Planets under the storm

Large-scale Structures in the Disk of Young, Magnetically Active Solar-like Stars

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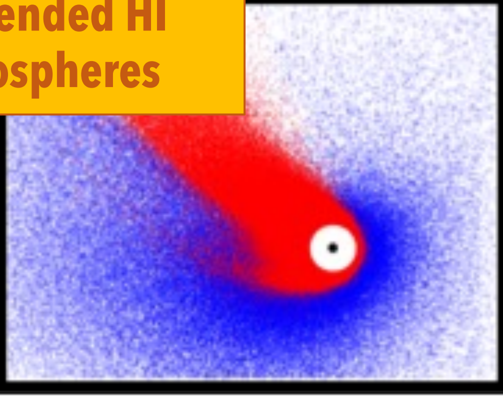
JcUVa

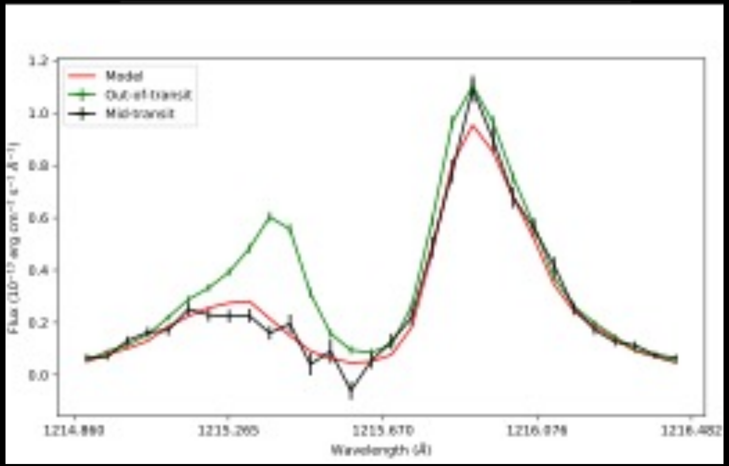
Introduction

Formation of structures: An unavoidable consequence of the interaction of planets and the local environment

Effect of strong XUV radiation

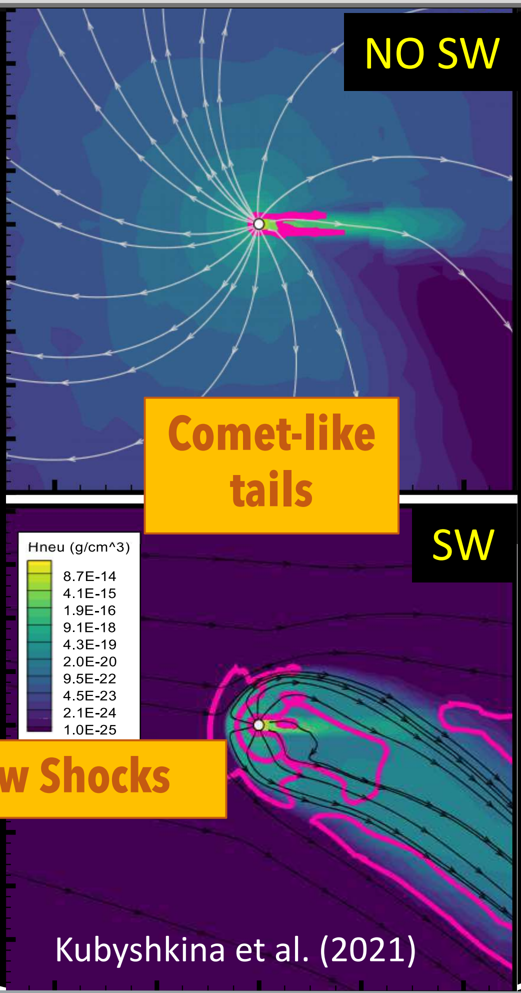
Extended HI exospheres





L-yα absorption of GJ 436b
Kislyakova et al. (2019)

Interaction with stellar winds



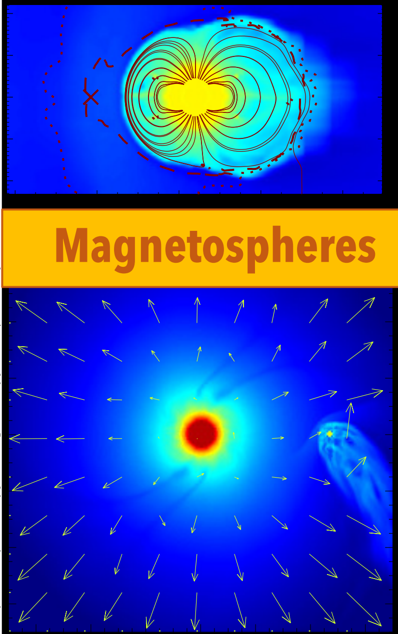
Comet-like tails

Bow Shocks

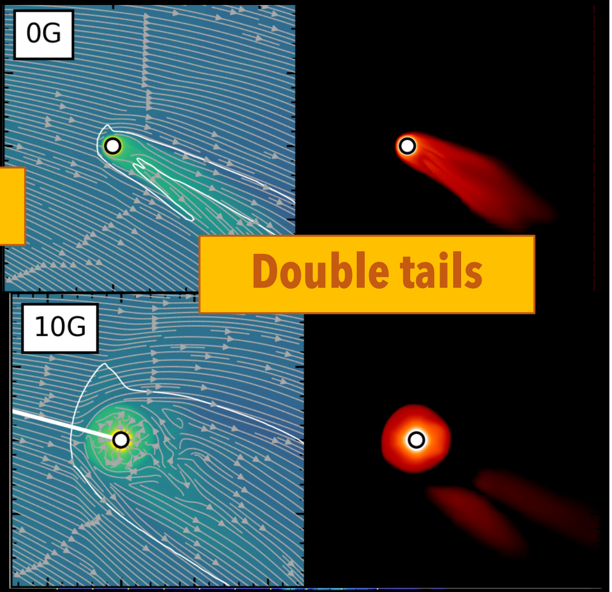
Kubyshkina et al. (2021)

Interaction of SW and magnetized planets

Magnetospheres



Matsakos et al. (2015)

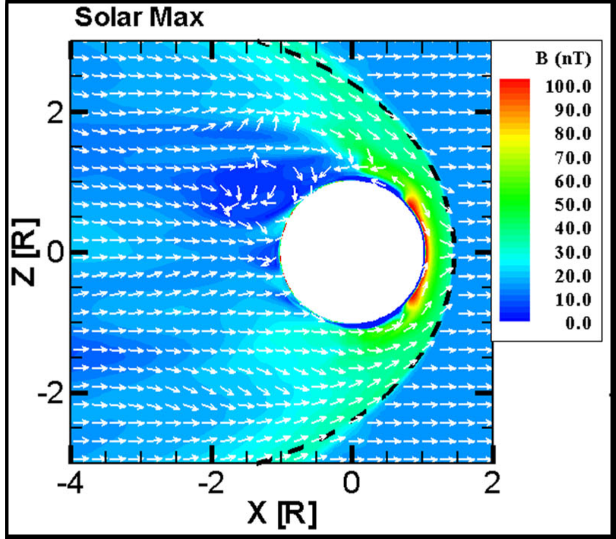


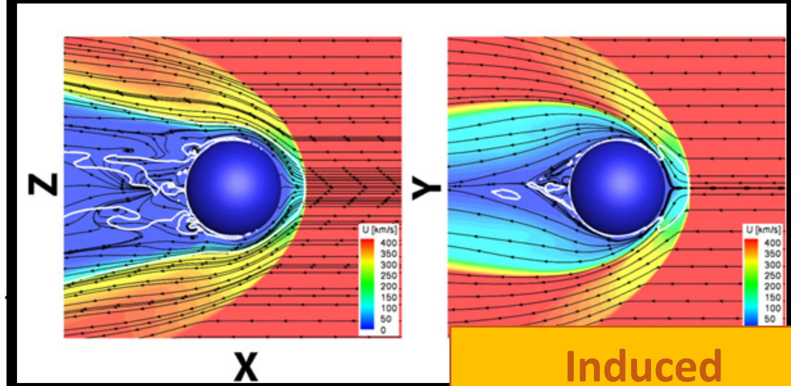
Double tails

Carolan et al. (2021)

Introduction

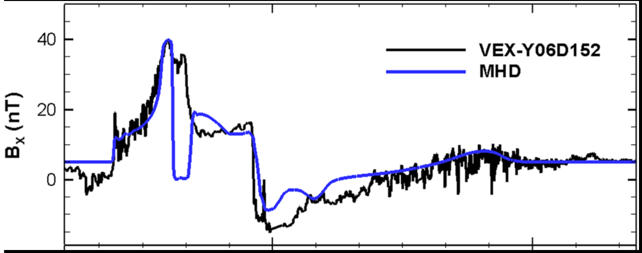
Interaction of SW and unmagnetized/thin ionosphere planets



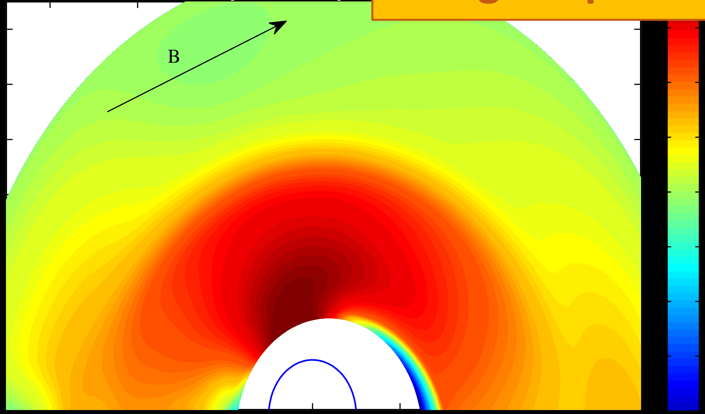


Cohen et al. (2015)

Induced Magetospheres



Ma et al. (2013)



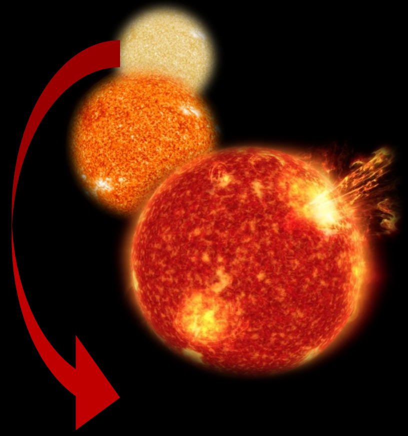
Erkaev et al. (2017)

- Structures are dependent on the **PROPERTIES OF THE PLANET**
- The **STELLAR WIND** modifies and shapes the extension of these structures
- The **MAGNETIC FIELD** leads to the formation of different structures

Stellar Activity

Young Sun-like stars **have faster rotation velocities**, a **higher magnetic/coronal activity** as well as significantly **higher mass loss rates.**

As stellar winds are an extension of the global stellar corona into the interplanetary space, they are expected to be **denser, hotter, faster and more magnetized** compared to the Gyr-old stars.

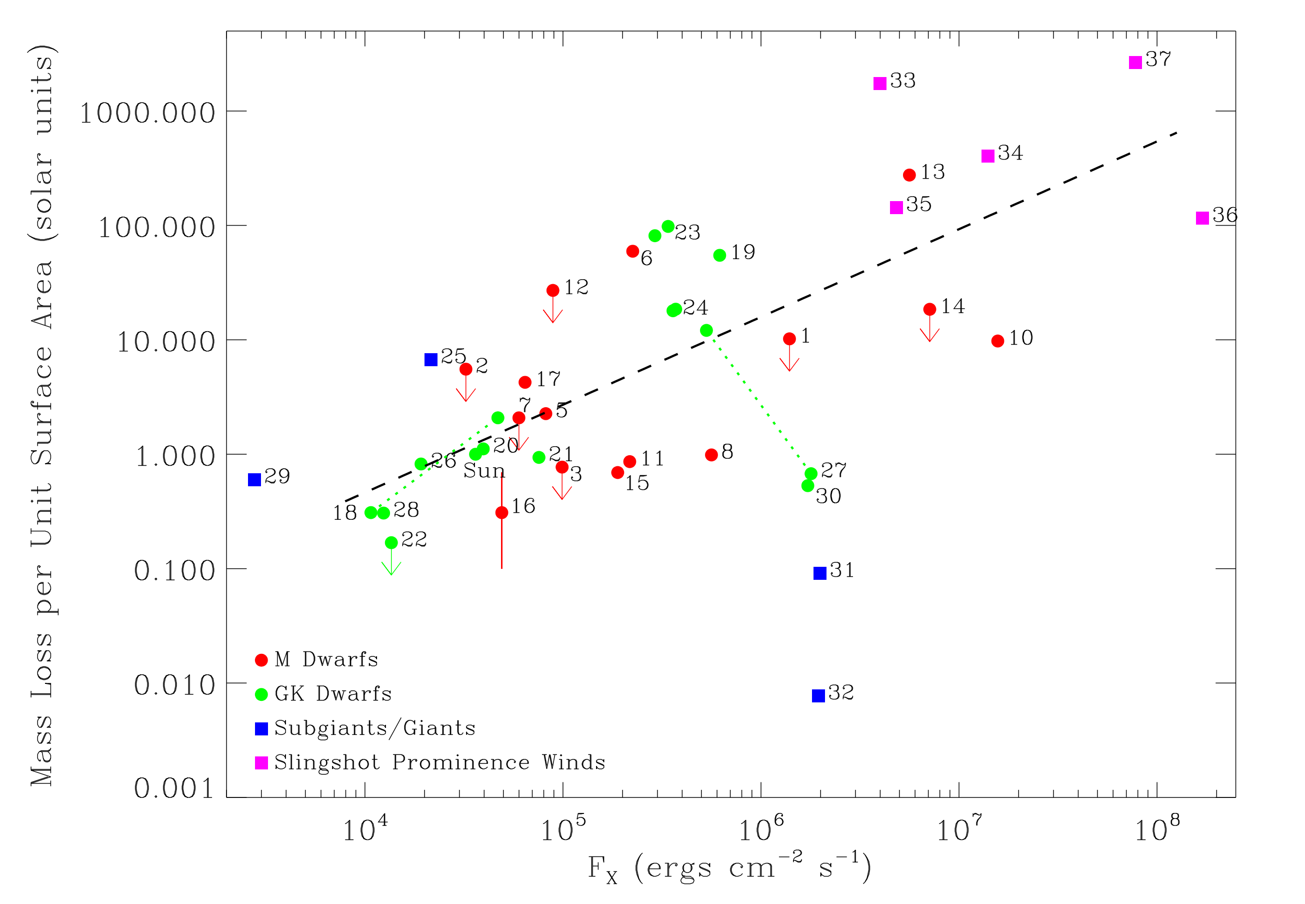


Thermal pressure gradient — **Centrifugal force** — **Magnetic field in the SW base**

$$V_r \frac{dV_r}{dr} = -\frac{1}{\rho}\frac{dp}{dr} - \frac{GM_\star}{r^2} + \frac{V_\phi^2}{r} - \frac{B_\phi}{4\pi\rho r}\frac{d}{dr}(rB_\phi)$$

Stellar gravity

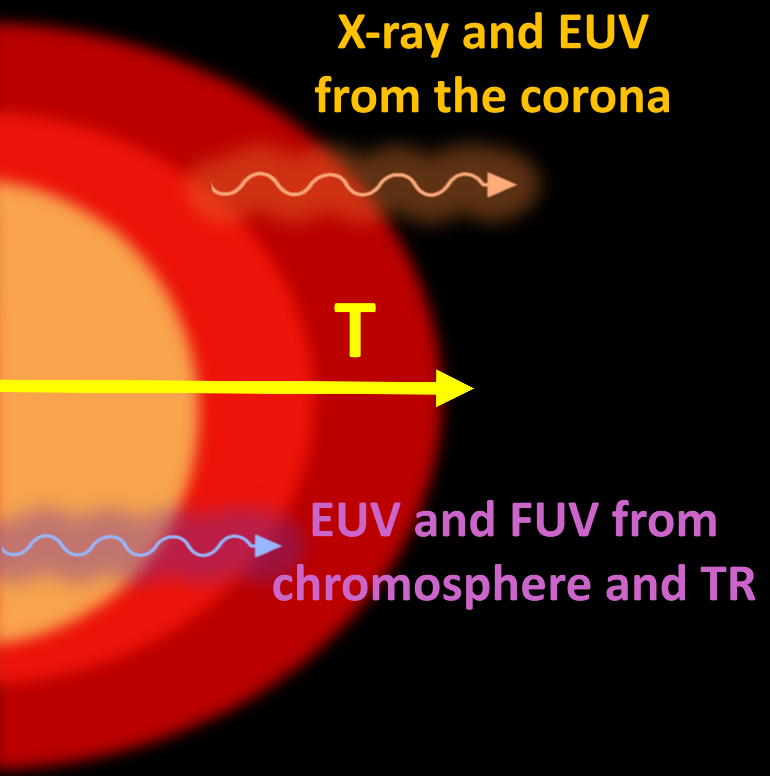
Detection of Stellar Winds in the Lyman-alpha line: Mass loss rates

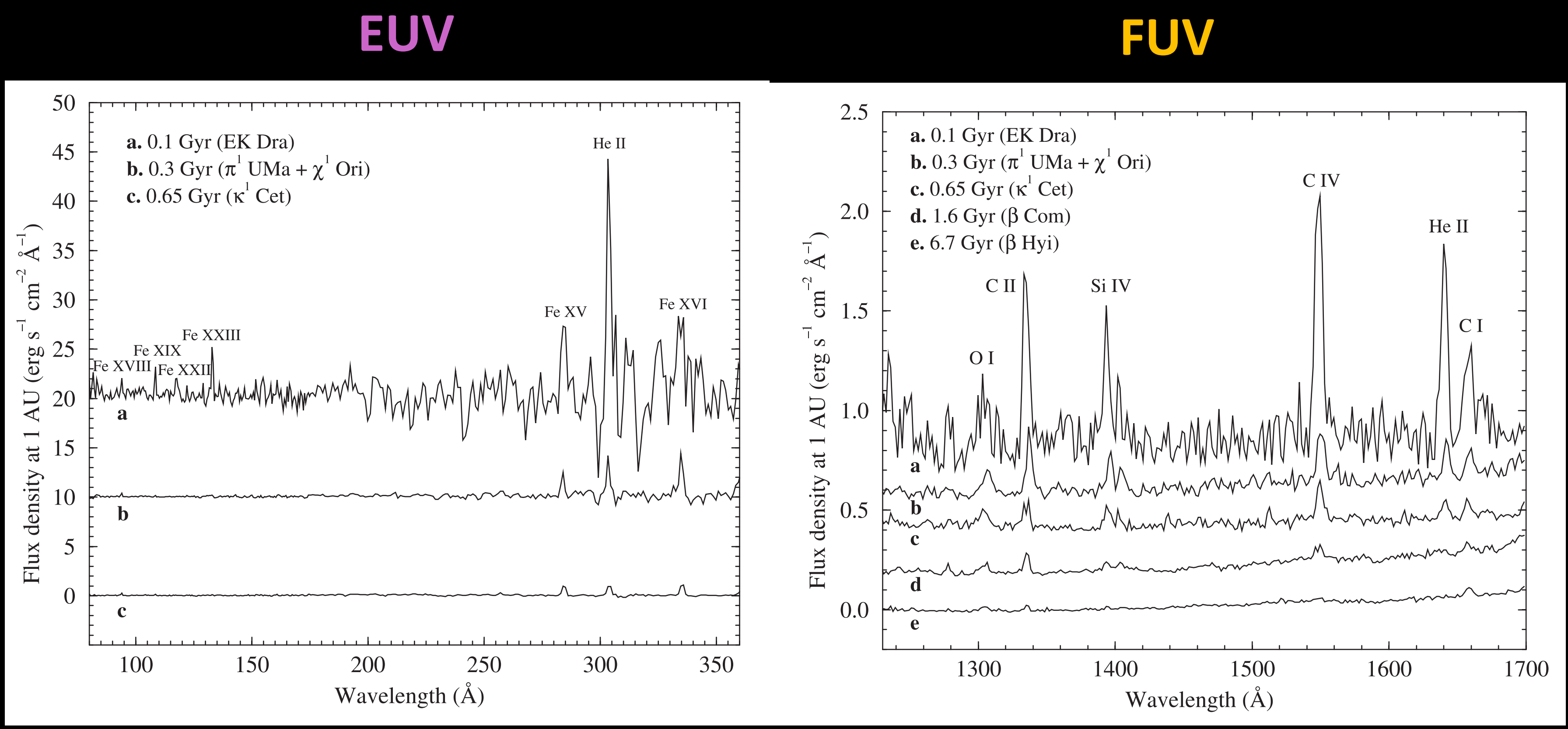


Wood et al. (2018)

Importance of UV tracers

The heating of plasma in the chromosphere, the transition region and the corona due to magnetic energy dissipation leads to some footprints of this activity in the UV and X ray spectrum of the star.





Ribas et al. (2005)

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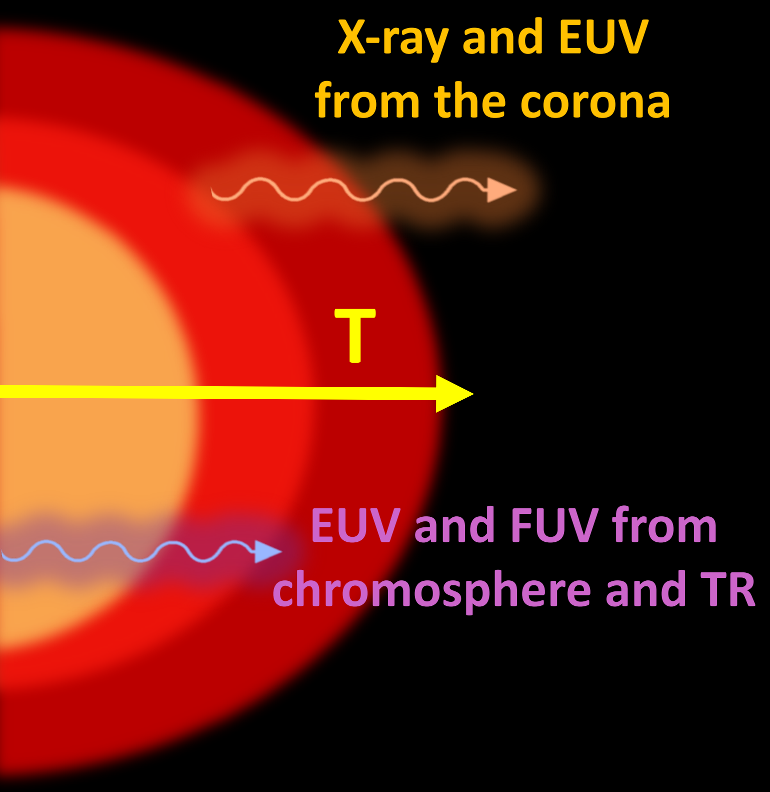
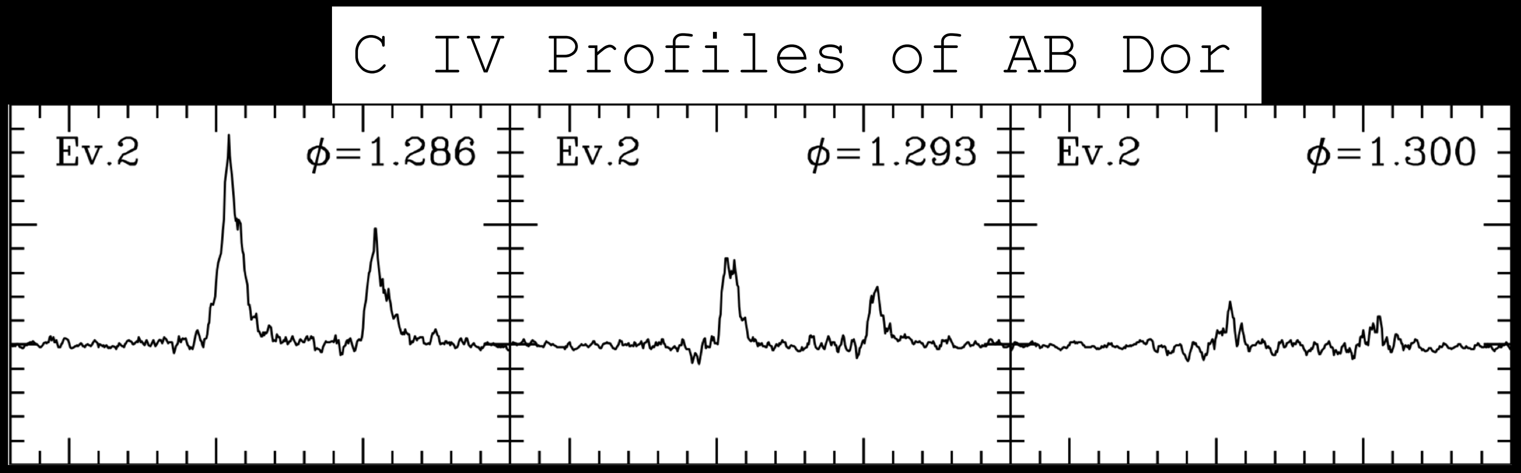
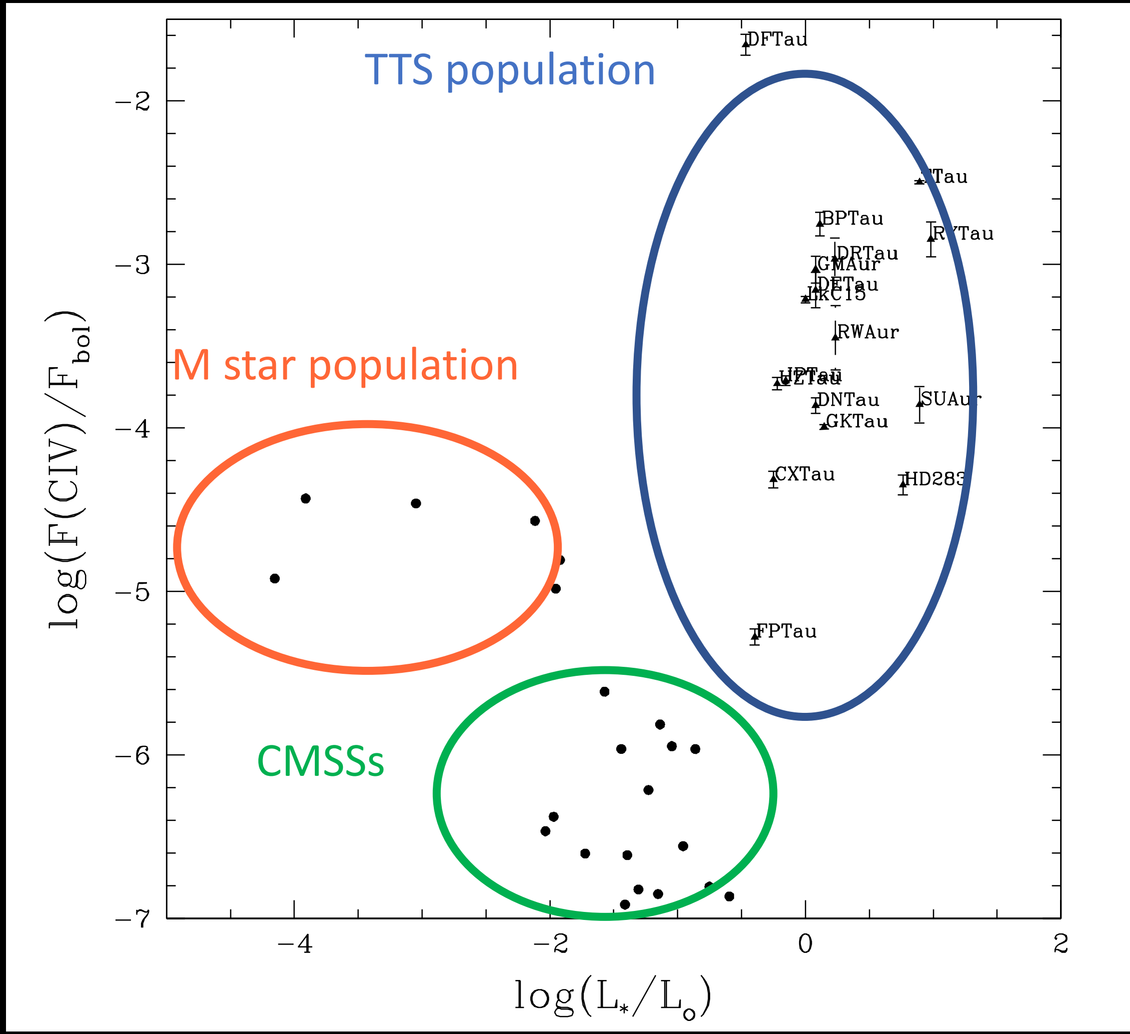


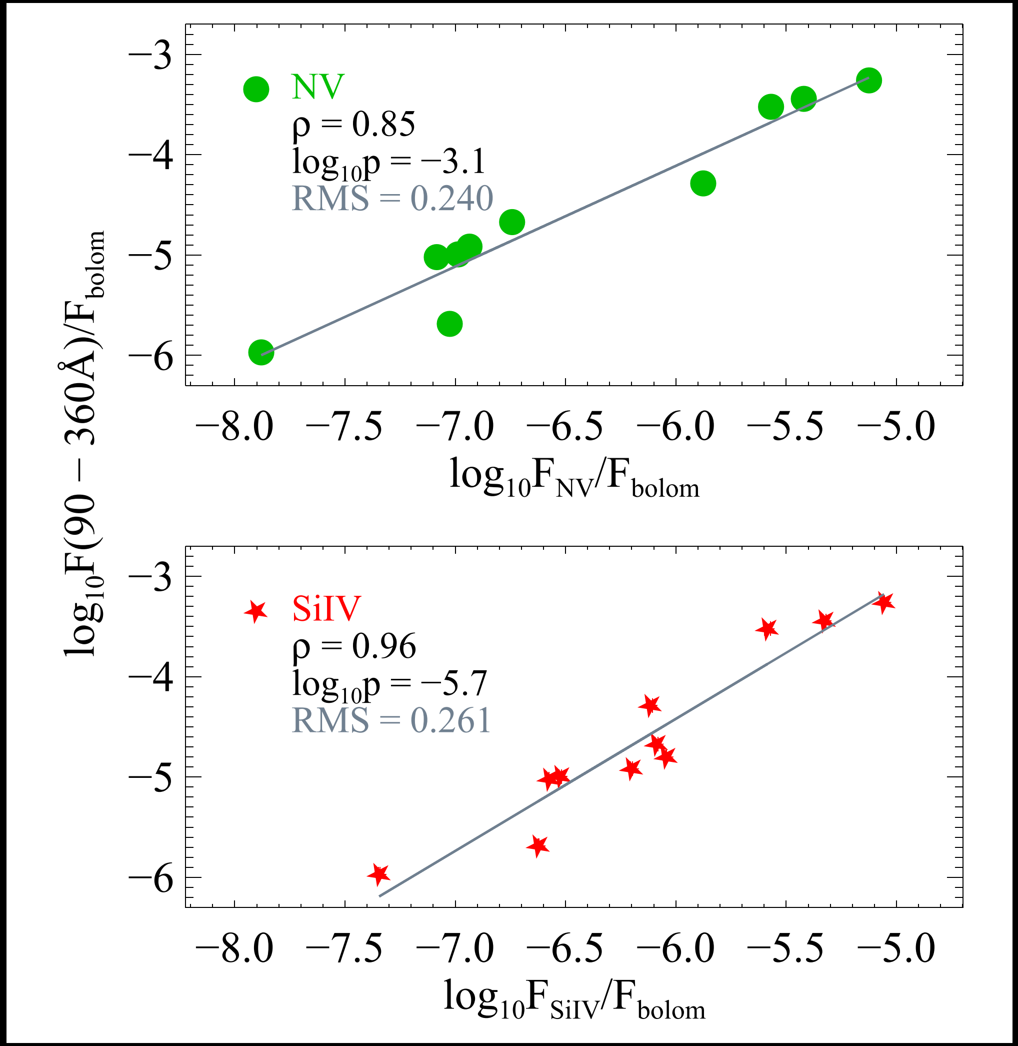


Gómez de Castro (2002)

Importance of UV tracers



Gómez de Castro & Marcos-Arenal (2012)



France et al. (2018)

Strong Winds: Numerical Simulation

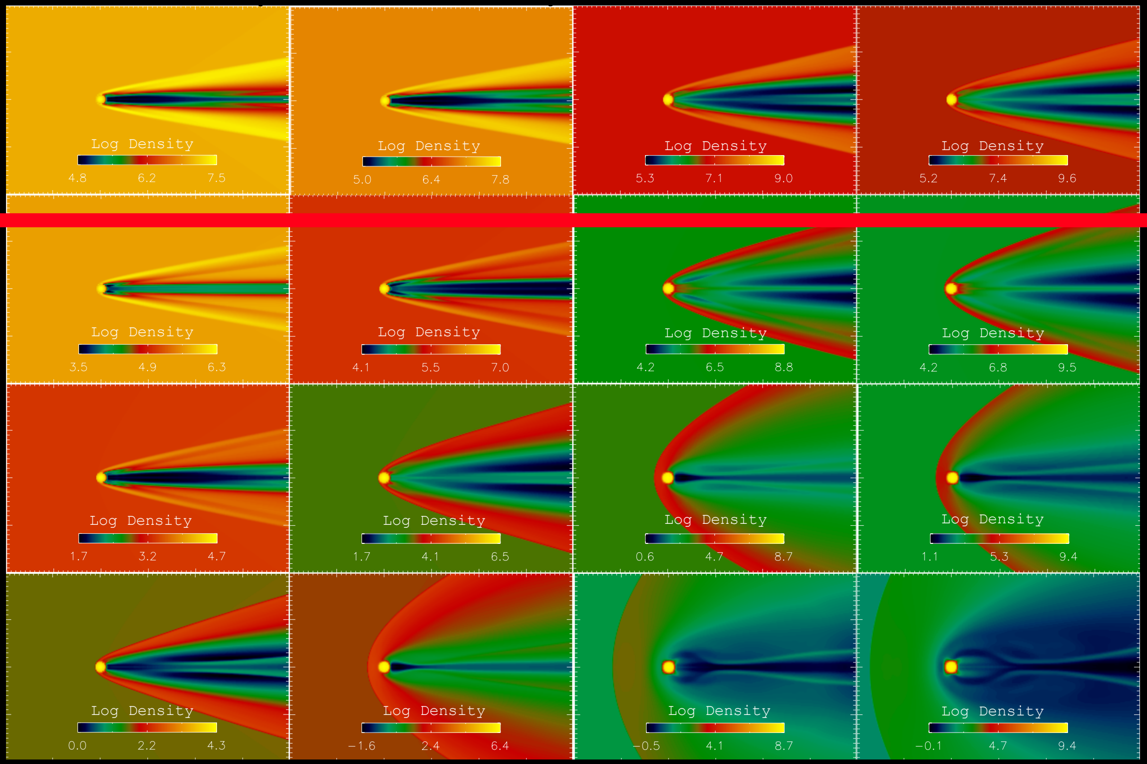
MODELS INCLUDING STRONG WINDS

- Not considering the magnetic field of the central star: **hydrodynamic interaction**
- **High plasma beta winds**

OUR NEW MODEL (IN PREP.)

- Planet without extended atmosphere. Thin ionosphere.
- Unmagnetized
- **Analytical solution of fast rotator winds:** AB Dor case
- Supermagnetosonic **MAGNETIZED** winds
- **Low beta winds**

Strong magnetized winds (β>1)



Canet & Gómez de Castro (2021)

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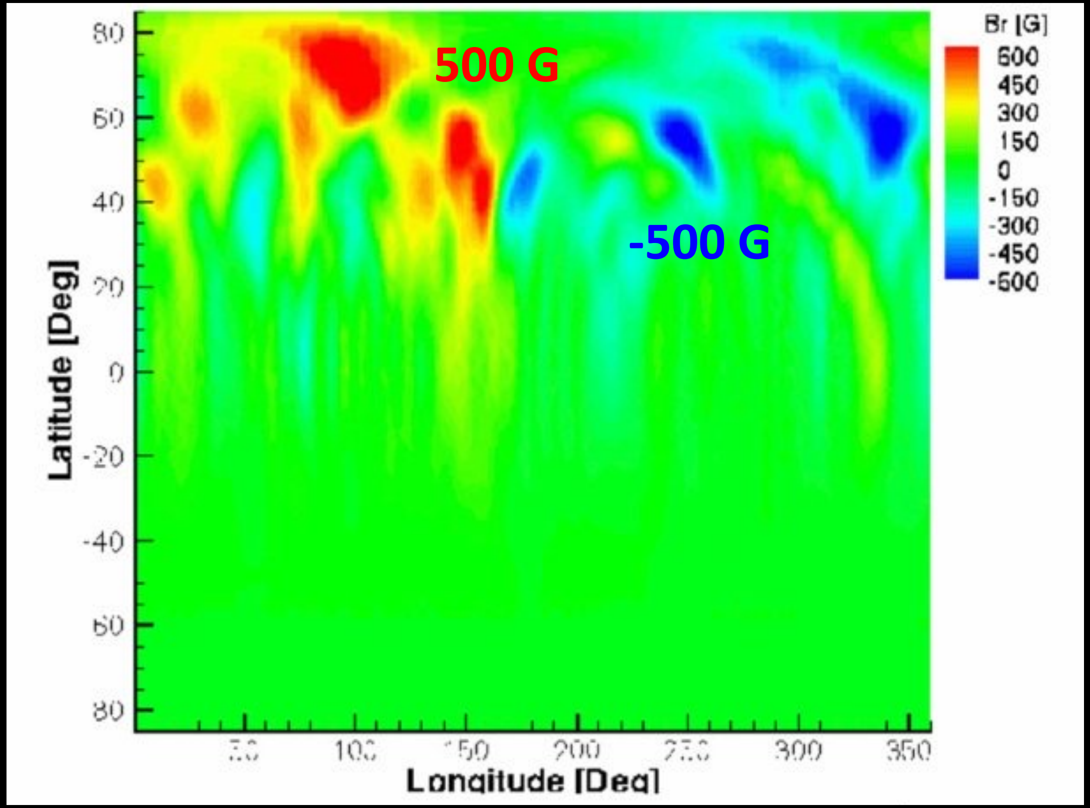
AB Doradus: A Fast-Rotating Star

Why AB Doradus?

- ✓ Young (50 - 100 Myr) late type (K0V) star
- ✓ d = 15.3 pc
- ✓ R = 0.86 $R_{\odot}$, M = 0.76 $_{\odot}$
- ✓ **Fast rotation:** $P_{rot,\star}$ = 0.5 days
- ✓ **Strong signs of magnetic activity (surface** magnetic fields >= 500 G, starspots)
- ✓ 77% of the XUV flux corresponds to the X-ray band
- ✓ X- ray luminosities that are over two orders of magnitude larger than those observed on the Sun



Magnetic field maps from Doppler-Zeeman Imaging: Adapted from Cohen et al. 2010

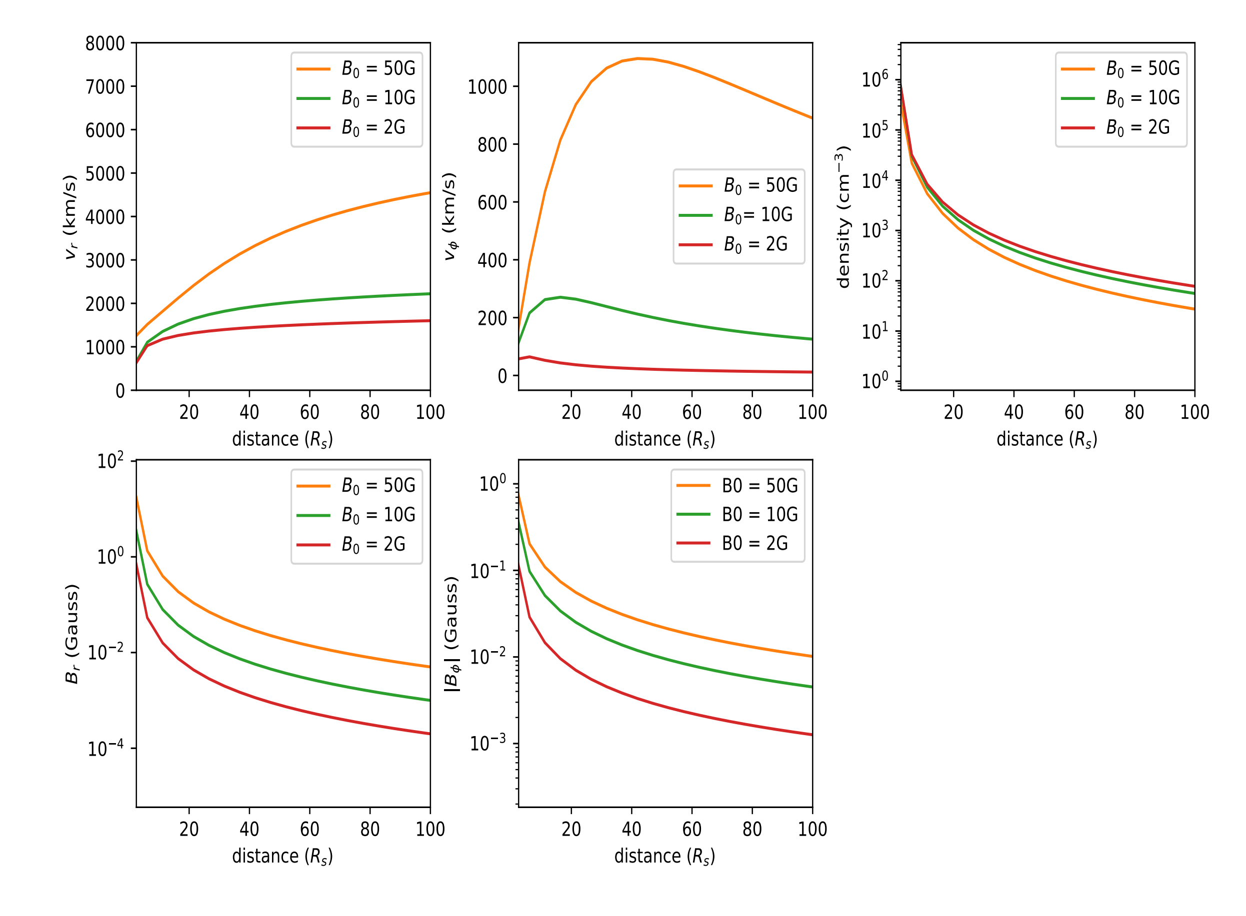
The Wind of AB Dor

An analytical approach

- Fast Magnetic rotators: Stellar winds are accelerated due to **magneto-centrifugal forces**
- Weber & Davis (1976): Solution of MHD conservation equations for fast magnetic rotators

Model Inputs

- ❖ $M_\star$, $R_\star$
- ❖ $P_{rot,\star} = 0.5$ days
- ❖ $B_{r0\star}$ [2-50] G (according to ZDI maps of AB Dor)
- ❖ $\dot{M}_\star$ [**1x10^{-13} - 1x10^{-11}**] $M_\odot\ yr^{-1}$ (rotation-mass loss relations for solar-like stars)
- ❖ T_{wind} ~ **7 MK** (F_X flux – coronal temperature relations). FIXED.



Numerical Simulation

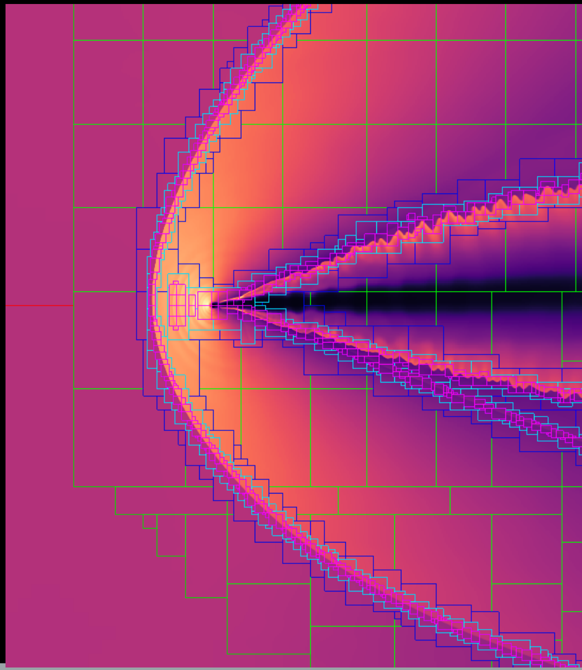
- **2.5D. Cartesian coordinates**
- **Wind is injected** from the left side of the domain: **orientation of the MF** is took into account
- **Corotating frame of reference**
- Planet is defined as an **internal boundary**: Earth-sized planet
- **Reflecting conditions** for the normal components of the magnetic field and velocity
- No planetary wind is considered
- AMR: 5 levels of refinement. High resolution in the vicinity (5 Rp) of the planet and pressure gradients (shock)

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = 0$$

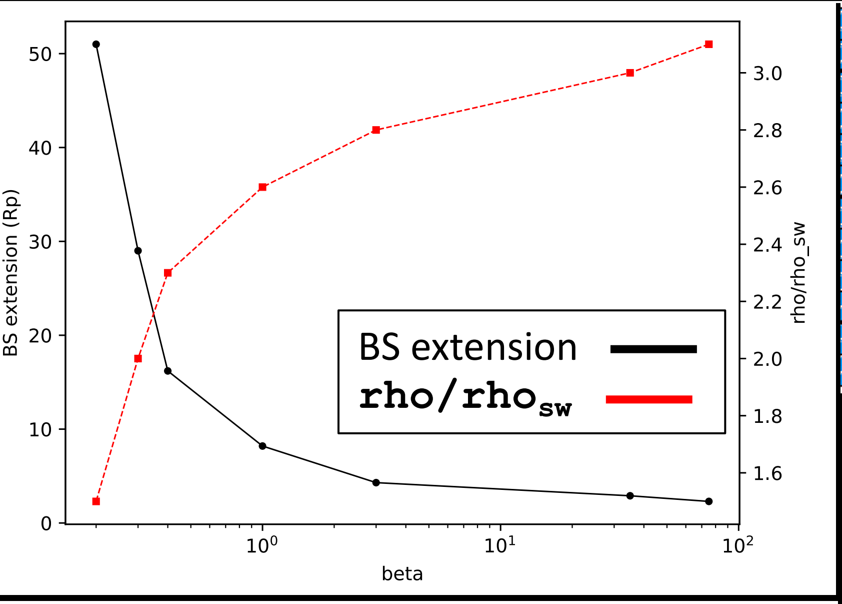
$$\frac{\partial (\rho \mathbf{v})}{\partial t} + \nabla(\rho \mathbf{v}\mathbf{v} - \mathbf{B}\mathbf{B}) + \nabla p_t = \rho(\mathbf{g}_* + \mathbf{g}_\mathbf{p}) + F_{cor} + F_{cent}$$

$$\frac{\partial E}{\partial t} + \nabla((E + p_t)\mathbf{v} - \mathbf{B}(\mathbf{v} \cdot \mathbf{B})) = \rho \mathbf{v}(\mathbf{g}_* + \mathbf{g}_\mathbf{p})$$

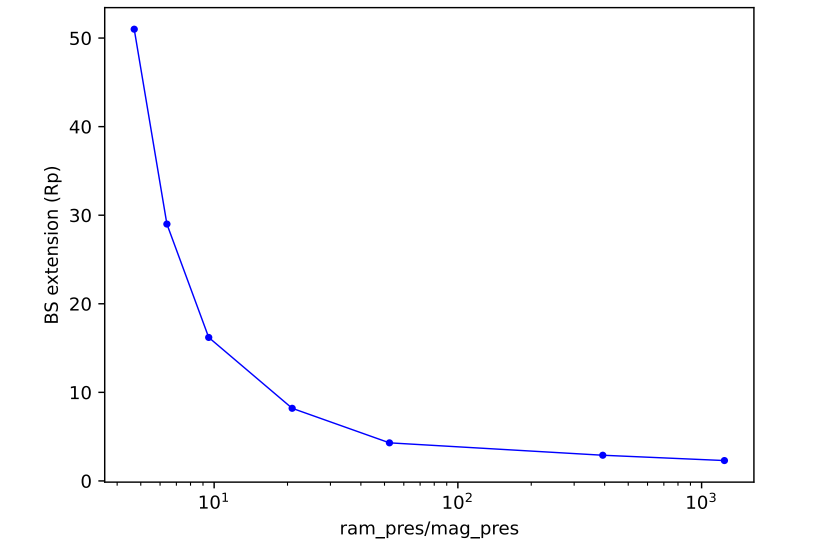
$$\frac{\partial \mathbf{B}}{\partial t} + \nabla(\mathbf{v}\mathbf{B} - \mathbf{B}\mathbf{v}) = 0$$

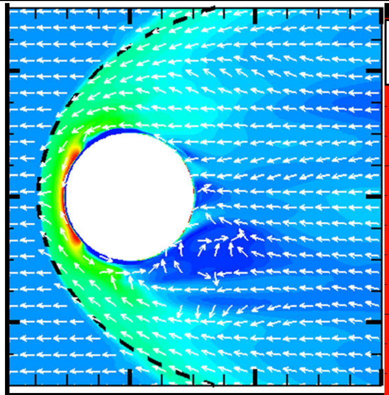


Results

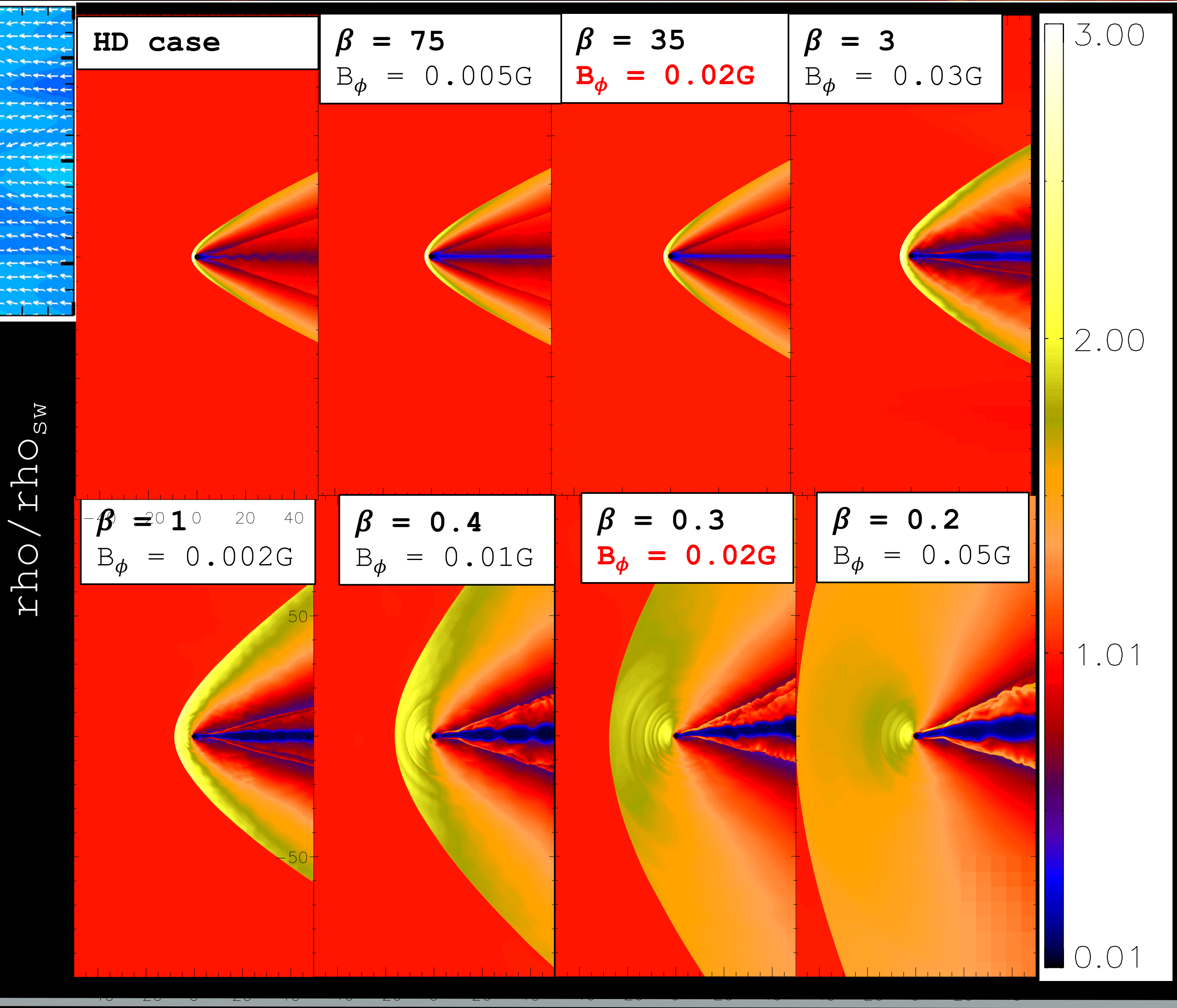


Ram pressure/Mag pressure



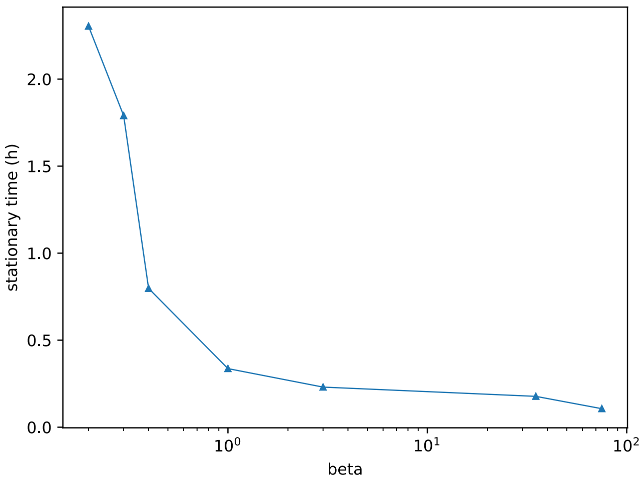


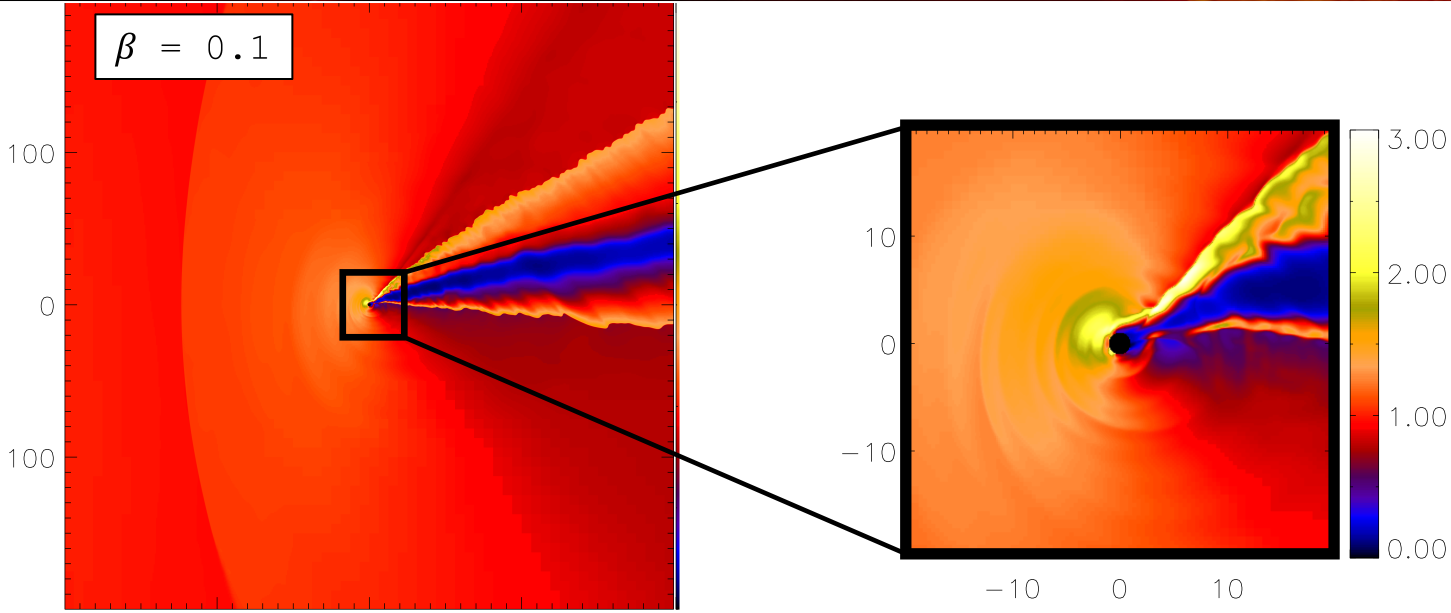
Venus

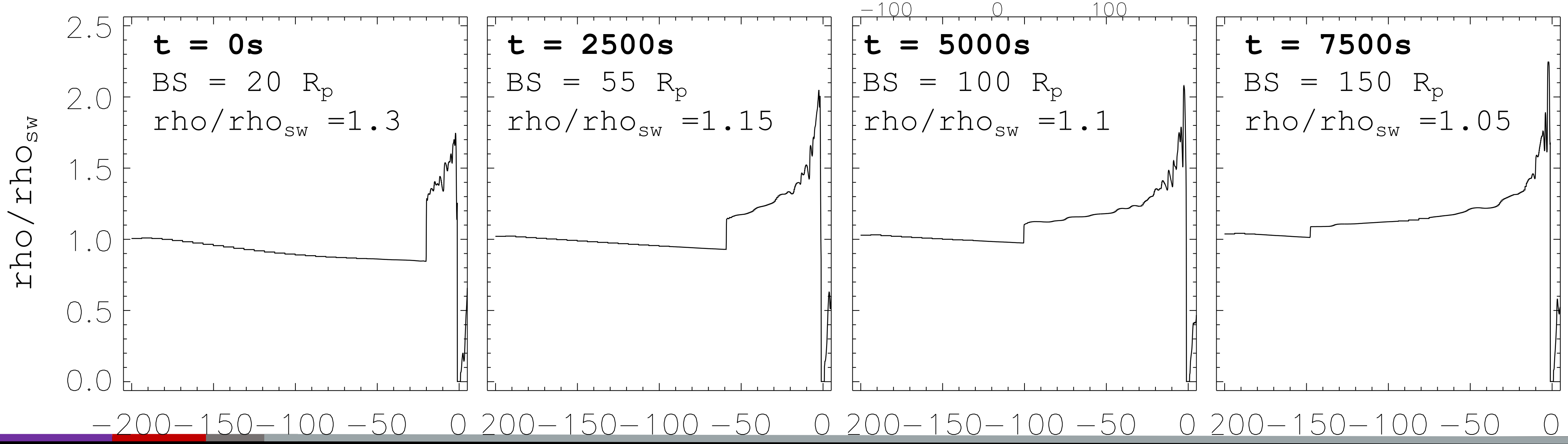


Results

The low-plasma β case

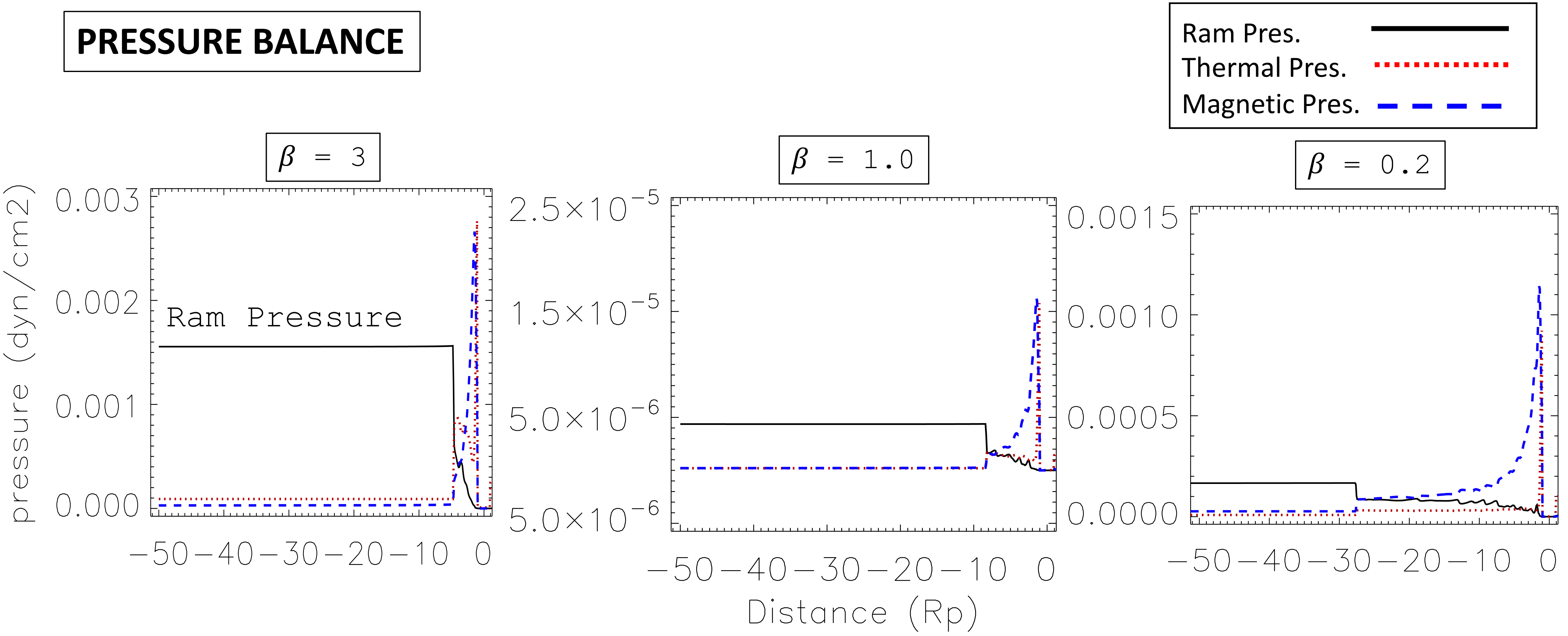






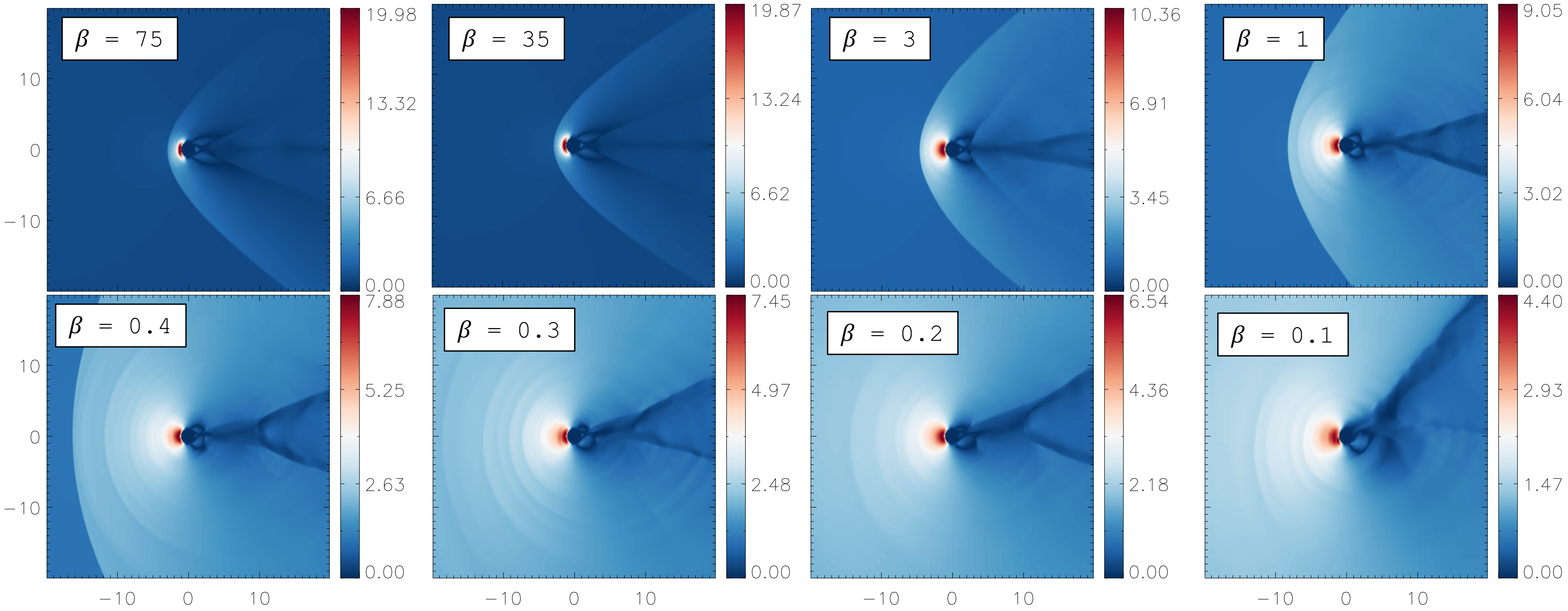
Results

PRESSURE BALANCE



INDUCED MAGNETOSPHERES

$B_\phi / B_{\phi,sw}$



To Summarize

- We studied the interaction between unmagnetized planets and **strong stellar winds**
- High resolution **UV spectroscopy** result in a useful tool to identify **magnetically active young stars**

. Low beta winds are considered in this study: strong influence of the interplanetary magnetic field

- **Large density structures** are formed around the planet for **low plasma beta winds**
- These structures could reach more than **200 planetary radii**
- The ratio between the density inside and outside the shock **decreases** with the plasma beta parameter
- MHD simulations indicate that a strong **magnetic field piles up** in front of the planetary obstacle
- As a result, **induced magnetospheres** are formed around the planet in all cases.