Current status report of the Austrian High Resolution Solar Physics Group

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Abstract

In the recent years a new High Resolution Solar Physics Working Group established itself in Graz with the help of the Austrian Science Fund (FWF) and its approved projects. The group leader and his team are working on such diverse subjects such as small-scale solar magnetic fields as seen by MBPs, the interaction of these fields with the granulation, flow-field analysis, theoretical modelling of magnetic flux tubes, coronal holes, and small-scale activity within these holes. In this contribution we would like to give a short overview of these topics and the current status of research.

1. INTRODUCTION

We restarted our small group in October 2016 with the launch of the FWF project: The interaction of the solar granulation with small-scale magnetic fields". Since then the group has grown in size and consists now of the PI a senior researcher, one PhD as well as a master student, one senior volunteer researcher, and an associated team member. Currently we undertake research covering in a broad sense the modelling, simulation, and observation of small-scale solar magnetic fields. In the following we wish to introduce the team members and their current field of research as well as the state of the art of their research. This small report will be closed by an outlook and first glimpses of obtained data during a combined space and ground based observational campaign carried out in autumn 2017 at the European largest solar telesecope – GREGOR (see Schmidt et al. 2012 [1]).

2. OBSERVATIONS OF MBPS

The team-leader (D.U.) is heavily involved in research on Magnetic Bright Points (MBPs). MBPs are small-scale highly concentrated magnetic field regions in the solar photosphere (see Utz et al. 2013 [2]). They appear bright in the so-called G-band (see Schüssler, et al. 2003 [3]), a molecular band of CH molecules close to the blue continuum. The magnetic field strength of MBPs reach generally beyond the 1 kG regime and they are very small in size with just a few hundreds of km in diameter. Due to their large field strength, narrow diameter, and possibility to characterise them as flux tubes, they are of high interest for the field of MHD wave creation and propagation studies (e.g., Jess et al. 2009 [4]) and thus in respect to the coronal heating problem. Moreover, they are highly dynamic with time-scales of just a few minutes ever undergoing formation, dissolution, splitting and merging events (e.g. Utz et al. 2014 [5]). While a principle theory for their formation is known – the convective collapse theory – much less is known how and why they disappear and dissolve. Thus, MBPs are of great interest for the principle understanding of the interaction of the solar convective plasma flows as seen by granulation with magnetic fields.

However, currently the team focuses less on the dynamic side of MBPs and more on the long-time behaviour.

It is a very well-established fact that the Sun undergoes a solar cycle established with the most prominent variation character, the changing sunspot number (Schwabe 1844 [6]). While it is thus known for hundreds of years that the large- scale magnetic features undergo such cyclic variations, it is not understood, yes even contradictory, what happens with small-scale solar magnetic fields. Some authors found evidence that small-scale magnetic fields vary in accordance with the sunspot cycle, while others state that they are indeed anticyclic to the sunspot cycles with some studies even indicating that there is no variation at all (see Jin et al. 2011 [7]).

Thus, our team focuses at the moment on the long-time evolution of MBPs and analyses for that purpose the Hinode/SOT (see Kosugi et al. 2007 [8] and Tsunetat et al. 2008 [9]) G-band synoptic data set which was recorded from early on in the mission until a recent CCD fail in February 2016.

We obtained all the available data, some 6000 G-band images, carefully selected only the sharpest, non-de-focused and fully transmitted ones. Then we applied an automated image segmentation and MBP identification algorithm before analysing the data for the variation of the number of MBPs as well as characteristic size.

The outcome of this work can be found in full details in Utz et al. 2016 [10], 2017 [11], and 2018 [12], but can be summarized as follows:

- MBPs follow the solar sunspot cycle; however, they are temporally shifted with the sunspots going ahead in the cycle.
- The temporal shift between the declining and rising phase of the sunspot cycle in respect to the MBP cycle are different.
- The number of MBPs close to the disc centre is slightly different at the northern and southern hemisphere with a more prominent hemisphere similar to the sunspot cycle.
- The number of MBPs at disc centre can be modelled via an ad-hoc model considering the sunspot number, sunspot appearance rate, number of MBPs, as well as an acting surface dynamo.
- As the number of MBPs at disc centre can be modelled it can be also quite well predicted out of a starting number and the sunspot number.
- The size distribution of MBPs follows a Gamma distribution (see Fig. 1) and is temporally variable.
- At the solar minimum the MBP features seem to be slightly smaller while during the maximum the size distribution is shifted to slightly larger sizes.

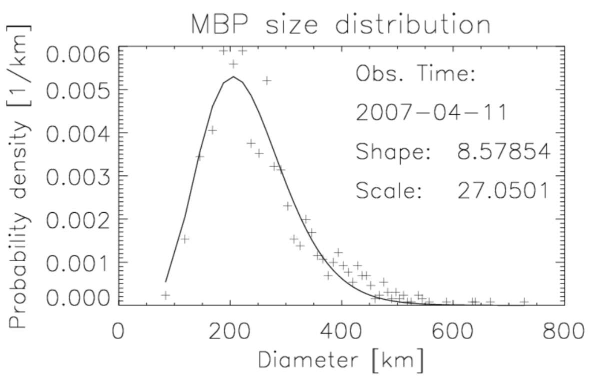

Figure 1. An exemplary MBP size distribution created via the Hinode/SOT G-band data set and fitted by a Gamma distribution.

3. MODELLING OF SMALL-SCALE MAGNETIC FLUX TUBES

Another topic we are currently interested in is the modelling of small-scale solar magnetic flux tubes. MBPs as discussed before can be seen as the cross-section of such kG strong vertical expanding flux tubes (see, e.g., Shelyag et al. 2010 [13]). The idea behind expanding flux tubes is that the magnetic field within the solar photosphere can be thought of existing in strong concentrated flux bundles within the solar network region. These flux bundles or flux tubes (if they appear roundish; else also flux sheets) expand with height in the solar atmosphere as the gas pressure decreases.

The interesting point concerns now exactly this opening of the flux tube, as it influences the evolution of the magnetic field in the atmosphere, i.e. the field direction but also the strengths. The ratio of the field strength to the gas pressure and its evolution, practically expressed as plasma Beta, is an important paramter for wave processes (see, e.g., Grant et al 2015 [14]). Simplified one can immeadiately imagine that a plasma dominated solar atmosphere will feature different wave types than a magnetic field dominated atmosphere. Thus the shape of the flux tube will have important consequences for the flux tube as a wave guide.

Figure 2 shows our principle approach to this kind of problem of finding a good flux tube model:

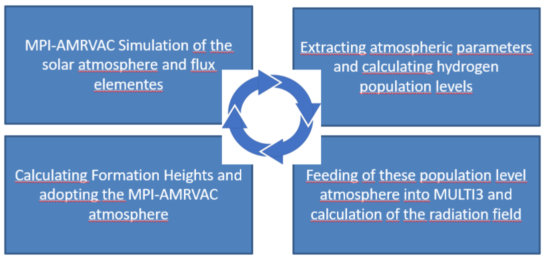

Figure 2. Schematic approach to the flux tube modelling problem. Step one: Setting up a flux tube model in MPI-AMRVAC; Step two: Extracting a vertical cut through the atmosphere; Step three: Calculating the excitation levels and populations of the hydrogen atom and feeding the Multi 3 code (code for non-LTE radiative transfer); Step four: Calculating the formation heights and adopting the model flux tube atmosphere;

The ultimate goal of our flux tube modelling is twofold: on the one side we wish to calculate formation heights of spectral bands like the G-band and Ca II H band as well as artifical G-band and Ca II H images for different flux tube parameters and models, on the other side we wish to have a realistic flux tube model for wave propagation simulations.

For a current first model atmosphere see Fig. 3 and for all the details about how to construct such a model see Utz et al. 2016 [15]. A quite strong magnetic flux tube element (about 200 G) is sided by two parasitic internetwork flux elements. The corresponding formation heights of this flux tube ensemble is shown in Fig. 4. Due to the relatively weak magnetic field

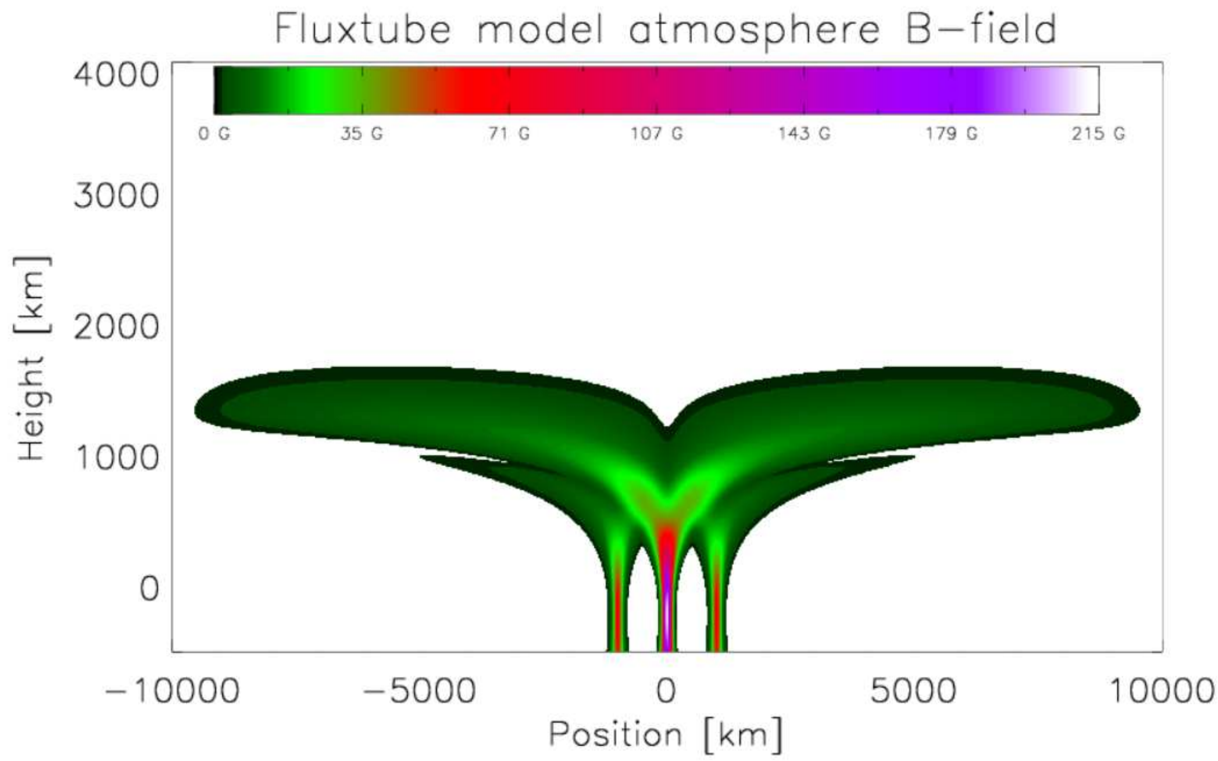

Figure 3. An exemplary model flux tube atmosphere with one network sheet element squeezed by two parasitic opposite internetwork elements. Due to the opposite polarity the parasitic elements form low lying arcade structures.

strength reached so-far in the central magnetic element (around 200 G) the effects on the formation heights are yet quite insignificantly. However, in future flux tube models we will implement stronger elements for which the caused effects will become stronger and more prominent.

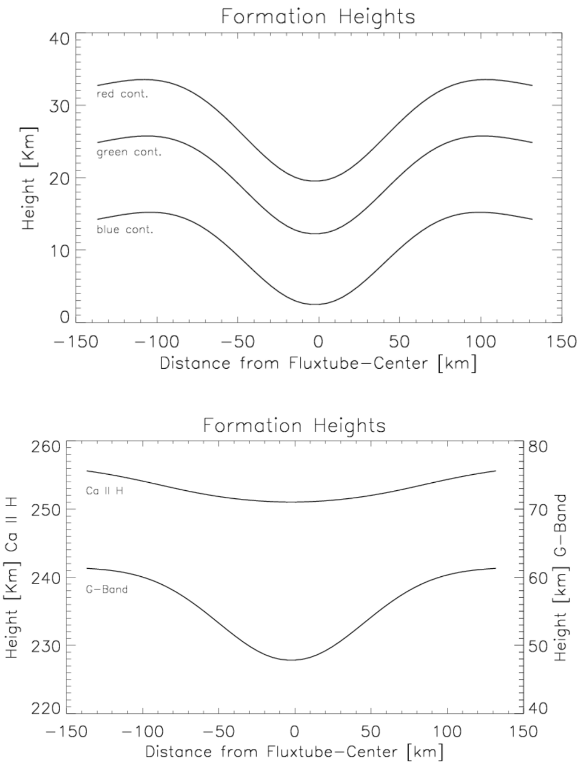

Figure 4. First test cases of calculated formation heights for the flux tube ensemble from Fig. 3. The top panel shows the 3 continuum bands while the lower panel illustrates the G-band and Ca II H band formation height across the magnetic flux tube element.

4. FLOW FIELD ANALYSIS

Another topic, the working group is involved in, is the analysis of flow fields on the solar surface. Of special interest in these regards is the study of the evolution of flow fields during the formation of active regions. While active regions are already of interest due to their higher dynamics, in the moment of flux emergence we can expect changes in the flow fields which should manifest themselves in the corresponding velocity distributions. Indeed, this was observed by us and all the details can be found in Campos Rozo et al. 2018 a) b) [16,17].

In this proceeding we would only like to show an example of a created flow field map from an SDO/HMI data set (see Pesnel et al. 2012 [18]). The data were treated by a newly algorithm (see Diaz Baso, C. J. et al 2018 [19]) which tries via deep learning methods and a neuronal network to improve the resolution available in the data. In the case of the current images the neuronal network was trained by higher resolved Hinode magnetograms and then applied successfully on SDO data to improve the spatial resolution of the available magnetograms. Afterwards we calculated via the LCT method (see November and Simon 1988 [20]) implemented in Python (the methods, including a graphical user interface, can be found and downloaded from: https://github.com/Hypnus1803/FlowMapsGUI) the flow fields within the FOV. The result can be seen in Fig. 5 with red arrows indicating the obtained velocities for the one polarity and blue arrows for the other polarity. In case of interest in these methods please contact J. I. Campos Rozo[1].

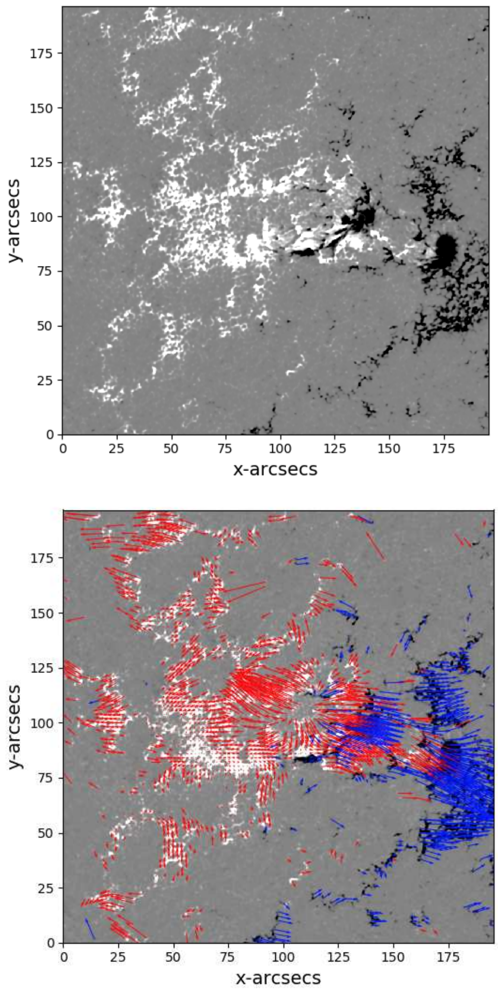

Figure 5. A test data set of SDO HMI data treated by the spatial resolution improving algorithm of Diaz Baso et al. 2018 [19]. Afterwards the flow field has been analysed by a Python implementation of a LCT algorithm. The top panel shows the improved magnetogram and the lower panel the calculated flow fields.

5. CORONAL HOLE INVESTIGATIONS AND RELATIONS TO THE UNDERLYING MAGNETIC FIELD TOPOLOGY

Another interesting current research topic of our group focuses on coronal holes (CH) and the magnetic field topology below these CHs (see, e.g., the upcoming work of Hofmeister et al. 2018 [21]) as well as the small-scale magnetic field dynamic which can be found below them causing many interesting small-scale activity phenomena.

Currently we are analysing a CH observed during a GREGOR (see Schmidt et al. 2012 [1]) combined observational campaign (see also next section). Unfortunately, no GREGOR data were available due to bad seeing on the particular day of the coronal hole analysis, but many interesting space-born data were taken by Hinode, IRIS (see De Pontieu et al. 2014 [22]), and SDO. In Fig. 6 the CH is shown with marked FOVs for the various instruments taking data during the time period.

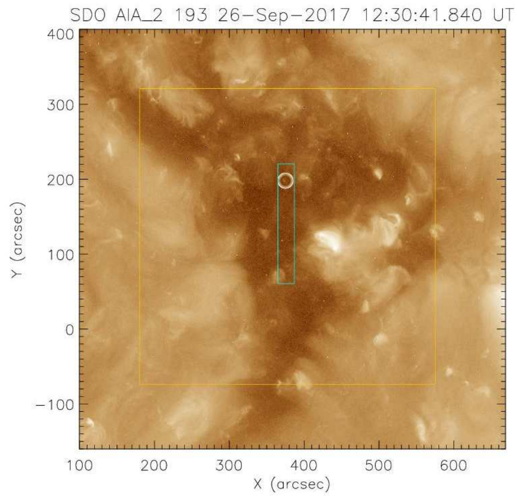

Figure 6. A small zoom-in of a full disc image taken by AIA 193 channel of the SDO spacecraft is shown. The larger highlighted area (orange) marks the FOV of the XRT telescope of Hinode whereas the smaller rectangular box in the centre highlights the EIS FOV. The circle demarks the position where small-scale activity was found in the form of two micro-flares and a jet.

In the analysed data we found a small-scale active region producing within roughly 10 minutes two microflares and a small-scale jet event (see Fig. 7 and for more details Krikova et al. 2018 [22]).
After this very short overview of our current research activities we would also like to outline future prospects due to the obtained data from a GREGOR observational campaign performed last year in late September.

6. COMBINED GREGOR OBSERVATIONAL CAMPAIGN OF SEPTEMBER 2017

The group submitted with the help of co-proposers (e.g. Peter Gömöry from Astronomical Institute of the Slovak Academy of Sciences and many colleagues from AIP in Potsdam) an observational proposal both to the GREGOR (see Schmidt et al. 2012 [1]) and VTT (see Schroeter et al. 1985 [24]) ground-based observatories as well as to Hinode and IRIS spacecraft teams. The proposal was accepted, and the campaign launched on the 18^{teen} of September until 30^{teen} of September 2017.

Unfortunately, due to bad weather influences like Calima (high concentrations of Sahara dust), low lying clouds or bad seeing, data were only taken on 3 days

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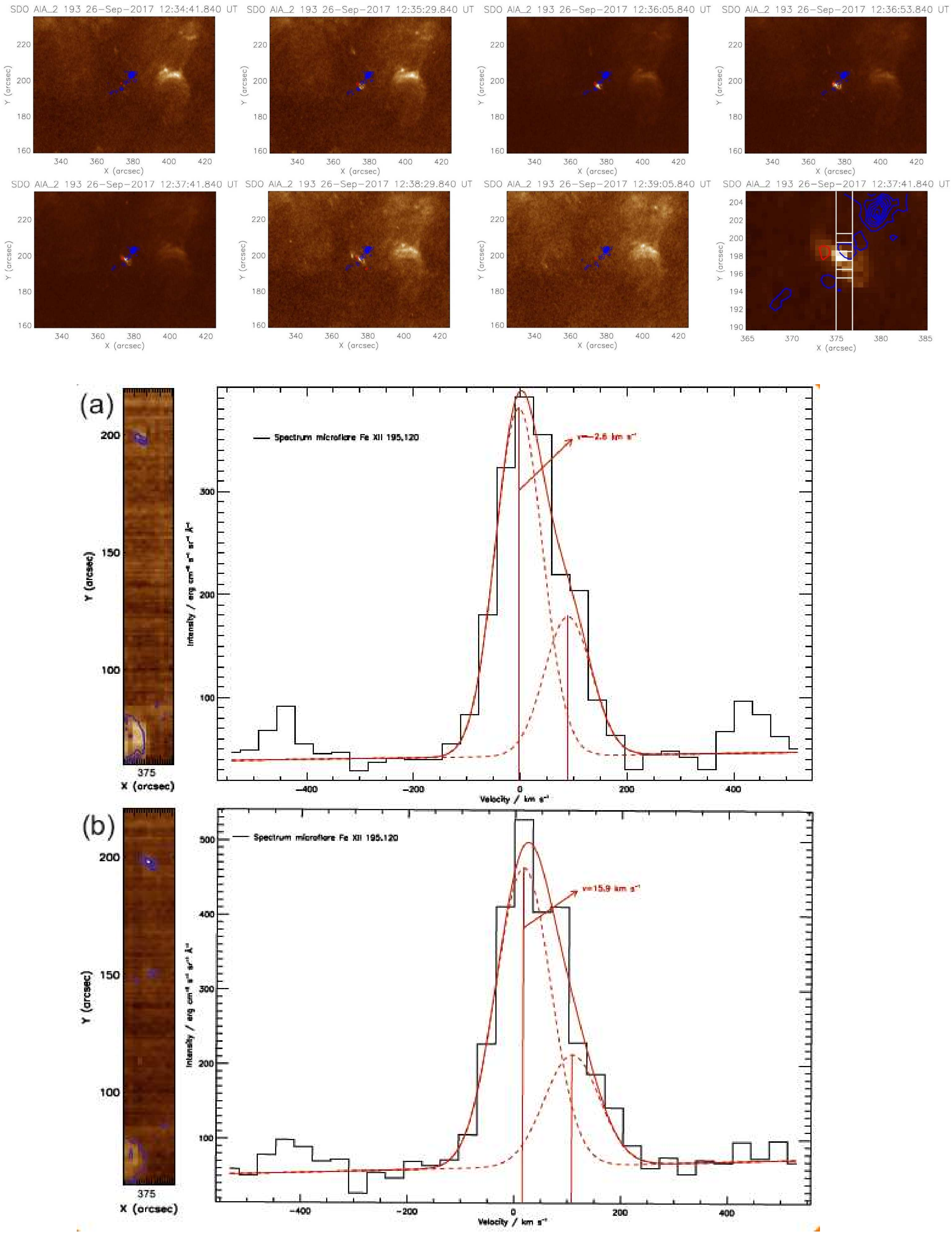

Figure 7. Top: 7-time instances of the AIA 193 channel (roughly 45 sec. cadence) are shown belonging to the second micro-flare event. Last panel shows the EIS slit position over the micro-flare event. The contours in the images give the magnetic fields as seen by SDO/HMI. Below: the two instances of the microflare as seen by the EIS spectra of the Fe XII line. On the left side the integral intensity of the line is shown, while the right panels give the spectral two component line fits. While we practically cannot detect any flows in the first micro-flare event (the slight upflow is within the accuracy of the analysis), which was also (at least in the moment of data acquisition) weaker than the second one; the second micro-flare event shows strong and clear downflows. For more details see Krikova et al. 2018.

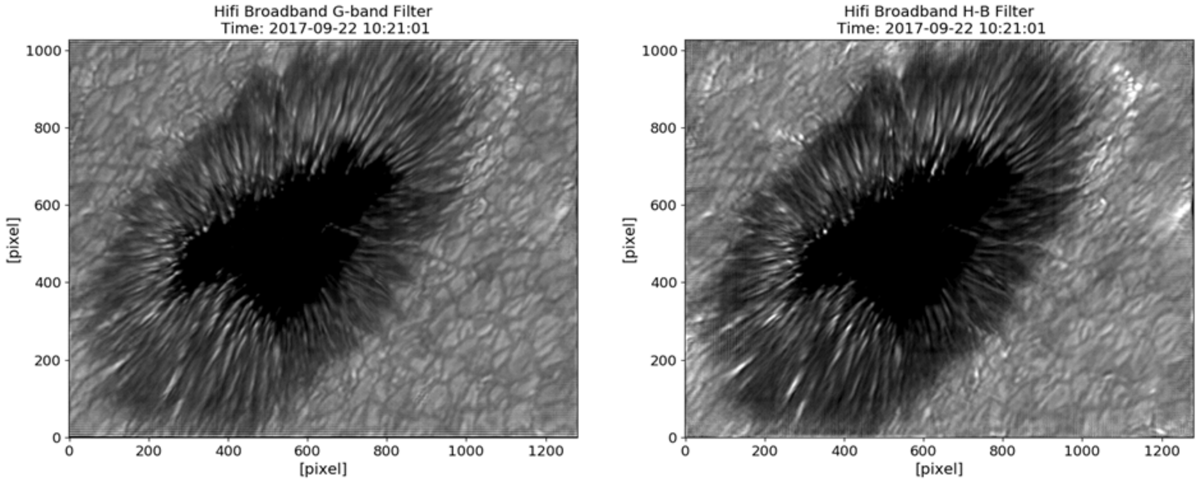

Figure 8. Two image examples (MOMFBD reconstructed) of the data sets taken on the 22nd of September by GREGOR/HiFi instrument with a G-band filter (left side) and H-β filter (right side).

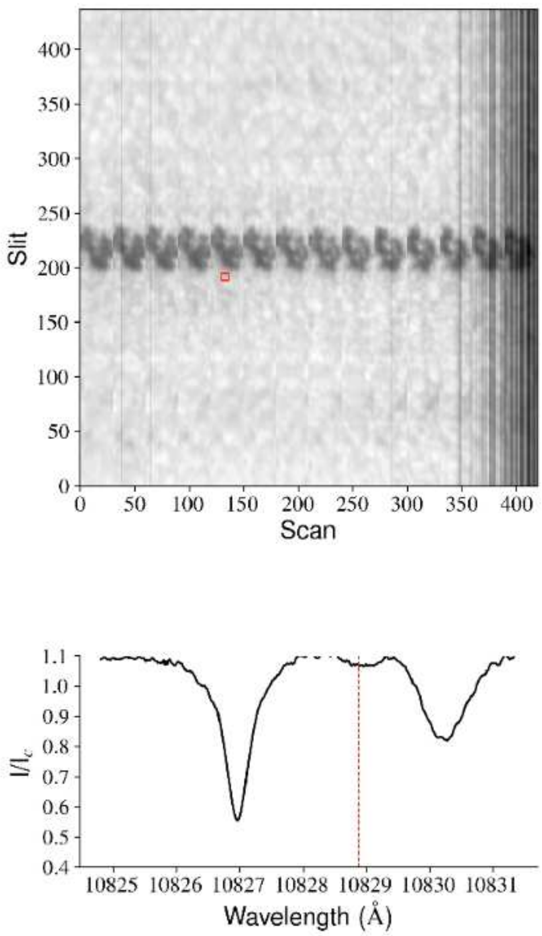

Figure 9. One of the GRIS line scan data set is shown. At the end of the scans the seeing becomes unfortunately too bad. However, several useful and interesting line scans are available.

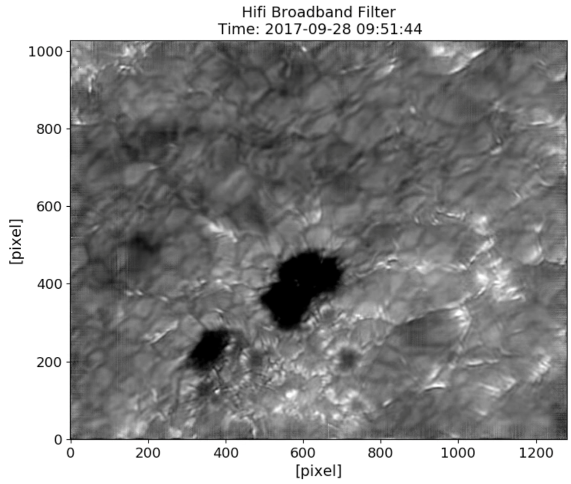

Figure 10. An exemplary G-band image of the HiFi instrument is shown corresponding to the previous data set.

by the ground-based facilities. These were the 22nd of September when we have been able to obtain some acceptable sunspot images of NOAA 12681 in G-band as well as in H-β supported by some GRIS scans of a photospheric Si line as well as a chromospheric He I line and VTT scans of H α and a Ca line. An example of this data set can be seen in Fig. 8.

More interesting data were obtained on the 28th and 29th of September (see e.g. Figs. 9 and 10) when GREGOR was pointing on the trailing section of NOAA 12682 were we found a highly dynamic small-scale solar magnetic field forming ever-changing magnetic pores. The analysis of this data will be our short time future research focus with the data being reduced right now and a series of workshops to be hold for detailed discussions and analysis.

5. CONCLUSIONS

The newly established (with the help of FWF grant 27800 N) high resolution solar physics working group in Graz started to engage successfully in a quite broad range of activities regarding the small-scale magnetic field/plasma interaction in the solar atmosphere. The topics vary from direct observations of magnetic field proxies such as MBPs over the modelling of single isolated and/or more complex flux tube models in the solar atmosphere with the prospect of interesting wave propagation simulations to coronal holes and activity within such coronal holes.

Besides, we have recently obtained a very interesting multi instrument data set during an observational campaign with GREGOR performed last year. This was only possible due to the support of the Leibniz Institut für Astrophysik Potsdam who shared a part of their observational time with our group. The obtained data are currently in the process of being reduced and need further analysis which we wish to perform in the coming months.

Acknowledgments

This research work was performed in the frame of a FWF stand alone project: P 27800 N. The group wishes to express their enourmous gratitude to the FWF for enabling all the work done so far. Moreover, the group is very thankful to the Hinode team for providing now already for more than 10 years excellent data. Hinode is a Japanese mission developed and launched by ISAS/JAXA, with NAOJ as domestic partner and NASA and STFC (UK) as international partners. It is operated by these agencies in co-operation with ESA and NSC (Norway). HMI/SDO data were obtained from the Joint Science Operation Center (JSOC), and they are courtesy of NASA/SDO and the AIA, EVE, and HMI science teams. The 1.5-meter GREGOR solar telescope was built by a German consortium under the leadership of the Kiepenheuer Institute for Solar Physics in Freiburg with the Leibniz Institute for Astrophysics Potsdam, the Institute for Astrophysics Göttingen, and the Max Planck Institute for Solar System Research in Göttingen as partners, and with contributions by the Instituto de Astrofísica de Canarias and the Astronomical Institute of the Academy of Sciences of the Czech Republic. IRIS is a NASA small explorer mission developed and operated by LMSAL with mission operations executed at NASA Ames Research center and major contributions to downlink communications funded by ESA and the Norwegian Space Centre.

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