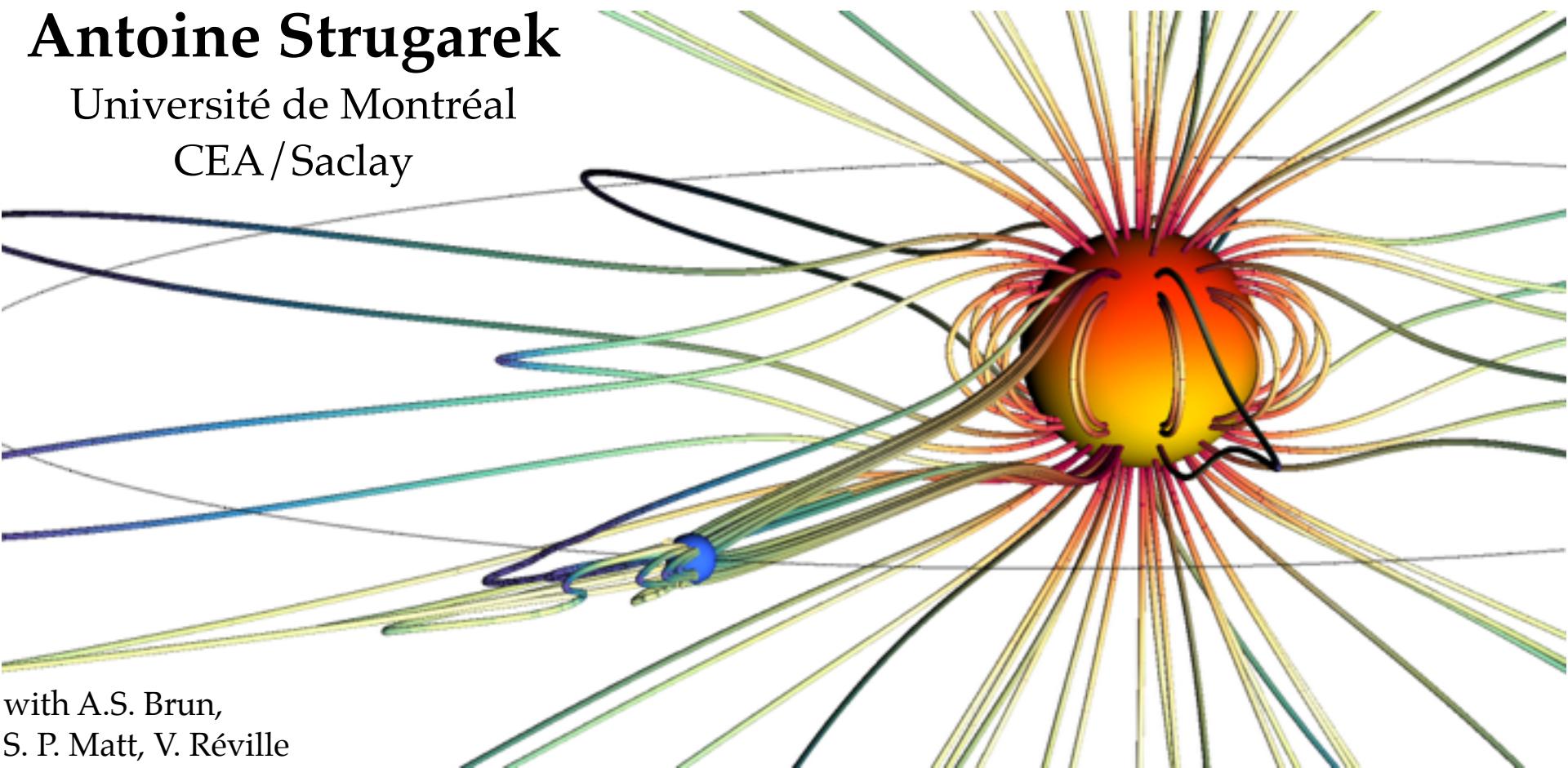


ON THE DIVERSITY OF MAGNETIC STAR-PLANET INTERACTIONS

THE CASE OF CLOSE-IN PLANETS

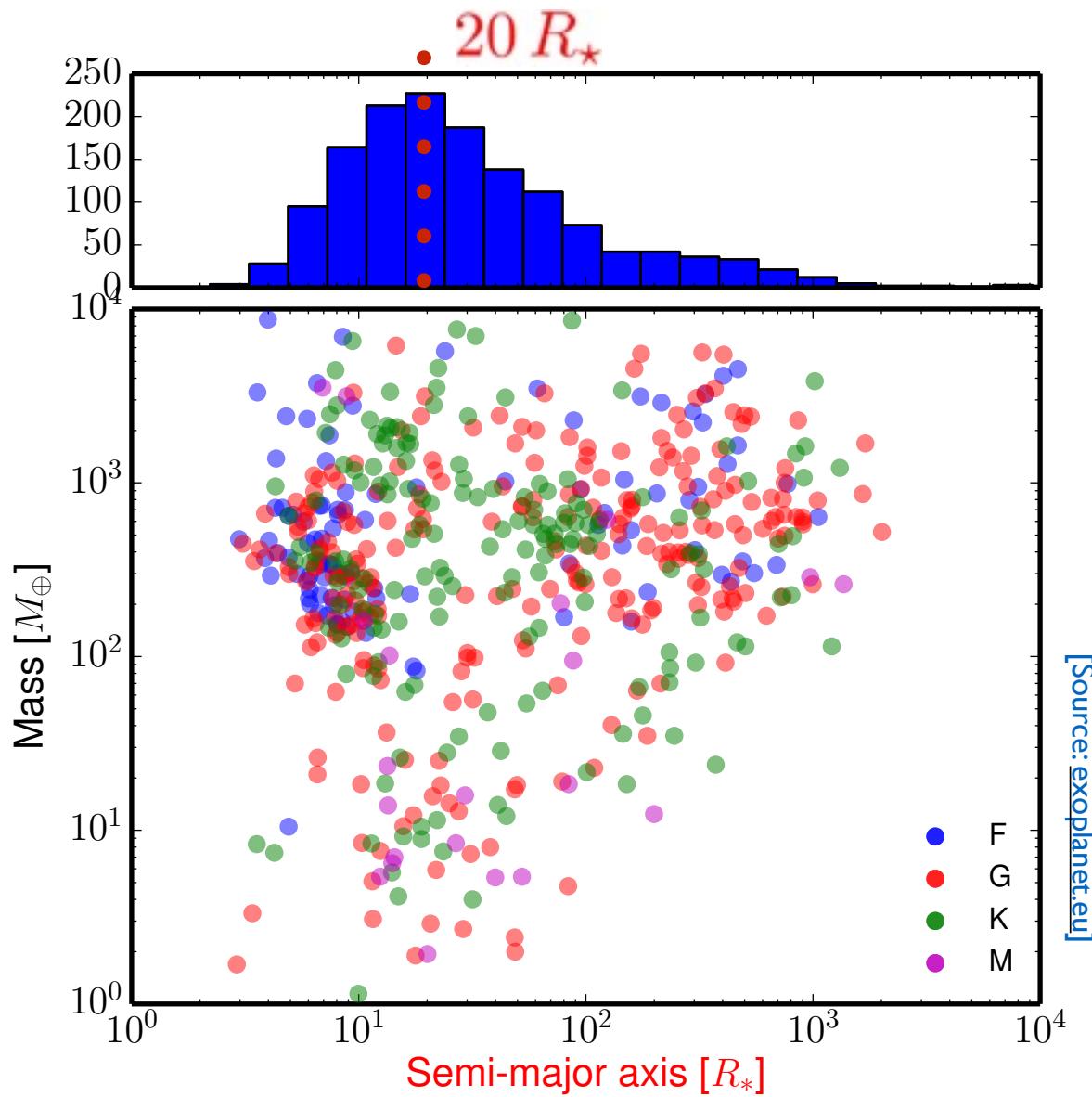
Antoine Strugarek

Université de Montréal
CEA/Saclay



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

WE KNOW A LOT OF VERY CLOSE EXOPLANETS



COMPARED TO THE PLANETS IN THE SOLAR SYSTEM, PLANETS ORBITING CLOSE TO THEIR STARS

Interact with a **stronger** stellar wind **magnetic field**

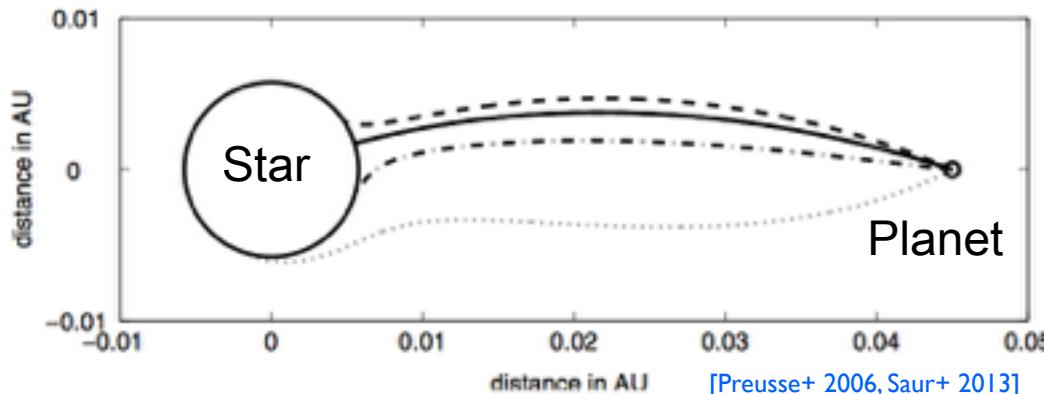
Develop stronger tidal interactions

Are exposed to stronger radiation from their host

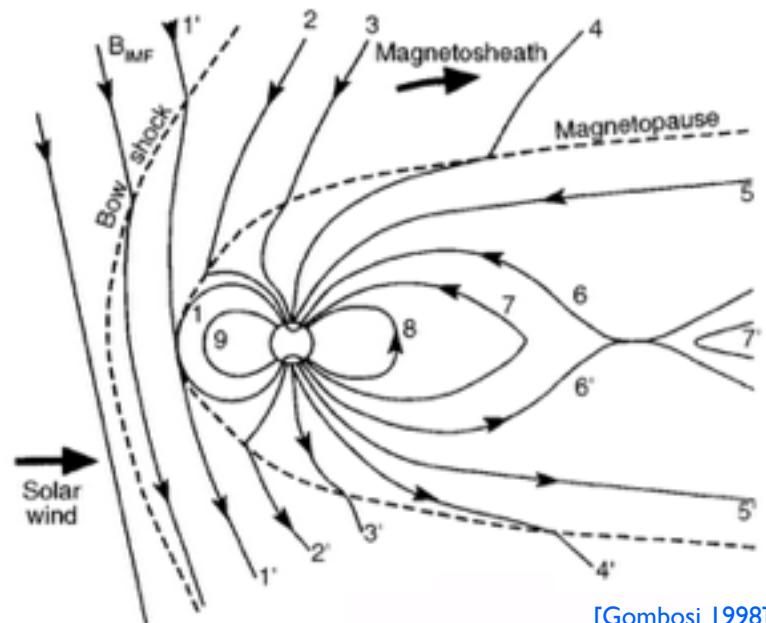
Orbit in a denser interplanetary medium

...

MAGNETIC INTERACTIONS: ALFVÉN WINGS



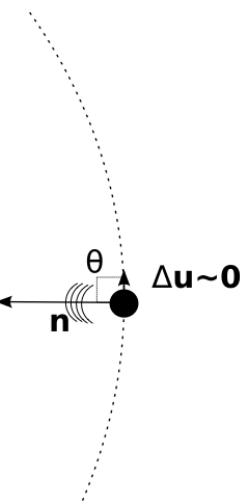
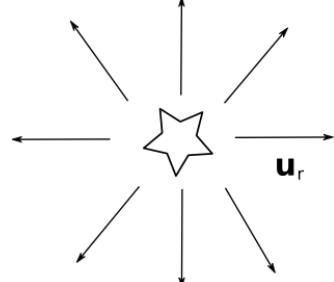
**Sub-Alfvénic interaction:
star-planet connection**



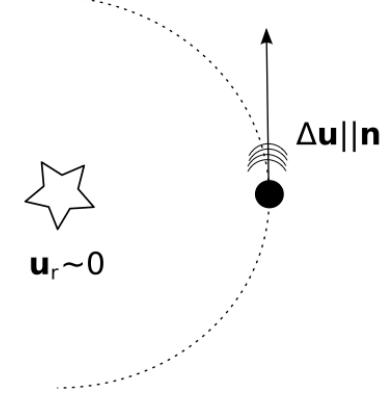
**Super-Alfvénic interaction:
shock formation**

ALFVÉNIC REGIMES AND SHOCK FORMATION

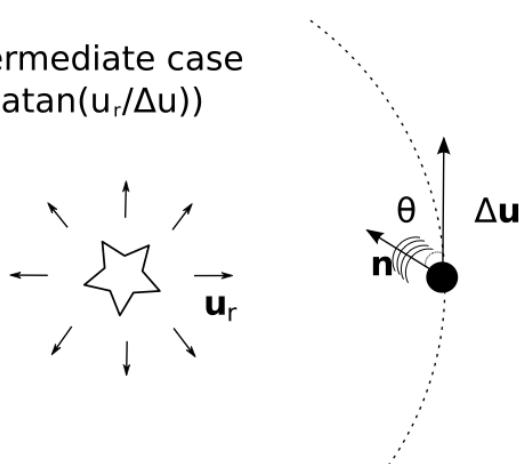
(a)
dayside-shock
($\theta=90^\circ$)



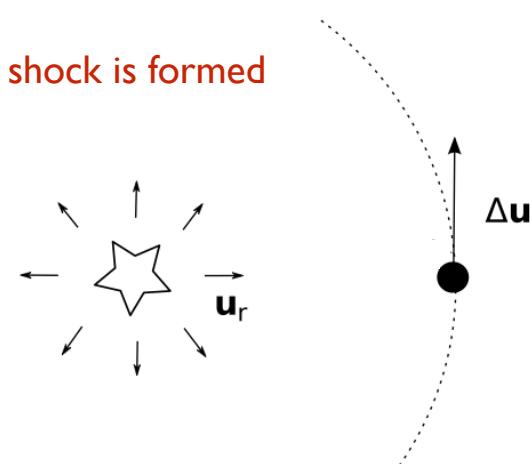
(b)
ahead-shock
($\theta=0^\circ$)



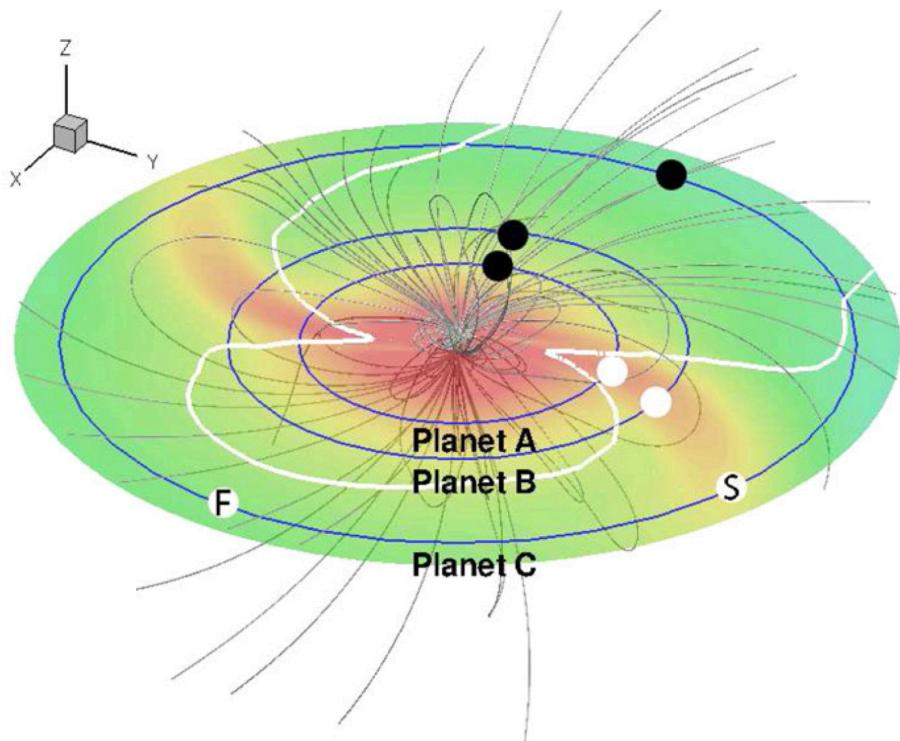
(c)
intermediate case
($\theta=\text{atan}(u_r/\Delta u)$)



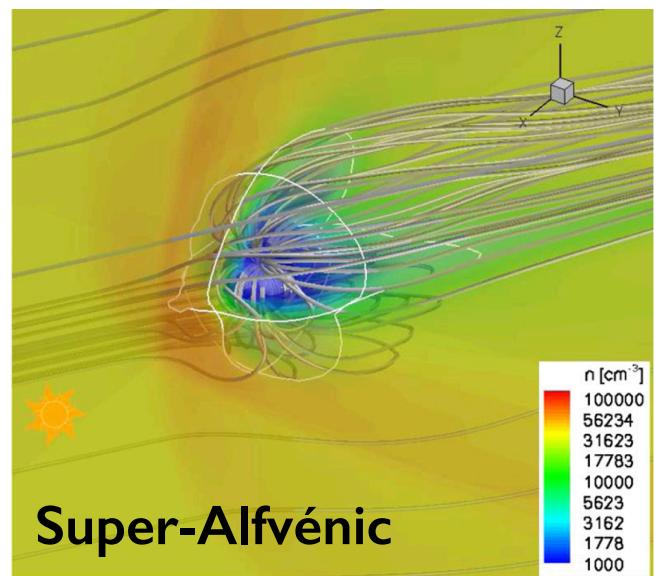
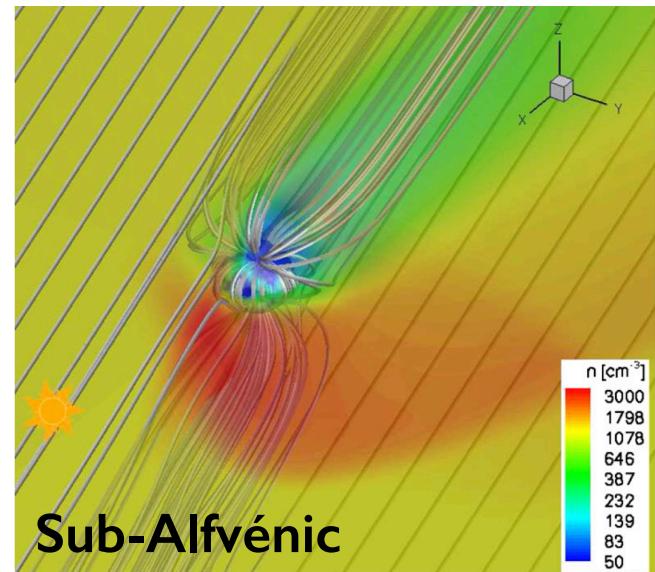
(d)
No shock is formed



A TYPICAL CASE WITH MULTIPLE INTERACTION REGIMES: M-DWARF EV LAC

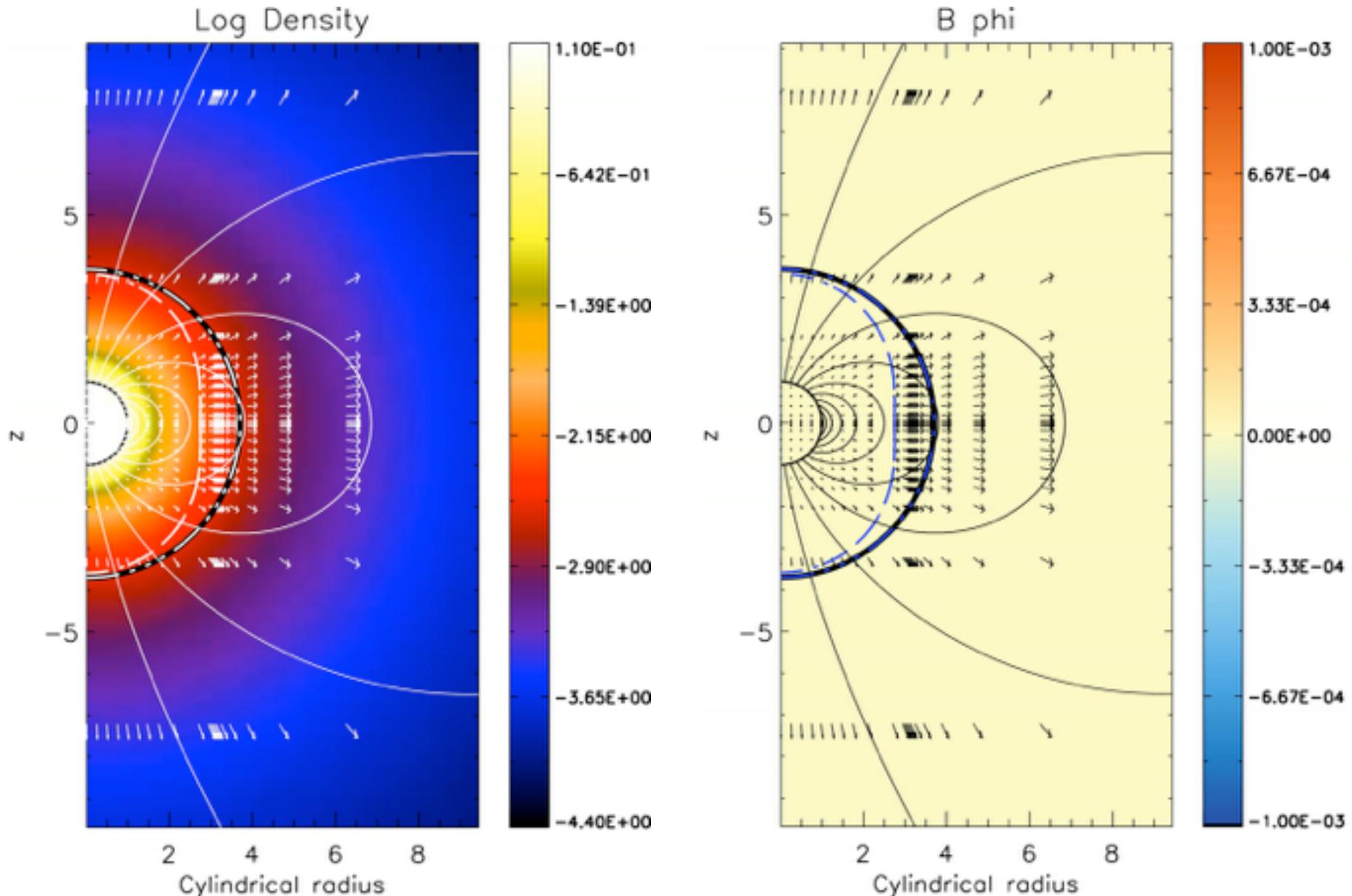


[Cohen+ 2014]

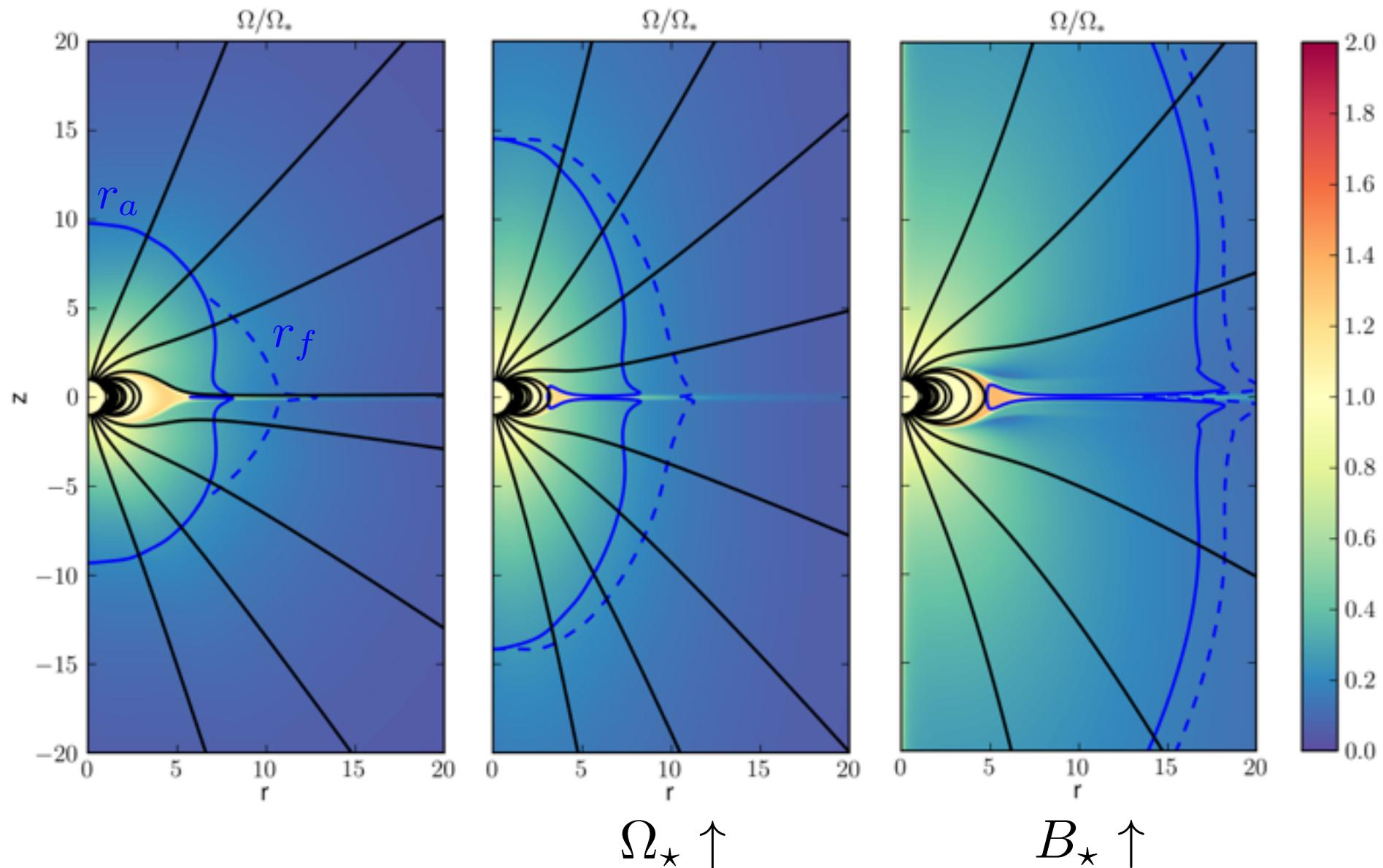


WHERE DOES THE ALFVÉNIC TRANSITION OCCUR IN STELLAR WINDS?

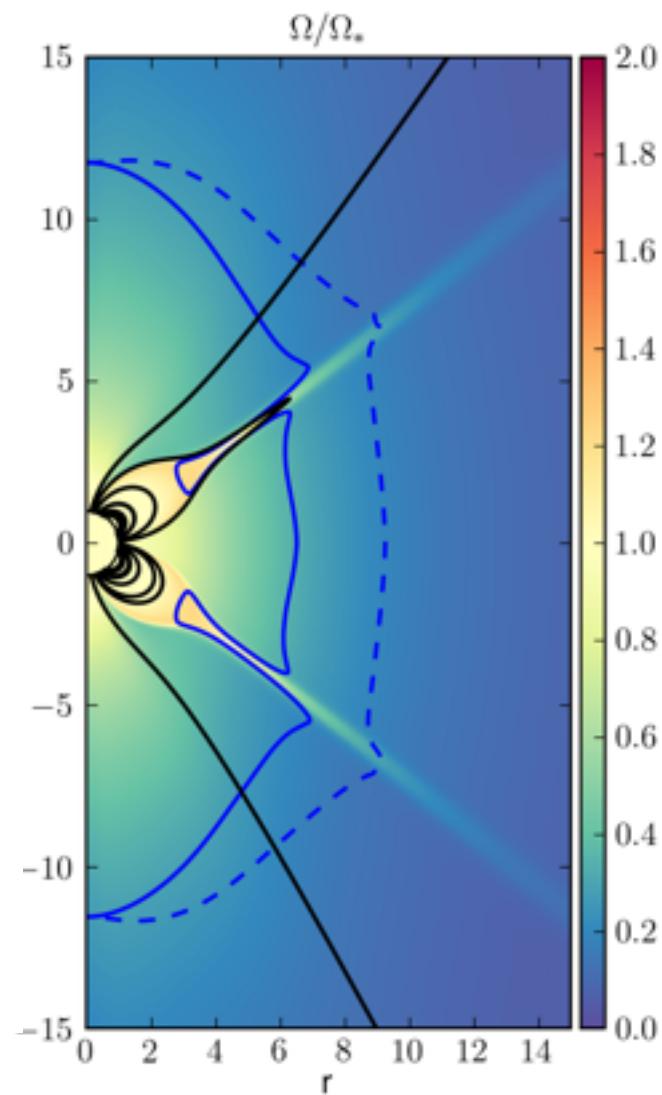
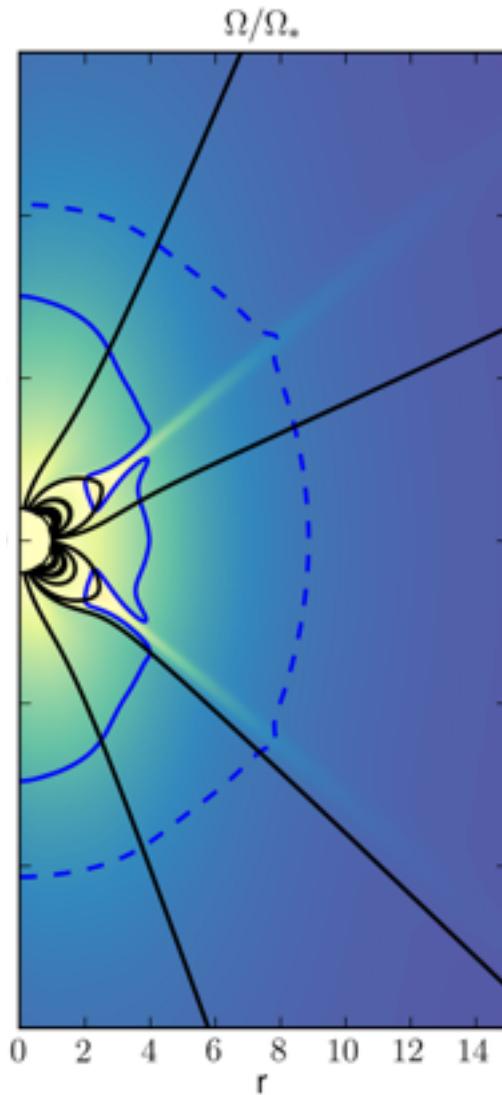
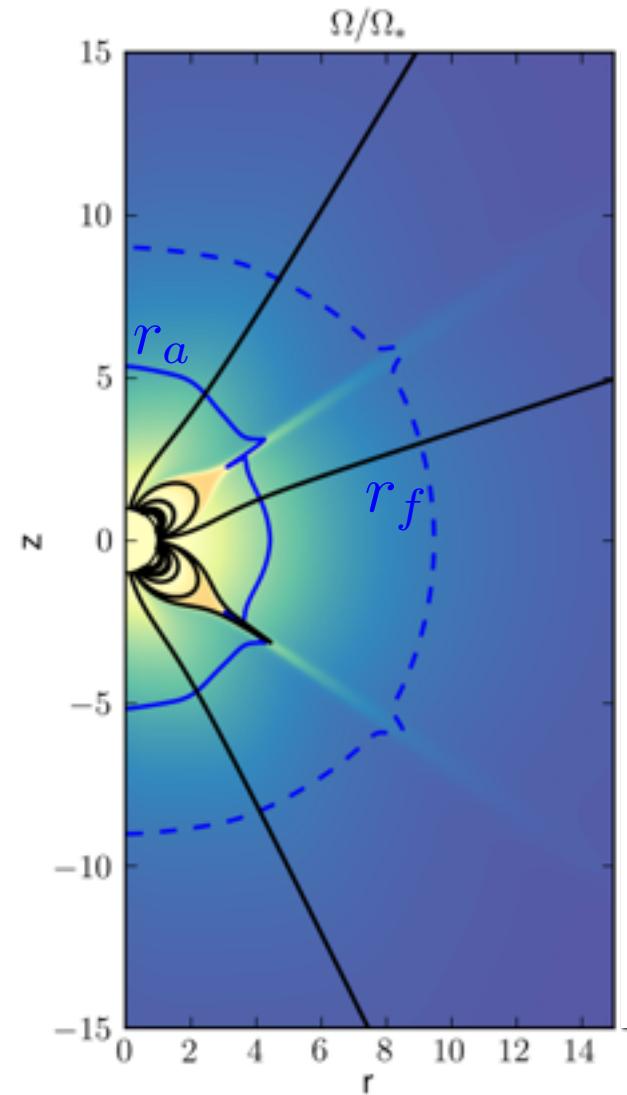
THERMALLY-DRIVEN STELLAR WINDS: STRUCTURE



THERMALLY-DRIVEN STELLAR WINDS: DIPOLAR FAMILY



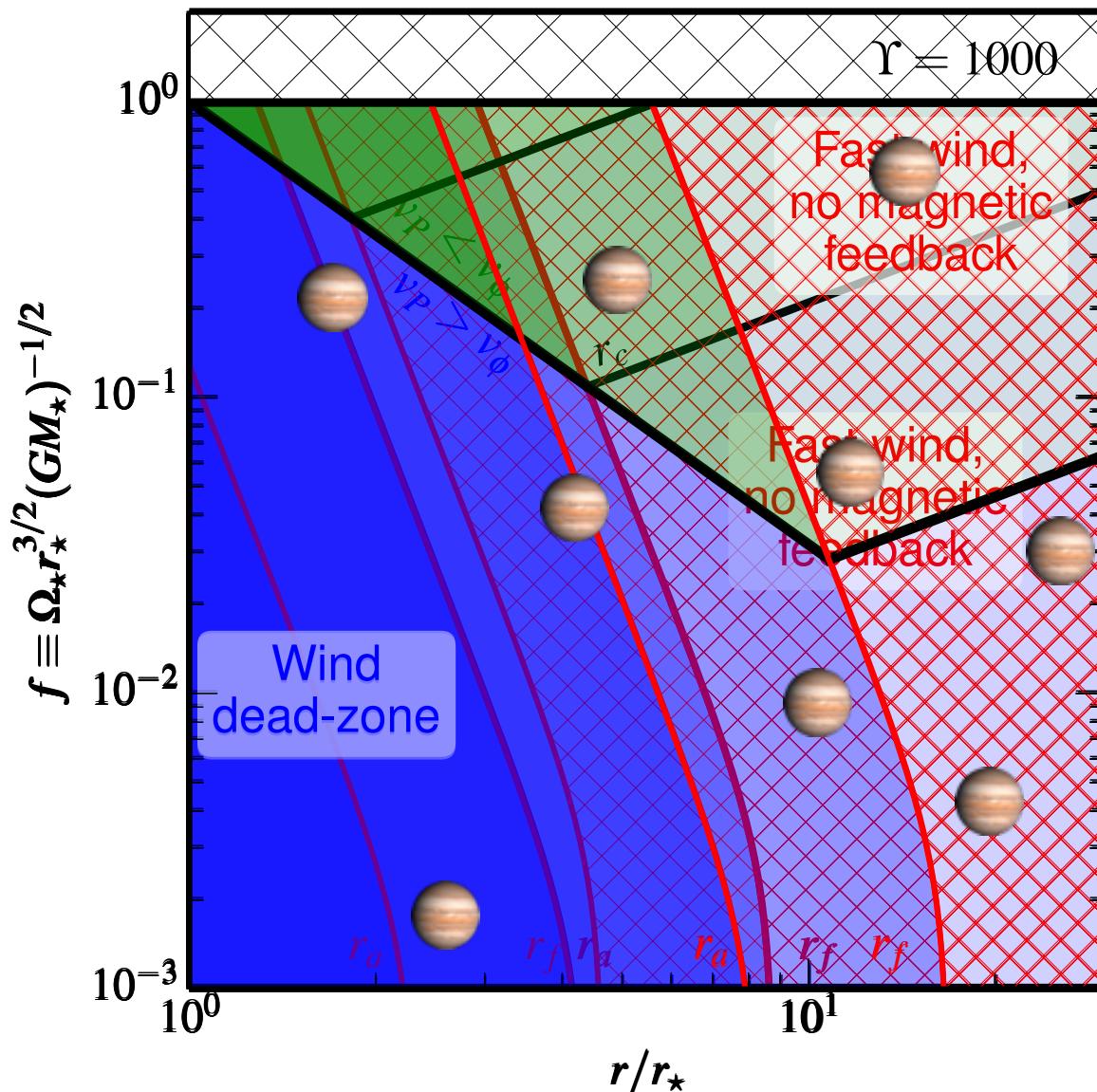
THERMALLY-DRIVEN STELLAR WINDS: QUADRUPOLAR FAMILY



$\Omega_\star \uparrow$

$B_\star \uparrow$

STAR-PLANET MAGNETIC INTERACTIONS: WHAT TO EXPECT



$$\Upsilon = \frac{B_\star^2 r_\star^2}{\dot{M}_\star v_{esc}}$$

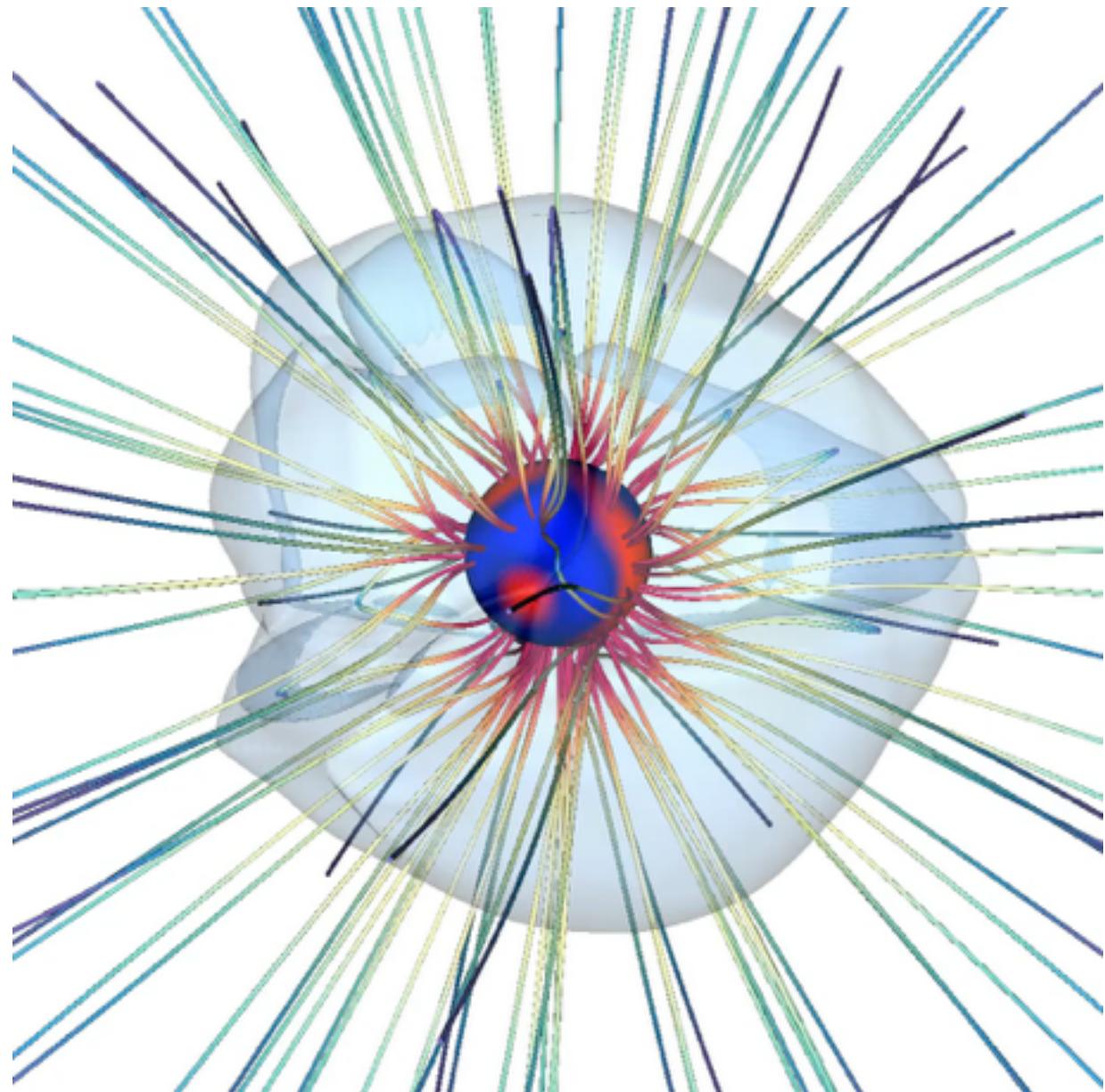
[Ud Doula & Owocki 2002;
Matt+ 2012]

Wind dead-zone
 $v_\varphi \propto r$

Fast wind
 $v_\varphi \propto r^{-1}$

HDI89733: EFFECT OF REALISTIC TOPOLOGIES

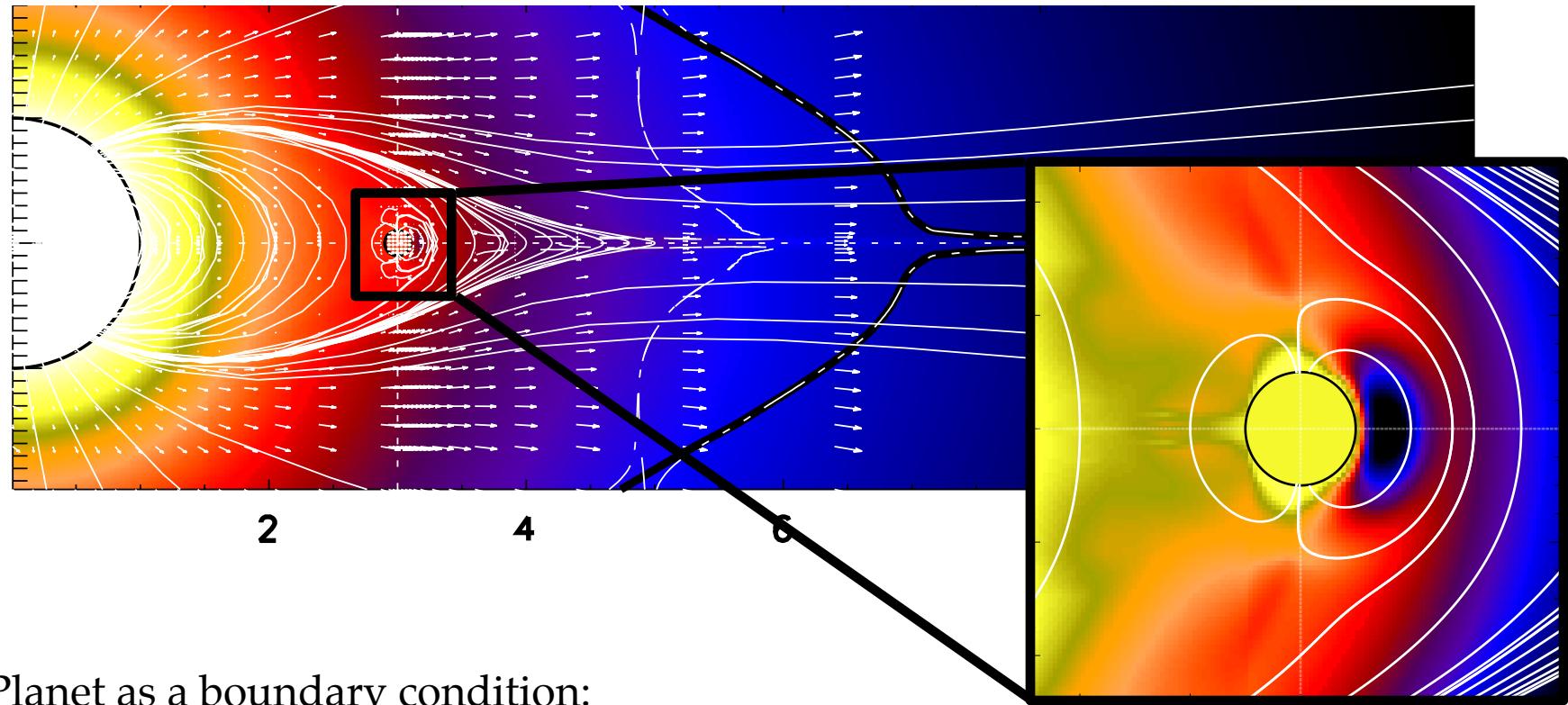
Magnetic map
from ESPaDOnS,
courtesy R. Fares



WHAT CONTROLS THE STRENGTH OF
MAGNETIC INTERACTIONS?

WHAT ARE THE ASSOCIATED TIME-SCALES?

MODELLING A PLANET (AND ITS MAGNETOSPHERE)



Planet as a boundary condition:

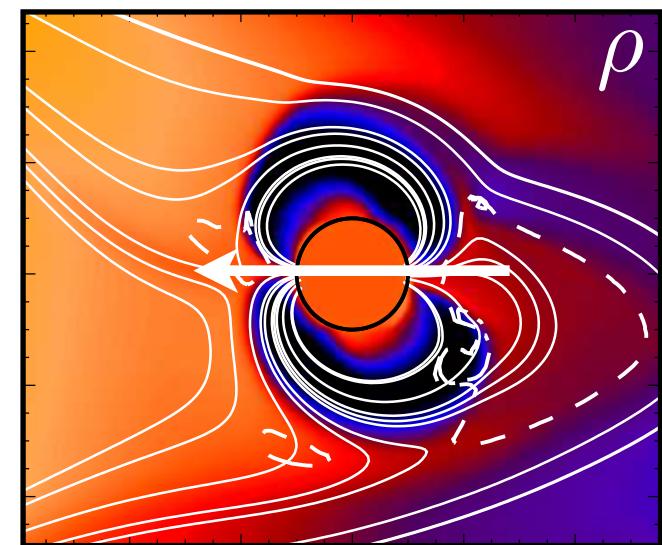
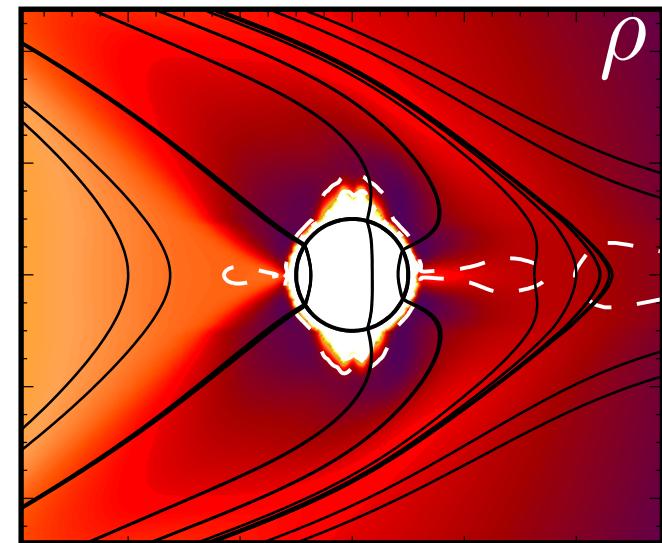
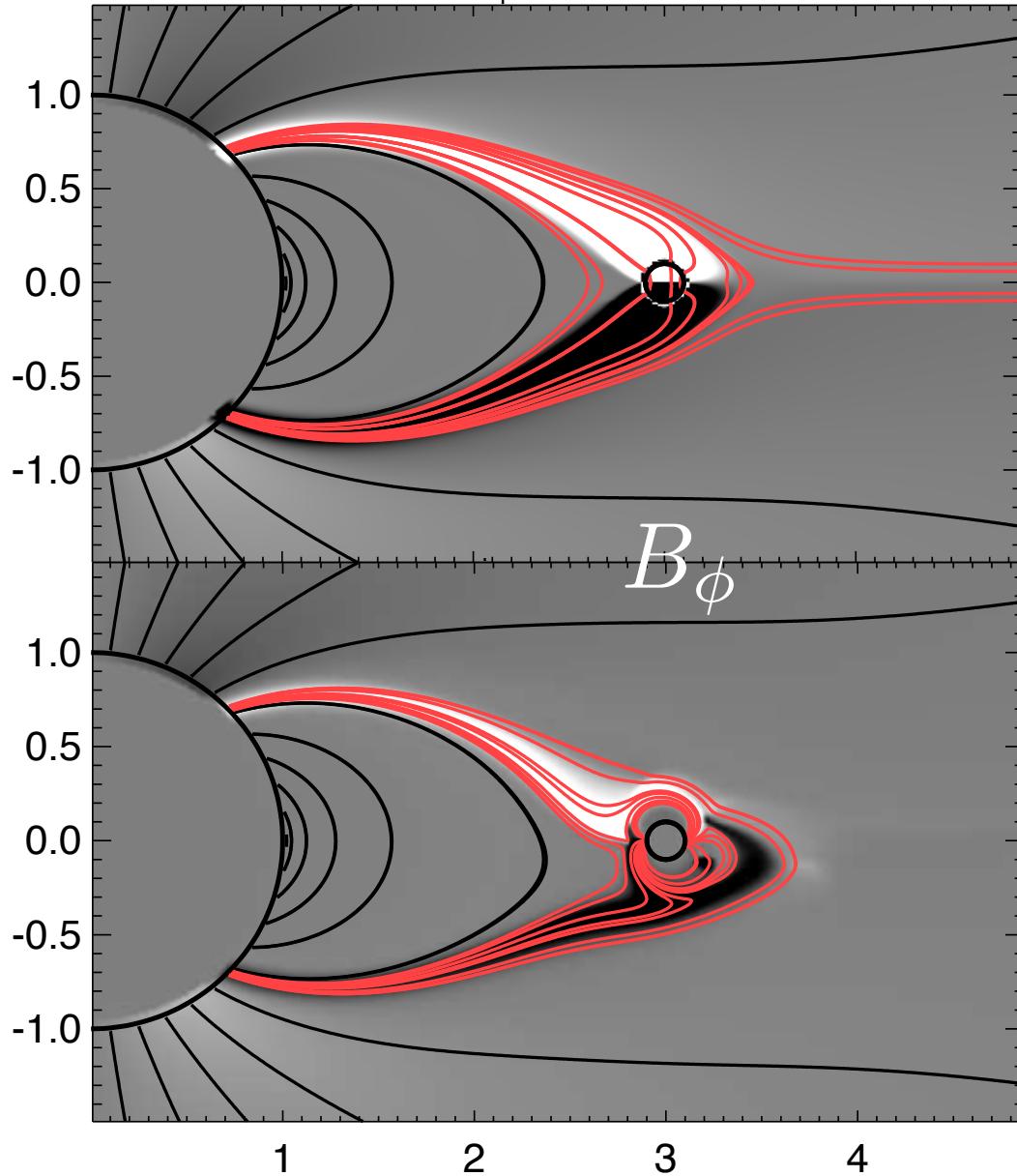
- * Zero velocity condition
- * Keplerian orbital velocity
- * **Fixed pressure**
- * **Density & magnetic field BC**
depends on planet type

Planet radius = 10 % stellar radius

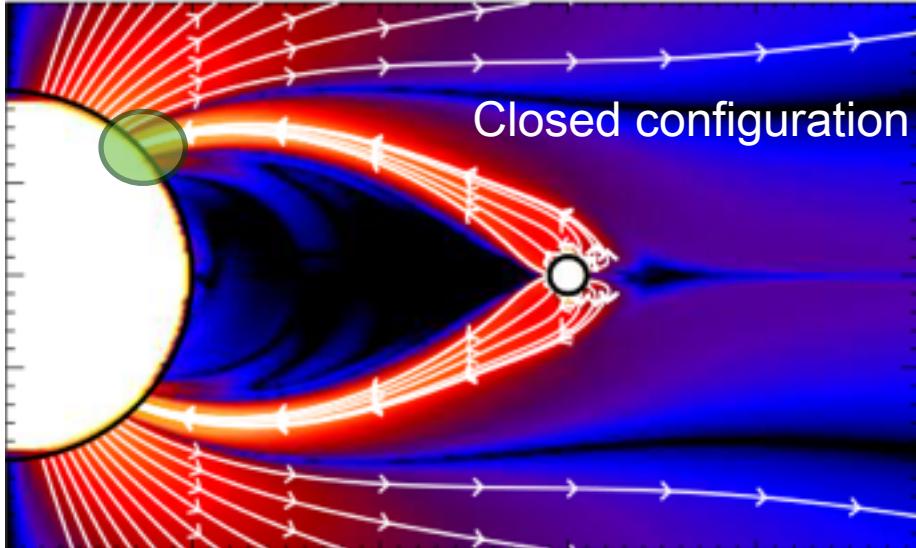
Planet mass = 1% stellar mass

~ e.g., Corot-27b, WASP-18b

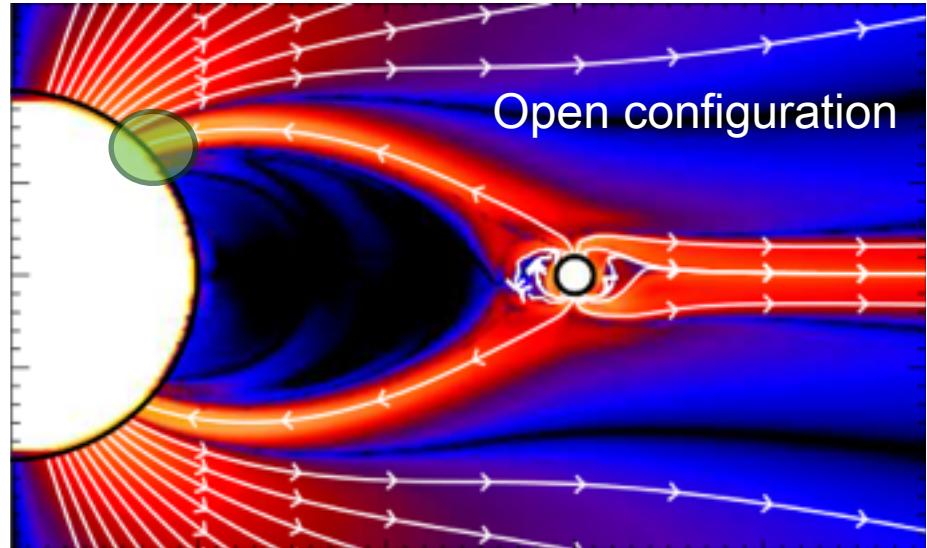
SUB-ALFVÉNIC REGIME: UNIPOLAR AND DIPOLAR CASES



ANGULAR MOMENTUM TRANSFERS



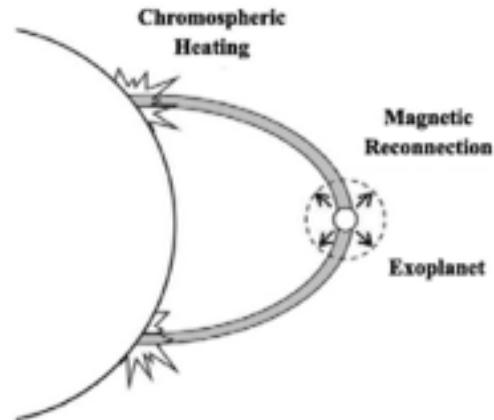
Closed configuration



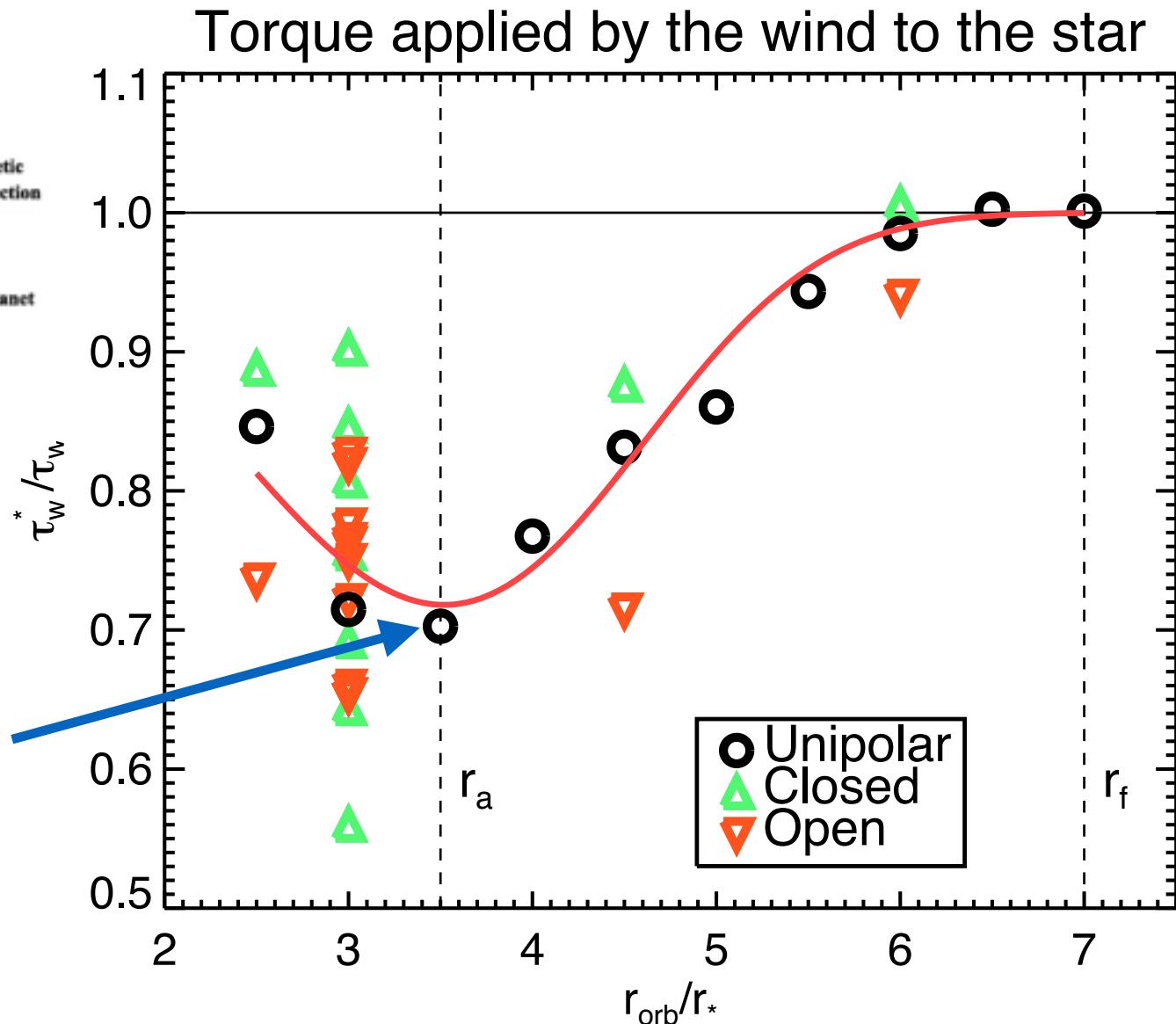
Open configuration

$$\mathcal{F} = \rho \varpi v_\phi \mathbf{v}_p - \varpi B_\phi \frac{B_p}{v_p} \mathbf{v}_p$$

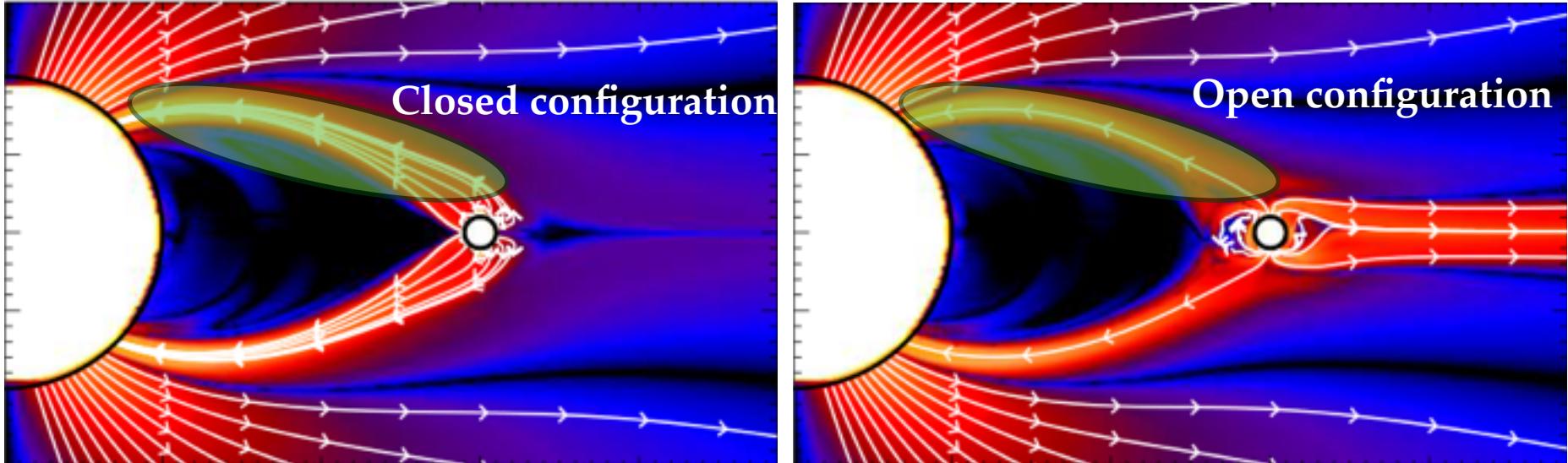
EFFECT ON THE STELLAR SURFACE: MODIFICATION OF THE WIND



Effect maximized
near the
Alfvén surface

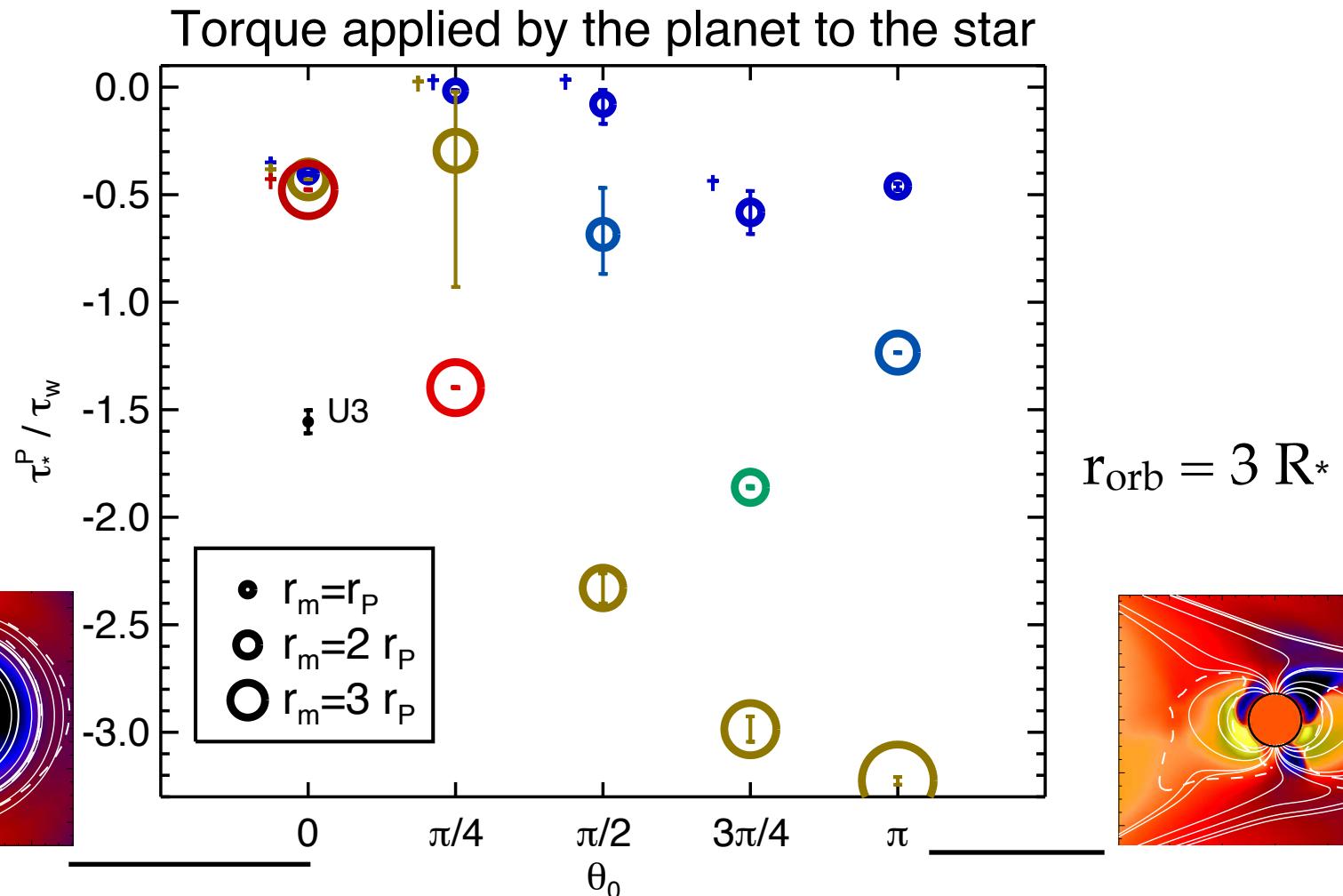


ANGULAR MOMENTUM TRANSFERS



$$\mathcal{F} = \rho\varpi v_\phi \mathbf{v}_p - \varpi B_\phi \frac{B_p}{v_p} \mathbf{v}_p$$

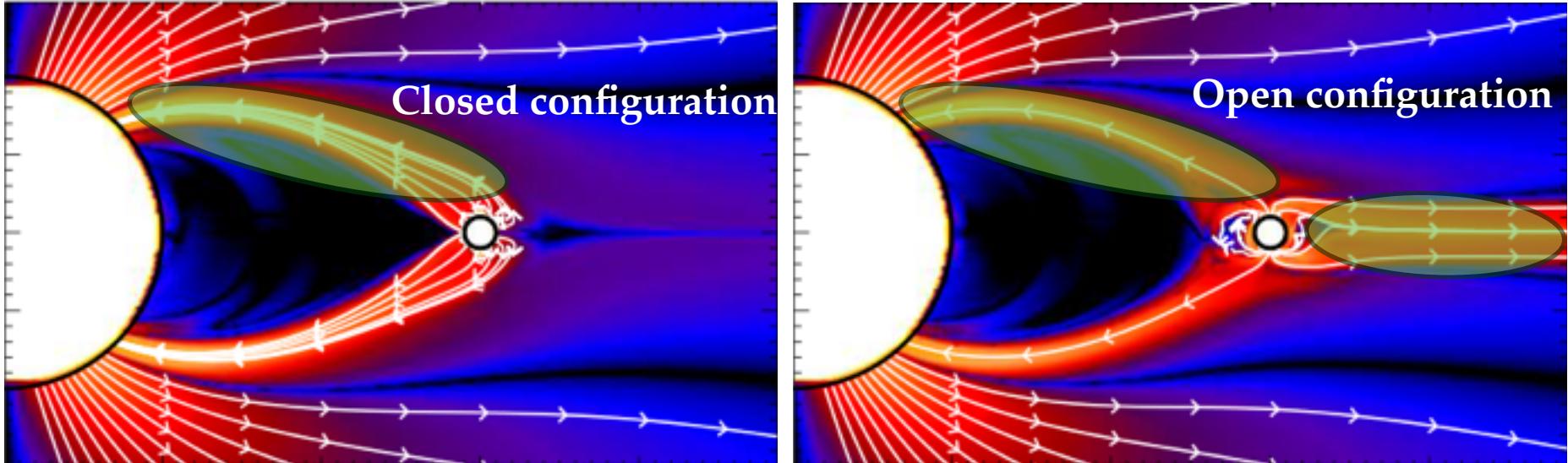
EFFECT ON THE STAR: MAGNETO-GYROCHRONOLOGY



Parametrization

$$\frac{\tau}{\tau_w} = c \left(\frac{B_P}{B_w} + b \right)^p \cos \left(\frac{\theta_0 - \Theta}{s} \right)$$

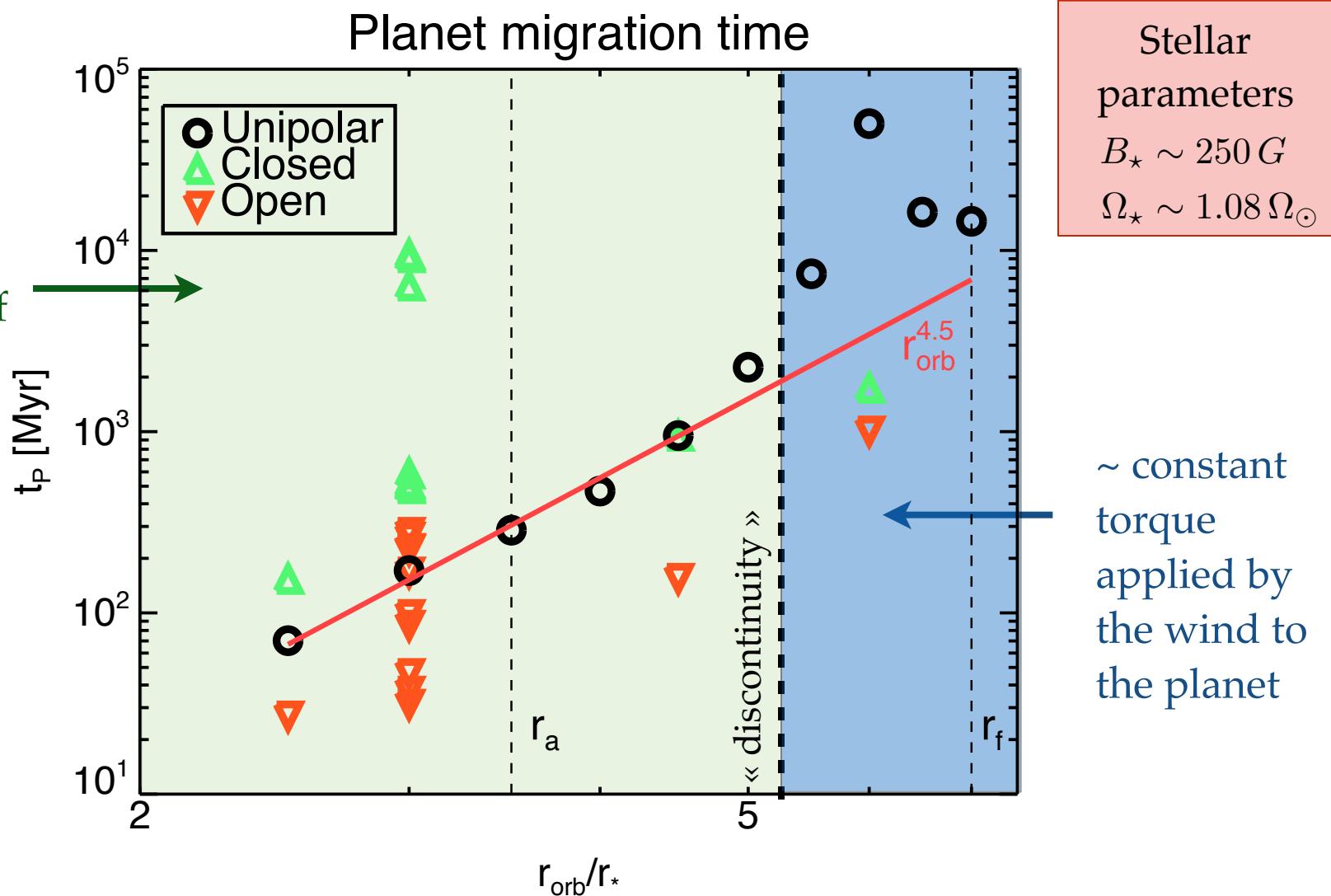
ANGULAR MOMENTUM TRANSFERS



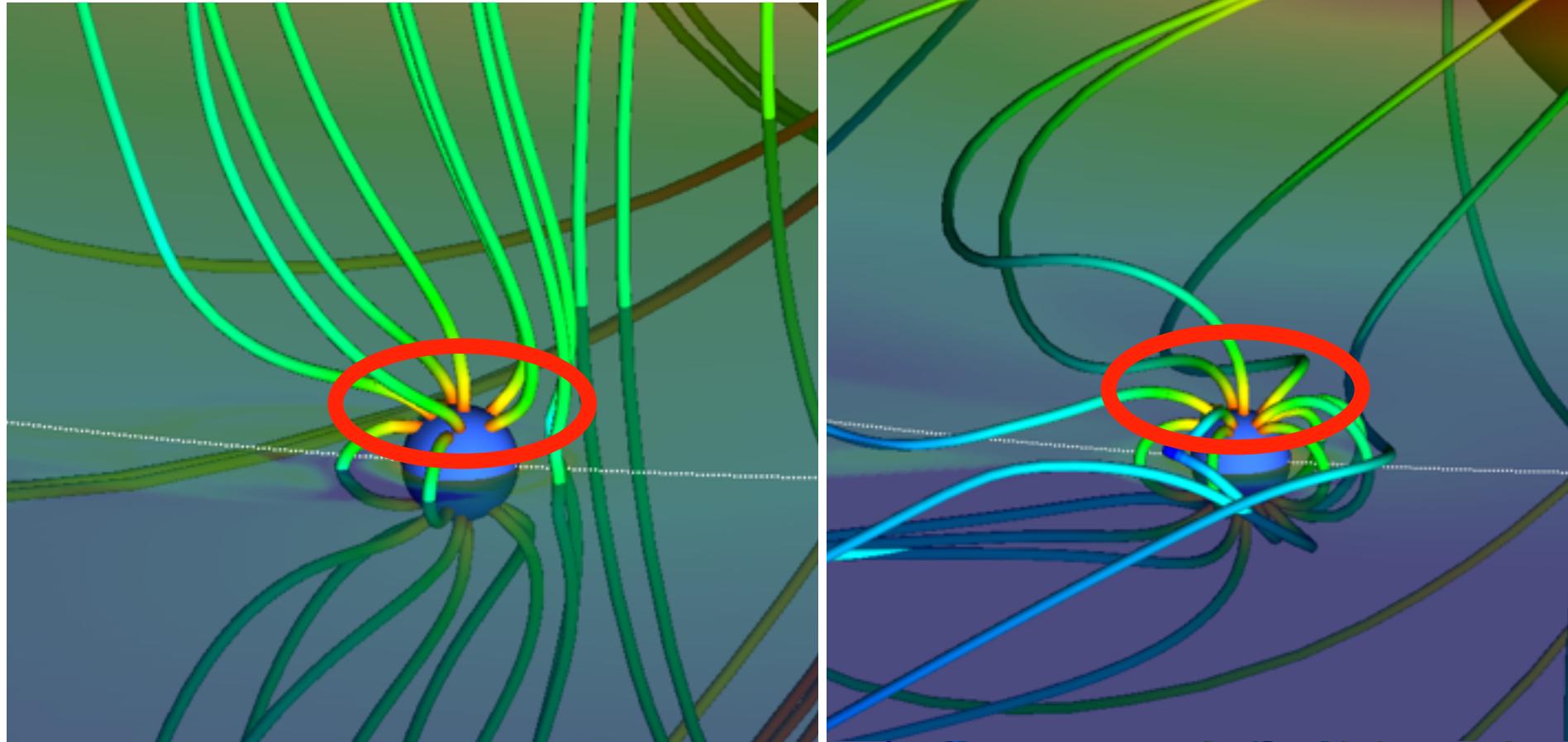
$$\mathcal{F} = \rho\varpi v_\phi \mathbf{v}_p - \varpi B_\phi \frac{B_p}{v_p} \mathbf{v}_p$$

MAGNETIC TORQUE AS A SOURCE OF PLANET MIGRATION

star-planet
exchange of
angular
mom.



MAGNETIC TOPOLOGY AND MAGNETIC INTERACTIONS



The magnetic torque originates mainly from the connection
of the planet's field to the ambient magnetic field

TAKE HOME MESSAGES

Close-in planets are expected to interact **magnetically** with their host in a large variety of ways

The knowledge of the **location** of the **stellar wind's Alfvén surface** is **mandatory** to estimate the effect of magnetic interactions

👉 **Rotation, magnetic field, mass loss rate and coronal T** of the host

The magnetic interactions **strongly depend** on the **strength and topology** of the stellar **and** planetary magnetic field

[Strugarek+, ApJ 2014]

The **habitable zone of cool stars** can be **very close**: planets in the HZ around M-dwarfs can also orbit inside the Alfvén surface and be subject to intense magnetic interactions