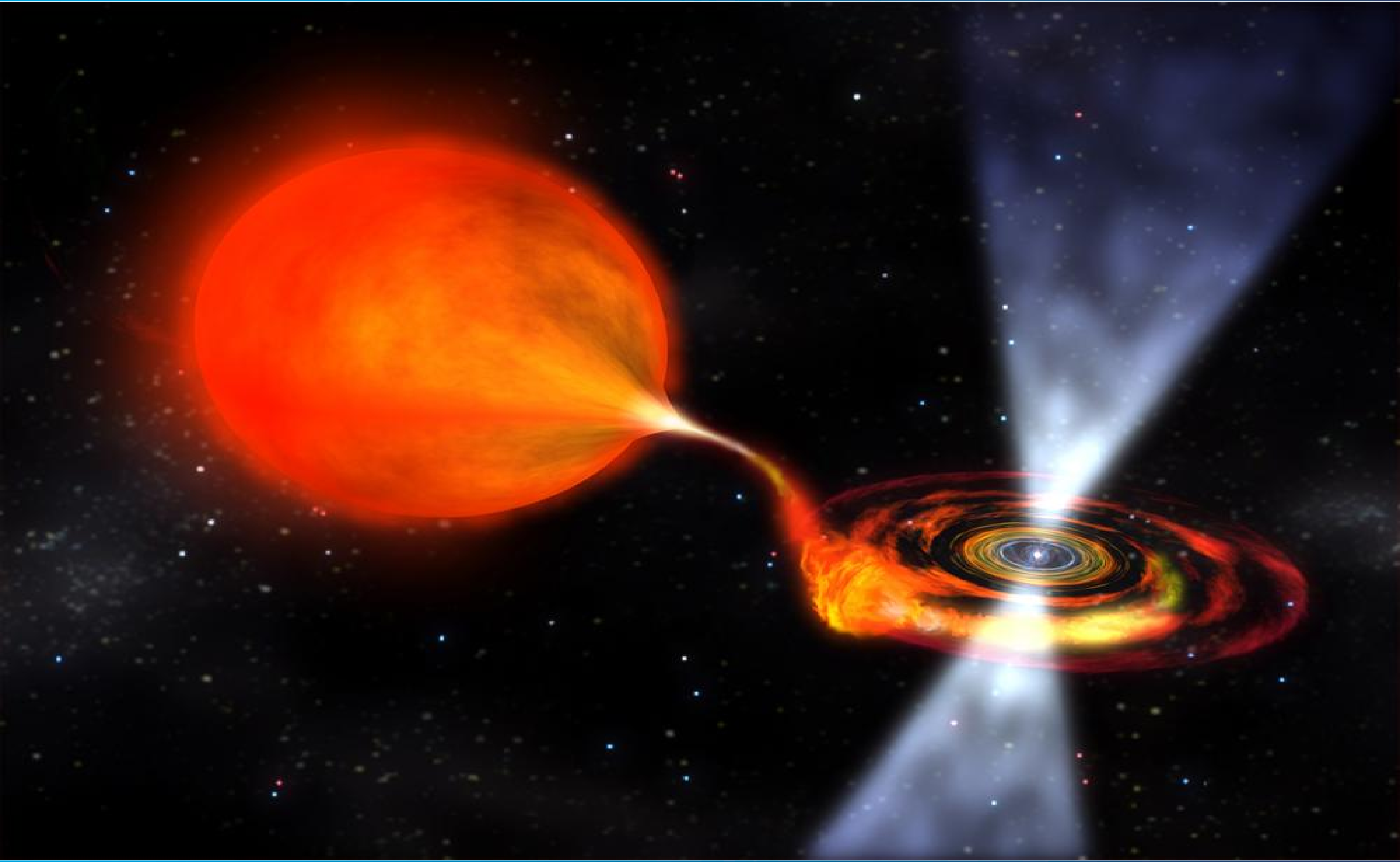
DTU Space
National Space Institute

X-ray binaries



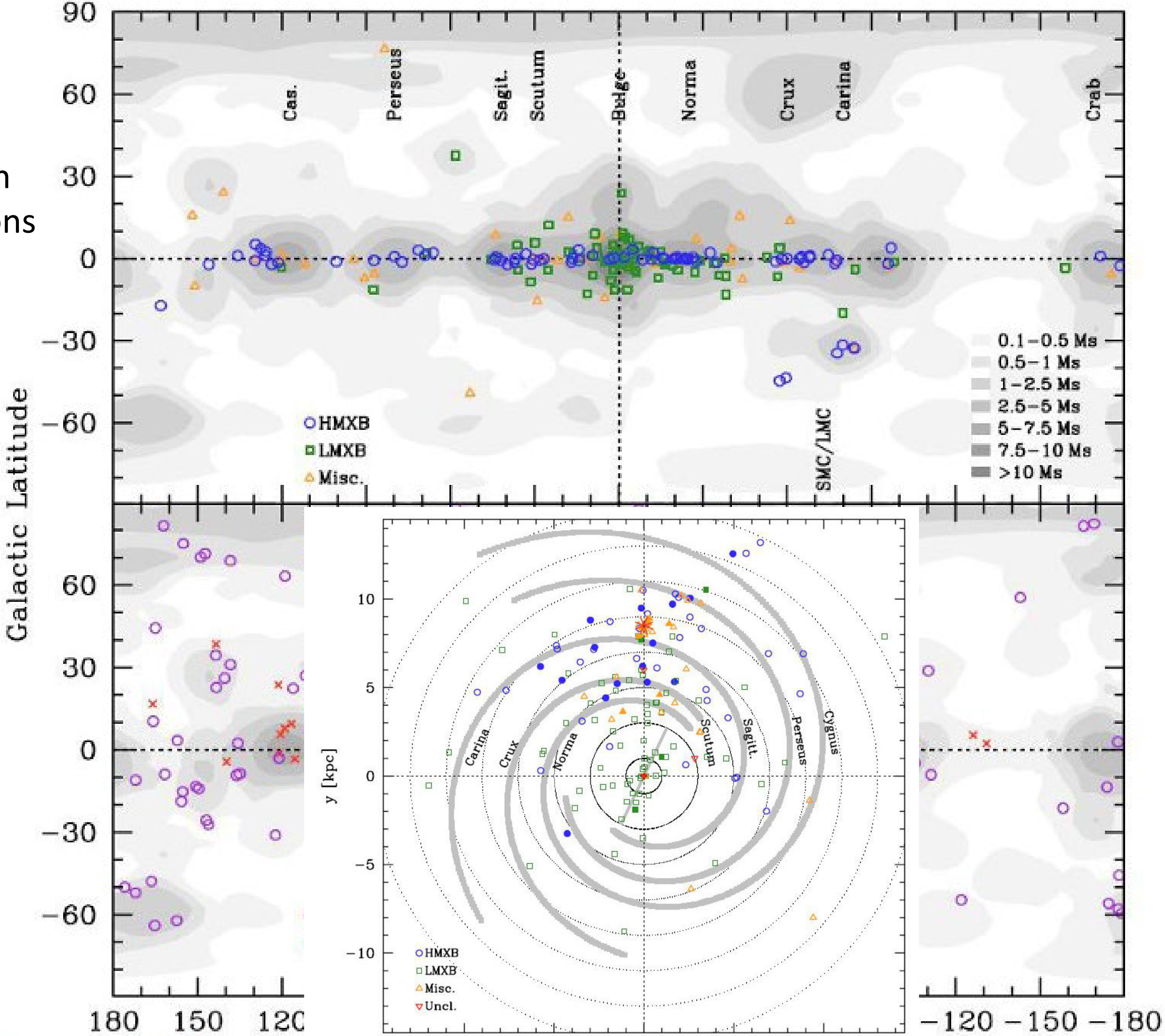
Classification after the mass of the companion

Characteristics

	HMXB	LMXB
X-ray spectra:	$kT \geq 15$ keV (hard)	$kT \leq 10$ keV (soft)
Type of time variability:	regular X-ray pulsations no X-ray bursts	only a very few pulsars often X-ray bursts
Accretion process:	wind (or atmos. RLO)	Roche-lobe overflow
Timescale of accretion:	10^5 yr	10^7–10^9 yr
Accreting compact star:	high **B**-field NS (or BH)	low **B**-field NS (or BH)
Spatial distribution:	Galactic plane	Galactic center and spread around the plane
Stellar population:	young, age $< 10^7$ yr	old, age $> 10^9$ yr
Companion stars:	luminous, $L_{opt}/L_x > 1$ early-type O(B) stars $> 10\,M_\odot$ (Pop. I)	faint, $L_{opt}/L_x \ll 0.1$ blue optical counterparts $\leq 1\,M_\odot$ (Pop. I and II)
Orbital periods:	days to months	minutes to hours
	$M_{Comp} > M_{CO}$	$M_{Comp} < M_{CO}$

IMXB: Intermediate-Mass X-ray Binaries (M_{comp} 1-10 $M_\odot$)… Why are they so rare?

HMXBs
LMXBs
population
distributions



(Bodaghee et al., 2007)

Accretion onto compact objects

Efficiency of accretion as energy release depends on compactness $\frac{M}{R}$

Process	$\mathrm{J\,kg^{-1}}$	$f(\mathrm{H} \Longrightarrow \mathrm{He})$	$f(mc^2)$
$\mathrm{H} \Longrightarrow \mathrm{He}$ ($E = \Delta M c^2$)	6.3×10^{14}	1.0	0.007
Accretion onto white dwarf	8.0×10^{12}	1/80	8.9×10^{-5}
Accretion onto Neutron star	1.9×10^{16}	30	0.21
Accretion onto Black hole	4.5×10^{16}	70	0.5

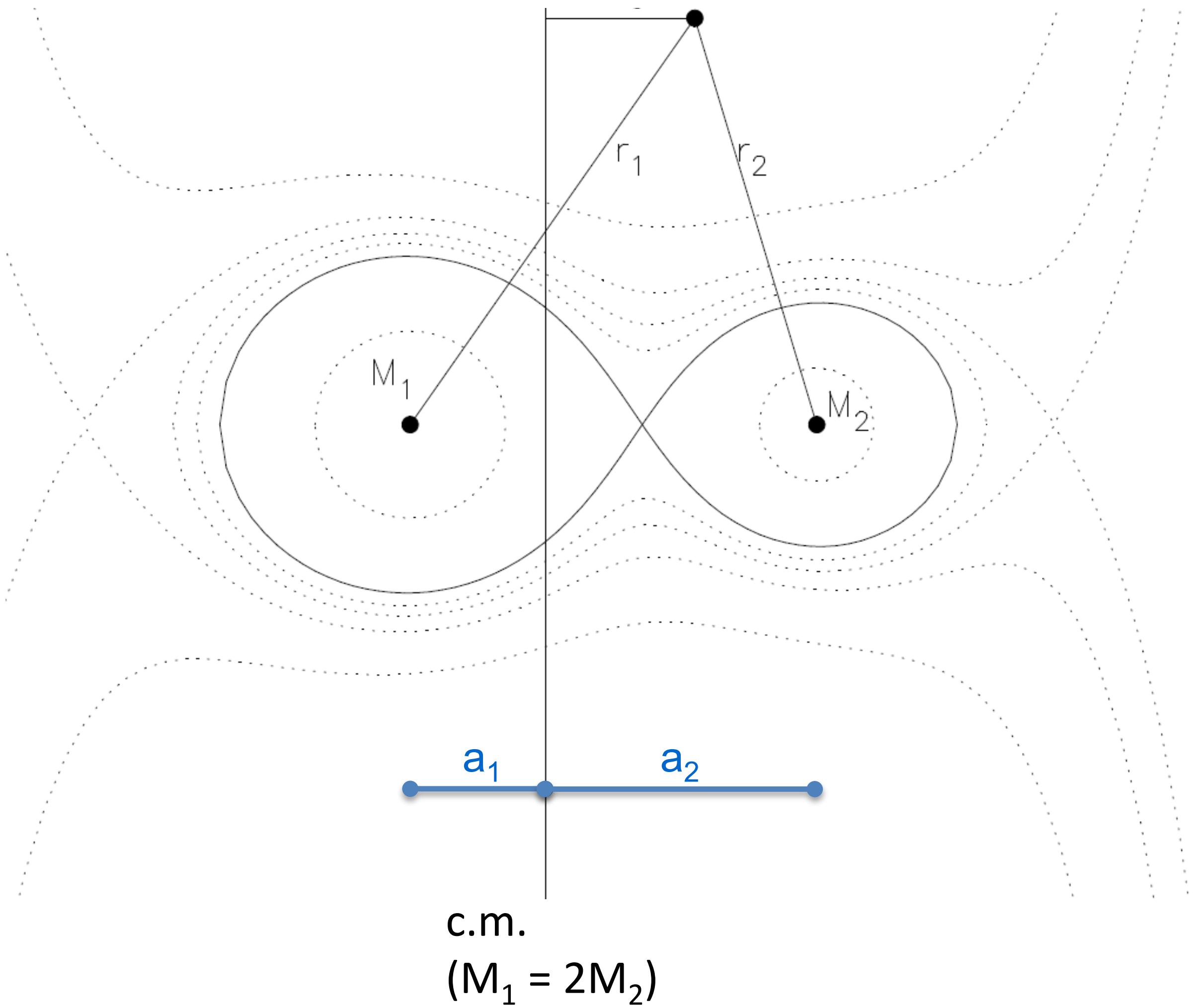
Liberation of *gravitational potential energy* as material falls on the surface of the object :

$$L_{\rm acc} = \frac{GM\dot{M}}{R}$$

Accretion *efficiency* (in terms of the rest-mass energy liberated) $\eta = \frac{GM}{Rc^2}$.

$$L = \eta \dot{M} c^2$$

Gravitational equipotential lines in binary systems



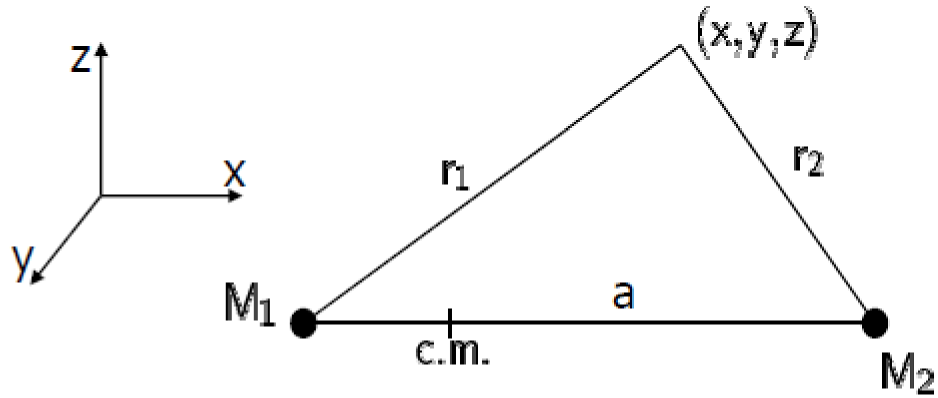
$a = a_1 + a_2$

$M_1\, a_1 = M_2\, a_2 \Rightarrow a_1 = M_2/(M_1 + M_2)*a$

Equipotential surfaces in binary stars

$$r_1^2 = x^2 + y^2 + z^2$$

$$r_2^2 = (x-a)^2 + y^2 + z^2$$



mass ratio $q = \frac{M_2}{M_1}$

$$x_{c.m.} = \frac{M_2}{M_1+M_2}a = \frac{q}{1+q}a$$

Gravitational terms

Centrifugal term

Roche potential: $$\phi_R = -\frac{GM_1}{r_1} - \frac{GM_2}{r_2} - \frac{1}{2}\omega^2\left[(x-x_{c.m.})^2 + y^2 + z^2\right] \quad \omega = \frac{2\pi}{P} = 2\pi f = \sqrt{\frac{G(M_1+M_2)}{a^3}}$$

(Potential grav. energy per unit mass)

Edouard Roche (1820-1883)

Joseph Lagrange (1736-1813)

The Roche potential depends on *q* and *a*

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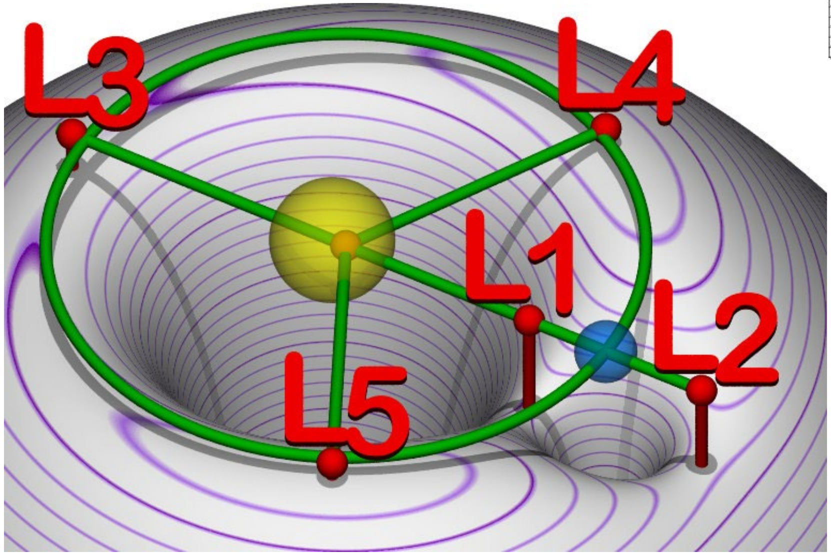
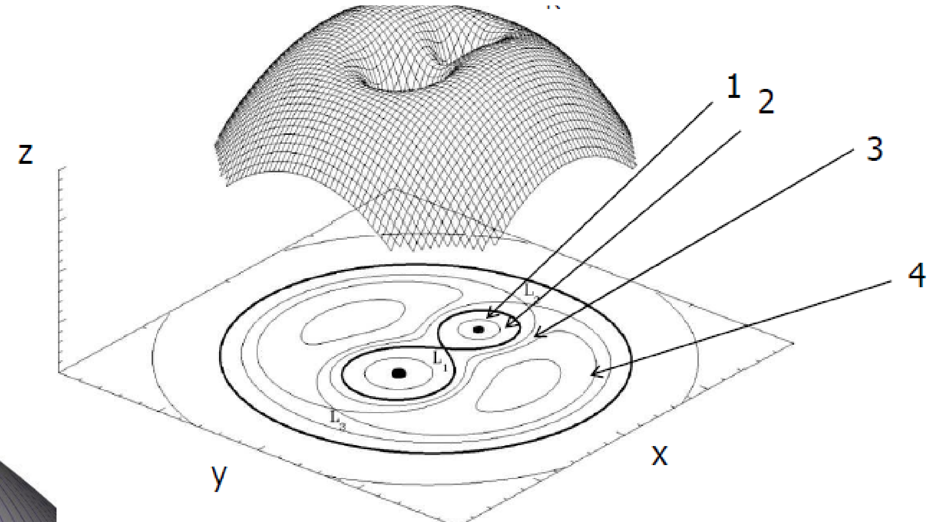
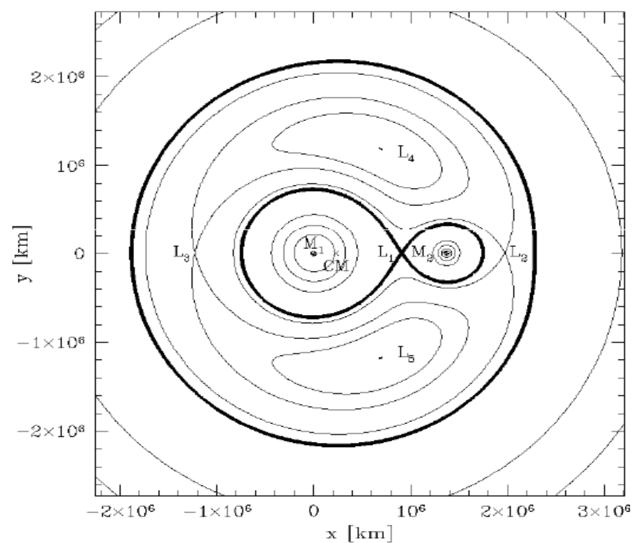


ases from 1-4 surfaces



Equipotential surfaces: Φ_R = const.

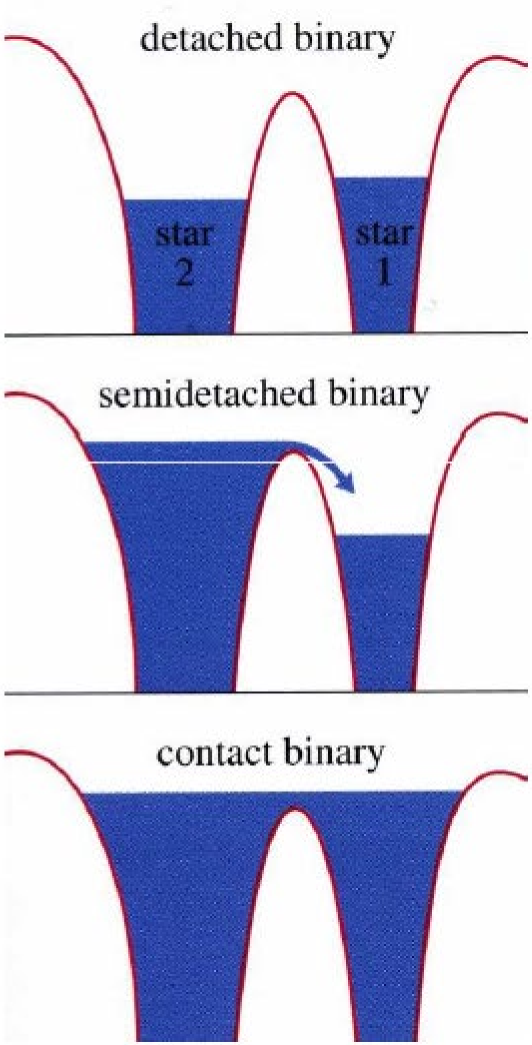


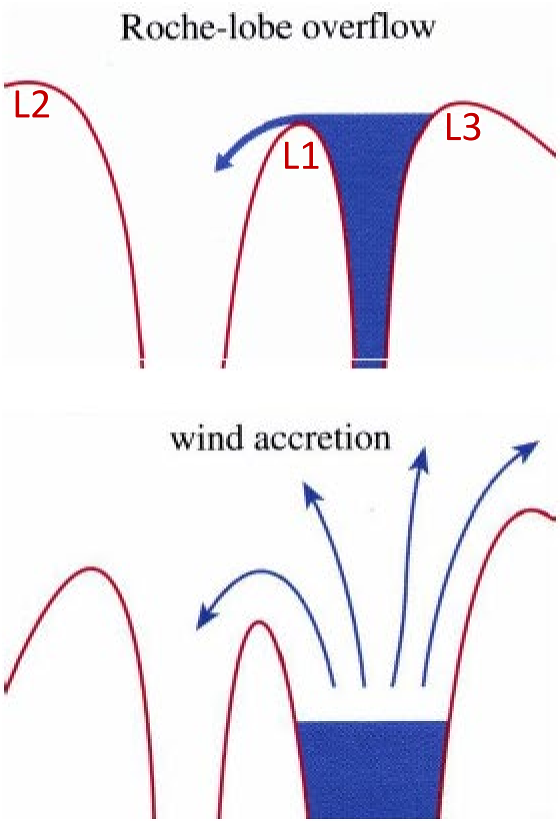
$q = 0.2, \ P_{orb} = 7h$

5 "Lagrangian" points:

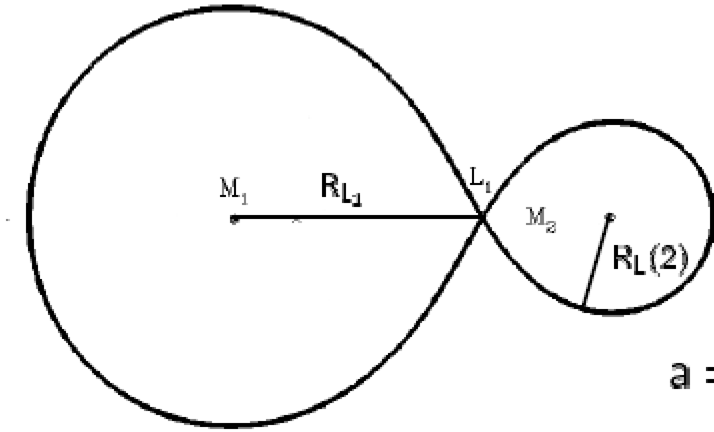
$\nabla \phi_R = 0$

Binary configurations and mass transfer





Roche lobes: useful approximations



$$a = \left(\frac{P_{orb}^2 G(M_1 + M_2)}{4\pi^2}\right)^{1/3}$$

$$a = 3.53 \times 10^8 (M_1/M_\odot)^{1/3}(1+q)^{1/3} P_{orb}^{2/3}(h)\ m$$

$$R_{L_1} = (1.0015 + q^{0.4056})^{-1} \quad (0.04 \le q \le 1)$$

$$R_{L_1} = 0.5 \quad 0.227 \log q \quad (0.1 \le q \le 10)$$

Eggleton (1983):

$$\frac{R_L(2)}{a} = \frac{0.49q^{2/3}}{0.6q^{2/3} + \ln(1+q^{1/3})}$$

volume-equivalent radius of the secondary star Roche lobe

$$\frac{R_L(2)}{a} = 0.462 \left(\frac{q}{1+q}\right)^{1/3}$$ $0.1 \le q \le 1$ 2% accuracy (Paczynski 1971)

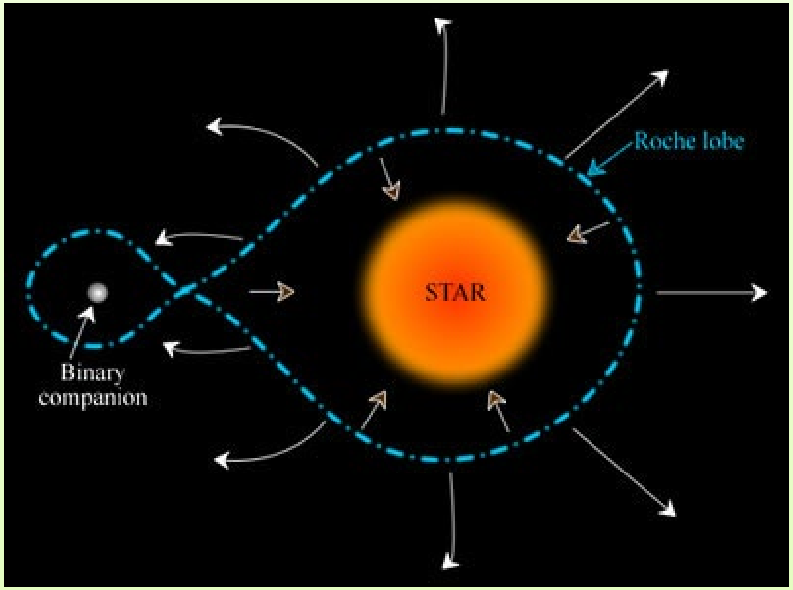
$R_L(2) = f(q) \times a \Leftrightarrow R_L(1) = f(1/q) \times a$

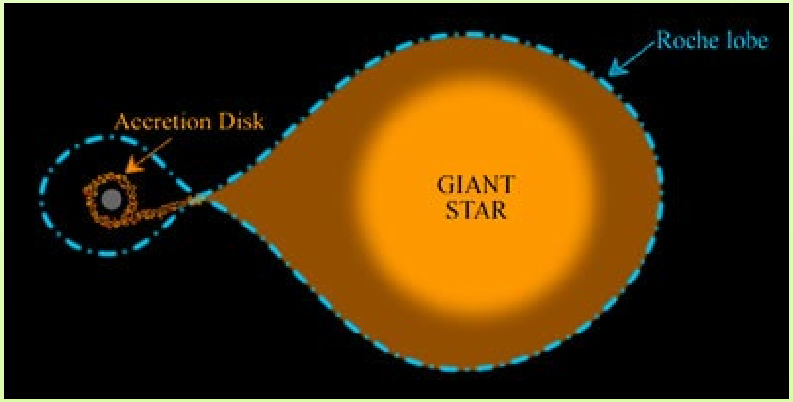
The Roche Lobe

The term ‘Roche-lobe' is used to describe a distinctively shaped region surrounding a star in a binary systems.

This teardrop-shaped space defines the region in which material is bound to the star by gravity.

Any material outside the Roche-lobe of a star may, depending on its initial location, energy and momentum, either escape the system completely, orbit both stars, or fall onto the binary companion.





Steady accretion

- Two possible avenues for mass transfer:
  1. Accretion from the stellar wind of the companion (*Bondi-Hoyle* accretion)
  2. *Roche lobe overflow* through the L1 point

- An additional constraint is the *stability* of the mass transfer (angular momentum conservation)

Weighing XRBs

- Determining the mass of the donor involves measuring the motion of one object, either the donor (optical spectroscopy $\Rightarrow$ K) or the NS (via pulsations $\Rightarrow$ a_x sin i).
- We calculate the *mass function*

$$f_{\rm X}(M) = \frac{M_2^3 \sin^3 i}{(M_2 + M_{\rm X})^2} = \frac{4\pi^2 a_{\rm X}^3 \sin^3 i}{GP^2} = \frac{PK_{\rm X}^3}{2\pi G}$$

and assume the NS mass from radio pulsars.

The obtained value provides a lower limit on M_2