Phys 321: Lecture 10

Close Binary Star Systems

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Close binary star systems

- At least half of all stars are multiple star systems
- A system consisting of two stars are called binary star systems
- We concern such systems in which the two stars are close to each other – ***close*** binary star systems
- These star systems are usually ***tidally locked***, meaning the two stars are always facing each other with synchronous rotation, otherwise the tidal interaction would cause dissipation of the rotational and orbital energy of the system

Potential energy in a close binary system

Consider a test mass m in the close binary system, the "centrifugal force" it feels from the system

$$\mathbf{F}_c = m\omega^2 r\,\hat{\mathbf{r}},$$

Which induces a fictitious "centrifugal potential energy"

$$U_f - U_i = \Delta U_c = -\int_{\mathbf{r}_i}^{\mathbf{r}_f} \mathbf{F}_c \cdot d\mathbf{r}$$

$$\Delta U_c = -\int_{r_i}^{r_f} m\omega^2 r\,dr = -\frac{1}{2}m\omega^2\left(r_f^2 - r_i^2\right)$$

Note only changes in potential energy is meaningful, we can assign $U_c = 0$ at $r = 0$, so the centrifugal potential energy becomes

$$U_c = -\frac{1}{2}m\omega^2 r^2.$$

Effective gravitational potential

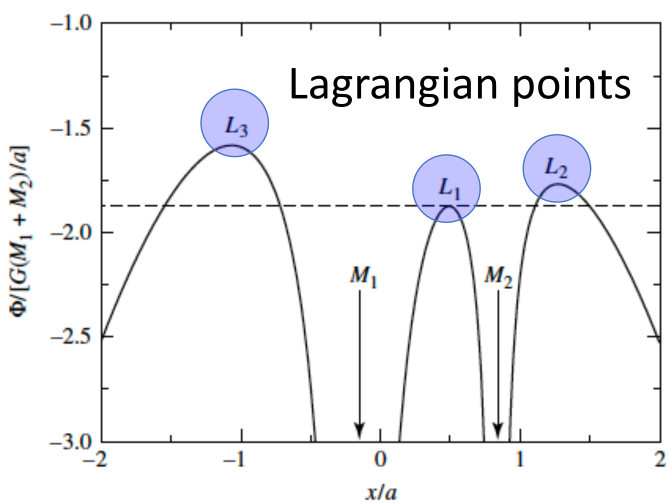
Effective gravitational potential energy (with the centrifugal potential energy)

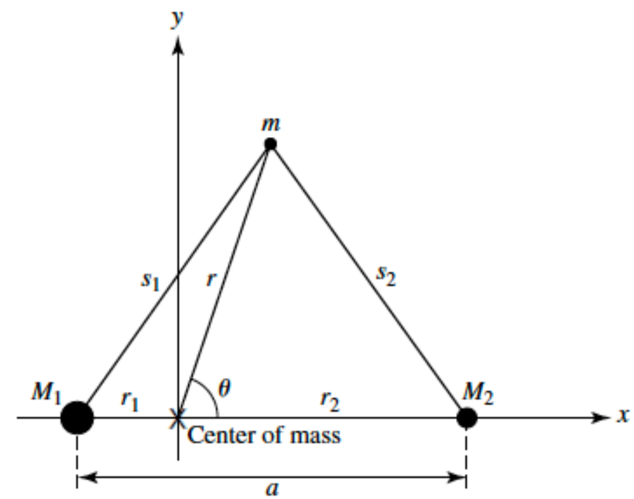
$$U = -G\left(\frac{M_1 m}{s_1} + \frac{M_2 m}{s_2}\right) - \frac{1}{2} m\omega^2 r^2$$

And the effective gravitation potential is

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

Effective gravitation potential along x:

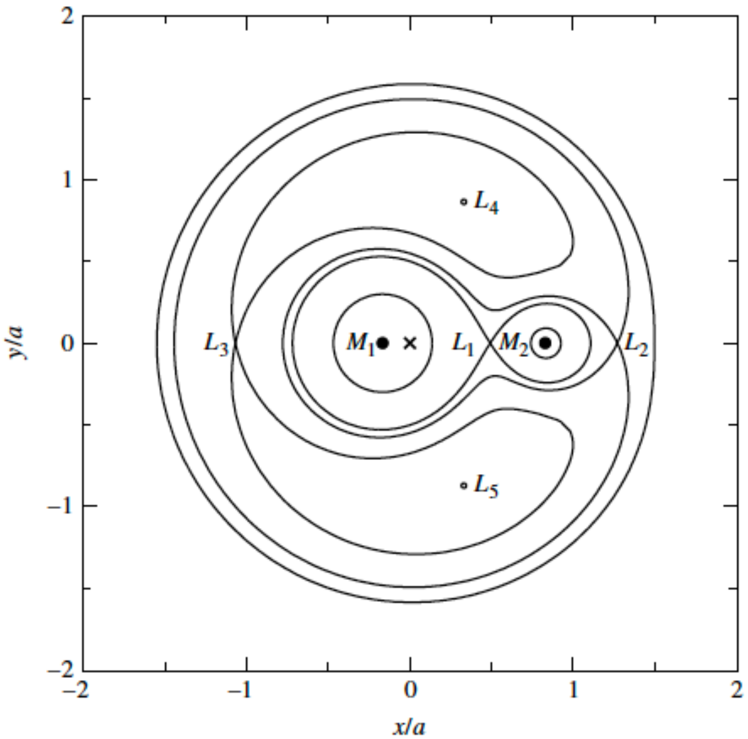


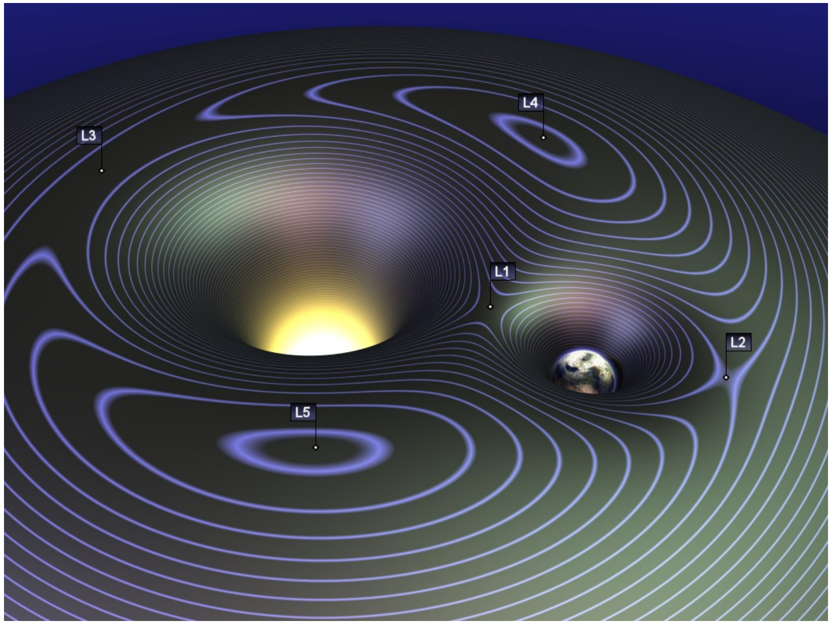


$$r_1 + r_2 = a \quad \text{and} \quad M_1 r_1 = M_2 r_2.$$

Kepler's 3rd law: $\omega^2 = \left(\frac{2\pi}{P}\right)^2 = \frac{G(M_1 + M_2)}{a^3}.$

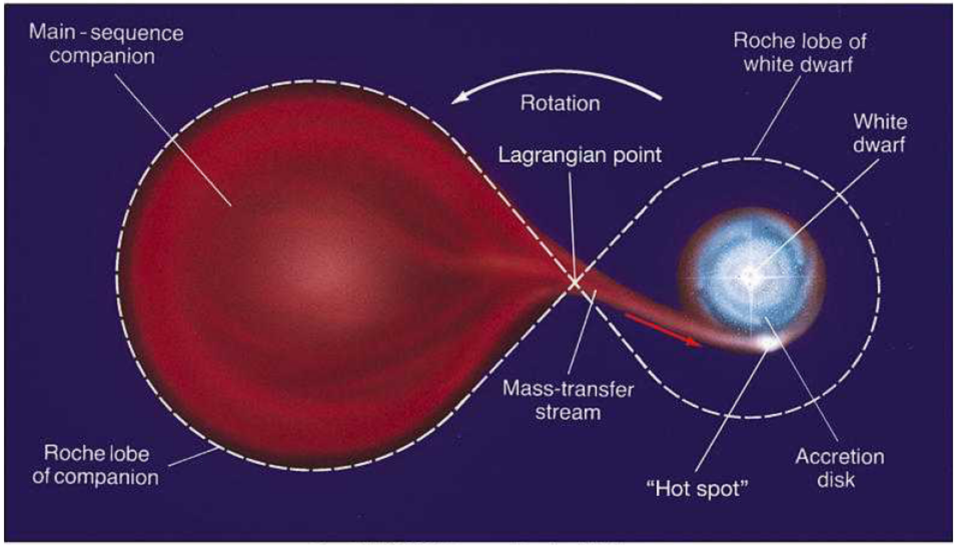
Lagrangian Points

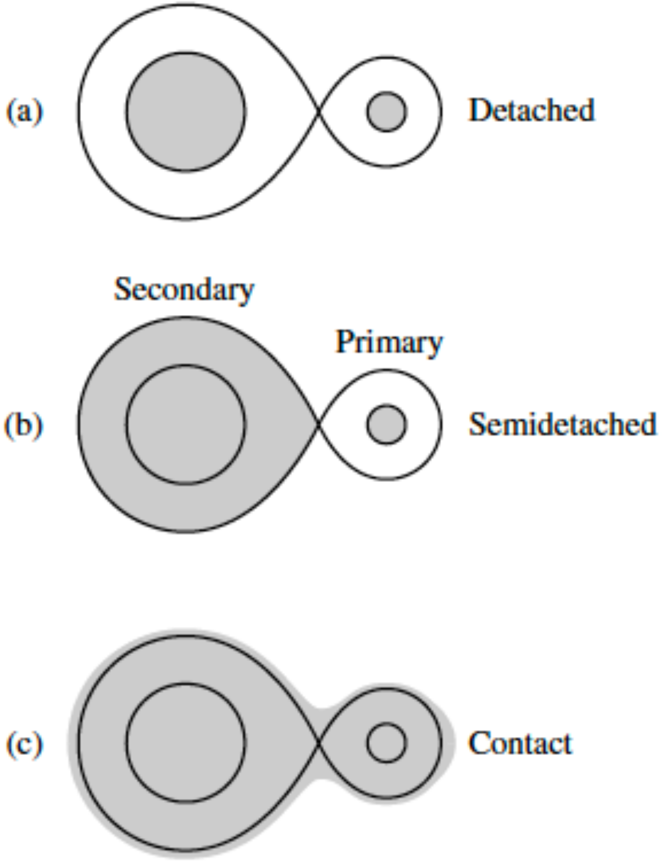




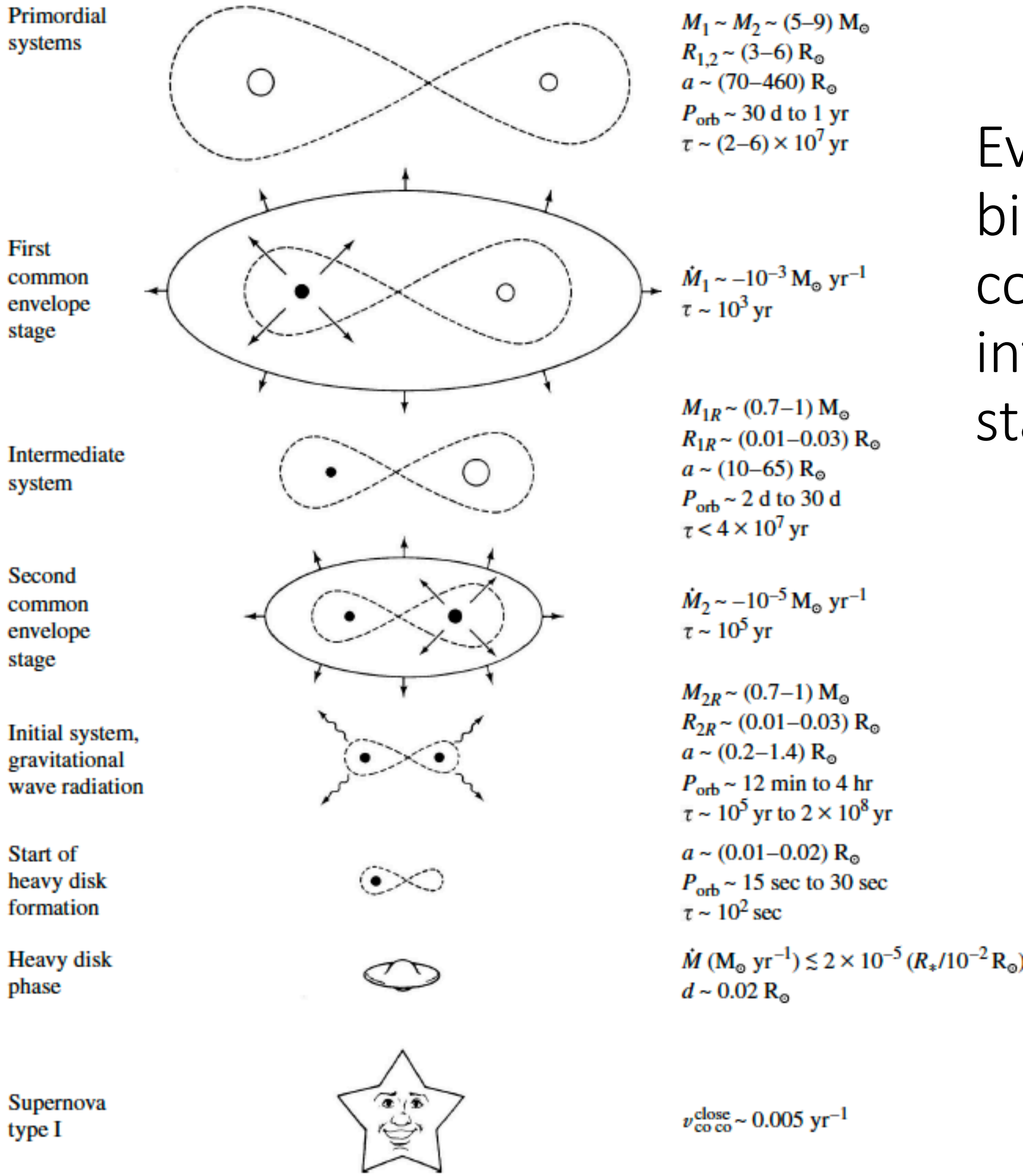
Five metastable points in the binary system, which are located at the “hill-top” position of the effective gravitational potential

Classes of Binary Star Systems





Evolution of a binary system that consists of two intermediate-mass stars



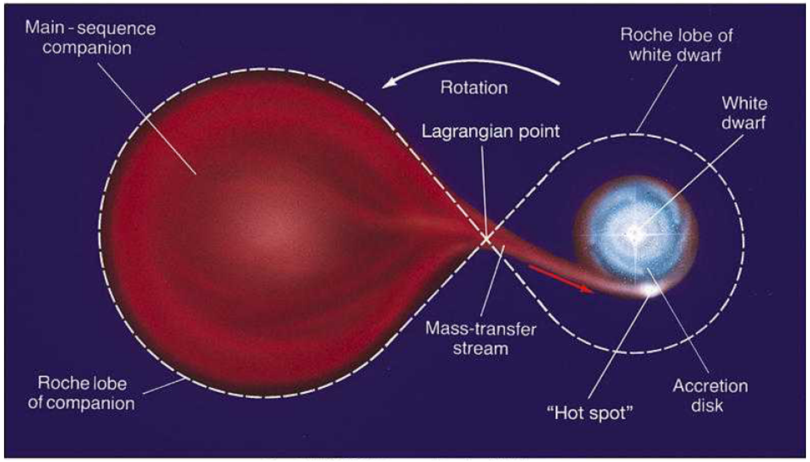
Cataclysmic Variables

- When a **white dwarf** is the **primary component** of a semidetached binary system, the result can be a dwarf nova, a classical nova, or a supernova

Type	Time	Example	M_{max}	Dm	Energy per Outburst (J)	Cycle	Mass Ejected per Cycle (M_o)	Velocity of Ejection (km/s)	Mass of Star (M_o)
Supernova I		Tycho's	-20	>20	10^{44}		< 1	10,000	1
Supernova II			-18	>20	10^{43}		?	10,000	>4
Novae	Fast	GK Per = Nova Per	-8.5 to -9.2	11 to 13	$6x10^{37}$	10^6 y ?	10^{-5} to 10^{-3}	500 to 4000	1 to 5
	Slow	DQ Her	-5.5 to -7.4	9 to 11				100 to 1500	0.02 to 0.3
	Recurrent	T Cr B	-7.8	8	10^{37}	18 to 80 y	5×10^{-6}	60 to 400	2
Dwarf Novae		U Gem SS Cyg	+5.5	4	$6x10^{31}$	40 to 100 d	10^{-9}		~0.4

Cataclysmic Variables

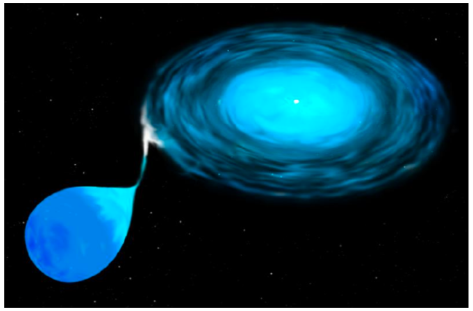
- **Dwarf Novae**: due to quasi-periodic brightenings in the accretion disk around a white dwarf. Mass loss rate from the inflated secondary star is about 10^{-11} to 10^{-8} solar masses per year.
- **Classic Novae**: due to higher accretion rate onto the white dwarf. Peak luminosity of a nova can reach about 10^5 solar luminosity
- **Type Ia Supernovae:** exact mechanism not well understood, but involves the accretion of material from the companion to the primary white dwarf, resulting in its mass close to 1.4 solar mass, the Chandrasekhar limit



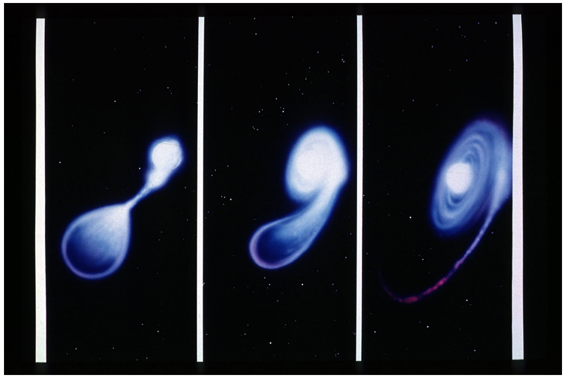
Type Ia Supernovae

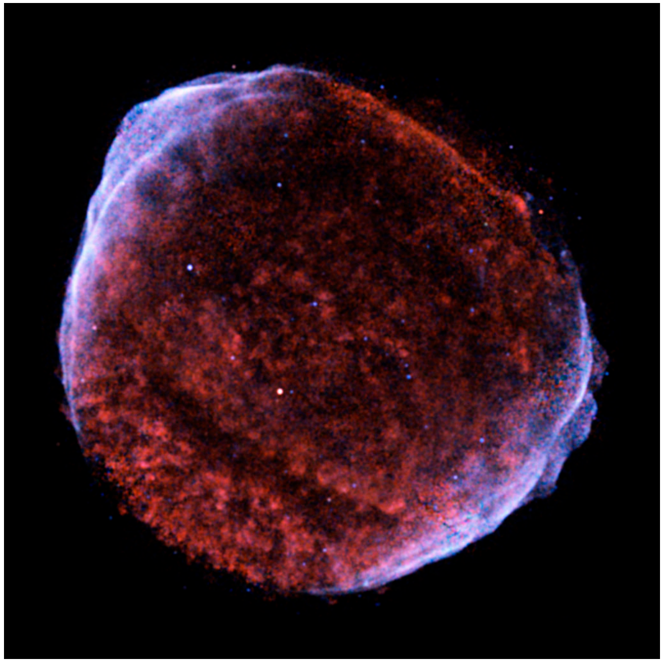
Two possible scenarios:

- **Single degenerate progenitors**: one white dwarf and one subgiant or main-sequence companion



- **Double degenerate progenitors:** the merge of two white dwarfs



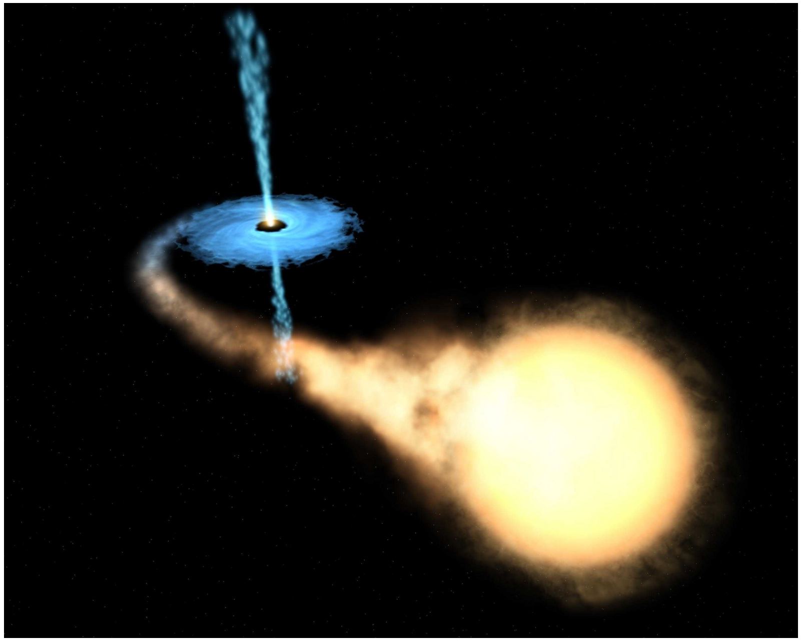


SN1006: Remnant of a Type Ia Supernova exploded in 1006 AD. Brightest supernova in recorded history, probably exceed 16 times the brightness of Venus

The absolute luminosity is well constrained using their light curves.
Used as the brightest "**standard candles**" to measure distance

Neutron stars and black holes in binaries

- X-ray binaries: If the primary is a neutron star or a black hole, the gravitational potential energy from the infalling gas from the companion converts (much more efficiently than nuclear fusion!) to radiation in the optically-thick accretion disk. Stefan-Boltzmann's law says the radiation peaks at X-rays
- **Double neutron star/black hole binaries:** Excellent laboratory for gravitational waves



Black hole merger and gravitational waves