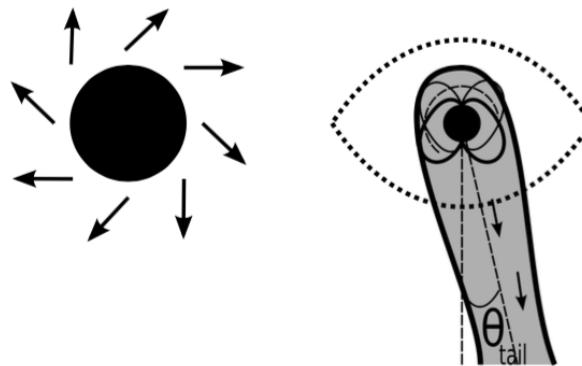
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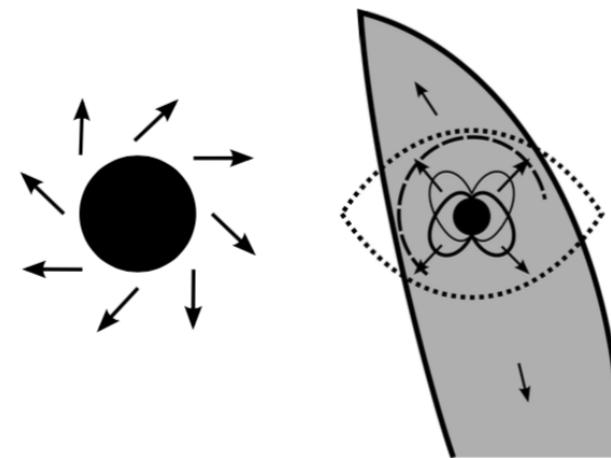


Planetary 'winds' and material accretion on the host

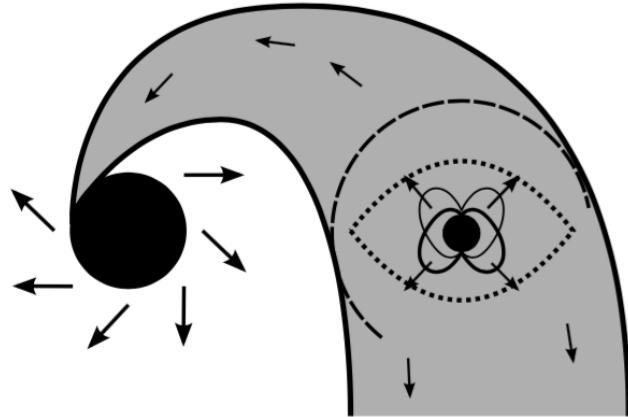
Type I: bowshock and thin tail



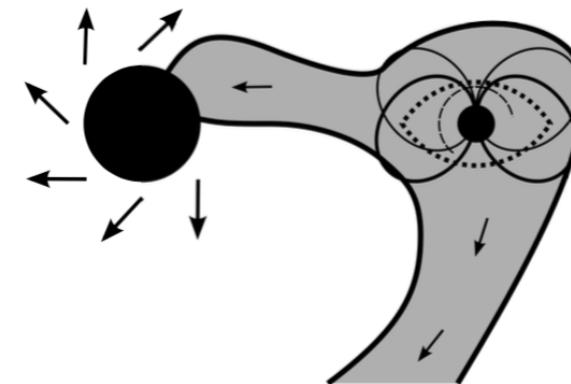
Type II: colliding winds and tail



Type III: strong planetary-wind, accretion and tail

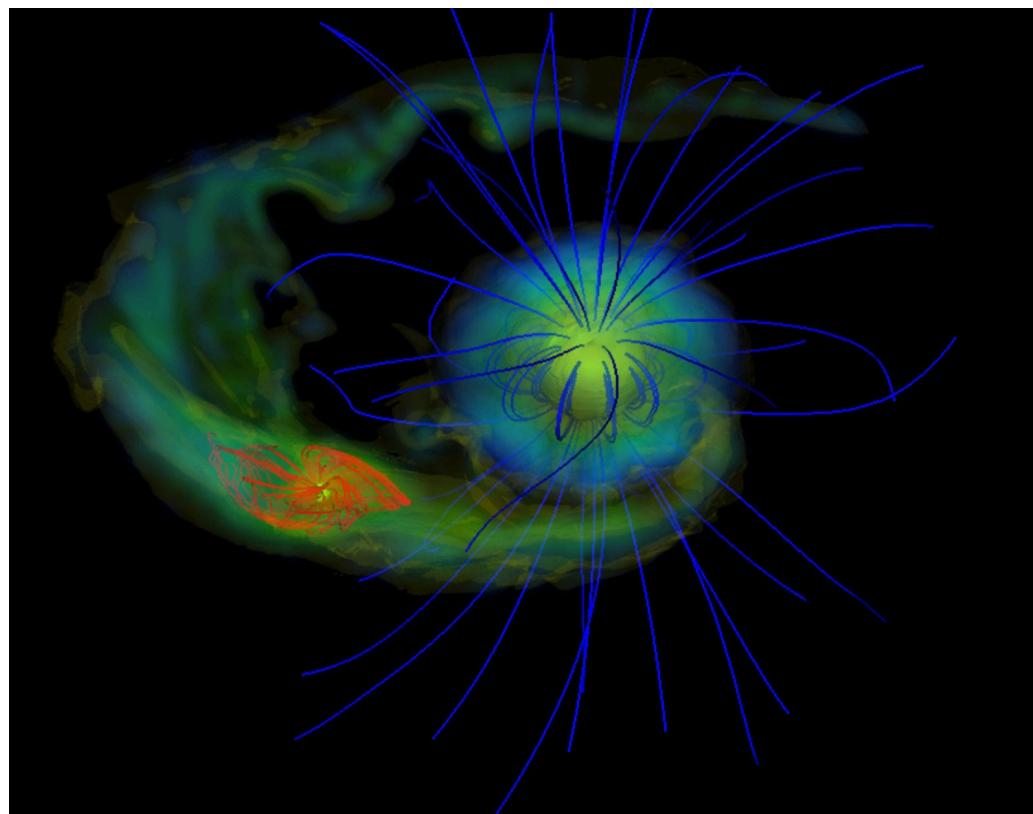
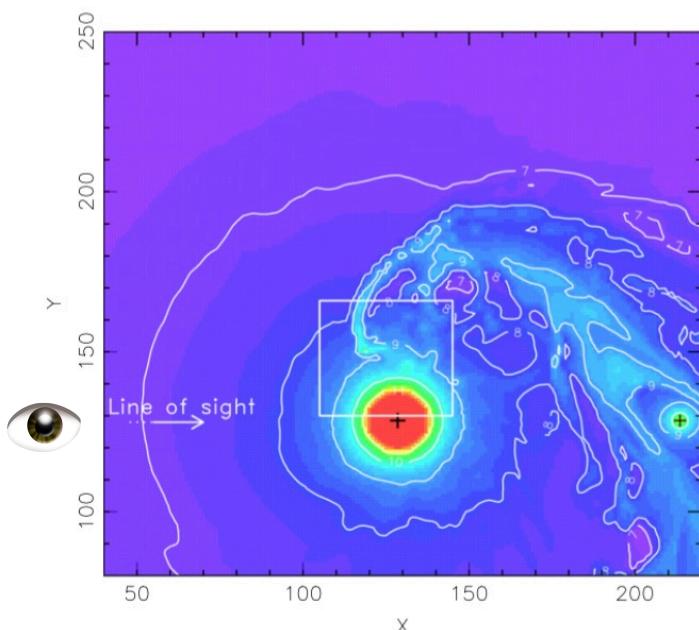


Type IV: Roche-lobe overflow, accretion and tail



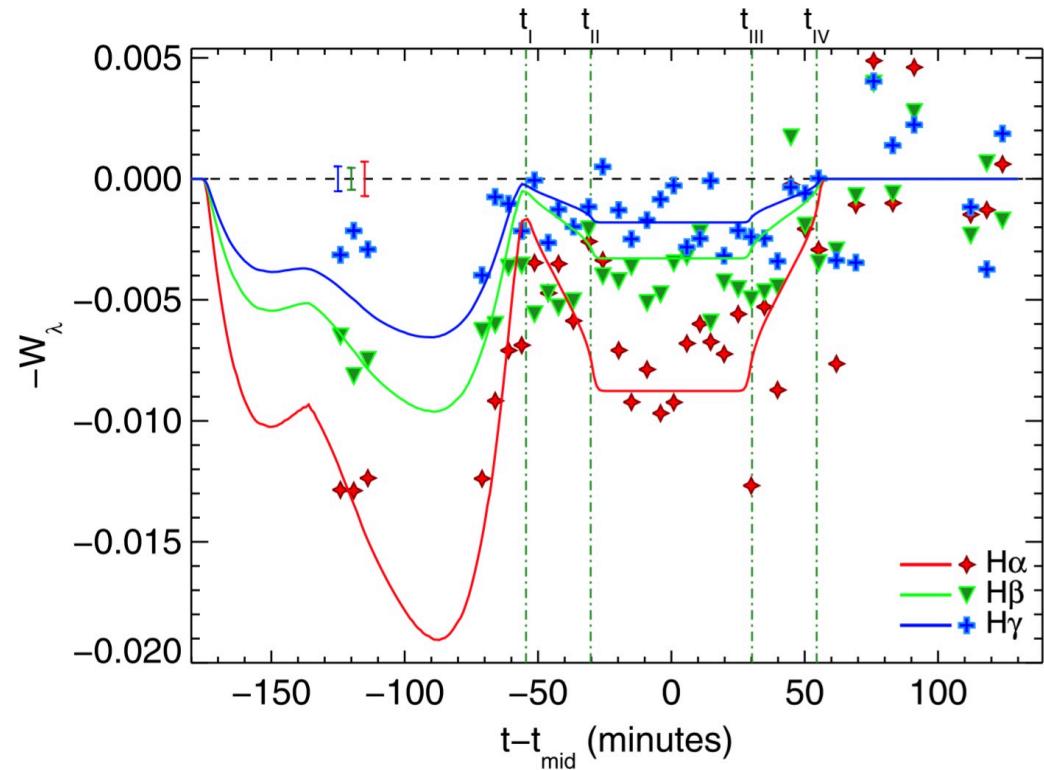
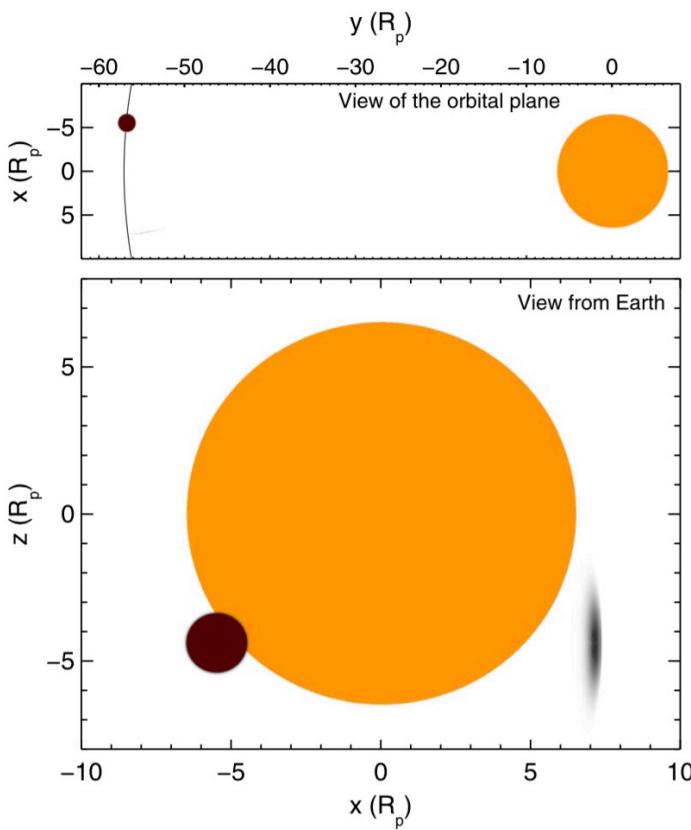
Planetary ‘winds’ and material accretion on the host

Different scenarii for the interaction, in some of them some planetary (atmospheric) material is able to fall onto the central star.



This mechanism promotes the monitoring of the central star **out of transit** due to the phase lag

Transit spectroscopy of HD 189733b: bow-shock trace?

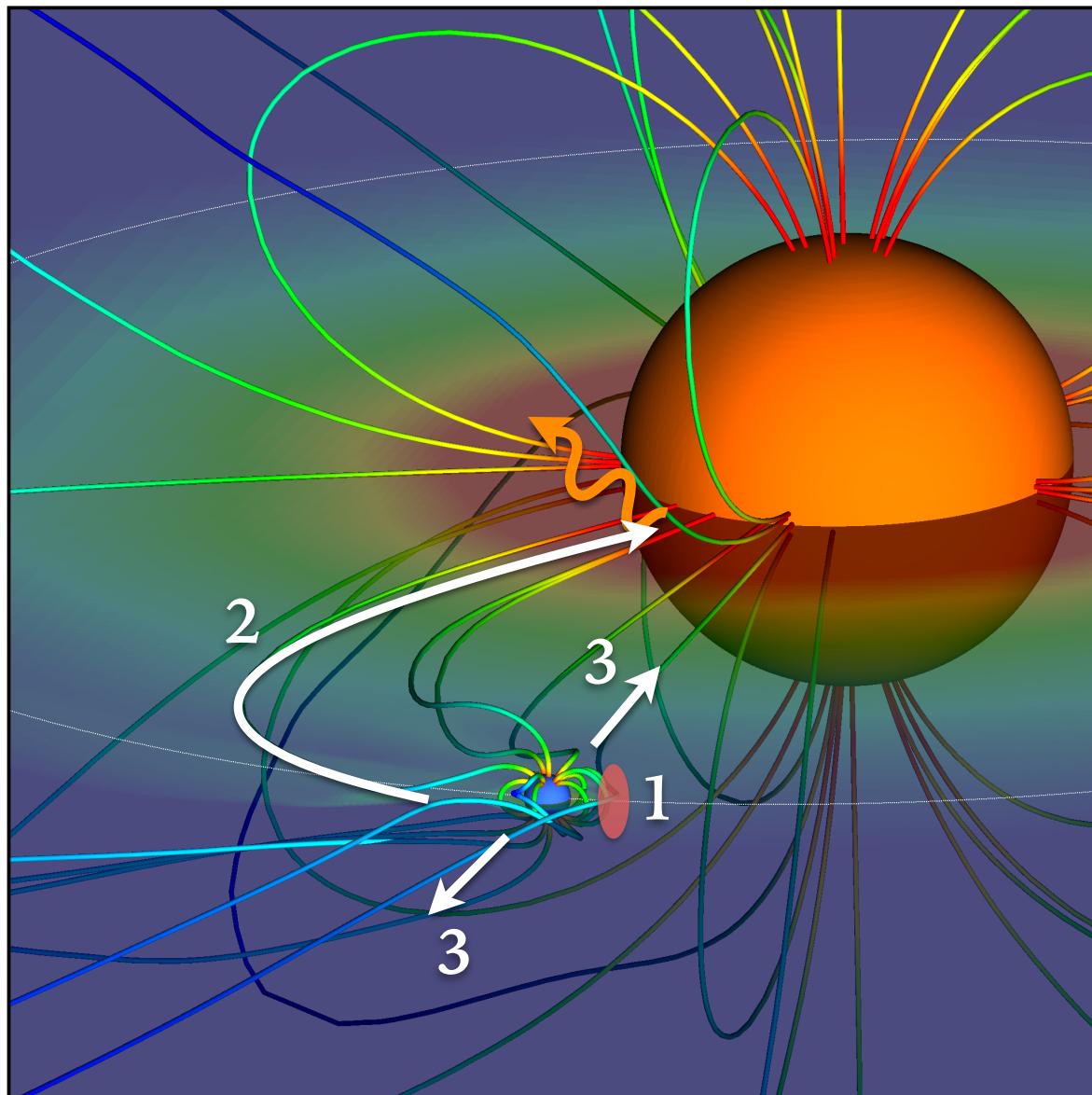
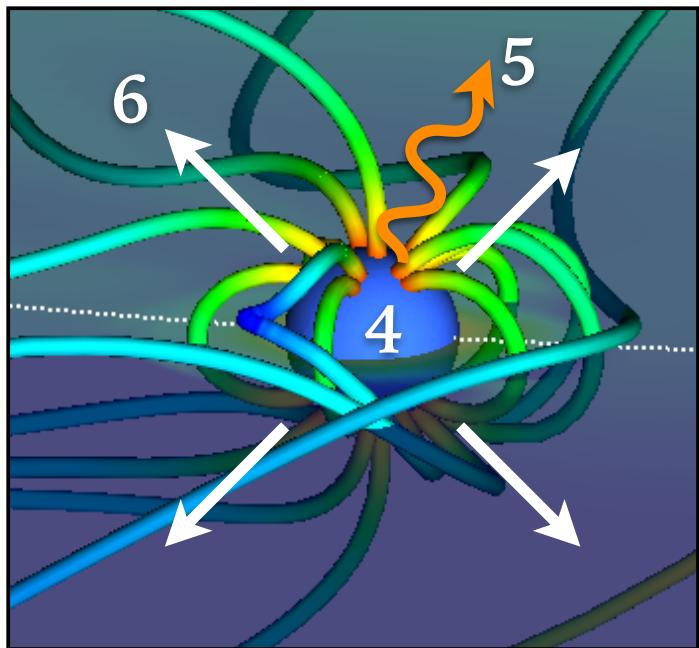


Missing data to confirm/refute scenario:

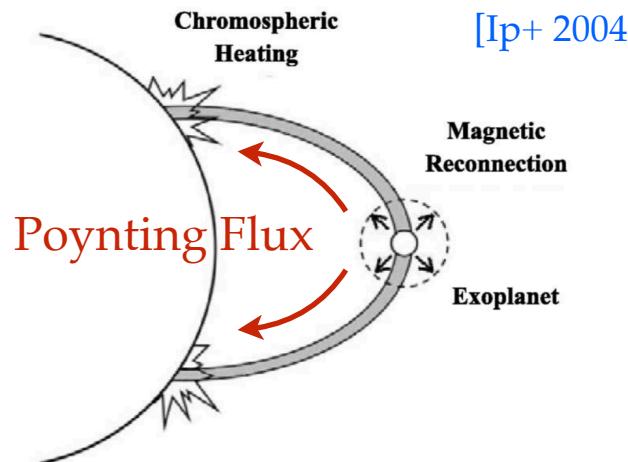
- Stellar magnetic topology/wind
- **More pre-transit observations**
- More realistic bow-shock model **(to constrain B_{planet})**

Main effects of magnetic star-planet interactions

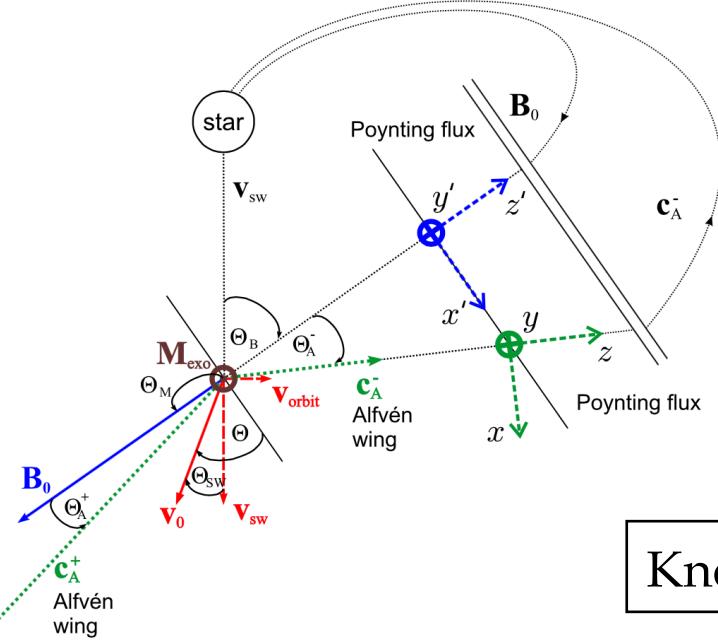
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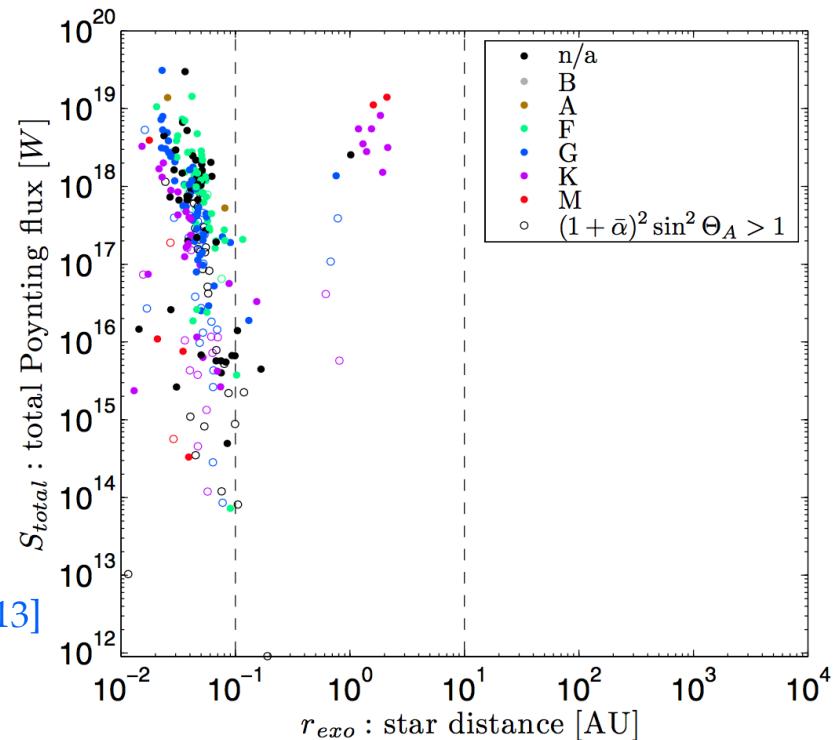
A first guess based on analytical models



[Ip+ 2004]

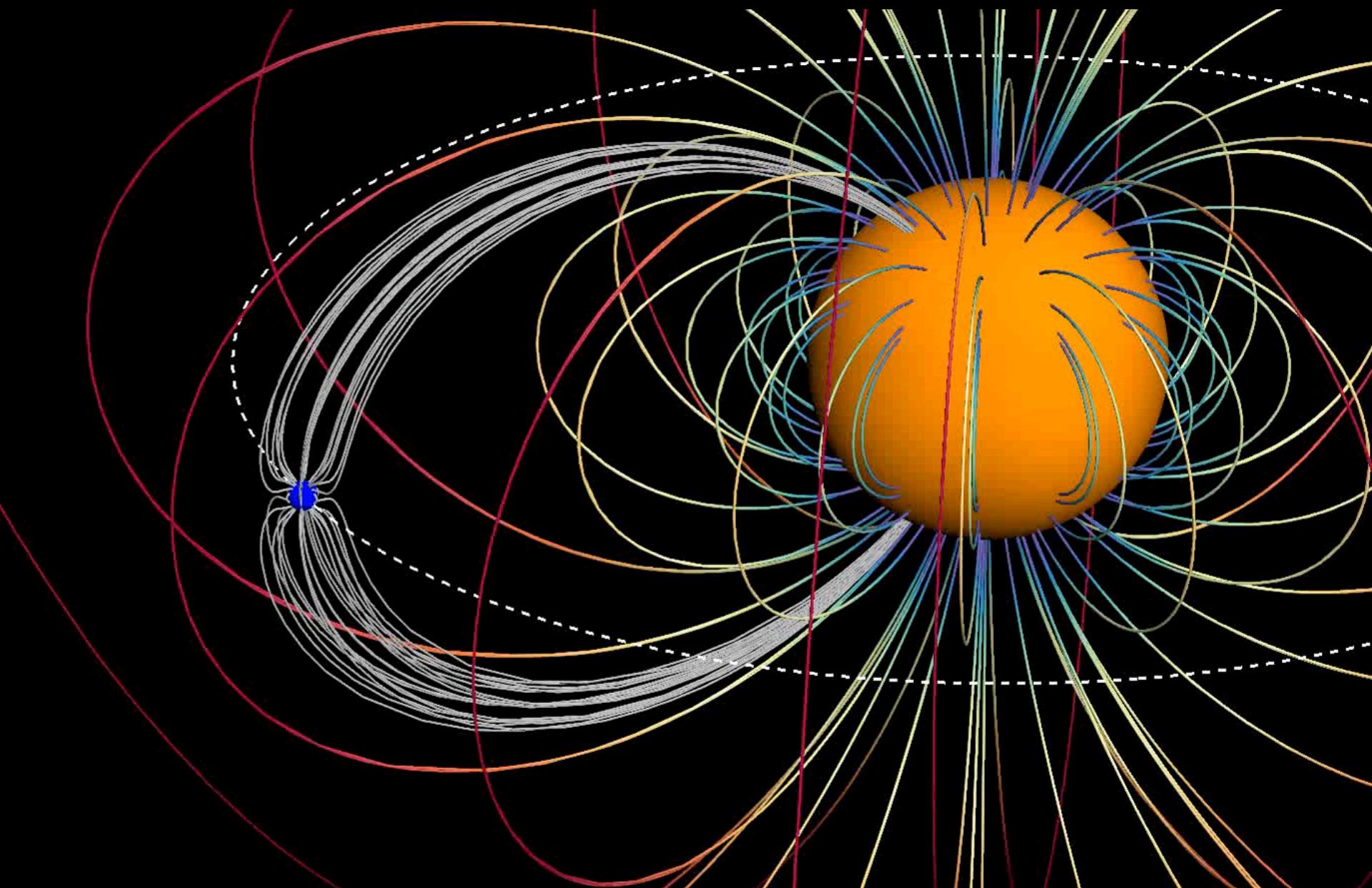


[Saur+ 2013]

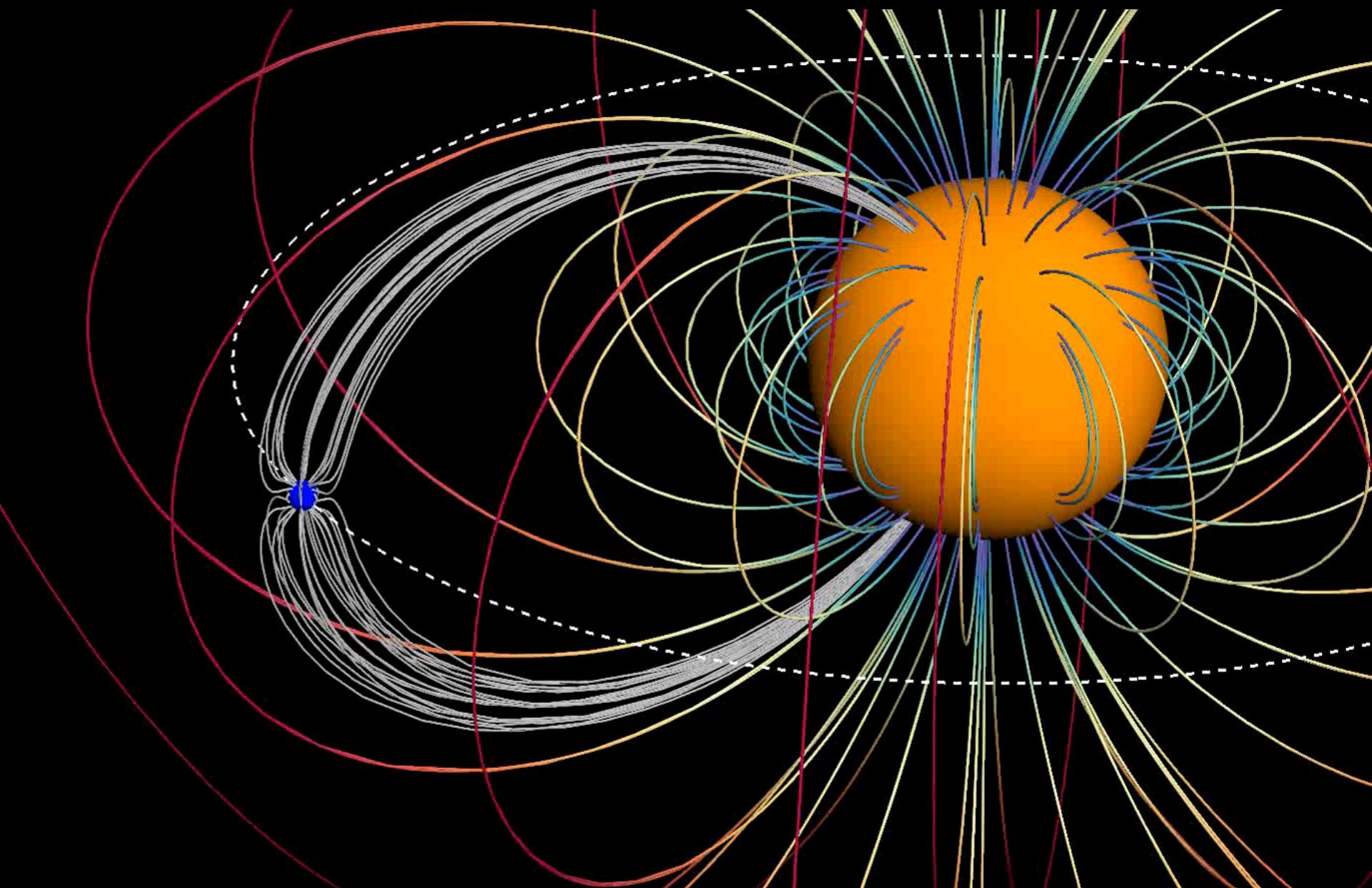


Known exo-planets: expected fluxes 10^{14} – 10^{20} W

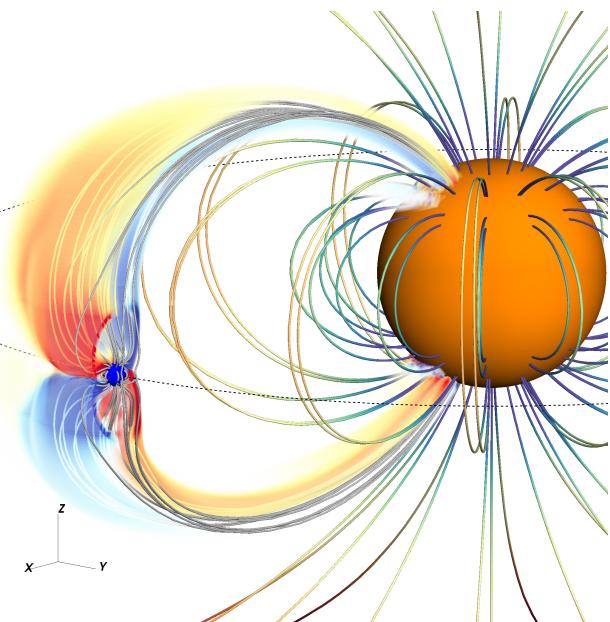
3D modelling of magnetic star-planet interactions



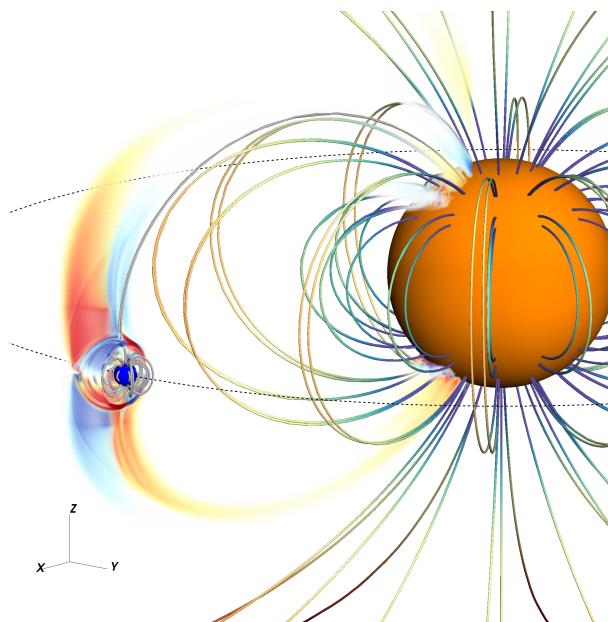
3D modelling of magnetic star-planet interactions



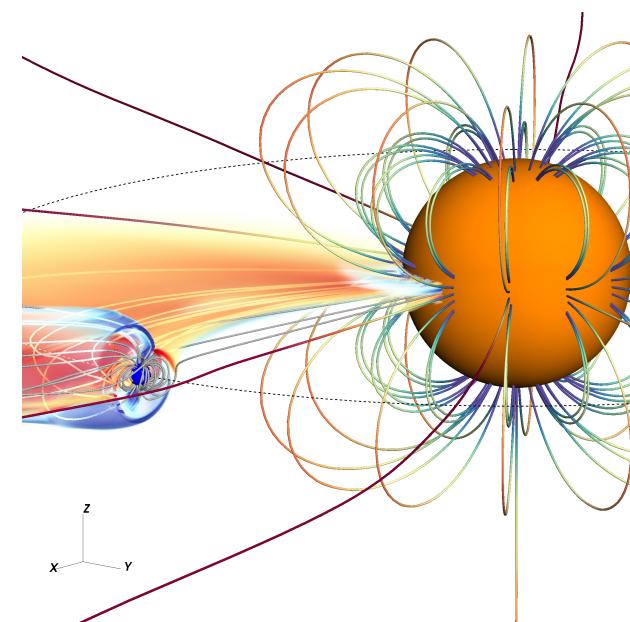
3D modelling of star–planet interactions: topology effects



Two strong Alfvén wings



Two weak Alfvén wings

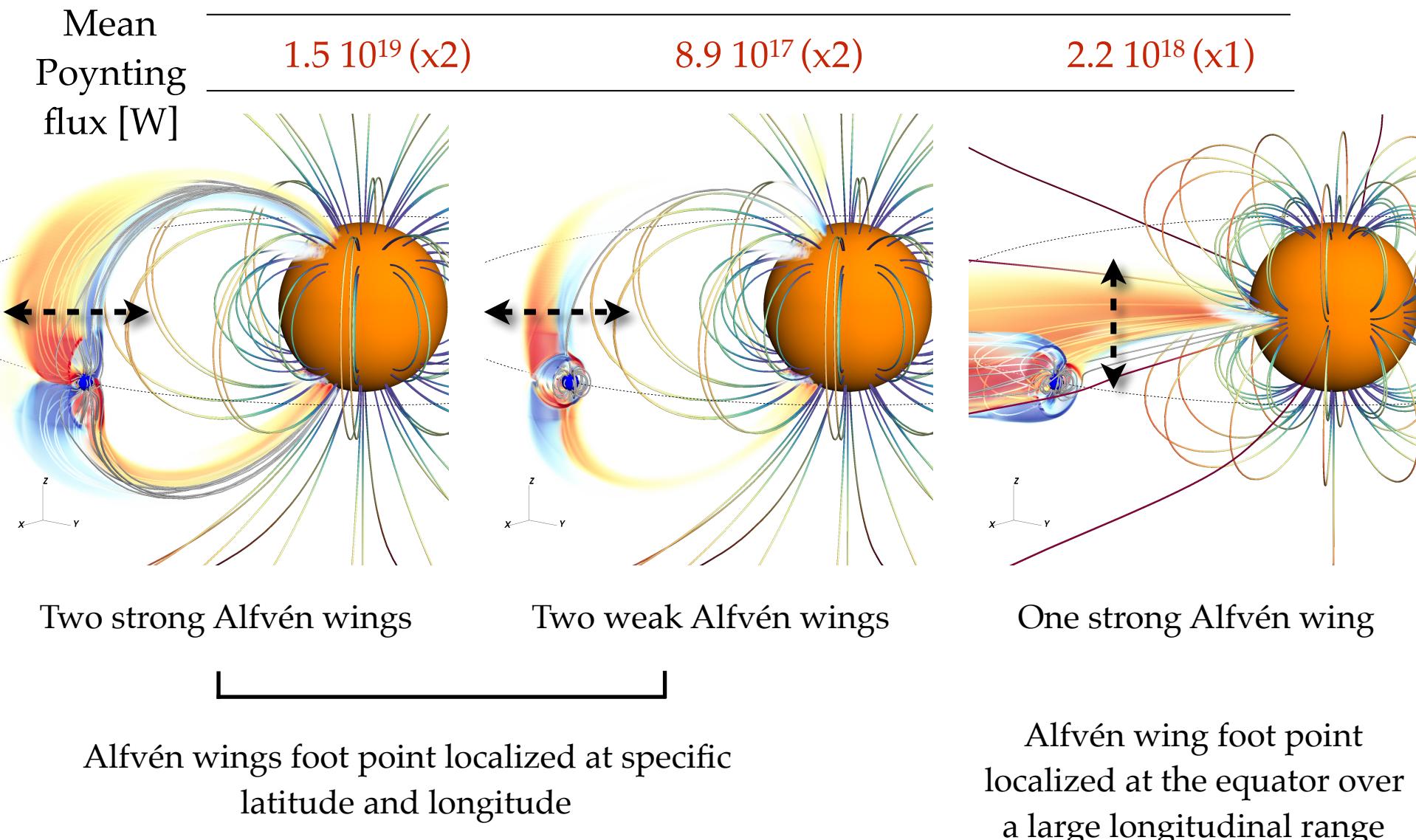


One strong Alfvén wing

Alfvén wings foot point localized at specific latitude and longitude

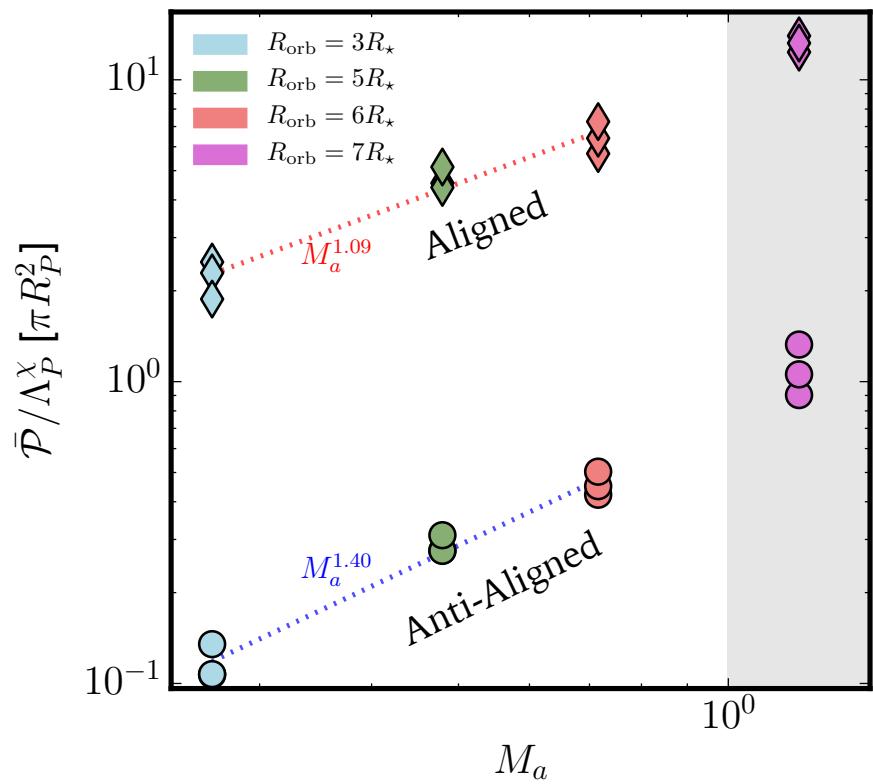
Alfvén wing foot point localized at the equator over a large longitudinal range

3D modelling of star-planet interactions: topology effects



Poynting flux in Alfvén wings: parametrization

$$\mathcal{P} = A_1 \pi \left(c_d S_w M_a^\xi \bar{\eta}_a^{\nu_3} \right) \cdot \left(R_P^2 \bar{\eta}_P^{\nu_4} \right) \cdot \left(\Lambda_P^\chi \right)$$



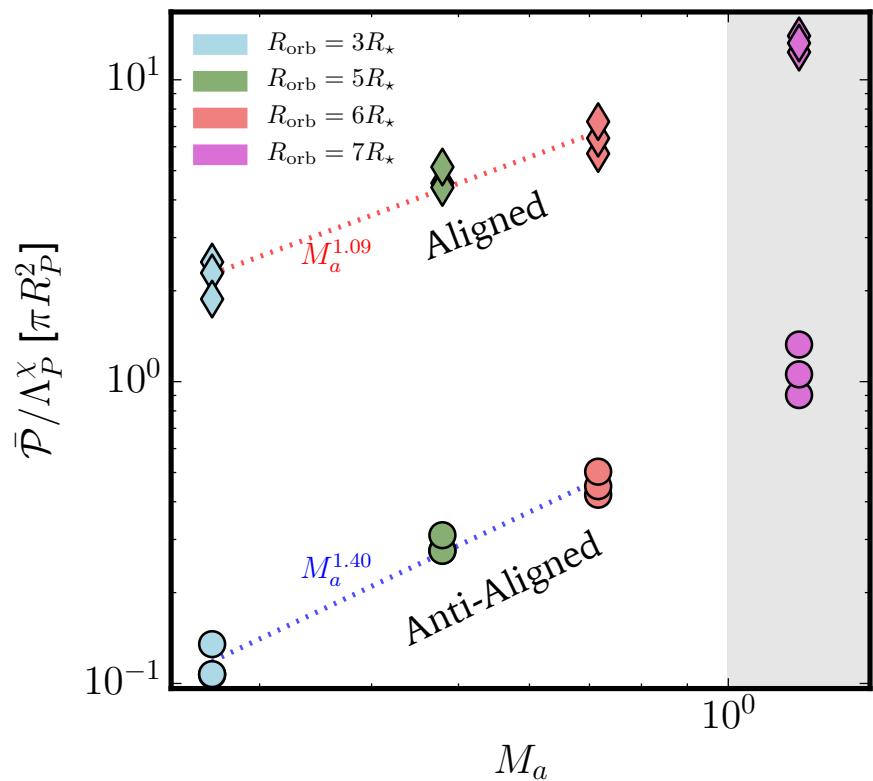
Poynting flux in Alfvén wings: parametrization

Poynting flux Reconnection eff.

$$\mathcal{P} = A_1 \pi \left(c_d S_w M_a^\xi \bar{\eta}_a^{\nu_3} \right) \cdot \left(R_P^2 \bar{\eta}_P^{\nu_4} \right) \cdot \left(\Lambda_P^\chi \right)$$

drag coeff. Alf. Mach

Wind-dependant parameters
(magnetic field, density, velocity)

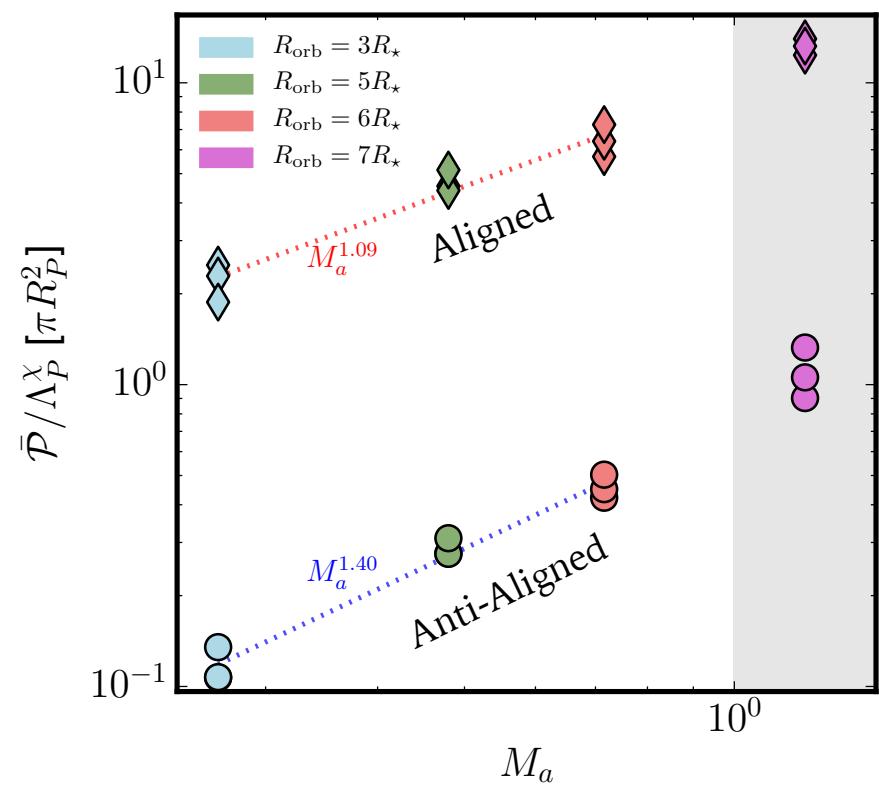


Poynting flux in Alfvén wings: parametrization

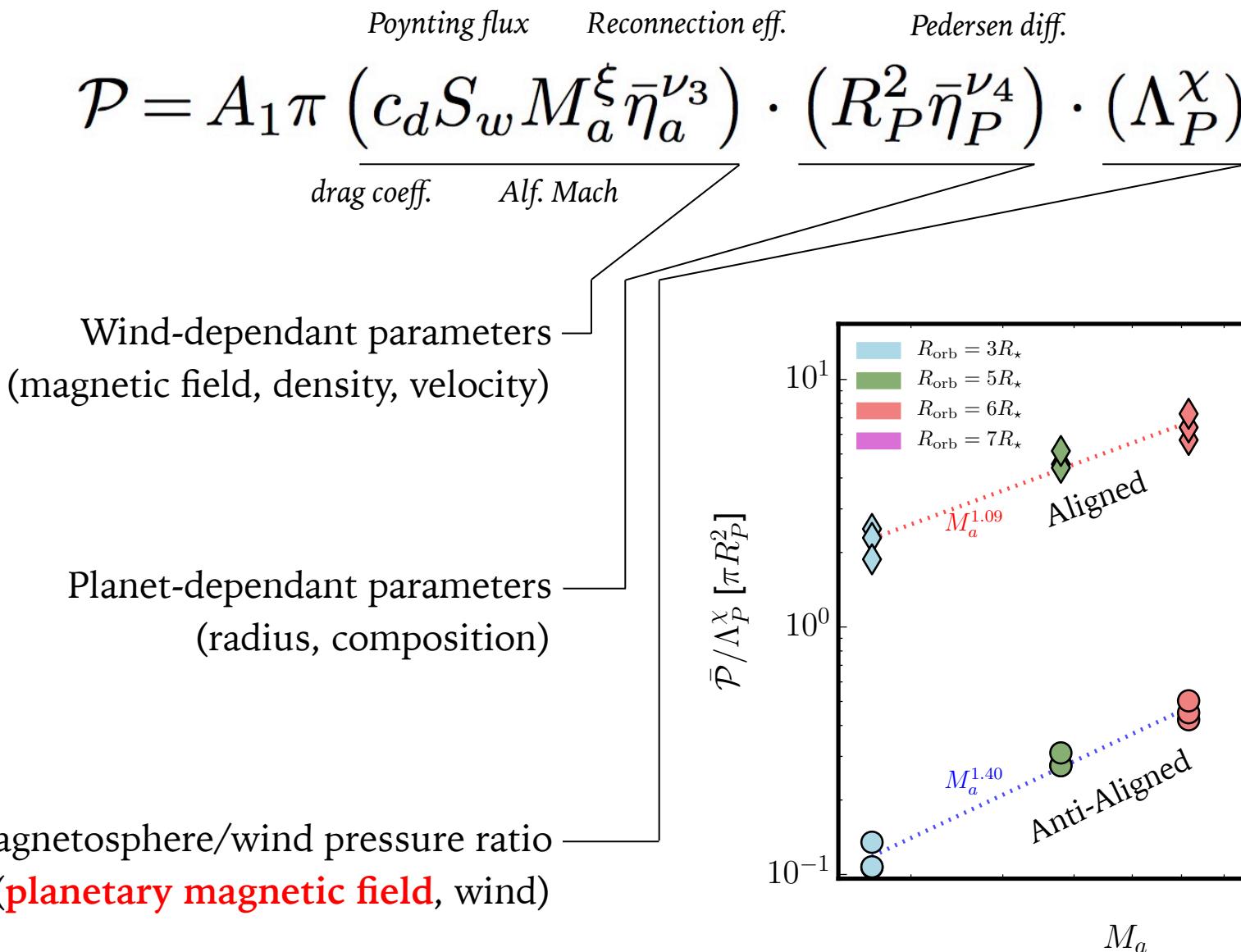
$$\mathcal{P} = A_1 \pi \underbrace{\left(c_d S_w M_a^\xi \bar{\eta}_a^{\nu_3} \right)}_{\text{drag coeff.}} \cdot \underbrace{\left(R_P^2 \bar{\eta}_P^{\nu_4} \right)}_{\text{Alf. Mach}} \cdot \underbrace{\left(\Lambda_P^\chi \right)}_{\text{Pedersen diff.}}$$

Wind-dependant parameters
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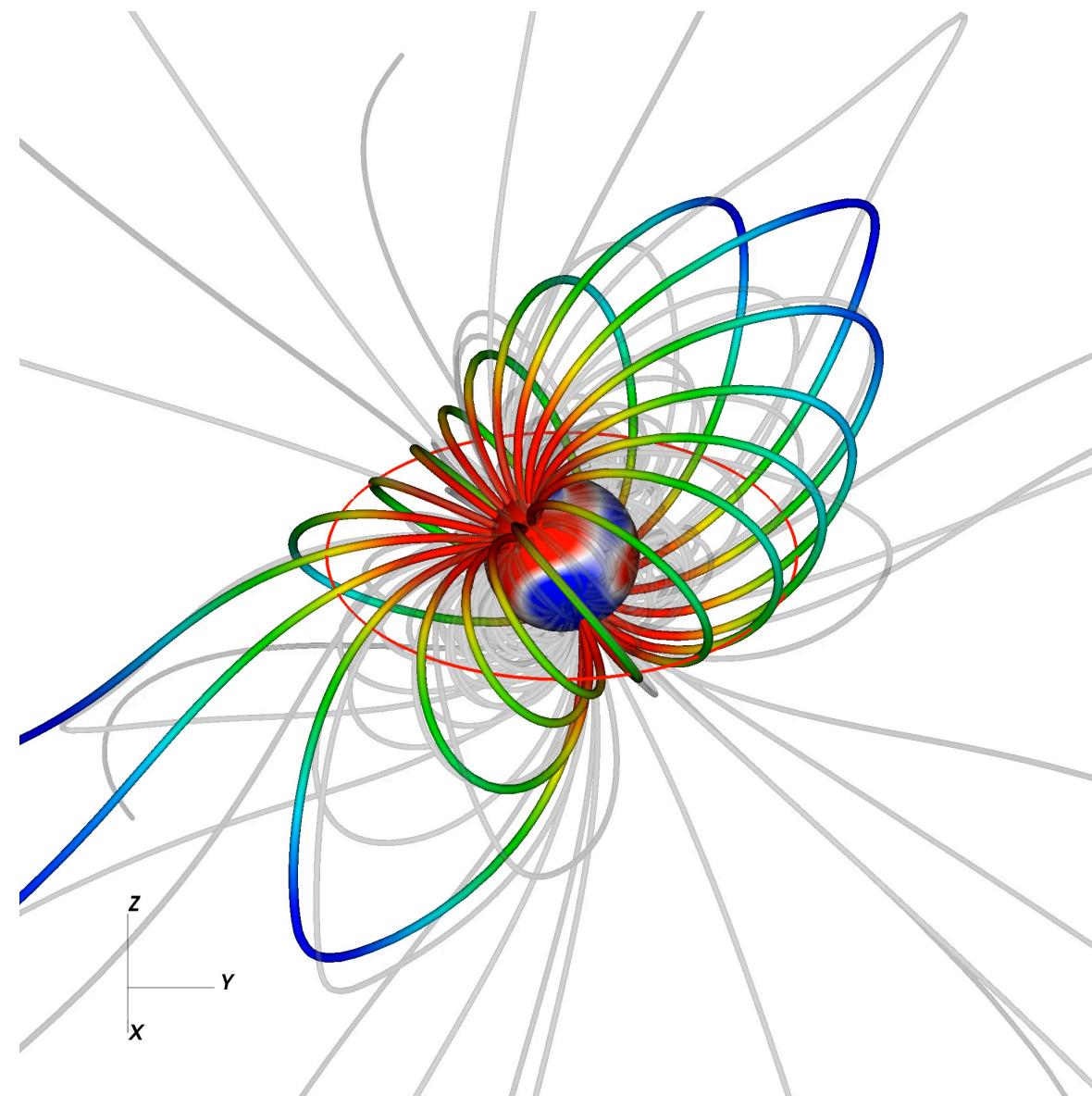
Planet-dependant parameters
(radius, composition)



Poynting flux in Alfvén wings: parametrization



Application: Kepler 78 wind model using an observed ZDI map

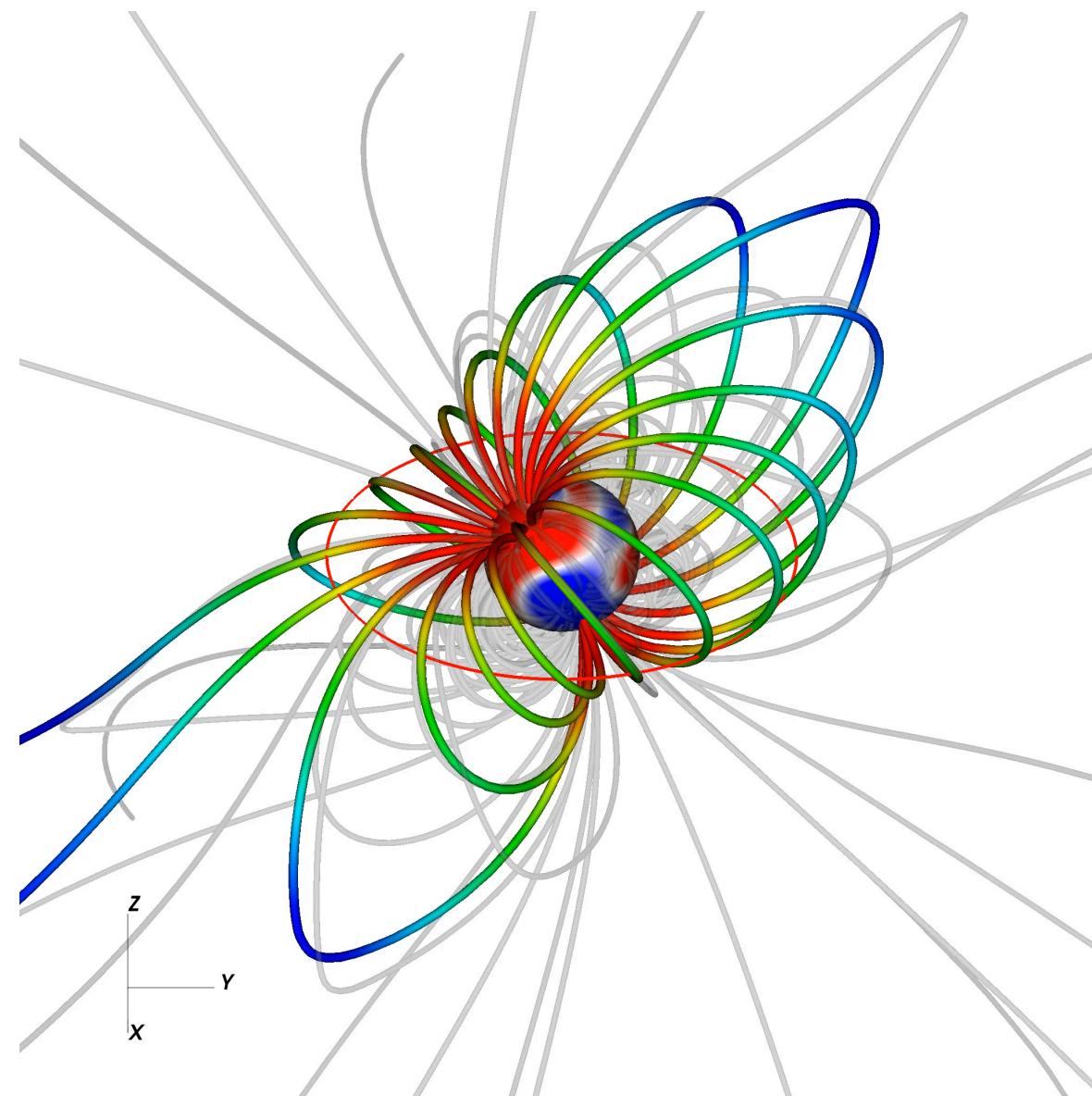


Stellar and Planet parameters

T_{eff} [K]	5089 ± 50
M_{\star} [M_{\odot}]	0.81 ± 0.08
R_{\star} [R_{\odot}]	$0.74 +0.1,-0.8$
P_{rot} [days]	12.5

R_p [R_{\oplus}]	$1.16 +0.19,-0.14$
M_p^1 [M_{\oplus}]	1.86 ± 0.25
R_{orb} [R_{\star}]	$3.0 +0.5,-1.0$

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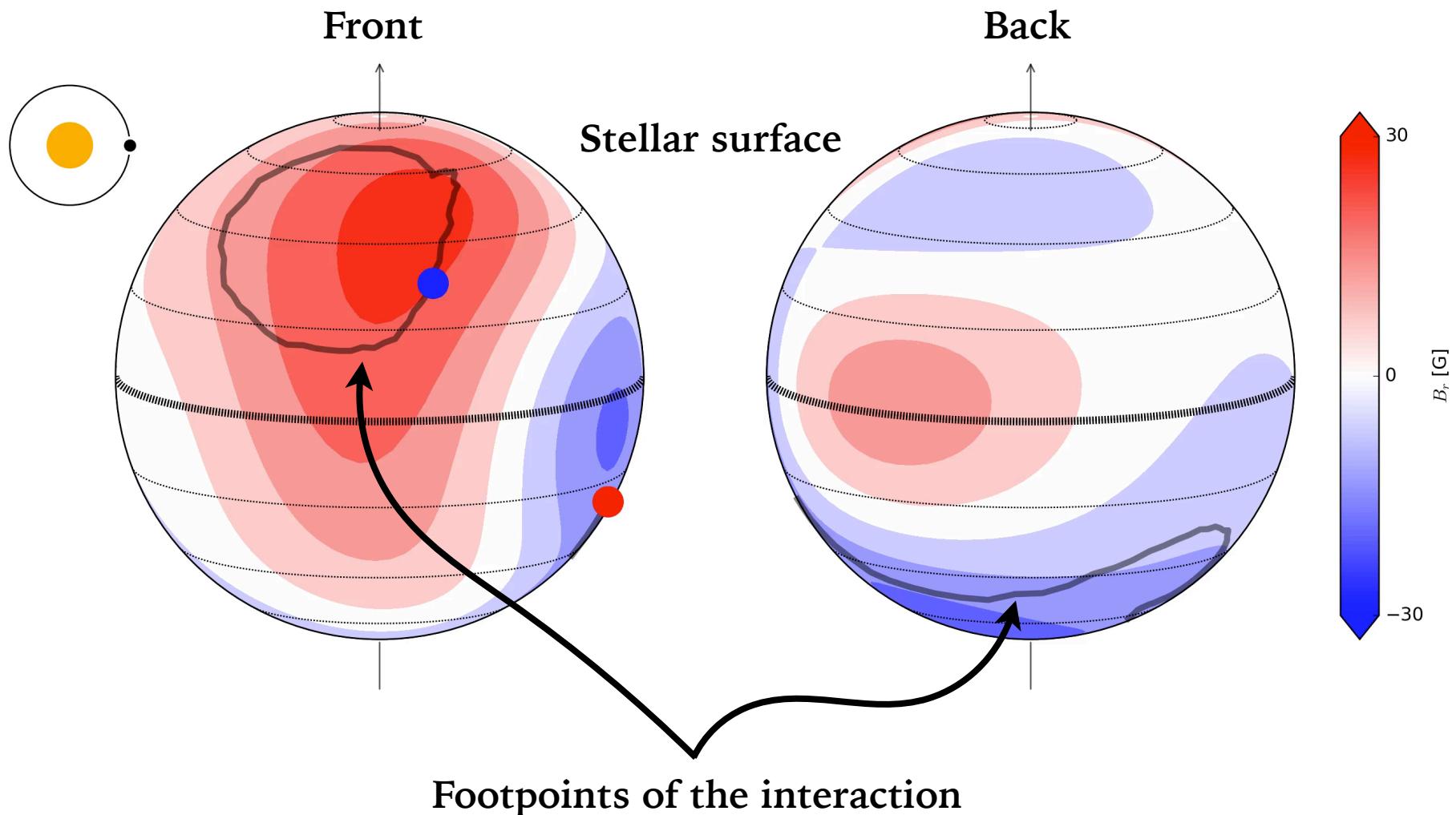


Stellar and Planet parameters

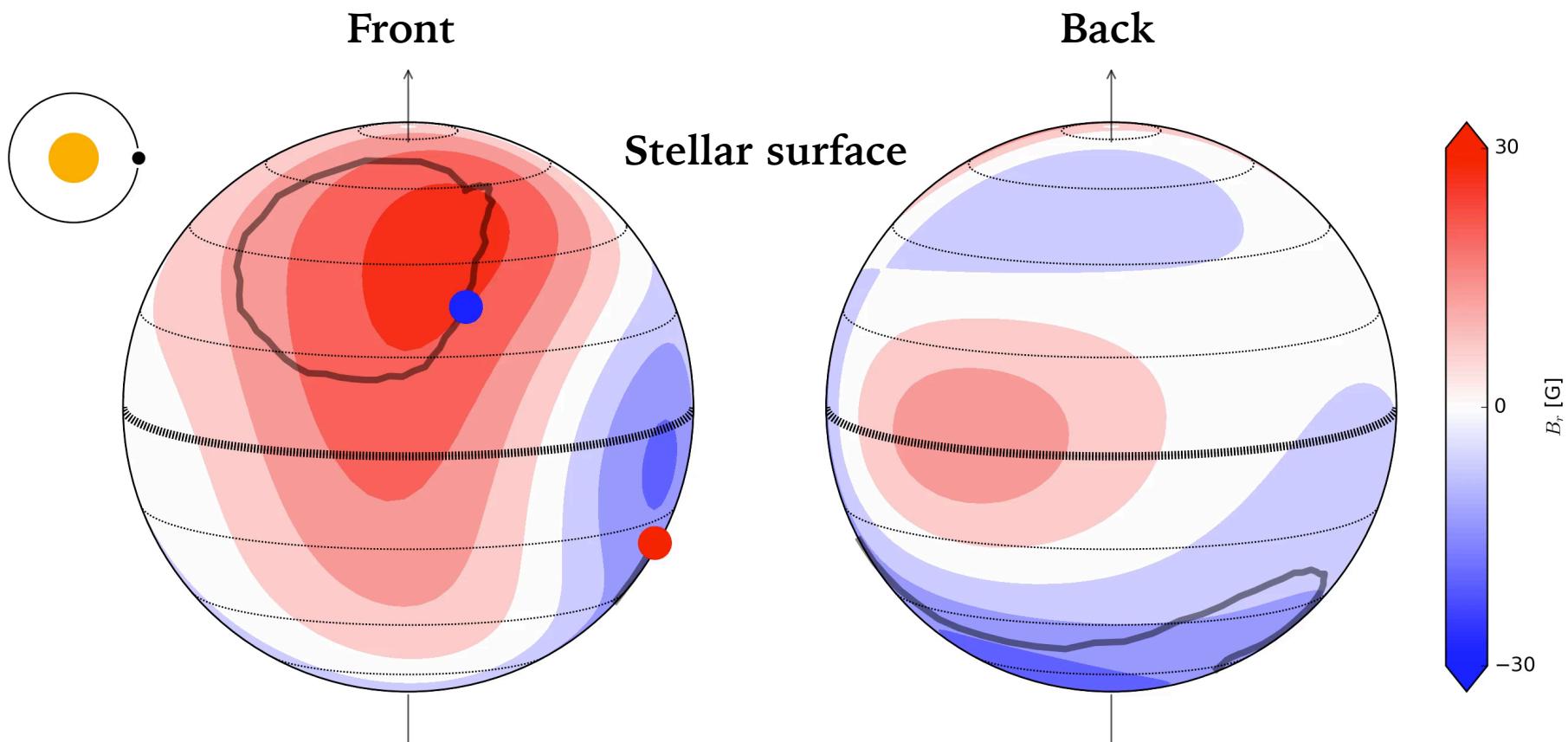
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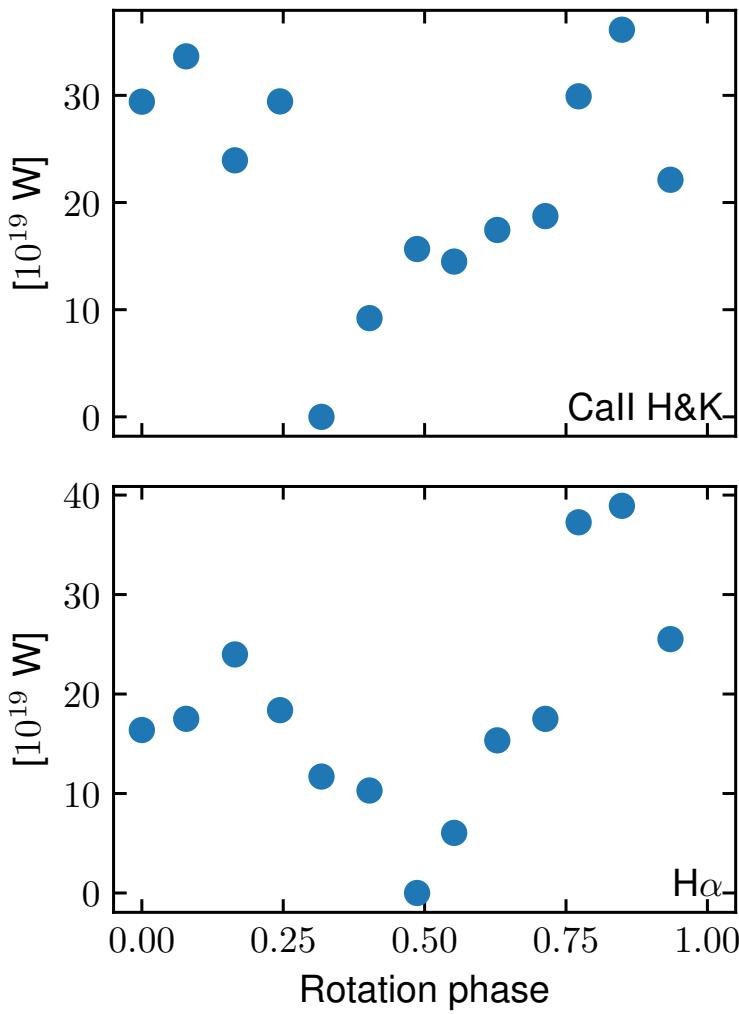
Footpoints of the interaction at the stellar surface



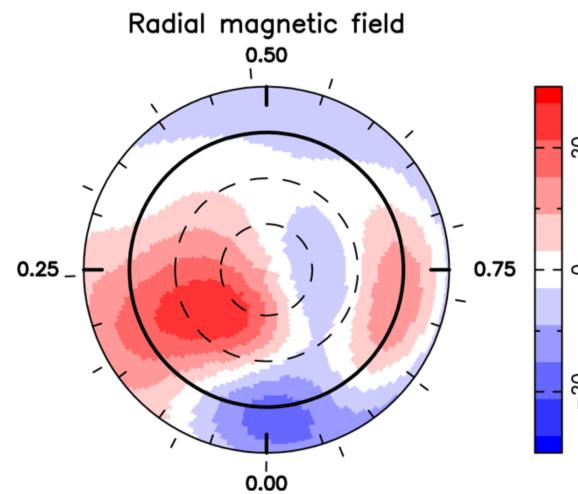
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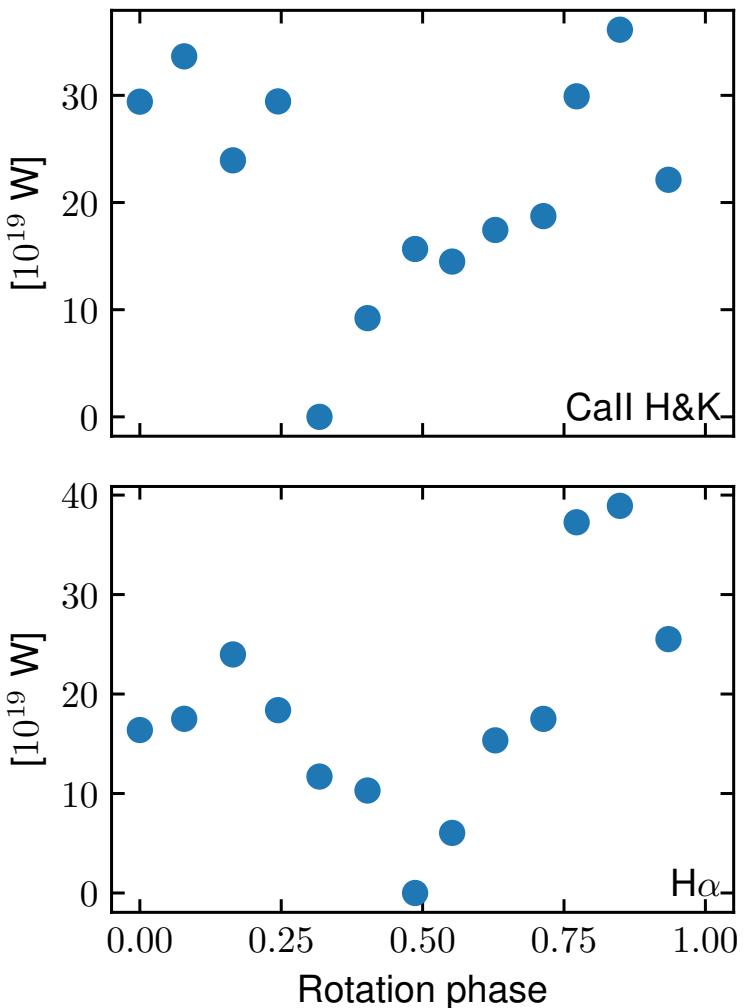
Anomalous emissions/absorption: is there enough power?



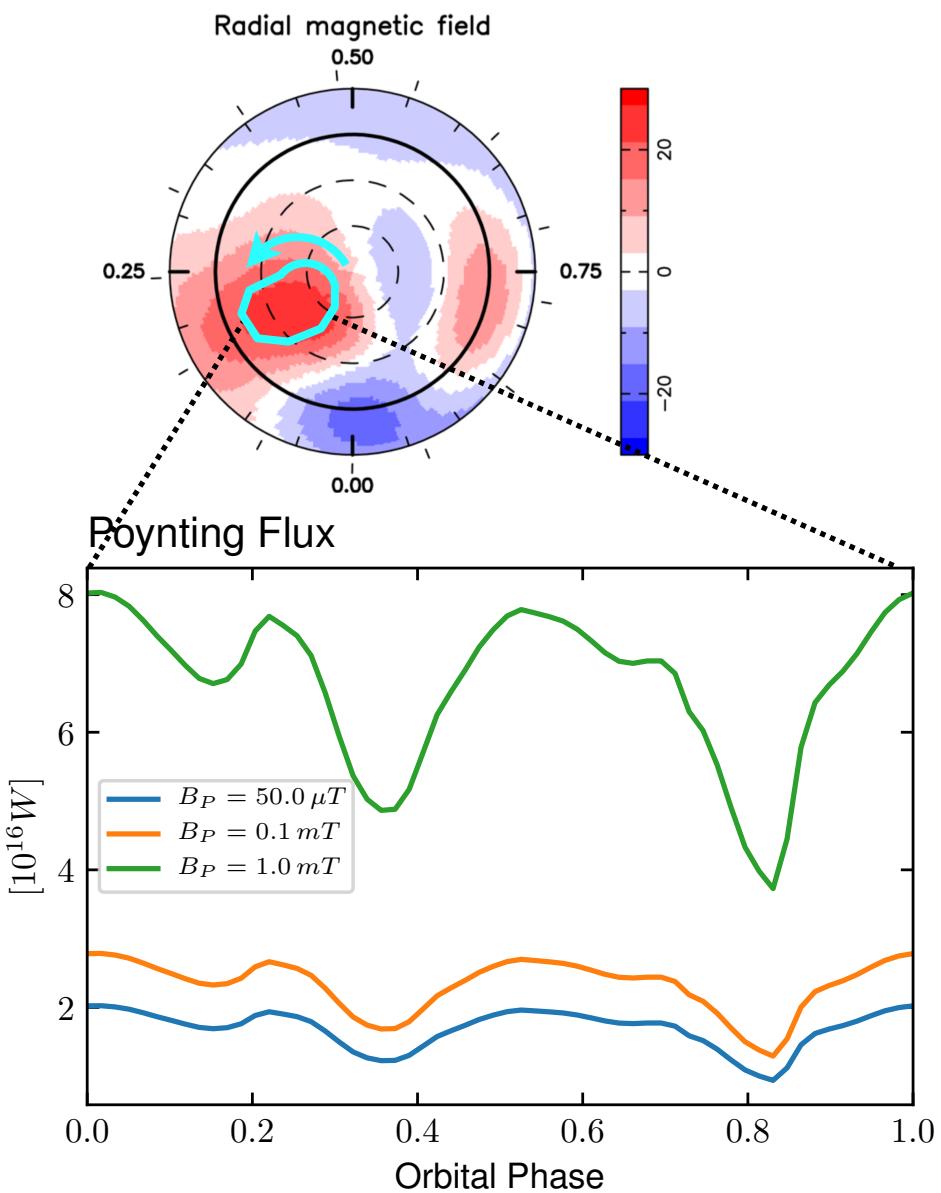
[Moutou+, MNRAS 2016]



Anomalous emissions/absorption: is there enough power?



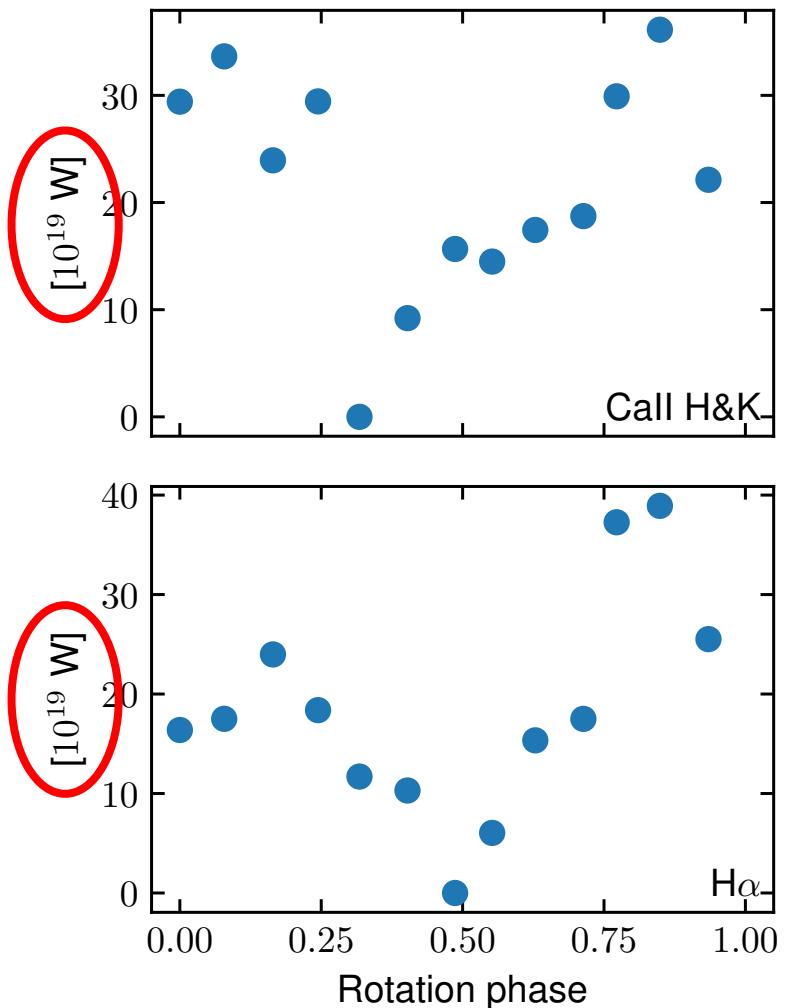
[Moutou+, MNRAS 2016]



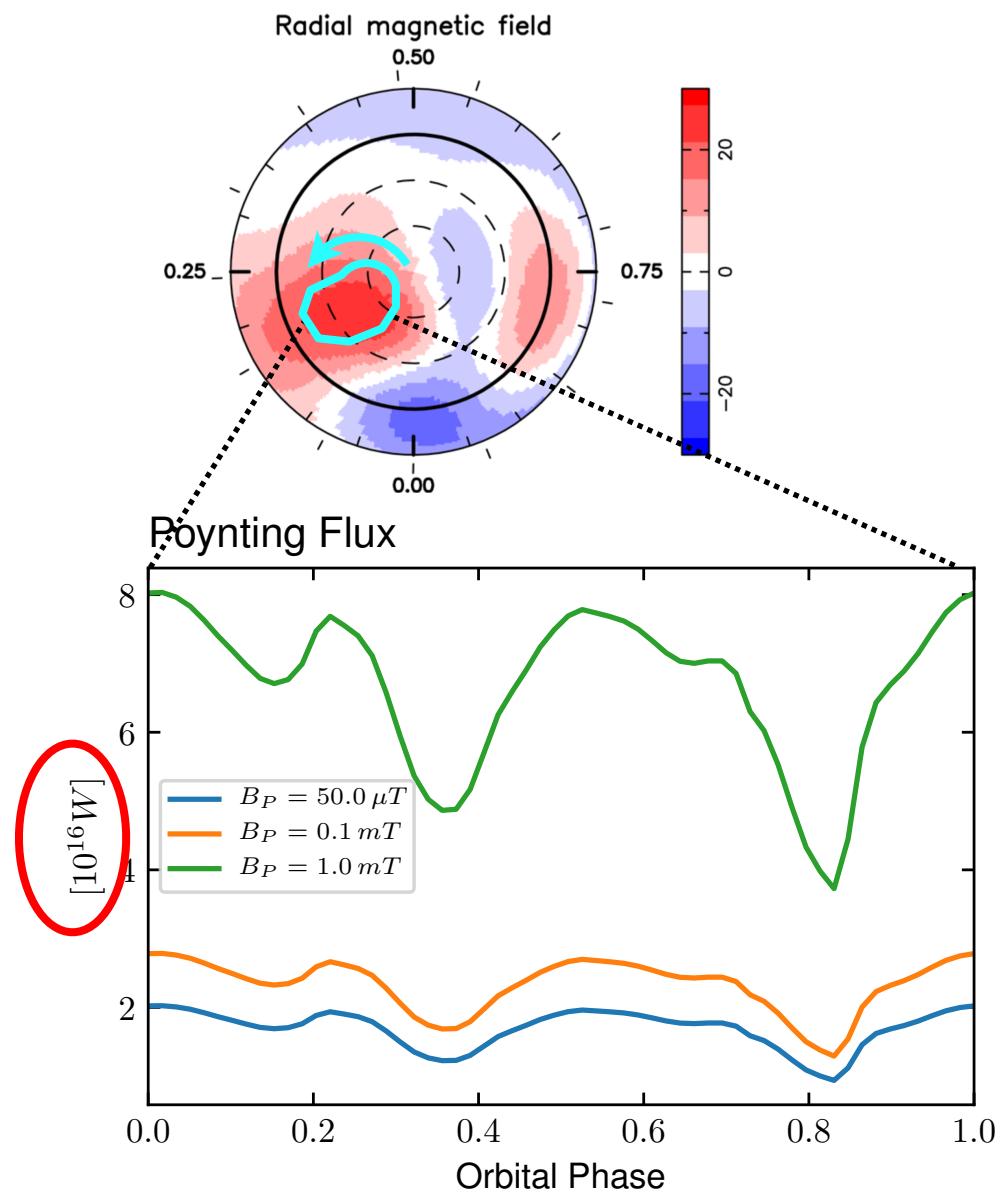
A. Strugarek

[Strugarek+, in prep]

Anomalous emissions/absorption: is there enough power?

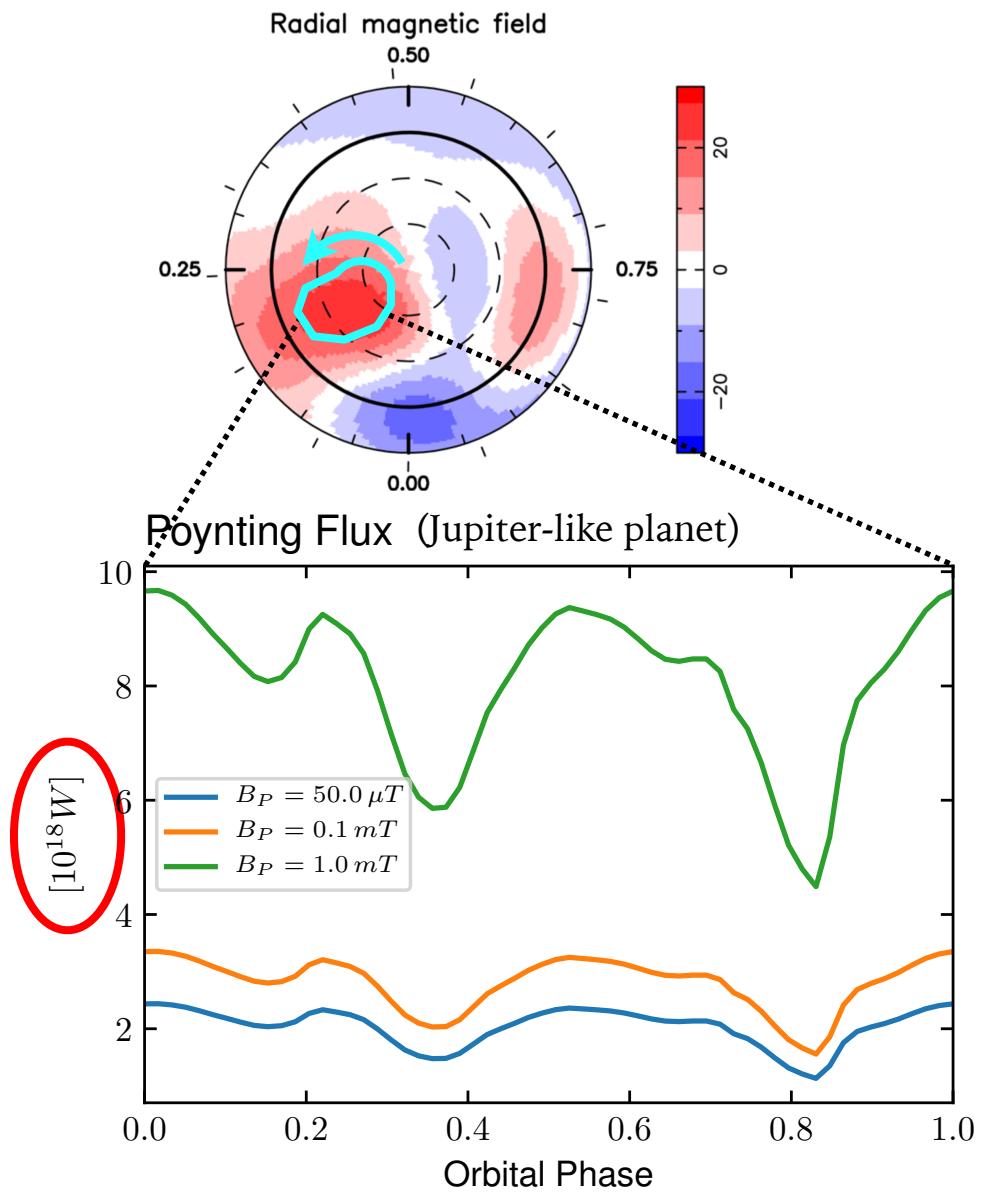
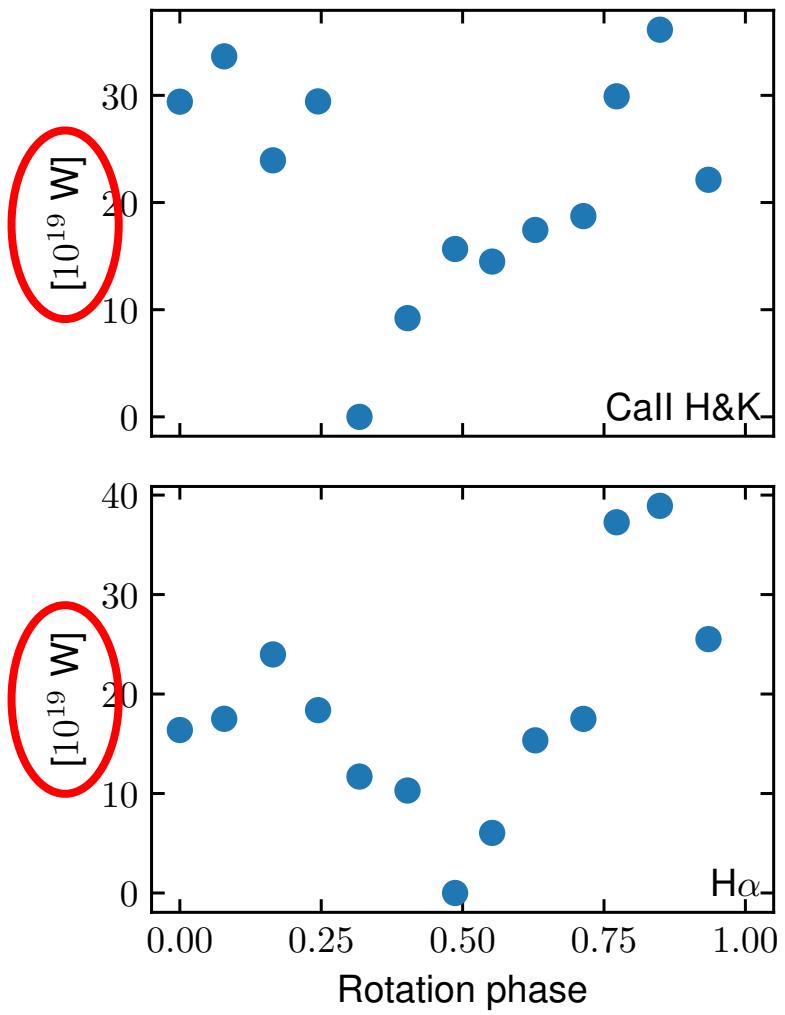


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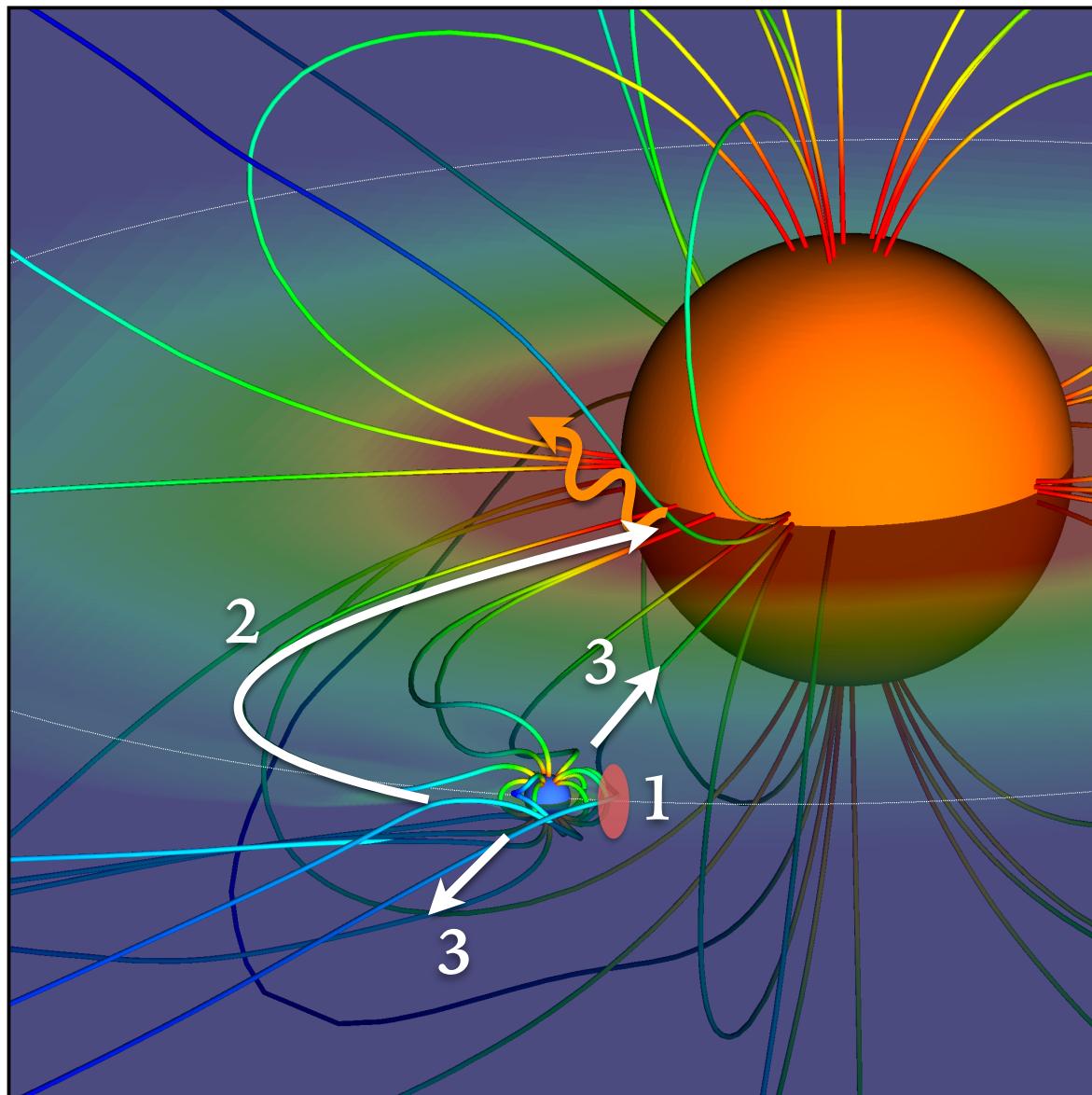
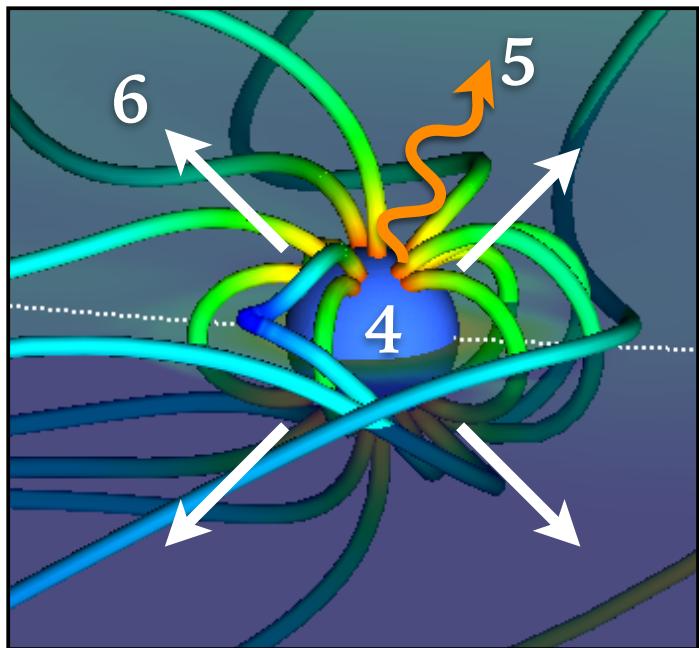
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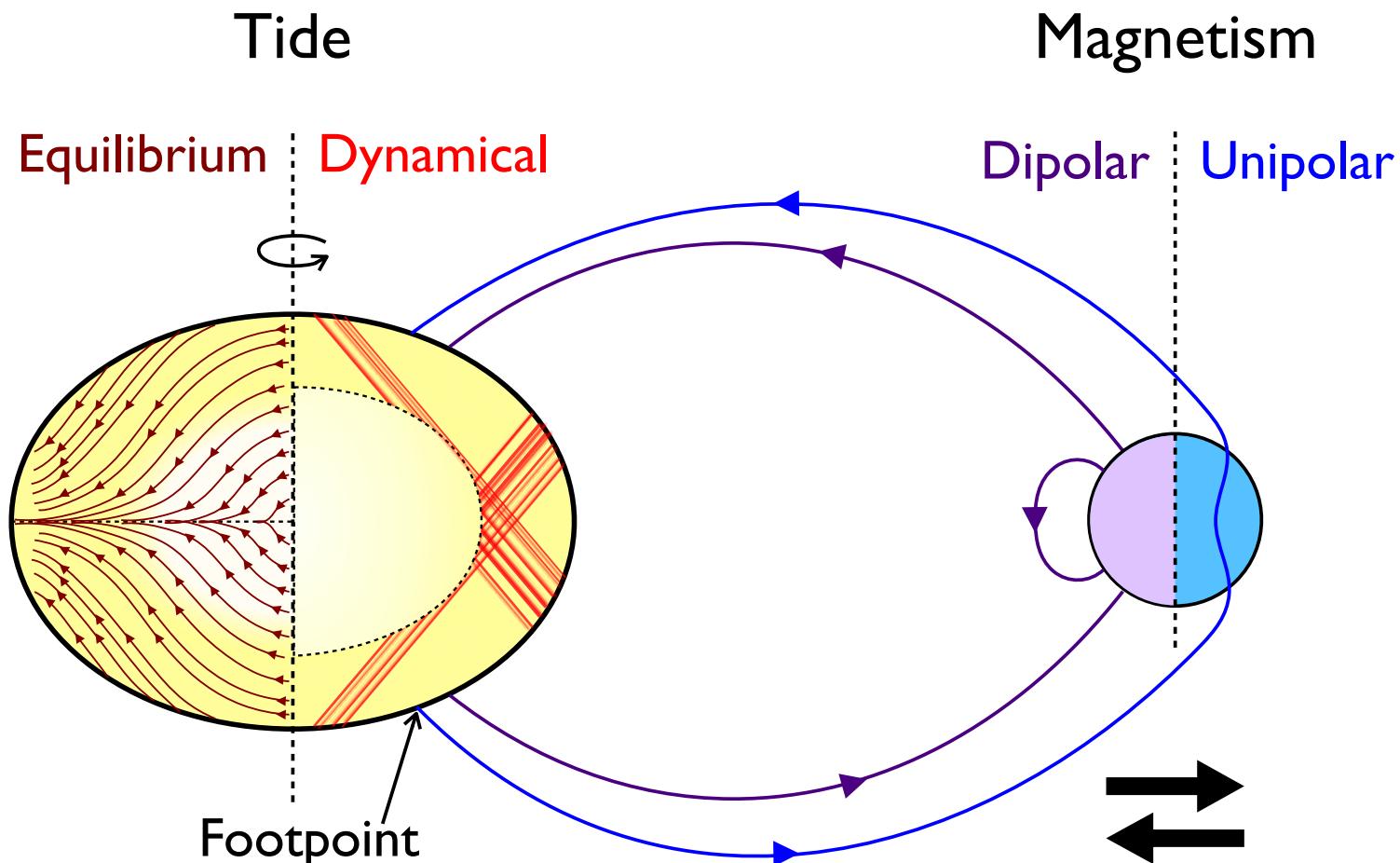


Main effects of magnetic star-planet interactions

1. MHD shock
2. Energy channeling
3. Planet migration
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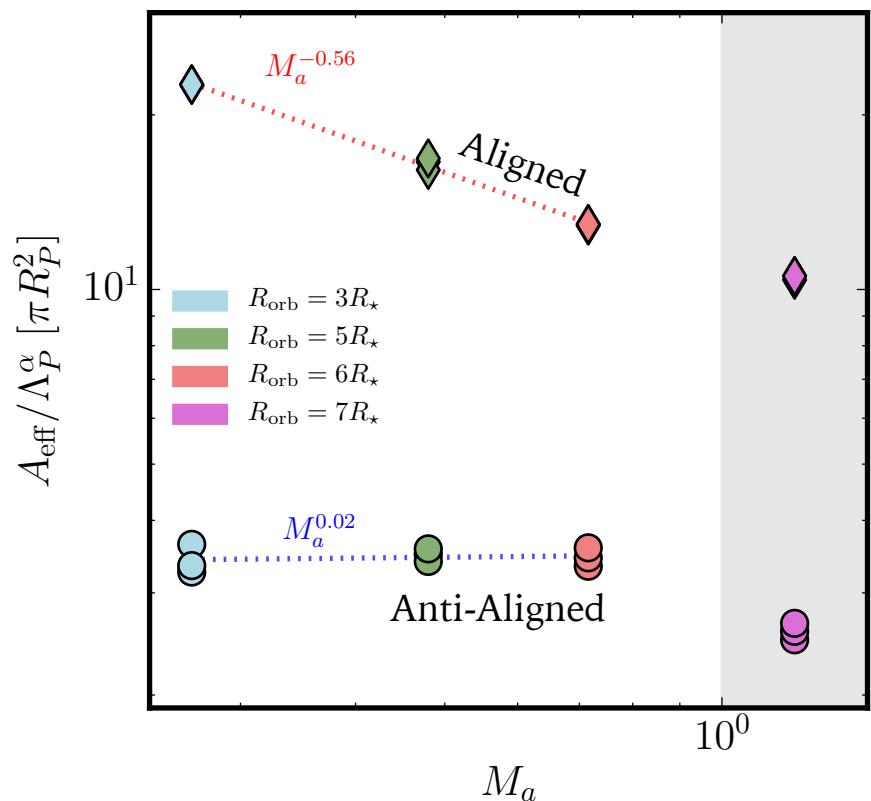


Magnetic vs tidal torques in close-in systems



Magnetic torque: parametrization

$$\mathcal{T} = A_0 \pi \left(c_d P_t M_a^\beta \bar{\eta}_a^{\nu_1} \right) \cdot \left(R_P^2 R_o \bar{\eta}_P^{\nu_2} \right) \cdot (\Lambda_P^\alpha)$$



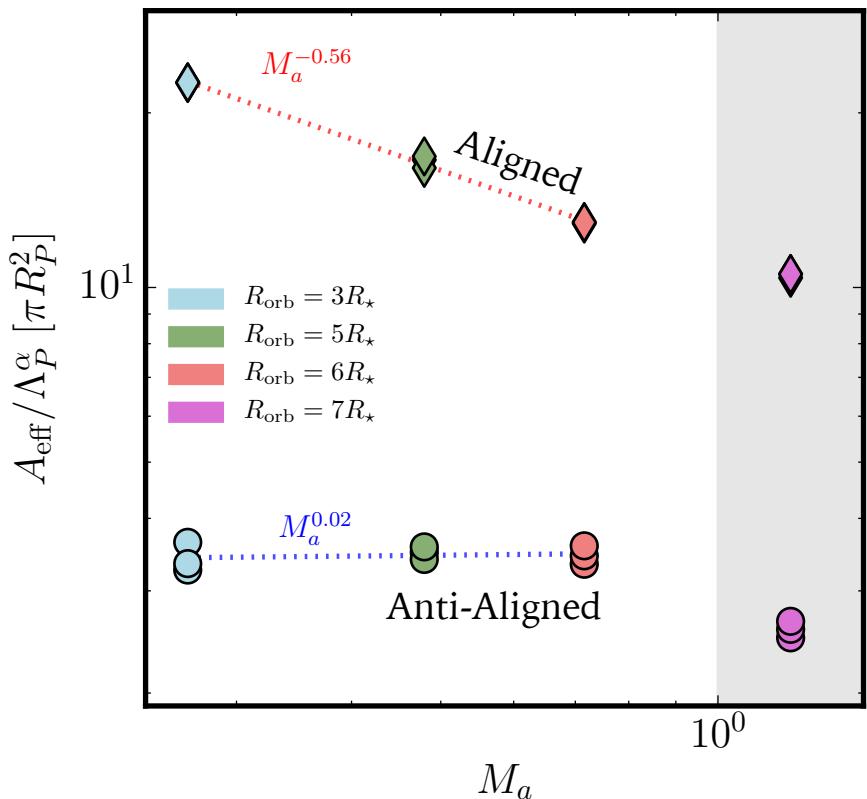
Magnetic torque: parametrization

Wind Pressure Reconnection eff.

$$\mathcal{T} = A_0 \pi \left(c_d P_t M_a^\beta \bar{\eta}_a^{\nu_1} \right) \cdot \left(R_P^2 R_o \bar{\eta}_P^{\nu_2} \right) \cdot (\Lambda_P^\alpha)$$

drag coeff. Alf. Mach

Wind-dependant parameters
(pressure, magnetic field, density)

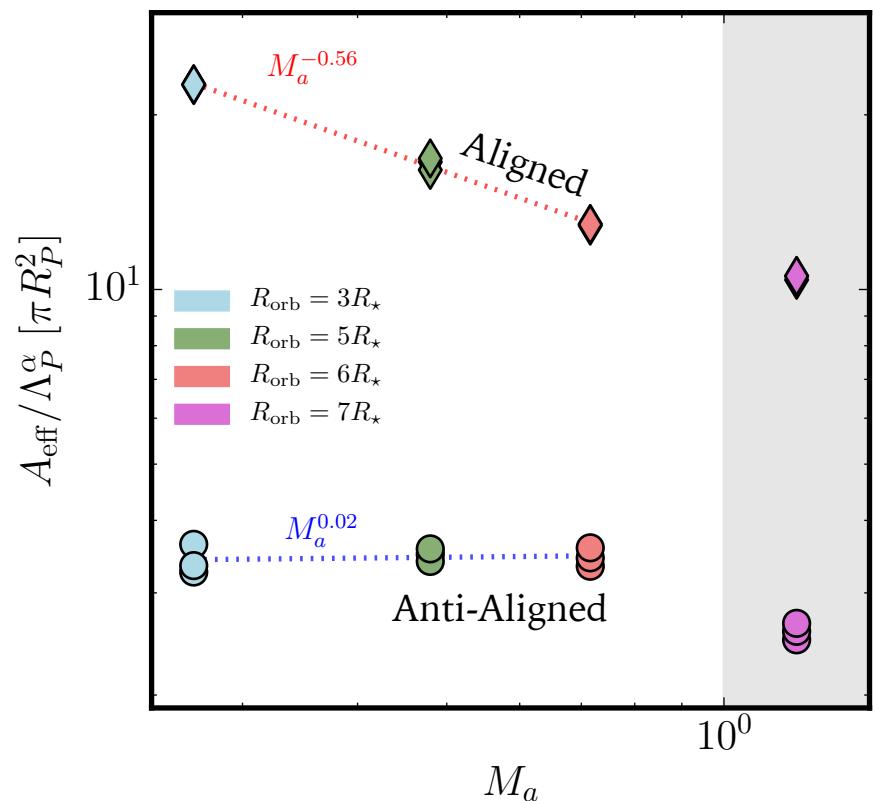


Magnetic torque: parametrization

$$\mathcal{T} = A_0 \pi \left(\underbrace{c_d P_t M_a^\beta \bar{\eta}_a^{\nu_1}}_{\text{drag coeff.}} \right) \cdot \left(\underbrace{R_P^2 R_o \bar{\eta}_P^{\nu_2}}_{\text{Alf. Mach}} \right) \cdot (\Lambda_P^\alpha)$$

Wind-dependant parameters
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Planet-dependant parameters
(radius, orbital radius, composition)



Magnetic torque: parametrization

Wind Pressure Reconnection eff. Orbital Rad. Pedersen diff.

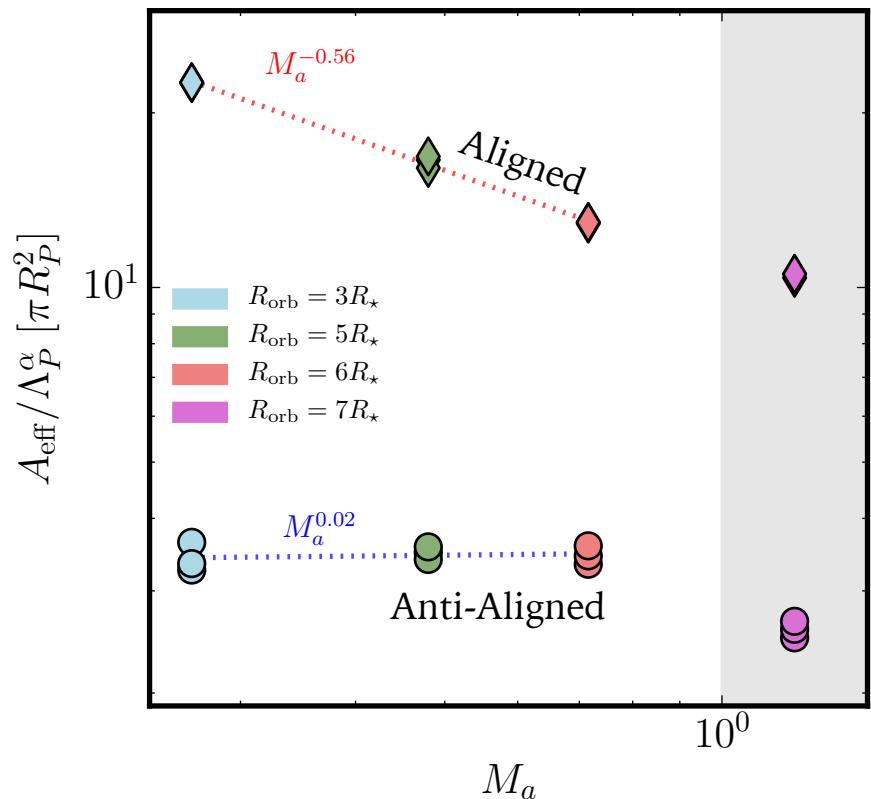
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drag coeff. Alf. Mach

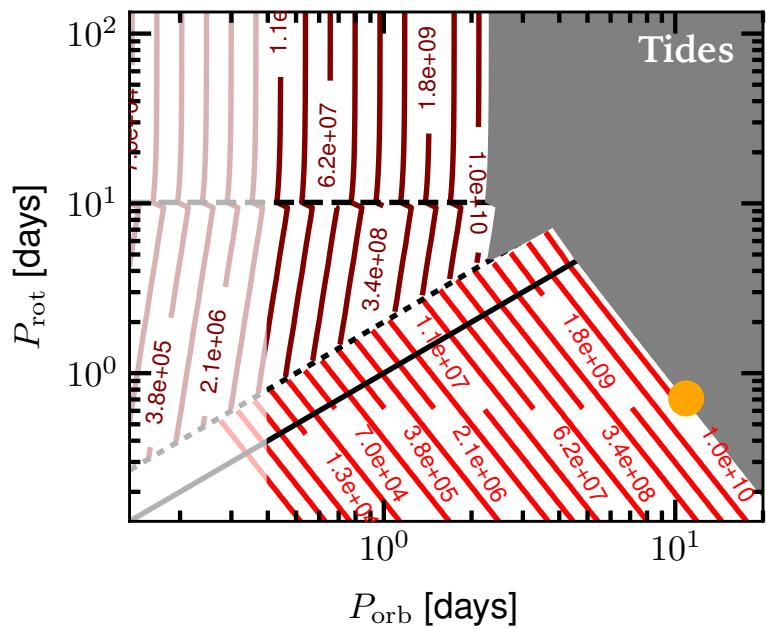
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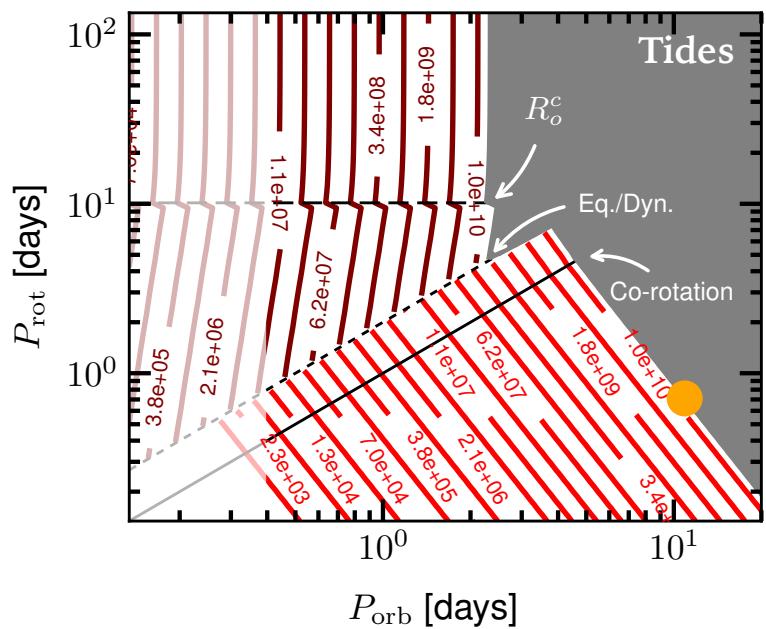
Magnetosphere/wind pressure ratio
(planetary magnetic field, wind)



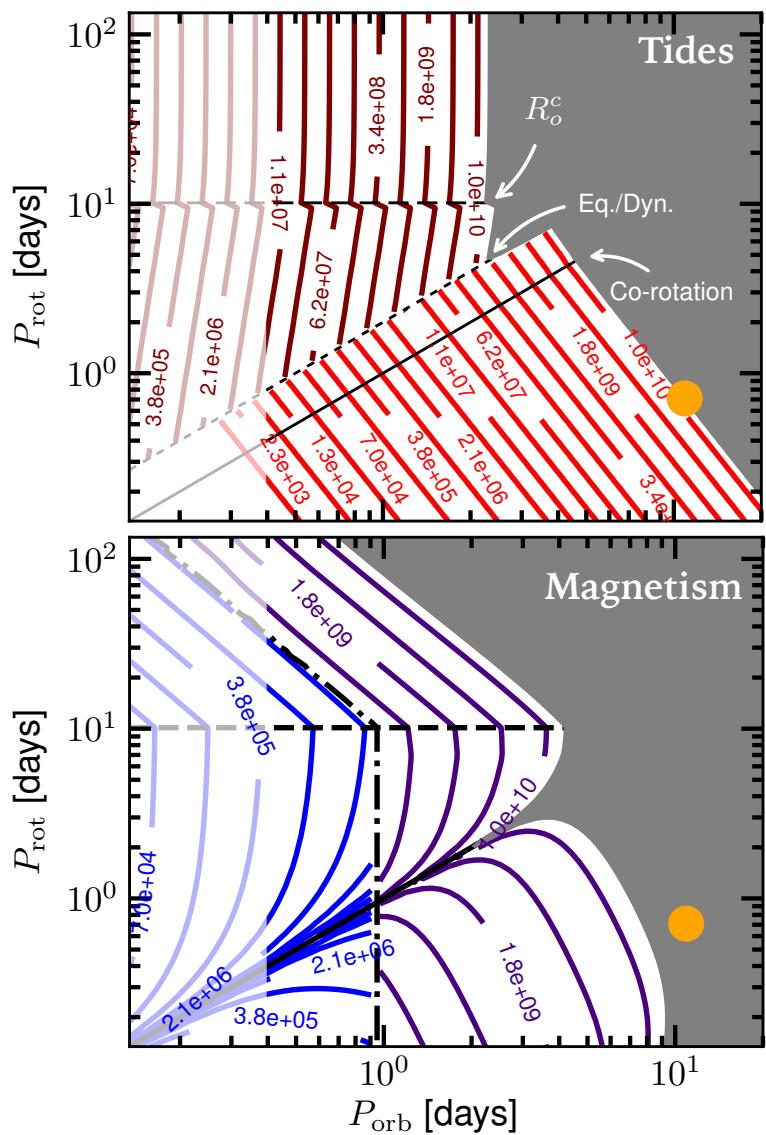
Application: T Tauri with hot Jupiter (like Tap 26 system)



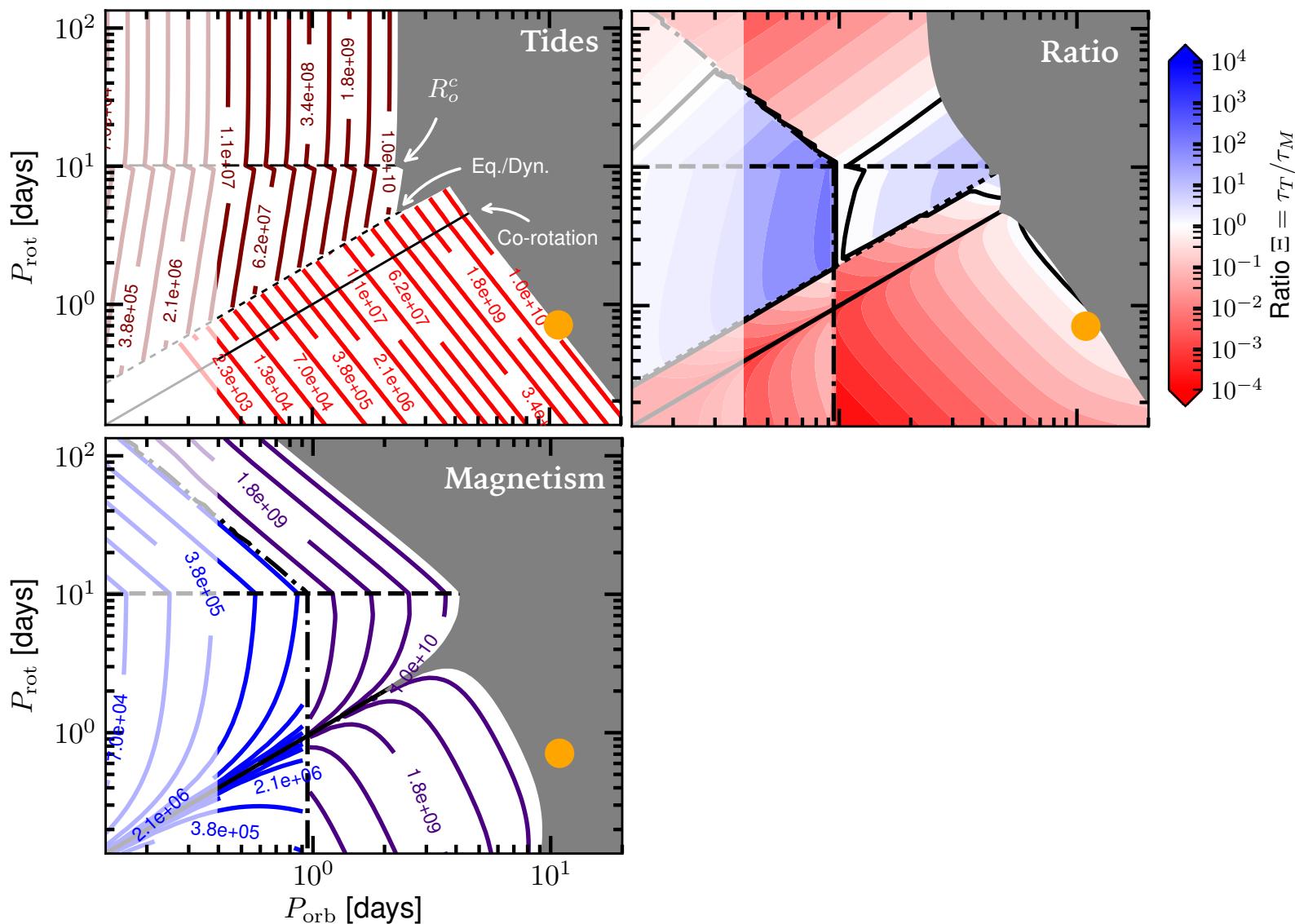
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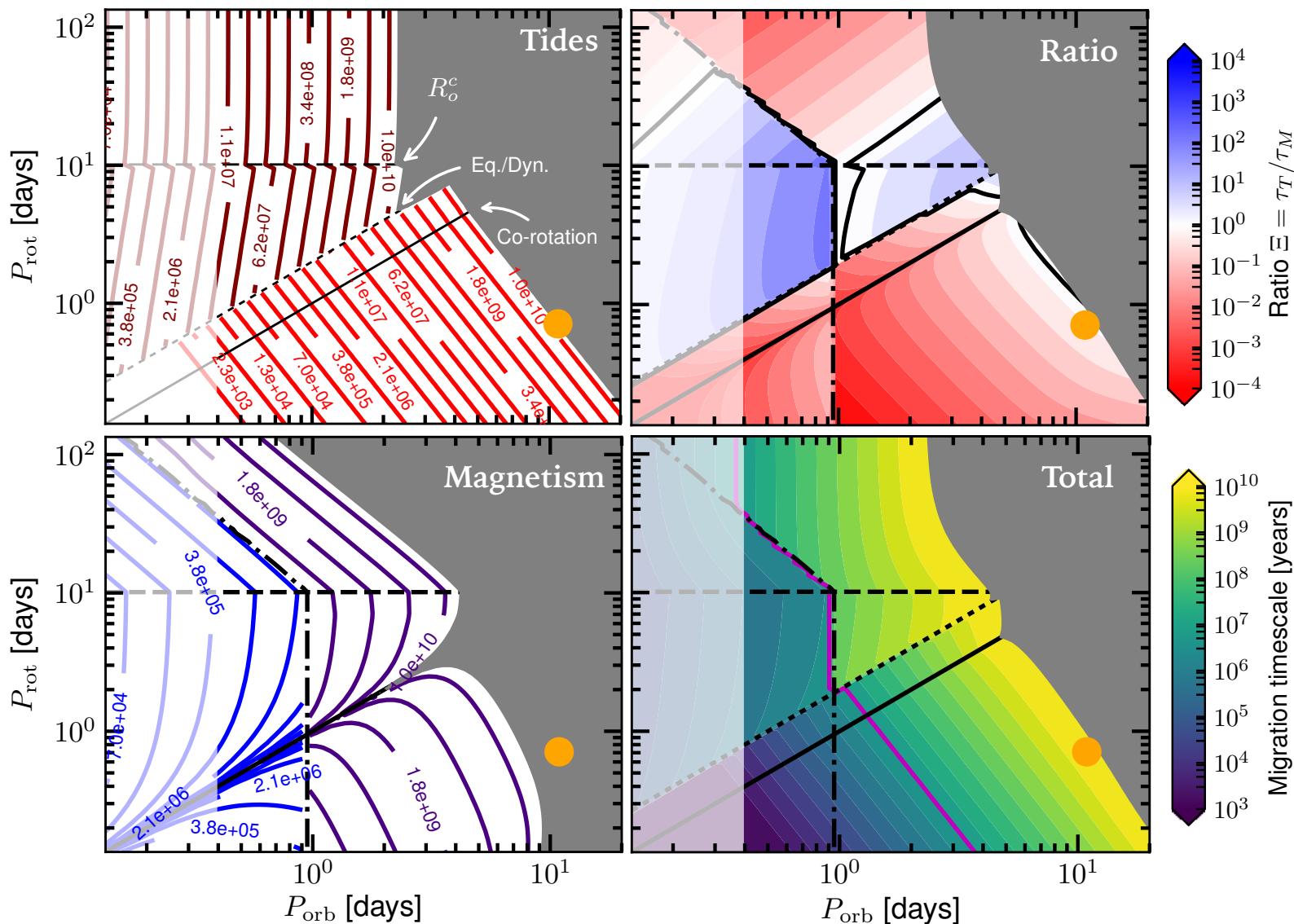
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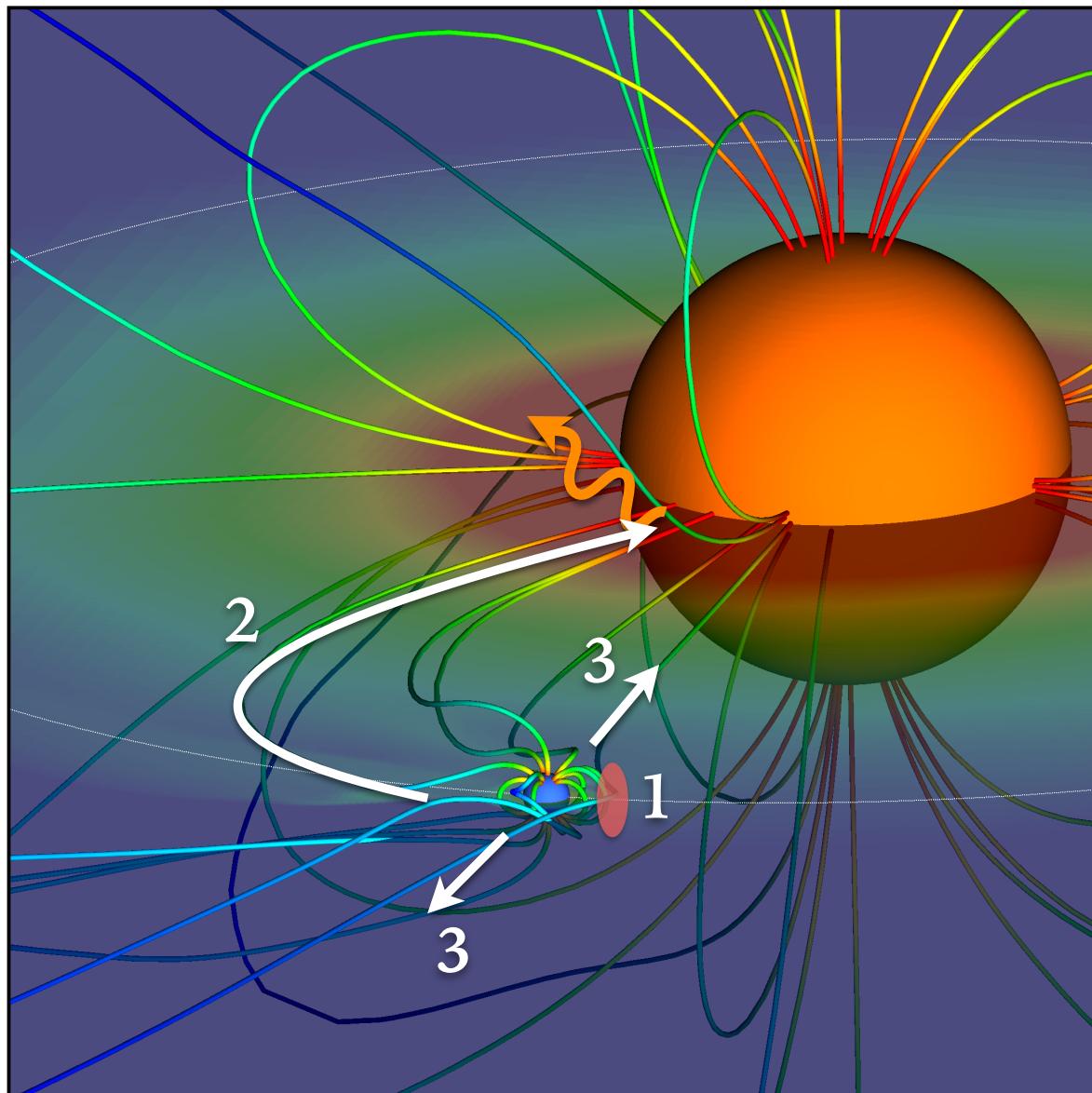
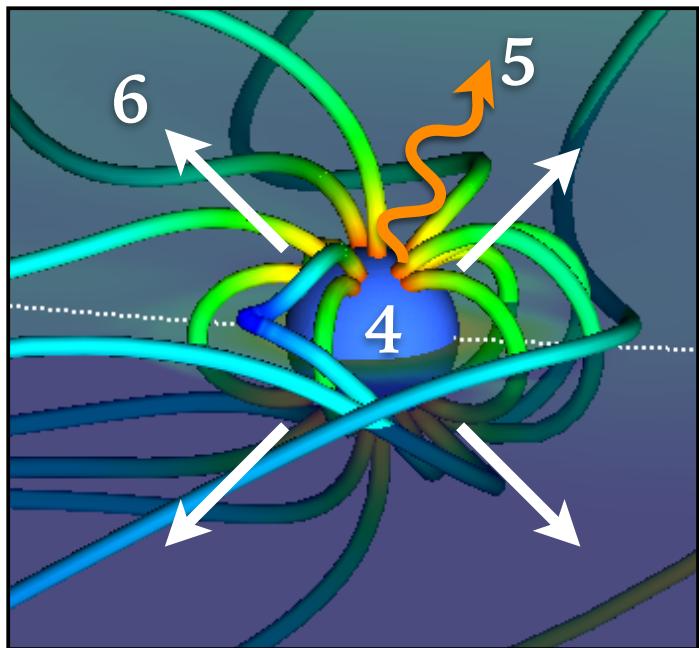


Application: T Tauri with hot Jupiter (like Tap 26 system)



Summary: main effects of magnetic star–planet interactions

1. MHD shock
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Thank you for your attention

