REVIEW OF RF15-I X-RAY PHOTOMETER OBSERVATIONS

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ABSTRACT

RF15-I is a joint Czech-Polish Solar Soft/Hard X-ray broad-band photometer aboard the INTERBALL-Tail Probe satellite. By observing the Sun (since August 1995) in the energy bands: 2-3-5-8 and 10-15-30-60-120-240 keV, this photometer provides complementary data to GOES, BATSE and YOHKOH/HXT.Here, we present examples of reduced high-time resolution observations for several flares observed. These observations will be used subsequently in order to study flare energetics, statistics and diagnostics of the flare acceleration processes. Determination of important plasma parameters is envisaged. The data may support also the analysis of magnetospheric plasma.

Key words: solar physics; flares; X-ray observations

1. THE INSTRUMENT

The RF15-I solar X-ray photometer (Sylwester *et al.*, 1999) is equipped with two detector systems looking at the entire Sun:

- proportional argon gas-filled detector (Prop.)
- scintillation detector (Scint.)

The main characteristics of energy channels are summarised in Table 1. The proportional detector nominally measures the soft X-ray solar flux in the three energy channels 2-3-5-8 keV each 2 s in the flare mode. When the rate in channel s2 falls below 10 c/s threshold, the photometer switches to patrol mode and records the solar flux in two channels only (s2 and h1) each 8 s. We have found that starting from the end of 1997 the appropriate boundaries of energy channels in the proportional detector began to decrease due to ageing of the Fe^{55} calibration source. No such effect is observed for the scintillation detector. As indicated in the Table 1, the scintillation detector measures the hard X-ray flux in the five energy bands. In the energy range 10-15 keV (h1) the data are collected synchronous with the softer proportional detector channels (s1, s2, s3) each 2 s. In the upper four energy ranges the data are collected each .125 s provided that appropriate rate thresholds (40 c/s for all channels) are exceeded.

Table 1. Characteristics of RF15-I energy bands.

Channel #	ΔE [keV]	Detector	Δt [s]
s1	2 - 3	Prop.	2/8
s2	3 - 5	Prop.	2/8
s3	5 - 8	Prop.	2/8
h1	10 - 15	Scint.	2/8
h2	15 - 30	Scint.	0.125
h3	30 - 60	Scint.	0.125
h4	60 - 120	Scint.	0.125
h5	120 - 240	Scint.	0.125

2. THE OBSERVATIONS

The RF15-I was switched on August 6, 1995 and is active at present. All three softer channels and the hard channel (h1) show excellent records of the solar X-ray variability similar to that reported from the GOES satellite. Examples of RF15-I measurements are presented in Fig. 1 (upper left panel). The data are plotted each 2 s, which corresponds to the flare cadence of the instrument. For the period shown no emission above 15 keV was detected. The energy coverage of RF15-I is superior to the GOES. The four lower channels of RF15-I cover the wavelength band between 0.8 Å and 6.2 Å so the overall correlation between GOES and RF15-I should be, as expected, very good. The comparison of RF15-I and GOES records is shown in the upper right panel of Fig. 1. In order to remove statistical noise one minute averages are displayed. Reportedly, there were three small flares present in the period shown: two of B2.5 and one of B3.2 GOES class. Only for the B3.2 flare the emission above 10 keV was strong enough to be seen. Several weaker flare events (GOES class A3 - A5) can be easily distinguished on both Goes and RF15-I light-curves. In the bottom panel of Fig. 1 a part of the record (between 09 UT and 14 UT) is presented showing a quasi-periodic sequence of these small flare events. Their amplitude is seen to decrease with time. At the bottom of this panel the temperature and emission measure variations are shown as calculated from s1 and s2 data. No significant temperature variations during these small flares are observed, so the X-ray flux variability comes essentially as a result of emission measure changes.

We have found it very unexpected that there is present quiet-Sun emission in the 10-15 keV band in the period of the lowest solar activity (August 1995).

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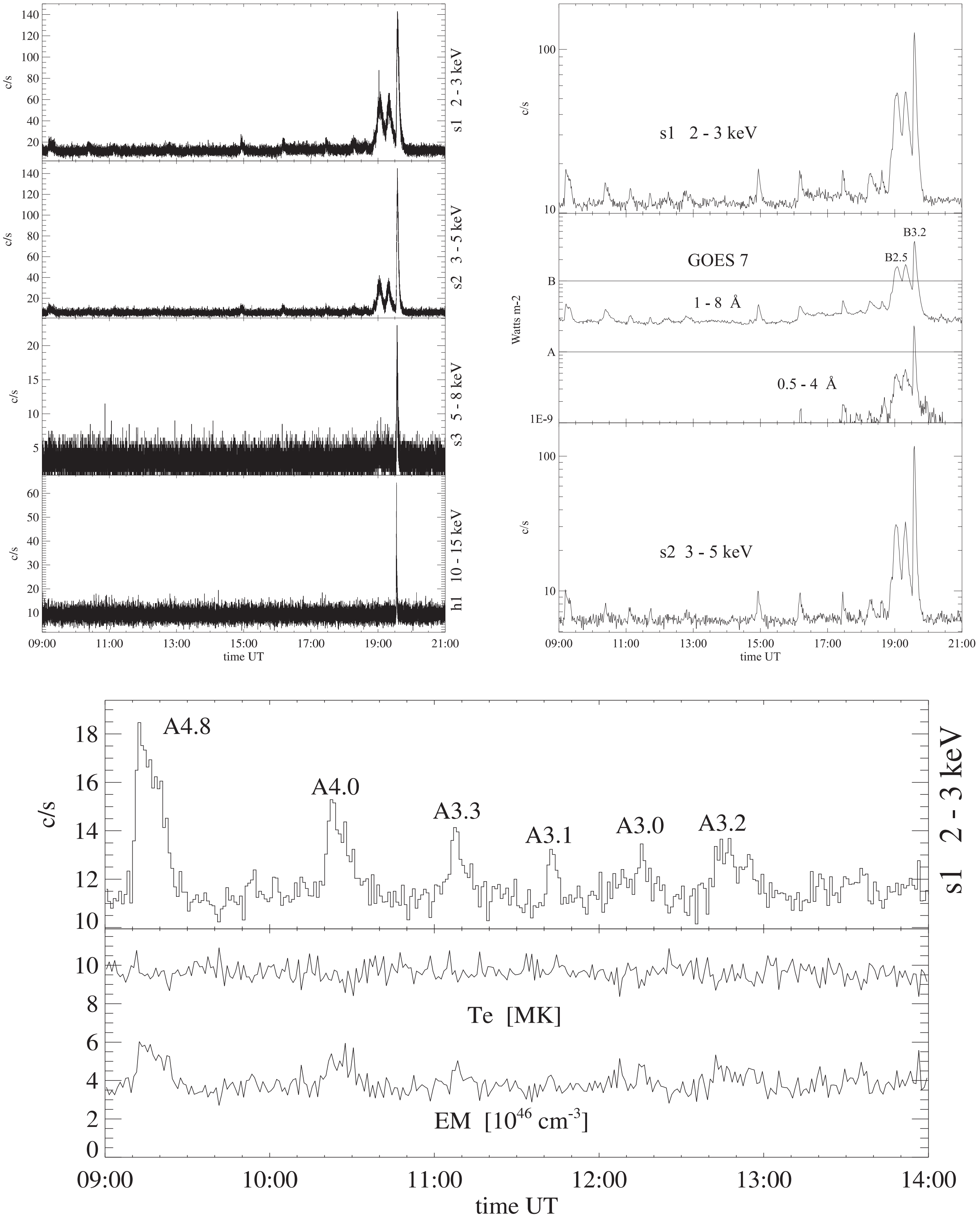

Figure 1. Upper left: Full time resolutions of RF15-I light-curves as measured on August 8, 1995. Upper right: Comparison of one minute averages detected in channel s1 and s2 of RF15-I with corresponding GOES 7 light-curves. Bottom: Example of quasi-periodic sequence of small flares observed in the softest channel with corresponding temperature and emission measure as determined (in the isothermal approximation) from s1 and s2 rates.

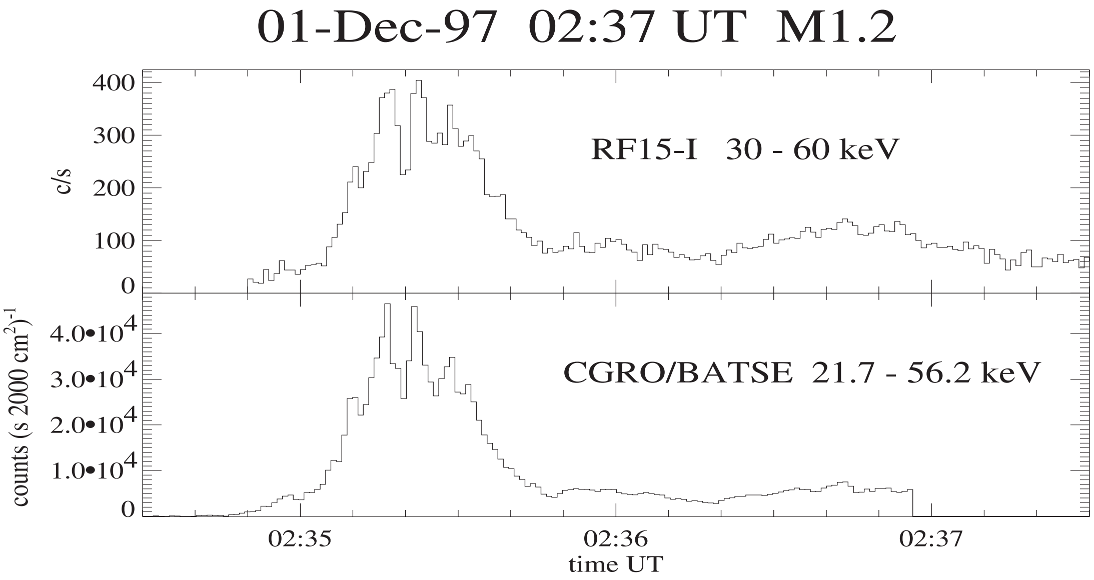

Figure 2. Comparison of CGRO/Batse and channel h3 of RF15-I light-curves.

Since the RF15-I observes the solar X-ray radiation in the range covering both soft and hard bands, it is important to make the cross-comparison of the observed variability for the harder part of the spectra also. In Fig. 2 we present detailed comparison of CGRO/Batse and RF15-I observations. BATSE data represent fluences in the 21.7 - 56.2 keV band and RF15-I variations has been plotted for h3 (30 - 60 keV) channel. It is seen that the two compares very well to the smallest detail.

The orbital period of Interball satellite is ≃ 96 hours. It is much longer period as compared with Yohkoh or CGRO (≃ 95 min). Therefore it often happens that Interball observes flares during frequent Yohkoh or CGRO nights. These many RF15-I observations provide a valuable complement to the hard X-ray monitoring of the solar variability. In Fig. 3 we present another example of comparison between CGRO/Batse and RF15-I observations, but in wider energy bands (BATSE channel 0 (25.8 - 59.6 keV) and 1 (∼60 - 110 keV) and RF15-I channel h3 (30 - 60 keV) and h4 (60 - 120 keV)).

During the first three years of observation, RF15-I has secured about 1800 well-observed flares. Well-observed means that the entire flare profile has been followed and no signature of magnetospheric particle contamination is seen. The six of flares observed were of X, 48 of M and 576 of C GOES class. All flares with GOES class above C3 (256) have clear emission component seen in channel h2 (15 - 30 keV) and all flares above M3 class (20) have the emission in channel h3 (30 - 60 keV) noticeable. It is known that the GOES class of flares does not necessarily represents the flare high energy spectra properly (e.g. McDonald *et al.*, 1999). This effect is especially well seen in RF15-I measurements. There are numerous cases where B class flare spectra are harder than C or even M class flare spectra. We illustrate this effect in Figs. 4 and 5.

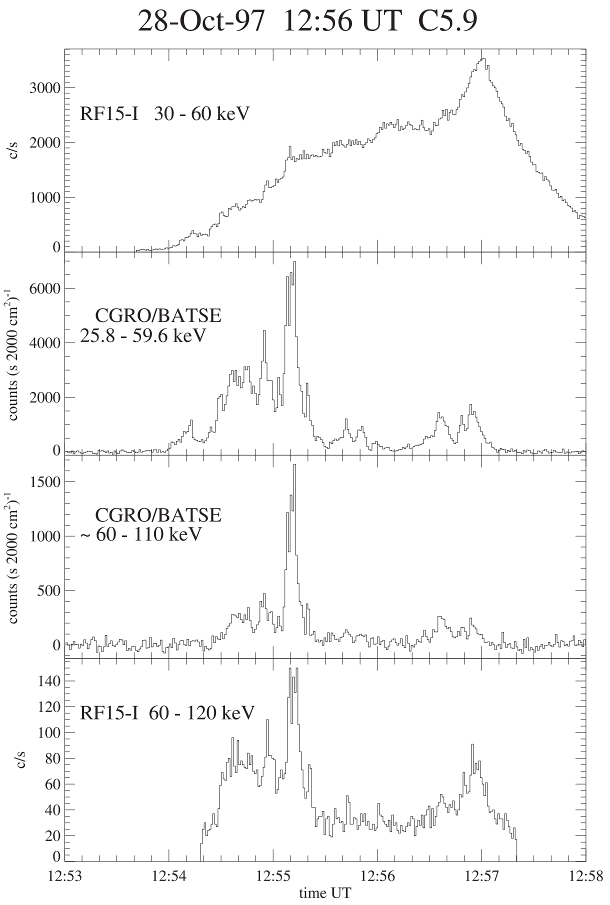

Figure 3. Comparison of CGRO/Batse channel 0 and 1 with RF15-I channel h3 and h4.

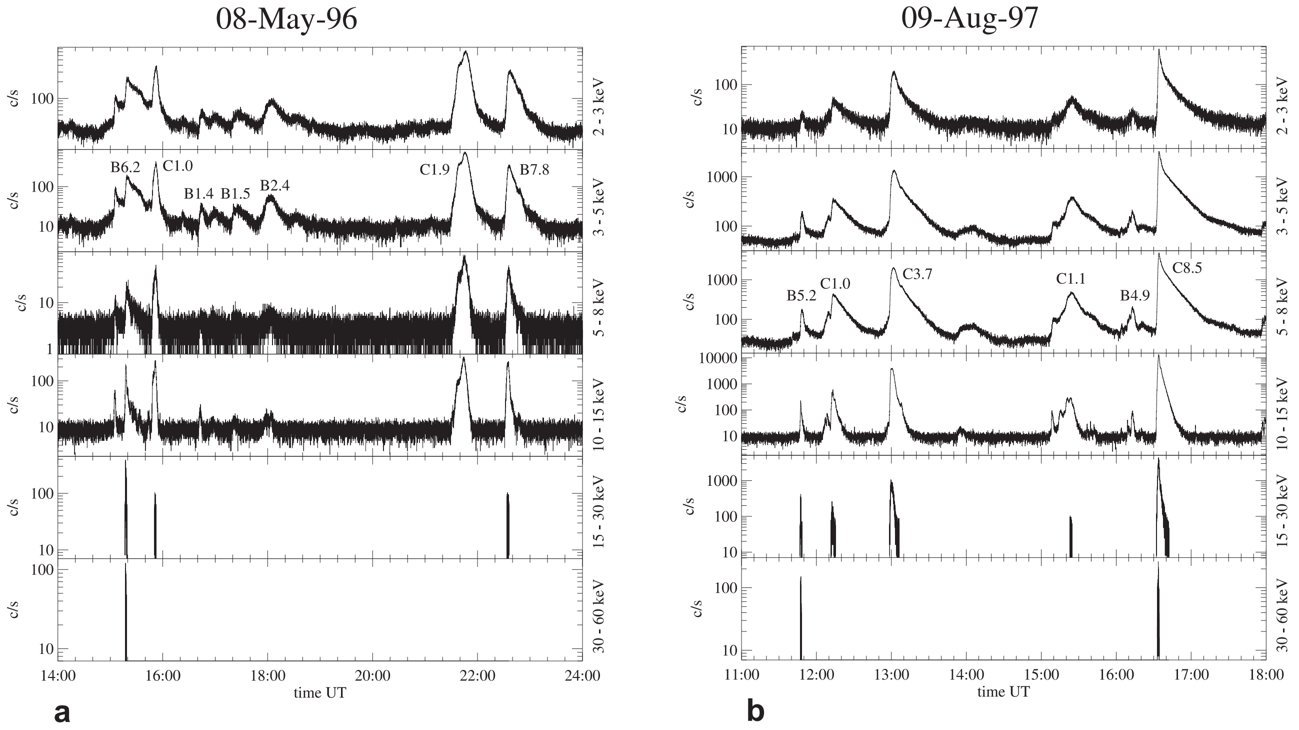

Figure 4. Examples of flares with very different soft/hard emission characteristics as seen by RF15-I.

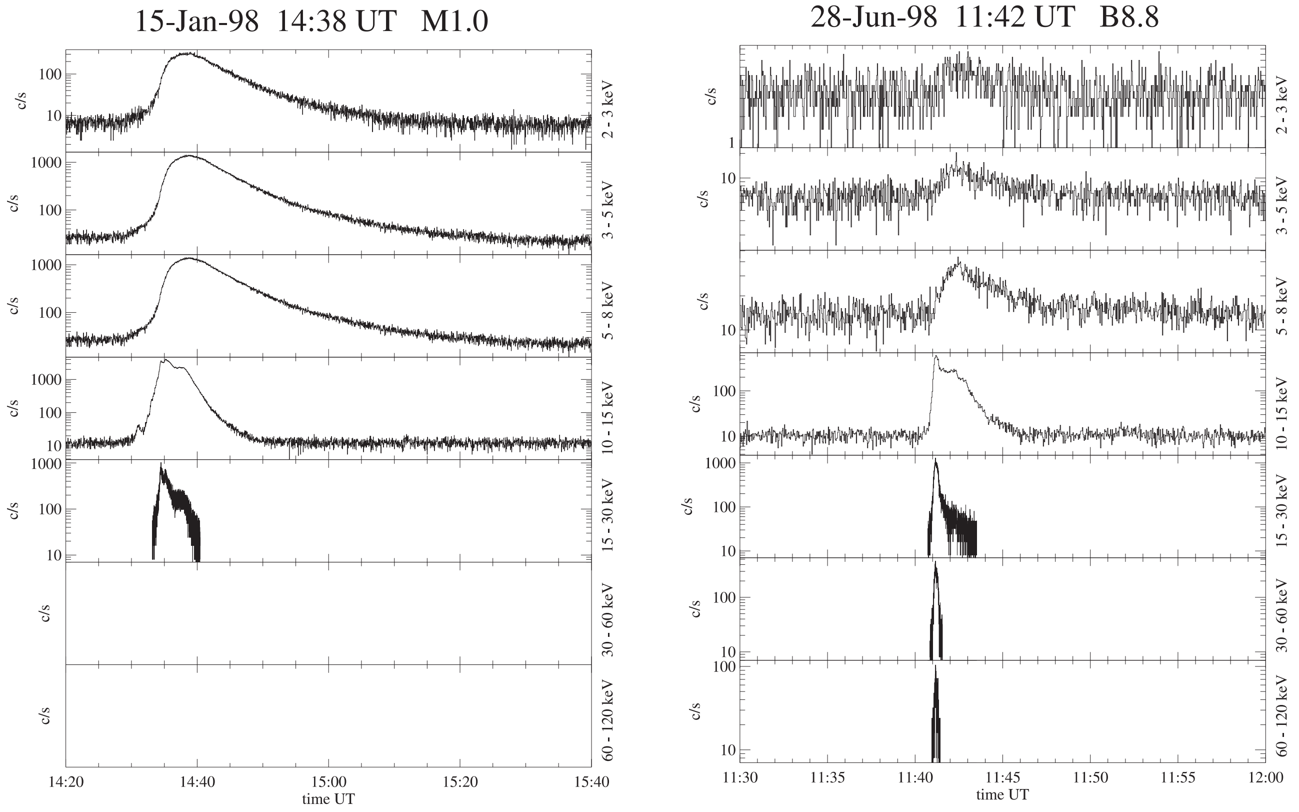

Figure 5. Comparison of M1.0 and B8.8 flares with unusual hardness ratios.

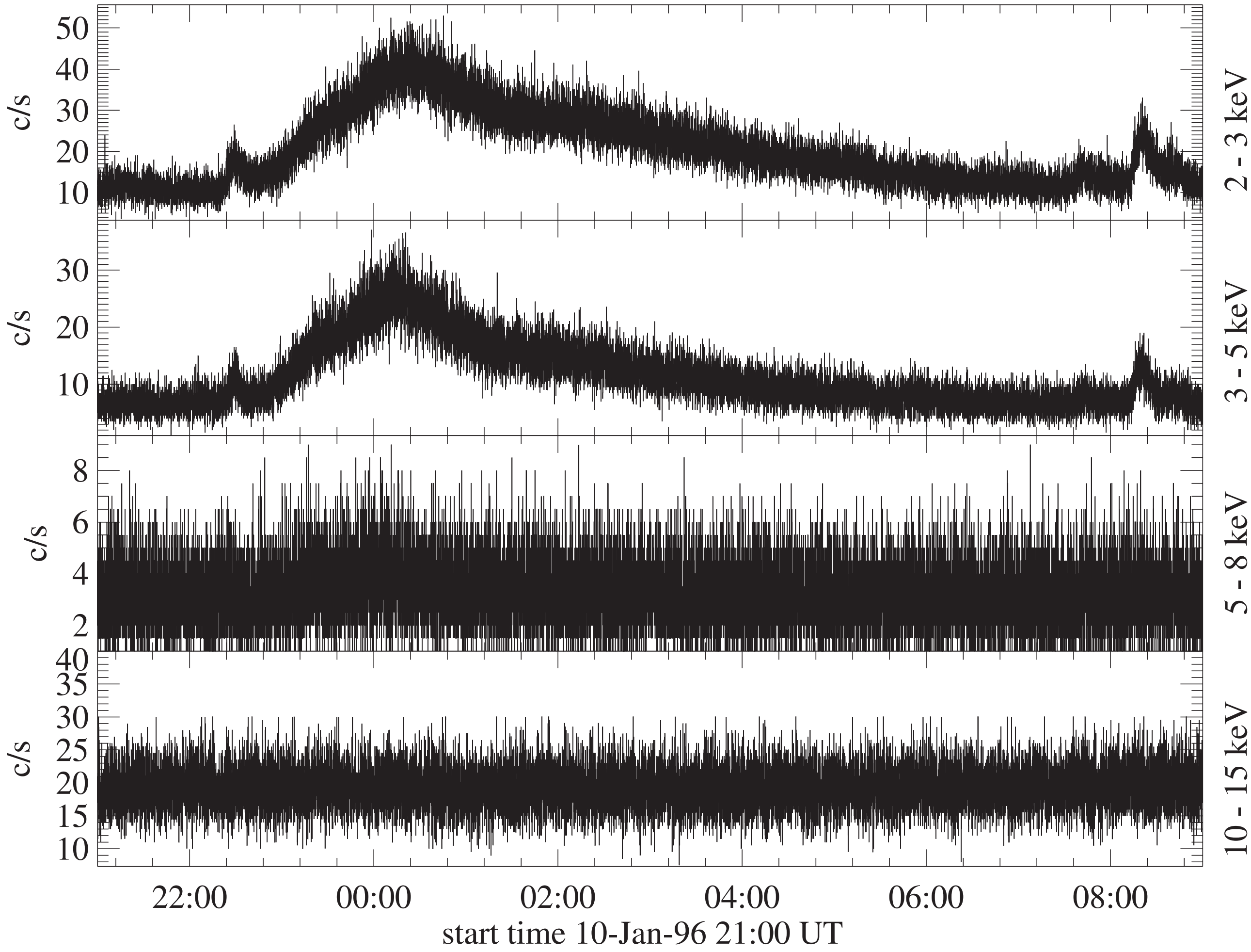

Figure 6. Example of super-soft Long Duration Event (LDE) of only ∼ B1.0 GOES class.

In Fig. 4 we present the light curves covering a series of flares observed on May 8, 1996 and August 9, 1997. For May 8, a B6.2 flare (Fig. 4a) at 1518 UT has clear hard emission component (above 30 keV) and it's emission in 15 - 30 keV range is stronger than respective emission of the following C1.0 flare at 1551 UT. In contrast, the C1.9 flare observed at 2145 UT has no detectable emission seen above 15 keV. In another striking example, (for August 9, 1997) a B5.2 flare (Fig. 4b) at 1148 UT has been observed to possess significant emission extending above 30 keV with the intensity similar to the stronger C8.5 flare at 1634 UT. On the contrary, the three C class flares observed between 12 and 16 UT have no hard X-ray emission component above 30 keV.

From the beginning of the Interball mission, we have observed many flares of class C not having significant emission above 15 keV and several class M events not accompanied with the emission above 30 keV. On the contrary, we have observed numerous flares of class B with significant emission above 30 keV. This frequency occurrence is somewhat unexpected. The statistical analysis of X-ray spectra hardness for the flares investigated is in progress. An example of the discussed behaviour is presented in Fig. 5 where the M1.0 flare is apparently lacking the emission above 30 keV. This event is to be compared with the "unimportant" B8.8 flare for which the significant emission above 60 keV is pronounced.

As the RF15-I is capable of observing very week events, we have identified (possibly for the first time) a category of soft, low intensity, long duration flares. An example is presented in Fig. 6. The flare shown is of B1.0 GOES class only. However, the decay time for this event was ≈ 8 hours. The rise time was about 2 hours for this flare. Since no emission has been observed above 10 keV, corresponding plasma temperature has to be low for this peculiar event.

The X-ray detectors have been intended to switch-off during the crossing of Van Allen radiation belts. The threshold for switching has been set up in the way that only important passages have had to activate the switch-off. Because of setting this threshold level at the relatively high value, the RF15−I recorded many events which may be related to the passage of magnetospheric structures. The signatures can be identified in the data related to crossing of polar caps, aurora, magnetosheath and boundary layers. Occasionally we have ob-

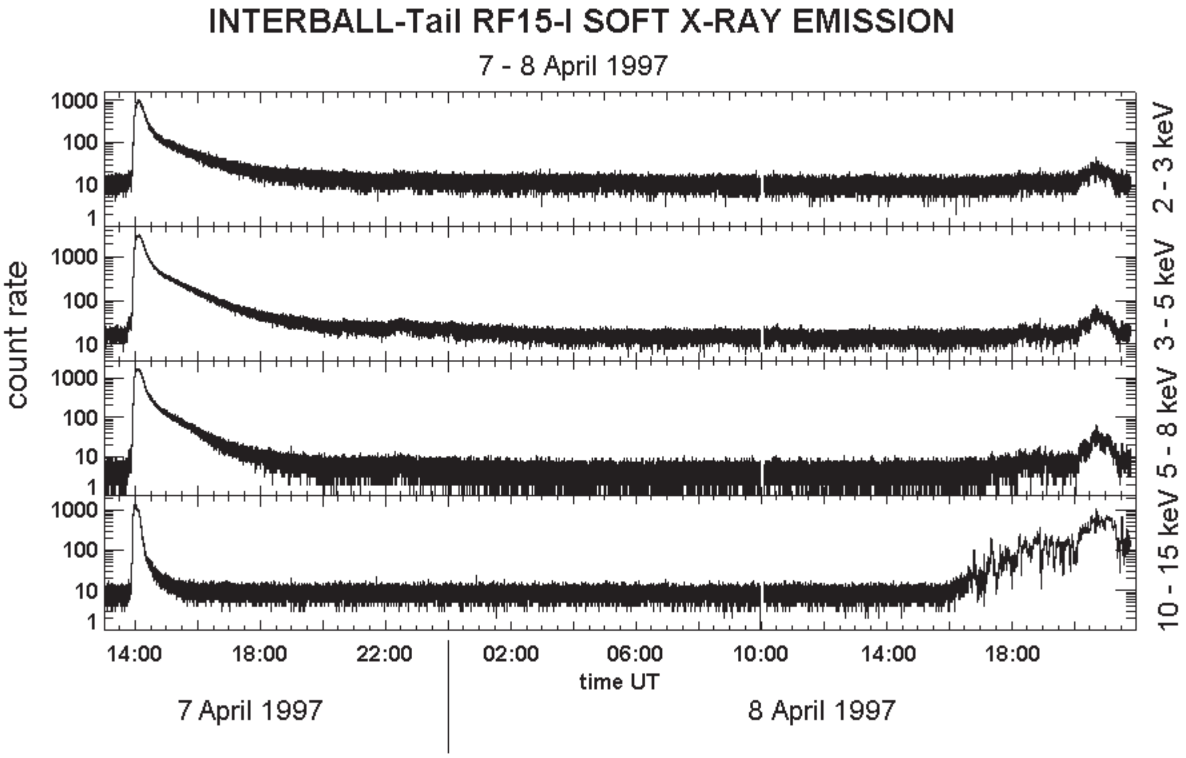

Figure 7. The entire history of April 7, 1997 CME flare event as recorded by RF15-I. The X-ray radiation from this event (GOES class C6.8) is seen around 1400 UT. Around 1600 UT on April 8 SEP particles from this flare reached the vicinity of INTERBALL which caused increased signal. We can see that the signal in the higher energy band (h1) started to rise first.

served particle events of solar origin (SEP) following solar flares and/or CME's events. In Fig. 7 we present example of CME related emission recorded on April 7, 1997. This flare has been well observed by EIT and LASCO instruments (http://www-istp.gsfc.nasa.gov/istp/cloud_apr97). Approximately an hour after this flare had been observed in X-rays, the large CME structure had developed. Related energetic particles reached the INTERBALL-Tail satellite outside the magnetosphere on April 8, 1997 around 1600 UT and caused substantial signal recorded by RF15-I photometer.

3. SUMMARY

We present examples of reduced high-time resolution observations of RF-15I soft/hard X-ray photometer placed aboard the INTERBALL-Tail Probe. RF-15I is presently the most sensitive solar photometer ever flown in the 10 - 15 keV and the only X-Ray instrument measuring the integral solar flux in the energy range 2 - 240 keV. By observing the Sun since August 1995 this photometer has provided complementary data to GOES, BATSE and YOHKOH/HXT measurements. Collected data are constituting a rich source for investigations of flare energetics and statistics. The observations collected will be used in order to make diagnostics of acceleration processes and for determination of physically important flaring plasma parameters. Moreover, still growing RF15-I database will allow for studies of various energetic particle events present inside the Earth magnetosphere. These data may be also useful in analysis of the phenomena connected to space weather research. All the data yet reformatted are accessible on-line from our web site: http://www.cbk.pan.wroc.pl/rf15-i_www/default.htm.

ACKNOWLEDGMENTS

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