The importance of time-dependent MHD solar wind simulations in the frame of the PUNCH mission

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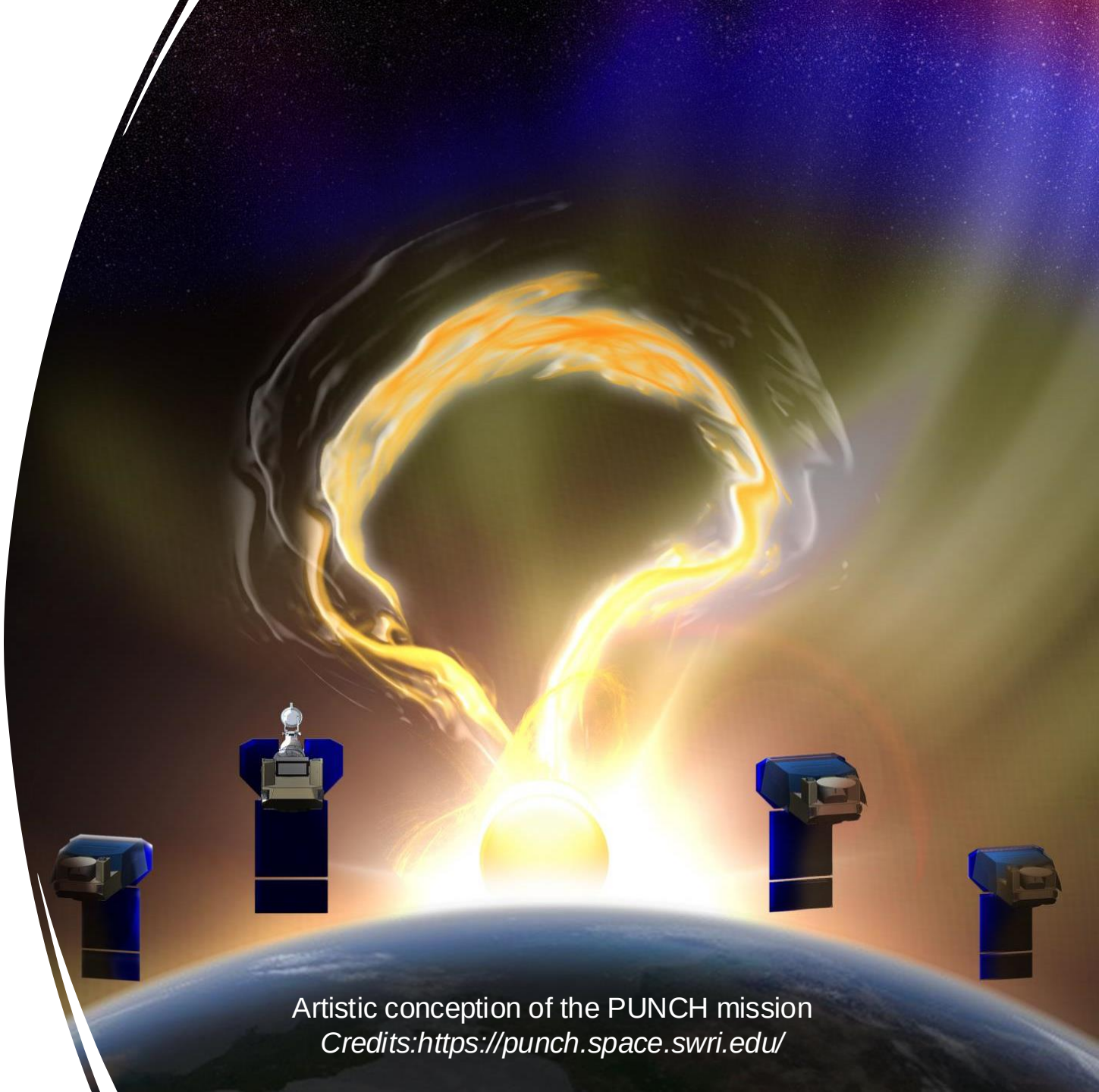


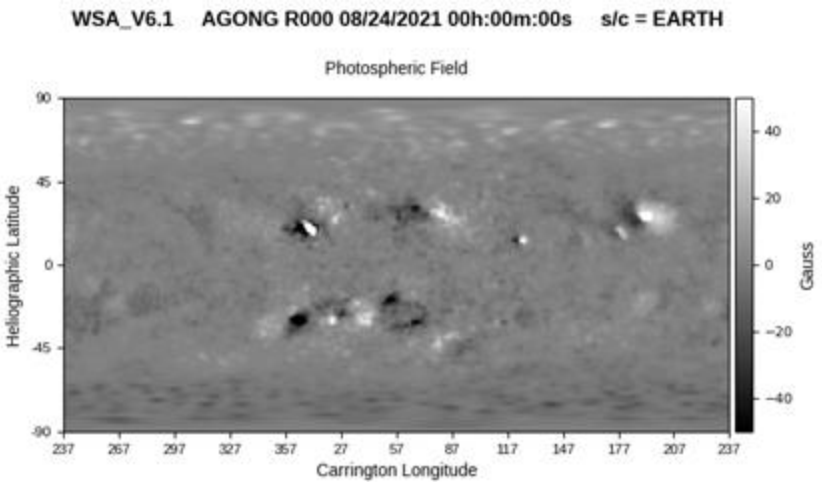
Artistic conception of the PUNCH mission
Credits:https://punch.space.swri.edu/

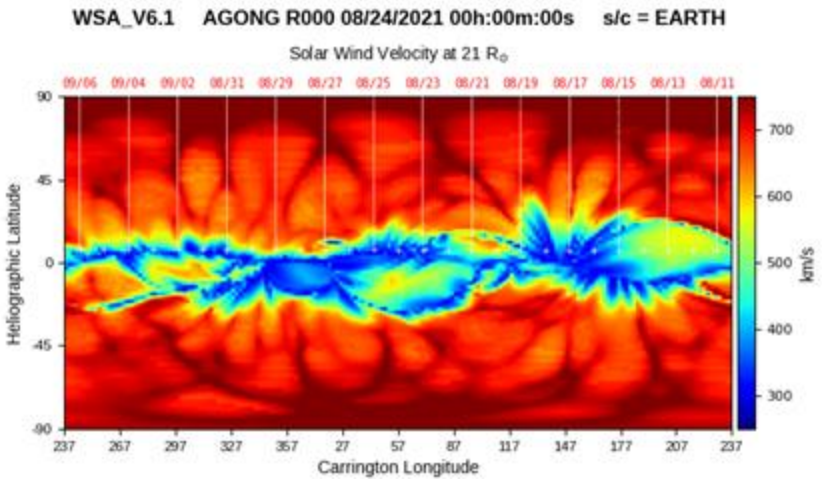
Time dependent MHD simulations with WSA + GAMERA-Helio

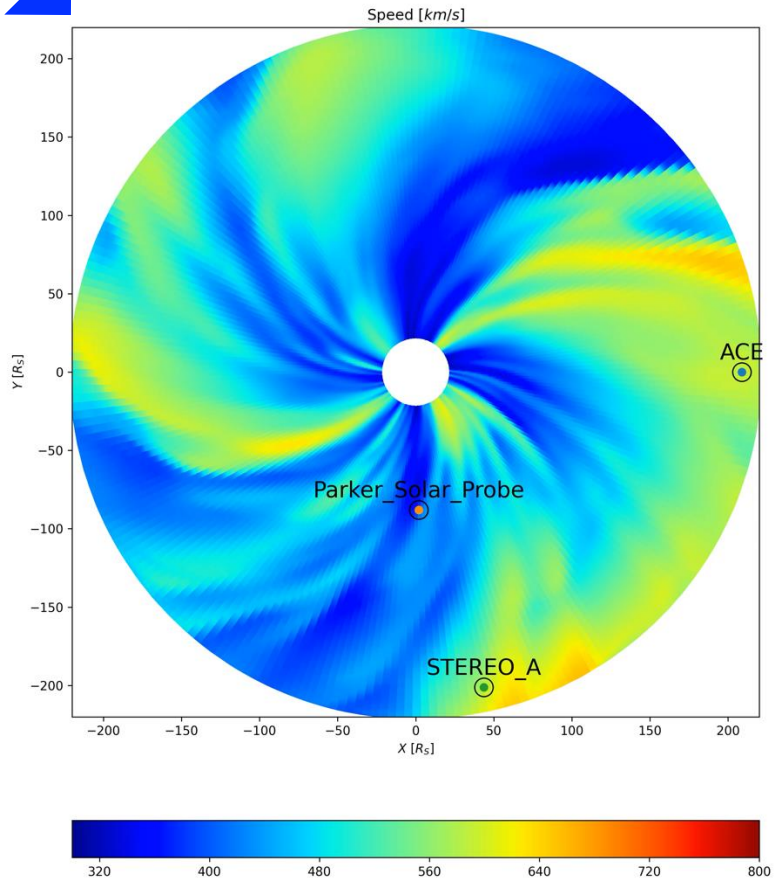
Multiple GONG/ADAPT photospheric maps (24h, 12h, 6h, 2h cadence)

Multiple WSA solutions

GAMERA-Helio dynamic solar wind







For WSA: see Arge+2003; 2004

For GAMERA: Merkin+2016, Zhang+2019, Mostafavi+2022, Provornikova+2024,

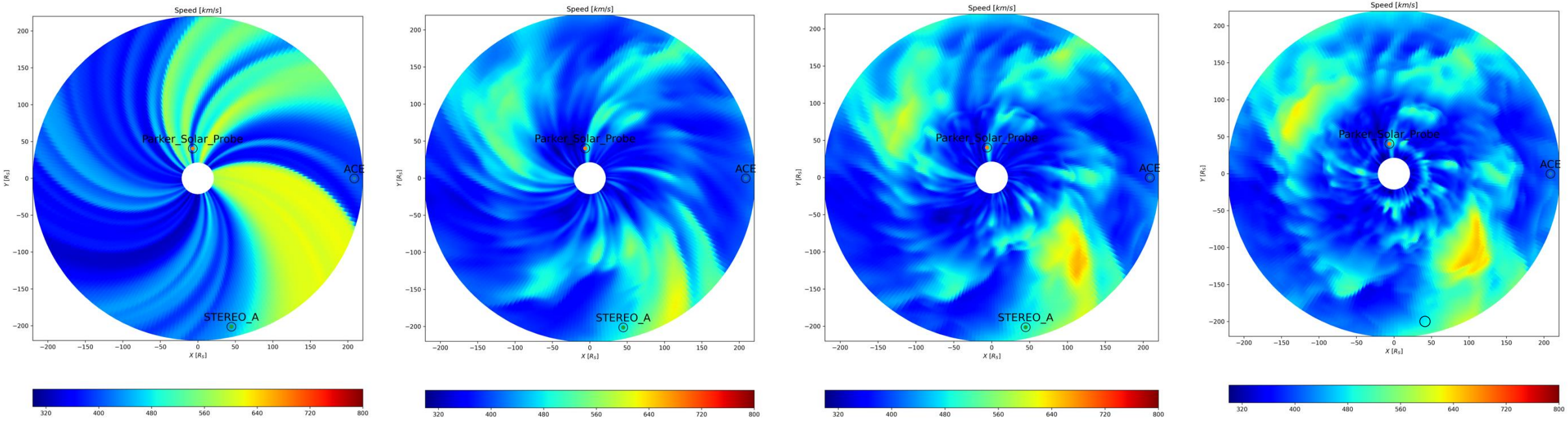
Steady-state vs time-dependent solar wind *(Samara et al., in prep.)*

Steady-state (magnetogram on 2020-01-26)

Time-dependent (**24h** updating cadence)

Time-dependent (**6h** updating cadence)

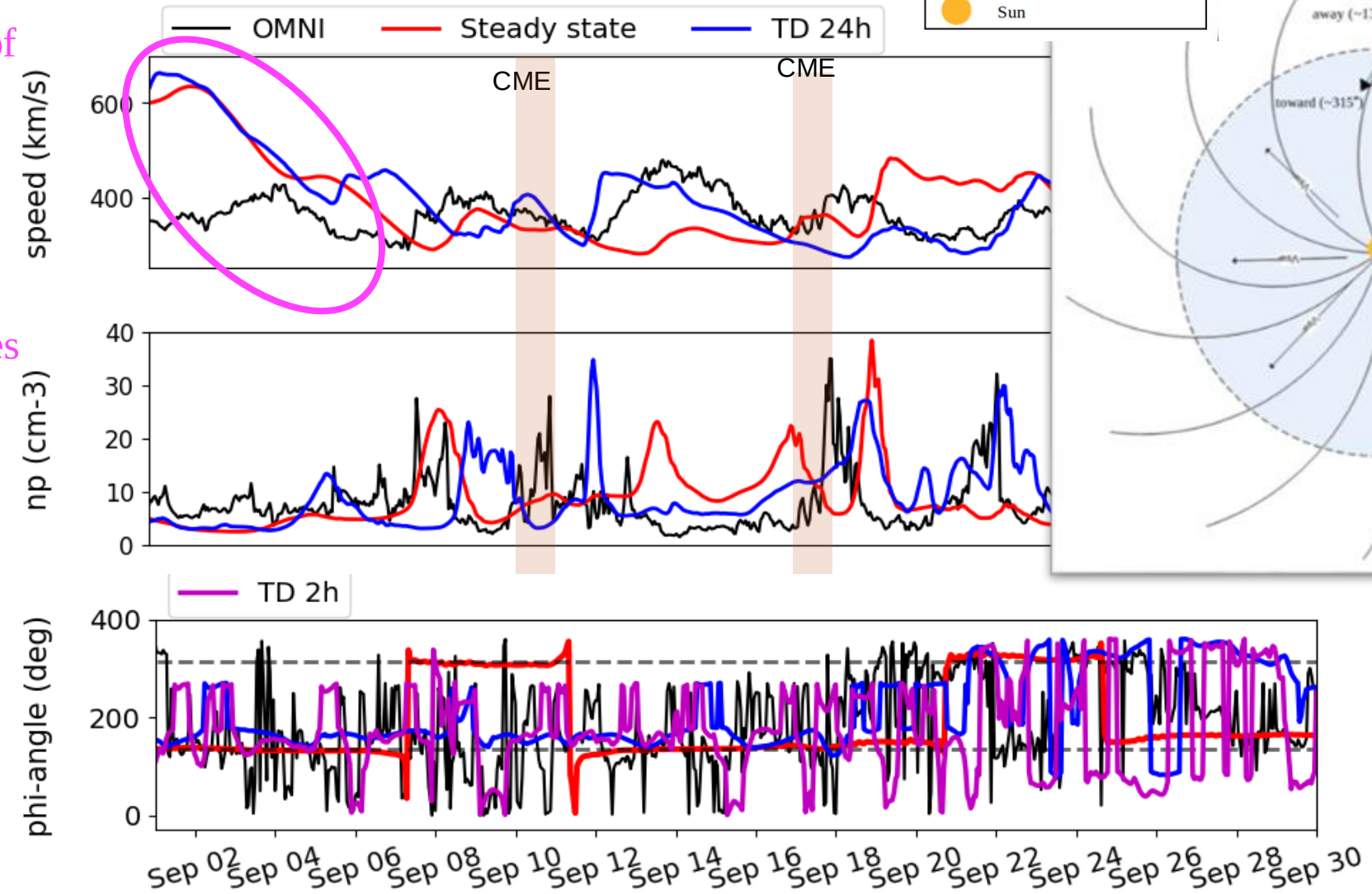
Time-dependent (**2h** updating cadence)

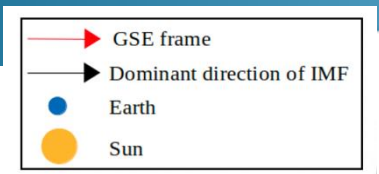


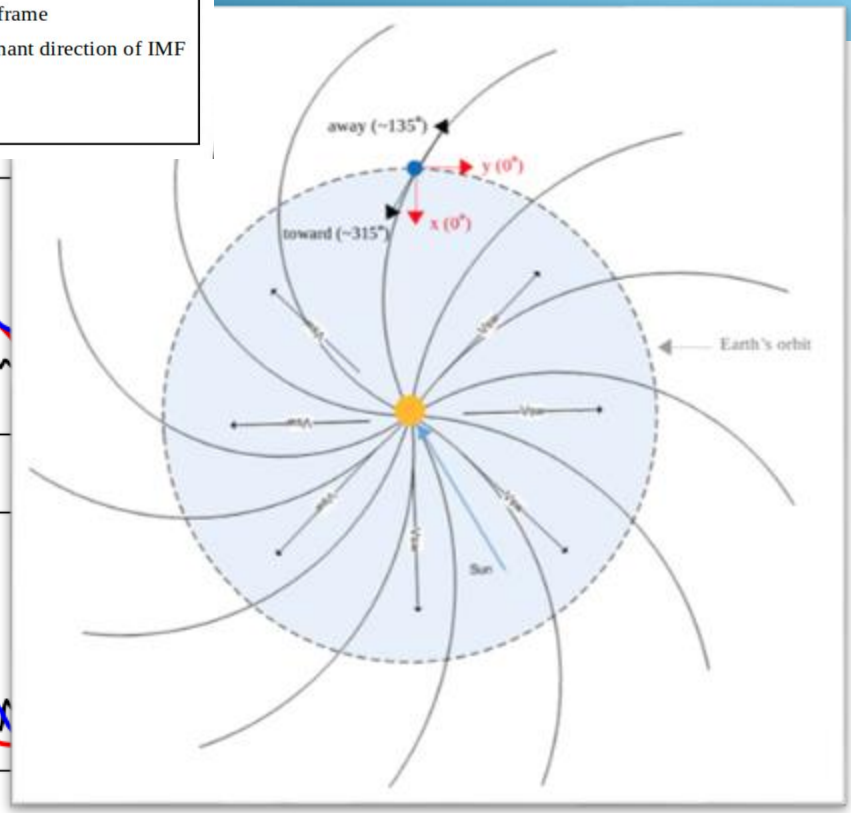
- The more frequently we update the magnetograms and the boundary conditions, the finer structures we get in the modelled solar wind.
- Some artifacts arise as we increase the frequency cadence. We currently further analyze them by also testing magnetograms from different observatories.

Evaluation of modeling results in the heliosphere

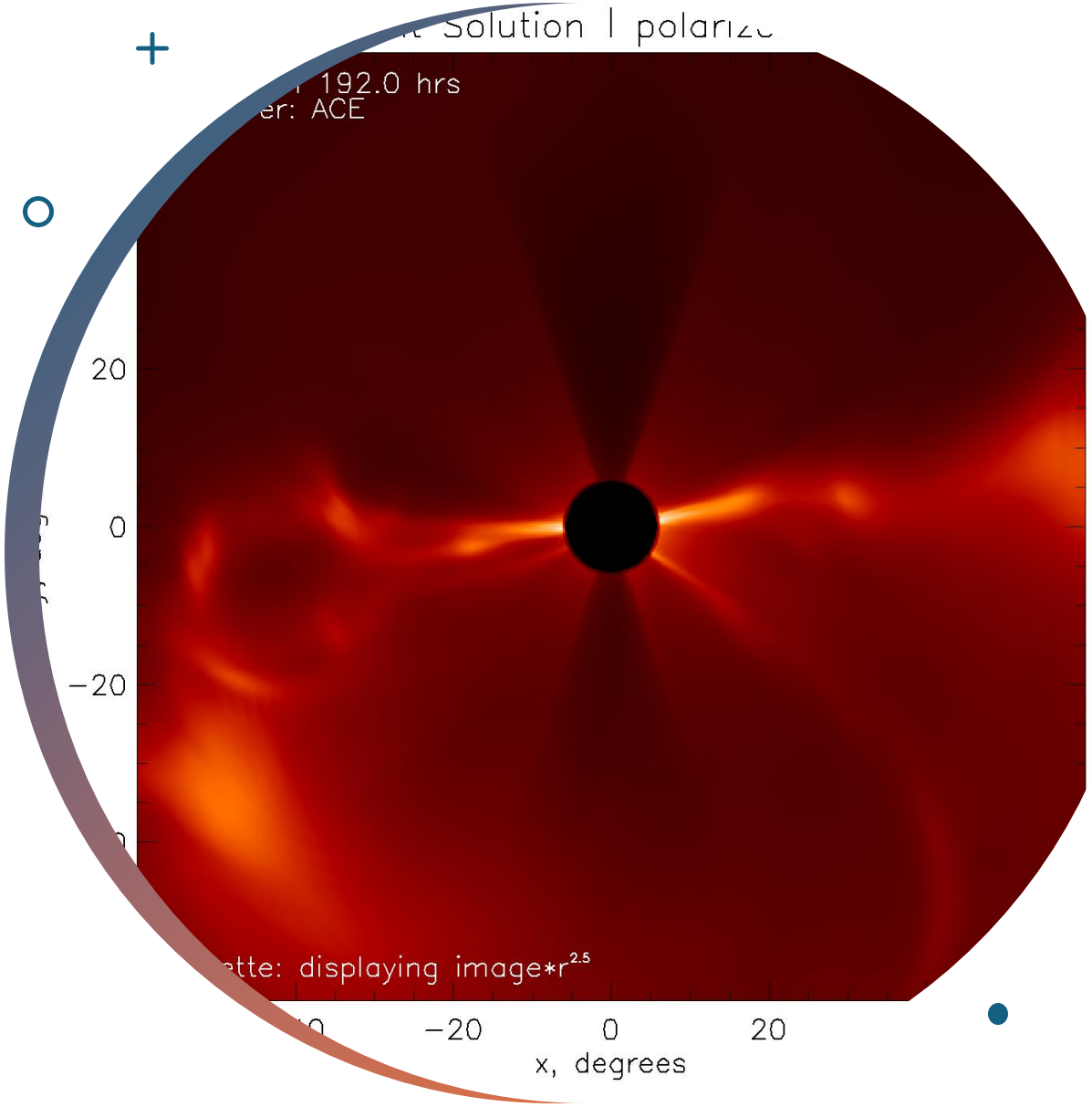
Partial emergence of active region from the invisible side of the Sun, that led to erroneous coronal topologies and wrong connectivities with Earth





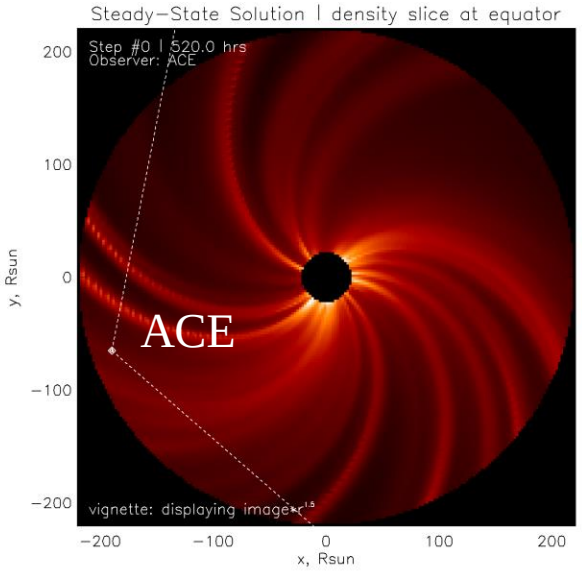


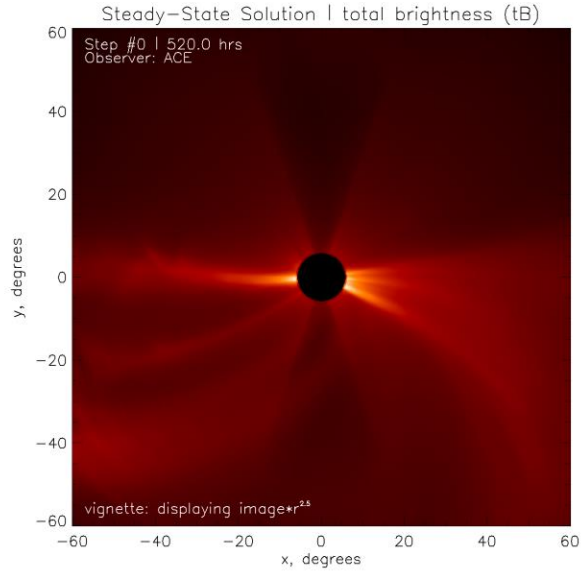
Realistic prediction of the phi-angle -> more precise SEP transport

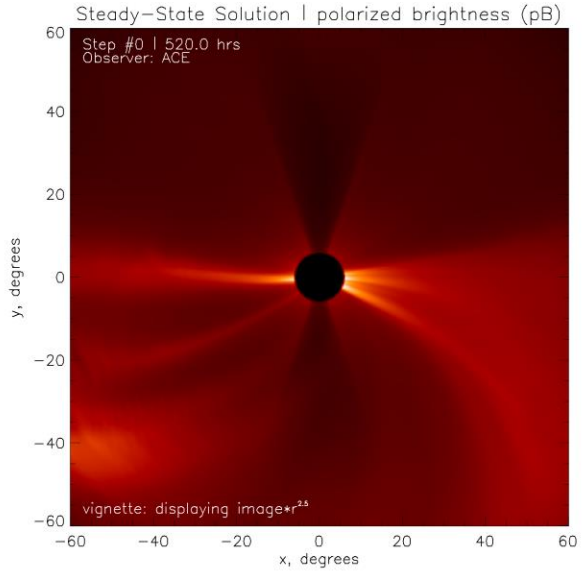


Synthetic WL images with GAMERA-Helio

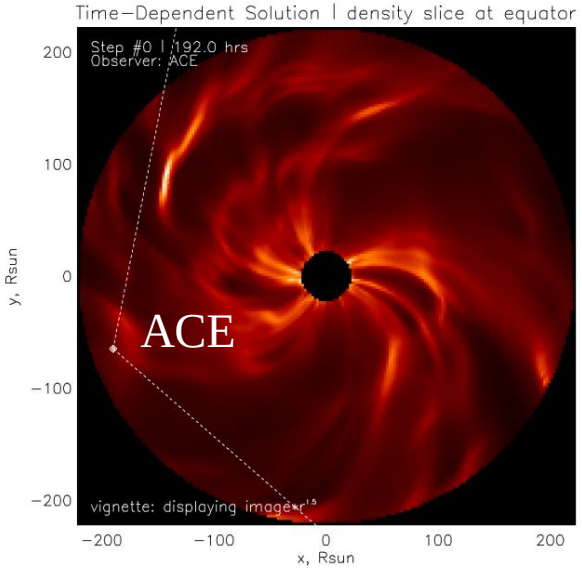
Synthetic White Light images from **ACE** point of view

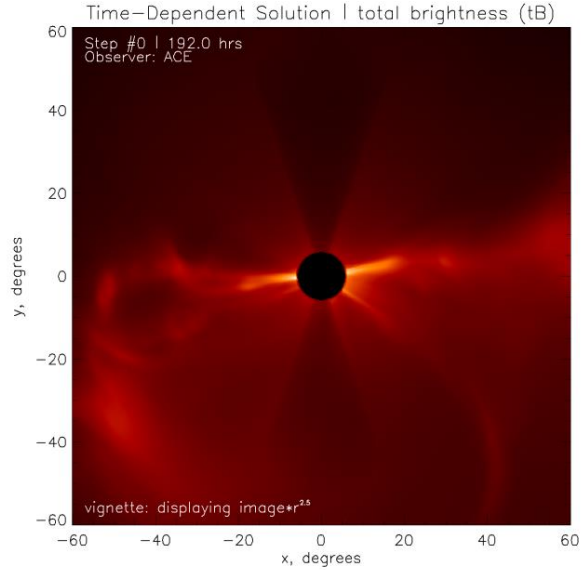


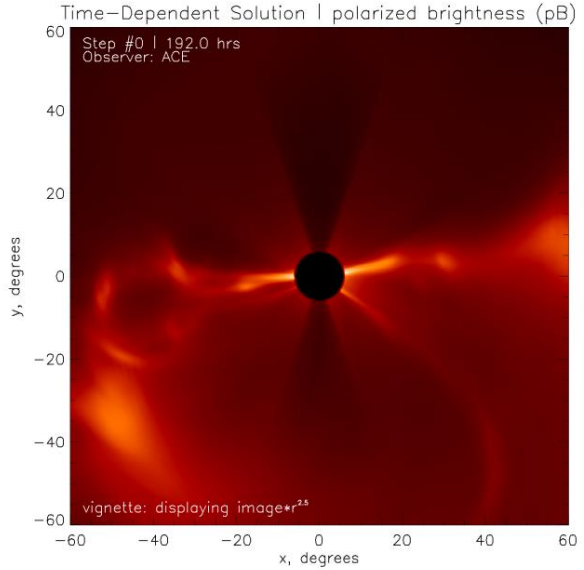




Steady state







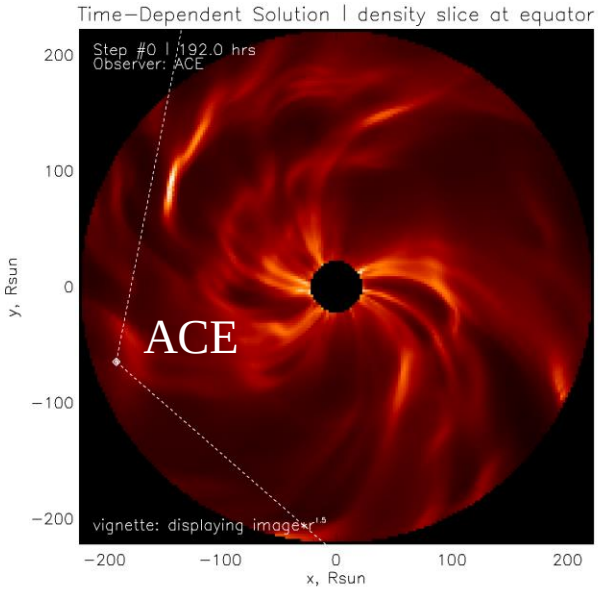
Time-dependent

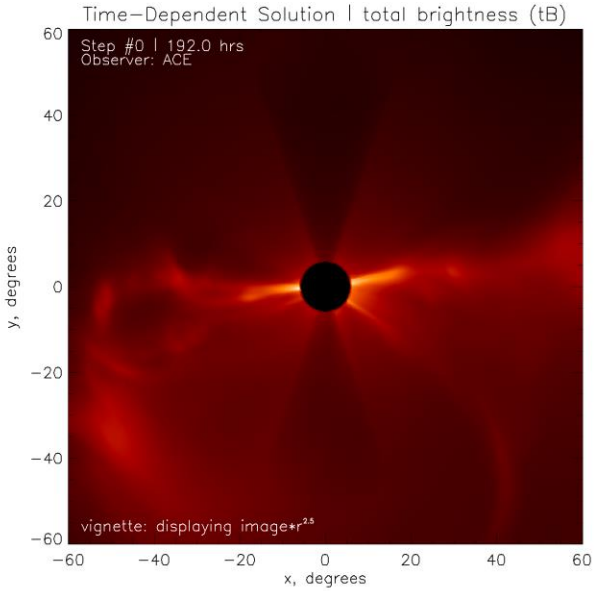
density slice at equator, showing the observer and field of view (120º)

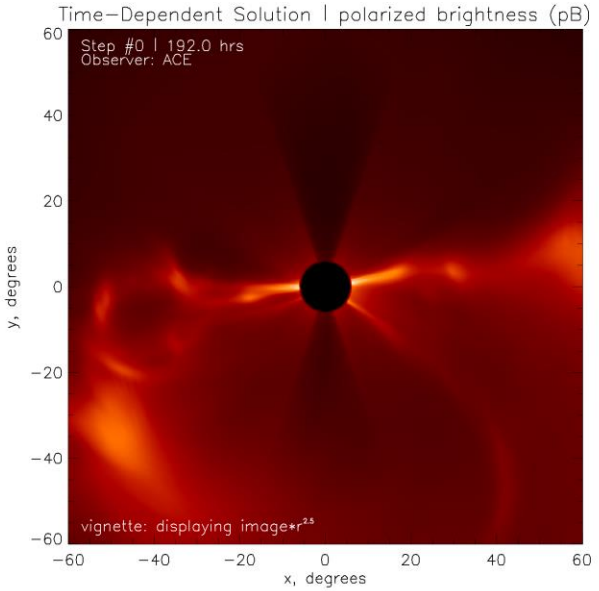
white light, **total brightness**

white light, **polarized brightness**

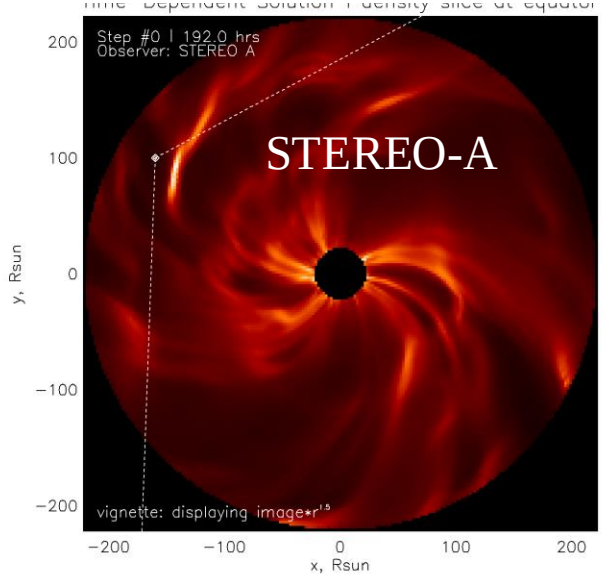
Synthetic White Light images from **ACE & STA** point of view

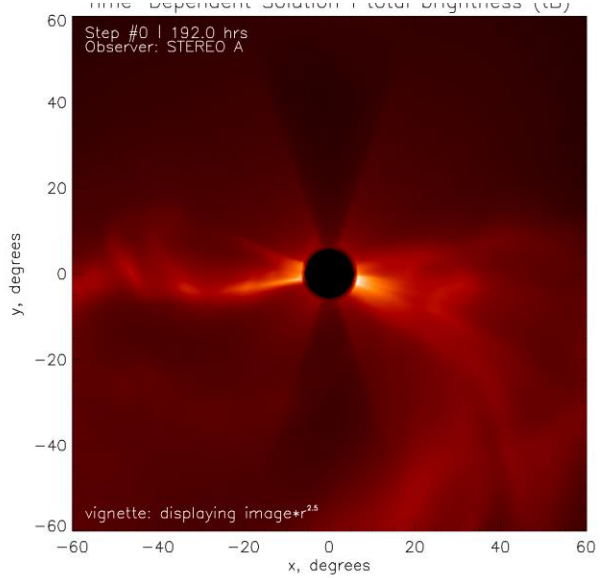


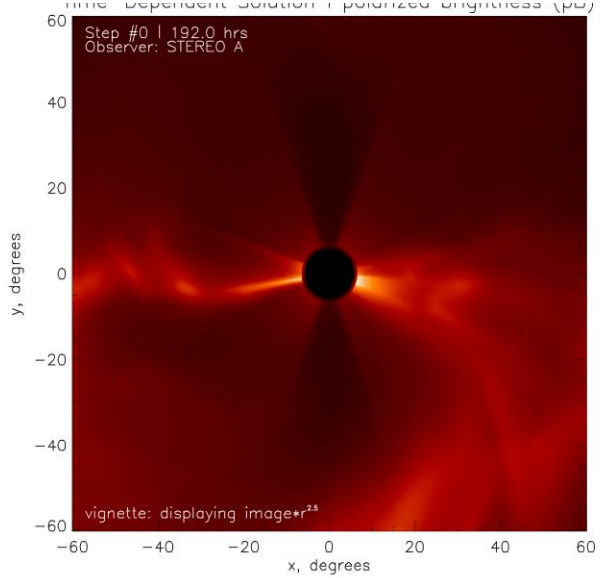




Time dependent at ACE







Time dependent at STEREO-A

density slice at equator, showing the observer and field of view (120º)

white light, **total brightness**

white light, **polarized brightness**

Summary and next steps

- Time-dependent MHD solar wind simulations are crucial for realistic representation of the solar wind and for supporting existing and upcoming missions. They enable to interpret observations and understand physical processes that take place in the solar wind.

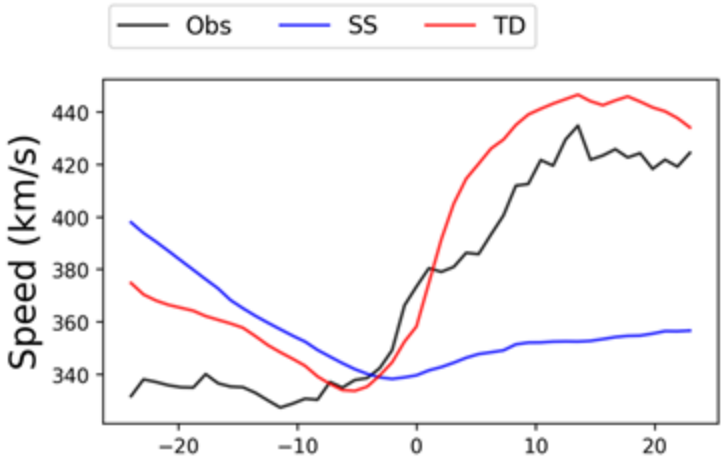
- Time-dependence is also crucial for more realistic modeling of CMEs and SEPs.

- Our approach is quick, efficient and allows validation of results with observations throughout the heliosphere (modeling output are in good agreement with spacecraft observations). We are actively investigating and quantifying different assumptions in our approach which include different sources of magnetograms, the WSA sensitivity in the transition between slow and fast solar wind, etc.

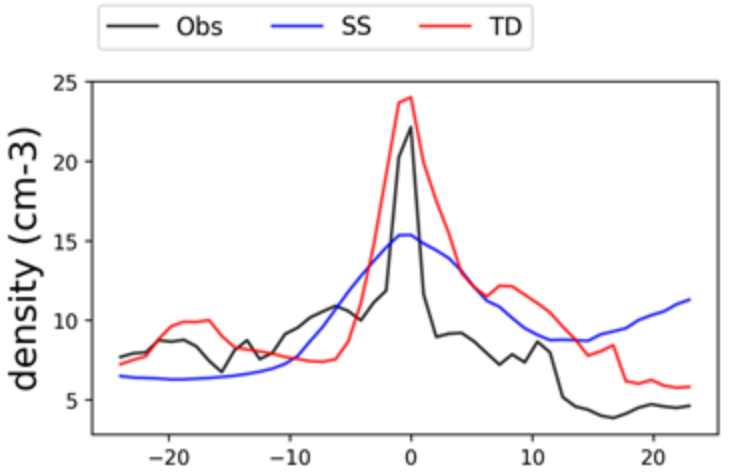
- Synthetic white-light images reveal different solar wind features in the steady-state and time-dependent modeling approaches. Analysis and physical interpretation of these features is ongoing and will help us to prepare for the analysis of the PUNCH observations.

Superposed epoch analysis

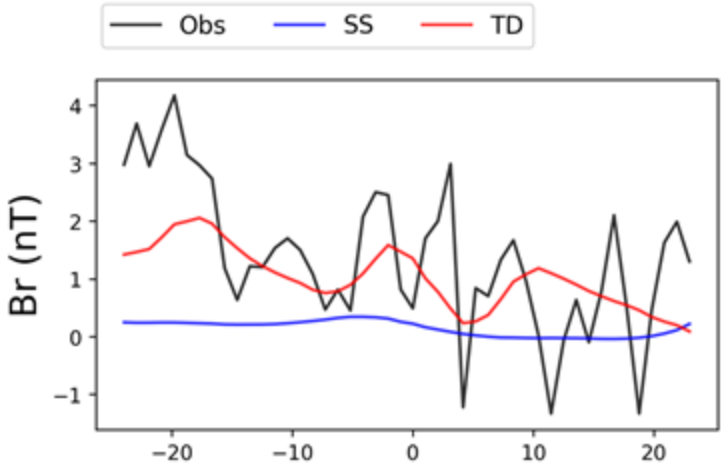
Identification of differences on the SIRs profiles between the **steady-state** and **time-dependent** approach



TD **speed** profile better than steady state



TD **density** profile better than steady state



TD **Br** profile better than steady state

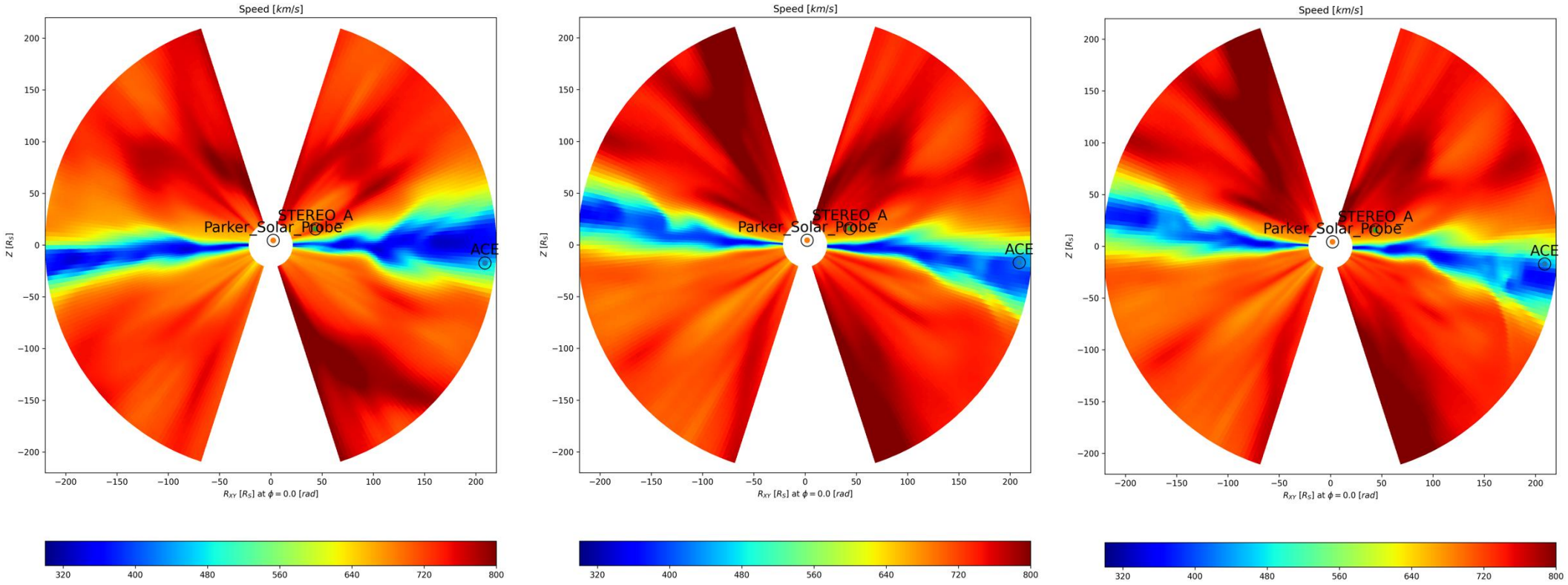
Steady-state vs time-dependent solar wind *(Samara et al., in prep.)*

Meridional plane

Steady state (magnetogram on 2020-01-26)

Time-dependent (**24h** updating cadence)

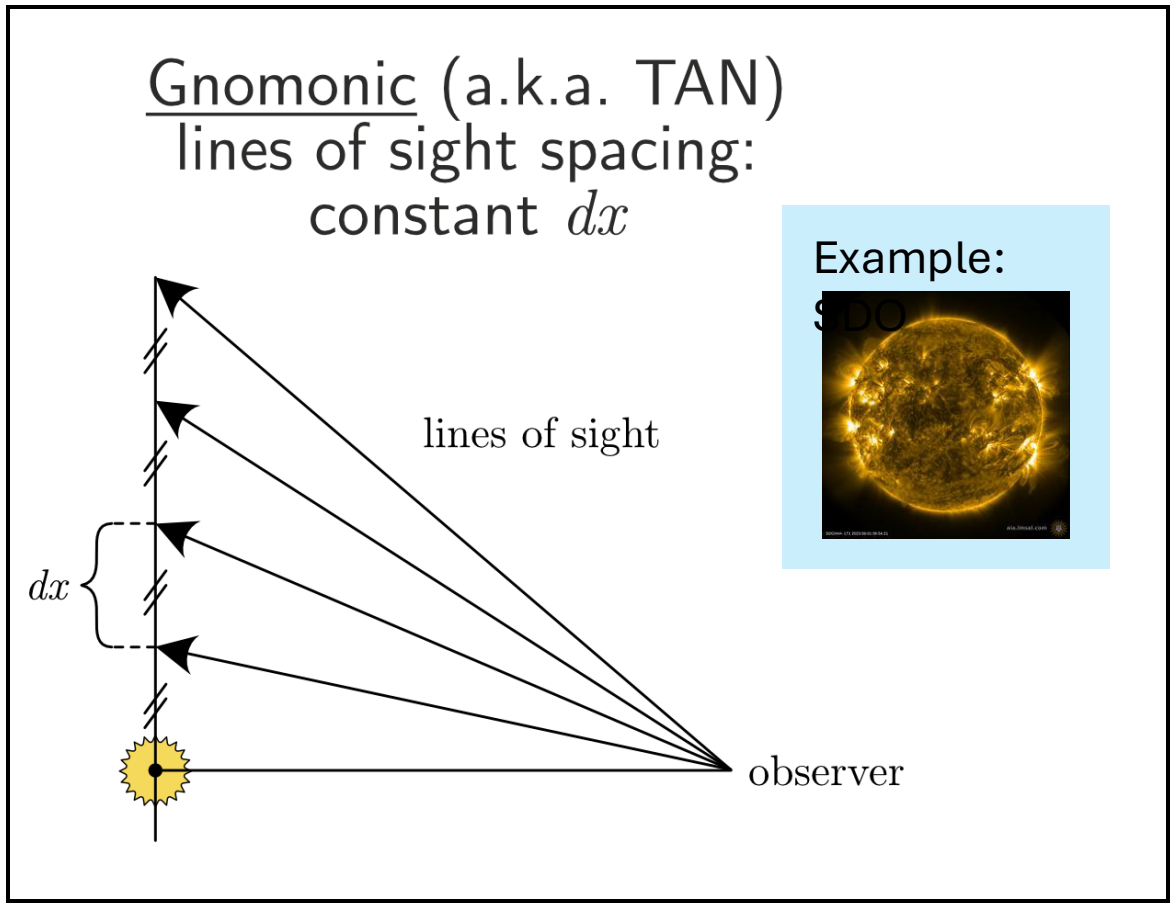
Time-dependent (**12h** updating cadence)

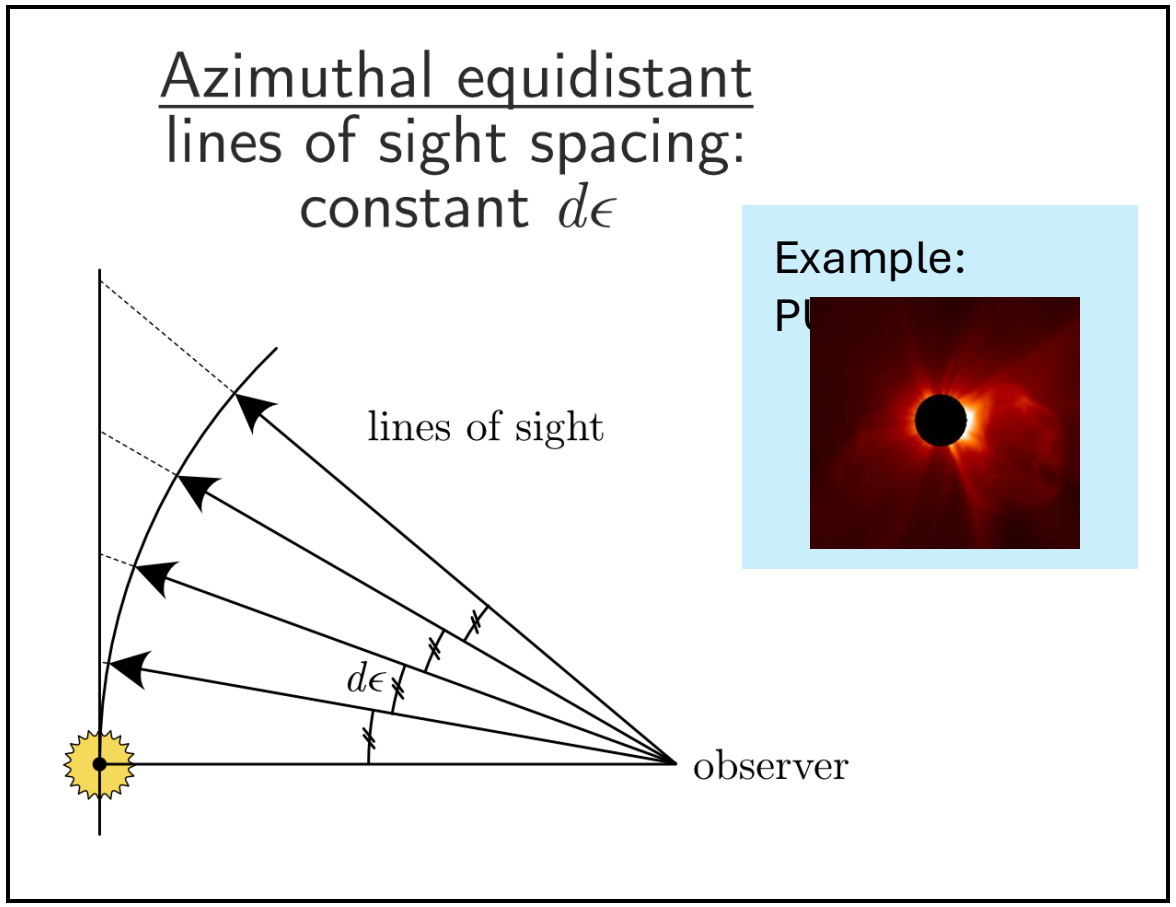


Courtesy: Anna Malanushenko

Projections: azimuthal equidistant projection

- PUNCH will have a *very* wide field of view
- So, it'll have a somewhat unusual projection (for heliospheric obs.)





Courtesy: Anna Malanushenko

Useful papers: Billings (1966) Chapter 6; Vourlidas&Howard (2005); Howard&Tapping (2009); Howard&DeForest (2012)

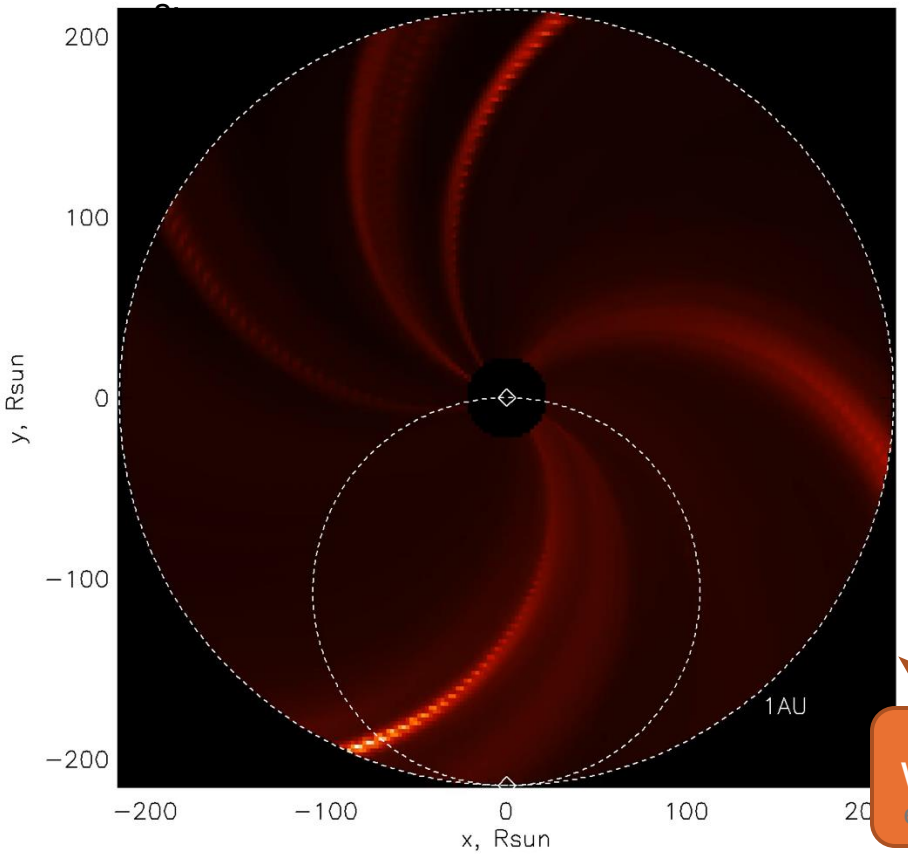
Thomson scattering

- We have to integrate density along the line of sight *times* some geometric factors:

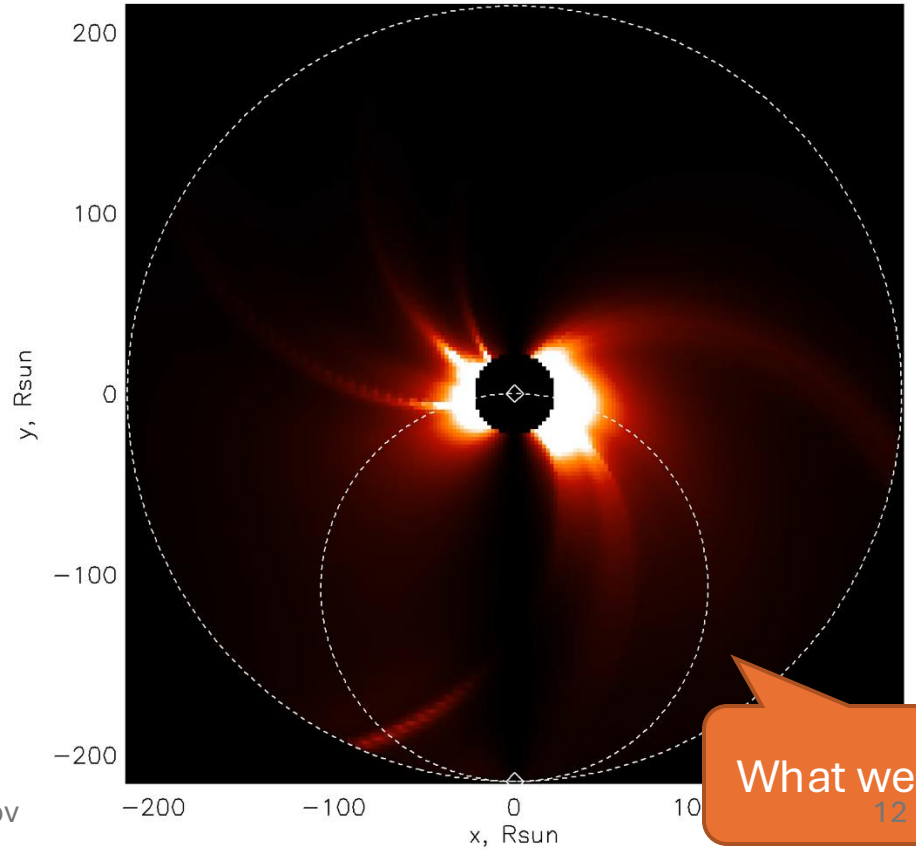
$$pB = C_0 \int_0^\infty N(l) f_2(r) \sin^2 \chi \, dl$$

density *slice* at equator (vignette:

(vignette: r^2)



What we want



What we have

GAMERA-Helio frame for 2021-09-01 00:19:01.665000