Can Machine Learning solve the „Bz Problem“ in solar coronal mass ejections?

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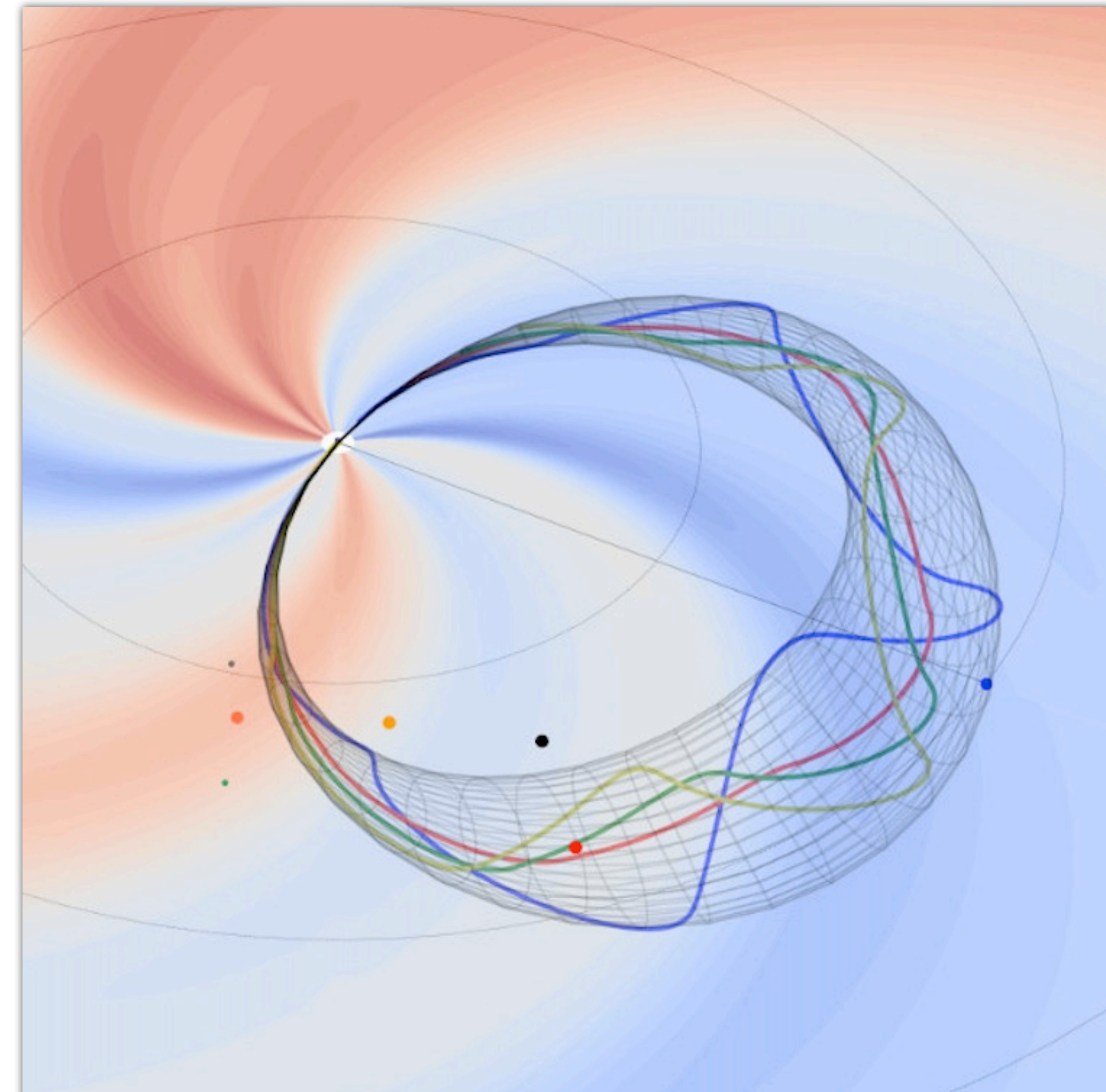

credit: C. Möstl, A. Weiss, and M.A. Reiss

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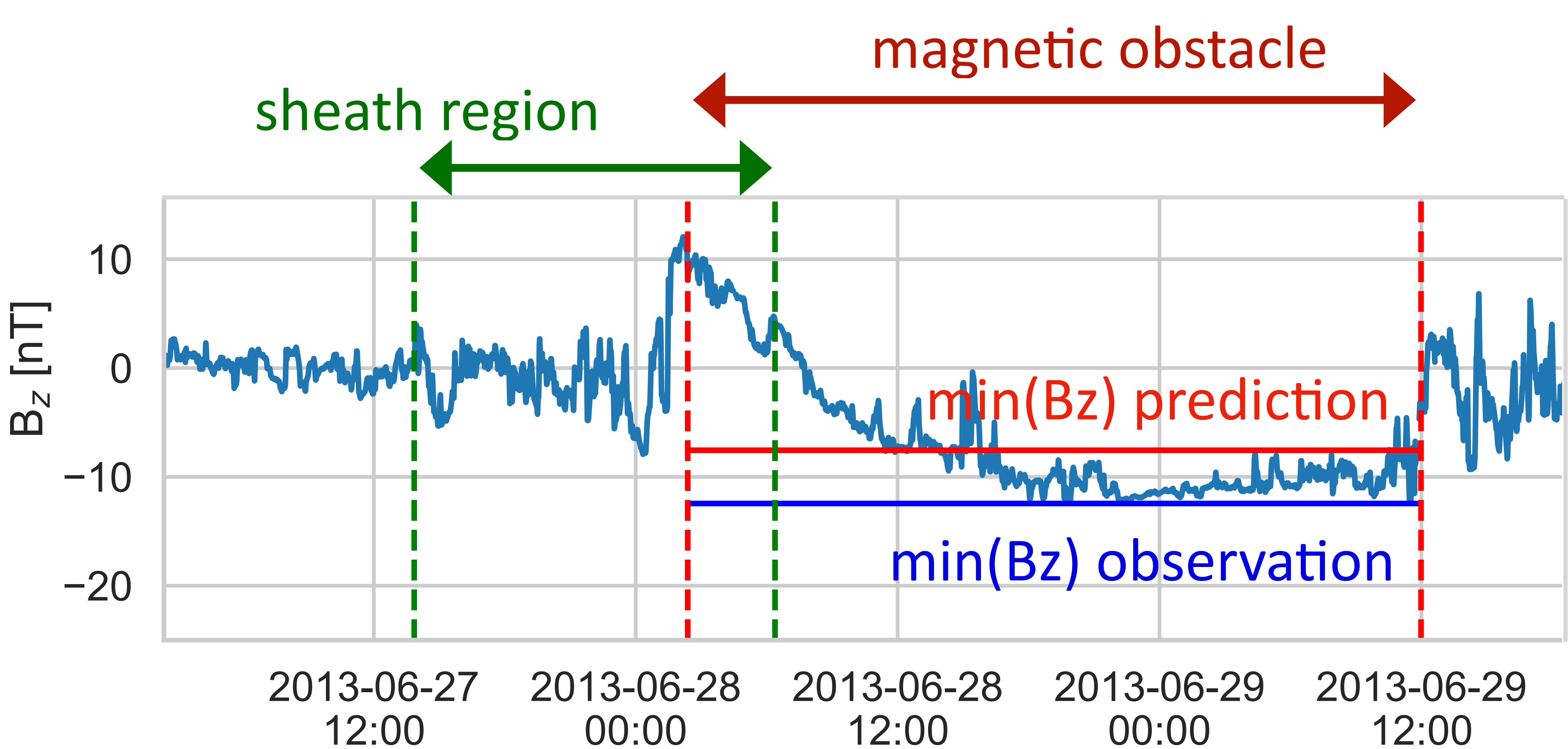
We study if upstream in situ measurements are useful for predicting estimates of the Bz component in ICMEs before they arrive at Earth

Overview - Predictive Bz Tool



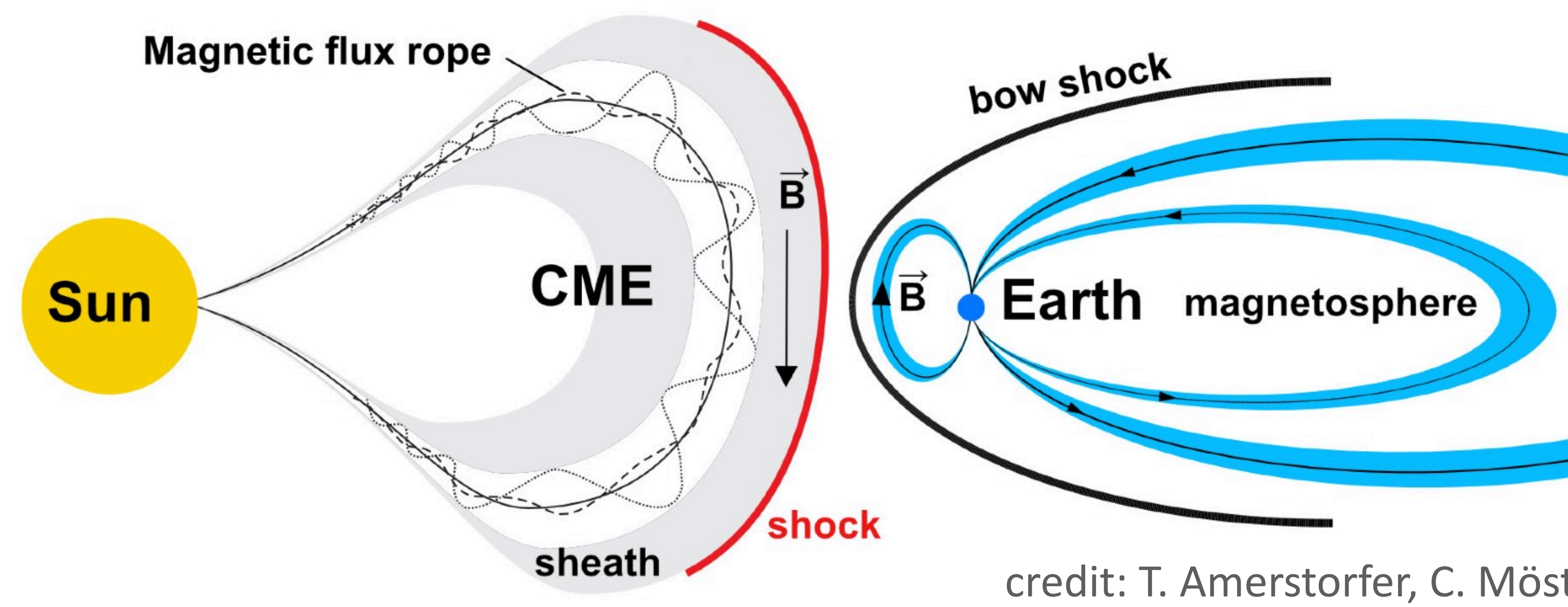
Reiss et al., 2021b

Content

1. Why does accurate Bz prediction in ICMEs matter?
2. What's the research question and how does the predictive tool work?
3. What are the results?
4. What are the lessons learned and future objectives?

Why does accurate Bz prediction in ICMEs matter?

- Energy input into the Earth's magnetosphere is largely determined by the Bz component of the IMF
- The **Bz problem** refers to the lack of Bz forecasting capabilities
- The **Bz problem** is most challenging during ICMEs when accurate Bz predictions are needed most
- Progress is hindered by observational limitations (Vourlidas et al. 2019)
- Without a definitive physical solution, it is worthwhile to study predictive tools (Chen et al., 1996, 1997; Riley et al., 2017; Owens et al., 2017; Salman et al., 2018)



credit: T. Amerstorfer, C. Möstl

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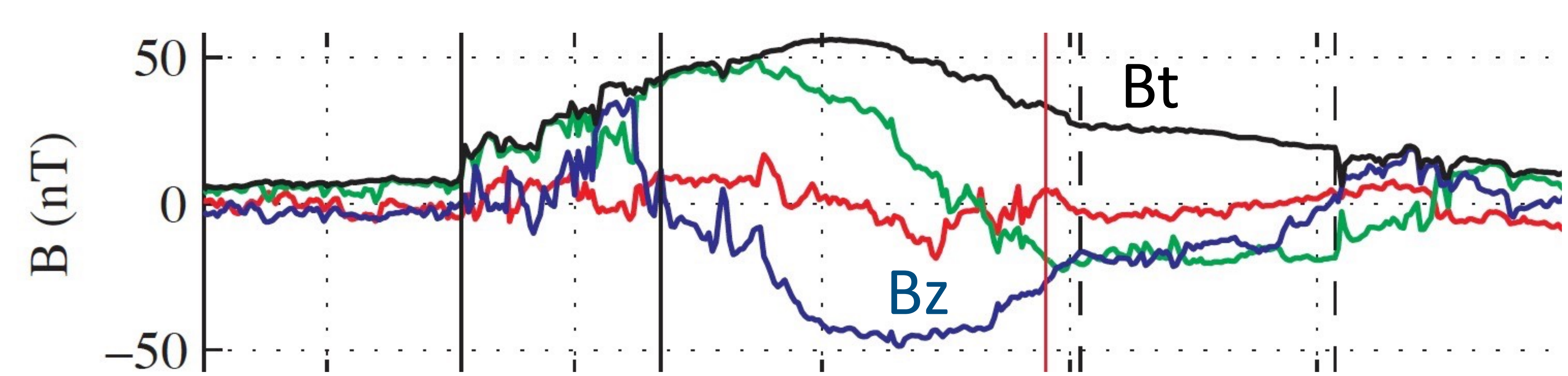


Möstl et al., 2008

What’s the research question and how does the predictive tool work?

Research Question

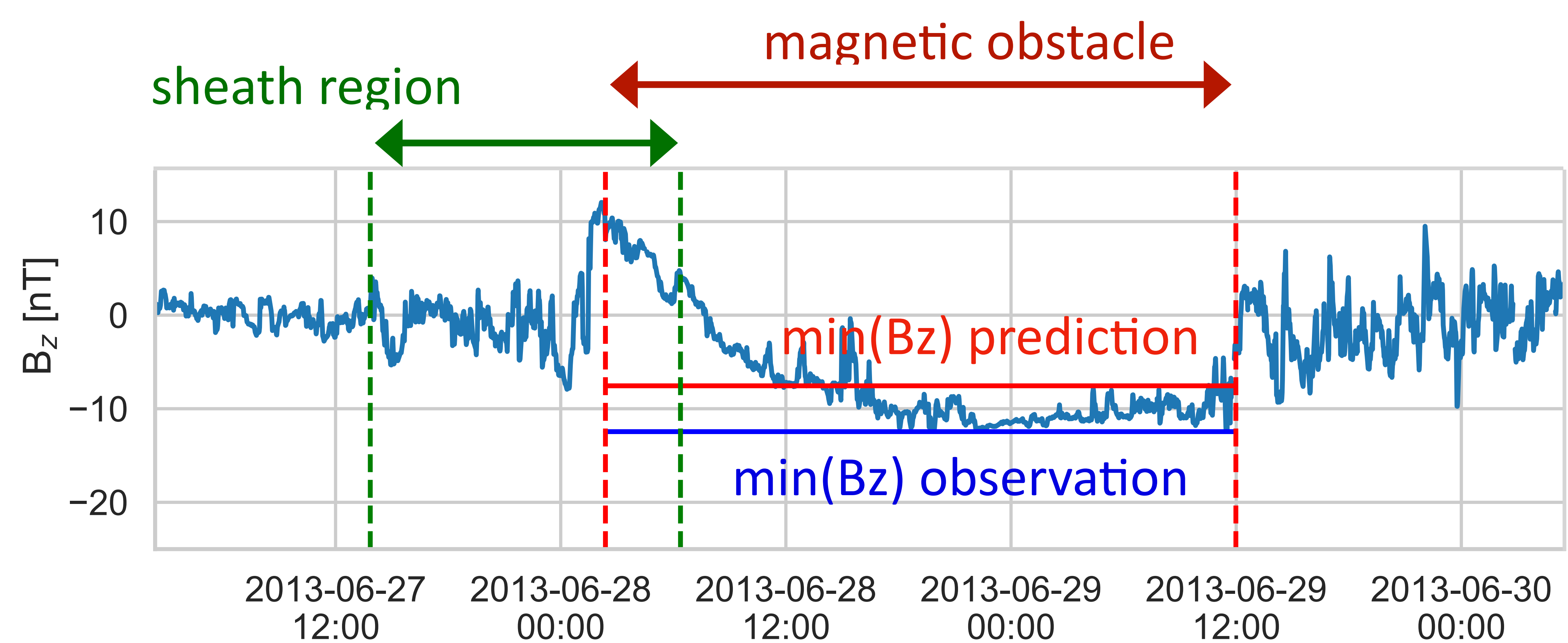
- We study if upstream in situ measurements of the sheath region and the first few hours of the magnetic obstacle are sufficient to predict estimates of the Bz component in ICMEs

Proposed Tool

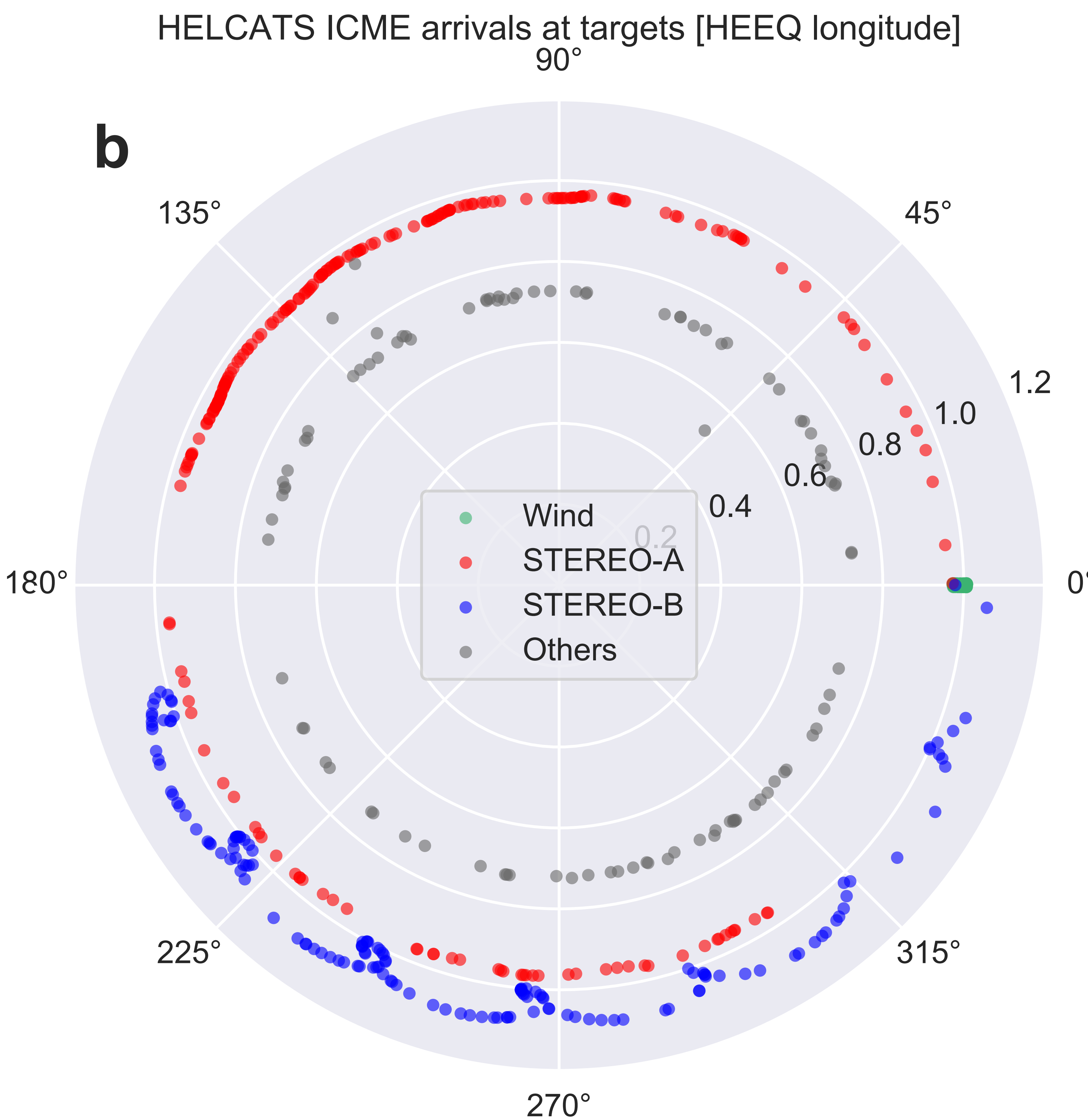
- To do so, we develop a predictive Bz tool based on machine learning that is trained and tested on 348 ICMEs from Wind, STEREO-A, and STEREO-B measurements (2007 to 2021)

Tool Components

1. Data Input
2. Feature Extraction
3. Machine Learning



To develop the predictive tool we use the Helio4Cast ICME catalog



Key Points

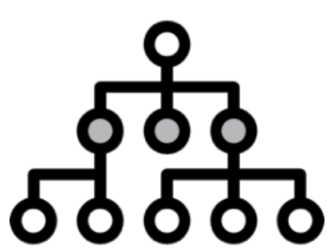
- ICME catalog includes events observed from 2007 to 2021
- Lists physical properties from WIND, STEREO-A, and STEREO-B measured close to 1 AU
- Living ICME catalog consists of manually added events (Möstl et al., 2020)
- From this ICME catalog, we select **348 ICMEs** with a clear magnetic obstacle signature
- Catalog open-access at https://helioforecast.space/icmecat

How does the predictive tool work?

Input:
42 features
and 2 targets

1. **Data Input (Features and Targets)**
   Study physical properties of 348 ICMEs from the ICME catalog including magnetic field data, plasma density and temperature

2. **Feature Extraction**
   For 7 different physical properties, we compute 6 statistical measures, which results in 42 features

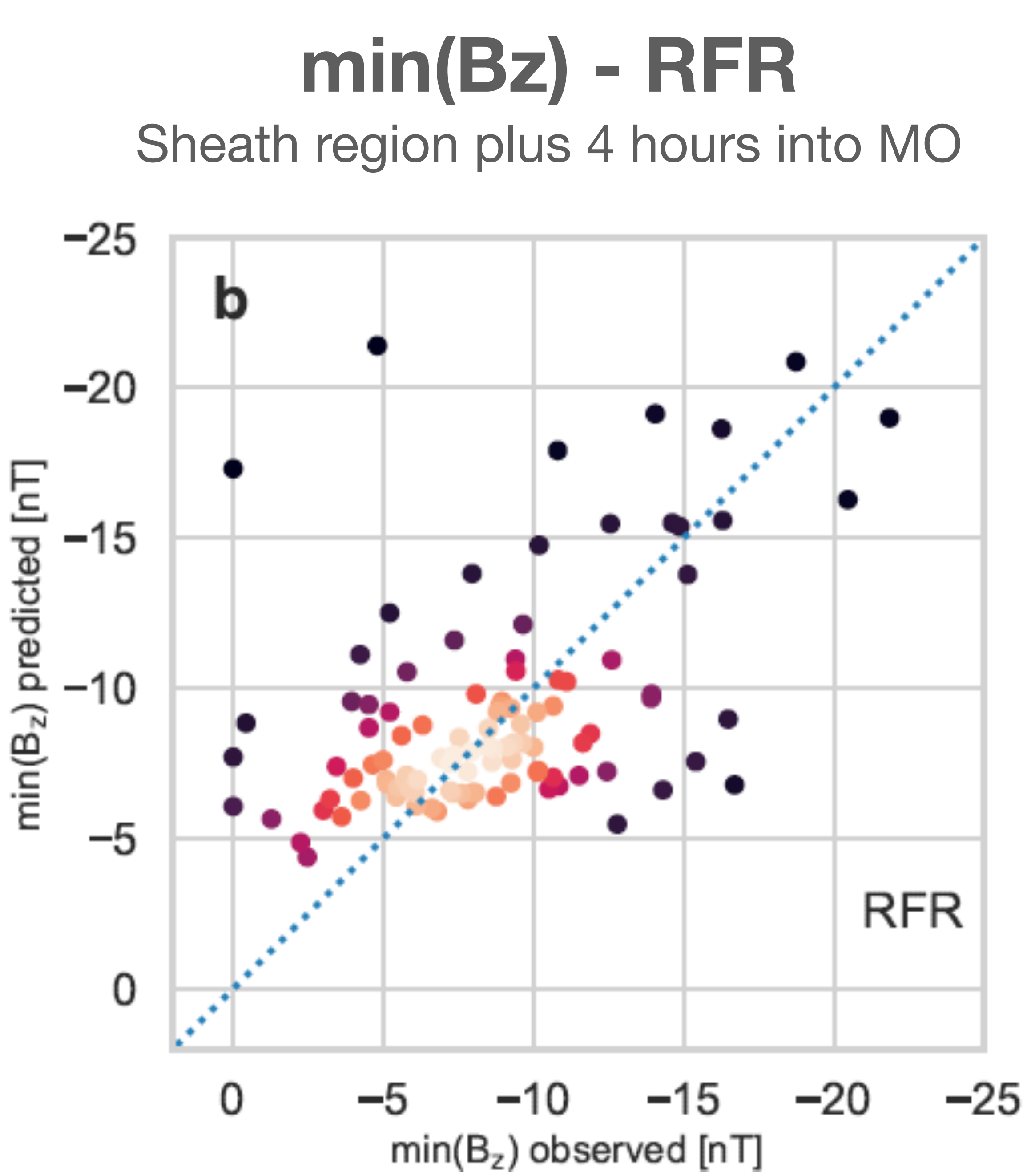


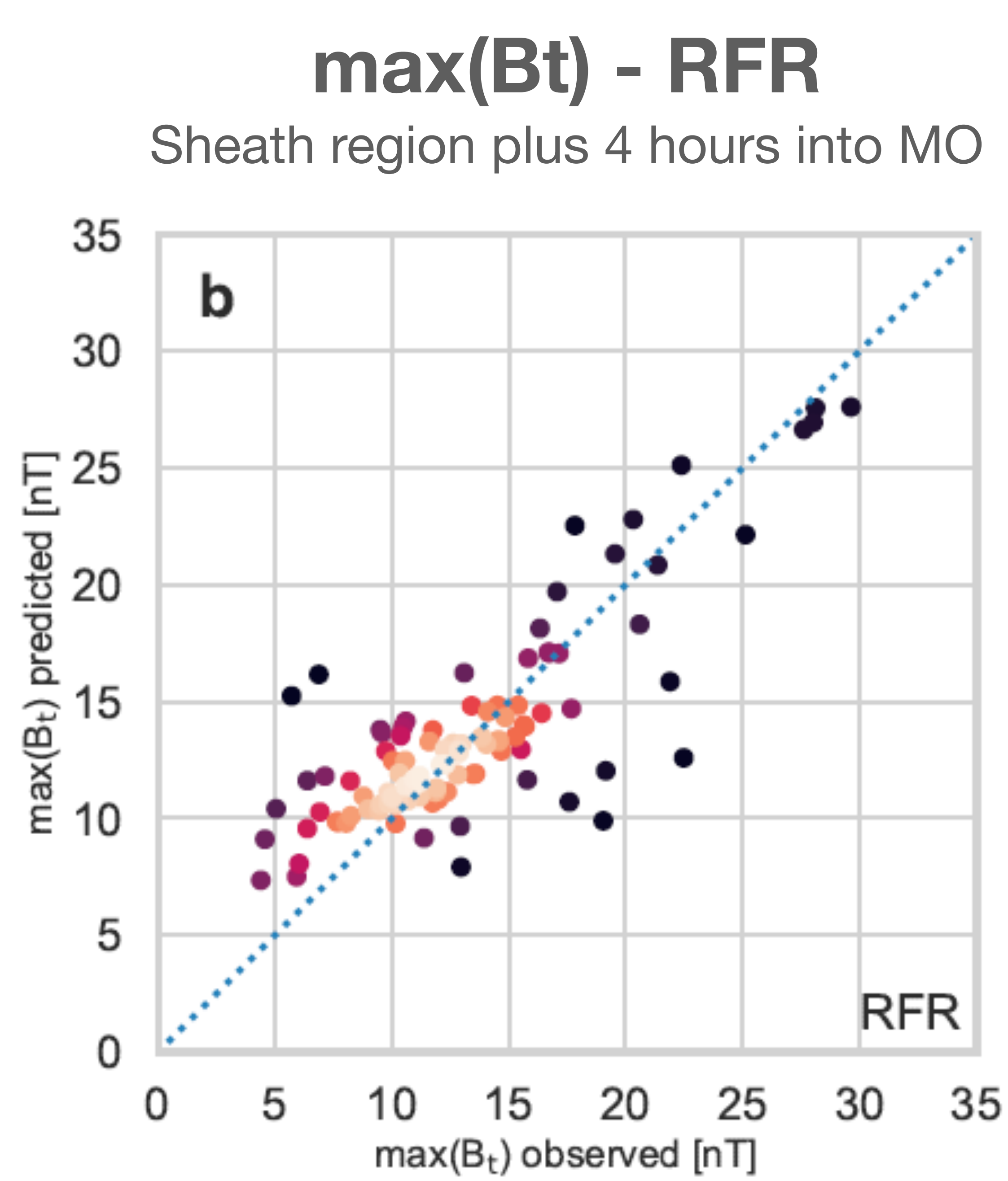
3. **Machine Learning Algorithms**
   Use Linear regressor (LR), random forest regressor (RFR), and gradient boosting regressor (GBR) from the Python package Scikit-Learn

Training and Testing:
Split the data into 70% training and 30% testing, where the test set is not used in training. During the training, we use a 5-fold cross validation and apply early stopping

Output:
min(Bz)
max(Bt)

What are the results?





Error Measures

min(Bz)	RMSE [nT]	Corr. Coeff R
GBR	4.77	0.71
RFR	4.73	0.70
LR	11.97	0.32
NN	5.03	

max(Bt)	RMSE [nT]	Corr. Coeff R
GBR	3.20	0.91
RFR	3.79	0.88
LR	9.48	0.54

Data and figures from Reiss et al., 2021b

What are the lessons learned?

- min(Bz) and max(Bt) predictions are considerably easier than predicting the Bz time series
- The question of how well we can extrapolate the predictive Bz skill to operations remains
- Applying the predictive tool in operations needs an accurate automated ICME detection (e.g., Telloni et al., 2019; Nguyen et al., 2019)
- Combining our predictive tool with an automated ICME detection algorithm introduces new problems we would need to work on

Future perspectives

- Develop a framework that combines the predictive Bz tool with automated ICME detection
- Work on new strategies to forecast the temporal evolution of the Bz component
- Use a semi-empirical flux rope model (Weiss et al., 2021a, 2021b) to fit the rest of the magnetic flux rope from the first few hours of the ICME

Summary: Machine Learning for predicting the Bz component in ICMEs

Key Points

- Studied the research question if upstream in situ measurements are sufficient for predicting the Bz component in ICMEs
- Selected machine learning as tool to answer this question on the example of 348 ICMEs.
- Found reasonable results for estimates of the Bz component:
  min(Bz): MAE of 3.12 nT and PCC of 0.71
  max(Bt): MAE of 2.23 nT and PCC of 0.91
- Predictive tool is far from solving the Bz problem but the prototype shows promising first results

Links

Open Access: Link

GitHub: https://github.com/helioforecast

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