ENERGY TRANSPORT IN DEEP UMBRAL LAYERS∗

A.A. van Ballegooijen
Astronomical Institute at Utrecht
Zonnewijde 2
3512 NL Utrecht, The Netherlands

ABSTRACT

A high resolution IR spectrum of a sunspot umbra was used to construct models of the temperature structure in the deepest accessible layer in a sunspot. The spectrum was obtained with the Fourier Transform Spectrometer at the McMath telescope at KPNO and covers the wavelength range from 1.1 to 2.3 μm. To calibrate the intensity we used a similar spectrum of the photosphere and the photospheric model of Ayres (1978), which is a revised version of the Vernazza et al. (1976) model. The photospheric straylight contribution to the umbral intensity, estimated with the hydrogen line at λ = 1.282 μm, is smaller than 6%. Models of temperature T(τ_{0.5}) versus optical depth at λ = 0.5 were generated iteratively, assuming a simple distribution of the integrated radiative flux F(τ_{0.5}) = \int F_\lambda d\lambda with two free parameters F_1 and F_2:

\[ F(\tau_{0.5}) = F_1, \quad \tau_{0.5} \leq 1 \]

\[ = F_1 + (F_2 - F_1) \left( \frac{\tau_{0.5} - 1.0}{\tau_m - 1.0} \right), 1 \leq \tau_{0.5} \leq \tau_m \]

\[ = F_2, \quad \tau_{0.5} \geq \tau_m \]

The monochromatic flux \( F_\lambda(\tau_{0.5}) \) was calculated using only

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continuous opacity sources. For $\tau_m = 2.5$ and 4.0 the parameters $F_1$ and $F_2$ were fitted to yield the emergent intensity of the uncorrected data; the errors of fit are 0.26% and 0.35% r.m.s. respectively, well within the accuracy of the data and the calibration. The radiative flux $F_2$ in the deep layers is smaller than the surface flux $F_1$ by 29% for $\tau_m = 2.5$ and by 39% for $\tau_m = 4.0$. For both models $F_1$ corresponds to $\tau_m$ an effective temperature of 4190 K.

Since we neglected line blanketing effects, the radiative flux may have been overestimated and the decrease of $F(\tau_{0.5})$ with optical depth may be partly due to a decreasing contribution of molecular and atomic lines to the opacity. However, the magnitude of the effect and the fact that it occurs at large optical depth indicate that the decrease of radiative flux with depth is partly real. This would require an alternative energy transport mechanism immediately below the level $\tau_{0.5} = 1$ in the umbra.

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References: