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Pulsing Sources (Cont'd):

Cataclysmic Variables:

The cataclysmic variables are of special interest because they displa a very wide range of different types of accretion. In some of them, direct evidence has been found for the presence of accretion discs. These variable stars comprise a mixed bag of close binary stars, but one common ingredient is the presence of a compact star onto which accretion takes place. The companion is usually a late-type star near to or on the main sequence in which Roche lobe overflow takes place onto the compact star, which is normally a white dwarf.

The different types of cataclysmic variables largely reflect differen in the geometries by which the accretion takes place. Here we focus on the dwarf novae, where the white dwarf regularly brightens by 2 to 5 magnitudes, and it is assumed that this brightening is associated with the process of disc accretion. The dwarf novae is of particular interest so far as the accretion disc itself is concerned. In these systems, it is possible to observe directly the optical and UV emissions from the disc. In the case of X-ray pulsars, the light is either dominated by the companion star (like in the high mass binary systems), or by reprocessed X-ray light (as in the case of low mass binaries). For dwarf novae, it is possible to reconstruct the two-dimensional temperature distribution in the disc through a procedure known as eclipse mapping. It has been seen that the reconstructed temperature follows closely the relation $T(R) \propto R^{-3/4}$ that was derived. The theory therefore appears to be in good agreement with observations.

Not all cataclysmic variables are magnetic, although at least $\frac{1}{3}$ of white dwarfs in binaries do have a measurable magnetic field, compared with only ~2% of the isolated ones. This could be due to the action of repeated nova eruptions (recurrent novae systems), which may uncover submerged magnetic field lines below the stellar surface.

The magnetic cataclysmic variabels (m CV's) divide into two subclasses: the DQ Herculis and the AM Herculis (both named after their archetypal binaries). Of the roughly 100 m CV's known, about $\frac{2}{3}$ are member of the AM Herculis class. while $\frac{1}{3}$ belong to the DQ Herculis class. The DQ Herculis binaries show evidence for the presence of an accretion disc, and have a white dwarf spin period T_{spin} much smaller than the orbital period T_{orb}, suggesting a small magnetic fiel that is not strongly coupled to the binary. Indirect estimates of their field strengths fall in the range $\sim(5-30)\times 10^{6}$ G. The AM Herculis binaries contain a white dwarf synchronized to the binary ($T_{spin} = T_{orb}$), no accretion disc, and larger magnetic fields $\sim(7-200)\times 10^{6}$ G.

The know AM Herculis systems typically have $T_{orb} \lesssim 3$ h, while the known DQ Herculis systems typically have orbital periods $T_{orb} \gtrsim 3$ h. It is believed that DQ Herculis systems evolve into AM Herculis, and hence these are intrinsically similar systems observed at different evolutionary phases. This is an attractive picture for the following reasons;

1- As a close binary evolves, T_{orb} decreases as a result of mass transfer (as discussed before). Thus the know DQ Herculis systems ($T_{orb} \gtrsim 3h$) will eventually have periods $T_{orb} \lesssim 3h$, like those of the AM Herculis systems.

2- The Roche lobe of the degenerate dwarf shrinks as accretion proceeds. At the same time, the magnetic radius increases because the mass transfer rate decreases. Eventually the two radii cross, at which point the disc disappears.

3- Magnetic Coupling between the white dwarf and the companion increases rapidly as the binary separation and the mass transfer rate both decrease, so that synchronization of T_{spin} and T_{orb} becomes more likely.

We can try to understand qualitatively how close binary evolution may proceed. The period of the mCV's has a sharp cut-off at $T_{orb} \sim 80$ min, with a deficit of systems in the 2-3 h gap. For binary periods $T_{orb} \gtrsim 10^h$, the binary separation is so large that the companion must be significantly evolved in order to fill its Roche lobe. It is therefore believed that such binaries are driven by nuclear evolution of the companion. Mass transfer due to accretion then results in a decrease of T_{orb}.

For $T_{orb} \lesssim 3h$, evolution is due to gravitational wave radiation. This process extracts angular momentum and drives the companion closer to the white dwarf, hence decreasing T_{orb}. Simulation show that this mechanism gives a minimum orbital period of $\sim 1.2\,h$. This corresponds to the transition of the secondary from the main sequence to the degenerate sequence. Degenerate stars get bigger as they lose mass by accretion. For a degenerate companion $M < M_\odot$, accretion therefore continues, while binary separation and T_{orb} increases since $q<1$. This explains the turn around at minimum period $T_{orb} \sim 1.2$ h.

Other mechanisms could drive binary evolution effectively at intermediate binary periods $3\,h \lesssim T_{orb} \lesssim 10\,h$. One such possibility that has received great attention is magnetic braking, in which the strongly magnetized companion couples to its stellar wind, losing angular momentum in its efflux.

Finally, the gap in the orbital period distribution may result from the fact that the systems have a very low mass transfer rate between T_{orb} of 2 and 3 h. This may occur because the companion star is driven out of equilibrium. It therefore shrinks back to its main sequence radius and comes out of contact with its Roche lobe. The evolutio

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timescale will be very long as the binary separation decreases solely due to the emission of gravitational waves. The companion will come back into contact when the radius of the Roche lobe equals the main sequence radius, but this happens at a very low rate.