PHYC 581: High Energy Astrophysics
Fall 2014

Lec 27: 11/19/2014

Pulsing Sources (Cont'd):

X-ray Pulsars:

What distinguishes X-ray pulsars from radio pulsars is the fact that the former are in binary systems and powered by accretion, while the latter are isolated and powered by rotation.

The observed spin period of X-ray pulsars is between 2.5 ms and 3 h, with most of them in the ~1-1000 s range. The X-ray pulsars fall into two subclasses based on the companion's spectral type. Most of them have massive binary partners, either OB supergiants or Be stars. The second class is associated with cooler low-mass main sequence stars, which have masses, luminosities, and temperatures similar to those of the Sun. In both cases, the neutron star is invisible optically, and hence the optical observations refer to the companion star.

In the case of high-mass binaries, it is possible to measure the individual masses of the neutron star and its companion. For the low-mass binary systems, however, it is much more difficult to estimate masses. Normally, it is not possible to measure the velocity of the low-mass companion, which is faint and its light overwhelmed by the light from the accretion disk. The velocity may still be measured for the X-ray pulsar. However, what is observed at X-ray wavelengths is strongly dependent on the angle of inclination of the binary plane to the plane of the sky. The brightest and most luminos sources are those in which the orbital plane is viewed face-on. The compact X-ray pulsar is then observed unobstructed by the disk or the companion. However, this geometry also means that it is difficult to determine the binary properties of the orbit by using the Doppler shift due to the radial component of the velocity. As a result of this selection effect, it proved much more difficult to obtain definitive evidence for the binary nature of low-mass X-ray binaries than the cataclysmic variables (in which the compact object is a white dwarf).

As discussed earlier, X-ray emission by X-ray pulsars is due to accretion from the companion funneled to the polar caps by the pulsar magnetic field. In the case of high-mass binaries, accretion results from the gravitational capture of the stellar wind. The supergiant companions have a large mass-loss rate $\dot{m} \sim 10^{-6} M_\odot \, yr^{-1}$ in this way. In the case of low-mas binaries, the accretion is due to Roche lobe overflow.

The low-mass binary membership of accretion-powered pulsars is greatly underrepresented. One possible explanation could be that neutron stars in these systems are weakly magnetized, and hence accrete over the whole stellar surface, which mitigates any possible pulsed emission associated with rotation.

The spectra of X-ray pulsars exhibit no sharp features. As discussed earlier, the plasma falling onto polar caps converts gravitational potential energy into heat, which is then radiated by a combination of Bremsstrahlung and Synchrotron processes. The X-rays must transfer through the magnetized, optically thick medium in the accretion column, which simulations suggest to be unstable. There is a blending that takes place via a superposition of emission components at different heights within the funnel. Most of the power is emitted in the 2-20 keV range, with a rapid fall off above ~20 keV. This is the reminiscent of the Bremsstrahlung shoulder that we discussed earlier on.

Cataclysmic Variables:

The cataclysmic variables are of special interest because they display a very wide range of different types of accretion. In some of them, direct evidence has been found for the presence of accretion disks. 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 occurs. The companion is usually a late type star near 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 differences in the geometries by which the accretion happens. Here we focus on the dwarf nova, where the white dwarf regularly brightens by 2 to 5 magnitudes, and it is assumed that the brightening is associated with the process of disk accretion. The dwarf nova class is of particular interest so far as the accretion disk itself is concerned. In these systems, it is possible to observe directly the optical and UV emissions from the disk. In the case of X-ray pulsars, the light is either dominated by the companion star (in the case of high-mass binaries), or by reprocessed X-rays (in the case of low-mass binaries). For dwarf nova, it is possible to reconstruct the two-dimensional temperature distribution in the disk 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, as compared with only $\sim 2\%$ of the isolated ones. This could be due to the action of repeated nova eruption (recurrent nova systems), which may uncover the submerged magnetic field lines below the stellar surface.

The magnetic cataclysmic varibles (mCV's) are divided into two subclasses; the DQ Herculis and the AM Herculis (both named after their archetypal binaries). Of the roughly 100 mCV's known, about $\frac{2}{3}$ are members 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 disk, and have a white dwarf spin period P_{spin} much smaller than the orbital period P_{orb}. This suggests a small magnetic field that is not strongly coupled to the binary. Indirect estimates of their field strength fall in the range $\sim(5-30)\times10^6$ G. The AM Herculis binaries contain a white dwarf synchronized to the binary ($P_{spin} = P_{orb}$), no accretion disk, and larger magnetic fields $\sim(7-200)\times10^6$ G.

The known AM Herculis systems typically have $P_{orb} \lesssim 3h$, while the known DQ Herculis systems typicall have orbital periods $P_{orb} \gtrsim 3h$. 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, P_{orb} decreases as a result of mass transfer (as discussed before). Thus the known DQ Herculis systems ($P_{orb} \gtrsim 3h$) will eventually have periods $P_{orb} \lesssim 3h$, 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 disk 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 P_{spin} and P_{orb} becomes more likely.