FIRST DETECTION OF >100 MeV GAMMA-RAYS ASSOCIATED WITH A BEHIND-THE-LIMB SOLAR FLARE

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ABSTRACT

We report the first detection of >100 MeV gamma-rays associated with a behind-the-limb solar flare, which presents a unique opportunity to probe the underlying physics of high-energy flare emission and particle acceleration. On 2013 October 11 a GOES M1.5 class solar flare occurred ~9:9 behind the solar limb as observed by STEREO-B. RHESSI observed hard X-ray (HXR) emission above the limb, most likely from the flare loop-top, as the footpoints were occulted. Surprisingly, the Fermi Large Area Telescope (LAT) detected >100 MeV gamma-rays for ~30 minutes with energies up to 3 GeV. The LAT emission centroid is consistent with the RHESSI HXR source, but its uncertainty does not constrain the source to be located there. The gamma-ray spectra can be adequately described by bremsstrahlung radiation from relativistic electrons having a relatively hard power-law (PL) spectrum with a high-energy exponential cutoff, or by the decay of pions produced by accelerated protons and ions with an isotropic pitch-angle distribution and a PL spectrum with a number index of ~3.8. We show that high optical depths rule out the gamma-rays originating from the flare site and a high-corona trap model requires very unusual conditions, so a scenario in which some of the particles accelerated by the CME shock travel to the visible side of the Sun to produce the observed gamma-rays may be at work.

Key words: Sun: flares – Sun: X-rays, gamma rays

1. INTRODUCTION

During its first six years in orbit, the Fermi Large Area Telescope (LAT; Atwood et al. 2009) has detected >30 MeV gamma-ray emission from more than 40 solar flares, nearly 10 times more than EGRET (Thompson et al. 1993) on board the Compton Gamma-ray Observatory (Forrest et al. 1985) on board the Solar Maximum Mission (SMM) and CORONAS-F (Kuznetsov et al. 2011). The Fermi detections sample both the impulsive (Ackermann et al. 2012a) and the long-duration phases (Ackermann et al. 2014) including the longest extended emission ever detected (~20 hr) from the SOL2012-03-07 GOES X-class flares (Ajello et al. 2014).

Our understanding of solar flares has also been shaped by decades of hard X-ray (HXR) observations, notably by the detection of conjugate footpoint sources by SMM (Hoyng et al. 1981), coronal sources above soft X-ray loops by Yokoh (e.g., Masuda et al. 1994; Petrosian et al. 2002), and double coronal sources suggestive of magnetic reconnection in between by RHESSI (e.g., Sui & Holman 2003; Liu et al. 2008, 2013). These and many other observations support the standard flare model involving magnetic reconnection and associated particle acceleration in the corona (for reviews, see, e.g., Holman et al. 2011). There are alternatively proposed scenarios, including (re-)acceleration of particles in the chromosphere (e.g., Fletcher & Hudson 2008; Haerendel 2012), supported by, e.g., Martínez Oliveros et al. (2012).

Of particular interest are those flares whose footpoints are occulted by the solar limb, allowing coronal emission to be imaged in greater detail than in normal situations dominated by bright footpoints (e.g., Krucker et al. 2007; Krucker & Lin 2008).

In this Letter, we present Fermi and RHESSI observations of such a flare whose position was confirmed to be behind the limb by STEREO-B. While gamma-ray emission up to tens of MeV resulting from proton interactions has been detected before from occulted solar flares (e.g., Vestrand & Forrest 1993; Barat et al. 1994; Vilmer et al. 1999), the significance of this particular event lies in the fact that this is the first detection of >100 MeV gamma-ray emission from a footpoint-occulted flare and presents a unique opportunity to diagnose the mechanisms of high-energy emission and particle acceleration in solar flares.

2. OBSERVATIONS AND DATA ANALYSIS

2.1. Observational Overview

On 2013 October 11 at 07:01 UT a GOES M1.5 class flare occurred with soft X-ray emission lasting 44 minutes and peaking at 07:25:00 UT. Figure 1 shows the GOES, STEREO-B, RHESSI, Fermi Gamma-ray Burst Monitor (GBM; Meegan et al. 2009), and LAT light curves of this flare. The LAT detected >100 MeV emission for ~30 minutes with the maximum of the flux occurring between 07:20:00 and 07:25:00 UT. RHESSI coverage was from 07:08:00 to 07:16:40 UT, overlapping with Fermi for 9 minutes.

Images in Figure 2 from the STEREO-B Extreme-ultra Violet Imager (Wuelser et al. 2004) and the SDO Atmospheric Imaging Assembly (AIA; Lemen et al. 2012) of the photosphere indicate that the active region (AR) was ~9:9 behind the limb at the time of the flare. LASCO on board the Solar and Heliospheric Observatory (SOHO) observed a backsides asymmetric-halo CME associated with this flare beginning at 07:24:10 UT with a linear speed of 1200 km s$^{-1}$ (SOHO LASCO CME CATALOG 2013) and a bright front over the northeast. Both STEREO spacecraft detected energetic electrons, protons, and heavier ions including helium, as well as type-II radio bursts indicating the presence of a coronal–heliospheric shock. STEREO-B had an unblocked view of the entire flare and detected a maximum rate of
$3.5 \times 10^6$ photons s$^{-1}$ in its 195 Å channel, corresponding to a GOES M4.9 class (Nitta et al. 2013) if it had not been occulted.

### 2.2. Data Analysis

We performed an unbinned likelihood analysis of the LAT data with the *gtlike* program distributed with the *Fermi ScienceTools* For RHESSI data, we applied the CLEAN imaging algorithm (Hurford et al. 2002) using detectors 3–9 to reconstruct the X-ray images. We used the FITS World Coordinate System software package (Thompson & Wei 2010) to co-register the flare location between STEREO and SDO images. The STEREO light curves are pre-flare background subtracted, full-Sun integrated photon rates.

### 2.3. Localization of the Emission

We measure the location of the LAT >100 MeV gamma-ray emission (as described in Ajello et al. 2014) and find a best-fit position for the emission centroid at heliocentric coordinates of ($-850',70''$) with a 68% error radius of 250'', as shown in Figure 2(b). RHESSI X-ray sources integrated over

$7.01 \pm 0.60$ UT. The vertical dashed line represents flare start time (7:01 UT).

![Figure 1. Light curves of the 2013 October 11 flare as detected by (a) GOES, (b) STEREO, (c) RHESSI, (d) GBM, (e) LAT, and heights of the RHESSI emission centroid (f) with the same color coding as in (c). *Fermi* exited the South Atlantic Anomaly (SAA) at 06:57:00 UT. The vertical dashed line represents flare start time (7:01 UT).](image)

07:11:04–07:16:44 UT are shown as 80%-level, off-limb contours in Figure 2(d). The temporal evolution of the projected RHESSI source heights above the solar limb are shown in Figure 1(f). The higher-energy emission generally comes from greater heights, consistent with expectations for a loop-top source (e.g., Sui & Holman 2003; Liu et al. 2004). Moreover, from SDO/AIA movies we find no signature of EUV ribbons, even in the late phase during the RHESSI night. Together, these observations provide convincing evidence that the footpoints were indeed occulted.

The LAT measured four photons with energies >1 GeV and reconstructed direction less than 1° from the center of the solar disk. All, including a 3 GeV photon, arrived after 7:19:00 UT (outside of the RHESSI coverage).

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3 We used version 09-30-01 available from the *Fermi* Science Support Center [http://fermi.gsfc.nasa.gov/ssc/](http://fermi.gsfc.nasa.gov/ssc/). We selected *P7REP_SOURCE_V15* photon events from a 12° circular region centered on the Sun and within 100° from the local zenith (to reduce contamination from the Earth’s limb).
2.4. Spectral Analysis

We fit the LAT gamma-ray spectral data with three models. The first two, a pure power law (PL) and a PL with an exponential cut-off (PLEXP) are phenomenological functions that may describe bremsstrahlung emission from accelerated electrons. The third model uses templates based on a detailed study of the gamma-rays produced from pion decay (updated from Murphy et al. 1987).

We rely on the likelihood ratio test (TS; Mattox et al. 1996) to estimate the significance of the source (TS_{PL}) as well as to estimate whether the addition of the exponential cut-off is statistically significant. To this end we define $\Delta TS = TS_{\text{PLEXP}} - TS_{\text{PL}}$, which is equivalent to the corresponding difference of maximum likelihoods computed between the two models. The significance in $\sigma$ can be roughly approximated as $\sqrt{TS}$.

For each interval where PLEXP provides a significantly better fit than PL ($\Delta TS > 20$) we also fit the data with a series of pion-decay models to determine the best proton spectral index following the same procedure described in Ajello et al. (2014). The TS values for PLEXP and pion-decay fits cannot be directly compared (Wilks 1938); however, the PLEXP approximates the shape of the pion-decay spectrum (see Figure 3), thus we expect the pion-decay models to provide a similarly acceptable fit. We studied the effect of the LAT systematic uncertainties (mainly from the effective area, as considered here) via the bracketing technique described in Ackermann et al. (2012b).

The RHESSI and GBM NaI spectral data are independently fitted with one or two thermal components plus a broken PL with an index fixed to 2 (to avoid energy divergence) below the break. Table 1 summarizes the spectral analysis results. Data from BGO$_0$ are analyzed using the procedure described in Fitzpatrick et al. (2012) with an additional 5% systematic error on the background estimation. Figure 3 shows the combined spectra from RHESSI, GBM, and LAT in four integration intervals. The discrepancy (up to a factor of 2.5) between the RHESSI and GBM flux values is likely due to pile-up in the RHESSI detector, and cannot be easily corrected. As is evident from Figure 3, more energy is radiated in HXR than gamma-rays.

3. DISCUSSION

We have analyzed the data of the 2013 October 11 solar flare from Fermi, RHESSI, SDO, and STEREO. STEREO-B images indicate that the flare occurred in an AR 9°9 behind the limb. RHESSI and GBM NaI detected HXRs up to 50 keV from the flaring loop-top. The most unusual aspect of this flare is the LAT detection of photons of energies $\epsilon > 100$ MeV for about 30 minutes with some photons having energies up to 3 GeV. Electrons or protons with energies $E > \epsilon$ can produce these photons after traversing a column depth of matter $N(E) > 10^{25}$ and $10^{26}$ cm$^{-2}$, respectively, which is much larger than the depth $\sim 10^{20}$ cm$^{-2}$ penetrated by HXR-producing electrons. For occulted flares the emitted photons must traverse even larger depths where they may be scattered and absorbed. We consider three scenarios for the emission site of the gamma-rays: (i) deep below the photosphere of the flare site; (ii) in the corona above the limb, suggestive of trapping of particles, e.g., by strongly converging magnetic fields; and (iii) CME-shock accelerated particles traveling back to the Sun.

3.1. Emission Below the Photosphere

For the first scenario we need continuous acceleration of particles because they penetrate deep into the solar atmosphere and lose energy in a fraction of a second. Most of the radiation they produce also comes from deep within the photosphere so we need to calculate the optical depth, $\tau(\epsilon) = \sigma N(\epsilon)$ from the emission site to the Earth. For $\epsilon > 100$ MeV photons the main absorption is via pair production with a cross section $\sigma_{\text{pp}} \sim 0.035 \times \sigma_0$, where $\sigma_0$ is the Thomson scattering cross...
The Astrophysical Journal, Letters, 805:L15 (6pp), 2015 June 1

Table 1

Spectral Analysis of LAT, GBM, and RHESSI Data

| LAT Time Intervals | Time Interval (2013/10/11 UT) | TSPL | ΔTS\(^a\) | Photon Index | Cutoff Energy\(^b\) (MeV) | Proton Index | Flux\(^c\) (10\(^{-2}\) ph cm\(^{-2}\) s\(^{-1}\)) |
|-------------------|--------------------------------|------|----------|--------------|-----------------|-------------|----------------|
| 07:10:00-07:15:00 | 16                             | 5    | 1.80 ± 0.35\(^{+0.024}_{-0.020}\) | ...           | ...             | 0.60 ± 0.26\(^{+0.05}_{-0.04}\) |
| 07:15:00-07:20:00 | 987                            | 22   | 0.21 ± 0.24\(^{+0.16}_{-0.14}\) | 145 ± 27\(^{+9}_{-8}\) | 3.7 ± 0.2 ± 0.1 | 24.1 ± 1.5\(^{+1}_{-1}\) |
| 07:20:00-07:25:00 | 1146                           | 92   | 0.23 ± 0.27\(^{+0.11}_{-0.10}\) | 162 ± 26\(^{+7}_{-6}\) | 3.5 ± 0.2 ± 0.1 | 28.2 ± 1.7\(^{+1}_{-1}\) |
| 07:25:00-07:30:00 | 435                            | 45   | -0.42 ± 0.58\(^{+0.15}_{-0.15}\) | 95 ± 21\(^{+4}_{-3}\) | 4.3 ± 0.4 ± 0.1 | 13.7 ± 1.3\(^{+0.8}_{-0.7}\) |
| 07:30:00-07:35:00 | 55                             | 4    | 2.36 ± 0.24\(^{+0.09}_{-0.09}\) | ...           | ...             | 4.1 ± 1.1\(^{+0.4}_{-0.3}\) |
| 07:08:00-07:35:00 | 2885                           | 233  | 0.2 ± 0.2\(^{+0.15}_{-0.13}\) | 147 ± 15\(^{+1}_{-0}\) | 3.7 ± 0.2\(^{+0.1}_{-0}\) | 14.2 ± 0.5\(^{+0.9}_{-0.8}\) |
| 07:16:40-07:35:00 | 2855                           | 204  | 0.4 ± 0.2\(^{+0.14}_{-0.128}\) | 155 ± 16\(^{+1}_{-0}\) | 3.8 ± 0.2\(^{+0.1}_{-0}\) | 22.1 ± 0.8\(^{+1}_{-0.8}\) |

| RHESSI and GBM Time Intervals | Broken Power Law | 1st Thermal Component | 2nd Thermal Component |
|-------------------------------|------------------|-----------------------|-----------------------|
|                               | E\(^{\text{break}}\) (keV) | Index | Plasma Temperature (keV) | Plasma Temperature (keV) | Flux\(^c\) (ph cm\(^{-2}\) s\(^{-1}\)) |
| 07:08:00-07:10:58\(^a\)       | 17.9 ± 0.5       | 3.76 ± 0.04            | 2.23 ± 0.06            | ...                     | 52 ± 1 |
| 07:08:00-07:10:58\(^a\)       | 17.9 ± 0.9       | 3.88 ± 0.03            | 1.9 ± 0.1             | ...                     | 55 ± 1 |
| 07:11:10-07:16:40\(^b\)       | 16 ± 2           | 4.24 ± 0.07            | 1.92 ± 0.02            | 0.62 ± 0.03             | 253 ± 5 |
| 07:11:10-07:16:40\(^b\)       | 21 ± 5           | 3.52 ± 0.05            | 2.9 ± 0.04             | 1.54 ± 0.16             | 630 ± 10 |
| 07:16:40-07:35:00             | 20 (fixed)       | 2.56 ± 0.06            | 2.71 ± 0.07            | 1.27 ± 0.04             | 399 ± 8 |
| 07:08:00-07:35:00             | 20 ± 8           | 3.22 ± 0.05            | 2.8 ± 0.02             | 1.34 ± 0.08             | 388 ± 8 |

Notes: Intervals (a) and (b) of Figure 3 excluded due to lack of statistics. Statistical errors are shown first and systematic errors follow.

\(^a\) ΔTS = TS\(_{\text{PLEXP}}\)−TS\(_{\text{PL}}\)

\(^b\) From the fit with PLEXP model.

\(^c\) Integrated flux between 100 MeV and 10 GeV calculated for the best-fit model.

\(^d\) Photon index from the fit with PL.

\(^e\) Integrated flux between 10 and 100 keV calculated for the best-fit model.

\(^f\) RHESSI spectral fit results. At 07:10:59 UT RHESSI changed its attenuator.

For non-relativistic electrons and protons the Coulomb collision dominates, and for both particles we have

\[ N(E) = N_0 \frac{\mu m_e}{m_p} \left(\frac{E}{m_e c^2}\right)^2 / \gamma. \]  

(3)

The energy dependence of the proton loss rate is similar to that of electrons. The Coulomb losses dominate at low energies, but for proton energies \(E > 0.3\) GeV pion production becomes significant, and at \(E > 4.5\) GeV (\(\gamma \gtrsim 4\)) it becomes the dominant loss mechanism, and like electron bremsstrahlung, it gives

\[ dE/d\ell \propto \gamma \ln \gamma. \]

Making the same approximation as above we get the same equations, (1) and (2), but now with \(N_0 = 6 \times 10^{25} \text{ cm}^{-2}\) and \(\gamma_0 = 4.0\) (for \(\ln \Lambda = 30\)).

An electron of energy \(E\) radiates photons of energy \(\epsilon = E/\eta < E\) with \(\eta \sim 2\). Similarly, assuming that protons of energy \(E\) produce a \(\pi^0\) with similar energy that decays into two photons of equal energies we can again set \(\eta \sim 2\) (the exact value of \(\eta\) will not change our conclusions drastically). For relativistic electrons the radiated photons will be beamed along the pitch angle of the electrons. As shown by McTiernan & Petrosian (1990) there will be strong center-to-limb variation of gamma-ray flux, but for flares at a few degrees behind the limb this effect can be ignored.

For a flare at the center of the solar disk (helio-longitude \(\phi = 0\), or angle to the limb \(\theta \equiv \pi/2 - \phi = \pi/2\)), the optical depth is \(\tau(\epsilon) = N(E) \epsilon \sigma\) and increases toward the limb at a rate that depends on the ambient density profile; \(N_\gamma(\epsilon, \theta) = \int_0^\infty n(r) dr\), where \(r = \sqrt{R^2 + 2RI \sin \theta + I^2}\).
and \( R \) is the distance from the center of the Sun at the depth of emission \( N(E) \). The photons of interest here are produced below the photosphere at column densities \( N > 10^{23} \text{ cm}^{-2} \) and densities \( n > 10^{17} \text{ cm}^{-3} \), where both quantities increase exponentially with a scale height \( H \ll R_{\odot} \). Consequently, most of the contribution comes from within a scale height at a radius \( R \sim R_{\odot} \) corresponding to the column depth \( N(\eta e) \) described above. If we define \( \Delta = \frac{R}{H} \) and \( d\lambda = dR/R \), we get

\[
N_\eta(\epsilon, \theta) = N(\eta e) A e^\Delta \int_0^\infty e^{-\lambda(1+\lambda \sin \theta+\lambda^2/2)} d\lambda.
\]

(4)

For occulted flares \( \theta < 0 \). Since \( \Delta \gg 1 \) most of the contribution to this integral comes from very small \( \lambda \) so we can use the approximation \( \sqrt{1+2\lambda \sin \theta + \lambda^2} \approx (1 + \lambda \sin \theta + \lambda^2 \cos^2 \theta)/2 \). This gives

\[
N_\eta(\epsilon, \pm 0) = N(\eta e) \sqrt{\pi A/2} e^{\epsilon^2} \left[ 1 \mp \text{erf}(\sqrt{\epsilon}) \right].
\]

(5)

where \( \xi \equiv A \tan^2(\theta/2) \). Thus, we get \( N_\eta(\epsilon, \pi/2) = N(\eta e) \) and \( N_\eta(\epsilon, 0) = N(\eta e) \sqrt{\pi A/2} \) for flares at the center and limb of the Sun. However, we are interested in behind-the-limb flares with \( |\theta| \ll 1 \) so that \( \xi \approx \theta^2 A/2 = 0.1(\theta^2)^2 (10^3 \text{ km/H}) \). For angles \( |\theta| > 3^\circ \) the error functions \( \text{erf}(\sqrt{\xi}) \approx 1 \) and

\[
N_\eta(\epsilon, -\theta) = 2 N(\eta e) \sqrt{\pi A/2} e^{\epsilon^2}.
\]

We can use these expressions to calculate the optical depth.

Let us consider HXRs emitted by nonrelativistic electrons. For a 50 keV photon emitted by a \( \mu = 0.5 \) and \( E = 100 \text{ keV} \) electron (and using the Thomson cross section) we find \( \tau(50 \text{ keV}, \theta = \pi/2) < 10^{-3} \) at the center of the disk, \( \tau(50 \text{ keV}, \theta = 0) \approx 0.02 \) at the limb, and a rapid increase as \( e^{0.1\epsilon^2} = 1.2 \) for a behind-the-limb flare. At \( \theta = -10^\circ \) and \( H = 1000 \text{ km}, \) the optical depth is \( 10^3 \).

For gamma-rays the optical depth is considerably larger because they are emitted deeper in the photosphere. For a flare near the center of the solar disk the optical depth for a 100 MeV photon, emitted either by a \( \sim 200 \text{ MeV} \) electron or \( >350 \text{ MeV} \) proton, is about 0.2 and 0.1, respectively. But for a flare at the limb these values increase by \( \sqrt{\pi A/2} = 33 \times (10^3 \text{ km/H})^{1/2} \). For reasonable average pitch angles \( \bar{\theta} > 0.1 \) and even if we include the effects of non-radial field lines this could give \( \tau > 1 \).

Once the flare source region moves behind the limb, the optical depth increases exponentially as \( e^\epsilon \) or \( e^{0.1\epsilon^2} \) making the detection of any flare for \( |\theta| > 2^\circ \) impossible. This is also true for the 1–10 MeV BGO photons even though the protons producing them do not penetrate as deeply. Considering that the flare occurred at \( \sim 10^9 \) behind the limb, we conclude that this scenario is untenable.

### 3.2. Emission in the Corona

The key feature of this behind-the-limb flare is the detection of \( >100 \text{ MeV} \) emission for \( \sim 30 \) minutes. To explain this observation, we also consider the scenario where the photons are produced in the corona by high-energy particles injected promptly into a magnetic trap (e.g., Aschwanden et al. 1997) at \( >10^9 \text{ cm} \) (minimum height needed for a source \( \sim 10^9 \) behind the limb to be visible above the limb) above the transition region. For particles to be trapped efficiently we need sufficiently strong field convergence to trap most particles and a low level of turbulence so that the scattering time would be much longer than the energy loss time. Otherwise most of the particles will be scattered into the loss cone and radiate deep in the solar atmosphere as in scenario 3.1.

Let us first consider protons with an energy loss rate given by Equation (1) with \( \delta = 1, \, N_0 = 6 \times 10^{25} \text{ cm}^{-2} \) and \( \gamma_5 = 4.0 \). This gives an energy loss time for a 1 GeV proton of \( t_0 \sim 2 \times 10^{15} \text{ s} \cdot \text{cm}^{-3}/n \) so for the observed duration of \( <2000 \text{ s} \) we need a density \( n > 10^{12} \text{ cm}^{-3} \), which is what one encounters below the occulted transition region and not at \( >10^9 \text{ cm} \) above it. The energy loss rate for electrons in the coronal region is dominated by Coulomb collisions at low energies and synchrotron losses for magnetic fields \( B > 10 \text{ G} \) or inverse Compton losses at lower fields. This rate is again described by Equation (1) but with \( \delta = 2, \, N_0 = 5 \times 10^{22} \text{ cm}^{-2} \) and \( \gamma_5 = 21.5 \times (n/10^{10} \text{ cm}^{-3})^{1/2} \times (B/100 \text{ G})^{-1} \).

As shown in Petrosian (2001), this gives rise to flat spectra at low energies and a sharp cutoff at \( \gamma \sim \gamma_5 \) with these electrons carrying most of the energy with the longest lifetime of \( t_0 \sim \gamma_5\pi/2(\Delta n) \). For the production of \( >100 \text{ MeV} \) protons we need electrons with \( \gamma_5 \sim 300 \) so that for a lifetime of 30 minutes we need \( n > 10^{11} \text{ cm}^{-3} \) and \( B \sim 25 \text{ G} \). While these values for the density (magnetic field) are somewhat higher (lower) than the ones found at \( 10^9 \text{ cm} \) above the transition region, they cannot be fully ruled out. Also, a photon index \( \Gamma \sim 0 \) requires injected electrons with spectral index \( \sim 1 \) (for a thin target case), which is much higher than those encountered at lower energies. Thus, this model requires strong convergence, low turbulence and hard spectra. In view of the LAT detection of SOL2014-09-01 flare with \( \gamma \sim 36^\circ \) (paper in preparation) that requires a trap at a height \( >10^{10} \text{ cm} \), this model becomes less plausible.

### 3.3. Acceleration in CME Shocks

A third possibility is that particles accelerated by a shock associated with this flare originating behind the limb find their way to the photosphere visible to Fermi where they produce gamma-rays. This requires a magnetic connection between the acceleration site and the visible photosphere, e.g., large overlying loops. Such a connection must have been absent during the impulsive phase and for HXR-producing electrons that are most likely accelerated in smaller loops with both footpoints occulted. Otherwise we would expect a detection of HXRs from the footpoints on the visible side. Furthermore, the LAT emission error circle allows for the gamma-ray emission to occur on the visible side of the disk. This also means that the extended-phase gamma-ray producing particles were not accelerated in small loops and, like longer lasting SEPs, most likely were accelerated in the shock of the CME. Since the magnetic lines draping the CME are most likely connected to the occulted AR, this requires cross-field diffusion that allows migration of particles from the field lines connected to the AR to those connected to the visible disk. The presence of a strong and short scale turbulence capable of scattering the accelerated particles with a mean free path comparable to their gyro radii will facilitate this migration (Zhang et al. 2003). A longer trapping time of accelerated particles in the downstream region, say, e.g., by converging field lines rooted at the Sun, can also help this migration. This model requires further study.

In conclusion, the multiwavelength observations of this behind-the-limb flare have provided some interesting
theoretical puzzles which can be resolved by more detailed investigation of the scenarios discussed above.

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