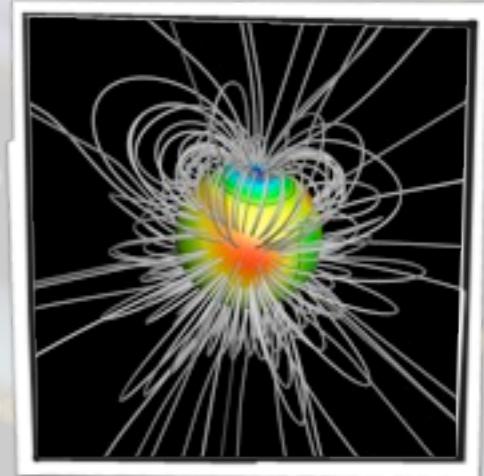
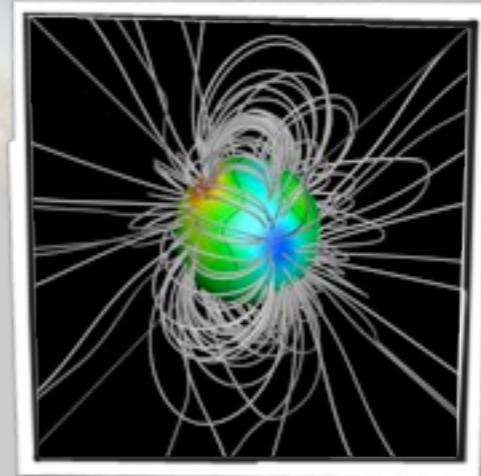
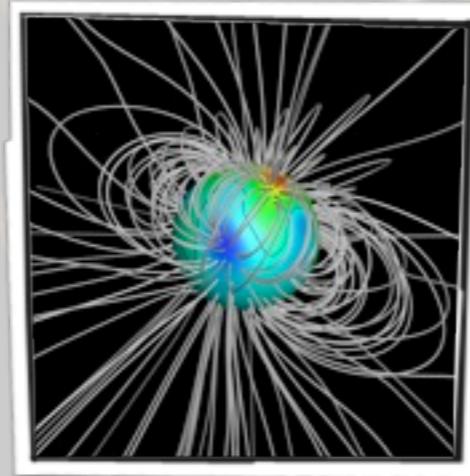
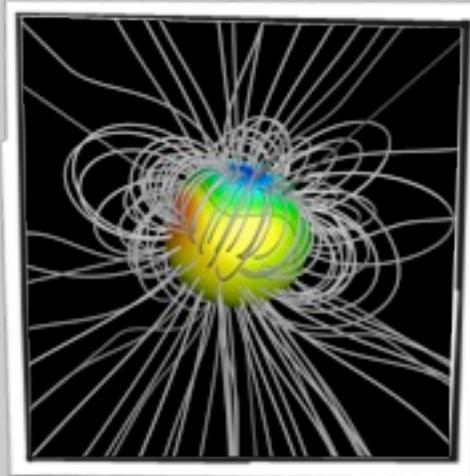


Magnetic interactions and habitability

Aline Vidotto

Ambizione Fellow - Swiss NSF
University of Geneva



Outline

1. Interactions between a magnetised planet and a magnetised star

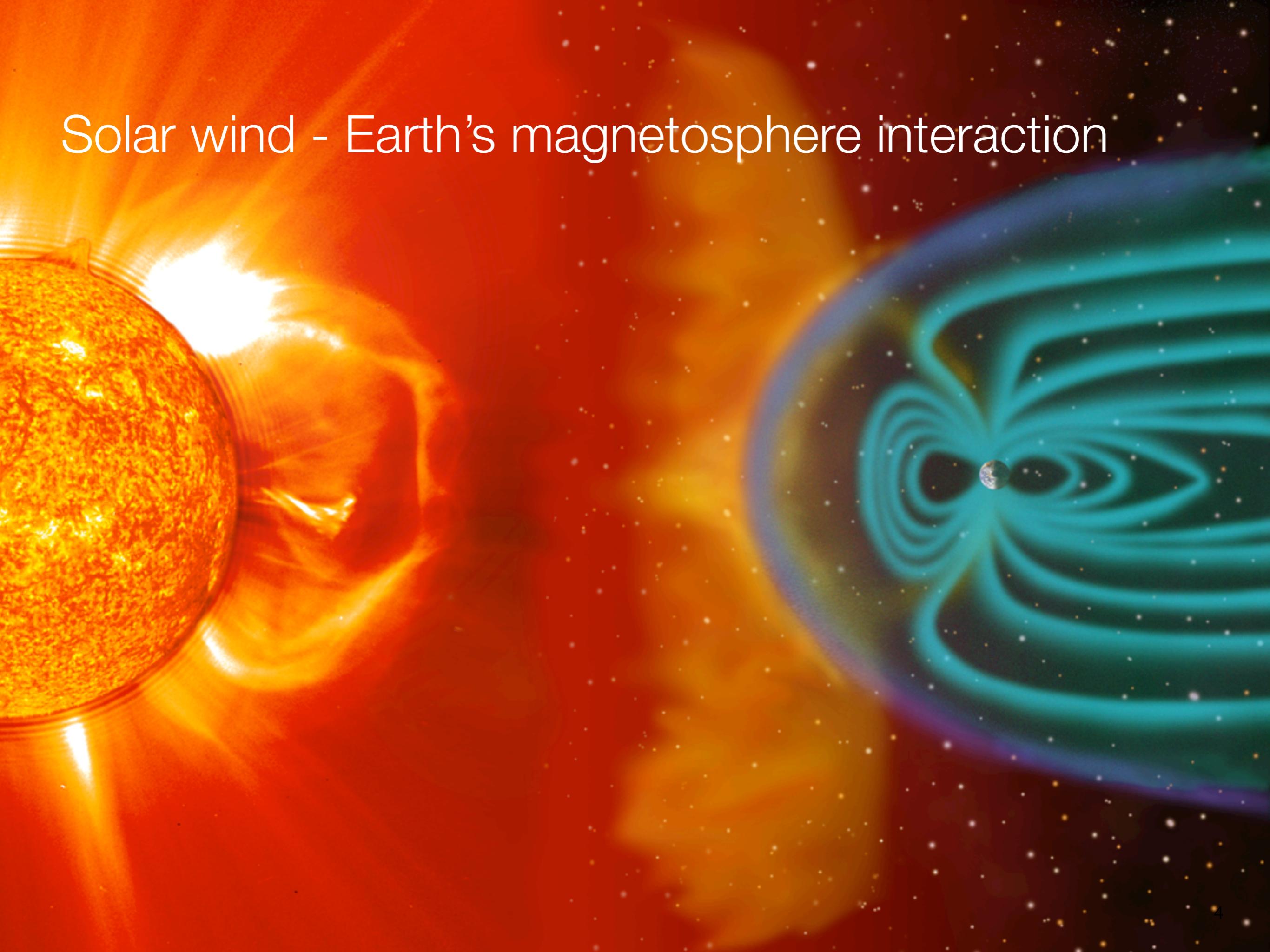
- ▶ bow shock formation
- ▶ radio emission
- ▶ chromospheric activity enhancement
- ▶ planetary migration
- ▶ interactions with stellar CMEs & background wind

2. Stellar winds of cool stars - observations & models

3. What effects the stellar wind/magnetism could play on planetary habitability?

1. Interactions between a magnetised planet and a magnetised star

Solar wind - Earth's magnetosphere interaction

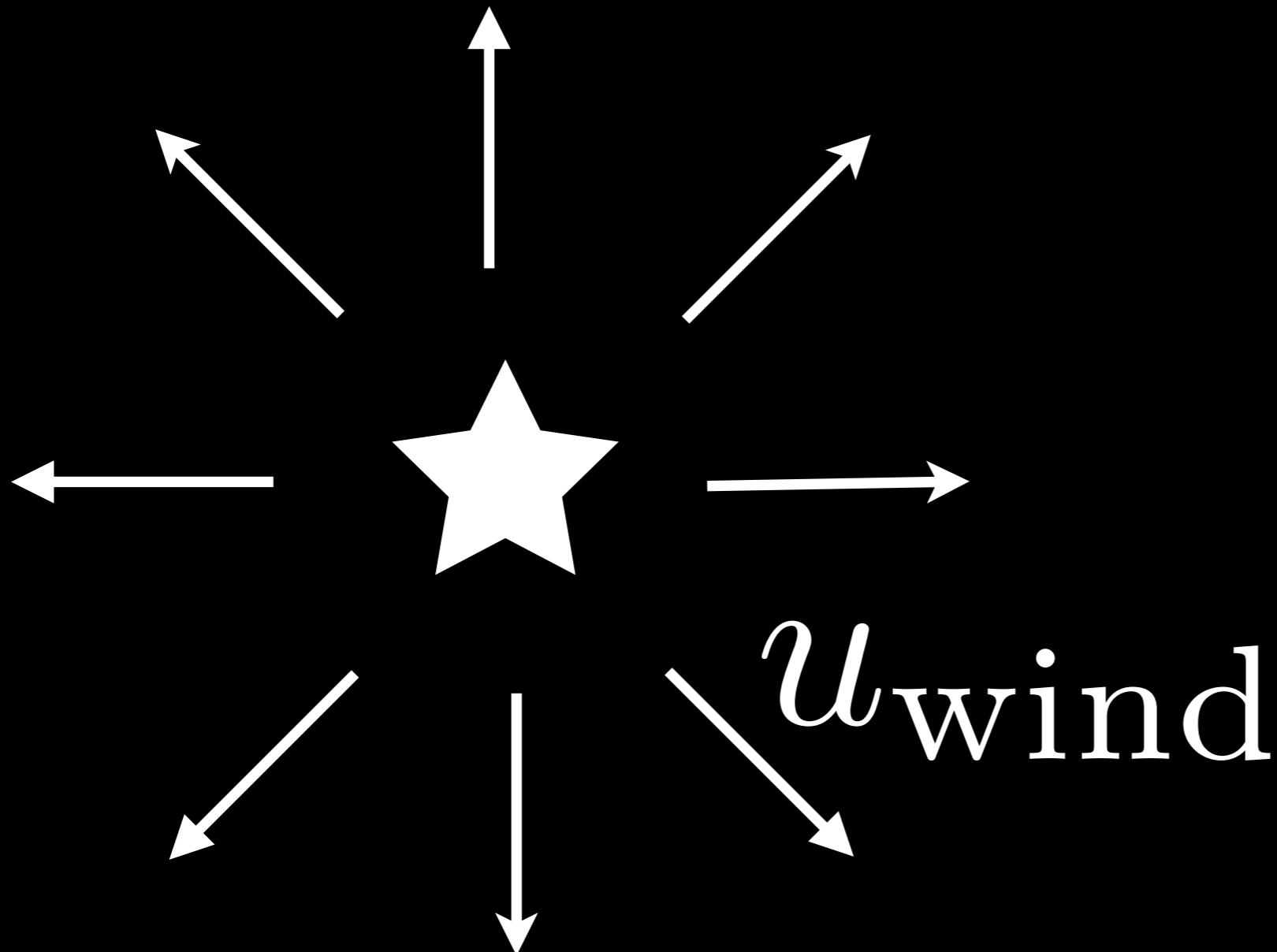


Solar wind - Earth's magnetosphere interaction

- Similar interactions occur in **exoplanets**
- Key **difference** wrt Earth: close-in location of hot-Jupiters.
 - ▶ high density environment
 - ▶ higher ambient magnetic fields
 - ▶ lower wind velocities (acceleration zone)
 - ▶ high Keplerian velocities

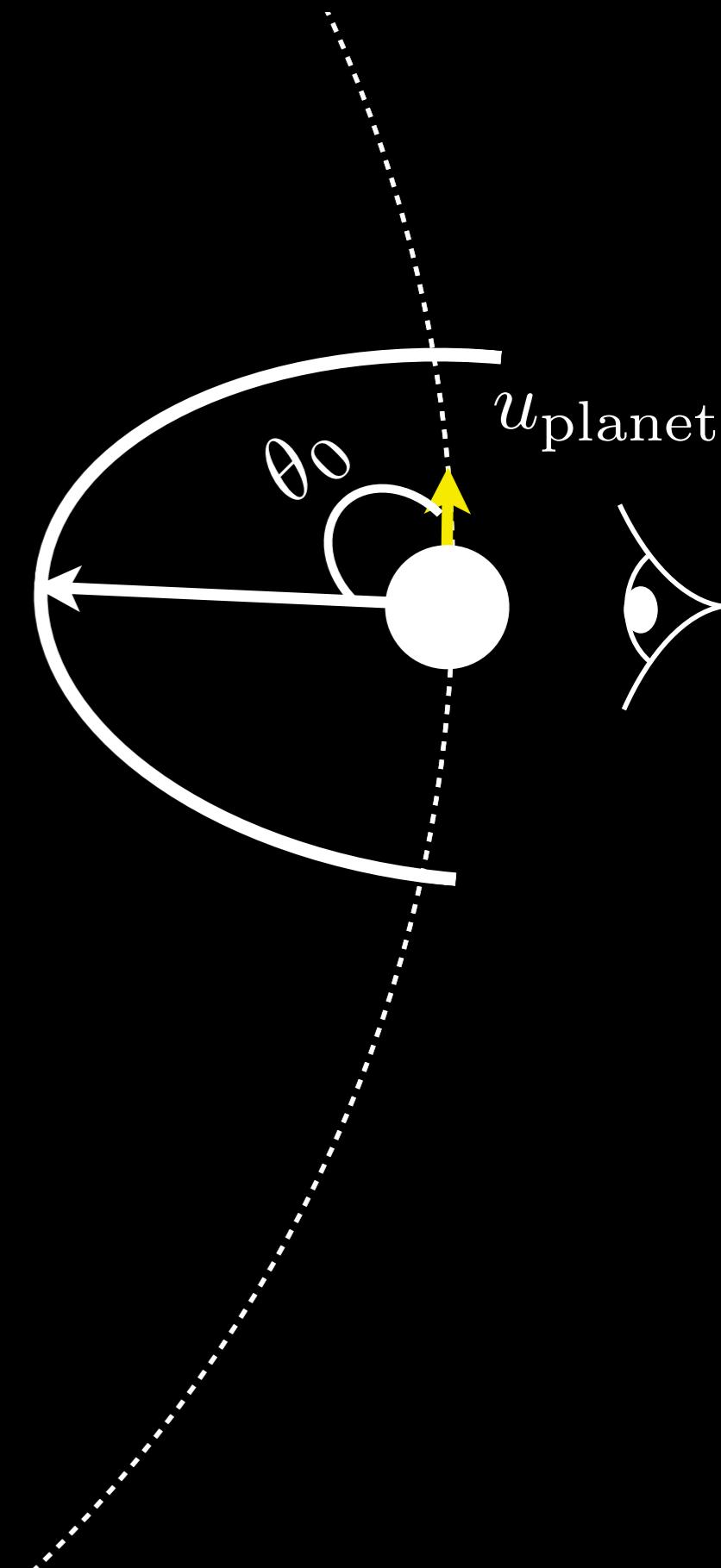
Stellar wind - planet interactions

animation credit: Joe Llama



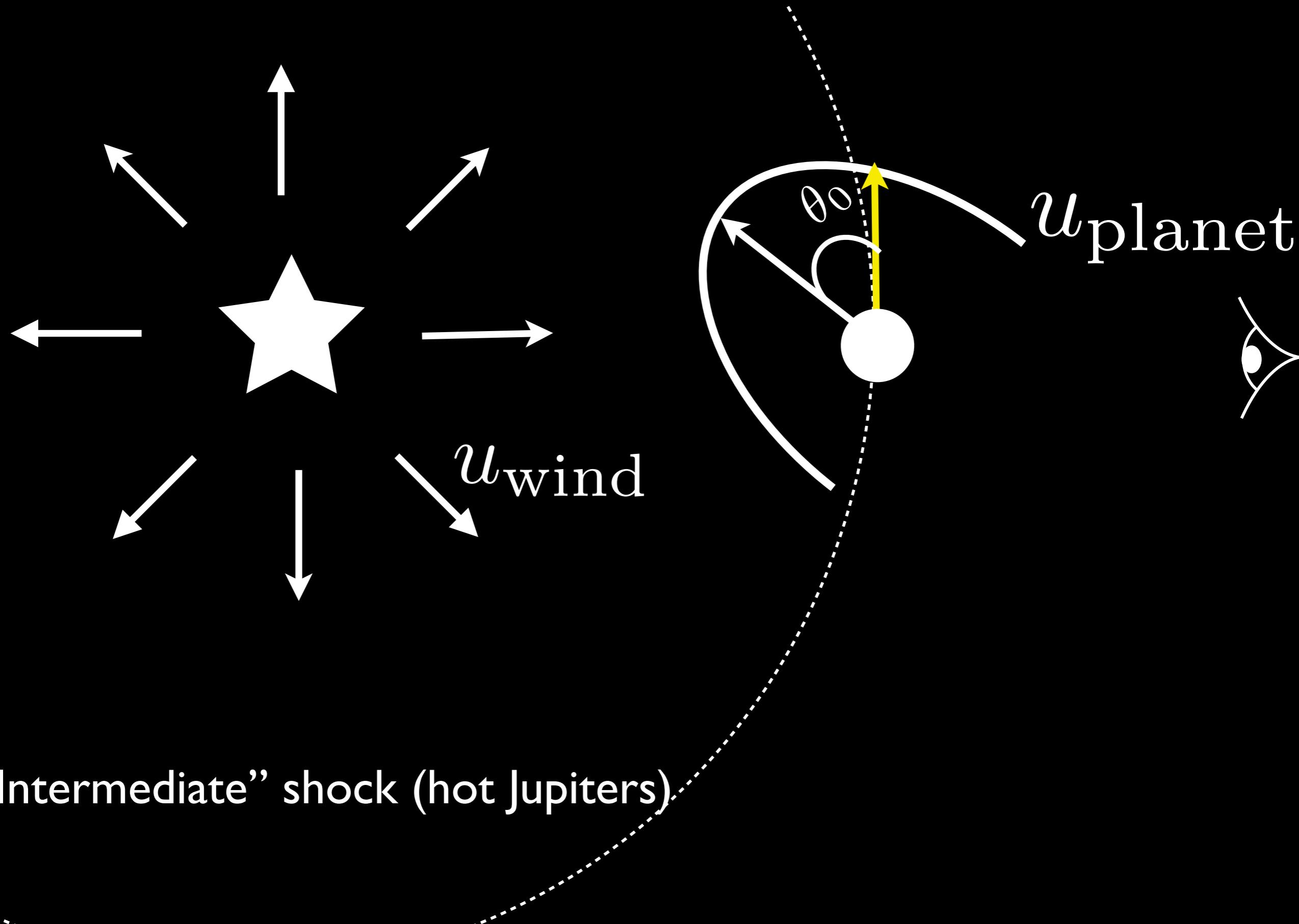
u_{wind}

“Dayside” shock (~Earth’s case)



Stellar wind - planet interactions

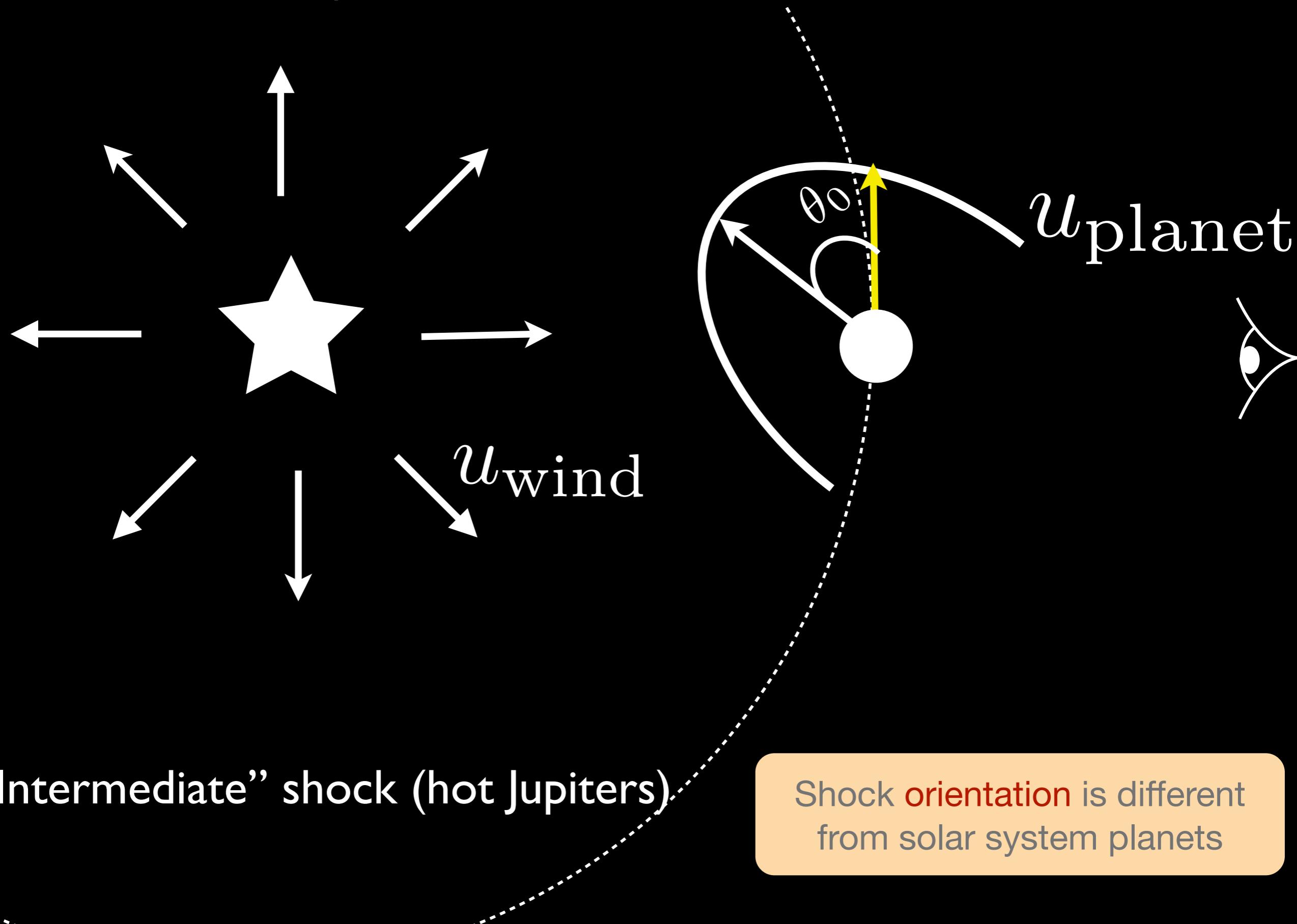
animation credit: Joe Llama



“Intermediate” shock (hot Jupiters)

Stellar wind - planet interactions

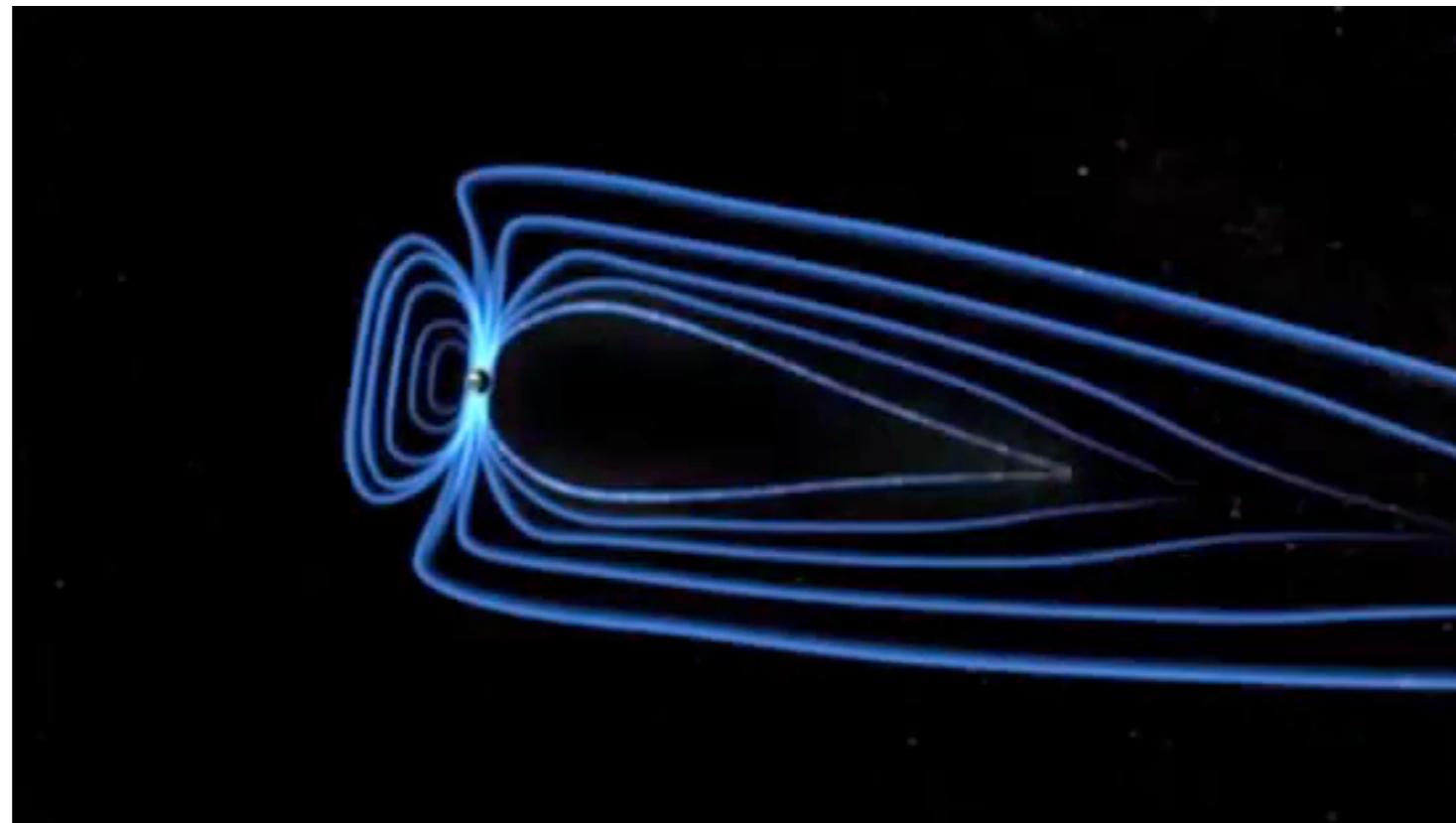
animation credit: Joe Llama



Stellar wind - planet interactions: planetary radio emission

- Interaction between the stellar wind and the magnetised planet: reconnection that releases energetic electrons → aurora & radio emission

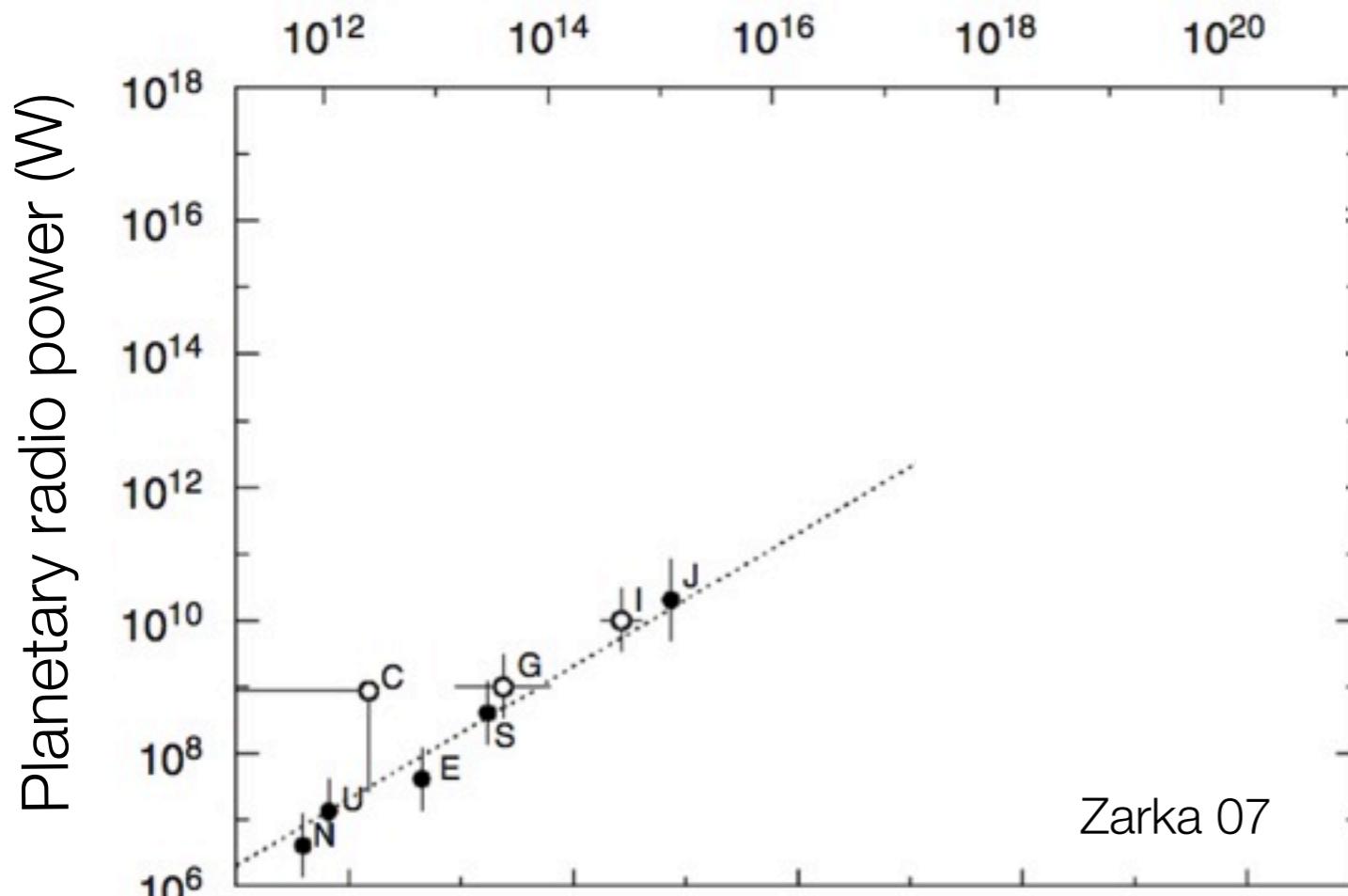
Northern Lights: illustration of the process of auroral emission at the Earth



Credit: NASA

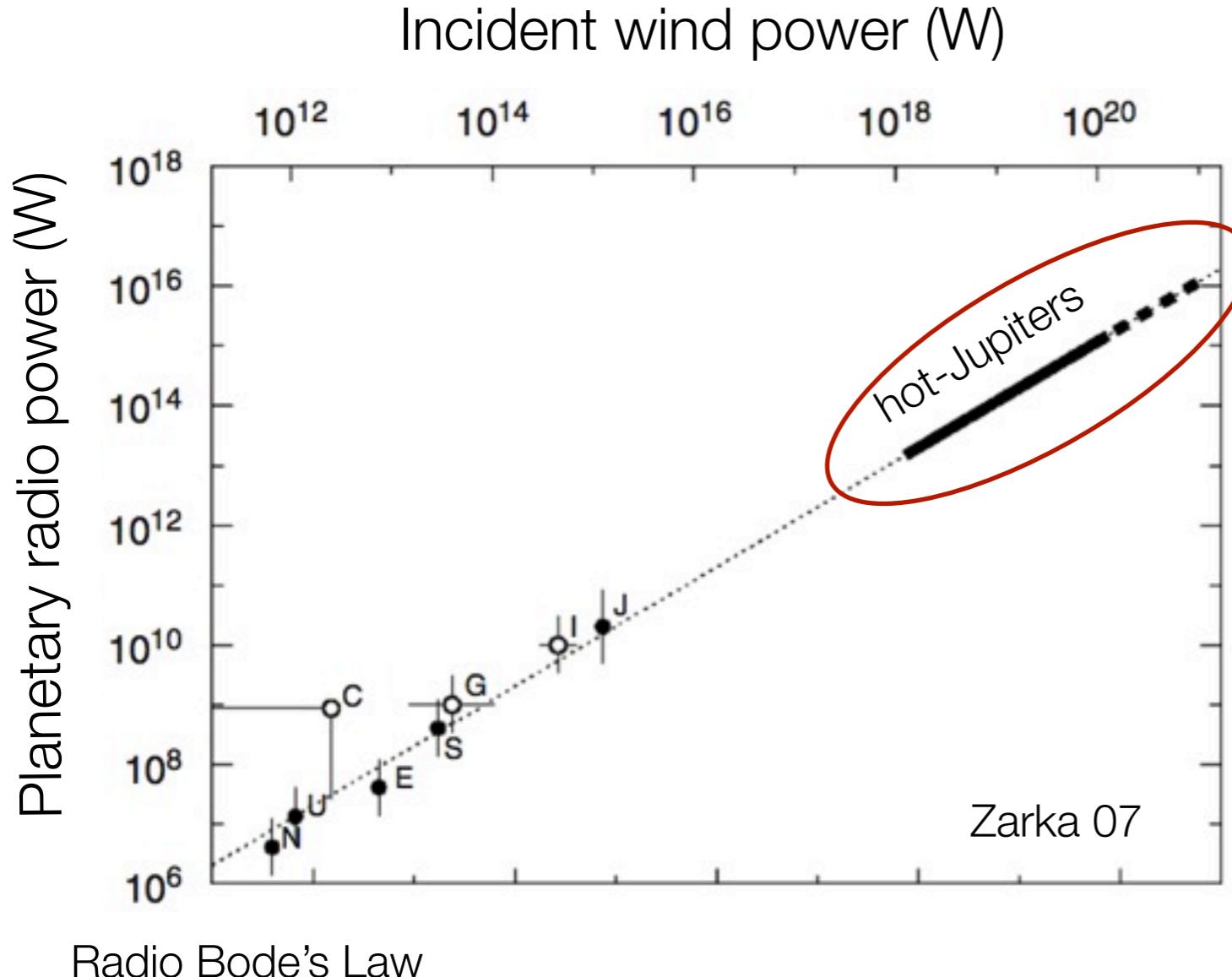
Stellar wind - planet interactions: planetary radio emission

Incident wind power (W)



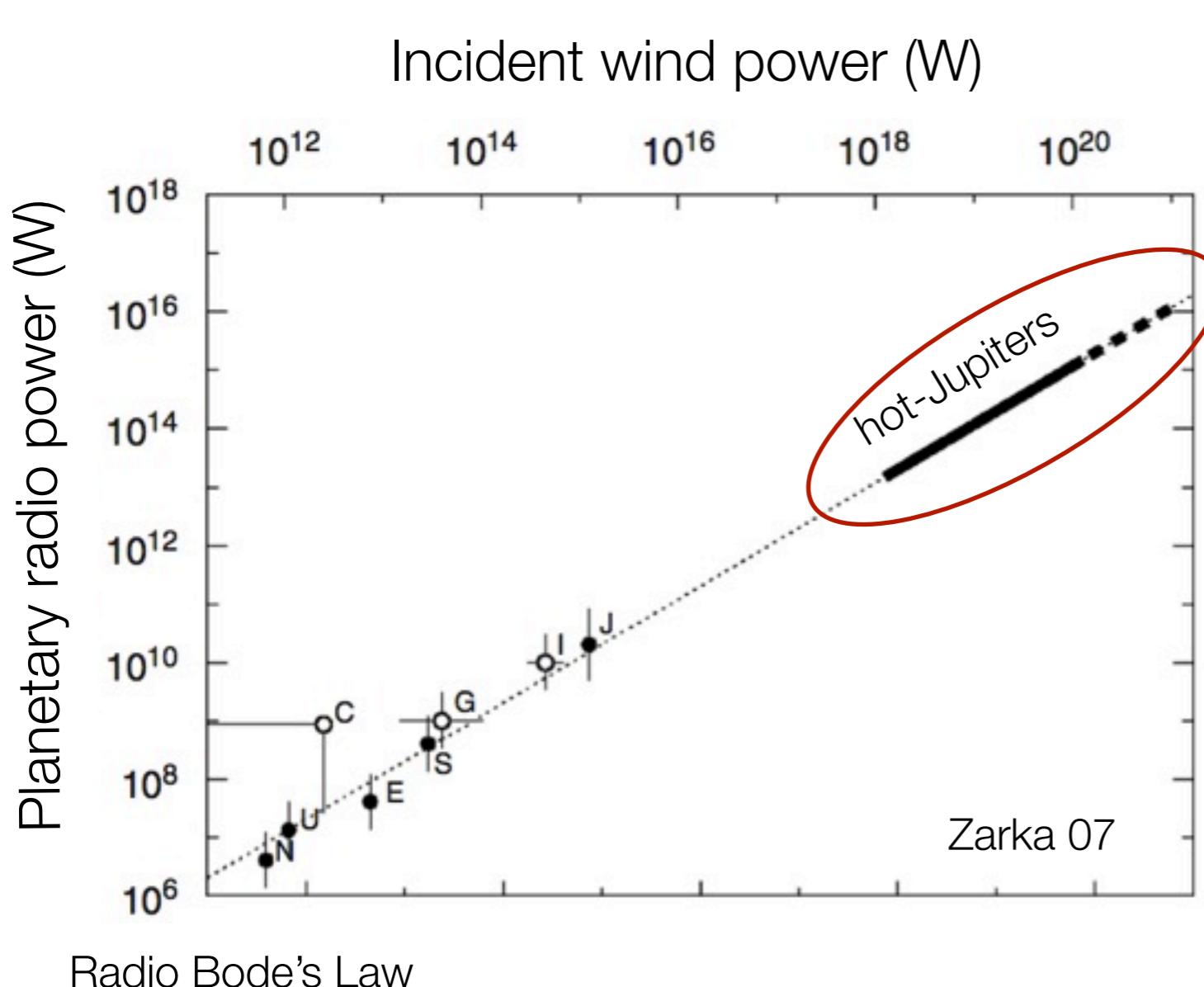
- Estimated cyclotron radio emission from hot-Jupiters:
 - ▶ **direct** detection of exoplanets
 - ▶ detection would demonstrate that a planet is **magnetised**

Stellar wind - planet interactions: planetary radio emission



- Estimated cyclotron radio emission from hot-Jupiters:
 - ▶ **direct** detection of exoplanets

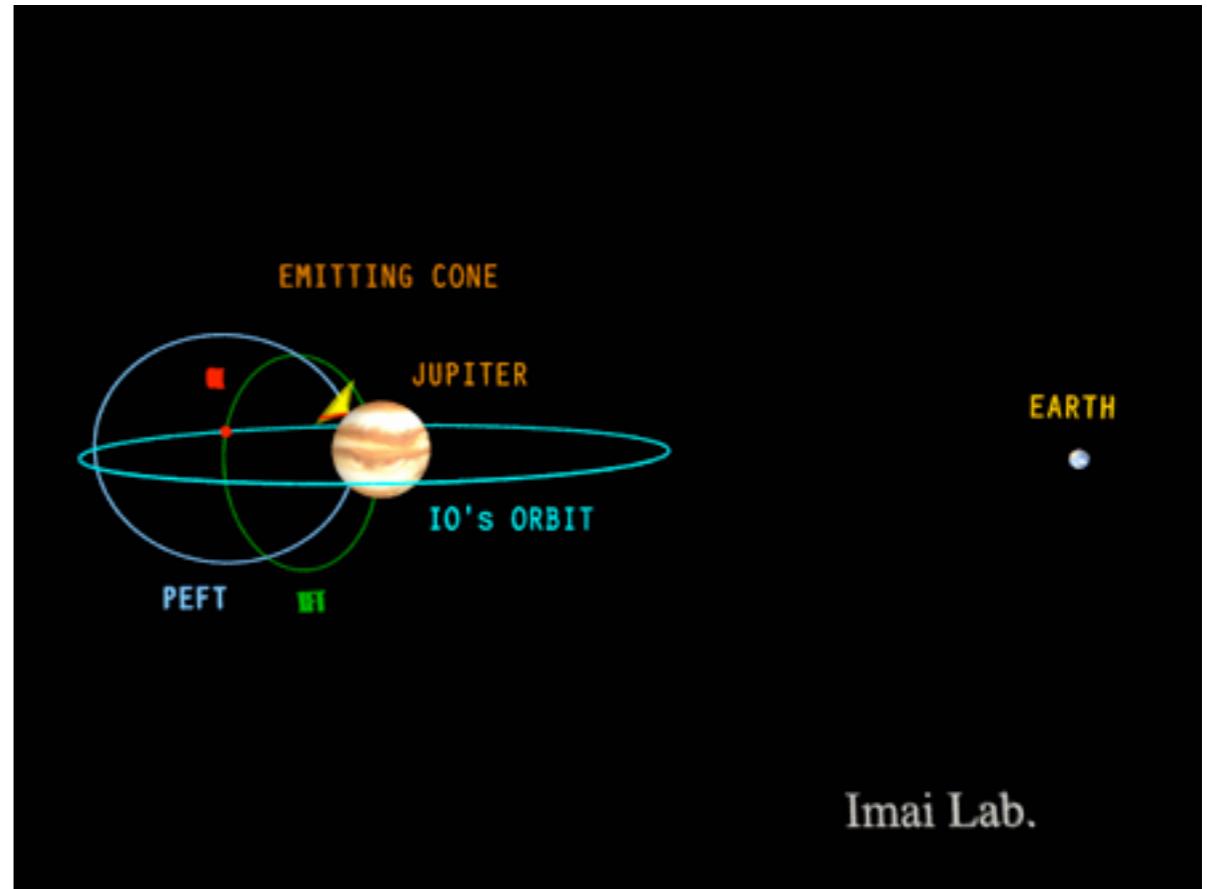
Stellar wind - planet interactions: planetary radio emission



- Estimated cyclotron radio emission from hot-Jupiters:
 - ▶ **direct** detection of exoplanets
 - ▶ detection would demonstrate that a planet is **magnetised**

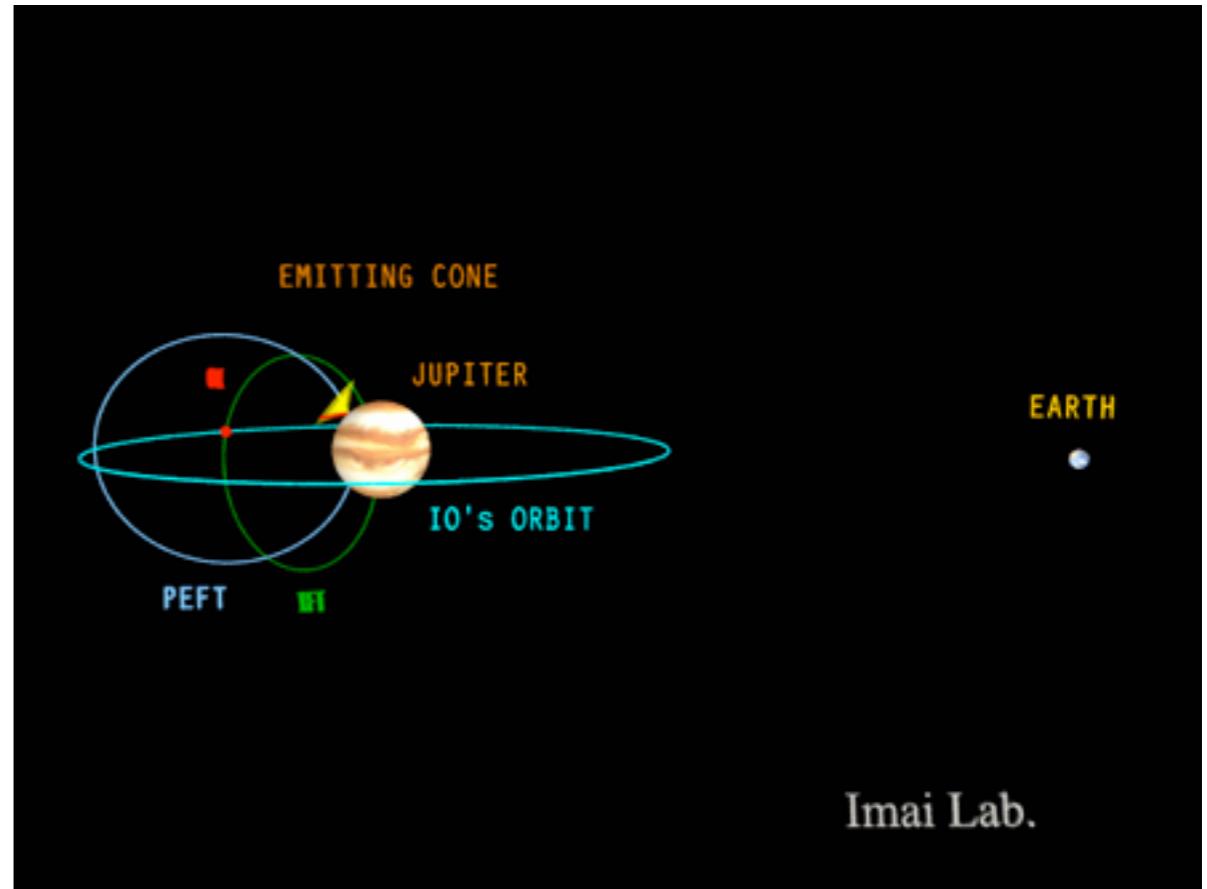
Stellar wind - planet interactions: planetary radio emission

- Radio emission from exoplanets: **unsuccessful** so far
(Winglee+ 86, Bastian+ 00, Lazio & Farrell 07, Lazio+ 10, and many other works)
 - Observations not sensitive enough?
 - Low wind power?
 - Small planetary field? Frequency mismatch.
 - Emission beam not directed towards us?
- Instruments (e.g., LOFAR) with great potential of detection are just now becoming available
(Griessmeier+07,11,etc)



Stellar wind - planet interactions: planetary radio emission

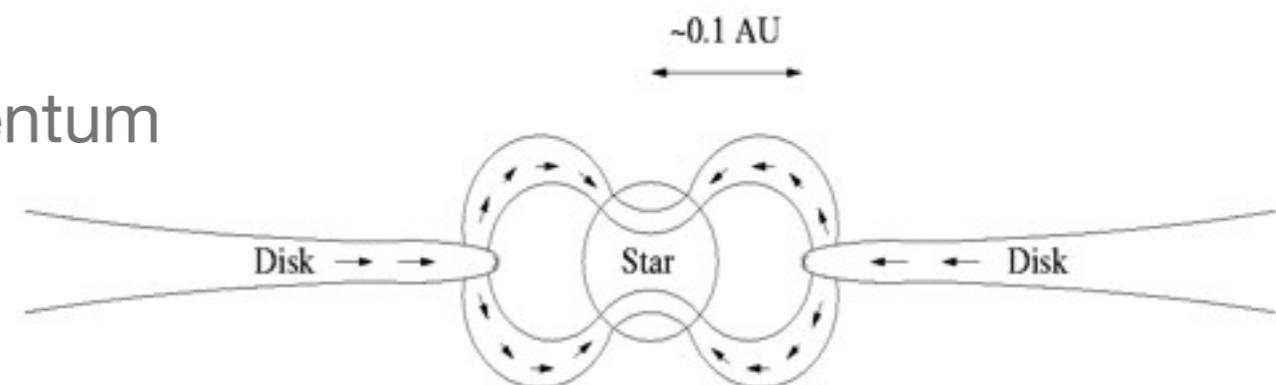
- Radio emission from exoplanets: **unsuccessful** so far
(Winglee+ 86, Bastian+ 00, Lazio & Farrell 07, Lazio+ 10, and many other works)
 - Observations not sensitive enough?
 - Low wind power?
 - Small planetary field? Frequency mismatch.
 - Emission beam not directed towards us?
- Instruments (e.g., LOFAR) with great potential of detection are just now becoming available
(Griessmeier+07,11,etc)



P. Zarka's talk

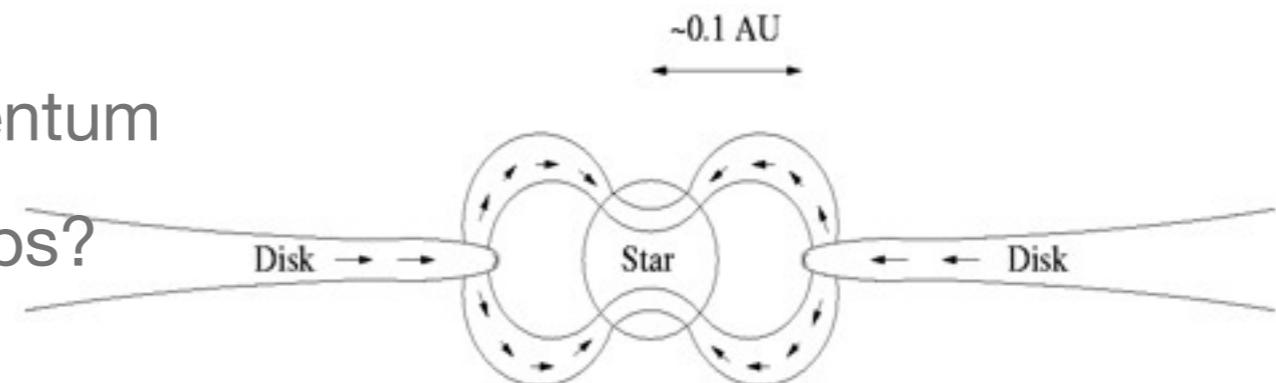
Stellar wind - planet interactions: planetary migration at early phases

- Disk-interaction removes angular momentum



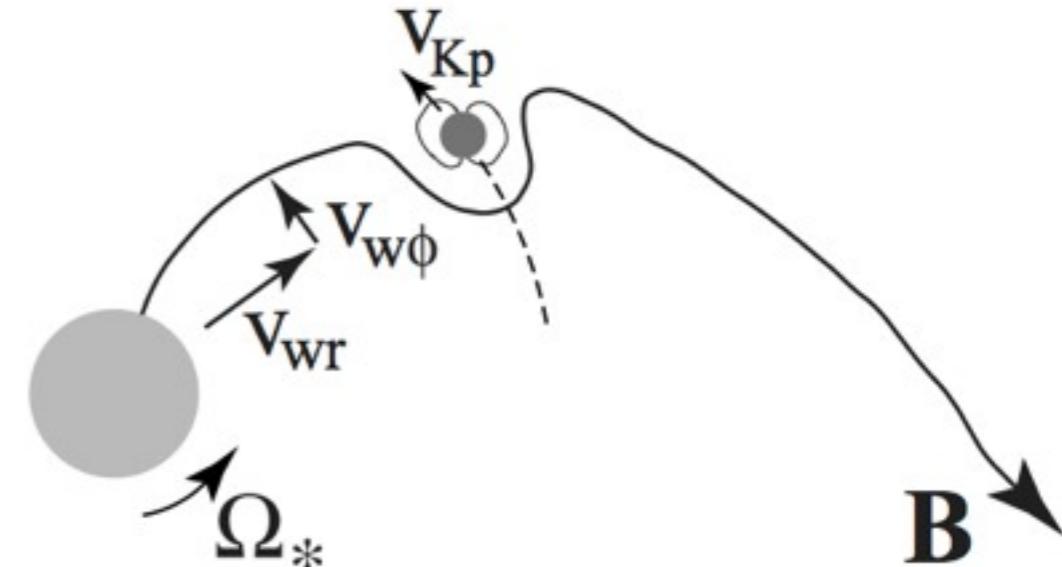
Stellar wind - planet interactions: planetary migration at early phases

- Disk-interaction removes angular momentum
- Magnetospheric cavity → migration stops?



Stellar wind - planet interactions: planetary migration at early phases

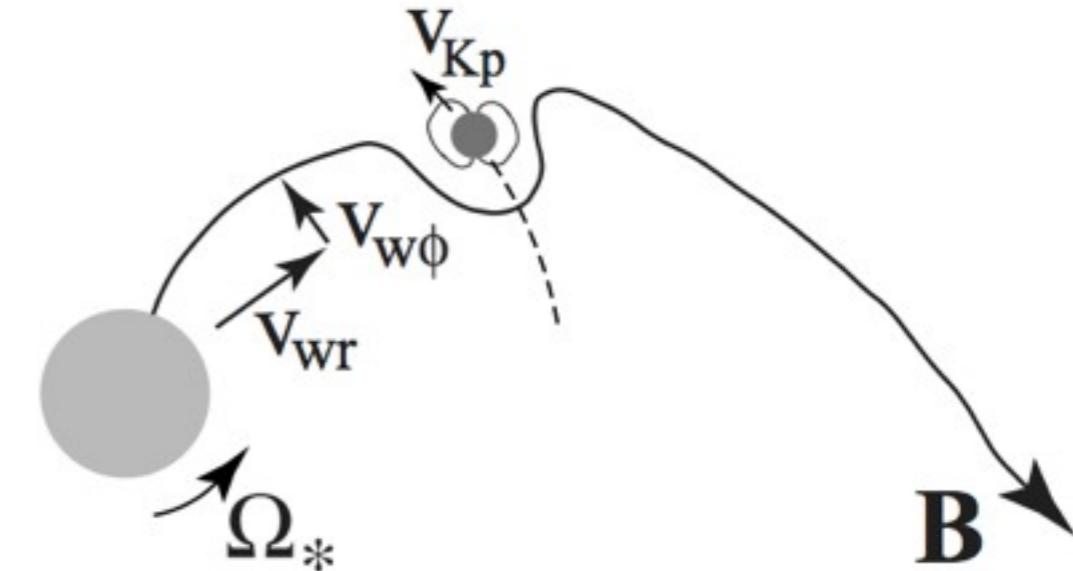
- Disk-interaction removes angular momentum
- Magnetospheric cavity → migration stops?
- Lovelace+08: **magnetic torques** exerted by the stellar wind could favour the planet migration



Lovelace+08

Stellar wind - planet interactions: planetary migration at early phases

- Disk-interaction removes angular momentum
- Magnetospheric cavity → migration stops?
- Lovelace+08: **magnetic torques** exerted by the stellar wind could favour the planet migration
 - ▶ wind exerts a total pressure p_{tot} (=mag +ram) on the cross section πr_M^2 of the planet → this force produces a torque @ the planetary orbit r

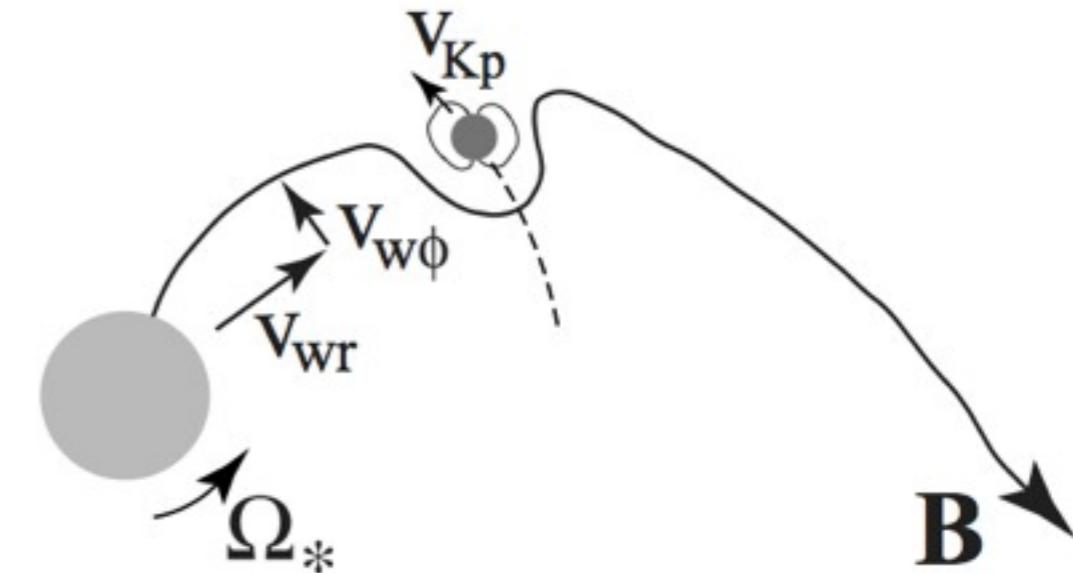


Lovelace+08

$$\left| \frac{dL_p}{dt} \right| \simeq (p_{\text{tot}} \pi r_M^2) r$$

Stellar wind - planet interactions: planetary migration at early phases

- Disk-interaction removes angular momentum
- Magnetospheric cavity → migration stops?
- Lovelace+08: **magnetic torques** exerted by the stellar wind could favour the planet migration
 - ▶ wind exerts a total pressure p_{tot} (=mag +ram) on the cross section πr_M^2 of the planet → this force produces a torque @ the planetary orbit r
 - ▶ orbital AM: $L_p = M_p v_K r$



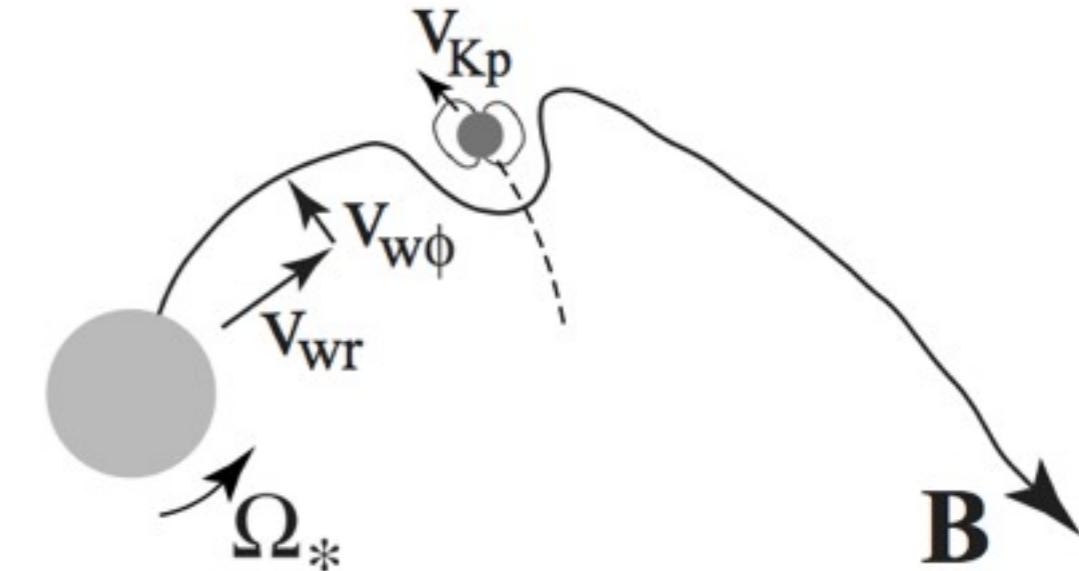
Lovelace+08

$$\left| \frac{dL_p}{dt} \right| \simeq (p_{\text{tot}} \pi r_M^2) r$$

$$\left| \frac{dL_p}{dt} \right| \simeq \frac{1}{2} M_p v_K \frac{dr}{dt} \simeq \frac{1}{2} M_p v_K \frac{r}{\tau_w}$$

Stellar wind - planet interactions: planetary migration at early phases

- Disk-interaction removes angular momentum
- Magnetospheric cavity → migration stops?
- Lovelace+08: **magnetic torques** exerted by the stellar wind could favour the planet migration
 - ▶ wind exerts a total pressure p_{tot} (=mag +ram) on the cross section πr_M^2 of the planet → this force produces a torque @ the planetary orbit r
 - ▶ orbital AM: $L_p = M_p v_K r$
 - ▶ τ_w : timescale for appreciable motion of the planet (Lin+96)



Lovelace+08

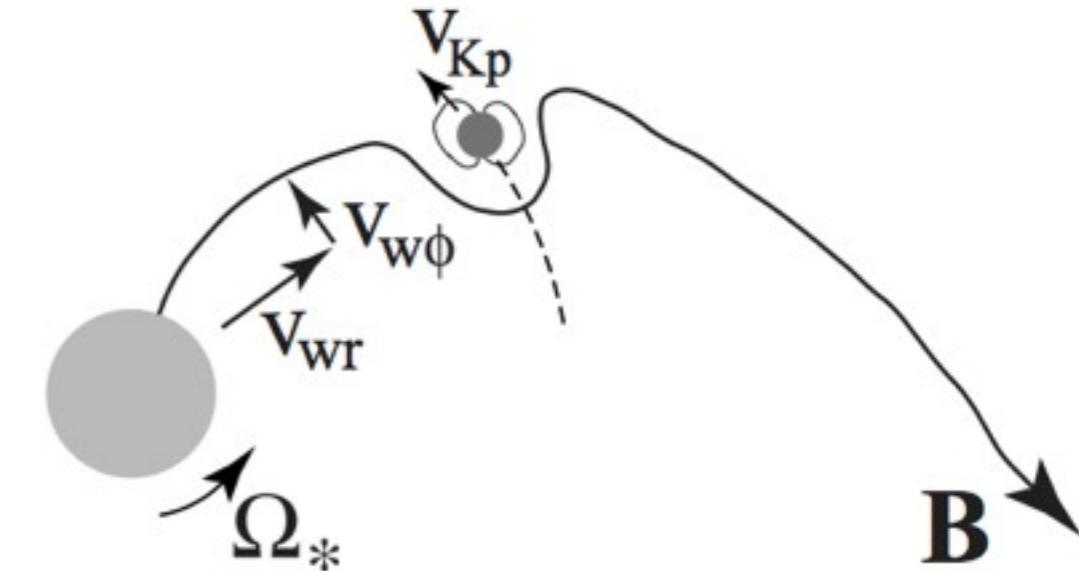
$$\left| \frac{dL_p}{dt} \right| \simeq (p_{\text{tot}} \pi r_M^2) r$$

$$\left| \frac{dL_p}{dt} \right| \simeq \frac{1}{2} M_p v_K \frac{dr}{dt} \simeq \frac{1}{2} M_p v_K \frac{r}{\tau_w}$$

$$\tau_w \simeq \frac{1}{2} \frac{M_p v_K}{p_{\text{tot}} \pi r_M^2}$$

Stellar wind - planet interactions: planetary migration at early phases

- Disk-interaction removes angular momentum
- Magnetospheric cavity → migration stops?
- Lovelace+08: **magnetic torques** exerted by the stellar wind could favour the planet migration
 - ▶ wind exerts a total pressure p_{tot} (=mag +ram) on the cross section πr_M^2 of the planet → this force produces a torque @ the planetary orbit r
 - ▶ orbital AM: $L_p = M_p v_K r$
 - ▶ τ_w : timescale for appreciable motion of the planet (Lin+96)
- Is it an important effect?



Lovelace+08

$$\left| \frac{dL_p}{dt} \right| \simeq (p_{\text{tot}} \pi r_M^2) r$$

$$\left| \frac{dL_p}{dt} \right| \simeq \frac{1}{2} M_p v_K \frac{dr}{dt} \simeq \frac{1}{2} M_p v_K \frac{r}{\tau_w}$$

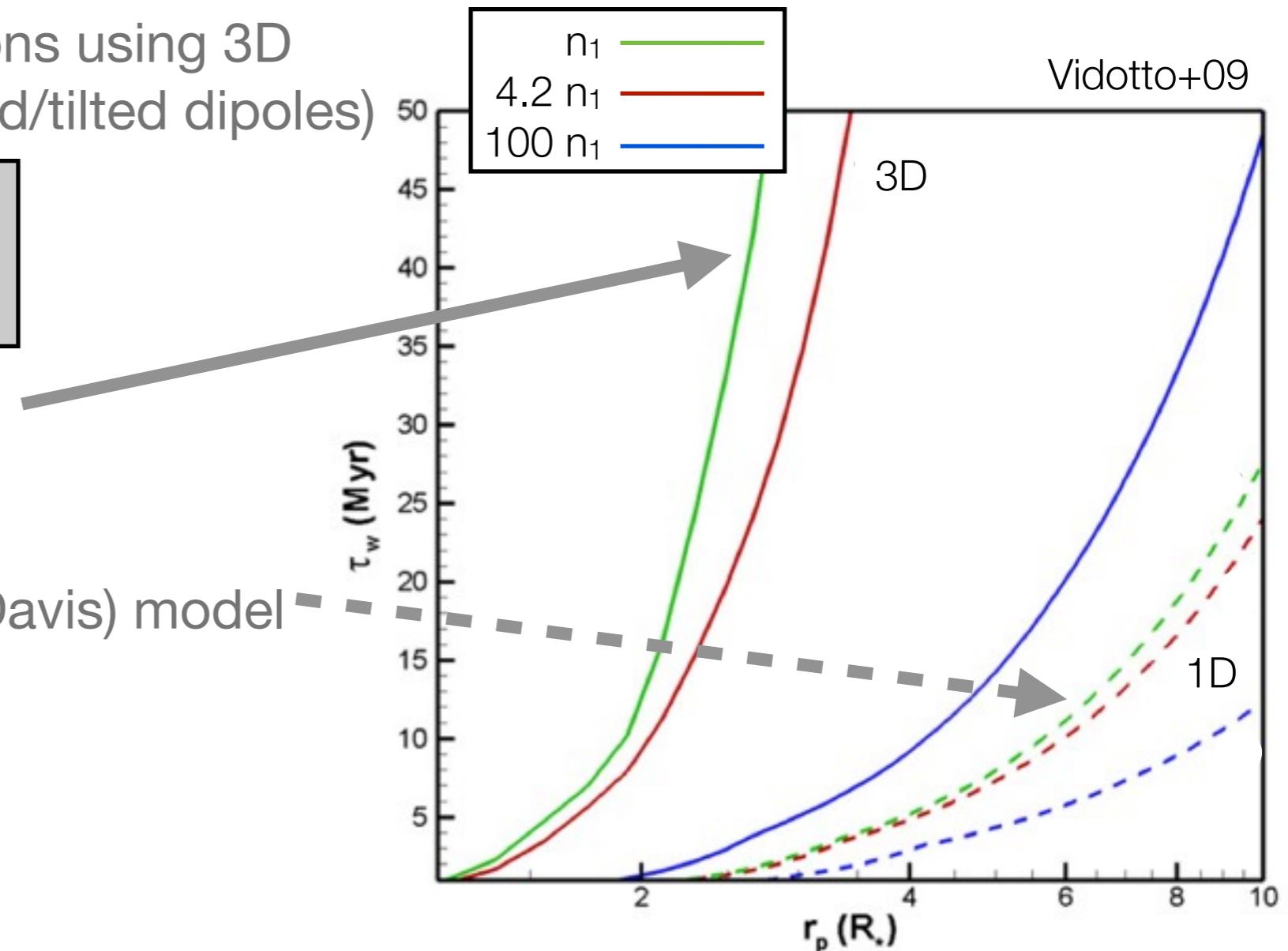
$$\tau_w \simeq \frac{1}{2} \frac{M_p v_K}{p_{\text{tot}} \pi r_M^2}$$

Stellar wind - planet interactions: planetary migration at early phases

- Vidotto+09, 10a: calculations using 3D stellar wind models (aligned/tilted dipoles)

$$\tau_w \simeq \frac{1}{2} \frac{M_p v_K}{p_{\text{tot}} \pi r_M^2}$$

- Solid lines: 3D models
 - ▶ $\tau_w > 50 - 100$ Myr
- Dashed lines: 1D (Weber-Davis) model
 - ▶ $\tau_w \sim 2 - 20$ Myr



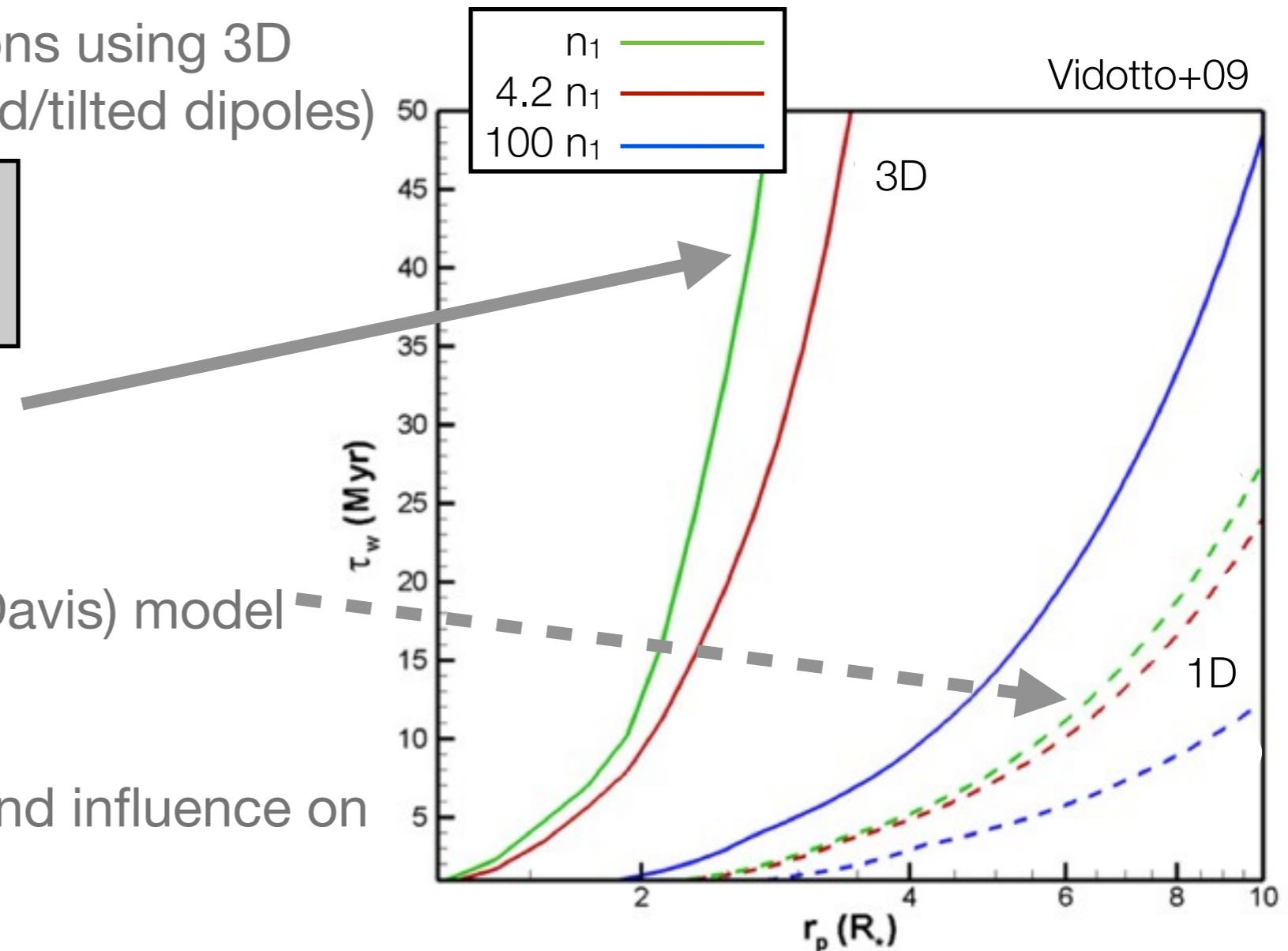
$$dM/dt \approx 10^{-9} - 8 \times 10^{-8} M_{\text{sun}}/\text{yr}$$

Stellar wind - planet interactions: planetary migration at early phases

- Vidotto+09, 10a: calculations using 3D stellar wind models (aligned/tilted dipoles)

$$\tau_w \simeq \frac{1}{2} \frac{M_p v_K}{p_{\text{tot}} \pi r_M^2}$$

- Solid lines: 3D models
 - $\tau_w > 50 - 100$ Myr
- Dashed lines: 1D (Weber-Davis) model
 - $\tau_w \sim 2 - 20$ Myr
- 1D models over-predict wind influence on planetary migration



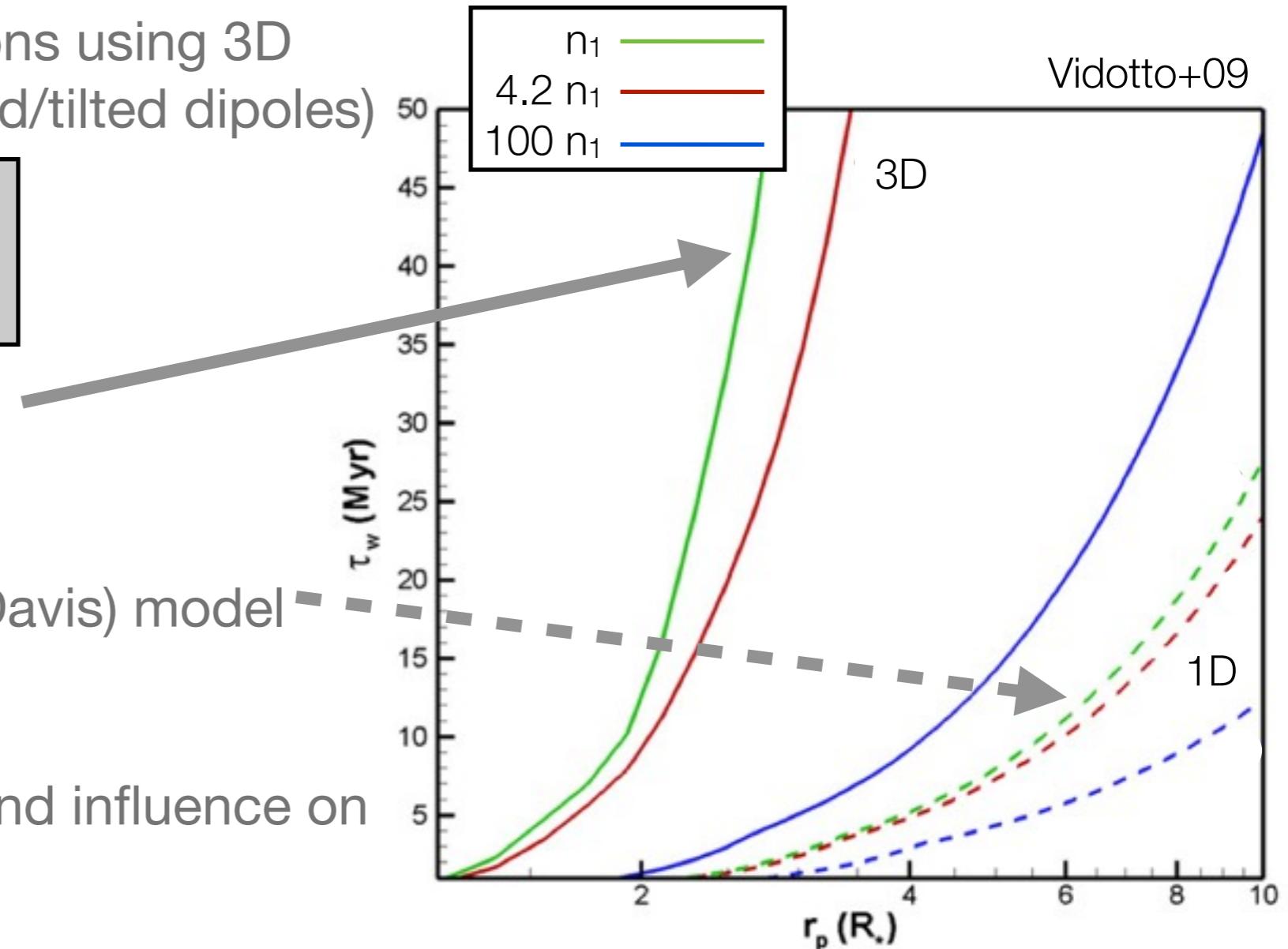
$$dM/dt \approx 10^{-9} - 8 \times 10^{-8} M_{\text{sun}}/\text{yr}$$

Stellar wind - planet interactions: planetary migration at early phases

- Vidotto+09, 10a: calculations using 3D stellar wind models (aligned/tilted dipoles)

$$\tau_w \simeq \frac{1}{2} \frac{M_p v_K}{p_{\text{tot}} \pi r_M^2}$$

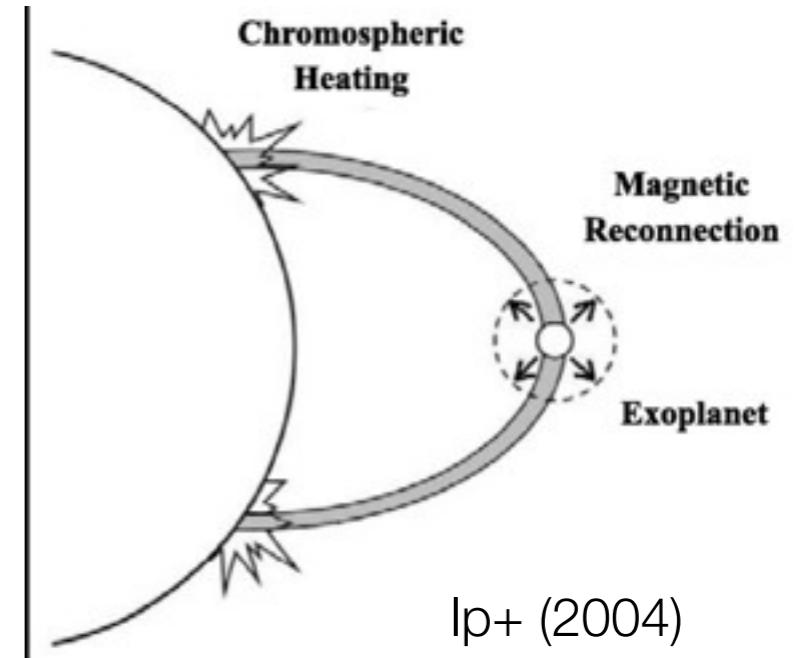
- Solid lines: 3D models
 - $\tau_w > 50 - 100$ Myr
- Dashed lines: 1D (Weber-Davis) model
 - $\tau_w \sim 2 - 20$ Myr
- 1D models over-predict wind influence on planetary migration
- wind likely **not** to have a big influence on planetary migration



$$dM/dt \approx 10^{-9} - 8 \times 10^{-8} M_{\text{sun}}/\text{yr}$$

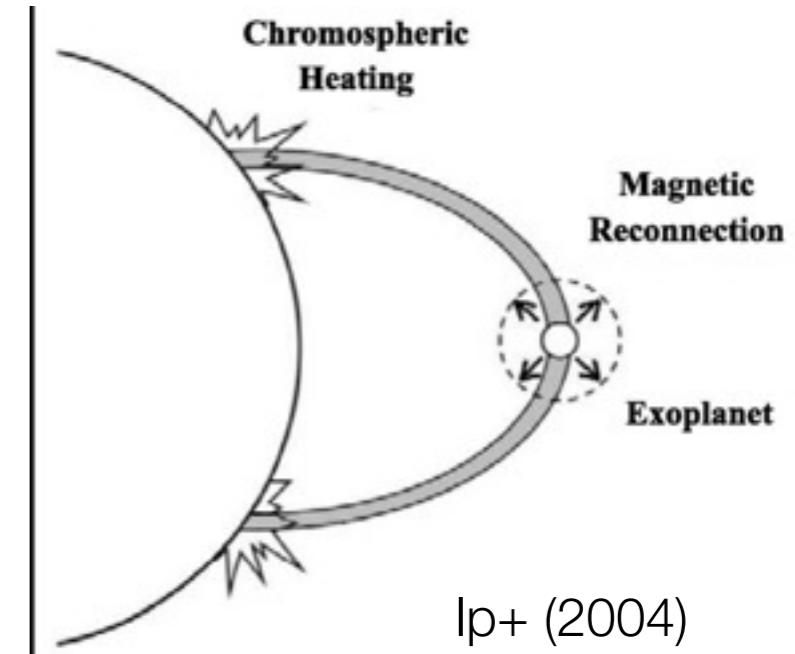
Stellar wind - planet interactions: Planet-induced stellar activity

- Magnetospheric interactions
 - ▶ enhanced heating, stellar activity
 - ▶ activity modulated by P_{orb}

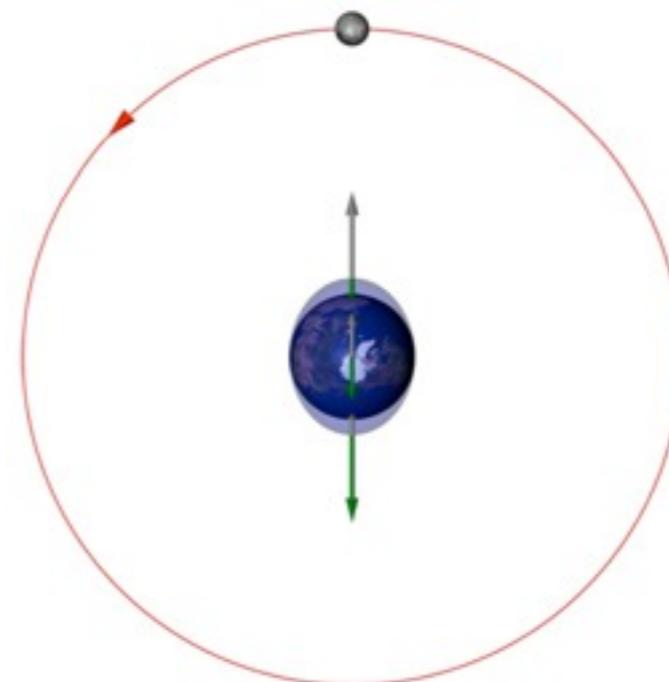


Stellar wind - planet interactions: Planet-induced stellar activity

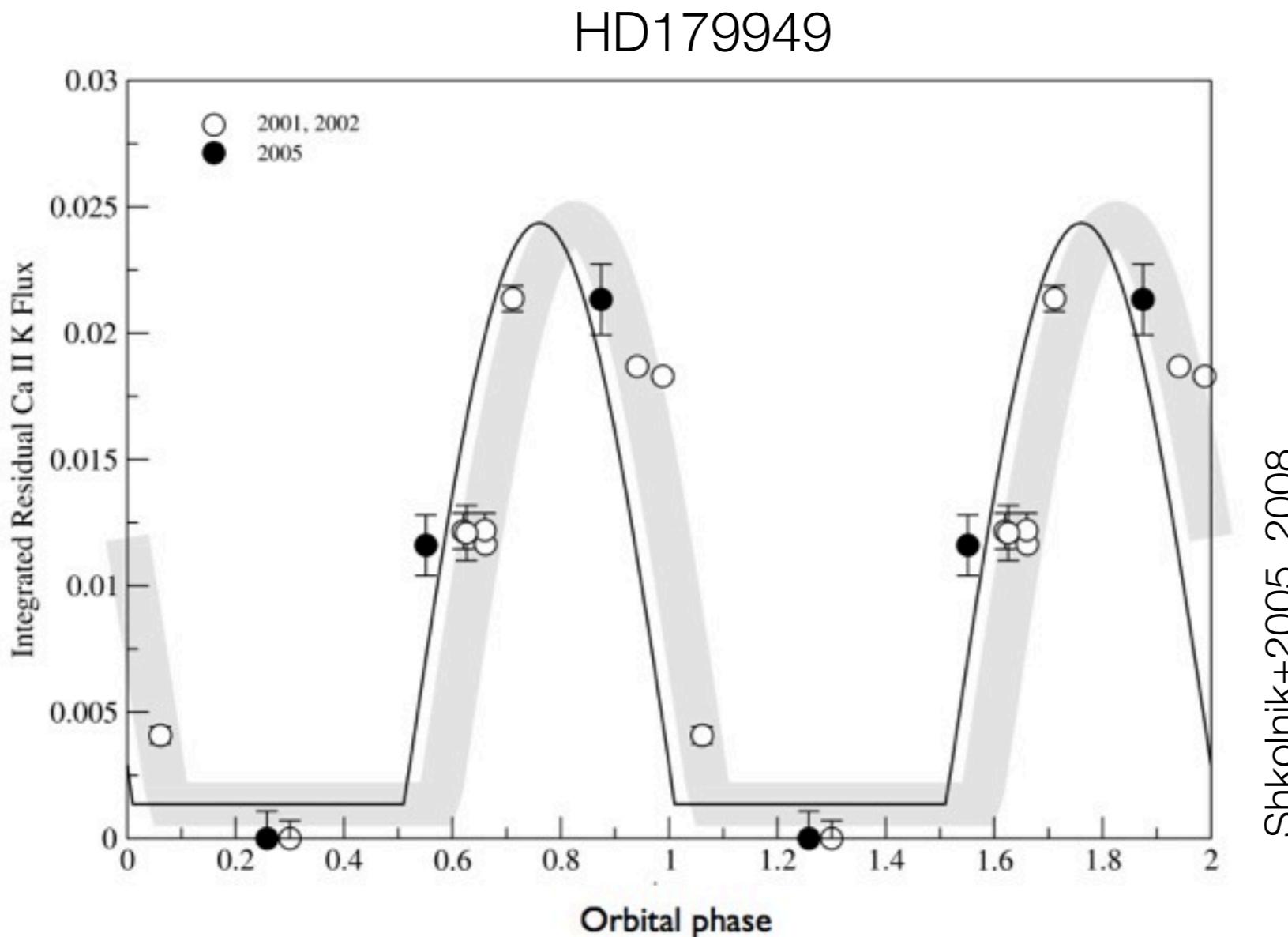
- Magnetospheric interactions
 - ▶ enhanced heating, stellar activity
 - ▶ activity modulated by P_{orb}
- Activity enhancement could also be of **tidal origin**:
 - ▶ expansion/contraction bulges → waves → non-radiative energy → enhanced heating, stellar activity
 - ▶ activity modulated by $P_{\text{orb}}/2$



Ip+ (2004)



Stellar wind - planet interactions: Planet-induced stellar activity

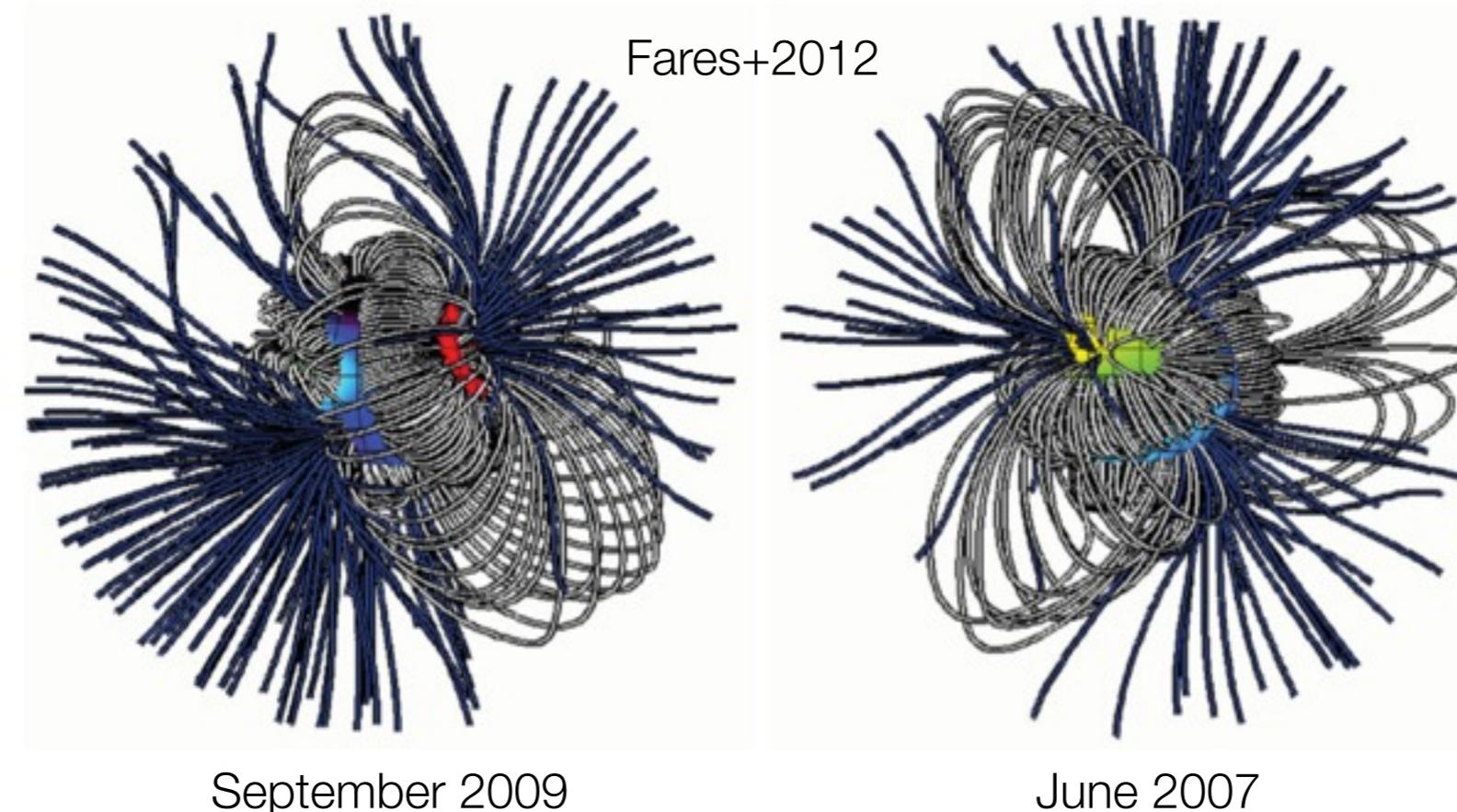


- At some epochs:
 - ▶ Activity modulated by P_{orb} : **anomalous**
 - ▶ phase lag: activity & subplanetary phase ($\phi=0$)
- At other epochs:
 - ▶ activity modulated by stellar P_{rot} :
normal stellar activity

Excess activity occurred only once per orbit → observations consistent to **magnetic** interactions

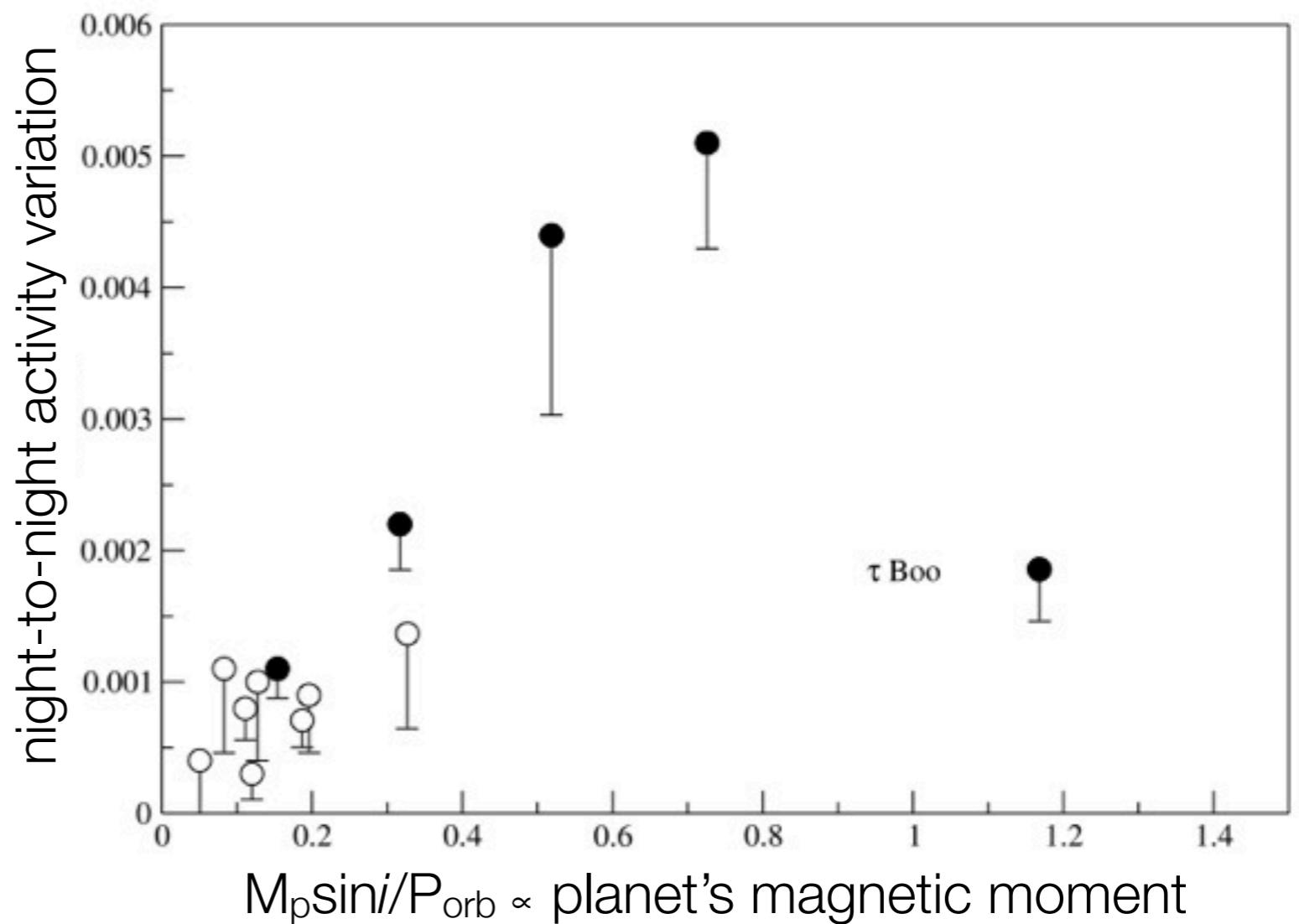
Stellar wind - planet interactions: Planet-induced stellar activity

- What could cause the “on/off” nature?
 - ▶ Variations in stellar magnetic field → from super to sub-Alfvenic regime?
 - ▶ orbiting inside the Alfen surface (information can only travel upstream) → realistic stellar wind models



Stellar wind - planet interactions: Planet-induced stellar activity

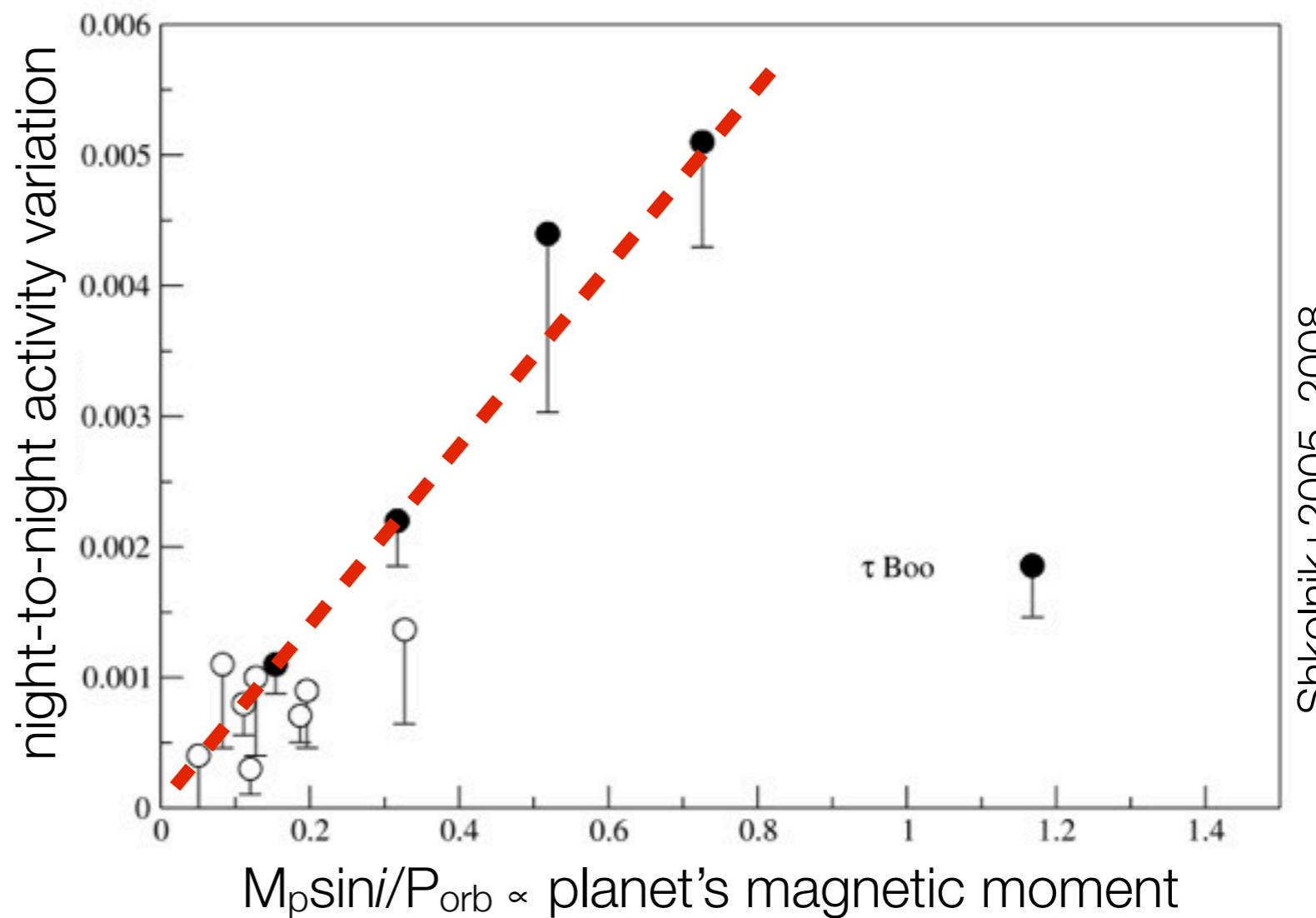
- Correlation between stellar activity and planet's magnetic moment → possibility to measure planetary magnetic field B_p ?
- Needs **calibration**: one can only infer the relative strength of B_p .



Shkolnik+2005, 2008

Stellar wind - planet interactions: Planet-induced stellar activity

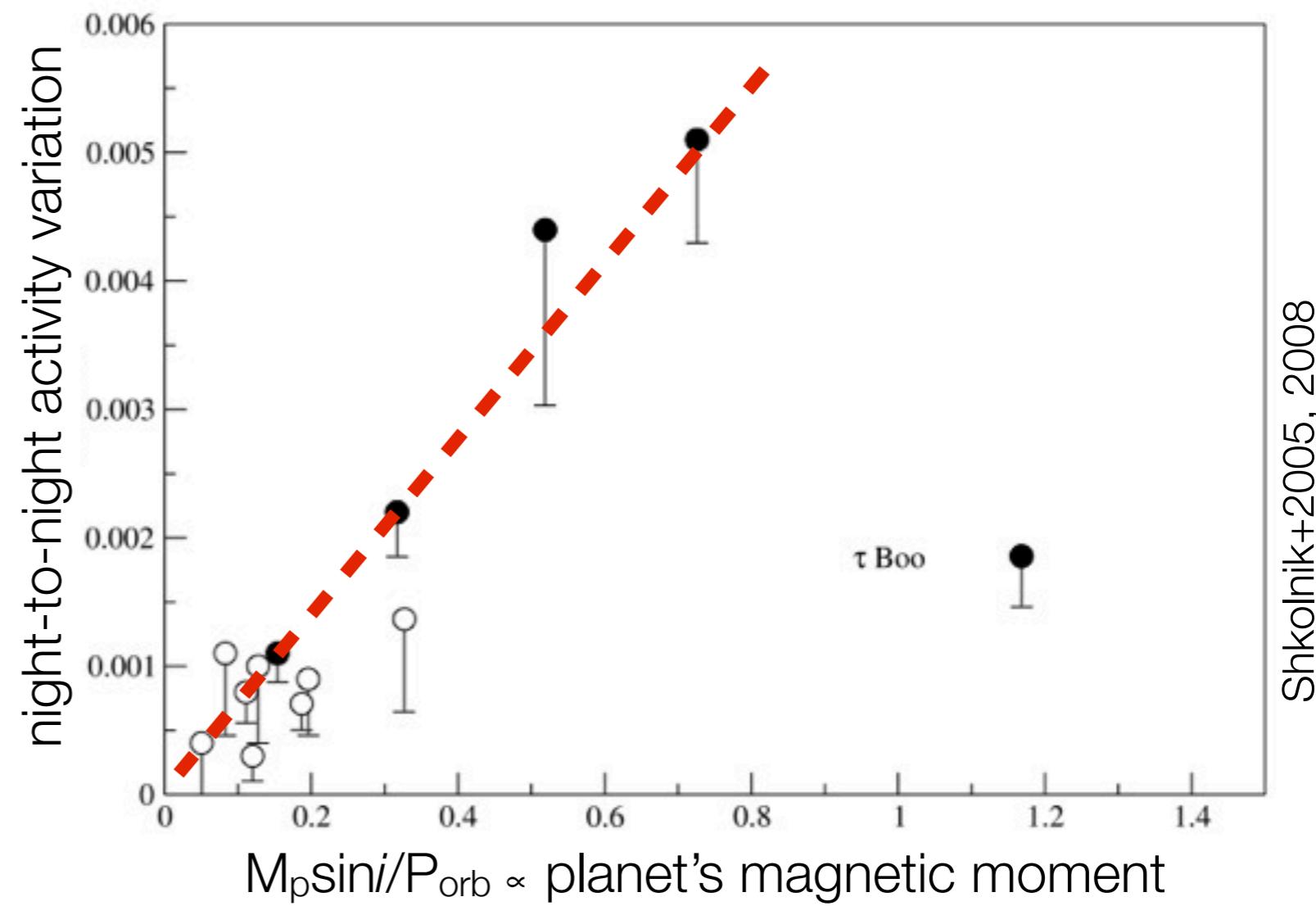
- Correlation between stellar activity and planet's magnetic moment → possibility to measure planetary magnetic field B_p ?
- Needs **calibration**: one can only infer the relative strength of B_p .



Shkolnik+2005, 2008

Stellar wind - planet interactions: Planet-induced stellar activity

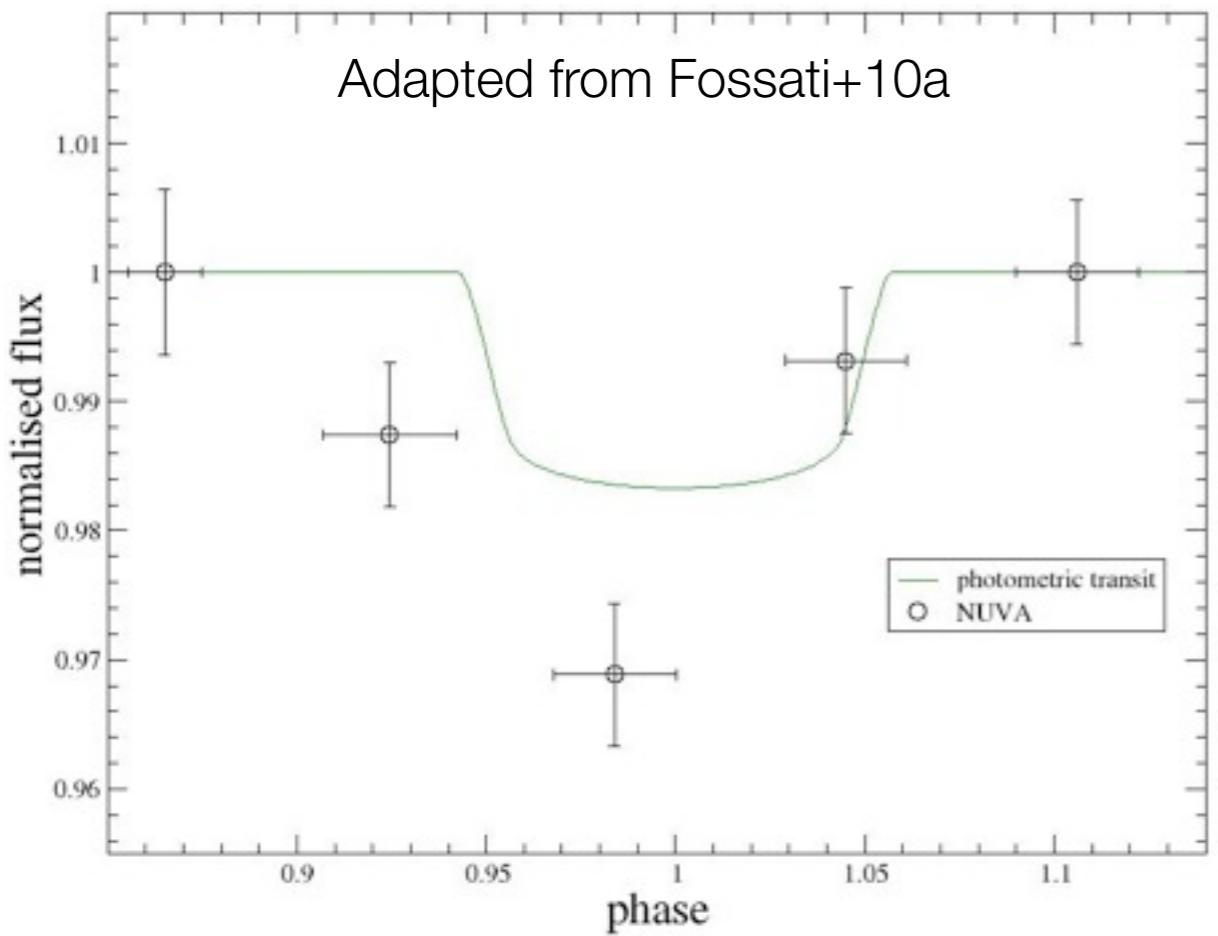
- Correlation between stellar activity and planet's magnetic moment → possibility to measure planetary magnetic field B_p ?
- Needs **calibration**: one can only infer the relative strength of B_p .



N. Lanza's talk

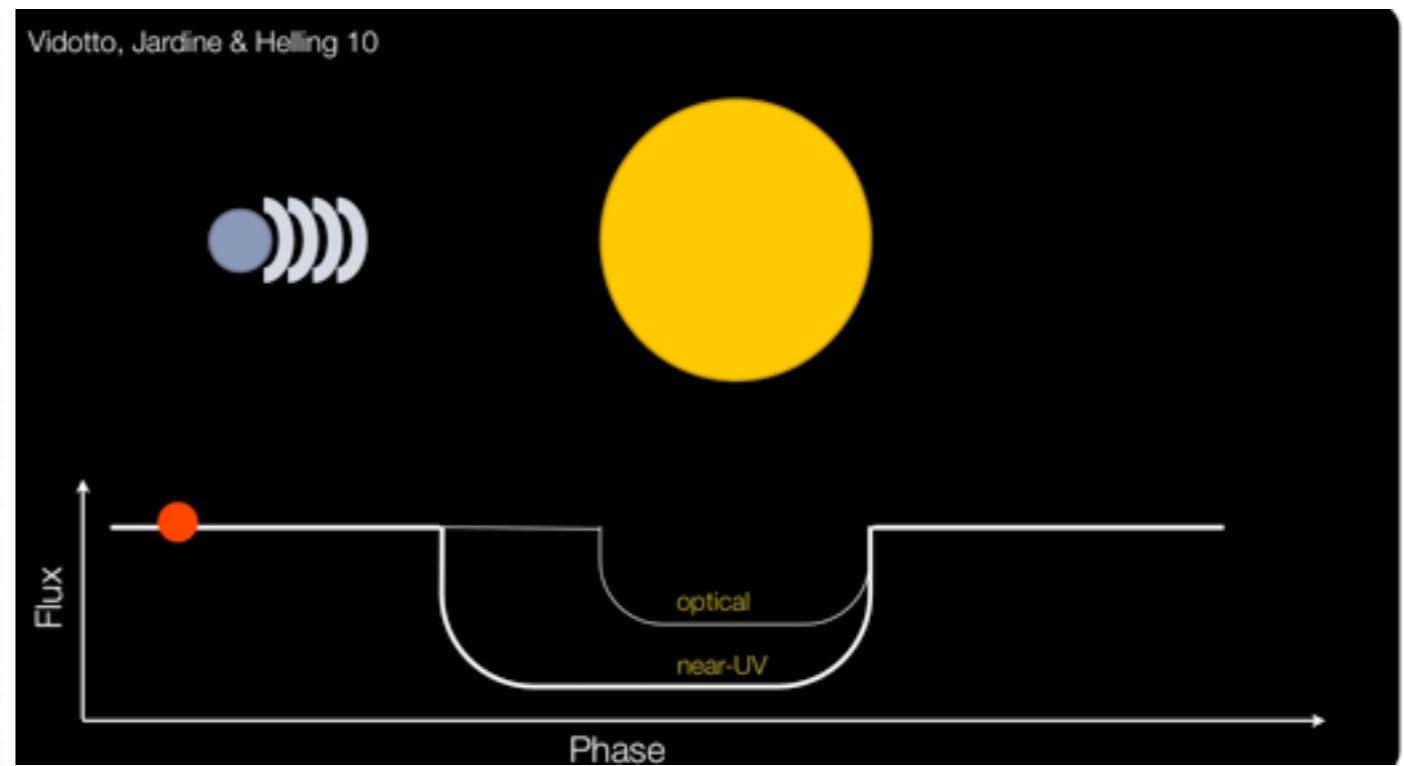
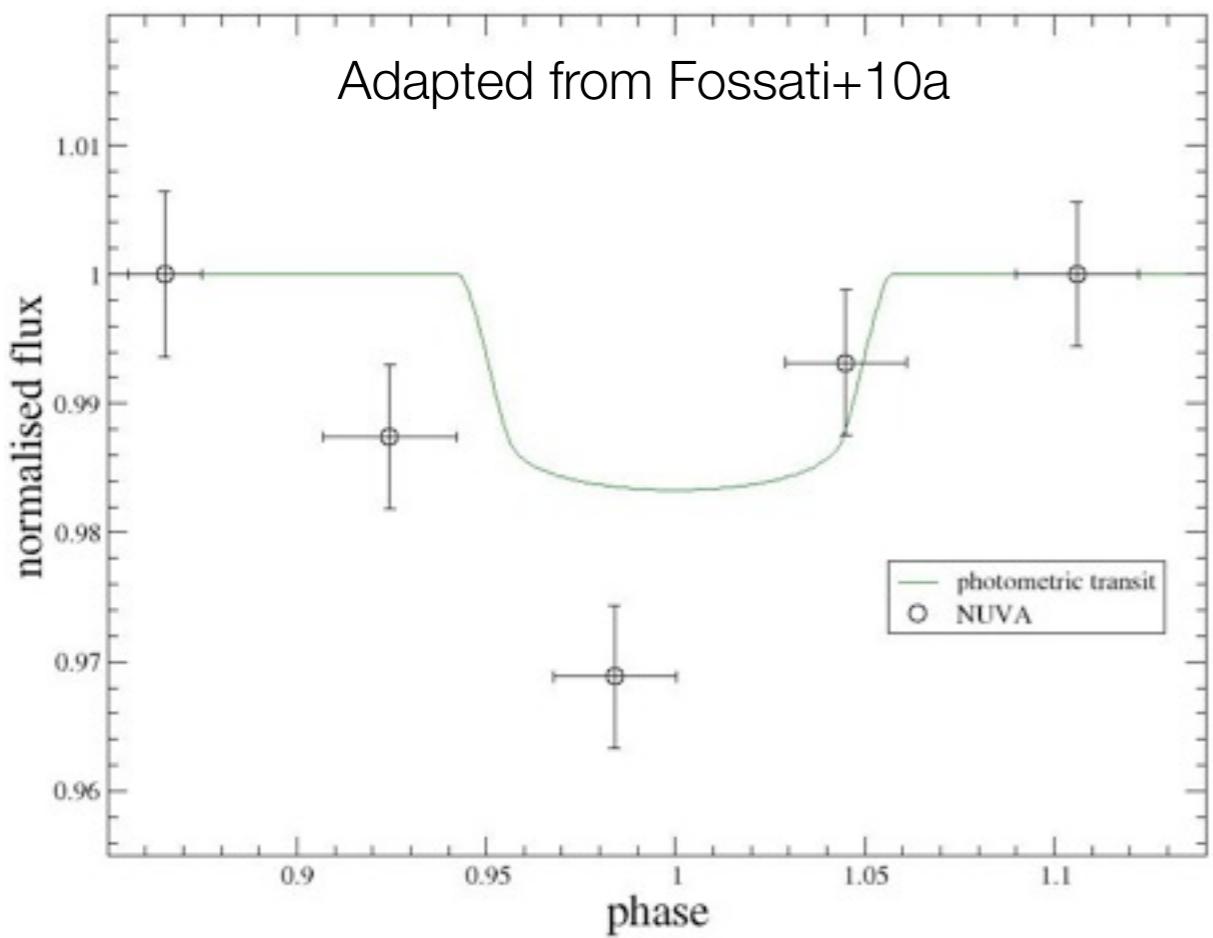
Interaction of planets and stellar winds: detection of bow shock around planetary magnetosphere

- Transits of bow shocks in the near-UV → detection of planetary magnetic fields? (Vidotto+ 2010, 2011a,b,c)



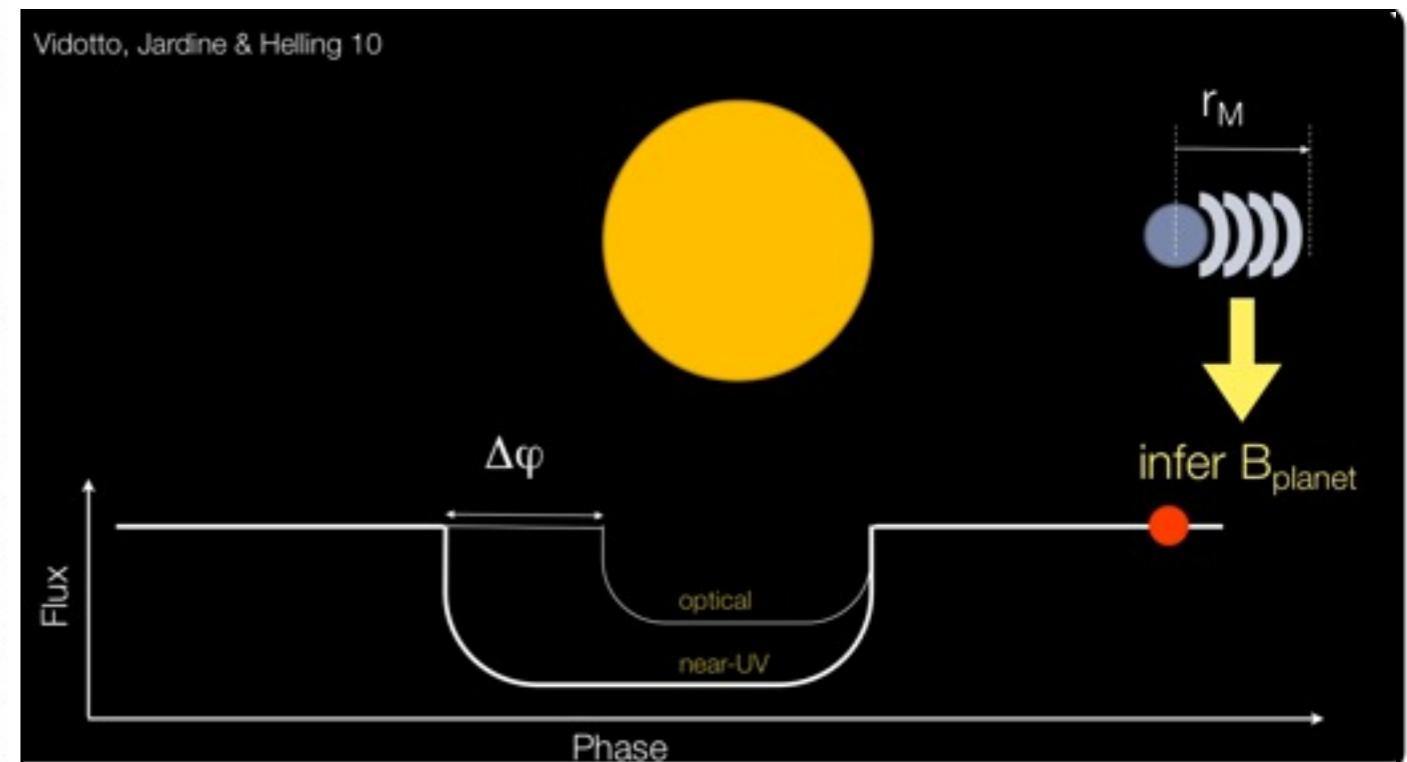
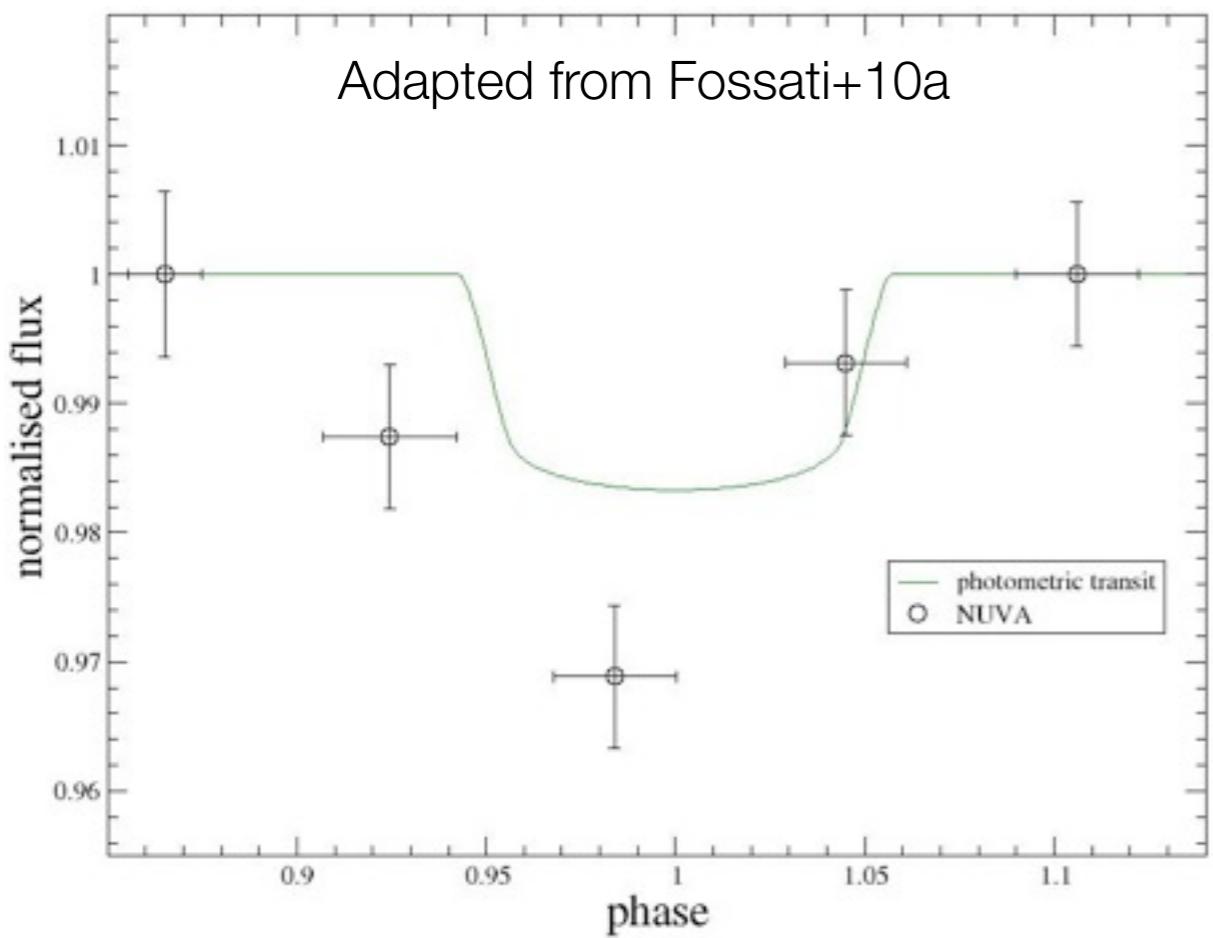
Interaction of planets and stellar winds: detection of bow shock around planetary magnetosphere

- Transits of bow shocks in the near-UV → detection of planetary magnetic fields? (Vidotto+ 2010, 2011a,b,c)

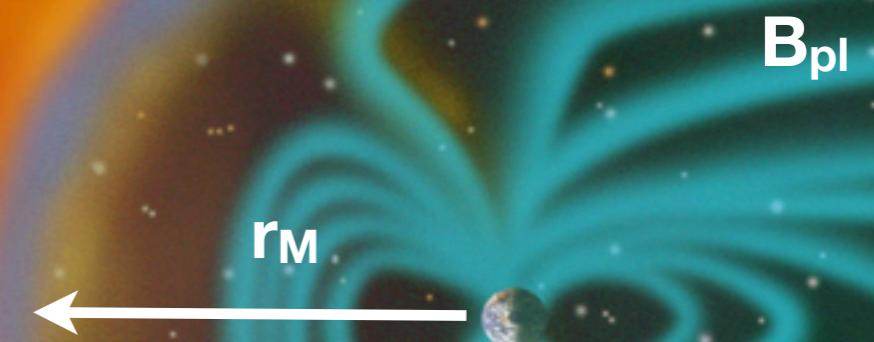


Interaction of planets and stellar winds: detection of bow shock around planetary magnetosphere

- Transits of bow shocks in the near-UV → detection of planetary magnetic fields? (Vidotto+ 2010, 2011a,b,c)



Estimating the sizes of planetary magnetospheres

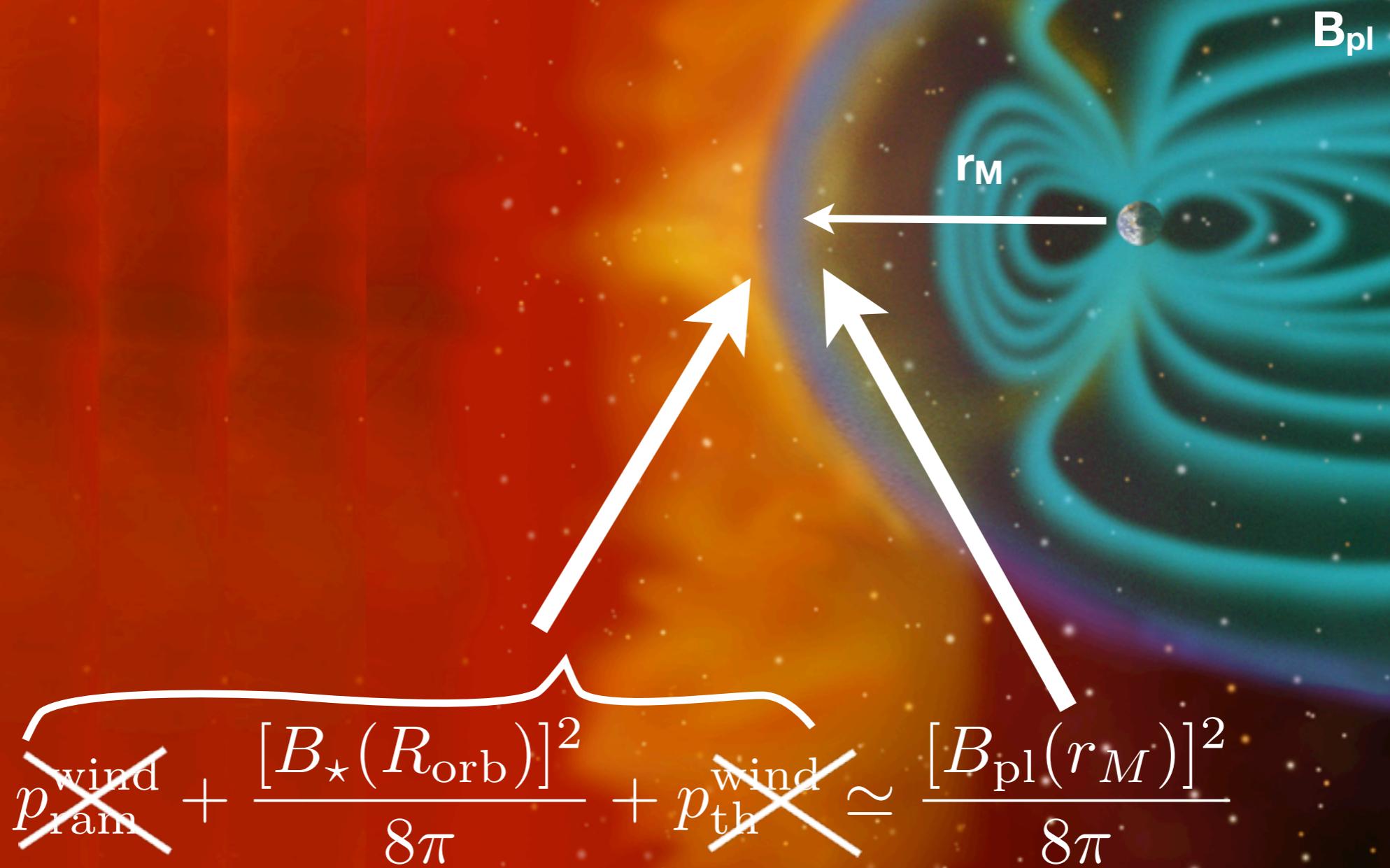


Estimating the sizes of planetary magnetospheres

The diagram shows a star on the left with a colorful, multi-layered atmosphere. On the right, a small blue sphere representing Earth is positioned within a large, teardrop-shaped magnetic field region. The field lines are shown as concentric ellipses, with the most intense field (blue) closest to the planet and fading (green) further out. A horizontal double-headed arrow labeled r_M indicates the radius from Earth to the edge of the magnetosphere. A white arrow points from the star towards the magnetosphere.

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

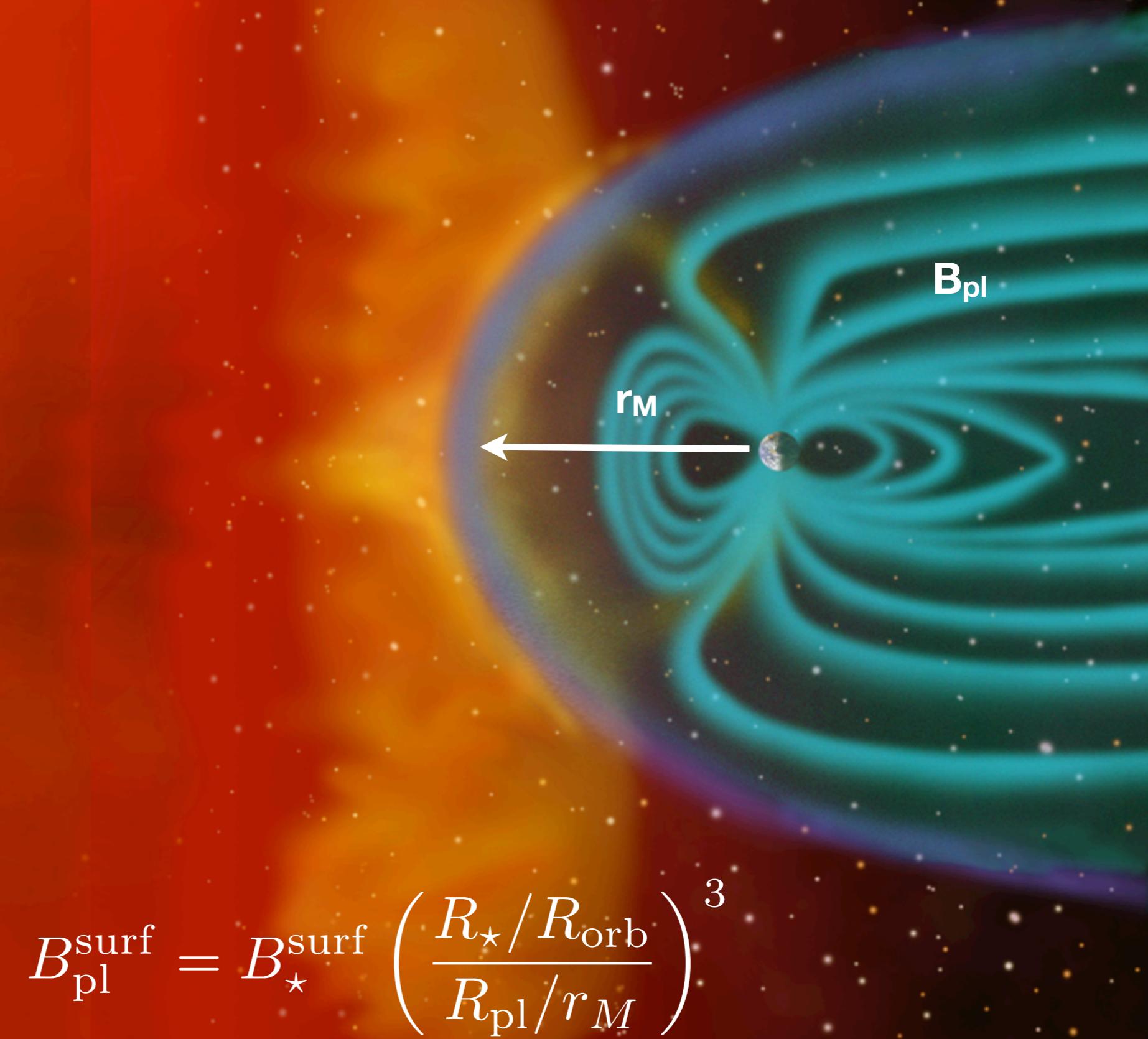
Estimating the sizes of planetary magnetospheres



The diagram shows a star on the left with a colorful, multi-layered atmosphere transitioning from red to blue. A small Earth is positioned on the right side of a large, greenish-blue magnetic field line labeled B_{pl} . A horizontal double-headed arrow between the star and the Earth is labeled r_M .

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

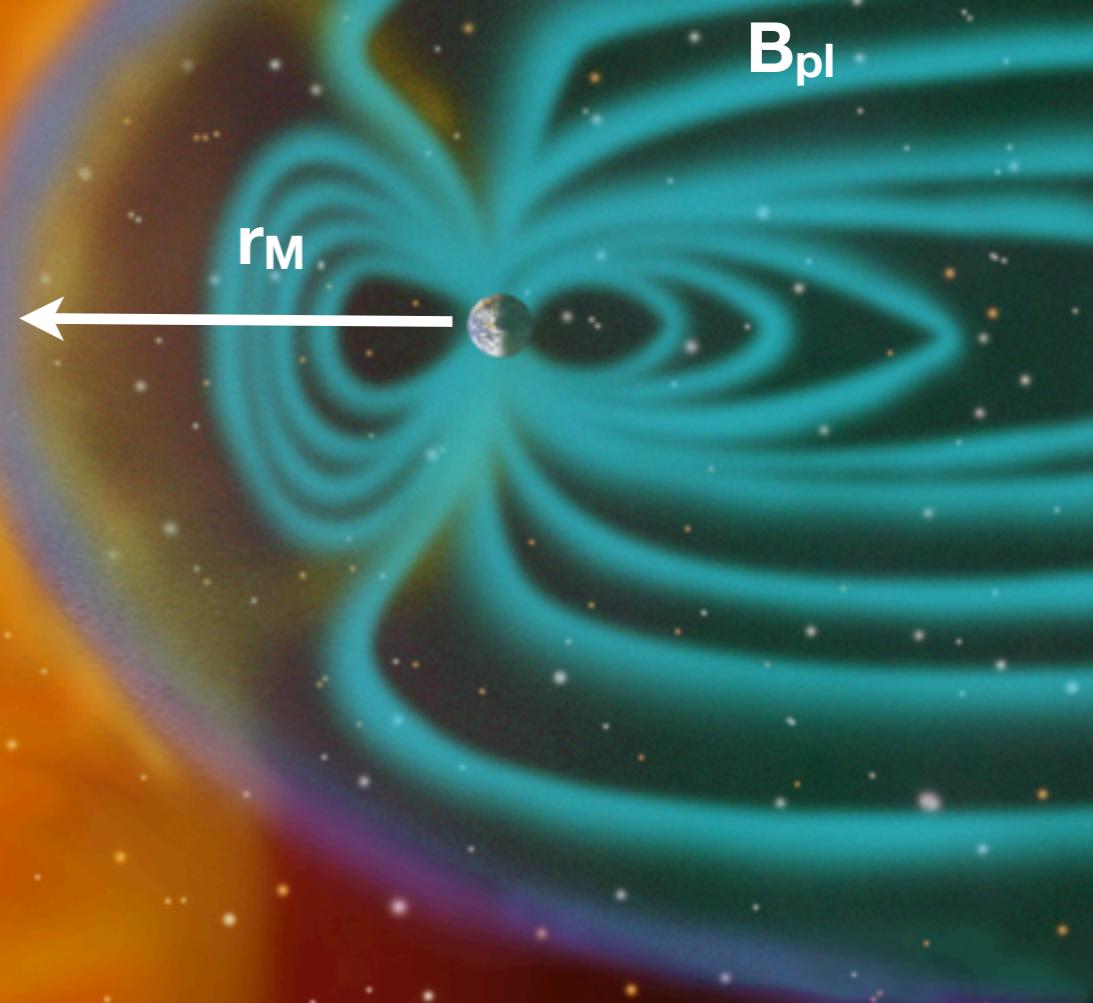
Estimating the sizes of planetary magnetospheres



Estimating the sizes of planetary magnetospheres

For WASP-12 & WASP-12b:

- $R_{\text{orb}} = 3.15 R_*$
- Distance to the shock: $r_M = 4.2 R_p$
- Observational upper limit B_* (Fossati+10b):
 $B_*^{\text{surf}} < 10 \text{ G.}$



$$B_{\text{pl}}^{\text{surf}} = B_*^{\text{surf}} \left(\frac{R_*/R_{\text{orb}}}{R_{\text{pl}}/r_M} \right)^3$$

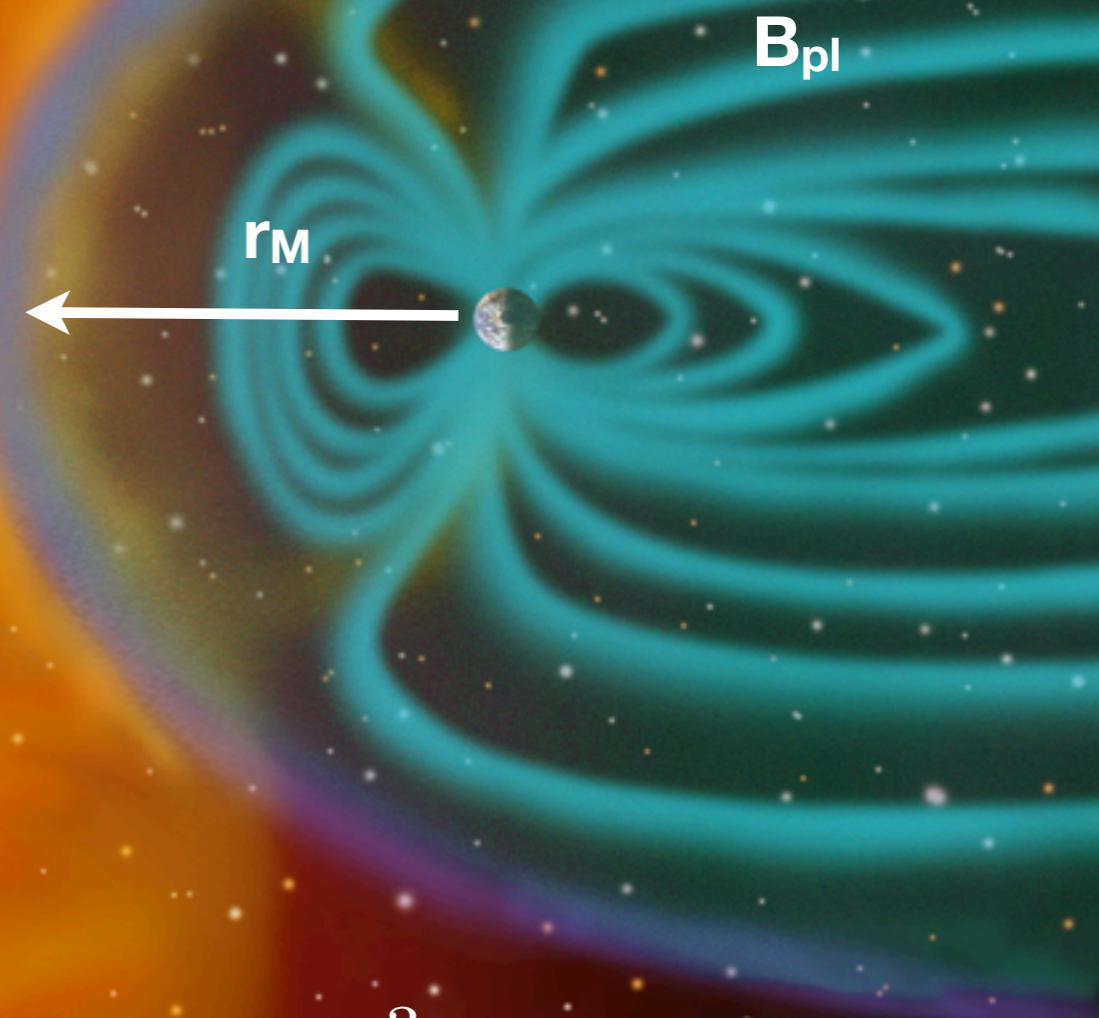
Estimating the sizes of planetary magnetospheres

For WASP-12 & WASP-12b:

- $R_{\text{orb}} = 3.15 R_*$
- Distance to the shock: $r_M = 4.2 R_p$
- Observational upper limit B_* (Fossati+10b):
 $B_*^{\text{surf}} < 10 \text{ G.}$

$$B_{\text{pl}}^{\text{surf}} < 24G$$

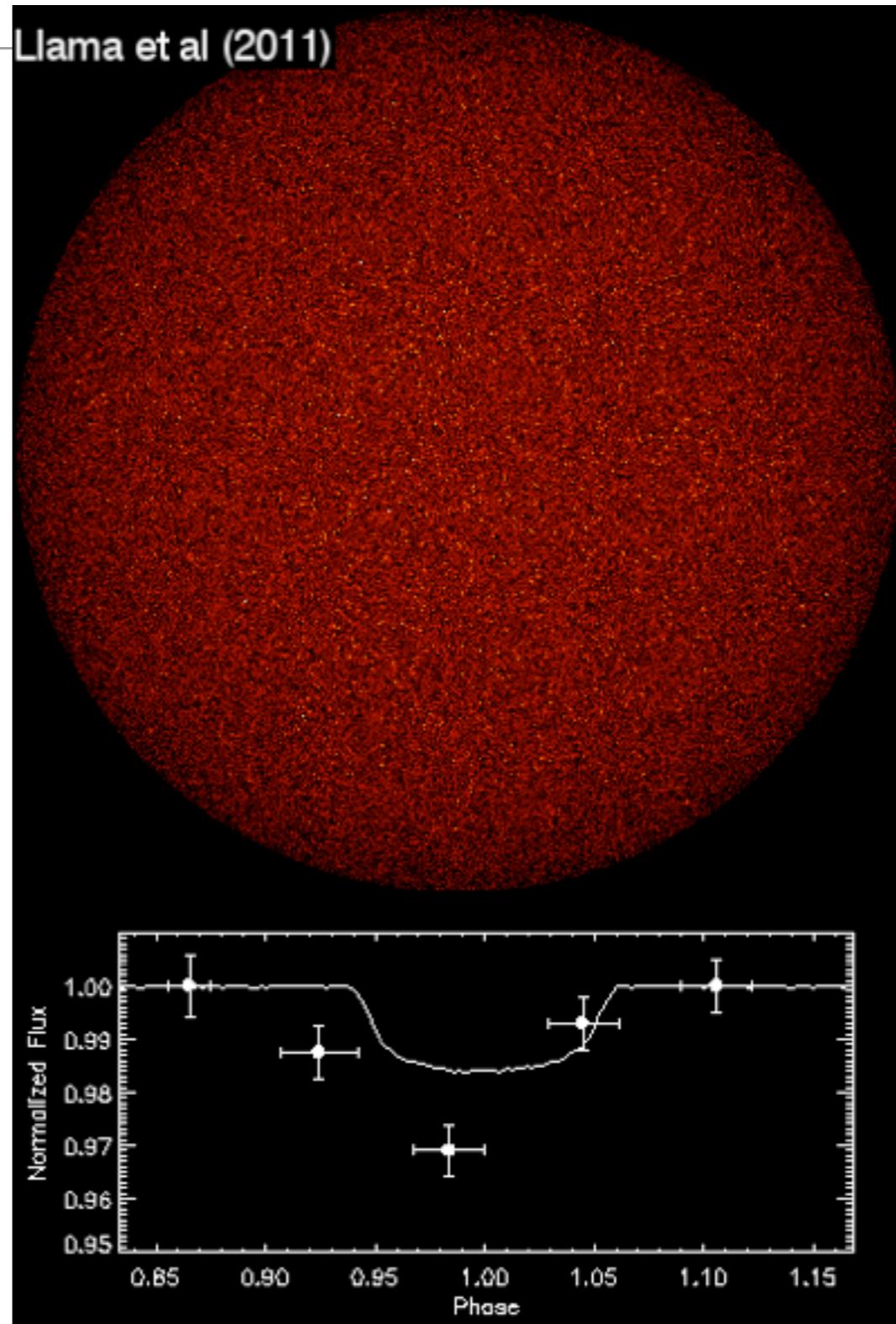
$$B_{\text{pl}}^{\text{surf}} = B_*^{\text{surf}} \left(\frac{R_*/R_{\text{orb}}}{R_{\text{pl}}/r_M} \right)^3$$



Interaction of planets and stellar winds: detection of bow shock around planetary magnetosphere

Llama+11:

- Modelled a simple bow shock using **radiative transfer simulations** and fit the data
- Degenerate solution
- Support the hypothesis that a bow shock can explain the observed early ingress.

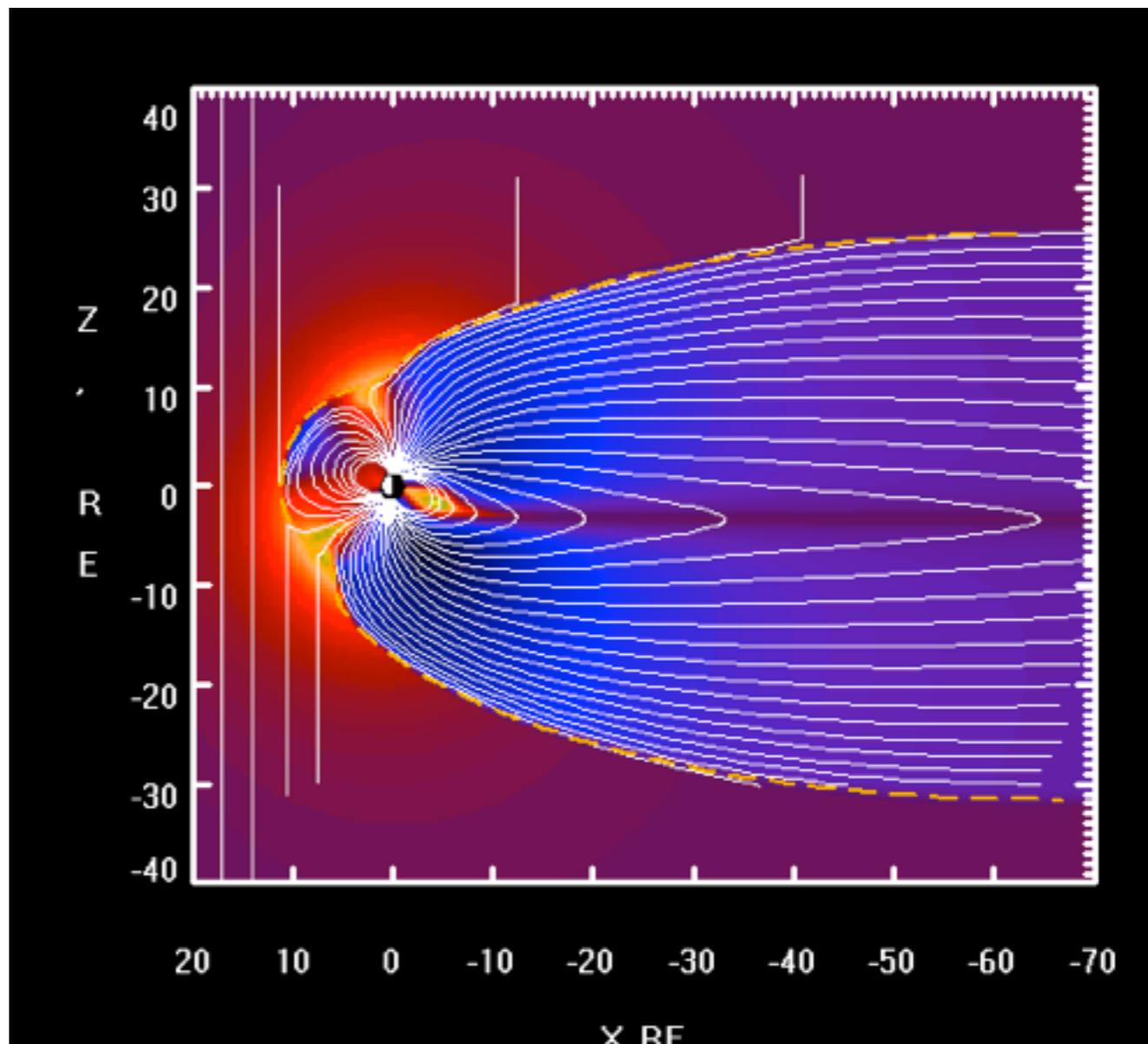


Interaction of planets and stellar winds: temporal variability

Variations in shock properties

(Vidotto, Jardine & Helling, 11b)

- Non-axisymmetric stellar corona
- Planetary obliquity
- Intrinsic variations of stellar magnetic field (variations in stellar wind, **CMEs**, flares, magnetic cycles)

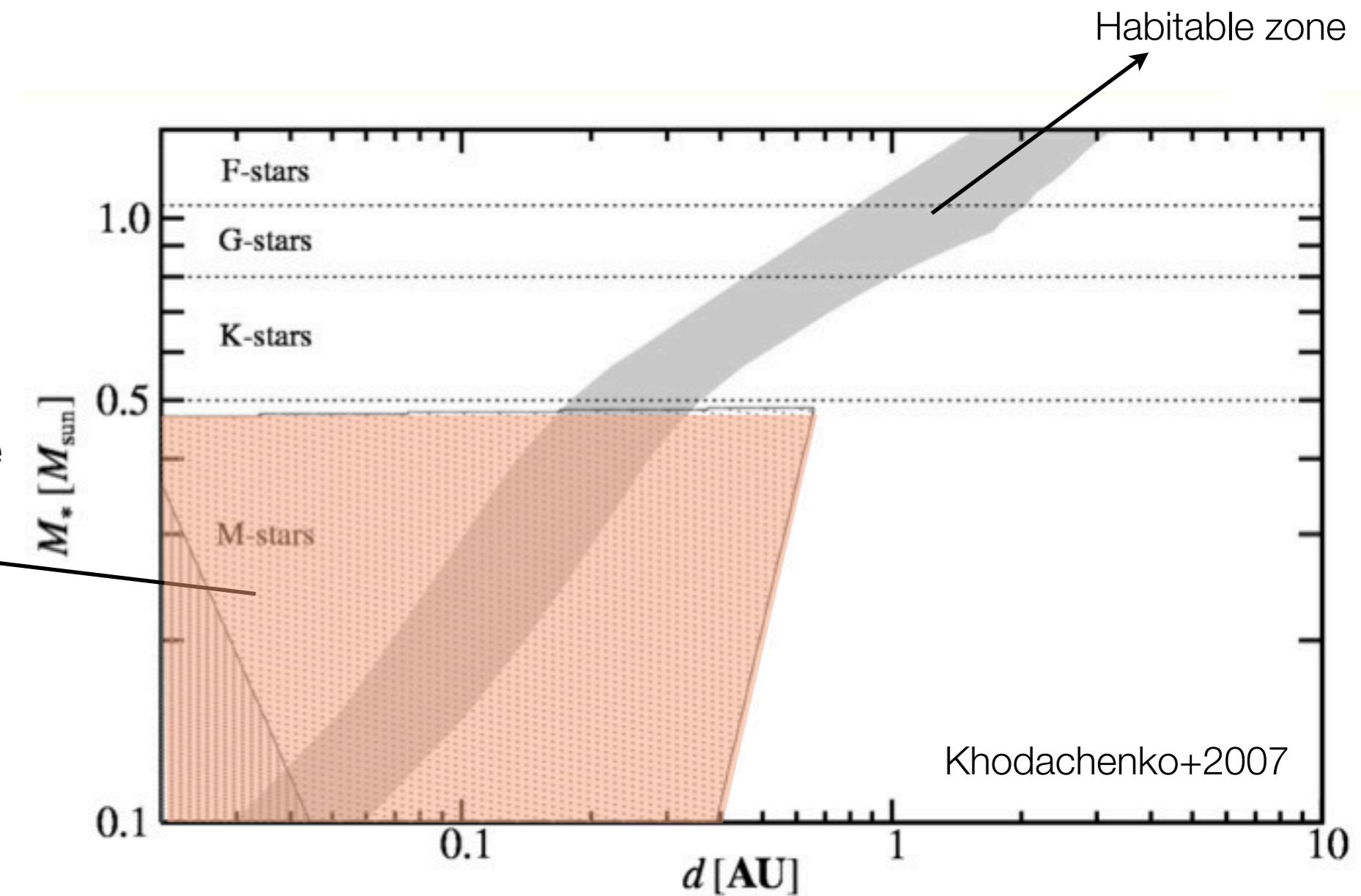


Credit: Tsyganenko

Interaction of planets and stellar winds: temporal variability

- CMEs: able to further reduce the planetary magnetosphere
(Khodachenko+2007a,b,2011; Griessmeier+2007; Lammer+2007)

► Strong magnetospheric compression by CMES: $r_M < 2R_p$
→ important to assess atmosphere erosion by stellar wind/CMEs.



Summary: Interactions of planets and stellar winds

1. Bow-shock formation
2. Planetary radio emission
3. Anomalous stellar activity
4. Planetary migration



Possibility to “detect”
planetary magnetic fields

- In all these cases, the stellar wind plays an **important** role in the characterisation of the (magnetic) environment around the planet.
- In all cited cases, observations of wind-related processes occurring in the planet can help **characterise** the stellar wind [e.g., transit asymmetries]

Summary: Interactions of planets and stellar winds

1. Bow-shock formation
2. Planetary radio emission
3. Anomalous stellar activity
4. Planetary migration



Possibility to “detect”
planetary magnetic fields

**A. Strugarek’s &
J. Varela’s
talks**

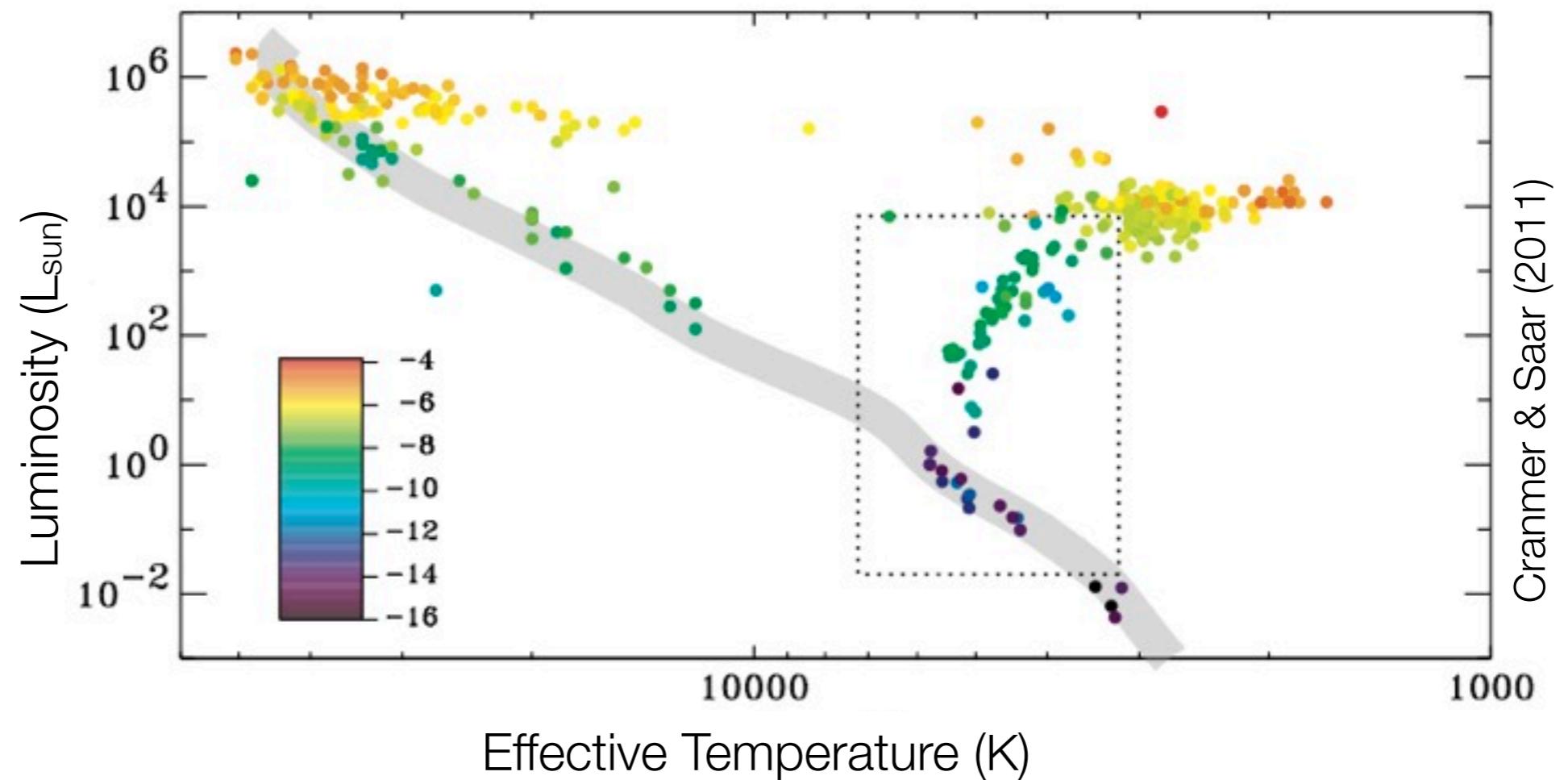
- In all these cases, the stellar wind plays an **important** role in the characterisation of the (magnetic) environment around the planet.
- In all cited cases, observations of wind-related processes occurring in the planet can help **characterise** the stellar wind [e.g., transit asymmetries]

What do we know about stellar winds of
cool, dwarf stars?

2. Stellar winds of cool, low-mass stars

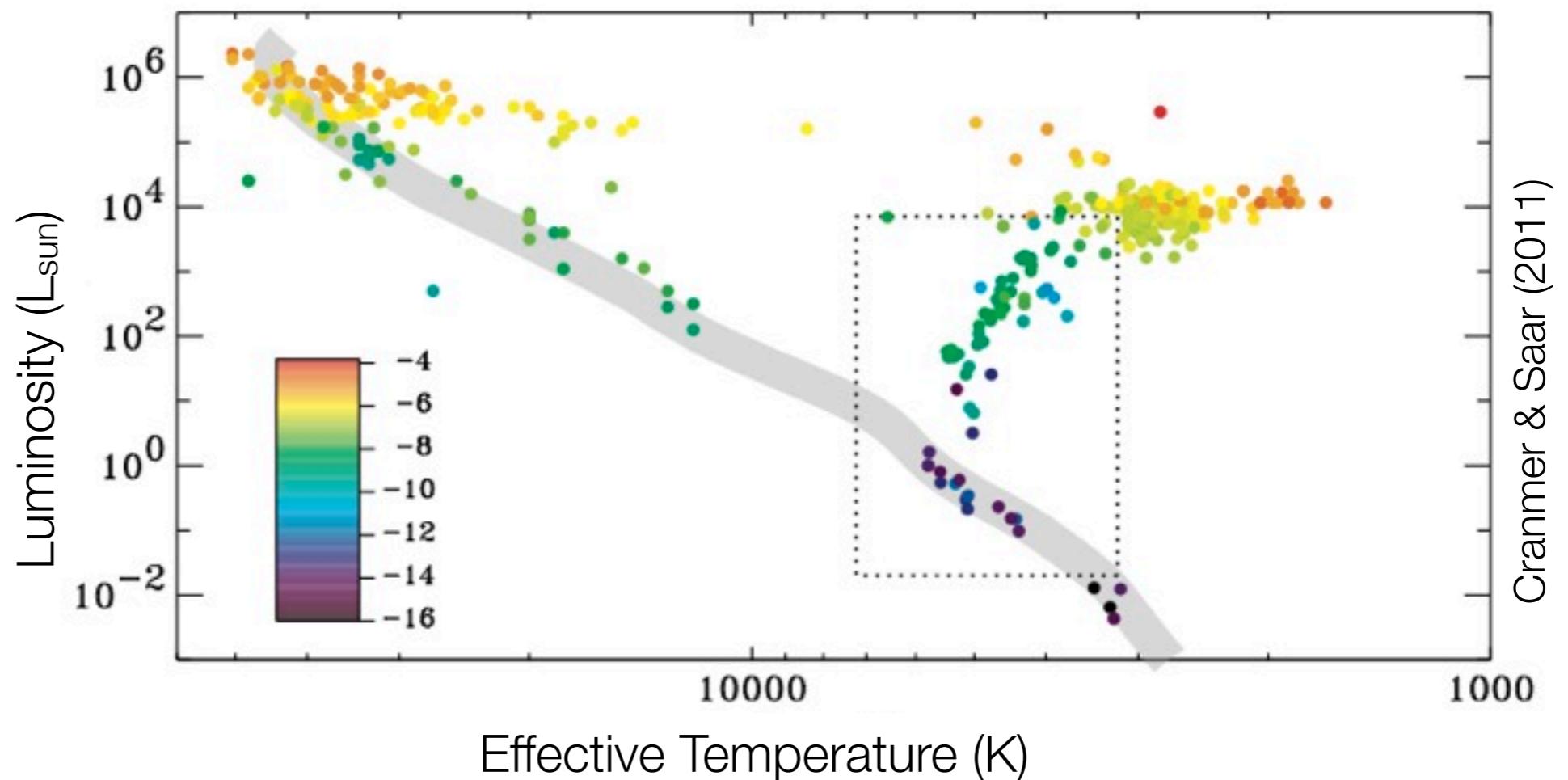
Brief overview of mass loss across HR diagram

- Observationally derived mass-loss rates (M_{sun}/yr) across the HR diagram:



Brief overview of mass loss across HR diagram

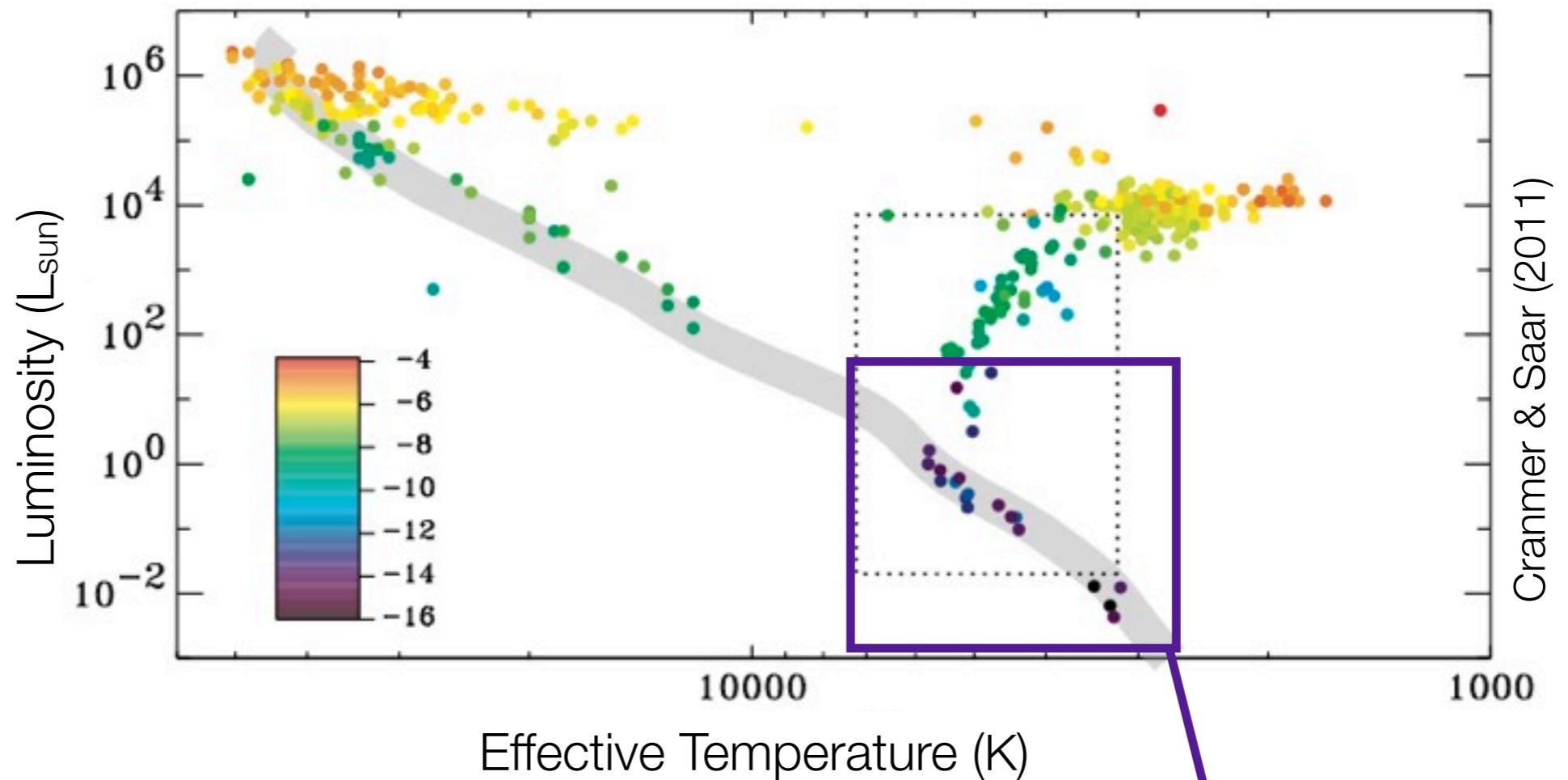
- Observationally derived mass-loss rates (M_{sun}/yr) across the HR diagram:



- solar mass-loss rate: $10^{-14} M_{\text{sun}}/\text{yr}$ (purple colour)

Brief overview of mass loss across HR diagram

- Observationally derived mass-loss rates (M_{sun}/yr) across the HR diagram:

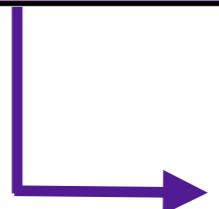


- solar mass-loss rate: $10^{-14} M_{\text{sun}}/\text{yr}$ (purple colour)
- cool, main-sequence stars: **estimates** suggest 10^{-16} to $10^{-12} M_{\text{sun}}/\text{yr}$

How to detect winds of cool stars?

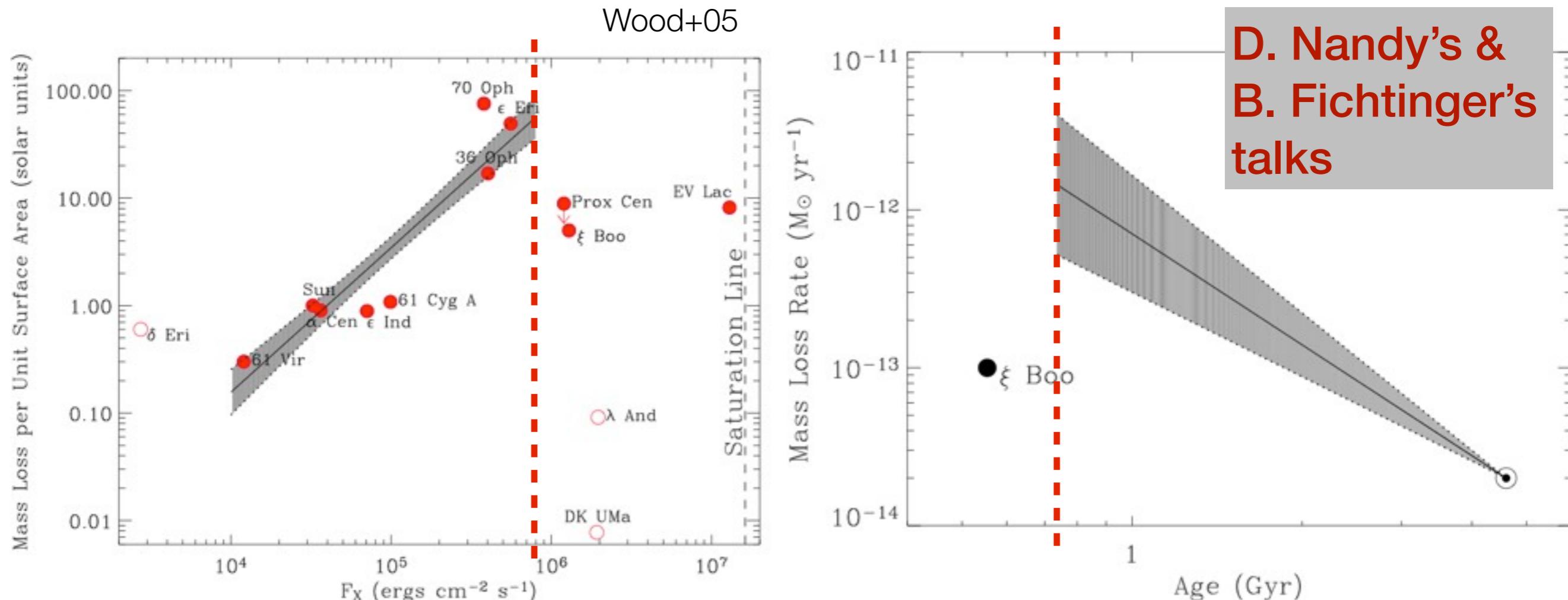
- ▶ Tenuous winds: challenging to obtain dM/dt
- ▶ A few clever, **indirect** methods have been proposed

Method	$\dot{M}_{\text{Prox Cen}} (\dot{M}_{\text{sun}})$
Radio free-free emission	<350 (Lim+1996)
Charge-exchange induced X-ray emission	<14 (Wargelin & Drake 2002)
Astroospheric Ly-a absorption	<0.2 (Wood+2001)



Most successful technique so far: but limitations remain

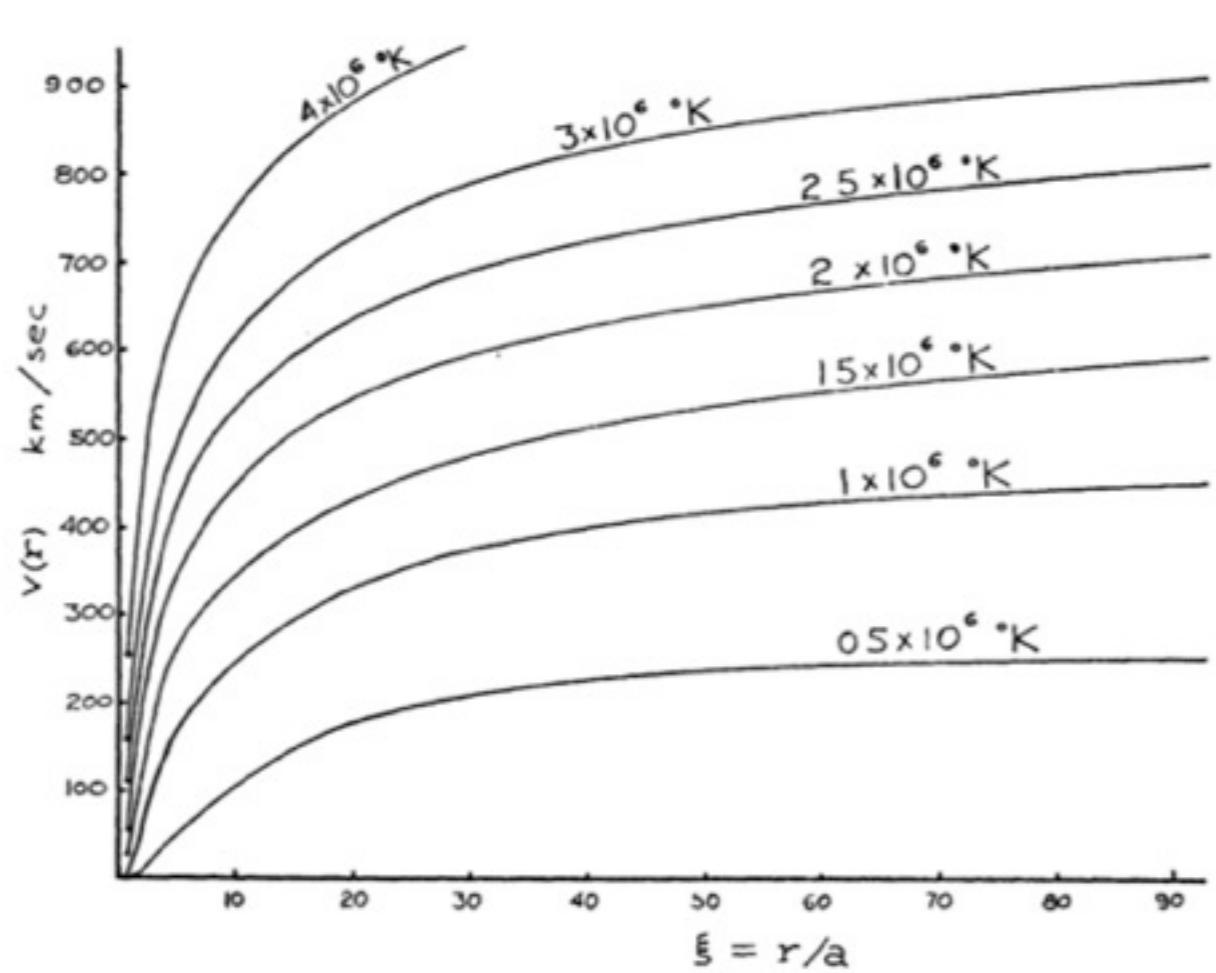
Astrospheric measurements of dM/dt



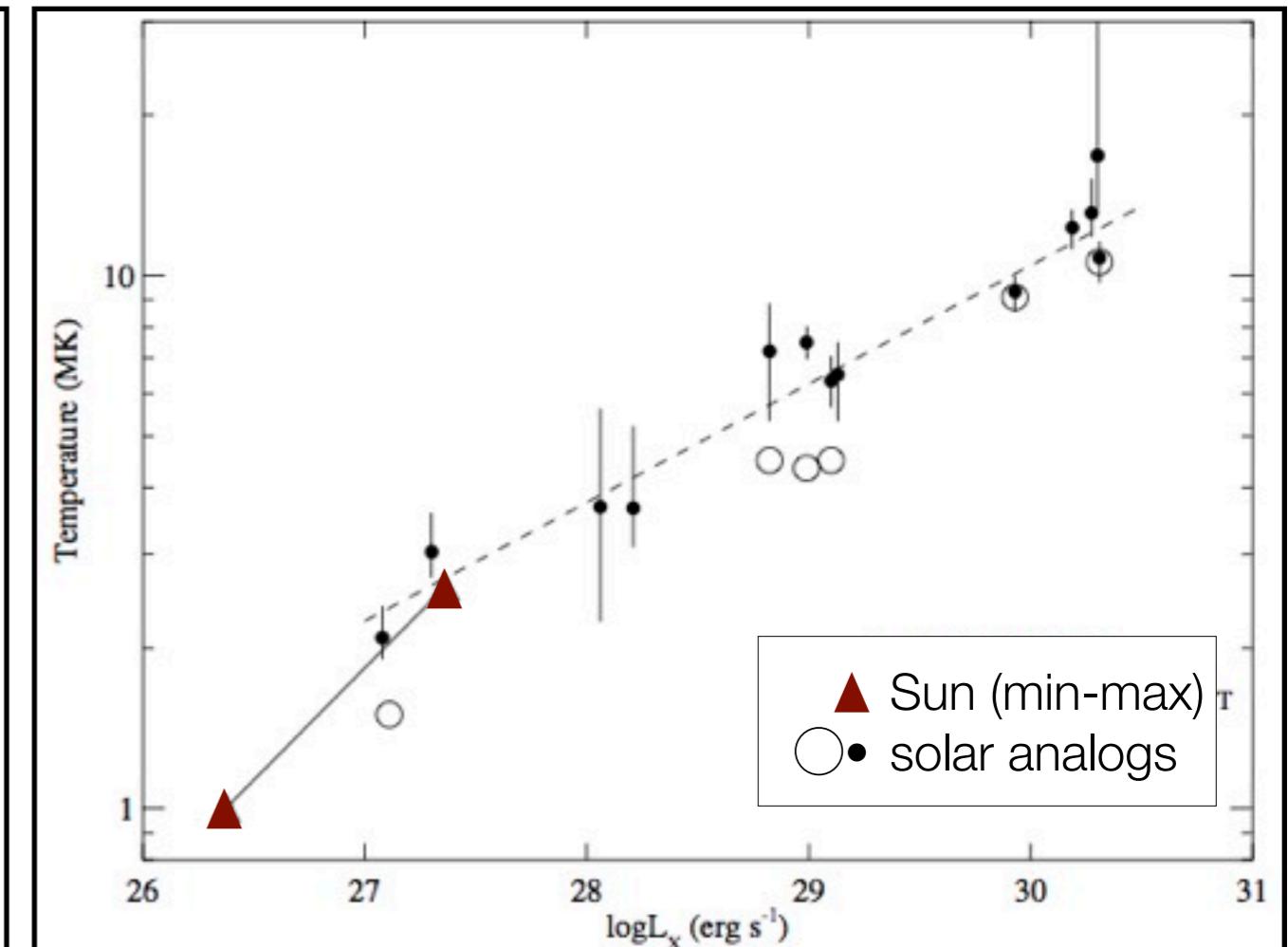
- $\dot{M} \propto F_X^{1.34 \pm 0.18}$
- $F_X \propto t^{-1.74 \pm 0.34}$
(Ayres 1997)
- ▶ $\dot{M} \propto t^{-2.33 \pm 0.55}$

The solar wind was ~ 100 times more massive than the present-day \dot{M} → implications for planets in the early Solar System.

What we infer about winds of cool stars



Parker 58 isothermal model: u_∞ is **very** sensitive to coronal wind temperatures



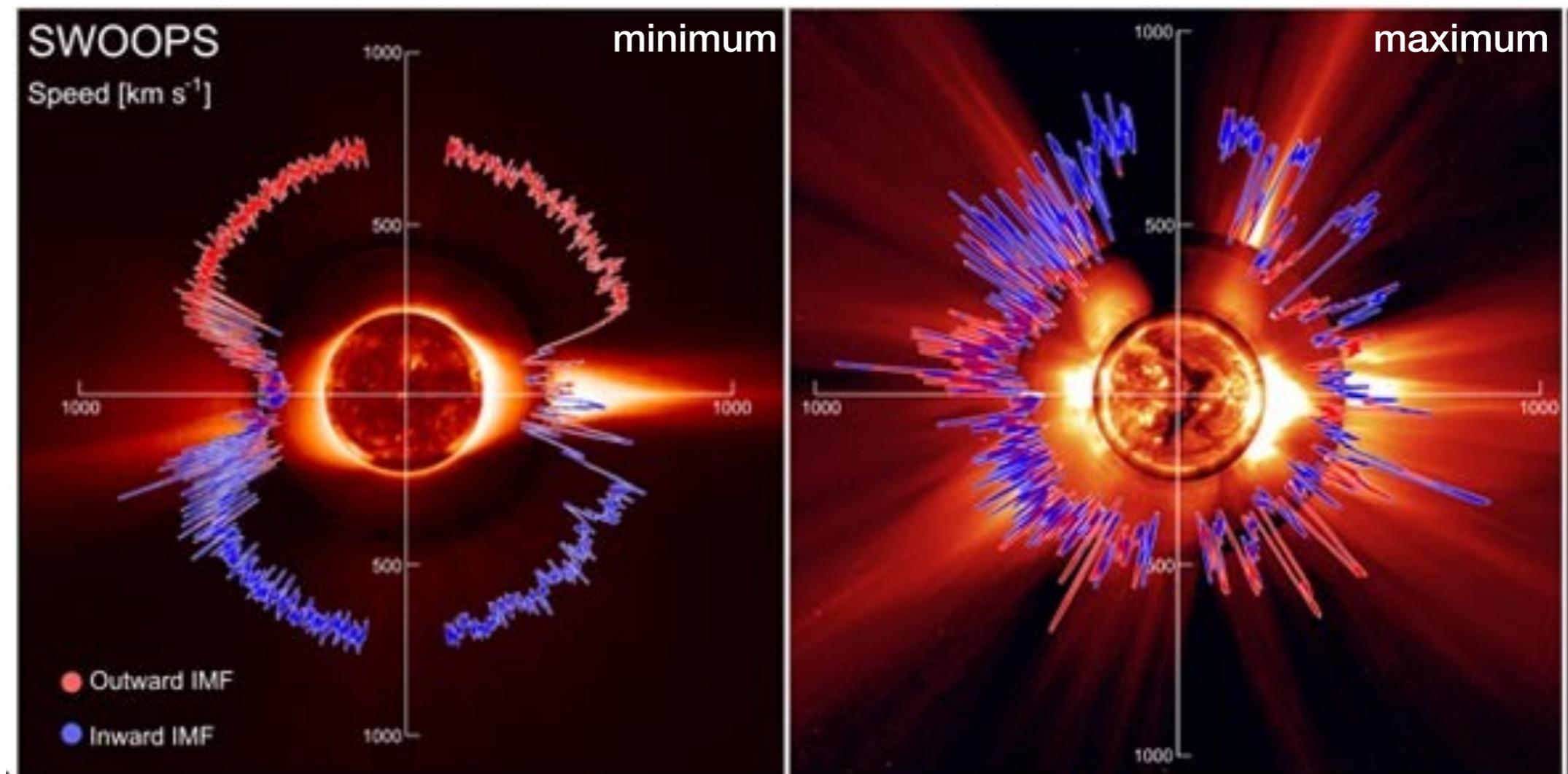
Temperature of the X-ray emitting coronae of solar analogs (Guedel+04)

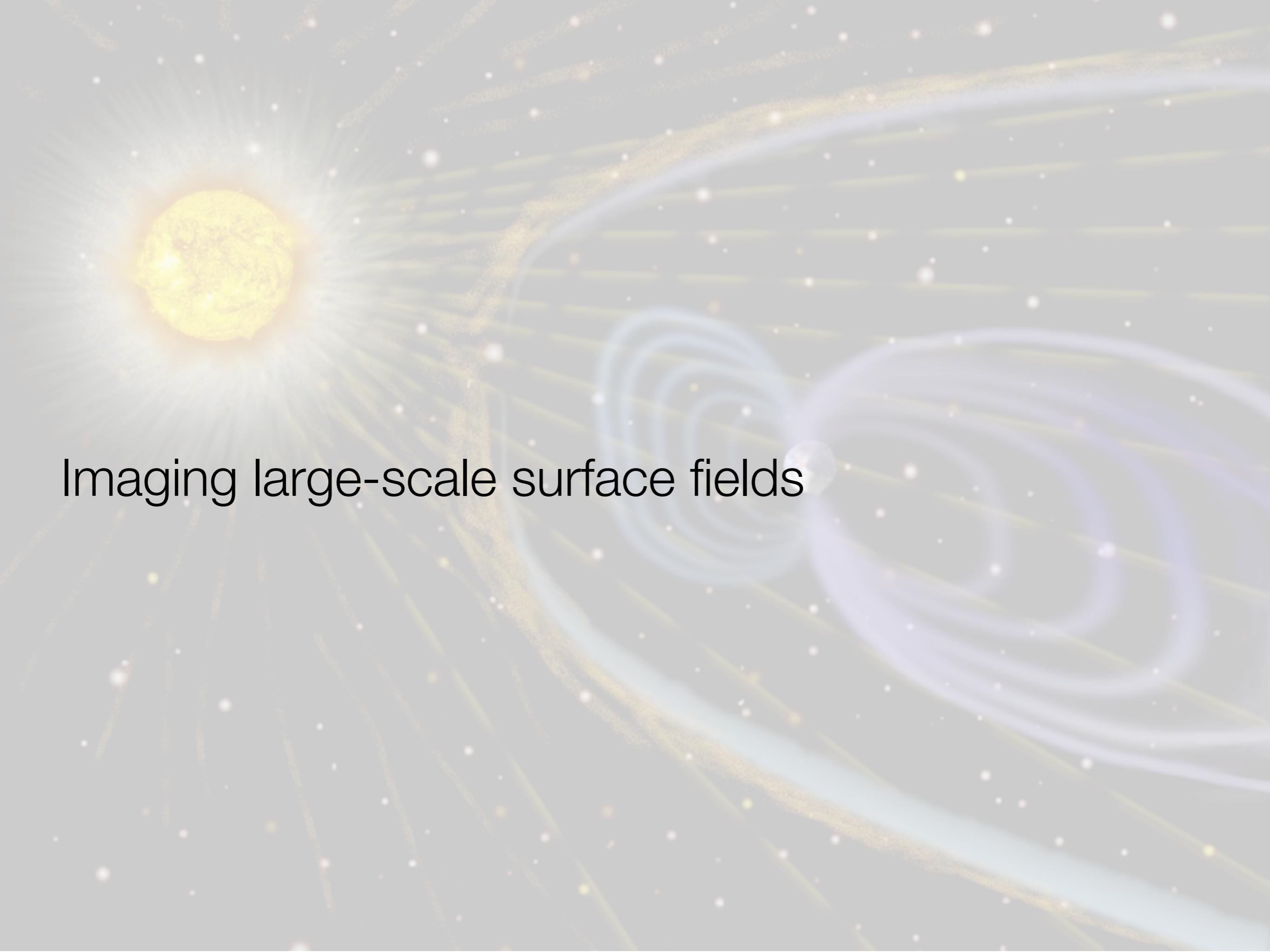
Therefore, coronal winds might have a **variety** of velocity profiles.

What we infer about winds of cool stars

- Stellar wind structure depends on the stellar magnetic field

Solar wind as measured by Ulysses

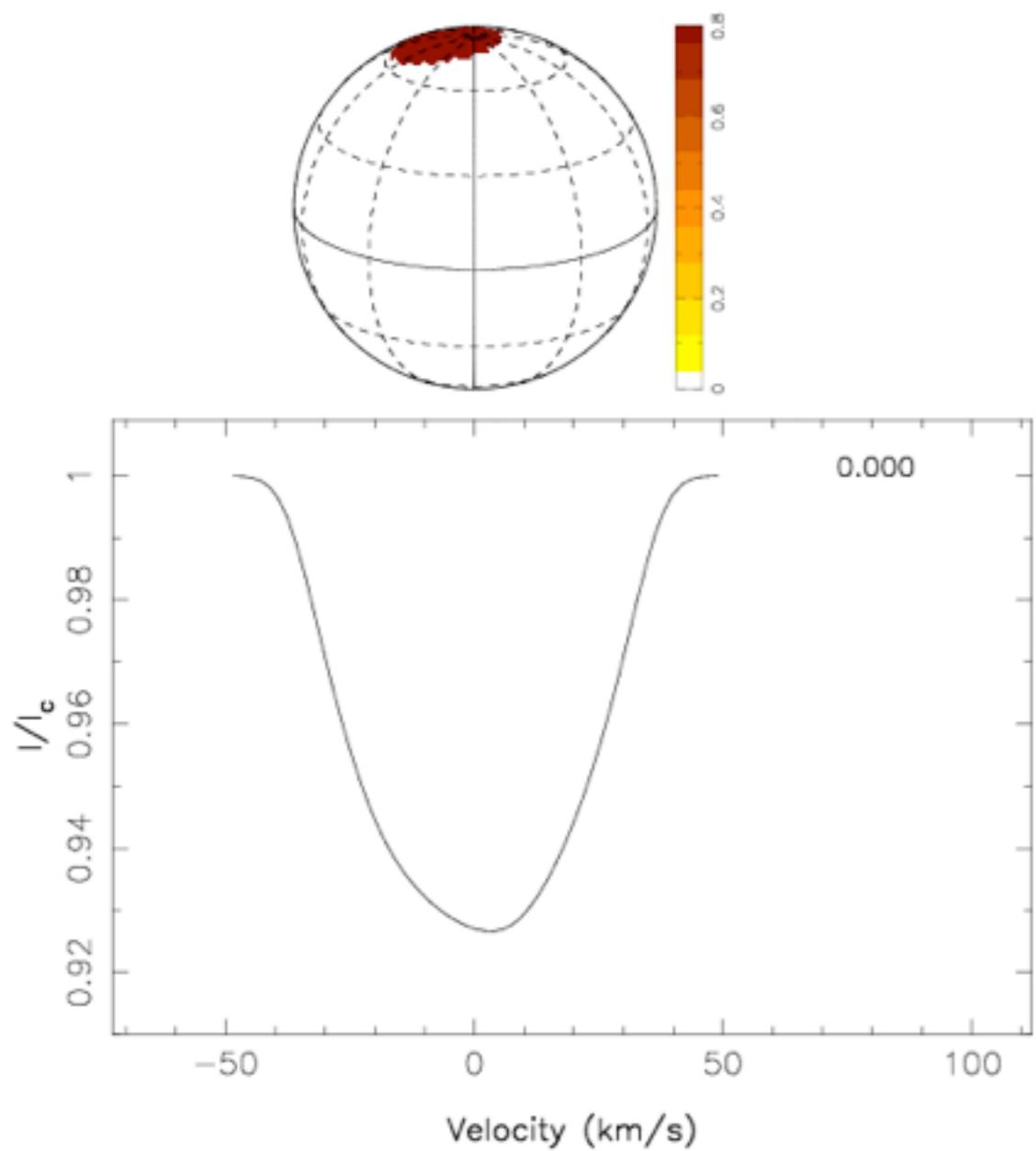




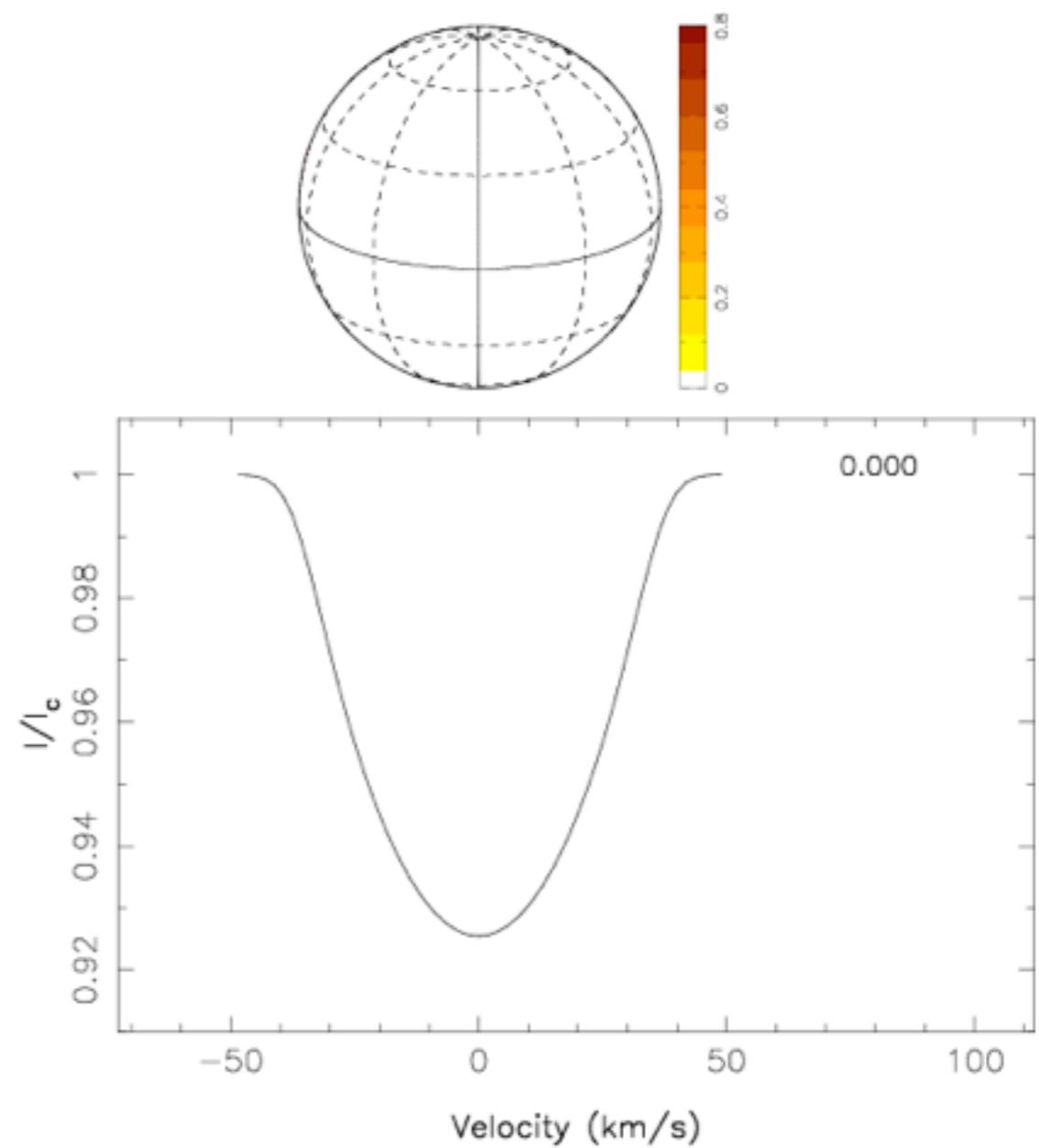
Imaging large-scale surface fields

How do we map stellar surface magnetic fields?

Doppler Imaging



Credit: J.-F. Donati



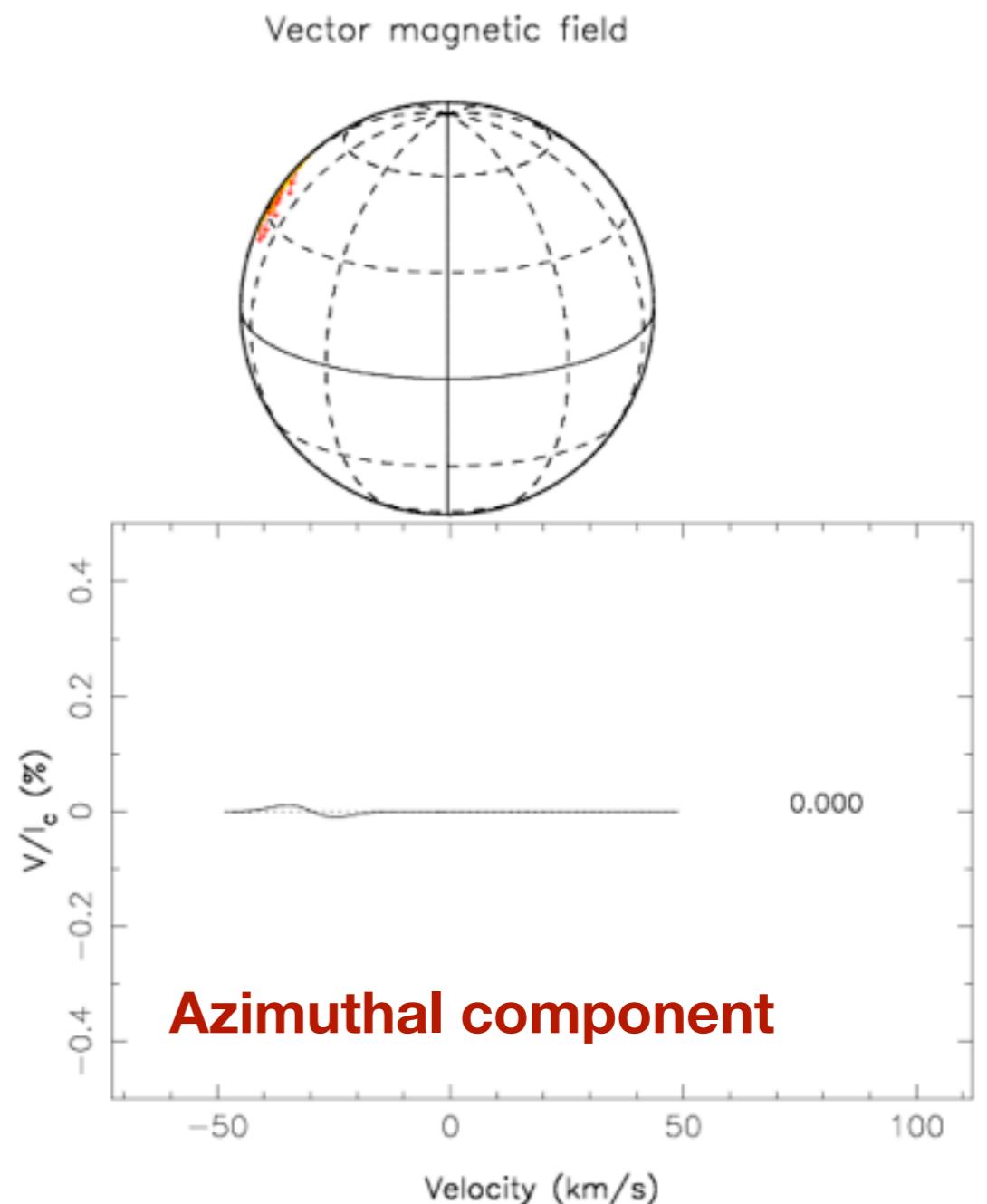
Credit: J.-F. Donati

How do we map stellar surface magnetic fields?

Zeeman Doppler Imaging

- Zeeman effect: magnetic field splits lines
- **Stokes V = $\circlearrowleft - \circlearrowright$**
- Track Stokes V → get field along observer's direction (B_{los})

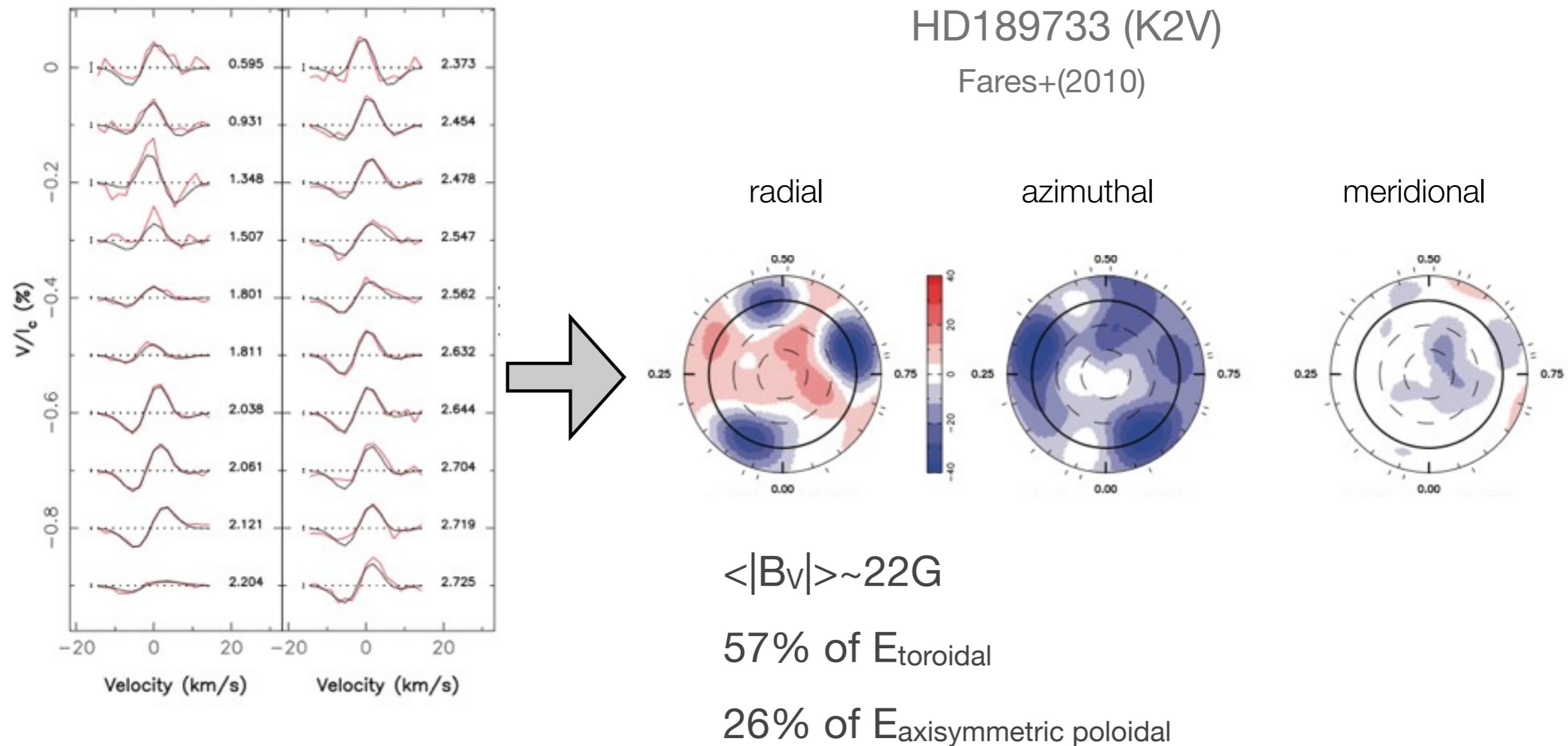
$$B_{\text{los}} = -2.14 \times 10^{11} \frac{\int v \frac{V(v)}{I_c} dv}{\lambda g_{\text{lan}} c \int \left[1 - \frac{I(v)}{I_c} \right] dv}$$



Credit: J.-F. Donati

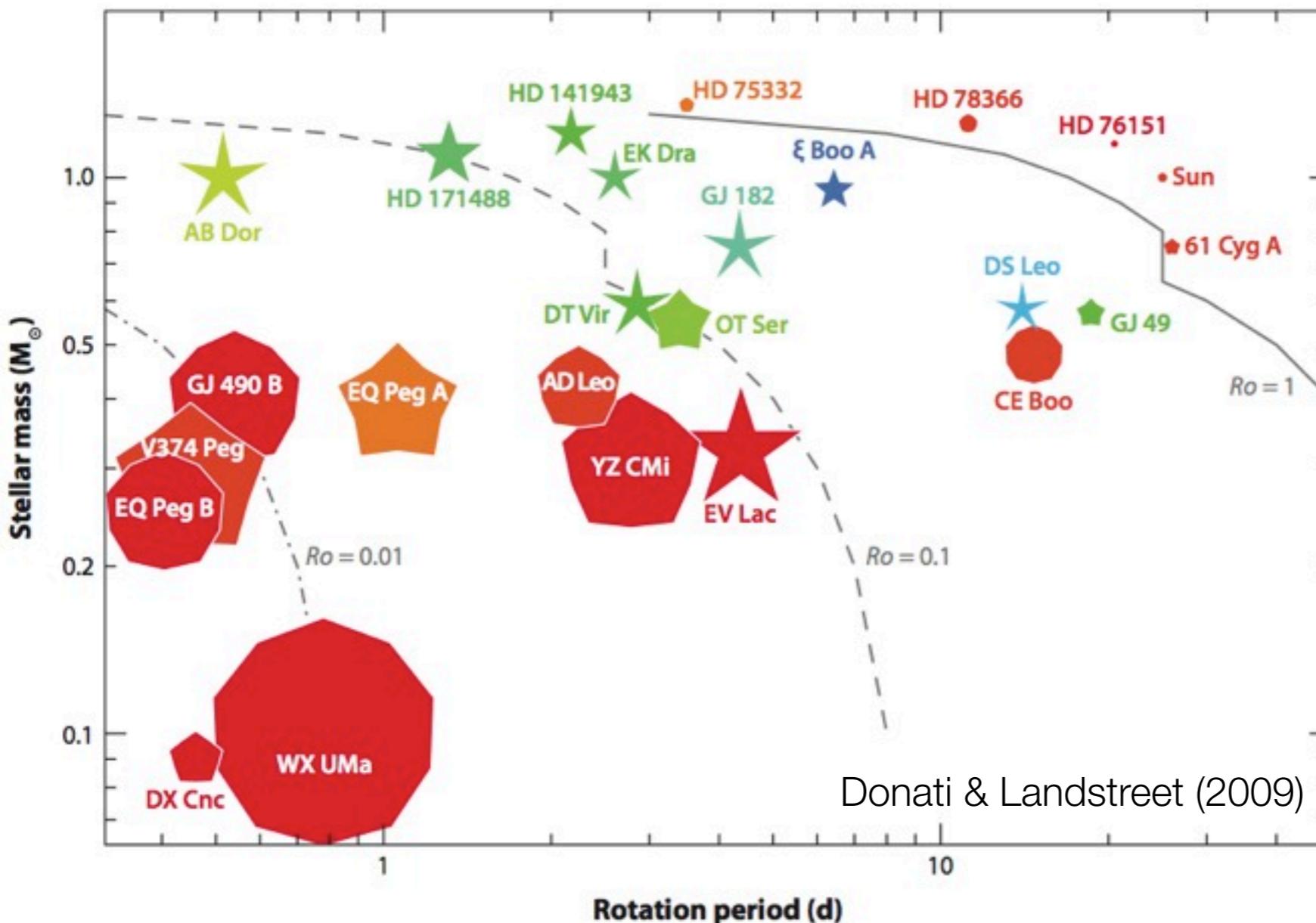
How do we map stellar surface magnetic fields?

- From Stokes V profile → use **inversion techniques** to derive B_r, B_ϕ, B_θ



What we infer about winds of cool stars

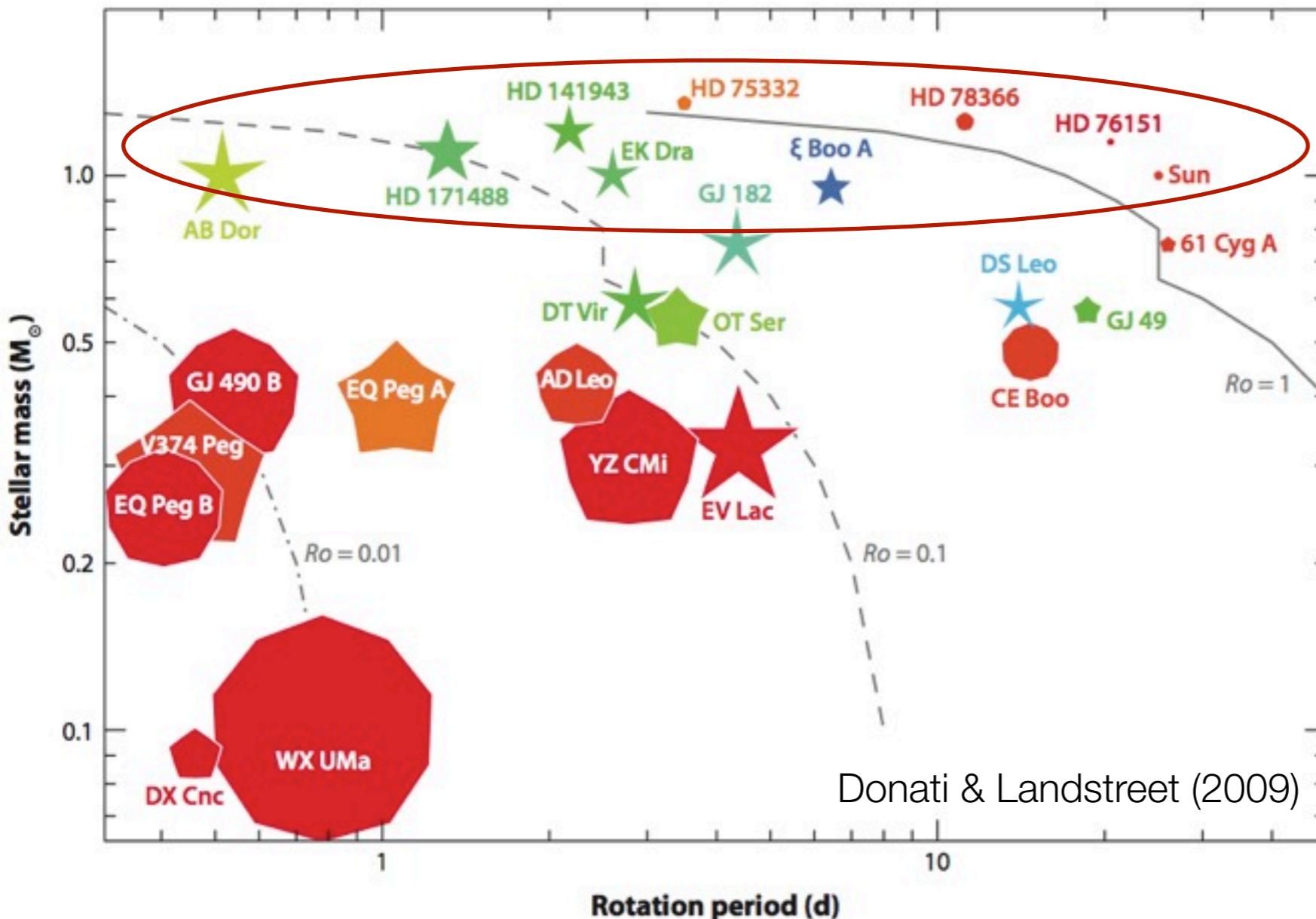
Zeeman Doppler imaging: magnetic fields of cool stars



- Size: magnetic energy
- Colour: purely toroidal (blue) or poloidal (red) fields.
- Shape: purely axisymmetric (decagon) or non-axisymmetric (star).

What we infer about winds of cool stars

Zeeman Doppler imaging: magnetic fields of cool stars

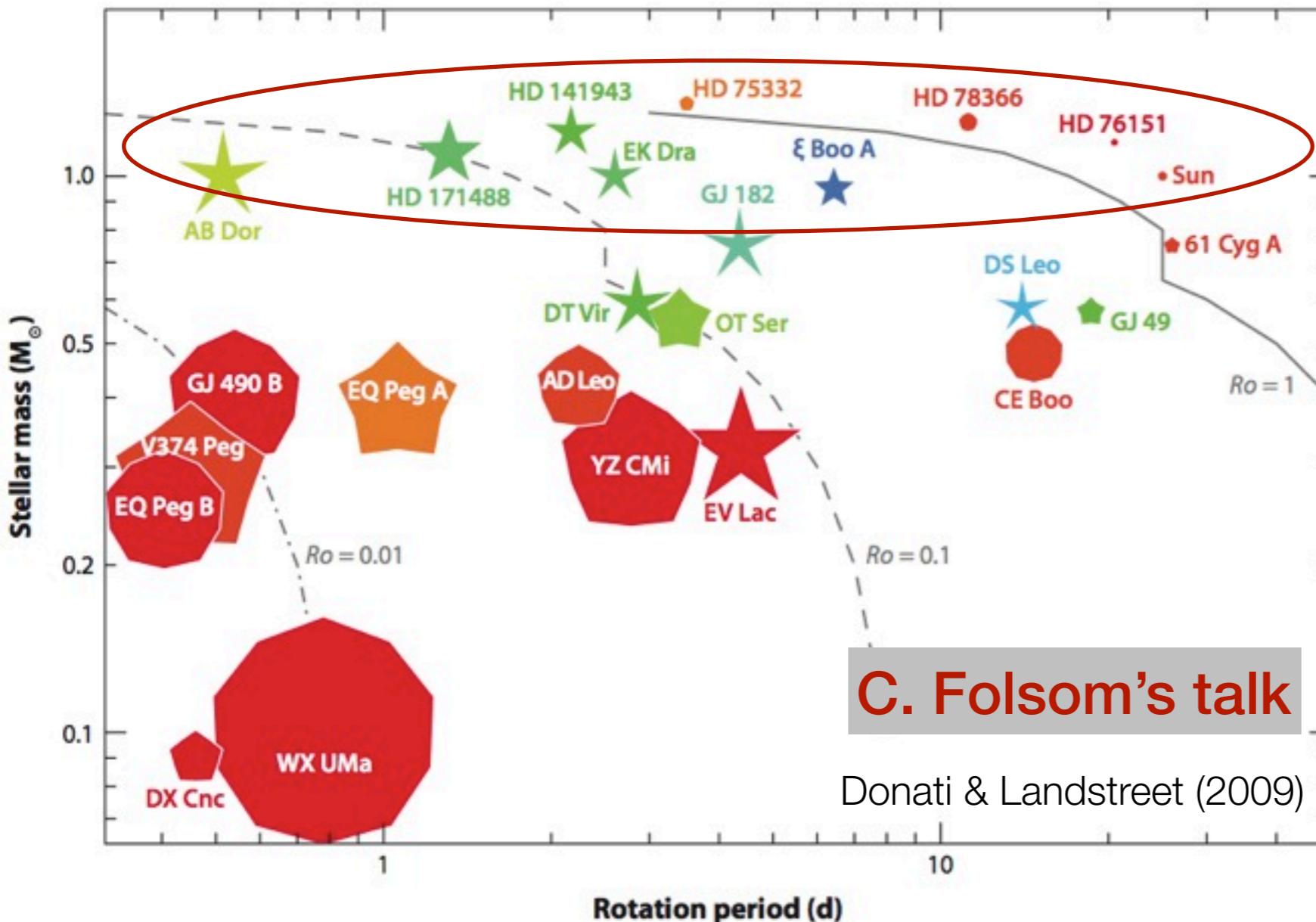


- Size: magnetic energy
- Colour: purely toroidal (blue) or poloidal (red) fields.
- Shape: purely axisymmetric (decagon) or non-axisymmetric (star).

Variety of intensities and topologies

What we infer about winds of cool stars

Zeeman Doppler imaging: magnetic fields of cool stars

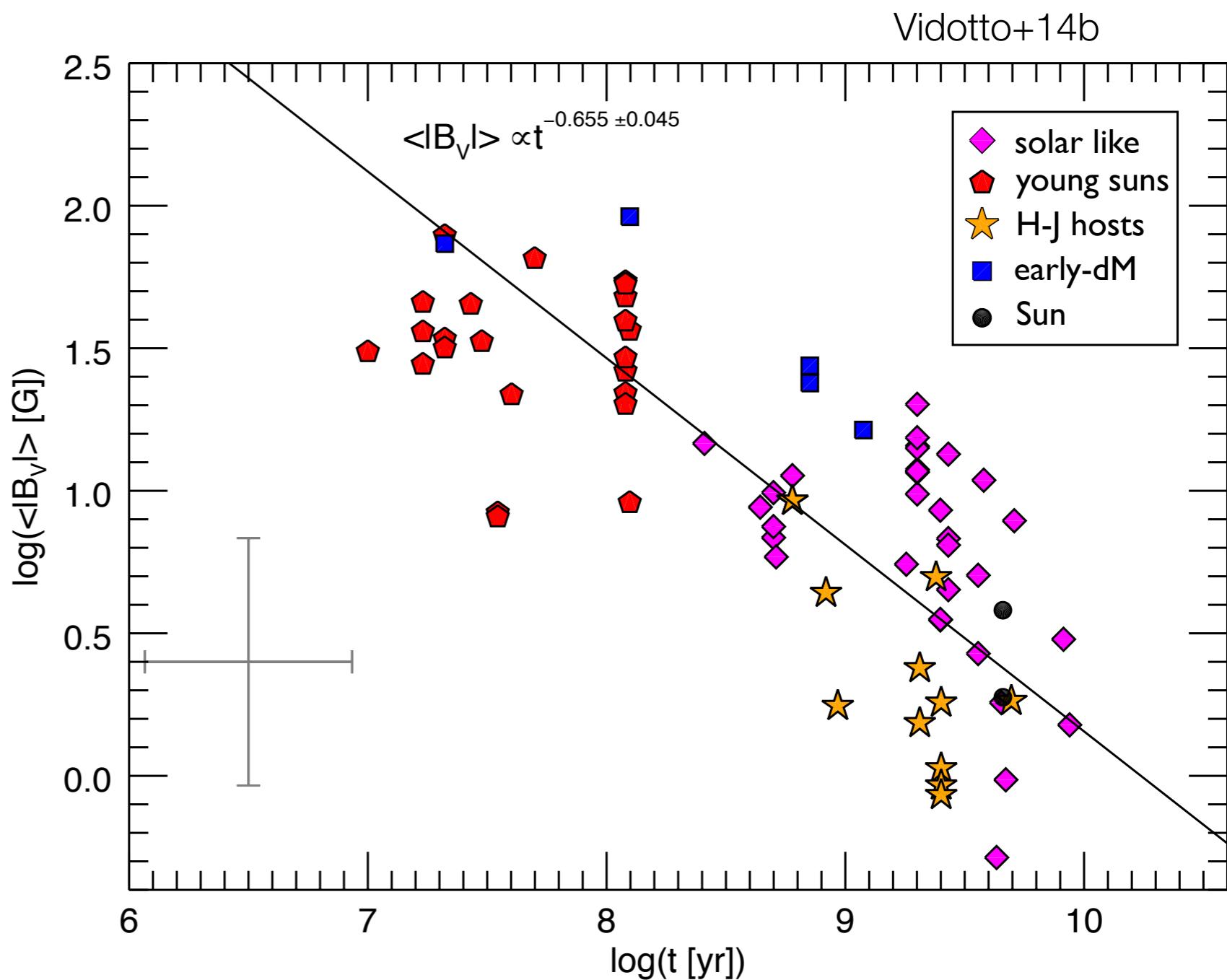


- Size: magnetic energy
- Colour: purely toroidal (blue) or poloidal (red) fields.
- Shape: purely axisymmetric (decagon) or non-axisymmetric (star).

Variety of intensities and topologies

What we infer about winds of cool stars

- And magnetism evolves in time...
- Large-scale magnetic field correlated with age
- ~74 ZDI maps (only objects with age estimates)
- “magnetochronology”?



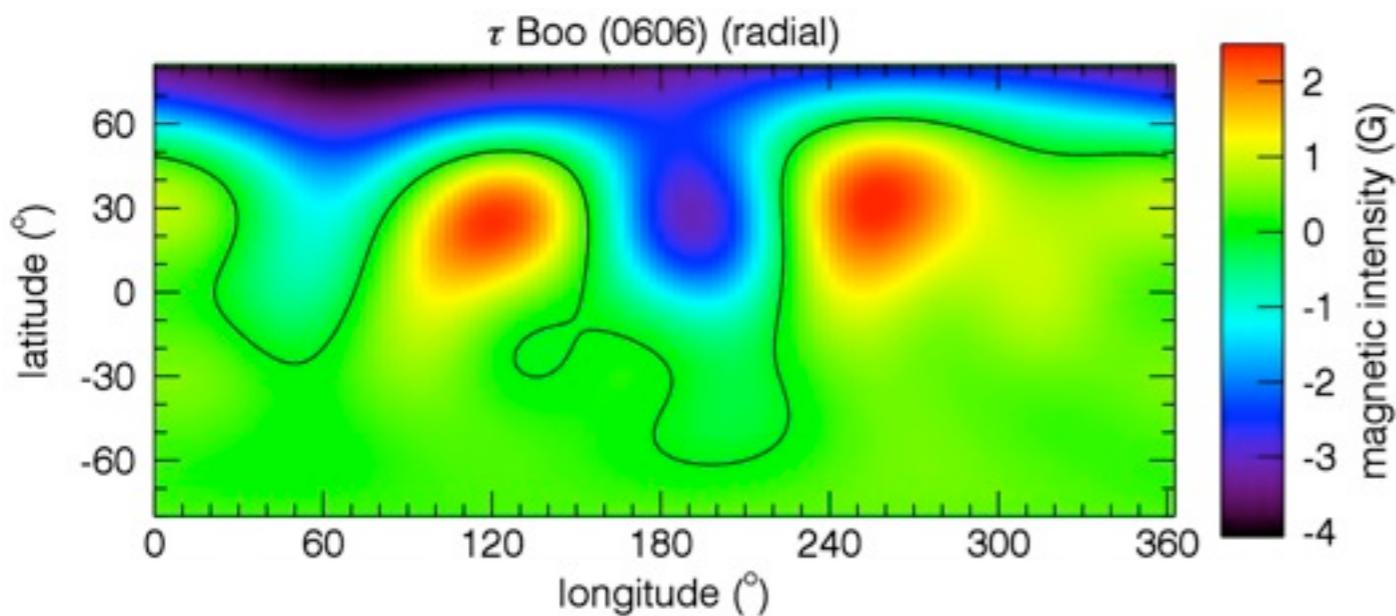
What we infer about winds of cool stars

Variety of:

- ▶ coronal temperatures
 - ▶ magnetic field intensities & topologies
 - ▶ rotation rates
 - ▶ magnetic & activity cycles
-
- indicate coronal winds might come in **different** flavours...
 - may not be identical to solar wind: **major gap**

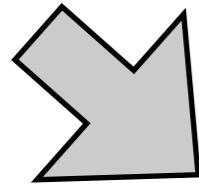
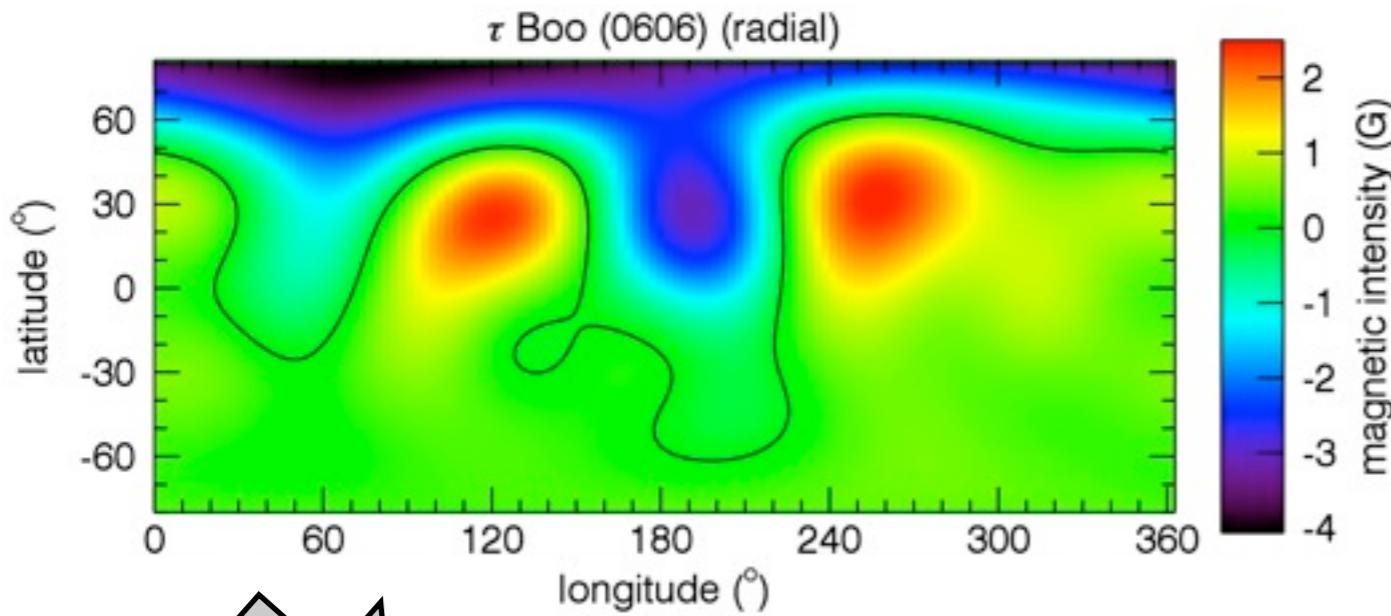
Data-driven wind simulations

τ Boo observations (Catala+07, Fares+09):

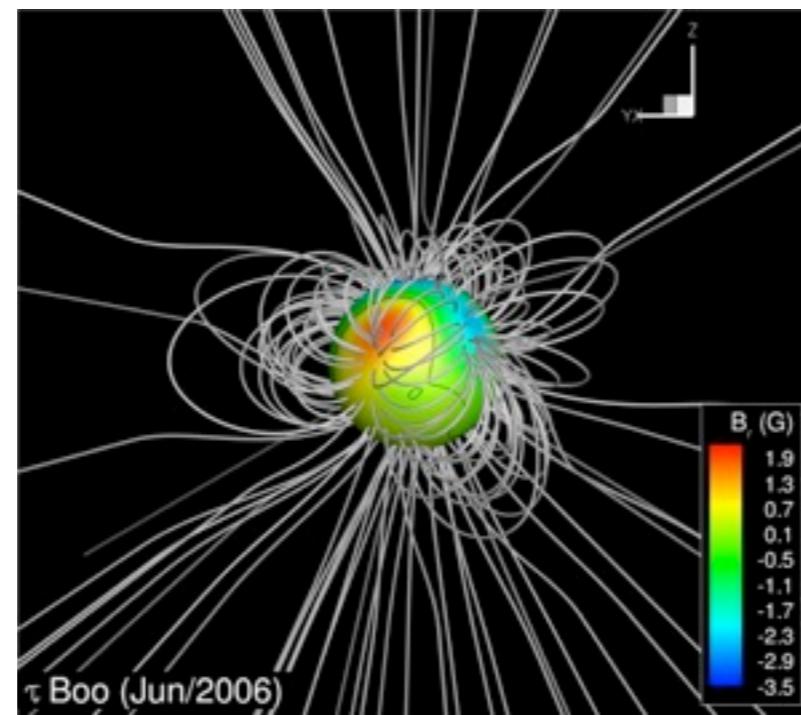


Data-driven wind simulations

τ Boo observations (Catala+07, Fares+09):

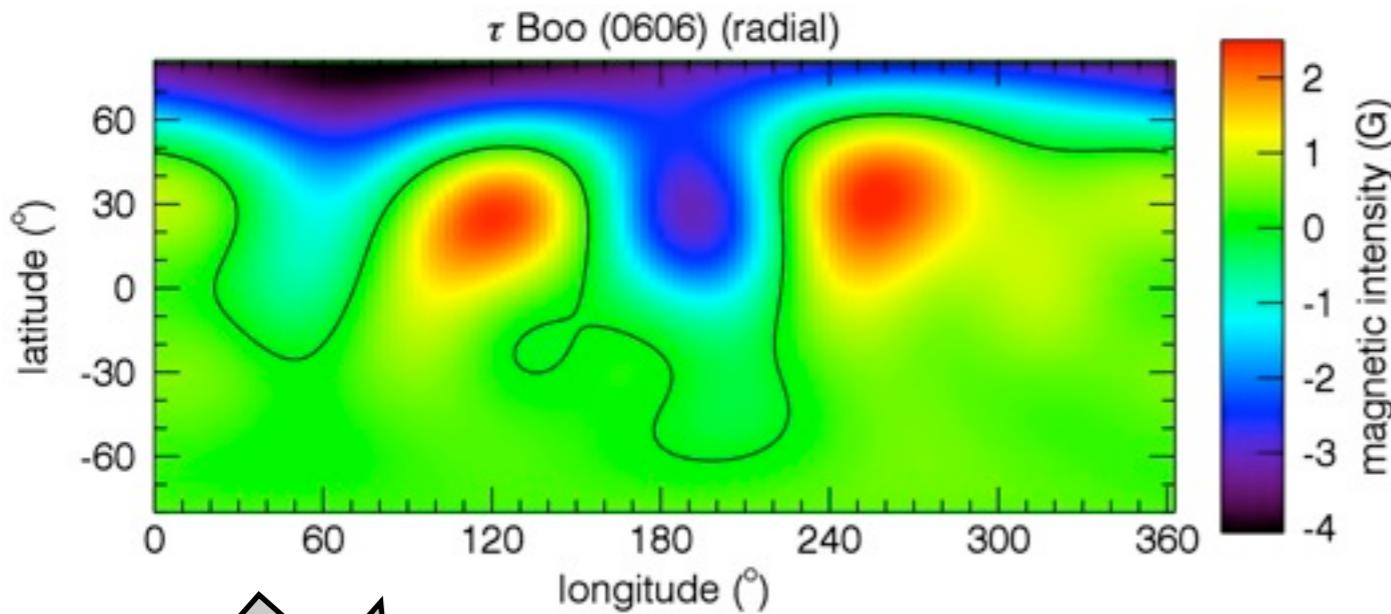


Initial state:
potential field
incorporated in
MHD simulations

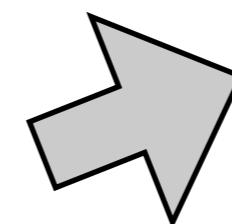
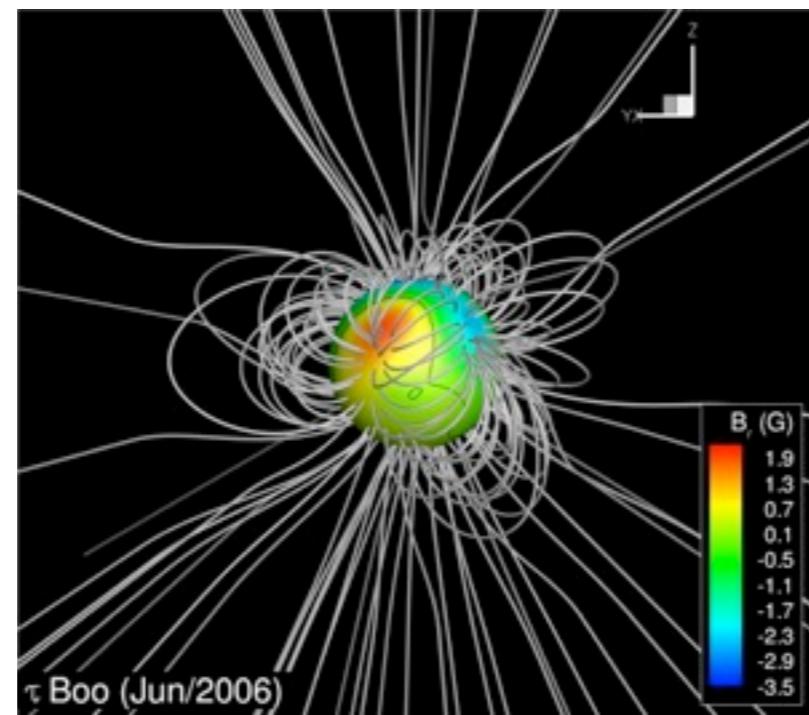


Data-driven wind simulations

τ Boo observations (Catala+07, Fares+09):

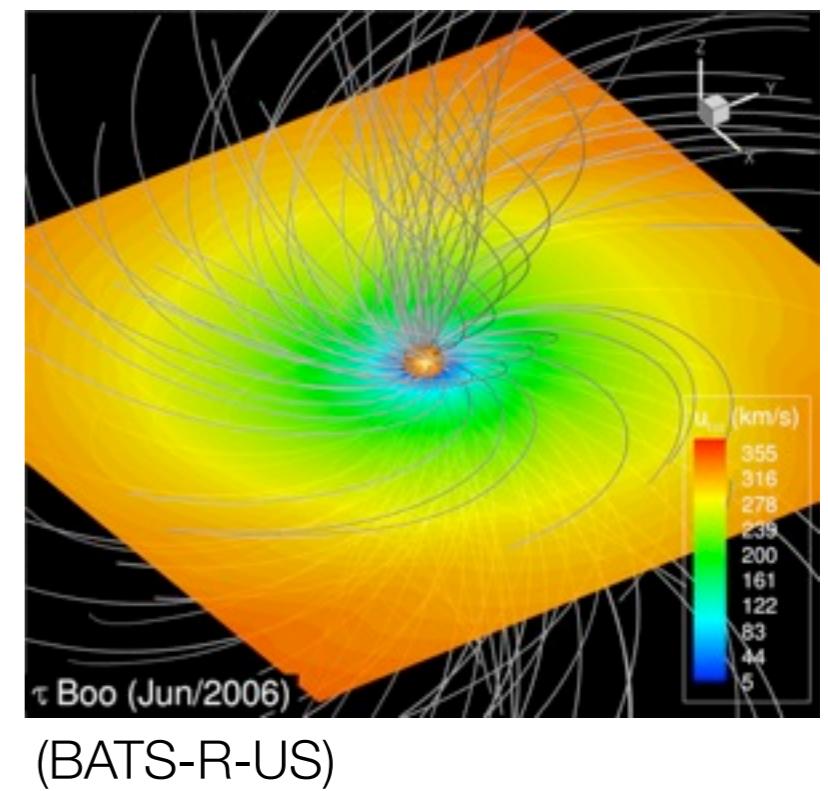


Initial state:
potential field
incorporated in
MHD simulations

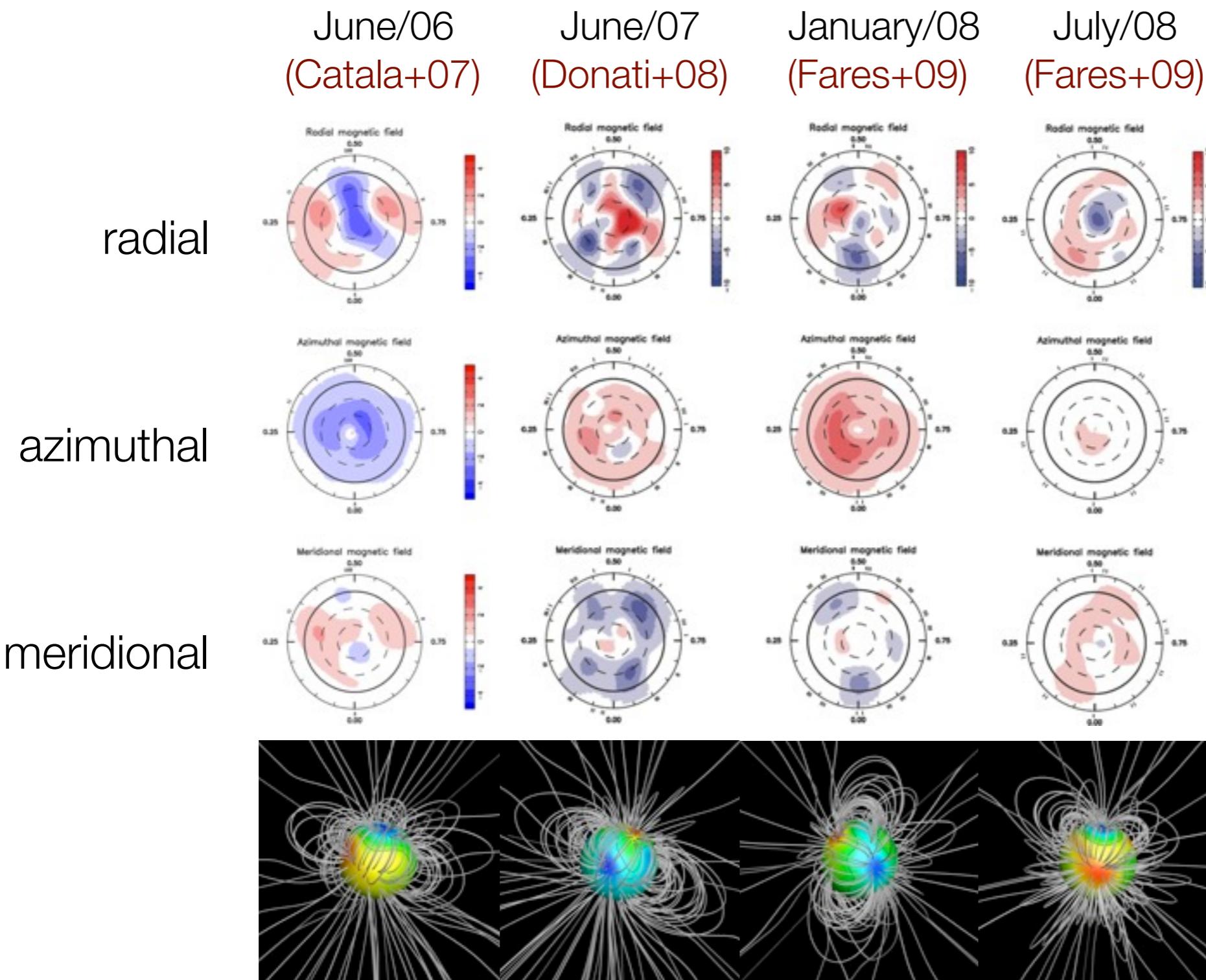


→ more on the technique & other objects: Vidotto+09a, 10ab, 11a, 12, 14a, 15; etc

Final state: self-consistent MHD wind solution



Magnetic Cycles: τ Boo



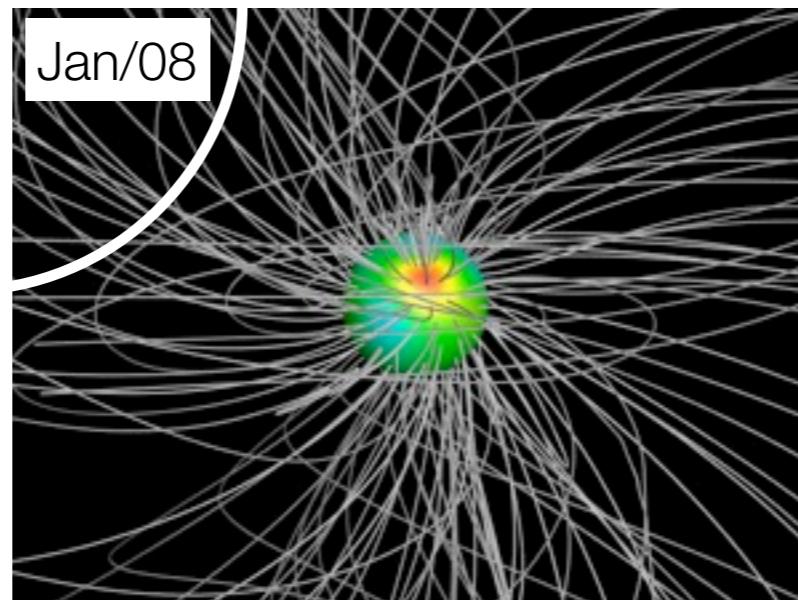
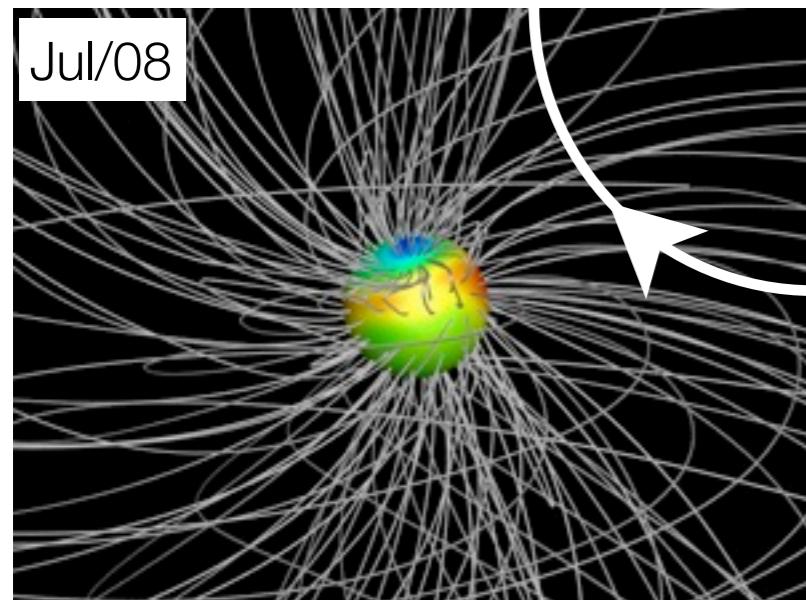
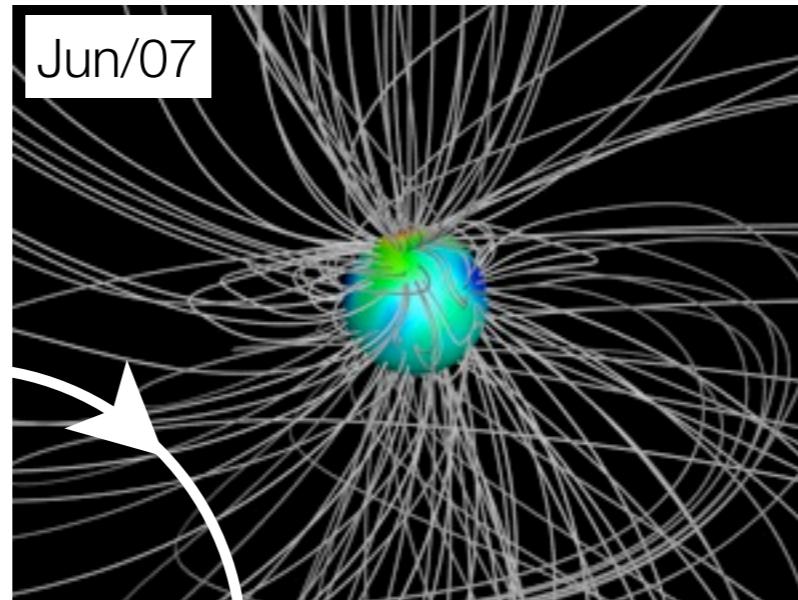
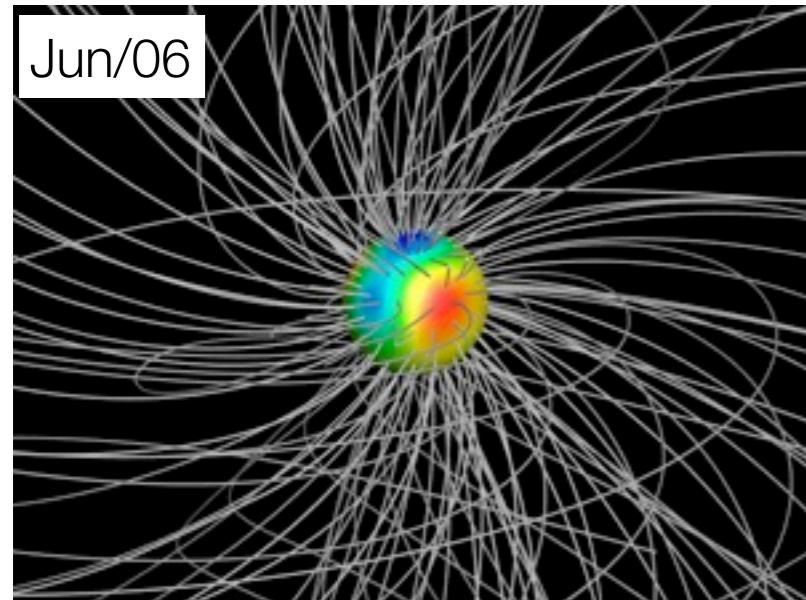
Planet-host star:

- $1.34 M_{\odot}$
- $P_{\text{rot}} = 3$ days
- age ~ 2.5 Gyr

$P_{\text{cycle}} = 2$ years
(Fares+09)

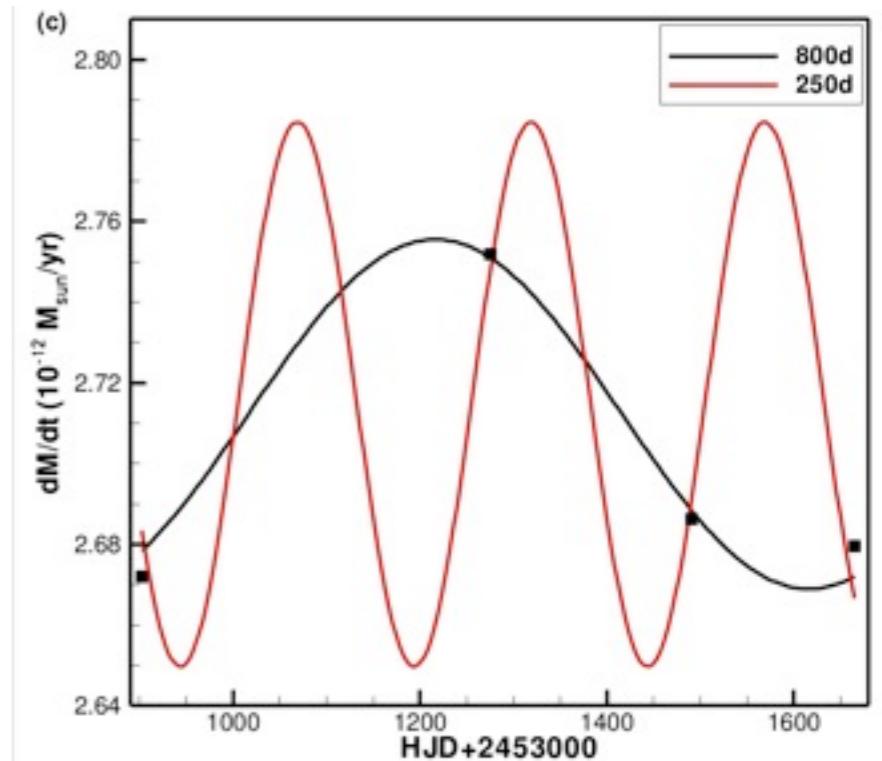
Evolution along magnetic cycle: τ Boo

Vidotto+12



$P_{\text{cycle}} = 2$ years (Fares+09)

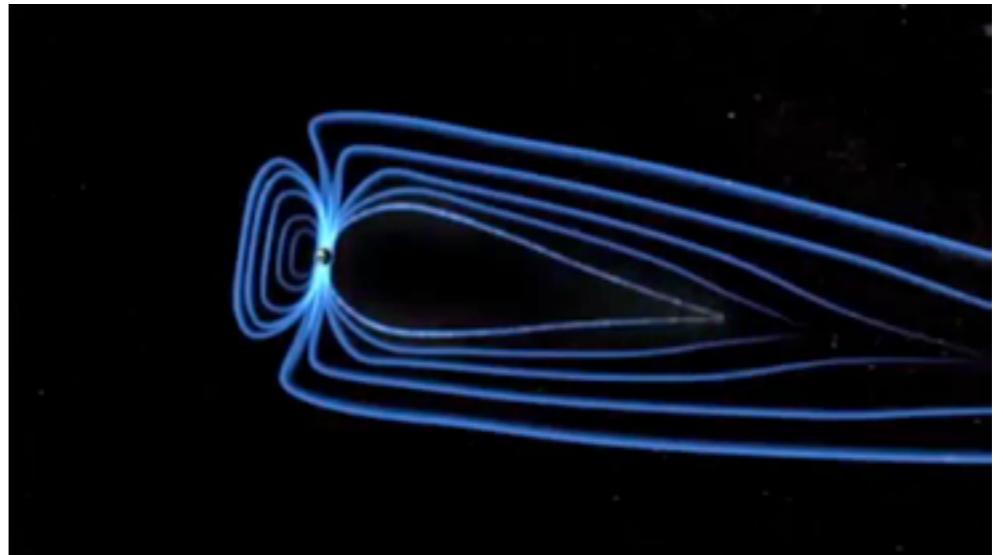
mass-loss rate: **~135 M_{\odot}**



Enhanced dM/dt + extreme orbital distance (<0.05 AU) \rightarrow significant effects on the exoplanet

Radio emission from exoplanets

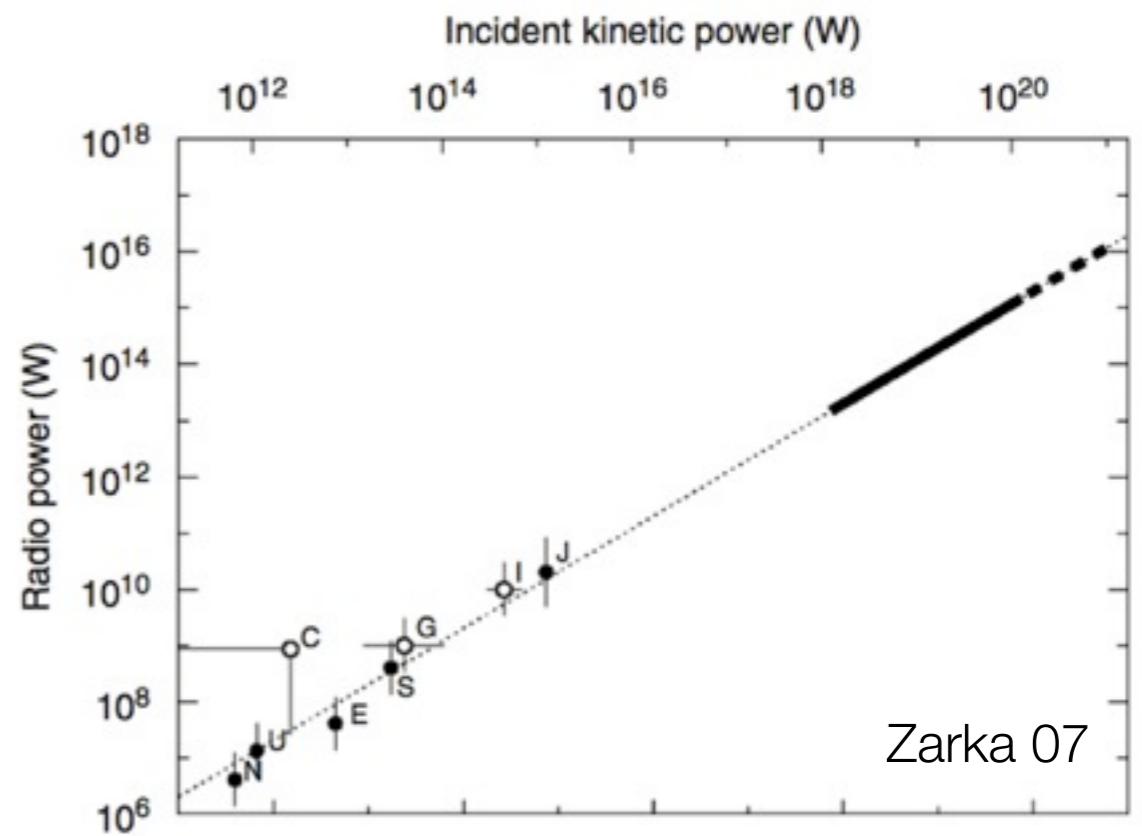
- τ Boo b: potential candidate
 - ▶ proximity of the system (15.6 pc)
 - ▶ close-in, giant planet @ 0.0462 au
- Output of simulations → radio flux

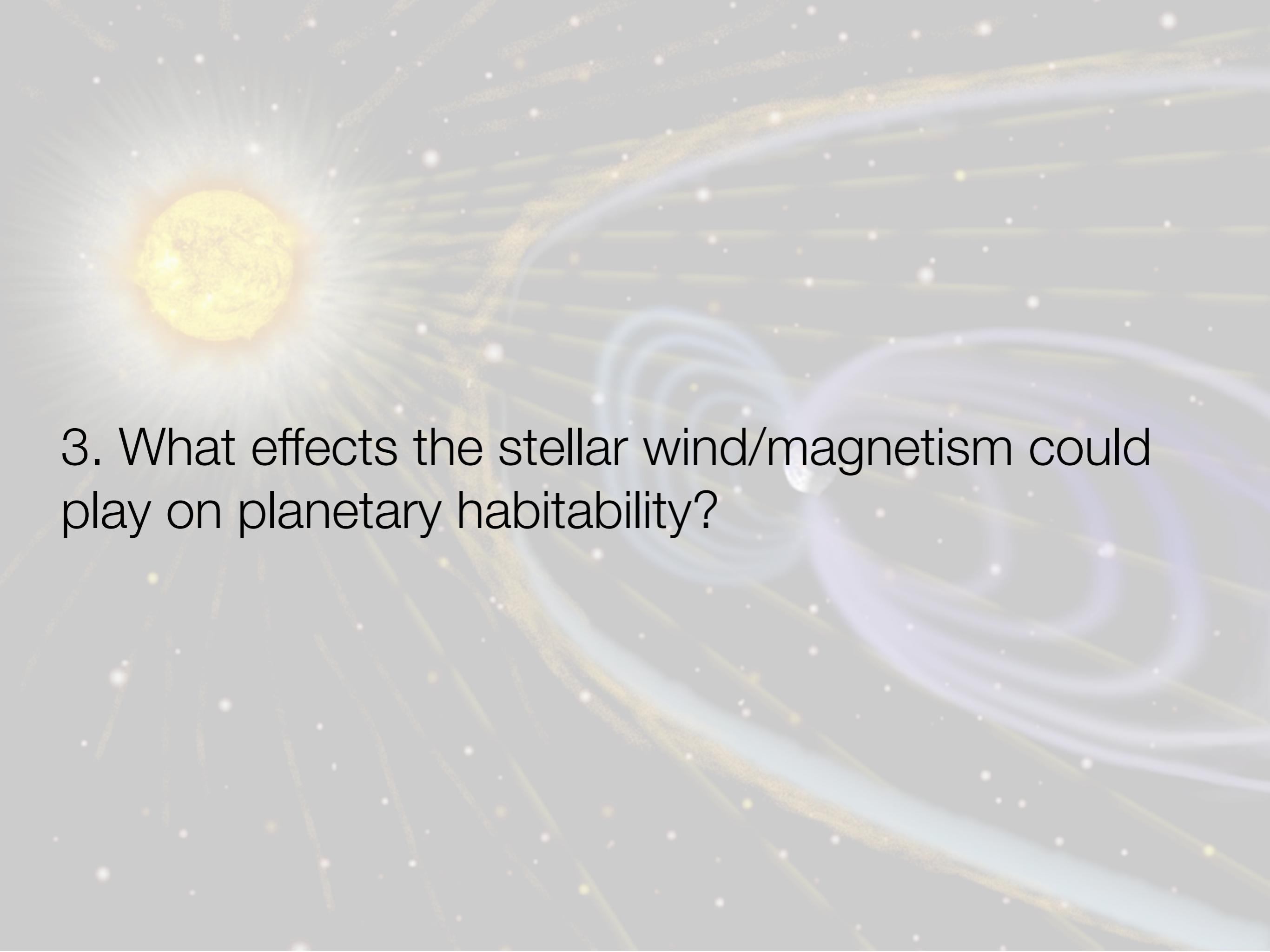


Credit: NASA

$$P_{\text{radio}} = 10^{-5} P_{\text{kin}}^{\text{wind}}$$

B_p (G)	r_M (R_p)	frequency (MHz)	radio flux (mJy)
14	3.4	~34	1.4
1	1.4	~1.9	1.4

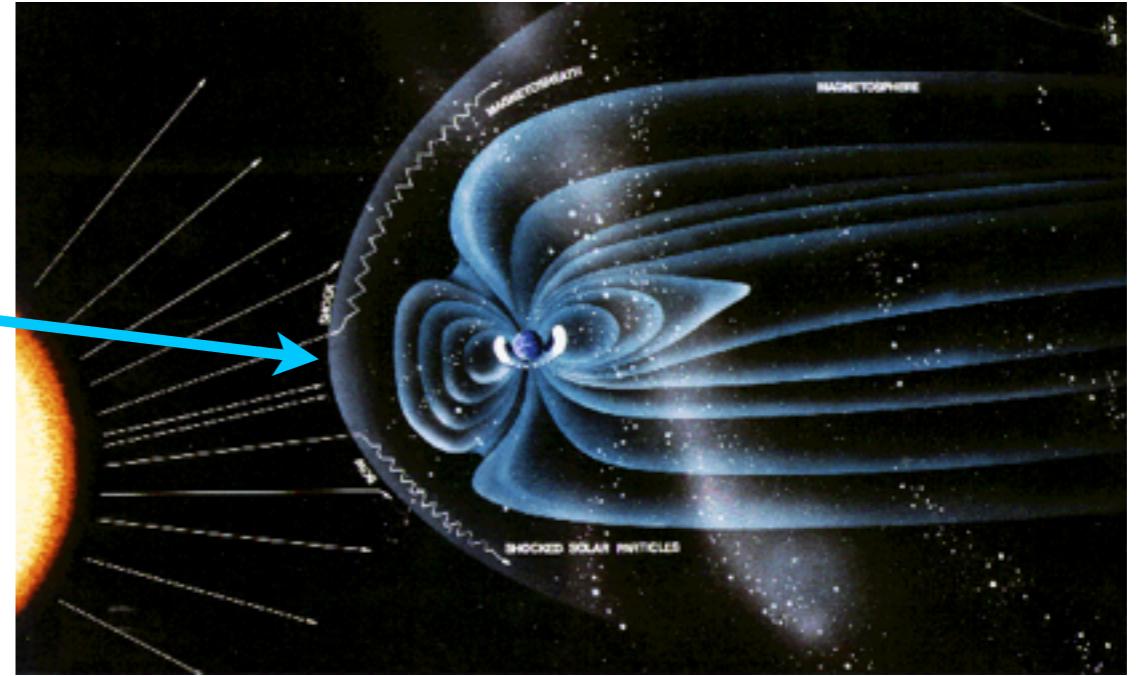




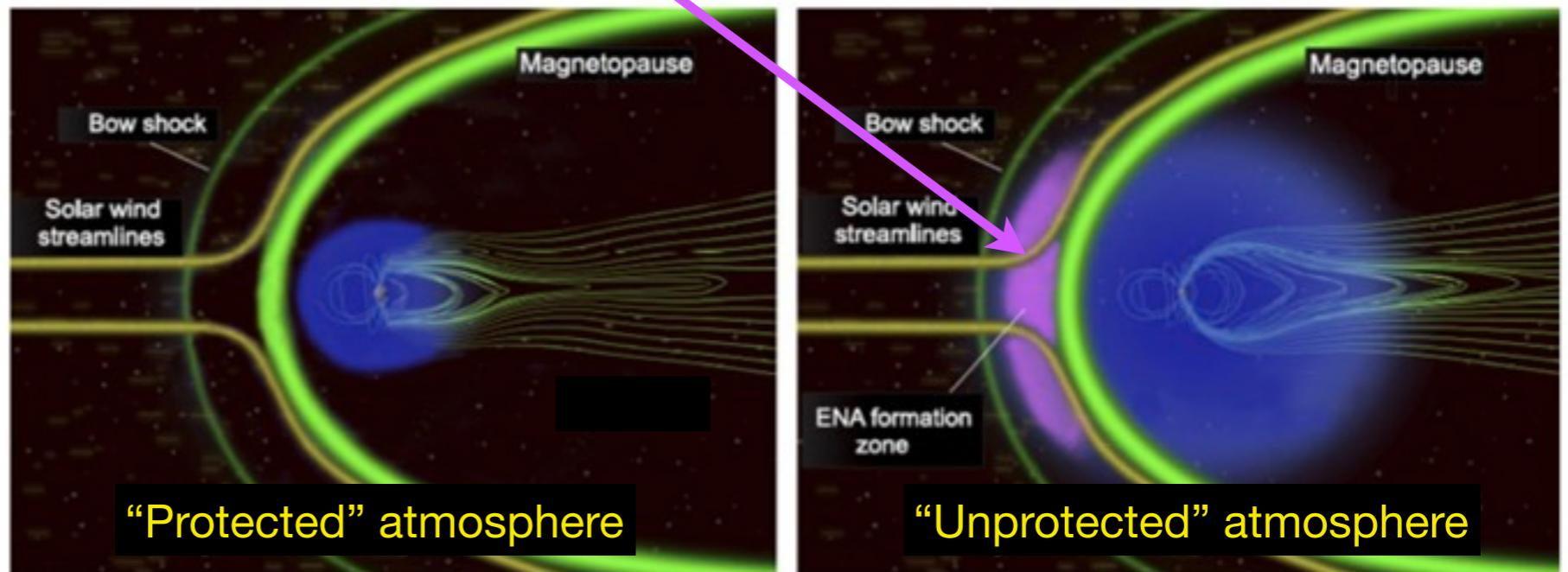
3. What effects the stellar wind/magnetism could play on planetary habitability?

Interaction of planets and stellar winds

- Bow shock formation → pressure of stellar wind/corona compresses planetary **magnetosphere**
- Strong wind and/or insufficient planet's magnetic field → small magnetospheres: can **expose** the planet's atmosphere to erosion by cosmic particles



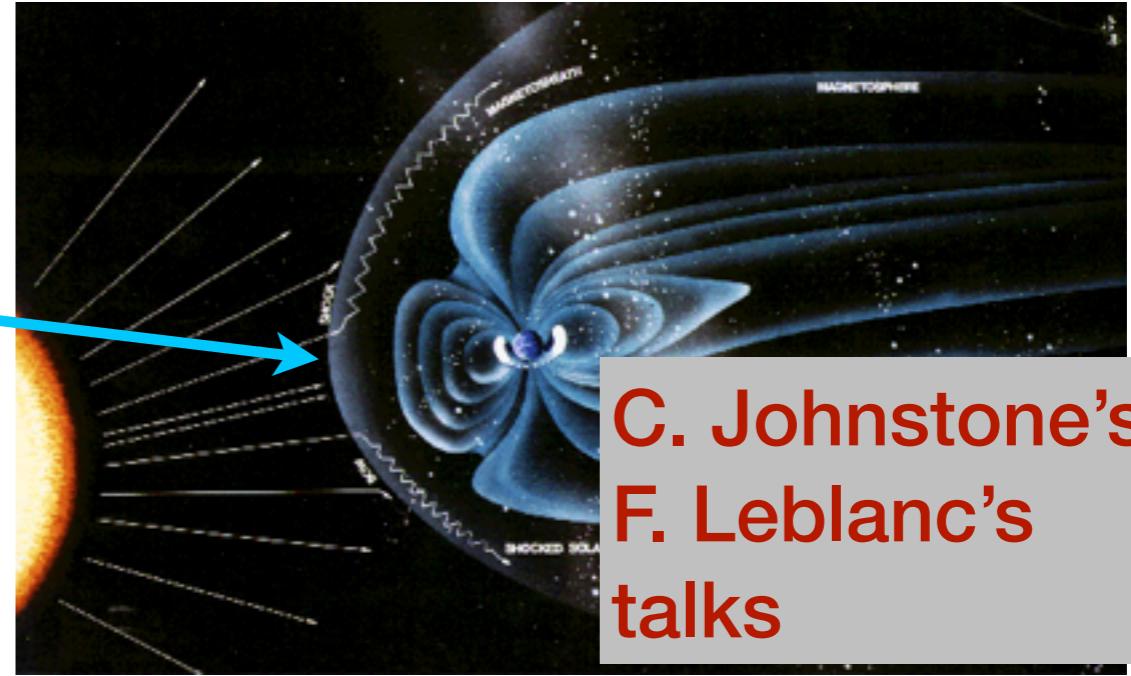
Magnetic protection of atmospheres: essential for habitability



Lammer+ 2011

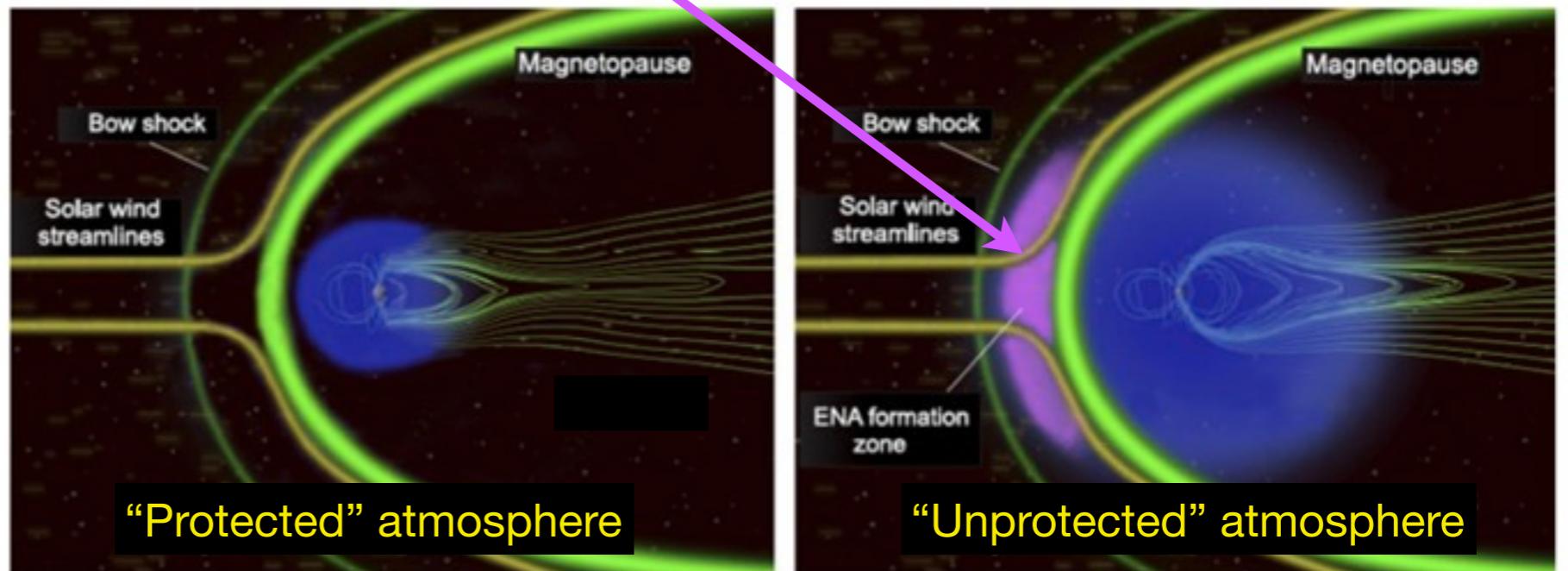
Interaction of planets and stellar winds

- Bow shock formation → pressure of stellar wind/corona compresses planetary **magnetosphere**
- Strong wind and/or insufficient planet's magnetic field → small magnetospheres: can **expose** the planet's atmosphere to erosion by cosmic particles



C. Johnstone's & F. Leblanc's talks

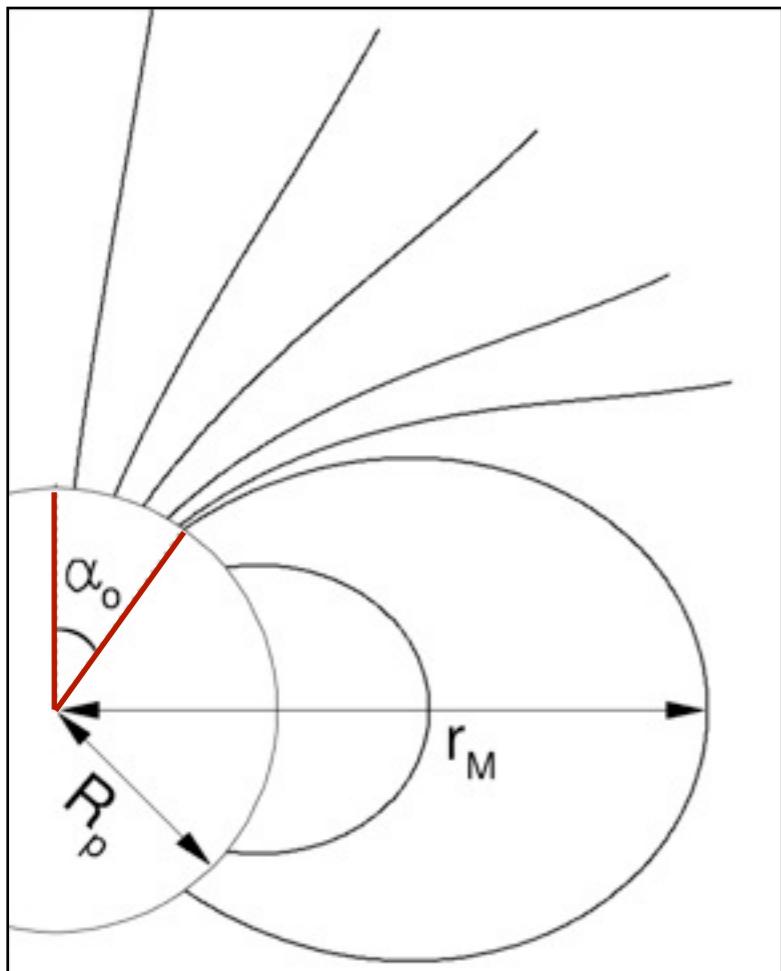
Magnetic protection of atmospheres: essential for habitability



Lammer+ 2011

Planetary ‘magnetic shield’

Large magnetosphere



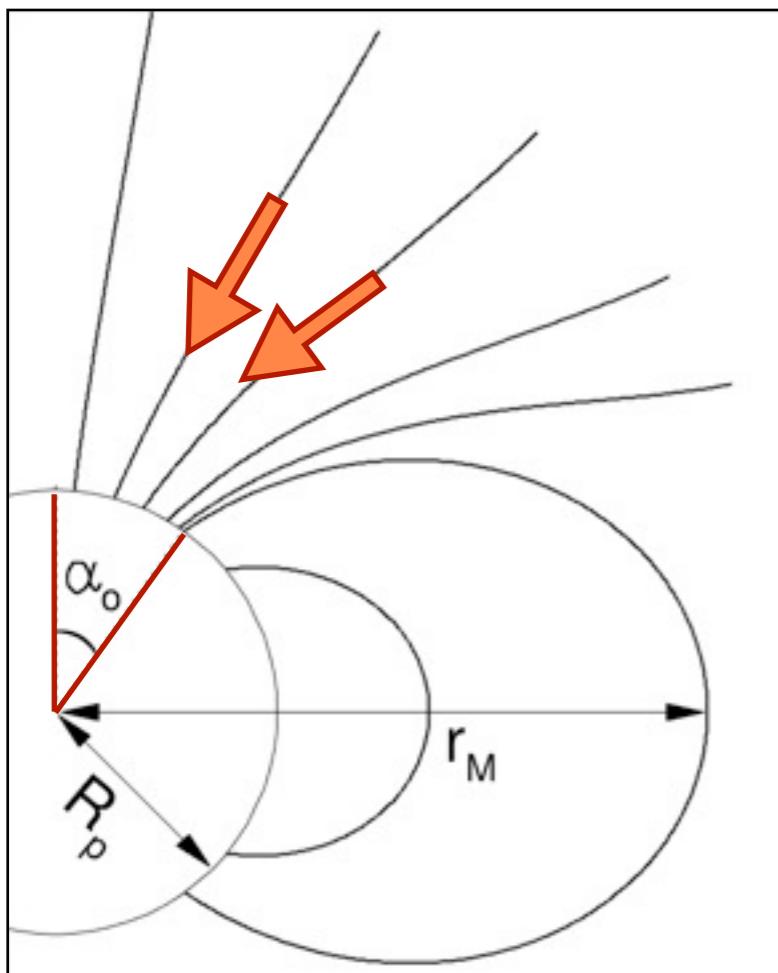
Small auroral oval a_0

$$\alpha_0 = \arcsin \left[\left(\frac{r_p}{r_M} \right)^{1/2} \right]$$

(Siscoe & Chen 75, Tarduno+10,
Vidotto+11a, Zuluaga+12)

Planetary ‘magnetic shield’

Large magnetosphere



Precipitating electrons

- ▶ auroral emission:
radio, IR, visible, UV,
X-ray
- ▶ electron heating,
enhancing
atmospheric
evaporation →
blown away by the
solar wind

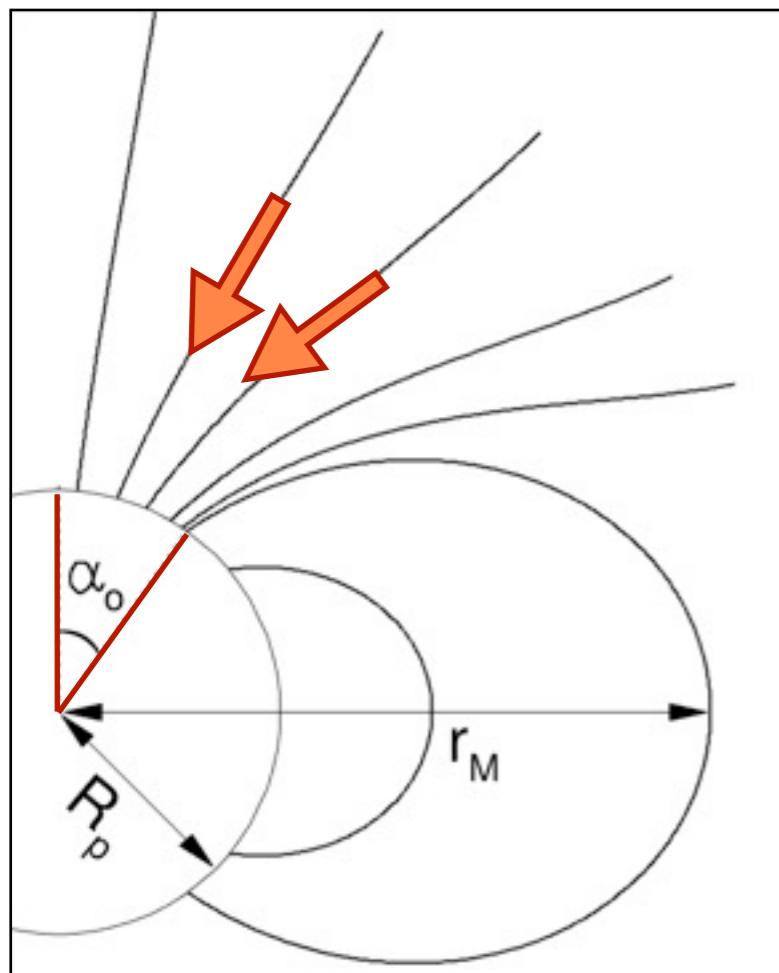
Small auroral oval α_0

$$\alpha_0 = \arcsin \left[\left(\frac{r_p}{r_M} \right)^{1/2} \right]$$

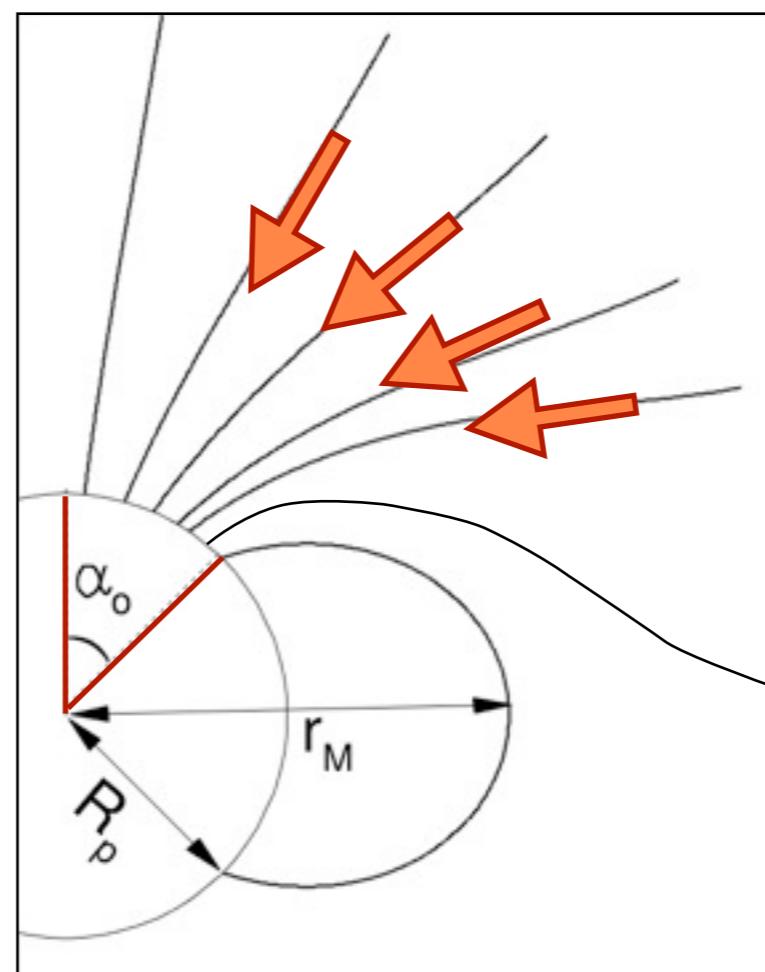
(Siscoe & Chen 75, Tarduno+10,
Vidotto+11a, Zuluaga+12)

Planetary ‘magnetic shield’

Large magnetosphere



Small magnetosphere



Small auroral oval α_0

$$\alpha_0 = \arcsin \left[\left(\frac{r_p}{r_M} \right)^{1/2} \right]$$

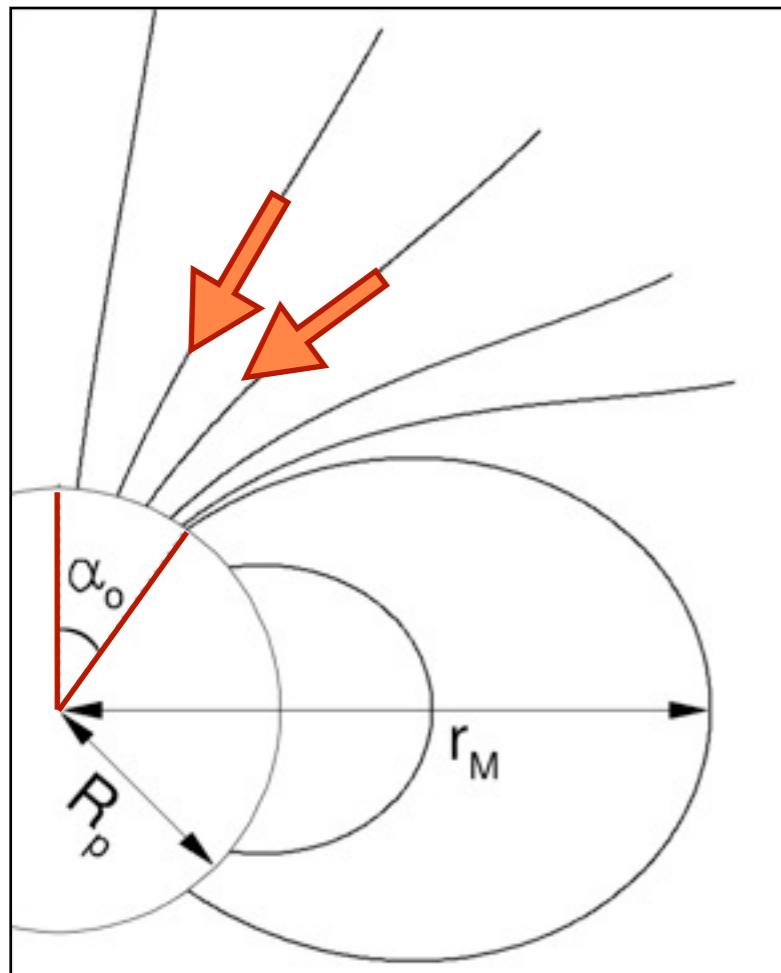
(Siscoe & Chen 75, Tarduno+10,
Vidotto+11a, Zuluaga+12)

Precipitating electrons

- ▶ auroral emission:
radio, IR, visible, UV,
X-ray
- ▶ electron heating,
enhancing
atmospheric
evaporation →
blown away by the
solar wind

Planetary ‘magnetic shield’

Large magnetosphere

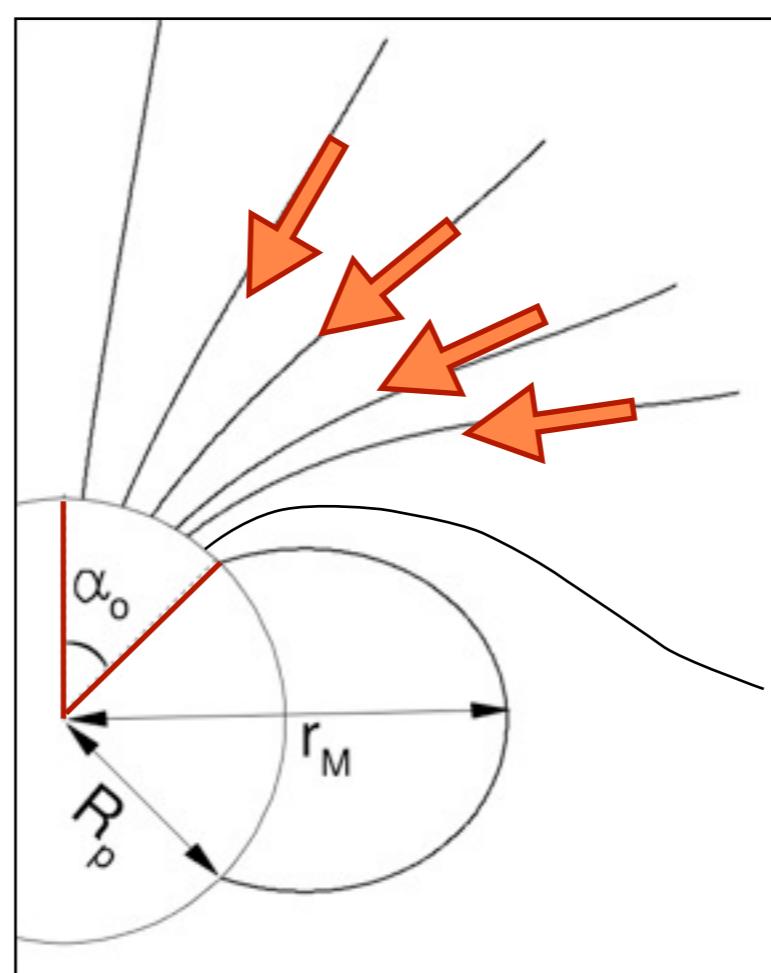


Small auroral oval α_0

$$\alpha_0 = \arcsin \left[\left(\frac{r_p}{r_M} \right)^{1/2} \right]$$

Magnetic interactions and habitability

Small magnetosphere



Large auroral oval α_0

(Siscoe & Chen 75, Tarduno+10,
Vidotto+11a, Zuluaga+12)

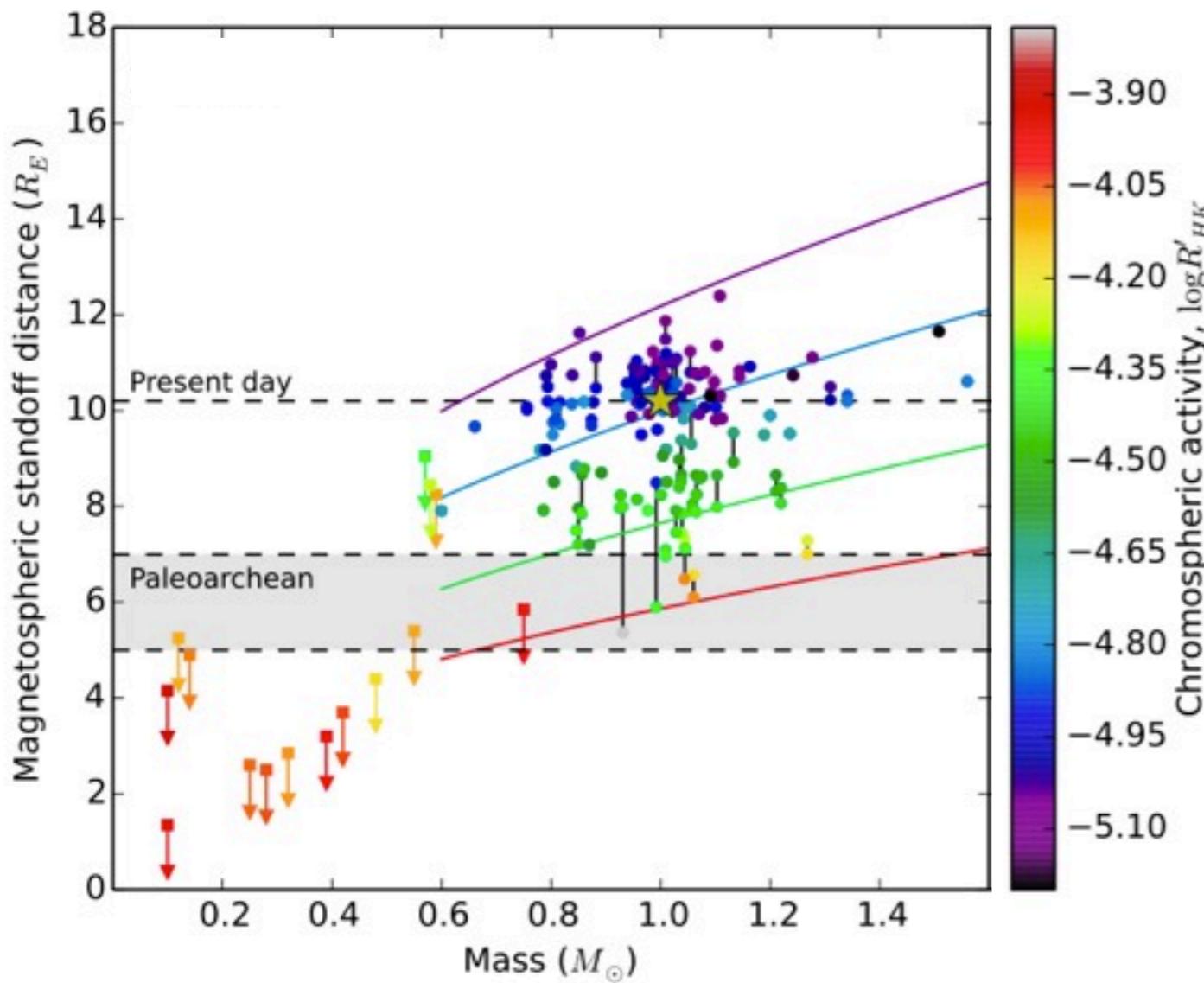
Precipitating electrons

- ▶ auroral emission: radio, IR, visible, UV, X-ray
- ▶ electron heating, enhancing atmospheric evaporation → blown away by the solar wind

Potential impact on habitability

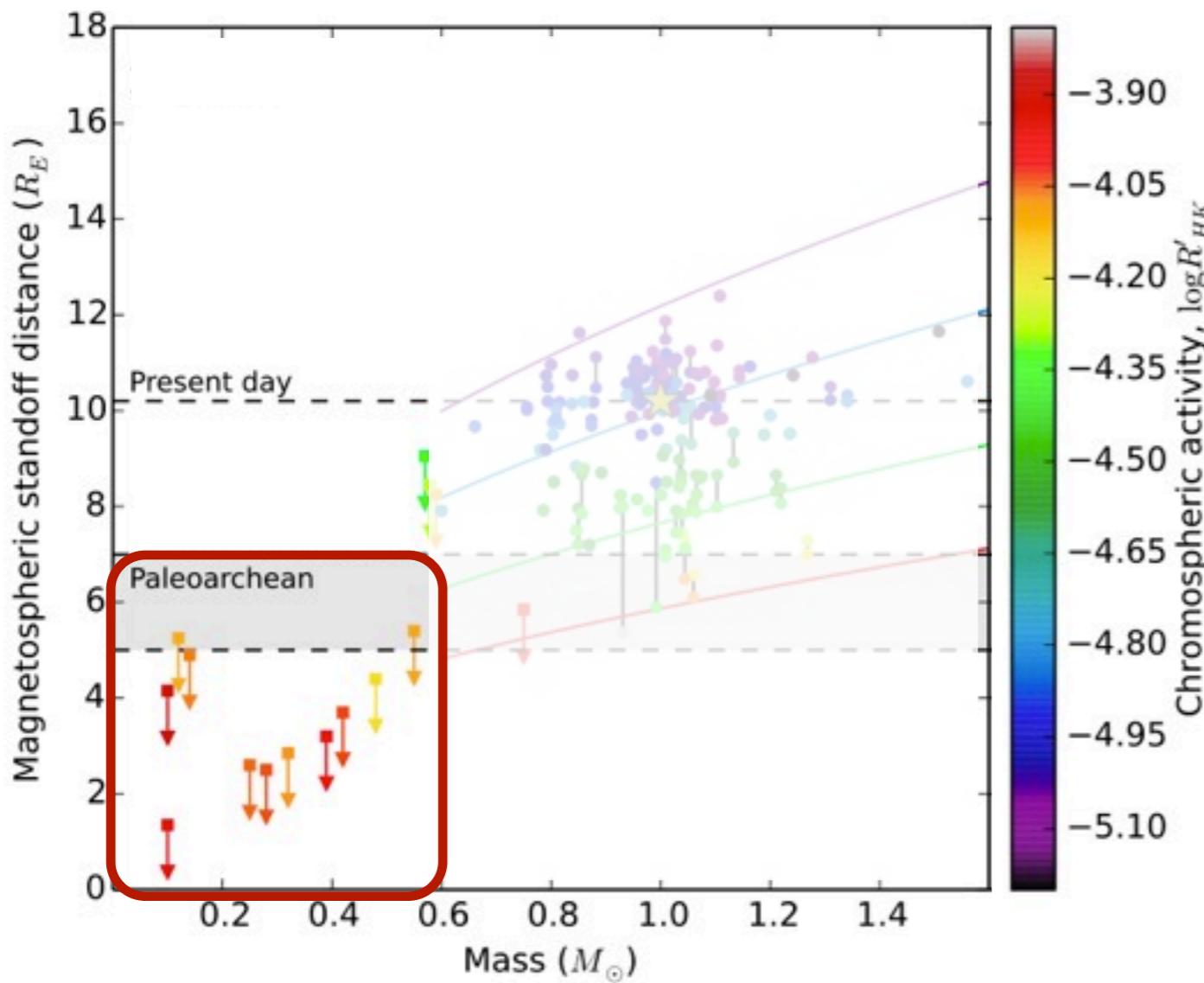
For an Earth-twin at the Habitable Zone

See+2014: 1D stellar wind models for >160 objects



For an Earth-twin at the Habitable Zone

See+2014: 1D stellar wind models for >160 objects

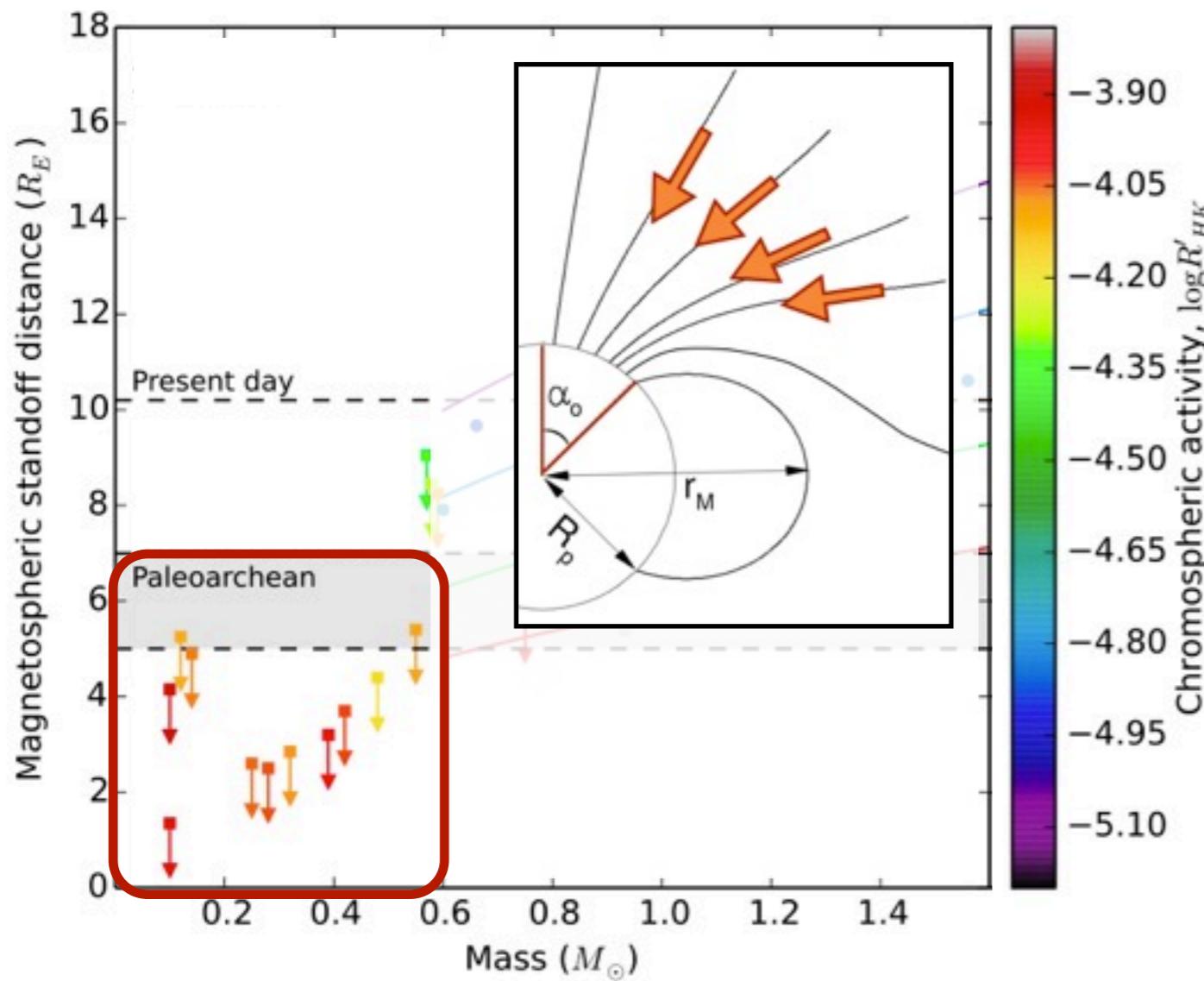


M dwarfs (Vidotto+13):

- upper limit → considering only information on the stellar magnetic field (Donati+2008, Morin+2008, 2010)

For an Earth-twin at the Habitable Zone

See+2014: 1D stellar wind models for >160 objects

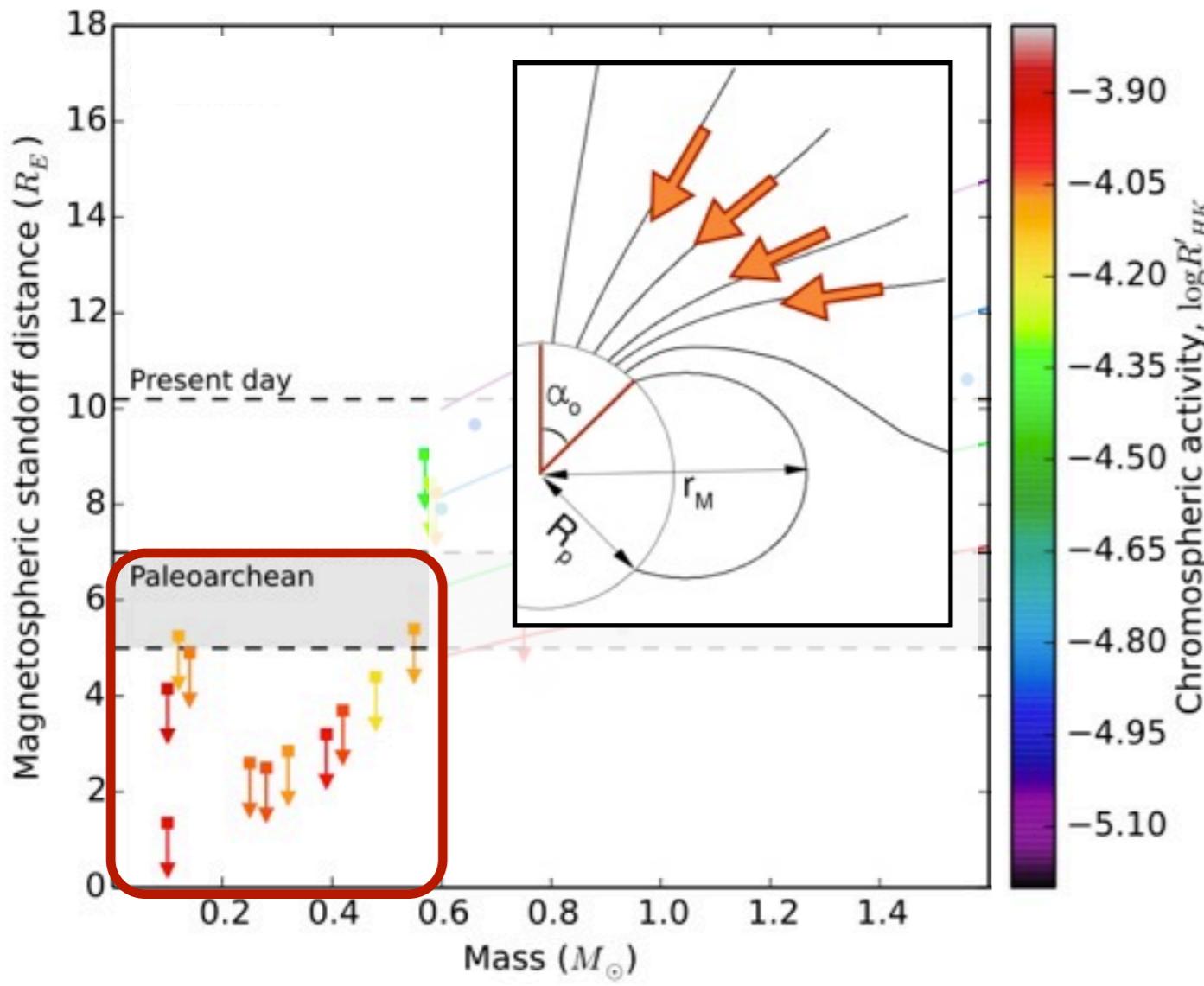


M dwarfs (Vidotto+13):

- upper limit → considering only information on the stellar magnetic field (Donati+2008, Morin+2008, 2010)
- Unprotected area of the planet:
 - ▶ 11-100% if at **inner HZ**
 - ▶ 5-44% if at **outer HZ**

For an Earth-twin at the Habitable Zone

See+2014: 1D stellar wind models for >160 objects



M dwarfs (Vidotto+13):

- upper limit → considering only information on the stellar magnetic field (Donati+2008, Morin+2008, 2010)
- Unprotected area of the planet:
 - ▶ 11-100% if at **inner** HZ
 - ▶ 5-44% if at **outer** HZ
- **Active dM stars:**
 - ▶ habitability → imperative that planets can regenerate their atmospheres

Conclusion: main points of this talk

- Stellar wind of solar-like stars:
 - ▶ might not be similar to solar wind
 - ▶ important role in the characterisation of the magnetic environment around planets,
 - observations of B_{star} are **essential**

Conclusion: main points of this talk

- Stellar wind of solar-like stars:
 - ▶ might not be similar to solar wind
 - ▶ important role in the characterisation of the magnetic environment around planets,
 - observations of B_{star} are **essential**
- Stellar wind - planet interaction:
 - ▶ signatures useful to characterise the stellar wind **and** magnetic fields of planets
 - ▶ important to assess habitability

4th Bcool Meeting



BCool 2015: Fourth Bcool meeting

2-6 Feb 2015 Geneva (Switzerland)

2-6 February 2015
Geneva - Switzerland

<http://bcool2015.sciencesconf.org>

Thank you!