SH021-08: An Empirically Driven MHD Model to Predict the Solar Wind at Parker Solar Probe and Solar Orbiter during the Current Solar Minimum

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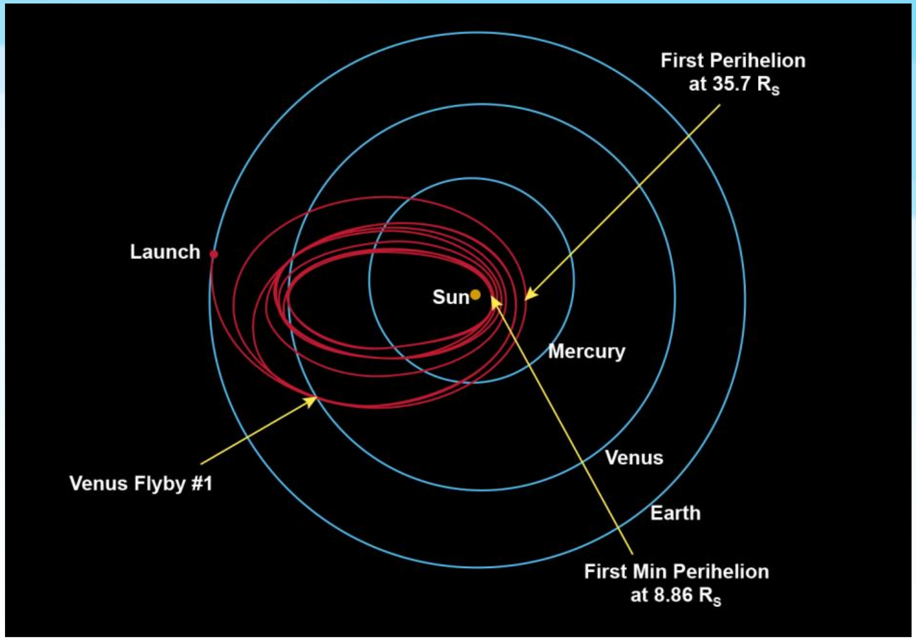
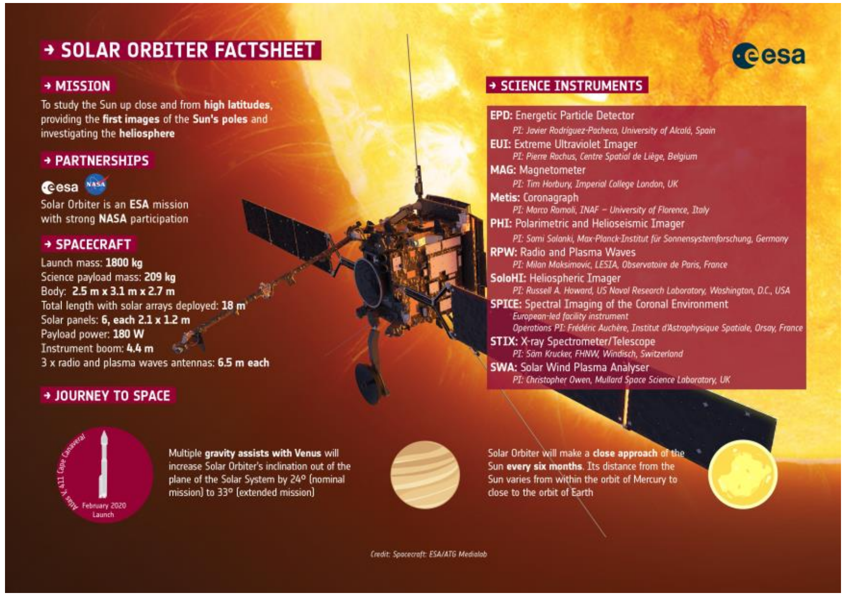
➢Parker Solar Probe (PSP)

- The first spacecraft mission ever to directly explore the solar corona (launch date: 12 August 2018)
- Four major instruments on board to observe the solar atmosphere: FIELDS (PI: S. D. Bale), IS⊙IS(PI: D. J. McComas), WISPR (PI: R. Howard), and SWEAP (PI: J. Kasper)
- First perihelion on 05 November 2018; Second perihelion on 04 April 2019; Third perihelion on 01 September 2019; Fourth perihelion on 29 January 2020; Fifth perihelion on 7 June 2020; Sixth perihelion on 27 September 2020



PSP trajectory. Image credit: NASA (http://parkersolarprobe.jhuapl.edu)



➢Solar Orbiter (SolO)

- The first spacecraft mission ever to take images of the Sun at close distances and at higher latitudes (launch date: 10 February 2020)
- Six remote-sensing instruments to image the Sun and its surroundings and four in situ instruments to directly monitor the space environment
- First perihelion on 15 June 2020 and a close approach of the Sun every six months thereafter

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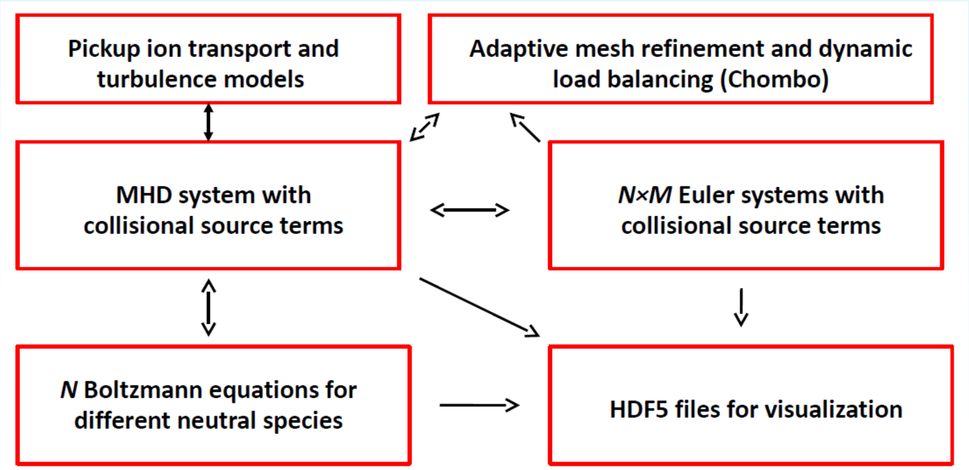
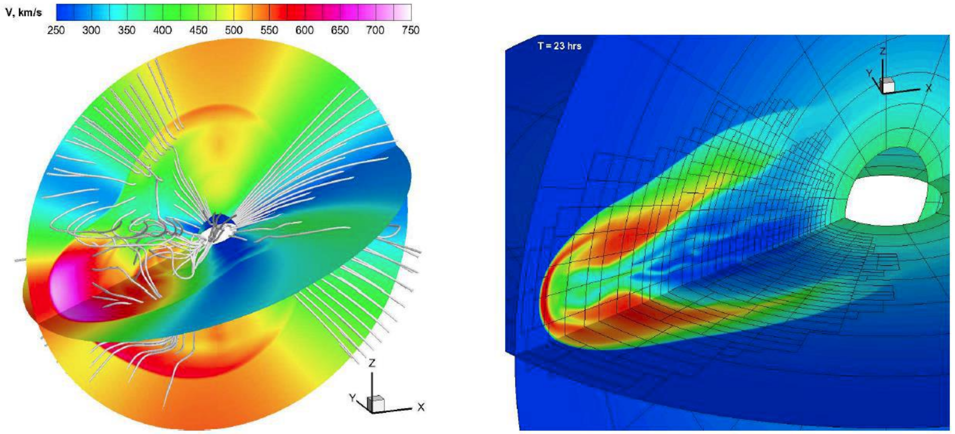
Modeling Software: Multi-Scale Fluid-Kinetic Simulation Suite (MS-FLUKSS)



Block diagram of MS-FLUKSS



Pogorelov et al. 2017 JPCS

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- A package of numerical codes designed at UAH/CSPAR to model the **heliosphere in multiple scales and resolution** (Pogorelov et al. 2014 XSEDE)
- **Adaptive mesh refinement** based on Chombo architecture (Colella et al. 2007 JPCS) for computational efficiency
- Scalable to >160,000 cores and portable across multiple computational platforms
- **MHD** treatment for solar wind/interstellar plasma and **fluid** treatment for neutral atoms (1, 2, 4, or 5 fluids) (Pogorelov et al. 2008 ASP)
- **MHD** treatment for solar wind/interstellar plasma and **kinetic** treatment for neutral atoms (Pogorelov et al. 2008 ASP; Borovikov et al. 2008 ASP; Heerikhuisen et al. 2008 ASP)
- **Turbulence** models for super-Alfvenic solar wind (Pogorelov et al. 2012 AIP; Kryukov et al. 2012 AIP)
- Time-dependent solar wind models driven by realistic boundary conditions (Kim et al. 2014 JGR; Kim et al. 2016 ApJ; Kim et al. 2017 ApJL; Lamy et al. 2018 GRL; Kim et al. 2020 ApJS)
- Data-constrained simulations of flux-rope coronal mass ejections (Singh et al, 2019 ApJ; Singh et al. 2020 Space Weather)
- In this study, we solve the Reynolds averaged MHD equations with interstellar pickup ions and turbulence model (e.g., Breech et al. 2008 JGR, Kryukov et al. 2012 AIP)

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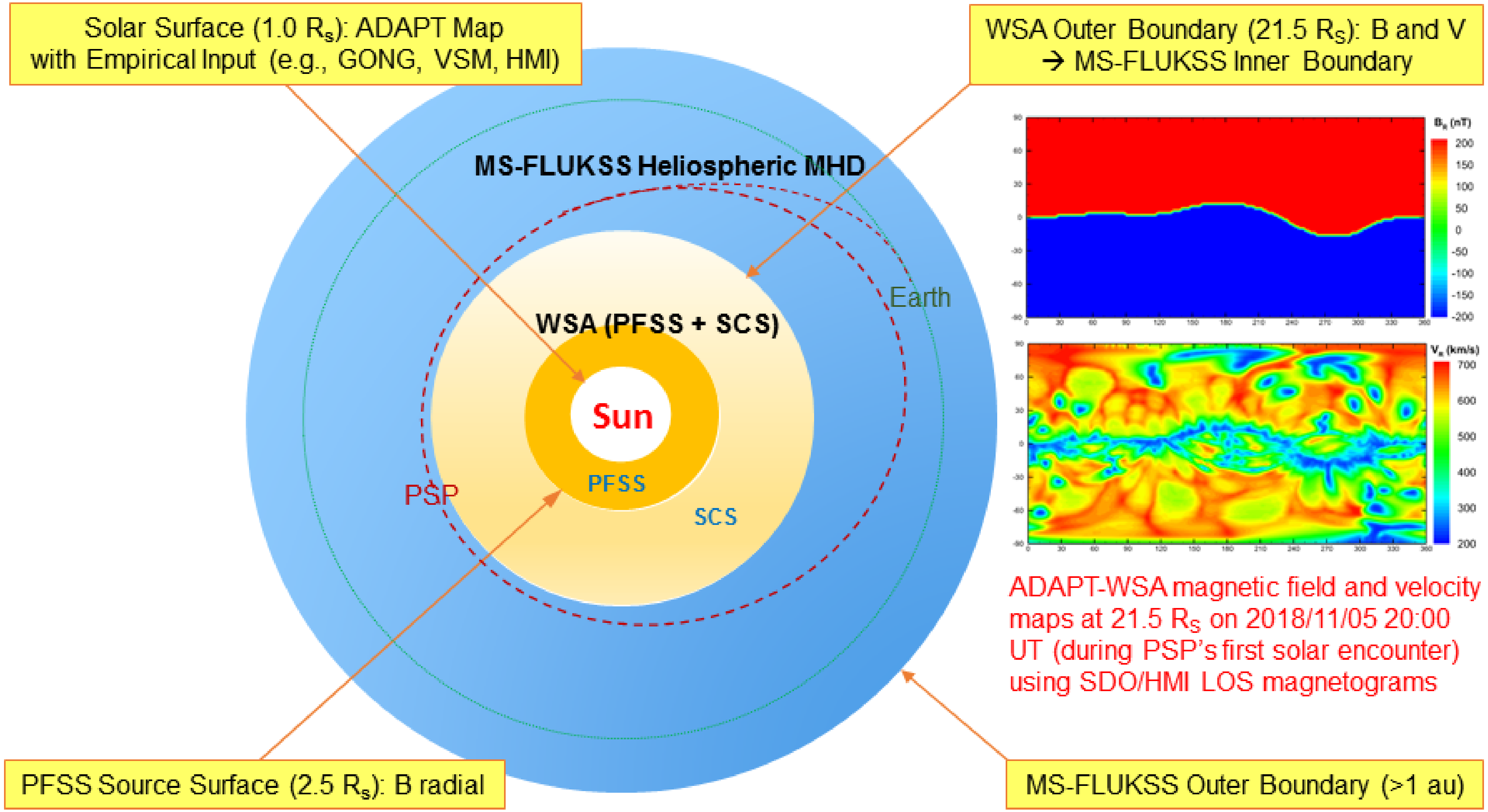
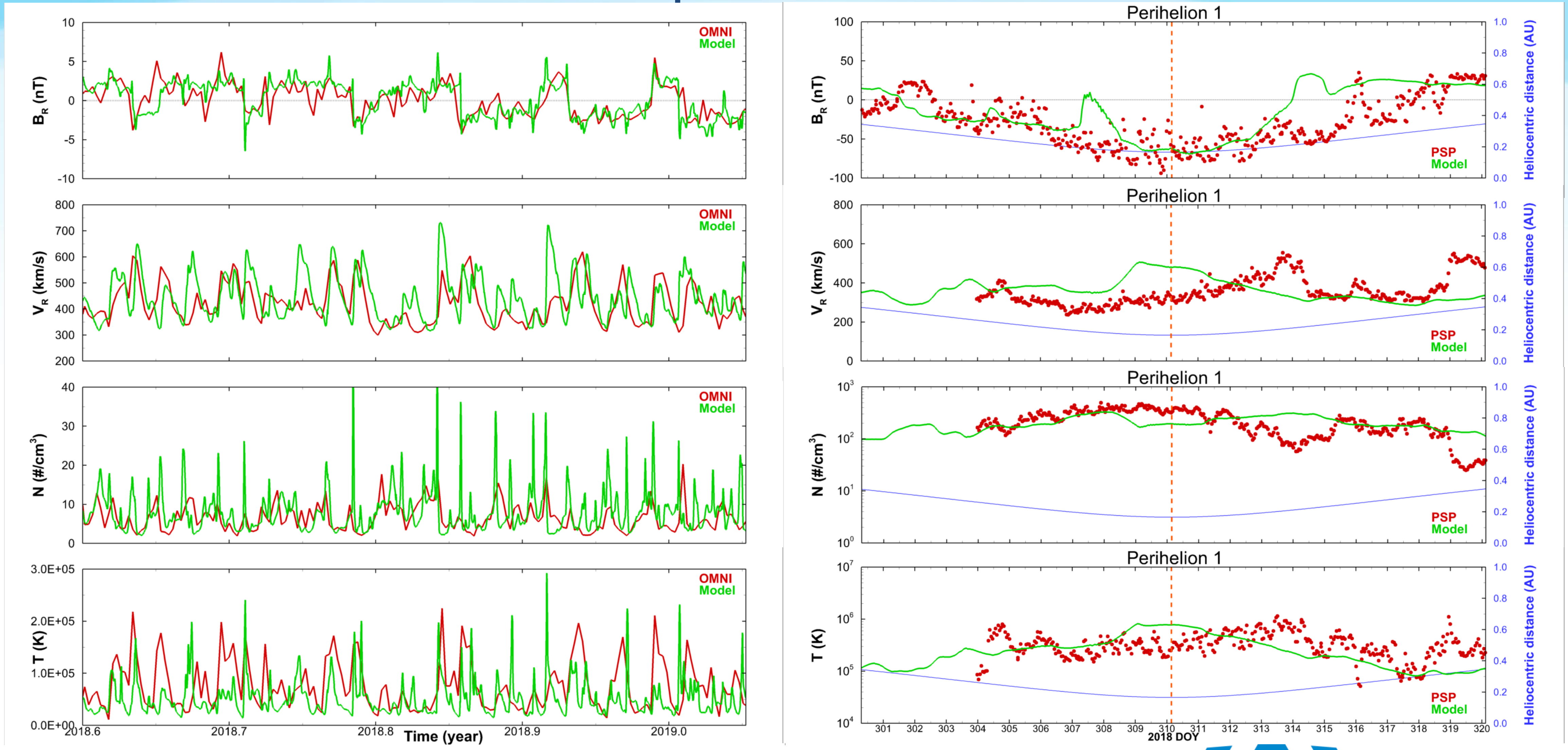
WSA + MS-FLUKSS Solar Wind Model (e.g., Kim et al. 2020 ApJS)



ADAPT-WSA magnetic field and velocity maps at 21.5 R_S on 2018/11/05 20:00 UT (during PSP's first solar encounter) using SDO/HMI LOS magnetograms

ADAPT: Air Force Data Assimilative Photospheric flux Transport model (Arge et al. 2010 AIP)
PFSS: Potential Field Source Surface model (Schuler & Altenkirch)
SCS: Shatten Current Sheet model (Shatten)
WSA: Wang-Sheeley-Arge empirical coronal model (Arge et al. 2003 AIP; Arge et al. 2004 AIP)

PSP Orbit 1: Comparisons at Earth and PSP



MS-FLUKSS driven by ADAPT-WSA using SDO/HMI LOS magnetograms compared with OMNI data at Earth and PSP data during PSP's first orbit (perihelion around 2018.85)

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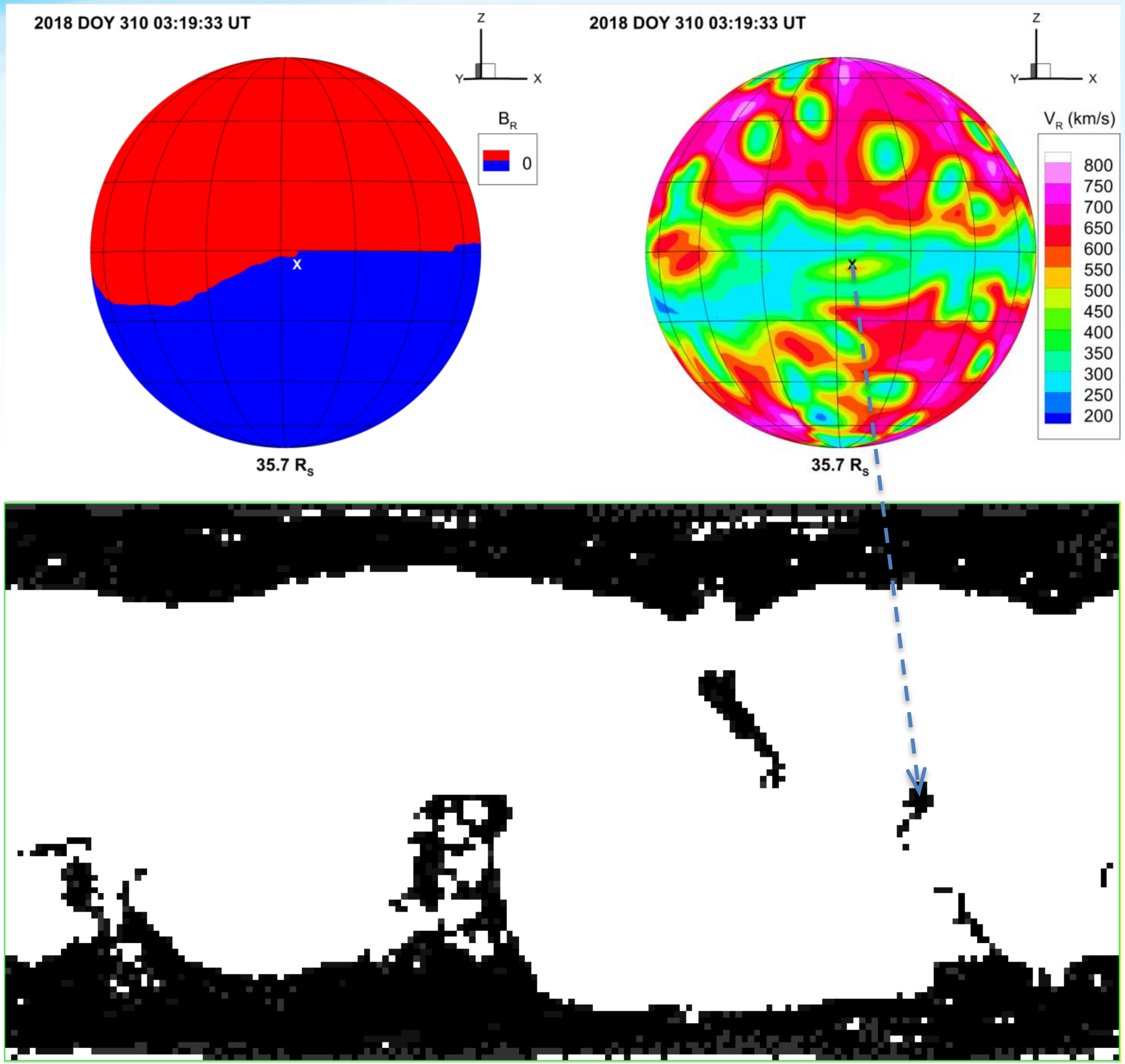
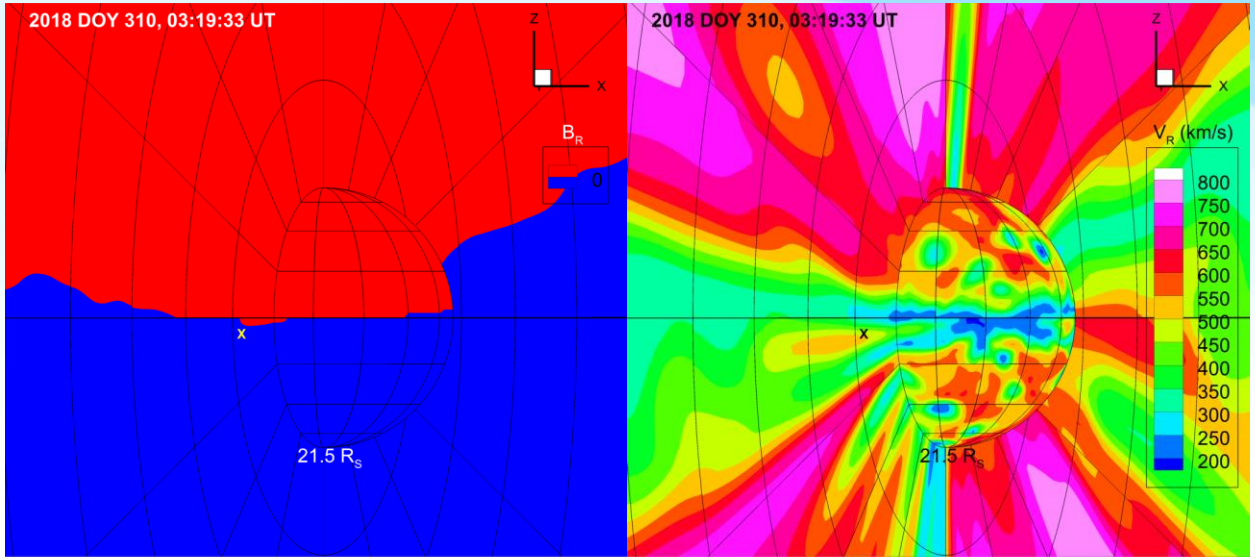
Magnetic Connectivity of PSP at Perihelion 1





Radial components of magnetic field and solar wind velocity shown on a spherical slice at the perihelion distance of 35.7 R_s (top left) and on a vertical slice in 3D (top right) on 2018/11/06 03:19:33 UT, where a dashed line connects the PSP location marked by an X to the source region in the coronal hole map on the photosphere (bottom left).

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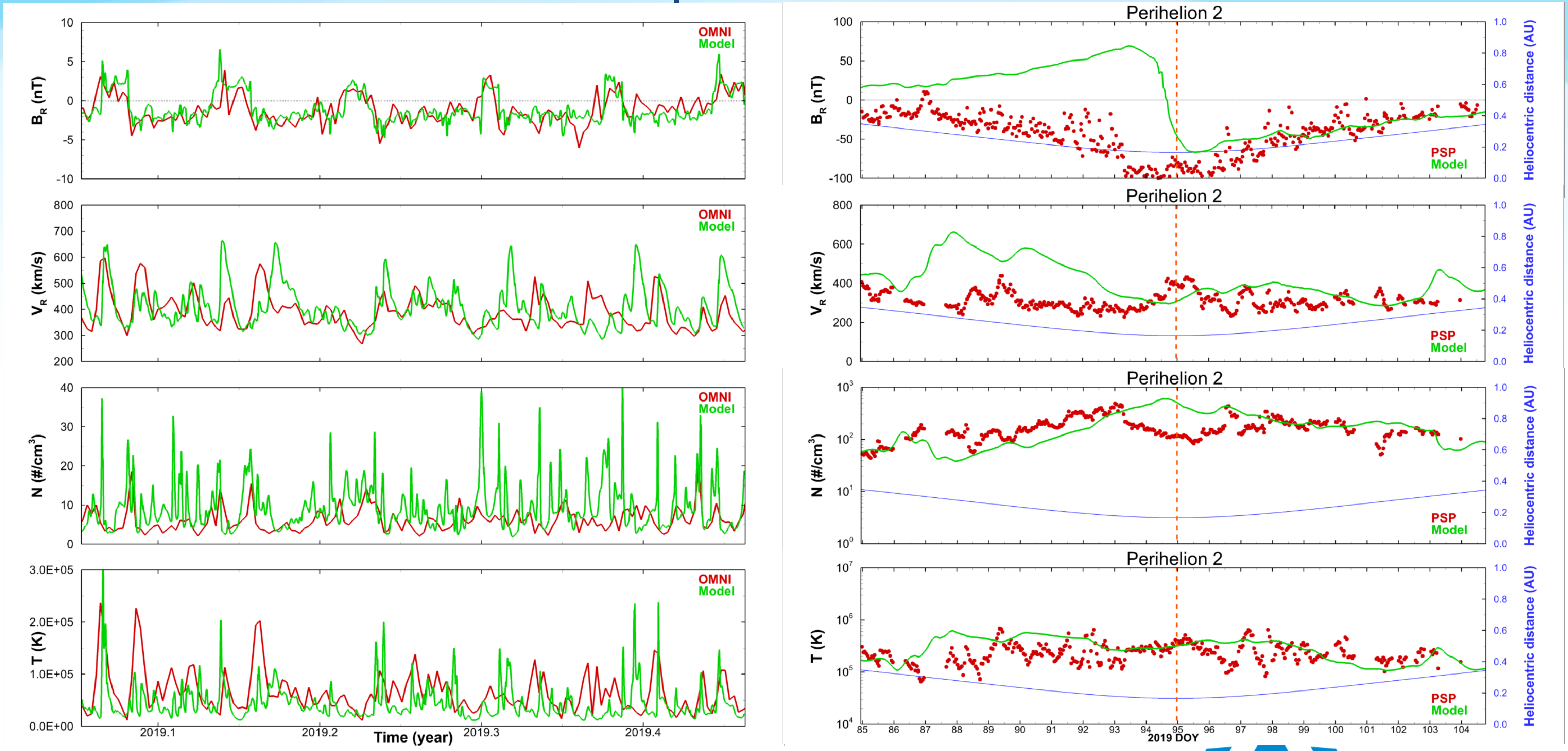
PSP Orbit 2: Comparisons at Earth and PSP



MS-FLUKSS driven by ADAPT-WSA using SDO/HMI LOS magnetograms compared with OMNI data at Earth and PSP data during PSP's second orbit (perihelion around 2019.26)

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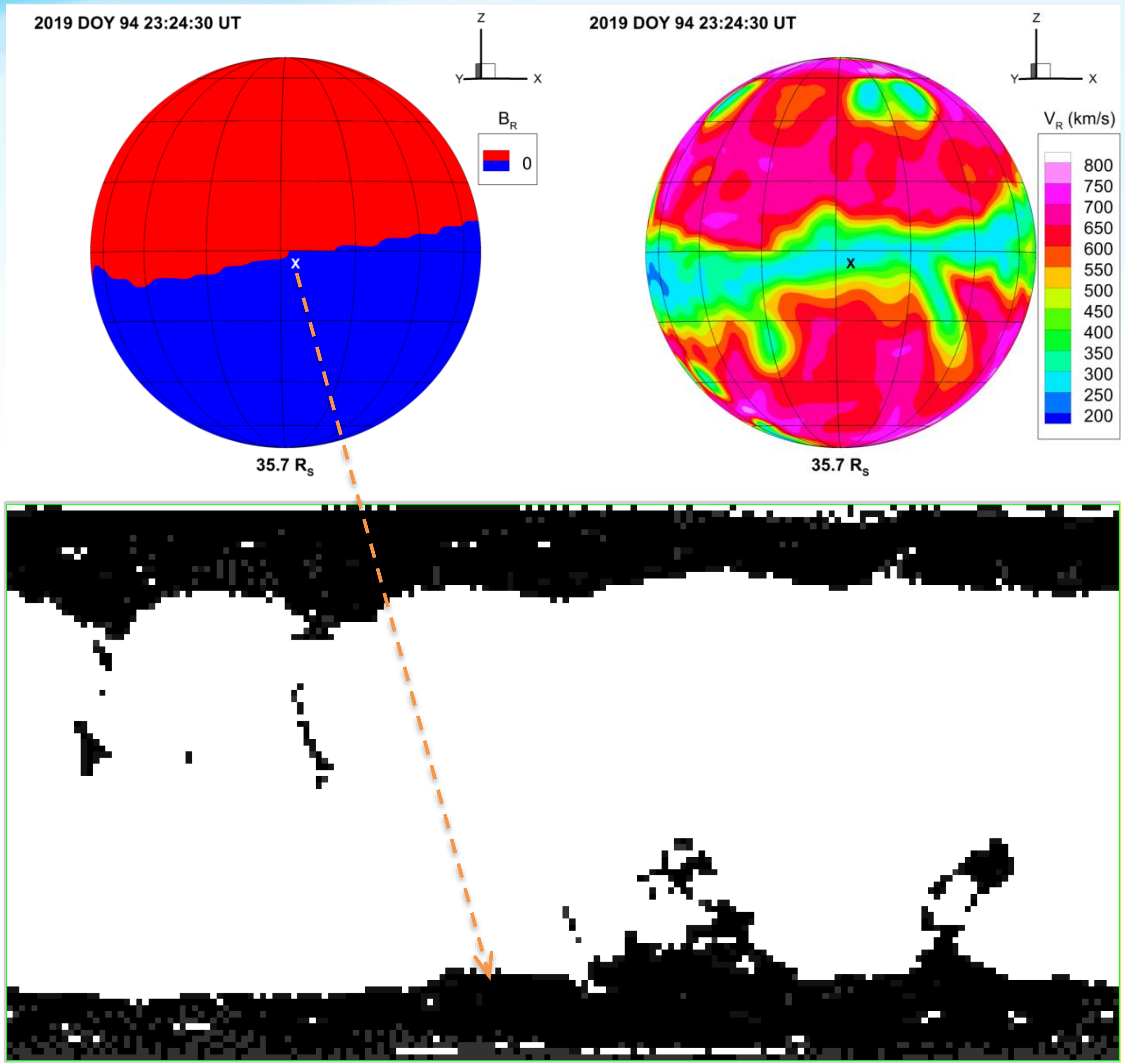
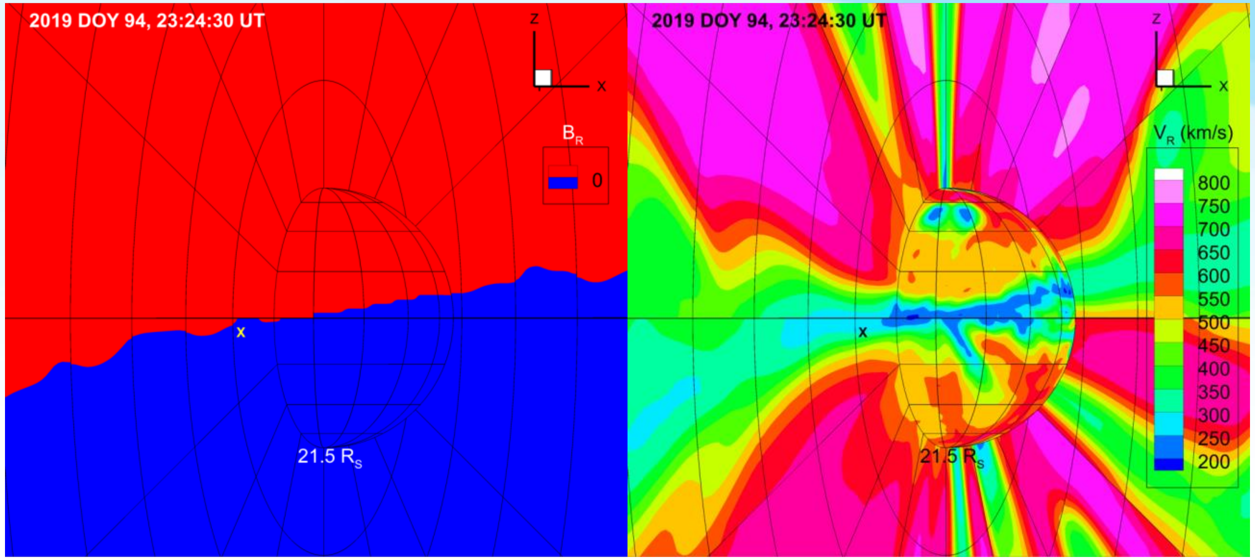
Magnetic Connectivity of PSP at Perihelion 2





Radial components of magnetic field and solar wind velocity shown on a spherical slice at the perihelion distance of 35.7 R_s (top left) and on a vertical slice in 3D (top right) on 2019/04/04 23:24:30 UT, where a dashed line connects the PSP location marked by an X to the source region in the coronal hole map on the photosphere (bottom left).

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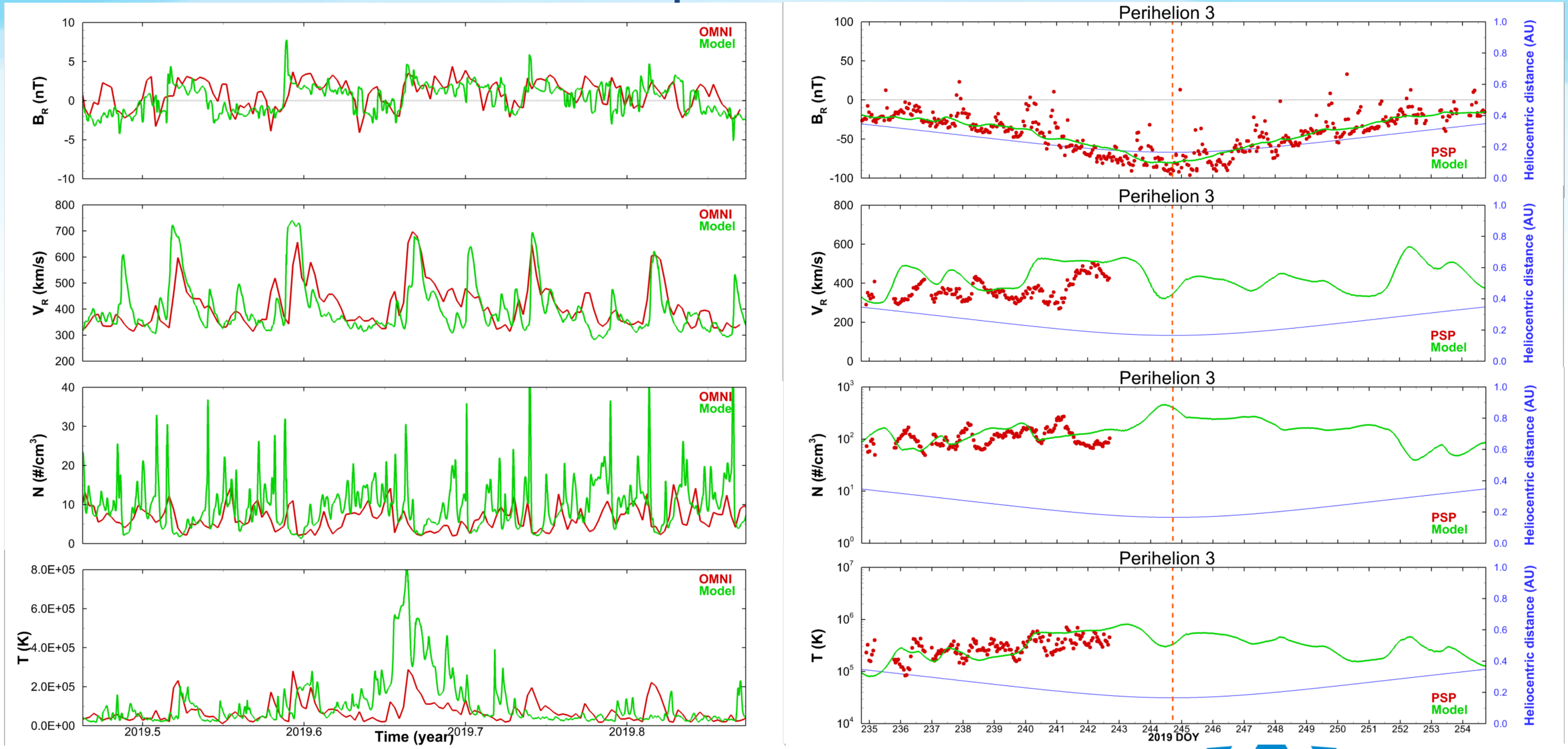
PSP Orbit 3: Comparisons at Earth and PSP



MS-FLUKSS driven by ADAPT-WSA using SDO/HMI LOS magnetograms compared with OMNI data at Earth and PSP data during PSP's third orbit (perihelion around 2019.67)

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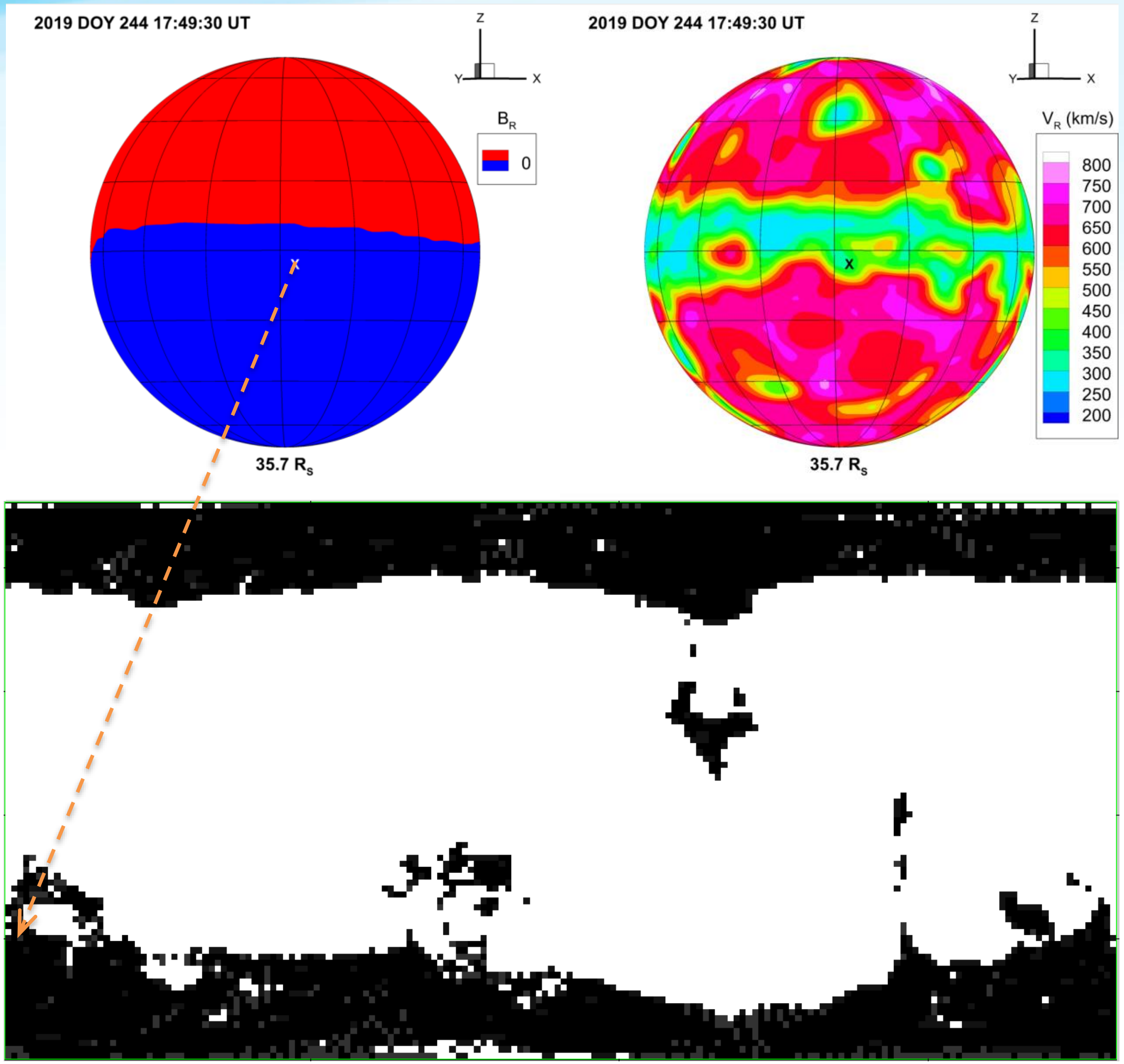
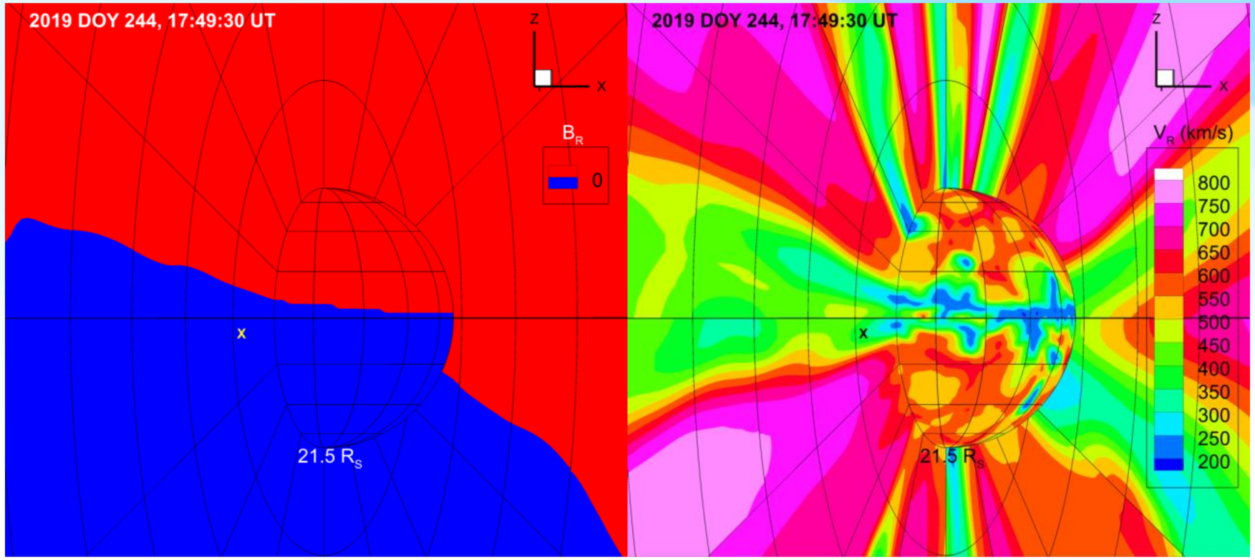
Magnetic Connectivity of PSP at Perihelion 3





Radial components of magnetic field and solar wind velocity shown on a spherical slice at the perihelion distance of 35.7 R_s (top left) and on a vertical slice in 3D (top right) on 2019/09/01 17:49:30 UT, where a dashed line connects the PSP location marked by an X to the source region in the coronal hole map on the photosphere (bottom left).

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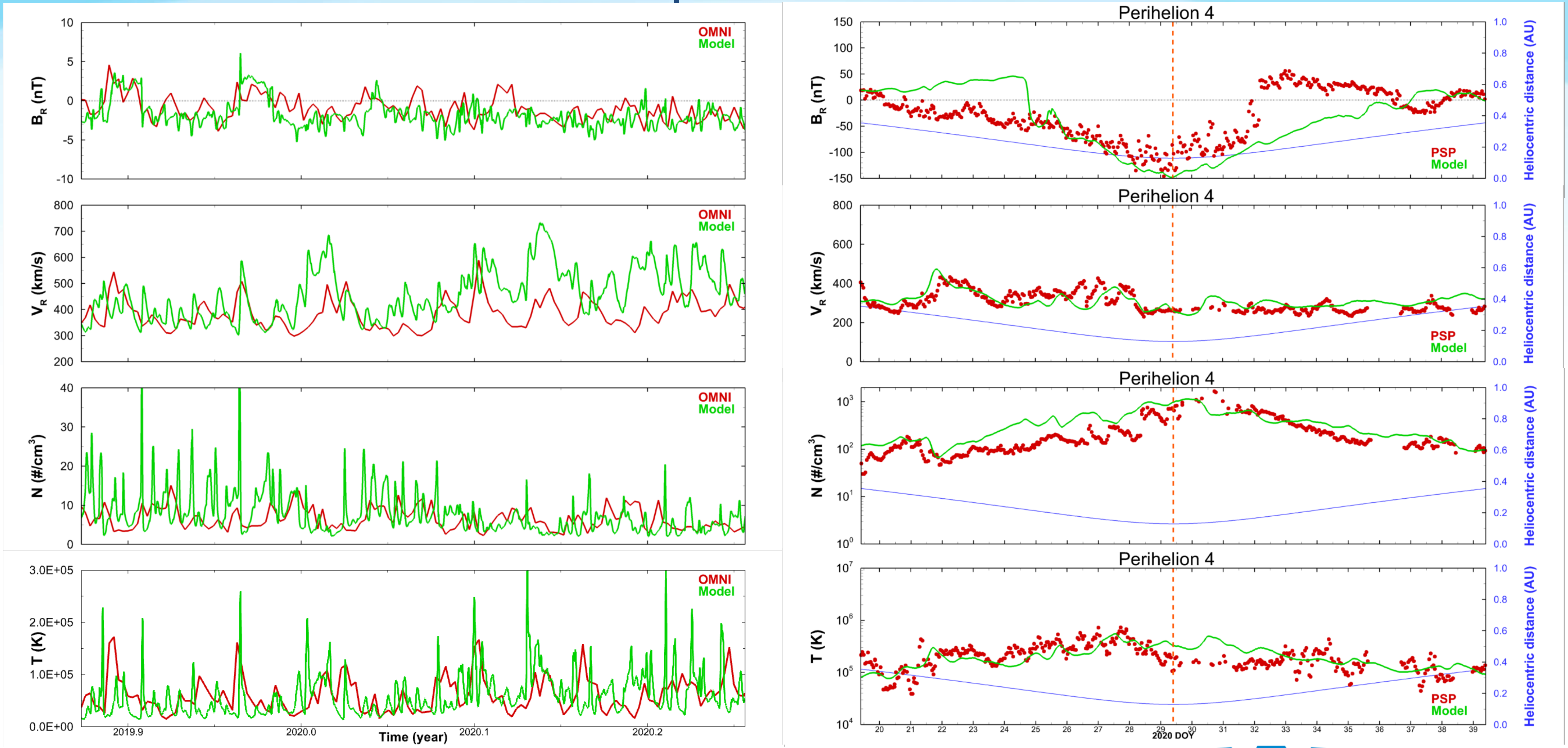
PSP Orbit 4: Comparisons at Earth and PSP



MS-FLUKSS driven by ADAPT-WSA using SDO/HMI LOS magnetograms compared with OMNI data at Earth and PSP data during PSP's fourth orbit (perihelion around 2020.08)

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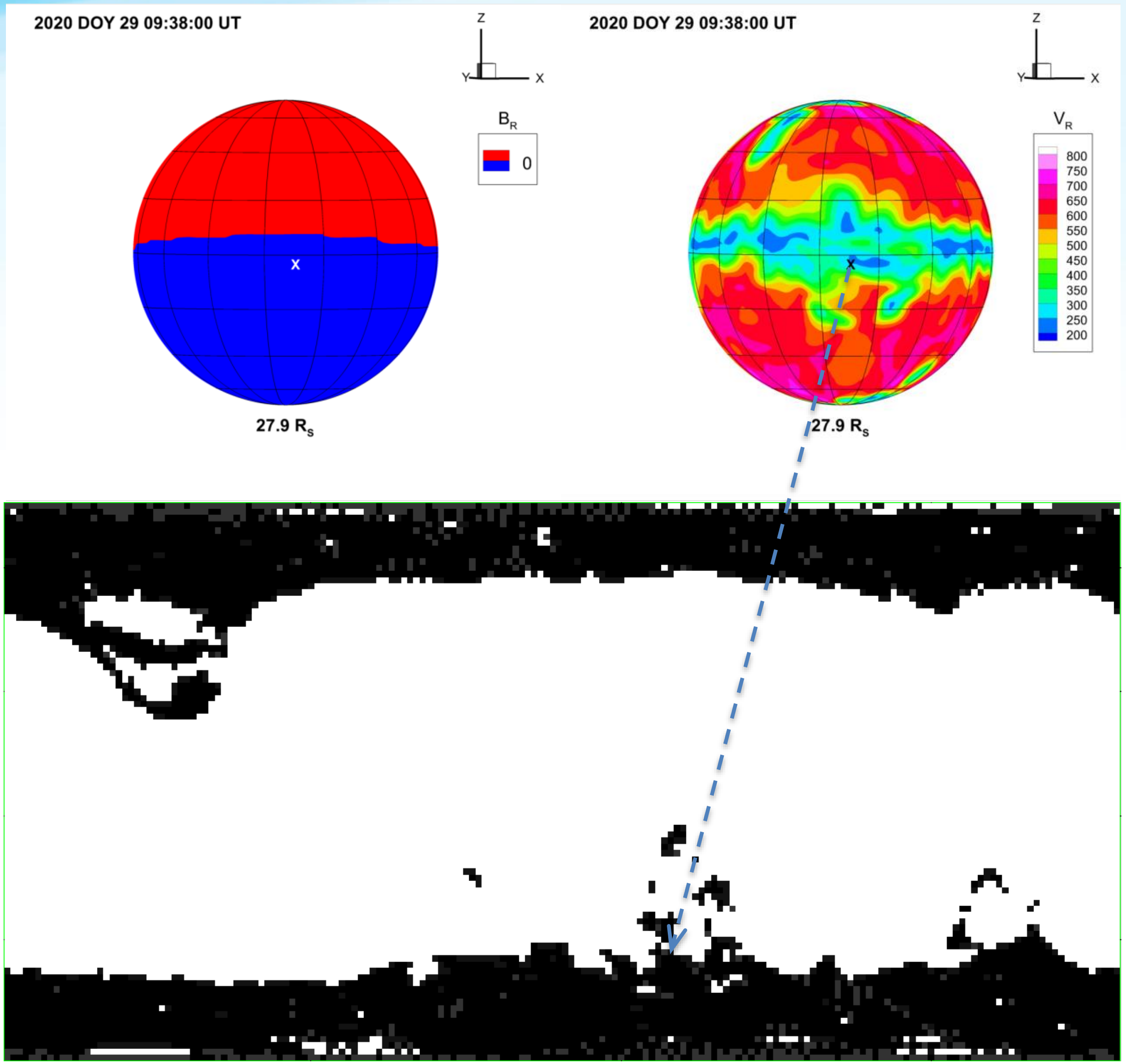
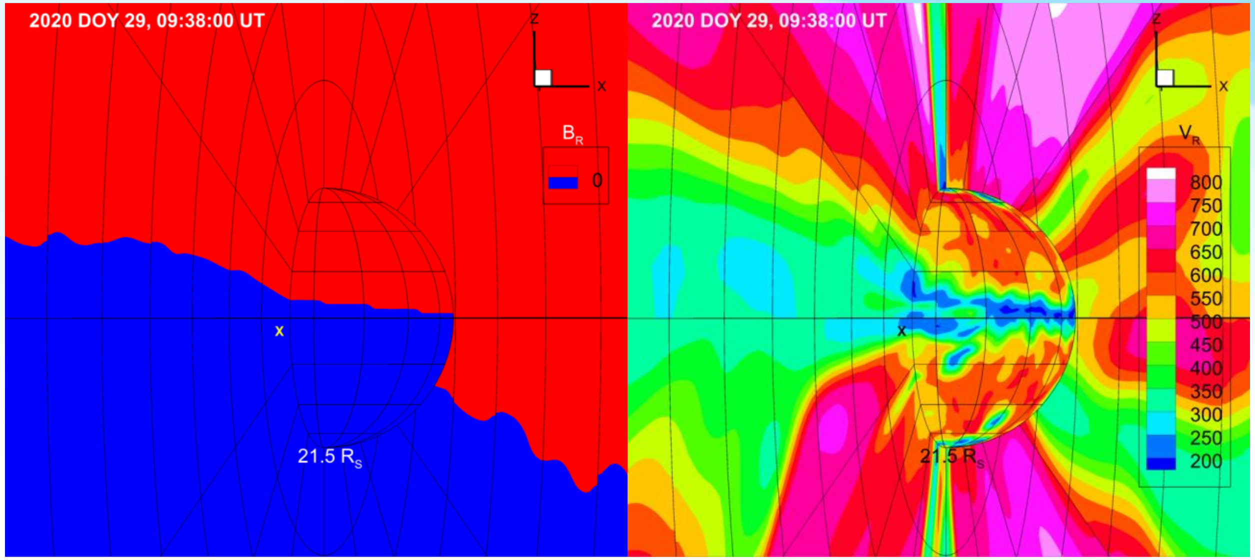
Magnetic Connectivity of PSP at Perihelion 4





Radial components of magnetic field and solar wind velocity shown on a spherical slice at the perihelion distance of 27.9 R_s (top left) and on a vertical slice in 3D (top right) on 2020/01/29 09:38:00 UT, where a dashed line connects the PSP location marked by an X to the source region in the coronal hole map on the photosphere (bottom left).

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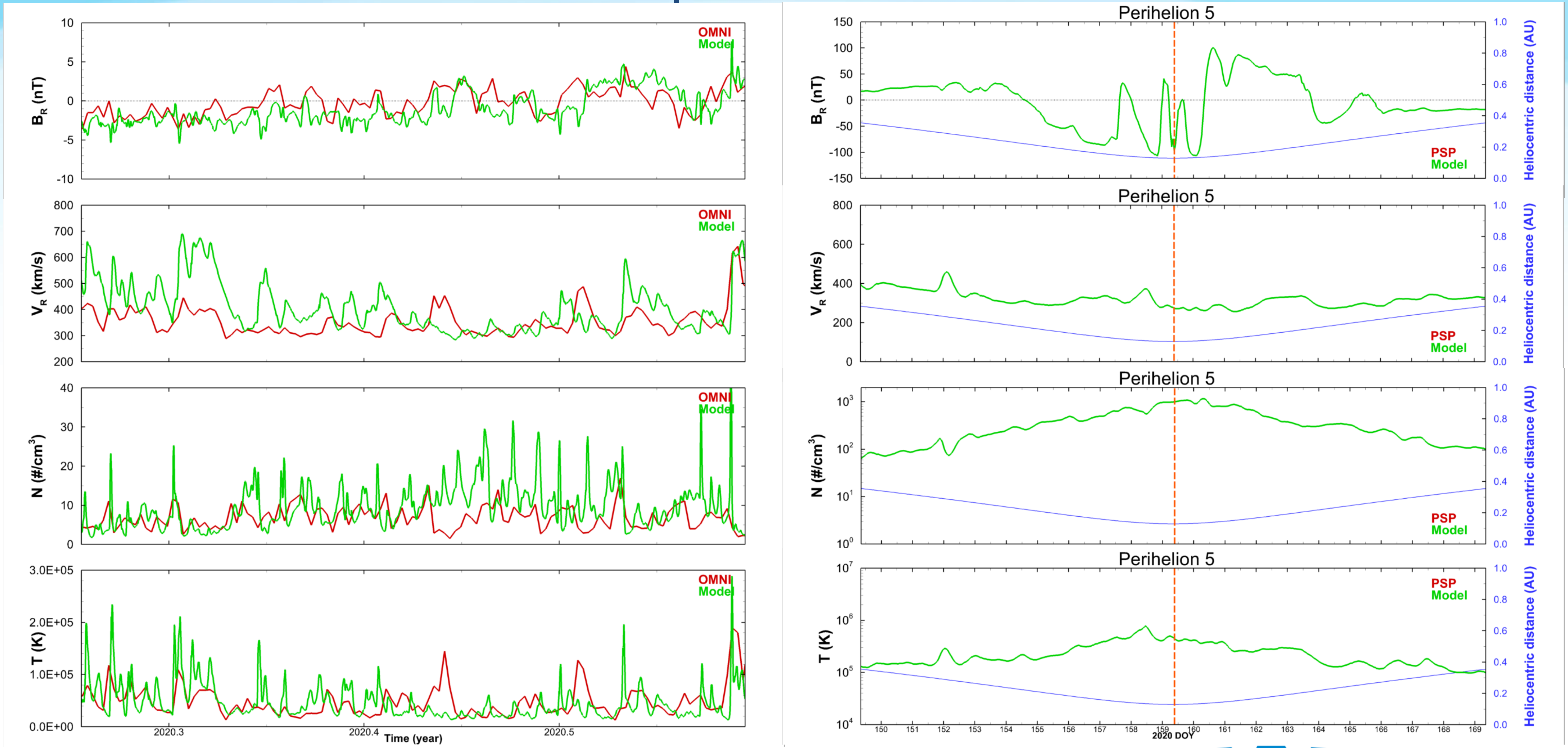
PSP Orbit 5: Comparisons at Earth and PSP



MS-FLUKSS driven by ADAPT-WSA using SDO/HMI LOS magnetograms compared with OMNI data at Earth and PSP data during PSP's fifth orbit (perihelion around 2020.43)

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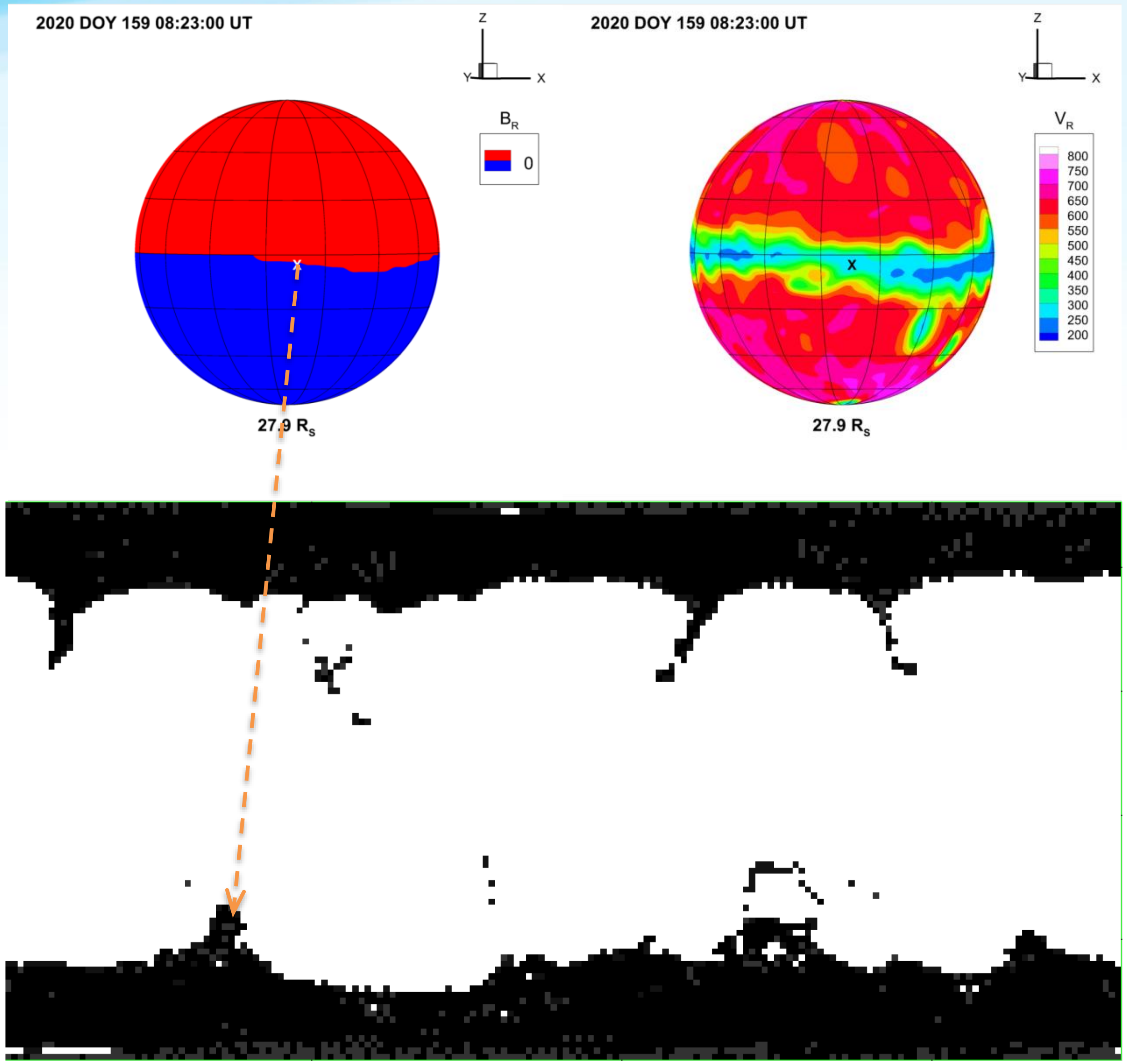
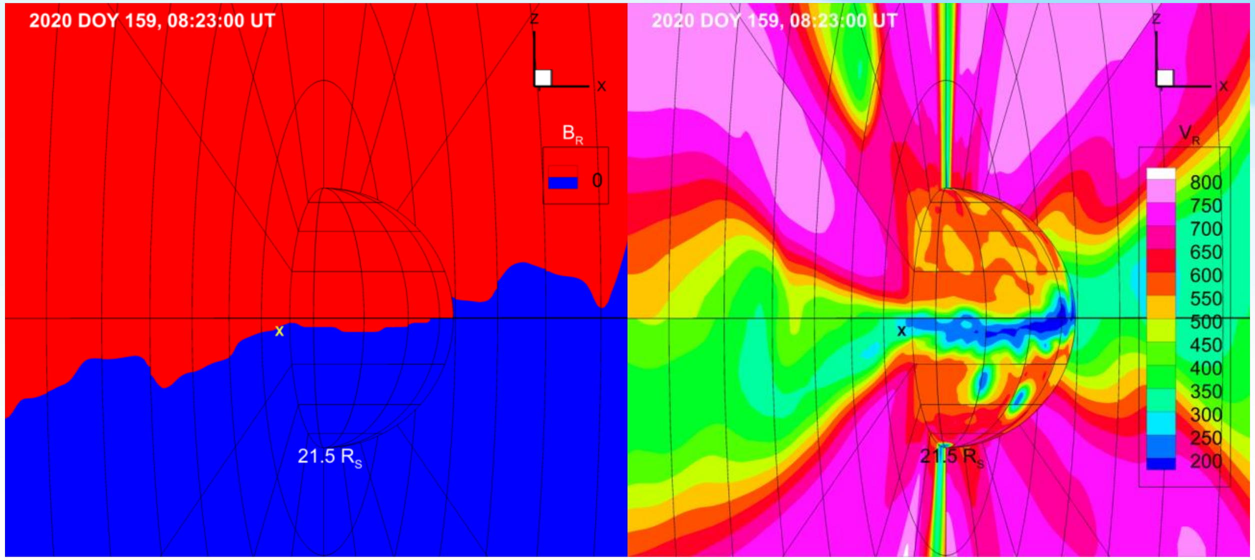
Magnetic Connectivity of PSP at Perihelion 5





Radial components of magnetic field and solar wind velocity shown on a spherical slice at the perihelion distance of 27.8 R$_s$ (top left) and on a vertical slice in 3D (top right) on 2020/06/07 08:23:00 UT, where a dashed line connects the PSP location marked by an X to the source region in the coronal hole map on the photosphere (bottom left).

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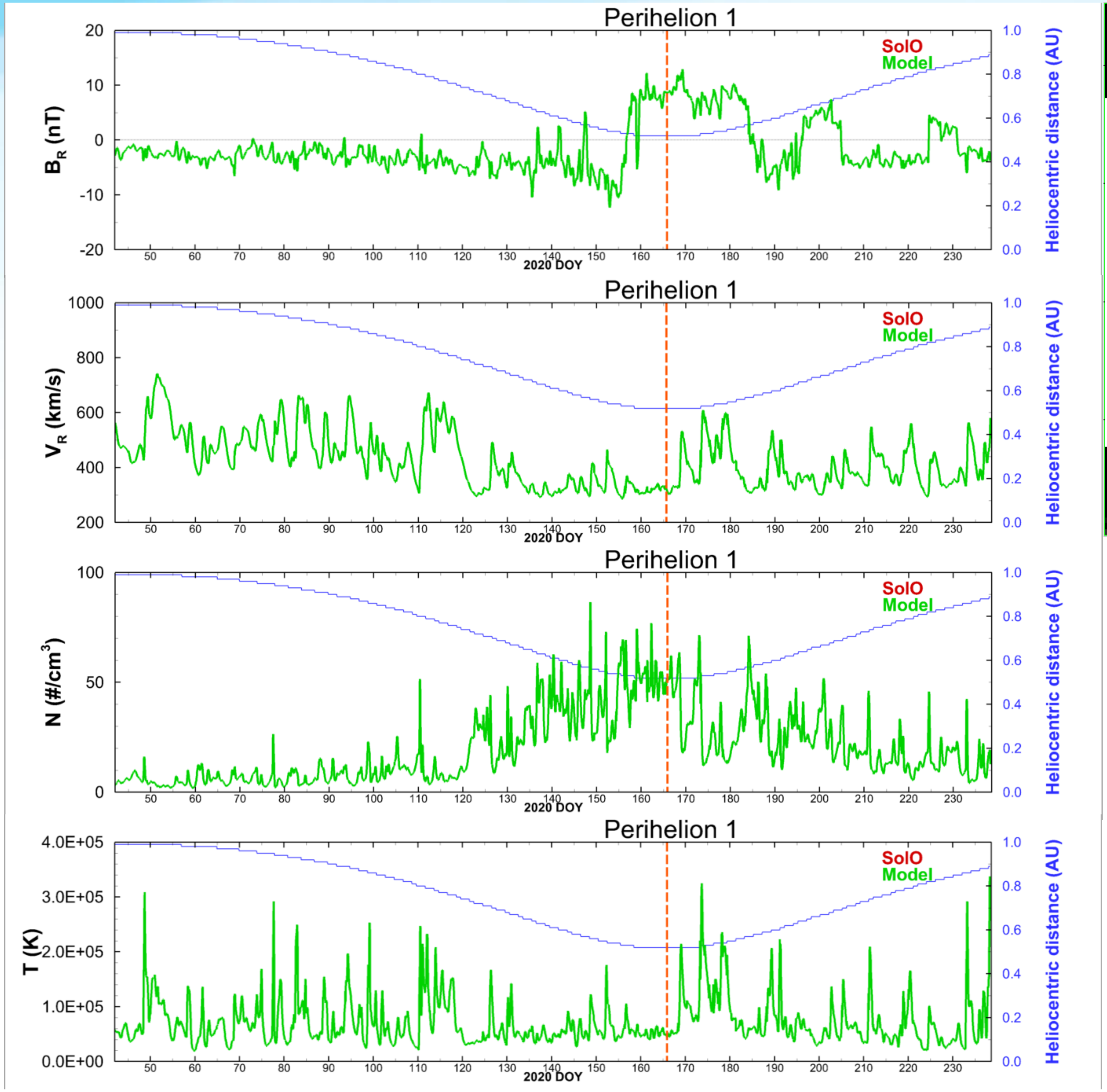
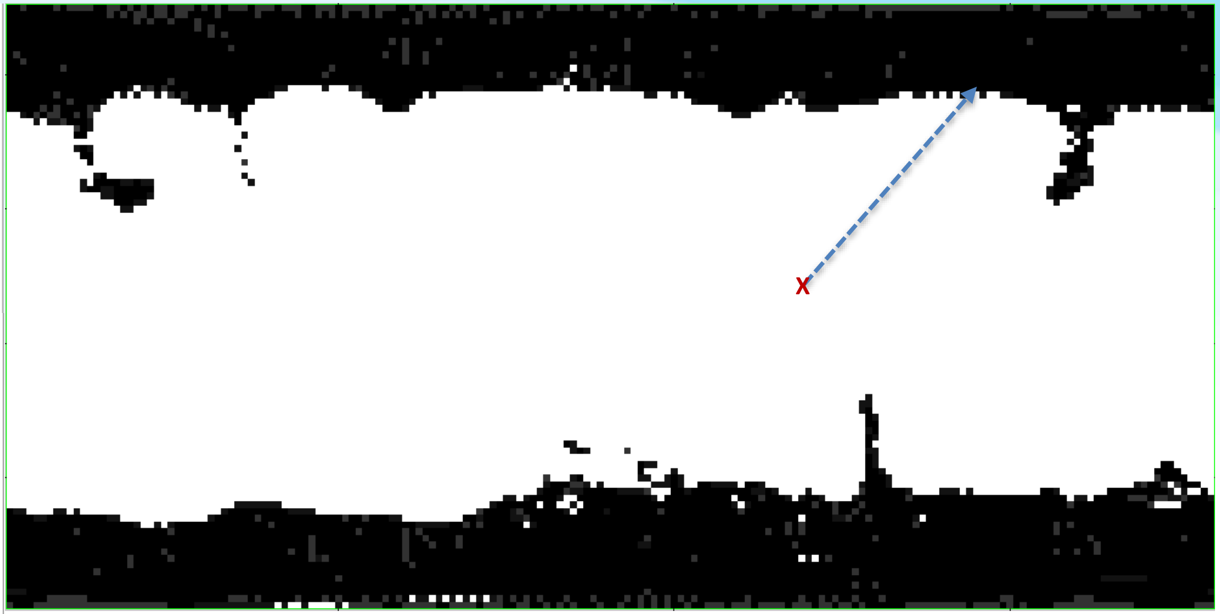
Model Prediction at Solar Orbiter





Simulation results along the trajectory of Solar Orbiter during its first orbit (left). The perihelion is marked by an orange dashed line at 15 June 2020 (DOY 167). The slow stream encountered at the close approach is traced to a source region in the coronal hole map on the photosphere (top right).

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Summary

- MS-FLUKSS 3-D heliospheric MHD model coupled with ADAPT-WSA coronal model (using SDO/HMI LOS magnetograms) to simulate the time-dependent flow of the ambient solar wind in the inner heliosphere
- Model performs reasonably at Earth and PSP, particularly during the first and third PSP orbits
- Model suggests that PSP was magnetically connected to an equatorial coronal hole at the first perihelion and to the southern polar coronal hole at perihelion 2-5
- Model deviates from PSP observations during the first half of the second solar encounter, possibly due to a rapidly evolving active region on the far side of the Sun at that time (Kim et al. 2020 ApJS)
- Model velocity is consistently larger than observed at Earth during PSP’s fourth and fifth orbits, possibly due to the large uncertainties in the polar fields and the flat heliospheric current sheet as polar coronal holes have been the predominant sources of the solar wind in the recent periods
- Model “predicts” predominantly dense and slow (<400 km/s) solar wind streams at PSP that are magnetically connected to an extension of the southern and northern polar coronal holes during the fifth solar encounter
- Model “predicts” a slow stream originating from the northern polar coronal hole boundary at Solar Orbiter at the first perihelion