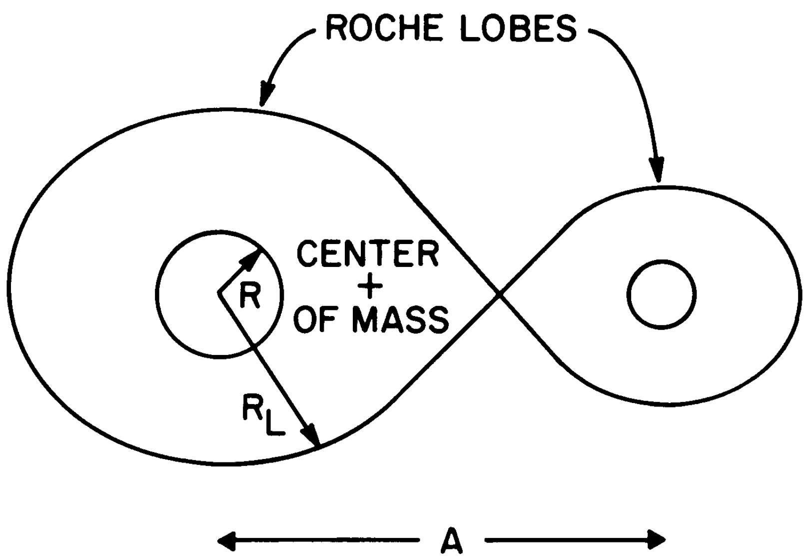
How do Stars Evolve with a Companion?

A major fraction of all stars are gravitationally bound to another star forming what is know as a **Binary Star System**. The stars orbit one another as a pair. The structure of the combination is sketched below:



The two stars exert a gravitational force on each other which is balanced by the fact that they are in circular orbits around their common point where the mass averages out. This common point is called the **center of gravity** and represents the relative location in the system where the motion through space is uniform. We normally adopt a coordinate system which moves with this center of gravity so that the stars move relative to the point in circular or elliptical orbits. Most stars have experienced enough tidal drag so that the orbits are almost perfectly circular.

Some important things to note about binary configurations

- We often make another change in our point of view of the sytem and use a system which is rotating at the same rate the two stars revolve around each other. This is not a stationary system and cannot be put on the same fundamental basis as other coordinate system allowed under the Special Relativity Theory.

- Objects moving freely in a rotating coordinate system will experience an apparent force. This is just because the system is not stationary or moving in a straight line.

- A level surface is defined so that a fluid at rest will form a part of it.

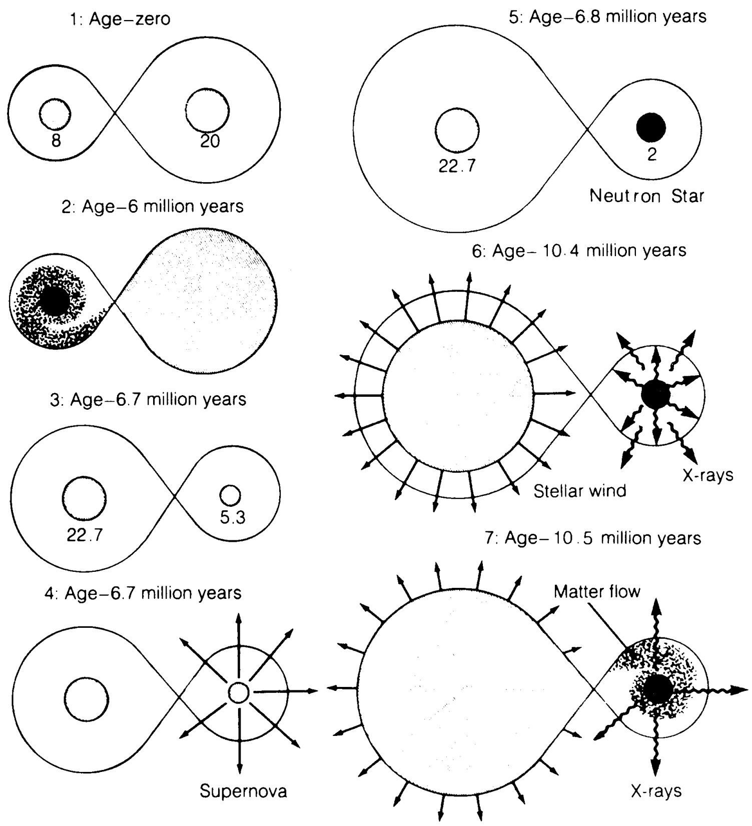
- In a binary star system, a special level surfaces which is shared equally between the stars forms what is called the **Roche Lobes**. Other level surfaces inside the Roche Lobes are separated and tend toward spheres. Level surfaces outside the Roche Lobes have a figure 8 shape.

- When an object moves from a higher level surface to a lower level surface, it loses gravitational potential energy which can be converted into energy of motion or kinetic energy.

- As stars evolve, they can fill their Roche Lobe and spill matter onto their companion.

A sample evolutionary sequence with mass exchange

When a star overflows its Roche Lobe, most of the matter is assumed to go onto the companion. The size of the lobe depends on the masses and when the more massive star loses some mass to the companion, its Roche Lobe decreases in size so that the exchange accelerates.

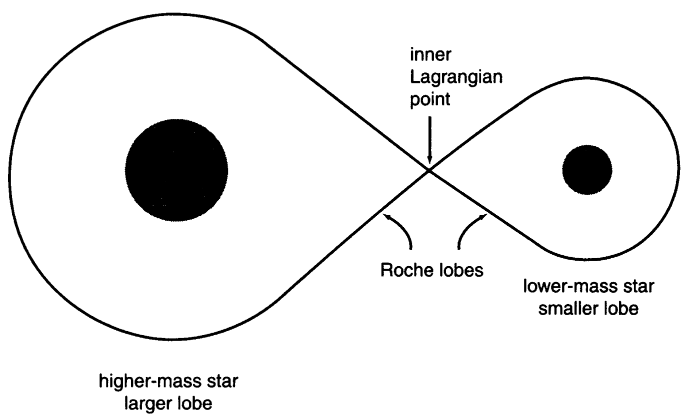


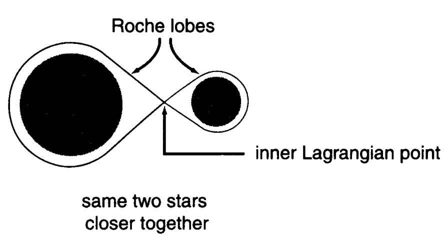
The masses of the stars are indicated at each stage of evolution. Since the white dwarf-like core of the evolved star remains small compared to the size of the Roche Lobe, the mass transfer stops before it can alter the quantum pressure supported core. If the core has too much mass to be a stable white dwarf, it can undergo a supernova explosion which would leave behind a neutron star. The originally less massive star in the meantime has become the more massive star and it will in turn evolve into a red giant spilling its matter back to the neutron star. As the matter transferred to the neutron star falls into the deep gravitational hole and as it hits the surface of the neutron star, it generates X-rays which make it detectable as an X-ray source.

The quantities which describe and define a binary system.

In contrast to the situation with a single star where only the initial mass was needed to define a system, with a binary it is necessary to look at three quantities:

1. The initial mass of the more massive star which is called the **Primary**.
2. The initial mass of the less massive star or the ratio of this mass to that of the primary. This latter is called the **Mass ratio**.
3. The separation between the two stars or the orbital period. These two quantities are related by the binary star equivalent of Kepler's Third Law of planetary orbits.

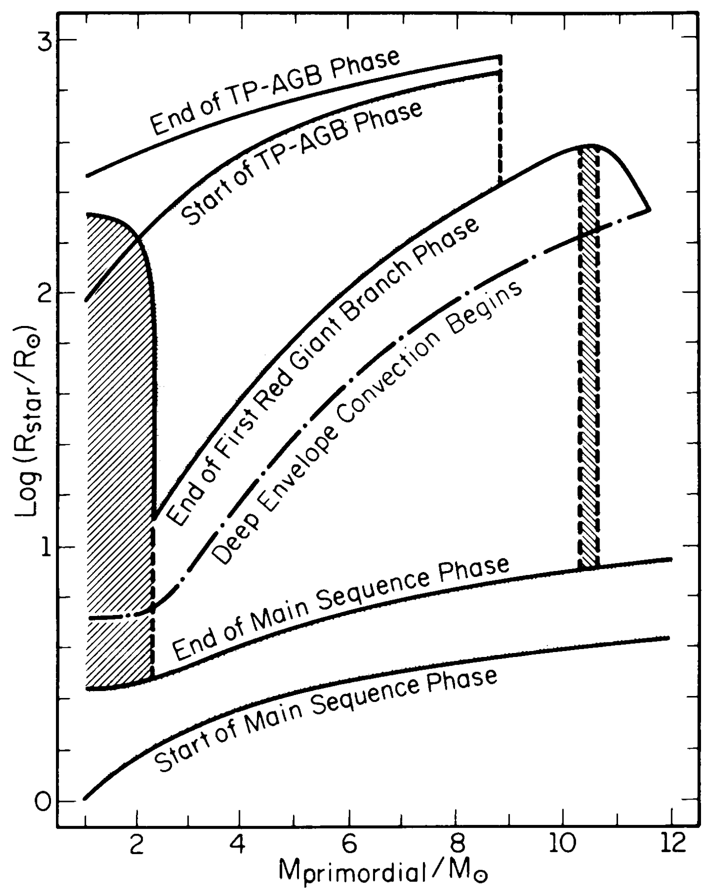




This sketch shows the effect of bringing two stars which are otherwise the same into a binary system with two different separations and orbital periods. The lower figure shows a system with a short period while the upper figure has a longer period. The amount of expansion permitted the star before it overflows the limit imposed by the Roche Lobe is clearly much less for the shorter period system.

The size of stars at different stages of evolution.

As stars evolve, they change their size. Especially during the red giant phase, the increase in volume is extreme. By the time a star is divided into two parts – the quantum pressure core and the distended envelope, it is easy to pull off the envelope and leave just the core. The closer binaries can begin their mass exchange while they are still in a state where it is possible to alter the structure of the deepest interior. As a summary of radii of stars in various stages of evolution we have:

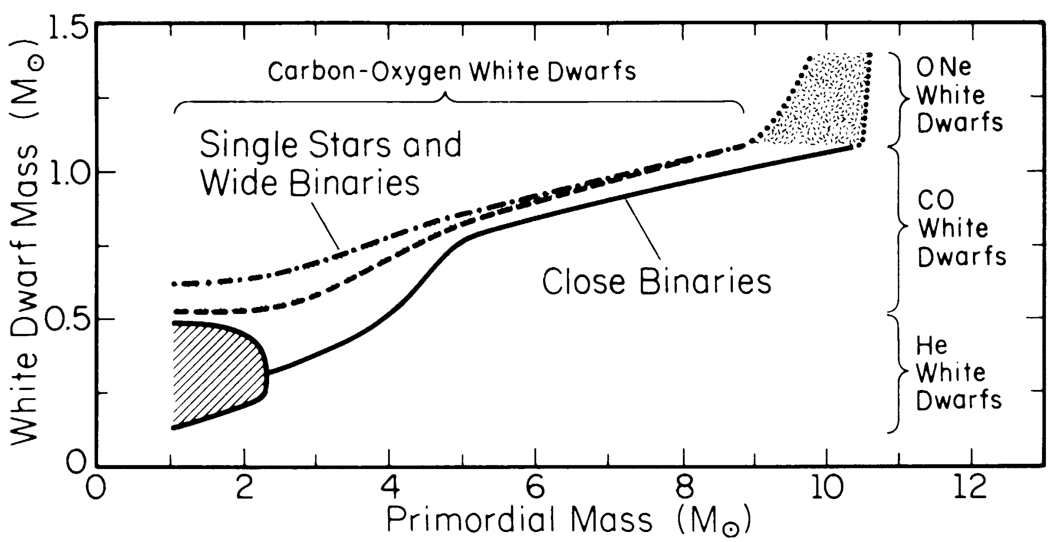


The mass of the primary component of a binary system is shown along the bottom scale and the radius of this star without a companion is shown along the vertical scale. Evolutionary states are denoted by the location of the nuclear burning. The Red Giant Branch (RGB) refers to a star with a quantum pressure core of Helium and a single Hydrogen burning shell source. The Asymptotic Giant Branch (AGB) refers to a Carbon/Oxygen/Neon quantum pressure core with both a Hydrogen burning and a Helium burning shell. The letters TP denote the fact that such a dual shell star undergoes a series of mild instabilities known as Thermal Pulses. Each pulse may last ten to one hundred years and be separated from others in the sequence by one to one hundred thousand years.

White Dwarf Masses

For an individual star whether in a binary or as a single, the end of the evolution comes with the stripping off the Hydrogen and leaving behind of a quantum pressure supported white dwarf. Once the hydrogen is gone, the mechanism to permit a red giant has been removed since a red giant can only form where there is a Hydrogen rich layer over a layer without Hydrogen. After the Hydrogen rich layer is gone, the primary source of nuclear fuel is also gone since 90% of all the nuclear energy comes from the step which converts Hydrogen to Helium.

The removal of the Hydrogen rich layer occurs by way of a strong stellar wind for the single star and by way of mass transfer for the star in a binary system. The remaining mass in the star is then a function of the mechanism whereby the Hydrogen was stripped off. The residual mass for the quantum pressure star is given by this figure:

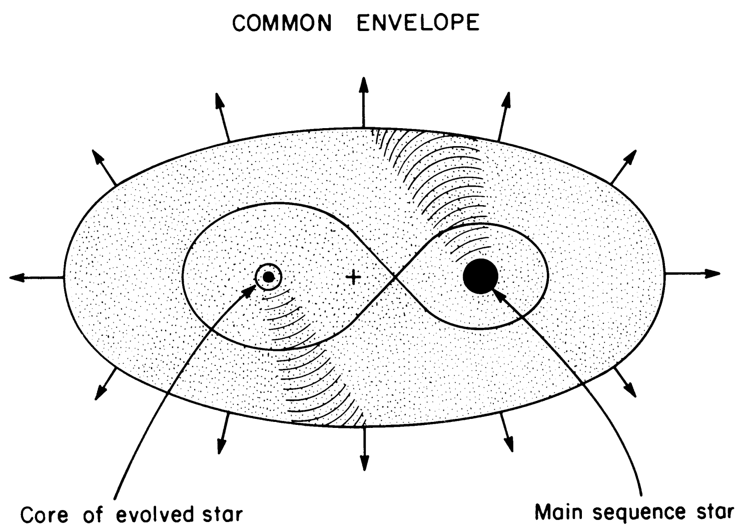


Note that the masses left behind by the binary is less than that for a single star. The composition of the quantum pressure white dwarf depends on how soon the mass transfer stars for the system. If the Roche Lobe is close, the hydrogen envelope can be pulled off before the star has a chance to ignite its helium burning.

Intermediate configurations

While mass is being transferred, there are two things which can happen:

1. The mass may not be incorporated into the receiving star fast enough so it swells up to form a Common Envelope Binary:



2. The system can lose its rotational momentum called **angular momentum** to several processes and shrink: