Response to Brian Welsch's Comment

Hi, Brian. As your comments tend to be, this one is very penetrating. The contrivance you propose that would project an apparently submerged transient acoustic source from an acoustic disturbance confined to the solar surface *is viable*, at least in principle. In our opinion, it deserves attention at least equal that of refractive warping, but there was not nearly enough space in our *Letter* to adequately address either. So, here it is now: While the discussion of refractive warping applies to this same issue, our understanding of the prescription you propose could work with *no* refractive warping at all. It has vivid analogies in the phenomenae of "real" and "virtual" images in standard electromagnetic optics with lenses and holograms, a visage so often encountered therein that one easily forgets the magic in it. Both of these terms refer to an apparent source or other visage where there is no physical object in fact, not even a refractive anomaly. This could be readily contrived in a region of quiet Sun, for example, by a force field that acted upon the photosphere by applying a transient downward pressure over a thin ring whose radius, r, is something like 1,400 km at its onset, and which proceeds thence to collapse inward along the solar surface over the succeeding minute as plotted below:

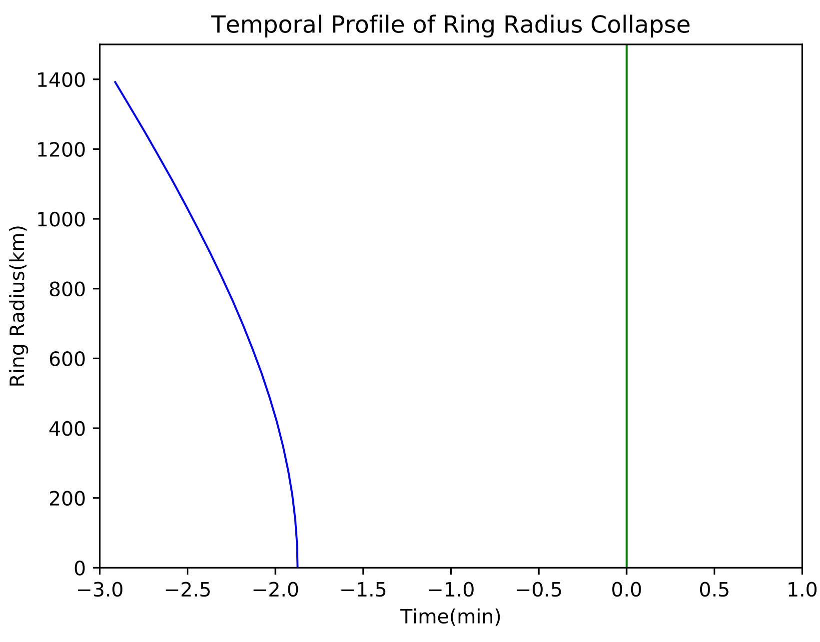

Figure 1. Plot of ring radius of a disturbance prescribed to project an apparent compact source at a depth of 1,150 km beneath the base of the quiet solar photosphere. Vertical green line marks the moment at which the disturbances condenses to a compact acoustic concentration at depth 1,150 km.

The resulting inwardly traveling force transient would drive a quasi-spherical wave front into the underlying medium that would propagate downward and inward toward a point

1,150 km directly beneath the center of the erstwhile circular disturbance at the overlying surface. The entire constituency of this disturbance would converge momentarily into a compact concentration about said point three minutes after the onset of the overlying disturbance, through which it would then pass directly, to reinflate back to a transient wavefront, now expanding outward and downward into the underlying medium further beneath. This transient would be, at least locally, quite similar to the downwardly propagating component of the wave that *would* be emitted directly by a transient monipolar source fixed at the location of the submerged concentration just left behind. Upon refracting back to the Sun's surface, either of these disturbances would make a ripple thereupon which would elicit from our diagnostics a seismic signature that was similarly submerged, we're convinced.

In principle, a ready control for the foregoing hypothesis is simply to look at the Sun's surface directly overlying the apparent source to see whether any such disturbance was apparent a few minutes before the time at which the submerged signature appeared in the acoustic source-density map. This squeezes the prescribed driving surface disturbance into the extreme early impulsive phase of the flare. Among the complications that confront this control in practice are the following:

(1) The bandwidth, $\Delta\nu$, of the 9.0–11.0-mHz spectrum, in which the submerged signature appears is only 2 mHz. Hence, the temporal resolution,

$$\Delta t \;=\; \frac{1}{0.002 \text{ Hz}} \;=\; 500 \text{ sec} \;=\; 8.33 \text{ min}, \tag{2}$$

afforded is insufficiently short to separate the epoch of the disturbance from that of the submerged source, nor of the other ambient disturbances that abound in the flaring outer atmosphere during the impulsive phase.

(2) The foregoing 2-mHz band is squeezed tightly up against HMI's Nyquist frequency (11.1 mHz), where aliasing renders it ambiguous, for example, whether a train of ripples is collapsing inward or expanding outward. (Aliasing is the effect that makes the spokes of wagon wheels appear to be rotating backwards in spagetti westerns.)

(3) The acoustic field in the general locality of the source is cluttered by contributions from other, apparently shallower sources, and

(4) The medium directly above the apparent submerged source is infused with a strong thermal anomaly, dense magnetic flux stochastically distributed, and a probable Wilson depression. We understand that these anomalies refract acoustic waves so as to impair, if not completely destroy, the coherence of a wave to be excited as prescribed above. This has the strong analogy in familiar electromagnetic optics to the effect of a *showerglass*, whose function is to impair the coherence of electromagnetic radiation passing through it. In fact, in local helioseismology at large, this phenomenon is literally called "the acoustic showerglass effect," and an active region within which this effect is of diagnostic concern is called an acoustic showerglass. A practical example of the manifestations of said impairment in the familiar electromagnetic spectrum is seen in the visible radiation coming off of the girl (courtesy of

Vincent van Gogh) behind the showerglass through which the photo below is rendered.

Figure 2. Impairment of electromagnetic coherence due to phase variations induced by refractive anomalies in a showerglass.

The acoustic showerglass effect manifested by a strong active region renders helioseismic signatures in its photosphere essentially useless for imaging acoustic anomalies that lie directly beneath it. A similar impairment of coherence is enacted upon waves excited in the active-region photosphere and traveling downward from thence into the underlying solar interior. It is nevertheless still possible, in principle, to redesign a transient disturbance such as that described above, phase-correcting it for the showerglass effect so that the resulting wave arrives stigmatically at the depth prescribed after all. How to formulate such a correction might be prohibitive to contrive by design, given our insufficient knowledge of the acoustic anomalies that lie more than a few km beneath any magnetic photosphere. Even so, how this could still simply just happen by accident need not be any less probable than the ideality developed at some length above so far as we might presently propose to judge. Because of all this, we find ourselves fairly well settled, at least for now, into what is by far the more familiar scientific disposition for us: that the submerged acoustic signatures we are finding lend positive support to the hypothesis of submerged acoustic sources, but not in any way definitive proof of it.