Common Envelopes

Robert Izzard

Argelander Institute For Astronomy
University of Bonn

With help from:
Thomas Tauris
Christopher Tout
Philip Hall

Argelander Institut für Astronomie

Common Envelope Evolution

i. Physics: Energy and Angular Momentum

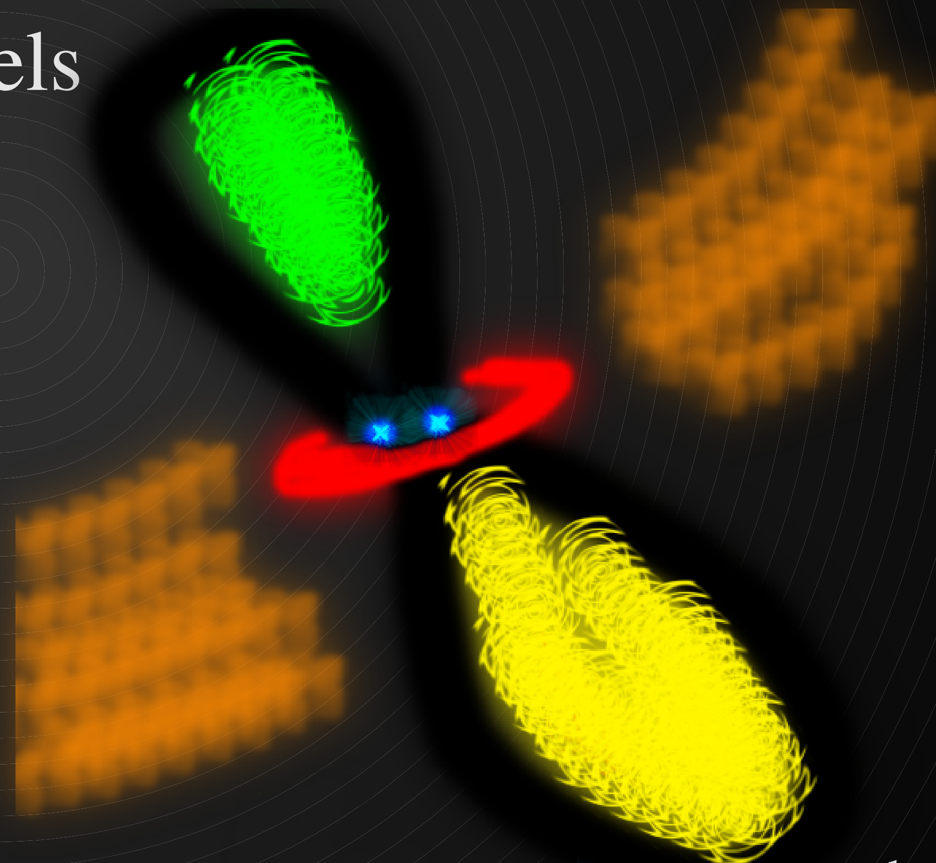
ii. Detailed CEE models

iii. Parameterised CEE models

iv. Constraints

v. Other objects

vi. Future

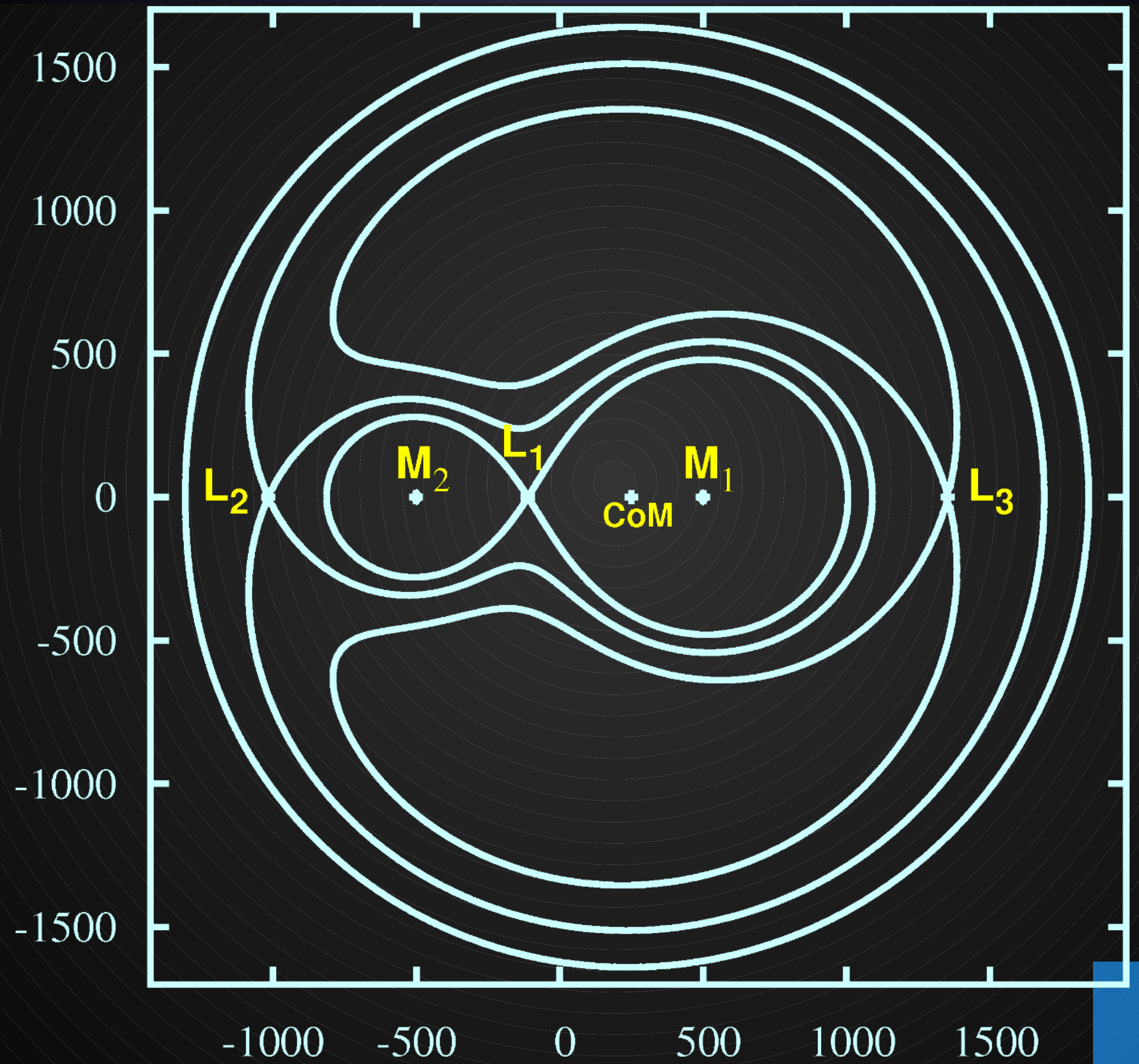


What I am convinced I know *for sure* about common envelope evolution:

Something happens...

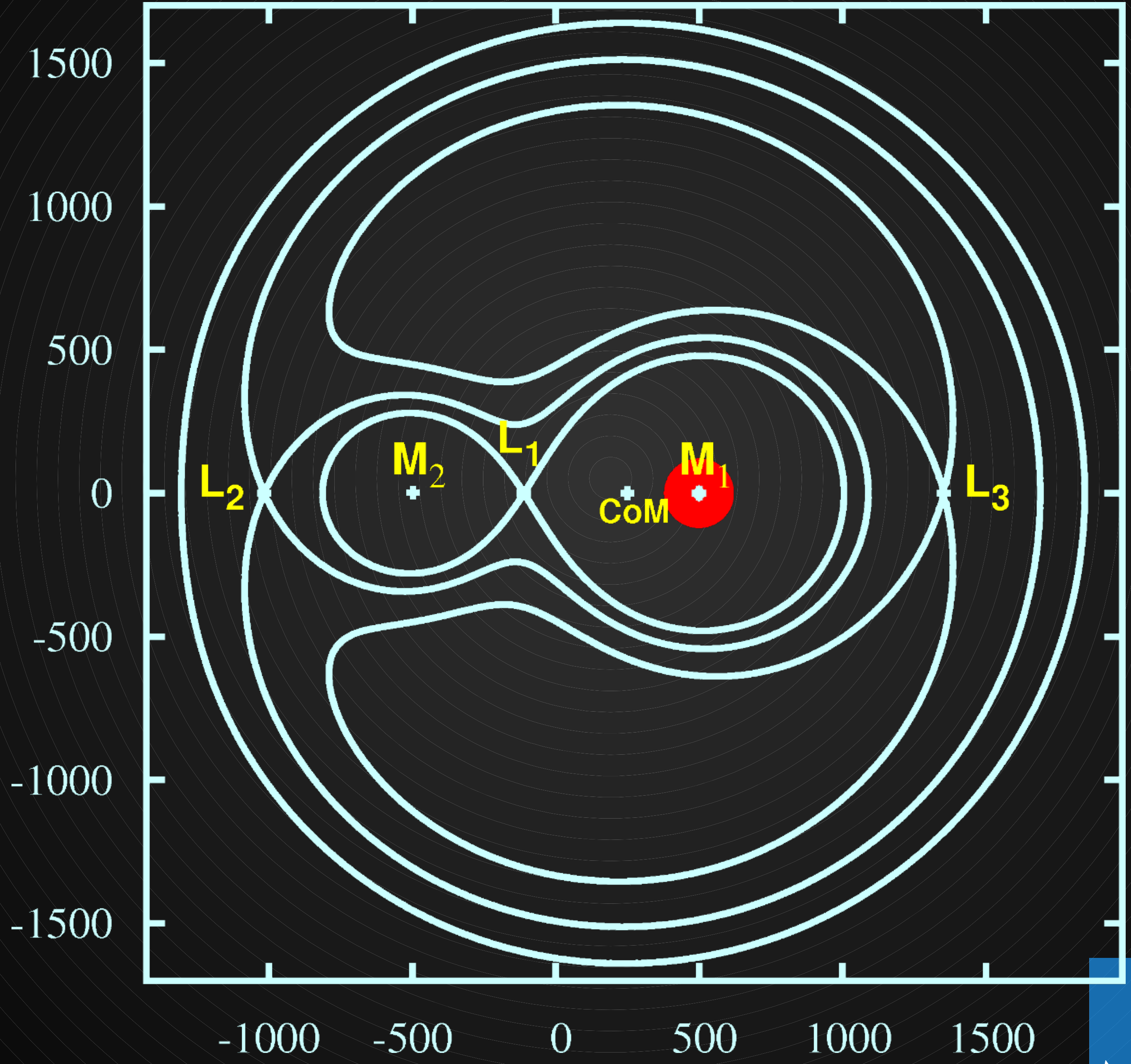
Argelander Institut für Astronomie

Physics of the CE Phase



$M_1 = 1.5\,\mathrm{M}_\odot$
$M_2 = 0.5\,\mathrm{M}_\odot$
$q = 3$

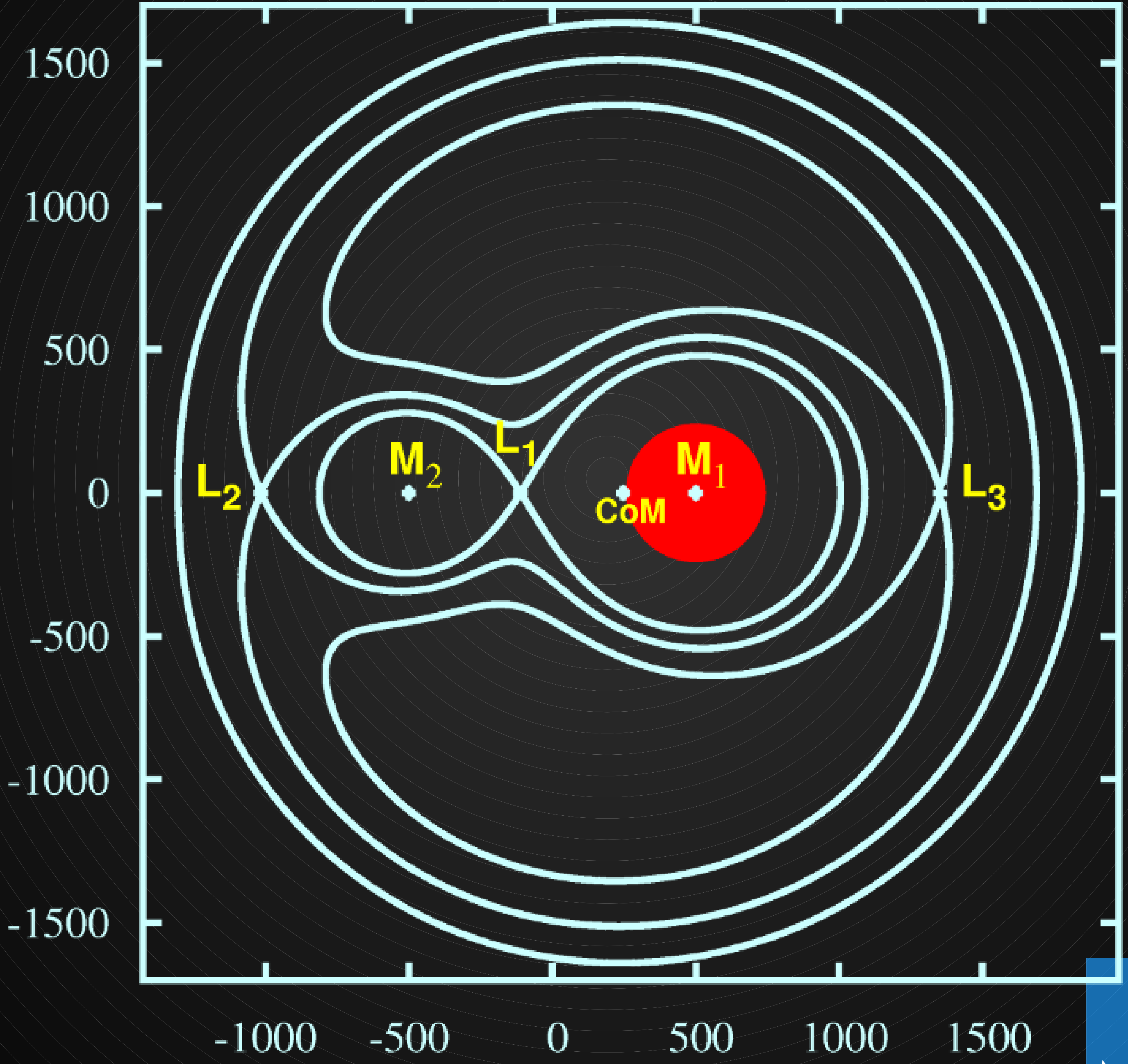
Physics of the CE Phase



$M_1 = 1.5\,\mathrm{M}_\odot$
$M_2 = 0.5\,\mathrm{M}_\odot$
$q = 3$

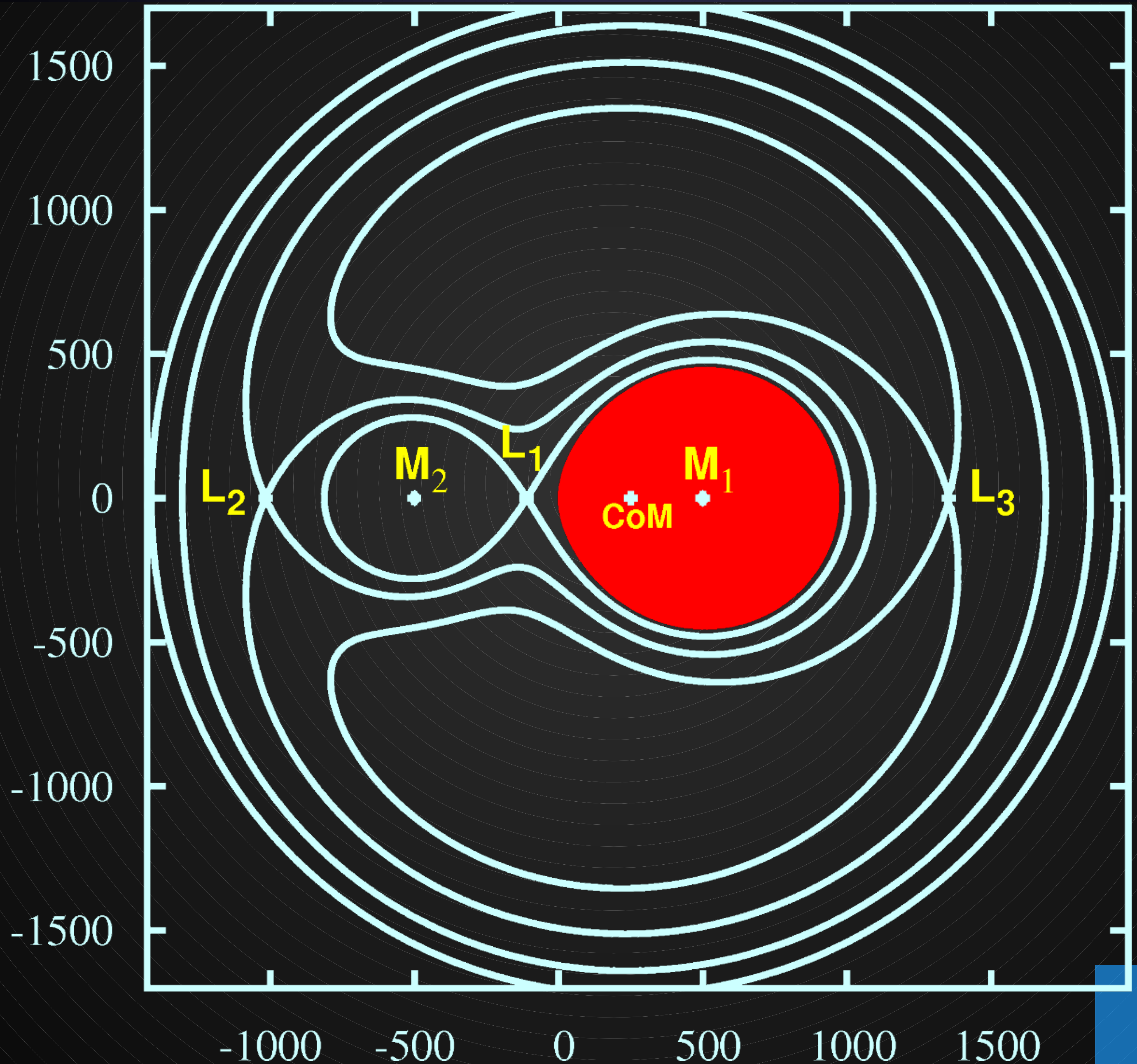
Argelander Institut für Astronomie

Physics of the CE Phase



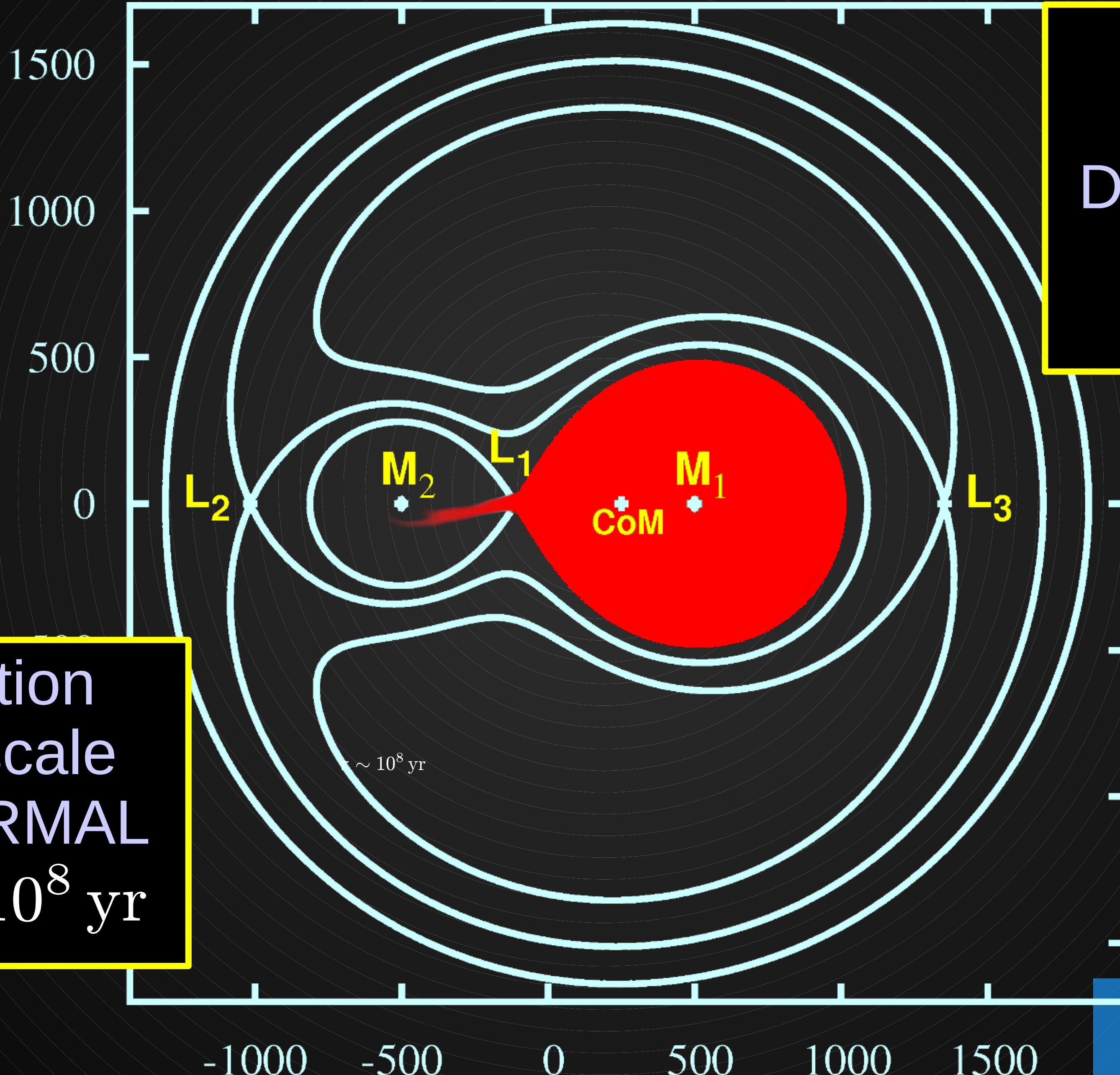
$M_1 = 1.5\,\mathrm{M}_\odot$
$M_2 = 0.5\,\mathrm{M}_\odot$
$q = 3$

Physics of the CE Phase



$M_1 = 1.5\,\mathrm{M}_\odot$
$M_2 = 0.5\,\mathrm{M}_\odot$
$q = 3$

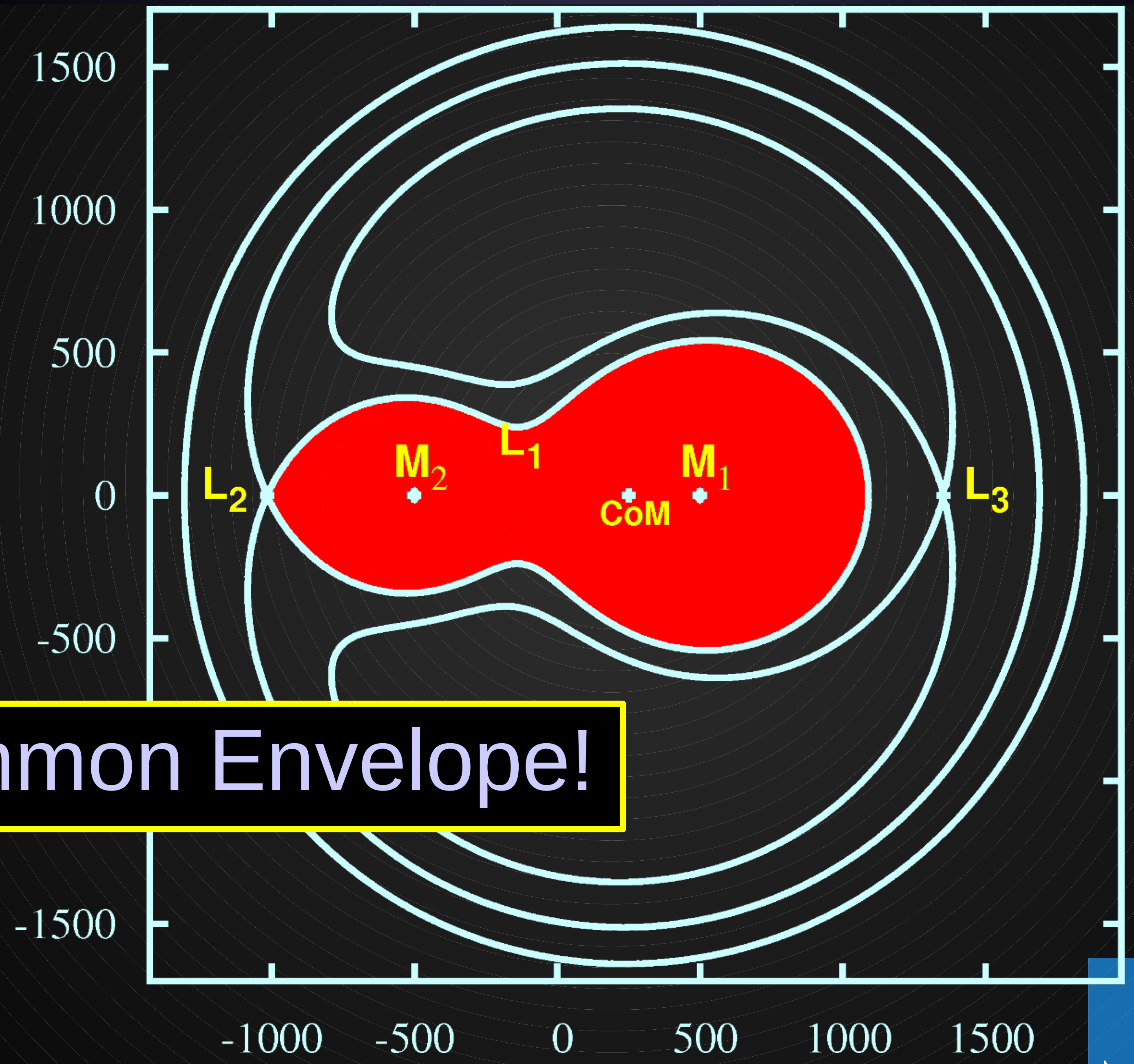
Physics of the CE Phase



RLOF
Timescale
DYNAMICAL
$\tau \sim 1\,\mathrm{yr}$

Accretion
Timescale
THERMAL
$\tau \sim 10^8\,\mathrm{yr}$

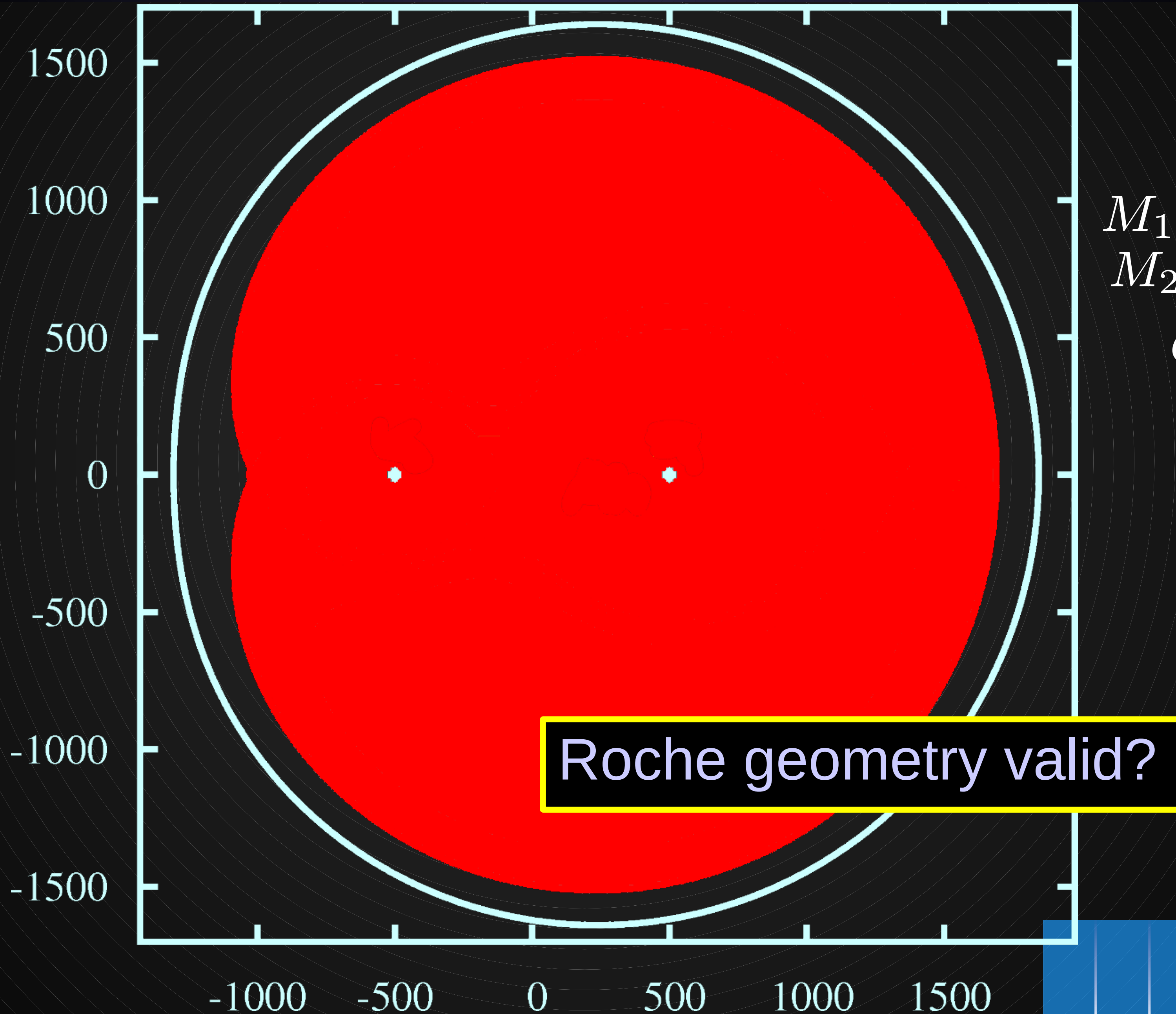
Physics of the CE Phase



$M_1 = 1.5\,\mathrm{M}_\odot$
$M_2 = 0.5\,\mathrm{M}_\odot$
$q = 3$

Common Envelope!

Physics of the CE Phase

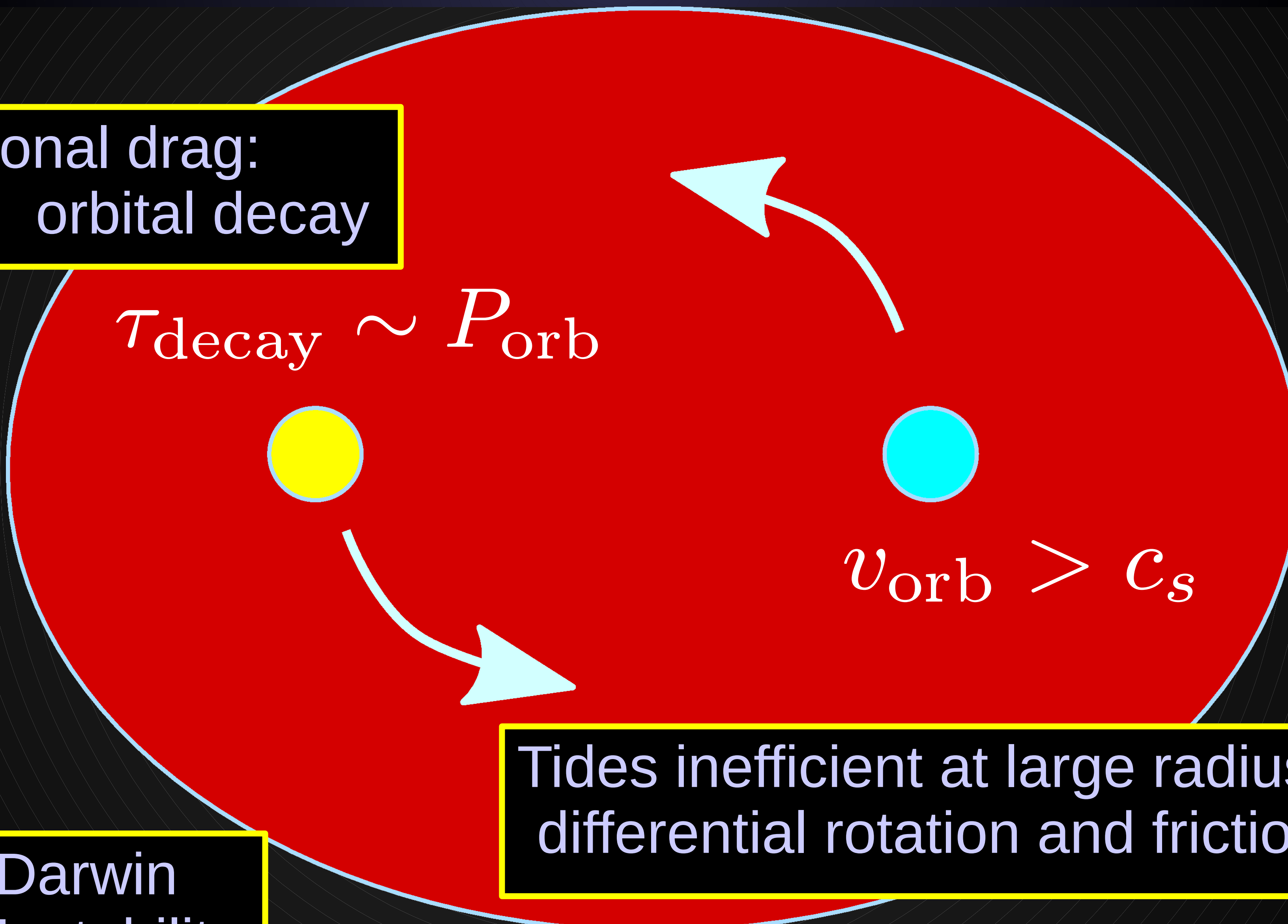


$M_1 = 1.5\,\mathrm{M}_\odot$
$M_2 = 0.5\,\mathrm{M}_\odot$
$q = 3$

Argelander Institut für Astronomie

CE Phase I: Co-rotation lost

Frictional drag:
orbital decay

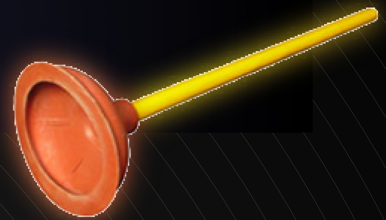


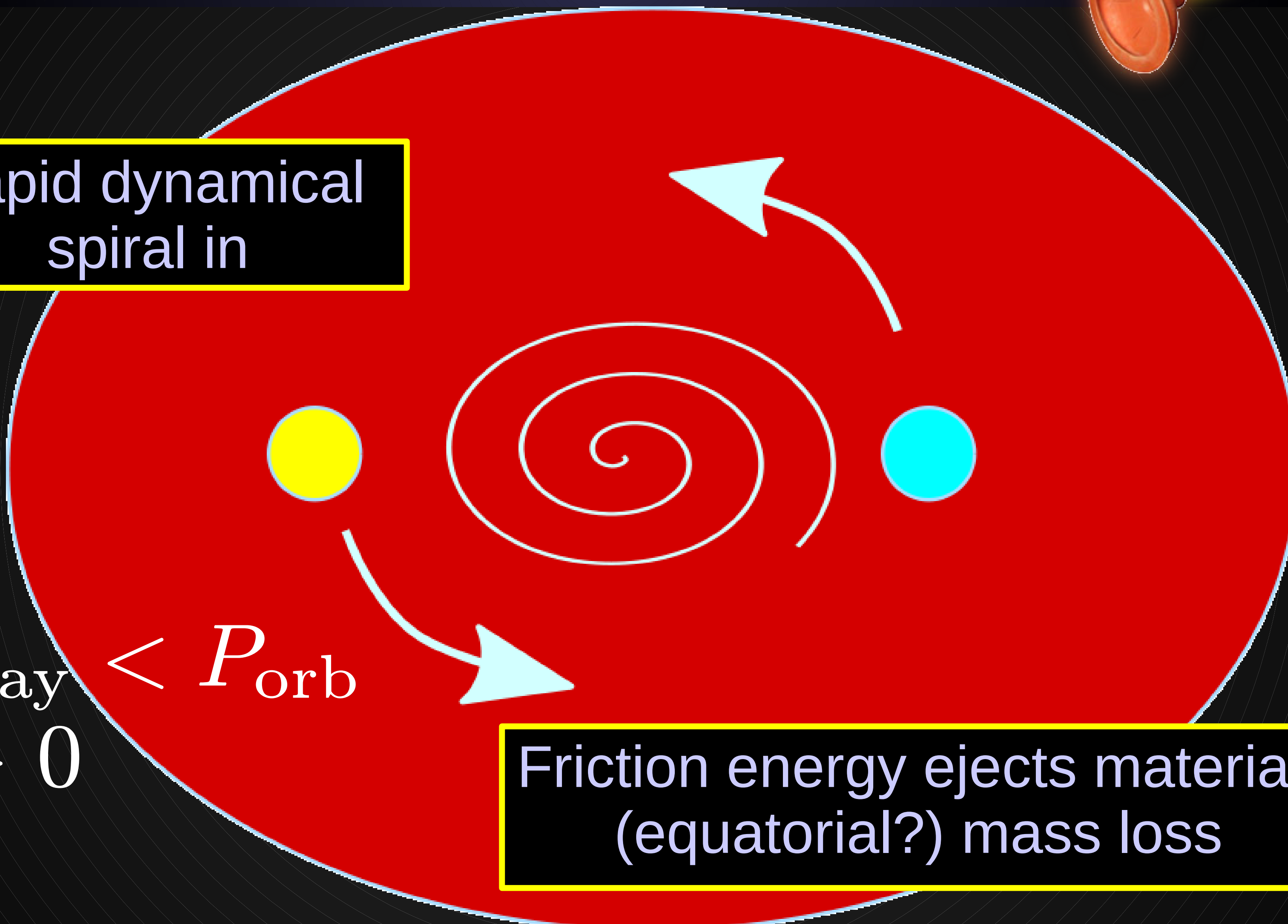
Tides inefficient at large radius:
differential rotation and friction

Darwin
Instability

Argelander
Institut
für
Astronomie

CE Phase II "The Plunge"





$$\tau_{\rm decay} < P_{\rm orb}$$

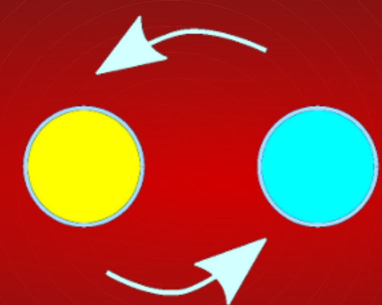
$$e > 0$$

CE Phase III: slow inspiral

Drag $\propto$ density and shear

- Reduced density
- Co-rotation near centre

Both effects slow spiral in:
Energy *radiated* away



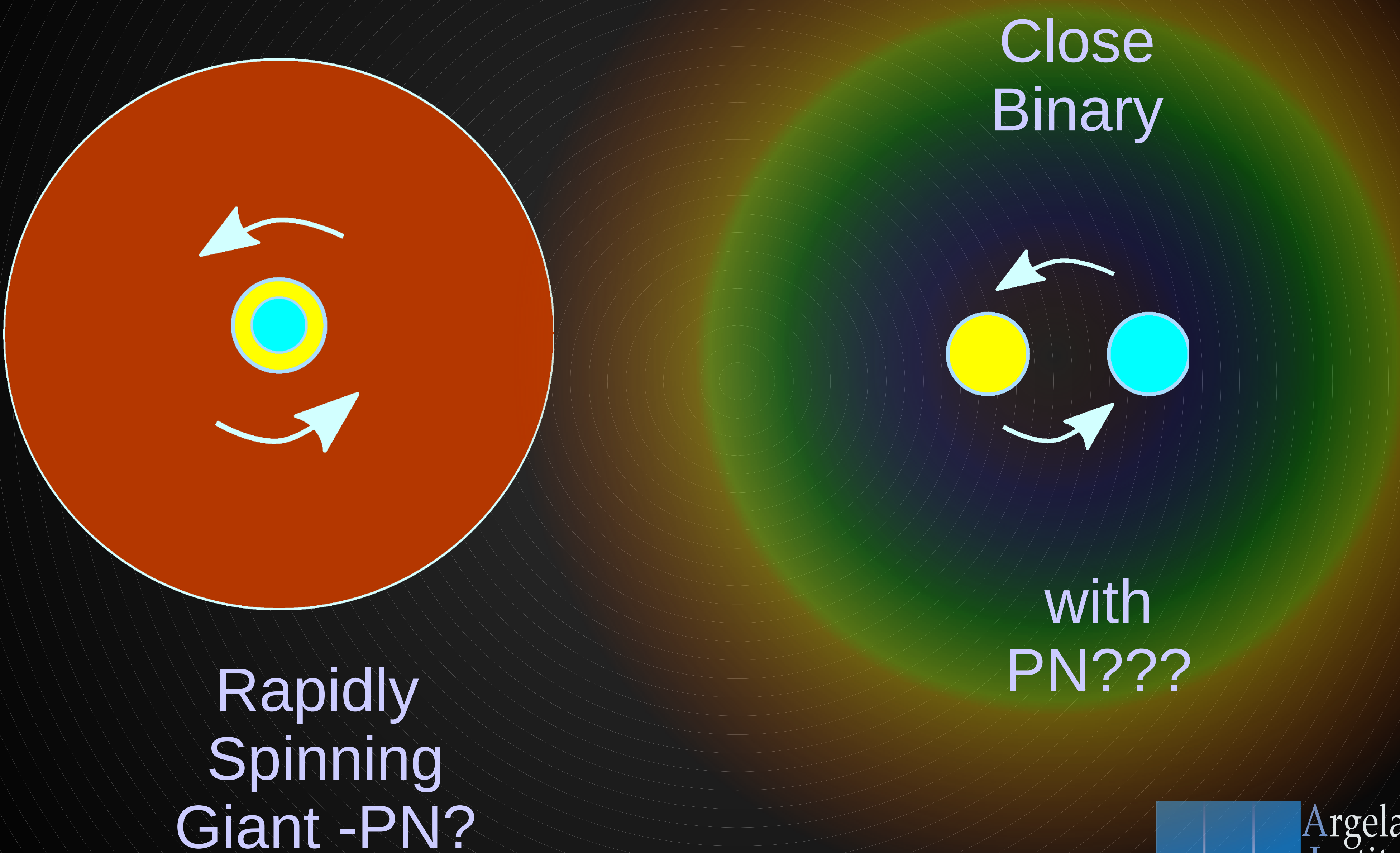
$$\tau_{\mathrm{decay}} \sim 100 - 1000\ \mathrm{yr}$$

But ejection continues!

Orbit is *much* smaller!

Argelander Institut für Astronomie

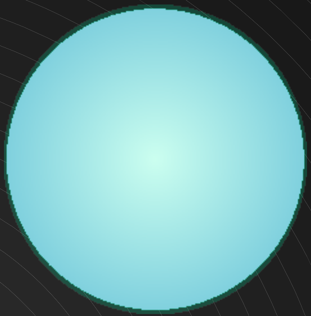
Final Fate

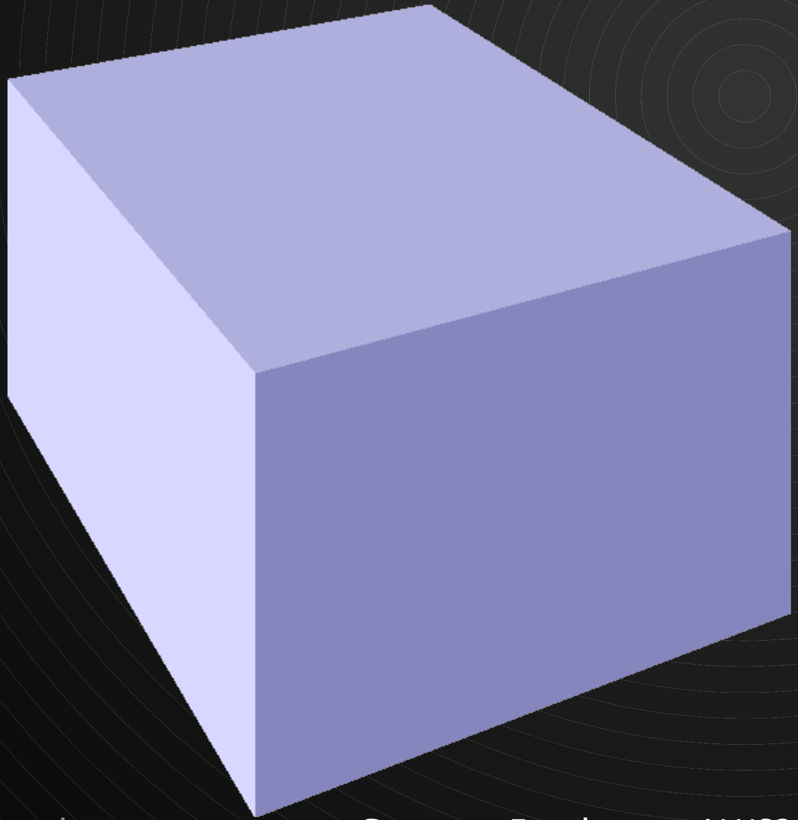


Argelander
Institut
für
Astronomie

Detailed models of CEE

1D





3D

1D models

- Parameterise drag luminosity
- Include energy source in stellar code

Meyer & Meyer-Hofmeister 1978
Podsiadlowski 2001

- Good for following all relevant timescales

  e.g. slow-fast-slow transitions

- Also exploring possibilities e.g. nucleosynthesis

e.g. Ivanova, *Podsiadlowski & Spruit* 2001

- Is a 3D process even approximately 1D (or 2D?)

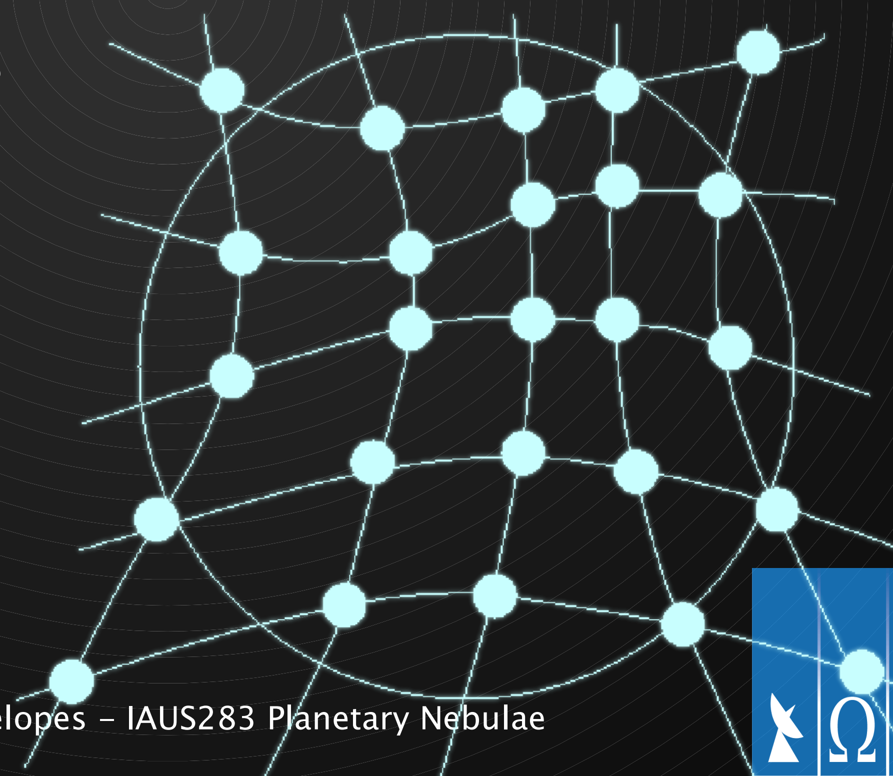
Argelander Institut für Astronomie

3D models

- Relatively few models in literature
- *Taam*, *Ricker*, *Sandquist*, etc. are pioneers
- Early models use Smoothed Particle Hydrodynamics
- More recently mesh codes (work in progress!)
- Good for fast phases

  e.g. plunge
- Bad for slow phases

  e.g. final spiral



Argelander Institut für Astronomie

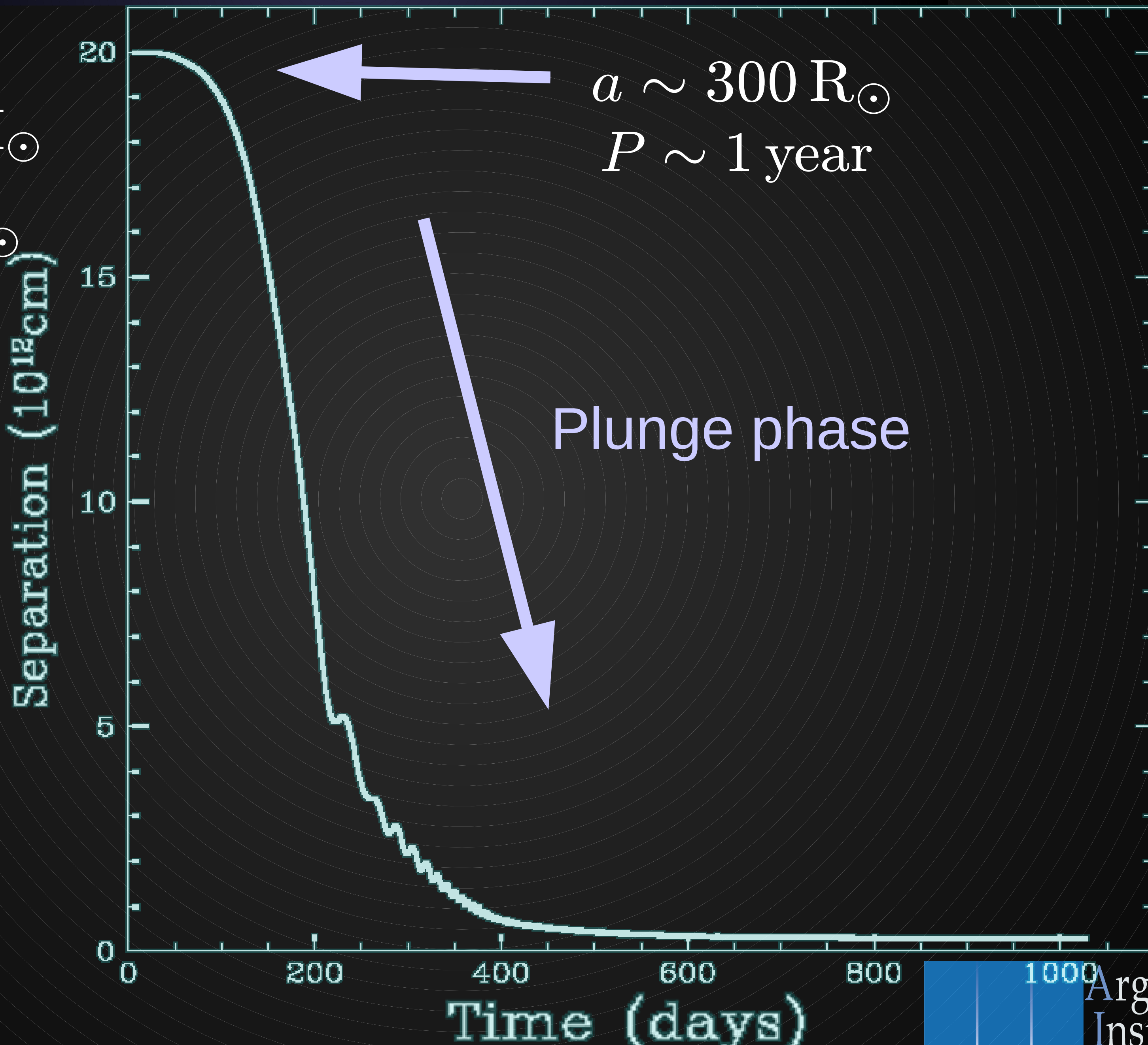
Sandquist et al 1998

$M_1 = 3\,\mathrm{M}_\odot$

$M_{c1} = 0.7\,\mathrm{M}_\odot$

$M_2 = 0.4\,\mathrm{M}_\odot$

$a \sim 300\,\mathrm{R}_\odot$
$P \sim 1\,\mathrm{year}$

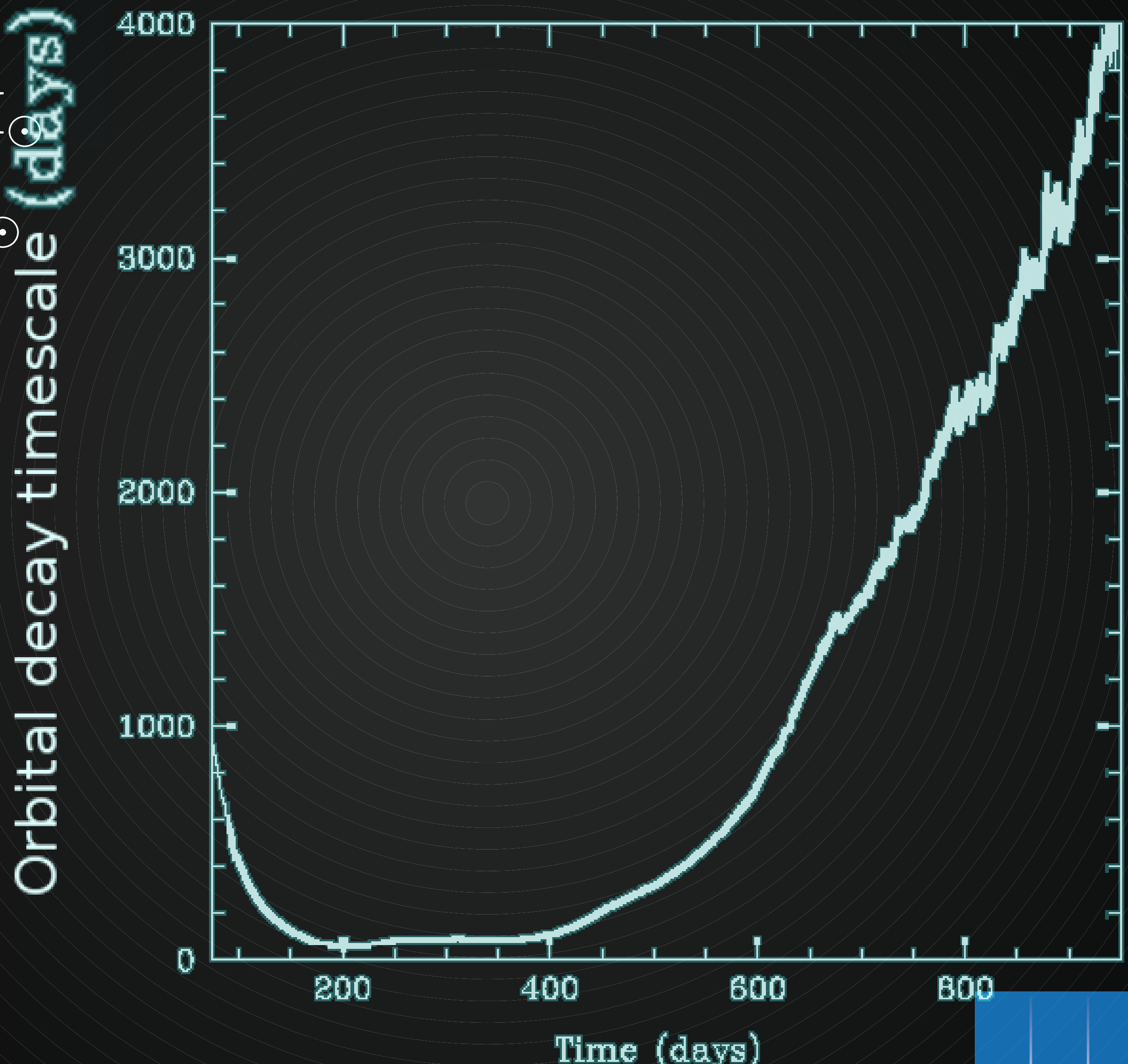


Sandquist et al 1998

$M_1 = 3\,\mathrm{M}_\odot$

$M_{c1} = 0.7\,\mathrm{M}_\odot$

$M_2 = 0.4\,\mathrm{M}_\odot$

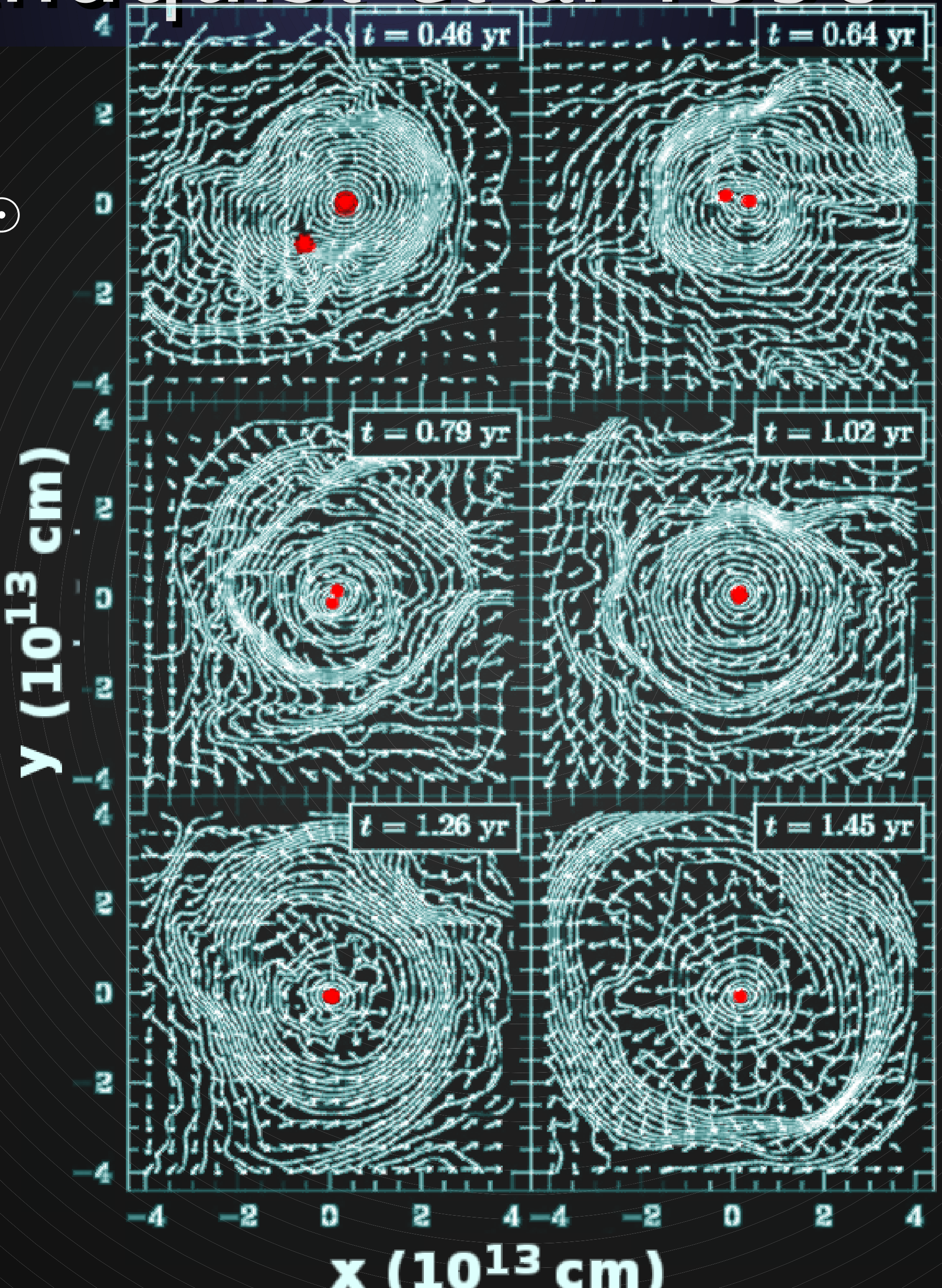


Sandquist et al 1998

$M_1 = 3\,\mathrm{M}_\odot$

$M_{c1} = 0.7\,\mathrm{M}_\odot$

$M_2 = 0.4\,\mathrm{M}_\odot$



Density

In orbital plane

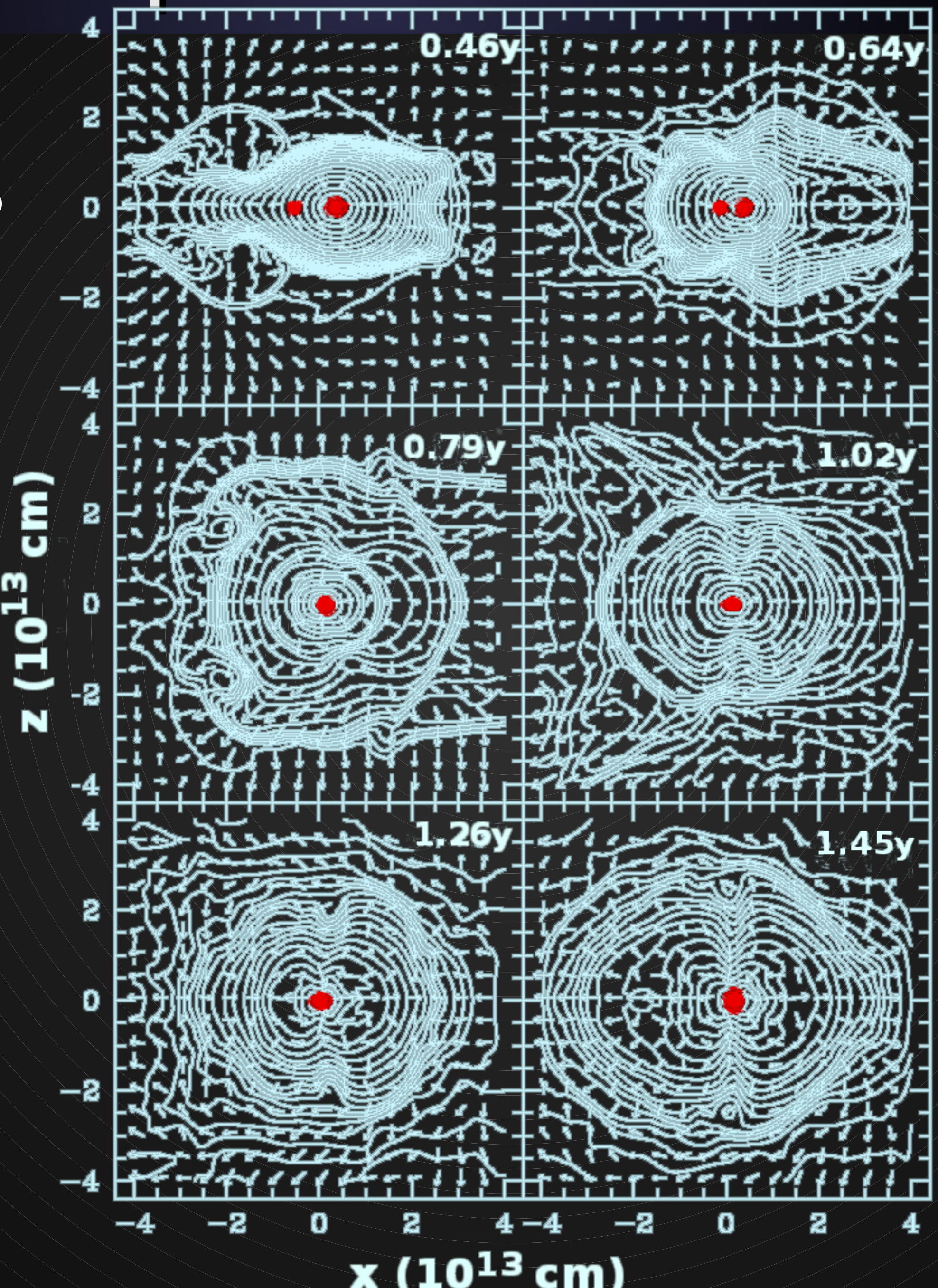
3D Grid code

Sandquist et al 1998

$M_1 = 3\,\mathrm{M}_\odot$

$M_{c1} = 0.7\,\mathrm{M}_\odot$

$M_2 = 0.4\,\mathrm{M}_\odot$



Density

Perpendicular to orbital plane

3D Grid code

Argelander Institut für Astronomie

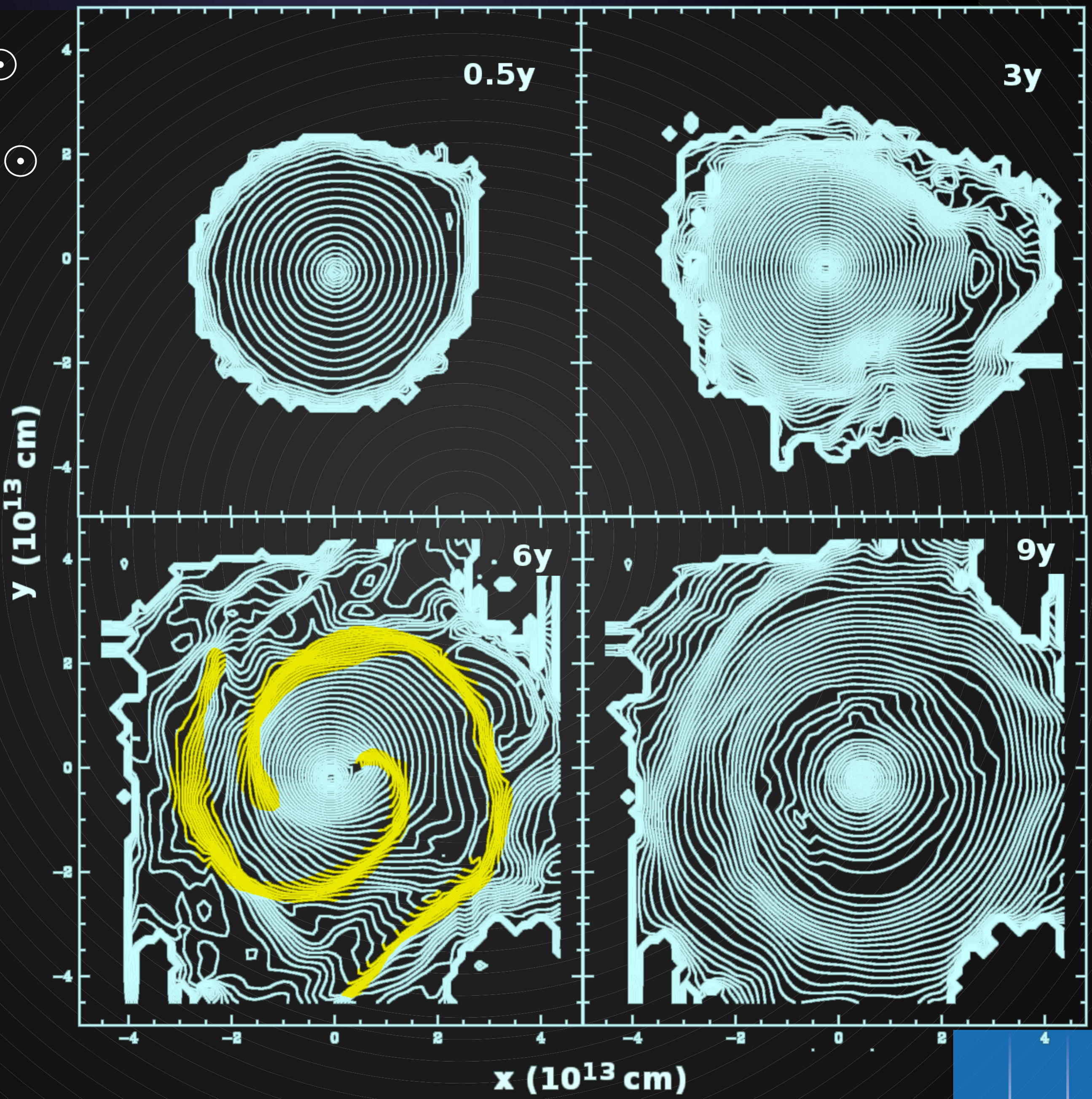
de Marco et al 2003

$$M_1 = 1.25\,\mathrm{M}_\odot$$

$$M_{c1} = 0.56\,\mathrm{M}_\odot$$

$$M_2 = 0.1\,\mathrm{M}_\odot$$

$$P = 6.2\,\mathrm{y}$$



Density

In orbital plane

3D Grid code

Argelander Institut für Astronomie

de Marco et al 2003

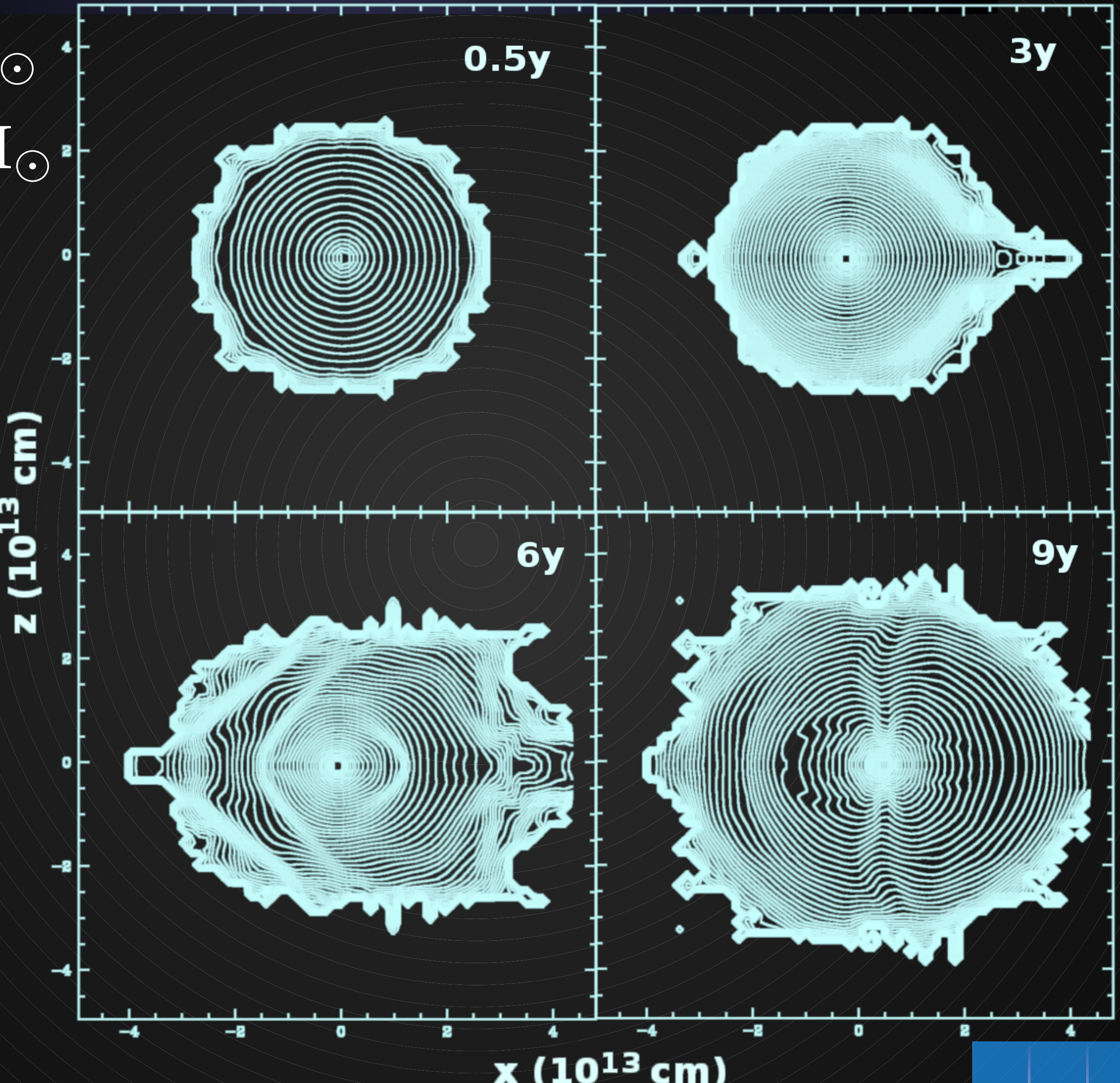
$M_1 = 1.25\,\mathrm{M}_\odot$

$M_{\mathrm{c}1} = 0.56\,\mathrm{M}_\odot$

$M_2 = 0.1\,\mathrm{M}_\odot$

Density

Perpendicular to orbital plane

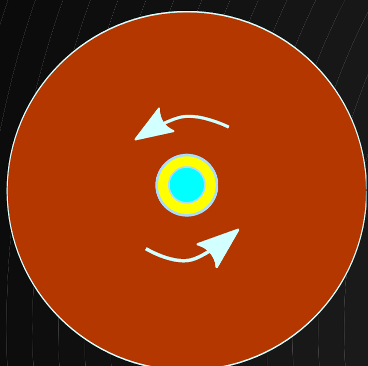


3D Grid code

Argelander Institut für Astronomie

de Marco et al 2003

- Envelope loss:
  - 4% in "Benchmark" model

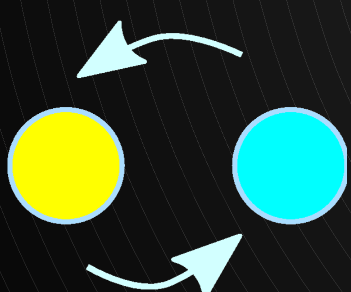


$$M_1 = 1.25\,\mathrm{M}_\odot \;\; M_{c1} = 0.56\,\mathrm{M}_\odot \;\; M_2 = 0.1\,\mathrm{M}_\odot$$

leads to merger

  - 84% in "TP10" model

$$M_1 = 1.04\,\mathrm{M}_\odot \;\; M_{c1} = 0.60\,\mathrm{M}_\odot \;\; M_2 = 0.1\,\mathrm{M}_\odot$$



results in close-binary

Ricker & Taam 2008

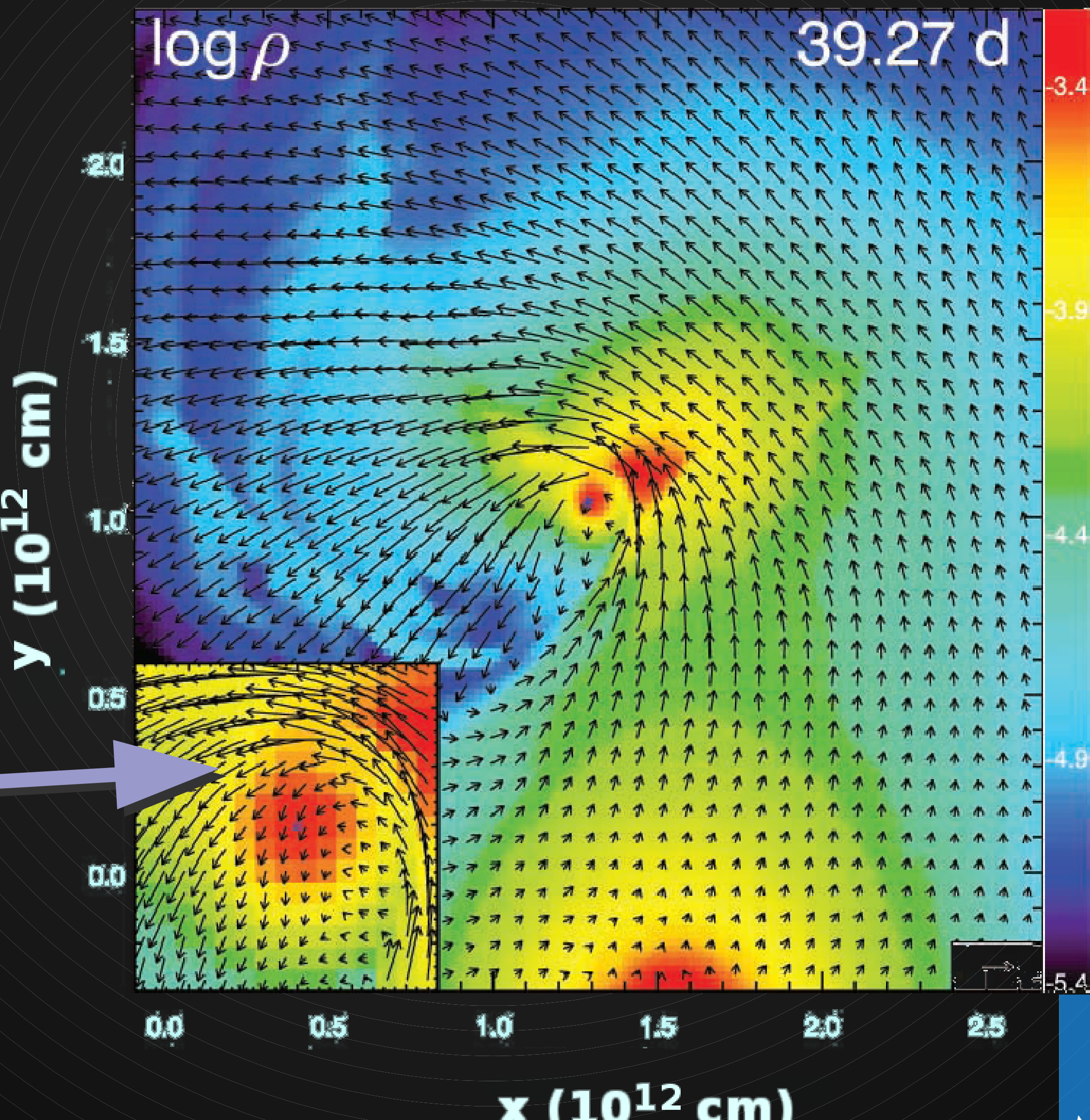
Focus on companion accretion

$M_1 = 1.05\,\mathrm{M}_\odot$

$M_{c1} = 0.36\,\mathrm{M}_\odot$

$M_2 = 0.6\,\mathrm{M}_\odot$

$P = 44\,\mathrm{days}$



Not uniform flow!

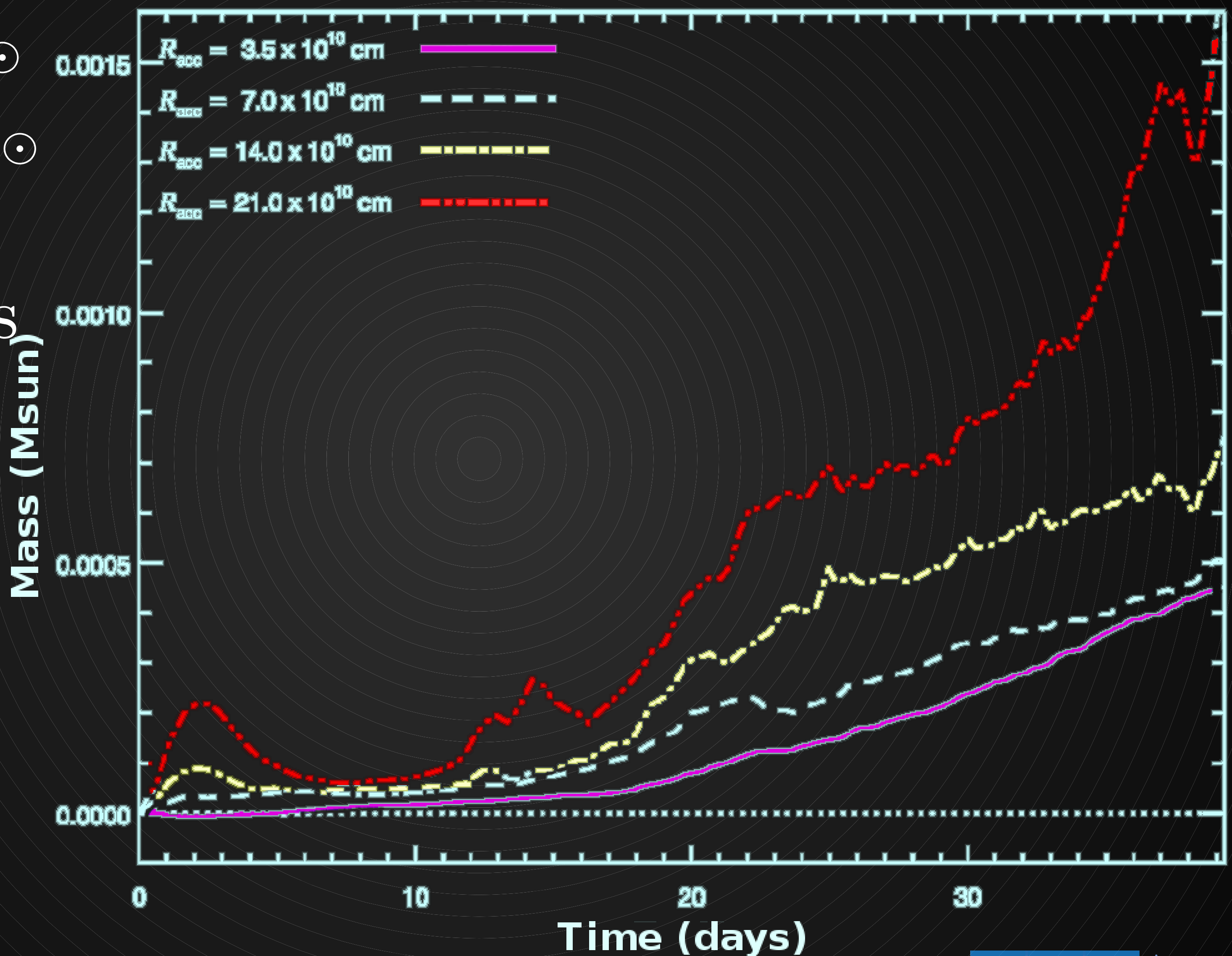
Ricker & Taam 2008

$M_1 = 1.05\,\mathrm{M}_\odot$

$M_{c1} = 0.36\,\mathrm{M}_\odot$

$M_2 = 0.6\,\mathrm{M}_\odot$

$P = 44\,\mathrm{days}$



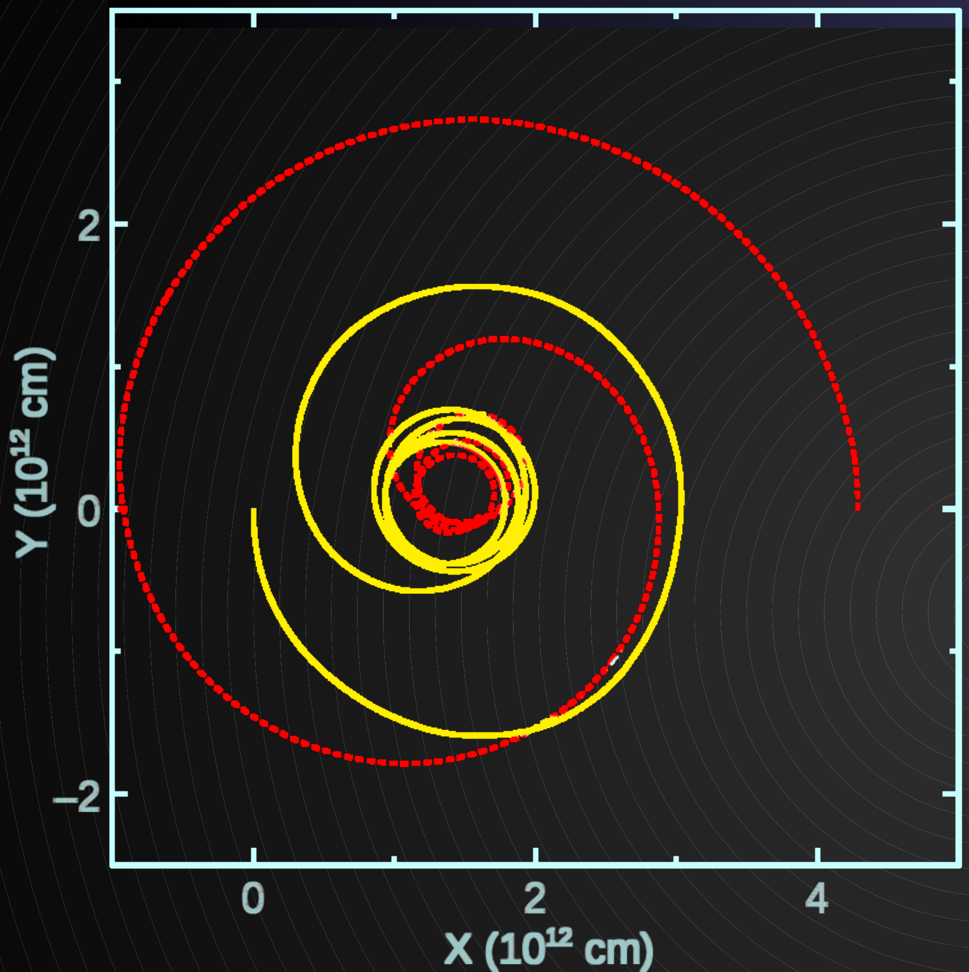
Small amount of mass can be accreted (chemically peculiar secondary?)

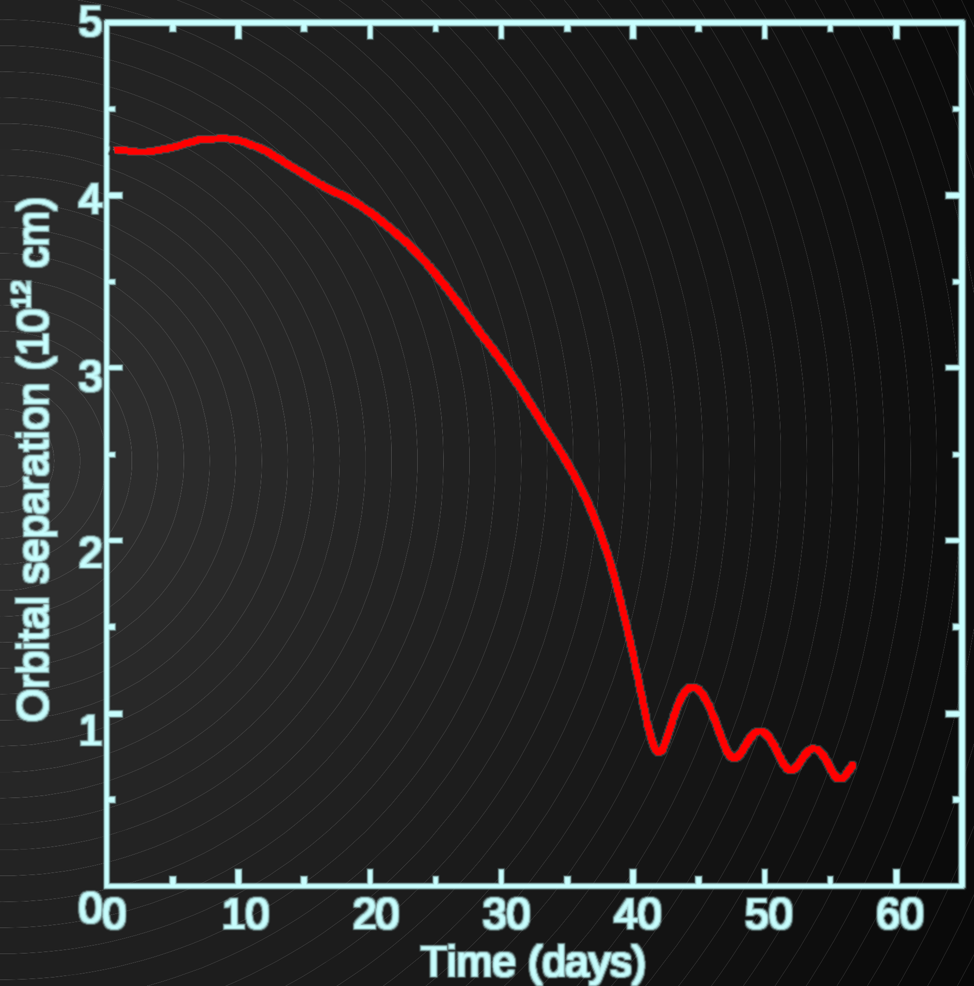
… But rate << Bondi-Hoyle

Argelander Institut für Astronomie

Ricker & Taam 2011

arXiv:1107.3889
Last bloody week!





$M_1 = 1.05\,\mathrm{M}_\odot$

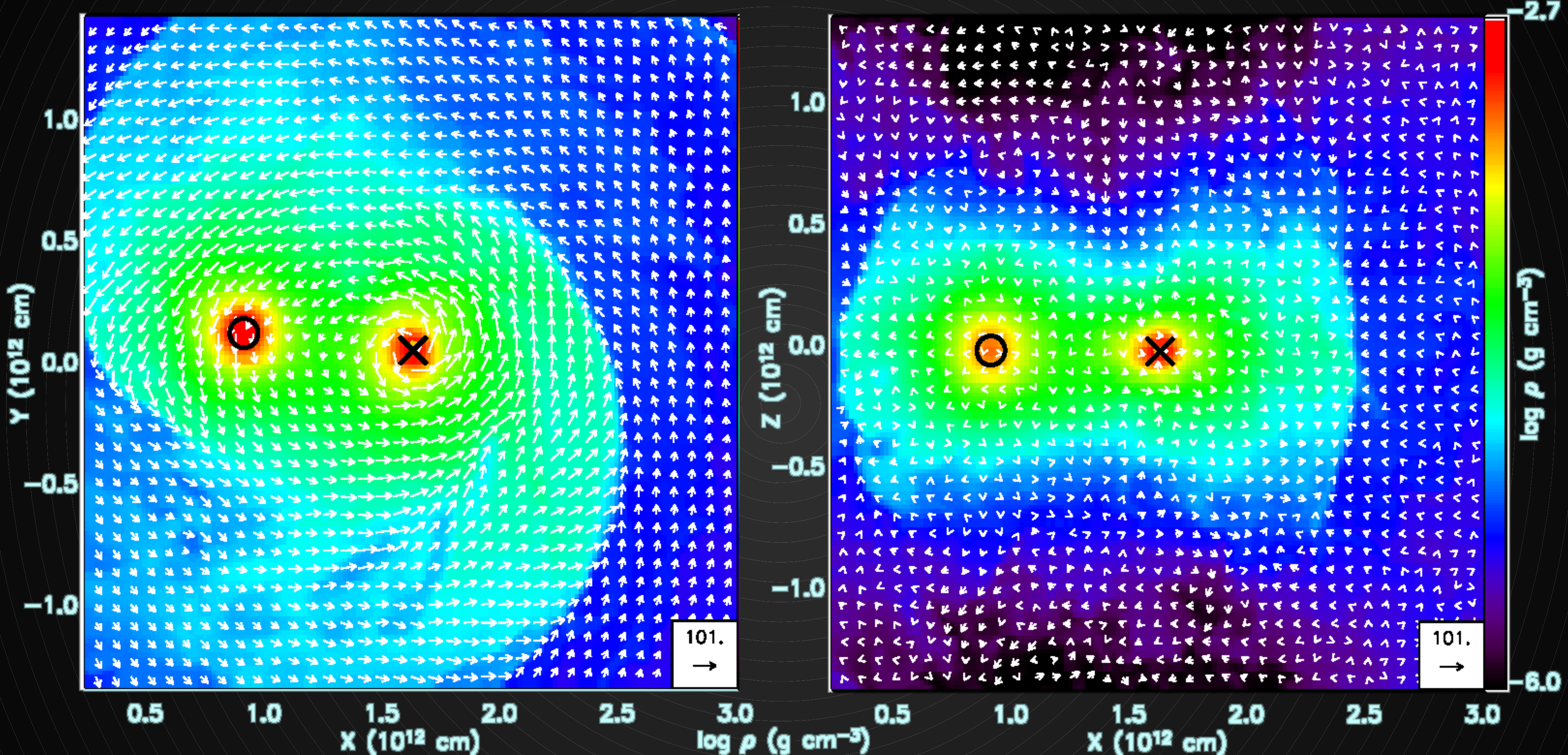
$M_{c1} = 0.36\,\mathrm{M}_\odot$

$M_2 = 0.6\,\mathrm{M}_\odot$

Argelander Institut für Astronomie

Ricker & Taam 2011

arXiv:1107.3889



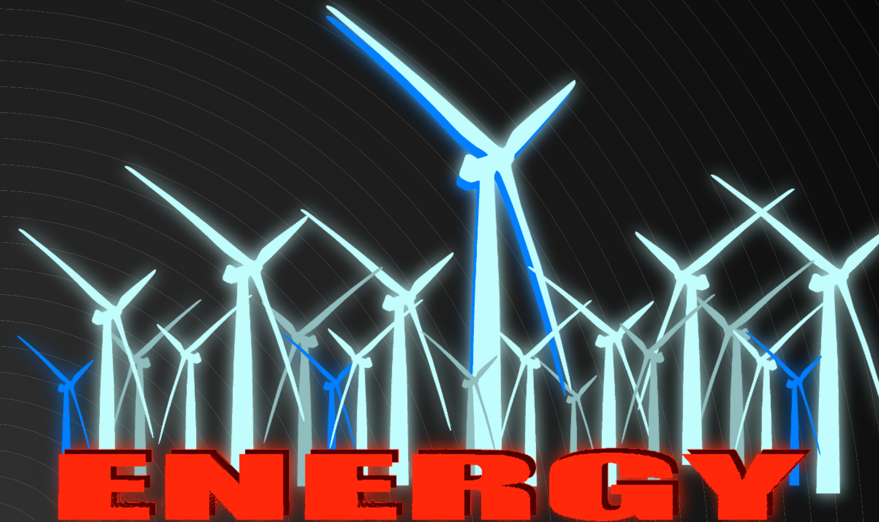
$t = 56\,\mathrm{days}$

$M_1 = 1.05\,\mathrm{M}_\odot \quad M_{c1} = 0.36\,\mathrm{M}_\odot \quad M_2 = 0.6\,\mathrm{M}_\odot$

Argelander Institut für Astronomie

Parameterised models of CEE

α



vs

γ

Energy Budget

$$-\frac{G\,M_1 M_2}{2a}$$

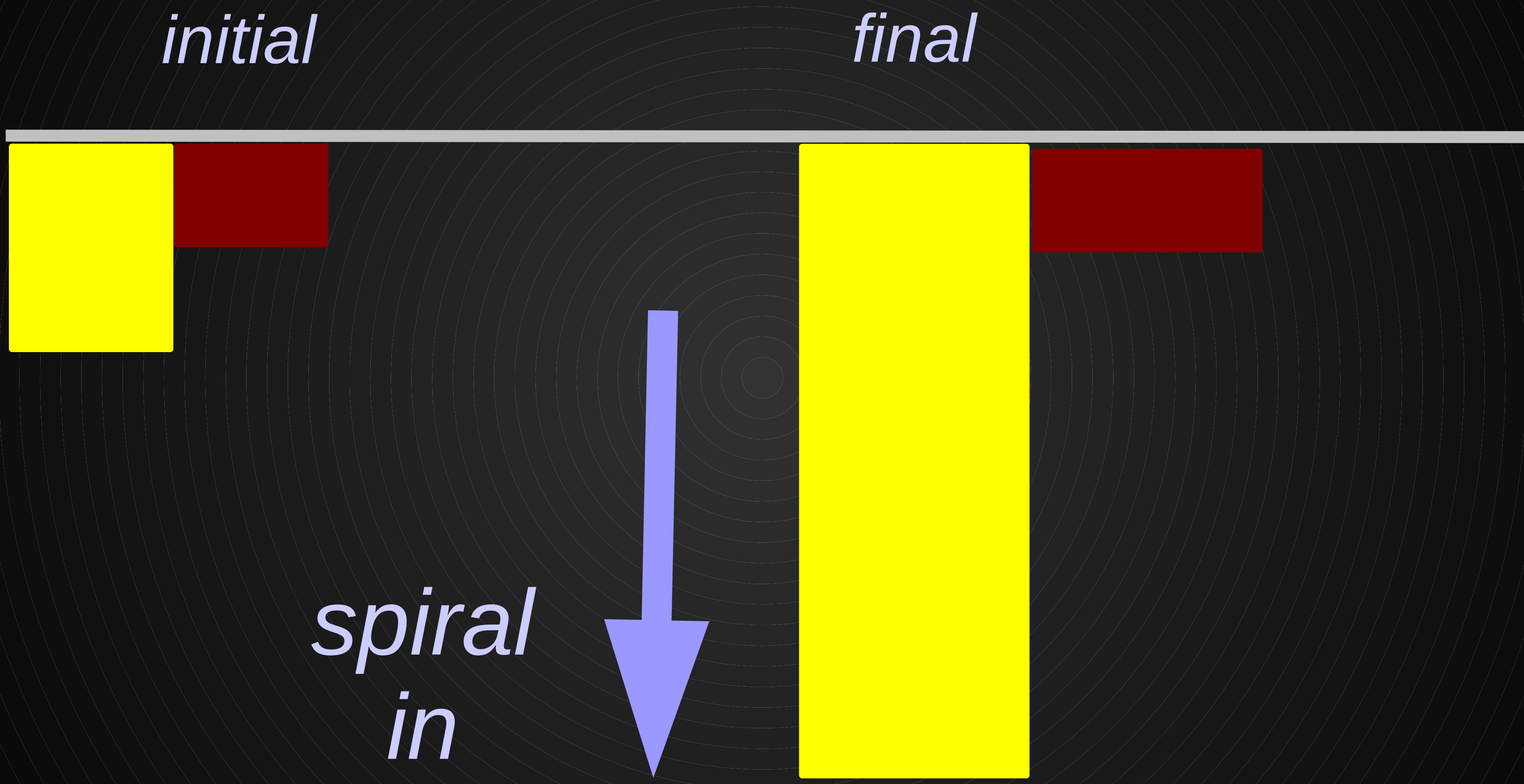
Orbit

$$-\frac{G M_1 M_{1\mathrm{env}}}{\lambda R_1}$$

Envelope

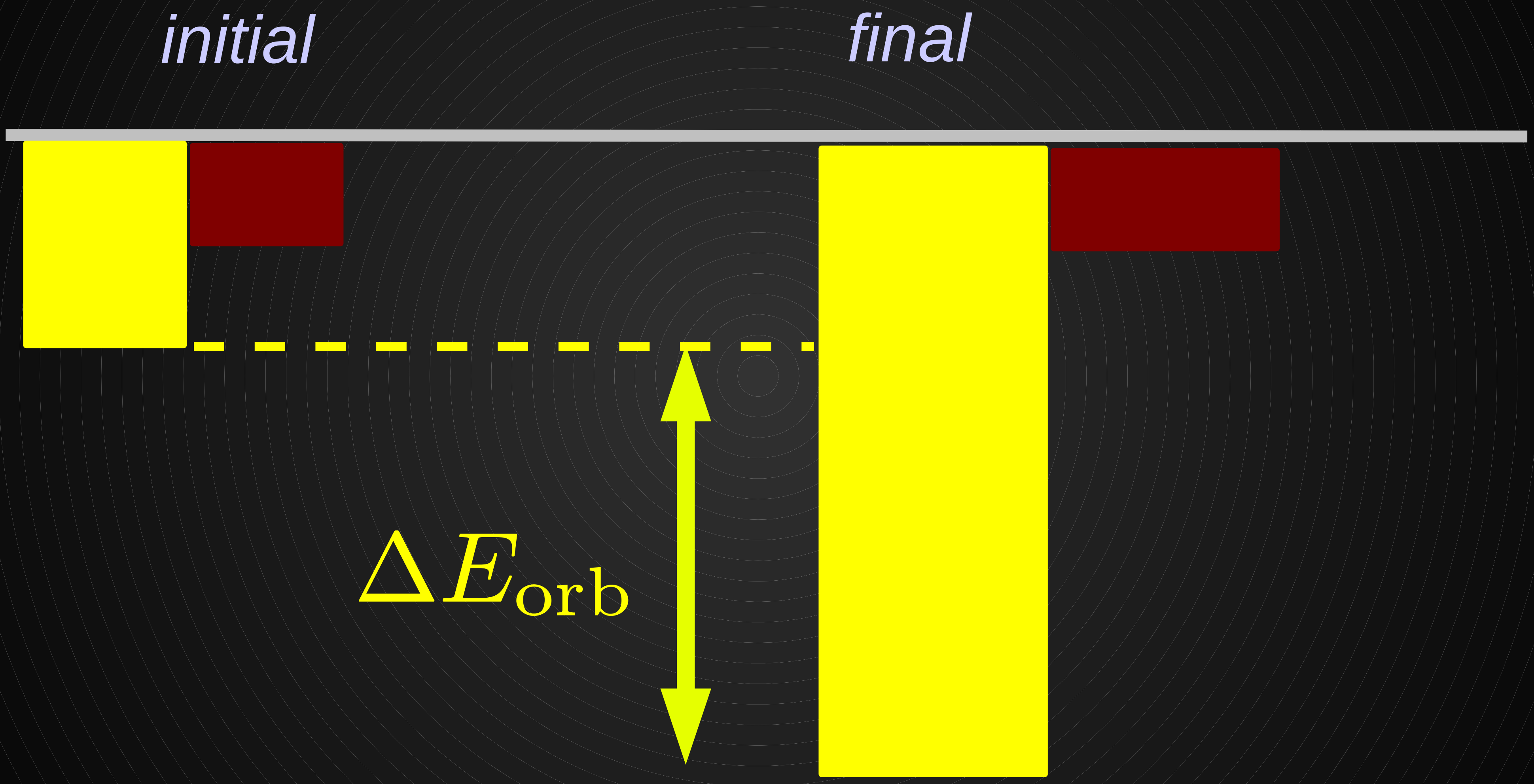
Argelander Institut für Astronomie

Energy Budget



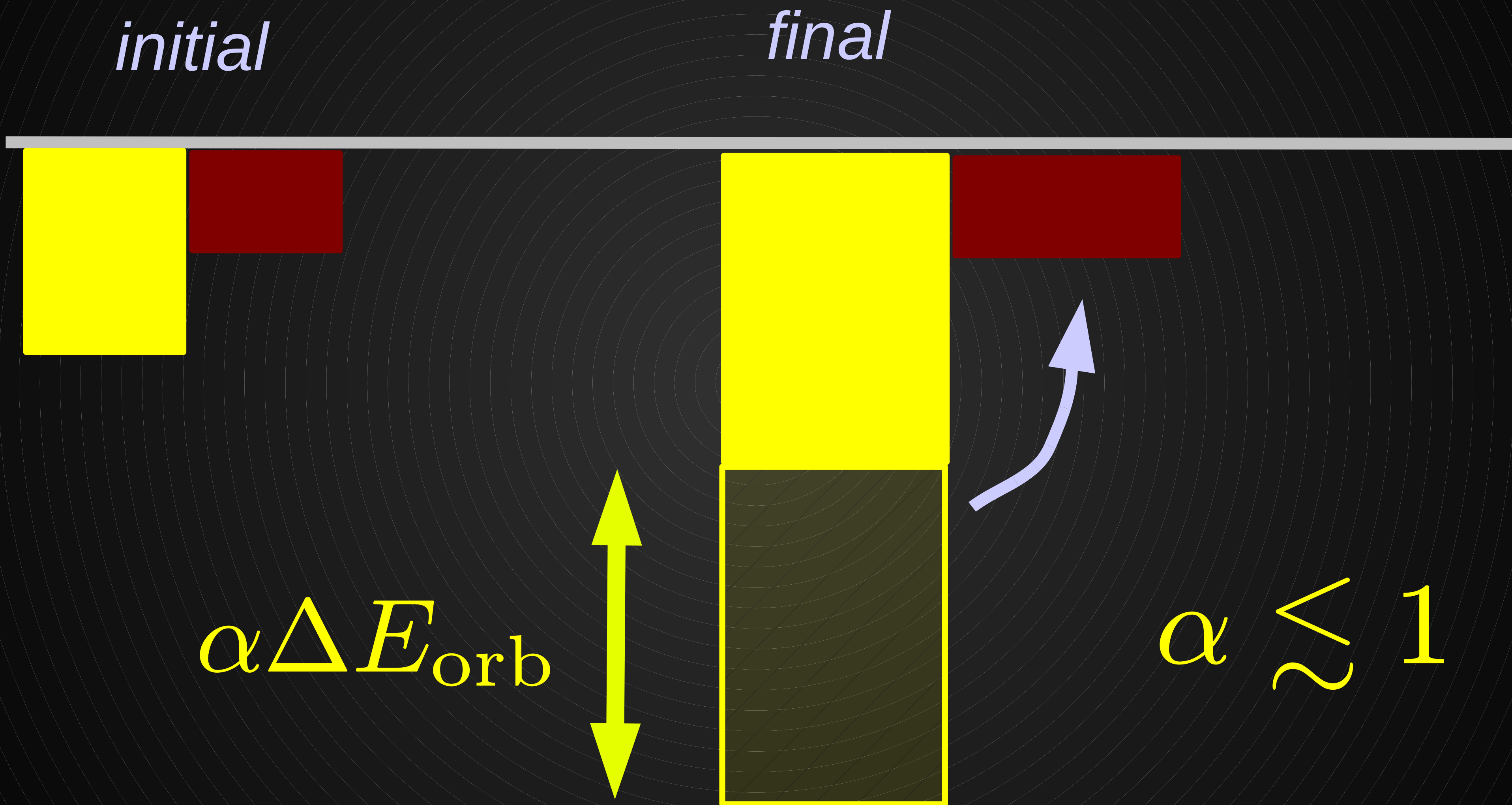
Argelander
Institut
für
Astronomie

Energy Budget



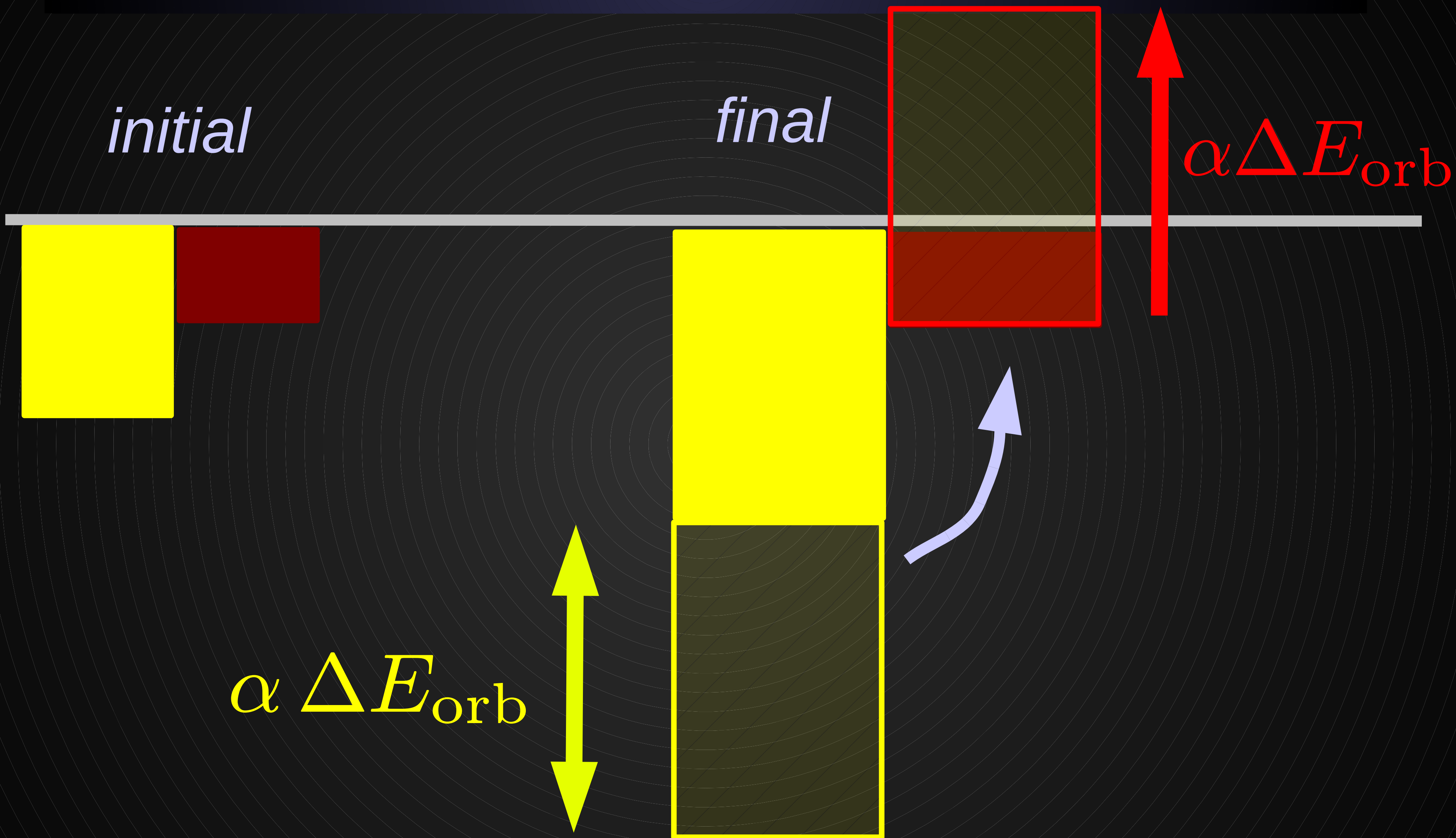
Argelander Institut für Astronomie

Energy Budget

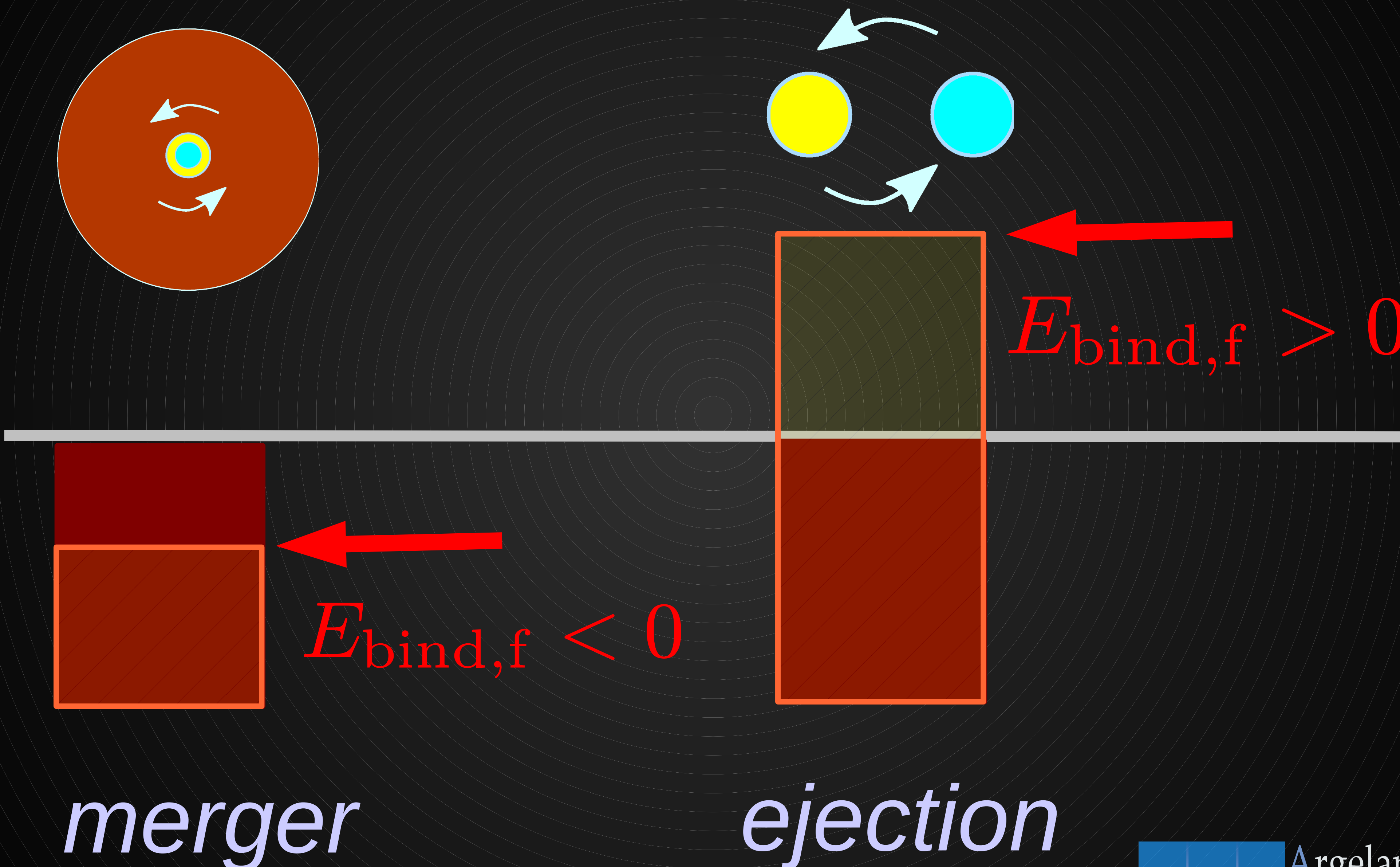


Argelander Institut für Astronomie

Energy Budget



Enevelope Fate



Argelander Institut für Astronomie

The α prescription

$$\Delta E_{\mathrm{bind}} = \alpha\, \Delta E_{\mathrm{orb}}$$

$$\Longrightarrow$$

$$\frac{a_f}{a_i} = f\,(M_1,\, M_{\mathrm{c}1},\, M_2, \alpha,\, \lambda)$$

Beware alternative α prescriptions!

See e.g.
Tutukov & Yungelson 1979
Yungelson et al 1983
Iben & Tutukov 1984
Webbink 1984, *2008*
Also *Zorotovic et al* 2010, *De Marco et al* 2010/11

The α prescription

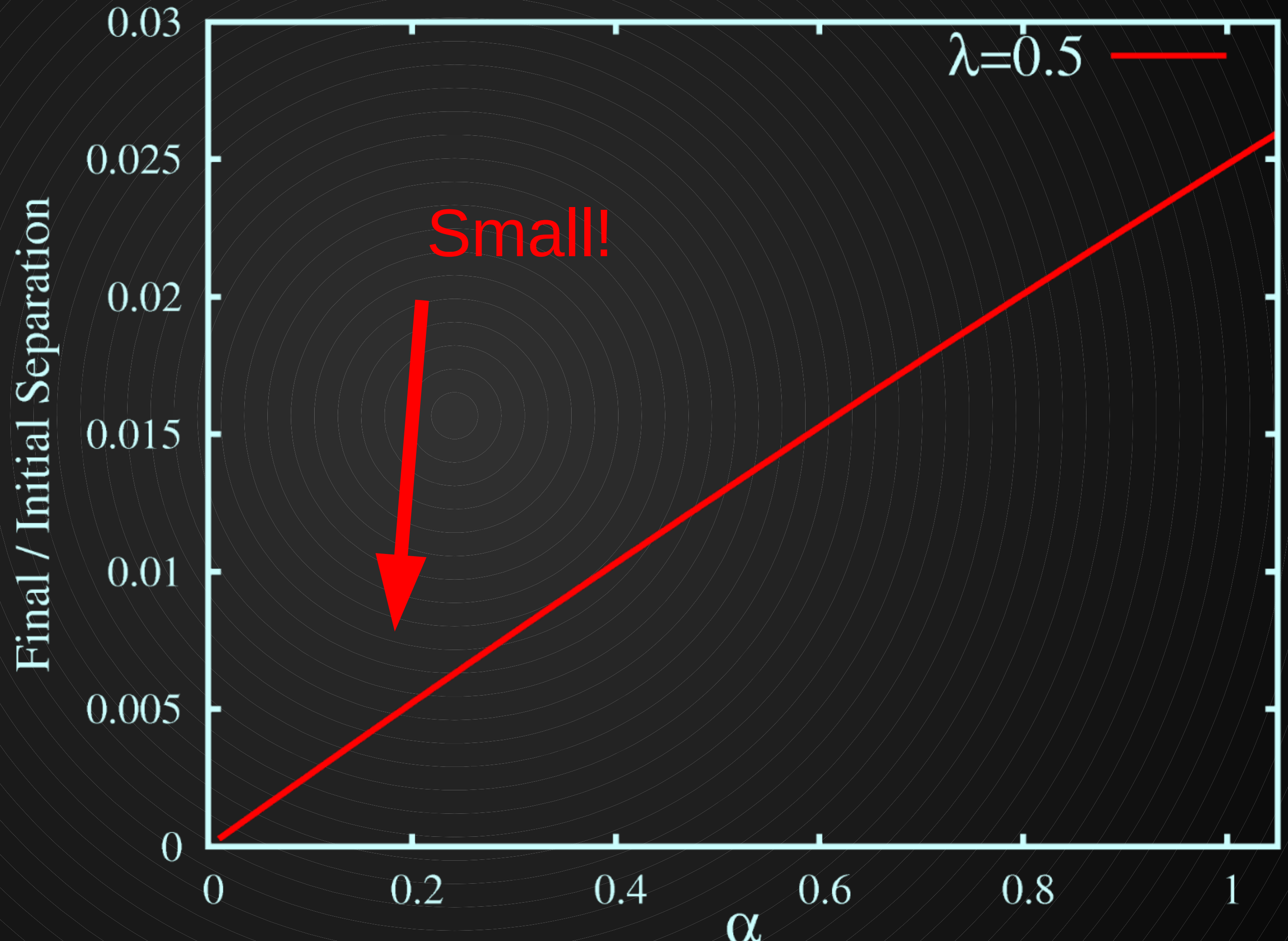
$$\frac{a_f}{a_i} = f\left(M_1,\ M_{\mathrm{c1}},\ M_2, \alpha,\ \lambda\right) \sim \mathrm{small}$$

$$M_1 = 1.5\,\mathrm{M}_\odot$$

$$M_{\mathrm{c1}} = 0.6\,\mathrm{M}_\odot$$

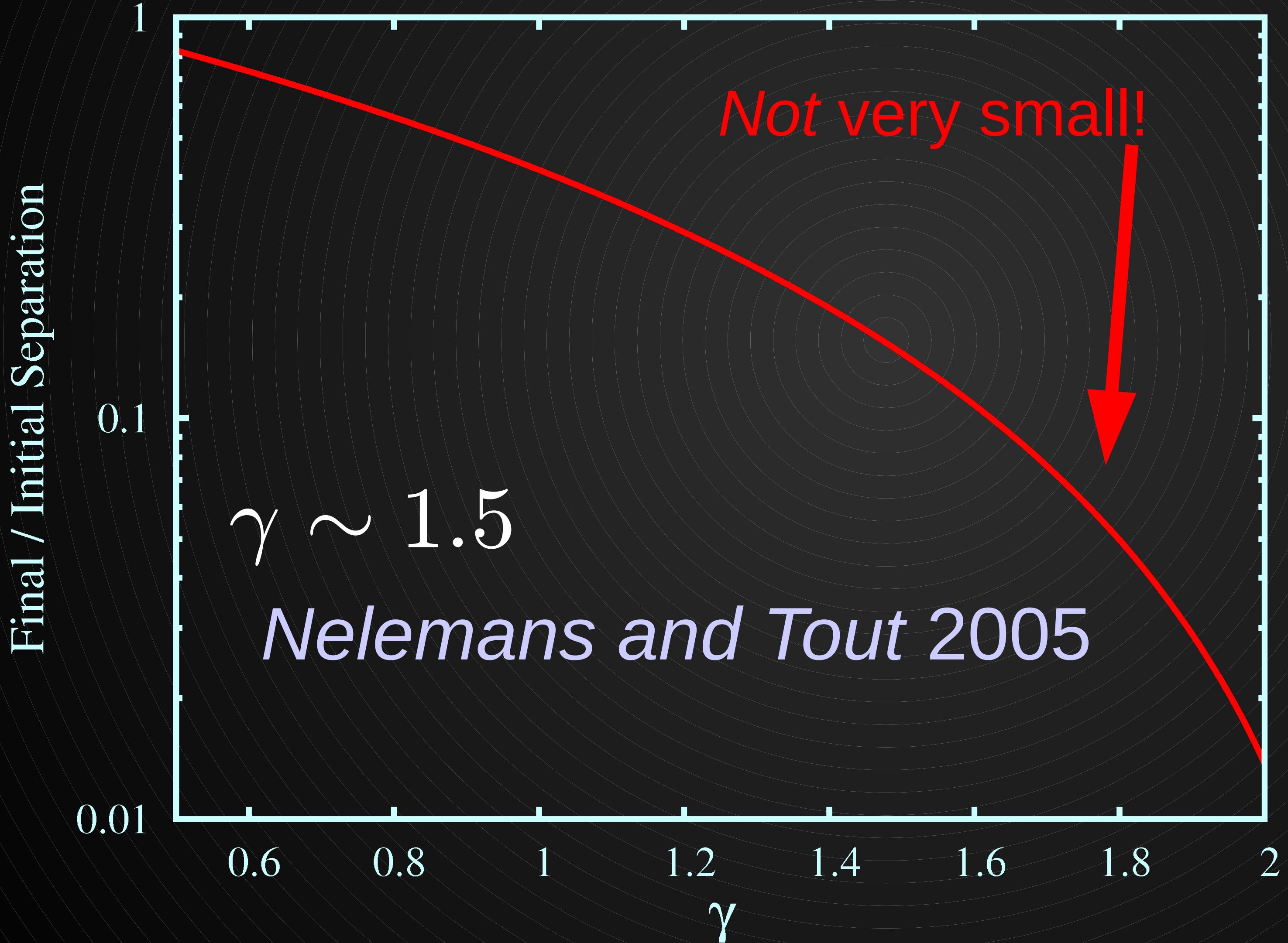
$$M_2 = 0.5\,\mathrm{M}_\odot$$

$$q = 3$$



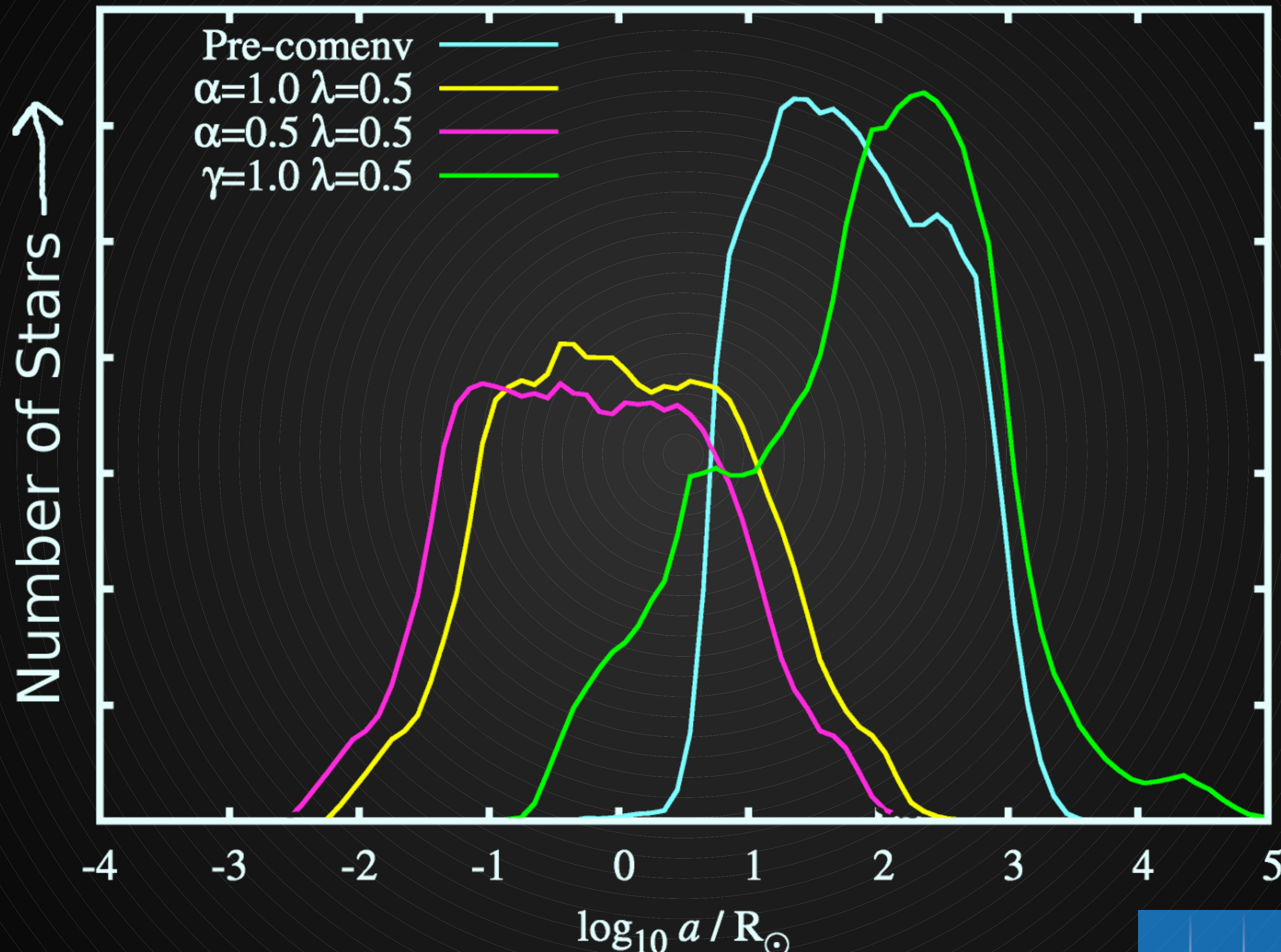
The γ prescription

$$\frac{\Delta J}{J} = \gamma \frac{M}{M_1 + M_2}$$



Argelander Institut für Astronomie

α & γ predictions



Constraining α

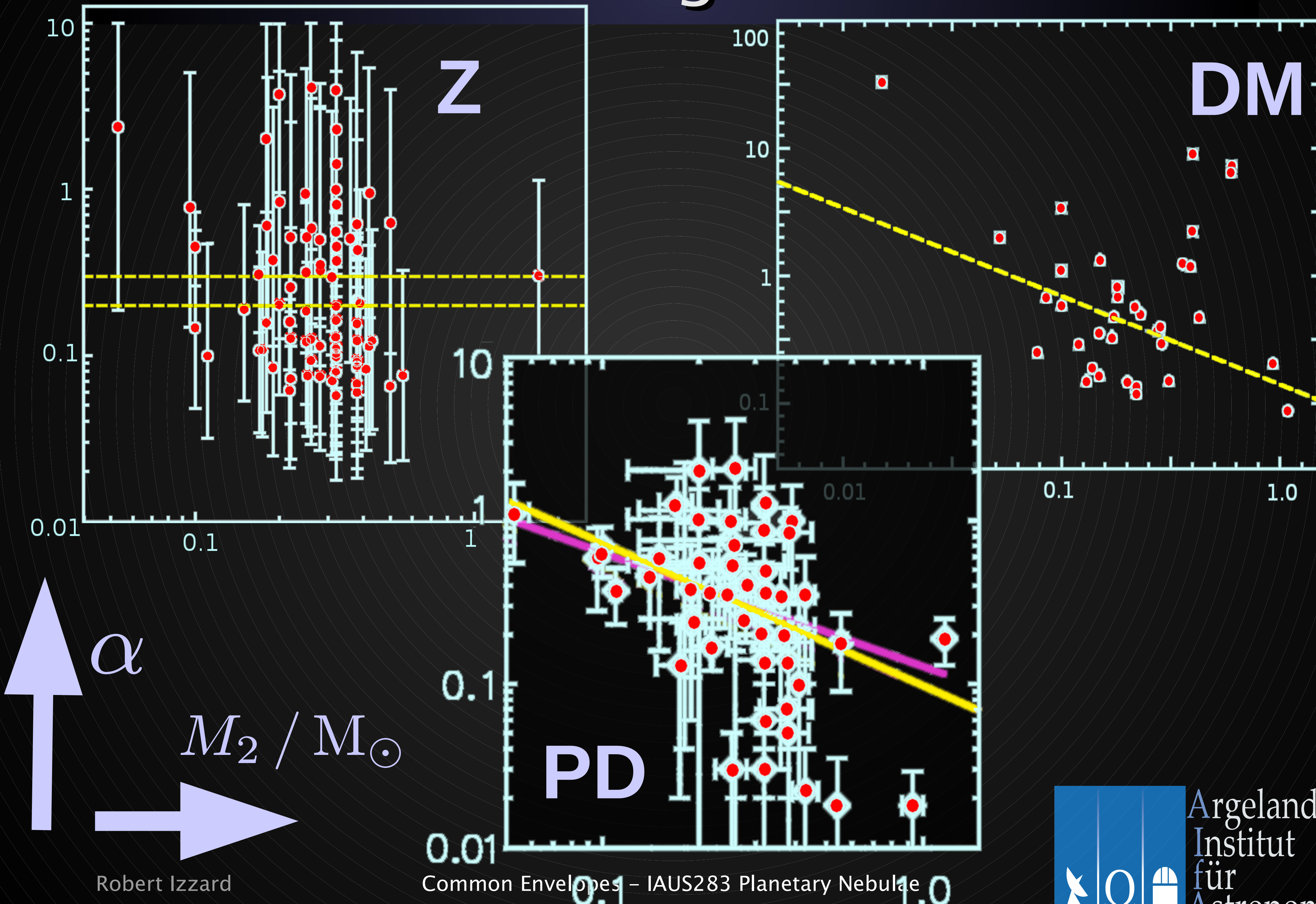
- Most population studies assume α=constant
- Three groups recently attempted to constrain α
  - Zorotovic et al 2010

    WD/MS binaries, 35 from SDSS, 25 from literature
  - De Marco et al 2010

    31 systems, mixed types (de Marco 2009)
  - Davis et al 2011

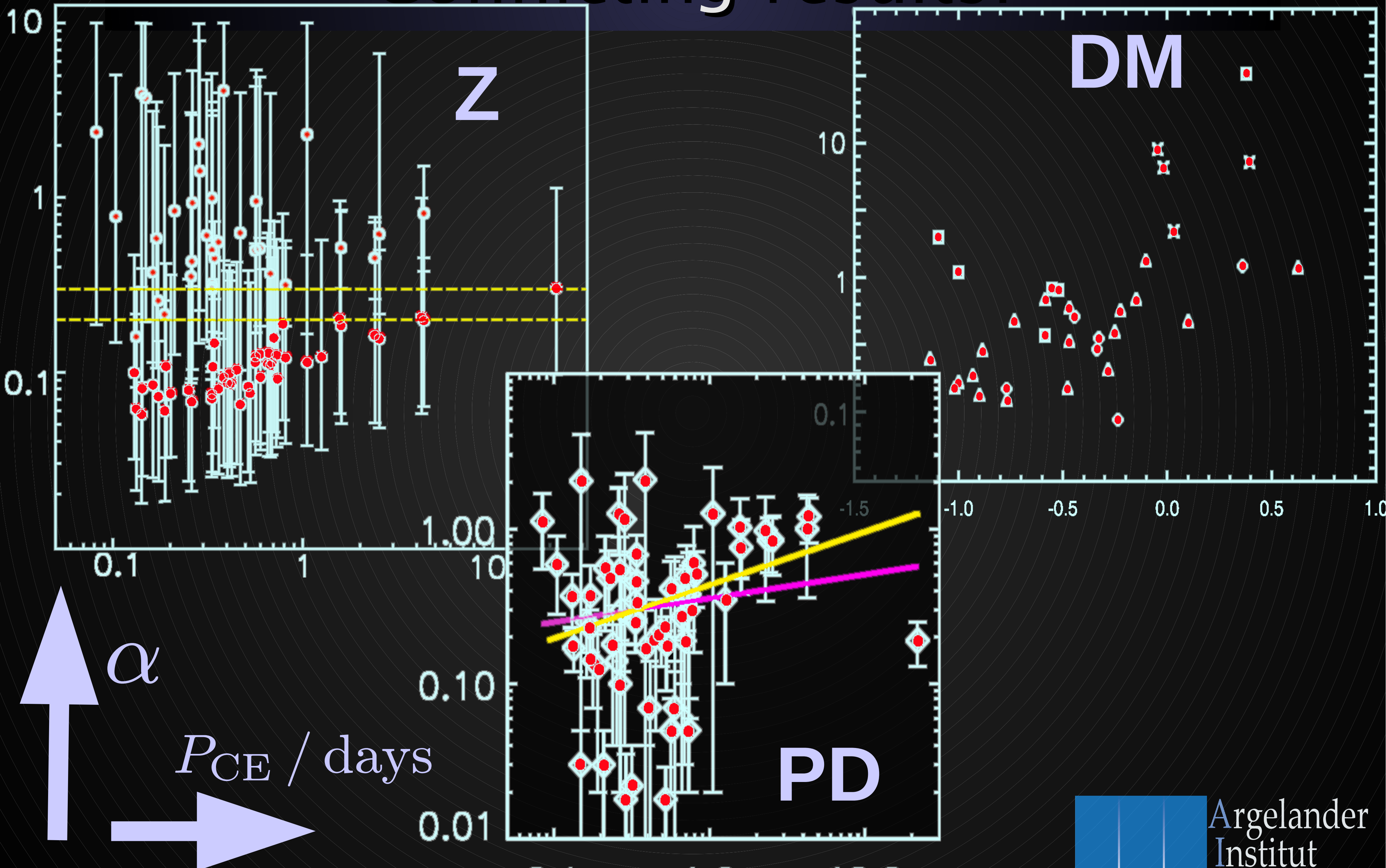
    35 WD/MS binaries, 14 sd+MS (Ritter & Kolb 2003)

Conflicting results?



Argelander Institut für Astronomie

Conflicting results?



Argelander Institut für Astronomie

Improving λ

$$-\frac{GM_1 M_{1\mathrm{env}}}{\lambda R_1}$$

- *Dewi & Tauris* 2000; *Tauris & Dewi* 2001

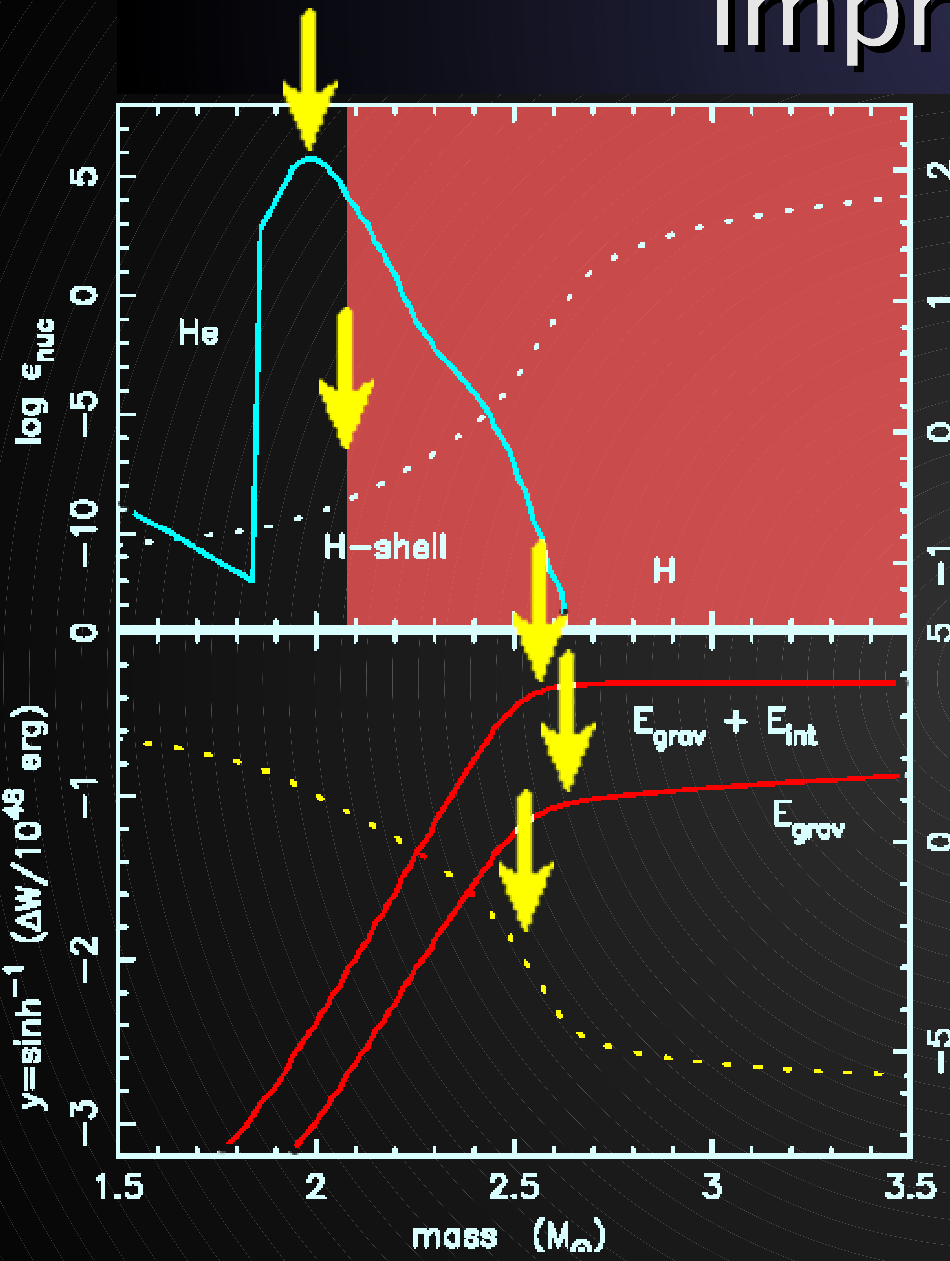
  Uncertainty in where/how to calculate λ

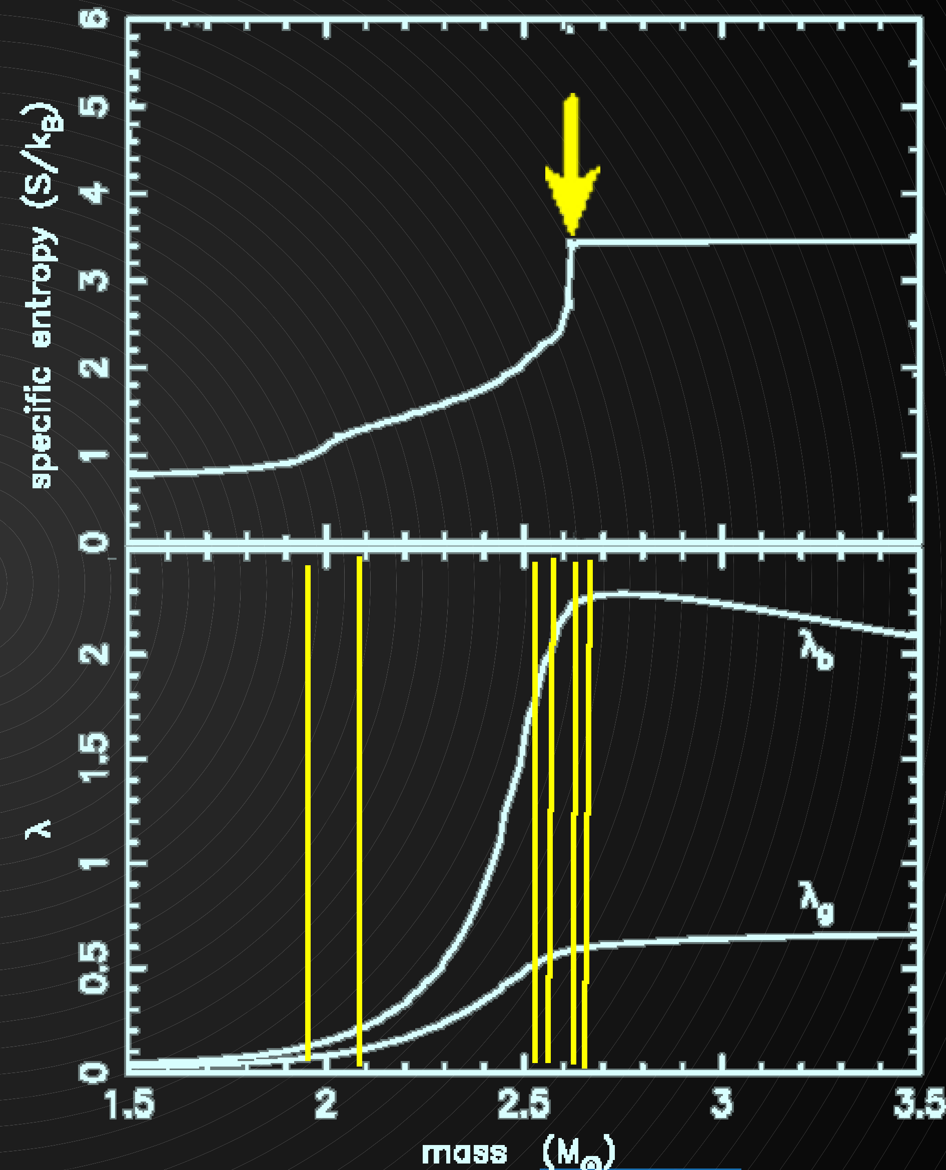
  Fitting functions already in many binary codes

Argelander Institut für Astronomie

Improving λ

$$-\frac{G M_1 M_{1\mathrm{env}}}{\lambda R_1}$$





Dewi & Tauris 2000; *Tauris & Dewi* 2001

$4\,M_\odot$

Argelander Institut für Astronomie

Improving λ

$$-\frac{GM_1 M_{1\mathrm{env}}}{\lambda R_1}$$

- *Dewi & Tauris* 2000; *Tauris & Dewi* 2001

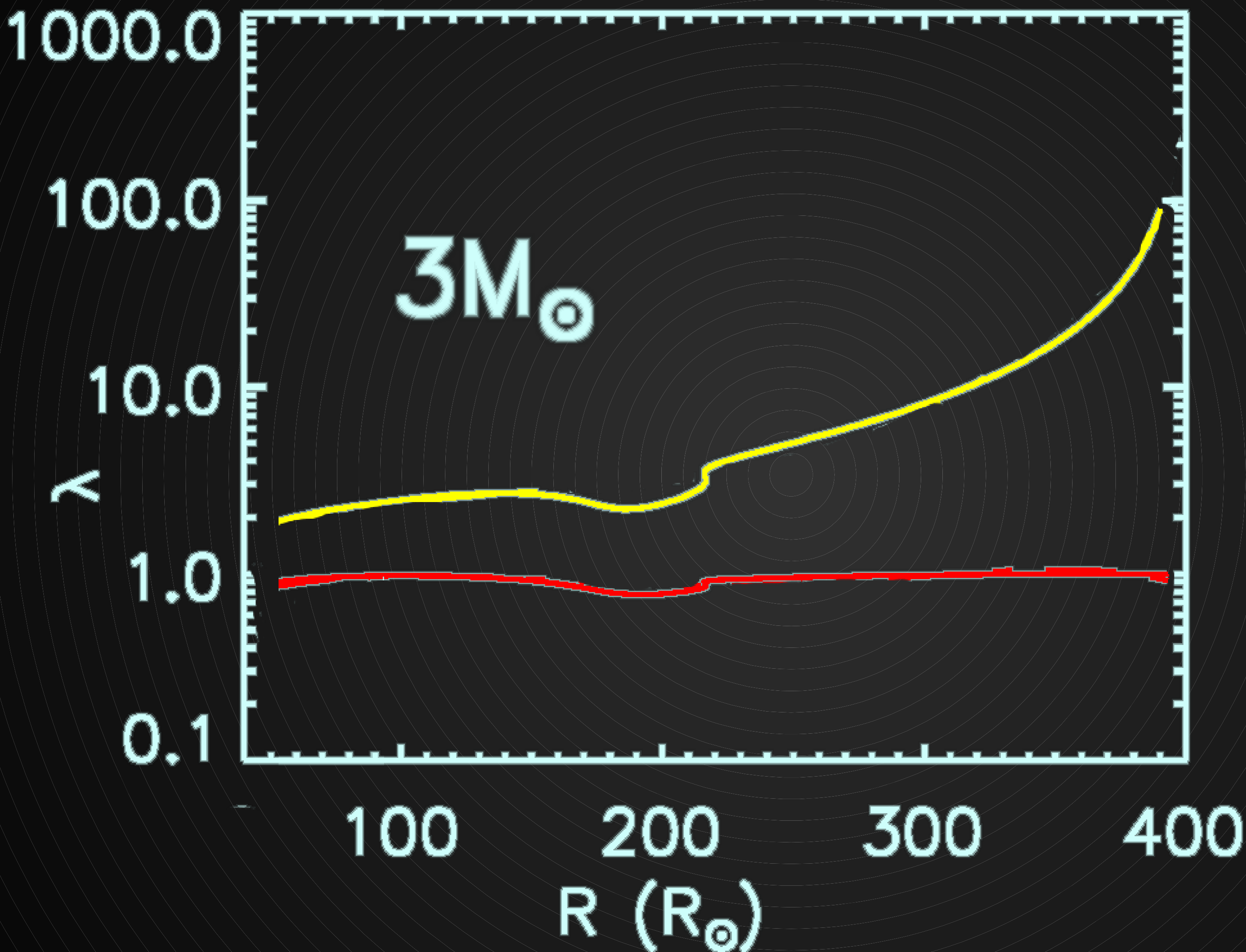
  Fitting functions already in many binary codes

- Recent updates:

- *Xu & Li* 2010 $1 \leq M/\mathrm{M}_\odot \leq 20$ $Z = 0.001, 0.02$

Improving λ

$$-\frac{GM_1 M_{1\mathrm{env}}}{\lambda R_1}$$



With internal energy

Only gravitational energy

Xu & Li 2010 Z=0.02

Argelander Institut für Astronomie

Improving λ

$$-\frac{GM_1 M_{1\mathrm{env}}}{\lambda R_1}$$

- *Dewi & Tauris* 2000; *Tauris & Dewi* 2001

  Fitting functions already in many binary codes

- Recent updates:
- *Xu & Li* 2010 $1 \leq M/\mathrm{M}_\odot \leq 20$ $Z = 0.001, 0.02$
- *Loveridge, van der Sluys & Kalogera* 2010

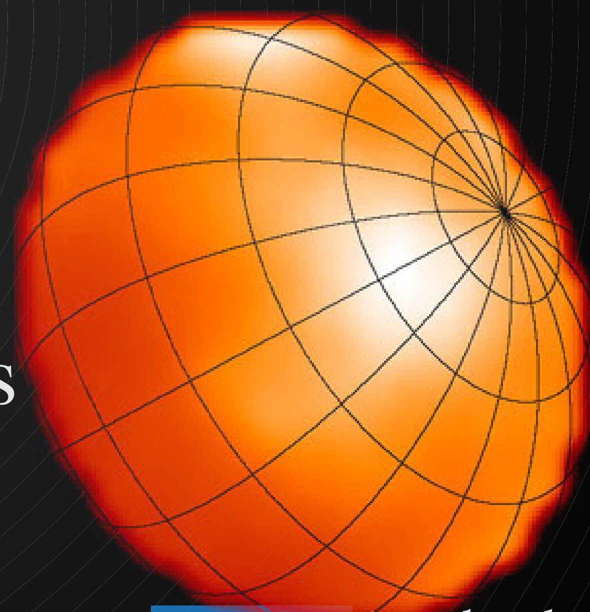
  $0.8 \leq M/\mathrm{M}_\odot \leq 100$ $Z = 10^{-4} \leq Z \leq 0.03$

- See also *Ivanova* 2011 discussion of

  divergence and compression points

Other objects and CEE

- Cataclysmic variables (classical novae, SNIa)
- Close double white dwarfs (SNIa)
- Short-period barium/CH stars (P<100 days, e=0.1!)
- Mergers (FK Com, R-type carbon stars?)
- Massive stars ("all" binaries!) :



SNIc

Gamma-ray bursts

rapid rotators

NS-NS/BH etc etc etc

Conclusions or *Where next* ?

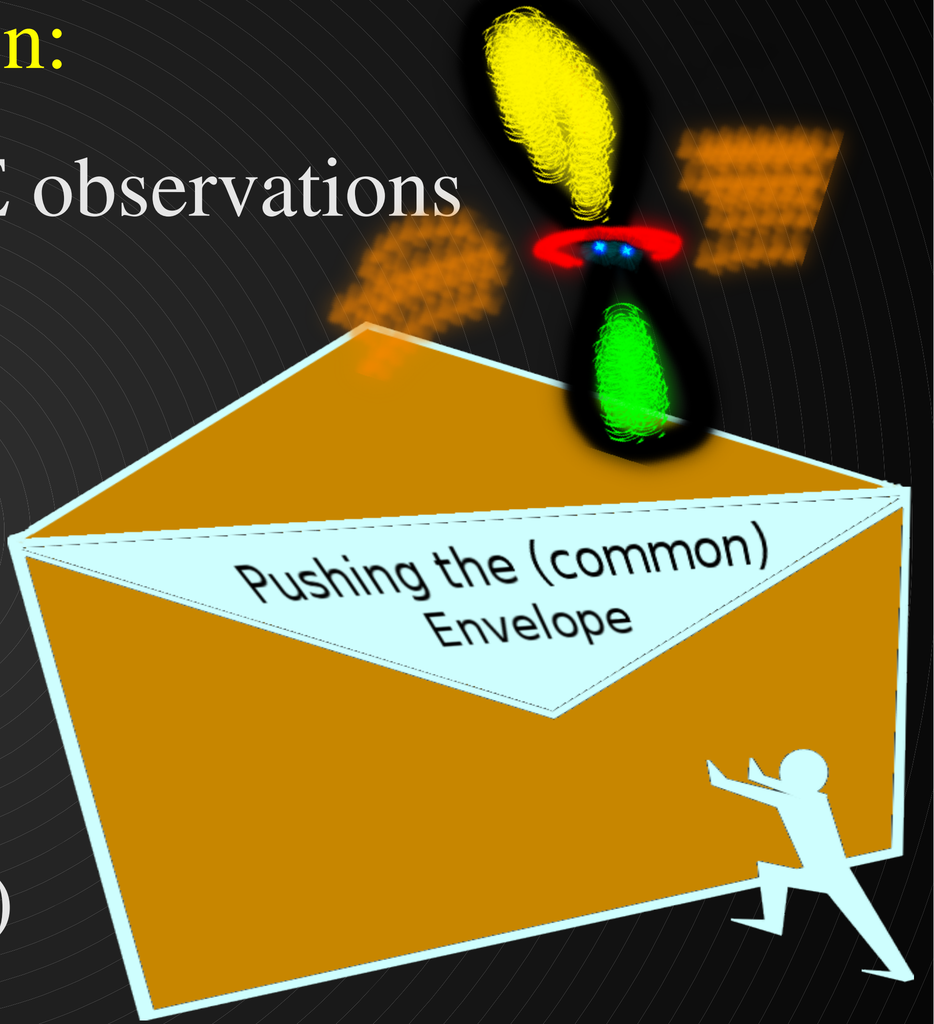
Current research is focused on:

- Constraining α from post-CE observations
- 3D simulations
- Improved algorithms for λ

We need:

- Better statistics (more systems!)
- Further constraints (such as?)
- Bigger brains, larger computers,

better simulations all the way to THE END.



Argelander Institut für Astronomie