THE ASTROPHYSICAL JOURNAL, 183:L91–L93, 1973 July 15

UPPER LIMITS TO THE X-RAY EMISSION FROM β PERSEI DURING RADIO FLARES*

C. R. CANIZARES, J. E. NEIGHBOURS, G. W. CLARK, W. H. G. LEWIN, H. W. SCHNOPPER, AND G. F. SPROTT
Department of Physics and Center for Space Research
Massachusetts Institute of Technology
Received 4 April 1973; revised 1973 May 9

ABSTRACT

No X-rays attributable to β Persei were detected in the energy range 0.9–10 keV by the MIT X-ray detector on the OSO-7 during an 18-day observation in which numerous radio flares were reported. Upper limits on X-ray emission are established which indicate that the Hjellming model of thermal bremsstrahlung is untenable.

Subject headings: eclipsing binaries — radio sources — variable stars — X-ray sources

I. INTRODUCTION

Algol (β Persei) is the most thoroughly studied of the radio-emitting binary stars. Its radio behaviour is erratic, showing both quiescent periods and flares (Hjellming, Webster, and Balick 1972). During quiescent periods, the spectrum derived from observations at 8.085 and 2.695 GHz remains flat. Some flares show a lower flux at the higher frequency, which is characteristic of nonthermal production processes. However, the occurrence of numerous flares which are stronger at the higher frequency led Hjellming (1972) to propose that these outbursts are due to bremsstrahlung from a partially self-absorbed hot plasma. According to this model (Hjellming 1972; Hjellming, Webster, and Balick 1972) the data imply values of the plasma temperature, electron density, and size which are consistent with an emitting region with dimensions of the order of the separation of the close binary pair of the β Per system and a cooling time of the order of hours, similar to the typical decay times for flares. A prediction of this model is that β Per should be a very strong X-ray source during the radio flares.

II. X-RAY MEASUREMENTS

The MIT X-ray instrument aboard the OSO-7 satellite scanned β Per continually from 1972 January 31 to February 17, a period for which Hjellming, Wade, and Webster (1972) have reported radio outbursts from the source. The detector used for these observations (Clark *et al.* 1973) has a 3° FWHM field of view, which means that β Per and the X-ray source associated with the Perseus cluster of galaxies (Fritz *et al.* 1971) are often viewed together. In order to determine the flux attributable to β Per, a maximum-likelihood fit was made to all the data in 0.5-day intervals. About half of these coincide with the radio observations. Fits in 90-minute intervals were also made for the times of radio flares. The fitting program searches for the intensities of two point sources, one at the position of β Per and the other at the center of the Perseus cluster source. We present the results of fits to data from three proportional counters sensitive over the ranges 0.9–1.5, 1–6, and 3–10 keV. The observations from one counter and the best fit curve for a typical 0.5-day period are shown in figure 1.

* Supported in part by the National Aeronautics and Space Administration under contract NGL 22-009-015.

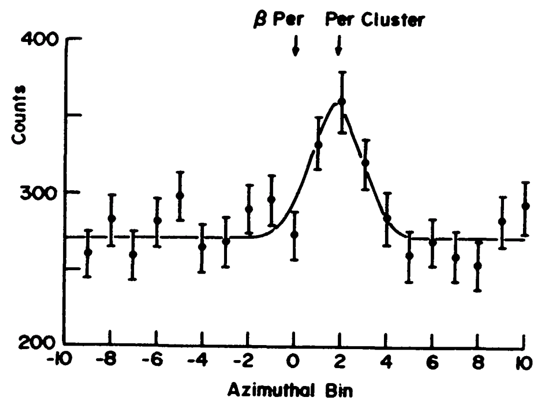

FIG. 1.—Total counts accumulated from 1800 UT 14 February to 0600 UT 15 February 1972 from the region of β Persei in the 1–6 keV detector. The azimuthal bins are 1°.4 wide. The curve shows the result of a maximum-likelihood fit to point sources located at β Per and the Perseus cluster. The width of the peak reflects the 3° FWHM collimator response.

There is no indication of X-ray emission from β Per at any time during the observation. The fits do occasionally yield very small positive values (typically $\sim 6 \times 10^{-11}$ ergs cm^{-2} s^{-1} keV^{-1}, 1–6 keV) for the flux at the position of β Per. These, however, can be attributed to excess counts in the wings of the Perseus cluster source distribution due to its 0°.5 extent (Forman *et al.* 1972). We take as upper limits to the X-ray flux from β Per values which are 3 standard deviations above these small fitted values. Typical limits for the 90-minute and 0.5-day periods and for the entire observation are listed in table 1. The maximum X-ray luminosities have been calculated using a distance to the source of 25 pc (Frieboes-Conde, Herczeg, and Høg 1970).

III. DISCUSSION

The radio data of Hjellming, Wade, and Webster (1972) collected during the X-ray observations show numerous indications of radio outbursts. In particular, on February 14–15, the radio flux at 8.085 GHz increased from 0.136 to 0.208×10^{-26} W m^{-2} Hz^{-1} in 2 hours and then fell to half-maximum in about 7 hours. The flux at 2.695 GHz showed a much smaller variation.

Following Hjellming (1972) one can derive from radio measurements at two

UPPER LIMIT TO X-RAY EMISSION FROM β PERSEI

Integration Time	Energy Range (keV)	Flux (10^{-10} ergs cm^{-2}s^{-1}keV^{-1})	Luminosity (10^{30} ergs s^{-1}keV^{-1})
90^m	0.9–1.5	30	210
90^m	1–6	2.7	19
90^m	3–10	1.5	11
0.5^d	0.9–1.5	10	70
0.5^d	1–6	0.9	6.3
0.5^d	3–10	0.5	3.5
18^d	0.9–1.5	2.5	17
18^d	1–6	0.5	3.3
18^d	3–10	0.2	1.2

frequencies certain relations among the electron temperature T_e, the electron density N_e, and the source diameter D, for the plasma model of radio emission. These parameters are uniquely determined if one assumes, in addition, that the reduction in flux is due either to free expansion of the source with approximately the sound velocity or to cooling as a result of thermal bremsstrahlung losses. Typical values during the February 14–15 flare are $T_e \simeq 10^8$–10^9 ° K, $N_e \simeq 4$–50×10^8 cm^{-3}, and $D \simeq 0.3$–0.7 a.u. The X-ray flux at Earth distance (25 pc) from such a plasma would be 2–10 $\times 10^{-8}$ ergs cm^{-2} s^{-1} keV^{-1} in the 0.9–1.5 keV range, 3–50 $\times 10^{-8}$ ergs cm^{-2} s^{-1} keV^{-1} in the 1–6 keV range, and 0.2–30 $\times 10^{-8}$ in the 3–10 keV range. These expected fluxes, which are similar to those derived for other flares, are between 1 and 4 orders of magnitude greater than the upper limits listed in table 1.

We thus conclude that the failure to detect X-rays makes any simple model of thermal-bremsstrahlung radio emission untenable. This result, together with the observation of occasional nonthermal radio spectra and of several large-scale radio intensity fluctuations on a time scale of minutes (Hjellming, Webster, and Balick 1972), strongly suggests that most of the radio emission must be ascribed to complex nonthermal phenomena. Jones and Woolf (1973) have proposed one such model in which radio emission is caused by plasma waves which are excited by mass transfer between the close binary pair. They suggest that X-rays may be produced in a shock front, and they use the available kinetic power to set a maximum possible X-ray luminosity of $\sim 6 \times 10^{33}$ ergs^{-1} at radio maximum. The data of table 1 indicate that no more than a few percent of this available power could emerge as 1–10 keV X-rays.

We thank C. Heinz for assistance in the data analysis.

REFERENCES

Clark, G. W., Bradt, H. V., Lewin, W. H. G., Markert, T. H., Schnopper, H. W., and Sprott, G. F. 1973 *Ap. J.*, **179**, 263.
Forman, W., Kellogg, E., Gursky, H., Tananbaum, H., and Giacconi, R. 1972, *Ap. J.*, **178**, 309.
Frieboes-Conde, H., Herczeg, T., and Høg, E. 1970 *Astr. and Ap.*, **4**, 78.
Fritz, G., Davidsen, A., Meekins, J. F., and Friedman, H. 1971 *Ap. J.* (*Letters*), **164**, L81.
Hjellming, R. M. 1972, *Nature Phys. Sci.*, **238**, 52.
Hjellming, R. M., Wade, C. M., and Webster, E. 1972, *Nature Phys. Sci.*, **236**, 43.
Hjellming, R. M., Webster, E., and Balick, B. 1972, *Ap. J.* (*Letters*), **178**, L139.
Jones, T. W., and Woolf, N. J. 1973, *Ap. J.*, **179**, 869.