Discovery of a New Torque Reversal of the Accreting X-ray Pulsar 4U 1626–67 by Fermi/GBM

A. Camero-Arranz
Fundación Española de Ciencia y Tecnología (MICINN), C/Rosario Pino,14-16, 28020- Madrid, Spain
E. Beklen
Middle East Technical University (METU), 06531 Ankara, Turkey
M. H. Finger
Universities Space Research Association, 6767 Old Madison Pike, Huntsville, AL 35806
N.R. Ikhsanov, C.A. Wilson-Hodge
NASA/Marshall Space Flight Center, Huntsville, AL 35812
P. Jenke
ORAU/NPP, Oak Ridge, TN 37831

Recent X-ray observations by Fermi/GBM discovered a new torque reversal of 4U 1626–67 after 18 years of steady spinning down. Using Swift/BAT observations we were able to center this new torque reversal on Feb 4 2008, lasting approximately 150 days. From 2004 up to the end of 2007, the spindown rate averaged at a mean rate of \( \dot{\nu} = -4.8 \times 10^{-13} \) Hz s\(^{-1}\) until the torque reversal reported here. Since then it has been following a steady spinup at a mean rate of \( \dot{\nu} = 4 \times 10^{-13} \) Hz s\(^{-1}\). The properties of this torque reversal, as well as the lack of correlation between the X-ray flux and the torque applied to the neutron star before this transition, challenges our understanding of the physical mechanisms operating in this system.

1. INTRODUCTION

The accreting–powered pulsar 4U 1626–67 was discovered by Uhuru [11]. This low mass X–ray binary (LMXB) consists of a 7.66 s X–ray pulsar accreting from an extremely low mass companion (0.04 M\( \odot \) for \( i = 18^\circ \)) [30]. Although orbital motion has never been detected in the X–ray data, pulsed optical emission reprocessed on the surface of the secondary revealed [30] the 42 min orbital period. The faint optical counterpart (KZ TrA, \( V\sim 17.5 \)) has a strong UV excess and high optical pulse fraction [33, 34]. A persistent 48 mHz quasi-periodic oscillation (QPO) has been detected in the X–ray emission [24, 46]. [37] inferred a neutron star magnetic field in the range (2.4–13) \( \times 10^{12} \) G. To compute this magnetic field range a source distance of 5–13 kpc was assumed [7, and references therein]. A \( \sim 37 \) keV absorption cyclotron feature was found in the 0.1–200 keV BeppoSAX spectrum [37].

For more than a decade after the discovery of pulsations [44] the source underwent steady spin–up at a mean rate of \( \dot{\nu} = 8.5 \times 10^{-13} \) Hz s\(^{-1}\) (see Fig 1 Top). Monitoring of the source by the Burst and Transient Source Experiment (BATSE) on board the Compton Gamma Ray Observatory (CGRO) starting in April 1991, found the pulsar spinning down, implying a changed sign in the accretion torque [3, 14]. During the 7 years after the first torque reversal, the pulsar spun–down at a rate of \( \dot{\nu} = -7.2 \times 10^{-13} \) Hz s\(^{-1}\) [3].

We present a long term timing and spectral analysis using all the available Fermi/GBM data since its launch in 2008 June 11 and over 5 yr of hard X-ray Swift/BAT data from 2004 up to 2009.

2. Fermi/GBM

2.1. OBSERVATIONS

Since 2008 June 11 4U 1626–67 has been continuously monitored by the Gamma-ray Burst Monitor (GBM) [25], on board the Fermi observatory. Timing analysis was carried out with GBM CTIME data, with 8 channel spectra every 0.256 seconds. The total exposure time was \( \sim 13.75 \) Ms. The GBM is an all-sky instrument sensitive to X–rays and gamma rays with energies between \( \sim 8 \) keV and \( \sim 40 \) MeV. GBM includes 12 Sodium Iodide (NaI) scintillation detectors and 2 Bismuth Germanate (BGO) scintillation detectors. The NaI detectors cover the lower part of the energy range, from 8 keV to about 1 MeV. The BGO detectors cover the energy range of \( \sim 150 \) keV to \( \sim 40 \) MeV. Only data from the NaI detectors were used in the analysis.

2.2. TIMING ANALYSIS AND RESULTS

All intervals of CTIME data from the 12 NaI detectors are selected for analysis after excluding those containing high voltage transients, phosphorescence events, rapid spacecraft slews, South Atlantic Anomaly induced transients, electron precipitation events and gamma-ray bursts (see Mark H. Finger et al., these proceedings). Source pulses are then separated from the background by fitting the rates in all detectors with a background model, and subtracting the best fit model. Then we combine the residuals over detectors with time dependent weights which are
proportional to the predicted (phase averaged) count rates from the pulsar.

Short intervals (~300s) of these combined residuals are then fit with a constant plus a Fourier expansion to determine a pulse profile. The profiles are divided into six day intervals and the pulse frequency and mean profile determined in each interval with a search of pulse frequency for the maximum of the \( Y_n \) (n=2) statistic [13].

Our monitoring of 4U 1626–67 with Fermi/GBM starting in 2008 August, discovered the pulsar spinning–up [6]. Fig 1 (Right) shows the pulse frequency history using data from this monitoring. 4U 1626–67 seems to be increasing in \( \dot{\nu} \). Follow-up Fermi/GBM observations confirm that the pulsar it is currently spinning–up at a mean rate of \( \sim \dot{\nu}=4\times10^{-13} \) Hz s\(^{-1}\).

3. Swift/BAT

3.1. OBSERVATIONS

The Swift Gamma-ray mission [15] was launched on 2004 November 20. The hard X–ray (15–150 keV) Burst Alert Telescope (BAT) on board Swift, monitors the entire sky and it produces continuous streams of rate data. For the present study we have analyzed more than 4 years of BAT quadrant rates observations (1.6 sec sampling; four energy bands; four separate spatial quadrants) when 4U 1626–67 was visible (total exposure time \( \sim 13 \) Ms). For the hardness ratio analysis we used count rates from the Swift/BAT transient monitor results provided by the Swift/BAT team [1].

3.2. TIMING ANALYSIS AND RESULTS

A similar procedure was followed for the Swift/BAT quadrant rates timing analysis. Initial good time interval (GTI) files are obtained using the maketime ftool

\[ http://heasarc.gsfc.nasa.gov/docs/swift/results/transients \]
(heasoft-6.6.1)$^2$. Then a filtered version of the quadrant rates is obtained, to then finally be barycentered using the tool barycorr. With the tool batmasking the pixel exposure fraction for each quadrant is computed for the center of each (refined) GTI interval. Pulse profiles for each good GTI interval are computed. First the rates for each quadrant are fit to a quadratic-Fourier expansion. Then the Fourier coefficients are combined using the quadrant exposures to produce mean profiles (with units of counts s$^{-1}$ cm$^{-2}$). In a final stage, the $Y_n$ (n=2) statistic is again used in intervals of 35 days and a frequency search for pulsations is carried out. The spin rates were computed by fitting a linear function to the frequencies, which were divided into 21 time intervals.

Swift/BAT observations allowed us to cover the evolution of this second torque reversal. We found that the pulsar spun–down at a mean rate of $\dot{\nu} = -4.8 \times 10^{-13}$ Hz s$^{-1}$ until the source reversed torque. Fig 1 (Left) shows that the transition took place at around MJD 54500 (2008 Feb 04) and lasted approximately 150 days. In the bottom panel of Fig 2 we can see that there is a strong correlation between the Swift/BAT count rate and the spin–up rate especially during the reversal. We have not observed any significant change in pulse shape, not even during the reversal.

4. RXTE

4.1. OBSERVATIONS

The Rossi X-ray Timing Explorer (RXTE) $^3$ carries 3 instruments on board. The Proportional Counter Array (PCA) $^{21}$ (2–60 keV), the High Energy X-ray Timing Experiment (HEXTE) $^{18}$ (up to 200 keV) and the All Sky Monitor (ASM) $^{22}$ (2–10 keV). Two RXTE/PCA observations from 2008 March 5 and 13 were used (ID 93431–01–01–00 and 93431–01–02–00; 7.174 ksec). For spectral analysis we selected PCA Standard–2 data and HEXTE Standard Modes (Archive) data (64-bin spectra every 16s). For the long–term hardness ratio analysis we used the ASM daily flux averages in the 1.5–12 keV energy range from the HEASARC archive.$^3$

4.2. SPECTRAL ANALYSIS AND RESULTS

RXTE/PCA (2.5–20 keV) and HEXTE (18–100 keV) spectra were fitted in XSPEC 11.3.2 with two models used by $^{41}$. Using these models allows us to compare our spectral study with previous works by $^{22, 25, 37, 41}$ and update the long-term X-ray flux history of 4U 1626–67 relative to the flux measured by HEAO 1 (Chakrabarty et al. (1997); Krauss et al. (2007)) . The first model includes a low-energy absorption, a blackbody component, a power law and a high-energy cutoff at $\sim$20 keV (WABS (GAUSS+BBODY+POWLA W) HIGH-ECUT). A broad line near 6.5 keV significantly improves the present fit and indicates the presence of an iron line, also suggested by $^{41}$ in their (0.7–100 keV) spectral analysis of this source. The column density of cool material in the line of sight was fixed in our study since it could not be constrained. A value of $1.3 \times 10^{21}$ cm$^{-2}$ was selected from $^{25}$. The spectral parameters obtained are shown in Table 1. We fit in addition the same model with a bremsstrahlung instead of a blackbody component, obtaining a compatible fit. Table I summarizes the spectral parameters obtained.

5. HARDNESS RATIO ANALYSIS

Fig 3 shows Hardness–intensity diagram (HID) for 4U 1626–67 using BAT count rate. The hardness ratio (HR) was defined as the ratio 15–50keV/1.5–12keV (BAT/ASM). To reduce large uncertainties the light curves were rebinned and then the HR were computed. This allow us to study the long-term spectral variability of 4U 1626–67 , including the transition, since the 2 RXTE observations do not provide us any direct comparison between before and after the torque reversal. From that figure we can see that there is a transition from hard to soft during this new reversal of 4U 1626-67.
Discussing a possibility to explain the torque reversals in 4U 1626–67 has also been mentioned by [48].

The difficulty to fit the transition timescales observed exceeds the dynamical timescale in the hot disk in thermore, both reversals have occurred at almost the shoulders on the pulse fundamental appearing. They claimed that the observed behavior of the source can- not be a simple case of increased mass transfer rate, but is also a change in the accretion flow parameters. A dramatic change in the power spectra between the last observation of 4U 1626–67 during the spin-down phase (2003) [23], and observations made soon after the new torque reversal has been recently reported by [22], with the 35–48 mHz QPO no longer being present, and wide shoulders on the pulse fundamental appearing. They claimed that the observed behavior of the source cannot be a simple case of increased mass transfer rate, but is also a change in the accretion flow parameters.

Analyzing the evolution of the source energy spectrum and possible correlation between the torque and X-ray luminosity of the pulsar, [50] proposed a scenario in which the torque reversal in 1990 is associated with a state transition of the accretion disk to a geometrically thick, hot and, possibly, sub-Keplerian phase. Following this idea one could associate the 2008 torque reversal with an inverse transition of the disk into its previous geometrically thin Keplerian phase. However, the reason for such a transition is rather unclear since the level of X-ray flux measured before and even after the 2008 reversal is smaller than that measured during the reversal in 1990. Furthermore, both reversals have occurred at almost the same timescale (about 150 days), which significantly exceeds the dynamical timescale in the hot disk in which its transition to the ground state is expected. The difficulty to fit the transition timescales observed in 4U 1626–67 has also been mentioned by [18], who discussed a possibility to explain the torque reversals in terms of the warped disk transition into a retrograde regime.

A correlation between the torque applied to the neutron star in 4U 1626–67 and X-ray flux of the system in the above mentioned models has been adopted as one of the basic assumptions. To test the validity of this assumption using data derived before 1993 was rather complicated. This is illustrated in Figure 4 which shows the 4U 1626–67 X-ray flux history. We can see all previous flux measurements and two RXTE/PCA observations (unfilled squares) in the 2–20 keV band. The cross point is inferred from PCA flux and the fractional change in the Swift/BAT rate.

All previous studies of 4U 1626–67 were focused on modeling the spin-up torque applied to the neutron star from the accreted material. It was widely believed that the spin behavior of the pulsar depended mainly on variations of the mass accretion rate onto the stellar surface and therefore, the rate of mass transfer between the system components. A dramatic change in the power spectra between the last observation of

### Table I

| Observation (MJD) | $\alpha^*$ | $E_{\text{cut}}^1$ | $E_{\text{Fold}}^1$ | Gaussian $^{1}$ | Gaussian $^{\sigma\dagger}$ | $T_{\text{Body}}^1$ | $T_{\text{Brem}}^1$ | Flux $^{***}$ | $\chi^2$(DOF) |
|------------------|------------|-------------------|-------------------|----------------|-----------------|----------------|----------------|---------------|---------------|
| 93431–01–01–00   | +0.75(2)   | 18.2 $^{+0.1}_{-0.3}$ | 8.5(4)            | 6.0 $^{+0.5}_{-0.17}$ | $1.6^{+0.3}_{-0.2}$ | 2.4 $^{+4}_{-0.8}$ | 0.615 $^{+0.006}_{-0.018}$ | 0.0013 1.01(8) | 1.15(114)     |
| (54530)          | +0.74(2)   | 18.2 $^{+0.3}_{-0.2}$ | 8.5 $^{+0.3}_{-0.4}$ | 6.4 $^{+0.17}_{-0.4}$ | $1.4^{+0.1}_{-0.2}$ | 1.5 $^{+1.2}_{-0.6}$ | 1.74 $^{+0.12}_{-0.14}$ | 0.108 1.01(1) | 1.15(114)     |
| 93431–01–02–00   | +0.71 $^{+0.06}_{-0.04}$ | 17.90 $^{+0.19}_{-0.3}$ | 8.4 $^{+0.5}_{-0.6}$ | 6.2 $^{+0.6}_{-0.4}$ | $1.5^{+0.4}_{-0.2}$ | 2.2 $^{+1.9}_{-0.8}$ | 0.654 $^{+0.04}_{-0.005}$ | 0.0013 1.006(12) | 1.29(114)     |
| (54538)          | +0.71 $^{+0.04}_{-0.05}$ | 17.96 $^{+0.14}_{-0.2}$ | 8.4(6)            | 6.9(2)          | $0.3^{+0.4}_{-0.3}$ | 0.396 $^{+0.14}_{-0.015}$ | 2.47 $^{+0.3}_{-0.08}$ | 0.068 1.004(9) | 1.28(114)     |

$^*$ Photon Index

$^+$ kEV

$^{1}$ $(\text{Lumin}/10^{39}\text{erg s}^{-1})(\text{d}/10\text{kipc})^{-2}$

$^{2}$ $3.05 \times 10^{-5}(4\pi d^2)^{-1} \times \text{Emission measure}$

$^{***} \times 10^{-9}\text{erg cm}^{-2}\text{s}^{-1}(2-100\text{keV})$

6. DISCUSSION

Figure 4: The X-ray flux history of 4U 1626–67 relative to the flux measured by HEAO 1, in the same energy band, from previous works (Chakrabarty et al. (1997): circles; Orlandini et al. (1998): triangle; Krauss et al. (2007): stars) and two recent RXTE/PCA observations (unfilled squares) in the 2–20 keV band. The cross point is inferred from PCA flux and the fractional change in the Swift/BAT rate.
change (2.5 factor) in the \textit{Swift}/BAT rate, since no spectral changes across the transition have been observed according to the present work.

As seen from Figure 4, the X-ray flux during the spin-down phase has decreased by a factor of 2. This indicates that the mass accretion rate onto the surface of the neutron star, \( M \), and, correspondingly, the spin-up torque applied to the star \( T_{su} \),

\[
K_{su} = \dot{M} (GM_{ns}r_{in})^{1/2},
\]

during this phase have also decreased by at least the same value. If the spin-down torque applied to the neutron star during this time were constant one would expect the pulsar to brake harder at its fainter state close to the end of the spin-down phase. However, observations show the situation to be just the opposite. The spin-down rate of the neutron star during this phase has decreased from \( \dot{\nu} \sim 7 \times 10^{-13} \text{Hz s}^{-1} \) to \( 5 \times 10^{-13} \text{Hz s}^{-1} \) (see Figure 1), implying that the pulsar was braking harder at its brighter stage just after the torque reversal in 1990. According to the equation governing spin evolution of an accreting neutron star,

\[
2\pi I \dot{\nu} = K_{su} - K_{sd},
\]

this means that the spin-down torque, \( K_{sd} \), during the spin-down phase has been decreasing simultaneously with the spin-up torque but at a higher rate and, therefore, the pulsar spin evolution during this time has been governed mainly by variations of \( K_{sd} \) rather than \( K_{su} \) (here \( I \) is the moment of inertia of the neutron star). This conclusion seriously challenges the possibility of modeling the spin history of 4U 1626–67 solely in terms of variations of \( M \), and suggests that the dramatic increase of X-ray flux observed in 2008 torque reversal may be a consequence rather than a reason for this event.

With the lack of correlation between the X-ray flux and the torque applied to the neutron star, modeling of the spin-down torque appears to be the main target for theoretical studies of the system. Unfortunately, this part of modeling of the magneto-rotational evolution of neutron stars remains so far a work in progress.

Perna et al. (2006) proposed a model where simultaneous accretion from a disk onto the neutron star, some material from near the disk-magnetosphere boundary is ejected, and either escapes from the system or is recycled back into the accretion disk. Their model predicts, however, that the luminosity after a spin-down to spin-up torque reversal would be higher than the luminosity after a spin-up to spin-down torque reversal, which is the opposite of what occurred for 4U 1626–67 for this new reversal. Moreover, for 4U 1626–67 they predicted the full spin-down/spin-up cycle would take thousands of years, again inconsistent with the present observations.

Finally, the spectral evolution of 4U 1626–67 during the torque reversal differs from that expected in models which suggest significant changes of the accretion flow structure in spin-up/spin-down transitions [e.g., 43, 50]. As seen from Figure 3, the spectrum becomes the hardest during the reversal and the value of the hardness ratio before and after these events does not differ significantly. This indicates that the recent torque reversal can be associated with changes of physical conditions in the inner part of the disk or in the region of its interaction with the magnetosphere rather than a significant change of the accretion flow geometry. The errors of the observations are, however, too large for a justification of particular transition model.

7. CONCLUSIONS

We report on a discovery of a new spin-down to spin-up torque reversal in 4U 1626–67. It occurred after about 18 years of the pulsar’s steadily spinning down and was centered on 2008 Feb 4. The transitions lasted \( \sim 150 \) days and was accompanied by an increase in the \textit{Swift}/BAT count rate of a 2.5 factor \( (\sim 150\%) \). The pulsar spectrum was harder during the torque transition than before or after. A strong correlation between torque and luminosity is inferred only during the transition. The spin-up and spin-down rates before and after the transition were almost identical \( (\sim |\dot{\nu}| = 5 \times 10^{-13} \text{Hz s}^{-1}) \). However, the pulsar was braking harder at the beginning of the spin-down epoch in 1990 than at its end in 2008. Furthermore, the spin-down rate during this epoch was decreasing simultaneously with the decreasing of the source X-ray luminosity. Finally, the spin-down to spin-up torque reversal in 2008 occurred at lower luminosity as the spin-up to spin-down torque in 1990. These properties cannot be explained with existing models and appear to be a clue for further progress in understanding the mechanism governing the torque reversals in the accretion-powered pulsars.

Acknowledgments

A.C.A. thanks for the support of this project to the Spanish Ministerio de Ciencia e Innovación through the 2008 postdoctoral program MICINN/Fulbright under grant 2008-0116. N.R.I. acknowledges support from NASA Postdoctoral Program at NASA Marshall Space Flight Center, administered by Oak Ridge Associated Universities through a contract with NASA, and support from Russian Foundation of Basic Research under the grant 07-02-00535a. M.H.F. acknowledges support from NASA grant NNX08AG12G. We also want to thank all the \textit{Fermi}/GBM team for its help.
References

[1] Anzer, U., & Boerner, G. 1980, A& A, 83, 133
[2] Anzer, U., & Boerner, G. 1983, A& A, 122, 73
[3] Bildsten, L., Chakrabarty, D., Chiu, J., Finger, M. H., Grunsfeld, J. M., Koh, T., Prince, T. A., & Wilson, R. 1994, in AIP Conf. Ser. 304, Change in accretion torque in the binary accreting pulsar 4U 1626-67, ed. C. E. Fichtel, N. Gehrels, & J. P. Norris (Melville, NY: AIP), 294
[4] Bildsten, L., et al. 1997, ApJS, 113, 367
[5] Bradt, H. V., Rothschild, R. E., & Swank, J. H. 1993, A& AS, 97, 355
[6] Camero-Arranz, A., Finger, M.H., Ikhsanov, N.R., Wilson-Hodge, C.A. & Beklen, E., 2009, ApJ (accepted)
[7] Chakrabarty, D. 1998, ApJ, 492, 342
[8] Chakrabarty, D., Wang, Z., Juett, A. M., Lee, J. C., & Roche, P. 2002, ApJ, 573, 789
[9] Chakrabarty, D., et al. 1997, ApJ, 474, 414
[10] Day, C. S. R., & Stevens, I. R. 1993, ApJ, 403, 322
[11] Deeter, J. E., Boynton, P. E., Lamb, F. K., & Zylstra, G. 1989, ApJ, 336, 376
[12] Dupree, A. K., et al. 1980, ApJ, 238, 969
[13] Finger, M. H., Bildsten, L., Chakrabarty, D., Prince, T. A., Scott, D. M., Wilson, C. A., Wilson, R. B., & Zhang, S. N. 1999, ApJ, 517, 449
[14] Fritz, S., Kreykenbohm, I., Wilms, J., Stauber, R., Bayazit, F., Pottschnidt, K., Rodriguez, J., & Santangelo, A. 2006, A& A, 458, 885
[15] Gehrels, N., et al. 2004, ApJ, 611, 1005
[16] Ghosh, P., & Lamb, F. K. 1979, ApJ, 234, 296
[17] Giacon, R., Murray, S., Gursky, H., Kellogg, E., Schreier, E., & Tananbaum, H. 1972, ApJ, 178, 281
[18] Gruber, D. E., Blanco, P. R., Heindl, W. A., Pelling, M. R., Rothschild, R. E., & Hink, P. L. 1996, A & AS, 120, C641
[19] Hinkle, K. H., Fekel, F. C., Joyce, R. R., Wood, P. R., Smith, V. V., & Lebzelter, T. 2006, ApJ, 641, 479
[20] Inam, S., Sahiner, S., & Baykal, A. 2009, MNRAS, 395, 1015
[21] Jahoda, K., Swank, J. H., Giles, A. B., Stark, M. J., Strohmayer, T., Zhang, W., & Morgan, E. H. 1996, Proc. SPIE, 2808, 59
[22] Jain, C., Paul, B., & Dutta, A. 2009
[23] Kaur, R., Paul, B., Kumar, B., & Sagar, R. 2008, ApJ, 676, 1184
[24] Kommers, J. M., Chakrabarty, D., & Lewin, W. H. G. 1998, ApJ, 497, L33
[25] Krauss, M. I., Schulz, N. S., Chakrabarty, D., Juett, A. M., & Cottam, J. 2007, ApJ, 660, 605
[26] Krivonos, R., Produit, N., Kreykenbohm, I., Stauber, R., von Kienlin, A., Winkler, C., & Gehrels, N. 2003, Astronomer’s Telegram, 211, 1
[27] Lamb, F. K., Pethick, C. J., & Pines, D. 1973, ApJ, 184, 271
[28] Lamb, F. K., Shibazaki, N., Alpar, M. A., & Shaghah, J. 1985, Nature, 317, 681
[29] Levine, A., Bradt, H., Cui, W., Jernigan, J. G., Morgan, E. H., Remillard, R., Shirey, R. E., & Smith, D. A. 1996, ApJ, 469, L33
[30] Levine, A., Ma, C. P., McClintock, J., Rappaport, S., van der Klis, M., & Verbunt, F. 1988, ApJ, 327, 732
[31] Lipunov, V. M. 1992, in Astrophysics of Neutron Stars, ed. V. M. Lipunov, G. Borner, & R. S. Wadhwa (Berlin: Springer)
[32] Lovelace, R. V. E., Romanova, M. M., & Bisnovatyi-Kogan, G. S. 1995, MNRAS, 275, 244
[33] McClintock, J. E., Bradt, H. V., Dossey, R. E., Jernigan, J. G., Canizares, C. R., & Hiltner, W. A. 1977, Nature, 270, 320
[34] McClintock, J. E., Li, F. K., Canizares, C. R., & Gridnlay, J. E. 1980, ApJ, 235, L81
[35] Meegan, C. A., et al. 2009, ApJ, submitted
[36] Middleditch, J., Mason, K. O., Nelson, J. E., & White, N. E. 1981, ApJ, 244, 1001
[37] Orlandini, M., et al. 1998, ApJ, 500, L163
[38] Paczyński, B., & Sienkiewicz, R. 1981, ApJ, 248, L27
[39] Perna, R., Bozzo, E., & Stella, L. 2006, ApJ, 639, 363
[40] Petterson, J. A., Rothschild, R. E., & Gruber, D. E. 1991, ApJ, 378, 696
[41] Pravdo, S. H., et al. 1979, ApJ, 231, 912
[42] Pringle, J. E., & Rees, M. J. 1972, A& A, 21, 1
[43] Rappaport, S. A., Fregeau, J. M., & Spruit, H. 2004, ApJ, 606, 436
[44] Rappaport, S., Markert, T., Li, F. K., Clark, G. W., Jernigan, J. G., & McClintock, J. E. 1977, ApJ, 217, L29
[45] Reynolds, A. P., Quaintrell, H., Still, M. D., Roche, P., Chakrabarty, D., & Levine, S. E. 1997, MNRAS, 288, 43
[46] Shinoda, K., Kii, T., Mitsuda, K., Nagase, F., Tanaka, Y., Makishima, K., & Shibazaki, N. 1990, PASJ, 42, L27
[47] Vaughan, B. A., & Kitamoto, S. 1997
[48] Wijers, R. A. M. J., & Pringle, J. E. 1999, MNRAS, 308, 207
[49] Wilson, R. B., Fishman, G. J., Finger, M. H., Pendleton, G. N., Prince, T. A., & Chakrabarty, D. 1993, in AIP Conf. Ser. 280, Compton Gamma Ray Observatory, ed. M. Friedlander, N. Gehrels, & D. J. Macon (Melville, NY: AIP), 291
[50] Yi, I., & Vishniac, E. T. 1999, ApJ, 516, L87