Astrophysics

Missing link of pulsar evolution

Charles Bailyn

THE discovery[1] of the eclipsing millisecond pulsar PSR1957+20 has sent theoreticians scurrying to find a place for this remarkable object in the complex life-cycle of radio pulsars and their cousins, the low-mass X-ray binaries. E.S. Phinney *et al.*[2], W. Kluzniak *et al.*[3], and E.P.J. van den Heuvel and J. van Paradijs[4] show that the pulsar represents an evolutionary link, hitherto only hypothesized, between low-mass X-ray binaries and isolated pulsars observed to have millisecond periods.

Pulsars are rotating neutron stars which beam radiation towards an observer once each spin period; most have pulse periods of about 1 second but a few have periods up to a thousand times shorter. These high rotation speeds are thought to result from a period of accretion earlier in the life of the neutron star. In this model, gas from a nearby binary companion star accumulates in an accretion disk around the neutron star. As this material subsequently settles onto the neutron star it brings with it a high specific angular momentum, spinning up the neutron star to the short spin periods required for millisecond pulsations.

The gravitational energy released during the accretion phase manifests itself in high X-ray luminosities and the system is observed as a bright X-ray source, not a radio pulsar. After the termination of accretion, the neutron star is 'uncovered' and emerges as a radio pulsar. How and why accretion ends and, in the case of isolated (non-binary) millisecond pulsars, how the binary companion is removed, have not until now been understood. PSR1957+20 has provided dramatic confirmation of an important process in this regard, being an intermediate evolutionary stage between low-mass X-ray binaries (LMXBs) and isolated millisecond pulsars.

Companion

The size of the eclipsing region of the companion of PSR1957+20 is estimated to be 0.7 times that of the Sun. Changes in the pulse timing as the pulsar approaches and recedes from us in its binary orbit give a velocity and size for the orbit, and thus an estimate of the companion's mass of 0.02 solar masses. These measurements of the size and mass of the companion lead to an apparent paradox, because an object of these dimensions would be ripped apart by the tidal field of the pulsar itself.

The resolution to this problem is contained in two papers[5,6] by Kluzniak's colleagues, submitted to the *Astrophysical Journal* a few months before the discovery of PSR1957+20. They suggest that energy released by the gradual spin-down of a millisecond pulsar is transferred to a binary companion in the form of mega-electron-volt photons, which give rise to a strong wind from the companion. Such a wind would suffice to block the radio emission from the pulsar to a distance many times the radius of the companion. In this case the companion star itself could be compact enough not to be tidally disrupted. Thus PSR1957+20 belongs to that select group of astronomical objects for which theoretical explanations existed before their discovery.

The papers by Phinney *et al.*[2], Kluzniak *et al.*[3] and van den Heuvel and van Paradijs[4] apply this model directly to PSR1957+20 and explore various evolutionary consequences. The authors agree that the pulsar luminosity suffices to drive the wind required to create the observed eclipses, and also that within 10^8 years, the companion will be completely evaporated. In this time, the pulsar spin-down will not be significant, so PSR1957+20 will evolve into an isolated millisecond pulsar.

Having concurred on the present and future status of the eclipsing pulsar, Phinney *et al.*[2] and Kluzniak *et al.*[3] differ over the past evolution of the system. Phinney *et al.*[2] suggest that the neutron star's companion (the secondary) in the precursor LMXB system was a main-sequence star of 0.6 solar masses and that the system had a 5-hour orbital period. If mass transfer suddenly stopped at this point, perhaps because of changes in the internal structure of the main-sequence star that occur at this mass, the uncovered pulsar would begin to evaporate the secondary. The mass and angular momentum driven off from the secondary would then result in a system with the parameters of PSR1957+20.

In contrast, Kluzniak *et al.*[3] begin with a secondary of less than 0.1 solar masses and an orbital period of about 1 hour. As the secondary becomes less massive, gravitational radiation becomes less effective at driving mass transfer. Traditionally, the resulting gradual decrease in luminosity has been thought to mark the demise of LMXBs as observable objects. But Kluzniak *et al.* suggest that mass transfer may be driven by megaelectron-volt γ-rays which are produced at the boundary between the accretion disk and the magnetosphere of the neutron star. This radiation creates a wind from the secondary, which is accreted into a disk and from there onto the neutron star without loss of angular momentum, driving the system apart as the mass ratio becomes more extreme. Eventually this source of accretion also becomes small and the pulsar becomes uncovered in a system close to the present parameters of PSR1957+20. According to this scheme all dying LMXBs will be reborn as millisecond pulsars.

Cataclysmic variables

van den Heuvel and van Paradijs[4] apply the wind-evaporation idea to another question in LMXB evolution. They note that cataclysmic variables, which are similar to LMXBs except that they have white dwarf primaries instead of neutron stars, are known to have a range of periods (2–3 hours) in which mass transfer apparently ceases. This is probably also true for LMXBs: none with a period in this range is known. When the mass transfer turns off in an LMXB, the uncovered pulsar quickly evaporates the companion. Thus, although cataclysmic variables with orbital periods below 2 hours are thought to have evolved through the gap by gravitational radiation, this process cannot occur in LMXBs; instead these become millisecond pulsars. There is some observational support for this, in that the few LMXBs with periods below the gap are thought to have degenerate white-dwarf secondaries and different evolutionary paths altogether.

These three papers[2-4] make clear that the evolution of LMXBs and millisecond pulsars must now be considered as one subject, involving the same physical processes. The vast energy output of LMXBs means that we have identified all of these objects contained in our Galaxy. Equally certainly, we are only seeing the tip of a vast iceberg of millisecond pulsars, as the discovery of five millisecond pulsars in globular clusters over the past year confirms.

Thus future progress in this area could be dominated by studies of the millisecond pulsars, both in and out of binary systems. We can also expect increasing understanding of PSR1957+20 itself — recently an optical counterpart has been discovered[7] and the pulse period derivative has been determined (Fruchter, A.S., personal communication). □

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7. Kulkarni, S.R., Djorgovski, S. & Fruchter, A.S. *Nature* (in the press).

Charles Bailyn is at the Harvard–Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, Massachusetts 02138, USA.