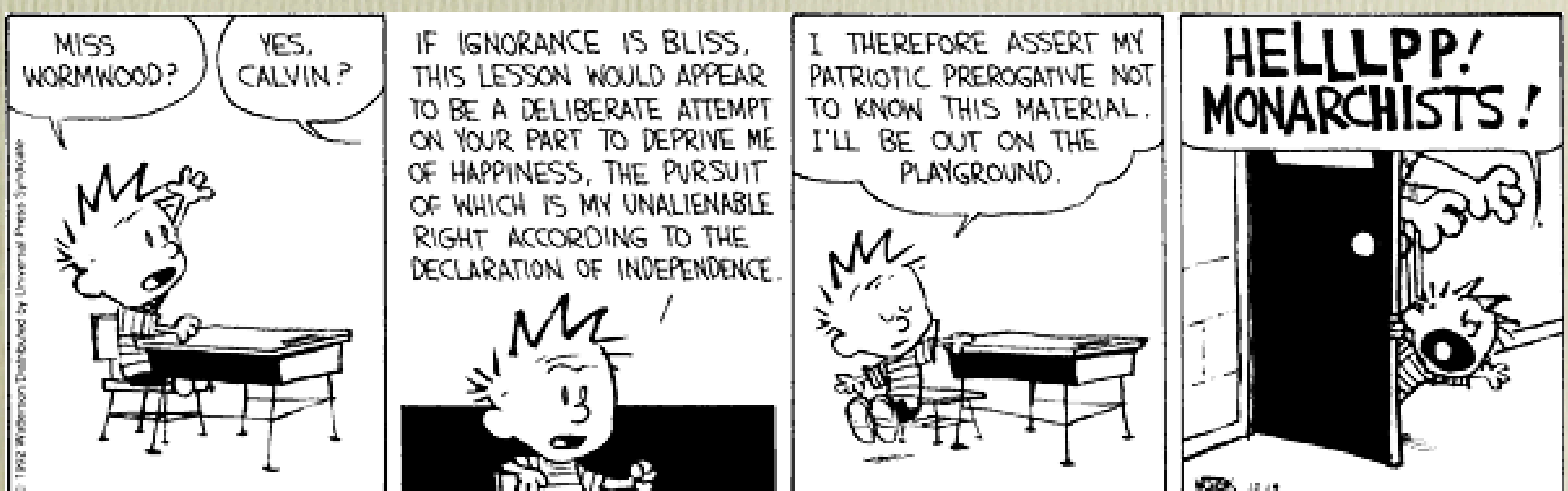
Dr. Reed L. Riddle

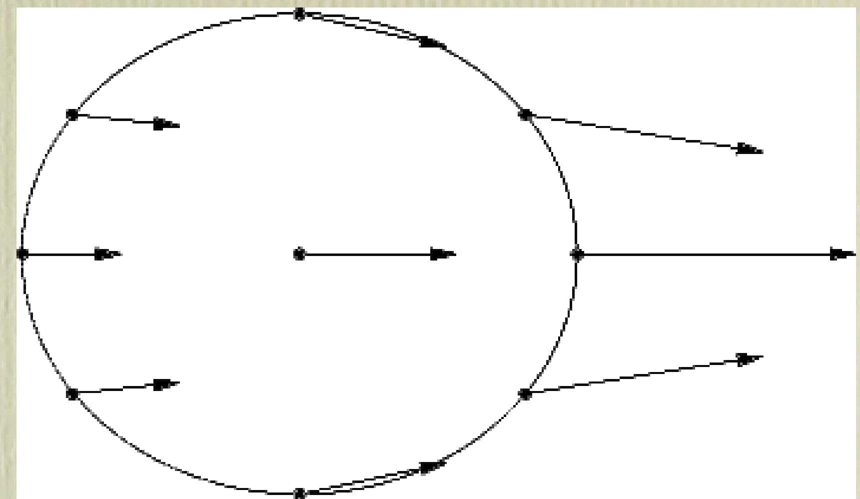
Close binaries, stellar interactions and novae

Guest lecture
Astronomy 20
November 2, 2004

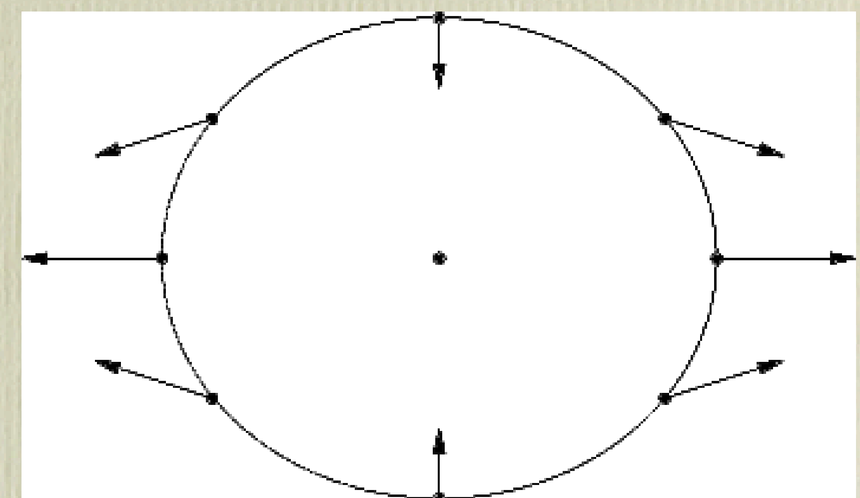


Gravitational Tides

- Look at the forces acting on one body orbiting another
  - more pull on closer side



- Subtract center of mass force
  - object is “squashed” and “stretched”



Gravitational Tides

- Gravitational tides are a differential force

- Force of gravity:

$$F = -\frac{GMm}{r^2}$$

- Differential of gravitational force over ***dr***:

$$dF = \left(\frac{dF}{dr}\right)dr = \frac{2GMm}{r^3}dr$$

- Tidal force is:
  - proportional to mass of the primary
  - inversely proportional to distance cubed

- Eventually, tidal force circularizes orbits and synchronizes rotation
  - constant of angular momentum
  - minimum energy state

Gravitational Tides

- What if an object gets too close?
- Stars close enough to each other will have large gravitational influence
- Lagrange points
  - points of local gravitational stability
- Roche Lobe
  - equipotential surface -- Equal Potential
  - balance of gravitational force between two stars
- Mass transfer
  - stellar winds (miniscule)
  - Roche Lobe overflow (maybe)
  - much mass is lost to the system
- Stellar interactions
  - Algol paradox
  - spectroscopic observations of "streams"

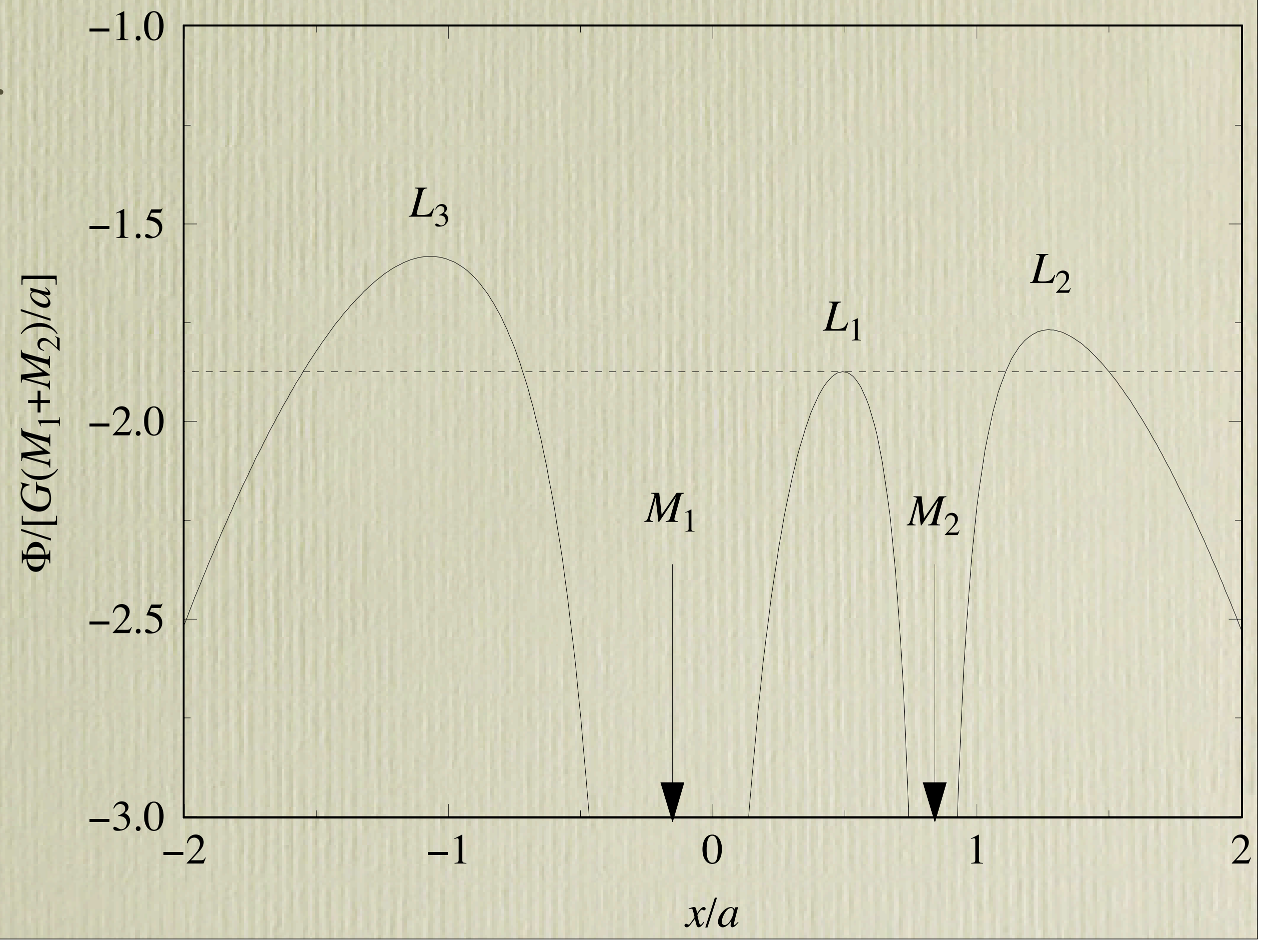
Lagrange Points

- Points of gravitational stability in two body system

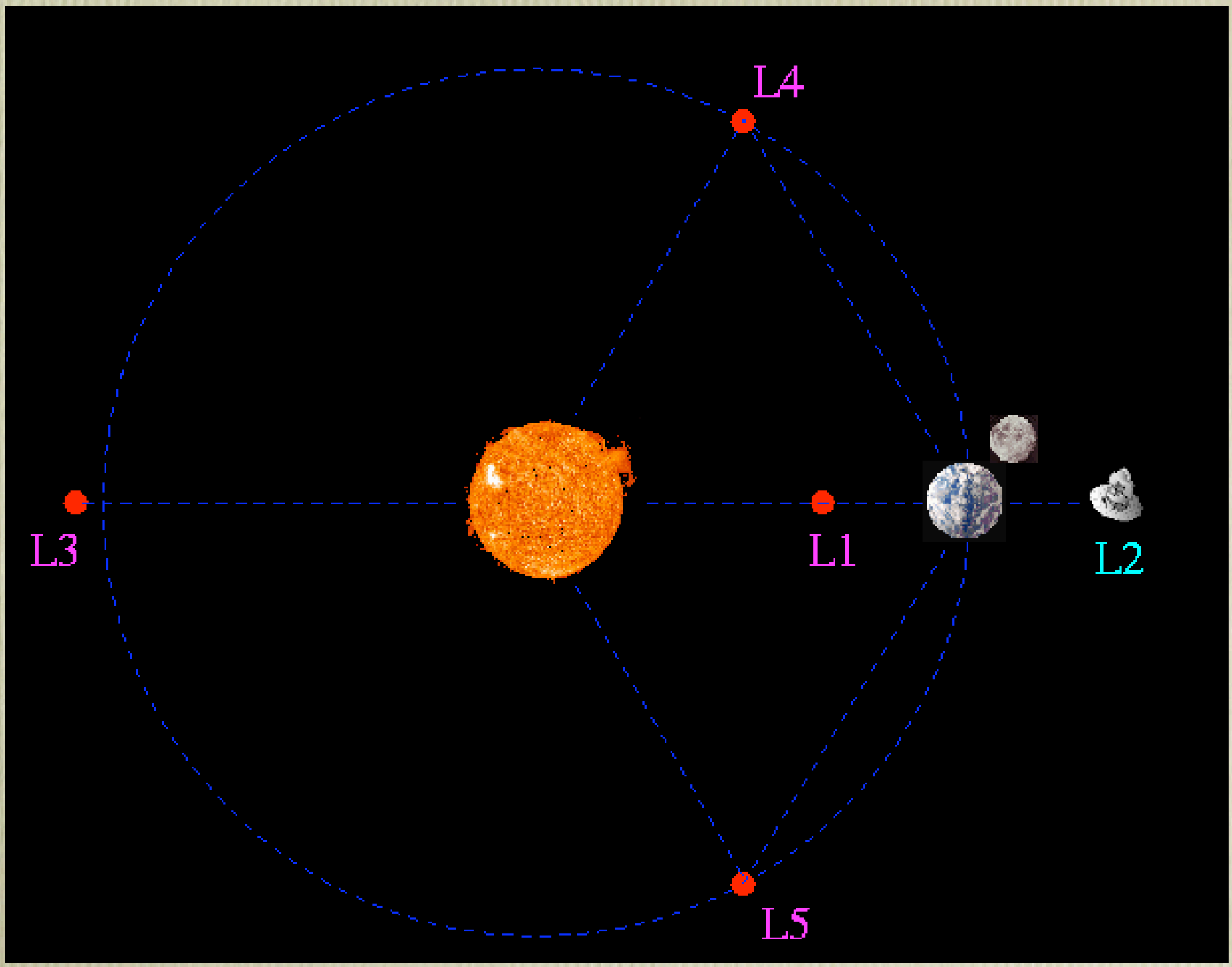
- Five points
  - L_1, L_2, L_3 are unstable to perturbations
  - L_4, L_5 can be stable

- Mass transfer can occur through the L_1 point

- Large energy release from material that is transferred between two stars

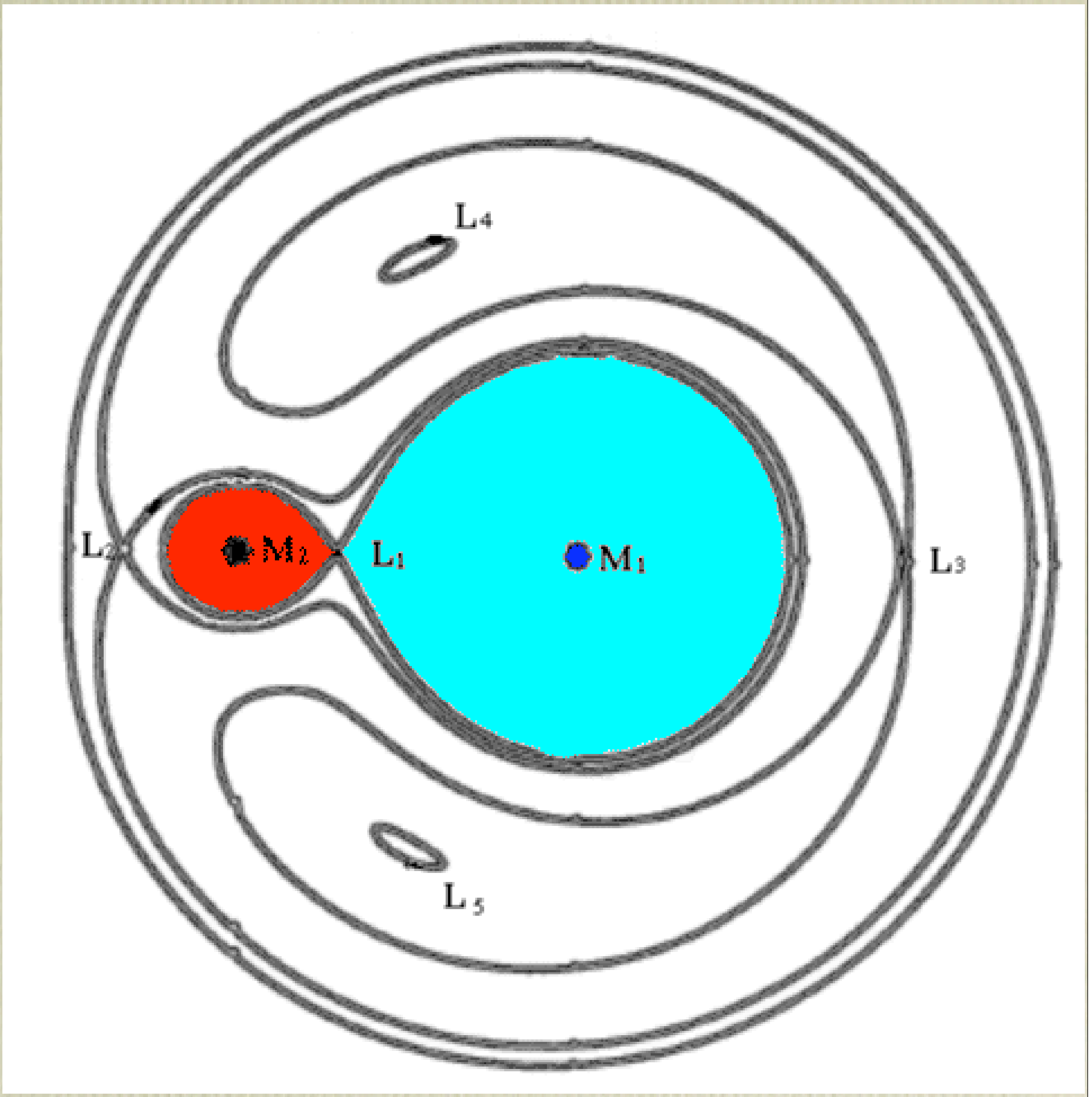


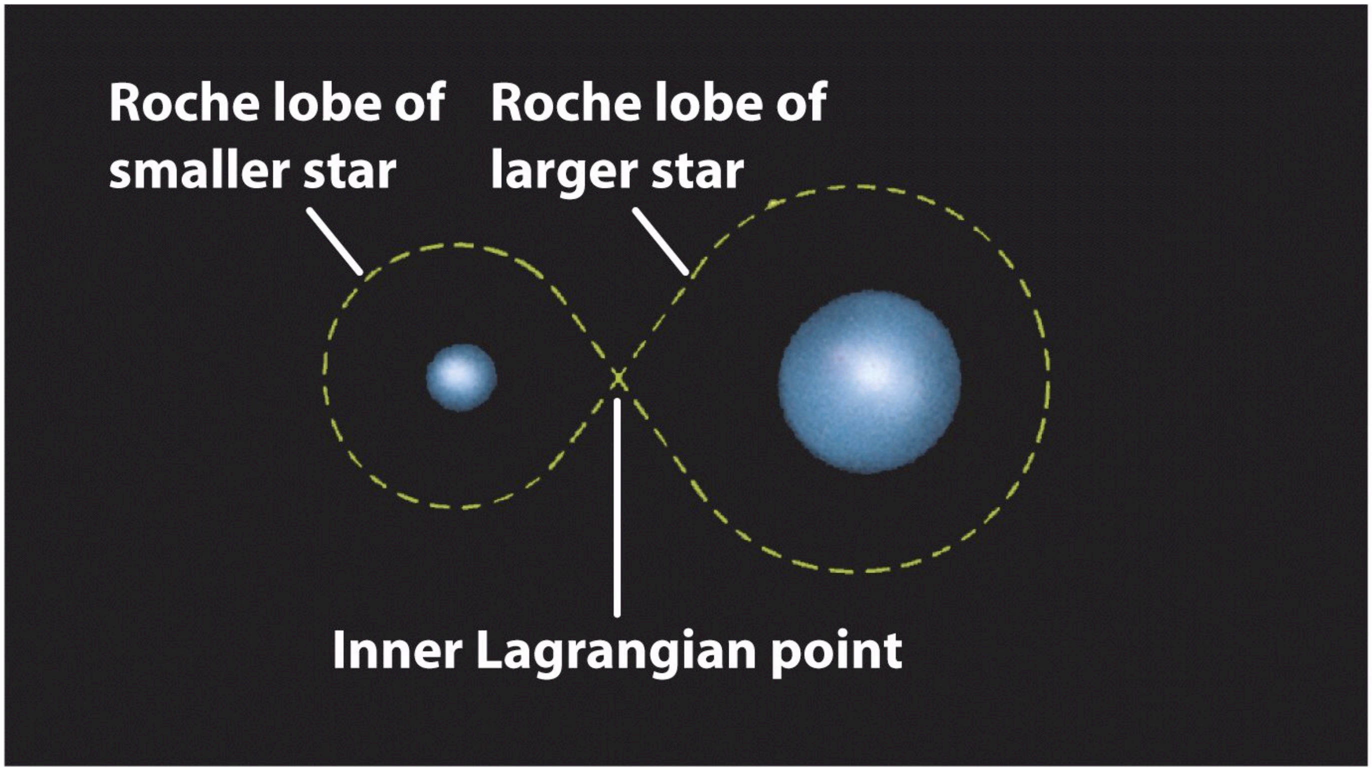
Lagrange Points



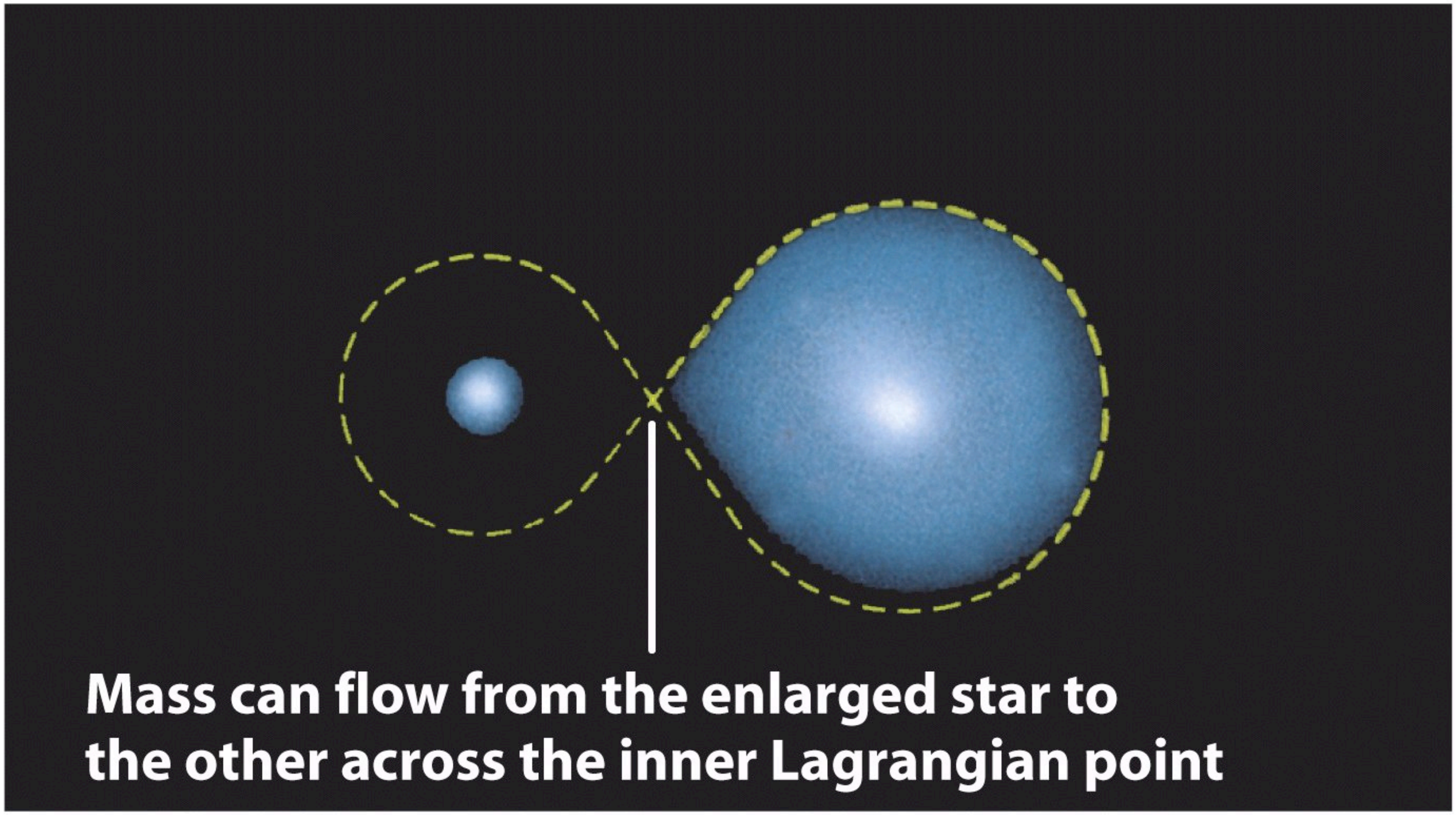
Roche Lobe

- Named for Edouard Roche, who calculate the Roche limit for planets
- Equipotential surfaces of gravitational force in a two body system
- Material that crosses the Roche lobe can be transferred to the other star, into orbit in the system, or ejected

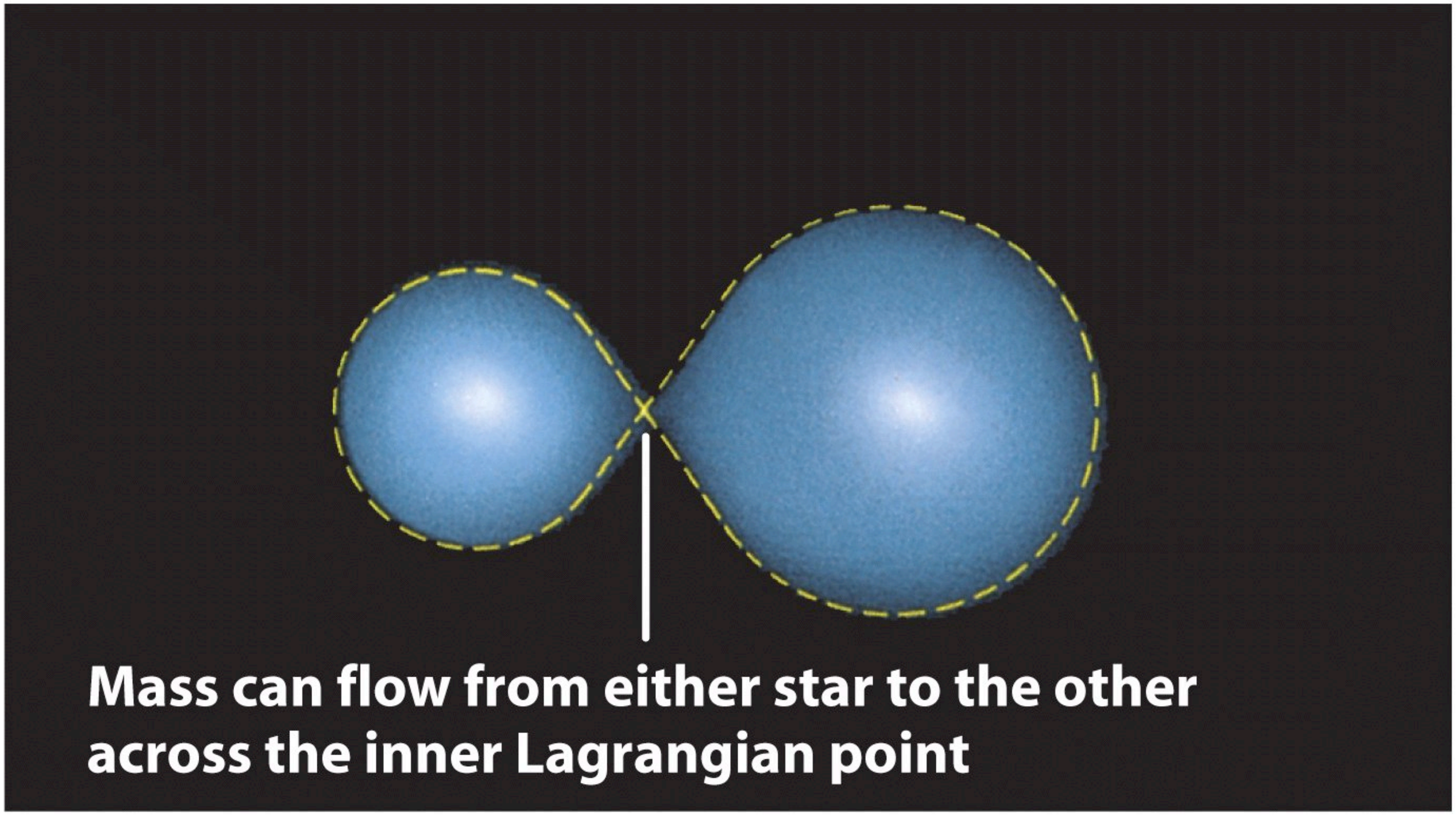




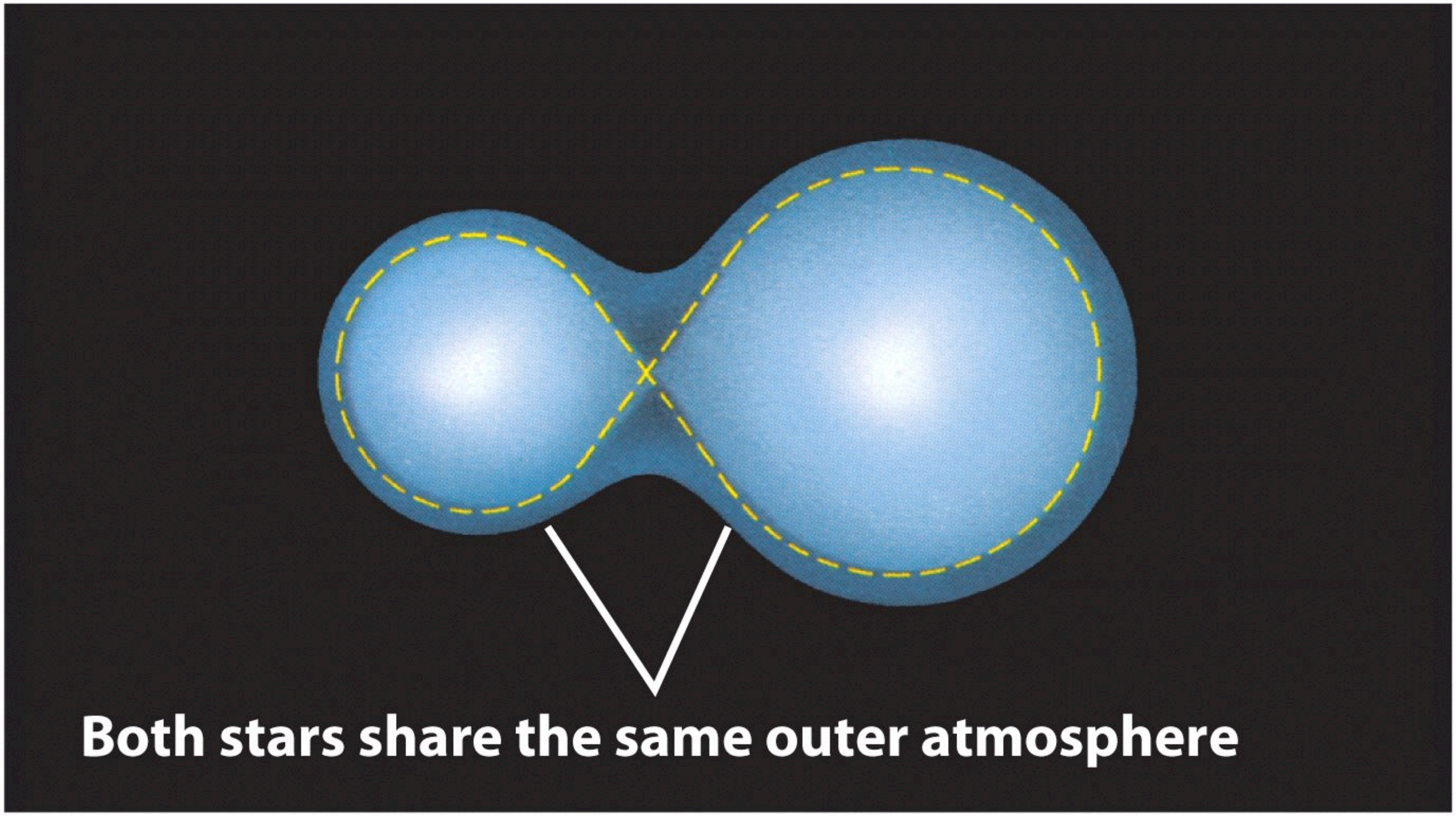
Detached binary: Neither star fills its Roche lobe.



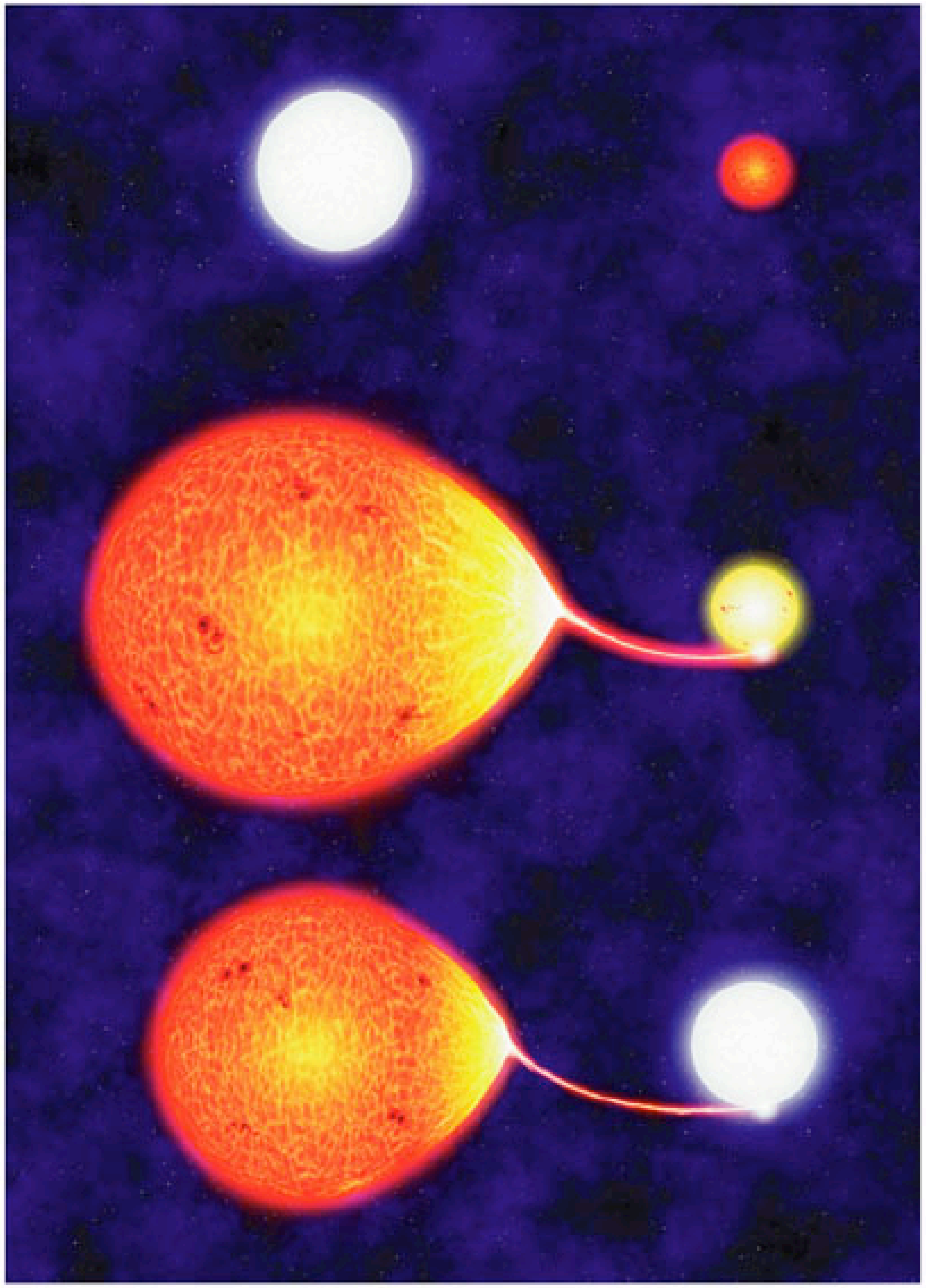
Semi-detached binary: One star fills its Roche lobe.

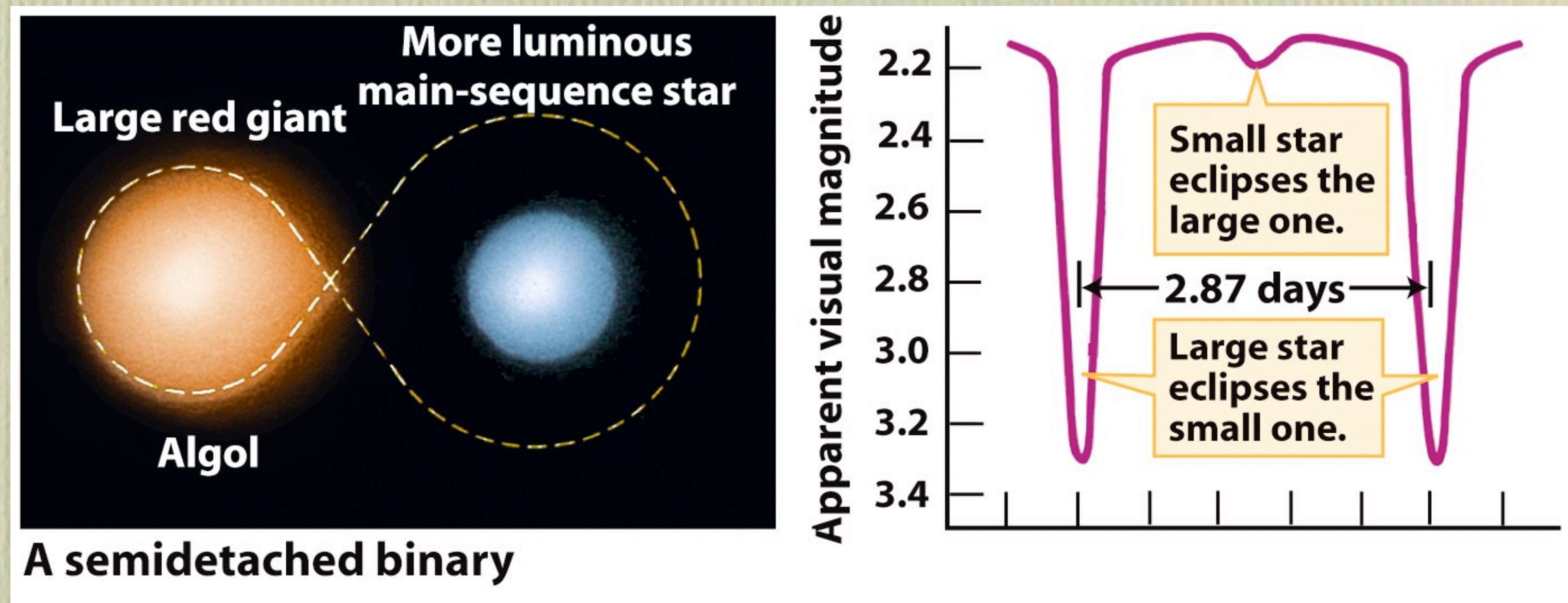


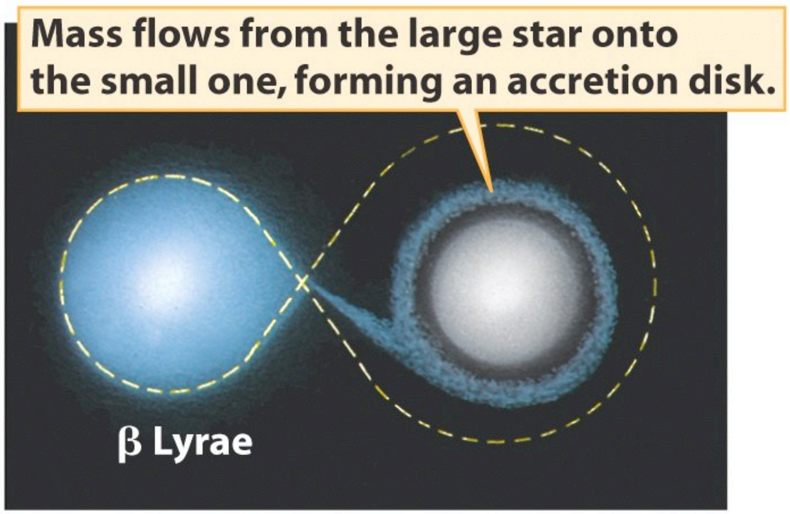
Contact binary: Both stars fill their Roche lobes.



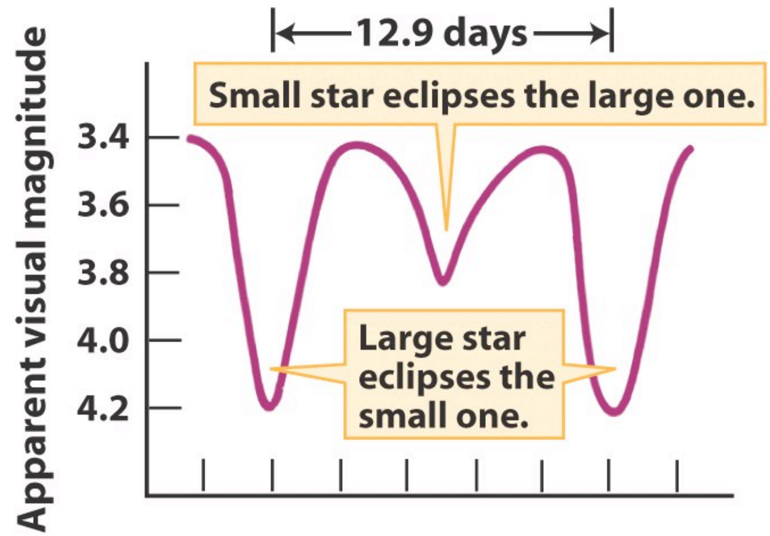
Overcontact binary: Both stars overfill their Roche lobes.

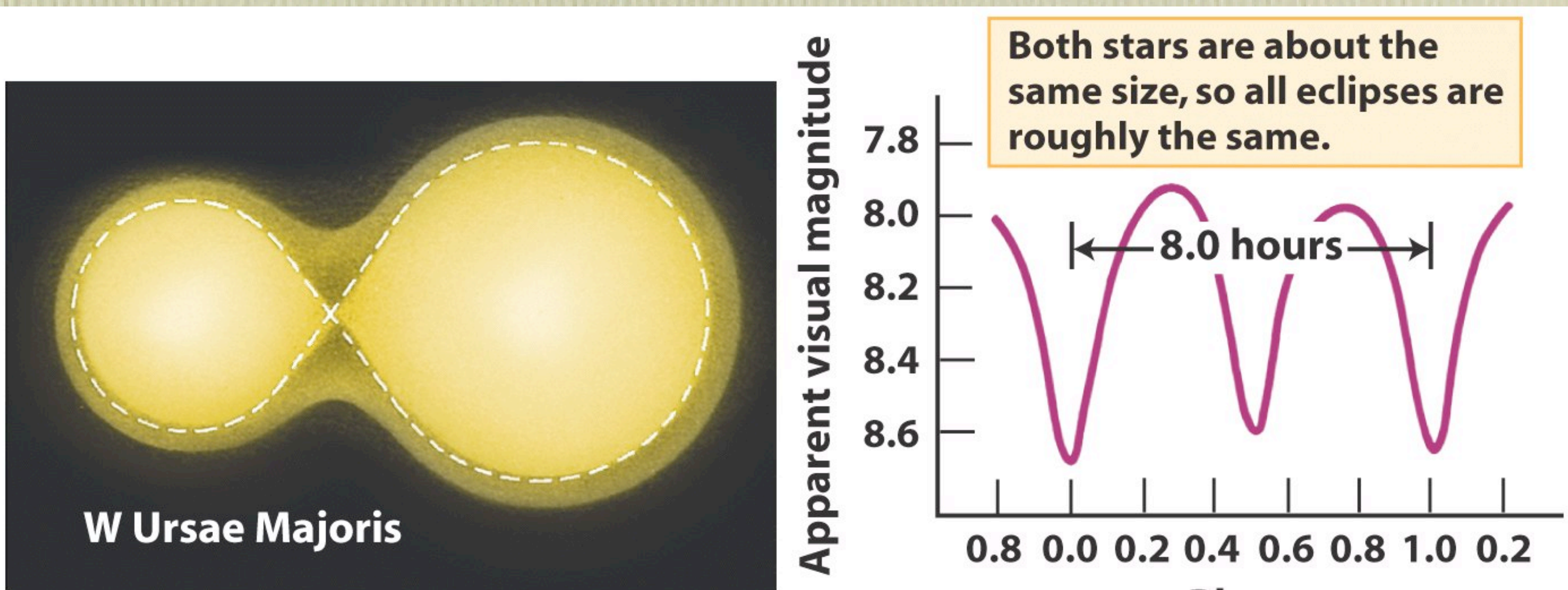



More luminous main-sequence star
Large red giant
Algol
A semidetached binary
Apparent visual magnitude
2.2
2.4
2.6
2.8
3.0
3.2
3.4
Small star eclipses the large one.
2.87 days
Large star eclipses the small one.



A semidetached binary with mass transfer



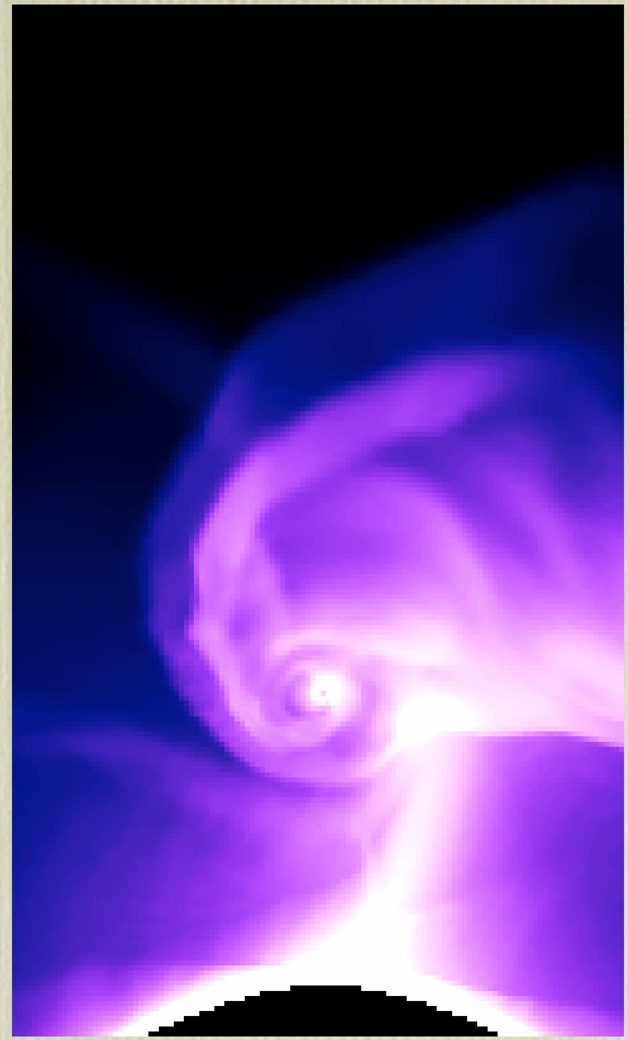


An overcontact binary

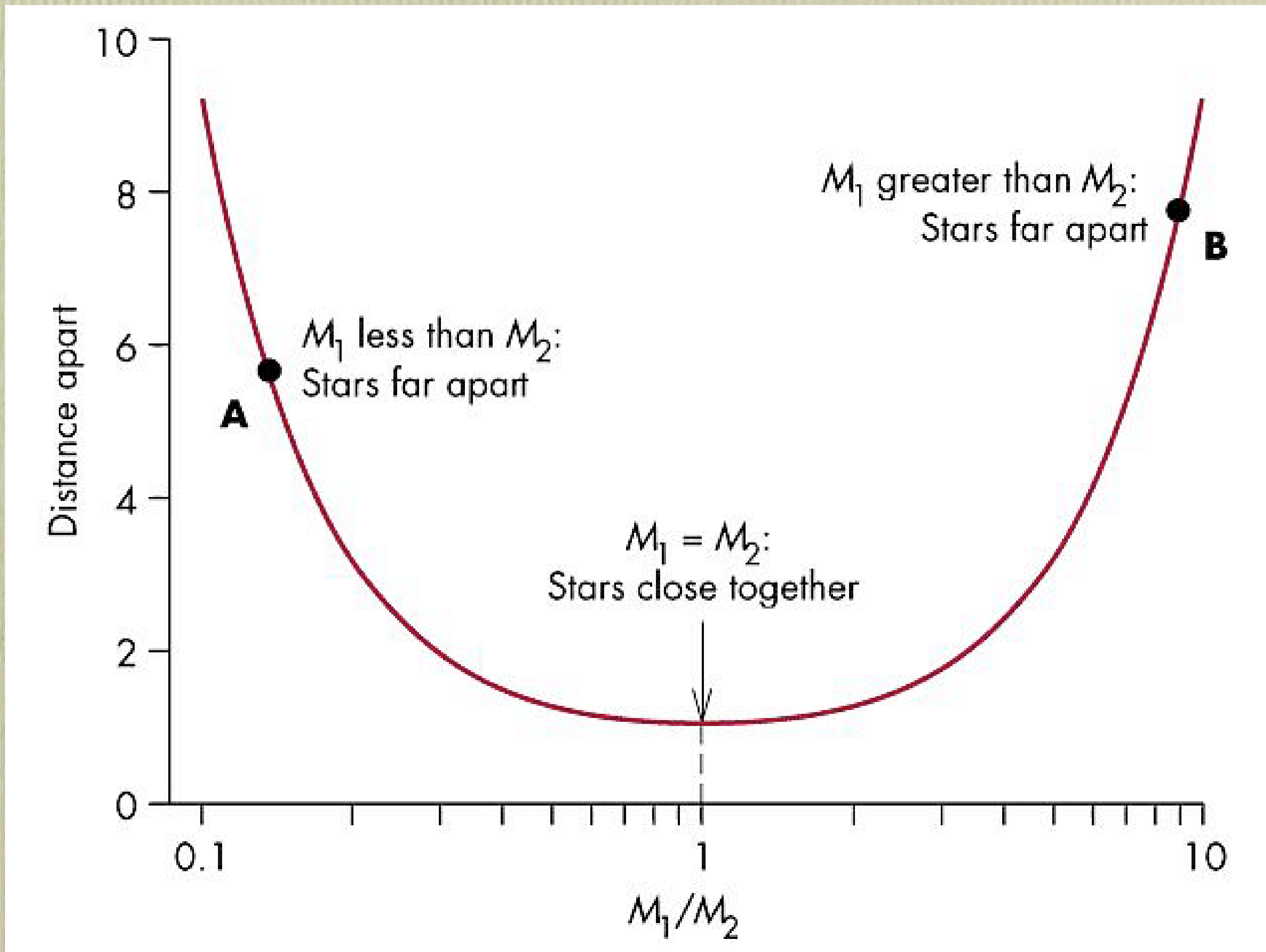
Mass Transfer

- Transfer depends on
  - distance between stars
  - mass fraction of the stars
  - dynamics of the binary system
  - types of stars

- Stars are sloppy eaters
  - mass outside Roche lobe can leave system
  - mass transferred through L_1 can leave system



- As mass is transferred, stars move closer until $M_1 = M_2$



Types of Close Binaries

- **Algols** - Algol systems comprise two 'normal' main sequence or subgiant stars in a semi-detached system.

- **W Serpens Stars** - These are active Algol systems.

- **RS Canum Venaticorum Stars** - Chromospherically active binaries of F and later spectral type components.

- **BY Draconis Stars** - Similar to RS Canum Venaticorum systems.

- **W Ursae Majoris Contact Systems** - Short period (0.2 to 0.8 day) contact binaries exhibiting very high levels of magnetic activity.

- **Barium and S-Star Binaries** - Long period binaries in which the originally more massive component evolved into a white dwarf, transferring some of its nuclear-processed gas to a giant type K or M companion.

Types of Close Binaries

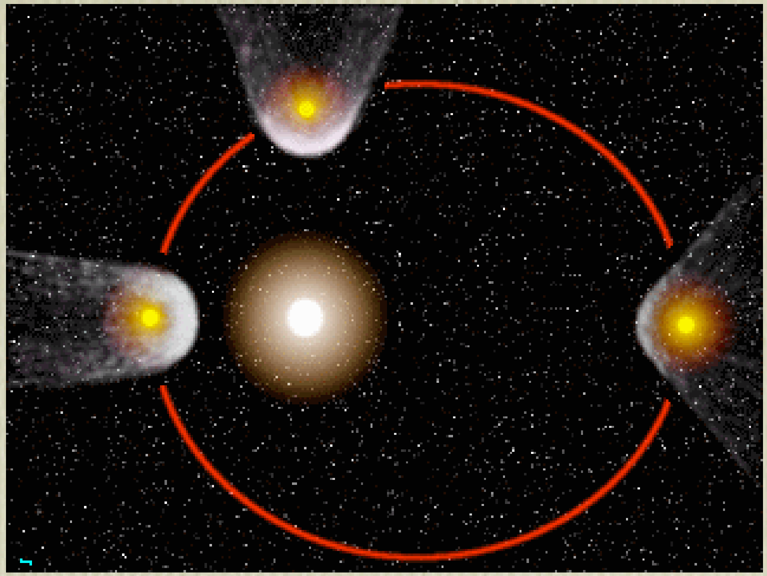
- **Zeta Aurigae Systems** - Long period binaries comprising interacting type G or K supergiant and hot (~type B) companion. Although not originally interacting systems, they become so when the more massive star evolves to become a supergiant.

- **VV Cephei Systems** - Similar to Zeta Aurigae binaries except a type M supergiant replaces the G or K type.

- **Symbiotic Binaries** - Long period (~200 to 1500 days) interacting binaries comprising a cool type M giant (sometimes a pulsating Mira-type variable) and a hot accreting companion such as a white dwarf, sub-dwarf, or low-mass main sequence star. Where the cool star fills its Roche lobe, the system becomes a symbiotic Algol.

- **Post-Common Envelope Binaries** - Usually comprising a hot white dwarf or subdwarf, and a cooler secondary, which have passed through the common envelope phase. The binary nuclei of planetary nebulae are examples.

Types of Close Binaries



- **Massive binaries**
  - O and B stars
  - large, fast stellar winds
  - short lifespans

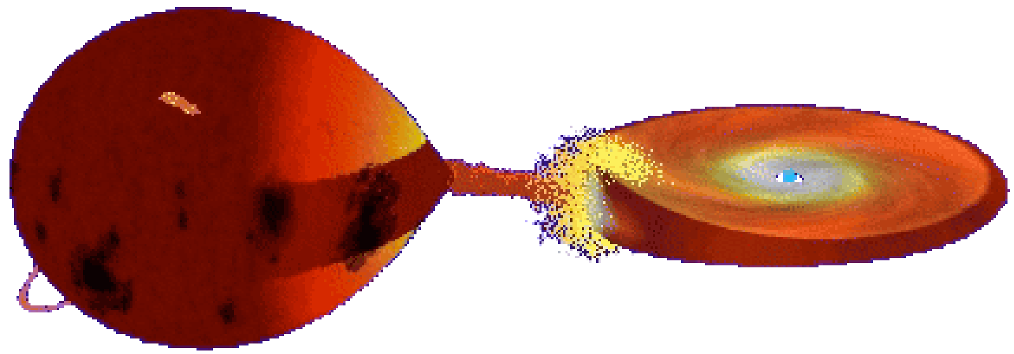
- Colliding winds
  - X-ray observations
  - spectroscopic observations of "streams"
  - shock front between stars

- "Exciting" evolution
  - intense interactions
  - stars large enough to supernova

- **X-Ray Binaries** - Binaries with a neutron star or, more rarely, a black hole primary. Accretion onto the primary produces strong x-ray emissions.

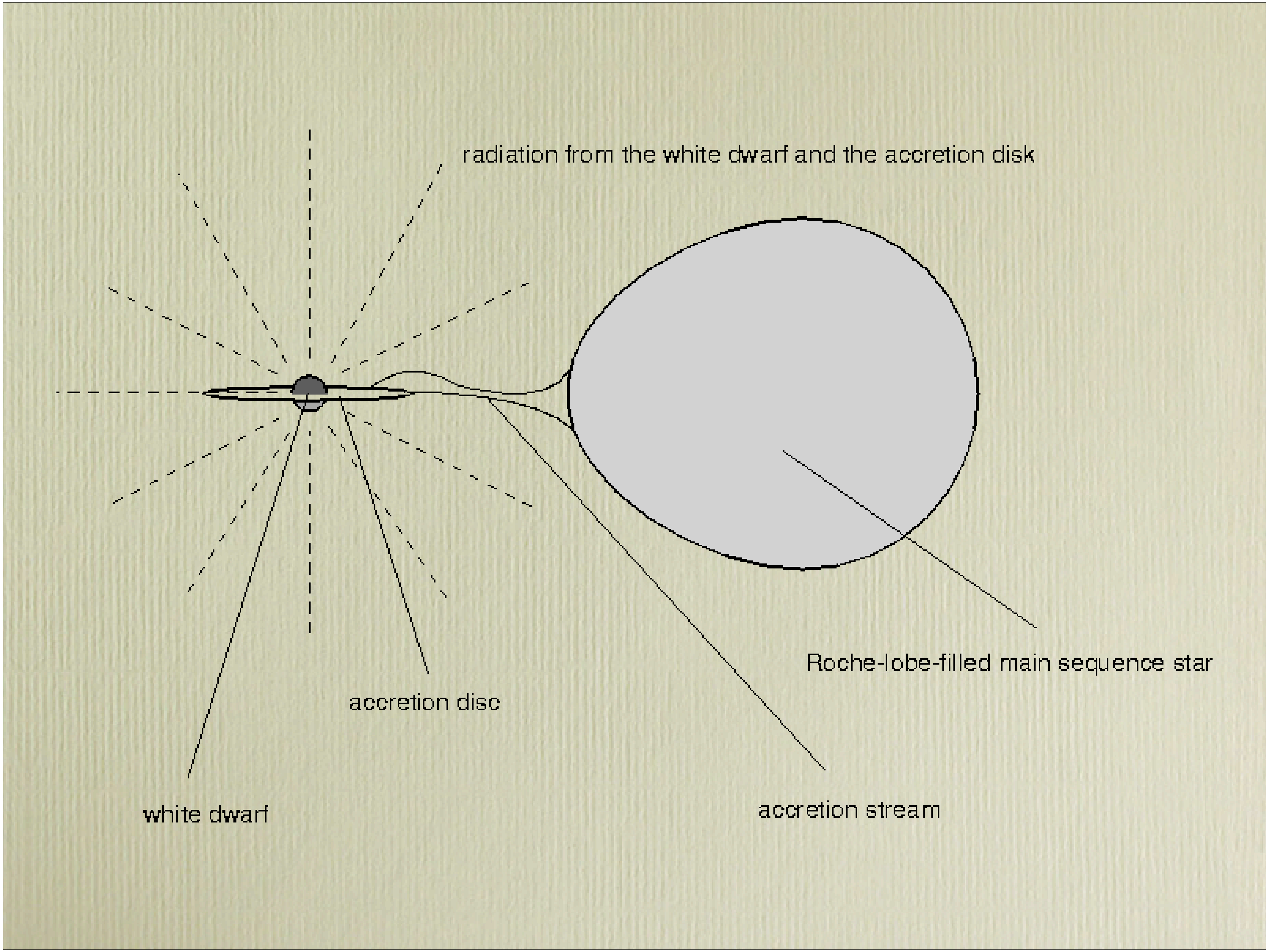
Novae

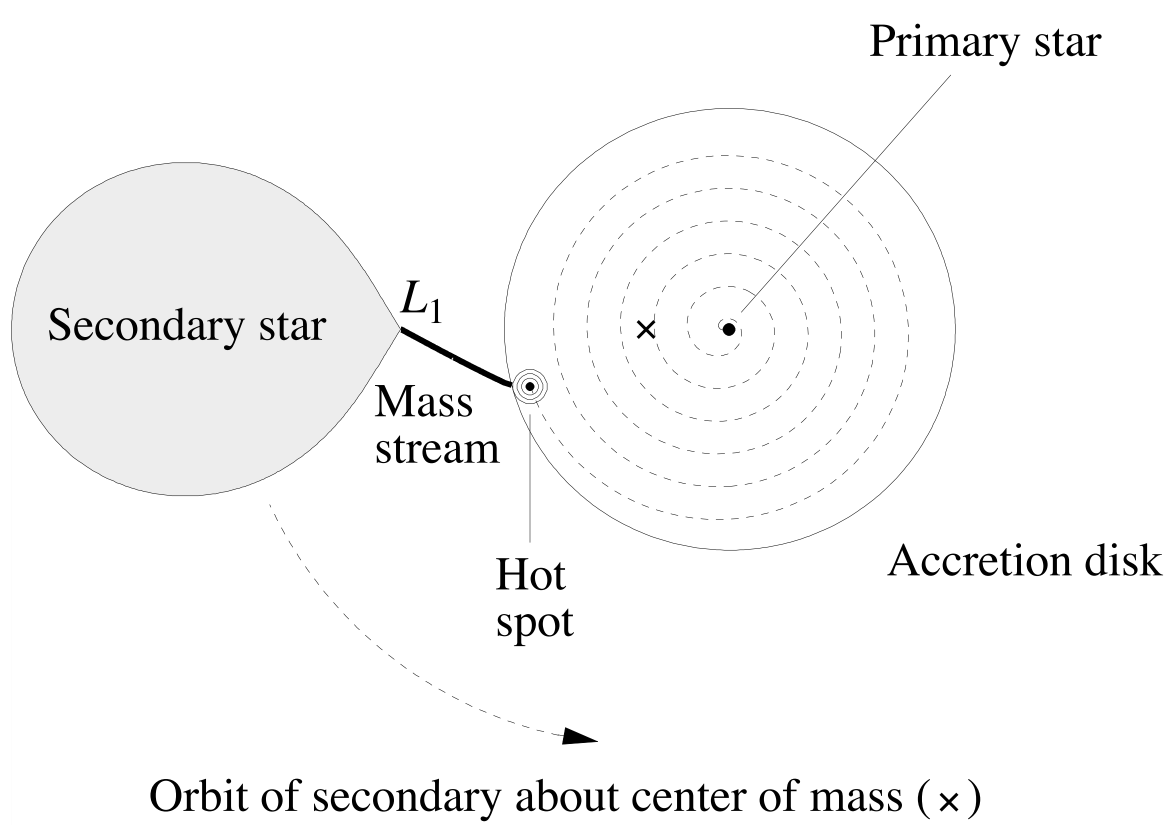
- A classical nova is a rapid brightening of a star, which then fades over a few weeks

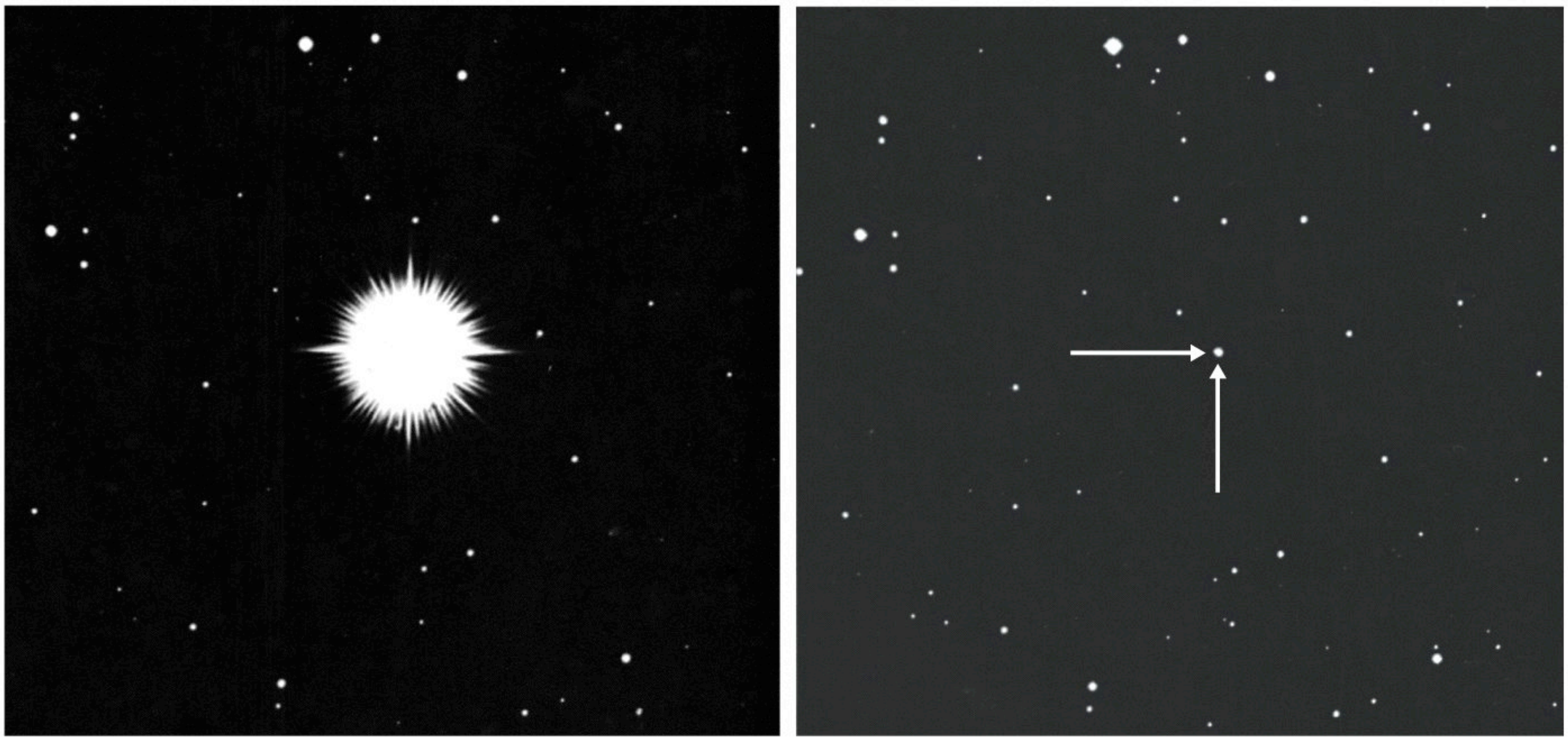


- Novae are thought to result from the explosion of an accreted gas layer on the **surface** of a white dwarf:
  - Surface layer builds up until temperature and density at base ignite nuclear fusion.
  - Layer is blown off in the explosion, which produces a nova plus an expanding shell.

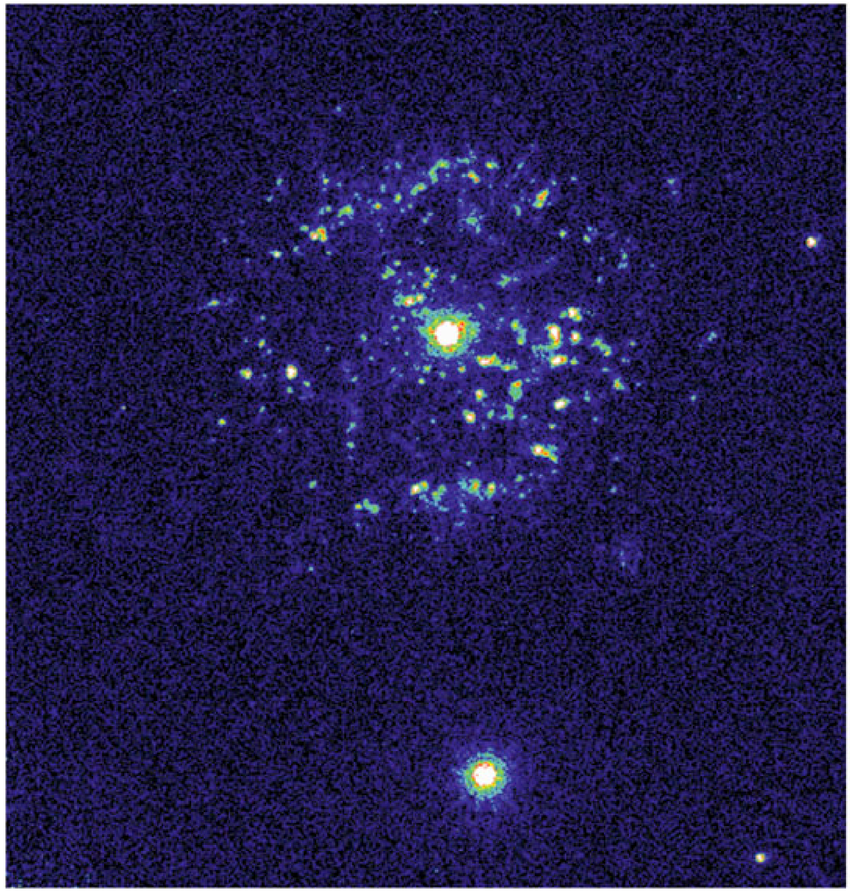
- Process repeats on a time scale of thousands of years.
- Analogous process on neutron star surfaces is called a Type 1 X-ray burst.

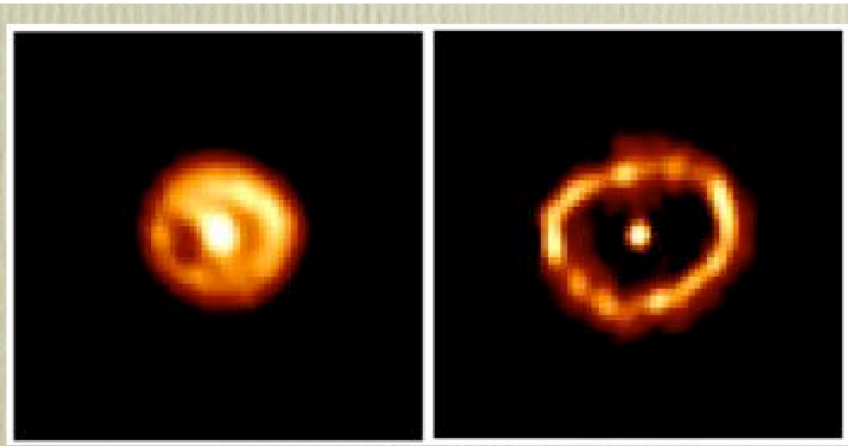

radiation from the white dwarf and the accretion disk
Roche-lobe-filled main sequence star
accretion disc
white dwarf
accretion stream

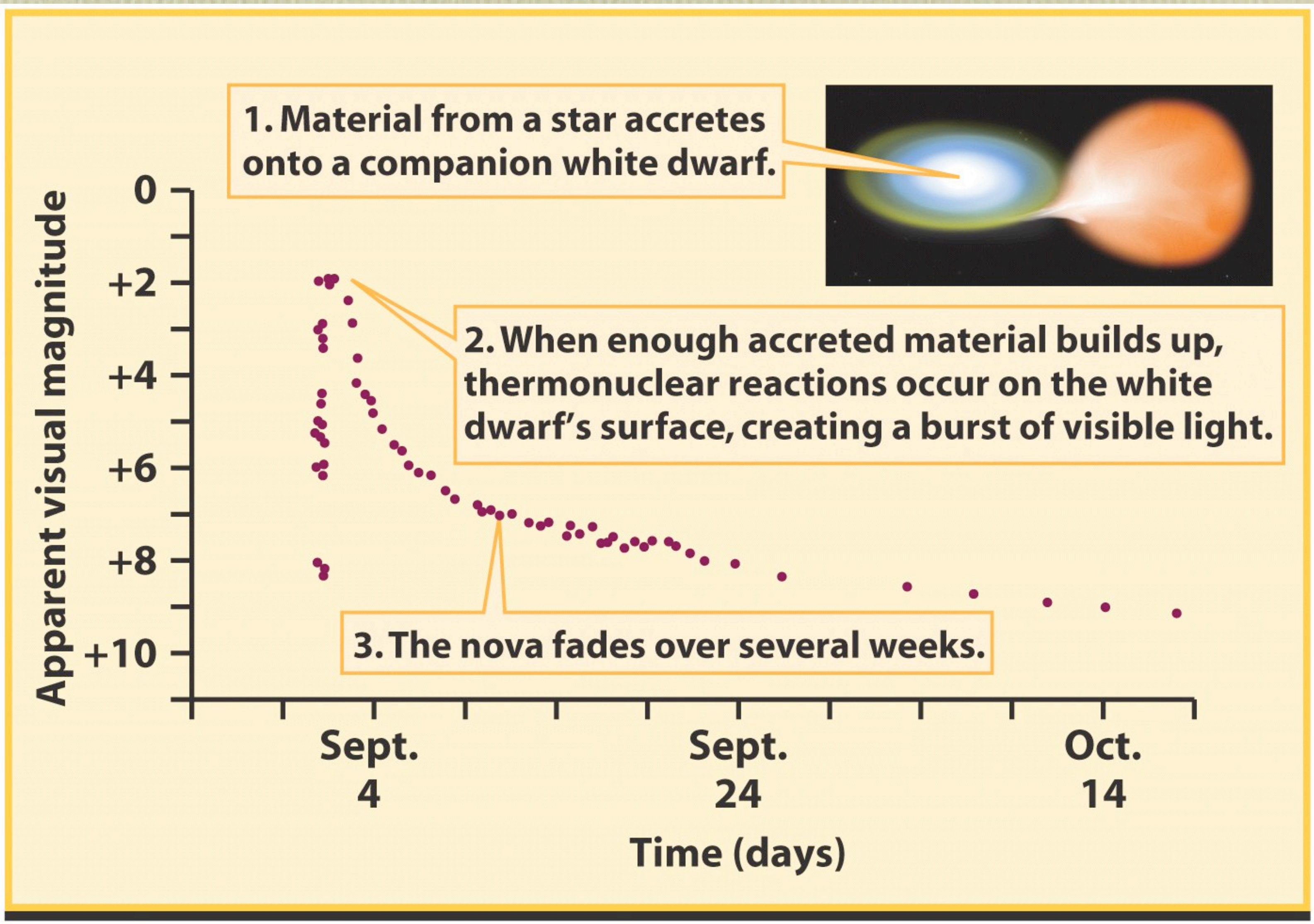

Primary star
Secondary star
L_1
Mass
stream
Hot
spot
Accretion disk
Orbit of secondary about center of mass (×)



(a) Nova Herculis 1934 shortly after peak brightness **(b)** Two months later



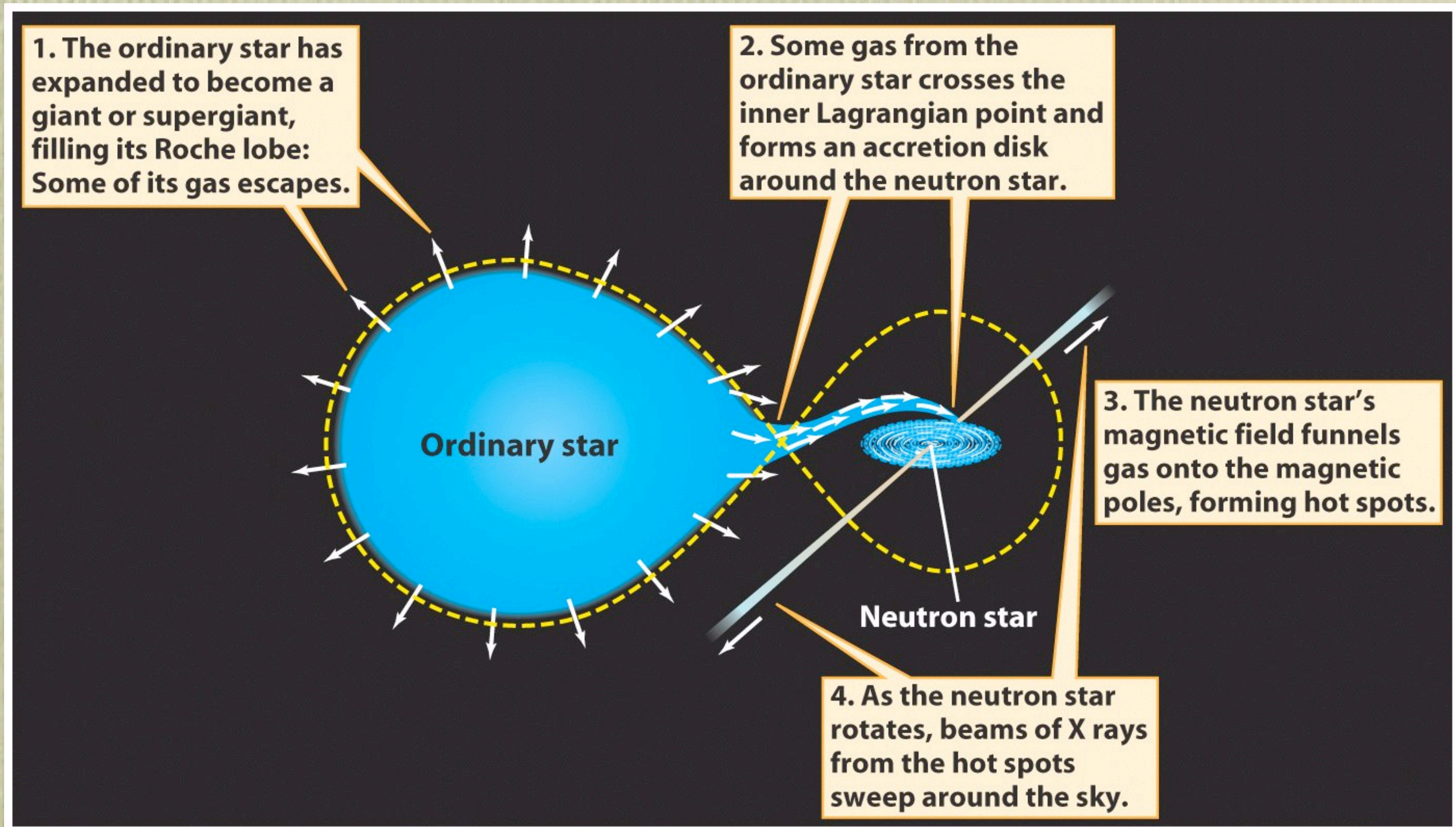


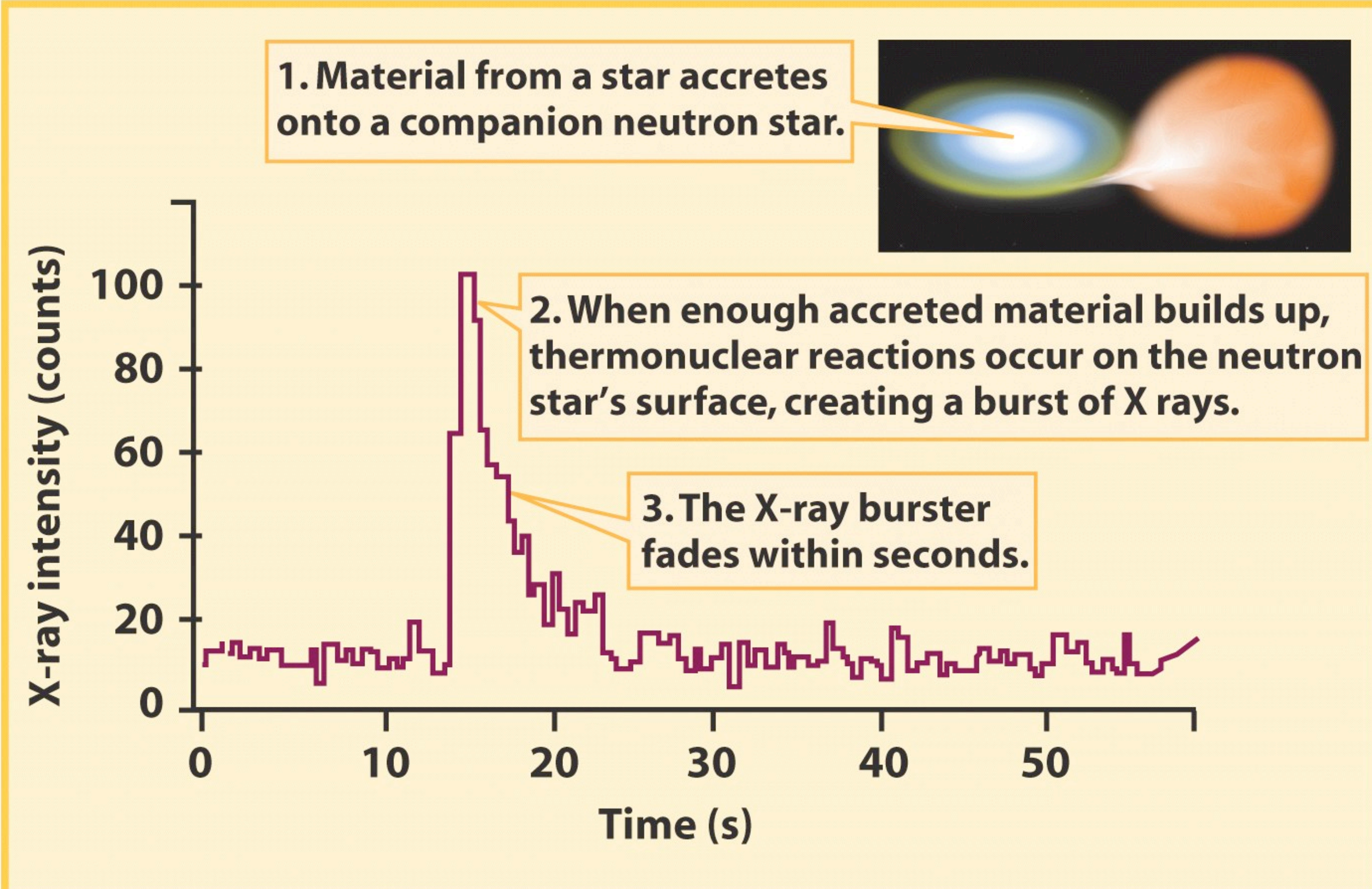


1. Material from a star accretes onto a companion white dwarf.
2. When enough accreted material builds up, thermonuclear reactions occur on the white dwarf's surface, creating a burst of visible light.
3. The nova fades over several weeks.
Apparent visual magnitude
0
+2
+4
+6
+8
+10
Sept. 4
Sept. 24
Oct. 14
Time (days)

Simulation of a nova explosion

Depending upon the accretion rate, accumulating gas can either build up without exploding, explode periodically as a nova, or burn steadily.


1. The ordinary star has expanded to become a giant or supergiant, filling its Roche lobe: Some of its gas escapes.
2. Some gas from the ordinary star crosses the inner Lagrangian point and forms an accretion disk around the neutron star.
Ordinary star
3. The neutron star's magnetic field funnels gas onto the magnetic poles, forming hot spots.
Neutron star
4. As the neutron star rotates, beams of X rays from the hot spots sweep around the sky.


1. Material from a star accretes onto a companion neutron star.
2. When enough accreted material builds up, thermonuclear reactions occur on the neutron star's surface, creating a burst of X rays.
3. The X-ray burster fades within seconds.
X-ray intensity (counts)
0
20
40
60
80
100
0
10
20
30
40
50
Time (s)