Skoltech

May
25.2022

This presentation participates in OSPP
EGU
Outstanding Student & PhD candidate Presentation contest

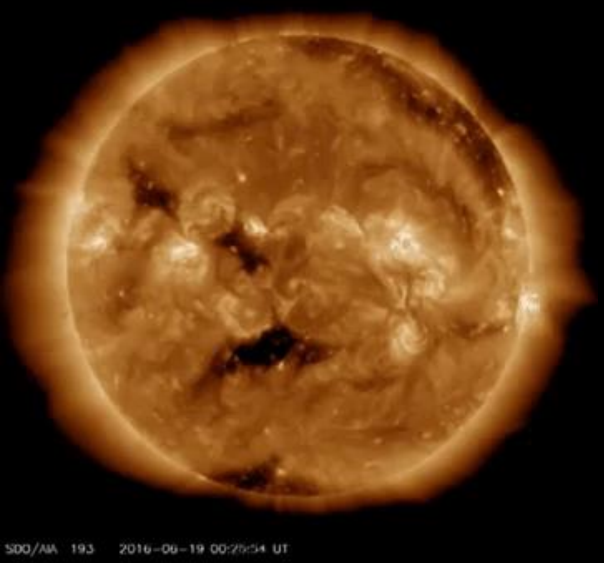
# Geomagnetic Storms Forecasting from Solar Coronal Holes

Nitti S.[1], Podladchikova T.[1], Hofmeister S.[2], Veronig A.[3,4], Verbanac G.[5], and Bandic M.[6]

[1] Skolkovo Institute of Science and Technology, Moscow, Russia
[2] Leibniz Institute for Astrophysics Potsdam, Potsdam, Germany
[3] Institute of Physics, University of Graz, Graz, Austria
[4] Kanzelhöhe Observatory for Solar and Environmental Research, Austria
[5] Department of Geophysics, Faculty of Science, University of Zagreb, Zagreb, Croatia
[6] Astronomical Observatory Zagreb, Zagreb, Croatia

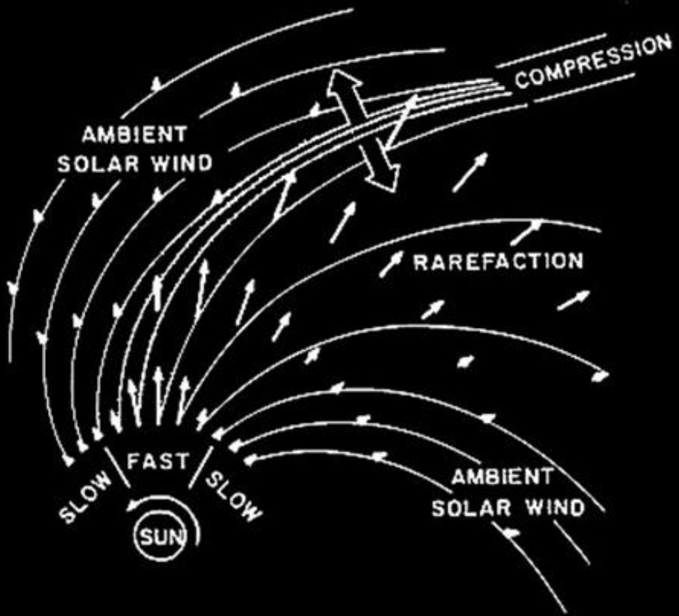
# Background

Skoltech



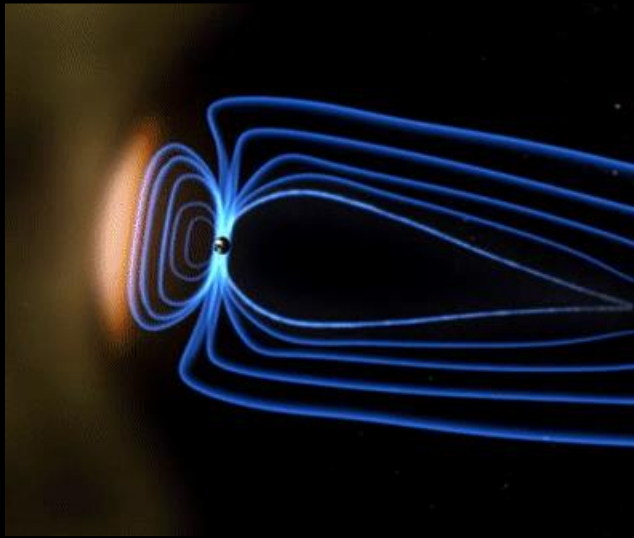

Coronal holes (CHs) are regions of open magnetic flux and sources of fast solar wind

*Credits NASA*




Fast solar wind interacts with slow solar wind forming corotating interaction regions (CIRs)

*Credits Echer and Gonzalez, 2006*



CIRs interacts with the Earth’s magnetosphere causing recurrent geomagnetic storms

*Credits NASA*

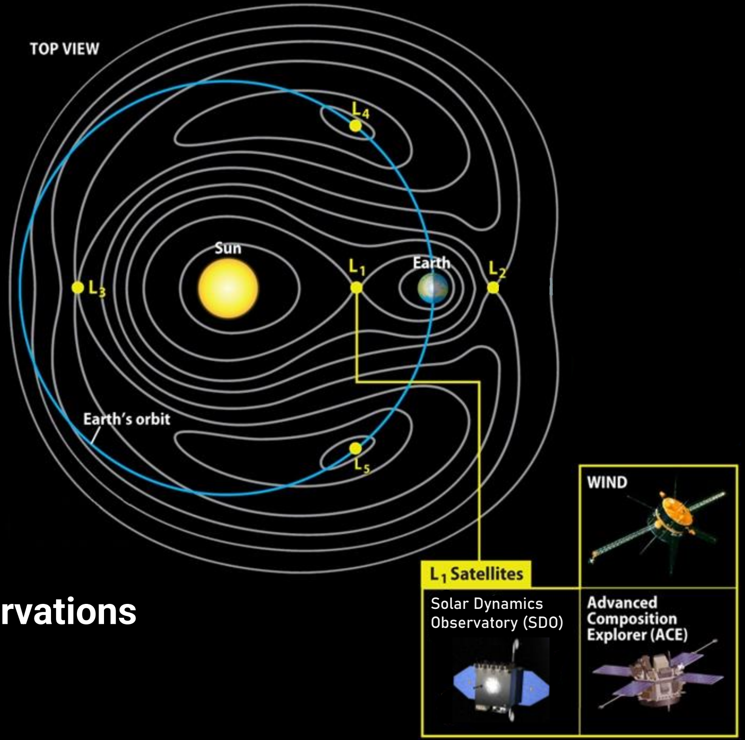
# Geomagnetic Storms Forecasting

Skoltech

## Current Approaches

**Quantitative prediction**
Source: real-time measurements at L1
Time: 1 hour
Reliability: reliable

**Qualitative prediction from Sun observations**
Source: Coronal Mass Ejections, Coronal holes
Time: 2-6 days
Reliability: not reliable
(Vrsnak et al., 2007 a, b)




## Our Approach

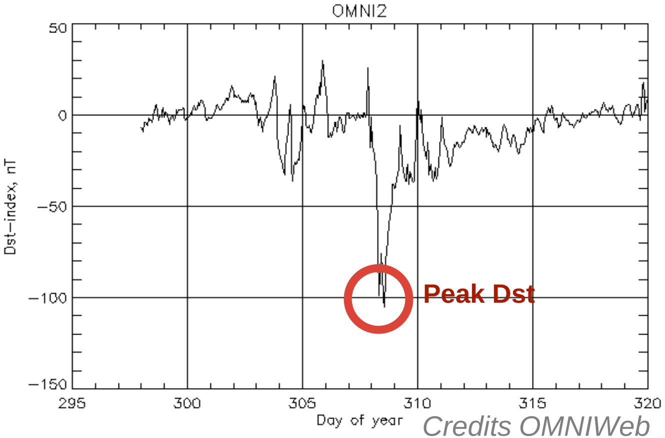
**Quantitative prediction from Sun observations**
Source: Coronal holes, magnetograms
Time: 2-6 days

*Credits Astronomy.com*

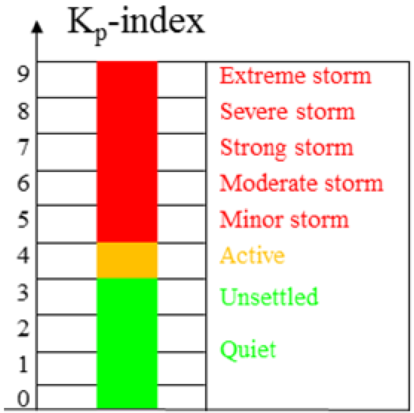
# Dataset

*We focus on the period from October 2010 to December 2020, covering most of the Solar Cycle 24.*

- ➔ **Coronal hole** data (area, magnetic flux) detected from the Atmospheric Imaging Assembly (AIA) and Helioseismic Imager (HMI) onboard NASA's SDO satellite, within the central slice covering 15 degrees in longitude;
- ➔ **Solar wind** plasma and speed data from NASA ACE and Wind satellites through the OMNI data base.
- ➔ **Geomagnetic indeces** Dst (Disturbance storm-time) and Kp, retrieved from the OMNIweb dataset


Credits OMNIWeb




Credits STCE.be

**Prediction Model**:

$$Dst\ (Kp) = f(Coronal\ holes\ Area, Polarity, Day\ Of\ Year)$$

## Step 1

**Associate** time-samples in different data to the same geomagnetic storm

## Step 2

Find how the magnetic **polarity** from the Sun is preserved while reaching Earth.

## Step 3

Find a function to estimate **solar wind speed** from coronal holes area.

## Step 4

Analyze and reproduce the **seasonal variation** of the geomagnetic activity

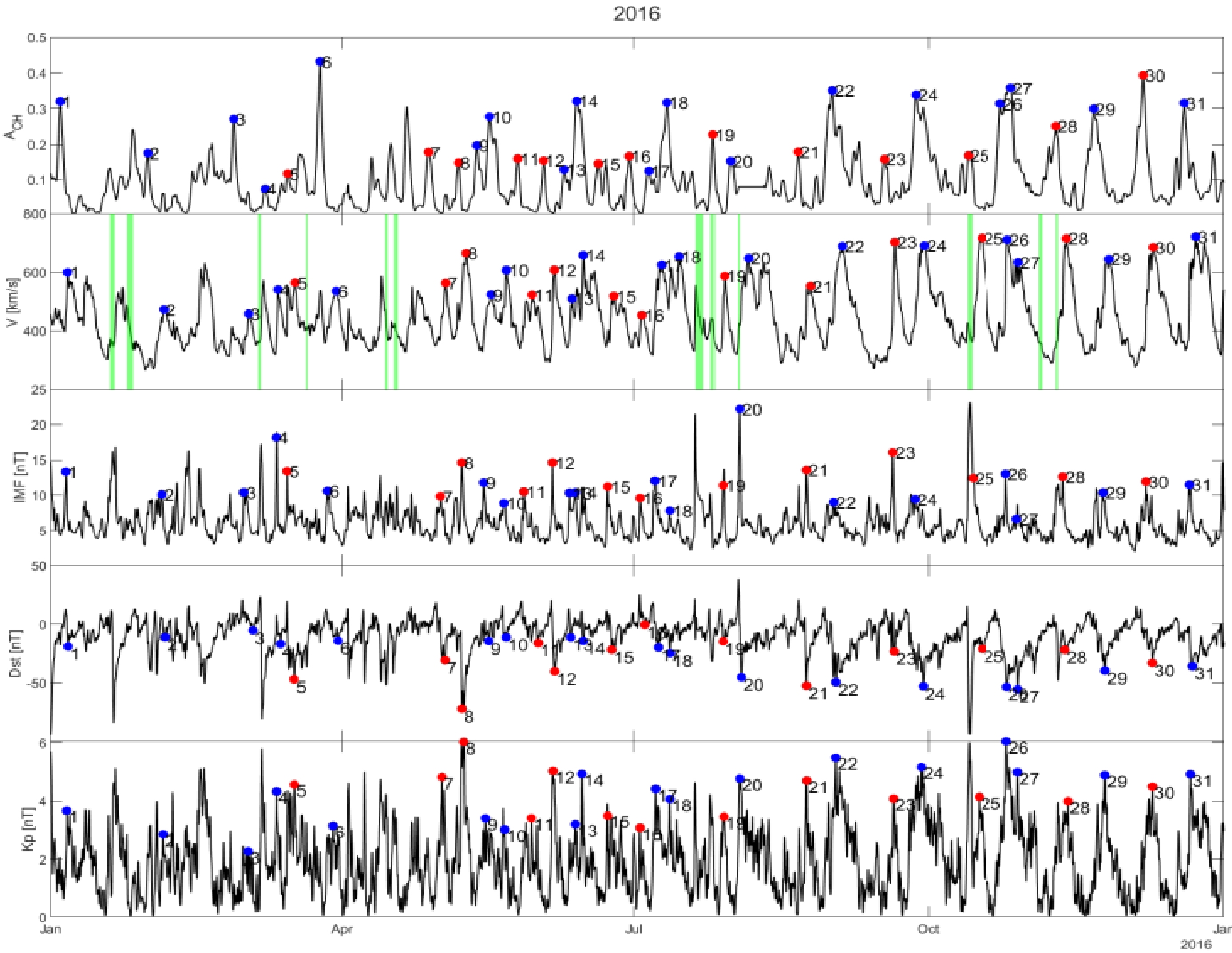
## Step 5

**Combine** the models of geomagnetic activity and solar wind speed

# 1. Event association

**Aim:** Creating a cascade of association to the same geomagnetic event among different time-series.

**Result:** The automatic algorithm found 258 associations.



# 2. Polarity Estimation and Comparison

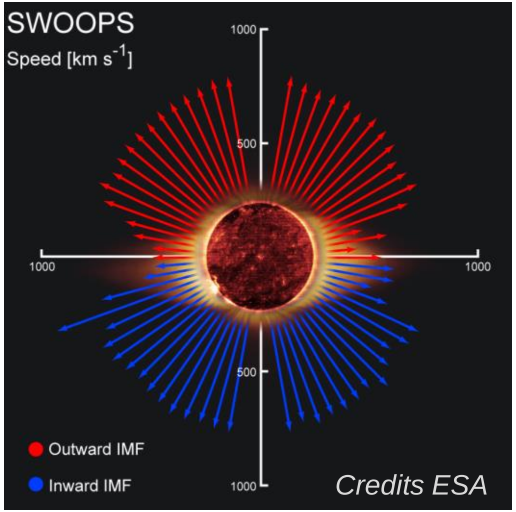
Skoltech

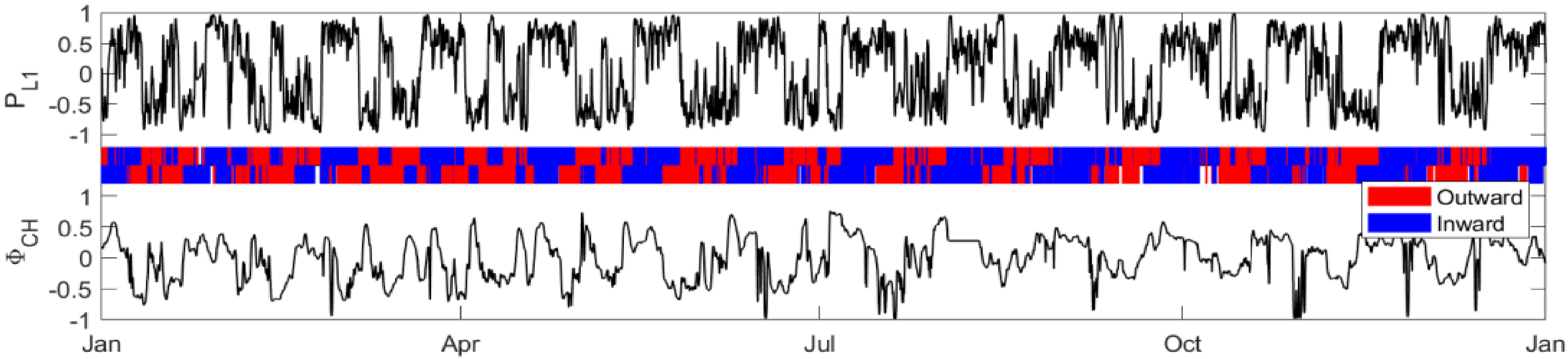
**Aim**: Filtering the dataset by the matching polarity on the Sun and at L1.

- Polarity at **L1** (Neugebauer, 2002):
  $P = (B_r - \Omega R cos\lambda B_t / V)/(\sqrt{1 + (\Omega R cos\lambda / V)^2} \sqrt{B_r^2 + B_t^2})$

- Polarity on the Sun derived from the open magnetic flux **on coronal hole** in fractional area.

**Result**: 83% of the events shares the same polarity.



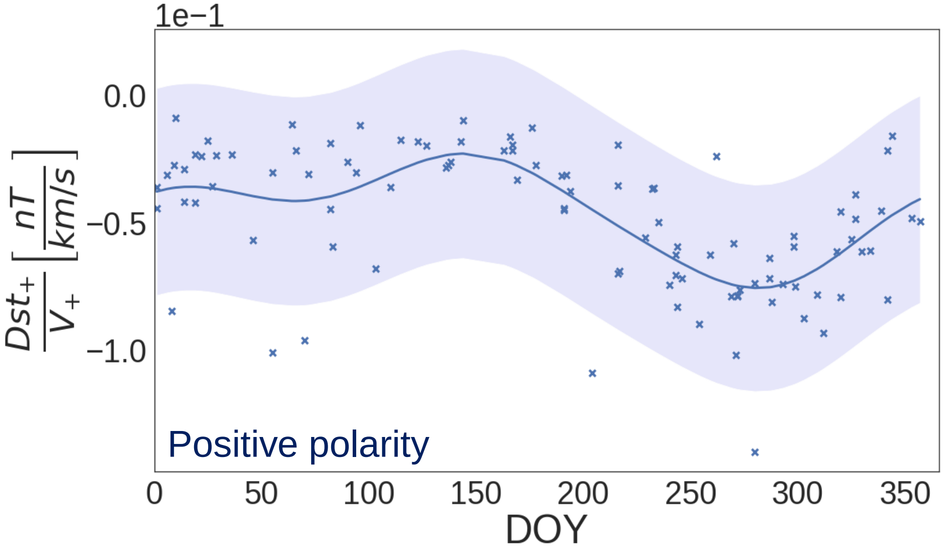
**Method**: Gaussian process regression (GPR) model to describe the functions $\frac{Dst}{V}$, as function of:

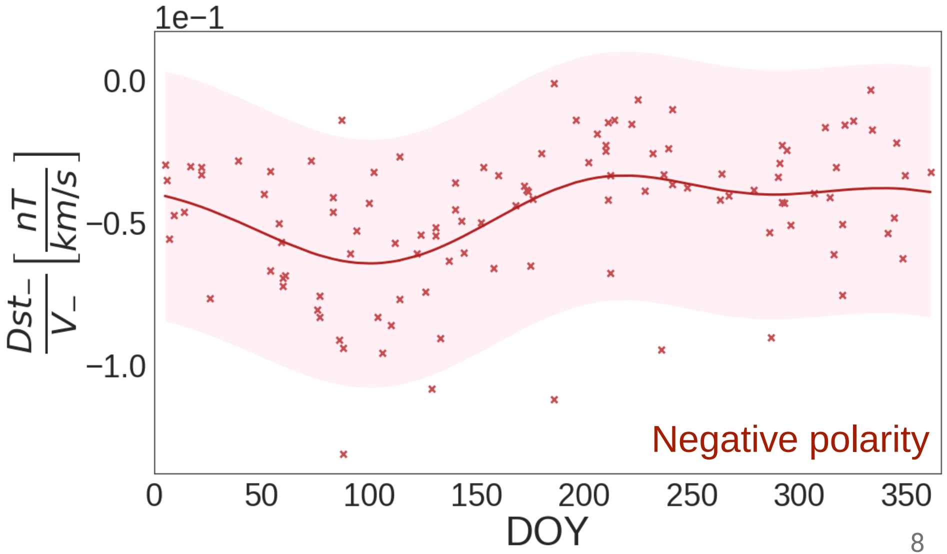
- Polarity
- Day of the year

$$\frac{Dst}{V}(DOY) \sim GP\left(m_p(DOY), \sigma_p(DOY)\right)$$

$$k_p(x, x') = \sigma_p^2 \, exp\left(-\frac{2}{l^2} sin^2\left(\pi \frac{|x - x'|}{p}\right)\right) + \sigma_n^2 I$$

$$x = DOY; \quad p = 365.25 \, days$$



# 4. Solar wind velocity prediction from CHs fractional area

Skoltech

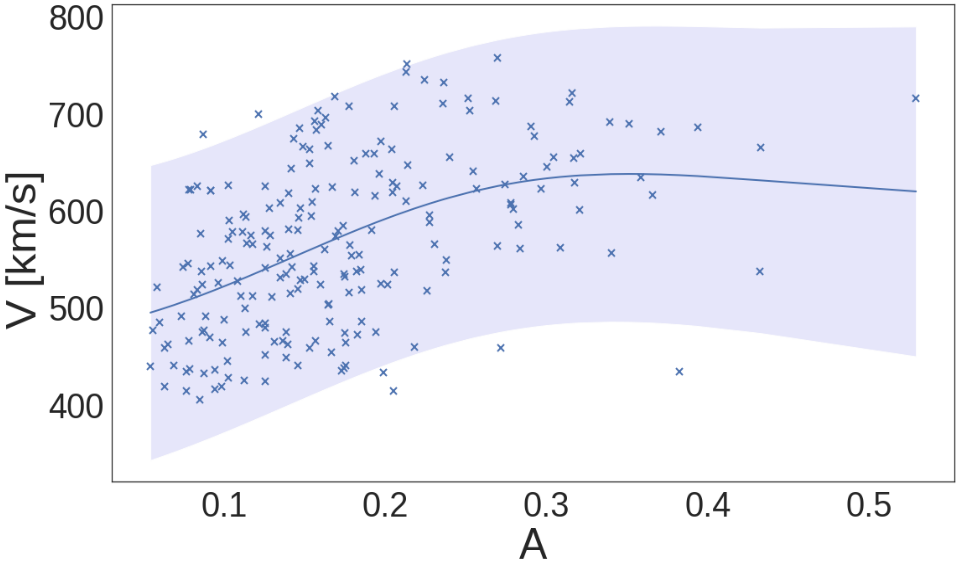
**Method**: Gaussian process regression (GPR) model to describe the solar wind velocity, V , as function of:

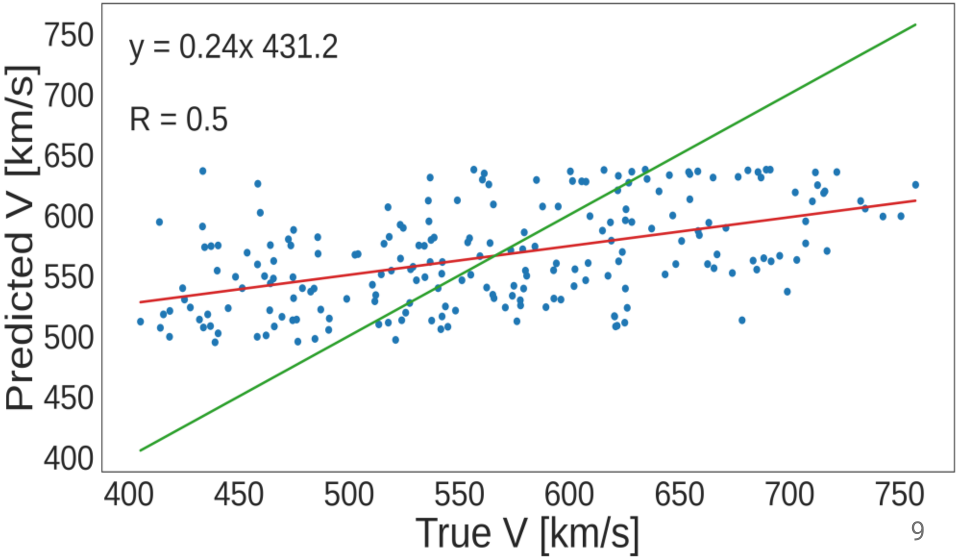
- Coronal holes area (A)

$$V(A) \sim GP(m(A), \sigma(A))$$

$$k_r(x, x') = \sigma_r^2 \, exp\left(-\frac{|x - x'|^2}{2l^2}\right) + \sigma_n^2 I$$

$$x = CHs\ area$$



Skoltech

**Prediction Model**:

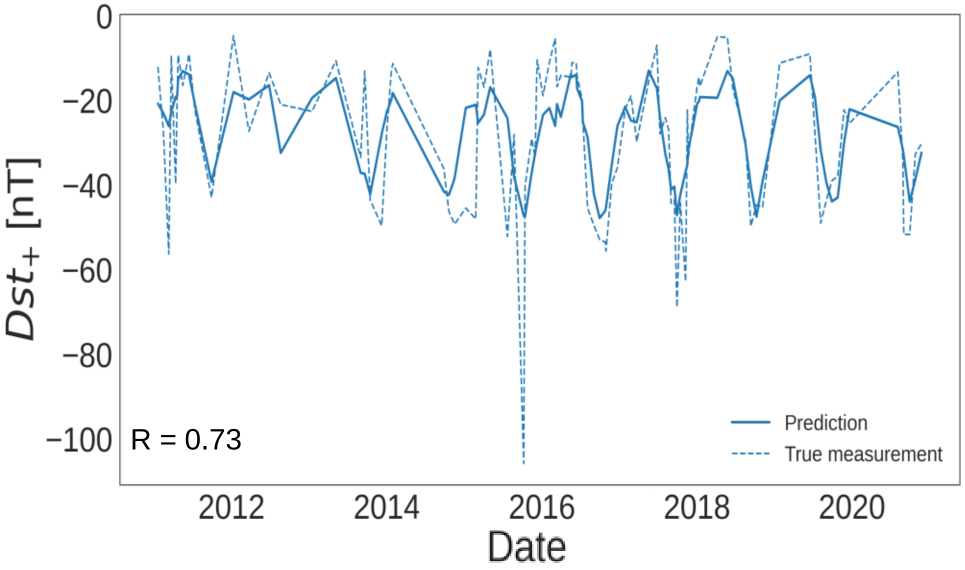
$$Dst = f(Coronal\ holes\ Area, Polarity, DOY)$$

**Method**:

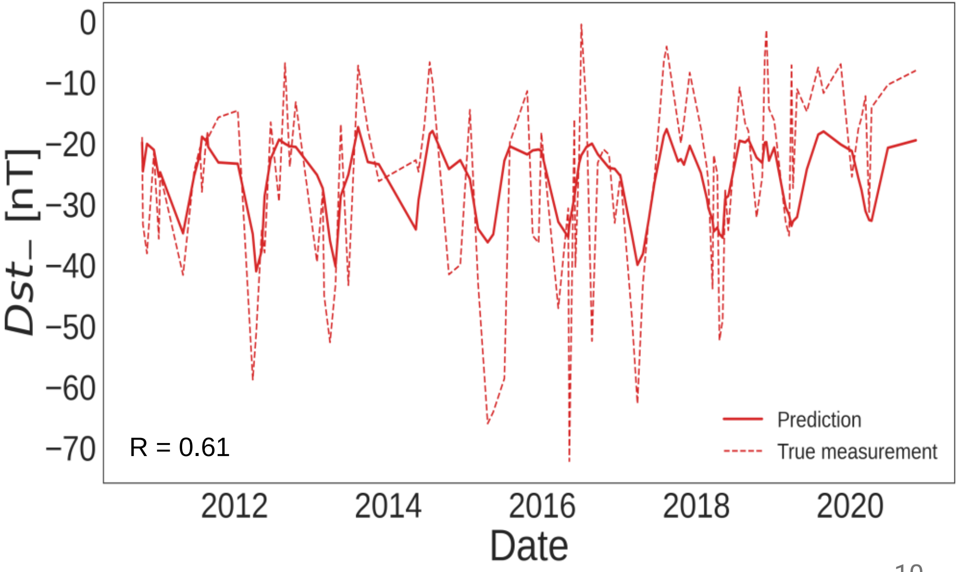
$$\frac{Dst}{V}(DOY) \sim GP\left(m_p(DOY), \sigma_p(DOY)\right)$$

$$V(A) \sim GP\big(m_r(A), \sigma(A)\big)$$

Positive polarity



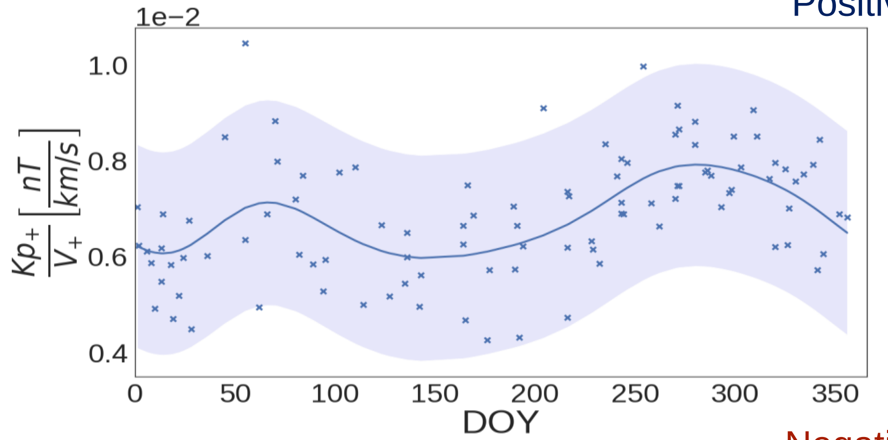

Negative polarity

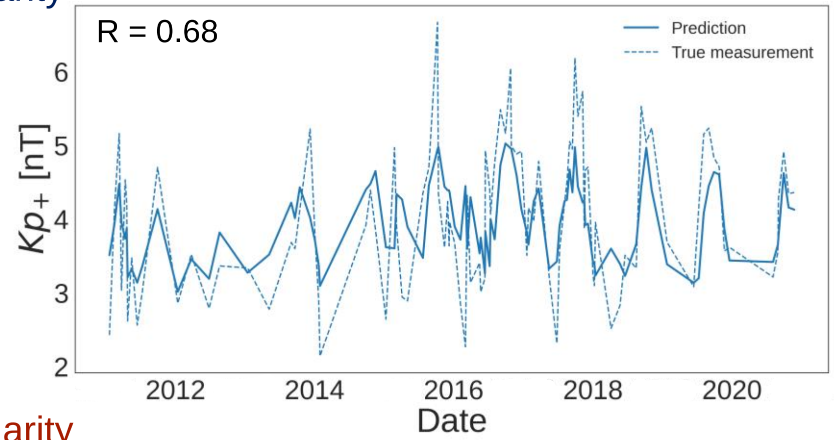


# 5. Forecasting of Kp index

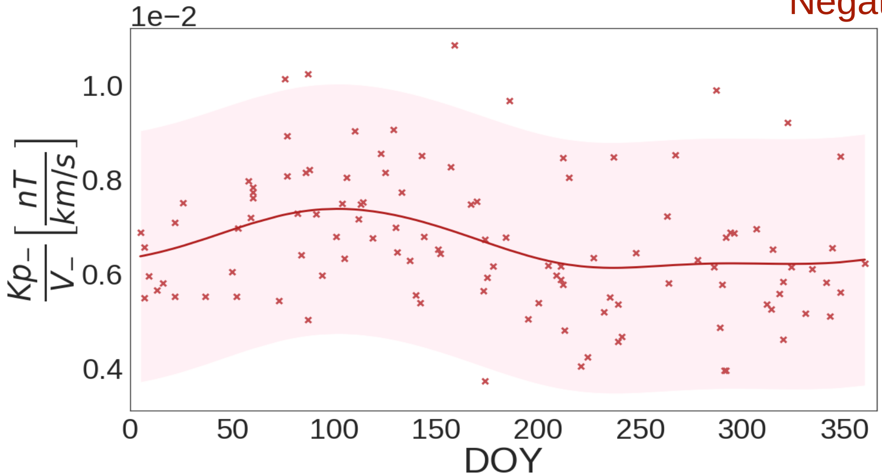
Skoltech

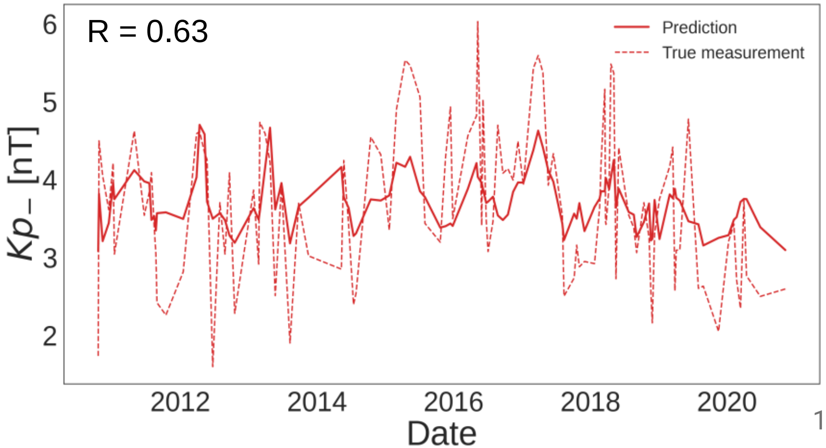
Positive polarity




Negative polarity



# Conlcusions and Discussions

Skoltech

- A new forecasting algorithm of geomagnetic storms associated with the high-speed streams from the coronal hole is developed. The correlation coefficient between the predicted and observed Dst (Kp) index reaches R = 0.61/0.73 (0.63/0.68), for coronal holes having the negative/positive polarity on the Sun.
- We demonstrate that the inward/outward direction of the magnetic field originating from the base of a coronal hole is preserved in more than 83% of cases when compared to the related magnetic field measured at Earth.
- These results demonstrate that the proposed technique opens a possibility to predict geomagnetic storms associated with the high-speed streams **directly from solar observations**, which results in the extension of the lead time from hours up to 6 days.

# Literature review


- Owens, Forsyth 2013: https://link.springer.com/article/10.12942%2Flrsp-2013-5
- Cranmer 2009: https://link.springer.com/article/10.12942%2Flrsp-2009-3
- Richardson 2018: https://link.springer.com/article/10.1007%2Fs41116-017-0011-z
- Russell and McPherron, 1973: https://ui.adsabs.harvard.edu/abs/1973JGR....78...92R/abstract
- Vrsnak, Temmer, Veronig 2007a: http://adsabs.harvard.edu/abs/2007SoPh.. 240..315V
- Vrsnak, Temmer, Veronig 2007b: http://adsabs.harvard.edu/abs/2007SoPh.. 240..331V
- Rotter et al. 2012: http://adsabs.harvard.edu/abs/2012SoPh..281..793R
- Verbanac et al., 2014: https://ui.adsabs.harvard.edu/abs/2014EGUGA..16.1887V/abstract
- Verbanac et al., 2010: https://www.aanda.org/articles/aa/abs/2011/02/aa14617-10/aa14617-10.html
- Verbanac et al.,2011: https://ui.adsabs.harvard.edu/abs/2011A%26A...533A..49V/abstract
- Verbanac and Bandic, 2021: https://doi.org/10.1007/s11207-021-01930-1
- Neugebauer, 2002: https://ui.adsabs.harvard.edu/abs/2002JGRA..107.1488N/abstract
- Lockwood et al., 2020: https://doi.org/10.1051/swsc/2020023

# Thanks for your attention

Any questions?