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Advances in Space Research 35 (2005) 1723–1727
ADVANCES IN SPACE RESEARCH (a COSPAR publication)
www.elsevier.com/locate/asr

The thermal X-ray spectrum of the 2003 April 26 solar flare

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Received 29 October 2004; received in revised form 4 January 2005; accepted 8 March 2005

Abstract

Observations and their analysis of the thermal X-ray spectrum of the M2 flare on 2003 April 26 are described. The spectrum observed by the *RHESSI* mission cover the energy range from ~5 to ~50 keV. With its ~1-keV spectral resolution, intensities and equivalent widths of two line complexes, the Fe line group at 6.7 keV (mostly due to Fe XXV lines and Fe XXIV satellites) and the Fe/Ni line group at 8 keV (mostly due to higher-excitation Fe XXV lines and Ni XXVII lines) were obtained as a function of time through a number of flares. The abundance of Fe can also be determined from *RHESSI* spectra; it appears to be consistent with a coronal value for at least some times during the flare. Comparisons of *RHESSI* spectra with those from the RESIK crystal spectrometer on *CORONAS-F* show very satisfactory agreement, giving much confidence in the intensity calibration of both instruments.
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Keywords: Sun; X-ray; Spectra

1. Introduction

The *RHESSI* mission has been operating successfully since its launch on 2002 February 5, and has observed many thousands of solar flares. The instrument (Lin et al., 2002) has nine cooled germanium detectors and modulation collimators which enable flare spectra and images to be obtained from the soft X-ray region (3 or 4 keV) to γ-rays (17 MeV). Aluminium disks (attenuators) are moved in front of the detectors at high count rates to prevent detector saturation. The instrument's relatively high resolution, ~1 keV at energies less than 20 keV, enable line features in the spectrum at 6.7 keV (Fe line feature) and 8.0 keV (Fe/Ni line feature) to be observed. A flare continuum is also present which, at the flare impulsive stage, consists of a non-thermal component with relatively flat energy dependence and a thermal component with steeper spectrum.

This paper is concerned with analysis of spectra during the M2 flare of 2003 April 26 in the energy range ~2–20 keV, which has been observed by both *RHESSI* and the RESIK crystal spectrometer (Sylwester et al., 2004) on the Russian *CORONAS-F* spacecraft. The 2–20 keV range is of great interest since it is where the non-thermal component begins to be evident over the thermal component. We report on attempts to derive parameters for the thermal component as well as the absolute abundance of Fe in the flare plasma from line emission during this flare.

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0273-1177/$30. Published by Elsevier Ltd on behalf of COSPAR.
doi:10.1016/j.asr.2005.03.106

2. Theoretical X-ray spectra in the 3.8–10 keV range

We first briefly describe line and continuum emission from thermal solar flare plasmas in the range 3.8–10 keV. More details are given by Phillips (2004). The emission has been calculated for solar plasmas by Mewe et al. (1985) (MEKAL code) and Dere et al. (1997) (CHIANTI code). In analyzing *RHESSI* spectral data, we have used both codes, though most of the illustrations here are from CHIANTI. In the *RHESSI* range, the thermal spectrum consists of free–free and free–bound continua and two line features at 6.7 and 8 keV that, for flare temperatures $\lesssim 20$ MK, are made up of He-like Fe (Fe XXV) lines (transitions $1s^2 - 1snl$, $n \geqslant 2$, l = s, p, etc.) and Fe XXIV dielectronic satellites. At higher temperatures, Fe XXVI and Ni XXVII lines contribute to both features. Illustrations of theoretical spectra in the 1–12 keV range at various temperatures are given in Fig. 1.

With *RHESSI*'s spectral resolution, individual lines, in particular the Fe XXIV satellite structure at 6.6–6.7 keV, cannot be resolved. However, because the lines are all due to Fe and have a known dependence on temperature, and as the continuum is well observed by *RHESSI*, we can find the Fe/H abundance. Spectral fits to the thermal spectrum, defined by the continuum slope and intensity, give temperature T and volume emission measure $\mathrm{EM} = \int N_e^2 \mathrm{d}V$ (N_e = electron density, V = emitting volume), which can be easily found, assuming an isothermal plasma. Other spectral fits, involving a multi-thermal plasma (i.e., two or more values of T) or a temperature distribution have been applied elsewhere in our analyses.

A convenient way of expressing the intensity of the two *RHESSI* line features is through the equivalent width (energy width of a portion of the continuum at the line's energy with flux equal to that of the line feature). The variation of equivalent width with T is given in Fig. 2 (solid line) based on CHIANTI.

3. RHESSI observations

We illustrate our *RHESSI* flare thermal spectral analyses in the 4–10 keV range with observations made during an M2 flare with maximum at 03:08 UT on 2003 April 26. There were several changes in the *RHESSI* attenuator state (see Smith et al., 2002), from A0 (no attenuator) to A1 (thick and thin attenuator) to A3 (thick attenuator) and the reverse sequence. A 'spectral response matrix' created by the analysis software takes account of all known effects that modify the input spectrum including the attenuator states.

RHESSI spectra were fitted with standard analysis software over the energy range 3–100 keV. In our investigations, we sometimes used the spectral output from individual detectors, while for some purposes data from seven of the nine detectors summed were more appropriate: in such cases, data from detectors 2 and 7, which have poorer spectral resolution, were omitted. A first-guess spectrum with appropriate parameters found from previous analysis was folded through the *RHESSI* spec-

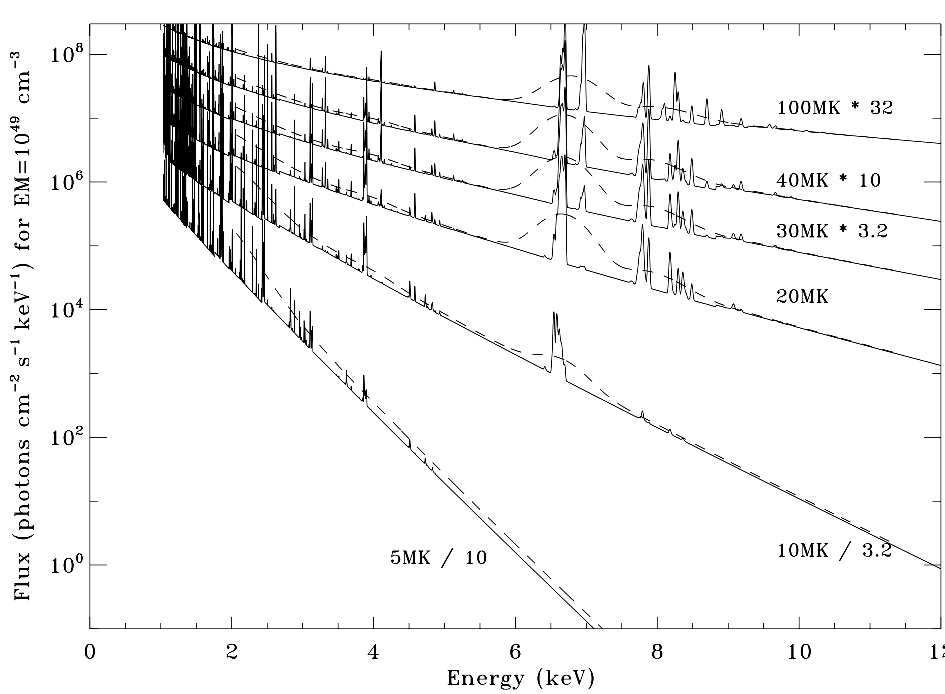

Fig. 1. CHIANTI X-ray line and continuum spectra for temperatures indicated. Solid lines: spectral resolution (FWHM) 0.05 keV; dashed lines: FWHM 0.8 keV. Coronal abundances (Feldman and Laming, 2000) and ion fractions of Mazzotta et al. (1998) are assumed.