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RAPID SPINDOWN OF SGR 1900+14 FOLLOWING ITS SUPERBURST

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ABSTRACT. SGR 1900+14 had a brief episode of exceedingly rapid spindown immediately following its 1998 Aug. 27 superburst. On a timescale of hours, it increased its period by a part in 10^4. The corresponding $\dot{P} \sim 10^{-8}$ is orders of magnitude higher than the typical quiescent rate of $\dot{P} \sim 6 \times 10^{-11}$.

1. Introduction

The spindown history of SGR 1900+14, shown in Figure 1, shows a discontinuity between the last pre-superburst observations, in 1998 May-June, and measurements made in the days following the superburst (Woods *et al.*, 1999a). The long-term average spindown rates both before the superburst, and in the months following the superburst, are each consistent with a typical spindown rate of $\dot{P} \sim 6 \times 10^{-11} ss^{-1}$. However the extrapolations of those two measurement periods are discrepant by $\sim 5 \times 10^{-4} s$, or 10^{-4} of the neutron star's $5.16s$ period.

If the excess period change accumulated uniformly through the interval June–August, this would require a spindown of roughly double the typical value. SGRs are known to have variable spindown rates and, indeed, the last May-June observations are consistent with this higher rate.

Alternatively, if the excess period change occurred between the superburst and the

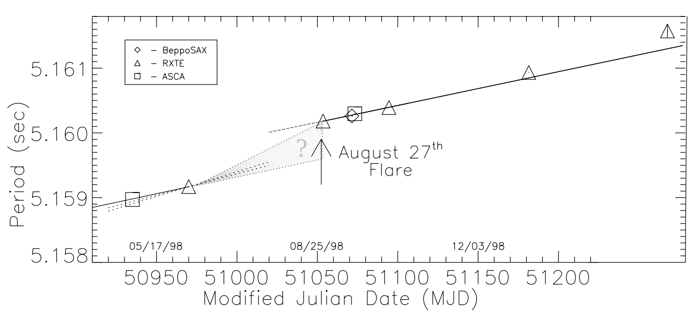

Fig. 1. Period history of SGR 1900+14, 1998 May to 1999 January. Adapted from Woods *et al.*, (1999a).

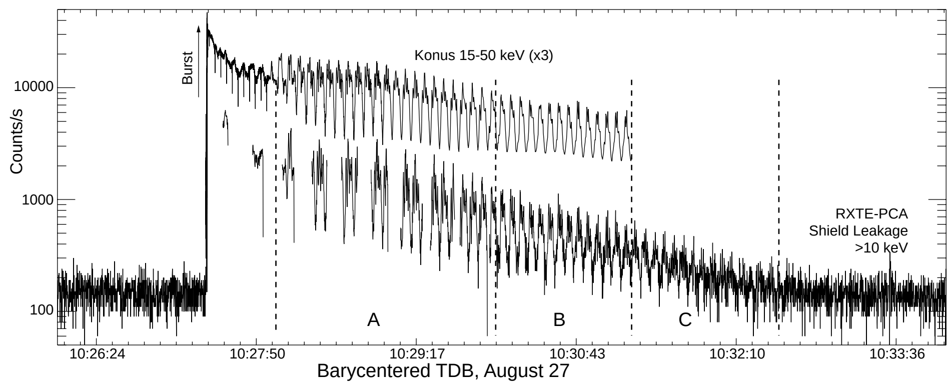

Fig. 2. Tail emission following the Aug. 27 superburst. Gaps in the PCA data during interval A are instrumental, due to buffer overflows.

follow-up observations beginning the next day, this would require an enormous $\dot{P}$, orders of magnitude higher than the typical rate.

Observations of the very strong pulsations in the superburst's tail are of too short a duration to resolve between the two periods. However, by comparing the phase of those pulsations against the extrapolated phase from the following weeks, the rapid and sustained spindown scenarios can be distinguished. This phase comparison indicates that the spindown occurred in a few hours following the burst.

2. Data and Analysis

Pulsations from SGR1900+14 have been observed by ASCA (Hurley *et al.*, 1999), BeppoSAX (Woods *et al.*, 1999b), RossiXTE (Kouveliotou *et al.*1998, Woods *et al.*, 1999a), and the BSA radio observatory (Shitov, 1999). These pulsations were found in the quiescent flux, exclusive of bursts. The main peaks of the bursts themselves occur equally often, and with equal intensities, at all phases (Palmer, 1999).

The tail of the August 27 superburst (Fig. 2) shows extremely strong, complex (4 peaks per cycle with significant persistent substructure) pulsations in its tail. These pulsations were seen by several instruments including KONUS-WIND (Mazets *et al.*, 1999), and PCA-RXTE, as leakage through its shield. In addition, the PCA also observed strong pulsations in the tail of a burst on August 29 during pointed observations.

XTE observations from 1998 Aug. 30-Sept. 27 form a good baseline for the post-burst spin ephemeris of the source. Trial foldings to find the maximal χ^2 of the pulse profile yield a 'September Ephemeris' of t_0 = 1998 Sept. 1.0 TDB, $P = 5.160197(1)s$, $\dot{P} \sim 6.1(3)\times10^{-11}ss^{-1}$, where quoted uncertainties are based on a maximum phase error of 0.1 cycles (2 phase bins). Systematic effects due to changes in the pulse profile do not allow confidence in reducing this phase uncertainty, even though the formal error from counting statistics is much lower. The χ^2 map (Fig. 3) shows no significant sidelobes, precluding aliasing.

Figure 4a shows a synopsis of the 1998 Aug.-Sept. observations of the SGR. Figure 4b

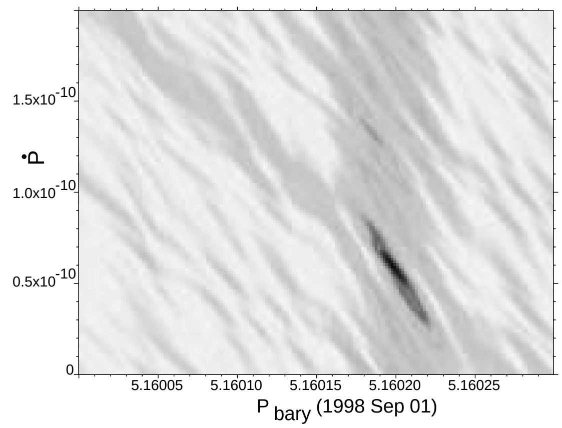

Fig. 3. Pulsation detection *vs.* Period and Period derivative of SGR 1900+14 during the interval 1998 Aug. 30–Sept. 27, based on RXTE-PCA observations.

shows the corresponding pulse profiles based on folding using the September Ephemeris. The quiescent pulse profiles (beginning with the Aug. 28 observation the day after the superburst) all line up fairly well. However, the pulse profile from the tail of the superburst (far left) shows a large phase shift.

The value of the phase shift is ambiguous, due to the change in pulse profile between the burst tail and the quiescent pulsations during the following days. Figure 5 shows the pulse profile of superburst tail in more detail, and compares it to the quiescent profile for the following two days. The agreement of Konus and PCA light curve shape and phase during interval B demonstrates shows that barycentering, done manually for Konus and using the *fxbary* FTOOL (Blackburn, 1995) for the PCA, was consistently applied.

Four main peaks in the tail pulsations are labelled–a more detailed analysis shows even more substructure. Identifying which peak (if any) of the tail corresponds to the main peak on the following days is ambiguous. Peak 1, corresponding to the smallest phase shift, has almost disappeared by the start of interval B, 47 seconds after the start of the burst. The other three peaks are all plausible, but a phase shift of $\Delta\phi_3 = 0.42$ cycles, appropriate for Peak 3, allows the shape of the quiescent pulse to neatly envelope the peaks in Interval C. This does not exclude peaks 2 and 4, but using the phase shift for those peaks (0.26 and 0.62 cycles, respectively) would lead to similar conclusions, as is discussed below.

The sign of the phase shifts, as quoted, is appropriate for rapid spindown (increasing period) between the tail of the burst and data taken the next day. The potential ambiguity of an integral number of spins (*i.e.* $\Delta\phi_3 = 1.42$ cycles) is eliminated below.

3. Spindown Rates

The spin ephemeris of SGR 1900+14 derived from the post-superburst data does not accurately predict the phase of emission at the time of the superburst. This phase error

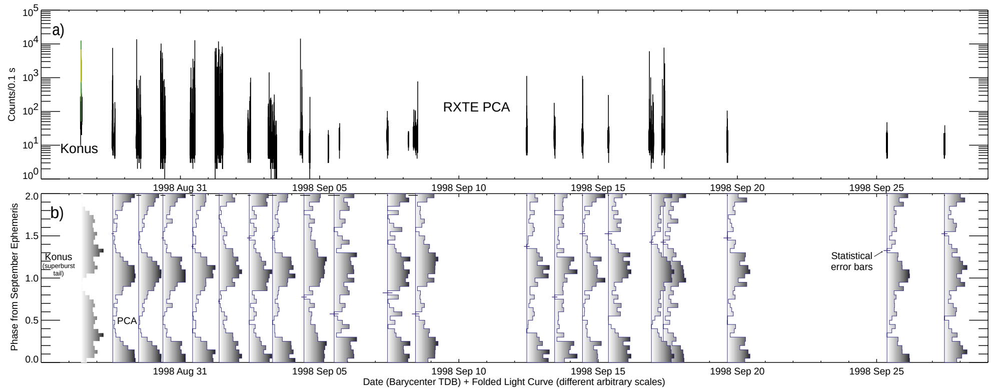

Fig. 4. SGR 1900+14 behavior, 1998 Aug. 27 - Sept. 27. All data is from the RXTE PCA except for the Konus superburst data on Aug 27. *a)* Observations and count rates–vertical spikes above the typical 10 counts/0.1s rate indicate baby bursts. *b)* Pulse profile folded using the 'September Ephemeris' for the superburst tail (Konus, Aug. 27) and during quiescent times with bursts excluded.

is a consequence of error in the predicted period, accumulated over the interval between the superburst and the following observations: $\Delta\phi = \int \Delta P(t)/P^2 dt$. A constraint on the size of the period error inversely constrains the duration over which it must have persisted, allowing us to determine the timescale of the spindown.

The 1996 Sept. – 1998 June long term average spindown rate is $\sim 6 \times 10^{-11} ss^{-1}$, as is the rate for 1998 Sept. However, extrapolations in both directions to the time of the 1998 Aug. 27 superburst give a discrepancy of $\Delta P = 0.57$ ms. If the forward extrapolation accurately predicts the spin rate at the time of the superburst, the backward extrapolated ephemeris will accumulate phase error at an initial rate of one cycle per $T_\delta = P^2/\Delta P = 13.1$ hours.

A phase error of $\Delta\phi_3 = 0.42$ could be accumulated in a time $\tau_0 = T_\delta \Delta\phi = 5.4$ hours. This corresponds to the model where the neutron star continues to spin at the higher speed for a time τ_0 after the burst, then instantaneously slows down bya part in 10^{-4}. As such, it provides a lower limit on the time between the superburst and the completion of the spindown.

More reasonably, we can model the spindown as a constant $\dot{P}_{fast}$ over an interval $\tau_1 = 2T_\delta \Delta\phi = 10.8$ hours, which requires $\dot{P}_{fast} = \Delta P/\tau_1 = 1.5 \times 10^{-8} ss^{-1}$. This spindown rate is $250\times$ the typical quiescent $\dot{P}$. Any other functional form for the spindown requires a higher $\dot{P}_{fast}$ at least part of the time.

Duncan (*priv. comm.*) has a model in which the period shortly after the burst is $P(t) = P_0 + \Delta P/(1 + \tau_D/t)$. For this model, $\tau_D = 2.2$ hours would fit the first day's phase shift, but there would be an additional 0.1 cycle shift on the following day, which is not apparent in Fig. 5.

No functional form in which $\dot{P}$ decreases monotonically back to the typical value after the burst is consistent with the extra-turn interpretation with $\Delta\phi_{3alias} = 1.42$.

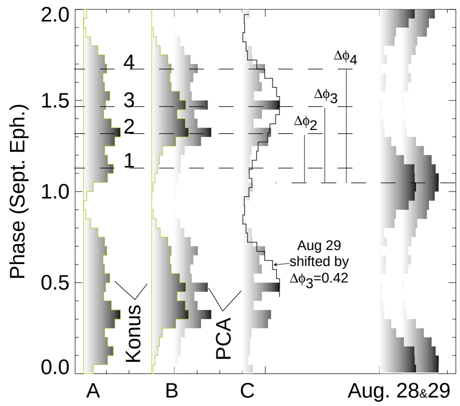

Fig. 5. SGR 1900+14 superburst tail pulsations, for the intervals shown in Fig. 2, compared to those of the following two days. Data are from *A* Konus, *B* Konus & PCA shield leakage, *C* PCA shield leakage, and *Aug 28&29*PCA pointed observations. Time intervals chosen are based on data availability: the PCA data was interrupted by buffer overflows during interval A, and Konus data ends with interval B.

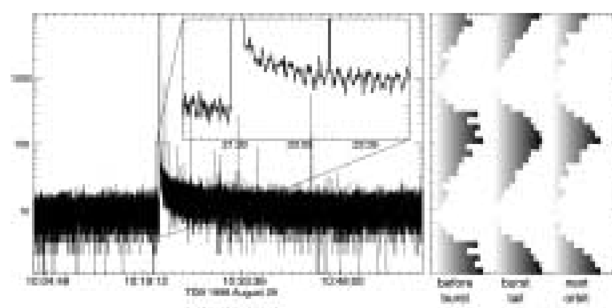

Fig. 6. The 'Big Baby' burst of 1998 Aug. 29, as seen by the RXTE-PCA. The pulsations in its tail are in phase with those before and after the burst.

4. Discussion

If any phase from peaks 2 through 4 of the tail pulses corresponds to the peak of the quiescent emission, then SGR 1900+14 must have had a spindown rate orders of magnitude higher than its typical $\dot{P}$ for a few hours after the superburst.

One possible objection to this is that the tail emission may be beamed in a different body-centered direction than the quiescent emission, causing a shift between spin phase and emission phase. However, the large (but not super) baby burst from SGR 1900+14 two days later, on Aug 29, also shows strong pulsations in its tail. These tail pulses are in phase with the the quiescent pulses before and after this burst (Fig. 6). It is therefore reasonable to assume that the superburst tail emission and the quiescent emission are indeed beamed in the same direction.

A typical glitch in a radio pulsar is a spin rate increase event, thought to be produced by sudden coupling of the neutron star crust to its superfluid interior which is still rotating at an earlier, faster rate. An Anomalous X-ray Pulsar, thought to be a similar object to an SGR, has also shown such a spin-up glitch (Kaspi *et al.*, 2000).

The August 27 spindown event is different from a typical glitch in both sign and magnitude ($\Delta P/P = 10^{-4}$ *vs.* $\sim -10^{-6}$ for a 'giant glitch'). Since the magnetosphere is providing the braking force, it is moving more slowly than the superfluid interior, and thus coupling cannot cause a spindown. Slowing the spin by increasing the moment of inertia of the neutron star is energetically infeasible ($\sim 10^{49}$ erg). Therefore, it is more likely that the SGR is shedding angular momentum.

If the SGR superburst generated a massive wind held in co-rotation by the magnetosphere until it decouples at the light cylinder, then $\sim 10^{20}g$ of this wind would slow the neutron star by the required amount. The energetic cost of lifting this wind against gravity is $\sim 10^{40}$ erg, or $\sim 10^{-3}$ of the total flare X-ray energy. This level of torque on the neutron star can be supported by magnetar-level magnetic fields of $10^{14}G$ with a distortion of less than 10^{-9} radian at the surface of the star. Line emission suggesting the presence of iron around the SGR has been seen in the August 29 burst (Strohmayer & Ibrahim, 2000), which may be crust material blown into circumstellar space as part of the wind.

5. Conclusion

For an interval of several hours following its superburst, SGR 1900+14 had a spindown rate that was orders of magnitude higher than its typical rate during quiescence. This spindown is consistent with a wind with reasonable mass and energy parameters.

6. Acknowledgements

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References

Blackburn, J.K.: 1995 *ASP Conf. Ser.* **77** 367.
Hurley, K., *et al.*: 1999 *Astrophys. J. Lett.* **510**, L111.
Kaspi, V.M., Lackey, J.R. & Chakrabarty, D.: 2000 *Astrophys. J. Lett.* **537**, L31.
Kouveliotou, C., *et al.*: *Nature* **393**, 235.
Mazets, E.P. *et al.*: 1999 *Astron. Lett.* **25**, 635.
Palmer, D.M.: 1999 *Astrophys. J. Lett.* **512**, L113.
Shitov, Y.P.: 1999 *IAUC* 7110.
Strohmayer, T.E. & Ibrahim, A.I.,: 2000 *Astrophys. J. Lett.* **537**, L111.
Woods, P.M., *et al.*: 1999a, *Astrophys. J. Lett.* **524**, L55.
Woods, P.M., *et al.*: 1999b, *Astrophys. J. Lett.* **518**, L103.