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A GIANT OUTBURST FROM SGR 1900+14 OBSERVED WITH THE *BEPPOSAX* GAMMA-RAY BURST MONITOR

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ABSTRACT

We report the detection by the Gamma-Ray Burst Monitor on board *BeppoSAX* of the strongest and longest outburst ever detected from SGR 1900+14. Oscillations are detectable with a period of ~5.16 s for the entire duration of the event (~300 s). The temporal analysis reveals also a remarkable periodic substructure: after about 35 s from the event onset, each 5.16 s pulse shows a pattern of four subpulses and a dip, each separated by ~1 s. Significant spectral variation is detected during the event and for each individual oscillation. The first and most intense part of the outburst is quite hard and similar to what was previously detected from the "March 5 event." A hard nonthermal spectral component persists for ~200 s. SGR 1900+14 was proposed to be a strongly magnetized neutron star ($B \gtrsim 10^{14}$ G) undergoing violent instabilities by internal magnetic/crustal stresses. However, the onset of an apparent 1 s periodicity within the 5.16 s pulsations and the observed spectral properties show a complex behavior that is not satisfactorily modeled yet.

Subject headings: gamma rays: bursts — stars: individual (SGR 1900+14) — stars: neutron — X-rays: stars

1. INTRODUCTION

Soft gamma-ray repeaters (SGRs) are compact objects undergoing spasmodic instabilities producing X-ray super-Eddington subsecond outbursts. The accurate positioning of SGR 0525−66 (the source of the "March 5 event," showing the first evidence of a ~8 s periodicity: Mazets, Golenetskii, & Gur'yan 1979a; Cline et al. 1980) and SGR 1806−20 (Murakami et al. 1994) confirmed that some SGRs are within Galactic supernova remnants (Kulkarni & Frail 1993). The combination of a relatively long timescale oscillation (interpreted as rotation of a magnetized compact object) and a lifetime comparable with that of the associated remnant supported a model based on a strongly magnetized ($B \sim 10^{14}$–10^{15} G) neutron star for SGR 0525−66 (e.g., Duncan & Thompson 1992; Paczyński 1992; Thompson & Duncan 1995). The recent detection of 7.47 s pulsations in the persistent flux from SGR 1806−20 with period derivative 8.3×10^{-11} s s^{-1} (Kouveliotou et al. 1998a) corroborated this model for that repeater.

Among the four SGRs confirmed today, SGR 1900+14 is peculiar for the absence of a surrounding supernova remnant (however, it lies close to the less than 10^4 yr old supernova remnant G42.8+0.6: Vasisht et al. 1994; Hurley et al. 1999a; Murakami et al. 1999). Three outbursts of moderate intensity from this source were first detected in 1979 (Mazets et al. 1979a). The source was detected again in 1992 (Kouveliotou et al. 1993) and in 1998 May (Kouveliotou et al. 1998b; Hurley et al. 1999a). *ASCA* and *RXTE* observations revealed a 5.16 s periodicity in the quiescent X-ray (2–10 and 2–20 keV, respectively) emission with period derivative $\sim 1 \times 10^{-10}$ s s^{-1} (Hurley et al. 1999b; Kouveliotou et al. 1999). On 1998 August 27, a very strong outburst from SGR 1900+14 was detected by *Konus-Wind*, *Ulysses*, and *BeppoSAX* (Cline, Mazets, & Golenetskii 1998; Hurley et al. 1999a; Feroci et al. 1998). The 5.16 s periodicity was unambiguously detected during the outburst. Transient radio emission was also detected (Frail, Kulkarni, & Bloom 1999) 1 week after the event. These observational elements support an interpretation of these phenomena in the framework of the *magnetar* model (Thompson & Duncan 1995). However, in this Letter we present data of the August 27 outburst from SGR 1900+14 that are not yet explained by the current magnetar model.

2. GRBM OBSERVATION

The strong outburst from SGR 1900+14 triggered the Gamma-Ray Burst Monitor (GRBM: Frontera et al. 1997; Feroci et al. 1997) on board the *BeppoSAX* satellite on 1998 August 27 10:22:15.7 UT. The GRBM experiment consists of four CsI(Na) detection units, 10 mm thick, with a geometric area of ~1100 cm^2. The data available from the GRBM include 1 s ratemeters from each of the four units in two partially overlapping energy ranges (40–700 keV and greater than 100 keV). Assuming no significant contribution from the spectral region above 700 keV (in which the detector efficiency is less than 10%), we derive light curves in the two separate bands, 40–100 and 100–700 keV (Amati et al. 1997). (The correctness of the peak fluxes given below is subject to this assumption.) A dedicated memory allocated to the GRBM records, for each trigger, the 40–700 keV light curve of the event from 8 s before to 98 s after the trigger, with a minimum time resolution of 7.8125 ms (9 bit counters). For each unit, 240 channel energy spectra are continuously available, integrated over fixed time intervals of 128 s, regardless of triggers.

The event from SGR 1900+14 was detected by the four GRBM detection units. The event occurred at an elevation angle of 48° with respect to the GRBM equatorial plane, at an azimuthal angle of 29° with respect to the unit 1 axis, and 61° with respect to unit 4. The average effective area of unit 1 at this direction varies from ~56 cm^2 at 60 keV to ~365 cm^2 at 280 keV. For the analysis presented here, we used only the signal from unit 1, for which we have the highest signal-to-noise ratio. The count rates in the other units are strongly affected by scattering effects and energy-dependent obscuration by the satellite structures.

The estimated event duration is about 300 s. The total net

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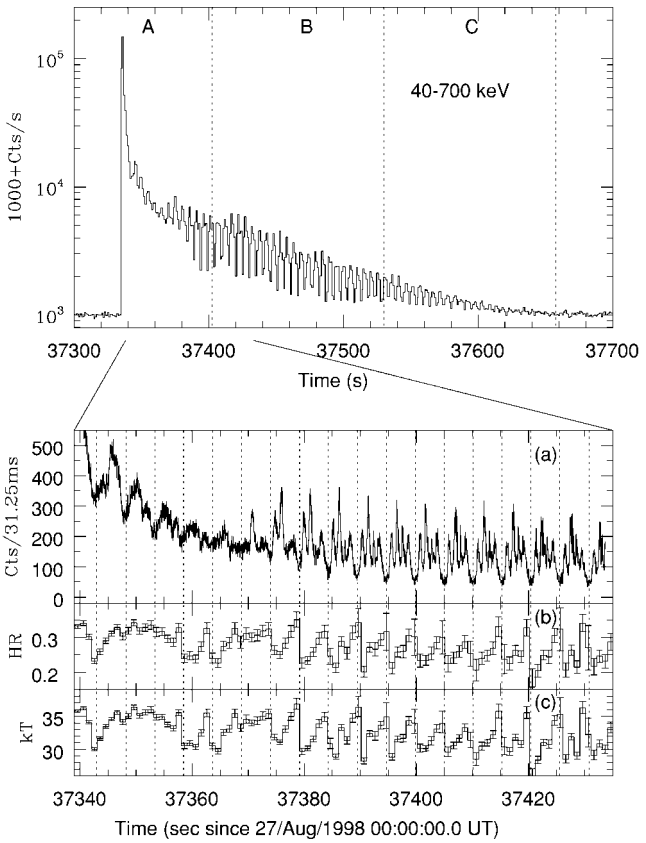

FIG. 1.—*Top*: 40–700 keV 1 s background subtracted light curve of the event (a value of 1000 counts s^{-1} has been added for display purposes). The dashed vertical lines define the intervals A, B, and C for which we have the time-averaged energy spectra. *Bottom*: (*a*) High-resolution light curve (rebinned at 31.25 ms) of the available portion of the event (~100 s); (*b*) 1 s resolved spectral evolution described in terms of the simple hardness ratio HR = (100–700 keV)/(40–100 keV) and (*c*) in terms of an equivalent *kT* of an optically thin thermal bremsstrahlung; 1 σ errors are shown. The vertical dotted lines are spaced by one period according to Hurley et al. (1999a).

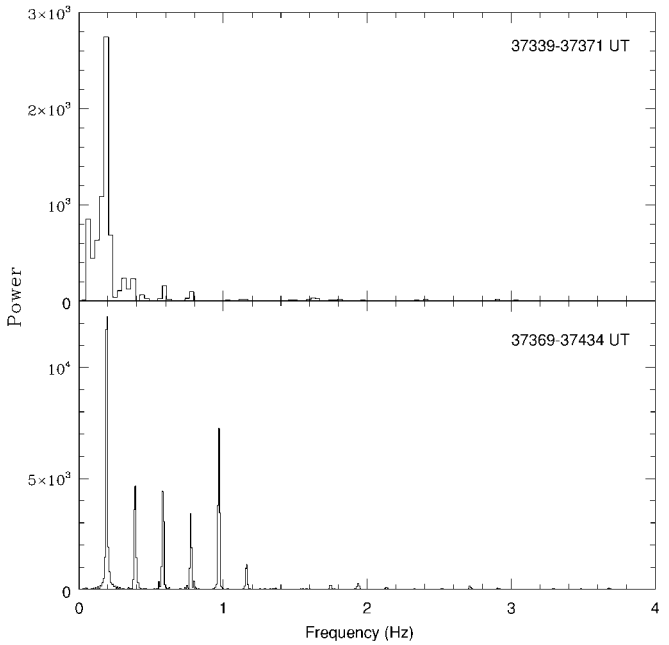

FIG. 2.—Power spectral density of the 7.8 ms light curve in the 40–700 keV range. *Top*: Time interval from 37339.11–37371.11 UT, demonstrating the presence of the 5.16 s pulsation from the beginning of the event. *Bottom*: Last 64 s of the high-resolution light curve (from 37369.13 to 37433.68 UT), when the 1 s subpulse structure is clearly set. (A four-degree polynomial detrending procedure has been applied.)

counts were 1,007,699 in 40–700 keV and 301,235 above 100 keV. The net peak count rate in 40–700 keV was 147,812 counts s^{-1} (average background ~880 counts s^{-1}) and 67,025 counts s^{-1} in the greater than 100 keV band (average background ~1,000 counts s^{-1}). These values replace those reported in Feroci et al. (1998), being corrected for dead-time and end-scale effects. In particular, we corrected our 1 s light curve in the 40–700 keV range for one counter recycle (one recycle implies an additive contribution of 65,535 counts s^{-1}) by comparing the 1 s resolution data with our high time resolution data (see below) and with the data from *Ulysses* (Hurley et al. 1999a). This correction is what we consider the most likely to be applied, but some uncertainty remains, and we present lower limits to the peak flux and fluence. The 40–700 keV peak flux is detected 1 s after the pulse rise and is greater than 2.10×10^{-4} ergs cm^{-2} s^{-1}. The measured fluence in the same band is greater than 1.5×10^{-3} ergs cm^{-2}. Assuming a source distance of 5 kpc (Hurley et al. 1999c) and isotropic emission, we obtain a luminosity of 6×10^{41} ergs s^{-1} at the peak and a luminosity of $\sim 3 \times 10^{40}$ ergs s^{-1} in the subsequent ~70 s. The total energy detected by the GRBM in the 40–700 keV band corresponds to $\sim 5 \times 10^{42}$ ergs. These flux values are obtained assuming a power-law spectrum whose index is computed on the 1 s time-scale from the two GRBM energy bands.

In Figure 1, we show the 1 s background-subtracted light curve (*top panel*), together with the 7.8 ms light curve (rebinned at 31.25 ms; *bottom*, panel *a*) for the time interval during which it is available and not affected by saturation. In fact, given the intensity of the event, the counters of the high-resolution data were saturated at the event peak. For this reason, we cannot determine the event rise time for timescales shorter than 1 s. The 5.16 s periodicity is clearly detectable in the 1 s resolved light curve, superposed on the general decay for the entire duration of the event. After a rapid decay during the first 2 s (faster in the 100–700 keV range than in 40–100 keV), the decay can be approximated with two exponential laws, with time constant $\tau \sim 5$ s for the first ~15 s and $\tau \sim 80$ s for the subsequent decay. The modulation of the oscillation with a ~32 s period is due to the sampling effect of a 5.16 s period at a 1 Hz frequency. The 31.25 ms light curve shows that, in addition to the 5.16 s periodicity, ~35 s after the beginning of the event the 5.16 s pulse is composed of four pulses and a dip equally separated in time by approximately 1 s (see § 3). In the high-resolution light curve, we see no statistically significant evidence for the precursor reported by Hurley et al. (1999a) (in the 25–150 keV band, ~0.4 s before the sharp rise). Given the comparable statistical and temporal quality of our data in the 40–700 keV, we are led to the conclusion that the spectrum of the precursor appears to be much softer than the rest of the emission.

3. TEMPORAL ANALYSIS

Figure 2 shows the power spectral density (PSD) for two portions of the 7.8 ms light curve. The PSD of the first part (37339.11–37371.11 s UT) is shown in the top panel and clearly demonstrates the presence of the 5.16 s pulsation since the beginning of the event. In the bottom panel of Figure 2,

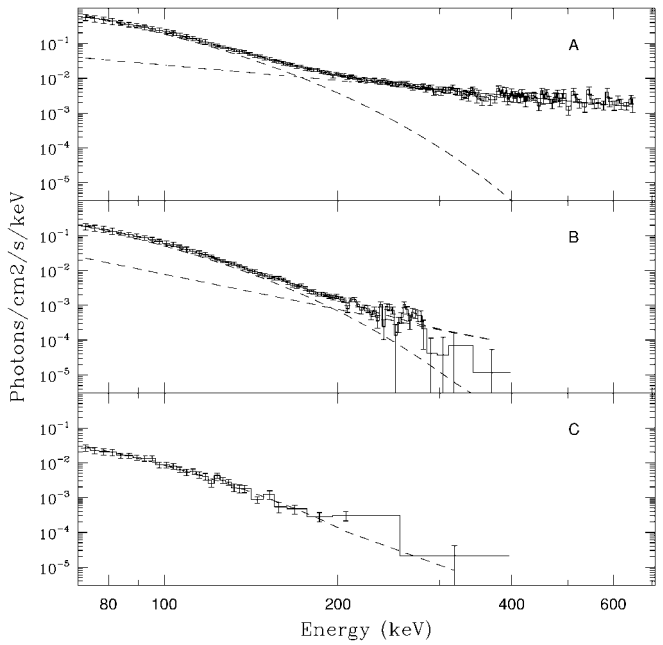

FIG. 3.—Fit to the GRBM spectrum (the individual spectral components are shown as dashed lines) in the energy range (*a*) 70–650 keV and (*b*, *c*) 70–400 keV with a model including (*a*) OTTB ($kT = 31$ keV) plus PL ($\alpha = 1.47$) for the time interval from 0 to 67 s with respect to the trigger time, (*b*) OTTB plus PL with $kT = 28$ keV and $\alpha = 4.5$ for the time interval from 68 to 195 s, and (*c*) OTTB with $kT = 29$ keV for the time interval from 196 to 323 s.

we show the PSD for the time interval 37369.13–37433.69 s UT, when the repetitive 1 s pattern is clearly set. The latter PSD shows the presence of the fundamental oscillation at 0.194 Hz and of its harmonics at 0.389, 0.580, 0.775, 0.969, and 1.161 Hz. Higher orders harmonics (up to $n = 19$) are not visible in the plot because of scale compression. Our best estimate of the main pulsation (computed by using the nineteenth-order harmonic at 3.679044 Hz to increase the accuracy) is 0.1936 ± 0.0008 Hz (the baricenter correction is negligible), consistent with the more accurate *ASCA* measurement of 0.19384 Hz. (Hereafter, the quoted errors correspond to a 90% confidence level.) What is remarkable in the PSD shown in the bottom panel of Figure 2 is the strong enhancement of the power associated with the $n = 5$ harmonic at 0.969 Hz. This is basically a measurement of the 1 s periodic structure within the 5.16 s pulse. We have also searched for the period of the repetitive pattern with no a priori assumptions: the maximum χ^2 is obtained for a period of 1.03 ± 0.03 s, which corresponds to one-fifth of the fundamental period.

Using the 1 s resolution data, we have detected the fundamental oscillation at 0.194 Hz in the PSD obtained separately for the 40–100 and 100–700 keV energy bands. A test for a phase shift in these two energy bands using a cross-correlation analysis gave negative results.

4. SPECTRAL ANALYSIS

4.1. *Time-averaged Analysis*

The available 240 channel energy spectra for this event have initial and final times, with respect to the trigger time, as follows: 0–67 s (interval A), 68–195 s (interval B), and 196–323 s (interval C). We fitted to these spectra the phenomenologically established[6] spectral law for SGRs: an optically thin thermal bremsstrahlung (OTTB: e.g., Mazets et al. 1979b; Kouveliotou et al. 1993). A 10% systematic error has been added to the statistical error to account for the calibration uncertainties at the large off-axis direction.

The spectrum in interval A cannot be fitted with a simple OTTB law, showing an excess at high energies (similar to that reported for the beginning of the March 5 event; e.g., Mazets et al. 1982; Fenimore et al. 1996). This is likely due to the strong spectral evolution as it appears from the 1 s ratemeters (see below), where we note a very hard spectrum during the first seconds, becoming much softer soon after the peak. Assuming different spectral components for these two fractions of interval A, we fitted the energy spectrum with the sum of an OTTB and of a single power law [PL; $I(E) \propto E^{-\alpha}$)]. The best-fit parameters are $kT = 31.2 \pm 2.5$ keV and photon index $\alpha = 1.47 \pm 0.16$ (reduced $\chi^2 = 0.705$ with 186 degrees of freedom [dof]). However, the spectrum can be equally fitted with the sum of a PL and a blackbody (BB), with $\alpha = 1.71 \pm 0.15$ and BB temperature $kT = 16.4 \pm 0.8$ keV (reduced $\chi^2 = 0.74$). In interval B we first used a simple OTTB law. The best fit to the spectrum has $kT = 34.2 \pm 1.2$ keV and reduced $\chi^2 = 1.996$ (75 dof). We noted in the residuals the existence of a hard excess that was likely biasing upward the determination of kT. Thence, we added a PL component to the fit, and the best-fit parameters are $kT = 27.6 \pm 1.9$ keV and $\alpha = 4.5 \pm 0.2$ (reduced $\chi^2 = 1.360$, 73 dof). Substituting the OTTB with a BB gives a reduced $\chi^2 = 1.424$ (73 dof) with $kT = 15.5 \pm 1.0$ keV and $\alpha = 4.5 \pm 0.1$. For interval C, we obtain a satisfactory OTTB fit with $kT = 28.9 \pm 1.4$ keV (reduced $\chi^2 = 1.06$, 71 dof). Figure 3 shows the three energy spectra and best-fit models.

4.2. *Time-resolved Analysis*

We used the two-channel, 1 s ratemeters to study short-timescale spectral variation. We show our results in terms of a hardness ratio (HR; counts in 100–700 keV divided by those in 40–100 keV) and of the equivalent temperature kT of an OTTB law. The first 2 s can be described by an extraordinary high $kT = 3200$ keV evolving to 60 keV, or with a value of HR = 4.06 decreasing to HR = 0.75, respectively. (We note that the peak values of kT and HR might be biased upward by the approximation mentioned in § 2). The subsequent evolution is shown in Figure 1 (*bottom*) in the time interval for which the high time resolution data are available. The HR and kT vary with the same ~5 s periodicity as in the light curve, with the hardness of the pulse increasing almost linearly with phase, in a ramplike fashion, with distinct maxima correlated with the dips in the light curve. The global trend of the HR is a softening of the spectrum.

5. DISCUSSION

The huge event from SGR 1900+14 strikingly resembles the famous 1979 March 5 event. The main similar characteristics are (1) their long duration with respect to usual SGRs bursts, (2) the impressive periodic pattern overimposed to a smooth exponential decay, and (3) the short initial hard peak. On the other hand, the August 27 event shows peculiarities not

[6] We note that the OTTB model is purely phenomenological and most likely without a physical basis for an optically thick radiating medium (see, for instance, Fenimore, Laros, & Ulmer 1994). We use it here for simplicity and to relate our results to other reports quoted in the SGR literature.

reported for the March 5 event: (a) a much longer first peak (~1 s versus ~150 ms); (b) a hard spectral component persisting for 200–300 s; (c) a strong evolution of the pulse shape, leading to a 1 s subpulse periodicity; and (d) a periodic spectral variation.

Our results show a complex behavior of SGR 1900+14 in outburst that can be summarized as follows.

1. A clear determination of the 5.16 s periodicity *from the beginning of the outburst.* We note that this feature was not detected by *Ulysses* (Hurley et al. 1999a), implying that it is related to the hard photons, similar to the nondetection with the GRBM of the precursor detected by *Ulysses*. Our period determination is consistent (within an uncertainty of 0.02 s) with the *ASCA* measurement, implying that such a large outburst caused a glitch with $\Delta P/P < 3.1 \times 10^{-3}$.

2. We see a clear transition after ~35 s in the shape of the 5.16 s pulse profile. At the beginning, the pulse is composed of two broad pulses, with relative intensity gradually changing with time. At the sixth pulse from the onset of the outburst, the two peaks become sharper, and gradually two additional narrow peaks appear. A striking feature of these four pulses is their equal mutual distance in time and their phase stability within the 5.16 s period. This feature appears in the PSD as a net enhancement of the $n = 5$ harmonic with respect to the others, corresponding to a periodicity of 1.03 ± 0.03 s. It looks like the 5.16 s periodicity in this part of the outburst is basically due to the lack/occultation of a fifth peak that one could have expected instead of the 5.16 s dip.

3. The determination of a complex spectral evolution showing a very hard initial outburst pulse followed by a softer emission that is strongly modulated in agreement with the periodic pulse structure. We notice a "see-saw" behavior of the HR, with the highest hardness corresponding to the dips of the light curve. If the dip would be due to an occultation, this would imply that a persistent hard component is present in the emitted spectrum. A hard component is observed in the time-averaged spectra as a PL component additional to the single OTTB (see Fig. 3, *top and middle*).

4. Finally, we note that the decay of the event light curve as detected by the GRBM is well approximated by a double exponential law and cannot be described by a power law as derived for the *Ulysses* light curve (Hurley et al. 1999a). Also, this difference is likely related to the different *Ulysses-BeppoSAX*/GRBM bandpasses.

The emerging picture is that of a complex phenomenon involving a nontrivial response of a compact object, most likely a highly magnetized neutron star with a structured emitting region, to a major explosive event. Our point 2 is worth of special attention. The emitting region surrounding the compact object is first subject to a violent readjustment following the initial strongly super-Eddington outburst (possibly related to a relativistic ejection producing the transient radio emission; Frail et al. 1999). Subsequent evolution and settling of the 1 s periodic feature reveals a highly structured emitting region with the excitation of higher order, possibly resonant oscillating modes. This feature is unprecedented among SGR strong outbursts detections. Trapping in a magnetosphere of emitting "blobs" (Thompson & Duncan 1995) corotating with the surface of a neutron star, or having their proper oscillation mode, might explain the harmonic content of the time variable power spectrum of SGR 1900+14.

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REFERENCES

Amati, L., et al. 1997, Proc. SPIE, 3114, 176
Cline, T. L., et al. 1980, ApJ, 237, L1
Cline, T. L., Mazets, E. P., & Golenetskii, S. V. 1998, IAU Circ. 7002
Duncan, R. C., & Thompson, C. 1992, ApJ, 392, L9
Fenimore, E. E., Laros, J. G., & Ulmer, A. 1994, ApJ, 432, 742
Fenimore, E. E., et al. 1996, ApJ, 460, 964
Feroci, M., et al. 1997, Proc. SPIE, 3114, 186
———. 1998, IAU Circ. 7005
Frail, D., Kulkarni, S., & Bloom, J. 1999, Nature, in press
Frontera, F., et al. 1997, A&AS, 122, 357
Hurley, K. et al. 1999a, Nature, 397, 41
———. 1999b, ApJ, 510, L107
———. 1999c, ApJ, 510, L111
Kouveliotou, C., et al. 1993, Nature, 362, 728
Kouveliotou, C., et al. 1998a, Nature, 393, 235
———. 1998b, IAU Circ. 6929
———. 1999, ApJ, 510, L115
Kulkarni, S., & Frail, D. 1993, Nature, 365, 33
Mazets, E. P., Golenetskii, S. V., & Gur'yan, Yu. A. 1979a, Soviet Astron. Lett., 5(6), 343
Mazets, E. P., et al. 1979b, Nature, 282, 587
Mazets, E. P., Golenetskii, S. V., Gur'yan, Yu. A., & Ilyinskii, V. 1982, Ap&SS, 84, 173
Murakami, T., et al. 1994, Nature, 36, 129
———. 1999, ApJ, 510, L122
Paczyński, B. 1992, Acta Astron., 42, 145
Thompson, C., & Duncan, R. C. 1995, MNRAS, 275, 255
Vasisht, G., et al. 1994, ApJ, 431, L35