The dependence of the [FUV-MUV] colour index on solar cycle

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SOLAR PHYSICS UTOV

https://www.fisica.uniroma2.it/~solare/en/

Abstract: The dependence of solar UV variability on solar cycle is investigated using far UV (115-180nm) and middle UV (180-310nm) fluxes from SOLSTICE/SORCE experiment and Mg II index Bremen composite. The SOLSTICE [FUV-MUV] colour is introduced to study the solar UV spectral slope during the cycle. The calculated colour is corrected for aging effects due to an efficiency reduction of SOLSTICE FUV irradiance. In order to extract the 11-year scale variation, the Empirical Mode Decomposition (EMD) is applied to the data sets. We found that the [FUV-MUV] colour strongly correlates with the Mg II index.

The radiative and particle output of the Sun is variable on different time scales, from seconds to the evolutionary scale of the star. These fluctuations, due to instabilities and non-stationary processes related to solar magnetic field dynamics and evolutionary mechanisms, affect the energy balance of the Earth's surface and atmosphere, thus influencing our climate (e.g. Haigh, 2007).

Fluctuations of the total (TSI) and spectral (SSI) solar irradiance indicate that the main feature of solar variability, at least in the last centuries, is the 11-year Schwabe cycle. This cycle is distinctly observed with different physical (e.g. TSI, SSI, Mg II or F10.7 fluxes) and synthetic (e.g. sunspot number) indices.

Magnesium II index dataset

The Mg II core-to-wing ratio is a good proxy for the solar UV and facular component of the TSI (e.g. Dudok deWit et al., 2009). The Mg II index is calculated as the ratio between h and k emission doublet at 280 nm, which originates in the solar chromosphere, and a reference continuum intensity at specific wavelengths in the wings of the Mg II absorption band. The continuum around the doublet is originated in the photosphere.

$$I = \frac{4[E_{279.8} + E_{280.0} + E_{280.2}]}{3[E_{276.6} + E_{276.8} + E_{283.2} + E_{283.4}]}$$

The Mg II Bremen composite signal, i.e., daily Mg II index values, is downloaded from the University of Bremen website:
http://www.iup.uni-bremen.de/gome/gomemgii.html

SORCE SOLSTICE dataset

The investigation of SSI as not quite possible until 2003 with the launch of the NASA's SORCE.

The used datasets are downloaded from LASP SORCE website http://lasp.colorado.edu/home/sorce/data/. The SOLSTICE data obtained from the LASP SORCE website is version 15 data that includes data up to October 2015. SSI measurements present zero values corresponding to missing data, which leads to non physical gaps in the monthly means of the intensities in both spectral regions. A data interpolation is required.

The [FUV-MUV] colour index

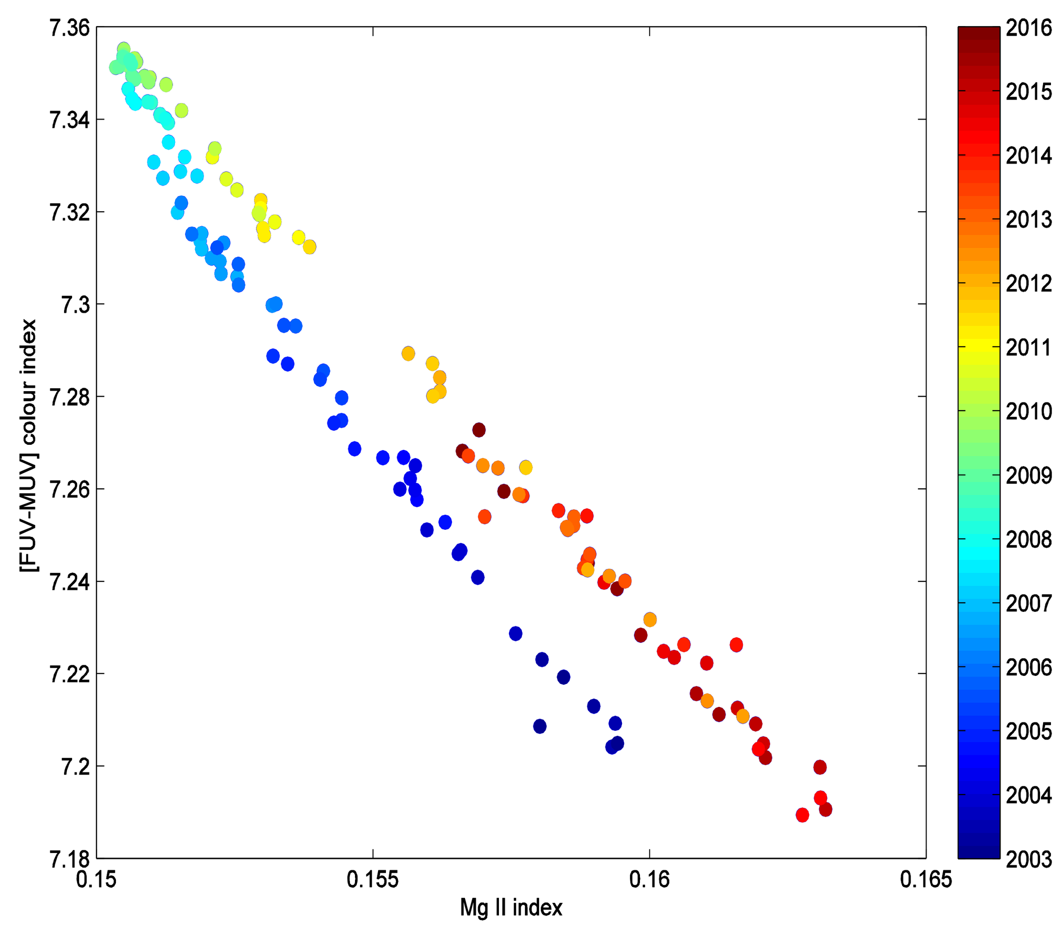
The FUV and MUV monthly means are used to analyze the behavior of the [FUV-MUV] colour index. The colour index is calculated by the difference between the measurements of the magnitude of the Sun at two different wavelengths (i.e., 147.5nm and 245nm, for FUV and MUV, respectively), [FUV-MUV] colour is defined as:

$$[FUV-MUV] = -2.5 log \frac{\lambda_{FUV}}{\lambda_{MUV}} \frac{e^{\frac{hc}{\lambda_{MUV} KT}} - 1}{e^{\frac{hc}{\lambda_{FUV} KT}} - 1}$$

The local slope permits to derive the colour temperature, i.e., the temperature for which the [FUV-MUV] colour of a blackbody radiator fits the solar one.

The figure shows the dependence of the colour on both Mg II index and time. The data sets cover the time between May 2003 and October 2015. UV slope is sensitive to solar activity.

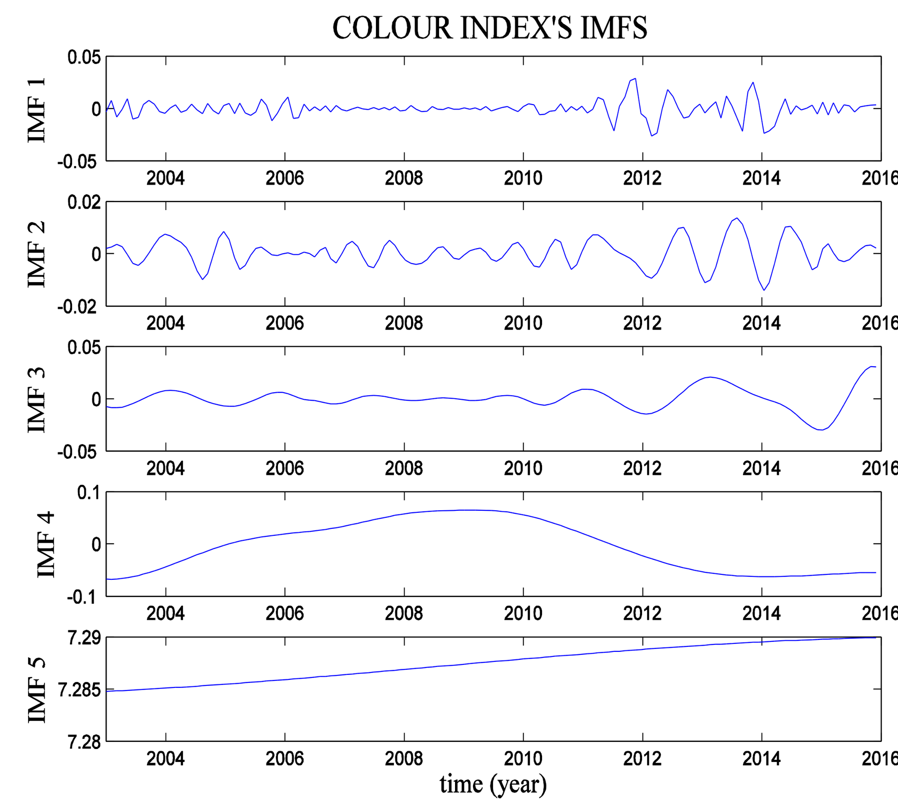
We point out the existence of two separate slopes, which merge during the solar minimum. Starting from this minimum the Mg II index is seen to increase while the colour index decreases. Around the maximum in 2013, the Mg II index reaches a maximum of 0.163 and colour index is at the minimum observed value of 7.19. The two observed slopes can be due to the SOLSTICE instrument degradation (e.g. Snow et al., 2014).



Empirical Mode Decomposition analysis

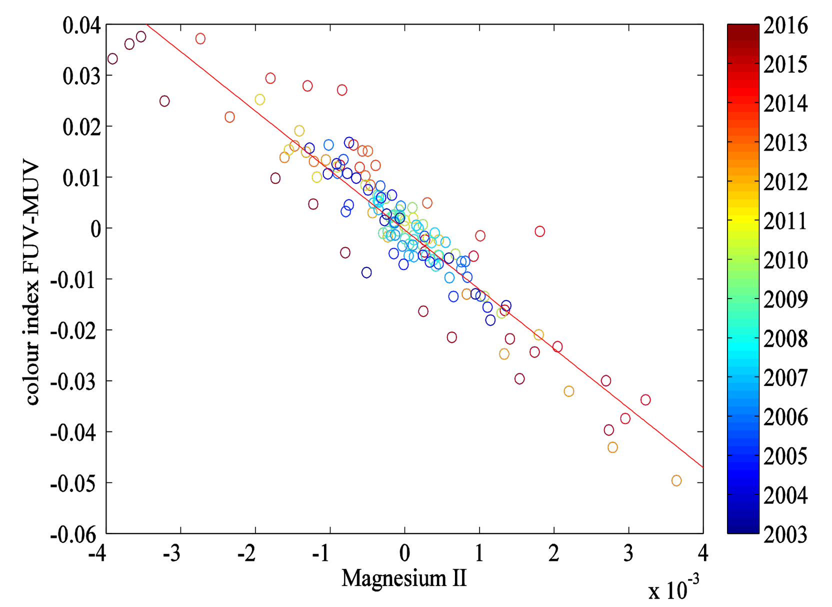
The signals associated to [FUV-MUV] colour index and Mg II flux have been studied for the time period (May 2003-October 2015). Their variability derives form activity of the Sun which is non-stationary, therefore an adaptive analysis is required. The Empirical Mode Decomposition (EMD) analysis is a signal processing technique developed by Huang et al. (1998) to especially analyze nonlinear, chaotic, and non-stationary signals. The EMD's main aim is to synthesize any signal as the sum of a finite number of functions, (Intrinsic Mode Functions or IMFs) computed a posteriori directly from the signal by an algorithm called the sifting process.

EMD is applied to Mg II monthly mean time series and to [FUV-MUV] colour index, resulting in 4 components for the Mg II index and 5 component for [FUV-MUV] colour index (figure shows the result of the EMD applied to [FUV-MUV] colour index).

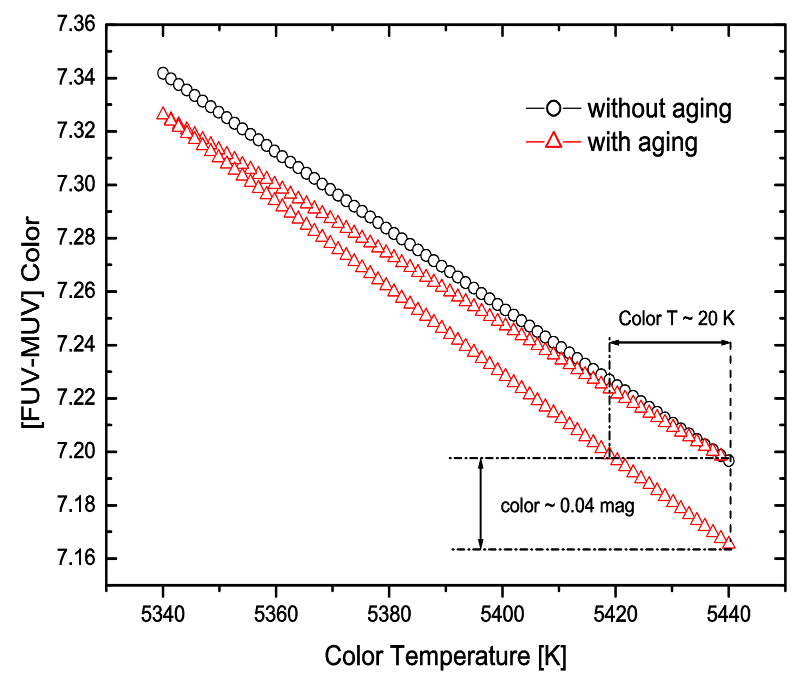


The IMFs of the colour index [FUV-MUV] are shown from the first (highest frequency) to the last (lowest frequency) starting from the top.

The first two components have the highest frequencies thus they are likely affected by "solar noise", so they haven't been considered in this work focused on the dependence on 11-years Schwabe cycle. Quasi biennial variation seem to rule the third components, while data trend is contained in the fourth components and corresponds to the solar cycle 11-years period.



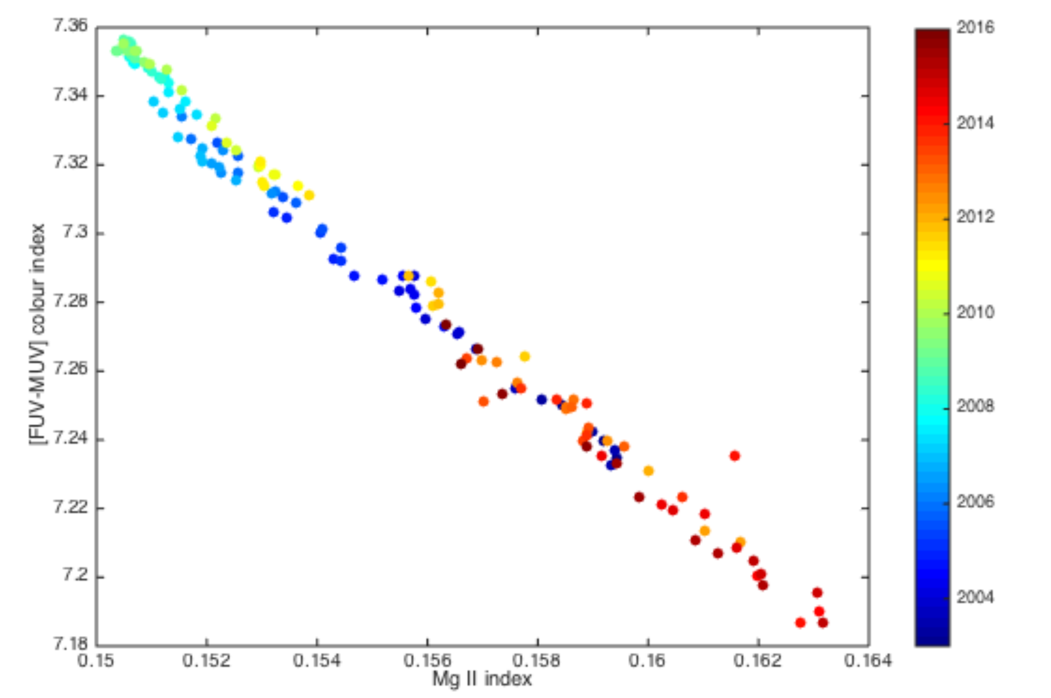
Scatter plot synthesized without the 11-y components. The circles represent the data, while the line represents the linear correlation. Data colour goes from blue to red and reflects the temporal evolution.



The colour index dependence on colour temperature assuming a linear dependence during the solar cycle. Black symbols show the relation without FUV channel ageing. Red symbols show the colour index variation considering a FUV channel ageing of a factor 0.0002 per month. This corresponds to a total reduction of 2.8% during the period and produces a colour temperature change of about 20 K.

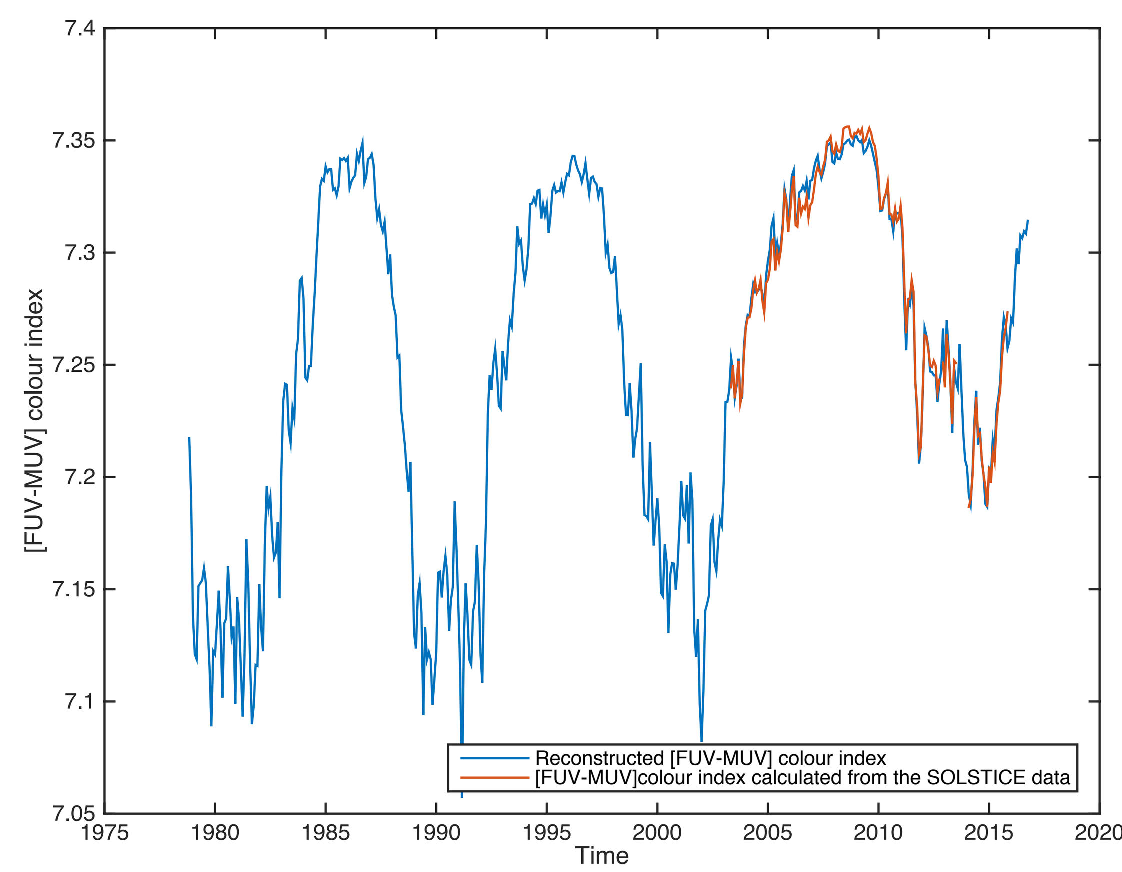
Reconstruction of the [FUV-MUV] colour index

First step in the reconstruction of the [FUV-MUV] colour index is removing of the ageing of the FUV channel.



Correlation between the Mg II index and the [FUV-MUV] colour index after removing ageing of the FUV channel

The best fit was found to be linear (y=-12.8859x + 9.28945) and it was used to reconstruct the [FUV-MUV] colour index in the past, for the period Mg II index is available.



Reconstruction of the [FUV-MUV] colour index using the correlation with Mg II index