# X-Ray/Gamma-Ray Observations of the
# PSR B1259−63/SS 2883 system near Apastron

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# ABSTRACT

We report the results from X-ray and hard X-ray observations of the PSR B1259−63/SS 2883 system with the *ASCA* and the *CGRO* satellites, performed between 1995 February and 1996 January when the pulsar was near apastron. The system was clearly detected in each of the two *ASCA* observations with luminosity in the 1–10 keV band of $L_X = (9 \pm 3) \times 10^{32} \ (d/2 \ \text{kpc}) \ \text{erg s}^{-1}$, while OSSE did not detect significant hard X-rays from the system. X-ray spectra obtained with *ASCA* show a single power-law spectrum with a photon index of $1.6 \pm 0.3$. No pulsations were detected in either the *ASCA* nor the OSSE data. Combined with previous results from X-ray and hard X-ray observations, we obtained binary modulation in X-ray luminosity and photon index of high energy emission from the system for the entire orbit. The results are in agreement with predictions based on synchrotron emission model from relativistic particles in a shocked pulsar wind interacting with the gaseous outflow from the Be star.

*Subject headings:* pulsars: individual: PSR B1259−63 — stars: neutron — stars: individual: SS 2883 — binaries: eclipsing — stars: emission line, Be — X-rays: stars

# Final Report for NASA NAG 5-2948
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This report covers the period December 1, 1996 through May 25, 1998 for NASA grant NAG 5-2948 through the ASCA Guest Investigator Program, for the project "**Magnetospheric Accretion in PSR 1259-63**", Dr. Lynn R. Cominsky, Principal Investigator, Department of Physics and Astronomy, Sonoma State University, Rohnert Park, CA 94928.

For the past two years, a paper has been in progress reporting both the results of the OSSE observations and the ASCA observations of PSR 1259-63 at apastron. It is now finished and submitted to the Astrophysical Journal. A copy of the paper as submitted is attached to this report. Dr. Cominsky, the PI of this grant, is the second author on the paper, which acknowledges support from this grant.

The apastron observations of PSR 1259-63 were found to be consistent with the shocked wind model proposed in earlier work by many of the same authors. Although no significant signal was detected in OSSE data, together with the weak ASCA detection, significant limits were placed on the physical conditions present at apastron.

# 1. Introduction

The PSR B1259−63/SS 2883 system is a binary consisting of the radio pulsar PSR B1259−63 and the Be star SS 2883. PSR B1259−63 is a 48 ms radio pulsar, discovered by Johnston et al. (1992a). The pulsar's parameters were determined by Manchester et al. (1995) using radio timing observations with the Parkes 64-m radio telescope, covering the two periastron passages in 1990 and in 1994. The radio timing observations have shown that the pulsar is in a 3.4 yr, binary orbit with eccentricity $e = 0.86$. Further radio observations with the Parkes telescope have been improving our understanding of the dynamical properties of the binary (Wex et al. 1998). The companion star has been identified as the Be star SS 2883 from optical observations, and the mass and radius of SS 2883 were estimated to be $\sim 10~M_\odot$ and $\sim 6~R_\odot$, respectively (Johnston et al. 1992b).

From the dispersion measure (DM) of the pulsar and a model for the galactic electron distribution (Taylor and Cordes 1993), the estimated distance to the source is 4.6 kpc, although DM-derived distances are uncertain often to a factor of $\sim 2$. Johnston et al. (1994) argue on the basis of photometric observations that the distance to SS 2883 cannot be greater than 1.5 kpc. In this paper we adopt a compromise distance of 2 kpc.

The first attempt to detect X-rays from the PSR B1259−63/SS 2883 system was in observations made using the *Ginga* satellite in 1991. However, *Ginga* failed to detect significant X-ray emission from the system (Makino and Aoki, private communication). The first low-level X-ray detection was by Cominsky et al. (1994) who observed the system just after apastron using *ROSAT* in September 1992 ("*ROSAT* obs 2" and "*ROSAT* obs 3" in Fig. 1). The observed X-ray luminosity in the *ROSAT* band was $(0.07 - 2) \times 10^{34}$ erg s$^{-1}$, depending on the assumed spectral model. A subsequent analysis by Greiner et al. (1995) of archival *ROSAT* data taken just before apastron in February 1992 ("*ROSAT* obs 1" in Fig. 1), reveals significant X-ray emission at level consistent with the result of Cominsky

et al. (1994).

The PSR B1259–63/SS 2883 system was observed with the *ASCA* satellite at six different orbital positions (hereafter *ASCA* obs 1 through *ASCA* obs 6) and with the OSSE instrument on-board the *CGRO* satellite at two different orbital positions: one near periastron and the second near apastron (hereafter OSSE obs A and OSSE obs B). *ASCA* observations 1–3 have been previously reported by Kaspi et al. (1995), *ASCA* obs 4 has been reported by Hirayama et al. (1996), and OSSE obs A has been discussed by Grove et al. (1995). In Figure 1 we provide a schematic drawing of the pulsar's orbit around the systemic center of mass, together with the approximate location of the pulsar during all six *ASCA* observations, the three *ROSAT* observations reported by Cominsky et al. (1994) and Greiner et al. (1995), and the two OSSE observations. Also, for completeness, Table 1 gives a summary of the six *ASCA* observations and the two OSSE observations and of the orbital geometry for an assumed Be star mass $M_c = 10 \ M_\odot$.

In this paper, we present the new *ASCA* data for obs 5 and obs 6, which were obtained near apastron, at phases similar to the *ROSAT* observations which occurred one 3.4 yr orbital cycle earlier (Cominsky et al. 1994; Greiner et al. 1995). We also present the OSSE obs B apastron results. The observations give us X-ray luminosity in 2 – 10 keV band at apastron which constrains theoretical models (e.g. Tavani, Arons, and Kaspi 1994; Tavani and Arons 1997). Also, in these observations, the smallest luminosity in the orbit gives us maximum sensitivity to search for pulsations from magnetospheric emission as seen in spin-powered pulsars.

## 2. Observations

As with the four earlier *ASCA* observations, during obs 5 and obs 6, the two SIS detectors were operated in 1-CCD faint mode with a time resolution of 4 s. *ASCA*'s

two GIS detectors were in PH mode with time resolution better than 4 ms, high enough to potentially study 48 ms pulsations from PSR B1259−63. For the two week OSSE observation, spectra were accumulated in a sequence of two-minute measurements of the source field alternated with two-minute, offset-pointed measurements of background fields. A total exposure time of $4.8 \times 10^5$ s of the highest-quality data was collected on the source field, with an approximately equal time on the background fields. Simultaneously with the spectroscopy data, count-rate samples in eight energy bands at 8-ms resolution were collected to search for pulsed emission at the radio period.

The OSSE instrument consists of four large-area NaI(Tl)–CsI(Na) phoswich detector systems (Johnson et al. 1993) and covers the energy range from 50 keV to 10 MeV with good spectral resolution, and a field of view of approximately 3.8 by 11.4 degrees. OSSE had previously observed this object in 1994 Jan. at periastron. In both observations, care was taken to minimize the effect of the galactic diffuse continuum emission and to avoid nearby bright point sources, such as the X-ray binaries GX 301-2, Cen X-3, and 2S 1417-624. The observations have similar orientations with respect to the galactic plane and similar background fields of view, and should therefore be subject to similar, minimal systematic effects.

One possible systematic effect is the inclusion of flux from the serendipitous source AX J1302−64, in the OSSE data. This weak source is seen in both the *ROSAT* data (Greiner et. al. 1995) and the *ASCA* data (Kaspi et al. 1995; Hirayama et al. 1996), but does not contaminate either analysis due to the imaging nature of the instruments. It is possible, however, that the source has flux in the OSSE bandpass, which could have added to that detected in this region in the periastron OSSE obs A data, although the required spectrum would be unusual for an accreting binary. We argue that the correlated variability seen in the *ASCA* and OSSE observations, in which the flux at periastron is more than a factor of ten greater than that detected near apastron in both instruments,

makes it unlikely (but not impossible) that the OSSE obs A flux arises from AX J1302−64. A detailed analysis of AX J1302−64 will be presented elsewhere.

## 3.   Data Analysis & Results

### 3.1.   Spectral Results from ASCA data

In both observations obs 5 and obs 6, the PSR B1259−63/SS 2883 system was clearly detected with both SIS and GIS. The observed positions of the X-ray source were coincident with the position of PSR B1259−63 to within 1′, the accuracy of the attitude determination of the *ASCA* satellite. The method of analysis used to reduce the data from obs 5 and obs 6 is identical to that used for the first four *ASCA* observations (Kaspi et al. 1995; Hirayama et al. 1996).

After subtracting the background spectra, the source spectra from the combined *ASCA* GIS and SIS obs 5 and obs 6 data were fitted with the XSPEC package with a single power law model with photoelectric absorption. For completeness, the results of the independent three-parameter fits with the single power law model are given in Table 2 for all six *ASCA* observations. We also fitted the data with a thermal bremsstrahlung model. In all cases, reduced $\chi^2$-values were only slightly higher for the thermal model compared with that for the power-law model, and we could not rule out the former on the basis of the *ASCA* observations alone. No evidence was found for any line features in the spectra. The upper limits for Iron K emission line flux are listed in Table 2. The absence of emission lines argues in favor of the power law model.

Due to the smaller luminosities at apastron, the X-ray photon indices and column densities in Table 2 are consistent with the entire range of values observed at periastron. In Figures 2 and 3 the changes in the photon index and the flux are plotted against the

binary separation, assuming masses of 1.4 $M_\odot$ for PSR B1259−63 and 10 $M_\odot$ for SS 2883. The X-ray flux at apastron is ∼ 10 times smaller than that near periastron. In this figure, we also show luminosity results from the previous X-ray missions (Makino & Aoki, private communication; Cominsky et al. 1994; Greiner et al. 1995) converted into the 1–10 keV band, taking into account the best-fit photon indices and their errors.

## 3.2. Search for X-ray Pulsations in the ASCA data

We have searched the obs 5 and obs 6 data for evidence that the X-ray emission from the PSR B1259−63/SS 2883 system is pulsed at the 48 ms radio period using the same procedures followed by Kaspi et al. (1995) and Hirayama et al. (1996). These procedures were: 1) epoch folding; 2) $Z^2$ test (Buccheri et al.); 3) search in $P - \dot{P}$ space. The first two searches were done within $\pm 1\mu s$ from the expected pulse period of PSR B1259−63, as determined by Manchester et al. (1995) with the radio observations. Even though Wex et al. (1998) showed that the timing model for PSR B1259−63 by Manchester et al. (1995) does not fit the radio data obtained after MJD 49600, the period range we choose is wide enough to cover the entire range of possible periods. Searches for pulsations using the epoch-folding method were also done with $j = 8, 16, 32$ to ensure sensitivity to a variety of pulse profiles. In addition, searches in the 0.5–2 keV and 2–10 keV bands were performed individually to detect possible narrow-band pulsations.

In conclusion, we detected no X-ray pulsations at the radio period, using any pulse searching technique. The upper limits to the pulsed component were estimated using the epoch-folding method described in Leahy et al. (1983) and are listed in Table 3. The limits were estimated by the pulsation searches with the epoch-folding method with $j = 32$ for three energy bands: 0.5–10 keV (full band), 0.5–2 keV, and 2–10 keV. The $Z^2$ searches (Buccheri et al. 1983) yielded similar results. In the table, upper limits on the amplitude of

counting rates, $\Delta N_\gamma$ divided by net exposure time, are also listed.

### 3.3. OSSE Data Analysis and Results

The method of analysis was similar to that used for the periastron data, and is described more fully by Grove et al. (1995). No statistically significant unpulsed emission is detected by OSSE from PSR B1259-63 near apastron. Upper limits in several energy bins spanning 50 keV to 10 MeV are shown in Figure 4, together with the *ASCA* binned data for both obs 5 and obs 6. Also shown for comparison are the *ASCA* obs 1–4 and OSSE obs A periastron spectra, which have fluxes about ten times greater. At periastron, OSSE detected emission between 50 keV and $\simeq 200$ keV at $\simeq 5\sigma$ significance, as reported by Grove et al. (1995). Based on nearby measurements of the diffuse emission and on galactic symmetry, Grove et al. argued that the positive detection at periastron was not likely residual galactic emission. The null detection we report here strengthens this argument, and severely restricts the possibility that small-scale, local fluctuations in the diffuse emission could have been responsible for the observed flux at periastron.

### 4. Discussion

Comparison of our *ASCA* results with the *ROSAT* results by Cominsky et al. (1994) and Greiner et al. (1995) helps us to interpret the time variability in X-ray luminosity. The PSR B1259−63/SS 2883 system has been observed with *ROSAT* three times around the previous apastron passage in 1992, two of which were performed at almost the same orbital phases (Fig. 1). The X-ray luminosities derived from *ROSAT* data are consistent with the *ASCA* results in this paper (Fig. 3), after being converted into the 1–10 keV band, taking into account of the best-fit photon indices and their errors. This fact supports that the idea

the observed time-variability in the X-ray luminosity is due to the change in the pulsar's position in the binary system and not to intrinsic fluctuations of the X-ray emission.

Results from the *ASCA* and OSSE observations near periastron in 1994 (Kaspi et al. 1995; Grove et al. 1995; Hirayama et al. 1996) indicates that a shock-powered emission model provides a natural way to account for the periastron observations (Tavani, Arons, and Kaspi 1994; Tavani and Arons 1997). The RXTE/PCA upper limit on X-ray flux (Cominsky et al., private communication) also agrees with a prediction from a shock emission model by Tavani and Arons (1997). In addition, recent analysis of RXTE/ASM observations at the periastron passage in 1997 gave an upper limit on X-ray flux as $(0.5 \pm 2.4) \times 10^{-11}$ erg s$^{-1}$ cm$^{-2}$ at 2 – 10 keV band (Kaspi and Remillard 1998), which favors a shock emission rather than accretion-powered emission at periastron.

In a shock emission model, the observed X-rays are due to synchrotron emission from $e^{\pm}$ pairs with $\gamma = 10^6 \sim 10^7$ (Tavani, Arons, and Kaspi 1994; Kaspi et al. 1995; Hirayama et al. 1996; Tavani and Arons 1997). The power law spectrum with photon index $\alpha \sim 1.6$, observed when the pulsar was farther than 1000 lt-s from the Be star, required the shock acceleration mechanism to create $e^{\pm}$ pairs with an energy spectrum $N(\gamma) \propto \gamma^{-2}$ just behind the shock front (Hirayama et al. 1996). The apparent softening of the spectral index could be understood in terms of enhanced radiative cooling (Kaspi et al. 1995; Hirayama et al. 1996; Tavani and Arons 1997). The decrease in X-ray flux near periastron provided additional evidence in favor of this explanation.

Binary modulation of X-ray luminosity and photon index observed can quantitatively be interpreted with a non-thermal diffuse nebular emission model by Tavani and Arons (1997). They show that shock-powered emission with radiative cooling explains the X-ray properties observed around periastron, such as the spectral softening and the luminosity variation. In this paper, we have shown that the apastron X-ray luminosity is smaller than

that at periastron by about one order of magnitude, and has spectral properties consistent with those obtained the post-periastron observation (*ASCA* obs 4) in qualitative agreement with the model by Tavani and Arons (1997).

The *ASCA* obs 5 sets the most strict upper limit on pulsed luminosity from magnetospheric emission among all the X-ray observations so far. From Table 3, pulsed luminosity of 48 ms pulsations should be smaller than $3.02 \times 10^{31}$ erg s$^{-1}$ with 99% confidence with 2 kpc for the distance to the pulsar and 1 sr. for solid angle of pulsed emission assumed, respectively. Saito (1997) and Saito et al. (1998) systematically studied pulsed luminosity from spin-powered pulsars in the X-ray band based on the *ASCA* observations and found an empirical relationship between pulsed luminosity and spin-down luminosity as $L_{\mathrm{X(pulsed)}} = 10^{34} \times (\dot{E}_{\mathrm{rot,38}})^{3/2}$ erg s$^{-1}$, where $L_{\mathrm{X(pulsed)}}$ is pulsed luminosity in 2 – 10 keV band when 1 sr of pulse solid angle assumed, and $\dot{E}_{\mathrm{rot,38}}$ is spin-down luminosity in unit of $10^{38}$ erg s$^{-1}$. Based on this relationship, pulsed luminosity from PSR B1259−63 is estimated to be $7.53 \times 10^{30}$ erg s$^{-1}$, which is smaller than our best upper limit, but which lies within a scatter of data points for spin-powered pulsars presented in Saito (1997) and Saito et al. (1998). This suggests that the distance to the pulsar should not be significantly smaller than 2 kpc.

Table 1. Geometry of the PSR B1259–63/SS 2883 system near *ASCA* and OSSE

observations

| Observation | MJD | True Anomaly[a] | $s(10^{12}$ cm$)$[b] | $s/R_c$[c] | Reference |
|---|---|---|---|---|---|
| *ASCA* obs 1 | 49349 | −75° | 15 | 36 | Kaspi et al. 1995 |
| obs 2 | 49362 | 8° | 10 | 24 | Kaspi et al. 1995 |
| obs 3 | 49378 | 90° | 18 | 45 | Kaspi et al. 1995 |
| obs 4 | 49411 | 127° | 39 | 93 | Hirayama et al. 1996 |
| obs 5 | 49755 | 170° | 130 | 310 | this paper |
| obs 6 | 49942 | 178° | 140 | 340 | this paper |
| OSSE obs A | 49355 – 49375 | −47° ∼ +81° | 10 – 16 | 24 – 39 | Grove et al. 1995 |
| obs B | 50071 – 50084 | −176° | 140 | 340 | this paper |

[a]True anomaly is zero at periastron.

[b]Binary separation for assumed Be star and pulsar masses of $M_c$=10 $M_\odot$ and $M_p$=1.4 $M_\odot$.

[c]Assuming a companion radius $R_c$ of $6R_\odot$.

Table 2. Model parameters for the *ASCA* observations of the PSR B1259−63/SS 2883

system

| Dataset | $N_H$[b] | Photon Index[b] | 1–10 keV Flux[b,c,d] | $\chi_\nu^2$ | Fe Emission-Line Flux[d,e] |
|---------|----------|-----------------|----------------------|--------------|----------------------------|
| obs 1 | 0.60(4) | 1.78(5) | 3.43(19)/2.96(16) | 0.97 | < 1.1/1.9 |
| obs 2 | 0.58(3) | 1.96(4) | 1.54(8)/1.42(7) | 0.96 | < 0.67/0.41 |
| obs 3 | 0.58(4) | 1.69(4) | 3.08(18)/2.76(16) | 1.22 | < 4.0/3.6 |
| obs 4 | 0.56(6) | 1.61(6) | 2.15(18)/1.88(16) | 0.98 | < 3.8/1.6 |
| obs 5 | 0.5(3) | 1.6(3) | 0.17(5)/0.18(5) | 0.71 | < 0.40/0.67 |
| obs 6 | 0.5(2) | 1.6(2) | 0.19(6)/0.18(5) | 0.84 | < 0.65/0.11 |

[a]In units of $10^{22}$ cm$^{-2}$.

[b]Numbers in parentheses represent 90% confidence interval uncertainties in the last digit quoted. The uncertainties quoted are statistical, and do not include any contribution for unknown systematic calibration errors.

[c]In units of $10^{-11}$ erg cm$^{-2}$ s$^{-1}$.

[d]Numbers for SIS/GIS.

[e]In units of $10^{-5}$ photons cm$^{-2}$ s$^{-1}$.

Table 3.   Upper limits on X-ray pulsation[a]

| Dataset | 0.5–10 keV | 0.5–2 keV | 2–10 keV |
|---------|------------|-----------|----------|
| obs 1 | 8.71% (0.0338) | 15.1% (0.0204) | 11.8% (0.0280) |
| obs 2 | 7.58% (0.0155) | 13.4% (0.0114) | 10.7% (0.0125) |
| obs 3 | 8.38% (0.0302) | 18.4% (0.0243) | 11.3% (0.0253) |
| obs 4 | 15.1% (0.0378) | 22.2% (0.0187) | 15.3% (0.0249) |
| obs 5 | 29.1% (0.0110) | 44.8% (0.00642) | 36.3% (0.00828) |
| obs 6 | 29.9% (0.0125) | 49.6% (0.00783) | 37.0% (0.00902) |

[a]Upper limits in the table are estimated with 99% confidence, being given as fractional amplitude of sinusoidal pulse assumed. Counting rates corresponding to the upper limits are also listed in parentheses in the table in units of photons $s^{-1}$. Note that, due to the smaller luminosities in obs 5 and obs 6, these data give higher upper limits in fraction, but more strict upper limits in pulsed flux.

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Fig. 1.— Binary orbit of the PSR B1259−63/SS 2883 system. An elliptical line shows the orbit of PSR B1259−63 and a diamond with a cross in the ellipse indicates the center of gravity of the system. The figure also shows the positions of PSR B1259−63 when observed with *ASCA* (this work), *ROSAT* (Cominsky et al. 1994; Greiner et al. 1995), and *Ginga* (Makino and Aoki, private communication) at various locations on the orbit. The OSSE instrument on the *CGRO* satellite observed PSR B1259−63 for three weeks during the periastron passage in 1994 and for two weeks near apastron in 1995/6 as indicated with thick lines on the orbit. When the pulsar is at the right side of the vertical line in the figure, no radio pulsations were detected and the radio flux decreased significantly (Johnston et al. 1992b).

Fig. 2.— Photon indices of the PSR B1259−63/SS 2883 system from obs 1 through obs 6 are plotted against binary separation assuming 1.4 $M_\odot$ for PSR B1259−63 and 10 $M_\odot$ for SS 2883.

Fig. 3.— Luminosities of the PSR B1259−63/SS 2883 system from obs 1 through obs 6 are plotted against a binary separation assuming masses of 1.4 $M_\odot$ for PSR B1259−63 and 10 $M_\odot$ for SS 2883, and a distance to the PSR B1259−63/SS 2883 system $d = 2$ kpc. In the figure results from the previous X-ray missions are also plotted (Makino & Aoki, private communication; Cominsky et al. 1994; Greiner et al. 1995) with the luminosities in the literature extrapolated to the 1–10 keV band.
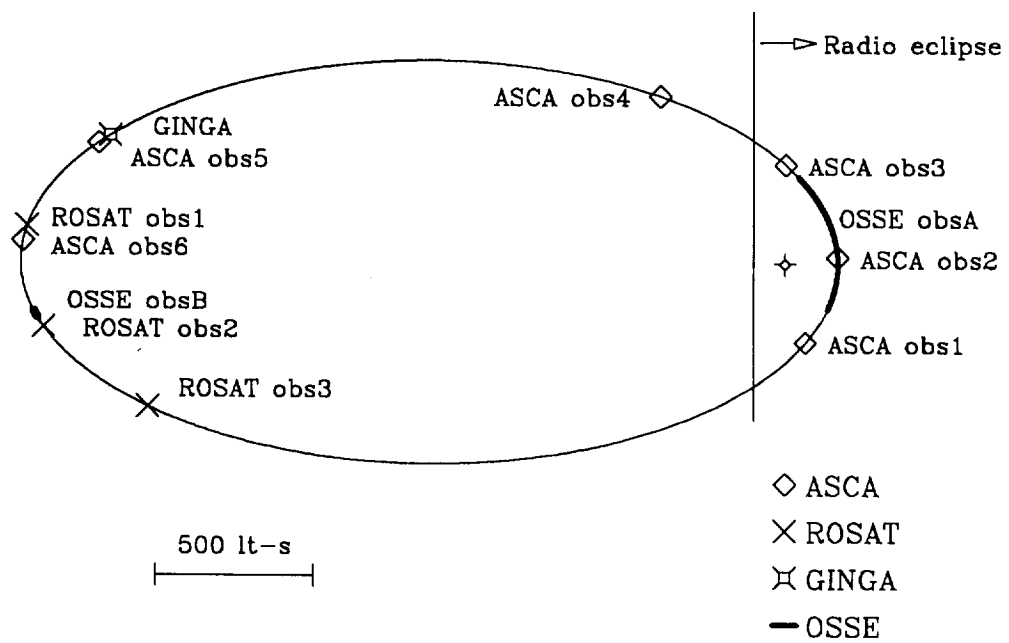
Fig. 4.— Unfolded spectra obtained for the six *ASCA* observations (Kaspi et al. 1996; Hirayama et al. 1996; this paper) and the two OSSE observations (Grove et al. 1995; this paper). For the figure, masses of 1.4 $M_\odot$ for PSR B1259−63 and 10 $M_\odot$ for SS 2883, and a distance to the PSR B1259−63/SS 2883 system $d = 2$ kpc are assumed. Note that the exposure times for the OSSE observations differ (see table 1).
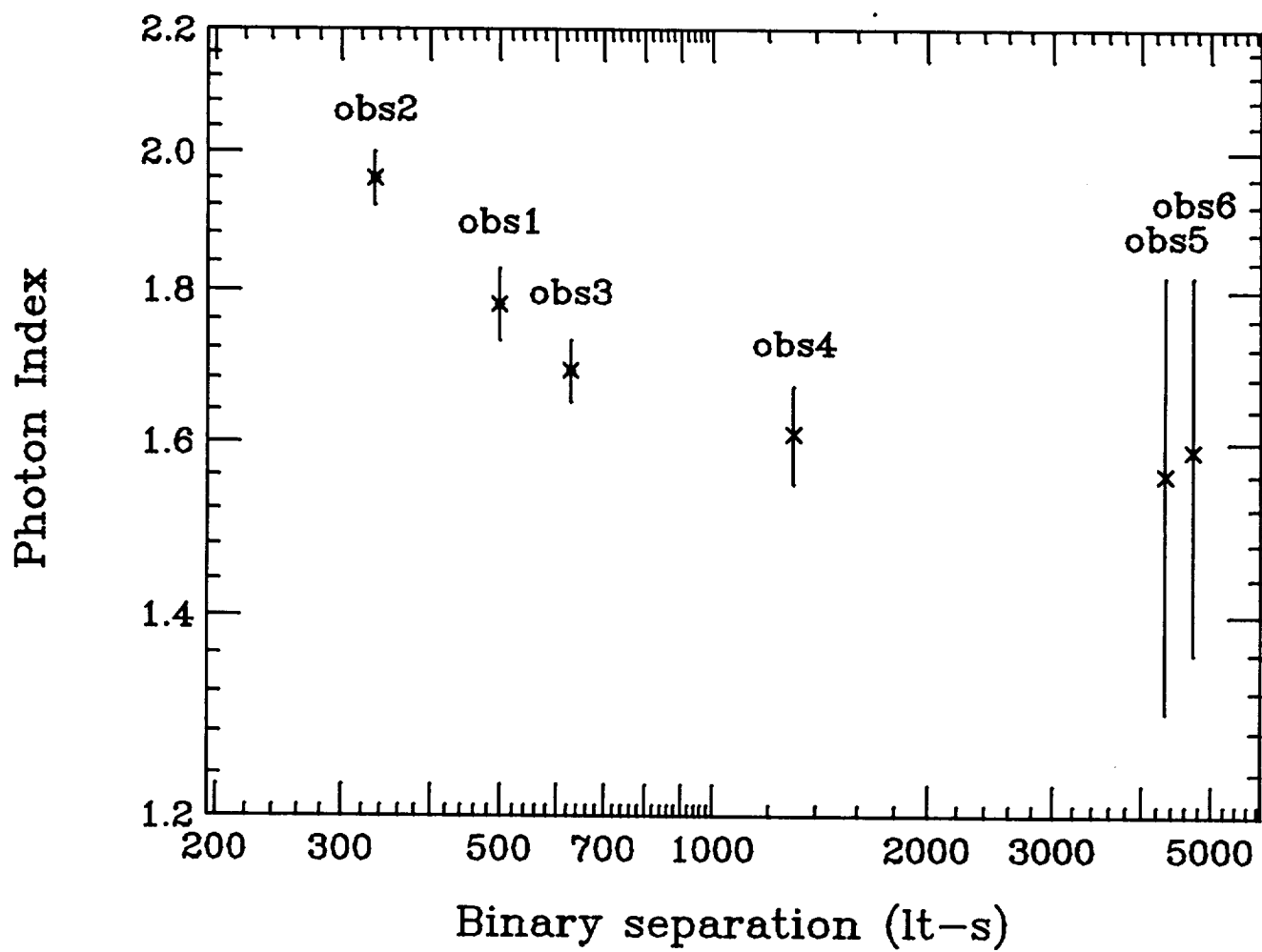
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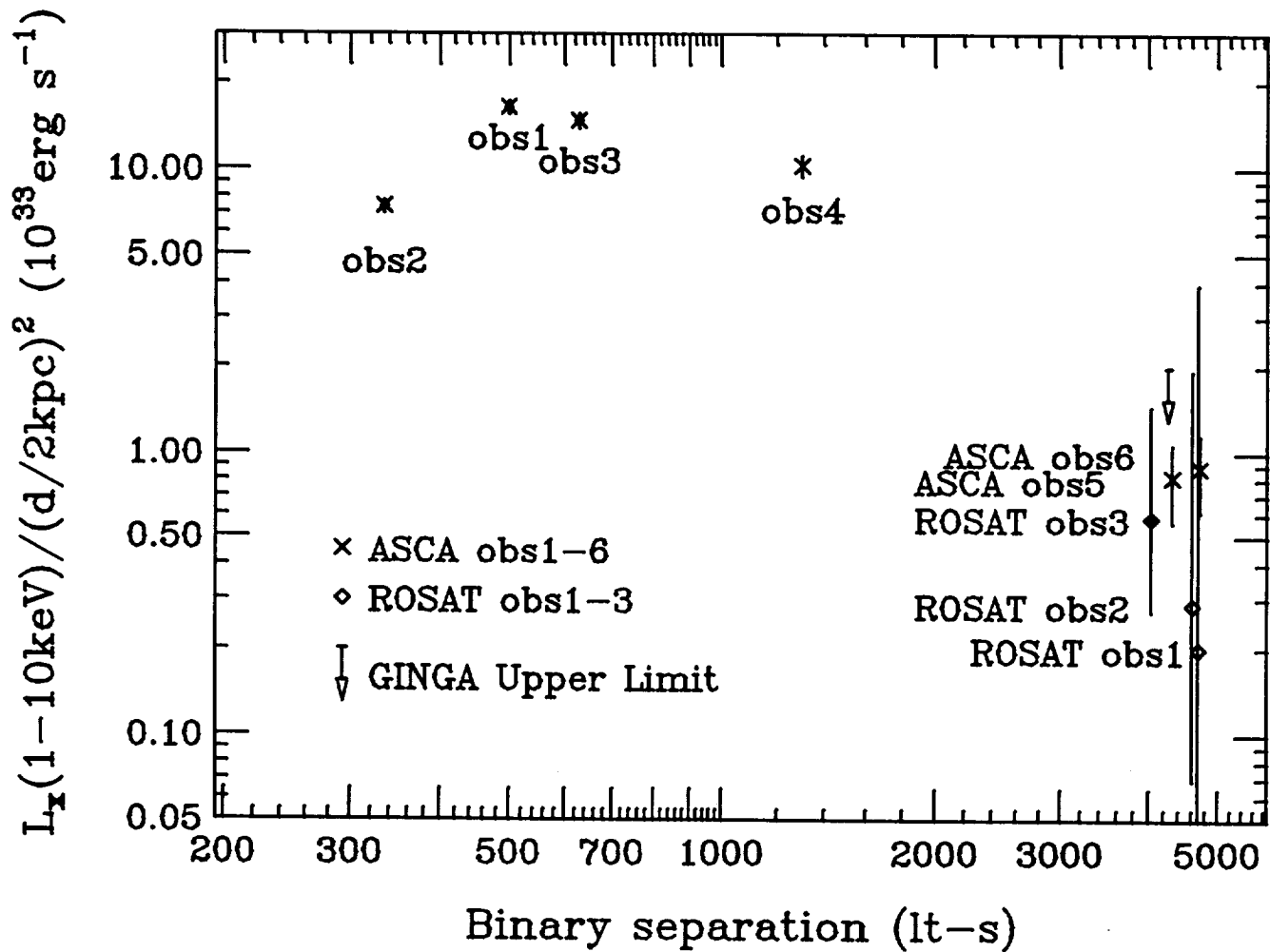
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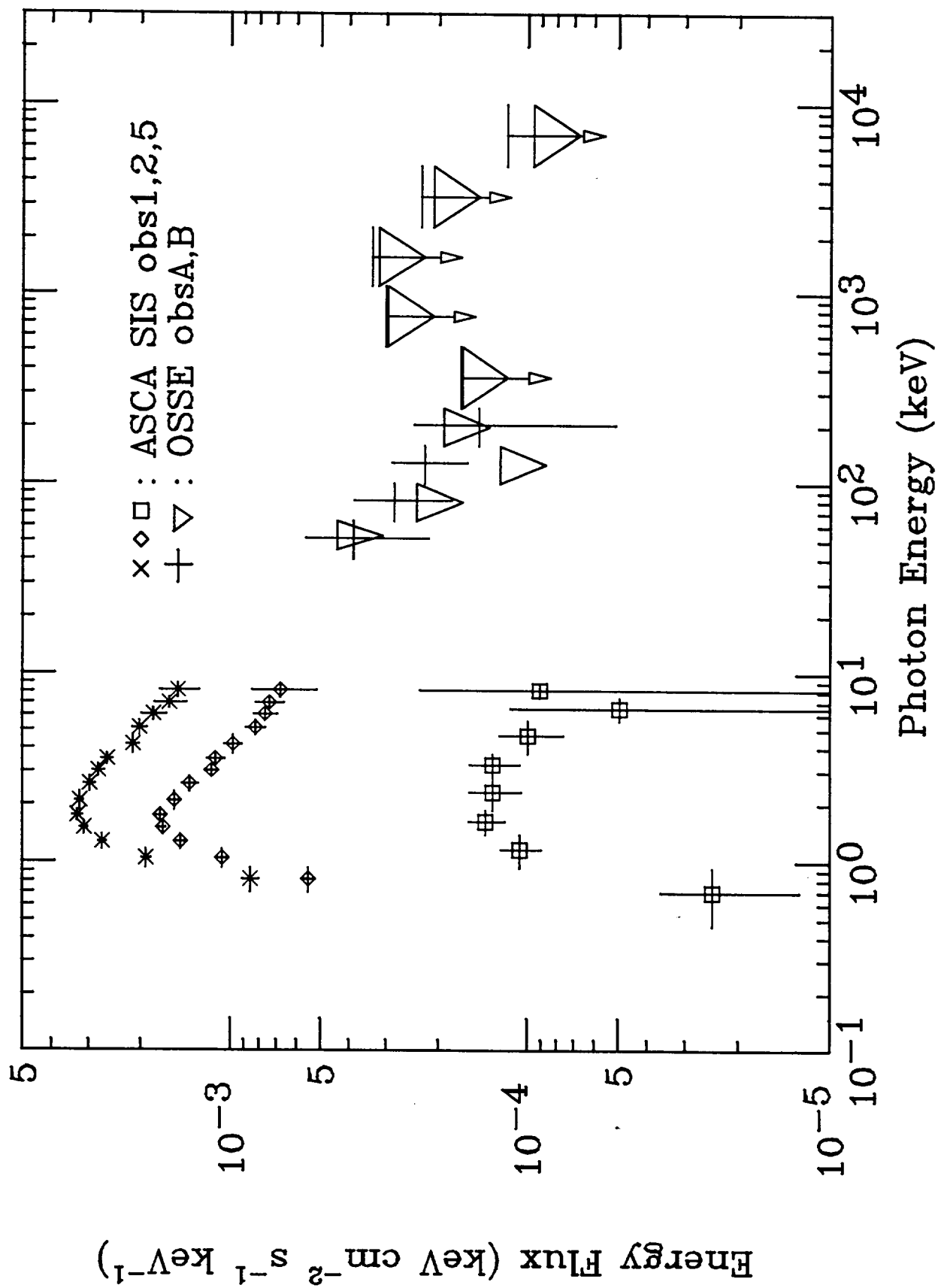
Fig. 3.— Luminosities of the PSR B1259−63/SS 2883 system from obs 1 through obs 6 are plotted against a binary separation assuming masses of 1.4 $M_\odot$ for PSR B1259−63 and 10 $M_\odot$ for SS 2883, and a distance to the PSR B1259−63/SS 2883 system $d = 2$ kpc. In the figure results from the previous X-ray missions are also plotted (Makino & Aoki, private communication; Cominsky et al. 1994; Greiner et al. 1995) with the luminosities in the literature extrapolated to the 1–10 keV band.

Fig. 4.— Unfolded spectra obtained for the six *ASCA* observations (Kaspi et al. 1996; Hirayama et al. 1996; this paper) and the two OSSE observations (Grove et al. 1995; this paper). For the figure, masses of 1.4 $M_\odot$ for PSR B1259−63 and 10 $M_\odot$ for SS 2883, and a distance to the PSR B1259−63/SS 2883 system $d = 2$ kpc are assumed. Note that the exposure times for the OSSE observations differ (see table 1).

ASCA SIS obs1,2,5 × ◇ □

OSSE obsA,B + ▽

Photon Energy (keV)

Energy Flux (keV cm$^{-2}$ s$^{-1}$ keV$^{-1}$)

**Final Report for NASA NAG 5-2948**
**Prepared by Dr. Lynn R. Cominsky, Principal Investigator**
**May 25, 1998**

This report covers the period December 1, 1996 through May 25, 1998 for NASA grant NAG 5-2948 through the ASCA Guest Investigator Program, for the project **"Magnetospheric Accretion in PSR 1259-63"**, Dr. Lynn R. Cominsky, Principal Investigator, Department of Physics and Astronomy, Sonoma State University, Rohnert Park, CA 94928.

For the past two years, a paper has been in progress reporting both the results of the OSSE observations and the ASCA observations of PSR 1259-63 at apastron. It is now finished and submitted to the Astrophysical Journal. A copy of the paper as submitted is attached to this report. Dr. Cominsky, the PI of this grant, is the second author on the paper, which acknowledges support from this grant.

The apastron observations of PSR 1259-63 were found to be consistent with the shocked wind model proposed in earlier work by many of the same authors. Although no significant signal was detected in OSSE data, together with the weak ASCA detection, significant limits were placed on the physical conditions present at apastron.