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L. J. KALUZIENSKI
S. S. HOLT
E. A. BOLDT
P. J. SERLEMITSOS

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GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

ALL-SKY MONITOR OBSERVATIONS OF THE DECAY OF A0620-00
(Nova Monocerotis 1975)

L. J. Kaluzienski*, S. S. Holt, E. A. Boldt,
and P. J. Serlemitsos

Laboratory for High Energy Astrophysics
NASA/Goddard Space Flight Center
Greenbelt, Maryland 20771

ABSTRACT

The All-Sky X-ray Monitor onboard *Ariel* 5 has observed the 3-6 keV decline of the bright transient X-ray source A0620-00 on a virtually continuous basis during the period September 1975 - March 1976. The source behavior on timescales $\gtrsim$ 100 minutes is characterized by smooth, exponential decays interrupted by substantial increases in October and February. The latter increase was an order-of-magnitude rise above the extrapolated exponential fall-off, and was followed by a final rapid decline below a level of $\sim$0.05 cm^{-2}-sec^{-1} by late March. Upper limits of 2.5% and 10% were found for any periodicities in the range $0^{d}.2$ - 10^{d} during the early and later decay phases, respectively. A probable correlation between the optical and 3-6 keV emission from A0620-00 has been noted, effectively ruling out models involving traditional optical novae in favor of Roche-lobe overflow in a binary system. The existing data on the transient X-ray sources is consistent with two distinct luminosity-lifetime classes of these objects.

*Permanent Address: University of Maryland, College Park

I. INTRODUCTION

A0620-00 (Nova Monocerotis 1975) was discovered by the Sky Survey Experiment onboard *Ariel* 5 at a level of ∿ .005 x Sco X-1 on 3 August 1975 (Elvis *et al.* 1975). By 11 August the source had reached its maximum flux level (1-10 keV) of ∿ 4 x Sco X-1 (Doxsey *et al.* 1976), which was maintained for several days before commencement of the decline phase. A0620-00 is the first transient source to be unambiguously identified optically (Boley *et al.* 1976), and has been associated with the recurrent nova V616 Monocerotis which exhibited a similar outburst in 1917 (Eachus *et al.* 1976). The source has subsequently been observed in the infrared (Kleinmann *et al.* 1975; Citterio *et al.* 1976) and radio bands (Davis *et al.* 1975; Owen *et al.* 1976). SAS-3 observations (1.3 - 5 keV) conducted ∿ 5 months after maximum have revealed an ∿50% sinusoidal modulation at $P = 7^{d}.8 \pm 0^{d}.7$ (Matilsky 1976).

In this paper we report 3-6 keV observations of the decay of A0620-00 by the *Ariel* 5 All-Sky Monitor from shortly after maximum light thru March 1976 when it disappeared below the effective experimental threshold of ∿0.05 $cm^{-2}sec^{-1}$, as well as upper limits for periodic modulation. In Section III concurrent optical observations are compared with the X-ray variability, and implications of these and other observations on models for A0620-00 are dicussed in Section IV. In Section V we examine the available evidence for a two-component luminosity (and frequency) distribution of the transient sources, analogous to that proposed for the "permanent" galactic X-ray binaries (cf. Margon and Ostriker 1973).

II. EXPERIMENTAL RESULTS

All of the data reported here are obtained from the Ariel 5 All-Sky X-Ray Monitor (ASM), a complete description of which may be found in Holt (1976). The experiment is a scanning X-ray pinhole camera which observes most of the celestial sphere each orbit. The important parameters are a pinhole area of 1 cm^2, an average duty cycle for source observation of $\sim$ 1 percent, and an efficiency of $\sim$ 60 percent in the energy range 3-6 keV. The finest temporal resolution of the experiment is one orbit ($\sim$100 minutes), and there is no energy resolution available in the data within the 3-6 keV acceptance window.

a) Light Curve

Figure 1 is a semi-log display of the ASM A0620-00 data through November 1975. The points obtained prior to day 325 (1975) represent single-orbit ($\sim 0^d.07$) measurements of the flux, while those obtained afterward are $\sim$ 1/2 day averages. Error bars reflect the $\pm$ 1σ statistical uncertainty which generally exceeds any possible systematic error in the analysis. The arrows indicate onset of the emission and approximate commencement of the decline (Elvis et al. 1975), reflecting the relatively brief risetime typical of the transient sources. The source first entered the field-of-view of the ASM on day 230, and the first group of points is roughly consistent with the fluxes at maximum light recorded by X-ray detectors with thresholds below 3 keV (Elvis et al. 1975; Doxsey et al. 1976). A search for emission from the source in the interval between launch of Ariel 5 (15 October 1974) to its discovery by the Sky Survey Experiment revealed no emission $\gtrsim$ 0.1 cm^{-2}-sec^{-1} during the ~ 70% of this time interval that the source region was monitored by the ASM. We can thus rule out the type of extended, low-level activity exhibited by A1524-61 ($\gtrsim$ one-tenth of maximum for at least one month prior to the onset of the main flare, Kaluzienski et al. 1975), since the above limit on early emission from A0620-00 is almost three orders of magnitude below maximum.

It is clear from Figure 1 that any attempt to fit the decay with a simple power-law or exponential function yields an unacceptable result, even when the secondary increase occurring in October is excluded. This increase (representing ~75% higher flux than that expected from an extrapolation of the early September decline) is qualitatively similar to the post-maximum increases observed in Cen X-4 (Evans et al. 1970), 3U1543-47 (Matilsky et al. 1972), and most recently in A0535+26 (Pounds 1976). Shorter intervals, however, could be fit fairly well and the dashed lines represent best exponential fits to the pre- and post-increase decline phases, with e-folding times of 29^d and 21^d, respectively. The acceptable values of χ^2 resulting from these fits reflect the smoothness of this phase of the decay on timescales from ~100 minutes - ~ 1 week. Although this is consistent with other X-ray observations on shorter timescales (Doxsey et al. 1976), optical variations of ~ 0.5 magnitudes over ~hours - 1 day during this period have been reported by Matsuoka et al. (1976). The solid line in Figure 1 is the best 1/t fit to the early September data commencing at maximum light, which is drawn in for comparison with the similar decay expected in a "colliding shells" model (Brecher and Morrison 1975) of the transient sources.

We note, however, that the relatively high ASM low-energy threshold ($\sim$ 3 keV), combined with the progressive softening of the source spectrum (Pounds 1976), may cause the flux observed by the ASM to decline more rapidly than that which would be measured by a photometer with lower threshold energy.

Figure 2 illustrates the ASM data over the final decay stage of A0620-00 from $\sim$December 1975 until its disappearance below the experimental threshold in late March 1976. All of the points here are $\sim$ 1/2 day averages, and the dashed line is an extrapolation of the post-October exponential fit in Figure 1. Although the exponential decline is approximately followed through mid-January, significant fluctuations on a timescale of $\sim$1/2 day are now evident, with the source disappearing below the ASM threshold on several occasions. Similar variations on a timescale of hours-days in the 1.3 - 5 keV flux during the same period have been reported from SAS-3 (Matilsky and Zubrod 1976). A final dramatic increase in flux before disappearance of A0620-00 occurred in early February, representing at least an order-of-magnitude deviation above the level expected from extrapolation of the exponential decline. The subsequent decay is correspondingly more rapid than in the earlier phases (e-folding time $\lesssim 10^d$), reminiscent of the decay light curves of Cen X-4 (Evans et al. 1970) and 3U1543-47 (Li et al. 1976).

b) Periodicity

Since the magnitude of a periodic modulation of the 3-6 keV flux may be correlated with the source intensity, we have analyzed the single-orbit and 1/2-day data in Figures 1 and 2 separately. In the first case, the best-fit exponentials from the September and October-November data were subtracted out separately, and the residuals folded over trial periods in the range 0.2 - 10 days in intervals fine enough that a regular variation should be revealed by a well-defined peak in the χ^2 distribution. Neither this procedure, nor a fast fourier transform performed on the single orbit data, succeeded in the detection of any modulation in excess of $\sim$3%. This is equivalent to an upper limit of 2.3% fractional sinusoidal amplitude on any 3-6 keV modulation in the range searched during this phase of the decay. The 1/2-day data were tested for periodicity in a similar manner. Although the average value of χ^2 is higher due to random fluctuations (see Figure 2, $\sim$ day 350) and the limited number of cycles at the upper end of the period range, no clear maximum in the vicinity of $7^d.8$ is evident. A small enhancement in the χ^2 distribution is present at $P \simeq 8$ days, and we estimate the upper limit to any sinusoidal variation in the range $7^d.8 \pm 0^d.7$ to be $\lesssim$10%.

The ASM upper limits for the early light curve are of the same order as results obtained by the *Ariel* 5 Sky Survey Experiment (Elvis *et al*. 1975) and SAS-3 (Doxsey *et al*. 1976) at higher frequencies, with reported upper limits on periodicity of 3% (200s - 2d, 2-18 keV) and $\sim$ 2% (0.2 ms - 435s, 1 - 10 keV), respectively, during the rise and early decline phases. The absence of a detectable 3 - 6 keV modulation at the suggested $\sim 7^d.8$ X-ray or $\sim 3.9^d$ optical (cf. Duerbeck and Walter 1976) periods during this stage may be indicative of an extended emission region and/or a high orbital inclination, and agrees with B magnitude measurements of Matsuoka et al. (1976) over the same interval who found an upper limit of 0.05 magnitudes on any periodicities in the 2 - 64 day range. With respect to the later decline we note that the SAS-3 period is based on observations between 1975 day 372-404 (during which the ASM coverage is only ∿ 30%) and does not include the February increase (see Figure 2). The absence of a clear ∿ 7.8 day modulation in our data may be reconciled with the ∿50% sinusoidal modulation (1.3 - 5 keV) reported by Matilsky (1976) if the effect is more conspicuous below the ASM low energy threshold, or if it was present at that level only during the time that the ASM coverage was incomplete.

III. COMPARISON WITH OPTICAL OBSERVATIONS

Since the identification of V616 Monocerotis as the optical counterpart of A0620-00 (Boley et al. 1976) several observers have monitored the source in the optical band. Of considerable interest are observations made in the vicinity of the 3-6 keV increases during October 1975 and February 1976. B magnitude measurements of Matsuoka et al. (1976) during September clearly show an increase in the optical emission of ∿ 0.6 magnitudes concurrent (to an accuracy of ≃1 week due to a gap in ASM coverage, see Figure 1) with the October 3-6 keV rise. Their data also show a roughly exponential decay (e-folding time ≃1 month) in B magnitude during September in good agreement with the 3-6 keV X-ray observations, but somewhat more rapid than the ∿60 day decay time observed in UBV by Duerbeck and Walter (1976) over the same time span. The February increase is again apparently reflected in the optical data, with an increase of ∿50% between 19 January - 16 March implied by the visual magnitude estimates of Bortle (1976a,b). A final rapid optical decline commenced at about the time of this last observation, the source brightness decreasing approximately one magnitude by 31 March (Bortle 1976c), and another ~2 magnitudes during April (Martynov 1976). Thus, although the X-ray and optical increases are apparently correlated, the optical variation may lag the corresponding X-ray behavior by as much as ~2 weeks. We note also the discrepancy between the mean decay time constants over the initial decline (August - January) of the optical ($\tau_o \simeq 2$ 1/2 months) and 3-6 keV ($\tau_x \simeq 1$ month) fluxes. This latter inconsistency can not arise entirely from the high threshold of the ASM (the soft X-ray spectrum of A0620-00 does not allow us to distinguish between a temperature decrease and a true luminosity decrease), as SAS-3 measured a flux (1.3 - 5 keV) of ≃ 0.2 x Crab on 7 January (Matilsky 1976) in good agreement with the ASM data. Both the slower decay rate and the observed "lag" of the optical emission with respect to the final rapid disappearance at X-ray energies can apparently be reconciled with a mechanism in which soft X-ray and UV (as well as higher energy X-ray) heating contribute significantly to the production of the optical emission.

Combination of the X-ray or optical decay time constant with the X-ray flux at maximum light allows an estimate of the total energy released in the outburst. With $\tau \simeq 1 - 2$ 1/2 months and $S_{max} \simeq 1.0 \times 10^{-6}$ erg-cm^{-2}-sec^{-1} (E >1 keV, Elvis et al. 1975), we obtain E (> 1 keV) ≃ 3-8 x 10^{44} D_1^2 ergs, where $D_1 \equiv D/1$ kpc. Assumption of an ~ 10% conversion efficiency of mass to radiation in an accretion process implies a total mass exchange of $\Delta M \lesssim 5 \times 10^{-9} D_1^2 M_\odot$, and a mean accretion rate of

$\dot{M} \lesssim 6 \times 10^{-8} D_1^2 \ M_{\odot}\text{-yr}^{-1}$. We note that these values are not unreasonable for distances $\lesssim 3$ Kpc.

IV. A0620-00 MODELS

a) Traditional Novae

The association of A0620-00 with a recurrent nova has renewed speculation that some fraction of the transient sources may originate in traditional optical nova outbursts (Brecher and Morrison 1975; Eachus et al. 1976; Gorenstein and Tucker 1976). The resemblance of the X-ray light curves of A0620-00 and earlier transient sources to those of optical novae has been noted by several observers (Matilsky and Zubrod 1976; Eachus et al. 1976). A number of difficulties with this association in the present instance have been pointed out, however, such as the absence of stellar absorption and emission lines (Gull et al. 1975; Boley et al. 1976), the high X-ray to optical luminosity ratio ($\gtrsim 10^3$ in contrast to $\lesssim 10^{-4}$ for Nova Cygni 1975; Hoffman et al. 1976), the inconsistency of optically thin bremsstrahlung in producing the observed optical and infrared radiation (Kleinmann et al. 1975), and physically distinct radio emission from that observed in several novae (Owen et al. 1976). We have earlier noted an apparent discrepancy between the observed exponential decay and the 1/t fall-off expected in the colliding shells hypothesis (Brecher and Morrison 1975). The correlation of the X-ray and optical emission during the October and February increases represents additional evidence against a traditional optical nova origin for A0620-00, since in the nova models the X-ray and optical emission is hypothesized to originate in two well-separated regions (i.e. hot, expanding gas shell vs. surface of a white dwarf, Brecher and Morrison 1975; Gorenstein and Tucker 1976). Although A0620-00 is the only transient source for which concurrent optical observations exist, the characteristic X-ray behavior exhibited by several earlier sources (e.g. extended pre-flare emission; secondary maxima; substantial emission $\gtrsim$ 5 years after peak) is apparently inconsistent with a nova mechanism, as well. Finally, the existence of an $\sim 7\overset{d}{.}8$ modulation of the X-ray emission (Matilsky 1976) is completely irreconcilable with the traditional nova interpretations, as discussed in the following section.

b) Episodic Accretion

Several different binary models involving episodic variations in the mass transfer rate have been suggested for A0620-00 and similar transient sources. Endal et al. (1975) have proposed a model in which an Algol type binary undergoes sporadic mass transfer from a sub-solar mass companion onto a white dwarf, citing the difficulty in forming neutron stars or black holes in low mass systems. Calculations of Fabian et al. (1976), however, have pointed out that luminosities exceeding $\sim 10^{36}$ erg-sec^{-1} are problematic via accretion onto white dwarfs, which is apparently well below the maximum emitted from A0620-00 ($L_{max} \gtrsim 10^{38} D_1^2$ erg -sec^{-1}, 1 - 10 keV). Another model, suggested by Li et al. (1976) to explain the behavior of 3U1543-47 and other so-called "X-ray novae", involves Roche-lobe overflow onto a collaposed object resulting from periodic expansion of a red giant companion. In the case of A0620-00, Ward et al. (1975) have reported that B magnitude measurements of V616 Monocerotis in the quiescent state (Palomar Observatory Sky Survey Charts, circa 1955) appear to rule out a giant as the companion since the distance would be $\gtrsim$15 Kpc, but are consistent with a red dwarf at D $\simeq$ 500 pc. Additionally, the correlation of the 3-6 keV and optical fluxes lessens the probability of a red giant primary in that the optical emission should be dominated by the giant, and relatively insensitive to changes in the X-ray luminosity. Other accretion models, including the eccentric orbit binary hypothesis (McCluskey and Kondo 1971; Tsygan 1975; Pacini and Shapiro 1975; Clark and Parkinson 1975) and very slow, steady build-up ($\gtrsim 10^3$ yr) of an accretion disk until triggered by an instability (Amnuel et al. 1974), can apparently also be ruled out for A0620-00. Avni et al. (1976) have shown that an eccentricity in excess of ∿0.99 would be required for A0620-00, and the presumed recurrence time of ∿59 yrs. (Eachus et al. 1976) is far shorter than the timescale expected in the latter model.

The existence of a class of binaries exhibiting nova-like optical outbursts and consisting of a red and blue dwarf pair (hence, "dwarf novae") has been known for some time. In contrast to the standard nuclear burning interpretation, however, several models have been proposed in which the outburst is attributed to episodic mass transfer from the red to blue component (Bath et al. 1974; Osaki et al. 1974). The optical emission is presumed to arise from reprocessing of UV and soft X-ray radiation in an accretion disk, at a "hot spot" where the accreting matter intercepts the disk, and from X-ray heating of the red star's atmosphere. Avni et al. (1976) have suggested that A0620-00 may represent a dwarf nova-type system with a neutron star or black hole as the accreting object. In this model, the gravitational energy released via accretion onto the collapsed member resulting from episodic overflow of the red companion's Roche-lobe is responsible for the X-ray outburst. While in "normal" dwarf novae the bulk of the radiation emerges in the optical and UV bands, X-ray emission dominates in the red dwarf-neutron star/black hole system and a transient X-ray source is produced. The accretion rate required to generate the observed X-ray luminosity of A0620-00 ($L_x \gtrsim 10^{38} D_1^2$ erg-s^{-1}) is (assuming 10% mass-energy conversion efficiency) $\dot{M}_{max} \approx 2 \times 10^{-8} D_1^2 M_\odot$-yr^{-1}. Interestingly, this rate (for $D_1 \lesssim 3$) is within the limits of that predicted for self-excited mass transfer in dwarf novae ($\dot{M} \gtrsim 1.5 \times 10^{-7} M_\odot$-yr^{-1}, Bath et al. 1974).

The X-ray dwarf nova analogy is consistent with other aspects of A0620-00. In particular, the correlation of the X-ray and optical increases is expected in such a system where the optical and X-ray emission originate in a common region (i.e., accretion disk) or are connected via a reprocessing mechanism (e.g., X-ray heating of the "normal" star). In addition, the reported optical period at $3^d.92$ during the early decline (Duerbeck and Walter 1976) and periods at approximately twice this value from X-ray and optical observations during the later decay (Matilsky 1976; Chevalier et al. 1976) are consistent with a binary system in which the optical variability is initially dominated by an extended atmosphere viewed from differing aspects (similar to the double-maximum light curve of HDE 226868), followed by predominance of X-ray heating of the contracting star at the orbital period ($\sim 7^d.8$), reminiscent of the Her X-1 - H_z Her system. The absence of X-ray eclipsing (the $7\overset{d}{.}8$ modulation reported by Matilsky (1976) is sinuosoidal rather than eclipse-like, and the present data indicate that this modulation is certainly not present at the reported level of ∿50% during most of the observable lifetime of the source) is not surprising with the relatively small optical star, and Avni et al. (1976) have computed an eclipse probability of only $\lesssim$37% for reasonable system parameters. We should also point out here, however, that the existence of a $7\overset{d}{.}8$ binary period is difficult to account for in the dwarf nova model where the longest expected period is ∿ 3 days (Avni et al. 1976), independent of the mass of the X-ray component. The nature of the optical companion in A0620-00 is thus still uncertain, as the evidence is apparently inconsistent with both a dwarf and giant class star.

Several characteristics of A0620-00 are consistent with accretion models in general. Ricketts et al. (1975), for example, have pointed out that a marked softening in the X-ray spectrum during the rise phase is consistent with a growing accretion disk, and Stoeger (1976) has discussed a scenario in which an instability in the developing disk accounts for the observed "pre-cursor" peak (Elvis et al. 1975). The resemblance of A0620-00 to other established X-ray binaries is also significant. Several observers have noted a resemblance between V616 Monocerotis and Sco X-1, especially in the colors (Eachus et al. 1976), B magnitude, and ratio of X-ray to optical radiation at maximum light (Boley et al. 1976), and the appearance ∿ 3 weeks after maximum of weak emission at NIII λλ 4634-4640 and He II λ 4686 (Peterson et al. 1975).

In addition, Cowley and Crampton (1975) have reported evidence for a "hot spot" on the accretion disk in Sco X-1, analogous to that expected in the dwarf nova models, and have noted the similarity of the implied masses and $0^{d}.787$ period to those of old novae and cataclysmic variables. The A0620-00 transient radio event has been compared by Owen et al. (1976) to similar episodes in Cyg X-3, which has also been likened to a dwarf nova system (Davidsen and Ostriker 1974). Finally, Citterio et al. (1976) have pointed out that measurements of the infrared flux made in October 1975 are consistent with a source that is self-absorbed in that band, similar to the case of Sco X-1. The similarities of the optical, infrared, radio, and X-ray characteristics of A0620-00 to known galactic X-ray sources clearly favor models involving sudden changes in the rate of mass transfer in binary systems as the triggering mechanism in the transient X-ray sources.

The problem of divergent distance estimates for A0620-00 can also be resolved within the context of accretion models. Eachus et al. (1976) have derived a distance of D = 11 ± 3 Kpc based on the typical rate of fading of other recurrent novae, while a more conservative estimate of .5 Kpc $\lesssim$ D $\lesssim$ 3 Kpc is consistent with the sharp interstellar absorption lines observed by Gull et al. (1976), and an Eddington-limited luminosity at maximum for a 1 - 10 $M_{\odot}$ accreting object. Although the optical evolution of these systems may resemble that of recurrent novae, the peak optical luminosity will be considerably less since the radiation emerges primarily in the X-ray region. The assumption of an accretion rate comparable to that of ordinary recurrent novae and the observed ratio of $L_x/L_{opt} \approx 10^3$ imply an absolute visual magnitude at maximum of $M_v \sim 1$ instead of the typical value of ~ -6 (Payne-Gaposhkin 1964). The corresponding distance of $D \approx 500$ pc should be taken only as a rough lower limit, since effects such as self-excited mass transfer will tend to increase the rate of mass exchange in the X-ray system.

V. TRANSIENT X-RAY SOURCES

With the increased sky coverage and greater sensitivity of X-ray experiments since Uhuru, the classification of sources as transient has become increasingly ambiguous. For example, several "transient" sources have been detected at levels exceeding a few percent of maximum as long as five years after the initial outburst (Pounds 1976; Forman et al. 1976). Extended low-level emission has also been observed prior to the main flare, as in the case of A1524-61 (Kaluzienski et al. 1975). On the other hand, "permanent" sources may exhibit transient-like outbursts, such as the June 1975 flare of Aql X-1 (3U1908+00) (Buff 1975; Kaluzienski et al. 1976). These observations strongly suggest that the transient sources can be understood within the standard galactic X-ray binary interpretation (i.e., a non-degenerate star in a binary system with an accreting neutron star/black hole).

From the discovery of Cen X-2 in April 1967 (Harries et al. 1967) through the launch of Ariel 5 in October 1974, a total of approximately five "unqualified" transient sources (i.e., sources exhibiting the characteristic nova-like X-ray light curve and satisfying the approximate condition $L_{max}/L_{min} \gtrsim 100$) had been detected via rocket flights and the Uhuru satellite. Note that highly variable sources whose long-term behavior is characterized by extended, intermittent high and low states (e.g., Cir X-1) are not included within our definition. We have also excluded the recently discovered "weak, highlatitude" transients (cf. Ricketts et al. 1976), to which the ASM is totally insensitive, in the following discussion.

The pre-Ariel 5 transients are characteristically bright ($S_{max} \gtrsim$ Crab), long-lived ($\tau_{av} \gtrsim$ 1 month) sources appearing (except for Cen X-4) within 5° of the galactic plane. The relative insensitivity of the earlier instruments to transient events resulting from incomplete and non-uniform sky coverage make these observations of limited value for quantitative estimates of transient source parameters (i.e., rate of occurrence, luminosity and spatial distribution). In particular, the detection of at least five additional transients during the first $\sim$ year of Ariel 5 operation suggests that the predominance of bright, long-duration transients in the earlier data may be reasonably attributed to observational selection effects. We attempt, here, to apply the virtually continuous coverage of $\gtrsim$ 80% of the X-ray sky at a level $\gtrsim$ 1/3 Crab available with the ASM which, together with the transient source observations of other Ariel 5 experiments, has considerably reduced such selection effects. In this regard, we note that the ASM has a sensitivity of $\sim$ 0.2 Crab for sources which have a duration of $\gtrsim$ 1 week for $|b| \gtrsim 10°$, and somewhat worse ($\sim$ 0.3 Crab on the average, depending on source confusion) for comparable on-times in the galactic plane.

The first result evident from the Ariel 5 observations is that the concentration of the earlier transients at low galactic latitude is not a result of observational bias, and is indicative of a galactic disk distribution with distances $\gtrsim$ 1 Kpc, similar to the variable galactic sources (cf. Kaluzienski et al. 1975). Furthermore, although the total number of transient sources is small and the statistics correspondingly poor, there appears to be evidence in the entire sample for a grouping into bright, long-lived, relatively soft transients and weak, shorter-duration, harder-spectral sources. An estimate of the corresponding relative peak luminosities can be obtained by combining the observed source frequencies with a galactic geometry. If we assume that the transient sources may occur anywhere in the galactic plane with roughly equal probability and peak absolute luminosity, the adoption of an effective experimental threshold at the level of the Crab nebula yields, after Silk (1973),

$$\frac{L}{\tau} \left(\frac{\text{erg-s}^{-1}}{\text{yr}}\right) \approx 3.6 \times 10^{38} \; \frac{N(> S_o, t)}{t(\text{yr})} \; R_{15}^2 \; \left(\frac{S_o}{S_{crab}}\right) , \qquad (1)$$

where $N(> S_o, t)$ is the number observed above an intensity S_o in time t, with a mean time τ between source appearances at peak luminosity L in the galaxy (of radius $R_{15} \equiv R/15$ Kpc). The detection of three sources of the long-duration variety during the first year of Ariel 5 operation implies a value of $\tau \gtrsim 0.1$ yr (on the average), and hence $L \gtrsim 10^{38}$ erg-sec^{-1}. The obvious deficiency of these sources with intensities $\lesssim$ Crab (the three Ariel 5 sources presumably belonging to this class, A1524-61, A1742-28, and A0620-00, attained peak brightnesses $\gg$ Crab) contradicts a sensitivity-limited size spectrum from a uniform disk population, as would be expected from a class of Eddington-limited sources ($M \sim 1\ M_{\odot}$) so distributed. The peak flux of A0620-00 ($S \simeq 50 \times S_{crab}$) then implies that even the most distant sources will attain fluxes comparable to the Crab, while the majority will exceed that level at maximum. Thus, we expect that essentially all of these long-duration transients occurring since the launch of Ariel 5 have been observed. As a result of their intrinsic brightness, proximity to the plane, and longevity, sources belonging to this class (Cen X-2, Cen X-4, and 3U1543-47) were detectable with relatively high efficiency even without continuous all-sky coverage.

In contrast, the harder-spectral, shorter-duration transients are consistent with a source population that is intrinsically less luminous at maximum. The short lifetime of these sources allows a value of τ as small as $\sim 10^{-3}$ without conflicting with any measurements of which we are aware (the most restrictive being the upper limit for a galactic "ridge", Holt et al. 1974). Equation (1) implies that there can be ~ 100 sources of this kind in the galaxy each year, with peak luminosity $L \lesssim 10^{37}$ erg-sec^{-1} (Kaluzienski et al. 1975a). Two such sources were extensively observed during the first year of Ariel 5 observations, A1118-61 ($S_{max} \lesssim 0.1$ Crab, Ives et al. 1975) and A0535+26 ($S_{max} \simeq$ 1.5 Crab, Rosenberg et al. 1975), with several other candidates reported from both Ariel 5 and SAS-3 in IAU circulars. The possible deficiency of these sources at a level $\lesssim$ 1/2 Crab is ascribable in this case primarily to the relative insensitivity of the ASM to short-lived sources just above the experiment threshold.

The consistency of the observations with two distinct luminosity classes of transient X-ray sources distributed ∿ uniformly in the galactic plane is reconcilable with standard galactic X-ray binary models in which the supply of accreting material is relatively discontinuous, occurring only in infrequent, short-lived episodes. The existence of two classes of transient sources may then be interpreted primarily in terms of the mode of mass-exchange. The consistency of the high peak luminosity of the long-duration sources with an Eddington-limited mass flow is suggestive of Roche-lobe overflow onto an ∿ 1 $M_{\odot}$ compact object. While a number of the "variable" galactic sources are probably also Eddington-limited (Margon and Ostriker 1973), Aquila X-1 (3U1908+00) may be the best candidate for a "stable" counterpart of the long-duration transients in view of its nova-like X-ray flares (cf. Kaluzienski *et al.* 1976). The weak, short-lived sources, on the other hand, are at least an order of magnitude less luminous at maximum, and the flare mechanism can be reconciled with sudden changes in the density of the wind emanating from the optical companion. These transients are more readily associated with the "variable" sources as evidenced by the characteristics they share in common (e.g., pulsing) with sources such as Vela X-1 (3U0900-40) and Cen X-3. Finally, it is interesting to note the similarity of our conclusion to the proposed bi-modal luminosity distribution of the more permanent X-ray sources (cf. Margon and Ostriker 1973), with the brighter group emitting at a luminosity consistent with an Eddington-limited 1 $M_{\odot}$ secondary, and the weaker group radiating at a luminosity which is at least an order of magnitude lower.

REFERENCES

Amnuel, P. R., Guseinov, O. H., and Rakhamimov, Sh. Ju. 1974, Ap. and Space Sci., 29, 331.

Avni, Y., Fabian, A. C., and Pringle, J. E. 1976, M.N.R.A.S., 175, 297.

Bath, G. T., Evans, W. D., Papaloizou, J., and Pringle, J. E. 1974, M.N.R.A.S., 169, 447.

Boley, F., Wolfson, R., Bradt, H., Doxsey, R., Jernigan, G., and Hiltner, W. A. 1976, Ap. J. (Letters), 203, L13 (see also IAU Circ. No. 2819).

Bortle, J. 1976a, IAU Circ. No. 2918.

Bortle, J. 1976b, IAU Circ. No. 2935.

Bortle, J. 1976c, IAU Circ. No. 2941.

Brecher, K., and Morrison, P. 1975, Bull. Am. Astr. Soc., 7, 538.

Buff, J. 1975, IAU Circ. No. 2788.

Chevalier, C., Ilovaisky, S. A., and Mauder, H. 1976, IAU Circ., No. 2957.

Citterio, O., Conti, G., Di Beneditto, P., Tanzi, E. G., Perola, G. C., White, N. E., Charles, P. A., and Sanford, P. W. 1976, M.N.R.A.S., 175, 35p.

Clark, D. H., and Parkinson, J. H. 1975, Nature, 258, 408.

Cowley, A. P. and Crampton, D. 1975, Ap. J. (Letters), 201, L65.

Davidsen, A., and Ostriker, J. P. 1974, Ap. J., 189, 331.

Davis, R. J., Edwards, M. R., Morison, I., and Spencer, R. E. 1975, Nature, 257, 659.

Doxsey, R., Jernigan, G., Hearn, D., Bradt, H., Buff, J., Clark, G. W., Delvaille, J., Epstein, A., Joss, P. C., Matilsky, T., Mayer, W., Mc Clintock, J., Rappaport, S., Richardson, J., and Schnopper, H. 1976, Ap. J. (Letters), 203, L9.

Duerbeck, H.W., and Walter, K. 1976, Astron. Astrophys., 48, 141.

Eachus, L., Wright, E., and Liller, W. 1976, Ap. J. (Letters), 203, L17.

Elvis, M., Page, C. G., Pounds, K. A., Ricketts, M. J., and Turner, M. J. L. 1975, Nature, 257, 656 (see also IAU Circ. No. 2814).

Endal, A S., Devinney, E. J., and Sofia, S. 1975, submitted to Ap. J. (Letters).

Evans, W. D., Belian, R. D., and Conner, J. P. 19 0, Ap. J. (Letters), 159, L57.

Fabian, A. C., Pringle, J. E., and Rees, M. J. 1976, M.N.R.A.S. , 175, 43.

Forman, W., Jones, C., and Tananbaum, H. 1976, submitted to Ap. J. (Letters).

Gorenstein, P., and Tucker, W. H. 1976, Annual Review of Astronomy and Astrophysics, 14, to be published.

Gull, T. R., York, D. G., Snow, T. P., Jr., and Henize, K. G. 1976, submitted to Ap. J. (Letters); see also IAU Circ. No. 2819.

Harries, J. R., McCracken, K. G., Francey, R. J., and Fenton, A. G. 1967, Nature, 215, 38.

Hoffman, J. A., Lewin, W. H. G., Brecher, K., Buff, J., Clark, G. W., Joss, P. C., and Matilsky, T. 1976, Nature, 261, 208.

Holt, S. S., Boldt, E. A., Serlemitsos, P. J., Murray, S. S., Giacconi, R., Kellogg, E. M., and Matilsky, T. A. 1974, Ap. J. (Letters), 188, L97.

Holt, S. S. 1976, Ap. and Space Sci. (in press).

Ives, J. C., Sanford, P. W., and Bell-Burnell, S. J. 1975, Nature, 254, 578.

Kaluzienski, L. J., Holt, S. S., Boldt, E. A., and Serlemitsos, P. J., Eadie, G., Pounds, K. A., Ricketts, M. J., and Watson, M. 1975, Ap. J. (Letters), 201, L121.

Kaluzienski, L. J., Holt, S. S., Boldt, E. A., and Serlemitsos, P. J. 1975a, Nature, 256, 633.

Kaluzienski, L. J., Holt, S. S., Boldt, E. A., and Serlemitsos, P. J. 1976, Symposium on X-Ray Binaries, NASA SP-389, 311.

Kleinmann, S. G., Brecher, K., and Ingham, W. H. 1975, preprint.

Li, F. K., Sprott, G. F., and Clark, G. W. 1976, Ap. J., 203, 187.

Margon, B., and Ostriker, J. P. 1973, Ap. J., 186, 91.

Martynov, D. Ya. 1976, IAU Circ. No. 2953.

Matilsky, T., Giacconi, R., Gursky, H., Kellogg, E., and Tananbaum, H. 1972, Ap, J. (Letters), 174, L53.

Matilsky, T., and Zubrod, D. 1976, presented at meeting of HEAD/AAS, Cambridge, Mass.

Matilsky, T. 1976, IAU Circ. No. 2949.

Matsuoka, M., Tsunemi, H., Eiraku, M., Inoue, H., Koyama, K., Maeda, Y., Takagishi, K., and Watanabe, E. 1976, preprint (ISAS RN12).

Mc Cluskey, G. E., and Kondo, Y. 1971, Ap. and Space Sci., 10, 464.

Osaki, Y. 1974, Publ. Astron. Soc. Japan, 26, 429.

Owen, F., Balonek, T., Dickey, J., Terzian, Y., and Gottesman, S. 1976, Ap. J. (Letters), 203, L15 (see also IAU Circ. no. 2823).

Pacini, F., and Shapiro, S. L. 1975, Nature, 255, 618.

Payne-Gaposhkin, C. 1964, *The Galactic Novae* (New York: Dover).

Peterson, B., Jauncey, D. L., and Wright, A. E. 1975, *IAU Circ*. No. 2837.

Pounds, K. A. 1976, presented at meeting of HEAD/AAS , Cambridge, Mass.

Ricketts, M. J., Pounds, K. A., and Turner, M. J. L. 1975, *Nature*, **257**, 657.

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.

Silk, J. 1973, *Ap. J.*, **181**, 747.

Stoeger, W. R. 1976, *Nature*, **261**, 211.

Tsygan, A. I. 1975, *Soviet Astronomy A.J.*, **18**, 798.

Ward, M. J., Penston, M. V., Murray, C. A., and Clements, E. D. 1975, *Nature*, **257**, 660.

FIGURE CAPTIONS

Figure 1 — A0620-00 light-curve (3-6 kev) thru November 1975. Points prior to day ∿ 320 are single-orbit measurements, while those afterward represent ∿ 1/2 day averages. Error bars reflect the $\pm 1\sigma$ statistical uncertainties. The dashed lines are best exponential fits to the pre- and post- October increase data, and the solid line is the best 1/t fit referenced to ~ the time of maximum light. The Crab Nebula has an intensity of ∿ 1.1 in these units. The arrows represent the times of source discovery and maximum X-ray flux.

Figure 2 — Later decline of A0620-00. All points are ∿ 1/2 day averages, and the dashed line is an extrapolation of the post-October exponential decay of Figure 1. Upper limits represent measurements of a source flux $\lesssim 0.1\ cm^{-2}\text{-}sec^{-1}$.

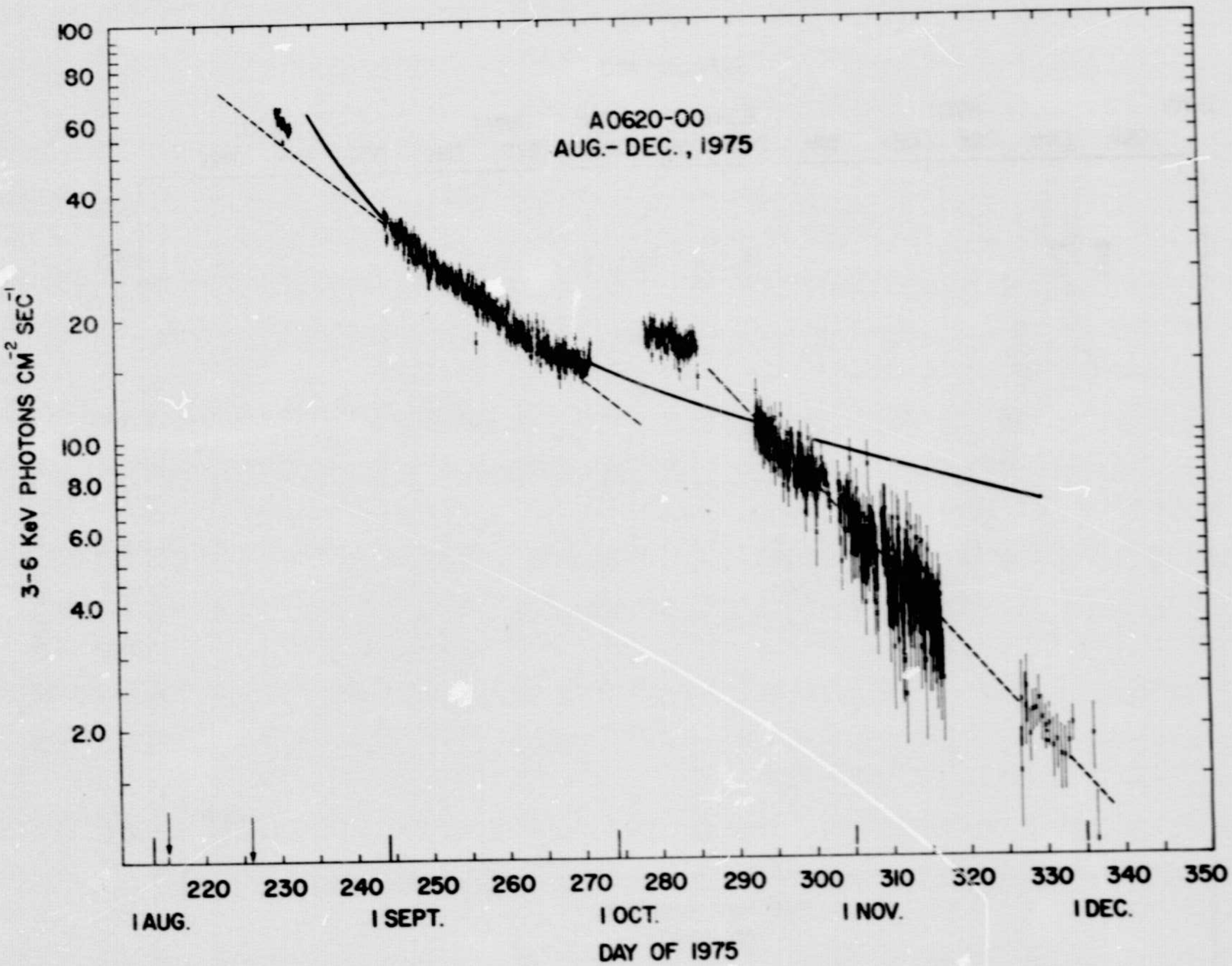
A0620-00
AUG.- DEC., 1975
3-6 KeV PHOTONS CM^{-2} SEC^{-1}
100
80
60
40
20
10.0
8.0
6.0
4.0
2.0
220 230 240 250 260 270 280 290 300 310 320 330 340 350
1 AUG.
1 SEPT.
1 OCT.
1 NOV.
1 DEC.
DAY OF 1975

Figure 1

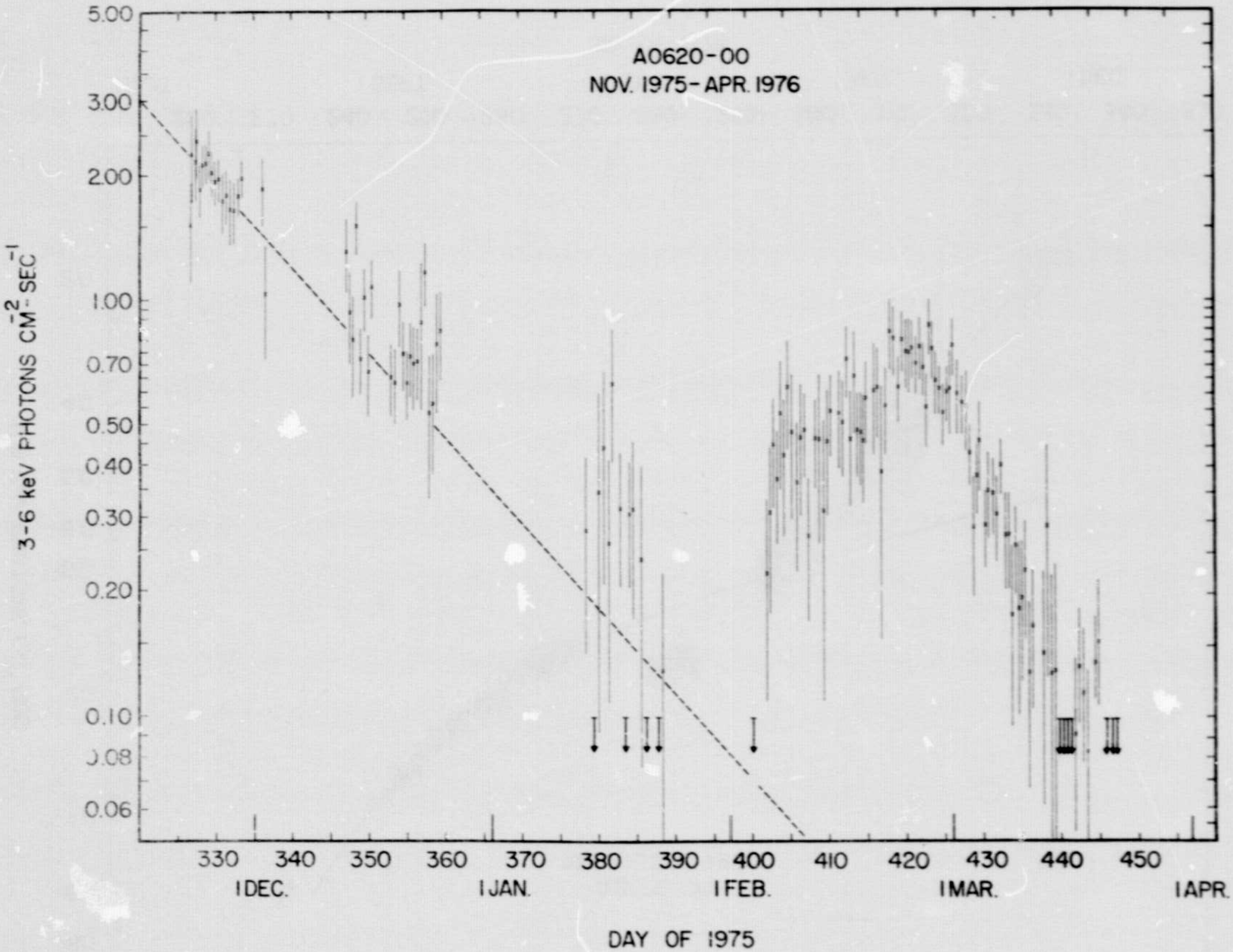
A0620-00
NOV. 1975 - APR. 1976
3-6 keV PHOTONS CM^{-2} SEC^{-1}
5.00
3.00
2.00
1.00
0.70
0.50
0.40
0.30
0.20
0.10
0.08
0.06
330
340
350
360
370
380
390
400
410
420
430
440
450
1 DEC.
1 JAN.
1 FEB.
1 MAR.
1 APR.
DAY OF 1975

Figure 2