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A TWO COMPONENT X-RAY SPECTRUM FROM SMC X-1

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ABSTRACT

We present HEAO-1 A2 and Einstein SSS observations of SMC X-1. An unpulsed soft component is found with a blackbody temperature of 0.16 keV and an area for the emission region of 10^{15}-10^{17} cm^2. The hard X-ray component is pulsed; the phase-averaged spectrum is a power law with $\alpha \sim 0.5$ up to 17 keV above which it steepens. The SSS sets an upper limit of $< 4 \times 10^{21}$ H cm^{-2} to any absorption and is consistent with that expected from the wind of Sk160. Absorption dips with a timescale of several hundred seconds are seen immediately following an eclipse exit and are probably caused by inhomogeneities in the wind of Sk160.

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[2] Now at VPI&SU

I. INTRODUCTION

The 3.9 day eclipsing X-ray binary system SMC X-1 contains a 0.72s X-ray pulsar in orbit about the B0 supergiant Sk 160 (Schreier et al. 1972; Webster et al. 1972; Lucke et al. 1976). The X-ray luminosity varies from $\lesssim 10^{37}$ erg s^{-1} (Seward and Mitchell 1981) up to $\sim 10^{39}$ erg s^{-1} (Price et al. 1971; Ulmer et al. 1971; Coe et al. 1981). The high X-ray luminosity and the measured secular decrease in the pulse period (Davison 1977; Primini, Rappaport and Joss 1977; Darbo et al. 1981) leaves no doubt that the pulsar is an accreting magnetized neutron star. Many authors have noted that since a neutron stars mass is unlikely to exceed $\sim 2\ M_\odot$, the peak luminosity observed from this source exceeds the Eddington limit by a factor of 5. Basko and Sunyaev (1976a, BS) pointed out that just such a violation of the Eddington limit might be expected for accretion onto a magnetized neutron star, because the 10^{12} G magnetic field will cause asymmetries in both the accretion flow and outgoing radiation field. BS find that at such high luminosities the material flowing through the magnetosphere will be optically thick and that it may intercept and reprocess a substantial fraction of the outgoing emission into an intense soft blackbody component. Unpulsed X-ray emission at 0.25 keV has been detected from SMC X-1 by Lucke et al. (1976) and by Bunner and Sanders (1979), but it is unclear how this flux is related to the pulsed continuum at higher energies. We have used the Solid State Spectrometer (SSS; 0.5-4.5 keV) on Einstein and the proportional counters from the HEAO-1 A2 experiment (MED, 2-20 keV; and HED, 2-60 keV) to study the spectral properties of SMC X-1. An unpulsed blackbody component is detected by the SSS. We discuss how this soft emission compares to a similar component seen from Her X-1 and how it fits in with the Super-Eddington model of BS. The SSS also allows a sensitive determination of the photo-electric absorption in the line of sight. We show that the measured absorption supports the hypothesis that the stellar wind of Sk 160 is normal.

II. RESULTS

a. HEAO-1

The HEAO-1 A2[+] experiment (Rothschild et al. 1979) obtained scanning data in the 2-60 keV energy band from 1978 April 26 to May 10 and observed SMC X-1 to be undergoing a transition from a high to a low state. This is shown in Figure 1 for the HED detectors. The eclipse every 3.89 days can be clearly seen, and yields an epoch for eclipse center of JD2443626.83±0.07, consistent with the current best ephemeris (Bonnet-Bidaud and van der Klis 1981). The eclipse duration was poorly defined but was also consistent with past measurements. SMC X-1 was not detected in two subsequent pointed observations on 1978 May 15 and 17. It was also not detected in scanning observations made between 1977 Oct 26 and Nov. 9.

Pulsations were seen during the high state of SMC X-1, but pulse phase spectroscopy could not be done because of the configuration of the experiment. The phase average spectrum taken when the source was bright is well represented by a power law with an energy index α of 0.5±0.1, modified at energies greater than E_C by an exponential cutoff of the form $\exp[(E_C-E)/E_F]$ with $E_C = 17 \pm 2$ keV and $E_F = 10 \pm 3$ keV. A similar spectrum was determined by Coe et al. (1981) by combining data from two Ariel V experiments. The incident spectrum deconvolved from the detector response using the best fit parameters is given in Figure 2. There was no change in the spectrum

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[+] The A2 experiment on HEAO-1 is a collaborative effort led by E. Boldt of GSFC and G. Garmire of CIT, with collaborators at GSFC, CIT, JPL and UCB.

associated with the transition to the low state; in particular the absorption did not increase. The peak 0.5 to 60 keV flux was 1.7 x 10^{-9} erg cm^{-2} s^{-1}. During the pointed observations the flux was < 4 x 10^{-11} erg cm^{-2} s^{-1}. The upper limit equivalent width to any iron K line between ~ 6.4 and 6.7 keV was < 420 eV.

b. SSS

There were three SSS observations on 1979 April 23, May 9 and May 11. The energy resolution of the SSS is ~ 0.18 keV, several times better than that of the HEAO-1 A2 proportional counters at ~ 2 keV. Co-aligned with the SSS is a Monitor Proportional Counter (MPC; 2-10 keV). The details of these observations are given in Table 1. The peak flux decreased by a factor of three from the first to the second observation. Both the second and third MPC observations are shown in Figure 3 with a time resolution of 25.6 s. Also shown is the MPC spectral hardness ratio given by the ratio of the counts in the 4-10 keV to those in the 2-4 keV bands. The binary phase is shown using the period of 3.89239 days found by Bonnet-Bidaud and van der Klis (1981) and an eclipse phase zero of JD2442836.6823 (Primini et al. 1976). Based on this an exit from eclipse occurred ~ 1 hr prior to the start of the third observation at binary phase ~ 0.08. The count rate after eclipse can be seen in Figure 3 to undergo two dips that involve a hardening of the spectrum. The reduced flux and change in the hardness ratio are consistent with an approximately constant source luminosity being obscured by various amounts of cold material ranging up to ~ 5 x 10^{23} atoms cm^{-2}. If the initial increase in flux is the actual eclipse exit, it would require either a $\dot{P}/P$ of 10^{-3}, a factor 100 larger than the previous upper limit (Bonnet-Bidaud and van der Klis 1981), or an increase in the eclipse duration from ~ 57° to ~ 68°; both of these possibilities are unlikely. These were the only absorption events seen during our HEAO-1 and Einstein observations.

The pulsations were clearly seen in all the uneclipsed SSS data and yielded a pulse period the same as with that reported by Darbo et al. (1981) from the MPC observations taken simultaneously. The pulse light curve from the first observation is shown in Figure 4 divided up into three energy bands. The pulse profile in the 1.3-4.5 keV band is similar to that reported by past observers (cf. Lucke et al. 1976). In the two lowest energy bands the amplitude decreases and in the 0.5 to 0.8 keV band there is little if any evidence for a modulation > 5% amplitude. Lucke et al. (1976) have also reported a similar effect down to an energy of 0.25 keV.

The spectrum during the first observation when the source was bright (and the statistics good) could not be acceptably fit with a simple power law plus absorption model (Table 1). A two component model of a power law (consistent with that seen by HEAO-1 A2) and a low energy component did give acceptable χ^2. The form of the soft component was not well defined. A blackbody model is probably the most physically meaningful and Table 1 gives the best fit parameters for this along with the observed fluxes. There is some uncertainty in the low energy response of the SSS (cf. Holt et al. 1979) and this is the predominant reason for the large uncertainties in the blackbody component. The pulse height and incident spectra are shown in Figure 5. The dashed lines indicate the contribution of the power law component and it is evident that the blackbody component begins to dominate below 1.3 keV, the point where the amplitude of the pulsations decreases. We conclude from this that the blackbody component is not substantially pulsed. There was no evidence for any emission or absorption features in the SSS spectrum with an equivalent width > 10 eV.

The other two SSS observations on 1979 days 139 and 141 when the source was faint were not of such good statistical precision and a single power law model gave acceptable fits. A soft excess with a luminosity relative to the hard component similar to that seen when the source was bright would not have been detected. The absorption during all the observations when the flux was unperturbed by absorption dips was < 4.5 x 10^{21} H cm^{-2}. During the two absorption events seen on 1979 day 131 the average absorption increased to (2.5 ± 1.3) x 10^{22} H cm^{-2}.

III. DISCUSSION

a. The High Energy Spectrum

Indications of a high energy break in the spectrum of SMC X-1 were first inferred from > 20 keV measurements by Ulmer et al. (1973) and later confirmed by Coe et al. (1981). The data presented here have the advantage of covering the region of the break with a single detector. The value of the cutoff parameter E_c for SMC X-1 is approximately the same as those of other X-ray pulsars (White, Swank and Holt 1982). These high energy cutoffs are probably caused by the energy dependence of the Thomson scattering cross-sections in a strong magnetic field (e.g. Boldt et al. 1976; Pravdo and Bussard 1981), although other factors such as the optical depth and temperature of the atmosphere may also be important (cf. Meszaros et al. 1982). Another contributing factor could be from a broad electron cyclotron absorption line at ~ 35 keV (Bussard 1980). The similarity of the cutoff energies in X-ray pulsars suggests that the surface conditions on these neutron stars are comparable.

b. The Distance to Sk 160 and the Luminosity of SMC X-1

The distance to the SMC is usually taken to be ~ 65 kpc (e.g. Webster et al. 1972), however observations of Sk 160 have lead to the conclusion that its observed spectral properties combined with the X-ray eclipse duration give a distance of only ~ 45 kpc (Primini et al. 1976; Conti 1978; Howarth 1982). This would put this system well this side of the main body of the SMC and brings into question the currently accepted distance estimate to the SMC. As noted by Howarth (1982) there is still considerable controversy over this issue (see also Hodge 1981) with estimates ranging from 53 kpc (de Vaucouleurs 1978) to 71 kpc (Sandage and Tamann 1971). The peak X-ray luminosity observed by HEAO-1 and Einstein corresponds to $5 \times 10^{38} \times (d/50 \text{ kpc})^2$ erg s^{-1} in the 0.5 to 60 keV band. Coe et al. (1981) observed a luminosity of $9 \times 10^{38} \times (d/50 \text{ kpc})^2$ erg s^{-1}. Even the lowest distance estimate of ~ 40 kpc still gives a luminosity of a factor of 3 above the Eddington limit for a 1.4 M_O star. In the following discussion we will adopt 50 kpc as the distance to SMC X-1.

It is notable that the only other two super-Eddington X-ray pulsars known are in the LMC. These are LMC X-4 (6×10^{38} erg s^{-1}; White, Swank and Holt 1982; Kelley et al. 1982) and A0538-66 (~ 10^{39} erg s^{-1}; White and Carpenter 1978; Skinner et al. 1982). Given the greater number of X-ray sources within our own galaxy it is curious that there are no cases of super-Eddington luminosity from local X-ray pulsars.

c. The Soft Component

The measured 0.16 keV temperature and luminosity of the blackbody component gives a spherical surface area for the emission region between 10^{15} and 10^{17} cm^2 (Table 1). This is much larger than the ~ 10^{13} cm^2 surface area of a neutron star. The infalling material is brought into co-rotation by the magnetic field of the neutron star at the Alfven radius where the magnetic field pressure equals the ram pressure. This radius is not very sensitive to the mass transfer rate and for this case is ~ 10^8 cm, which yields a total area of ~ 10^{17} cm^2, similar to the observed values. Following BS we can estimate the optical depth τ through the Alfven shell to be

$$\tau = 0.15 \times R_8^{-1/2} . (1-\beta)^{-1} . \eta^{-1} . \frac{L_x}{L_{Edd}} . v_f^{-1}$$

where R_8 is the radius of the Alfven shell in units of 10^8 cm, η is the fraction of the shell through which material is flowing and β is the fraction of the emission intercepted by the neutron star surface (~ 0.4) and V_f is the ratio of the material's velocity relative to its free-fall value. For a super-Eddington luminosity and a covering fraction η of ~ 0.1, an optical depth of a few is obtained. Therefore it is plausible that, as predicted by BS, the soft component is associated with reprocessing in optically thick material flowing through the magnetosphere. The fact that no absorption features are seen in the SSS spectra means that either the area of this material is less than that of the X-ray emission region or that the material is located out of the line of sight. Shadowing by the optically thick material cannot contribute to the formation of the hard X-ray pulse and some sort of magnetic beaming must be operating.

This is the second case of a soft emission component from a binary X-ray pulsar. Shulman et al. (1975) and Catura and Acton (1975) discovered a similar blackbody component from Her X-1 with a temperature of 0.11 keV and an emitting area of ~ 10^{15} cm^2 (McCray et al. 1982). In Figure 4 the pulse light curve of Her X-1 seen by the SSS is compared with that of SMC X-1. It is clear that the two are fundamentally different with the soft emission from Her X-1 showing a strong modulation in anti-phase with the hard pulse. There are currently two models for this emission, both of which locate it in the magnetosphere of the neutron star. McCray and Lamb (1976) and Basko and Sunyaev (1976b) suggested that it comes from an optically thick band of magnetospheric material that periodically shields the X-ray source, causing both the high and the low energy pulse. McCray et al. (1982) recently found that the expected spectral emission and absorption features from such an optically thick partially ionized shell are not seen. They proposed an alternate model where the emission is intrinsically beamed parallel to the field lines in a pencil beam and that the reprocessing takes place exclusively on the inner edge of the accretion disk. Because the inclination of Her X-1 is $\sim 85^0$ the nearside of the inner edge of the disk is hidden from view and the reprocessed component is only seen when the hard X-ray beam points away from the observer. At lower inclinations the azimuthal symmetry would cause the soft pulse to become less pronounced.

It cannot be ruled out that the inner edge of the disk also gives an important contribution to the reprocessed flux from SMC X-1. The emission from SMC X-1 is almost certainly a fan beam, otherwise the inflowing gas stream would be disrupted by the outgoing photons (cf. BS). The lack of any modulation may either reflect the lower inclination of this system of $53\text{-}73^0$ (Primini, Rappaport and Joss 1977) such that the entire inner edge of the disk is seen, or indicate that the beam does not intercept the disk and that, although the covering factor is small, the $\tau > 1$ material in the magnetosphere is uniformly distributed when averaged over large angles.

d. The Stellar Wind of SK 160

Many authors have argued that unless there is something very unusual about the stellar wind of Sk 160 the X-ray emission cannot be driven from gravitational capture by the neutron star of material in the stellar wind, and that Sk 160 is undergoing Roche lobe overflow (Conti 1978; Petterson 1978; Bonnet-Bidaud and van der Klis 1981). This view is supported by the lack of any of the factor of ten or more erratic variability from SMC X-1 similar to that seen from other OB supergiant/neutron star systems where accretion from the stellar wind is presumably more important such as 4U1700-37 and 4U0900-40 (Mason, Branduardi and Sanford 1976; Charles et al. 1978; White, Kallman and Swank 1983). If the wind of Sk 160 is normal for a B0 supergiant then a mass loss rate of $\sim 5 \times 10^{-7}$ M_0 yr^{-1} with a terminal velocity of ~ 1500 km s^{-1} are to be expected (Conti 1978). A velocity law of the form $v = v_\infty (1-R*/R)^{1/2}$, where R is the distance from a star with radius R*, gives a column density through the wind at the conjunction of the neutron star of 7.6×10^{21} H cm^{-2} and a density for the wind at the X-ray source n_X of $\sim 5 \times 10^9$ cm^{-3}.

Such a low density wind will be largely ionized by the X-ray source. Following Hatchett and McCray (1977) a quantity $q = \xi D^2 n_X/L_X$ can be defined, where D is the distance from the primary to the neutron star, that gives surfaces of constant ionization parameter ξ. If $q > 1$ the surfaces surround the X-ray source and if $q < 1$ they surround the primary. For the normal wind parameters given above and the observed luminosity, ξq^{-1} is about 10^4. Oxygen and the other low z elements are essentially completely ionized for $\xi > 10^3$, so the X-ray source will ionize the wind except for a region very near Sk 160 (and of course the volume occulted by Sk 160) and only interstellar absorption should be seen from SMC X-1. The reddening of Sk 160 gives $E_{B-V} \sim 0.1$ (Bonnet-Bidaud et al. 1981) which predicts an $N_H \sim 10^{20}$ H cm^{-2} (Gorenstein 1975), consistent with our upper limit. If the X-ray emission is driven by stellar wind capture then the wind velocity must be exceptionally low or the mass loss rate very high, both of which will give $q > 1$ (Bonnet-Bidaud and van der Klis 1981). The upper limit to any X-ray absorption given by the SSS supports the view that the wind of Sk 160 is normal. Further the constancy of the absorption during the transition to a low state seen by both Einstein and HEAO-1 shows that the low states are <u>not</u> caused by the immersion of the X-ray source in the wind, such as is thought to occur on occasions for Cen X-3 (Schreier et al. 1976).

The absorption events seen following eclipse are notable because they occur when our view of the X-ray source is sampling only ~ 2 R_0 above the photosphere of Sk 160 (the radius of which is ~ 20 R_0). The homogeneous model assumed above would indicate this region is near the boundary of complete ionization for metals. Inhomogeneities in the outer envelope of Sk 160 could produce absorbing clumps of material with ~10^{23} atoms cm^{-2}. Similar timescale absorption variations are seen from 4U1700-37 (White, Kallman, and Swank 1983) which further suggests that there are inhomogeneities in the wind.

IV. SUMMARY

The principle results of this paper can be summarized as follows:

1. There is an unpulsed soft component from SMC X-1 with a blackbody temperature of ~ 0.16 keV and an emission surface area between 10^{15} and 10^{17} cm^2. This probably originates from reprocessing of the original X-ray emission on material in the magnetosphere of the neutron star.
2. The hard X-ray spectrum is a flat power law with a break at ~ 17 keV, and is similar to that seen from other X-ray pulsars.
3. The absorption is usually $< 4 \times 10^{21}$ H cm^{-2} and supports the hypothesis that the wind of Sk 160 is normal. Absorption dips are seen close to eclipse i.e. when viewing through regions where the wind of the primary will not be fully ionized. These probably reflect inhomogenities in the stellar wind.

ACKNOWLEDGMENTS

We would like to thank Tim Kallman, Jules Halpern and our colleagues at GSFC for useful discussions, in particular Steve Holt.

TABLE 1a: EINSTEIN OBSERVATIONS

			SSS Spectral Fits		
Day (1979)	Binary Phase	MPC (ct s^{-1})	α	N_H(H cm^{-2})	χ^2/dof
113	0.41 - 0.45	~ 43	0.5	2×10^{21}	372/65
129	0.58 - 0.61	~ 16	0.8±0.3	$< 5 \times 10^{21}$	95/65
131	0.09 - 0.12	2-14	0.3±0.3	$< 4 \times 10^{21}$	60/65

TABLE 1b: 1979 DAY 113 - TWO COMPONENT FIT

N_1	α	N_H (H cm^{-2})	F_p[a] (erg $cm^{-2}s^{-1}$)	N2	kT (keV)	F_B[b] erg $cm^{-2}s^{-1}$	χ^2/dof
0.068	0.2±0.1	$<4 \times 10^{21}$	1.8×10^{-9}	43	0.18±0.05	1.1×10^{-9} to 1.3×10^{-10}	61/62

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[a] 0.5-60 keV

[b] 0.05-4 keV

REFERENCES

Basko, M.M., and Sunyaev, R.A. 1976a, M.N.R.A.S. 175, 395. (BS)

Basko, M.M., and Sunyaev, R.A., 1976b, Soviet Astr 20, 537.

Boldt, E.A., Holt, S.S., Rothschild, R.E. and Serlemitsos, P.J. 1976, Astr. Ap. 50, 161.

Bonnet-Bidaud, J.M., Ilovaisky, J.A., Mouchet, M., Hammerschlag-Hensberge, G., van der Klis, M., Glencross, W.M., and Willis, A.J. 1981, Astr. Ap. 101, 184.

Bonnet-Bidaud, J.M., and van der Klis, M. 1981, Astr. Ap. 97, 134.

Bunner, A.N., and Sanders, W.T. 1979, Ap. J. 228, L19.

Bussard, R.W. 1980, Ap. J. 237, 970

Catura, R.C., and Acton, L.W. 1975, Ap. J. 202, L5.

Charles, P.A., Mason, K.O., White, N.E., Culhane, J.L., Sanford, P.W., and Moffatt, A.J.F. 1978, M.N.R.A.S. 183, 813.

Coe, M.J., Bell-Burnell, S.J., Engel, A.R., Evans, A.J., and Quenby, J.J. 1981, M.N.R.A.S. 197, 247.

Conti, P. 1978, Astr. Ap. 63, 225.

Darbo, W., Ghosh, P., Elsner, R.F., Weisskopf, M.C., sutherland, P.G., and Grindlay, J.E. 1981, Ap. J. 246, 231.

Davison, P.J.N. 1977, M.N.R.A.S. 179, 15p.

de Vaucouleurs, G. 1978, Ap. J. 223, 730.

Gorenstein, P. 1975, Ap. J. 198, 95.

Hatchett, S., and McCray, R. 1977, Ap. J. 211, 552.

Hodge, P.W. 1981, Ann. Rev. Ast. Ap. 19, 357.

Holt, S.S., White, N.E., Becker, R.H., Boldt, E.A., Mushotzky, R.F., Serlemitsos, P.J., and Smith, B.W. 1979, Ap. J. 234, L65.

Howarth, I.D. 1982, M.N.R.A.S. 198, 298.

Kelley, R.L., Jernigan, J.G., Levine, A., Petro, L.D. and Rappaport, S. 1982, preprint.

Lucke, R., Yentis, D., Freidman, H., Fritz, G., and Shulman, S. 1976, Ap. J. 206, 625.

Mason, K.O., Branduardi, G., and Sanford, P.W. 1976, Ap. J. 203, L29.

McCray, R., and Lamb, F.K. 1976, Ap. J. 204, L115.

McCray, R., Shull, J.M., Boynton, P.E., Deeter, J.E., Holt, S.S., and White, N.E. 1982, Ap. J., in press.

Meszaros, P., Harding, A.K., Kirk, J.G., and Galloway, D.J. 1982, preprint.

Petterson, J. 1978, Ap. J. 224, 625.

Pravdo, S.H., and Bussard, R.W. 1981, Ap. J. 246, L115.

Price, R.E., Groves, D.J., Rodrigues, R.M., Seward, F.D., Swift, C.D. and Toor, A. 1971, Ap. J. 168, L7.

Primini, F., Rappaport, S., Joss, P.C., Clark, G.W., Lewin, W., Li, F., Mayer, W., and McClintock, J. 1976, Ap. J. 210, L71.

Primini, F., Rappaport, S., and Joss, P.C. 1977, Ap. J. 217, 543.

Rothschild, R. et al. 1979, Sp. Sci. Instr. 4, 269.

Sandage, A., and Tamann, G. 1971, Ap. J. 167, 293.

Schreier, E., Giacconi, R., Gursky, H., Kelley, E., and Tananbaum, H. 1972, Ap. J. 178, L71.

Schreier, E., Swartz, K., Giacconi, R., Fabbiano, G., and Morin, J. 1976, Ap. J. 204, 539.

Seward, F.D., and Mitchell, M. 1981, Ap. J. 243, 736.

Shulman, S., Friedman, H., Fritz, G., Henry, R.C., and Yentis, D.J. 1975, Ap. J. 199, L101.

Skinner, G.K., Bedford, D.K., Elsner, R.F., Leahy, D., Weisskopf, M.C., and Grindlay, J. 1982, Nature 297, 568.

Ulmer, M.P., Baity, W.A., Wheaton, W.A., and Peterson, L.E. 1973, Nature Phys. Sci. 242, 121.

Webster, B.L., Martin, W.L., Feast, M.W., and Andrews, P.J. 1972, Nature Phys. Sci. 240, 183.

White, N.E., and Carpenter, G.F. 1978, M.N.R.A.S. 183, 11p.

White, N.E., Kallman, T.R., and Swank, J.H., 1983, in preparation.

White, N.E., Swank, J.H., and Holt, S.S., 1983, in preparation.

FIGURE CAPTIONS

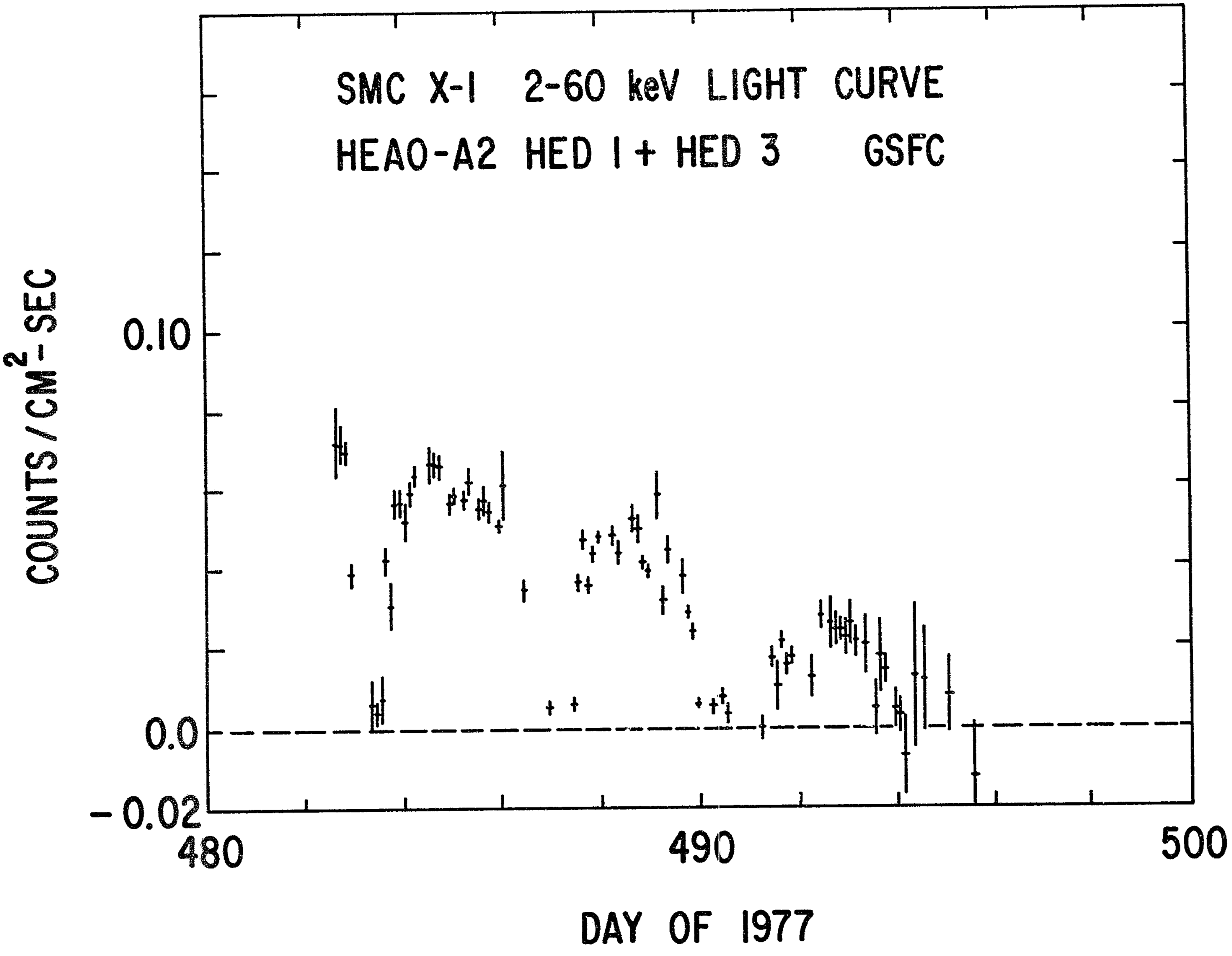
Figure 1 - The flux from SMC X-1 during scanning observations of HEAO-1 A2.

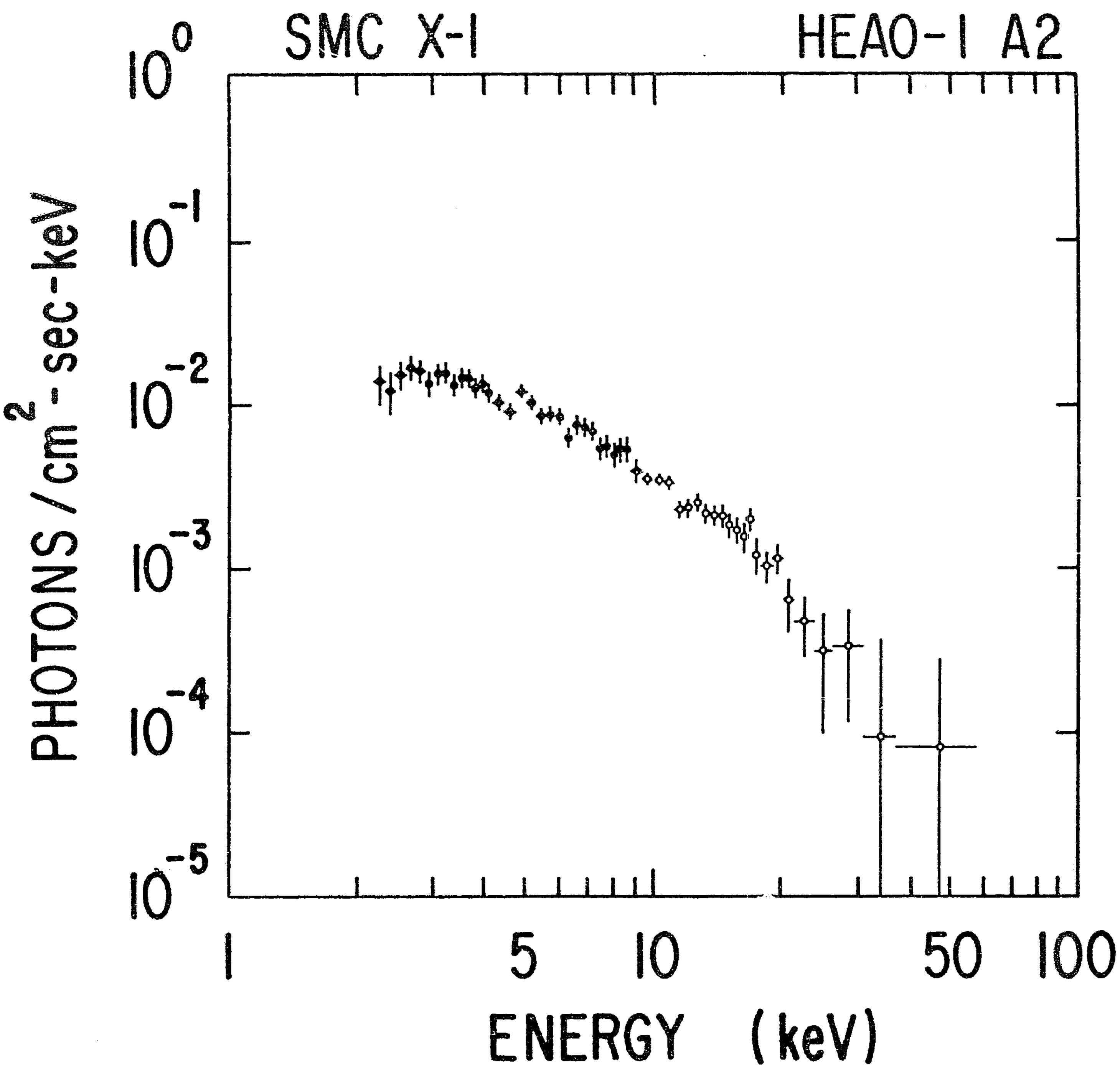
Figure 2 - Hard X-ray incident spectrum of SMC X-1 observed with HEAO-1 A2 Medium Energy Detector (filled circles) and High Energy Detector No. 3 (open circles).

Figure 3 - The MPC count rates and hardness ratio of SMC X-1 given with a time resolution of 25.6s. Eclipse exit occurred at $\phi \sim 0.08$.

Figure 4 - Pulse profiles as a function of energy for SMC X-1 and Her X-1. The average intensities have been normalized to 1.0 for each profile. Typical error bars (1σ) are shown in the bottom right of each panel.

Figure 5 - Soft X-ray observed PHA and incident spectra of SMC X-1 observed with Solid State Spectrometer of the Einstein Observatory. Dashed lines represent the contribution from the hard power law component.


SMC X-1 2-60 keV LIGHT CURVE
HEAO-A2 HED 1 + HED 3 GSFC
COUNTS / CM^2 - SEC
0.10
0.0
-0.02
480
490
500
DAY OF 1977


SMC X-1
HEAO-1 A2
PHOTONS / cm^2 - sec - keV
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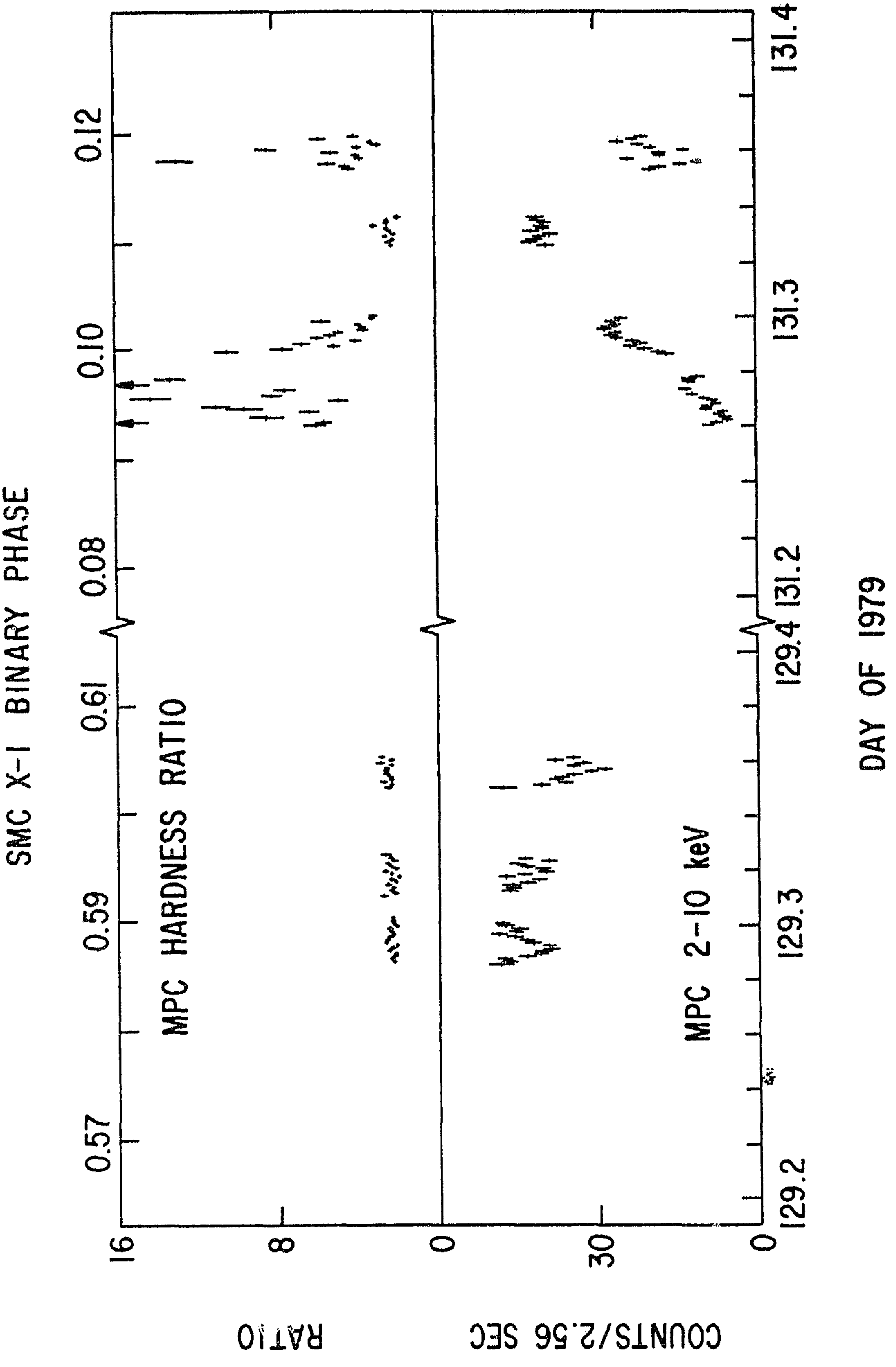
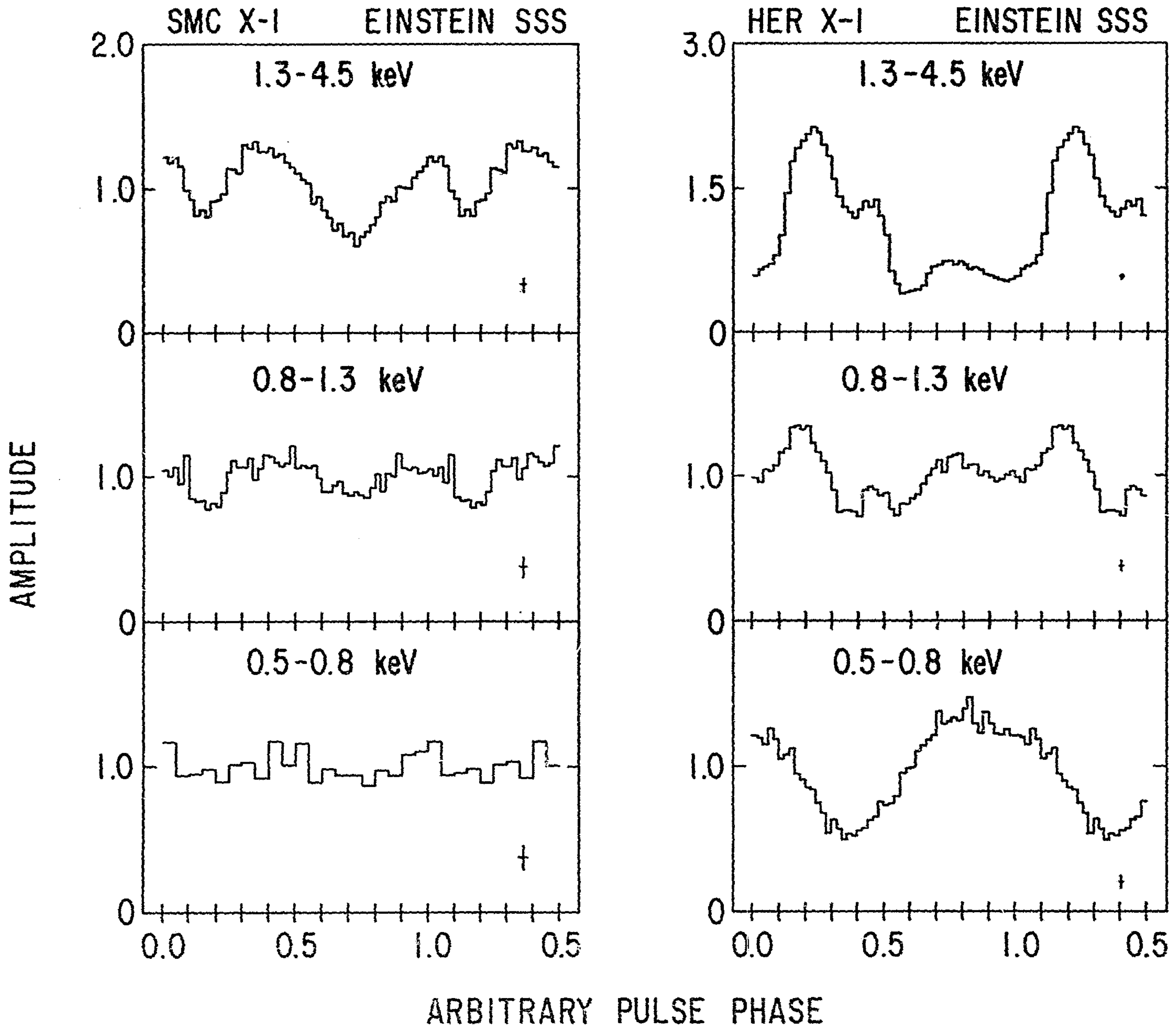
10^{-2}
10^{-3}
10^{-4}
10^{-5}
1
5
10
50
100
ENERGY (keV)


SMC X-I BINARY PHASE
0.57
0.59
0.61
0.08
0.10
0.12
MPC HARDNESS RATIO
MPC 2-10 keV
RATIO
16
8
0
COUNTS/2.56 SEC
30
0
129.2
129.3
129.4
131.2
131.3
131.4
DAY OF 1979


SMC X-1
EINSTEIN SSS
HER X-1
EINSTEIN SSS
1.3-4.5 keV
0.8-1.3 keV
0.5-0.8 keV
1.3-4.5 keV
0.8-1.3 keV
0.5-0.8 keV
2.0
1.0
0
3.0
1.5
0
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1.0
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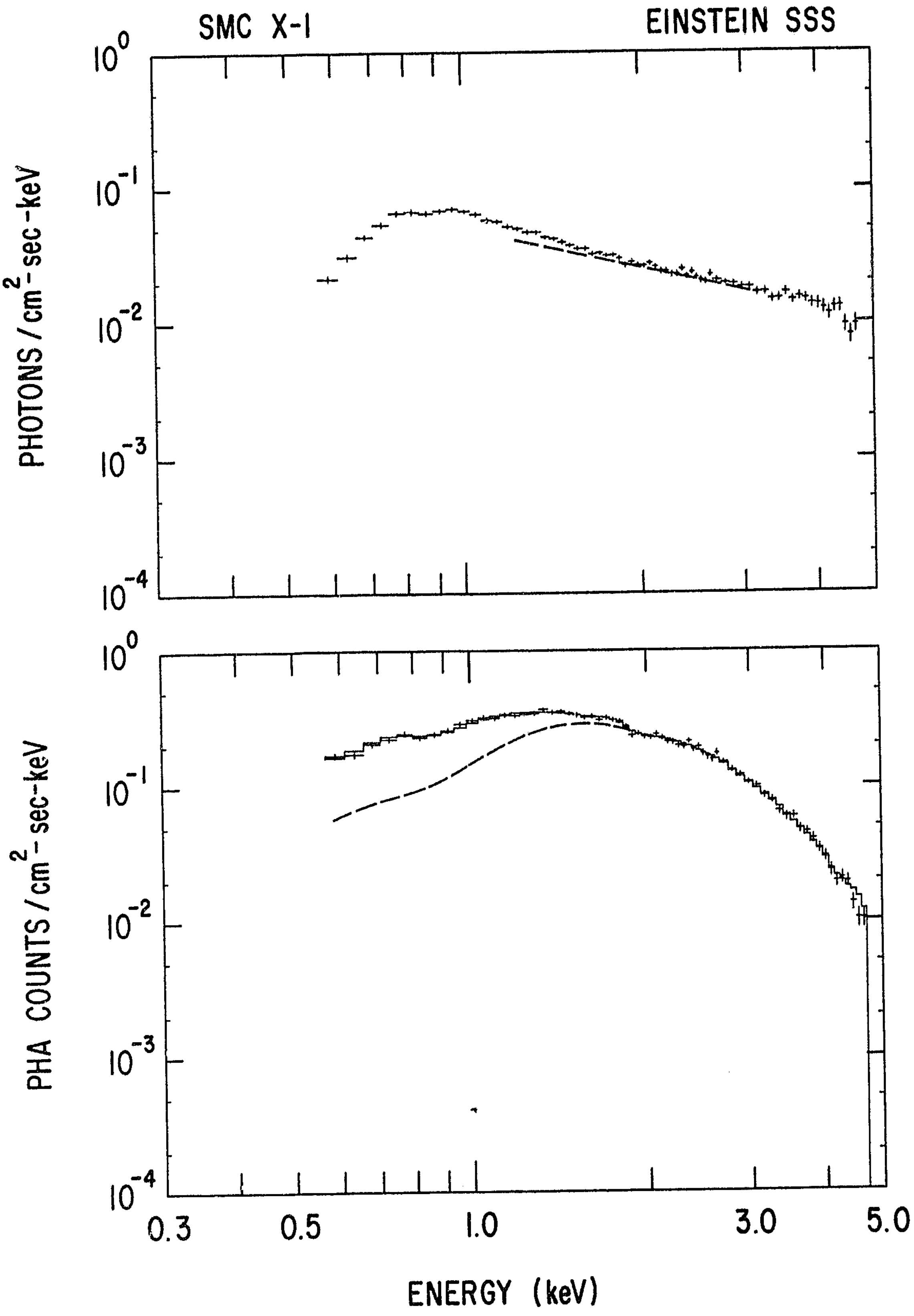
0.5
1.0
0.5
ARBITRARY PULSE PHASE


SMC X-1
EINSTEIN SSS
PHOTONS / cm² - sec - keV
PHA COUNTS / cm² - sec - keV
10⁰
10⁻¹
10⁻²
10⁻³
10⁻⁴
0.3
0.5
1.0
3.0
5.0
ENERGY (keV)

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