ENERGY RELEASE AND INITIATION OF A SUNQUAKE IN A C-CLASS FLARE

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ABSTRACT

We present an analysis of the C7.0 solar flare from 2013 February 17, revealing a strong helioseismic response (sunquake) caused by a compact impact observed with the Helioseismic and Magnetic Imager on board the Solar Dynamics Observatory (SDO) in the low atmosphere. This is the weakest known C-class flare generating a sunquake event. To investigate the possible mechanisms of this event and understand the role of accelerated charged particles and photospheric electric currents, we use data from three space observatories: RHESSI, SDO, and Geostationary Operational Environmental Satellite. We find that the photospheric flare impact does not spatially correspond to the strongest hard X-ray emission source, but both of these events are parts of the same energy release. Our analysis reveals a close association of the flare energy release with a rapid increase in the electric currents and suggests that the sunquake initiation is unlikely to be caused by the impact of high-energy electrons, but may be associated with rapid current dissipation or a localized impulsive Lorentz force in the lower layers of the solar atmosphere.

Key words: Sun: chromosphere – Sun: flares – Sun: helioseismology – Sun: magnetic fields – Sun: X-rays, gamma rays

Supporting material: animation

1. INTRODUCTION

One interesting effect produced by flare energy release in the solar atmosphere is the excitation of helioseismic waves, so-called sunquakes (Kosovichev & Zharkova 1998). Such waves usually propagate as expanding ripples from local impact sources occupying several pixels in the Helioseismic and Magnetic Imager (HMI) Dopplergrams. The cause of these events is a subject of intense debate (e.g., Donea 2011; Kosovichev 2014). Generally, the necessary condition for producing sunquakes is a sudden momentum enhancement in the lower solar atmosphere. One possible agent of such a disturbance is chromospheric heating due to the injection of accelerated charged particles postulated by the standard model of solar flares (for a recent review see Fletcher et al. 2011). Models of the gas dynamics processes induced by nonthermal electron beams (e.g., Kostiuk & Pikelner 1975; Fisher et al. 1985; Kosovichev 1986) predict the formation of a shock wave or chromospheric condensation moving toward the solar photosphere, and thus transferring momentum into the low atmosphere. Kosovichev & Zharkova (1995) discussed such beam-driven mechanisms of sunquakes. However, plasma momentum transfer can also be caused by other mechanisms, such as the sharp enhancement of the pressure gradient due to flux-rope eruption (e.g., Zarkov et al. 2013) or an impulse of the Lorentz force which can be stimulated by electric currents in the lower solar atmosphere (Fisher et al. 2012). It is also possible that different sunquake events are caused by different mechanisms. Usually, sunquakes are associated with M and X class flares. However, many X-class flares did not produce sunquakes (e.g., Donea 2011), whereas these events had been noted during relatively weak M-class flares (Martínez-Oliveros et al. 2008; Kosovichev 2014).

In this paper, we discuss observations of the C7.0 flare of 2013 February 17, which produced a rather strong sunquake initiated during the hard X-ray (HXR) burst. We use data from four space instruments: EUV observations from SDO/AIA (Lemen et al. 2012); level-1 filtergrams, Dopplergrams, and vector magnetic field measurements from SDO/HMI (Scherrer et al. 2012); integrated soft X-ray (SXR) emission from the Geostationary Operational Environmental Satellite (GOES; Donnelly et al. 1977); and X-ray spectroscopic imaging data from RHESSI (Lin et al. 2002). We investigate potential mechanisms of sunquake initiation and find that, despite the precise temporal coincidence between the HXR impulse and the photospheric impact, this event is not consistent with the standard flare model because the HXR source and the sunquake impact were at different spatial locations, namely, at two different footpoints of a flare loop. Our analysis of the vector magnetograms leads to the suggestion that electric currents in the low atmosphere may play a significant role in sunquake initiation.

2. GENERAL DESCRIPTION OF THE EVENT AND SUNQUAKE

The flare event of 2013 February 17 was observed in active region NOAA 11675. This event consists of two subflares clearly separated in time and space: the first subflare is of the C7.0 GOES X-ray class, and the second subflare reached M1.9 peak intensity. The entire duration of the double flare is approximately 8 minutes, starting at 15:46:00 UT and ending at 15:54:00 UT (Figure 1). The highest energy of the HXR emission (maximum at 15:47:20 UT) detected by RHESSI during the first subflare is ∼1 MeV. The second subflare is characterized by weaker intensity and energy (<300 keV) of the HXR emission which reached maximum at 15:50:30 UT.
Figures 2(a) and (b) presents the AIA images in the 94 Å channel. The temporal and spatial resolutions are 12 s and 1″ (with the angular pixel size of 0″.6). The preflare state reveals a compact loop-like structure where the flare process occurs.

The sunquake is observed as an expanding circular wave in the HMI Dopplergrams filtered in the high frequency range, 5–6 mHz, to isolate the sunquake signal from the convective noise. The wave amplitude is comparable with the convective and acoustic noise on the solar surface. The wave signal is identified in a series of Dopplergram difference images filtered with a Gaussian filter with a width of 1 mHz, centered at 6 mHz. This series is presented as a movie associate with Figure 3. Figure 3(a) shows the moment of the compact flare impact and Figure 3(b) presents a Dopplergram image, taken about 20 minutes after the impact, showing a sunquake wavefront as part of a circular-shaped ripple. For a recent review of sunquakes and their properties, see Kosovichev (2014). The sunquake waves are often anisotropic. In this case, the wave signal was mostly visible in the west and north–west directions. The anisotropy may be caused by the motion of the wave source, usually related to the motion of flare ribbons. In this case, we did not detect a significant source motion. However, in the west and north–west direction, the wave front traveled through the leading sunspot. Thus, the wave propagation was affected by the sunspot magnetic field, but apparently the amplitude of this wave front is still best observed. The propagation of the sunquake wave is also illustrated in the time–distance diagram (Kosovichev & Zharkova 1998; Zharkova & Zharkov 2007) presented in Figure 3(c). The time–distance diagram is constructed by tracking the frequency–filtered Dopplergrams with solar differential rotation, and remapping these into the heliographic coordinates using the Postel’s projection. Then, the Dopplergram signal at equal distances from the impact is averaged for different moments of time and the averaged signals are stacked together in the form of a time–distance diagram (Figure 3(c)). This diagram shows the location of the sunquake impact at the initial distance and 15:47–15:50 UT, and the sunquake wave signal as a series of inclined ridges at distances from 10 to 25 Mm and in a time interval of 16:03–16:20 UT. The strongest sunquake signals are usually observed 20 minutes after the impact. Such time–distance diagrams help to identify the sunquake events, and also to detect the source motion. Unlike in other flares, in this case, there was no significant source motion. Similar to the Dopplergram images, the time–distance diagram is quite noisy because of the convective noise and random acoustic waves, which may create complicated interfere patterns. The sunquake signals are identified as a relatively regular inclined ridge pattern, the inclination of which follows the theoretical time–distance relation of helioseismic acoustic waves. This relation, calculated in a theoretical ray-path approximation using Equations (72)–(80) of Kosovichev (2011a) for the standard solar model (Christensen-Dalsgaard et al. 1996), is shown in Figure 3(d) as dashed curve. This represents the time–distance
relation for acoustic waves that are excited at the solar surface which travel into the solar interior where they are reflected back to the surface because of increasing sound speed. Because the sunquake wave is frequency band-limited (most of the signal is concentrated around the acoustic cut-off frequency), it forms oscillatory wave packets which are displayed as a series of nearly parallel ridges on the time–distance diagram. This pattern corresponds well to previous observations of sunquakes (e.g., Kosovichev 2006, 2011b; Kosovichev & Sekii 2007; Zharkov et al. 2013). The image (movie) and time–distance analyses provide unambiguous evidence of the initiation of a helioseismic response in this flare event. Moreover, further analysis shows that the sunquake is initiated by the first (C-class) subflare with the initiation point at the flare impulse signal.

The initiation of the sunquake is observed as a strong localized impulse in the HMI Dopplergrams (Figures 2(h), 3(a)) and line-of-sight magnetogram (Figure 2(c)) at \(\approx 15:47:54\) UT. We note that while these data show the location of the impact because of the rapid variations during the flare impulse, the Doppler velocity and magnetic field measurements in the impact pixels can be inaccurate. Therefore, we use the original level-1 HMI filtergram data from the two HMI cameras to locate the exact time and location of the flare impact. Panels (c) and (d) of Figure 2 show the time difference between the HMI filtergram images (from HMI Camera-1). We see that compared to the preflare time during the flare, there is enhancement of emission in the pixels associated with the AIA brightenings and the place of the sunquake initiation visible in the Dopplergrams and magnetograms. The timing of the photospheric impact is illustrated in

Figure 2. Location of the sunquake initial impact. AIA 94 Å images: (a) before and (b) during the flare; (c) line-of-sight Dopplergram showing the impact location; time differences: (d) before and (e) during flare of the HMI level-1 filtergram; (f) comparison with RHESSI 50–100 keV intensity contours (40%, 60%, 80%, and 90%); (g) HMI intensity and (h) line-of-sight magnetogram showing the impact location.
Figure 1 (bottom), which shows the signals from both HMI cameras as a function of time. The periodic variations of these curves are due to line scanning. The plot shows that the photospheric impact coincides with the HXR impulse within 3 s (the HMI camera resolution).

3. SPATIAL STRUCTURE OF THE FLARE REGION

Here, we present a description of the spatial structure of the flare region according to the RHESSI and AIA/SDO observations. RHESSI uses a Fourier technique to reconstruct X-ray emission sources (Hurford et al. 2002). We apply the CLEAN algorithm to synthesize the X-ray images using detectors 1, 3–6, and 8 (the signal integration times are shown in the titles of Figures 4(a) and (d)). The RHESSI HXR and SXR contour images are compared with the corresponding AIA 94 Å images for the time interval covering the HXR peaks of both flares. To compare the positions of the EUV and X-ray sources with the structure of the magnetic field, we plot the polarity inversion line from the HMI magnetogram (black curves). The structure of the EUV emission sources is rather complicated. There are ribbon-like structures located on both sides of the magnetic field inversion line. During the HXR burst, we observe a loop-like structure with one footpoint associated with strong HXR
emission (25–200 keV) and the other footpoint located at the location of the photospheric impact (sunquake initiation), which also coincides with a weak HXR emission source (it is also shown in Figure 2(f)). The total emission intensity of the weaker X-ray source is approximately five times less than the emission intensity of the stronger HXR source. If the sunquake were initiated by the impact of high-energy electrons, then their impact would occur at the location of the intensive energy loss of the accelerated particles and coincide with the strongest HXR emission source. However, we observe the opposite situation when the sunquake impact correlates with a weaker X-ray source. This indicates that the sunquake is unlikely be generated by the impact of high-energy electrons.

The second subflare has an SXR source (6–12 keV) coinciding with the HXR source (25–50 keV) and saturated UV emission above the magnetic field inversion line. However, this subflare is located ∼3 Mm away from the location of energy release in the first subflare and according to our analysis is not associated with the sunquake.

The relative location of the HXR source and the photospheric impact was studied using various algorithms of image reconstruction provided by the RHESSI team (Schwartz et al. 2002; here, we present the results of the CLEAN algorithm), and both level-1 and level-2 HMI observables. It is worth noting that the mapping procedure for HMI level-1 data differs from mapping based on high-level data. For referencing the angular Cartesian coordinates to the CCD HMI pixels, we use special level-1 keywords from FITS headers, X0 LF and Y0 LF, which are CCD coordinates of the Sun’s disk center after the limb fitting procedure. Mapping was performed using the IDL Map Software for Analyzing Solar Images of D. M. Zarro, which is available in the SolarSoft software package.

4. ANALYSIS OF RHESSI SPECTRA: ACCELERATED PARTICLES AND HEATING

To determine the properties of the accelerated particles, the plasma, and their energetics, we use the RHESSI data in the range 5–250 keV. We investigate two spectra taken during the HXR peaks of two subflares. The power-law approximation $f(E) = AE^{-\gamma}$ (A is normalization coefficient) is considered for the HXR nonthermal emission $\geq 20$ keV. To simulate the presence of the low-energy cutoff, we use the broken power law (Holman 2003) with a fixed photon spectral index $\gamma_0 = 1.5$ below the break energy ($E_{\text{low}}$). For the first subflare, an additional break energy ($E_{\text{br}}$) is considered, and thus for this case we have two spectral indices $\gamma_1 (E_{\text{low}} < E < E_{\text{br}})$ and $\gamma_2 (E > E_{\text{br}})$. For the second subflare, we consider only one spectral index $\gamma_1 (E > E_{\text{low}})$ and also make a pileup correction as the count rate is sufficient to observe such an effect.

The thermal SXR spectrum $\leq 20$ keV is approximated by one-temperature thermal bremsstrahlung emission with two parameters: temperature ($T$) and emission measure (EM). To estimate the plasma properties, the RHESSI spectra are fit by the radiation model and the least-squares technique.
implemented in the OSPEX package with seven free parameters (EM, T, A, $E_{low}$, $\gamma_1$, $E_{onw}$, and $\gamma_2$) for the first subflare and five parameters (EM, T, A, $E_{onw}$, and $\gamma_1$) for the second subflare. Figure 5 displays results of the model fitting.

From the thermodynamics point of view, the second subflare is hotter than the first one but the EM is smaller. The volume $V$ of the UV loop estimated in the previous section is $10^{26}$ cm$^3$, so that the plasma density is $n_1 = \sqrt{(EM_1/V)} \approx 6 \times 10^{10}$ cm$^{-3}$ for the first subflare. The plasma density for the second subflare, assuming the same flare region volume, is $n_2 \approx 2 \times 10^{11}$ cm$^{-3}$. Due to compactness of the flare region, the plasma density within the magnetic loops is rather high.

The HXR photon spectrum is harder for the first HXR burst than for the second. The normalization coefficient $A$ of the HXR spectrum is also one order of magnitude larger in the case of the first subflare. This means that the acceleration process is more efficient during the first subflare. The total flux $F_l$ (electrons s$^{-1}$) of the accelerated electrons can be estimated following the work of Syrovatskii & Shmeleva (1972):

$$F_l(E_{low} < E < E_{high}) = 1.02 \times 10^{34} \frac{\delta^2}{E_{low}^{\beta(\delta_1, 1/2)}} \frac{I_{ph}(E_{low} < E < E_{high})}{1 - \left(E_{low}/E_{high}\right)^{\delta_1}},$$

where $E_{high}$ is the upper energy cutoff, $\delta_1 = \gamma_1 - 1$ is the spectral index of the accelerated electrons in the HXR emission region, $\beta(x, \gamma)$ is the beta function, and $I_{ph}(E_{low} < E < E_{high})$ photons s$^{-1}$ cm$^{-2}$ is the energy-integrated photon spectrum in the range shown in the brackets. From the fitting results using this formula, we obtain electron fluxes $F_{l1} \approx (2.0 \pm 1.2) \times 10^{35}$ and $F_{l2} \approx (0.10 \pm 0.06) \times 10^{35}$ electrons s$^{-1}$ for the first and second subflares. Despite the lower GOES class of the first subflare, we observe more energetic electrons involved in the acceleration process of this subflare than in the second one. Theoretically, these electrons could contribute to the sunquake initiation. However, the discrepancy between the locations of the sunquake impact and the strongest HXR emission source indicates that the beam-driven origin of the sunquake is unlikely. In the next section, we will discuss more quantitatively the energetics and momentum transfer associated with the sunquake impact in the solar photosphere.

To estimate the fluxes of the nonthermal electrons in both HXR emission sources, we use the imaging spectroscopy technique. In Figure 2, we show the results of our imaging spectral analysis of the \textit{RHESSI} data. The X-ray spectra are calculated for two circular regions marked in the \textit{RHESSI} CLEAN image (Figure 6(c)). The spectra and the model fits are presented in panels (a) and (b). The X-ray spectra are fit using a combination of a single-temperature thermal model and a broken power-law nonthermal model. One can see that the low-energy cutoff is determined with large errors which lead to large uncertainties on the fluxes, momentum, and energetics of the nonthermal electrons (their values are presented in Figure 6 panels (d), (e), and (f)). The estimated values show that the sunquake impact was accompanied by a smaller flux of the injected nonthermal electrons compared with the flux at the more intensive HXR source. It is worth noting that the low-energy cutoff $E_{low}$ deduced from the imaging spectroscopy is $\approx 20$ keV, while the model fitting of the spatially integrated spectra gives values $\approx 30$ keV. Such uncertainty is related to the dominance of the thermal component of the X-ray spectrum, masking the low-energy part of the HXR nonthermal spectrum associated with accelerated electrons.
5. ELECTRIC CURRENTS IN THE FLARE REGION

Local heating by electric currents or an impulsive Lorentz force can also be a source of the sunquake. In this section, we consider the evolution of the electric currents at the photosphere level. To estimate the horizontal electric currents, we use the Faraday law applied to the 45 s line-of-sight HMI magnetograms with a spatial resolution of 1″ and pixel size of 0″.5:

\[ \oint_C \mathbf{E} \cdot d\mathbf{l} = -\frac{1}{c} \frac{d}{dt} \left( \int_S \mathbf{B} \cdot d\mathbf{S} \right). \]

We can estimate the average transverse component of the electric field as \( \langle E_\perp \rangle = \frac{|F_\perp|}{cL} \), where \( F_\perp \) is total magnetic flux inside a contour with length \( L \), which covers the flare region. The evolution of \( \langle E_\perp \rangle \) presented in Figure 1 (gray histograms in top panels) shows that both subflares correlate with the peaks of \( \langle E_\perp \rangle \).

To calculate the vertical currents, we use the disambiguated HMI vector magnetic field data (Centeno et al. 2014) with time cadence 720 s, and the same spatial resolution as in the line-of-sight magnetograms. The vertical electric current density is calculated from the HMI vector magnetograms using Ampere’s law (e.g., Guo et al. 2013):

\[ j_z = \frac{c}{4\pi} (\nabla \times \mathbf{B})_z = \frac{c}{4\pi} \left( \frac{\partial B_y}{\partial y} - \frac{\partial B_x}{\partial k} \right). \]

The resulted \( j_z \) map during the flare, effectively averaged over 12 minutes due to the HMI temporal resolution, is presented in Figure 4. Figure 7 displays the evolution of \( \langle j_z \rangle \) averaged through the flare region with an area of \( \approx 1.5 \times 10^{18} \) cm², and reveals a maximum corresponding to the flare region. We estimated errors for \( \langle j_z \rangle \) as the standard deviation of the \( j_z \) distribution in the quiet Sun regions.

In Figure 4, we see that the location of sunquake generation correlates with strong electric currents, and that there is no significant HXR emission in this place. The HXR is mostly emitted from the source located on the other side of the magnetic field polarity inversion line at the opposite footpoint of the flare loop. Such observation, and the time evolution of \( \langle j_z \rangle \) and \( \langle E_\perp \rangle \), can be evidence of a non-beam-driven origin of the sunquake. The correlation with the location of the strongest electric currents suggests that the sunquake event could be initiated due to local heating or an impulsive Lorentz force in the flare region.

6. DISCUSSION

In this section, we discuss the contributions of the electric currents and nonthermal electrons in the flare energy release and generation of the sunquake.

For the estimated fluxes of accelerated electrons for the first subflare, the total kinetic power is \( P_{\text{total}} \approx 1.5 \times 10^{37} \) erg s⁻¹, in the HXR peak. To estimate the Joule heating in the sunquake generation region, we need to estimate the effective electric conductivity \( \sigma_{\text{eff}} \). In the regime of electric current dissipation, the magnetic Reynolds number is \( R_m = 4\pi \sigma_{\text{eff}} L^2/(c^2 \tau) \approx 1 \), where \( \tau \) is the characteristic time of electric current dissipation (~100 s, the duration of the HXR burst) and \( L \) is the characteristic length scale (~1″, the size of the impulsive region on the Dopplergrams). For these characteristic values, we obtain \( \sigma_{\text{eff}} \approx 10^6 \) CGS units. This value is substantially lower than the theoretical Spitzer conductivity (Kopecký & Kuklin 1966). However, recent studies of the partially ionized...
The plasma of the solar chromosphere show that the electric conductivity can be substantially reduced due to Pedersen resistivity (e.g., Leake et al. 2012) or due to small-scale MHD turbulence (Vishniac & Lazarian 1999). The volumetric energy release is $Q_e \approx J^2/\sigma_{\text{eff}} \approx 8 \times 10^{27} \text{erg s}^{-1}$ for $J \approx 0.3 \text{A m}^{-2}$. The total energy release due to the dissipation of electric currents in the sunquake region is $Q_e^{\text{tot}} \approx 3 \times 10^{27} \text{erg s}^{-1}$, estimating the volume for a box with length scale $L \sim 1^\circ$. Therefore, we see that $Q_{\text{phot}} \approx Q_e^{\text{tot}}$, and both types of energy release have an energy budget sufficient to explain heating in the flare according to the GOES data: the change of the plasma internal energy, $d(3nk_B T V)/dt \sim 10^{27} \text{erg s}^{-1}$, and the radiation losses, $L_{\text{rad}} \sim 5 \times 10^{26} \text{erg s}^{-1}$.

Theoretical arguments (Kosovichev 2014) show that a strong impulsive force in the lower solar atmosphere is needed to produce the observed sunquake waves which carry substantial momentum. The sunquake momentum can be estimated from the initial impact as $p_{\text{eq}} \sim \rho L^3 v \sim 10^{22} \text{ g cm}^{-1}$ for $\rho \sim 10^{-8} \text{ g cm}^{-3}$ (photospheric value) and $v \sim c_s \sim 10 \text{ km s}^{-1}$, where $c_s$ is the photospheric sound speed. In principle, the force generating the sunquakes can be produced directly by energetic electron beams. The total momentum of injected nonthermal electrons is

$$p_e \sim \tau \sqrt{2 m_e} \int_{E_{\text{low}}}^{\infty} f(E) \sqrt{E} \, dE,$$

where $m_e$ is the electron mass, $f(E)$ is the distribution function of nonthermal electrons, and $\tau$ is the characteristic time of the injection. For the first HXR burst, using the imaging spectroscopy technique, we found that the momentum of the injected electrons in the bright HXR source is $\sim(11.0 \pm 5.3) \times 10^{19} \text{ g cm}^{-1}$, which is approximately two times larger than in the weaker HXR source (see panels (d), (e), and (f) in Figure 6) where the photospheric impact was observed. Such results contradict the beam-driven initiation of the sunquake wave, as the sunquake impact was observed at the location of the lower fluxes of the nonthermal electrons.

The momentum of the accelerated protons can be much larger than in the case of electrons and can lead to stronger disturbances in the solar atmosphere. Assuming that the protons roughly (not accounting collisions) have energy $E_p \approx E_c$, the momentum contained in the proton beam is $p_p \approx p_e \sqrt{(m_p/m_e)} \sim 45 p_e \sim 0.5 \times 10^{22} \text{ g cm}^{-1}$. We see that the momentum of accelerated protons represents a more probable agent of sunquake initiation than the momentum of the electrons.

The observations show that while the sunquake impact and the HXR impulse are simultaneous in time, they are clearly separated in space and located at different footpoints of the flare magnetic loop. In addition, we find that the impact location correlates with the strongest electric currents. This suggests that energetic particles may be accelerated by the electric field at the location of sunquake initiation, and then the particles travel along the flare magnetic loop to the other footpoint and caused the HXR emission.

The impulsive plasma motion in the lower solar atmosphere may be caused by fast heating due to Joule dissipation or a sharp increase of the Lorentz force. In the first case, we can estimate the plasma momentum as $p_j \sim \tau \nabla P \sim p_j L^2$, where $\nabla P$ is the pressure gradient on the length scale, $L$. The pressure can be estimated from the energy equation

$$\frac{dp}{ds} = \frac{j^2}{\sigma_{\text{eff}}} - L_{\text{rad}},$$

where $L_{\text{rad}}$ is the radiation heat loss, which is the main source of cooling in the lower solar atmosphere. From this equation $p \sim j^2/\sigma_{\text{eff}}$, and hence $p_j \sim (\tau L^2)/\sigma_{\text{eff}} \sim 10^{23} \text{ g cm}^{-1}$.

The plasma momentum associated with the Lorentz force is $p_L \sim j B r L^2/c \sim 10^{22} \text{ g cm}^{-1}$, where $B \sim 100 \text{ G}$ is the magnetic field in the sunquake source and $c$ is the speed of light.

From the estimated values of $Q_e$, $p_p$, and $p_L$, one can conclude that the appearance of strong electric currents in the lower solar atmosphere is sufficient to explain the flare energy release and generation of the sunquake. Moreover, these estimates show that the electric current driven disturbances are sufficiently strong and that the electric currents are concentrated at the location of sunquake initiation while the strongest HXR impulse is $\sim 3 \text{ Mm}$ away. Therefore, it is likely that not only do high-energy particles play a significant role in the flares, as assumed by the standard flare model, but electric currents in the lower solar atmosphere can also be a significant part of flare energy release. In our recent paper, we discuss the relationship between electric currents and the fine structure of flare ribbons (Sharykin & Kosovichev 2014).
7. SUMMARY AND CONCLUSION
The main results of the work are as follows.

1. We observed a strong sunquake event in a weak C-class flare.
2. The sunquake is initiated, within 3 s observational accuracy, during the burst of the HXR emission.
3. The location of the photospheric impact associated with sunquake generation corresponds to the weaker HXR emission source while there is no significant photospheric impact in the stronger HXR emission source, which is located at the opposite footpoint of the flare loop observed in the EUV AIA images.
4. The location of the photospheric impact associated with sunquake initiation corresponds to the most intense electric currents.
5. The total (C7.0-M1.9) flare event temporarily correlates with the maxima of the vertical and transversal electric currents estimated in the energy release site.

The main conclusion of the presented observational results is that the helioseismic response (sunquake) and flare energy release in the lower solar atmosphere may have a strong connection to photospheric electric currents. The sunquake impact may be initiated by a pressure gradient caused by a rapid current dissipation or impulsive Lorentz force. The discovery of the strong photospheric impact produced by a weak C7 flare, which initiated the helioseismic response, opens new perspectives for studying flare energy release and transport because such flares usually have relatively simple magnetic topology and do not saturate detectors of space- and ground-based telescopes. However, our results show that high spatial and temporal resolutions are needed for these studies.

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