STEADY MASS-LOSS FROM SUPERMASSIVE STARS

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Abstract. Structures of Newtonian super-massive stars are calculated with the opacity for Compton effect \( \kappa_0/(1 + \alpha T) \), where \( \kappa_0 = 0.2(1 + X) \) and \( \alpha = 2.2 \times 10^{-9} \text{ K}^{-1} \). The track of the Main-Sequence is turned right in the upper part of the HR diagram. Mass loss will occur in a Main-Sequence stage for a star with mass larger than a critical mass. The cause of mass loss and the expansion of the radius is continuum radiation pressure. The critical mass for mass loss is \( 1.02 \times 10^6 M_\odot \) for a Population I star, and \( 1.23 \times 10^5 M_\odot \) for Population III star. Mass loss rates expected in these stars are \( 3.3 \times 10^{-3} \) and \( 4.0 \times 10^{-3} M_\odot \text{ yr}^{-1} \), respectively.

1. Introduction

Some authors have suggested that mass loss does not occur for very massive stars. Appenzeller and Fricke (1971) obtained static Main-Sequence solutions with no mass-loss for masses in the range \( 5 \times 10^5 - 5 \times 10^7 M_\odot \). Nomoto and Sugimoto (1974) examined the surface boundary condition, and found a static solution for a \( 10^3 M_\odot \) star. They concluded that no steady mass-loss would occur in such a star.

However, the possibility of steady mass-loss cannot be discussed from their solutions. In both these works the opacity is assumed to be constant. The change of opacity is essential for the acceleration of matter.

The present paper shows the solutions for super-massive stars with a Compton opacity. These solutions indicate steady mass-loss occurs even in the Main-Sequence stages.

2. Numerical Results

Stellar structure is obtained from simultaneous numerical integration of the equations of hydrostatic balance, mass continuity, energy transfer and energy conservation. The boundary conditions and method of numerical calculation is same as that described in Kato (1984). We use the opacity formula for Compton scattering

\[
\kappa = \frac{\kappa_0}{1 + \alpha T},
\]

where \( \alpha = 2.2 \times 10^{-9} \text{ K}^{-1} \) and \( \kappa_0 = 0.2(1 + X) \). The chemical abundance of hydrogen, helium, and heavy elements are assumed to be \( X = 0.8, Z = 0.02 \) for Population I stars, \( X = 0.8, Z = 10^{-7} \) for Population III stars.


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Figure 1 shows the locus of the Main Sequence for both populations. The upper parts of the curves turn to the right, because the surface region is very extended in such stars. The crosses denote the critical mass for steady mass-loss. More massive stars must have mass outflow.

The mass loss and expansion of the surface region of the stars is caused by a radiation pressure gradient. In these stars, the luminosity is very close to the Eddington luminosity $4 \pi cGM/\kappa$ which decreases outward. Therefore, some amount of photon flux is blocked in the outer regions of the stars, which causes matter to be pushed upward (for interior structure of such stars, see Kato, 1985b).

In the stars of critical mass (the crosses in Figure 1) the thermal energy at the surface region is comparable to the gravitational energy. We should expect that a steady mass-loss will occur in the stars to the right side of the crosses.

The mass-loss rate in stars very near to the critical mass is estimated as follows. When a steady mass-loss has just occurred, the structure is almost the same as that of the static solution, just as the critical point of a solar-wind-type solution is very close to the photosphere (cf. Kato, 1985a). Therefore, the mass-loss rate is calculated from

$$\dot{M} = 4\pi r_{ph}^2 \rho_{ph} v_{ph} = 4\pi r_{ph}^2 \rho_{ph} \sqrt{\frac{kT_{ph}}{\mu m_a}},$$

where $\mu$ and $m_a$ are the mean molecular weight and atomic mass unit, respectively. The mass loss rate is $3.3 \times 10^{-3} M_\odot \text{ yr}^{-1}$ for Population I stars, and $4.0 \times 10^{-3} M_\odot \text{ yr}^{-1}$ for Population III stars.