Simulation of the Ionizing Region in Starforming Nebulae

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Abstract

This research studied the numerical method to simulate the HII-region, which is ionized by high-temperature O or B-type stars. We develop a computer program to determine the extent of the HII region and compared to the theoretical value based on the Strömgen sphere theory. In one particular simulated scenario, we have found that an HII region surrounding a 40,000 K star with radius of 10 solar radii would be approximately 72 pc in radius. For the future work, we plan to extend our one-dimension (1D) model into two or three-dimension (2 and 3D) models to simulate the real HII regions in the universe.

Introduction

Starforming regions are areas containing large amount of dust and gas fundamental to star formation in the galactic plane of the Milky Way and spiral galaxies. Stars form at the densest part of these regions where gas density is sufficiently high to cause the gravitational collapse of gas into protostars.

While stars are forming, the hottest stars in the region such as the O and B stars will emit strong radiation that will ionize nearby neutral hydrogen gas. The ionization activates neutral hydrogen (HI) into ionized hydrogen (HII), which is not stable and its recombination results in emission line that makes starforming region appears red in color astrophotographs (due to the Hα emission). NGC 604 and M42, the Orion Nebula, are among the famous examples of HII regions with images taken by the *Hubble Space Telescope*. In this work, we determine the size of the HII region using a computer simulation that aim to capture as many physical processes as possible.

Theory

In 1939, the Danish astrophysicist named Benght Strömgen published his theory on the sphere of ionized hydrogen around a young star of the spectral classes O or B. Its counterpart in the real world is the HII-region, a type of an emission nebula. And the Strömgen's equation can be expressed as

$$\frac{x^2}{1-x} = \frac{2\pi}{c^2}\frac{R_*^2}{r^2}\frac{\int_{\nu_{LL}}^{\infty} \nu^2 \left(e^{\frac{h\nu}{kT_*}}-1\right)^{-1} e^{-\tau_\nu} a_\nu(\nu)}{N\alpha_B} d\nu$$

Where $\tau_\nu = N a_\nu \int_{R_*}^{r} (1-x)dr$, r is the distance from the star, x is the ionization fraction at r, c is the speed of light, τ is the optical depth, ν is the wavelength, R* and T* are the radius and surface temperature of the star, respectively, and h and k are the Planck's constant and the Boltzmann constant, respectively.

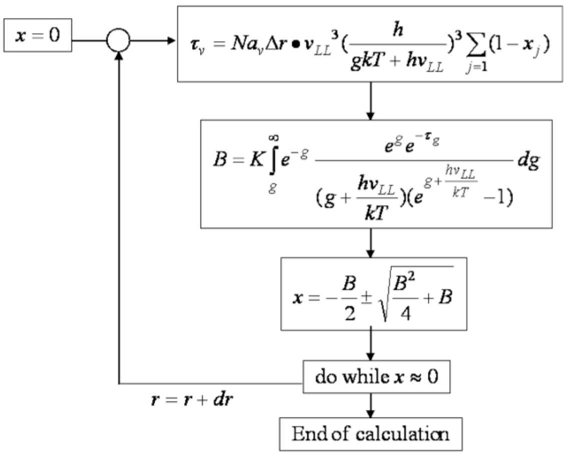
Methodology

First, we simplify the equation above using a fundamental numerical analysis to transform it into an easier form for calculation. So, the new approximate equations using Gaussian Quadrature, can be written as

$$\frac{x^2}{1-x} = K\int_g^{\infty} e^{-g} \frac{e^g e^{-\tau_g}}{(g+\frac{h\nu_{LL}}{kT})(e^{g+\frac{h\nu_{LL}}{kT}}-1)} dg$$

Where $\tau_\nu = Na_\nu \Delta r \bullet \nu_{LL}{}^3 (\frac{h}{gkT + h\nu_{LL}})^3 \sum_{j=1} (1 - x_j)$

This equation needs to be solved iteratively since the optical depth, τ, depends on the ionization fraction, x, and vice versa. So we use the C++ language to write a simulation program to solve this equation (algorithm shown in Fig. 1) with the input conditions for a star with surface temperature of 40,000 K and its radius of 10 solar radii. The resulting ionization fraction from our simulation is shown in Fig. 2.



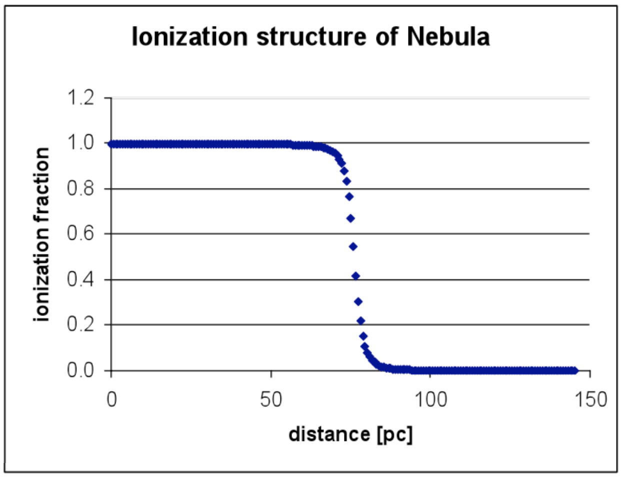


Fig.1 Algorithm for the Strömgen sphere calculation

And **Fig.2** Graph plots the relation between ionization fraction and distance from the star.

Conclusion

We have found that an HII region surrounding a 40,000 K star with radius of 10 solar radii would be approximately 72 pc in radius. We will extend the C++ code for this 1D simulation to full 3D grid to simulate the real nebulae in the future works.

References

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