X-661-76-260

PREPRINT

NASA TM X-71236

RECURRENT X-RAY OUTBURSTS FROM AQUILA X-1

(NASA-TM-X-71236) RECURRENT X-RAY OUTBURSTS FROM AQUILA X-1 (NASA) 12 p HC A02/MF A01 CSCL 03B

N77-13960

Unclas
G3/93 57872

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

DECEMBER 1976

GSFC — GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

RECURRENT X-RAY OUTBURSTS FROM AQUILA X-1

L.J. Kaluzienski[1], S.S. Holt, E.A. Boldt, and P.J. Serlemitsos

Laboratory for High Energy Astrophysics
NASA/Goddard Space Flight Center
Greenbelt, Maryland 20771 U.S.A.

A high degree of variability has been associated with Aquila X-1 (3U1908+00) since its occasional observation in early rocket surveys[1,2,3], and its appearance as a variable source of moderate brightness in the _Uhuru_ catalog[4] ($S \sim 0.07 - 0.2\ S_{crab}$). Later observations of the source have been made from OSO-7[5] during 1971-1973 which suggest the existence of "low" ($S \lesssim 0.02\ S_{crab}$) and "high" ($S \sim 0.5\ S_{crab}$) intensity states, and from OAO Copernicus, where the source was reported at levels at least an order of magnitude below the _Uhuru_ range during intermittent exposures over a two-year period through 1975 May[6]. This apparent quiescent state was interrupted in 1975 June by a sudden flare[7] (factor of $\gtrsim 20$ increase) to the level of the Crab nebula. Observations of the declining source by the Sky Survey Instrument (SSI) on _Ariel_-5 revealed an $\sim 10\%$ sinusoidal modulation[8] (2-18 keV) at the period $P = 1\overset{d}{.}3 \pm 0\overset{d}{.}04$. By August the flux had decayed back to the pre-outburst intensity ($< .003\ S_{crab}$) as measured by the SSI[9], which instrument observed the same low flux from Aql X-1 again in 1976 January. In 1976 June, the All-Sky Monitor (ASM) on _Ariel_-5 detected an additional outburst of this source[10], which was confirmed by the SSI[11]. We report here ASM observations of Aquila X-1 obtained between the launch of _Ariel_-5 in 1974 October and 1976 November, and compare them with the

[1]Also, Dept. of Physics and Astronomy, University of Maryland

previously cited additional data available. We suggest that the totality of these measurements imply that Aql X-1 may provide a plausible connection between dwarf novae and the very bright, long-duration transient X-ray sources[12].

The proximity of Aql X-1 to the sources Ser X-1 (3U1837+04) and 3U1901+03 ($S_{max} \sim 0.3\ S_{crab}$ and $0.1\ S_{crab}$, respectively) make unambiguous detection of a low Aql X-1 flux ($\lesssim 0.2\ S_{crab}$) problematic in the ASM standard resolution mode (see ref. 13 for a complete experiment description). Consequently, occasional fluctuations in detector background and other systematic effects could conceivably result in "accidental" flux measurements (with low probability) as high as $\sim 0.3\ S_{crab}$ for this particular source. The data obtained during the 1975 and 1976 flares of Aql X-1 are illustrated in Figure 1, and represent the only unambiguous detections of the source over the $\sim$25 months of ASM operation during which the duty cycle for daily monitoring of the Aquila-Serpens region was > 75%. These plots consist of $\sim$ 1/2 day averages of the 3-6 keV flux (incident photons) with corresponding $\pm\ 1\sigma$ statistical error bars (estimated 1σ systematic errors are smaller than the statistical uncertainties). The upper limits obtained (0.1 $cm^{-2}sec^{-1}$) immediately prior to the 1975 flare are consistent with the SAS-3 observations[7], and no positive detections of the source above $\sim 0.2\ cm^{-2}sec^{-1}$ were made during the preceding 7 1/2 months. A similar search of the ASM data over the period between the flares yielded no unambiguous source sightings through 1976 April, with a possible detection at $\sim 0.3\ cm^{-2}sec^{-1}$ (for $\sim$ 1 day) two weeks prior to the 1976 outburst. We note finally that the apparently differing peak flux levels of the flares are actually consistent with a single limiting value ($S_{max} \approx S_{crab}$), as degradation in the effective 3-6 keV detector efficiency of ∿ 10% between the two flare observations can not be excluded.

As a 1.3-day modulation has been reported[8] from the 1975 SSI flare data (obtained during the time interval in Figure 1a labelled "equator"), we have investigated both the 1975 and 1976 ASM data for periods in the range 0.3-3 days. The technique employed consisted of separately folding the data over the range of trial periods and noting deviations in the χ^2-period distribution to the hypothesis of source constancy. The most prominent peak in the 1975 ASM data is, indeed, consistent with the SSI result. As the two experiments have mutually exclusive fields-of-view, the ASM result at a level of 3% ± 1% is an independent measure of the same effect, but cannot be claimed to be an independent detection owing to its marginal statistical significance. Assuming its reality, we can refine the period estimation to 1.28 ± 0.02 days. No such modulation is evident at this period in the 1976 data, however, with statistical errors comparable to those in 1975.

A summary of the totality of the 1971-76 data is displayed in Figure 2, from which there is a clear indication that the OSO-7 data are consistent with flaring episodes similar to those in 1975-76. As there is no exact period which can be fit to the four flares for which there is observational evidence, we have derived a mean flare interval of 435 days with an rms scatter of ∼10%, and have indicated a possible history of identical flares which satisfy all of the observations.

The irregularity of the proposed flare cycle has several obvious implications for source models. In particular, Jones et al.[14] have recently reported recurrent flares from 3U1630-47 similar to those discussed here, but which exhibit a regular period of P = 615$\pm$5 days. Those authors have suggested that the 3U1630-47 flare cycle may represent the orbital period of an eccentric binary system (as has also been suggested for several transient sources[15,16]), but the observed scatter in the presumed Aquila X-1 flare period is inconsistent with the relatively precise timing expected from binary phase-related variations in the accretion flow. The same consideration lessens the likelihood of an association of the present behavior with a Mira Variable-type binary as proposed for the transients 3U1543-47[17] and A1118-61[18], or with a Her X-1 -like precession-governed modulation[19,20] (as opposed to actual flares).

We suggest that the observations are most easily interpreted in terms of an "X-ray dwarf nova" binary of the type proposed by Avni, Fabian, and Pringle[21] for the transient source A0620-00, as the observed X-ray phenomenology is not unlike that of the optical light curves of dwarf novae (and some recurrent novae). Using the empirical period-amplitude relation for U Gem stars and recurrent novae of Payne-Gaposchkin[22], the inferred luminosity ratio $L_{max}/L_{min} \sim 500$ (assuming that most of the radiation emerges in X-rays) yields an expectation value for the interval between flaring episodes of ~465 days. The excellent agreement between the predicted and observed mean flare cycles should not be taken literally, as the uncertainty in L_{max}/L_{min} implies a correspondingly wide dispersion in the expectation flare interval. Recognizing further that X-ray dwarf novae may deviate significantly from period-amplitude relations describing their optical analogues[21,23], we can conclude only that the observed flare interval is not inconsistent with that which might be expected from such a source. The close similarity of the two ASM flare light curves is another model constraint, as it suggests detailed reproduceability. This characteristic of the source behavior can be reconciled with accretion dwarf nova models invoking relatively continuous mass transfer to an accretion disk which is eventually "dumped" by an instability[24] or, alternatively, quasi-periodic unstable Roche-lobe overflow of the red star[23]. In the former model, the similarity of the flares results from the comparable amounts of material accumulated between episodes, while in the latter a high regularity of the magnitude of Roche-lobe spills and/or a feedback loop (regulated first by self-excited transfer and later by Eddington-limited flow) may be implied. Finally, we note that the non-flaring source behavior observed by _Uhuru_[25] may be analogous to the "standstills" observed in several dwarf novae including Z Cam[24] ($S_{standstill} \sim 0.3 - 0.5\ S_{max}$).

The similarity of the Aql X-1 flares reported here to the more extreme episodes of the transient X-ray sources has been pointed out by several observers[8,26]. The abrupt ($\lesssim$ 1 week) rise by ~2 orders of magnitude and subsequent gradual nova-like decay (e-folding time ~ 1 month) back to the pre-flare level are reminiscent of the characteristic transient source light curves, apparently differing only in the degree of brightening (L_{max}/L_{min} for transients is, by definition, $\gtrsim 10^3$) and the absence of a clear precursor peak. This behavior is, on the other hand, qualitatively different from the recurrent flares of Cyg X-1[27] or the extended "highs" (sometimes lasting for hundreds of days) exhibited by sources such as Cen X-3. In the context of a transient source association for Aql X-1, we note that the relatively soft flare X-ray spectrum[6] suggests a generic relation to the class of "long-duration" transients[12] (e.g., A0620-00, A1524-62, and A1742-28), as opposed to the harder-spectral, shorter-lived transients exemplified by A1118-61 and A0535+26. The identification of the transient A0620-00 with a recurrent nova[28] and the resemblance of the long-term behavior of Aql X-1 to both the transient X-ray sources and dwarf novae suggests that at least some members of the former group may arise from systems similar to the latter, but with the blue-dwarf binary component replaced by a neutron star or black hole.

The authors are indebted to R. Rothschild for bringing the availability of the OSO-7 observations to our attention. L.J.K. acknowledges support from the University of Maryland.

REFERENCES

1. Friedman, H., Byram, E.T., and Chubb, T.A., Science, 156, 374 (1967).
2. Seward, F., An Illustrated Catalog of Cosmic X-Ray Sources, LLL Report UCID-15622 (1970).
3. Price, R.E., Seward, F.D., and Swift, C.D., Astrophys. J., 176, 611 (1972).
4. Giacconi, R., Murray, S., Gursky, H., Kellogg, E., Schreier, E., Matilsky, T., Koch, D., and Tananbaum, H., Astrophys. J. Suppl., No. 237, 27, 37 (1974).
5. Markert, T.H., Ph. D. Thesis (1974).
6. Davidsen, A., Sanford, P., Davison, P., and Mason, K., I.A.U. Circ., No. 2793 (1975).
7. Buff, J., I.A.U. Circ., No. 2788 (1975).
8. Watson, M.G., Mon. Not. R. astr. Soc., 176, 19P (1976).
9. Villa, G., Page, C.G., Turner, M.J.L., Cooke, B.A., Ricketts, M.J., and Pounds, K.A., Mon. Not. R. astr. Soc., 176 (in the press).
10. Kaluzienski, L.J., Holt, S.S., Esfandiari, M., Boldt, E.A., and Serlemitsos, P.J., I.A.U. Circ., No. 2965 (1976).
11. Watson, M.G., Private communication (1976).
12. Kaluzienski, L.J., Holt, S.S., Boldt, E.A., and Serlemitsos, P.J., Astrophys. J. (in the press).
13. Holt, S.S., Astrophys. Space Sci., 42, 123 (1976).
14. Jones, C., Forman, W., Tananbaum, H., and Turner, M.J.L., Center for Astrophys. Preprint, No. 589 (1976).
15. Pacini, F., and Shapiro, S.L., Nature, 255, 618 (1974).

REFERENCES (CONT.)

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

17. Li, F.K., Sprott, G.F., and Clark, G.W., Astrophys. J., 203, 187 (1976).

18. Fabian, A.C., Pringle, J.E., and Rees, M., Nature, 255, 618 (1975).

19. Roberts, W.J., Astrophys. J., 187, 575 (1974).

20. Petterson, J.A., Astrophys. J. Lett., 201, L61 (1975).

21. Avni, Y., Fabian, A.C., and Pringle, J.E., Mon. Not. R. astr. Soc., 175, 297 (1976).

22. Payne-Gaposchkin, C., The Galactic Novae (North-Holland Publishing Company, Amsterdam, 1957).

23. Bath, G.T., Evans, W.D., Papaloizou, J., and Pringle, J.E., Mon. Not. R. astr. Soc., 169, 447 (1974).

24. Osaki, Y., Publ. Astron. Soc. Japan, 26, 429 (1974).

25. Jones, C., Private communication (1976).

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

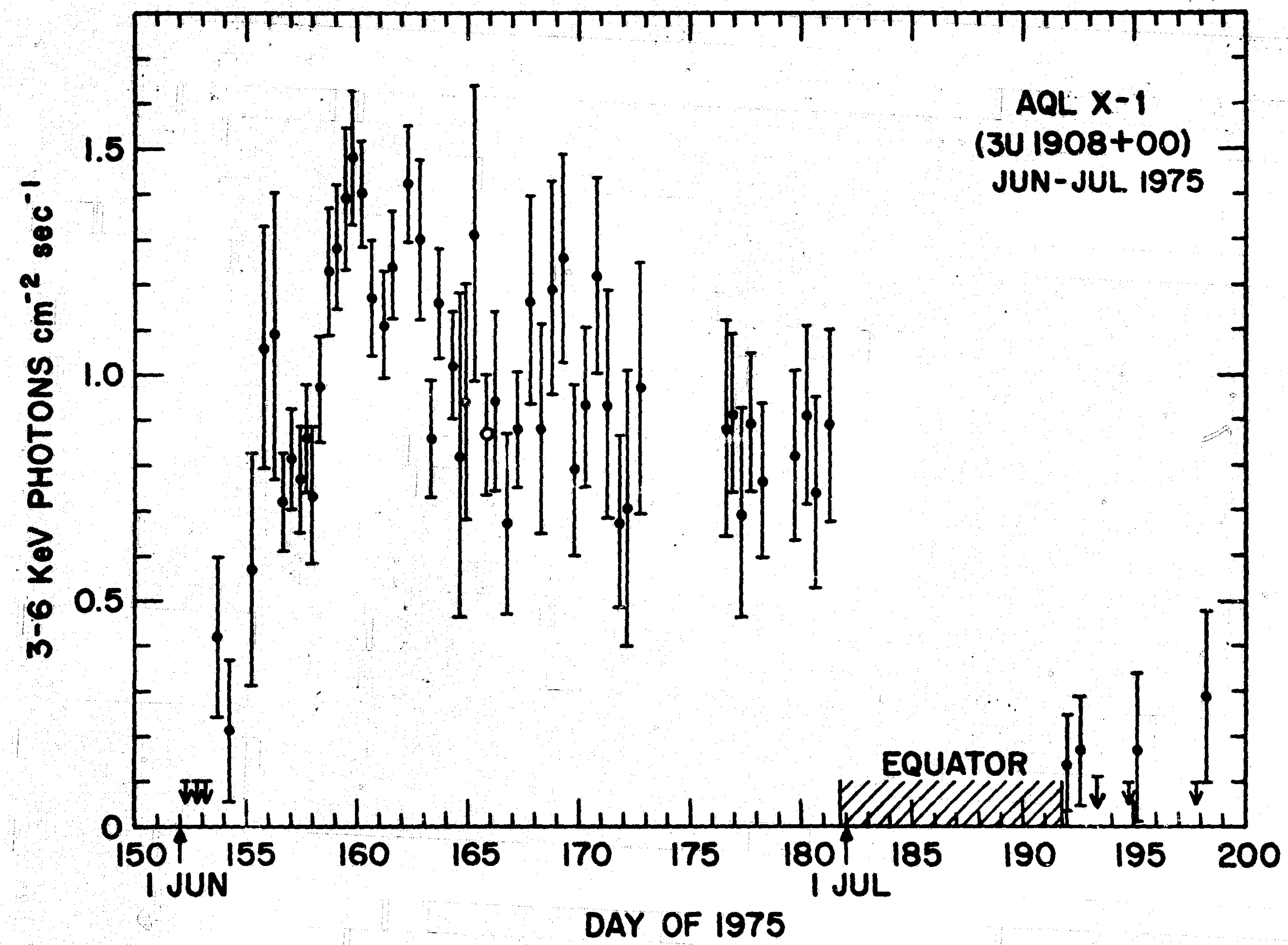
27. Holt, S.S., Kaluzienski, L.J., Boldt, E.A., and Serlemitsos, P.J., Nature, 261, 213 (1976).

28. Eachus, L.J., Wright, E.L., and Liller, W., Astrophys. J. Lett., 203, L17 (1976).

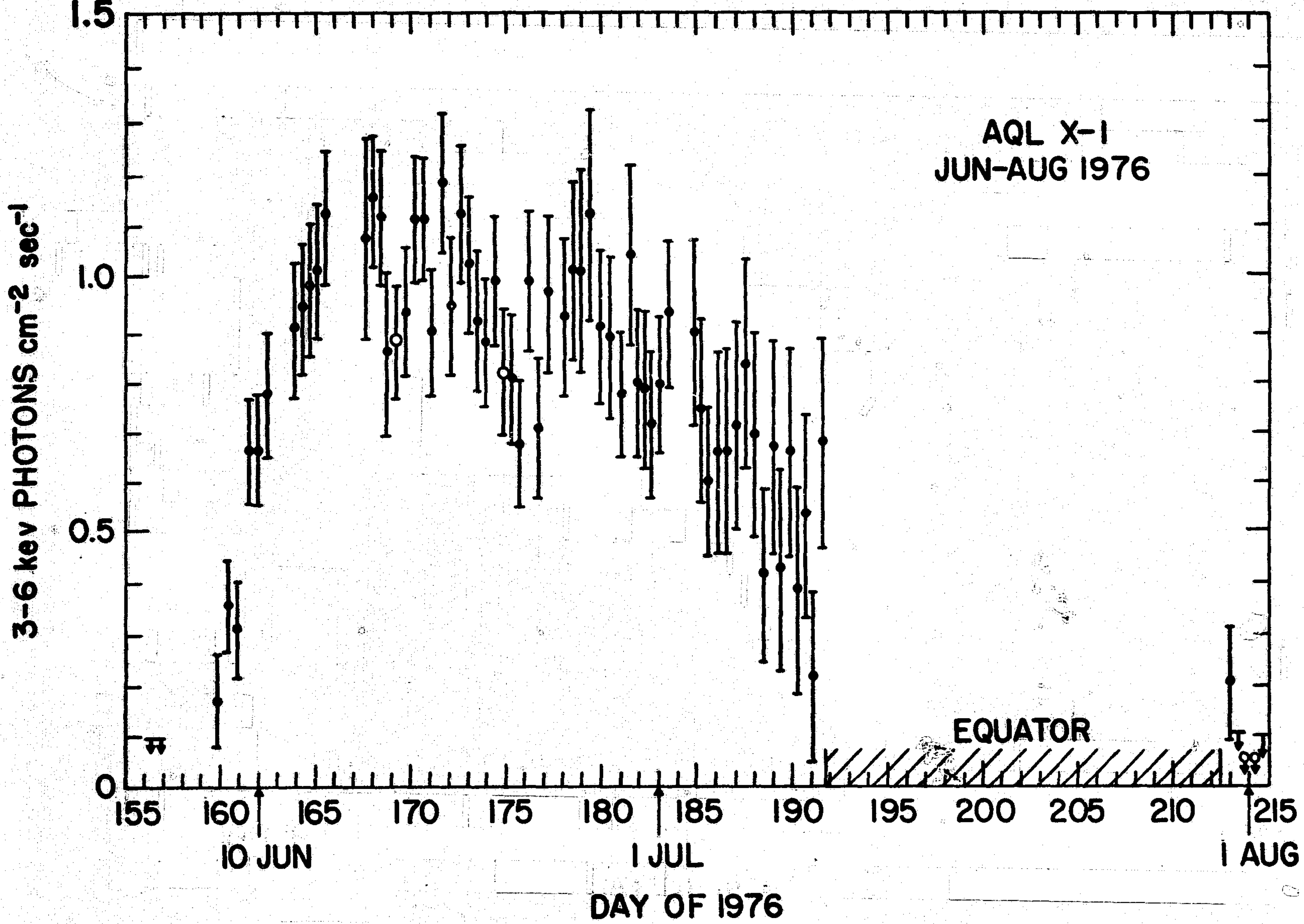
FIGURE CAPTIONS

Figure 1 ASM chronologies of the 1975 (a) and 1976 (b) flares of Aquila X-1. The points are ∿ 1/2-day averages, and the error bars are $\pm 1\sigma$ (statistical error only). The shaded areas labelled "equator" are times when Aquila X-1 was close to the equatorial plane of the Ariel-5 satellite; during these times the source was inaccessible to the ASM, but observable by the SSI.

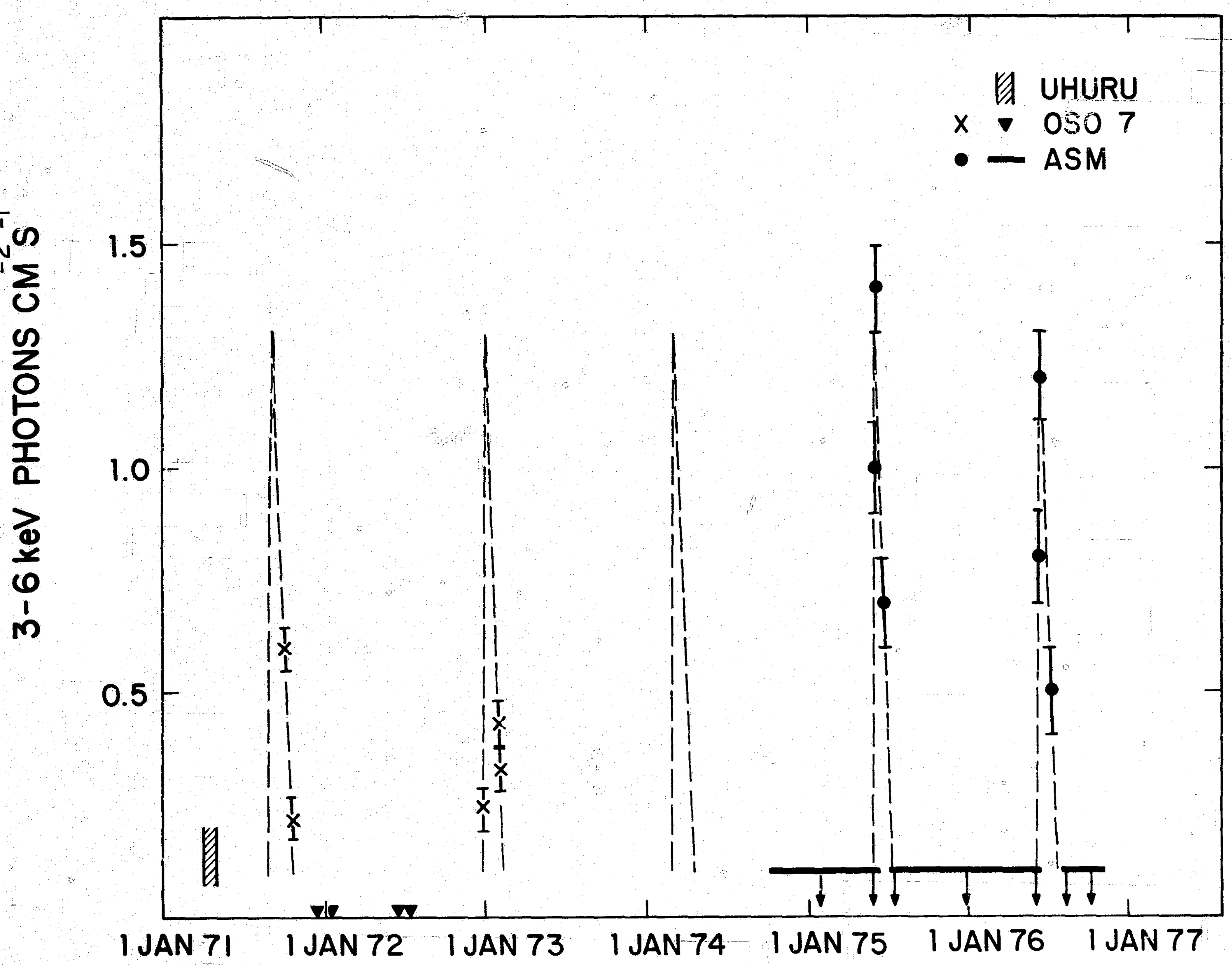
Figure 2 Summary of Aquila X-1 observations over the period 1971-1976. The OSO-7 data is taken from Markert[5] and has been approximately converted to ASM units via normalization with respect to the Crab nebula. Error bars in all data have been conservatively estimated to include possible systematic and normalization errors. Intermittent Copernicus[6] measurements during 1973-1975 (not displayed) are at the level ∿ .01-.02, and do not preclude a 1974 outburst as hypothesized.



AQL X-1
(3U 1908+00)
JUN-JUL 1975
3-6 KeV PHOTONS cm^{-2} sec^{-1}
0
0.5
1.0
1.5
150
155
160
165
170
175
180
185
190
195
200
1 JUN
1 JUL
EQUATOR
DAY OF 1975



AQL X-1
JUN-AUG 1976
3-6 kev PHOTONS cm^{-2} sec^{-1}
1.5
1.0
0.5
0
155
160
165
170
175
180
185
190
195
200
205
210
215
10 JUN
1 JUL
1 AUG
EQUATOR
DAY OF 1976


UHURU
X OSO 7
ASM
3-6 keV PHOTONS CM^{-2} S^{-1}
1.5
1.0
0.5
1 JAN 71
1 JAN 72
1 JAN 73
1 JAN 74
1 JAN 75
1 JAN 76
1 JAN 77