LPHYS2266 - Physics of the upper atmosphere and space

The WIND Mission

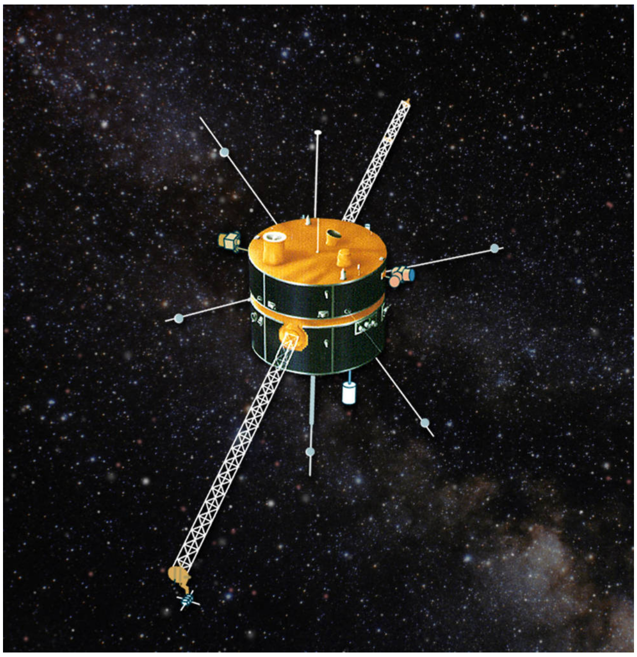

Figure 1: *Wind spacecraft. Figure from Nasa images[2]*

Professor:
Viviane Pierrard

Work done by :
Amaury Laridon

École de Physique

Faculté des Sciences

April 14, 2023

Contents

1 Important characteristics of the WIND mission

Launch date	November 1, 1994
End date	Still Used
Type of orbit	Small "halo" orbit
Perigee	265 Earth radii
Apogee	235 Earth radii
Main used instruments	Plasma, Magnetospheric and ionospheric studies

`Wind` was launched on November 1, 1994 and is the first of two NASA spacecraft in the Global Geospace Science initiative and part of the ISTP Project (International Solar Terrestrial Physics).[4] The objective of the ISTP program was to study the origin of solar variability and activity, the transport of manifestations of that activity to the Earth via plasma processes, and the cause-and-effect relationships between that time varying energy transport and the near-earth environment.[9]
The science objectives of the `Wind` mission are,

1. Provide complete plasma, energetic particle, and magnetic field input for magnetospheric and ionospheric studies.
2. Determine the magnetospheric output to interplanetary space in the up-stream region.
3. Investigate basic plasma processes occurring in the near-Earth solar wind.
4. Provide baseline ecliptic plane observations to be used in heliospheric latitudes from ULYSSES.

The initial design lifetime of `Wind` was three to five years. Nevertheless since it last repositioning and permanently parked position in L1 (Lagrange point) halo orbit in 2004, `Wind` continues to provide high-quality solar wind measurements.[6] `Wind` has on-board propulsion with redundant subsystems. It has a cylindrical form of approximatively 2.8m in diameter by 1.25m high with body-mounted solar cells. `Wind` has experiment booms deployed along both Z-axes with a spin rate of 20rpm around an axis within 1 degree of normal to ecliptic.[6]
The `Wind` mission has four different phases. For the first nine months of operation, `Wind` was placed in a double-lunar swingby orbit near the ecliptic plane, with apogee from 80 to 250 Earth radii and perigee of between 5 and 10 Earth radii. In this orbit, lunar gravity assists were used to keep its apogee over the day hemisphere of the Earth, and magnetospheric observatiothreens are made.
`Wind` was then inserted into a small "halo" orbit, about the sunward Sun-Earth gravitational equilibrium point (L1), varying from 235 to 265 Earth radii. In this orbit `Wind` measures the incoming solar wind, magnetic fields and particles continuously and 29,5provides an approximately one-hour warning to the other ISTP spacecraft of changes in the solar wind.
In 2001 and 2002 `Wind` has executed a distant prograde orbit that took it $+/-$ 300 Re leading and legging Earth. This orbit provided a wide baseline to study solar wind structures and correlations.
In 2003, `Wind` reached the L2 Lagrange point 240 Re anti-sunward from Earth providing a 500 Re spatial separation from ACE solar wind observations along with measurements of the distant Earth magnetotail.

In this report we will mainly be focused on the small "halo" orbit period in order to study the data associated to incoming solar wind, magnetic fields ans particles. The main experiments and instruments (`Wind` has 8 experiments) from which we will retrieve and analyze some data are the following,

- Energetic Particule Acceleration, Composition and Transport (EPACT)
- Magnetic Fields Instrument (MFI)

- Solar Wind and Suprathermal Ion Composition Studies (SWICS/STICS)
- Solar Wind Experiment (SWE)

2 Plot of interesting data

`Wind` halo orbit

A first interesting figure[1] (Fig(2) is the `Wind` predicted orbit from the 2 december 1997 and the 29 april 1998 which correspond to the beginning and end of the halo orbit loop.[7]

We can clearly see from Fig(2) the particular type of `Wind`'s orbit. This one is characterized by a nearly stationary trajectory in the (x_{GSE}, y_{GSE}) plane but with an almost circular motion in the (y_{GSE}, z_{GSE}) plane. We understand that `Wind` was well beyond the Moon orbit since in Earth radii the Moon is at a distance of a bit more than $60Re$ or the distance of `Wind` during that orbit is at a bit more than $200Re$. We can also see that the distance of `Wind` with Earth is almost constant as we can expect from that type of "halo" orbit.

Plasma flow speed, photon density, temperature and electric field intensity

Secondly it is interesting to have a look at the *OMNI_HRO_1MIN* data set which consist of one minute averaged definitive multispacecraft interplanetary parameters. *Wind* is one of the main spacecraft used for building those data which are solar magnetic field and plasma data sets time-shifted to the Earth's bow shock nose. Time shifting is based on the assumption that solar wind magnetic field values observed by a spacecraft at a given time and place lie on a planar surface (a "phase front") convecting with the solar wind, and that the same values will be seen at a different place at the time that the phase front sweeps over that location.[5]

Figure(3) shows plasma flow speed, proton density, temperature and electric field intensity during the halo orbit loop period. All the signals have a strong variability and noise. Nevertheless the first interesting features of those time series is what seems to be coherent signal variations at some particular times. For example at the end of April, the biggest maxima of temperature time series near $1,3.10^6\,{}^\circ K$ seems to occur at the same time that the biggest maxima of the plasma flow speed which has a value of almost $700km/s$.
A second remarkable signal coherence is near the 10th of March 1998 where the biggest maxima in the electric field intensity arrives at, what seemed to be, the same time as a temperature maxima and a plasma flow speed maxima.It seems nevertheless that this phenomena happens just after a maxima in the proton density.
A plausible hypothesis is that a more important plasma flux is carrying more ionized particles which their interactions raise the temperature and create a more important electric field, all of those effects beeing captured by `Wind's` detectors.

3 Activity Indices

Figure(4) display some geomagnetic and sun activity index. Following Kp index we can count 4 storms and 10 under stormy weather during the time series. Following Dst index we have 9 storms during the time series. From the list of Solar Particles Events (SPE)[1] we can see that they were a particle event from April 20 to April 21 in 1998 which is well captured by the *OMNI* data set since we have a value of $Kp * 10 > 50$ and a Dst value such that $Dst < -50nT$. During this event the number of daily sunspot was quite low (less than 40). What is interesting is that the biggest and all the others solar or geomagnetic storms captured

[1] A GitHub repository : `https://github.com/AmauryLaridon/LPHYS2266` has been made to centralize all the data, figures and the Julia script made for plotting and analyze the data.

by the *OMNI* data set are not associated with SPE according to the NOAA's data[1]. For example near the 8th of March 1998 we have the lowest value of Dst index in the time series which is a day or two after the maxima of Kp index. The values associated to those two index should clearly corresponds to geomagnetic storms and furthermore we also have a local maxima at the same time in the proton QI (solar wind) measure but nevertheless those are not reported in the SPE data base.
How to solve this problem ? If we look at Fig.(5) we see that the high energy proton flux $(28 - 72MeV)$ only has a peak around the 20 and 21 April 1998. Therefore it seems that around those days a very high velocity solar wind made mainly of proton with high energies is responsible for the SPE reported in the NOAA data base. The figure is not shown here but a look at the Solar Lyman-alpha ray intensity clearly shows a maxima a few days before the SPE which suggest the origin in the Solar activity.
For all the others storms captured by the *OMNI* data set, Fig.(6) shows that indeed they were protons density anomalies but those where associated to low average energy protons which does not exceed a value of more than $1MeV$ except for the SPE event which saturates the measuring device. This could be a reason why those events where not critical enough to be reported as a Solar proton event that affects the Earth environment.

4 Cause of the observed time variations

Now we want to understand and quantify if the observed time variations are due to the orbit of the satellite of to solar (geomagnetic) activity. First the figures of the temperature, plasma flow speed, proton density, Kp and Dst index and GSE_Z coordinate are produced from the raw data of the Wind Mission during the halo loop period and are available on the GitHub. By inspection of Fig(4) and Fig(3), it seems visually that there is a relatively good correlation between the time variation of the plasma flow speed and the Kp and Dst index. It seems to be also the case for temperature variations and the solar activity index. For the proton density and the solar activity index it seems to be more noisy.

If we want to compare those different data set in their variations in order to see whether there is some linear correlation we have to interpolate the data set because they don't have the same initial time resolution. Indeed the variables data set (temperature, flow speed and proton density) have an initial time resolution of 1 minute whereas the index data set has a 1 hour time resolution and lastly the orbital data set a 10 minutes time resolution. With the purpose of loosing the least amount of precision on the data I decided to simply pick the data of the dataset wit the higher temporal resolution that corresponds to time of observation of the lowest resolution data set. Therefore I do not interpolate or extrapolate any data.
The data sets are all contaminated with singular values corresponding to measures that saturates the resolution of the different detectors. A simple arithmetic mean based on the two previous values before the singularity has been applied and this allows to reproduce pretty well the figures given by the CDAWeb interface.

A computation of the linear correlation between the different data sets gives the following values,

(Data set 1, Data set 2)	Correlation coefficient
(Temperature, Kp)	0.331
(Plasma flow speed, Kp)	0.469
(Proton density, Kp)	0.129
(Temperature, Dst)	-0.312
(Plasma flow speed, Dst)	-0.484
(Proton density , Dst)	0.270
(Temperature, GSE_Z)	0.012
(Plasma flow speed, GSE_Z)	-0.185
(Proton density, GSE_Z)	-0.03

We can see that as intuitively mention we have the strongest correlation with the plasma flow speed and the Kp and Dst index. After that we have a small linear link between temperature and the solar activity index. We also observe that there is no linear correlation between the GSE_Z component i.e between the most significant orbital variable[2] and the measured variables. Even if the correlation coefficient are not very high (even for the relation between plasma flow speed and solar index) the values obtained gives us a strong belief that the temporal variations observed by the `Wind` mission are coming from solar activity and not from orbital variations.
Figures Fig(7 - 10) show the scatter plots between different relevant data set and allow visual inspection of the previously mentioned results.

References

[1] NOAA Space Environment Services Center. Solar proton events affecting the earth environment. `https://umbra.nascom.nasa.gov/SEP/`.

[2] NASA images. Wind spacecraft. `https://www.nasa.gov/sites/default/files/styles/full_width/public/thumbnails/image/wind_spacecraft.jpg?itok=kcfHLtm-`.

[3] NASA. Cdaweb data explorer wind mission. `https://cdaweb.gsfc.nasa.gov/cgi-bin/eval2.cgi`.

[4] NASA. Istp project. `https://pwg.gsfc.nasa.gov/istp/misc/istp_project.html`.

[5] NASA. One min and 5-min solar wind data sets at the earth's bow shock nose. `https://omniweb.gsfc.nasa.gov/html/HROdocum.html`.

[6] NASA. Wind : Understanding interplanetary dynamics. `https://pwg.gsfc.nasa.gov/wind.shtml`.

[7] NASA. Wind extended mission trajectory event timeline. `https://pwg.gsfc.nasa.gov/istp/wind/Timeline.htm`.

[8] NASA. Wind mission. `https://hpde.io/SMWG/Observatory/Wind`.

[9] NASA. Wind spacecraft. `https://wind.nasa.gov/`.

[10] Pierrard V. *LPHYS2266 - Physics of the upper atmosphere and space*. UCLouvain, 2023.

[2]Because we are looking at an halo orbit we can see from Fig.(2) that the only relevant position component is the GSE_Z component.

5 Annexe

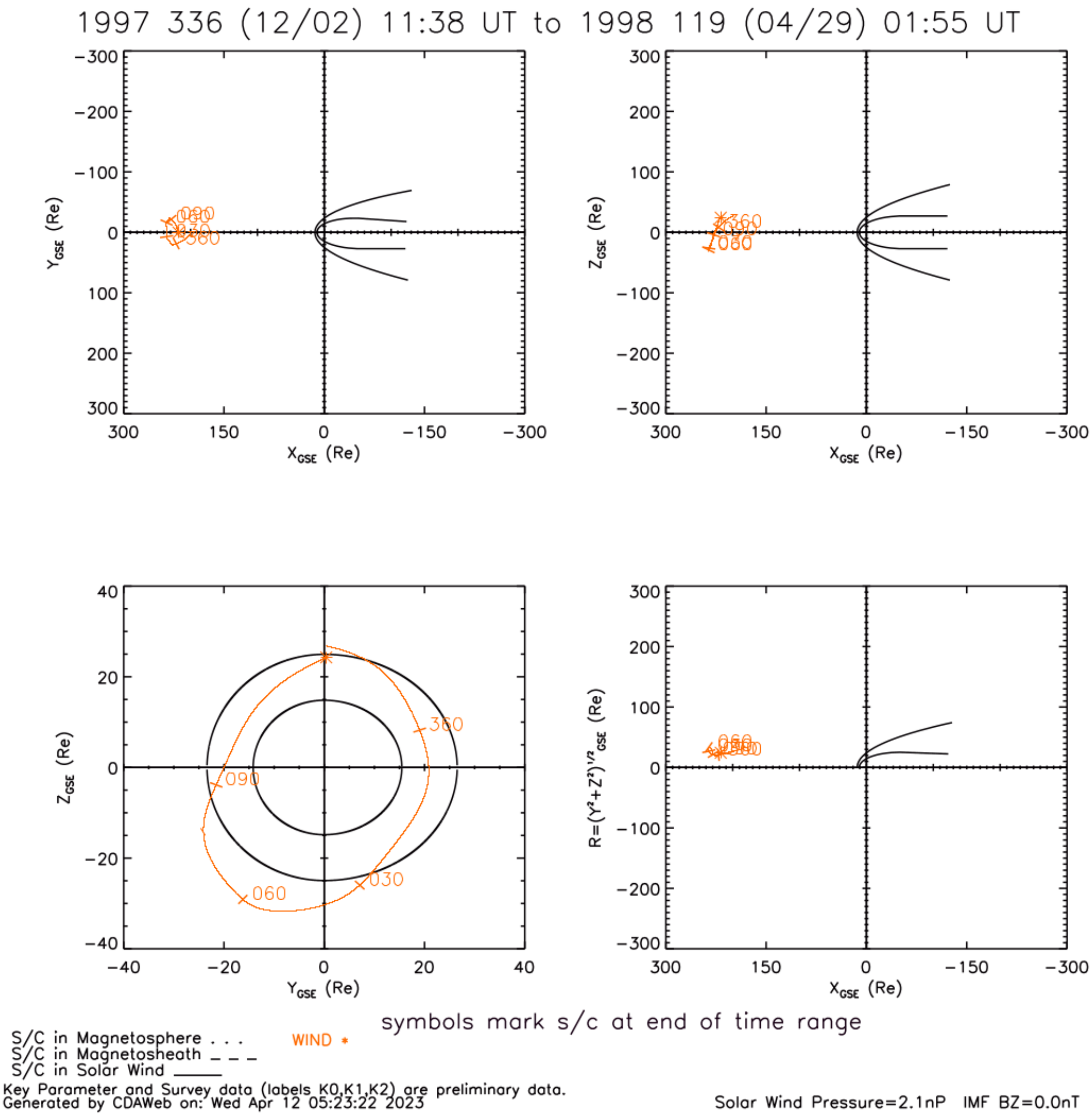

Figure 2: *Wind predicted orbit form 2 december 1997 to 29 april 1998. Beginning and end of the halo orbit loop. Coordinates corresponds to Geocentric Solar Ecliptic (GSE) cartesian coordinates (orbit display) measured in Earth radii Figure from Wind extended mission trajectory event timeline[7]*

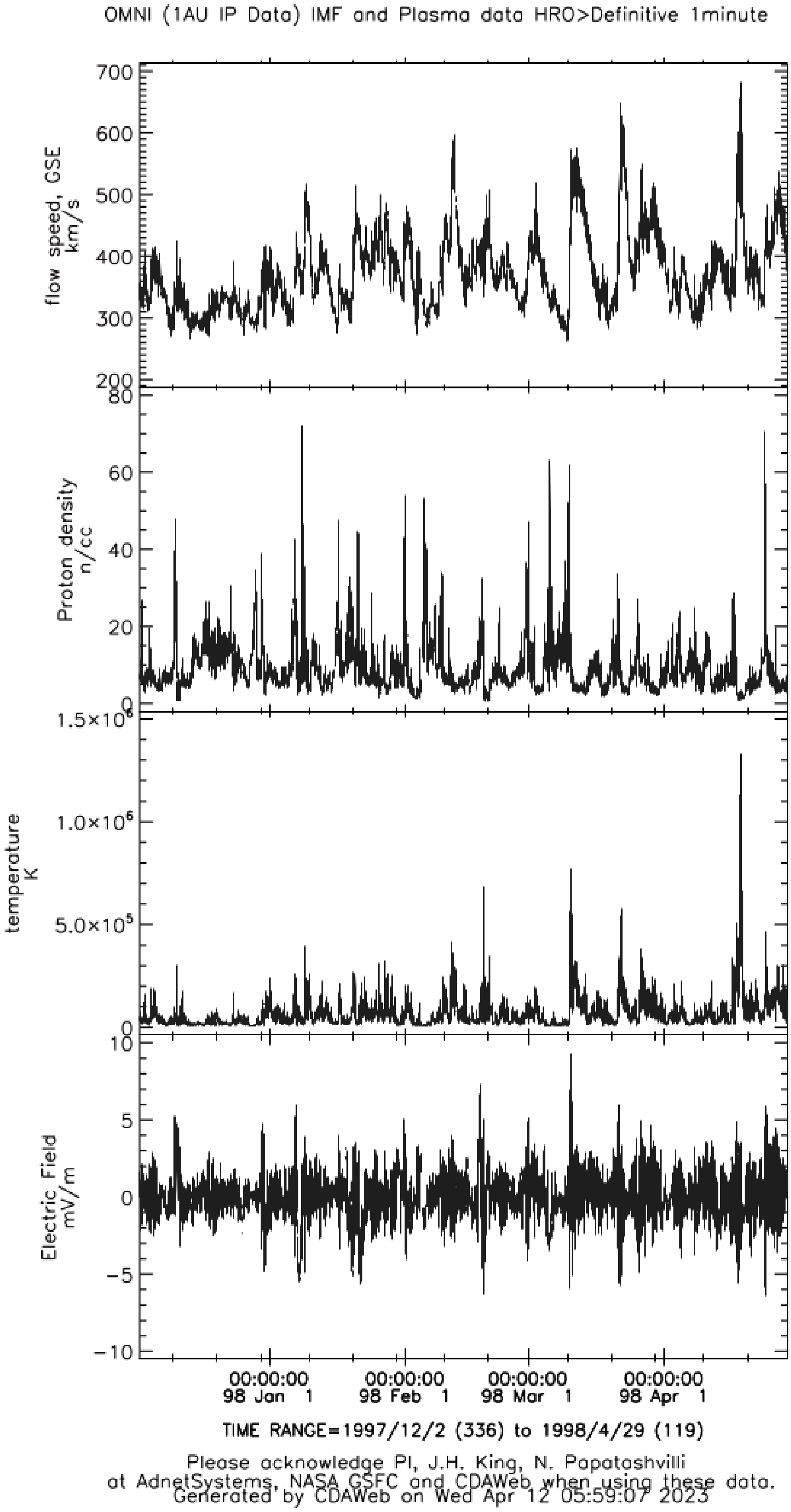

Figure 3: *OMNI_HRO_1MIN plasma flow speed, photon density, temperature and Electric field intensity during the halo orbit period. Figure made with CDAWeb from data of NASA[3]*

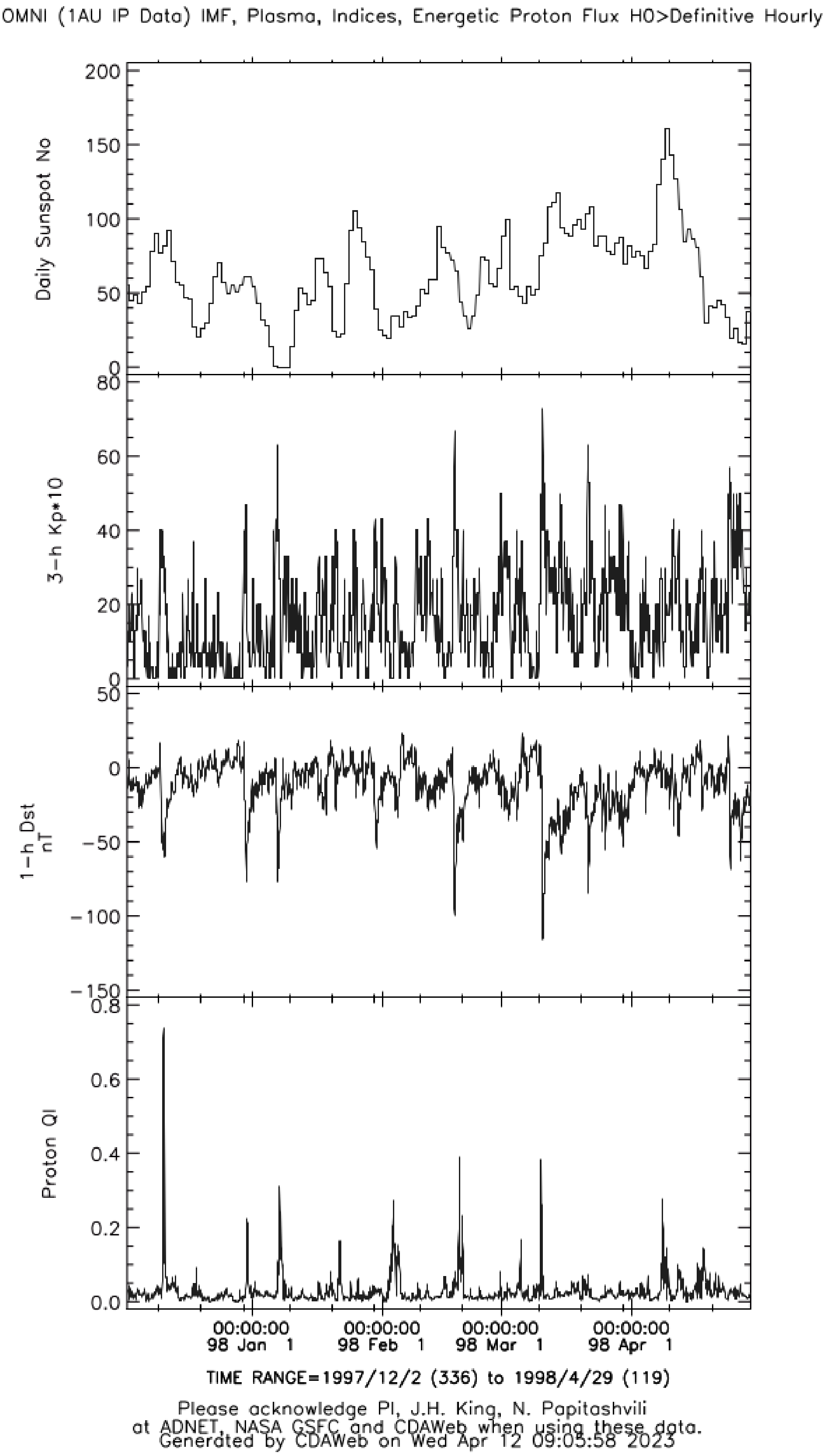

Figure 4: *OMNI2_H0_MRG1HR data set of Daily sunspot number, Kp index (pay attention that the plot is here $Kp * 10$), Dst index and Proton QI or solar wind measure (magnetic energy density/kinetic energy density). The time series follows the halo orbit period Figure made with CDAWeb from data of NASA[3]*

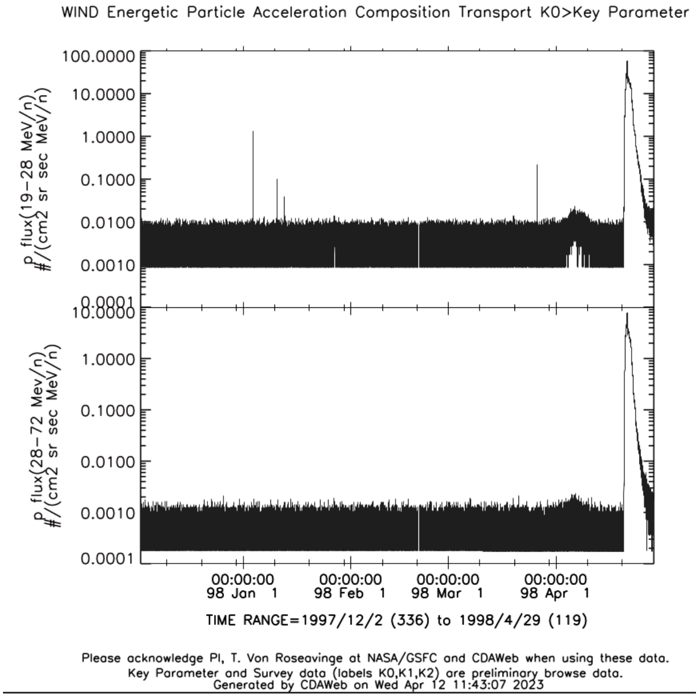

Figure 5: *Proton flux from* $19MeV$ *to* $28MeV$ *from* $28MeV$ *to* $72MeV$ *during the halo orbit period. Data from the WI_KO_EPA time series of* `Wind`*. Figure made with CDAWeb from data of NASA[3]*

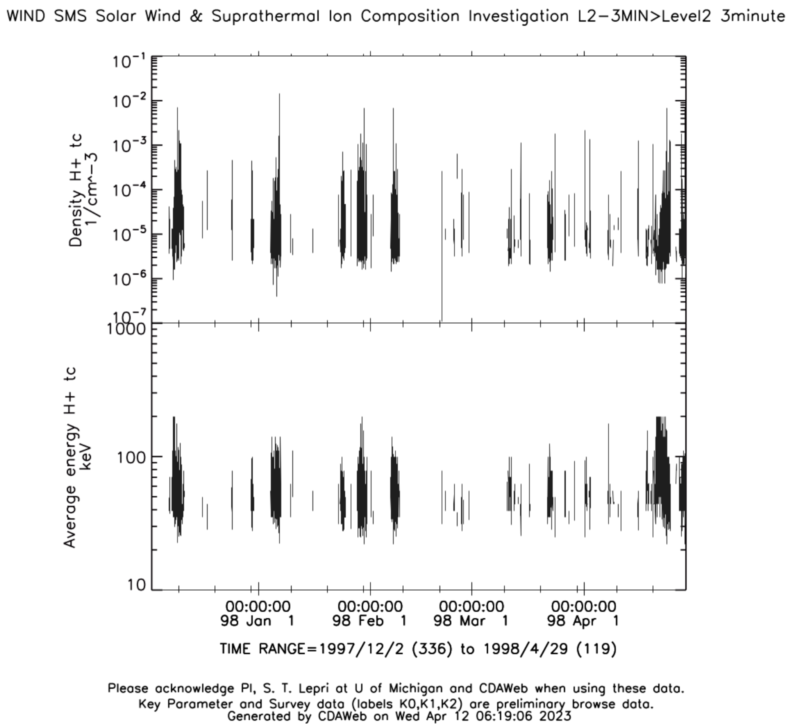

Figure 6: *Density of* H^+ *triple coincidence and average density of* H^+ *triple coincidence in keV during the halo orbit period. Data from* `Wind`*'s SMS instrument. Figure made with CDAWeb from data of NASA[3]*

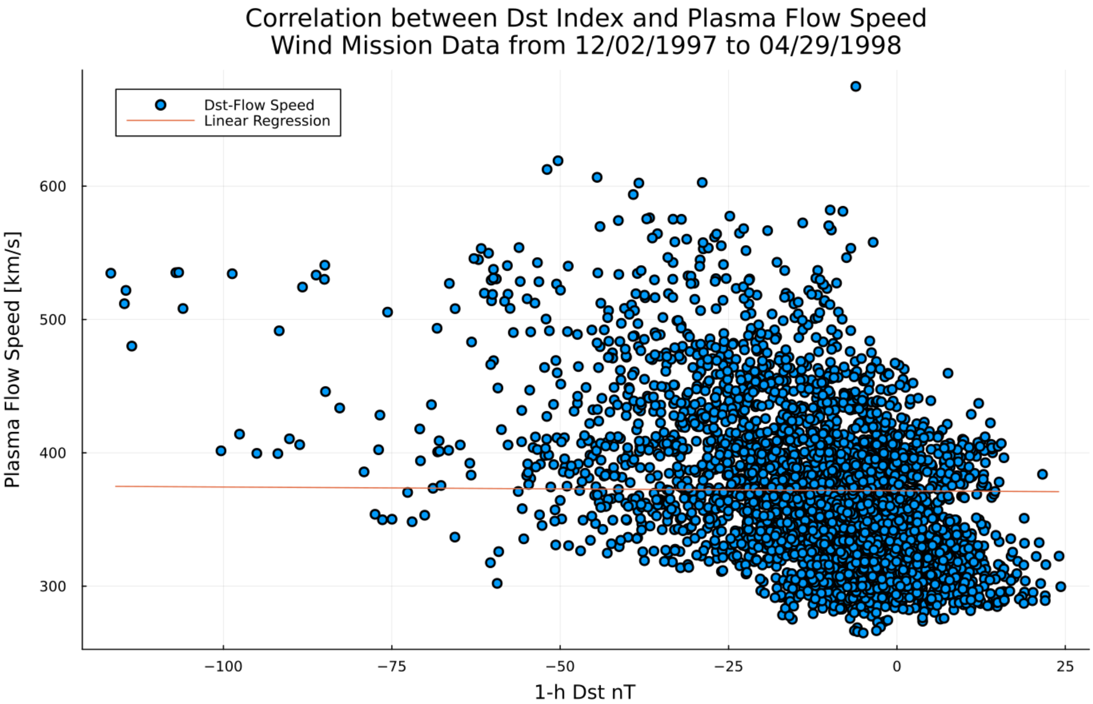

Figure 7: *Correlation between the Dst index and Plasma flow speed during the halo loop period of* `Wind`*. Figure made with the Julia script available on the Github*

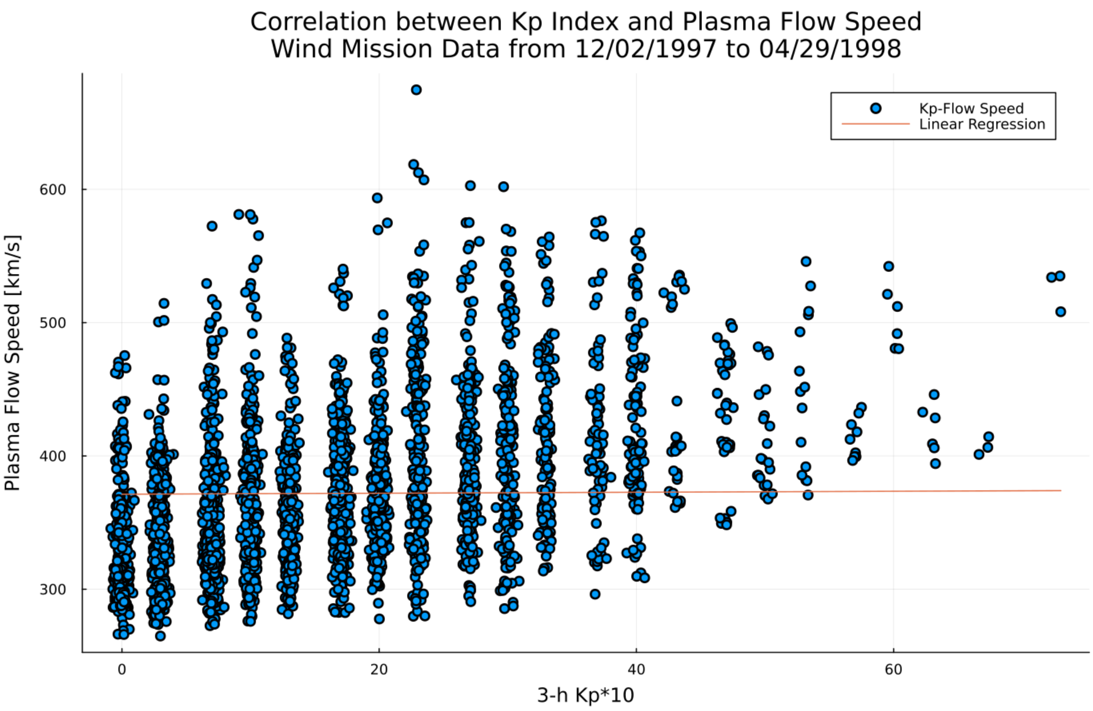

Figure 8: *Correlation between the Kp index and Plasma flow speed during the halo loop period of* `Wind`*. Figure made with the Julia script available on the Github*

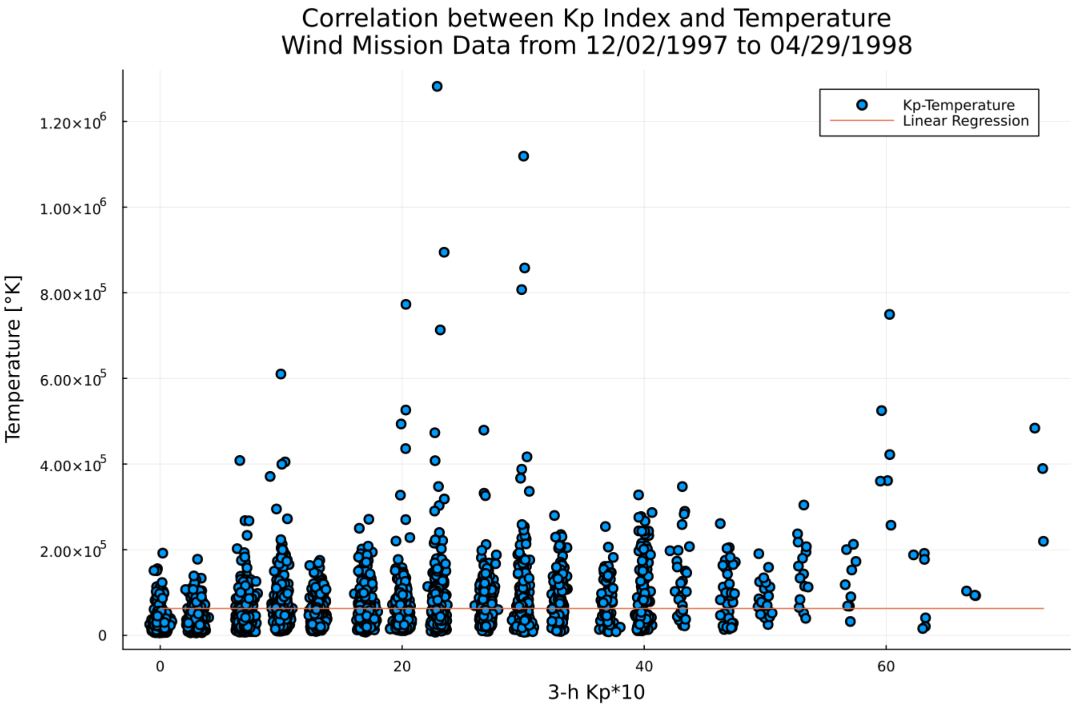

Figure 9: *Correlation between the Kp index and Temperature during the halo loop period of* `Wind`. *Figure made with the Julia script available on the Github*

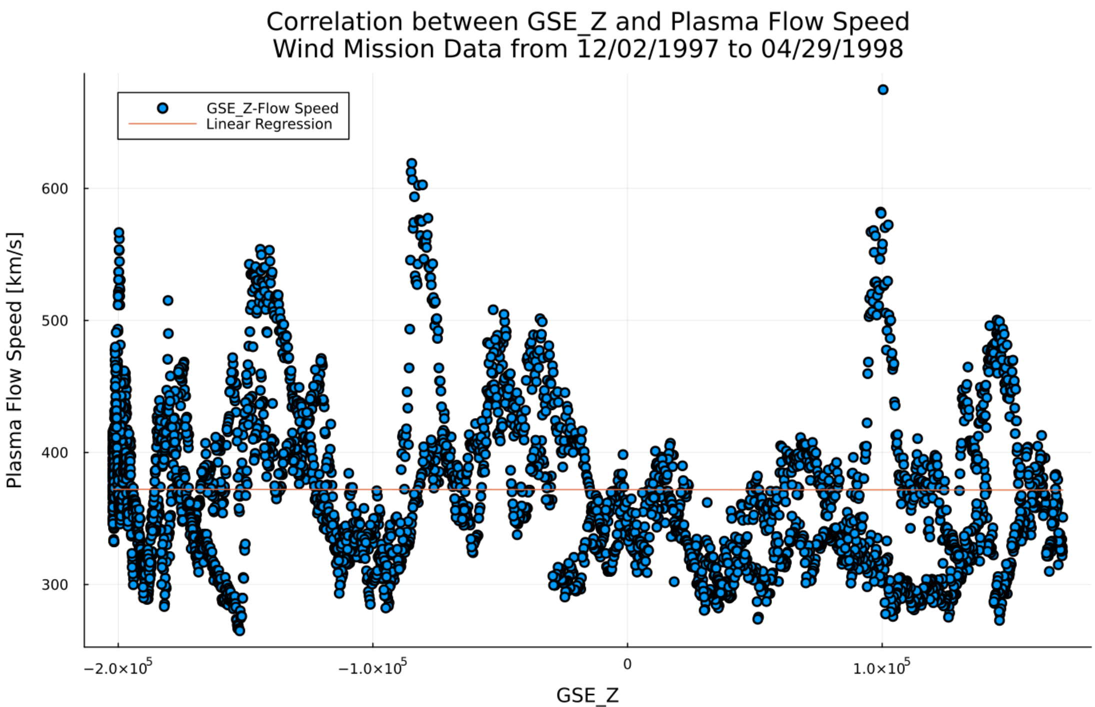

Figure 10: *Correlation between the GSE_Z orbital component and Plasma flow speed during the halo loop period of* `Wind`. *Figure made with the Julia script available on the Github*