Waves in coronal loops observed during flaring events

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Abstract

We present an analysis of the waves found in the active region NOAA 1748, from 12 May 2013 at 20:00:00 UT to 13 May 2013 at 04:00:00 UT. During this time the M1.9, M1.2, C9.3, and X1.7 flares occurred, which were recorded by the GOES-15 spacecraft. We studied them by using high spatial resolution AIA/SDO images in EUV and UV, founding wave packages of high- and low-frequency from the photosphere to the corona. We report that the temporal profile of these waves showed damping after and before the flares. This damping was clearest between the M1.9 and M1.2 flares.

Introduction

Studying oscillations and waves during transient events, allow us to understand part of the dynamic in the solar atmosphere. As an example, the energy dissipated by them can heat the plasma in some structures, e.g., coronal loops [1]. Also, they can affect the periodicity of quasi-periodic pulsations [2], which are observed during the flares.

In a previous paper [3], the temperature and the density distribution along the loops perturbed by a C1.9 flare were shown. Here, was observed that the brightness distribution along the loops was non-symmetric. This was explained by the magnetic field distribution along the extrapolated field lines. These last, coincide with the observed loops. There, the Alfvén velocity was dominant, and her distribution coincides with her brightness asymmetry. On the other hand, the sound speed was dominant in the loop where the flare started.

Actually, the Atmospheric Imaging Assembly (AIA) on board the Solar Dynamics Observatory (SDO), allow us to analyse these events with good spatial and temporal resolution. This instrument provides full-disk images of the Sun in ultraviolet (UV) and extreme ultraviolet (EUV). The images have a spatial resolution of $\approx 0.6''$ by pixel and temporal cadence of 24 (for UV) and 12 (for EUV) seconds.

In this work, we present an evolution of flaring events occurred in 12 and 13, May 2013. We observed waves in seven harmonics along the coronal loops. They were seen, simultaneously, in different layers of the solar atmosphere. Thus, we analyse the trajectory and behaviour of these waves from the photosphere to the corona.

Observation and Data Processing

The active region NOAA 1748 was located in the north-eastern solar limb (N10E89). There, the M1.9, M1.2, C9.3, and X1.7 flares were seen, between 12 and 13 May 2013 (Figure 1). GOES-15 and SDO/AIA spacecraft observed these flares. At the same time, a CME with a velocity of 403 ± 53 km s^{-1} was observed together with three coronal waves. However, in a further analysis, we saw that these events were not closer of the loops studied.

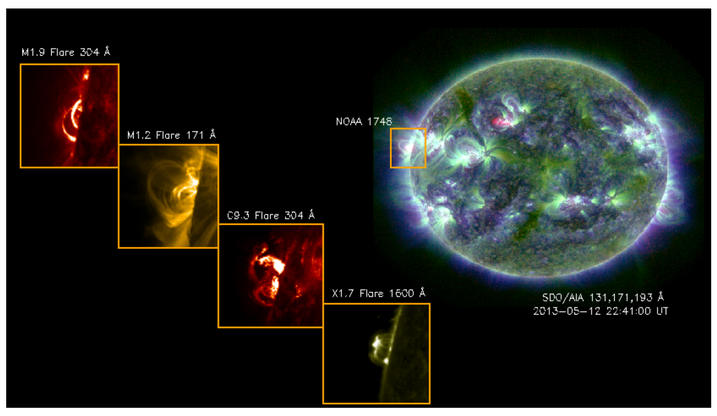

Figure 1: *Active region NOAA 1748 from SDO/AIA at 131, 171 and 193 Å. At right we show the active region located at N10E89 (orange square). At left we present snapshots of M1.9, M1.2, C9.3 and X1.7 flares observed at 304, 171, 304, and 1600 Å, respectively.*

We requested SDO/AIA data in nine band passes (1600, 1700, 304, 171, 193, 211, 131, 335, and 94 Å), from 12 May 2013 at 20:00:00 UT to 13 May 2013 at 04:00:00 UT. We processed and aligned the data fits by using aia_prep.pro, available in the solar software (SSW). Then, we carefully chose not saturated images ($102''$,$150''$) to make 3D data cubes (x, y, t) for further analysis. We did it for all nine SDO/AIA band passes.

Detected waves

We used the pixelised wavelet filtering method (PWF) [4] for detecting waves in NOAA 1748. This method calculates the wavelet transform over the time signal (t) of each pixel (x,y) of the 3D data cube. Next, the resulting 4D cube (x,y,t,f) is filtered by frequencies (f) of interest. Then, the detected periodicities, in the spatially integrated global power spectrum, are shown. Finally, we get a set of narrowband maps for oscillations found in the region. Each map allows us to know the spatial distribution of these oscillations. We also can analyse the temporal evolution of the waves found, making videos with the narrowband maps.

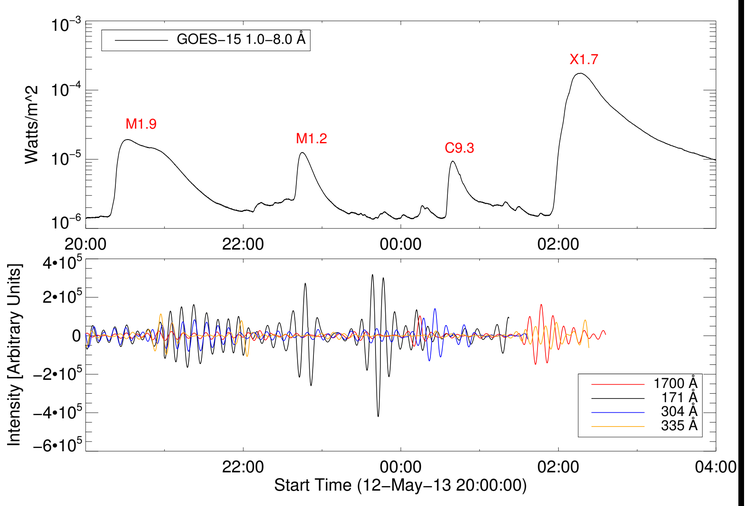

Figure 2: *Time filtered signal for waves of 10 minutes found in 1700, 171, 304, and 335 Å. The wave packages match with the period of flaring events (M1.9, M1.2, C9.3, X1.7) showing in GOES-15 curve in the channel 1.0-8.0 Å.*

For each flaring interval and between them, we searched for oscillatory patterns. The profile of the most of the filtered time signal had pulses and damping shape. In Figure 2 we show the wave packages of 10 minutes found during the flaring events. We chose the filtering time signal in 1700, 171, 304, and 335 Å of nine band passes analysed. However, we observed this profile in all SDO/AIA channels studied. We observed more wave packages and damping shape after M1.9 and before the M1.2 flares. In particular, for waves of 10, 5 and 2 minutes.

We saw standing and travelling waves of 38, 19, 10, 5, 2, and 1 minute, all time, in 1700 and 1600 Å. These band passes belong to the temperature minimum, photosphere and chromosphere regions. We also saw these waves in the footpoints of the loops observed in 171 Å, i.e., transition region and corona layers.

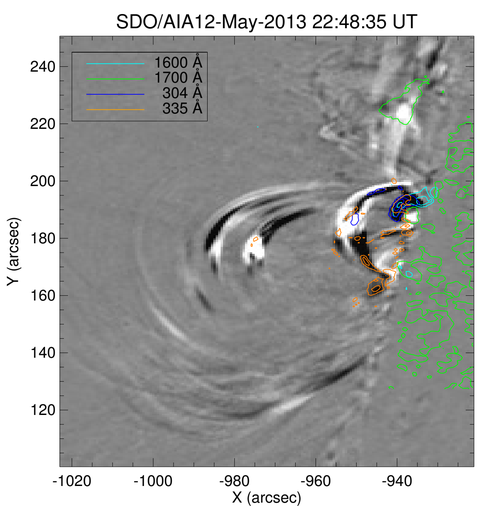

Figure 3: *Waves of 5 minutes present in the active region NOAA 1748 during the M1.2 flare. Background image represents waves of 5 minutes found in 171 Å. Contours show the waves of 5 minutes seen in 1600, 1700, 304 and 335 Å at once.*

During the M1.2 flare (22:37 – 22:52 UT) we observed waves of 5 minutes in the footpoint of loops, in 1600 and 1700 Å. Simultaneously, we saw these waves along the loops observed in 304, 171, and 335 Å (Figure 3). A movie of these waves is available in the e-poster presentation.

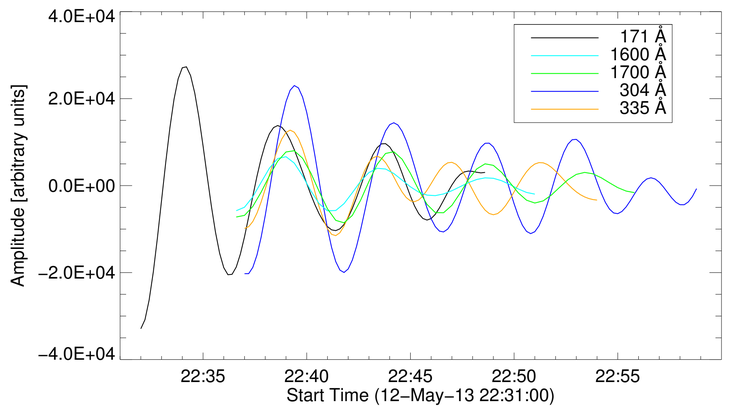

Figure 4: *Time profile of the waves of 5 minutes represented in Figure 3. The profile shape indicates damping during the period of M1.2 flare.*

We observed wave packages of 5 minutes in 1600, 1700 and 335 Å during the X1.7 flare (01:53 – 02:32 UT). In C9.3 flare (00:32 – 00:46 UT), the wave amplitude decreased along the small flaring loops, in 304 and 94 Å. However, in 171 Å, the wave amplitude grew.

On the other hand, we observed waves of 10 minutes damped in 1600 and 1700 Å and with amplitude growing in 335 Å, during the X1.7 flare. Also, until the peak flare, we saw waves of 2 and 1 minutes in 1600, 1700, and 335 Å.

Summary and final remarks

We detected standing and travelling waves of 38, 17, 10, 5, 2, and 1 minutes and 32 seconds. We observed waves of 10 and 5 minutes, simultaneously, from the photosphere to the corona. These waves also have a damping profile. On the other hand, we observed waves of 2 minutes in the photosphere (1700 Å). One minute later, we saw this wave in the chromosphere (304 Å) and 10 minutes later in the corona (211, 171 Å). Thus, the waves started in the footpoint of the loops and travel along them. We present a movie of these waves in the e-poster presentation.

The observed damping profiles suggest that the energy dissipated by the waves in the inner layer can generate waves in the outer layers of the solar atmosphere.

In a further analysis, we will show the released energy by the waves found in this flaring event. We will focus our attention in damping profile before the flares occurrence, e.g., before the M1.2 flare. We also will analyse the temperature and density profile along the loops in a similar way as in [3]. Thus, we could know what is the role that these waves played in the flares studied.

Acknowledgements: The data used are courtesy of SDO/AIA and GOES facilities. We would like to thank to the Brazilian agency FAPESP (Grant No. 2017/23026-6) by the financial support.

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