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THE X-RAY PULSARS 4U1145-61 and 1E1145.1-6141

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ABSTRACT

Observations of the X-ray sources near 4U1145-61, with three separate experiments spanning four years, are presented. We confirm the presence of two periodicities at 291 and 297 seconds. The location of the shorter period is isolated to within 3 arc minutes of 4U1145-61. The spectrum of 4U1145-61 is a power law ($\alpha \sim 1.5$) out to at least 60 keV with a 500 eV EW iron line at 6.7 keV. The inferred spectrum of the other is absorbed ($N_H \gtrsim 10^{23}$ H atoms cm^{-2}). We find no evidence for a monotonic variation in either pulse period ($\frac{\dot{P}}{P} < 10^{-4}$ yr^{-1}) over four years.

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I. INTRODUCTION

White et al. (1978) discovered two X-ray pulsations with periods of 291 and 297 seconds from the vicinity of 4U1145-61 using Ariel 5 observations made in late 1977. The field of view of their instrument was several square degrees and they could not distinguish whether the pulsations originated either from two separate sources within one degree of 4U1145-61 or from the same source. A recent Imaging Proportional Counter observation by the Einstein Observatory has resolved this problem by revealing the presence of a second source 1E1145.1-6141 that is ~ 20 arc minutes to the north of 4U1145-61 (2S1145-61, Lamb et al. 1980). This observation also indicated that the new source is associated with the 297s period and that 4U1145-61 is pulsed with the shorter period. We report here a number of observations of 4U1145-61 and 1E1145.1-6141 made by OSO-8, HEAO-1 and Einstein between 1975 and 1979.

II. TEMPORAL ANALYSIS

In all but the case of the Einstein observation, the fields of view of the instruments used in this study were larger than 1 square degree and thus included both sources. The data were searched for the two periods using the power spectrum technique described in White et al. (1976). The results of this search are given in Table 1 and can be summarized as follows:

Einstein - the Solid State Spectrometer (SSS; Joyce et al. 1978) and Monitor Proportional Counter (MPC; Giacconi et al. 1979) on the Einstein Observatory made two observations of 4U1145-61 in January and July 1979, 3 and 36 hours long centered on the position of the optical counterpart HEN 715. Because the field of view of the SSS is 6 arc minutes while that of the MPC is 1.5^{o}, the MPC viewed both sources while the SSS simultaneously only saw 4U1145-61. The power spectrum of the July 79 observation is shown in Figure 1. It is clear that both periods were detected in the MPC but only the shorter one was present in the SSS date. This confirms the presence of the two pulsations and restricts the origin of the 291 s period to within 3 arc minutes of HEN 715. In January 1979 only the 291 s period was detected, but because the observation was only 3 hours long the upper limit to the amplitude of the other period is not very restrictive (Table 1).

OSO-8 - The A detector (Serlemitsos et al. 1976) observed this region of the sky for 5 days starting on 1975 July 19. Both pulsations were detected, at levels such that the *a priori* probabilities that the detections arose from random fluctuations were 10^{-10} and 10^{-2}, for the longer and shorter periods, respectively. A second observation was made by the C detector for 2.5 days starting on 1976 January 24. In this case only the 297 second period was detected (probability of 10^{-4}); however if the 291 second pulsation had been present at the level seen six months earlier it would have been below our detection threshold.

HEAO-1 - A six hour pointed observation was made on 1978 August 2 by the A2[+] experiment (Rothschild et al. 1978). Only the 291 second period was

[+]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.

detected (probability < 10^{-30}) with an upper limit to the amplitude of the 297 s pulsation ∿ 25 times less than that of the shorter period.

The HEAO-1 data were folded into two broad energy bands about the 291 second period. We also folded the MPC and SSS 1979 July data about this period. Because almost a year separated the HEAO 1 and 2 observations we used the MPC profile to time align the SSS light curve with the HEAO-1 data. These profiles are shown in Figure 2 and it can be seen that the 291 second pulsation is approximately sinusoidal with little if any energy dependence. Both the HEAO-1 and SSS data are uncontaminated by the new source and both yield a peak to mean modulation amplitude of ∿20%. We subtracted from the July MPC observation a sine wave plus d.c. flux with the period, phase and intensity of the shorter period and folded about the 297 second period. This is also shown in Figure 2. The longer pulsation shows some evidence for an interpulse and has a pulsed fraction three times larger than 4U1145-61. To test for energy dependence in the 297 second pulse we split the MPC data into two energy bands: 1.5 to 3.5 keV and 4.6 to 14.0 keV. A power spectrum analysis revealed the 297 second period to be present only in the high energy band. The pulse fraction of the 291 second period was the same in the MPC low energy band as in the SSS and HEAO 1 data, indicating no flux from 1E1145.1-6141 at low energies. If it is assumed that the continuum of the new source is relatively flat then this implies that the new source was highly absorbed ($N_H \gtrsim 1 \times 10^{23}$ H atoms cm^{-2}).

If it is assumed that the pulse fraction of each period is independent of intensity, the pulse amplitudes from the SSS and MPC observations can be used to obtain a measure of the total flux from each pulsation. These are given in Table 1 and though they are only crude values they do show that the flux from each source varies by at least an order of magnitude.

III. SPECTRAL ANALYSIS

We obtained a 64 channel PHA spectrum for 4U1145-61 from the HEAO 1 pointed observation from both the MED (1.5 to 18 keV) and HED (3 to 60 keV) detectors, which are shown in Figure 3. Both spectra are best-fit by a 1.5 power law with no high energy cut off below 60 keV. There is a strong (EW $\sim$ 500 eV) relatively narrow iron line at 6.7 keV. There is no evidence for any 291 s pulse phase variability. The best fitting parameters are given in Table 1. The fit for the MED was improved if an additional low temperature ($\sim$ 0.7 keV) component was included, with a luminosity comparable to that in the 2-6 keV band.

The SSS gives 128 channels of PHA with an energy resolution of $\sim$ 160 eV. For both SSS observations the spectrum was consistent with the power law of 1.5 seen by HEAO 1. We can set EW upper limits of 150 eV and 60 eV for broad and narrow line emission respectively from either Si or S at 1.75 and 2.45 keV. There was no evidence for the low temperature component seen by HEAO 1. We note that the IPC observation also revealed evidence for a bright extended source $\sim$ 25 arc minutes to the east of 4U1145-61 (R.C. Lamb, private comm.). This may be responsible for the soft component seen by HEAO 1.

IV. DISCUSSION

The fact that the 297 s period was not detected by the HEAO 1 detectors implies that 1E1145.1-6141 was either turned off or at a very low level during this observation. Therefore the HEAO 1 spectrum is, to the lowest order, just that of the 291 s pulsar 4U1145-61. This spectrum is remarkably like that of the 38-s pulsar (OA01653-40) in that it has no high energy cutoff below $\sim$ 60 keV, little variation in the spectrum with pulse phase and strong iron line emission (see White and Pravdo 1979 and discussions therein). Most X-ray pulsars in binaries have spectra which are both variable with pulse phase, and cut off near 15 keV (e.g. Holt et al. 1974; Pravdo et al. 1979). These two effects may be due to the presence of a superstrong magnetic field ($B \sim 10^{12}$ gauss) in the emission region (Boldt et al. 1976; Pravdo, Bussard and Kylafis 1980). We can speculate that either the magnetic fields of both 4U1145-61 and the 38 s pulsar are either much weaker (or stronger?) or we are sampling a different range of magnetic latitude.

Ariel 5 obtained a spectrum in December 1978 which, contrary to the HEAO 1 result, indicated a power law of index 1.0 with a high energy cutoff at 8.5 keV (White et al. 1978). However, the Ariel 5 measurement was made when both pulsations (i.e. both sources) were at a detectable level (Table 1) and the spectrum must be a combination of that from each of the two pulsars. We have found that 1E1145.1-6141 is more absorbed and this combined with the 1.5 power law from 4U1145-61 could qualitatively reproduce the Ariel 5 spectrum. The fact that 1E1145.1-6141 was off when the HEAO 1 measurement was made was very fortuitous and future spectral measurements of either these sources will be difficult, unless an instrument with a small field of view or imaging capability is employed.

Given in Table 1 are all the heliocentric pulse period measurements, including those from Ariel 5. The two Ariel 5 measurements were separated by one hundred days and the measured periods changed in opposite directions by 0.2 and 0.1 seconds for the longer and shorter periods respectively. However Table 1 shows a much less dramatic change in either period, i.e. $\lesssim$ 0.5 s over 4 years

($\dot{P}/P < 10^{-4}$). The short term period changes could result from intrinsic 'jitter' in the pulse period (e.g. Lamb, Pines and Shahan 1978). An alternate explanation is that they result from orbital effects. The size of the variations correspond to velocities of $\sim$ 100 km s^{-1} which is what might be expected for a conventional X-ray binary system with an orbital period of one or two hundred days. Ariel 5 set lower limits to orbital variations less than $\sim$ 40 days for both sources. Unfortunately the observations to date are too fragmented to yield a unique orbital solution. These period measurements do suggest however that both pulsars are in similar binary systems with periods of the order of 100-200 days.

The similarities between these two pulsars, i.e. their pulse periods and suggested orbital periods, is made even more striking by their close spatial location. It is notable that this region of sky contains at least four other X-ray pulsars within a $2^{0} \times 10^{0}$ area (Cen X-3, A1118-61, 4U1258-61 and 4U1223-62) which currently represents about one third of the currently known X-ray pulsars. The galactic latitude of these six sources ranges from $292\text{-}304^{0}$ and is towards the Carina-Centaurus section of the galaxy (see Bok, Mine and Miller 1970 and references therein). In this direction we are viewing down the Carina spiral feature, which is relatively unobscured out to at least 6 kpc and rich in population I objects. It has been noted that X-ray pulsars tend to be associated with O and B stars (Maraschi et al. 1976; Bradt et al. 1977) and this sample of sources contains no exceptions. Positive optical identifications have been made for Cen X-3, 4U1145-61, 4U1223-62 and 4U1258-61, all with O or B type stars. Distance estimates of 8, 1.5, 2 and 2 kpc respectively place all these sources within the Carina feature. Thus it may be more than fortuitous that there is a clustering of X-ray pulsars in this direction, as this association suggests that they are the result of pulsar formation in a homogeneous cloud of progenitors.

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REFERENCES

Bok, B.J., Mine, A.A., and Miller, E.W. 1979, IAU Symp. No 38, 246.

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

Bradt, M.V. et al. 1977, Nature 269, 21.

Giacconi, R. et al. 1979, Ap. J. 230, 540.

Holt, S.S., Boldt, E.A., Rothschild, R.E., Saba, J.R., and Serlemitsos, P.J. 1974, Ap. J. 190, L109.

Joyce, R.M., Becker, R.H., Birsa, F.B., Holt, S.S., and Noordzy, M.P. 1978, IEEE Trans. Nuc. Sci. 25, 453.

Lamb, F.K., Pines, D. and Shahan, J. 1978, Ap. J. 224, 969.

Lamb, R.C., Markert, T.M., Hartman, R.E., Thompson, D.J., and Bignami, G.F. 1980, this issue.

Maraschi, L., Treves, A., and van den Heuvel, H.P.J. 1976, Nature 259, 292.

Pravdo, S.H., Bussard, R., and Kylafis, N. 1980, in preparation.

Pravdo, S.H., White, N.E., Boldt, E.A., Holt, S.S., Serlemitsos, P.J., Swank, J.H., Szymkowiak, A.E., Tuohy, I., and Garmire,

Rothschild, R., Boldt, E.A., Holt, S.S., Serlemitsos, P.J., Garmire, G., Agrawal, P., Riegler, G., Bowyer, S., and Lampton, M. 1979, Space Sci. Inst, in press.

Serlemitsos, R., Becker, R., Boldt, E.A., Holt, S.S., Pravdo, S.H., Rothschild, R., Swank, J.H. 1976, X-Ray Binaries Symposium, NASA SP-389.

White, N.E., Mason, K.O., Huckle, M.E., Charles, P.A., and Sanford, P.W. 1976, Ap. J. 209, L119.

White, N.E., Parkes, G.E., Sanford, P.W., Mason, K.O., and Murdin, P.G. 1978, Nature 274, 664.

White, N.E., and Pravdo, S.H. 1979, Ap. J. 233, L121.

TABLE 1: 4U1145-61 PULSE PERIODS PARAMETERS

SATELLITE	DATE	PULSATION A (1E1145.1-6141) PERIOD(s)	PULSATION A (1E1145.1-6141) FLUX (10^{34} erg s^{-1} kpc^{-2})	PULSATION B (4U1145-61) PERIOD(s)	PULSATION B (4U1145-61) FLUX (10^{34} erg s^{-1} kpc^{-2})
OSO 8	1975 Jul 21	297.29 ± 0.02	0.7	291.77 ± 0.03	1.2
OSO 8	1976 Jan 25	297.24 ± 0.06	0.8	----	$\lesssim 1.2$
Ariel 5	1977 Oct 1	297.270 ± 0.012	0.8	291.888 ± 0.012	3.1
Ariel 5	1977 Dec 7	297.498 ± 0.018	0.8	291.798 ± 0.012	12
HEAO 1	1978 Aug 2	-----	$\lesssim 0.06$	291.95 ± 0.24	1.5
Einstein	1979 Jan 25	-----	$\lesssim 2.0$	291.6 ± 1.8	1.3
Einstein	1979 Jul 15	297.66 ± 0.15	0.4	291.72 ± 0.15	0.7

The HEAO 1 flux was determined from the spectral results. The other fluxes are for the 2 to 15 keV band assuming a rab like spectrum. These are meant only as a crude indicator to the luminosities of the two pulsations and they could be in error by up to a factor 2 from one satellite to another.

TABLE 2a - 4U1145-61: CONTINUUM PARAMETERS[a]

DETECTOR	POWER LAW NORMALIZATION	NUMBER INDEX α	N_H 10^{21} H-atoms cm^{-2}	THERMAL NORMALIZATION	kT_{soft} (keV)	χ^2/d.o.f.
MED	0.0285	1.65	< 3.6	---	---	62/44
MED	0.0225 ± 0.0013	1.52 ± 0.03	< 3.6	0.087 ± 0.055	0.74 ± 0.00	29/42
HED	.0236 ± 0.0028	1.54 ± 0.05	---	---	---	53/44

TABLE 2b - 4U1145-61: IRON LINE PARAMETERS[a]

DETECTOR	LINE ENERGY (keV)	EQUIVALENT WIDTH (keV)	LINE PHOTONS 10^{-4} Photons cm^{-2} sec^{-1}	INTRINSIC WIDTH (keV)
MED	6.71 ± 0.06	0.62 ± 0.06	7.72 ± 0.76	< 1.1
HED	6.73 ± 0.11	0.28 ± 0.07	3.43 ± 0.87	< 1.1

[a] 1 sigma errors quoted

FIGURE CAPTIONS

Figure 1 - The power spectra of the MPC and SSS. The two periods are marked by A and B for the 297 and 291 s periods respectively.

Figure 2 - The pulse profiles of the two periods. The phase is arbitrary. The MPC and SSS amplitudes are uncertain by up to 10%. Note that the scale for 1E1145.1-6141 is a factor two smaller than that for 4U1145-61.

Figure 3 - The PHA and inverted spectra from HEAO 1 of 4U1145-61.

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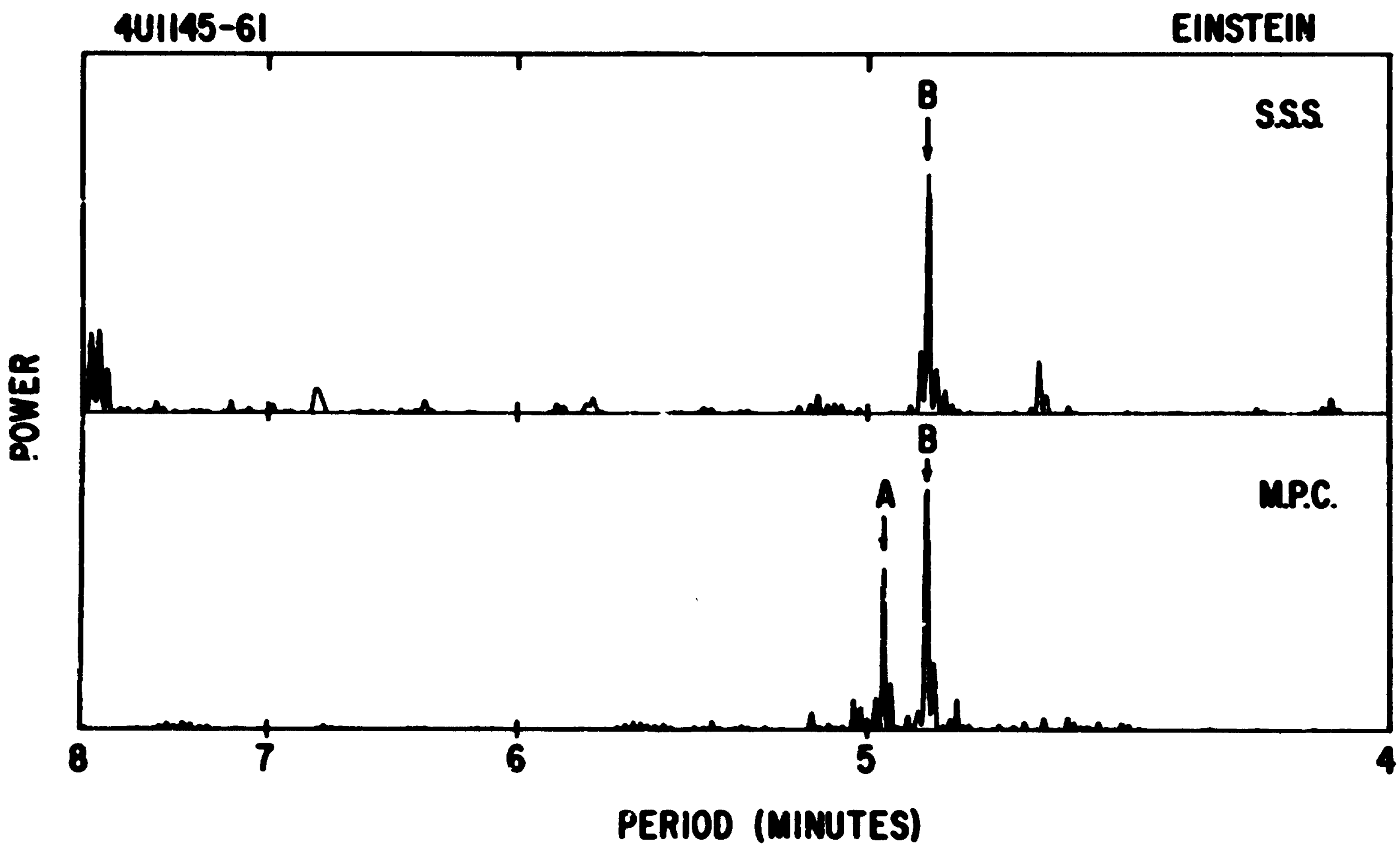
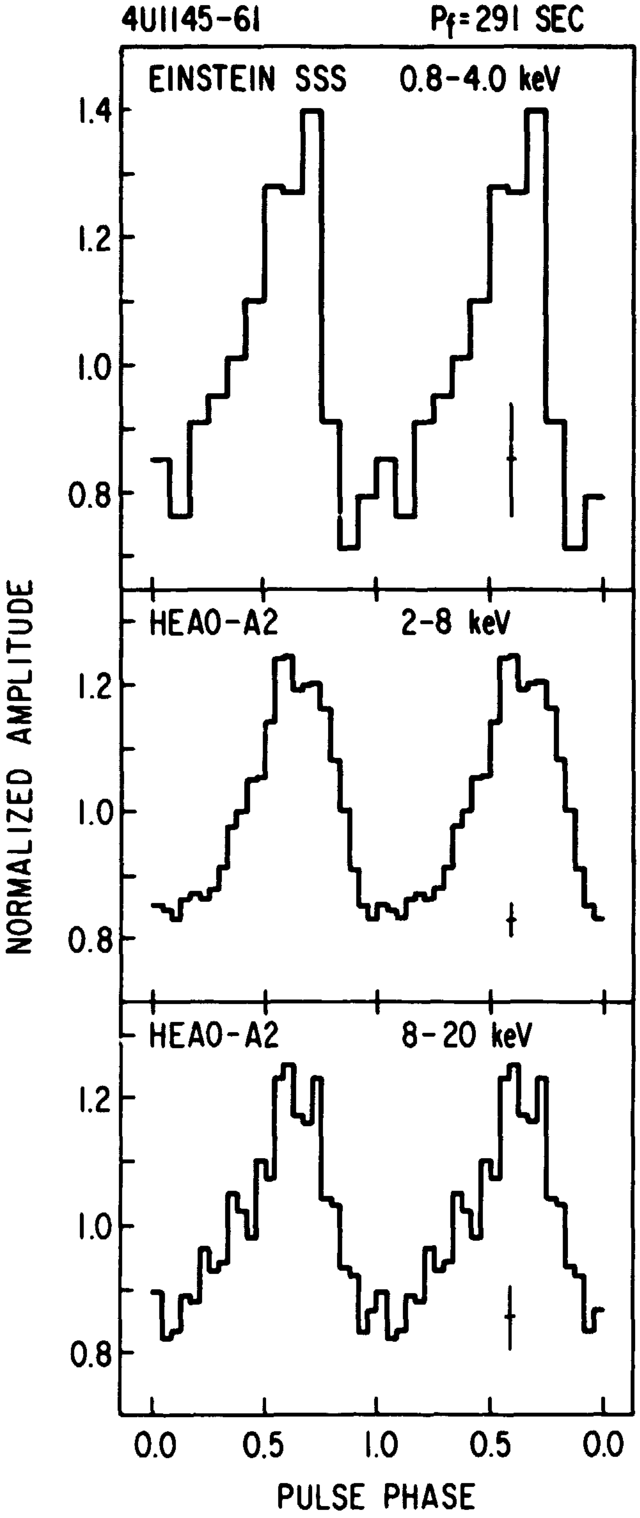
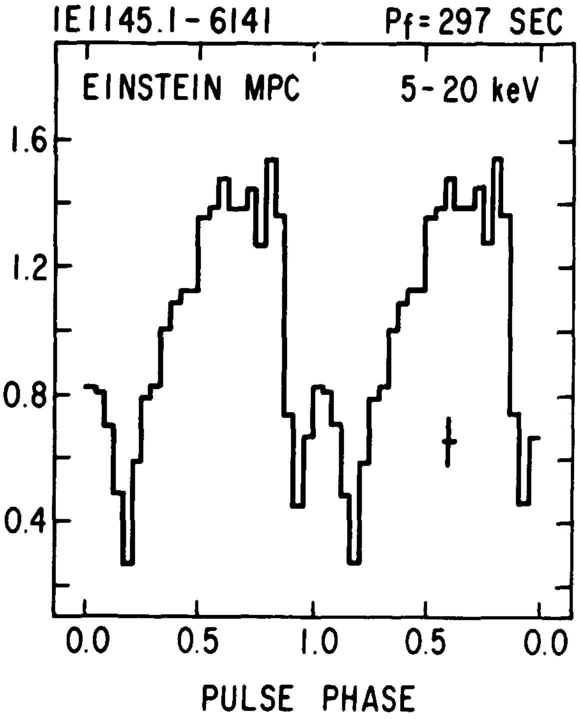
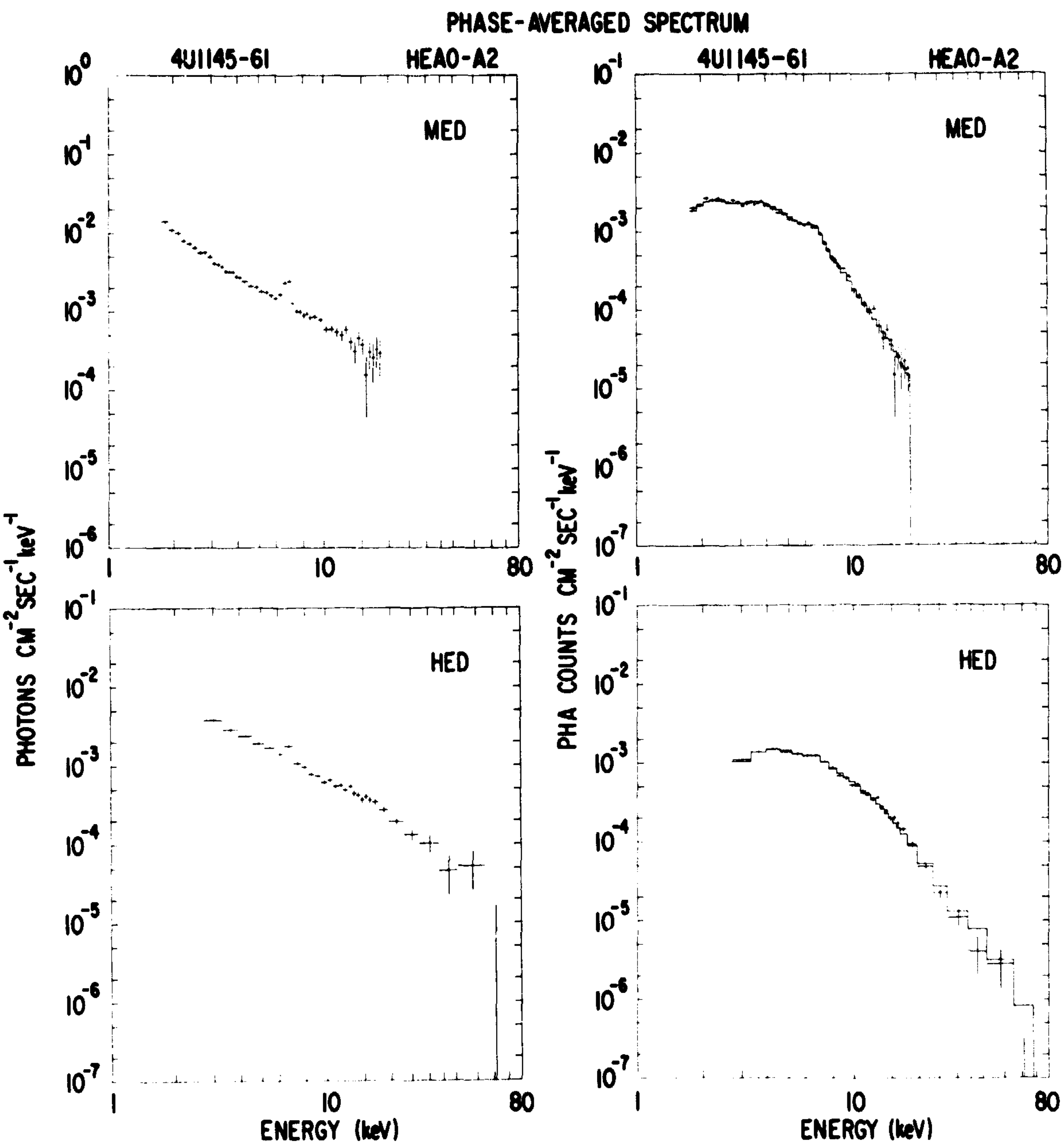


4U1145-61
EINSTEIN
S.S.S.
M.P.C.
B
A
POWER
8
7
6
5
4
PERIOD (MINUTES)


4U1145-61
Pf=291 SEC
EINSTEIN SSS
0.8-4.0 keV
HEAO-A2
2-8 keV
HEAO-A2
8-20 keV
NORMALIZED AMPLITUDE
1.4
1.2
1.0
0.8
0.0
0.5
1.0
PULSE PHASE


IE1145.1-6141
Pf=297 SEC
EINSTEIN MPC
5-20 keV
1.6
1.2
0.8
0.4
0.0
0.5
1.0
PULSE PHASE


PHASE-AVERAGED SPECTRUM
4U1145-61
HEAO-A2
MED
HED
PHOTONS CM^-2 SEC^-1 keV^-1
PHA COUNTS CM^-2 SEC^-1 keV^-1
ENERGY (keV)
1
10
80
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7

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16. Abstract

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