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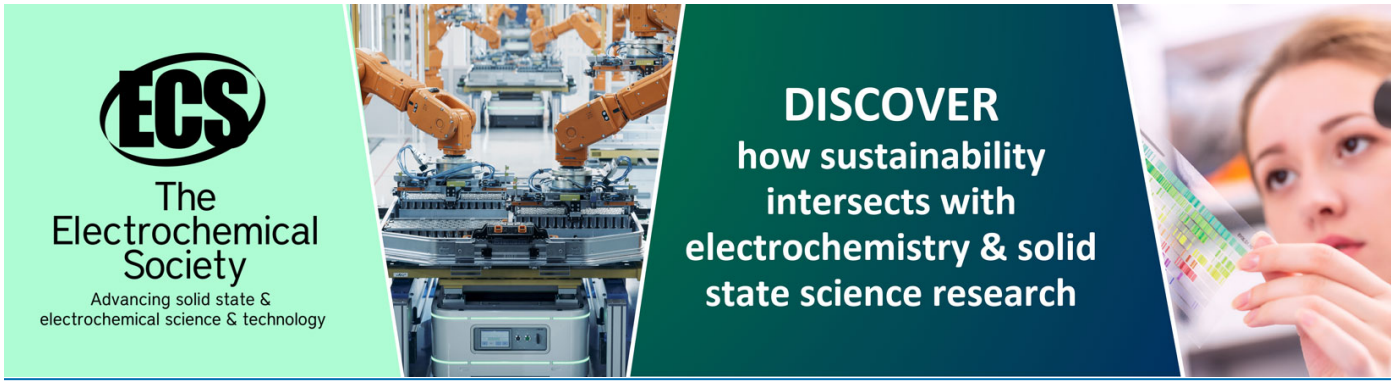

Evolution effect of BD+60º2522 to Bubble Nebula NGC 7635

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Abstract. Bubble Nebula is a bubble formed by the interaction between the stellar wind of BD+60°2522 with ambient interstellar gas. We use a web-based stellar evolution code, the EZ-web, to construct the evolution of BD+60°2522. From the evolution, we obtain the age of the system needed for the interstellar bubbles model. Then from the model, we determine parameters such as radius, expansion velocity, luminosity, temperature, and density of the Bubble.

1. Introduction

Bubble Nebula is an interstellar bubble located in the Perseus Arm of the Galaxy, and cataloged as NGC 7635. First discovered in 1787 by a British astronomer William Herschel, it is an enormous bubble being formed by the interaction between the stellar wind of a hot massive star, BD+60°2522, with its surrounding. This star is an O6.5IIIef star [4] with mass $45M_{\odot}$ [5], radius $15R_{\odot}$, luminosity $398{,}000L_{\odot}$, and effective temperature 37,500 K (data from Simbad). The image of Bubble Nebula taken by NASA's Hubble Space Telescope was chosen as the mark of the 26th anniversary of the launch of Hubble telescope into the Earth orbit on April 24, 1990 (figure 1 in this paper).

Figure 1. Image of Bubble Nebula NGC 7635 taken by NASA's Hubble Space Telescope as the mark of the 26th anniversary of the launch of Hubble telescope into the Earth orbit (https://www.nasa.gov/).

As a massive star, BD+60°2522 has already experienced mass loss since its Zero Age Main Sequence (ZAMS) stage. The mass loss rate is $10^{-5.76}$ $M_{\odot}$/year [3], and believed to form the bubble. According to

[3], the expanding velocity and radius of NGC 7635 are 36 km/s and 1.5 pc. This makes age of the bubble as 4 x 10^4 years. This number is different to the result of [5] for the age of BD+60°2522, i.e. 2 x 10^6 years. This shows that NGC 7635 is not formed at the beginning of the evolution of BD+60°2522. The first bubble has already expanded and merged with the ambient interstellar medium [5].

In this work, we calculate physical parameters of Bubble Nebula, such as radius, expanding velocity, luminosity, temperature, and gas density, based on the evolution of BD+60°. We use web-based stellar evolution code, EZ-web (http://www.astro.wisc.edu/~townsend/), for the evolution, and models of the formation of interstellar bubble from [2, 11, 10, 1].

2. Data and method

The formation of NGC 7635 is affected by the evolution of its central star, BD+60°2522. We adopt metallicity Z = 0.02 and 61 $M_\odot$ as the initial mass. The effect of convective overshooting is not included. We obtain present parameters for BD+60°2522: the age of 4.53 x 10^4 years, luminosity 5.42 x 10^5 $L_\odot$, and effective temperature 4.64 x 10^4 K.

For the age of BD+60°2522 in main sequence stage, we obtain 3.37 x 10^6 years. Comparing this to the result from [5] for the age of the star in main sequence stage, i.e. 4 x 10^6 years, it is not different significantly.

3. Results and discussion

According to a model from [11] a bubble was formed by the interaction between stellar wind and the interstellar gas which has constant atom density (n_0 = 1 cm^{-3}). As is shown in figure 2, the interaction yields four regions: stellar wind region (a), inner shocked stellar wind region (b) with radius R_1, outer shocked interstellar gas region (c) with radius R_2, and ambient interstellar gas (d). [10] and [1] applied this model to the formation of Bubble Nebula NGC 7635, as is shown in figure 3.

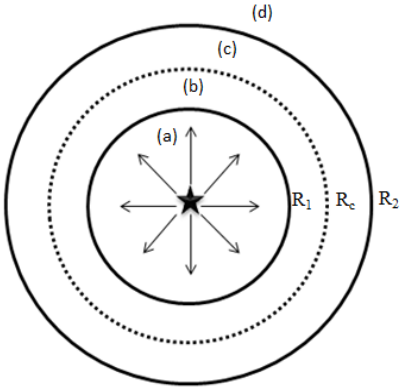

Figure 2. Schematic view for the formation of bubble around a massive star [11]. Expanding stellar wind is indicated in (a), inner shocked stellar wind in (b), outer shocked interstellar gas in (c), and ambient interstellar gas in (d). Region (a) and (b) is separated by R_1, (b) and (c) by R_c, while (c) and (d) by R_2.

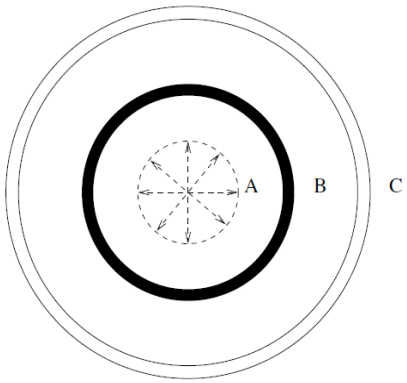

Figure 3. Schematic view for the formation of Bubble Nebula NGC 7635 [10]. Expanding wind hits the inner shock (dashed line), then kinetic energy is converted into thermal energy, which pushes a shell (thick line) into H II region (B), then pushes a shell (double line) into the interstellar medium (C).

To obtain the Bubble's physical parameters, such as the outer shell radius (R_2), expanding velocity (V_2), and stellar wind luminosity (L_w), we use equations from [2,11] written below,

$$R_2(t) = 27 L_{36}^{\frac{1}{5}} n_0^{-\frac{1}{5}} t_6^{\frac{3}{5}} \text{ pc} \quad (1)$$

$$V_2(t) = 16 L_{36}^{\frac{1}{5}} n_0^{-\frac{1}{5}} t_6^{-\frac{2}{5}} \text{ km/s} \quad (2)$$

$$L_w = \frac{1}{2} \frac{dM_w}{dt} V_w^2 \quad (3)$$

Here, n_0 is the density for interstellar gas (n_0 = 1 cm^{-3}), t_6 is the age of BD+60°2522 in main sequence stage, in 10^6 years (t_6 = 3.37 x10^6 years), $\frac{dM_w}{dt}$ is the mass loss rate for BD+60°2522 ($\frac{dM_w}{dt} = 10^{-5.76}\, M_\odot/\text{years}$ [3]), V_w is stellar wind velocity and L_{36} is stellar wind luminosity in 10^{36} erg/s. Table 1 shows parameters determined from equations (1) – (3) for different stellar wind velocities from some references.

Table 1. Parameters obtained from equations (1) – (3) for different stellar wind velocities of BD+60°2522

Stellar wind velocity, V_w (km/s)	References	Stellar wind luminosity, L_w (10^{36} erg/s)	Bubble's shell radius (pc)	Bubble's expanding velocity (km/s)
1800	Johnson (1980) [6]	1.7745	60.5228	10.6425
2200	Johnson (1982) [7]	2.6507	65.5812	11.5320
2500	Johnson (1982) [7]	3.4230	69.0218	12.1370
2700	Leitherer (1988) [9]	3.9925	71.1796	12.5165

Using parameters in table 1, we calculate temperature, density, and luminosity of Bubble Nebula using equations from [2] which are

$$T = 1.6 \times 10^6 \left(L_{36}^{8/35} n_0^{2/35} t^{-6/35} \right) \text{ K} \quad (4)$$

$$n = 0.01 \left(L_{36}^{6/35} n_0^{19/35} t_6^{-22/35} \right) \text{ cm}^{-3} \quad (5)$$

$$L = 3.8 \times 10^{32} \left(L_{36}^{37/35} n_0^{18/35} t_6^{16/35} \right) \text{ erg/s} \quad (6)$$

The results are shown in table 2 for different stellar wind velocities as in table 1.

Table 2. Parameters obtained from equations (4) – (6) for different stellar wind velocities of BD+60°2522

Stellar wind velocity, V_w (km/s)	References	Bubble's temperature (10^6 K)	Bubble's gas density (cm^{-3})	Bubble's luminosity (10^{33} erg/s)
1800	Johnson (1980) [6]	1.4967	0.0057	1.3335
2200	Johnson (1982) [7]	1.6405	0.0061	2.0383
2500	Johnson (1982) [7]	1.7392	0.0064	2.6708
2700	Leitherer (1988) [9]	1.8015	0.0065	3.1428

According to [8], interaction between stellar wind and ambient interstellar medium is in snowplow phase (like a snowplow piles up snow in front of it as it moves forward), which consists of two condition, energy conserving and momentum conserving modes. Energy conserving mode is reached when L_b <

L_w, while $L_b > L_w$ for momentum conserving mode. We obtain $L_b < L_w$ for Bubble Nebula, which means that Bubble Nebula is now in energy conserving mode of snowplow phase.

4. Conclusion

From the calculation based on model from [11], we obtain radius of Bubble Nebula NGC 7635 is 60.52 – 71.18 pc, which is expanding with velocity 10.64 – 12.52 km/s. This condition is reached at the age of the central star BD+60°2522 of 3.37 x10^6 years, i.e. age of its main sequence stage. The temperature of NGC 7635 is (1.5 – 1.8) x 10^6 K with gas density 0.006 cm^{-3}.

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