The exoplanetary magnetosphere extension in Sun-like stars based on the solar wind and solar UV emission

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Outstanding Student & PhD candidate Presentation contest

Aim of the work

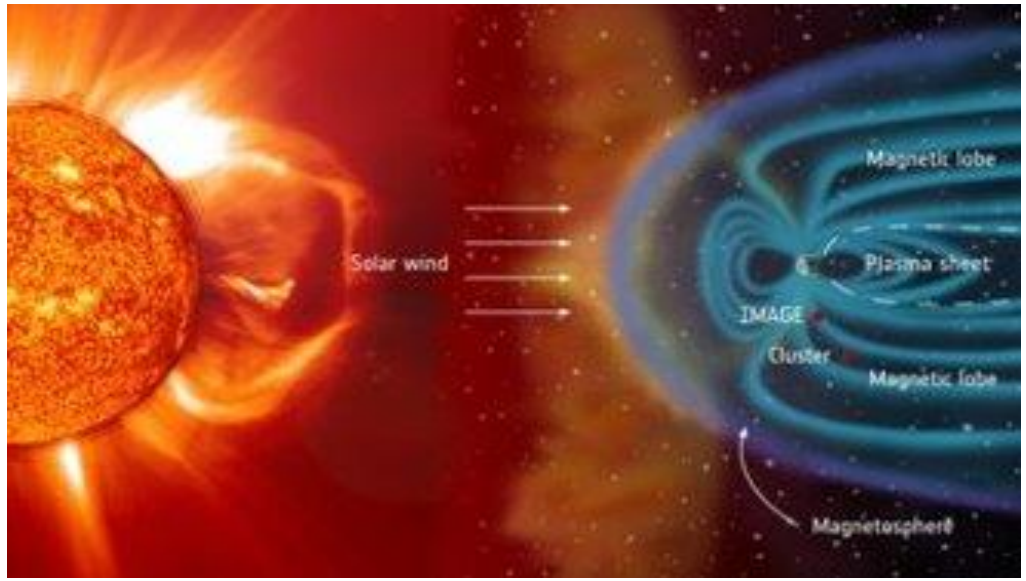
SUN AS A ROSETTA STONE: long-term relation between solar UV activity and near-Earth solar wind properties, with the aim to use Sun-calibrated relations on Sun-like stars.

- Solar magnetic activity → **Ca II K index** (Bertello et al. 2017 composites)
- Solar wind parameters → **Speed and dynamic pressure** (OMNI database)

The gradients balance between SW dynamic pressure and Earth's magnetic field pressure establishes the compression of the magnetosphere.

$$\left|\nabla\left(\frac{1}{2}\rho v^2\right)\right| \simeq \left|\nabla\left(\frac{B^2}{8\pi}\right)\right| \rightarrow \boxed{R_{MP} = \left(\frac{\mu_0 f_0^2 M_E^2}{8\pi^2 P}\right)^{1/6}}$$

Grießmeier et al. (2004)



Ca II K index – SW dynamic pressure relation → **Ca II K index - R_{MP} relation**

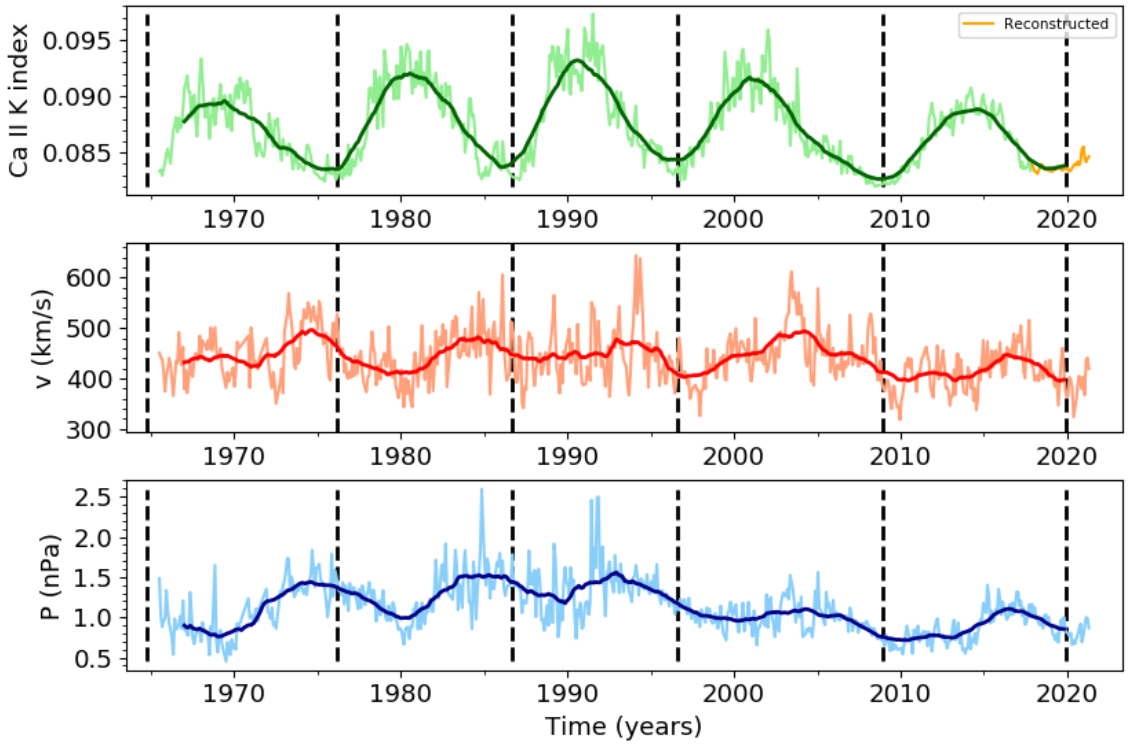
Dataset

The dataset used for the work consists of:

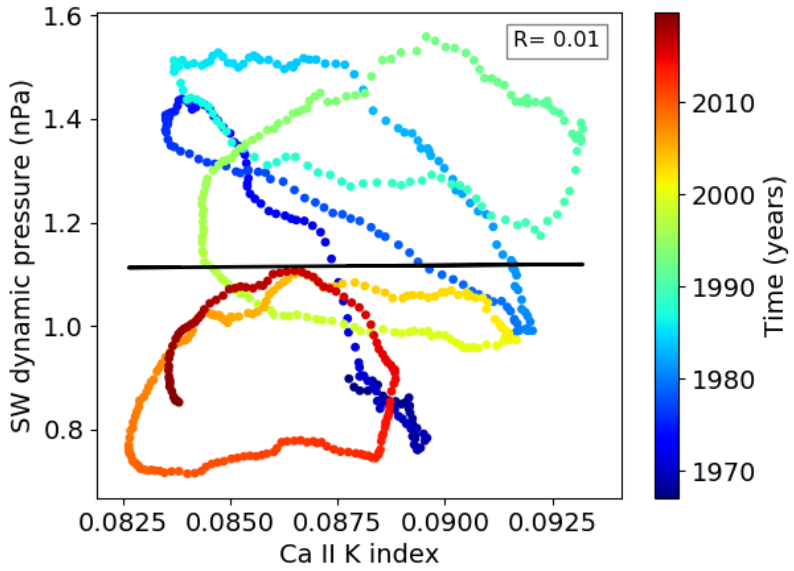
- *Ca II K index* (Jul. 1965 – Oct. 2017) and *Mg II index* (Nov. 1978 – Apr. 2021);
- Solar wind *speed* and *dynamic pressure* OMNI data (Jul. 1965 – Apr. 2021).

Time interval investigated: July 1965 – April 2021 → **5 solar cycles (20-24)**

Long-term analysis: 37-month moving average



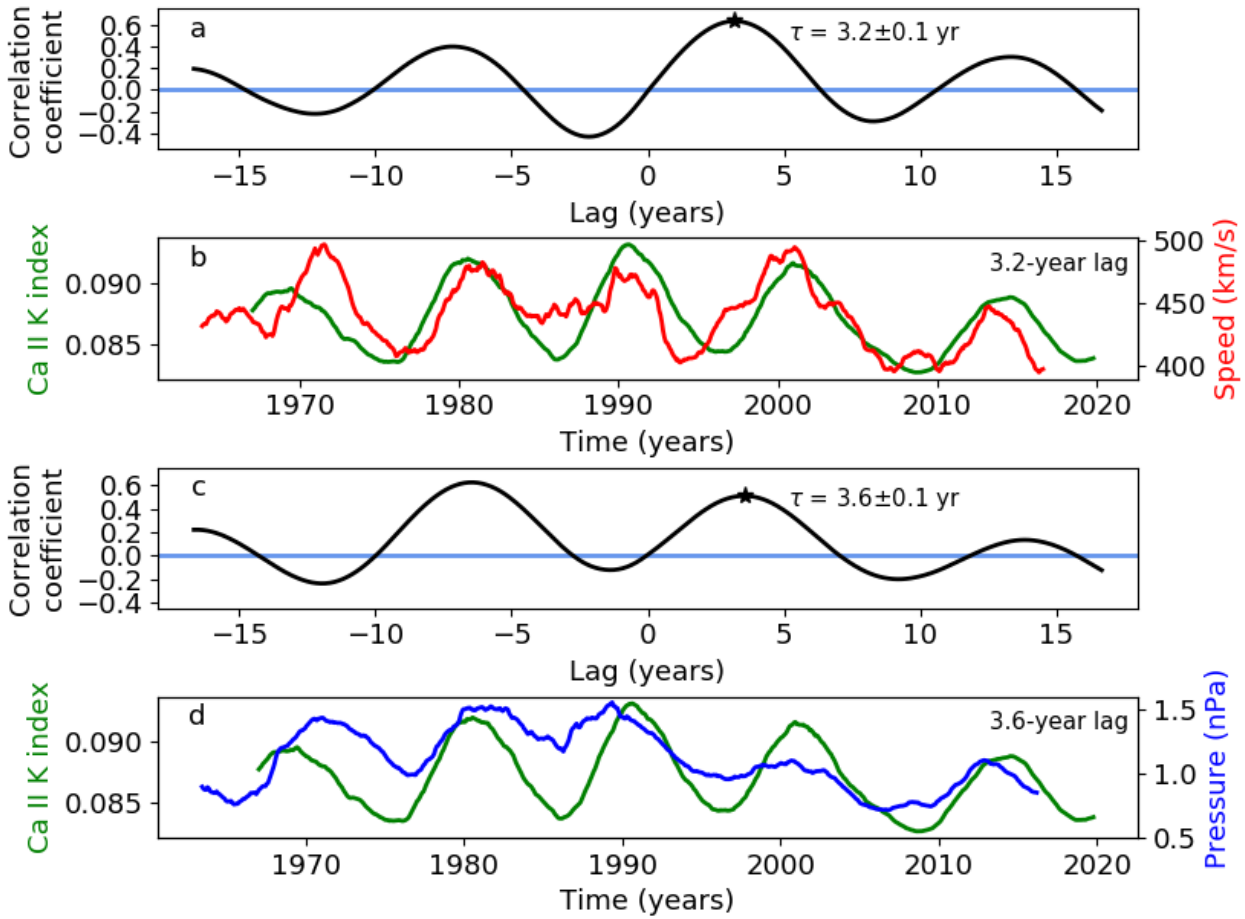
No correlation over the whole time interval



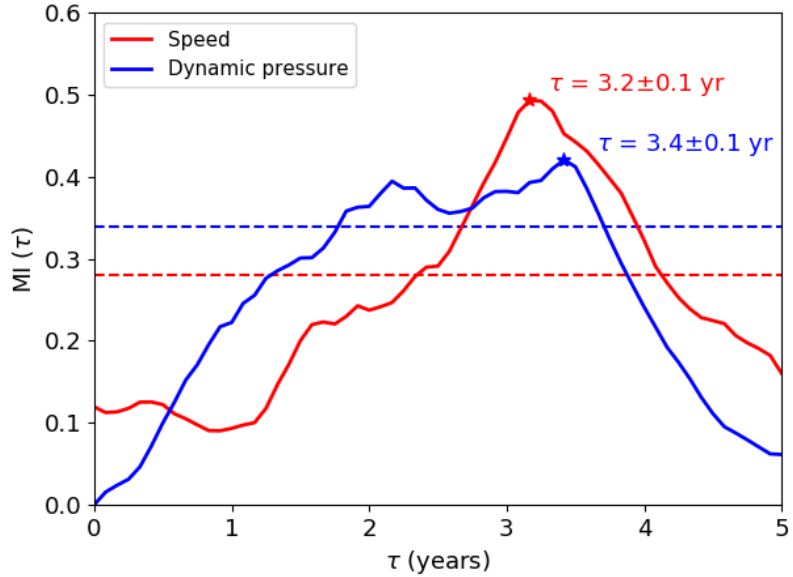
Reda et al. (2021)

Cross correlation and mutual information analysis

Cross correlation analysis to assess a time delay



Mutual information to consider a non-linear relation



The lag is consistent between the two techniques:

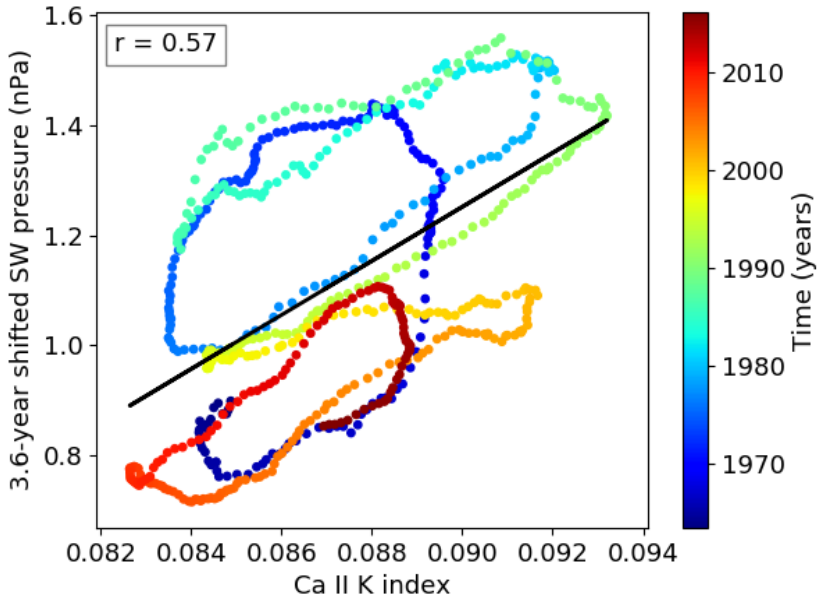
- **3.2-year lag of SW speed to Ca II K ;**
- **3.6-year lag of SW dynamic pressure to Ca II K.**

Reda et al. 2022a (submitted to MNRAS)

Ca II K – solar wind relations and magnetopause standoff distance

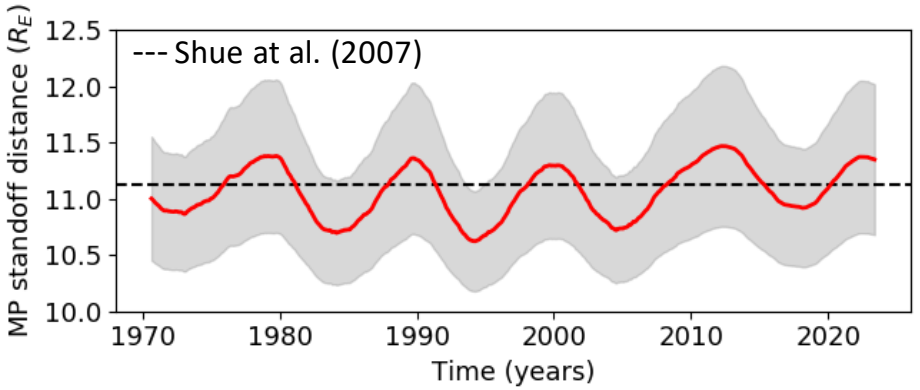
A positive correlation between Ca II K and SW dynamic pressure emerges when the time lags are considered.

Ca II K – solar wind dynamic pressure relation



$$P(nPa) = (49.1 \pm 2.8) Ca\ II\ K + (-3.2 \pm 0.2)$$

We then used the relation to compute the **Earth's magnetopause standoff distance**.



$$R_{MP} = \left[\frac{\mu_0 f_0^2 M_E^2}{8\pi^2 10^{-9} (\alpha\, Ca\, II\, K + \beta)} \right]^{1/6}$$

Reda et al. 2022a (submitted to MNRAS)

Extension of the model to Sun-like stars

The advantage of having used a physical proxy, as the Ca II K index, is that the relations found for the Sun can be extended to Sun-like stars.

Ca II H & K lines (Mount Wilson HK Project) → **Magnetosphere extension of fictitious Earth-twin exoplanets around a sample of 10 Sun-like stars** → Relation with the atmospheric erosion (habitability)

Star	Spectral type	T_{eff} (K)	log g ($cm\,s^{-2}$)	log R_0	Ca II K	R_{MP} (this work) (R_E)	R_{MP} (See et al. (2014)) (R_E)
HD 10780	K0 V	5327 ± 44	4.54 ± 0.06	$+0.124^{+0.000}_{-0.000}$	0.164 ± 0.017	8.63 ± 0.29	8.83
HD 100180	G0 V	5989 ± 44	4.38 ± 0.06	$+0.290^{+0.000}_{-0.000}$	0.089 ± 0.012	10.91 ± 1.03	10.74
HD 13043	G2 V	5897 ± 44	4.27 ± 0.06	$+0.324^{+0.000}_{-0.004}$	0.078 ± 0.011	12.05 ± 1.91	10.06
HD 179958	G4 V	5760 ± 44	4.39 ± 0.06	$+0.324^{+0.016}_{-0.017}$	0.080 ± 0.011	11.77 ± 1.63	11.02/10.59
HD 185144	G9 V	5246 ± 44	4.55 ± 0.06	$+0.253^{+0.006}_{-0.000}$	0.125 ± 0.014	9.38 ± 0.42	9.75/9.50
HD 34411	G1.5 V	5911 ± 44	4.37 ± 0.06	$+0.347^{+0.534}_{-0.119}$	0.076 ± 0.011	12.37 ± 2.29	10.8
HD 71148	G5 V	5818 ± 44	4.29 ± 0.06	$+0.290^{+0.009}_{-0.010}$	0.102 ± 0.012	10.16 ± 0.64	10.56/10.15
HD 76151	G3 V	5790 ± 44	4.55 ± 0.06	$+0.169^{+0.008}_{-0.000}$	0.137 ± 0.015	9.10 ± 0.37	10.07/9.30
HD 86728	G3 V	5700 ± 44	4.29 ± 0.06	$+0.340^{+0.004}_{-0.000}$	0.076 ± 0.011	12.37 ± 2.29	10.83
HD 9562	G1 V	5939 ± 44	4.13 ± 0.06	$+0.390^{+0.004}_{-0.000}$	0.071 ± 0.011	13.61 ± 4.44	10.74

Table 1. Colum 1: star ID; Column 2: spectral type according to SIMBAD; Columns 3 and 4: effective temperature and surface gravity from Valenti & Fischer (2005); Column 5: logarithm of the Rossby number (R_0) from Table 1 in Marsden et al. (2014); Column 6: average Ca II K index value. The last two columns show the comparison of the magnetospheric standoff distances from this work and from See et al. (2014) for fictitious Earth-twin planets orbiting these stars. In the last column, stars with large activity ranges are listed with minimum and maximum standoff distances.

The agreement with previous literature results for the same stars is good!

Reda et al. 2022a (submitted to MNRAS)

Conclusions and future developments

Long-term relation among solar UV activity and solar wind properties

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By using cross correlation we find 3.6-year lag of SW dynamic pressure to Ca II K index

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We extend the relation calibrated on the Sun to a sample of 10 Sun like stars

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We focus on the magnetosphere extension as it is related to atmospheric erosion in exoplanets

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Further developments

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Synergic strategy with asteroseismology to characterize the habitability conditions around Sun-like stars
(Di Mauro et al. submitted to ApJ, Reda et al. submitted to Frontiers)

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Reconstruction of the Earth's magnetosphere in the past and middle-term forecasts (in preparation)

References:
- Reda et al. (2021), *"Correlation of solar activity proxy with solar wind dynamic pressure in the last five solar cycles"*, Il Nuovo Cimento C
- Reda et al. (2022a), *"The exoplanetary magnetosphere extension in Sun-like stars based on solar wind-solar UV relation"*, submitted to MNRAS
- Reda et al. (2022b), *"On the time lag between solar wind dynamic parameters and solar activity UV proxies"*, submitted to Adv. Space Res.
- Reda et al. (2022c), *"A synergic strategy to characterize the habitability conditions of exoplanets hosted by solar-type stars"*, submitted to Frontiers
- Di Mauro et al. (2022), *"On the characterization of GJ 504: a magnetically active planet-host star observed by TESS"*, submitted to ApJ