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OBSERVATIONS OF THE HIGHLY VARIABLE X-RAY SOURCE GX 339—4*

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ABSTRACT

Observations with the MIT experiment on the OSO-7 have led to the discovery of an X-ray source, GX 339—4, which varies in intensity by at least a factor of 60 over hundreds of days but shows no evidence of periodic behavior or abrupt intensity changes on time scales from 3 minutes to 13 days. The observations show intense HIGH states, LOW states with spectra consistent with increased absorption, and OFF states, when no statistically significant signal is observed. The behavior is unlike that of any previously reported X-ray source.
Subject headings: variable stars — X-ray sources

I. INTRODUCTION

The bright variable X-ray source GX 339—4, first reported by Markert *et al.* (1973), has been observed extensively by the MIT 1–60 keV X-ray detector aboard the OSO-7 satellite. Our observations show variations in intensity by large factors on time scales of weeks and months with associated systematic spectral changes. No evidence of eclipses or other periodic variations is seen during continual observations for periods of up to 13 days.

II. DATA COLLECTION AND ANALYSIS

The source, located at $\alpha = 16^{h}58.8^{m} \pm 0.8^{m}$, $\delta = -48°41' \pm 12'$ (1950.0), $l^{II} = 338\overset{\circ}{.}93 \pm 0.20$, $b^{II} = -4\overset{\circ}{.}27 \pm 0.20$, has been scanned on 12 separate occasions for a total of about 42 days, between 1971 October and 1973 January. Observations were obtained for about 12 days with a detector with a 1° (FWHM) field of view; the remaining observations were obtained with a detector with a 3° (FWHM) field of view. For both detectors, signals were recorded in three proportional counters designated TW, NE, and AR with sensitivities in the energy ranges 1–1.5 keV, 1–6 keV, and 3–10 keV, respectively. No statistically significant signals were detected in two additional counters sensitive above 15 keV. Details of the MIT OSO-7 experiment have been published elsewhere (Clark *et al.* 1973).

The observed intensities, corrected for collimator response, are summarized in figure 1. The relatively large error bars of the 3° data points (*open circles*) reflect uncertainties in accounting for the effects of other nearby and possibly variable sources. Data from the TW 3° counter have been omitted entirely because of their large uncertainties.

The variability of the source is apparent from figure 1. The intensity in the NE counter ranged from below the limits of detectability (~ 1 count per second) in 1972 May (day 488) to approximately 65 counts per second in 1972 December (day 718). At maximum intensity the source was about one-third as bright as the Crab Nebula in the energy range 1–6 keV. Assuming a thermal-bremsstrahlung spectrum with $kT =$ 1.7 keV, the average energy flux on day 718 was 8×10^{-9} ergs cm^{-2} s^{-1}. This result

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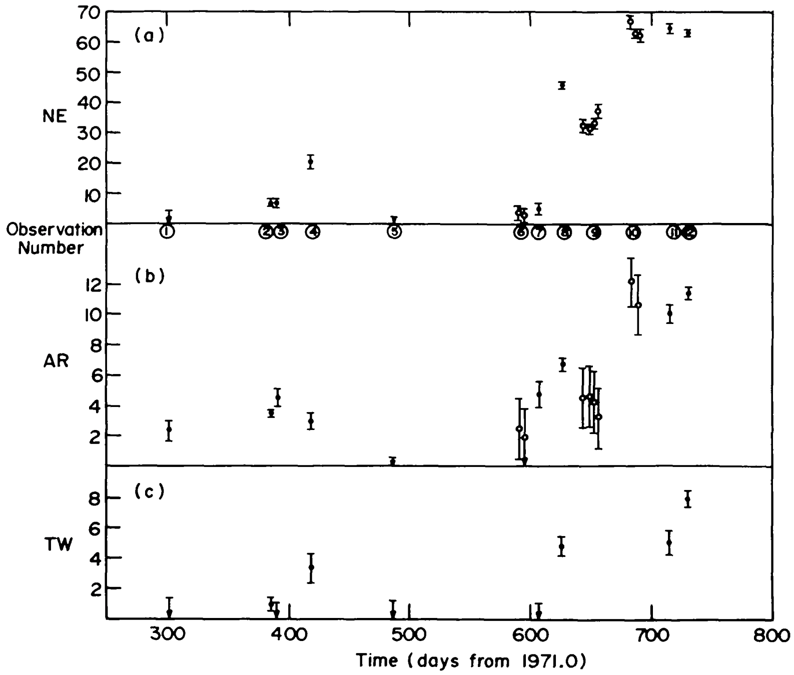

FIG. 1.—Counting rate in counts per second, corrected for the collimator response function, from GX 339—4 in the NE, AR, and TW counters as a function of time measured from 1971 January 0. *Solid circles,* data from the 1° (FWHM) detector; *open circles,* data from the 3° (FWHM) detector. Each point represents from 1 to 4 days of continual observation. Error bars represent 1 σ counting statistics and our best estimates for systematic errors due to uncertainties in position and aspect.

is relatively insensitive to the value of kT or to the type of spectrum chosen. For convenience in the subsequent discussion, we shall refer to a LOW state for which the NE counting rate was less than 10 counts per second (observations 1, 2, 3, 5, 6, 7) and a HIGH state for which it was greater than 20 counts per second (observations 4, 8, 9, 10, 11, 12). Observations 1 and 5 could be classified as OFF states since no statistically significant signal was found when the source position was scanned. The failure of the source to appear in the early galactic-plane scans of the *Uhuru* satellite (Giacconi *et al.* 1972) suggests even more extended OFF states.

On time scales from one day down to the minimum resolving time of the detectors ($\sim$ 3 minutes), GX 339—4 does not appear to vary outside of the expected statistical fluctuations. Fourier analyses have been performed and indicate an upper limit on any periodic component of the intensity of 40 percent for periods ranging from 3 minutes to 1 day. In general we estimate an upper limit of about 25 percent to nonstatistical fluctuations for the NE counter signal during high states and of about 100 percent for all other observations.

Nonetheless, variations of at least several counts per second per day must exist because, for example, we observed a transition from 5 counts per second to 45 counts per second during the 18 days from observations 7 to 8. No abrupt intensity changes are observed, and most of the sightings of the source are too short to show a slow increase. However, the two HIGH-state observations made with the 3° detector (observations 9 and 10) last 13 and 10 days, respectively; both are consistent with an intensity gradient approximately equal to 0.5 counts per second per day.

III. SPECTRUM

In figure 1, one can see that the ratios of the intensities in the HIGH and LOW states are much greater for the NE counter than for the AR counter. The ratio of the TW intensities is also greater, although the poorer statistics of the TW counter make this conclusion somewhat tentative. Based at least on the NE and AR intensities, however, we observe a softening of the spectrum during LOW states which suggests absorption of the X-rays by material near the source. This interpretation can be made more quantitative as shown in figure 2. Here the logarithms of the ratios of the counting rates are displayed in the manner of two-color diagrams in optical astronomy. The coordinate grid lines, labeled kT and E_a, are the loci of representative points for a thermal-bremsstrahlung spectrum (Chodil *et al.* 1968), where E_a is a cutoff energy due to interstellar absorption.

Results from seven observations are plotted. Data from the remaining sightings did not have sufficient accuracy to be useful in these graphs. The HIGH states, although differing in NE intensity by up to a factor of 3, occupy a single region of the plot which is clearly separated from that of the LOW states. The HIGH states have values of kT near 1.7 keV and values of E_a near 1.2 keV. Because of the poor statistics of the TW counter, it is impossible to determine the spectral parameters of the LOW states.

The transitions between HIGH and LOW states may be made by any path connecting the corresponding regions of figure 2. Two simple possibilities are that the cutoff energy remains constant at 1.2 keV but the temperature increases to about 20 keV, or that kT remains constant at 1.7 keV but the cutoff energy changes from 1.2 to 3.0 keV. The latter case, shown as a dashed line in the figure, is perhaps more plausible since it implies a change in the emission measure of at most a factor of 3 in transitions from HIGH to LOW states. If E_a does not change, however, the observed NE and AR intensities imply that the emission measure changes by as much as a factor of 20.

We also analyzed the spectral data in terms of a power law, and found, for the HIGH states, values of the energy spectral index α near 2.5 and values of the cutoff energy E_a near 1.3 keV. For the LOW states we were again unable to determine the spectral

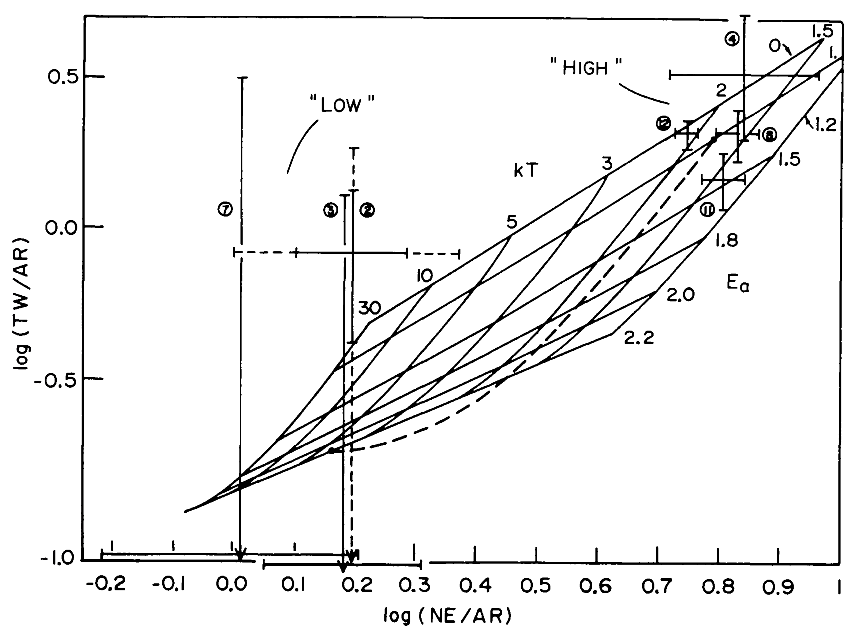

FIG. 2.—Intensity ratio diagram for seven extended observations of GX 339−4. The grid is calculated for a thermal-bremsstrahlung spectrum. Each observation is labelled as in fig. 1 and has 1 σ error bars, except for observation 2 which has both 1 σ and 2 σ error bars indicated. The dashed line has a constant $kT = 1.7$ keV and has endpoints at $E_a = 1.2$ keV and $E_a = 3.0$ keV. It represents a transition between high and low states due to increased absorption.

parameters. As above, a plausible explanation of the transitions invokes a change in the absorption cutoff alone.

IV. DISCUSSION

The behavior of GX 339—4 is unlike that of any other X-ray source so far reported. The intensity varies by factors of at least 60 over hundreds of days and yet shows no evidence of abrupt changes on a time scale from 3 minutes to 13 days. GX 339—4 could be a noneclipsing binary system—it shows recurrent LOW and OFF states reminiscent of the "dips" and $\sim$ 24-day OFF states of Her X-1 (Giacconi *et al.* 1973). However, the LOW states of GX 339—4, which can be explained by obscuration of the source by intervening matter, last much longer than the absorption "dips" of Her X-1. If GX 339—4 is an eclipsing binary, its period must be greater than 13 days.

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