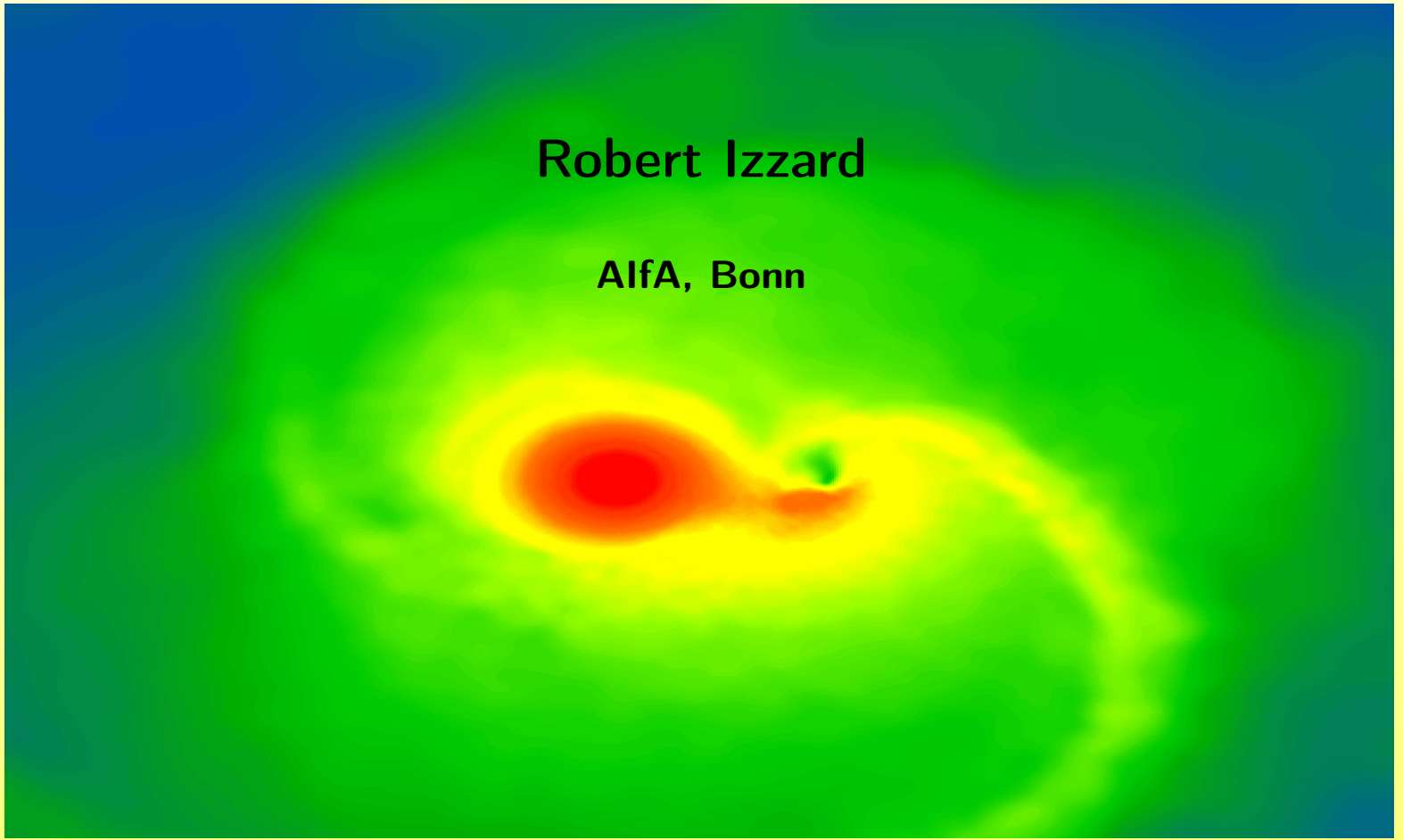
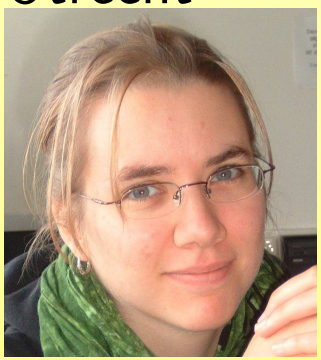
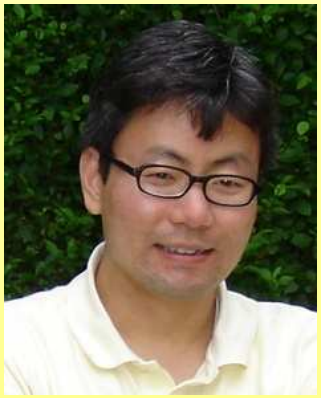
Mass Transfer in Binary Stars



Robert Izzard

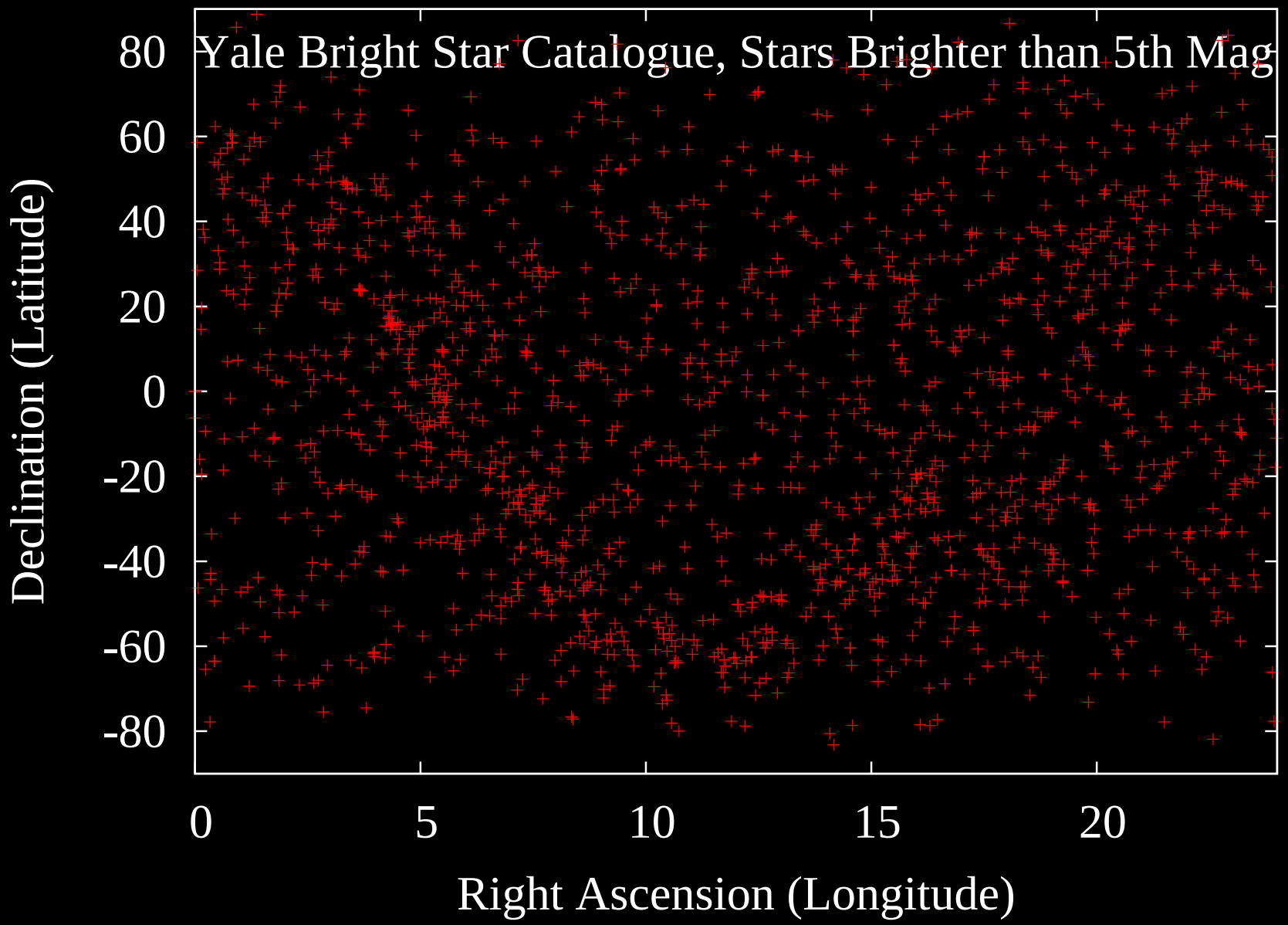
AIfA, Bonn

Co-conspirators

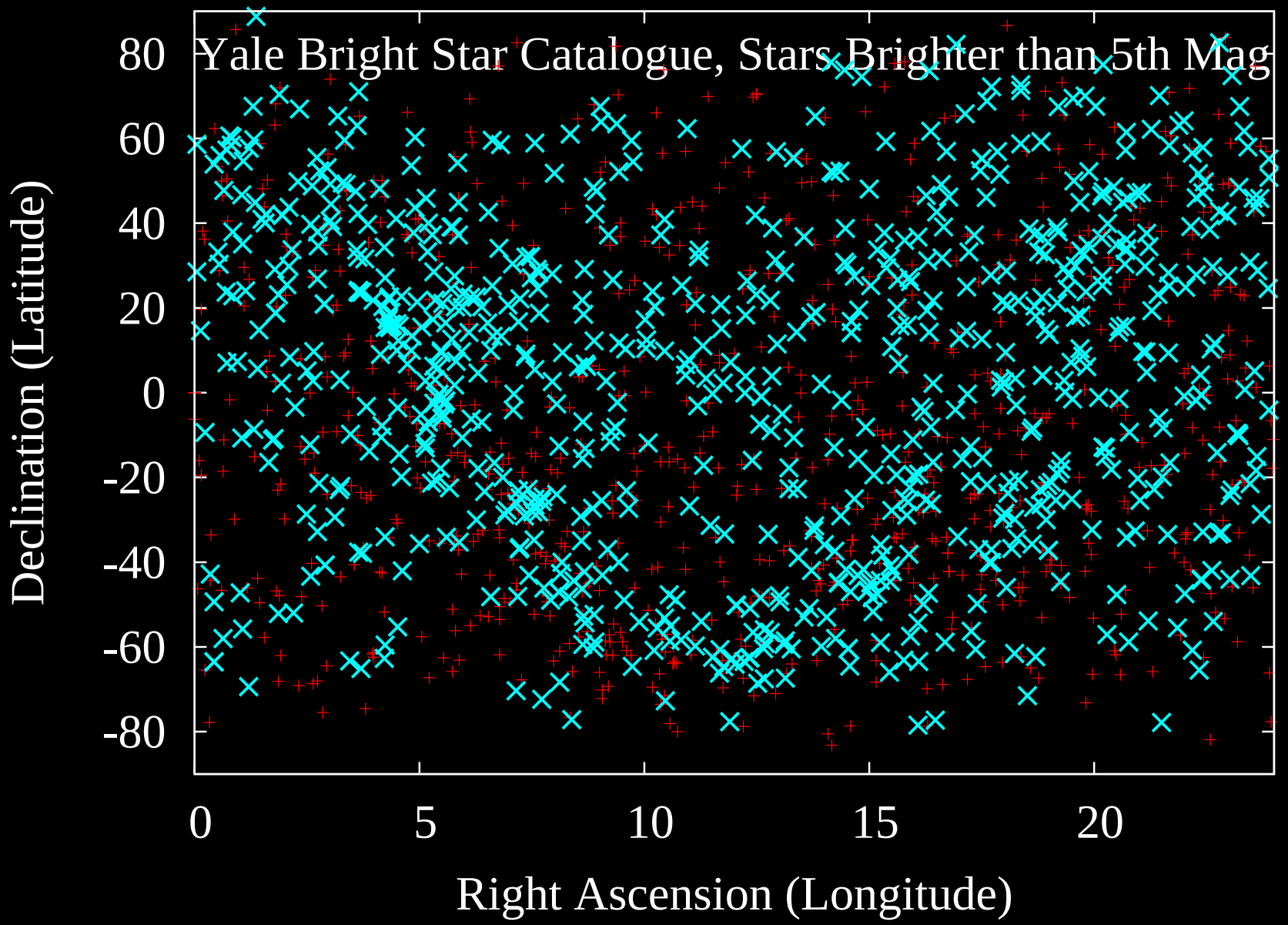
Tyl Dermine, ULB 	Ross Church, Lund 	Shazrene Mohamed, Bonn 	Selma de Mink, Utrecht/Bonn/STScI 
Ines Brott, Utrecht 	Norbert Langer, Utrecht/Bonn 	Sung-Chul Yoon, Bonn 	VLT/FLAMES team ULB (Jorissen) EU 

1. Why do we care about Binary Stars?
2. Single vs Binary Evolution
3. RLOF vs Wind Accretion
4. e.g. Wind mass transfer: Barium Stars
5. e.g. RLOF in Massive Stars
6. Where do I (we?) go next?

Night Sky


Yale Bright Star Catalogue, Stars Brighter than 5th Mag
Declination (Latitude)
80
60
40
20
0
-20
-40
-60
-80
0
5
10
15
20
Right Ascension (Longitude)

Night Sky Binaries



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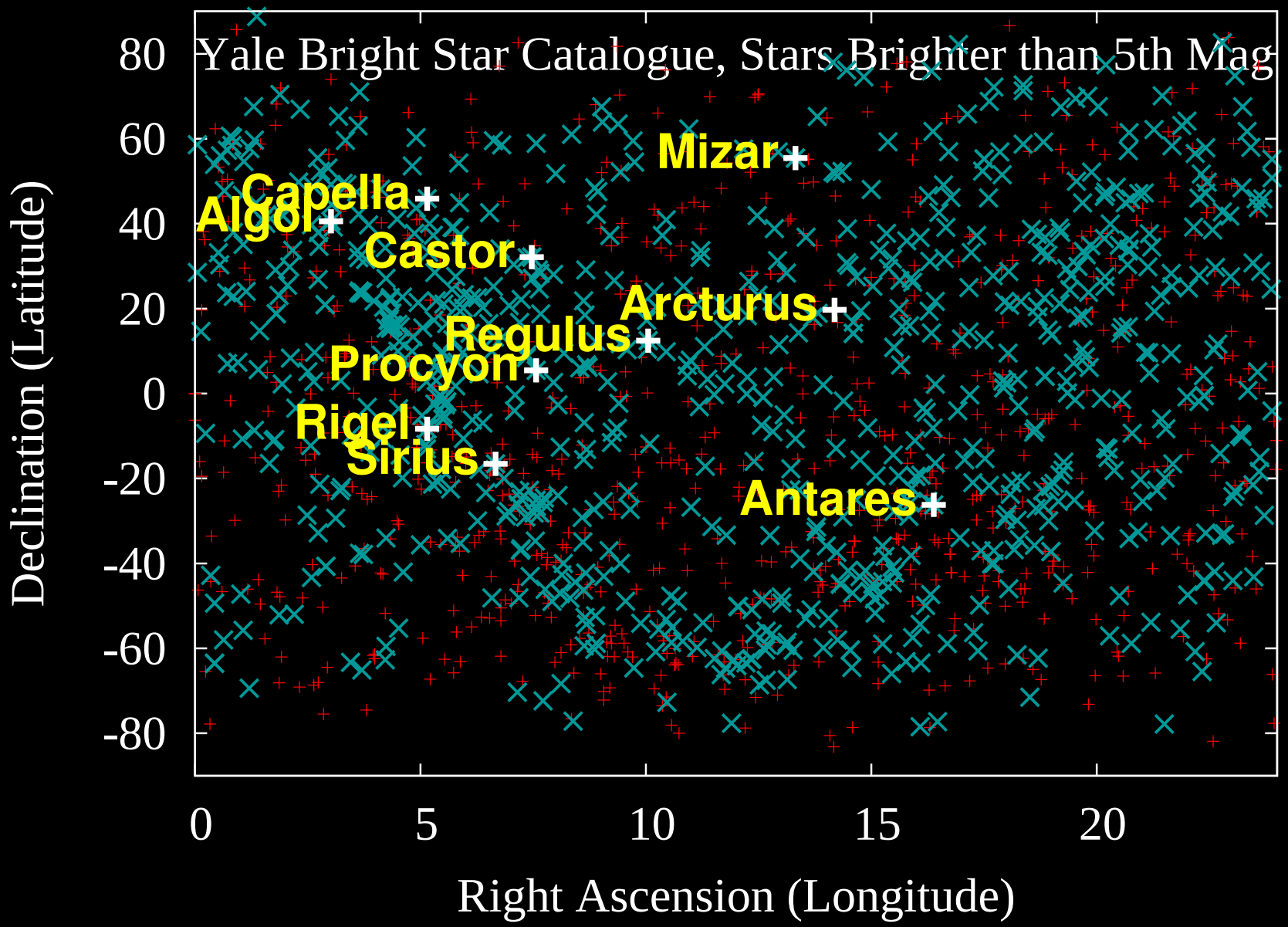
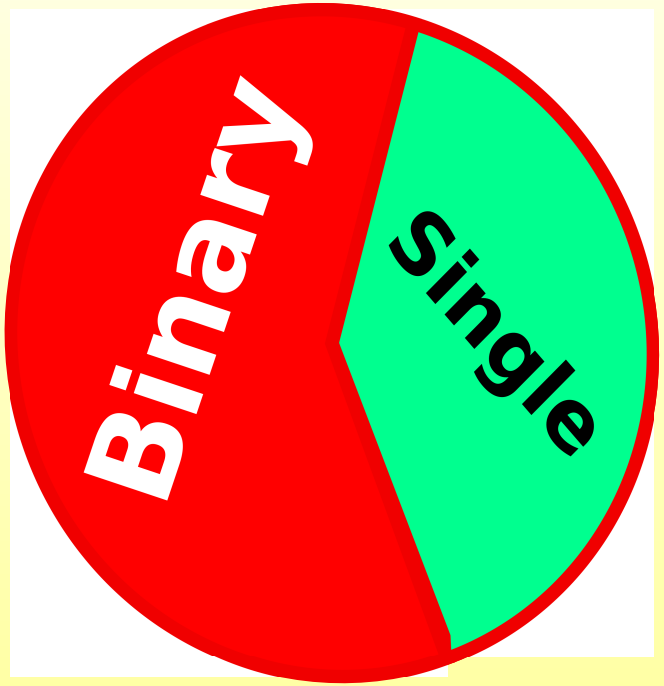


Useful numbers

Stars brighter than 5th magnitude in Yale catalogue

- 1618 star systems
- 825 single-star systems
- 793 binary-star systems
- Binary System Fraction $= \frac{793}{1618} = 49\%$
- 51 single stars : 98 stars in binaries
  - Binary Star Fraction $= \frac{793 \times 2}{825 + 793 \times 2} = \frac{1586}{2411} = 66\%$



- **Most stars are in binaries!**

Why Binaries?

- Accurate stellar masses, radii, luminosities
- Gamma-ray bursts:
  long and short, very old! ($z \sim 8$)
- Type Ia supernovae: Standard candles (?)
  Tell us Universe is expanding?
- Galactic Chemical Evolution: SN Ia, Ic, novae
- Stellar mergers
- X-ray binaries, CVs, AM CVns (grav waves)
- Chemically peculiar stars (my favourites!)
- Vital to understanding galaxies, stellar clusters, star formation, even cosmology...

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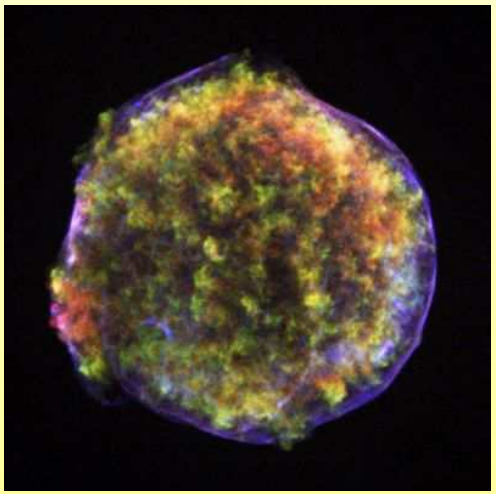

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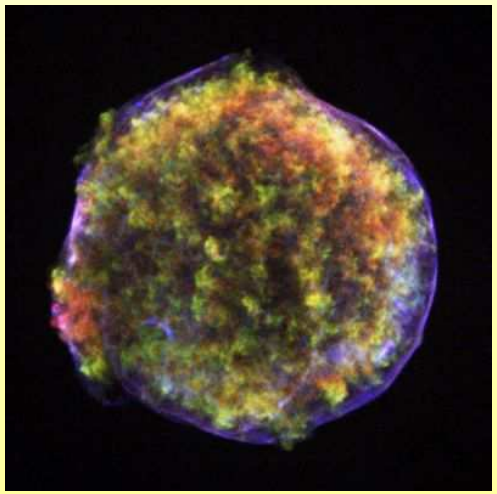

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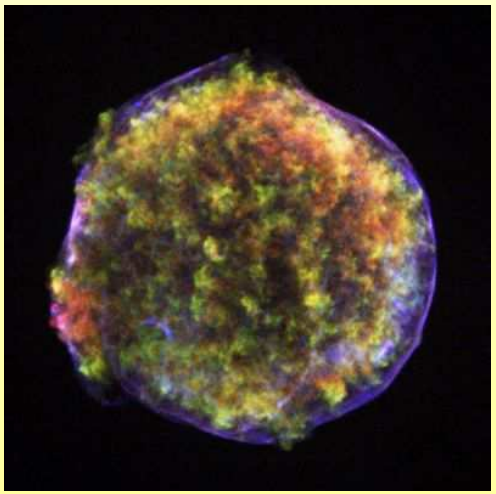

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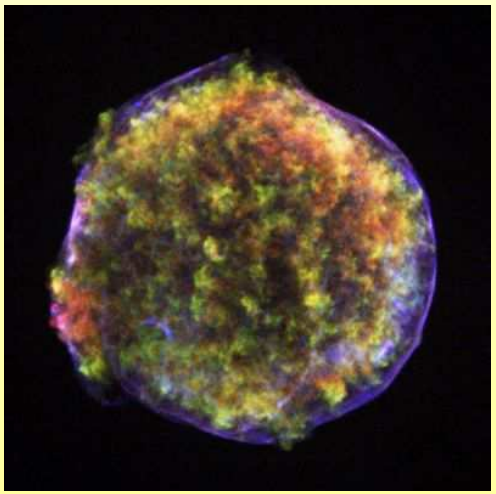

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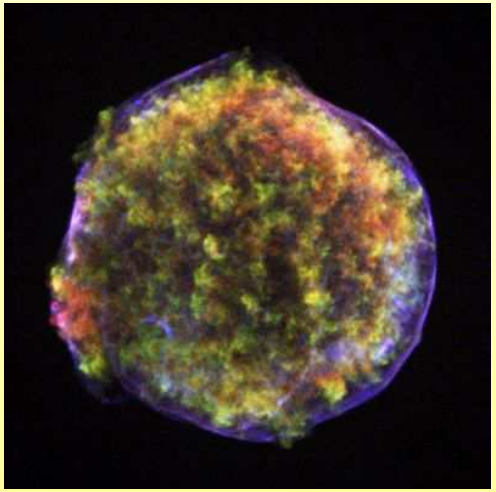
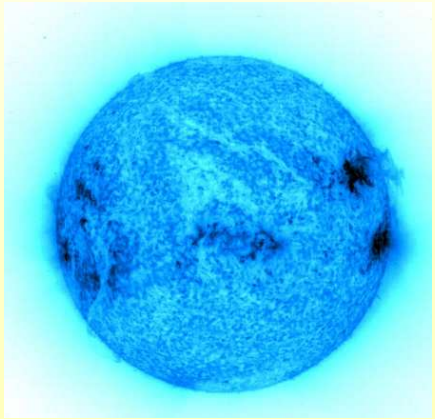
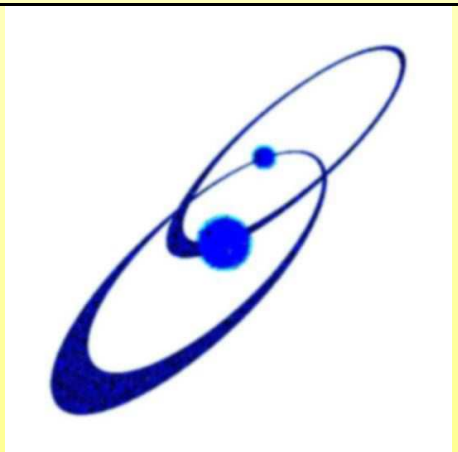


Why are binaries so different?

Compare:

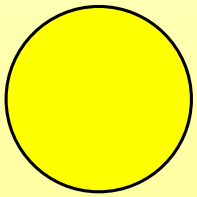
Single star evolution





Binary star evolution

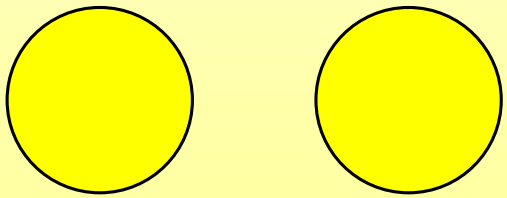
Single Star Evolution



0

Time/Gyr $\rightarrow$

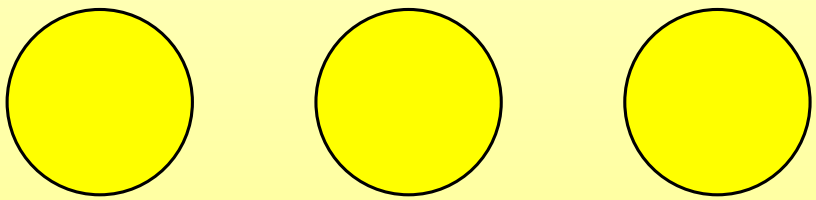
Single Star Evolution



0 5

Time/Gyr $\longrightarrow$

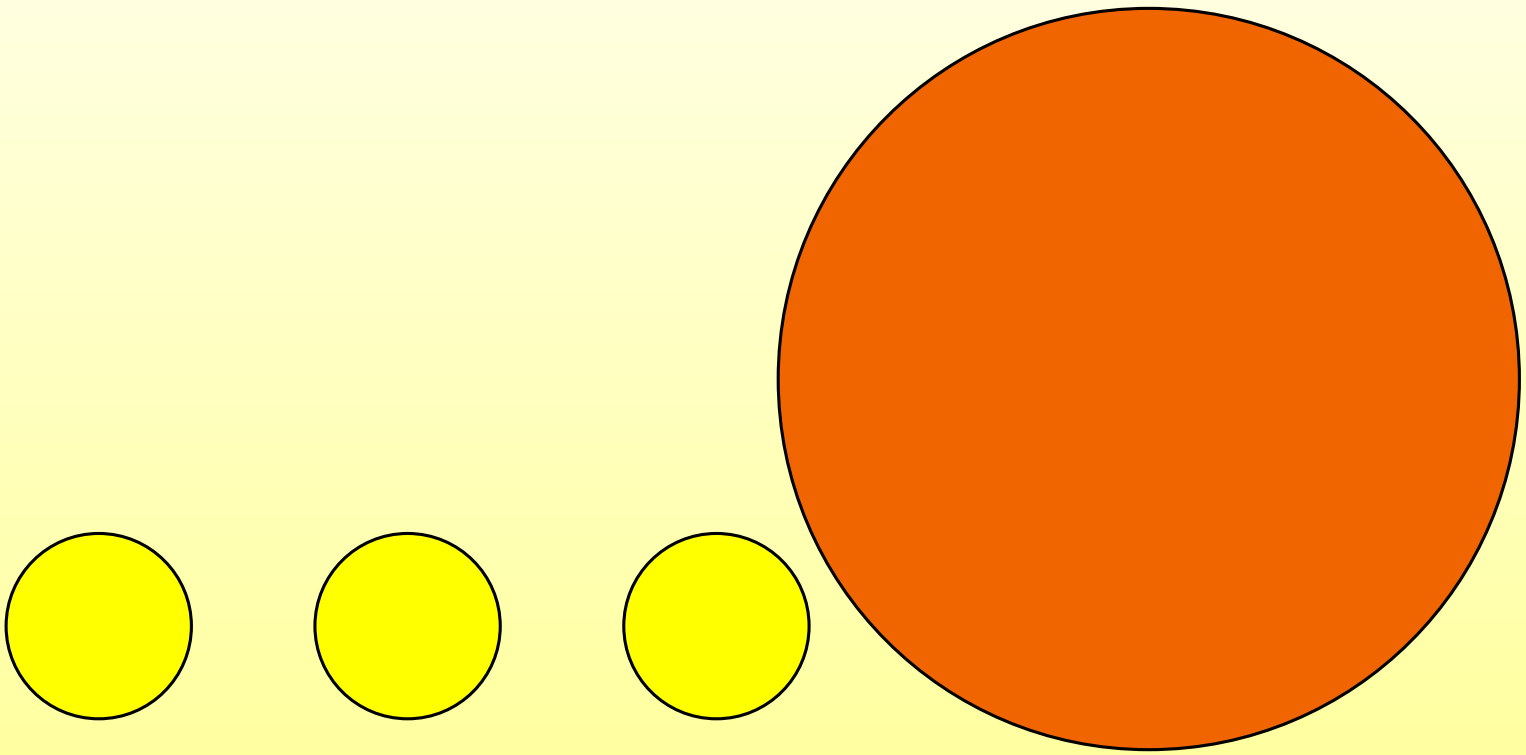
Single Star Evolution



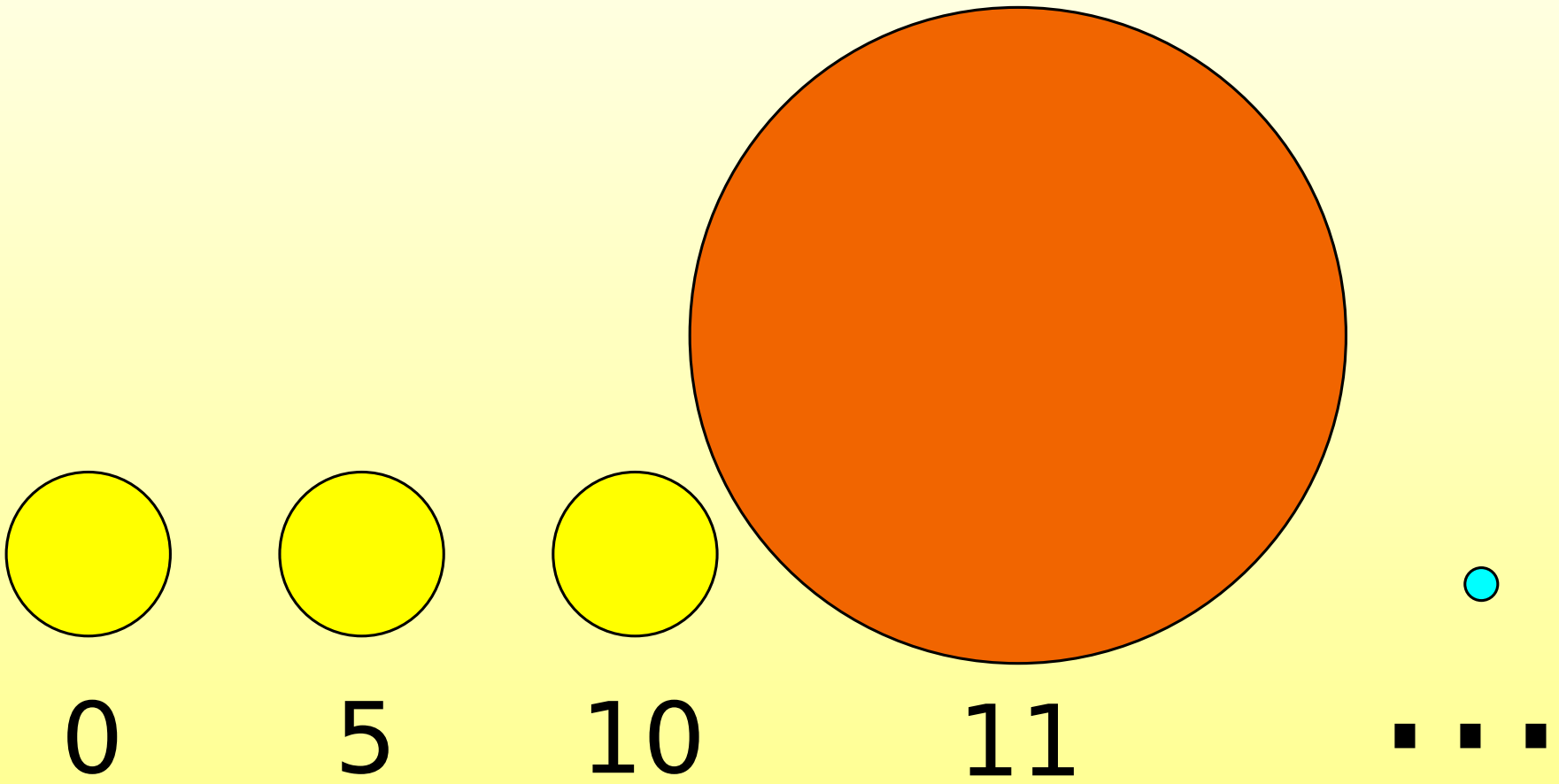
0 5 10

Time/Gyr $\rightarrow$

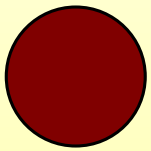
Single Star Evolution

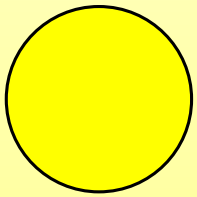


Single Star Evolution



Binary Star Evolution





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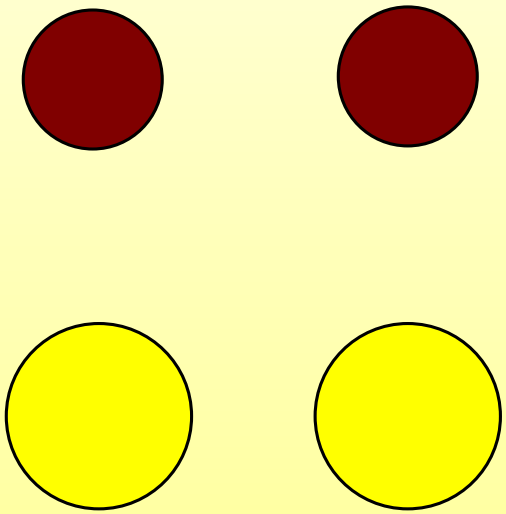
Time/Gyr $\longrightarrow$

Binary Star Evolution



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Time/Gyr $\longrightarrow$

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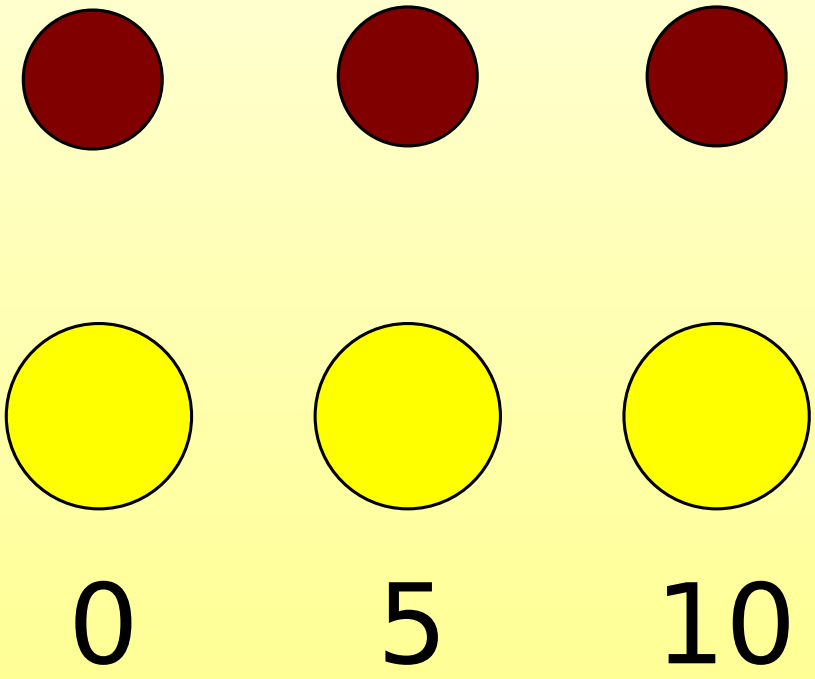

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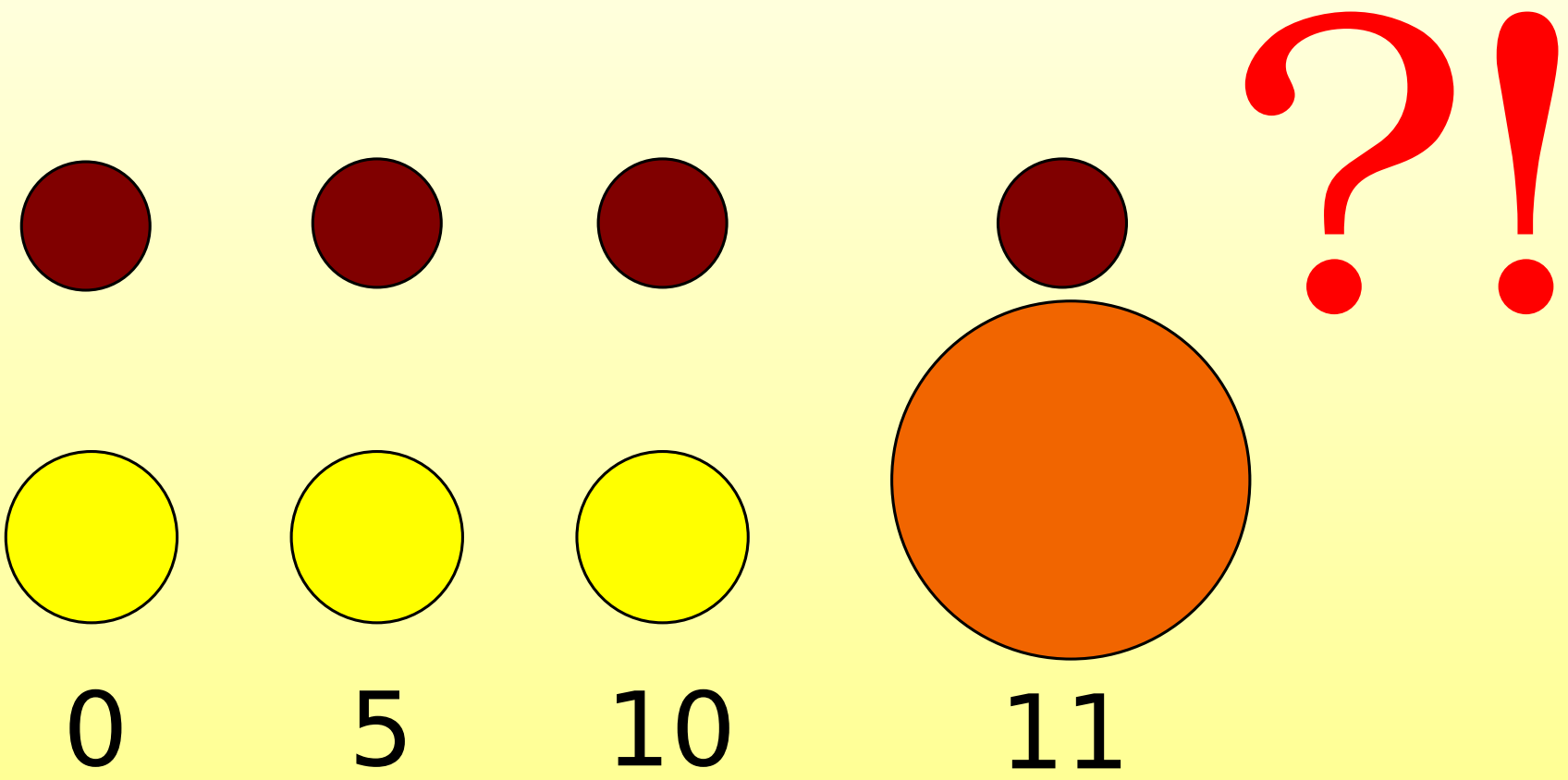
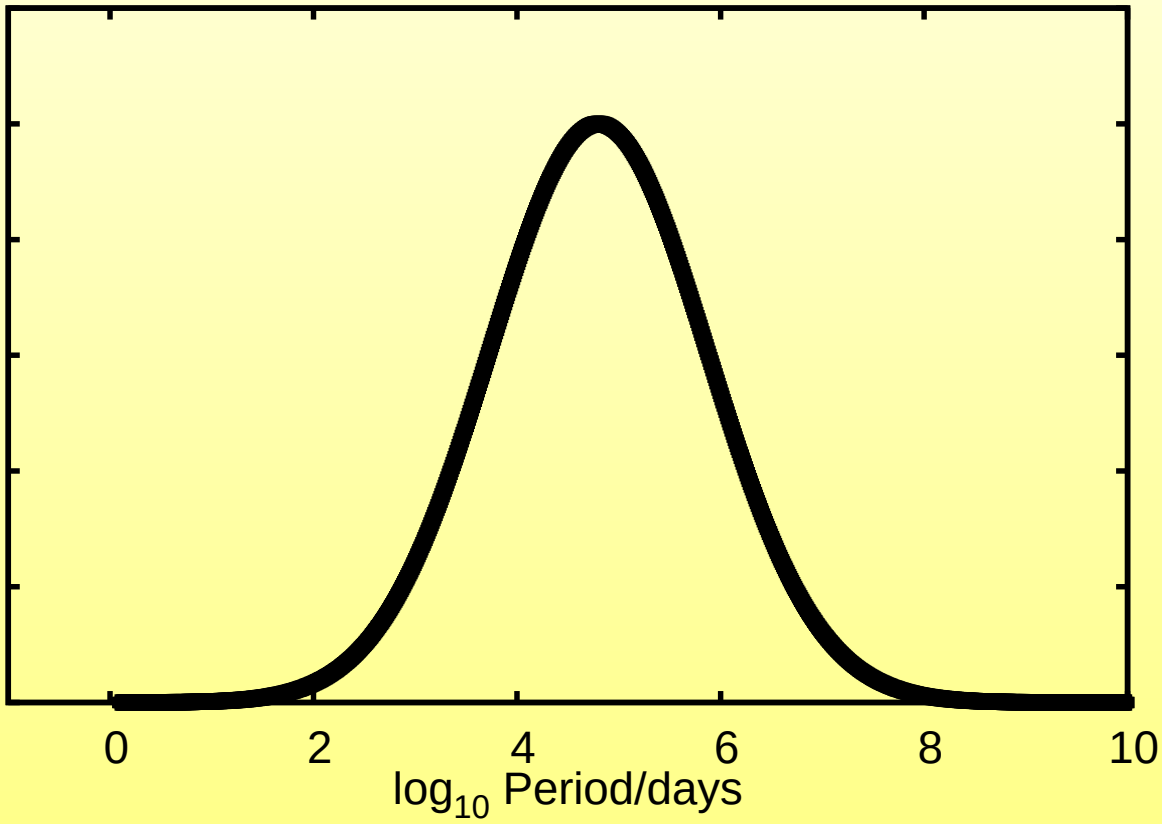


What happens next?

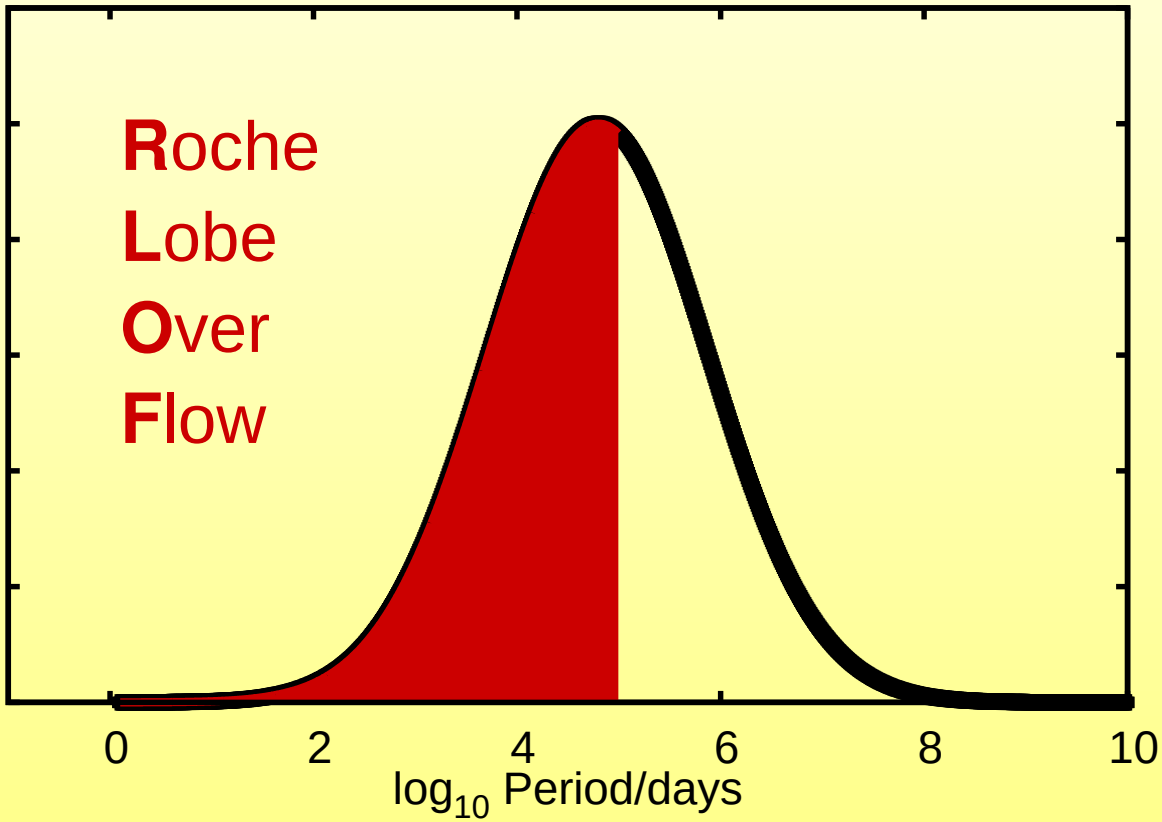
Transfer of

1. Mass M
2. Angular Momentum J



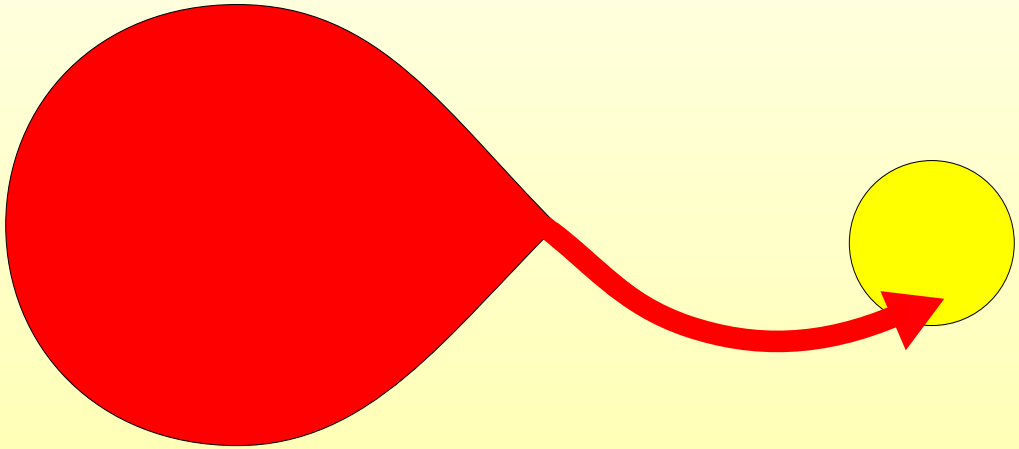
What happens next?

1. **Close binary**: Roche-lobe overflow
2. . . .



Close binary: Roche-lobe Overflow

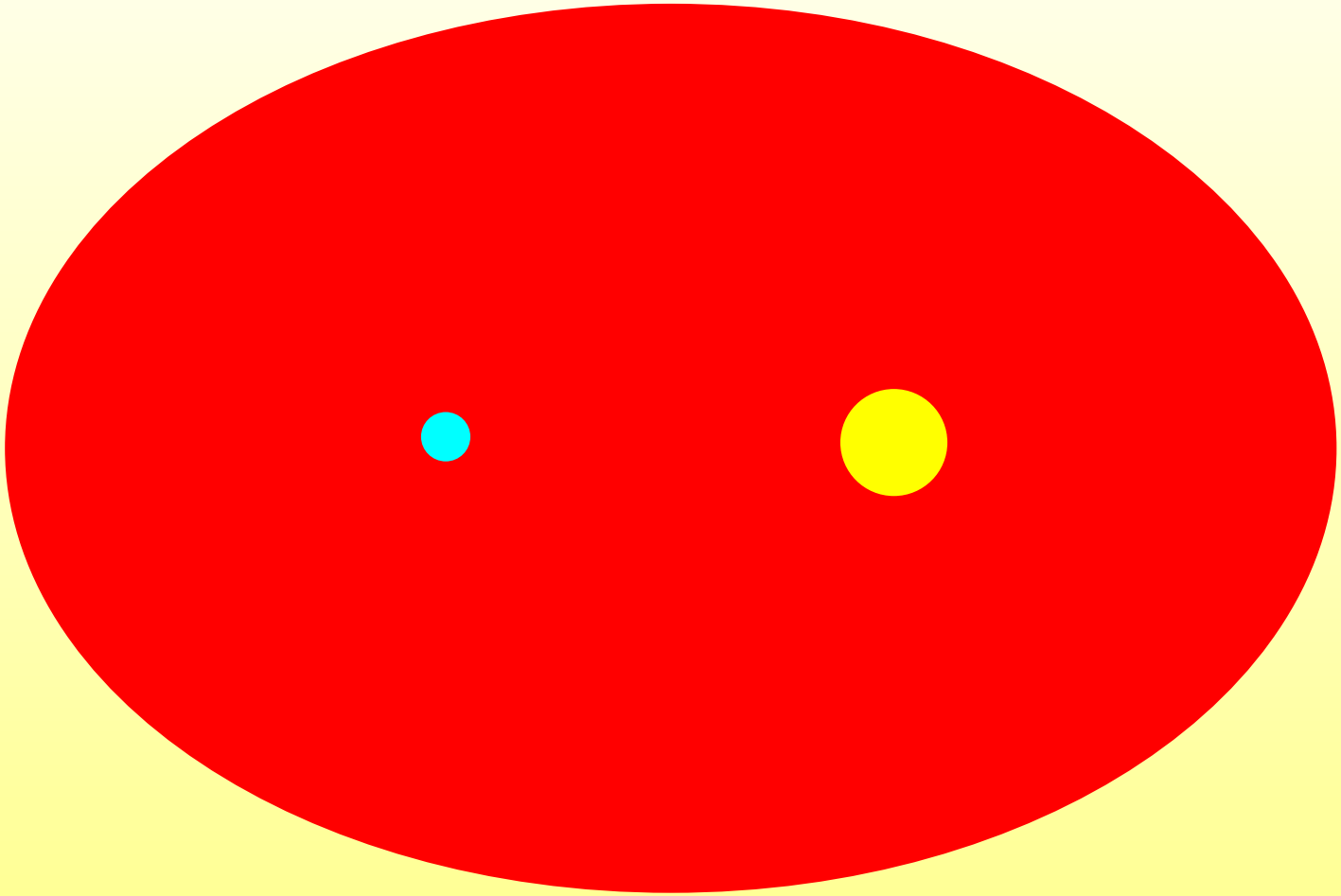
Roche Lobe overflow



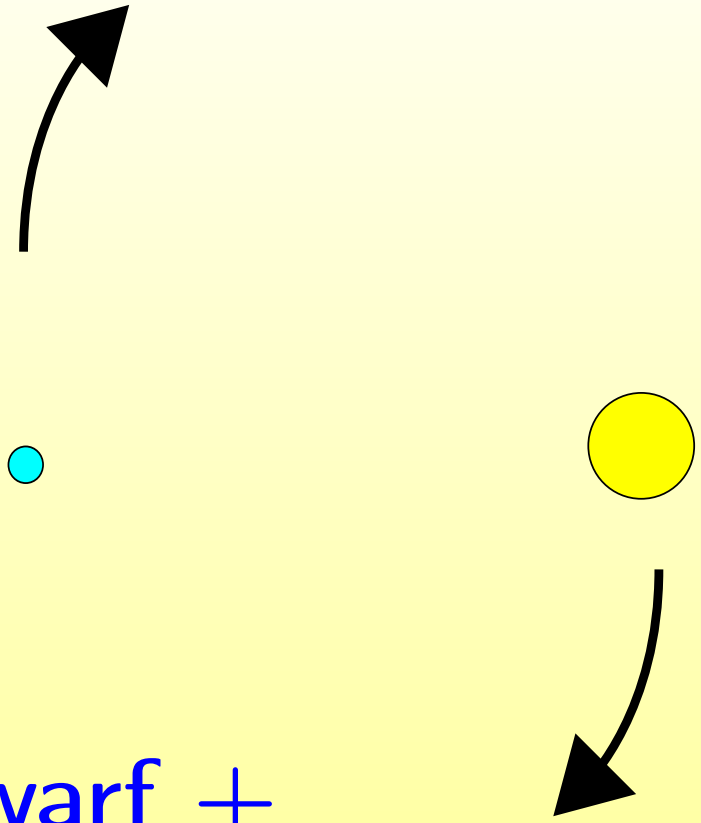
ΔM and ΔJ spin up +tides

Play Ross Church's movies

Often not “conservative”: Common Envelope



Chemical peculiarities ???

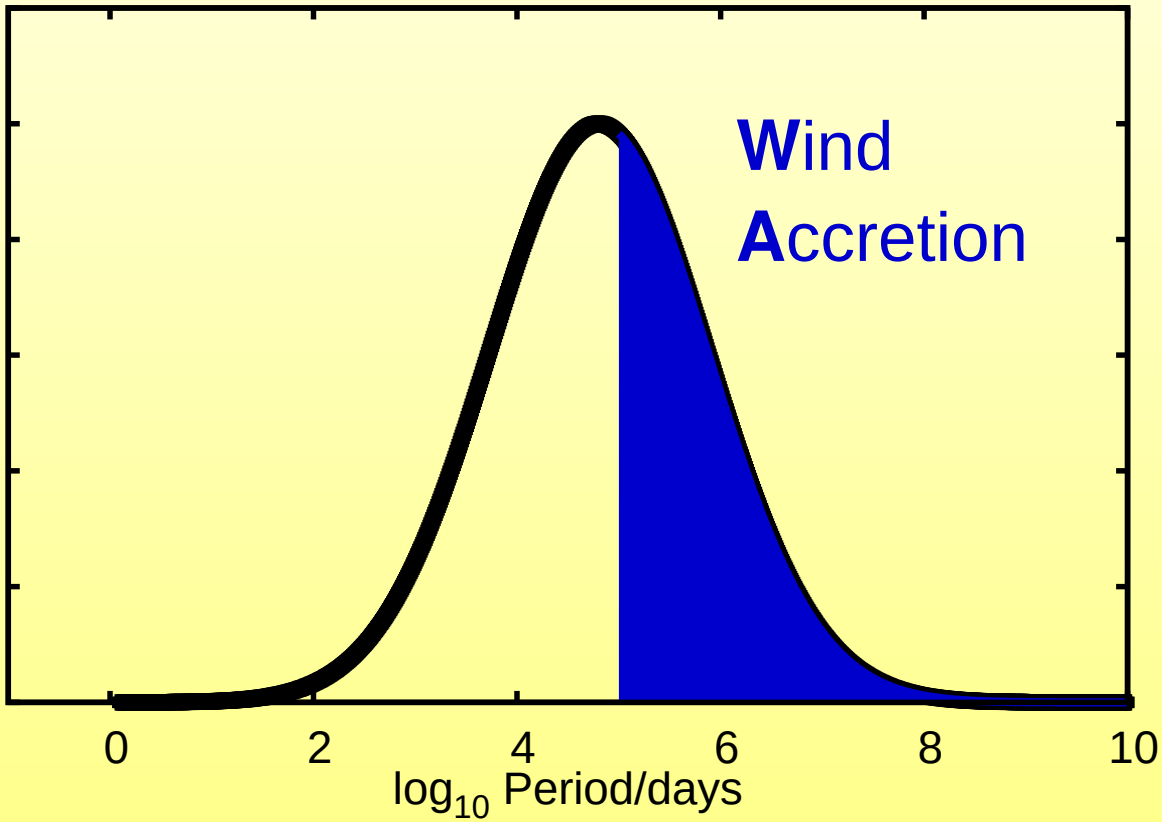


White Dwarf +
Chemically Normal? Star

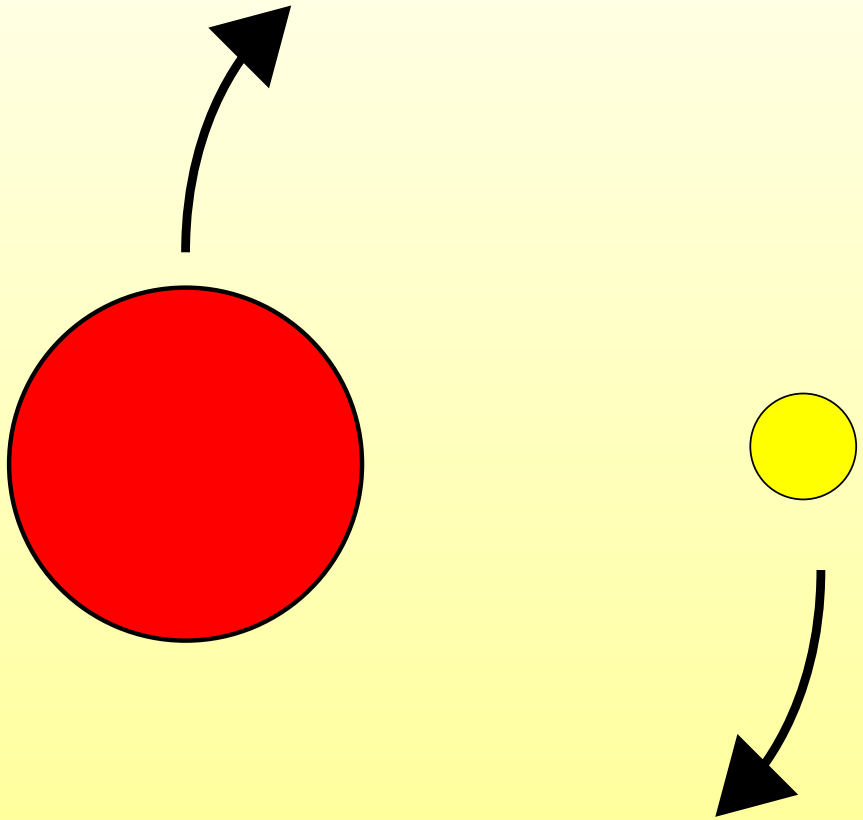
Massive stars: WD→NS or BH

What happens next?

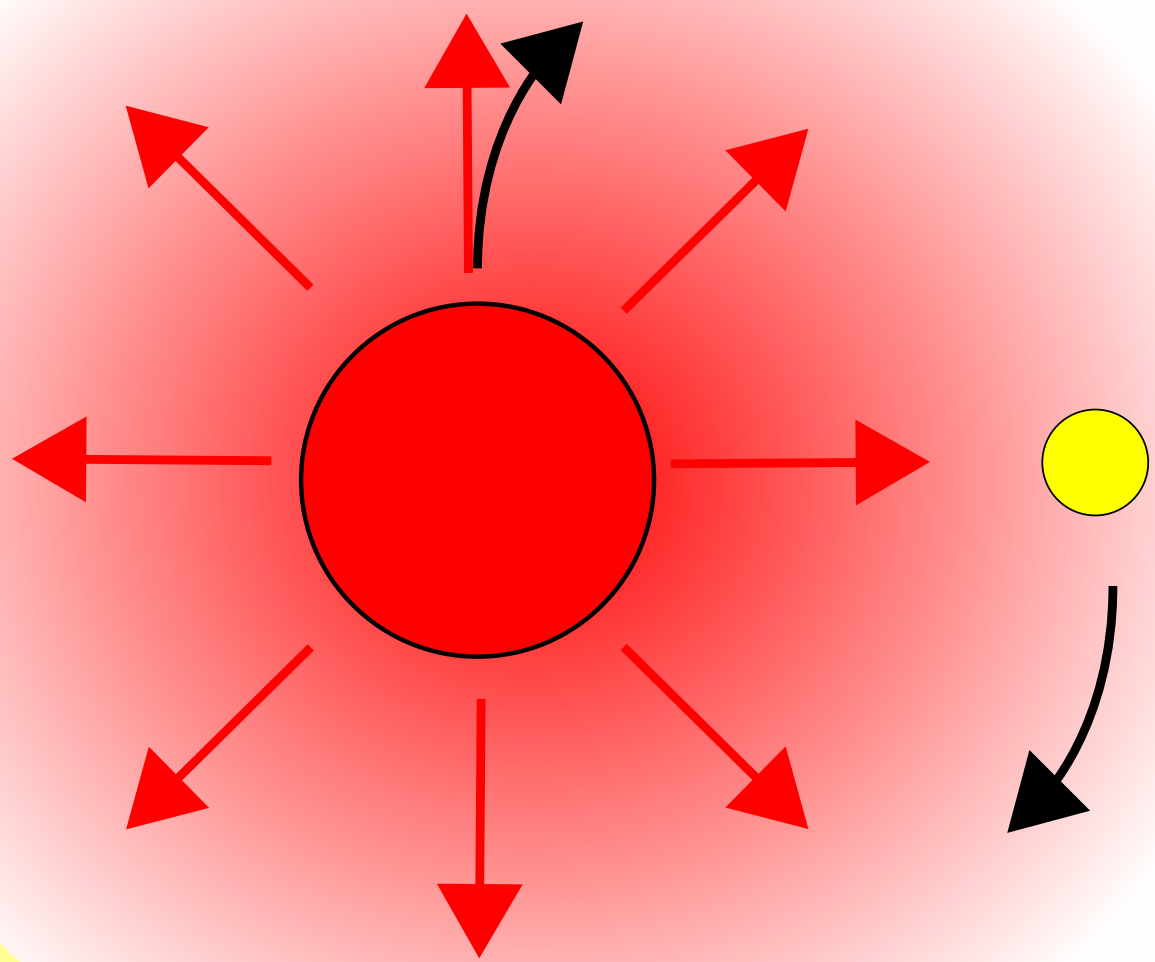
1. **Close binary**: Roche-lobe overflow
2. **Distant binary**: Wind accretion



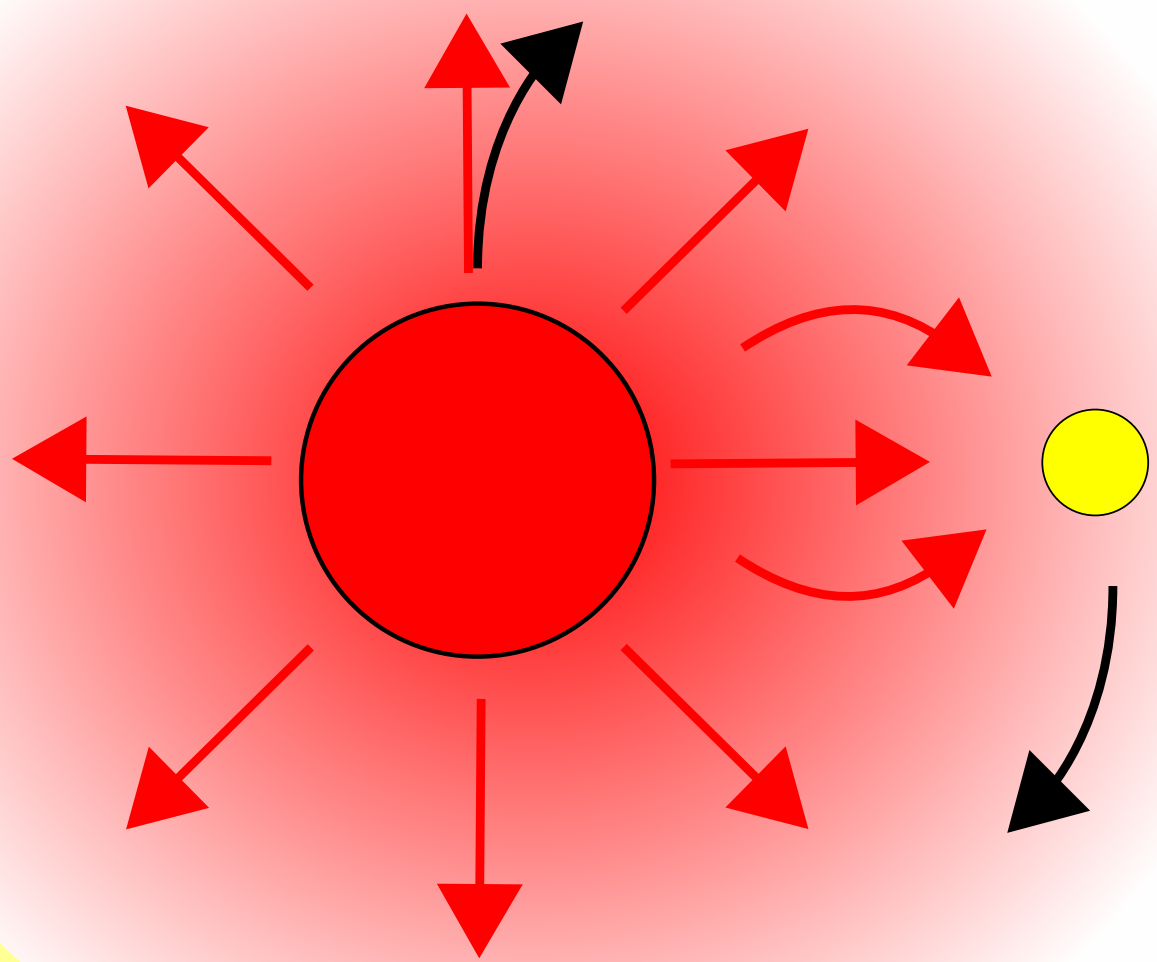
Distant Binary: Wind Accretion



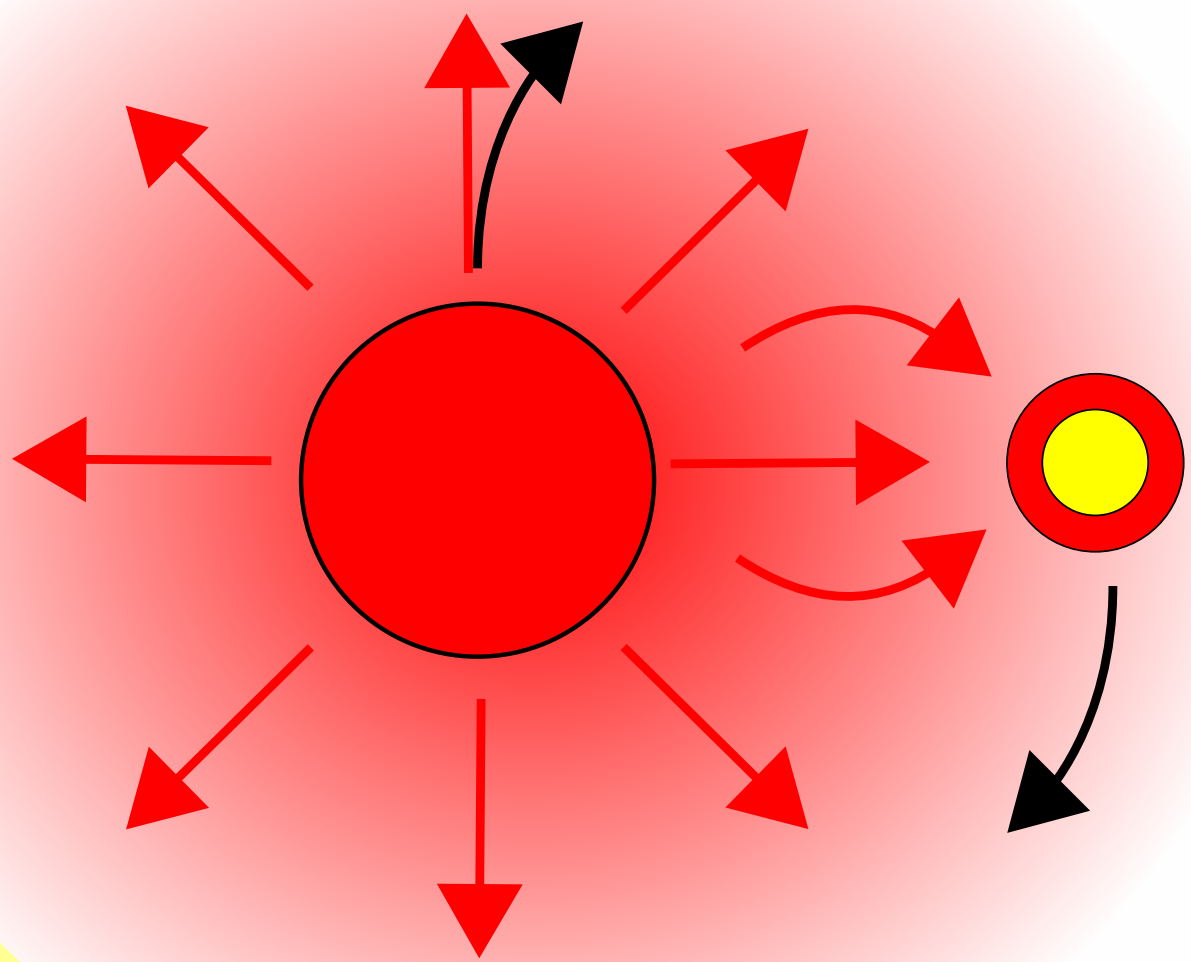
Wind Accretion: Giant Wind



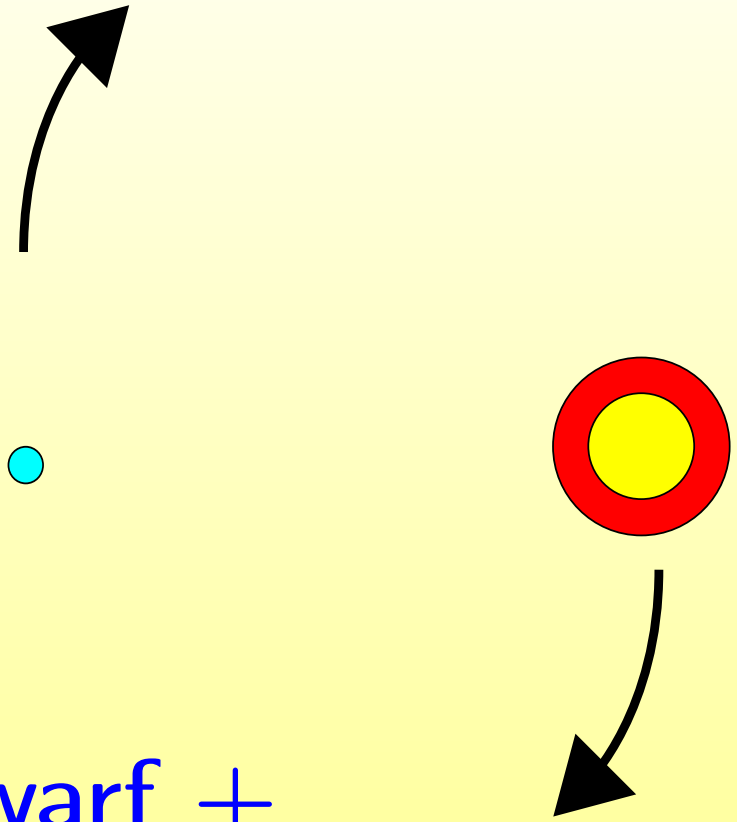
Wind Accretion: Gravitational Focusing



Wind Accretion: Accretion



Wind Accretion 6: Primary Death



White Dwarf +
Chemically Peculiar Star

So we understand it all?

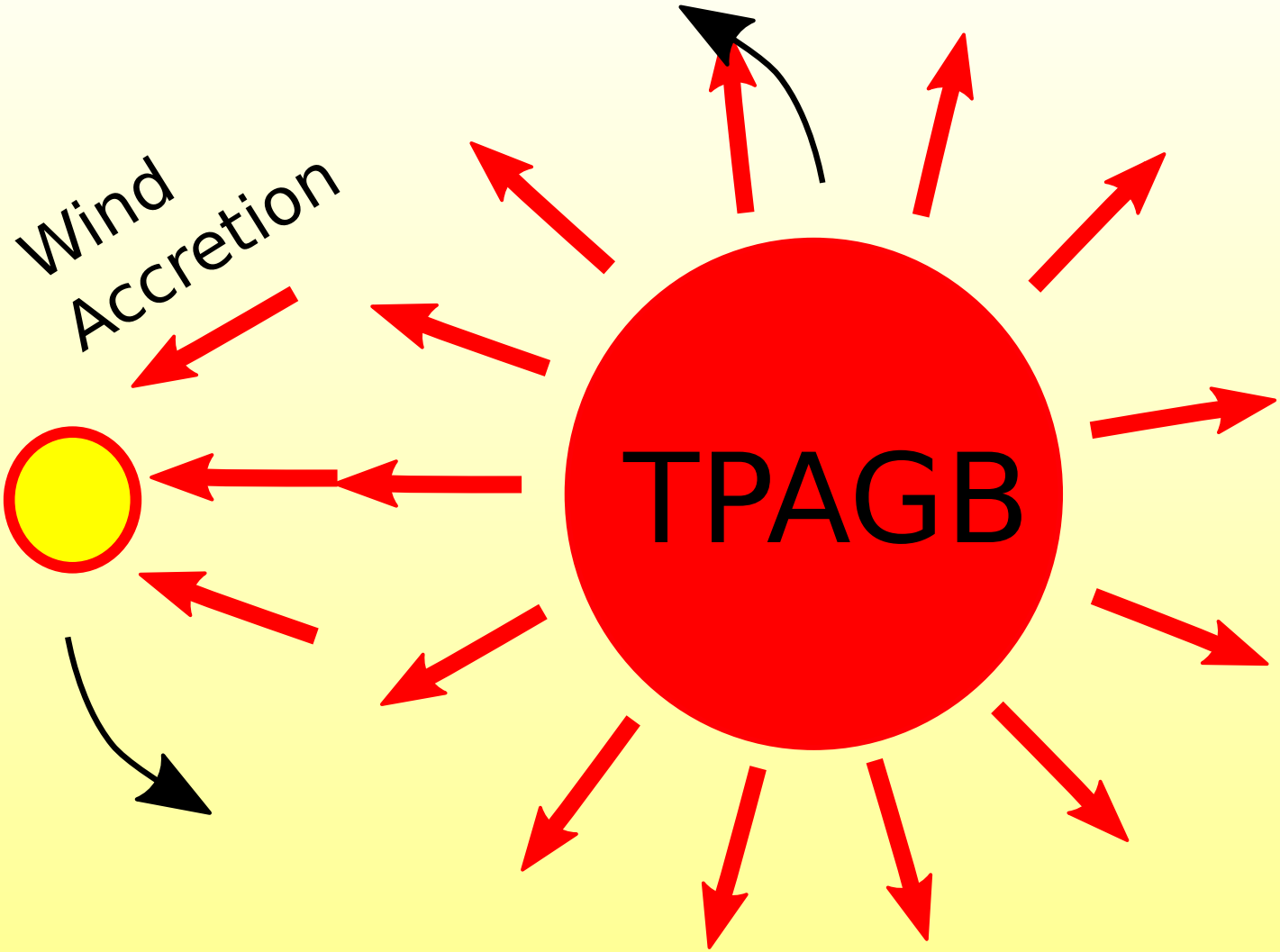
- At a qualitative level, yes... (perhaps)
- But quantitatively ...
  little agreement between models and observations!

Two examples for you:

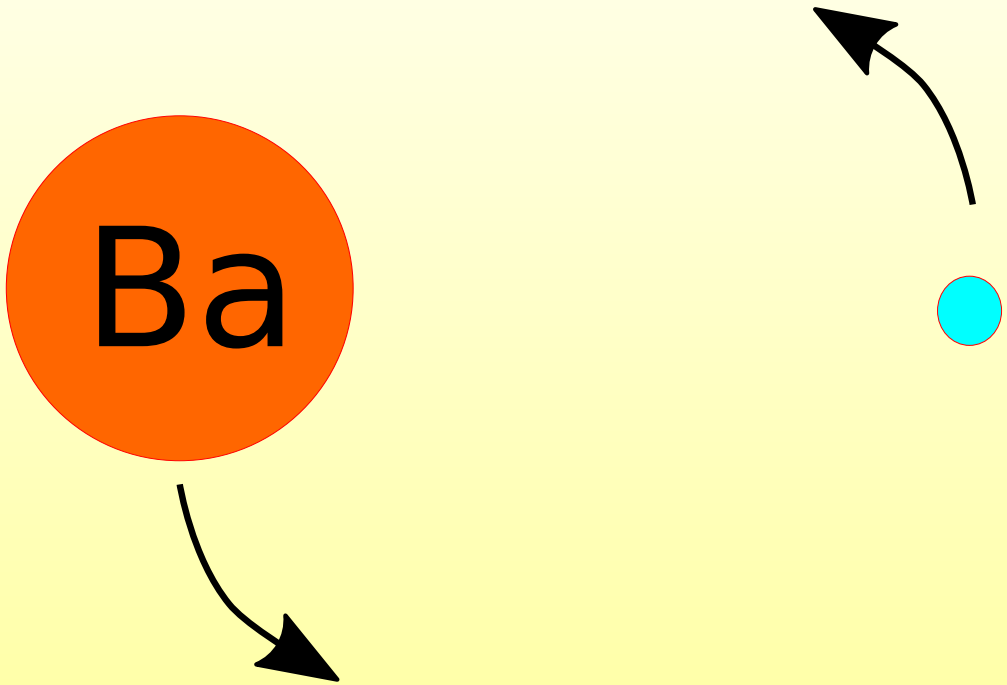
1. **Barium stars**
   - Low mass $1 - 3\,\mathrm{M}_\odot$
   - Wind accretion
   - Complete observation set: [Ba/Fe], P and e
2. **Massive main sequence stars**
   - High mass $> 10\,\mathrm{M}_\odot$
   - Roche lobe overflow
   - Observation set expanding rapidly

What is a barium star?

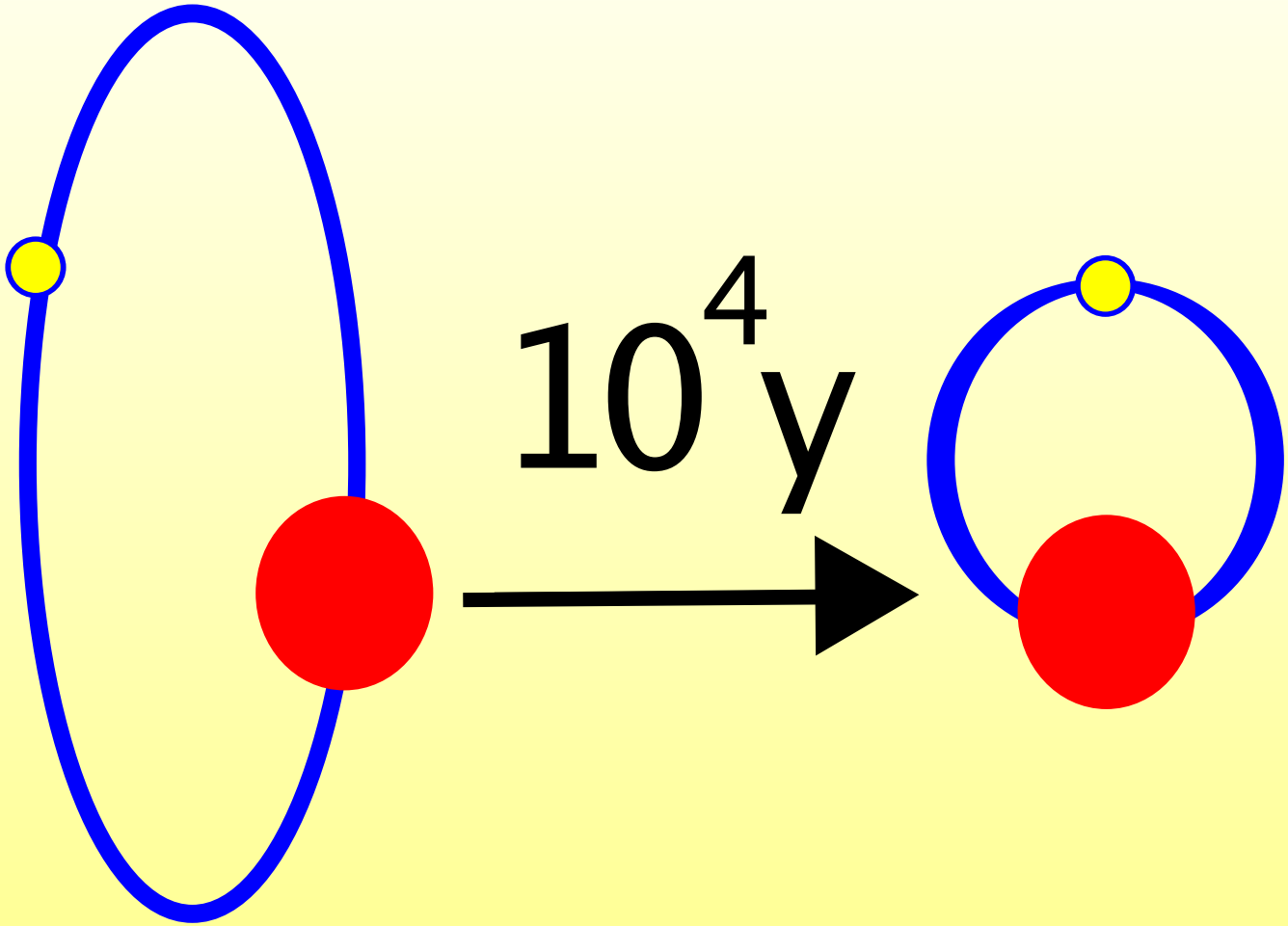
How to make a Ba star?



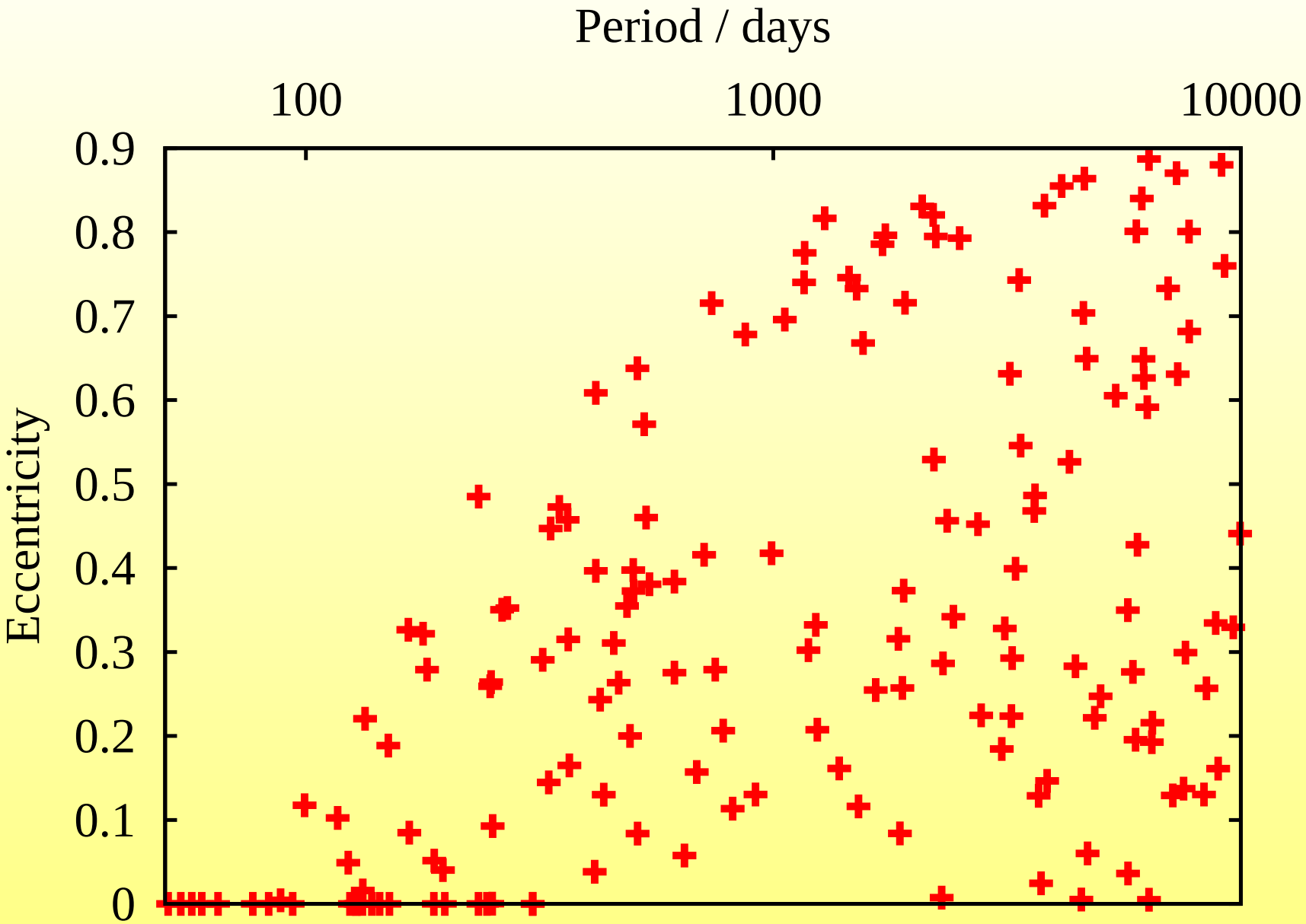
The barium star now



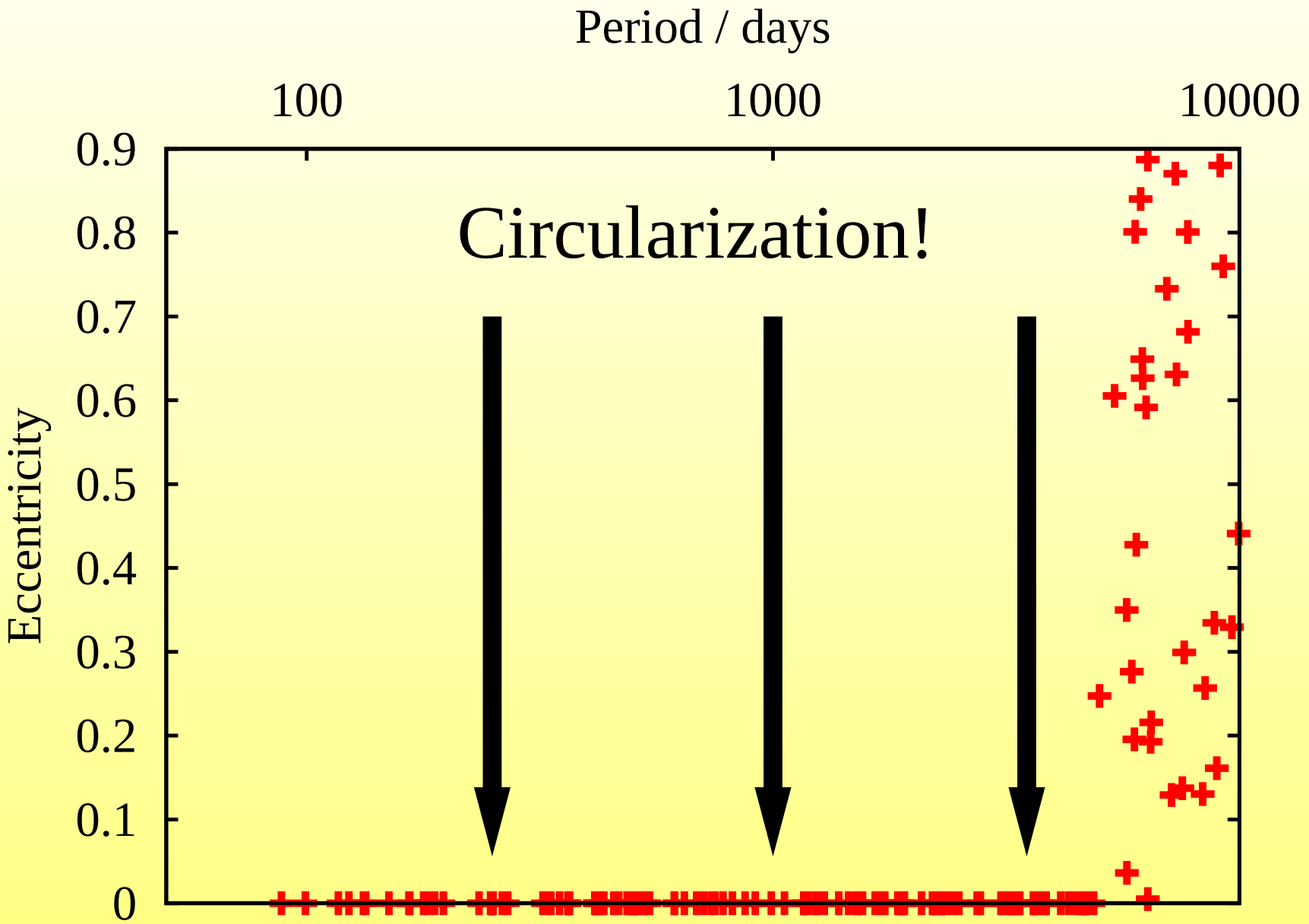
Tidal Circulari[sz]ation $\tau \sim (\mathit{separation}/\mathit{radius})^8$



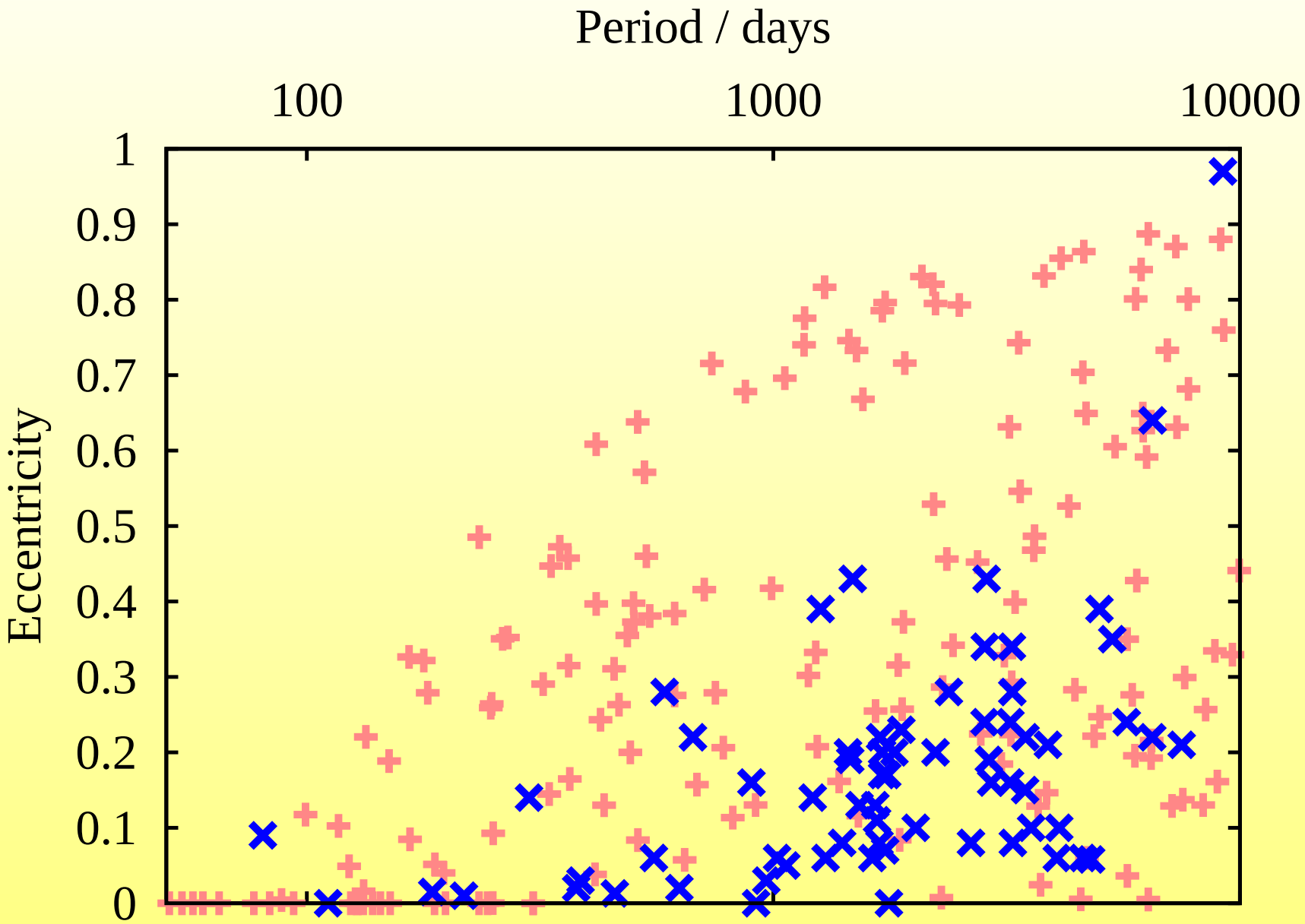
Observations: GK giants (Jorissen data)



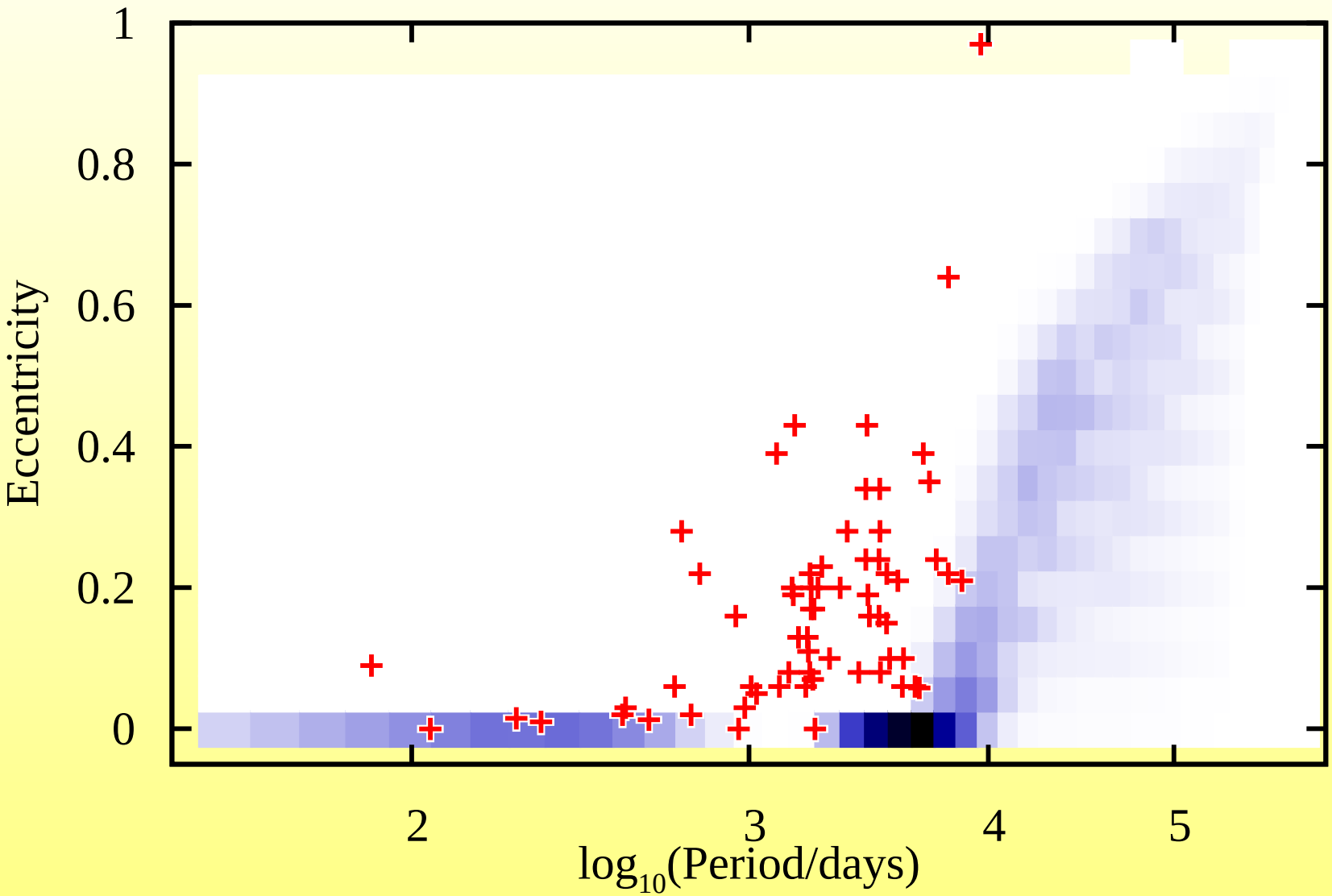
Expected result for Ba stars



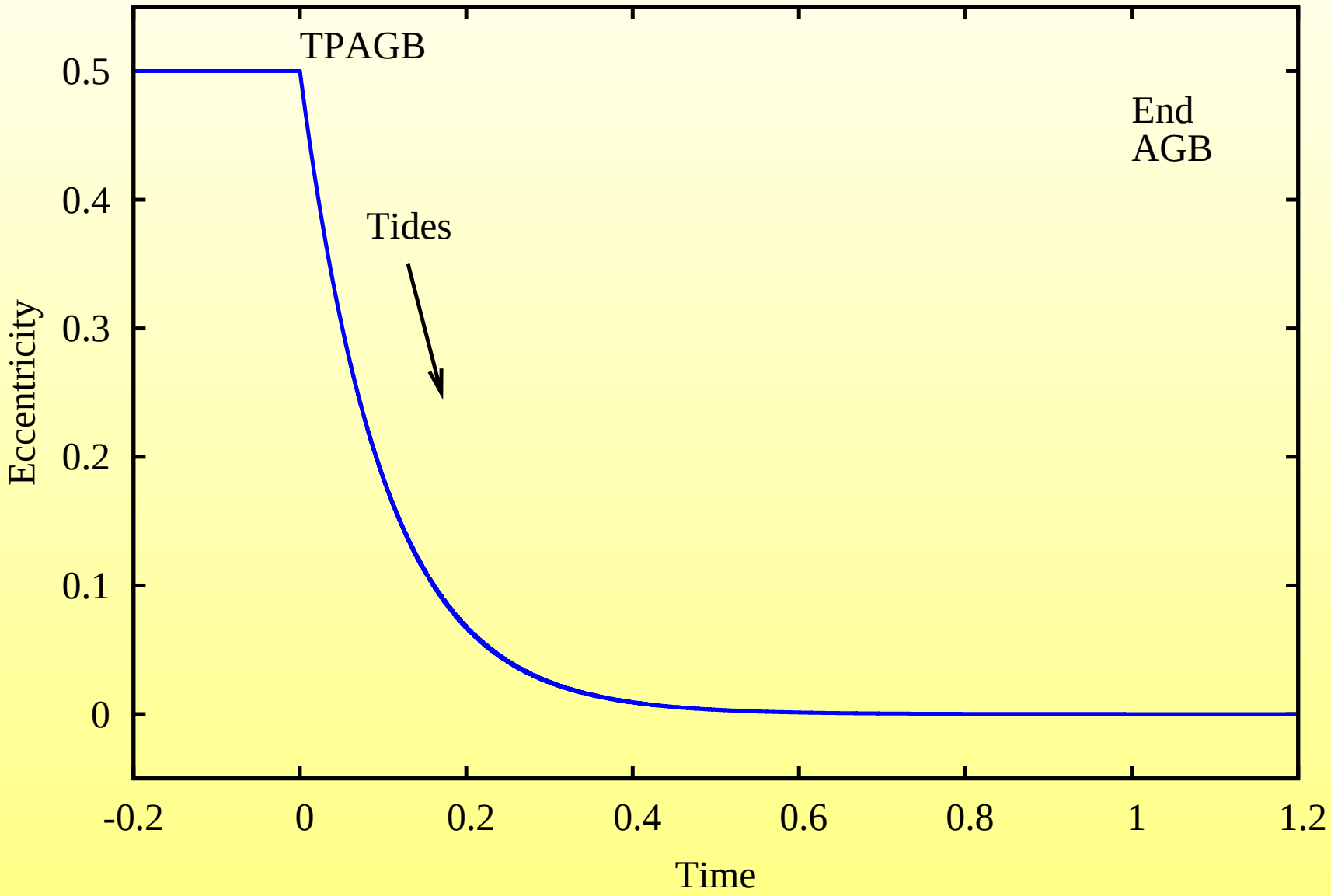
Not what we see! They are eccentric



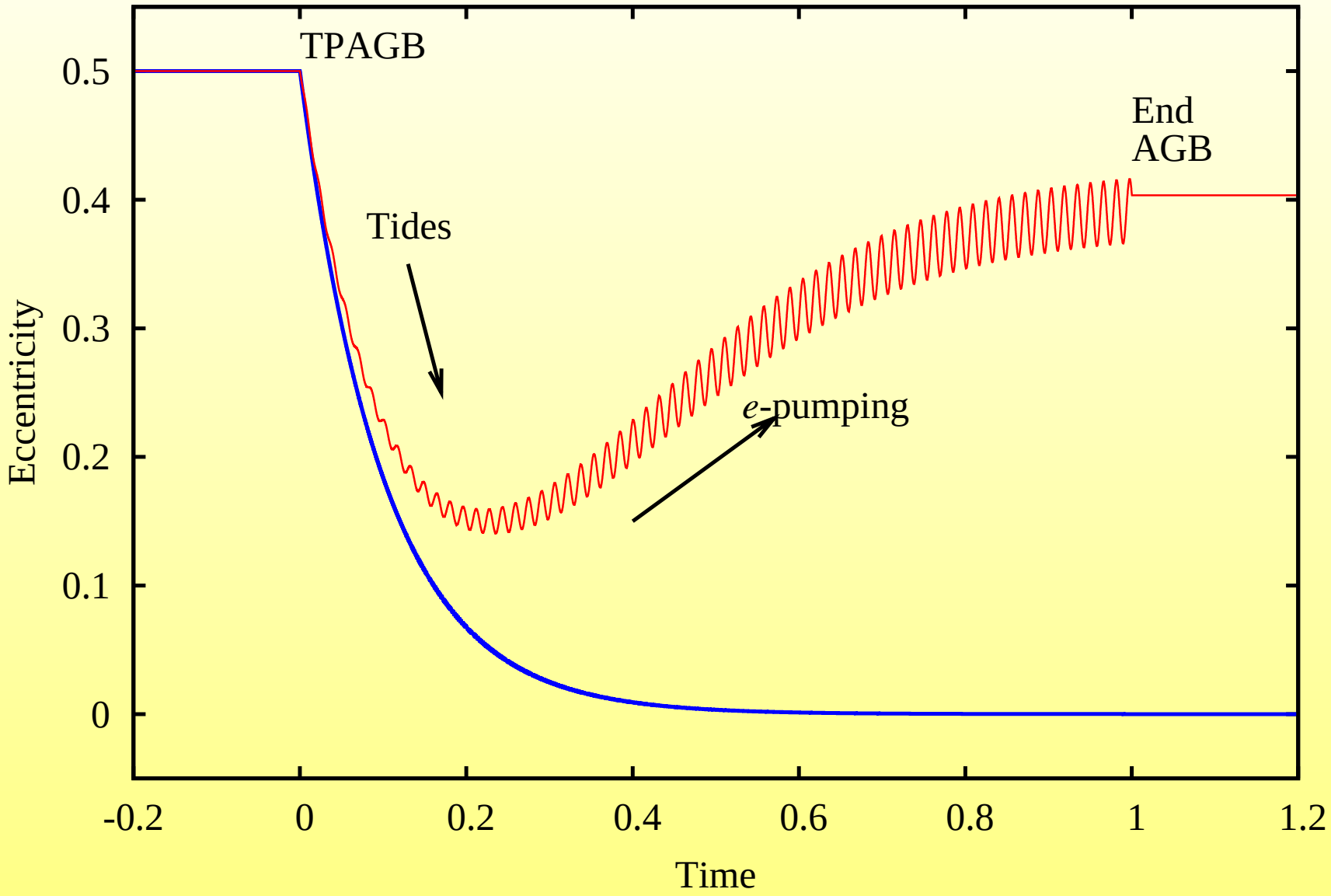
Confirmed in canonical model



What is happening?



What is happening?



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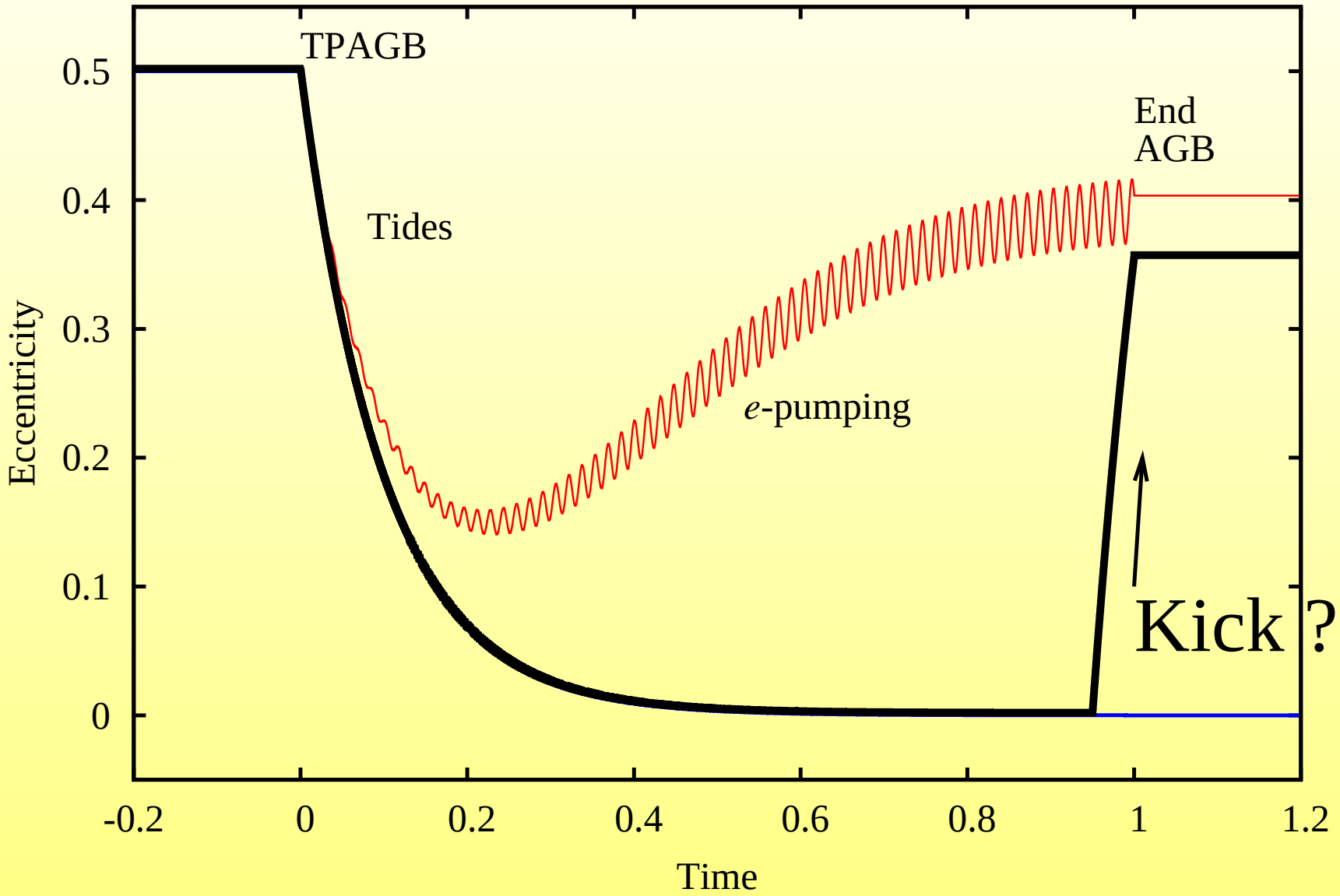
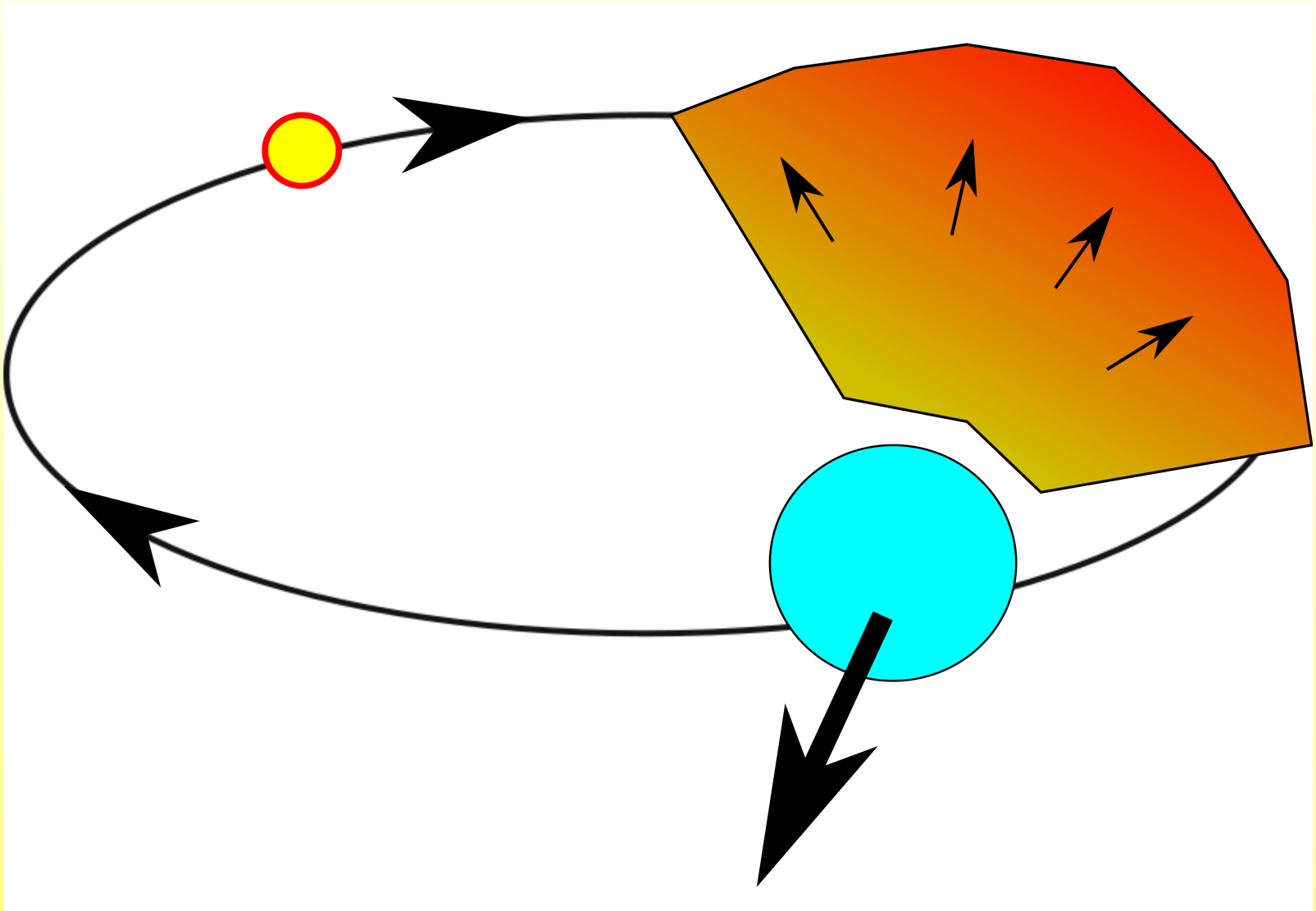
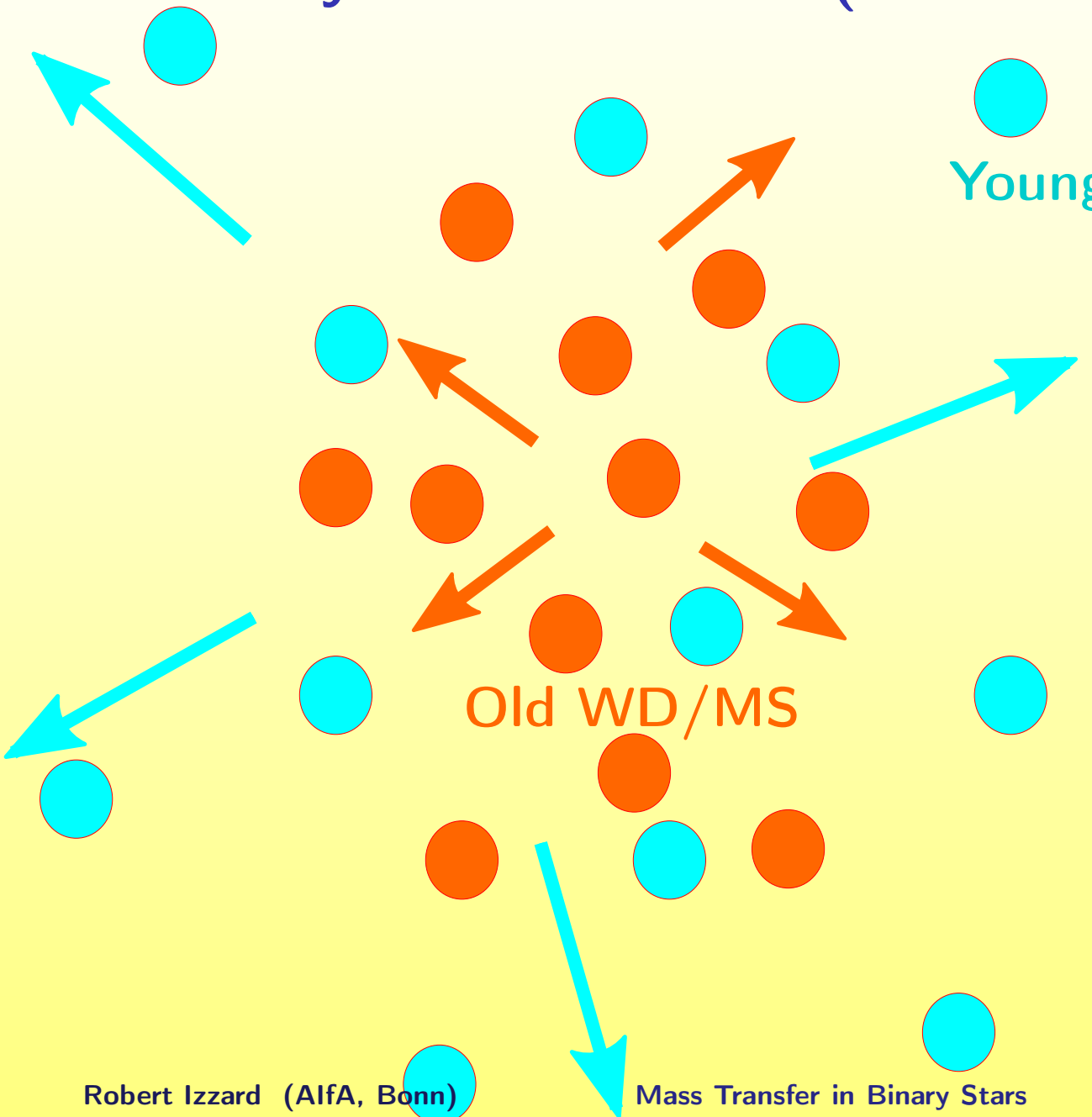


Solution 1: Kick The WD



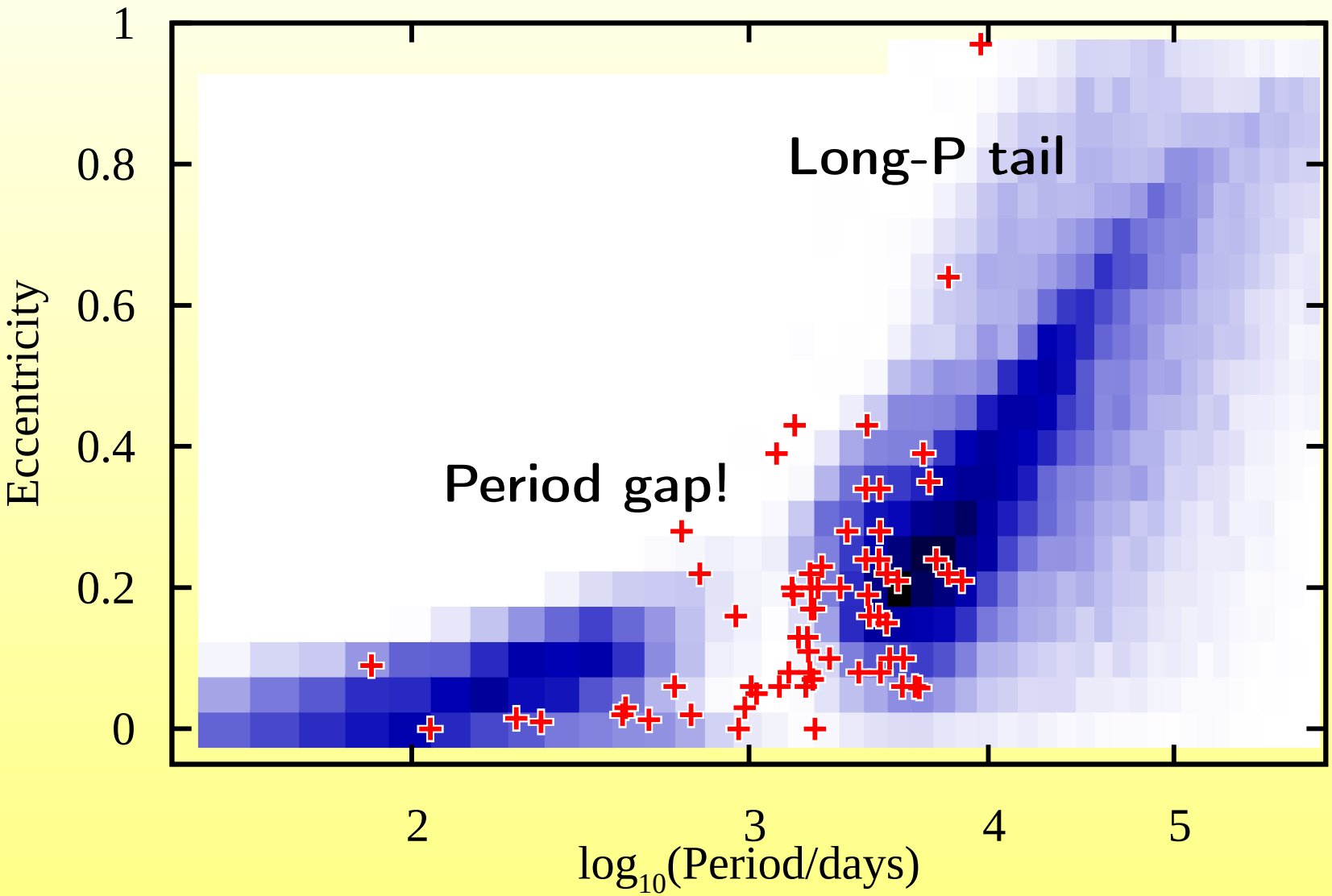
Not Crazy! Seen in GCs (Davis et al.)



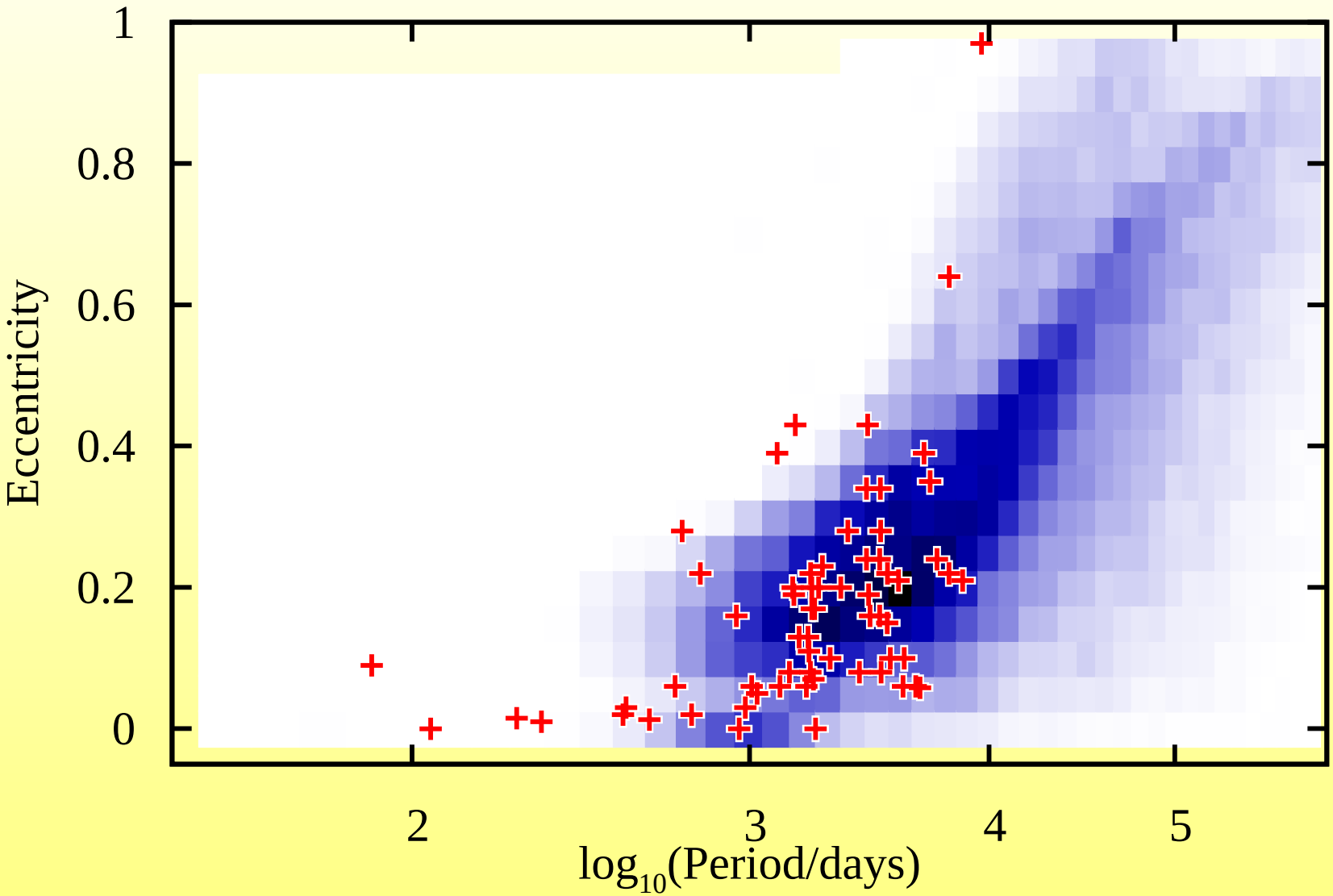
Single and binary stars!

Apply WD kick $4\,\mathrm{km\,s^{-1}}$

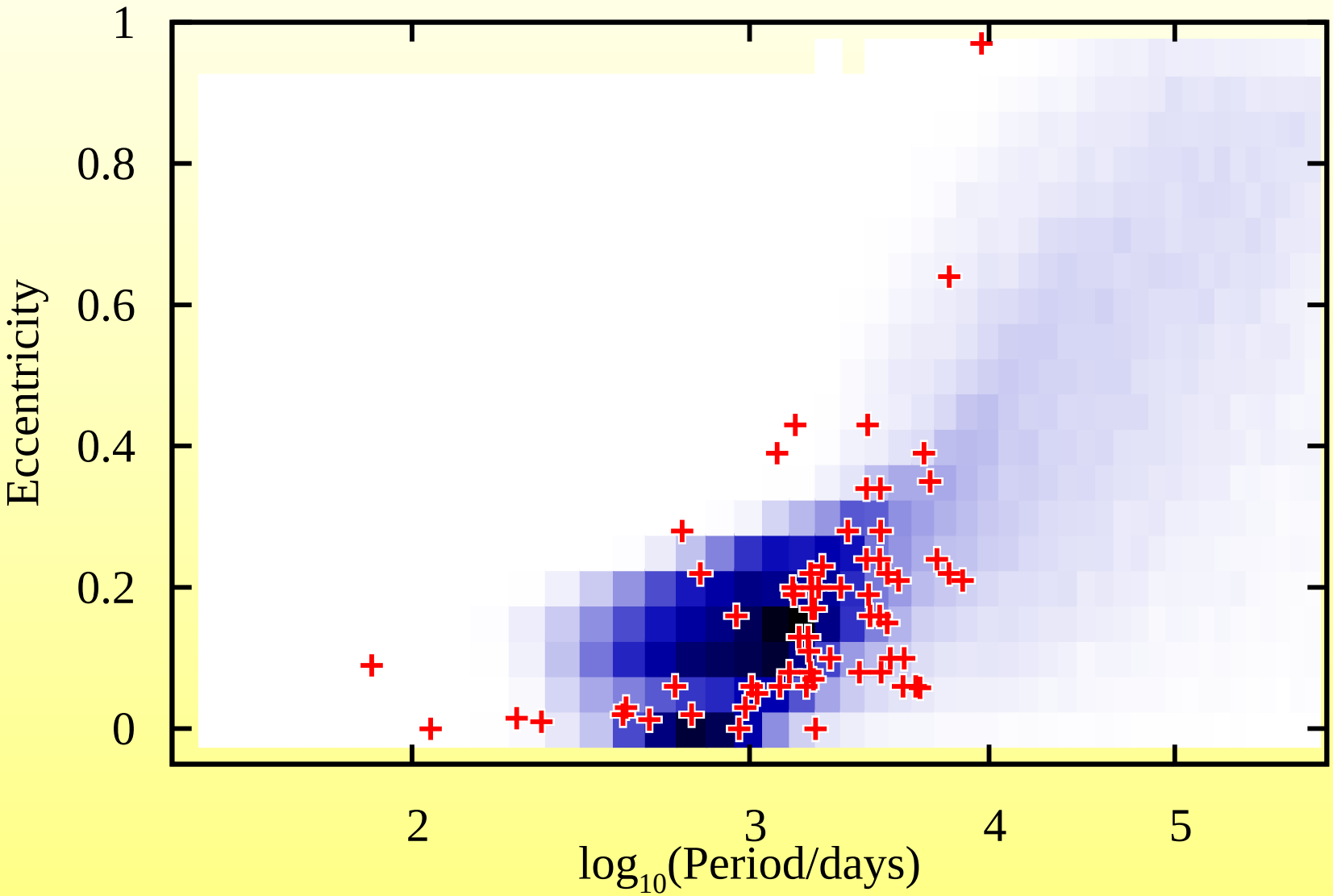
Still Problems!



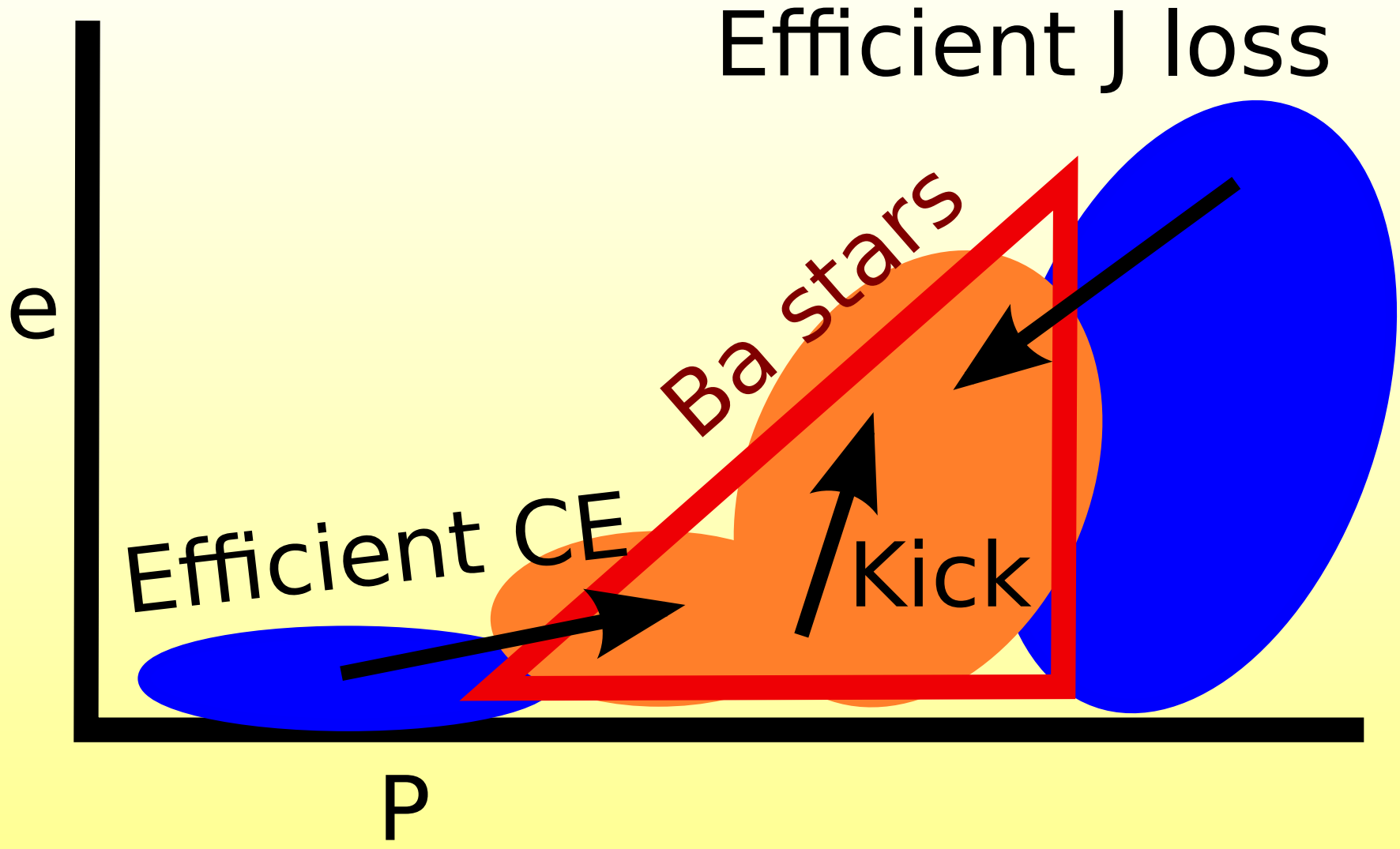
4km/s kick+efficient CE ejection



4km/s kick + efficient CEE and $-\Delta J_{\rm orb}$

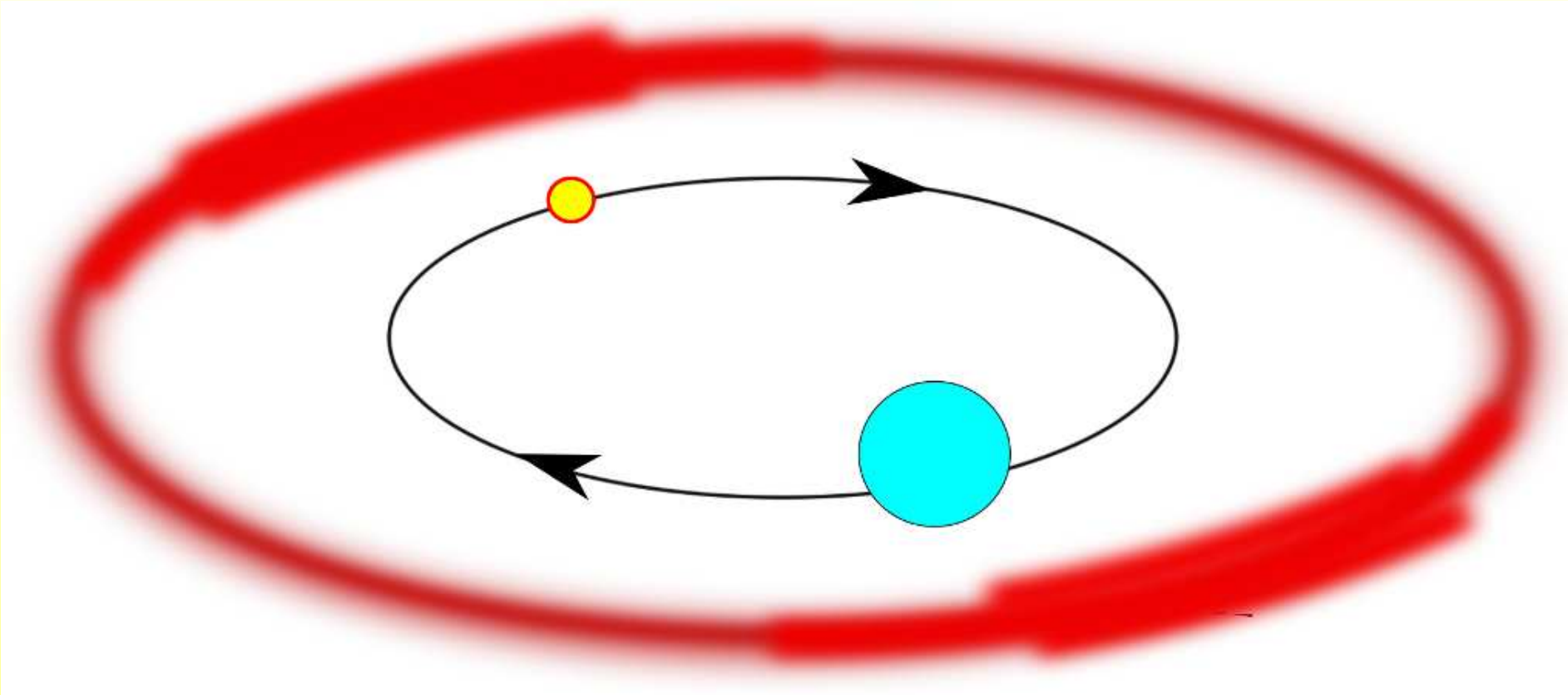


Solution 1: How To Make Ba Stars. . . ?

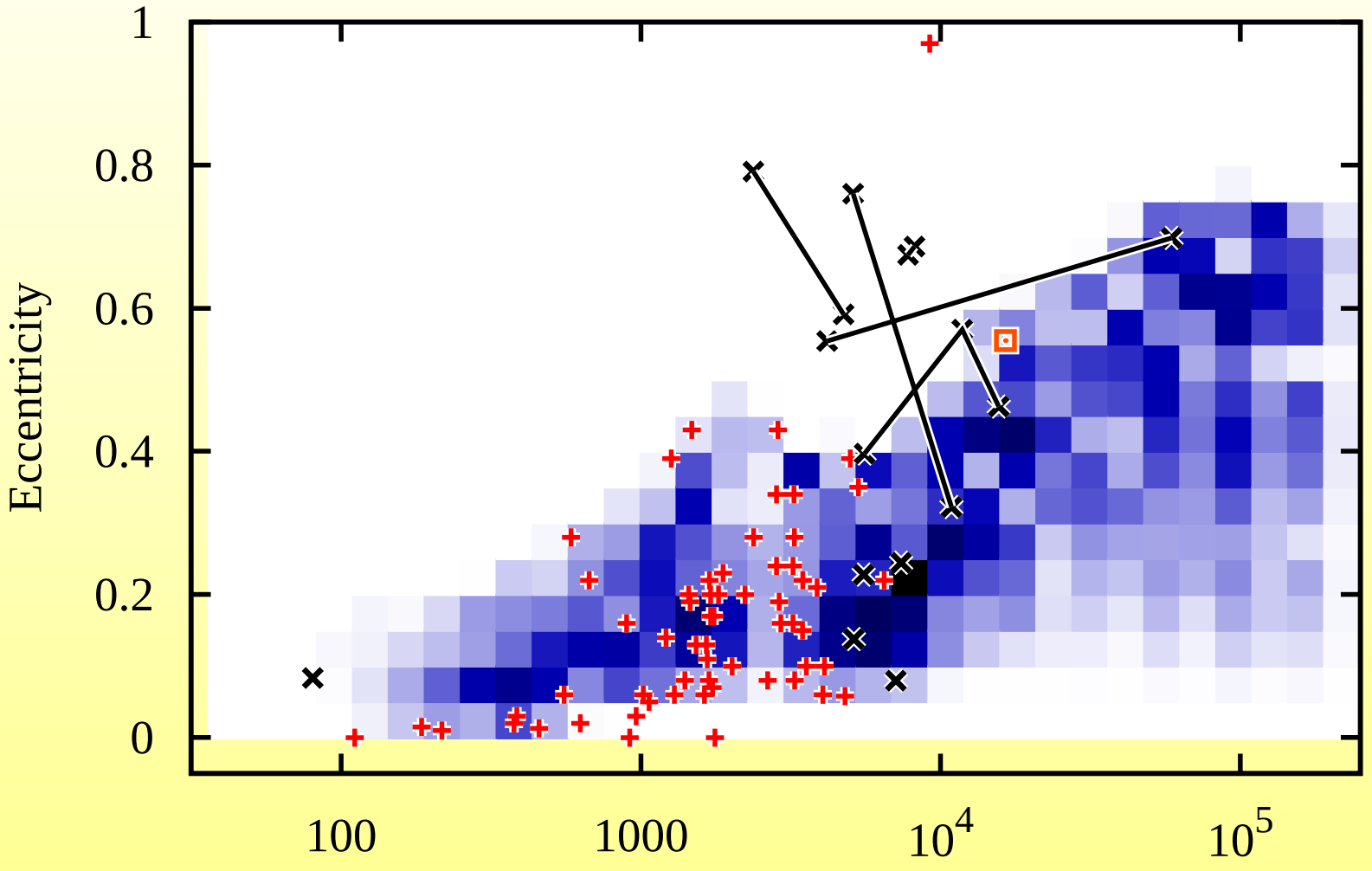


Izzard, Church and Dermine 2010 (A&A accepted)

Solution 2: Circumbinary Disk?

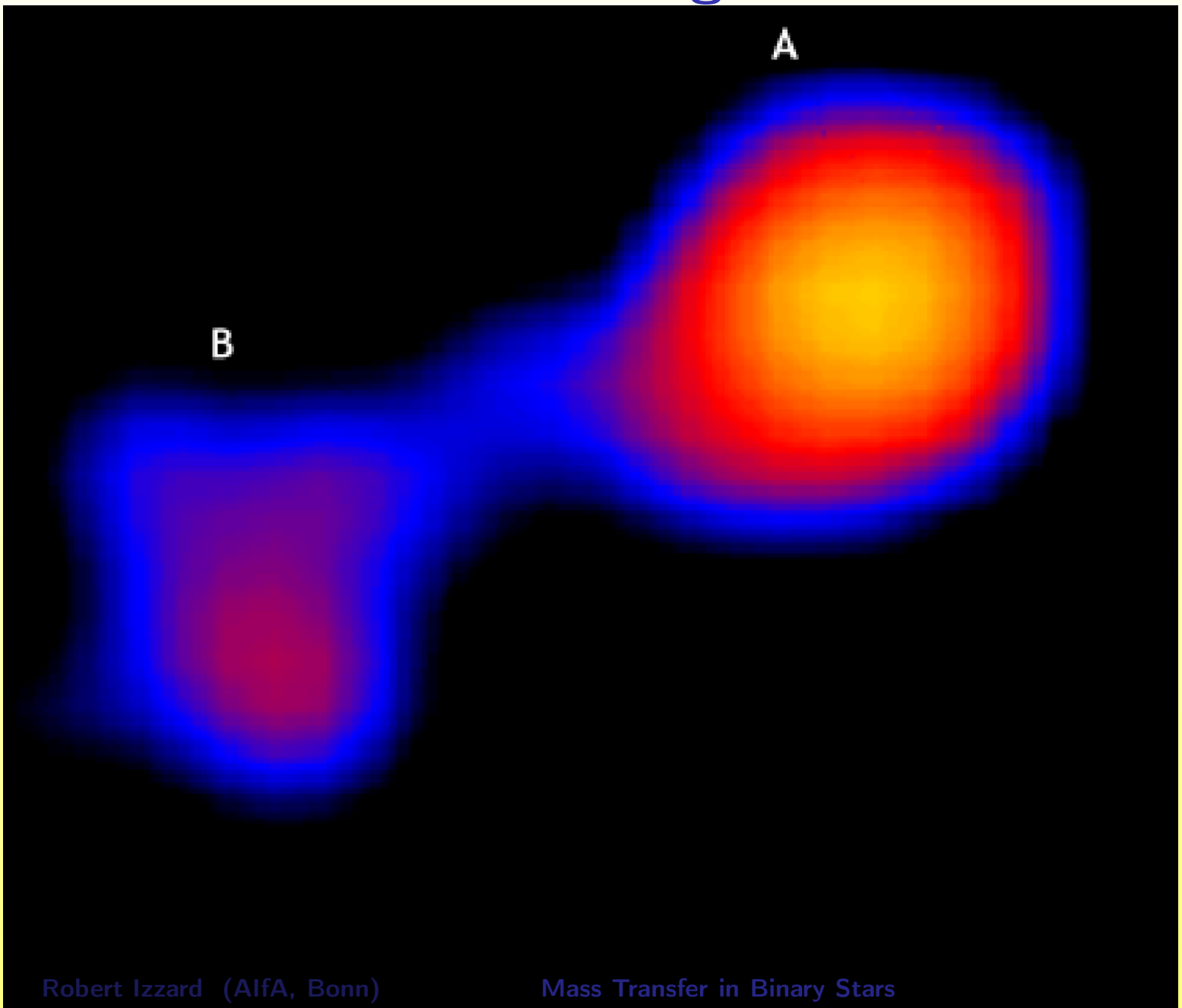


Some eccentricity, same old problems?



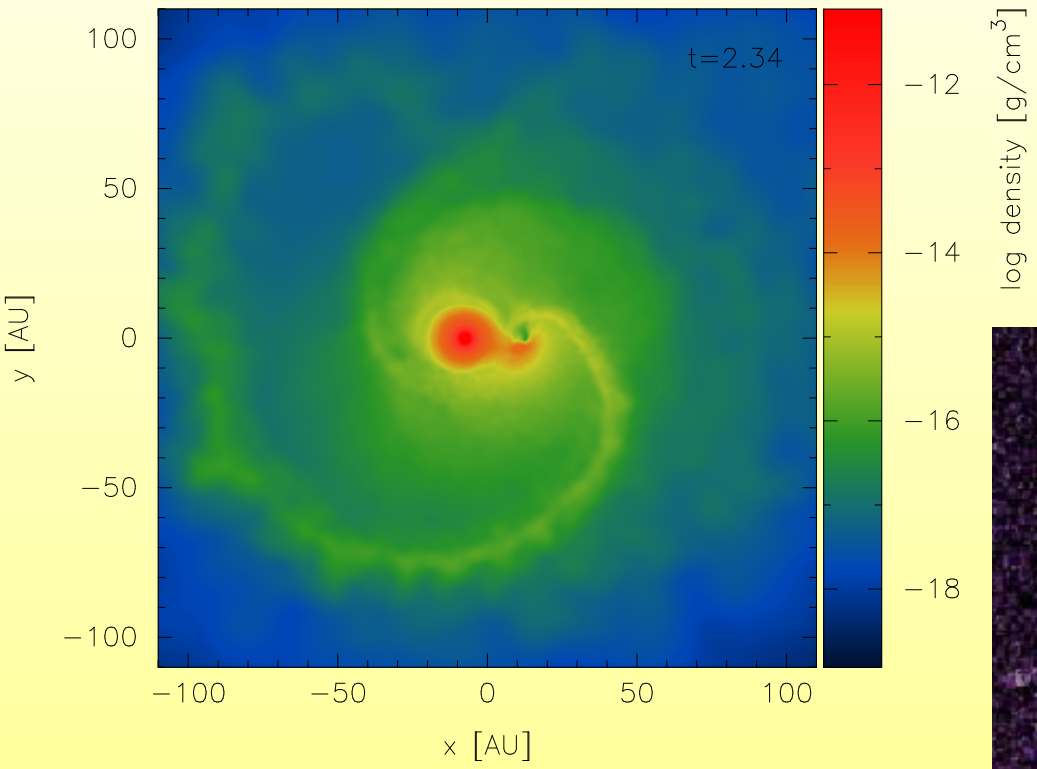
Dermine et al. (in preparation)

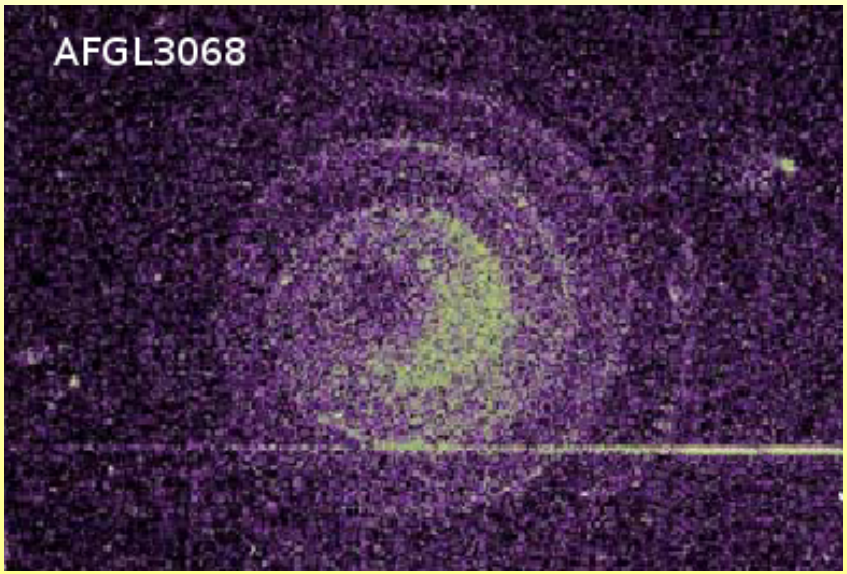
Wind Mass Transfer? e.g. Mira



Play movies

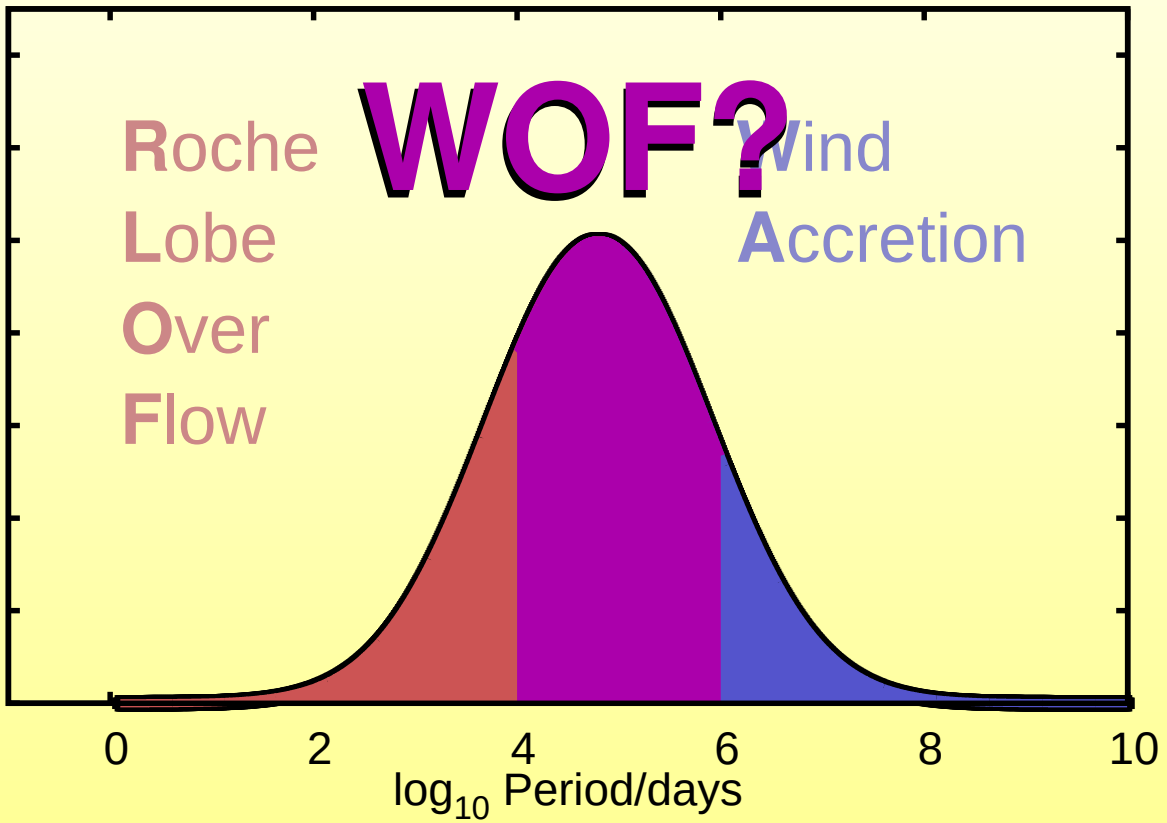
Play Shazrene Mohamed's movies



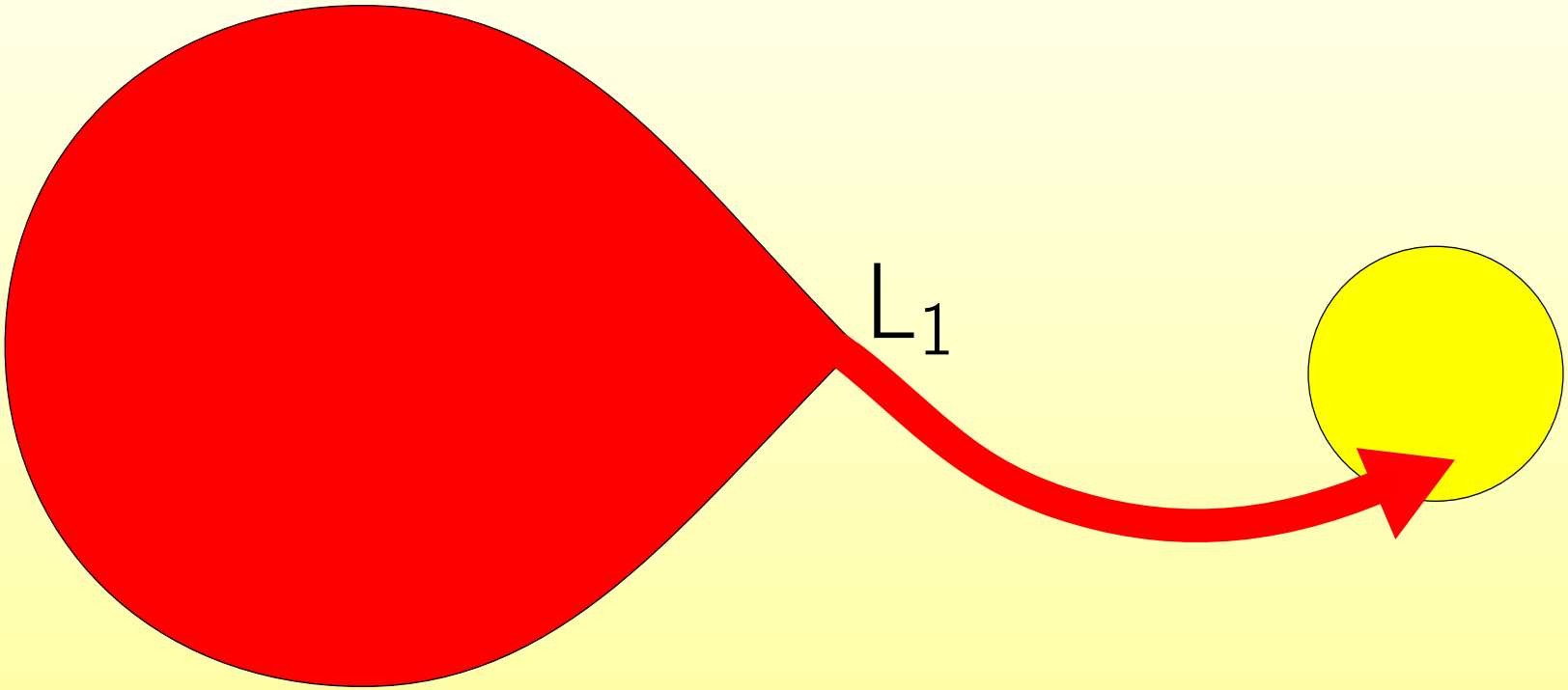


Morris et al. 2004, Mauron & Huggins 2006

Wind OverFlow?

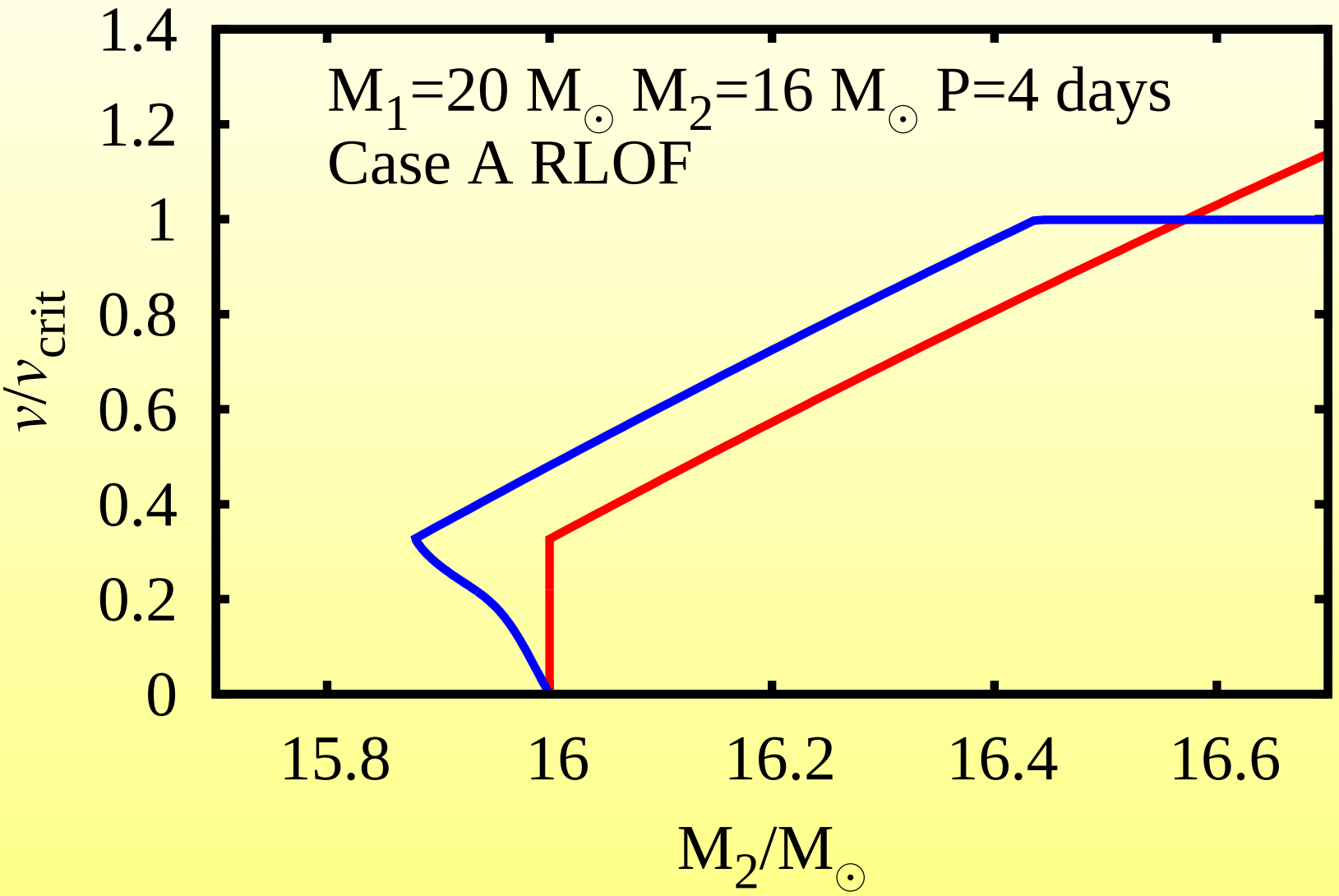


RLOF (in Massive Stars)



RLOF (in Massive Stars)

- Often "conservative": Spin up is important!



Spun Up Massive Stars

Why are they interesting?

Rotation→Instabilities→**Mixing**

In low-mass stars:

$$\tau_{\text{rotational mixing}} \ll \tau_{\text{H-burning}}$$

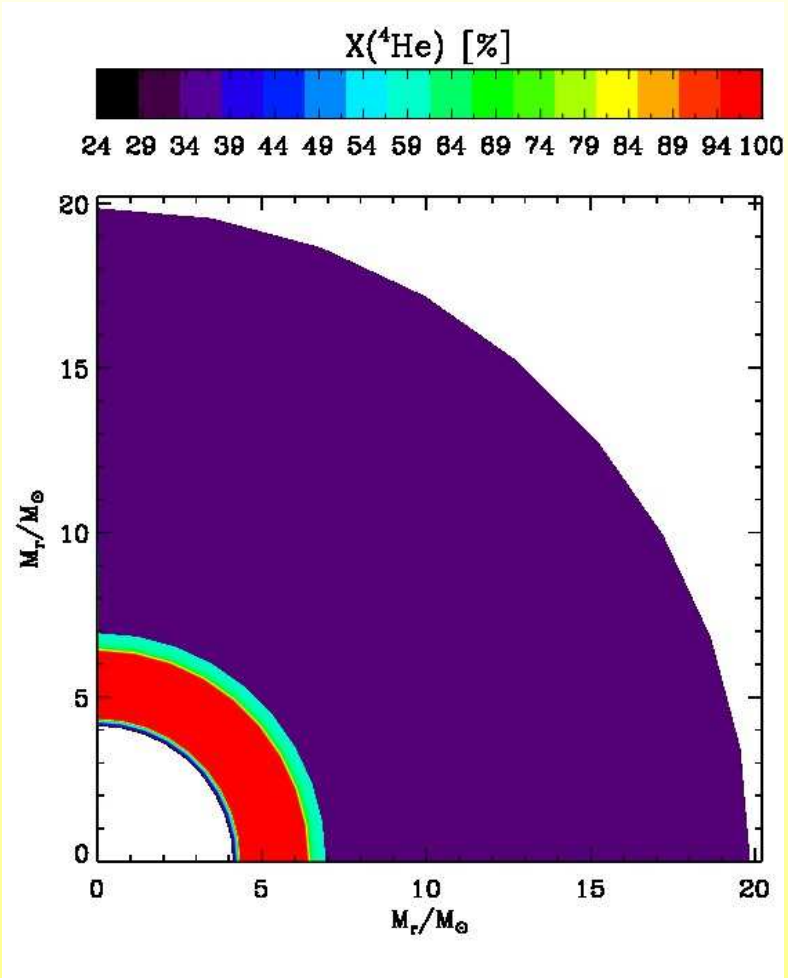
In massive stars:

$$\tau_{\text{rotational mixing}} \sim \tau_{\text{H-burning}}$$

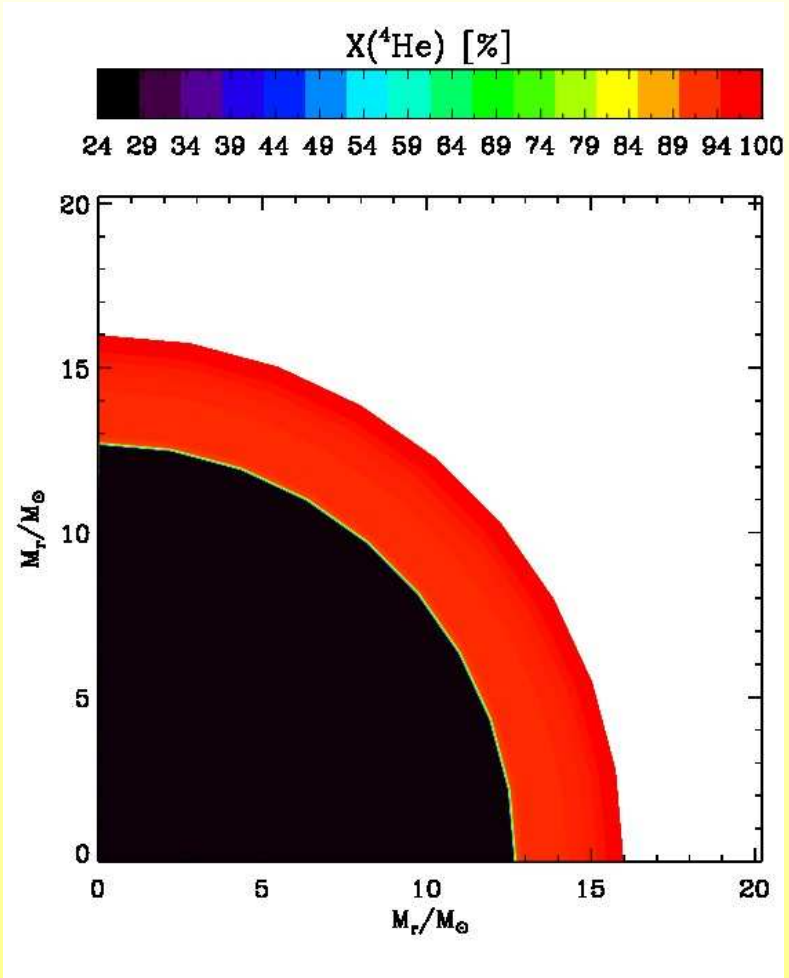
1. H-burnt material (He,N) at the surface! "Chemically homogeneous"
2. Smaller stars

Sung-Chul Yoon's Movies

Single stars, $M = 20\,\mathrm{M}_\odot$, $Z = 0.05 Z_\odot$



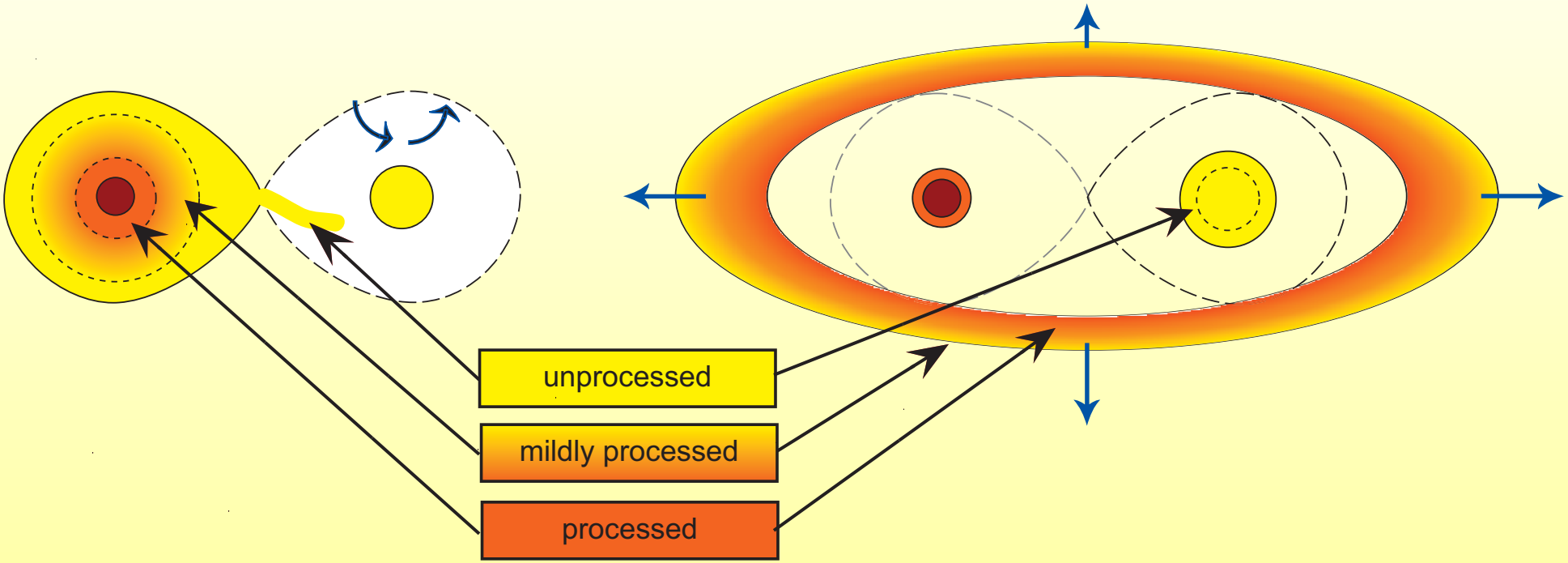
$v/v_{\mathrm{crit}} = 15\%$



$v/v_{\mathrm{crit}} = 60\%$

At Critical Rotation

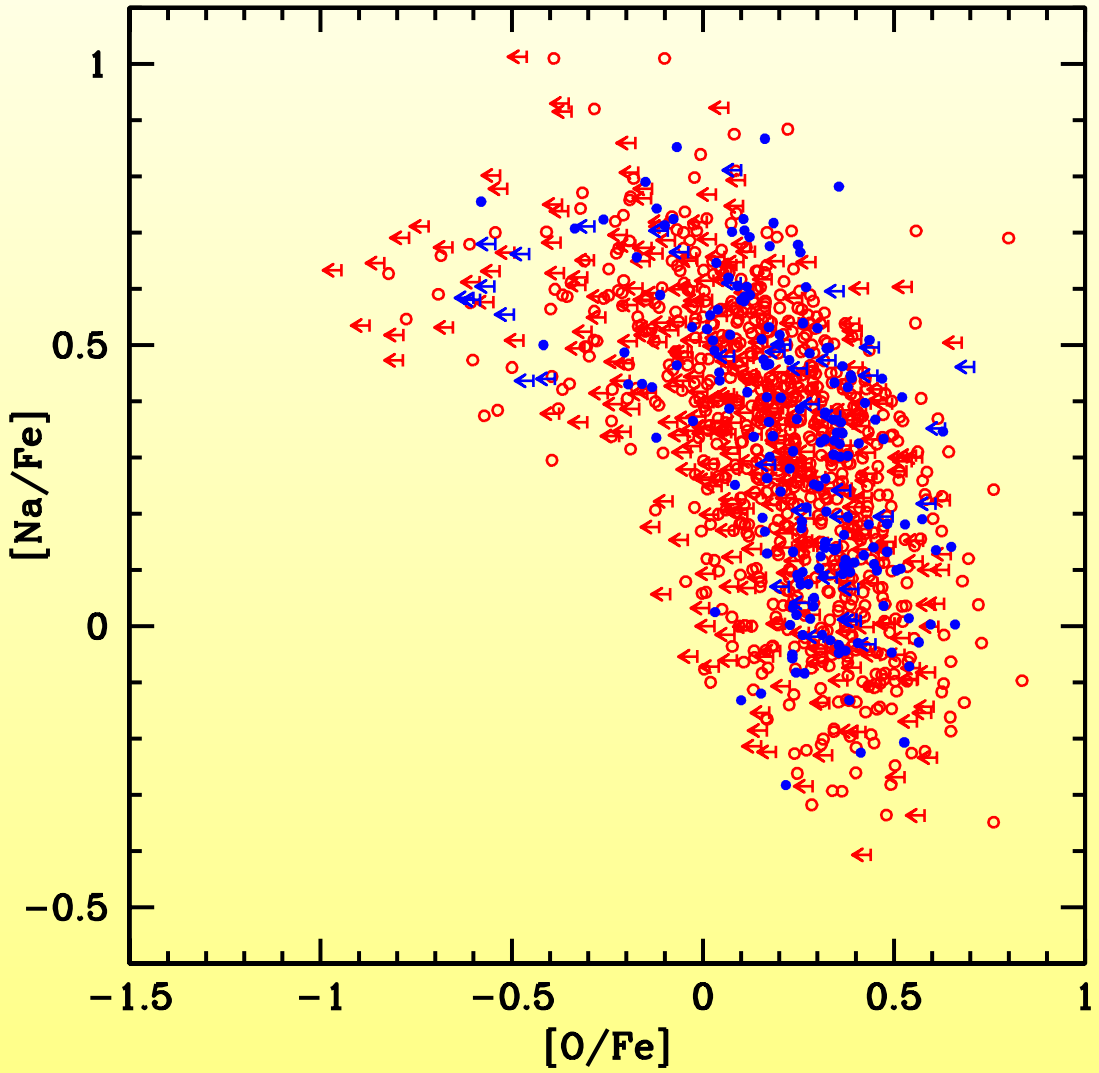
Mass cannot be accreted → lost to interstellar medium!



Ejected material:
He, N, **Na**, **Al** ↑
C, O, **Mg** ↓

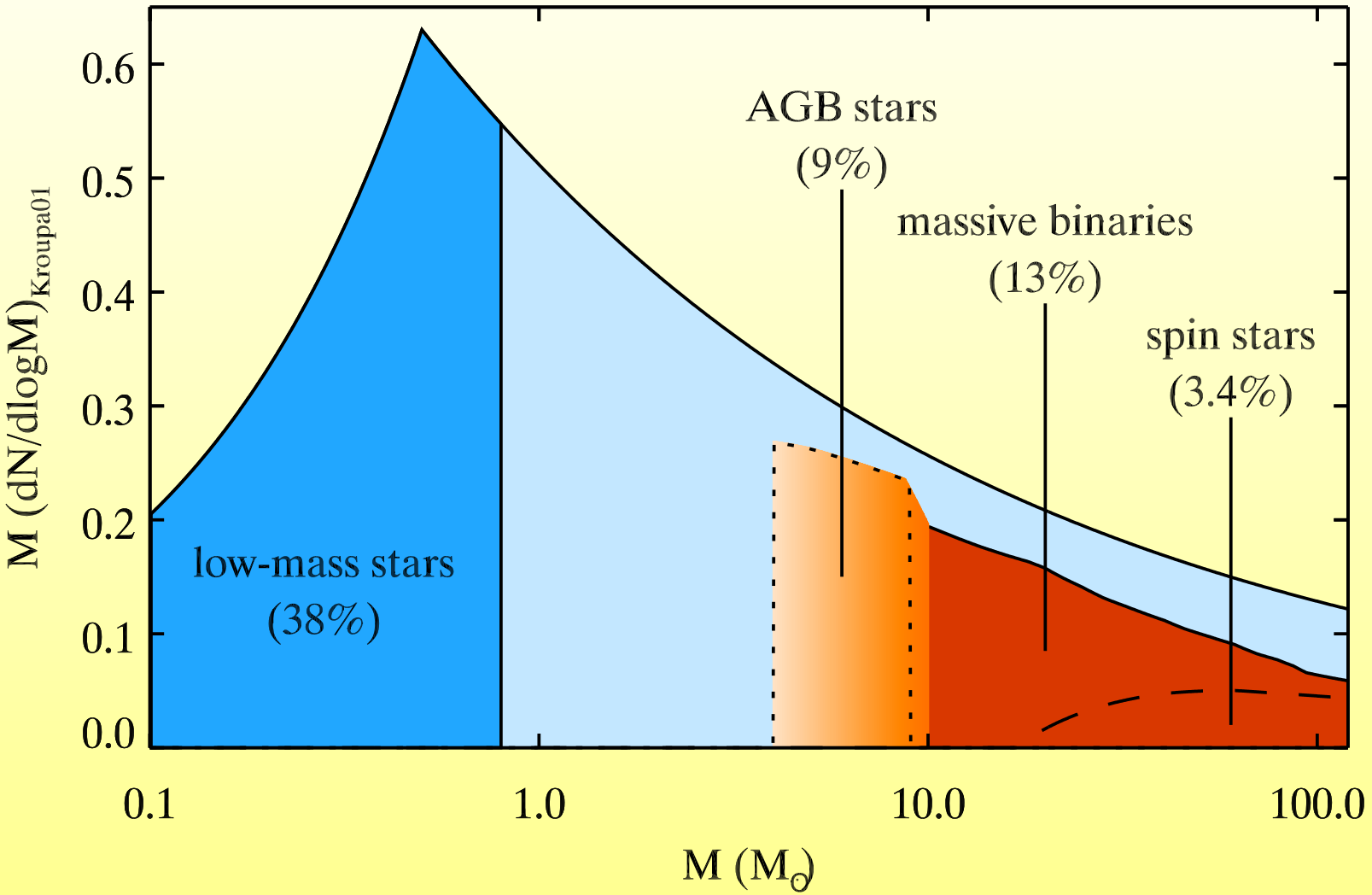
Consequences for Globular Clusters

Stars in Globular Clusters have O-Na and Al-Mg anticorrelations



Caretta et al. 2009

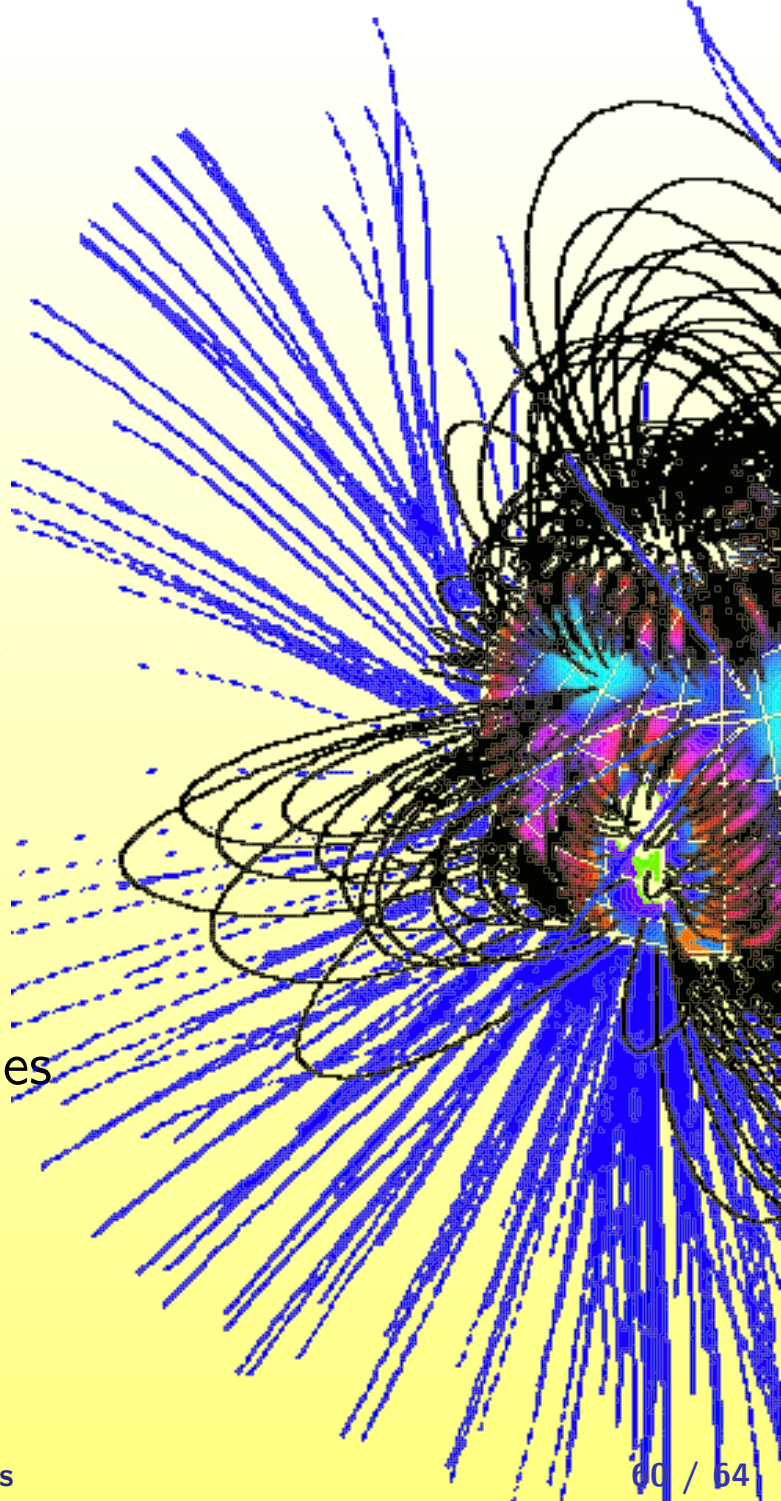
Are massive binaries responsible?



De Mink et al. 2009

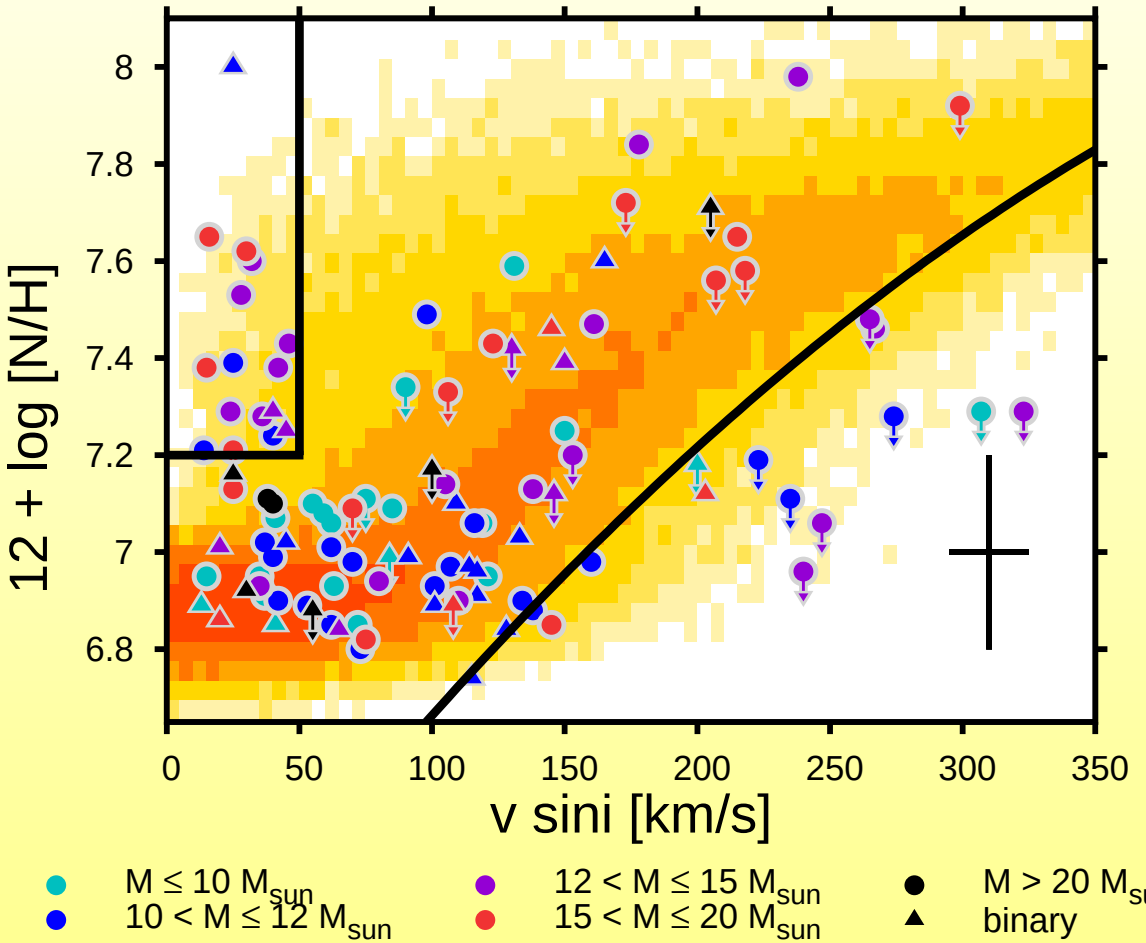
Before you get comfortable

1. We do not understand mixing, e.g.:
   - rotation
   - magnetic fields
   - thermohaline etc.
2. We do not understand how binaries affect the big picture:
   - Spin Up: RLOF, tides, more mixing?
   - Spin Down: Wind, tides, less mixing?
3. Main sequence models are wrong
4. We cannot always see that they are binaries
5. **CONNECTED PROBLEMS:**
   all related to each other



e.g. Nitrogen in B type stars

Obs: VLT-FLAMES survey of Massive (B/MS) Stars (Hunter et al. 2008/9)
vs Models of rotating single stars from Ines Brott (et al. in preparation)



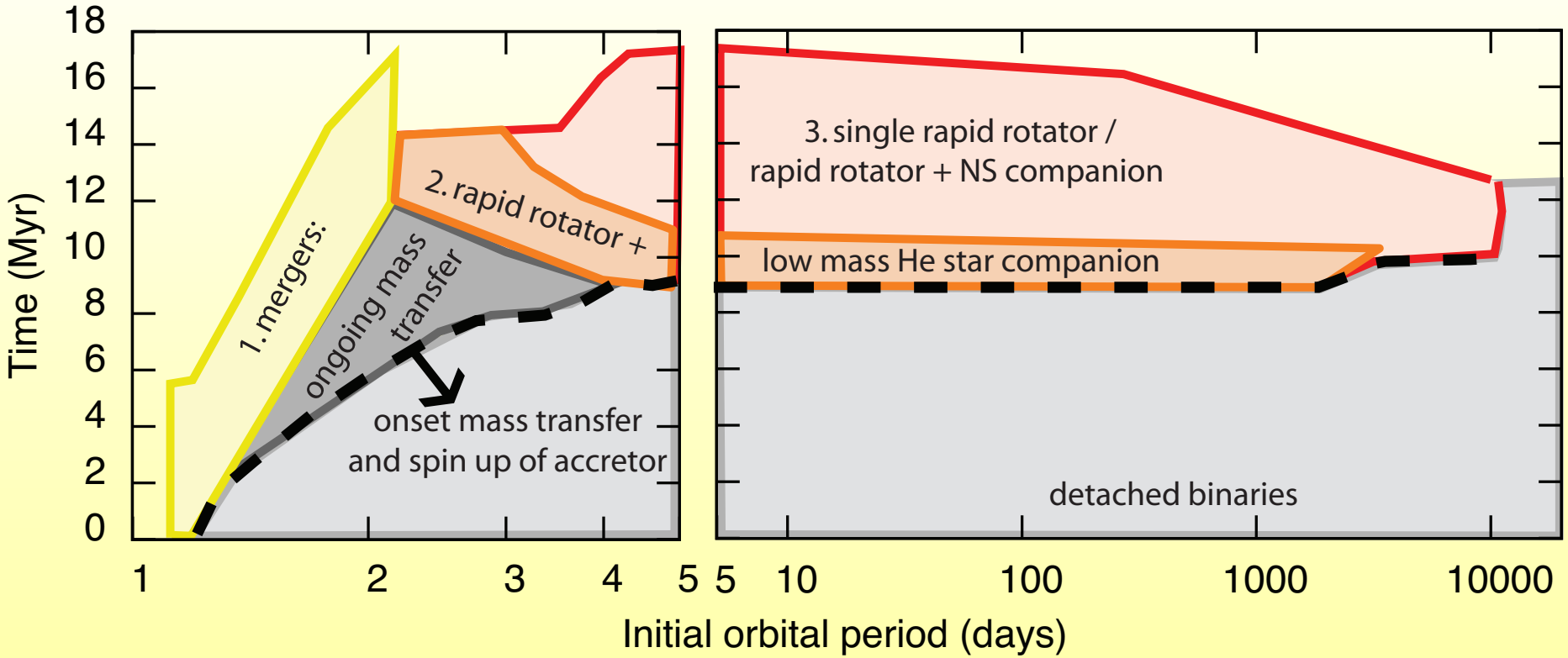
Binaries?

Mass Transfer?

These are Main Sequence Stars: "Understood"!

ADVERTISEMENT: **VLT Tarantula survey coming out soon: 10^3 stars!**

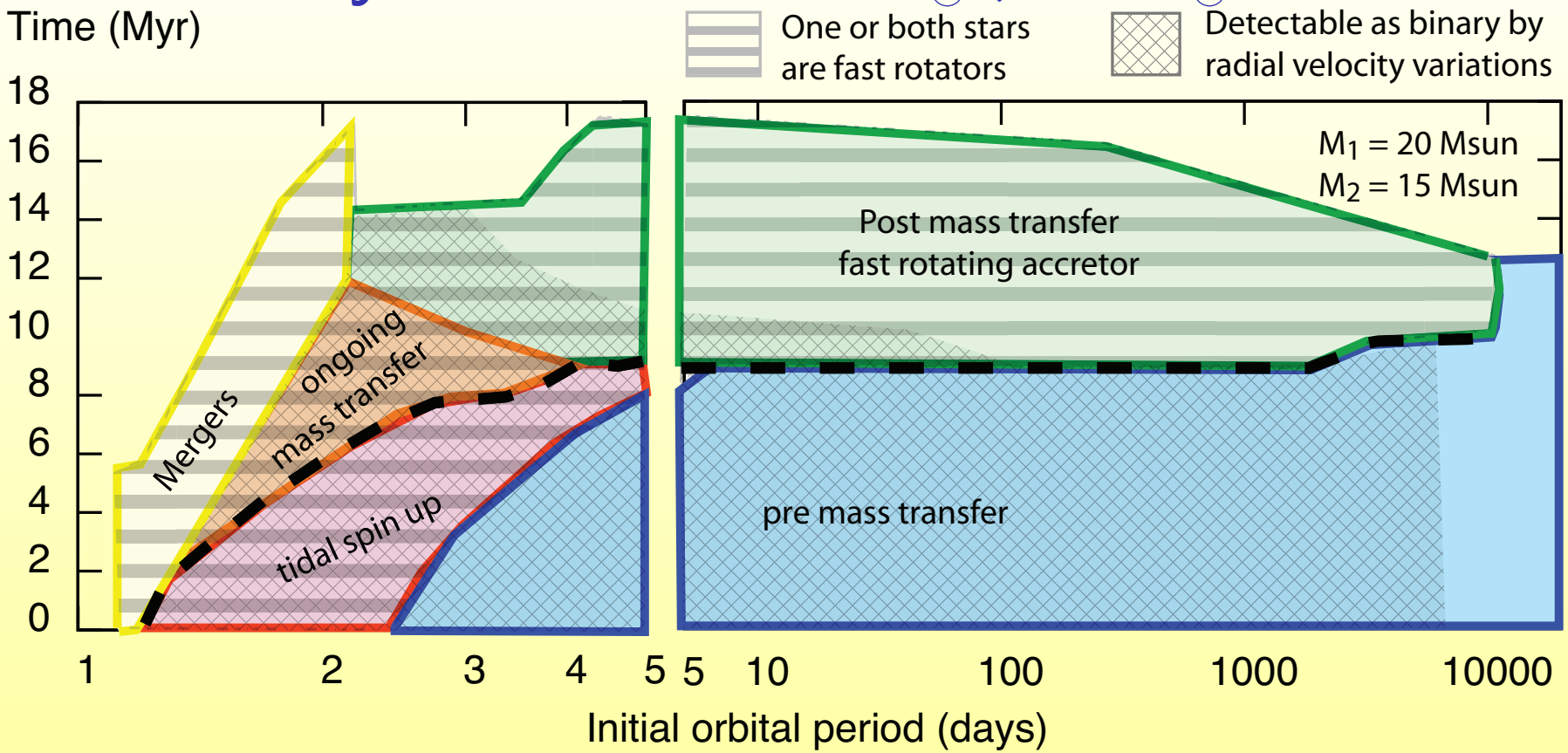
Close binary evolution: $20\,M_\odot + 15\,M_\odot$



Calculated by Selma de Mink with
binary_c/nucsyn population synthesis code.

http://www.astro.uni-bonn.de/~izzard/binary_c.html

Close binary evolution: $20\,M_\odot + 15\,M_\odot$



Calculated by Selma de Mink with binary_c/nucsyn population synthesis code.

http://www.astro.uni-bonn.de/~izzard/binary_c.html

Where do I/we go from here?

New Observations
VLT Tarantula etc.

Stellar models:
Mixing
Nucleosynthesis

Binary Population Model:
Quantitative
Statistical

Hydro models:
Mass Transfer
Stellar Mergers

Understand Physics of Stars