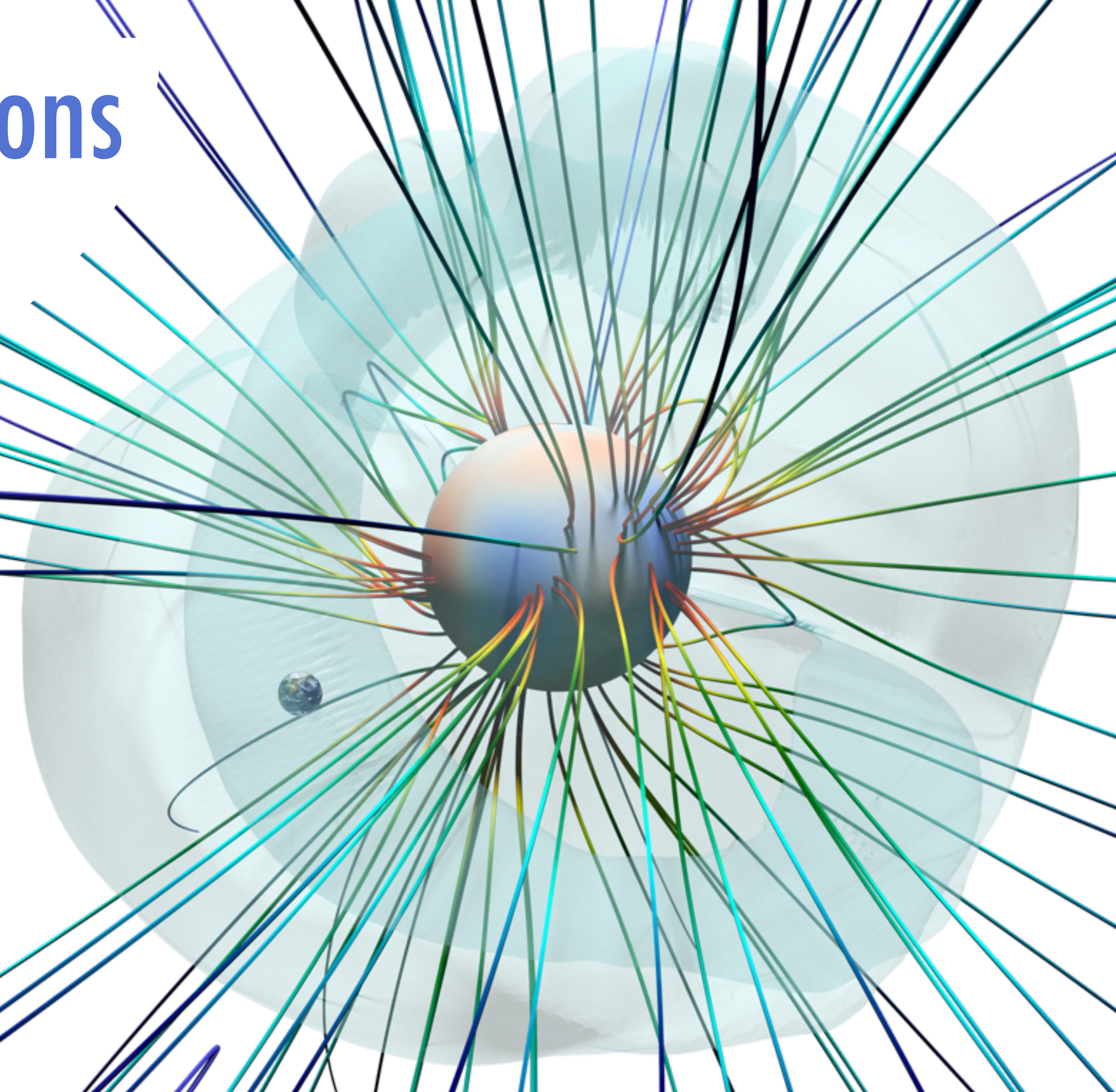
Partage de simulations numériques avec le code PLUTO

Antoine Strugarek

CEA Paris-Saclay, France

With B. Perri, A.S. Brun, V. Réville, S. Hazra, R. Pinto, E. Buchlin, F. Regnault, B. Vaidya, A. Paul

Special thanks: A. Mignone



What is PLUTO?

PLUTO is a modular parallel code with a multi-physics, multi-algorithm framework for solving gas and plasma dynamics

It is designed for multi-D compressible plasma with high Mach numbers:

- Compressible Euler/Navier-Stokes
- Ideal/Resistive MHD
- Relativistic extensions
- Heating/colling processes with chemical network
- Hybrid treatments of kinetic physics

Mignone+ 2007

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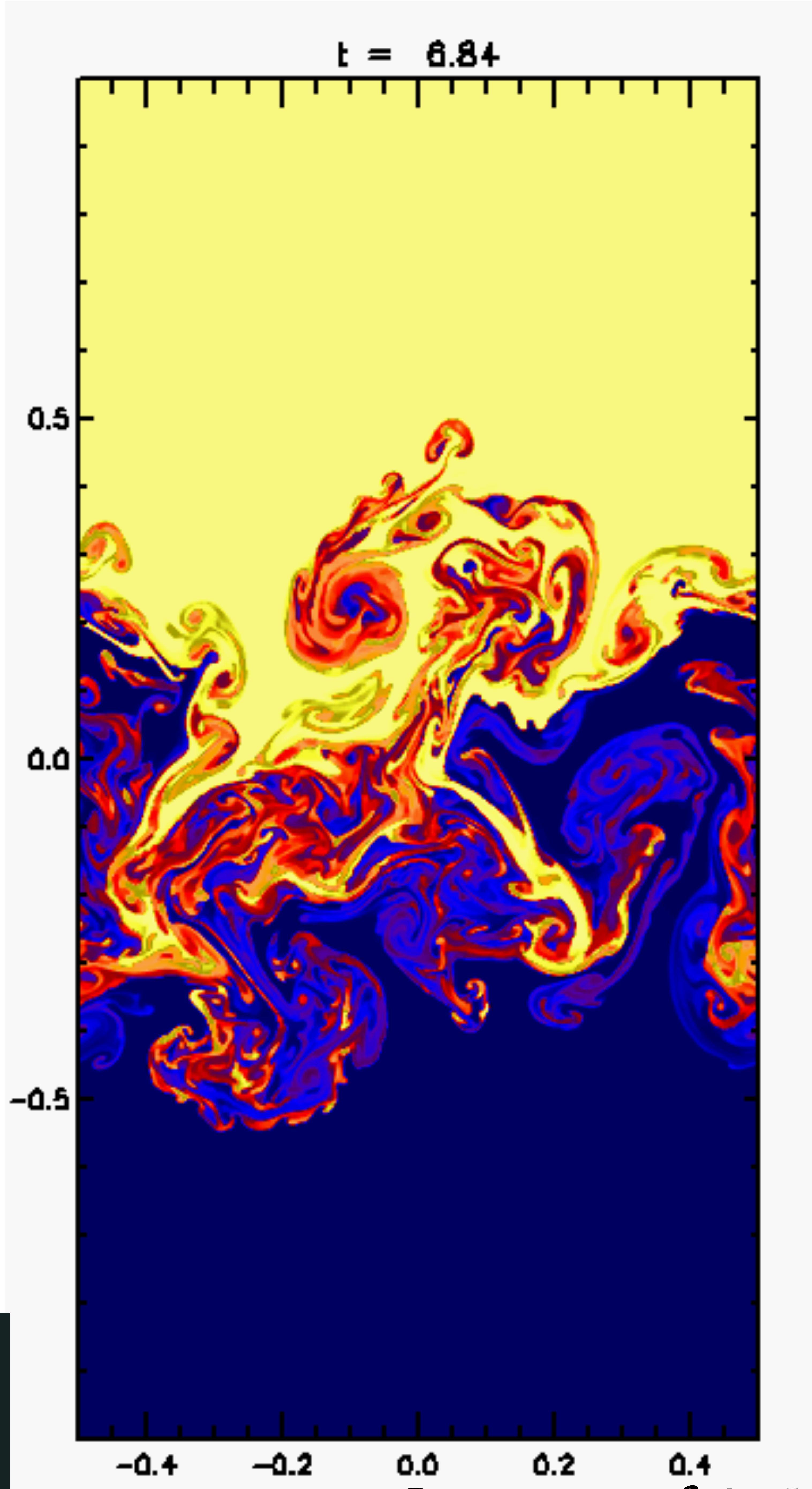

Courtesy of A. Mignone

PLUTO webpage

Home Code Overview Gallery Download Documentation Meetings

The PLUTO Code for Astrophysical GasDynamics

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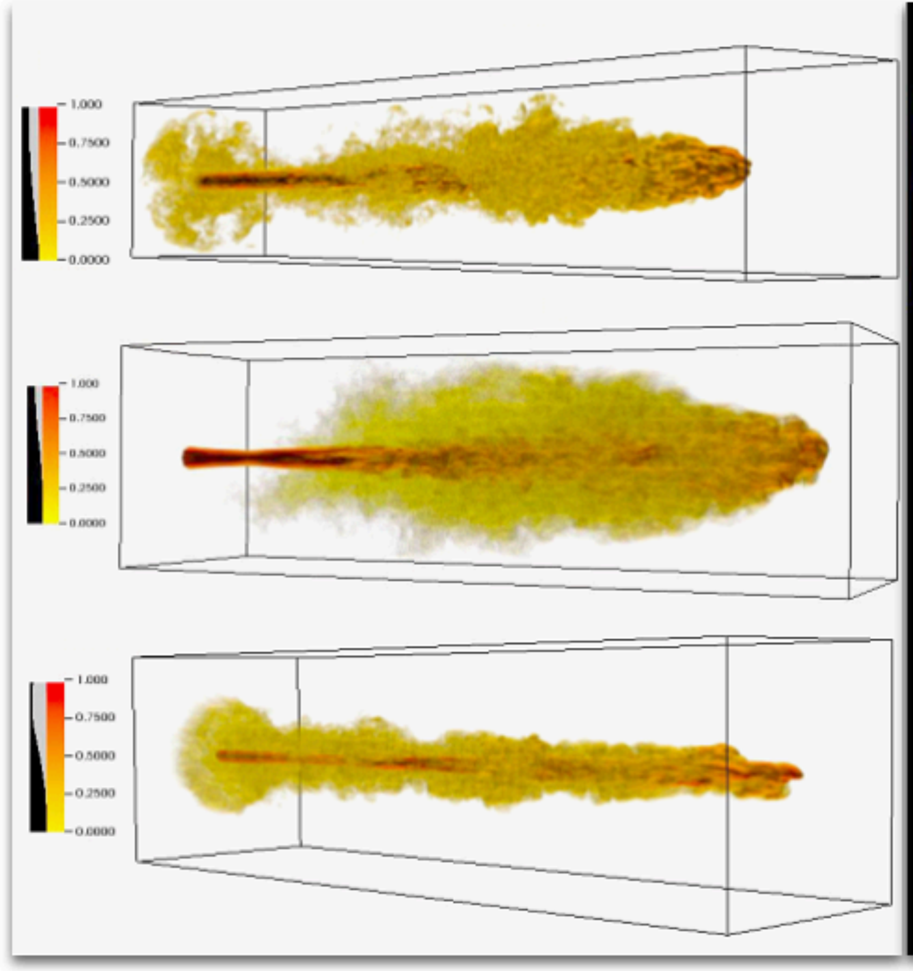
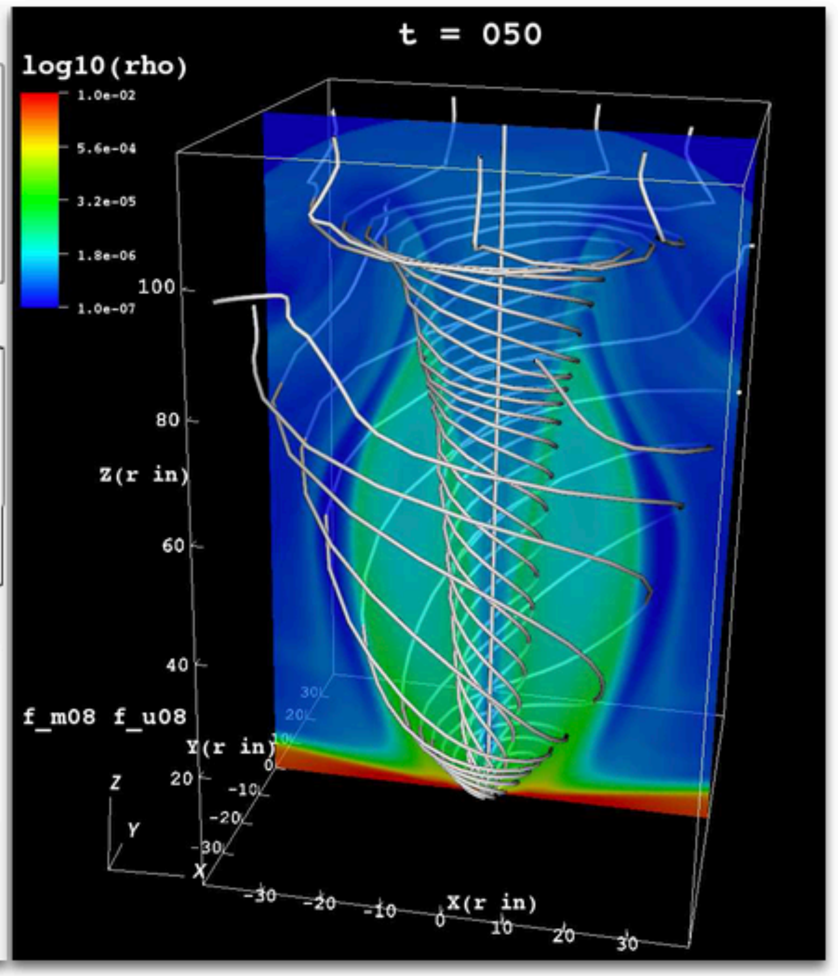
The PLUTO Code

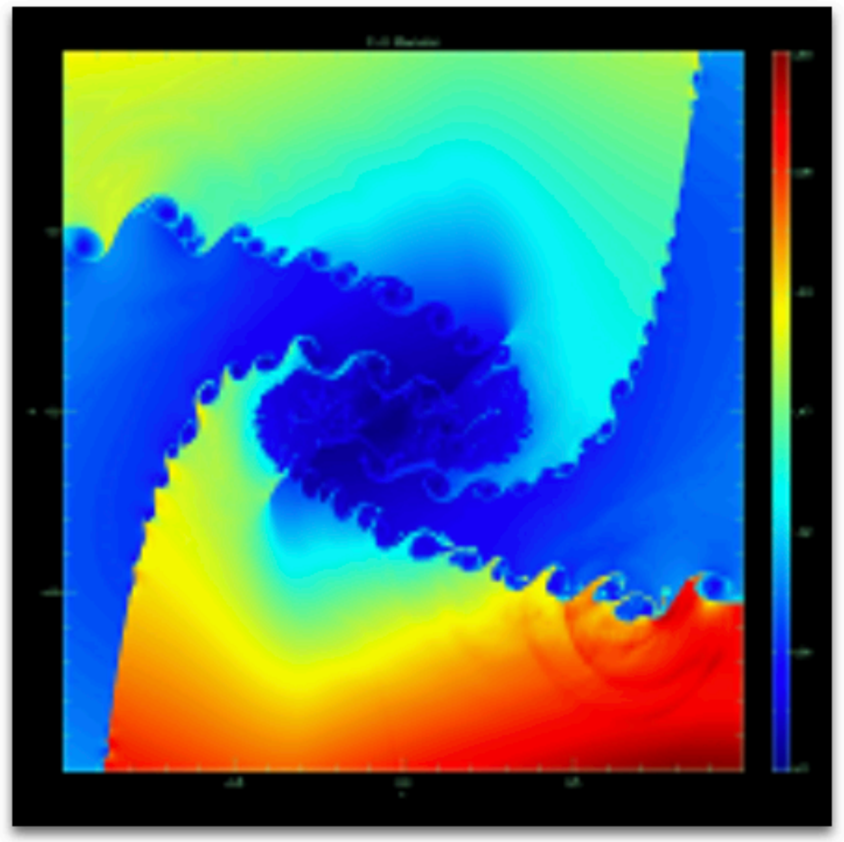
https://groups.google.com/g/pluto_users

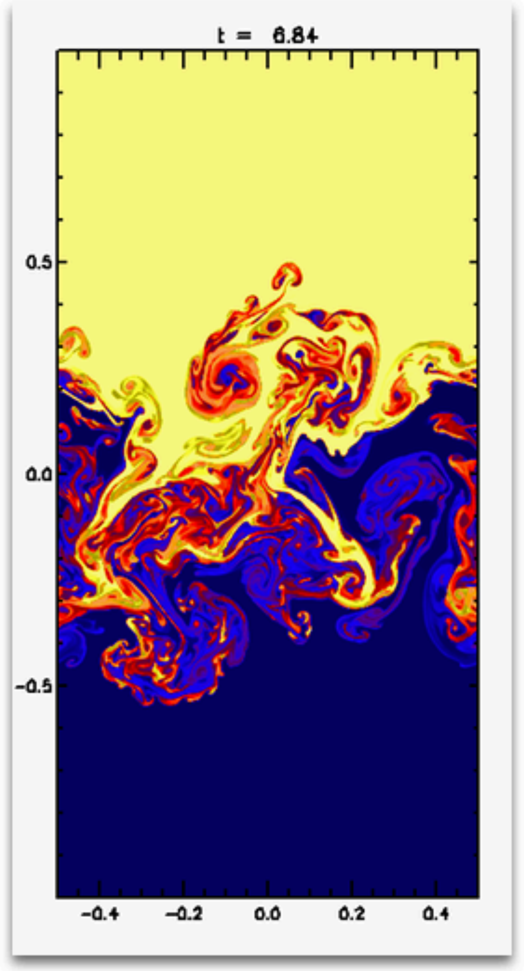
Mignone+ 2007

http://plutocode.ph.unito.it







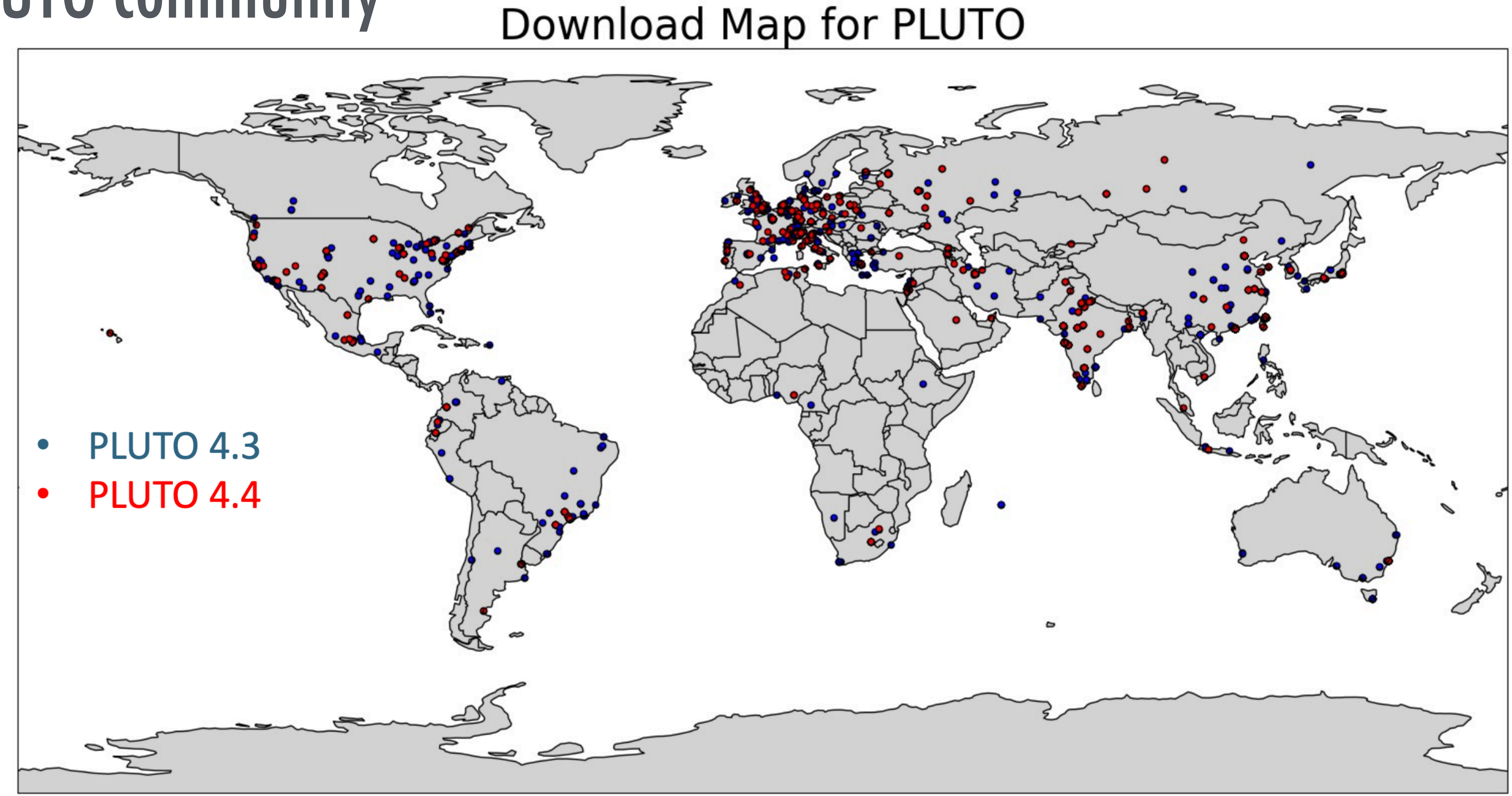


Code Version: 4.4-patch2 (Jun 2021)

PLUTO is a freely-distributed software for the numerical solution of mixed hyperbolic/parabolic systems of partial differential equations (conservation laws) targeting high Mach number flows in astrophysical fluid dynamics. The code is designed with a modular and flexible structure whereby different numerical algorithms can be separately combined to solve systems of conservation laws using the finite volume or finite difference approach based on Godunov-type schemes.

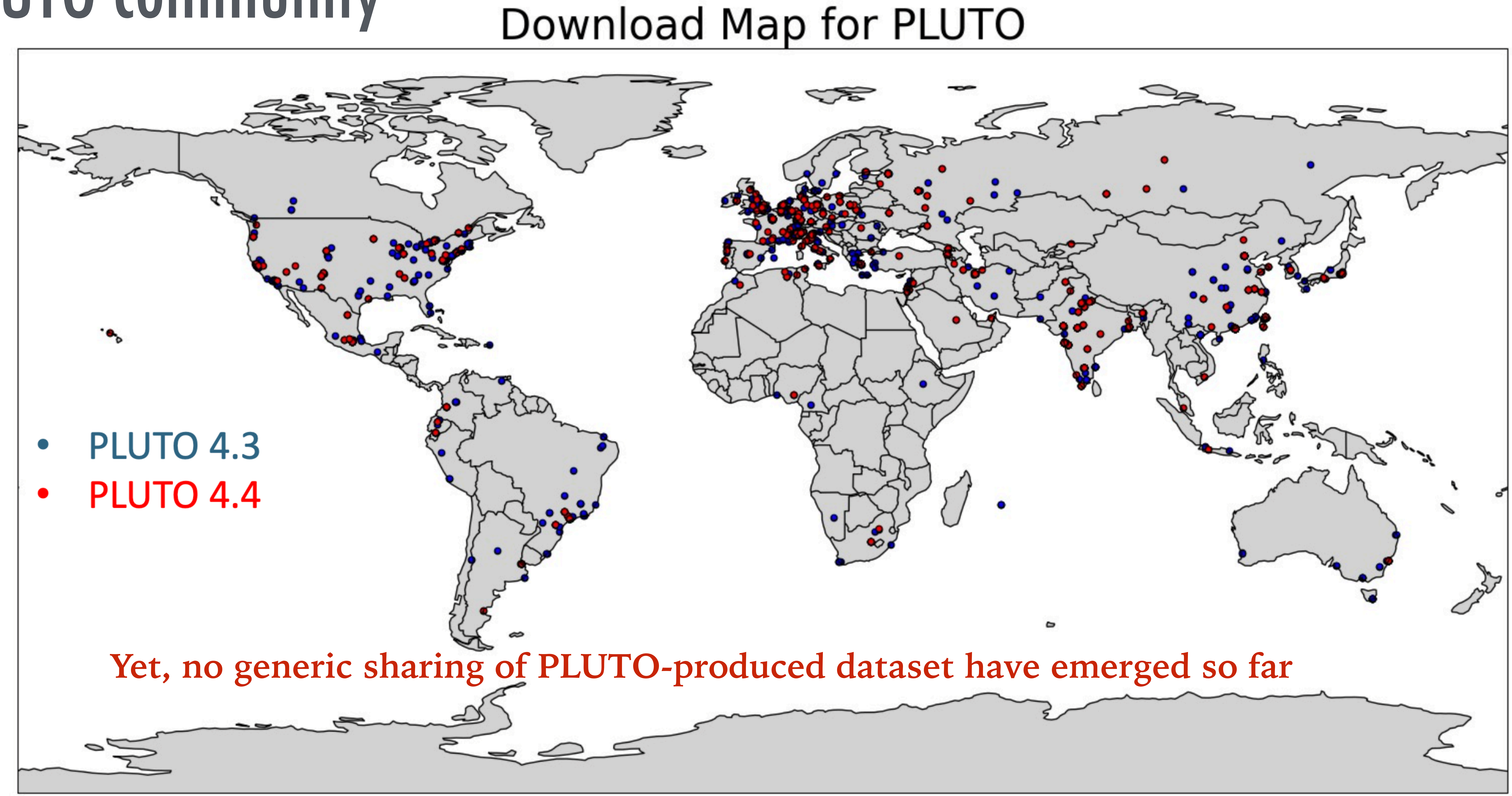
Courtesy of A. Mignone

PLUTO community



Courtesy of A. Mignone

PLUTO community

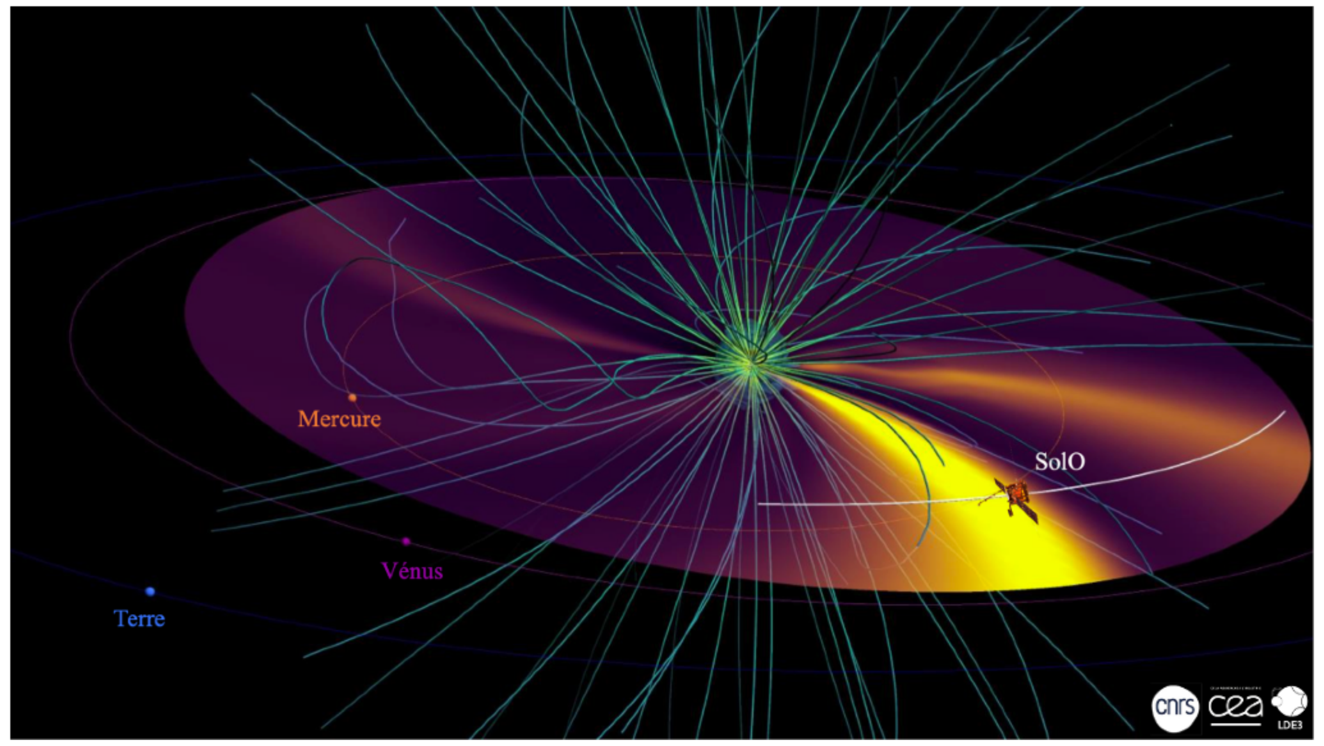


Yet, no generic sharing of PLUTO-produced dataset have emerged so far

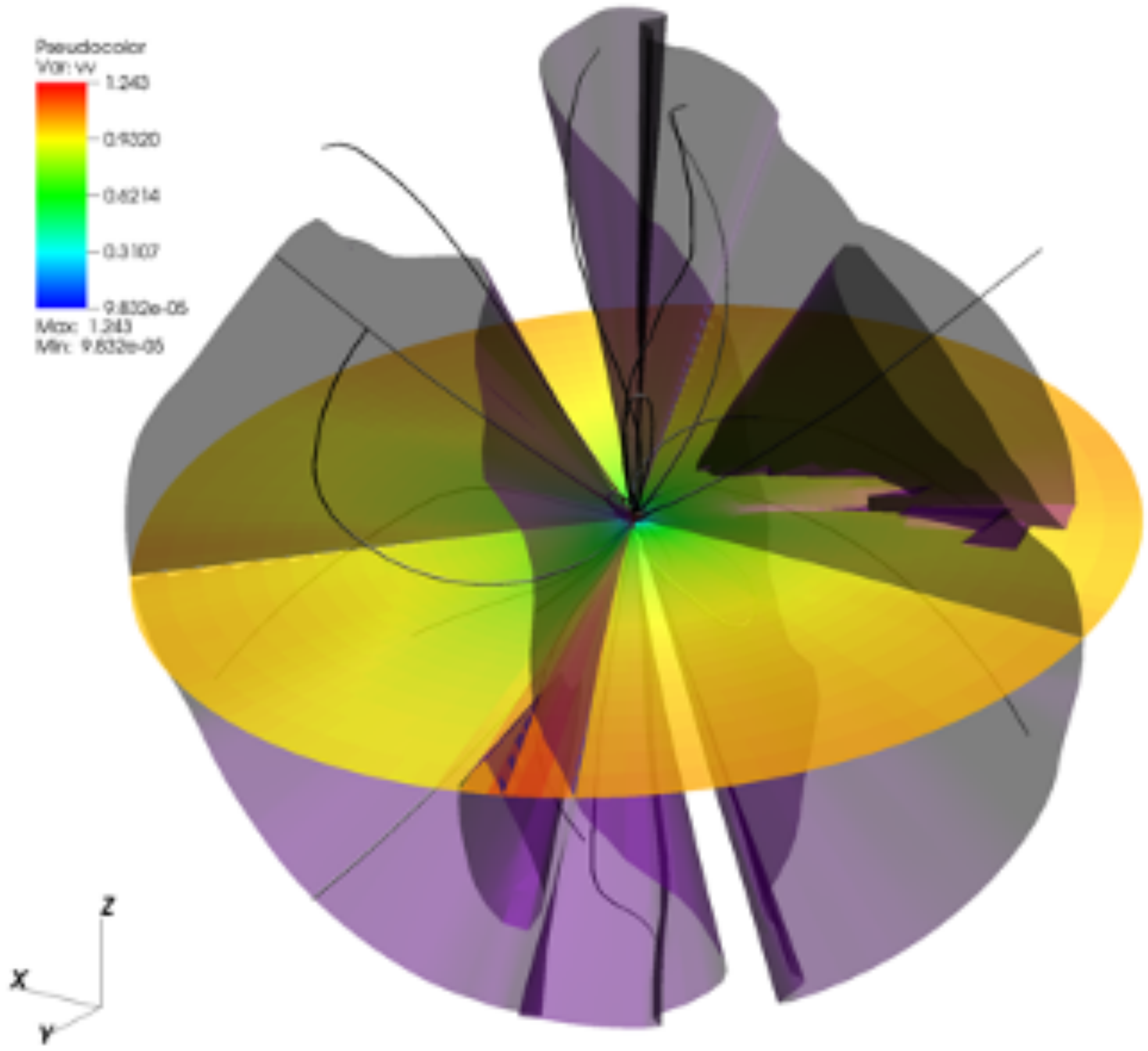
Courtesy of A. Mignone

My feedback on attempts to share simulation data and code

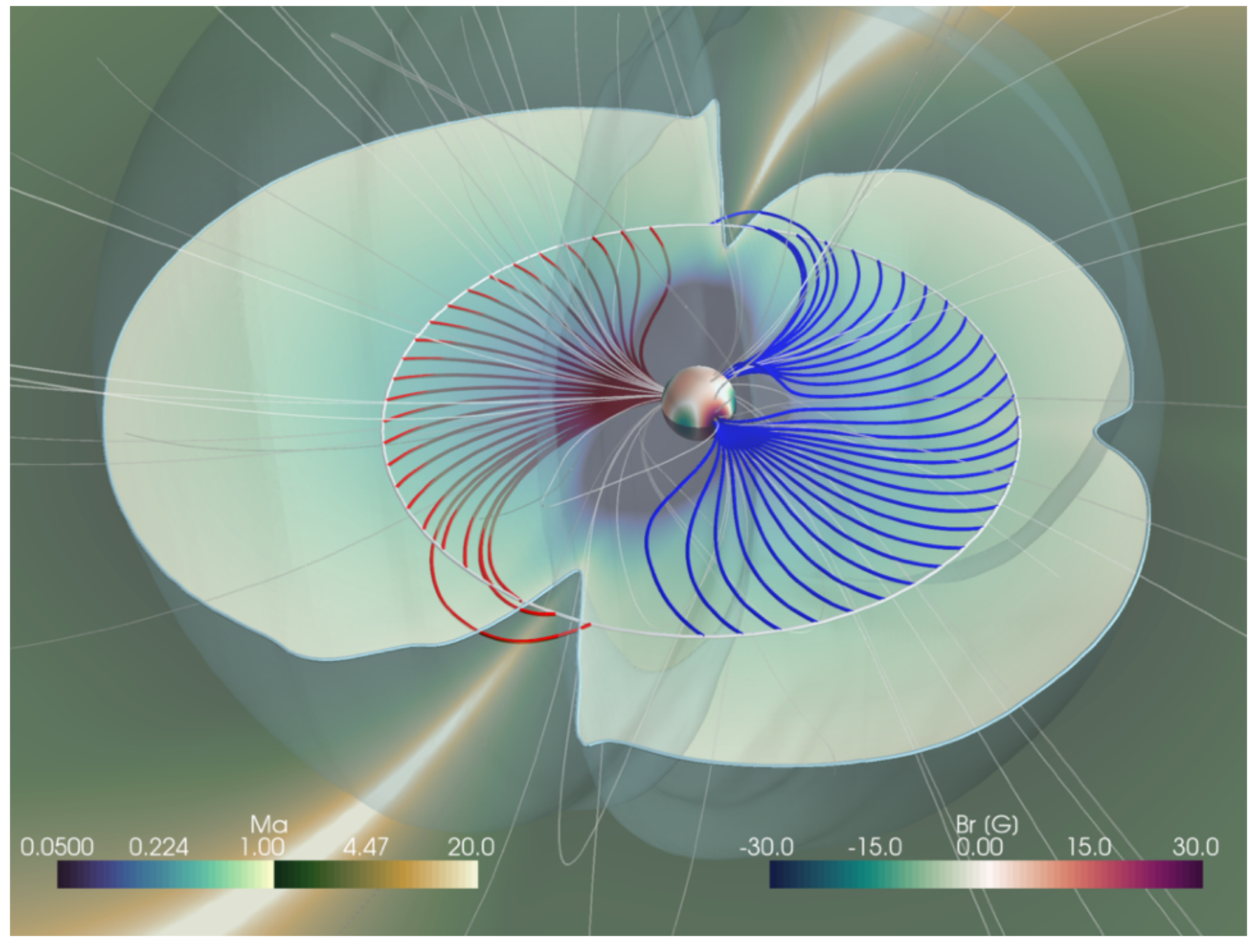
Wind-Predict and the Virtual Space-Weather Modelling Center



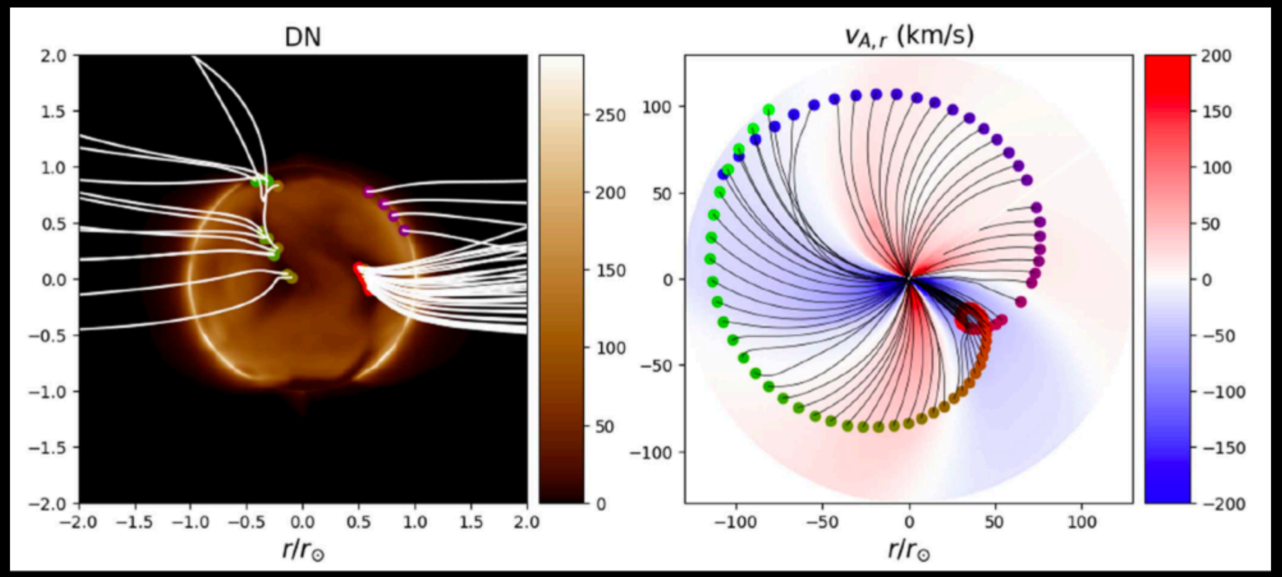
Cosmic ray diffusion coefficient from large-scale wind simulations



Star-planet interaction models



The WindPredict team



In-situ validation

Réville

WindPredict

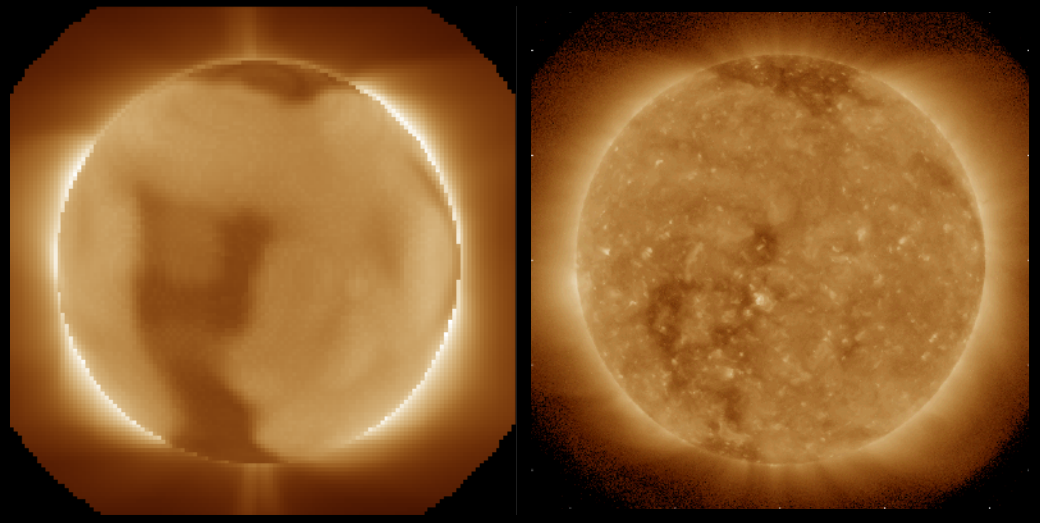
Core physics: **PLUTO** code

Mignone et al. 2007

Réville

Strugarek

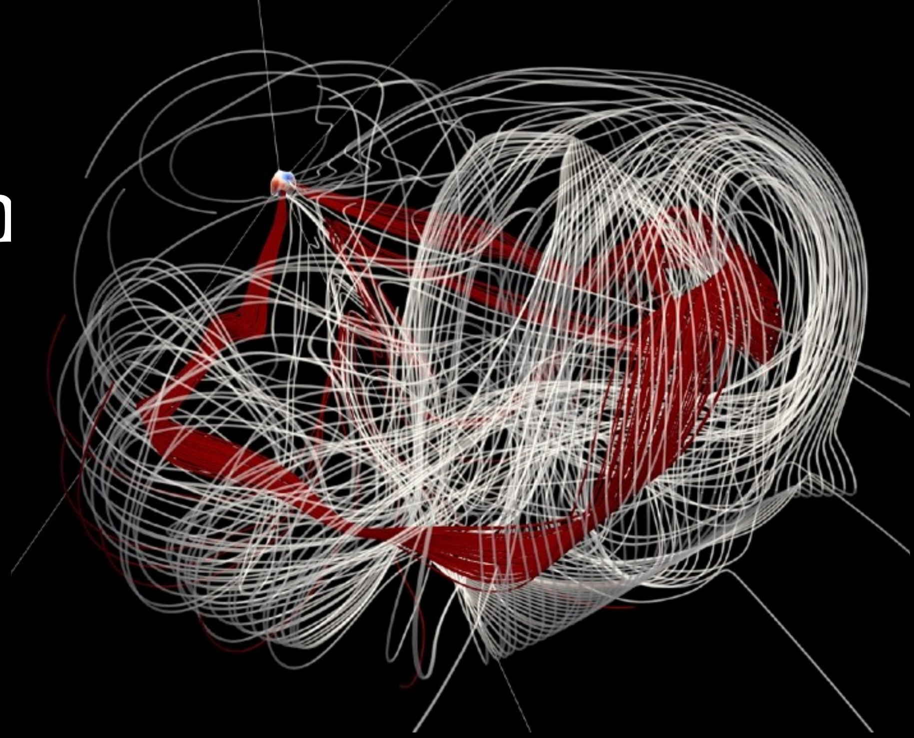
Brun



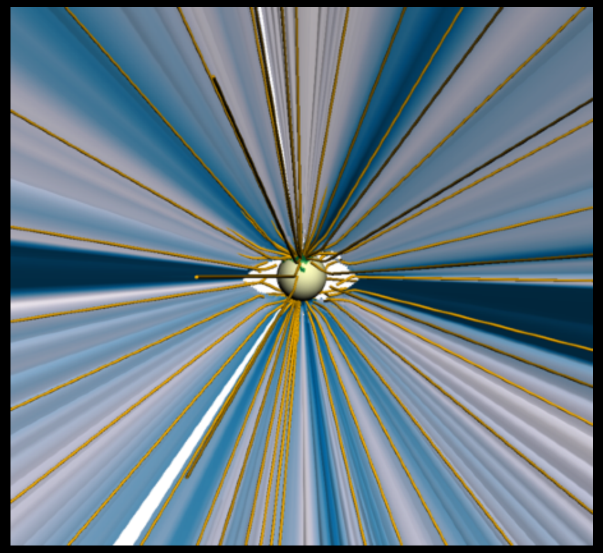
UV+White Light validation

Parenti

CME propagation with AMR

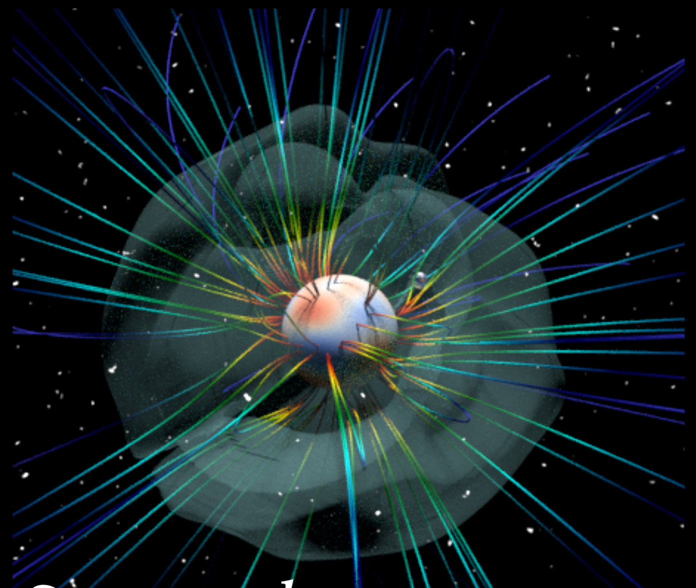


Regnault



Comparisons WindPredict-MULTI-VP

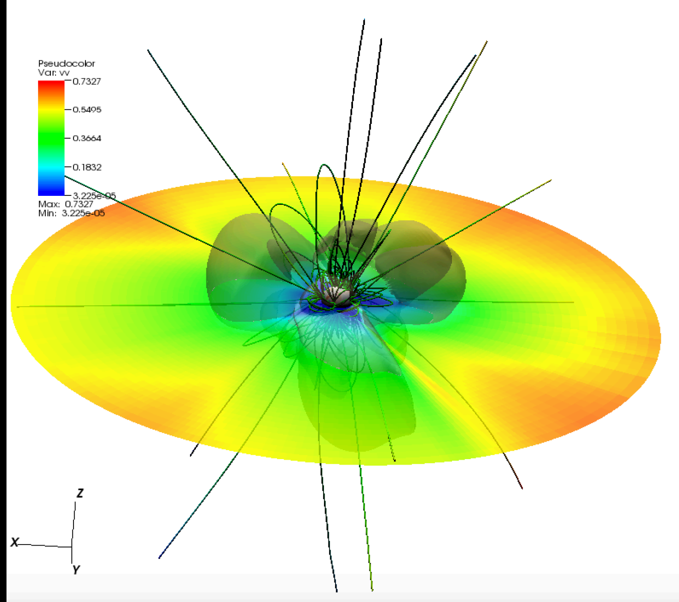
Pinto



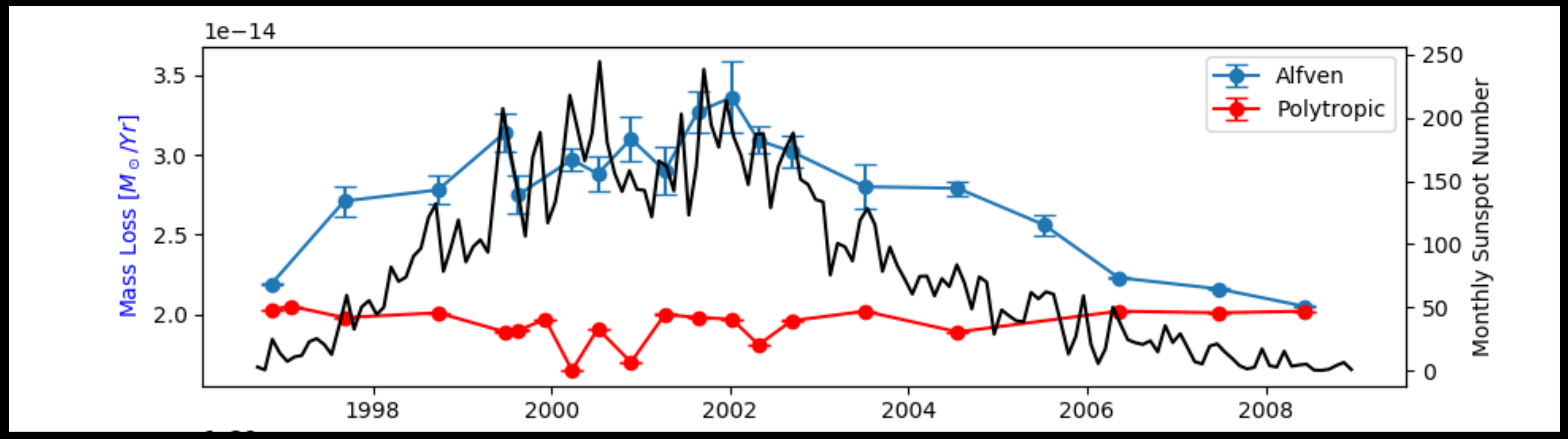
Strugarek

Star-planet interactions

VSWMC integration



Perri

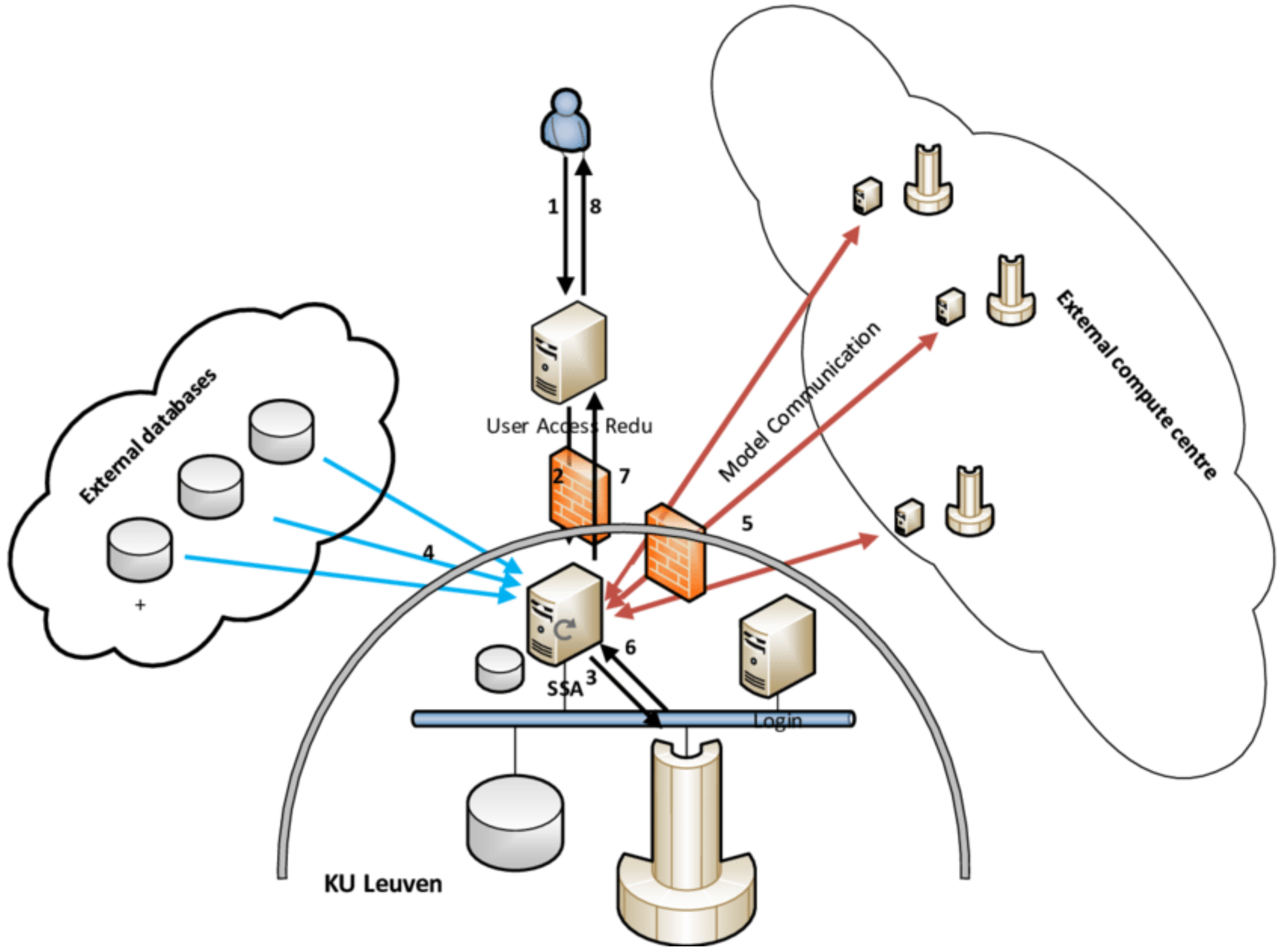


Hazra

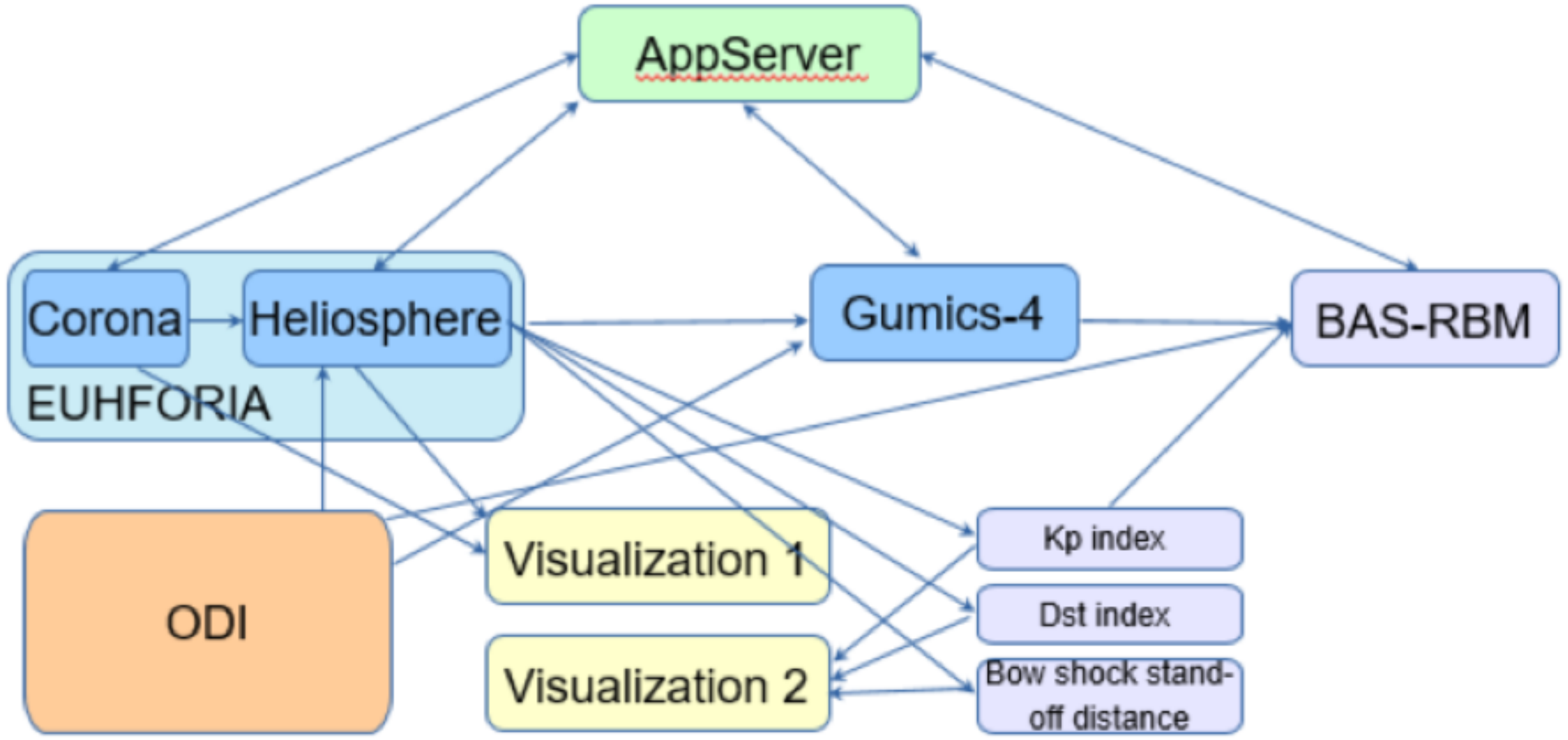
Polytropic/AW-driven comparisons

Virtual Space Weather Modelling Center (VSWMC)

Open end-to-end (Sun to Earth) space weather modeling system
Allows the coupling between existing space weather models
From user perspective, selection of parameters + retrieve results as GUI visualization



[Poedts+2020]



[Poedts 2019]

→ Uses the strength and assets of each model, from the corona to the Earth

Courtesy of B. Perri

Wind-Predict in the VSWMC

- → Provides magnetic field, wind speed, temperature and density at 21.5 Rs
- → Alternative to EUHFORIA corona (WSA empirical model)

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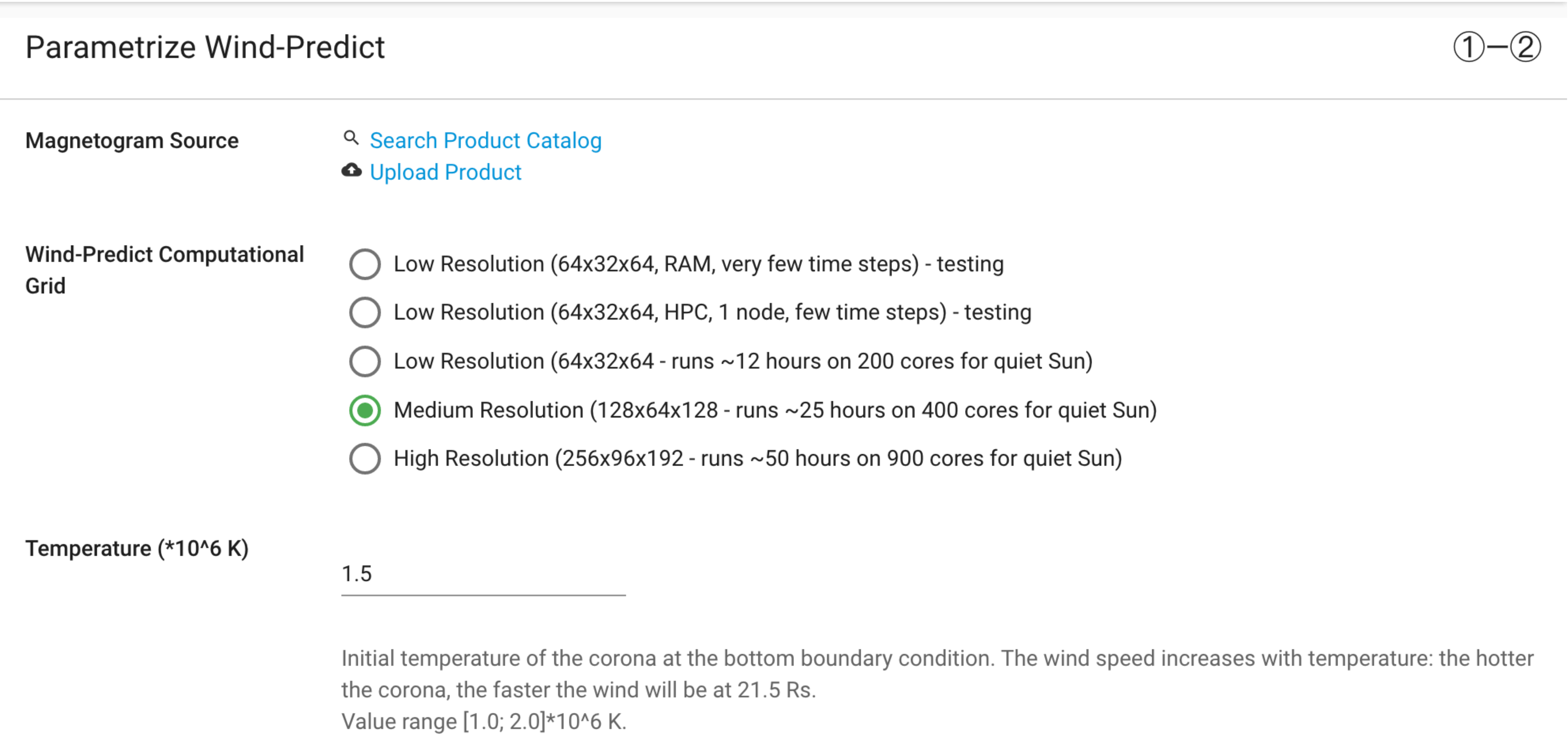

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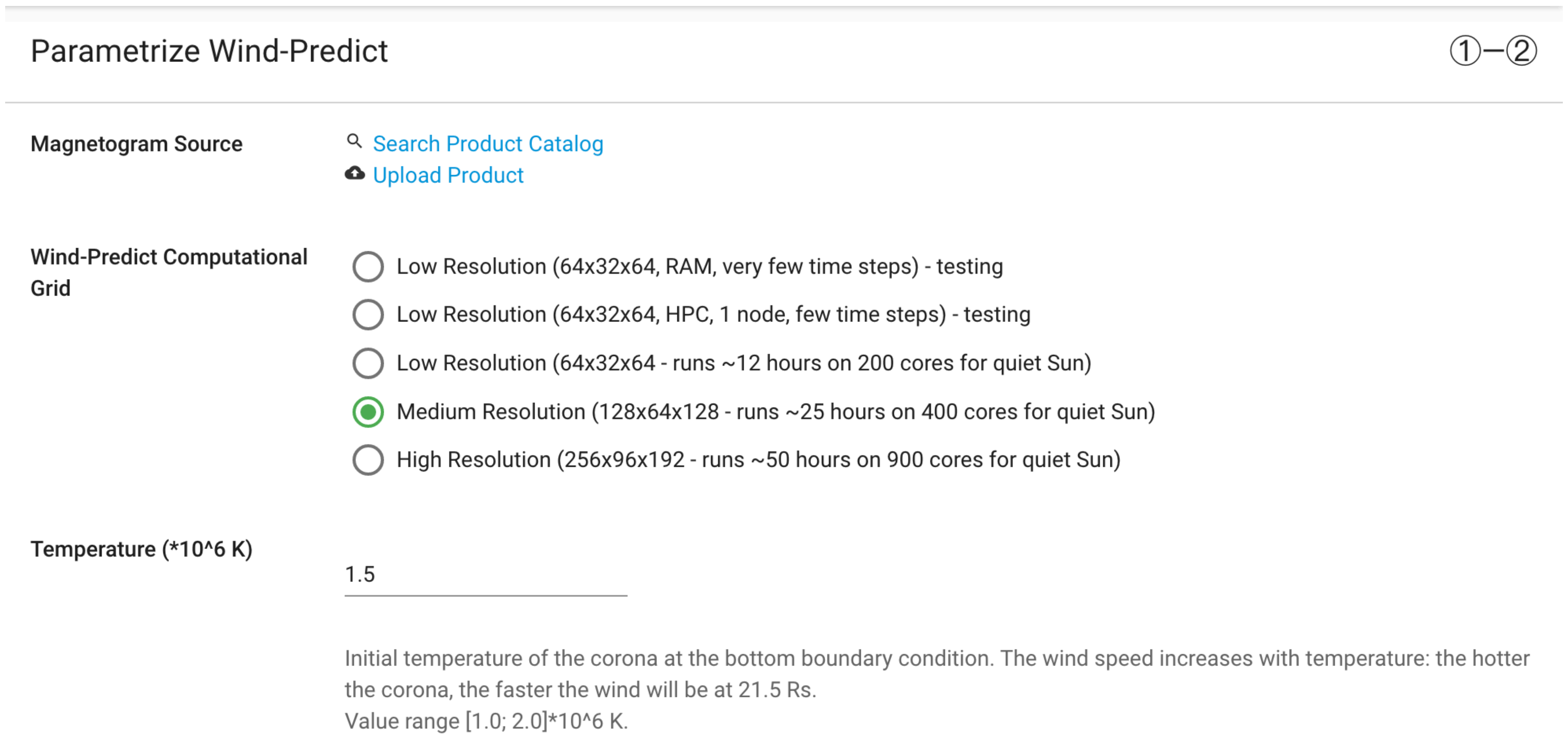

Parametrize Wind-Predict ①–②

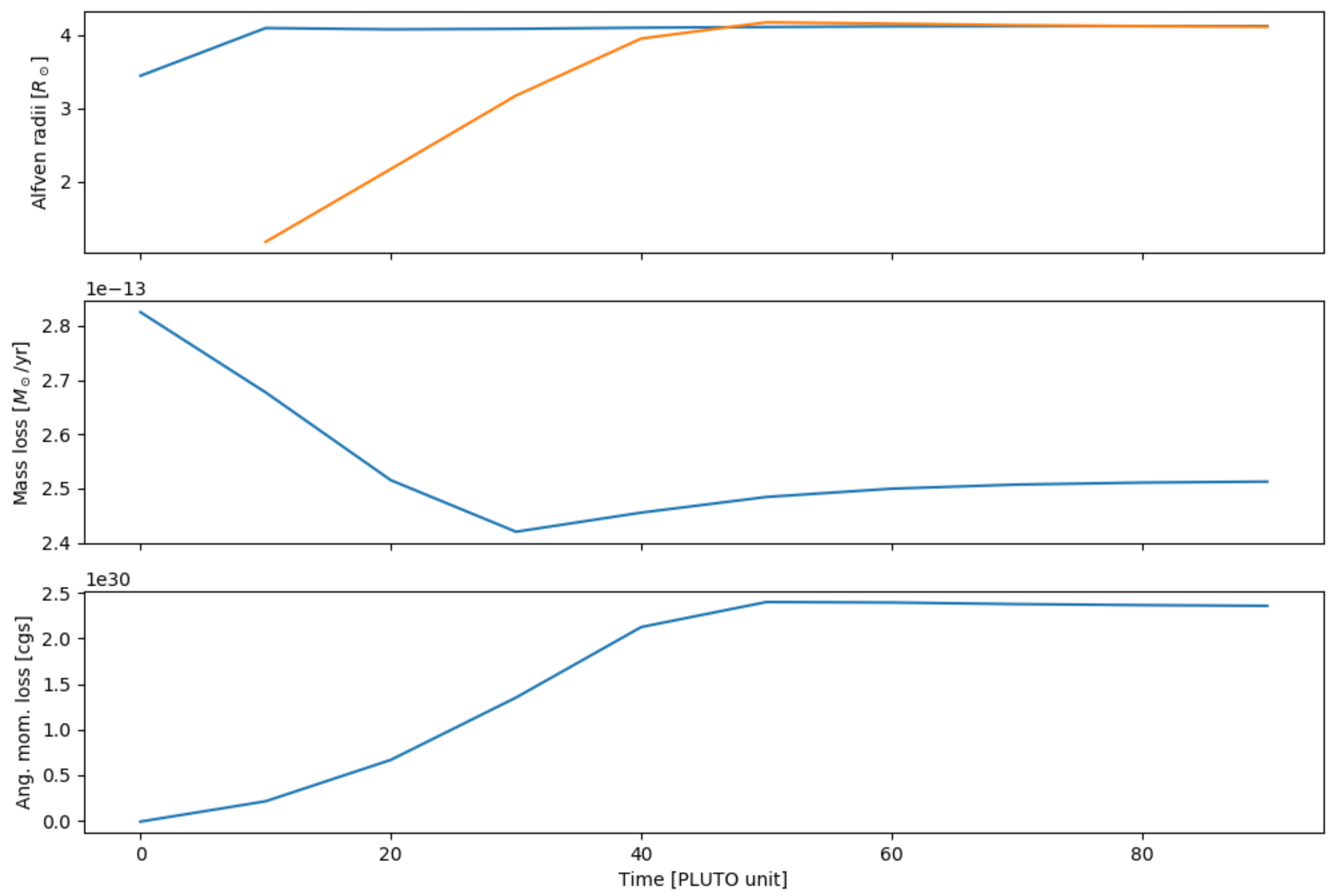
Magnetogram Source
Search Product Catalog
Upload Product

Wind-Predict Computational Grid
- Low Resolution (64x32x64, RAM, very few time steps) - testing
- Low Resolution (64x32x64, HPC, 1 node, few time steps) - testing
- Low Resolution (64x32x64 - runs ~12 hours on 200 cores for quiet Sun)
- Medium Resolution (128x64x128 - runs ~25 hours on 400 cores for quiet Sun)
- High Resolution (256x96x192 - runs ~50 hours on 900 cores for quiet Sun)

Temperature (*10^6 K)
1.5

Initial temperature of the corona at the bottom boundary condition. The wind speed increases with temperature: the hotter the corona, the faster the wind will be at 21.5 Rs.
Value range [1.0; 2.0]*10^6 K.

Types of outputs provided so far:



1D: validate numerical convergence

Courtesy of B. Perri

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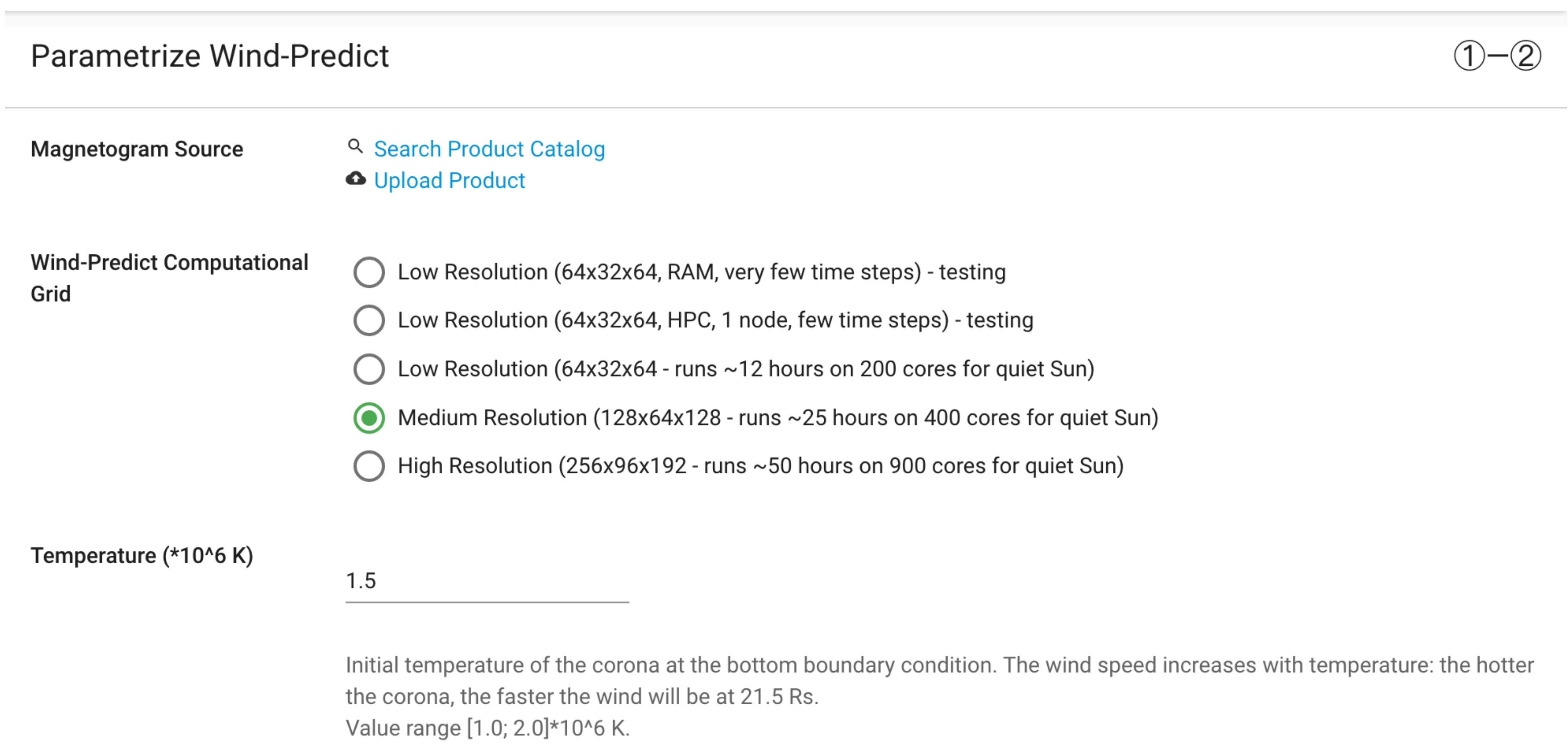

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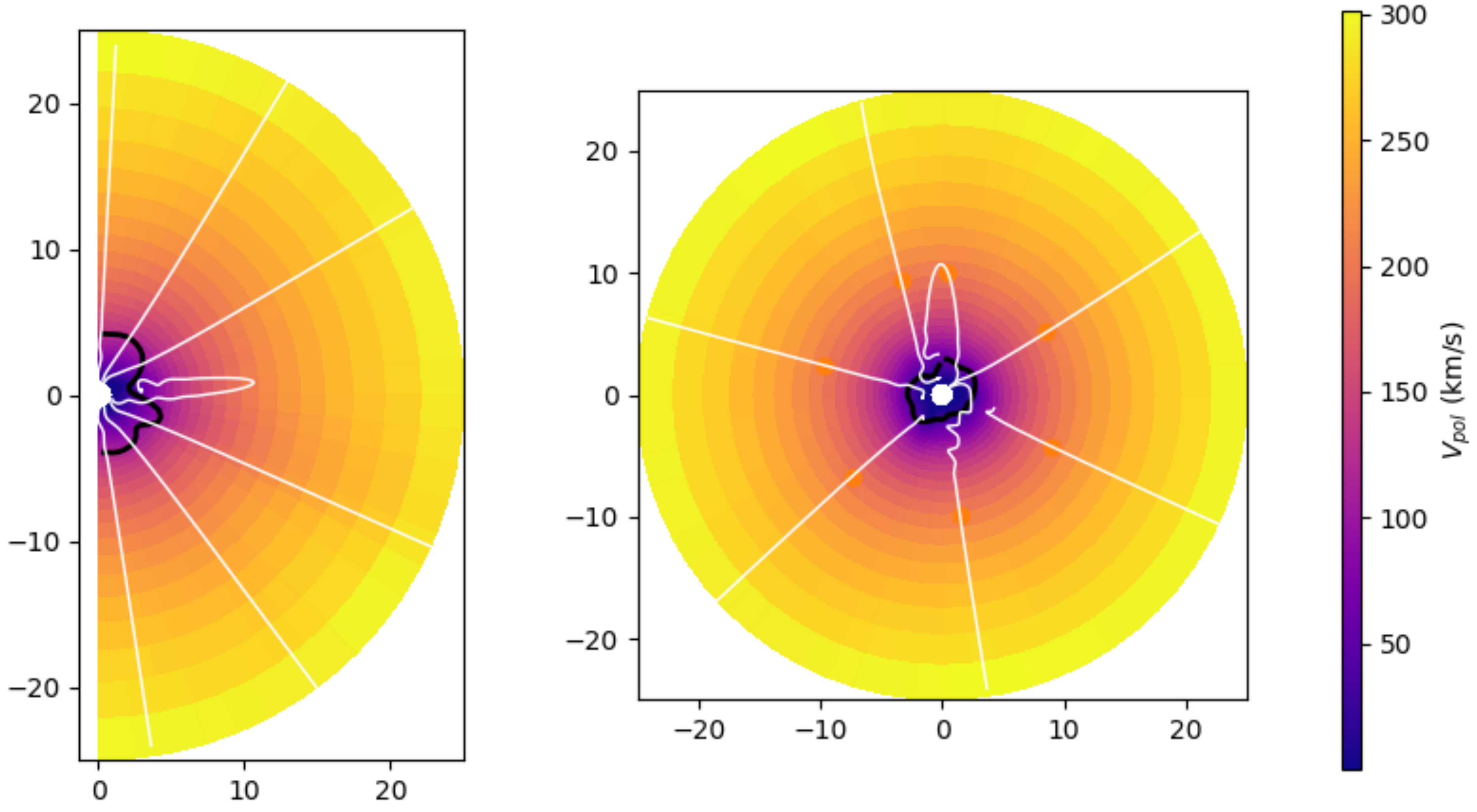

2D: visualise and analyse the wind configuration

Courtesy of B. Perri

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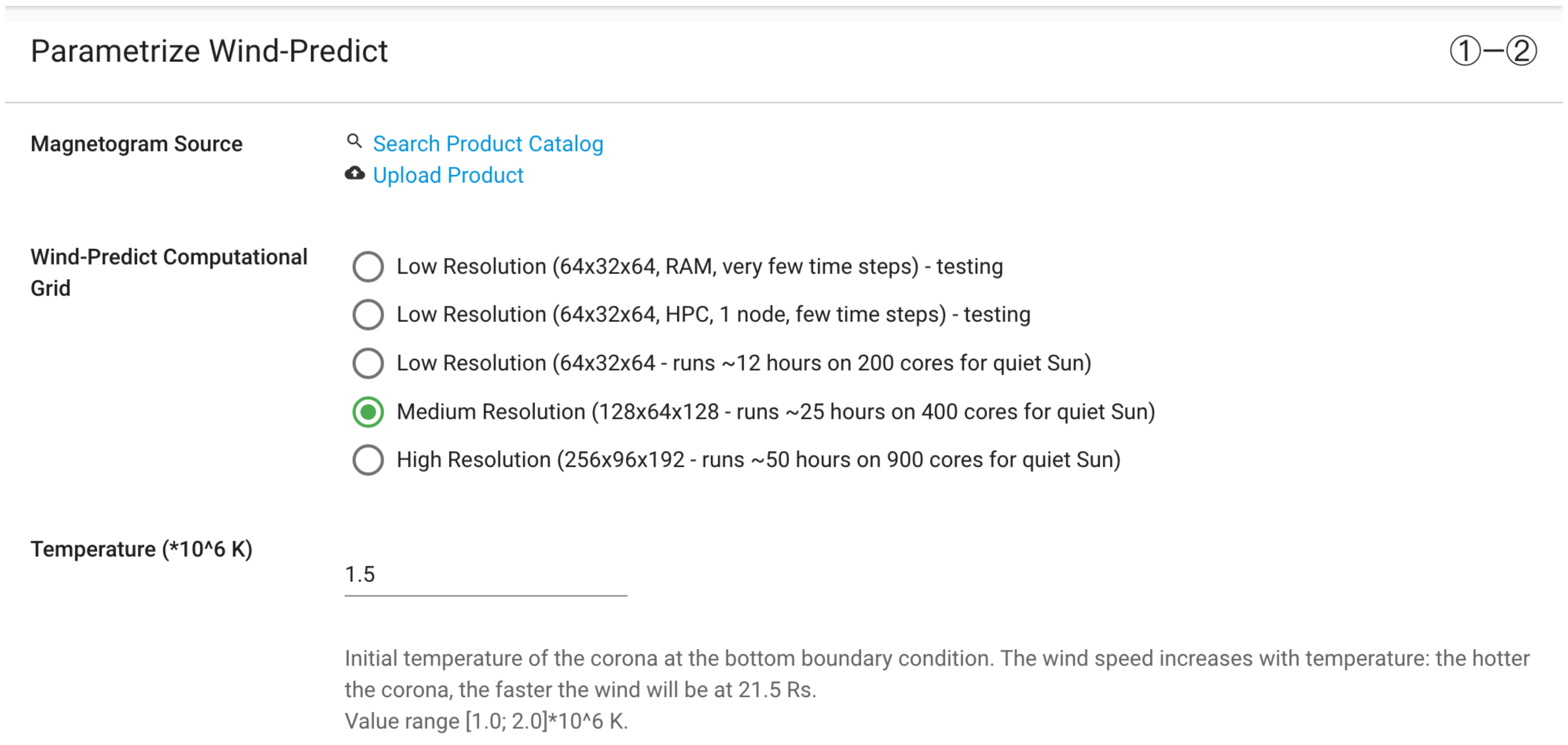

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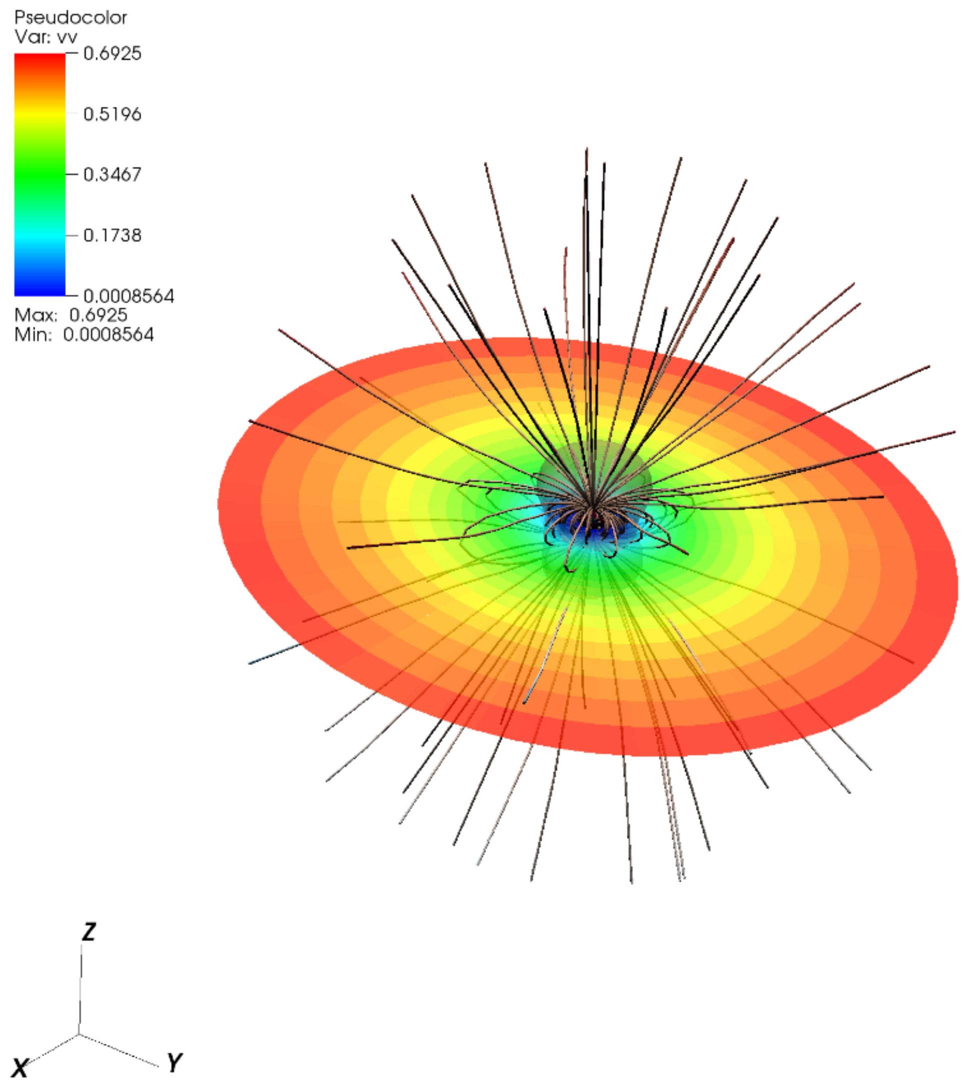
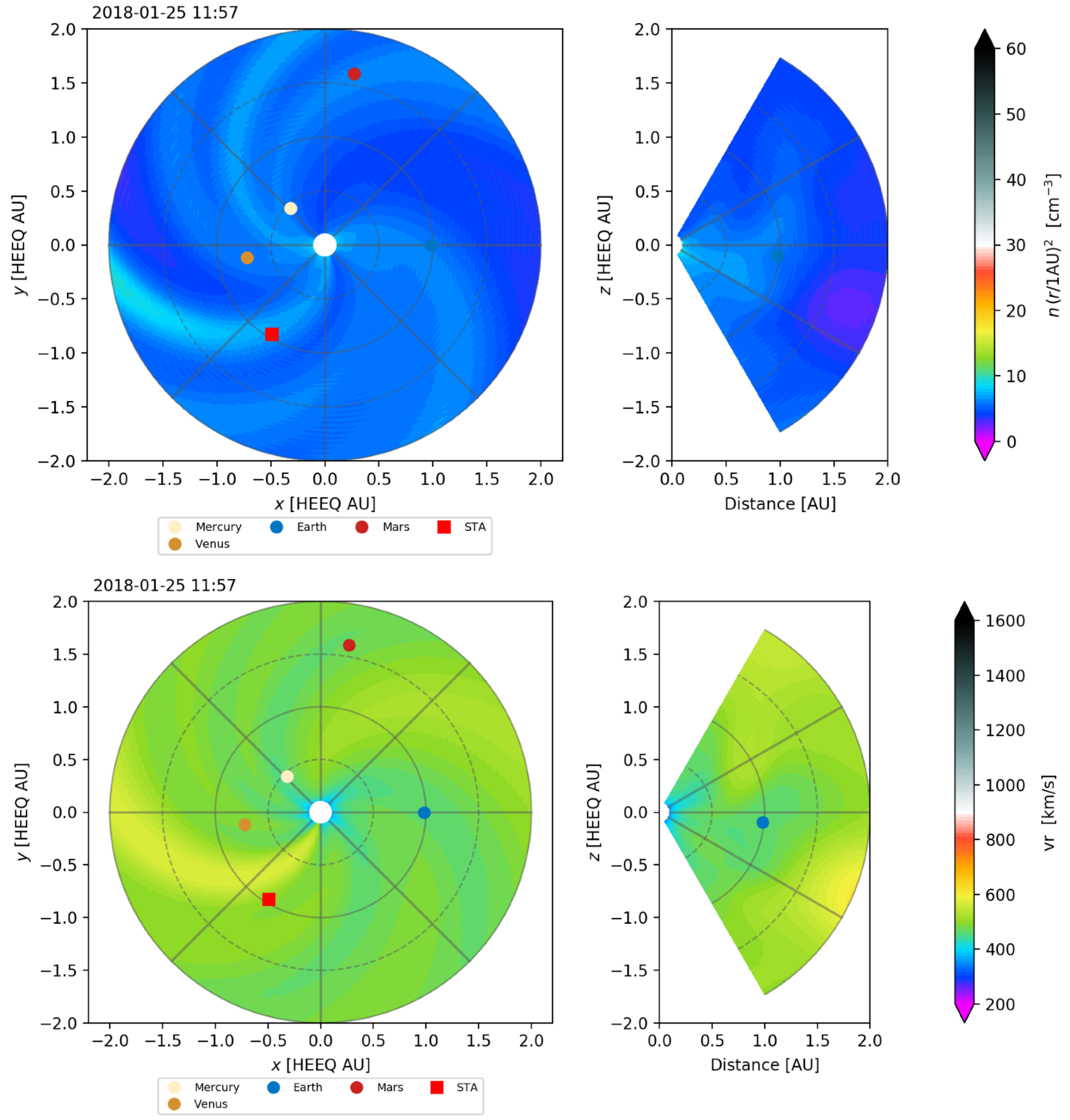


3D: visualise the magnetic configuration

Courtesy of B. Perri

Coupling with EUHFORIA

Coupling with EUHFORIA to compare in-situ data at 1 AU:



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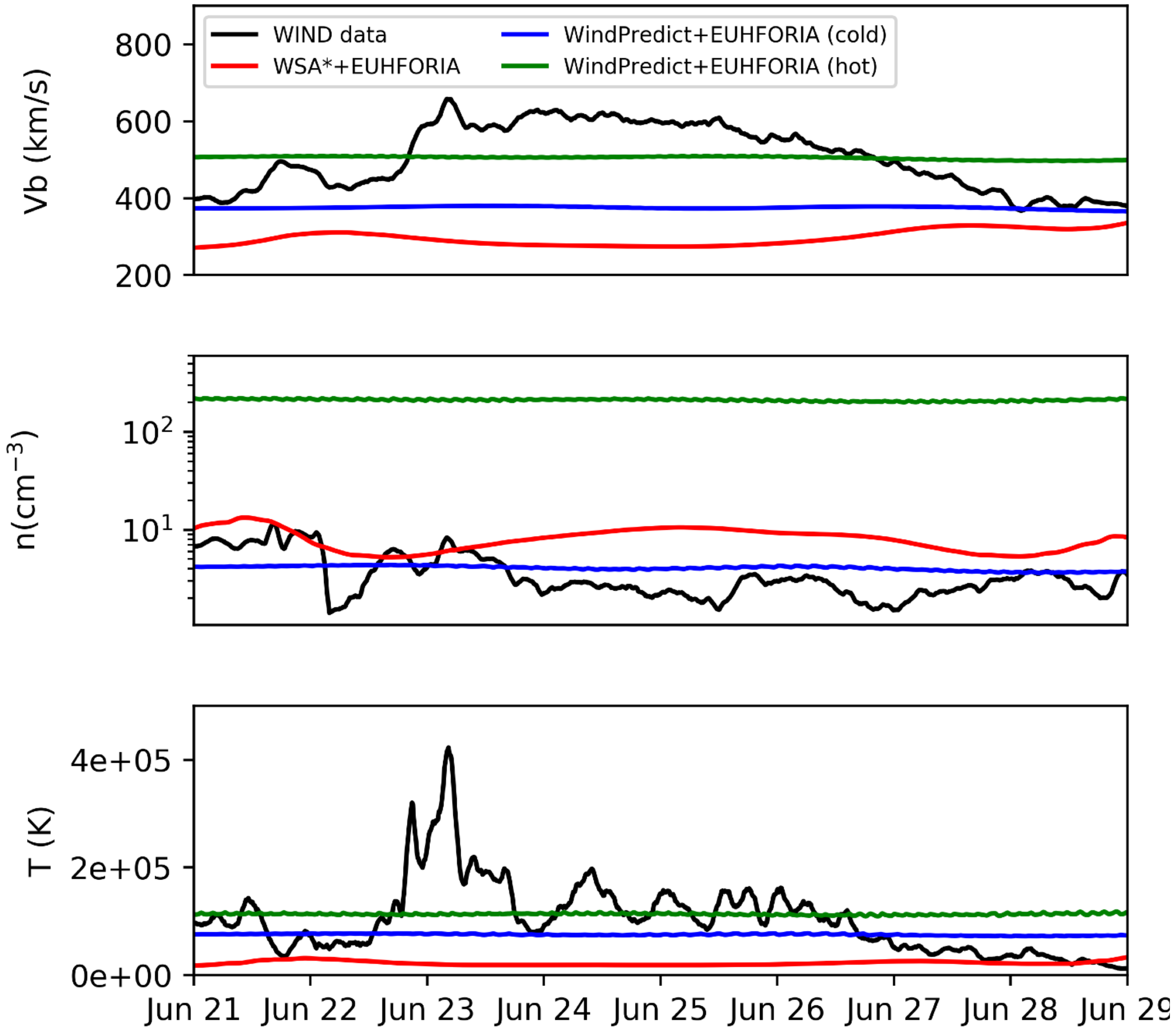


Massively time-consuming (ESA documentation, testing, maintenance)

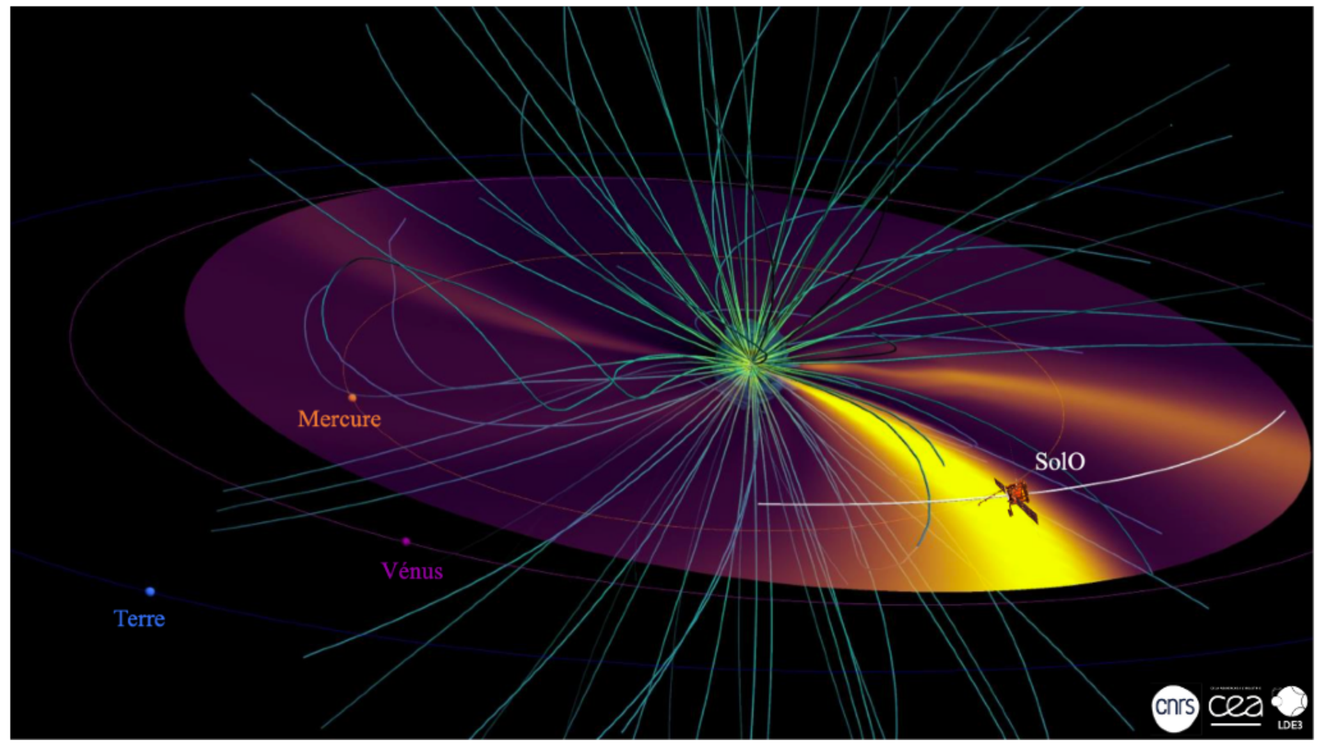
Should be financed as long as ESA maintains VSWMC

Some aspect are generic (code-coupling strategies) but oriented for Space Weather

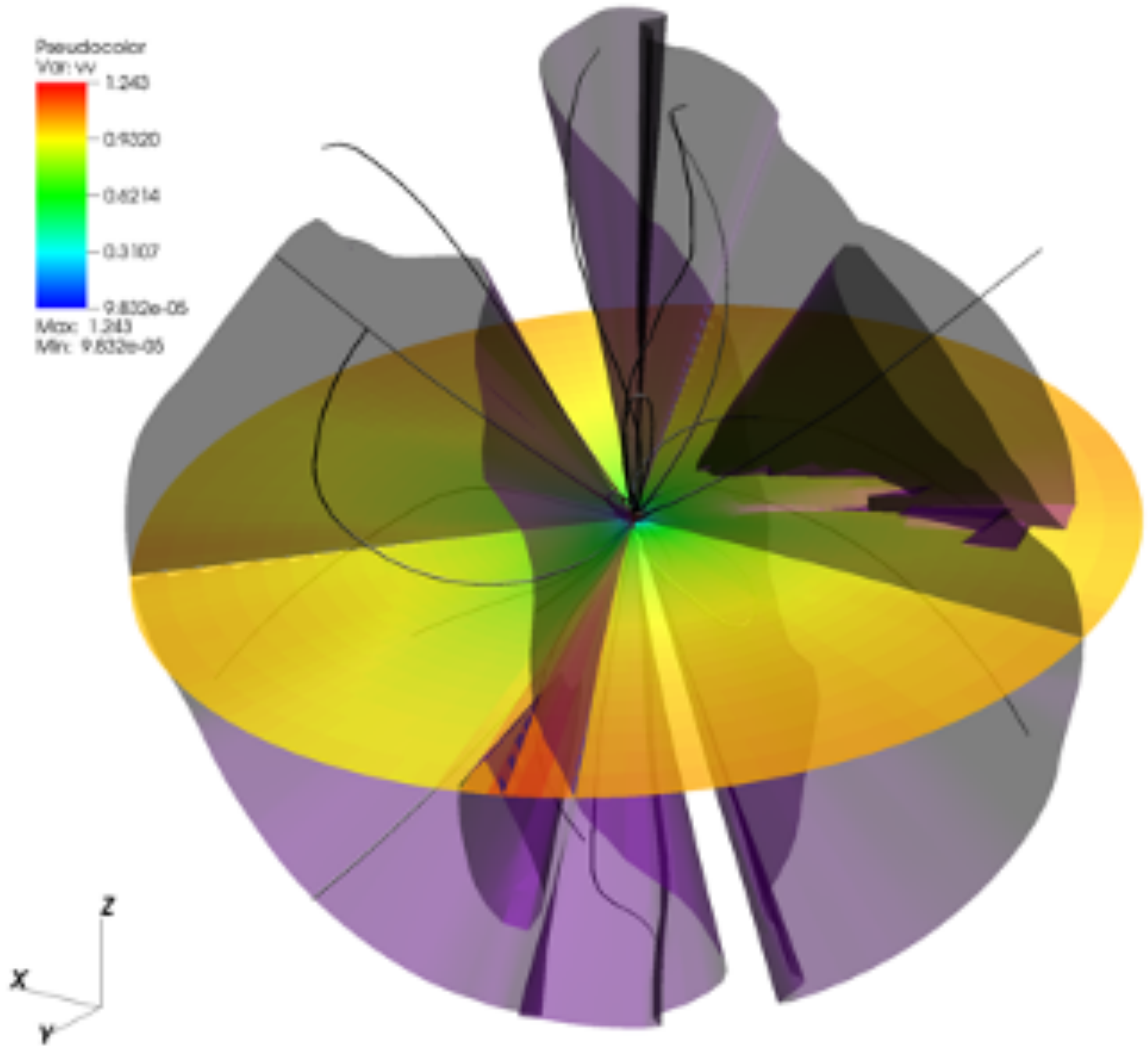
Courtesy of B. Perri

My feedback on attempts to share simulation data and code

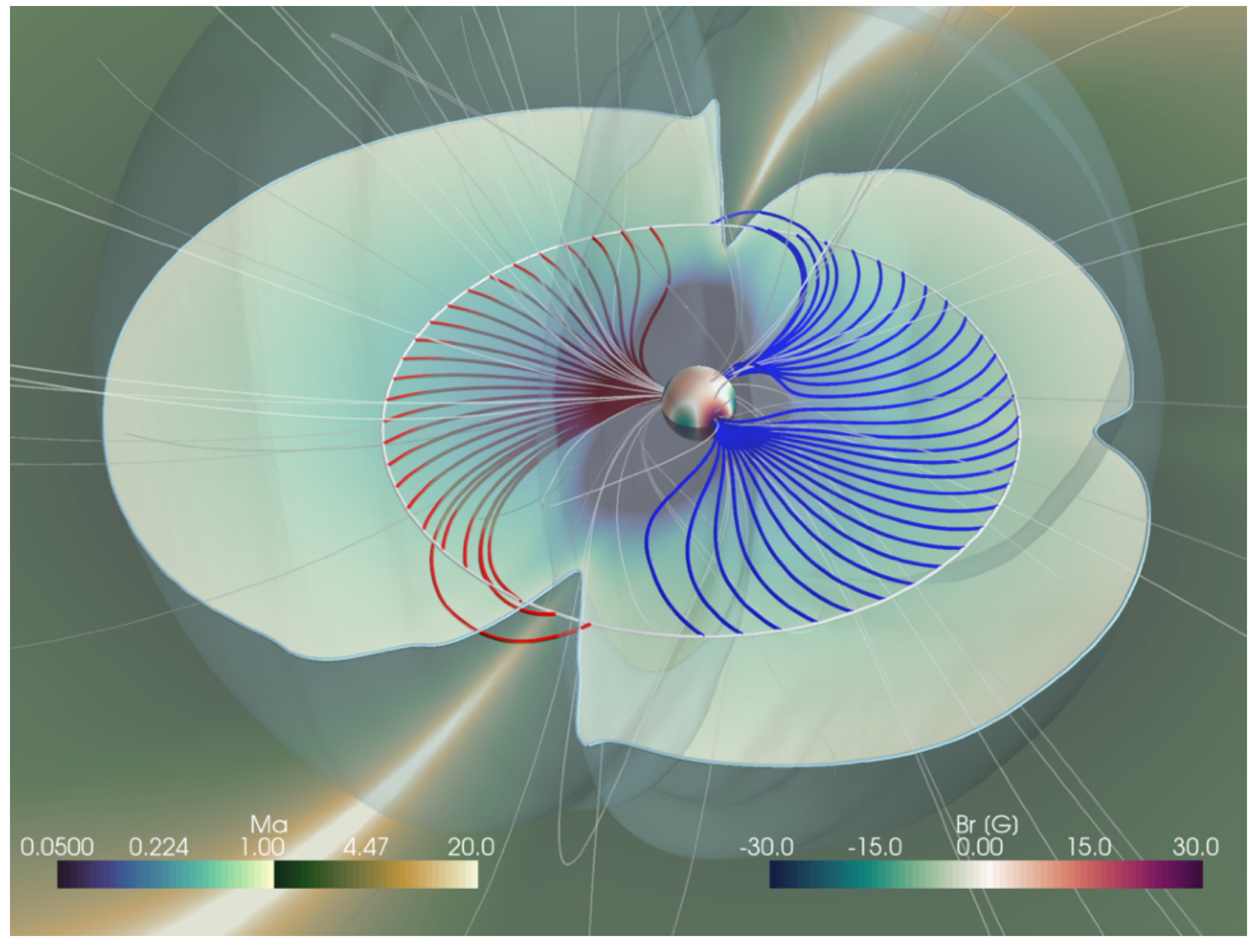
Wind-Predict and the Virtual Space-Weather Modelling Center



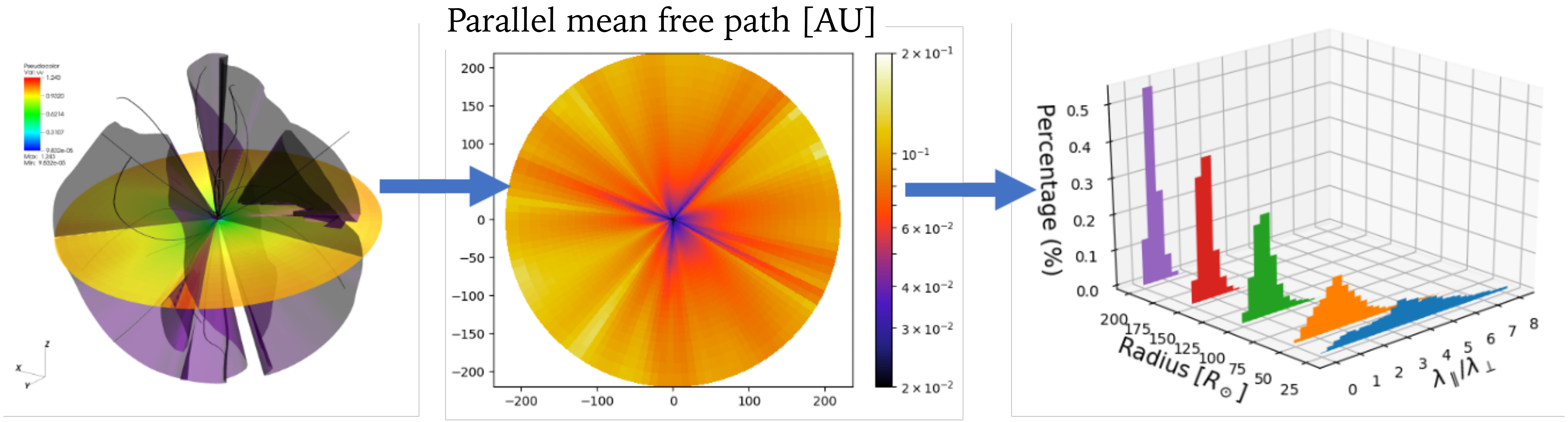
Cosmic ray diffusion coefficient from large-scale wind simulations



Star-planet interaction models



Assessing diffusion coefficients of cosmic rays from wind simulations



We use realistic configurations of min and max of activity to combine all these effects

We derive 3D maps of parallel and perpendicular diffusion + statitics with distance to the Sun

Perri et al. 2018

The MEDOC database

- Created in 1996, as *SoHO data and operations center*
- Since then, *many other solar data sets*, but also *value-added products* and *tools* to use data $\longrightarrow$ facilitate data exploitation

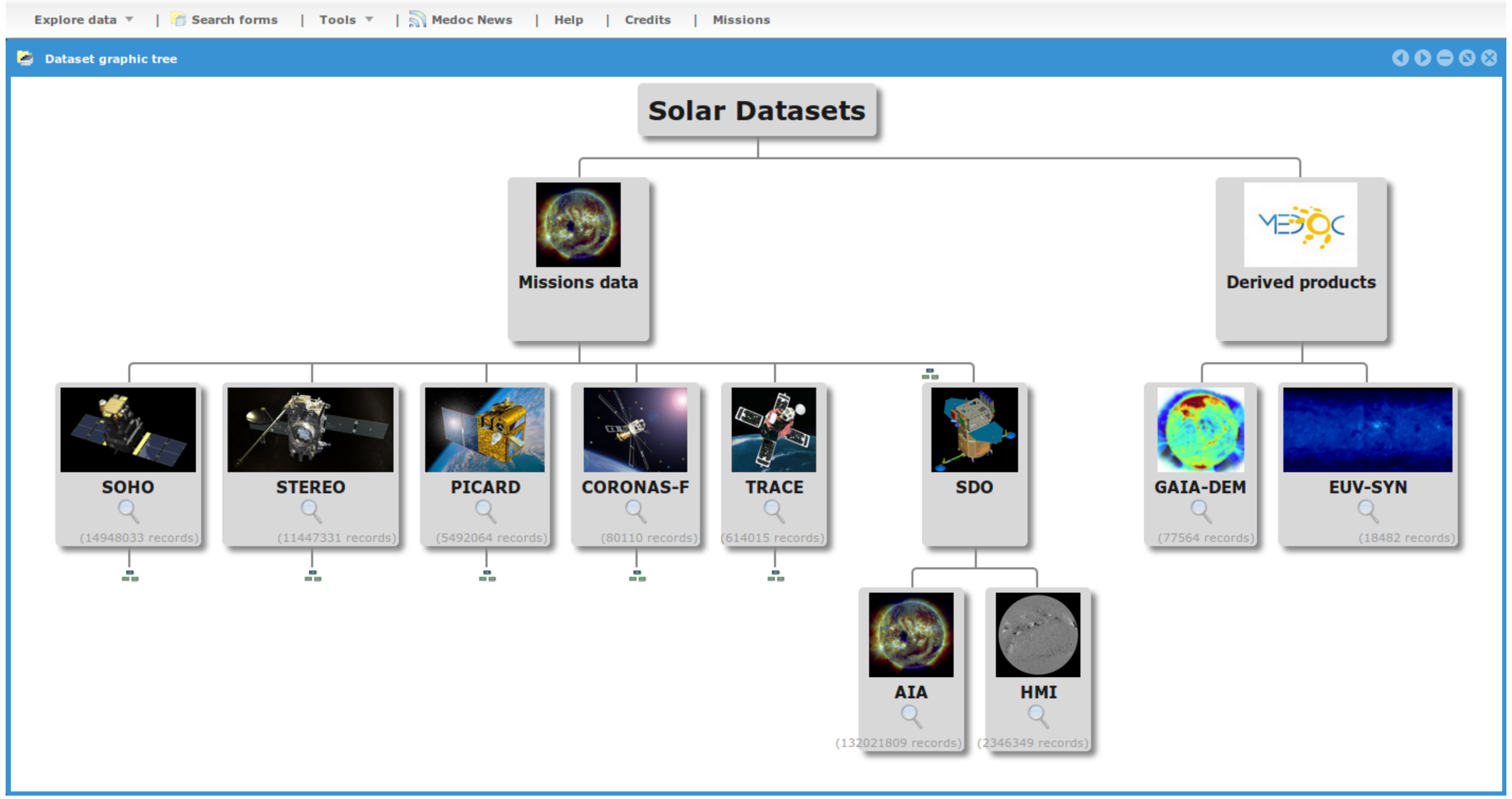
- Funding from CNES, CNRS, Univ. Paris-Saclay. About 6 FTEs work for MEDOC.
- Projects/collaborations: CDPP, BASS2000, Solar Orbiter, ESA/S2P, EC, Paris-Saclay...

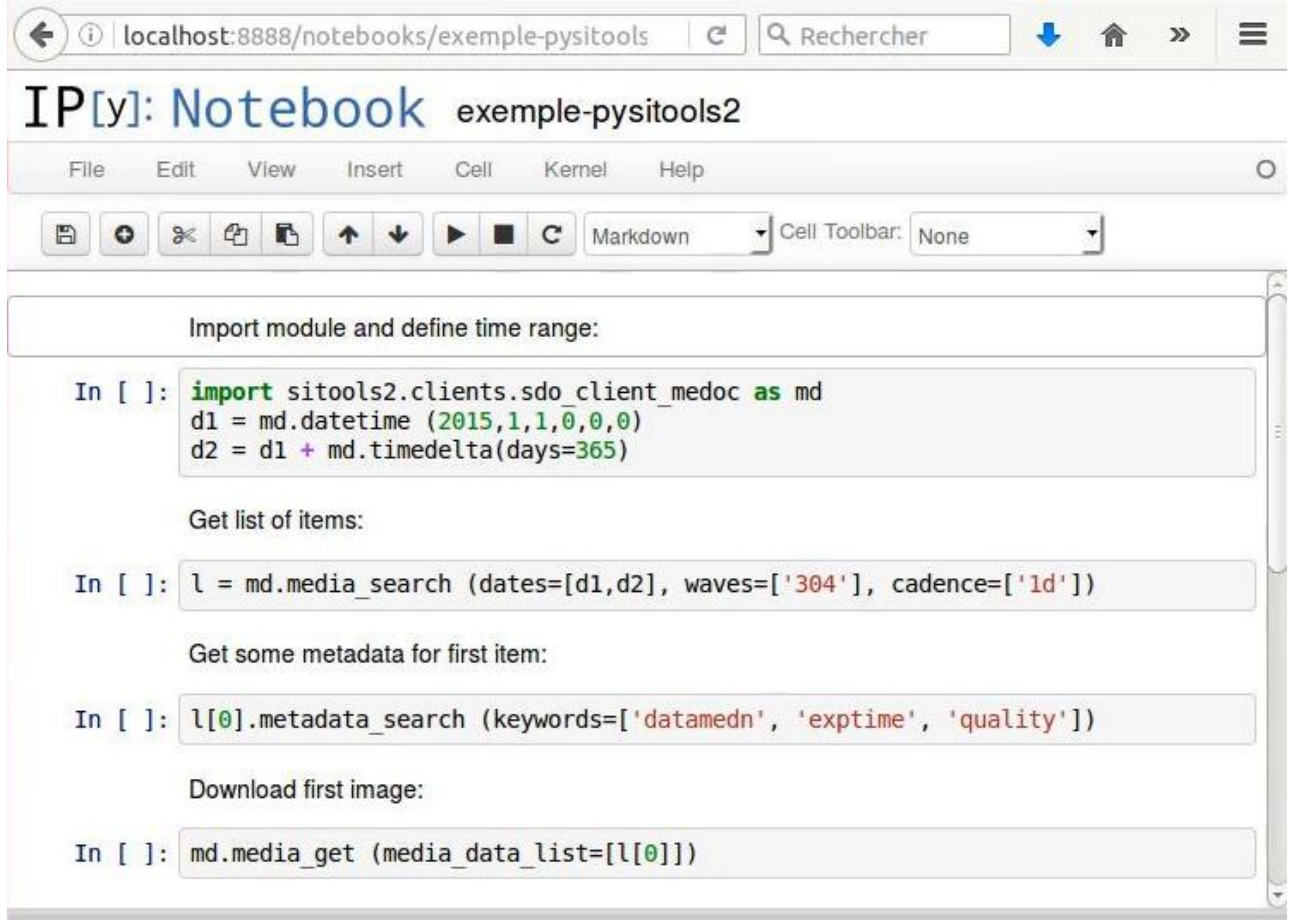
Courtesy of E. Buchlin

The MEDOC database: interfaces for data access

Several interfaces, now mostly regrouped into a unique interface:
`http://idoc-medoc.ias.u-psud.fr/`

- Based on *SiTools2*, developed by CNES; transition planned to REGARDS (CNES).
- Includes web services. MEDOC has developed IDL and Python clients



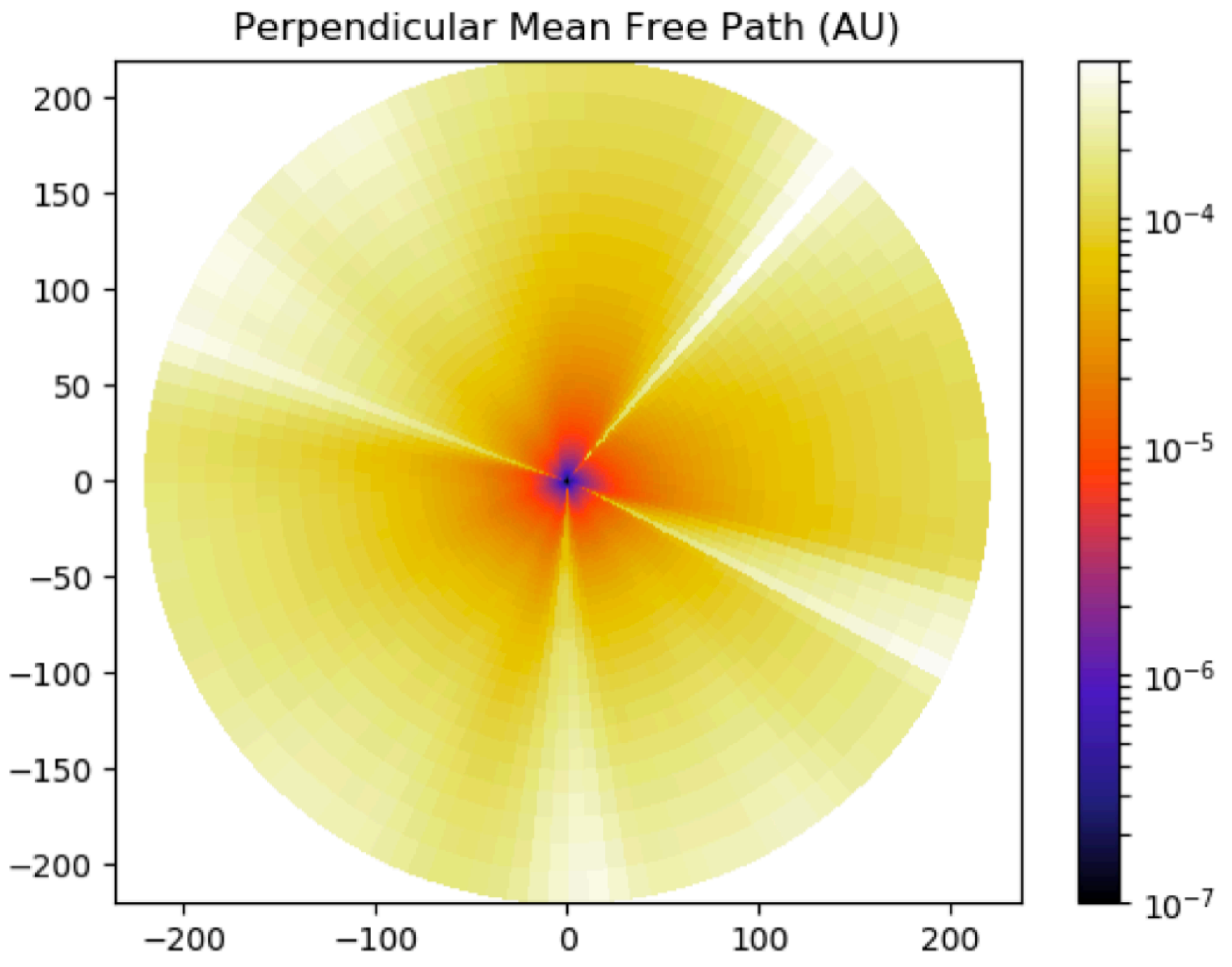


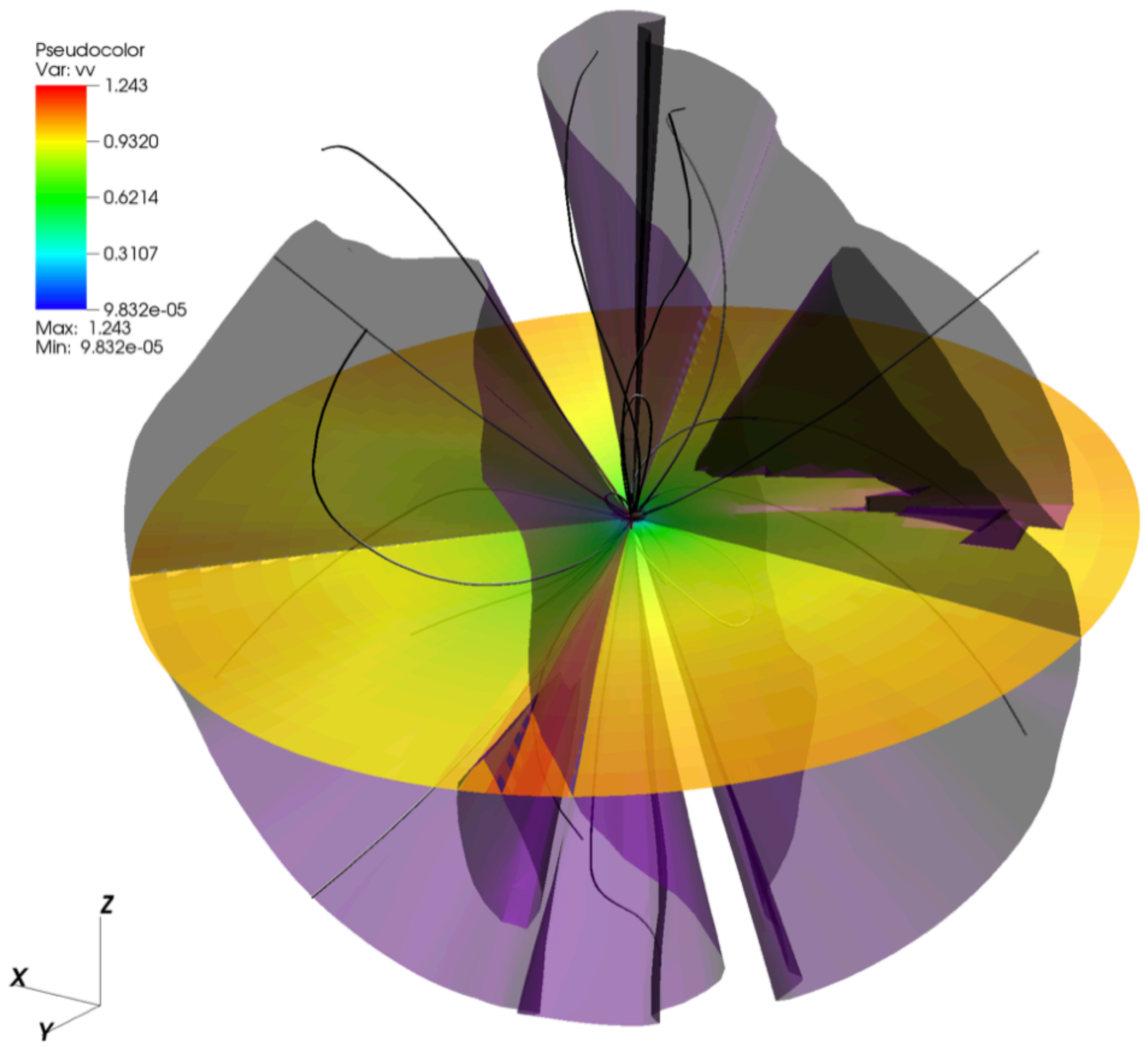
Courtesy of E. Buchlin

The MEDOC database: simulation of the solar wind and cosmic rays

Cosmic rays in simulations of the solar wind

This webpage, hosted at the MEDOC data center, provides output data from MHD simulations performed using the Wind-Predict model (Réville et al. 2015, Perri et al. 2018), based on the PLUTO code (Mignone et al. 2007). They also include cosmic rays diffusion coefficients parallel and perpendicular to the magnetic field lines, computed using a Python post-processing pipeline.





Simulations

This data-set includes 5 simulations: 3 of them performed in 2.5D and 2 of them performed in 3D. All simulations correspond to a relaxed state of the wind for a given magnetic field configuration, there is hence no time evolution.

- The 2.5D simulations are theoretical studies of the influence of the magnetic field on the cosmic rays diffusion: the corona is set at 1.5 MK, and only the magnetic field parameters are changed.
  - Case D1 is a dipole of low amplitude (0.5 G at the surface at the equator).
  - Case Q1 is a quadrupole of low amplitude.
  - Case D10 is a dipole of strong amplitude (5 G at the surface at the equator).
- The 3D simulations are set using synoptic maps of a minimum of activity (October 1995) and a maximum of activity (August 1999), already published in another study (Réville & Brun 2017), and run up to 1 AU. Thus we provide 3D maps of the diffusion coefficient of cosmic rays in the inner heliosphere for realistic complex configurations.

Static webpage

Links to download data and basic reading software

Custom data format, not IVOA-compatible for now.

My feedback on attempts to share simulation data and code

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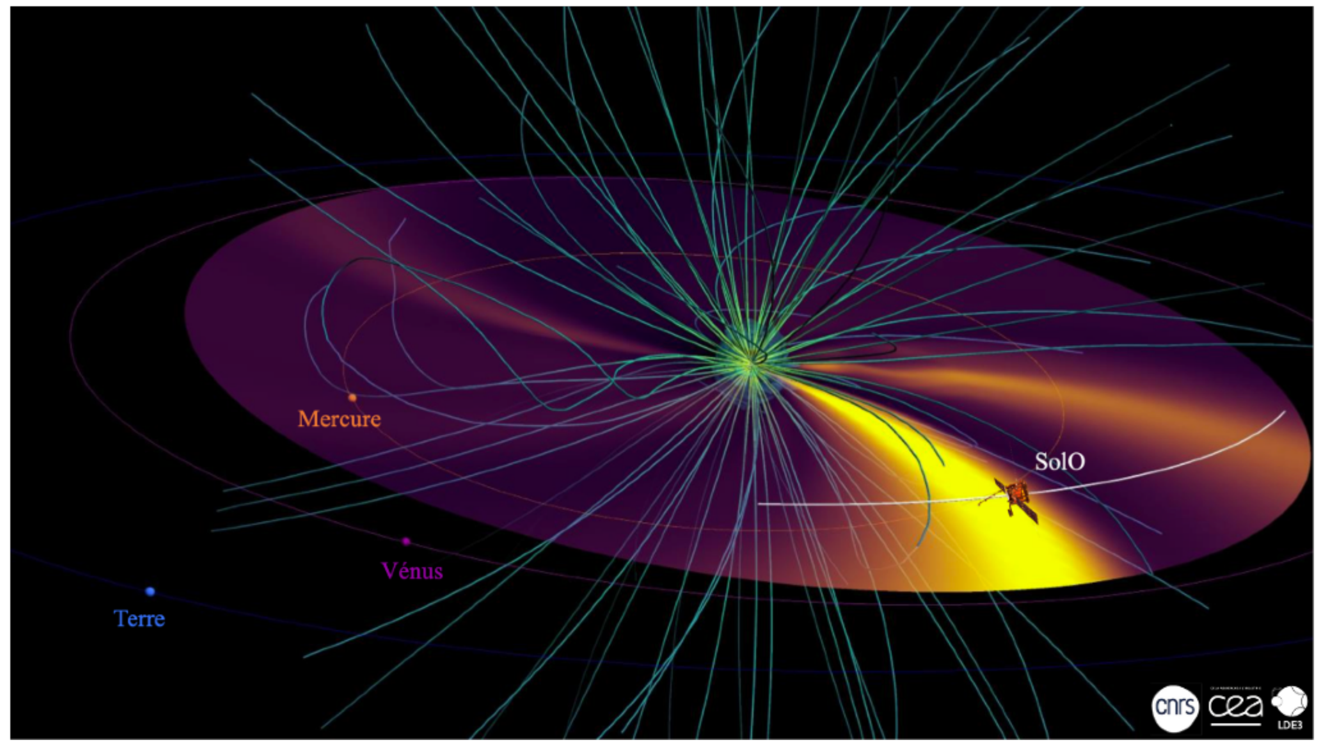

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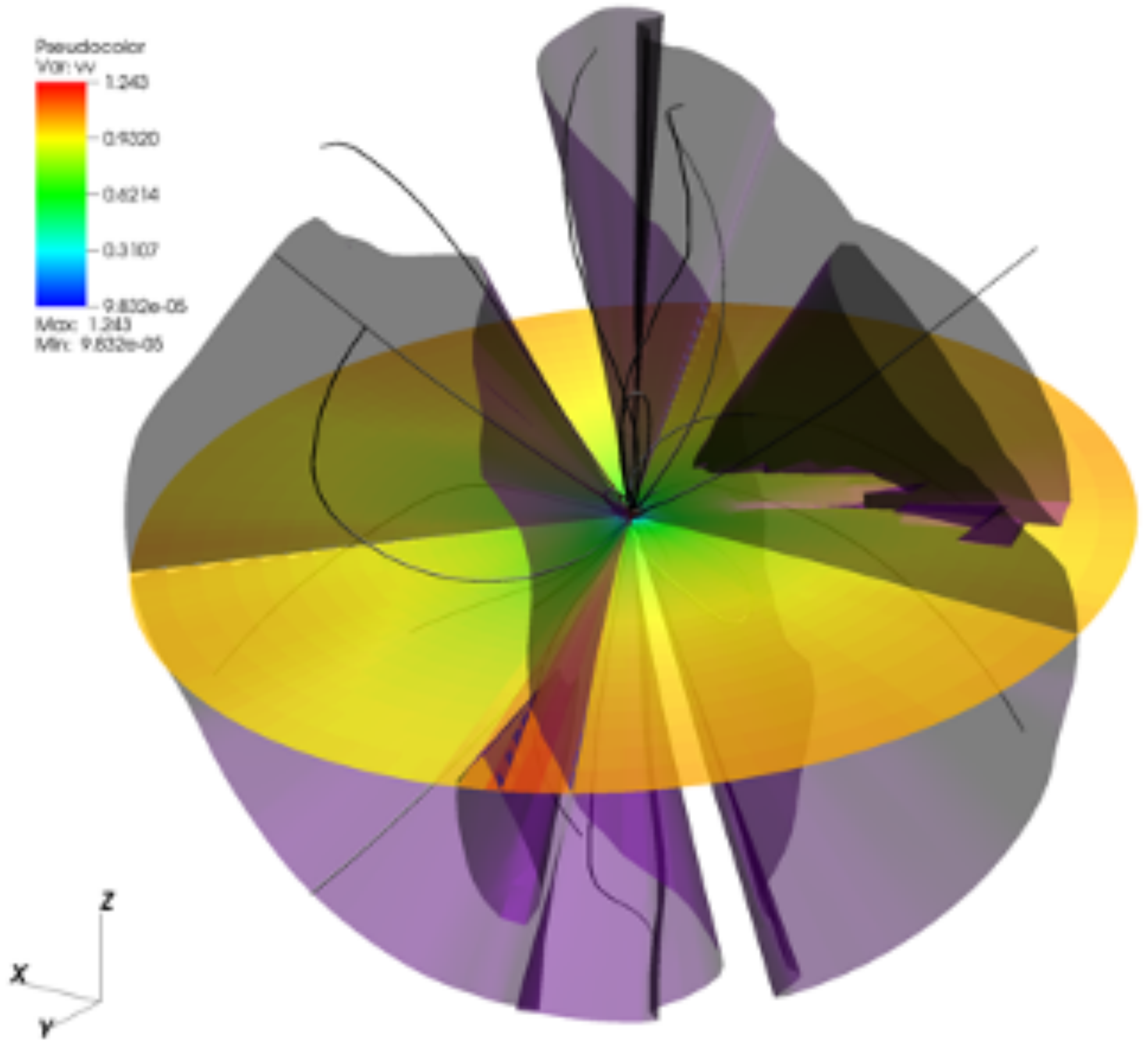
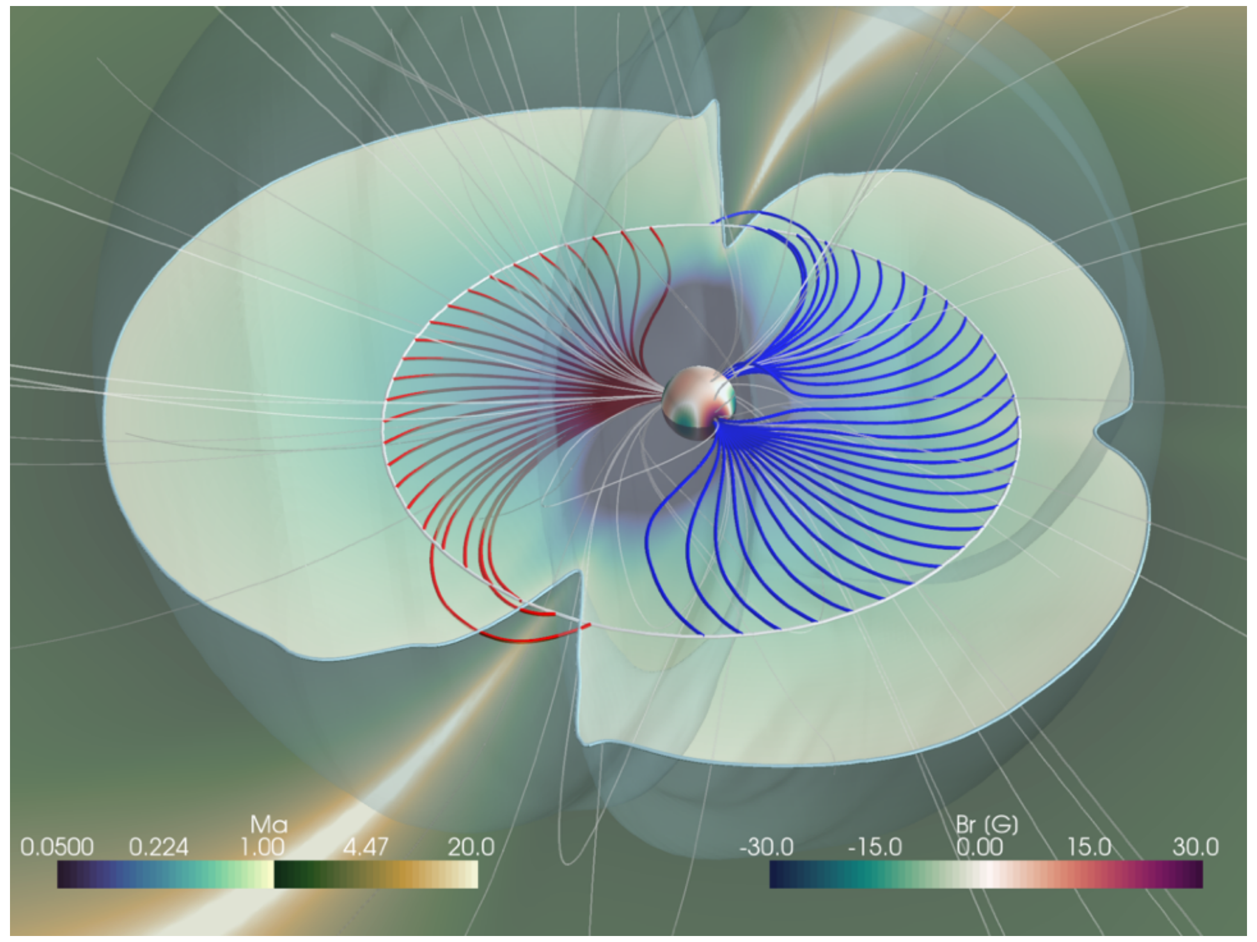
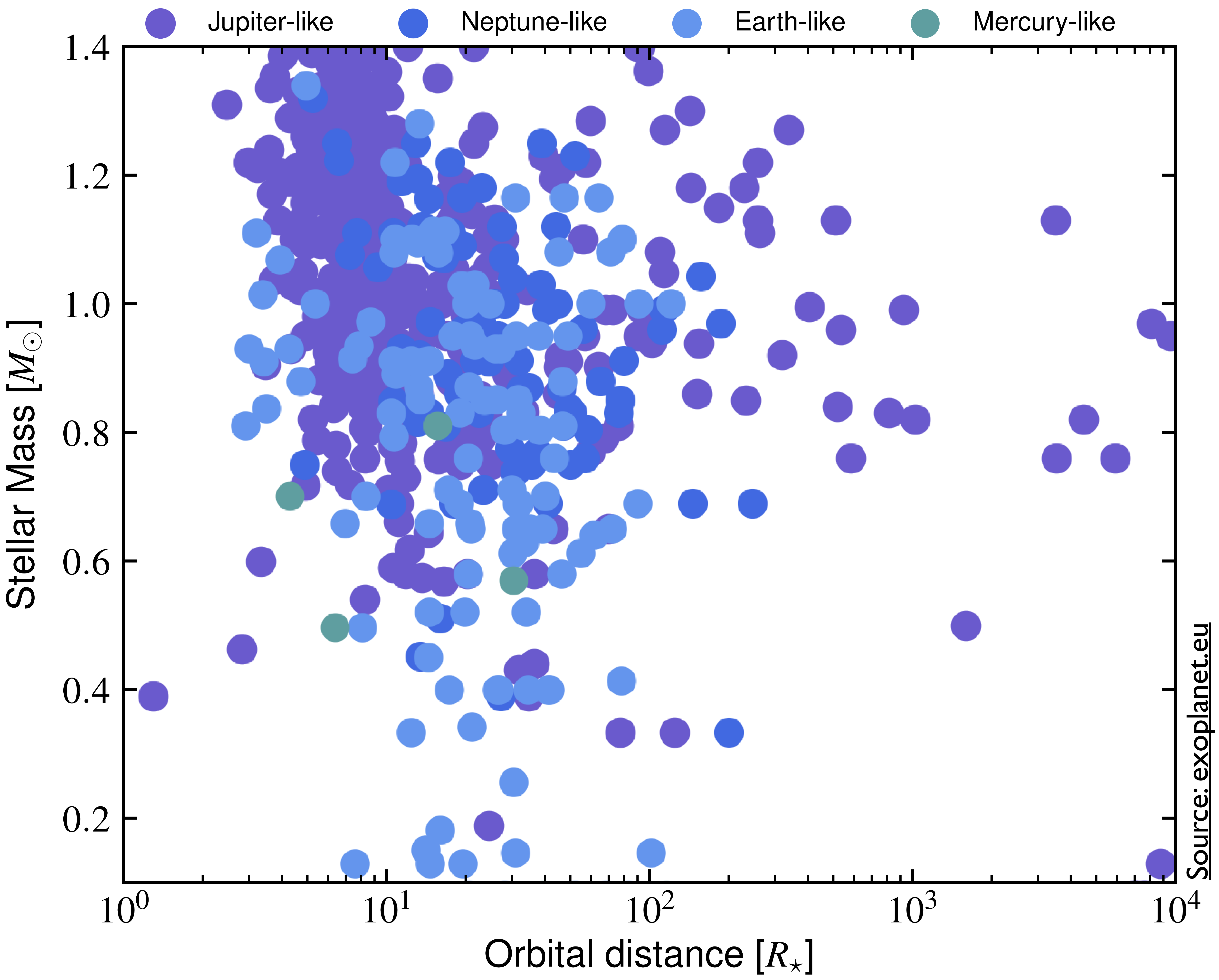


Star-planet interaction models



A view on the exoplanet population



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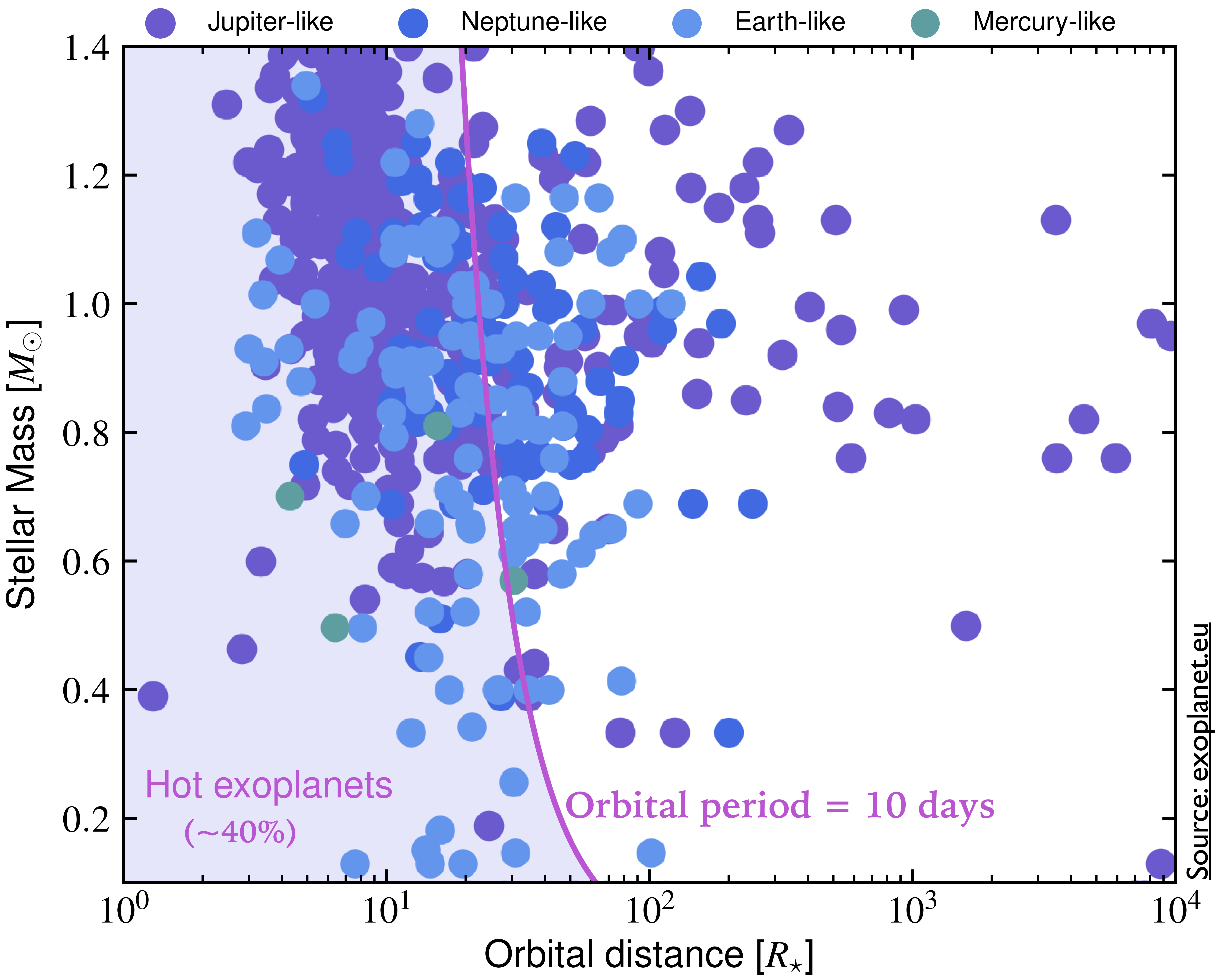

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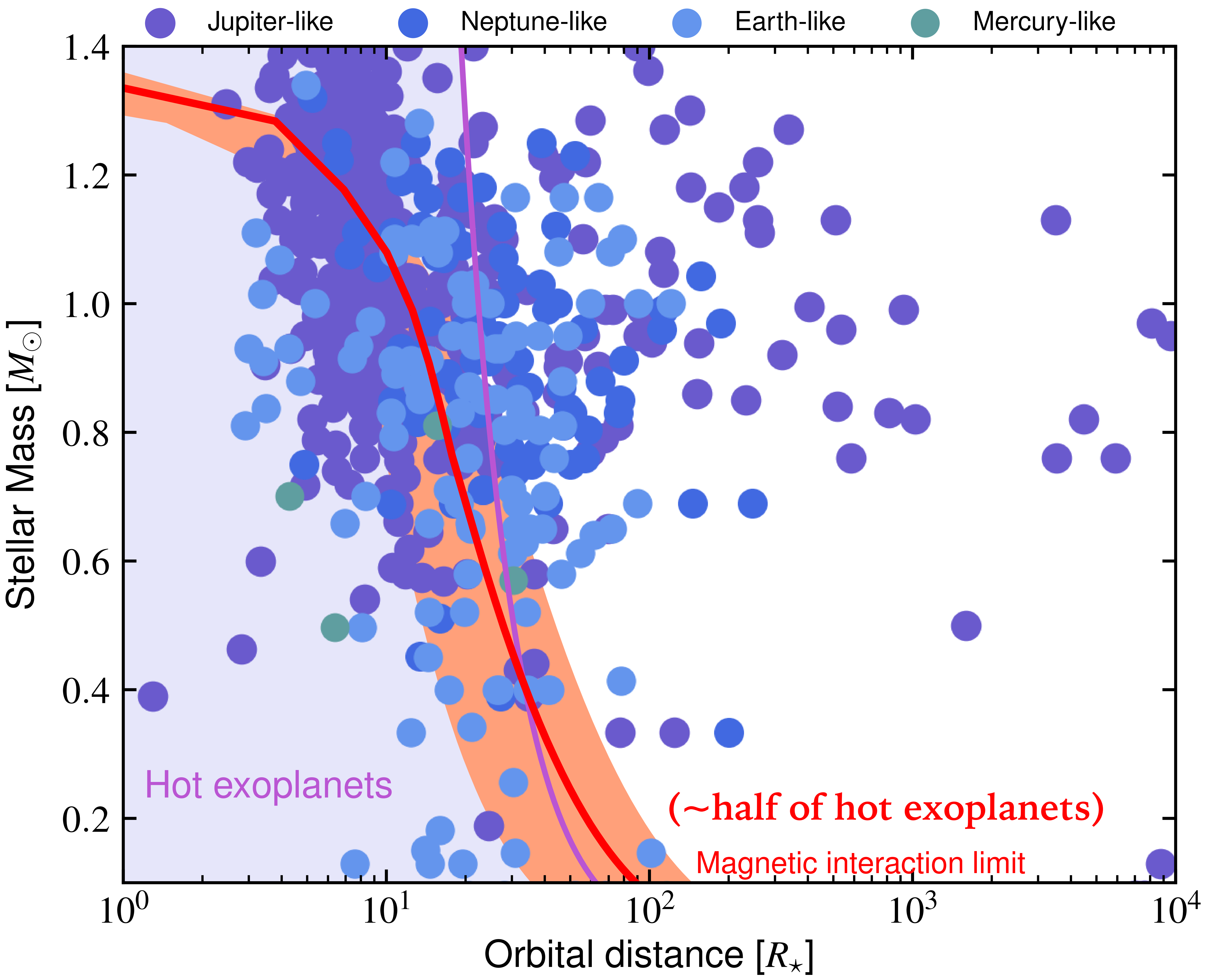

starAML 1D code
Réville+ 2015

Exoplanets-A H2020 project: prediction of exoplanets' environment

EXOPLANETS-A

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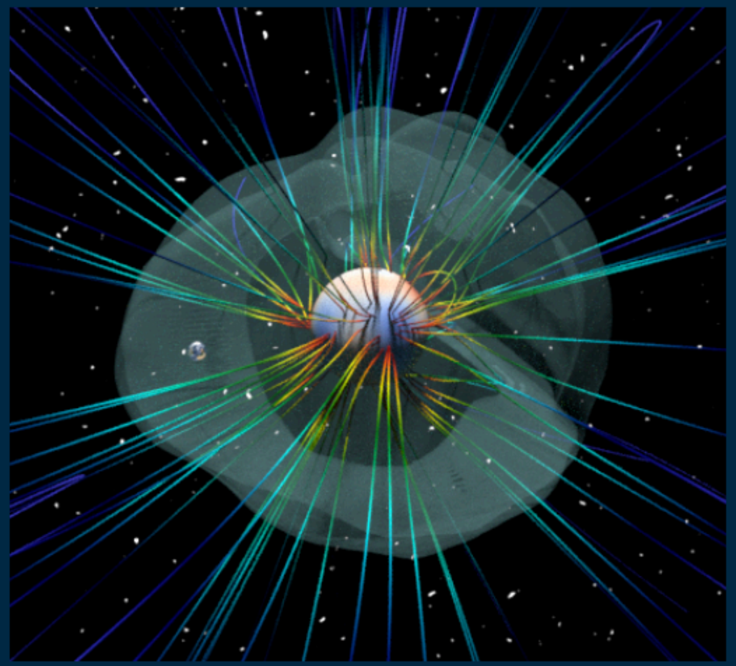
- Space missions
- Codes and Results
- Catalogues
  - Exoplanets & Host stars
  - → Star-planet interactions
- Publications

Home > Exoplanet science > Catalogues > Star-planet interactions

Star-planet interactions

Stars and planets are gravitationally linked. But they interact in many other ways as well: tides, magnetism, winds, irradiation are all factor of star-planet interaction that can affect both the planet and its hosting star.

The star-planet interaction catalogue provides a list of parameters that can be used to assess the strength of these interactions: X and UV stellar flux, plasma conditions at the planetary orbit, tidal dissipation coefficients, among others. The majority of these parameters were estimated thanks to cutting-edge models at the forefront of the research on exoplanetary science.



Numerical simulation of an exoplanet on close-orbit around HD 189733

Credits: CEA/A. STRUGAREK

→ Download Table

→ Download Readme

References:

Strugarek 2018 – Models of Star-Planet Magnetic Interaction

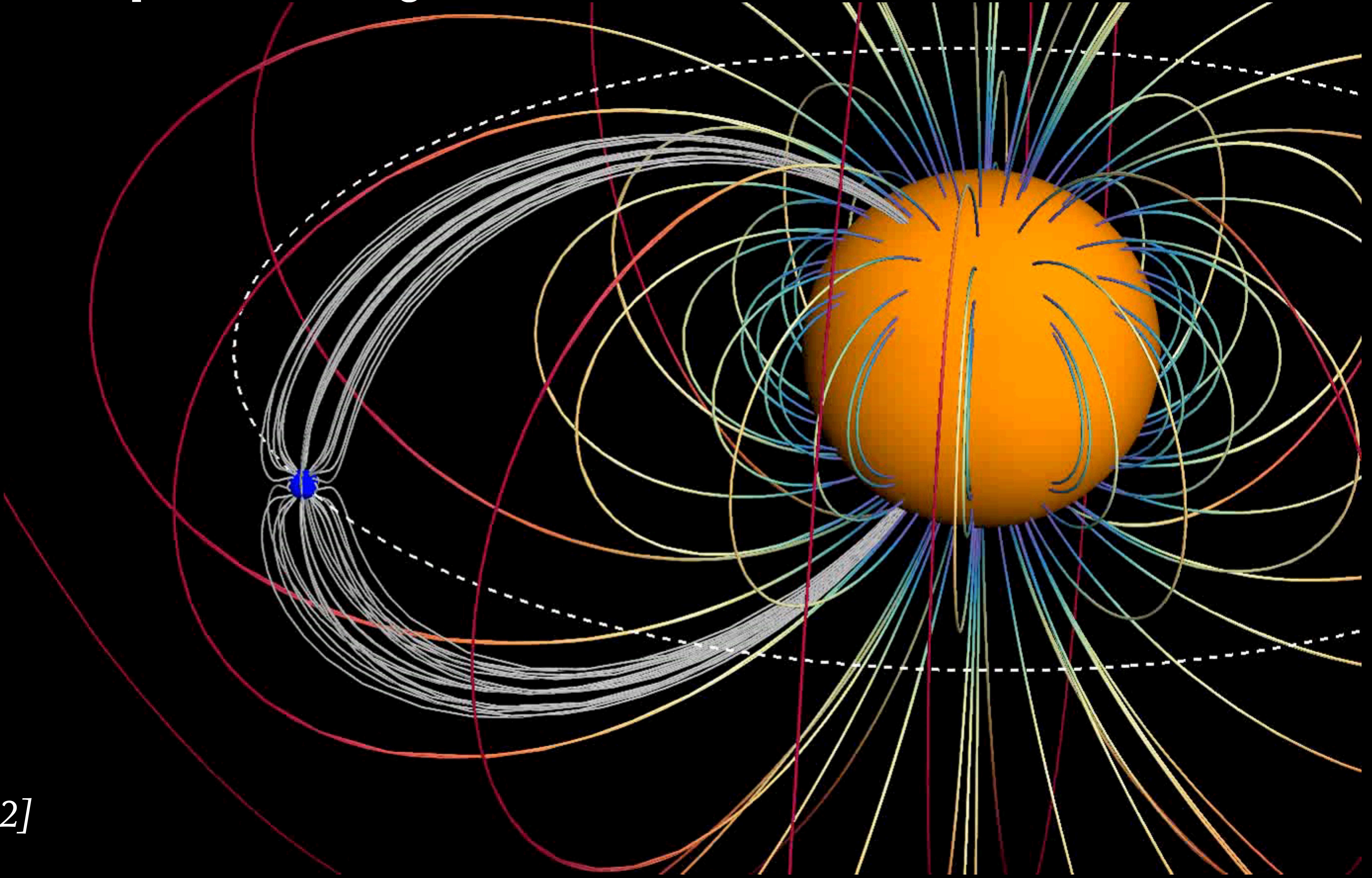
Strugarek et al. 2017 – The Fate of Close-in Planets: Tidal or Magnetic Migration?

Réville et al. 2015 – From Solar to Stellar Corona: The Role of Wind, Rotation, and Magnetism

3D modelling of star-planet magnetic interactions

Ideal and Resistive MHD global simulations

[Strugarek+ 14,15,16,19,22]



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Ideal and Resistive MHD global simulations

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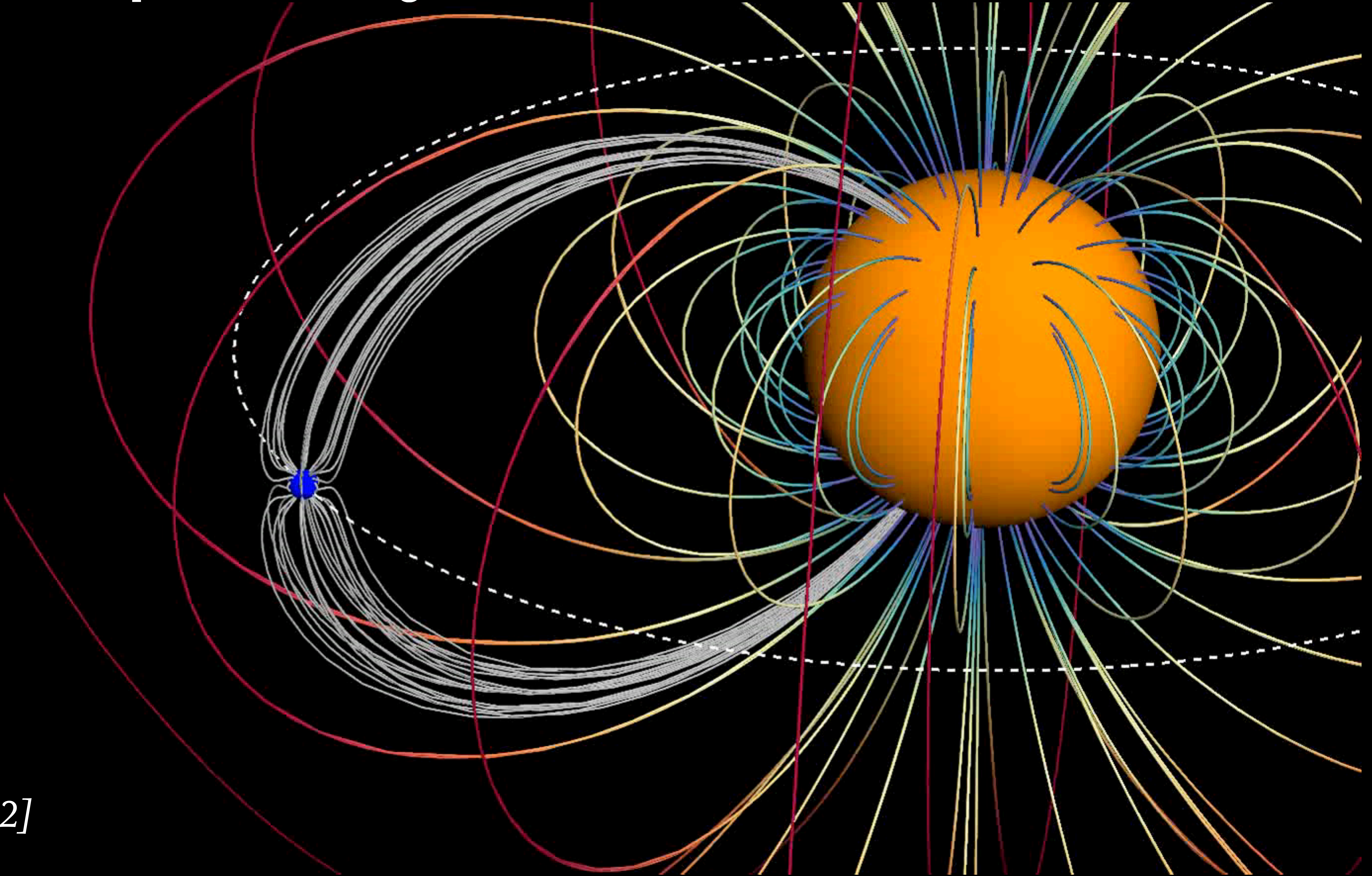
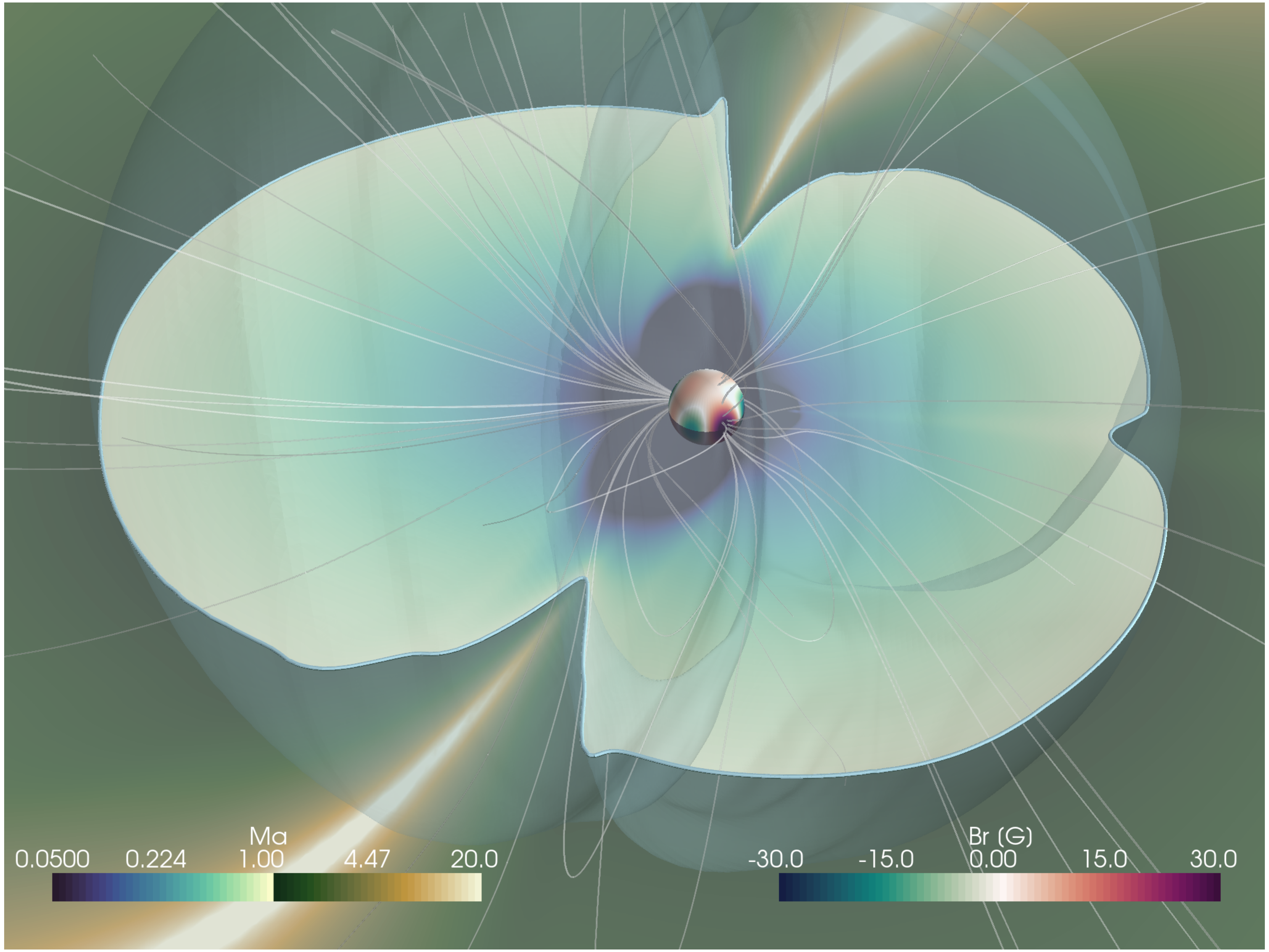


Detailed modelling of HD 189733, August 2013



The hot Jupiter HD 189733b **could orbit within the Alfvén surface**

But the **connectivity is modulated** by the 'complex' **magnetic topology** of the star

-> Need for sharing 3D pre-computed datasets to be easily interfaced

[Strugarek+ 22]

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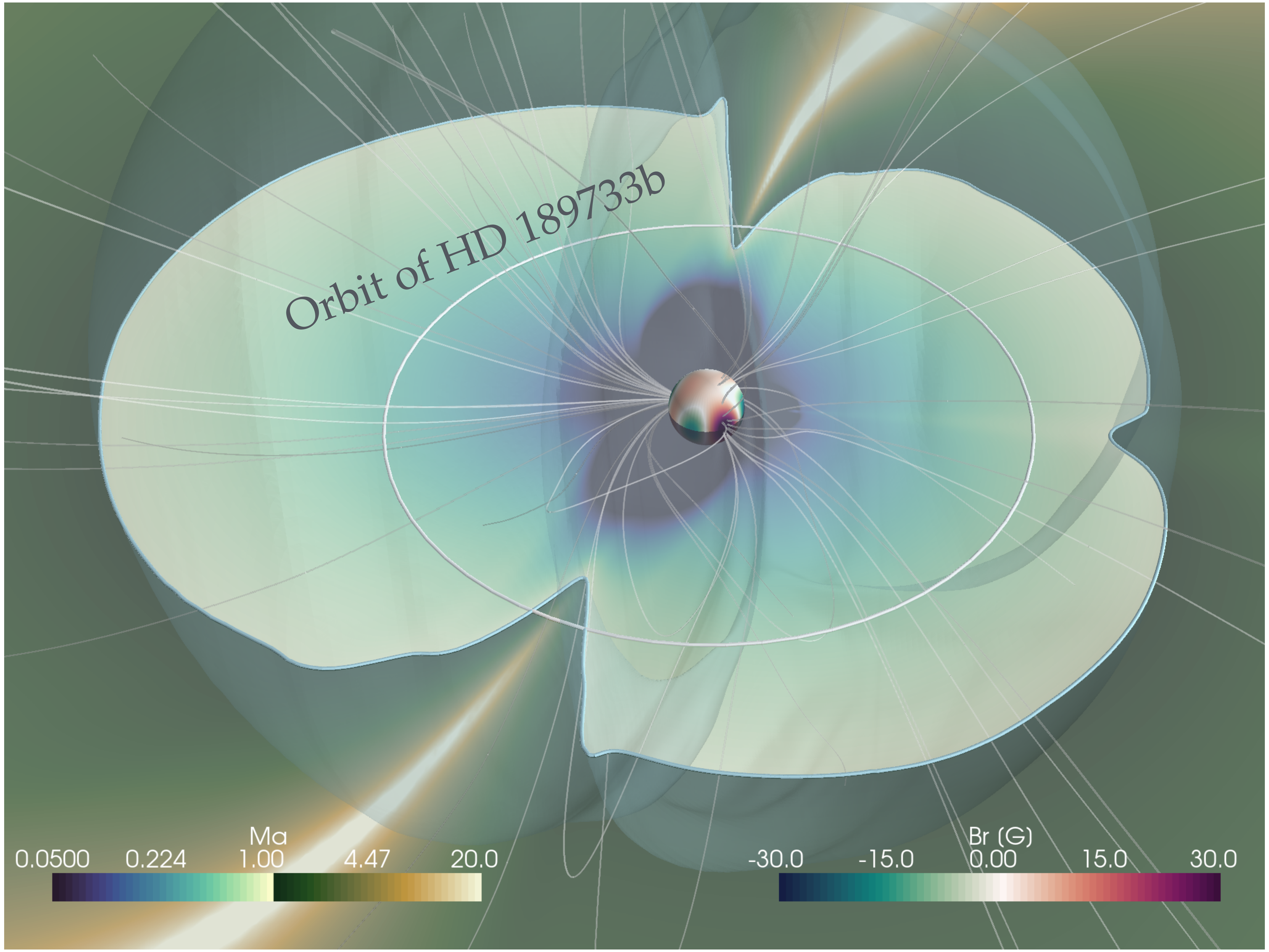

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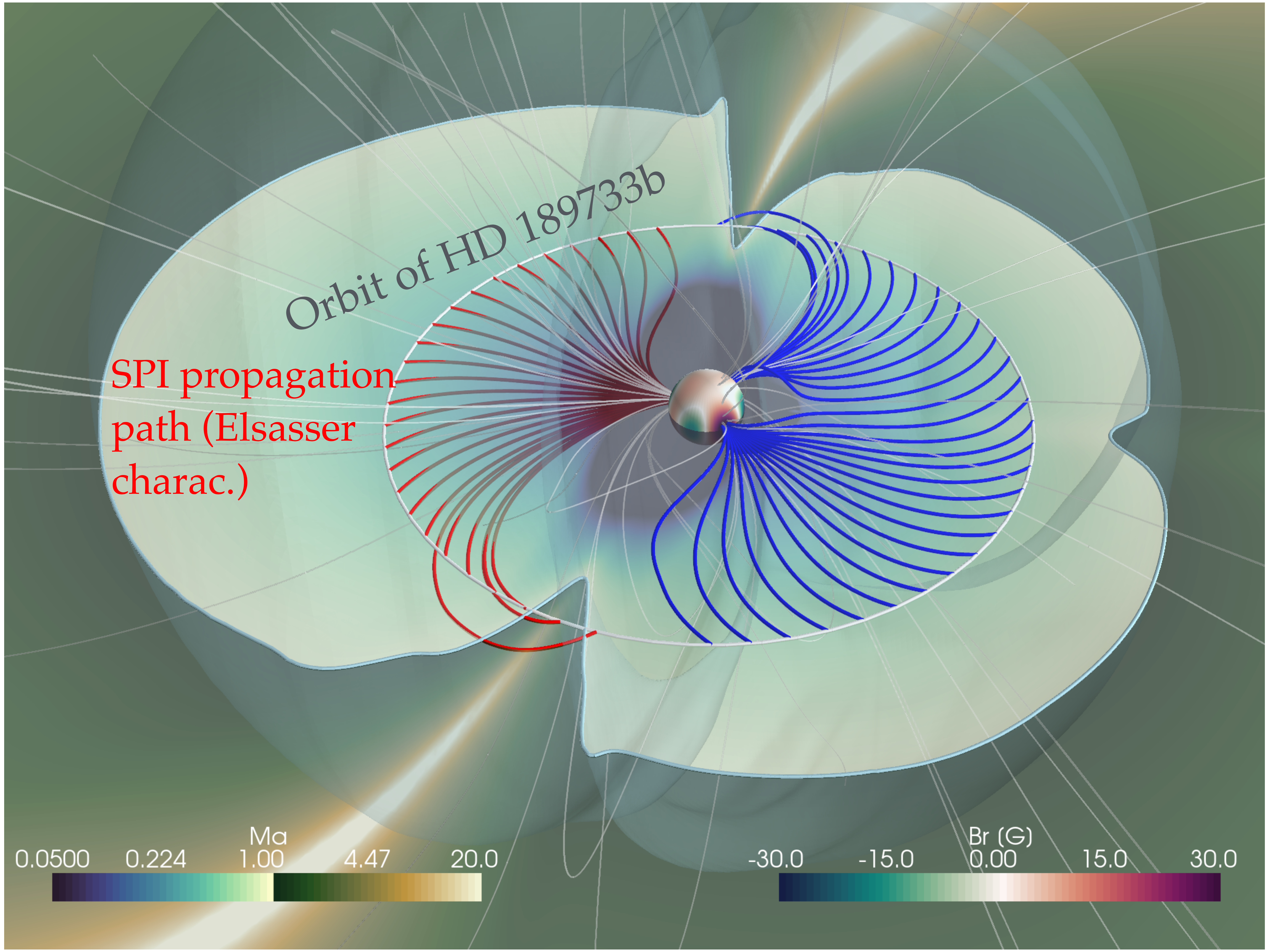
[Strugarek+ 22]

Detailed modelling of HD 189733, August 2013



The hot Jupiter HD 189733b **could orbit within the Alfvén surface**

But the **connectivity is modulated** by the ‘complex’ **magnetic topology** of the star

-> Need for sharing 3D pre-computed datasets to be easily interfaced

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Magnetic interactions in HD 189733

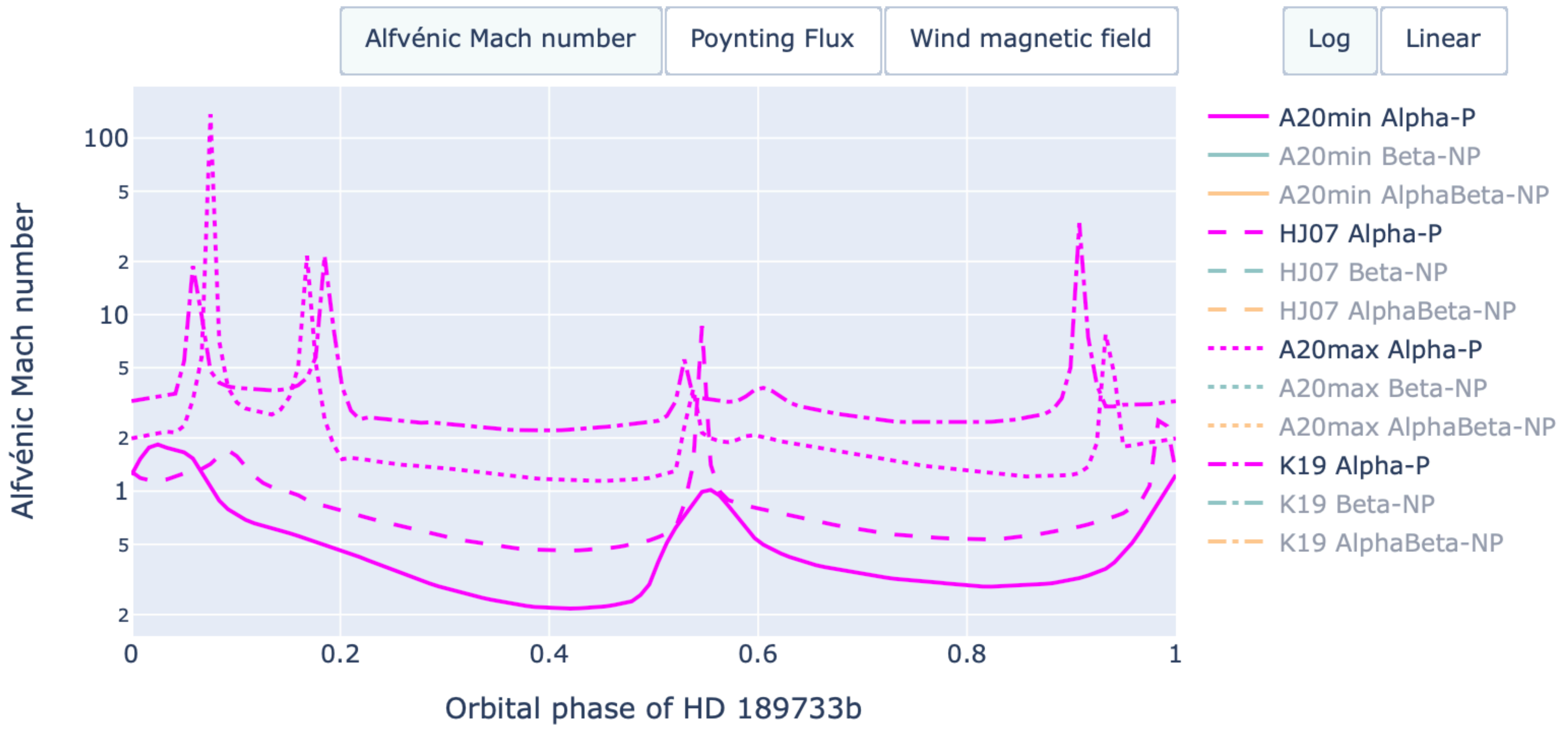
Cite me

Summary

A set of twelve 3D MHD simulations of the environment of HD 189733. This star possesses a hot Jupiter on a close-in orbit. We provide the tools to extract the stellar wind quantities along the planetary orbit. The set of simulations is decomposed into

- 3 different magnetic field extrapolation methods ($\alpha-\mathrm{P}$ [Alpha-P], $\beta-\mathrm{NP}$ [Beta-NP], $\alpha\beta-\mathrm{NP}$ [AlphaBeta-NP])
- Four different (density, temperature) at the base of the corona of HD 189733 (A20min, HJ07, A20max, K19)

The following interactive plot allows a quick browse of the models.



Hurdles

- In the past, no incentive to share the data which is a **time-consuming** activity
- Data can be sometimes too large to be shared easily
- Standard can evolve fast and tools appear/disappear, not always easy to maintain a given solution
- Fear of giving away byproducts to be published by others

Some Solutions

- **Mandatory** sharing is the upcoming norm. What about more **positive ways to incentivise** (e.g. bonus of computing hours for projects that share their data?)
- If the data is too large and/or only accessible through a secured network: **solutions exist**, e.g. Galactica architecture
- Publish **data with DOI or something equivalent**, that could be referenced in ADS like simbad objects for instance
- Encourage to use the same tools for day-to-day analysis and sharing format/tools