Solar Cycle 24 UV Radiation: Lowest in more than 6 Decades

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Abstract. Using spectra taken by the robotic telescope "TIGRE" (see Fig. 1 and the TIGRE-poster presented by Schmitt et al. at this conference) and its mid-resolution ($R = 20,000$) HEROS double-channel echelle spectrograph, we present our measurements of the solar Ca II H&K chromospheric emission. Using moonlight, we applied the calibration and definition of the Mt. Wilson S-index, which allows a direct comparison with historic observations, reaching back to the early 1960's. At the same time, coming from the same EUV emitting plage regions, the Ca II H&K emission is a good proxy for the latter, which is of interest as a forcing factor in climate models.

Our measurements probe the weak, asynchronous activity cycle 24 around its 2nd maximum during the past winter. Our S-values suggest that this maximum is the lowest in chromospheric emission since at least 60 years – following the longest and deepest minimum since a century. Our observations suggest a similarly long-term (on a scale of decades) low of the far-UV radiation, which should be considered by the next generation of climate models. The current, very interesting activity behaviour calls for a concerted effort on long-term solar monitoring.

1. S-index: A way to bridge the decades

Most measurements, whether space- or ground-based, suffer shifts or drifts whenever the instrumentation or calibration equipment is changed. In that respect, Olin Wilson's S-index of the chromospheric activity, seen as emission in the Ca II H&K line cores, is a perfect choice. Our solar S-values, taken from lunar spectra, are calibrated by the same list of stars used by the Mt. Wilson team (see e.g. Duncan et al. 1991). For a more detailed description of this process, see Schröder et al. (2012) and the poster on first TIGRE-results presented at this conference by Mittag et al.

Figure .1: TIGRE, formerly the Hamburg robotic telescope, with its $R \approx$20,000 double-channel (red & blue) spectrograph is now operating from Guanajuato, Mexico. "TIGRE" (Telescopio International de Guanajuato, Robotico Espectroscopico) is a joint project of the Universities of Hamburg, Guanajuato and Liège.

While Baliunas et al. (1995) never saw the Sun in any of its minima touch the basal flux S-level of inactive ("flat") main sequence stars (visible in the survey of Duncan et al. (1991) as a cut-off at around S=0.150), in 2008/9 the Sun did! In the minima of the 1970's and 1980's the smoothed S-values hovered above 0.160, distinctly larger than the S-values of "flat activity" stars with only basal chromospheric emission. By contrast in 2008/9 it averaged around 0.155 and on some plage-free days even got down to 0.150 (see Fig. 2 here and Schröder et al. (2012) for more details)!

2. The dismal activity of cycle 24

Hence, the present cycle no. 24 was anticipated with much interest. The installation of TIGRE (formerly the Hamburg robotic telescope) in Guanajuato, Mexico (see poster on TIGRE by Schmitt et al.) last year allowed us to spectroscopically monitor the Sun (using the Moon) over the period of autumn 2013 to spring 2014, which covers the 2nd maximum of this cycle. This activity maximum was driven by the southern solar hemisphere and came 2 years later and out of phase with the peak of northern activity. It brought the largest sunspot groups and the strongest flare activity of the current cycle, slightly exceeding the activity of the sharp first maximum in December 2011 driven by the northern solar hemisphere.

Fig. 3 illustrates the active appearance of the solar chromosphere in the Helium line at 304 nm on a typical day in May 2014 (right, by SDO), contrasting with an entirely

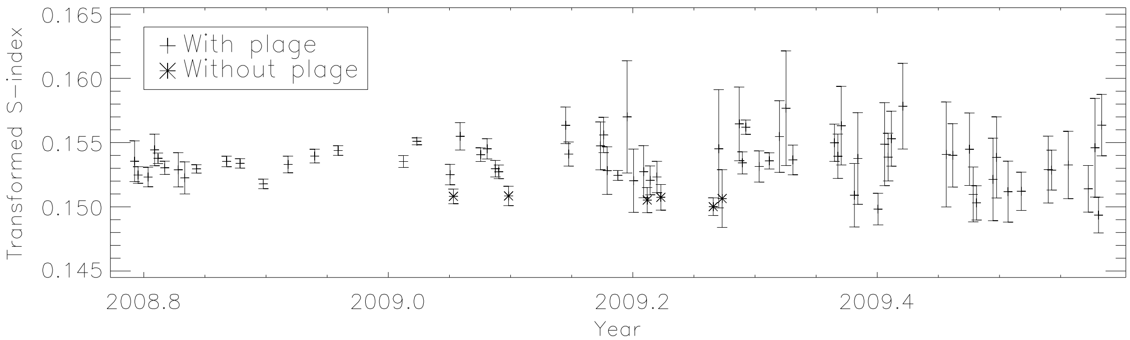

Figure .2: The extraordinary minimum of 2008/09 had a number of very inactive, even plage-free days, during which the Sun reached its basal flux level of S≈ 0.150.

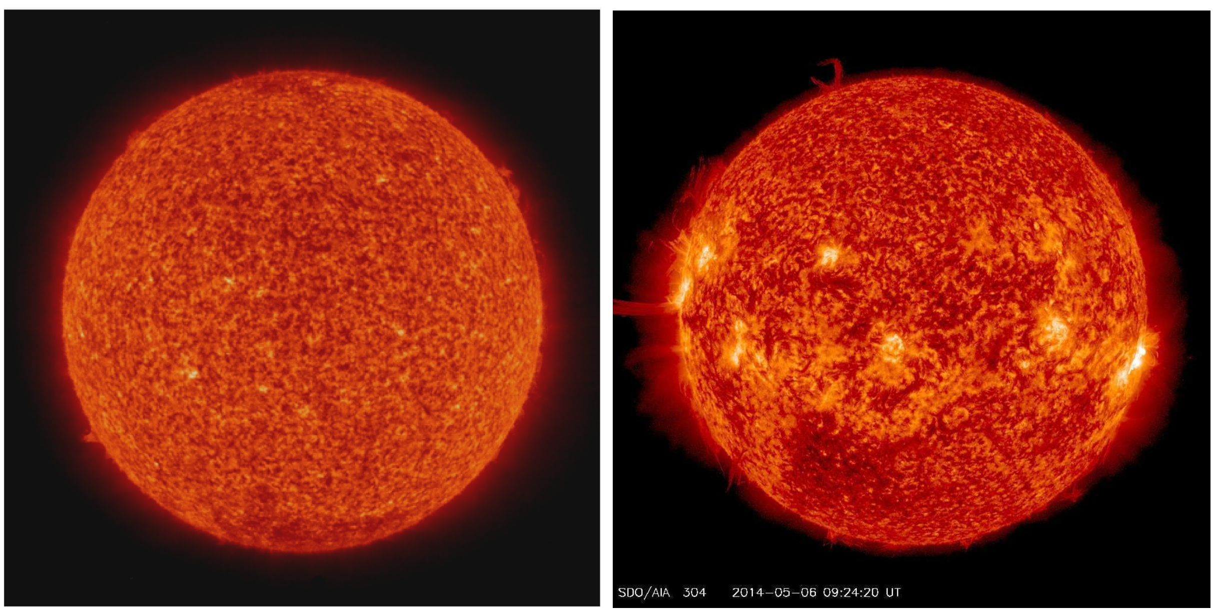

Figure .3: Several times, the solar chromosphere in the extraordinary minimum showed no sign of activity (left, SOHO-EIT, 304 nm), not even a plage, and the solar S-index reached its basal level of 0.150. Compare this to the rich chromospheric appearance in January 2014 (right, SDO, 304 nm)! Nevertheless, the S-index then rose to only between 0.170 and ≈0.175.

inactive day without even a plage as in February 2009 (SOHO-EIT. Indeed, our S-values from the past winter should about represent the strongest chromospheric emission of cycle 24. Nevertheless, in the spectrum of the entire Sun, Ca II H&K emission has not really increased that much:

In Fig. 4 we compare the hardly visible chromospheric emission in the core of the Ca II K line of such an inactive day (S≈ 0.15) with a typical active day (S≈ 0.17) in the past

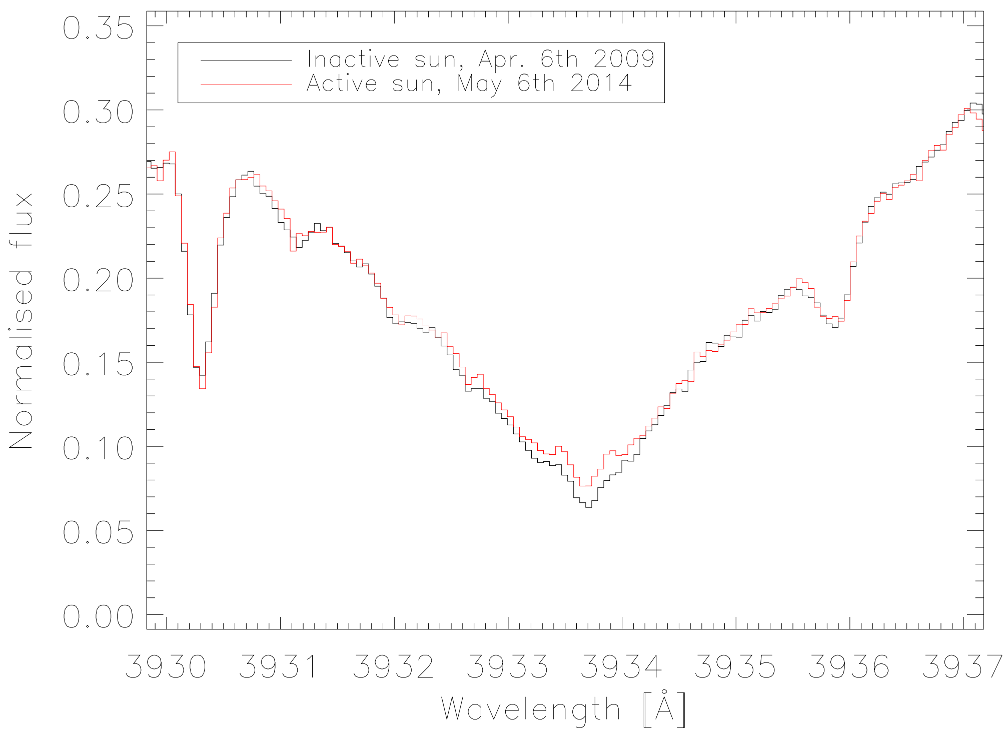

Figure .4: The solar chromospheric emission in the core of the Ca II K line at basal flux level (S≈0.15, as several times in 2008 and 2009) and at modest activity (S≈0.17) typical for the maximum of cycle 24.

winter. Smoothed over a month or so, our S-values of those months (see Fig 5) peak around only 0.172. That was the average over the whole previous cycle 23 (Hall et al. 2007), which saw a smoothed peak about S≈0.19.

3. Climate consequences of a historic underachiever?

The relatively weak past cycle 23 compared in strength to cycle 20 of the 1960's, which was the first solar activity cycle recorded by S-values from the Mt. Wilson team (see Fig. 6 from Baliunas et al. 1995). By contrast, cycles 21 and 22 of the 1970's and 1980's were about the strongest of the whole past century. They seem to compare only with cycle 19 of the 1950's and so represent the solar output around the past Gleissberg (or "grand") maximum.

Compared to those cycles 21 and 22, the chomospheric emission around the maximum of present cycle 24 is closer to the solar minimum emission of the 1980's (compare Fig. 5 with Fig. 6)!

The Ca II H&K emission of the active Sun stems from the same plages and hotter plasma as does the EUV and near-UV radiation. The latter and its variation is of much impact to stratospheric conditions and plankton growth and so constitutes a climate forcing factor.

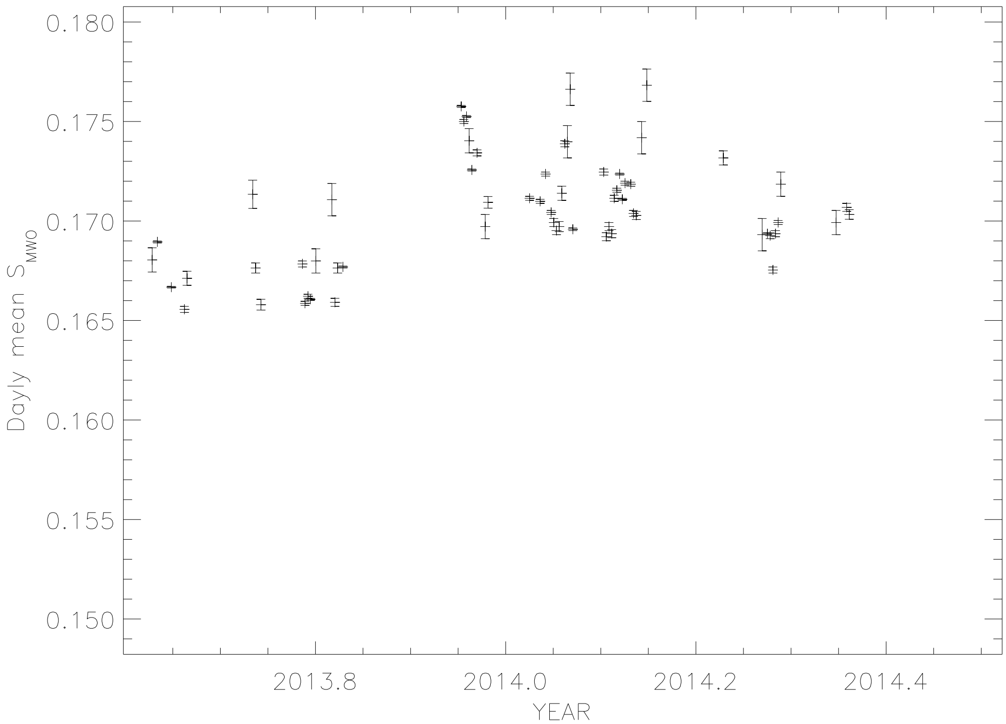

Figure .5: The second maximum of cycle 24 in 2013/14 produced the best disply of sunspots and flares. Nevertheless, our smoothed, well-calibrated S-values peak around only 0.172.

We regard Ca II H&K emission as a valuable proxy to the chromospheric UV and EUV radiation. While the latter can nowadays be observed with space-based instruments like SOLSTICE, such observations do not offer any direct comparison with data from 50 years ago.

Looking ahead, an average $< S >$ value for the whole cycle 24 will probably fall between 0.160 and 0.165 (minimum years: 0.150-0.160, maximum years: 0.165-0.175). Consequently, we must regard the current decade as being under "eternal solar minimum conditions" by 1980's solar UV radiation standards. See Schmidt et al. (2010) for such climate models with the HARMONIA code. Approaching a new "grand" minimum, *even lower UV forcing* must be expected for the next 1-3 decades.

Obviously, here is an urgent need to study amplification mechanisms, mainly known as "top-down" for the stratospheric impact and "bottom-up" for the ocean surface water warming. These seem to give UV forcing, despite its small share of total irradiation, an impact on local climate patterns, i.e. the Jet stream and North-Atlantic Oscillation (NAO), and the southern El-Niño-la-Niña Oscillation.

Certainly, the 1980's solar UV spectrophotometry still used by most climate models is now outdated. Consequently, a concerted effort by the solar-stellar community is required to provide up-to-date solar data for future climate models.

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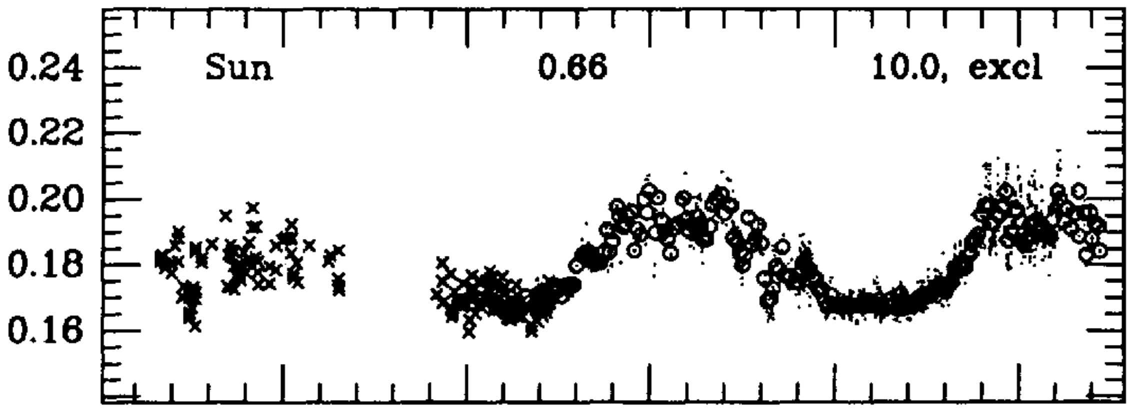

Figure .6: S-values of cycles 20-22 reported by Baliunas et al. 1995: averages of cycle 21 and 22 exceeded 0.20. By comparison the current chromospheric emission is extraordinarily low, well underscoring the weak cycle 20.

References

Baliunas, S. L., Donahue, R. A., Soon, W. H., et al. 1995, ApJ, 438, 269

Duncan, D. K., Vaughan, A. H., Wilson, O. C., et al. 1991, ApJS, 76, 383

Hall, J. C., Lockwood, G. W., & Skiff, B. A. 2007, AJ, 133, 862

Schmidt, H., Brasseur, G. P., & Giorgetta, M. A. 2010, Journal of Geophysical Research (Atmospheres), 115, 0

Schröder, K.-P., Mittag, M., Pérez Martínez, M. I., Cuntz, M., & Schmitt, J. H. M. M. 2012, A&A, 540, A130