

Simulating the Environment around Planet-Hosting Stars

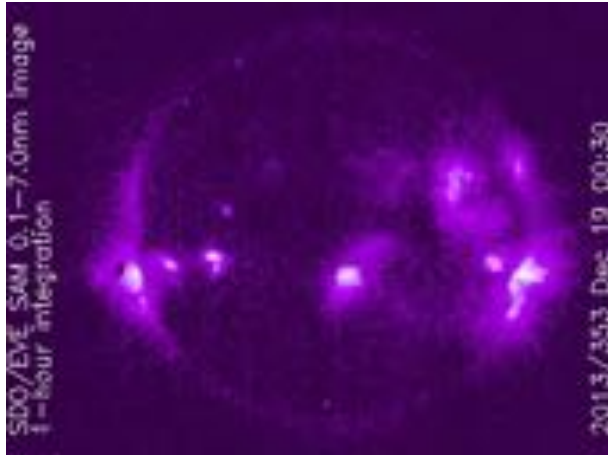
Julián David Alvarado-Gómez
jalvarad@eso.org

In collaboration with:
G. Hussain, J. Grunhut (ESO)
O. Cohen, C. Garrafo, J. J. Drake (CfA)
T. I. Gombosi (CSEM – U. Michigan)



Motivation: Understand the effects of stellar magnetic fields on the surrounding environment

High-Energy Emission



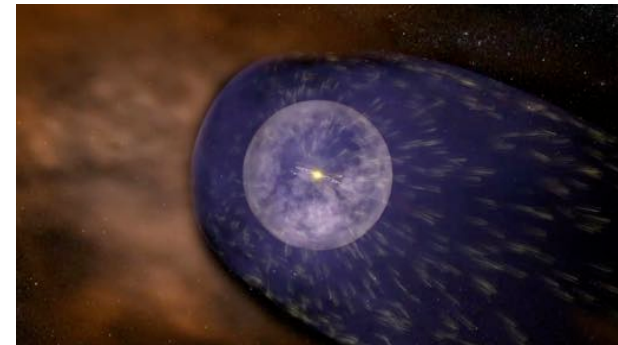
Coronal Structure + Stellar Wind + Planetary Environment



Transient Phenomena (Flares/CMEs)



Astrospheres



Advanced Observational Techniques ↔ Detailed Numerical Simulations

This Study:

Targets: Moderately active, planet-hosting **Sun-like** stars

Data: High-Resolution spectropolarimetric time-series from HARPSpol@ESO3.6m

Technique: Zeeman-Doppler Imaging (ZDI)

Result: Surface distribution of the large-scale magnetic field

Name	Spectral Type	T_{EFF} [K]	R_{\star} [R_{\odot}]	M_{\star} [M_{\odot}]	P_{ROT} [d]	Activity		$M_p \sin(i)$ [M_{J}]	a [AU]
						$\log(R'_{\text{HK}})$	$\log(L_X)$		
HD 1237	G8V	5572	0.86	1.00	7.00	− 4.38	29.02	3.37	0.49
HD 22049	K2V	5146	0.74	0.86	11.68	− 4.47	28.22	1.55	3.39
HD 147513	G5V	5930	0.98	1.07	10.00	− 4.64	28.92	1.21	1.32

References:

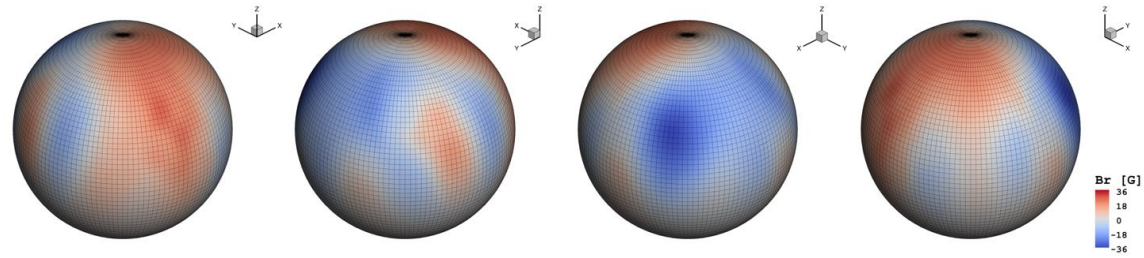
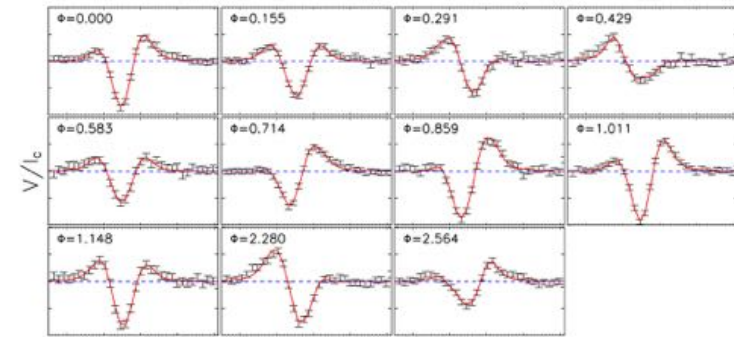
Target systems astrophysical properties.

HD1237 (GJ 3021): Naef et al. (2001)

HD 22049 (ϵ Eridani) : Drake & Smith (1993), Hatzes et al. (2000), Benedict et al. (2006)

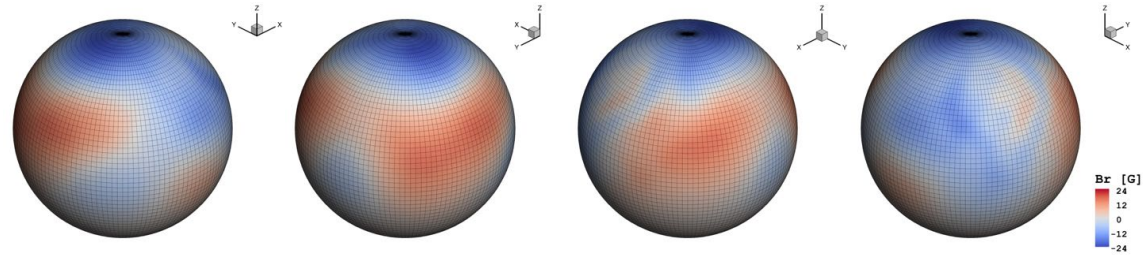
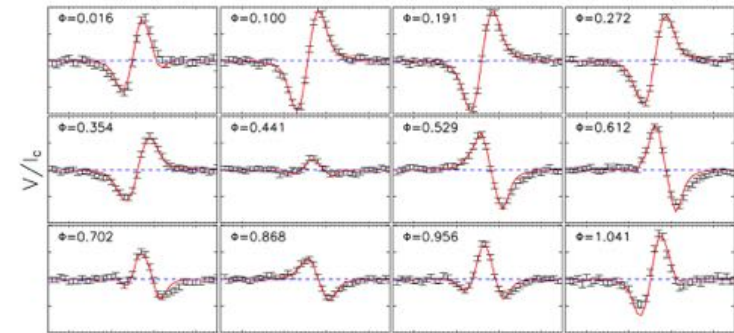
HD 147513 (62 G Scorpii): Mayor et al. (2004)

HD 1237 (GJ 3021)



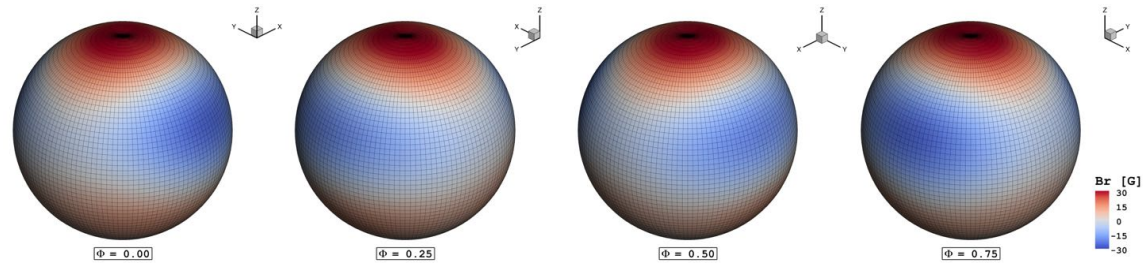
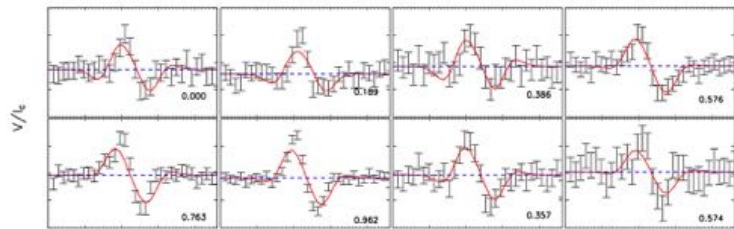
(Alvarado-Gómez et al. 2015)

HD 22049 (ϵ Eridani)



(Piskunov et al. 2011, Jeffers et al. 2014)

HD 147513 (62 G Scorpii)



(Hussain et al. 2016)

Space Weather Modeling Framework (SWMF)

State-of-the-art 3D MHD code used and validated in different Heliophysics domains

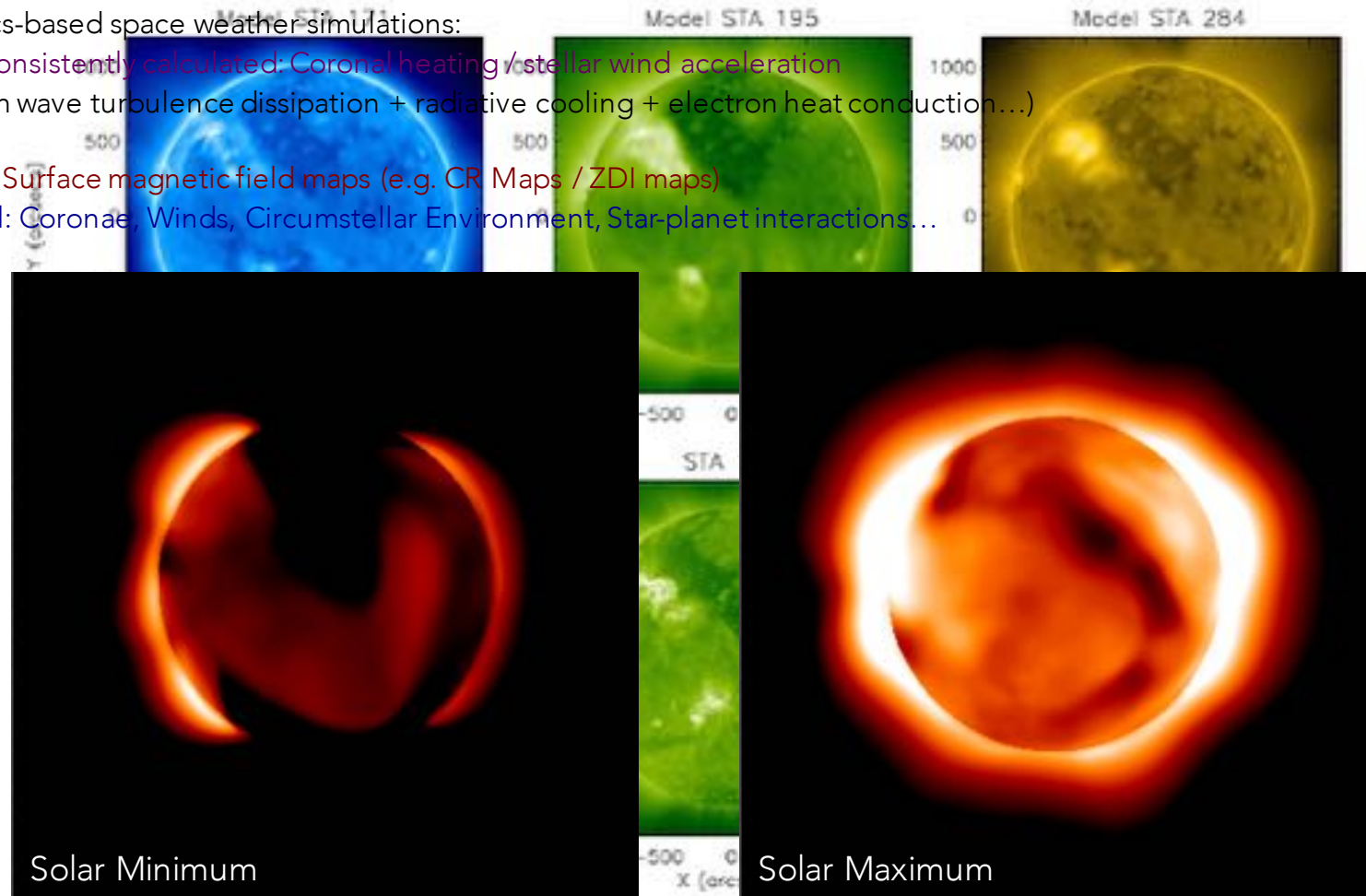
High-performance / parallel computing

Physics-based space weather simulations:

Self-consistently calculated: Coronal heating / stellar wind acceleration
(Alfven wave turbulence dissipation + radiative cooling + electron heat conduction...)

Input: Surface magnetic field maps (e.g. CR Maps / ZDI maps)

Model: Coronae, Winds, Circumstellar Environment, Star-planet interactions...

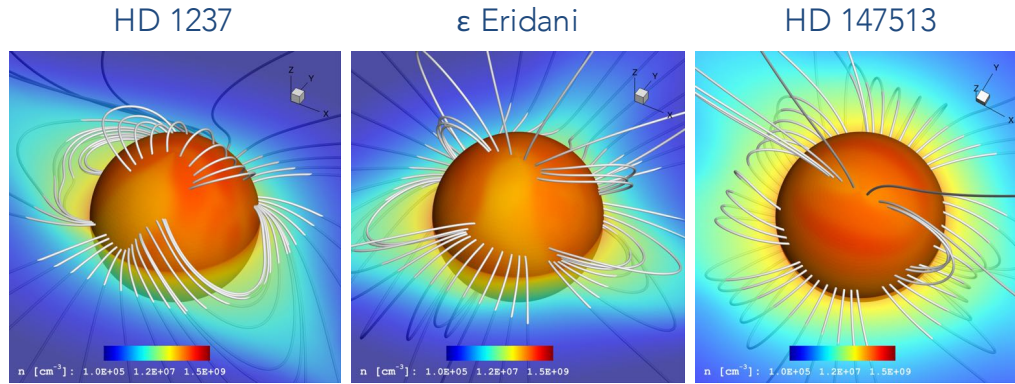


3D Coronal Structure

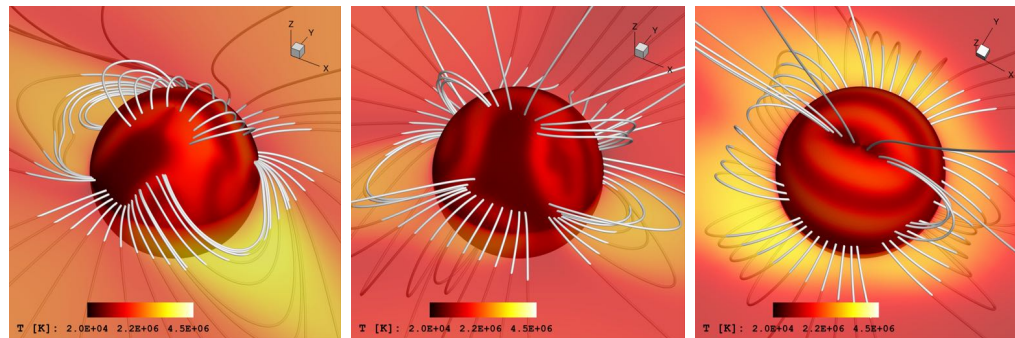
Coronal features: Field topology

Coronal thermodynamic conditions: Field strength (Unsigned flux)

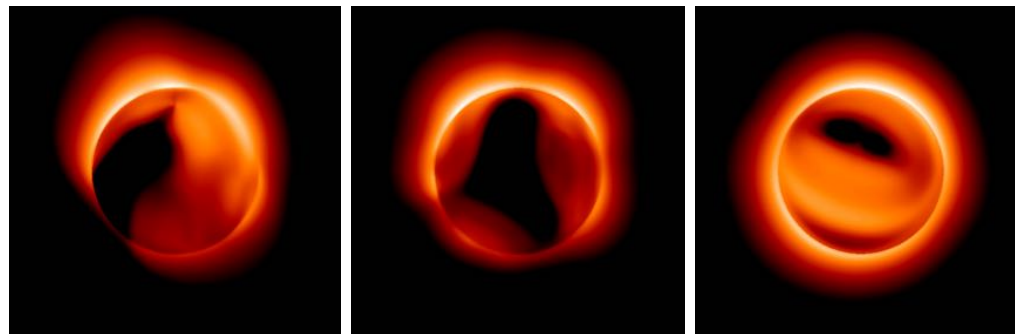
DENSITY



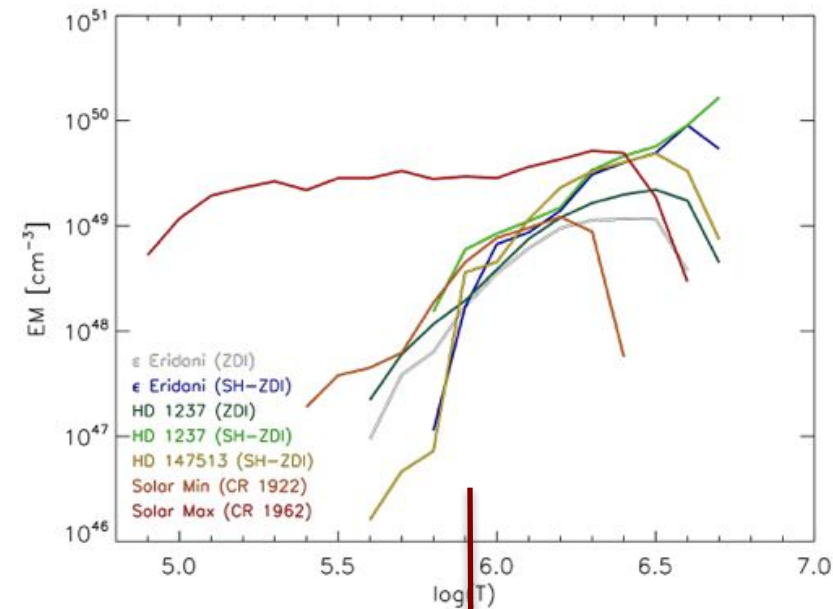
TEMPERATURE



SXR EMISSION



Emission Measure (EM) Distribution

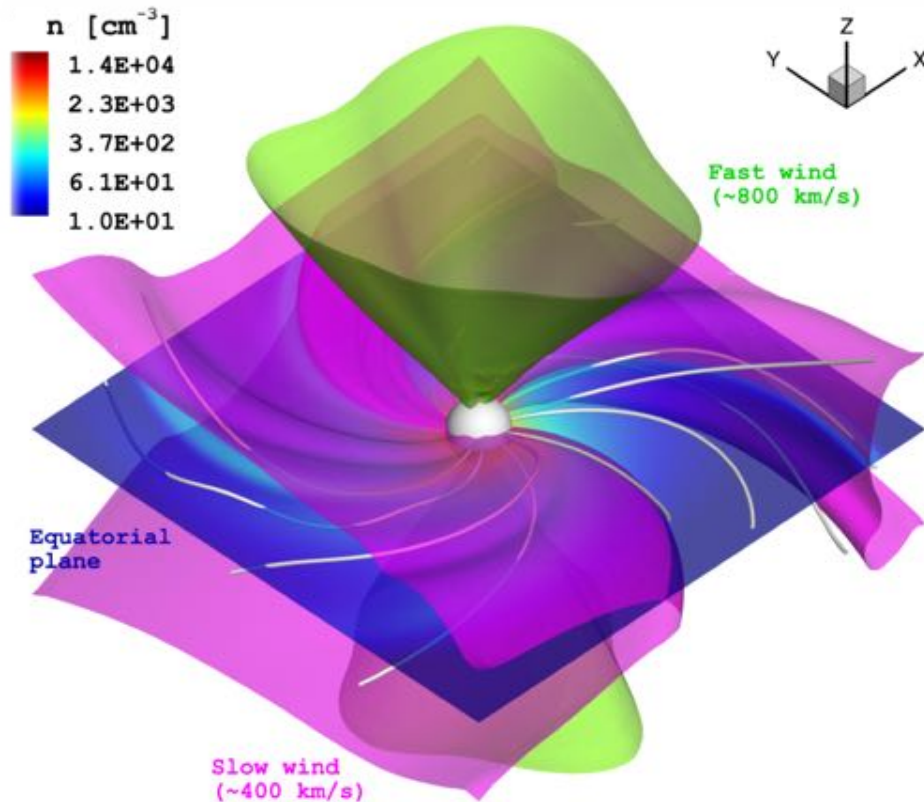


Synthetic Spectra

(Alvarado-Gómez et al. 2016a)

Solar Wind Structure

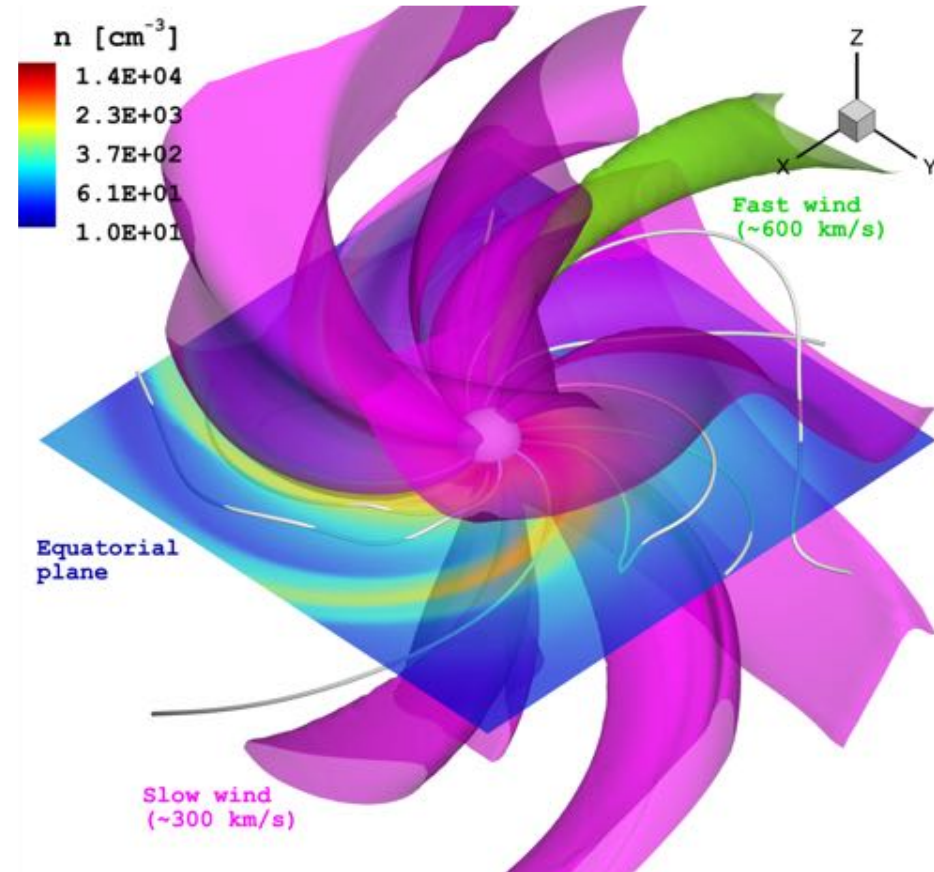
Solar Minimum



Fast-wind from the poles
(Coronal Holes)

Slow-wind along the Equatorial plane
("Ballerina Skirt")

Solar Maximum



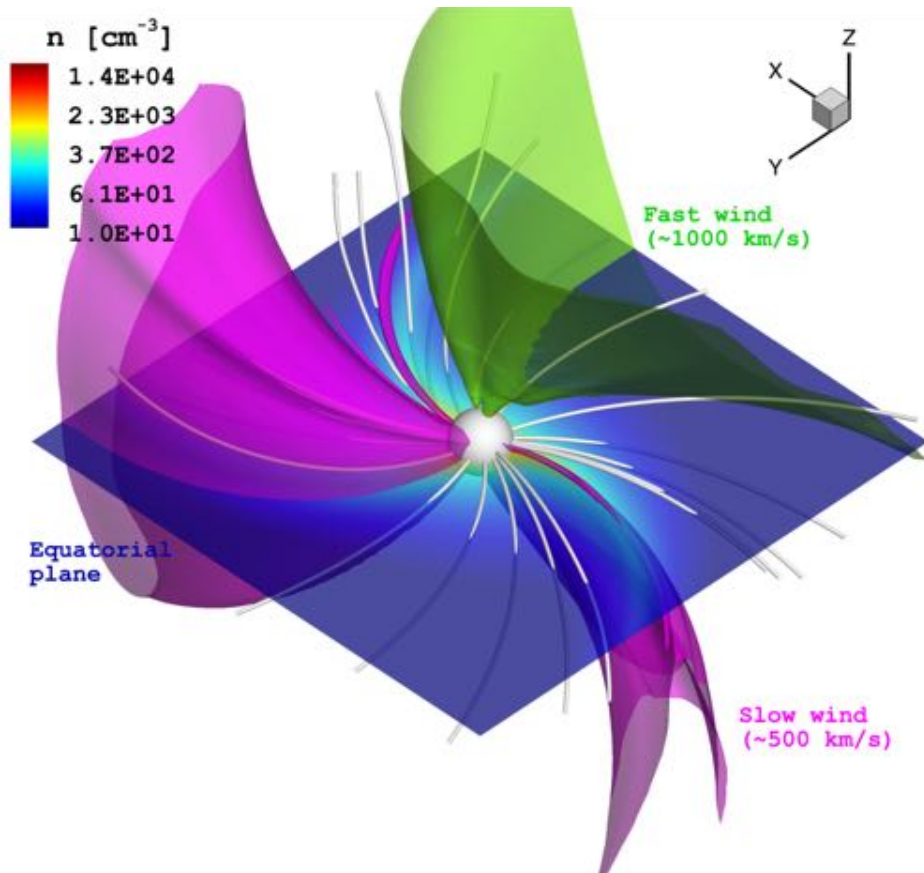
Slow-wind dominates the structure
(closed-field regions)

Almost no fastwind regions
Increased complexity

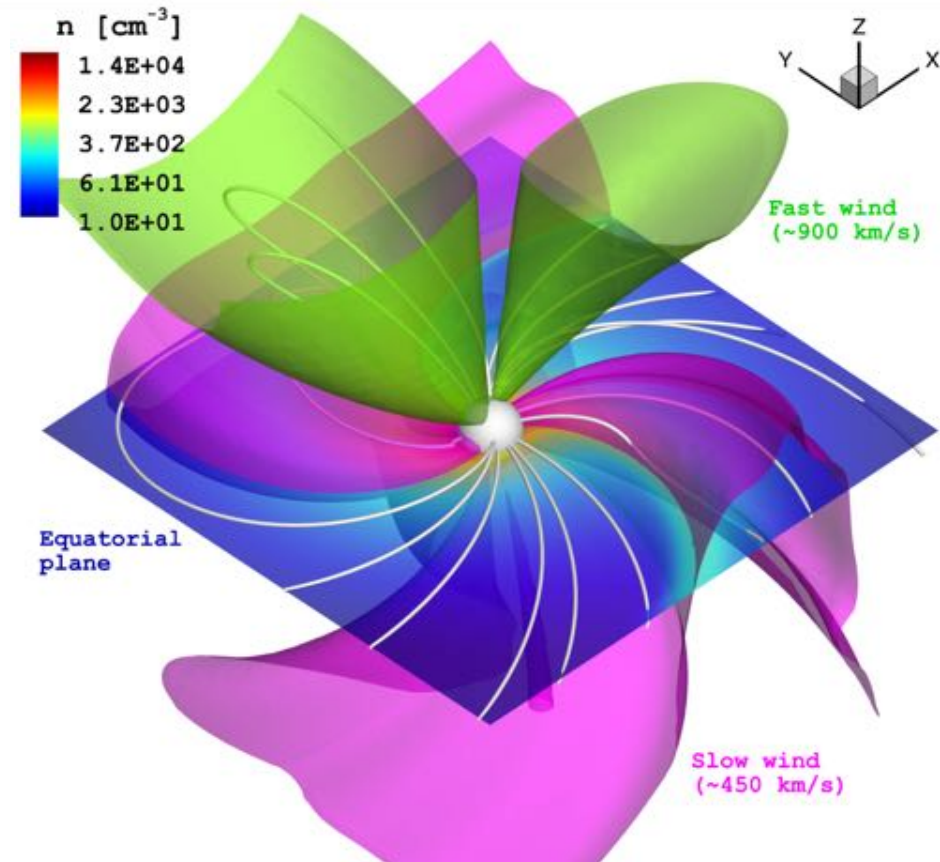
Alvarado-Gómez et al. (2016b, submitted)

Stellar Wind Structure

HD 22049 (ϵ Eridani)



HD 147513 (62 G Scorpii)



Alvarado-Gómez et al. (2016b, submitted)

Mass loss: $\sim 1 - 5 \dot{M}_{\odot}$

$\sim 6 \dot{M}_{\odot}$

Angular momentum loss: $\sim 1 - 12 \dot{J}_{\odot}$

$\sim 4 \dot{J}_{\odot}$

HD 1237 (GJ 3021)

Jupiter-mass planet
located at ~ 0.5 AU
($P_{\text{ORB}} = 133.7 \pm 0.2$ days, $e = 0.49$)
(Naef et al. 2001)

Strong wind-planet
interactions along
the orbit

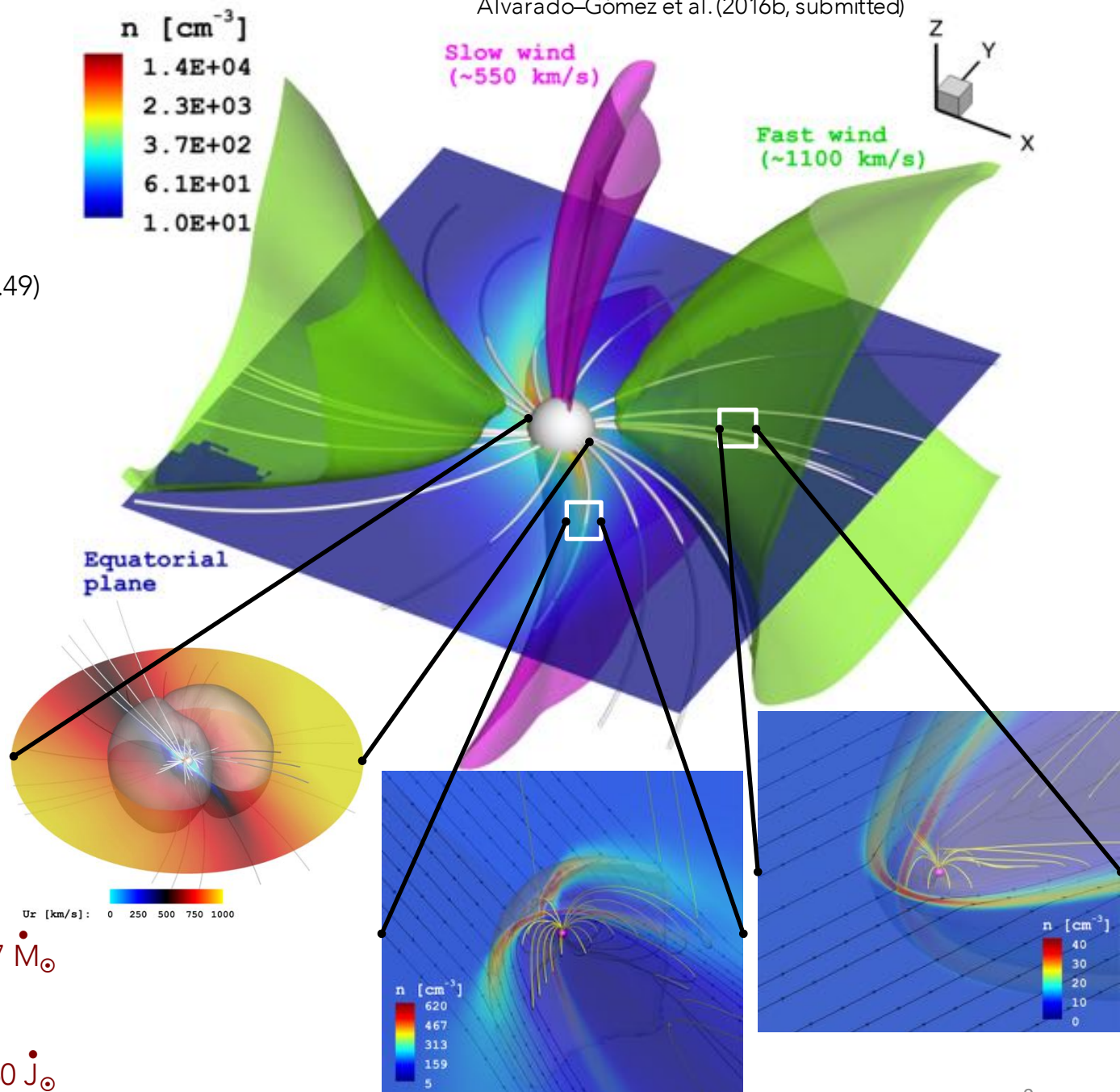
Potentially detectable
in Radio
($F_R \sim 12$ mJy)

Mass loss:

$$\sim 3 - 7 \dot{M}_{\odot}$$

Angular
momentum loss:

$$\sim 7 - 60 \dot{J}_{\odot}$$



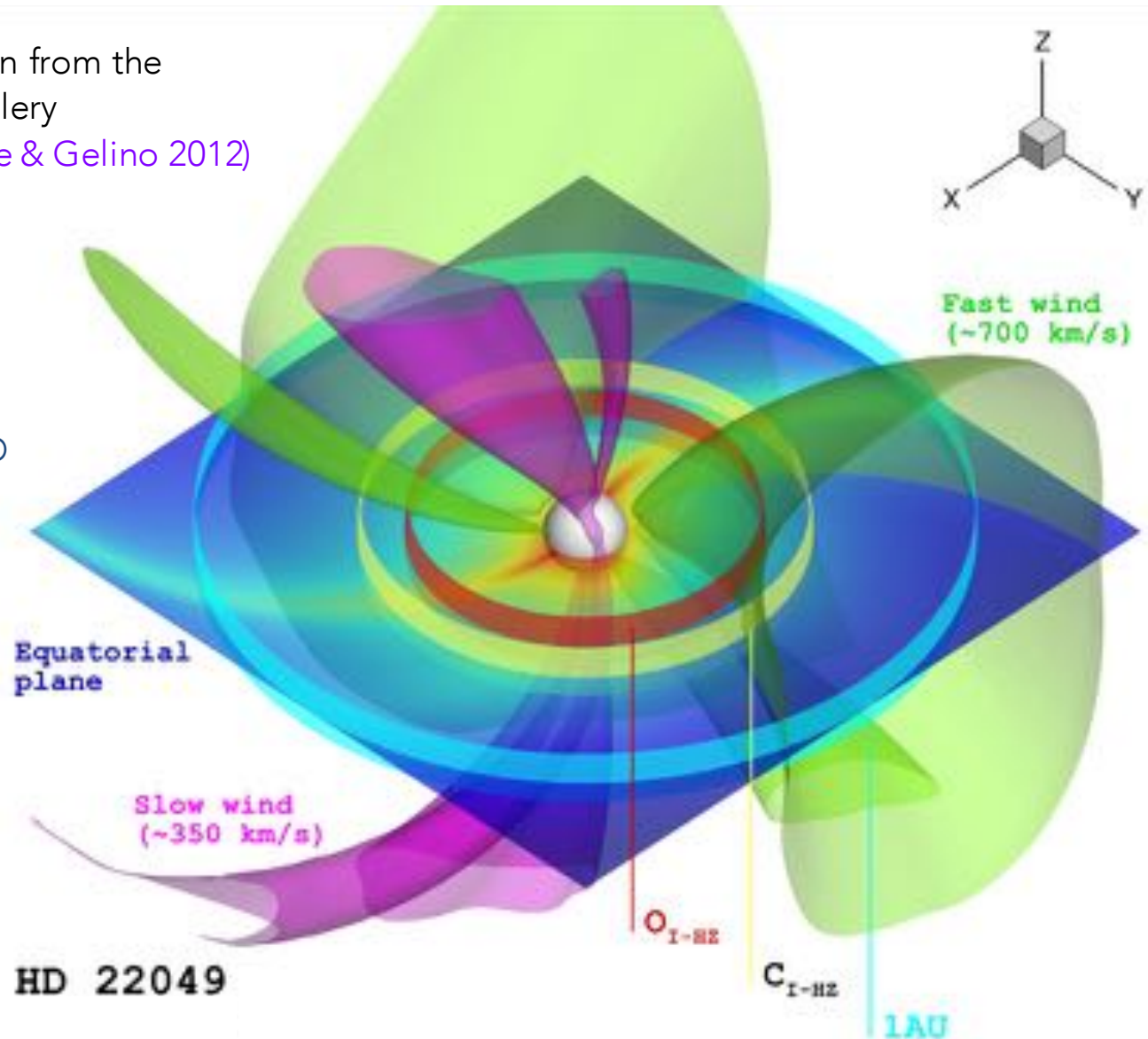
Inner HZs boundaries taken from the
Habitable Zone Gallery

(<http://www.hzgallery.org/> - Kane & Gelino 2012)

MHD Characterization of the 3D
structure of the stellar wind.

Dynamical determination of
the HZ inner boundary

- Stellar wind properties
- Host-star activity level
- Planetary magnetospheric shielding



Alvarado-Gómez et al. (2016b, submitted)



Far Beyond the Sun: Mapping the Magnetic Cycle of the Young Solar-Analog ι Horologii

J. D. Alvarado-Gómez^{1,3} • G. Hussain¹ • O. Cohen² • J. Sanz-Forcada³ • B. Stelzer⁴ • E. M. Amazo-Gómez⁵ • J. J. Drake² • J. Grunhut¹

¹European Southern Observatory (ESO), Garching bei München, Germany
²Harvard-Smithsonian Center for Astrophysics (CfA), Cambridge MA, United States
³Instituto Nacional de Técnica Aeroespacial (INTA), Madrid, Spain
⁴INAF - Osservatorio Astronomico di Palermo, Palermo, Italy
⁵Universitäts-Sternwarte, Ludwig-Maximilians-Universität, München, Germany

Contact: J. D. Alvarado-Gómez
E-mail: jdalvarado@eso.org
Web: AstroPedia



Poster 59

Abstract

We present the initial results from a recent HARPSp/BESOP observational campaign devoted to map the magnetic cycle of ι Horologii, using Zeeman Doppler Imaging (ZDI). Additional large-scale magnetic field maps at different epochs are being recovered. Detailed 3D MHD simulations, driven by the recovered ZDI maps, are used to self-consistently model the coronal structure, stellar wind and astrospheric conditions around the star. These models will be compared with an ongoing X-ray monitoring of the cycle using XMM-Newton, and possibly, with stellar wind diagnostics from HST. Furthermore, as ι Horologii is a planet hosting star, our observations and numerical simulations will be also used to understand the effects of magnetism and activity on habitability, and to study stellar wind and planetary exosphere interactions during different stages of the on-going magnetic cycle.

Scientific Rationale

Nowadays the large-scale surface magnetic field topology in stars different from the Sun can be retrieved using the technique of Zeeman Doppler Imaging (ZDI, Donati & Brown 1997; Hussain et al. 2000; Pakunov & Kochukhov 2002). Long-term ZDI monitoring of a few Sun-like targets have shown different time-scales of variability in the large-scale magnetic field. This includes, fast and complex evolution without polarity reversals (HN Peg, Borisuk et al. 2011), erratic polarity changes (ξ Boo, Morgerhuter et al. 2012) and hints of magnetic cycles with single (HD 190771, Petit et al. 2009), and double (T Boo, Fares et al. 2009; Mengel et al. 2016) polarity reversals on a time-scale of 1-2 years.

Contrary to the solar case, none of these proposed "magnetic cycles" show a coincident time-scale with the chromospheric Ca H&K activity tracer in the star. It is unclear whether this is a reflection of a different type of magnetism-activity relation, or an observational bias introduced by the methods used in these studies (e.g. insufficient cycle sampling with ZDI). This is critical for the coronal activity (which shows the largest variation during the solar cycle), given the difficulty of X-ray monitoring over cycle time scales in other stars.

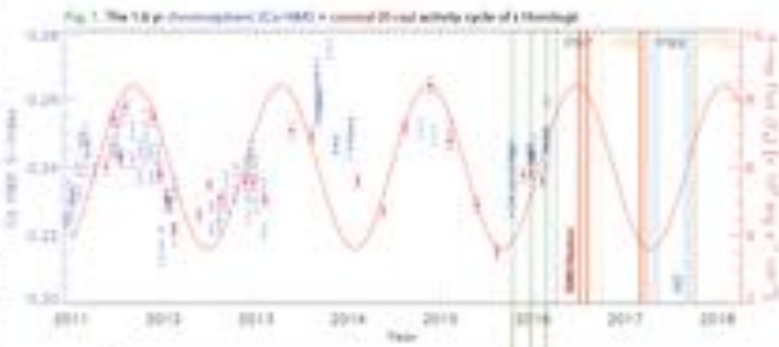


Fig. 1: The 1.8 μ m chromospheric Ca H&K activity cycle of ι Horologii

Observing Campaigns & Status

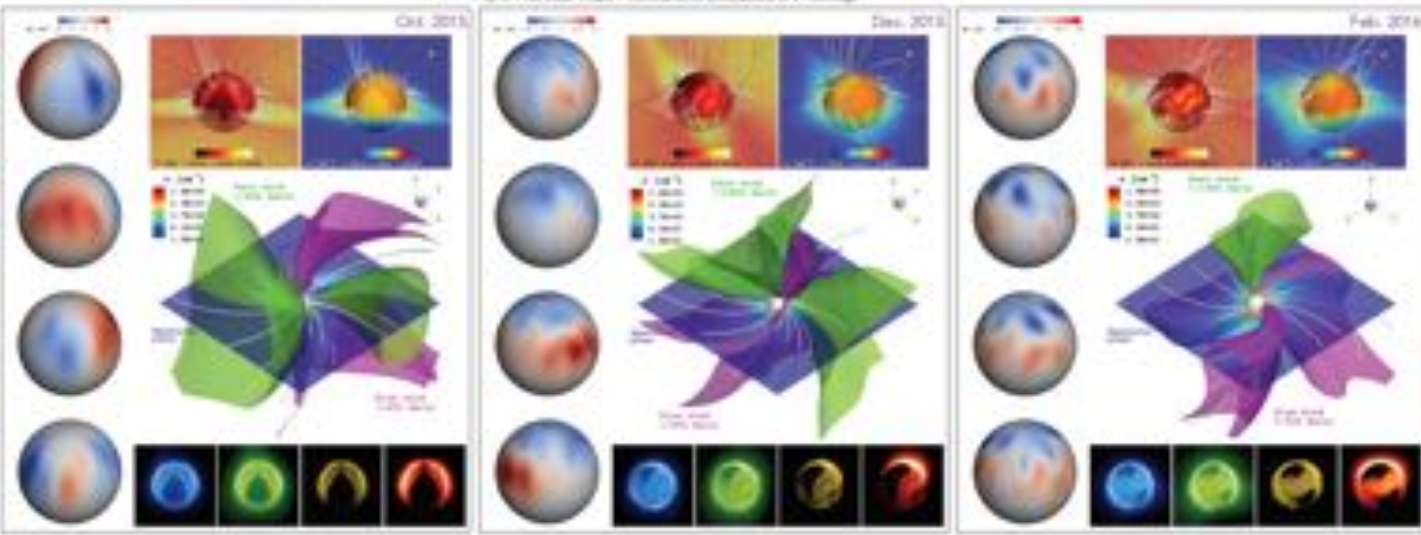
- ESO P16 - Completed
(ID: 094.D-0257, PI: Alvarado-Gómez)
- ESO P17 - Scheduled
(ID: 097.D-0428, PI: Alvarado-Gómez)
- ESO P18 - Approved
(ID: 096.D-0187, PI: Alvarado-Gómez)
- ESO P19 + P120 - To be submitted
- HST/STIS Cycle 34 - Submitted
(ID: Y15, PI: Alvarado-Gómez & Drake)
- XMM-Newton Cycle - Scheduled
(ID: Y054, PI: Sanz-Forcada)

Going Far Beyond the Sun

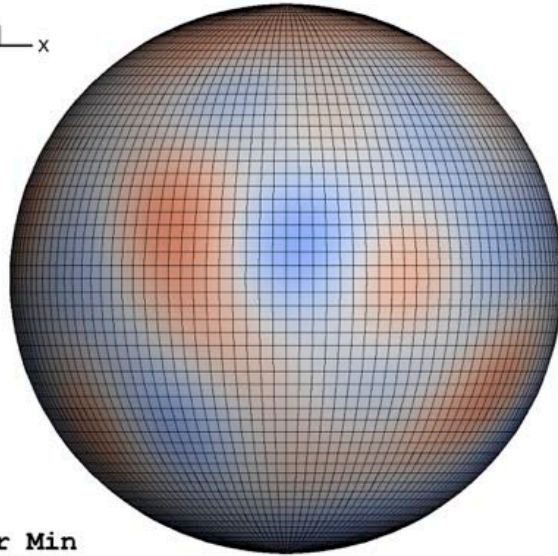
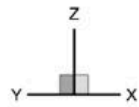
In this context, we began in 2015 a long-term observational campaign to map (and fully resolve) the magnetic cycle of ι Horologii: the only single star (apart from the Sun), with a confirmed chromospheric and coronal activity cycle known to date (Fig. 1, see Sanz-Forcada et al. 2013).

Our program in P16 successfully led to the first 3 ZDI maps of this object (Fig. 2, left), revealing a significant increase in the magnetic field strength and complexity towards activity maximum, which will be covered by our P17 campaign (see Fig. 1).

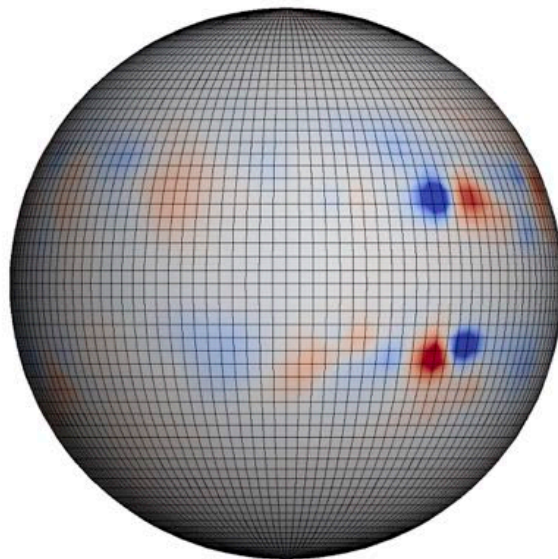
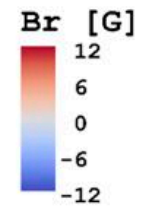
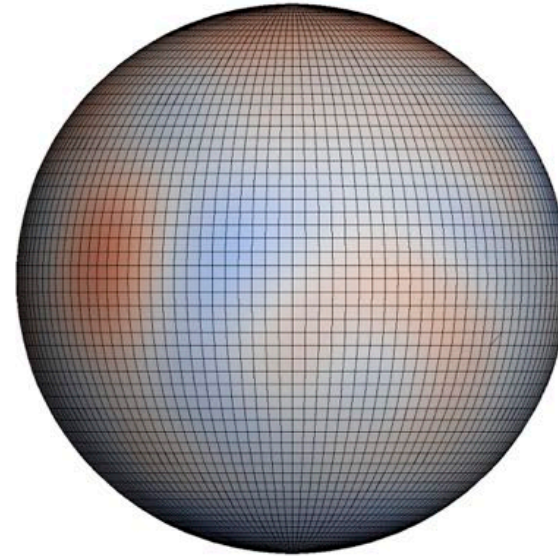
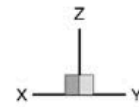
In addition, detailed 3D MHD simulations of the corona, wind and exoplanetary environment in this system are being constructed (Fig. 2, right), using the ZDI maps as boundary conditions. These models will be compared with our on-going XMM-Newton observations of this star, and possibly, with UV stellar wind diagnostics from HST (Fig. 1).



MDI/SOHO Synoptic Magnetograms (Carrington Maps)

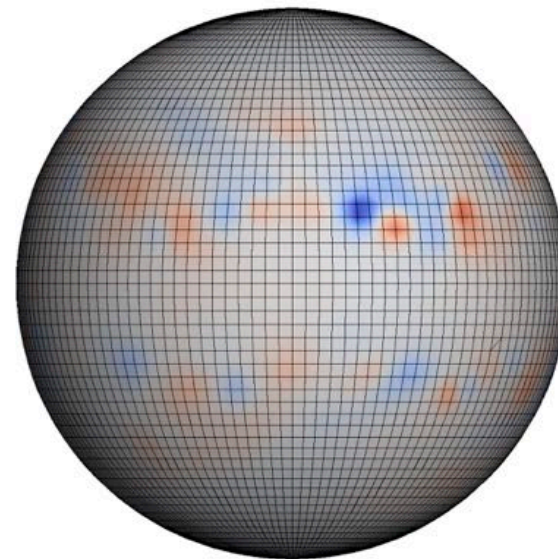


Solar Min
(CR 1922)

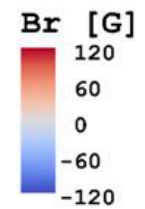


Solar Max
(CR 1962)

$\Phi = 0.25$



$\Phi = 0.75$



Observations: High-Resolution Spectropolarimetry

NARVAL@TBL



$D = 2 \text{ m} \mid R \sim 65000$
 $\lambda \sim 370 - 1050 \text{ nm}$

ESPaDOnS@CFHT



$D = 3.6 \text{ m} \mid R \sim 70000$
 $\lambda \sim 370 - 1050 \text{ nm}$

HARPSpol@ESO-3.6m



$D = 3.6 \text{ m} \mid R \sim 120000$
 $\lambda \sim 378 - 691 \text{ nm}$

Future instruments/upgrades:

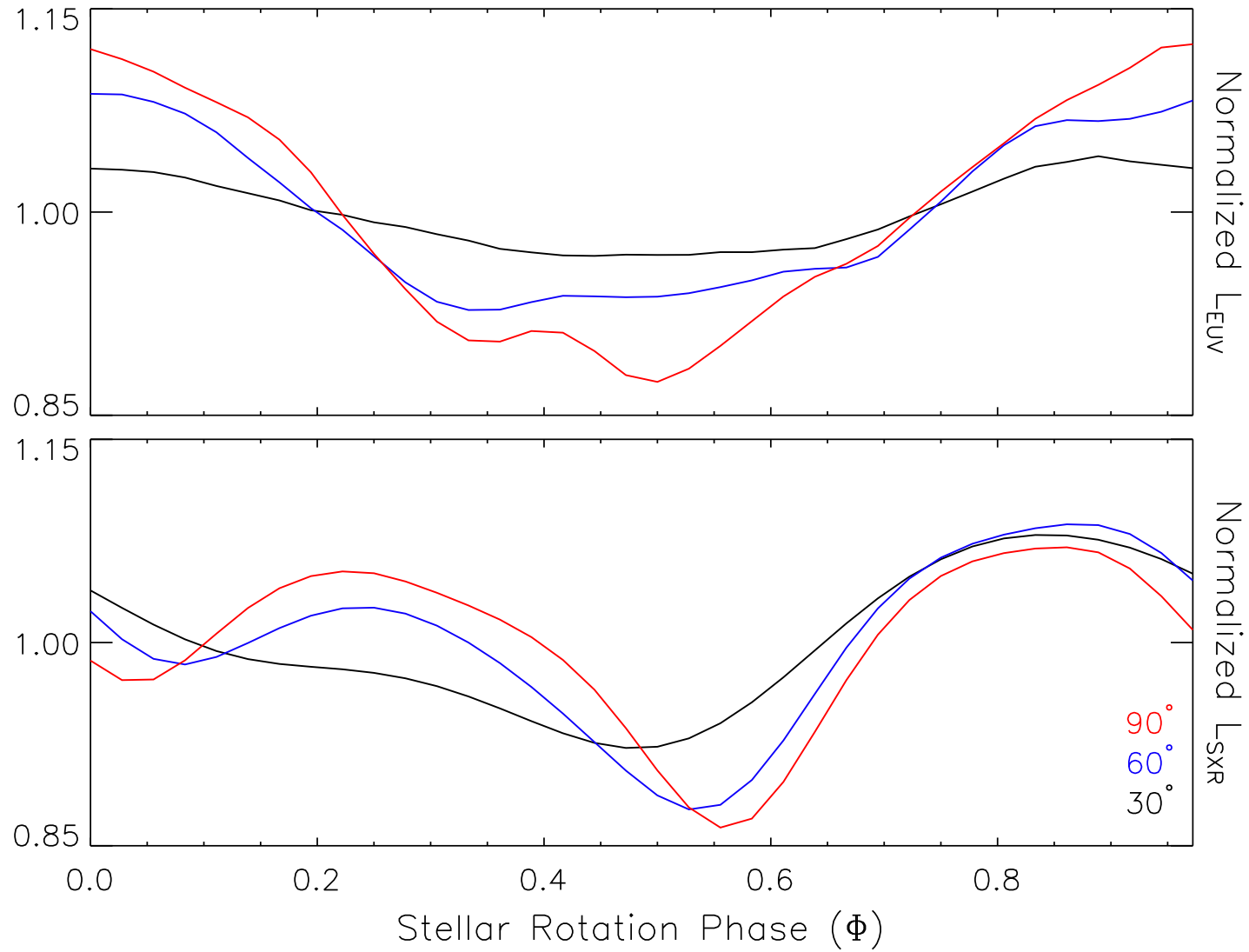
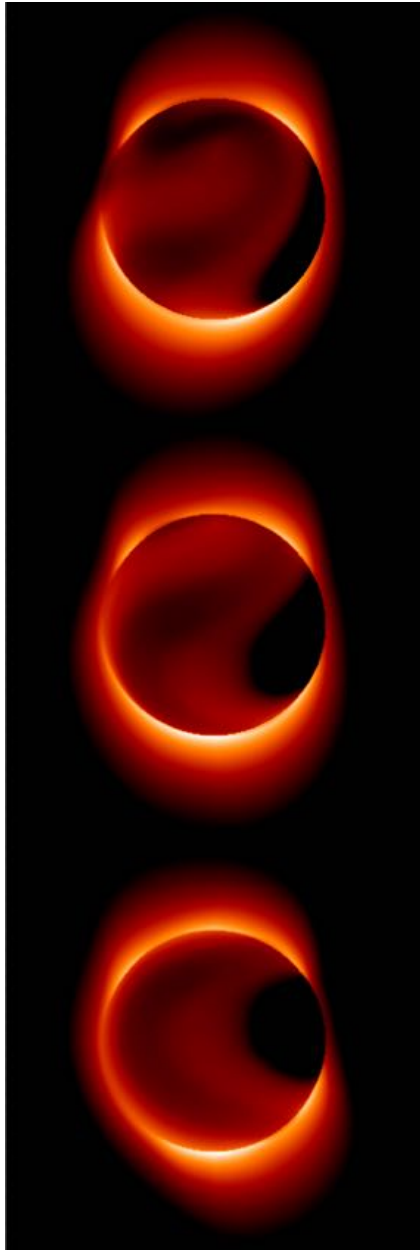


RV precision $< 3 \text{ m/s}$
First Light: ~ 2018



$R \sim 75000 \mid \lambda \sim 0.98 - 2.35 \mu\text{m}$
RV precision $\sim 1 \text{ m/s}$
First Light: ~ 2017

Rotational modulation of the high-energy emission



(Alvarado-Gómez et al. 2016a)

Astrospheres: Mass loss – Activity Relation

Mass loss rates estimates only for 10 Sun - like (G-K type) stars

Apparent correlation between mass loss and x-ray activity (Physical Units!)

Open questions: 2 regimes? (π^1 UMa) – Models in the high activity end? – Binariness?

