Comparison between H$\alpha$ and Yohkoh Soft X-Ray Images of Emerging Flux Regions

Goro Kawai and Hiroki Kurokawa
Kwasan and Hida Observatories, Kyoto University, Yamashina, Kyoto 607

Saku Tsuneta and Toshifumi Shimizu
Institute of Astronomy, The University of Tokyo, Mitaka, Tokyo 181

Kazunari Shibata
National Astronomical Observatory, Mitaka, Tokyo 181

and

Loren W. Acton, Keith T. Strong, and Nariaki Nitta*
Lockheed Palo Alto Research Laboratory, Palo Alto, CA 94304, U.S.A.

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Abstract

We carried out a detailed comparison between H$\alpha$ and Yohkoh Soft X-ray (SXR) images of three emerging flux regions. The main results are: (1) In general, SXR bright features coincide well in space with H$\alpha$ arch filament systems in the emerging flux regions (EFR). (2) Some young and active parts of EFRs are especially bright in SXR. (3) The SXR structures related to EFR show fairly rapid changes in both brightness and shape. These results are consistent with the model that the emerging cool loops of EFRs evolve into hot coronal loops through some heating processes.

Key words: Sun: chromosphere — Sun: corona — Sun: emerging flux regions — Sun: X-rays

1. Introduction

A solar-active region grows with a successive emergence of magnetic flux from below the photosphere; the youngest stage of this process is called an emerging flux region, or EFR (Zirin 1972). The emerging flux region is characterized by rising magnetic loops, or the so-called arch filament system (AFS) in light of the H$\alpha$ line (Bruzek 1967; Zwaan 1987). The H$\alpha$ loops of AFS, the temperature of which is around 10^4 K, are believed to evolve into coronal loops of some million degrees through unknown heating mechanisms.

In fact, the soft X-ray telescope on board Skylab found many bright X-ray features over the ephemeral regions (Golub et al. 1977) as well as emerging flux regions (Krieger et al. 1976; Webb and Zirin 1981). The detailed process of this evolution, however, has not yet been observed, due to a lack of high spatial and temporal resolution of the soft X-ray (SXR) observation.

The Soft X-ray Telescope (SXT) aboard the Yohkoh satellite provides us not only with soft X-ray images of high spatial and temporal resolution, but also with cospatial sunspot images from the SXT aspect telescope (Tsuneta et al. 1991). They enable us for the first time to carry out detailed studies of the spatial relation between the bright soft X-ray structures and various H$\alpha$ features, i.e., AFSs, plages, small filaments, etc. in and around the emerging flux regions.

This Letter reports on preliminary results concerning such studies for three emerging flux regions, i.e., EFRs in NOAA 6968, NOAA 6973 and NOAA 6974 on 1991 December 15–16. H$\alpha$ data were taken with the Zeiss Lyot filter of the 60-cm Domeless Solar Telescope at the Hida Observatory, Kyoto University. Magnetograms of NOAA 6968 and 6974 were supplied by the Okayama Astrophysical Observatory.

Unfortunately, Yohkoh/SXT observed these EFRs only in the Full Frame Image mode. The spatial resolution of SXR images is about 5" and the temporal resolution is about 10–90 min in this observing mode.

In order to fit the SXR and H$\alpha$ images we used the sunspot images of SXT. The alignment error was about one or two pixel size of the SXR image, i.e., 5" or 10".

2. NOAA 6973

This region is located at N20 W20 and is a typical EFR with arch filament systems. Figure 1 shows the evolution of this region in H$\alpha$-5.0 Å, H$\alpha$, SXR with a short exposure (78 ms) and SXR with a long exposure
(2668 ms).

The western part of the AFS, which connects pores c1 and c2 with d, is rapidly growing. Comparing figure 1a with figure 1i, it is found that c1 and c2 merged into one larger sunspot and that sunspot d was also becoming larger. Figures 1b and 1j show that arch filaments in this part grew both longer and darker. Detailed comparisons between the Hα and SXR structures are given in figure 2, where the Hα loops, plages, sunspots and SXR emission contours are shown by the thin lines, dotted area, shaded area and thick lines, respectively. Notice that the western part of the AFS coincides with the brightest feature of SXR.

On the other hand, the eastern part of the AFS, which connects pores a1 and a2 with b, doesn’t show such a rapid change. Note that the SXR emission of this part is weaker than that of the western part, while the Hα arch filament is more conspicuous in the eastern part than in the western part.

A new magnetic emergence was found in the southwest part of the pre-existing AFS. The new conspicuous
Fig. 2. Spatial relation among sunspots, Hα and soft X-ray features of NOAA 6973. The field of view is the same as that of figure 1. Frames (a), (b) and (c) correspond to figures 1a–d, 1e–h and 1g–l, respectively. Thin line: Hα dark feature, dotted area: Hα bright feature, shaded area: sunspot, thick line: Soft X-ray with short exposure (contour levels are arbitrary), thick dashed line: Soft X-ray with long exposure.

Fig. 3. Comparison among Hα-5.0 Å [(a), (e)], Hα [(b), (f)], soft X-ray with 0.1 μm Al filter and 78 ms exposure [(c), (g)] and a photospheric magnetogram (d) of NOAA 6974. The signs p1–p4 and f1–f2 in frame (d) are positive and negative magnetic poles, respectively. The sign s in frame (a) is the slit of the spectrograph.

Hα arch filaments and Hα plage at 0211 UT (indicated by an arrow in figure 1j) should be noted. They are the youngest features as well as the brightest in SXR at 0235 UT. (figure 1k, figure 2)

3. NOAA 6974

This region is located at S18 W03 and had four developed sunspots on 1991 December 16. Figure 3 shows Hα-5.0 Å, Hα and SXR images of this region at 0006–26 UT and 0234–35 UT in the same field of view. It also shows the photospheric magnetic fields measured during
0120–0236 UT. The signs p1−p4 and f1−f2 in figure 1d are positive and negative magnetic poles, respectively.

Though more than one day had passed since the birth of this region, the new magnetic flux still continued to emerge at the innermost part of the region. The Hα arch filament system connecting the innermost sunspots, f1 and p2 (as seen in figure 3b and 3f), is clear evidence of new flux emergence.

Figure 4 shows a spatial relation among sunspots, Hα features and SXR contour. Notice that one of the brightest SXR structures coincides with the emerging Hα arch filaments within the error of alignment.

The SXR image shows another brightest structure, which connects p2 and f2 along the southern boundary of the EFR. In fact, Solar Geophysical Data reports a C3.4-class flare from 0217 UT to 0225 UT with no information concerning its location. This SXR structure may be a remnant of this flare.

4. NOAA 6968

This region was located at S16 E11 on 1991 December 16. Though the main sunspots of the region were already observed five days before, a new emerging flux region appeared in the eastern part of the region on this day. Figure 5 shows the Hα and SXR evolution of this region. It also shows the Hα-5.0 Å image at 0240 UT and the photospheric magnetic field measured during 0120–0236 UT.

There are three bright SXR structures (A, B and C) in this region (figure 5f). The brightest SXR structure (A) coincides well with the arcade of the western Hα loop system. Since the bipolar magnetic field pattern at the footpoints of the loops were already found two days before, it is not considered to be young. However, figure 5g shows new sunspots appearing at the western footpoints of the loops; they developed further on December 17 according to the Solar Geophysical Data. This means that flux emergence still continued in this part, and that the Hα loop system is a manifestation of the flux emergence. This thus indicates that SXR structure A is bright along the arcade of the emerging flux loops.

In the central part of the region some activated Hα superpenumbrae correspond well to SXR bright structures B at 0238 UT. It is not clear, however, whether or not it was related to flux emergence under the superpenumbrae.

On the contrary, the eastern new EFR did not coincide with the SXR bright features. SXR structure C was not located above the Hα AFS, but near to its southern boundary (figure 6). At 0143 UT, when structure C was brightest, no conspicuous Hα feature could be seen at the location of structure C. In figure 6b, the separation between points a (Hα arch filament) and b (SXR bright feature) is about 26”, which is too large to be attributed to some alignment error. If this deviation is due to a projection effect, the SXR structure is 43,000 ± 16,000 km higher than the Hα arch filament. It may be better, however, to interpret this SXR structure as being located around the south-east boundary of the EFR, rather than just above the EFR.

5. Summary and Discussion

The main results of this study are summarized as follows:

1. In general, SXR bright features coincide well in space with Hα arch filament systems in emerging flux regions.

In NOAA 6973, 6974, and the western part of NOAA 6968, emerging Hα loops and SXR bright structures are well cospatial. In the case of the eastern EFR in NOAA 6968, however, the SXR bright
Fig. 5. Comparison among Hα [(a), (c), (e)], soft X-ray with 0.1 μm Al filter and 78 ms exposure [(b), (d), (f)], Hα-5.0 Å [(g)] and a magnetogram [(h)] of NOAA 6968. The square in frame (a) is the slit of the spectrograph. Squares in (a), (c) and (e) indicate the field of view of figure 6. A, B and C in (f) are SXR bright features.
structure seems to be located not above the AFS but near the boundary of the EFR.

2. Some young and active parts of EFRs are especially bright in SXR.

In NOAA 6973, the eastern part of AFS is static and not so bright in SXR, while the new and rapidly growing parts of the EFR at the west and the southwest of the AFS are the brightest (figure 2).

3. SXR structures related to EFR show fairly rapid changes in brightness and shape.

For example, the new EFR in NOAA 6973 (indicated by the arrow in figure 1) became about 6.6-times brighter in SXR between 0006 UT and 0235 UT. (The data number is 263 at 0006 UT and 1726 at 0235 UT with 0.1 μm Al filter and 78.0 ms exposure).

The first result that SXR was bright above Hα AFS is consistent with the idea that Hα loops of AFS evolve into coronal loops. The second and the third results suggest that the Hα loops of AFS are strongly heated by a fast reconnection in some young and rapidly-growing EFRs. A recent numerical simulation by Shibata et al. (1992) shows that hot plasma is created by a reconnection between emerging and pre-existing magnetic fields, and that they are quickly transferred to the outside of the EFR. In NOAA 6973, Hα AFSs are covered with an SXR bright area (figure 2), which is consistent with their simulation result.

The displacement between SXR bright structure C and the eastern AFS in NOAA 6968 (figure 5, 6) results in another problem. In this case, the emerging flux might expand laterally and reconnect with pre-existing fields at the EFR boundary. The rapid change of the brightness of structure C may be produced by heating due to such a magnetic reconnection.

In order to study the heating process of emerging Hα loops in more detail, SXT observations with higher spatial and temporal resolution in the Partial Frame Image mode are necessary, simultaneously with high-resolution Hα observations from the ground.

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References