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A MODEL FOR THE MILLISECOND PULSAR PSR 1937+214

(Letter to the Editor)

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Abstract. We suggest a model for the millisecond pulsar 1937+214, according to which the immediate progenitor of the pulsar was a binary consisting of two neutron stars of unequal mass. The heavier neutron star was spun up by the transfer of angular momentum from the orbit, and the lighter neutron star was tidally disrupted, leaving behind a millisecond pulsar.

It has been suggested that the millisecond pulsar PSR 1937+214 is an old neutron star which was spun up by accretion from a surrounding Keplerian disc (Radhakrishnan and Srinivasan, 1982; Alpar *et al.*, 1982). An alternative hypothesis is that the pulsar formed by coalescence of two neutron stars which had constituted a binary like PSR 1913+16 (Henrichs and van den Heuvel, 1983). Both these models face difficulties.

Massive binaries required by the accretion disc models are unlikely to live sufficiently long to allow the required amount of spin-up matter ($\geq 0.1 M_\odot$) to be accreted; in low mass binaries the compansion star is still expected to be present (Henrichs and van den Heuvel, 1983). Moreover, if the magnetic field of the millisecond pulsar is only $\sim 10^7$ G, then the accretion times are uncomfortably long, $\sim 10^{10}$ yr (Sivaram and Kochhar, 1984).

Coalescence also seems to have difficulties in providing the right period for a plausible range of neutron star masses. The two neutron stars would fuse together if they are of equal mass and just touching each other. They are expected to corotate. The period of each is given by $P_{ms}^2 = 5.6/\rho_{14}$, where $P = P_{ms} \times 10^{-3}$ s and $\rho = \rho_{14} \times 10^{14}$ g cm^{-3}, the average density. Here, general relativistic effects are ignored but they are not expected to contribute more than 10% (Kochhar and Sivaram, 1984).

Since the radius of a neutron star remains almost constant for mass range of interest, $\rho \sim M$. Thus short periods are possible only for heavier neutron stars. Taking typical values to be $M = 1 M_\odot$ and $R = 10^6$ cm, the corotation period $P_{ms} = 1$ ms. During coalescence a fraction of the angular momentum and a few tenths of a solar mass would be lost from the system (Clark and Eardley, 1977). Ignoring these small losses, we find that coalescence of two $1 M_\odot$ neutron stars would yield a $2 M_\odot$ neutron star with a period of about 2 ms. If the final product is a $1 M_\odot$ neutron star, the period would be longer. Shorter periods would be possible if the neutron star masses were higher, but then the resultant star would be a Kerr black hole rather than a neutron star. Thus, it would be extremely difficult to form a $1 M_\odot$ millisecond pulsar by coalescence of two neutron stars.

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We now suggest an alternative model, based on the detailed calculations of Clark and Eardley (1977). The starting point is a 1913 + 16 type binary consisting of two neutron stars, except that now their masses are unequal. The evolutionary history leading to such a system has been given by e.g. Srinivasan and van den Heuvel (1982). Because of gravitational radiation the orbital radius of the neutron star binary would decrease to a point where the lighter member is at its tidal (Roche) radius; the orbital period would then be a few milliseconds. The tidal coupling ensures the corotation of the two neutron stars.

Mass transfer would take place from the lighter to the heavier star, spinning up the heavier star, and changing both the Roche radius and the separation. If the lighter star can manage to keep out of its Roche radius, the system would be stable. Otherwise, the lighter star would be disrupted. The stability of the system depends upon the amount of angular momentum transfered from the orbit to the heavier star. If it is large, the lighter star would be pushed inside its tidal radius and disrupted. Since the heavier star is already spinning very fast, the debris is expected to disperse in a few orbits (Clark and Eardley, 1977). Alternatively the debris could be accreted by the still intact neutron star spinning it down to a period longer than 1 ms.

We suggest that the millisecond pulsar 1937 + 214 is such a spun-up old neutron star whose companion, a much lighter neutron star, was tidally disrupted and dispersed.

A possible immediate progenitor is a specific model discussed by Clark and Eardley (1977). The binary consists of two neutron stars of mass $1.3 M_\odot$ and $0.8 M_\odot$ separated by 33.5 km, corresponding to a period of ~ 3 ms. A fraction η of the available angular momentum is accreted by the heavier star. If $\eta = 0.25$, the orbit remains stable. If, however, η takes a value close to the maximum permissible value of 0.4, the heavier neutron star would be spun up to a period of 1 ms on accretion of $\sim 0.1 M_\odot$ of mass, the lighter star would be pushed inside its tidal radius and disrupted, leaving behind a single, millisecond neutron star. Since it is an old neutron star, its magnetic field will be low; and it can correspond to the millisecond pulsar 1937 + 214.

If the parameter $\eta = 0.25$, say, the binary will not be disrupted. It will consist of a millisecond neutron star and a $\sim 0.3 M_\odot$ neutron star. This will, however, not correspond to the binary millisecond pulsar 1953 + 29, because the separation between the two neutron stars in the model is very small unlike in the case of PSR 1953 + 29.

The spinning up of an old neutron star by transfer of angular momentum from the orbit to the neutron star is attractive because it is very rapid, and independent of the magnetic field strength and the neutron star mass.

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