# The fate of S-AGB stars

or

Why won’t my code converge?

# Work in Progress!
# No answer yet!

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# Overview

Massive AGBs fail to converge when $M_{env}$ about 2 $M_{\odot}$

Numerical problem?

Physical problem?

# Overview

Massive AGBs fail to converge when $M_{env}$ about 2 $M_\odot$

~~Numerical problem?~~

Physical problem?

$L > L_{Edd}$

Extreme low $\rho$ below BCE

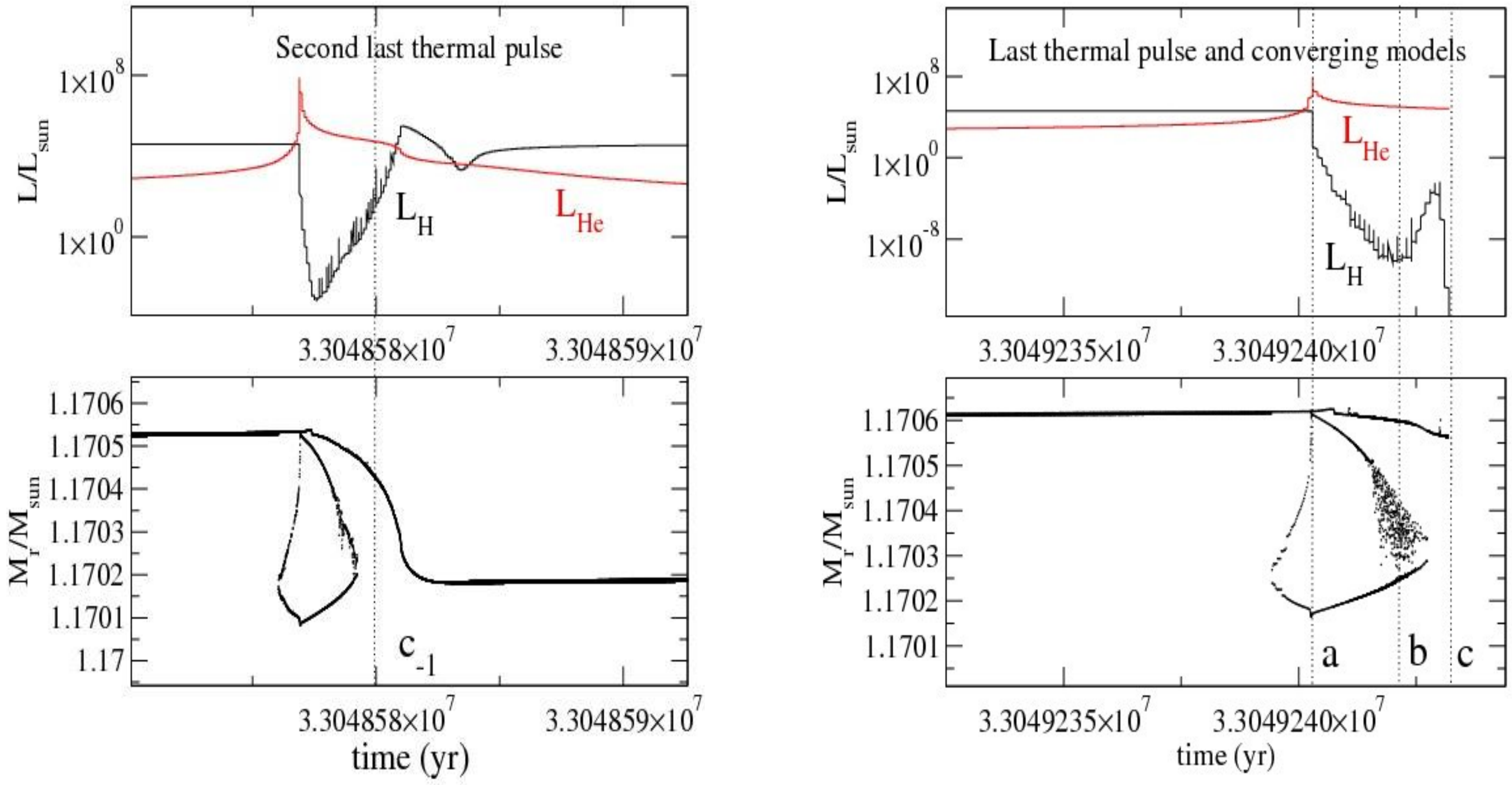
# Looking at the facts: when does it happen?

- The divergence happens for different evolution codes (EVOLV, MONSTAR)
- Can be delayed by increasing alpha (MLR)=>

  increasing mixing efficiency (Herwig et al., Althaus et al,…)

# Looking at the facts: when does it happen?

## Comparison: the last two TPs



# Pg < 0

- Code dies with negative gas pressure
- T and P are dependent variables
  - So values chosen by matrix solution
  - $P_{rad} = 1/3aT^4$ then known
  - $P_{gas} = P - Prad$ is known
  - Then the e.o.s. tells us $\rho$
- So a Pg < 0 error means $P_{rad}$ provides all of P
- ie $\beta < 0$ and $L > L_{Edd}$
- See Wood and Faulkner 1986!!

# Looking at the facts: contribution P/P$_{rad}$ in the hydrostatic case

$$\beta \rightarrow 0$$

Radiative case:

$$\frac{dP_{rad}}{dP} = \frac{\kappa\rho L_r}{4\pi c G M_r}$$

then:

$$\frac{P_{rad}}{P} = 1-\beta \approx \frac{L}{L_{Edd}}$$

with: $L_{Edd} = \frac{4\pi c G M}{\langle\kappa\rangle}$

Convective case:

$$\frac{dP_{rad}}{dP} = \frac{\kappa\rho L_r}{4\pi c G M_r}\frac{\nabla}{\nabla_r}$$

then:

$$\frac{P_{rad}}{P} = 1-\beta \approx \frac{L}{L'_{Edd}}$$

with: $L'_{Edd} = \frac{4\pi c G M}{\langle\kappa\rangle}\frac{\nabla_r}{\nabla}$

# Looking at the facts

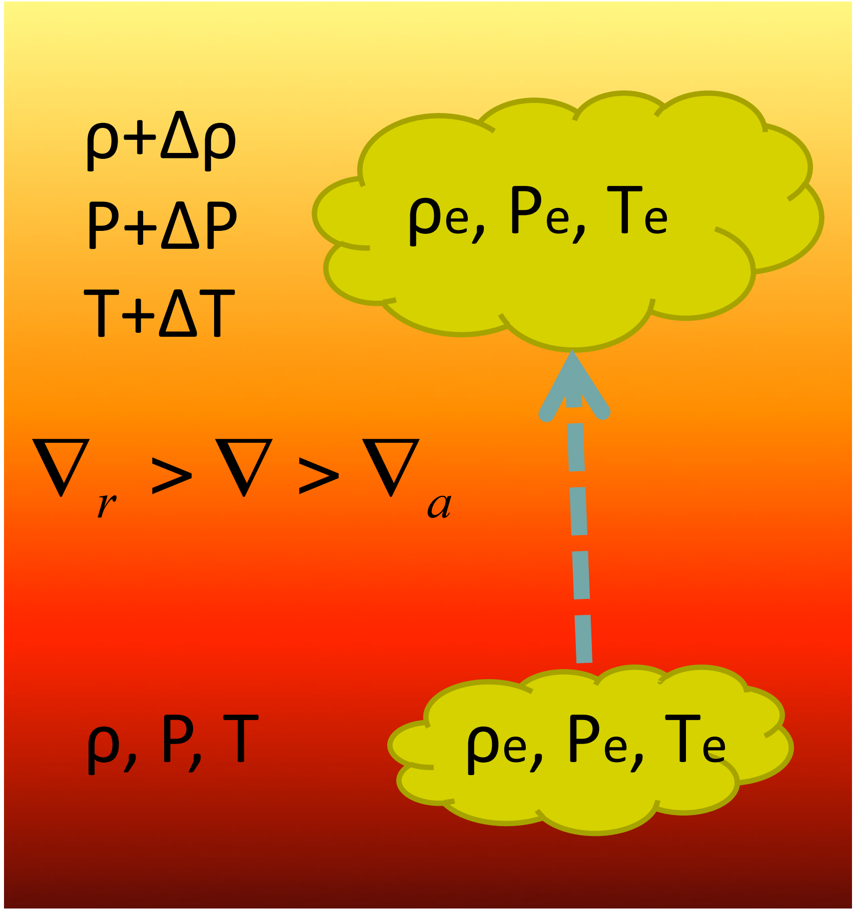
## Conductivity radiation-to-convection

$$(\nabla - \nabla_e)^{3/2} = \frac{8}{9} U (\nabla_r - \nabla)$$

$$U = \frac{3acT^3}{C_p \rho^2 \kappa \ell_m^2}\sqrt{\frac{8H_p}{g\delta}}$$

U >> convection inefficient

U << convection efficient



ρ+Δρ

P+ΔP

T+ΔT

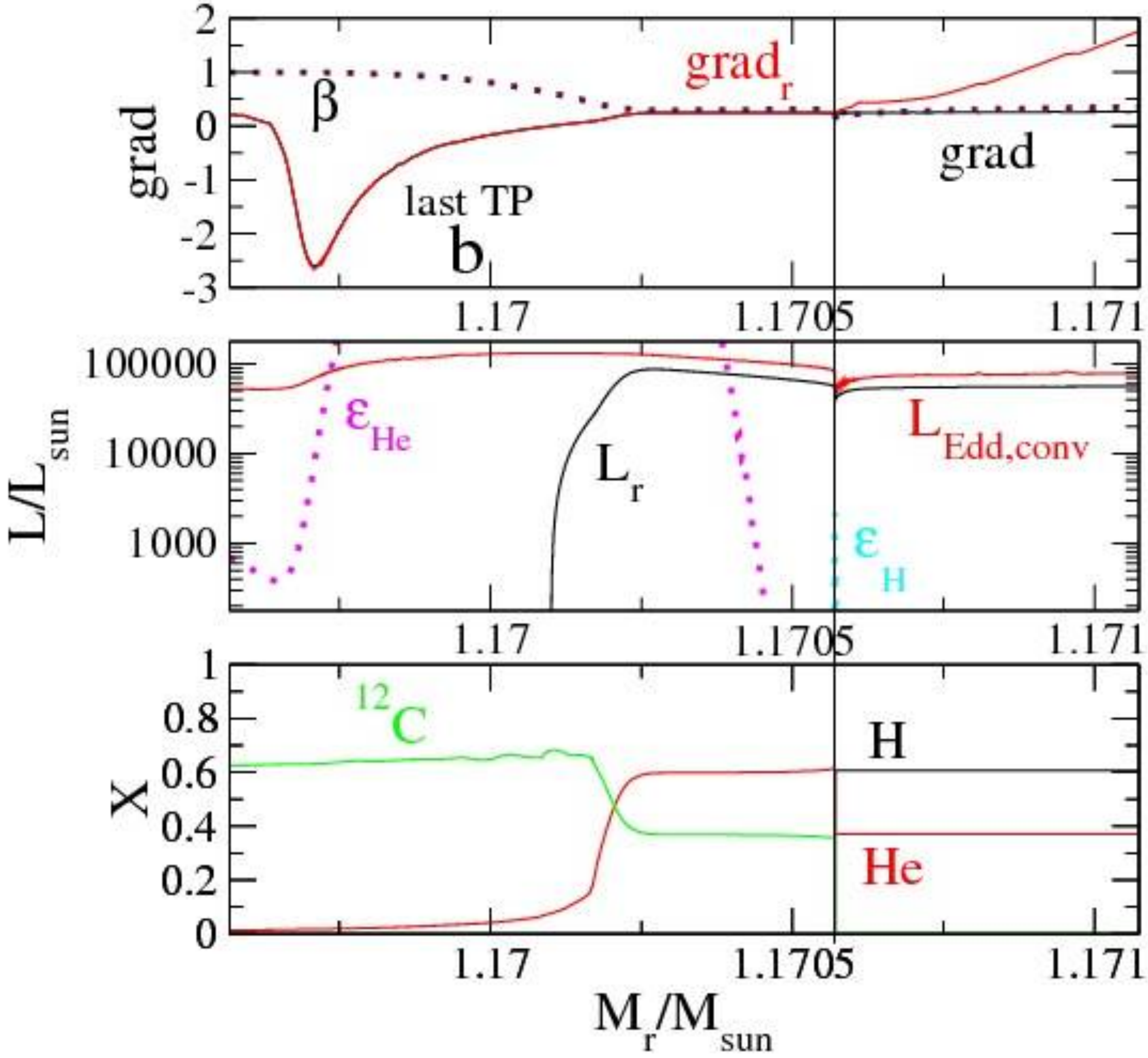
ρe, Pe, Te

$\nabla_r > \nabla > \nabla_a$

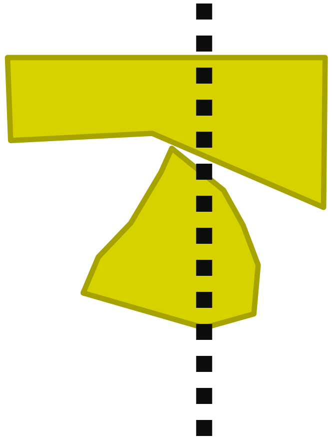
ρ, P, T

ρe, Pe, Te

# We have very inefficient convection here…



After last TP



# What pushes L > $L_{Edd}$ ?

$$L'_{Edd} = \frac{4\pi c G M}{\langle \kappa \rangle} \frac{\nabla_r}{\nabla}$$

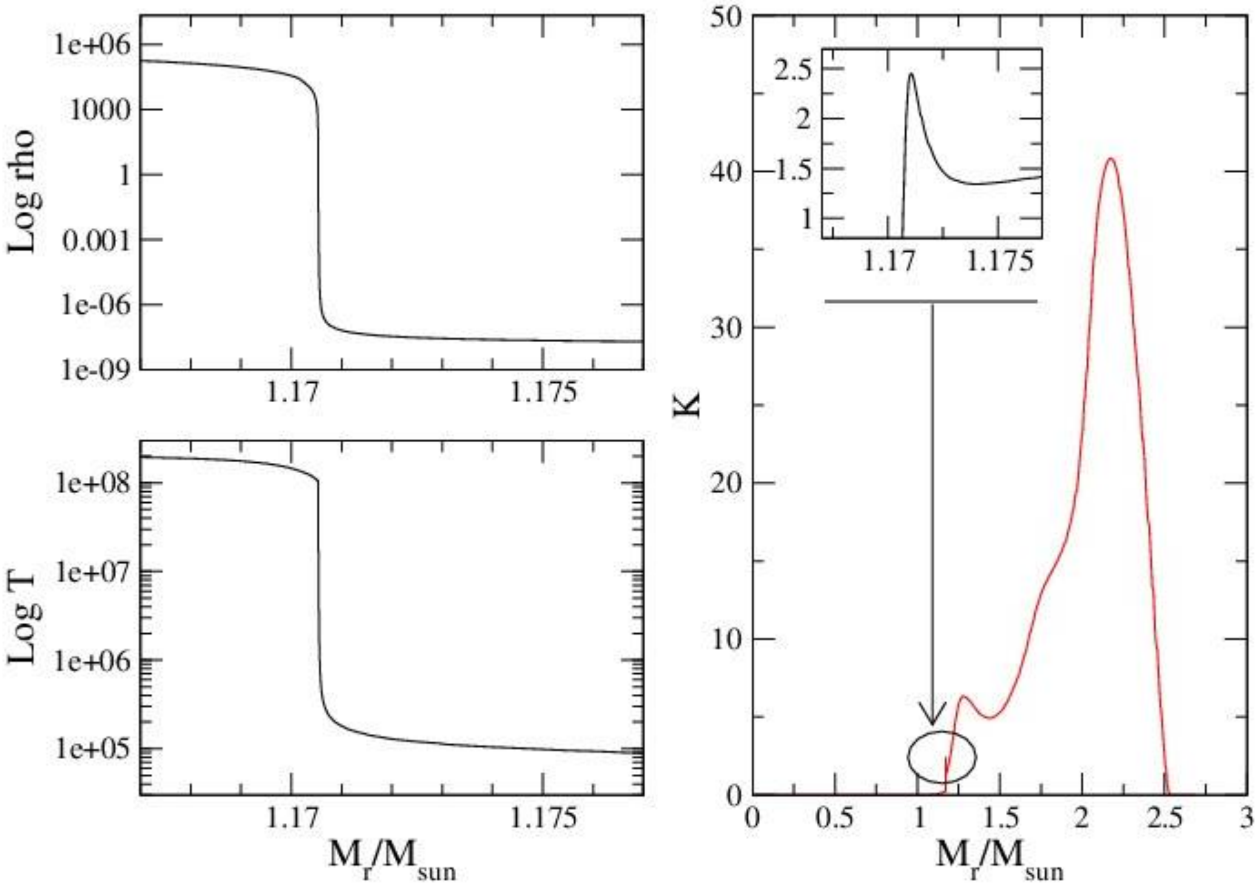
Reduce $L_{Edd}$ by increasing <κ> ???

# Hypothesis κ-peak

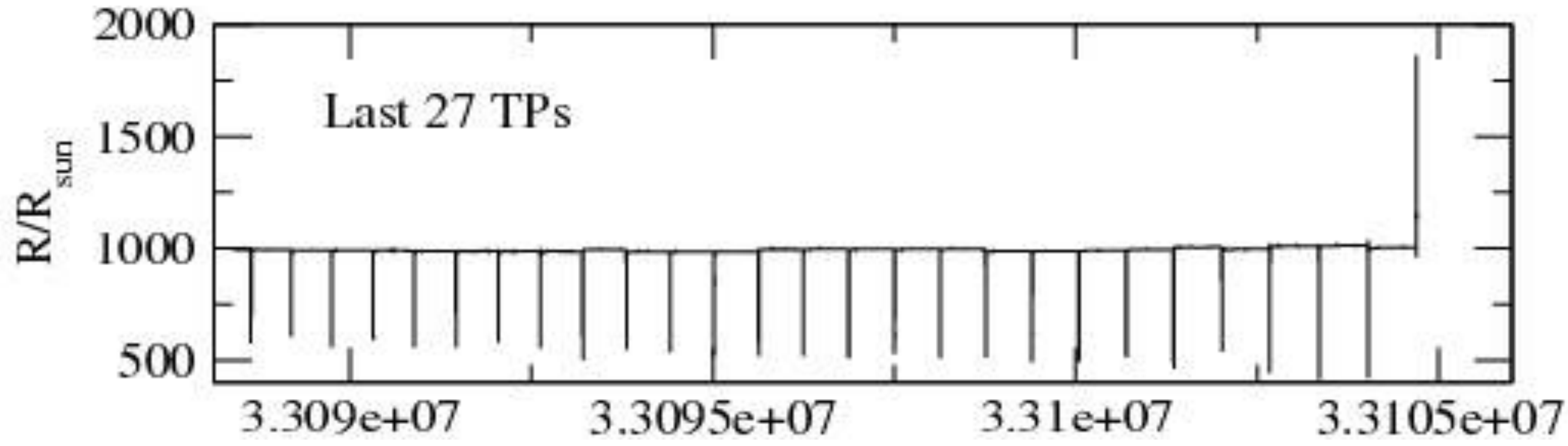
- Petrovic et al (2006)
  - OPAL opacity tables display a peak due to presence of Fe, Ni at T aprox. 250000 K
  - This peak causes ***huge inflation*** and departure of hydrostatic equilibrium in WR stars
- Could this be our case?

# Testing the κ-peak hypothesis:

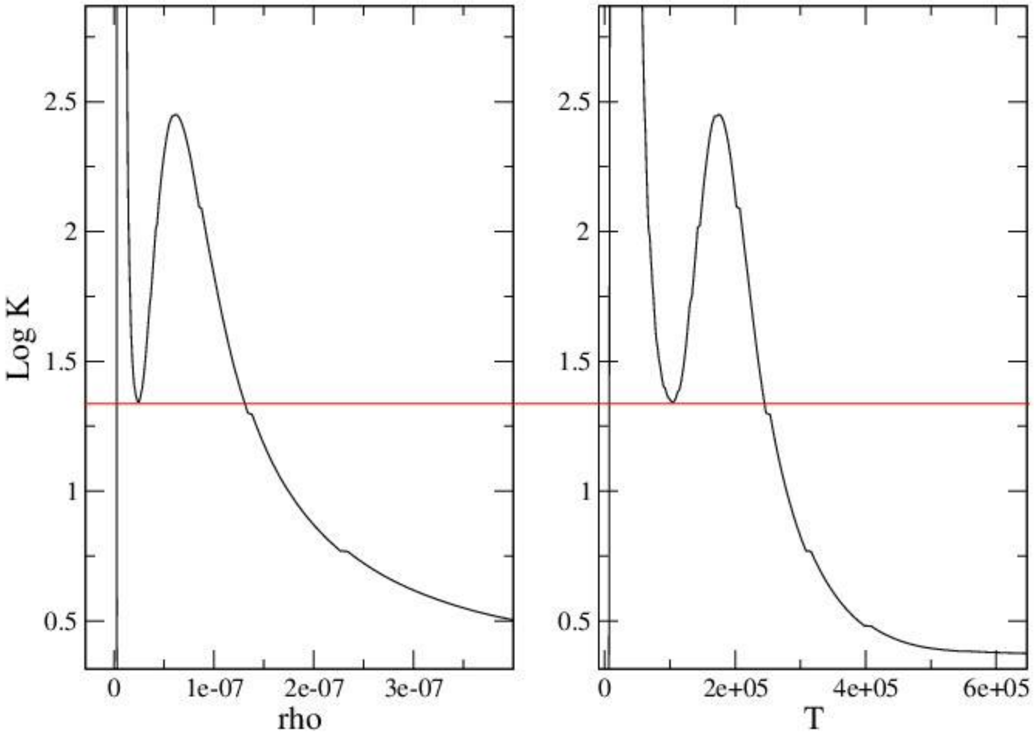
## We do find the κ-peak



# Look at that radius!

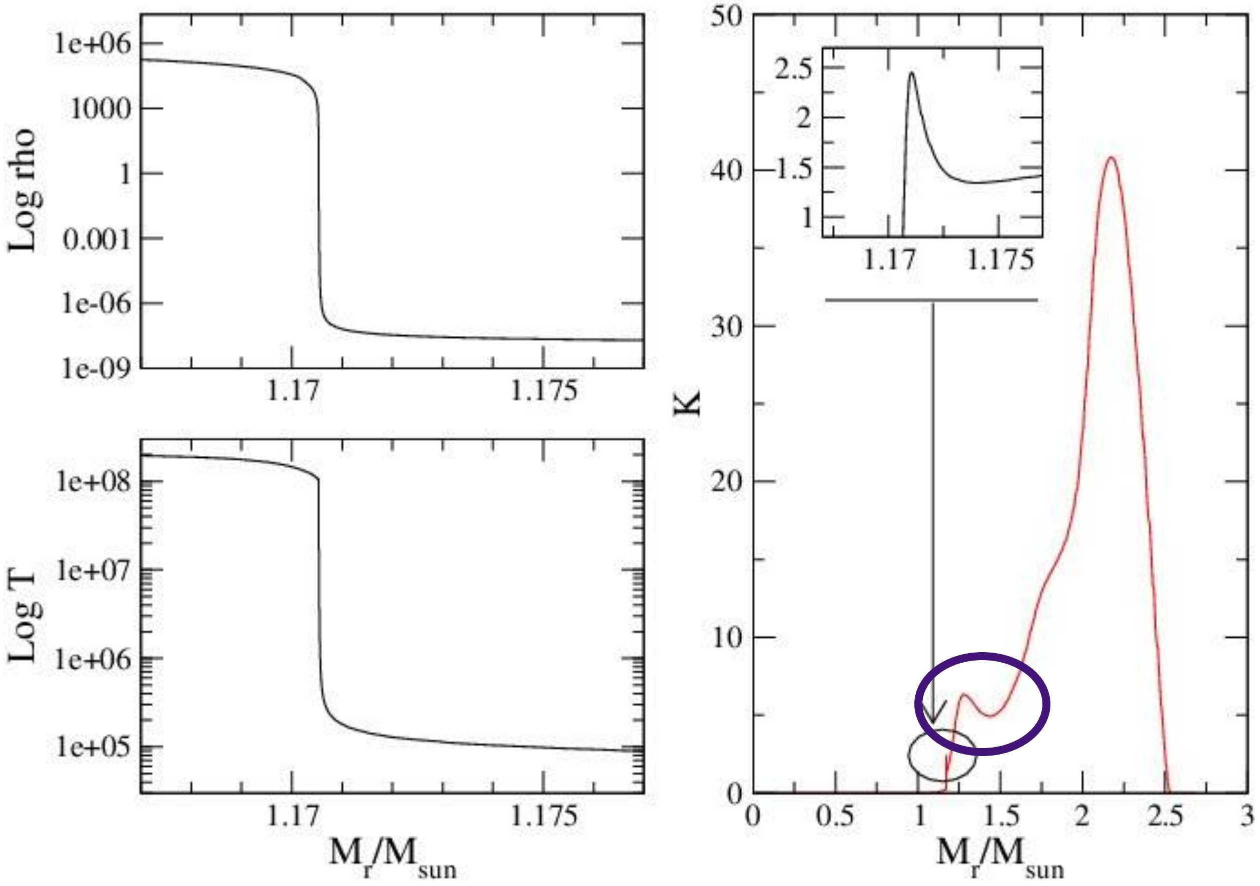


# Testing the κ-peak hypothesis:

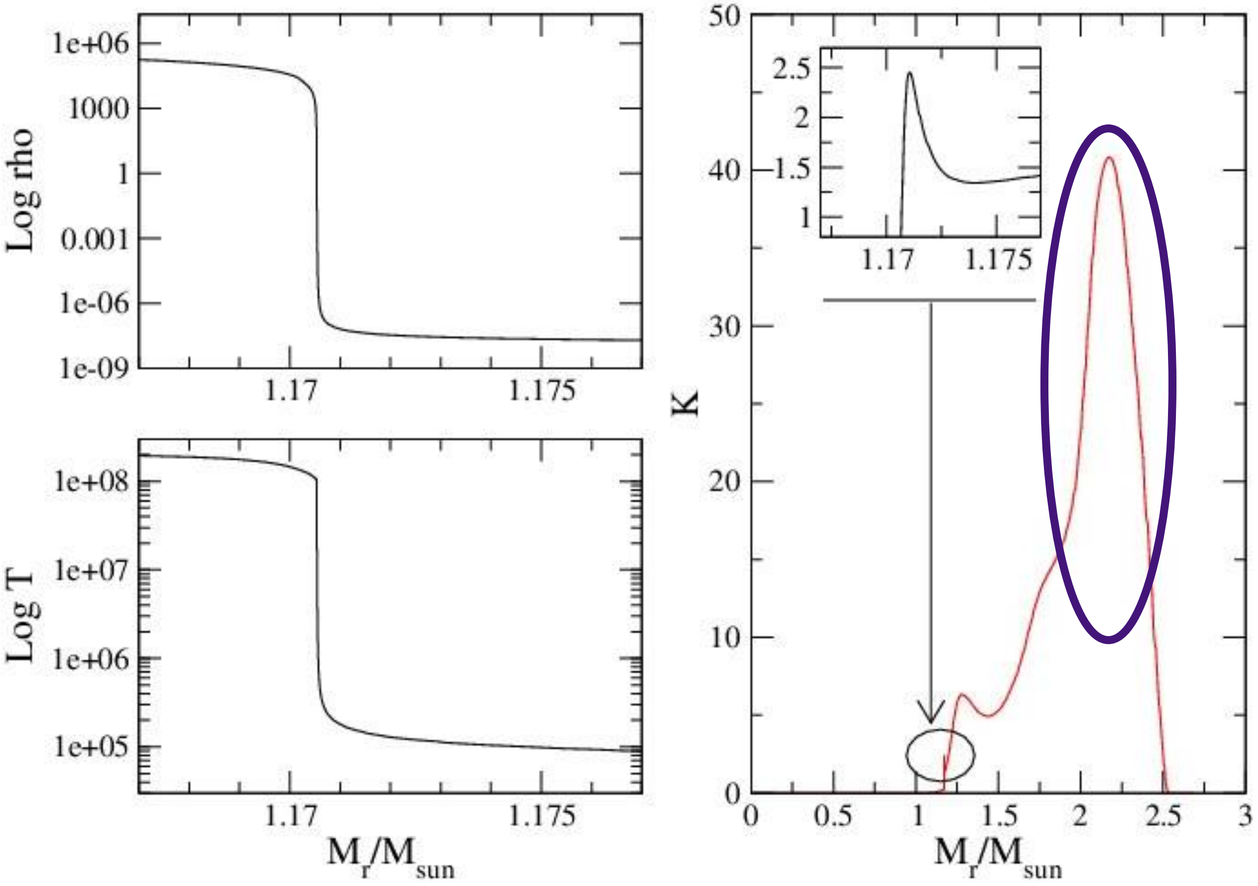


- We smoothed out the peak
- and the code keeps converging!
- The star lost a further 0.5 $M_{sun}$
- Before it died again!.

# But there is another larger opacity peak…

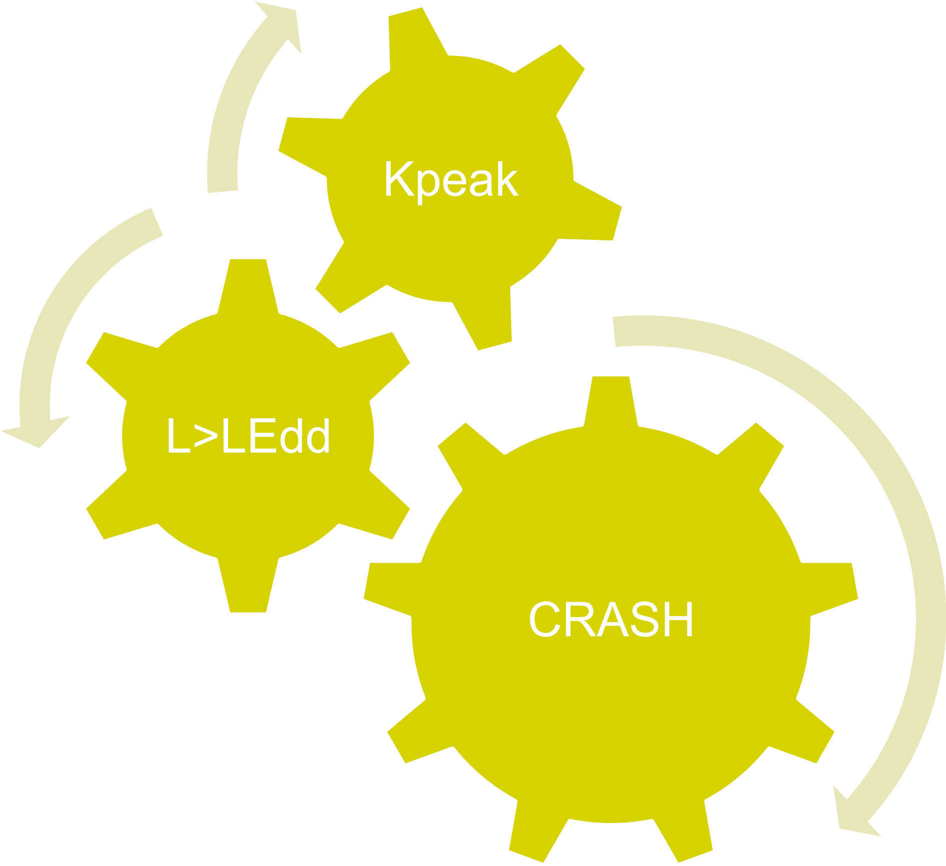


# And another!



Log rho
1e+06
1000
1
0.001
1e-06
1e-09
1.17
1.175
Log T
1e+08
1e+07
1e+06
1e+05
1.17
1.175
$M_r/M_{sun}$
K
50
40
30
20
10
0
2.5
2
1.5
1
1.17
1.175
0
0.5
1
1.5
2
2.5
3
$M_r/M_{sun}$

# Hypothesis κ-peak



Kpeak

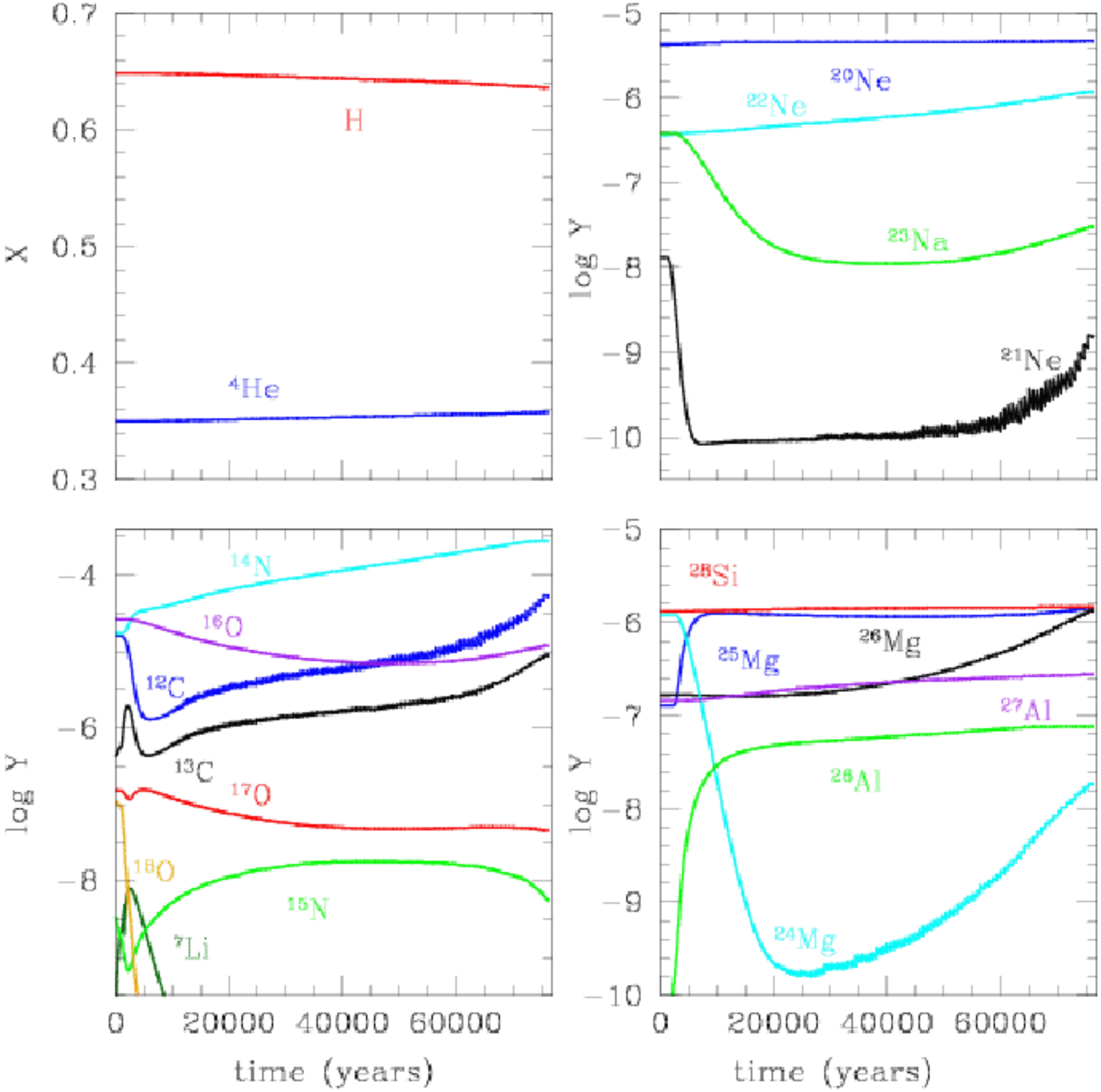
L>LEdd

CRASH

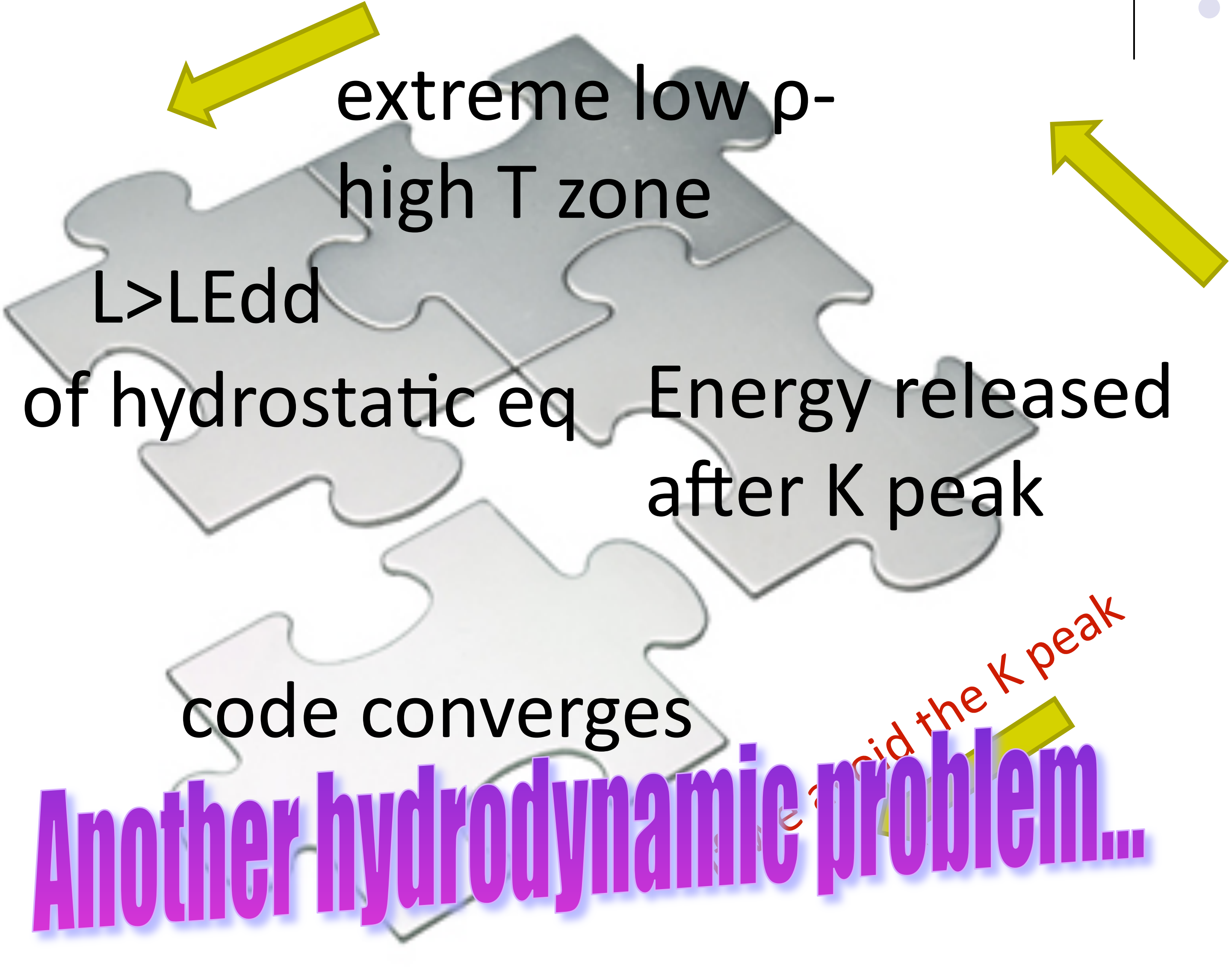
# Multiple κ-peaks

- We doubt the star can avoid its fate…
- Deep envelope and low density mean a region of increasing opacity
- The high luminosity drives dramatic expansion
- In our hydrostatic case its supersonic!
  - $10^3 - 10^4\ R_\odot$ per year!
- What does a REAL star do?
- We think the energy involved < binding energy of the envelope
- But it might drive periodic, enhanced mass-loss at least?

# We need to sort this out!



# The general picture



extreme low ρ-
high T zone

L>LEdd

Loss of hydrostatic eq

Energy released
after K peak

code converges

we avoid the K peak

Another hydrodynamic problem...