Automatic detection of magnetopause and bow shock crossing signatures in MESSENGER magnetometer data

Alexander Lavrukhin (1), David Parunakian (1), Dmitry Nevskiy (1,2), Ute Amerstorfer (3), Andreas Windisch (4), Sahib Julka (5), Christian Möstl (3), Martin Reiss(3), Rachel Bailey (3), Michael Granitzer (5) and Johannes Hoffer (4).

1. M.V.Lomonosov Moscow State University, Skobeltsyn Institute of Nuclear Physics (SINP MSU), Moscow, Russia (lavrukhin@physics.msu.ru)
2. Faculty of Physics, M.V.Lomonosov Moscow State University, Moscow, Russia
3. Space Research Institute, Austrian Academy of Sciences, Graz, Austria
4. KNOW-CENTER GmbH, Graz, Austria
5. University of Passau, Passau, Germany

Abstract

The magnetosphere of Mercury is rather small and highly dynamic, due to its weak internal magnetic field and its close proximity to the Sun. The changing solar wind conditions principally determine the locations of both the Hermean bow shock and magnetopause. In 2011 – 2015 MESSENGER spacecraft completed more than 4000 orbits around Mercury, thus giving a data of more than 8000 crossings of bow shock and magnetopause of the planet. This makes it possible to study in detail the bow shock, the magnetopause and the magnetosheath structures.

In this work, we determine crossings of the bow shock and the magnetopause of Mercury by applying machine learning methods to the MESSENGER magnetometer data. We try to identify the crossings for the complete orbital mission and model the average three-dimensional shape of these boundaries depending on the external interplanetary magnetic field (IMF). Further, we try to clarify the dependence of the two boundary locations on the heliocentric distance of Mercury and on the solar activity cycle phase. Also, we study the effect of the IMF partial penetration into the Hermean magnetosphere. The results are compared with the obtained previously in other works.

This work may be of interest for future Mercury research related to the BepiColombo spacecraft mission, which will enter the orbit around the planet at December 2025.

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Bow shock

Quasi-perpendicular bow shock generally includes an abrupt change in magnetic field strength, referred to as the shock ramp, preceded by the magnetic field's gradual rise - the foot. The field right at the ramp and behind it is higher than its eventual downstream value - this local maximum in magnetic field strength is called the overshoot. For quasi-parallel shock conditions, there is often little or no increase in the magnetic field magnitude and the boundary can only be marked by the onset of stronger variability in the magnetic field magnitude.

(on the right): Scheme illustrating the bow shock wave and magnetopause. An example interplanetary magnetic field orientation is shown in blue. Quasi-parallel and quasi-perpendicular regions of the shock surface are indicated (adapted from Masters et al., 2013).
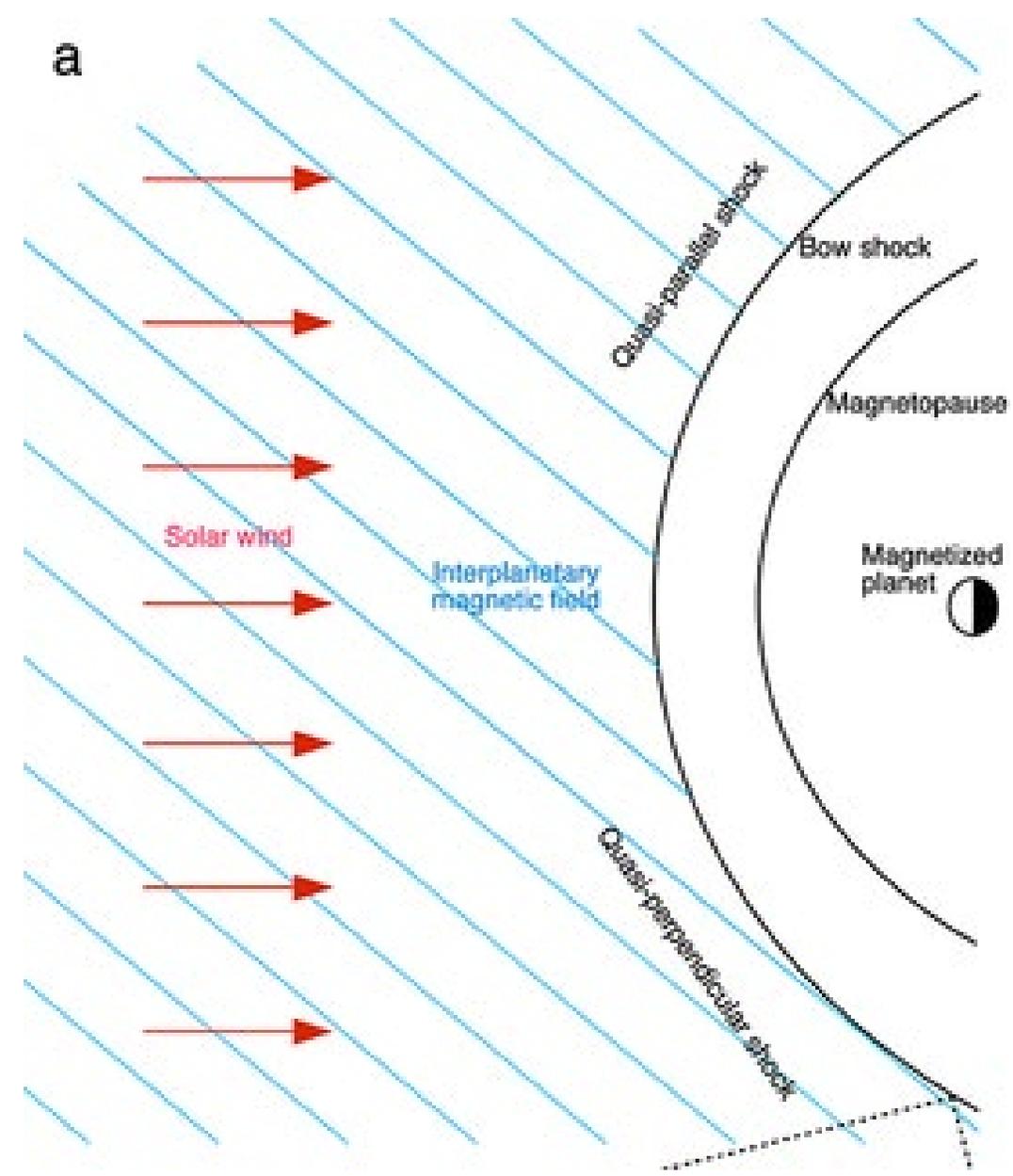
Magnetopause

Magnetopause crossings can be identified either by a rotation in the magnetic field direction (abrupt change of one of the components of the magnetic field), or by increase in variability just before the quiet region inside the magnetosphere.
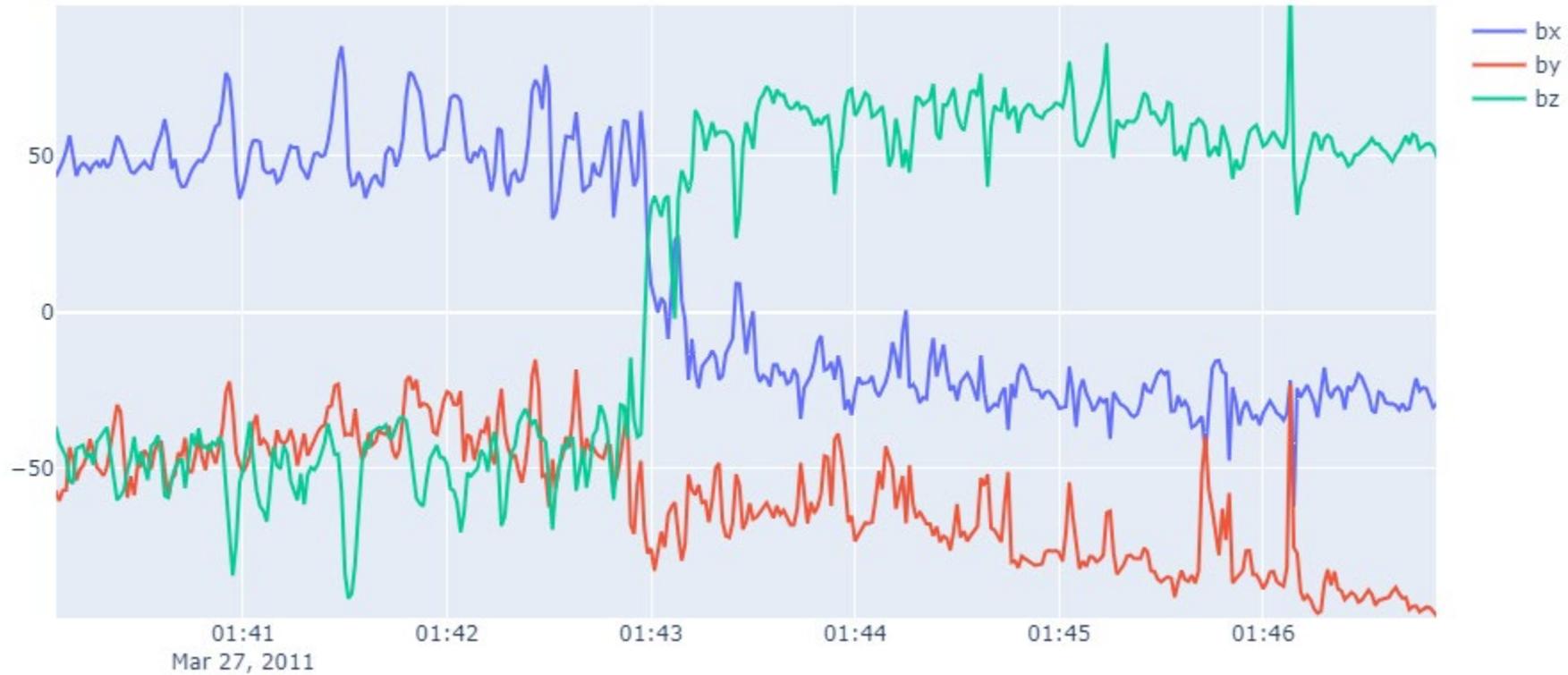
Labeling the data

We have thus labeled the times which were characterizing the beginning and the end of bow shock and magnetopause crossings. Sometimes there were several boundary crossings due to the changing solar wind conditions, in this case we have chosen the very first and the very last crossings of the boundary.

(on the right): One of MESSENGER orbits with labeled bow shock and magnetopause crossings. Top – magnetic field magnitude, bottom – magnetic field bx, by and bz components vs time. Black lines shows the outer/inner boundaries of the bow shock and magnetopause.
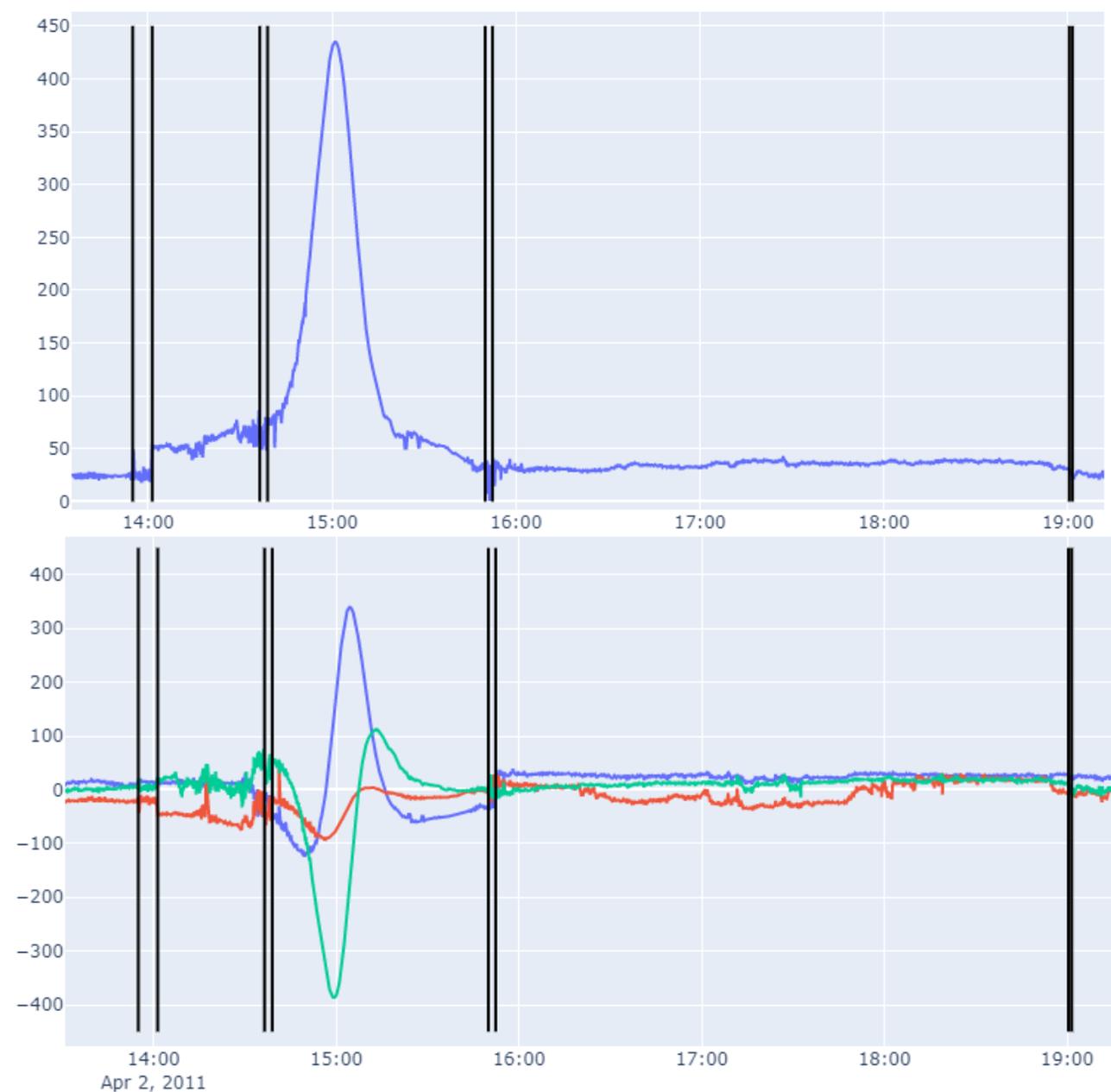
Preliminary results

To get the preliminary results for first 50 labeled orbits, we have used a simple 3 layer Convolutional neural network (CNN) with kernel size of 3 and shared weights across all channels.

Each layer activations are passed through batch normalisation and rectified linear activation functions. At the moment the classification of magnetopause and magnetosheath is a bit low, we expect using data from more orbits will improve that.

(on the right): a confusion matrix for classification, trained on the first 50 orbits, using a CNN.
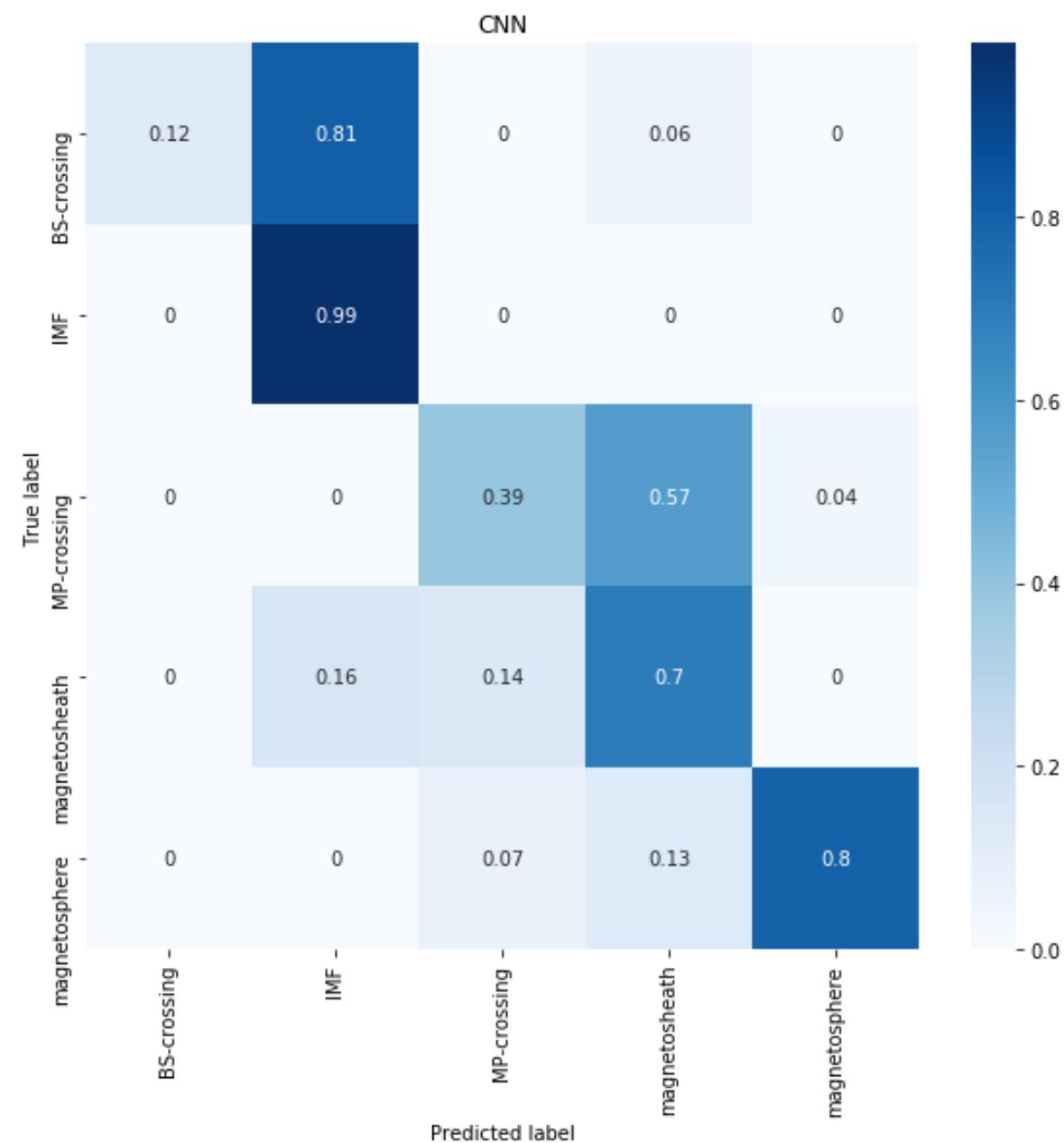
Discussion

We have labeled the bow shock and magnetopause crossings for the first 50 orbits completed by MESSENGER spacecraft. This data was used as a train set for the neural network (Convolutional neural network in our case).

The preliminary results show that the detection of the bow shock crossing is rather unreliable, but the magnetopause detection is better. Magnetosheath and magnetosphere regions were detected with high accuracy.

Our next steps will include usage of different models and increase of the labeled orbits number. We will compare the obtained results with the recent work by Philpott et al. (2020), where authors have identified magnetopause and bow shock crossings for the complete orbital mission. Further, we will model the average three-dimensional shape of these boundaries depending on the external interplanetary magnetic field (IMF).

Acknowledgements

References

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