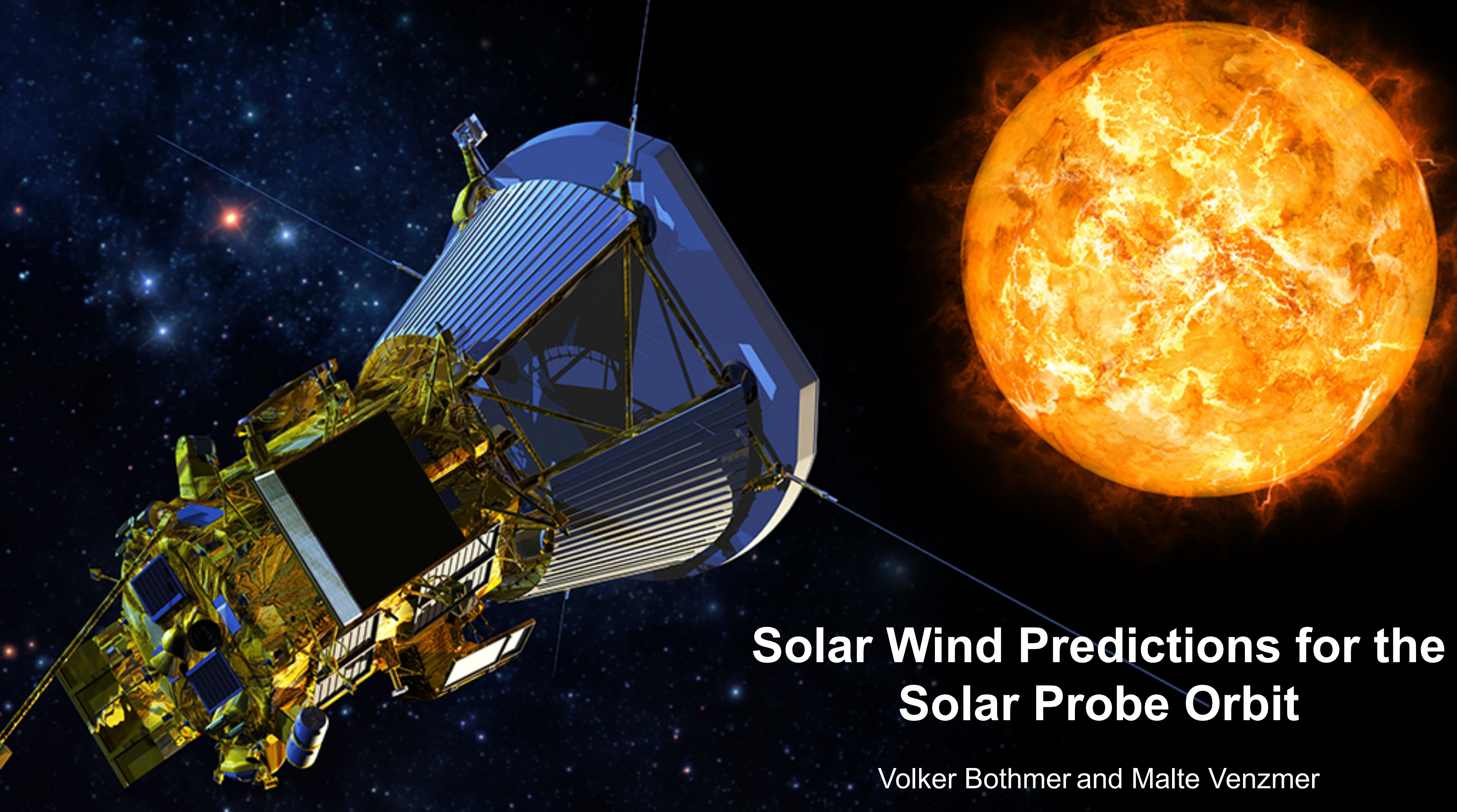


Solar Wind Predictions for the Solar Probe Orbit

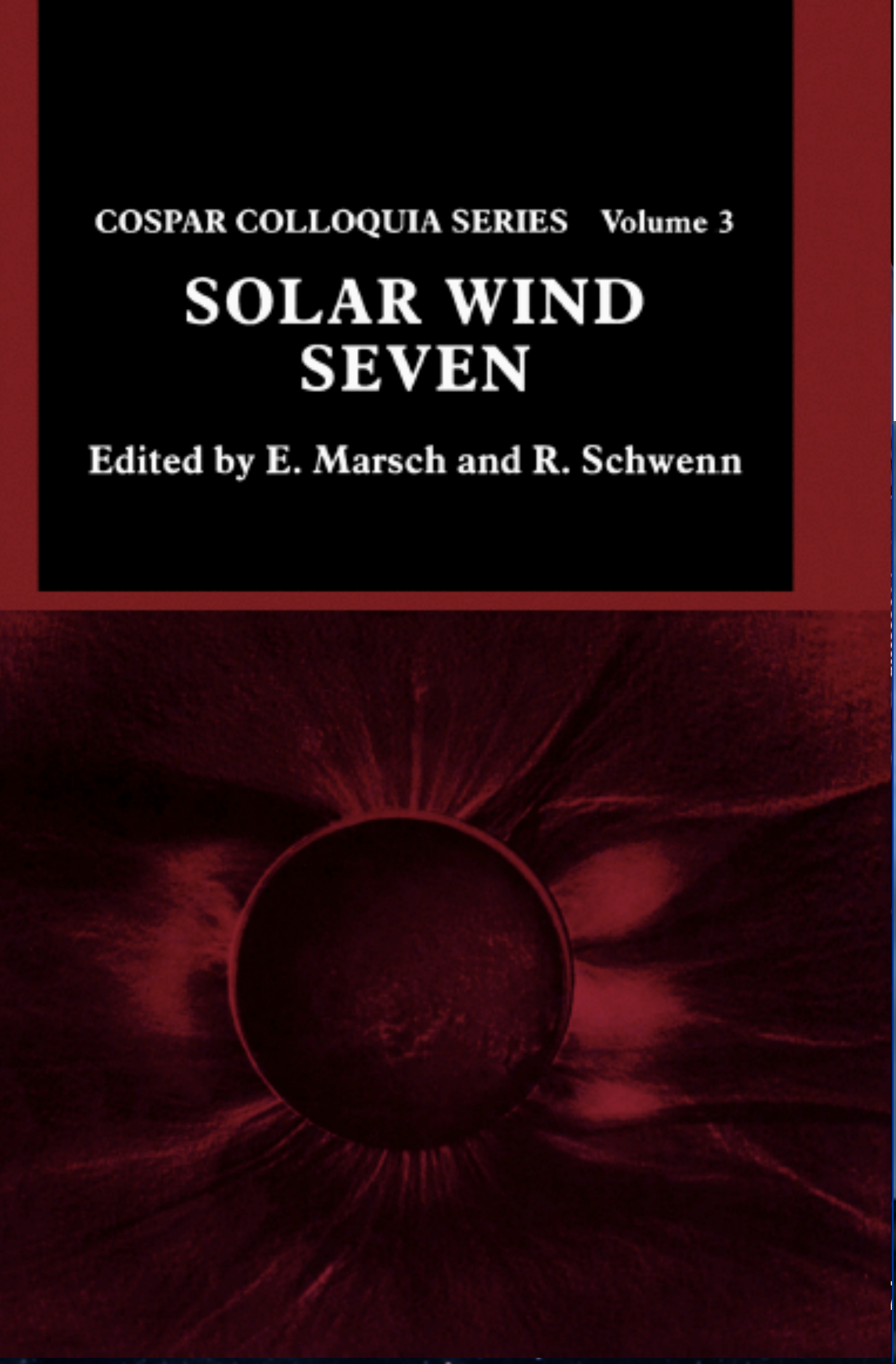
Volker Bothmer and Malte Venzmer

Institute for Astrophysics
University of Göttingen
Germany

Solar Probe Plus

A NASA Mission to Touch the Sun

JOHNS HOPKINS
APPLIED PHYSICS LABORATORY



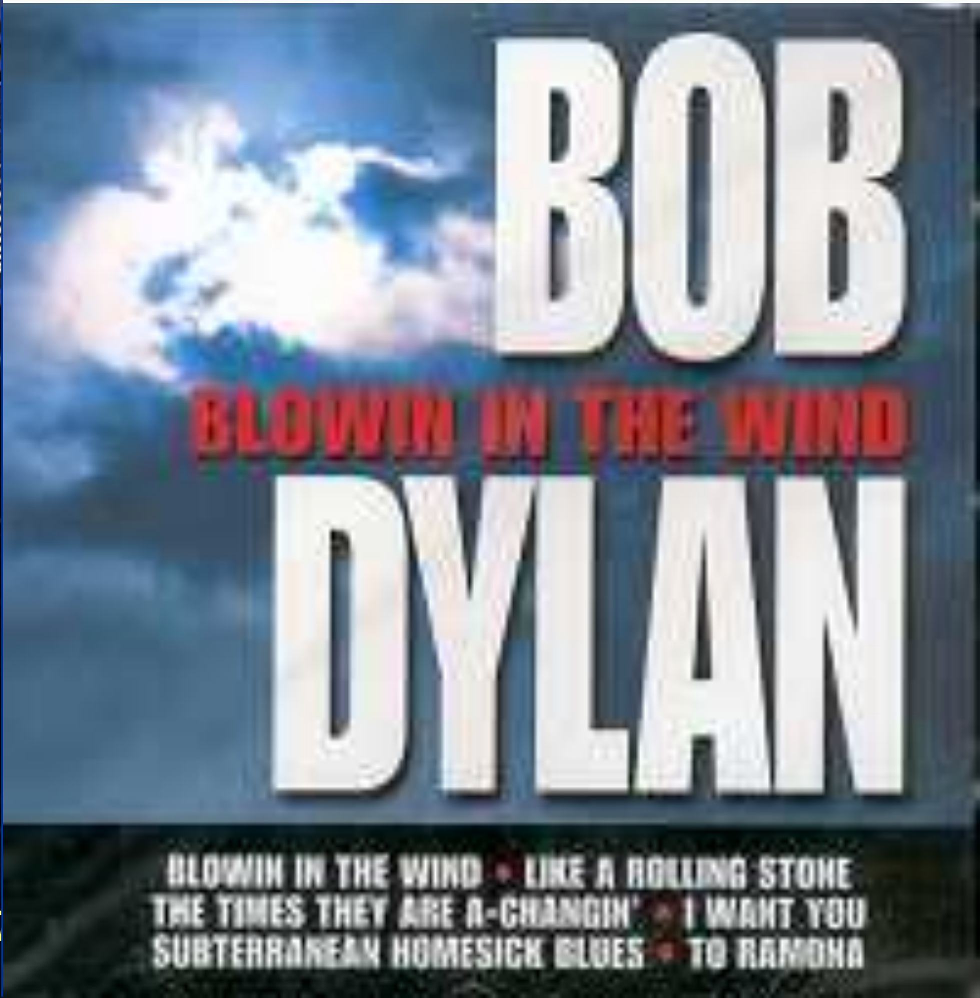
COSPAR COLLOQUIA SERIES Volume 3

SOLAR WIND SEVEN

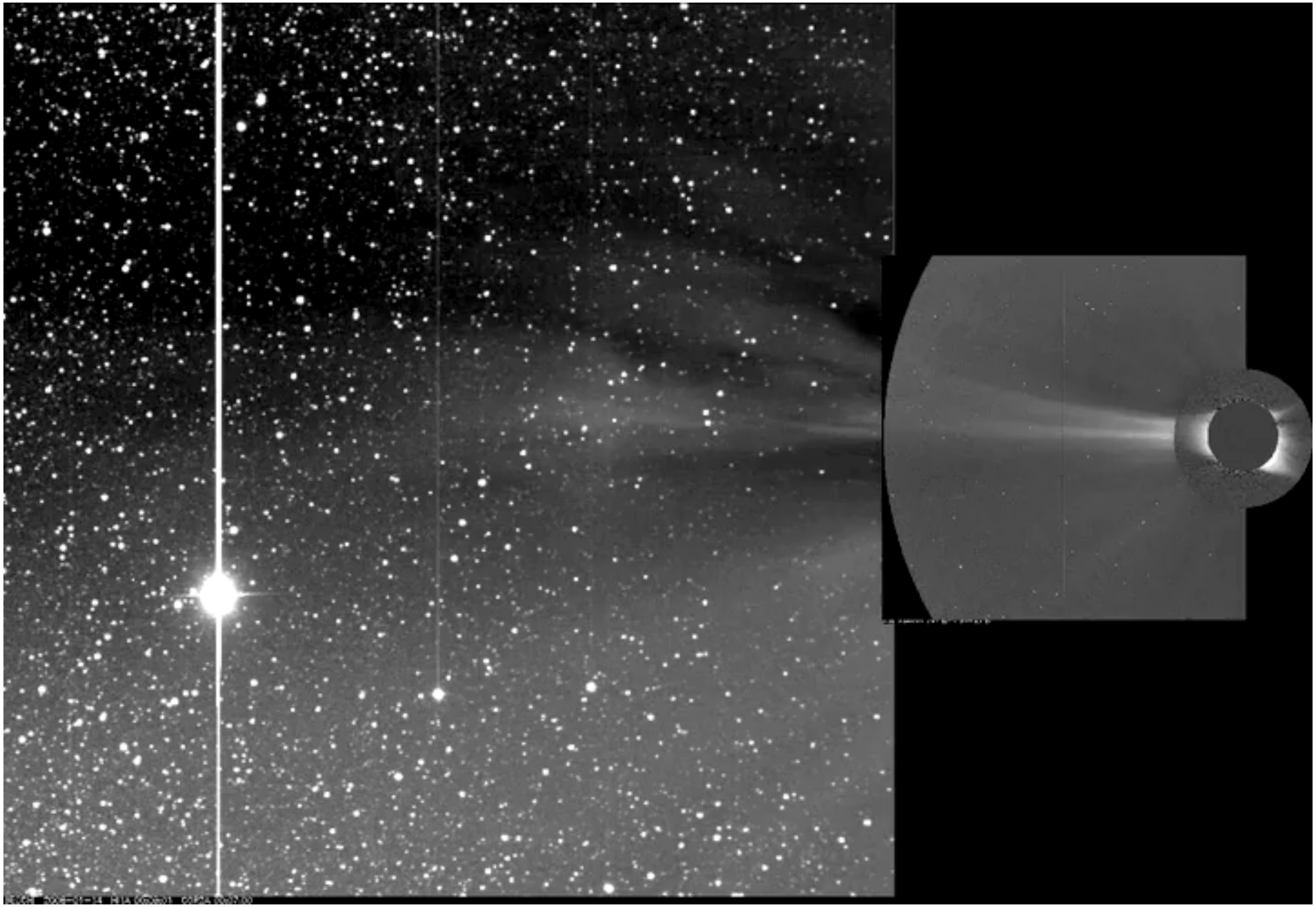
Edited by E. Marsch and R. Schwenn

Dr. Bothmer
Best wishes to the bus driver, become scientist, adding a new twist to magnetic fields in the solar wind.

Gene Parker
6 October 1998

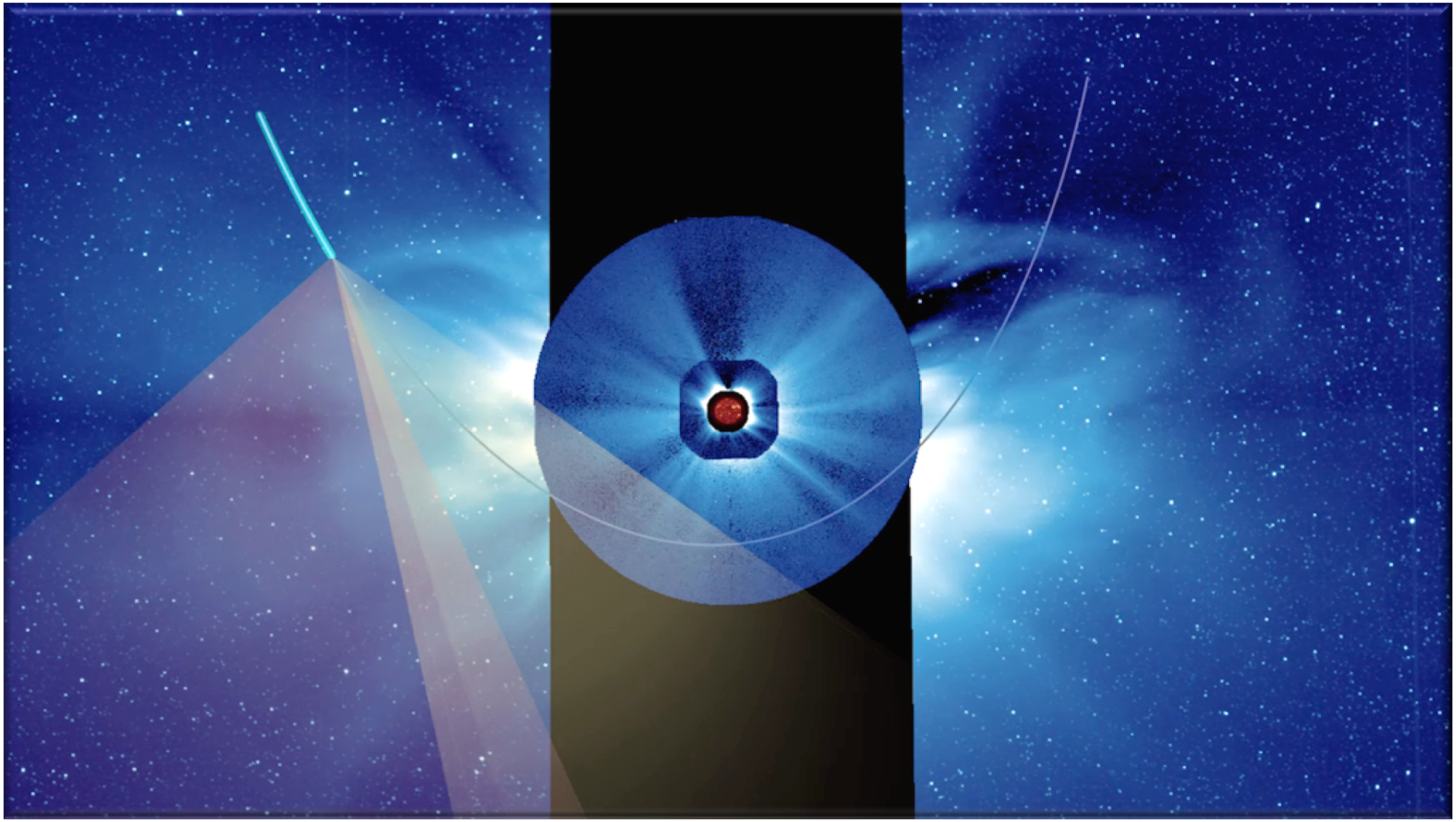


What will the Solar Wind Conditions Look Like during the PSP Orbit?



Vourlidas, 2016

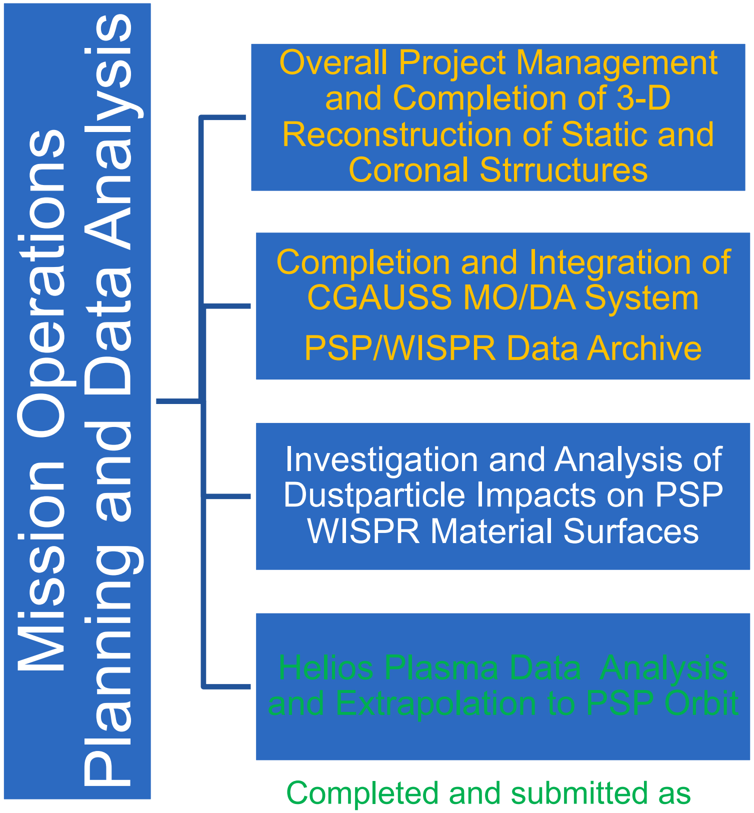
What will the Solar Wind Conditions Look Like during the PSP Orbit?



WISPR Consortium

CGAUSS (Coronagraphic German And US Parker SolarProbe Survey) – German Contribution to WISPR on PSP

DLR-NASA (Implementing Arrangement): 03/2012-09/2026



Mission Operations Planning and Data Analysis

Overall Project Management and Completion of 3-D Reconstruction of Static and Coronal Strructures

Completion and Integration of CGAUSS MO/DA System

PSP/WISPR Data Archive

Investigation and Analysis of Dustparticle Impacts on PSP WISPR Material Surfaces

Helios Plasma Data Analysis and Extrapolation to PSP Orbit

Completed and submitted as publication to A&A

CGAUSS Team

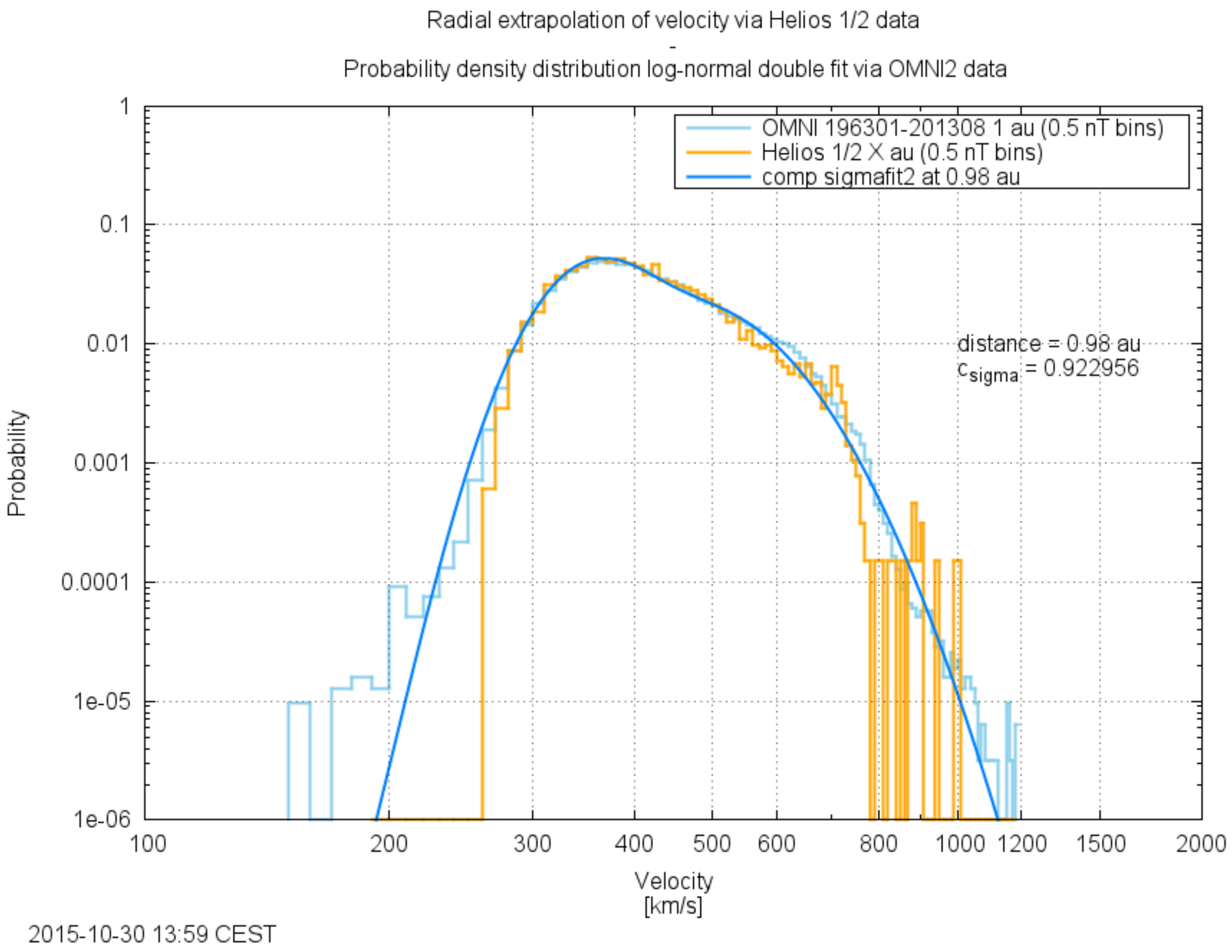
CGAUSS PI
Volker Bothmer

CGAUSS PS
Giuseppe Nisticó

PhD
Malte Venzmer

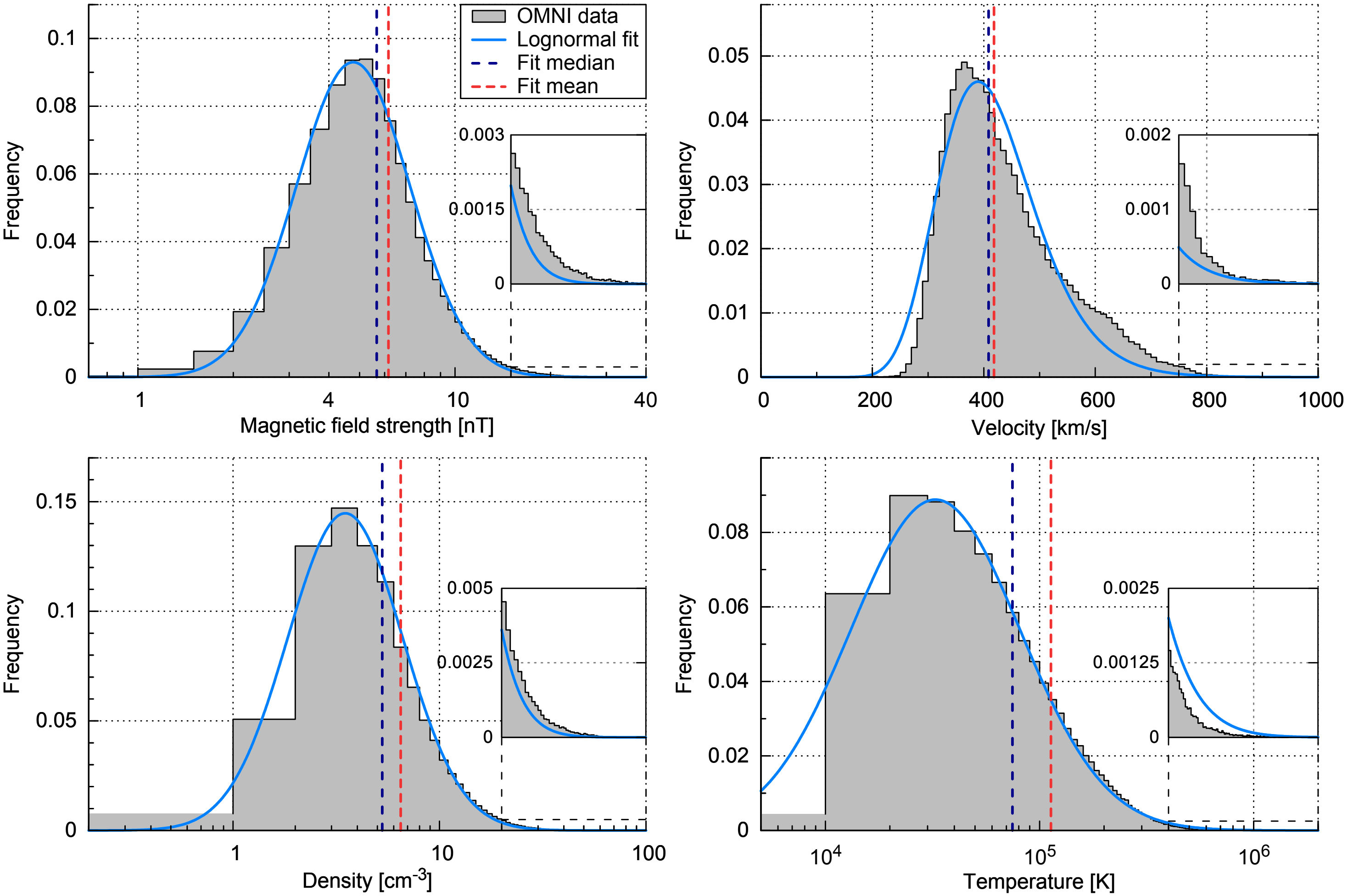
National Collaborators:
Ralf Srama and Team @ MPIK Heidelberg

Starting Point: Solar Wind Parameter Frequency Distribution Functions (V, B, N, T) - OMNI & Helios 1 & 2 Data



Radial extrapolation of velocity via Helios 1/2 data
-
Probability density distribution log-normal double fit via OMNI2 data

OMNI Frequency Distribution Functions - B, V, N, T Hourly Averages - November 1963 until December 2016

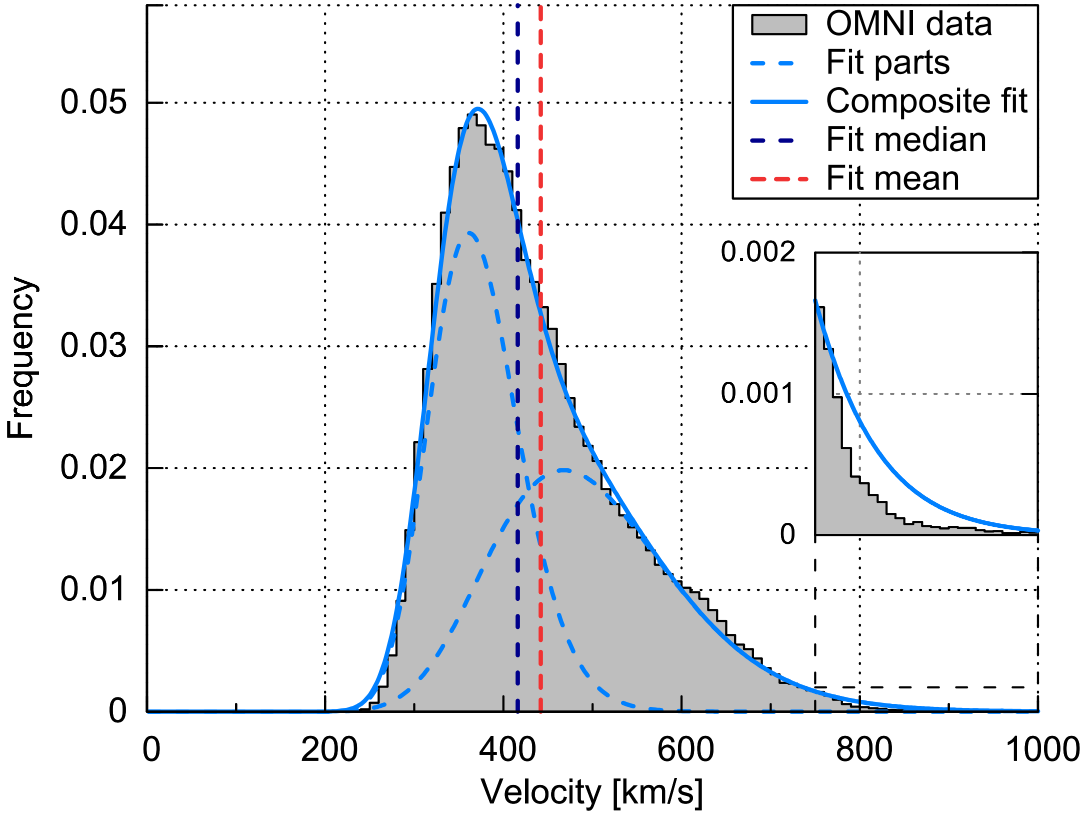


Bins:
0.5 nT;
10 km/s;
1 cm^{-3};
10^3 K

Fit through lognnormal functions:

$$W(x) = \frac{1}{\sigma\sqrt{2\pi}x}\exp\left(-\frac{(\ln x-\mu)^2}{2\sigma^2}\right)$$

Velocity Frequency Distribution

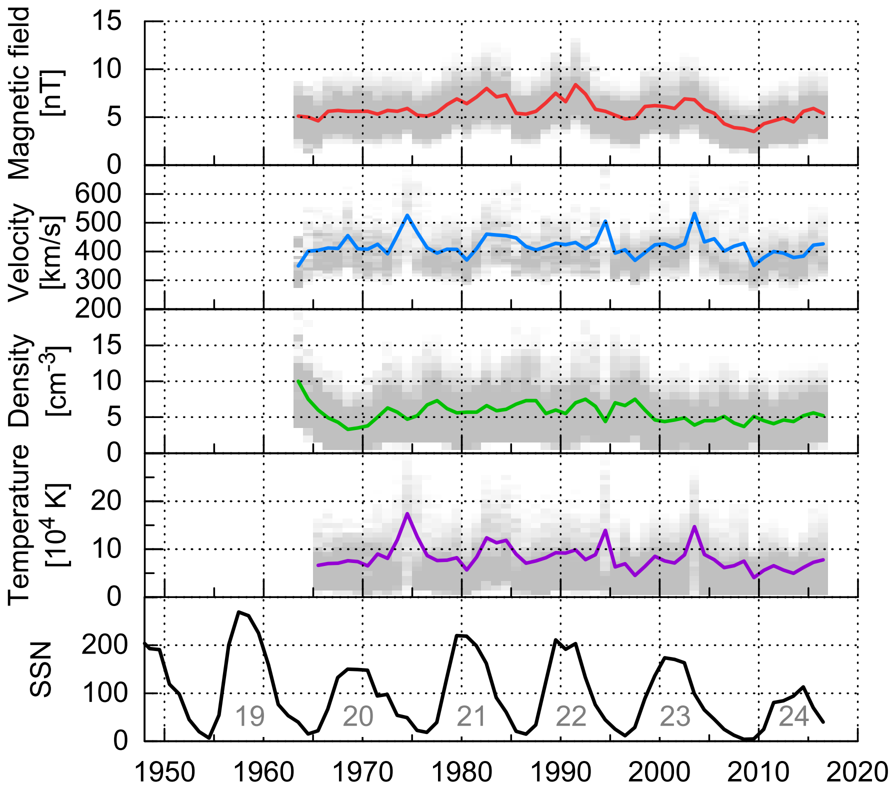


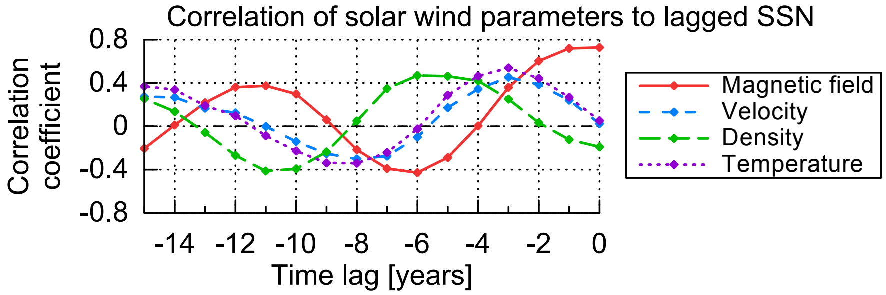
Fit through combination of 2 lognnormal functions:

$$W_{\mathrm{II}}(x) = c \cdot W_1(x) + (1 - c) \cdot W_2(x)\,.$$

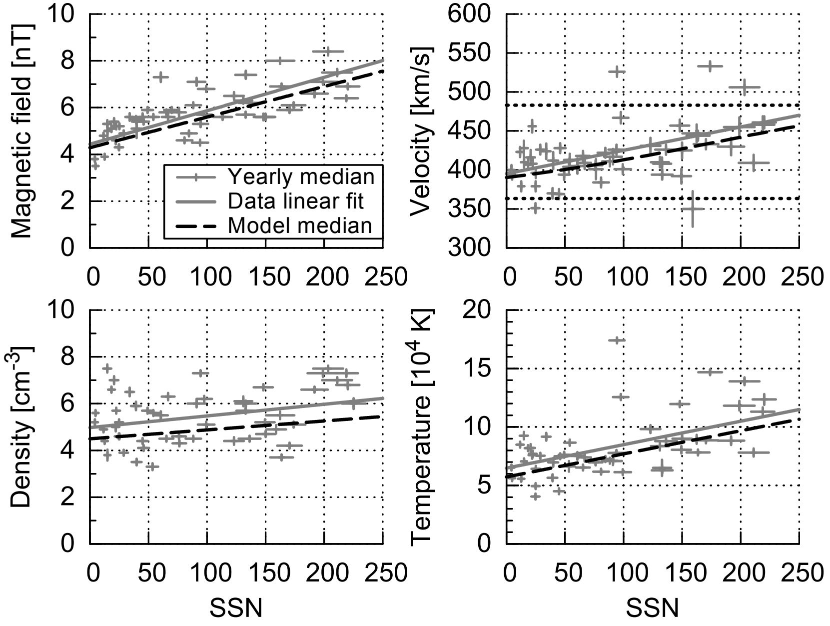
$$\int W_{\mathrm{II}}(x)\,\mathrm{d}x = 0 \qquad \text{and} \qquad \int x\, W_{\mathrm{II}}(x)\,\mathrm{d}x = 0$$

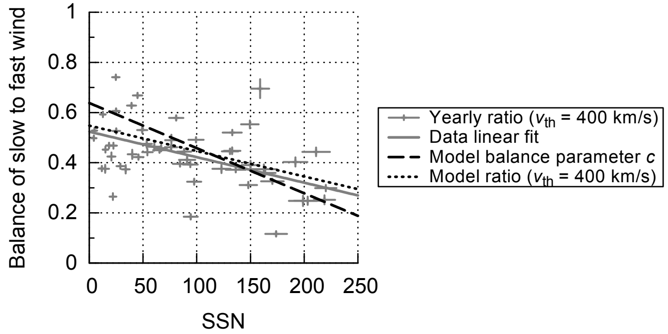
Solar Wind Parameters and SSN



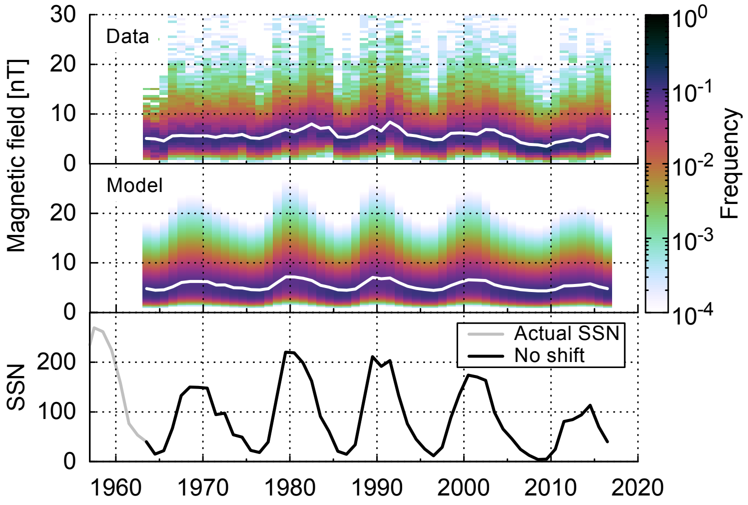


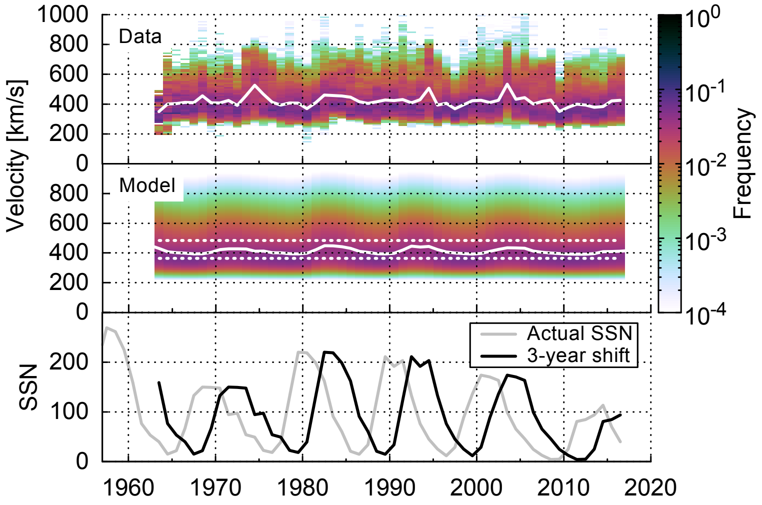
$$x_{\text{avg}}(ssn) = (1 + a_{\text{avg}}) \cdot x_{\text{med}}(ssn)$$

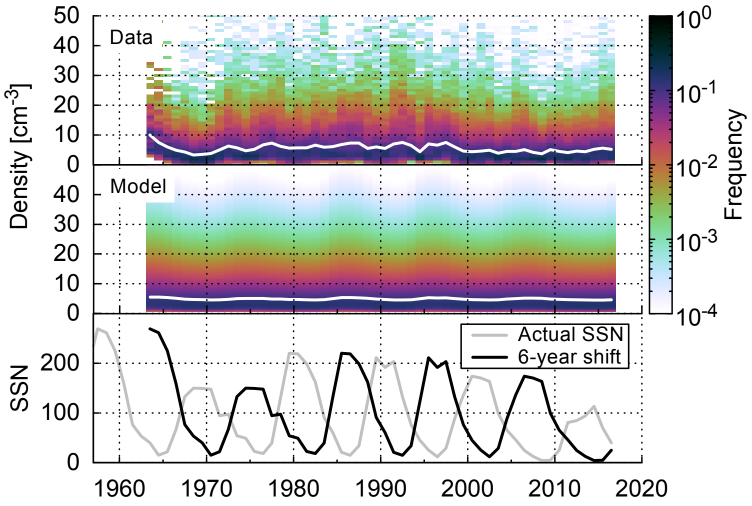


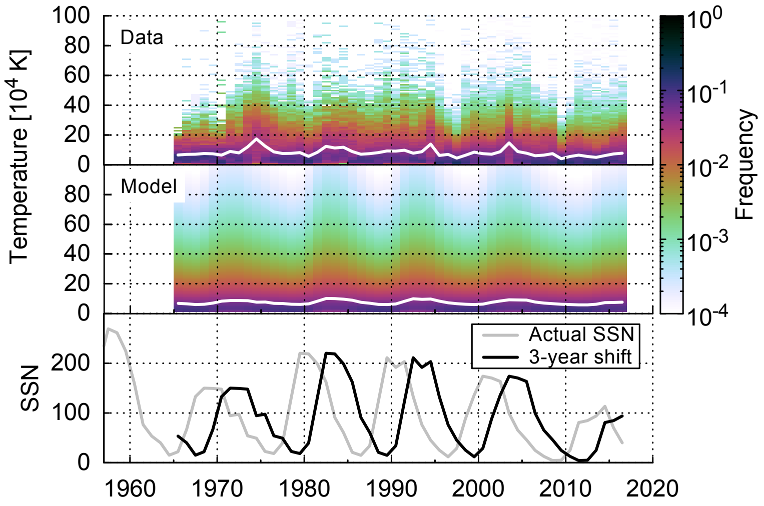


Solar Wind Parameters and SSN – W’(x, SSN)

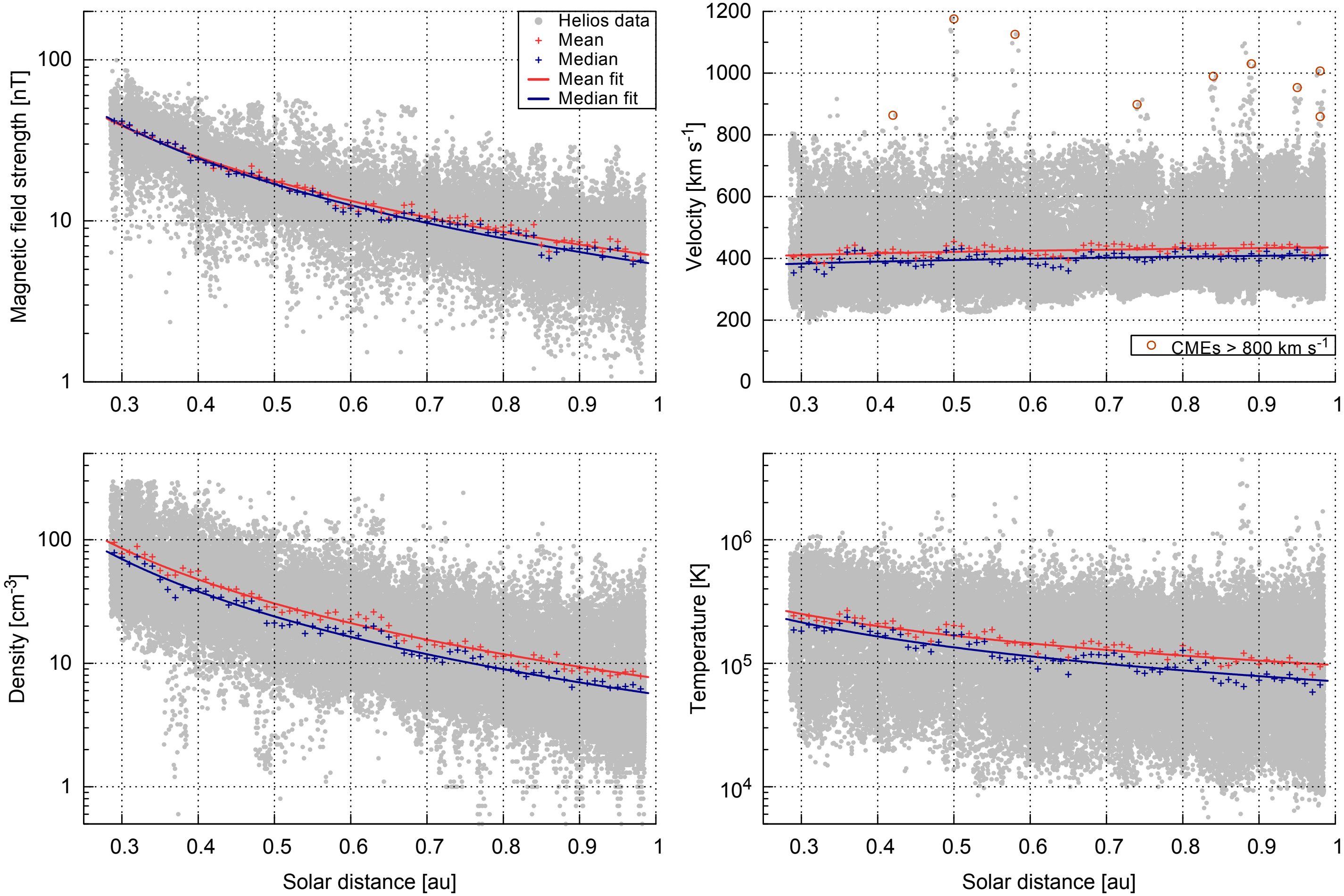








Helios radial dependencies between 0.29 and 0.98 au – Hourly Averages



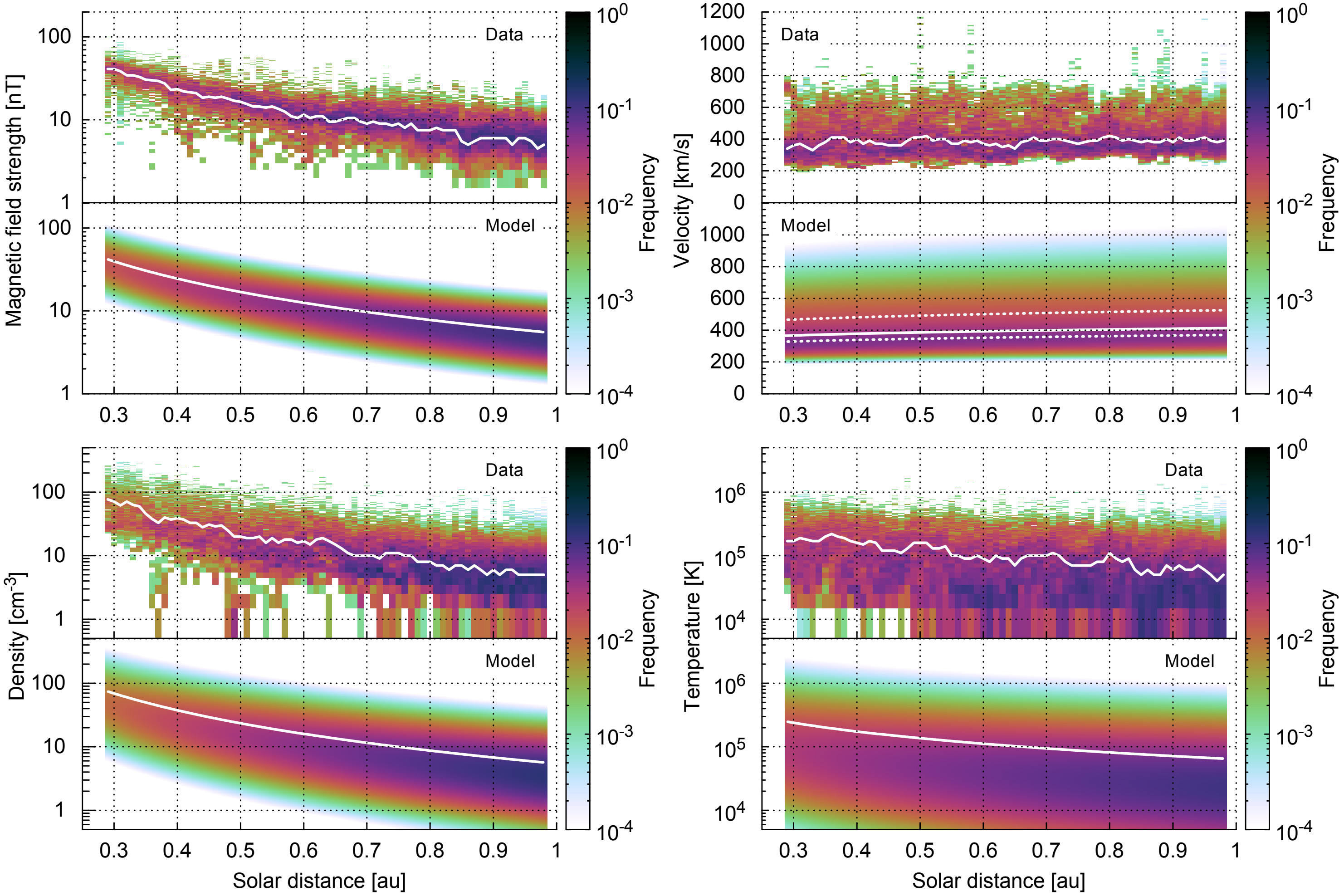
Bins of
0.01 au

V: Circles
denote
CME
events

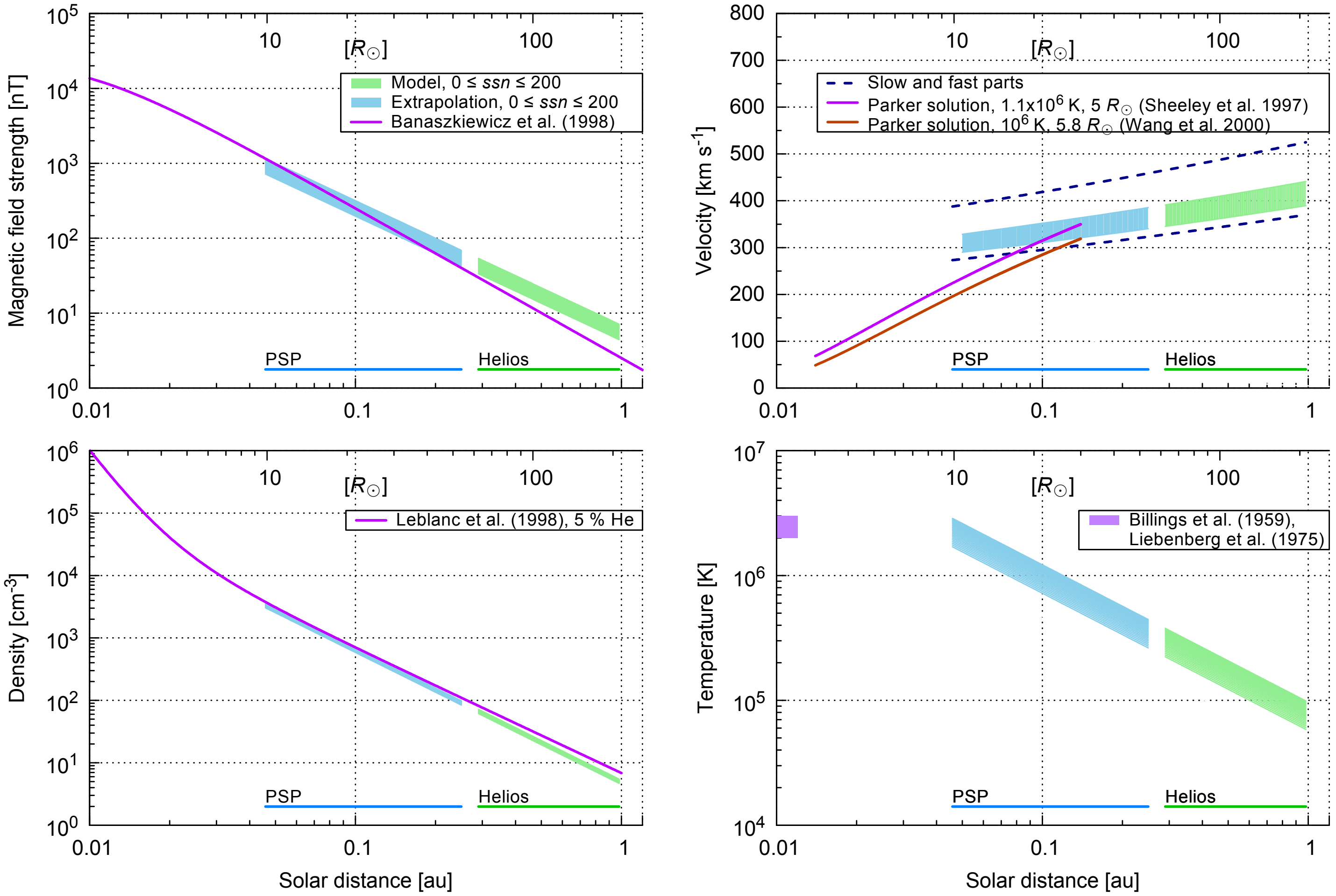
Power
law fits:

$$x(r) = d \cdot r^e$$

Frequency Distributions of SW Parameters wrt radial distance – Helios Data

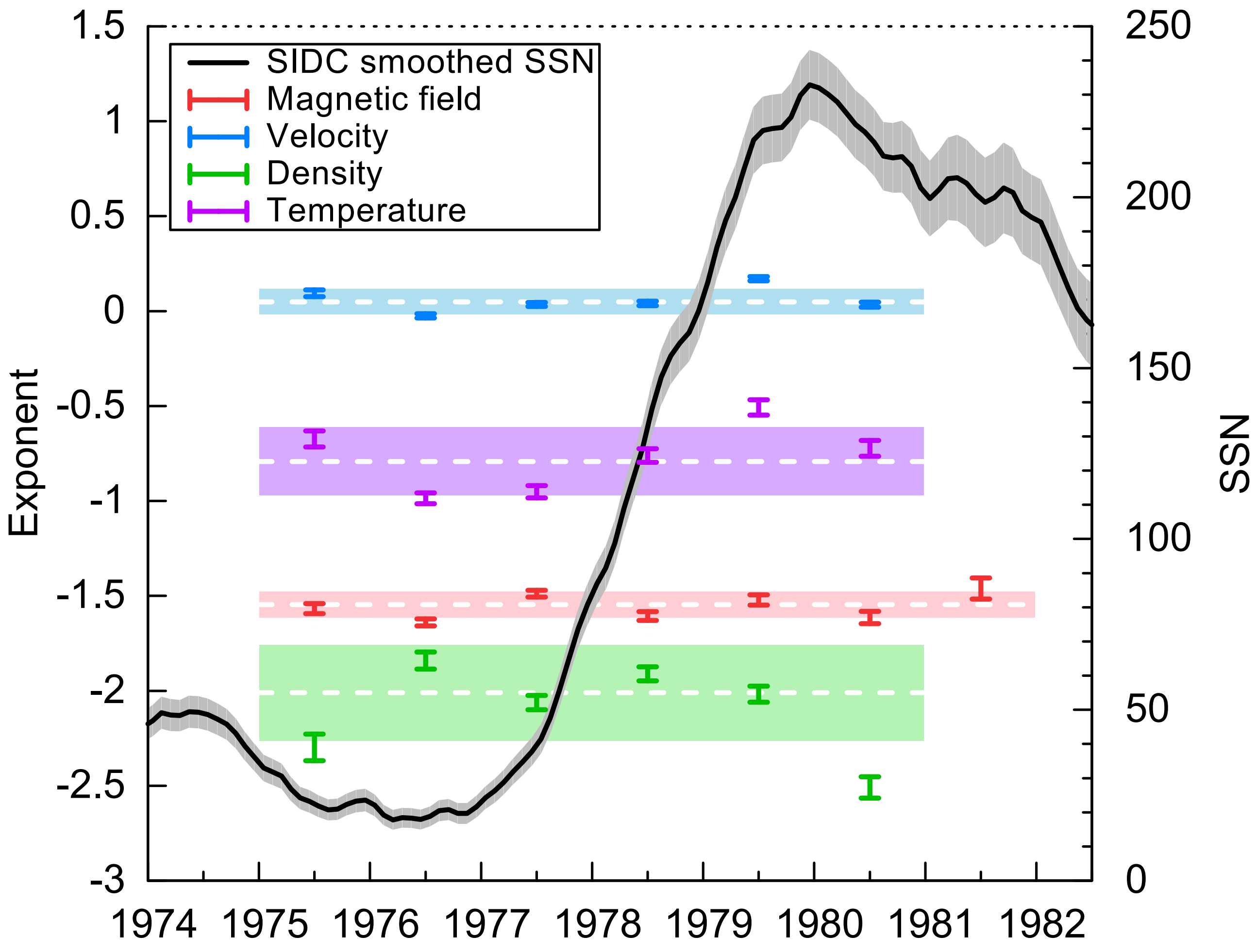


Model Extrapolations and Comparisons

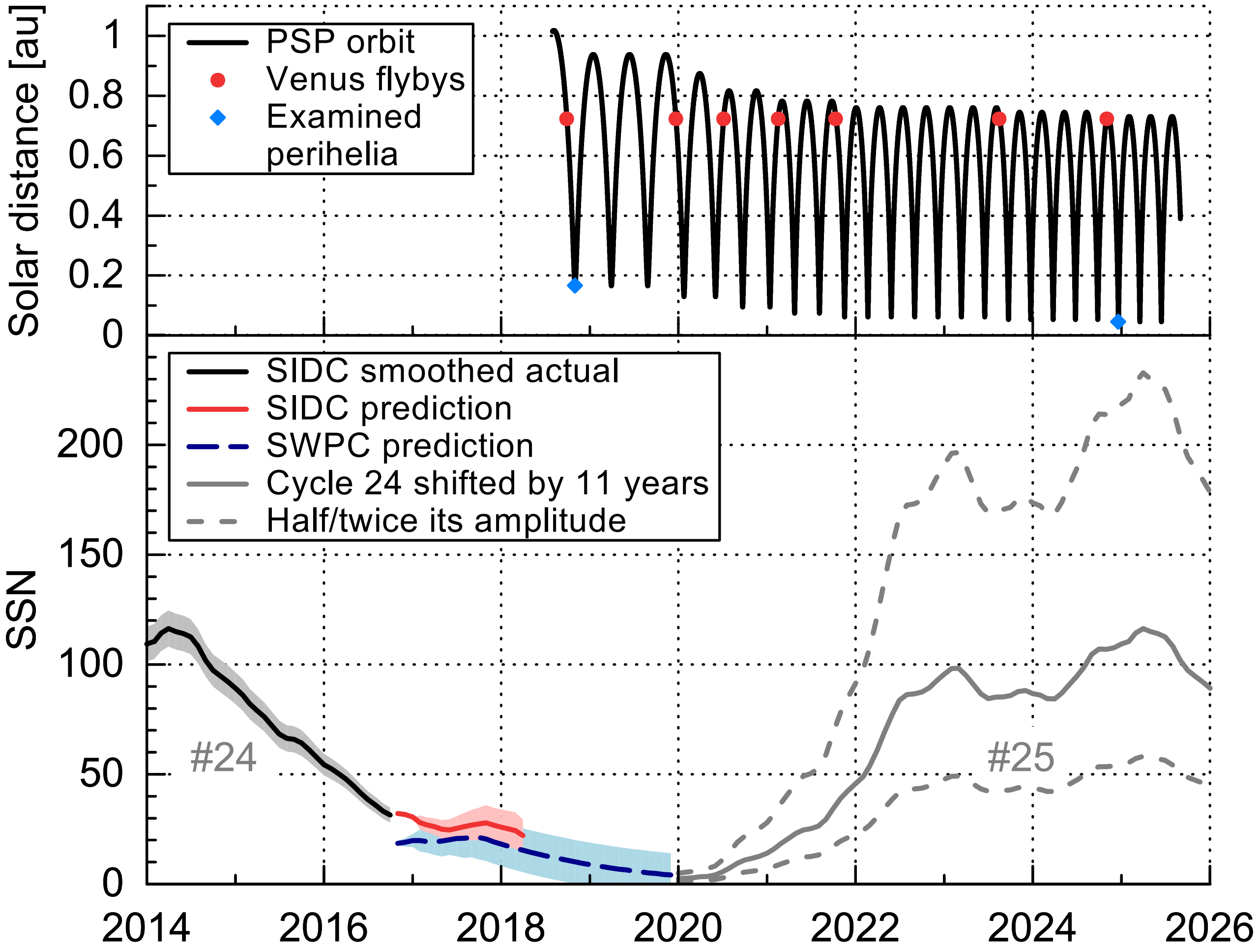


$$x_{\mathrm{med}}(ssn, r) = (a_{\mathrm{med}} \cdot ssn + b_{\mathrm{med}}) \cdot r^{e'}$$

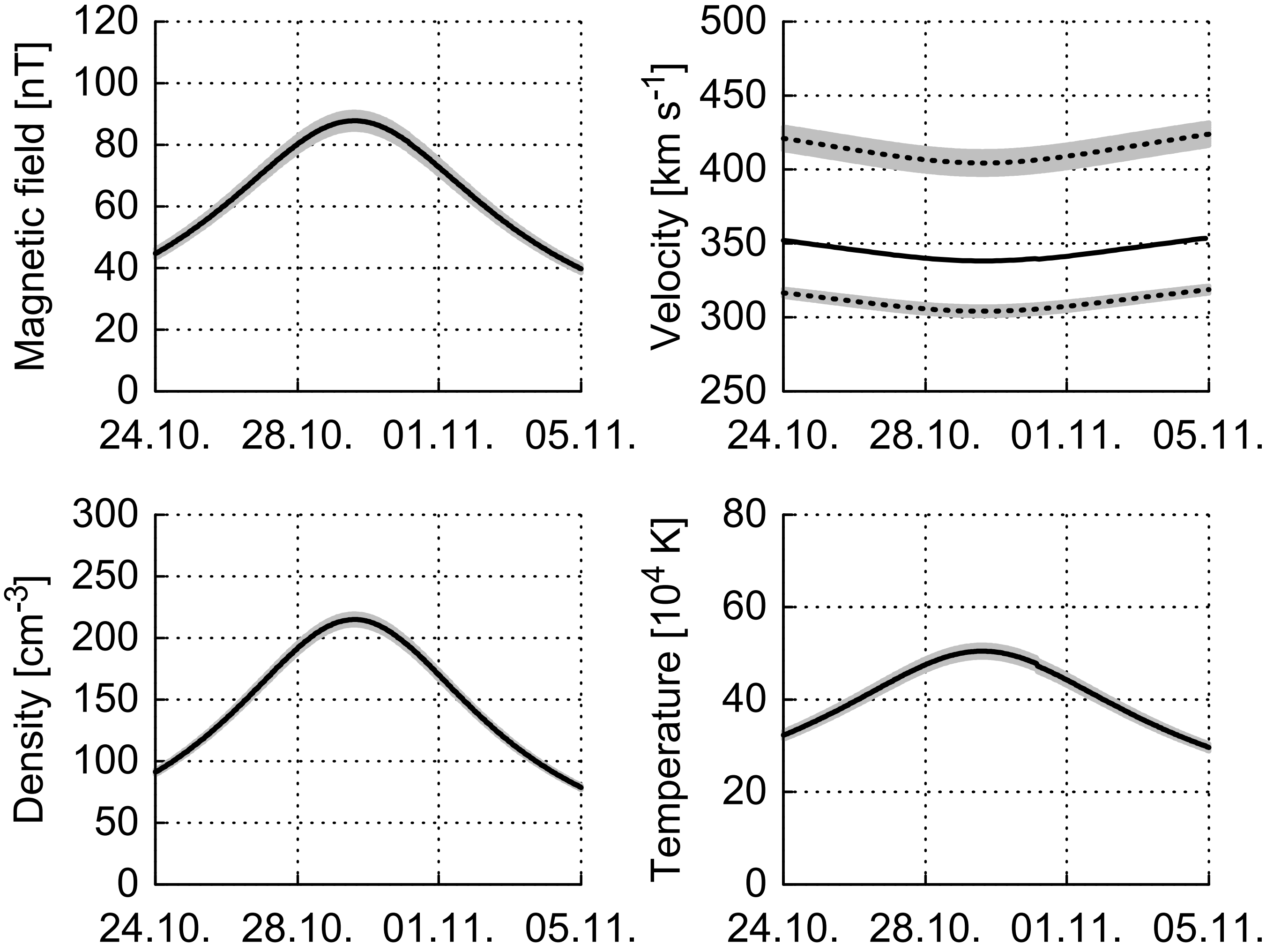
Helios Yearly Variations of SW Parameters Fit Exponents and SSN



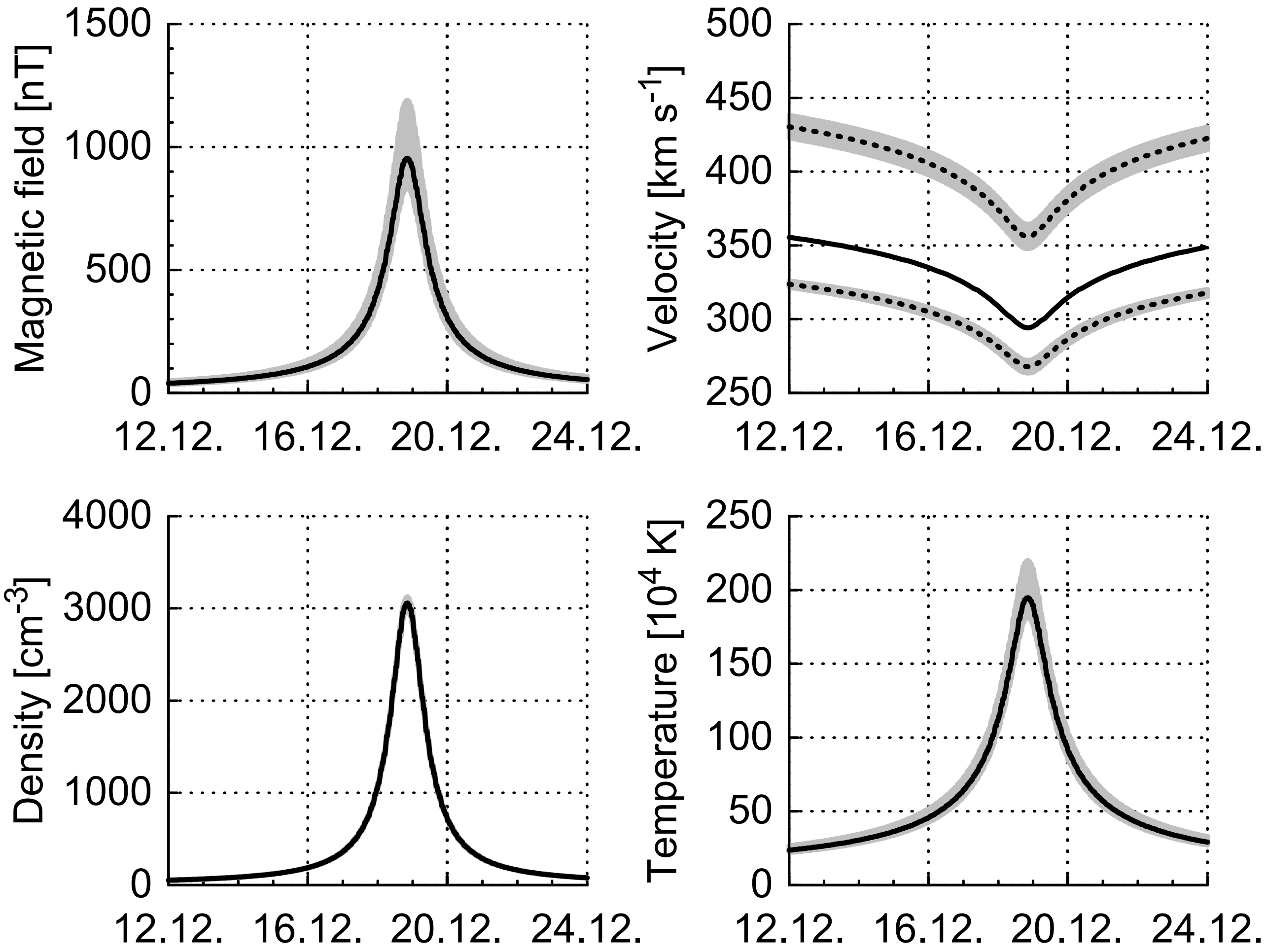
Predictions for PSP Orbit



Predictions for 1st PSP Perihel in 2018 @ 0.16 au



Predictions for PSP Perihel in 2024 @ 0.0459 au (9.86 R_S)



Summary

- The dependency of the magnetic field strength median value on solar activity and radial distance is:

$$B_{\mathrm{med}}(ssn, r) = (0.0131\ \mathrm{nT} \cdot ssn + 4.29\ \mathrm{nT}) \cdot r^{-1.66}$$

This approximation seems valid above 20 *R* , however near PSP’s closest perihelion the actual values might be found to be slightly higher.

- **The estimated magnetic field strength values for PSP’s first and closest perihelion are 87 nT and 943 nT.**

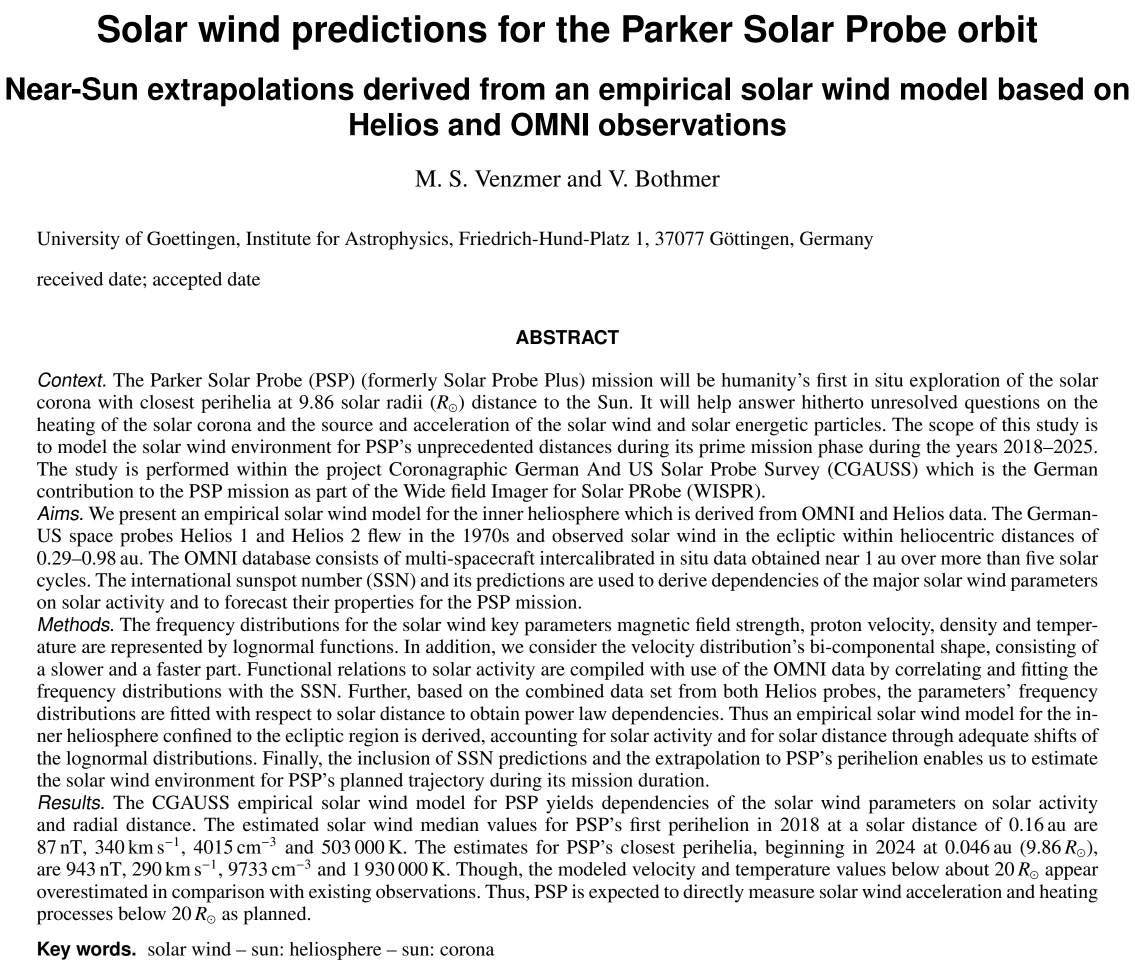
- **The radial dependencies of the proton velocity median values for slow and fast solar wind are:**

$$\mathbf{v_{slow}(\mathit{r})=363kms\ 1 \cdot \mathit{r}^{0.099}}$$
$$\mathbf{v_{fast}(\mathit{r})\ =483\ km\ s \cdot \mathit{r}^{0.099}}$$

These relations appear valid above about 20*R* solar distance, below they overestimate the actual solar wind velocities obtained from remote measurements.

- The calculated median velocity values for PSP’s first and closest perihelion are 340 km/s and 290 km/s
- The share of their frequency distributions to the overall solar wind velocity distribution is depending on solar activity, their balance was found to be $c(ssn)=- 0.00180 \cdot ssn+0.64$
  At solar minimum with sunspot number around 0 the slow wind contributes about 64 % and dropping to 28 % during solar maximum conditions with sunspot numbers around 200
- **The median proton density relation is found to be: $n_{\mathrm{med}}(ssn, r) = (0.0038\ \mathrm{cm}^{-3} \cdot ssn + 4.50\ \mathrm{cm}^{-3}) \cdot r^{-2.11}$**
- **This relation seems valid throughout the full PSP orbital distance range, even down to about 8 R_S**
- **The estimated density values for PSP’s first and closest perihelion are 214 cm^{-3} and 2951 cm^{-3}**
- The derived correlation function for the median proton temperature is: $T\mathrm{med}(ssn, r) = (197\ \mathrm{K} \cdot ssn + 57\ 300\ \mathrm{K}) \cdot r^{1.10}$
- Around PSP’s perihelion this relation seems to provide too high temperature values in comparison to coronal measurements - The estimated temperature values for PSP’s first and closest perihelion are 503 000 K and 1 930 000 K
- **The overestimation of the extrapolated velocity and temperature values at distances below 20 *R* indicate the occurrence of solar wind acceleration and heating processes, which PSP will thus be able to directly measure as planned.**

Acknowledgements



Solar wind predictions for the Parker Solar Probe orbit

Near-Sun extrapolations derived from an empirical solar wind model based on Helios and OMNI observations

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received date; accepted date

ABSTRACT

Context. The Parker Solar Probe (PSP) (formerly Solar Probe Plus) mission will be humanity's first in situ exploration of the solar corona with closest perihelia at 9.86 solar radii ($R_\odot$) distance to the Sun. It will help answer hitherto unresolved questions on the heating of the solar corona and the source and acceleration of the solar wind and solar energetic particles. The scope of this study is to model the solar wind environment for PSP's unprecedented distances during its prime mission phase during the years 2018–2025. The study is performed within the project Coronagraphic German And US Solar Probe Survey (CGAUSS) which is the German contribution to the PSP mission as part of the Wide field Imager for Solar PRobe (WISPR).
Aims. We present an empirical solar wind model for the inner heliosphere which is derived from OMNI and Helios data. The German-US space probes Helios 1 and Helios 2 flew in the 1970s and observed solar wind in the ecliptic within heliocentric distances of 0.29–0.98 au. The OMNI database consists of multi-spacecraft intercalibrated in situ data obtained near 1 au over more than five solar cycles. The international sunspot number (SSN) and its predictions are used to derive dependencies of the major solar wind parameters on solar activity and to forecast their properties for the PSP mission.
Methods. The frequency distributions for the solar wind key parameters magnetic field strength, proton velocity, density and temperature are represented by lognormal functions. In addition, we consider the velocity distribution's bi-componental shape, consisting of a slower and a faster part. Functional relations to solar activity are compiled with use of the OMNI data by correlating and fitting the frequency distributions with the SSN. Further, based on the combined data set from both Helios probes, the parameters' frequency distributions are fitted with respect to solar distance to obtain power law dependencies. Thus an empirical solar wind model for the inner heliosphere confined to the ecliptic region is derived, accounting for solar activity and for solar distance through adequate shifts of the lognormal distributions. Finally, the inclusion of SSN predictions and the extrapolation to PSP's perihelion enables us to estimate the solar wind environment for PSP's planned trajectory during its mission duration.
Results. The CGAUSS empirical solar wind model for PSP yields dependencies of the solar wind parameters on solar activity and radial distance. The estimated solar wind median values for PSP's first perihelion in 2018 at a solar distance of 0.16 au are 87 nT, 340 km s^{-1}, 4015 cm^{-3} and 503 000 K. The estimates for PSP's closest perihelia, beginning in 2024 at 0.046 au (9.86 $R_\odot$), are 943 nT, 290 km s^{-1}, 9733 cm^{-3} and 1 930 000 K. Though, the modeled velocity and temperature values below about 20 $R_\odot$ appear overestimated in comparison with existing observations. Thus, PSP is expected to directly measure solar wind acceleration and heating processes below 20 $R_\odot$ as planned.

Key words. solar wind – sun: heliosphere – sun: corona

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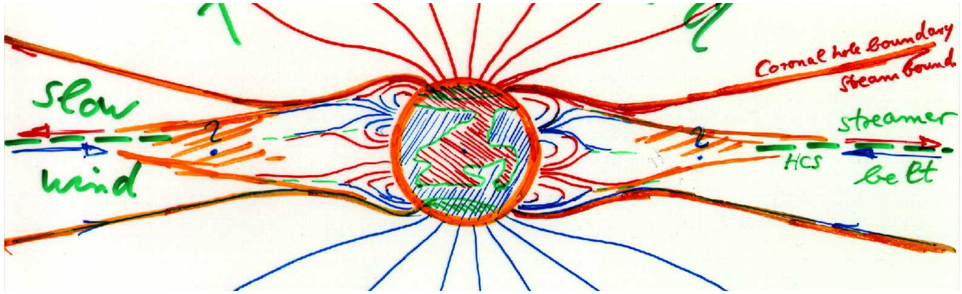
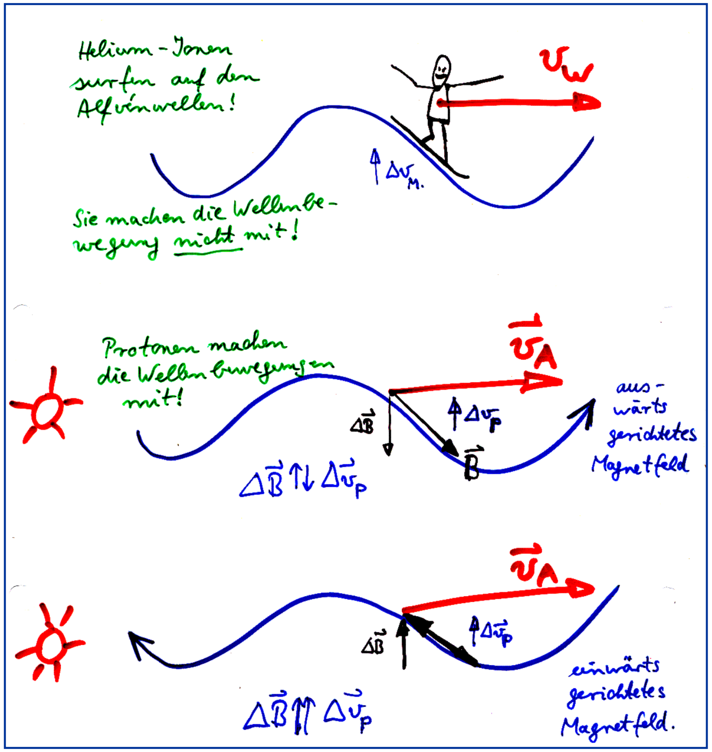
The authors thank the Helios and OMNI PIs/teams for creating and making available the solar wind in situ data. The Helios and the OMNI data are supplied by the NASA Space Science Data Coordinated Archive (NSSDCA) and the Space Physics Data Facility (SPDF) at NASA's Goddard Space Flight Center (GSFC). Additional thanks for maintaining and providing the international sunspot number series goes to the World Data Center – Sunspot Index and Long-term Solar Observations (WDC-SILSO) at the Solar Influences Data Analysis Center (SIDC), Royal Observatory of Belgium (ROB). The PSP SPICE kernel was kindly provided by Angelos Vourlidas.

Thank you so much Rainer !





Lectures at Göttingen University
in 2001/2

Solar Corona & Alpha Particles
as Solar Wind Surfers