BCS Spectra from Flares on 6th September 1992

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Abstract

We have studied time evolution of BCS spectra of He like S XV, Ca XIX and Fe XXV ions observed by the Yohkoh satellite for two flares on 6th September 1992 at 05:05 (M2.4 class) and 08:59(M3.3 class). Electron temperatures for S XV, Ca XIX and Fe XXV ions are derived through synthetic spectra mainly from the intensity ratios of the satellite lines to the resonance line. Apparent ion temperatures are derived from the line width of S XV and Ca XIX spectra. The blue shifted components in the rising phase are separated from the main component in Ca XIX spectra. The emission measures and other parameters derived from the spectra are compared with HXT and radio data. The ion ratios derived from the ratios of line intensities are studied relating to the ionization equilibrium.

1. Plasma parameters from BCS spectra

We can obtain the following plasma parameters from BCS spectra ;
i) electron temperature from the intensity ratios of the satellite lines to the resonance line, ii) ion temperature from the line broadening, iii) volume emission measure from the absolute line intensity, iv) ion ratios from the intensity ratios among the lines produced by the inner-shell excitation. These values for each ion are derived as a function of time.

2. Time evolution of the BCS spectra

The light curves of the integrated intensities are shown in Fig.1. The intensity of the Fe XXV increases very rapidly comparing to that of S XV. The maximum temperature from Fe XXV ions is about 2 keV(2.3×10^7K) at 1 - 2 min. before the period when the counting rates are maximum. The Time dependence of the electron temperature derived from BCS spectra of S XV, Ca XIX and Fe XXV (He-like ions) are shown in Fig.2. The error for the electron temperatures is estimated to be within 20% in the later phases.

Time dependent spectra are classified into four phases as follows,

1) Initial phase (05:10 - 05:13)... Counting rates are very low, almost constant and increases gradually with time. The Ca XIX spectra show the electron temperature around 1 keV and larger line broadening than that in the later phases indicating a turbulence. Apparent ion temperatures of the main component are about 2 - 3 keV for Ca XIX and S XV. This indicates that the turbulence begins before the increase of the X-ray flux.

2) Rising phase (05:13 - 05:16)... Counting rate begins to increase very rapidly. The electron temperatures increase following the increase of the counting rate. Line widths become broader than those in the initial phase and the blue shifted component appears obviously at the beginning of the rising phase. The apparent ion temperature of the blue shifted component is about 10 keV and the relative velocity to the main component is

about 200 km/s. The apparent ion temperature including main component and blue shifted component reaches the maximum value at the beginning of the rising phase (05:14) and decreases towards the maximum phase. The blue shifted component is shown in Fig.3.(2).

3) Maximum phase (05:16 - 05:18) ... Counting rates and the electron temperatures for Ca XIX and S XV reach the maximum. The maximum electron temperature from Fe XXV is about 2 keV just before the maximum phase. Line widths of the main component become narrow indicating no turbulence. The blue shifted component is still seen but the ratio to the main component is small (about 20%). The ion temperature from Ca XIX goes down and reaches the values lower than the electron temperatures to be around 1.5 keV.

4) Decay phase (05:18 - 05:25)... The electron temperature decreases from 2 keV to 1 keV as well as the counting rates. The ion temperature becomes a little larger that in the maximum phase to be around 1.5 - 2 keV.

3. The blue shifted component in the rising phase

Ca XIX spectra in the initial and rising phase show broad line width which indicate more than two blue shifted components[1] as shown in Fig.3. We tentatively tried to fit the spectra with two components; the main component and the blue shifted component as shown in Fig.3(b). The wavelength of the main component is fixed from those in the initial phase and the decay phase. During the rising phase the apparent ion temperature of the main component is about 4 keV whereas that of the blue shifted component is around 10 keV which indicate the turbulence of 140 km/s and 220 km/s respectively. The relative velocity of the two components is derived to be 180 km/s from the wavelength shift of 1.9×10^{-3}A in Ca spectra. This component goes down to 100 km/s towards the maximum phase. It seems that the intensity of the blue shifted component reaches the maximum before the maximum phase and only the main component increases afterwards. The ratio of the blue shifted component to the main component is about 20 - 30 % at the beginning and increases up to 100%. But this ratio decreases from the end of the rising phase.

It is interesting to compare HXT data and radio data in the rising phase. In the initial phase when Ca XIX line begin to be observed, HXT(13.9 - 22.7 keV)[2] is not detected whereas SXT and radio emission (17GHz) are detected. In the rising phase when the blue shifted component reaches 100% of the main component, HXT begins to increase and HXT reaches the maximum value when the blue shifted component stops to increases. HXT begins to decay earlier than BCS flux. Time behavior of radio heliograph peak brightness temperature and the polarization degree at 17 GHz obtained in Nobeyama Observatory[3] is similar to HXT flux after the rising phase. The polarization degree from radio is about 50 % in the initial phase, decreases down very rapidly to 20 % until the maximum phase and then increases again slowly up to 30 % in the decay phase. The time behaiviour of the polarization degree is very similar to that of the apparent ion temperature obtained from Ca XIX. It indicates that the turbulence from BCS data and the acceleration of electron from radio data are correlated to the strength of the magnetic field.

4. Volume emission measure

The volume emission measures n_e^2V are derived from the intensity of the resonance line of He-like ions. The observed line intensity is written as

$$I_w = \varepsilon_v (n(He)/n(Z))(n(Z)/n_H)(n_H/n_e)n_e^2 V/(4\pi r^2)$$

photons cm^{-2} s^{-1} sr^{-1},

where ε_v is the emissivity of the line in cm^3 s^{-1}, V is the volume in cm^3, r is the distance from the earth to the Sun in cm, n(He), n(Z), n_H and n_e are the density of the He-like ions, element Z, atomic hydrogen and electron respectively. We have used electron temperature derived from BCS spectra to obtain the emissivity ε_v. The value of He-like ion abundance, n(He)/n(Z), is assumed in ionization equilibrium. The solar abundance are assumed as n(S)/n(H) = 2 x 10^{-5}, n(Ca)/n(H) = 5 x 10^{-6} [4], n(Fe)/n(H) = 5 x 10^{-5}. The emission measure from S and Fe ions is about 1 - 2 x 10^{49} cm^{-3} at maximum for both two flares. The emission measure derived from Fe XXV is always smaller by about factor of two than those from Ca and S ions.

Total energy assuming solar abundance is estimated to be 2 x 10^{26} erg s^{-1} at maximum phase with the value of cooling rate 2 x 10^{-23} erg s^{-1} cm^3. The electron density is obtained to be 7 x $10^{10}$$cm^{-3}$ at maximum phase using the value for V = 2 x 10^{27} cm^3 from a SXT [5] image.

5. Ion abundance

The ion abundance ratios n(Li)/n(He) derived from Fe XXV spectra are always larger than those in the ionization equilibrium, where n(Li) is the ion densities of Li-like ions. We had the same results for the flare on January 21st 1992[6]. This result indicates that the ionization balance is not in ionization equilibrium in solar flares although this problem has to be discussed more carefully with the atomic data. The emission measure from Fe spectra assuming the derived ion abundance in non equilibrium ionization is increases by about 80%.

References

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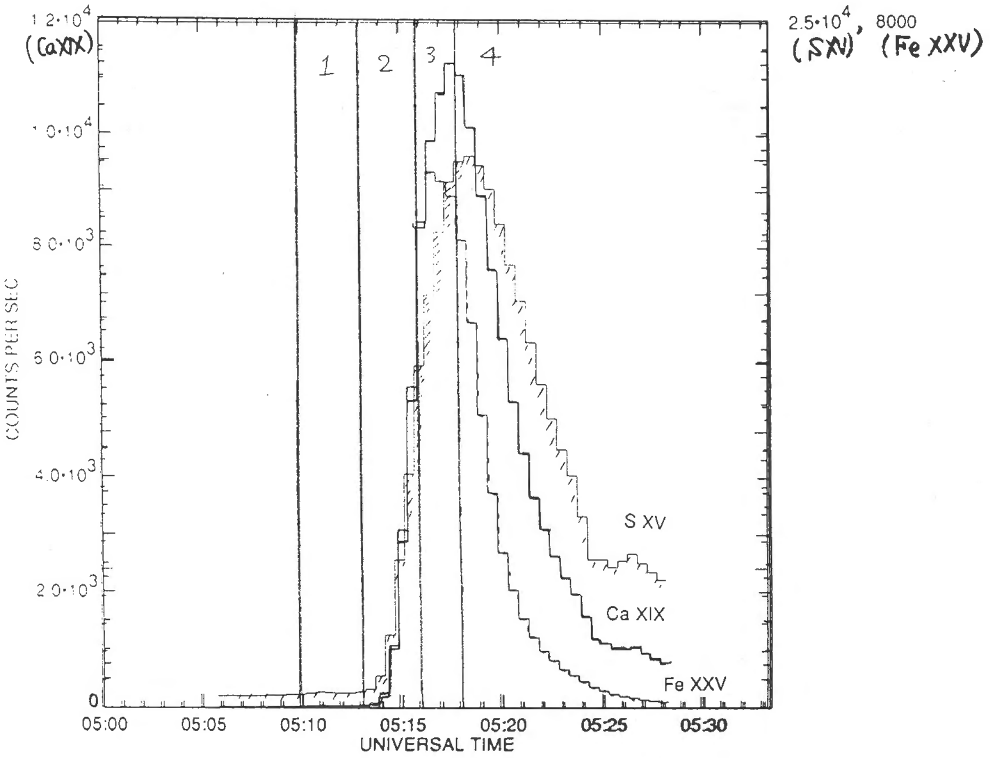

Fig.1. The light curves of the integrated intensities of S XV, Ca XIX and Fe XXV.

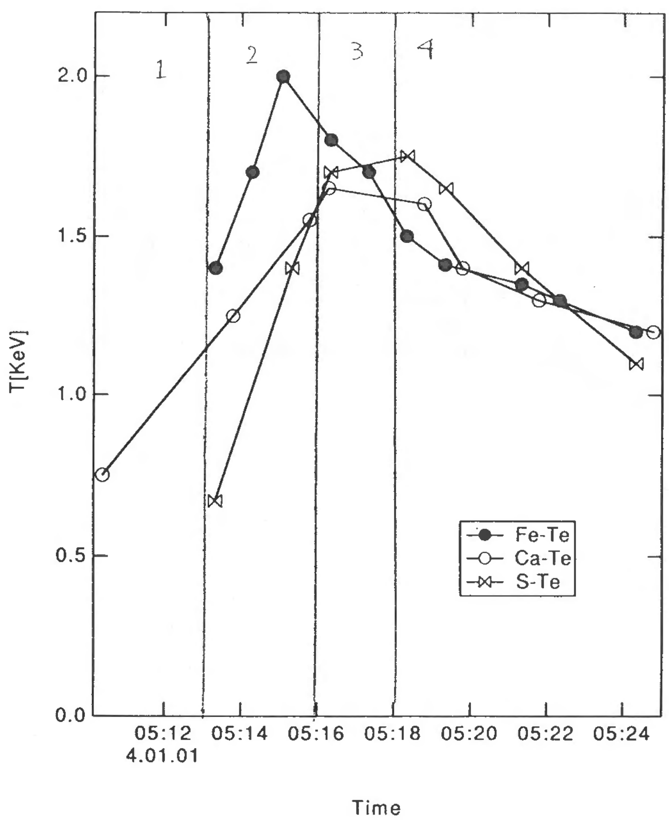

Fig.2 The Time evolution of the electron temperature derived from BCS spectra of S XV, Ca XIX and Fe XXV (He-like ions).

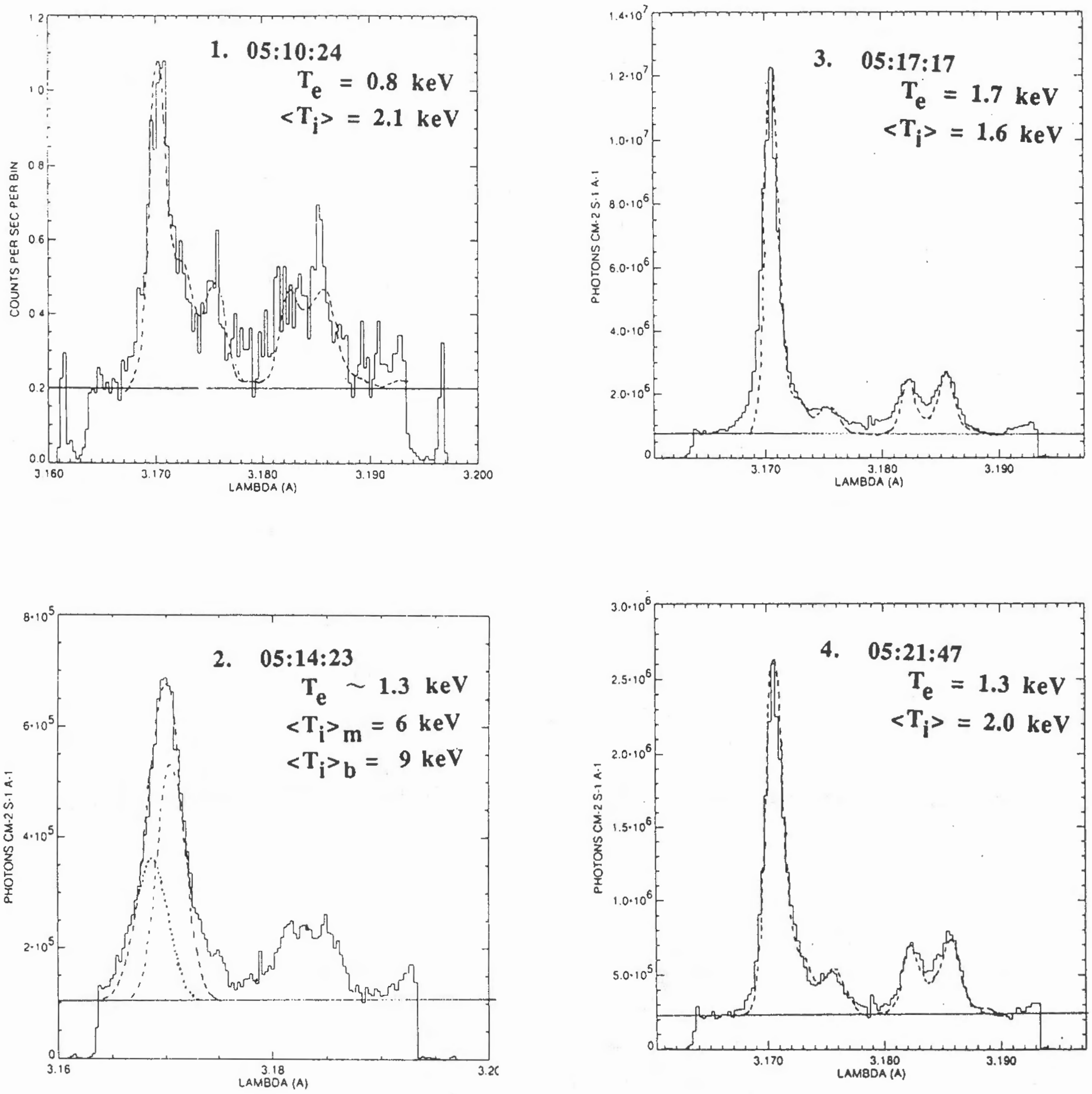

Fig.3 The Ca XIX spectra in four phases. $<T_i>$ indicates the apparant ion temperature. 1)Initial phase. 2)Rising phase. The main ($<T_i>_m$) and the blue shifted ($<T_i>_b$) components are fitted saparately. 3) Maximum phase. 4) Decay phase.