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On the manifestation in the Sun-as-a-star magnetic field measurements of the quiet and active regions

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Abstract. The best way to test the stellar magnetic field mapping codes is to apply them, with some changes, to the Sun, where high-precision disk-integrated and disk-resolved observations are available for a long time. Data sets of the full-disk magnetograms and the solar mean magnetic fields (SMMF) measurements are provided, for example, by the J.M.Wilcox Solar observatory (WSO) and by the Sayan Solar observatory (SSO). In the second case the measurements in the Stokes-meter mode simultaneously in many spectral lines are available. This study is devoted to analysis of the SSO quasi-simultaneous full-disk magnetograms and SMMF measurements. Changes of the SMMF signal with rotation of the surface large-scale magnetic fields are demonstrated. Besides, by deleting of selected pixels with active regions (AR) from the maps their contribution to the integrated SMMF signal is evaluated. It is shown that in some cases the role of AR can be rather significant.

Keywords. Sun: photosphere, Sun: magnetic fields

1. Introduction and Motivation

Observations of the solar magnetic fields with different spatial (angular) resolution are important. No doubts that the dominant tendency in present experimental solar physics is to achieve extremely high resolution up to the parts of arc second. This holds for the new space missions (Hinode, SDO), and for the largest ground-based telescopes (GREGOR, NST, ATST, etc.) as well. But establishment of this fact does not mean at all that observations with moderate or even with low spatial resolution, including integral observations of the Sun-as-a-star, became unimportant. There are a lot of applications where spectral and polarimetric low-resolution observations with high sensitivity and high accuracy are very demanded. Among the examples are the problems connected with solar-terrestrial physics. Indeed, it is sufficient to have the full-disk magnetograms with a resolution of no more than several dozens of arc seconds for calculations of the magnetic field structures in the corona and in the interplanetary media. Even more, the best correlation of interplanetary magnetic field (IMF) structures is found with the Sun-as-a-star, or, in other words, with the solar mean magnetic field (SMMF) measurements.

The other "ecological niche" of such kind observations belong to solar-stellar relations. A significant progress in observations of the magnetic fields on the stars has been achieved recently (Donati *et al.*, 2008; Strassmeier, 2009). Quite reliable measurements of the extremely weak magnetic fields even on the solar-type stars are available now (Petit *et al.*, 2008). And a lot of efforts are undertaken in the attempts to construct the surface distribution of stellar magnetic fields. Naturally, the best way to justify such methods of stellar mapping, at least for the case of solar twin stars, is to apply them to solar data. Indeed, the Sun is the only celestial body where disk-integrated and

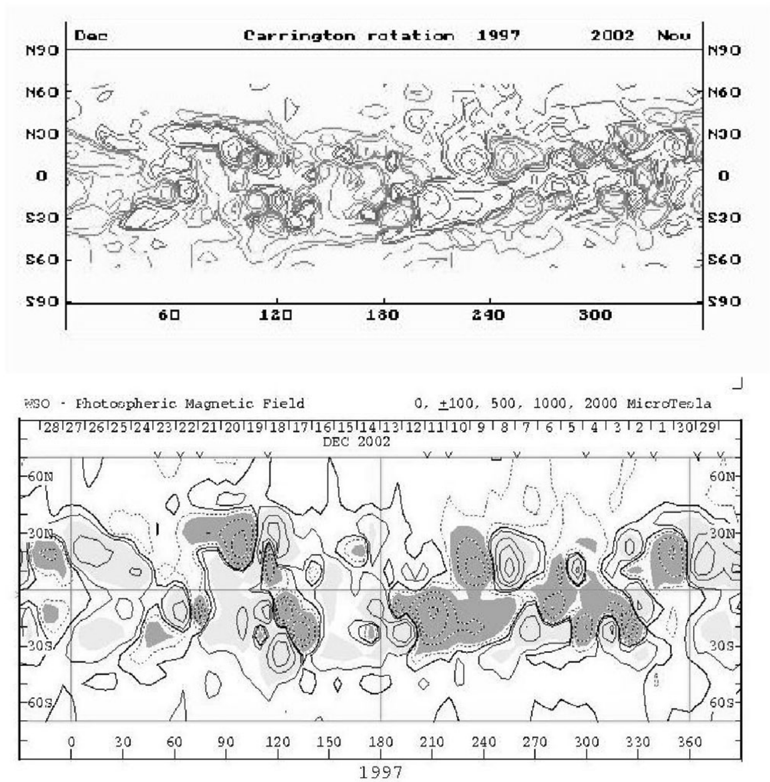

Figure 1. Large-scale solar magnetic fileds synoptic maps for the Carrington rotation 1997, constructed from SSO (top panel) and WSO (bottom panel) observations.

disk-resolved observations of magnetic fields are available simultaneously. And observations with sub- arc second spatial resolution are not necessary in this case. Observations with a resolution of about some arc minutes are sufficient.

At present time there are only two observatories in the world which provide regularly quasi simultaneous observations of the magnetic field of the Sun-as-a-star and full-disk magnetograms. It is the J.M.Wilcox Solar observatory (WSO) at Stanford, USA (Scherrer *et al.*, 1977), and the Sayan Solar observatory (SSO) in Russia (Demidov *et al.*, 2002). The advantage of the SSO observations with the Solar Telescope of Operative Predictions (STOP) is that they are made in the Stokes-meter mode, when the Stokes I and Stokes V parameters for many spectral lines are registered simultaneously. Usually, several lines in the vicinity of Fe I λ525.02 nm are observed.

One of the essential questions of the interpretation of SMMF measurements is the origin of such signals. Understanding that is important for the pure solar physics, and for stellar physics as well. It was shown earlier by Scherrer *et al.* (1972) and Kotov *et al.* (1977), that the main source of the SMMF is the rather weak large-scale back-ground magnetic field, covering the most part of the solar surface, and the role of active regions is small. However, it is known, that the SMMF strength is weak during the periods of minimal solar activity, when the number of active regions (AR) is small, and strong enough during the epochs of maximal activity. Besides, the model simulations of the temporal evolution of SMMF, regarding bipolar AR as sources of the flux (Sheeley *et al.*,

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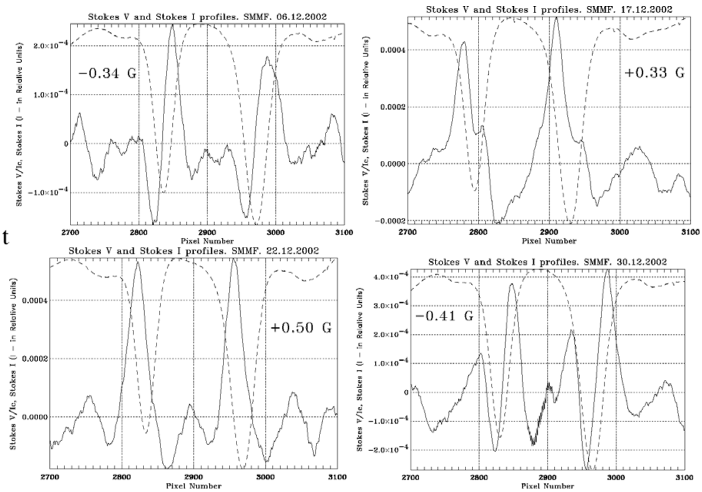

Figure 2. Stokes I and Stokes V/I_c profiles for the lines Fe I λ525.02 nm and Fe I λ525.06 nm for the sevaral days of the period, corresponding to the Carrington rotation 1997 (see Figure 1). The numbers in the panels are the SMMF strengths for the Fe I λ525.02 nm.

1985), show a good correspondence with reality. Thus sometimes a contribution of AR in the formation of the SMMF signals could be significant.

2. Results

One of the objectives of stellar observatios is to obtain the surface distribution of the magnetic fields. In the case of the Sun such distributions are presented in synoptic maps. Examples of such maps for the Carrington rotation (CR) 1997 are shown in Figure 1: the top panel is constructed on the basis of the STOP SSO measurements, and the bottom one is the WSO map (http://soi.stanford.edu/data). It is seen that despite of the differences in the spatial resolution used (about 3 arc min in the WSO and about 100″ in the SSO), the two maps are similar.

During the rotation of the Sun, different magnetic field structures are visible in the central zone of the solar disk (Demidov *et al.*, 2002), and, as a consequence, different SMMF strengths and Stokes profiles are registered. Some examples of Stokes V and Stokes I profiles for the pair of lines Fe I λ525.02 nm and Fe I λ525.06 nm for the different phases of the CR 1997 are shown in Figure 2.

To explore the role of AR in the formation of the SMMF signal, the following experiment was made. First of all, the real observed disk-integrated Stokes V profiles and magnetic field strengths B for the line Fe I λ525.02 nm were compared with the zonal Stokes V profiles and stregths B, calculated for different circular zones of solar disk using all corresponding points (pixels) of the magnetograms. Then the same procedure was repeated after deleting those pixels where AR are situated. For different days, different results were obtained depending on the number of deleted pixels and their position on the solar disk. Examples for two days with different results are shown in Figures 3 and 4. Figure 3 shows the magnetograms for 7 March 2001 (left panel) and 29 March 2001 (right panel), where pixels (by number N = 25 in the first case and N = 60 in the second), corresponding to AR, are deleted. Figure 4 shows the impact of deleting for the these days. Two top panels show the correlation coefficents between integrated and zonal Stokes V profiles, while the bottom panels show the behaviour of the magnetic field strengths B.

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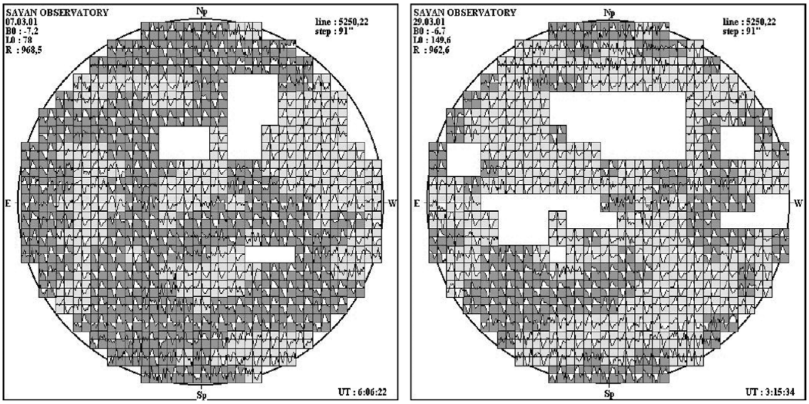

Figure 3. SSO magnetograms for 7 March 2001 (left panel) and 29 March 2001 (right panel) with deleted active regions pixels.

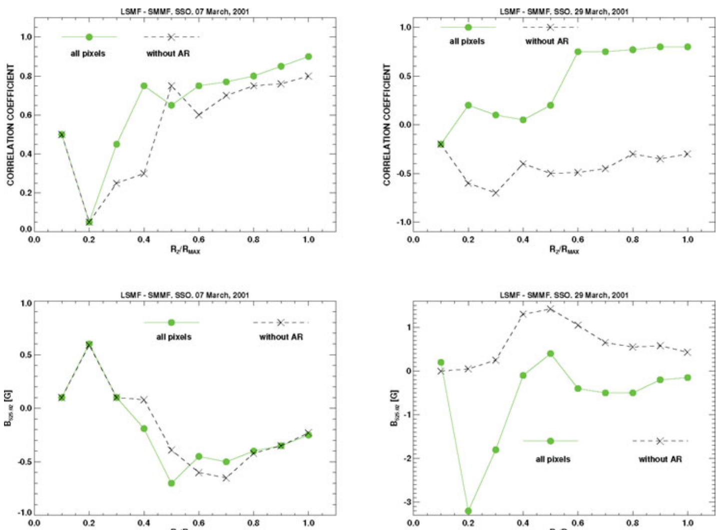

Figure 4. Top panels: comparison of the correlation coefficients between disk-integrated and zonal Stokes V profiles of the line Fe I $\lambda 525.02$ nm for the cases when all pixels are taken into account (solid lines), and when active region pixels are deleted (dash lines). Bottom panels: the same as for the top panels, but for the magnetic field strengths B.

It is easy to see that the influence of the deleted AR is almost negligible for the first day, but is rather essential for the second one.

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