The observed Mn I 539.5 nm line profiles in solar spots and plages

O. Andriyenko, IC AMER NAS of Ukraine and RAS, Kiev, Ukraine – Terskol, Russia
MAO NAS of Ukraine, Kiev, Ukraine, olexa @mao.kiev.ua

Abstract
From observations of the Sun as a star made at Kitt Peak it is known that MnI 539.5 nm line profile varies during solar activity cycle. This line becomes weaker in maximum and stronger in minimum of solar activity cycle. Amplitude of the variation is larger than 1% in the equivalent width as well as in the central depth. Such behavior is unusual for a photospheric line. Till now it remains unexplained. This work aims to shed some new light on the problem. During 2002-2003 years observations of MnI 539.5 in different spots and plages at various heliocentric angles were made in order to collect some statistics. The line is weaker in plages and stronger in spots. The profiles are quite different in different spots and plages.

1. INTORDUCTION

Neutral manganese 539.5 nm line was included in a program for long time spectral observations of the Sun as a star at Kitt Peak. Unless other photospheric lines included in the program this line showed an outstanding variability during solar cycle (W. Livingston and Wallace, 1987). Amplitudes of the variations are more than 1% for equivalent width and central depth. The line becomes weaker in maximum and stronger in minimum of solar activity cycle. Such a "chromospheric" behavior is rather enigmatic. It is still unclear what cause this variability.

MnI 539.5 nm line is very sensitive to temperature. Still about 3 K amplitude of photosphere temperature changing with solar cycle is required to fit the manganese line variations (S. Erkapic and I. Vince, 1995). From the other hand Gray and Livingston (1996) obtained 1.5 K amplitude of the temperature variations from observations of carbon 538.0 nm line.

I. Vince and S. Erkapic (1997) also examined possibility of the line variations due to influence of plages. According to their theoretical calculations plages should cover about 10% of the solar surface in maximum of solar cycle to provide observed 539.5 nm line variations. Furthermore calculated profiles behave opposite to observed ones. I. Vince et al (2000) observed the manganese line in a plage, from the observations they estimated that about 3% of the solar surface has to be covered with plages in the maximum – still too much. In addition weakening of 539.5 nm line in plages is partly compensating by its strengthening in spots (I. Vince et al, 2002).

Doyle et al (2001), using NLTE calculations, have shown that MnI 539.5 nm line is sensitive to the optical pumping of other manganese line. Namely, the MnI uv1 line (279.48 nm) overlaps with the MgII k line (279.5 nm). As 539.5 nm and uv1 lines have the same lower excitation level, optical pumping from MgII k line decreases population of the level and MnI 539.5 nm line becomes weaker.

2. OBSERVATIONS AND THEIR TREATMENT

Observations were made on ATsU-26 horizontal solar telescope that is placed at Terskol observatory. The observatory is situated on Terskol peak (3100 m above sea level) that is a spur of Elbrus Mountain. The telescope has 65 cm spherical main mirror with 17.7 m focal distance. It is equipped with 5 camera spectrograph, diameters of the collimator and cameras are 30 cm, their focal distances are 8 m, the grating is 20×25 cm with 600 grooves/mm. The optical scheme of the telescope and the spectrograph is shown on Fig. 1.

The spectrograph has a wooden box that provides nearly thermo-stable environment. Typical instrumental profile of the spectrograph in 4th spectral order is about 17 mA FWHM (full width at half magnitude). It is measured regularly with help of He-Ne laser. Typical scattered light in the spectrograph is about 7%. It was measured particularly in saturated telluric oxygen lines (764 nm).

Observations were carried out in August of 2002 and 2003 years. Selected manganese lines were observed in different solar spots and plages as well as in quite regions in order to collect some statistic. I accepted suggestion of Dr. I. Vince and observed Mn

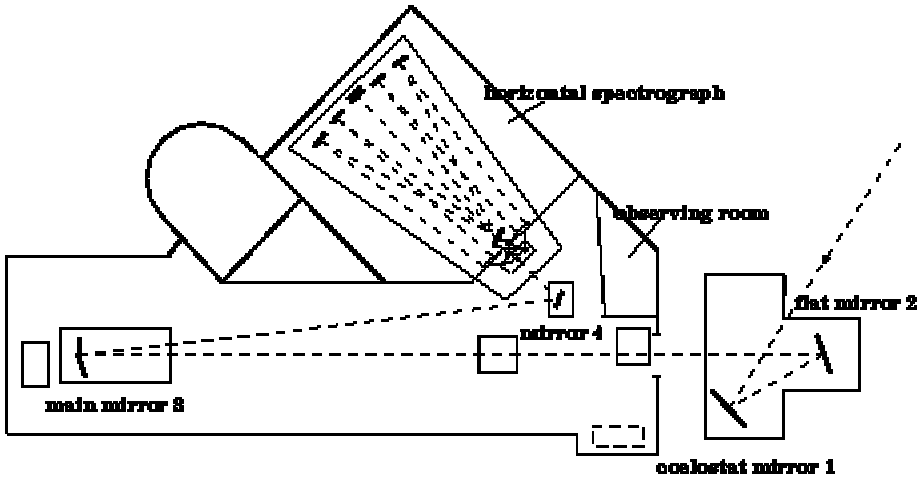

Fig. 1 Optical scheme of the AtsU-26 telescope and the spectrograph.

539.5, 542.4, 543.3 and 601.7 nm lines. Lines with the same (0.0 eV for 539.5 and 543.3 nm lines) and with different (2.14 eV for 542.4 nm line and 3.07 for 601.7 nm line) lower excitation levels were chosen to check the optical pumping hypothesis. Here observations of 539.5 nm line are presented. Observations of other lines will be presented in a separate paper later. Observations were made with ST-7 CCD camera installed in the central camera of the spectrograph. The line was observed in 5^{th} spectral order.

In any position at the solar disk the line was observed for at least 10 min with 15 sec cadence with aim to exclude possible influence of 5 min oscillations. Images for a flat field were obtained with help of telescope defocusing. Before and after of each observational sequence I took images for scattered light estimation, for that I covered central part of the entrance slit with a diaphragm. I also took dark current shots regularly. With help of these auxiliar data each image in an observational sequence was corrected for a dark current, a flat field and a scattered light level. Then on each image from a sequence a certain spatial feature (for instance central part of umbra) was picked up. Spectra from CCD rows covered by the feature were averaged. Thus sequences of CCD images were reduced to sequences of profiles for certain features on the solar disk. The latter ones were in own turn averaged. Resulting profiles were normalized for the continuum level and then corrected for the instrumental profile.

Thus spatially and temporarily averaged profiles were obtained in different details on solar disk. From these profiles such parameters as central depth, FWHM and equivalent width were derived. These parameters are subject for further analysis.

In May of 2002 year observations of Mn I 539.5 nm line were carried out in quite regions from the center to the limb of the solar disk. The treatment procedure was practically the same as described above with the only difference: instead of selecting a spatial feature, spectra were averaged along the slit.

2. RESULTS

On Fig. 2 MnI 539.5 nm line profiles observed in preceding spots of AR0424 (the thin solid line), AR0425 (the short dashed line), AR0431 (the dashed-dotted line), and in plages of AR0424 (the dashed-double-dotted line), and AR0431 (the long-dashed line). Observations were made on 7 August 2003 in AR0424, AR0425 and on 14 August 2003 in AR0431. With the thick solid line the profile in the center of the solar disk is shown.

It is easy to note that the line is stronger in spots and weaker in plages. The profile parameters are presented in Table 1.

Table 1

	EW, mÅ	FWHM, mÅ	CD
spot in AR0424	163.4	251.6	0.597
spot in AR0425	146.3	232.6	0.576
spot in AR0431	99.6	189.4	0.504
spot in AR0087	298.0	250.0	0.981
plage in AR0424	52.8	153.8	0.331
plage in AR0431	64.7	153.3	0.414
center of the sol. disk	73.7	151.7	0.477
from the Liège atlas	74.3	151.9	0.479

On Fig. 3 MnI 539.5 nm profiles in umbra of preceding spot of AR0087 (the dashed-double-dotted line), in vicinity of AR0087 (the solid line), and in different parts of the penumbra (other lines) are shown. Observations of this active region were made on 25 August 2002.

One can see that the line is almost saturated in the umbra (CD=0.981). From the other hand in vicinity of the spot the line is also strengthen (CD= 0.808) even more than in spots of other observed active regions.

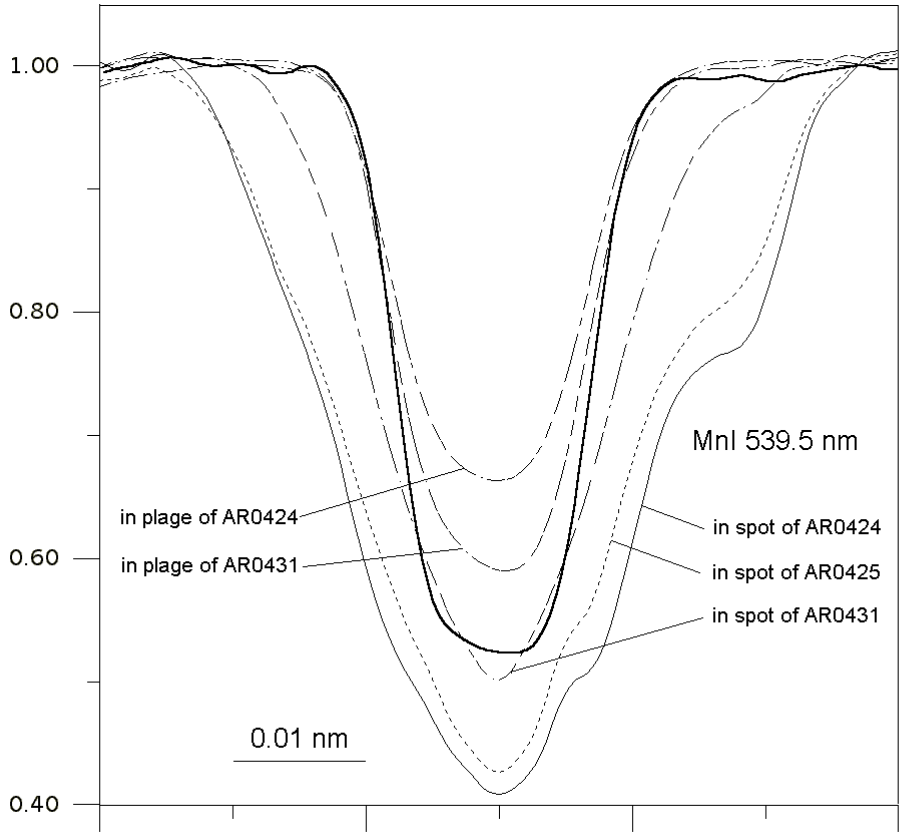

Fig. 2. Profiles in spots and plages of AR0424, AR0425, and AR0431 observed on 7 and 14 August 2003. Thick line – profile in the center of the solar disk.

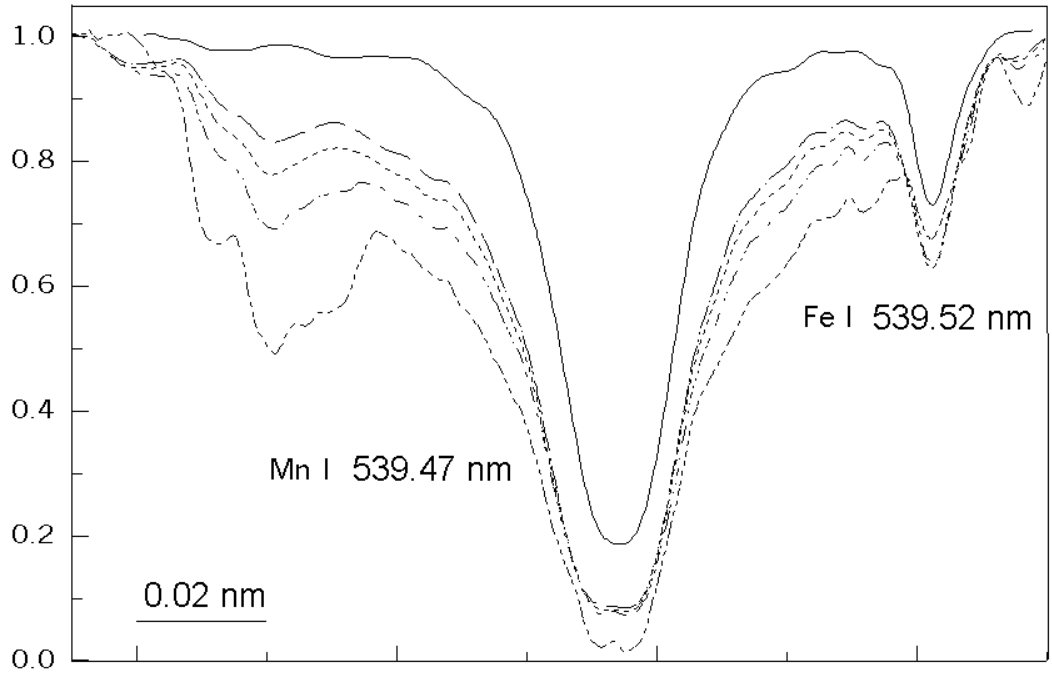

Fig. 3. Profiles in penumbra and umbra of the preceding spot of AR0087. The solid line – profile in vicinity of the spot. Observations were made on 25 August of 2002.

On May 4 of 2002 center-to-limb observations of the 539.5 nm line were made. Line profiles were measured in 5 heliocentric angles $cos\theta$ = 1.0, 0.803, 0.603, 0.436, 0.265. Line profiles parameters derived from the center-to-limb observations are presented in Table 2.

Table 2

$cos\theta$	EW, mÅ	FWHM, mÅ	CD
1.0	73.7	151.7	0.477
0.830	78.4	154.2	0.487
0.603	88.7	159.9	0.533
0.436	99.3	170.8	0.560
0.265	104.9	186.3	0.547

Photometric accuracy of the profiles is about 0.3%. Systematic errors are ≤ 0.5%.

3. DISCUSSION

The observations presented in this paper are in qualitative agreement with results of other authors (Vince I. et al, 2000, 2002, Malanushchenko et al, 2004). They also found that Mn I 539.5 nm line is strengthen in spots and weaken in plages. Unfortunately they did not publish numerical values of the line profile parameters. So, it is impossible to compare the results quantitatively.

From the above results it is impossible to make a conclusion about reliability of the optical pumping hypothesis. Treatment and analysis of others observed lines are required. It is also needed to make NLTE calculations in order to model the observed profiles.

As one can easy see from the figures, the profiles are quite different in different spots and plages. An outstanding case is AR0087. More observations, preferably in several spectral lines simultaneously, are needed to collect more data that should help to make reliable conclusions.

Acknowledgements

This work was in part supported with INTAS grant No.00-00084.

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