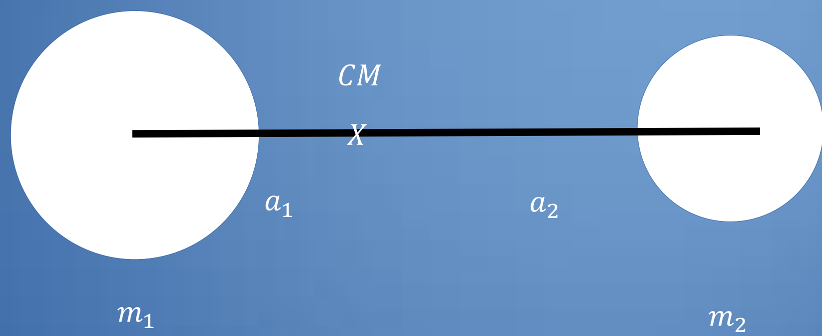
Evolution of binary stars

Outline

- **What is a binary?**
- Mass transfer in binary systems
- Evolution in binary stars
- Late evolutionary states
- MESA

What are binary systems?

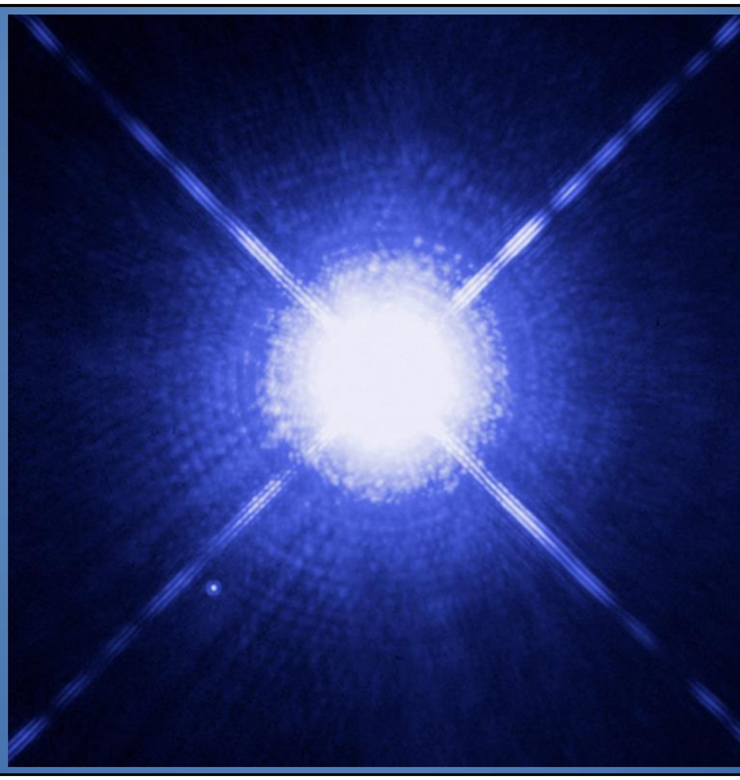


What are binary systems?

- Visual binary

Sirius A & B

- A = MS
- B = WD



Source: www.nasa.gov

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What are binary systems?

- Visual binary
- Spectroscopic binary
  - Single line
  - Double line

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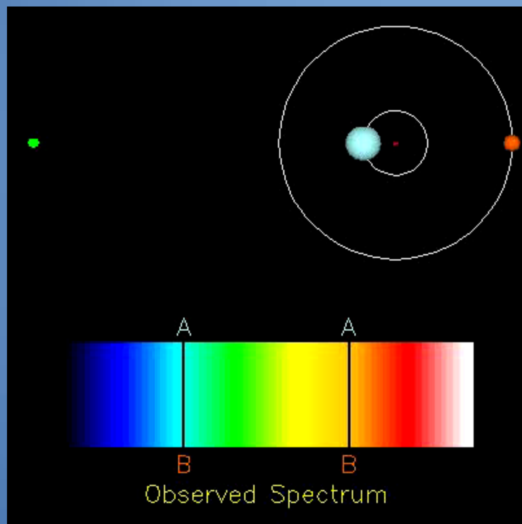
Double line

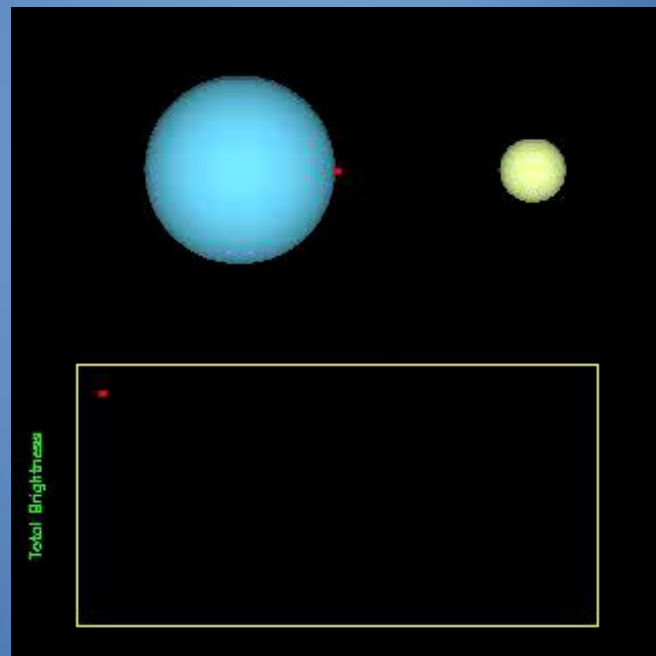


Source: R. Pogge, Ohio State University

What are binary systems?

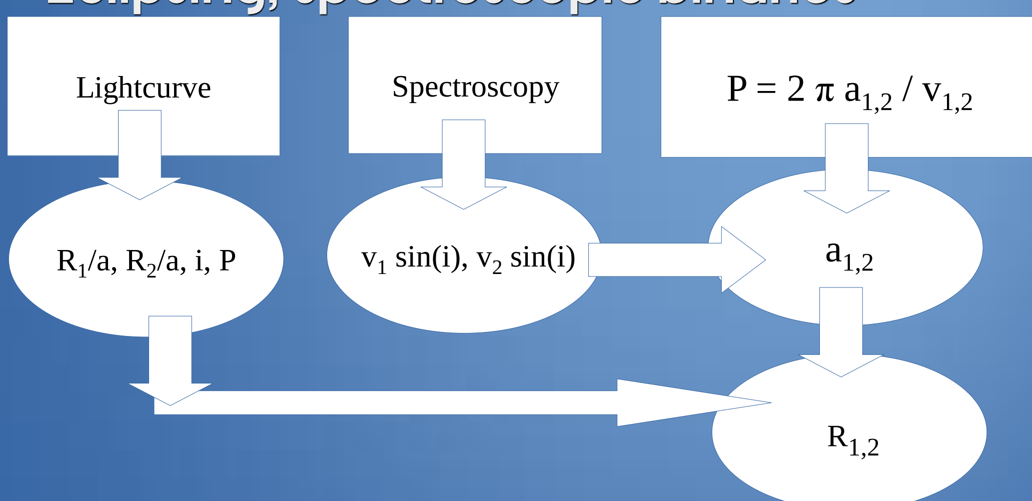
- Visual binary
- Spectroscopic binary
  - Single line
  - Double line
- Photometric binary
  - Eclipsing
  - Non-eclipsing

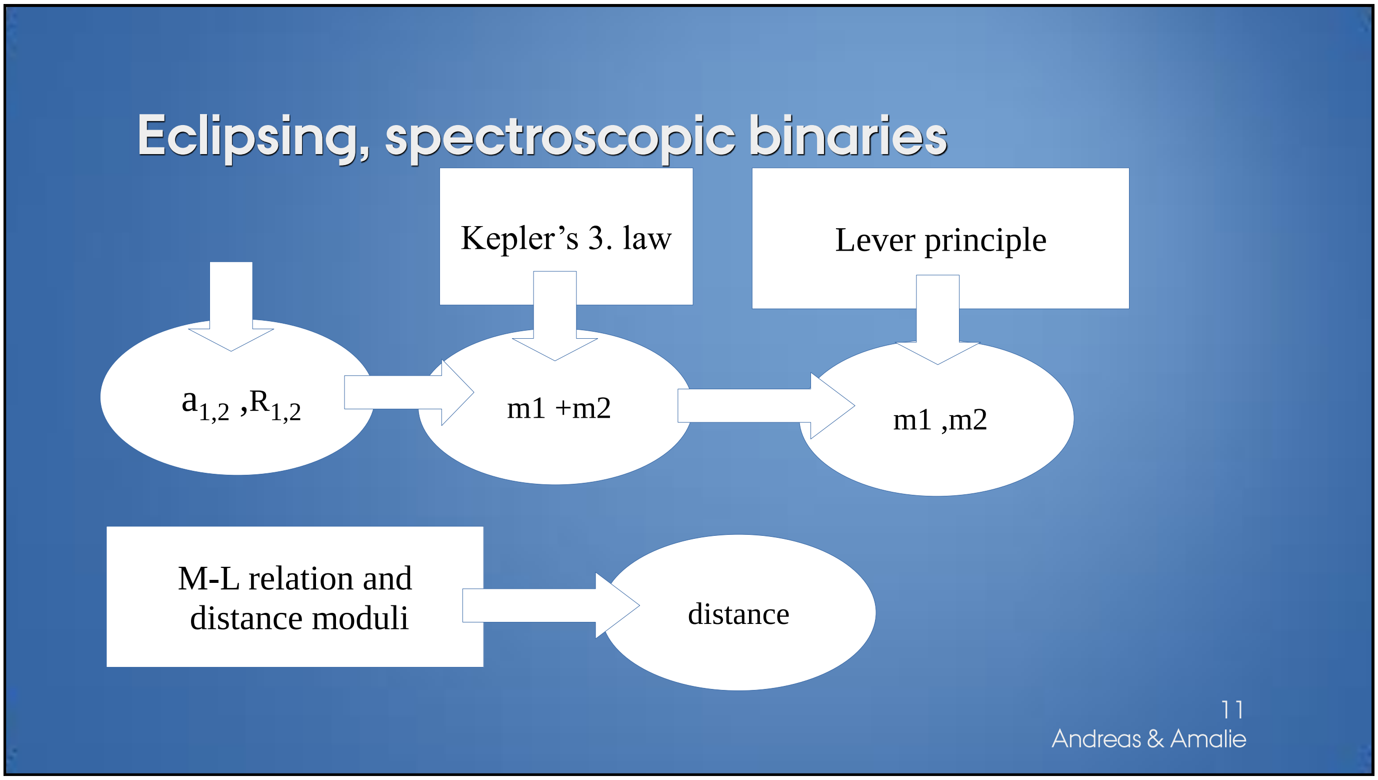
.Eclipsing binary



Source: Nick Risinger @ ESO, www.youtube.com/watch?v=RiopyxtDqw0

Eclipsing, spectroscopic binaries




Eclipsing, spectroscopic binaries
Kepler's 3. law
Lever principle
a1,2 ,R1,2
m1 +m2
m1 ,m2
M-L relation and distance moduli
distance
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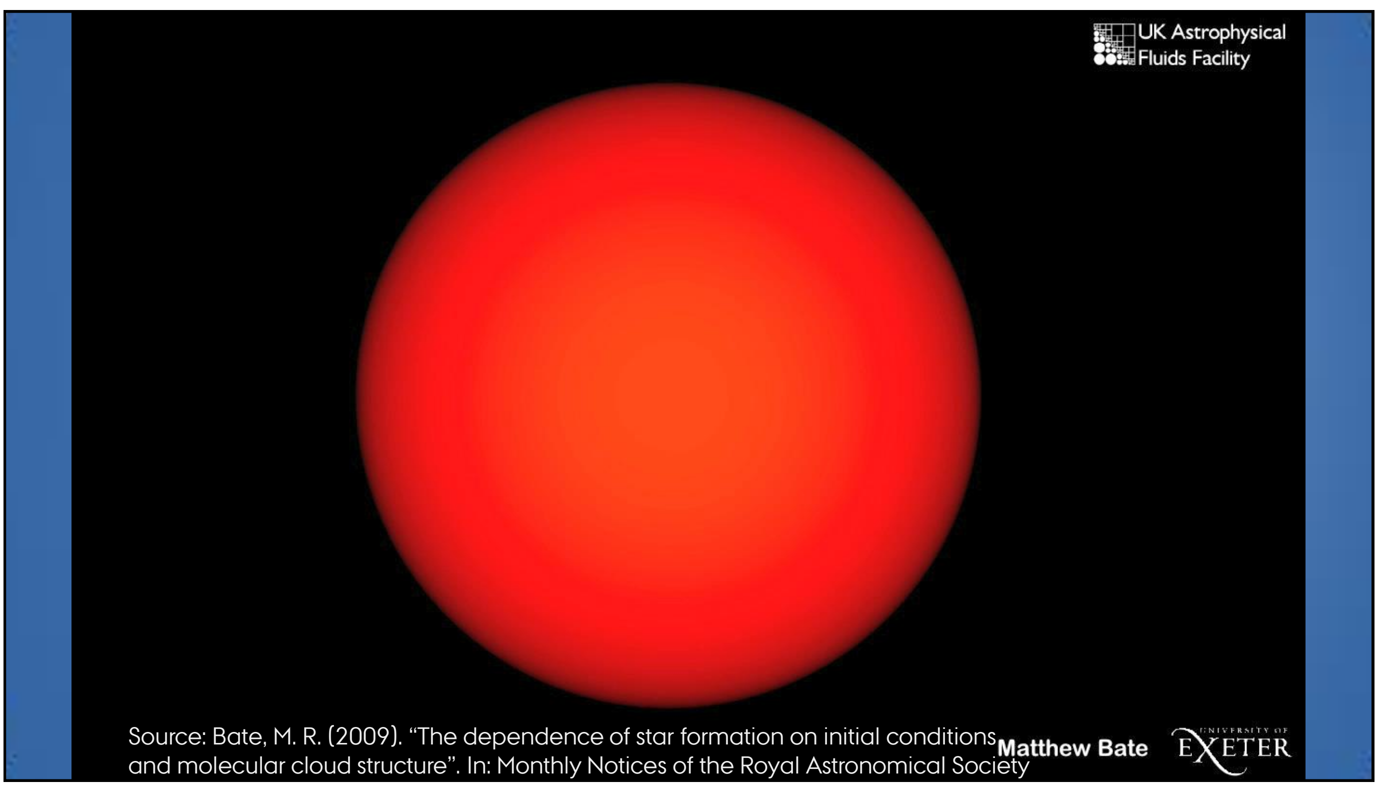
UK Astrophysical Fluids Facility
Source: Bate, M. R. (2009). "The dependence of star formation on initial conditions and molecular cloud structure". In: Monthly Notices of the Royal Astronomical Society
Matthew Bate
UNIVERSITY OF EXETER

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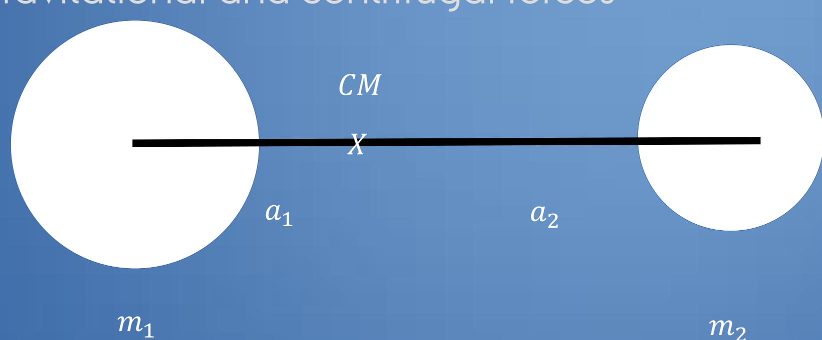
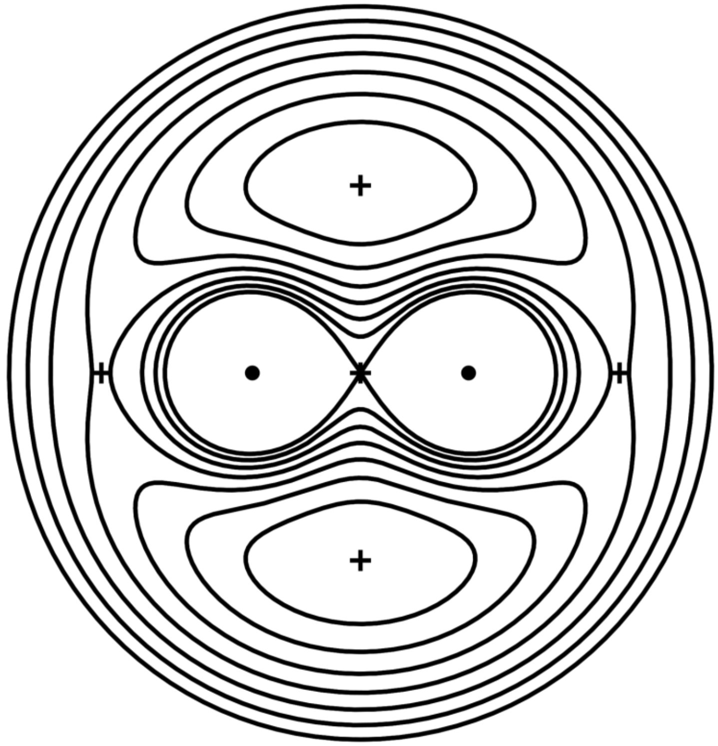
Restrictive three-body problem

- Effective potential
- Gravitational and centrifugal forces



Roche potential

- Point sources
- Circular orbit
- Synchronized stellar rotation
- Co-rotating frame

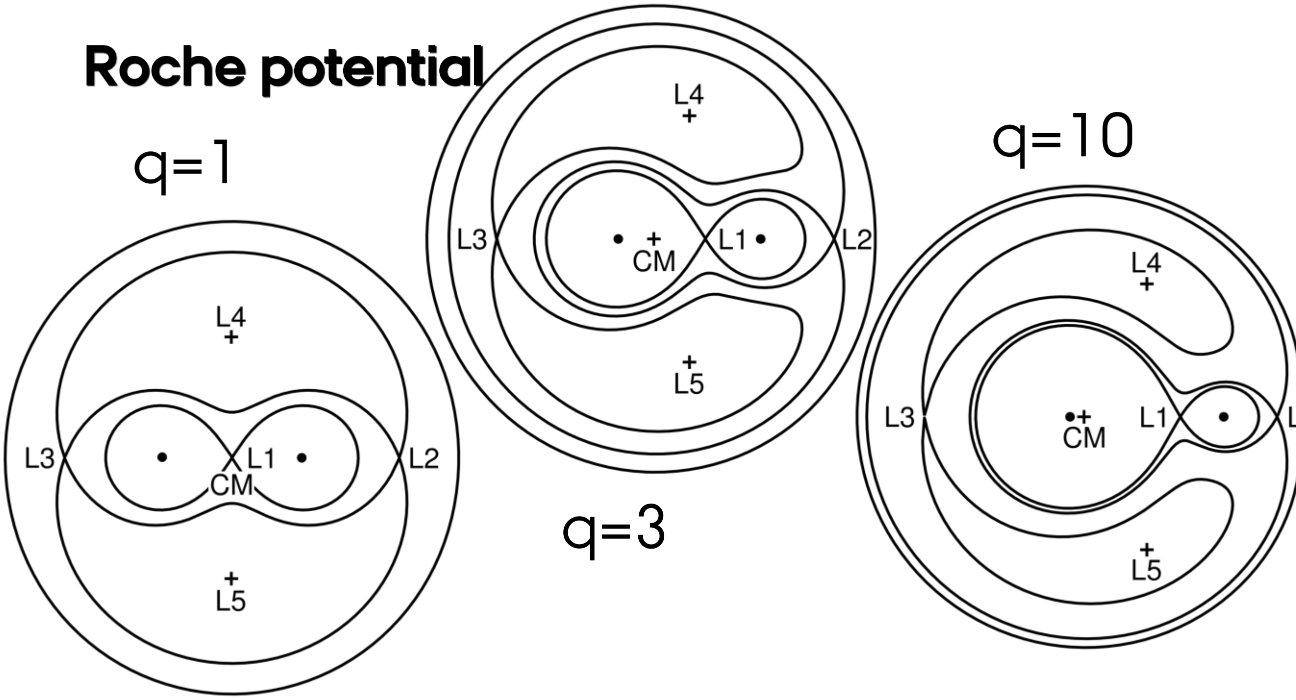


Eggleton formula

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

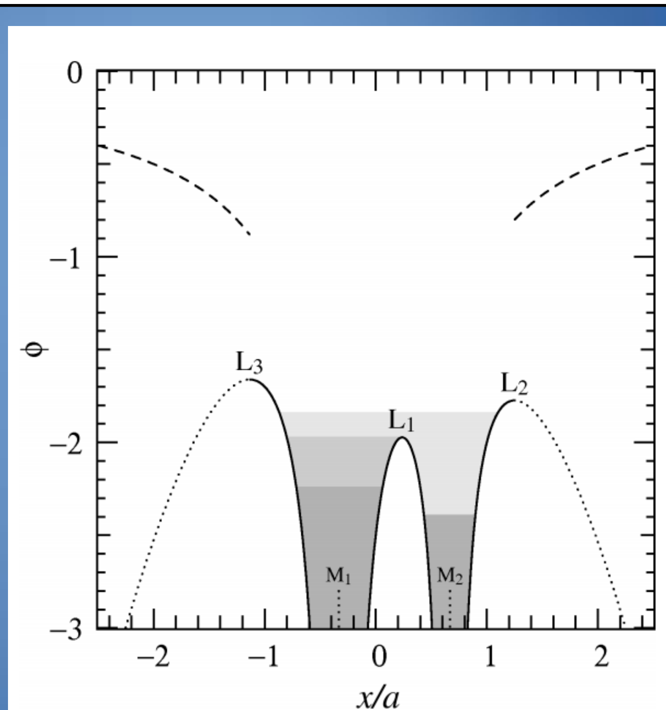
$$q = \frac{m_1}{m_2}$$

Roche potential



Lagrangian points

- q = 2
- Roche Lobe overflow



Source: O. Pols, Lecture notes, Utrecht University,
www.astro.ru.nl/~onnop/education/binaries_utrecht_notes/

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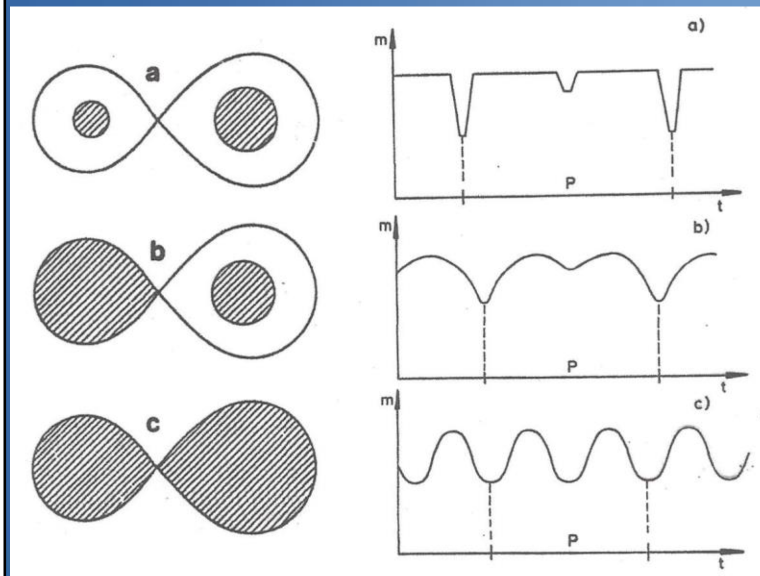
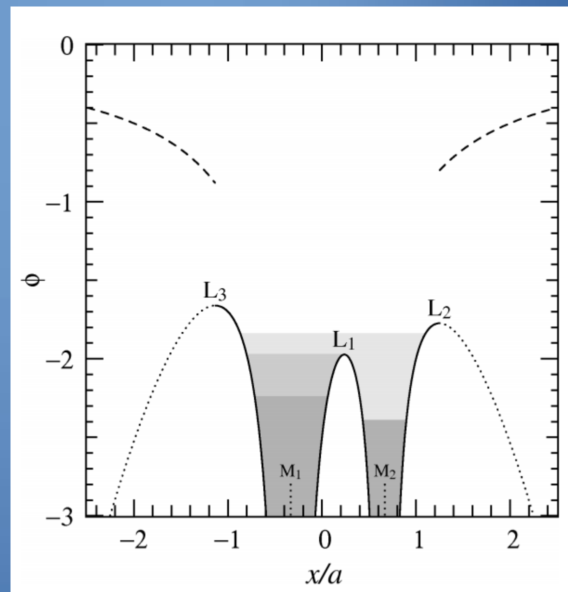
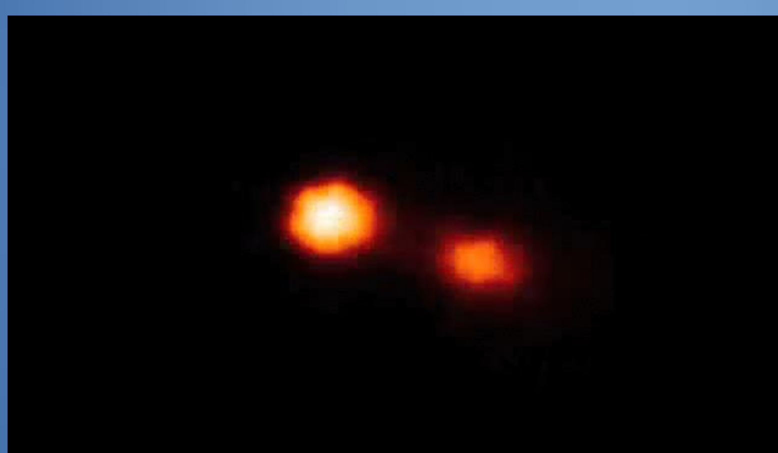
Roche Lobe Overflow



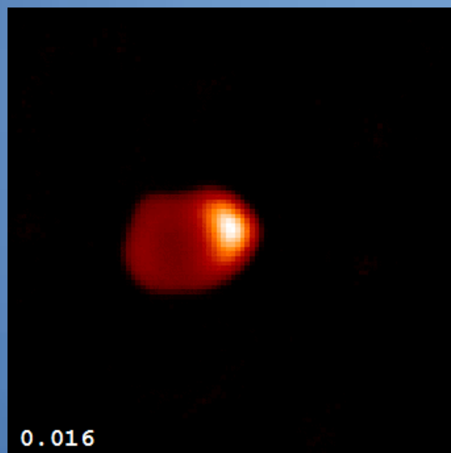


β Lyrae



Source: Zhao et al., *First Resolved Images of the Eclipsing and Interacting Binary β Lyrae*, 2008, ApJL

Algol Paradox

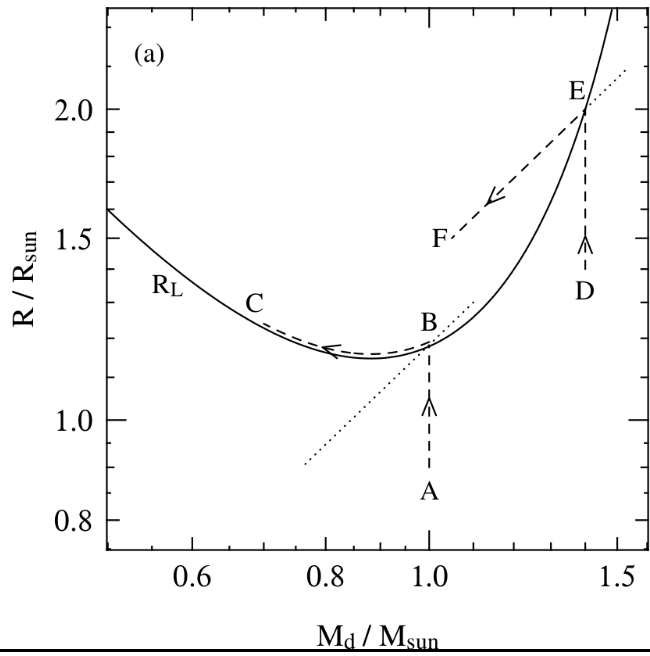


Source: F. Baron et al., *Imaging the Algol Triple System in H Band with the CHARA Interferometer*, 2012, ApJ

Stability of mass transfer

- Stability criteria for donor
- 1) respond of the donor radius to the imposed mass loss
- 2) orbit (R_L) respond to mass transfer
- Orbital evolution
  - Non conservative mass transfer

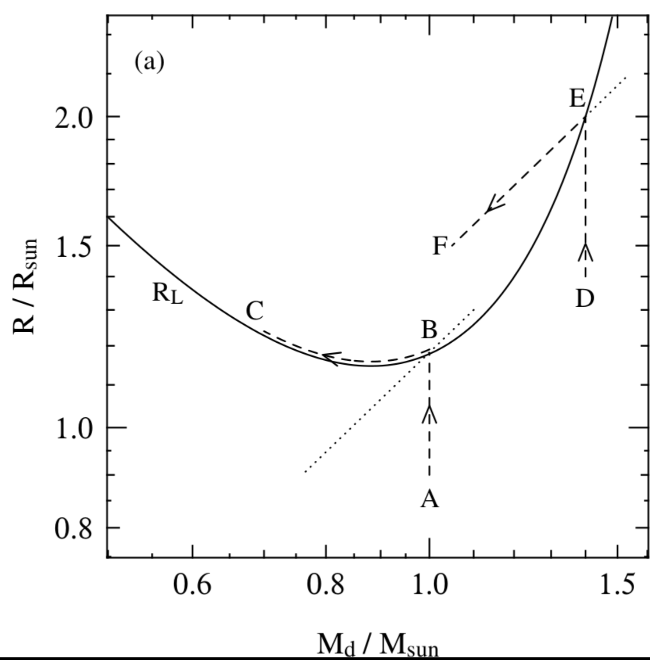
Stability of mass transfer



$$\zeta_* \equiv \frac{d \log R_\mathrm{d}}{d \log m}$$

$$\zeta_\mathrm{L} \equiv \frac{d \log R_\mathrm{L}}{d \log m}$$

Stability of mass transfer



$$\zeta_* \geq \zeta_\mathrm{L}$$

$$\zeta_* < \zeta_\mathrm{L}$$

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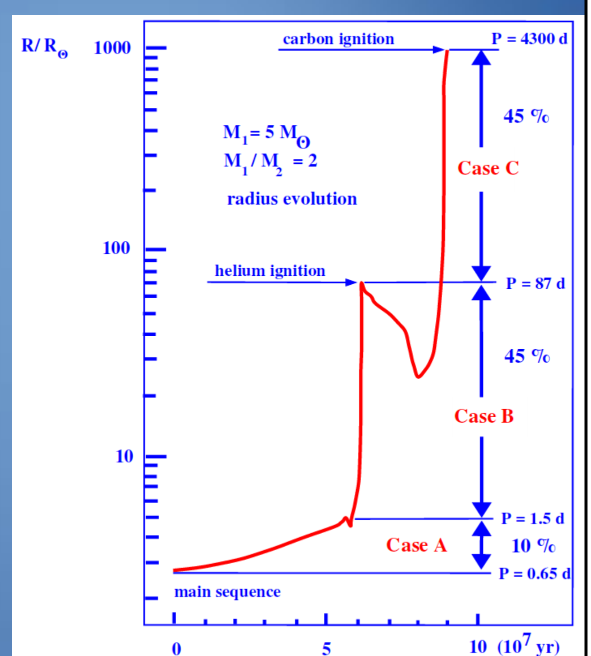
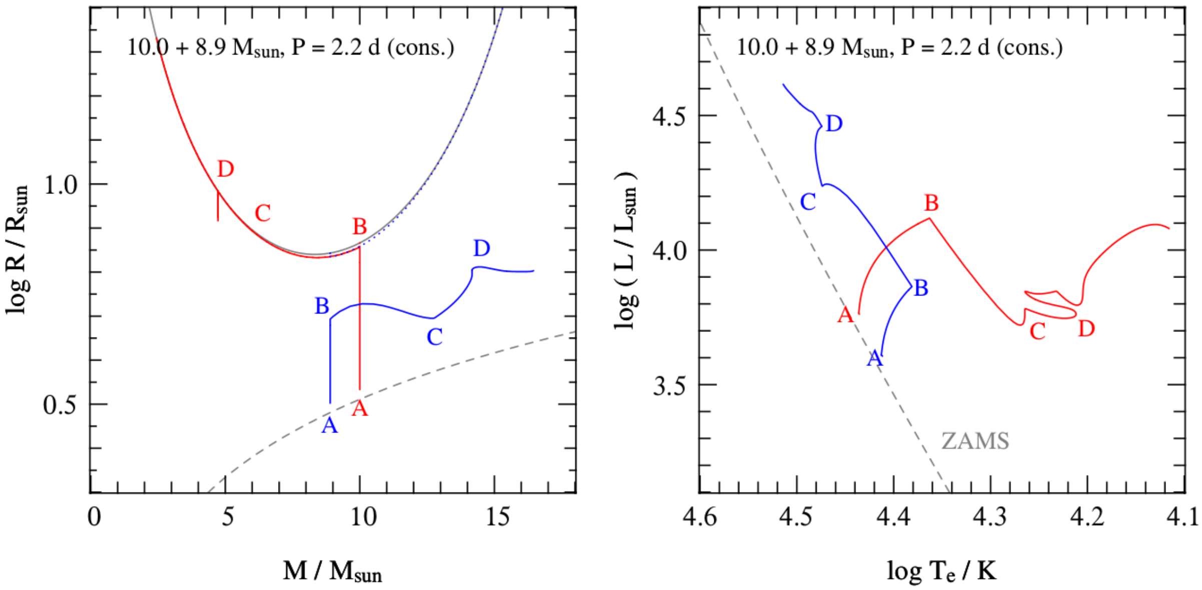
Roche Lobe Overflow

- Case A – Hydrogen core burning
- Case B – Depleted hydrogen core
- Case C – After Helium ignition

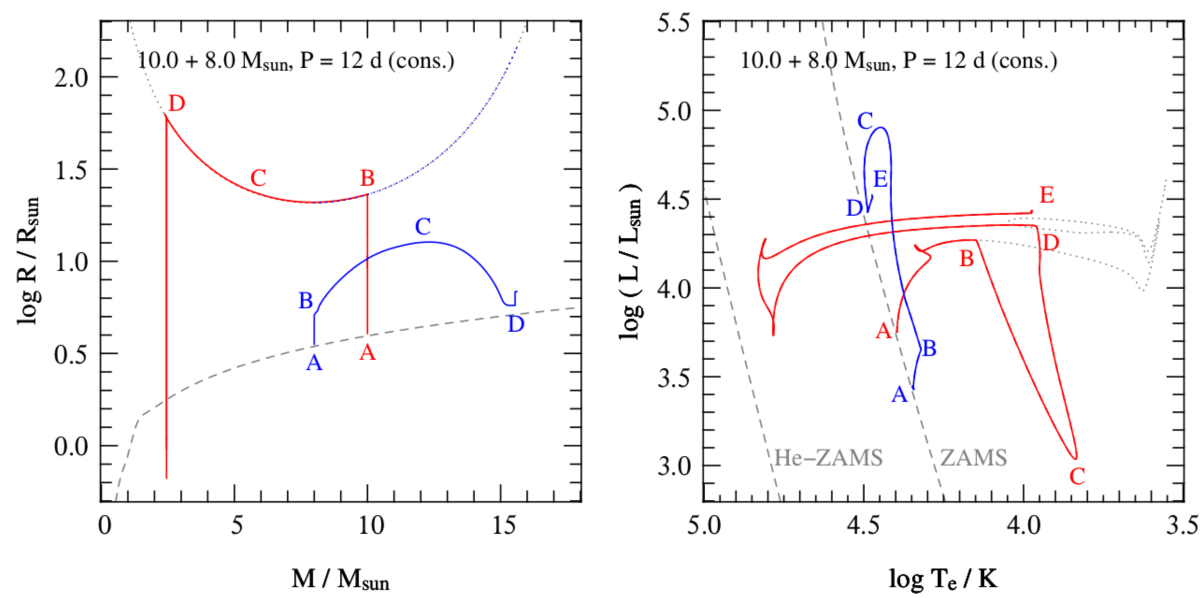


Case A



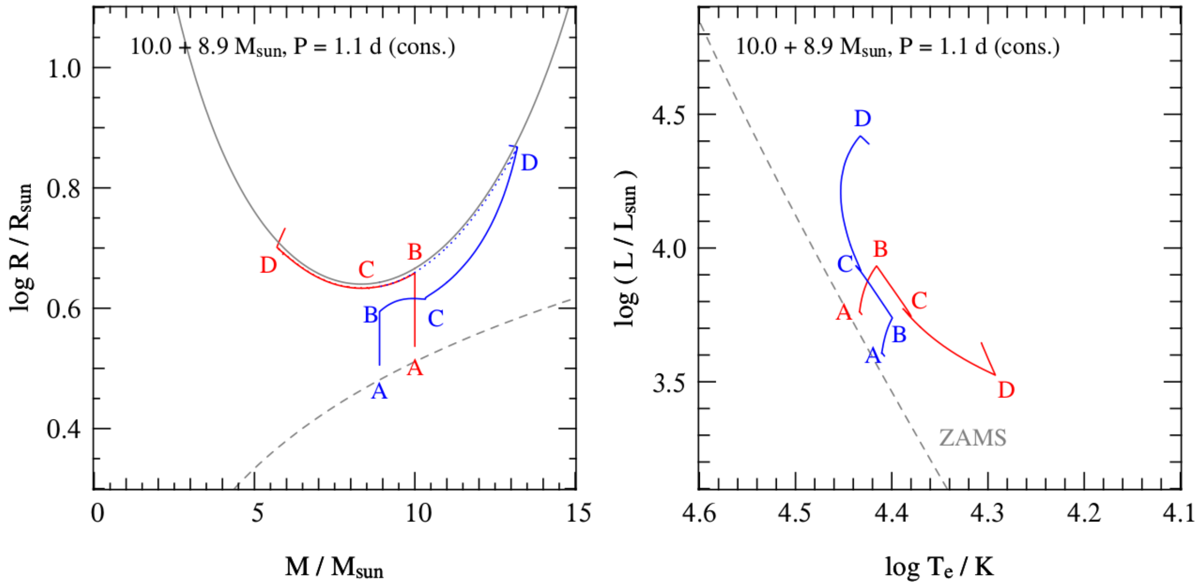
Source: O. Pols, Lecture notes, Utrecht University,
www.astro.ru.nl/~onnop/education/binaries_utrecht_notes/

Case B ("long" period)



Source: O. Pols, Lecture notes, Utrecht University,
www.astro.ru.nl/~onnop/education/binaries_utrecht_notes/

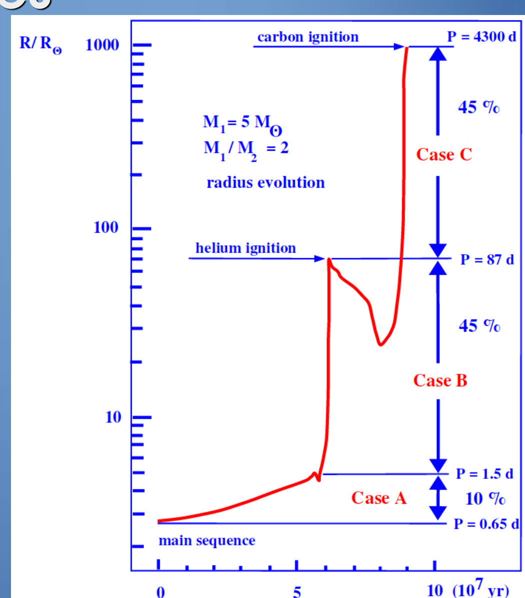
Case B ("short" period)



Source: O. Pols, Lecture notes, Utrecht University, www.astro.ru.nl/~onnop/education/binaries_utrecht_notes/

Roche-Lobe overflow Cases

- Case A – Hydrogen core burning
- Case B – Depleted hydrogen core
- Case C – After Helium ignition



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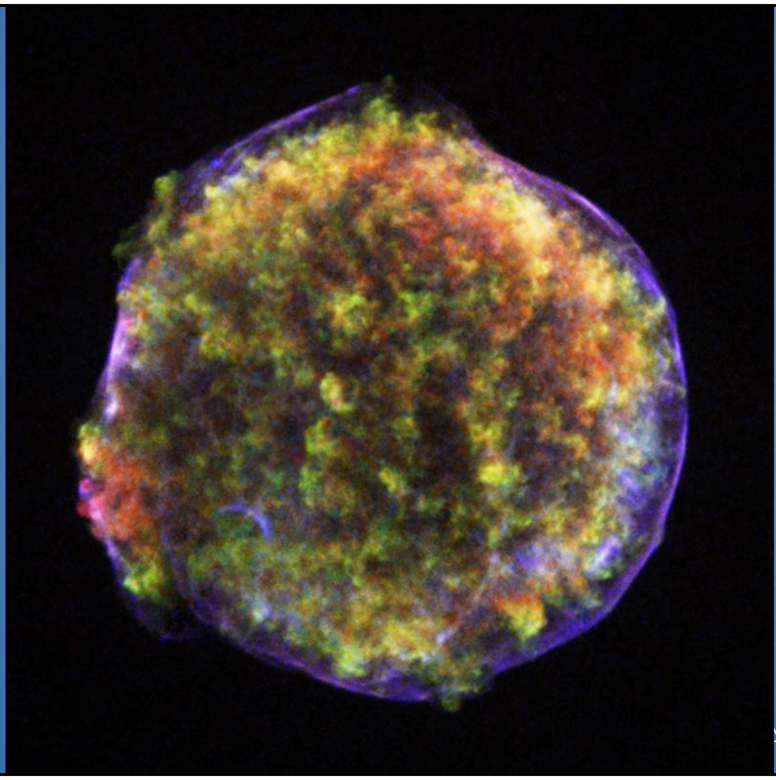

Type 1A Supernova

- M_{wd}< 1.44 solar masses
- Core reaches ignition T for carbon fusion
- energy (10^{51} erg)
- M_v = −19.3

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Single degenerate

- Close binary system
- WD – MS/RG

Source: ESO, www.youtube.com/watch?v=5YZkAoR3WLE,

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Double degenerate

- WD-WD
- One every 100 years

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.Double-degenerate white-dwarf merger

Original source: http://www.eso.org/public/videos/eso1505a/

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Summary

- Binaries are two stars gravitationally bound to one another, orbiting there common barycenter
- Using the Roche potential, the most important way mass-transfer can be described: Roche Lobe Overflow
- RLOF depends radius of star compared to the Roche radius.
- Mass transfer changes the evolutionary path of the stars
- Binaries are progenitors for Type 1A SNe

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