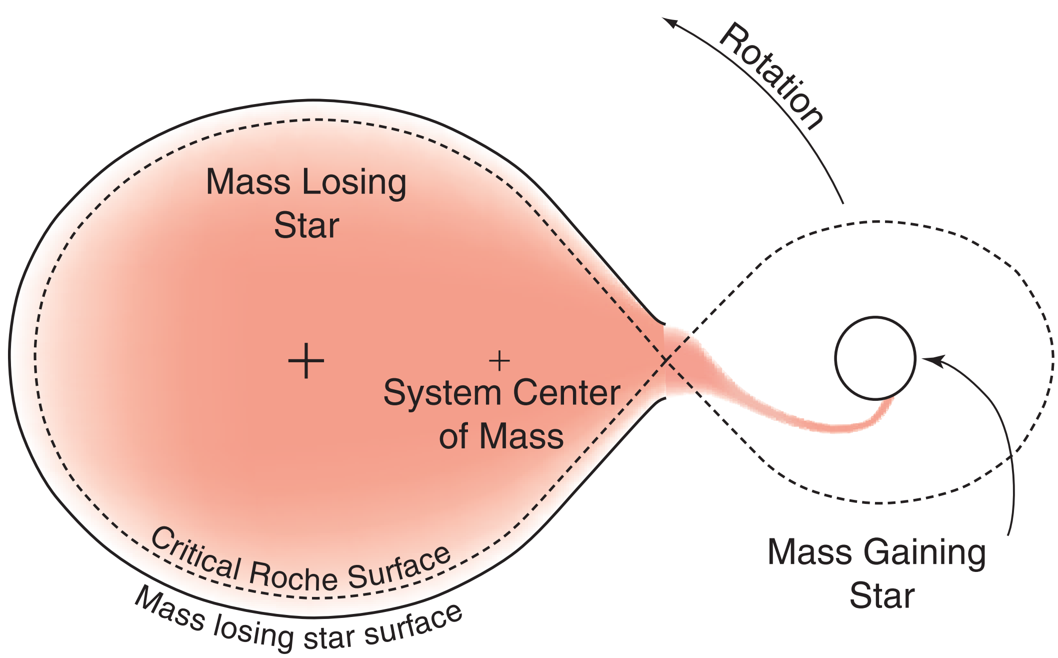
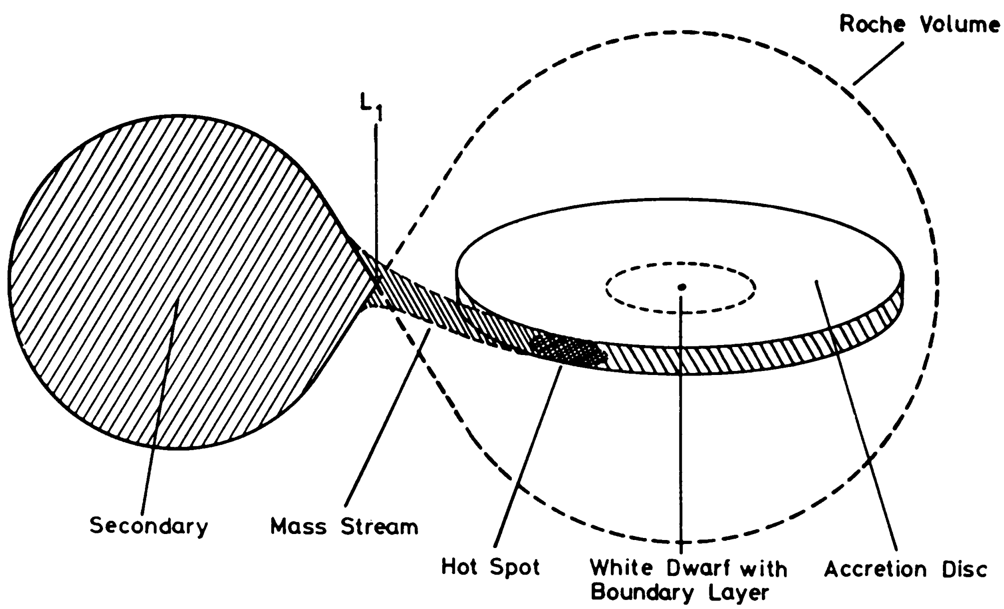
Roche Lobe Overflow

The mass transfer process occurs by way of the mass above the critical Roche surface being pushed into the domain of the mass gaining star. The whole system is rotating and as long as the matter is stationary in the system, it feels no additional force. The forces of gravity from the two masses along with the centrifugal force due to rotation are all included in the Roche gravitational potential energy surfaces. However, when matter moves, it experiences an additional apparent force called the Coriolis force. This deflects the stream to the side and causes the mass transfer stream to go into a looping orbit. The gas pressure is important for holding open the stream just as it leaves the mass losing star but as the stream falls away from the L_1 point, it becomes dominated by the gravity and Coriolis forces and is concentrated into a more compact jet. These features of the mass transfer process are sketched below. The figure shows a main sequence star receiving the transfer stream but it could also be a disk surrounding a compact star.



Mass Transfer onto a Disk

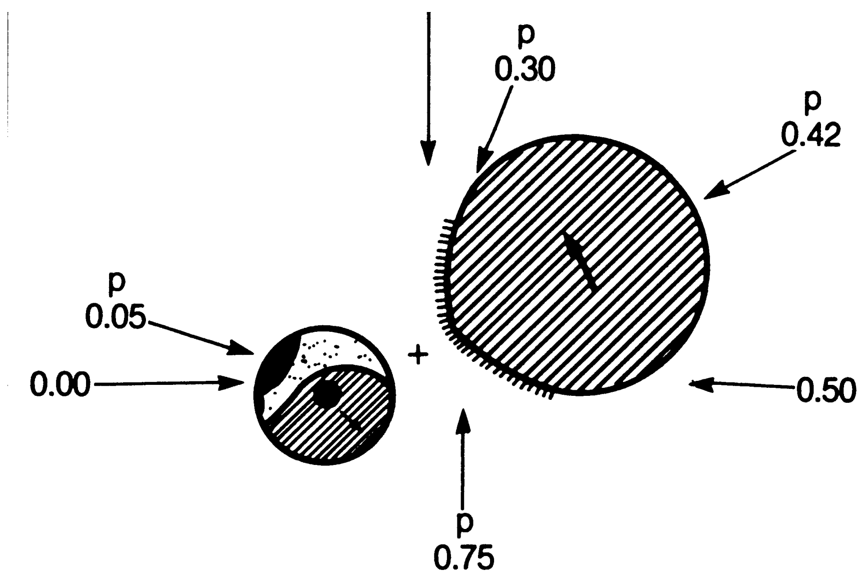
When the mass gaining star is compact its surface is below the level where the transfer stream reaches its nearest approach. When the mass gaining star is compact, during the very first stages of the transfer, the stream misses the mass gaining star and goes into an orbit around it. As more material is built up, a disk forms which has enough mass to stop the transfer stream and force it to become incorporated into the disk instead of going into a new orbit. After some mass transfer, a disk builds up so that subsequently the stream strikes the disk before it reaches it distance of closest approach. This pattern is shown below:



This diagram shows the configuration of the mass overflow from the Critical Roche Surface onto an accreting white dwarf with a disk surrounding it. The Mass Stream strikes the mass containing disk in a hot spot where the excess energy of the stream is absorbed by the disk. If this energy were not absorbed, the stream would have too much energy to go into a nearly circular orbit and would move closer to the white dwarf center before swinging back out.

The Disk Hot Spot

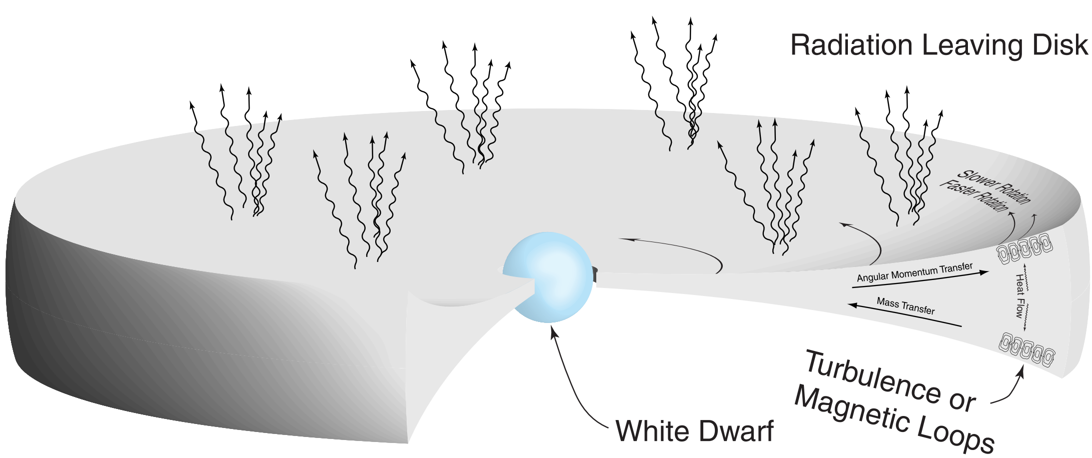
When the mass transfer stream strikes the edge of the disk, there is a difference in the velocity – the disk is in a nearly circular orbit while the transfer stream is trying to move closer to the gravitational center of the mass gaining star. This difference in velocity causes the stream to undergo a collision which results in it abruptly losing its velocity component toward the center of the mass gaining star. This collision converts the kinetic energy of motion into heat (it is as if two cars on the freeway sideswipe each other with the guilty party being instantly vaporized – swift justice). The heat generated by the collision is visible and can be studied through eclipses by some binary systems which have a favorable orientation. The brightness pattern on the disk near the hot spot is shown in the figure below:



The mass losing star is on the right, the transfer stream is not shown but strikes the disk in the area which is shaded black. The dotted area is heated by some of the turbulence generated near the hot spot. The row of vertical lines on the mass losing star indicate that this part of this star is altered by the radiation from the hot spot. Typically the matter near a region of high temperature is caused to glow like fluorescent lamp. This glow is seen in the spectrum of the system. The numbers labeled by p and running between 0 and 0.75 represent a phase fraction of the orbital period. The zero point is somewhat arbitrary.

Disk structure and disk instabilities.

The mass transferred to the disk builds up a large enough density that the disk becomes opaque (it will block the light from anything on the far side). The heat dissipated in the interior of the disk cannot escape directly and builds up the temperature. This increases the thickness of the disk so that it has a distinct edge like a discus or Frizbee. The dissipation of the energy occurs due to the internal friction which in turn is a result of small scale magnetic field loops or as a result of small scale turbulence (this is a motion superposed on a larger scale motion). The lateral motions or the transverse magnetic fields couple the disk annuli together and try to make them rotate at the same rate. However, because of the gradient of the pull of gravity from the white dwarf, the inner annulus rotates faster than the outer and they cannot be brought to rotate with the same period. The friction tries to slow down the inner annulus and tries to speed up the outer annulus. This causes the inner annulus to move further inward and causes the outer annulus to try to move outward. The inner ring succeeds whereas the outer ring encounters more matter coming in and is blocked. The overall disk configuration is sketched below:



Structure of a thick disk surrounding a white dwarf and resupplied with matter by a mass losing star. The indicated turbulence or magentic field causes friction that in turn is the source of heat for the turbulence. This is a self-sustaining process which is unstable - more heat means more friction means more turbulence.

Disk Instability

The friction in the disk is double valued depending on the thickness and internal temperature of the disk. At high temperature, the turbulence is increased because the disk becomes more opaque. At low temperature, the turbulence is mild and there is not much cause for energy dissipation. When the viscosity is high, the matter in the disk is rapidly transported to the white dwarf. This leads to a cyclic process where:

1. The disk start with a small amount of mass.

2. Mass transfer builds up the disk at its outer edge with some mass working its way inward.

3. The thickening disk becomes more opaque and heat builds up inside.

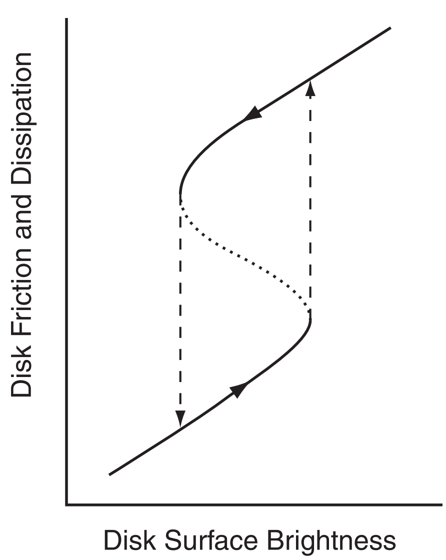
4. The heat generates turbulence which increases the friction.

5. The disk thickens and the turbulence becomes large so that the mass can be transported quickly onto the white dwarf.

6. The disk becomes thin and cools off, lowering the friction, the temperature and the turbulence.

7. The disk returns to its quiet state.

The pattern of friction is shown below:



The path the matter in the disk takes between its two states of high and low friction. It never traverses the section in the middle but rather makes an abrupt shift either from low friction during the outburst or from high to low as it cools off.