INVESTIGATION OF X-RAY VARIABILITY IN HIGHLY ACTIVE COOL STARS

(GINGA Visting Investigator Program)

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Final Report

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I. Introduction

The goals of this program were to obtain and analyze *Ginga* X-ray observations of highly active cool star coronae in an effort to better understand the nature of their time variability. The possible types of variability to be studied included x-ray occultations via eclipses in a binary system, rotational modulation of X-ray emission, flares, and a search for "microflaring."

At the inception of this program, we began communications with Dr. Koyama of ISAS, who informed us that we would be given approximately one week of observing time on GINGA (including background observations) , with the number of stellar targets not to exceed three. Dr. Yutaka Uchida of the University of Tokyo was named as our primary science contact. After a series of computer mail exchanges with Dr. Uchida, we jointly agreed to begin our program with a 3 day observation (including one day background) of σ^2 CrB, an active RS CVn system with a long history of successful x-ray observations, including significant flaring. This binary system is in synchronous rotation with a period of 1.14 days. Our observation would be the first time this system was observed for two succesive orbital periods. Hence we would be able to see if any variability in the stellar x-ray emission was correlated with particular locations of the stellar disk, or instead the variability was mostly of a stochastic or flaring nature.

After our successful observation of σ^2 CrB (see below), and in consultation with Dr. S. Tsuneta at U. Tokyo, we decided that a study of a somewhat brighter source, also with a history of flaring, would be appropriate. We therefore requested that our remaining time be devoted to a study of the eclipsing variable star Algol (β Per). Algol is similar to RS CVn systems in that the secondary star is of spectral type K0 IV (the primary is B8 V), and the binary period is 2.867 days. It also shows evidence of considerable stellar activity as seen in *EXOSAT* observations.

II. Observations and Sumarry of Results

Observations of both σ^2 CrB and Algol were carried out successfully by *Ginga*. The σ^2 CrB observations occurred on 27-30 June 1988, and the Algol observations on 12-14 January 1989. In the σ^2 CrB observation, we also obtained simulatneous IUE and VLA observations during part of the *Ginga* observation.

The results from each of these observations are detailed in the attached preprints of papers submitted to the proceedings of the 1989 Seattle Cool Star Workshop (see §IV below). In both cases, the observations were highly successful. In the case of σ^2 CrB, we observed almost continous variability, with at least one flare detected in X-ray, radio, and ultraviolet bands simultaneously. The Algol results were even more spectacular, with *Ginga* detecting a large flare lasting more than one half day. The Algol flare pulse-height spectra also clearly showed the presence of highly ionized Fe line emission. The Fe line equivalent width was significantly variable during the flare rise and decay phases, and demonstrated quantitative disagreement with standard models of the line emission.

Details of these two observations are given in the attached preprints.

III. Foreign Travel Associated with this Program

Because this program was specifically a *Visiting* Investigator Program, the Principal Investigator undertook to spend as much time as possible, within the existing funding and time constraints, at ISAS and visiting with U. Tokyo scientists. Two separate trips to ISAS were made: the first for 2 months in September-October 1988, and the second for $1\frac{1}{2}$ months in March-April 1989. During the first trip, data reduction and analysis of the σ^2 CrB observation were performed. Also, during this time, target selection and obeservational planning were carried out for the Algol observation. During the second trip, data reduction and analysis of the Algol observation were performed.

During both visits, the P.I. worked directly with many members of the ISAS *Ginga* team on a daily basis, receiving much help and assistance in the data reduction and analysis tasks. This is especially significant, as the *Ginga* team is quite small by U.S. standards, and it is to their great credit that they were able to take on the burden of assisting (usually several) U.S. investigators while they maintained their regular duties of operating the *Ginga* spacecraft and developing software, in addition to writing papers! In particular, I must thank Prof. F. Makino, Dr. F. Nagase, Dr. K. Mitsuda, Mr. K. Hayashida, Dr. R. Corbet, Dr. T. Kii, and the rest of the *Ginga* team for making the P.I.'s visits so fruitful and enjoyable. The P.I. also undertook several visits to the U. of Tokyo and the National Astronomical Observatory of Japan (in Mitaka - formerly Tokyo Astronomical Observatory) to discuss the *Ginga* results with his collaborators Drs. Y. Uchida and S. Tsuneta. In addition, he had many useful discussions at ISAS with visitors such as K. Makishima, T. Watanabe, K. Koyama, M. Arnaud, and J. Hughes.

IV. Presentations and Publications

During the P.I.'s visits to Japan, he presented two colloquia at ISAS on preliminary results of the *Ginga* observations described above. In addition, during visits to the U. of Kyoto, and U. of Nagoya, he also presented these results at colloquia. Poster papers on the two observations were given at the 6th Cambridge Cool Star Workshop at Seattle, WA in September 1989. The attached two preprints will be submitted (1 Nov 1989) to the above conference proceedings. It is also anticipated that a presentation of the Algol observation will be given as a poster paper at the January 1990 AAS meeting in Washington. More extensive versions of these results are currently being prepared for submission to refereed journals.

Co-ordinated *Ginga*, IUE and VLA Observations of Flaring Activity in σ^2 CrB

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ABSTRACT

The RS CVn system σ^2 Corona Borealis (=TZ CrB) was observed by the Large Area Counter (LAC) on the *Ginga* X-ray satellite for a period of 2.5 days, or approximately 2 binary orbits. Throughout the *Ginga* observing period, σ^2 CrB exhibited almost continuous X-ray variability on time scales ranging from minutes to days. The average LAC count rate was 4.2±1.2 cts s^{-1} (1.7–11.0 keV) corresponding to $L_x \sim 10^{29.6}$ erg s^{-1} (2–10 keV), depending upon the assumed source spectrum. The summed X-ray pulse height spectrum from several "flare-like" events compared with similar spectra from "quiescent" periods shows evidence of increased coronal temperatures, consistent with frequent flare activity. Co-ordinated observations with IUE and the VLA which cover most of one such episode indicate both microwave and ultraviolet flaring. The time of maximum flux at the longest VLA wavelength (20 cm) precedes the soft X-ray peak by at least 30 minutes, suggesting a large size scale for the flare volume.

I. Introduction

σ^2 Corona Borealis (=HR 6063 =HD 146361 =TZ CrB) is an RS CVn-type binary system consisting of F6 and G0 dwarfs in an $\sim 1.^d14$ period orbit. Detailed information on the system is given in the compendium of Strassmeier *et al.* (1988). Originally detected in X-rays by the HEAO-1 satellite (Walter *et al.* 1980, Agrawal *et al.* 1980), σ^2 CrB was subsequently observed by several instruments on board the *Einstein* X-ray Observatory (Walter and Bowyer 1981; Swank *et al.* 1981; Agrawal *et al.* 1981, 1986) During an extended observation (28 hours) of the system with *EXOSAT*, a strong X-ray flare lasting about 2 hours was detected (van den Oord *et al.* 1988). Beginning with the initial analysis of the SSS data by Swank *et al* (1981), most of the X-ray observations can be modeled by a two component thermal plasma with $T_1 \sim$ 5-6 MK and $T_2 \sim$ 30-50 MK and similar emission measures $n_e{}^2V \sim 10^{53}$ cm^{-3}. Lemen *et al.* (1989), using *EXOSAT* TGS data, have consistently modeled the 0.06–1.2 keV spectrum of σ^2 CrB with a two temperature model having $\sim$ 6 and 24 MK components. With the launch of the *Ginga* satellite by Japan's Institute of Space and Astronautical Science (ISAS) in 1987, an opportunity arose through the NASA/ISAS *Ginga* Visiting Investigator program to conduct a long-duration observation of the σ^2 CrB system. Co-ordinated observations with the International Ultraviolet Explorer (IUE) and Very Large Array (VLA) were also scheduled for a period of approximately 12 hours during the extended (60 hour) *Ginga* observing period.

II. X-ray Observations

The *Ginga* observation of σ^2 CrB began at 2054 UT on 27 June 1988 and ended at 0512 UT on 30 June 1988. Observation of a nearby (3.0° away) background region was performed from 0210 to 2051 UT on 27 June 1988. All observations were conducted with the LAC experiment, which consists of 8 sealed Be-window collimated proportional counters having a total peak effective area of ~ 4000 cm^2 and a $1.08° \times 2.0°$ FWHM field of view. The LAC responds to X-rays in the range 1.5-37 keV and the energy resolution of the LAC is 18% FWHM at 5.9 keV. The sensitivity of the LAC is such that a source with a 2-10 keV flux of 1 milliCrab ($\sim 2.0 \times 10^{-11}$ erg cm^{-2} s^{-1}) will produce approximately 10 cts s^{-1} in the LAC when all 8 counters are summed together. A detailed description of the LAC is given by Turner *et al.* (1989). A description of the *Ginga* satellite is given in Makino (1987).

The average flux level for σ^2 CrB is ~ 5 *Ginga* cts s^{-1}, or about 10% of the detector background. A sophisticated background subtraction procedure which models the time-varying orbital background component in the LAC has been developed by Hayashida *et al.* (1989). Such modeling is able to reduce the uncertainty in the detector internal background to ~ 0.86 count/sec (1σ). Further small corrections for the deviation of the local background from the all-sky average are obtained by taking an observation of a nearby background region. It is also usual to exclude LAC data when the LAC line-of-sight approaches the earth limb. We conservatively excluded included observations made $< 8°$ off-limb, with relatively minor loss of data. The background-subtracted source light curve (128 sec samples), using the Hayashida *et al.* procedure coupled with the above data selection criteria, is shown in Figure 1.

III. X-ray Analysis

The extent of intrinsic source variability is apparent when comparing to the background observation. Fitting a trial constant source intensity to the light curve yields an average count rate of 4.2 ± 1.2 cts s^{-1} (1.7–11 keV). A χ^2 test of a constant count rate model yields a reduced χ^2 of 4.0/306 d.o.f. This can be compared to a mean count rate for the background day observation on 27 June of 0.22 ± 0.48 cts s^{-1} and a reduced χ^2 of 0.94/108 d.o.f. Thus source constancy is formally ruled out. Visual inspection of the data suggests the source undergoes a slow modulation of $\sim$25% in count rate, with a number of "flare-like" events. Periodogram analysis yields a possibly significant periodicity at ~ 0.45 d. However, the periodogram is heavily influenced by high count rates during "flare-like" episodes.

Fitting the LAC pulse-height spectrum is somewhat problematic for a source with this a low signal-to-noise ratio, *and* such clear variability. In addition, while earlier data on σ^2 CrB clearly require at least two temperature components, the lower temperature component is only poorly constrained by the lack of sub-keV energy response of the LAC. Marginally unacceptable fits are obtained for the entire data set using a 2T thermal bremstrahllung model: $\chi_\nu{}^2$=1.60/26 d.o.f. with $T_1 = 23 \pm 4$ MK, $EM_1 = 10^{53.1}$ cm^{-3}, $T_2 = 7^{+3}_{-2}$ MK, $EM_2 < 10^{54}$ cm^{-3}. Acceptable fits are obtained when the data is divided into "flaring" and "quiescent" sections. In this case, the "quiescent" results are: $\chi_\nu{}^2$=0.99/26 d.o.f. with $T_1 = 23 \pm 8$ MK, $EM_1 = 10^{53.0}$ cm^{-3}, $T_2 < 9$ MK, $EM_2 < 10^{54}$ cm^{-3}. The "flaring" results are: $\chi_\nu{}^2$=1.22/26 d.o.f. with $T_1 = 35^{+10}_{-7}$ MK, $EM_1 = 10^{53.2}$ cm^{-3}, $T_2 = 7^{+4}_{-2}$ MK, $EM_2 \sim 10^{54}$ cm^{-3}. This porvides some evidence of the expected temperature rise for the "flaring" episodes (all quoted errors are 90% L.O.C., 2 parameters).

IV. Co-ordinated Ultraviolet and Radio Observations

VLA 6 cm and alternating 20 and 3.8 cm observations were obtained from 2357 UT on 27 June to 1117 UT on 28 June 1988. In addition, we obtained 3 ESA IUE shifts, during which 11 SWP (low resolution) and 15 LWP (high resolution) exposures were taken. E. Guinan graciously allowed us to trade an ESA shift for one of his US shifts in order to obtain coverage during the low background orbits for *Ginga*. This proved to be fortunate, as can be seen in Figure 2: a flare was clearly detected by the VLA, IUE, and *Ginga* near 1100 UT on 28 June. We note that the 3.8 and 6 cm fluxes are still rising or reaching a peak during one of the X-ray data gaps. This suggests that the peak of the X-ray flare may have occurred during an earth occultation, from which we infer a much larger event than the earlier "flare-like" episodes. This conclusion is consistent with the lack of similar radio–X-ray correlation during the earlier periods of increased X-ray emission at roughly 0130 and 0530 on 28 June. In addition, there is an $\sim$ 40 minute delay between the 20 cm microwave peak and that of the 6 cm flux. In a typical solar-like magnetic loop structure, the microwave opacity should increase at longer wavelengths (Gibson 1984). Unit optical depth will thus be reached much higher in the loop for 20 cm radiation compared to 6 cm radiation. Hance, if all the microwave peaks are emission from the same loop structure (but see Kundu *et al.* 1989), then the time difference may be a propagation delay for accelerated particles traveling along magnetic field lines, or the time for a heat conduction front to reach the stellar chromosphere and begin evaporating material into the corona.

Acknowledgements

We wish to thank all the members of the *Ginga* LAC team at ISAS, elsewhere in Japan, and in the UK, without whose dedication this opportunity would not have been possible. We also wish to especially thank F. Makino, F. Nagase, K. Mitsuda, K. Hayashida, and R. Corbet for their hospitality, understanding, and help with the *Ginga* data analysis software. We owe E. Guinan at least a few beers for swapping a US IUE shift for an ESA one, and J. Hughes for help with the *Ginga* spectral fits. R.A.S. and B.M.H. were supported by NASA Contract NAS8-37655 under the *Ginga* Visiting Investigator Program and by the Lockheed Independent Research Program.

References

Agrawal, P.C.,*et al.*, 1980, M.N.R.A.S., **190**, 853.
Agrawal, P.C.,*et al.*, 1981, M.N.R.A.S., **196**, 73P.
Agrawal, P.C.,*et al.*, 1986, M.N.R.A.S., **219**, 777.
Gibson, D., 1984, Proc. Cool Star Workshop, Lecture Notes in Physics **193**, p. 197.
Hayashida, K.,*et al.*, 1989, Pub. Astron. Soc. Japan, in press.
Kundu, M.R., *et al.*, 1989, Sol. Phys., **121**, 153.
Lemen, J.,*et al.*, Ap. J., **341**, 474.
Makino, F., 1987, Astrophys. Lett. and Comm., **25**, 223.
Strassmeier, K.G.,*et al.*, 1988, Astron. Astrophys. Suppl., **72**, 291.
Swank, J.H.,*et al.*, 1981, Ap.J., **246**, 208.
Turner, M.J.L.,*et al.*, 1989, Pub. Astron. Soc. Japan, in press.
Walter, F.M.,*et al.*, 1980, Ap. J., **236**, 212.
Walter, F.M., and Bowyer, S., 1981, Ap.J., **245**, 671.
van den Oord, G.H.J., *et al.*, 1988, Astron. Astrophys., **205**, 181.

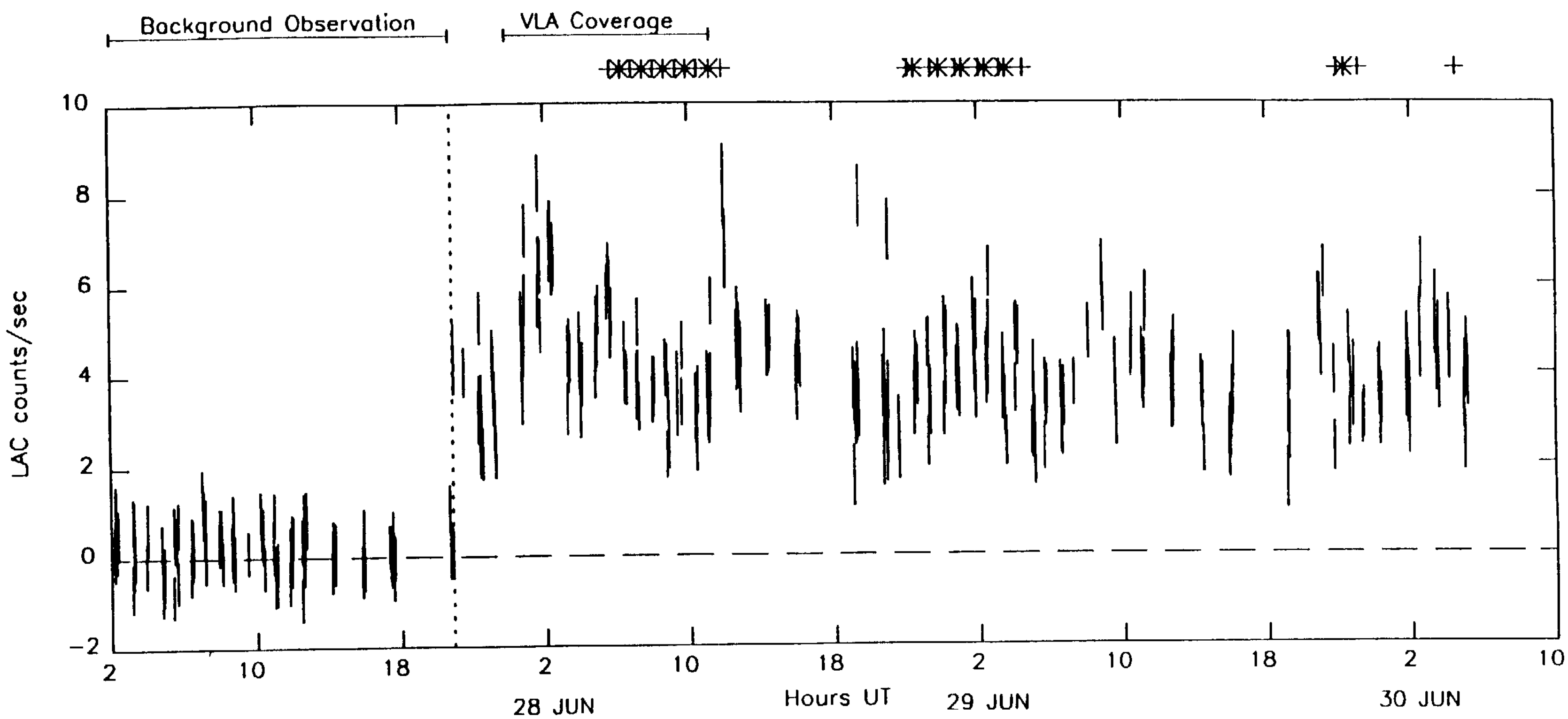

Figure 1. X-Ray light curve for σ^2 CrB observation for pulse-height energies 1.7-11 keV, 128 s binning. Data to the left of the vertical dashed line is from the background region observation. The VLA coverage period is marked above the plot. In addition, midpoints of the IUE exposures are given by (+)'s=SWP, and (X)'s=LWP.

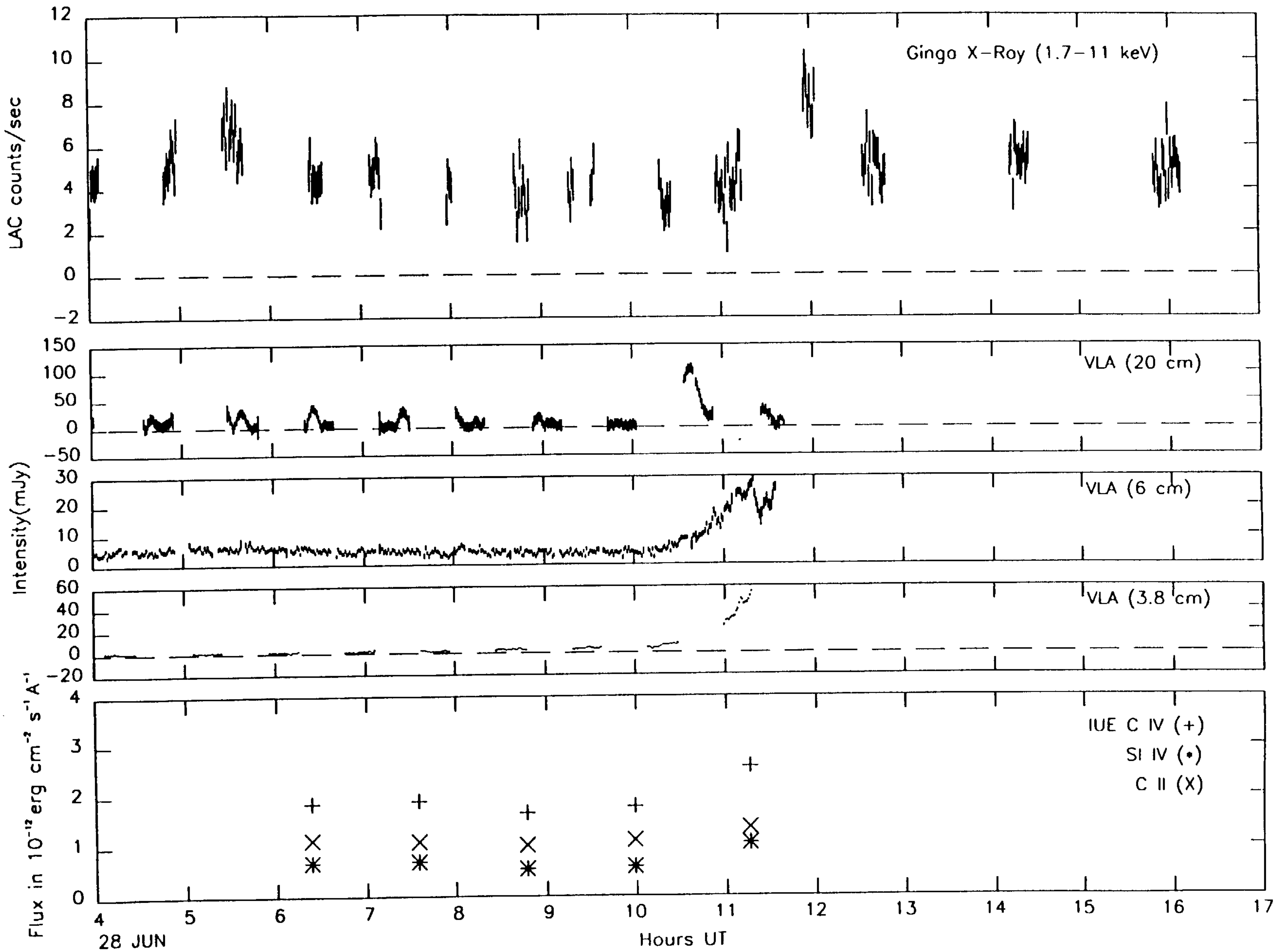

Figure 2. X-Ray, microwave and ultraviolet co-ordinated data for 28 June. X-ray binning is 64 s, VLA data are 60 s averages, and the IUE SWP line fluxes are from 30 min exposures centered about the plotted points.

Ginga Observations of a Long-Duration X-ray Flare In the Algol System

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ABSTRACT

Algol (β Per) was observed by the Large Area Counters (LAC) on the *Ginga* X-ray satellite for $\sim$ 2 days in January 1989, including both the primary optical eclipse and most of the secondary eclipse. No evidence for X-ray eclipses was seen. A large ($L_x \sim 10^{31}$ erg s^{-1}) flare lasting over 12 hours was detected prior to and during secondary eclipse. The flare began with a peak temperature $\sim$ 69 MK, gradually decaying to $\sim$ 36 MK. High temperature Fe line emission is clearly detected in the proportional counter data. The Fe line equivalent width is strongly variable during the flare, ranging from 0.4-1.0 keV. During most of the flare decay, the observed equivalent width is in strong disagreement with theoretical predictions for an optically thin plasma. Similar behavior has also been observed by *Ginga* in a large flare on UX Ari: in both events, opacity effects at line center may be playing a significant role.

I. Introduction

Algol, the well-known "demon" star, is a B8 V + K0 IV partially eclipsing binary system with period $2^d.867$ (see e.g., Richards *et al.* 1988 and references therein). The Algol system was first detected in X-rays by SAS-3 (Schnopper *et al.* 1976) and confirmed as an X-ray source by Harnden *et al.* (1977). *Einstein* Observatory SSS observations during primary optical eclipse showed no evidence of an X-ray eclipse, suggesting that the K0 IV secondary accounted for most of the X-ray emission (White *et al.* 1980). Observations during the secondary optical eclipse by *EXOSAT* were interpreted as evidence for a very shallow X-ray eclipse. During the *EXOSAT* observation, a large flare was detected, lasting about 4 hrs (White *et al.* 1988, van den Oord *et al.* 1988). Under the auspices of the NASA/ISAS *Ginga* Visiting Investigator Program, we obtained a 2-day observation of Algol in January of 1989 which included coverage of the entire primary eclipse and most of the secondary eclipse.

II. X-ray Observations

The *Ginga* observation of Algol began at 2128 UT on 12 Jan 1989 and ended at 1803 UT on 14 Jan 1989. Observation of a nearby ($\sim$3.0° away) background region was performed from 0226 to 1039 UT on 15 Jan 1989. All observations were conducted with the LAC experiment, which 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 1.5-37 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 (1987).

The background-subtracted light curve (128 sec samples), using the Hayashida *et al.* (1989, see also paper by Stern *et al.* in these proceedings) procedure is shown in Figure 1. The large X-ray flare is obvious: in addition, a smaller flare is seen at about 13 to 16 hrs UT on 13 January. There is no evidence for an X-ray eclipse of the primary star, confirming the earlier *Einstein* SSS result of White *et al.* (1980). The secondary eclipse begins well after the peak of the large flare, and mid-eclipse is at 1424 UT on 14 Jan. No eclipse of the flaring region is evident. This suggests that the flaring region is either very large or is not occulted during the (partial) secondary eclipse.

III. Analysis and Discussion

For the large flare, we have summed the X-ray pulse-height spectra into 11 time intervals roughly corresponding to the groups of contiguous data seen in Figure 1. Before model-fitting, we subtracted the quiescent spectrum corresponding to ~ 1800-2300 UT on Jan 13. All the resultant spectra were adequately modeled by a thermal bremsstrahlung spectrum + Fe line emission. An example of such a fitted spectrum is given in Figure 2. Fitting the quiescent X-ray spectrum is made difficult by contamination from the nearby Perseus cluster, which is a bright X-ray source: the quiescent spectrum is, however, well fit by a two-component thermal bremsstrahlung spectrum at temperatures ~ 15±5 MK and ~ 100MK. The second component is most likely Perseus cluster contamination. In Figure 3 we show the derived temperature and emission measure (EM) for the flare as a function of time (90% L.O.C., single parameter), and in Figure 4 we show the equivalent width (EW) of the Fe line as a function of time. The flare peak temperature is about a factor of 3 hotter than that of the largest solar flares, though comparable with T_{max} in the *EXOSAT* flare. In the *Ginga* flare, the peak temperature is reached at or near the beginning of the flare, well over 2 hours before the EM peak. This may be due either to a large loop size scale for the flare, hence a gradual density buildup from chromospheric evaporation, or possibly sequential involvement of an arcade of magnetic loops, as in a solar two-ribbon flare. The relevant e-folding time scales for the flare decay are as follows: temperature, $\tau_T \approx 52{,}000$ s, luminosity, $\tau_{L_x} \approx 20{,}000$ s, and emission measure, $\tau_{EM} \approx 22{,}000$ s. The risetimes for L_x and EM are about a factor of three shorter than the corresponding decay times. As in other large X-ray flares of this type, radiative cooling is likely to dominate, as otherwise an uncomfortably large number of loops (> 10) must be flaring (see, e.g., White *et al.* 1986, van den Oord *et al.* 1988). Under the radiative cooling hypothesis, the derived flare parameters are as follows: electron density $n_e \approx 2 \times 10^{10}$ cm^{-3} ; loop height H $\approx 1.6 \times 10^{11}(N\alpha_{0.1}^{-2}(\Gamma+1))^{(-1/3)}$ cm, where N=number of loops, α= loop aspect ratio (normalized to 0.1), Γ = loop expansion factor (see e.g., van den Oord *et al.* 1988 for equations used to derive these quantities).

In Figure 5 we show the measured Fe line equivalent width plotted against temperature and compared with the most recent theoretical calculations of Rothenflug and Arnaud (1985) for a solar-abundance thin plasma. The observed and predicted values are in substantial disagreement for the lower temperature data taken during the flare decay phase. This is in contrast to the much shorter duration *EXOSAT* flare seen by White *et al.*, where the measured EW was consistent with theory, albeit with much greater uncertainty than in the present flare. Non-equilibrium effects are probably ruled out because of the long time scale of the present flare and the lack of noticeable shift in the Fe-line centroid to lower ionization stages during the rise phase of the flare. Continous absorption is not likely, as the low energy portion of the X-ray spectrum does not show evidence of any cut-off. Tsuru *et al.* (1989) have seen a similarly variable Fe-line equivalent width in *Ginga* observations of two flares on UX Ari. They have suggested resonance scattering as a possible explanation. This scenario would require an asymmetric structure (i.e., a loop?) which is opaque at line center along the line-of-sight, remaining optically thin in the continuum. Using the results of Acton (1978), and Rothenflug and Arnaud (1985), we estimate $\tau_0 \approx 1$ at line center for Fe XXV at a column density $n_e l \approx 3 \times 10^{21}$ cm^{-2}. For the derived n_e of $\approx 2 \times 10^{10}$, this corresponds to column length of $\sim 1.5 \times 10^{11}$ cm, roughly comparable with the loop height derived above. Thus line opacity effects may account for the observed Fe line equivalent width variation. The Fe line variability could also be similar to that seen in Ca XIX during solar flares, which have been attributed to abundance changes resulting from the flare heating process (Sylwester *et al.* 1984).

Acknowledgements

We wish to thank all the members of the *Ginga* LAC team at ISAS, elsewhere in Japan, and in the UK, without whose dedication this opportunity would not have been possible. We especially wish to thank F. Makino, K. Mitsuda, and K. Hayashida for their hospitality, understanding, and help with the *Ginga* data analysis software. We also acknowledge helpful discussions with T. Watanabe, K. Koyama, K. Makishima, T. Ohashi, T. Tsuru, M. Arnaud, J. Hughes, K. Strong and J. Lemen. R.A.S. and B.M.H. were supported by NASA Contract NAS8-37655 under the *Ginga* Visiting Investigator Program and by the Lockheed Independent Research Program.

References

Acton, L.W., 1978, Ap.J., 225, 1069.
Harnden, F.R., *et al.*, 1977, Ap.J., **214**, 418.
Hayashida, K.,*et al.*, 1989, Pub. Astron. Soc. Japan, in press.
Makino, F., 1987, Astrophys. Lett. and Comm., *25*, 223.
Richards, M.T., *et al.*, 1988, A.J., **96**, 326
Rothenflug, R., and Arnaud, M., 1985, Astron. Astrophys., **144**, 431.
Schnopper, H.W., *et al.*, 1976, Ap.J.(Letters), **222**, L119.
Strassmeier, K.G.,*et al.*, 1988, Astron. Astrophys. Suppl., **72**, 291.
Swank, J.H.,*et al.*, 1981, Ap.J., **246**, 208.
Sylwester, J., *et al.*, 1984, Nature, **310**, 665.
Tsuru, T.,*et al.*, 1989, Pub. Astron. Soc. Japan, in press.
Turner, M.J.L.,*et al.*, 1989, Pub. Astron. Soc. Japan, in press.
van den Oord, G.H.J, *et al.*, 1988, Astron., Astrophys., XXXX.
White, N.E., *et al.*, 1980, Ap.J.(Letters), **239**, L69.
White, N.E., *et al.*, 1986, Ap.J., **301**, 262.

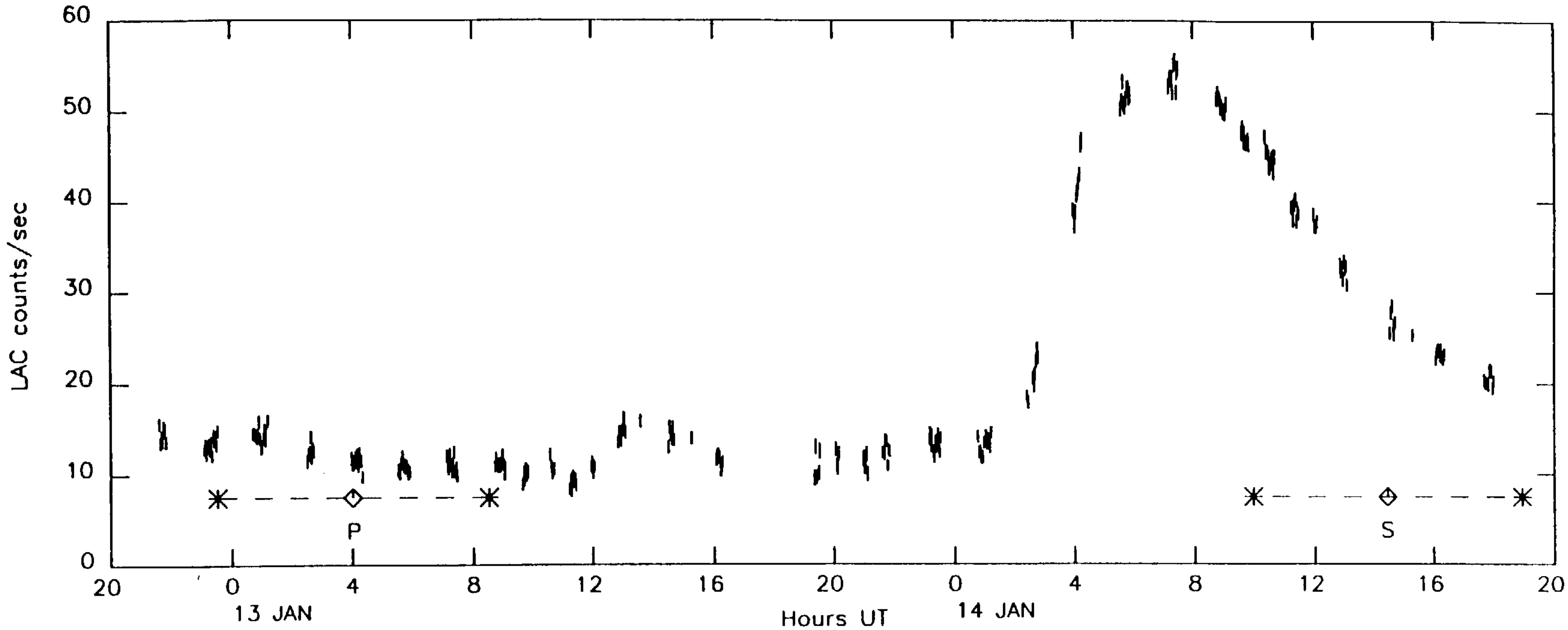

Figure 1. X-ray light curve (1.2—18 keV) for Algol observation. Midpoints of primary (P) and secondary (S) optical eclipses are indicated by diamonds. Dashed lines indicate approximate eclipse duration between 1st and 4th contact (*).

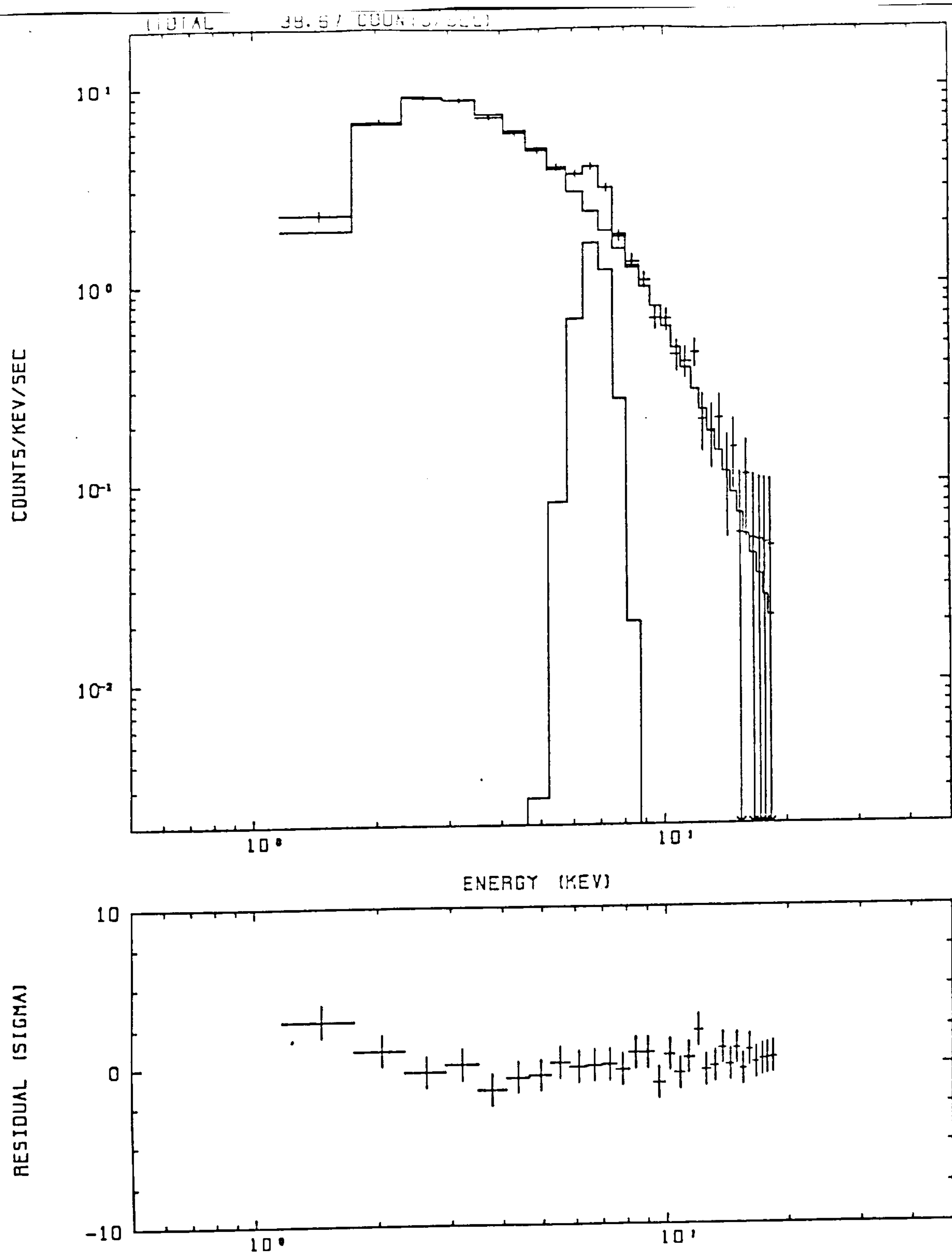

Figure 2. Pulse-height spectrum for Algol during rise phase ($\sim$ 4 hrs UT) of large flare. (Top) Data are indicated by crosses with error bars. Model fit includes two components: thermal bremsstrahlung and Fe line. Solid lines indicate each component and net model spectrum. (Bottom) Spectrum fit residuals (σ).

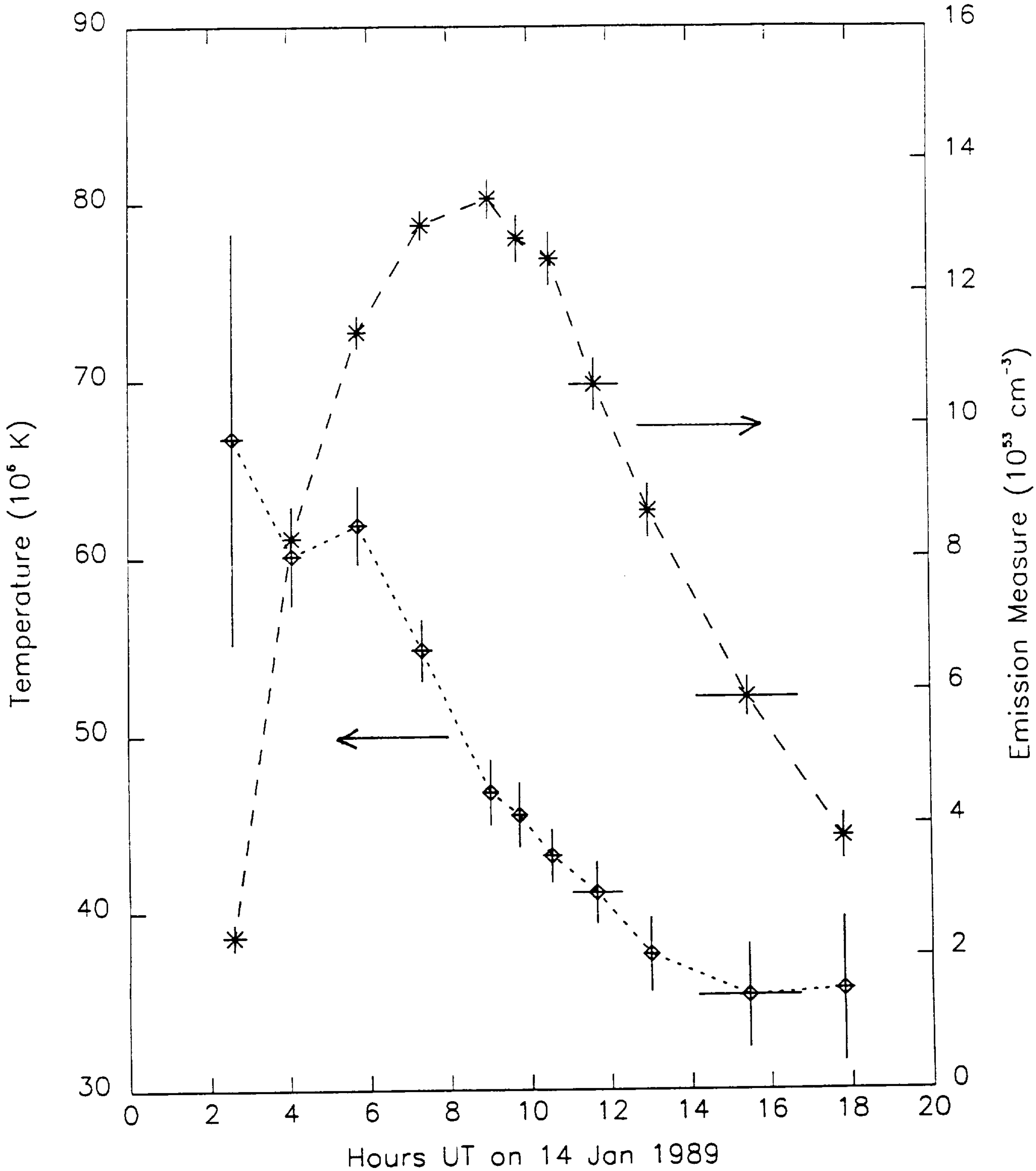

Figure 3. Emission measure (right hand scale) and Temperature (left hand scale) as a function of time during flare.

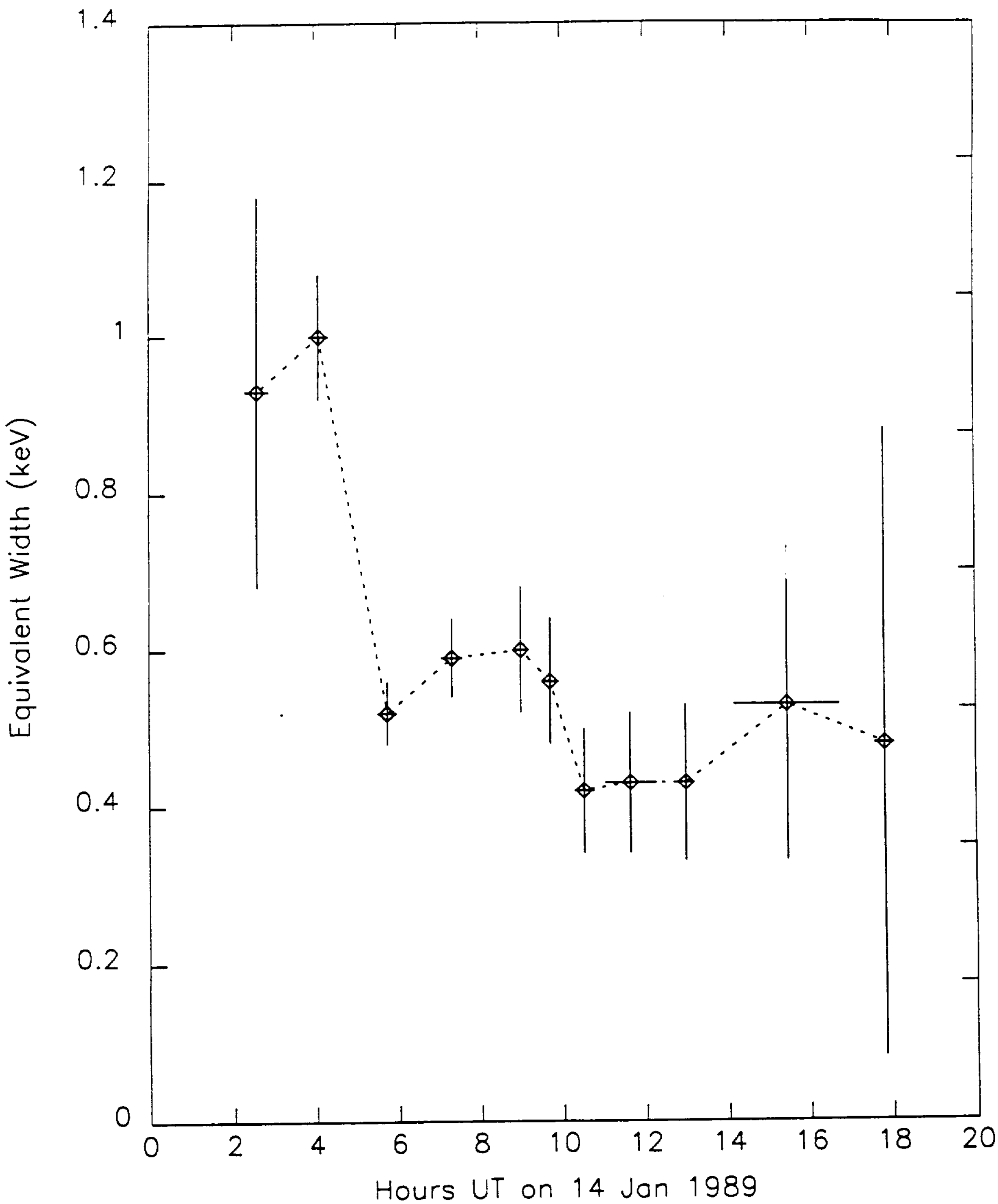

Figure 4. Equivalent width of Fe line during flare.

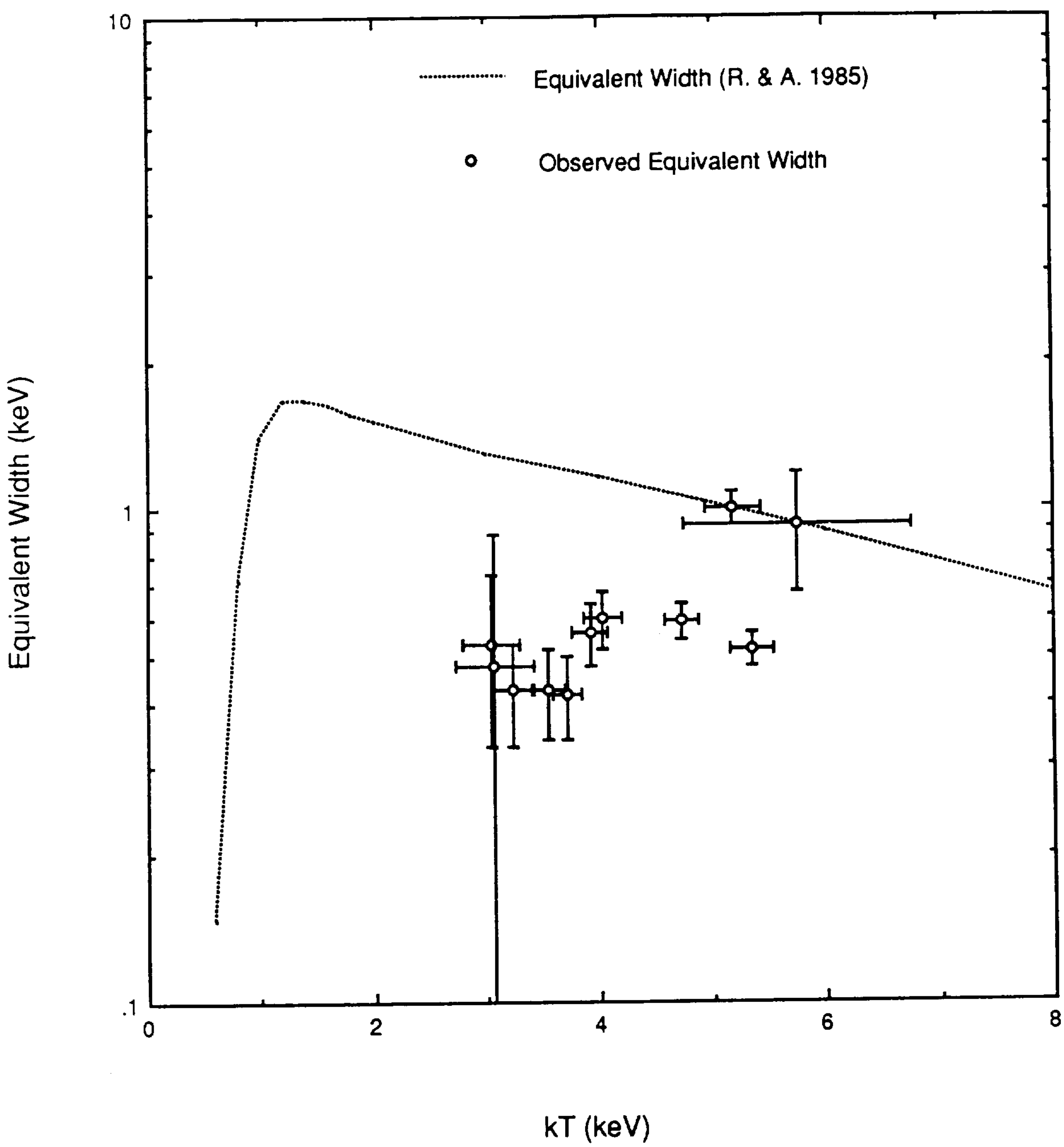

Figure 5. Equivalent width of Fe line plotted against continuum temperature during flare (open circles with 90% error bars). Dotted line indicates theoretical calculations for solar-abundance thin plasma (Rothenflug and Arnaud 1985).

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16. Abstract

X-Ray observations of two active stellar binary systems were obtained with the GINGA satellite. Flaring activity was detected on in the GINGA 1.7- 11 keV band and simultaneously in the microwave region using IUE data. ALGOL was also observed by GINGA: a large flare which lasted well over 12 hours was detected, reducing a maximum temperature of 65 million k, and showing evidence of highly ionized Fe line emission.

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