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What can He II 304 Å tell us about transient seismic emission from solar flares?

C. Lindsey[1] and A. C. Donea[2]

[1]NorthWest Research Associates, Colorado Division,
3380 Mitchell Lane, Boulder, Colorado, USA
email: clindsey@nwra.com

[2]Center for Astrophysics, School of Mathematical Science
Monash University, Victoria 3800, Australia

Abstract. After neary 20 years since their discovery by Kosovichev and Zharkova, the mechanics of the release of seismic transients into the solar interior from some flares remain a mystery. Seismically emissive flares invariably show the signatures of intense chromosphere heating consistent with pressure variations sufficient to drive seismic transients commensurate with helioseismic observations—under certain conditions. Magnetic observations show the signatures of apparent magnetic changes, suggesting Lorentz-force transients that could likewise drive seismic transients—similarly subject to certain conditions. But, the diagnostic signatures of both of these prospective drivers are apparent over vast regions from which no significant seismic emission emanates. What distinguishes the source regions of transient seismic emission from the much vaster regions that show the signatures of both transient heating and magnetic variations but are acoustically unproductive? Observations of acoustically active flares in He II 304 Å by the Atomospheric Imaging Assembly (AIA) aboard the Solar Dynamics Observatory (SDO) offer a promising new resource with which to address this question.

Keywords. Sun: flares, magnetic fields, UV radiation, helioseismology, chromosphere

1. Introduction

After neary 20 years since their discovery by Kosovichev & Zharlova (1998), the mechanics of the release of seismic transients into the solar interior from some flares remain a mystery. It has been suggested that transient seismic emission, when it happens, is driven by localized heating of the chromosphere of the magnetic region that hosts the flare (Kosovichev 1998, Donea & Lindsey 2005, Lindsey & Donea 2008). Another possibility is photospheric Lorentz-force transients motivated by magnetic reconfiguration, such as due to magnetic reconnection (Hudson, Fisher & Welsch 2008, Fisher *et al.* 2012). What is mysterious is the extreme locality of the source regions of seismic transients emanating from flares—as opposed to far more expansive regions showing intense transient disturbances, both thermal and magnetic, but from which no significant seismic emission emanates. What is different about the compact seismic-source regions from their much more expansive surroundings that show the signatures of violent transient disturbances, both thermal and magnetic, while remaining acoustically quiet?

A great deal of diagnostic attention to thermal signatures that may be associated with flares has concentrated on near-UV observations of flares by AIA, recognizing that excess near-UV emission emanates from a heated chromosphere or transition region just above the seismic source, supposedly in the underlying photosphere. The practical problem with the near-UV observations is that pixels upon which EUV images are projected generally saturate and bleed during bright flares, obscuring the UV source distribution after the early impulsive phase. We have largely neglected He II 304 Å because it is significantly "contaminated" by coronal sources that are generally far above, hence far removed, from chromosphere and photosphere, which we think must be the immediate sites of acoustic emission into the Sun's interior. However, recent attention paid to AIA observations of He II 304 Å by A. Parashiv, D. Lacatus and A. Donea has shown advantages to He II 304 Å observations by SDO/AIA that promise to outweigh the contamination problem.

What is most conspicuous in the "chromospheric" component† of the He II 304 Å source distribution is a system of flare ribbons that sweep across vast swaths of the active region during the impulsive phase of the flare. It is these flare ribbons—the footpoints of coronal magnetic loops thought to conduct accelerated particles into the underlying chromosphere—that are suspected of playing a crucial role in the mechanics that excite transient seismic emission from certain highly distinctive locations.

Notwithstanding significant coronal contamination, He II 304 Å emission from the ribbon-footpoints of flaring loops is generally clear and distinctive. Moreover, saturation during bright flares is generally avoided by appropriately shorter exposures being inserted into the imaging sequence during flares. So, He II 304 Å observations clearly show the progression of flare ribbons across seismic source regions during the impulsive phases of acoustically active flares.

2. Examples

In the few instances we have examined so far, the seismic-source regions are initially outside of the flare ribbons, but one of the ribbons invariably sweeps across each of the seismic-source regions during the impulsive phase. Figure 1 shows an example in a flare with a single, relatively weak but significant compact seismic source: During the early impulsive phase, the flare ribbon lies north of the seismic source (centered in the red circle, see bottom-left frame). In a period of 40 seconds, the EUV ribbon sweeps southward completely across the seismic source (bottom-right frame). This sweeping motion of flare ribbons is well known, and characteric of flare ribbons over tens of thousands of km in length, whether or not there is an acoustic-source region in its path. When we now look for some quality that distinguishes the ribbon as it crosses the location of a compact seismic source, an anomaly becomes apparent: the ribbon becomes distinctly jagged—possibly fragmented on a microscopic scale (bottom-right frame of Figure 1). A similar behavior is seen in Figure 2, in a flare that has two fairly strong, compact seismic sources.

Zharkov *et al.* (2011) and Zharkov *et al.* (2013) have already capitalized on the relationship between acoustic sources in the flare of 2011-02-15 and associated flare ribbons. In this instance, the flare ribbons (visible in Hinode CaII H observations) are not necessarily jagged in the neighborhood of the source, but are nevertheless anomalous in that they are tightly "kinked" in the source regions. In one instance this appears to be associated with the seismic source being located at the extreme end of the flare ribbon. This observation is now confirmed by AIA He II 304 Å observations of the same flare, which show a tight morphological similarity between Ca II-H and AIA-He II 304 Å flare ribbons.

† While applying this terminology, we have to suspect that the EUV radiation imaged has emanated from the transition layer overlying the chromosphere rather than the chromosphere itself, although the emitting material may very likely have been distinctly chromospheric before the onset of the flare. The point of the attention to the flare ribbons is to identify as closely as possible the *horizontal location* of the associated chromosphere and underlying photosphere, since these must (we think) play a crucial role in transient seismic emission into the underlying solar interior

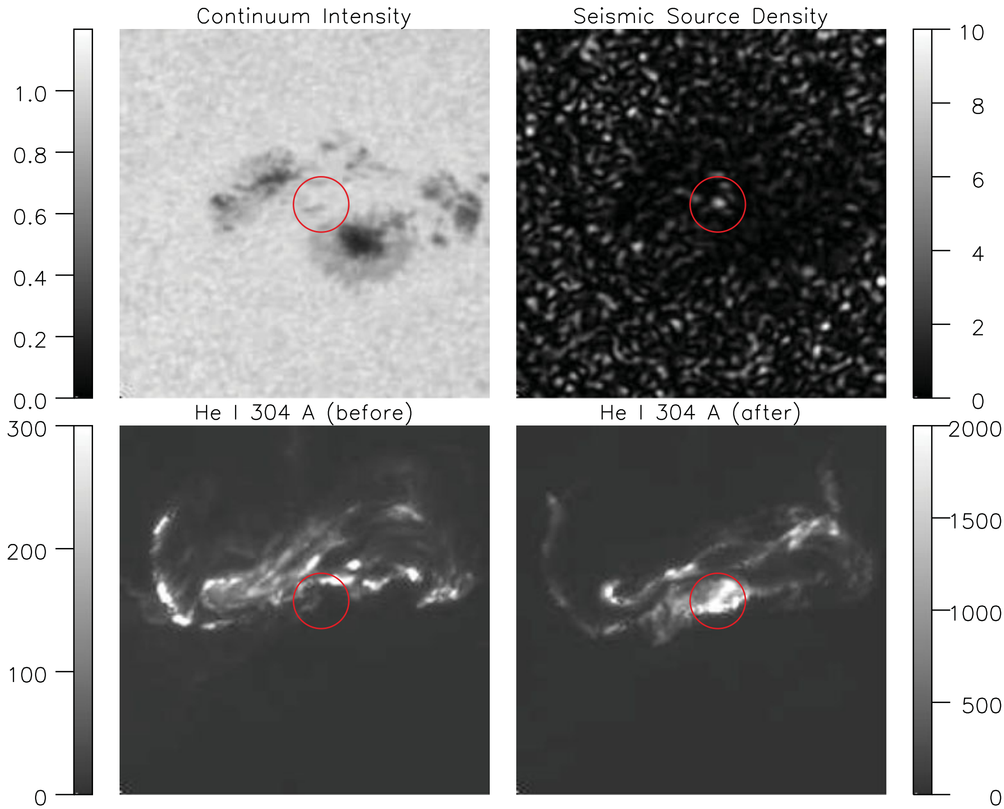

Figure 1. Visible-continuum (upper-left), seismic (upper-right) and He II 304 Å (bottom row) observations of the X1.0-class flare of 2014-03-29, from NOAA AR 12017. He II 304 Å ribbon sweeps from north (lower left) to south (lower right) across the single acoustic source, circled in red. The ribbon splits apart, showing a bright Y-shaped feature (lower right) as it crosses the region of the seismic source. (Some of the He II 304 Å emission appears to come from the coronal loops overlying the flare ribbons.)

3. Discussion

So far, we have run this analysis on only four flares, including the two shown in Figures 1 and 2 and the one Zharkov *et al.* (2013) studied. So our statistics are quite thin at this moment. However, they are strong enough to lead us to suspect that He II 304 Å offers a promising resource that may lead us to new insight into the physics of transient seismic emission from flares. This promise is greatly reinforced by the full coverage of nearly every flare in solar cycle 24 by AIA. If something like the foregoing results are born out by further observations, it appears that several questions will have emerged:

(*a*) What do anomalies characterizing flare ribbons over seismic source regions say about the 3-D magnetic configuration in the seismic source region before and during a flare?

(*b*) Did this peculiarity in the magnetic configuration exist before the onset of the flare, or could it possibly have evolved during the impulsive phase during which it was observed?

(*c*) If the former, then what about such a magnetic configuration makes it peculiarly conducive to the transmission of a seismic transient into the underlying solar interior during a flare, whether motivated by heating, by Lorentz force transients or some other

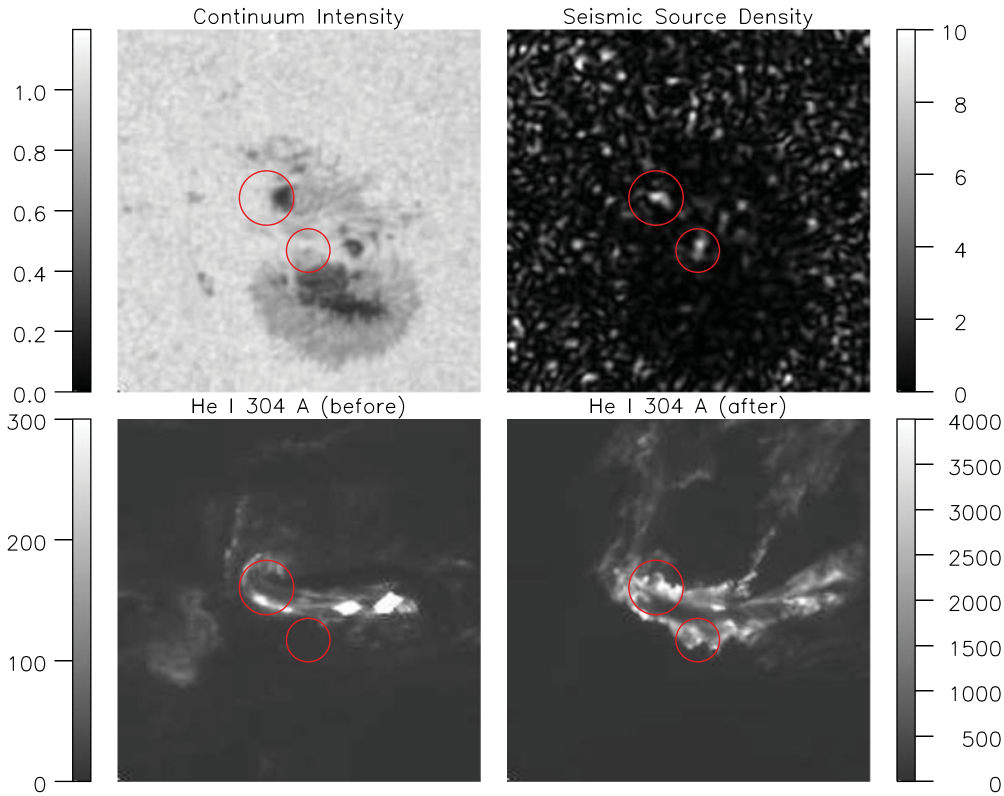

Figure 2. Visible-continuum (upper-left), seismic (upper-right) and He II 304 Å (bottom row) observations of the X3.3-class flare of 2013-11-05, from NOAA AR 11890. Southern He II 304 Å ribbon sweeps southward across the south-western acoustic source region becoming jagged and fragmented as it crosses it. Northern ribbon, initially very dim, brightens and becomes similarly jagged and fragmented in the neighborhood of the north-eastern seismic source.

mechanism? Resources for addressing these questions, both observational and theoretical, are considerable and promising.

We greatly appreciate insights of Alin Parashiv and Danielle Lacatus into He II 304 Å observations by AIA of jets, eruptions and flares.

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