A Remarkably Narrow RHESSI X-Ray Flare on 2011 September 25

Brian R. Dennis1 and Anne K. Tolbert1,2

1 Solar Physics Laboratory, NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA; brian.r.dennis@nasa.gov
2 American University, Washington, DC, USA

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Abstract

The unusually narrow X-ray source imaged with the Ramaty High Energy Solar Spectroscopic Imager (RHESSI) during an impulsive spike lasting for ~10 s during the Geostationary Operational Environmental Satellite C7.9 flare on 2011 September 25 (SOL2011-09-25T03:32) was only ~2" wide and ~10" long. Comparison with Helioseismic and Magnetic Imager magnetograms and Atmospheric Imaging Assembly images at 1700 Å shows that the X-ray emission was primarily from a long ribbon in the region of positive polarity with little if any emission from the negative polarity ribbon. However, a thermal plasma source density of ~10^{12} cm^{-3} estimated from the RHESSI-derived emission measure and source area showed that this could best be interpreted as a coronal hard X-ray source in which the accelerated electrons with energies less than ~50 keV were stopped by Coulomb collisions in the corona, thus explaining the lack of the more usual bright X-ray footpoints. Analysis of RHESSI spectra shows greater consistency with a multi-temperature distribution and a low-energy cutoff to the accelerated electron spectrum of 22 keV compared to 12 keV if a single-temperature distribution is assumed. This leads to a change in the lower limit on the total energy in electrons by an order of magnitude, given the steepness of the best-fit electron spectrum with a power-law index of ~6.

Unified Astronomy Thesaurus concepts: Solar X-ray emission (1536); Solar flares (1496); Solar x-ray flares (1816); X-ray observatories (1819)

1. Introduction

The C7.9 flare of interest, designated as SOL2011-09-25T03:32, was first studied by Guo et al. (2012a, 2012b, 2013), who treated it as a coronal hard X-ray (HXR) source because no obvious footpoints were detected. They fitted the observations with a collisional model with an extended electron acceleration region and a sufficiently high coronal density, such that the accelerated electrons would lose all of their energy in the legs of the magnetic loop before reaching the chromospheric footpoints. The measured increase in source length with increasing photon energy was taken as evidence to quantify the parameters of this model. However, Dennis et al. (2018) pointed out that this interpretation was probably incorrect as the source was so narrow with a FWHM of ~2", and there was evidence of weak emission from at least one footpoint at high energies that would affect the measured energy dependence of the source length. Also, it was found that the linear X-ray source was near co-spatial with one of two possible ribbons apparent in the Atmospheric Imaging Assembly (AIA) 1700 Å images that themselves lay in a location with strong positive and negative magnetic fields situated between the two major sunspots of the active region.

This paper is a report on the detailed analysis of this unusual event with an emphasis on determining the physical nature of the X-ray source and the significance of its location with respect to the strong magnetic field magnitudes and gradients. A comparison is presented in the Appendix of nine image reconstruction algorithms available in the Ramaty High Energy Solar Spectroscopic Imager (RHESSI) software and of their ability to reproduce the finest features of this unusually narrow source.

2. Observations

The flare SOL2011-09-25T03:32 occurred on 2011 September 25 in NOAA active region 11302 at N12E50 (X = -700", Y = 151"), peaking at 03:32 UT. The X-ray lightcurves from RHESSI (Lin et al. 2002) in three energy bins and from the Geostationary Operational Environmental Satellite (GOES) are shown for a two hour period in Figure 1. The C7.9 flare of interest is near the end of this time interval and appears as the impulsive spike in the 25–50 keV lightcurve matched by the rapid rise in the GOES fluxes at the same time. Two earlier peaks apparent in this figure are not relevant to the current discussion except that their decaying flux adds to the RHESSI count rates below ~12 keV during SOL2011-09-25T03:32. The earlier emission peaking at 01:57 UT was from AR11295 at X = 884", Y = 419". The GOES M4.4 event peaking at 02:33 UT was actually from two different active regions, one from the same active region as SOL2011-09-25T03:32 but the other from AR 11303 located at X = 775", Y = -491".

More detailed RHESSI lightcurves of SOL2011-09-25T03:32 are shown in Figure 2. The short impulsive peak at 03:31:18 UT can be seen most clearly in the 25–50 keV lightcurve. The decrease in the count rates at 03:29:48 UT is the result of the thin attenuators being inserted in the optical path of each detector at that time. Also shown are the time derivatives of the GOES lightcurves with an impulsive peak coincident with the impulsive HXR peak as expected from the Neupert Effect (Neupert 1968).

2.1. Imaging

RHESSI imaging is based on the measurement of the solar X-ray flux that is modulated by nine bi-grid collimators as the
spacecraft rotates (Hurford et al. 2002). Various algorithms are available in the RHESSI software to reconstruct images from these measurements using different techniques (see the Appendix for a discussion of all currently available image reconstruction methods). Some algorithms, such as CLEAN and Pixon, use the modulated count rates in the different detectors directly, while others, such as MEM_NJIT and VIS_FWDFIT, use visibilities computed from the modulated count rates in each detector. A visibility is defined as a vector representation of the amplitude and phase of the modulation at a given spacecraft roll angle with most instrumental artifacts removed (Hurford et al. 2002).

The RHESSI 12–25 keV color image in Figure 3 reveals a long but remarkably narrow source with a width of $\sim 2\,''$. The white contours show the corresponding image made with the VIS_FWDFIT method under the assumption that the source is a single elliptical Gaussian. The best fit to the visibilities was obtained with a FWHM width of $2.0 \pm 0.2$ and length of $15.8 \pm 0.4$. Note that unless the assumption of two or more sources were made—an ellipse plus a circular Gaussian say—VIS_FWDFIT cannot reveal the possible additional compact source suggested in the MEM_NJIT image at the extreme southwest end (the compact source at $X = -693, Y = 149$) or the possible extension to the north. A double source assumption, however, did not lead to a significant reduction in the reduced $\chi^2$ value from that obtained with the single-ellipse assumption. Thus, the existence of the separate footpoint source suggested in the MEM_NJIT image cannot be considered as statistically significant.

The existence of this long narrow source is revealed in the RHESSI lightcurves for the individual detectors at this time. They show remarkably strong modulation in all detectors, including Detector #1, which is behind a subcollimator with a nominal FWHM resolution of $2.3''$. Figure 4 shows the measured count rates (in red) in each detector and the predicted count rates (in black) from the reconstructed MEM_NJIT image as a function of the “regularized roll angle” defined as the spacecraft roll angle corrected for the offset between the spin axis and the mean subcollimator optical axis. For this plot, the count rates are summed modulo the spacecraft spin period ($\sim 4\,s$) for the 64 $s$ interval duration used for the image. Significant sinusoidal modulation is evident in these plots for all detectors. The detectors behind the subcollimators with the coarser grids (#5–9) show modulation at all roll angles, while the detectors behind the finer grids (#1–4) show modulation over two limited ranges in regularized roll angle ($\sim 90^\circ$–$150^\circ$ and $\sim 280^\circ$–$300^\circ$). This is the expected modulation signal for an asymmetrical source with a width much smaller than its length. The agreement between the measured and predicted rates is an indication of how well the reconstructed image matches the data. This agreement is quantified with the Cash or C-statistic$^5$ (Cash 1979), given as a separate value for each detector and as an overall value for all detectors together) for comparison with values obtained with other reconstruction methods (see the Appendix).

Another way of showing the modulation in the different detectors is to plot the amplitude of the visibility vectors (Schwartz et al. 2002; Schmahl et al. 2007) for each detector as a function of the position angle defined as the spatial direction of each grid response referenced to solar north. This is essentially the same as plotting just the amplitudes of the oscillations seen in Figure 4 but here plotted for only a half rotation from $0^\circ$ to $180^\circ$ with the second half rotation assumed.

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$^5$ https://hesperia.gsfc.nasa.gov/rhessi/software/imaging-software/cash/cash_oddities.html
to be identical and added to the first, an option known as “combine conjugates.” Such a plot is shown in Figure 5. Here again, the characteristics of an asymmetric source are dramatically evident with the peaks in the visibility amplitudes for each detector showing the position angle of the smallest dimension of the source and the valleys showing the position angle of the largest dimension. From this analysis, another quantitative indication of how well the image fits the count rates is given by the reduced \( \chi^2 \) values computed from the measured and predicted visibility vectors weighted by the statistical uncertainties. These values are listed in the figure for each detector and for all detectors together. The summed reduced \( \chi^2 \) values are used for comparison with values obtained for other reconstruction methods (see the Appendix).

The VIS_FWDFIT method is unique among all the currently available reconstruction algorithms in giving source dimensions with uncertainties. The source flux, centroid location in \( X \) and \( Y \), width, and length are determined to give the best fit to the measured visibilities using a weighted chi-squared value. The uncertainties are determined from a Monte Carlo analysis using 20 randomly chosen sets of visibilities distributed according to their statistical uncertainties. Images were made with this method in three energy ranges spanning the expected thermal and nonthermal domain between 6 and 50 keV with results listed in Table 1. Surprisingly, neither the shape nor the dimensions of the source change appreciably with energy as the emission switches from predominantly thermal to nonthermal presumably at energies above \( \sim 10 \) keV (see Section 2.2). The width perhaps decreases from \( 2'' \) at low energies to below \( 2'' \) in the 25–50 keV energy bin but no obvious footpoints show up and the source length stays constant at \( \sim 15'' \).

Overlaying RHESSI images of this flare onto Solar Dynamics Observatory/Helioseismic and Magnetic Imager (SDO/HMI) magnetograms shows that it was located centrally between the two major sunspots in AR 11302 along the neutral line between oppositely directed magnetic fields. This is shown in Figure 6, where the RHESSI white contours show the location of the 12–25 keV emission. An expanded version is shown in Figure 7 with the addition of the SDO/AIA 1700 Å contours. Note that the AIA contours show two sources, one in the region of strong negative magnetic field and one in the region of positive magnetic field. This suggests that they are the two ribbons of the flare. The RHESSI source lies mainly along the longer ribbon-like feature. Interestingly, the weak source to the southwest of the main line source in the MEM_NJIT image shown in Figures 3 and 7 is located within \( \sim 2'' \) of the more compact source in the 1700 Å image. This is within the usual discrepancy found between RHESSI and AIA images.

### 2.2. Spectroscopy

Detailed spectral analysis shows that the source can be detected above background to energies as high as 50 keV during the impulsive peak in the 25–50 keV lightcurve at 03:30:18 UT shown in Figures 1 and 2. The RHESSI count flux spectra for a 4 s interval about that time are shown in Figure 8 along with thermal, nonthermal, and albedo spectra that together best fit the measurements. Figure 8 (top) shows the measured background-subtracted count flux spectrum (black histogram with \( \pm 1 \sigma \) error bars) between 3 and 50 keV in 0.3 keV bins summed over the front segment of all nine germanium detectors except for \#2 and \#7 as they had poorer energy resolution and sensitivity below \( \sim 10 \) keV. The red histogram is the sum of the following functions giving the best fit (reduced \( \chi^2 = 0.94 \)) to the measured spectrum between 6 and 50 keV:

- \( \text{vth} \): single-temperature thermal spectrum with an emission measure (EM) of \( 1.9 \times 10^{59} \) cm\(^{-3} \) and a temperature of 0.87 keV (10 MK). The Fe abundance was assumed to be
that is also seen more convincingly at 6 keV as the compact red source at the extreme southwest end of the line feature at 10%, 50%, and 90% of the peak count rates of the front segments of all nine germanium detectors were used to make this image. The white contours are thick2 ⋅ \text{keV}^{-1} \text{cm}^{-3}

\text{photons cm}^{-2} \text{s}^{-1} \text{arcsec}^{-2}

\text{RHESSI color image in the 12–25 keV energy range made with the MEM\_NJIT reconstruction method for the 64 s duration of the 25–50 keV peak from 03:30:08 to 03:31:12 UT seen in Figure 2. The count rates of the front segments of all nine germanium detectors were used to make this image. The white contours are 10\%, 50\%, and 90\% of the peak flux for the elliptical source reconstructed with the VIS\_FWDFIT algorithm. Note the possible evidence for separate emission seen as the compact red source at the extreme southwest end of the line feature at } x = -693\degree, y = 149\degree \text{ and the extension to the north in green at } x = -713\degree, y = 168\degree \text{ that is also seen more convincingly at 6–12 keV (not shown).}

Figure 3. RHESSI color image in the 12–25 keV energy range made with the MEM\_NJIT reconstruction method for the 64 s duration of the 25–50 keV peak from 03:30:08 to 03:31:12 UT seen in Figure 2. The count rates of the front segments of all nine germanium detectors were used to make this image. The white contours are 10\%, 50\%, and 90\% of the peak flux for the elliptical source reconstructed with the VIS\_FWDFIT algorithm. Note the possible evidence for separate emission seen as the compact red source at the extreme southwest end of the line feature at } x = -693\degree, y = 149\degree \text{ and the extension to the north in green at } x = -713\degree, y = 168\degree \text{ that is also seen more convincingly at 6–12 keV (not shown).}

0.5 times the coronal Chianti chromospheric value for all the thermal functions used here.

\text{thick2\_ynorm: A cold thick-target bremsstrahlung X-ray spectrum from a power-law electron distribution with a flux at 50 keV of } (1.5 \pm 0.1) \times 10^{32} \text{ electrons s}^{-1} \text{keV}^{-1}, \text{ an index } (\delta) \text{ of } 6.0 \pm 0.1, \text{ and a low-energy cutoff } (E_c) \text{ of 12 keV.}

\text{albedo: predicted albedo spectrum for an isotropic source at the given location on the solar disk following Kontar et al. (2006).}

The best-fit spectrum shows that the contributions of the thermal and nonthermal components are equal at ~10 keV. The value of ~12 keV obtained for } E_c \text{ is usually taken to be an upper limit to its true value, because a lower value would give an equally good fit to the data (Ireland et al. 2013). However, if a higher temperature thermal component is also present, this can be a false assumption as indicated below.

An equally valid fit, shown in Figure 8 (bottom), was obtained when the single-temperature function was replaced with a multi-temperature model in which the differential emission measure (DEM) is a power-law function of temperature of the form

\text{DEM}(T) = A \left(\frac{T}{2}\right)^{-\alpha} \text{cm}^{-3} \text{keV}^{-1}, \quad (1)

where } T \text{ is the temperature in keV and } A \text{ is the DEM at } T = 2 \text{ keV. This function, called } \text{multi\_therm\_pow in Figure 8, }

\text{is restricted to the temperature range between } T_{\text{min}} \text{ and } T_{\text{max}}. \text{ Fitting this function to the count flux spectrum with } A \text{ and } \alpha \text{ as free parameters and } T_{\text{min}} \text{ and } T_{\text{max}} \text{ fixed at their default values of 0.5 keV and 5 keV, respectively, gives an acceptable value of the reduced } \chi^2 (=1.03). \text{ The best-fit values of } A \text{ and } \alpha \text{ are } (9.1 \pm 0.4) \times 10^{46} \text{ cm}^{-3} \text{keV}^{-1} \text{ and } 6.0 \pm 0.2, \text{ respectively, but the low-energy cutoff } (E_c) \text{ is increased from the 12 keV obtained with the single-temperature assumption up to 22 keV. We compared this very steep DEM function with the DEM deduced using the method given by Hannah & Kontar (2012) with AIA images taken of this flare at this time in the six channels with temperature coverage above 1 MK (the 94, 131, 171, 193, 211, and 335 Å channels). Although there is some uncertainty in the fluxes in some channels because of bleeding from the brightest pixels, particularly in the 171 Å channel, the two functions cross at a DEM of a few times } 10^{24} \text{ cm}^{-3} \text{K}^{-1} \text{ (using a source area of } 2 \times 10^{-7} \text{ arcsec}^2 = 1.2 \times 10^{17} \text{ cm}^2) \text{ at a temperature of } \sim 1 \text{ keV (} \sim 12 \text{ MK). AIA does not significantly constrain the DEM at higher temperatures and RHESSI does not constrain it at lower temperatures. Changing } T_{\text{min}} \text{ from 0.5 to 1 keV has little effect on the goodness of fit to the RHESSI data except for the lowest energy point in the 6–7 keV bin. This point is also directly dependent on the Fe abundance so it is impossible to determine these two parameters independently of one another with attenuators in place. (A better approximation to the expected function would be for the DEM in all}
multi_therm functions to be set to a fixed value equal to its value at $T_{\text{min}}$ for all lower temperatures, rather than to zero as is currently the case.

A third possible thermal function—the sum of two single-temperature spectra ($v_{\text{th}} + v_{\text{th}}$) with different temperatures—also gave an acceptable fit to the count rate spectrum for this

Figure 4. Measured count rates in red for the 12–25 keV energy band in the front segment of each of the nine germanium detectors plotted vs. “regularized roll angle.” Overlaid in black are the count rates predicted from the image shown in Figure 3 made using the MEM_NJIT reconstruction algorithm. Both the measured and calculated count rates are accumulated modulo the spacecraft spin period for the duration of the 64 s time interval starting at 03:30:08 UT that was used to make the image.
In this case, the two temperatures were 0.7 ± 0.2 and 1.7 ± 0.1 keV with corresponding emission measures not well constrained at \((4 ± 4) \times 10^{59}\) cm\(^{-3}\) and \((2.1 ± 0.3) \times 10^{47}\) cm\(^{-3}\), respectively.

Since both a single and a double temperature function and a power-law DEM all give acceptable values of \(\chi^2\), there is no way to determine which is correct from spectral analysis alone. One way to differentiate between them is to estimate the magnitudes of the thermal and nonthermal components as a function of energy based on the impulsiveness of the lightcurves. One would expect that the thermal emission would vary more gradually than the nonthermal emission based on the idea that there is steady heating compared to the impulsive particle acceleration. Also, any impulsive heating by the particles would decay more gradually because of the longer cooling time as expected based on the Neupert Effect (Neupert 1968). The impulsive peak at 03:30:18 UT offers the opportunity to track its relative amplitude as a function of energy as compared to the more gradually varying emission seen at lower energies. The definition of the gradual and impulsive components is shown in Figure 9. The gradual component is the count flux above the pre-flare background level and below a linear interpolation between the fluxes in pre- and post-peak 4 s intervals (20 s on either side of the peak). The impulsive component is the flux above the gradual component. In Figure 10, the plotted points with ±1σ statistical uncertainties are the ratio of these impulsive and gradual components as a function of energy as compared to the more gradually varying energy seen at lower energies. The definition of the gradual and impulsive components is shown in Figure 9. The gradual component is the count flux above the pre-flare background level and below a linear interpolation between the fluxes in pre- and post-peak 4 s intervals (20 s on either side of the peak). The impulsive component is the flux above the gradual component. In Figure 10, the plotted points with ±1σ statistical uncertainties are the ratio of these impulsive and gradual components as a function of energy. This plot shows that the impulsive peak was not evident in the lightcurves up to \(\sim 10\) keV (ratio \(\ll 1\)) consistent with the gradual increase expected for the thermal emission. Above 10 keV, the impulsive peak...
became more dominant over the gradual component up to \( \sim 30 \) keV as expected for the more impulsive nonthermal emission. Above 30 keV, the measured flux becomes closer to the pre-flare background with the resulting larger error bars.

Also shown in Figure 10 for comparison with the impulsive-to-gradual ratios are the thermal-to-nonthermal ratios obtained from the spectral fitting of three assumed thermal functions—isothersmal (vth), two temperature (vth+vt), and the power-law DEM (multi_therm_pow). As can be seen, the ratios determined from both the single and double temperature functions deviate from the impulsive/gradual ratios at the higher energies, whereas the ratios from the power-law DEM function agree over all the energies up to at least 30 keV.

The ratios of both the thermal/nonthermal and impulsive/gradual ratios all increase with decreasing energy below \( \sim 6 \) keV. This is presumably because the thin attenuators were moved into the light path of each detector just before the peak, thus strongly attenuating the X-ray fluxes at low energies. Most of the counts recorded with energies below 6 keV are then from higher energy X-rays that are photoelectrically absorbed but the K-shell fluorescence photon (\( \sim 10 \) keV) escapes (Smith et al. 2002). Thus, the recorded counts below \( \sim 6 \) keV can be expected to have the same ratio for X-rays with 10 keV more energy than the measured energy loss in the detector. This is shown by the ratios for the 3–4 keV X-rays being the same as for the 13–14 keV X-rays.

This timing analysis thus supports the conclusion reached from the spectral analysis that the thermal and nonthermal emission contribute equally at \( \sim 15 \) keV and that the low-energy cutoff cannot be much below \( \sim 20 \) keV. If it were, one would expect the impulsive peak to be evident to lower energies. This is similar to the conclusion reached by Sui et al. (2005) based on their method combining spatial, spectral, and temporal analysis to determine the cutoff energy but they did not consider the effects of a non-thermal plasma contributing significantly to the X-ray spectrum at higher energies.

### 3. Discussion

We have presented detailed analysis of an unusually narrow X-ray source with an FWHM width close to the 2” resolving power of the finest \textit{RHESSI} grids. Other small sources imaged with \textit{RHESSI} have been reported by Dennis & Pernak (2009) but they were usually in pairs at energies above \( \sim 25 \) keV and were interpreted as footpoint sources with some extent along the corresponding ribbon. There is no such unambiguous interpretation of the \textit{RHESSI} observations for this event. This narrow source is detected not just in the nonthermal hard X-ray energies above 25 keV but, as shown in Table 1, extends in energy down to at least 6 keV where the counts are dominated by thermal emission, as shown in Figures 8 and 10.

The comparison with the HMI magnetic field image in Figures 6 and 7 shows that the \textit{RHESSI} source lies along the eastern end of the neutral line between two strong and uniform magnetic fields. The AIA 1700 Å contours in Figure 7 show what may be interpreted as a long ribbon in the region of positive magnetic polarity coincident with the \textit{RHESSI} source. The second more compact source is in the region of higher negative magnetic field strength. It is at the same location as a possible weak compact source seen in the \textit{RHESSI} image made with the MEM_NJIT reconstruction algorithm shown in Figure 3. Perhaps this second compact ribbon is so weak in X-rays because the accelerated electrons are mirrored by the stronger magnetic field resulting in weaker bremsstrahlung emission. AIA images at other wavelengths show a narrow source extending from the two ribbons with an extension in a northerly direction not seen with \textit{RHESSI}.

Thus, one interpretation of this event is that very low-lying loops extend from the compact ribbon in the west to different footpoints along the linear ribbon to the east, with further extensions to the north. The thermal loops seen with \textit{RHESSI} at energies below \( \sim 15 \) keV happen to lay over the footpoints seen at higher energies and so the same long narrow source is seen at all energies.

Another possible interpretation is that the X-ray source is of sufficiently high density that the accelerated electrons deposit...
all of their energy in the coronal part of the loop or loops before reaching the footpoints—the assumption made originally by Guo et al. (2012a, 2012b, 2013, 2014). To test this model, we estimated the density \( n \) in the X-ray source from the EM determined from the RHESSI spectral analysis and the source volume \( V \) from the RHESSI images. The best fit to the measured spectrum for the single-temperature assumption \( \langle v \rangle \) gives \( EM = 1.9 \times 10^{49} \) cm\(^{-3} \) (Figure 8). The source volume under the assumption of a single horizontal cylinder with the diameter of the circular cross section equal to the measured FWHM source width of 2\( '' \) and the measured length of 10\( '' \)

\[ V = \pi/4 \times 2^2 \times 10 \text{ arcsec}^3 = 31 \times (7.6 \times 10^7) \text{ cm}^3 = 1.4 \times 10^{25} \text{ cm}^3. \]

Using the relation, \( EM = n^2 V \) gives \( n = 1.2 \times 10^{12} \) cm\(^{-3} \).

Calculating the density from the multithermal model (multi_therm_pow) is more complicated, as it depends on the ill-defined minimum temperature. The integrated EM from \( T_{min} \) to \( T_{max} \) is given by

\[ EM = \frac{A 2^\alpha}{(\alpha - 1)} \left[ \frac{1}{T_{min}^{\alpha-1}} - \frac{1}{T_{max}^{\alpha-1}} \right] \text{cm}^{-3}. \]

For \( T_{min} = 0.5 \text{ keV} \) and \( T_{max} = 5 \text{ keV} \), \( EM = 1.2 \times 10^{49} \) cm\(^{-3} \), giving a density of \( n = 1.4 \times 10^{12} \) cm\(^{-3} \), similar to the density obtained for the single-temperature case. Increasing \( T_{min} \) to 1 keV decreases the density to \( 3 \times 10^{11} \) cm\(^{-3} \).

With these estimates of the plasma density and source length, we can calculate the energy needed for an electron to reach the footpoints before losing all of its energy to Coulomb collisions. This energy can be calculated from the following relation (Holman et al. 2011, Equation (2.4)) of the evolution of the electron energy \( (E) \) with plasma electron column density \( (N_e) \):

\[ E^2 = E_0^2 - 2KN_e, \]

where \( E_0 \) is the initial electron energy and \( K = 3 \times 10^{-18} \text{ keV}^2 \text{ cm}^2 \), with the Coulomb logarithm equal to 23. We assume that all the electrons are injected at the center of the X-ray source and that the density is the same at all locations within the source so that \( N_e \) is equal to the source density times half the source length. For a single-temperature source, this energy is then 49 keV, while for the multi_therm_pow case, the energy is 57 keV. Thus, in either case, most of the electrons producing the nonthermal X-ray emission would be stopped in the loop before reaching the footpoints, thus explaining why no HXR footpoints were detected. In fact, examination of the AIA 1700 Å images at the time of the HXR impulsive peak does show bright saturated pixels at the purported location of the western footpoint suggesting that a significant flux of accelerated electrons does reach that footpoint, but not enough to be detectable with the RHESSI imaging capability.

Another test of the thick-target coronal loop model is the appearance of the flare in the images of the different AIA channels. The 94, 131, and 193 Å images should show emission from the hot \( \gtrsim 10 \text{ MK} \) plasma with more spatial detail than is possible with RHESSI. The 94 Å images at the time of the HXR peak show bright areas over the two purported ribbons seen in the 1700 Å images. The 131 Å images show saturated pixels at the location of the RHESSI source as expected, but with an extension to the western bright points seen in the 1700 Å images and a weaker extension to the north. The 193 Å images show saturated pixels all along the bright ribbons seen in the 1700 Å images including at the location of...
the RHESSI source, again suggesting that some high-energy electrons do reach the footpoints of the loops.

4. Conclusions

The unusually narrow X-ray source imaged with RHESSI during an impulsive spike lasting for ~10 s during the GOES C7.9 flare on 2011 September 25 (SOL2011-09-25T03:32) was only ~2″ wide and ~10″ long. Comparison with HMI magnetograms and AIA images at 1700 Å shows that the X-ray emission was primarily from a long ribbon in the region of positive polarity with little if any emission from the negative polarity ribbon. It is not clear why the X-ray source is located over this ribbon although it may be that the negative magnetic field was stronger and/or with greater convergence at that location to cause more magnetic mirroring.

The absence of clear double footpoints explains why this event was selected by Guo et al. (2012a, 2012b, 2013) as a coronal hard X-ray flare. Indeed, a thermal plasma source density of ~10^{12} cm^{-3} estimated from the RHESSI-derived EM and source area shows that this could best be interpreted in this way such that electrons accelerated in the corona to

Figure 8. Top: RHESSI measured and fitted count flux spectra summed over the front segments of all detectors except for #2 and #7 for a 4 s interval centered on the peak in the 25–50 keV lightcurve at 03:30:18 UT. The measured count fluxes (shown in black with ±1σ statistical uncertainties) are fitted to the sum (shown in red) of a single-temperature thermal function (vth in green), the bremsstrahlung spectrum from electrons with a power-law distribution (thick2_vnorm in yellow), and the albedo from an assumed isotropic source (in pink). The blue line is the background spectrum estimated from the pre- and post-flare count rates. Bottom: Same as top plot but with the single-temperature thermal function replaced with a differential emission measure (DEM) that is a power-law in temperature with an index of 6.0 between temperatures of 0.5 and 5 keV (multi_therm_pow in green).
energies of less than $\sim 50$ keV would be stopped by Coulomb collisions before reaching the footpoints. However, as pointed out by Dennis et al. (2018), the measured increase in source length used by these authors to determine various parameters of the source region is probably incorrect because it does not take into account the presence of weak footpoints at higher energies and the difficulty associated with determining the source length in a loop viewed from almost directly overhead.

This exceptionally narrow source has afforded the opportunity to test the ability of RHESSI’s finest grids to modulate the incident X-ray flux with the expected amplitude. While such modulation was demonstrated before launch, the fact that very few flares have shown any modulation in the two detectors behind the grids with the finest pitch brought into question the continued alignment of the two finest grid pairs after launch. In retrospect, it is not surprising that most HXR sources are $> a$ few arcseconds in extent because even a point source near disk center at an altitude near the top of the chromosphere ($\sim 3$ Mm or $3''$ above the photosphere) will appear as an extended source with a FWHM of many arcseconds because of the albedo component (Kontar & Jeffrey 2010). Separating the direct source from the albedo component has proved to be very difficult despite the detection by Schmahl & Hurford (2002) of “core–halo” structures with “core” sizes of $\lesssim 6''$ to $14''$ and “halo” sizes of $\sim 40''$.

Another capability afforded by this highly impulsive event is the evaluation of the relative fractions of thermal and nonthermal emission as a function of energy. This is based on the assumption that the impulsive peak lasting for just three RHESSI 4 s rotation periods was from a power-law nonthermal distribution of electrons and the more gradually varying component was from a thermal distribution. With these assumptions, it was possible to show that the spectrum at the time of the impulsive peak was not consistent with either a single or a two-temperature thermal function but was consistent with a power-law DEM as a function of temperature. The thermal and nonthermal components were of equal intensity at a photon energy of 15 keV.

The upper limit on $E_c$ (the low-energy cutoff to the electron spectrum) determined for the power-law DEM model was 22 keV compared to 12 keV for the single-temperature assumption. Since the total energy in electrons scales inversely with $E_c^{2-3}$, this factor of $\sim 1.8$ increase in $E_c$ results in a decrease in the lower limit on the total energy in electrons by an order of magnitude, given that the spectral analysis gives $\delta = 5.8 \pm 0.2$ for any of the three thermal assumptions. A similar result was found by Doschek et al. (2015) in analyzing a different impulsive event. This shows that it is always important to consider a multithermal model in quoting a lower limit to the total energy in electrons, because assuming an isothermal model can result in a order of magnitude error in that estimate. This is pointed out in a recent paper by Aschwanden et al. (2019), who also discuss three other possible models for establishing more accurate values of the low-energy cutoff that are beyond the scope of this paper.

A new method has been suggested by Kontar et al. (2019) for determining the total accelerated electron rate and power using a “physically self-consistent warm-target approach that involves the use of both hard X-ray spectroscopy and imaging data.” They claim that for a flare observed with RHESSI, they can determine not just an upper limit to the low-energy cutoff but also a lower limit so that a value is determined with a $\pm 7\%$ uncertainty at the $3\sigma$ level, an accuracy never previously
claimed. It remains to be seen if this estimate of the uncertainty is realistic and if the multithermal nature of the hot plasma found for the flare studied in this paper can be incorporated into their analysis. They use a single-temperature fit to the RHESSI spectrum in their Figure 2, and although they give a reduced chi-squared value of 1.18, they have used unreasonably large systematic uncertainties on the measured count rates and the residuals show large systematic variations at energies below \(\sim 20\) keV, suggesting that a multithermal model is required.

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Appendix
Comparison of Image Reconstruction Algorithms

This event provides an opportunity to compare the performance of the different RHESSI image reconstruction algorithms when there is clear evidence of significant modulation in the count rates of detectors #1 and #2. The RHESSI imaging concept is described by Hurford et al. (2002) with brief descriptions of the image reconstruction algorithms that were available immediately following the launch of RHESSI in 2002 February. More algorithms are now available in RHESSI software, particularly using visibilities computed from the modulated count rates in each detector. A visibility is defined as a vector representation of the amplitude and phase of the modulation at a given spacecraft roll angle with most instrumental artifacts removed (Hurford et al. 2002).

We have made images of this particular flare using all of the currently available algorithms and evaluated their performance in each case. The following is a discussion of the source dimensions obtained with the different algorithms and the relative quality of the images in terms of the agreement between the measured count rates or visibilities and the predicted values from the reconstructed images. Images were made with each algorithm for the same time interval (03:30:08 to 03:31:12 UT) and energy bin (12–25 keV) using the default settings in each case unless indicated otherwise. The results are summarized in Table 2.

Values of the source intensity and the FWHM width and length obtained with each algorithm are listed in Table 2. The intensity was obtained by simply summing the flux over all 0.5 square pixels in the 129 × 129 array used for each image. An indication of the background flux outside the main source was obtained by summing the flux in pixels with >10% of the peak flux and expressing that as the listed fraction of the total intensity. This fraction gives an indication of the extent of weak fluxes away from the main source region. The image made with VIS_FWDFIT is expected to have the largest such fraction because it is based on the assumption that there is no emission outside of the assumed Gaussian source.

The source width and length were obtained using the IDL procedure HSI_GET_EXTENT.PRO. It computes the standard deviations, $\sigma$, for a source region rotated through 180° in 4° increments and summed over one dimension. Before this procedure was called, all pixels with fluxes less than 10% of the peak flux were zeroed to reduce the effects of small fluxes in the images far from the main source. The minimum and maximum values of the calculated $\sigma$ were converted to FWHM values (FWHM = $2\sqrt{2\ln2 \times \sigma} = 2.35\sigma$) and listed as the source width and length, respectively.

Also listed in Table 2 for each algorithm are two measures of how good the reconstructed images predict the observations. These are the C-statistic relating the measured and predicted modulation count profiles as a function of regularized roll angle (see Figure 4) and the reduced $\chi^2$ values derived from the relation between the measured and predicted visibilities (see Figure 5).

Three images were made using the VIS_FWDFIT image reconstruction algorithm with the assumptions that the source was either a circular or an elliptical Gaussian or a curved loop structure with a Gaussian distribution along and perpendicular to its length. This algorithm is unique in providing the listed statistical ±1σ uncertainties on the source dimensions based on a Monte Carlo analysis using 20 randomly chosen sets of visibilities distributed about the best-fit visibilities according to their statistical uncertainties.

1. VIS_FWDFIT is a visibility-based version of the forward-fitting method described in Hurford et al. (2002). It starts by assuming that there are a number of sources (usually ≤3) in the chosen field of view that can be any combination of circular, elliptical, or curved loop-shaped Gaussians. Some or all of the parameters describing each source (the flux, location, size, and orientation of an elliptical or loop-shaped Gaussian) are adjusted until the model-predicted visibilities agree best with the measured visibilities in a $\chi^2$ sense. This approach offers fast determinations of these source parameters. However, as with any forward-fitting method, it is critical that the assumptions concerning the number of sources and their shapes match reality.

Both an elliptical source and the loop model give excellent fits to all visibility amplitudes and modulation profiles. The values of the source length and width with uncertainties are listed in Table 2. C-statistic and reduced $\chi^2$ values are both in the acceptable range except for the value of 3.54 obtained with the circular Gaussian source assumption. At 2.02 ± 0.25, this algorithm with the loop model gives close to the lowest value for the source width of any of the reconstruction algorithms. The peak fraction is also the highest at 0.86–0.90 because no “noise” is allowed outside the range of the assumed sources.

2. MEM_NJIT is a Maximum Entropy Method (MEM) algorithm based on visibilities that was originally developed at New Jersey Institute of Technology (NJIT). It provides the best fit to the visibility amplitudes especially for the subcollimators with the finest pitch as indicated in Figure 5. This is borne out by the relatively small value of the reduced $\chi^2$ of 1.25. The similarly small value of the C-statistic (1.19) shows the good agreement between the predicted and measured count rates shown in Figure 4. As a result of this close agreement with the visibilities for the finest subcollimators, MEM_NJIT gives the smallest value for the source width of any algorithm. The relatively small value of the peak fraction of 0.46, on the other hand indicates that there is significant low-level emission from locations away from the main source, a contention that is borne out by images at lower energies that show significant emission to the northeast of the main source in agreement with the bright extension at this location seen in AIA images at this time.

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4. https://hesperia.gsfc.nasa.gov/rhessi/software/imaging-software/image-algorithm-summary/index.html

5. https://hesperia.gsfc.nasa.gov/rhessi/software/imaging-software/vis-fwdfit/index.html

6. https://hesperia.gsfc.nasa.gov/rhessi/software/imaging-software/mem-njit/index.html
MEM_GE has recently been added to the RHESSI software. It is similar to MEM_NJIT but more robust against the problem of breakup into multiple compact sources that can occur with MEM_NJIT. As a result, for this particular time interval, it shows less detailed structure than MEM_NJIT with a factor of ∼2 smaller visibility amplitudes for the finer subcollimators leading to a nest source dimension of up to a factor of 2 larger than that obtained with other algorithms. The peak fraction and the C-statistic are comparable to those obtained with MEM_NJIT but the reduced χ² value is higher, commensurate with the poorer reproduction of the visibility amplitudes for the finer subcollimators.

UV_smooth starts with the measured visibilities for the selected detectors. It interpolates these visibilities in the uv plane and reconstructs the image using a fast Fourier transform inversion. Ringing effects are reduced by imposing a positivity constraint (Massone et al. 2009). This algorithm gave poor fits to visibility amplitudes for the coarser grids and poor fits to the average fluxes in each detector. This results in the large value of

| Algorithm            | Flux (ph. cm⁻² s⁻¹) | Width (arcsec) | Length (arcsec) | Peak Fraction | Cash Statistic | Reduced χ² |
|----------------------|---------------------|----------------|-----------------|---------------|---------------|------------|
| VIS_FWDFIT (circle)  | 125 ± 2             | 11.0 ± 0.4     | 11.0 ± 0.4      | 0.90          | 1.9           | 2.08       |
| VIS_FWDFIT (ellipse) | 125 ± 2             | 2.0 ± 0.27     | 15.8 ± 0.44     | 1.6           | 1.77          | 1.46       |
| VIS_FWDFIT (loop)    | 125 ± 2             | 2.0 ± 0.18     | 15.9 ± 0.4      | 1.6           | 1.41          | 1.41       |
| MEM_NJIT             | 150                 | 1.6            | 10.4            | 0.46          | 1.2           | 1.25       |
| MEM_GE               | 146                 | 2.4            | 9.9             | 0.47          | 1.2           | 1.62       |
| UV_Smooth            | 211                 | 4.1            | 10.8            | 0.48          | 5.6           | 5.59       |
| EM                   | 157                 | 2.0            | 9.6             | 0.50          | 2.5           | 1.46       |
| VIS_CS               | 144                 | 5.5            | 12.0            | 0.74          | 1.2           | 2.08       |
| VIS_WV               | 153                 | 5.9            | 12.8            | 0.84          | 1.4           | 2.09       |
| Pixon                | 157                 | 2.3            | 11.7            | 0.54          | 2.5           | 1.51       |
| Clean disable        | 246                 | 11.3           | 17.7            | 0.86          | 3.7           | 2.32       |
| Clean full_resid     | 248                 | 11.2           | 17.6            | 0.86          | 3.5           | 2.29       |
| Clean scaled_resid   | 129                 | 7.1            | 13.3            | 0.87          | 3.6           | 2.29       |
| Clean old_scaled_resid| 144              | 6.2            | 12.2            | 0.89          | 3.8           | 2.64       |
| Clean no_resid       | 130                 | 7.1            | 13.3            | 0.87          | 3.5           | 2.29       |
| Clean media_mode     | 128                 | 7.1            | 13.3            | 0.87          | 3.7           | 2.32       |

#### CBWF = 1.0

| Clean no_resid | 128. | 1.9 | 13.3 | 0.76 | 3.5 | 1.39 |

#### CBWF = 2.0

| Clean no_resid | 130. | 2.9 | 12.4 | 0.71 | 3.5 | 1.60 |

#### Point-source components only (CBWF=10.0)

| Clean no_resid | 128. | 1.9 | 13.3 | 0.76 | 3.5 | 1.39 |

**Note.** The additional values given for the VIS_FWDFIT images with ±1σ uncertainties were obtained from the Monte Carlo analysis incorporated in that procedure. The image obtained using the MEM_NJIT image reconstruction algorithm is shown in Figure 3. The peak fraction is the fraction of the counts remaining after all pixels with fluxes less than 10% of the peak flux were zeroed. See text for descriptions of the two parameters, the C-statistic and the reduced χ², that quantify how well the count rates predicted from the reconstructed images match the measured count rates and the visibilities, respectively. The results using the Clean reconstruction method with different control parameters shown in the bottom half of the table are described in the text.

3. **MEM_GE** has recently been added to the RHESSI software. It is similar to MEM_NJIT but more robust against the problem of breakup into multiple compact sources that can occur with MEM_NJIT. As a result, for this particular time interval, it shows less detailed structure than MEM_NJIT with a factor of ~2 smaller visibility amplitudes for the finer subcollimators leading to a finest source dimension of up to a factor of 2 larger than that obtained with other algorithms. The peak fraction and the C-statistic are comparable to those obtained with MEM_NJIT but the reduced χ² value is higher, commensurate with the poorer reproduction of the visibility amplitudes for the finer subcollimators.

4. **UV_smooth** starts with the measured visibilities for the selected detectors. It interpolates these visibilities in the uv plane and reconstructs the image using a fast Fourier transform inversion. Ringing effects are reduced by imposing a positivity constraint (Massone et al. 2009).

This algorithm gave poor fits to visibility amplitudes for the coarser grids #6–9 and poor fits to the average fluxes in each detector. This results in the large value of

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7 https://hesperia.gsfc.nasa.gov/rhessi/software/imaging-software/mem-ge/index.html

8 https://hesperia.gsfc.nasa.gov/rhessi/software/imaging-software/uv-smooth/index.html

9 https://hesperia.gsfc.nasa.gov/rhessi/software/imaging-software/uv-smooth/uv_smooth-documentation.pdf
the source width that is a factor of two larger than the width obtained by other algorithms. The C-statistic and reduced $\chi^2$ values are also very high.

5. *EM,* the Expectation Maximization algorithm, is based on the Lucy–Richardson Maximum Likelihood method for solving inverse problems (Benvenuto et al. 2013). It gives one of the smallest source widths but the C-statistic is quite large at 2.46. The reduced $\chi^2$ value is in the acceptable range.

6. *VIS_Cs* uses a custom Gaussian basis on the assumption that sources can be represented as linear combinations of a number of Gaussian distributions (Felix et al. 2017). It produced visibility amplitudes in Detectors #1 or #2 that were only $\sim$10% and 30% of the measured amplitudes, respectively, even with the “sparseness” parameter set to zero. Thus, the source width of 5.5 is significantly larger than that found with other algorithms. The C-statistic is one of the lowest values obtained, as this method deliberately minimizes this quantity. This is acceptable providing that there are no sources out of the field of view or that an extended source does not exist with no modulation by the coarsest subcollimators used in reconstructing the image.

7. *VIS_FWDFIT* is a finite Isotropic waVElet transform Compressed Sensing image reconstruction algorithm based on visibilities (Duval-Poo et al. 2018). This algorithm gave poor fits to the visibility amplitudes for subcollimators #1, 2 and 3. As a result it gives the large value of 5.9 for the source width, at least a factor of 2 larger than that obtained by other algorithms. The C-statistic is in the acceptable range but reduced $\chi^2$ is high at 2.09.

8. *Pixon* is an adaptation of the program used to analyze data from Yohkoh/HXT (Metcalf et al. 1996). It aims to produce the simplest model for the image that is consistent with the data. No normalization of the detector sensitivities based on the measured average fluxes was used. This results in a larger value for $\chi^2$ and the C-statistic than would be obtained if this normalization were used but does not significantly change the dimensions of the source in the reconstructed image. Pixon gives a source width of 2.3, close to the smallest value obtained by any algorithm. The peak fraction is surprisingly low, presumably due to significant weak emission away from the main source. This could indicate that the assumption of a single elliptical or loop structure assumed for VIS_FWDFIT is not adequate and may explain the larger values of the reduced $\chi^2$ for that algorithm.

9. *CLEAN* is an iterative algorithm based on the assumption that the image can be well represented by a superposition of multiple point sources (Hurford et al. 2002). We have explored various ways of estimating the source parameters using the basic CLEAN algorithm and give the values obtained in Table 2. The C-statistic and $\chi^2$ values were computed in the same way as for all the other reconstruction techniques. For each case, we used the standard cleaning process in which up to 100 point sources are obtained from the back-projection image. The resulting image is convolved with a Gaussian with a FWHM representative of the combined resolution of subcollimators used in making the image. In addition, a fraction of the residual image remaining of the dirty map after all the point sources and their side lobes have been subtracted can be added back into the final reconstructed image as an indication of the uncertainties involved and the possibility of a more extended source or sources in the image that cannot be well represented by the 100 CLEAN point-source components.

We found that the source width obtained with CLEAN using the standard default settings (listed as the “Clean disable” algorithm in Table 2 was significantly larger than that obtained by other methods—11.7 versus 1.6 obtained with MEM_NJIT. Part of the problem is that the FWHM of the convolving Gaussian is too large. Better agreement with other algorithms can be obtained by dividing the width of the convolving Gaussian by a factor of two using the so-called “clean beamwidth factor” (CBWF) of 2.0. The results listed in Table 2 show that using CBWF = 2.0 gives significantly smaller source widths than using CBWF = 1.0, as expected, but still factors of 2 or 3 larger than the widths given by other algorithms. The values of reduced $\chi^2$ are smaller, reflecting the better agreement with the visibilities of detectors 1 and 2 but the flux and C-statistic values remain unchanged.

Following Dennis & Pernak (2009), we used an alternative method of determining source dimensions by considering the location and intensity of the point sources alone. This is most easily achieved by using CBWF = 10. The resulting source dimensions are listed in the last line of Table 2. This method gives a significantly smaller value of the source width (1.9 versus 11.7 using the default settings) that is similar to the values of 2.02 ± 0.18 and 1.6 obtained with VIS_FWDFIT and MEM_NJIT, respectively. Much improved values of the reduced $\chi^2$ were also obtained (1.39 versus 2.34). The source flux (307 photons cm$^{-2}$ s$^{-1}$) and C-statistic (3.6) were the same, because the same regression coefficient was used to normalize the expected and measured counts.

Several techniques (see below for details of each one) have been devised and are available in the RHES~ image software to ensure that the final reconstructed image predicts detector count rates that agree with the measured rates as closely as possible. The different methods are listed for handling the residuals remaining in the back-projection “dirty” map after the 100 point-source components and their side lobes are removed. The simplest approach, the so-called “media_mode,” is to not add the residuals to the final image at all.

These methods for producing the final image are controlled in the software by the clean_regress_combine parameter, which has the following five choices (prior to 2018 April, it was an on/off switch):

\[10 \text{https://hesperia.gsfc.nasa.gov/rhessi/software/imaging-software/em/index.html}\]
\[11 \text{https://hesperia.gsfc.nasa.gov/rhessi/software/imaging-software/vis-cs/index.html}\]
\[12 \text{https://hesperia.gsfc.nasa.gov/rhessi/software/imaging-software/vis-wv/index.html}\]
\[13 \text{https://hesperia.gsfc.nasa.gov/rhessi/software/imaging-software/pixon/index.html}\]
\[14 \text{https://hesperia.gsfc.nasa.gov/rhessi/software/imaging-software/clean/index.html}\]
(a) disable—no regression, residual map added to component map or not, according to media mode setting (this is the default);
(b) full_resid—regression of the component map expected counts against the observed. Scale the component map by the regression coefficient and add the unscaled residual map;
(c) scaled_resid—First do the steps for “full_resid” but then take the counts minus the scaled expected counts and regress that against the expected counts from the residual map. Form the new map from the scattered component map added to the newly scaled residual map;
(d) old_scaled_resid—Only method available prior to 2018 April. Regression on the expected counts from the component and residual maps;
(e) no_resid—Perform the regression of “full_resid,” scale the component map by the regression coefficient and do not add any of the residual map. This has the same effect as the so-called “media mode” with the component map scaled to match the measured count rates.

In the preferred methods (full_resid or no_resid), the predicted counts from the component map are regressed against the observed counts and then scaled by the regression coefficient. In the full_resid option, the unscaled residual map is added to the new component map but this gives a higher source flux than the other algorithms if integrated over the whole image. Better agreement is obtained by not including the residuals in estimating the source flux as in the “no_resid” or “media_mode” options.

In all cases, except when no residuals are included in the image, negative values appear in pixels away from the main source. In those cases, the listed source flux and peak fraction values were calculated using only the positive values.

In conclusion, it appears that the “best” values for the parameters for the 12–25 keV source as determined using HSI_GET_EXTENT are a source width between 1/6 (MEM_NJIT) and 2/3 (MEM_GE) and a length between 9.6 (EM) and 14/1 (VIS_FWDFIT loop). This is in agreement with the values and uncertainties for the loop width obtained directly with VIS_FWDFIT (2.02 ± 0.25) but not with the loop length (15.9 ± 0.48). This is presumably because of the different assumptions used in the two cases.

Based on these results, we can provide advice on which reconstruction algorithms are most able to accurately characterize this particular source and presumably most images that show fine structure with significant visibility amplitudes in RHESSI’s finest subcollimators. VIS_FWDFIT gives accurate source parameters with uncertainties provided that the assumptions concerning the number and shapes of the sources are correct and complete. Other algorithms such as MEM_NJIT, CLEAN, and Pixon can be used to check on those assumptions. It would seem that UV_SMOOTH, VIS_CS, and VIS_WV are not optimized for images with such fine structure. CLEAN is a special case in that it can give the finest source dimensions comparable to those obtained with VISFWDFIT and MEM_NJIT but only if the point-source components are used without convolving them with a Gaussian or adding the residuals left over from the back-projection dirty map.

**ORCID iDs**

Brian. R Dennis @ https://orcid.org/0000-0001-8585-2349

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