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FINAL REPORT

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ROSAT Investigation of Flaring and Activity on Prox Cen

Period of Performance: May 5, 1992 to May 4, 1993

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As stated in the proposal, the objective of this program was to "investigate with high sensitivity the low-level flare activity which may underlie coronal heating." This has been done.

ROSAT observations of Prox Cen were scheduled for 50 ks spread out from February 26 through March 10, 1992. These were actually carried out as shown in the following appendices. Unfortunately because of spacecraft problems many of these pointings turned out to contain no useful data or extremely truncated valid data sets. Considerable time was spent trying to determine which of the data would be scientifically useful and which would not. Fortunately several developments took place to augment the original data in such a way that the scientific goal of advancing the study of flaring and variability was able to be achieved after all. These are as follows:

(1) A second round of ROSAT observations was carried out in February 1993 which only came to the attention of the P.I. in April 1993 when a new data tape arrived. While limited to approximately 7000 s of additional data it provides an extremely valuable baseline of quiescent observations superimposed on which there appears to be the sought-for microvariability.

(2) Simultaneous IUE observations were requested and obtained. These resulted in 12 long-wavelength and 12 short-wavelength spectra which have now been processed.

(3) Data from the UK WFC are available via the collaboration with Dr. G. Bromage.

(4) The "cleaned-up" original data set was found to include one major flare and 2 moderate flares.

Because of the problems with the original data set, the unexpected acquisition of new data only two months ago, and the availability of IUE and WFC data an article on Prox Cen for publication is not ready at this time. Such an article is being developed and can be completed as part of ongoing ROSAT research efforts on stellar coronae and flaring.

An important scientific finding turned up when we looked beyond the flawed data set to other related observations relevant to the scientific objectives. This led to what may be an important discovery concerning the impulsive phase of flares. Co-Investigator Schmitt had obtained optical photometry and ROSAT light curves of the prototype flare star of the category of which Prox Cen is a member, UV Ceti. Upon doing detailed timing analysis it was found that impulsive soft X-ray bursts occurred in conjunction with two separate optical flare events. We believe this to be the first observation of soft X-ray bursts related to flares and our hypothesis is that these two soft X-ray bursts are the same phenomenon as the impulsive phase of solar flares that have heretofore only been observed at higher energies. These two rapid transients in the ROSAT PSPC light curve would not have been discovered were it not for the optical flares. In addition, both events have an identical 30 s time lag between the optical and the X-ray bursts. This ROSAT observation could provide to be of signficant important. An article has been submitted to *Science* by Schmitt, Haisch and Barwig.

Bernhard Haisch
Palo Alto, California
April 30, 1993

APPENDIX: Original scheduled pointings of Prox Cen for 1992

18	PROXIMA CENTAURI	920226	14:58:30	1491	PSPC	Op	S2B	HAISCH
47	PROXIMA CENTAURI	920227	11:41:30	1530	PSPC	Op	S2B	HAISCH
16	PROXIMA CENTAURI	920227	13:18:00	1470	PSPC	Op	S2B	HAISCH
26	PROXIMA CENTAURI	920229	13:09:15	1476	PSPC	Op	S2B	HAISCH
37	PROXIMA CENTAURI	920229	14:45:00	1438	PSPC	Op	S2B	HAISCH
52	PROXIMA CENTAURI	920229	17:55:30	1477	PSPC	Op	S2B	HAISCH
32	PROXIMA CENTAURI	920229	19:32:30	1409	PSPC	Op	S2B	HAISCH
61	PROXIMA CENTAURI	920229	21:12:15	1155	PSPC	Op	S2B	HAISCH
54	PROXIMA CENTAURI	920229	22:50:00	1079	PSPC	Op	S2B	HAISCH
1	PROXIMA CENTAURI	920301	02:06:45	688	PSPC	Op	S2B	HAISCH
50	PROXIMA CENTAURI	920301	02:57:13	632	PSPC	Op	S2B	HAISCH
51	PROXIMA CENTAURI	920301	11:28:15	1484	PSPC	Op	S2B	HAISCH
29	PROXIMA CENTAURI	920301	17:51:00	1395	PSPC	Op	S2B	HAISCH
2	PROXIMA CENTAURI	920301	21:08:00	1124	PSPC	Op	S2B	HAISCH
55	PROXIMA CENTAURI	920302	03:19:30	585	PSPC	Op	S2B	HAISCH
11	PROXIMA CENTAURI	920302	06:33:00	1605	PSPC	Op	S2B	HAISCH
7	PROXIMA CENTAURI	920302	16:10:15	1397	PSPC	Op	S2B	HAISCH
21	PROXIMA CENTAURI	920304	04:46:30	1630	PSPC	Op	S2B	HAISCH
65	PROXIMA CENTAURI	920304	17:36:30	1305	PSPC	Op	S2B	HAISCH
40	PROXIMA CENTAURI	920304	22:33:15	697	PSPC	Op	S2B	HAISCH
34	PROXIMA CENTAURI	920305	07:56:30	1332	PSPC	Op	S2B	HAISCH
23	PROXIMA CENTAURI	920305	09:33:30	1231	PSPC	Op	S2B	HAISCH
44	PROXIMA CENTAURI	920305	11:09:30	1187	PSPC	Op	S2B	HAISCH
46	PROXIMA CENTAURI	920305	12:45:30	1208	PSPC	Op	S2B	HAISCH
57	PROXIMA CENTAURI	920305	17:32:00	1213	PSPC	Op	S2B	HAISCH
14	PROXIMA CENTAURI	920305	19:12:45	856	PSPC	Op	S2B	HAISCH
12	PROXIMA CENTAURI	920305	22:29:30	601	PSPC	Op	S2B	HAISCH
60	PROXIMA CENTAURI	920306	11:05:15	1103	PSPC	Op	S2B	HAISCH
63	PROXIMA CENTAURI	920305	14:20:30	1238	PSPC	Op	S2B	HAISCH
48	PROXIMA CENTAURI	920306	12:40:45	1123	PSPC	Op	S2B	HAISCH
9	PROXIMA CENTAURI	920306	14:15:45	1187	PSPC	Op	S2B	HAISCH
64	PROXIMA CENTAURI	920306	15:51:30	1125	PSPC	Op	S2B	HAISCH
42	PROXIMA CENTAURI	920307	11:00:30	1067	PSPC	Op	S2B	HAISCH
59	PROXIMA CENTAURI	920307	12:36:00	1036	PSPC	Op	S2B	HAISCH
5	PROXIMA CENTAURI	920307	14:11:00	1080	PSPC	Op	S2B	HAISCH
62	PROXIMA CENTAURI	920309	22:52:25	1265	PSPC	Op	S2B	HAISCH
36	PROXIMA CENTAURI	920310	01:04:30	840	PSPC	Op	S2B	HAISCH

APPENDIX: Actual intervals of useable ROSAT data for 1992 and 1993

Reading from Qpoe file: rp502_all_sti.qp
Writing to Time Filter list: rp502_all_tim.lis

This is the Prox Cen February 1992 data which was processed by ROSAT in March '92.

Good Time Intervals

	start	end	duration	
Flare-	55209678.00	55209876.00	198.00	
	55473993.00	55474539.00	546.00	
	55560168.00	55560580.00	412.00	
	55622687.00	55623673.00	986.00	
	55904703.00	55904707.00	4.00	← disregarded
Flare-	55907449.00	55907977.00	528.00	
	55907979.00	55908407.00	428.00	
Flare -	55915069.00	55915914.00	845.00	

Reading from Qpoe file: rp201_all_sti.qp
Writing to Time Filter list: rp201_test.lis

This is Prox Cen data obtained in February 1993 and processed by ROSAT in March '93.

Good Time Intervals

start	end	duration
84571394.00	84572194.00	800.00
84576400.00	84577924.00	1524.00
84616616.00	84617688.00	1072.00
84657844.00	84658218.00	374.00
84691542.00	84692194.00	652.00
84742830.00	84744244.00	1414.00
84759844.00	84761104.00	1260.00
85012751.00	85013509.00	758.00

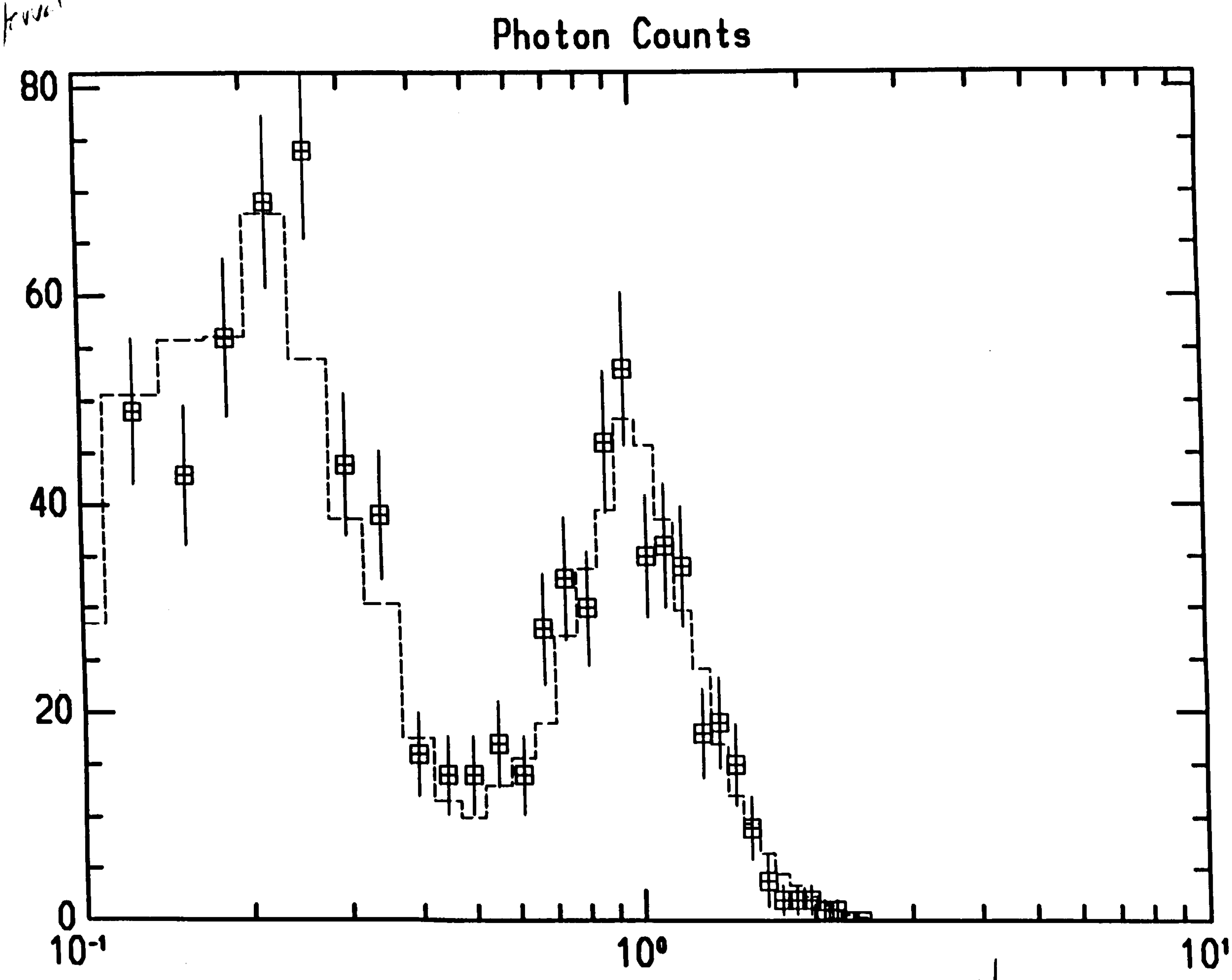
APPENDIX: Coordinated IUE spectra obtained

[HAISCH]PROX_92OBS.LIST

LWP	22476	A	920229	13:45:17
LWP	22476	B	920229	14:09:26
SWP	44079	A	920229	14:57:06
SWP	44079	B	920229	15:37:56
LWP	22477	A	920229	16:17:17
LWP	22477	B	920229	16:42:01
SWP	44080	A	920229	17:10:13
SWP	44080	B	920229	17:45:55
LWP	22478	A	920229	18:24:28
LWP	22478	B	920229	18:48:01
SWP	44081	A	920229	19:16:17
SWP	44081	B	920229	19:52:20
LWP	22479	A	920229	20:30:57
LWP	22479	B	920229	20:54:40
SWP	44082	A	920229	21:22:24
SWP	44082	B	920229	22:04:29
LWP	22480	A	920229	22:43:16
LWP	22480	B	920229	23:07:18
SWP	44083	A	920229	23:33:53
SWP	44083	B	920301	00:16:13
LWP	22481	A	920301	00:54:35
LWP	22481	B	920301	01:18:10
SWP	44084	A	920301	01:44:46
SWP	44084	B	920301	02:19:27

APPENDIX: Two-temperature model fit for the 198 s major flare

1.1" interval
198 s



EM_1 keV

$\sim EM_2$ in $10^{?}$ of EM

keV

min Chi-Squared = 32.90 for abs(17.0000)*ray(11.3332 0.2000 cosmic 100)+ray(0.8000 1.0428

using abs(17.00)*ray(0.20:0.30,cosmic,100.00)+ray(0.80,0.50:2.00,cosmic 100.00)

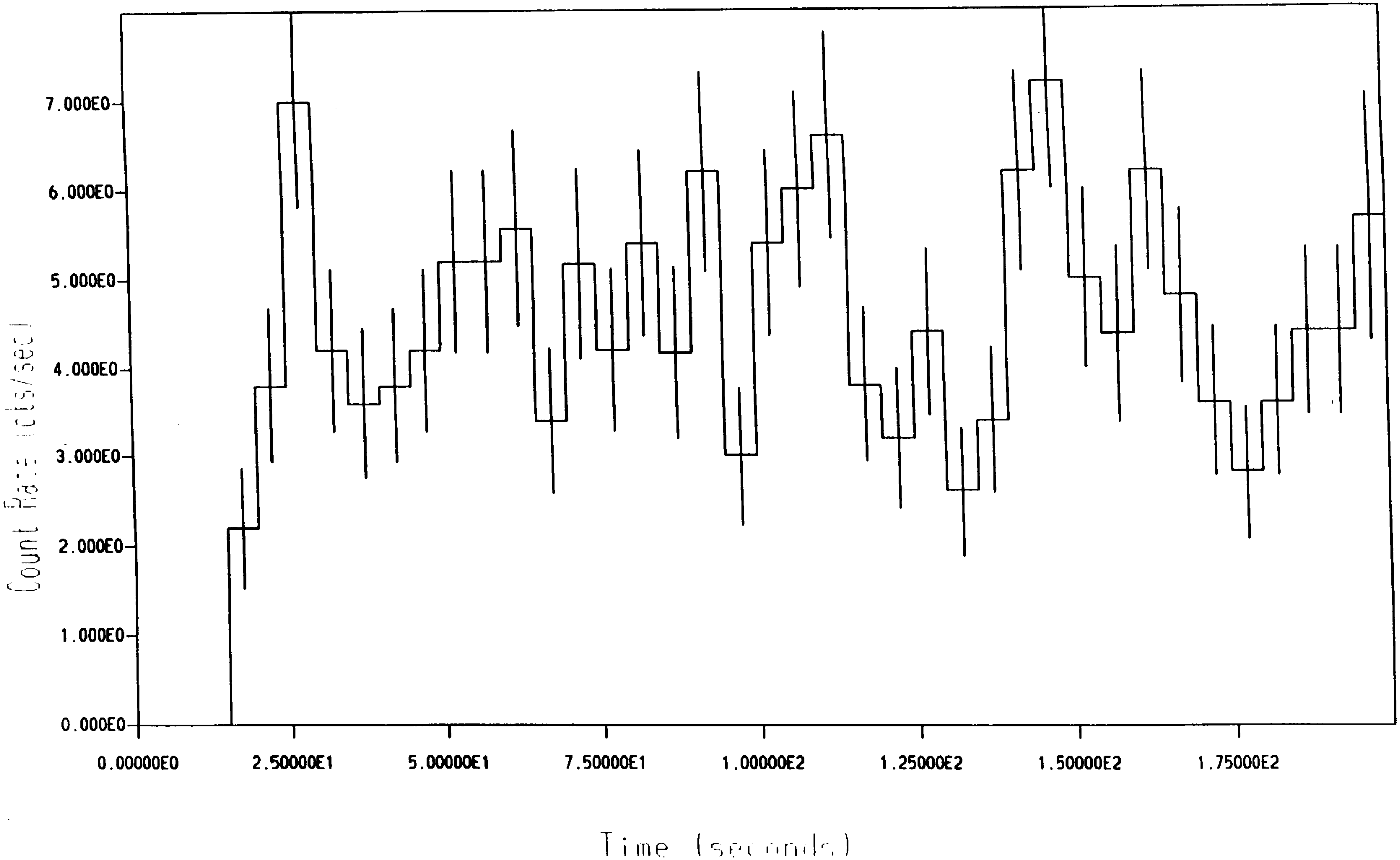
aa502.1 abs[3:34]

APPENDIX: Examples of light curves from 1992 and 1993 data. Analysis underway.

Light Curve : rp502_1_5_ltc.tab

MJD Start: 48682 76087.000s
Clock Start: 55209678.000s
Duration: 198.000s
Tot Cnts: 838

Src Region: CIRCLE 7675. 7824. 250.
Bkg Region: ANNULUS 7675. 7824. 260. 350.
Num of Bins: 40
Bin Length: 5.000000000E0s



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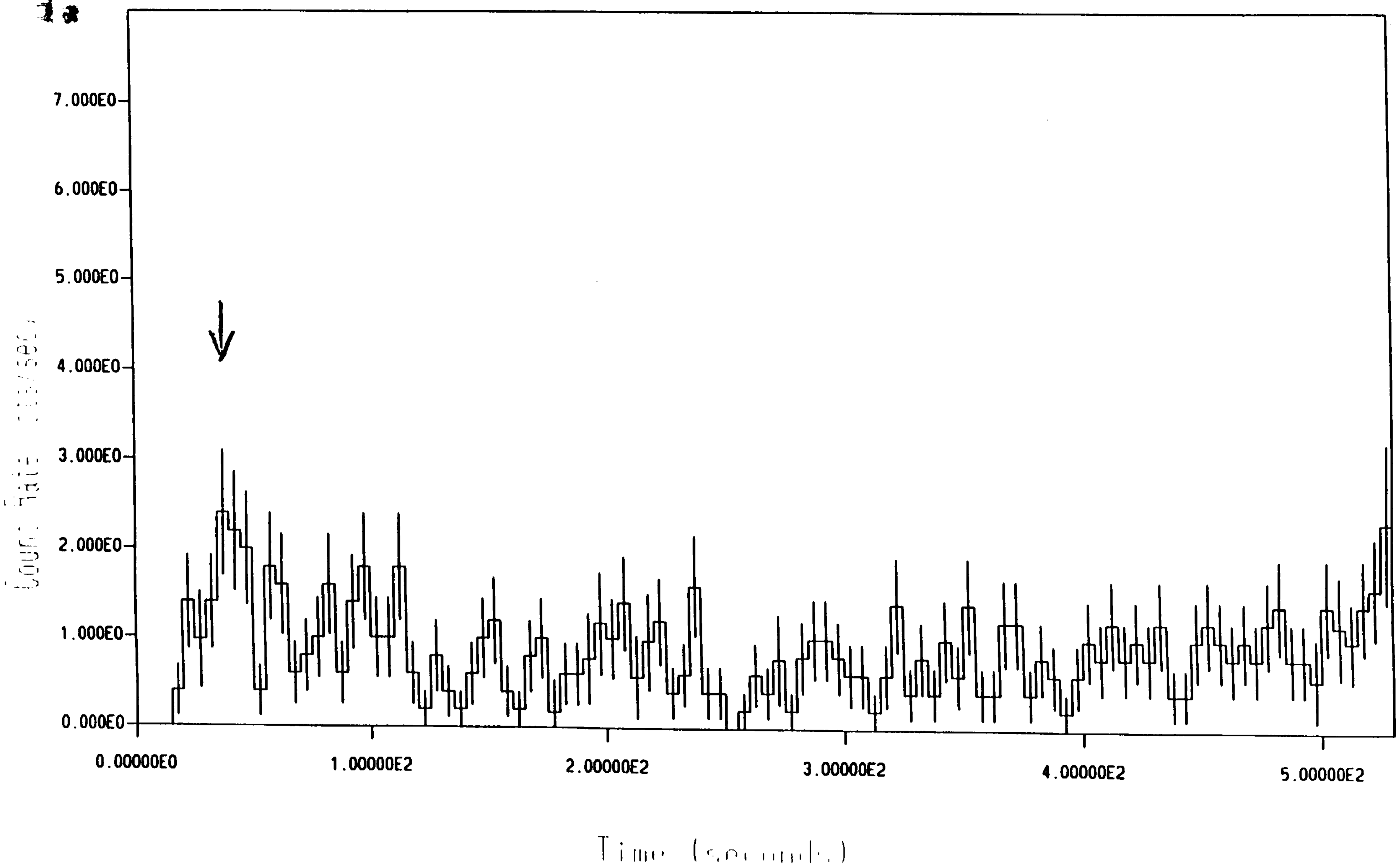
Light Curve : rp502 6_5_ltc.tab

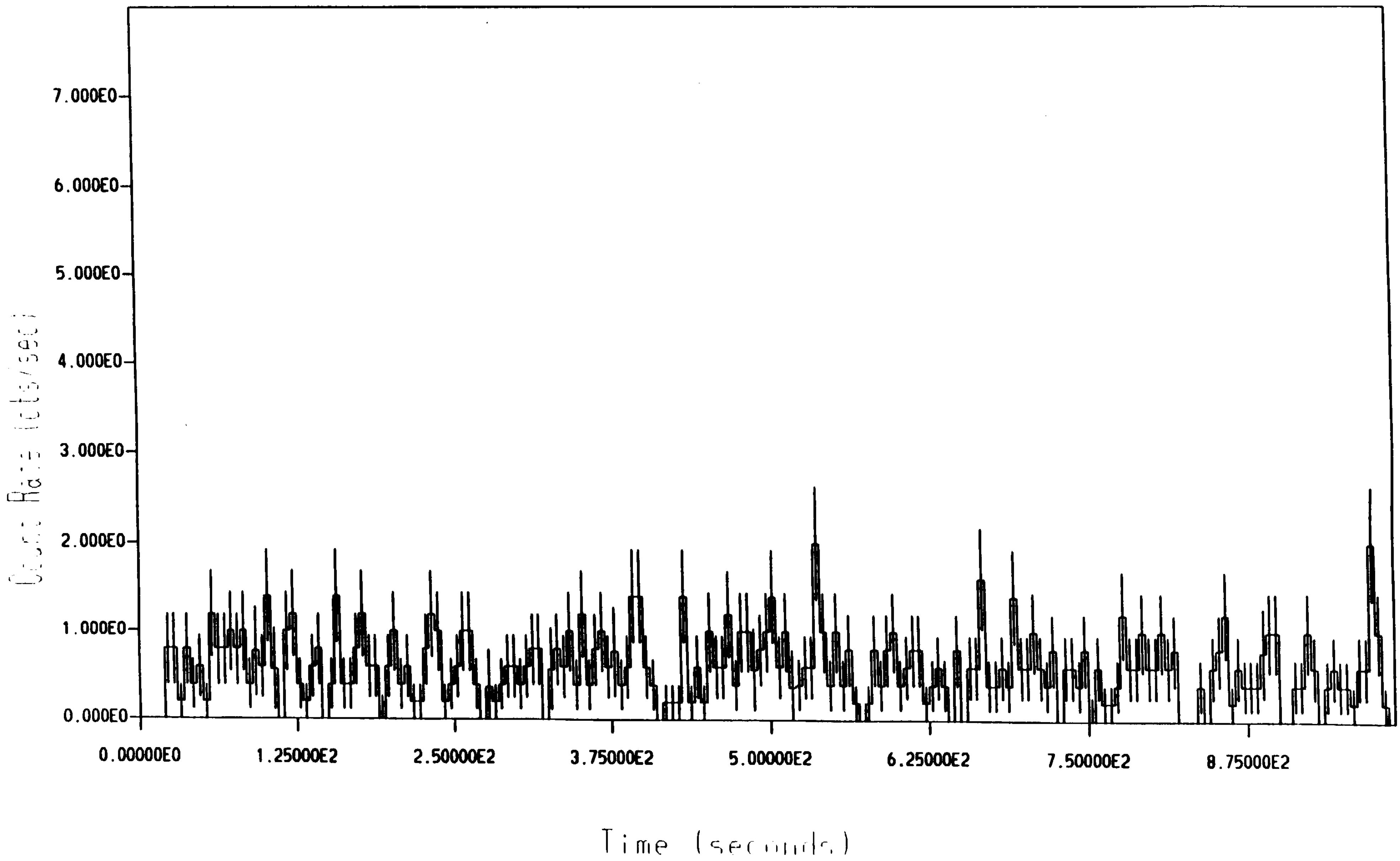
MJD Start: 48690 82658.000s
Clock Start: 55907449.000s
Duration: 528.000s
Tot Cnts: 455

Src Region: CIRCLE 7675. 7824. 250.
Bkg Region: ANNULUS 7675. 7824. 260. 350.
Num of Bins: 106
Bin Length: 5.000000000E0s



Light Curve : rp502_4_5_llc.tab

MJD Start: 48687 57096.000s   Src Region: CIRCLE 7675. 7824. 250.
Clock Start: 55622687.000s   Bkg Region: ANNULUS 7675. 7824. 260. 350.
Duration: 986.000s   Num of Bins: 198
Tot Cnts: 589   Bin Length: 5.000000000E0s



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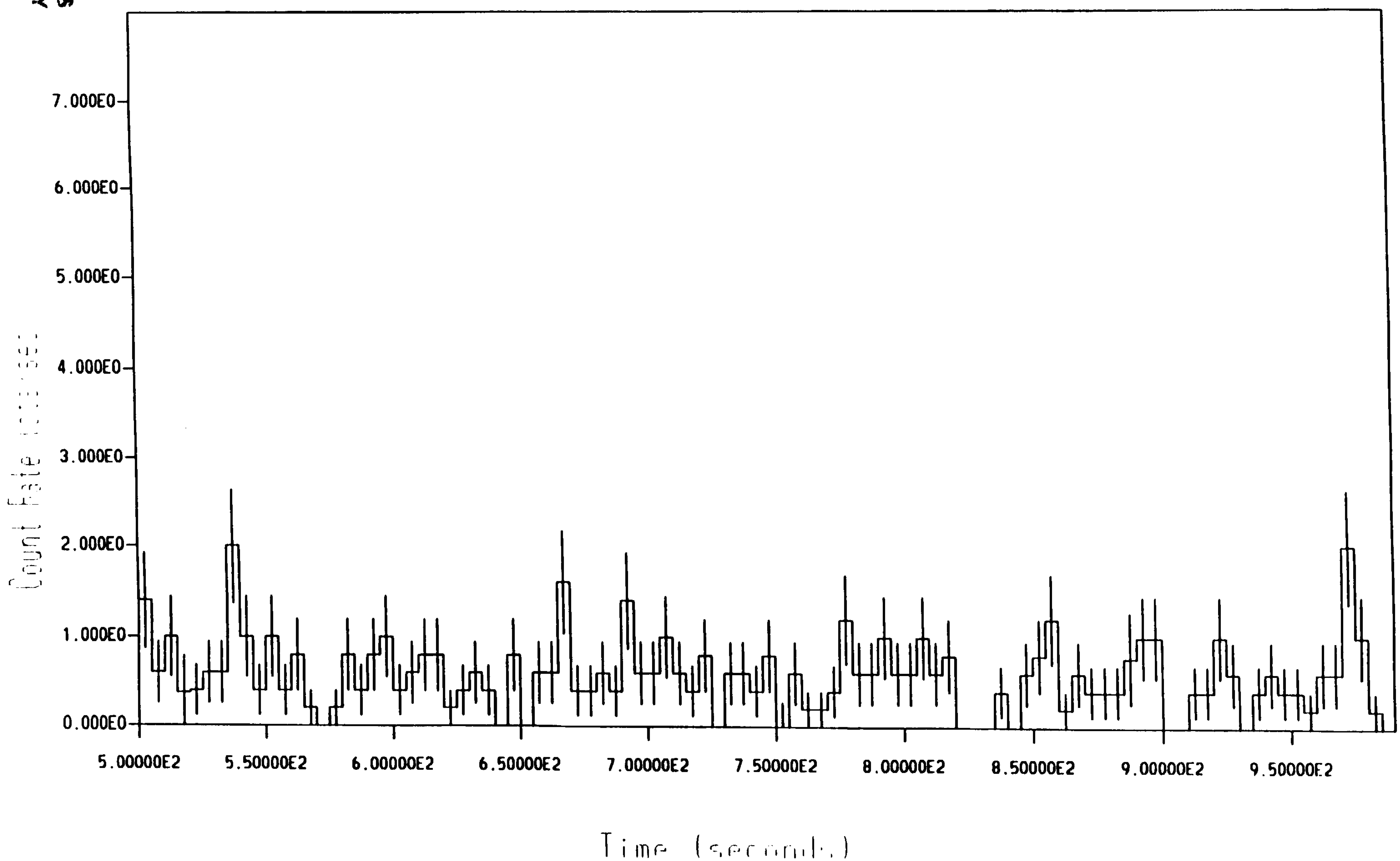
Light Curve : rp502_4_5_ltc.tab

MJD Start: 48687 57096.000s   Src Region: CIRCLE 7675. 7824. 250.
Clock Start: 55622687.000s   Bkg Region: ANNULUS 7675. 7824. 260. 350.
Duration: 986.000s   Num of Bins: 198
Tot Cnts: 589   Bin Length: 5.000000000E0s

+ X-axis Range Limits Used - Not reflective in Header Info



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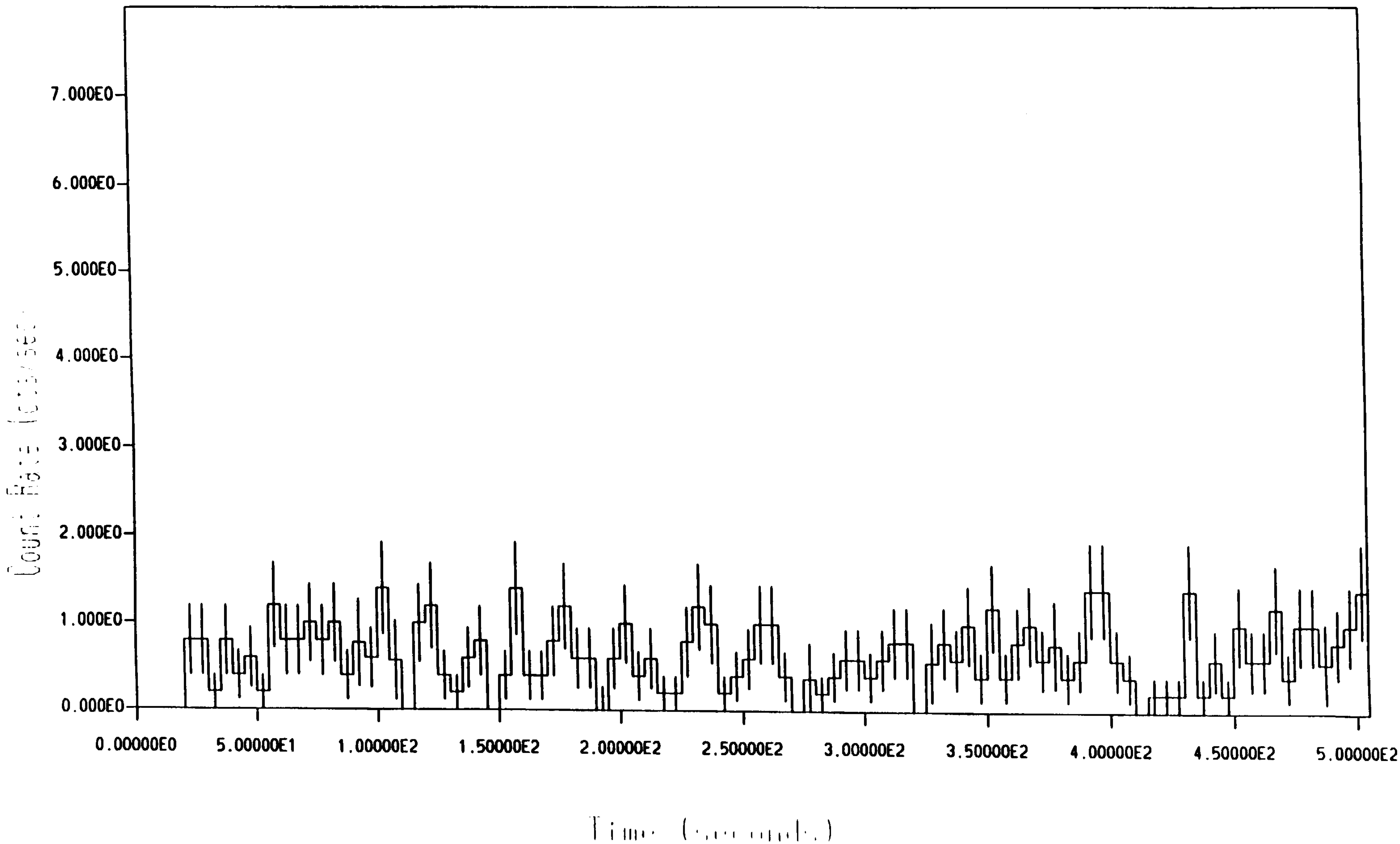
Light Curve : rp50' 4_5_llc.tab

MJD Start: 48687 57096.000s   Src Region: LIRLLE 7675. 7824. 250.
Clock Start: 55622687.000s   Bkg Region: ANNULUS 7675. 7824. 260. 350.
Duration: 986.000s   Num of Bins: 198
Tot Cnts: 589   Bin Length: 5.000000000E0s

* X-axis Range Limits Used Not reflective in Header Info



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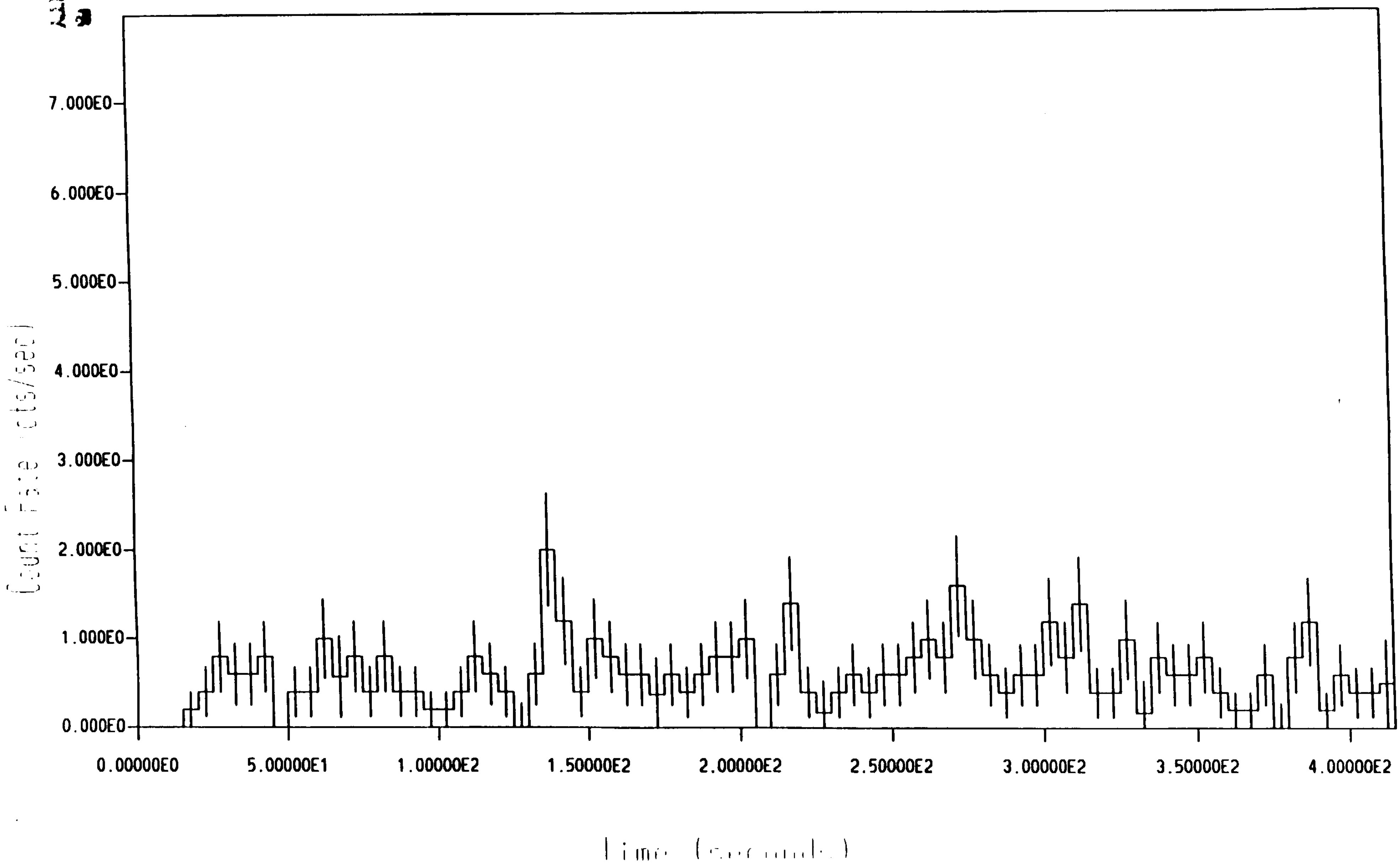
Light Curve : rp502_3_5_ltc.tab

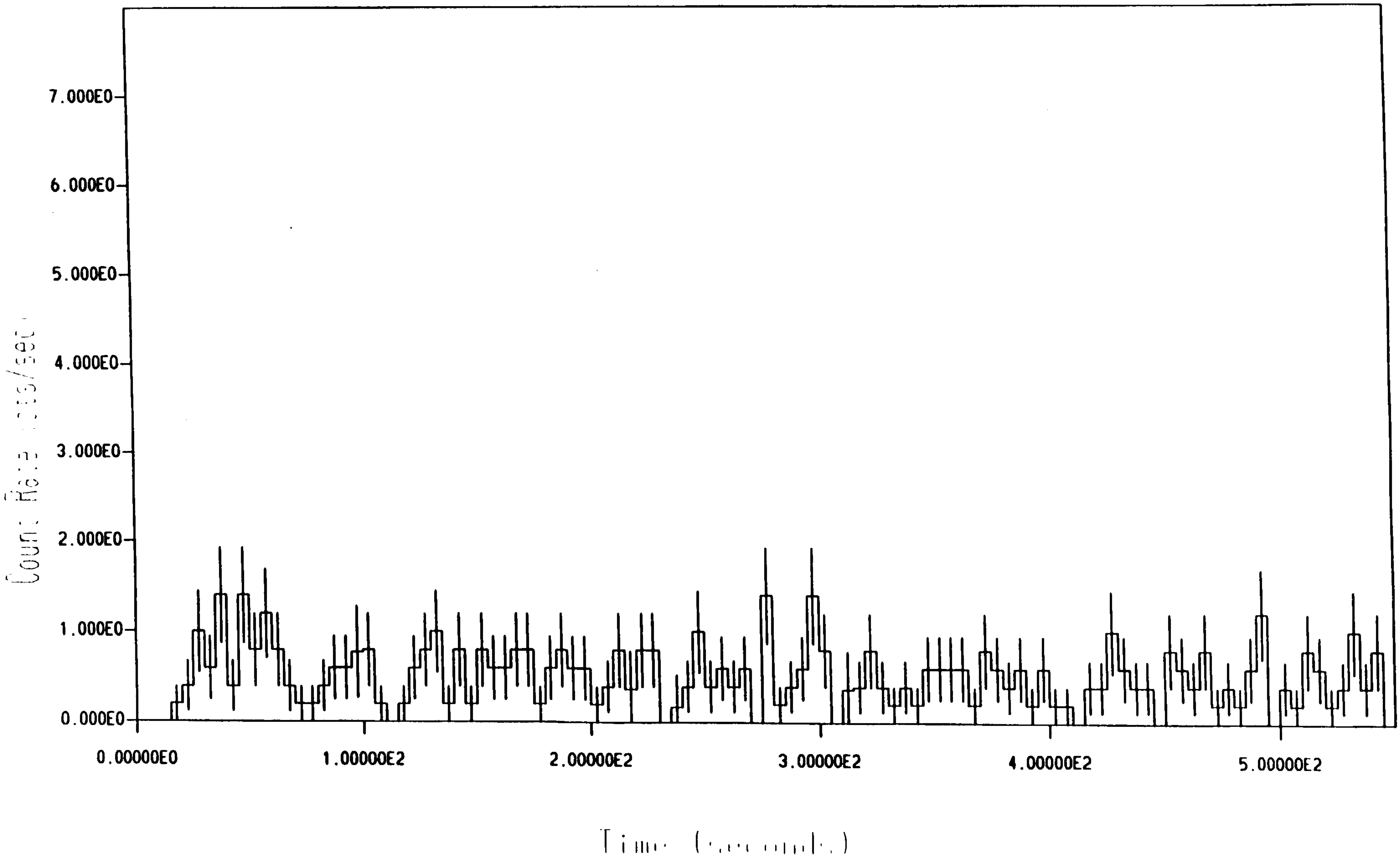
MJD Start: 48686 80977.000s
Clock Start: 55560168.000s
Duration: 412.000s
Tot Cnts: 244

Src Region: CIRCLE 7675. 7824. 250.
Bkg Region: ANNULUS 7675. 7824. 260. 350.
Num of Bins: 83
Bin Length: 5.000000000E0s



Light Curve : rp502_2_5_ltc.tab

MJD Start: 48685 81202.000s   Src Region: CIRCLE 7675. 7824. 250.
Clock Start: 55473993.000s   Bkg Region: ANNULUS 7675. 7824. 260. 350.
Duration: 546.000s   Num of Bins: 110
Tot Cnts: 282   Bin Length: 5.000000000E0s



Simultaneous optical and X-ray observations of impulsive soft X-ray bursts on UV Ceti

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submitted to SCIENCE

1 INTRODUCTION

The physical processes leading to coronal heating have been central themes of research in solar and stellar physics, ever since X-ray observations with the *Einstein* Observatory (cf., Vaiana *et al.* 1981) and ROSAT (cf., Schmitt 1992) have demonstrated the ubiquity of X-ray emission among late-type stars. These observations showed that coronal heating must occur irregardless of those specifics of a star which lead to its location in the Hertzsprung-Russell diagram, i.e., surface temperature and luminosity; in particular, the total X-ray output and - by implication - the total coronal heating - were found to vary by a few orders of magnitude from star to star (cf., Rosner, Golub and Vaiana 1985). Most hitherto obtained stellar X-ray detections refer to quiescent X-ray emission, where we use the term "quiescent" purely operationally in the sense that the observed X-ray emission appeared to be steady during the individual observations. Flaring stellar X-ray emission has of course also been observed (see the review by Haisch, Strong and Rodonò 1991 and references therein), and specifically, the ROSAT all-sky survey observations have shown X-ray flares on all types of stars except O-type stars (Schmitt 1992). Thus, the long known dichotomy between quisecent and flaring solar X-ray emission can be fully extended to the case of late-type stars in general.

The distinction between quiescent and flaring X-ray emission has so far been made only from the observational point of view; a far more interesting question is of course whether the physical processes leading to quiescent and flaring X-ray emission are the same or not. Spatially resolved X-ray observations of the solar corona at lower energies (typically in the range 0.2 - 5 keV) show - at least outside flares - all coronal structures to be steady on the time scales of the radiative cooling time or the Alfven travel time (Vaiana and Rosner 1978); hence all changes in coronal structure can be interpreted in the context of the evolution of quasistatic models which require some form of stationary energy input ("heating") to balance the radiative energy losses. On the other hand, spatially unresolved observations of solar hard X-rays above 20 keV (cf., Lin *et al.* 1984) have revealed a wealth of variability on time scales of a few seconds; these hard X-rays are thought to be the thermal bremsstrahlung from non-thermal (i.e., somehow accelerated) electrons. Weaker hard X-ray flares ("microflares") are found to occur far more frequently than stronger flares; in fact, the cumulative distribution of the number of events ($N > F$) in excess of some peak flux (F) varies inversely proportional to the peak flux without any apparent cut-off at threshold. Therefore one may see only the "tip of the iceberg" and a lot of power can still be hidden in unresolved events of lower flux. As pointed out by Lin *et al.* (1984), a straightforward extrapolation of the observed log N - log F relationship can easily account for the total "quiescent" energy output of the solar corona. These observations together with theoretical considerations of the stability configuration of solar coronal magnetic fields (cf., Parker reference) have lead to an alternative view that quiescent and flaring X-ray emission may actually be manifestations of the same physical heating processes.

It is natural to extend these ideas also to the case of stellar X-ray emission. This has been done by Butler *et al.* (1986), who present evidence for stellar microflares from X-ray observations obtained with the EXOSAT satellite and simultaneously obtained H_γ spectra, by pointing out a high degree of correlation between the simultaneously recorded variations in the X-ray and H_γ flux. Since some of the observed variations appeared to occur on time scales as short as 30 seconds, they were coined as "microflares" by Butler *et al.* (1986) in analogy to the hard X-ray microflares, and they further proposed that a signifcant reduction in sensitivity would yield far more low level flares and that stellar X-ray emission might be viewed simply as a "succession of microflares".

The microflare interpretation presented by Butler *et al.* (1986) has been challenged by Collura, Schmitt and Pasquini (19??) and by Pallavicini, Stella and Tagliaferri (1990), who confirm the wide-spread X-ray variability found in flare stars, but argue that the statistically significant X-ray variability time scales are of the order of a few hundred seconds and hence much more comparable to the typical time scales of compact loop flares observed on the Sun. At any rate, the recently undertaken comparative studies of flares on the Sun and on other stars have considerably advanced our understanding of these energetic, often explosive phenomena (see recent reviews by Haisch, Strong and Rodonò 1991; Pallavicini 1991; Haisch and Rodonò 1989). However, one of the main limitations in comparison of solar and stellar flares has been the lack of any stellar observations of the very important impulsive phase (IP). In the case of solar flares, the impulsive phase is most evident in hard X-rays (HXR) at energies between approximately 20 to 200 keV in which bursts on time scales of seconds are observed just prior to major soft X-ray enhancements. While there is actually some activity evident in slowly rising soft X-ray flux prior to the IP, it is the rapid onset of IP bursts that signals the solar flare onset. On the stellar side, the flare observations at the highest energy consist of a few light curves at energies less than 10 keV obtained by the EXOSAT Observatory ME experiment (see Haisch *et al.* 1987). These light curves are very similar to those obtained by the low-energy telescope on EXOSAT which show the evolution of thermal flare plasma ($T \approx 10^7$ K) during the gradual phase. For some stellar flares temperatures considerably higher than 10^7 K have been measured (cf., a flare on II Peg observed with the GINGA satellite; Kellett *et al.*1992), but in no case was it possible to provide evidence for **non-thermal** stellar X-ray emission.

As far as the impulsive phase X-ray emission from a stellar flare is concerned, it had been thought that this emission was unobservable with present instrumentation since X-ray imaging techniques (which are required to obtain data with sufficient sensitivity) are available only out to energies a few keV with presently available X-ray telescopes and to $\sim$ 10 keV with the next generation of instruments. However, on the Sun, a by stellar standards rather inactive star, the hard X-ray flux exceeds the thermal (soft) X-ray flux only at energies above $\sim$ 20 keV, and thus the prospect of measuring IP X-ray emission of stellar flares appeared grim. In this article we report on simultaneous ROSAT pointed soft X-ray (SXR) observations and ground-based UBV photometry during two low-level flares on the archetypal flare star UV Ceti which appear to demonstrate a previously unrecognized soft X-ray impulsive component in the X-ray flux of UV Ceti. While the precise physical implications of our observations remain unclear at this moment, we argue that our data show the signature of X-ray emission from the IP phase of a stellar flare rather than those of microflares or compact loop flares previously reported.

2 OBSERVATIONS

The data to be reported in this article were obtained on 2 January 1992 between 18:00 and 20:00 hrs UT. The X-rays were recorded with the position sensitive proportional counter (PSPC) onboard ROSAT. The PSPC is a very low background proportional counter operating in photon counting mode in the band pass 0.1 - 2 keV with an energy resolution $\Delta E/E \sim 0.43$ at 1 keV. A detailed description of ROSAT and its onboard instrumentation can be found in Pfeffermann *et al.* (1986). The optical data were taken at the Wendelstein Observatorium (text from H. Barwig).

In figure 1 we show the basic result obtained with our measurements, i.e., the simultaneously recorded light curves in the U and B band as well as at soft X-ray energies between 0.1 - 2 keV. In order to obtain the optical light curves, we removed the simultaneously measured sky background and divided by the also simultaneously measured constant comparison star; the mean level of the signal thus determined was arbitrarily set to zero. Further, we applied a running mean of 5 seconds to our data (which were originally recorded at 1 second time resolution) in order to filter out measuring noise. For the X-ray observations, UV Ceti was actually placed 40 arcmin off the optical axis of the X-ray telescope in order to avoid count rate fluctuations caused by the various wire grid systems inside the PSPC (cf., Pfeffermann *et al.* 1986); on axis, the focus of the X-ray telescope is so sharp that X-ray sources may be partially obscured by these wires necessary to build up the electric fields to measure the electrons produced by the photoabsorbed X-ray photons. The disadvantage of placing a source off-axis is, however, that source signal is lost because of the reduced effective area due to telescope vignetting and the background signal increases because a larger extraction radius must be chosen in order to collect all source photons. We corrected the X-ray light curve for the loss due to vignetting, but did not subtract background. We of course checked the uniformity of the background in our UV Cet observation and found that during no time it should amount to more than 2 percent of the observed signal from UV Cet; since this is much smaller than the statistical error in our count rates, the background is negligible. In figure 1 we show the optical and X-ray light curves obtained in the manner described above. The optical data are shown with the full time resolution (but a 5 sec running has been applied), while the X-ray data is binned into TBD sec bins, the time axis is shown in units of heliocentric Julian date.

During our simultaneous ROSAT monitoring program we observed two relatively weak optical flares. The first (optical) flare centered on UT TBD showed an impulsive phase with an overall duration of only $\sim$ 10 seconds; it was only detectable because of the small integration times of the photometer. The second (optical) flare, peaking at UT TBD, showed both an impulsive phase as well as a gradual phase, and we could detect excess emission above the normal photospheric background of UV Ceti for a total of TBD minutes after flare onset. Both flares have similar recorded peak magnitudes with $\Delta U \approx 1.2$ mag and $\Delta B \approx 0.4$ mag, but have obviously a rather different light curve morphology, indicating different intrinsic properties. It is of course possible that the first impulsive flare also had a gradual phase below our detection threshold; at any rate, its gradual phase emission must have been surpressed relative to the impulsive phase. The X-ray light curve appears - on first inspection - more or less constant in the first half of the observation, while we find a clear soft X-ray enhancement after UT TBD, i.e., after the onset of the second flare.

However, alerted by these optical spikes, we carefully investigated the X-ray light curves during the times immediately after the optical flare onset and we found clear evidence of two short-lived soft X-ray bursts which are well above the noise and of high statistical significance (see below). In order to more clearly show these X-ray spikes we chose to show the X-ray light curve for the time interval preceding the soft X-ray enhancement in a different way. Instead of the normal procedure of taking equal time steps and counting the numbers of events recorded in each interval, we took an individual photon recorded at time, say, t_j, determined the arrival times of the nth photon recorded before and after t_j, i.e., t_{j-n} and t_{j+n}, and associate with each photon recorded at time t_j the instantaneous count rate $c_j = (2n+1)/(t_{j+n} - t_{j-n})$. This representation has the advantage that the error of each rate point is the same (because it is derived from the same number of photons), however, adjacent data points are not independent but are correlated out to n points on either side. This calculation was carried out with n = 19, and the result is shown in figure 2; two spiky bursts are clearly visible at times TBD and TBD; note that figure 2 represents an instantaneous count rate **not corrected for telecsope vignetting**. For comparison, we have also indicated in figure 2 the peak times of the simultaneously recorded optical flares. We wish to emphasise that the X-ray spikes would almost certainly have escaped our notice in the longer bin sizes typically used for analysis; in the subsequent section we will give a precise appraisal of the statistical significance of these X-ray spikes. Curiously, both SXR bursts are delayed with respect to the $U-$ and $B-$band flares by approximately 25 and 40s. We are confident that an error in the temporal alignment of the optical and X-ray light curves can be excluded, and believe that this surprising temporal relationship between optical and SXR bursts is in fact consistent with previously reported observations of a flare on EV Lac observed by the (former) Soviet *Astron* experiment (Burnasheva *et al.*1989). In that observation of 6 February 1986, a short-lived optical flare is followed 50 s later by a UV burst attributed to the C IV (1550 Å) line (Katsova and Livshits 1989, 1991).

3 THE STATISTICAL SIGNIFICANCE OF THE FLARES

In this section we wish to discuss the statistical significance of three features in the X-ray light curve shown in figure 1 and 2; the soft X-ray enhancement after TBD, and the two X-ray spikes observed at TBD and TBD. In order to properly assess this significance it is necessary to go back to the individual photons recorded from UV Cet (rather the corrected light curve shown in figure 1). Since the mean (uncorrected) count rate of UV Ceti was only 0.58 cts/s, in an integration time of 10 seconds, the approximate overall duration of the first optical pulse, one expects to record only 5.8 counts; thus Poissonian statistics has to be applied in order to check whether the actually recorded integer number of events is consistent with this expectation or not. As to the soft X-ray enhancement, we recorded 258 photons in a 300 s time interval between TBD and TBD; if the count rate had indeed been constant, only 174 photons shoueld have been recorded and therefore the soft X-ray enhancement is certainly real. Next, we studied the individual photon arrival times of all the photons recorded during and immediately after the peak of the optical flares. For the first impulsive flare, optically recorded at UT TBD, we count in a 12 second time interval (which is the approximate length of the optical flare) centered on UT TBD, 19 photons while we expect to record 6.37, assuming again the count rate to be constant; for the second optical flare the corresponding number is 17 (cf., figure 2). Recording 19 (17) or more photons while 6.37 are expected, has an occurrence probability of $\sim 4\ 10^{-5}$ ($\sim 4\ 10^{-4}$) in a **single** trial. Since the optical and X-ray flare did not occur simultaneously, it must be taken into account that more than one trial was made. How many trials were really made is more difficult to establish and boils down to the question of how large a delay between optical and X-ray flare one is willing to accept. If one takes the view that anything within three minutes after the optical flare would have been accepted as a X-ray counterpart, the number of trials would be 18, and hence the probability to record 19 or more photons in one of these 18 bins by chance becomes $7\ 10^{-4}$.

4 DISCUSSION AND CONCLUSIONS

Our UV Cet observing campaign has not been the first campaign to provide a a simultaneously recorded X-ray and optical data set, and therefore it is useful to compare our results with a previous multiwavelength observation of a flare on UV Ceti. deJager (*et al.* 1989) reported on coordinated measurements of a much larger flare on the same star in which the $U-$ and $B-$band enhancements were approximately 50 to 100 times more intense. Comparing the optical and soft X-ray flux ratios of these flares by taking the peak EXOSAT LE count rate for the gradual phase of that event (0.8 cts s^{-1}), converting (approximately) to flux, $f_x \approx 9 \times 10^{-11}$ erg/cm^2/s, and then reducing that by the same factor of 50 to 100, we find a scaled SXR flux of $f_x \approx 9 - 18 \times 10^{-13}$ $erg/cm^2/s$. This would result in an approximate PSPC count rate of 0.15 to 0.3 cts s^{-1}. Indeed, approximately 3 to 4 minutes after the second impulsive UV event, the PSPC shows a gradually rising count rate over a period of approximately 6 minutes, peaking at just under 1 ct s^{-1}. We interpret this as the gradual (thermal) phase of the small flare triggered at the time of the two impulsive UV bursts. The rise time of this gradual SXR component (around TBD minutes) falls between the relatively rapid rise (2 minutes) observed with the Exosat LE telescope by deJager *et al.*(1989) and the slow rise (50 minutes) observed on EQ Peg by Haisch *et al.*(1987). Indeed, we note that the LE light curve of the EQ Peg flare (Fig. 1 of Haisch *et al.*1987) displays a single-bin SXR peak at the flare onset, which in light of the present observations we suggest as a possible analogous manifestation of a SXR impulsive event.

We find ourselves confronted by two questions: (1) What could be the source of such short-lived SXR bursts? (2) What could account for the time delay between the optical and SXR bursts?

On the Sun, impulsive white light emission is a certain indicator of accompanying HXR bursts (L. Acton, priv. comm.). Thus the simplest explanation for our SXR impulsive events would be to assume that there was an HXR burst, and that this HXR burst spectrum can be extrapolated to energies as low as 1 to 2 keV, the upper end of the ROSAT PSPC band pass. The solar HXR flare spectrum is thought to result from bremsstrahlung when electron beams interact with the chromospheric layers of the solar atmosphere (see Haisch, Strong and Rodonò 1991 and references therein). The cutoff for electron energy power spectra translates into assumed minimum HXR energies of 10 to 20 keV. While this is the predominant view, Kane (1987) has reported on non-thermal electron spectra that do appear to extend down to 2 keV.

Alternatively, the observed spiky emission could also be interpreted as thermal emission. For example, impulsive solar EUV spectra in the form of emission lines have been obtained by *Skylab* (Widing 1982, Widing and Hiei

1984), and by OSO-7 (Neupert 1989). In the case of the OSO-7 observation, the coronal emission line of Fe XI (180.4 Å) forming at $1 - 1.5 \times 10^6$ K shows a light curve that is very similar to the simultaneous impulsive $15 - 60$ keV HXR burst. Holman, Kundu and Kane (1989) also report on a temperature spike in the SXR emission (determined by GOES) coincident with the HXR bursts measured by the Solar Maximum Mission Hard X-ray Burst Spectrometer. Given the rather broad response of the PSPC

$(0.1 - 2.4$ keV), either an extension of HXR spectra into the hard end of the PSPC response or a contribution by emission lines in the soft end could explain the observed PSPC signal; solar observations provide support for either interpretation. However, one also needs to account for the time delay. Turning again to the optical events, based on multicolor photometry and spectroscopy allowing them to derive an effective temperature (16000 K) for the optical radiation, deJager *et al.*(1989) were able to derive an area for their optical flare, $A \approx 6 \times 10^{17}$ cm^2. From our high-time resolution data we have determined color temperatures during the flare as well as for the quiescent emission. While the color temperatures measured during quiescence correspond to a spectral type between M2 - M6, which is consistent with the spectral classification of UV Ceti as M5.5e, we find during the flare an equivalent spectral type between B2 - B7. Therefore our color measurements are consistent with the value of 16000 K derived by deJager *et al.*(1989) for their much larger flare from spectroscopic (rather than photometric) observations. If we then simply attribute the factor of 50 to 100 reduction in $U-$ and $B-$ spikes to a change in flare area (and not to temperature), we arrive at an area $A \approx 0.6 - 1.2 \times 10^{16}$ cm^2 for both of our flares.

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15. Supplementary Notes

16. Abstract

The objective of this program was to investigate with high sensitivity the low-level flare activity which may underlie coronal heating. Significant progress was made. Analysis of 50 ks of ROSAT observations of the flare star Proxima Centuari was carried out. Supporting observations were also obtained and studied which included a breakthrough observation of a soft X-ray burst which may be a manifestation of the heretofore unobserved (on a star) impulsive phase of a flare.

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