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Magnetic bright point dynamics and evolutions observed by *Sunrise*/IMaX and other instruments

D. Utz[1,2], J. C. del Toro Iniesta[1], L. Bellot Rubio[1] S. Thonhofer[1,2] and J. Jurčák[3]

[1] IAA - Instituto de Astrofísica de Andalucía, CSIC, Glorieta de la Astronomía, s/n, ES–18080 Granada, Spain
[2] IGAM/Institute of Physics, University of Graz, Universitätsplatz 5, AT–8010 Graz, Austria
[3] Astronomical Institute of the Czech Academy of Sciences, Fricova 298, CZ–25165 Ondrejov, Czech

Abstract

In this proceeding we will have a closer look on recent observations and results regarding the dynamics and evolution of so-called magnetic bright points (MBPs). MBPs are manifestations of kG magnetic field strong flux concentrations seen in the solar photosphere. They belong to the class of small-scale solar magnetic features with diameters starting from low values around the current observational resolution limit - about 100 km - up to a few hundred km. They might play an important role in several key research questions like the total solar irradiance variation (TSI variation) as well as the solar atmospheric heating problem. Especially their dynamic behaviour is of interest for the heating problem as they might trigger all kinds of MHD waves which travel up to the higher solar atmospheric layers, where they can get damped leading to a heating of the plasma. Furthermore they might engage in magnetic field reconnection processes leading consequently also to a heating. Due to these reasons, and also for the sake of a better understanding of the physical processes involved on small-scales, detailed investigations on the dynamical behaviour and evolution of such magnetic field proxies like MBPs is in order. In this conference proceeding we wish to give in a first part an overview about the obtained knowledge so far. In a second part we highlight recent results regarding the dynamical evolution of plasma parameters of MBPs such as magnetic field strength, temperature, and line of sight velocity. This proceeding is completed by an outlook on what can and should be done in the near future with available data from recent telescopes.

1 Introduction

Magnetic bright points (MBPs) are among the most fascinating and interesting small-scale magnetic features of the Sun. They were discovered in the 70's of the last century and since then studied in ever more detail. Among the first to report about these features have been Dunn & Zirker (1973)[11], e.g., compare their Fig. 7 with recent observations. Since these early days the observational capabilities as well as the methods enabling sophisticated numerical experiments have improved fantastically. A major step forward was achieved by the implementation of a G-band filter at the Pic du Midi observatory in the 80's introducing a new standard observable —the G-band filtergram (see, e.g., Muller and Roudier 1984[22]). For informative purposes we show in the top panel of Fig. 1 an image taken by the 50 cm solar refractor installed at the Pic du Midi observatory. In comparison to it we display a recent exposure taken by the 1 m aperture Swedisch Solar Telescope (SST) in the lower half. The left side displays the full field of view while the right side shows the, by a rectangle, marked detail.

Due to the improving observational and computational capabilities, MBPs also receive more and more interest from theoreticians in regards of modelling and explaining their properties (see, e.g., Criscuoli and Rast 2009[7]). Among other research topics, MBPs play an important role in the study of the total solar irradiance variation (TSI variation; for more information see Solanki et al. 2013[36]). The acronym MBP already states the most fundamental and important characteristics of them. They are magnetic, which means that they posses magnetic fields in the kG range, see Utz et al. (2013)[39]; they are very bright compared to their surrounding, this is especially true when they are observed within molecular bands like the G-band (see, e.g., Schüssler et al. 2003[32]); and they posses very small sizes in the range of a few hundreds of kilometres down to the current resolution limit (see, e.g., Wiehr et al. 2004[44]). Theoretically they can be best described by the thin flux tube model (see Fisher et al. 2000[12]) and their creation can be understood by the convective collapse model (see Spruit 1976[33]).

Thus the question arises why they are still a concern for research and what is interesting about them. These are two questions we try to answer in this proceeding. In the next two chapters we wish to outline why it is interesting to study their dynamics and dynamical behaviour and we will try to summarise the results found in literature. Chapter 4 and 5 will then deal with their temporal evolution. In Chapter 4 we will motivate again our research before we will outline our recent results in Chapter 5. The final chapter will summarise the proceeding and give an outlook on future perspectives.

2 Dynamics of MBPs

2.1 Motivation: why is the dynamic of MBPs important?

Except of the principle interest of any researcher to know as many details about the subject of his study and possible fundamental impacts of extended basic knowledge, the dynamics of MBPs are of vital interest for atmospheric heating theories and models. In principle the

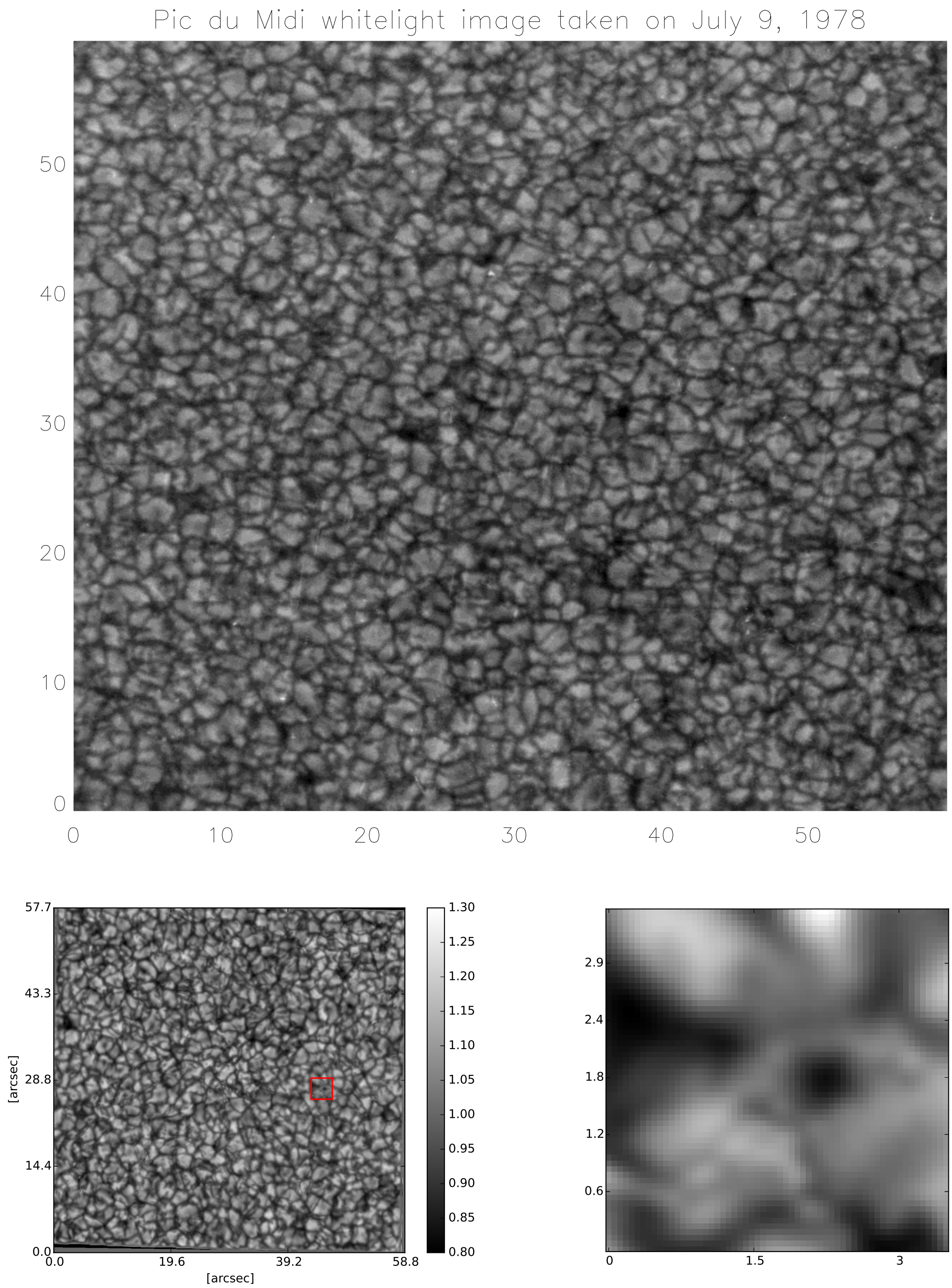

Figure 1: Top panel: the shown example is among the best white-light images of its time taken by the 50 cm solar refractor at Pic du Midi observatory on July 9, 1978 by Richard Muller (private communication). Lower panel: a recent image taken by the CRISP device belonging to the 1 m SST instrument (left: full FOV; right: marked detail).

Table 1: Overview on MBP lifetimes found in literature. In de Wijn et al.(2008)[10] magnetograms were used for the identification of the small-scale magnetic fields (instead of MBPs). Taken from Utz et al. (2010)[37] and extended by some recent results.

Paper	reported MBP lifetime [min]
de Wijn et al.(2008)[10]	10
Möstl et al.(2006)[20]	4.4 ($\pm$2.4)
de Wijn et al.(2005)[9]	3.5
Sánchez Almeida et al.(2004)[30]	< 10
Berger & Title(1996)[3]	$\sim (6-8)$
Utz et al.(2010)[37]	2.5
Abramenko et al.(2010)[1]	3 (depending on the used distribution function)
Bodnárová et al.(2013)[4]	3.0 ($\pm$2.7)

community came up with two approaches to the solar atmospheric heating problem (see, e.g., Walsh and Ireland 2003[43], or Klimchuk 2006[17]): the AC approaches or alternate current mechanisms, which summarises all kinds of wave heating mechanisms; and the DC or direct current models, which are based on reconnection heating. There is already some literature dealing with both mechanisms in regards of the MBP dynamics from simulations as well as from observations (see, e.g., Heggland et al. 2009[14] and Chitta et al. 2012[6]).

Among the more interesting wave heating studies is the one of Vigeesh et al. 2009[42], who investigated in detail the influence of the dynamics of the driver of the flux tube which carries the wave to the upper atmosphere. The interesting outcome of the study was that the amount of energy which can get injected into the upper atmosphere might vary by a factor of up to 20 depending on the initial conditions of the photospheric driver. As MBPs are proxies for the footpoints of such flux tubes which carry these waves, the dynamic of the MBPs is exactly the needed input for the wave simulation models but also a necessary input for reconnection models.

2.2 Lifetime and velocity distributions

Lifetime

While the lifetime is not of such a grave importance for the wave heating mechanisms, except if the features would live too short to provide a stable environment as an energy flux carrier, it is of interest for magnetic flux balances as well as for theories describing the magnetic flux transport. The shorter the MBPs, as proxies for the strongest small-scale magnetic fields, live, the more new flux must be created on the surface, due to surface dynamos, or replenished from subsurface regions via flux emergence. In literature one can find values from a few minutes up to tenths of minutes. For more details we refer to Table 1. The mental note to be taken from this table is that the observed and measured lifetime of the features became considerably smaller in the recent years. While in the beginning of MBP observations it was thought that these magnetic structures are stable on the tenths of minutes, the recent observations suggest that the photosphere on such scales is much more dynamic with mean lifetimes in the range of a few minutes, or, as Abramenko et al. 2010[1] state, about 98.9% of all MBPs live less than 120 s. They argue that these findings were only possible due to the highly improved temporal cadences available nowadays, revealing the true highly dynamic evolution of these features.

Velocity

The velocity distribution is of great importance as a key parameter to describe the driver of wave heating models. Thus it is one of the parameters measured already quite often for MBPs with a variety of instruments. As a result it is well established that MBPs display random walk movements with a velocity in the range of a few km/s (see, e.g., Nisenson et al. 2002[23], Fig. 4, de Wijn et al. 2008[10], Fig. 7, or Utz et al. 2010[37], Fig. 8). From theory it follows that if the x as well as the y component of the velocity of a feature follows a Gaussian distribution that in such a case the effective velocity, $\sqrt{(x^2 + y^2)}$, will follow a so-called Rayleigh distribution. Remarkably the width of the distribution is dependent on the temporal and spatial resolution of the data set used as shown in Utz et al. 2010[37] and verified by a numerical experiment in Utz et al. 2012[38]. The question not answered satisfactorily up to now is: if velocities can become arbitrary high for data sets resolved better in time? That the obtained and measured velocities increase when measured with an improved temporally resolved data set was shown by the afore mentioned studies and explained by the fact that a random walker might cover an arbitrary distance between two fixed points in time when the position is just measured more often during the two fixed time instances (see also Fig. 2). But while the observational study (Utz et al. 2010[37]) pointed to a certain maximum parameter for the Rayleigh distribution, and thus for the velocity, the simple random walk model and simulation (Utz et al. 2012[38]) indicated arbitrary high velocities.

2.3 Recent *Sunrise* Results

Sunrise is a balloon borne instrument which was flown twice in the Earths atmosphere. The science payload consists of two scientific instruments. The Sunrise Filter Imager (SuFi; see Gandorfer et al. 2011[13]) and the Imaging Magentograph eXperiment (IMaX; see Martínez Pillet et al. 2011[19]). All the major details about the first *Sunrise* flight in June 2009 and a summary of the available data can be found in Solanki et al. (2010)[35]. From the small-scale magnetic field dynamics, as indicated by MBPs, the most important publication was probably the study of Jafarzadeh et al. (2013)[15]. In this paper the authors investigated bright points as seen in the Ca II H line. They found larger velocities than usually reported in the photospheric counterpart features. Most notably they saw that single features might become fainter for some time before re-brightening again. The used term for such features was persistent flashers. Such behaviour was also reported by Bodnárová et al.(2013)[4] for bright points seen in the photosphere and might shed light on the different lifetime distributions reported recently compared to previous works (see also Table 1 of this work). Probably in the past, when the temporal resolution was not sufficient, persistent flashers were not resolved as reappearing shorter living multitude of features but as unique single features with an

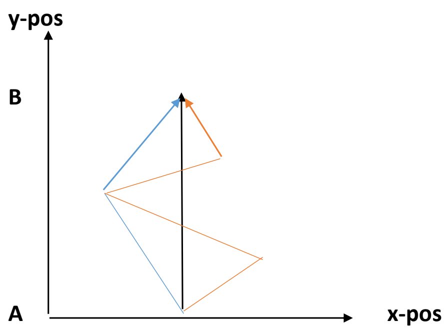

Figure 2: schematic illustration of the increase of distance between two fixed positions in time and space of a random walker by an increasing temporal resolution. If a feature is observed with a certain resolution at point A in one instance and in the next at point B, it might be observed being not on the line of direct connection in a time step in between both instances (blue-line). The total blue path between A and B is longer than the shortest possible connection which is normally also assigned as the traveled distance by the feature. By increasing the temporal resolution further (e.g. orange line) the distance grows while the time between A and B stays the same. Thus the increasing temporal resolution is leading to an increasing observed velocity.

attributed much larger lifetime explaining the discrepancy in the various studies.

Other interesting results gained by *Sunrise* on small-scale magnetic fields concerned the first observation of a fully resolved magnetic flux tube as described in the study by Lagg et al. (2010)[18] or a comparison between observed photospheric bright points with properties deduced from MHD simulations (see Riethmüller et al. 2014[28]). Finally, we would like to return to MBPs and mention a study done again by Ca II H bright points for the deduction and estimation of the the magnetic diffusion coefficient (see Jafarzadeh et al. (2014)[16]).

3 MBP evolutionary tracks

3.1 Motivation

Why is it important to track MBPs and learn more about their temporal evolution? To analyse this question we should have first of all a look on what we know, and what explanations we have at hand. For this purpose we created a simple sketch of a possible evolution of three interesting MBP parameters (see Fig. 3). In black line the evolution of the area of the structure is given, while the green line illustrates the LOS velocity, and the red line the magnetic field strength. In full line we show an expected behaviour while dashed lines symbolize yet unknown territory. Why is the beginning of the evolution known or what do we expect?

Since the 70's of the last century the community became familiar with the so-called convective collapse hypothesis (see Spruit 1976, 1979[33, 34], Parker 1978[26]). Here the

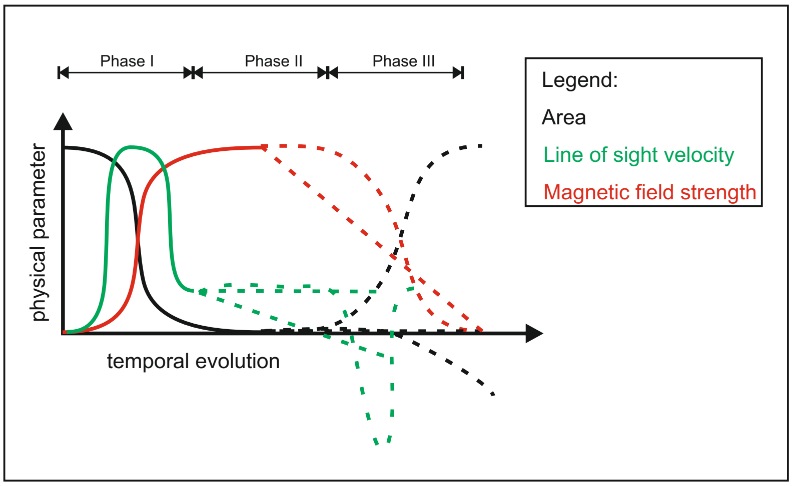

Figure 3: Shows a sketch of a possible MBP evolution. One could divide the whole evolution of a MBP in three phases: a creation phase, shown in solid lines as theories exist of how to create MBPs; a second phase, where the feature is in some kind of equilibrium (how is that reached and how is the feature stabilised?); and a final phase, when the feature dissolves; Phase 2 and 3 are shown in dashed lines as to symbolise that much less is known about that evolutionary stages.

idea is that a strong magnetic field prohibits the normal convective energy transport to the solar surface. Thus the plasma begins to cool down due to radiative losses. The cooler plasma becomes heavier and starts to sink down and thus evacuating the magnetic field patch which starts to shrink in very short time—the collapse. But what happens later on? Is the feature than stable and/or what stabilises or destabilises the feature? A possible contribution to destabilise a thin flux tube is the interchange or flute instability (see Parker 1955[24], Piddington 1975[27]). In a later publication Parker (1975)[25] states that an adjustment of the temperature field around, e.g., a sunspot could overcome such an instability. A few other possibilities are discussed in literature too (see, e.g., Bünte et al. 1984[5]). Among the possible candidates are swirl like velocity fields around the flux tubes (see Schüssler 1984[31]), constraining them in their shape.

And the final question still needing an answer is: Why and how does the flux tube at the end dissolves and what happens to the energy stored in the magnetic field?

3.2 Case studies

To increase the knowledge about the creation, evolution, and dissolution of MBPs a study was performed by Utz et al. 2014[41] with *Sunrise*/IMaX data. A first understanding can be gained by following individual evolutions of MBPs as, e.g., the one depicted in Fig. 4. Here we see in the upper part from top to bottom maps of plasma parameters, namely blue line-wing intensity (used for tracking the feature), continuum intensity, temperature at log $\tau = -2$, magnetic field strength, line of sight velocity. All the plasma parameters were obtained with the SIR inversion code (Ruiz Cobo and del Toro Iniesta 1992[29]) using one node (no height dependence, i.e., constant with height) except for the temperature where two nodes were used. The temporal evolution is given by the image sequence from left to right. We see that the bright point is formed in the centre of three granules, which was already reported earlier for a similar case by Muller 1983[21]. Moreover, the response in the continuum is quite weak while there is a clear brightening in the higher atmosphere and thus some heating process must be happening. In the $v_{\rm LOS}$ map a clear downflow at the start of the evolution can be seen which is later on replaced by an upflow when most likely a 5 min p-mode oscillation moves through the region of interest (bear in mind that the data have not been p-mode filtered).

In the lower part of Fig. 4 we show the evolution of the parameters as curves. The red line illustrates the maximum of a 5 pixel wide box centred around the barycentre of the MBP while the blue line depicts the minimum within the box, the black line states the barycentre itself, and the green line the average $\pm\sigma$ within the afore mentioned 5 pixel wide box. Clearly the first brightening is associated with a fast downflow of up to 4 km/s, a shrinkage in size, and a strong temperature response in the higher atmosphere. Shortly before the end of the feature (around 200 s) a second amplification of the magnetic field happens from 300 to 600 G, although this time it is not clearly associated with a strong upflow, but, however, still with a shrinkage in size; As we have seen in the upper panel, it seems that a p-mode generated wave-train was going through the region of the magnetic field and thus probably we see just a compression of the magnetic field structure which leads via flux conservation to an increase of the magnetic field.

As we have seen from this single tracked case it makes sense to study the evolution of single features. This was done, e.g., by Utz et al. 2013, 2014[41, 40]. But additional knowledge can be gained by doing statistics on such evolutionary tracks.

3.3 Statistical results

The statistical analysis conducted in Utz et al. 2014[41] yielded a distribution of initial magnetic field strengths around the equipartition magnetic field strength with individual maximal field strengths reached during the evolution being usually 2 to 4 times stronger than the initial ones. When the features dissolve they show again field strengths within the range of equipartition field strengths. The LOS velocities have shown in general downflows and only very seldom upflows have been witnessed. The magnetic field strength distribution during all time steps follows log-normal distributions as was already shown by Utz et al. 2013[39]. While researchers find in observations like the previous one, or the one of Beck et al. 2007[2], a whole distribution of magnetic field strengths from lower values stretching all the way up to the kG range, investigators retrieve from computer simulations usually only MBPs with kG field strengths (Riethmüller et al. 2014[28]). A possible explanation was given by Criscuoli et al. 2014[8] when they were investigating the effects of the point spread function of the instrument on the retrieved magnetic field strength distribution. The authors of this paper argue that due to observational limitations such as diffraction, sampling, or the point spread function of the instrument, the theoretical magnetic field strength distribution is smoothed

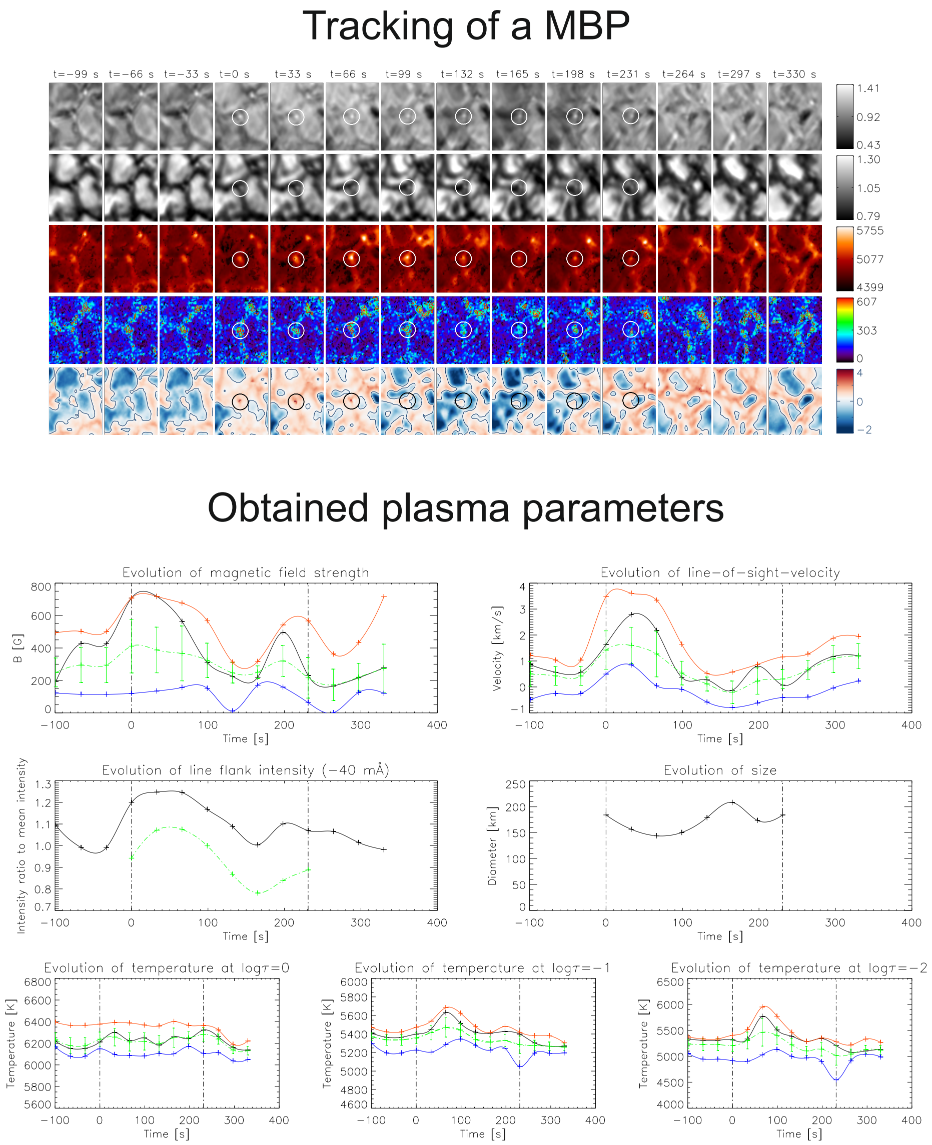

Figure 4: Top panel: five important plasma maps from top to bottom: blue line-flank intensity given as [data/mean(data)], continuum intensity given as [data/mean(data)], temperature map at log $\tau = -2$ given in [K], magnetic field strength map [G], and LOS velocity map [km/s]. The evolution of the region of interest with time is shown and the tracked MBP is marked by a white circle; Lower panel: the obtained plasma parameters of the MBP and their temporal evolution; from right top to left bottom: magnetic field strength, line of sight velocity, blue line-flank intensity, size, and temperature at log $\tau = 0, -1, -2$; The different line colors represent: the maximum in a 5 by 5 pixels^2 box (red), the barycentre (black), the minimum in the previously stated box (blue), and the average quantity $\pm\sigma$, its standard deviation (green).

and widened to cover also smaller values. A final word can maybe be spoken when the 4 m aperture solar telescope class will be operational.

4 Summary and outlook

In this contribution we gave a short review on the topic of small-scale magnetic fields as seen by MBPs starting with a historical perspective and motivating the research and interest in them. We outlined the importance of MBPs for the solar atmospheric heating problem as well as the lack in knowledge about their evolution after their creation. We summarised the properties of important dynamic parameters such as their lifetime and velocity. This was followed by some new results on their temporal evolution.

Due to nowadays available high resolution data we wish to emphasize on some interesting new research questions. One obvious approach to shed more light on the topic of MBPs would be to combine evolutionary studies with investigations on their dynamical properties. This means in detail to investigate what happens to the plasma parameters like temperature, magnetic field strength, and line of sight velocity, during moments when the features receive high accelerations due to the larger convective flow field in their surrounding. In detail the question should be answered, how the horizontal velocity is coupling and influencing the other parameters?

Other interesting research questions come with increasing detail work. As shown in Utz et al. 2014[41] often the initial downflow creating the MBP is accompanied by a temporally as well as spatially co-located upflow (see also Fig. 5). What is the importance of this upflow? Why is it formed? Is it still inside the magnetic feature or outside of the feature? Are these upflows created by previously downflowing plasma being repelled and then pushing up to the surface again? Maybe somehow leaving the flux tube? Moreover there are questions not concerning these upflows. What about the plasma flows inside the flux tube? Is the plasma flowing down replenished by plasma from the higher atmosphere? Is the MBP acting as a siphon and dragging down plasma from higher up and thus connecting the chromosphere with the photosphere? Or is the plasma just downflowing in the lower photosphere and not moving at all, or maybe even transported up into the higher atmosphere? To put all of these in a simple sentence: what is happening inside the flux tube during its evolution with respect to its height and time?

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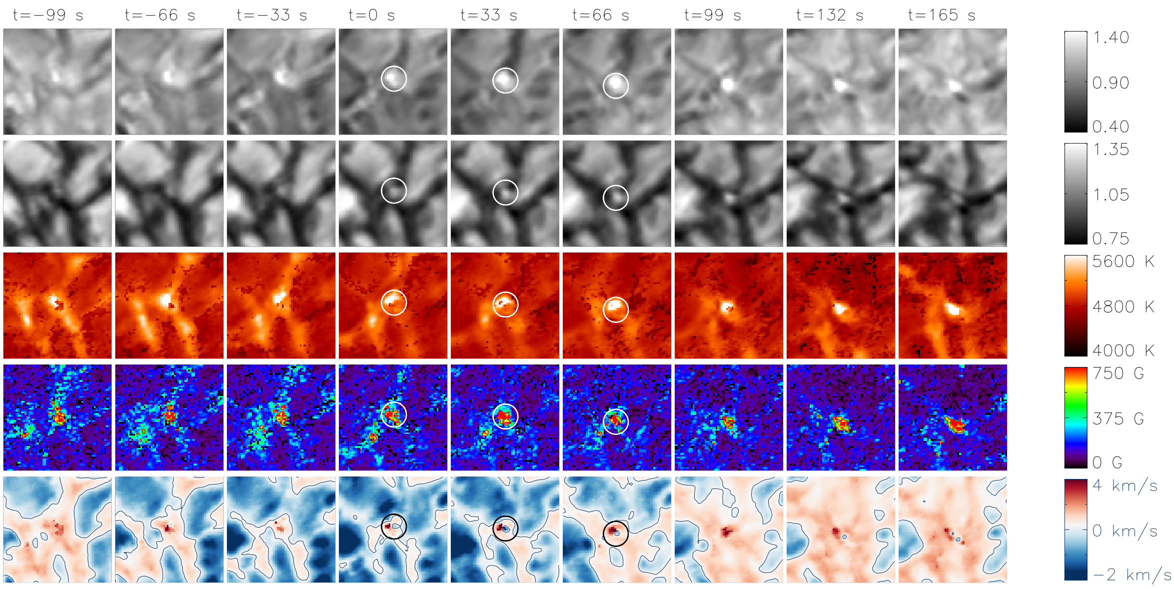

Figure 5: five important plasma maps showing small scale upflow similar to Fig. 4. Interestingly the tracked small-scale upflows seem to be strongly correlated and co-located temporally as well as spatially with the downflows related to the strong magnetic field patch.

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