

A Star Losing Mass in a Wind Proportional to Its Luminosity Lives Longer Even Losing Fuel, Whatever Its Mass

— with luminosity set by the current mass to the power 3.5, a star lightened by wind grows dimmer and uses fuel more slowly, so the lifetime factor is set by the wind strength alone, and losing only the outer layers lengthens life further than losing fuel with them —the separator is whether the wind carries off fuel with the mass or only the outer layers — [Paper 997]

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Abstract

Heavier stars have more fuel yet burn out sooner, and their estimated lifetimes are sensitive to the exponent of luminosity (Paper 892). Mass loss by the star was not included there. Setting the luminosity of the stars of Paper 892 to the current mass to the power 3.5, this paper steps through the lifetime when mass is lost in a wind proportional to luminosity, for a wind carrying off fuel with the mass and one carrying off only the outer layers, and compares with closed forms. No new theorem or law is claimed. First, even losing fuel, the lifetime lengthens: for wind strengths ε (the share of mass that would be lost if the wind blew at constant luminosity for the windless lifetime) of 0.1, 0.3, 0.5 and 0.9, the lifetime was 1.136102, 1.489333, **1.992274** and 3.772327 times the windless one, and the final mass was e to the minus ε of the initial (Section 2). Second, losing only the outer layers lengthens it further: keeping the fuel and losing only the outer layers, the lifetime was 1.205395, 1.918989, **3.725483** and 140.101229 times, and the final mass was 1 minus ε of the initial (Section 2). Third, the lifetime factor does not depend on the star's mass: for masses 1, 5 and 20 (windless lifetimes 10.000000, 0.178885 and 0.005590 billion years), the lifetime factors for the same wind strength agreed within 10^{-9} (Section 3). Fourth, stepped lifetimes matched closed forms: the stepped values agreed within a relative **8.669×10^{-5}** with the factor $(e \text{ to the } 2.5\varepsilon \text{ minus } 1) \text{ over } 2.5\varepsilon$ for fuel-carrying wind and $((1 \text{ minus } \varepsilon) \text{ to the minus } 2.5 \text{ minus } 1) \text{ over } 2.5\varepsilon$ for outer-layer wind (Section 3). Fifth, the separator is whether the wind carries off fuel with the mass or only the outer layers: outer-layer over fuel-carrying lifetime was 1.060992 at $\varepsilon = 0.1$ and **37.139206** at 0.9. In both cases the star grew lighter and dimmer and used fuel **more slowly** (Section 4). **Keywords:** stellar lifetime, mass loss, stellar wind, mass-luminosity relation, fuel, stellar evolution.

Scope of this paper (scope note): No new theorem or law is claimed: that heavier stars are brighter and shorter-lived, that stars lose mass in winds, and that a star that has lost mass is dimmer, are known in the theory of stellar structure and evolution. These are set values: the luminosity exponent 3.5, burnable fraction 0.1 and solar lifetime of 10 billion years are model values of Paper 892, and wind strengths of 0 to 0.9 and the two ways of carrying off mass are set here. They correspond to no star. Luminosity follows the current mass: luminosity is taken to follow the current mass to the power 3.5. Changes of luminosity as fuel is used, internal structure, convection, evolutionary stages and supernovae are not included. The wind is simplified: the wind carries off mass in proportion to luminosity; the fuel-carrying wind removes fuel in proportion to its share of mass, and the outer-layer wind leaves the fuel. Relation to earlier papers: Paper 892, in its scope note, did not enter internal structure, leaving out differences in nuclear reactions, convection and mass loss; this paper sits in the seat of mass loss (no earlier occupant). Paper 892 showed that heavier stars have more fuel yet burn out sooner, and that their estimated lifetimes are sensitive to the exponent of luminosity. Here the change in lifetime when the same stars lose mass in a wind is counted. What is added: stepping through lifetimes for two ways of carrying off mass and four wind strengths, giving closed forms and final masses and confirming agreement, confirming with three masses that the lifetime factor does not depend on stellar mass, giving the ratio of lifetimes between the two ways, and placing the separator on “with the fuel, or only the outer layers”.

1. Notation and the Question

Star: as in Paper 892, with mass in solar units and time in billions of years, luminosity is $L = M^{3.5}$, initial fuel (burnable mass) is $F = 0.1M_0$ and fuel is used at rate $L/100$ (a solar lifetime of $0.1/(1/100) = 10$). A wind carries off mass in proportion to luminosity, with strength ε (the share of mass that would be lost if the wind blew at constant luminosity for the windless lifetime).

For a wind carrying off fuel with the mass, and for one carrying off only the outer layers, respectively,

$$\frac{dM}{dt} = -\beta L, \quad \frac{dF}{dt} = -\frac{L}{100} - \beta L \frac{F}{M}; \quad \frac{dM}{dt} = -\beta L, \quad \frac{dF}{dt} = -\frac{L}{100}$$

with $\beta = \varepsilon/10$. The lifetime is the time the fuel runs out, stepped at 10^{-4} of the windless lifetime. Dividing by mass gives $F/M = 0.1 + \ln(M/M_0)/(100\beta)$ for the fuel-carrying wind and $F = 0.1M_0 + (M - M_0)/(100\beta)$ for the outer-layer wind, so the fuel runs out at masses $M_0 e^{-\varepsilon}$ and $M_0(1 - \varepsilon)$, and the lifetime factors are

$$\frac{e^{\varepsilon(p-1)} - 1}{\varepsilon(p-1)}, \quad \frac{(1 - \varepsilon)^{-(p-1)} - 1}{\varepsilon(p-1)} \quad (p = 3.5)$$

Question: when a star loses mass in a wind proportional to luminosity, how does its lifetime change, and how does that depend on what the wind carries off?

2. Lifetime Factors

Computation 2.1: factor over the windless lifetime (closed form) and share of final mass.

wind strength ε	fuel-carrying	final mass	outer layers	final mass	outer over fuel-carrying
0.1	1.136102	0.904837	1.205395	0.900000	1.060992
0.3	1.489333	0.740818	1.918989	0.700000	1.288489
0.5	1.992274	0.606531	3.725483	0.500000	1.869965
0.9	3.772327	0.406570	140.101229	0.100000	37.139206

The stepped values (mass 1) were 1.136100, 1.489300, 1.992200 and 3.772000 for fuel-carrying wind and 1.205400, 1.919000, 3.725400 and 140.100900 for outer layers, within a relative 8.669×10^{-5} of the closed forms, with final masses within 6.539×10^{-6} .

Observation 2.2

even losing fuel, the lifetime lengthened. A star lightened by wind dims as mass to the power 3.5, and uses fuel more slowly: with fuel-carrying wind the fuel falls in proportion to mass, but the dimming acts more strongly on lifetime, and the factor exceeded 1 for every wind strength.

3. Independent of Stellar Mass

Computation 3.1: for masses 1, 5 and 20 (windless lifetimes 10.000000, 0.178885 and 0.005590 billion years), the stepped factors for both ways and all four wind strengths were the same for the three masses within 10^{-9} .

Observation 3.2

the lifetime factor was set by the wind strength alone. Both the wind rate and the fuel-use rate are proportional to luminosity, and luminosity is a power of mass, so dividing mass by the initial mass leaves no initial mass in the equations: the closed forms contain no initial mass either.

4. The Separator

Observation 4.1

the separator is whether the wind carries off fuel with the mass or only the outer layers. Losing only the outer layers, the fuel runs out at $M_0(1 - \varepsilon)$, a lighter and dimmer star than the $M_0 e^{-\varepsilon}$ of fuel-carrying wind, so outer-layer over fuel-carrying lifetime widened from 1.060992 at $\varepsilon = 0.1$ to 37.139206 at 0.9. At $\varepsilon = 0.9$ with outer layers, the final mass was 0.100000 of the initial, equal to the burnable fraction 0.1.

Observation 4.2

what is not said. Changes of luminosity as fuel is used, internal structure, convection, evolutionary stages, supernovae and real stellar wind strengths are not treated. What is shown is how, in a model with luminosity set by current mass, a wind lengthens lifetime and what sets that lengthening.

5. Roll Call and Closing

1. a wind proportional to luminosity and fuel (Section 1): two ways of carrying off mass and closed forms.
2. fuel-carrying, **1.992274** times at $\varepsilon = 0.5$ (Computation 2.1): longer even losing fuel.
3. outer layers, **3.725483** times (Computation 2.1): longer still.
4. stepped values within **8.669×10^{-5}** (Computation 2.1): match closed forms.
5. the same factor for masses 1, 5 and 20 (Computation 3.1): independent of stellar mass.
6. with the fuel, or only the outer layers (**37.139206** at $\varepsilon = 0.9$) (Observation 4.1): the separator; the scope note of Paper 892.

Closing: A star losing mass in a wind proportional to its luminosity lives longer even losing fuel, whatever its mass. Setting the luminosity of the stars of Paper 892 to the current mass to the power 3.5 and blowing a wind proportional to luminosity, the lifetime at $\varepsilon = 0.5$ was 1.992274 times with fuel carried off and 3.725483 times with only outer layers, the same for masses 1, 5 and 20: stepped lifetimes matched closed forms within a relative 8.669×10^{-5} , and outer-layer over fuel-carrying widened to 37.139206 at $\varepsilon = 0.9$. The separator is whether the wind carries off fuel with the mass or only the outer layers. Placed among the earlier papers: to the stellar lifetimes Paper 892 counted at constant mass, the mass loss Paper 892 did not include was added. To be honest: lifetimes were stepped and compared with closed forms in one model with luminosity set by current mass. How a wind changes lifetime, and no further.

References

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