

# 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

## 1 Solar wind

## 2 Geomagnetic impact of the solar wind

## 3 Solar wind model for the inner heliosphere

## 4 End matter

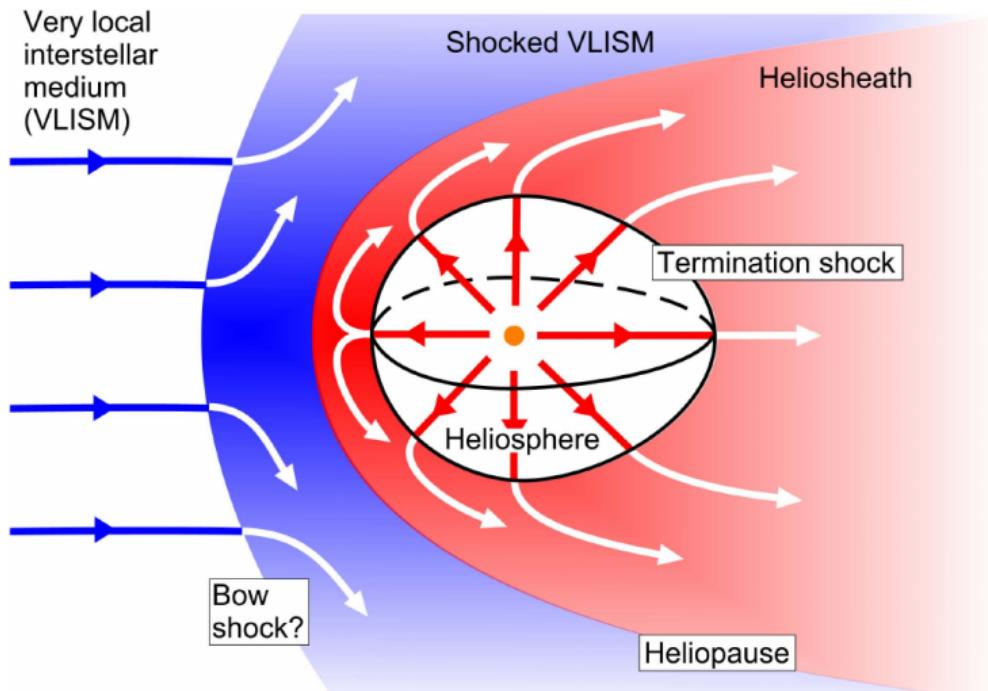
# Solar wind



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

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Geomagnetic impact of the solar wind

A horizontal row of 20 red circles, evenly spaced, used as a visual element in the page header.

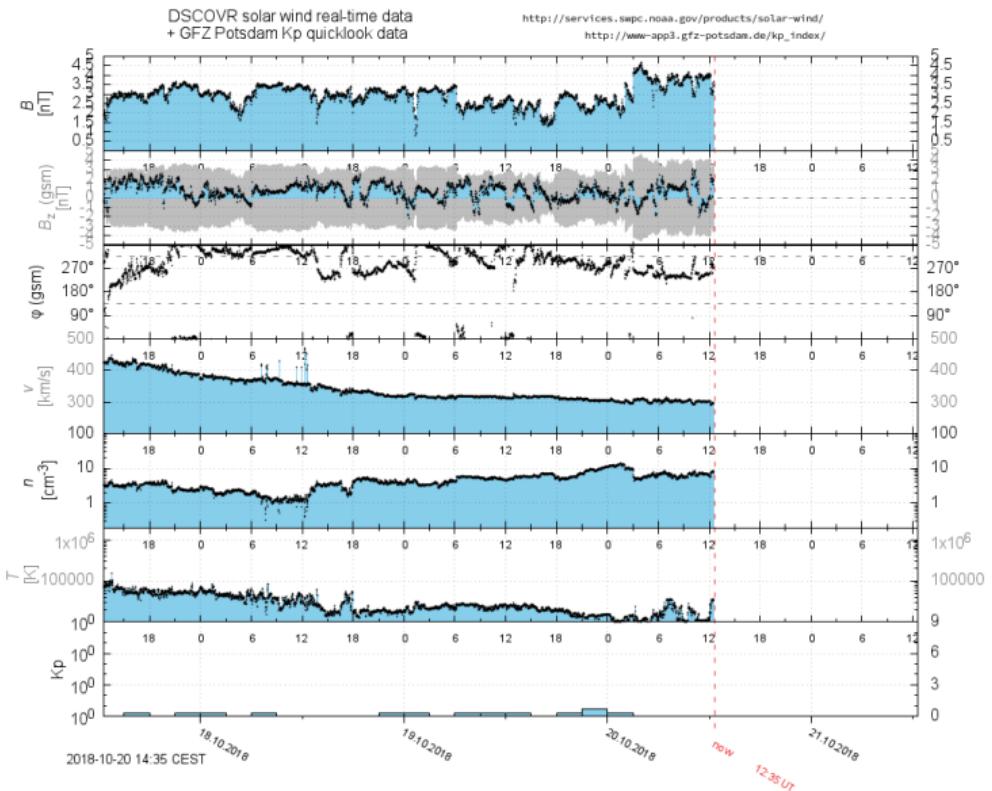
## Solar wind model for the inner heliosphere

## End matter

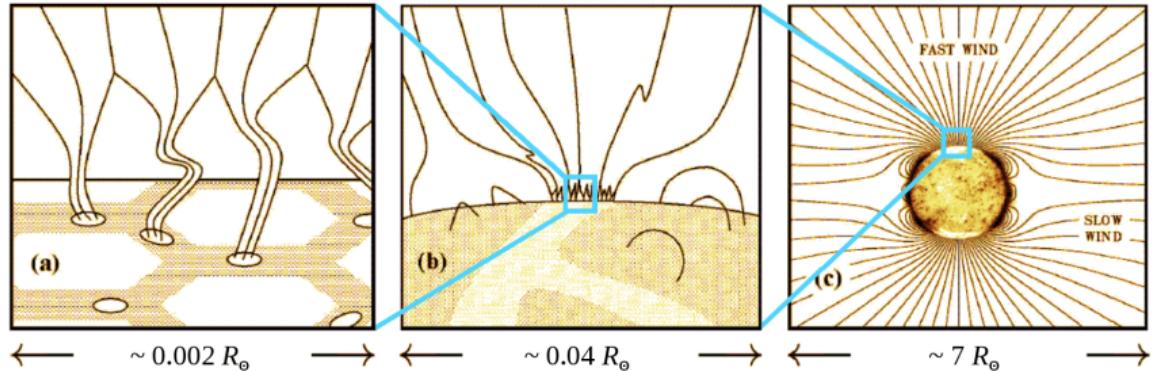
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## References

## Solar wind

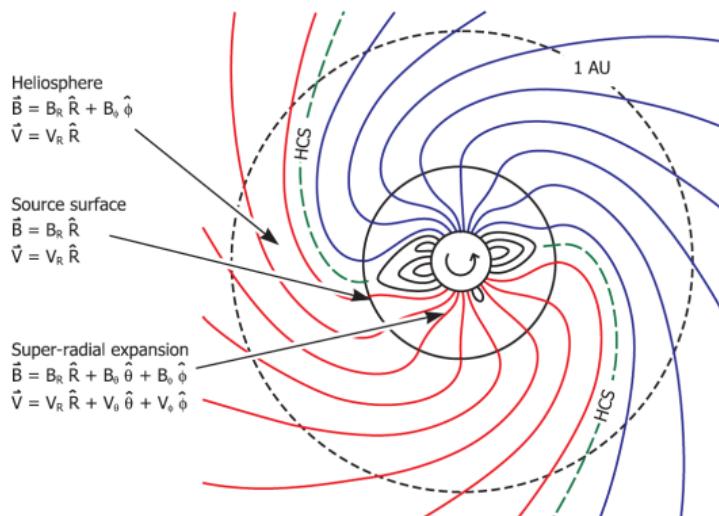


# Solar magnetic field



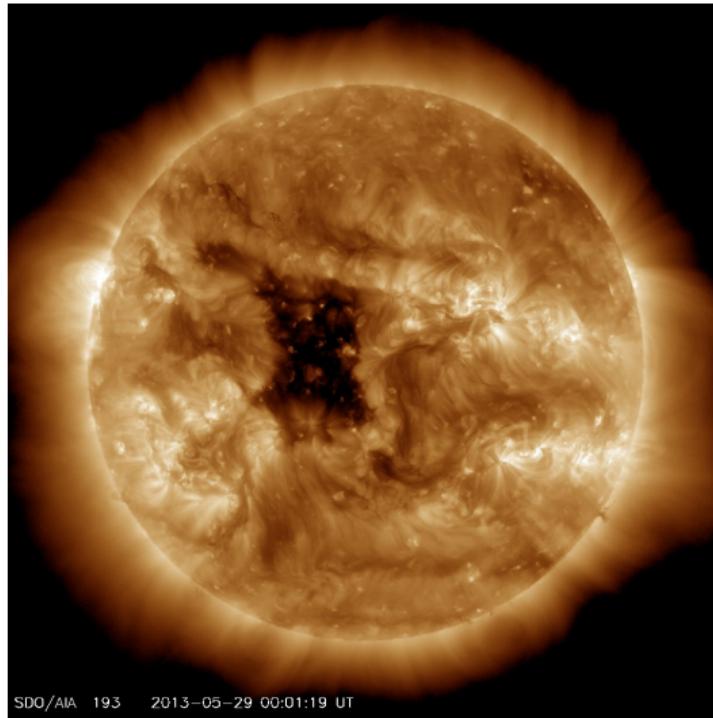
Courtesy of S. R. Cranmer

# Solar magnetic field



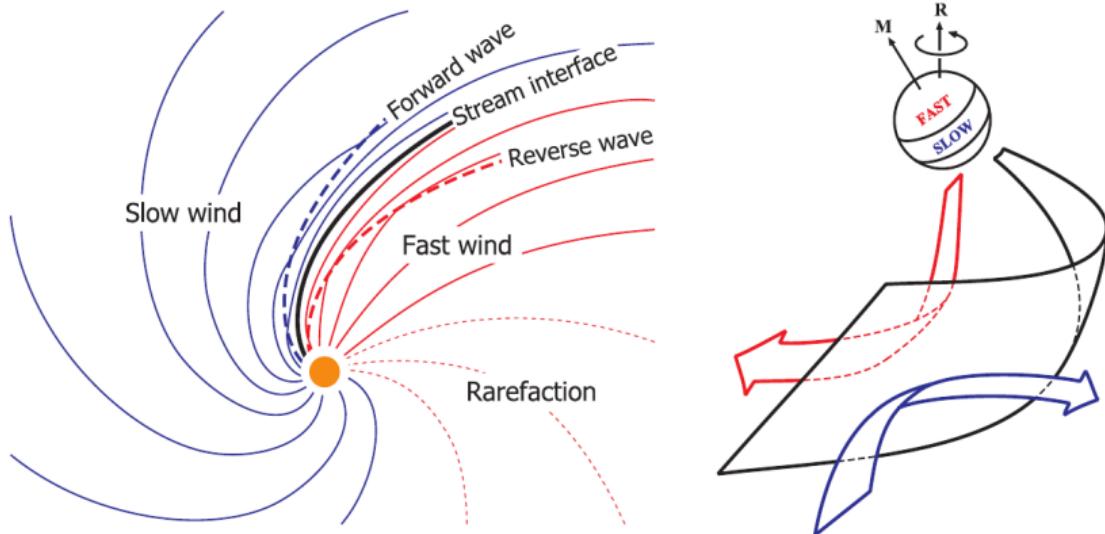
Credit: Owens & Forsyth (2013, Fig. 1), adapted from Schatten et al. (1969, Fig. 1)

## 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

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Geomagnetic impact of the solar wind

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Solar wind model for the inner heliosphere

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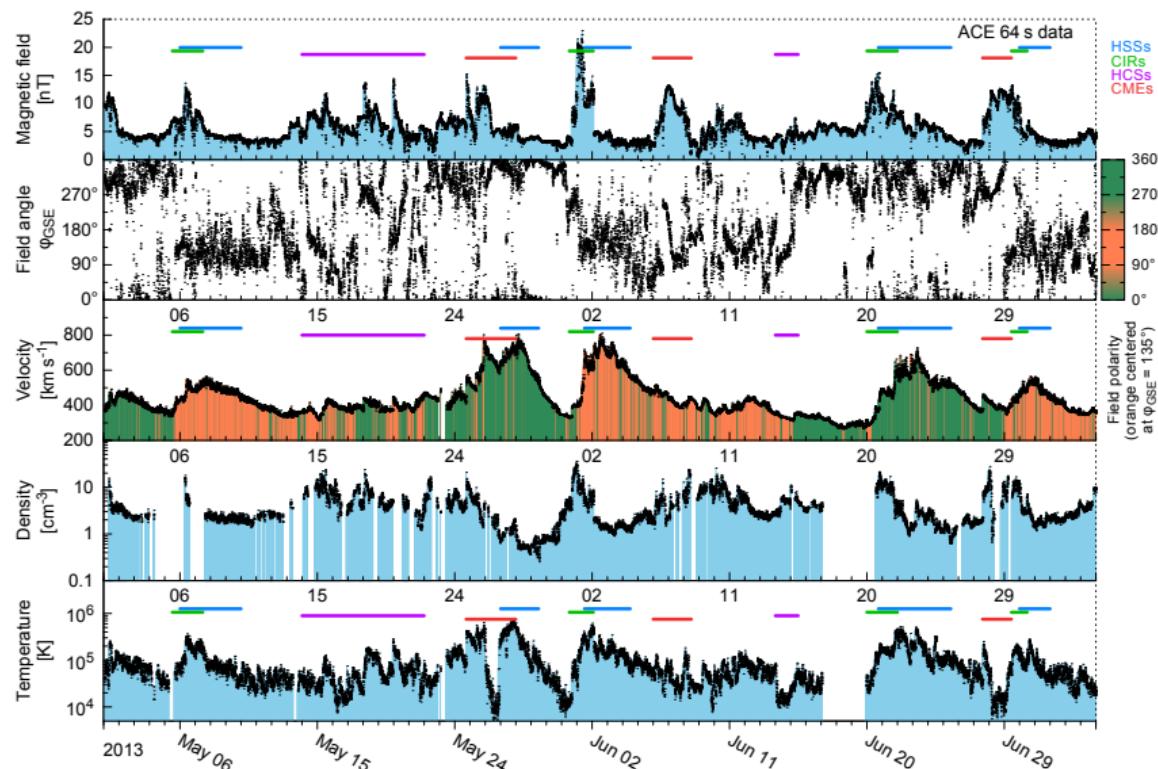
End matter

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References

# Solar wind

## In-situ example



Solar wind  
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Geomagnetic impact of the solar wind  
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Solar wind model for the inner heliosphere  
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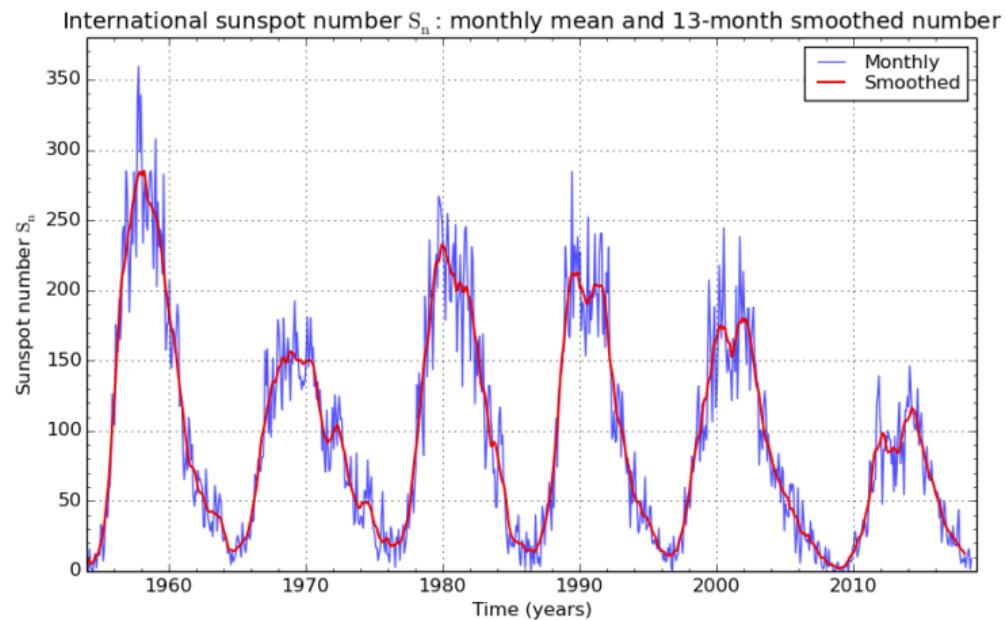
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References

# Solar activity

## Sunspots

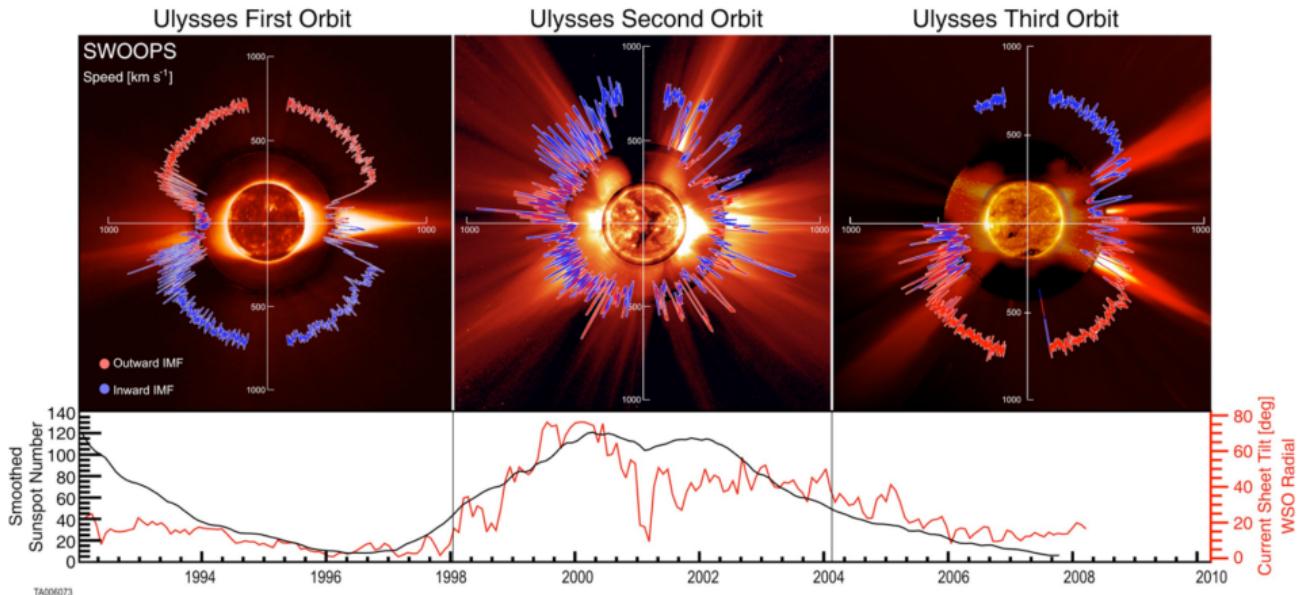
# Solar activity



SILSO graphics (<http://sidc.be/silso>) Royal Observatory of Belgium 2018 September 1

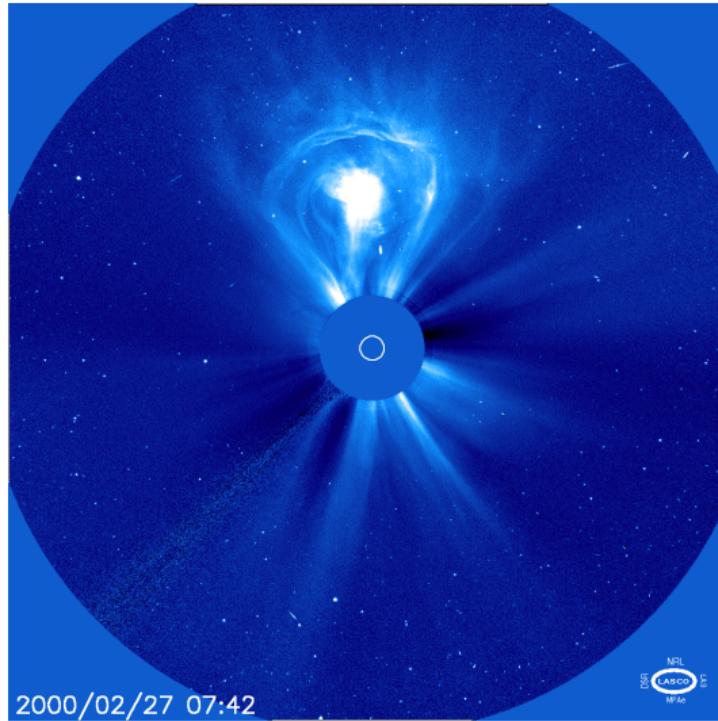
► Magnetic butterfly diagram

# Solar activity



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

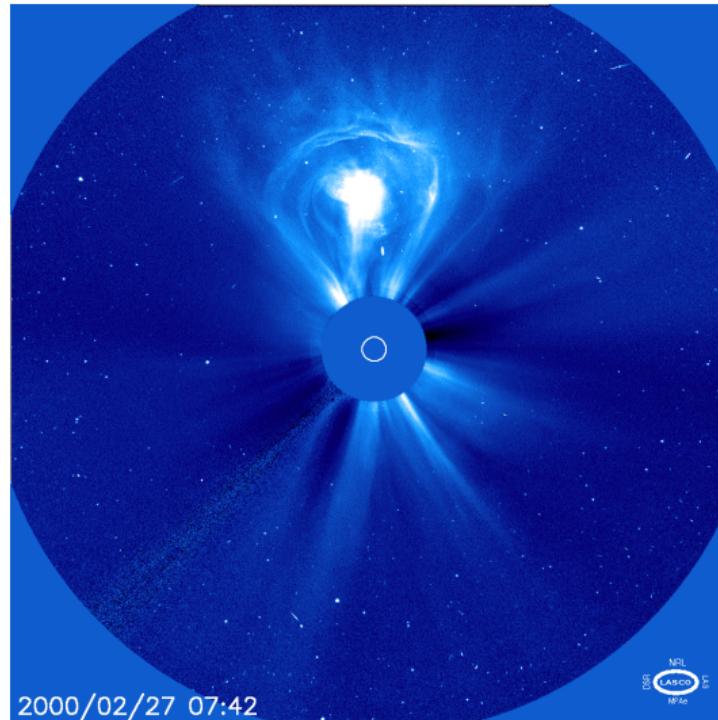
# Coronal mass ejections



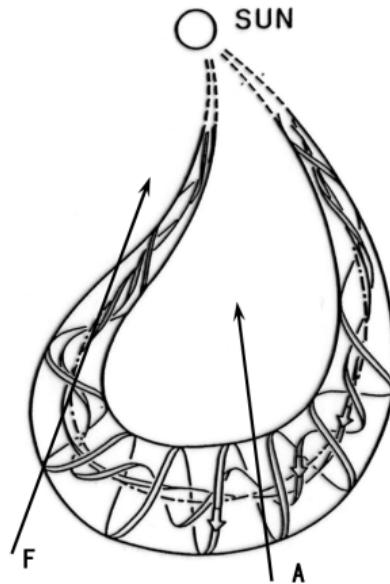
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Courtesy of SOHO/LASCO consortium. SOHO is a project of international cooperation between ESA and NASA

# Coronal mass ejections

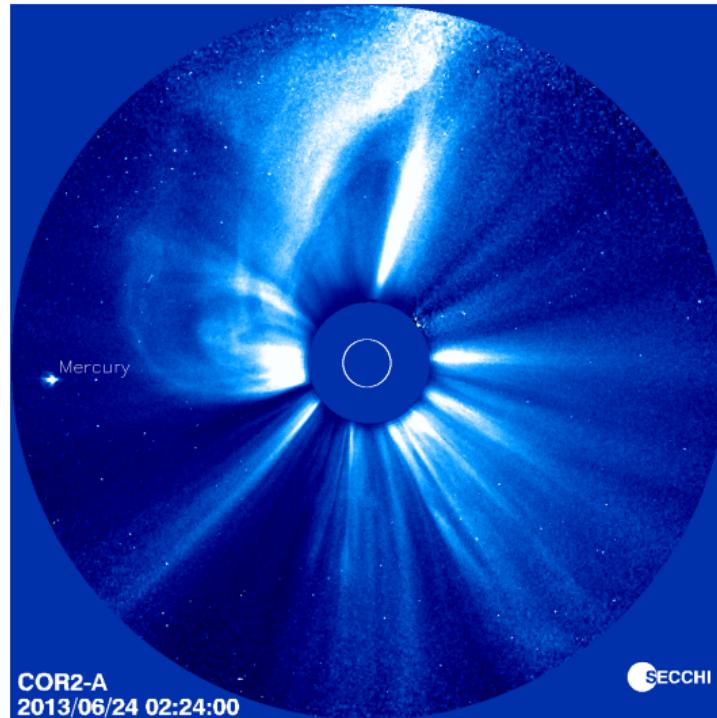


Courtesy of SOHO/LASCO consortium. SOHO is a project of international cooperation between ESA and NASA

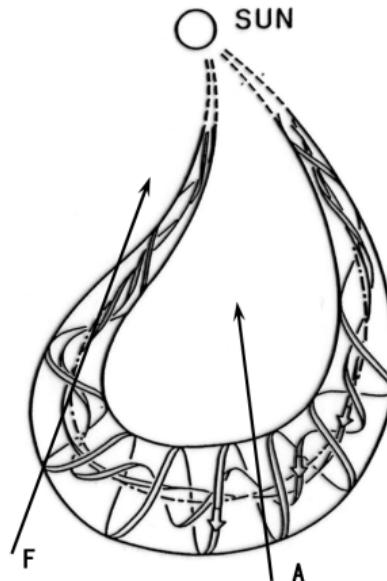


Credit: Marubashi & Lepping (2007, Fig. 1, panel (a))

# Coronal mass ejections

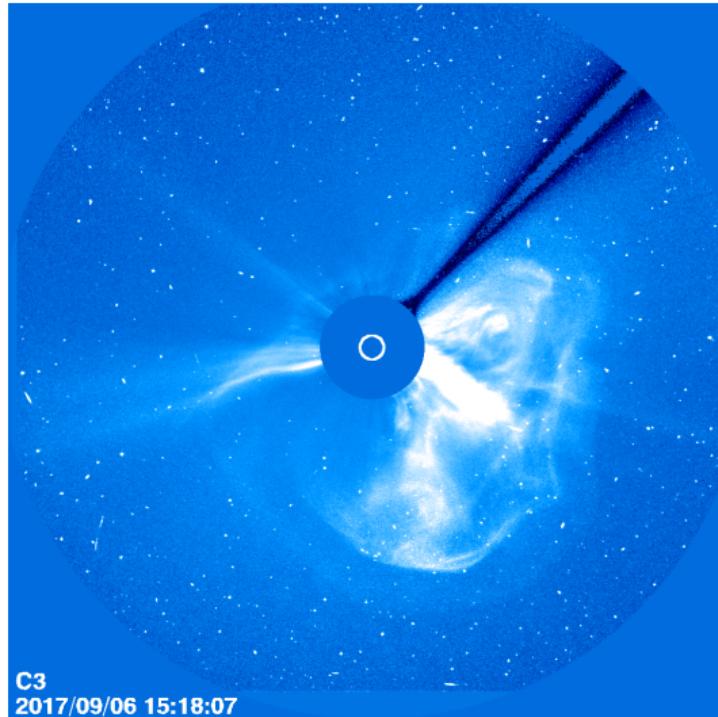


Courtesy of STEREO/COR2 consortium (NASA)



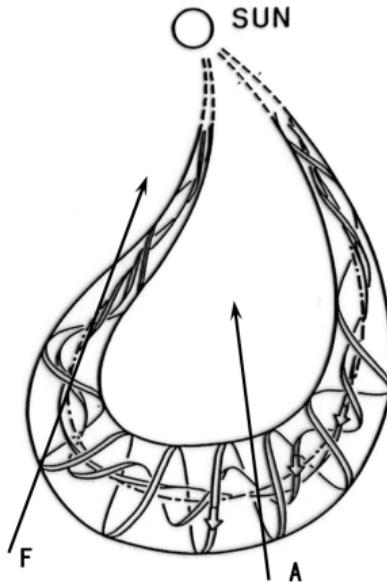
Credit: Marubashi & Lepping (2007, Fig. 1, panel (a))

# Coronal mass ejections



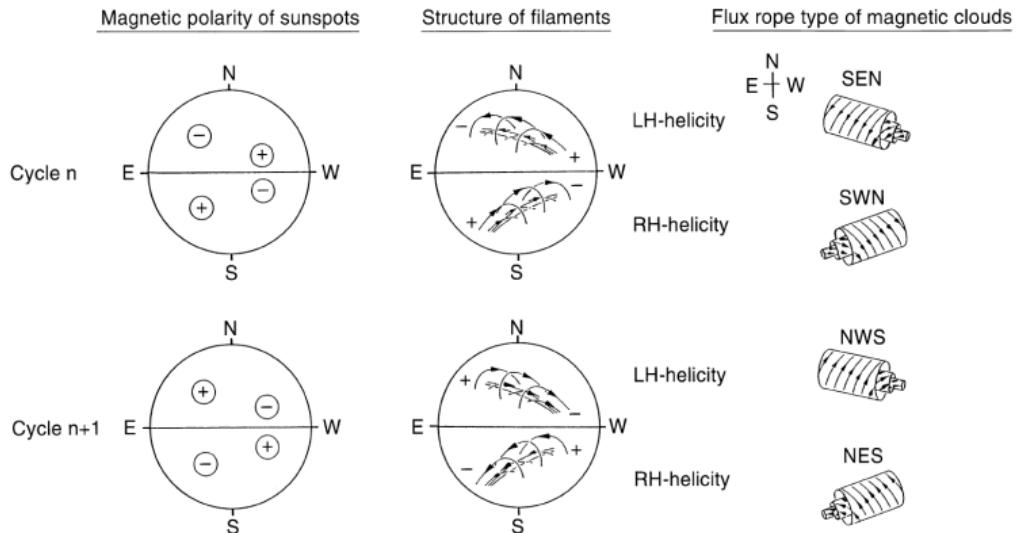
C3  
2017/09/06 15:18:07

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)

Solar wind

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Geomagnetic impact of the solar wind

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Solar wind model for the inner heliosphere

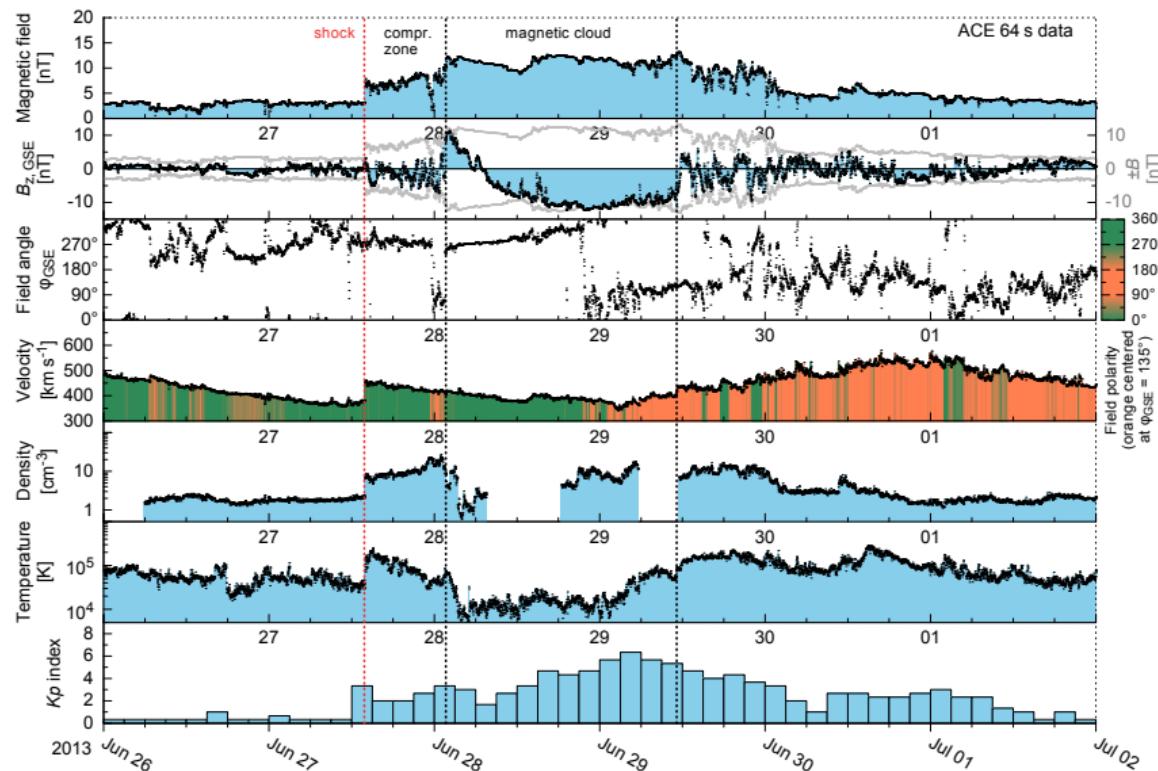
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End matter

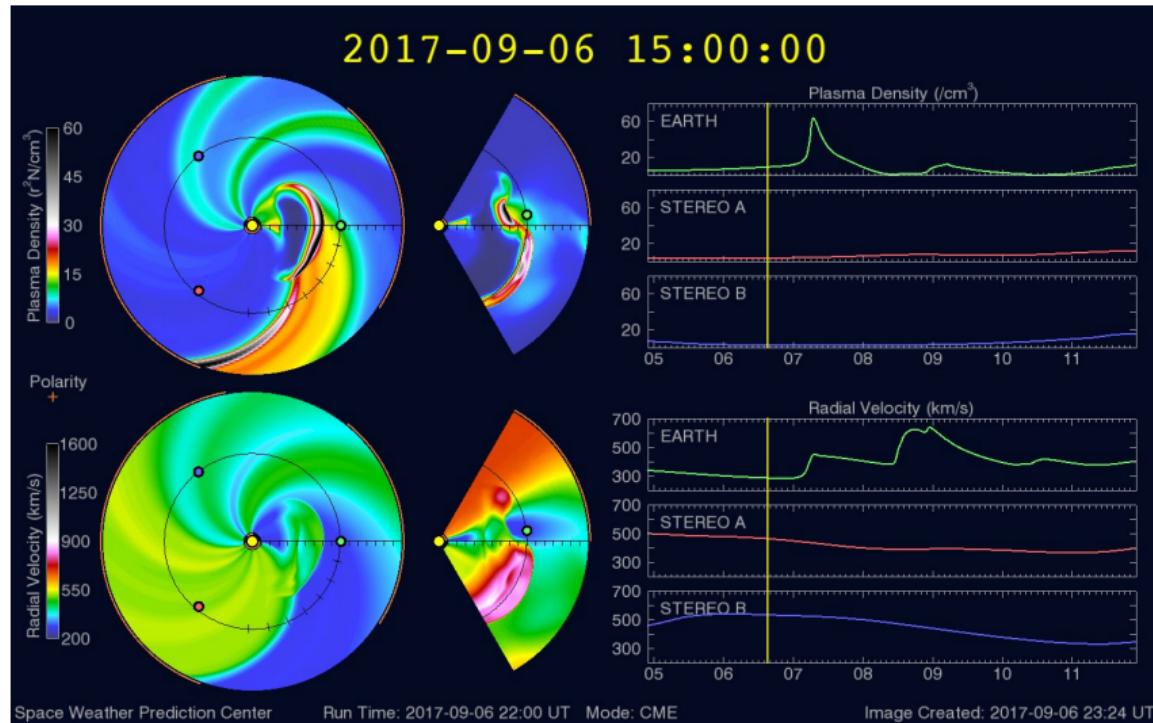
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References

# In-situ CMEs



# Solar wind and CME forecast



## 1 Solar wind

## 2 Geomagnetic impact of the solar wind

## 3 Solar wind model for the inner heliosphere

## 4 End matter

Solar wind  
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Geomagnetic impact of the solar wind  
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Solar wind model for the inner heliosphere  
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End matter  
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References

# Geomagnetic impact of the solar wind

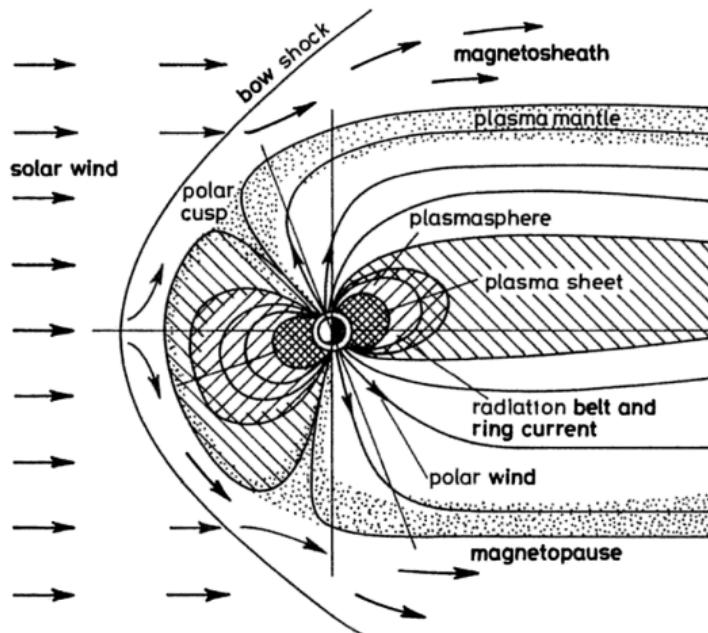
images...

# Geomagnetic impact of the solar wind

## Aims

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

# Magnetosphere



Credit: Davies (1990, Fig. 2.12)

Solar wind  
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Geomagnetic impact of the solar wind  
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Solar wind model for the inner heliosphere  
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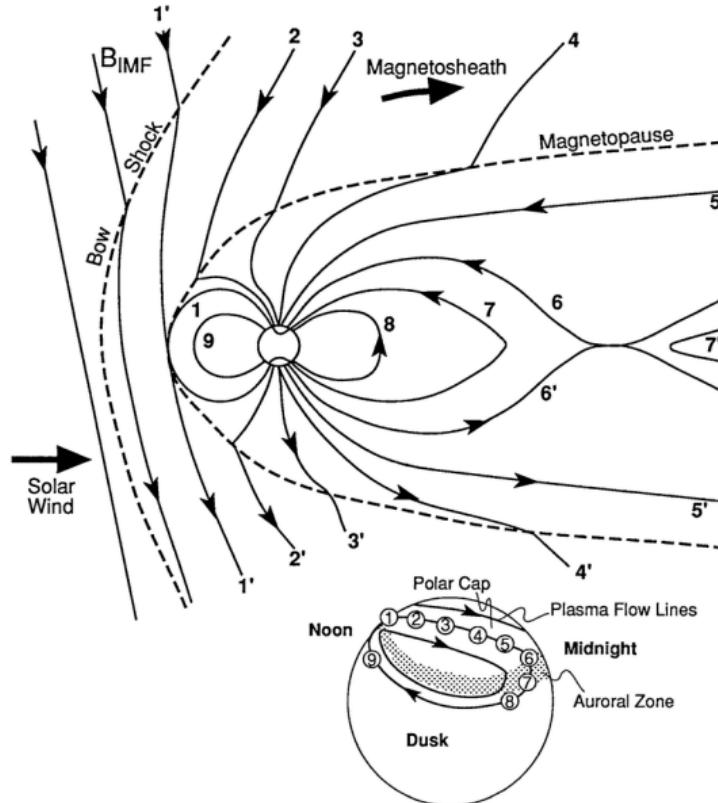
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References

# Magnetosphere

4 interaction mechanisms

# Magnetosphere



Credit: Hughes (1995, Fig. 9.11)

Solar wind  
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Geomagnetic impact of the solar wind  
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Solar wind model for the inner heliosphere  
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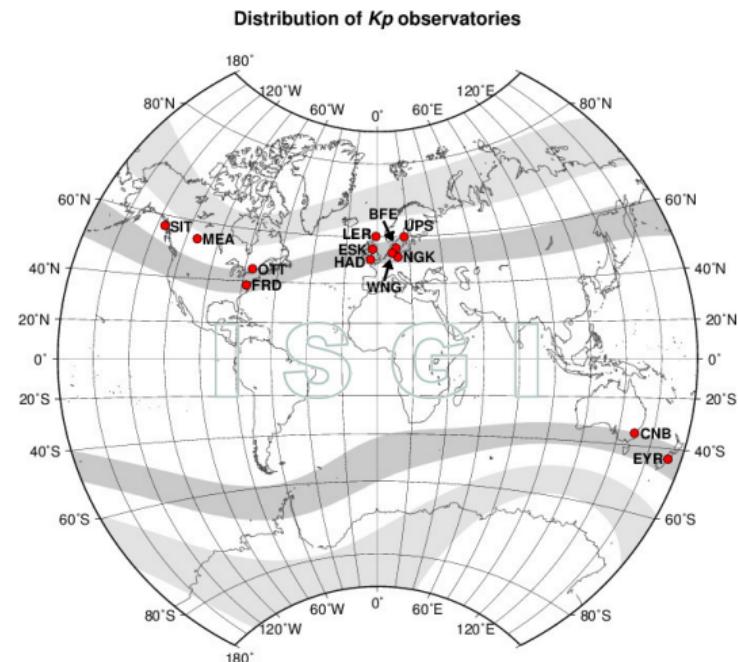
References

# Magnetosphere

4 factors for merging flux rate

# K<sub>p</sub> index

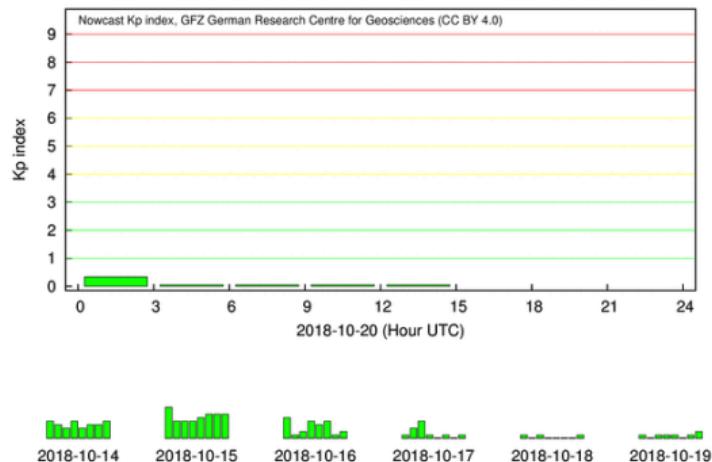
13 observatories...



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

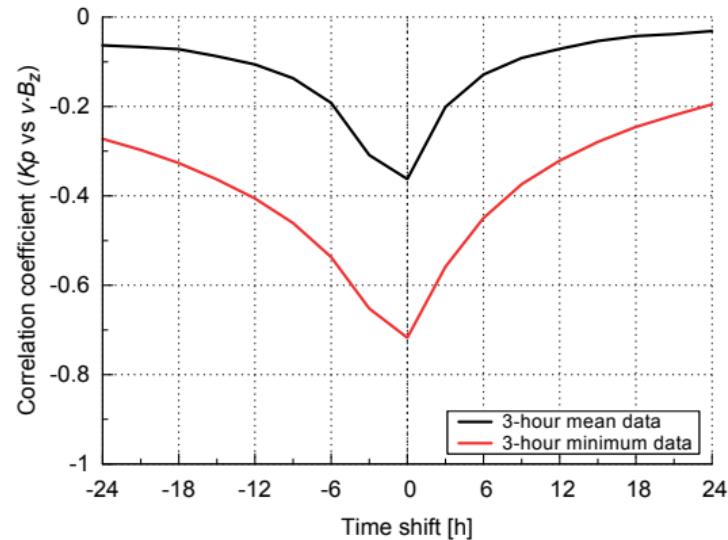
# K<sub>p</sub> index

## Quicklook K<sub>p</sub>



Credit: GFZ Potsdam, 2018

# Solar wind electric field



Solar wind  
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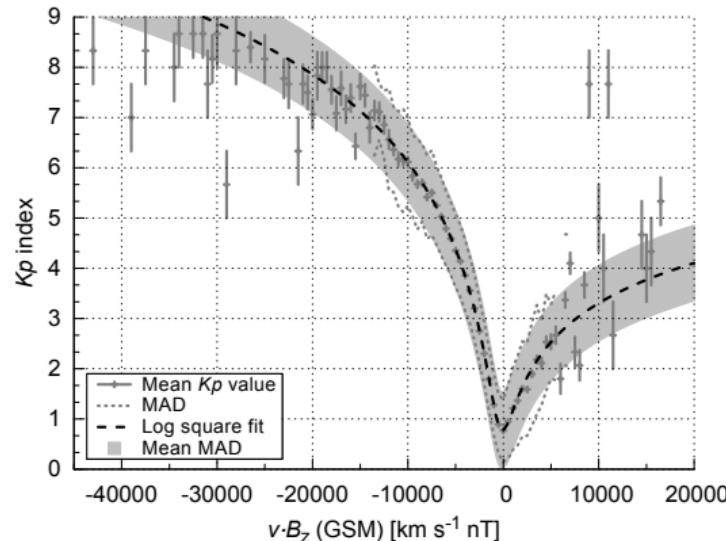
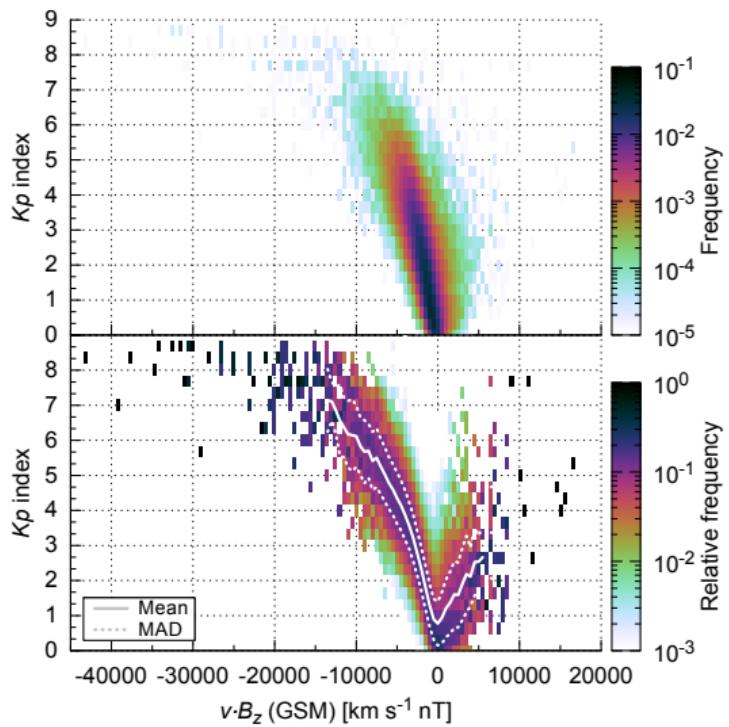
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Solar wind model for the inner heliosphere  
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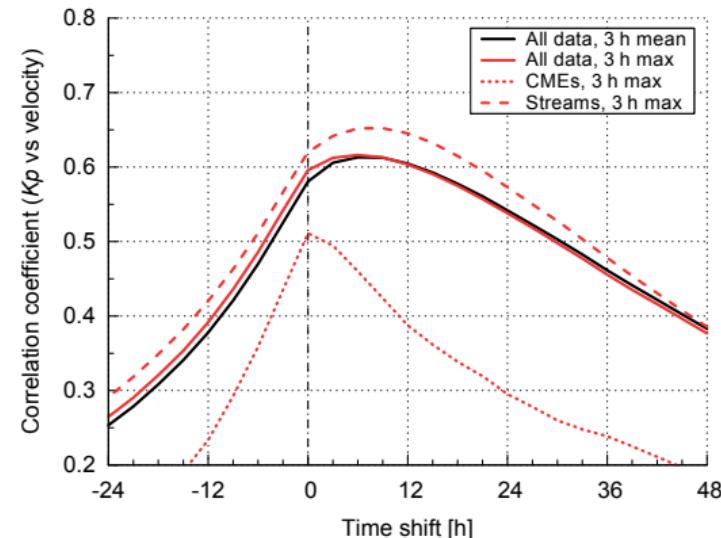
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References

## Solar wind electric field



# Solar wind velocity



Solar wind  
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Geomagnetic impact of the solar wind  
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Solar wind model for the inner heliosphere  
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End matter  
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References

# Solar wind velocity

CME – stream separation  
Solar Wind Structures list

Solar wind  
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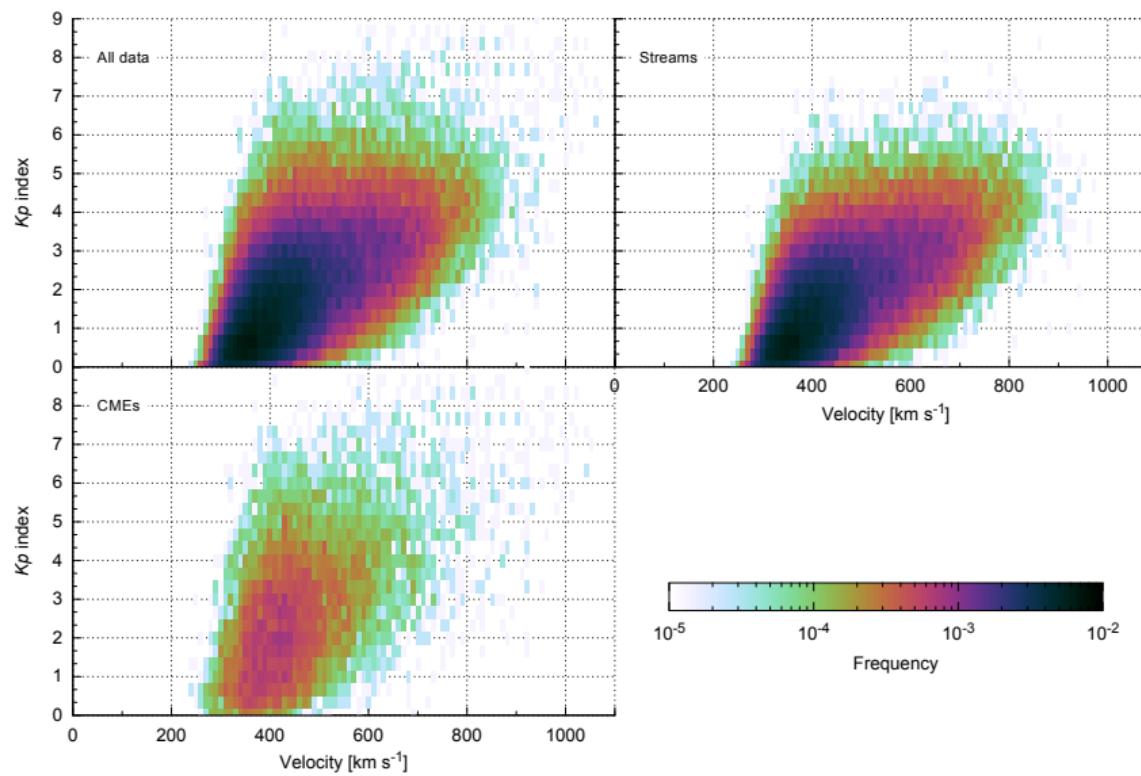
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Solar wind model for the inner heliosphere  
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## Solar wind velocity



Solar wind

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Geomagnetic impact of the solar wind

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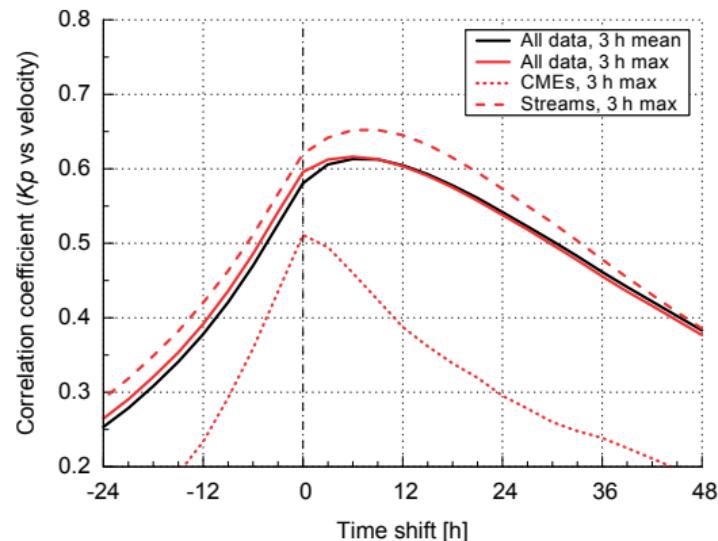
Solar wind model for the inner heliosphere

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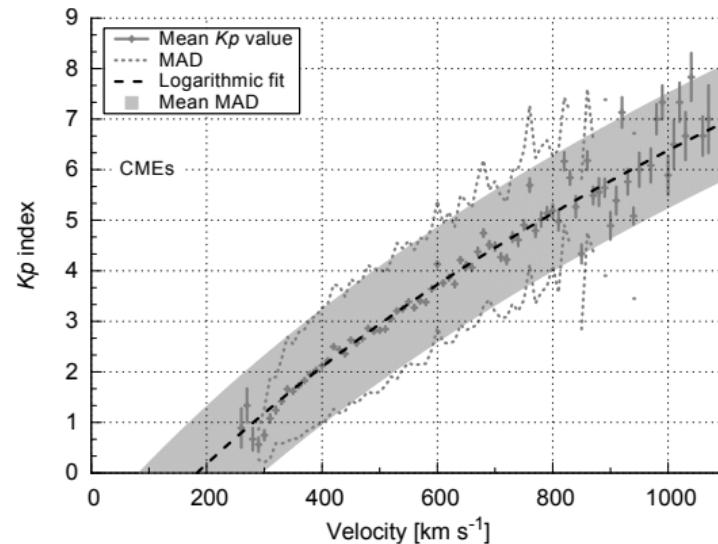
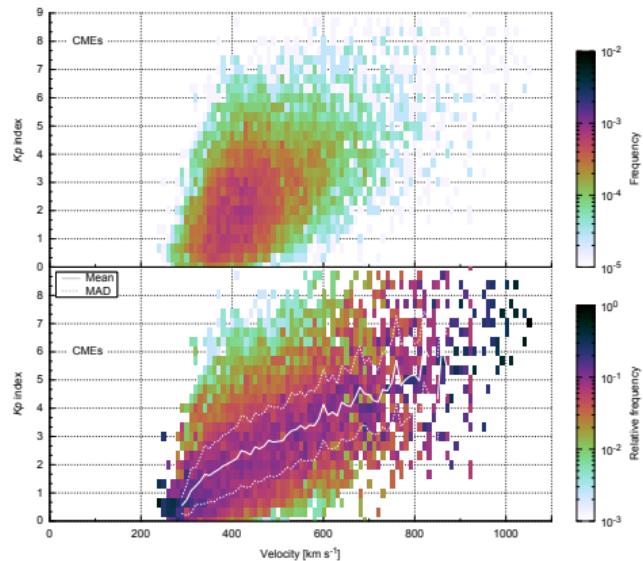
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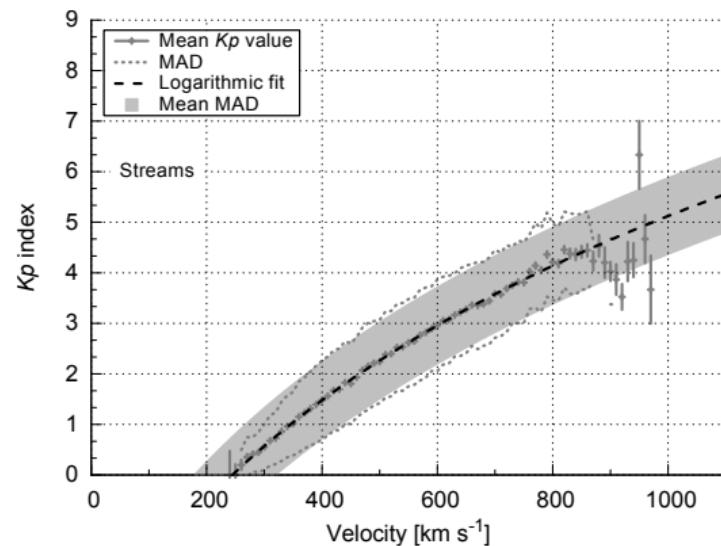
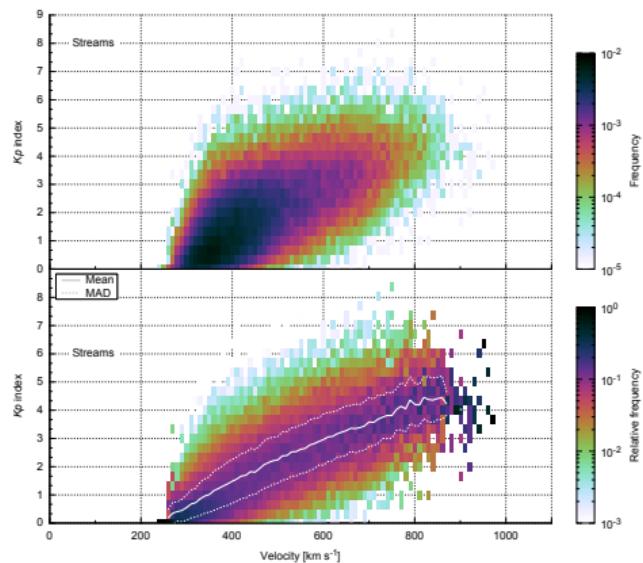
References



# CME velocity



# Stream velocity



### Solar wind

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## Geomagnetic impact of the solar wind

A horizontal row of 15 small circles. The first 14 circles are white with a thin red outline, arranged in a straight line. The 15th circle, located at the end of the row, is solid black.

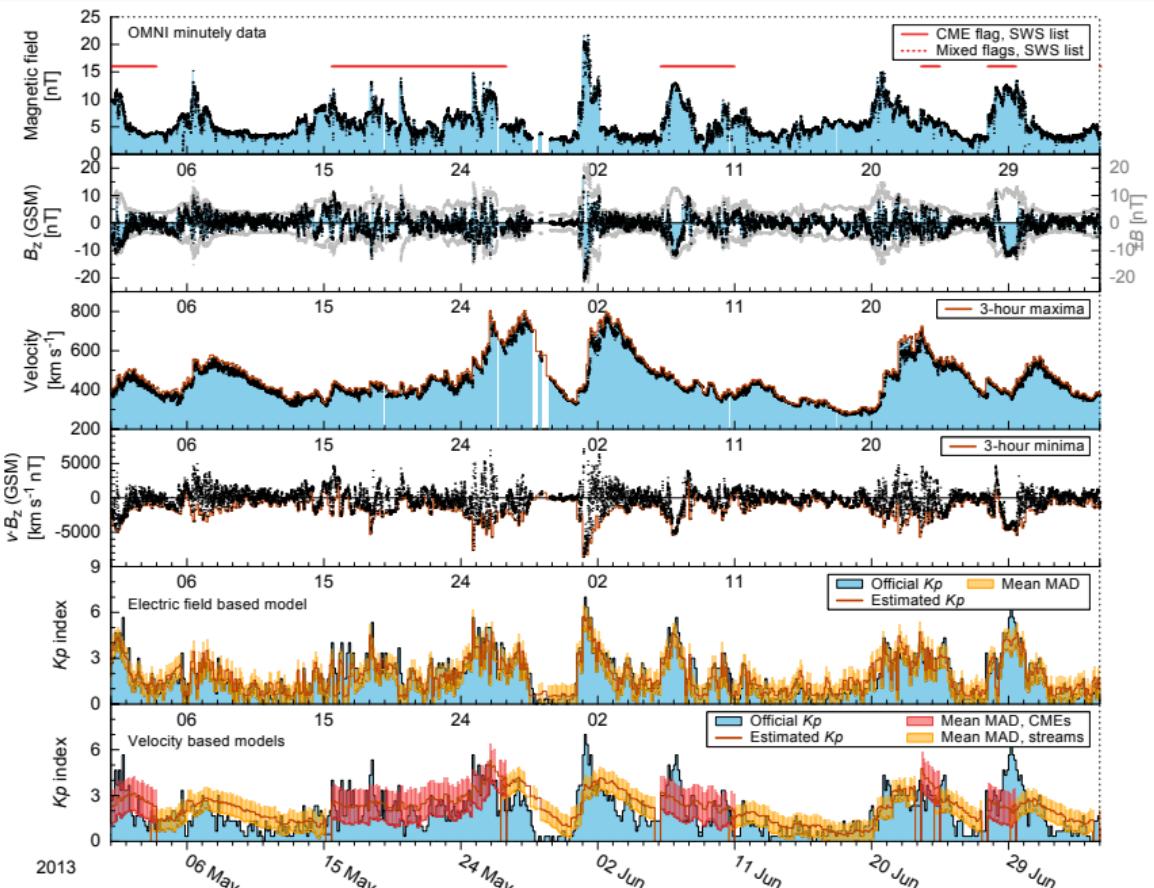
## Solar wind model for the inner heliosphere

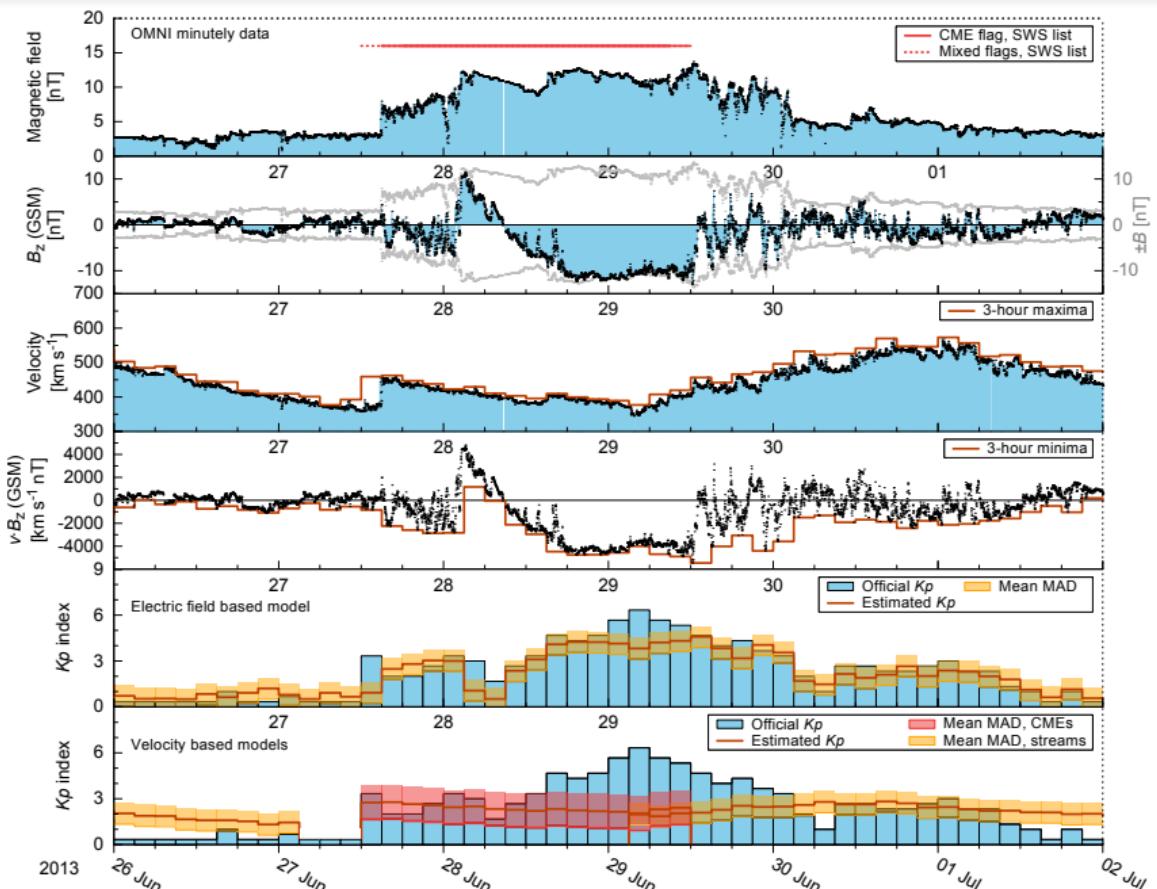
A horizontal row of fifteen small, light blue circles, each containing a number from 1 to 15 in a black serif font. The circles are evenly spaced and arranged in a single line.

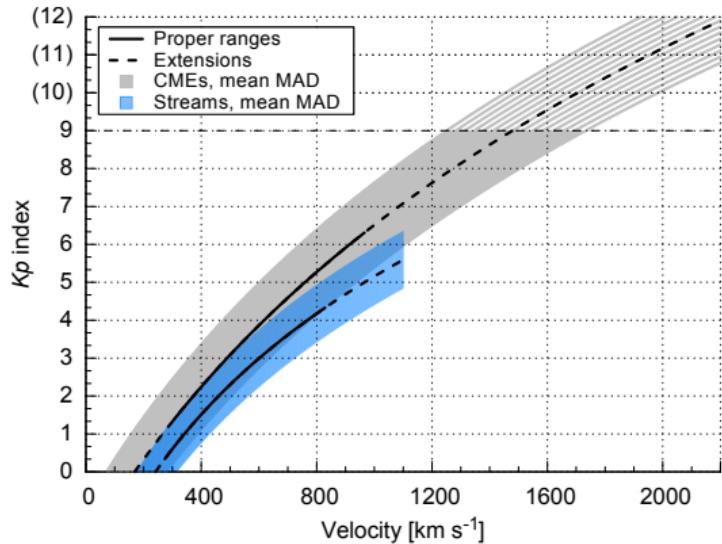
### End matter

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## References







# Results

Predictive  $K_p$  models based on relations with

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

# 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  $K_p$
- The prediction models perform well for their limited input information

» Prediction performance

## 1 Solar wind

## 2 Geomagnetic impact of the solar wind

## 3 Solar wind model for the inner heliosphere

## 4 End matter

## 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

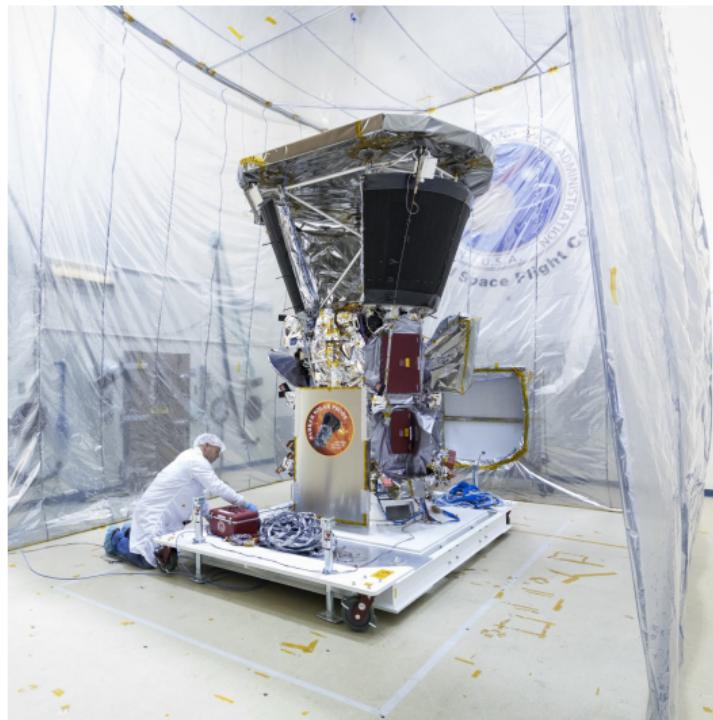
special scientific interest:  
coronal heating  
solar wind acceleration

# Sun–Earth evolution of the solar wind

## Aims

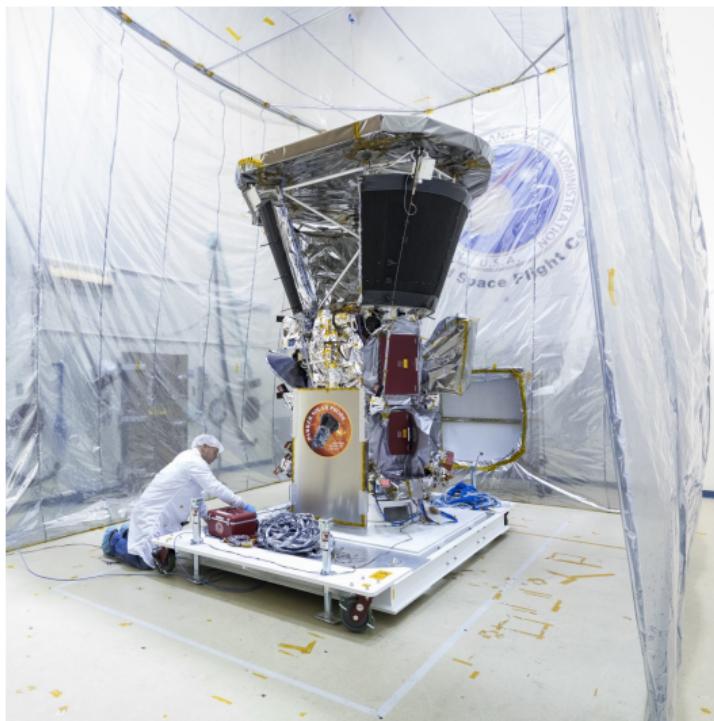
Solar wind model for the inner heliosphere and prediction of the near-Sun environment  
for the PSP orbit

# Parker Solar Probe

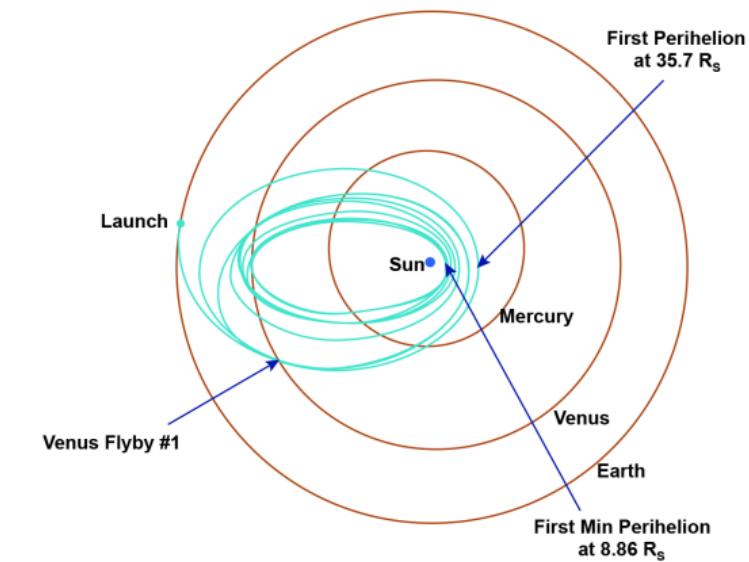


Credit: NASA/Johns Hopkins APL/Ed Whitman, 2017

# Parker Solar Probe



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



Credit: NASA/Johns Hopkins APL, 2018

Solar wind  
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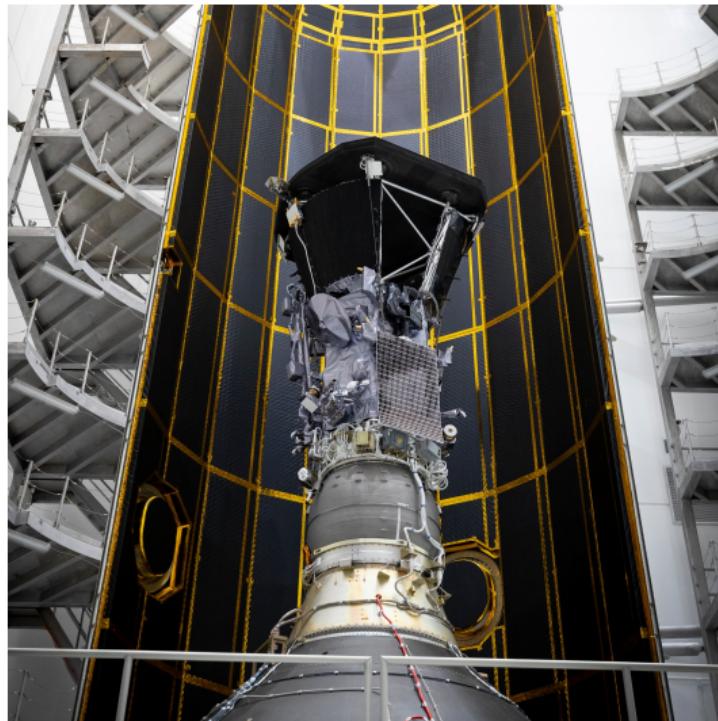
Geomagnetic impact of the solar wind  
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Solar wind model for the inner heliosphere  
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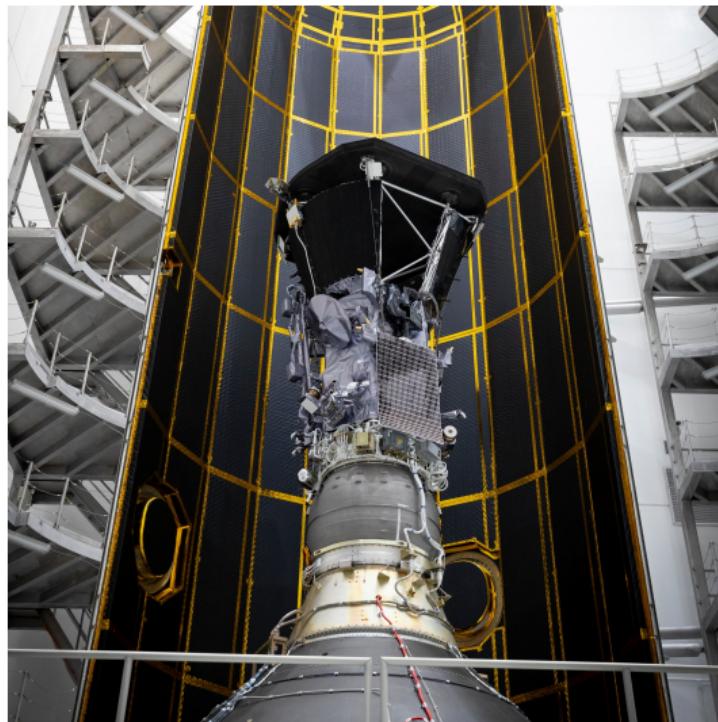
References

# 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

Solar wind  
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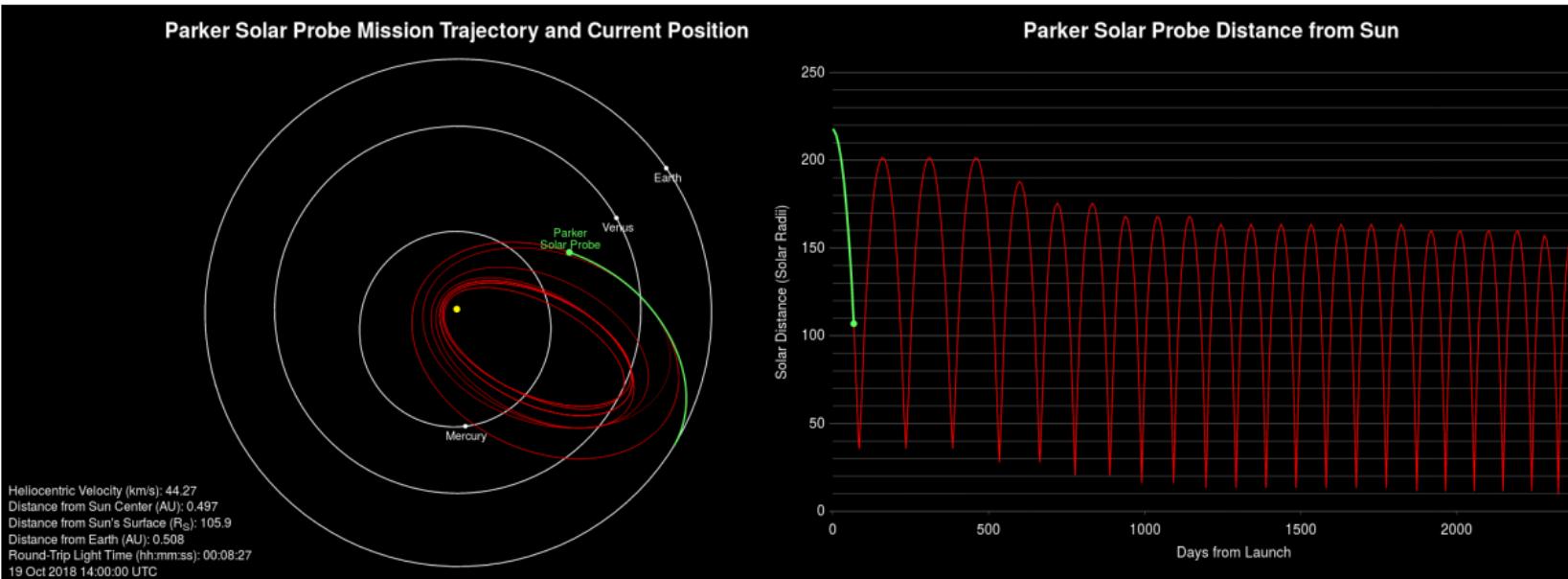
Geomagnetic impact of the solar wind  
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Solar wind model for the inner heliosphere  
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End matter  
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References

# PSP's current position



Credit: NASA

Solar wind

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Geomagnetic impact of the solar wind

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Solar wind model for the inner heliosphere

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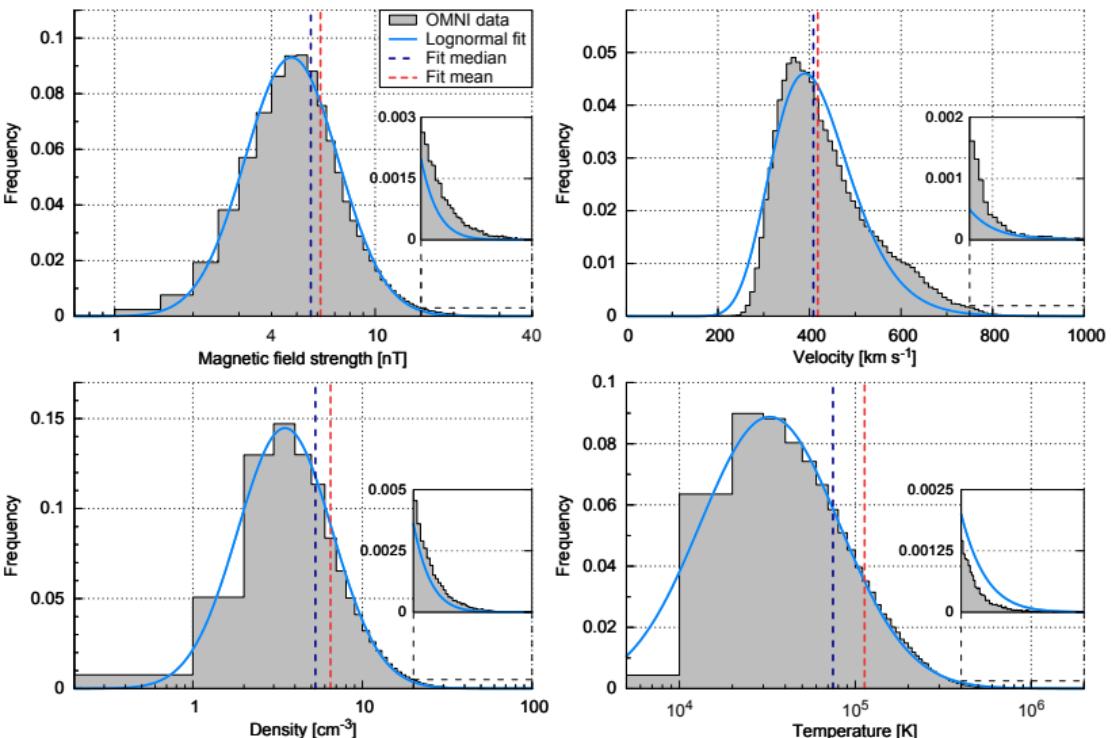
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References

## motivation

# Frequency distributions



Solar wind

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Geomagnetic impact of the solar wind

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Solar wind model for the inner heliosphere

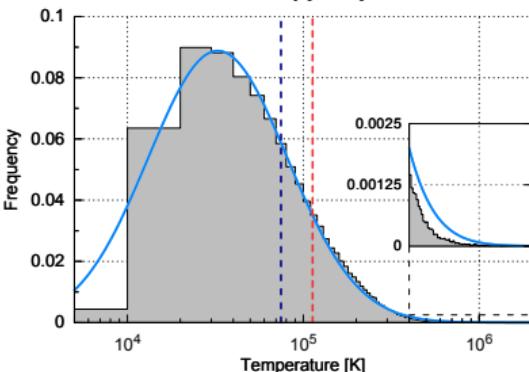
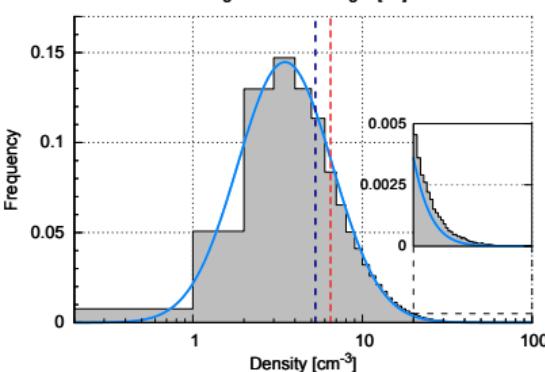
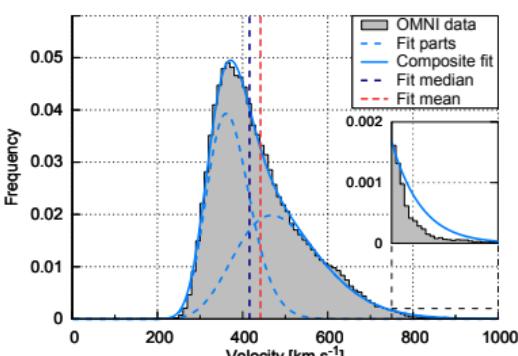
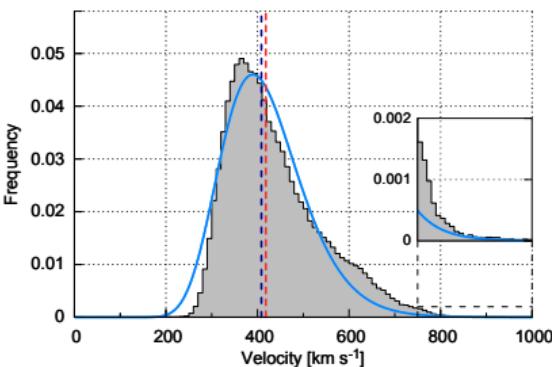
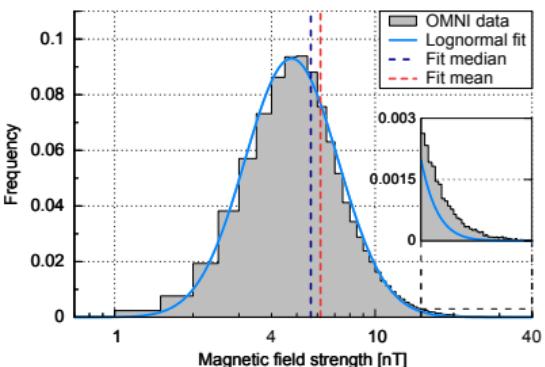
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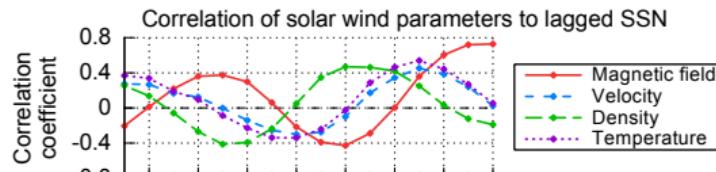
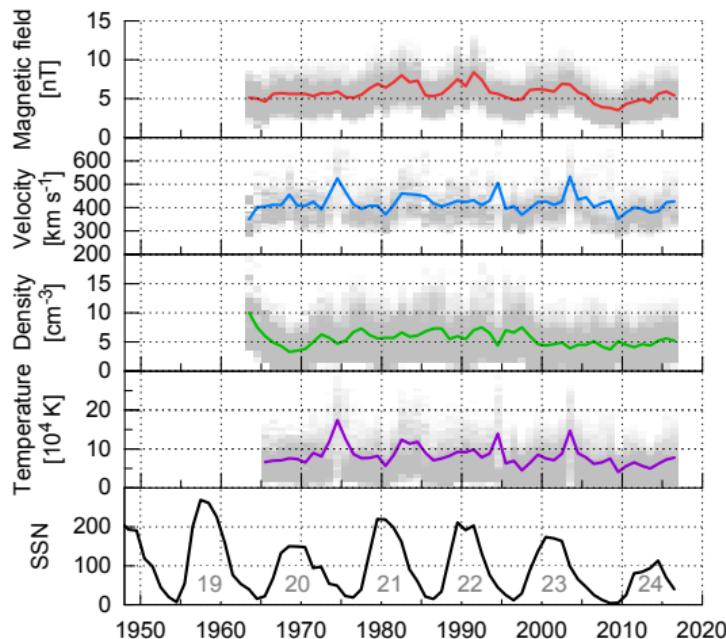
# Frequency distributions



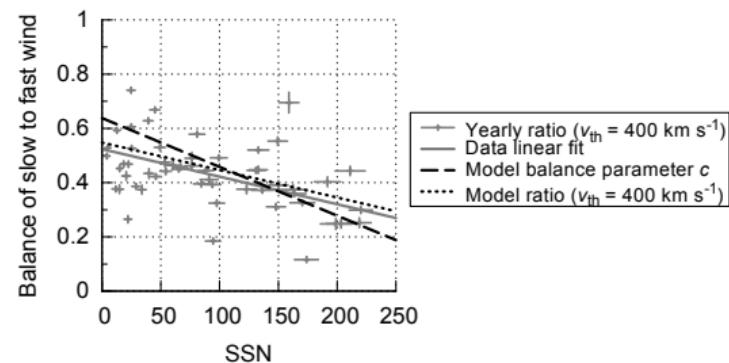
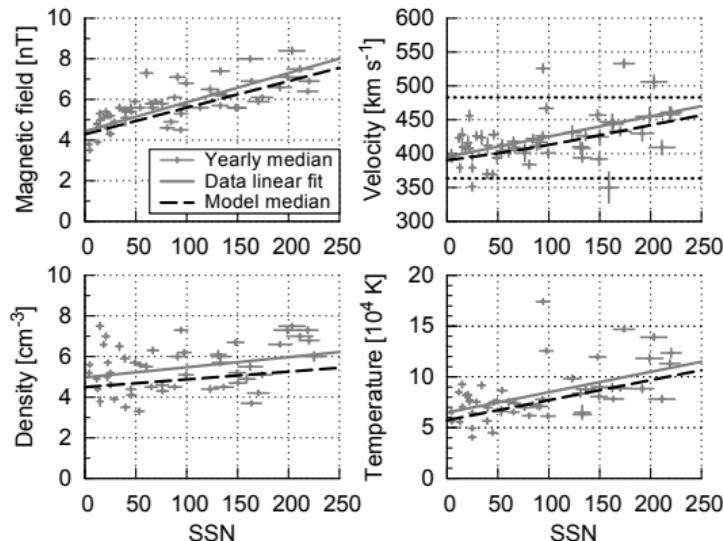
» Lognormal distribution



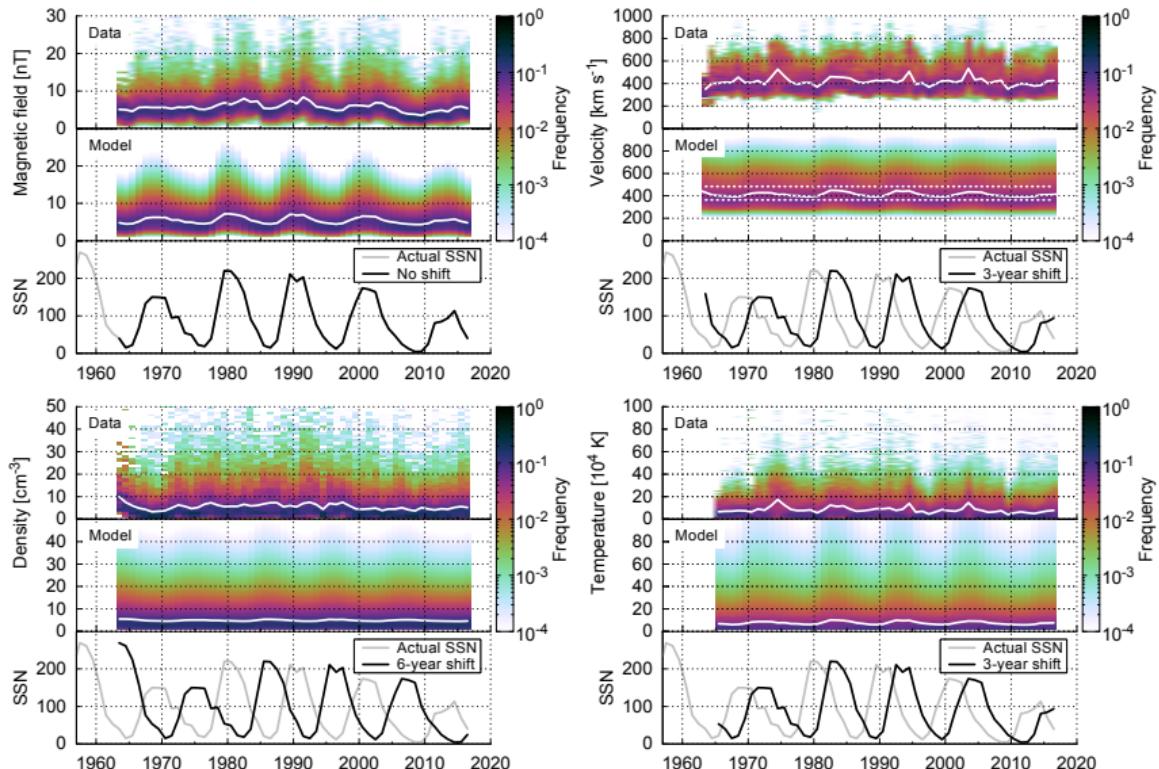
# Sunspot number dependence



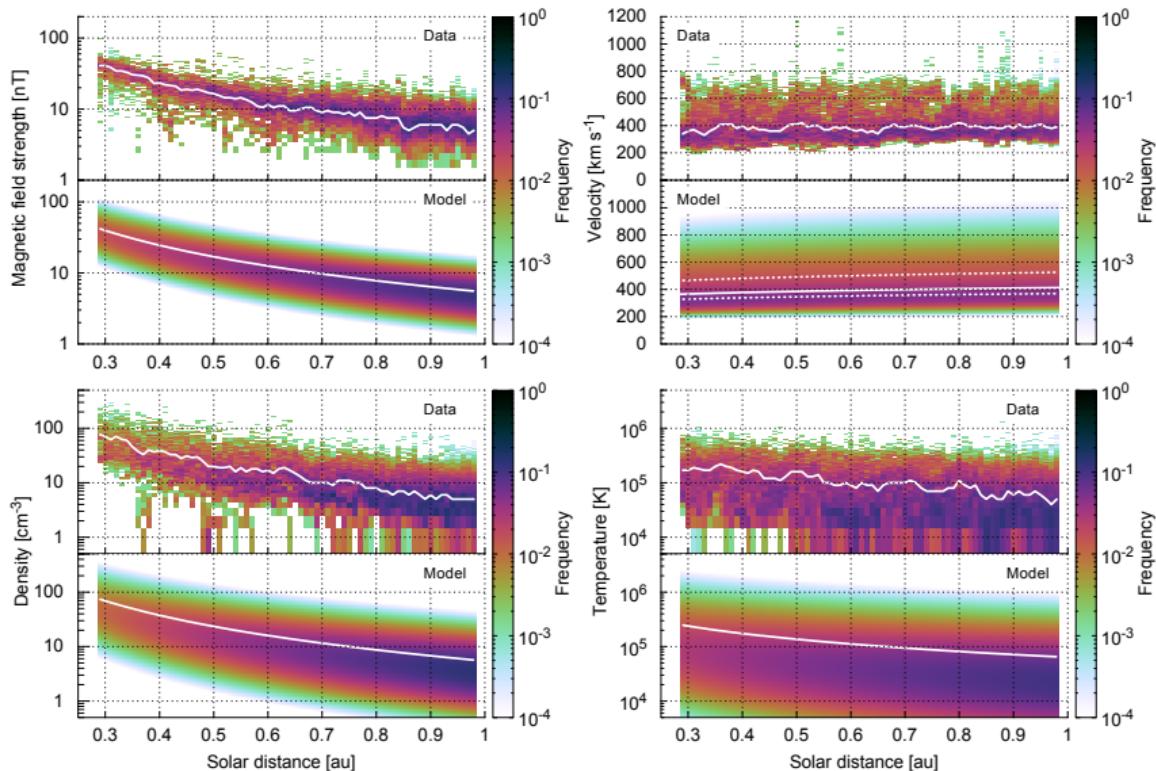
# Sunspot number dependence



# Sunspot number dependence



# Solar distance dependence



Solar wind

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Geomagnetic impact of the solar wind

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Solar wind model for the inner heliosphere

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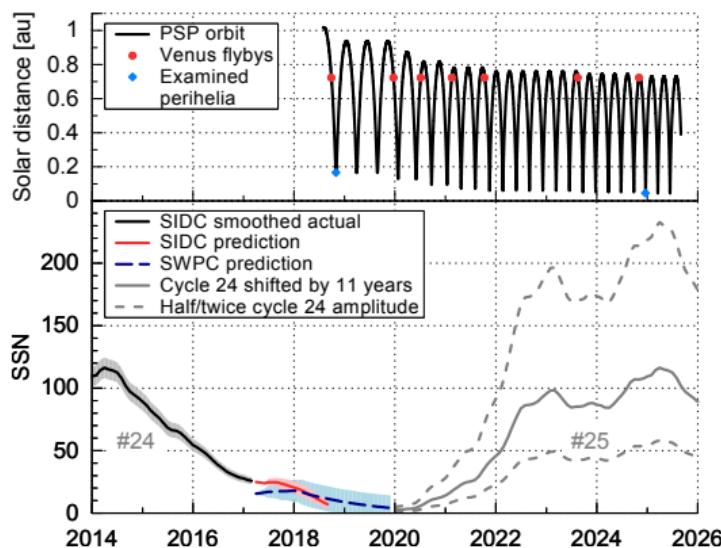
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References

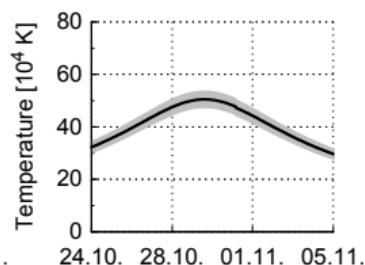
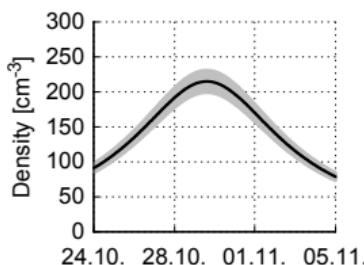
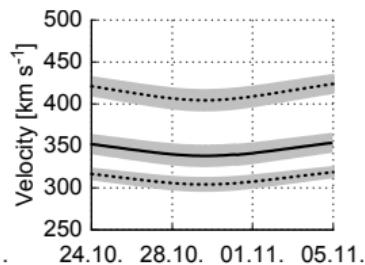
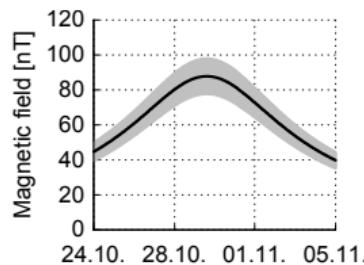
combine models, extrapolation

# SSN prediction



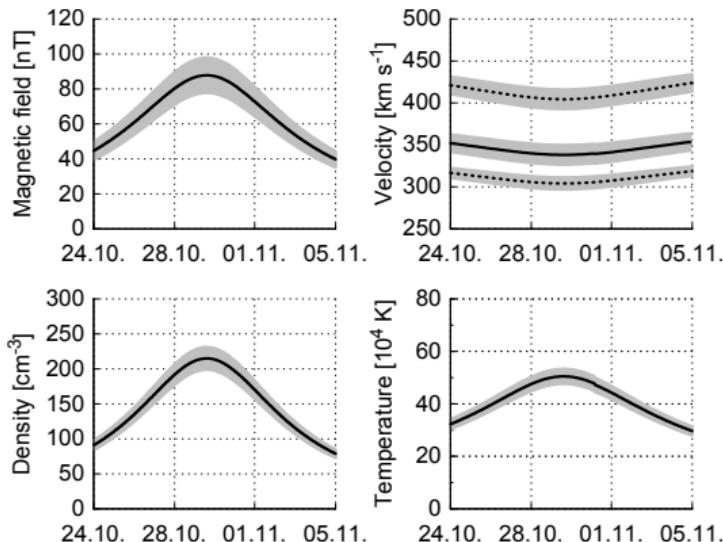
# PSP orbit prediction

First perihelion ( $9.86 R_{\odot}$ )

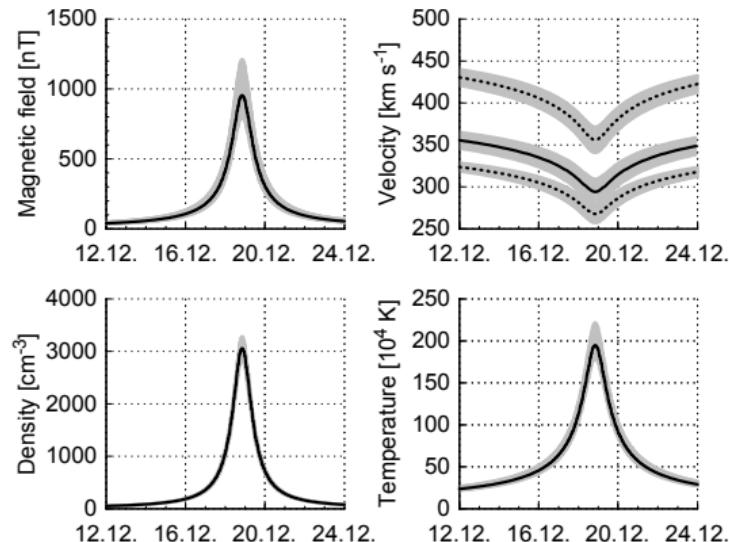


# PSP orbit prediction

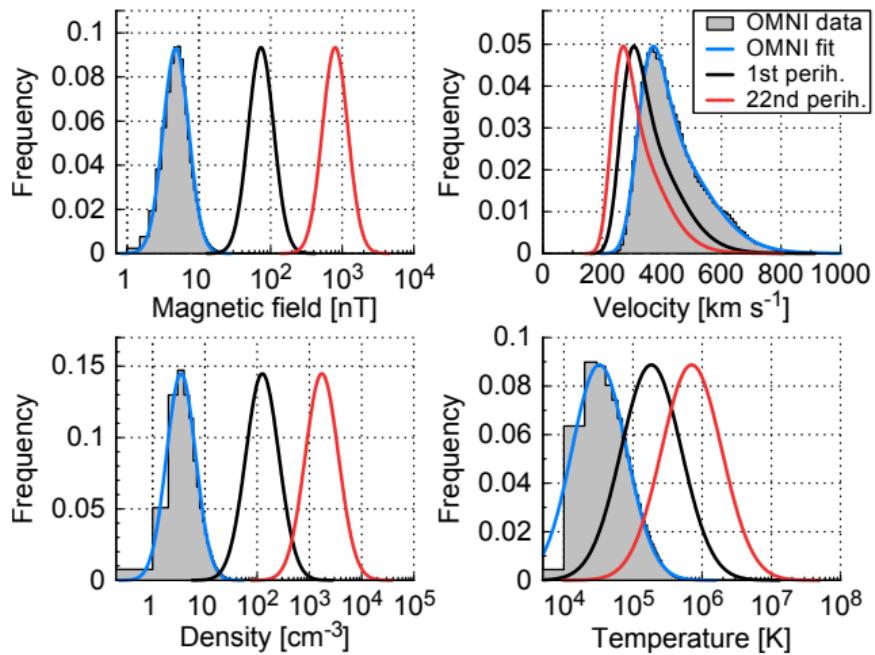
First perihelion ( $9.86 R_{\odot}$ )



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 - $\downarrow$  Solar wind is still being accelerated up to  $20 R_{\odot}$
- Temperature discrepancy - $\downarrow$  Solar wind is still being heated up to  $20 R_{\odot}$

## 1 Solar wind

## 2 Geomagnetic impact of the solar wind

## 3 Solar wind model for the inner heliosphere

## 4 End matter

Solar wind  
ooooooooooooooo

Geomagnetic impact of the solar wind  
oooooooooooooooooooo

Solar wind model for the inner heliosphere  
oooooooooooooooooooo

End matter  
○●

References

# Thank you!

# References |

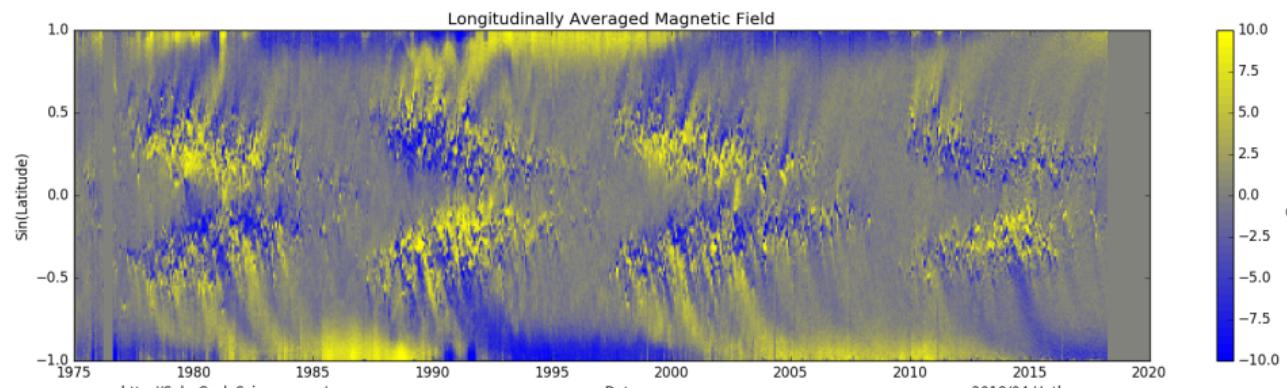
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## 5 Backup slides

- Solar wind
- Chapter2
- SW model

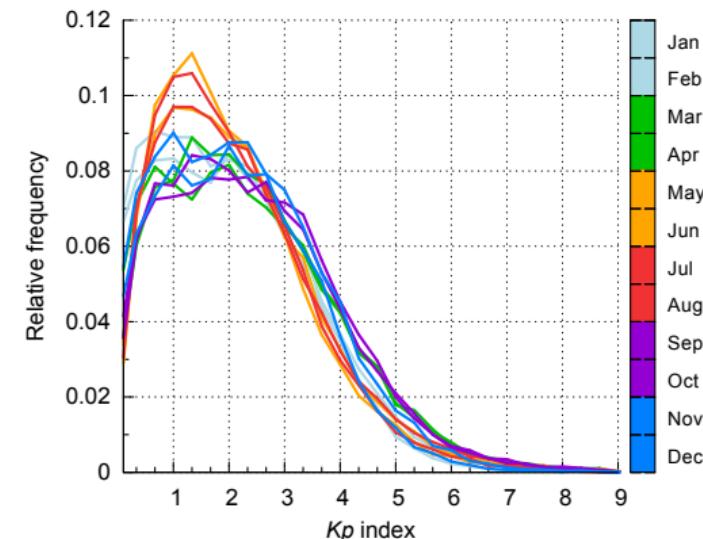
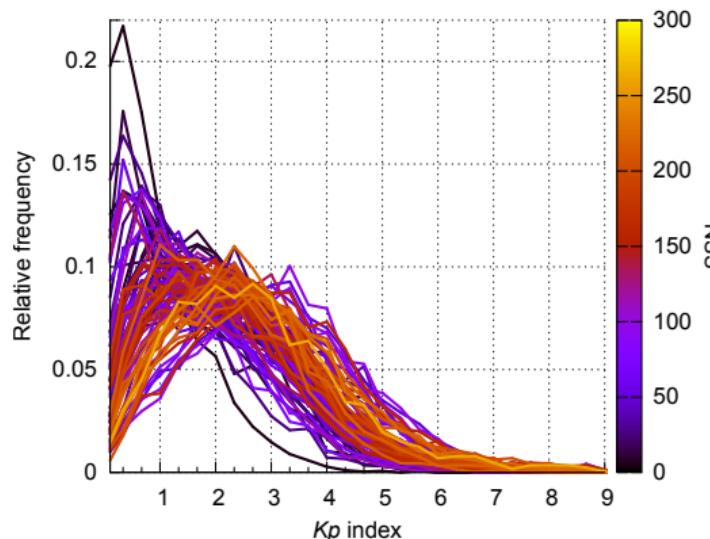
# Solar activity

## Magnetic butterfly diagram

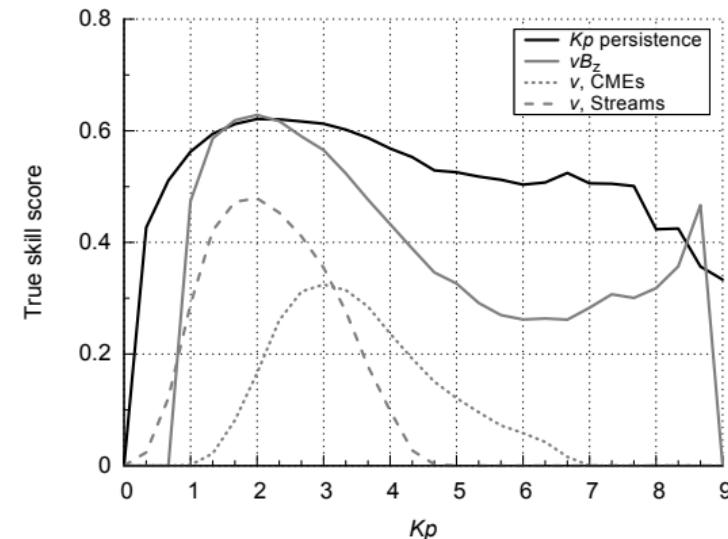
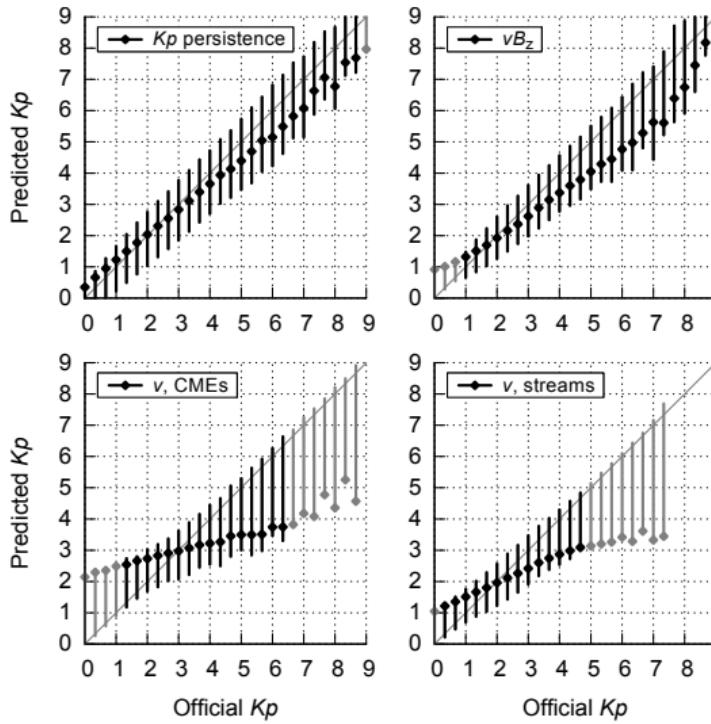


Courtesy of David Hathaway, Solar Cycle Science, 2018, updated version of Hathaway (2015, Fig. 17)

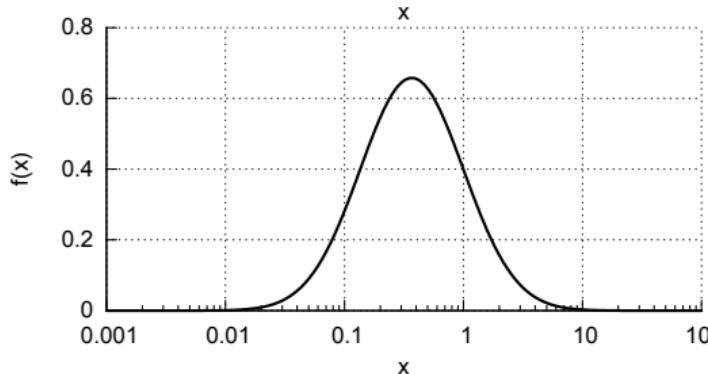
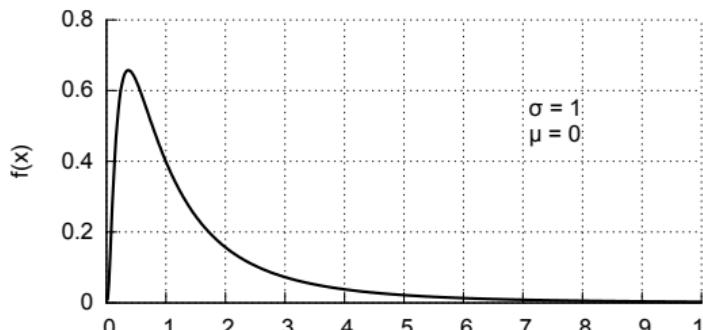
# K<sub>p</sub> long-term variations



# 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 ( $\mu$ ) and shape parameter ( $\sigma$ )