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TRANSIENT X-RAY SOURCES IN THE GALACTIC PLANE

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ABSTRACT

Uhuru observations of the galactic plane indicate the presence of four X-ray sources not previously characterized as transient: MX 0836−42 (Markert *et al.*), A1918+14 (Seward *et al.*), and 4U 1730−22 and 4U 1807−10 (Forman *et al.*). X-ray light curves as well as positional and spectral information are presented for these sources and for 4U 1908+00, a recurrent transient source. The frequency, duration, and intensity of galactic plane transients during the *Uhuru* lifetime are discussed. Transient X-ray sources appear to be divided into two classes based primarily on an observed bimodal spectral temperature distribution.

Subject headings: interstellar: molecules — molecular processes — X-rays: general

I. INTRODUCTION

Centaurus X-2 was the first X-ray source to be described as "transient" (Chodil *et al.* 1968 and references therein). Since those early observations, many sources have been detected with similar X-ray light curves (see Table 1 for references). These transient X-ray sources have been observed with many types of detectors over different energy ranges and for various time intervals. However, for all transient sources the X-ray emission was detected at an intensity well above the survey limit for an interval of length greater than ~1 day which was short compared with the total amount of time the region was observed. This is the simplest observational definition of transient and may include sources of a type previously described as "highly variable." Transient outbursts have occurred only once for most sources; but as observations continue to be made, more "recurrent transients," i.e., sources with multiple outbursts, are reported (Jones *et al.* 1976; Kaluzienski *et al.* 1977*a*; Clark and Li 1977; Ricker and Primini 1977).

In this paper, we present *Uhuru* observations of four sources which satisfy the above definition of transient and of one source which is a recurrent transient, as well as a summary of all existing observations. The frequency of occurrence, intensity distribution, and spectral characteristics of transient sources will be discussed and compared with those of similar but less sensitive surveys (Kaluzienski *et al.* 1977*b*). Transient sources are observed to be divided into two classes based primarily on spectral temperatures (Maraschi *et al.* 1976; Kaluzienski *et al.* 1977*b*), and the relationship between these classes and existing models is discussed.

II. OBSERVATIONS

A summary of the observations for the 24 low-galactic-latitude ($|b^{II}| < 7°$) transient and recurrent transient X-ray sources is given in Table 1. Several transient events at higher latitudes have also been reported (Barnden and Francey 1969; Evans, Belian, and Conner 1970; Harries *et al.* 1971; Shukla and Wilson 1971; Conner, Evans, and Belian 1969; Rappaport *et al.* 1976; Cooke 1976; Ricketts, Cooke, and Pounds 1976; Forman *et al.* 1978) but will not be discussed in this paper, as they may represent distinctly different phenomena. All the galactic plane transients were detected at intensities well above the survey limit for a time interval $\tau_{\min}$ in days (Table 1, col. [4]) which is short (less than 50%) compared with the total amount of time the region was observed. For a source that was continuously monitored and for which exponential decay from the peak was observed, τ_e, the *e*-folding time constant in days, is given in column (5). Column (6) lists the maximum equivalent *Uhuru* intensity (2–6 keV) reported for each source. Column (7) gives the best 3 σ upper limit to persistent emission from the transient source from either the experiment which detected the outburst or the *Uhuru* lifetime based on the 4U catalog (Forman *et al.* 1978). $S_{\mathrm{HI/UL}}$ (col. [8]) is the lower limit on the maximum range in intensity for each source, calculated from columns (6) and (7). Column (9) lists the published exponential temperature spectral parameter (Jones 1977) or the equivalent for non-*Uhuru* transients. The five sources at the bottom of Table 1 were later detected at intensities comparable to or greater than the original primary maximum and thus may be classified as recurrent transients.

The *Uhuru* X-ray observatory scanned the galactic plane frequently during 2.5 years following its launch on 1970 December 12. During this time, nine transient and three recurrent transient X-ray sources were observed within 7° of the galactic equator ($|b^{II}| \leq 7°$). The *Uhuru* observations of seven of these sources have been previously reported (Kellogg *et al.* 1971; Matilsky *et al.* 1972; Forman, Jones, and Tananbaum 1976*a*, *b*; Jones *et al.* 1976; Tananbaum *et al.* 1976). In this paper we present the data for the remaining

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TABLE 1

OBSERVATIONS OF TRANSIENT AND RECURRENT TRANSIENT X-RAY SOURCES

Source (1)	l^{II} (2)	b^{II} (3)	$\tau_{\min}$ (4)	τ_e (5)	Observed High (6)	Best Upper Limits (7)	$S_{\mathrm{HI/UL}}$ (8)	Exp. Temp. (keV) (9)	References (10)
4U 0115+63........	125.92	+1.03	>50	~14	70	<5	>14	>15	7
A0620−00.........	209.96	−6.54	>100	~25	~50000	<5	>10000	<3	13–15
MX 0836−42.......	261.93	−0.97	>50	...	55	<2	>27	6 ± 2	19
A1118−61.........	292.6	−1.1	44	~7	~75	<5	>15	>15	20–21
Cen X-2............	310.2	0	>44	~20	~6500	<5	>1300	<3.5	22, 37
Centaurus transient	313	0	>30	...	~10	<5	>2	>15	23
A1524−62.........	320.2	−4.49	>100	~60	~900	<2	>450	5 ± 1.5	24
4U 1543−47........	330.93	+5.36	>110	~10	2000	<10	>200	<3	29–30
4U 1730−22........	4.47	+5.89	>60	~30	125	<4	>31	4 ± 1	1
4U 1735−28........	359.57	+1.56	>2	...	565	<40	>14	4.8 ± 9	34
A1742−28.........	359.94	−0.04	>18	...	~2300	<40	>57	3 ± 1	36
A1743−29.........	359.6	−0.42	...	...	~150	<40	>3	...	35
A1745−36.........	354.1	−4.2	...	...	~250	<10	>25	...	32
MX 1746−20.......	7.7	+3.8	>45	...	150	<7.5	>20	4 ± 0.5	3, 4
MX 1803−24.......	6.1	−1.9	...	...	~1000	<2	>500	...	2
4U 1807−10........	18.6	+3.93	...	...	10	<2	>5	...	1
4U 1901+03........	37.21	−1.39	>80	...	87	<2	>43	>15	7
A1918+14.........	49.7	+0.45	>13	...	45	<5	>9	6 ± 2	8
Cep X-4............	98.96	+3.4	>15	...	~75	3	>25	>15	9
A0535+26.........	181.5	−2.65	54	~19	~2000	2.4	>833	>15	10–12, 25
MX 0656−07.......	220.17	−1.66	>15	...	~80	<3	>27	5 ± 2	16–18
4U 1608−52........	330.91	−0.84	...	...	~1100	<3	>367	Variable	26–28
4U 1630−47........	336.9	+0.28	>50	...	220	<10	>22	2 ± 0.5	31
4U 1908+00........	35.67	−4.00	>12	...	400	<10	>40	3.5 ± 0.5	1, 5, 6, 33

REFERENCES.—(1) Forman *et al.* 1978. (2) Jernigan 1976. (3) Forman, Jones, and Tananbaum 1976*b*. (4) Markert *et al.* 1975. (5) Kaluzienski *et al.* 1977*a*. (6) Watson 1976. (7) Forman, Jones, and Tananbaum 1976*a*. (8) Seward *et al.* 1976. (9) Ulmer *et al.* 1973. (10) Rosenberg *et al.* 1975. (11) Coe *et al.* 1975. (12) Kaluzienski *et al.* 1975*a*. (13) Elvis *et al.* 1975. (14) Kaluzienski *et al.* 1977*b*. (15) Matilsky *et al.* 1976. (16) Clark 1975. (17) Carpenter *et al.* 1975. (18) Kaluzienski *et al.* 1976. (19) Markert *et al.* 1977. (20) Eyles *et al.* 1975*a*. (21) Ives, Sanford, and Bell-Burnell 1975. (22) Chodil *et al.* 1968. (23) Wheaton, Baity, and Peterson 1975. (24) Kaluzienski *et al.* 1975*b*. (25) Ricker and Primini 1977. (26) Tananbaum *et al.* 1976. (27) Li 1976. (28) Clark and Li 1977. (29) Matilsky *et al.* 1972. (30) Li, Sprott, and Clark 1976. (31) Jones *et al.* 1976. (32) Davison, Burnell, and Ives 1976. (33) Holt and Kaluzienski 1977. (34) Kellogg *et al.* 1971. (35) *Ariel 5* group 1976. (36) Eyles *et al.* 1975*b*. (37) Francey 1971.

five sources, three of which (Aql X-1, MX 0836−42, A1918+14) were originally reported by other experimenters (Friedman, Byram, and Chubb 1967; Markert *et al.* 1975*b*; Seward *et al.* 1976). No emission was detected from any of these sources during the *Uhuru* lifetime other than that present during the isolated outbursts which are described below.

a) *MX 0836−42 = 4U 0836−42*

First reported by Markert *et al.* (1975*b*) from *OSO 7* observations, MX 0836−42 is present in the *Uhuru* data during two week-long surveys of the galactic plane, in 1971 December and 1972 January, approximately 1 month apart. The peak intensity observed for this source is 60 counts s^{-1}; the minimum length of time the source appeared above background, $\tau_{\min}$, is 50 days. Figure 1*a* shows the X-ray light curve of MX 0836−42, which includes both *Uhuru* and *OSO 7* data (Markert *et al.* 1977).

Combining the *OSO 7* and *Uhuru* positional information yields the following improved 90% confidence location for the source:

Center:

$$\alpha = 129\overset{\circ}{.}130,\ \delta = -42\overset{\circ}{.}655;$$

Corners:

$$\alpha = 129\overset{\circ}{.}300,\ \delta = -42\overset{\circ}{.}520;$$

$$\alpha = 128\overset{\circ}{.}925,\ \delta = -42\overset{\circ}{.}760;$$

$$\alpha = 128\overset{\circ}{.}985,\ \delta = -42\overset{\circ}{.}780;$$

$$\alpha = 129\overset{\circ}{.}350,\ \delta = -42\overset{\circ}{.}540.$$

b) *4U 1730−22*

The source 4U 1730−22 (Forman *et al.* 1978) is typical of that subset of well-observed transient X-ray sources whose light curves are characterized by exponential decay from the peak with *e*-folding time constant τ_e. This decay may be interrupted by a plateau, secondary maxima, extreme variability, or another outburst. Although we do not scan the galactic plane during the initial rise in source intensity of 4U 1730−22, Figure 1*b* shows the observed part of the exponential decay, which has $\tau_e \approx 30$ days and a possible secondary maximum.

The energy spectrum of this source may be derived according to the procedure described by Jones (1977). For an exponential spectrum, $kT = 4 \pm 1$ keV and the upper limit on the low-energy absorption is 2.25 keV. For a power law spectrum, the energy spectral

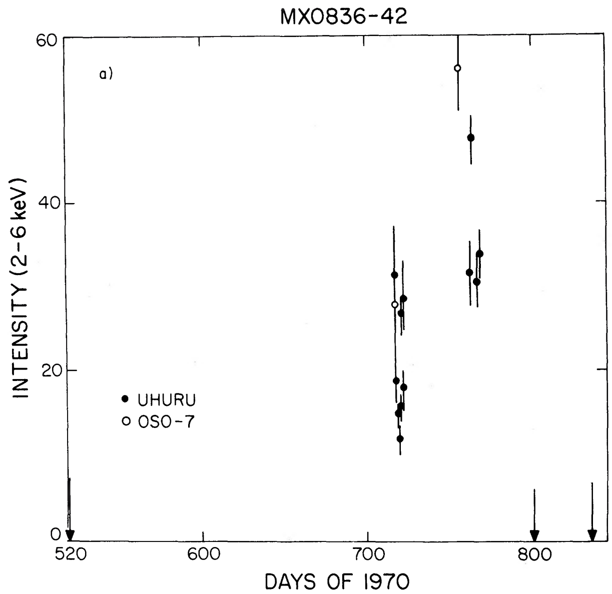

FIG. 1*a*

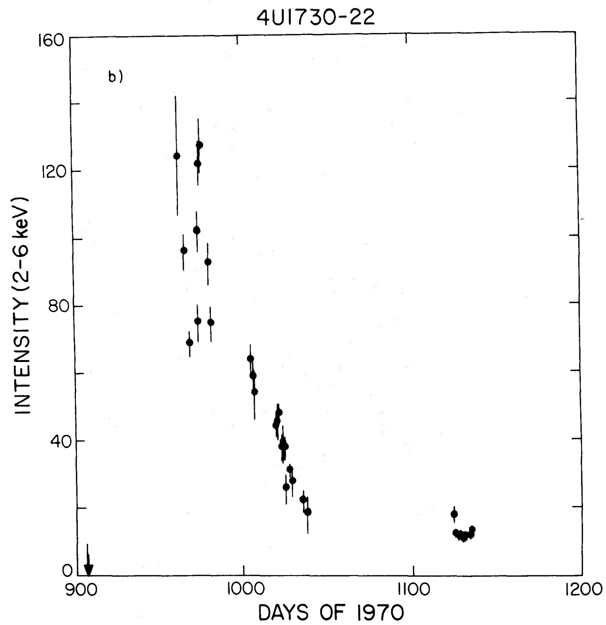

FIG. 1*b*

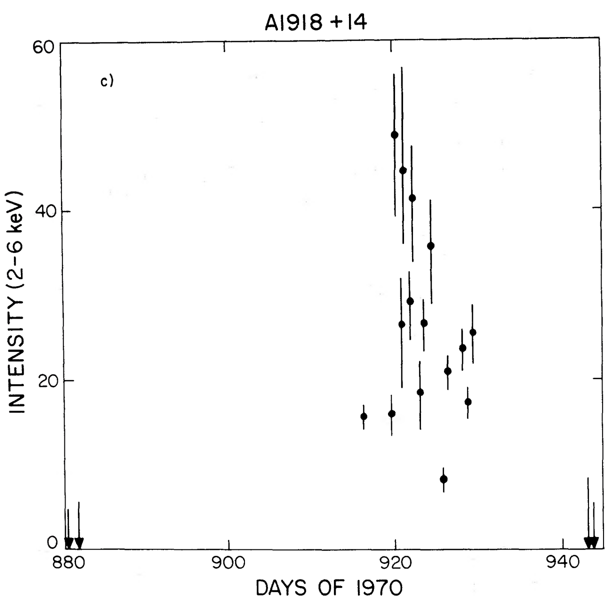

FIG. 1*c*

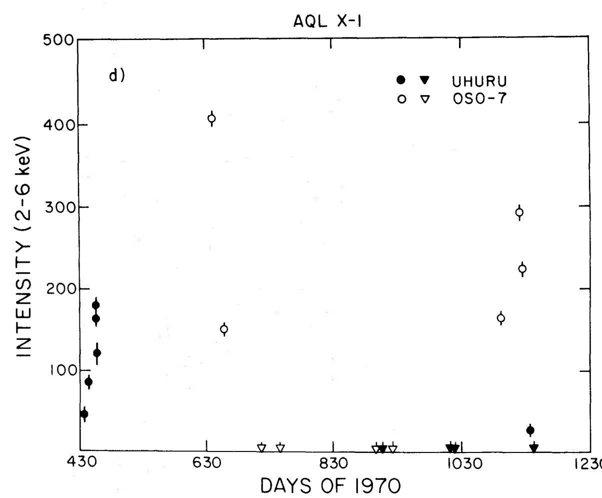

FIG. 1*d*

FIG. 1.—Light curves of (*a*) MX 0836−42, (*b*) 4U 1730−22, (*c*) A1918+14, and (*d*) Aql X-1 are shown which indicate the transient nature of these sources.

index $\alpha = 1.9 \pm 0.4$, with an upper limit on the low-energy cutoff $E_a \gtrsim 3.00$ keV. The formalism used is that of Avni (1976) and of Lampton, Margon, and Bowyer (1976) for estimating two parameters simultaneously at the 90% confidence level, $\chi^2{}_{\min} + 4.6$.

c) *4U 1807−10*

Observed above the survey limit for only 1 day, at the end of the *Uhuru* data, 4U 1807−10 was discovered during the preparation of the 4U catalog (Forman *et al.* 1978). The observed intensity of 10 counts s^{-1} is a factor of 3 above adjacent upper limits but is too low to allow accurate spectra to be determined.

d) *A1918+14*

A1918+14 was initially reported by Seward *et al.* (1976) as a weak variable source with maximum intensity ~10 *Uhuru* counts. During 1972 July, an

X-ray source consistent in location with A1918+14 was detected above background for $\tau_{\min} \approx 2$ weeks; assuming the source to be A1918+14, we find the peak intensity was ~ 50 counts s^{-1} (Fig. 1*c*). This is a factor of 10 increase above adjacent upper limits and a factor of 5 above the observed *Ariel* peak intensity. This outburst was the only emission from A1918+14 detected by *Uhuru*. Both exponential and power law spectral shapes adequately fit the *Uhuru* observations of A1918+14. For an exponential spectrum, $kT = 6 \pm 2$ keV with an upper limit on the low-energy absorption of 1.75 keV. When the observations are fitted to a power law spectrum, the upper limit on the low-energy cutoff is 2.75 keV and the energy spectral index is $\alpha = 1.25 \pm 0.25$.

e) Aql X-1 = 4U 1908+00

Kaluzienski *et al.* (1977*a*) have summarized the existing observations of Aql X-1, a recurrent transient X-ray source first detected by Friedman, Byram, and Chubb (1967). More recently, an additional outburst has been reported by Holt and Kaluzienski (1977). Figure 1*d* is the X-ray light curve of Aql X-1, from 1971 January to 1973 March, including observations from both *Uhuru* and *OSO 7* (Markert 1975). Note that persistent emission is not observed from Aql X-1 and that all of the positive detections occur during the repeated flares.

III. ANALYSIS

Using the *Uhuru* observations, it is possible to calculate the occurrence rate of outbursts at different luminosities from transient sources in the galactic plane. *Uhuru* surveyed the entire galactic plane, $|b^{\text{II}}| \leq 7°$, at irregular intervals for $\sim 2\frac{1}{2}$ years (~ 800 days) to a limit of 10 counts s^{-1}. For each non-plane scanning data segment lasting N days, a transient outburst of duration $\tau_{\min}$ days would not have been detected during the first $N - \tau_{\min}$ days of the interval. Sky coverage is therefore more complete for outbursts with larger values of $\tau_{\min}$, and the sky coverage correction factors C_i can be calculated by

$$C_i = \frac{1}{800}\left[800 - \left(\sum_{j=1}^{j=m} N_j - \tau_{\min_i}\right)\right],$$

where the summation is taken over all the non-plane data segments of length $N_j > \tau_{\min_i}$. The annual rate ρ at which transient outbursts occur may be calculated from the data in Table 2 as follows:

$$\rho = \sum_{i=1}^{n} \frac{N_{\text{obs}_i}}{2.5} \times \frac{1}{C_i}, \tag{1}$$

where N_{obs_i} is the number of outbursts observed in 2.5 years (col. [2]) in each interval in $\tau_{\min}$, C_i is the sky coverage correction factor (col. [3]) for each interval in $\tau_{\min}$, and n is the number of 10 day intervals in $\tau_{\min}$. By definition, $\tau_{\min}$ is a lower limit to the actual duration of the outburst for those sources which were not continuously monitored; the sky coverage factors

TABLE 2

OBSERVED AND CORRECTED OCCURRENCE RATES FOR TRANSIENT X-RAY OUTBURSTS

$\tau_{\min}$ (1)	N_{obs_i}* (2)	C_i† (3)	ρ_i (rate yr^{-1}) (4)
10–20	2	0.36	2.2
21–30	0	0.52	0
31–40	0	0.62	0
41–50	1	0.70	0.6
51–60	3	0.77	1.6
61–70	1	0.81	0.5
71–80	0	0.84	0
81–90	1	0.86	0.5
91–100	0	0.89	0
101–110	0	0.91	0
111–120	1	0.94	0.4
			$\rho = 5.8$ yr^{-1}

* In 2.5 yr.

† Sky coverage correction factor.

C_i were derived for the minimum $\tau_{\min}$ in each 10 day interval. These factors combine to make ρ an upper limit. Since a source emitting 1.7×10^{37} ergs s^{-1} at the maximum galactic distance of ~ 25 kpc would be detectable above the *Uhuru* survey limit of 10 counts s^{-1} and since some of the outbursts may be from less luminous objects, the rate $\rho = 5.8$ yr^{-1} thus determined is an upper limit on the annual number of transient sources exceeding $\sim 10^{37}$ ergs s^{-1}.

It is interesting to compare the outburst rate and luminosity limit thus calculated with those resulting from the assumption that all outbursts from transient sources occur at the same luminosity within a thin galactic disk of radius R and scale height $h \ll R$. In this case, the relationship between L and $\tau^{-1} = \rho$ can be derived by following Silk (1973) and Kaluzienski (1977), who define the number-flux relation for such transient sources as follows:

$$N(> S_0, t) = \int_0^{R_0} n_s(2\pi h r' dr'), \tag{2}$$

where $N(> S_0)$ is the number of outbursts observed above the survey limit S_0 in a time t; n_s is the number density of transients in the Galaxy; and the limiting radius $R_0 = (L/4\pi S_0)^{1/2}$, where the luminosity L is assumed constant for the entire group of sources. The diffuse flux due to unresolved sources in the disk as measured by an omnidirectional detector is

$$I_d = \frac{L\langle t_L \rangle}{\tau}\left(\frac{\langle \alpha \rangle}{4\pi^2 R^2}\right) \text{ ergs cm}^{-2}\text{ s}^{-1}\text{ rad}^{-1}, \tag{3}$$

where

$$\langle t_L \rangle = \sum_{i=1}^{n} \frac{\rho_i \times \tau_{\min_i}}{365 \times \rho}$$

gives the average duration of the outburst; and $\alpha = 1 + \ln(2R/h)$, where R is the radius and h is the scale height of the disk containing the transients. The mean α may be calculated from the limits on R/h

defined by the entire population of transient sources (Kaluzienski 1977). Substituting $\langle t_L \rangle = 0.10$ and $\langle \alpha \rangle = 6.25$ in equation (3) yields

$$I_a \geq \frac{L}{\tau}(1.4 \times 10^{-49}) \text{ ergs cm}^{-2}\text{ s}^{-1}\text{ deg}^{-1} . \quad (4)$$

The upper limit on the diffuse flux in the Galaxy I_a can be estimated from the difference in background levels observed by *Uhuru* between galactic and extragalactic scans. This flux does not exceed 2 *Uhuru* counts in the $\frac{1}{2}° \times 5°$ collimator (FWHM) or 6.8×10^{-11} ergs cm^{-2} s^{-1} deg^{-1} (2–6 keV). Thus the limiting value on L/τ can be found from equation (4):

$$4.9 \times 10^{38} \geq L/\tau .$$

This limit is similar to that found by Kaluzienski *et al.* (1977*b*) and implies that, if all transients were 10^{38} ergs s^{-1} at peak, then no more than 4.9 yr^{-1} could occur without violating the upper limit to a galactic "ridge," or, if all were 10^{37} ergs s^{-1}, 49 yr^{-1} could occur, and so on. Our observed limit, $\rho \leq 5.8$ yr^{-1}, on outbursts in excess of 10^{37} ergs s^{-1} therefore provides a significantly more sensitive limit on the number of 10^{37} ergs s^{-1} transient sources than can be obtained from the galactic ridge calculation.

Figure 2 is a plot of exponential temperature versus $\tau_{\min}$ for all the well-observed transient sources listed in Table 1. The distribution of transients with respect to characteristic spectral temperature appears to be bimodal, while the distribution in $\tau_{\min}$ seems continuous. The bimodal temperature distribution observed is similar to that found by Maraschi *et al.* (1976), who considered a subset of uniformly observed transients. There is an apparent deficiency of transient sources with temperatures between 7 and 15 keV relative to the nontransient galactic sources (Table 3). The data for the persistent sources were taken from Jones (1977), who analyzed *Uhuru* spectral data for all relatively bright galactic sources.

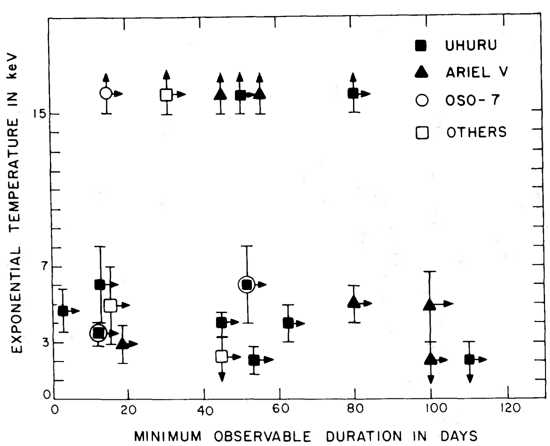

FIG. 2.—The minimum observable duration ($\tau_{\min}$, Table 1, col. [4]) is plotted versus the exponential spectral temperature (Table 1, col. [9]) for all well-observed transient sources in Table 1.

TABLE 3

COMPARISON OF SPECTRAL TEMPERATURE DISTRIBUTION FOR TRANSIENT AND PERSISTENT X-RAY SOURCES

Temp. (keV)	No. of Transients	No. of Nontransients
< 7.......	13	24
7–15......	0	11
> 15......	6	6

IV. DISCUSSION

Many definitions of transient sources have been formulated (Kaluzienski 1977; Pounds 1976) in attempts to physically quantize what is basically an observational phenomenon. A source will appear transient if it is present above the survey limit of a detector for an interval which is short compared with the amount of time the region is observed. Highly variable sources may therefore appear transient, and there may not be a physical basis for considering the two as separate phenomena. Of the 24 sources listed in Table 1, two are identified with stars and exhibit sinusoidal modulations suggestive of orbital periods (A0620−00 = V616 Mon [Boley *et al.* 1976; Matilsky *et al.* 1976] and Aql X-1, a faint flaring star [Thorstensen, Charles, and Bowyer 1977; Watson 1976]); two are tentatively identified with OB stars (A1118−61 [Chevalier and Ilovaisky 1975] and A0535+26 [Liller 1975]); and one is identified with a late-type star (A1524−62 [Murdin *et al.* 1977]). One transient is associated with a globular cluster (MX 1746−20 = NGC 6440); two pulsate slowly (A0535+26 and A1118−61); three exhibit irregular intensity variations prior to the primary peak (A1524−62, A0535+26, and A1118−61); and four have apparent secondary maxima (4U 1543−47, 4U 1730−22, A0620−00, and A1524−62). (See Table 1 for references.)

Kaluzienski *et al.* (1977*b*) have suggested the existence of two classes of galactic plane transients, the first of longer duration, higher intrinsic luminosity, and lower X-ray temperature than the second. This suggestion was primarily based on data from the *Ariel 5* All Sky Monitor, which has a survey limit a factor of 30 times higher than that of *Uhuru* and would therefore not be able to detect sources similar in intensity to 4U 1730−22. The division of transient sources into two classes based on the bimodal temperature distribution seems clear (Fig. 2). On the other hand, there is no convincing evidence for a difference in detectable duration between the two groups. The ranges in $\tau_{\min}$ (the amount of time during which the outburst was detected) for the softer and harder transients are 2–110 and 15–80 days, respectively. A possible systematic effect to consider is that sources which have higher observed intensities or apparent luminosities can be observed above our detector threshold for longer durations and therefore may have larger values of $\tau_{\min}$. Since the percentage of sources with apparent peak luminosities greater than 100 counts s^{-1} is higher for the softer than for the harder transients, we might expect the softer transients to show values of τ_{min} systematically larger than those of the harder transients. The distribution of τ_{min} values is similar for both groups, however (see Fig. 2), and there is therefore no convincing evidence for a difference in detectable duration between the two groups.

There is also no convincing evidence for a difference in intrinsic luminosity between the two groups. Optical identifications and therefore reliable distance estimates exist for very few transient sources. The softer group has a higher percentage of sources with apparent luminosities in excess of 100 counts s^{-1} than does the harder group, but this effect may be due to a different spatial distribution and/or to an intrinsic luminosity difference. Furthermore, outbursts in which the maximum emission occurs above 15 keV may actually have intrinsic X-ray luminosities considerably greater than those estimated for the 2–6 keV energy band. Relatively weak outbursts of short duration are observed to occur in both spectral classes.

The quantity which is least affected by various observational biases is the intrinsic energy spectrum of a source. Jones (1977) has noted that regularly pulsating sources have temperatures greater than 10^8 K and has associated these characteristics with binary systems containing neutron stars. Two of the six transients with high temperatures exhibit pulsations. The other four sources with high temperatures were not observed in the same manner, and similar analyses were apparently either nonconclusive or not applicable to the type of observation. The similarity of this class of transient sources to persistent sources in binary systems containing neutron stars has been noted by Coe *et al.* (1975) and Avni, Fabian, and Pringle (1976) among others, as well as by Kaluzienski (1977), who suggests that this class of transient sources results from an increase in the stellar wind of a massive early-type optical companion. This interpretation seems reasonable and is supported by the observed pulsations and tentative identification of the two *Ariel 5* transients A0535+26 and A1118−61 with early-type stars (Ives, Sanford, and Bell-Burnell 1975; Rosenberg *et al.* 1975; Liller 1975; Chevalier and Ilovaisky 1975).

There are 13 transient sources listed in Table 1 that have exponential temperatures less than 7 keV. Their lack of observable pulsations or other short–time-scale variability and their steeper characteristic spectra do not support the conventional neutron star binary system models for these transients. Three sources are confidently identified with stars, and one is associated with a globular cluster; but the positional uncertainties of the remaining nine sources are too large to permit identifications in the galactic plane.

Kaluzienski (1977) has associated this cooler class of transient sources with Roche lobe overflow of a low-mass, late-type optical star in a close binary system with luminosity near or at the Eddington limit ($\sim 10^{38}$ ergs $M_{\odot}^{-1}$). This mechanism for X-ray production is also believed to explain the observations of Her X-1 (cf. Pravdo 1976 and references therein), which has a flat, hard spectrum; is believed to be a neutron star; and emits two orders of magnitude below the Eddington limit (Schreier *et al.* 1972; Clark *et al.* 1972; Holt *et al.* 1974). Jones (1977) interprets hard spectra as indicating the presence of a neutron star in a close binary system, independent of the mechanism of mass transfer. If this interpretation is correct, then the difference in the spectrum between Her X-1 and the cooler class of transient sources may be accounted for by a different type of collapsed object, such as a white dwarf or black hole, or by an optically thick plasma surrounding the central hard source which degrades the initial photons by Compton scattering (Maraschi, Treves, and van den Heuvel 1977).

Another type of model has been proposed by Brecher, Ingham, and Morrison (1977) and by Gorenstein and Tucker (1976). In the Gorenstein and Tucker model, the transient outburst is the result of a hydrogen-burning flash on the surface of a white dwarf in a close binary system, which is embedded in an extended cloud of circumstellar material $\sim 10^{14}$ cm. The shell of matter ejected by the hydrogen flash would form a shock wave as it drove through the surrounding material which would heat the cloud and produce X-rays by thermal bremsstrahlung. The cloud would then expand and cool, which would account for the spectral softening often observed. This model also explains the lack of short–time-scale variability, but it predicts line emission from the hot circumstellar material and an absence of periodicities. These two additional constraints are not consistent with the observations of A0620−00, which has a reported 8 day period (Matilsky *et al.* 1976) and upper limits on line emission two orders of magnitude too low for an optically thin model (Griffiths, Ricketts, and Cooke 1976).

V. CONCLUSIONS

The number of transient outbursts with X-ray luminosities in excess of 10^{37} ergs s^{-1} is limited by the *Uhuru* observations to no more than 5.8 yr^{-1}. There appear to be two classes of transient X-ray sources, which differ primarily with respect to their observed temperatures. Weak or short-lived transients are observed to occur in both spectral classes.

Although no model currently proposed will account for all the observations, there is increasing evidence for the accreting binary interpretation of transient X-ray sources. The harder class of transients may be produced by an increase in the stellar wind of an early-type optical star onto a neutron star companion (Kaluzienski 1977), but for the softer class the mechanism remains uncertain.

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REFERENCES

Ariel 5 group. 1976, *IAU Circ.*, No. 2934.
Avni, Y. 1976, preprint.
Avni, Y., Fabian, A., and Pringle, J. 1976, *M.N.R.A.S.*, **175**, 297.
Barnden, L. R., and Francey, R. J. 1969, *Proc. Astr. Soc. Australia*, **1**, 236.
Boley, F., Wolfson, R., Bradt, H., Doxsey, R., Jernigan, G., and Hiltner, W. A. 1976, *Ap. J. (Letters)*, **203**, L13.
Brecher, K., Ingham, W. H., and Morrison, P. 1977, *Ap. J.*, **213**, 492.
Carpenter, G. F., Eyles, C. J., Skinner, G. K., Willmore, A. P., and Wilson, A. M. 1975, *IAU Circ.*, No. 2852.
Chevalier, C., and Ilovaisky, S. A. 1975, *IAU Circ.*, No. 2778.
Chodil, G., Mark, H., Rodrigues, R., and Swift, C. D. 1968, *Ap. J. (Letters)*, **152**, L45.
Clark, G. W. 1975, *IAU Circ.*, No. 2843.
Clark, G. W., Bradt, H. V., Lewin, W. H. G., Markert, T. H., Schnopper, H. W., and Sprott, G. F. 1972, *Ap. J. (Letters)*, **177**, L109.
Clark, G. W., and Li, F. 1977, *IAU Circ.*, No. 3090.
Coe, M. J., Carpenter, G. F., Engel, A. R., and Quenby, J. J. 1975, *Nature*, **256**, 630.
Conner, J. P., Evans, W. D., and Belian, R. D. 1969, *Ap. J. (Letters)*, **157**, L157.
Cooke, B. A. 1976, *Nature*, **259**, 564.
Davison, P., Burnell, J., and Ives, J. 1976, *IAU Circ.*, No. 2925.
Elvis, M., Page, C. G., Pounds, K. A., Ricketts, M. J., and Turner, M. J. L. 1975, *Nature*, **257**, 656.
Evans, W. D., Belian, R. D., and Conner, J. P. 1970, *Ap. J. (Letters)*, **159**, L57.
Eyles, C. J., Skinner, G. K., Willmore, A. P., and Rosenberg, F. D. 1975*a*, *Nature*, **254**, 577.
———. 1975*b*, *Nature*, **257**, 291.
Forman, W., Jones, C., Cominsky, L., Julien, P., Murray, S., Peters, G., Tananbaum, H., and Giacconi, R. 1978, *Ap. J. Suppl.*, submitted. (Center for Astrophysics preprint, No. 763.)
Forman, W., Jones, C., and Tananbaum, H. 1976*a*, *Ap. J. (Letters)*, **206**, L29.
———. 1976*b*, *Ap. J. (Letters)*, **207**, L25.
Francey, R. J. 1971, *Nature Phys. Sci.*, **229**, 229.
Friedman, H., Byram, E. T., and Chubb, T. A. 1967, *Science*, **156**, 374.
Gorenstein, P., and Tucker, W. 1976, *Ann. Rev. Astr. Ap.*, **14**, 373.
Griffiths, R., Ricketts, M. J., and Cooke, B. A. 1976, *M.N.R.A.S.*, **177**, 429.
Harries, J. R., Tuohy, I. R., Broderick, A. J., Fenton, K. B., and Luyendyk, A. P. J. 1971, *Nature Phys. Sci.*, **234**, 149.
Holt, S. S., Boldt, E. A., Rothschild, R. E., Saba, J. L. R., and Serlemitsos, P. J. 1974, *Ap. J. (Letters)*, **190**, L109.
Holt, S. S., and Kaluzienski, L. J. 1977, *IAU Circ.*, No. 3031.
Ives, J. C., Sanford, P. W., and Bell-Burnell, S. J. 1975, *Nature*, **254**, 578.
Jernigan, G. 1976, *IAU Circ.*, No. 2957.
Jones, C. 1977, *Ap. J.*, **214**, 856.
Jones, C., Forman, W., Tananbaum, H., and Turner, M. J. L. 1976, *Ap. J. (Letters)*, **210**, L9.
Kaluzienski, L. J. 1977, GSFC X-661-77-107.
Kaluzienski, L. J., Holt, S. S., Boldt, E. A., and Serlemitsos, P. J. 1975*a*, *Nature*, **256**, 633.
———. 1976, *IAU Circ.*, No. 2935.
———. 1977*a*, *Nature*, **265**, 606.
———. 1977*b*, *Ap. J.*, **212**, 203.
Kaluzienski, L. J., Holt, S. S., Boldt, E. A., Serlemitsos, P. J., Eadie, G., Pounds, K. A., Ricketts, M. J., and Watson, M. 1975*b*, *Ap. J. (Letters)*, **201**, L121.
Kellogg, E., Gursky, H., Murray, S., Tananbaum, H., and Giacconi, R. 1971, *Ap. J. (Letters)*, **169**, L99.
Lampton, M., Margon, B., and Bowyer, S. 1976, *Ap. J.*, **208**, 177.
Li, F. K. 1976, *IAU Circ.*, No. 2936.
Li, F. K., Sprott, G. F., and Clark, G. W. 1976, *Ap. J.*, **203**, 187.
Liller, W. 1975, *IAU Circ.*, No. 2936.
Maraschi, L., Huckle, H., Ives, J., and Sanford, P. 1976, *Nature*, **263**, 34.
Maraschi, L., Treves, A., and van den Heuvel, E. P. J. 1977, *Ap. J.*, **216**, 819.
Markert, T. 1975, Ph.D. thesis, MIT.
Markert, T., Backman, D. E., Canizares, C. R., Clark, G. W., and Levine, A. M. 1975*a*, *Nature*, **257**, 32.
Markert, T., Bradt, H. V., Clark, G. W., Lewin, W. H. G., Li, F. K., Schnopper, H., Sprott, G. F., and Wargo, G. F. 1975*b*, *IAU Circ.*, No. 2765.
Markert, T. H., Canizares, C. R., Clark, G. W., Hearn, D. R., Li, F. K., Sprott, G. F., and Winkler, P. F. 1977, *Ap. J.*, **218**, 801.
Matilsky, T., *et al.* 1976, *Ap. J. (Letters)*, **210**, L127.
Matilsky, T. A., Giacconi, R., Gursky, H., Kellogg, E. M., and Tananbaum, H. D. 1972, *Ap. J. (Letters)*, **174**, L53.
Murdin, P., Griffiths, R. E., Pounds, K. A., Watson, M. G., and Longmore, A. J. 1977, *M.N.R.A.S.*, **178**, 27P.
Pounds, K. 1976, *Comments Ap.*, **6**, No. 5, 145.
Pravdo, S. 1976, GSFC X-661-76-280.
Rappaport, S., Buff, J., Clark, G., Lewin, W. H. G., Matilsky, T., and McClintock, J. 1976, *Ap. J. (Letters)*, **206**, 139.
Ricker, G., and Primini, F. 1977, *IAU Circ.*, No. 3078.
Ricketts, M. J., Cooke, B. A., and Pounds, K. A. 1976, *Nature*, **259**, 546.
Rosenberg, F. D., Eyles, C. J., Skinner, G. K., and Willmore, A. P. 1975, *Nature*, **256**, 628.
Schreier, E., Levinson, R., Gursky, H., Kellogg, E., Tananbaum, H., and Giacconi, R. 1972, *Ap. J. (Letters)*, **172**, L79.
Seward, F. D., Page, C. G., Turner, M. J. L., and Pounds, K. A. 1976, *M.N.R.A.S.*, **175**, 39P.
Shukla, P. G., and Wilson, B. G. 1971, *Ap. J.*, **164**, 265.
Silk, J. 1973, *Ap. J.*, **181**, 747.
Tananbaum, H., Chaisson, L. J., Forman, W., Jones, C., and Matilsky, T. A. 1976, *Ap. J. (Letters)*, **209**, L125.
Thorstensen, J. R., Charles, P. A., and Bowyer, S. 1977, *IAU Circ.*, No. 3088.
Ulmer, M. P., Baity, W. A., Wheaton, W. A., and Peterson, L. E. 1973, *Ap. J. (Letters)*, **178**, L121.
Watson, M. G. 1976, *M.N.R.A.S.*, **176**, 19P.
Wheaton, W. A., Baity, W. A., and Peterson, L. E. 1975, *IAU Circ.*, No. 2761.

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