EARLY EVOLUTION OF AN X-RAY EMITTING
SOLAR ACTIVE REGION

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(Received 18 May, 1977)

Abstract. The birth and early evolution of a solar active region has been investigated using X-ray observations from the Lockheed Mapping X-Ray Heliometer on board the OSO-8 spacecraft. X-ray emission is observed within three hours of the first detection of Hα plage. At that time, a plasma temperature of $4 \times 10^6$ K in a region having a density of the order of $10^{16}$ cm$^{-3}$ is inferred. During the fifty hours following birth almost continuous flares or flare-like X-ray bursts are superimposed on a monotonically increasing base level of X-ray emission produced by plasma with a temperature of the order $3 \times 10^6$ K. If we assume that the X-rays result from heating due to dissipation of current systems or magnetic field reconnection, we conclude that flare-like X-ray emission soon after active region birth implies that the magnetic field probably emerges in a stressed or complex configuration.

1. Introduction

The purpose of this paper is to investigate the birth and early evolution of a solar active region as observed at X-ray wavelengths. X-rays provide the most definitive indication of energetic processes and high temperature plasma. However, instrumental limitations have prevented previous studies (Dodson and Hedeman, 1956; Born, 1974; Glackin, 1975) from adequately evaluating these aspects of the earliest phases of active region formation. The X-ray data to be discussed in this paper were obtained with the Lockheed Mapping X-Ray Heliometer (MXRH) on the NASA Orbiting Solar Observatory-8 (OSO-8) spacecraft.

To put the X-ray observations into perspective, it is appropriate to review briefly current ideas on the birth and early development of active regions. When observing in Hα or Ca-K, the first indication of active region birth is a pair of small bright plages (often called foculli until they are large enough to be called plages) connected by Arch Filament Systems (AFS) (Bruzek, 1967, 1969; Weart, 1970). These young regions emerge at, or very quickly drift to, the border of supergranules (Bumba and Howard, 1964; Born, 1974). Associated with the developing plage is a bipolar magnetic field structure (Harvey and Martin, 1973) that is growing at about $10^{16}$ Max s$^{-1}$ (Mosher, 1976). Slowly rising magnetic arches, identified with flux tubes, would account for the photospheric magnetic feature and the AFS. These rising tubes carry some photospheric material upward which subsequently flows down the legs of the arches under gravity. An individual arch emerges, rises and becomes optically invisible in approximately 30 min. About ten arches (the AFS) are visible at any instant, and the general pattern is maintained for a few days. The high, invisible arches contribute to the total magnetic flux of the region.
The growth of a region usually terminates within a day or two of birth and the region begins to dissipate. However, a few regions continue to enlarge in plage area, magnetic complexity, flare productivity, etc. Roughly speaking, the probability of reaching any specified intensity in these indices varies inversely with the magnitude of the intensity. Eventually, all regions disintegrate.

X-ray observations, when studied within the context of active region formation discussed above, provide information on formation and evolution at coronal levels, especially the formation of the active region coronal condensation. However, no previous X-ray instrument could provide continuous long term coverage of the full disk with spatial resolution adequate to separate a new weak region from the other regions on the disk. Good temporal and spectral resolution are also required to interpret the conditions in the evolving plasma.

In the next section we will describe briefly the MXRH instrument which provides these capabilities and with which we have now observed more than a dozen active region births. We will concentrate on one particular region, McMath 13811, which was born in late August 1975. This region was chosen by selecting from the data for the last half year of 1975 all regions which were born within 60° of the central meridian and developed into major centers of activity before crossing the west limb. Four regions were found and of these the data available for McMath 13811 were the most complete. Though each region evolved differently in detail, the characteristics that apply to McMath 13811 generally apply to the other three regions so the evolution described here appears to be typical.

This study of McMath 13811 encompasses 50 hr beginning at 1400 UT on 19 August 1975. For the 32 hr following our study interval, the X-ray region showed a generally increasing average intensity, number of flares and peak flare emission until limb obscuration on 22 August. The region (redesignated McMath 13831) was inactive during its second disk passage.

2. The Mapping X-Ray Heliometer

The MXRH was activated in orbit on June 22, 1975. The instrument responds to X-rays in the 1.5–30 keV energy range, has a spatial resolution of about 2 min of arc, and maps the entire solar disk every 40 s. Longer integration times are required to detect regions of weak emission.

The instrument looks radially outward from the rotating wheel of the OSO-8 satellite. It contains three detection systems, each collimated in one dimension with Oda-type mechanical collimators (Bradt et al., 1968; Oda, 1965). The collimators have a full width at half maximum transmission of 2 min of arc, although other instrumental effects broaden the instrument response function to about 4 min of arc under some conditions. Each field-of-view is tilted 120° from the others. These three systems are called Vertical, Slant A and Slant B, with the Vertical system field-of-view parallel to the satellite spin axis. As the wheel rotation sweeps these fields-of-view past the Sun, three one-dimensional count rate distributions are obtained.