Low-FIP to High-FIP Gamma-Ray Line Ratio in an Impulsive Flare on 6 November, 1997

M.Yoshimori, A.Shiozawa, and K.Suga
Department of Physics, Rikkyo University, Tokyo 171-8501, Tokyo, Japan

Abstract

Yohkoh observed strong gamma-ray emission from a flare at 11:52 UT on 6 November, 1997. We found that a ratio of low FIP (Mg, Si and Fe) to high-FIP (C,N,O and Ne) narrow line fluxes was enhanced by a factor of 3 in the decay phase, while the ratios of narrow lines from elements with similar FIPs were nearly constant throughout the flare. It suggests two possibilities: (1) the ratio of low-FIP to high-FIP elemental abundances at the γ-ray production site was increased in the decay phase or (2) the location of the γ-ray production site could have changed with time, progressing from the photosphere to the corona.

1 Introduction:

The SMM narrow γ-ray line observations of 19 solar flares revealed flare-to-flare variations in ambient solar abundances (Share and Murphy, 1995). Moreover, the OSSE observation of a very long-duration flare of 4 June, 1991 indicated that a ratio of (Mg+Si+Fe) to (C+N+O) line fluxes varied with time (Murphy *et al.*, 1997). We need more γ-ray specral data to advance the understanding of the solar ambient abundances. Yohkoh obtained a new result on the temporal change in γ-ray spectrum in the course of an impulsive flare. It confirms the previous Murphy *et al*'s result from the long duration flare. We discuss possibilities for the temporal variation of the ambient abundances.

2 Observation and Result:

Yohkoh observed a flare (X9.0/2B) at 11:52 UT on 6 November, 1997. It lasted for about 200 s and the γ-ray spectrum at 0.5-100 MeV was measured with two BGO scintillation spectrometers (128 energy channels for 0.5-15 MeV and 16 energy channels for 15-120 MeV). Prompt nuclear γ-ray lines of C, N, O, Ne, Mg, Si and Fe, neutron capture line and higher-energy γ-rays were detected. In order to make spectral analyses, we used a least squares fitting technique which is a similar method as descrived in Murphy *et al.* (1990). We assumed that the γ-ray spectrum consists of bremsstrahlung continuum (single power law) and ten narrow and five broad lines (Gaussians). Here we fixed the line center energies and line widths at their theoretical values (Murphy *et al.*, 1990).

The counting rate time profiles at 1.04-1.51, 2.22, 4.00-7.23 and 10-20 MeV are plotted in Fig.1. This flare showed similar temporal variations at these energies except 2.22 MeV. The 2.22 MeV line is delayed because it takes about 100 s for neutron capture on proton. In order to study the temporal variations of narrow lines, we show the time sequential γ-ray count spectra from 11:52:36 to 11:55:32UT in Fig.2. The integration time is about 20 s for each γ-ray count spectrum. The second and third spectra were measured at the peak phase of the flare. We see the neutron capture line at 2.22 MeV, C and O lines at 4.44 and 6.13 MeV and a complex of Fe (1.24 MeV), Mg (1.37 MeV), Ne (1.63 MeV) and Si (1.78 MeV) lines at 1-2 MeV. In addition, two weak line features are seen around 5.3 and 7 MeV. These are due to complexes of lines resulting from excitation and spallation of N and

O. The bremsstrahlung continuum is dominant in the peak phase but the 2.22 MeV line is prominent in the decay phase because the decay time of the neutron capture line is longer than those of bremsstrahlung and prompt nuclear lines.

Meyer (1985a, b) concluded from the observations of solar energetic particles and solar wind that the elements separate based on the level of their first ionization potential (FIP). The abundances of elements in the flare plasma are grouped with respect to their FIPs. The elements with FIPs exceeding about 11 eV fall into the high-FIP category (C, N, O and Ne), while the elements below about 10 eV into the low-FIP category (Mg, Si and Fe). We search for the time variations of low-FIP (Mg+Si+Fe) and high-FIP (C+N+O+Ne) narrow lines for the rise (11:52:36-11:53:20 UT), peak (11:53:20-11:54:00 UT) and decay (11:54:00-11:56:12 UT) phases of the flare. The ratios of (Mg+Si) to Fe, Ne to (C+N+O) and (Mg+Si+Fe) to (C+N+O) lines for the three phases are shown in Table 1.

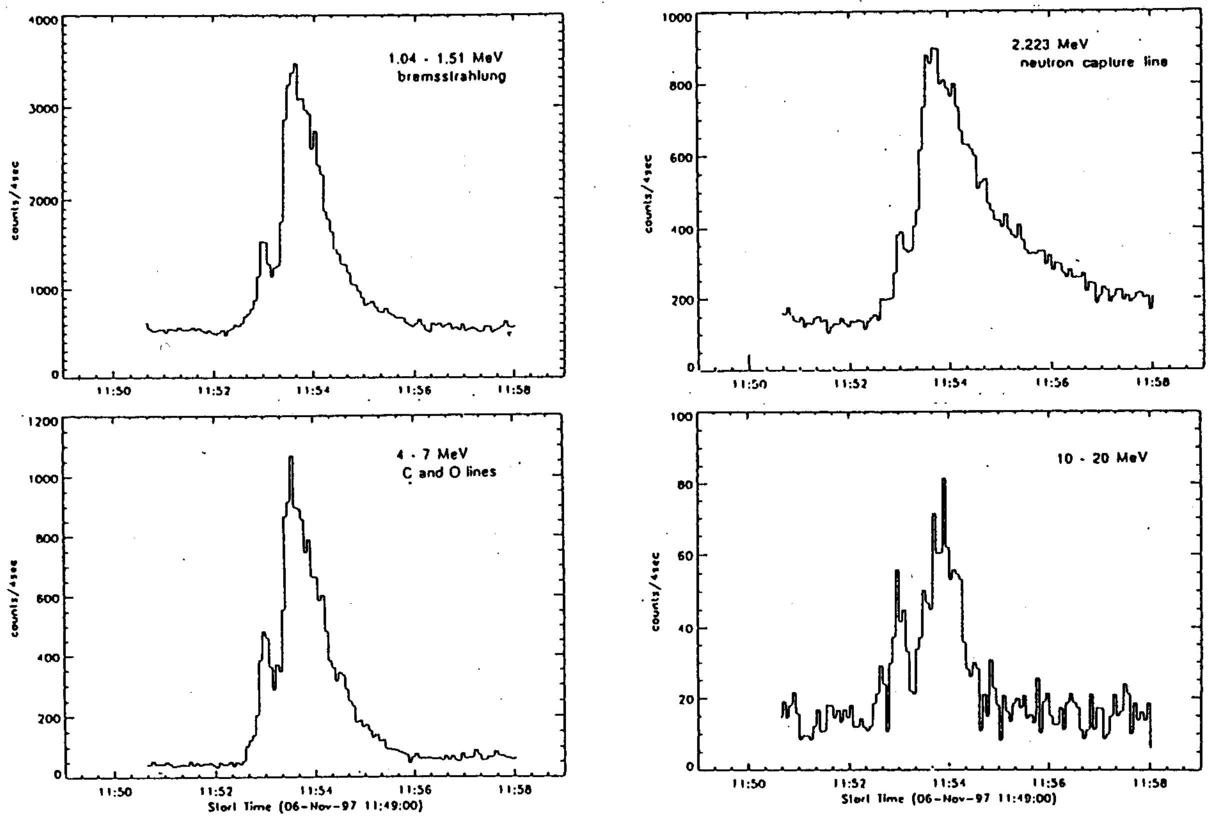
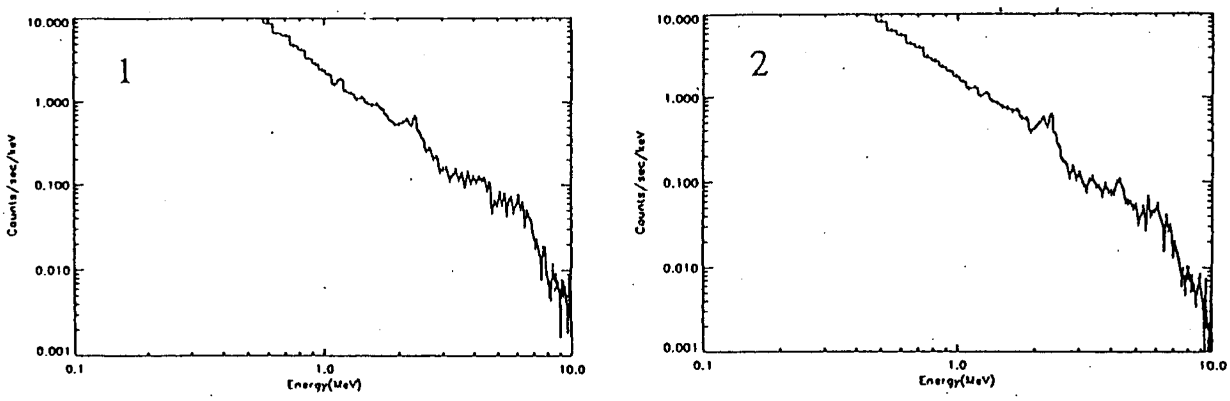


Fig.1 Time profiles of 1.04-1.51, 2.22, 4.00-7.23 and 10-20 MeV emission.



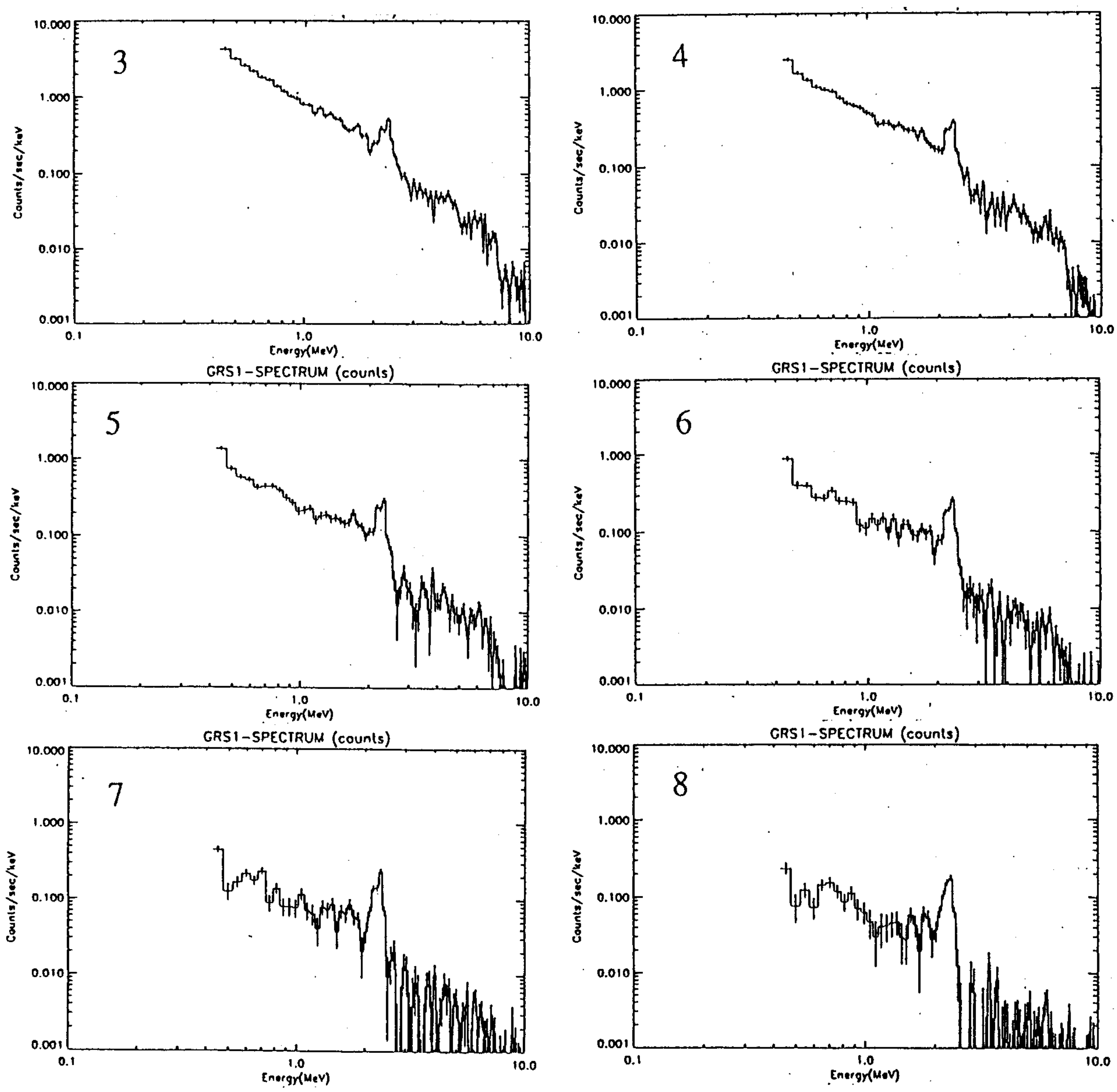


Fig.2 Temporal variation of γ-ray count spectra from 11:52:36 to 11:55:32 UT.

The ratios of (Mg+Si) to Fe and Ne to (C+N+O) lines are nearly constant within the errors throughout the flare, while the ratio of (Mg+Si+Fe) to (C+N+O) lines increased in the decay phase.

Ratio	Rise	Peak	Decay
(Mg+Si)/Fe	2.16 ± 0.91	1.90 ± 0.61	2.38 ± 0.89
Ne/(C+N+O)	0.48 ± 0.10	0.45 ± 0.06	0.50 ± 0.14
(Mg+Si+Fe)/(C+N+O)	0.52 ± 0.05	0.60 ± 0.10	1.80 ± 0.30

Table 1 Ratios of (Mg+Si) to Fe, Ne to (C+N+O) and (Mg+Si+Fe) to (C+N+O) lines for the rise, peak and decay phases.

3 Discussion:

Share and Murphy (1995) have shown from the SMM observations of 19 flares that the ratio of flare-averaged (Mg+Si+Fe) to (C+N+O) line fluxes varied from flare to flare. The ratios ranged from 0.2 to 0.8. Moreover, the 1991 June 4 flare exhibited that the ratio gradually increased with time. The ratio was 0.3 at 4:00 UT, 0.46 at 4:45 UT, 0.56 at 4:55 UT and 0.84 at 5:03 UT (Murphy *et al.*, 1997). The ratio represented about a factor of 2.7 enhancement. This flare exhibited that the ratio increased as the flare progressed. We found from the present Yohkoh γ-ray observation that the impulsive flare also showed a similar increase in the ratio. The ratio did not change in the rise and peak phases but was enhanced by a factor of about 3 in the decay phase.

On the other hand, the ratios of (Mg+Si) to Fe and Ne to (C+N+O) line fluxes are nearly constant throughout the flare, indicating that the line fluxes from elements with similar FIPs correlate with one another. The results of the 19 flares observed with SMM (Share and Murphy, 1995) indicated that the ratios of flare-averaged low-FIP to low-FIP and high-FIP to high-FIP line fluxes did not depend on the flares, suggesting that the ratios do not vary with time within a flare.

The present flare-averaged ratios of (Mg+Si) to Fe, Ne to (C+N+O) and (Mg+Si+Fe) to (C+N+O) line fluxes are in agreement with those obtained from the observations of 19 SMM γ-ray flares and 1991 June 4 flare within the experimental errors. The ratio of low-FIP to high-FIP elements in the corona was reported to be 3 to 4 times as large as that in the photosphere (Grevesse, 1984; Breneman and Stone, 1985; Reames, 1995). The fact that the observed ratio of (Mg+Si+Fe) to (C+N+O) line fluxes increased as the flare progressed suggests the possibilities of the temporal change in the atmospheric abundances of the γ-ray production site. Although this ratio depends on the spectrum of accelerated protons, the proton spectrum did not much vary with time (power law index is 3.3 ± 0.3 during the flare). Two possibilities are considered: One is the efficient transport of low-FIP elements to the γ-ray production site and the other is a change of γ-ray production site from the photosphere to the corona. Regarding the first possibility, whether the elemental abundances at a flare site change in a short time scale of about 100 s seems to be questionable. Regarding the second one, if the magnetic mirror points move upward to the corona from the chromosphere-photosphere, the second one may be possible. Yohkoh hard X-ray images of the 1997 November 6 flare showed clear double footpoint sources. The distance between two hard X-ray sources was almost constant in the rise and peak phases but it increased gradually in the decay phase. Now we can not judge whether the change in the location relates with the movement of the mirror points. We need more improved γ-ray spectral data to solve the problem of time dependence of solar atmospheric abundances. γ-ray data of high quality can be expected to obtain in the 23rd solar maximum.

References

Breneman,H,H. and Stone,E.C. 1985, ApJ. Lett. 299, L57.
Gan, W.Q .1998, ApJ, 496, 992.
Grevesse,N. 1984, Physica Scripta, T8, 49.
Meyer,J.P. 1985(a), ApJS. 57, 151.
Meyer,J.P. 1985(b), ApJS.57, 173.
Murphy,R.J., Share,G.H., Letaw,J.R. and Forrest,D.J. 1990, Apj. 358, 298.
Murphy, R.J. ,Share,G.H.,and Grove,J.E. *et al.* 1997, ApJ. 490, 883.
Reames,D.V. 1995, Adv. Space. Res. 15, (7)41.
Share,G.H. and Murphy,R.J. 1995, ApJ. 452, 933.