High resolution observations of emerging active regions: from large to small scales

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Abstract

Using data acquired during some observational campaigns at THEMIS, DST, DOT and SST telescopes, coordinated with other instruments (IOACT, BBSO, TRACE, EIT/SOHO, MDI/SOHO, SOT/HINODE), the first evolutionary phases of some active and ephemeral regions have been analysed, in order to study the morphology and dynamics of magnetic structures (pores, spots, AFS) during their emergence. The results obtained have provided indications on the atmospheric layers where the first manifestations of the emerging AR or ER are observed, on the upward velocity of the AFS, on the asymmetries in downward motions in the AFS legs, and on the consequences of the interaction of the rising new magnetic field lines with the atmospheric ambient fields. These results might provide significant information for the modeling of rising flux tubes in the solar atmosphere and represent physical constraints for numerical simulations.

Long-lived Active Region

A recurrent AR (NOAA 10050) has been observed by THEMIS in IPM mode from July 26 to August 2, 2002, during a coordinate observational campaign with other ground- and space-based instruments (IOACT, TRACE, EIT/SOHO, MDI/SOHO).

The THEMIS images were acquired in 18 spectral points along the Hα (11 points) and Fe I (7 points) lines. The velocity along the line of sight (LOS) in photosphere and chromosphere was deduced from the Doppler shift of the centroid of the line profile in each spatial point with respect to the median of the line centroid in the whole field of view.

These measures show that the arches of an AFS crossing the polarity inversion line (Fig. 1) are characterized by an upward motion at their tops, which decreases as the active region develops, and a downward motion at their ends, which is asymmetric between the preceding and the following sides of the AR (the AFS f-leg exhibits higher downflows than the p-leg). Furthermore, we found that, within the limits of the temporal cadence and spatial resolution of the instruments used, the first evidence of the active region formation was initially observed in the transition region and lower corona, simultaneously with the initial increase of the magnetic flux, and later on (i.e. after about 6 h) in the inner layers (chromosphere and photoshere). See Spadaro et al. (2004) for further details.

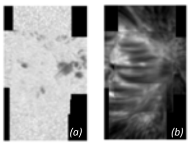

Fig. 1 Reconstructions of NOAA 10050 obtained from the images acquired by IPM in the continuum at 538.096 nm (*a*) and in the centre of the Hα line (*b*), on July 27.

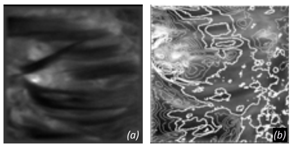

Fig. 2 *(a)* Image in the centre of the Hα line and *(b)* velocity map of the area characterized by the AFS, taken on July 27 at 9:32 UT. Thick contours indicate upward plasma motions, while thin contours indicate downward plasma motions. The velocity contours are drawn every 2 kms^{-1}.

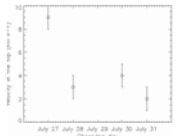

Fig. 3 Plot of the maximum velocities measured at the top of AFS during each observing day.

Short-lived Active Region

A short-lived AR (NOAA 10407) has been observed from July 11 to July 17, 2003, by THEMIS in IPM mode.

The images were acquired in 18 spectral points along the Hα (12 points) and Fe I (6 points) lines and in two different fields of view, called sectors A and B. The LOS velocity was determined with the same procedure used for the study of the long-lived AR.

Fig. 4 shows the AFS located between the two emerging magnetic polarities of the AR Eastern pores. On July 14 (Fig. 4), we can distinguish 5 arch filaments (AFSs): 2, named β and γ, seeming almost stable during the analyzed time interval, and 3, named α, ε and δ, more dynamic.

The top of each AF is characterized by a plasma positive velocity, which indicates the upward motion of the entire AFS, rising in the chromosphere. At the same time, the ends of the AFs generally exhibit negative velocity, which can be interpreted as signatures of a downward plasma motion along the magnetic field lines in the footpoints (see Fig. 5). The velocity values relevant to the upward motions decrese over the evolution of the region (see Fig. 6*(a)*). On the other hand, the AFS preceding legs show a higher downflow than the following ones (see Fig. 7*(b)*-*(c)*).

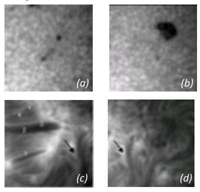

Fig. 4 Photospheric images of Sector A *(a)* and Sector B *(b)* and chromosperic images of the same fields of view *(c* and *d)* acquired by THEMIS on July 14. The letters indicate the AFS analyzed. The asterisks in *(c)* indicate the position of the pores visible in *(a)*.

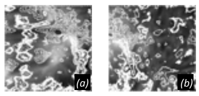

Fig. 5 Velocity maps obtained using the Hα profile in sector A *(a)* and B *(b)* on July 14. Thick (thin) contours indicate upward (downward) plasma motion. The velocity contours are drawn every 1 kms^{-1}.

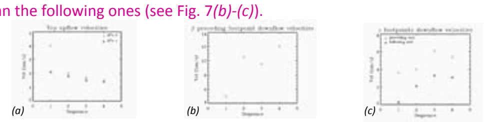

Fig. 6 *(a)* Plots of the maximum upflow velocities measured at the top of the AFs β and γ. *(b)* Plot of the maximum downflow velocities measured in the preceding end of AF β. *(c)* and in the preceding and following ends of AF γ.

The first evidence of the active region formation was initially observed in the transition region and lower corona, and later on (after about 7 hr) in the inner layers. See Zuccarello et al. (2005) for further details.

Comparison between Long-lived and Short-lived Active Regions

The characteristics shared by both the long-lived and short-lived ARs analyzed are: the first signatures of ARs emergence are initially observed in the outer atmospheric layers, simultaneously with the sudden increase of magnetic flux in photosphere, and later on in the chromosphere; AFs are characterized by a decreasing upward motion during the ARs lifetime;

On the other hand, the differences are: the appearance of the short-lived AR in photosphere and chromosphere is almost synchronous, while there is a time delay of ~ 8 hours between the appearance in chromosphere and photosphere for the long-lived AR; during the AR formation the magnetic flux increases by about one order of magnitude in the long-lived AR and by only a factor 2 in the short-lived AR; the displacement of the center of symmetry of each polarity in the short-lived AR is mainly directed westward, while it is diverging from the neutral line in the long-lived AR; the downward plasma motion in the AFS loop legs is asymmetrical: a higher plasma downflow is measured in the preceding leg in the short-lived AR, while it is observed in the following leg in the long-lived AR.

Small Bipolar Regions

A small bipolar region with a lifetime of 4 days, which can be considered an intermediate structure between a short-lived AR and an ephemeral region (ER), was observed by the IBIS instrument (Cavallini, 2006) at DST on October 3, 2006, along the Ca II (λ=854.21 nm) line.

We selected a sample of mottles and an AFS (see Fig. 7). We used two methods to evaluate the LOS plasma velocity in these structures: the **Doppler shift of the line centroid** and the **cloud model**. The Doppler shift method was applied to all the structures, while the cloud method was applied only to the mottles and to the central part of the AFS.

A motion characterized by alternate upward and downward plasma flows along the main axis of the mottles was recorded. We found the same behavior with both methods for all the mottles analyzed, although the values deduced with the cloud model were usually higher, by a factor of 2, than those deduced by the Doppler shifts (see Fig. 8). This agreement confirms that the irregular behavior of the LOS velocity along the mottles should depend only on their intrinsic characteristics.

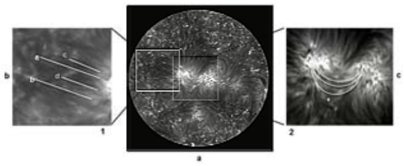

Fig. 7 *(a)* Whole field of view of the region observed in the Ca II line (854.21 nm) by IBIS at 15:52:51 UT. *(b)* and *(c)* show the sub-fields analyzed in this study, with the corresponding structures labeled.

Another interesting result concerns the presence of an AFS when the magnetic flux was decreasing and the knots of opposite polarities, after an initial phase of separation, were approaching each other. The appearance of an AFS in this phase of magnetic region evolution is in contrast with current models of active region formation (see, e.g., Zuccarello et al., 2009). However, the LOS velocities evaluated are similar, both in trend and in order of magnitude, to those observed for the short-lived active region: upward motions of about 1.5 km s^{-1} at the top and downward motions of about -2.0 km s^{-1} near the footpoints, without any asymmetry. See Contarino et al. (2009) for further details.

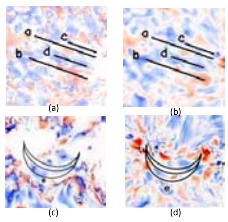

Fig.8 Maps of the LOS velocity for the mottles *(a-b)* and the AFS *(c-d)* obtained with the cloud model *(a-c)* and Doppler shift methods *(b-d)*. Blue (red) areas indicate upward (downward) plasma motions. Black lines outline the analyzed structures.

Ephemeral Regions

We studied the emergence of ERs around AR NOAA 10971 observed by SOT aboard the HINODE satellite on September 30, 2007, during a joint observational campaign with the SST, DOT and other ground-based solar telescopes. We analyzed filtergrams in the G band and in the Ca II H line, magnetograms in the Na I D1 line and spectropolarimetric raster scans in the Fe I doublet around λ=603.2 nm. The Na I D1 magnetograms sequence shows the emergence of a small bipolar region, with flux content of about 1.5 x 10^{19} Mx with size of few megameters, which appeared at the internal edge of the main negative polarity of the AR. This ER led to the appearance of bright points in the G band and to intensity enhancements in the Ca II H line core (Fig. 9).

We also studied the emergence of another ER, occurring outside of the AR. This region is correctly Hale-oriented and its morphology agrees with what theoretical models predict about emerging flux tubes structure: the presence of an upflow component, with weak field strength in the emergence zone, as shown by Lites et al. (1998). Moreover, we point out that in this ER there is an asymmetry between the preceding and the following legs of the bipole: f appears to be more vertical, with stronger field strength than the p polarity, which makes it appears stronger the downflow along the LOS in the most vertical polarity, agreeing with Spadaro et al. (2004). See Guglielmino et al. (2008) for further details.

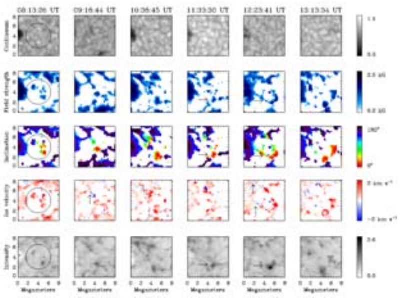

Fig.9 Temporal sequence of maps of continuum intensity (first row), magnetic field strength (second row), field inclination (third row), LOS velocity (forth row) obtained with the SIR inversion code, and cospatial filtergrams of the Ca II H intensity (fifth row), in negative color table.

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