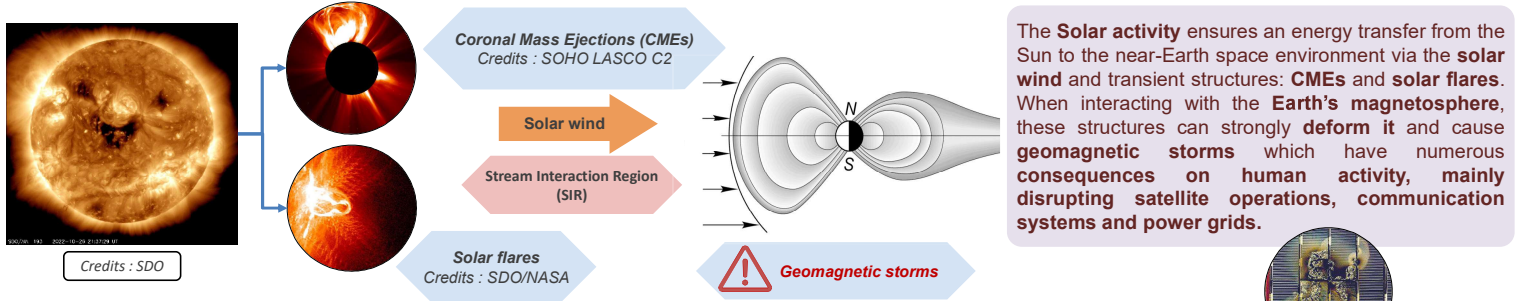


# Deep-learning for the prediction and modelisation of the effect of CMEs on the Earth's magnetosphere

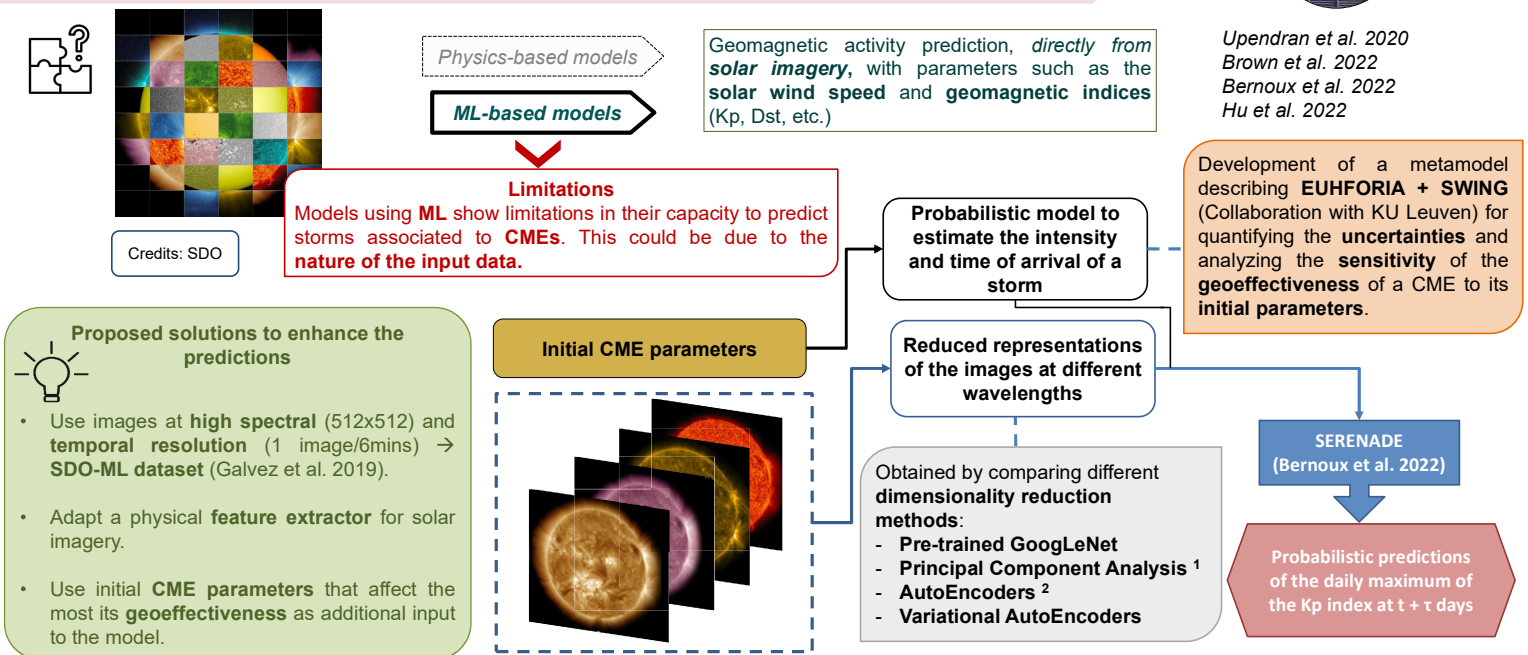
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## I. Context and objectives



## II. Problematic and approach



## III. Feature extraction from images and Kp index predictions using SERENADE

**GoogLeNet** (Szegedy et al. 2015, used in SERENADE)

- ImageNet (Deng et al. 2009) pre-trained Convolutional Neural Network.

**VAE** (Pinheiro Cinelli et al. 2021)

- Projects **non linearly** the data onto the **latent space (LS)** keeping the **important information**.
- Decodes** the LS to **reconstruct** the original data.

- Projection: Probabilistic distribution  $\mu, \sigma$
- Sampling:  $z = \text{Sampling}(\mu, \sigma)$
- Upsampling: Output = decoder(z)

### Preliminary results

- GN predictions very unstable → could lead to false alerts.
- VAE predictions much more stable and smooth.
- Lower CRPS for VAE (Continuous Ranked Probability Score, equivalent to the MAE in the case of a probabilistic forecast).

### Next steps

- Exhaustive test-bench.
- With further fine-tuning → better capture of CME associated storms.
- Experiment with images of different nature (magnetograms and coronagraphs) and initial CME parameters.

## IV. Analysis of the impact of a CME's initial parameters on its geoeffectiveness

**Polynomial chaos expansion<sup>3</sup>**: metamodel describing the 2 models

**Sobol indices<sup>4</sup>**: quantify the effect of each input parameter on the final output: max Kp.

**Case study – CME July 2012**

Parameter	Default value	Uncertainties
Speed (s)	763 km/s	563 km/s – 963 km/s
Radius (r)	16.8 $R_{Sun}$	15.19 $R_{Sun}$ – 18.41 $R_{Sun}$
Density (d)	$10^{-18} kg/m^3$	$5 \times 10^{-18} kg/m^3$ – $7.3 \times 10^{-17} kg/m^3$
Temperature (T)	$0.8 \times 10^6 K$	$0.16 \times 10^6 K$ – $4 \times 10^6 K$
Tilt angle (t)	-135deg	-155deg – -115deg
Toroidal flux (f)	$1 \times 10^{14} Wb$	$0.5 \times 10^{14} Wb$ – $0.75 \times 10^{14} Wb$

Variation of the CME initial parameters given to EUHFORIA

**Kp index Metamodel - Sobol indices**

**What affects the value of maximum Kp index the most?**

- From the first order index → The variation of the **density** parameter.
- From the total order → the interaction between the **density** and the rest of the parameters, namely with the **radius** parameter.

<sup>1</sup>Greenacre et al. 2022, <sup>2</sup>Bank et al. 2023, <sup>3</sup>Cresta et al. 2009, <sup>4</sup>Owen 2013