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LOCATION OF THE NORMA TRANSIENT WITH THE *HEAO 1* SCANNING MODULATION COLLIMATOR

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ABSTRACT

We have obtained a precise position for an X-ray transient source in Norma. The location uncertainty includes a variable star previously suggested to be the optical counterpart. This transient is associated with the steady X-ray source MX 1608−52 and probably with an X-ray burst source. A binary system containing a low-mass primary and a neutron-star or black-hole secondary of a few solar masses is consistent with the observations.

Subject headings: X-rays: binaries — X-rays: bursts — X-rays: sources

I. INTRODUCTION

The X-ray source MX 1608−52 (Li 1976; Markert *et al.* 1977), first noticed in a flaring state by Kaluzienski *et al.* (1975) for a few days in 1975 November, has been undergoing a new active phase since the beginning of 1977 July, as reported by the *SAS 3* (Clark and Li 1977; Doxsey, Clark, and Li 1977) and *Ariel 5* (Kaluzienski and Holt 1977*a,b*) satellites. The presence in the same region of the sky of steady X-ray emission, as observed by the *OSO 7* (Li 1976) and *Uhuru* (Tananbaum *et al.* 1976; Forman *et al.* 1978) satellites, and of bursting activity (Belian, Conner, and Evans 1976; Grindlay and Gursky 1976; Tananbaum *et al.* 1976) makes MX 1608−52 a potentially complex and interesting X-ray source. In this letter we report the results of the *HEAO 1* scanning modulation collimator (MC) observations of the source in the "transient-like" state and discuss its nature on the basis of the X-ray behavior and of the identification with an optical object (Grindlay 1977).

II. IDENTIFICATION

a) The Transient Source

Our measurement of the position of the transient source, which we designate as H1608−522, was obtained from six transits of the source in the 30″ modulation collimator (MC1) and five transits in the 4′ modulation collimator (MC2) (Gursky *et al.* 1978; Schwartz *et al.* 1978). The scans were chosen on the grounds that a good aspect solution was available for the portion of the orbit containing H1608−522. The method used to calculate the error box is described by Gursky *et al.* (1978). The uncertainty in the source position is mainly due to aspect error. The rms deviations of the lines of position for the single scans are 6″.6 for MC1 and 4″.9 for MC2. An independent test of the quality of the aspect solution is given by the fact that Sco X-1 is present in four of the orbits. The position of Sco X-1 determined with these orbits is 0″.2 from the true position for MC1 and 1″ for MC2. The rms deviations are, respectively, 7″ and 5″, comparable with the rms deviations of the H1608−522 lines of position. The result of this analysis is shown in Figure 1, where the *HEAO 1* error diamond, obtained by the intersection of the two 90% probability lines, is plotted with the *SAS 3* 90% confidence error circle and the 4U error box.

The *HEAO 1* error contour is centered on R.A. = $16^{h}08^{m}53^{s}$, decl. = −52°17′29″ and covers an area of 0.3 square arcmin. The area in common to the MC error box and the *SAS 3* error circle (Apparao *et al.* 1978) is 224 square arcsec.

The average intensity in the spectral range of 1–15 keV is found to be ∼.3 of the Crab from 1977 August 30 to September 8. The fit to a bremsstrahlung spectrum (with Gaunt factor) of the counting rates from the three spectral channels of the MC experiment gives a spectrum of the form

$$\frac{dI}{dE} = I_c \exp(-E/kT)\left(\frac{E}{kT}\right)^{-0.4} \exp(-\sigma N_{\mathrm{H}})$$

where $I_c = 0.65 \pm 0.20$ keV cm^{-2} s^{-1} keV^{-1}, the exponential temperature $kT = 8 \pm 2$ keV, and the equivalent hydrogen column density to the source $N_{\mathrm{H}} = 2.5$ $(\pm 1.5) \times 10^{22}$ N_{H} cm^{-2}. The quoted errors represent the systematic uncertainty in calibrating our spectral response.

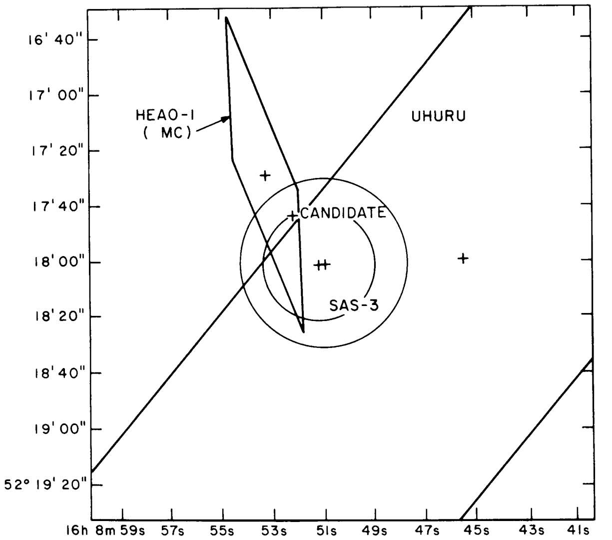

FIG. 1.—The MC error diamond for the position of H1608−522 is plotted with the *SAS 3* 30″ radius (Doxsey *et al.* 1977) and 20″ radius (Apparao *et al.* 1978) error circles and the 4U error box. The centers of the error boxes and the position of the optical candidate are indicated by crosses.

b) *Optical Candidate*

Grindlay and Liller (1978) proposed as the optical counterpart a stellar object that appeared on a red-IR plate taken in 1977 August during the flareup of H1608−522. This object was below the plate limit ($m \geq$ 23–24) on a previous exposure, taken when the source was not flaring. They report a magnitude m_I = 18.2 in the wavelength range of 7000–9000 Å. The position of the Grindlay and Liller candidate is plotted in Figure 1 and falls within the MC error box, in the area where it overlaps the *SAS 3* error circle.

c) *The Steady X-ray Source*

On statistical grounds there is good reason to believe that the steady 4U source and the X-ray transient discovered by *Ariel 5* are the same object, as suggested by Clark and Li (1977). In fact, eight transient X-ray sources have been observed in the galactic plane between 320° $\leq l^{\rm II} \leq$ 360° and $-5° \leq b^{\rm II} \leq 5°$ (Cominsky *et al.* 1978). Considering the area covered by 4U error boxes in the same region of the sky, the number of transient X-ray sources associated by chance coincidence with a 4U source is 0.007. The previous calculation may underestimate the probability, since it is an *a posteriori* estimate of the event. Our data show that no other source greater than or equal to 30 *Uhuru* counts s^{-1} (2 σ) is present, except possibly in the 1/16 of the 4U error box which intersects with the joint periodicities of the spacing of both collimators.

d) *The Bursting Source*

The region of the sky in Norma near R.A. = 16$^{\rm h}$8$^{\rm m}$ and decl. = −52° has been of interest since the observations from 1969 June to 1970 August of 10 bursts of X-rays in the 3–12 keV energy range, of intensity several times that of the Crab and of duration 2 to 128 s (Belian, Conner, and Evans 1976). Bursts from the same region were also discovered by Grindlay and Gursky (1976) in the *Uhuru* data. Their error box for the bursting source overlaps the center of the *Vela* box (Belian, Conner, and Evans 1976) and includes the *OSO 7* and the 4U error boxes for the steady source and the *SAS 3* (Doxsey, Clark, and Li 1977; Apparao *et al.* 1978) and *HEAO 1* positions for the flaring source (Fig. 2). Grindlay and Gursky (1976) find that there is more than 10% probability that a steady X-ray source will be in their error box due to chance coincidence. However, Tananbaum *et al.* (1976) report that

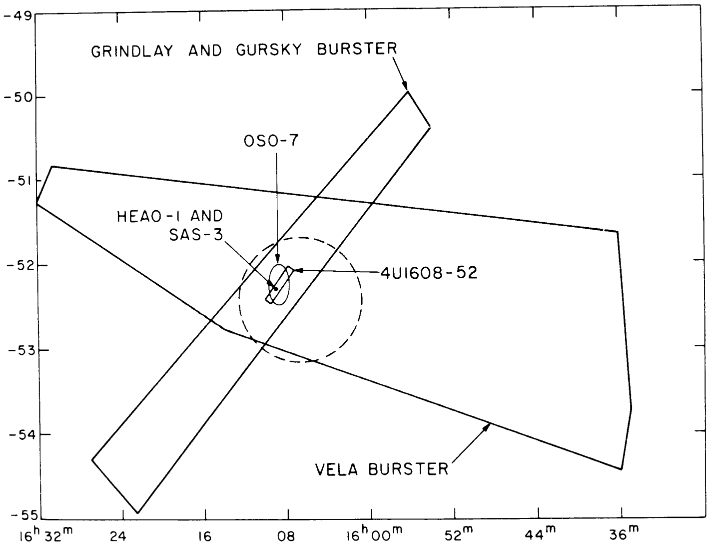

FIG. 2.—The *HEAO 1* and *SAS 3* position of the transient H1608−522 are plotted with the 4U (Forman *et al.* 1978) and *OSO 0* (Markert *et al.* 1977) error boxes for the steady source and the Grindlay and Gursky (1976) and the *Vela* error boxes (Belian *et al.* 1976) for the burster. The radius of dotted circle is the rms deviation of the positions of the centers of the collimator for the observations reported by Belian *et al.*

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two high-intensity events occurred on 1972 May 10 and 11 at the location of 4U 1608−52 and calculate the number of steady X-ray sources that could be associated by chance coincidence with their events to be 0.06. A calculation as performed in § II *c* would predict 0.03 transient sources associated by chance only. The Tananbaum *et al.* (1976) events were observed by the narrow *Uhuru* collimator (0°.5 FWHM), and that does not strictly allow for unequivocal identification as bursts based on their time structure. However, the facts that they occurred within 7 hours of the second set of Grindlay and Gursky events, and furthermore that their spectra are similar, suggest that the transient H1608−522 is a burster as well as a steady source.

III. DISCUSSION

Table 1 summarizes the flaring activity as observed by the *Ariel 5*, *SAS 3*, and *HEAO 1* satellites. After a short observation on 1975 October 30–November 9 by *Ariel 5* (Kaluzienski 1977), when MX 1608−52 was seen at a flux of 0.3 to 0.7 of the Crab Nebula, the source flared up again at the beginning of 1977 July and was still flaring throughout 1977 September 8, when it exited the MC field of view. A certain amount of variability in the flux was noticeable during the decay. The *e*-folding time, from an extrapolation of the light curve, appears to be $T_e \sim 60$ days. This behavior seems quite similar (Pounds 1976; Kaluzienski *et al.* 1977) to the behavior of the observed "soft" X-ray transients like A1524−61 or A0620−00.

TABLE 1

TIME HISTORY OF TRANSIENT BEHAVIOR

Observation Time	Intensity (fraction of Crab)	References
1975 Oct 30, Nov 9.	0.3–0.7	Kaluzienski 1977
1977 Jul 5........	Reaches 1.1	Clark and Li 1977
1977 Jul 9........	0.8	Clark and Li 1977
1977 Jul 10.......	0.5	Clark and Li 1977
1977 Jul 24.......	0.6	Apparao *et al.* 1978
1977 "early August"........	0.6	Kaluzienski and Holt 1977*a*
1977 Aug 12–22...	0.45	Kaluzienski and Holt 1977*a*
1977 Aug 30–Sep 8.	0.3	Present measurements
1977 Sep 3........	0.68	Kaluzienski and Holt 1977*b*
1977 Sep 5........	0.35	Kaluzienski and Holt 1977*b*

From the low-energy cutoff of the spectrum of the steady *Uhuru* source, Tananbaum *et al.* (1976) calculate $A_v \leq 7.9$ mag for the absorption of the radiation from the optical companion and $D_X \leq 12$ kpc for the distance to the X-ray star. The lower limit on the visual magnitude of the companion is $m > 23$–24 when the source is not flaring (Grindlay 1977). Using the upper limits on the absorption and the distance, we obtain a lower limit for the absolute magnitude $M_v > 0$–1. This suggests that we are not dealing with a supergiant or a giant star. If the source is 12 kpc away we obtain $E \sim 3 \times 10^{38}$ ergs s^{-1} for the luminosity at the peak of the 1977 July outburst and $E \sim 9 \times 10^{36}$ ergs s^{-1} for the luminosity in the steady state, as observed by *Uhuru.* This independently suggests that MX 1608−52 cannot be farther away than 12 kpc if the X-ray source is an object of few solar masses. The fact that the source emits X-rays at a quite high intensity when in the flaring or bursting states suggests that we are not dealing with a white dwarf. White-dwarf models (Pringle 1976, and references therein), even in the case of radial accretion, cannot account for luminosities higher than 10^{36} ergs s^{-1}. We propose that MX 1608 − 52

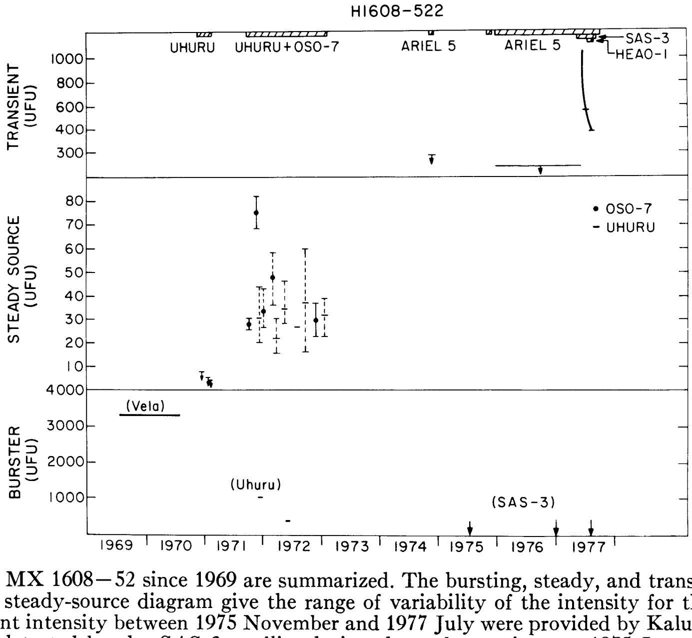

FIG. 3.—The observations of MX 1608−52 since 1969 are summarized. The bursting, steady, and transient behaviors are plotted separately. The dotted lines in the steady-source diagram give the range of variability of the intensity for the time the intensity is plotted. The upper limits for the transient intensity between 1975 November and 1977 July were provided by Kaluzienski (1977, private communication). Bursts have not been detected by the *SAS 3* satellite during three observations on 1975 June 17–30, 1976 December 30–1977 January 4, and 1977 July 25–28 (Hoffman *et al.* 1977; Hoffman 1977, private communication).

is a binary system where the X-ray emitter is a neutron star or a black hole of few solar masses and the optical companion is a low-mass star. The time history, as shown in Figure 3, suggests that bursts may be associated with the faint steady state even if we cannot completely exclude their occurrence in the transient state because of the incomplete coverage since 1975. In the neutron-star hypothesis this could suggest that when the source is faint and bursting, there is slow accretion of material and the rate is regulated by magnetospheric effects, giving bursts with a mechanism like the one suggested by Baan (1977) and Lamb *et al.* (1977). If the X-ray source is a black hole, disk instabilities could be invoked (Liang 1977; Wheeler 1977). An increase in the accretion rate (Faulkner 1974, and references therein) could then cause the source to become a transient in either case.

IV. CONCLUSION

A reexamination of the observations on the Norma burster and on the steady source MX 1608−52 suggests that these are coincident with the transient source observed by the *HEAO 1* satellite from 1977 August 30 to September 8. No orbital periodicity or pulsations have been reported for this source. The intensity has been seen to vary in time scales of ~1 day to 1 hour both in the steady state and in the decay after the 1977 July outburst (Tananbaum *et al.* 1976; Kaluzienski and Holt 1977*a*,*b*). The light curve of the 1977 July event, the soft spectrum, and the optical observations, which exclude an early-type supergiant optical counterpart, suggest that MX 1608−52 is another member of the low-mass binary class of galactic X-ray transients (Pounds 1976; Murdin *et al.* 1976; Griffiths *et al.* 1978), if it is indeed a binary. The observational evidence concerning H1608−522 is the first to suggest an association of X-ray bursters with X-ray transients. Future monitoring of burst sources and of transient sources will be needed to probe the general validity of this behavior.

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