Small-scale photospheric upflows and their evolution with time

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Abstract

Small-scale magnetic fields can be seen in the photosphere – often manifested as so-called magnetic bright points (MBPs). Theoretically MBPs are described via the slender flux tube model which corresponds to the idea that MBPs can be represented by single isolated evacuated magnetic flux tubes. A widespread concept for their creation is the convective collapse process which requires strong downflows inside the magnetic field a.k.a flux tube.

Such downflows, followed by an amplification of the magnetic field, have been observed in the recent years and hence such observations can be interpreted as first evidence of this basic scenario of convective collapse. In a recent work the authors have found that spatially related to such downflows within magnetic flux tubes also small-scale localised upflows can be identified. In the present study we wish to shed more light on these small-scale upflows and investigate their relationship with the downflows and further interesting plasma parameters like temperature and magnetic field strength.

1. Introduction

Among the most fascinating small-scale solar magnetic features are so-called magnetic bright points (MBPs). They are studied since the 70´s of the previous century (e.g. Dunn and Zirker 1973) but due to the recent installation of high resolution telescopes the interest in them has further grown significantly. They are thought to be made up of single isolated flux tubes and hence represent elementary building blocks of the solar magnetic field. The standard model for their creation is the convective collapse scenario which was introduced by theoretical works in the 70´s of the last century (see Parker 1978 and Spruit 1976). In recent times more and more evidence was gathered in support of this basic creation scenario (see Nagate et al. 2008, Fischer et al. 2009, and others). These investigations collected more and more facts and detailed insights into the creation of the MBPs and strengthened the afore mentioned theory. On the other hand practically nothing is known about their further evolution. Are MBPs stable features and if so what stabilizes them? If not, is there a cause for their instability, and much more important, how do they dissolve? To shed more light into these questions it is essential to study the evolution of MBPs. The best way to do this is of course by spectro-polarimetric means to get additional information about the involved plasma parameters such as temperature, magnetic field strength and LOS velocities.

In a recent study (Utz et al. 2014) the authors worked already on this interesting problem and found that the evolution of MBPs, or to be more exactly, the evolution of the LOS velocity seems to be coupled with surrounding plasma upflows. To go into more detail, we found during all observations of MBPs practically only downflows inside of them, but in a fraction of roughly 10% of the observed tracks we were able to identify spatially and temporally co-located small-scale upflows (co-located to the downflows). In this follow up study we wish to obtain more details about this small-scale upflows. In chapter two we will give a short summary about the used data, while chapter 3 will deal with the analysis, followed by chapter 4, the preliminary results. In chapter 5 we summarise the current understanding of the found results and give an outlook how we wish to proceed.

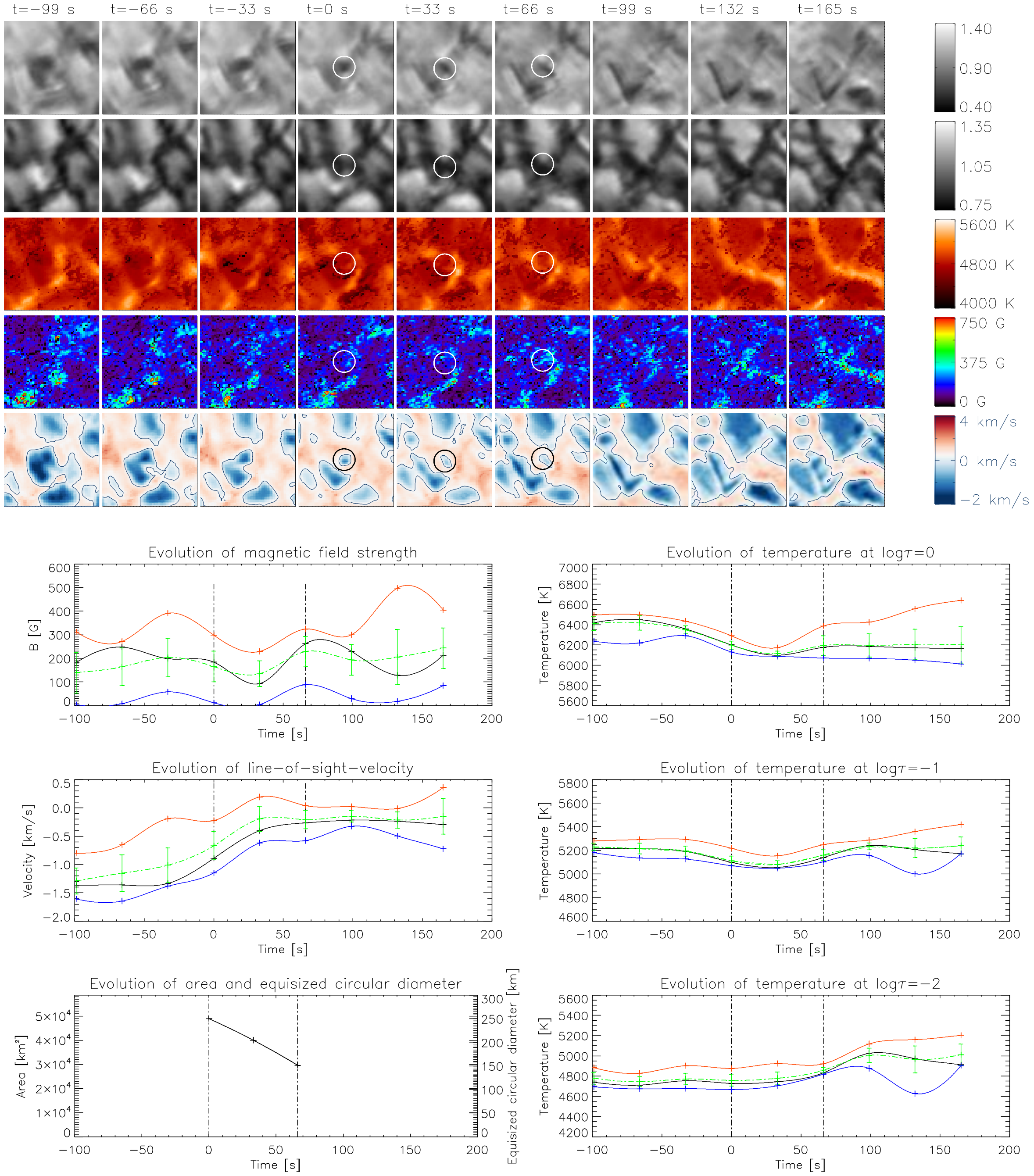

Fig. 1. First exemplary case – a granular fragment: upper block of figures: evolution of the tracked feature in different plasma parameter maps; from top to bottom: line wing intensity, continuum intensity, temperature, magnetic field strength, LOS velocity; the feature is marked by a circle; maps are clipped to enhance their contrast; values are displayed accordingly to the colour bars. bottom block of figures: left column (top to bottom): magnetic field strength, LOS velocity, size; right column (top to bottom): temperatur at log τ=0, -1, -2; red, blue, green lines illustrate the evolutions for the maximum, minimum, average value of a 5 by 5 pixel^2 box centred at the barycentre (black line); vertical dashed dotted lines illustrate the tracking period of the feature;

2. Data

For our study we used data taken by the Sunrise mission which is a balloon-borne instrument flown already twice in the stratosphere. The Sunrise mission (for a detailed mission description see Barthol et al. 2011) consists of an one meter telescope mounted on a gondola to be flown by a balloon in the stratosphere (about 30 km above sea-level). Two such flights happened up to now. The first one was sheduled for early June 2009 (see Solanki et al. 2010) showing mostly the quiet Sun and the second one followed up in June 2011 showing a more active Sun. The scientific payload consists of two instruments:

SuFI, the Sunrise Filter Imager (Gandorfer et al. 2011), an instrument designed to observe the solar atmosphere (photosphere and chromosphere) in the near-ultraviolet and visible in 5 wavelength bands (214 nm, 300 nm, 312 nm, 388 nm - Cn band head - and 397.6 nm – Ca II H). The FOV of the instrument is approximately 15 by 40 arcsec².

The other instrument onboard the gondola is IMaX – Imaging vector Magnetograph eXperiment which conducts observations of doppler shifts and polarization in the Zeeman-sensitive photospheric

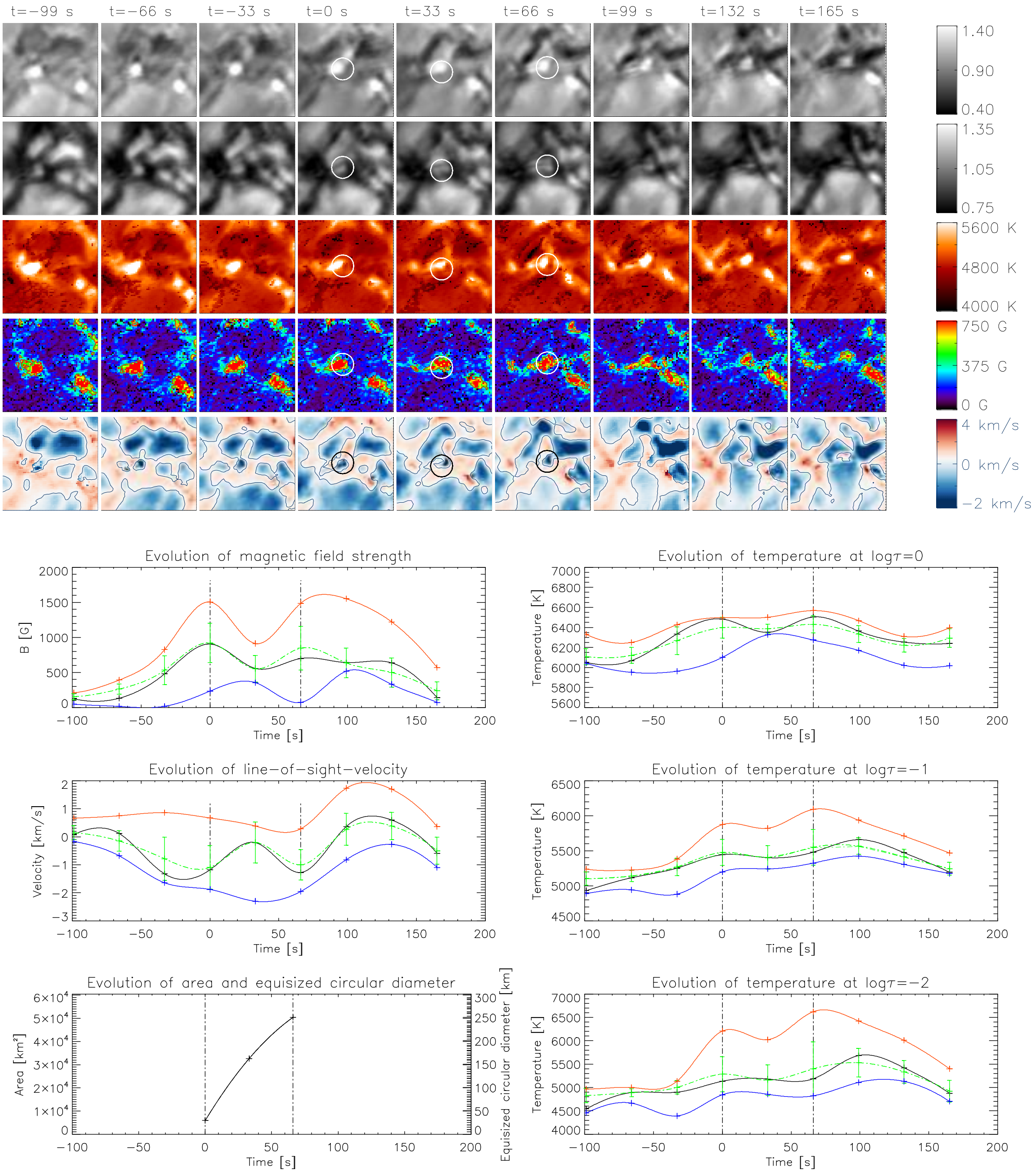

Fig. 2: Similar to Fig. 1 but for a small-scale upflow within a magnetic element;

spectral line of neutral iron at 525.02 nm.

In our study we used IMaX data from the 9th of June 2009. The data were taken between 0:36 UT and 2:02 UT and comprise two data sets (the first one ending at 0:58 UT and the second one starting at 1:31 UT). Both data sets were recorded in the V5-6 mode. This mode comprises all 4 polarization states and 5 wavelength samples around the iron line center (-80 mÅ, -40 mÅ, 40 mÅ, 80 mÅ, and 227 mÅ – continuum) accumulated within 6 single exposures to increase the signal to noise ratio (for more details about IMaX see Martínez Pillet et al. 2011). The data were already pre-calibrated (dark current, flat field corrected; Stokes demodulated and a phase diversity reconstruction algorithm applied) when we obtained them from the mission webpage. All the details about the data reduction can be found in the afore mentioned paper. The SIR code (Stokes inversion by response functions, Ruiz Cobo and del Toro Iniesta 1992) was applied on the spectropolarimetric data with a simple model for the solar atmospheric stratification. I.e. one node was considered for each one of the parameters such as the magnetic field and its angles, LOS velocity, microturbulence and two nodes for the temperature stratification.

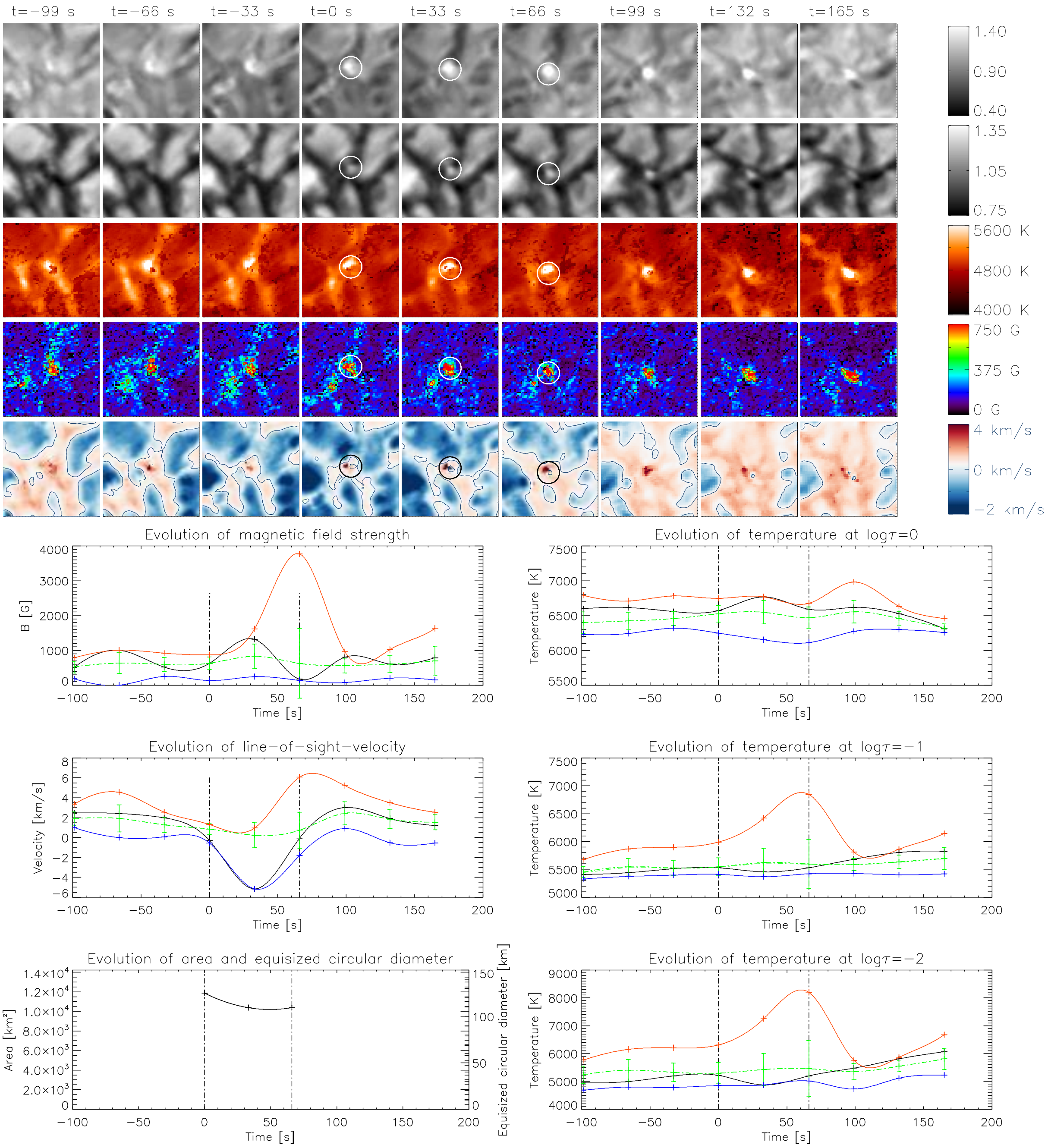

Fig. 3. Similiar to Fig. 1 and 2 but for an interacting small-scale upflow with a small-scale downflow;

3. Analysis

An automated image segmentation and identification algorihm was applied on the data. The full description of the algorithm can be found in Utz et al. 2009, 2010. In contrast to earlier works we did not apply the algorithm on intensity maps but used it directly on LOS velocity maps. The application of the algorithm on these maps enabled us to detect small-scale photospheric upflows. After the identification of such upflows we performed a tracking of the identified featues as described in Utz et al. 2014. The final point of the analysis is the extraction of the interesting information which was done in a similar fashion to the previously mentioned paper, i.e. we extracted plasma parameters of interest from the identified barycentre positions as well as the maximum, minimum and average quantities in a subfield box of 5 pixels^2 centred around these barycentre positions.

4 Results:

We start this section with the analysis of a few case studies to give a first impression of how the evolution of small-scale photospheric upflows can look like, before we go into a more detailed statistical analysis.

4.1 Small-scale upflow case studies:

a) The granular fragment

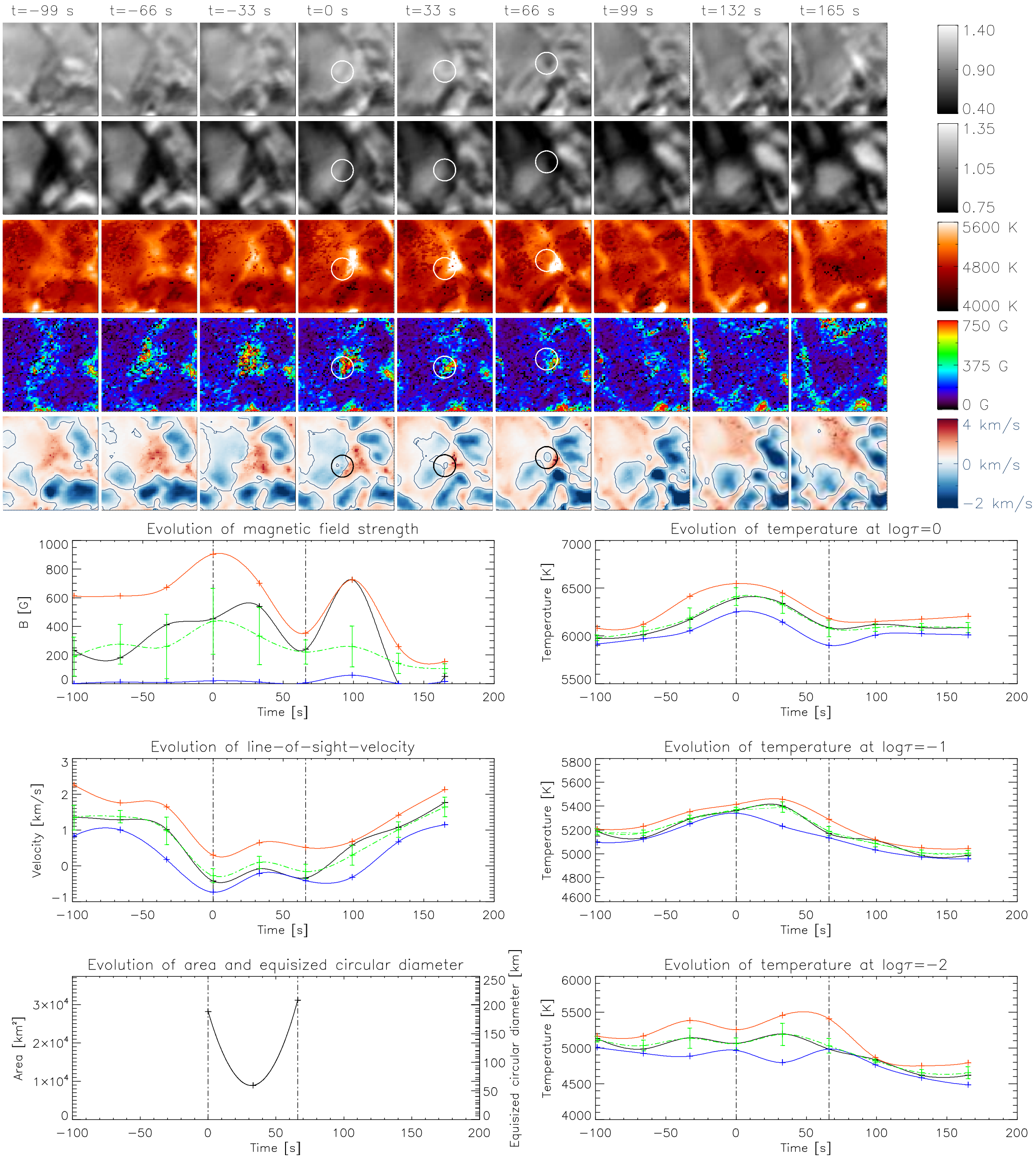

Fig. 4.: Similar to Figs. 1, 2, 3 but for a dispersing magnetic field;

A quite typical case of found evolutions is the from us at this point termed “granular fragment” case. In this evolutionary scenario a former granular upflow is becoming weaker and hence smaller in size. When it is small enough it is detected as small intergranular upflow and tracked by our algorithm. For an overview of the plasma maps see Fig. 1 top panels. Below of this plasma maps the detailed evolution of the plasma parameters within a region of interest (ROI) – 5 pixels sidelength box centred around the barycentre – is depicted with different lines, red – maximum, blue – minimum, green – average, and black – barycentre values of the box of ROI. Clearly the granular fragment is non magnetic as the maximum reached field strengths are low (below 300 G) and hence still compatible with image noise and weak intergranular fields. The LOS velocity shows the trend of the weakening of the granular upflow, and finally we can state that the

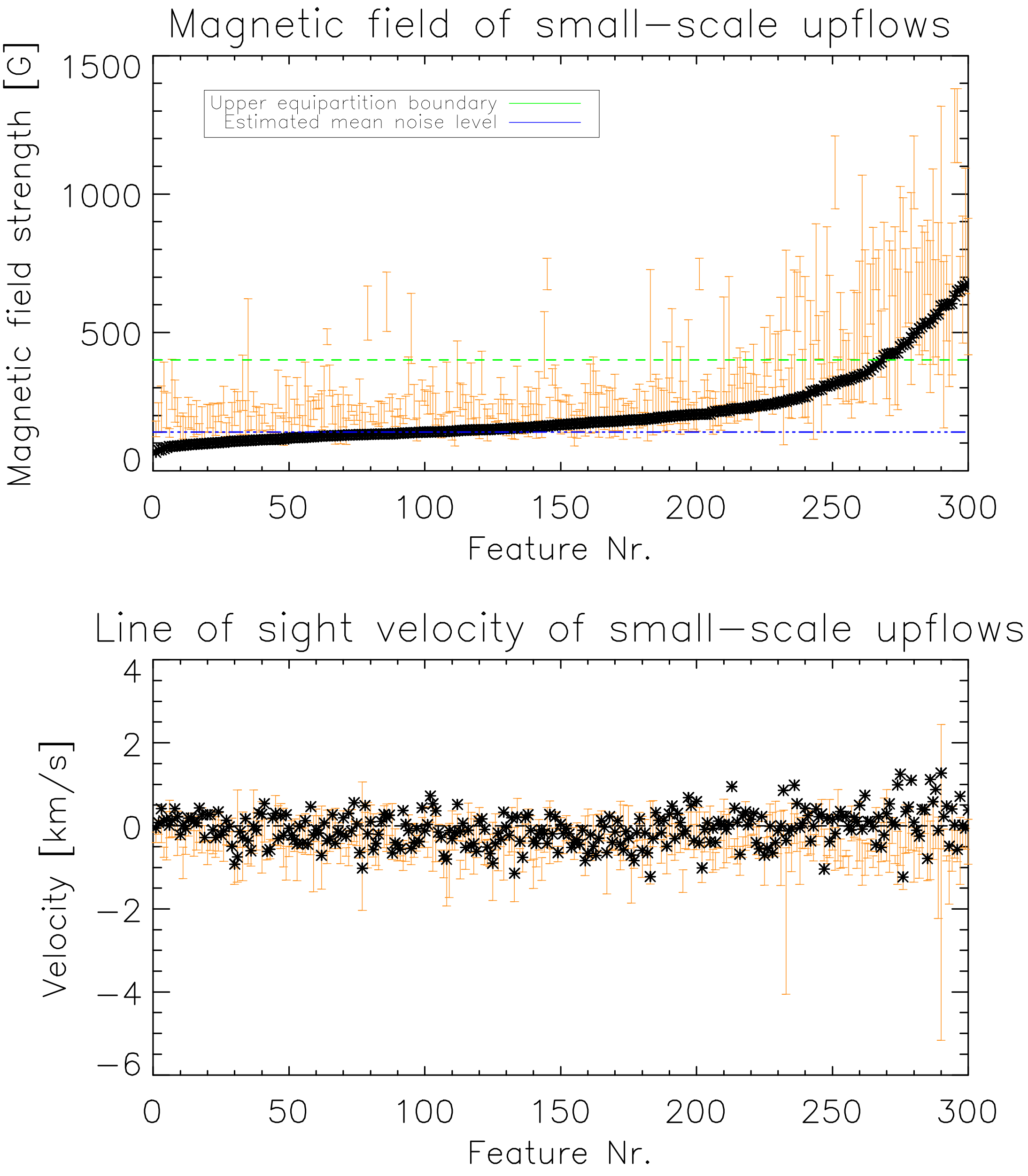

Fig. 5: top panel: the distribution of found magnetic fields sorted with increasing magnetic fields. The dashed green line gives the upper boundary of the equipartition magnetic field strength. The dashed blue line illustrates the noise level in the data;
lower panel: the distribution of the LOS velocities of the identified small scale upflows.

temperature evolution is quite insignificant. Also the size is shrinking as expected for a weakening granular upflow.

b) small-scale upflow within a magnetic element

The second case (depicted in Fig. 2) is more interesting as it shows a weak upflow within a magnetic field patch. This is interesting, as commonly downflows are associated with magnetic fields. At least this picture is generally accepted probably due to the idea that strong magnetic fields should suppress convective upflows. Interestingly, but physically totally plausible, the upflow leads to a weakening of the magnetic field and to an increase of the found structure in size. Obviously also a temperature response is associated to this evolution.

c) small-scale upflow interacting with a downflow

These were actually the cases we were looking for when we started the current investigation. One can clearly see in Fig. 3 – upper panels – that an interaction of the detected small-scale upflow with a strong downflow situated close by is occuring. A look into the evolution of the plasma parameters shows that after the occurence of the very strong upflow of close to 5 km/s, a strong downflow of 6 km/s sets in and that most likely both together are responsible for the amplification of the magnetic field up to 3 kG, which is indeed an amazing and very strong magnetic field. Furthermore there is a significant temperature response to be seen in the higher atmosphere.

d) dispersion of magnetic field

To complete the resulsts section on specific case studies we wish to present a 4th case, illustrating the dispersion/cancelation of a dispersed magnetic field by inflowing granular material. In the images before the tracking one can observe a granular upflow to the left of a region with dispersed magnetic fields and downflows. During the evolution it seems that the granular flow sweeps over into the region of intergranular dispersed downflows and magnetic fields. Due to this process the small dispersed downflows stops and the magnetic field starts to disappear. The question which arises here, and cannot be satisfactorily answered right now, is if the magnetic field was taken subsurface by the inflowing material and hence swallowed or if it has been previous a kind of flux emergence with low lying loops which became released to the higher atmosphere. Whatever the detailed processes observed in case number 4 the magnetic field drops from around 600 G to around 200 G which means into the noise level/background.

4.2 Statistically inferences

To gain a better understanding of the small-scale upflows which have been investigated in this study we applied some simple statistical methods on the tracked evolutions. The result can be seen in Fig. 5 where we display in the upper panel the deduced magnetic field strength of the evolutions during three critical evolutionary stages. In black asterisk the initial magnetic field strength is shown while the vertical bar gives the maximum and final magnetic field strength during the evolution of the small-scale upflows. The tracks were sorted by increasing initial magnetic field strengths (given as asterisks). Clearly two thirds of the found evolutions are non magnetic and might belong to the granular fragment feature class. Nevertheless about one third of features are indeed magnetic and show upflows. These features probably belong to the interesting cases two and three (or even to the fourth). In the lower panel we show a simliar plot for the line of sight velocity measurements.

5 Conclusions and outlook:

The present paper shows the first preliminary results of a currently ongoing study on small-scale photospheric upflows. First results indicate that a wealth of interesting details can be learnt and studied. Furthermore obtained preliminary statistically inferences are promising and reveal the magnetic nature of a significant fraction of the studied small-scale upflows. The most interesting feature class to be studied in more detail is for sure the interaction between downflows and upflows. Probably a combination of the identification of small-scale upflows and downflows within the LOS maps will help to increase the rate of detection of these interesting cases. A pure identification based only on upflows shows, like in the present study, a high fraction of less interesting non magnetic granular fragments.

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