THE ASTROPHYSICAL JOURNAL, 312:122–133, 1987 January 1

PERSISTENT EMISSION AND BURSTS FROM AQUILA X-1 OBSERVED BY *EINSTEIN*

M. CZERNY,[1] B. CZERNY,[2] AND J. E. GRINDLAY
Harvard-Smithsonian Center for Astrophysics
Received 1985 December 2; accepted 1986 June 26

ABSTRACT

The recurrent transient/X-ray burster Aql X-1 was observed by the *Einstein* satellite during its outburst in 1979 March and April. Thermal bremsstrahlung provided good spectral fits for eight out of a total of 10 observations; however, the X-ray spectrum of Aql X-1 is also well fitted by a two-component model in which radiation comes from a boundary layer and from an irradiated accretion disk. The latter interpretation of the observed spectral changes indicate that the accretion rate of the boundary layer was close to the critical temperature. The inclination angle of the system derived from this model is 33°.

Two bursts were recorded by the *Einstein* MPC instrument. The first one exhibited an extremely long tail in which the count rate at $\sim$2500 s after the burst maximum exceeded the count rate before the burst by a factor of $\sim$25%. The second burst, observed 4 days later (when the persistent emission was already 2 times lower) had a similar peak luminosity but a much less pronounced tail with the emission enhanced by only $\sim$7% 500 s after the burst. Fits of our two-component spectrum model to the tails of bursts indicate that the enhanced emission after the bursts results from an increase of the accretion rate in the innermost parts of the disk.

The source was also observed half a year after the outburst and was probably detected by the MPC. The radiation flux in the 1.2–10 keV band in the quiescent state was $2.08(\pm 0.22) \times 10^{-11}$ ergs s^{-1} cm^{-2}, or some 440 times lower than the maximum persistent flux value observed during the outburst.

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

I. INTRODUCTION

The broad class of Galactic X-ray sources commonly called low-mass X-ray binaries (LMXRBs) is well distinguished from the massive X-ray binaries (for a review, see Lewin and Joss 1981, 1983). Several of the LMXRBs are X-ray transients, and observations of two transient sources, Cen X-4 and Aql X-1, provided the first definitive proof that some LMXRBs are in fact binary systems containing low-mass companions. This was based on observations of the optical counterparts of Cen X-4 and Aql X-1. During transient X-ray outbursts, the optical counterparts of these sources are relatively bright and exhibit spectral features typical of accretion disks, whereas during intervals of low (generally undetectable) X-ray emission they are several magnitudes fainter, and their spectra are typical of K-type main-sequence stars (Thorstensen, Charles, and Bowyer 1978; Canizares, McClintock, and Grindlay 1979; Charles *et al.* 1980; van Paradijs *et al.* 1980).

Presumably most LMXRBs are systems containing accreting old neutron stars with low magnetic fields ($B \lesssim 10^9$ G). Physical processes occurring in the vicinity of non magnetized accreting neutron stars are still not very well understood. A recent review of the properties of persistent emission is given by White and Mason (1985). Spectral shapes and variability may indicate the presence of three components in X-ray emitting regions of LMRXBs: an accretion disk, a neutron star (or a boundary layer). and a hot corona. A model consisting of a soft, multicolor component (representing the radiation of the accretion disk) and of a hard, blackbody component (emitted by the boundary layer) was successfully fitted to the data of several LMXRBs by Mitsuda *et al.* (1984). Spectra of several other sources were fitted by a power law which suggests that in those systems the Comptonization by a hot corona may be important (White and Mason 1985). However, models used so far to interpret the observed data were rather ad hoc parameterizations of the spectrum and were not self-consistent from the theoretical point of view. The first self-consistent two-component model spectrum with well-defined physical assumptions was presented by Czerny, Czerny, and Grindlay (1986, hereafter Paper I). Contrary to models of Mitsuda *et al.* (1984), it gives accretion rates in LMXRBs in agreement with our present knowledge of those systems.

In § II we present the *Einstein* observations of persistent emission from Aql X-1 during its outburst in 1979 March–April. We apply our two-component model, together with other spectral fits, to interpret the observed spectra. Fits to the two-component model favor a low optical depth (scattering) in the corona (negligible Comptonization effect), small inclination angle of the system, and give a maximum value of $\sim 10^{-9}$ $M_\odot$ yr^{-1} for the accretion rate during the outburst.

Einstein recorded two unusual bursts from Aql X-1. Both showed spectral softening during their decay, which is typical for type I bursts, but the spectra were systematically broader than blackbody spectra. They also showed enhanced emission after the bursts. It was especially prominent for the first burst recorded, when the number of photon counts per second recorded $\sim$2500 s after burst maximum still exceeded the number of photon counts per second before the onset of the burst by a factor of $\sim$25%. We discuss these bursts in § III, and we use our two-component model to show that the enhanced emission is very probably caused by an increased accretion rate in the disk.

One of the most important questions concerning transient sources is the actual ratio of emission in high and low states. In § IV we describe the probable measurement of emission from Aql X-1 made by the *Einstein* satellite approximately half a

[1] On leave from Warsaw University Observatory, Warsaw.
[2] On leave from N. Copernicus Astronomical Center, Warsaw.

year after its outburst. Finally, in § V we summarize and discuss our results.

II. THE PERSISTENT EMISSION OF AQUILA X-1 DURING ITS 1979 MARCH–APRIL OUTBURST

Aql X-1 exhibits X-ray outbursts that last ~ 1 month, typically once a year (e.g., Kaluzienski *et al.* 1977; Charles *et al.* 1980). This source was observed several times by the Monitor Proportional Counter (MPC) on board the *Einstein* satellite during its outburst in 1979 March–April. (For a description of the MPC see Grindlay *et al.* 1980.) The observed flux was decreasing during the period covered by our observations, with the highest value $F(1.2\text{–}10 \text{ keV}) \approx 9.2 \times 10^{-9}$ ergs cm^{-2} s^{-1}, recorded on March 31. The source was then about 20% weaker than the maximum observed luminosity for this outburst, as can be estimated approximately from the observations of Holt and Kaluzienski (1979). They observed Aql X-1 with the *Ariel 5* satellite on March 26 and 27, when the flux was ~ 0.5 Crab in the 3–6 keV band, whereas from *Einstein* observations on March 31 the flux can be estimated as ~ 0.4 Crab in the same energy band. The 1979 March–April outburst was much weaker than the one observed in 1978 June–July–August, when the flux in the 2–10 keV band reached a maximum of 2.2×10^{-8} ergs cm^{-2} s^{-1} (Charles *et al.* 1980), or about ~ 1.3 Crab.

The X-ray light curve of Aql X-1 as recorded by the *Einstein* MPC is presented in Figure 1 and Table 1. Apart from two bursts, the observed flux was highly constant on the time scale of $\sim 10^3$ s. Changes of the emission level within an accuracy of a few percent were recorded during single observations, which lasted typically $1\text{–}3 \times 10^3$ s.

We made fits of standard theoretical spectra (i.e., power law, thermal bremsstrahlung, and blackbody) to the persistent (nonburst) emission of Aql X-1 as observed in all eight PHA channels (1.2–20.0 keV) of the MPC instrument. Power-law and blackbody spectra usually gave very bad fits (except at the very end of the outburst—see below). In most cases (in eight out of 10 observations) the observed emission was well fitted by a simple bremsstrahlung model, as shown in Table 1. The table gives the time of the observation, the effective integration time, the observed flux in 1.2–20 keV band (together with the 1 σ error), the bremsstrahlung temperature in keV (with 90% confidence error), and the reduced values of χ^2 (for 5 d.o.f.).

We also made fits of our theoretical spectra of LMXRBs, as

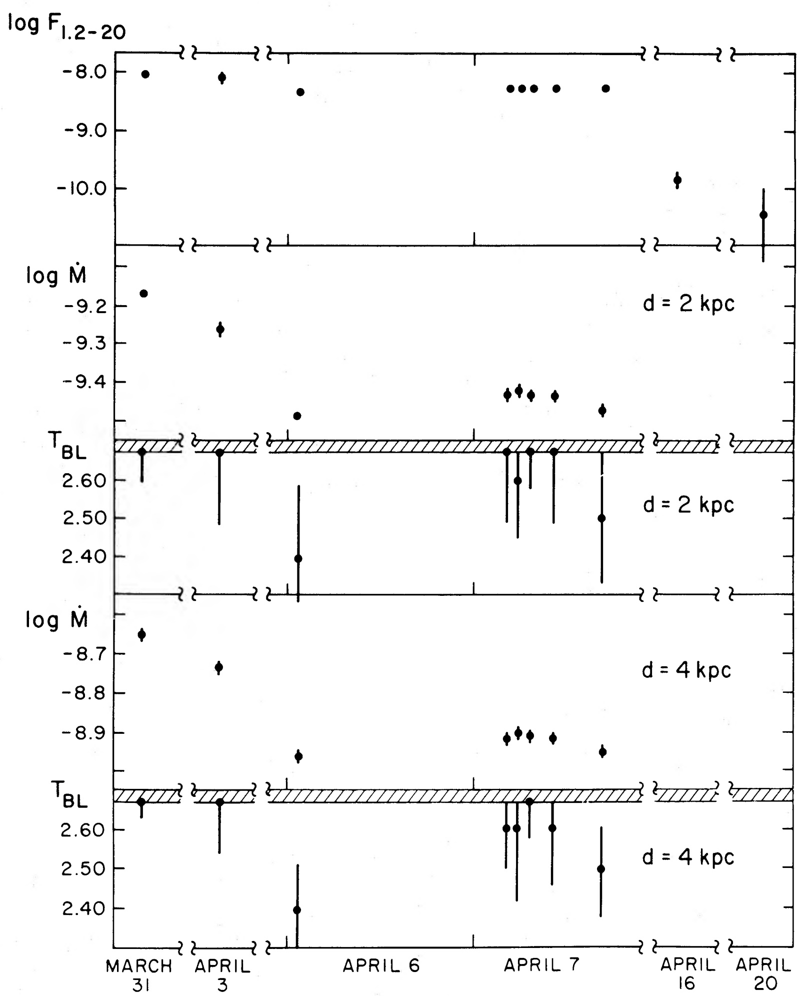

FIG. 1.—X-ray light curve of Aql X-1 during its outburst in 1979 March–April. The radiation flux is given in the 1.2–20 keV band (from eight channels of the *Einstein* MPC instrument) in ergs cm^{-2} s^{-1}. The values of accretion rates $\dot{M}$ (in solar masses per year) and values of the boundary layer temperature T_{BL} (in keV) result from fitting to our theoretical model for an adopted distance to the source of 2 kpc and 4 kpc, respectively. The values of temperature above 2.67 keV were not permitted by the model because of the Eddington limit. The errors in flux are 1 σ, whereas other errors represent the 90% confidence level.

TABLE 1

MODEL PARAMETERS FOR AQUILA X-1 OBSERVATIONS

Time of Observation (1979)	Integration Time (s)	$F_{1.2-20\ \mathrm{keV}}$	kT_{BREM}	χ^2_{red}	$d = 2$ kpc			$d = 4$ kpc		
					$\log \dot{M}$	kT_{BL}	χ^2_{red}	$\log \dot{M}$	kT_{BL}	χ^2_{red}
Mar 31; 00:40–01:38......	2575.36	$1.04(\pm 0.05) \times 10^{-8}$	$5.74^{+0.17}_{-0.35}$	4.34	$-9.165^{+0.010}_{-0.011}$	$2.67_{-0.07}$	1.34	$-8.645^{+0.010}_{-0.013}$	$2.67_{-0.03}$	2.30
Apr 3; 22:14–22:15......	40.96	$8.50(\pm 0.46) \times 10^{-9}$	$5.74^{+0.41}_{-0.46}$	0.46	$-9.260^{+0.020}_{-0.018}$	$2.67_{-0.18}$	0.94	$-8.730^{+0.013}_{-0.016}$	$2.67_{-0.13}$	0.56
Apr 6; 00:57–01:31......	998.40	$5.10(\pm 0.27) \times 10^{-9}$	$4.86^{+0.16}_{-0.28}$	0.41	$-9.480^{+0.011}_{-0.012}$	$2.40^{+0.19}_{-0.07}$	2.52	$-8.960^{+0.013}_{-0.016}$	$2.40^{+0.12}_{-0.03}$	2.44
Apr 7; 03:58–04:26......	445.44	$5.60(\pm 0.30) \times 10^{-9}$	$5.43^{+0.34}_{-0.32}$	0.18	$-9.430^{+0.009}_{-0.023}$	$2.67_{-0.18}$	1.58	$-8.920^{+0.015}_{-0.010}$	$2.60^{+0.07}_{-0.10}$	1.46
Apr 7; 05:43–06:01......	353.28	$5.71(\pm 0.30) \times 10^{-9}$	$5.14^{+0.38}_{-0.12}$	1.01	$-9.420^{+0.012}_{-0.015}$	$2.60^{+0.07}_{-0.15}$	1.16	$-8.905^{+0.017}_{-0.012}$	$2.60^{+0.07}_{-0.18}$	0.94
Apr 7; 06:59–07:36......	532.48	$5.67(\pm 0.30) \times 10^{-9}$	$5.74^{+0.38}_{-0.32}$	0.06	$-9.430^{+0.080}_{-0.014}$	$2.67_{-0.10}$	2.72	$-8.910^{+0.010}_{-0.018}$	$2.67_{-0.09}$	2.34
Apr 7; 10:12–10:46......	655.36	$5.54(\pm 0.29) \times 10^{-9}$	$5.43^{+0.13}_{-0.40}$	0.29	$-9.435^{+0.011}_{-0.020}$	$2.67_{-0.18}$	1.92	$-8.920^{+0.011}_{-0.012}$	$2.60^{+0.07}_{-0.14}$	2.14
Apr 16; 16:39–16:54......	778.24	$5.11(\pm 0.27) \times 10^{-9}$	$4.86^{+0.32}_{-0.12}$	2.48	$-9.470^{+0.016}_{-0.011}$	$2.50^{+0.17}_{-0.17}$	2.36	$-8.955^{+0.018}_{-0.008}$	$2.50^{+0.10}_{-0.12}$	2.14
Apr 16; 12:29–14:50......	3156.48	$1.44(\pm 0.27) \times 10^{-10}$	$3.68^{+0.44}_{-0.44}$	10.10	$-10.910^{+0.055}_{-0.047}$	$2.20^{+0.47}_{-0.30}$	1.98	...	...	...
Apr 20; 23:18–00:44......	1387.52	$3.47(\pm 2.88) \times 10^{-11}$	$1.15^{+0.57}_{-0.44}$	0.35	...	...	...	...	...	...

described in Paper I. This model assumes that the spectrum is the sum of two components. One component is the spectrum of the boundary layer, which has a blackbody shape but with the color temperature higher than the effective temperature due to the dominant role of electron scattering as the opacity source (van Paradijs 1982; Czerny and Sztajno 1983; London, Taam, and Howard 1984; Ebisuzaki, Hanawa, and Sugimoto 1984). Following Ebisuzaki, Hanawa, and Sugimoto (1984) we assume that the ratio of color and effective temperatures is equal to 1.4. The relation between the accretion rate and the temperature at the surface of the boundary layer is determined by the energy balance. The second component is the spectrum of the optically thick stationary accretion disk which extends to the surface of the neutron star. The disk is illuminated by the boundary layer and its emitted spectrum is the sum of blackbody spectra with different temperatures determined by the irradiating and intrinsic fluxes. The free parameters of our model are: the mass M and the radius R of the neutron star, the color temperature of the boundary layer T_{BL}, the accretion rate $\dot{M}$, the inclination angle of the system i, the distance to the source d, and the absorption to the source expressed in terms of the hydrogen column density N_{H}. A detailed description of the model is presented in Paper I.

The assumption of stationarity in modeling the disk spectrum (i.e., $\dot{M}$ = constant throughout the disk) requires additional comment since we are dealing with an outburst. The X-ray spectrum originates in the innermost parts of the disk, $r \lesssim 4 \times 10^7$ cm, where the characteristic viscous time scale (see Pringle 1981 for a definition) is $\sim 4 \times 10^3$ times shorter than for the entire disk ($r \approx 10^{10}$ cm). Therefore the accretion rate in the inner parts of the disk adjusts immediately to the slow changes in the outer disk regions. The typical duration of a single observation (a few hundreds of s) is of course much shorter than those long-term changes ($\sim$days), and the steady state approximation is valid.

In order to reduce the number of free parameters we fixed the mass and the radius of the neutron star at values 1.4 $M_\odot$ and 3 gravitational radii (i.e., 12.5 km), respectively. We performed computations for two assumed distances to the source, 2 and 4 kpc, which are close to the extreme values permitted by the optical brightness of Aql X-1 during quiescence, provided the companion is a main-sequence star (Thorstensen, Charles, and Bower 1978). The computations were made in two steps. In the first step we fitted four parameters ($\dot{M}$, T_{BL}, N_{H}, cos i) to all observations apart from those which contained bursts. The best fits (smallest values of χ^2) were obtained for values of cos i in the range 0.77–0.90. The best fit of cos i for all the data was calculated by summation of χ^2 distributions for all time sequences. The obtained values for cos i are 0.834 ± 0.009 ($d = 2$ kpc) and 0.839 ± 0.007 ($d = 4$ kpc) with errors calculated as $\chi^2_{\mathrm{min}} + 2.7$ (90% confidence level for one interesting parameter; Avni 1976).

Unless Aql X-1 is a three-body system (which is quite possible for LMXRBs that have their origin in globular clusters; Grindlay 1985), its inclination should be constant. Therefore we fixed the value of cos i at 0.8375 (i.e., $i \approx 33°$) and repeated our computations. This leaves three free parameters: $\dot{M}$, T_{BL}, and N_{H}, i.e., 5 degrees of freedom. The results are presented in Figure 1 and Table 1. Table 1 also gives the values of logarithm of accretion rate in $M_\odot$ yr^{-1}, the color temperature of the boundary layer in keV (errors are 90% confidence), and the reduced values of χ^2 for both adopted distances. Note that the temperature of the boundary layer is given for an observer placed on the neutron star surface and should be divided by the redshift factor $1 + z$ (which is equal to 1.225 for our set of neutron star parameters) to obtain the value measured near Earth. We also did not allow T_{BL} to exceed the value 2.67 keV, which is the Eddington limit value of the color temperature of the boundary layer as required by our assumptions (see Paper I for details).

Since the luminosity of the source calculated from the model depends mainly on the accretion rate, there is nearly a linear dependence between $\dot{M}$ and the observed flux (Fig. 2). The character of the relation between T_{BL} and $\dot{M}$ is much less obvious. It seems that the temperature of the boundary layer has its highest possible value for an accretion rate higher than 5.5×10^{-10} $M_\odot$ yr^{-1} ($d = 2$ kpc) or 1.1×10^{-9} $M_\odot$ yr^{-1} ($d = 4$ kpc) and drops down for smaller values of $\dot{M}$. This effect can be also seen directly when the hardness ratio, defined as the ratio of the count rate recorded in the 4.9–10 keV band to the count rate recorded in the 2.4–4.9 keV band, which is plotted versus the logarithm of accretion rate (Fig. 3). Similar behavior was observed for the source in the globular cluster NGC 1851 (Paper I) and for many other Galactic bulge sources. Unfortunately, a lack of data for lower values of the luminosity and the unknown distance to Aql X-1 does not allow us to test for transitions in the structure of the boundary layer as a function of the accretion rate. For higher accretion rates, the boundary layer can possibly be described as proposed by Fujimoto and Hoshi (1985). Comparison of our fitted

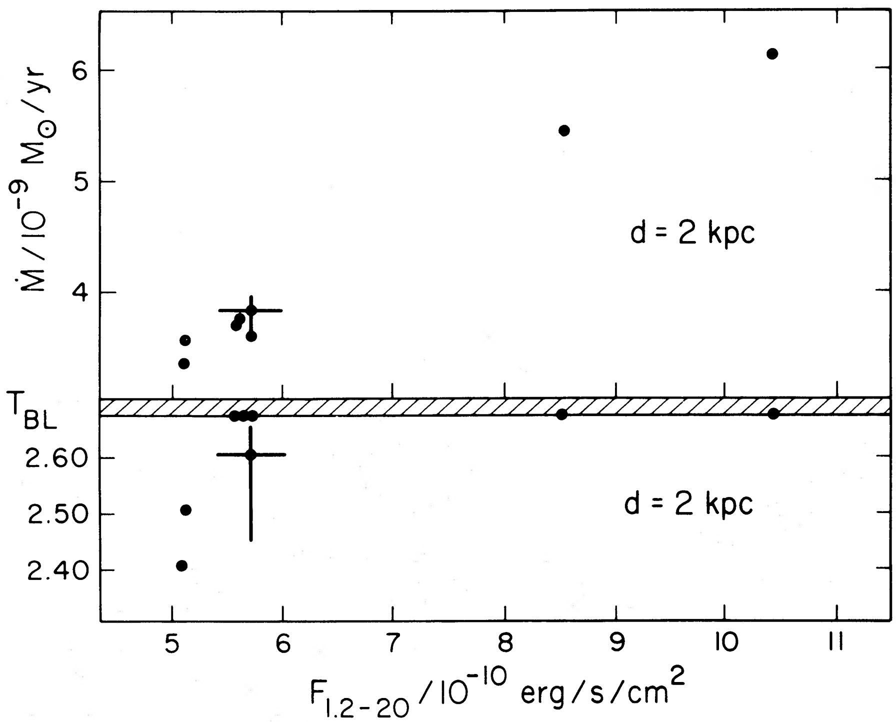

FIG. 2.—Accretion rate $\dot{M}$ and boundary layer temperature T_{BL} as a function of X-ray flux in 1.2–20 keV band for adopted value of distance 2 kpc. The relation between $\dot{M}$ and $F_{1.2-20}$ is almost linear. The value of T_{BL} is always consistent with the highest possible value (2.67 keV) for $F_{1.2-20} > 5.3 < 10^{-10}$ ergs s^{-1} cm^{-2} and seems to decrease rapidly below this value. Error bars represent the 90% confidence level.

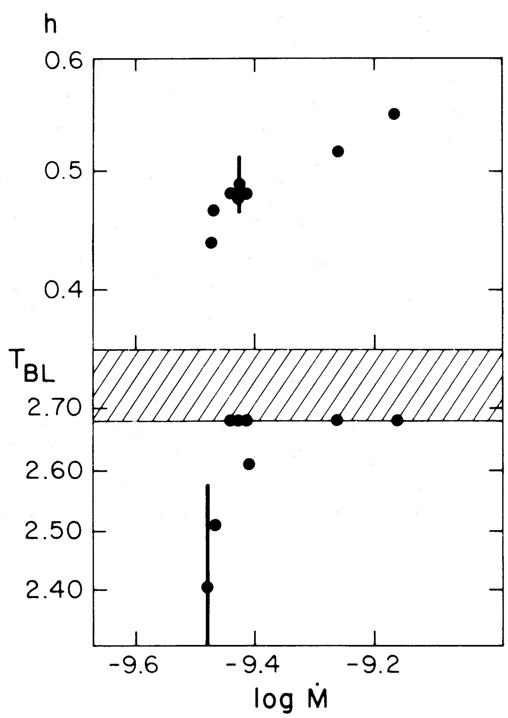

FIG. 3.—The hardness ratio h (defined as counts in the 4.9–10.2 keV band divided by counts in the 2.4–2.9 keV band) and the boundary layer temperature (defined on the neutron star surface) plotted vs. the accretion rate in solar masses per year for an assumed distance $d = 2$ kpc to the source. The temperature seems to decrease for accretion rates smaller than 3.5×10^{10} $M_\odot$ yr^{-1}. Error bars represent the 90% confidence level.

value of T_{BL} equal to 2.67 keV with their predictions somewhat favors the larger value of the distance to Aql X-1 ($d = 4$ kpc, i.e., $\dot{M} \approx 1.5 \times 10^{-9}$ $\dot{M}_\odot$ yr^{-1}). However, since Fujimoto and Hoshi (1985) did not take into account the relativistic corrections and used a slightly different neutron star radius (10 km), such a comparison cannot be conclusive.

The fitted values of N_H lie in the range of (1×10^{21})–(6×10^{21}) ($d = 2$ kpc) and (2×10^{21})–(6×10^{21}) ($d = 4$ kpc) and are higher for the first two observations (i.e., on March 31 and April 3) than for others. These values are consistent with the estimated reddening of the optical counterpart of Aql X-1 (Thorstensen, Charles, and Bowyer 1978).

Finally, we discuss the observations at the end of the outburst. By April 16 the source had decayed to only ~ 1.4% of its flux during the first *Einstein* observation. Fits to our model yielded $\dot{M} = 1.1 \times 10^{-11}$ $M_\odot$ yr^{-1}, $T_{BL} = 2.2$ keV, and $N_H = 4 \times 10^{21}$ ($d = 2$ kpc). The fits were acceptable, but such a low accretion rate is probably beyond the range of applicability of our model. The standard analysis gave a very bad fit to bremsstrahlung spectra, and much better ($\chi^2_{red} = 2.64$) to power law, with the energy index equal to 1.3. On April 20, Aql X-1 was already very weak, with flux only ~ 0.3% of that on March 31. The spectrum was extremely soft, but the small number of recorded counts makes it impossible to precisely determine its shape. Fits to power-law, bremsstrahlung, and blackbody spectra were acceptable, and the best parameters obtained were energy index equal to $2.8^{+1.9}_{-0.8}$ for power law, $kT = 1.15^{+0.57}_{-0.44}$ keV for bremsstrahlung, and $kT = 0.43^{+0.09}_{-0.07}$ keV for blackbody (errors represent 90% confidence). It is possible that there was a high energy excess present in the spectrum, because the flux in the energy range 1.2–10 keV was only $1.41(\pm 0.31) \times 10^{-11}$ ergs s^{-1} cm^{-2} compared to the formally calculated flux in the 1.2–20 keV band which was

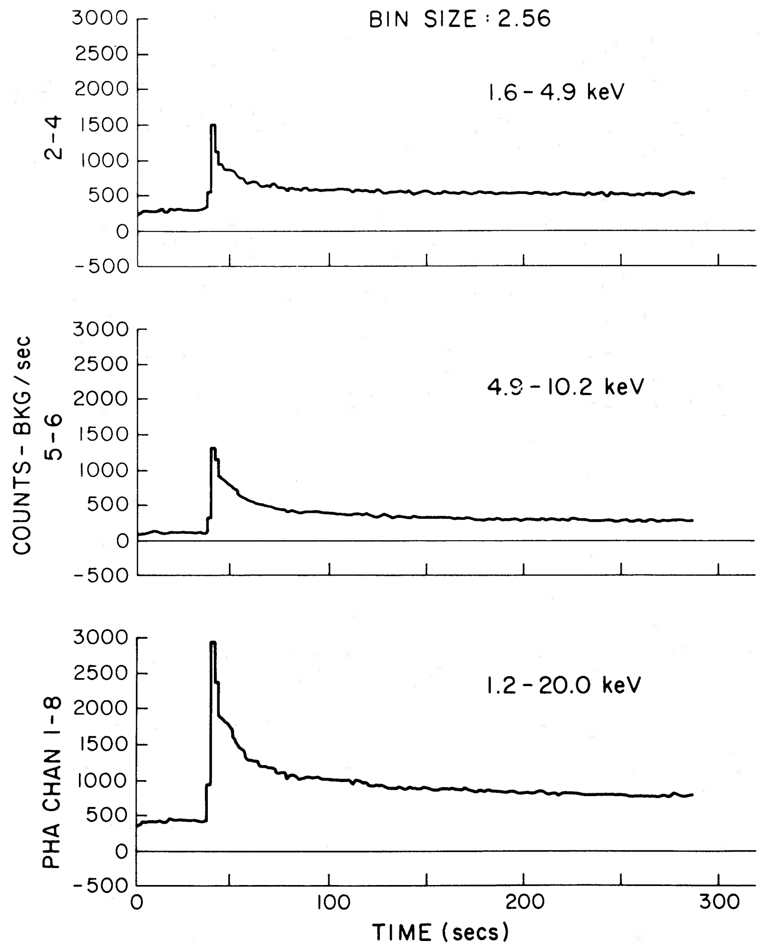

FIG. 4*a*

FIG. 4.—The light curves of burst 1 (*a*) and 2 (*b*) (see text for burst times and parameters)

$3.47(\pm 2.87) \times 10^{-11}$ ergs s^{-1} cm^{-2} (here quoted errors represent 1 σ level). However, the errors in channels 7 and 8 of the MPC instrument, which cover the energy range 10–20 keV, are large so that we cannot make any definitive statement. Quite probably on April 20, Aql X-1 attained the state of its minimum X-ray luminosity (see § IV).

III. BURSTS

During the 1979 March–April outburst of Aql X-1 two type 1 X-ray bursts were recorded by the MPC. The first occurred on April 3 when the persistent emission was still high ($F_{1.2-20.0\,\mathrm{keV}} = 8.5 \times 10^{-9}$ ergs cm^{-2} s^{-1}). The other one was observed 4 days later (April 7) when the persistent emission was 40% weaker. The peak luminosities were similar in both cases ($7.4[\pm 0.4] \times 10^{-8}$ ergs cm^{-2} s^{-1} and 7.5 ± 0.5 ergs cm^{-2} s^{-1} in the 1.2–20 keV band, respectively; persisitent emission not subtracted). These fluxes are approximately the same as for bursts observed by *Hakucho* during the 1980 May outburst (Koyama *et al.* 1981). The burst profiles are shown in Figure 4. As can be seen from Figure 4 the first burst exhibited an extremely long tail. At $\sim$2500 s after the burst maximum (and the end of this *Einstein* observation) the total count rate was still some 25% higher than before the burst. The spectrum was softer after the burst than before. Only a very small increase in the total count rate was observed $\sim$500 s after the second burst. However there was a spectral hardening in the persistent emission after the second burst which caused the energy flux in the 1.2–20 keV band to be higher after this burst than before it. This effect is discussed in more detail at the end of this section.

The total energy released during the first 40.96 s of the bursts in the 1.2–20 keV band, calculated after subtracting the persistent emission, was $\sim 1.2 \times 10^{-6}$ and $\sim 7.7 \times 10^{-7}$ ergs cm^{-2}, respectively. This result is independent of the method of subtraction of the persistent emission, i.e., whether level of the persistent emission is determined before or after the burst.

The χ^2 values of spectral fits to the data recorded in the first few (2.56 s) bins of both bursts were unacceptable for any standard spectrum, i.e., blackbody, power-law, or bremsstrahlung. This was probably caused mainly by the relatively long (2.56 s) integration time when compared to the time scale for changes of the conditions at the neutron star surface near the burst maximum. For the remaining bins, the values of χ^2_{red} were acceptable for blackbody fits. The obtained values of the temperature and the normalization constant were the same within their errors whether we subtracted the persistent emission before or after the bursts, with somewhat better values of χ^2_{red} in the latter case.

The properties of both bursts are summarized in Tables 2 and 3. The persistent emission as determined after the bursts

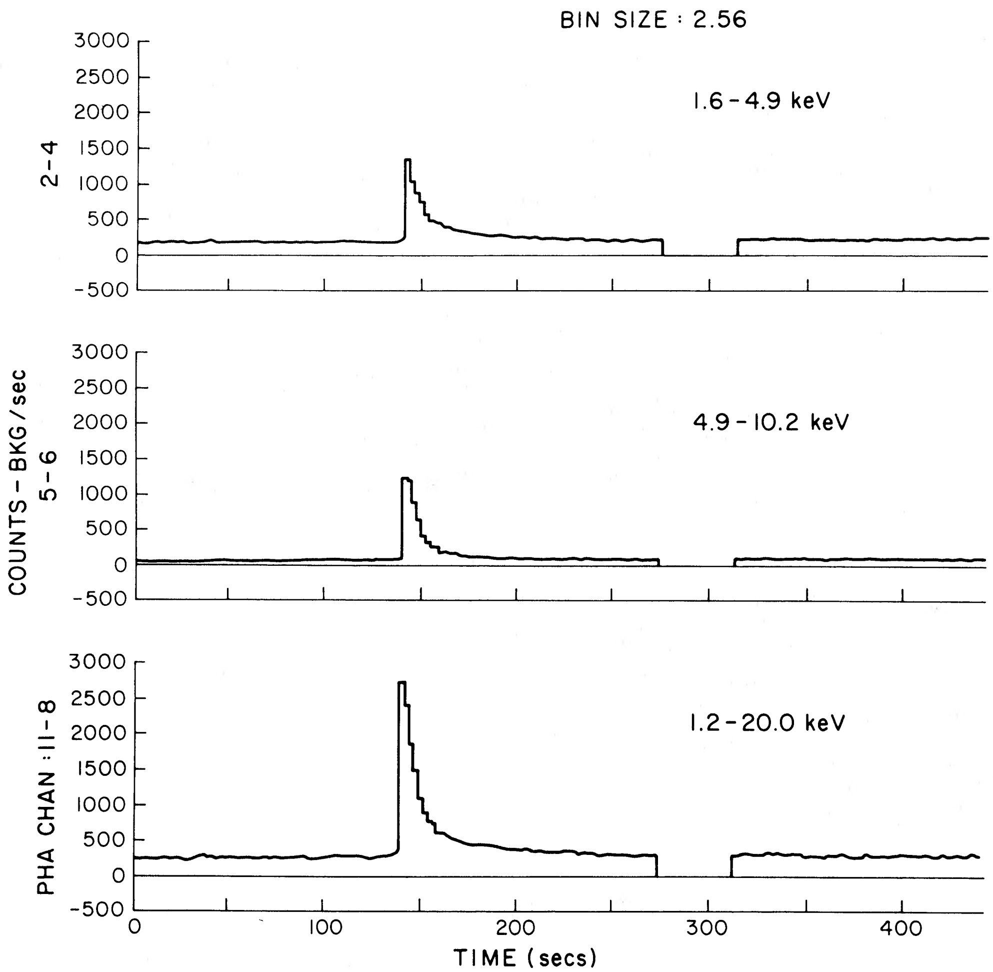

FIG. 4b

TABLE 2

DERIVED PROPERTIES OF BURST 1

Bin Number	kT (keV)	$\chi^2_{\rm red}$	C	$F_{1.2-20.0} \times 10^8$	$f(1+\zeta)$
1	2.02 ± 0.17	2.68	0.06	1.34 ± 0.11	0.08 ± 0.02
2	1.95 ± 0.08	7.16	0.40	6.53 ± 0.39	0.39 ± 0.05
3	2.38 ± 0.10	0.76	0.17	5.93 ± 0.37	0.25 ± 0.02
4	2.26 ± 0.10	0.34	0.15	4.20 ± 0.26	0.16 ± 0.01
5	2.26 ± 0.10	1.32	0.14	3.73 ± 0.24	0.15 ± 0.01
6	2.17 ± 0.10	0.70	0.14	3.43 ± 0.22	0.16 ± 0.02
7	2.20 ± 0.10	1.96	0.13	3.37 ± 0.22	0.12 ± 0.01
8	2.06 ± 0.11	0.58	0.13	2.53 ± 0.17	0.14 ± 0.02
9	2.13 ± 0.11	1.72	0.12	2.52 ± 0.17	0.12 ± 0.01
10	2.02 ± 0.10	2.18	0.12	2.06 ± 0.14	0.12 ± 0.01
11	2.06 ± 0.12	0.56	0.11	2.13 ± 0.15	0.11 ± 0.02
12	2.06 ± 0.11	1.00	0.11	2.05 ± 0.14	0.11 ± 0.02
13	2.10 ± 0.13	1.58	0.10	1.87 ± 0.14	0.10 ± 0.02
14	2.01 ± 0.13	0.32	0.11	1.80 ± 0.13	0.10 ± 0.02
15	1.08 ± 0.13	0.64	0.09	1.86 ± 0.13	0.10 ± 0.02
16	1.92 ± 0.12	0.62	0.12	1.71 ± 0.12	0.11 ± 0.02

TABLE 3

DERIVED PROPERTIES OF BURST 2

Bin Number	kT (keV)	$\chi^2_{\rm red}$	C	$F_{1.2-20.0} \times 10^8$	$f(1+\zeta)$
1	0.80 ± 0.56	0.28	0.18	0.09 ± 0.05	0.04 ± 0.07
2	1.96 ± 0.07	7.70	0.40	$6{,}71 \pm 0.40$	0.41 ± 0.05
3	2.51 ± 0.08	2.22	0.16	6.97 ± 0.44	0.28 ± 0.02
4	2.32 ± 0.08	4.48	0.15	4.85 ± 0.30	0.20 ± 0.02
5	1.98 ± 0.08	0.48	0.18	2.97 ± 0.19	0.18 ± 0.02
6	1.82 ± 0.08	0.42	0.15	1.87 ± 0.13	0.14 ± 0.02
7	1.64 ± 0.08	1.86	0.16	1.31 ± 0.10	0.12 ± 0.02
8	1.59 ± 0.10	2.48	0.14	1.00 ± 0.08	0.11 ± 0.02
9	1.48 ± 0.09	0.92	0.17	0.89 ± 0.07	0.10 ± 0.02
10	1.19 ± 0.09	1.48	0.26	0.59 ± 0.06	0.15 ± 0.04
11	1.29 ± 0.12	1.06	0.20	0.64 ± 0.07	0.13 ± 0.04
12	1.27 ± 0.10	0.60	0.17	0.50 ± 0.06	0.10 ± 0.03
13	1.36 ± 0.15	0.48	0.12	0.43 ± 0.06	0.07 ± 0.03
14	1.11 ± 0.14	0.36	0.24	0.36 ± 0.05	0.11 ± 0.05
15	1.10 ± 0.13	0.48	0.20	0.32 ± 0.05	0.10 ± 0.05
16	0.95 ± 0.14	6.80	0.36	0.28 ± 0.04	0.13 ± 0.08

was subtracted. The columns of the tables show the bin number (1 bin = 2.56 s), the color temperature in keV, the reduced value of χ^2 (5 d.o.f.), the normalization constant in keV cm^{-2} keV^{-1}, the observed flux in the 1.2–20 keV band, and the radiating fraction of the neutron star surface combined with the correction for reflection of radiation by the disk. The latter quantity is given for the assumed distance of 2 kpc. There is an apparent difference between the bursts both in the luminosity profile and in the spectral changes. The peak luminosities in both bursts are comparable (the second burst is somewhat brighter), but the flux decreases more rapidly in the second burst. The blackbody temperature reached a higher value in the second burst, althouth ~ 10 s after the burst maximum it was already much below 2 keV, whereas in the first burst the temperature did not decrease as fast. This resulted in higher total energy of the first burst.

Despite the formal acceptability of the blackbody spectrum by the χ^2 test, the observed spectrum is systematically broader with an excess of photons at both high and (especially) low energies. This effect can be seen in Figure 5, where hardness versus softness ratios (both defined in the figure legend) are plotted. The observed points for both bursts are systematically on the right side of the line $N_H = 0$ computed for the blackbody spectrum. A similar effect was observed by Tawara *et al.* (1984) in the long bursts from GX 17+2. Note however that the other properties of bursts from Aql X-1 better resemble typical Type I bursts, with the peak luminosity ~ 8 times higher than the persistent emission. Slight departures of the spectrum from a blackbody shape are expected for type I bursts. The radiation of a very hot atmosphere of the accreting neutron star is not blackbody due to the domination of opacity by electron scattering (van Paradijs 1982; Czerny and Sztajno 1983; London, Taam, and Howard 1984; Ebisuzaki, Hanawa, and Sugimoto 1984) and can be treated as a blackbody only in the first approximation. In fact one can see from Figure 1 of London, Taam, and Howard (1984) that the Comptonized spectrum of the neutron star atmosphere is broader than that for a blackbody. Also, since even during bursts the distribution of the nuclear burning matter does not need to be spherically symmetric (Balucinska and Czerny 1985), allowing for the temperature gradient on the surface of the neutron star, we may expect some broadening of the spectrum. Some part of the

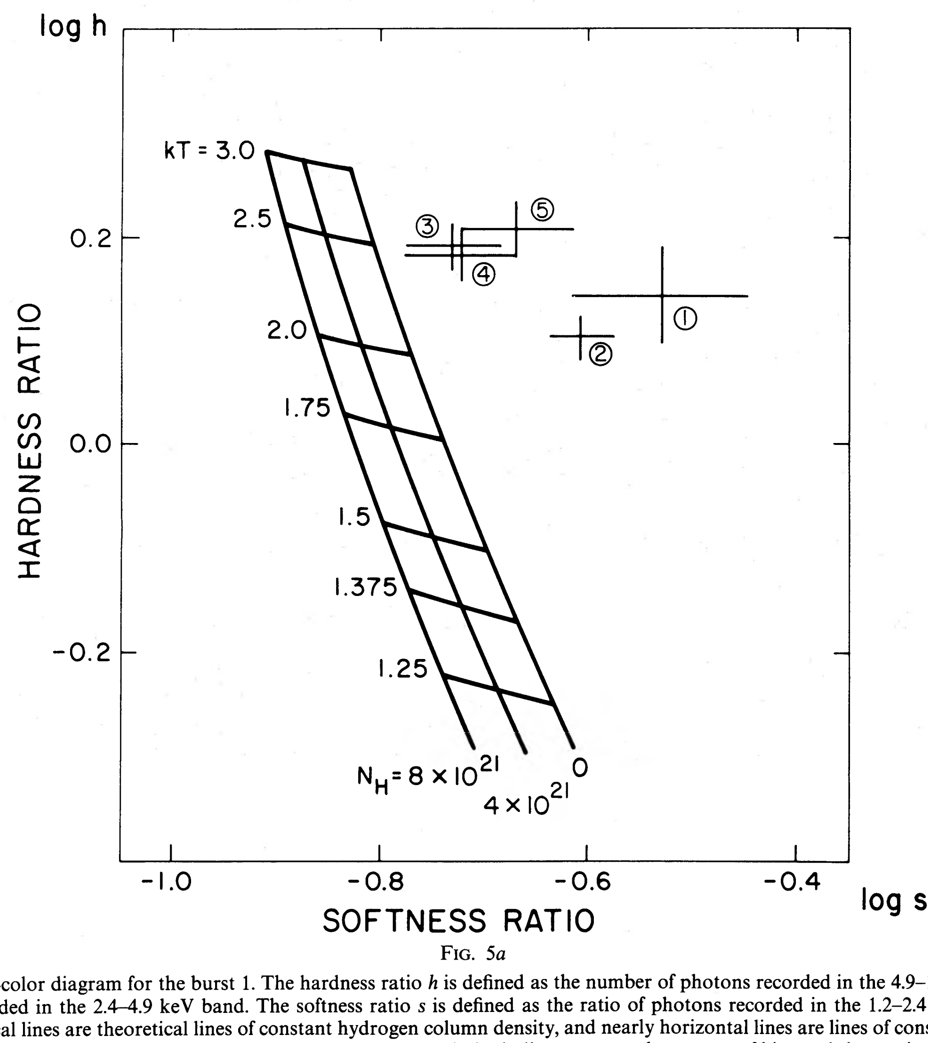

FIG. 5*a*

FIG. 5.—(*a*) The color-color diagram for the burst 1. The hardness ratio *h* is defined as the number of photons recorded in the 4.9–10.2 keV band divided by the number of photons recorded in the 2.4–4.9 keV band. The softness ratio *s* is defined as the ratio of photons recorded in the 1.2–2.4 keV and 2.4–4.9 keV bands, respectively. Nearly vertical lines are theoretical lines of constant hydrogen column density, and nearly horizontal lines are lines of constant blackbody temperature. Each cross represents one 2.56 s bin of observations of the burst. Numbers in circles indicate temporal sequence of bins and the persistent emission is subtracted. (*b*) Same as (*a*) but for burst 2.

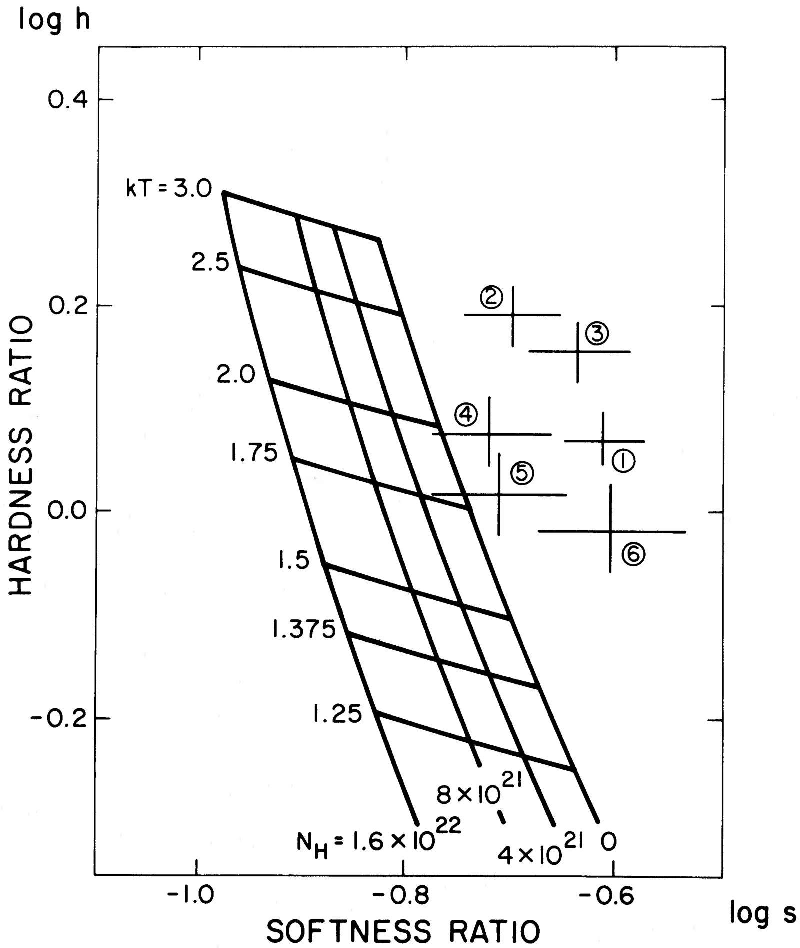

FIG. 5b

broadening can also be caused by scattering of the photons by the disk even if the scattering is mostly elastic (Lapidus and Sunyaev 1985).

An interesting question is what portion of the neutron star surface undergoes the thermonuclear flash during bursts. The estimation of the radiating area should be made very carefully. The effects which may influence the result are the departure of the observed spectrum from the blackbody shape, the dependence of the color versus effective temperature relation on the gravity and the chemical composition (London, Howard, and Taam 1984), and the increase of the observed flux by the scattering of photons from the disk surface (Lapidus and Sunyaev 1985; Paper I). During the course of our computations we neglected the first effect, in spite of the apparent differences between the observed and the blackbody spectra (see above). Some estimate of the error introduced can be obtained by the comparison of the values of the flux obtained in the 1.2–20 keV band without referring to the spectral shape, and the total flux calculated using the normalization constant from the blackbody fit. During the first 16 time bins of both bursts, the differences were always less than 10% and typically about 5%.

The method we used of treating the influence of Comptonization resembles to some extent the method of Sztajno *et al.* (1985). In the consideration of the emission of the boundary layer in the previous section, we adopted the ratio of color and effective temperatures equal to 1.4 (Ebisuzaki, Hanawa, and Sugimoto 1984). The following discussion is based, however, on model calculations of neutron star atmospheres done by London, Taam, and Howard (1984). From Figure 2 of their paper we can estimate the effective temperature when the color temperature is known. We applied the results for the normal chemical composition and the gravitational acceleration $g = 10^{14}$ cm s^{-2}, which is close to the gravity of the neutron star adopted in § II ($M = 1.4\ M_{\odot}$, $R = 3r_g = 12.4$ km, $g = 1.46 \times 10^{14}$ cm s^{-2}).

The observed flux from the neutron star is related to its effective temperature defined at the stellar surface $T_{\rm eff}{}^*$ by the formula

$$F = f\left(\frac{R}{d}\right)^2 \frac{\sigma T_{\rm eff}{}^{*4}}{(1+z)^2}(1+\zeta) \qquad (1)$$

if a large part of the star radiates (see Paper I). Here d is the distance to the source, $1 + z$ is the redshift factor, and σ is the Stefan-Boltzmann constant. The parameter f measures the radiating fraction of the stellar surface as visible by an observer at a given inclination angle, and ζ is the reflection coefficient of the radiation by the disk. We computed the factor $f(1 + \zeta)$ as a function of observed parameters and the adopted model of the neutron star (see Table 2). This factor has a maximum value close to the peak of the luminosity and subsequently decreases to the value of ~ 0.1 ($d = 2$ kpc) or ~ 0.4 ($d = 4$ kpc). This means that if the larger value of the distance is correct, a significant part of the stellar surface is brightened during the burst. The maximum value of $f(1 + \zeta)$ for $d = 4$ kpc is however equal to 1.6. Because the reflection factor ζ cannot exceed 0.5 (Paper I) and is less when the inclination $i \neq 0$, this means that either the radius of the neutron star is greater than 12.4 km, or, more probably, the true distance to Aql X-1 is smaller.

The bursts observed from Aql X-1 by Koyama *et al.* (1981) were somewhat brighter, but when we applied our method to the maximum of their burst 2 ($F = 10^{-7}$ ergs s^{-1} cm^{-2}, $T = 2.3$ keV) we again obtained $f(1 + \zeta)$ equal to 0.4 ($d = 2$ kpc) or 1.6 ($d = 4$ kpc).

The surprising result of our calculations is that the difference in burst profiles and spectral behavior is not reflected in the behavior of $f(1 + \zeta)$. In both cases its value seems to decrease after the burst maximum at the same rate. Because the reflection factor ζ should not change if the radiating part of the neutron star surface is fixed, it seems that the emitting area of the neutron star is decreasing. A decrease of radiating surface area after burst maximum was suggested by Balucinska and Czerny (1985) for the source Ser X-1. In our discussion of behavior of the quantity $f(1 + \zeta)$ during the burst, we neglected scattering of the emitted radiation in the accretion disk corona. A strong nonspherical corona may form in the course of the burst and cause additional anistropy of the emerging radiation flux.

Apart from the properties of the bursts near their maxima we also studied their tails especially because of the difference in their apparent behavior. This requires a careful discussion of the persistent emission. The persistent emission flux in the 1.2–20 keV band just before the first burst calculated from a 40.96 s interval of data was 8.50×10^{-9} ergs cm^{-2} s^{-1}, and the flux 1880 s after the burst maximum integrated over 409.6 s was 9.12×10^{-9} ergs cm^{-2} s^{-1}. The persistent flux before the second burst (778.24 s data set) was equal to 5.12×10^{-9} ergs cm^{-2} s^{-1}, and 470 s after the burst maximum (end of the observation) was 5.49×10^{-9} ergs cm^{-2} s^{-1}, (204.8 s interval), i.e., $\sim 7\%$ higher. Therefore we see that in both cases the persistent emission after the burst was in fact higher than before. We can get a better comparison of these effects when we calculate the flux in the tail of the first burst also 550 s after the burst maximum. The value is 1.13×10^{-8} ergs cm^{-2} s^{-1}, i.e., the increase is 33%, much higher than after the second burst, which is in agreement with our intuition from Figure 4.

It seems very improbable that such extended tails are due to thermonuclear burning in the accreted envelope of the neutron star. Although in some models of Ayasli and Joss (1982) thermonuclear burning lasted over 100 s, it is hard to believe that this process can operate for over 2000 s. (For a recent review of a thermonuclear model of X-ray bursts, see Joss and Rappaport 1984.) Another explanation of extended emission after bursts can be an increased accretion rate. In order to check this possibility we applied our two-component model spectrum as described in § II. We chose this particular spectrum for the subsequent analysis, because in this model the value of the accretion rate is obtained directly from spectral fits. As before we adopted the inclination angle $\cos i = 0.8375$ and two values of the distance to the source: 2 and 4 kpc. The values of the accretion rate, the boundary layer temperature, and the hydrogen column density were obtained by fitting model spectra to the data.

The results as a function of time after the burst maxima are shown in Figure 6. In the second burst the accretion rate was 7% ($d = 2$ kpc) or 8% ($d = 4$ kpc) higher 370 s after the burst maximum than it was before the burst, and it was slowly decreasing. The change of the boundary layer temperature from 2.50 keV before to 2.67 keV after the burst was reflected in a relative shift of photons from lower to higher energy channels in the MPC instrument. Therefore the total count rate was only very slightly increased and is hard to see in Figure 4.

The results obtained for the tail of the first burst are more complex. The formally fitted accretion rate was higher by as much as 62% 330 s after the peak than before, but this value was obtained for $N_H = 1.0 \times 10^{22}$, which is much higher than $N_H = 4 \times 10^{21}$ just before and 2000 s after the burst. The results indicate slow decrease of both $\dot{M}$ and N_H (Fig. 6*a*). About 1880 s after the burst maximum, the value of hydrogen column density returned to its value before the burst, but the accretion rate was still 8% higher.

Fixing the value of N_H at the same level as before the burst we also obtained the enhancement of the accretion rate, although fits were far from being acceptable. The apparent change of the N_H value may be caused by an increase in the stellar wind from the accretion disk. Note that the N_H values at the beginning of the Aql X-1 outburst, when the apparent persistent X-ray luminosity was high, were also higher than at the end of the outburst (see § II). However this interpretation is not correct if the wind is Compton driven (Begelman, McKee, and Shields 1983) and the outflowing gas is fully ionized. Another explanation is that shortly after the burst the situation is not steady state, and the departures from stationarity are mimicked by the enhancement of the N_H value when we fit our model spectra to observational data.

Although the problems with the N_H value may introduce some additional errors to the obtained values of the accretion rate, they cannot remove the basic result of our analysis, i.e., the increase of the accretion rate after bursts. As far as we know this effect has not been observed previously. It is in contradiction of the predictions made by Livio and Regev (1985) in their discussion of the possible impact of bursts on the accretion rate. Livio and Regev (1985) predicted that the burst would decrease the accretion rate in the disk, as the inner parts of the disk would be disrupted by the burst. However, in making such considerations we must remember that in the case of disk accretion the effect is not so obvious as it may be for spherical accretion. The matter in the disk moves along approximately circular orbits, with nearly Keplerian values of the gravitational energy and the angular momentum. The matter in the disk may gain some energy from the burst but will not gain angular momentum. In the case of noninteracting particles, this effect will change the orbits from circular to elliptical, but in a real disk the pressure and viscosity act to circularize the orbits. The gain of energy from the burst may then manifest itself in increased thermal energy and turbulence in the disk. If the turbulence is the main source of viscosity, then the accretion rate may be increased. We cannot investigate this effect in more detailed way, because the proper discussion of the time-dependent behavior of an accretion disk is very difficult and unfortunately up to now has mainly been limited to outbursts of dwarf novae (e.g., Meyer and Meyer-Hoffmeister 1982; Smak 1982).

A similar conclusion can be found in the paper of Fukue (1982) who discussed the propagation of a shock-wave through the disk. He pointed out that even if the disk is disrupted by the burst it will be rebuilt again on the dynamical time scale of less than 10 s.

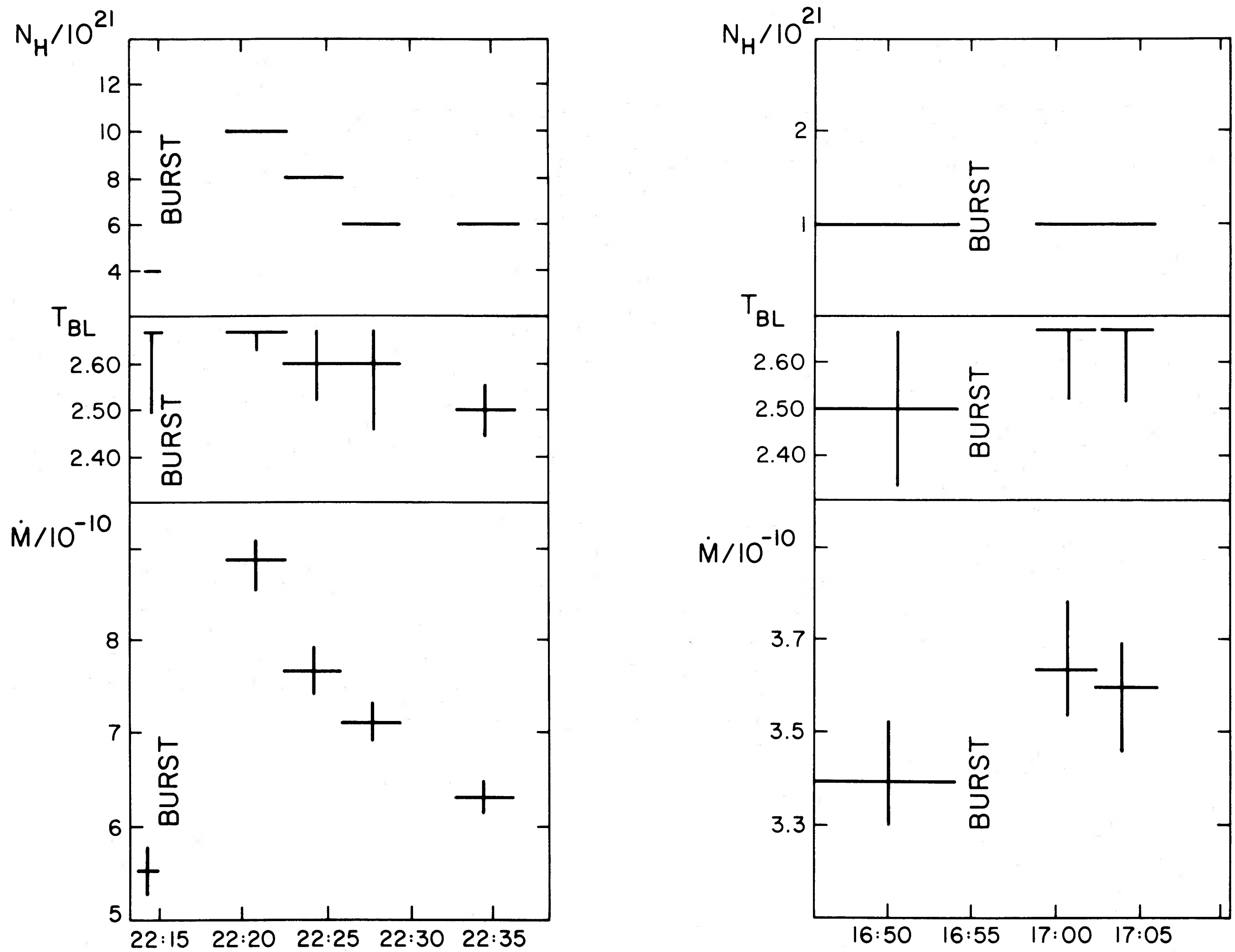

FIG. 6a FIG. 6b

FIG. 6.—The N_H value, the boundary layer temperature (in keV, defined on the neutron star surface) and the accretion rate before and after burst 1 (*a*) and burst 2 (*b*). The assumed distance is equal 2 kpc. Error bars represent the 90% confidence level.

IV. OBSERVATIONS OF AQUILA X-1 IN QUIESCENT STATE

Observations of Aql X-1 were made by the *Einstein* satellite on 1979 October 13, approximately half a year after the March–April outburst. Significant flux (at about the 10 σ level) was recorded by the MPC. Unfortunately, there was no imaging detector in the focal plane of the *Einstein* satellite during the observations, so we cannot be absolutely sure that the observed source was actually Aql X-1. However HRI observations during the outburst phase showed no other source within the 30′ HRI field of view suggesting that the source detected 6 months later by the MPC (within its somewhat larger 45′ field) is indeed Aql X-1 during quiescence.

The detected flux during the total of 9310.72 s of integration time was $2.08(\pm 0.22) \times 10^{11}$ ergs cm^{-2} s^{-1} in the 1.2–10 keV band and $5.59(\pm 2.34) \times 10^{-11}$ ergs cm^{-2} s^{-1} in the 1.2–20 keV band (the errors are 1 σ). These values are similar to those observed on April 20 at the end of the outburst. Also the spectrum is very soft, although not as soft as on April 20. The derived spectral parameters are energy index equal to $1.50^{+0.36}_{-0.26}$ for power law ($\chi^2_{\rm red} = 0.93$), and $kT = 2.79^{+1.15}_{-0.65}$ keV for bremsstrahlung ($\chi^2_{\rm red} = 2.08$), where the given errors represent 90% confidence. The blackbody fit was unacceptable, with $\chi^2_{\rm red} = 6.10$. The above similarities of both observations further strengthen the probability that the source observed on October 13 was indeed Aql X-1.

Comparison of formally calculated fluxes in 1.2–10 keV and 1.2–20 keV bands may again suggest an energy excess in hard X-rays, but the errors in the most energetic channels are too large to make this conclusion definitive.

Assuming that the X-ray emission during the quiescent state is spherically symmetric, we can derive the intrinsic luminosity of Aql X-1 to be $1.0(\pm 0.1) \times 10^{34} \times (d/2\ \text{kpc})$ ergs s^{-1} in 1.2–10 keV band and $2.7(\pm 1.1) \times 10^{34} \times (d/2\ \text{kpc})^2$ ergs s^{-1} in 1.2–20 keV band. These values are not corrected for interstellar absorption, which is, however, rather small (§ II). Assuming in turn that the X-ray emission is due to accretion only and that most of the energy goes in the 1.2–20 keV range we can find the accretion rate. The accretion luminosity $L_{\rm acc}$ seen from infinity is equal to $\dot{M}c^2 e_{\rm acc}$ (see, e.g., Czerny and Jaroszynski 1980), where $e_{\rm acc}$ is the efficiency of accretion equal to $1 - [1 - (r_g/R)]^{1/2}$, r_g is the gravitational radius, R is the radius of the neutron star, c is the speed of light, and $\dot{M}$ is the accretion rate.

The above expression may be formulated as

$$L_{\rm acc} = 1.04 \times 10^{34}\left(\frac{\dot{M}}{10^{-12}\ M_\odot\ {\rm yr}^{-1}}\right)\frac{e_{\rm acc}}{e_{\rm acc}(R = 3r_g)}\ {\rm ergs\ s}^{-1}\ . \tag{2}$$

It follows that the rate of accretion in Aql X-1 during the quiescent state should be of order 10^{-11} to 10^{-12} $M_\odot$ yr^{-1} for reasonable ranges of allowed distances to the source. Such an accretion rate may come from the remnants of the disk which developed during the outburst. Alternatively it may come from a fraction of a stellar wind produced by the secondary captured by the neutron star. If this fraction is or order of 10^{-3}, than the mass loss rate from the companion star should be of order 10^{-8} to 10^{-9} $M_\odot$ yr^{-1}. Such a stellar wind can be produced by the X-ray heating of the companion's surface (e.g., MacGregor and Vitello 1982), especially since the mass loss can be enhanced if the companion is close to filling the Roche lobe.

The X-ray luminosity of Aql X-1 derived in a quiescent state is typical for the most luminous of the population of weak X-ray sources recently discovered by Hertz and Grindlay (1983) in several globular clusters. Hertz and Grindlay (1983) suggested that these sources are primarily accreting white dwarfs and therefore their luminosity is at least 1.5 orders of magnitude less than the luminosity of strong globular cluster X-ray sources, which are accreting neutron stars. However, they also pointed out that some of these low-luminosity sources are probably neutron stars accreting at a low rate, since the transient source in NGC 6440 was detected in a low state. Our results for Aql X-1 also suggest that some of the weak globular cluster sources are in fact accreting neutron stars but observed in their low states (also proposed by Verbunt, van Paradijs, and Elson 1984). The possibility that some of the low-luminosity X-ray sources in globular clusters are transients is further strengthened by the observations of the source in Terzan 5. *Hakucho* discovered bursts from this source on 1980 August (Inoue *et al.* 1984), so probably its persistent emission during this period was at least 10^{36} ergs s^{-1}. On the other hand, *Einstein* observations gave only an upper limit equal to $10^{34.5}$ ergs s^{-1} (Hertz and Grindlay 1983). If the suggestion that some of the weak globular cluster X-ray sources are transients observed in low state is correct, then the number of LMXRBs in globular clusters may be somewhat greater than the 10 mentioned by Grindlay (1985), though this figure included Terzan 5.

V. SUMMARY AND DISCUSSION

The 1979 March–April outburst of Aql X-1 provided a good opportunity to study physical processes in LMXRBs. We used the MPC data to test the two-component model of X-ray spectrum of LMXRBs described in Paper I. Numerical fits were acceptable; however, we must stress that this does not mean that our model may be regarded as the unique interpretation of the observed spectrum since simple bremsstrahlung fits were usually also good (or even better). As pointed out in Paper I, the similarity of bremsstrahlung and two-component spectra is mainly caused by irradiation of the disk by the boundary layer. The effect of irradiation ensures that the temperature of the very inner parts of the disk is close to the temperature of the boundary layer, which in turn means that the overall emitted spectrum is smooth. We favor the two-component model since in the case of bremsstrahlung emission the radiating volume should be very large in order to account for the observed luminosities (White and Mason 1985).

Acceptable χ^2 values obtained for the two-component model indicate that there is no need to revise the underlying assumptions. As the high-energy part of the spectrum is satisfactorily explained by the emission of the optically thick boundary layer with the color temperature not exceeding the Eddington value, the Comptonization by a hot corona is probably not important for sources with the moderate accretion rates ($\sim 10^{-10}$ to 10^{-9} $M_\odot$ yr^{-1}) for which the model of Paper I is valid. The innermost parts of the disk are optically thick. This is in contrast with conclusions derived for several other LMRXBs by Mitsuda *et al.* (1984). The difference is caused by the difference in the temperature profile over the disk surface, as Mitsuda *et al.* (1984) did not take into account the irradiation effect. The values of all fitted parameters are in agreement with expectations. The derived accretion rate is entirely in the range expected for LMRXBs, whereas the model of Mitsuda *et al.* (1984) implicitly requires an accretion rate of the order 10^{-7} $M_\odot$ yr^{-1}. Our values of the accretion rate mainly depend on the total X-ray luminosity and are not very sensitive to details of the model. Of course the intrinsic luminosity and therefore the accretion rate depend on the adopted value of the distance to the system. In principle it should be possible to determine the accretion rate and hence the distance from the spectral shape. However, because the shape of the theoretical spectrum is not very sensitive to the accretion rate (see Fig. 6 of Paper I), but may depend on details of the model, such a procedure would require more elaborate theoretical models and much better spectral resolution than the resolution of the *Einstein* MPC.

The determination of the inclination angle of Aql X-1 depends on the relative importance of emission coming from the disk and from the boundary layer, as observed from different directions. Therefore it depends on details of the model, e.g., the assumed structure of the boundary layer. A rather small value ($i \approx 33°$) obtained in this paper is consistent with lack of eclipses or dips. Analysis similar to that presented in this paper may be very interesting for sources exhibiting dips (e.g., 4U 1916−05), in which the inclination is reasonably constrained. In principle such studies may provide information on the structure of the boundary layer. However, it is quite possible that for those sources the influence of hot coronas is more important (White and Mason 1985).

The values obtained for the temperature of the boundary layer are reliable because the radiation from its surface is mainly responsible for the observed counts in several higher energy MPC channels. Therefore, we could follow the changes of $T_{\rm BL}$ during the outburst. These data are important for testing theoretical models of the structure of the boundary layer since any such model should contain at least one free parameter describing the efficiency of the transfer of angular momentum. For the case of Aql X-1, in most observations the temperature of the boundary layer was close to the critical temperature (for our adopted values of mass and radius of the neutron star). It seems that when the accretion rate drops below some certain value (depending on the distance to the source) the temperature of the boundary layer also decreases. Unfortunately, because of the poor coverage by the observations of lower luminosity stages of the outburst, we cannot be sure that we really see the transition in the structure of the boundary layer in Aql X-1. Further observations of sources having accretion rates in a similar range will be extremely interesting.

Two bursts observed by *Einstein* during the 1979 March–April outburst of Aql X-1 distinguished themselves from typical bursts by having very long lasting tails. This was especially visible in the first burst recorded, when the extended emission lasted at least 2500 s after burst maximum. The flux after the second burst dropped down more rapidly (as in a typical type I burst), but the persistent emission was again slightly enhanced afterwards. By fitting theoretical spectra to observed counts we showed that the most probable explanation of this phenomenon (i.e., the enhanced emission after the bursts) is an increased accretion rate in the inner parts of the accretion disk. The difference in the increase of the accretion rate after the two bursts may be caused by the difference in the disk structure. The second burst occurred when the total luminosity of Aql X-1 was lower and the disk was presumably less massive, so its response might be not so strong. To resolve this problem it would be interesting to look at variations in burst profiles in other sources with variable accretion rates.

Our analysis indicates a departure of the burst spectra from a blackbody shape. It seems that not only the temperature but also the emitting area may decrease after burst maxima. There was no indication of envelope expansion during the bursts, which is consistent with the bursts' apparently small peak luminosity as a fraction of the hydrogen-rich Eddington limit; this fraction was equal approximately to $0.16(1 + z)(d/2 \text{ kpc})^2$ for both bursts (the effects of reflection from the disk may further diminish this value; see § III). Therefore the changes of the radiating area presumably reflect the changes in the fraction of the neutron star surface covered by thermonuclear burning. The condition that the emitting area cannot exceed the whole stellar surface constrains the distance to Aql X-1 ($d \lesssim 3.5$ kpc) unless the radius of the neutron star is very large.

The MPC instrument discovered weak but significant flux from the field in the vicinity of Aql X-1 approximately half a year after the 1979 March–April outburst. It is likely that the source of the observed flux was indeed Aql X-1, but further observations of Aql X-1 are required in order to definitely resolve this problem. If this detection is confirmed, it will be the second detection of a transient source in a low state (Hertz and Grindlay (1983). The ratio of the highest and the lowest flux measured by the *Einstein* MPC is about 440 (in the 1.2–10 keV band); however, if we take as the highest value the flux measured during maxima of previous and more prominent outbursts, we obtain for this ratio a value of about 1000. The flux measured by *Einstein* during 1979 October corresponds to an X-ray luminosity of Aql X-1 of approximately 10^{34} ergs s^{-1} for reasonable values of the distance. This luminosity is similar to luminosities of several weak X-ray sources in globular clusters and therefore again suggests that at least some of them may be neutron stars instead of being accreting white dwarfs.

This work was partially supported by NASA contract NAS8-30751.

REFERENCES

Avni, Y. 1976, *Ap. J.*, **210**, 642.
Ayasli, S., and Joss, P. C. 1982, *Ap. J.*, **256**, 637.
Balucinská, M., and Czerny, M. 1985, *Acta Astr.*, in press.
Begelman, M. C., McKee, C. F., and Shields, G. A. 1983, *Ap. J.*, **271**, 70.
Canizares, C. R., McClintock, J. E., and Grindlay, J. E. 1979, *Ap. J. (Letters)*, **236**, L55.
Charles, P. A., *et al.* 1980, *Ap. J.*, **237**, 154.
Czerny, B., Czerny, M., and Grindlay, J. E. 1986, *Ap. J.*, **311**, 241. (Paper I).
Czerny, M., and Jaroszynski, M. 1980, *Acta Astr.*, **30**, 157.
Czerny, M., and Sztajno, M. 1983, *Acta Astr.*, **33**, 213.
Ebisuzaki, T., Hanawa, T., and Sugimoto, D. 1984, *Pub Astr. Soc. Japan*, **36**, 551.
Fujimoto, M. Y., and Hoshi, R. 1985, *Ap. J.*, **293**, 268.
Fukue, J. 1982, *Pub. Astr. Soc. Japan*, **34**, 483.
Grindlay, J. E. 1985, in *Proceedings of Japan-US Seminar on Galactic and Extragalactic Compact X-ray Sources*, ed. Y. Tanaka and W. H. G. Lewin (Tokyo: ISAS), p. 215.
Grindlay, J. E., *et al.* 1980, *Ap. J. (Letters)*, **240**, L121.
Hertz, P., and Grindlay, J. E. 1983, *Ap. J.*, **275**, 105.
Holt, S. S., and Kaluzienski, L. J. 1979, *IAU Circ.*, 3342.
Inoue, H., *et al.* 1984, *Pub. Astr. Soc. Japan*, **36**, 855.
Joss, P. C., and Rappaport, S. 1984, *Ann. Rev. Astr. Ap.*, **22**, 537.
Kaluzienski, L. J., Holt, S. S., Boldt, E. A., and Serlemitsos, P. J. 1977, *Nature*, **271**, 630.
Koyama, K., *et al.* 1981, *Ap. J.*, **247**, 127.
Lapidus, I. I., and Sunyaev, R. A. 1985, *M.N.R.A.S.*, **217**, 291.
Lewin, W. H. G., and Joss, P. C. 1981, *Space Sci. Rev.*, **28**, 3.
———. 1983, in *Accretion Driven Stellar X-ray Sources*, ed. W. H. G. Lewin and E. P. J. van den Heuvel (Cambridge: Cambridge University Press), p. 41.
Livio, M., and Regev, O. 1985, *Astr. Ap.*, **148**, 133.
London, R. A., Taam, R. E., and Howard, W. M. 1984, *Ap. J. (Letters)*, **287**, L27.
MacGregor, K. B., and Vitello, P. A. 1982, *Ap. J.*, **259**, 267.
Meyer, F., and Meyer-Hoffmeister, E. 1982, *Astr. Ap.*, **106**, 34.
Mitsuda, K., *et al.* 1984, *Pub. Astr. Soc. Japan*, **36**, 741.
Pringle, J. E. 1981, *Ann. Rev. Astr. Ap.*, **19**, 137.
Smak, J. I. 1982, *Acta Astr.*, **32**, 199.
Sztajno, M., van Paradijs, J., Lewin, W. H. G., Trümper, J., Stollman, G., Pietsch, W., and van der Klis, M. 1985, *Ap. J.*, **299**, 487.
Tawara, Y., Hirano, T., Kii, T., Matsuoka, M., and Murakami, T. 1984, *Pub. Astr. Soc. Japan*, **36**, 861.
Thorstensen, J., Charles, P., and Bowyer, S. 1978, *Ap. J. (Letters)*, **220**, L1.
van Paradijs, J. 1982, *Astr. Ap.*, **107**, 51.
van Paradijs, J., Verbunt, F., van der Linden, T., Pedersen, H., and Wamsteker, W. 1980, *Ap. J. (Letters)*, **241**, L161.
Verbunt, F., van Paradijs, J., and Elson, R. 1984, *M.N.R.A.S.*, **210**, 899.
White, N. E., and Mason, K. O. 1985, *Space Sci. Rev.*, **40**, 167.

B. Czerny and M. Czerny: University of Leicester, Department of Astronomy, University Road, Leicester, LE1 7RH, United Kingdom

J. E. Grindlay: Center for Astrophycis, 60 Garden Street, Cambridge, MA 02138