Mem. S.A.It. Vol. 74, 663

Memorie della

Search for T_{eff} variations along the Solar Cycle

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Abstract. The measurements of the total solar irradiance (TSI) show the existence of variations on characteristic times going from few minutes to whole solar cycle, as a result of different physical mechanisms acting on different temporal scales. Along the cycle $\delta(TSI)$ is the order of 0.15%, in phase with the magnetic activity (cf. Fröhlich, 2000), attributed mainly to the overcompensation of the facular brightness vs the spot darkness and to a network variation. The problem of determining also a possible contribution due to a global variation of the photospheric background remains open.
Here we study the variations of the line-depth ratios measured by Gray and Livingston (1997a, 1997b) to determine δT_{eff} along the cycle and show that they cannot be attributed to a modulation of the photospheric background alone, but that active region effects are, probably, dominant.

Key words. Solar cycle, active regions, solar irradiance

1. Introduction

The existence of solar irradiance variations ($\delta(TSI) \simeq 0.15\%$) along the 11-yr cycle was confirmed definitively by active cavity bolometers measurements (cf. Fröhlich, 2000), but many uncertainties persist concerning the quantitative determination of the contributions by different sources. The proposed effects are:
(1) Overcompensation faculae-spots, which is clearly observed (Oster et al., 1982).
(2) Contribution of the network (Foukal and Lean, 1988), as confirmed by measures of the Rome Precision Solar Photometric Telescope (PSPT) by Ermolli et al. (2001).
(3) Changes of the photospheric background, suggested by the observed variations of the p-mode frequencies (Lydon, 1996).
An apparent confirmation of the background variation were the measured cyclic variations of T_{eff} sensitive lines (C I 538.032 nm, Fe I 537.959 nm and Ti II 538.102 nm) at Kitt Peak from 1978 to 1992 (Gray & Livingston (1997b, henceforth G&Lb). According to G&Lb, these lines are not affected by magnetic effects (no signal of rotation was found).
In particular Gray & Livingston (1997a, henceforth G&La) calibrated, by using observed spectra of several solar-like stars, the

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T_{eff} sensitivity (C_0) of the two line depth-ratios r (C/Fe and C/Ti) defined by the following approximate linear relation:

$$\delta T_{eff} = C_0 \frac{\delta r}{r} \quad (1)$$

Applying the result of this calibration to the solar data, they obtained as a result $\delta T_{eff} \approx 1.5K$, corresponding to the whole amplitude of measured irradiance variation; that did not leave room for the contributions to $\delta(TSI)$ due to the other effects, which, on the contrary, are well proven. Moreover the experimental calibration could not be reproduced by using 1D theoretical models (Kurucz, 1994) with different T_{eff} and constant gravity (Caccin and Penza, 2001).

In a previous paper (Caccin et al., 2002), we showed that G&La data can be well reproduced by 1D models, provided that the proper values of $\log g$ for individual stars are used, the stellar sample being affected by a significant gravity dispersion. Here we make preliminary evaluations of the possible effects of magnetic regions on these line ratios, by using suitable empirical models (RISE models, Fontenla et al., 1999). The capability of these models to reproduce different experimental data is tested by a comparison with some observations made at the PSPT of the Rome Observatory.

2. Magnetic cycle variations

2.1. Application of the stellar calibration

We apply the line-depth calibration of eq. 1 to the solar case (for more details, see Caccin et al., 2002), considering on the surface $r(T_{eff}, g)$ the curve at log(g)=4.44:

$$C_0^{-1} = \frac{\partial ln(r)}{\partial T}|_{SUN} \quad (2)$$

obtaining $C_0 = 576$ for C/Fe and $C_0 = 915$ for C/Ti. By application to the solar cycle variations $\delta r/r$ reported by G&Lb (0.0043 for C/Fe and 0.0032 for C/Ti), we obtain $\delta T_{eff} \approx 2.5 - 2.9K$, i.e. almost twice the observed total variations.

In disagreement with the G&Lb, however, we don't believe that these lines (in particular Fe and Ti, forming at smaller depths than C) don't feel the presence of active regions. Moreover, the same G&Lb data concerning the individual line variations cannot be reproduced only by a T_{eff} variation, thus supporting the idea that something else is occurring! In fact the three lines must respond in different manners to temperature changes (the C grows with increasing T_{eff}, while the Fe declines and the Ti remains practically constant); on the contrary, all of the observed line depths vary in the same direction.

$Modelname$	$Description$
$ModA$	$Fain\, Supergranule\, Cell$
$ModC$	$Average\, Sun$
$ModE$	$Average\, Network$
$ModF$	$Bright\, Network/Faint\, Plage$
$ModH$	$Average\, Plage$
$ModP$	$Bright\, Plage$
$ModS$	$Sunspot$

Table 1. Rise models description.

2.2. RISE models and comparison with PSPT data

The RISE models (Fontenla et al., 1999) are semiempirical atmospheric models, designed to represent across the solar disk the different active regions, summarized in Tab. 1.

We have calculated the center-limb of the network (modE) and facular (modF and modH) theoretical contrasts in the red (607.2 ± 0.5 nm) and blue (409.6 ± 0.25 nm) band, comparing them (Fig. 1 and 2) with the PSPT data, provided to us by the Solar Group of the Rome Observatory (for more details, see Ermolli et al., 1998 and Ermolli & Centrone, 2003).

We stress that the theoretical calcula-

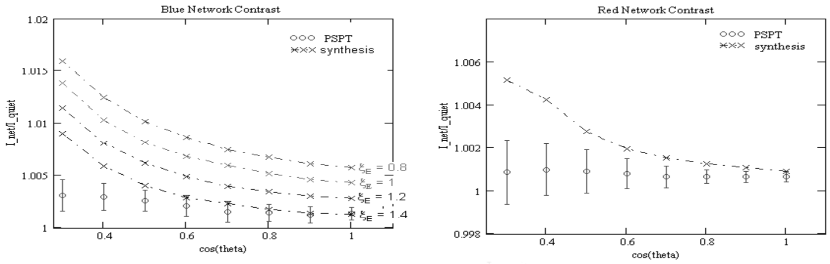

Fig. 1. Comparison between the theoretical network (modE) contrast and PSPT data. The microturbulence is kept constant for modC ($\xi_C = 1$ km/s), while is changed, for modE, from 1 to 1.4 km/s. The red contrast doesn't depend on the variation of ξ_E.

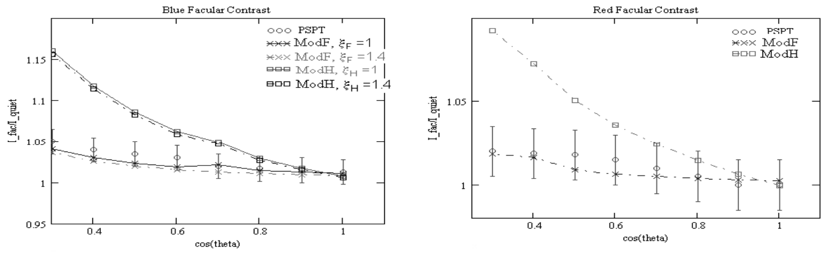

Fig. 2. Comparison between theoretical facular (modF and modH) contrast and PSPT data. As in Fig. 1, $\xi_C = 1$ km/s.

tions are made within LTE approximation, which, however, doesn't affect very much the results in the visible range. In fact, remaking the calculations by using models without chromospheric temperature rise (replaced by a linear extrapolation of the photospheric relation lg(T) vs lg(P) or vs lg(τ)), in analogy with Unruh et al. (2000), we obtained no substantial effect.
It's evident that, for the network, the blue contrast strongly depends on the choice of the microturbulence parameter, while the facular contrasts seem to be less "ξ-sensitive".

2.3. Effects of the active regions on the G&L line

To estimate the sensitivity to the presence of active regions, we calculate the line profiles by using the RISE models. The trend of the lines (Fig. 3) is rather clear for the Fe and Ti, which are weaker in the more active regions, thus suggesting that, probably, part of the effects measured by G&Lb was due to the active regions. The behavior of the C line, instead, is more uncertain: it doesn't vary very much and doesn't have a monotonic trend, resulting deeper for modE, F and H and weaker for modP. A preliminary confirmation of these results

$Line$	$BP1$	$BP2$	$BP3$	$\delta(ModE)$	$\delta(ModF)$	$\delta(ModH)$	$\delta(ModP)$
$Fe\,I$	−6.0%	−29%	−7.1%	−2.8%	−6.8%	−16.6%	−27%
$C\,I$	+4.2%	−18.7%	+16.5%	+0.8%	+2.6%	+4.6%	−1.0%
$Ti\,II$	−3.8%	−18.8%	−3.0%	−1.1%	−2.9%	−8.1%	−14.5%

Table 2. Observed line-depth differences between three bright points (BP) and the neighbouring quiet zone. The theoretical differences are made between the active region models and ModC.

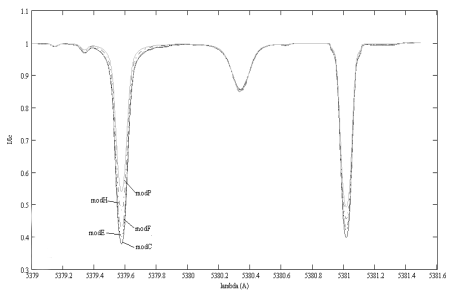

Fig. 3. Changes of the line-depth of C, Fe and Ti for the different RISE models. The micro-turbulence value is maintained constant for all the models.

comes from the observations made at the Dunn Solar Tower of the NSO Sacramento Peak Observatory (Penza et al., 2002), that highlight the line variations passing from a quiet zone to a bright point, as reported in Tab. 2. For Fe and Ti we have a good agreement with experimental data, remembering that we are comparing single measurements with theoretical results obtained by using models born to reproduce *average* behavior. It's more complicated to draw conclusions concerning the C line, because the same experimental data are of difficult reading, this line being so weak and the measures being affected by a blend (of probable telluric origin) in the blue wing.

3. Conclusions

1. We have shown that the line variations observed by G&Lb can not be caused only by a background δT_{eff}.
2. We have tested the capability of the FAL models to reproduce obserced spectral variations, comparing the theoretical network and facular contrasts with those measured at the Rome PSPT.
3. We have verified the G&Lb lines are sensitive to the presence of active regions, that, therefore, could be the main cause of their observed cyclic modulation.

Acknowledgements. We are grateful to R. Falciani, who has provided the results of the NSO observations and to the Solar Group of the Rome Observatory for the PSPT data.

References

Caccin, B., & Penza, V., 2000, Il Nuovo Cimento, *in press*
Caccin, B., Penza, V. & Gomez, M.T., 2002, A&A, 386, 286
Ermolli, I., Fofi, M., Bernacchia, C., Berrilli, F., Caccin, B., Egidi, A. & Florio, A., 1998, Solar Physics, 177, 1.
Ermolli, I., Berrilli F., Florio, A., 2001, Am. Geo. Un., Spring Meeting 2001, SP21A-03.
Ermolli, I., & Centrone, M., 2003, Mem. Sait., in press.
Fontela, J., White, O.R., Fox, A.P., Avrett, E.H. & Kurucz R.L., 1999, APJ, 518, 480.
Foukal, P. & Lean, J., 1988, APJ, 328, 347
Frölich, C., 2000, Space Science Rev, 94, 15
Gray, D.F., & Livingston, W.C., 1997a, APJ, 474, 798
Gray, D.F., & Livingston, W.C., 1997b, APJ, 474, 802
Kurucz, R.L., 1994, CD-ROM No. 19
Lydon T.J., Gunther D.B., Sofia S., 1996, APJ, 456, L127
Oster, L., Schatten, K.H. & Sofia, S., 1982, APJ, 256, 768
Penza, V., Caccin, B., Falciani, R., Cauzzi, G., Falchi, A., Smaldone, L.A., 2002, Themis Workshop, Toulose, April 2002, *in press.*
Unruh, Y.C., Solanki, S.K. & Fligge M., 2000, Space Sc. Rev., 94, 145.