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Moreton waves observed at Hida Observatory

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Abstract. Moreton waves are flare-associated waves observed to propagate across the solar disk in Hα, especially in the wing of Hα. The Flare Monitoring Telescope at Hida Observatory of Kyoto University observed 12 events associated with flare waves (i.e., Moreton waves and/or filament oscillations) in Hα from 1997 to 2002. We review our studies of Moreton waves based on these observations;
(1) relation between EIT wave and Moreton wave (Eto et al. 2002),
(2) simultaneous observation with X-ray wave (Narukage et al. 2002),
(3) three dimensional structure of flare-associated wave (Narukage et al. 2004),
(4) relation between Moreton waves and filament eruptions.

1. Introduction

Moreton waves are flare-associated waves observed to propagate across the solar disk in Hα, especially in the wing of Hα (Moreton 1960; Smith & Harvey 1971). The phenomenon was first reported in 1960 by Moreton. They propagate at speeds of 500–1500 km s^{-1} with arc-like fronts in somewhat restricted angles, and are often associated with type-II radio bursts (Kai 1969). The Moreton wave has been identified as the intersection of a coronal MHD fast-mode weak shock wave and the chromosphere (Uchida 1968; Uchida 1974). However, the generation mechanism of a Moreton wave has not yet been cleared.

Recently, many large-scale coronal transients have been discovered using the Extreme Ultraviolet Imaging Telescope (EIT) on board *Solar and Heliospheric Observatory* (*SOHO*). These features are now commonly called “EIT waves” (Thompson et al. 1998; Klassen et al. 2000). Moreover, *Yohkoh*/SXT discovered wave-like disturbances in the solar corona associated with flares (Khan & Hudson 2000; Khan & Aurass 2002; Hudson et al. 2003), which we call “X-ray waves” in this paper.

The purpose of this paper is to review our studies of the Moreton waves observed with the Flare Monitoring Telescope at Hida Observatory in Hα from 1997 to 2002.

2. Observations

The Moreton waves and/or filament oscillations were observed in Hα (line center and +/− 0.8 Å) with the Flare Monitoring Telescope (FMT) (Kurokawa et al. 1995) at Hida Observatory of Kyoto University. The FMT observed four full-disk images (in the Hα line center and +/− 0.8 Å, and continuum) and one solar limb image (in the Hα line center). These images were observed co-temporal. The time resolution of the FMT is several seconds. The pixel size was 4.2 arcsec. This FMT observed 12 events associated with the flare waves in Hα from 1997 to 2002. Table 1 shows the event list of the Moreton waves and/or filament oscillations.

date	peak time	NOAA AR	GOES class	Moreton wave	Filament oscillation
1997/11/03	04:38	8100	C8.6	490 km s^{-1}	—
1997/11/04	06:02	8100	X2.1	715 km s^{-1}	observed
1998/08/08	03:17	8299	M3.0	930 km s^{-1}	—
1999/02/16	03:12	8458	M3.2	—	observed
2000/03/03	02:14	8882	M3.8	1050 km s^{-1}	—
2000/06/04	22:10	9026	M3.2	—	observed
2000/06/15	23:43	9040	M2.0	observed	—
2000/07/16	06:14	9082	C3.8	observed	—
2001/04/10	05:26	9415	X2.3	—	observed
2001/05/12	23:35	9455	M3.0	observed	—
2001/12/19	02:32	9742	C4.9	observed	—
2002/08/22	01:57	0069	M5.4	observed	—

Table 1. Moreton waves and/or filament oscillations observed with FMT at Hida Observatory of Kyoto University.

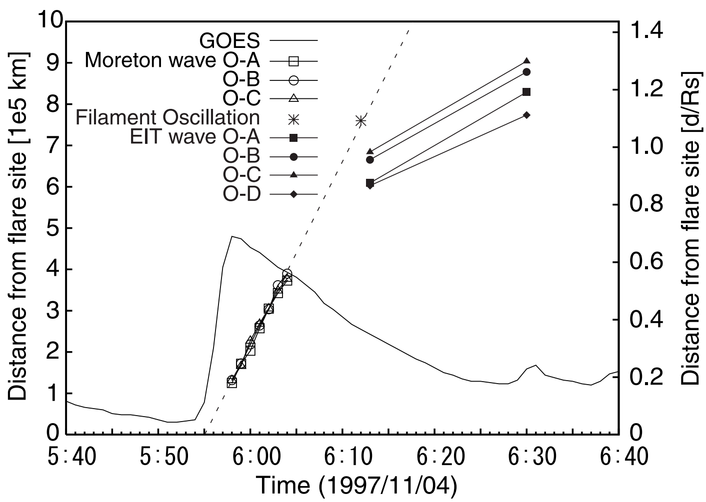

Figure 1. Time evolutions of the distance of the Moreton wave (open symbols) and the EIT wave (filled symbols) from the flare site. An asterisk at 06:12:00 UT represents the start of the filament oscillation and the distance of the filament from the flare site.

3. Relation between EIT wave and Moreton wave

We consider the relationship between two flare-associated waves, a chromospheric Moreton wave and a coronal EIT wave, based on an analysis of an X-class flare event in AR 8100 on 1997 November 4 (Eto et al. 2002). A Moreton wave was observed in Hα, Hα+0.8Å and Hα−0.8Å with the FMT at Hida Observatory. An EIT wave was observed in extreme ultraviolet with EIT on board *SOHO*. The propagation speeds of the Moreton wave and the EIT wave were approximately 715 km s^{-1} and 202 km s^{-1}, respectively. The times of visibility for the Moreton wave did not overlap those of the EIT wave, but the continuation of the former is indicated by a filament oscillation (see figure 1). Data on the speed and location clearly show that the Moreton wave differed physically from the EIT wave in this case. The Moreton wave preceded the EIT wave, which is inconsistent with an identification of the EIT wave with a fast-mode MHD shock.

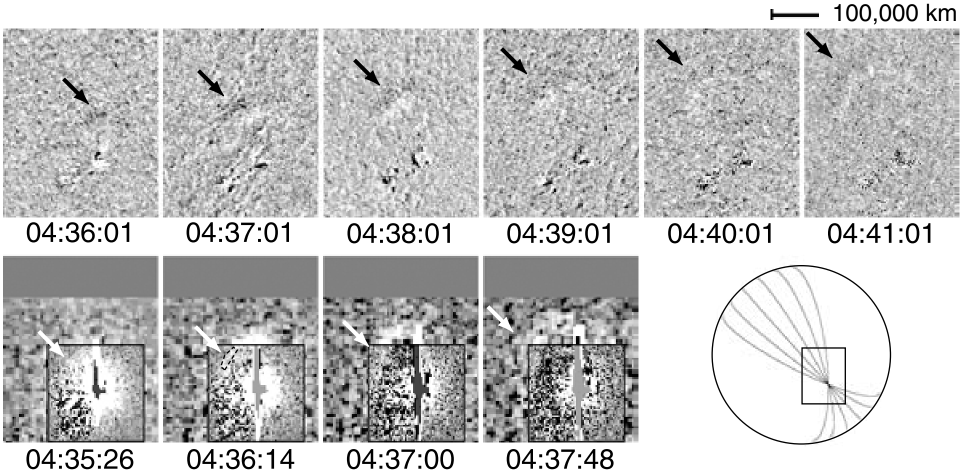

Figure 2. Observed images on November 3, 1997, at AR 8100. Top panels are Hα +0.8 Å "running difference" images of a Moreton wave (black arrows) observed with FMT. Bottom panels are soft X-ray "running difference" images of an X-ray wave (white arrows) taken with the *Yohkoh*/SXT Al-Mg filter.

4. Relation between X-ray wave and Moreton wave

We report the observation of a Moreton wave on November 3, 1997 (Narukage et al. 2002). The same region (AR 8100) was simultaneously observed in soft X-rays with the Soft X-ray Telescope (SXT) on board *Yohkoh*, and a wave-like disturbance ("X-ray wave") was also found (see figure 2). The position of the wave front as well as the direction of propagation of the X-ray wave roughly agree with those of the Moreton wave. The propagation speeds of the Moreton wave and the X-ray wave are about 490 $\pm$ 40 km s^{-1} and 630 $\pm$ 100 km s^{-1}, respectively.

Assuming that the X-ray wave is an MHD fast-mode shock, we can estimate the propagation speed of the shock, on the basis of MHD shock theory and the observed soft X-ray intensities ahead of and behind the X-ray wave front. The estimated fast shock speed is 400 – 760 km s^{-1}, which is in rough agreement with the observed propagation speed of the X-ray wave. The fast-mode Mach number of the X-ray wave is also estimated to be about 1.15 – 1.25. These results suggest that the X-ray wave is a weak MHD fast-mode shock propagating through the corona and hence is the coronal counterpart of the Moreton wave.

5. Three dimensional structure of flare-associated wave

We report on the simultaneous observation of a Moreton wave in Hα and two kinds of coronal expanding features in soft X-rays near the solar limb on March 3, 2000 (Narukage et al. 2004). We consider the faster X-ray feature and the slower one as being an "X-ray wave" and "ejecta", respectively. The chromospheric Moreton wave propagated on the solar disk at a speed of 1040 $\pm$ 100 km s^{-1}, whereas the coronal X-ray wave propagated outside of the disk toward the outer corona at 1400 $\pm$ 250 km s^{-1}. Based on MHD shock theory and observations, we identified the X-ray wave as MHD fast-mode shock. The fast-mode Mach number (M_A) of the X-ray wave was also estimated to be about 1.13–1.31, which decrease during propagation. The timing when the M_A became "1" is consistent with that of the disappearance of the Moreton wave. Our result is clear evidence for the Uchida model.

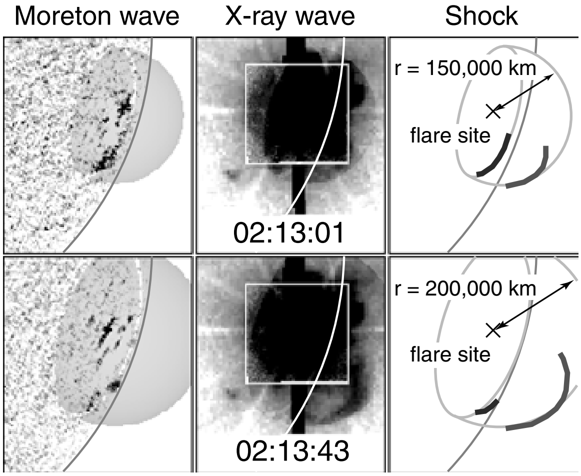

Figure 3. Observation of the 3-dimensional structure of the flare-associated shock wave.

Figure 3 shows the Moreton wave (left panels) and the X-ray wave (center panels). In the outline images (right panels), the wavefront of the Moreton waves corresponds to the intersection of the sphere and the solar disk, whereas the X-ray waves seem to be along the sphere. Hence, in the simplest approximation (symmetrical shock expansion), the propagation of these two waves indicates the 3-dimensional structure of the flare-associated shock wave (spheres).

6. Relation between Moreton waves and filament eruptions

In all events, filament eruptions were observed. Especially, in the case when the propagation of the Moreton waves was observed, the filaments erupted in the same direction after the waves propagated. Before the eruption, the filaments were invisible in Hα. In some cases of X-ray waves, X-ray ejecta were also observed. There is a strong correlation between the direction of Moreton waves (X-ray waves) and filament eruptions (X-ray ejecta). We consider that the filament eruptions are closely related to the Moreton waves and are the clue to the generation mechanism of the flare-associated waves.

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