The Physics of Sun and Star Spots
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Are the umbral dots, penumbral grains, and G band bright points formed by the same type of magnetic flux tubes?

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Abstract. Today's Solar Physics comes across of different type of fine structures in solar atmosphere including umbral dots and penumbral grains in sunspots, and G-band bright points in quiet Sun. In this report, we present evidence that umbral dots, penumbral grains, and, possibly, G band bright points are related to a common type of features in solar atmosphere magnetic flux tubes.

Keywords. Umbral dots, penumbral grains, sunspots, G-band bright points

1. Introduction

Stratospheric balloon-borne observations of sunspots in USA under leadership of M. Schwarzchild in 1959 (Danielson 1964), and balloon experiments in USSR under leadership of V. Krat (Krat *et al.* 1972) excited great interest and put forward many problems in physics of sunspot fine structure. The mechanism of emergence of so-called umbral dots, their relation with penumbral filaments are examples of questions raised by these observations. These earlier stratospheric observations had turned out to be insufficient for study the dots evolution, which require long-term observations; and the author was among the first observers, who begun studying the sunspots' fine structure using ground-based telescopes. Today's Solar Physics comes across different types of fine structures in solar atmosphere. In this report we present evidence to support that umbral dots, penumbral grains, and, possibly, G-band bright points are related to the same type of features magnetic flux tubes in solar atmosphere.

2. The telescope and observations

Horizontal solar telescope ATSU-5 used by us is one of the serial instruments (D=44 cm, F=1700 cm, where D is diameter of main mirror, and F is its focal length) developed by Russian optician V.N. Ponamarev 55 years ago. Ten years later, the majority of Soviet Union observatories were equipped with such telescopes. In 1964, ATSU-5 telescope was mounted in Tashkent Astronomical Observatory in the city of Tashkent. The territory of Uzbekistan is very sunny. In Tashkent, the average sunshine time is near 2900 hours per a year with a consistently very good seeing from June 20 to the beginning of October. The very good seeing takes place during windless and hot weather, frequently for several days before a cyclone. White light observations of sunspots, discussed in this article, were carried out in Cassegrain focus (diameter of solar disk is 60 cm) using high-speed 35 mm photographic camera (exposure time 0.01 sec). Bursts of images were taken during the periods of best seeing, based on visual control by the observer (the author of this article). Spectral observations were conducted in Newton (prime) focus of the telescope

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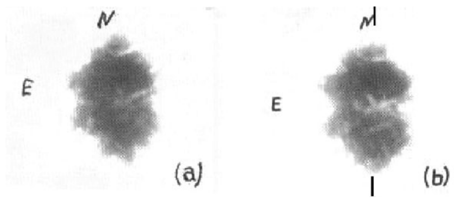

Figure 1. Two prints (a 0650 UT, b 0828 UT) of umbra of the unipolar sunspot observed 8 August 1981 at the ATSU-5 in Tashkent. Vertical touch on Fig. 1b shows position of spectrograph's slit at receiving spectrum presented on Fig. 3.

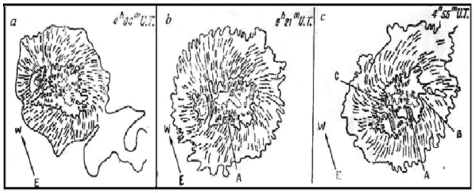

Figure 2. Drawing of penumbral grains and umbral dots (short filigree) of the large sunspot exhibiting counter-clockwise rotation for 14(a), 15(b) and 16(c) September 1977.

using ASP-20 horizontal spectrograph with linear dispersion of 0.6 Å / mm at optical wavelength. The spectra were recorded using photographic plates and film with exposure time of 1-3 seconds. The observations were used to study the magnetic field, fine structure and evolution penumbral filaments and umbral dots.

3. The results of sunspots fine structure studies

It was found that in most studied cases the umbral dots persist for more than 30 minute: 43 % of dots persist more than 60 minutes and 10% - more than 90 minutes. In their evolution, bright dots increase the brightness reaching the maximum during a relativity short time, and after that, gradually become weaker and expand. Finally, the dots break up and disappear (Sattarov 1981a). Most of bright dots are observed at the disk center side of penumbra umbra boundary (as in right side of umbra on Fig. 1 b).

In September 1977, a rotation of an unipolar sunspot with two umbrae (small northern and large southern umbra) was observed. During 13-16 September the spot rotated by 700 around its northern small umbra in counter-clockwise direction. The rotation affected the orientation of penumbral filaments (grains) and umbral fine structure, twisting them in clockwise direction. In the course of rotation, the main (large) umbra was deformed; its east boundary was "attacked" by brushes of penumbral grains, which appear as "peninsula" intruding into the umbra. The dots in front of "peninsula" were transformed into the bright penumbral grains. On the west boundary of main umbra, the opposite affect took place, i.e. the penumbral west boundary joined the umbra and the bright penumbral grains turned into the umbral dots (Sattarov 1981b). It appears that the magnetic flux tube that forms the large unipolar sunspot rotates, indeed. The rotation may be caused by interaction of the magnetic tube forming unipolar sunspot and the magnetic tubes of new sunspot group developed near the southern boundary of the penumbra of unipolar sunspot. The magnetic field of sunspot had southern (S) polarity, and the sunspot of leading (N) polarity of this new group had developed near it later (Sattarov 1981b). Between the white light observations we took spectrograms of sunspots by scanning their umbrae in selected (narrow or wide) spectral bands. In the

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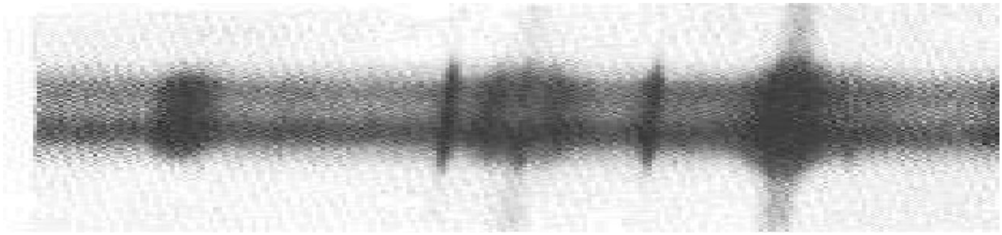

Figure 3. A part of the central section (noted in Fig. 1b by vertical stroke) spectrum with the line Fe I 6302.5 of the umbra printed on Fig. 1.

spectrograms we have identified individual bright points or their clusters. It was found that the magnetic field in umbral dots (or clusters of them) is more longitudinal than the field strength in the darkest regions of umbra. The field strength in umbral dots is about 20% lower than the field strength in the darkest regions of umbra (Sattarov 1982, Litvinov & Sattarov 1989).

As one can see on Fig. 3 spatial resolution of spectral observations is lower than the resolution of the white light images (compare Fig. 1 with Fig. 3). It is the result of blurring effect, which is larger near the boundary of umbra. In our estimate, the contribution of scatter light in brightness of sunspot is not significant. Fig. 3 shows the spectral line Fe I 6302.5 with telluric lines of both sides. On Fig. 3, one can see the simple doublet Zeeman splitting (middle white band on Fig. 3) on bright dot's cluster (Fig. 1b). If the scatted light was strong, we would see strong central component, which is not present on the middle white band. The observations of clusters of dots do not show measurable Doppler displacement. This implies that if there were plasma flows in dots the velocity of these flows should not exceed 100 m/s (Litvinov & Sattarov 1989).

4. Discussion and conclusions

Bright dots were observed near the disk side of penumbra-umbra boundary in the "intrusion" of penumbral material into the umbra. Rotation of the sunspot had transformed umbral dots into penumbral grains and penumbral grains into umbral dots. Umbral dots are associated with vertical magnetic tubes and, it seems, the rotation deflected umbral dots flux tubes from its vertical direction to more horizontal orientation prior to formation of penumbral peninsula in umbra. Magnetic field in penumbral grain flux tubes have more horizontal direction and sunspot rotation had deflected penumbral flux tubes on the opposite (limb) side of the umbra from its horizontal direction to more vertical position. Umbral dots and penumbral grains are the very small structural elements of solar atmosphere. The movie of a newly developing sunspot (Fig. 4 presents one of images of this movie) shows how the penumbral grains are formed. They develop in intergranular spaces from low contrast small photosphere features (it seems, from photosphere bright points), but not from granules themselves. Plasma flow velocities in umbral dots are as small as in intergranular spaces in the photosphere(Litvinov & Sattarov 1989, Lites *et al.* 1991). The umbral dots live longer than the photospheric granules, and it seems they may have a different mechanism of flaring up than granulation As it appears from our study, the granules cannot transform to the penumbral grains (as was suggested by some models of sunspot penumbra). The granules show plasma flows of sufficiently larger velocity directed vertically upward, whereas the dots have not show such strong plasma flows. Intergranular lanes exhibit bright points - a very small structural element of solar atmosphere. A sunspot movie (Nemirooff & Bonnel 2000) shows how the formation of

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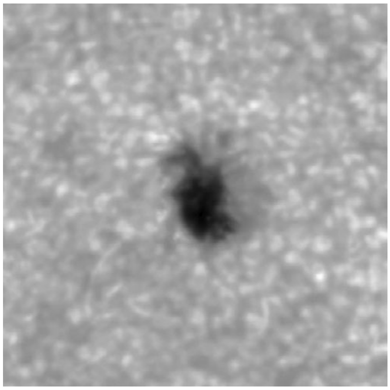

Figure 4. Small new sunspot observed at 8 August 1981 in ATSU-5 in Tashkent.

grains and photosphere bright points takes place near outside boundary of penumbra; both features go away: the grains move to umbra, while the bright points move to the surrounding photosphere. The grains and the bright points have opposite magnetic polarity. On sunspot images of low resolution the grains present inner and the photosphere bright points outer rings of Secchi. Therefore, we propose that the umbral dots, penumbral grains, and photosphere bright points are associated with the feature - magnetic flux tubes - which float to the solar surface in outside parts of sunspot penumbra.

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References

Danielson, R. E. 1964, *Astrophys. J.* 139, 45
Krat, V. A., Karpinsky, V. N., & Pravdjuk, L. M. 1972, *Solar Phys.* 26, 305
Sattarov, I. 1981a, *Morphology and Cyclicity of Solar Activity*, 122
Sattarov, I. 1981b, *Morphology and Cyclicity of Solar Activity*, 107
Sattarov, I. 1982, *Sun and Planetary System*, 96, 129
Sattarov, I. 1980, *Soviet Astron.* 24, 352
Litvinov, O.V., & Sattarov, I. 1989,Magnetic Fields and Corona, (Moscow, Nauka), 210
Lites, B. W., Bida, T. A., Johannesson, A., & Scharmer, G. B. 1991, *Astrophys. J.* 373, 683
Nemirooff, R.& Bonnel, J. 2000, Astronomy Picture Of the Day, 23/02/2000.

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