Highlights of Astronomy, Volume 14
IAU XXVI General Assembly, 14-25 August 2006
Karel A. van der Hucht, ed.

doi:10.1017/S1743921307010150

Continuum-driven *versus* line-driven mass loss and the Eddington limit

Stanley P. Owocki

Bartol Research Institute, University of Delaware, Newark, DE 19716, USA
email: owocki@bartol.udel.edu

Abstract. Basic stellar structure dictates that stars of $\sim 100\,\mathrm{M}_\odot$ or more will be close to the Eddington limit, with luminosities in excess of $10^6\,\mathrm{L}_\odot$, and radiation pressure contributing prominently to the support against gravity. Although it is formally possible to generate static structure models of even more massive stars, recent studies of dense clusters show there is a sharp cutoff at masses above $\sim 150\,\mathrm{M}_\odot$. This talk examines the role of extreme mass loss is limiting the masses of stars, emphasizing in particular that continuum driving, possibly associated with structural instabilities of radiation dominated envelope, can lead to much stronger mass loss than is possible by the usual line-scattering mechanism of steady stellar winds.

However, population studies of very young, dense stellar clusters now suggest quite strongly that there is a sharp cutoff at masses above ca. $150 M_\odot$ (see, e.g., the talk by Sally Oey, in this JD 05, p. 206). This is sometimes attributed to a mass limit on star formation by accretion processes, though there are competing formation scenarios by binary or cluster merging that would seem likely to lead to formation of even higher mass stars (see talks in JD14 and S237).

So given the above rough coincidence of the observational upper mass limit with the Eddington-limit domain of radiation-pressure dominance, it seems associated instabilities in stellar structure might actually be a more important factor in this upper mass limit, leading to extreme mass loss in LBV and/or giant eruption events, much as inferred from circumstellar nebulae observed around high mass stars like eta Carinae and the Pistol star.

Keywords. stars: early-type, stars: winds, outflows, stars: mass loss, stars: activity

---

In this Joint Discussion on *Calibrating the Top of the Stellar M - L Relation*, it is perhaps worth recalling that the steep overall scaling of stellar luminosity with mass was already worked out nearly a century ago by Eddington, Schwarzschild, and others, well before there were extensive atomic opacity tables, or even a full understanding of the core nuclear burning needed to sustain a star's luminosity. In fact, from just the two basic equations of stellar structure, namely hydrostatic equilibrium and radiative diffusion, one can readily find from homology relations (or from an even simpler dimensional analysis) the approximate basic scaling $L \propto M^3$ for gas-pressure-supported stellar envelopes at low or moderate mass, $M < 20\,\mathrm{M}_\odot$. If one follows this relation to higher masses, then for stars above about $100\,\mathrm{M}_\odot$ the outward radiation force from just electron opacity ($\propto L$) exceeds the inward force of gravity ($\propto M$), which defines the classical Eddington limit. Inclusion of radiation-pressure terms in the stellar structure equations still allows formal derivation of a bound, static envelope at an even much higher masses, with now a linear scaling of $L \propto M$ that keeps the stars just below the Eddington limit.

However, population studies of very young, dense stellar clusters now suggest quite strongly that there is a sharp cutoff at masses above ca. $150\,\mathrm{M}_\odot$ (see, e.g., the talk in this JD 05 by Sally Oey, p. 206). This is sometimes attributed to a mass limit on star formation by accretion processes. But given its rough coincidence with the Eddington-limit domain of radiation-pressure dominance, it seems that associated instabilities in stellar structure might also be an important factor in explaining this upper mass limit. Such instabilities could induce extreme mass loss in LBV and/or giant eruption events, much as inferred from circumstellar nebulae observed around high mass stars like eta Carinae and the Pistol star. This could reduce the stellar mass in a fraction of a nuclear burning time, effectively enforcing an upper mass limit.

Indeed, even in stars above only 0.1% this Eddington limit, the bound-bound opacity of metal ions can result in a steady outflow or 'wind' from the stellar surface layers, where the Doppler shift associated with flow acceleration implies an effective line desaturation that allows the line-force to sustain this accelerating outflow. But the saturation of lines in denser, deeper layers means such *line*-driving is unlikely to be the mechanism for more extreme mass loss events. By contrast for opacity from electron scattering or other continuum processes, the associated radiative flux and radiative remains nearly constant (without saturation) even at large optical depths. This implies that *continuum*-driving could indeed propel the much stronger mass loss of LBV or eruptive events, which are inferred to sometimes approach the energy or 'photon-tiring' limit of the available total luminosity.

Recent work has focused on how the 'porosity' associated with spatial clumping could reduce the net continuum force in the dense inner layers and so keep them gravitationally bound, but then lead to a net outflow from the surface layers where the clumps become optically thin and are thus subject to the full radiative force. Current efforts are focused on understanding the nature of both local and global instabilities in a radiation-pressure-dominated envelope near the Eddington limit, and particularly on how this could lead to envelope structure and/or super-Eddington luminosities for continuum-driven eruptions. A key issue is whether, unlike line driving, such continuum-driven mass loss might be relatively insensitive to metallicity, and thus might also be a central process in limiting the masses of Population III stars formed in the early Universe.