Properties of sunspots in cycle 23

I. Dependence of brightness on sunspot size and cycle phase

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ABSTRACT

Aims. In this paper we investigate the dependence of umbral core brightness, as well as the mean umbral and penumbral brightness on the phase of the solar cycle and on the size of the sunspot.

Methods. Albrechtsgen & Maltby (1978, Nature, 274, 41) reported an increase in umbral core brightness from the early to the late phase of solar cycle from the analysis of 13 sunspots which cover solar cycles 20 and 21. Here we revisit this topic by analysing continuum images of more than 160 sunspots observed by the MDI instrument on board the SOHO spacecraft for the period between 1998 March to 2004 March, i.e. a sizable part of solar cycle 23. The advantage of this data set is its homogeneity, with no seeing fluctuations. A careful stray light correction, which is validated using the Mercury transit of 7th May, 2003, is carried out before the umbral and penumbral intensities are determined. The influence of the Zeeman splitting of the nearby Ni I spectral line on the measured “continuum” intensity is also taken into account.

Results. We did not observe any significant variation in umbral core, mean umbral and mean penumbral intensities with solar cycle, which is in contrast to earlier findings for the umbral core intensity. We do find a strong and clear dependence of the umbral brightness on sunspot size, however. The penumbral brightness also displays a weak dependence. The brightness-radius relationship has numerous implications, some of which, such as those for the energy transport in umbrae, are pointed out.

Key words. Sun: sunspots

1. Introduction

Albrechtsgen & Maltby (1978, cf. Albrechtsgen & Maltby 1981; Albrechtsgen et al. 1984) reported a dependence of umbral core brightness on the phase of the solar cycle based on 13 sunspots observed at Oslo Solar Observatory. The umbral core is defined as the darkest part of the umbra. According to their findings, sunspots present in the early solar cycle are the darkest, while as the cycle progresses spots have increasingly brighter umbrae. Also, the authors did not find any dependence of this relation on the size or the type of the sunspot. Following this discovery Maltby et al. (1986) proposed three different semi-empirical model atmospheres for the umbral core, corresponding to early, middle and late phases of the solar cycle.

In order to explain the umbral brightness variation with solar cycle two hypotheses have been put forward. Schüssler (1980) proposed that umbral brightness may be influenced by the age of the sub-photospheric flux tubes, whereas Yoshimura (1983) suggested that the brightness of the umbra depends on the depth in the convection zone at which the flux tube is formed. Confirmation of these results appears important for two reasons. Firstly, this is the only strong evidence for a dependence of local properties of the magnetic features on the global cycle. E.g., the facular contrast does not depend on solar cycle phase (Ortiz et al. 2006). Secondly, such a confirmation appears timely in the light of the recent paper by Norton & Gilman (2004), who reported a smooth decrease in umbral brightness from early to mid phase in solar cycle 23, reaching a minimum intensity around solar maximum, after which the umbral brightness increased again, based on the analysis of more than 650 sunspots observed with the MDI instrument. This decrease in brightness contradicts the results of Maltby et al. (1986). Also, the data used by Norton & Gilman (2004) were not corrected for stray light and no sunspot size dependence of the brightness was discussed.

In this paper we investigate the dependence of umbral core brightness, as well as the mean umbral and penumbral brightness on the solar cycle and on the size of the sunspot. In the following section we describe the data selection. In the third section we deal with the data correction for stray light and for the influence of Zeeman splitting of the nearby Ni I absorption line on continuum measurements. In Sects. 4 and 5 we present our results. We discuss our results and compare them with earlier findings in Sect. 6.

2. Data selection

Continuum full disk images recorded by the Michelson Doppler Imager (MDI; Scherrer et al. 1995) on board the SOHO spacecraft are used in this analysis. The continuum images are obtained from five filtergrams observed around the Ni I 6768 Å mid-photospheric absorption line with a spectral pass band of 94 mÅ each. The filtergrams are summed in such a way as