The solar wind's geomagnetic impact and its Sun–Earth evolution

Predictive models for space weather and for the Parker Solar Probe orbit

PhD defense by
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Thursday, 1 November 2018, 14:00
Seminarraum Astrophysik (SR 17, F 05.104)

Two topics

Title

The solar wind's geomagnetic impact and its Sun–Earth evolution

–

Predictive models for space weather and for the Parker Solar Probe orbit

Two topics

Study 1

The solar wind's geomagnetic impact – Predictive models for space weather

Two topics

Study 1

The solar wind's geomagnetic impact – Predictive models for space weather

Study 2

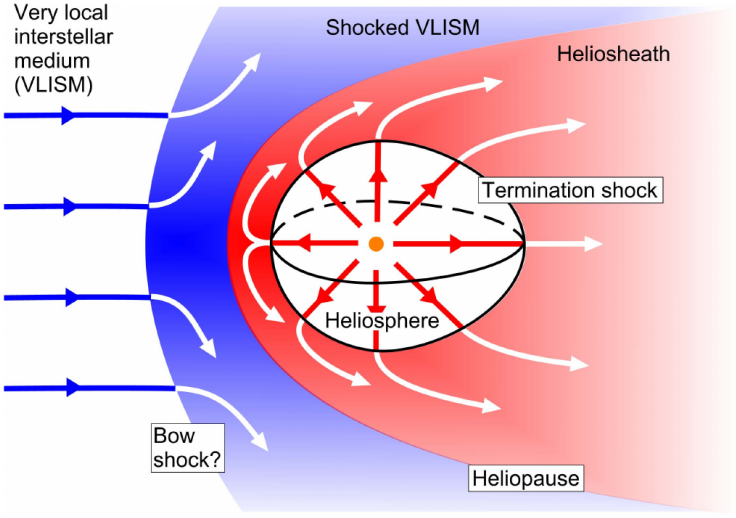
The solar wind's Sun–Earth evolution – Predictive models for the Parker Solar Probe orbit

Solar wind

Credit: Miloslav Druckmüller, Peter Aniol, Shaddia Habbal, 2017

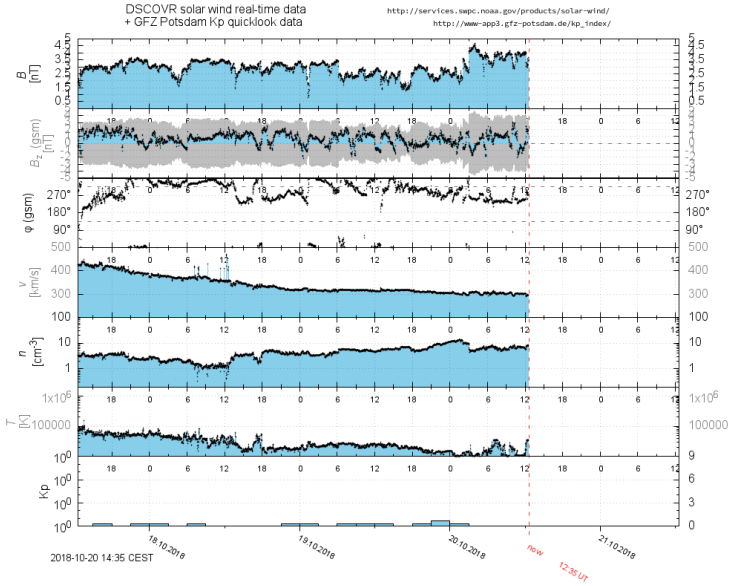
- flow of magnetized plasma
- consists of electrons, protons and 5% helium

Solar wind

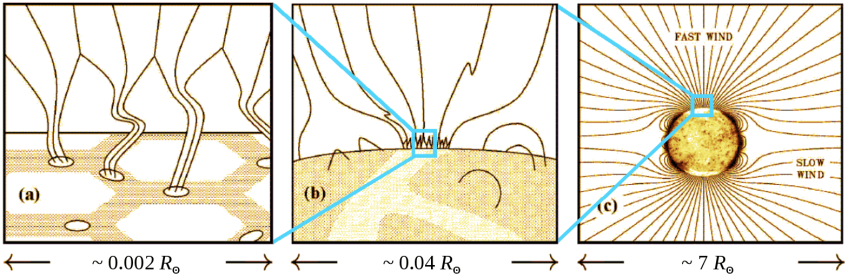


Credit: Owens & Forsyth (2013, Fig. 9)

Solar wind

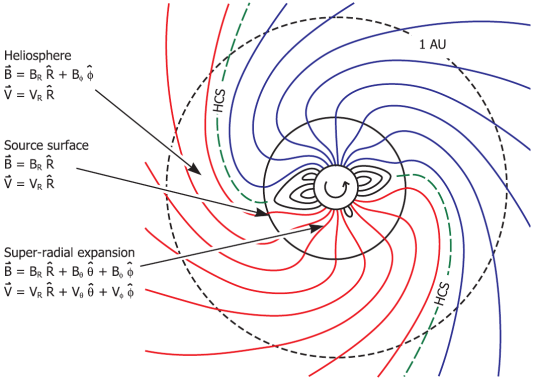

DSCOVR solar wind real-time data
+ GFZ Potsdam Kp quicklook data
http://services.swpc.noaa.gov/products/solar-wind/
http://www-app3.gfz-potsdam.de/kp_index/
B [nT]
Bz (gsm) [nT]
φ (gsm)
V [km/s]
n [cm-3]
T [K]
Kp
2018-10-20 14:35 CEST
18.10.2018
19.10.2018
20.10.2018
now
12:35 UT
21.10.2018

Solar magnetic field



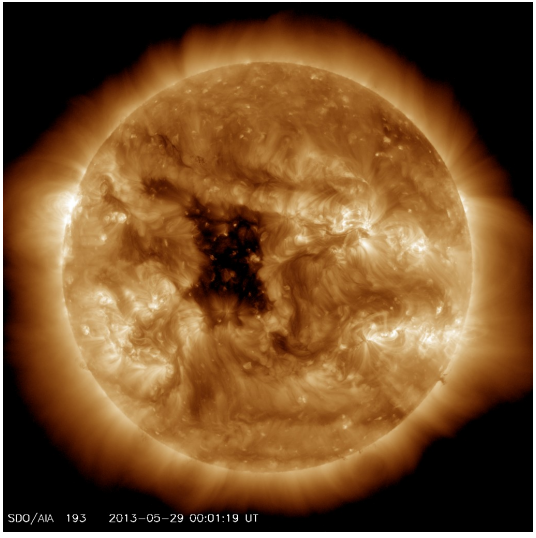
Courtesy of S. R. Cranmer

Solar magnetic field



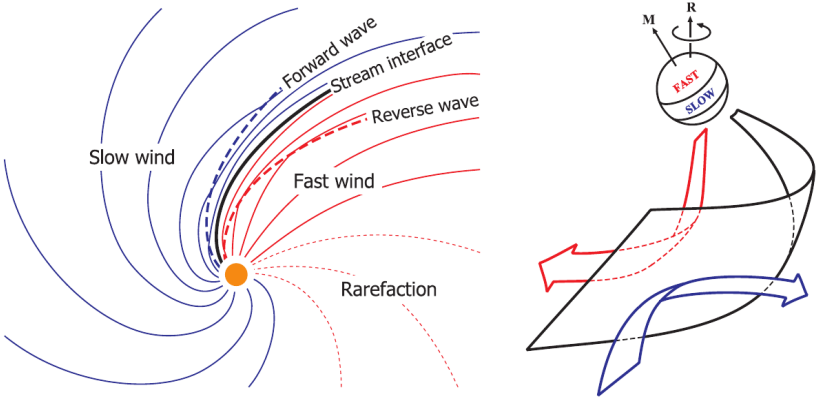
Credit: Owens & Forsyth (2013, Fig. 1), adapted from Schatten et al. (1969, Fig. 1)

Slow and fast solar wind



Credit: NASA/SDO and the AIA, EVE and HMI science teams

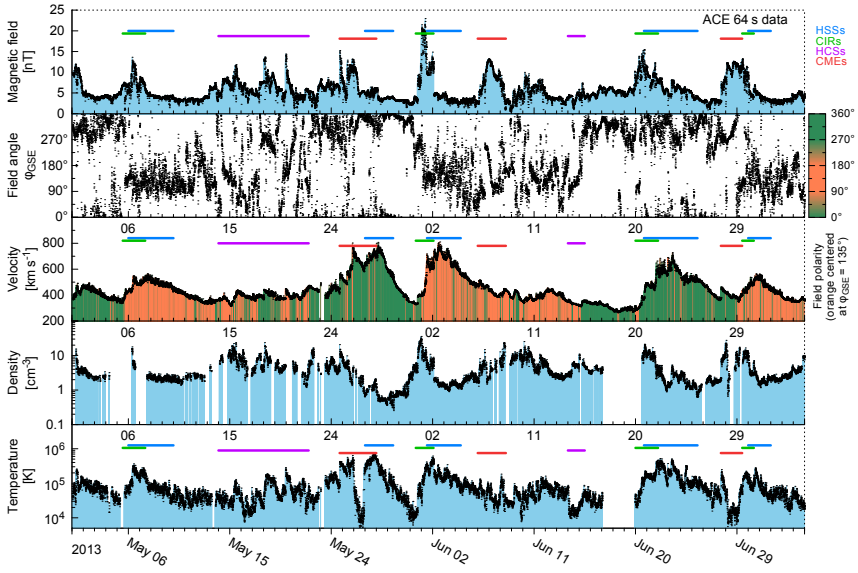
Slow and fast solar wind



Credit: Owens & Forsyth (2013, Fig. 7); right panel adapted from Pizzo (1991, Fig. 2)

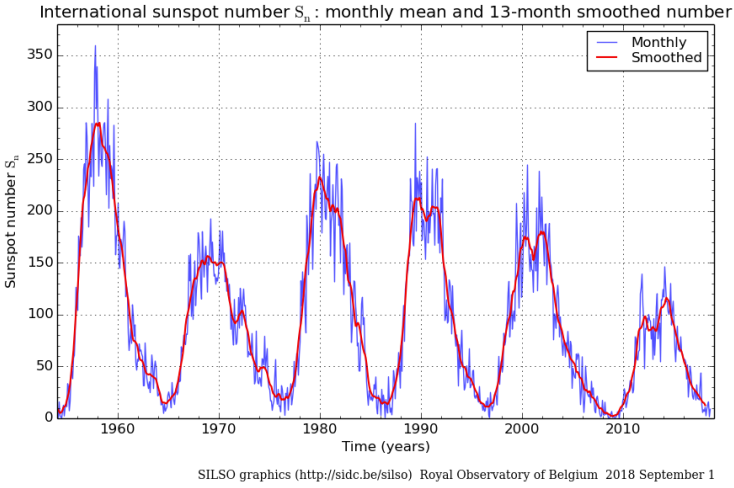
Solar wind

In-situ example



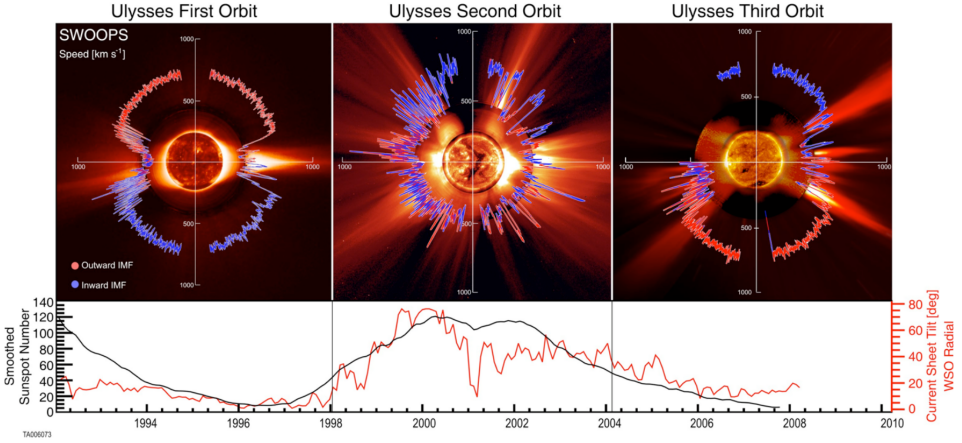
Solar activity
Sunspots

Solar activity



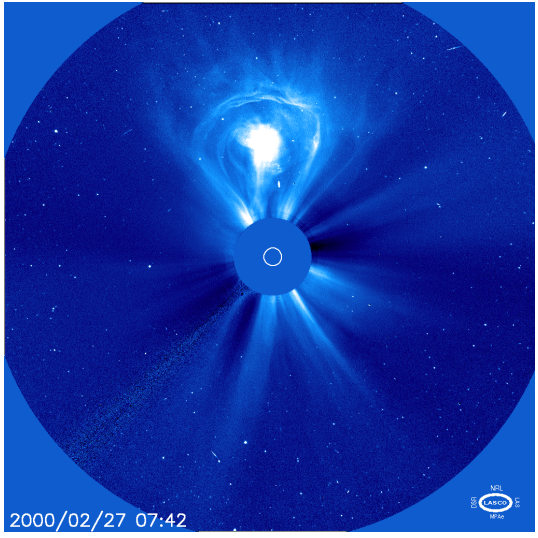
⏭ Magnetic butterfly diagram

Solar activity



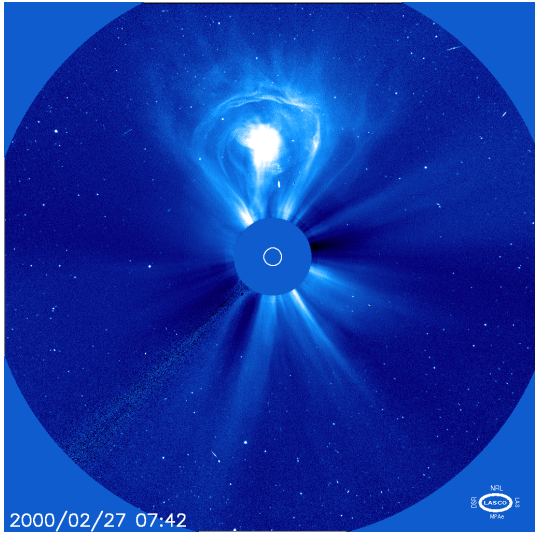
Credit: McComas et al. (2008a, Fig. 1)

Coronal mass ejections

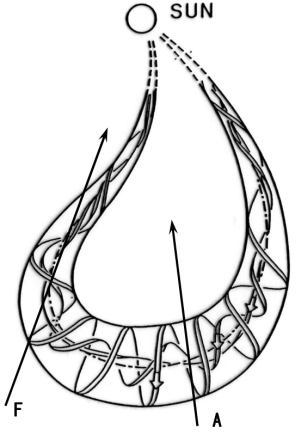


Courtesy of SOHO/LASCO consortium. SOHO is a project of international cooperation between ESA and NASA

Coronal mass ejections

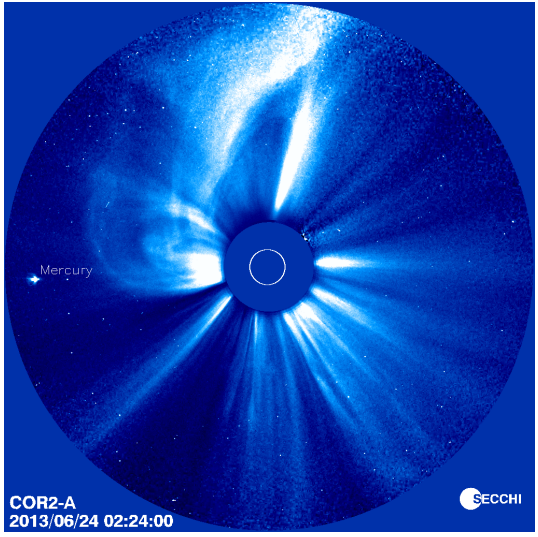


Courtesy of SOHO/LASCO consortium. SOHO is a project of international cooperation between ESA and NASA

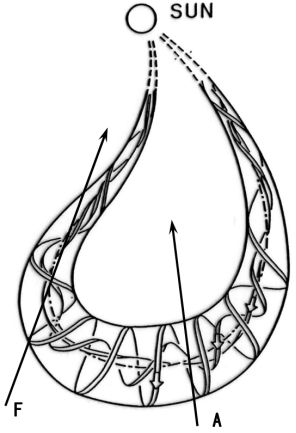


Credit: Marubashi & Lepping (2007, Fig. 1, panel (a))

Coronal mass ejections

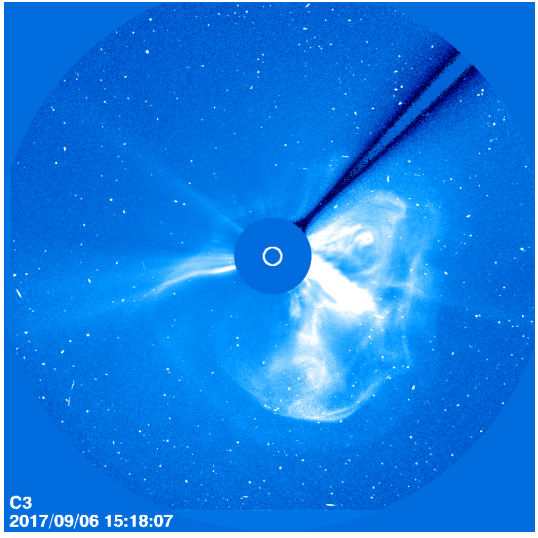


Courtesy of STEREO/COR2 consortium (NASA)

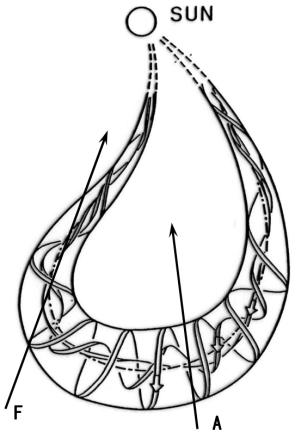


Credit: Marubashi & Lepping (2007, Fig. 1, panel (a))

Coronal mass ejections

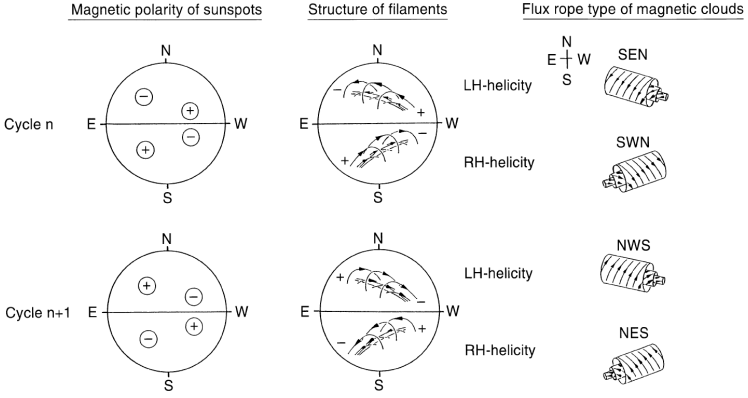


Courtesy of SOHO/LASCO consortium; SOHO is a project of international cooperation between ESA and NASA



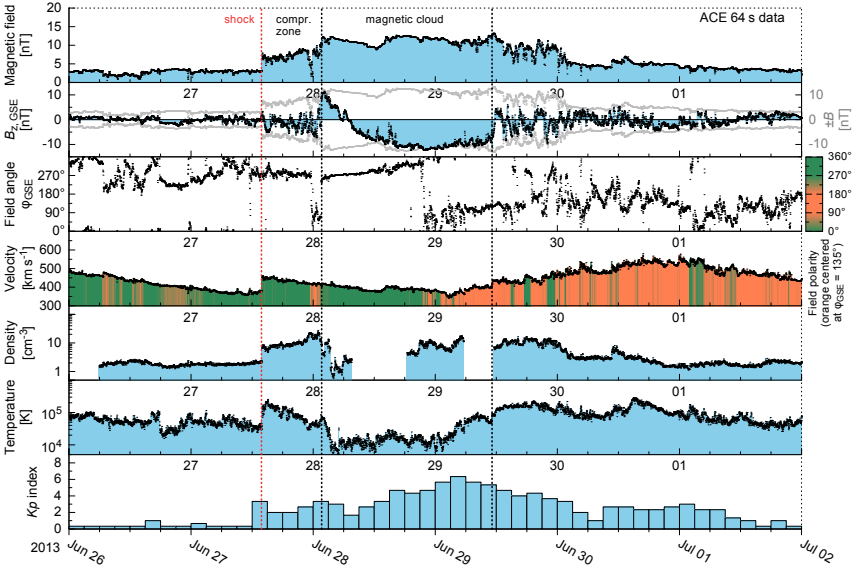
Credit: Marubashi & Lepping (2007, Fig. 1, panel (a))

CME orientation

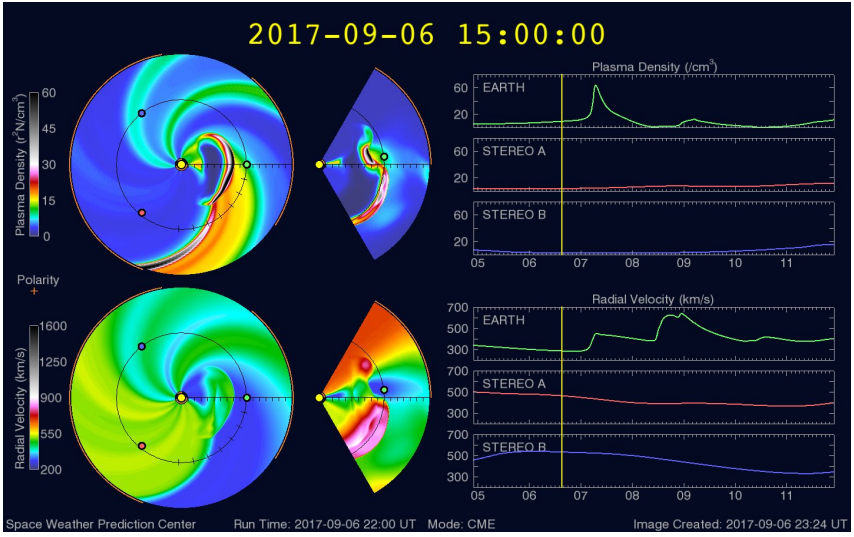


Credit: Bothmer & Schwenn (1998, Fig. 18)

In-situ CMEs


shock
compr. zone
magnetic cloud
ACE 64 s data
Magnetic field [nT]
$B_{z\,GSE}$ [nT]
Field angle φ_{GSE}
Velocity [km s^{-1}]
Density [cm^{-3}]
Temperature [K]
Kp index
±B [nT]
Field polarity (orange centered at φ_{GSE} = 135°)
27
28
29
30
01
2013 Jun 26
Jun 27
Jun 28
Jun 29
Jun 30
Jul 01
Jul 02

Solar wind and CME forecast



Credit: SWPC: WSA-Enlil Solar Wind Prediction. NOAA National Centers for Environmental Information

Geomagnetic impact of the solar wind

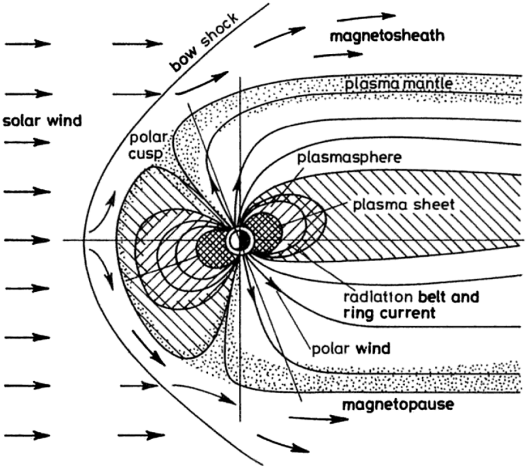
images...

Geomagnetic impact of the solar wind

Aims

Empirical relations to predict the Kp index from solar wind electric field and from CME and stream velocity

Magnetosphere

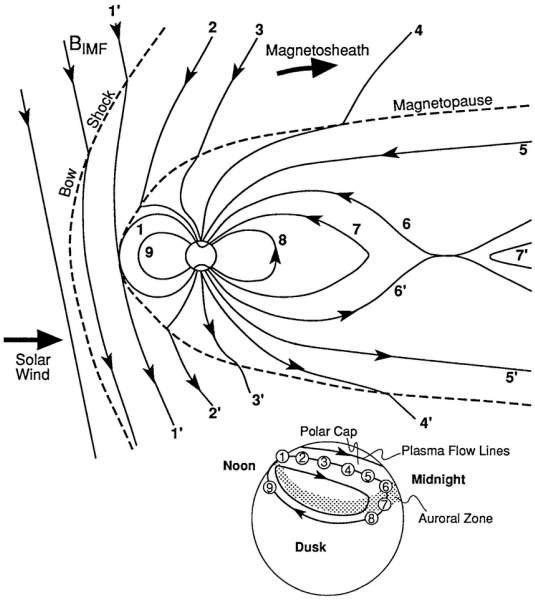


Credit: Davies (1990, Fig. 2.12)

Magnetosphere

4 interaction mechanisms

Magnetosphere



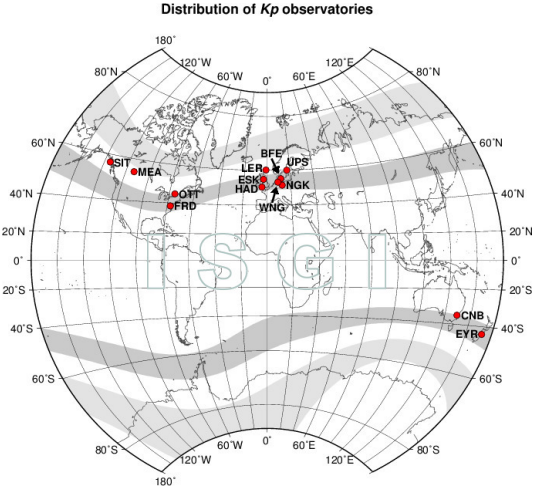
Credit: Hughes (1995, Fig. 9.11)

Magnetosphere

4 factors for merging flux rate

Kp index

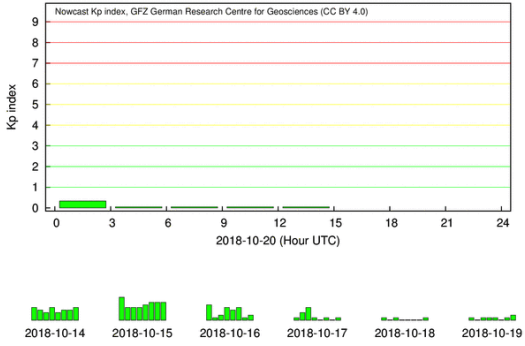
13 observatories...



Courtesy of International Service of Geomagnetic Indices (ISGI), 2013

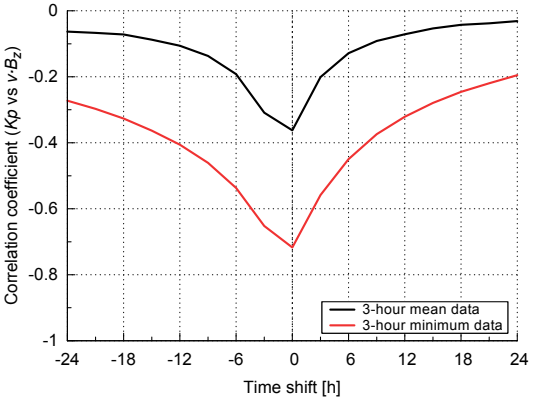
Kp index

Quicklook *Kp*

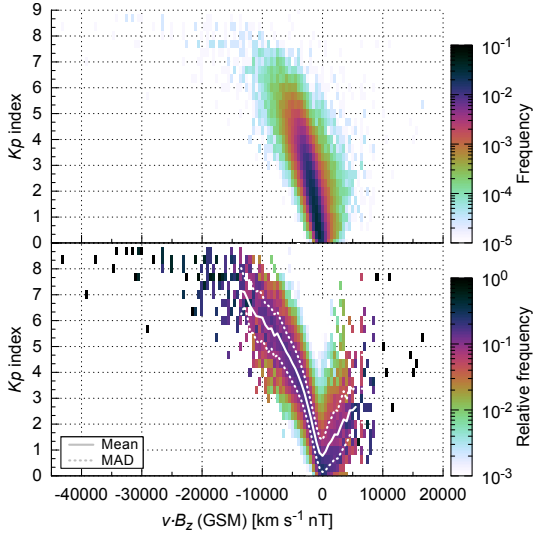


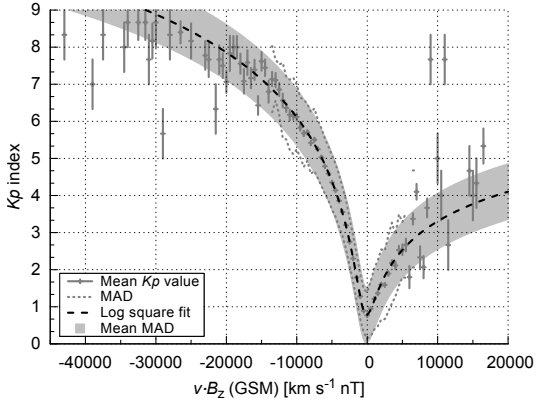
Credit: GFZ Potsdam, 2018

Solar wind electric field

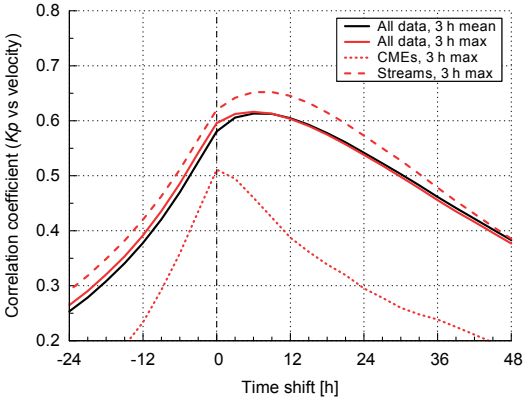


Solar wind electric field





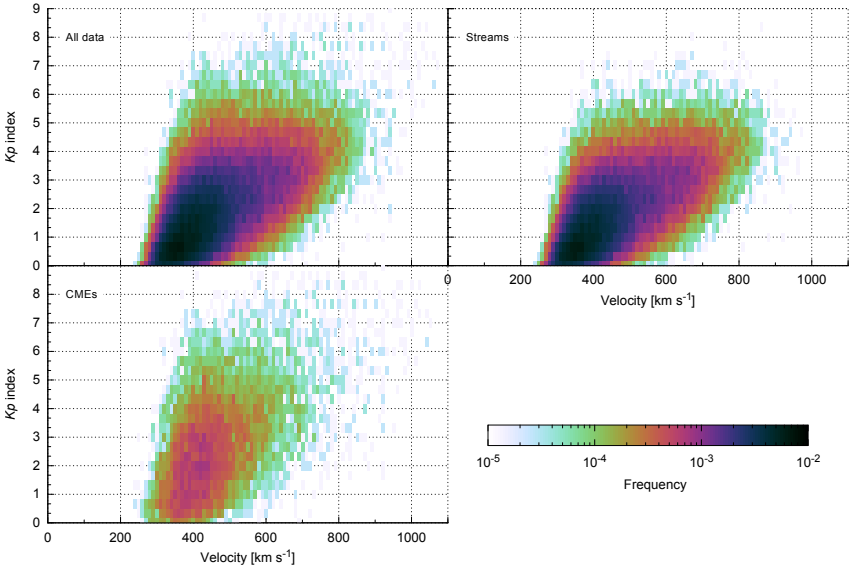
Solar wind velocity

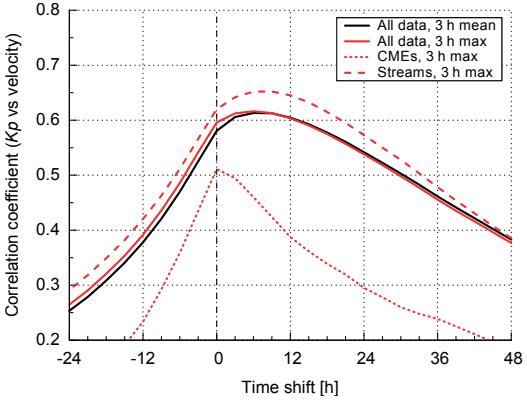


Solar wind velocity

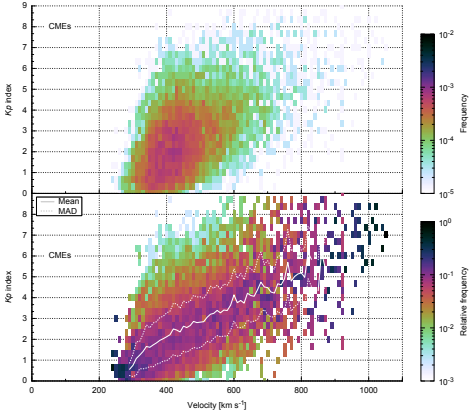
CME – stream separation
Solar Wind Structures list

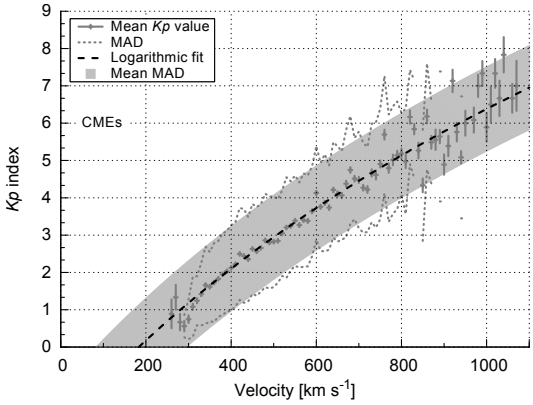
Solar wind velocity



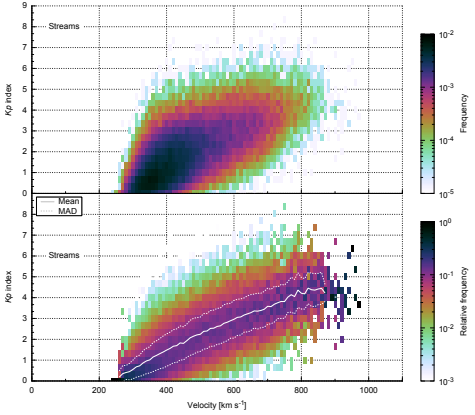

All data, 3 h mean
All data, 3 h max
CMEs, 3 h max
Streams, 3 h max
Correlation coefficient (Kp vs velocity)
Time shift [h]
0.8
0.7
0.6
0.5
0.4
0.3
0.2
-24
-12
0
12
24
36
48

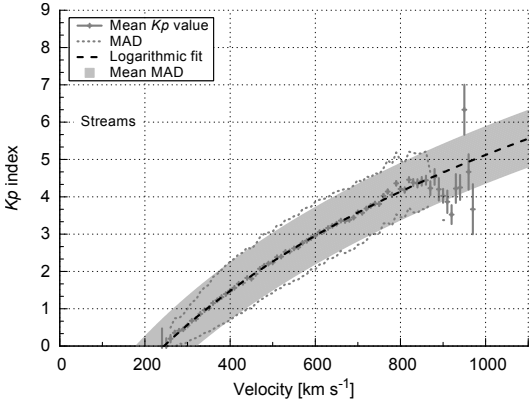
CME velocity

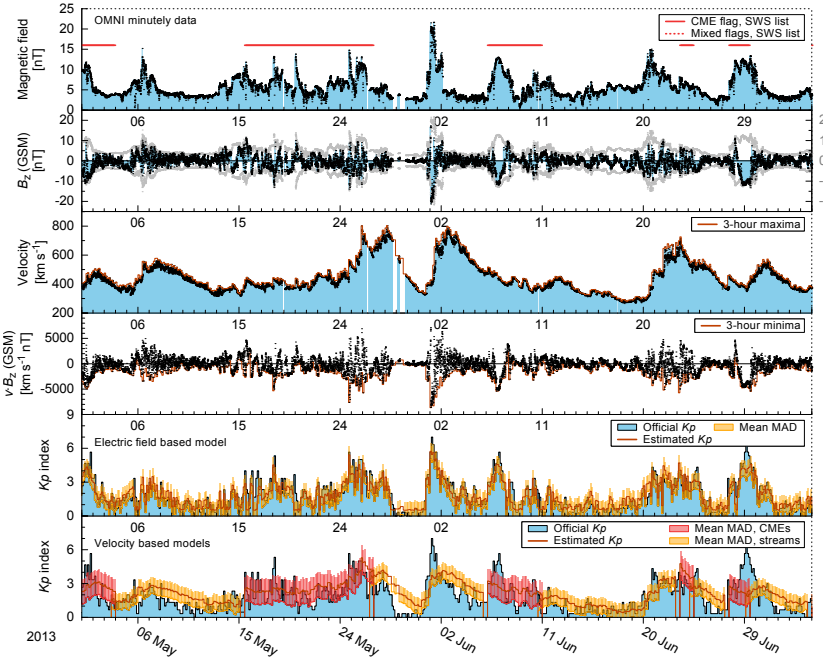


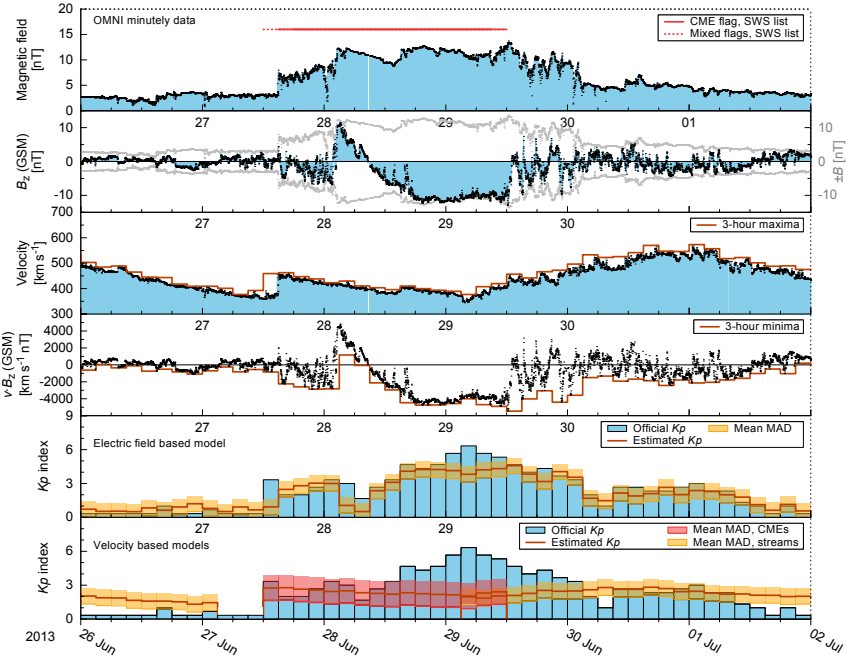


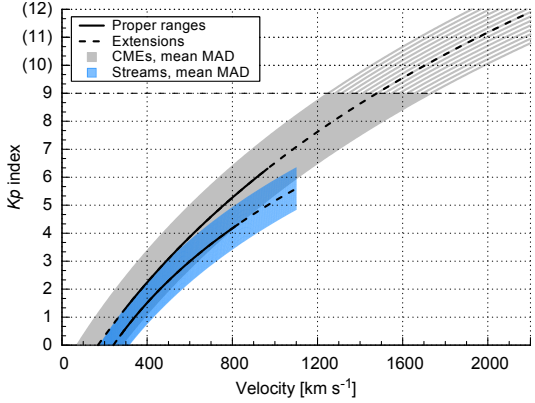
Stream velocity






OMNI minutely data
CME flag, SWS list
Mixed flags, SWS list
Magnetic field [nT]
B_z (GSM) [nT]
B_T [nT]
3-hour maxima
Velocity [km s^{-1}]
3-hour minima
vB_z (GSM) [km s^{-1} nT]
Official Kp
Estimated Kp
Mean MAD
Electric field based model
Kp index
Mean MAD, CMEs
Mean MAD, streams
Velocity based models
2013
06 May
15 May
24 May
02 Jun
11 Jun
20 Jun
29 Jun


OMNI minutely data
CME flag, SWS list
Mixed flags, SWS list
Magnetic field [nT]
B_z (GSM) [nT]
±B [nT]
3-hour maxima
Velocity [km s^{-1}]
3-hour minima
$v \cdot B_z$ (GSM) [km s^{-1} nT]
Official Kp
Mean MAD
Estimated Kp
Electric field based model
Kp index
Mean MAD, CMEs
Mean MAD, streams
Velocity based models
2013
26 Jun
27 Jun
28 Jun
29 Jun
30 Jun
01 Jul
02 Jul


(12)
(11)
(10)
9
8
7
6
5
4
3
2
1
0
Kp index
Proper ranges
Extensions
CMEs, mean MAD
Streams, mean MAD
0
400
800
1200
1600
2000
Velocity [km s-1]

Results

Predictive Kp models based on relations with

- solar wind electric field proxy (vB_z)
- velocity of CME-associated flows (v_{CME})
- velocity of solar wind streams (v_{stream})

Conclusions

- The processing of 3-hour extrema of high time resolution data captures short-term geoeffective magnetic features that are neglected when averaging over 3-hour intervals
- The isolated treatment of CMEs and streams is beneficial to the prediction accuracy of Kp
- The prediction models perform well for their limited input information

⏩ Prediction performance

Sun–Earth evolution of the solar wind

Solar wind measured in-situ throughout the heliosphere – except near-Sun

Sun–Earth evolution of the solar wind

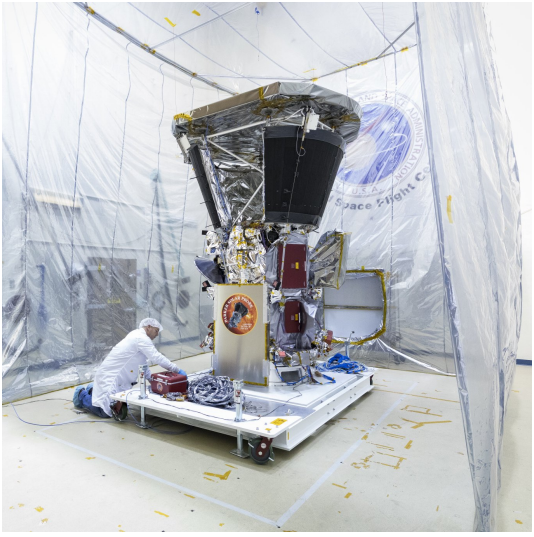
special scientific interest:
coronal heating
solar wind acceleration

Sun–Earth evolution of the solar wind

Aims

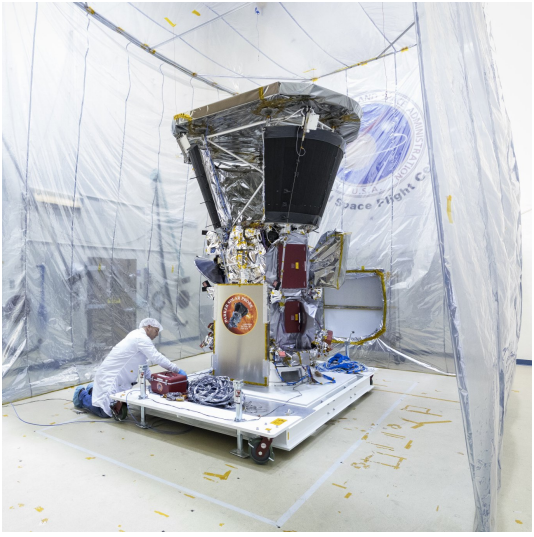
Solar wind model for the inner heliosphere and prediction of the near-Sun environment for the PSP orbit

Parker Solar Probe

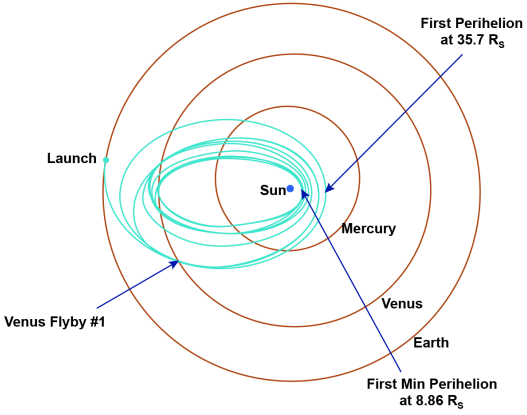


Credit: NASA/Johns Hopkins APL/Ed Whitman, 2017

Parker Solar Probe



Credit: NASA/Johns Hopkins APL/Ed Whitman, 2017



Credit: NASA/Johns Hopkins APL, 2018

Parker Solar Probe

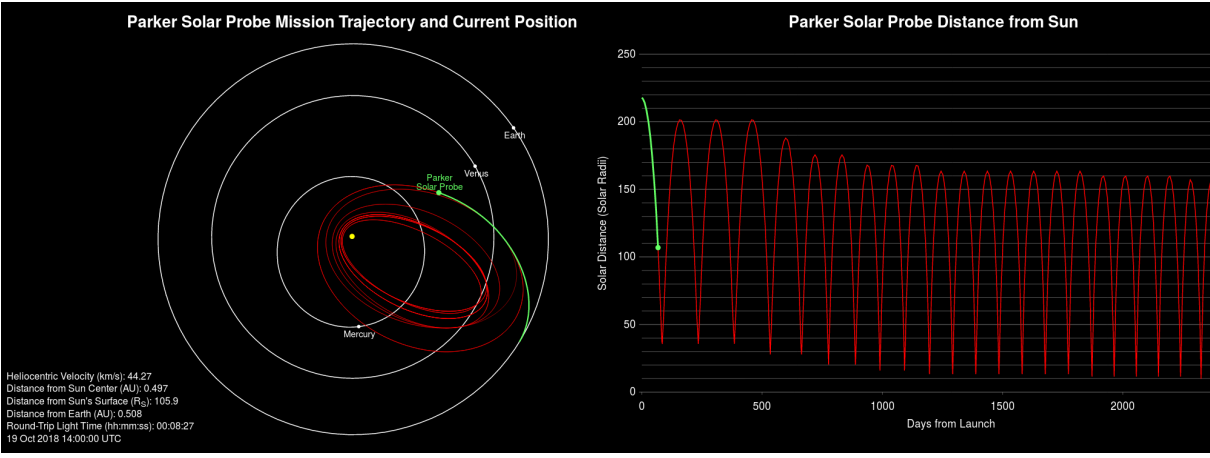
Credit: NASA/Johns Hopkins APL/Ed Whitman, 2018

Parker Solar Probe

Credit: NASA/Johns Hopkins APL/Ed Whitman, 2018

launch date, Venus flyby, first perihelion

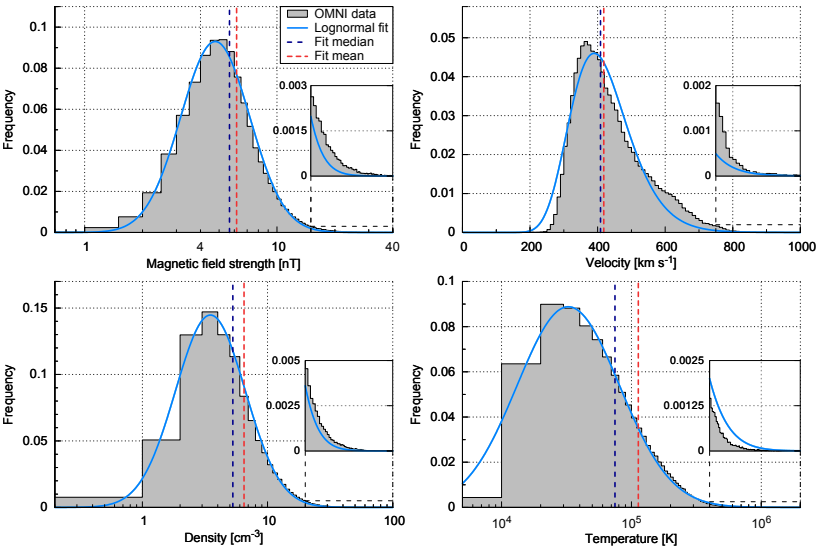
PSP's current position



Credit: NASA

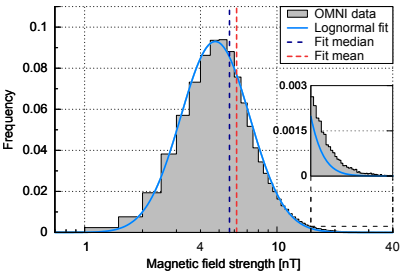
motivation

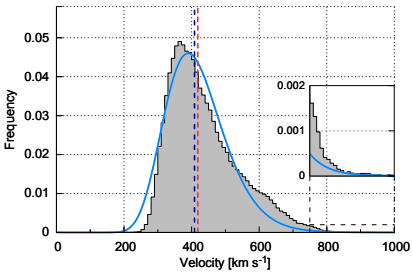
Frequency distributions

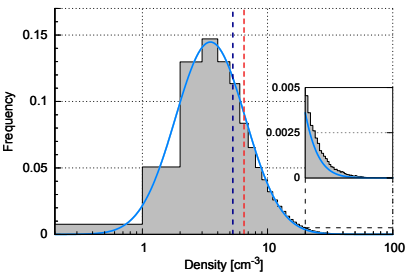


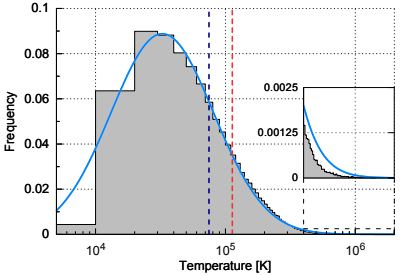
Lognormal distribution

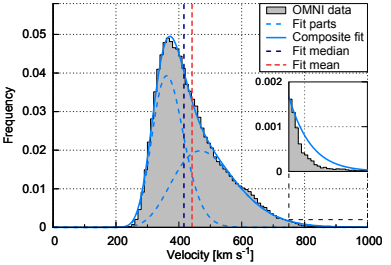
Frequency distributions





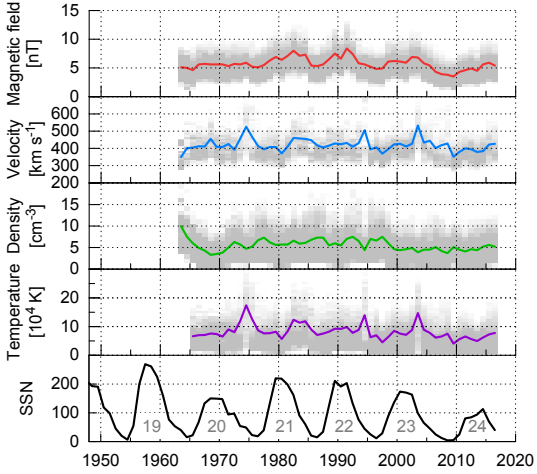


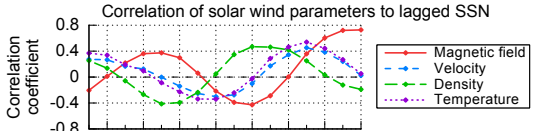




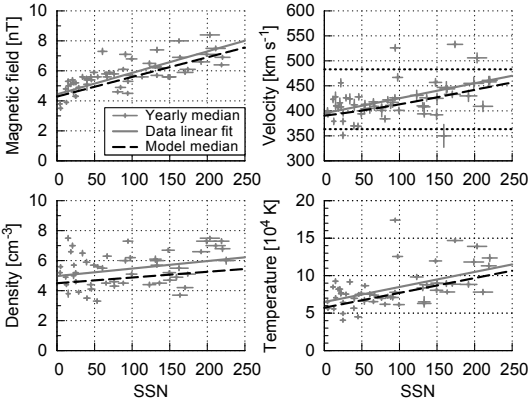
Lognormal distribution

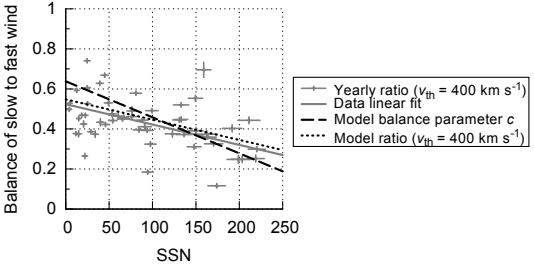
Sunspot number dependence



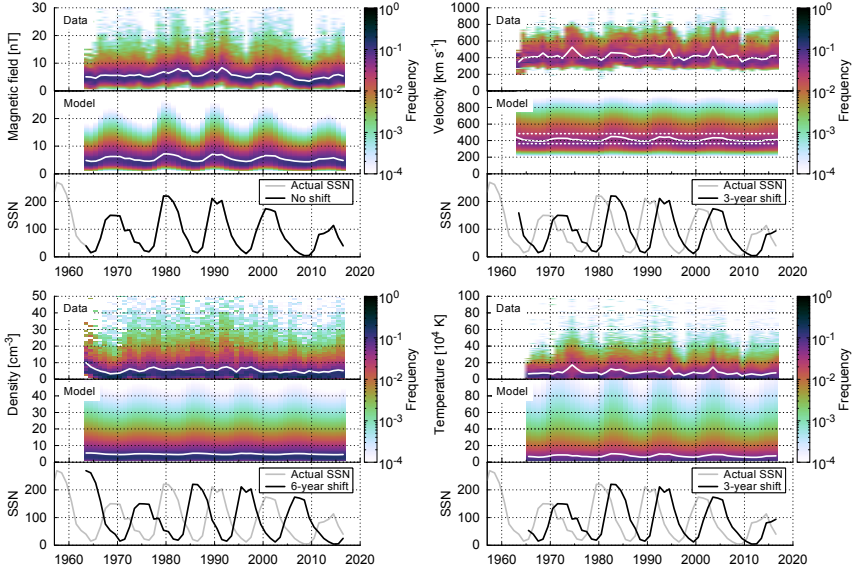


Sunspot number dependence

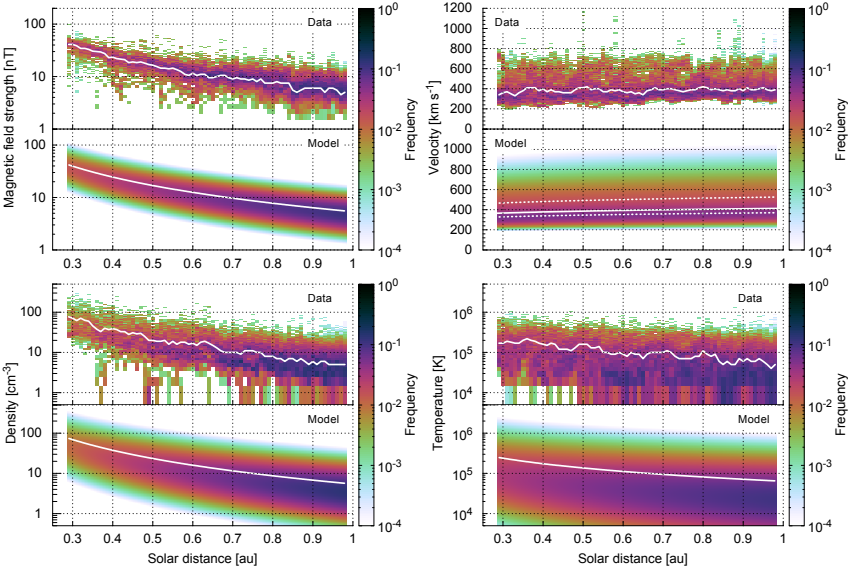




Sunspot number dependence

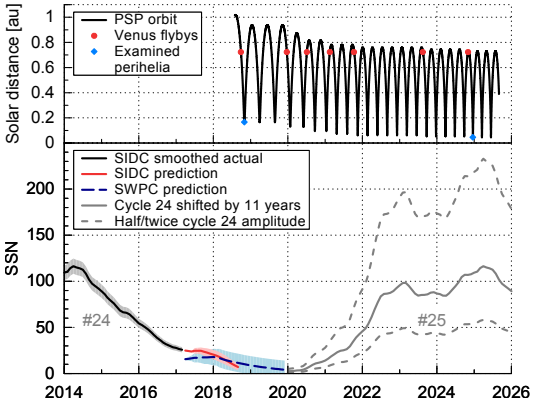


Solar distance dependence



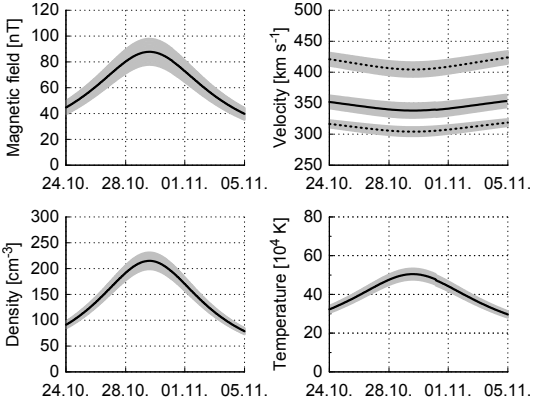
combine models, extrapolation

SSN prediction



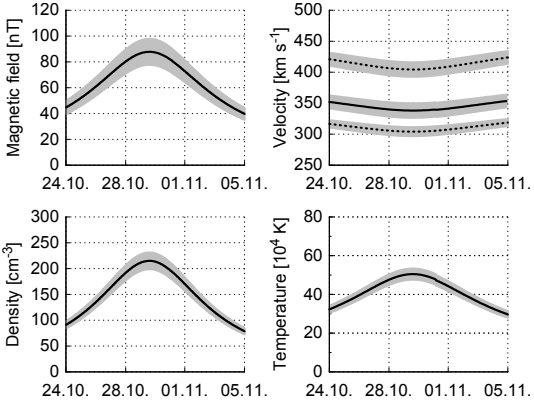
PSP orbit prediction

First perihelion (9.86 $R_\odot$)

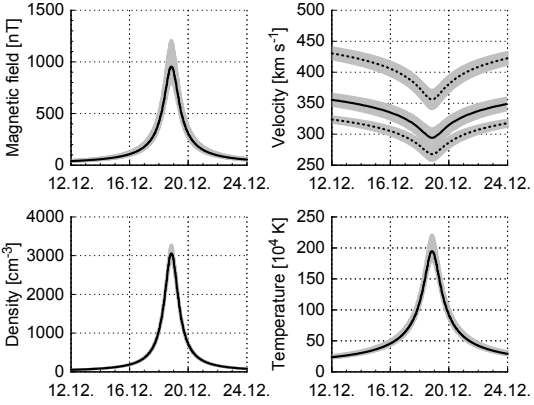


PSP orbit prediction

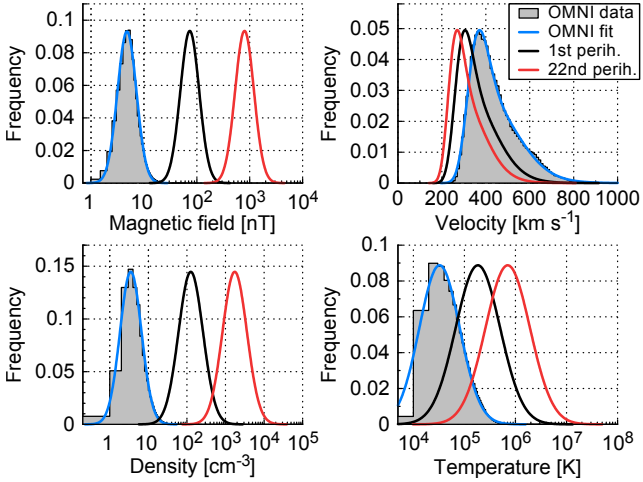
First perihelion (9.86 $R_\odot$)



First closest perihelion (36.7 $R_\odot$)



PSP perihelia prediction



Results

- Empirical solar wind model for the inner heliosphere
- Solar wind predictions for the PSP orbit

Conclusions

- Velocity discrepancy -¿ Solar wind is still being accelerated up to 20 $R_\odot$
- Temperature discrepancy -¿ Solar wind is still being heated up to 20 $R_\odot$

Thank you!

References I

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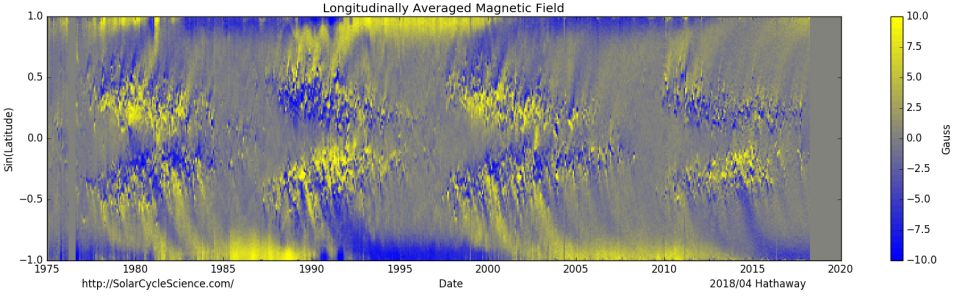
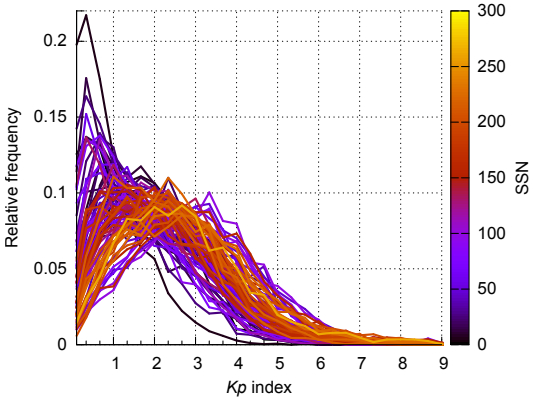
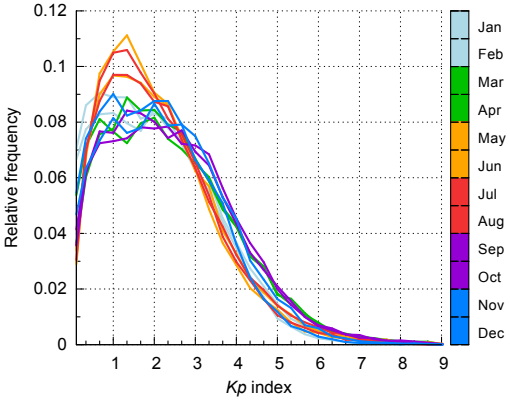
Solar activity
Magnetic butterfly diagram



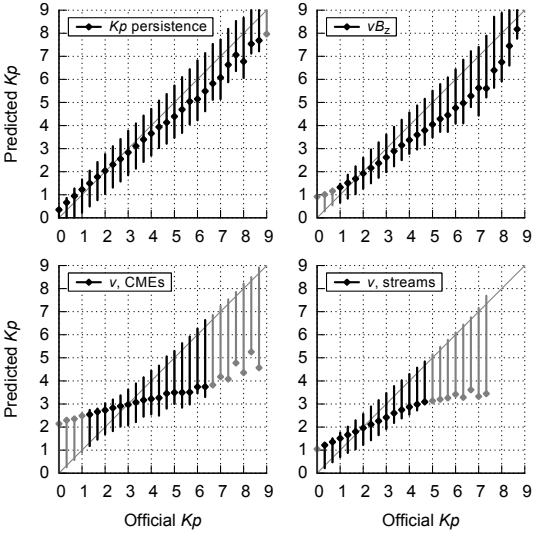
Courtesy of David Hathaway, Solar Cycle Science, 2018, updated version of Hathaway (2015, Fig. 17)

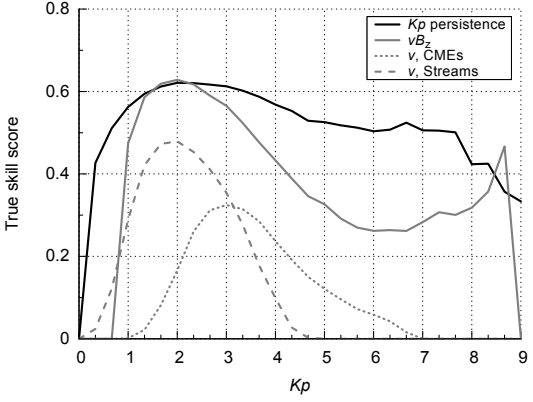
Kp long-term variations



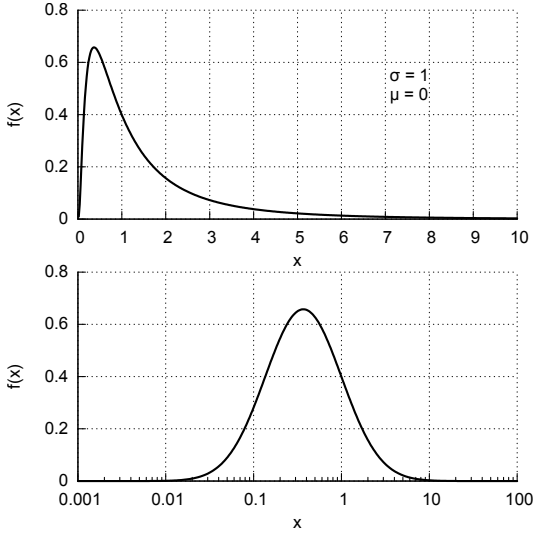


Prediction performance





Lognormal distribution



Probability density function:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}x}\, e^{-\frac{(\ln x-\mu)^2}{2\sigma^2}}$$

Location (μ) and shape parameter (σ)

first slide

A bit more information about this

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first slide

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Definition

A definition

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Sample frame title

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Examples

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Remark

Sample text

Important theorem

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Important theorem

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Examples

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Two-column slide

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$$E = mc^2$$

- First item
- Second item

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Sample

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Remark

Sample text

Sample

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Sample text

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Remark

Sample text

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backup slide

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Magnetic butterfly diagram

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