The Yohkoh BCS Flare Catalog

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Abstract

We make available a catalog of well developed flares observed with Yohkoh Bragg Chrystal Spectrometer (BCS). Temperatures, emission measures and lightcurves were computed. Flares were selected based on the GOES flare listing. Only those flares were included which were observed for more than 90 % of the flare time. All flares stronger than a GOES C5.0 class have been included. Plots of the flares were made which show the light curves in S XV, Ca XIX, Fe XXV and Fe XXVI, if possible on top of an image formed from the spectra with time. A plot of the temperature derived from the line emission is provided where possible.The catalog listing includes flare start time, maximum and end, peak flux in the four spectral lines, line-broadening, emission measure and temperature at peak flux for S XV, Ca XIX, and for the stronger flares also for Fe XXV.

Included is also a table and plots of lightcurve and temperatures from automatic fits to weaker flares. That list has not been checked for bad data but is useful to browse for interesting weaker flares for further study.

1 Introduction

The Yohkoh mission observed the Sun from September 1991 to 14 December 2001. On board were instruments to observe the Sun in X-Rays and gamma rays, providing imaging and spectral data. The BCS instrument provided spectra in four spectral bands of the whole sun. The spectral bands were two to a detector consisting of a gas-filled photomultiplier with position sensitive electrodes. The S XV multiplet at 5.02-5.13 Å share one detector with the Ca XIX multiplet at 3.16-3.19 Å and the strong Fe XXV multiplet at 1.82-1.90 Å shares a second detector with the weaker Fe XXVI multiplet at 1.75-1.81 Å. These multiplets are temperature sensitive over several temperature ranges. The ions producing these spectra are present over the following temperature ranges: S^{14+}: 2.5-20 MK, Ca $^{18+}$: 5-40 MK, Fe $^{24+}$ 12-100 MK, Fe $^{25+}$ $>$ 20 MK.

The Fe XXVI spectra are not well resolved due to detector limitations and the sharing of the detector with the strong Fe XXV multiplet. Fe XXV spectra yield only good temperatures for the stronger flares due to countrate limitations. On the other hand, S XV is sensitive enough to derive a temperature for even weak flares.

Although the detector cannot resolve the location of the flare on the Sun, there is a wavelength shift present depending on the (E-W) location of the source on the Sun, as can be readily understood as due to the incident angle of source photons onto the chrystal. This wavelength shift should not be confused with the blue-shift in the flare precursor.

2 Data selection, processing and overall accuracy

The data were selected by using the GOES flare listing. For each flare, the list provides a start time, time of maximum and a duration. For each flare in the list a search was made for BCS data. If the BCS data coverage was more than 90 %, we continued processing. First, for processing the Yohkoh BCS data, the start and end times of the GOES list were extended by 20 %. Next the data were calibrated, including the deadtime correction for flares stronger than C5.0. The resulting fluxes are used to derive a lightcurve by spectrally integrating. At maximum flux, the spectrum was plotted for S XV and Ca XIX, and an average spectrum over the flare peak was plotted for Fe XXV and Fe XXVI, provided enough counts were present.

We then fitted the spectra using the Solarsoft Yohkoh FIT_BCS routine which were originally written by J. Lemen. Hence, the atomic physics parameters were mainly derived from: for S XV: Bely-Dubau et al. (Paper VI) 1982, *MNRAS, 198,239* ;Bely-Dubau et al. (Paper VII) 1982, *MNRAS, 201, 1155* ; Cornille and Dubau 1990, *private comm. to G. Doschek* ; Vainshtein and Safronova 1978 *(VS78), ADNDT, 21, 49* ; Vainshtein and Safronova 1985 *(VS85), Phys Scr, 31, 519* ; Sampson, DH and Clark, *REH, 1979, J. Phys B, 12 no 19, 3257.* For Ca XIX: Bely-Dubau et al. (Paper VII) 1982, ; Hata and Grant 1982, *Private comm. to KJHP and J. Lemen.* (See ; their paper for He-like Fe and V in *MNRAS, 198, 1081*) ; Vainshtein and Safronova 1985, For Fe XXV: Bely-Dubau et al. 1979a, *MNRAS, 186, 405* ; Bely-Dubau et al. 1979b, *MNRAS, 189, 801* ; Bely-Dubau et al. 1982, *MNRAS, 198, 239* ; Hata and Grant 1982, *MNRAS, 198, 1081* ; Lemen et al. 1984, *A&A, 135, 313* ; Vainshtein and Safronova 1985. There are also some small tweaks to the wavelengths in the atomic data. Ionization balance calculations by (Arnaud, and Arnaud & Raymond) are used. The data were fit for an accumulation time between 9 and 30 seconds, depending on the length of the flare. The reliability of the temperature fits is largest for S XV, and not very good for Fe XXV, see figures 1, 2, and 3.

The Fe XXVI data are not useful for deriving a temperature, because data give a less reliable temperature when the count rates are low. Discrepancies in the derived temperatures for the different spectra may thus be due to fitting errors for the noisier data. For flares weaker than C5 the

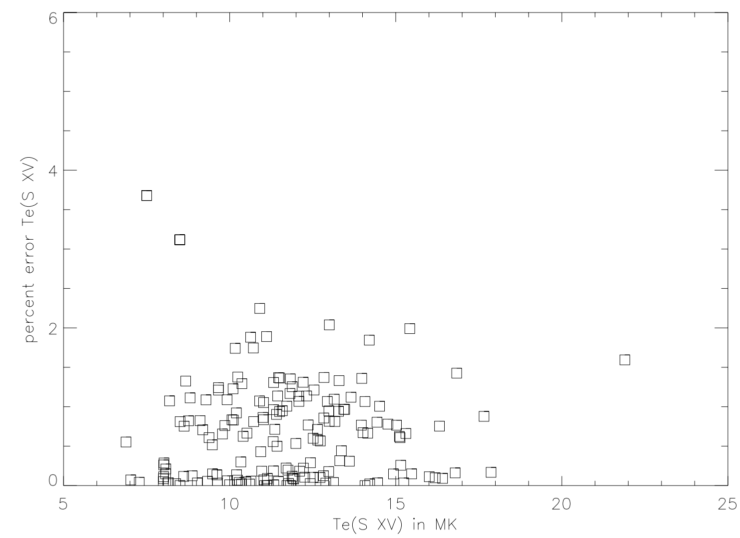

Figure 1: Error in the temperature fit for S XV.

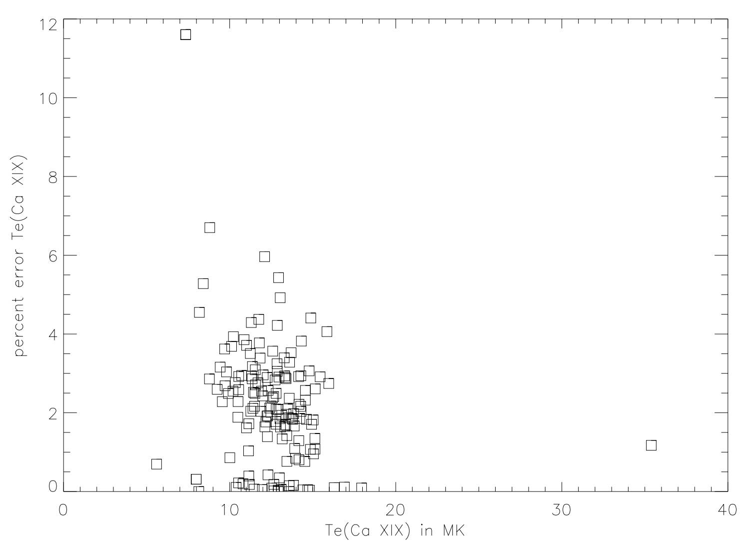

Figure 2: Error in the temperature fit for Ca XIX.

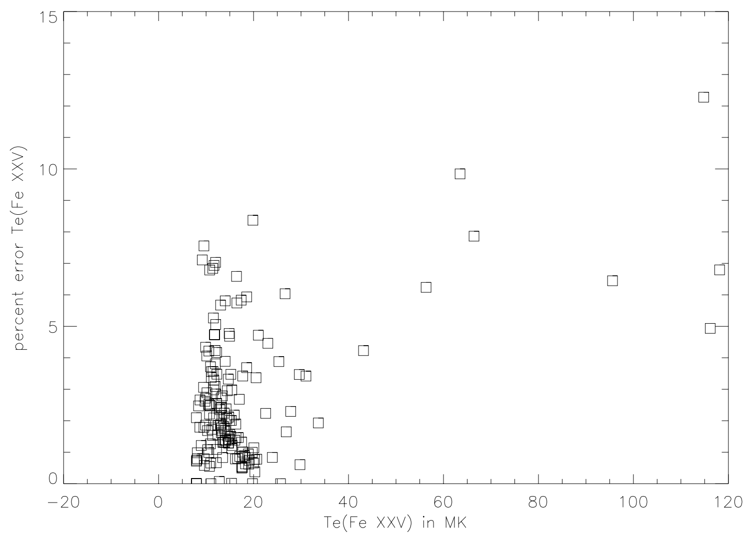

Figure 3: Error in the temperature fit for Fe XXV.

fitted temperatures become less and less reliable and should be treated with caution. The S 15 data are the most sensitive (largest count rates) and thus give the most reliable temperatures for the weak flares.

Since the emission measures in the table have been derived at flare maximum using the temperature derived for the specific ion, a temperature for which the ion is not very abundant, (for Fe^{24} that is outside the 20-50 MK range), the emission measures may be orders of magnitude wrong. In the table some of the most suspicious values have been noted. The tabular data provides fit-errors in the fitted temperature and emission measures for Fe XXV as computed by the fitting program so you can judge the reliability of these data.

The catalog data has been split up into two parts for this reason, one part for flares stronger than C5.0, and one for flares that are weaker, or did not get a GOES classification. The number of weaker flares is also about 10 times larger, and we have not had the time to weed out non-events, bad data, etc..

For clarity, GOES data are displayed also in the plots, provided they were available to us. In 1993 we were missing the GOES data and for nearly the whole of 1993 there are thus not plots included.

The data were generated semi-automatically. A visual check of the spectral line fitting was done randomly, and shows possible questionable fits to Ca XIX in the strongest flares due to line narrowing.

The same procedure was followed for weaker flares with either no GOES classification, or class B5-C5. Only the weak flare data for Jan.-Nov. 1992 have not been processed.

3 Statistical results from the Yohkoh BCS data

It is instructive to graphically display the physical data of all flares to investigate correlations.

For very strong flares the detector shows line narrowing due to charge buildup in the path taken by the line photons where the detector gas is not neutralizing in time between counts. In a plot of the fitted non-thermal line broadening at flare maximum against the GOES flare class, as a measure of flare strength, there is a clear drop in line broadening that sets in around flare stronger than C5.0.

This is the only instrumental effect seen.

A plot of the fitted temperatures for the three lines as a function of time (see figure 5) shows that during solar maximum there seems to be a second hot component present: Fe XXV temperatures deviate more frequently from those derived from S XV and Ca XIX.

4 History and recommended use of the data.

The work on this catalog was started when Dr. Foley was still with MSSL. He wrote the major part of the software on top of the regular Yohkoh BCS IDL routines which are made available in Solarsoft. The reliability of the fits depends in large part of the BCS Fitting program and the atomic physics used. Recently, the Chianti project has included new atomic physics data that might have given slightly different results. Within the time constraints of the current work using Chianti was not possible.

It is advisable to use the catalog mainly as a first point of access to the Yohkoh BCS data and for any further use to do a detailed analysis for flares of interest. For example, we could not properly report such things as observed blue-shifts as are sometimes seen during flare onset, since this would require a more detailed approach.

5 acknowledgements

Support from PPARC is acknowledged.

Over the years, a large number of people have contributed to the operations and monitoring of the BCS instrument. This include members of the Yohkoh team and the Yohkoh BCS instrument team at MSSL.

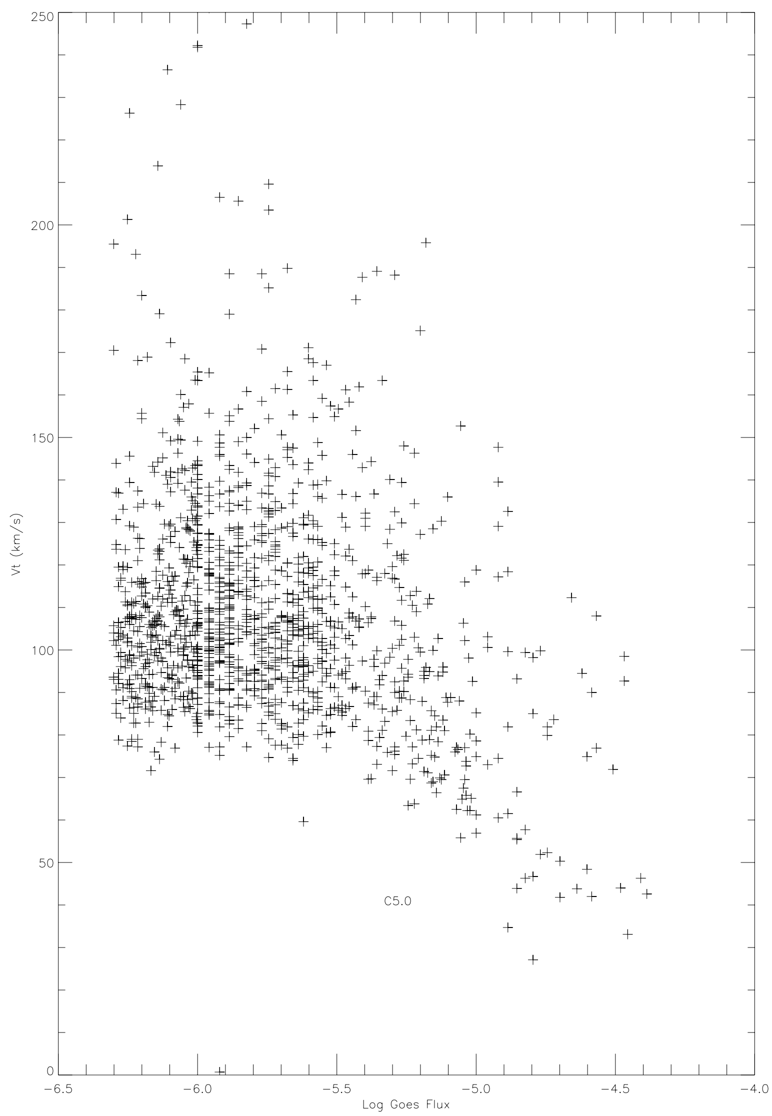

Figure 4: Turbulent line broadening as a function of maximum flux in S XV.

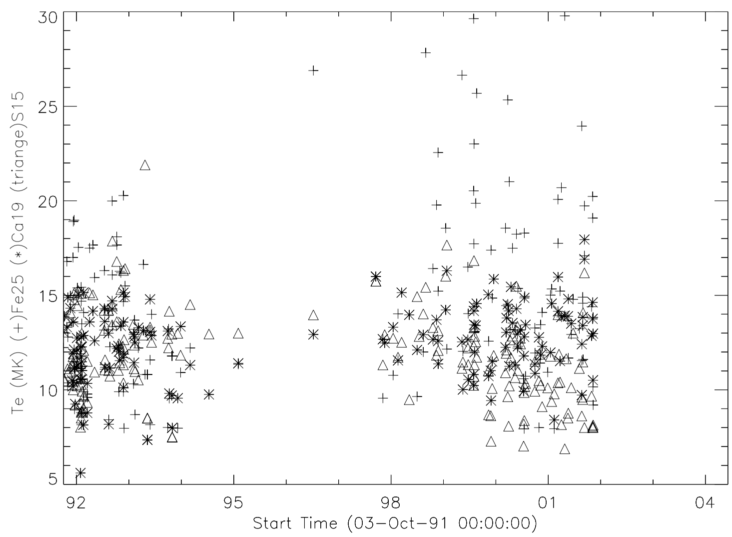

Figure 5: Temperatures at flare maximum as a function of time. The dip in 1997 is due to the solar cycle and much reduced number of large flares.