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1. Summary

This program involves analysis and interpretation of results from *GINGA* Large Area Counter (LAC) observations from a group of large stellar X-ray flares. All LAC data are re-extracted using the standard Hayashida method of LAC background subtraction and analyzed using various models avaliable with the XSPEC spectral fitting program. Temperature-emission measure histories are available for a total of 5 flares observed by *GINGA*. These will be used to compare physical parameters of these flares with solar and stellar flare models.

2. Technical Progress

Over the course of this project, the following work was accomplished:

(1) A list of known *GINGA* stellar x-ray flares was compiled, and those amenable to X-ray spectral analysis were selected for further work: these include flares in Algol, II Peg, UX Ari, HR 1099, and a flare in the dMe system EQ 1836.9+8002. The latter two sets of flare data were not previously analyzed (EQ 1836.9+8002 was analyzed with Prof. K. Makshima of Tokyo University and collaborators H. Pan and C. Jordan at Oxford University).

(2) LAC data from the above flare observations were extracted as both time-history count rate files and as time resolved pulse-height spectra. All data were extracted using the Hayashida *et al.* (1989) Method II. In all cases, we also examined (using the Hayashida *et al.* extraction program) possible correlations of the extracted count rates with orbital parameters such as earth elevation angle, trapped particle fluxes, etc., in order to remove any significant contamination to the flare spectra.

(3) After determining a "quiescent" period before or after each flare, the quiescent spectrum was subtracted from each of the extracted flare spectra. This allows us to remove any possible contribution from other unresolved sources in the *GINGA* fields

(4) Since the above extractions and subtractions were all performed on the ISAS Fujitsu Mainframe computer, they were then transferred to DEC workstations at ISAS. Using a program written by Ken Ebisawa, we then transformed the *GINGA* spectra and response matrices to XSPEC format so that spectral fitting could be accomplished.

(5) For the time resolved spectra from each of the above flares (ranging from a minimum of 5 spectra for HR 1099 to a maximum of 24 spectra for EQ 1839.6 + 8002) we fitted the data with XSPEC using 3 different models: (1) The latest Raymond-Smith plasma code, the (2) Mewe-Kaastra plasma code, and (3) a simple thermal bremsstrahlung continuum + Fe emission line. For all parameters, we derived 90% confidence, single-parameter errors on the emission measure, temperature, and either Fe- abundance or equivalent width.

(6) For the new flare data for HR 1099 (V711 Tau), we determined flare physical parameters based upon loop models. In addition, we discovered a significant difference in the derived Fe abundance in the quiescent data compared to the flare. The Fe abundance, which was low (10–20% of solar) during quiescence, increased by $\sim$ 3–4 times during the flare. The variation in the dervied Fe abundance may have important implication for both coronal heating and flare models which involve the separation of ions and neutrals, depending upon their first ionization potential (the "FIP" effect). This work is detailed in the attached manuscript, which will be submitted to a refereed journal.

(7) For the new flare data from EQ 1839.6+8002, we obtained an extremely high peak temperature of $>$ 100 MK, making this one of the hottest flares detected by *GINGA*. The flare is of relatively short duration, with an exponential decay time of $<$ 15 minutes, and a peak X-ray luminosity of $\sim 10^{31}$ erg s^{-1}, nearly 20% of the *bolometric* luminosity of the dMe star which is thought to be the origin of the flare. This flare is quite unusual for a dMe star, yet there is no other optical candidate within the *GINGA* field of view which could account for the flare. The results from this observation were presented at the 1994 European and (British) National

Astronomy Meeting in Edinburgh, Scotland by Dr. H.C. Pan. A copy of the poster paper is appended to this report.

(8) The combined results from all 5 flares have been analyzed on the basis of an emission measure-temperature diagram. Such a diagram has been used previously for the analysis of solar flares. However, given the qulity of the *GINGA* data, it should have signifiacnt application to stellar flares. In the next section, we describe the results of this analysis.

3. Analysis

3.1 *GINGA* Flares in the EM-T Diagram

Using a combination of analytical approximations and numberical modeling of hydronamic equations, the study of solar X-ray flares has been significantly advanced through the use of the denity-temperature or emission measure-temperature (EM-T) diagram (see Serio *et al.* 1991, Jakimiec *et al.* 1992, Sylwester *et al.* 1993a, Reale *et al.* 1994). The logarithmic slope of the flare emission measure (EM) vs the X-ray temperature (T) provides a diagnostic which can then be compared with the predictions of the hydrodynamic models. In particular, it is found that the slope is relatively high (≈ 1 in an EM-T diagram) for flares which decay after an abrupt cutoff in the flare heating, while for flares evolving in a quasi-steady state fashion (i.e. those which adhere to loop scaling laws with only slow changes in the heating parameters) show a much shallower slope, i.e., about 0.25 in the same diagram. In some cases, the flare decays do not exhibit a single value of the slope on the EM-T diagram: Sylwester *et al.* (1993b) interpret this as possibly different loop structures being involved in the flare.

The hope is, of course, that stellar X-ray flares may be interpreted in much the same way. Until recently, analyses of stellar X-ray flares have typically assumed the quasi-steady state (QSS) condition (e.g. van den Oord and Mewe 1989, Stern *et al.* 1992). However, some *GINGA* flares, such as that observed in II Peg (Doyle *et al.* 1991, 1992) do not obey the QSS condition: for that flare, Doyle *et al.* (1992) found that a relation between emission measure and temperature modeled by a "constant velocity" hypothesis produced consistent results. However, it is clear for the solar X-ray observations that any attempt to make all stellar X-ray flares adhere to a single scaling law is unlikely to succeed: the EM-T relationship will be determined by the particular characteristics of the flare under study, depending in particular upon the time history of the flare heating and the involvement of a single or multiple loop structures. Nevertheless, by studying the EM-T diagrams, we may at least hope to better understand the variety of stellar flares in a givaen star and in different stars. Reale *et al.* (1994) have begun this study by analyzing a ROSAT PSPC flare seen on the flare star Proxima Cen, which they find to have a slope of log T vs log EM of slightly < 1 (2 in the density-T diagram). This is similar to many solar solar flares which have a quick turnoff of heating. What are the results for the 5 *GINGA* flares?

For the 5 *GINGA* flares, we plot all the EM vs T values derived from the X-ray data in Figure 1. For those flares with rise phases, the progression in each plot is from the upper left to the upper right to the lower left of the plot. In those flares with only decay phases, the progression is from the upper right to the lower left only. Note that for the decay phase, there is a wide variety of observed EM-T slopes. In Table 1 below, we summarize the characteristics of these 5 flares.

Table 1: Ginga Flare Parameters

Star	log T_{max}	log EM_{max}	log τ_{decay}	EM-T slope
UX Ari	7.8	55.1	5.0	0.07
II Peg	7.9	54.3	3.3	2.3,0.6
Algol	7.8	54.0	4.3	0.33
EQ1839.6	8.0	54.0	2.9	0.46
HR 1099	7.7	53.8	3.7	0.29

Comparing the observed slopes and other parameters to the results of hydrodynamic modeling of solar flares in Jakimiec *et al.* (1992), we draw the following conclusions:

- no two of the *GINGA* flares are alike.

- only the HR1099 and part of the Algol flare decays appear to follow a "quasi-static" evolution.

- UX Ari, in particular, appears to be decaying so slowly in temperature that either the assumption of a single loop decay is incorrect, or additional heating must be occurring on a very large scale. It is possible that both conditions hold.

- for II Peg, there is a definite change of slope at log T $\sim$ 7.7, log EM52 $\sim$ 2.25. This may indicate a rapid turnoff of heating for some of the loops involved in the flare, with a gradual decay of flare heating for the remaining flare loops.

- we do not see any particular correlation of the EM-T slope with any of the other stellar parameters. This suggests that, like solar flares, the heating profile and magnetic loop geometry of each stellar flare is unique. We find that, contrary to suggestion of Reale *et al.* (1993), that the low gravity environments found in RS CVn systems do *not* yield high values of the EM-T slopes.

3.2 The Variable Fe Abundances

The issue of the variability of the Fe abundance in these flares is discussed in detail in the attached manuscript on HR1099 (V711 Tau).

4. Foreign Travel

Dr. R. Stern visited ISAS for the period 8 Sep to 12 Dec 1993. During this time, all of the above analysis was undertaken. Also, Dr. Stern had several meetings with Japanese scientists, including Profs. Uchida, Makshima, and Shibata in order to discuss analysis of the data and theoretical modeling approaches.

5. Presentations and Publications

- "What Solar Astronomers can Learn From the Stars," R. Stern, talk given at ISAS, December 1993

- "X-Ray Observations of the dMe Star EQ1939.6+8002," H.C. Pan, K. Makishima, R.A. Stern, and C. Jordan, 1994, poster presented at the 1994 meeting of the European and British Astronomical Society, Edinburgh, Scotland.

- "*GINGA* X-ray Observations of V711 Tau (HR1099), R.A. Stern, S. Tsuneta, Y. Uchida, 1994, in preparation (manuscript attached).

- "Physical Parameters of X-ray Flares Observed by *GINGA*, R. A. Stern *et al.* , 1994, in preparation.

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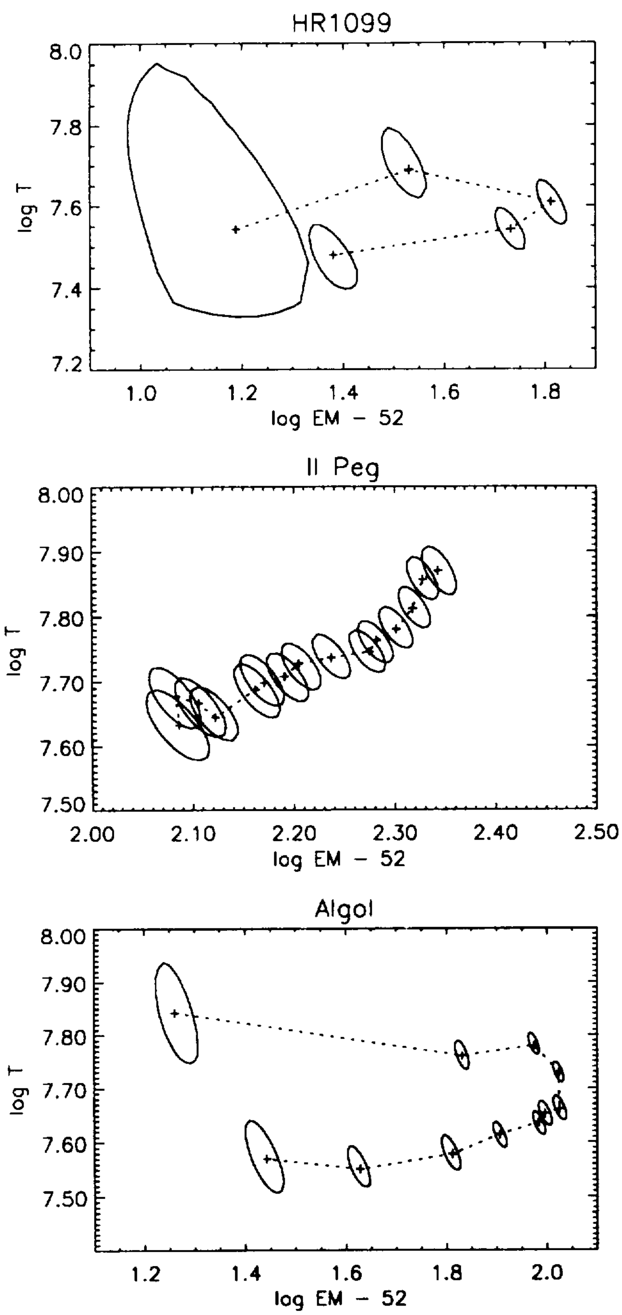
HR1099
log T
log EM − 52
1EQ1839.6+8002
log T
log EM − 52
II Peg
log T
log EM − 52
UX Ari
log T
log EM − 52
Algol
log T
log EM − 52

FIG 1.

X-ray Observations of the dMe Star EQ1839.6+8002

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1 Introduction

During the *GINGA* observation of the radio galaxy 3C390.3 on 1991 February 14, a giant flare, which showed a rapid ($\sim$ 4 minutes) tenfold flux rise followed by a $\sim$ 20 minutes decay, was detected between 22:30-23:00 (UT) (Inda et al. 1994). It has been suggested by Inda et al. (1994) that the flare was associated with EQ1839.6+8002, an M4Ve star at a distance of 15.2 pc (Fleming et al. 1988). Although the *GINGA* observations cannot resolve the star and 3C390.3, observations with *ROSAT* and *Einstein* clearly show this star as an X-ray source. This star was detected in the *Einstein* Extended Medium Sensitivity Survey (EMSS). The X-ray (0.3-3.5 keV) luminosity of the source from the EMSS was $\sim 2.2 \times 10^{28}$ erg s^{-1} (Fleming et al. 1988). Observations made with the *EXOSAT* Low Energy (LE) telescope give a source flux of $(17.2 \pm 0.2) \times 10^{-3}$ counts s^{-1} (0.05-2.0 keV) (Giomm et al. 1991). EQ1839.6+8002 was also serendipitously observed in the field of view of 3C390.3 by *ROSAT* in 1991 March and 1992 April.

We present the results from a detailed analysis of the *GINGA* flare, together with the soft X-ray data obtained from the *Einstein* IPC and the *ROSAT* PSPC.

2 X-ray Observations

2.1 *GINGA* Observations

The 3C390.3 field was observed with the *GINGA* Large Area Proportional Counter (LAC) in the pointing mode on 1991 February 14 9:10-23:08 (UT). The flare started at $\sim 22:30$ and lasted until the end of the observation. During the flare period, the *GINGA* LAC was in MPC1 L mode in which events from each of the LAC detectors were pulse-height analyzed and accumulated on board into 48 spectral channels covering an energy range of 1-36 keV, with time resolution of 16 seconds. The background is estimated using a standard set of background coefficients, each of which is derived from off-source observations made during period of 1990 October-December. The *GINGA* data were reduced using the Leicester Data Analysis System (LDAS). The X-ray spectra of EQ1839.6+8002 generated by LDAS were modelled with the XANADU-XSPEC package (Version 8).

2.2 *Einstein* and *ROSAT* Observations

EQ1839.6+8002 was serendipitously detected during the *Einstein* IPC observations of 3C390.3 on 1980 January 1, February 8 & 19, March 31, April 5-10 & 12-14 & 23, and May 3. The total exposure of the observations is $\sim$ 18884 seconds. The IPC data reduction was carried out with IRAF/PROS package (Version 2.2.1) and the IPC spectra of EQ1839.6+8002 were analyzed with XSPEC.

The *ROSAT* PSPC observations of 3C390.3 were made on 1991 March 18-19, 29-30, and 1992 April 11. EQ1839.6+8002 was observed in these periods with a total exposure of $\sim$ 11215 s. The PSPC data were reduced using the Starlink ASTERIX X-ray data reduction package (Version 1.6b) and the spectra of EQ1839.6+8002 were modelled with XSPEC.

3 Results

Figure 1(a) shows the flare light curves of EQ1839.6+8002 obtained with the *GINGA* LAC in energy bands (2-6 keV) (top panel) and (8-20 keV) (bottom panel) on 1991 February 14. Each data point represents a background subtracted X-ray count rate in a 16 second bin. A one sigma error is plotted with the data. The flare starts at $\sim$ 22:30:40. The 2-6 keV flux rapidly increases from 24 ± 3 counts s^{-1} to 129 ± 5 in about two minutes, and then rises more slowly to 164 ± 5 counts s^{-1} at 22:34:52. The characteristic times for the 2-6 keV flux during the rapid and slow rise periods are, respectively, $\sim$ 54 and

~ 481 seconds. The flux started to decay at $\sim$22:35:24 with an exponential decay time ~ 737 seconds. In the first two minutes of the flare, the hard X-ray (8-20 keV) flux rapidly rises from $\sim 5 \pm 2$ to $\sim 29 \pm 3$ with an exponential rise time ~ 52 seconds, which is similar to the behaviour of the 2-6 keV flux. However, the hard X-ray flux peaks earlier than the 2-6 keV flux and started to decay at $\sim$ 22:34:04. The characteristic decay time of the 8-20 keV flux is ~ 595 seconds.

Figure 1(b) shows the *Einstein* IPC observations between 1980 April 8-10. Although details on the source behaviour can not be obtained owing to large observational gaps, it is obvious that the source was in a flaring state on 1980 April 8-10. The flux ratio of the peak to the quiescent (an average over April 5-7, 12-14) is ~ 33.

During the ROSAT observations, EQ1839.6+8002 is in a quiescent state and no flare is seen. The source flux varies by a factor of ~ 2.

The *GINGA* spectra, after subtracting the pre-flare X-rays (including contributions from both EQ1839.6+8002 and the radio galaxy 3C390.3), have been fitted with a one temperature Raymond-Smith (RS) plasma model. **Figure 2 shows (filled and open circles respectively) the spectra obtained at the flare peak (1991 February 14 22:34:43–22:35:15) and in the decay phase near the end of the observation (1991 February 14 22:56:03–22:58:11). The results of the flare spectral modelling are plotted in Figure 3** which gives time history of the plasma temperature T_e, volume emission measure $Em(V)$, and X-ray luminosities of soft and hard X-rays. The temperature rises rapidly to 10.5×10^7 K at $\sim$ 22:32:51 and returns to the pre-flare level of $\sim 4.6 \times 10^7$ K in about 7 minutes. The emission measure $Em(V)$, however, continues to increase after the temperature reaches a maximum, and peaks about two minutes after the temperature. As shown in Figure 3, the variation of the hard X-ray (8-20 keV) luminosity follows that of the temperature, while the soft X-ray (2-6 keV) luminosity more or less follows the pattern of the emission measure. The total energy released in 2-20 keV energy band during the flare, after subtracting the pre-flare quiescent flux, is $\sim 10^{34}$ erg. At the peak of the 2-6 keV luminosity, the total luminosity is $\sim 10^{31}$ erg s^{-1}, about 20% of a typical M4Ve stellar surface luminosity.

Figure 2 also shows the X-ray spectra of EQ1839.6+8002 from the *ROSAT* observations in 1991 March (in barred crosses) and from the *Einstein* IPC observations in quiescent (in diamonds) and flare (in ellipses) states. The source (0.2-2 keV) luminosity from the *ROSAT* measurement is $\sim 3.3 \times 10^{28}$ erg s^{-1}, which is consistent with that from the *Einstein* during the source quiescent period. During the *Einstein* flare, the source (0.2-2 keV) luminosity becomes $\sim 3.2 \times 10^{29}$ erg s^{-1}, an order of magnitude higher than the source quiescent luminosity. As shown in Figure 2, the source intensity at 2 keV can vary for nearly four orders of magnitude from the quiescent state (as measured by PSPC and IPC) to the flare peak detected by *GINGA*.

Work is in progress on deriving other flare parameters from the variation in T_e and $Em(V)$. However, the large value of $Em(V)$ at the flare peak implies that even if the whole coronal volume is involved ($V = 4\pi R_{\star}^2(H/2)$, where $H/2$ is the isothermal scale height), the electron densities and pressures derived ($P_e \geq 3 \times 10^{18}$ cm^{-3} K) are comparable to those in the largest solar flares.

In conclusion, if EQ1839.6+8002 is indeed the source of the emission, then this relatively innocuous (but active) dMe star is producing a flare comparable with those detected from RS CVn systems. However, no such systems are known within the relevant *GINGA* field of view.

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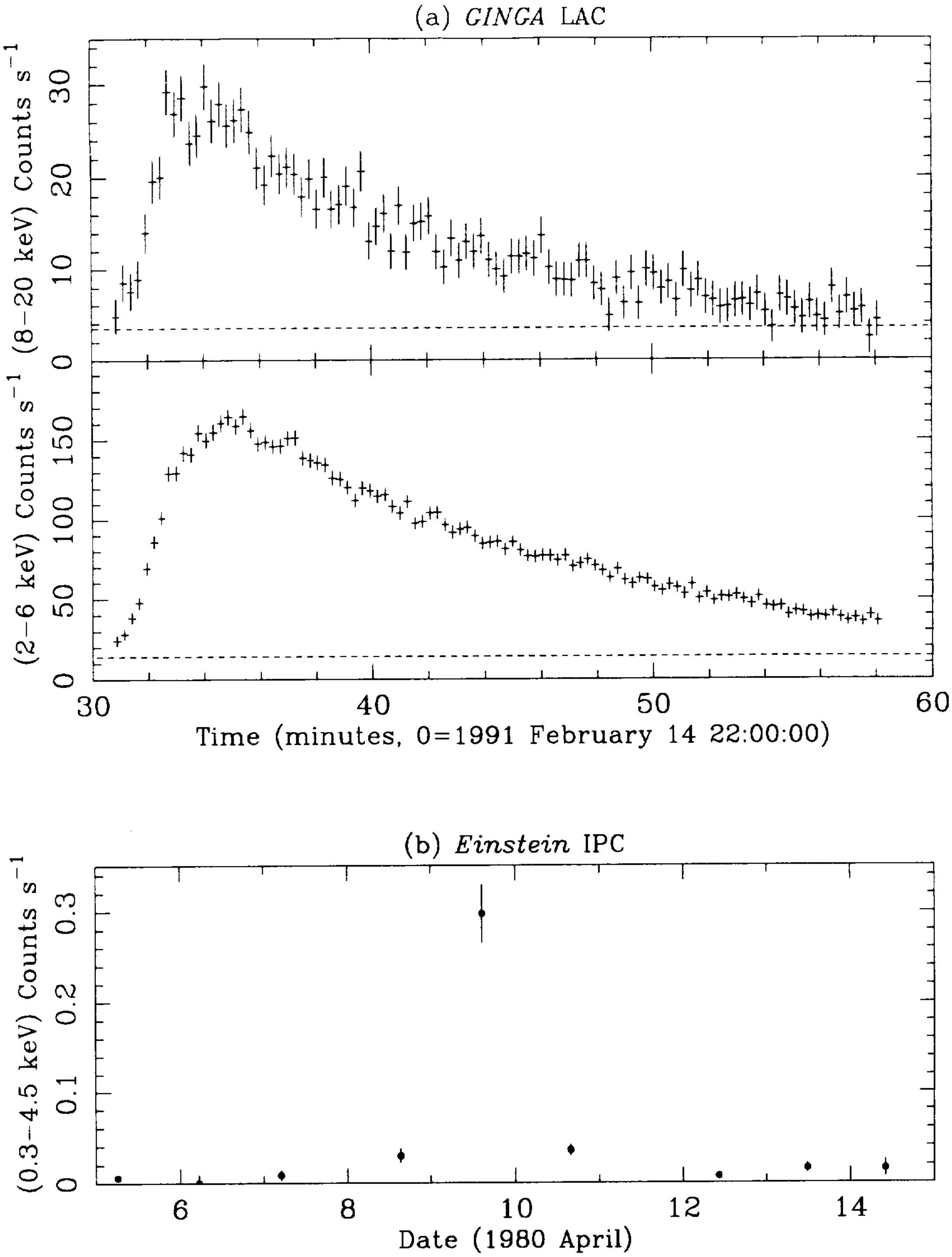

Figure 1: (a) X-ray flare light curves of EQ1839.6+8002 from *GINGA*. The dashed lines are pre-flare fluxes including contributions from both 3C390.3 and EQ1839.6+8002. (b) X-ray flare of EQ1839.6+8002 observed by *Einstein* in 1980 April.

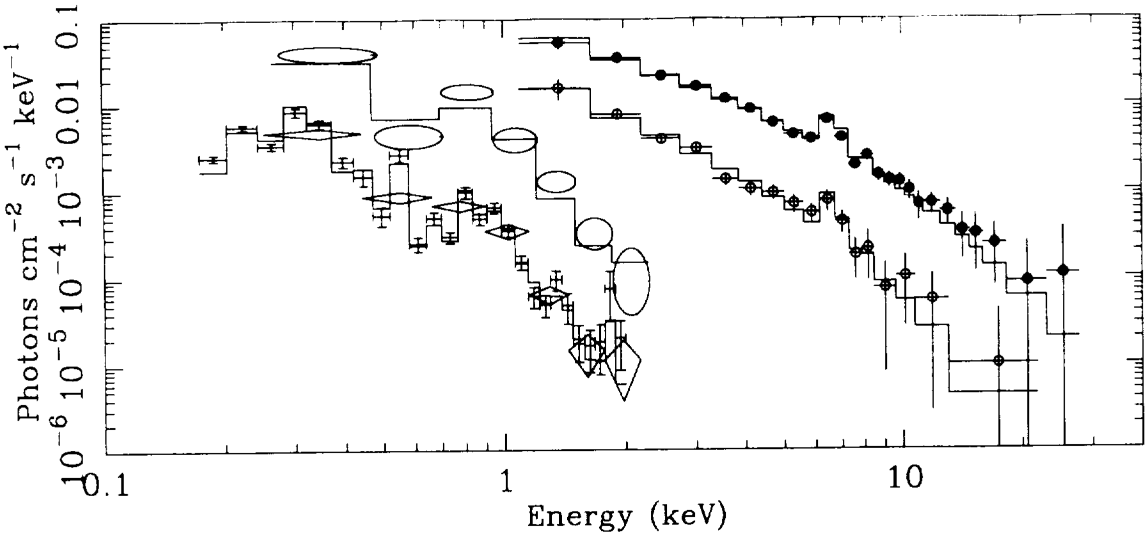

Figure 2: X-ray spectra of EQ1839.6+8002. The filled & open circles: the *GINGA* LAC spectra at 22:34:59 and at 22:57:07; The ellipses & diamonds: the IPC data in the flare and quiescent periods; The barred crosses: the PSPC spectrum.

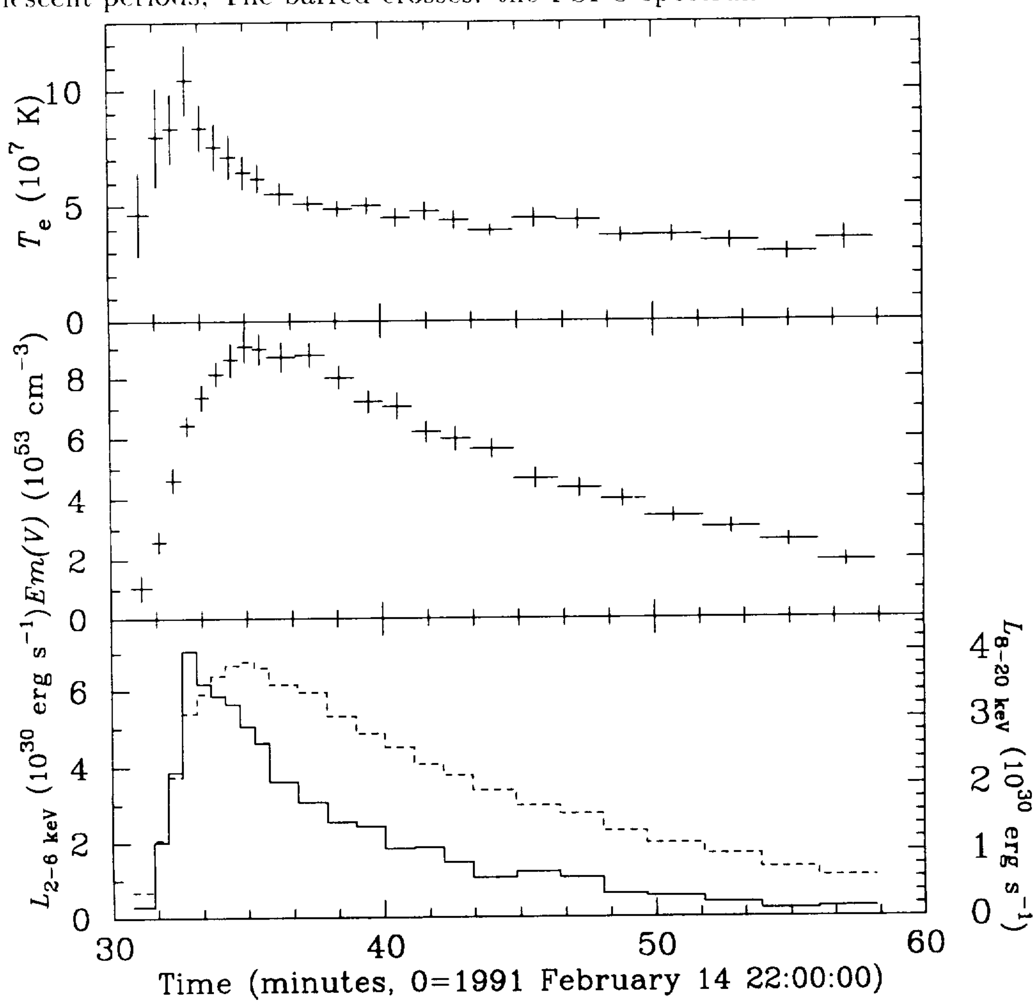

Figure 3: The variation of the temperature and emission measure of EQ1839.6+8002 as a function of time. The source X-ray luminosities in (2-6 keV) and (8-20 keV) are also shown in the dashed and solid lines.

GINGA X-Ray Observations of HR1099 (V711 Tauri)

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Abstract

The RS CVn binary HR1099 (V711 Tau) was observed for $\sim$ one binary orbit by the X-ray astronomy satellite GINGA. Near the beginning of the observation, an X-ray flare of several hours duration was detected. The peak temperature of the flare approached 50 MK, with a peak volume emission measure of $10^{53.8}$ cm^{-3}. Total flare energy was $\sim 10^{34.7}$ ergs. The abundance of Fe changed from a quiescent value of $\sim$ 10–20% to $\sim$ 50% of solar during the flare. Such variations in the Fe abundance were seen previously in *GINGA* observations of X-ray flares on UX Ari and Algol, and may be related to the "FIP effect" seen in the solar corona.

Subject headings: X-rays: stars, stars: coronae, X-rays: flares

1. Introduction

The RS CVn binary HR 1099 (V711 Tau) is one of the most intensively studied chromospherically active systems, with observations spanning the optical to the X-ray region. Originally shown to be an RS CVn system by Bopp and Fekel (1976), it was detected in X-rays during the HEAO-1 survey by Walter, Charles, and Bowyer (1978) and by the Copernicus satellite (in outburst) by White, Sanford, and Weiler (1978). A recent comprehensive review of the system can be found in Donati *et al.* (1992), and its detailed properties are reported in the compendium of Strassmeier *et al.* (1993).

V711 Tau exhibited X-ray, Hα, and Lyα flaring activity very soon after it was recognized as an RS CVn system (White, Sanford, and Weiler 1978, Weiler *et al.* 1978). Pye and McHardy (1983) reported a large X-ray outburst detected with the Ariel V sky survey. This flare had a decay time of 6 hours and a total X-ray energy output of 7×10^{36} erg (2-18 keV), reaching a maximum X-ray luminosity of 6×10^{32} erg s^{-1}. Linsky *et al.* (1989) described a flare seen on V711 Tau with high resolution spectra from IUE. Up to the present, estimates of the flare frequency on V711 Tau (or for that matter, on most RS CVn stars) has probably been limited more by the lack of observing time than by the the lack of flares.

With a 2.84 day rotational period, V711 Tau is a natural candidate for rotational modulation and spot modeling analyses. Numerous optical photometric studies, beginning with Bopp *et al.* (1977), and continuing up to the present (see references in Strassmeier *et al.* 1993) have shown the quasi-sinusoidal light variations characteristic of large starspot groups in RS CVn and BY Dra systems (an extensive study of five such systems, including V711 Tau can be found in Rodono *et al.* 1986). Dorren and Guinan (1990) found a long term (several years) variation in brightness at UV and optical wavelengths which suggests an activity cycle: interestingly, rotational modulation in UV line emission was not present during the activity maximum. Agrawal and Vaidya (1988) found evidence for correlated X-ray and optical variations over the course of an orbital period. The minimum of the X-ray flux seen in the *Einstein* IPC and MPC detectors corresponded with the optical wave maximum. In addition, Agrawal and Vaidya observed an X-ray flare lasting over an hour, with a peak temperature of $\sim$ 130 MK and with a total X-ray energy of $\sim 5\times10^{34}$ erg. More recently, Drake *et al.* (1994) may have detected possible rotational modulation from V711 Tau's corona in the extreme ultraviolet (60–180Å).

Given the extensive observational history and flaring potential of V711 Tau, it was a logical candidate for further studies using the *GINGA* X-ray satellite. Because of operational considerations, *GINGA* observations were usually conducted by continuously observing a target (subject to earth occultations and other interruptions) for two or more days. This afforded a rare opportunity to monitor V711 Tau in the X-ray region, with the hope of detecting a stellar flare. In the past, *GINGA* has been quite successful in catching large X-ray flares on UX Ari (Tsuru *et al.* 1989), II Peg (Doyle *et al.* 1991, 1992), σ^2 Corona Borealis (Stern *et al.* 1992a), and Algol (Stern *et al.* 1992b), using this observing approach. In this paper, we report our *GINGA* observation of V711 Tau lasting nearly one orbital period, including the detection of a strong X-ray flare.

2. *GINGA* Observations

V711 Tau was observed by the Large Area Counter (LAC) on *GINGA* from 0200 UT on January 26 1988 to 1800 UT on 28 January 1988. The LAC consists of 8 sealed Be-window collimated proportional counters having a total peak effective area of $\sim$ 4000 cm^2 and a 1.08° $\times$ 2.0° FWHM field of view. The LAC responds to X-rays in the range 1.2-37 keV with an energy resolution of 18% FWHM at 5.9 keV. A detailed description of the LAC is given by Turner *et al.* (1989). A description of the *Ginga* satellite is given in

Makino *et al.* (1987). The light curve and spectral data were extracted using the procedure of Hayashida *et al.* (1989); details of how this method is employed can be found in that reference and in Stern *et al.* (1992a). Briefly, the method uses a model of the orbital and long-term variation in detector background as a function of orbital parameters to produce an estimated LAC internal background. It also includes an estimate of the extragalactic diffuse sky background. The model is built up through a statistical analysis of thousands of satellite orbits and is limited primarily by fluctuations in the diffuse sky background such that the residual uncertainty in the background subtracted flux is about ± 0.9 ct s^{-1} in the 2-10 keV band (Hayashida *et al.* 1989). This is more than sufficient to detect variabilty and flaring in V711 Tau.

2.1. X-ray and Optical Lightcurves

In Figure 1 we plot the X-ray lightcurve for our observation of V711 Tau in the 1.7-9.9 keV energy band (128 sec bins) using L2 (the topmost layer) of the LAC counters (by *Ginga* standards, the source is relatively soft, and inclusion of deeper layes or higher energies for the LAC detectors adds no appreciable source flux, only internal or diffuse background). The X-ray flare near the beginning of the observation is quite obvious: in Figure 2 we show an expanded plot of the period encompassing the flare.

Although there are significant gaps in the temporal coverage due to orbital occultations, SAA passages, etc., a slow modulation of the source count rate is visible for most of the observation, with a noticeable drop in flux from 0200 UT on Jan 28 to the end of the observation. In an effort to discover possible explanations for either the slow modulation or the drop in flux, we compared our observations with the differential BV photometry of Mohin and Raveendran (1993) covering the time interval from Dec 27 1987 to Mar 12 1988. We converted the X-ray and V magnitude light curves to orbital phase using the ephemeris of Fekel (1983). In Figure 3 we plot the X-ray and differential V lightcurves as a function of orbital phase. Visual inspection suggests that, if a correlation is present, the optical *minimum* is associated with the X-ray *minimum*, although the optical minimum appears at a somewhat earlier phase (~ 0.45) than the X-ray minimum (~ 0.55). The X-ray lightcurve is complicated by what may be a small flare occuring about phase 0.6, as well as the large flare occurring after phase 0.8.

3. Analysis of the X-Ray Spectra

3.1. Quiescent Data

Because of the near-continuous variability of V711 Tau's X-ray lightcurve, it is difficult to establish a single "quiescent" period. We extracted LAC pulse-height spectra in a number of intervals on 27 and 28 Jan using procedures developed by Hayashida *et al.* (1989; see also Stern *et al.* 19992). The extracted *Ginga* spectra were converted to XSPEC-compatible data and response files using the program LAC2XSPEC (K. Ebisawa, private communication). We found that the quiescent spectra could not be successfully fit with 1 or 2 temperature *solar abundance* models using the Mewe-Kaastra (1992) code, but, allowing the Fe abundance to vary ("vmeka" model in XSPEC), acceptable fits were obtained (at the temperatures of the fit, the differences between the Mewe-Kaastra and Raymond 1993 models were relatively small, so we choose to discuss the remaining spectral analysis in terms of the Mewe-Kaastra models). The results of our spectral fitting for 5 quiescent intervals are given in Table 1.

Most notable in the quiescent spectra are the very low ($\sim$ 10–20%) Fe abundances required to produce acceptable fits. We note that, although 2 temperature components are required, the value of the lower temperature component ($\sim$ 10 MK) should be viewed with some caution, given the dropoff in LAC response below 2 keV. However, the derived Fe abundance is not significantly dependent upon the parameters for the lower T component, which contributes negligible emission at the ~ 6.7 keV energy of the Fe XXV/Fe XXVI line complex.

3.2. Flare Data

We extracted flare spectra over selected time intervals in a similar manner as the quiescent spectra were extracted and converted to XSPEC-format files. The time intervals selected are listed in Table 2. Since the flare occurred near the start of the observation, there were insufficient counts in the pre-flare spectrum, so we instead subtracted a quiescent spectrum corresponding to the overall flux minimum between ≈ 0600–1100 on 28 Jan 1988. Though this may tend to overestimate the flare count rates and emission measures somewhat, the effect should be $\lesssim$ 5–10%, based upon the approximate range of count rates in the X-ray light curve.

The flare data could in general be fit by single-temperature Mewe-Kaastra models, but once again, to obtain acceptable fits, the Fe abundance was left as a free paramater. In Table 2 we give the results of the flare data fits, and in Figure 4 we plot the pulse-height spectra for the quiescent interval chosen, and for the 5 flare time samples along with the best fit models for each. Unlike the quiescent data, the presence of Fe XXV/XXVI emission is quite clear near the flare peak (Figure 4 (c) and (d)). In Figure 5 we plot the time history of the derived flare parameters. The characteristic pattern of solar and stellar flares is evident, with the flare temperature of ~ 50MK peaking well before the peak emission measure of ~ 7×10^{53} cm^{-3}. Also, the Fe abundance required near the flare peak is ~ 50%, substantially higher than for the quiescent data.

4. Flare Energetics and Derived Parameters

We estimated the total X-ray energy in the flare using a similar procedure as Doyle *et al.* (1992). Although there is a large data gap near the peak of the flare (see Figure 2), we did observe both the rise and decay phases of the flare. As a lower limit to the X-ray energy, we may simply sum up the fluxes and times for which we fitted pulse-height data (Table 2). This yields $E_{tot}(1.7 - 10keV) \gtrsim 1.7 \times 10^{34}$ erg. A more realistic estimate of the X-ray energy release can be obtained by fitting the observed X-ray light curve with a double exponential function of the form:

$$F = a_0 + a_1 * (1. - exp(-\frac{(t - t_0)}{\beta\tau})) * exp(-\frac{(t - t_0)}{\tau})$$

where a_0 is the pre-flare count rate, a_1 is a scale factor for the peak flux, t_0 is the time of flare onset, τ is the flare decay time, and β is the ratio of flare rise to flare decay time. For the V711 Tau flare, we estimate $\tau \approx 4500$ sec, with rise time $\approx 30\%$ of the decay time. We use a conversion factor of 2.38×10^{-12} erg/count, derived from the XSPEC fits to the flare data (this factor varies by only a few % over the temperature range exhibited by the flare). Integrating our double exponential model, we derive a total energy of $E_{tot}(1.7 - 10keV) = 4.3 \times 10^{34}$ erg. This is comparable to the X-ray flare on V711 Tau observed by Agrawal and Vaidya (1988), but more than 100 times smaller than the V711 Tau flare seen with Ariel V (Pye and McHardy 1983). The corresponding totals for the II Peg flare of Doyle *et al.* (1992) are 4.6 and 18 $\times 10^{34}$ erg, or between $\sim$ 3–4 times larger, despite the much shorter (1300 s) decay time. This is to be expected, given the much larger count rate of the II Peg flare. For the two flares on UX Ari detected by *GINGA*, the total X-ray energy released was estimated to be $> 1 \times 10^{37}$ and $\sim 3 \times 10^{35}$ ergs. Thus the flare on V711 Tau is a relatively modest one in terms of total X-ray energy.

We may also derive decay time scales based upon the pulse-height fits to our data for the temperature and emission measure. Based upon exponential fits, we estimate $\tau_T \sim$ 16,500 s. and $\tau_{EM} \sim 6600$ s. Using the formalism of van den Oord and Mewe (1989), this results in effective decay times of ~ 7700 s. With the same formalism, if the flare is contained in a single loop, we derive a loop height H $\approx 5 \times 10^{10}$ cm, a volume of $\approx 3 \times 10^{31}$ cm^{-3}, and an electron density, $n_e \approx 1.5 \times 10^{11}$ cm^{-3}, assuming that, as is likely for most large stellar flares, it cools primarily via radiation (see, e.g., van den Oord and Mewe 1989, Stern *et al.* 1992).

5. Discussion

5.1. The Fe Abundance Variations

A brief comparison of Tables 1 and 2 indicates clearly that the Fe abundance measured in both the quiescent and flaring X-ray data is typically a factor of 2 or more below the solar values. The Fe abundance in quiescence is ≈10–20% of solar, and increases by a factor of 3–4 from the quiescent to the flaring state. Is this some artifact of the fitting process, or a real effect in the line-to-continuum flux? For reasons which we detail below, we believe it is a real effect.

One issue of concern for collimated (not imaging) detectors such as the LAC would be presence of another X-ray source in the *GINGA* LAC field of view ($\approx 1 \times 2$ deg.) A search of the Master X-ray catalog on the HEASARC/BROWSE system at GSFC turned up only a nearby transient Uhuru source, 4U0336+01, which, if in outburst at its 4U rate of 100 c/s, would have overwhelmed the signal from V711 Tau in *GINGA*. An examination of the ROSAT PSPC archive turned up no strong source of soft X-rays within 1 deg of V711 Tau. In addition, the relatively soft spectrum of V711 Tau in quiescence as seen by the *GINGA*

LAC suggests that all the flux is indeed coming from the RS CVn system.

A second question is the effect of the lower temperature component on the fitted Fe abundance parameter. In fact, the temperature of this component is low enough ($\sim$ 10 MK) that it does not contribute signifiacntly to either the line or continuum emission near the 6.7 keV energy of the Fe XXV/XXVI complex.

A third issue might be the statistical significance of the result; however, it is clear both by examining the 90% confidence limits and by visual inspection of the quiescent and flaring spectra in Figure 4 that no contribution from line emission at $\approx$ 6.7 keV can be seen in the quiescent spectrum, yet it is clearly present for several of the flare spectra. Thus we conclude that, whatever the physical cause, the apparent Fe abundance is different in the flaring and quiescent data.

Could non-thermal emission enhance the continuum sufficiently so as to lower the line-to-continuum ratio for the Fe XXV/XXVI complex at 6.7 keV, and thus produce an apparently small Fe abundance. This hypothesis has been suggested for a flare on AB Dor by Vilhu *et al.* (1991). However, we find this scenario unlikely, for the following reasons: (1) to produce the required continuum requires considerably more energy in the non-thermal particles than the thermal particles, which is rarely, if ever, the case in solar flares or quiescent solar X-rays, (2) the production of the non-thermal continuum must decrease relative to the thermal continuum during the flare in order to produce the observed change in the Fe abundance: again, this is the opposite of what occurs during solar X-ray flares, (3) the quiescent spectrum shows no hint of a hard, non-thermal tail at higher energies, which might be expected.

Another hypothesis is the resonance absorption model suggested by Tsuru *et al.* (1989) for the UX Ari X-ray flares. In this model, the resonance line of Fe XXV is optically thick (and the plasma distribution is anisotropic), resulting in resonance scattering of the line photons (and eventual destruction in the lower stellar atmosphere?), which leads to a lower than expected flux in the Fe XXV resonance line. It seems curious, however, that the opacity effects should *decrease* during the flare as compared to the quiescent corona, as the overall emission measure is *increasing*.

We are thus led to the strong possibility that the actual abundance of Fe is indeeed changing from quiescence to flare on V711 Tau. There is, in fact, ample evidence from solar studies that the abundances of elements in the corona are not the same as photospheric abundances, and do appear to change in different active regions and flaring portions of the solar corona. Studies of elemental abundances in Solar Energetic Particles (SEP) and the solar corona (Meyer 1985, 1992, Saba and Strong 1992) have shown strong departures from the solar photospheric values of Anders and Grevesse (1989). In particular, the abundance studies suggest that elements with a low first ionization potential or FIP ($\lesssim$ 9–10 eV) such as Si, Mg, and Fe are preferentially enhanced by $\gtrsim$ 4 times over photospheric values, compared to high-FIP elements such as C, Ne and O. No universally accepted explanation exists as yet for the solar results. One mechanism which could produce the FIP effect in the Sun requires the segregation of ions and neutrals in either the chromosphere or the photosphere through diffusion processes in the presence of electric and magnetic fields (Meyer 1993). Such processes are likely to depend upon the global structure of the stellar outer atmosphere and the level of magnetic flux generation in a given star. If there is a relationship between activity and coronal abundance as indicated by the solar X-ray data (Saba and Strong 1992), then stars of differing activity levels and atmospheric structures may well show different patterns of elemental enhancements or depletions. In addition, time variability of measured abundances is also quite possible.

In the case of V711 Tau, we note that the Fe abundance appeared to increase from quiescence to flare. Although quiescent *GINGA* X-ray data for Algol could not be used to derive an Fe abundance because of contamination from the nearby Perseus Cluster, the

Algol data did show that the Fe abundance was relatively high during the early phases of the Algol flare, declining by a factor of 2–3 in the late decay phases of the flare. In the Ca XIX solar observations of Sylwester *et al.* (1984), the line-to-continuum ratio appeared to increase during the early stages of flares, but decline during later stages *at the same temperature*. All of these results suggest that some process enhancing the Fe or low-FIP elemntal abundances operates more strongly during the onset of flares than in quiescent coronal heating.

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Figure Captions

Figure 1. X-ray lightcurve (1.7-9.9 keV) for V711 Tau. Errors are $\pm 1\sigma$.

Figure 2. Expanded X-ray lightcurve for X-ray flare.

Figure 3. X-ray and Optical (ΔV) lightcurves plotted versus binary phase. Optical data from Mohin and Raveendran (1993).

Figure 4. X-ray pulse height spectra for quiescent (a) and flaring (b-f) intervals during observation. Flare spectra have had the quiescent spectrum subtracted. The time intervals for (b)-(f) correspond to entries (a-e) in Table 2.

Figure 5. Fitted flare parameters as a function of time.

TABLE 1

2-T VMEKA FITS OF QUIESCENT DATA

Spectrum	Start and Stop Times (UT)				χ^2_ν	T_1 [1]	90% limits		EM_1 [2]	90% limits		T_2 [1]	90% limits		EM_2 [2]	90% limits		Fe abun [3]	90% limits	
(a)	27 Jan	3:31	27 Jan	6:52	0.75	13.2	7.8	18.2	4.20	2.66	6.02	38.3	29.5	61.8	3.65	1.52	5.58	0.01	0.00	0.22
(b)	27 Jan	7:57	27 Jan	11:37	1.38	10.3	7.8	13.2	4.29	3.51	5.02	34.5	30.6	40.1	5.05	3.89	5.97	0.12	0.01	0.25
(c)	27 Jan	12:45	27 Jan	17:46	0.83	7.1	3.6	11.1	4.01	2.49	14.68	28.3	25.6	31.9	6.39	5.27	(*)	0.19	0.03	0.37
(d)	28 Jan	2:01	28 Jan	8:29	1.35	10.3	6.2	14.4	2.91	1.96	3.90	29.6	25.6	36.6	4.04	2.66	(*)	0.10	0.00	0.30
(e)	28 Jan	9:36	28 Jan	17:51	0.94	7.4	4.8	10.1	3.84	2.86	7.50	29.6	26.7	33.4	4.48	3.75	5.12	0.11	0.00	0.27

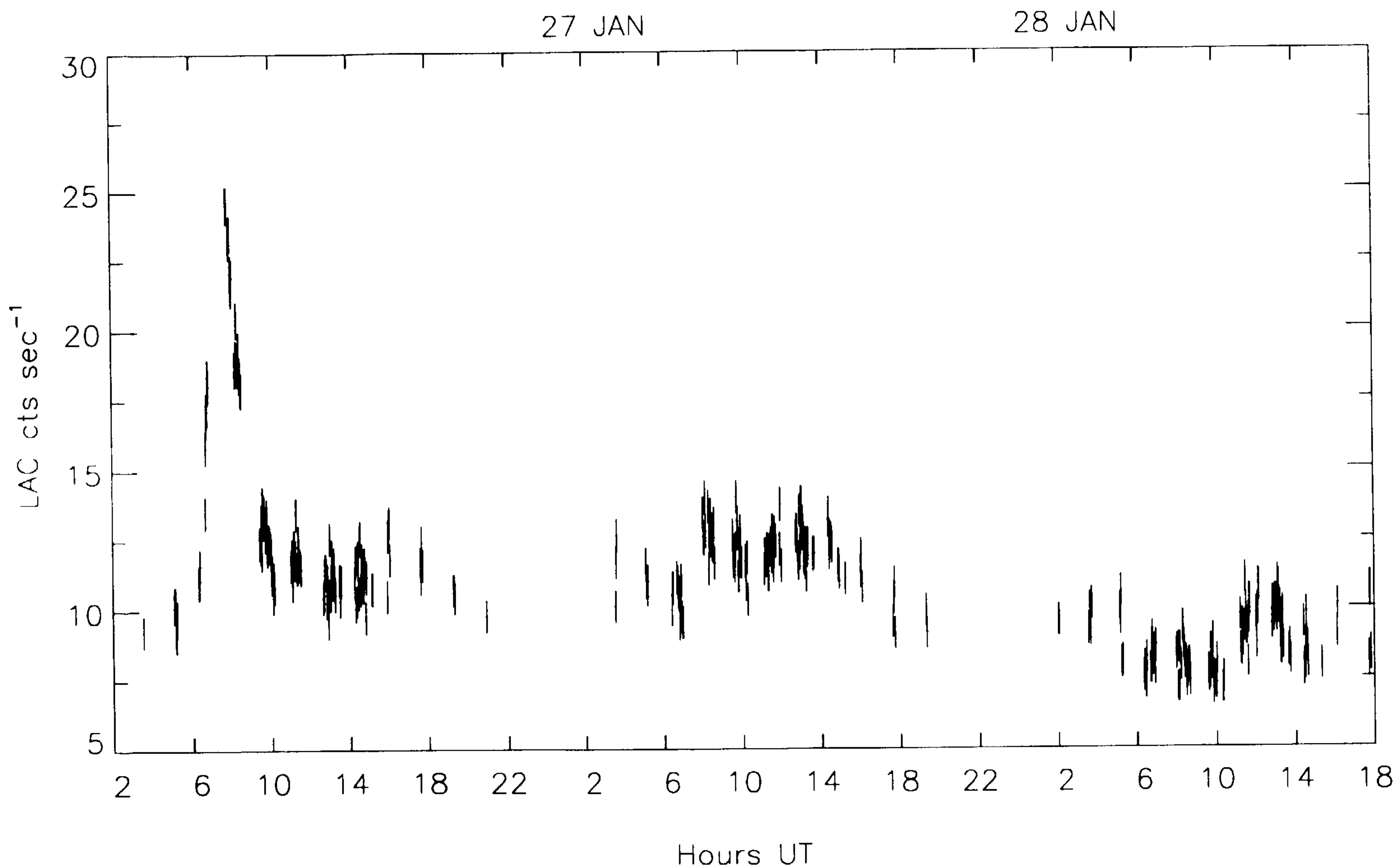
[1] 10^6 K
[2] 10^{53} cm^{-3}
[3] Relative to Solar Abundance of Anders and Grevesse (1989)
*failed to converge

TABLE 2

1-T VMEKA FITS OF FLARE DATA (26 JAN)

Spectrum	UT		χ^2_ν	T_1 [1]	90% limits		EM_1 [2]	90% limits		Fe abun [3]	90% limits		Flux [4]
(a)	6:17	6:22	1.10	36.1	23.0	66.6	1.52	0.11	2.02	0.89	0.87	4.23	8.5
(b)	6:36	6:49	1.65	49.0	42.4	57.4	3.37	3.11	3.65	0.55	0.23	0.91	22.2
(c)	7:47	8:04	1.03	39.7	36.1	43.9	6.59	6.25	6.94	0.53	0.30	0.79	37.6
(d)	8:10	8:29	0.76	34.9	31.9	38.4	5.41	5.13	5.72	0.46	0.22	0.75	27.7
(e)	9:23	10:10	0.90	29.2	25.6	33.9	2.44	2.24	2.64	0.47	0.03	1.03	10.8

[1] 10^6 K
[2] 10^{53} cm^{-3}
[3] Relative to Solar Abundance of Anders and Grevesse (1989)
[4] 10^{-12} erg cm^{-2} s-1



27 JAN
28 JAN
30
25
20
15
10
5
LAC cts sec^{-1}
2
6
10
14
18
22
2
6
10
14
18
22
2
6
10
14
18
Hours UT

FIG. 1

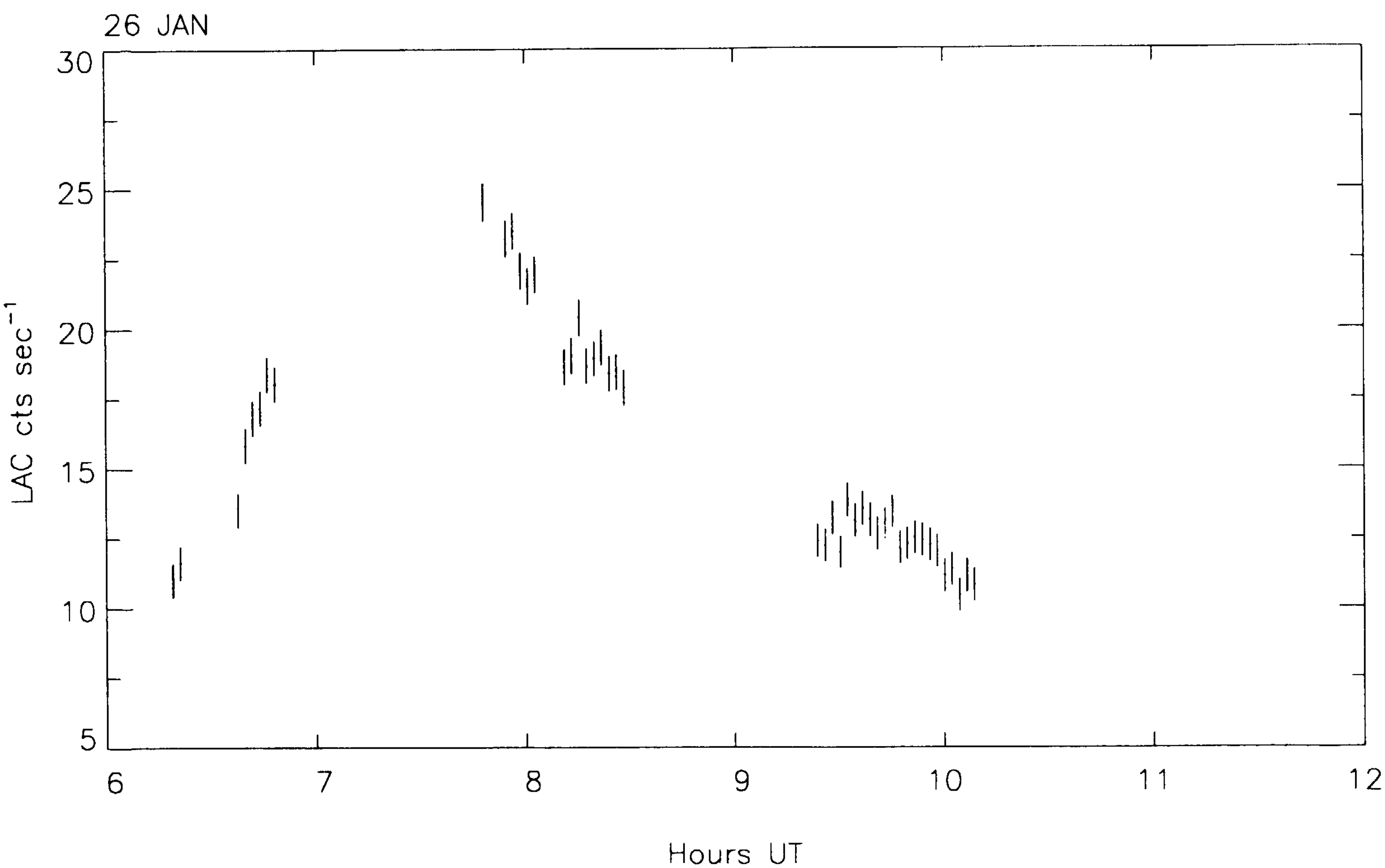


FIG 2.

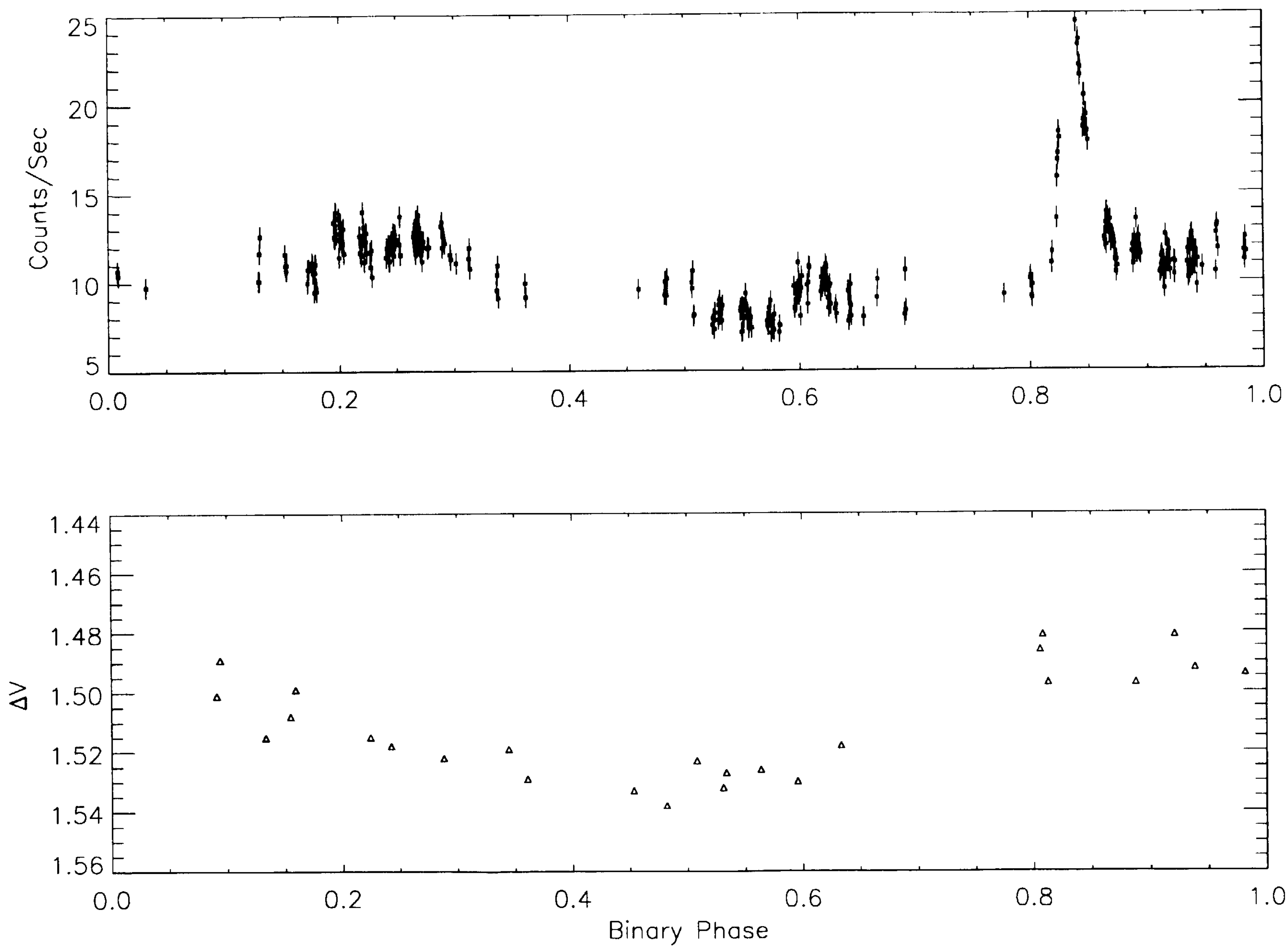

Counts/Sec
25
20
15
10
5
0.0
0.2
0.4
0.6
0.8
1.0
ΔV
1.44
1.46
1.48
1.50
1.52
1.54
1.56
Binary Phase

FIG 3.

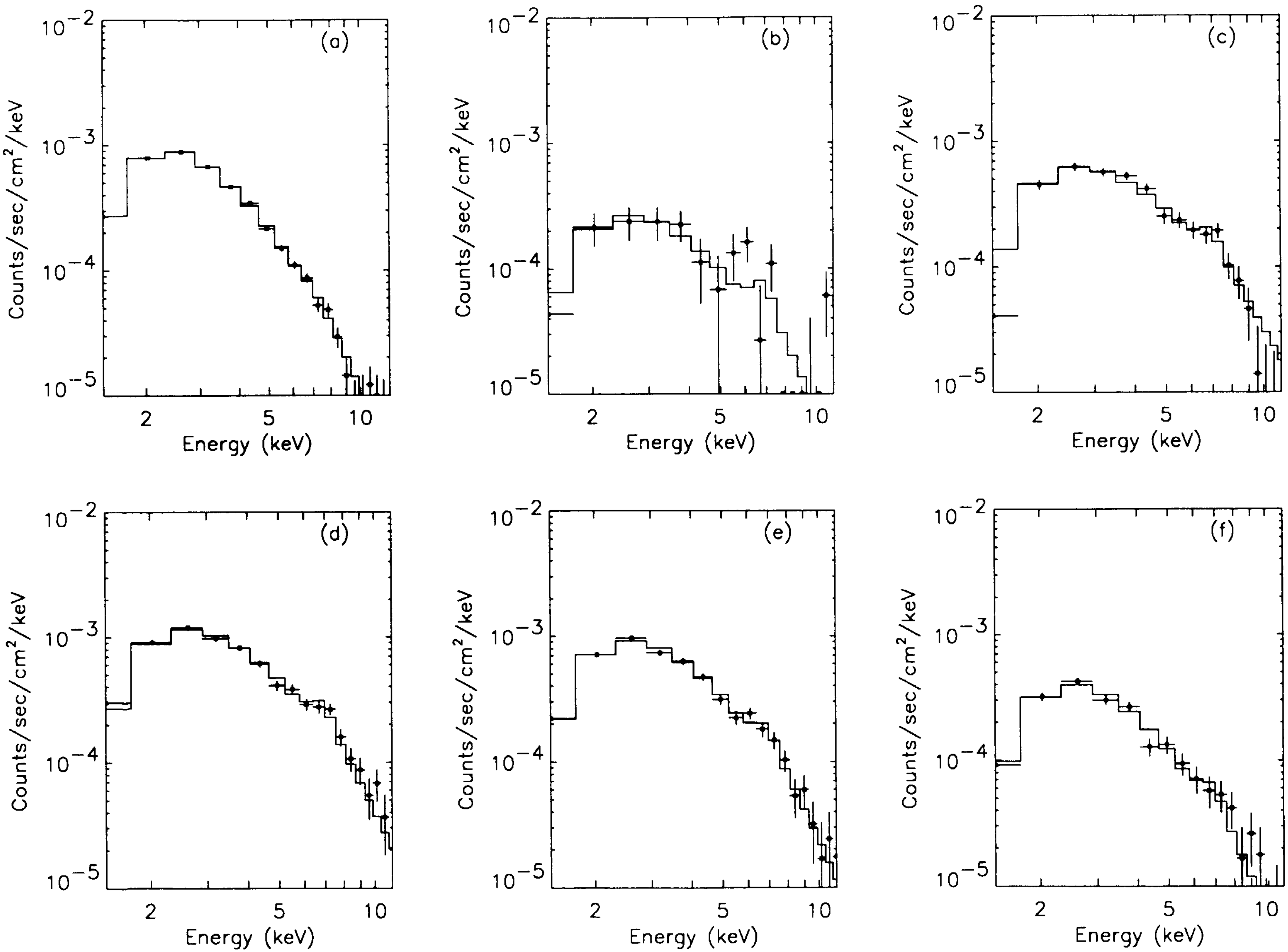
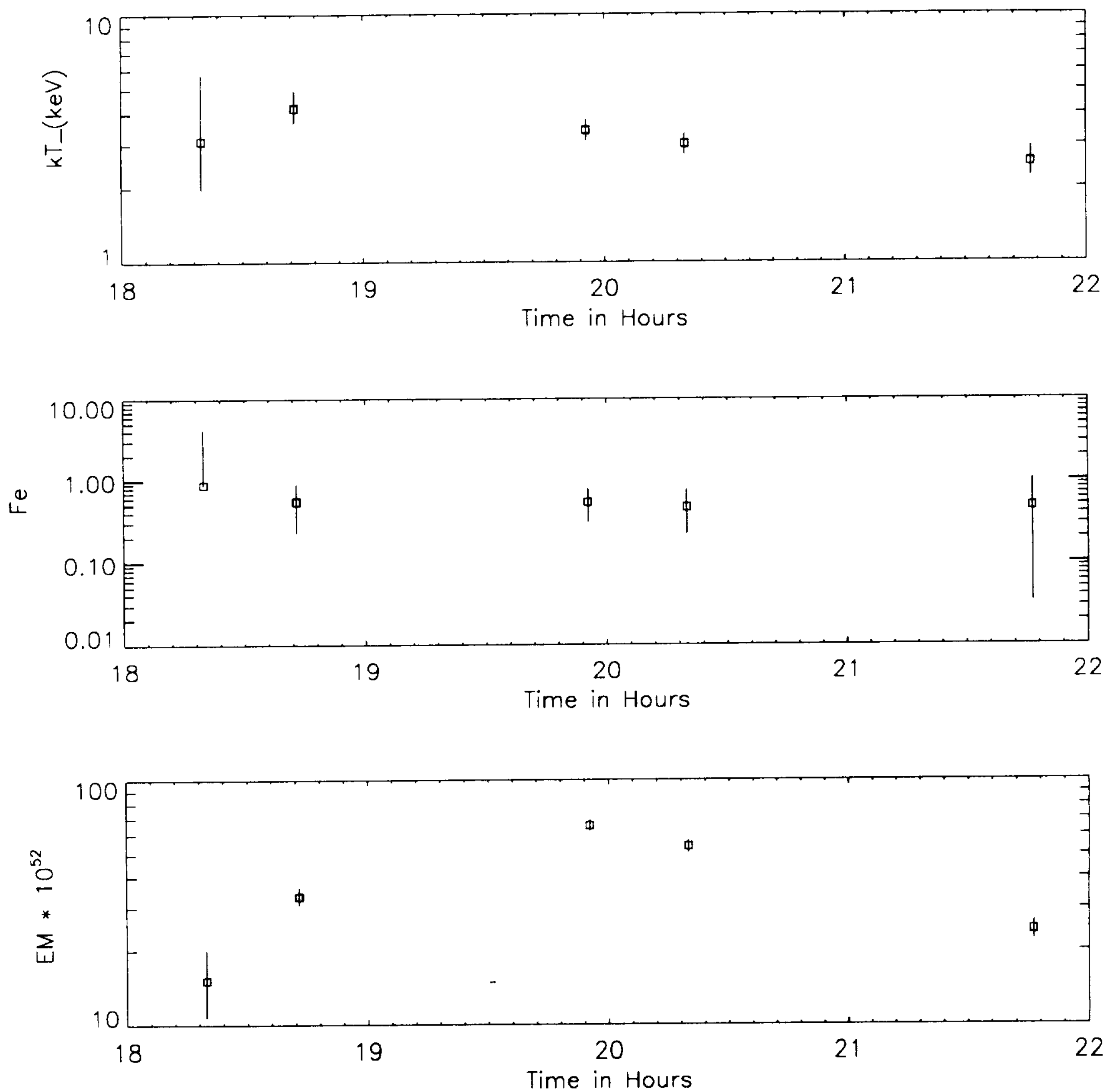


FIG. 4



10
1
kT_(keV)
18
19
20
21
22
Time in Hours
10.00
1.00
0.10
0.01
Fe
18
19
20
21
22
Time in Hours
100
10
EM * 10^{52}
18
19
20
21
22
Time in Hours

FIG. 5