An Investigation Into Magnetic Structures in The Solar Wind Plasma Using *Ulysses* Data

Student PI: Jack McDonald

Faculty Advisor: M. Anthony Reynolds, Ph.D.

Abstract

The solar environment has long been studied from Earth by the likes of Richard Carrington and company. Since the dawn of the space age, spacecraft have been sent to space to learn more about the solar wind. The European Space Agency's (ESA) *Ulysses* spacecraft, launched in 1990, was designed to observe the sun from a polar vantage point. With the instruments on board, *Ulysses* gave space and plasma physicists a unique opportunity to study the plasma around the sun. We have developed search algorithms to detect shocks and solitons within the solar wind using data from *Ulysses*. The algorithms can detect a variety of structures in the solar wind and we show, in detail, three events worth further investigation. Applying these algorithms to the 19-year data set from *Ulysses* will likely reveal many more structures worthy of study.

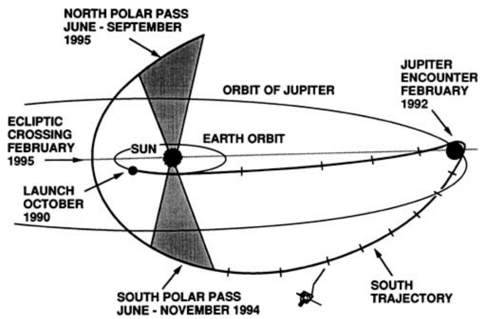

Figure 1: *Ulysses'* path from launch to it's first scientific orbit.[1]

Introduction

With ESA's Ulysses' data from a polar solar orbit vantage point, researchers have the ability to study new latitudes of the sun. Studying the solar wind at high latitudes allows for a deeper understanding of the solar environment and the sun itself. Specific structures, solitary waves, have been studied well in controlled settings in laboratories. Solitary waves, or solitons, are unique and definite structures that have exact solutions. In the future, it is intended that the events described in this investigation are further analyzed using rigorous mathematical methods. Using the ideal one fluid magnetohydrodynamics approximation, the most rudimentary approximation that can be used, the solar wind can be studied and analyzed to find useful results. The plasma β, Alfvén wave speed, and mass flux are all values calculated using the approximations and assumptions within this theory. The question in the solar wind plasma is where do certain structures come from? Only analyzing as much data as possible will allow for that question to be even remotely answered.

Background Methodology

In order to truly investigate magnetic structures within the solar wind there needs to be an understanding of certain aspects of high-level physics. This includes the one fluid magnetohydrodynamic approximation which assumes low frequency waves as well as infinite conductivity of a plasma.[2] It is only with this approximation that we can somewhat easily calculate values for different plasma characteristics

We also need to understand nonlinear second order differential wave equations. Or rather, we need to know the consequences of the Derivative Non-Linear Schrödinger (DNLS) equation.[3] Solitons described by the DNLS equation follow the characteristics of shorter, wider waves travel slower than taller, skinnier waves. Solitons are also two dimensional, meaning there is always one arbitrary component that does not vary.

Using the Ulysses Final Archive provided by the ESA, we are able to download all the data from the mission for free.[4] The instruments needed for this investigation are the magnetometer (VHM/FGM), the plasma data from the Solar Wind Plasma Investigation (SWOOPS), and of course, the spacecraft's telemetry data.

Results

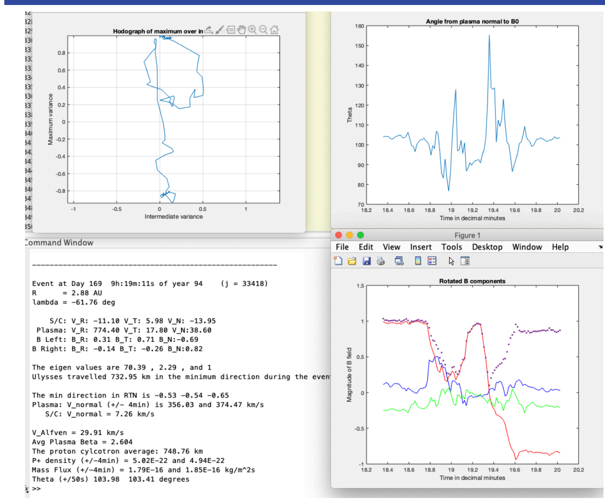

Figure 2: The first output from the code of a flagged event. This event is at Day 169 of 1994, 09:19:11 UTC. The top left graph is a hodograph, depicting the maximum and intermediate components. The top right is a plot of the angle of the magnetic field through the event. The bottom right depicts the magnetic field components rotated into the minimum variance direction.

Discussion

We have produced a fully functioning algorithm to search for such results in the future. Once the proper data is uploaded to the code, it can search through hours, days, or years to find the carefully chosen criteria specified by the user. In our search, we used the following criteria:

$$\frac{\mathbf{B}_i \cdot \mathbf{B}_f}{|B_i||B_f|} \leq \cos(\angle)$$

where B is the magnetic field, the *i* and *f* subscripts denote initial and final (with regards to the beginning or end of the search window of 30 seconds). The angle was usually chosen to be greater than 60 degrees, depending on how strict we wanted the results to be. This angle represents the total rotation of the magnetic field during the event. A two-dimensional wave, such as a soliton, always shows a rotation of the magnetic field as it passes the observation point.

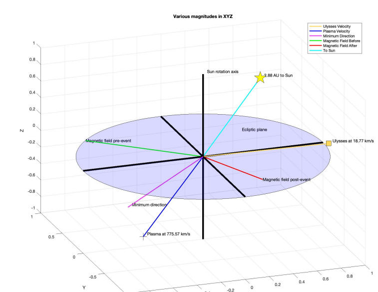

Figure 3: The second output by the code. This figure shows the vector directions of the values of interest. The blue shaded region represents a parallel plane with the ecliptic plane. The light blue line with a star at the end represents the direction to the sun. The green and red represent the direction of the magnetic field at the beginning and the end of the event. The pink is the minimum variance direction. The blue is the direction of the plasma velocity, and the gold is the direction of *Ulysses* velocity.

Conclusions

With the finished algorithm and three events found that are worthy of further study, there is more work to be done. However, we present the process of making an algorithm as well as independently verifying results from papers such as Tsurutani et al.[5] This algorithm can be of use for future researchers in the field using not only data from the Ulysses mission, but current solar orbiting spacecraft such as the National Aeronautics and Space Agency's (NASA) Parker Solar Probe and ESA's Solar Orbiter. There is a lot of data readily available online waiting to be analyzed, and this algorithm does everything needed to get results worthy of study.

Contact

Jack McDonald

Bachelor of Science, Astronomy and Astrophysics, 4th Year

Embry-Riddle Aeronautical University

mcdonj27@my.erau.edu

References

1. Page D.E. (1997), *Ulysses mission. In: Encyclopedia of Planetary Science.* Encyclopedia of Earth Science. Springer, Dordrecht. https://doi.org/10.1007/1-4020- 4520-4 423
2. Fried, Burton. D. (1988), *Modern Plasma Theory*, unpublished lecture notes.
3. Kasman, A. (2010), *Glimpses at Soliton Theory: The Algebra and Geometry of Nonlinear PDE's*, American Mathematical Society.
4. European Space Agency (n.d.) Ulysses Final Archive, http://ufa.esac.esa.int/ufa/
5. Tsurutani, B. T., et al. (1992) *Nonlinear Magnetosonic Waves and Mirror Mode Structures In The March 1991 Ulysses Interplanetary Event*, Geophysical Research Letters, Vol. 19, No. 12, Pages 1267-1270