FACULAR MODELS AND THE SUNSPOT ENERGY DEFICIT

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Abstract. The problem of the energy deficit in a sunspot is shown to be critically related to the depth of a given sunspot model. Recent facular models are discussed and a new model is derived from recent data using a two-dimensional radiative transfer analysis. The excess non-radiative energy required by this and other models is evaluated and it is shown that in some models this may account for a considerable fraction of the sunspot energy deficit. For these models the Alfvén energy travelling along the closed flux loops from the sunspot is insufficient to supply the requirements of the faculae and it is suggested that excess energy flux from below the faculae is also required. These results provide further support for 'deep' as opposed to 'shallow' sunspot models.

1. Introduction

The problem of the energy deficit in a sunspot has been investigated by several authors (e.g. Kiepenheuer, 1966; Wilson, 1968a). Consider a sunspot with umbral radius \(7 \times 10^3\) km and effective temperature 4000 K surrounded by a penumbra of width \(10^4\) km and effective temperature 5300 K. The energy flux through this area is \(3.58 \times 10^{29}\) erg s\(^{-1}\) compared with \(5.80 \times 10^{29}\) erg s\(^{-1}\) for a similar area of the photosphere at 5800 K. If the energy flux is assumed uniform at great depths (i.e. \(>2 \times 10^4\) km) this flux deficit of \(2.2 \times 10^{29}\) erg s\(^{-1}\) requires some explanation. Kiepenheuer considered the excess energy emitted in the associated faculae, the bright ring sometimes observed around sunspots and the Evershed flow and found that the photospheric faculae were the most likely explanation. He suggested that the total facular area is some four times that of the spot and of this, perhaps 2% is occupied by bright faculae emitting an excess of 10% over the normal photospheric flux. In an earlier discussion (Wilson, 1968a) I applied these values to the above model and obtained an excess flux of \(6.6 \times 10^{27}\) erg s\(^{-1}\). However, an examination of photographs of faculae near spots shows that this estimate of 2% is far too low and is not even consistent with Kiepenheuer's results for his own model. For a spot such as that shown in Figure 1a (31 August 1966) the area occupied by bright faculae must be nearly half that of the sunspot while in Figure 1b the area appears to equal that of the sunspot. If we adopt a figure of 50%, the excess flux is of order \(2.5 \times 10^{28}\) erg s\(^{-1}\) which is still an order of magnitude too small.

The problem is critically related to the depth scale of a sunspot. In the earlier discussion I suggested that, because the energy flux deficit was not observed in the umbra, a sunspot must be a deep phenomenon, i.e. the distortion of the normal energy flux pattern must extend to depths of order 20000 km. A model was put forward in which the normal energy flux is diverted around the base of a sunspot but...
Fig. 1. (a) Faculae surrounding a regular isolated sunspot near the west limb on 1 August 1966. This photograph was reproduced from Sacramento Peak white light patrol photographs. (b) Faculae in the neighbourhood of a sunspot at the limb. Photograph obtained at Kitt Peak Observatory on 12 September 1970.