On the nature of the Evershed effect

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Abstract

Observations of Stokes I and V profiles of 1.56 μm lines in and around sunspots near the solar limb are presented. These observations cast serious doubt on the standard interpretation of the photospheric Evershed effect in terms of a steady flow.

1. Introduction

The Evershed effect is generally thought to be produced by a steady horizontal outflow of material in the photospheric layers of penumbrae. In contrast to practically all previous observations, which have been restricted to visible spectra in unpolarized light, we analyze both Stokes I and V spectra and investigate two lines at 1.56 μm (namely the Landé $g = 3$, Fe I 1.5648 μm and $g_{\text{eff}} = 1.53$, Fe I 1.5653 μm lines).

Two sunspots near the solar limb ($\mu = \cos\theta \approx 0.5$–$0.6$) were observed with the McMath telescope along a slice passing radially through them. We determine magnetic field strength and inclination, velocity shift and broadening, non-magnetic stray-light and temperature from these data using an inversion technique. See Solanki et al. (1993) for more details on the data, analysis and results.

2. Results

The spectra from the limbward and discward penumbra show large relative shifts and Stokes I asymmetries (see Fig. 1). Best fits to the penumbral profiles are obtained for horizontal Evershed flow velocities between 2.5 km s^{-1} and 4.5 km s^{-1}, with an average value of 3.6 km s^{-1}.

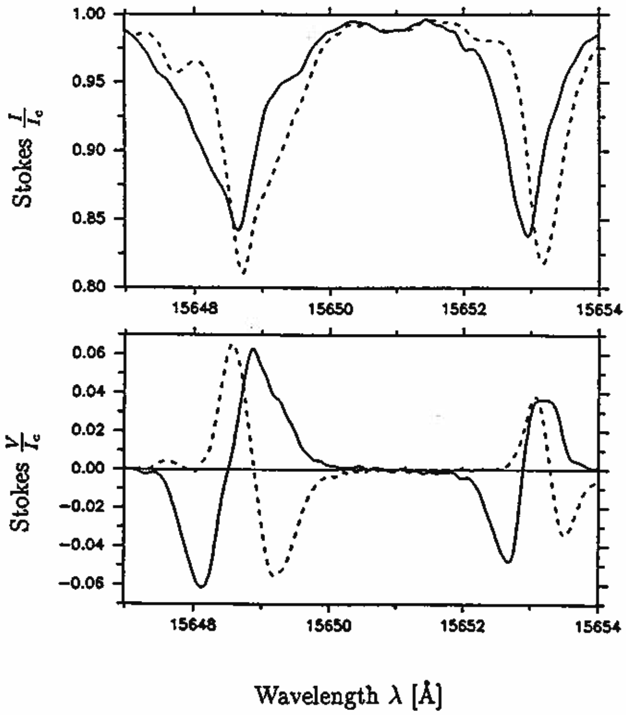

Figure 1: Stokes I (upper frame) and V profiles (lower frame) observed in the penumbra. Solid curves: discward penumbra, dashed curve: limbward penumbra.

Most of the spectra observed outside the visible contours of the sunspot still show non-vanishing V profiles, as expected for a canopy of horizontal magnetic field overlying a non-magnetic atmosphere. The most intriguing aspect of the superpenumbral data is that whereas the I profiles have roughly the same wavelength in the limbward and discward *superpenumbrae*, the V profiles are shifted by approximately 0.5–2 km s^{-1} towards the red and blue, respectively (see Fig. 2).

The difference between the shifts of the V and I profiles is explained by noting that the contributions to the Stokes I profiles of both lines peak well below the height of the canopy base. Consequently, the I profile wavelengths respond dominantly to velocities below the canopy. The V profiles, on the other hand, are only formed in the magnetic portion of the atmosphere, i.e. above the canopy, so that the V profile shifts reflect flows above the canopy base. Thus, our data suggest that the Evershed flow continues at a speed of 0.5–2 km s^{-1} beyond the outer boundary of the sunspot, but only above the base of the magnetic canopy, which lies $\gtrsim 300$ km above the $\tau = 1$ level at distances greater than 8000 km from the sunspot.

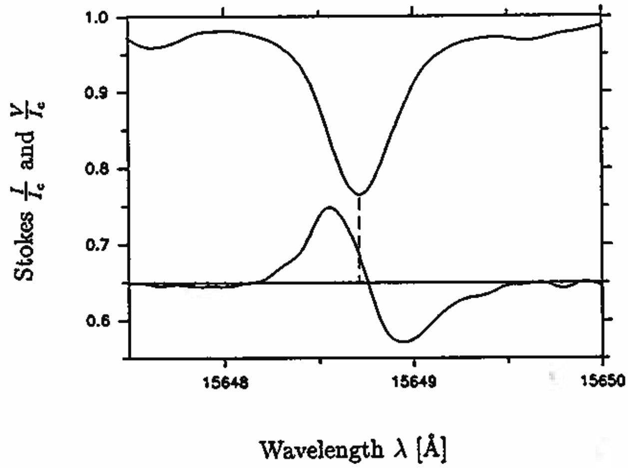

Figure 2: Stokes I and V profiles observed in the limbward part of the superpenumbral canopy of the sunspot. Note the wavelength shift of the V zero-crossing relative to the Stokes I line core.

Our best estimate of the mass flux due to the Evershed effect gives a value in the penumbra that is 10 times larger than in the superpenumbral canopy. The main reason for this difference is the larger height at which the flow is measured in the superpenumbra, coupled to the rapid decrease in density with height in the atmosphere.

3. Conclusions

The analysed lines exhibit the Evershed effect in both sunspot penumbrae and superpenumbral canopies. Although the line shifts associated with the Evershed effect are clearly seen beyond the visible outlines of the sunspot, they are restricted to heights above the canopy base. Since the gas density at these heights is an order of magnitude smaller than at the height at which the largest Evershed shifts are measured in the penumbra, the mass flux in the canopy is also an order of magnitude smaller than in the penumbra (under the assumption that the Evershed effect is caused by a steady outflow of matter). Thus, the limits set by the current observations cast serious doubts on steady flows as the source of the Evershed effect.

References

Solanki, S.K., Montavon, C.A.P., Livingston, W. (1993). A&A submitted