ON THE LIFETIME OF LOW MASS X-RAY BINARIES

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ABSTRACT

It is argued that the measured mass of the binary millisecond pulsar PSR 0021-72A provides a strong evidence that a rapidly spinning neutron star may drastically curtail the X-ray lifetime of a binary system.

In this paper we wish to point out an interesting implication of the measured mass of the recently discovered millisecond pulsar PSR 0021-72A in 47 Tucanae[1,2] as it suggests a possible resolution of one of the outstanding difficulties with the standard spin-up scenario for millisecond pulsars, and in particular, the evolutionary history of this pulsar.

Before stating the problem, we wish to briefly recall some of the properties of this pulsar (table 1). The spin period of the pulsar is $\sim$4.5 ms; the period derivative has not yet been measured. The orbital period is $\sim$32 min and the projected semi-major axis of the orbit of the pulsar in only $\sim$714 km. Of particular interest to the subsequent discussion is the very large eccentricity ($\sim$0.32) of the orbit, which suggests that this must be a fairly young system. Given such a tight binary, one expects several general relativistic effects to be very pronounced. Indeed the measured rate of precession of the periastron ($\sim 0^\circ.6$ day^{-1}) is 50 times larger than that for the Hulse–Taylor pulsar PSR 1913+16. Ables *et al.*[2] have also measured the Einstein time delay, which is $\sim 510\ \mu$s. The measurement of these two general relativistic effects has made possible the determination of two of the most important parameters of the binary system, namely the inclination of the orbit normal to the line of sight and the mass of the pulsar as well as that of its companion. It is remarkable that the orbit is viewed almost exactly face-on ($i = 0.38 + 0.01$ deg). The mass of the companion, presumably a white dwarf, is surprisingly large ($\sim 0.8\ M_\odot$). These two characteristics, and the large orbital eccentricity, have important implications which we shall now discuss.

Table 1 *Parameters of PSR 0021-72A*

Spin period	P	4.4789545(1) ms
Period derivative	$\dot{P}$	$< 10^{-15}$ s s^{-1}
Dispersion measure	DM	67 ± 2 cm^{-3} pc
Flux density at 430 MHz	S_{430}	4 ± 2 mJy
Projected semi-major axis	$a_p \sin i$	714 ± 9 km
Binary period	P_b	1942.0845 (20) s
Eccentricity	e	0.32 (1)
Apsidal rate	$\dot{\omega}$	0.565 (20) deg/day
Amplitude of Einstein delay	γ	$510 \pm 30\ \mu$s
Pulsar mass	m_1	$1.38 \pm 0.08\ M_\odot$
Companion mass	m_2	$0.77 \pm 0.05\ M_\odot$
Mean separation	a	300900 ± 4000 km
Orbital inclination	i	0.38 ± 0.01 deg

[From Ables *et al.* 1989]

Numbers in parentheses represent uncertainties in the last digits.

According to the standard picture, millisecond pulsars with low magnetic fields are spun up due to mass transfer in low mass X-ray binaries (LMXBs). The fact that three of the four millisecond pulsars in the galactic disk are in binaries with low-mass companions and circular orbits lends credibility to this hypothesis. The highly eccentric orbit of the pulsar in discussion therefore poses a problem. Also, the fact that one is viewing the orbit almost exactly face-on suggests that the spin axis of the pulsar is inclined at a fairly large angle with respect to the orbit normal; in a close binary in which there has been a mass exchange for a very long time ($\sim 10^8$ years) one should expect the spin axis to be aligned with the orbit normal. If the millisecond pulsar was indeed spun up by accretion then the large mass of its companion also poses a difficulty. Detailed evolutionary calculations[3] suggest that it is difficult to reconcile the measured mass of the companion with the duration of the mass transfer phase necessary to spin it up to a few milliseconds. Because of these difficulties one can rule out the possibility that PSR 0021-72A was spun up in the *presently* observed binary system. Ables *et al.*[2] and Wijers[4] have argued that the most plausible evolutionary route for the present system may be the following. The present system must be the result of a resonant exchange collision between a relatively wide binary with a circular orbit, in which the pulsar was spun up, and a $\sim 0.8\,M_{\odot}$ white dwarf. The very large eccentricity of the orbit and the fact that the spin axis of the neutron star is misaligned with the orbit normal can then be easily reconciled. While the arguments leading up to this conclusion are quite compelling, there is also a serious difficulty. Even if one grants that an exchange encounter can happen once in a Hubble time in a dense cluster such as 47 Tucanae, the 'phase space' for producing a binary with a very large eccentricity ($e \sim 0.99$ even if the encounter took place only $\sim 10^8$ years ago) is likely to be very small[5]. This would then imply that there must be a large number of binary millisecond pulsars as well as several low mass X-ray binaries in this cluster[6]. Although the presence of many binary millisecond pulsars cannot be ruled out at present, the absence of LMXBs poses a problem (though there is one known X-ray source in this cluster, its low luminosity, $\sim 10^{33}$–10^{34} erg s^{-1}, argues against it being a standard LMXB). This can only be reconciled if the lifetime of LMXBs is much less than is commonly believed. In the standard evolutionary models[3] for LMXBs the mass transfer at near-Eddington rate ($\sim 10^{-8}\,M_{\odot}\,yr^{-1}$) is expected to be sustained for $\gtrsim 10^8$ yr. Thus in order to drastically reduce the lifetime of the X-ray phase one must prevent the matter from the Roche-lobe overflowing companion from accreting onto the neutron star.

A mechanism for doing this has already been suggested by Ruderman *et al.*[7] After the neutron star accretes for about 10^7 yr at the Eddington rate, it will be spun up to a period ~ a millisecond, and the speed-of-light cylinder will be only a few stellar radii away. Let us now suppose that there are instabilities that cause large modulations in mass transfer rate, such that during a phase of low mass transfer, the Alfvén radius is pushed outside the light cylinder. Once this happens, as Ruderman *et al.*[7] have argued, the pressure of the low-frequency radiation from the millisecond neutron star will permanently quench the accretion of matter onto it. From then onwards the mass lost by the companion will be expelled from the system. Under these circumstances the lifetime of the X-ray phase would be the same as the spin-up time-scale, i.e. $\sim 10^7$ yr.

A similar problem has also arisen in the galactic disk. If LMXBs are the progenitors of millisecond pulsars then the ratio of the number of millisecond pulsars to that of LMXBs should be in the ratio of their lifetimes. While there are at most ~100 LMXBs in the disk, the number of millisecond pulsars has been estimated[8] to be $\gtrsim 10^5$. Therefore, even if millisecond pulsars live for ~ a Hubble time, there is an apparent problem if the lifetime of LMXBs is $\gtrsim 10^8$ yr as is generally believed. This has led Kulkarni and Narayan[8] to suggest that there might be other formation mechanisms for millisecond pulsars. However, this difficulty can be overcome[9] if the active lifetime of LMXBs is smaller by a factor of ~10 compared to the standard estimates.

If the mechanism suggested by Ruderman *et al.*[7] is the relevant one for reducing the lifetime of the X-ray phase, then there is one important implication for the mass of a spun-up millisecond pulsar. If the accretion phase lasts for $\sim 10^8$ yr, then the mass of the pulsar should be $\sim 2\,M_{\odot}$, whereas if the mass transfer stopped soon after spin-up, it should be ~ 1.4–$1.5\,M_{\odot}$. It is remarkable that the measured mass[2] of the millisecond pulsar PSR 0021-72A in 47 Tucanae is very close to $1.4\,M_{\odot}$. Hence, if this pulsar was indeed spun up in a mass transfer binary, it provides strong evidence for a relatively short lifetime of LMXBs (through the mechanism suggested by Ruderman *et al.*[7]), thereby strengthening the case for LMXBs as the progenitors of binary millisecond pulsars.

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1. Ables, J. G., Jacka, C. E., McConnel, D., Hamilton, P. A., McCulloch, P. M. and Hall, P. J., *Int. Astr. Union Circ. No. 4602*, 1988.
2. Ables, J. G., McConnel, D., Jacka, C. E., McCulloch, P. M., Hall, P. J. and Hamilton, P. A., *Nature* (*London*), 1989, (submitted).
3. Webbink, R. F., Rappaport, S. A. and Savonije, G. J., *Astrophys. J.*, 1983, **270**, 678.
4. Wijers, R. A. M. J., *Astron. Astrophys.*, 1989, **209**, L1.
5. Hut, P., *Astron. J.*, 1983, **88**, 1549.
6. van den Heuvel, E. P. J., van Paradijs, J., Srinivasan, G. and Verbunt, F., 1988, (unpublished).
7. Ruderman, M., Shaham, J. and Tavani, M., *Astrophys. J.*, 1989, **336**, 507.
8. Kulkarni, S. R. and Narayan, R., *Astrophys. J.*, 1988, **335**, 755.
9. Coté, J. and Pylyser, E., *Astron. Astrophys.*, 1989, **218**, 131.