Instabilities in LBVs and WR Stars

Knut Jørgen Røed Ødegaard

Institute of Theoretical Astrophysics, University of Oslo, P.O. Box 1029 Blindern, N-0315 Oslo, Norway

Abstract. Using a dynamical stellar code, detailed evolutionary models have been computed that follow the evolution and nucleosynthesis of massive stars from the pre-MS (accretion phase) up to the onset of O-burning. Various instabilities occur during the evolution. As an example, the evolution of a star with maximum mass 120 $M_\odot$ is discussed.

1 Ingredients of the models

The code is an extended version of the Göttingen dynamical stellar evolution code and includes:

- A large and flexible nuclear network consisting of up to 177 nuclear species from n and ^{1}H to ^{71}Ge linked by more than 1700 nuclear reactions. Initial metallicity Z = 0.02. The network and the diffusion equation are solved for each time step during the evolution.
- Modern rates for both strong and weak interaction processes as well as neutrino emission.
- Semiconvection, overshooting (0.2 H_P). The semiconvective diffusion parameter α (Langer et al. 1985) was set to 0.04.
- Mass loss using different prescriptions for O-stars (radiation driven), (Kudritzki et al. 1989), LBVs (parametric) and WR stars (Langer 1989).
- Improved grid distribution, a large number of grid points and artificial viscosity

1.1 Instabilities

In the present models instabilities occur in at least 3 different evolutionary stages. The overall evolution and the nucleosynthesis of the models were discussed in Ødegaard (1996).

The computations are started from a protostar with low temperature. The onset of nuclear burning can therefore be followed in detail. No nuclear species are assumed to be in equilibrium. Towards the end of the rapid growth of the core, pulses occur because light nuclear species are mixed into the core. The increased core luminosity causes spikes affecting both the size of the convective core (cf. Fig. 1) and the surface. In a new sequence computed according to the accretion scenario (Bernasconi and Maeder 1995), similar

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pulses occur when the stellar mass is exceeding 105 $M_\odot$. These pulses are even more violent and cause periodic appearances of one or more semiconvective layers above the convective core. The luminosity of the star varies 2 percent or less.

LBV pulsations are shown in the upper panel of Fig. 2. For a period of about 7800 years, $\dot{M}$ is very large, but variable, and reaches $\log \dot{M} = -2.15$. The time scales range from small variations in a few years or less to large variations in periods from 100 - 600 years.

The very heavy mass loss during the LBV stage and the succeeding WR-stages remove the outer layers completely, leaving a simple He-star. During subsequent burnings, the interior again becomes extremely complex with a large number of thin and active zones with convection as well as semiconvection. Local luminosities reach high values and the interior becomes rather dynamic. Waves seem to be excited and reach the surface, causing vibrations, as illustrated in the lower panel of Fig. 2. The total timespan of the plot is 1430 seconds.

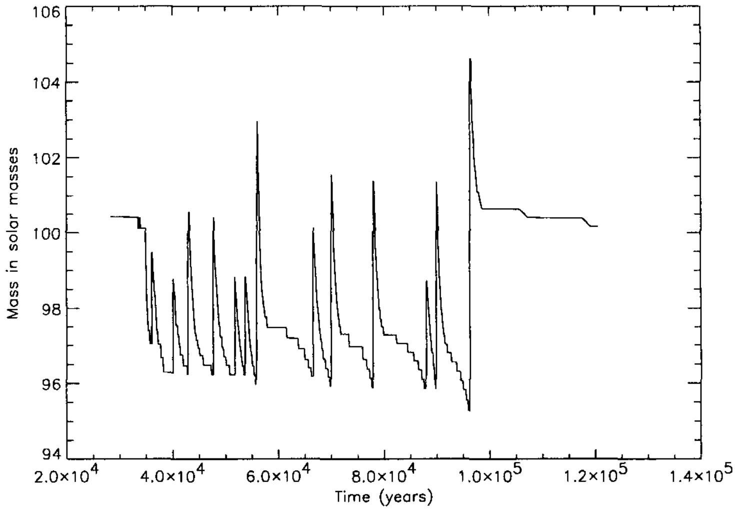

Fig. 1. Extention of convective core early in the evolution

References

Bernasconi, P.A., Maeder, A. (1995): About the absence of a proper zero age main sequence for massive stars. A&A, **307**, 829–839

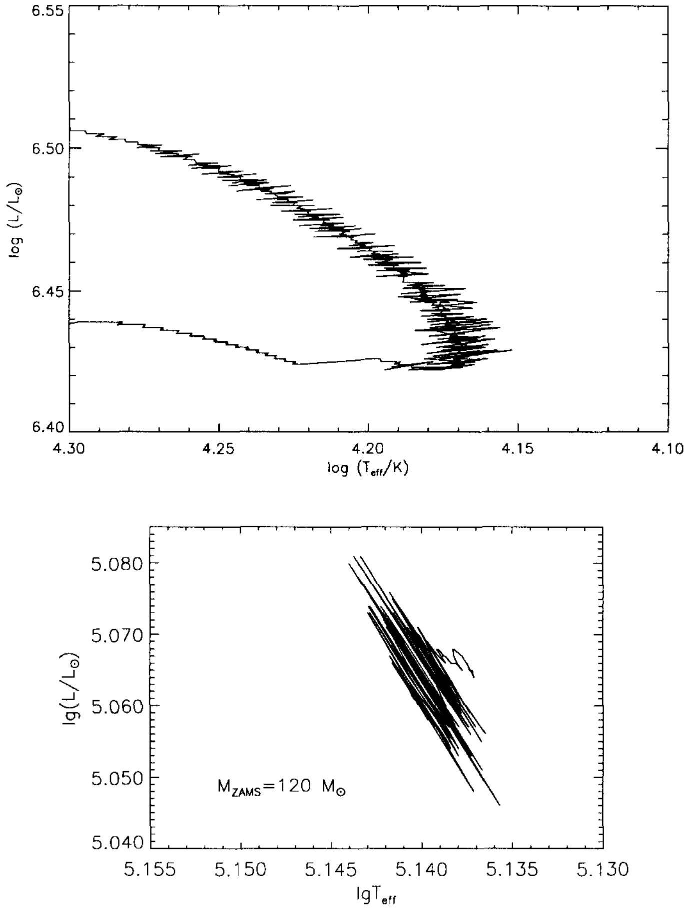

Fig. 2. Top panel: Pulsations during LBV stage. $M_{init} = 120 M_\odot$. **Lower panel:** Vibrations, probably caused by waves excited in the interior, affect the stellar surface during the transition from Ne-burning to O-burning.

Kudritzki, R.P., Pauldrach, A., Puls, Abbott, D.C. (1989): Radiation-driven winds of hot stars. VI. Analytical solutions for wind models including the finite cone angle effect. A&A, **219**, 205–218

Langer, N. (1989): Mass-dependent mass loss rates of Wolf-Rayet Stars. A&A, **220**, 135–143

Langer, N., El Eid, M.F., Fricke, K.J. (1985): Evolution of massive stars with semiconvective diffusion. A&A, **145**, 179–191

Ødegaard, K.J.R., (1996): Structure and evolution of single WR stars. Ap&SS, **238/1**, 107–111

Discussions

G. Koenigberger: What is the largest mass for a star in your model that can exist?
K. Ødegaard: The physics in my code (OPAL etc.) allow a mass of at least 200 $M_\odot$ at the MS for $Z = 0.02$. Pulsation mechanisms not taken into account in this case may strongly enhance mass loss for these very high masses.

Knuth Ødegaard and Joyce Guzik

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