The shortest period binary star?

The discovery of a binary star with a period of only 11 minutes was announced last week at the 9th European meeting of the International Astronomical Union. What does it mean?

PERIODICITIES in astronomical X-ray sources are legion, but occasionally one is discovered that leads to the postulation of either a new class of astronomical object, or a familiar object in a remarkable configuration. The latter would seem to be the case with the discovery, announced last week, of a bright X-ray source showing a coherent periodicity of 685 seconds. The interpretation is that the source is a neutron star in an orbit of diameter less than a seventh the radius of the Sun about a low-mass white dwarf, making the system, if the interpretation is confirmed, by far the shortest period binary system known.

We owe these results and interpretation to W. Priedhorsky of the Los Alamos National Laboratory, and L. Stella and N.E. White of the EXOSAT Observatory, who presented them at the International Astronomical Union meeting at the University of Leicester last week.

According to these authors, the 685-second oscillations on the emissions of X-ray source 4U1820−30 (which lies at the core of globular cluster NGC6624) have an amplitude of only 3 per cent, but are clearly present in all four observations made by EXOSAT in 1984–85. Normally one would expect a period of this order to represent the spin of a magnetized neutron star accreting matter from a bright, massive companion star onto its off-axis magnetic poles, the rotation of the poles causing variations in the radiation received on Earth.

4U1820−30 is, however, an X-ray burst source, that is, at irregular intervals it flares dramatically with rise times of a few seconds, and none of the 30 or so X-ray bursters that have been studied shows coherent pulsations. If the periodicity in 4U1820−30 were associated with the rotation of a neutron star, it would violate the empirical rule that bursting sources do not pulse, and pulsing sources do not burst. The bursts are probably the result of runaway nuclear burning of accreted matter accumulated on the surface of the neutron star, and the empirical rule suggests that this process works only if the neutron star does not have a strong magnetic field, as is required to produce regular pulses of X-ray emission at the spin period of the neutron star.

Priedhorsky *et al.* did indeed find direct evidence that the 685-second periodicity is unlikely to be the rotation of the neutron star. Since a neutron star generally gains angular momentum from the material that it accretes, one expects to see the spin period decrease with time. For a magnetized neutron star the lever arm of the accreting matter is large, and the moment of inertia relatively small, and as a result the spin-up can in many cases be measured. For 4U1820−30 there was no evidence for any spin-up in the year-and-a-half spanned by the EXOSAT observations, and the *post facto* discovery of the same period in observations made by the SAS-3 satellite in 1976 placed even stricter limits on the rate of any possible period change. Priedhorsky *et al.* argue that, given that spin periods are ruled out, this stability is characteristic of an orbital period. For such an ultra-short period the two stars must be separated by only about one seventh of the radius of the Sun, and the unseen companion to 4U1820−30 must be unusually small: the most likely candidate is a very low mass (about 0.07-solar-mass) white dwarf.

The main difficulty in understanding this result, however, is to see how such a binary system could have formed. The evolution of 'normal' low-mass binary systems in which a neutron star accretes from a small hydrogen-burning companion star never proceeds to periods shorter than 80 minutes, since the companion becomes too light to burn its nuclear fuel and starts to expand in response to mass loss. Fortunately there are other possibilities for 4U1820−30, which lies at the core of a globular cluster, one of the dense aggregations of some hundreds of thousands of stars containing some of the oldest stars in the galaxy.

It has long been known that X-ray binaries are much more common in globular clusters than one would expect from the numbers found elsewhere in the Galaxy. Accordingly, one needs a formation mechanism special to globular clusters. The very high stellar densities in cluster cores suggest that this mechanism may be the gravitational capture of companions by neutron stars. In another contribution to the meeting, F. Verbunt (Max-Planck Institut für Astrophysik, Garching) showed that capture of a low-mass red giant star by this process can be reasonably common. The core of such a star consists of degenerate helium (that is, it is an incipient white dwarf) surrounded by a large, tenuous envelope containing, initially at least, most of the star's mass. About one third of the neutron star–red giant captures are expected to be direct collisions, leading to the neutron star orbiting inside the giant's envelope. The resulting intense frictional drag on the neutron star causes it to lose angular momentum and hence to spiral inwards towards the degenerate core. At the same time the envelope is heated and is ultimately ejected entirely. Thus, the result of this collision and spiral-in process is the formation of a very close binary system consisting of a neutron star and a helium white dwarf. Depending on the stage of evolution of the giant when the capture occurred, the white dwarf can have a mass anywhere between 0.075 and 0.45 solar masses.

The subsequent evolution of such a binary is easy to predict: loss of angular momentum by gravitational radiation will cause the stars to spiral closer together and the period to shorten. Eventually at a period of a few minutes (depending on the white-dwarf mass) the stars will be so close that matter can be pulled off the white dwarf, leading to sufficient accretion onto the neutron star to turn it on as a bright X-ray source. As Verbunt showed, the properties of 4U1820−30 are generally as expected if it is an ultra-short period binary of this type.

Although the interpretation of this startling new result in these terms seems very appealing, the amplitude of the 11-minute periodicity is small, and one can think of other ways of producing it. For example, as suggested by Trumper (Max-Planck Institut für Extraterrestrische Physik, Garching) in the discussion following these papers, the period could represent the precession of a fast-rotating neutron star. Another possibility is that the periodicity is actually associated with an entirely separate (and presently unknown) X-ray source which just happens to lie within the field of view of the EXOSAT detectors when observing 4U1820−30. Because of their low formation rate and short life-times, systems like 4U1820−30 are expected to be rare. It is rather ironic, but fortunate for us, that it is the brightest globular cluster X-ray source, and the only one in which such a small amplitude periodic signal could have been detected with present instruments.

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