Theses of the dissertation titled

LONG-TERM RECURRENCES IN THE HELIOSPHERIC MAGNETIC FIELD

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Budapest
2019

Introduction

My research interests lie in the field of space weather: all processes taking place in interplanetary space that affect our life on Earth, either directly or indirectly through our space based satellites. One of the main actors of space weather is the solar wind: a constant outflow of magnetic plasma released with supersonic speed and changing intensity from the solar corona. The solar wind represents mass, energy and impulse, a part of which can be transferred to the Earth's magnetosphere by different processes. The interaction of solar wind plasma with the Earth results among others in the aurora and geomagnetic currents, but the increased dynamic pressure can cause geomagnetic storms as well. Increased energetic particle flux can severely damage our satellites.

My research activities are limited to background solar wind, consisting of slow and fast solar wind streams. I have investigated their interaction regions, the role of different parameters in propagation effects and recurring variations. An important result of the last century was that the radial magnetic flux is independent from the ecliptic latitude. The discovery was made by the Ulysses mission emerging by 80° from the ecliptic, and it was explained by the super radial expansion of magnetic field lines. The question I am answering in the doctoral thesis is whether there are any longitudinal recurrences in the interplanetary magnetic field. If yes, they will have a serious impact on space weather research, because they are perceived on Earth as recurring features and can easily be forecast.

Objectives

Summarising my work I have answered the following questions:

- Are there any longitudinal recurrences in the heliospheric magnetic flux density?

- In case there are, what process forms them? Do they contradict the theory of super-radial expansion of magnetic field lines?
- Do the identified structures (in the radial component of the heliospheric magnetic filed flux density) belong to one and the same source throughout their existence?
- Do they have specific features?
- How are they perceived in the datasets of different solar wind parameters?
- How can the newly coded solar wind propagation model be used in space weather research at different points in the heliosphere?

Analysing the recurrent features along the steps described above contributes to the reliability of space weather forecasts and solar research.

Methods

I have investigated different solar wind parameters (among others magnetic field, solar wind speed, solar wind density) for the past 50 years based on the OMNI dataset operated and maintained by NASA (National Aeronautics and Space Administration) Goddard Space Flight Center. I was searching for phenomena recurring with the solar rotation cycle on the long-term. I used mainly near-Earth spacecraft data, occasionally extending the dataset with other heliospheric space probes' measurements.

In order to compare the data measured at different points in space, and to define their source of origin in the corona, I developed a kinematic solar wind propagation model. The magnetic lasso model propagates solar wind measurements from the point of measurement to any other point in the inner heliosphere. It is a target-based model that can handle stream-stream interactions based on the different dynamic pressure of the streams.

Theses

Thesis 1.

The self-coded magnetic lasso solar wind propagation model is a target-based kinematic model. The model focuses on the target and aims to identify the magnetic field line that connects the target with the Sun. After investigating the possible field lines in the target's close environment (taking into account possible stream-stream interactions), the field line that reaches the target closest is selected, and solar wind parameters are propagated along the field line (*Dósa, 2018*).

Thesis 2.

The magnetic lasso propagation model performs well if compared with 1-dimensional magneto-hydrodynamic models. Solar wind data measured near Earth and *propagated* to Mars by different models were compared with measurements made near Mars by the Mars Express spacecraft. The correlation between measured and propagated data was very similar for the kinematic magnetic lasso model and for 1D MHD models.

Thesis 3.

The magnetic lasso model was used to propagate solar wind parameters to the comet CG/67P. Knowing the solar wind velocity and density data, one can estimate solar wind dynamic pressure and interpret processes taking place in the close environment of the comet (*Volwerk, 2016, Timár 2017 és 2019*).

Thesis 4.

Significant recurrent enhancements of the magnetic flux was observed during the declining phase of the 23rd solar cycle, lasting for 4-5 years. Corotating interaction regions (CIR) existing for such a long period have never before been observed. A further analysis of the structures was necessary (*Dósa, 2017*).

Thesis 5.

Investigating two further parameters (coronal temperature and the deviation of the velocity vector from the radial direction) I have proved that these structures are CIRs. This was supported by comparing near Earth magnetic flux measurements with measurements carried out closer to the Sun by the MESSENGER spacecraft. The results show that the structures of enhanced magnetic flux are less pronounced, or non-existent close the the Sun and develop radially as solar wind propagates (*Dósa, 2017*).

Thesis 6.

I have investigated the origin of the long-term recurrent features and came to the conclusion that although they seem to be one feature, they do not have the same source throughout their existence. This means that they are set together by different CIRs. The fast solar wind that caused each CIR to develop stems from a different coronal hole. Thus the structures do not have a lifetime of 4-5 years, but much less. This result poses the question, whether the active longitudes observed on the photosphere show the same trends as these seemingly active longitudes in interplanetary space?

First reactions to the published paper show that these results are of importance to solar physicists as well (*Lockwood, 2017*).

Publication in the scope of the thesis:

- Dósa, M., G. Erdős., 2017, Long-term longitudinal recurrences of the open magnetic flux density in the heliosphere, *Astrophysical Journal*, Vol 838, 104
- Dósa, M., Opitz. A., Dálya, Z., Szegő, K., 2018, Magnetic lasso: a new kinematic solar wind propagation method, *Solar Physics*, 293:127

- Volwerk, M., et al, including: Dósa, M., 2016, Mass-loading, pile-up, and mirror-mode waves at comet 67P/Churyumov-Gerasimenko, *Annales Geophysicae*, 34, 1-15.
- Timar, A., Nemeth, Z., Szego, K., Dósa, M., Opitz, A., Madanian, H., Goetz, C., Richter, I., 2017, Modelling the size of the very dynamic diamagnetic cavity of comet 67P/Churyumov-Gerasimenko, *MNRAS*, Volume 469, Issue Suppl_2, 21 July 2017, Pages S723–S730
- Timar A., Nemeth Z., Szego K., Dósa M., Opitz A., and Madanian H., 2019, Estimating the solar wind pressure at comet 67P from Rosetta magnetic field measurements, *Journal of Space Weather and Space Climate*, vol. 9 Paper: A3, 11p.

Further publications:

- Hettrich et al, including: Dósa, M., 2015, Atmospheric Drag, Occultation 'N' Ionospheric Scintillation (ADONIS) mission proposal, *Journal for Space Weather and Space Climate*, 5, A2