27 Astro notes 2018/10/29 - Mon - Close Binaries

27.1 Gravity in close binaries

Close binaries can be treated mostly by Newton's law of gravity. But it is often worthwhile to treat the potential in the rotating instead of non-ratating frame. The potential has two types of components: The potential from each of the stars:

$$U_s = -G\frac{Mm}{r}$$

one for each star. In order to be in the rotating from, there is an additional force, the centrifugal force $F = m\omega^2 r$. This leads to an overall potential:

$$U = -G\left(\frac{M_1 m}{s_1} + \frac{M_2 m}{s_2}\right) - \frac{1}{2}m\omega^2 r^2$$

where s_i is the distance from star i.

equipotential surfaces are show in figure 18.3

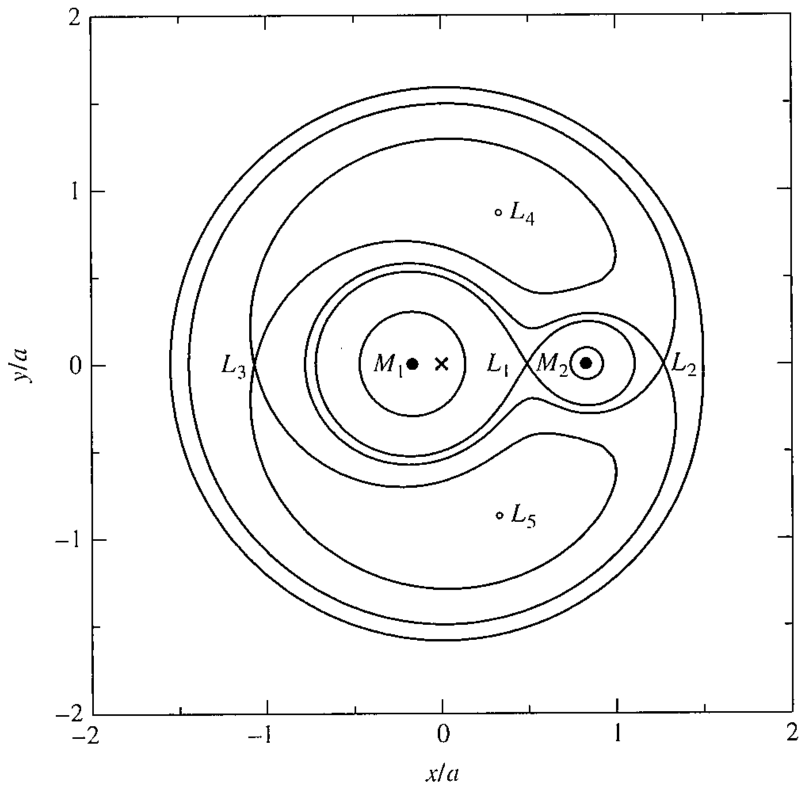
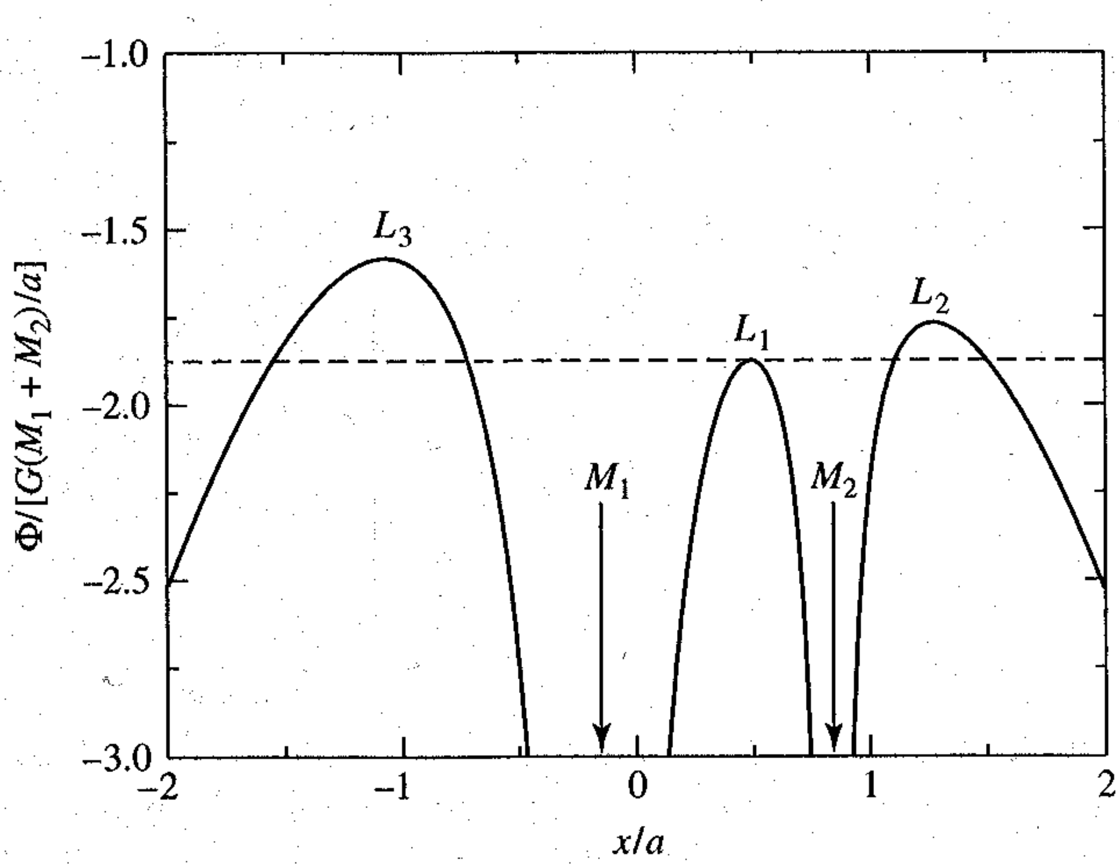


FIGURE 18.3 Equipotentials for $M_1 = 0.85\,\mathrm{M}_\odot$, $M_2 = 0.17\,\mathrm{M}_\odot$, and $a = 5 \times 10^8$ m $= 0.718\,\mathrm{R}_\odot$. The axes are in units of a, with the system's center of mass (the "×") at the origin. Starting at the top of the figure and moving down toward the center of mass, the values of Φ in units of $G(M_1 + M_2)/a = 2.71 \times 10^{11}$ J kg^{-1} for the equipotential curves are $\Phi = -1.875, -1.768, -1.583, -1.583, -1.768$ (the "dumbbell"), -1.875 (the Roche lobe), and -3 (the spheres). L_4 and L_5 are local maxima, with $\Phi = -1.431$.

Along the centerline through both masses this looks like this (fig 18.2):



27.2 Lagrange points

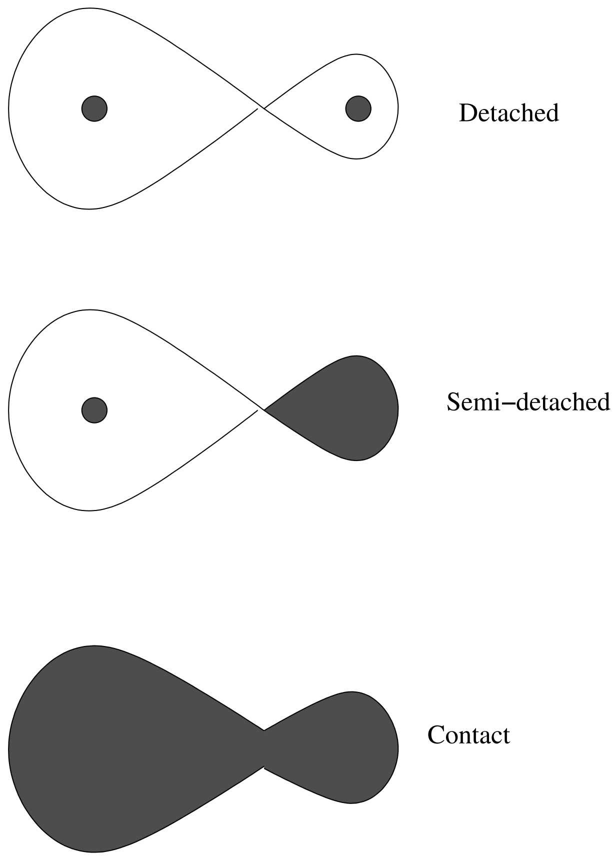
The Lagrange points are points of zero gradient in potential. They are all maxima or saddle points, and therefore unstable. The most important one is L_1 through which material can be transferred from being bound to one star to being bound to the other.

27.3 types of binaries

There are several general types of binaries

- Detached - just two stars
- semi-detached - one star filling its Roche lobe
- contact - both stars filling their Roche lobes

In semi-detached binaries, commonly mass is being transferred from the Roche-lobe filling star to the other star.



(primary and secondary are backwards from typical convention in the textbook. The more massive star has the larger Roche lobe and is also typically called the primary. Also, being more massive, it is typically the first to evolve into a giant star.)

If evolving, the first star to fill its Roche lobe is the more massive one, because it evolves first, but mass transfer from a more massive to a less massive star is unstable. Why? because moving material away from the center of mass causes the binary to shrink - thus causing more mass transfer. This instabality leads to a common envelope phase.

After this the star that evolved becomes a WD, then, if the second star is less massive than the WD when it fills its Roche lobe, the mass transfer process is stable.

27.4 Drivers of mass transfer

Mass transfer can be *driven* by several factors

- Orbital stability as described above - very short-term (10^4 years)
- wind - typically in a detached binary. If the primary is an evolved star with high mass loss, some of that wind can be captured by the other star. With a WD accreting these are one type of ”symbiotic” star.
- growth of Roche-lobe-filling star due to nuclear evolution - will evolve on timescale of late evolution, typically tens to hundreds of millions of years (10^7-10^8 yr)

- angular momentum loss as driver of binary evolution - causes binary to shrink
  - magnetically attached wind - as the binary loses mass like the solar wind (i.e. not fast mass loss) that wind can carry away angular momentum. Typically evolves on $\sim 10^8$ year timescales
  - gravitational radiation - very slow, system evolves on 10^9 year or longer timescales.

For gravitational radiation

$$\dot{P} = -\frac{96}{5}\frac{G^3M^2\mu}{c^5}\frac{P}{a^4} = -\frac{96}{5}\frac{G^3M^2\mu}{c^5}\left(\frac{4\pi^2}{GM}\right)^{4/3}\frac{1}{P^{5/3}}$$