

## **General Disclaimer**

### **One or more of the Following Statements may affect this Document**

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.
- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.
- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.
- This document is paginated as submitted by the original source.
- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.



## Technical Memorandum 79727

# HEAO 1 Observations of the X-Ray Pulsar 4U1626-67

(NASA-TM-79727) HEAO 1 OBSERVATIONS OF THE  
X-RAY PULSAR 4U1626-67 (NASA) 22 p HC  
A02/MF A01 CSCL 03A

N79-20946

Unclas  
G3/89 19647

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

**MARCH 1979**

National Aeronautics and  
Space Administration

**Goddard Space Flight Center**  
Greenbelt, Maryland 20771



# HEAO 1 OBSERVATIONS OF THE X-RAY PULSAR 4U1626-67

S.H. Pravdo\*, N.E. White\*, E.A. Boldt, S.S. Holt  
P.J. Serlemitsos, J.H. Swank, A.E. Szymkowiak\*

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

and

I. Tuohy and G. Garmire

California Institute of Technology  
Pasadena, California 91125

## ABSTRACT

We report results of an observation of the 7-s pulsar 4U1626-67 with the A2 experiment on HEAO 1. The phase-averaged X-ray spectrum between 0.7 and 60 keV is complex as are the constituent spectra which change radically as a function of pulse phase. Included in this spectral change is the sudden appearance ( $\Delta\phi \leq 0.1$ ) and subsequent decay of a continuum or emission feature with a mean energy of 19 keV which contains about  $\frac{1}{2}$  the power in this spectral range. Pulse timing results include a new determination of the pulse period and a factor 8 reduction in the upper limit for the light travel time for orbital periods between 1 and 7 hours. We discuss these findings for this system and compare them with the general nature of pulsar spectra.

Subject headings: pulsars - X-rays: sources - X-rays: spectra

\* Also Dept. of Physics and Astronomy, Univ. of Maryland

## I. INTRODUCTION

It has been established that X-ray pulsars belong to a spectral class which is characterized by an extremely hard spectrum (power law index  $\alpha \approx 1$ ) in the 2-15 keV energy band (e.g. Ulmer 1975). The 7-sec pulse period of 4U1626-67 was discovered when a crude study of its spectrum (Markert et al. 1977) indicated that it was a member of this spectral class and a good candidate for a period search (Rappaport et al. 1977). If this pulsar is a member of a binary system, then variations in the pulse arrival times due to radial orbital motion can determine the orbital light travel time ( $a_x \sin i$ ), the orbital period ( $P_{\text{orb}}$ ), and hence the mass function for the system. Rappaport et al. did not detect this effect but were able to exclude a significant amount of the  $a_x \sin i$  vs.  $P_{\text{orb}}$  plane in parameter space. This result and that of McClintock et al. (1977) which suggested a faint blue star as the optical counterpart, led to a model of a binary system containing a neutron star and a low mass dwarf companion with  $P_{\text{orb}} \approx 7$  hours (Joss, Avni, and Rappaport 1978). The optical identification was confirmed by Ilovaisky, Motch, and Chevalier (1978) when they detected 7-sec pulsations from the star.

The pulse profile is very energy dependent showing drastic changes in amplitude, phase, and structure over a relatively small energy range (Rappaport et al. 1977). However there have been to date no detailed spectral studies of this source. We present here a HEAO 1 pointed observation of 4U1626-67 from which we have been able to obtain pulse phase spectroscopy and further improve the upper limits to orbital motion.

## II. THE OBSERVATIONS

The HEAO 1 A2<sup>+</sup> X-ray spectroscopy experiment (Rothschild et al. 1978)

---

<sup>+</sup>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.

---

observed 4U1626-67 for 5 hours starting at 15 hrs UT on 1978, March 29. Three co-aligned proportional counters were utilized, each containing a different filling gas. They were 1) propane filled (LED 0.7 to 1.9 keV at this time), 2) argon filled (MED 1.7-18 keV), and 3) xenon filled (HED 3.-80. keV). The MED and HED counts were pulse height analyzed into 64 channels with a temporal resolution of 20 ms. The broad band accumulation interval of the LED was 80 ms with 10 channel pulse height analysis every 40 s. The diffuse and particle backgrounds were obtained from off source observations prior to this measurement. The LED background was determined using a field-of-view subtraction technique.

## III. THE PULSE PERIOD

Periodogram analysis of the data revealed the 7.6 s pulse to be clearly present in each of the detectors. The energy dependent nature of the pulse profile was also evident. In order to maximize the amount of pulse phase information available the counts were binned into three energy ranges: 0.7 to 1.9 keV; 3. to 14. keV; and 14 to 30 keV. Each 30 minutes of data were folded about the period determined by the periodogram analysis. The phase of each of these light curves relative to an arbitrary reference point was then determined by fitting each light curve to a standard template. This process was repeated twice, the first time with one of the 30 min

folds used as the template, the second time using a master template constructed by superposing each of the 30 min light curves (excluding the light curve being fitted) shifted according to the phases determined from the first iteration. The light curves constructed from the second iteration are shown in Figure 1. Six measurements of the pulse phase were obtained in each energy interval with one sigma uncertainties of 0.07 lt s in both the 3-14 and 14-30 keV bands and 0.15 lt s in the 0.7 to 1.9 keV band.

Joss et al. (1978) using SAS 3 set stringent upper limits to orbital motion with a period greater than 7 hrs. However for periods less than this their upper limit to the projected semi-major axis ( $a_x \sin i$ ) was of the order of only 0.8 lt s (Figure 2). The gross effective area of the A-2 detectors is  $\sim 20$  times greater than SAS. By combining the phase measurements from each energy band we see no evidence for orbital periods less than 7 hrs with  $a_x \sin i \gtrsim 0.1$  lt s/(2 sigma) (Fig. 2).

The heliocentric pulse period derived from these measurements was  $7.678174 \pm 0.000051$  (2 sigma). Joss et al. obtained a value of  $7.6806273 \pm 0.0000005$  a year earlier, which yields a  $\dot{P}/P$  of  $-3.2 \times 10^{-4} \text{ yr}^{-1}$ . This is almost twice that measured by Joss et al. but variations of this magnitude are typical in the spinup rates of other binary pulsars (e.g. Mason 1977).

#### IV. AVERAGE SOURCE PROPERTIES

The average X-ray luminosity of 4U1626-67 during the pointed observation was  $2.9 (\pm 0.3) \times 10^{35} \text{ d}_{\text{kpc}}^2 \text{ erg sec}^{-1}$  between 0.7 - 60 keV. This result is similar to that observed with UHURU (Giacconi et al. 1974) and OSO-7 (Markert et al. 1977) in the 2-6 keV range, and also consistent with

the result of Rappaport et al. (1977) with the 1-30 keV energy range of SAS 3. For one week in September 1977 we obtained scanning observations of 4U1626-67. The average intensity was a third lower to that observed six months later and a factor  $\sim 2$  variability was observed on timescales of hours. We can not comment on the existence of the  $\sim 10^3$  sec quasi-periodic intensity oscillations discussed by Joss et al. because systematic aspect uncertainties during HEAO 1 pointings can result in spurious effects with a similar time scale. The scanning data consists of  $\sim 2$  minutes of observation every  $\sim 35$  minutes and is also not relevant for the  $\sim 10^3$  sec timescale.

The phase-averaged spectrum between 0.7-60 keV is shown in Figure 3. Pravdo et al. (1978) discuss the method of spectral analysis. This spectrum is quite complex and can be fitted by a range of different models. Between 5-20 keV a power law number index of  $\sim 0.4$  adequately describes the data. Above 20 keV the spectrum falls off sharply. This is a canonical phase-averaged pulsar spectrum. Below 5 keV an additional thermal or blackbody continuum component is present in some models. The apparent column density of cool material in the line of sight (Brown and Gould 1970; Fireman 1974) is model-dependent but is always  $\lesssim 4 \times 10^{21}$  H atoms  $\text{cm}^{-2}$ . A very broad line near 6.5 keV (FWHM  $\gtrsim 2$  keV) with  $.001-.01$  photons  $\text{cm}^{-2} \text{sec}^{-1}$  significantly improves the model fits ( $\Delta\chi_r^2 = 1$ ) and could indicate the presence of broadened iron line emission which has been seen in other pulsars (see Pravdo 1979 and references therein). However, the average spectrum is composed of radically varying constituent spectra, and thus the models for it may be misleading.

## V. PULSE PHASE SPECTRA OF 4U1626-67

Although the broad-band intensity pulses shown in Figure 1 are a representation of the spectral evolution, the pulse features (e.g. the rise time) are sensitively dependent on the chosen broad-band energy limits. In a model in which the X-ray emission is angle-dependent (the super-strong magnetic field model e.g. Basko et al. 1975) there is more information in the energy distribution of photons at a particular phase than with the distribution of photons at a particular energy over all phases. Interpretation of the latter is difficult since one can not distinguish the separate effects of energy-independent intensity changes (an overall pulse envelope) and spectral changes with pulse phase. We show in Figure 4 the evolution of the 4U1626-67 spectrum across the pulse. Each spectrum, progressing down the left column and then the right column, is comprised of 0.1 phase. There is bimodal distribution among the 10 spectra displayed. Figure 5 shows spectra 3 and 8 superposed. Spectra 1-5 and 10 harden considerably with the addition of a continuum or broad emission feature centered near 19 keV. There is also a relative deficiency near 10 keV in these spectra. Again, as in the case of the phase-averaged spectrum, no simple continuum model can fit these data. We present examples of two possible classes of models.

A superposition of continuum components plus a high energy cutoff can describe the spectra in Figure 4. Table 1 lists relevant parameters ( $\alpha$ -power law index,  $E_c$  and  $E_f$ -cutoff parameters, T-temperature and L-luminosity) for continuum models containing either a thin thermal bremsstrahlung or a blackbody component and a power-law continuum which is



modified by a high energy cutoff factor of the form  $\exp [-(E-E_c)/E_F]$ . The variation of  $\alpha$ ,  $E_c$ , and  $E_F$  across the pulse are now familiar properties of other pulsar spectra including Her X-1 (Pravdo et al. 1978) and 4U0115+63 (Rose et al. 1979). There is both a spectrally hard pulse region and a soft pulse region, as well as a less dramatic spectral evolution within each region (Tables 1 and 2). A striking difference, however, between 4U1626-67 and Her X-1 is that the spectrally hard section of the pulse has a duty cycle of 0.60 in the former compared to only 0.16 in the latter.

The power emitted in the possible low energy continuum components remains fairly constant over the pulse. For the blackbody model the temperature and luminosity imply a source radius of  $\sim 1 \times 10^5 d_{\text{kpc}}$  cm. This radius is on the order of a neutron star size. A thermal source with this size would have an average density of  $4 \times 10^{19} d_{\text{kpc}} \text{ cm}^{-3}$  and could be ruled out because of the lack of observed low energy absorption or absorption edges. A radius greater than  $\sim 10^9$  cm is indicated from the thermal model.

Another class of models contains broad emission features rather than multiple continuum components (Table 2). A single thin bremsstrahlung continuum with a broad (FWHM  $\sim 15$  keV) emission line can also describe these spectra. The centroid energy of this feature ranges from  $\sim 19$  keV to  $\sim 7$  keV while the power in the line goes from  $\sim 0.65$  to  $\sim 0.33$  of the total power. If we assume that the lower energy feature is always present, then a two-line model marginally improves the fits for spectra 1-5, 10. The temperature of the continuum remains fairly constant throughout the pulse but changes from  $\sim 10$  keV in the single-line model to  $\sim 5$  keV in the two-line model.

## VI. DISCUSSION

We have found no evidence for any Doppler variation in the pulse phase of 4U1626-67 that might result from orbital motion with periods between 1 and 7 hours. Combining this with the upper limit for periods between 7 hours and 300 days obtained by Joss et al. implies one of the following models: 1) the pulsar is an isolated neutron star accreting matter from an interstellar cloud; 2) it is part of a binary system whose inclination is low; 3) the orbital period is less than 1 hour or greater than 300 days.

Joss et al. have discussed these possibilities in the light of their upper limits between 7 hours and 300 days. They discount the first two models as unlikely and propose a binary system with a period of the order of a few hours containing a neutron star accreting material from either a main sequence dwarf or a low mass white dwarf. For a white dwarf companion with  $\approx 0.2 M_{\odot}$ ,  $a_x \sin i$  would be  $\approx 0.10$  lt s, which is at our measured limit. However if the companion were a main sequence M dwarf of mass  $\sim 0.3 M_{\odot}$  then our new upper limit indicates that it is of low inclination (i.e.  $\approx 20^\circ$ ). Thus the nature of this pulsar remains very much an open question.

Since a neutron star becomes a pulsar because of its superstrong magnetic field (e.g. Lamb, Pethick, and Pines 1973) it is natural to assume that the phase-dependent spectral characteristics are caused by magnetic effects. However it is difficult to associate the magnetic field energy with a given spectral feature. In the case of 4U1626-67 one might conclude that  $B = 3 \times 10^{12}$  gauss because of the prominent feature at this energy. Or, since another feature may exist near 8 keV the field

strength could be half this value with the  $\sim 19$  keV feature the second harmonic. Alternatively if the high energy cutoff is interpreted as cyclotron absorption (Pravdo et al. 1978) this implies a field strength of  $\sim 6 \times 10^{12}$  gauss. This ambiguity results because no viable, comprehensive models that we are aware of now exist. Although there has been a considerable theoretical effort begun on this problem, in many cases important assumptions of the modelling may not have been justified. This particular situation probably requires use of the relativistically correct, strong-field cross sections (with photon  $E \sim \frac{eh}{mc} B$ ) in a high temperature ( $T > 20$  keV), optically thick plasma (Bussard 1978 and references therein).

It is interesting to note that the broad band (2-60 keV) intensity of 4U1626-67 does not appear to pulse. Over this energy range the narrow band pulses destructively interfere. The number of photons remains constant, while the energy content of the pulse decreases by 30% with a duty cycle of 0.40 (see Table 2). To explain this we must devise a phase-dependent mechanism which conserves photon number while substantially changing photon energy. Compton scattering does both. However, the fact that the transition from hard to soft spectra occurs within 0.1 phase (Figure 4) indicates that the mechanism can not have performed the isotropization which accompanies normal Compton scatterings. Anisotropic Compton scattering in a strong magnetic field (Canuto et al. 1971; Boldt et al. 1976) may therefore be an important part of the explanation.

There may be significance in a comparison of this source with Her X-1. In the 2-30 keV Her X-1 spectrum a single spectral form can adequately describe the spectrum over 84% of the pulse phase with only the normalization

left as a free parameter (Pravdo et al. 1978). The normalization changes by a factor  $\sim 3$  indicating a "background" component of emission which is spectrally but not spatially isotropic. A Compton scattering shell removed from the pulsar surface (Basko and Sunyaev 1976; McCray and Lamb 1976) with a suitable geometry could provide this emission and form the overall intensity envelope (Basko 1977). Another component of emission is viewed directly from the stellar surface in the Her X-1 hard X-ray "spectral pulse" (Pravdo et al. 1978). We suggest a connection between the presence of a background component in Her X-1 and the relatively small duty cycle of the spectral pulse. The Compton scattering shell could effectively shield the line of sight from most of the surface emission region. The 7-s pulsar has no background component and no broad-band intensity pulse. Perhaps in this case a Compton shell is either absent or too small to significantly shield any of the surface or to be the source of reflected X-rays. This shell is also thought to be the source of the intense soft X-ray ( $T \sim 10^6$  K) flux from Her X-1 (Catura and Acton 1975; Shulman et al. 1975). Therefore, we would not expect 4U1626-67 to be a strong soft X-ray source. The spectral evidence is not yet complete (i.e. for  $E < 0.7$  keV) but does tend to support this final point.

The spectrum of 4U1626-67 is so complex that at the present time no firm conclusions about the emitting regions can be made. Detailed modelling of the spectral changes across the pulse are required for further progress. However, these spectra are only the most extreme example of common X-ray pulsar phenomena. Recently features have been detected in the X-ray spectra of two pulsars. These have been interpreted as an emission

line in Her X-1 (Trumper et al. 1978) and an absorption line in 4U0115+63 (Wheaton et al. 1978), originating in the superstrong magnetic field ( $> 10^{12}$  gauss) at the surface of neutron stars. However in these analyses the assumption was made that a d.c. emission component exists and is found in the pulse intensity minimum. In both cases cited above the intensity minimum of the pulse was used as a background spectrum for the intensity maximum to obtain a "pulsed spectrum", although Trumper et al. obtained similar results of lower statistical significance using off-source background. Using the same procedure for the spectra shown in Figure 5 would result in dramatic non-physical spectral features. Rose et al. (1979) have discussed similar effects in the spectrum of 4U0115+63 in which a narrow feature can appear in the net spectrum. We conclude that in general, the d.c. component can not be eliminated by this method without the danger of subtracting one part of the pulsed emission from another and thereby creating spurious features.

We acknowledge useful discussions with F.K. Lamb, D.Q. Lamb, R. Lamb, P.L. Lamb, and J. Cash.

TABLE 1

## CONTINUUM MODELS

Spectrum $\phi$	$\alpha$	$E_C^1$	$E_F^1$	$T_{Th}^1$	$L_{Th}^*$	$T_{BB}^1$	$L_{BB}^*$	$L_{tot}^*$
0.	.26	22.7	7.0	1.6	3.6	0.64	2.9	7.8
0.1	.22	24.0	4.7	1.7	3.6	0.64	2.9	7.9
0.2	0.	22.9	5.8	1.6	2.4	0.65	3.1	7.3
0.3	0.	22.6	5.7	1.7	3.8	0.63	2.9	8.1
0.4	0.	21.7	5.4	1.7	3.8	0.63	2.9	8.1
0.5	.30	15.7	7.7	2.1	3.2	0.65	2.4	8.2
0.6	.50	13.3	7.6	1.8	2.3	0.68	2.8	8.4
0.7	.56	15.1	6.6	1.7	2.2	0.68	2.5	8.4
0.8	.48	14.9	7.8	1.5	1.8	0.65	1.7	8.7
0.9	.40	23.7	4.6	1.6	3.3	0.63	2.7	8.1
TYPICAL ERROR	.05	0.4	0.5	0.1	0.3	.02	0.3	0.5

<sup>1</sup> Cutoff parameters  $E_C$ ,  $E_F$  and temperature for the thin thermal  $T_{Th}$  and blackbody  $T_{BB}$  models in keV.

\* 2-10 keV luminosity in units of  $10^{34} d_{kpc}^2$  erg/s.

TABLE 2  
EMISSION FEATURE MODELS

Spectrum $\phi$	One Line Model			Two Line Model					
	$T_{TH}^1$	$E_L^1$	$L_L^+$	$T_{TH}^1$	$E_{L1}^1$	$L_{L1}^+$	$E_{L2}^1$	$L_{L2}^1$	$L_{TOT}^+$
0.	10.5	18.9	17.	4.6	18.2	19.	7.1	2.0	29.
0.1	11.2	19.3	17.	4.6	18.2	20.	6.3	1.9	26.
0.2	8.9	18.8	21.	7.1	19.1	21.	8.3	1.4	31.
0.3	8.8	18.5	22.	5.8	17.9	23.	7.7	0.4	31.
0.4	8.9	18.0	20.	5.8	17.2	22.	6.9	0.3	30.
0.5	10.0	9.2	14.	-	-	-	-	-	22.
0.6	11.7	8.1	6.1	-	-	-	-	-	18.
0.7	10.4	6.7	6.9	-	-	-	-	-	18.
0.8	11.0	6.2	11.	-	-	-	-	-	20.
0.9	<u>9.3</u>	<u>17.5</u>	<u>18.</u>	<u>4.8</u>	<u>17.4</u>	<u>19.</u>	<u>8.5</u>	<u>1.2</u>	<u>28.</u>
TYPICAL ERROR	2.6	2.7	0.8	0.6	1.0	0.8	0.8	0.2	1.8

<sup>1</sup> Thin thermal temperature  $T_{TH}$  and line energies  $E_L$  in keV.

<sup>+</sup> 2-60 keV luminosity in units of  $10^{34} d_{kpc}^2$  erg/s.

## REFERENCES

- Basko, M.M. 1977, *Astron Zh.* 54, 1050 (transl. in *Sov Astron* 21, 595).
- Basko, M.M. and Sunyaev, R.A. 1975, *Astr. Ap.* 42, 311.
- Basko, M.M. and Sunyaev, R.A. 1976, *M.N.R.A.S.* 175, 395.
- Boldt, F.A., Holt, S.S., Rothschild, R.E. and Serlemitsos, P.J. 1976, *Astr. Ap.* 50, 161.
- Brown, R.L. and Gould, R.J. 1970, *Phys. Rev.* D1, 2252.
- Bussard, R.W. 1978, Ph.D. Thesis, U. of Md.
- Canuto, V., Lodenguai, J., and Ruderman, J. 1971, *Phys. Rev.* D3, 2303.
- Catura, R.C. and Acton, L.W. 1975, *Ap. J. (Letters)* 202, L5.
- Fireman, E.L. 1974, *Ap. J.* 187, 57.
- Giacconi, R., Murray, S., Gursky, H., Kellogg, E., Schreier, E., Matilsky, T., Kock, D., and Tananbaum, H. 1974, *Ap. J. Supple.* 27, 37.
- Ilovaisky, S.A., Motch, C., and Chevalier, C. 1978, *Astr. and Ap.* 70, L19.
- Joss, P.C., Avni, Y., and Rappaport, S. 1978, *Ap. J.* 221, 645.
- Lamb, F.K., Pethick, C.J., and Pines, D. 1973, *Ap. J.* 184, 271.
- Markert, T.H., Laird, F.N., Winkler, P.F., Clark, G.W., Hearn, P., Li, F.K., Sprott, G.F., Bradt, H.V., Lewin, W.H.G., and Schnopper, H.W. 1978, to be published in *Ap. J. (Supple)*.
- Mason, K.O. 1977, *M.N.R.A.S.* 178, 81p.
- McClintock, J.E., Canezares, C.R., Bradt, H.V., Doxsey, R.E., and Jernigan, J.G. 1977, *Nature* 270, 320.
- McCray, R. and Lamb, F.K. 1976, *Ap. J. (Letters)* 204, L175.
- Pravdo, S.H., Proceedings of the Symposium on X-ray Astronomy, XXI COSPAR/IAU, Pergamon Press, Oxford, in press, 1979.
- Pravdo, S.H., Bussard, R.W., Becker, R.H., Boldt, F.A., Holt, S.S., and Serlemitsos, P.J. 1978, *Ap. J.* 225, 988.



Rappaport, S., Markert, T., Li, F.K., Clark, G.W., Jernigan, J.G., and

McClintock, J.E. 1977, Ap. J. (Letters) 217, L29.

Rose, L.A., Pravdo, S.H., Kaluziński, L.J., Marshall, F.E., Holt, S.S.,

Boldt, E.A., Rothschild, R.E., and Serlemitsos, P.J. 1978, Bull.

of AAS 10, 506.

Rose, L.A., Pravdo, S.H., Kaluziński, L.J., Marshall, F.E., Holt, S.S.,

Boldt, E.A., Rothschild, R.E., and Serlemitsos, P.J. 1979, submitted

to Ap. J.

Rothschild, R., Boldt, E., Holt, S., Serlemitsos, P., Garmire, G., Agrawal,

P., Riegler, G., Bowyer, S., and Lampton, M. 1978, NASA TM 79574,

submitted to Sp. Sci. Instrumentation.

Schulman, S., Friedman, H., Fritz, G., Henry, R.C., and Yentis, D.J.

1975, Ap. J. (Letters) 199, L101.

Trumper, J., Pietsch, W., Reppis, C., Voges, W., Staubert, R., and Kendziorra,

E. 1978, Ap. J. (Letters) 219, L105.

Ulmer, M.P. 1975, Ap. J. 196, 827.

Wheaton, W., Primwi, F., Tsiang, E., Howe, S., Campbell, P., Hoffman, J.,

Lewin, W., Gruber, D., Noland, P., Rothschild, R., Pelling, R., and

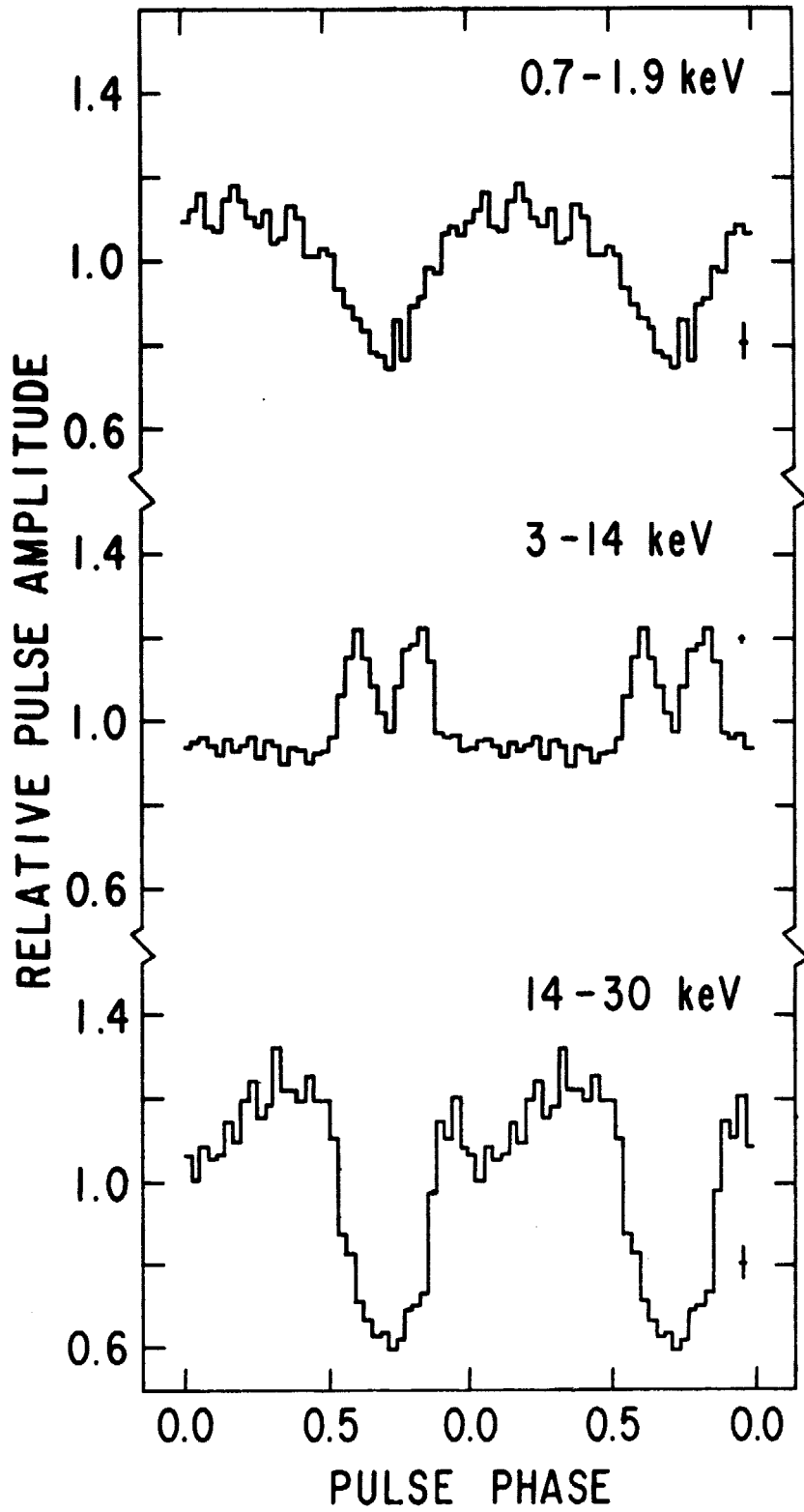
Peterson, L. 1978, Bull of AAS 10, 446.

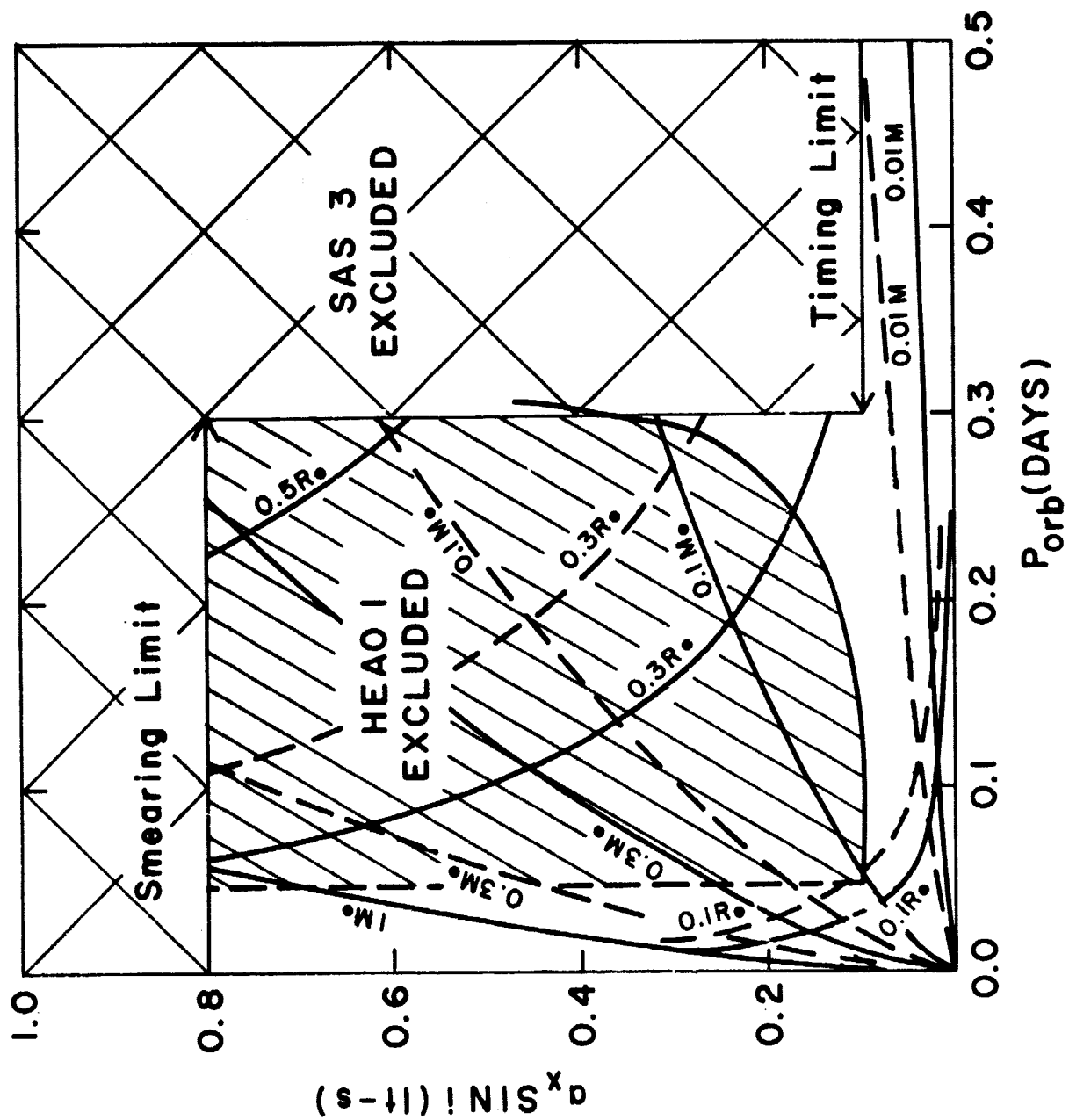
## FIGURE CAPTIONS

- Figure 1 - The master template obtained from these HEAO A-2 observations. One sigma uncertainties are shown. The amplitude has been normalized relative to the mean count rate above the background. The effective area of the HED in the 30-60 keV band is still of the order of  $\sim 50 \text{ cm}^2$  and the pulse was detected in this band. Although the statistics are not good quality the pulse profile is similar both in structure, amplitude, and phase to that seen in the 14-30 keV band.
- Figure 2 - The new upper limit of allowed values of  $a_x \sin i$  and  $P_{\text{orb}}$  obtained by HEAO A-2 superposed upon earlier SAS 3 measurements (taken from Joss et al.). The solid and dashed lines are loci of the indicated values of the mass and radius of the companion for  $M_x = 1.5 M_\odot$  and  $M_x = 0.5 M_\odot$  respectively. Both assume  $\sin i = 1$ .
- Figure 3 - The phase-averaged inferred incident spectrum of 4U1626-67.
- Figure 4 - The spectrum of 4U1626-67 as a function of pulse phase. Each spectrum corresponds to a successive 0.1 pulse phase starting in the upper left column and continuing down first the left and then the right column. The first spectrum begins at phase 0 as defined in the light curves in Fig. 1. Phase 0 corresponds to JD 2443596.5.
- Figure 5 - Superposition of spectra number 3 and 8.

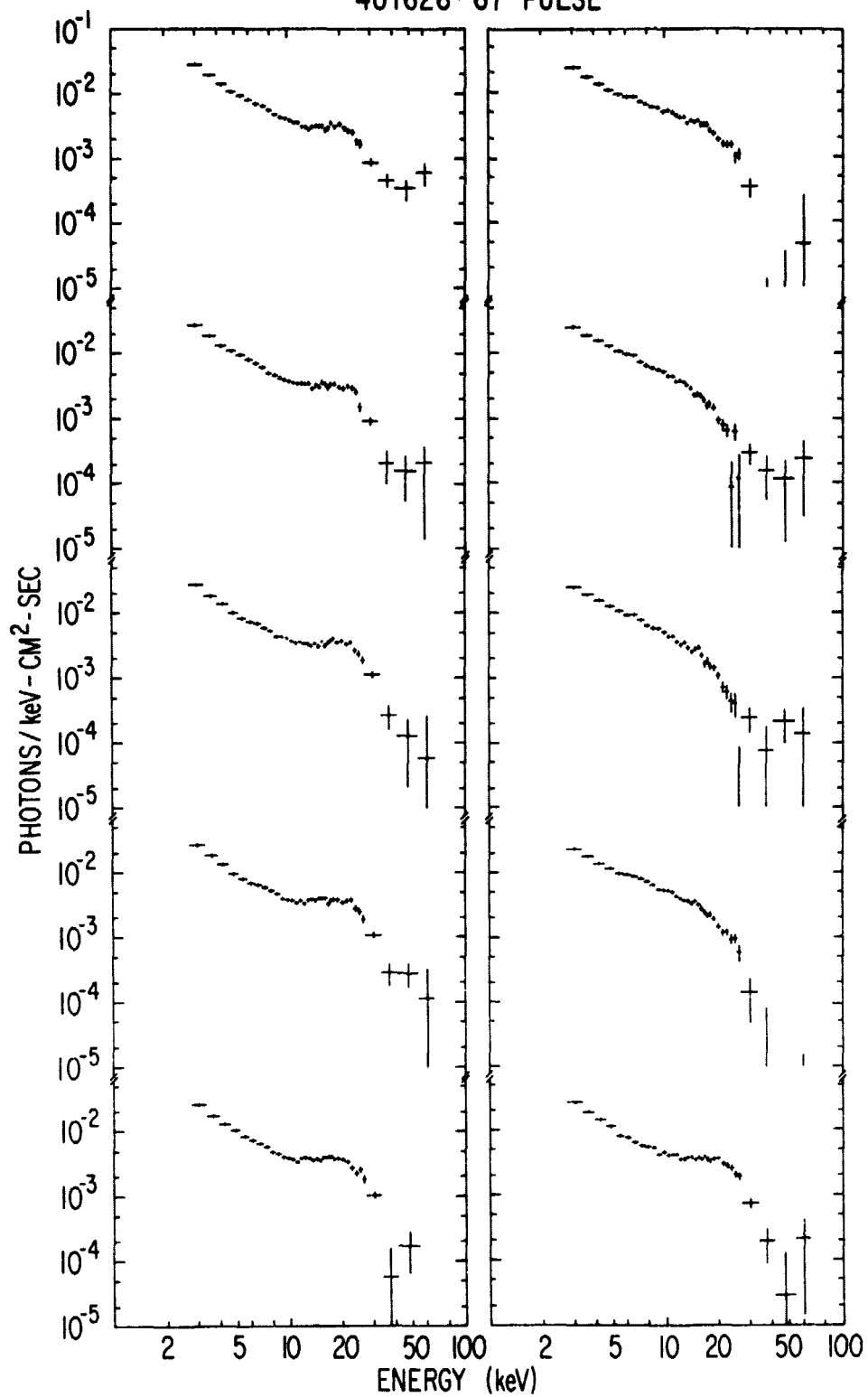
HEAO A-2

4U 1626-67

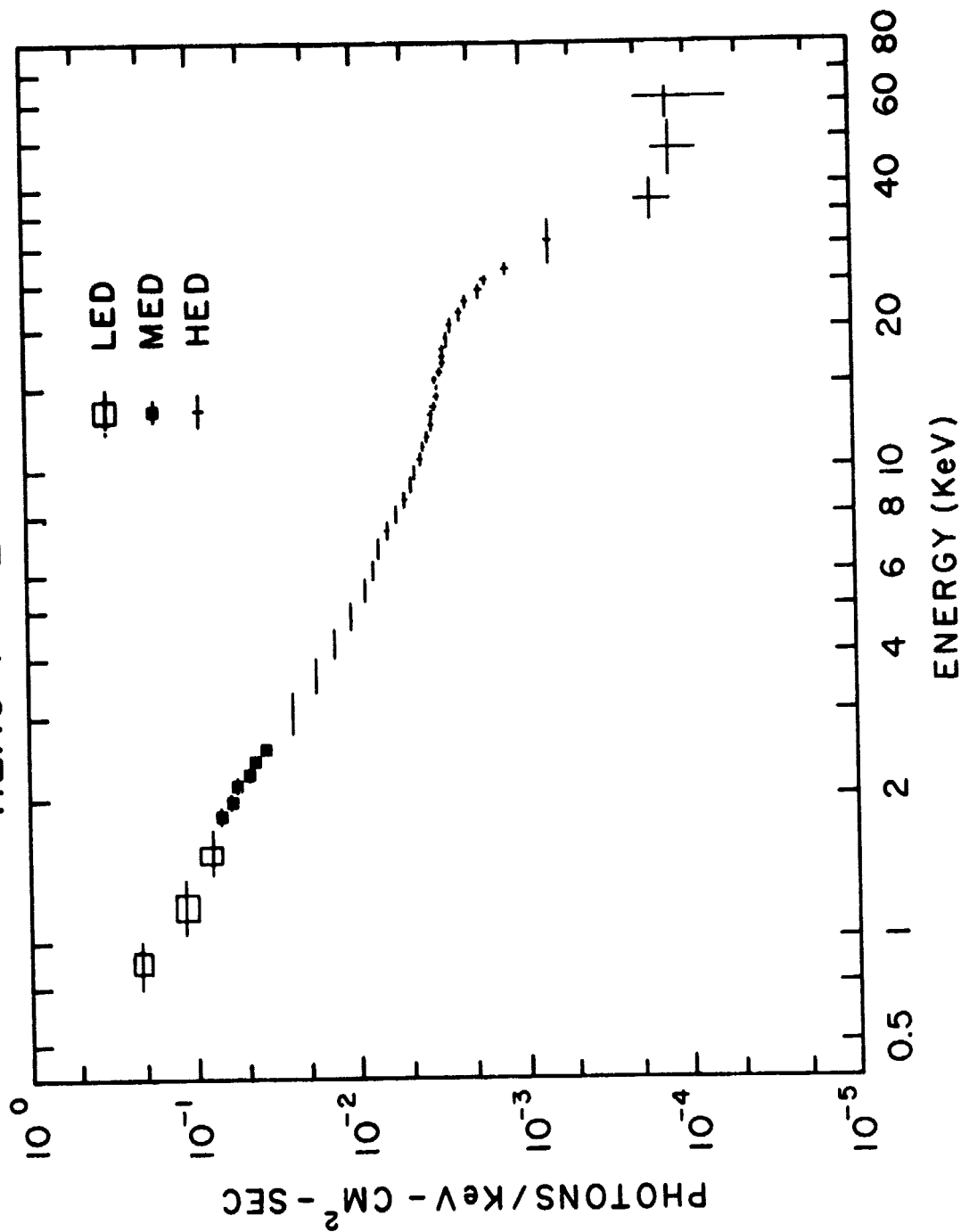




SPECTRAL EVOLUTION OF THE  
4U1626-67 PULSE



4U1626-67  
PHASE AVERAGED SPECTRUM  
HEAO 1 A2



4U1626-67 HEA0-A2

