Institut d'Astronomie et
d'Astrophysique de l'ULB

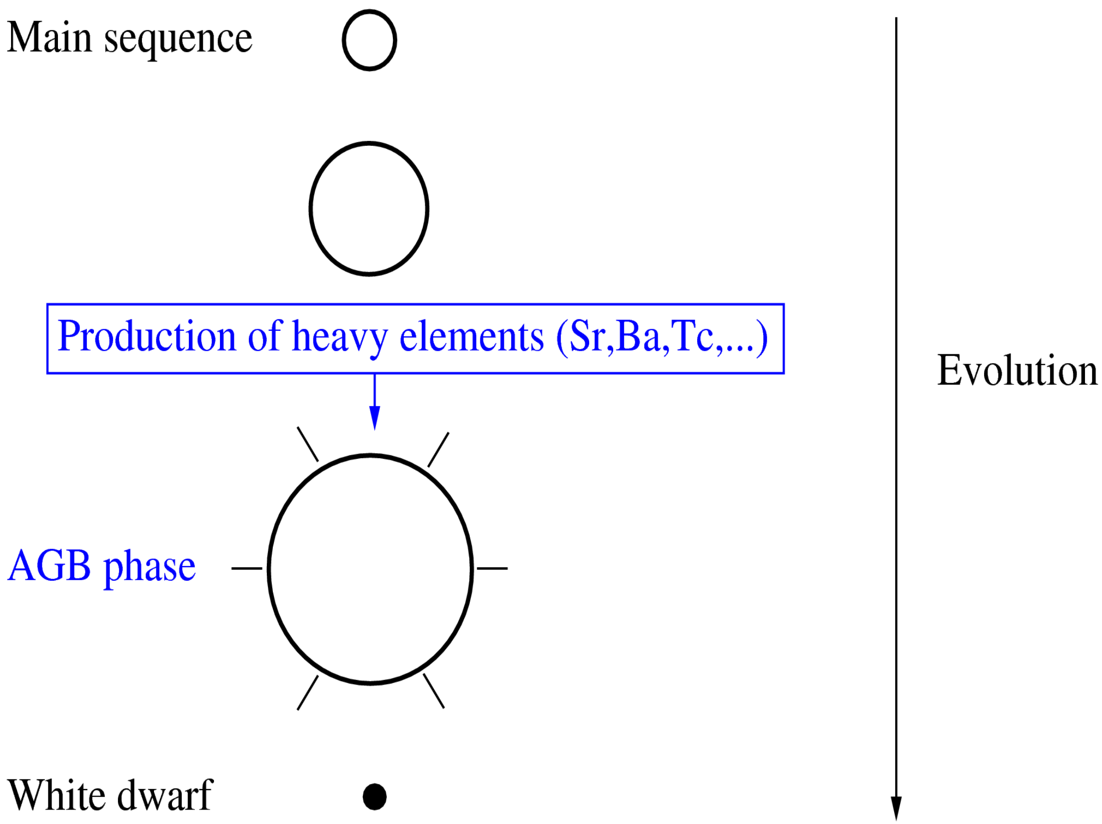
Contact Group
Meeting

RLOF stability revisited
in case of AGB star mass loss

Dermine Tyl
PhD student since October 2007

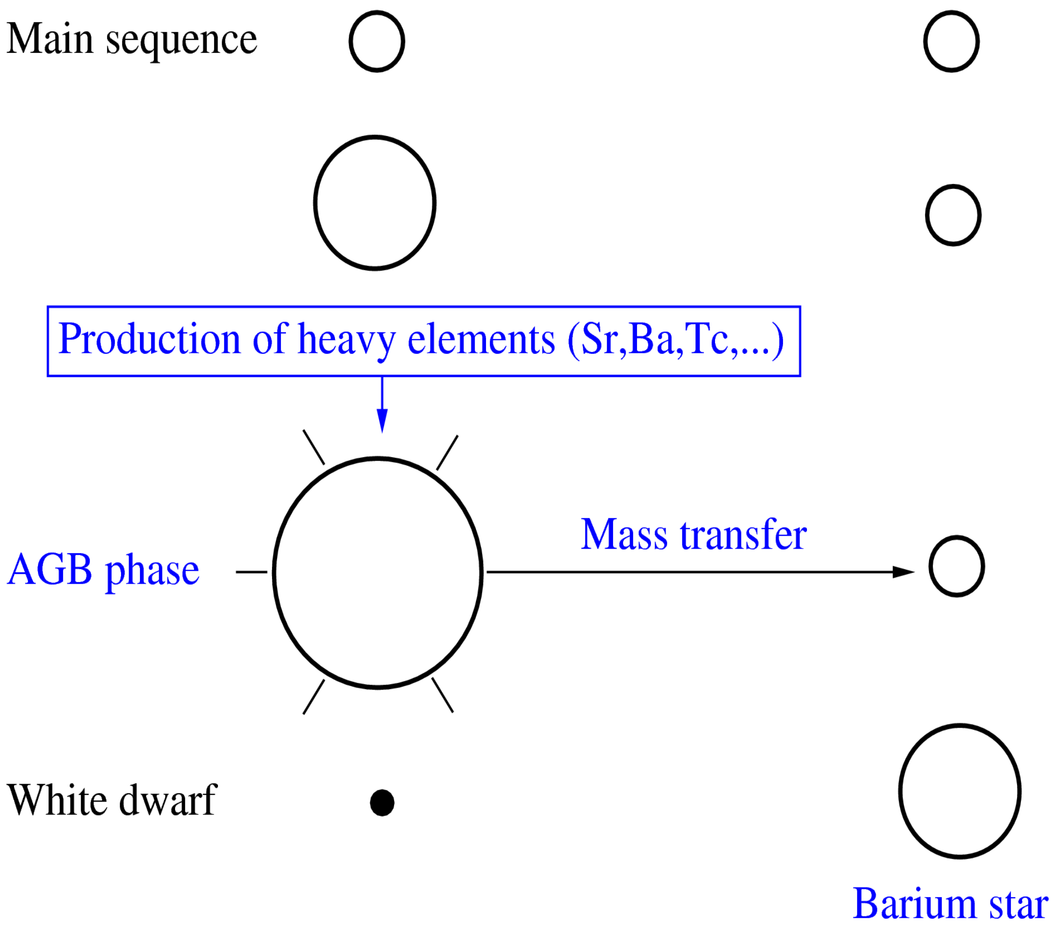
Promotor: A. Jorissen
Co-promotor: L. Siess

The post-mass transfer systems



- The AGB stars present a mass loss by wind.

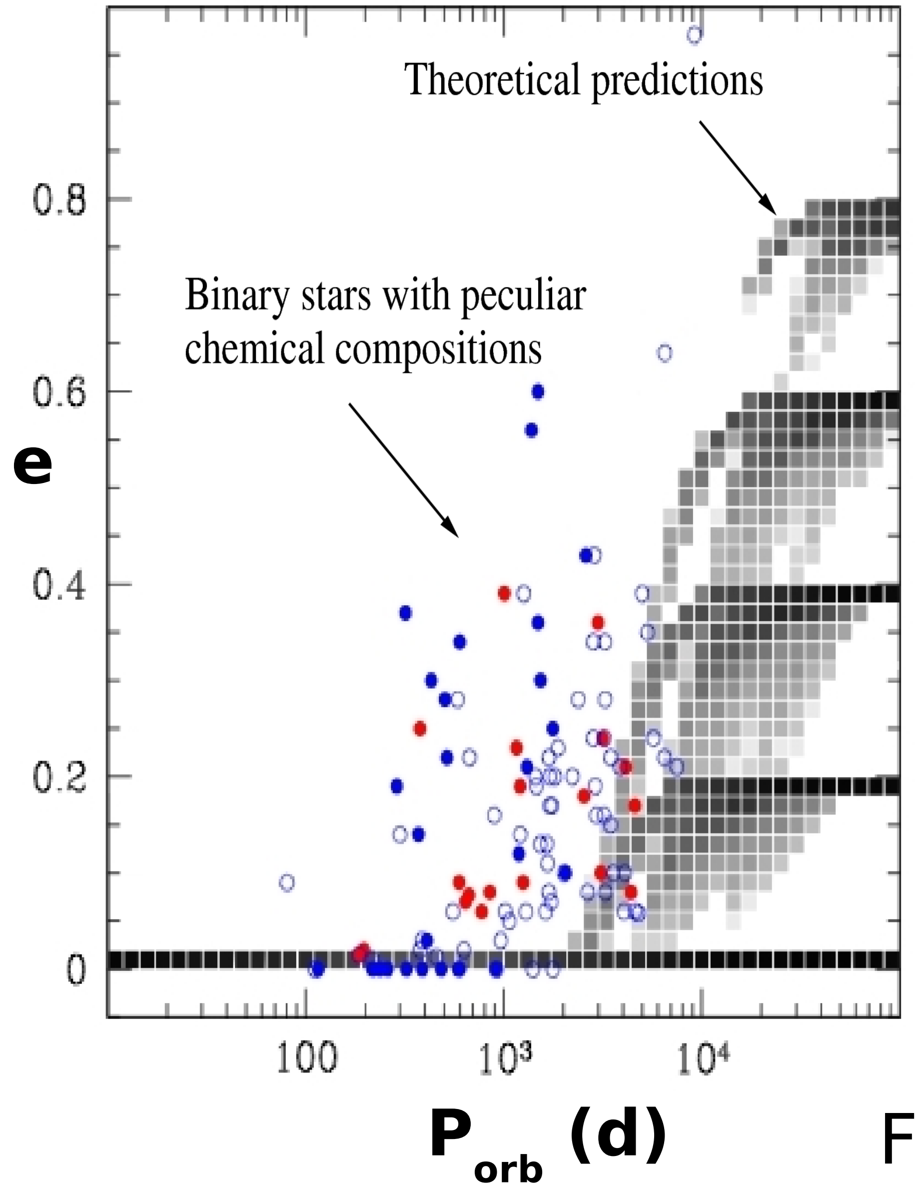
The post-mass transfer systems



- The AGB stars present a mass loss by wind.

→ Accounts for the C and Ba "et al." enrichment of some non-AGB stars in post-mass transfer binaries.

The e-log P_{orb} diagram



Frankowski (2007)

- AGB mass loss, mass transfer and tidal effect lead the orbital evolution of binaries.

But the orbital characteristics of many systems resist to the explanation by current theoretical models.

PhD Project

- Simulate the evolution of orbital elements of binary systems by a theoretical model, the "Transient torus" (Frankowski & Jorissen 2007), which include:

  - Tidal effects
  - Mass transfer
    - by wind accretion
    - by RLOF
  - Pulsation of star
  - Disk-orbit interaction

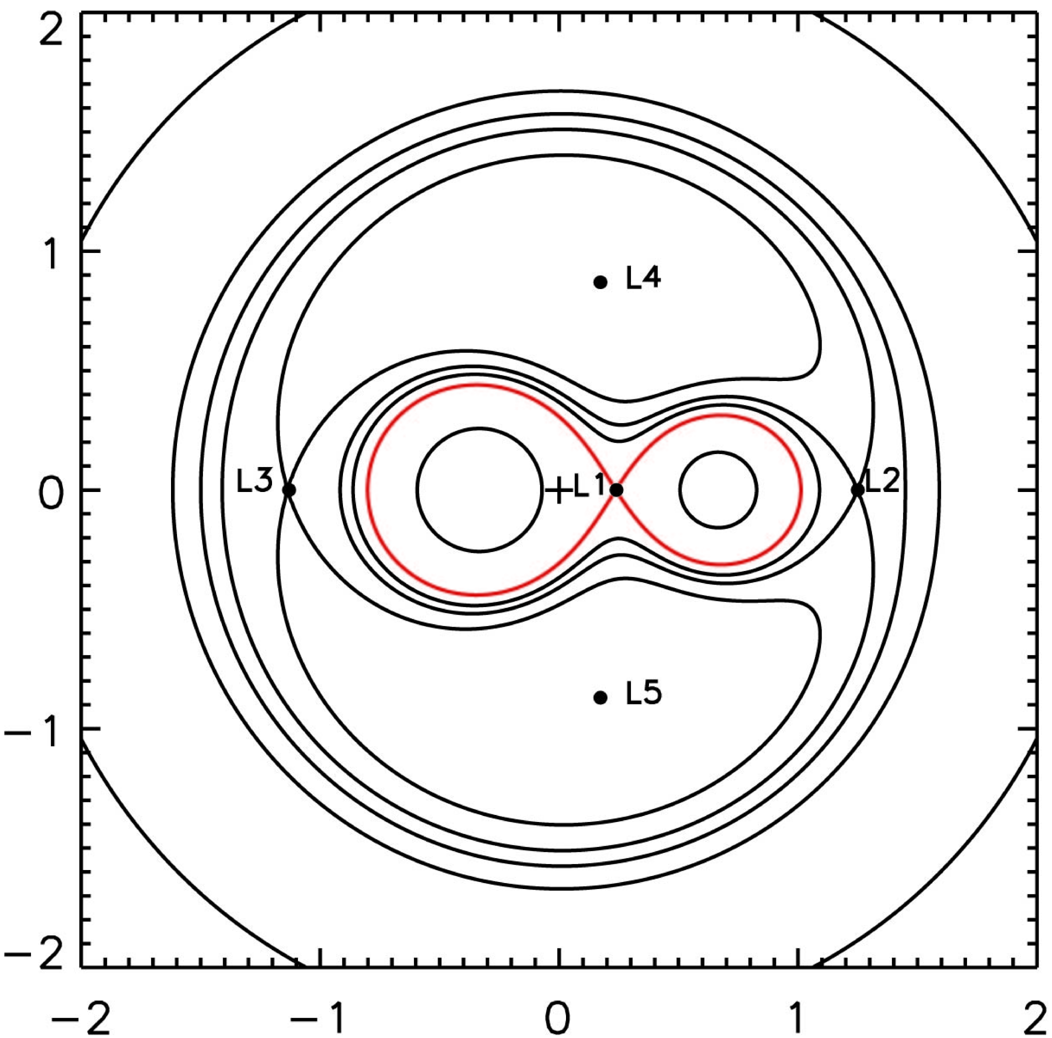
PhD Project

- Simulate the evolution of orbital elements of binary systems by a theoretical model, the "Transient torus" (Frankowski & Jorissen 2007), which include:
  - Tidal effects
  - Mass transfer
    - by wind accretion
    - by RLOF
  - Pulsation of star
  - Disk-orbit interaction
- Observational hints:
  - Large spin of the companion:
    56 Peg (Frankowski & Jorissen 2006), HD 165141 (Jorissen et al. 1996), ...
  - Presence of a circumbinary disk:
    (Van Winckel 2003)

PhD Project

- Simulate the evolution of orbital elements of binary systems by a theoretical model, the "Transient torus" (Frankowski & Jorissen 2007), which include:
  - Tidal effects
  - Mass transfer
    by wind accretion
    by **RLOF**
  - Pulsation of star
  - Disk-orbit interaction

Roche potential



- In the case of circular orbits in corotation, the effective potential is given by:

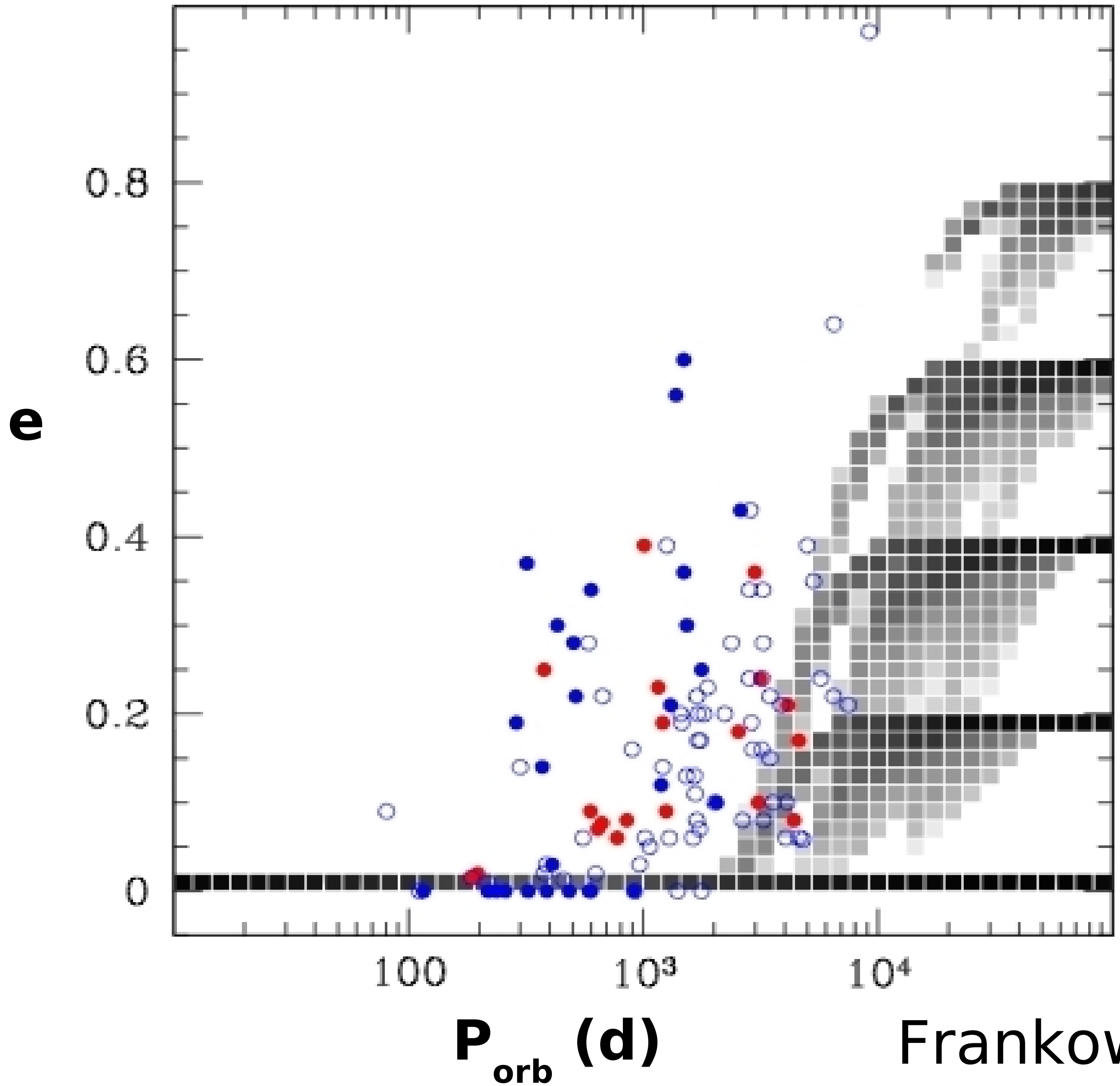
$$\Phi = -\frac{\mu}{r_1} - \frac{1-\mu}{r_2} - \frac{x^2+y^2}{2}$$

where $\mu = \frac{M_{AGB}}{M_{AGB}+M_2}$

$$r_1 = \sqrt{(x+1-\mu)^2 + y^2 + z^2}$$

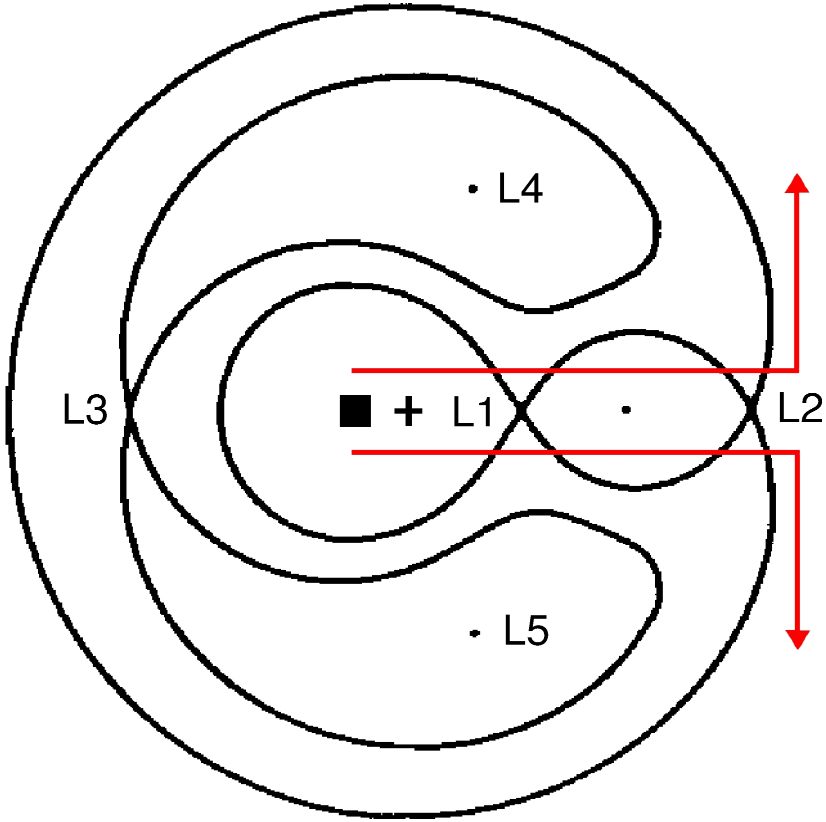
$$r_2 = \sqrt{(x-\mu)^2 + y^2 + z^2}$$

The e–log P_{orb} diagram



Frankowski (2007)

Modified Roche potential



Schuerman (1972)

- By taking the radiation pressure on dust into account and the gaz/grains coupling:

$$f = \frac{Radiation\ force}{Gravitational\ attraction}$$

$$\Phi = -\frac{\mu(1-f)}{r_1} - \frac{1-\mu}{r_2} - \frac{x^2+y^2}{2}$$

where

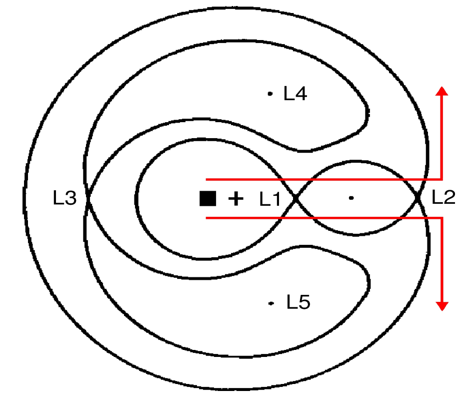
$$\mu = \frac{M_{AGB}}{M_{AGB}+M_2}$$

$$r_1 = \sqrt{(x+1-\mu)^2+y^2+z^2}$$

$$r_2 = \sqrt{(x-\mu)^2+y^2+z^2}$$

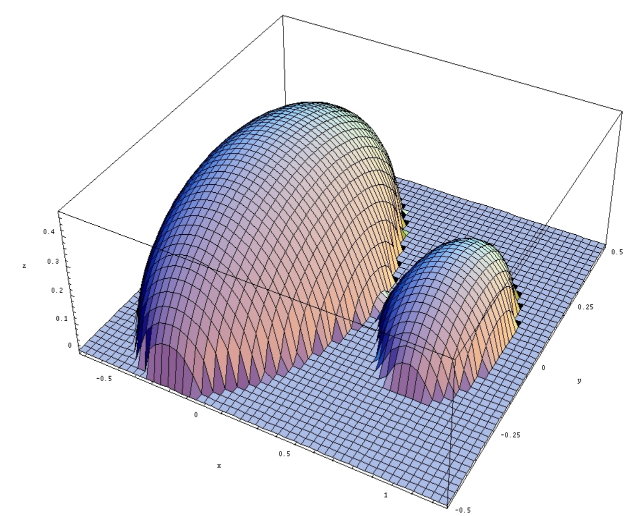
Roche radius $R_R(q,f)$

- $f = \dfrac{\textit{Radiation force}}{\textit{Gravitational attraction}}$



$$\longrightarrow \quad \phi = -\frac{\mu(1-f)}{r_1} - \frac{(1-\mu)}{r_2} - \frac{x^2+y^2}{2}$$

- Roche volumes for $q=\left(\dfrac{M_{AGB}}{M_2}\right) \in [0,\infty]$ and $f \in [0,1]$:



$$\frac{R_R(q,f)}{a} = \frac{A(f)\,q^{2/3}}{B(f)\,q^{2/3} + \log\left(1 + C(f)\,q^{1/3}\right)}$$

$$C(f) = 1 + f$$

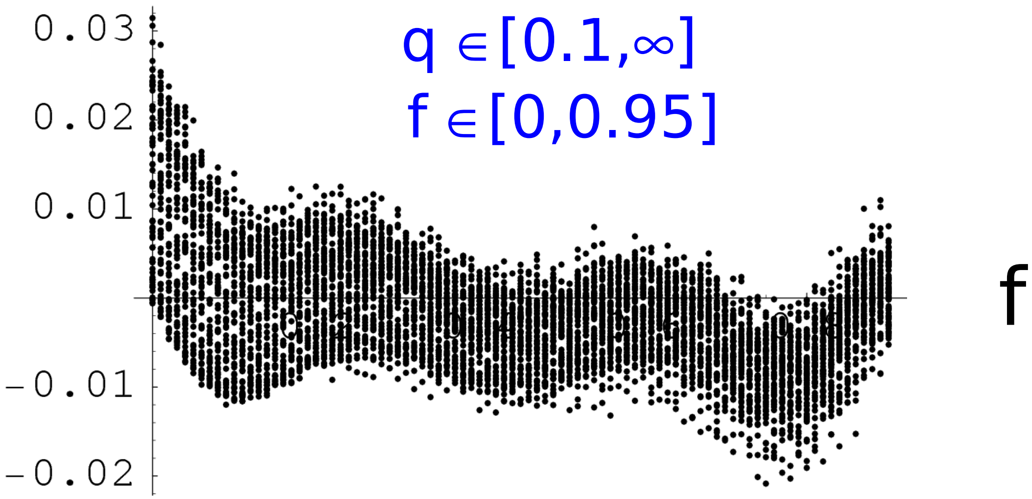
$$B(f) = 0.6(1 + 1/2 f)$$

$$A(f) = 0.49 + 0.08 f - 0.69 f^2 + 12.81 f^3 - 75.50 f^4 + 208.14 f^5 - 300.60 f^6 + 219.70 f^7 - 64.27 f^8$$

Precision of $R_R(q,f)$

- Numerical values are approximated by $R_R(q,f)$, to better than 3% over the range $q \in [0.1,\infty]$ & $f \in [0,0.95]$

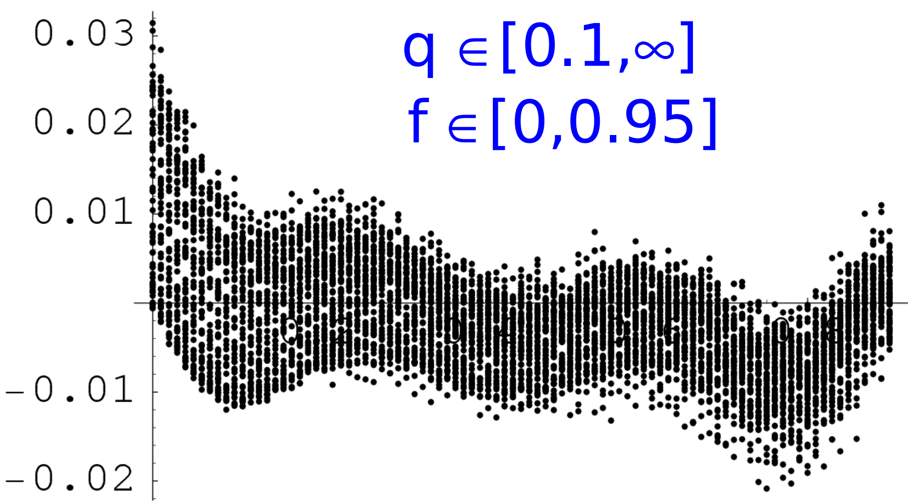
Relative Error



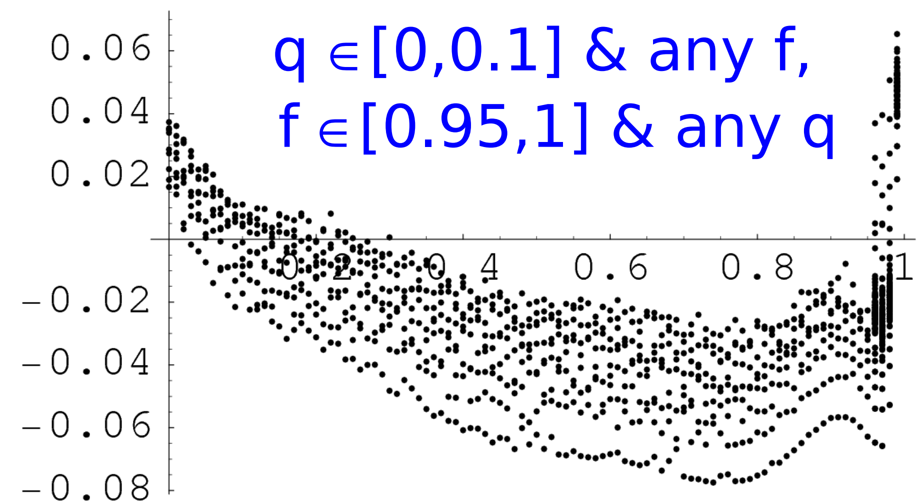
Precision of $R_R(q,f)$

- Numerical values are approximated by $R_R(q,f)$, to better than 3% over the range $q \in [0.1,\infty]$ & $f \in [0,0.95]$

Relative Error



Relative Error

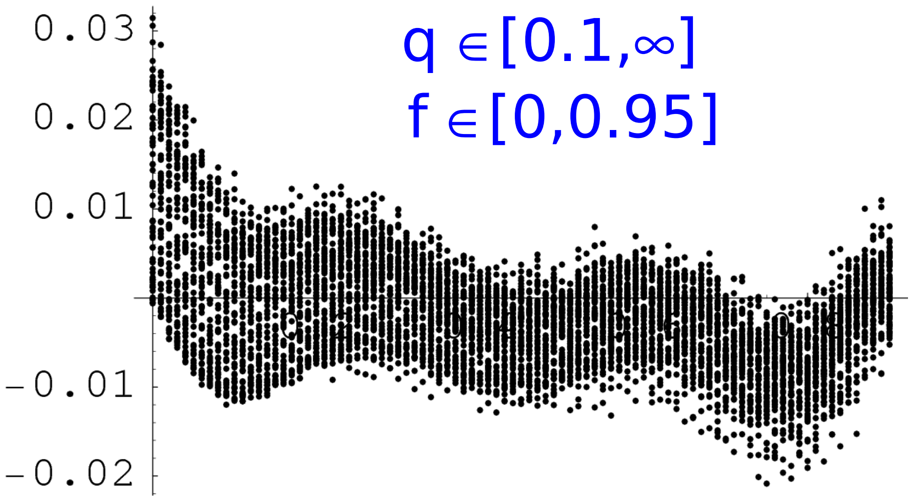


f

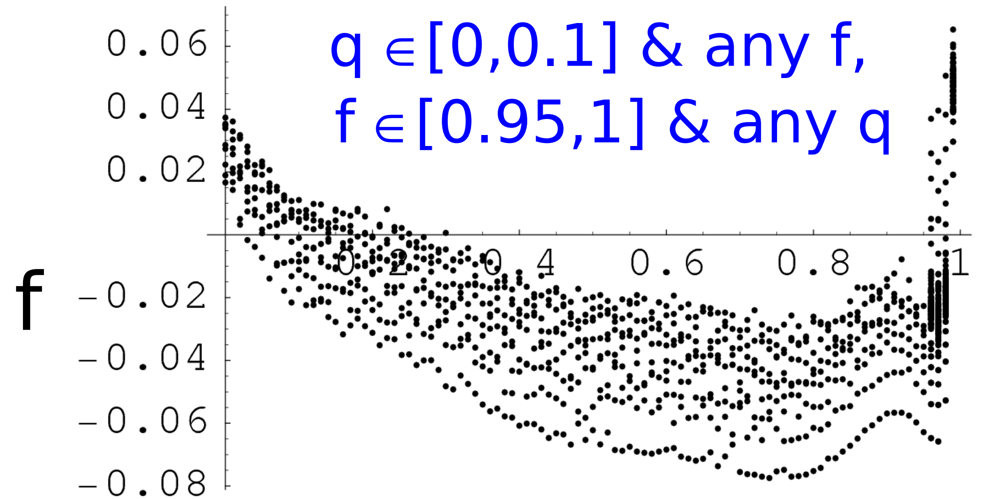
Precision of $R_R(q,f)$

- Numerical values are approximated by $R_R(q,f)$, to better than 3% over the range $q \in [0.1,\infty]$ & $f \in [0,0.95]$

Relative Error



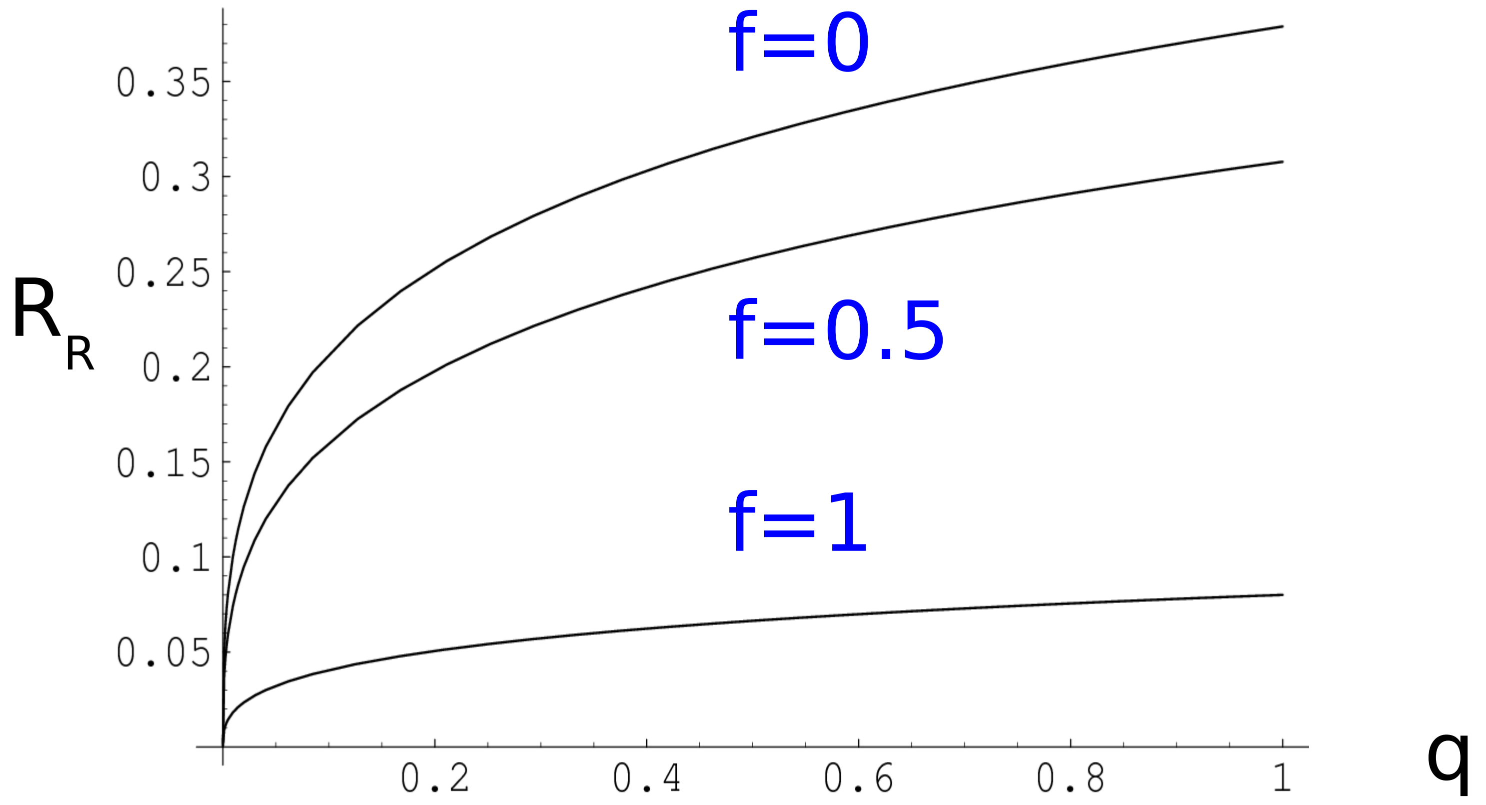
Relative Error



- $R_R(q,f=0) = R_R$ from Eggleton (1983)

Roche radius $R_R(q,f)$

- R_R ↘ by a factor ~5 from f=0 to f=1.



→ Important modifications of the binary evolution

Astrophysics application

1. R_R ↘ by a factor ~5 from f=0 to f=1.

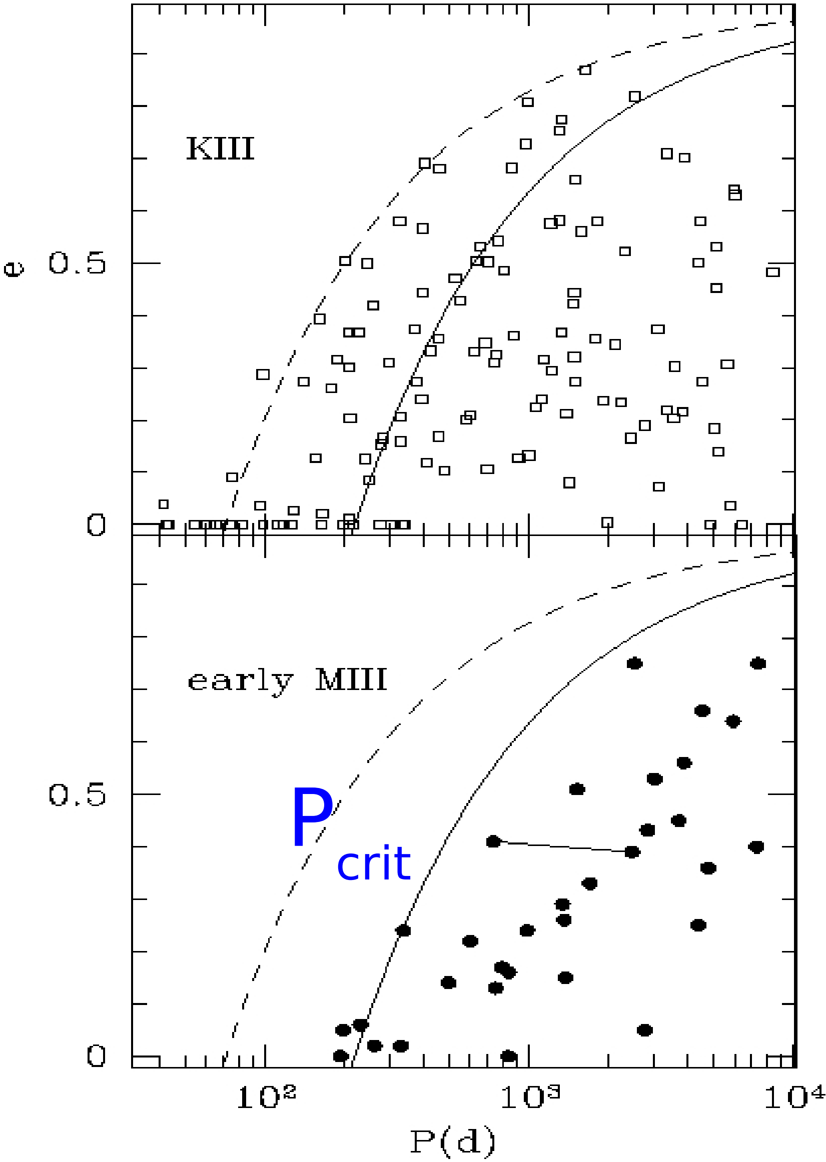
→ could be a solution for the too high predicted Roche radius of some symbiotic stars (Mikolajewska (2007)):

Ellipsoidal variations only if $R/R_R > 0.8$

Mikolajewska find $R/R_R = 0.5$

Astrophysics application

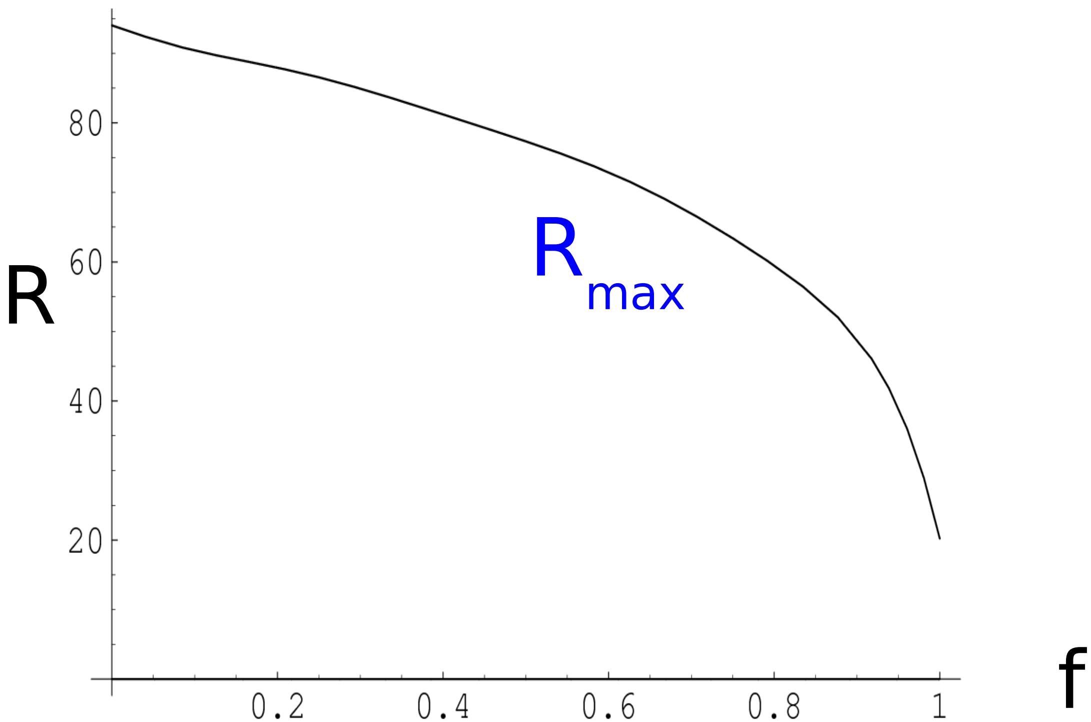
2. P_{crit}, the period below which the RLOF appears, ↗ by a factor ~10 from f=0 to f=1.



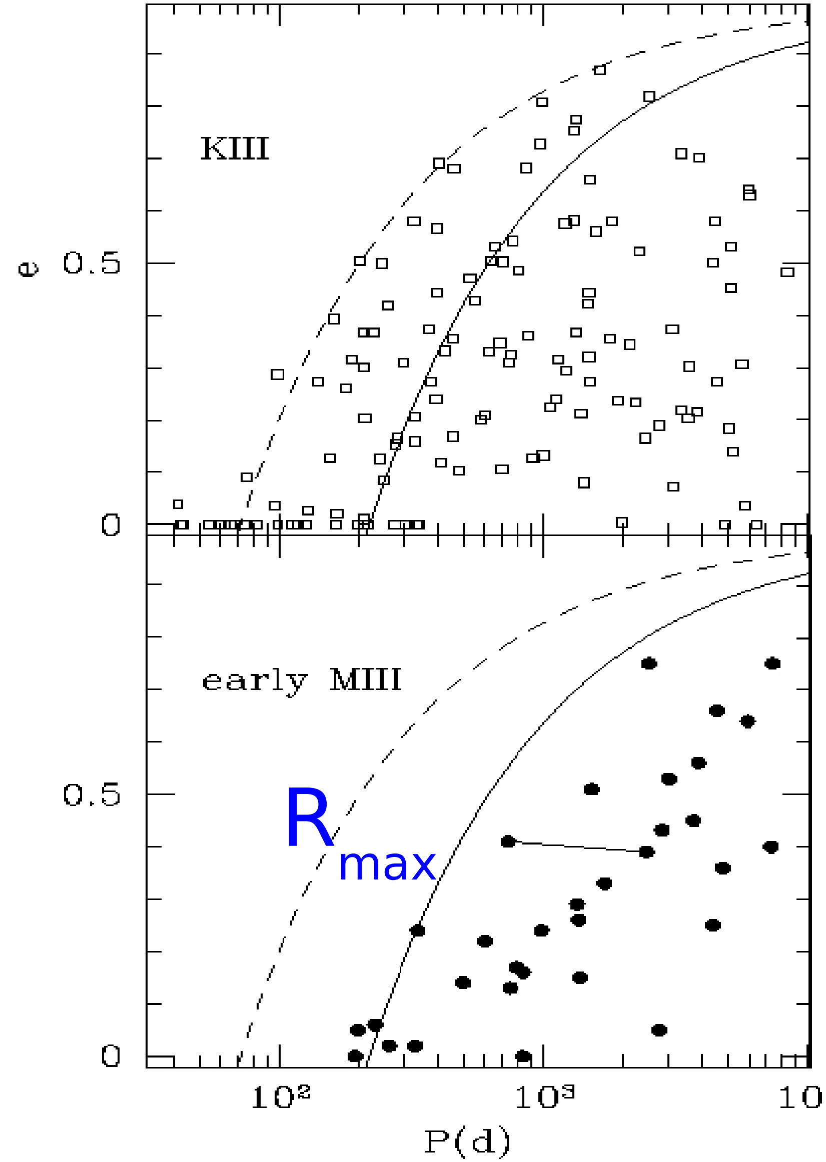
Mermilliod et al. (2007)
Jorissen et al. (2008)

Astrophysics application

2. P_{crit}, the period below which the RLOF appears, ↗ by a factor ~10 from f=0 to f=1.



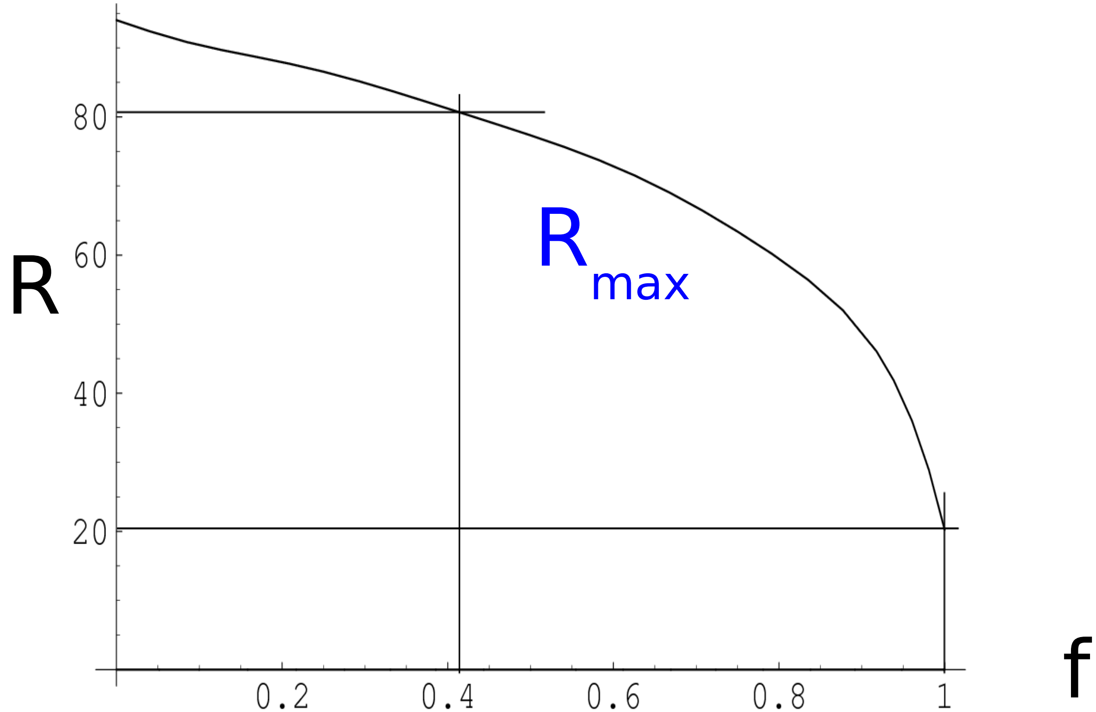
For $M=M_1+M_2=1.9\ M_O$

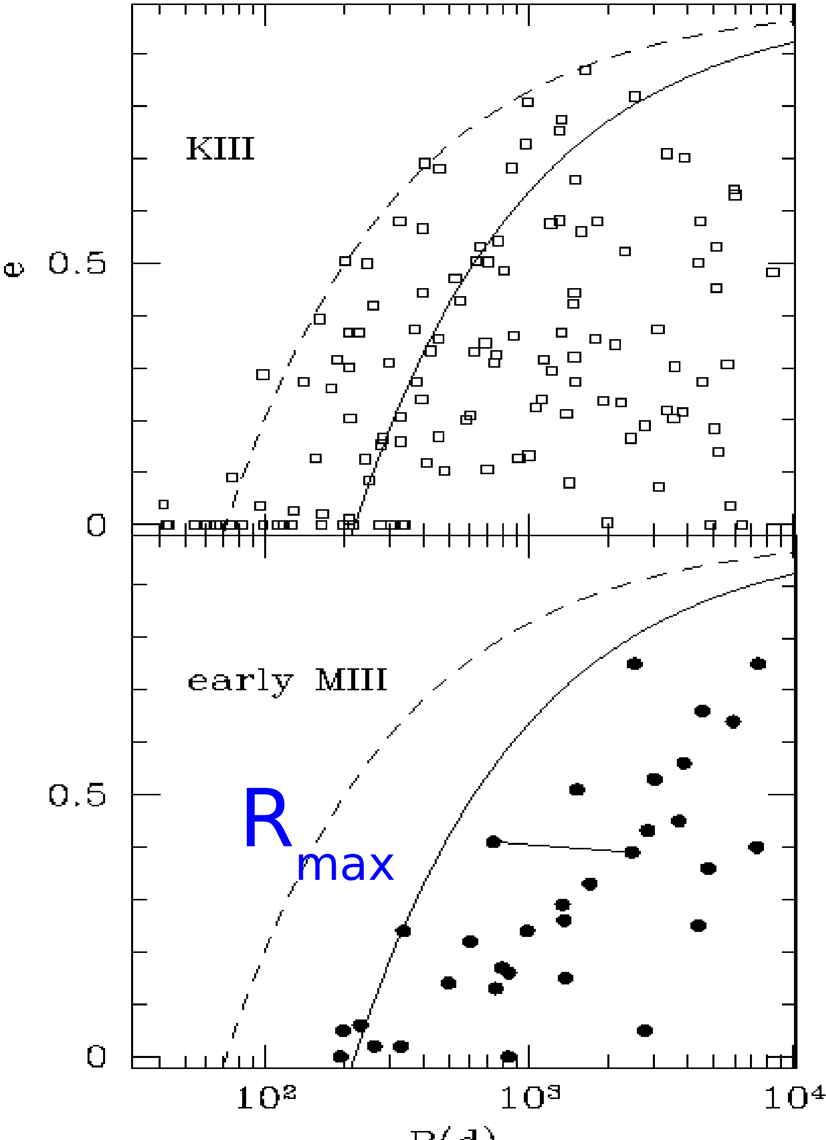


Mermilliod et al. (2007)
Jorissen et al. (2008)

Astrophysics application

2. P_{crit}, the period below which the RLOF appears, ↗ by a factor ~10 from f=0 to f=1.





R∈[20,80R_o] for M0 stars
(Dumm & Schild 1998)

Mermilliod et al. (2007)
Jorissen et al. (2008)

Conclusions

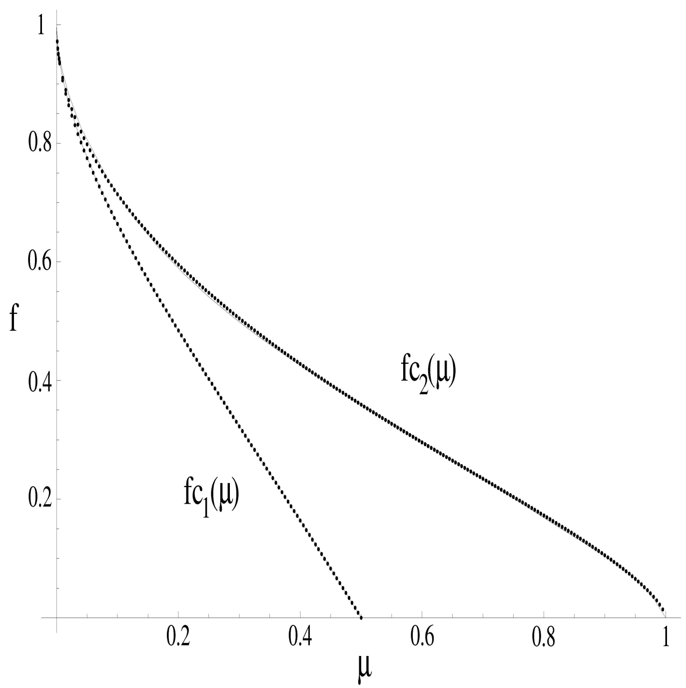
- P_{rad} is not negligible.
- The value of f can be near of 1.
- Have an important impact on the evolution of post-mass transfer binaries.

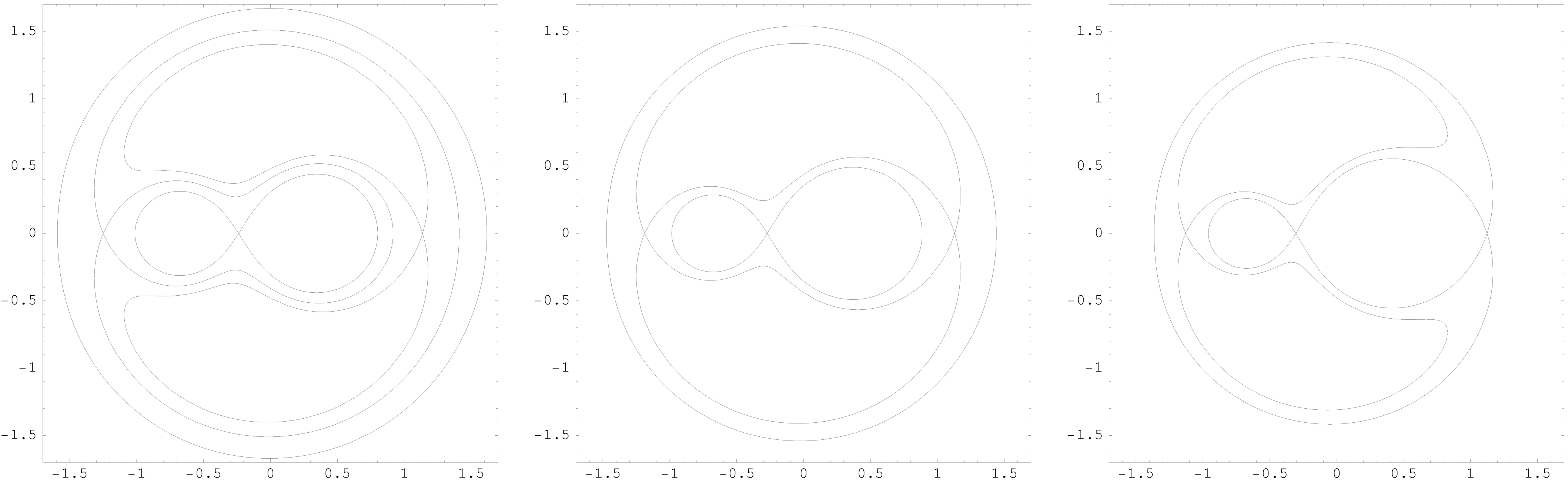
Annexes

Modified Roche potential

$$\phi = \frac{\mu\,(1-f)}{r_1} - \frac{(1-\mu)}{r_2} - \frac{x^2+y^2}{2}$$

- $fc_1(q)$: L_1 & L_3 share the same equipotential.
- $fc_2(q)$: L_2 & L_3 share the same equipotential.





RLOF satbility

Study of RLOF Stability

$$R_{AGB}(t_0+\Delta t)=R_{AGB}(t_0)+\frac{dR_{AGB}}{dM}\frac{dM}{dt}\Delta t \quad , \qquad R_R(t_0+\Delta t)=R_R(t_0)+\frac{dR_R}{dM}\frac{dM}{dt}\Delta t$$

$$\zeta_{AGB}=\frac{d\ln R_{AGB}}{d\ln M} \quad , \qquad \zeta_R=\frac{d\ln R_R}{d\ln M}$$

Stability condition: $If\ R_{AGB}(t_0)<R_R(t_0) => R_{AGB}(t_0+\Delta t)<R_R(t_0+\Delta t)$

$\Rightarrow$ $\boxed{\zeta_R < \zeta_{AGB}}$

→ Improvement of ζ_R and ζ_{AGB}

$\zeta_R(q,f)$

$$\zeta_R(q,f)=2\left(-\lambda+\frac{1-\eta-\delta}{1+q}+\gamma\delta(1+q)\right)+\frac{q}{1+q}(1-\eta)+2(\eta q-1)+\frac{d\ln R_R(q,f)/a}{d\ln q}(1+\eta q)$$

- Where,
  α = fraction of the mass loss escaped to infinity

  η = fraction of the mass loss accreted by the companion

  δ = fraction of the mass loss which form a circumbinary disk

  λ = drag exerted by the escaping wind on the orbital motion

Obtaining $\zeta_R(q,f)$

- $\zeta_R = \quad ... \quad + \dfrac{d\ln R_R}{d\ln q}$

Linked to the geometry of the Roche lobe.

Linked to the variations of the angular momentum associated with the mass loss.

Obtaining $\zeta_R(q,f)$

- $\zeta_R = \; ... \quad + \frac{d\ln R_R}{d\ln q}$

$$\downarrow$$

$\frac{d\ln R_R}{d\ln q}$ ↗ of ~10% from f=0 to f=1.

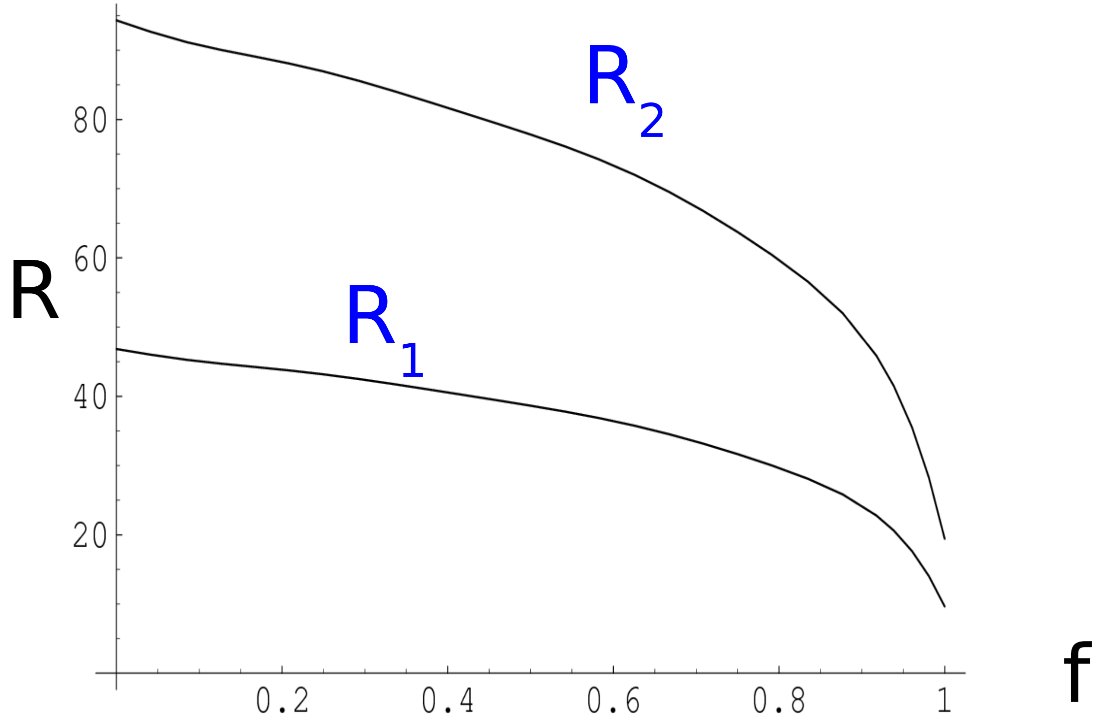
$\Rightarrow$ destabilize the system ($\zeta_R < \zeta_{AGB}$).

- If the companion accretes all the mass loss, ζ_R ↗ of ~1% from f=0 to f=1.

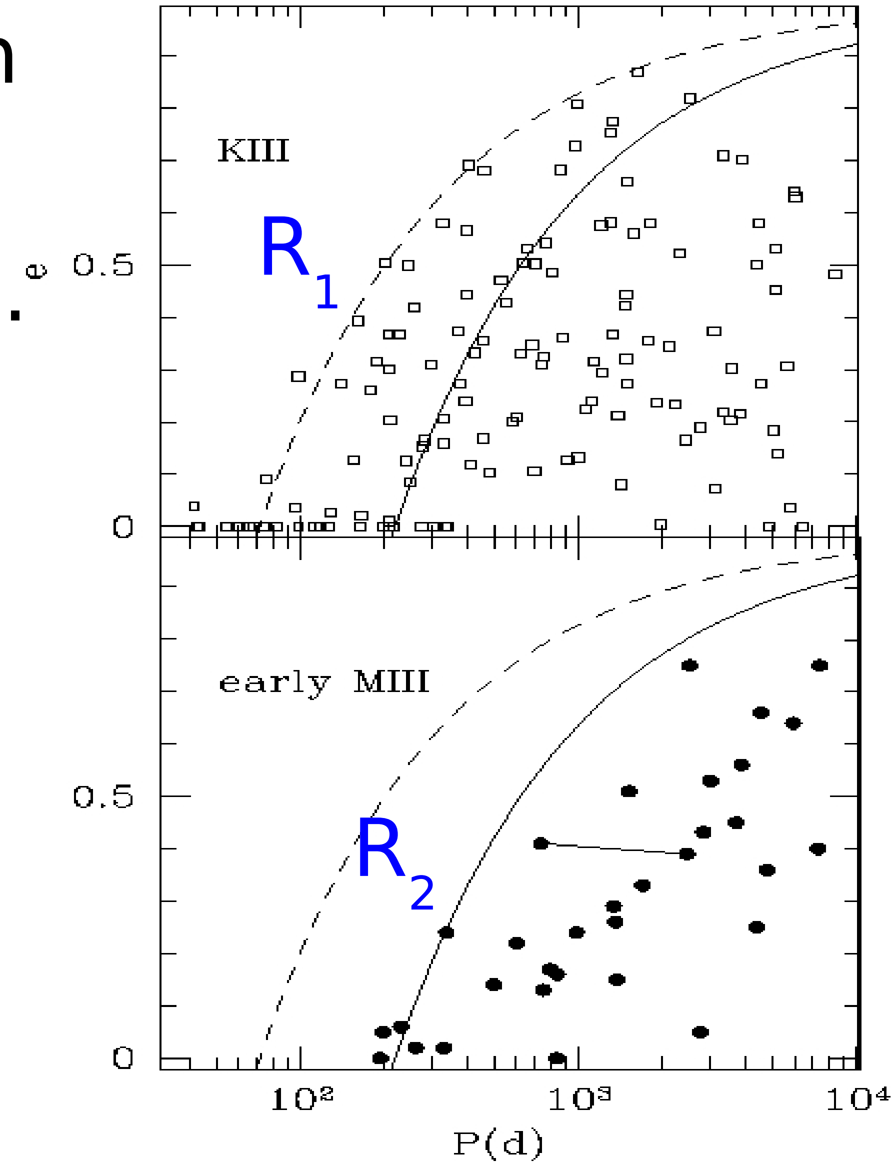
Rmax for MIII & KIII

Roche radius $R_R(q,f)$

- P_{crit}, the period below which the RLOF appears, ↗ by a factor ~10 from f=0 to f=1.



For $M=M_1+M_2=1.9\ M_O$

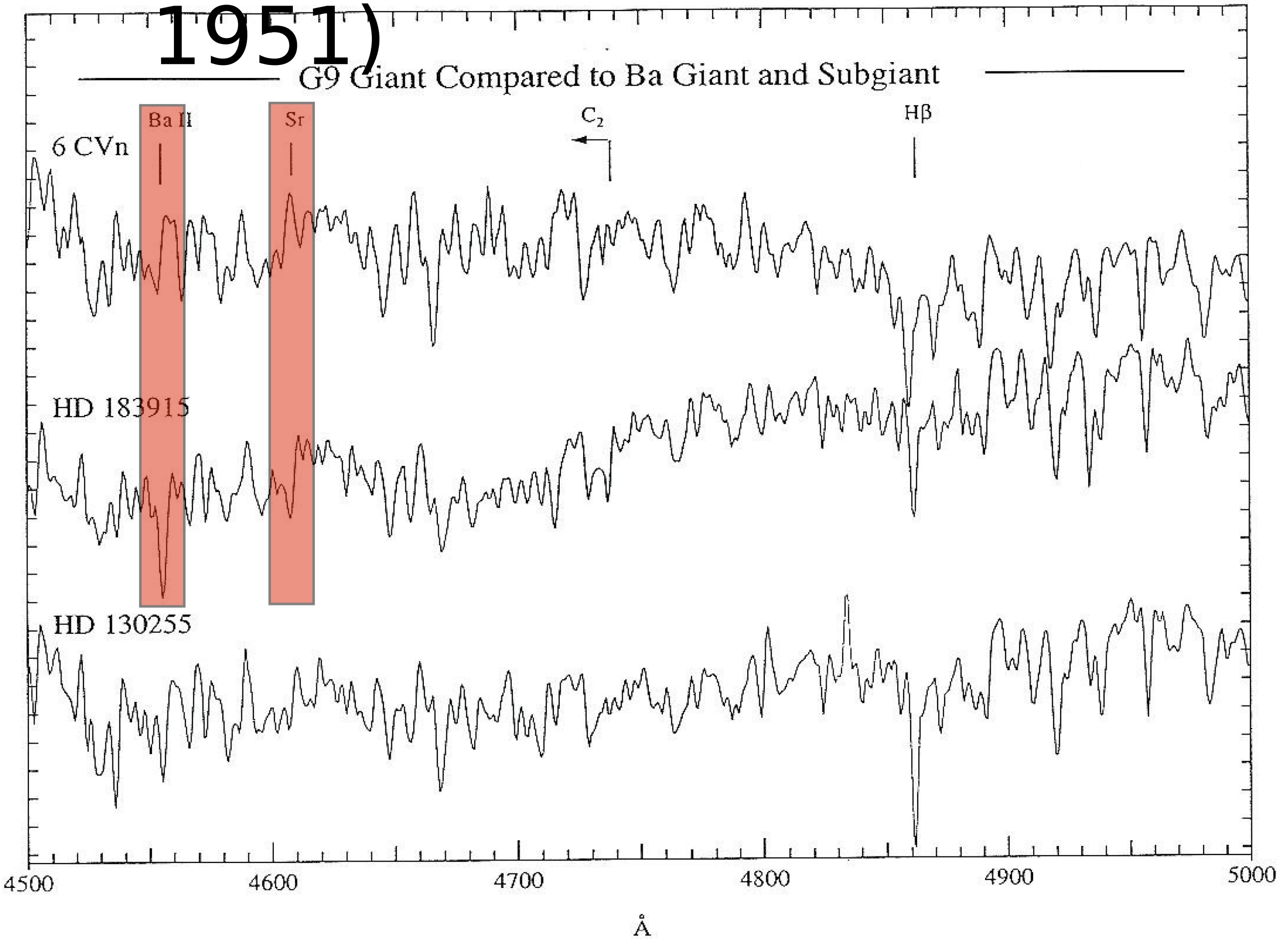


Mermilliod et al. (2007)

Jorissen et al. (2008)

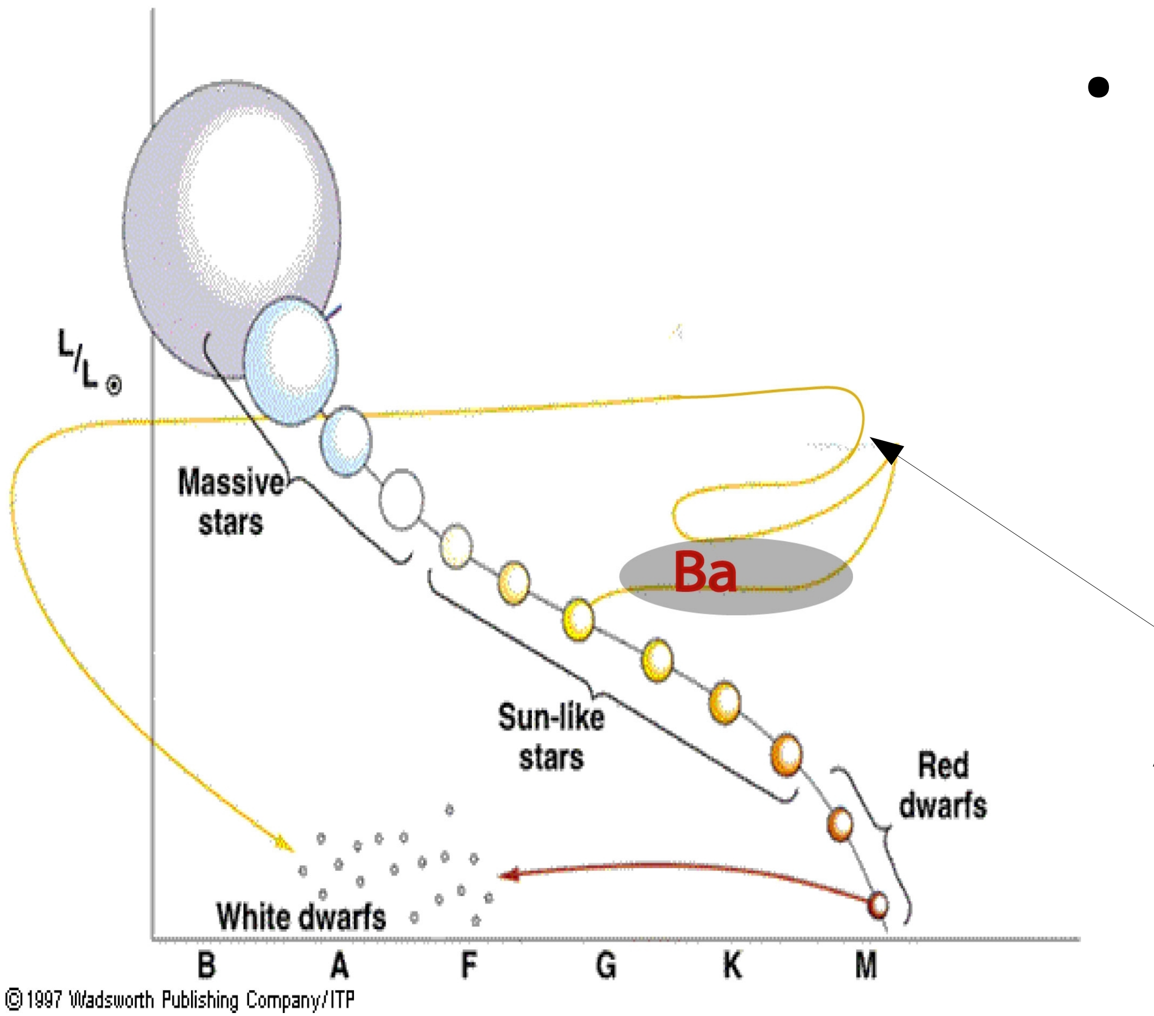
Le cas des étoiles à Ba

- Découverte d'étoiles à baryum (Bidelman & Keenan 1951)



- Étoile 1: G9 III normale
- Étoile 2: K0 III Ba3.5
- Étoile 3: G9 IV Ba2

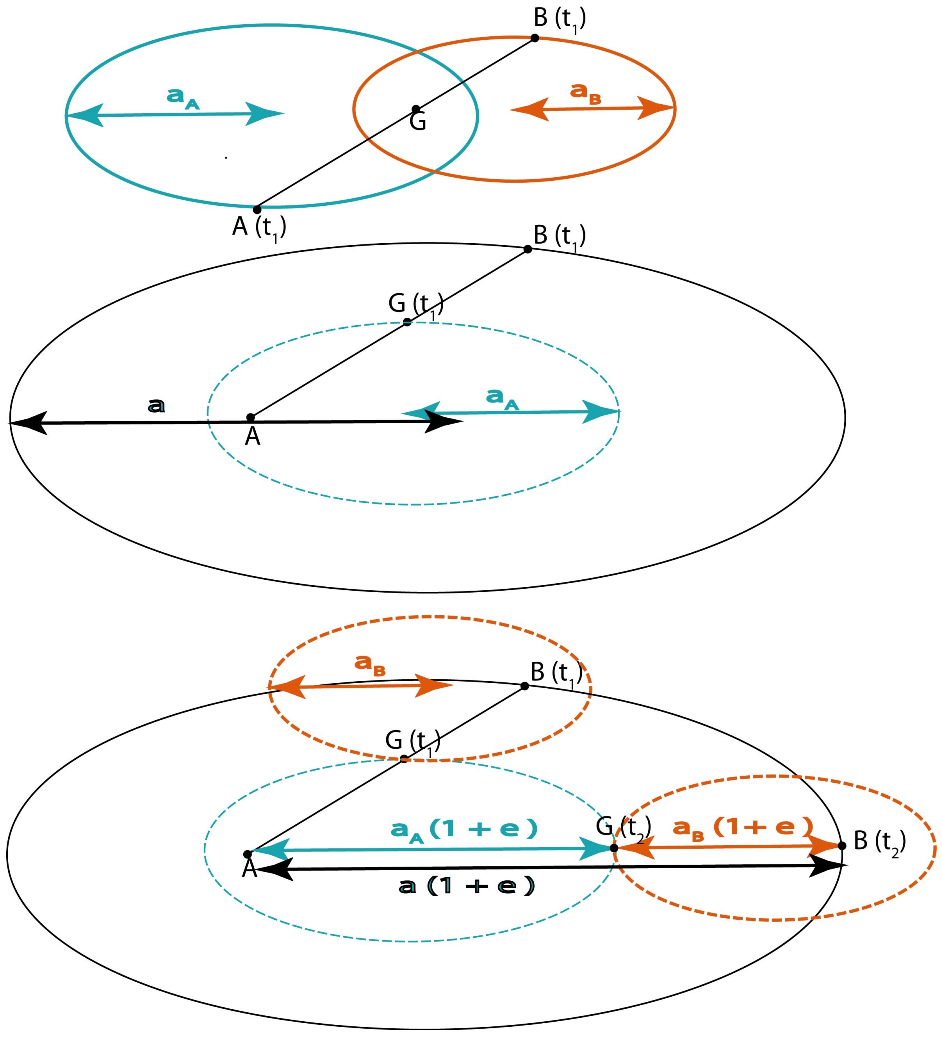
Le cas des étoiles à Ba



- Ces étoiles à Ba proviennent de la RGB.

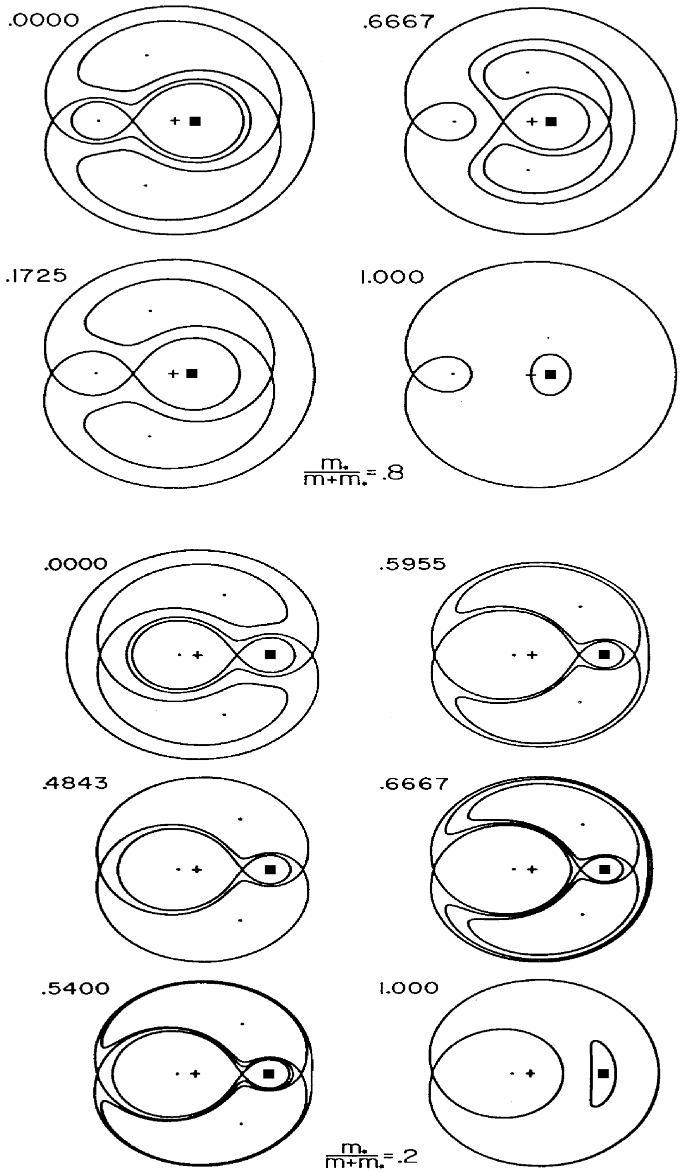
Mais le processus s a lieu dans les étoiles AGB ...

Orbites



- Orbite absolue
- Orbite relative
- $a = a_A + a_B$
  $a_A M_A = a_B M_B$ (déf de G)

Potentiel de Roche modifié

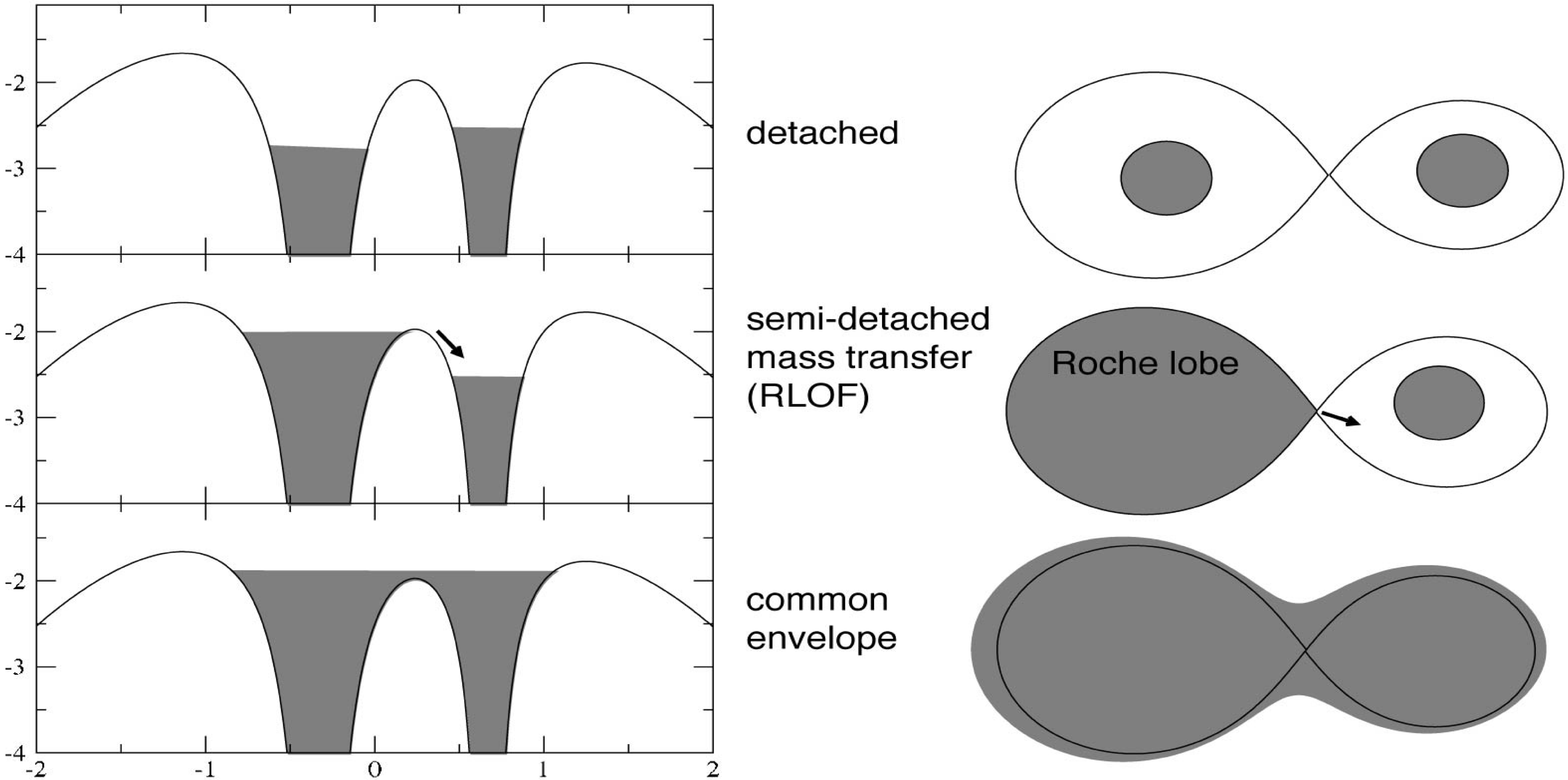


- Potentiel gravitationnel de 2 points massifs en corotation autour d'une orbite relative circulaire.

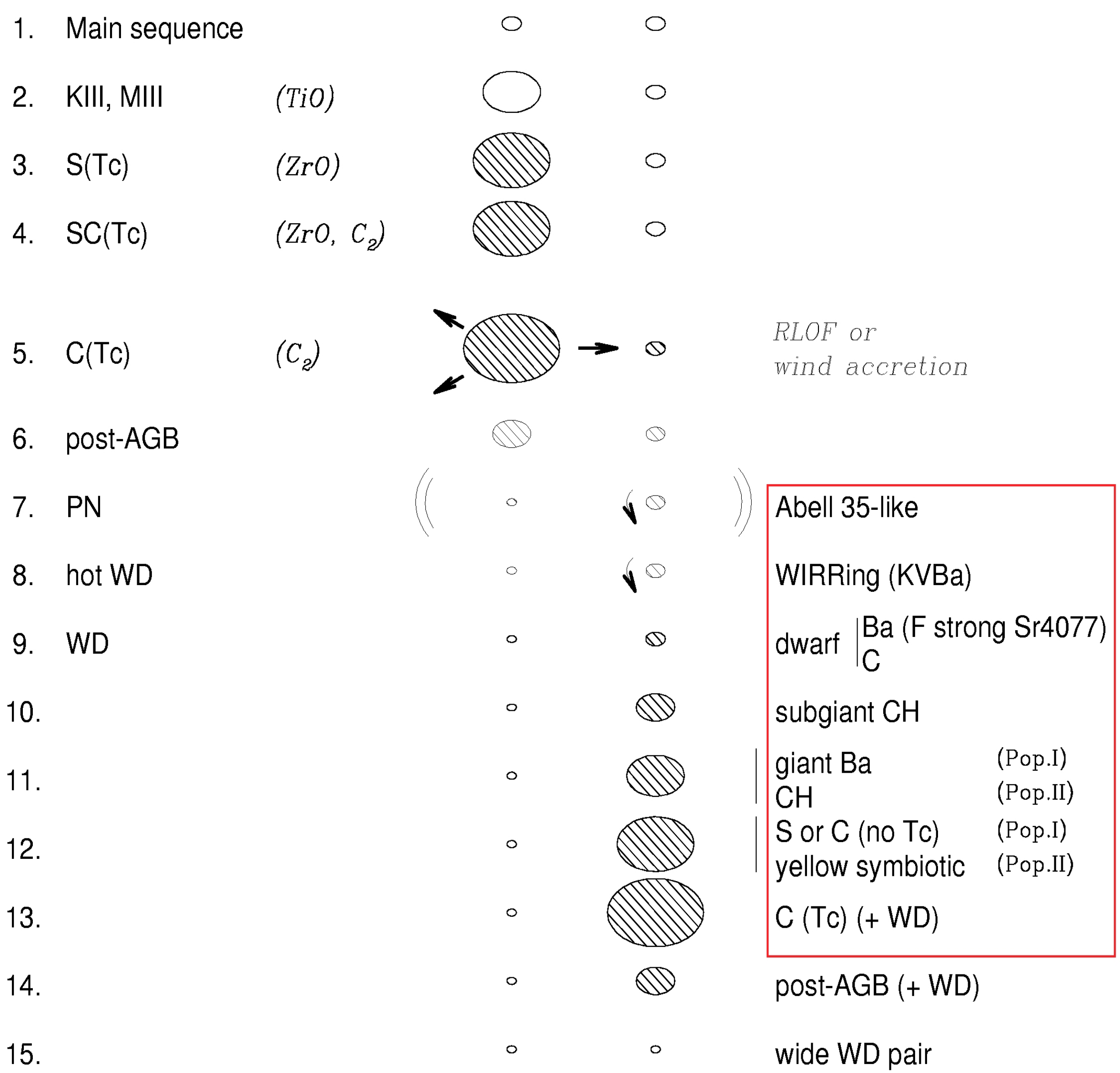
$$\phi = -\frac{\mu}{r_1} - \frac{(1-\mu)(1-f)}{r_2} - \frac{x^2+y^2}{2}$$

$$f = \frac{-dP_{rad}}{\rho\, dr}\left(\frac{G\,M_2}{r_2^2}\right)^{-1}$$

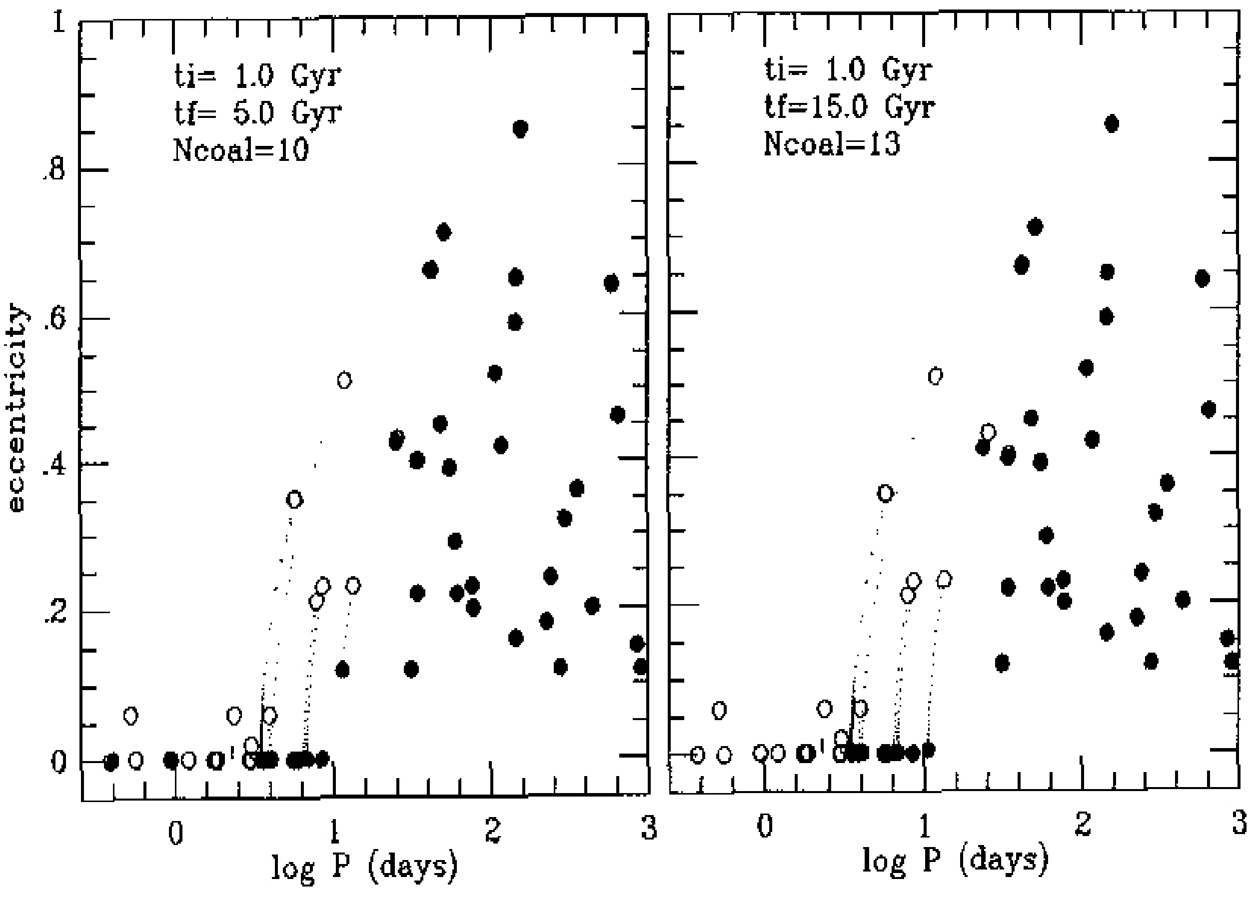
Types de binaire



Évolution schématique



Interaction de marée



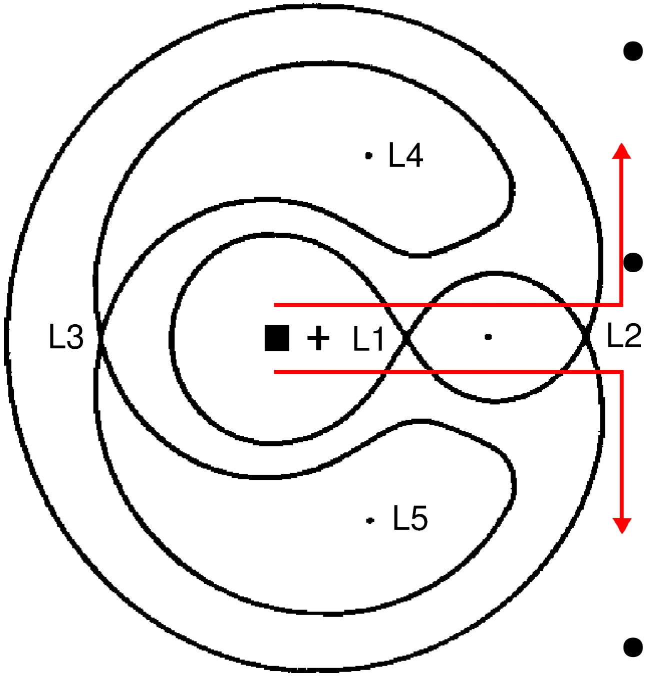
- Circularisation: e → 0
- Synchronisation

A. Duquennoy & M. Mayor

Références

- Eggleton, P. P., 2006, Evolutionary Processes in Binary and Multiple Stars, Cambridge University Press
- Frankowski 2007, in : R. L.M. Corradi, A. Manchado, N. Soker (eds.), Asymmetrical Planetary Nebulae IV, published electronically on http://www.iac.es/proyecto/apn4/pages/proceedings.php
- Frankowski & Jorissen, 2006, Baltic Astronomy 16, 104
- Jorissen 2003, in : H. Habing, H. Olofsson (eds.), Asymptotic Giant Branch Stars, Springer Verlag, New York, chapter 9
- Jorissen et al. 1998, A&A 332, 877
- Hjellming & Webbink 1987, ApJ 318, 794
- Hurley, Tout & Pols, 2002, MNRAS 329, 897
- Mastrodemos & Morris, 1998, ApJ 497, 303
- McClure et al., 1980, ApJ 238, L35
- Mermilliod et al., 2007, A&A 473, 829
- Ritter 1996, in : Wijers et al., Evolutionary processes in binary stars, Kluwer, Dordrecht, p. 226
- Theuns, Boffin & Jorissen, 1996, MNRAS 280, 1264
- Van Eck et Jorissen 2000, A&A 360, 196

The transient torus



Schuerman (1996)

- 1: Wind accretion
  → Important spin of the companion
- 2: Roche lobe overflow
- 3: Formation of a circumbinary torus by escaping matter through L2
- 4: Formation of a Keplerian disk

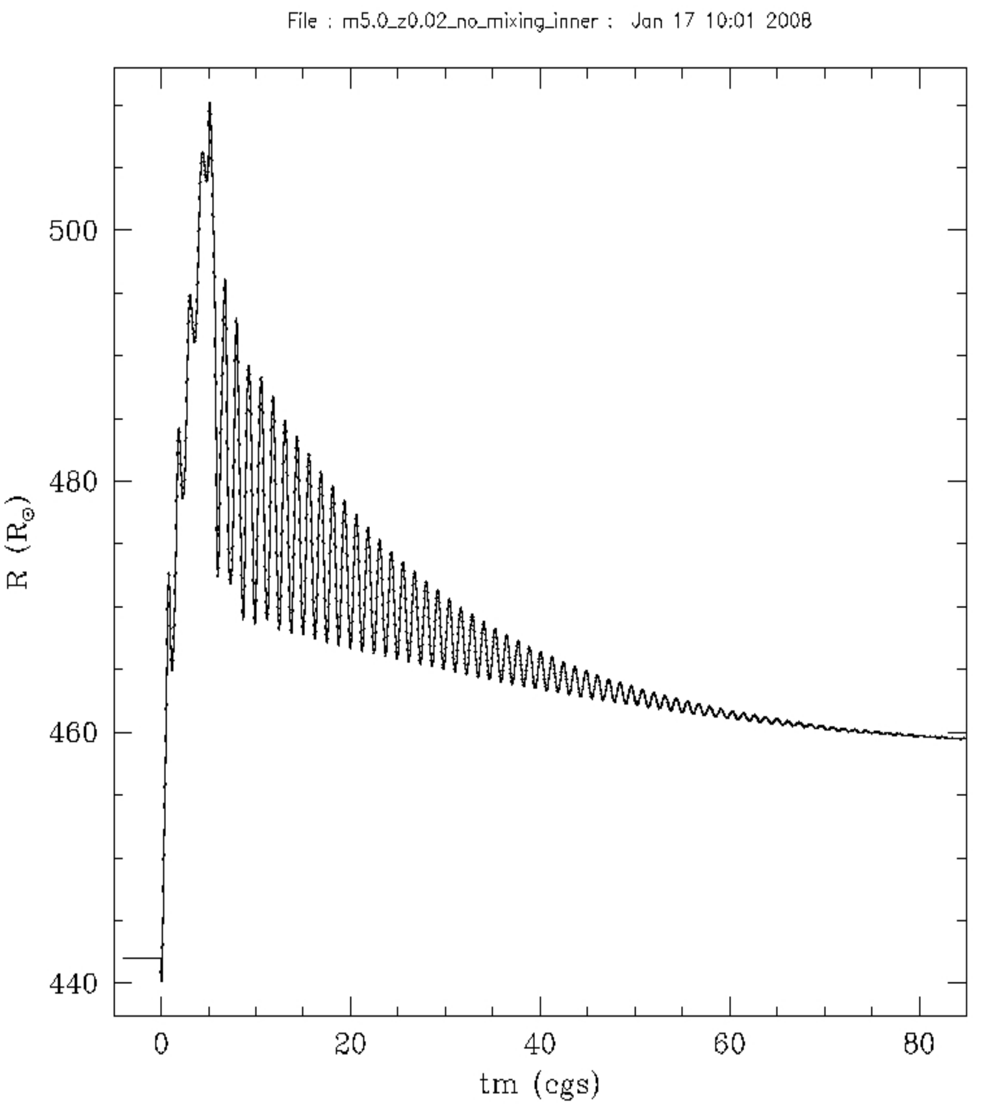
observational confirmations

Obtaining ζ_{AGB} by STAREVOL

- ζ_{AGB} calculate by polytropic models which not taking the star's structure into account.
- $$\zeta_{AGB} = \frac{d\ln R_R}{d\ln M} = -0.3 = \zeta_{polytrope}$$

  Ritter (1999)

- Future study:
  ζ_{AGB} for $\neq M_{envelope}$, $\neq M_*$ and at $\neq$ phases.



Obtaining ζ_{AGB} by STAREVOL

- ζ_{AGB} calculate by polytropic models which not taking the star's structure into account.

- $$\zeta_{AGB} = \frac{d\ln R_R}{d\ln M} = -0.3 = \zeta_{polytrope}$$

  Ritter (1999)

- Future study:
  ζ_{AGB} for $\neq M_{envelope}$, $\neq M_*$ and at $\neq$ phases.