Gamma Radiation From Flare-Accelerated Particles Impacting the Sun

Gerald H. Share[1]

Department of Astronomy, University of Maryland, College Park, MD 20742

Ronald J. Murphy

E.O. Hulburt Center for Space Research, Naval Research Laboratory Washington, DC 20375

We discuss how remote observations of gamma-ray lines and continua provide information on the population of electrons and ions that are accelerated in solar flares. The radiation from these interactions also provides information on the composition of the flaring chromosphere. We focus our discussion on recent *RHESSI* observations and archival observations made by *SMM* and *Yohkoh*.

1. INTRODUCTION

Eruptive solar events such as flares and shocks from coronal mass ejections (CMEs) accelerate electrons and ions to high energies. The solar energetic particles (SEPs) that reach interplanetary space have origins in both flares and CMEs (e.g. *Reames*, 1999) and there is debate over their relative importance (e.g. *Cane et al.*, 2003; *Tylka et al.*, 2005; *Li and Zank*, 2005). Timing (e.g. *Tylka et al.*, 2003) and composition studies support the idea that flares are primarily responsible for the 'impulsive' electron and ^{3}He-rich particle events in space and also contribute a seed population (*Mason, Mazur, and Dwyer*, 1999) for 'gradual' events that have their origin in CME-produced shocks. The processes that impulsively accelerate particles into interplanetary space along open magnetic field lines may also generate the ions and electrons along closed loops that interact in the chromosphere and photosphere.

In Figure 1 we show a cartoon depicting injection of accelerated particles (e.g. *Miller et al.*, 1997; *Aschwanden*, 2004) onto a closed magnetic loop, their transport, and their impact on the solar atmosphere. Calculations of the gamma-rays and neutrons resulting from these interactions have generally assumed that they take place in a thick target atmosphere (e.g. *Ramaty et al.*, 1996) having photospheric or coronal compositions (e.g. *Anders and Grevesse*, 1989; *Reames*, 1995); however, there was one flare in which the emission was believed to arise in a thin target (*Ramaty et al.*, 1997). The resulting continuum and line γ radiation provides a means to remotely measure the characteristics of these trapped particles and relate them to the particles that escape from the same acceleration site at the Sun on open field lines. The flares of 2003 October 28 and November 2, and 2005 January 20 offer the best opportunity for making simultaneous measurements of these two particle populations. Other papers in this monograph will discuss the particles measured in space. In this paper we discuss the relationship between the >100 keV photon emissions and both the accelerated particles and the solar material in which they interact. We summarize some preliminary results derived from new *RHESSI* and archival *SMM* and *Yohkoh* observations.

2. WHAT PRODUCTS OF PARTICLE INTERACTIONS TELL US ABOUT FLARE-ACCELERATED ELECTRONS AND IONS

In this Section we briefly discuss the products of flare-accelerated electrons and ions that impact the Sun (Figure 1). Electrons produce a bremsstrahlung continuum that reflects their spectrum. For example an electron spectrum following

[1]Also at Naval Research Laboratory, Washington, DC 20375

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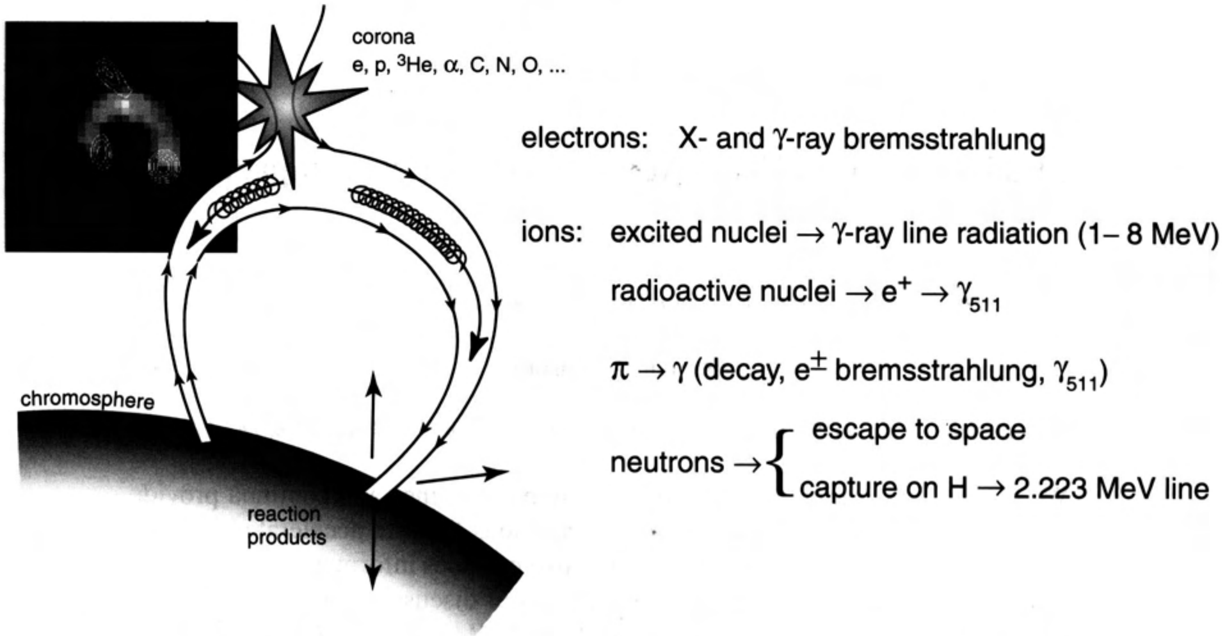

Figure 1. Cartoon showing particle acceleration, magnetic loop transport, interaction in the solar atmosphere, and interaction products. *Yohkoh* image of limb flare is shown in upper left corner (*Masuda et al.*, 1994).

a power-law in energy with index β produces a photon spectrum with index $\sim\beta - 1$ from 0.3-1.0 MeV (*Ramaty et al.*, 1993). Protons and α-particles interact with ambient solar nuclei to produce neutrons, γ-ray lines from transitions of excited nuclei to lower-energy states, positrons from radioactive nuclei (*Ramaty, Kozlovsky, and Lingenfelter*, 1979), and other forms of radiation. If the incident particles have energies above a few hundred MeV/nucleon, π mesons are produced that decay with emission of electrons, positrons, neutrinos and γ rays (*Murphy, Dermer, and Ramaty*, 1987). The neutrons can escape from the Sun and be detected at Earth before they decay (e.g. *Chupp et al.*, 1982), decay at the Sun, or be captured on H or ^{3}He; capture on H in a quiet photosphere produces ^{2}H with emission of a 2.223-MeV γ-ray having a width expected to be $\lesssim 1$ eV, while capture on ^{3}He produces no γ radiation (*Hua and Lingenfelter*, 1987).

The γ-ray lines from ambient nuclei excited by interaction of accelerated protons and α particles are Doppler broadened by nuclear recoil (*Ramaty, Kozlovsky, and Lingenfelter*, 1979; *Kiener, de Séréville, and Tatischeff*, 2001). The shape of the lines is dependent on the angular distribution, spectrum, and assumed α/p ratio of the accelerated particles and the viewing angle of the observer. The width of the line can be characterized by its full-width at half maximum (FWHM) although the shape is not always Gaussian. Alpha-particle interactions produce broader lines than do protons with the same energy/nucleon. The FWHM width of the 4.439 MeV line from de-excitation of ^{12}C is typically ~100 keV. Much larger Doppler widths result from interactions of accelerated heavy ions when they de-excite after interacting with ambient H or He; e.g. the width of the ^{12}C line is ~1 MeV FWHM. Positrons produced in radioactive decays, following the interactions, annihilate with electrons to produce a line at 511 keV having a width of a few keV and a continuum below that energy.

In Figure 2 we plot the γ-ray spectrum observed from 200 keV to 8.5 MeV by *RHESSI* during the decay phase of the 2003 October 28 flare. Earlier observations by *CORONAS-F* (*Veselovsky et al.*, 2004; *Kuznetsov et al.*, 2005) and by *INTEGRAL* (*Gros et al.*, 2004) revealed an ~1-min interval dominated by electron bremsstrahlung up to ~40 MeV followed by an ~3-min interval in which strong nuclear emission was observed. The spectrum in the Figure reveals all the different components described above. The most distinct features are the 511-keV annihilation line and 2.223-MeV neutron capture line that rise above both the electron bremsstrahlung continuum and 'narrow' and 'broad' nuclear lines from proton-α and heavy-ion interactions, respectively.

2.1. Bremsstrahlung from Flare-Accelerated Electrons

The best fitting bremsstrahlung continuum shown in Figure 2 has a shape approximated by two power laws with

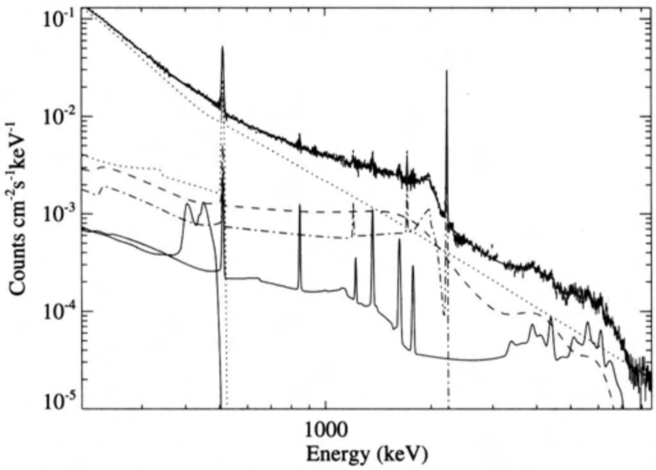

Figure 2. Fitted *RHESSI* count spectrum accumulated over the first 4 minutes of its observation of the 2003 Oct. 28 flare. Fits to the bremsstrahlung (dots), annihilation radiation (dots), and α-^{4}He (dot-dot-dash), narrow (solid), broad (dashes) and 2.22 MeV (dashes-dots) nuclear line components are shown separately.

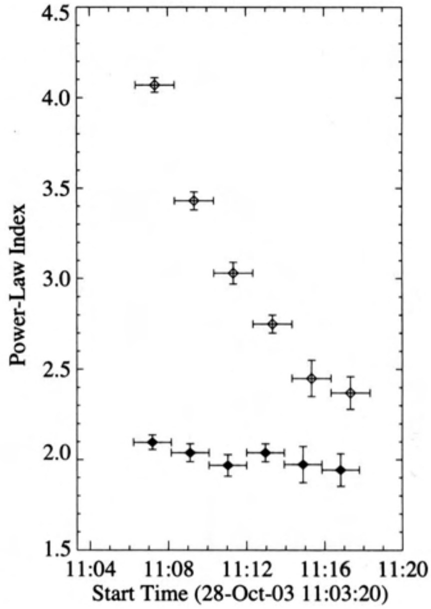

Figure 3. Temporal variation of the bremsstrahlung power-law indices below (open diamonds) and above (filled diamonds) the break energy during the 2003 October 28 flare.

spectral indices ~3.8 and 2.1 below and above an ~460 keV break energy, respectively. Such hardening was observed in several γ-ray flares (e.g. *Vilmer et al.*, 1999) and is larger than expected from relativistic effects (e.g. *McTiernan and Petrosian*, 1991). This suggests that the accelerated electron spectra may harden near ~1 MeV. The hardening in the October 28 flare may, in part, be due to a separate electron component from decay of high-energy pions whose neutral component appears to have been detected in high-energy γ-rays by *CORONAS-F* (*Veselovsky et al.*, 2004; *Kuznetsov et al.*, 2005). It will be interesting to compare the inferred electron spectrum at the Sun with that observed in space for this flare.

The bremsstrahlung spectrum hardened monotonically with time during the flare. This hardening is reflected in the decreasing power-law indices above and below the break energy that we plot in Figure 3; there was a similar hardening during the November 2 flare. It would be interesting to determine whether such hardening was observed in the electron spectrum observed in space. The high-energy electron spectrum can also vary rapidly but not monotonically in flares. This is illustrated in Figure 4 that displays variations in the single power-law index fit to the bremsstrahlung spectrum from the 1989 March 6 flare observed by *SMM*.

2.2. Nuclear Lines from Accelerated Particle Interactions

The 2003 October 28 and November 2 and 2005 January 20 flares offer a unique opportunity to compare accelerated ion spectra and composition at the Sun and in interplanetary space. Earlier studies (e.g. *Ramaty et al.*, 1993) used more limited data but demonstrated that the relative numbers of accelerated protons at the Sun and in interplanetary space is highly variable and may be correlated with whether the flare has an impulsive or gradual time profile in soft X-rays. Other papers in this volume discuss SEP observations. We discuss observations of the characteristics of the accelerated particles at the Sun inferred from γ-ray observations.

2.2.1. Directionality of interacting protons and α-particles. The shapes of the 'narrow' nuclear lines provide information on

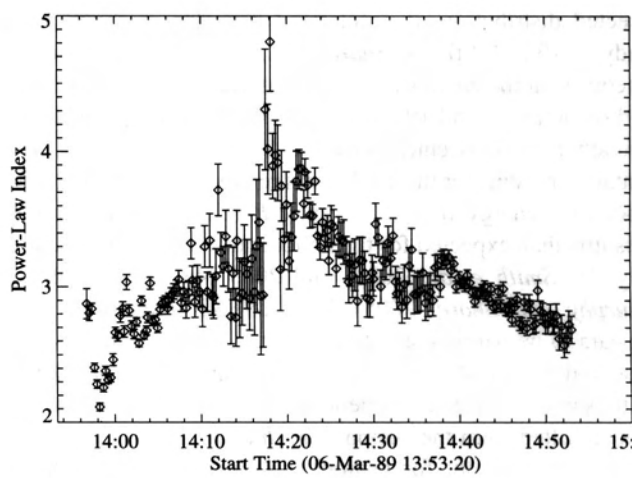

Figure 4. Temporal variation of the bremsstrahlung power-law index during the 1989 March 6 flare.

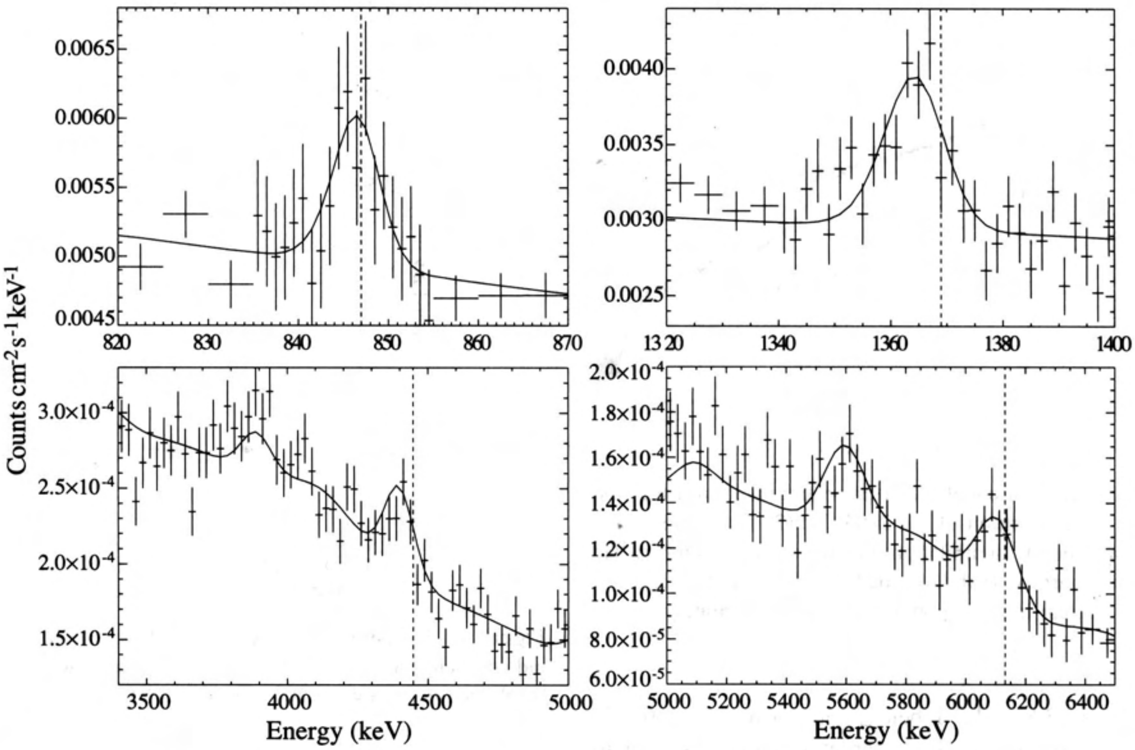

Figure 5. Fits to 4 lines observed by *RHESSI* during the 2003 October 28 flare. Instrumental Compton scattered and 1st escape peaks are visible at high energy. Top panels: ^{56}Fe and ^{24}Mg low FIP (First Ionization Potential) lines; Bottom panels: ^{12}C and ^{16}O high FIP lines. Dotted lines show the rest energies of the de-excitation lines.

the angular distribution of interacting protons and α-particles. We plot four of the lines used in the study of the 2003 October 28 flare in Figure 5. The lines are red-shifted from their laboratory energies (*Smith et al.*, 2004; *Gan*, 2005) by an amount that is consistent with both *INTEGRAL* observations (*Gros et al.*, 2004) and what is calculated for a broad downward-directed distribution of accelerated particles as found in a study of 19 *SMM* flares (*Share et al.*, 2002). We have simultaneously fit the energies of strong nuclear de-excitation lines in three *RHESSI* and 19 *SMM* flares to study their redshift as a function of heliocentric angle. In Figure 6 we plot the percentage line shift for these 22 flares relative to the 4.439 MeV laboratory energy of the ^{12}C line. *RHESSI* detected larger redshifts than expected for the heliocentric angles of the 2002 July 23 (*Smith et al.*, 2003) and 2003 November 2 flares (*Murphy and Share*, 2005). The *RHESSI* redshift at 70° appears to be barely consistent with the distribution of shifts observed by *SMM* in this preliminary analysis. Such large shifts suggest that the magnetic loops constraining the particles are tilted from the normal (*Smith et al.*, 2003). Such tilts are not uncommon; for example, *Bernasconi et al.* (1995) discuss measurements of flux tubes with an average inclination of ~14° relative to local vertical in the photosphere.

2.2.2. Spectrum of accelerated protons and α particles. Line-flux ratios provide an estimate of the energy spectrum of accelerated protons and α particles that impact the solar atmosphere (*e.g., Murphy and Share*, 2005). This is possible because the cross sections for γ-ray line production can have significantly different energy dependences (*Kozlovsky, Murphy, and Ramaty*, 2002). As discussed below these determinations are dependent on various assumptions about the accelerated particles and ambient composition. Comparison of fluxes in the ^{20}Ne (1.63 MeV) line and in the ^{16}O (6.13 MeV) and ^{12}C (4.43 MeV) lines provides information on the spectrum between ~2 and 20 MeV nucleon^{-1}. To determine the spectrum from ~10–50 MeV nucleon^{-1} we typically compare fluxes in the 511-keV annihilation line produced following β^+ radioactive decays with the ^{12}C and ^{16}O de-excitation lines. Comparison of the neutron-capture line with the ^{12}C and ^{16}O lines provides information on the spectrum from ~10-100 MeV nucleon^{-1}. Even though nuclear line spectrometers typically are only sensitive up to ~10-20 MeV they can detect evidence for protons up to hundreds of MeV nucleon^{-1} through detection of annihilation radiation from positrons following pion decay (see discussion in Section 4.2).

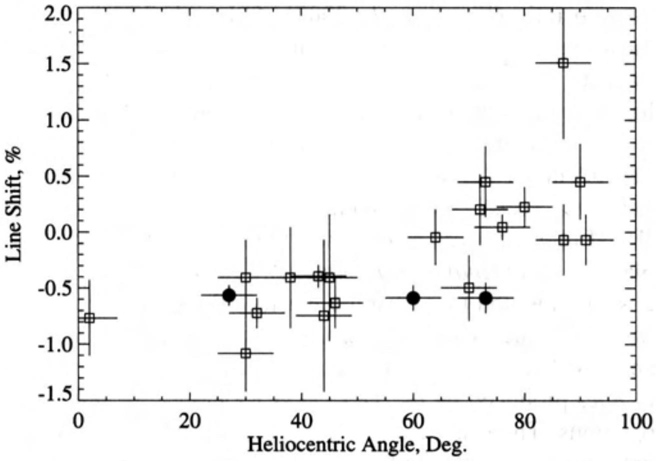

Figure 6. Measurements of the percent line shifts relative to the 4.43 MeV ^{12}C line vs. heliocentric angle made by *SMM* (squares) and *RHESSI* (solid circles, 2002 July 23: 72°; 2003 Oct. 28: 30°; Nov. 2: 60°).

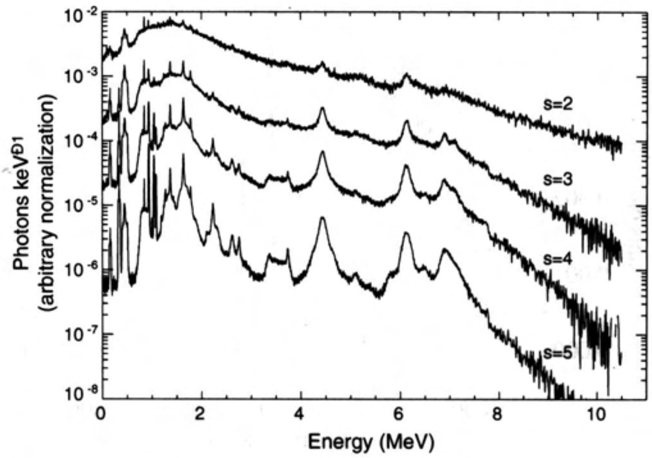

Figure 7. Calculated nuclear de-excitation spectra for four power-law indices. Text explains assumptions about accelerated-particle and ambient abundances.

Ramaty et al. (1995, 1996) evaluated the flare-averaged accelerated-particle spectra from 19 *SMM* flares (*Share and Murphy*, 1995). This determination was dependent on the assumed ambient and accelerated particle compositions and the simplification that all the accelerated particles have the same spectra. We assume a coronal ambient composition where the particles interact (*Reames*, 1995) and that the accelerated particles have an impulsive SEP composition. This latter composition (*Ramaty et al.*, 1996) is coronal (*Reames*, 1995) for C, N, Ne, Mg, Al, Si, S, Ca, and Fe relative to O but with Ne/O, Mg/O, Si/O and S/O increased by a factor of 3 and Fe/O increased by a factor of 10, α/O = 50, and α/p = 0.5. With these assumptions the average index for the 19 flares was ~4.3 between ~2 and 20 MeV nucleon^{-1} (*Share et al.*, 2002; *Murphy, and Share*, 2005).

From a preliminary analysis, under the same assumptions, we find that the spectra of the 2003 October 28 (in the decay phase) and November 2 flares in the same energy range were considerably harder than this average; the power-law indices were estimated to be 2.5 ± 0.4 and 2.5 ± 0.9, respectively, based on fluxes in the Ne, C, and O lines (*Share et al.*, 2004b). Measurement by *INTEGRAL* (*Kiener et al.*, 2005) of these same lines appears to confirm the hardness of the decay phase spectrum of the October 28 flare and indicates that the spectrum may have been even harder a few minutes earlier. Such a hard spectrum is also required to produce the observed 511 keV line flux (*Share et al.*, 2004a) and the π^o-decay γ-rays that were apparently observed by *CORONAS-F* just before the *RHESSI* observations began on October 28 (*Veselovsky et al.*, 2004; *Kuznetsov et al.*, 2005). *Gan* (2005) suggested that a steeper spectrum would be derived for an ambient Ne/O concentration of 0.15 in lieu of the value of 0.25 that was assumed (*Ramaty et al.*, 1996). The solar Ne/O ratio is uncertain with recent publications suggesting values from ~0.15 to 0.4 (*Drake and Testa*, 2005; *Bahcall et al.*, 2005; *Schmeltz et al.*, 2005; *Young*, 2005). Power-law spectral indices between about 3 and 4 were derived for the October 28 flare by comparing fluxes in the 2.223 MeV neutron capture line and the C and O de-excitation lines (*Share et al.*, 2004a; *Tatischeff, Kiener, and Gros*, (2005)); there are several other parameters that affect this measurement, however.

Perhaps the hardest spectrum of accelerated particles ever observed to impact the Sun occurred during the 2005 January 20 flare. It differs from the October 28 spectrum plotted in Figure 2 in that the narrow de-excitation lines are barely detectable, the annihilation line is much stronger relative to the 2.223-MeV neutron-capture line, and the bremsstrahlung and nuclear continua are more dominant. In Figure 7 we plot calculations of the nuclear de-excitation line spectra as a function of the spectral index of the accelerated particles. The nuclear continuum dwarfs the discrete lines for very hard spectra. The photon spectrum for this flare extended up to energies in excess of tens of MeV with evidence for pion-decay gamma rays based on *CORONAS-F* observations (*Priv. Comm. V. Kurt*, 2005). *RHESSI* observations throughout the flare show significant emission above 10 MeV over and above extrapolation of the hard X-ray bremsstrahlung. Such high-energy emission produces a significant amount of 511-keV line radiation from material around the *RHESSI* detectors. For this reason we cannot simply use the measured (511-keV)/(2.223-MeV) line ratio, without correction, to infer the spectrum of accelerated particles at the Sun. Work is in progress to determine this accelerated particle spectrum for comparison with the spectrum of solar energetic particles observed in space (*Mewaldt et al.*, 2005).

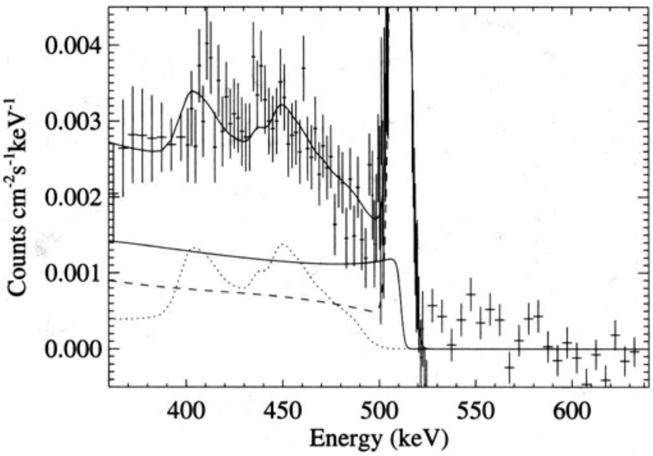

Figure 8. Fit to *RHESSI* 2003 October 28 spectrum revealing the α-^{4}He contribution (dots) to the total spectrum after bremsstrahlung and other nuclear contributions have been removed; fits to the annihilation line (dashes) and continuum (solid curve) are also plotted. From *Share et al.*, 2004; reproduced courtesy of the Univ. of Chicago Press.

2.2.3. Accelerated helium abundance. The intensity of the α-^{4}He fusion lines (^{7}Be and ^{7}Li) in flares observed by the *SMM* spectrometer has been found to be more intense than expected for assumed accelerated α/p and ambient ^{4}He/H abundances of 0.1 (*Share and Murphy*, 1997). *Kozlovsky, Murphy, and Share* (2004) set a 1 σ lower limit of 0.35 to the α/p ratio in the 2002 July 23 flare observed by *RHESSI*, consistent with the *SMM* observations. Plotted in Figure 8 is the spectrum between 350 and 650 keV accumulated from 11:06-11:10 UT during the 2003 October 28 flare after subtracting bremsstrahlung and nuclear contributions. The dotted line shows the best fit to the α-^{4}He line shape for a downward isotropic distribution of accelerated particles. (In Section 4.2 we discuss the annihilation line and its continuum that are also shown in the Figure.) If we assume that the accelerated-particle power-law index is 2.5 and ambient ^{4}He/H = 0.1, we obtain preliminary accelerated α/p ratios of 0.65 (−0.3, +0.15) and 0.4 (−0.15, +0.2) for the 2003 October 28 and November 2 *RHESSI* flares, respectively (*Share et al.*, 2004b). Due to differences in the p and α cross sections, we derive lower α/p ratios for softer particle spectra. We note that if the protons and α-particles had different spectral indices this will affect the value of the accelerated α/p ratio derived from the gamma-ray line measurements (*Toner and Mackinnon* (2004)). *Gan* (2005) concluded that the α/p ratio in both flares probably did not exceed 0.1. He based his conclusion on comparative studies of the Ne/O and n-capture/C line flux ratios; this method is rather indirect because the results are also dependent on other factors. *Tatischeff et al.* (2005) used a similar method but did not attempt to draw any conclusions about the ratio. As we mentioned earlier it is possible to use the measured de-excitation line shape to estimate the α/p ratio (*Smith et al.*, 2003). Although this method is most sensitive to the ratio for softer accelerated particle spectra than observed in these two flares, *Kiener et al.* (2005) have used it in the INTEGRAL study of the October 28 flare.

Our estimate of the accelerated α/p ratio is inversely dependent on the ambient ^{4}He/H ratio, assumed to be 0.1. *Feldman, Landi, and Laming* (2005) recently measured a ^{4}He/H ratio of 0.122 ± 0.024 in high-temperature solar flare plasmas. *Mandzhavidze, Ramaty, and Kozlovsky* (1997) suggested a method to determine whether these high α-He line fluxes are due to an elevated α/p ratio and/or to an elevated ambient ^{4}He/H ratio. This requires comparison of the fluxes in lines produced by α-^{56}Fe (339 keV) and p-^{56}Fe (847 keV) reactions. There is evidence for a weak line at 339 keV in data obtained with moderate resolution NaI spectrometers, consistent with an elevated α/p ratio (*Share and Murphy*, 1998). Our preliminary assessment is that the spectra of the October 28 and November 2 flares may be too hard for the 339-keV line to be detected because its production cross section peaks at low energies.

Our finding that the accelerated α/p ratio inferred from the gamma-ray measurements generally appears closer to 0.5 than to 0.1 can be compared with ratios from 0.005 to as high as 0.3 derived from interplanetary particle measurements, for impulsive events (*Reames*, *Meyer*, and *von Rosenvinge*, 1994; *Kallenrode, Cliver, and Wibberenz*, 1992). However, these measurements were for particle energies of 4.4-6.4 MeV nucleon^{-1} that are just below the threshold for the observed α-^{4}He fusion lines. *Torsti et al.* (2002) reported observations up to 100 MeV nucl^{-1} where the α/p-ratio ranged between 0.15-0.5 for more than 10 hr during particle events on 1998 May 27 and 1999 December 28.

The key line features for understanding the accelerated ^{3}He abundance appear near 0.937, 1.040, and 1.08 MeV (*Mandzhavidze, Ramaty, and Kozlovsky*, 1997). *Share and Murphy* (1998) found evidence for an average ^{3}He/^{4}He ratio of 0.1 in flares observed by *SMM* and *Mandzhavidze, Ramaty, and Kozlosky*, (1999) additionally suggested that a ratio as high as 1 have occurred in some flares. Such high ^{3}He/^{4}He ratios are consistent with what is observed in smaller impulsive solar energetic particle events (e.g. *Reames, Meyer, and Von Rosenvinge*, 1994). *Mason et al.* (2002) report ratios for 14 impulsive particle events that varied between ~0.1 and 6.5. *RHESSI* can more easily resolve the ^{3}He lines from other nearby lines. Based only on the 937-keV line, we obtained preliminary 99% upper limits of 0.8 and 2.5 on the ^{3}He/^{4}He ratios in the October 28 and November 2 flares, respectively (*Share et al.*, 2004b).

2.2.4. Accelerated heavy ions. From the fit to the overall *RHESSI* spectrum shown in Figure 2, we note that the broad nuclear lines (dashed curve) that are in part due to accelerated heavy ions impacting on ambient H can contribute up to about

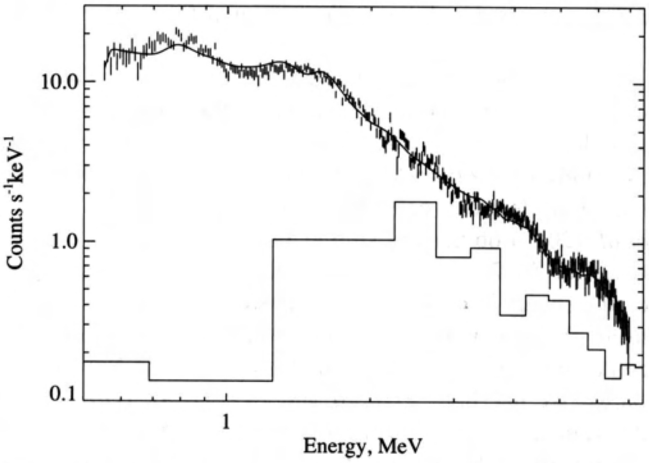

Figure 9. Broad nuclear-line component observed in the summed spectrum of 19 flares observed by *SMM*. The curve shows the calculated shape for accelerated particles with impulsive composition, α/p = 0.5, power-law index 4.5. The broad peaks near 0.8, 4, and 6 MeV are attributed to Doppler-broadened de-excitation lines from accelerated ^{56}Fe, ^{14}C, and ^{16}O. The highly broadened peak between 1-2 MeV is partly due to Doppler-broadened lines from ^{56}Fe, ^{24}Mg, ^{20}Ne, and ^{28}Si. The histogram is discussed in the text.

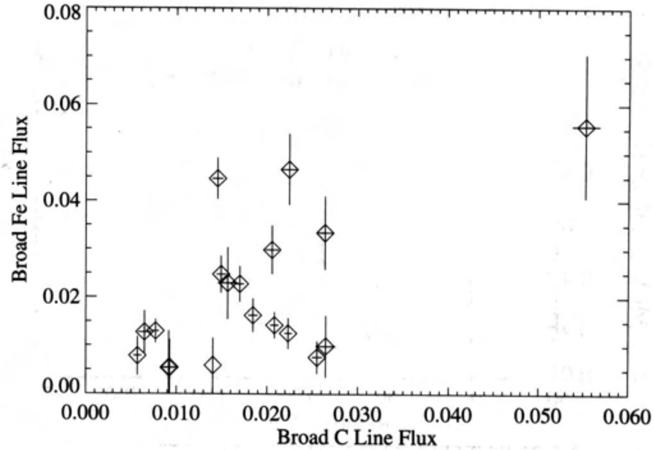

Figure 10. Comparison of broad ^{56}Fe and ^{12}C line fluxes in 19 *SMM* flares.

25% of the total flux in certain energy ranges. We see evidence for the broad lines near 4 MeV and 6 MeV, attributable to flare-accelerated ^{12}C and ^{16}O. Unfortunately, there is an intense instrumental and nuclear continua below the 2.223-MeV line that may mask the presence of the broadened lines at lower energy, including the ^{56}Fe line near 847 keV observed in flares by *SMM*. *Share and Murphy* (1999) presented the broad-line spectrum from the sum of 19 flares observed by *SMM*; this spectrum is plotted in Figure 9 after the narrow lines and bremsstrahlung have been subtracted. Highly Doppler-broadened lines from accelerated ^{56}Fe, ^{12}C, and ^{16}O appear to be resolved. Analysis indicated an ~ 5 × excess in the abundance of accelerated ^{56}Fe relative to its coronal ambient abundance, similar to that found in impulsive SEPs. The shape of the spectrum is also in agreement with calculations (solid curve) for accelerated particles with an impulsive SEP composition, α/p = 0.5 (see discussion in Section 2.2.3), power-law index 4.5, and downward isotropic distribution. Thus impulsively accelerated heavy ions at the Sun and in space may have similar compositions. We have preliminary evidence that the accelerated Fe concentration may be highly variable in flares. In Figure 10 we plot the broad ^{56}Fe line flux vs. the broad ^{12}C line flux observed in 19 *SMM* flares. We note that some of the variability may be due to flare-to-flare variations in the spectra of the accelerated particles.

Chadwick et al. (1999) have performed detailed calculations of the total γ-ray yield for various nuclei that can be used to determine the shape of the unresolved nuclear-line and continuum spectrum that have compromised our ability to study the accelerated heavy-ion component in flares. The histogram plotted in Figure 9 is a preliminary estimate of the shape of the unresolved nuclear line and continuum emitted from ^{27}Al.

3. COMPARISON OF ACCELERATED ELECTRONS AND IONS

3.1. Temporal Variations in Accelerated Ions and Electrons

Important information about the acceleration and transport of electrons and ions can be obtained by a comparison of the time histories observed in different energy bands of the hard X-ray and γ-ray spectra. *Chupp* (1990) discussed an early study of *SMM* data indicating that the peaks in individual bursts observed in the 4.1-6.4 MeV energy band (mostly due to ion interactions) were delayed between 2 s and 45 s from the corresponding maxima observed in the electron bremsstrahlung continuum near 300 keV (see also *Share and Murphy*, 2004c). This delay appears to be proportional to the rise time of the pulse. Some of these delays may be explained by transport effects in magnetic loops (*e.g.*, *Hulot et al.*, 1992; *Murphy and Share*, 2005).

Such delay analyses may not reveal the true complexity of the variation between the nuclear and electron emissions, however. In Figure 11 we show variations in the nuclear-line to bremsstrahlung ratio with time in two flares observed by *Yohkoh* (in the 4-7 MeV region) and one observed by *SMM* (from 0.3-8.5 MeV). The nuclear/bremsstrahlung ratio appears to increase with time during the 2001 August 25 flare, decrease with time during the 2001 April 15 flare,

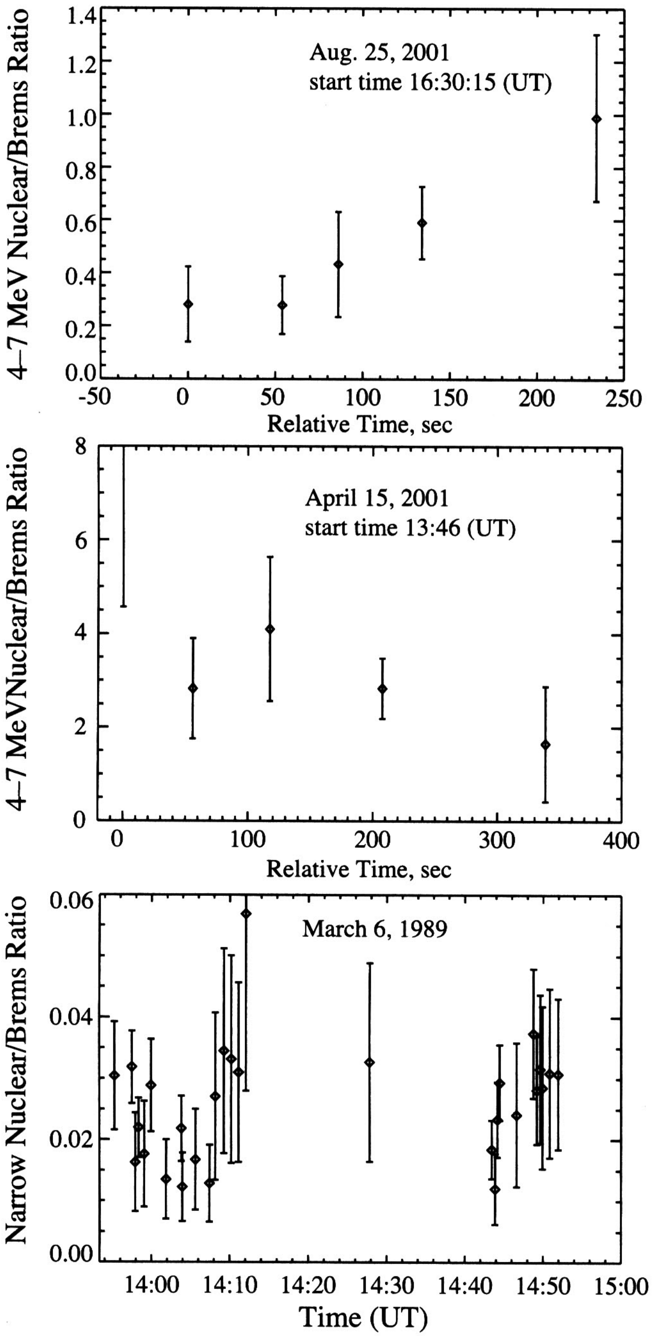

Figure 11. Nuclear to bremsstrahlung ratios vs. time observed by Yohkoh in the 2001 August 25 (top panel) and April 15 flares (middle panel) and by SMM in the 1989 March 6 flare (bottom panel).

and show variable behavior in the 1989 March 6 flare. These disparate variations are likely due to different phenomena such as transport in short and long loops, trapping, and distinct acceleration episodes. We are planning a systematic study of these variations in a large sample of flares.

3.2. Energy in Accelerated Electrons and Ions

Using the derived accelerated-particle spectra it is possible to compare the energies contained in flare-accelerated ions and electrons. *Ramaty and Mandzhavidze* (2000) performed this study for 19 flares observed by *SMM* and found that the ions and electrons contained comparable energies. *Emslie et al.* (2004) obtained a similar result for the 2002 July 23 flare; for the 2002 April 21 flare they placed an upper limit on the energy in ions that is just above that measured in electrons. We have made a preliminary estimate of the energies contained in protons in the 2003 October 28 and November 2 flares. We use both *RHESSI* and *INTEGRAL* (*Gros et al.*, 2004) data for the October 28 flare. The energy in protons is strongly dependent on both the spectrum and low-energy cutoff energy. The γ-ray line studies provide information on protons with energies $\gtrsim$ 3 MeV. We can obtain an estimate of the energy contained in the protons by assuming that the spectrum extends without a break down to 1.0 MeV and is flat below that energy. For a power-law index of 3 we estimate that protons contained $\sim 1.5 \times 10^{31}$ ergs in the October 28 flare and $\sim 0.5 \times 10^{31}$ ergs in the November 2 flare. At present there are no estimates for the energy content in electrons for these flares.

4. ACCELERATED PARTICLES PROBE THE SOLAR ATMOSPHERE AND PHOTOSPHERE

Flare-accelerated protons and alpha particles and secondary neutrons and positrons all act as probes of the flaring chromosphere and photosphere. Gamma-ray emission from their interactions have revealed a dynamic chromosphere that exhibits the FIP effect seen in the corona and puzzling evidence for striking temperature and ionization changes.

4.1. FIP Effect at Chromospheric Densities

Fluxes of narrow lines from ambient heavy nuclei observed from 19 flares (*Share and Murphy*, 1995) have been used by *Ramaty et al.* (1995) to infer that there is a strong FIP effect (overabundance of low first-ionization potential elements relative to their composition in the photosphere) where the particles interact ($\gtrsim 10^{14}$ H cm^{-3}; see *e.g.*, *Murphy and Share*, 2005), suggesting that the ambient plasma has a coronal composition. *Laming* (2004) provided an explanation for the FIP effect under less dynamic conditions at lower densities ($\sim 10^{12}$ H cm^{-3}). *Share and Murphy* (1995) pointed out that the FIP ratio appears to vary from flare-to-flare. The average low-FIP (Fe, Mg, Si) to high-FIP (Ne, C, O) line ratio for 19 *SMM* flares was ~0.45. *Murphy et al.* (1997) showed evidence that the FIP ratio can increase with time in an extended flare observed by *CGRO*/OSSE. Evidence for

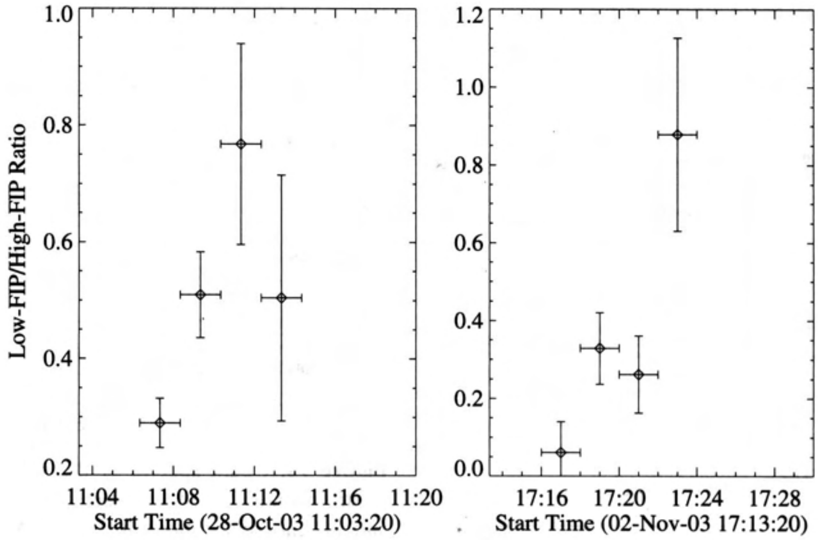

Figure 12. Variation in Low-FIP/High-FIP line ratio observed in the 2003 October 28 and November 2 flares observed by *RHESSI*.

increase in the ratio is also provided by *RHESSI* observations of the 2003 October 28 and November 2 flares (*Share et al.*, 2004b; *Shih et al.*, 2004) plotted in Figure 12. These observations suggest that the accelerated particles interact in ambient compositions that change with time. It would be of interest to determine whether chromospheric evaporation of this fractionated material could contribute significantly to the coronal material and provide seed material for subsequent acceleration into interplanetary space. We plan on studying the larger SMM data base for additional evidence of temporal changes in the ambient composition.

4.2. Positrons Probe the Chromosphere and Photosphere

Positrons are emitted in the radioactive decay of nuclei produced when flare-accelerated ions interact with the solar atmosphere (*Kozlovsky, Lingenfelter, and Ramaty*, 1987). The positrons annihilate directly and through formation of positronium. Annihilation of a positron with an electron yields either a line (2 photons) or continuum (3 photons) depending on the local density, temperature, and ionization state (*Crannell et al.*, 1976); thus the measured line-to-continuum ratio helps to determine the conditions of the ambient medium. Until the *RHESSI* 2002 July 23 flare observation (*Share et al.*, 2003), the 511-keV line had not been clearly resolved. The line had a width of 8.1 ± 1.1 keV which was consistent with both annihilation in an ionized medium $4–7 \times 10^5$ K and in a quiet atmosphere at 6000K. Detailed particle transport and interaction calculations are required to confirm our supposition that the latter location does not provide enough column depth for the production of radioactive nuclei and for the slowing down and annihilation of the positrons.

We have now studied annihilation radiation in four *RHESSI* flares. The 2003 October 28 flare produced the largest fluence of annihilation radiation observed to date (*Share et al.*, 2004a). It also displayed a remarkable change in width of the 511-keV line (see bottom panel of Figure 13). The width of the line changed from an average of ~6.5 keV to ~1 keV within about two minutes when there was no marked change in the bremsstrahlung, nuclear de-excitation line, and annihilation line fluxes. The change in line width is most clearly shown in Figure 14. There was a rapid change in the relative flux in the measured continuum below the line early in the flare (see third panel in Figure 13). This step-function increase below the line can be seen in Figure 8. We believe that the high continuum flux in the first 2-3 minutes is due to Compton scattering of the annihilation line under 5 to 10 g cm^{-2} of H. This depth is consistent with an e^+-origin from decay of π^+-mesons; γ- rays from π^o-meson decay were reported a few minutes earlier by *CORONAS-F* (*Veselovsky et al.*, 2004; *Kuznetsov et al.*, 2005). From fits to the line shapes we conclude that the broad line is likely to be due to annihilation in a $> 2 \times 10^5$ K medium and that the narrow line is produced at temperatures $< 10^4$ K, albeit in a highly ionized medium. These observations raise issues concerning the characteristics of the solar atmosphere during flares.

There have been two new developments since publication of the 2003 October 28 and November 2 annihilation radiation studies. *Murphy et al.* (2005) have developed an improved algorithm that calculates the 511-keV annihilation line spectrum and relative strength of the 3-γ continuum for a wide range of physical environments relevant to the flaring solar atmosphere. We are using these calculations to study the annihilation emission from all the flares observed by

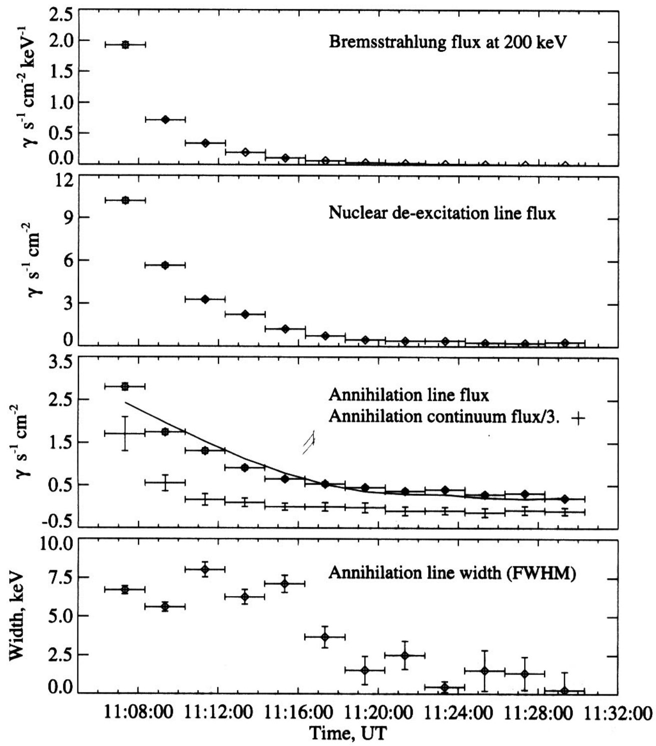

Figure 13. Time histories of the bremsstrahlung and total nuclear de-excitation line fluxes for the October 28 flare are plotted in the top two panels. Also shown are the time histories of the 511-keV annihilation line flux and width, as well as what we believe is the Compton scattered continuum below the line. From *Share et al.* (2004); reproduced courtesy of the Univ. of Chicago Press.

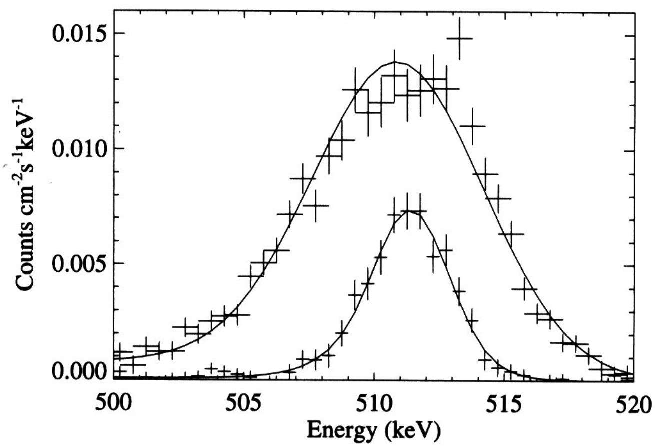

Figure 14. Count spectra of the solar 511-keV annihilation line (instrumentally broadened) derived by subtracting bremsstrahlung and nuclear contributions during the October 28 flare when the solar line was broad (11:06 - 11:16 UT) and narrow (11:18 - 11:30 UT). The solid curve is the best-fitting model that includes a Gaussian line and positronium continuum. From *Share et al.* (2004); reproduced courtesy of the Univ. of Chicago Press.

RHESSI. Recent studies indicate that the annihilation line shape is consistent with Gaussians over the entire October 28 flare, implying temperatures $> 2 \times 10^5$ K during the first 10 min and $< 10^4$ K (> 20% ionized) during the last 10 min. During both intervals, the inferred density is significantly $> 10^{14}$ H cm^{-3}. What is especially puzzling is the rapid, 2 minute, transition from broad to narrow line width (Figures 13 & 14). The line observed during the November 2 flare is also broad but it can be fit with the shape expected for annihilation in a quiet solar atmosphere at a temperature of 5000 K (*Murphy et al.*, 2005); there is uncertainty whether the continuum below the line is consistent with this origin, however.

The annihilation line studies, the hardness of the accelerated particle spectra, and the apparent detection of pion-decay radiation suggest that we are also studying sub-photospheric conditions with gamma rays. It is puzzling how the apparently high temperatures and ionization states can be supported at these densities. A new aspect is the detection of acoustic waves below the photosphere following the October 28 and 29 flares (*Donea and Lindsey*, 2005). Our preliminary estimates indicate that there is sufficient energy in $\gtrsim 100$ MeV protons to account for the acoustic waves. If this association with high-energy protons is correct, acoustic waves should have been detected after the 2005 January 20 flare. The intense bremsstrahlung and nuclear continuum combined with weak de-excitation line emission in the January 20 flare resembles the electron-rich events suggested by *Rieger, Gan, and Marschhäuser* (1998). Could these be due to episodes with very hard proton spectra that produce pions? The hard bremsstrahlung then could result from pion-decay electrons and positrons. Chupp (private communication, 2005) is studying high-energy spectra from electron-rich episodes in the 1989 March 6 flare to determine whether the high-energy gamma-ray spectrum is consistent with pion-decay emission.

4.3. Search for Photospheric ^{3}He using Fast Neutrons

Neutrons produced in accelerated particle interactions with the solar atmosphere can escape the Sun, decay, or slow down and get captured by either H or ^{3}He. Capture on H produces a line at 2.223 MeV while capture on ^{3}He is radiationless. Both the angular distribution of accelerated particles and concentration of ^{3}He affect the time profile of the capture line. *Murphy et al.* (2003) have compared the time history of the line with calculations to determine both the angular distribution of accelerated particles and photospheric

^{3}He concentration in the 2002 July 23 flare. The nuclear-line flux has been used as a surrogate for the acceleration time profile. A physically based transport model has been used in performing the analysis. We find that the accelerated particles suffer significant pitch-angle scattering in the corona, yielding a broad downward-directed distribution. Because pitch-angle scattering, spectral hardness, and ^{3}He all affect the neutron-capture line timehistory and the nuclear line flux was relatively weak, the photospheric ^{3}He abundance is not well constrained (^{3}He/H = (0.5-10.0) $\times 10^{-5}$). *Tatischeff, Kiener, and Gros* (2005) obtained a similar result for the 2003 October 28 flare.

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REFERENCES

Anders, E., and N. Grevesse, Abundances of the elements - Meteoritic and solar, *Geochim. et Cosmochim. Acta*, 53, 197-214, 1989.

Aschwanden, M., *Physics of the Solar Corona, An Introduction*, 842 pp., Springer/Praxis Publishing, Chichester, UK, 2004.

Bahcall, J.N., S. Basu, and A.M. Serenelli, What is the neon abundance of the Sun?, *Astrophys. J.*, 631, 1281-1285, 2005.

Bernasconi, P.N., C.U. Keller, H.P. Povel, and J.O. Stenflo, Direct measurements of flux tube inclinations in solar plages, *Astron. Astrophys.*, 302, 533-542, 1995.

Cane, H.V., T.T. von Rosenvinge, C.M.S. Cohen, and R.A. Mewaldt, Two components in major solar particle events, *Geophys. Res. Lett.*, 30, 8017, doi:10.1029/2002GL016580, 2003.

Chadwick, M.B., P.G. Young, S. Chiba, S.C. Frankle, *et al.*, Cross-section evaluations to 150 MeV for accelerator-driven systems and implementation in MCNPX, *Nucl. Sci. & Eng.*, 131, 293-328, 1999.

Chupp, E.L., Transient particle-acceleration associated with solar flares, *Science*, 250, 229-236, 1990.

Chupp, E.L., D.J. Forrest, J.M. Ryan, J. Heslin, *et al.*, A direct observation of solar neutrons following the 0118-UT flare on 1980 June 21, *Astrophys. J.*, 263, L95-L99, 1982.

Crannell, C.J., and G. Joyce, R. Ramaty, and C. Werntz, Formation of 0.511 MeV line in solar flares, *Astrophys. J.*, 210, 582-592, 1976.

Donea, A.-C., and C. Lindsey, Seismic emission from the solar flares of 2003 October 28 and 29, *Astrophys. J.*, in press, 2005.

Drake, J.D., and P. Testa, The 'solar model problem' solved by the abundance of neon in nearby stars, *Nature*, 436, 525-528, 2005.

Emslie, A.G., H. Kucharek, B.R. Dennis, N. Gopalswamy, *et al.*, Energy Partition in Two Solar Flare/CME Events, *J. Geophys. Res.*, 109, A10104, 2004.

Feldman, U., E. Landi, and J.M. Laming, Helium abundance in high-temperature solar flare plasmas, *Astrophys. J.*, 619, 1142-1152, 2005.

Gan, W.Q., Gamma-ray line analysis for the flares of 28 October and 2 November 2003, *Adv. Sp. Res*, 35, 1833-1838, 2005.

Gros, M., V. Tatischeff, J. Kiener, B. Cordier, *et al.*, *INTEGRAL*/SPI observation of the 2003 Oct 28 solar flare, *Proc. 5th INTEGRAL Workshop, Munich, Germany, ESA SP-552*, 669-676, 2004.

Hua, X.-M. and R.E. Lingenfelter, A determination of the (He-3)/H ratio in the solar photosphere from flare gamma-ray line observations, *Solar Physics*, 319, 555-566, 1987.

Hulot, E., N. Vilmer, E.L. Chupp, B.R. Dennis, and S.R. Kane, Gamma ray and X-ray time profiles expected from a trap-plus-precipitation model for the 7 June 1980 and 27 April 1981 solar flares, *Astron. Astrophys.*, 256, 273-285, 1992.

Kallenrode, M.-B, E.W. Cliver, and G. Wibberenz, Composition and azimuthal spread of solar energetic particles from impulsive and gradual flares, *Astrophys. J.*, 391, 370-379, 1992.

Kiener, J., N. de Séréville, and V. Tatischeff, Shape of the 4.438 MeV gamma-ray line of C-12 from proton and alpha-particle induced reactions on C-12 and O-16, *Phys. Rev. C*, 64, 025803, 2001.

Kiener, J., M. Gros, V. Tatischeff, and G. Weidenspointner, Properties of the energetic particle distributions during the October 28, 2003 solar flare from *INTEGRAL*/SPI observations, *Astron. Astrophys.*, in press, 2005.

Kozlovsky, B., R.E. Lingenfelter, and R. Ramaty, Positrons from accelerated particle interactions, *Astrophys. J.*, 316, 801-818, 1987.

Kozlovsky, B., R.J. Murphy, and R. Ramaty, Nuclear deexcitation gamma-ray lines from accelerated particle interactions, *Astrophys. J. (Supp.)*, 141, 523-541, 2002.

Kozlovsky, B., R.J. Murphy, and G.H. Share, Positron-emitter production in solar flares from ^{3}He reactions, *Astrophys. J.*, 604, 892-899, 2004.

Kuznetsov, S.N., V.G. Kurt, B.Y. Yushkov, I.N. Myagkova, and K. Kudela, Gamma-ray and high-energy particle measurements of the solar flare of 28 October 2003 on board *CORONAS-F*, *Solar Physics, submitted*, 2005.

Laming, J.M., A unified picture of the first ionization potential and inverse first ionization potential effects, *Astrophys. J.*, 614, 1063-1072, 2004.

Li, G., and G.P. Zank, Mixed particle acceleration at CME-driven shock and flares, *Geophys. Res. Lett.*, 32, L02101, doi:10.1029/2004GL021250, 2005.

Mandzhavidze, N., R. Ramaty, and B. Kozlovsky, Solar atmospheric and solar flare accelerated helium abundances and gamma-ray spectroscopy, *Astrophys. J.*, 489, L99-L102, 1997.

Mandzhavidze, N., R. Ramaty, and B. Kozlovsky, Determination of subcoronal ^{4}He and solar flare-accelerated ^{3}He and ^{4}He from gamma-ray spectroscopy, *Astrophys. J.*; 518, 918-925, 1999.

Mason, G.M., J.E. Mazur, and J.R. Dwyer, ^{3}He enhancements in large solar energetic particle events, *Astrophys. J.*, 525, L133-L136, 1999.

Mason, G.M., M.E. Wiedenbeck, J.A. Miller, J.E. Mazur, *et al.*, Spectral properties of He and heavy ions in ^{3}He-rich solar flares, *Astrophys. J.*, 574, 1039-1058, 2002.

Masuda, S, T. Kosugi, H. Hara, and Y. Ogawara, A loop top hard x-ray source in a compact solar-flareas evidence for magnetic reconnection, *Nature*, 371, 495-497, 1994.

McTiernan, J.M., and V. Petrosian, Center-to-limb variations of characteristics of solar flare hard x-ray and gamma-ray emission, *Astrophys. J.*, 379, 381-39, 1991.

Mewaldt, R., C., M.D. Looper, C.M.S. Cohen, G.M. Mason, *et al.*, Solar-particle energy spectra during the large events of October-November 2003 and January 2005, *Proc. 29th Int. Cosmic Ray, Pune, India, SH 1.2*, 101-104, 2005.

Miller, J.A., P.J. Cargill, A.G. Emslie, G.D. Holman, *et al.*, Critical issues for understanding particle acceleration in impulsive flares, *J. Geophys. Res.*, 102, 14631-14659, 1997.

Murphy, R.J., C.D. Dermer, and R. Ramaty, High-energy processes in solar flares, *Astrophys. J. (Supp.)*, 63, 721-748, 1987.

Murphy, R.J., B. Kozlovsky, J.G. Skibo, and G.H. Share, The Physics of Positron Annihilation in the Solar Atmosphere, *Astrophys. J. (Supp.)*, 161, -, 2005.

Murphy, R.J., and G.H. Share, What gamma-ray de-excitation lines reveal about solar flares, *Adv. Sp. Res.*, 35, 1825-1832, 2005.

Murphy, R.J., G.H. Share, J.E. Grove, W.N. Johnson, *et al.*, Accelerated particle composition and energetics and ambient abundances from gamma-ray spectroscopy of the 1991 June 4 solar flare, *Astrophys. J.*, 490, 883-900, 1997.

Murphy, R.J., G.H. Share, X.-M. Hua, R.P. Lin, *et al.*, Physical implications of *RHESSI* neutron-capture line measurements, *Astrophys. J.*, 595, L93-L97, 2003.

Ramaty, R., B. Kozlovsky, and R.E., Lingenfelter, Nuclear gamma-rays from energetic particle interactions, *Astrophys. J. (Supp.)*, 40, 487-526, 1979.

Ramaty, R. and N. Mandhavidze, Highly energetic physical processes and mechanisms for emission from astrophysical plasmas, *IAU Symposia*, 195, 123-132, 2000.

Ramaty, R., N. Mandzhavidze, B. Kozlovsky, and J.G. Skibo, Acceleration in solar flares – interacting particles versus interplanetary particles, *Adv. Sp. Res.*, (9), 275-284, 1993.

Ramaty, R., N. Mandzhavidze, B. Kozlovsky, and R.J. Murphy, Solar atmospheric abundances and energy content in flare-accelerated ions from gamma-ray spectroscopy, *Astrophys. J.*, 455, L193-L196, 1995.

Ramaty, R., N. Mandzhavidze, and B. Kozlovsky, Solar atmospheric abundances from gamma ray spectroscopy, *High Energy Solar Physics, ed. R. Ramaty, N. Mandzhavidze, and X-M Hua, AIP Conf. Proc.*, 374, 172-183, 1996.

Ramaty, R., N. Mandzhavidze, C. Barat, and G. Trottet, The giant 1991 June 1 flare: evidence for gamma-ray production in the corona and accelerated heavy ion abundance enhancements from gamma-ray spectroscopy, *Astrophys. J.*, 479, 458-463, 1997.

Reames, D.V., Coronal abundances determined from energetic particles, *Adv. Space Res.*, 15 (7), 41, 1995.

Reames, D.V., Particle acceleration at the Sun and in the heliosphere, *Space Sci. Rev.*, 90, 413-491, 1999.

Reames, D.V., Meyer, J.P., and von Rosenvinge, T.T., Energetic-particle abundances in impulsive solar-flare events, *Astrophys. J. (Supp.)*, 90, 649-667, 1994.

Rieger, E., W.Q. Gan, and H. Marschhäuser, Gamma-ray line versus continuum emission of electron-dominated episodes during solar flares, *Solar Physics*, 183, 123-132, 1998.

Schmelz, J.T., K. Nasraani, J.K. Roames, L.A. Lipper, and J.W. Garst, Neon lights up a controversey, the solar Ne/O abundance, *Astrophys. J.*, 634, L 197-L 200, 2005
Share, G.H., and R.J. Murphy, Gamma-ray measurements of flare-to-flare variations in ambient solar abundances, *Astrophys. J.*, 452, 933-943, 1995.
Share, G.H., and R.J. Murphy, Intensity and directionality of flare-accelerated alpha-particles at the Sun, *Astrophys. J.*, 485, 409-418, 1997.
Share, G.H., and R.J. Murphy, Accelerated and ambient He abundances from gamma-ray line measurements of flares, *Astrophys. J.*, 508, 876-884, 1998.
Share, G.H., and R.J. Murphy, Gamma-ray measurement of energetic heavy ions at the sun, *Proc. of the 26th Cosmic Ray Conference*, 6, 13-16, 1999.
Share, G.H., and R.J. Murphy, Solar Gamma-Ray Line Spectroscopy Physics of a Flaring Star, in Stars as Suns: Activity, *Evolution and Planets, IAU Conf. Series 219*, ed. A.K. Dupree and A.O. Benz, 133-144, 2004c.
Share, G.H., R.J. Murphy, J. Kiener, and N. de Sereville, Directionality of solar flare accelerated protons and alpha particles from gamma-ray line measurements, *Astrophys. J.*, 573, 464-470, 2002.
Share, G.H., R.J. Murphy, J.G. Skibo, D.M. Smith, *et al.*, High-resolution observation of the solar positron-electron annihilation line, *Astrophys. J.*, 595, L85-L88, 2003.
Share, G.H., R.J. Murphy, D.M. Smith, R.A. Schwartz, and R.P. Lin, *RHESSI* e^+ - e^- annihilation radiation observations: implications for conditions in the flaring solar chromosphere, *Astrophys. J.*, 615, L169-L172, 2004a.
Share, G.H., R.J. Murphy, D.M. Smith, R.P. Lin, and A.Y. Shih, Accelerated particle spectra and abundances in the 2003 October 28 and November 2 solar flares (abstract), *Fall AGU Mtg.*, SH13A-1135, 2004b.
Shih, A.Y., D.M. Smith, R.P. Lin, G.H. Share, *et al.*, *RHESSI* observations of gamma-ray lines from solar flares (abstract), *Fall AGU Mtg.*, SH24A-01, 2004.
Smith, D.M., G.H. Share, R.J. Murphy, R.A. Schwartz, *et al.* A.Y., High-resolution spectroscopy of gamma-ray lines from the x-class solar flare of 2002 July 23, *Astrophys. J.*, 595, L81-L84, 2003.
Smith, D.M., A.Y. Shih, R.J. Murphy, G.H. Share, R.A. Schwartz, and R.P. Lin, *RHESSI* spectroscopy of nuclear de-excitation lines in x-class flares (abstract), *AAS Mtg.*, 204, 02.01, 2004.
Tatischeff, V., J. Kiener, and M. Gros, Phyical implications of *INTEGRAL/* SPI gamma-ray line measurements of the 2003 October 28 solar flare, Proceedings of the 5th Rencontres du Vietnam, "New Views on the Universe", Hanoi, Vietnam, in press (astro-ph/0501121)
Toner, M.P., and A.L. MacKinnon, Do fast protons and α particles have the same energy distributions in solar flares?, *Solar Physics*, 223, 155-168, 2004
Torsti, J., L. Kocharov, J. Laivola, S. Pohjolainen, *et al.*, Solar particle events with helium-over-hydrogen enhancement in the energy range up to 100 MeV nucl^{-1}, *Solar Physics*, 205, 123-147, 2002.
Tylka, A.J., C.M.S. Cohen, W.F. Dietrich, S. Krucker, *et al.*, Onsets and release times in solar particle events, *Proc. of the 28th Cosmic Ray Conference*, 7, 3305-3308, 2003.
Tylka, A.J., C.M.S. Cohen, W.F. Dietrich, M.A. Lee, *et al.*, Shock geometry, seed populations, and the origin of variable elemental composition at high energies in large gradual solar particle events, *Astrophys. J.*, 625, 474-495, 2005.
Veselovsky, I.S., M.I. Panasyuk, S.I. Avdyushin, G.A. Bazilevskaya, *et al.*, Solar and Heliospheric Phenomena in October November 2003: Causes and Effects, *Cosmic Res.*, 42, 435-488, 2004.
Vilmer, N., G. Trottetet, C. Barat, R.A. Schwartz, S. Enome, A. Kuznetsov, R. Sunzaev, and O. Terekhov, Hard X-ray and gamma-ray observations of an electron dominated event associated with an occulted solar flare, *Astron. Astrophys.*, 342, 575-582, 1999.
Young, P.R., The Ne/O abundance ratio in the quiet Sun, *Astron. Astrophys*, 444, L45-L48, 2005.

G.H. Share and R.J. Murphy, E.O. Hulburt Center for Space Research Naval Research Laboratory Washington, DC 20375. (gerald.share@nrl.navy.mil and murphy@ssd5.navy.mil)