Investigation of Extreme Livetime Situations by Comparing HRBM and Telescope Mode Data

29 January 1997, UNH G. Rank

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Abstract

The COMPTEL Telescope Mode can suffer severe livetime restrictions during certain conditions, such as intense solar flares and GRB's. With the aid of housekeeping data, the instrumental livetime can be calculated for each superpaket and the measurement corrected. The purpose of this report is to study the reliability of our livetime correction for the telescope data.

COMPTEL uses two independent modes in parallel: the full telescope mode and the single detector mode. In contrast to the telescope, the single detector mode is only marginally affected by livetime losses even during extreme conditions. As a test for the telescope livetime correction, we compare the time profiles of both modes during the very intense solar flare on 11 June 1991.

We conclude that the livetime correction works well even for low livetimes. However, during the most extreme situations where the livetime is below about 4%, systematic errors influence the livetime calculation. We obtained a signal about 40% lower than expected during these conditions.

Analysis Method

For our test we chose the solar flare on 11 June 1991. This flare event was the most intense one observed in COMPTEL's field-of-view. The telescope livetime during the impulsive phase was as low as about 2.3%. A plot of the composite livetime and the major contributing components during the flare is shown in figure 1.

We compare the time profiles of the telescope and the single detector mode. We use count rates, not absolute flux values. Therefore, the rates are not expected to be the same, but their ratio should be constant. In the following plots, we align both time profiles for times late in the flare, where the telescope livetime is already high enough and the Earth horizon angle is still quite large.

As we study count rates, the different energy response must be taken into account. The burst detector is characterized by a broad NaI energy response, while the telescope has a much sharper response due to the application of an ARM selection. The different energy responses can be taken into account in two ways:
(1) As long as we look at large energy intervals, the different energy resolutions do not greatly influence the resulting rates.
(2) If we look at a narrow band, as the 2.2 MeV line region, it might be useful to open up the

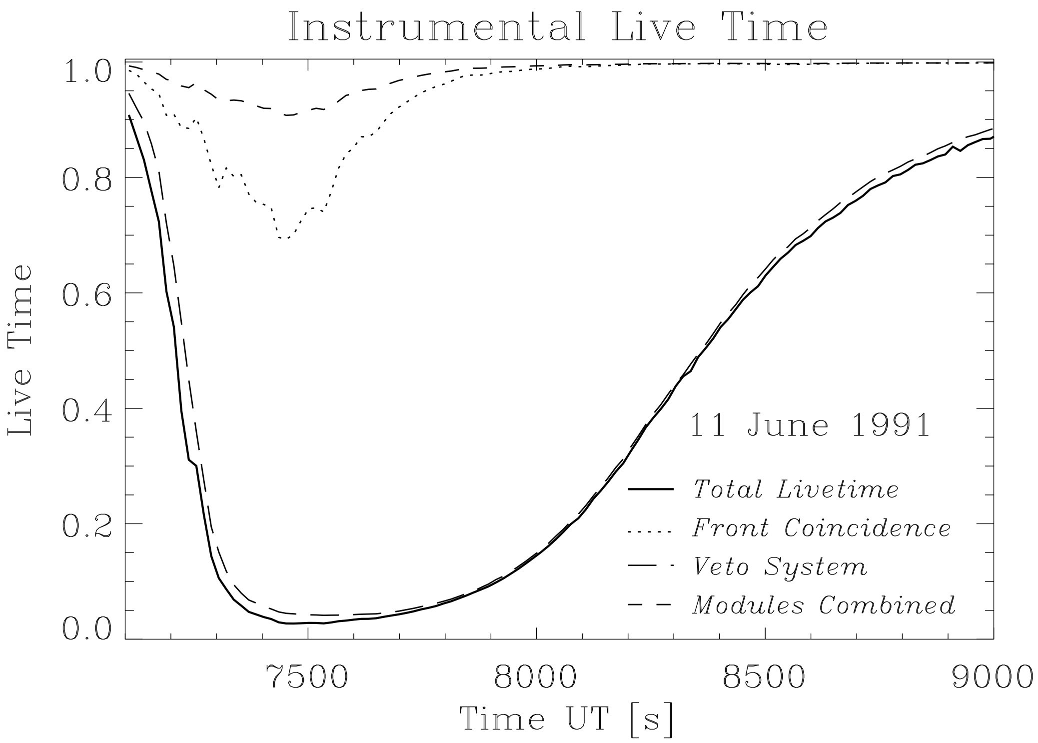

Figure 1: *Livetime behaviour for the 11 June 1991 flare.*

ARM window of the telescope mode. This degrades the energy resolution of the telescope and diminishes the differences in the energy response.

HRBM Data

At the beginning of the mission, only one of the two single burst modules was working: the High-Range Burst Mode (HRBM) detector D2-7, which is sensitive in the energy range of about 0.6–11 MeV. The data for the HRBM have been provided by Raid Suleiman for the three energy intervals of 0.7–11 MeV, 2.0–2.4 MeV and 3.0–7.0 MeV. The time binning for the burst mode is fixed. In our case, it was set to 12 s time bins, starting at 7185 s UT. In order to get overlapping bins, we chose multiples of 12 s for the telescope analysis, starting also at 7185 s UT.

The datasets contain count rates, which are background subtracted. The livetime correction has already been performed in the routine processing with correction factors below about 1%. For details on the HRBM analysis, see the masters thesis of Raid Suleiman (1995).

Telescope Mode Data

A detailed description of the data analysis is given later in this report. The flare data are taken from EVP-UNH-14762. Four background datasets are available, taken from EVP-UNH-14757 and EVP-UNH-14759. These datasets were created by EVPSLC and include the latest TOF and EHA corrections.

Selection	PHB	EHA	TOF	ARM
Set 1	$0° - 50°$	$-60° - 180°$	$115° - 130°$	$3.0\,\sigma$
Set 2	$0° - 50°$	$10° - 180°$	$115° - 130°$	$3.0\,\sigma$
Set 3	$0° - 50°$	$-60° - 180°$	$115° - 130°$	$90.0°$

Table 1: *Data selection sets used in this study. The other parameters are set to: D1E* $0.65 - 20.0\,MeV$, *D2E* $0.70 - 30.0\,MeV$, *PSD* $0 - 110\,chs$.

The correction for livetime is based on the results of Rob van Dijk's routine ENGSHD (the combined livetimes). For intense flares such as the 11 June flare, the scaler rates used for the livetime calculation are much larger than the range that was studied during COMPTEL's calibration phase. This might introduce systematic uncertainties in the calculations. For more details on the calculation of livetimes, see the Ph.D. thesis of Rob van Dijk (1996).

The event selections that were applied are given in table 1. Selection set 1 is the standard selecton set, which maximizes the signal-to-noise ratio. It can be seen that the EHA window is fairly wide open. This takes into account the fact that the impulsive phase of the flare occured close to sunrise. Selection set 2 tests the influence of this peculiar EHA choice, raising the lower limit to a value of $+10°$. Selection set 3 uses an unrestricted ARM value to disable the suppression of the Compton tail in the telescope mode. This is applied to the narrow 2.0-2.4 MeV region to decrease the differences in the energy response between the telescope and the HRBM.

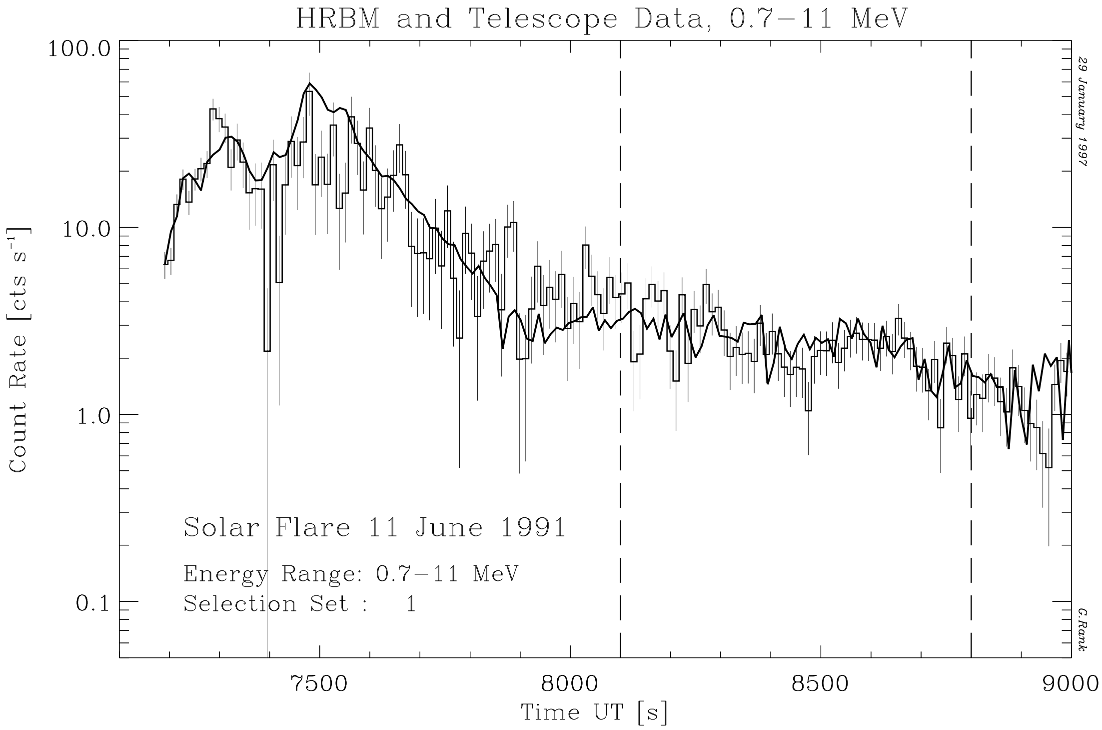

Figure 2: *Relative values of counting rates for the energy range 0.7 – 11 MeV. A binning of 12 seconds was used. The profiles are aligned for 8300 – 8800 s. The error bars represent statistical sampling errors only. (See text for details)*

Results for the Energy Interval 0.7 - 11 MeV

Figure 2 shows both datasets for the same time binning of 12 seconds (according to the HRBM binning). The HRBM data are plotted as solid curve, the telescope data as the histogram with error bars. They have been aligned for the interval from 8100 to 8800 seconds (between dashed lines) for this and all following plots. Selection set 1 has been used for the telescope analysis.

In figure 3 the same datasets are plotted in the same way, but a different binning of 48 seconds was used for the telescope. In the lower plot the difference between the time profiles is shown, using the same scaling factor as found above (i.e. the difference for the alignment interval is zero).

It is important to note, that the telescope data were corrected for livetime, but the error of the applied correction factor was set to zero! This means, that the error bars in figures 2 and the following represent only statistical sampling errors.

Away from the flare event, both curves show reasonable agreement. Around 7500 s the telescope mode under-estimates the signal by as much as 40%, relative to the HRBM curve. As the comparison with figure 1 shows, this is also the time period of minimal livetime. The duration of the interval with the composite livetime $< 4\%$ lasts about 200 sec (from 7370 s to 7570 s UT).

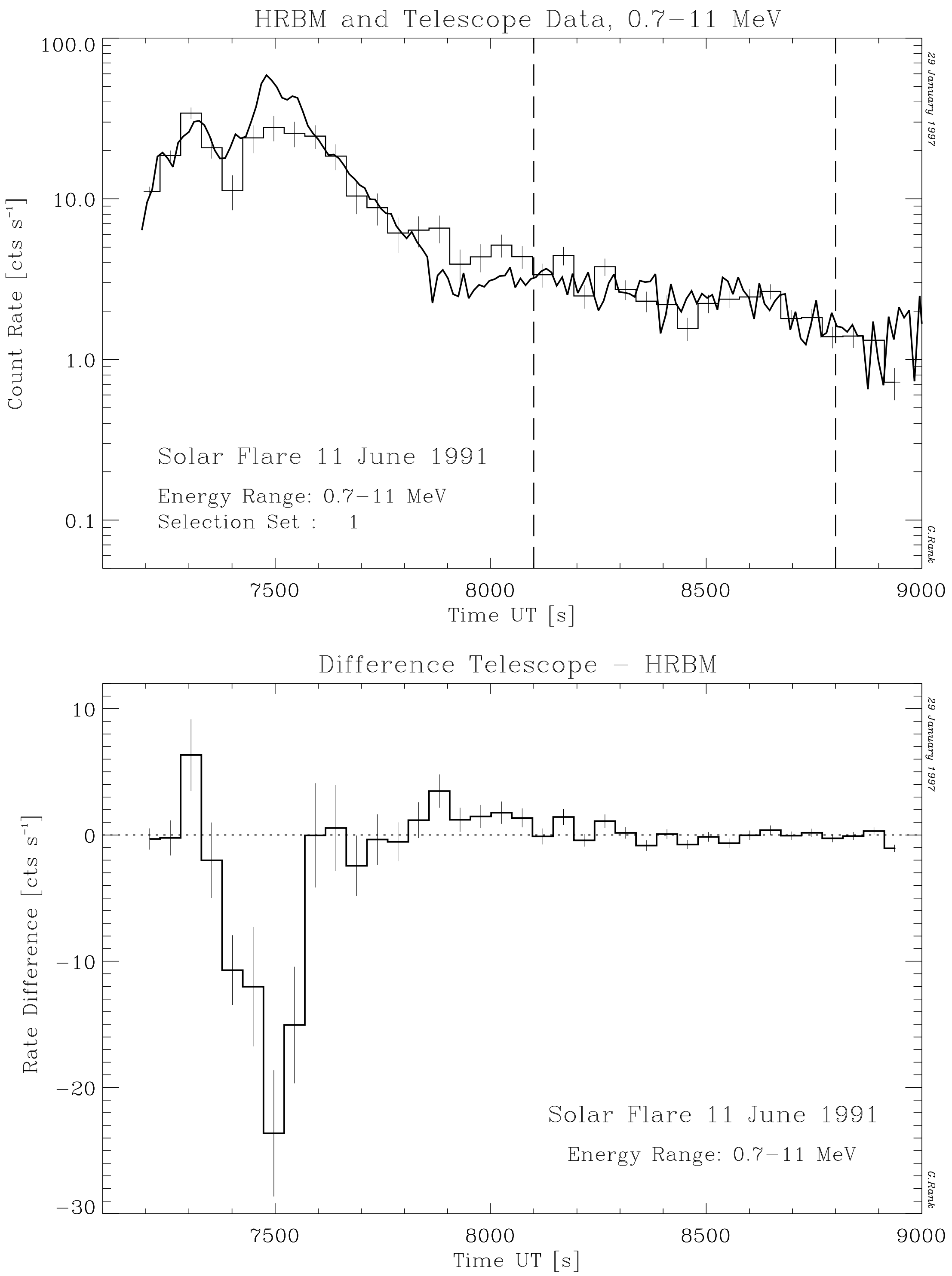

Figure 3: *Relative values and ratio of counting rates for 0.7 – 11 MeV. A binning of 48 seconds was used.*

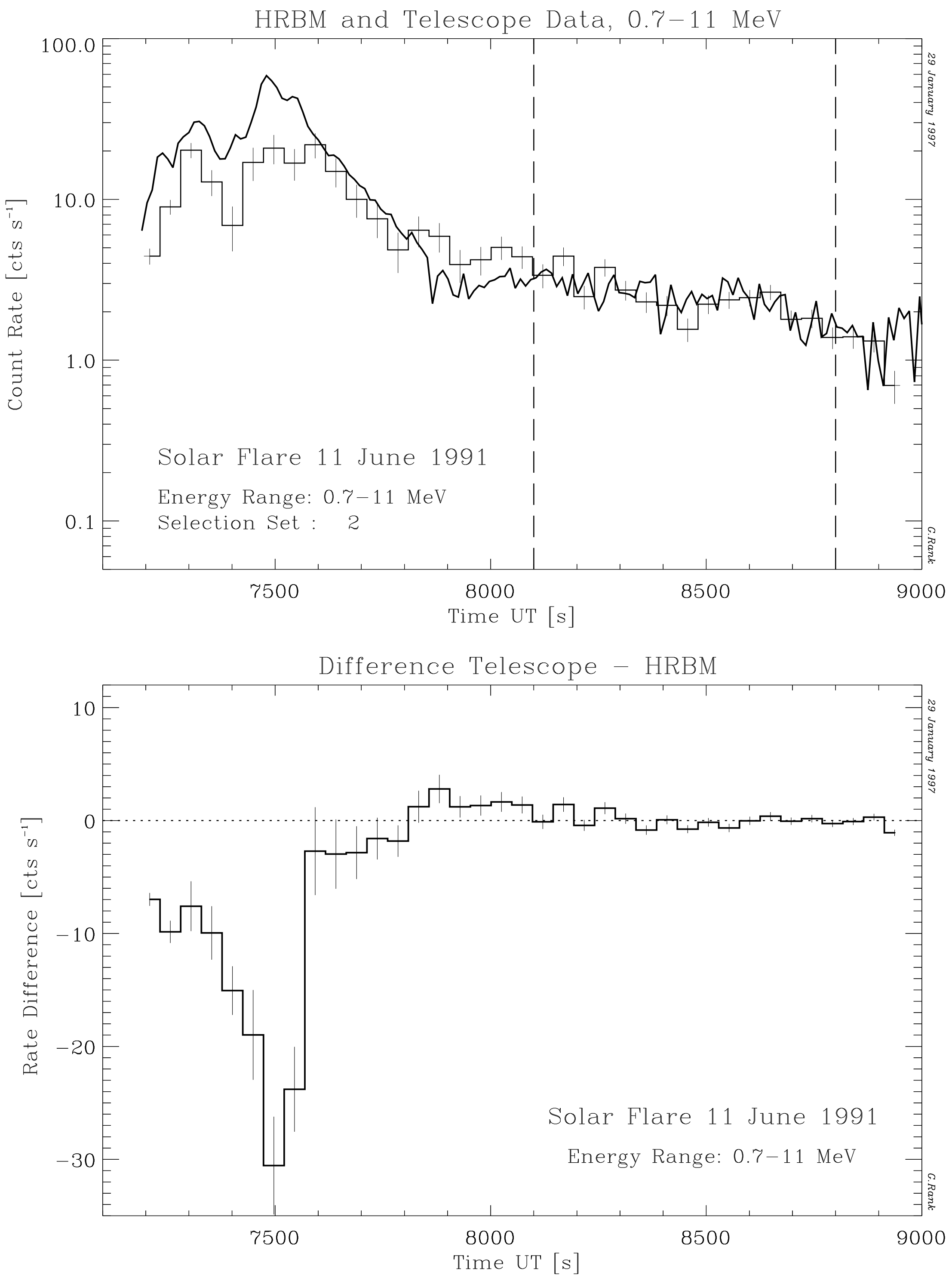

Figure 4: *Relative values of counting rates for 0.7 – 11 MeV. This comparison was done with a more restricted EHA angle (Selection 2). A binning of 48 seconds was used.*

To check the setting of the EHA window, selection set 2 is used in figure 4, applying a value of 10° to the lower EHA limit. At the beginning of the oservation period, only a very low count rate is registered. This clearly shows, that an open ARM angle is essential, when dealing with a strong source close to the Earth's horizon.

Results for the Energy Interval 2.0 – 2.4 MeV

Figure 5 shows the comparison for the energy range 2.0–2.4 MeV. This region is particularly interesting, since it contains the 2.223 MeV neutron capture line.

For this narrow range the differences of the energy responses might affect the used method. Therefore, we look also at a selection where the ARM angle is completely open (figure 6). Figures 5 and 6 reveal no significant differences. This shows that the different response functions do not affect the results of this analysis.

The statistical errors in figure 5 are larger than in figure 3 (for 0.0–11 MeV), due to a lower count rate in the narrow energy range. But the low estimate of the telescope around 7500 s is clearly present. During the time interval 7370 s to 7570 s again the flux is lower by about 40-50%. Like before, a tendency to over-estimate the flux around 7800 s to 8100 s is also visible, although still close to the statistical error ranges.

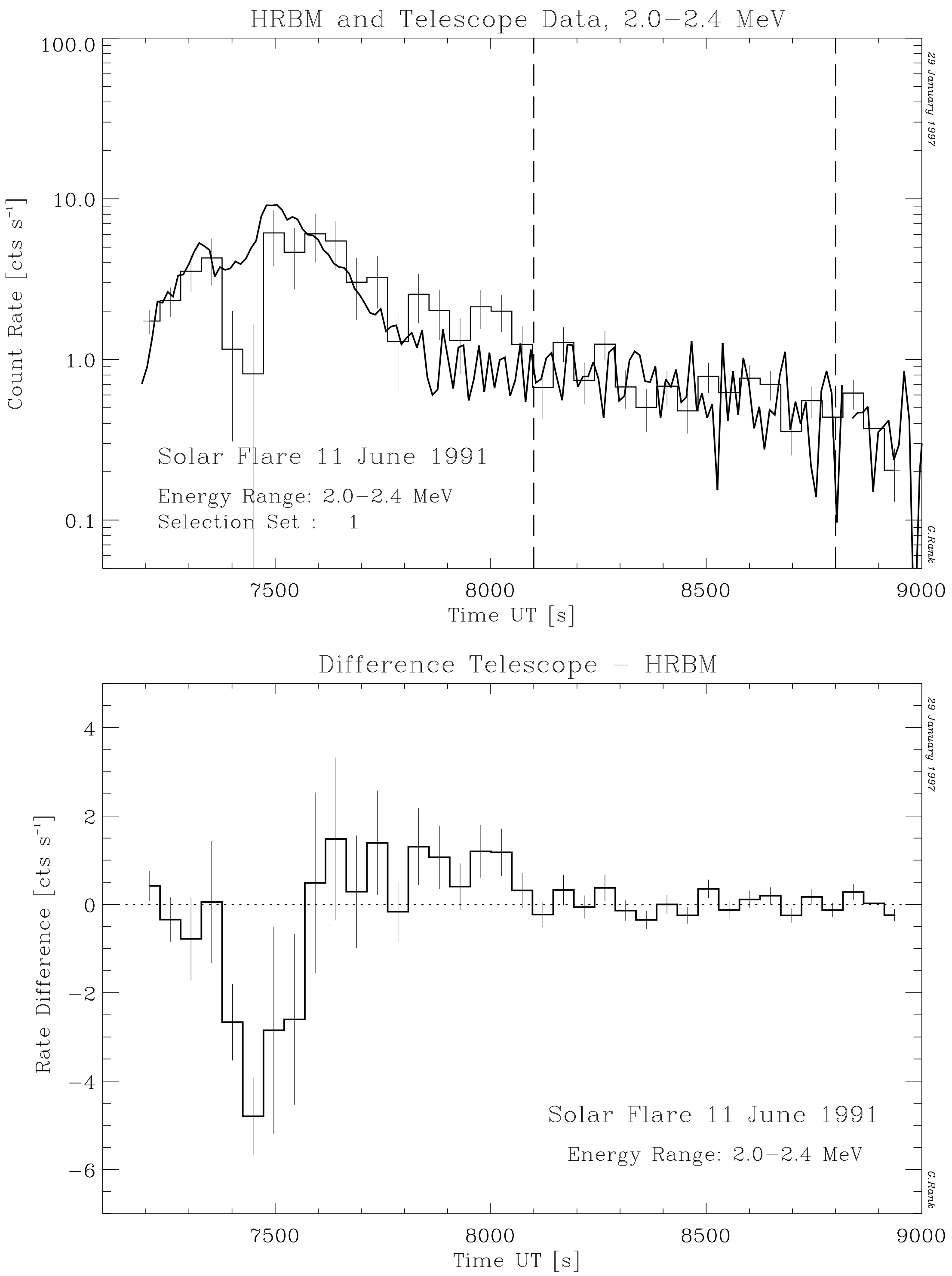

Figure 5: *Relative values and ratio of counting rates for 2.0 – 2.4 MeV. A binning of 48 seconds was used.*

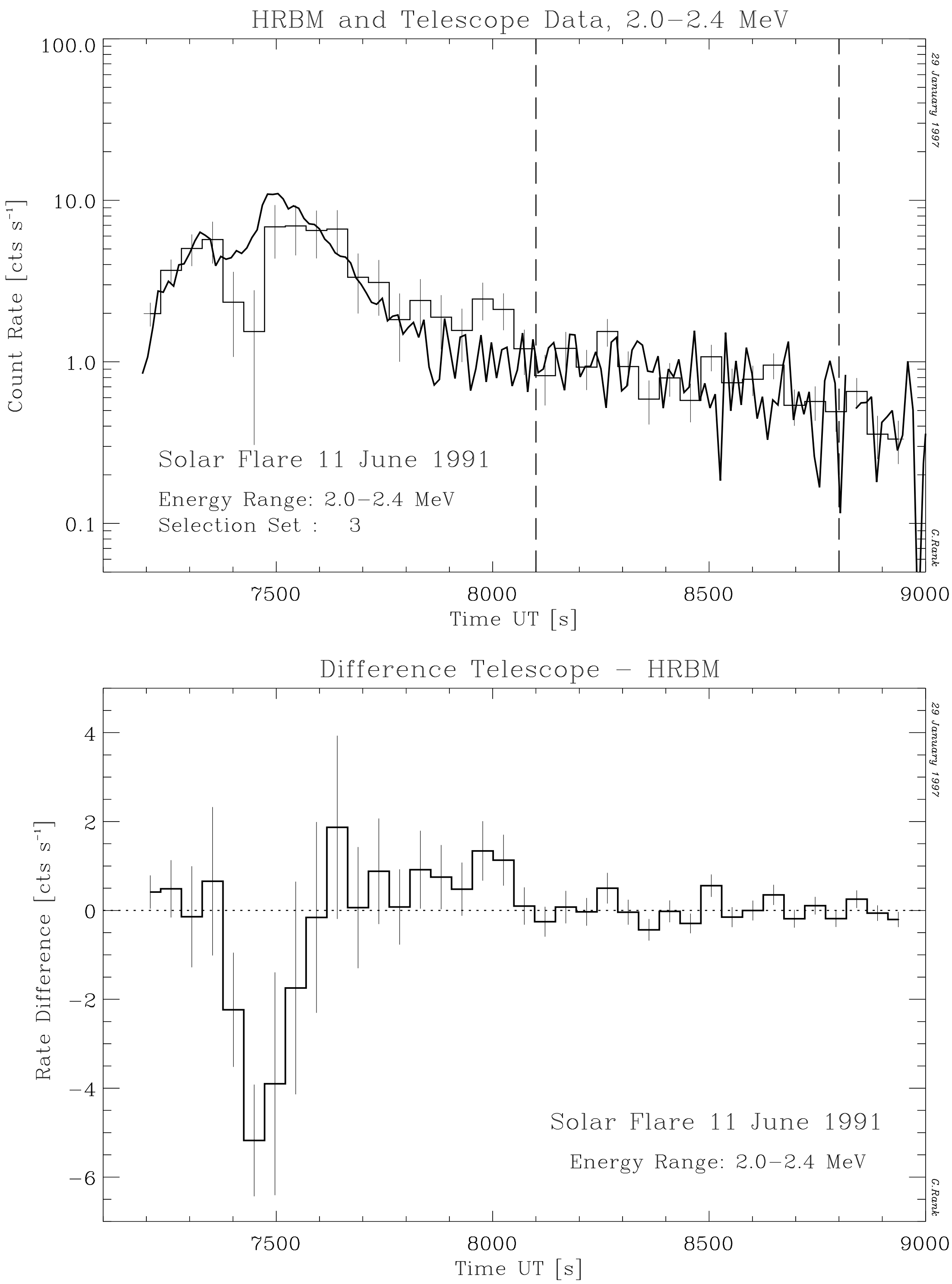

Figure 6: *Relative values and ratio of counting rates for 2.0 – 2.4 MeV. This comparison was done with an open ARM window (Selection 3). A binning of 48 seconds was used.*

Can livetime uncertainties explain the deviations?

The process of event sampling:
Up to now, only statistical errors of the sampling process have been taken into account. To find out if livetime uncertainty can explain the deviations that we have found, we first examine the process of data aquisition more closely. The telescope analysis basically consists of the following steps:
1) Time periods for the flare and four background periods are specified.
2) For each time period and each time bin the events are corrected for livetime losses and are summed.
3) For each time period and each time bin the background periods are averaged and then the agerage background signal is subtracted from the flare signal.

2) The sampling process for the flare and each of the background signals can be written as

$$S_X = \sum_{j=1}^{N_X} [\ 1 \cdot l_{Xj}\ ]$$

where X stands for Flare, Background 1, ... , Background 4. Each event ("1") is corrected by the appropriate livetime factor l_{Xj} and then all events in the bin are summed.

This is identical to multiplying the number of counts with the livetime l_X, as long as l_X is constant (e.g. the time bin includes only one superpaket, or l_X is only slowly varying):

$$S_X = l_X \cdot \sum_{j=1}^{N_X} [\,1\,] = l_X \cdot N_X$$

We use the first equation for the sampling process. To investigate the errors, we use the second equation, since it allows us to separate counting statistics from the livetime uncertainty in the error calculation. If the bin spans more than one superpaket, we use the maximal relative error that occurs within the bin, instead of an average one. So the livetime errors are somewhat over-estimated. Now we can write for the statistical error:

$$\Delta S_X = S_X \cdot \sqrt{(\frac{\Delta N_X}{N_X})^2 + (\frac{\Delta l_X}{l_X})^2} = S_X \cdot \sqrt{\frac{1}{N_X} + (\frac{\Delta l_X}{l_X})^2}$$

We have used Poisson statistics for the counting errors. For the livetimes, however, the error must be estimated independently (see next paragraph). The relative error of the livetime $\Delta l_X / l_X$ represents the maximal relative error in that bin.

3) For the total corrected signal S we get

$$S = S_F - S_B$$

and the statistical error is

$$\Delta S = \sqrt{(\Delta S_F)^2 + (\Delta S_B)^2}$$

where S_F and S_B stands for flare and background signal, respectively. The background signal is averaged from four background datsets according to

$$S_B = \frac{1}{4}\sum_{j=1}^{4}\left[\, S_{Bj}\,\right]$$

and the error is

$$\Delta S_B = \frac{1}{4}\sqrt{\sum \Delta S_{Bj}^2}.$$

Errors of the livetime correction factor:
The above is a complete discription of the uncertainties in the process of data aquisition. What remains to be studied is the uncertinty on the livetime correction factor Δl_X. We look at two ways to determine this value:
(1) An estimate of the statistical error of the composite livetime can be derived directly from the statistics of the scalars. Doing this, we get an unrealistically small error, due to the large scalar rates involved. Especially for the veto rates, which acount for most of the livetime losses, the rates go up during the flare and the error estimates decrease during these times.
(2) Another way to get an estimate of the uncertainty of the correction factor is to look at the distribution of the minitelescope livetimes. A study of this distribution was also done by Georg Weidenspointner (1996) for a large amount of data. However, his study was restricted to livetimes above ∼60% (only composite livetimes greater than 10 s within a superpaket have been accepted). All deviations from the mean composite livetime were reported to be below 0.3%.
Figure 7 shows the composite livetime (i.e. the average of all minitelescope livetimes with ”on”-status) and the standard deviation of the minitelescope livetimes (relative value in percent) for the 11 June flare. Before and after the flare the value is well within the range quoted in Georg Weidenspointner's report. During the flare, however, a standard deviation of up to 5% occurs.
The estimate of the uncertainties derived in the second way seems to be more realistic, since the value of the relative error is larger for the extreme situations.

Do the determined livetime uncertainlies explain the deviations?
We use the standard deviation of the minitelescope livetimes as the livetime error and re-calculate the data in figure 3. We find, that even for the worst case (lowest livetime, highest error: time bin around 7500 sec) the error induced by the correction does not influence the total error by much. The statistical errors of both the flare and each background period for this time bin are about 20%, all larger than the correction uncertainly of 5%.
In figure 8 we show the same result as in figure 3, but taking into account 10 times the errors in the correction factor! It can be seen, that even now the statistical uncertainty can not fully explain the deviations. This demonstrates that the deviations are at least in part due to systematic uncertainties.

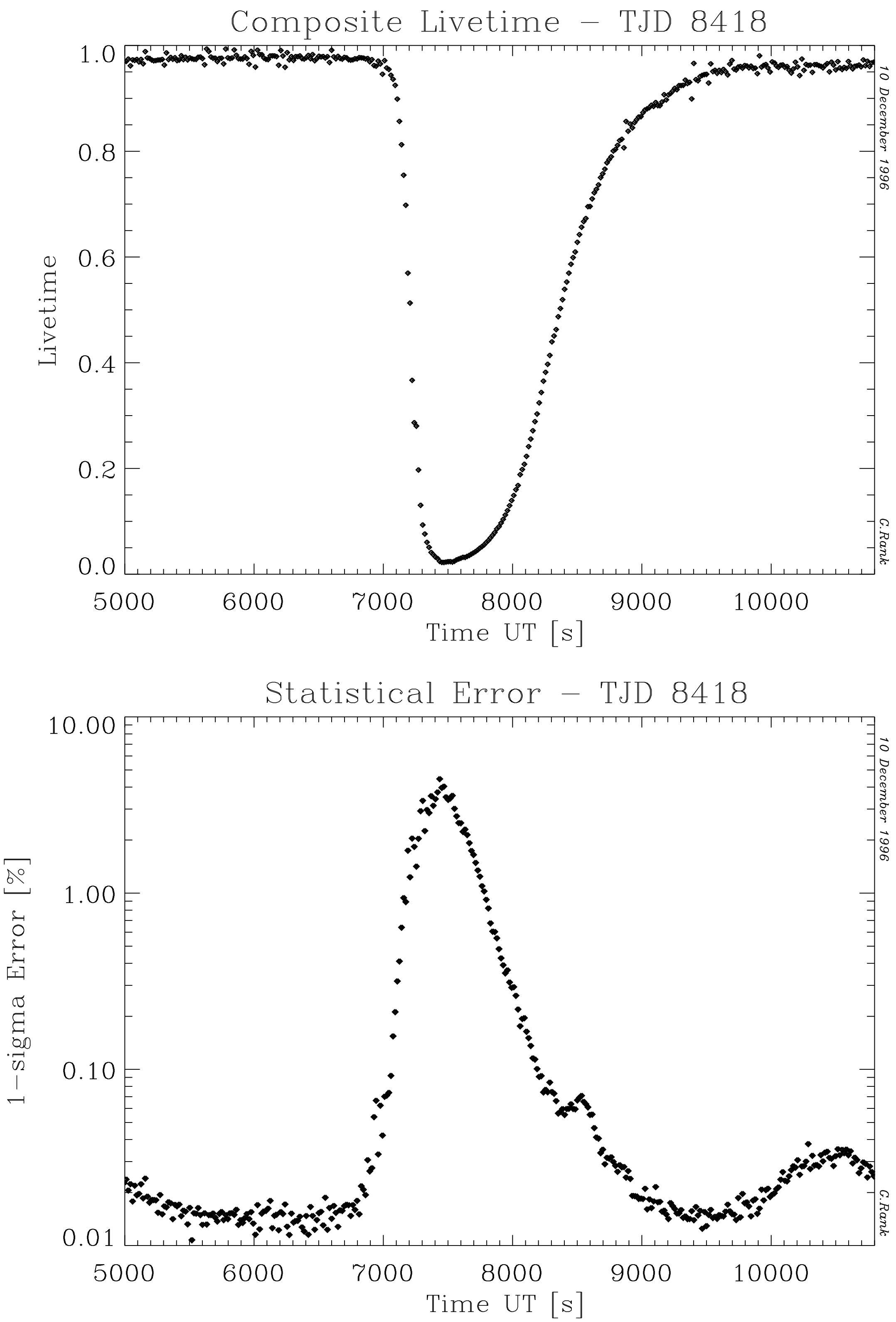

Figure 7: *livetime and statistical error of minitelescopes for 11 June 1991.*

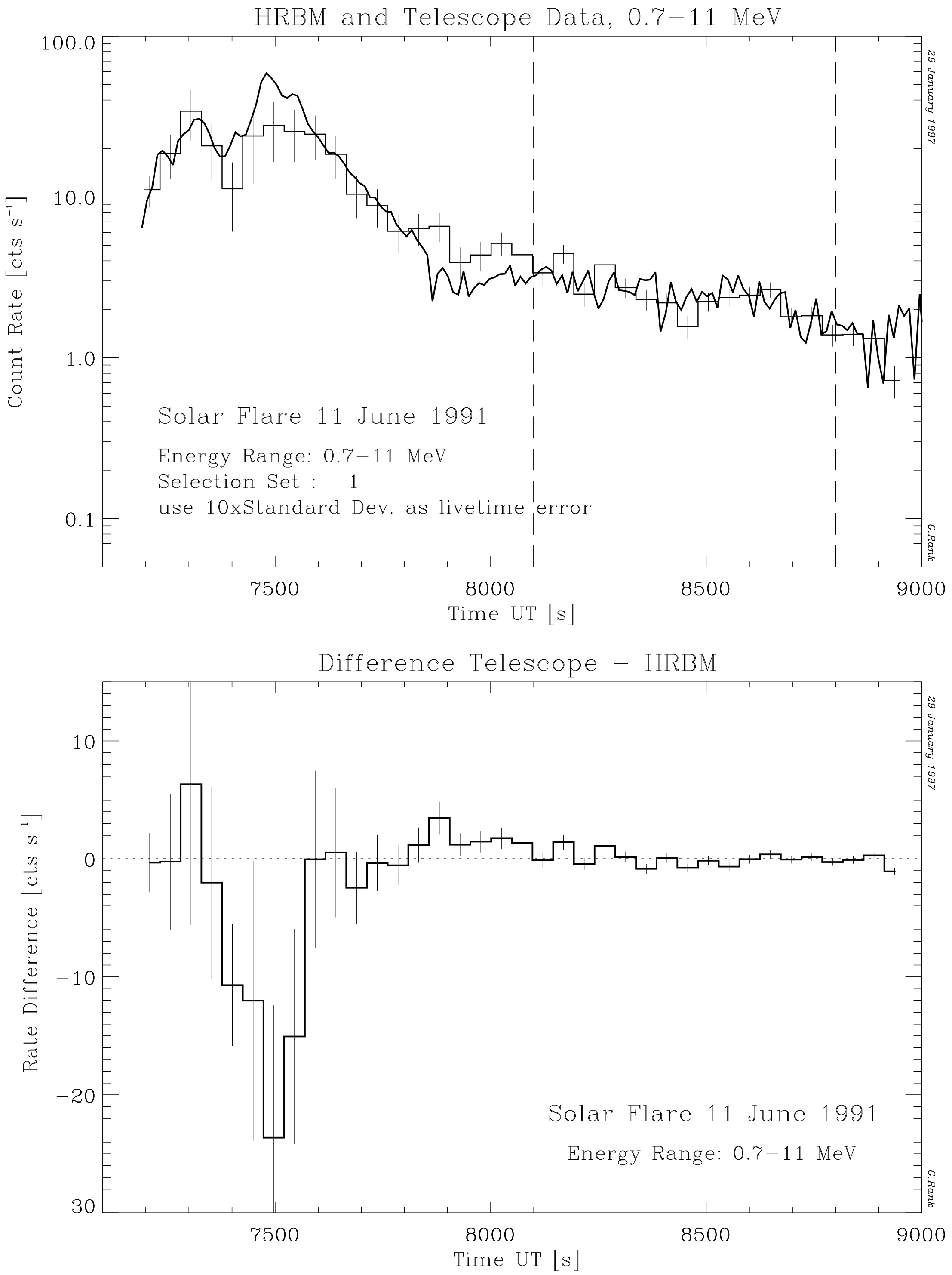

Figure 8: *Relative values and ratio of counting rates for the energy range 0.7 – 11 MeV. This plot resembles figure 3, but takes into account 10x the standard deviation of the minitelescopes as the livetime error.*

Conclusions

We have compared the time profiles of the COMPTEL telescope mode and HRBM for the solar flare on 11 June 1991. The main conclusions from this study are:

• A peculiar setting of the EHA was applied in the selection set. We showed that this is justified for an intense source near the Earth's horizon, as is the case for the flaring Sun shortly after orbital sunrise. The standard settings of the EHA do not produce the expected results.

• The Telescope mode and the HRBM disagree for the time interval of lowest livetimes. During this interval, the livetime values were ranging below about 4%, and the deviation is about 40% of the signal. The same result is obtained for the energy range 0.7–11 MeV and 2.0-2.4 MeV.

• The uncertainties of the livetime can be studied by looking at the standard deviation of the minitelescope livetimes. In contrast to the very low value $< 0.1\%$ that was established under normal conditions, the standard deviation can be higher under more extreme conditions. For the 11 June flare, we found an uncertainty of 5% in the worst case.

• Using the standard deviation of the minitelescope livetimes as the uncertainty of the livetime, the total error still is dominated by counting statistics.

• For a composite livetime below about 4%, systematic effects affect the determination of correct livetime factors. During these conditions, we found the livetime to be overestimated, therefore yielding a signal lower than expected. In our case the signal was lower by about 40%, while statistical counting errors can only account for less than half this amount.

References

Rob van Dijk, "Gamma-Ray Observations of X-ray Binaries with COMPTEL" Ph.D. thesis, SRON Utrecht, 1996

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Georg Weidenspointner, "Minitelescope Livetimes versus Composite Livetimes", report at MPE, Januar 1995