INTERACTION OF MEDIUM-SCALE AND LARGE-SCALE STRUCTURES IN THE SOLAR ATMOSPHERE

H. WÖHL

e-mail: hw@kis.uni-freiburg.de

Kiepenheuer-Institut für Sonnenphysik, Schöneckstr. 6, D-79104 Freiburg, Germany

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Abstract. The historic development of the search for interactions of sunspots and solar plasma around them is given as an example for interactions of medium-scale and large-scale structures on the sun. This new field of solar research gained most of its progress from combination of data of sunspot rotation measurements by tracer techniques with those of the plasma by Doppler shift measurements of spectral lines. The paper is concentrated on two main research projects: One was performed mainly at the German Vacuum Tower Telescope on Tenerife in the beginning of the nineties and another was started in Slovakia recently.

From the data obtained during the observational program performed from 1990 to 1992 it was found that the rotation velocity difference of the plasma in front and behind stable sunspots showed a linear dependence on the difference of the sunspot's rotation velocity as compared with the mean plasma velocity at the latitude of the sunspot observed. Although the sample of sunspots used was quite big (22 sunspots), the detected behavior was just not yet significant on the 3 \( \sigma \) level. To gain this significance, and in addition to obtain details about the plasma flow structure also north and south of the sunspots, the new observing program was started.

Key words: sunspot rotation, solar plasma, interaction

1. Introduction

The definitions used in the title need some explanations: Medium-scale structures are sunspots, prominences or filaments - all those structures are
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smaller than the solar radius. Large-scale structures are e.g. those of the solar rotation, the solar differential rotation or the whole sun. There are thousands of investigations published about the rotation of solar structures and the solar plasma. Only very few deal with possible interactions of the structures.

In the following I concentrate on my own main interest, the solar rotation determined from tracer measurements of sunspots and Doppler measurements of the solar plasma around them.

2. Some Important Detections

It is well known, that within the first years of telescopic observations of sunspots there was a discussion going on, whether these observed dark features are really a part of the sun. Still today the latin names of 'umbra' = shadow and 'penumbra' = half-shadow indicate this! Therefore it was and is of interest to know, whether the rotational velocity of the plasma around a sunspot has the same speed as the one determined from position measurements (tracer method) within a certain time span. If there are any differences in the velocities, then interactions of the structures can be expected.

Twenty years ago Beckers (1977) claimed, that the rotation velocity of the plasma around a sunspot is of the same order as the rotation velocity of the sunspot from tracer measurements. He used photographic detectors at that time, but wavelength references produced by laboratory absorption of molecular iodine allowed a very high precision - at least in wavelength. His sample of sunspots was rather small - just 5 spots. Nevertheless he gave within the conclusions of his paper a clear indication, that further research was necessary, because he wrote: 'The difference in the spot and photosphere plasma motions of about 100 m/s should leave a not-yet observed wake in the photospheric plasma.'

At that time there was still some discussion going on, whether the solar rotation determined from Doppler shift measurements of spectral lines originating in the photosphere is really smaller than that determined from sunspot positions: Svalgaard et al. (1978) e.g. claimed, that the

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lower plasma rotation velocities determined were caused by scattered light. Nowadays it is generally believed, that the observed lower plasma rotation velocities from Doppler measurements are real.

Balthasar et al. (1982) detected the braking of rotation velocities of slowly evolving, recurrent sunspots of the order of 0.3 to 0.8 m/s per day. Their interpretation was, that this braking is caused by an interaction of the magnetic flux tubes with the slower rotating plasma. When there is a braking of sunspots then the plasma rotation speed is clearly slower. In addition, from tracer measurements it was found, that stable recurrent sunspots exhibit final rotation velocities of the same order as those of the local plasma.

Koch (1984) confirmed - within his thesis - the detection of Beckers, that the rotation velocity of the plasma inside sunspots determined by the Doppler effect equaled to their rotation velocity determined from tracer techniques. But he found, that the rotation velocity of the plasma within sunspots was 30 m/s to 60 m/s higher than that of the plasma around the sunspots. Since he observed with a small pinhole, he could not give a detailed spatial distribution of the velocity fields. His sample of sunspots contained also only five sunspots. In addition he had to correct for a rather high amount of scattered light and he missed to give the positions around the sunspot where he performed his plasma velocity measurements.

An interesting result was found about a possible interaction of sunspots with the surrounding plasma by Collados et al. (1987). They detected an asymmetry of the width of the penumbrae of sunspots: The ones in the direction of the rotation (western penumbrae) were smaller than the ones on the opposite side (eastern penumbrae). When I learned - as a referee - about these new findings, I suggested to look for the time dependence of the asymmetries and indeed Collados et al. (1988) even found an increase of this asymmetry with time.

Within the last few years it was shown by several investigations (e.g. Zappala and Zuccarello, 1991) that all types of sunspots exhibit a reduction of their rotation velocities during their aging.

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3. A First Bigger Attempt and its Results

Lustig and Wöhl (1993) used two-dimensional velocity field measurements and detected an increase of the plasma rotation velocity in front of sunspots and a decrease of the velocity behind them. The plasma rotation velocity difference (the velocity on the western side of a sunspot minus the velocity on the eastern side of the same sunspot) was proportional to the difference of the sunspot rotation velocity as compared to the mean plasma rotation velocity in the latitude belt, where the sunspot was observed.

We performed very high precision position measurements of sunspots at the German Vacuum Tower Telescope (VTT) on Tenerife and added more tracer data from the Austrian observatory Kanzelhöhe. The velocity fields around the sunspots were scanned within an hour each using the Echelle spectrograph and large format (1024 * 1024 pixels) CCD cameras at the VTT. The sunspot positions were determined as often as possible during the passage of the sunspots over the disk, while the Doppler velocities of the plasma were only determined at positions near to the east and west limbs (between ± 40 degrees and ± 80 degrees distance to the central meridian). For the final reduction we averaged data in heliographic areas of two by four heliographic degrees centered plus and minus five degrees east and west, respectively, of the sunspots. The spectral line used was the magnetically non-split Fe I 557.61 nm line and laboratory iodine lines served as wavelength references to allow corrections for drifts of the spectrograph. Such drifts are well known and can be of the order of several Milliangstroems within one hour (1 mÅ equals to a Doppler shift of about 54 m/s at 557.61 nm), therefore it is necessary to correct for them.

The aim was to obtain a bigger amount of data as compared to earlier attempts. This aim was fulfilled with a sample of 22 sunspots observed from 1990 until 1992. Nevertheless the main result of the plasma velocity acceleration and braking was just not significant on a 3 σ level:

The plasma velocity difference (the velocity in the west minus the velocity in the east of the sunspots) was fitted as

$$(25 \pm 38) + (305 \pm 107) \ast \text{delv}[m/s]$$

where delv is the excess rotation speed of the sunspots as compared to the
mean plasma rotation velocity at the latitude, where the sunspots were observed. The dimension of delv used was degrees per day.

The sunspots were divided in two types:
The type I were stable sunspots, which did not show any following small sunspots. They were of a stable Zürich type H or I. Their rotation velocities varied from $-0.1 \text{ deg/day}$ up to $+0.5 \text{ deg/day}$ as compared to the local plasma rotation velocity at that latitude. The differences of the plasma rotation velocities (velocities in the west minus velocities in the east) of these sunspots were $-100 \text{ m/s}$ up to $+400 \text{ m/s}$.

The type II included stable sunspots, which had maximally few small following sunspots, but the surrounding of the preceding sunspot was still clear and the plasma within a few heliocentric degrees was not contaminated by spots. Their rotation velocities varied from $-0.4 \text{ deg/day}$ to $+0.8 \text{ deg/day}$ as compared to the local plasma rotation velocity at that latitude. The differences of the plasma rotation velocities (velocities in the west minus velocities in the east) of these sunspots were $-150 \text{ m/s}$ up to $+500 \text{ m/s}$.

4. The New Project Started in Slovakia

The results obtained so far are not yet significant enough. In addition it is also of interest to know the possible changes of the plasma rotation velocity north and south of the sunspots. Therefore a new observing project was started in cooperation with the slovak colleagues: This time we do not scan over the sunspot and its surrounding plasma, but a fiber optic with 12 points placed around the sunspots is used. The light from these positions is fed into a spectrograph and the spectra are then digitized and analyzed. The averaging of the local velocities of granulation and oscillation will now be performed more by averages in time - many spectra will be collected within one hour - than in space. Nevertheless some averaging in space will be caused by local seeing effects. Again iodine lines will serve as a wavelength reference. Precise coordinates of sunspots will be collected as often as possible by drawing. We intend to perform this project for several years at the slovakian observatories at Tatranska Lomnica and Hurbanovo.
In the autumn 1997 the first real data were collected at Tatranska Lomnica. Some more details of the project and especially about the fiber optic matrix used are given by Kučera et al. (1997).

5. Possible Additional Data, which May Be Used

The new Fabry Perot interferometer which is in operation at the German Vacuum Tower Telescope on Tenerife may serve for collecting some data about details of flow patterns around sunspots. There are two problems: The available field of view is limited. The stability in wavelength may be worse than necessary to find small changes in the rotation velocity of the solar plasma.

Another possibility may be to use data from the MDI (Michelson Doppler Imager) experiment on board of the satellite SOHO (SOlar Heliospheric Observatory). Again the precision and stability of the data are unknown. A proposal for using MDI data was accepted and data were received recently. Up to now no results of the reductions are available.

Acknowledgements

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Remarks

This invited talk was given July 1, 1997 at the fourth Hvar Astrophysical Colloquium on Hvar, Croatia. This is the updated version of August 25, 1997. For more and updated information about the research project described see my Web pages

http://www.kis.uni-freiburg.de/~hw/projects.html
References


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MEĐUDJELOVANJE USTROJSTAVA SREDNJIH I VELIKIH RAZMJERA U SUNĆEVOJ ATMOSFERI

H. WÖHL

e-mail: hw@kis.uni-freiburg.de

Kiepenheuer-Institut für Sonnenphysik, Schöneckstr. 6, D-79104 Freiburg,
Germany

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Sažetak. Povijesni razvoj istraživanja međudjelovanja Sunčevih pjega i plazme koja ih okružuje dan je kao primjer međudjelovanja ustrojstava srednjih i velikih razmjera na Suncu. Ovo novo područje fizike Sunca najviše je napravilo povezivanjem podataka mjerenja brzina rotacije Sunčevih pjega metodom praćenja s mjerenjima brzine rotacije plazme doplerovskom metodom. U članku se razmatraju dva glavna istraživačka projekta: prvi proveden uglavnom s Njemačkim vakuumskim toranjskim teleskopom na Tenerifi početkom 90-tih godina i drugi koji je započeo nedavno u Slovačkoj.

Iz podataka dobivenih opažanjima od 1990-92 ustanovljeno je da razlika u brzini rotacije plazme ispred i iza stabilnih Sunčevih pjega pokazuje linearnu ovisnost o razlici brzine rotacije same pjege prema srednjoj brzini rotacije plazme na helio grafskoj širini opažane pjege. Iako je uzorak opažanih pjega bio prilično velik (22 pjege), ustanovljeno ponašanje nije statistički značajno na razini 3 σ. Da bi se dokazala statistička značajnost kao i dodatno ustanovile potankosti ustrojstva tokova plazme sjeverno i južno od Sunčevih pjega započet je novi opažački program.

Ključne riječi: rotacija Sunčevih pjega, Sunčeva plazma, međudjelovanje