# Determination of magnetopause and bow shock shape based on convolutional neural network modelling of MESSENGER data

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EUROPLANET SCIENCE CONGRESS EPSC2020

EPSC2021-651

# Abstract

The magnetosphere of Mercury is rather small and dynamic, due to the planet's weak internal magnetic field, its proximity to the Sun and a significantly eccentric orbit. The locations of both the Hermean bow shock and magnetopause are principally determined by changes in solar wind conditions. In 2011 – 2015 MESSENGER spacecraft completed more than 4000 orbits around Mercury, thus producing a dataset of over 8000 crossings of bow shock and magnetopause. 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 attempt to identify the crossings for the complete orbital mission and model the average three-dimensional shape of these boundaries. The results are compared with those obtained earlier 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 in December 2025.

# Bow shock

A quasi-perpendicular bow shock crossing generally is characterised by an abrupt change in the 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 bow shock crossing 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.

Fig. 1: Illustration of 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).

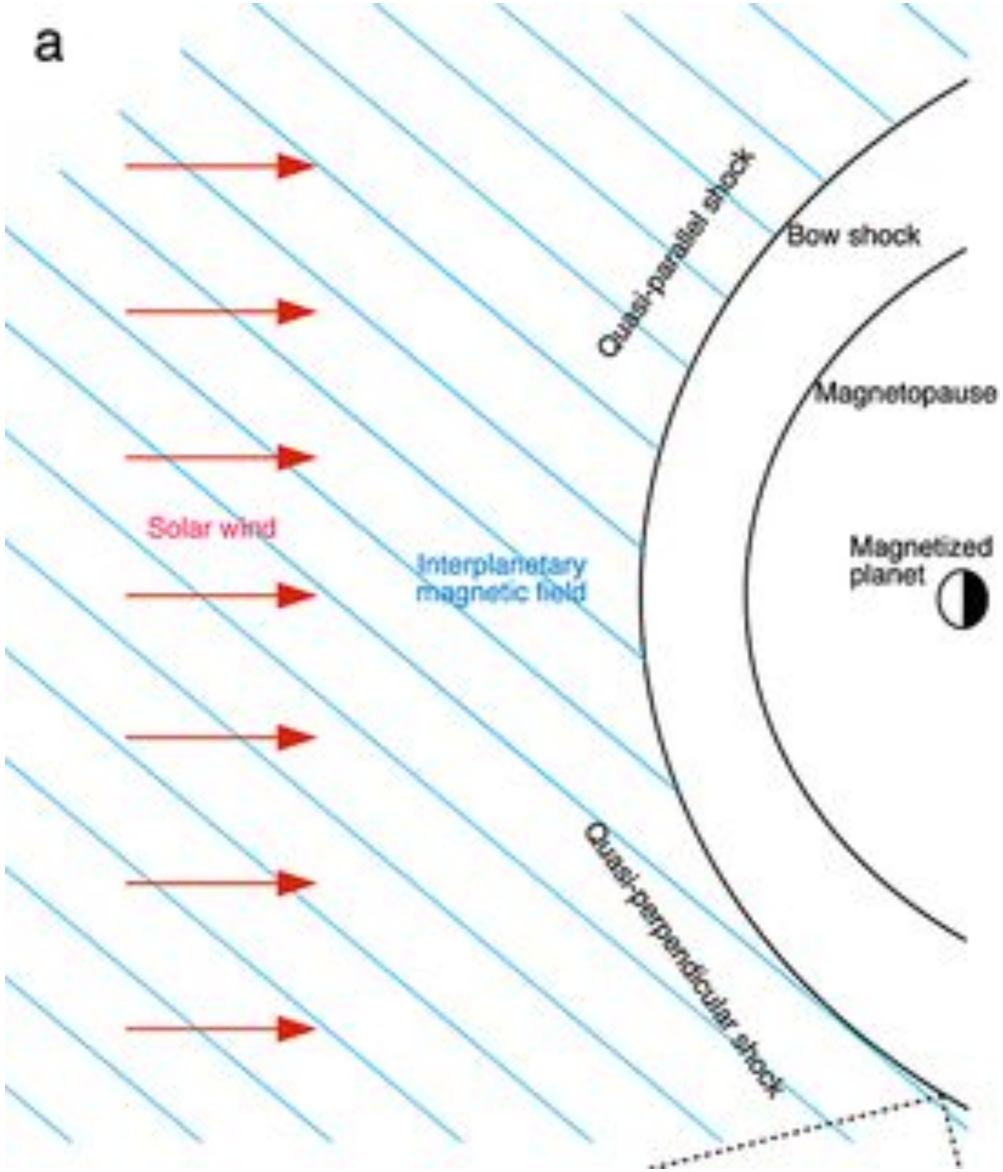
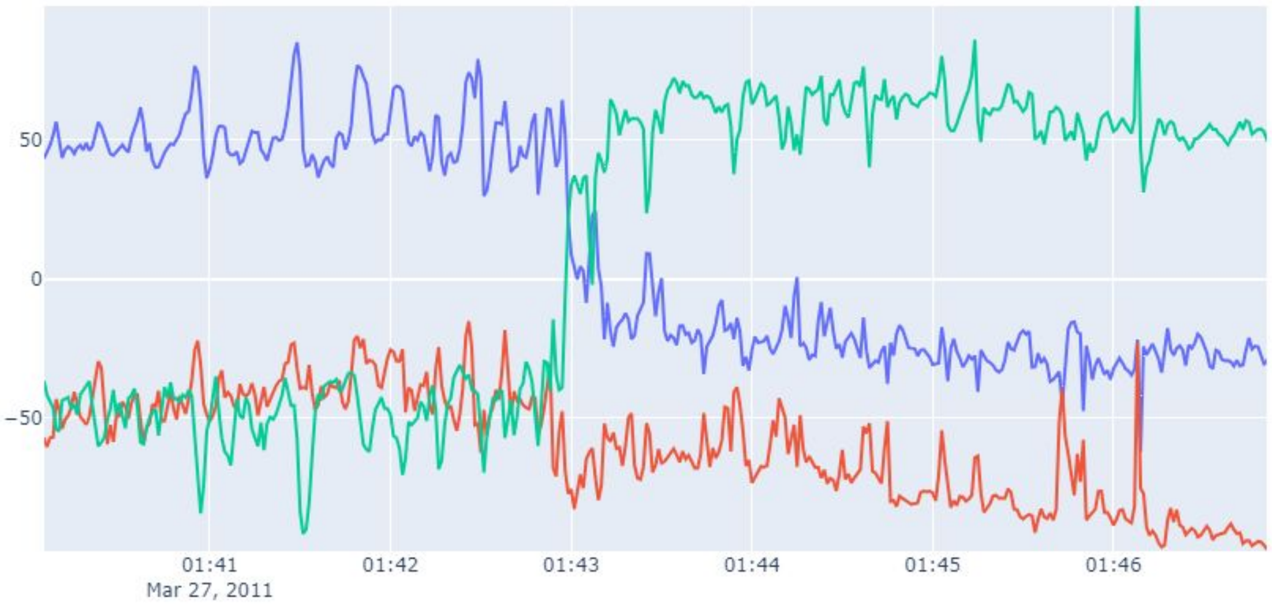



Fig.1

# 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 are using the timestamps characterizing the beginning and the end of bow shock and magnetopause crossings as labeled by Philpott et al. (2020). In many cases there are multiple 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.

Fig. 2 illustrates a time profile of magnetic field during one MESSENGER orbit with labeled bow shock and magnetopause crossings. Top – magnetic field magnitude, bottom – magnetic field Bx, By and Bz components. Black lines show the outer/inner boundaries of the bow shock and magnetopause.

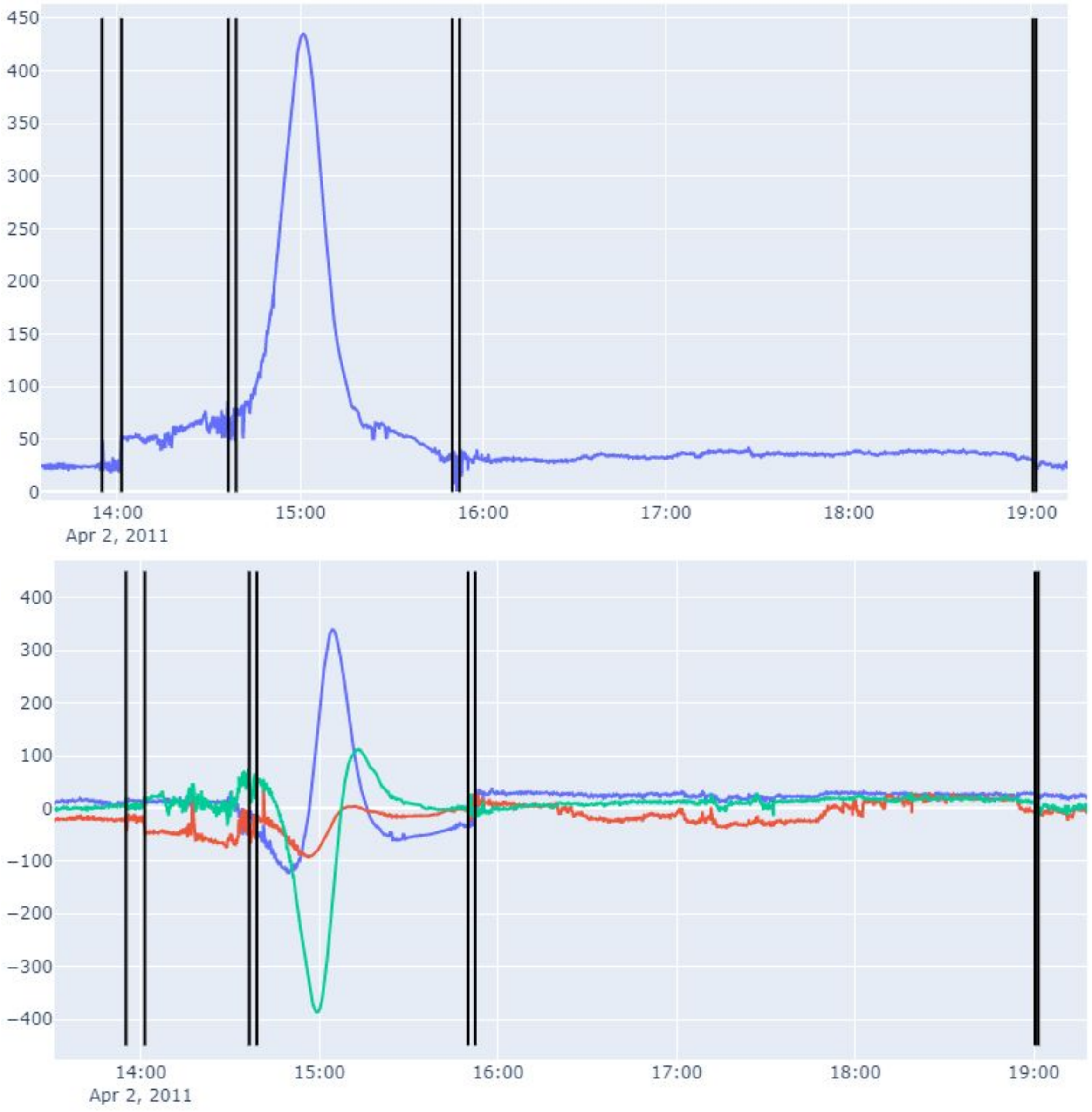



**Fig. 2**

# Preliminary results

To produce the currently available results we have built two distinct models. Predictions for orbits 1-3000 are produced with a model trained on a set randomly sampled from the first 784 orbits, and predictions for orbits 3000+ are produced using a training set of 500 orbits randomly sampled from the entire data set.

We use 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 (ReLu) functions before being passed to the final softmax layer.

Due to the imbalance in classes, the classification performance is biased; we expect that to improve with inclusion of data from other orbits and more sophisticated techniques.

Fig. 3 shows the confusion matrix for the classification performed on the dataset described above.

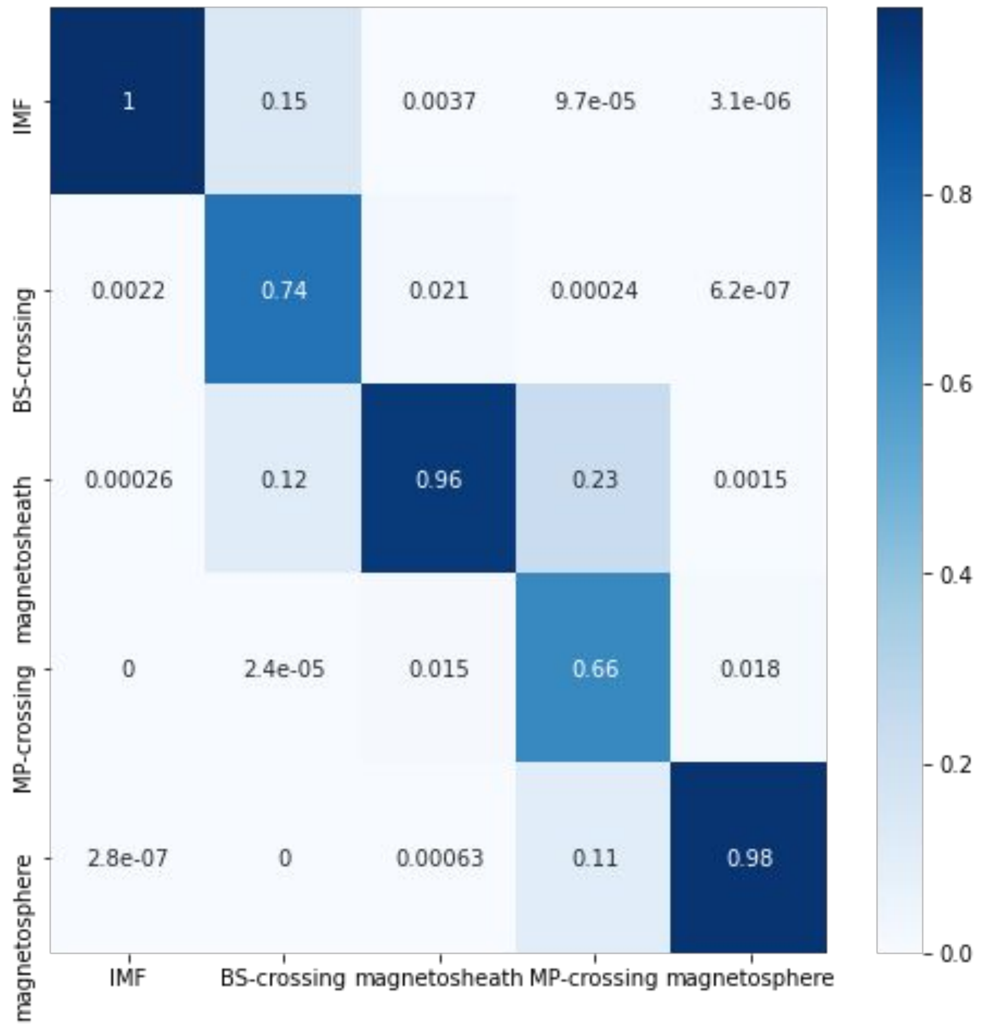
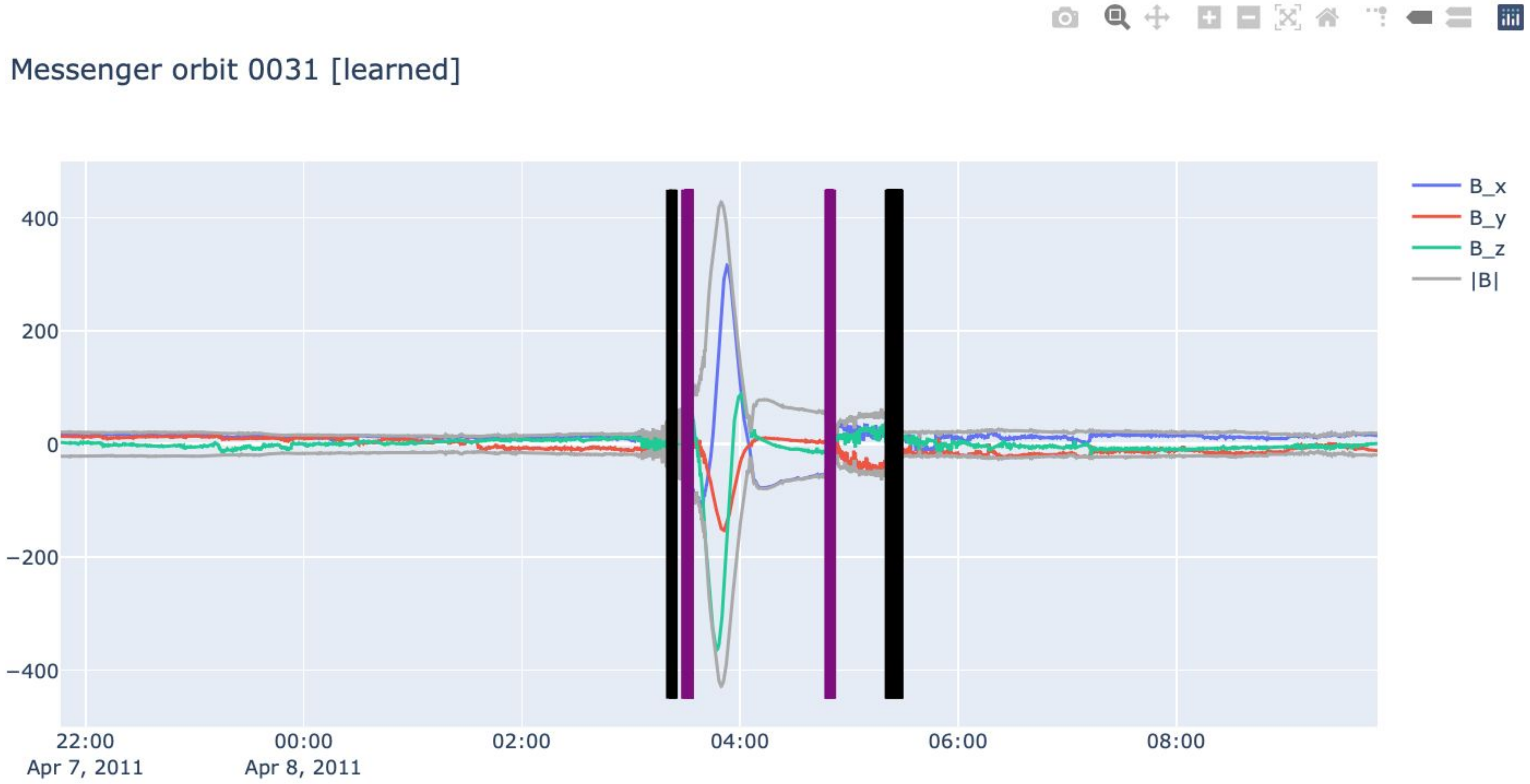



**Fig. 3**

# Preliminary results



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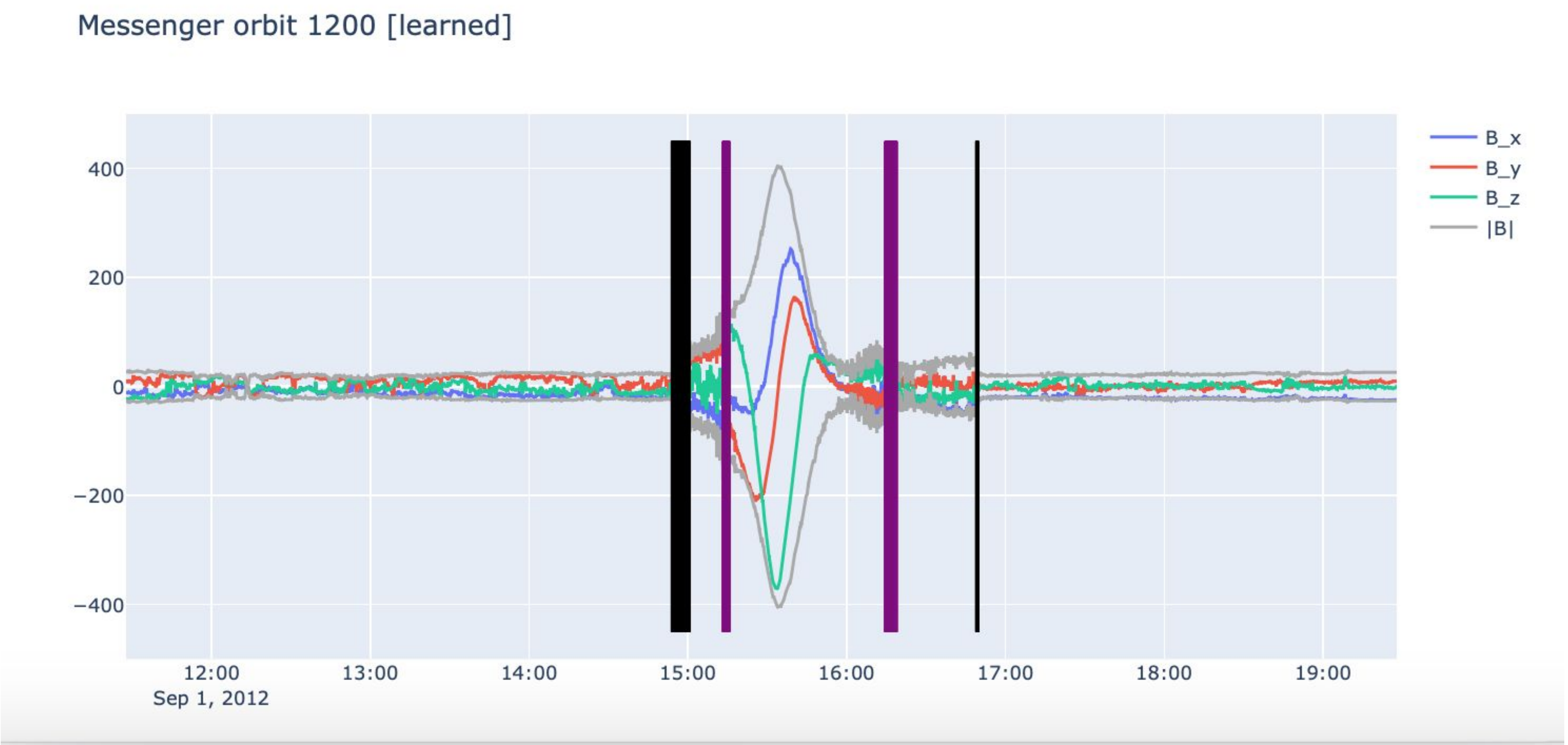

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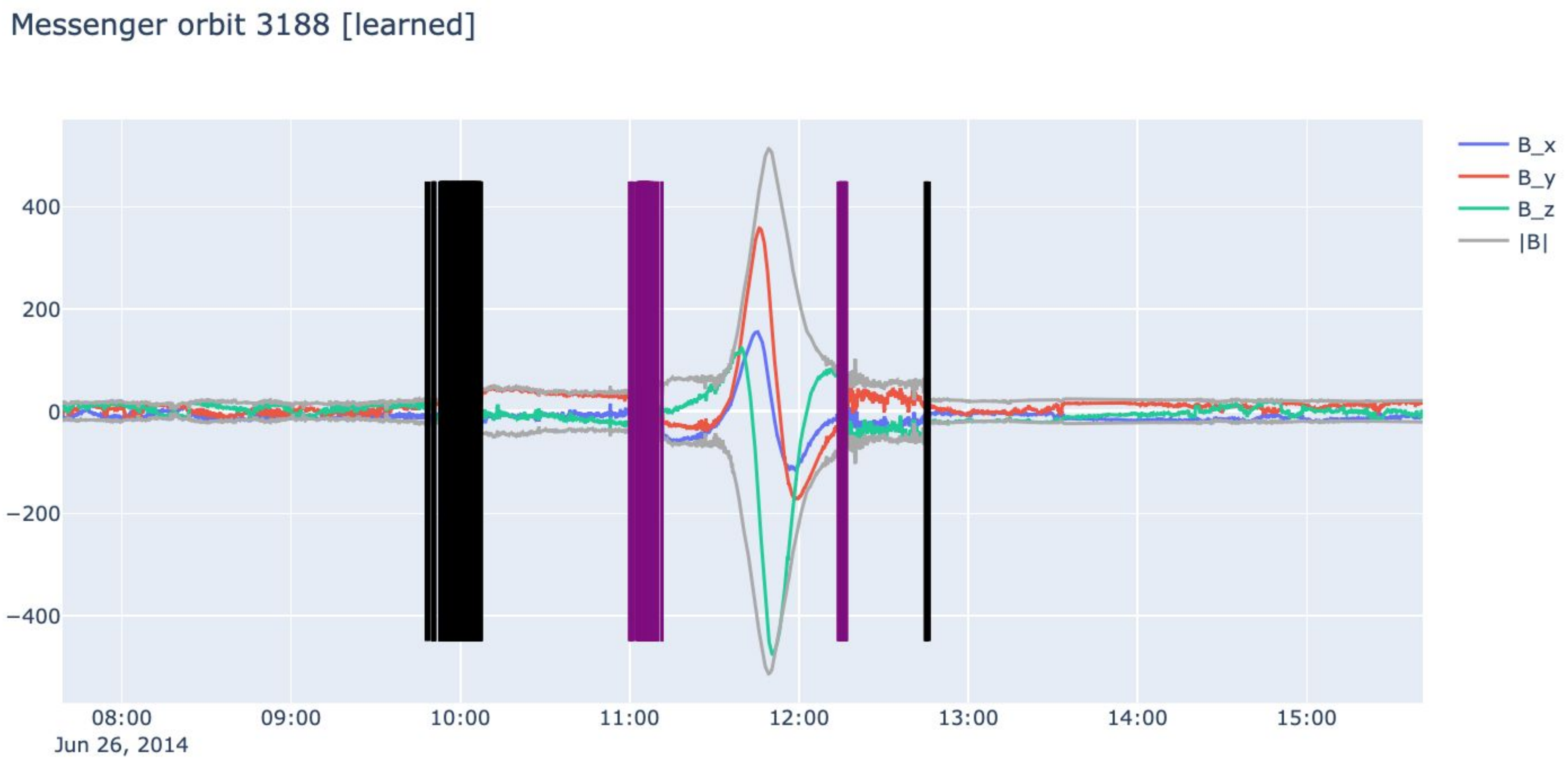

# Conclusions

We have prepared the bow shock and magnetopause crossings location for the total dataset obtained by MESSENGER magnetometer. This data was used as a training and testing set for a convolutional neural network.

We have used the trained CNN to find labels for all orbits. Our next steps will include post-processing, further model improvement and shape analysis. 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 dynamics of three-dimensional shape of these boundaries depending on the external interplanetary magnetic field (IMF).

We also intend to apply these results to data that will be obtained during the upcoming Mercury flyby by the BepiColombo mission in October 2021.

# Acknowledgements

This research work is carried out within the Europlanet 2024 Research Infrastructure, which has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 871149

The work was supported by the RFBR grant No 21-52-12025.

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