Ultraviolet Variability in the Sun and in Solar-like Stars

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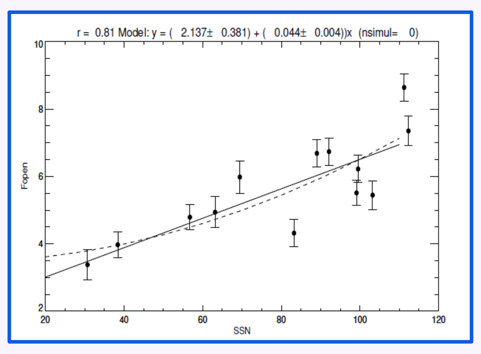
Abstract

The Sun is the only star for which it is possible to analyze irradiance variations due to magnetic activity in detail. Specifically, reconstructing Solar Irradiance variations over past epochs requires evaluating changes in active region coverage during the 11-year solar cycles and estimating the secular component with an ultra-decennial modulation. We employ an empirical approach based on a recent 1000-year-long record of open solar flux to reconstruct both components and derive the corresponding UV variations. In particular, we reconstruct the far UV (115-180 nm) and middle UV (180-310 nm) band, as well as the chromospheric Mg II index. Additionally, we present a preliminary analysis of UV time variations in other solar-like stars obtained from the analysis of the IUE (International Ultraviolet Explorer) data.

Solar UV reconstruction by open magnetic field

Our solar irradiance reconstruction is based on several relationships between active regions (ARs) and open magnetic field (F_0).

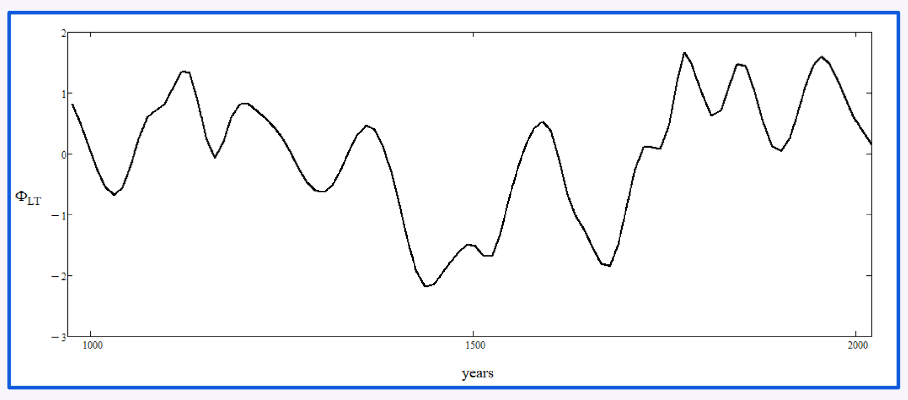
1) Relation between 11yr-averaged F_0[1] ($\overline{F_0}$) and - and the 11yr-averaged sunspot number SSN [2] ($\overline{SSN}$).



The open flux is available from 970 to 1900 A.C.

By applying the linear relation (left image) to $\overline{SSN}$ data for 1900-2018 A.C., we obtain a composite of $\overline{F_0}$ from 970 A.C. to the present.

We decompose the entire dataset of $\overline{F_0}$ through EMD approach and consider only the components with periodicities greater than 30 yr (ϕ_{LT})



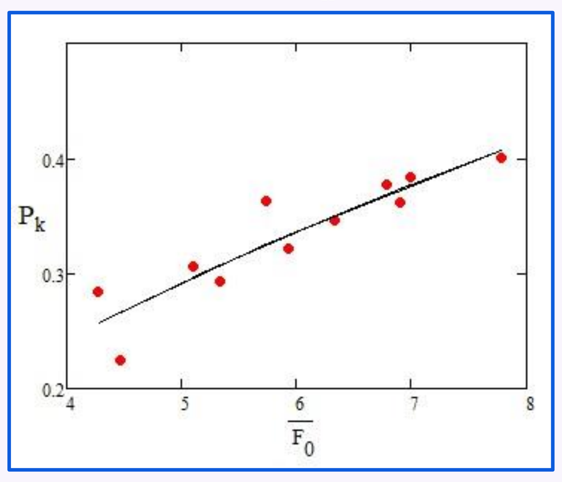
Standardized long-term modulation function

2) Relation between plage parameters and F_0

The plage areas[3], available starting 1892, are reproduced by fitting the following functional form[4]

$$\alpha_k(t) = \left(\frac{t-T0_k}{Ts_k}\right)^2 e^{-\left(\frac{t-T0_k}{Td_k}\right)^2} \quad \text{for } T0_k < t < T0_k + \tau_k$$

We are only interested in the plage coverage (α_f), because sunspots do not contribute to the variability of the UV bands. Because a strong correlation exists between $\overline{F_{0k}}$ and $\overline{\alpha_k}$, that is proportional to $(Td_k/Ts_k)^2 \equiv P_k^2$, we search for a correlation between P_k and $\sqrt{\overline{F_{0k}}}$:

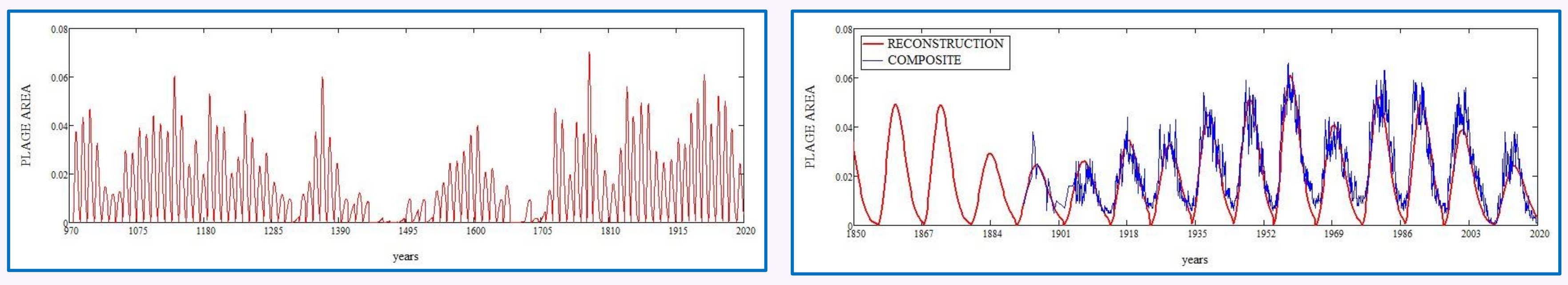


$$P_k = a\sqrt{\overline{F_{0k}}} + b$$

$a = 0.208 \quad (Wb^{-0.5})$

$b = -0.173$

By applying this relation to the entire $\overline{F_0}$ composite, we obtain the values of P_k and then of the Ts_k and Td_k since 970 A.C.



Left: reconstruction of plage coverage from 970 A.C. Right: same plot from 1900 A.C. with the composite data [3] for comparison .

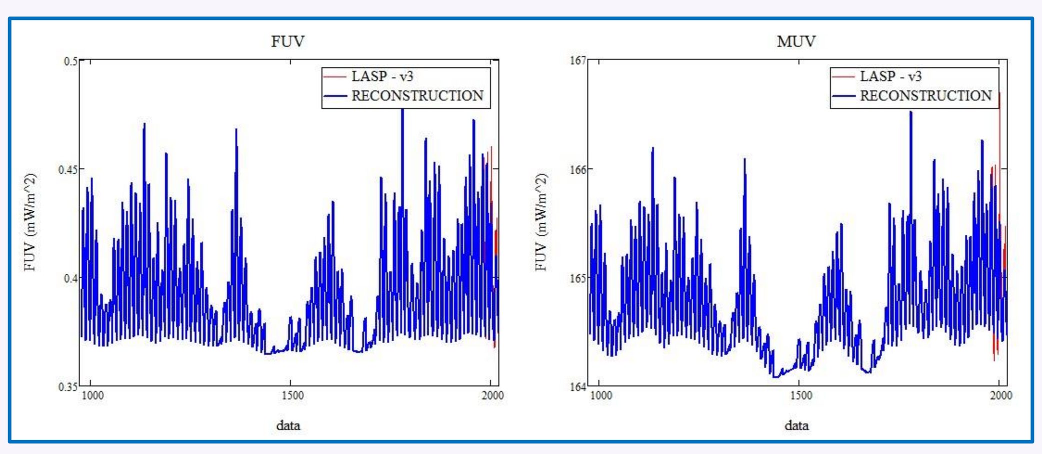
Irradiance variations are reproducible as the sum of the fluxes of the different quiet and active components weighed by corresponding coverage areas (for details, see *Penza et al, 2022[5]):*

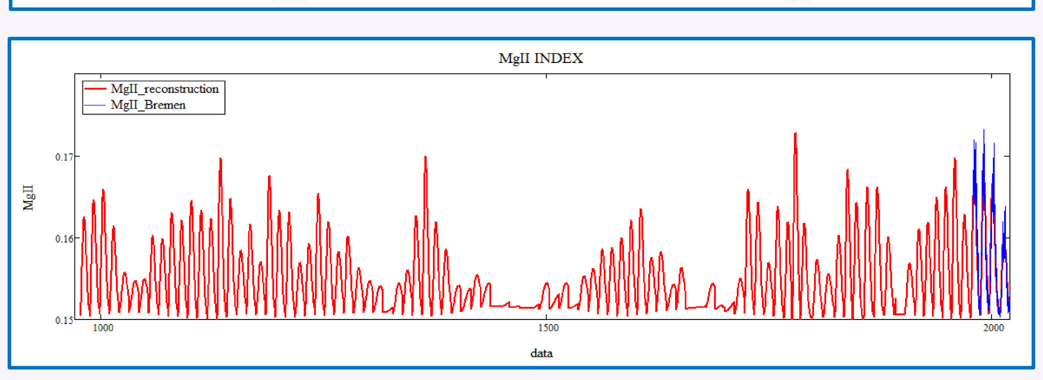
$$\delta F(\lambda_{UV},t) = \alpha_f(t)\delta_{fn}^{UV} + C_n^{UV}(1+\phi_{LT})N^{UV}_{norm} \qquad \text{(Eq. 1)}$$

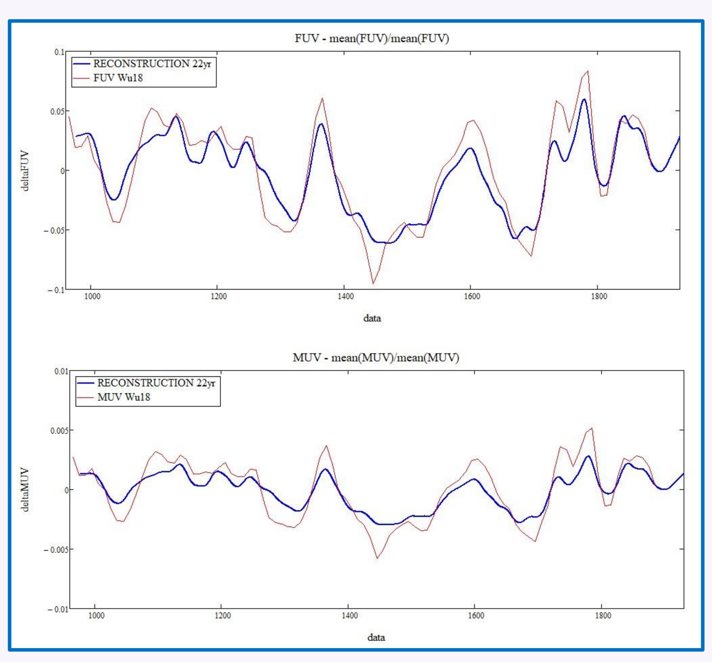
where δ_{fn}^{UV} is a mixed facular/network contrast and C_n^{UV} is the quiet-network contribution. These values are estimated by fitting Eq. 1 over single cycles ($\phi_{LT} = 0$) the SSI LASP composite data[4] integrated over the MUV (180-310 nm) and FUV (115-180 nm) bands. The value of the normalization factor N^{UV}_{norm} is obtained by fit with the entire composite dataset 1978-2020. By a similar approach, we reconstruct also the MgII core-to-continuum index: for the continuum we use the same values of MUV parameters, while for the core we compute them by fit with the Bremen composite[6].

Results for the solar case

The reconstructions of the two UV bands are shown in the plots below: it is evident that the modulation results stronger in MUV with respect to FUV. We show also the comparison between our reconstructions, smoothed over 22yr, and the SATIRE model ones (Wu et al. 2018)[7].





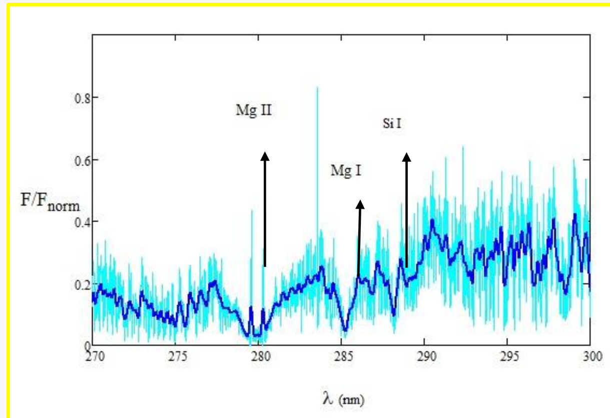


Stellar UV data

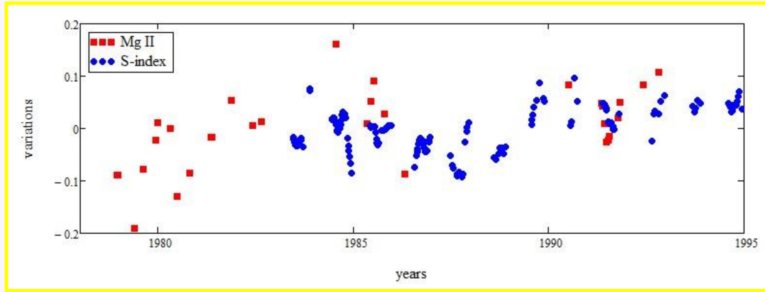
We consider the UV spectra available from IUE library[8] selecting stars with these characteristics:

- -G-K spectral type
- -the existence of high dispersion spectra on more than five days in at least three different years.
- -the presence in the spectrum of the three lines: Mg II h/k, Mg I and Si I between 276.5 and 288.5 nm

For each star, we compute the ratio core/continuum of all three lines; in particular we known that the Mg II is a proxy of stellar magnetic activity.



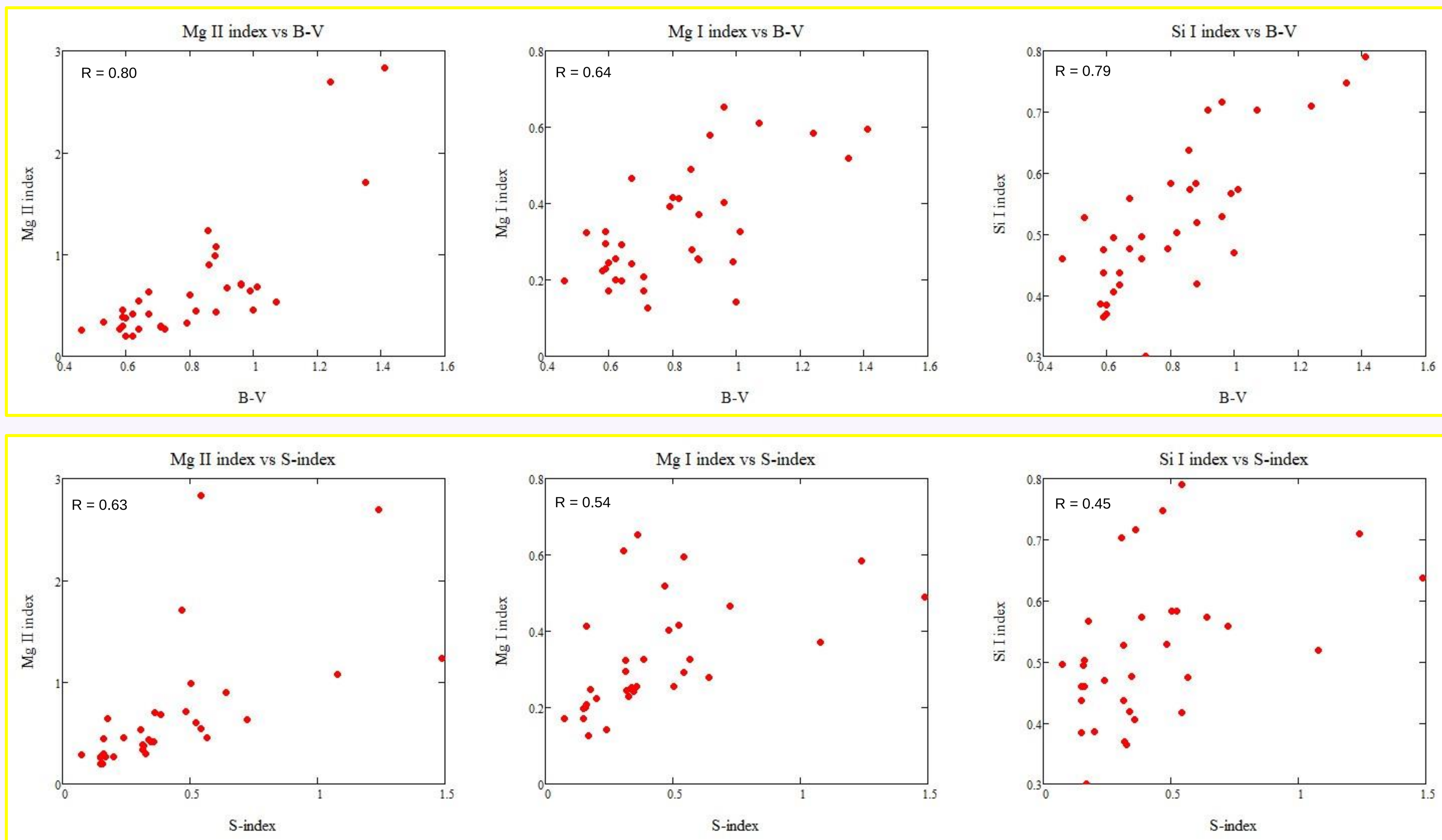
IUE spectrum of HD 115383



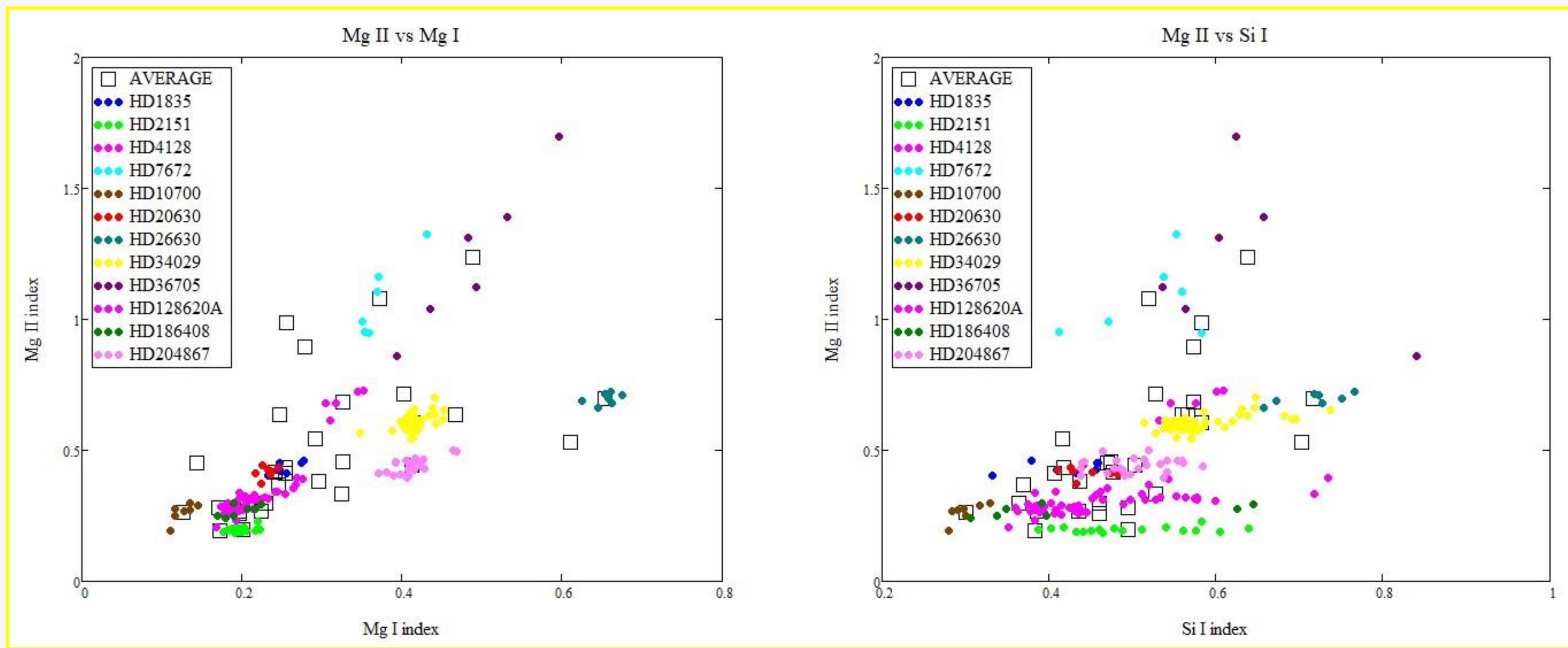
Temporal variations of Mg II and S-index for HD209750

We analyze the behavior of these lines from two points of view:

- the average relations between stars and with the stellar parameters and mean S-index[9]
- the temporal variations in the single stars



Relations between core-to-wing line ratios and B-V index (top panel) and S-index (bottom panel) for different stars. R represents the Pearson correlation coefficient.



Correlations between Mg II and Mg I and Si I line indices: the black-empty square are mean values for each star, the colored points are the single measured for the listed stars.

Results for the stellar case

- The three lines Mg II, Mg I and Si I between 276.5 and 288.5 nm show variations related both to the stellar parameters and to the activity level.
- All line indeces show good linear correlation with B-V color, while only MgII index shows a good correlation with the S-index. This last correlation seems to depend on B-V color.
- Linear relations with other stellar parameters, as gravity and metallicity, do not emerge (for this reason they are not shown).
- Three line indexes are correlated to each other both from star to star and, in many cases, along the temporal varations of the single star.
- The amplitude of the temporal variations in many cases is comparable or greater than that among the different stars.

Bibliography and sitography

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