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MONOCHROMATIC IMAGES OF SUNSPOTS IN LINEARLY POLARIZED RADIATION AND STRUCTURE OF THEIR MAGNETIC FIELDS

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ABSTRACT The monochromatic images of unipolar sunspots in the Stokes parameters Q and U of magneto–sensitive lines display a complicated structure. This is caused by the magneto–optical effect and also connected with the 3–D structure of spot magnetic fields. In the process of numerical simulation it is possible to check the regularities of the change of the angle of inclination of magnetic lines of force with distance from spot center.

1. INTRODUCTION

The monochromatic Q and U images of unipolar sunspots exhibit an interesting configuration. Each image consists of four quadrants and the neighboring ones have alternately plus and minus signs. Moreover, each quadrant contains a set of concentric closed curves. Figure 1 is the U image of a large spot observed in FeI λ 5324 on April 28, 1988 at the Huairou Station of the Beijing Observatory. Figure 2 is the longitudinal magnetogram of the same spot. It is impressive to note that these two images, belonging to one and the same spot, have drastically different shapes. Observations of the Marshall Space Flight Center yield the same result.

2. THEORETICAL INTERPRETATION

The peculiar configuration of the Q and U images of sunspots can be interpreted with the magneto–optical effect (Landi Degl' Innocenti, 1979). On the

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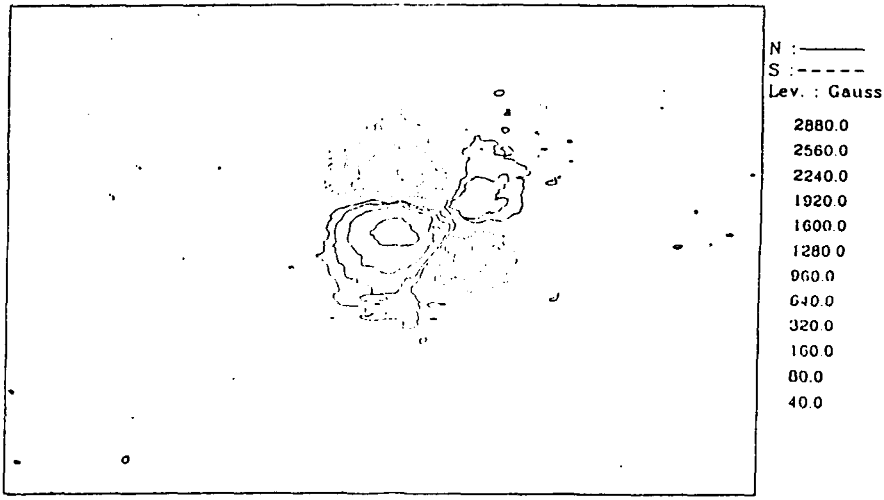

Fig. 1. Monochromatic U image of a sunspot.

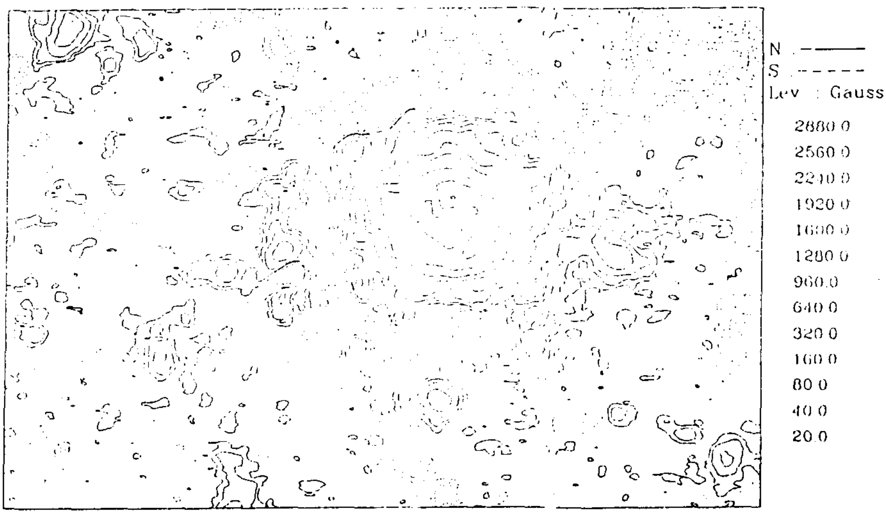

Fig. 2. Longitudinal magnetogram of the same spot.

basis of our former work (Ye Shi–hui and Jin Jie–hai, 1986), we performed numerical solutions of Unno–Beckers' equations, i.e.

$$\begin{cases} \cos\theta\dfrac{dI}{d\tau} = (1+\eta_I)(I-B) + \eta_Q Q + \eta_U U + \eta_V V, \\ \cos\theta\dfrac{dQ}{d\tau} = \eta_Q (I-B) + (1+\eta_I)Q + \rho_R U + \rho_W \sin 2\chi V, \\ \cos\theta\dfrac{dU}{d\tau} = \eta_U (I-B) - \rho_R Q + (1+\eta_I)U - \rho_W \cos 2\chi V, \\ \cos\theta\dfrac{dV}{d\tau} = \eta_V (I-B) - \rho_W \sin 2\chi Q + \rho_W \cos 2\chi U + (1+\eta_I)V. \end{cases}$$

The magneto–optical effect is represented by the following two coefficients:

$$\begin{cases} \rho_R = \dfrac{\eta_0}{H(0,a)} \cos\gamma [F(v - v_H, a) - F(v + v_H, a)], \\ \rho_W = \dfrac{\eta_0}{H(0,a)} \dfrac{\sin^2\gamma}{2} [F(v - v_H, a) + F(v + v_H, a) - 2F(v,a)], \end{cases}$$

where

$$F(v,a) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \frac{v}{u^2 + a^2} e^{-(u-v)^2} du.$$

Moreover, we computed the signals of linear polarization defined by

$$\tilde{Q} = \int Q(\lambda) f(\lambda) d\lambda \Big/ \int I(\lambda) f(\lambda) d\lambda ,$$
$$\tilde{U} = \int U(\lambda) f(\lambda) d\lambda \Big/ \int I(\lambda) f(\lambda) d\lambda ,$$

where $f(\lambda)$ is the transparency profile of the birefringent filter. Then we calculated for sunspots their theoretical Q and U images, which agree rather well with the observed ones.

3. INCLINATION OF MAGNETIC LINES OF FORCE

It is interesting to note that the theoretical Q and U spot images are concerned with the inclination angle γ of magnetic lines of force to the normal on the solar surface. In the fan–shaped model (Hale and Nicholson, 1938) γ is equal to a $\frac{\pi}{2}\rho$, where a is an adjustable coefficient and ρ is the distance from the spot center divided by the spot radius. We have found that for a = 1 theoretical images agree well with observed ones. But when a becomes smaller, e.g. a = 0.833 and 0.3, the agreement is worse (see Figure 3). This may possibly mean that for the fan–shaped model we have to use the formula $\gamma = \frac{\pi}{2}\rho$.

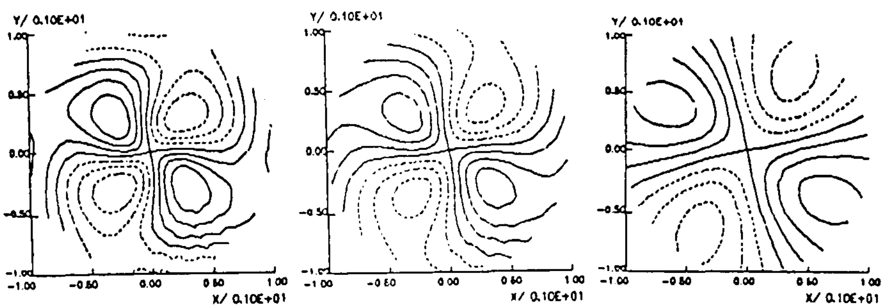

Fig. 3. Theoretical Q images computed for fan–shaped model with a = 1, 0.833 and 0.3(from left to right).

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We have also done numerical simulation with Osherovich's (1982) return–flux model and the agreement between theory and observation seems to be still better (figure 4). Therefore, we can say that this model may be closer to reality than the classical fan–shaped model.

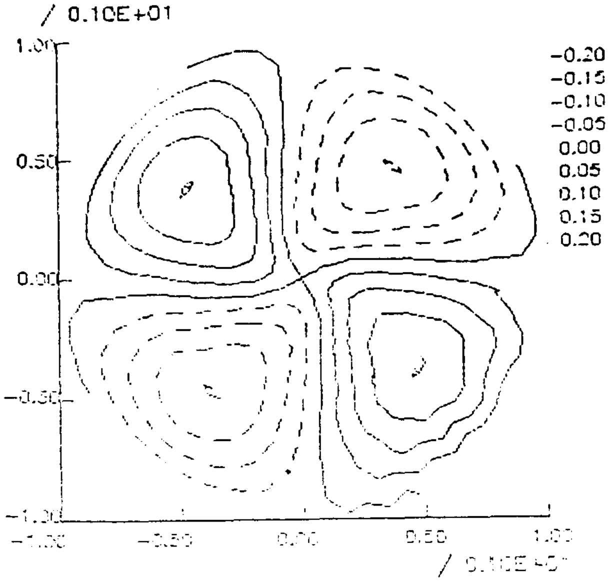

Fig. 4. Theoretical U image calculated with return–flux model.

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