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Stellar Wind and Radiation Pressures on Star-Forming Molecular Cloud

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Abstract

The investigation into the effects of wind and radiation pressures emitted by OB-type stars on star-forming molecular clouds constitutes a crucial area of research within astrophysics. As OB stars expel mass and release radiative energy, they exert pressure on nearby molecular clouds. This paper explores the impact of both wind and radiation pressure from OB stars on molecular clouds, examining how these forces influence the critical mass of the clouds in question. The approach taken involves a theoretical or mathematical framework, complemented by numerical analysis that utilizes a range of parameters associated with OB stars and molecular clouds. The findings indicate that an increase in wind and radiation pressure from OB stars leads to a reduction in the critical mass of the molecular cloud. This suggests that these pressures can have a dual effect, either dispersing or compressing the molecular cloud they affect. Furthermore, it was determined that the combined influence of wind and radiation pressure is more pronounced than the effects of either force acting independently, with radiation pressure demonstrating a somewhat greater impact than wind pressure based on the results obtained.

Keywords: molecular cloud; critical mass; OB star; stellar wind; stellar radiation; star formation

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1. Introduction

The influence of wind and radiation pressures emanating from OB-type stars plays a significant role in the dynamics of star-forming molecular clouds (MCs). MCs are the dense, cold regions of gas and dust where the intricate process of star formation occurs. These clouds, primarily composed of molecular hydrogen (H_2), serve as the main reservoirs of star-forming material in galaxies. Star formation within MCs is complex and shaped by both internal dynamics, such as gravitational collapse and magnetic fields, and external forces, especially those exerted by nearby massive stars. Among these external agents, OB-type stars—massive, hot, and short-lived stars are particularly influential due to their powerful stellar winds and intense ultraviolet (UV) radiation. These feedback mechanisms, involving both stellar winds and radiation pressure, play a critical role in regulating the physical conditions within MCs and, consequently, the star formation process itself [1].

OB-type stars generate stellar winds characterized by high-velocity outflows of ionized gas. These winds interact with the surrounding molecular material, creating expansive wind-blown bubbles. As these bubbles expand, they compress the gas within the cloud, potentially leading to localized increases in gas density. This "collect and collapse" process is thought to be one mechanism by which new star formation is triggered. However, if the pressure from the wind is excessive, it can instead disperse the gas, inhibiting further star formation [2,3]. The balance between compression and dispersal is a key element in understanding how stellar winds regulate star formation in MCs.

In addition to stellar winds, OB-type stars exert substantial radiation pressure, especially in the UV spectrum. The intense UV radiation emitted by these stars ionizes the surrounding gas, creating

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expansive HII regions—zones of ionized hydrogen. At the interface between these HII regions and the neutral gas, radiation pressure can drive gas compression, potentially leading to star formation. Conversely, radiation pressure can also act as an opposing force to gravitational collapse, making it harder for star formation to occur under certain conditions [4].

One crucial concept in understanding star formation within MCs is the critical mass required for gravitational collapse. The critical mass M_{crit} is defined as the threshold above which a cloud will collapse under its own gravity, leading to star formation. The value of M_{crit} is determined by several factors, including the internal thermal pressure, turbulence, magnetic fields, and the external pressures exerted by forces such as stellar winds and radiation from OB-type stars. Mathematically, the Jeans mass M_J provides a simplified expression for the critical mass under ideal conditions: $M_J = \left(\frac{5k_BT}{G\mu m_H}\right)^{3/2}\left(\frac{3}{4\pi\rho_0}\right)^{1/2}$ Where k_B is the Boltzmann constant, T is the temperature of the gas, G is the gravitational constant, μ is the mean molecular weight, m_H is the mass of a hydrogen atom, and ρ_0 is the initial density of the cloud. However, in the presence of external pressures such as those exerted by OB-type stars, the effective critical mass is modified, reflecting the dynamic interplay between internal cloud properties and external influences [5].

The effects of OB-type stars on the critical mass of MCs are particularly significant because they directly influence the star formation rate (SFR). The SFR is linked to the gas density within the MC through the well-known Kennicutt-Schmidt relation:

The presence of OB-type stars modifies the gas density by altering the internal dynamics of the cloud through both wind and radiation pressures, thereby affecting the SFR. The modification of the critical mass and gas density through these feedback mechanisms is a key area of theoretical exploration in this research [2].

The influence of OB-type stars on MCs is not limited to the local environment; it can also have galaxy-wide implications. The injection of energy and momentum into the interstellar medium (ISM) by these stars contributes to the larger-scale dynamics of galaxies, driving turbulence, regulating star formation, and even influencing the long-term evolution of galaxies. Theoretical models suggest that the interplay between OB-type star feedback and MCs could lead to a self-regulating star formation process, where the feedback from newly formed stars sets the conditions for subsequent star formation [2].

While much of the current understanding of OB-type star feedback is based on observational and simulation data, a robust theoretical framework is crucial for advancing our knowledge. Theoretical models can help predict how different conditions, such as varying wind pressures and radiation intensities, affect the star-forming potential of MCs.

The feedback from OB-type stars is critical for understanding the dynamics of star-forming regions; however, most studies have relied on observational or simulation-based approaches to explore these effects. While observational data provide valuable insights into the characteristics and distributions of MCs, they often lack the theoretical foundation needed to comprehensively interpret the underlying mechanisms at play. In contrast, simulation studies can mimic the complex interactions in star-forming regions, but they may not always accurately represent the physical processes involved, especially in regard to the specific contributions of stellar winds and radiation pressure from massive stars [5].

A significant gap exists in the literature regarding the development of detailed theoretical models that specifically examine how the combined feedback mechanisms of stellar winds and radiation pressure affect the critical mass and star formation rates in MCs. Current research has either focused on wind feedback or radiation feedback in isolation, without integrating the two into a comprehensive theoretical framework. This is a critical oversight, as the interplay between these feedback mechanisms can significantly influence the conditions necessary for star formation. Understanding how these forces work together is essential for providing a rigorous, quantitative understanding of the role OB-type stars play in regulating star formation [2,3].

Furthermore, addressing this gap is vital for advancing our understanding of how star formation is triggered or suppressed in environments where massive OB-type stars dominate. Given that OB-type stars are common in young star clusters, their feedback has far-reaching implications for the star formation process and the evolution of galaxies. Theoretical models that take into account both wind and radiation pressures will not only enhance our understanding of the immediate star-forming environments but also contribute to broader theories of galactic evolution. This research will build on existing astrophysical models, adapting them to account for the combined effects of wind and radiation pressures and extending them to a theoretical framework applicable to different star-forming regions, thus providing a holistic view of the impact of OB-type stars on star formation processes [5].

The purpose of this paper is to formulate the critical mass of star-forming MCs subjected to wind and radiation pressure from OB-type stars and analyze the effects of wind and radiation pressure from OB-type stars on stars forming MCs.

1.1. *MC Dynamics in the Presence of OB-type Stars*

MCs are the birthplaces of stars, with their internal processes governed by a delicate balance between self-gravity, thermal pressure, magnetic fields, and turbulent motions. However, the presence of massive OB-type stars, which have masses greater than 8 solar masses and surface temperatures exceeding 20,000 K, introduces additional complexities into these environments. OB-type stars emit copious amounts of ultraviolet (UV) radiation and drive powerful stellar winds, injecting both energy and momentum into the surrounding MC. As a result, they significantly alter the cloud's internal dynamics, influencing star formation through both constructive and destructive feedback mechanisms [3,6].

The radiation and stellar winds from OB-type stars can either trigger or suppress star formation depending on the balance between the compression of gas into dense clumps and the dispersal of the cloud material. This subsection explores the various ways in which OB-type stars impact the internal dynamics of MCs, particularly focusing on the roles of turbulence, fragmentation, the formation of filamentary structures, and the long-term evolution of wind-pressurized regions.zse4

1.2. *Critical Mass of MCs under External Pressures*

The concept of critical mass is a cornerstone in understanding the dynamics of MCs and their potential for star formation. This critical mass serves as a threshold that determines whether a cloud will undergo gravitational collapse to form stars. The presence of external feedback, particularly from high-mass OB-type stars, can significantly modify the conditions required for this collapse, thus influencing the rate and efficiency of star formation within these clouds [5,6].

The critical mass of a MC is not a fixed value; rather, it is contingent upon a variety of factors, including internal dynamics, external pressures, and the physical properties of the gas within the cloud. The interplay between these factors can either enhance or suppress the ability of a cloud to collapse and form new stars [3].

1.2.1. Critical Mass in Wind-Pressurized Clouds

To understand how external pressures, particularly from stellar winds, affect the critical mass of MCs, we can apply the virial theorem. This theorem provides a relationship between the kinetic and potential energies of a system, allowing us to quantify the conditions necessary for stability and collapse. The equation governing the virial equilibrium in a cloud subject to external wind pressure can be expressed as:

$$2K_{tot} + E_g + E_{ext} = 0 \tag{1}$$

$$E_{ext} = E_{rad} + E_{wd} \tag{2}$$

where K_{tot} denotes the total kinetic energy of the MC, which arises from the motion of gas particles within the cloud,, (E_g) represents the gravitational potential energy, a measure of the energy associated with the cloud's mass distribution,, E_{ext} is the external energy from wind and radiation of OB star exerted on the MC under consideration, E_{wd} is energy due to wind pressure from OB star , and E_{rad} is energy due to radiation pressure from OB star.

The introduction of P_{ext} in this equilibrium equation implies that for a cloud to reach gravitational instability and collapse, it must exceed a critical mass that accounts for both its self-gravity and the opposing forces generated by the external wind pressure. When the pressure from stellar winds increases, the necessary critical mass for the cloud to become unstable is elevated. Thus, clouds under the influence of strong stellar winds must accumulate additional mass to initiate collapse and star formation [7].

This relationship has profound implications for the star formation process. For instance, in regions of space where OB-type stars are abundant and exert significant wind pressure, the critical mass for collapse can be substantially higher than in quiescent regions, leading to delays in star formation [8].

1.2.2. Critical Mass in Radiation-Pressurized Clouds

In addition to mechanical pressures from stellar winds, radiation pressure from OB-type stars plays a pivotal role in influencing the critical mass necessary for MCs to collapse. OB stars emit copious amounts of high-energy radiation, generating an outward force that counteracts the inward gravitational pull. The effect of radiation pressure on the stability of a MC can be quantified using the following relation:

$$P_{\text{rad}} = \frac{L_\star}{4\pi R^2 c} \tag{3}$$

where: P_{rad} is the radiation pressure acting on the cloud, $L_\star$ denotes the luminosity of the OB-type star, which is a measure of the total energy output per unit time, d represents the distance from the star to the MC, and C is the speed of light in a vacuum.

The presence of radiation pressure necessitates that MCs accumulate a greater mass to maintain gravitational stability. In regions dominated by OB stars, the cumulative effects of radiation pressure can elevate the critical mass threshold significantly. This can lead to a scenario where the cloud remains stable and resists collapse until sufficient mass has been gathered, which may delay the onset of star formation [9].

The influence of radiation pressure is particularly significant in dense star-forming regions where multiple OB stars are present, as their combined radiation fields can substantially alter the physical conditions within surrounding MCs, further complicating the star formation process [10].

2. Theoretical Frame Work

The prevailing understanding indicates that the collapse and dispersion of clouds are contingent upon the strength of the forces exerted upon them. In this context, we have taken into account external forces, such as the wind and radiation emitted by OB stars, which significantly affect the rate at which the cloud collapses and consequently influence the star formation rate within the MC that envelops these OB type stars. Thus, in accordance with the virial theorem, we can derive the fundamental equations as follows:

From the Virial theorem $E_{\text{g}} + 2U = E_{\text{g}} + 2E_{\text{k}} = 0$, this indicates that gravitational energy and the internal energy are in balance means the MCs neither collapse nor expand unless the system is disturbed. The total energy of the system is related to gravitational potential energy E_{g} by $E_{\text{tot}} = E_{\text{g}} + U = E_{\text{g}} - \frac{1}{2}E_{\text{g}} = \frac{1}{2}E_{\text{g}}$, it implies that the internal energy must increase as the gravitational energy goes to negative. The total energy (E_{tot}) is negative means the MC is bound and stable. Where c is a numerical factor depending on the cloud's density distribution. We choose the value of this constant either 3/5 or 1 when we assume spherical uniform density cloud or need to consider uncertainty respectively.

This idea rests on the fact that the gravitational energy E_{g} has a negative sign, and it is a confining agent, while the internal energies (thermal, kinetic, or magnetic) are positive, and they are assumed to act as supporting agents against collapse. It is frequently described in the literature that if $E_{\text{g}} + 2E_{\text{k}} < 0$, the cloud must be contracting, while $E_{\text{g}} + 2E_{\text{k}} > 0$ it is expanding. For the MC to collapse under gravity in free-fall time $|\frac{E_g}{2}| > E_k$, this tells us that gravitational energy is dominating other counteracting energies.

The virial theorem serves as a fundamental tool for assessing the balance between internal gravitational forces and external pressures acting on MCs. The virial equation, which evaluates the stability of a cloud, can be expressed as:

$$2K_{Et} + E_g + E_{ext} = 0 \tag{4}$$

where K_{Et}, E_g and E_{ext} are the total kinetic energy or internal energy, gravitational energy, and total external emnergy. Kinetic energies encompass thermal, turbulent, and rotational forms, as identified in our analysis. The external energy sources are primarily derived from the winds produced by OB stars and the radiation emitted by these stellar entities (OB star). According to the above expression

$$2K_{Et} + E_g + E_{ext} < 0 \tag{5}$$

The cloud collapse. But if

$$2K_{Et} + E_g + E_{ext} > 0 \tag{6}$$

The cloud disperses

$$2K_{Et} + E_g + E_{ext} = 0 \tag{7}$$

The cloud is in equilibrium.

$$E_{th} = \frac{3}{2}\frac{K_B T_c M_c}{\mu m_H} \tag{8}$$

In this context, E_{th} represents the thermal energy associated with the cloud under consideration, while K_B denotes Boltzmann's constant. The variable T_c indicates the temperature of the cloud, and M_c refers to the mass of the MC. Additionally, μ signifies the mean molecular weight of hydrogen, which is approximately 2.8, and m_H represents the mass of a hydrogen atom.

$$E_{rot} = c_{rot} M_c R_c^2 \Omega_c^2 \tag{9}$$

where E_{rot} is the rotational energy of the cloud under consideration,c_{rot} is a numerical factor depending on the density distribution of the cloud. R_c radius of the MC, Ω_c rotational speed of the cloud in consideration.

$$E_{tr} = \frac{1}{2} M_c \delta^2 \tag{10}$$

where E_{tr} is the turbulent energy of the cloud under consideration, δ the three dimenstional turbulent velocity dispersion of MC. Such that $\delta^2 = \delta_x^2 + \delta_y^2 + \delta_z^2$. We assume that the this dispersion velocity is isotropic. therefore, $\delta_x^2 = \delta_y^2 = \delta_z^2$. Thus,

$$\left\langle \delta^2 \right\rangle = 3\delta_x^2 \tag{11}$$

where σ_x, σ_y and σ_z are the gas velocities in the Cartesian coor- dinate directions, respectively. The mechanical power of the wind from OB star is:

$$L_w = \frac{\dot{M}_w v_w^2}{2} \tag{12}$$

The mechanical enrgy of the wind is the mechanical power of the wind times the assumed age of the system. Thus:

$$E_w = L_w t \tag{13}$$

where L_w and t are the mechanical power of the wind and age of the system respectively.

$$E_w = \frac{1}{2}\dot{M}_w v_w^2 t \tag{14}$$

where E_w is the energy due to the wind from OB star which we considere it as mechanical energy applied by the wind on the cloud. $\dot{M}_w$ is the mass loss rate of the OB star, v_w is the wind speed.

$$E_{rad} = P_{rad} V \tag{15}$$

where E_{rad} is the radiation energy due OB star, P_{rad} is the the radiation pressure,V is the volume of the pbuble carrying radiation from OB star. Hence

$$V_{wb} = \frac{\dot{M}_w}{\rho_w} t \tag{16}$$

$$P_{rd} = \frac{L_\star}{4\pi d^2 c} \tag{17}$$

The luminosity of the OB star is denoted as $L_\star$, while d represents the estimated distance separating the cloud from the OB star. Additionally, c signifies the speed of light, which is the speed at which radiation propagates through space.

3. Model

Utilizing the theoretical framework, we begin to model the mass of the cloud by employing an equation that presumes the cloud is initially in a state of equilibrium.

$$E_g + 2K_{Et} + E_{ext} = E_g + E_w + E_{rad} + 2E_{th} + 2E_{rot} + 2E_{tr} = 0 \tag{18}$$

This occurs prior to the collapse, suggesting that

$$\mid E_g + E_w + E_{rad} \mid = 2E_{th} + 2E_{rot} + 2E_{tr} \tag{19}$$

The left side of the equation indicates that the energies are functioning in opposition to those present on the right side.

The MC colapses when :

$$\mid E_g + E_w + E_{rad} \mid > 2E_{th} + 2E_{rot} + 2E_{tr} \tag{20}$$

The MC disperses when:

$$\mid E_g + E_w + E_{rad} \mid < 2E_{th} + 2E_{rot} + 2E_{tr} \tag{21}$$

The state of the condition is contingent upon the intensity of the wind and the radiation emitted by the OB star. Should the pressure exerted by the wind and radiation from the OB star be exceedingly powerful, the cloud may undergo dispersion.

By replacing each energy component with the fundamental equations outlined in the theoretical framework, we obtain:

$$\mid \frac{3}{5}\frac{GM_c^2}{R_c} + \frac{1}{2}\dot{M}_w v_w^2 t + E_{rad} \mid = \frac{(2)3}{2}\frac{K_B T_c M_c}{\mu m_H} + 2c_{rot} M_c R_c^2 \Omega_c^2 + 2\frac{1}{2} M_c \sigma^2 \tag{22}$$

The rotational constant, denoted as c_{rot}, is influenced by the homogeneity and density of the cloud. As detailed by [11] in their study on the rotation of MCs in M 51, this constant assumes a value of 1/4 for a homogeneous disk, 1/6 for a disk with a surface density that decreases in proportion to r^{-1}, and 1/5 for a homogeneous sphere, with lower values applicable to spheres that are more centrally concentrated. For the purposes of this study, we will adopt the assumption of a homogeneous sphere for simplicity.

The research conducted by [11] indicates that the angular velocity, denoted as Ω, is approximately 0.05 km s^{-1} pc^{-1}, which is characteristic of a “rotating” MC.

This becomes

$$-\left(\frac{3}{5}\frac{GM_c^2}{R_c}+\frac{1}{2}\dot{M}_w v_w^2 t+E_{rad}\right)=\frac{(2)3}{2}\frac{K_BT_cM_c}{\mu m_H}+2c_{rot}M_cR_c^2\Omega_c^2+2\frac{1}{2}M_c\sigma^2 \tag{23}$$

The MMC collapses when

The minus sign shows the energies in the parenthesis are counter acting the sum of internal enrgy, rotaional energ and turbulent energy of the collapsing cloud. Now we rewrite this as:

This becomes

$$\frac{3}{5}\frac{GM_c^2}{R_c}+\frac{1}{2}\dot{M}_w v_w^2 t+E_{rad}+\frac{(2)3}{2}\frac{K_BT_cM_c}{\mu m_H}+2c_{rot}M_cR_c^2\Omega_c^2+2\frac{1}{2}M_c\delta^2=0 \tag{24}$$

When the cloud is equilibrium. This yields

$$\frac{3}{5}\frac{GM_c^2}{R_c}+\frac{1}{2}\dot{M}_w v_w^2 t+E_{rad}+3\frac{K_BT_cM_c}{\mu m_H}+2c_{rot}M_cR_c^2\Omega_c^2+M_c\delta^2=0 \tag{25}$$

using the relations between turbulent velocity dispersions, and homoginous sphere with rotational constant $1/5$ we have:

$$\frac{3}{5}\frac{GM_c^2}{R_c}+\frac{1}{2}\dot{M}_w v_w^2 t+E_{rad}+3\frac{K_BT_cM_c}{\mu m_H}+\frac{2}{5}M_cR_c^2\Omega_c^2+3M_c\delta_x^2=0 \tag{26}$$

The radiative energy received by the MC (MC) from the OB star is contingent upon the ratio of the disk area of the MC to the spherical area defined by the radial distance between the MC and the OB star, multiplied by the luminosity of the OB star. We express this relationship as $\int\overrightarrow{F}.d\overrightarrow{A}=F\pi R_c^2$, where πR_c^2 represents the perpendicular area of the MC. In this context, we also assume that $\overrightarrow{F}=F\hat{r}$. The underlying assumption is that the total angular area of the MC, as perceived from the OB star, is sufficiently small, allowing us to treat $\hat{r}$ as a constant,1. Here F = $\frac{L_\star}{4\pi d^2}$ is the flux of OB star over the sphere covered by the distance between the MC and the star (the OB star energy density at the mean distance of the MC from the OB star).

Therefore the radiative energy E_{rad} from the OB star incident on the MC under consideration is:

$$E_{rad}=\frac{L_\star}{4\pi d^2}(\pi R_c^2)t \tag{27}$$

where t is the inferred age of the system, d is the distance between the OB star and the MC under consideration. $L_\star$ luminosity of the OB star given by:

$$L_\star=4\pi R_\star^2\sigma T_\star^4 \tag{28}$$

Here $\sigma=5.670374419\times10^{-8}W/(m^2K^4)$ is Stephan Boltzmann's constant, $R_\star$ is radius of the OB star, $T_\star$ is temperature of the OB star. Inserting this in above equation we have:

$$\frac{3}{5}\frac{GM_c^2}{R_c}+\frac{1}{2}\dot{M}_w v_w^2 t+\frac{L_\star}{4\pi d^2}(\pi R_c^2)t+3\frac{K_BT_cM_c}{\mu m_H}+\frac{2}{5}M_cR_c^2\Omega_c^2+3M_c\delta_x^2=0 \tag{29}$$

This equation holds true when the system is in a state of equilibrium, neither collapsing nor dispersing. This means

$$\left|\frac{3}{5}\frac{GM_c^2}{R_c}+\frac{1}{2}\dot{M}_w v_w^2 t+\frac{L_\star}{4\pi d^2}(\pi R_c^2)\right|=3\frac{K_BT_cM_c}{\mu m_H}+\frac{2}{5}M_cR_c^2\Omega_c^2+3M_c\delta_x^2 \tag{30}$$

4. Critical Mass of MC Under the Influence of OB Star Wind and Radiation

Imagine a very long cylinder. The circular part faces the OB star. The long part does not. Clearly, the long part of the area does not help the cylinder absorb extra light from the OB star. We assume the MC which receives radiation from OB star is to be a disk. The reason we consider the MC to be a disk while calculating the received flux is similar. We will explain it in a different way which may be more intuitive. The OB star's light is spread across a full sphere of area $4\pi d^2$ where d is the distance between the OB star and the MC under consideration. The MC casts a disk-shaped shadow that covers πR^2 area of that Sphere. The shadow covers some fraction of the OB star's light. The fraction of the OB star's total luminosity that the MC receives is then $\frac{\pi R^2}{4\pi d^2}$ Taking this and beering in mind our assumption rearranging the equation above we have:

$$\frac{3}{5}\frac{GM_c^2}{R_c} = 3\frac{K_B T_c M_c}{\mu m_H} + \frac{2}{5}M_c R_c^2 \Omega_c^2 + 3M_c\delta_x^2 - \left(\frac{1}{2}\dot{M}_w v_w^2 t + \frac{L_\star}{4\pi d^2}(\pi R_c^2)t\right) \tag{31}$$

leads to:

$$\frac{3}{5}\frac{GM_c^2}{R_c} = 3\frac{K_B T_c M_c}{\mu m_H} + \frac{2}{5}M_c R_c^2 \Omega_c^2 + 3M_c\delta_x^2 - \left(\frac{1}{2}\dot{M}_w v_w^2 t + \frac{4\pi\sigma R_\star^2 T_\star^4}{4\pi d^2}(\pi R_c^2)t\right) \tag{32}$$

Dividing both side by M_c and solving for $M_c = M_{crt}$, assuming spherical cloud of mass $M_c = \frac{4}{3}\pi R_c^3 \rho_c$ and $L_\star = 4\pi R_\star^2 \sigma T_\star^4$, Now using these and solving for M_{crt} we get:

$$M_{crt} = \frac{5R_c}{3G}\left[\frac{3K_B T_c}{\mu m_H} + \frac{2R_c^2\Omega_c^2}{5} + 3\delta_x^2 - \frac{3t}{R_c^3\rho_c}\left(\frac{\dot{M}_w v_w^2}{8\pi} + \frac{\sigma R_\star^2 T_\star^4 R_c^2}{4d^2}\right)\right] \tag{33}$$

Equation (33) is the critical mass of the star forming MC under the influence of stellar wind and radiation from OB type stars. The area that we take into account is the component of the area that is perpendicular to the OB star's light (or the component of the normal vector of the area which is parallel to the OB star's light).

In short, the MC we assumed receives energy from 1 direction (the OB star) and only shows the OB star a disk-worth of area, but the OB star is emitting energy in all directions over the area of a sphere.

4.1. Critical Mass Under the Influence of Radiatio Pressure with no Significant Wind Pressure

When the pressure from wind of OB star is insignificant we have: This gives

$$M_{crt} = \frac{5R_c}{3G}\left[\frac{3K_B T_c}{\mu m_H} + \frac{2R_c^2\Omega_c^2}{5} + 3\delta_x^2 - \frac{3t}{R_c^3\rho_c}\left(\frac{\sigma R_\star^2 T_\star^4 R_c^2}{4d^2}\right)\right] \tag{34}$$

Equation (34) is the critical mass of the MC under the influence of radiation pressure from OB star with insignificant wind pressure.

4.2. Critical Mass Under the Influence of Wind Pressure with no Significant Radiaton

When the pressure from radiation of OB star is insignificant we have:

$$M_{crt} = \frac{5R_c}{3G}\left[\frac{3K_B T_c}{\mu m_H} + \frac{2R_c^2\Omega_c^2}{5} + 3\delta_x^2 - \frac{3t}{R_c^3\rho_c}\left(\frac{\dot{M}_w v_w^2}{8\pi}\right)\right] \tag{35}$$

Equation (35) is the critical mass of the MC under the influence of wind pressure from OB star with insignificant radiation pressure.

5. Numerical Analysis

We obtained the numerical results utilizing the critical mass established previously, along with the initial parameter values specified below. The initial number density of MCs (MCs) is approximated between $10^4 cm^{-3}$ and $10^5 cm^{-3}$, with a peak density around $10^5 cm^{-3}$, as noted by [12]. While some researchers, including [13–15], indicated that the mean cloud density n_{H2} typically ranges from approximately 25 cm^{-3} to 100 cm^{-3} in cloud complexes, clumps exhibit densities around $10^3 cm^{-3}$. Throughout this study, the initial number density in MCs has been set at $10^4 cm^{-3}$, corresponding to $\rho = 1.67 \times 10^{-20} gcm^{-3}$. Reference [16] reported that the angular velocity of most MCs is generally below 0.03 $kms^{-1}pc^{-1}$, although it can reach up to 1.5 $kms^{-1}pc^{-1}$ in certain instances, as noted by [17]. The angular velocity of various core types within an MC tends to exceed the average angular velocity of the entire cloud. The observed angular velocity Ω for cloud cores ranges from 0.3 $kms^{-1}pc^{-1}$ to 3 $kms^{-1}pc^{-1}$, which corresponds to $10^{-14} - 10^{-13} s^{-1}$, as documented by Goodman1993, [18,19].

In this study, we have considered the entire range of rotational velocities to thoroughly evaluate the effects of rotation, with Ω ranging from 0.01 $kms^{-1}pc^{-1}$ to 3 $kms^{-1}pc^{-1}$.

In Table 1, the first column presents the mass ejection rate ($\dot{M}$) of the OB star, while the second column indicates the temperature of the OB star T_{OB}. The third column details the radius of the OB star (R_{OB}), and the fourth column specifies the distance of the OB star(d_{OB}) from the MC (MC) under examination. The fifth column describes the wind speed (v_{wd}) emanating from the OB star, followed by the sixth column, which outlines the radius of the MC (R_c). The seventh column conveys the angular speed of the MC (Ω_c), and the eighth column provides the initial average density of the MC (ρ_c). The ninth column illustrates the critical mass of the MC (M_{crt}) when both radiation and wind pressure from the OB star are considered, whereas the tenth column reflects the critical mass of the MC when radiation pressure is more influential (M_{crtr}). Finally, the eleventh column indicates the critical mass of the MC when wind pressure prevails(M_{crtw}).

Figure 1 illustrates that the mass expelled from OB stars can contribute to an increase in star formation to a certain degree, and as the ejected mass continues to accumulate, it may lead to the dispersal of the surrounding cloud.

Figures 1–4 show the mass ejection rate from OB star, radius od OB star, temperature of OB star and the speed of wind from OB star vs the critical mass of the cloud under consideration at adistance of 400pc-500pc from the OB star.

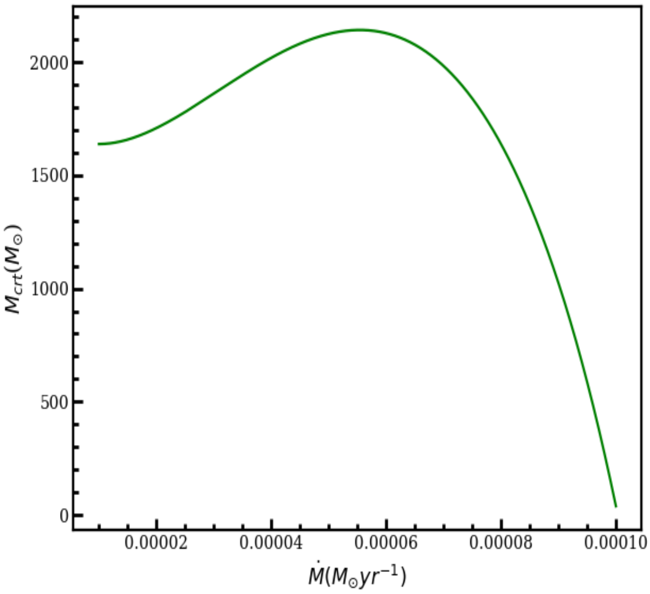

Figure 1. The critical mass of the cloud subjected to the radiation and stellar winds of OB stars in relation to the rate at which mass is ejected from these OB stars. This illustration demonstrates that when the mass ejection rate of an OB star is slightly reduced, the critical mass experiences a corresponding increase. Conversely, an elevation in the mass ejection rate leads to a reduction in the critical mass, suggesting that the material expelled from an OB star applies pressure on the surrounding MC, thereby facilitating its compression.

Table 1. Numerically generated results were obtained by varying physical parameters within the known ranges described in the literature using Equations (33),(34) and (35).

$\dot{M}$ (yr^{-1})	T_{OB} $(M_\odot)$	R_{OB} $(R_\odot)$	d_{OB} (pc)	v_{wd} (ms^{-1})	R_c (pc)	Ω_c (s^{-1})	ρ_c (kgm^{-3})	M_{crt} $(M_\odot)$	M_{crtr} $(M_\odot)$	M_{crtw} $(M_\odot)$
1.000e-04	7.017	100.00	400.556	30000.00	1.001	1.000e-13	1.000e-14	38.603	1411.591	320.621
9.816e-05	6.910	98.163	402.600	29591.836	1.021	9.816e-14	9.797e-15	253.543	1484.803	512.233
9.632e-05	6.802	96.326	404.643	29183.673	1.042	9.632e-14	9.595e-15	452.045	1554.423	689.353
9.448e-05	6.695	94.489	406.687	28775.510	1.062	9.448e-14	9.393e-15	635.152	1620.489	852.848
9.265e-05	6.587	92.653	408.731	28367.346	1.083	9.265e-14	9.191e-15	803.829	1683.024	1003.526
9.081e-05	6.480	90.816	410.774	27959.183	1.103	9.081e-14	8.989e-15	958.964	1742.042	1142.133
8.897e-05	6.373	88.979	412.818	27551.026	1.124	8.897e-14	8.787e-15	1101.379	1797.546	1269.363
8.714e-05	6.265	87.142	414.862	27142.857	1.144	8.714e-14	8.585e-15	1231.834	1849.535	1385.859
8.530e-05	6.158	85.306	416.905	26734.693	1.164	8.530e-14	8.383e-15	1351.028	1898.004	1492.219
8.346e-05	6.050	83.469	418.949	26326.530	1.185	8.346e-14	8.181e-15	1459.610	1942.945	1588.996
8.163e-05	5.943	81.632	420.993	25918.367	1.205	8.163e-14	7.979e-15	1558.182	1984.350	1676.705
7.979e-05	5.836	79.795	423.036	25510.204	1.226	7.979e-14	7.777e-15	1647.300	2022.209	1755.826
7.795e-05	5.728	77.959	425.080	25102.040	1.246	7.795e-14	7.575e-15	1727.481	2056.516	1826.805
7.612e-05	5.621	76.122	427.124	24693.877	1.267	7.612e-14	7.373e-15	1799.207	2087.269	1890.059
7.428e-05	5.513	74.285	429.167	24285.714	1.287	7.428e-14	7.171e-15	1862.926	2114.467	1945.978
7.244e-05	5.406	72.448	431.211	23877.551	1.307	7.244e-14	6.969e-15	1919.059	2138.118	1994.930
7.061e-05	5.298	70.612	433.255	23469.387	1.328	7.061e-14	6.767e-15	1967.999	2158.234	2037.259
6.877e-05	5.191	68.775	435.298	23061.224	1.348	6.877e-14	6.565e-15	2010.118	2174.834	2073.292
6.693e-05	5.084	66.938	437.342	22653.061	1.369	6.693e-14	6.363e-15	2045.767	2187.946	2103.339
6.510e-05	4.976	65.102	439.386	22244.897	1.389	6.510e-14	6.161e-15	2075.281	2197.609	2127.697
6.326e-05	4.869	63.265	441.429	21836.734	1.410	6.326e-14	5.959e-15	2098.979	2203.869	2146.652
6.142e-05	4.761	61.428	443.473	21428.571	1.430	6.142e-14	5.757e-15	2117.168	2206.783	2160.478
5.959e-05	4.654	59.591	445.517	21020.408	1.450	5.959e-14	5.555e-15	2130.145	2206.421	2169.444
5.775e-05	4.547	57.755	447.560	20612.244	1.471	5.775e-14	5.353e-15	2138.201	2202.865	2173.813
5.591e-05	4.439	55.918	449.604	20204.081	1.491	5.591e-14	5.151e-15	2141.619	2196.208	2173.845
5.408e-05	4.332	54.081	451.648	19795.918	1.512	5.408e-14	4.948e-15	2140.680	2186.558	2169.798
5.224e-05	4.224	52.244	453.691	19387.755	1.532	5.224e-14	4.746e-15	2135.662	2174.038	2161.928
5.040e-05	4.117	50.408	455.735	18979.591	1.553	5.040e-14	4.544e-15	2126.845	2158.785	2150.497
4.857e-05	4.010	48.571	457.778	18571.428	1.573	4.857e-14	4.342e-15	2114.509	2140.951	2135.767
4.673e-05	3.902	46.734	459.822	18163.265	1.594	4.673e-14	4.140e-15	2098.940	2120.705	2118.006
4.489e-05	3.795	44.897	461.866	17755.102	1.614	4.489e-14	3.938e-15	2080.425	2098.233	2097.488
4.306e-05	3.687	43.061	463.909	17346.938	1.634	4.306e-14	3.736e-15	2059.263	2073.739	2074.496
4.122e-05	3.580	41.224	465.953	16938.775	1.655	4.122e-14	3.534e-15	2035.758	2047.442	2049.322
3.938e-05	3.472	39.387	467.997	16530.612	1.675	3.938e-14	3.332e-15	2010.223	2019.584	2022.266
3.755e-05	3.365	37.551	470.040	16122.448	1.696	3.755e-14	3.130e-15	1982.984	1990.422	1993.644
3.571e-05	3.258	35.714	472.084	15714.285	1.716	3.571e-14	2.928e-15	1954.378	1960.236	1963.782
3.387e-05	3.150	33.877	474.128	15306.122	1.737	3.387e-14	2.726e-15	1924.755	1929.325	1933.020
3.204e-05	3.043	32.040	476.171	14897.959	1.757	3.204e-14	2.524e-15	1894.482	1898.010	1901.716
3.020e-05	2.935	30.204	478.215	14489.795	1.777	3.020e-14	2.322e-15	1863.938	1866.630	1870.242
2.836e-05	2.828	28.367	480.259	14081.632	1.798	2.836e-14	2.120e-15	1833.523	1835.551	1838.988
2.653e-05	2.721	26.530	482.302	13673.469	1.818	2.653e-14	1.918e-15	1803.652	1805.158	1808.363
2.469e-05	2.613	24.693	484.346	13265.306	1.839	2.469e-14	1.716e-15	1774.759	1775.861	1778.796
2.285e-05	2.506	22.857	486.390	12857.142	1.859	2.285e-14	1.514e-15	1747.301	1748.093	1750.734
2.102e-05	2.398	21.020	488.433	12448.979	1.880	2.102e-14	1.312e-15	1721.753	1722.310	1724.649
1.918e-05	2.291	19.183	490.477	12040.816	1.900	1.918e-14	1.110e-15	1698.612	1698.996	1701.032
1.734e-05	2.184	17.346	492.521	11632.653	1.921	1.734e-14	9.081e-16	1678.400	1678.656	1680.398
1.551e-05	2.076	15.510	494.564	11224.489	1.941	1.551e-14	7.061e-16	1661.658	1661.825	1663.287
1.367e-05	1.969	13.673	496.608	10816.326	1.961	1.364e-14	5.043e-16	1648.957	1649.061	1650.263
1.183e-05	1.861	11.830	498.652	10408.163	1.982	1.183e-14	3.026e-16	1640.890	1640.951	1641.915
1.000e-05	1.754	10.000	500.695	10000.000	2.002	1.000e-14	1.000e-16	1638.075	1638.110	1638.859

According to the results presented in the Fig5, radiation pressure exerts a more substantial influence than wind pressure.Nevertheless, when the MC (MC) is situated at a considerable distance from the O-type star, the pressures exerted by the star's radiation and stellar wind cease to have a distinct effect on the MC. At such great distances, the influence of both wind and radiation pressure becomes negligible.

Figures 5–10 illustrate the critical mass of the cloud in relation to the characteristics of the MC under the effects of wind and radiation pressure exerted by OB stars. These figures collectively demonstrate that the combined effects of radiation and wind pressure are significantly more pronounced than the effects of either OB star radiation or stellar wind acting independently. Furthermore, it is observed that the influence of radiation tends to be somewhat more substantial than that of the wind pressure from OB stars, particularly within a limited range of wind speeds.

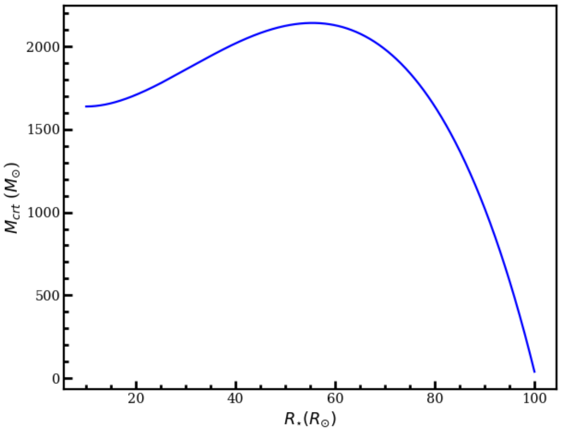

Figure 2. The relationship between the critical mass of the cloud exposed to the radiation and wind of an OB star and the size of the OB star is depicted in this figure. It demonstrates that as the size of the OB star grows, its luminosity correspondingly increases, resulting in significant radiation pressure. This pressure can either lead to the compression of the cloud or its dispersion.

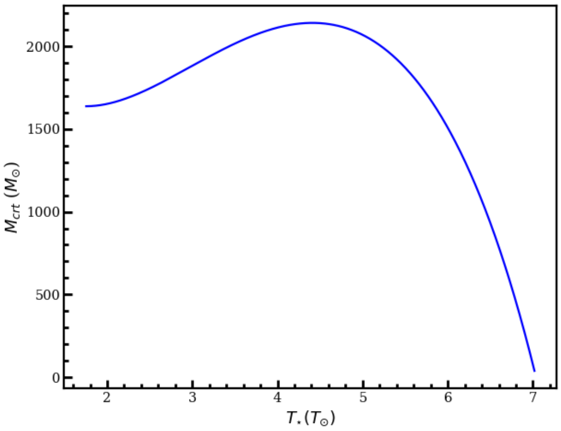

Figure 3. The relationship between the critical mass of the MC (MC) and the temperature of the O-type stars (OB) is significant. An increase in the temperature of OB stars leads to a reduction in the critical mass, which accelerates the collapse of the cloud. Nevertheless, if the temperature exceeds a certain optimal threshold, the cloud begins to dissipate.

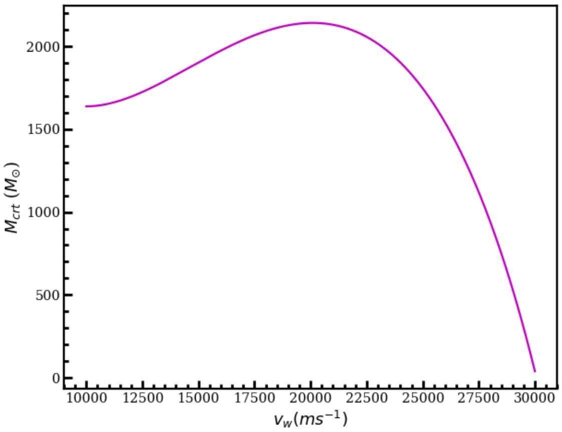

Figure 4. The relationship between the critical mass of a cloud exposed to the radiation and wind of an OB star and the temperature of that star is significant. As the velocity of the stellar wind escalates, the pressure it exerts correspondingly rises. This increase in pressure leads to a decrease in the critical mass of the cloud, and if the pressure surpasses the internal resistive capabilities of the MC, it may result in the dispersion of the cloud

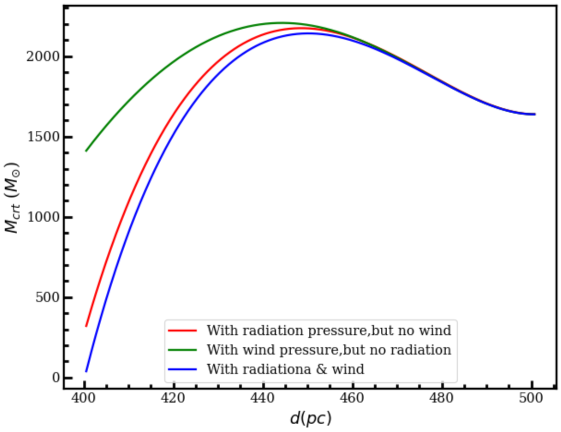

Figure 5. The significant mass of the cloud, affected by the OB stars under varying conditions, is analyzed in relation to the distance of the OB star from the cloud. The blue curve represents the cumulative impact of both radiation and wind pressure exerted by the OB star. In contrast, the red curve illustrates the scenario where only the radiation from the OB star is considered effective, while the green curve depicts the situation where wind pressure predominates, with radiation pressure being absent.

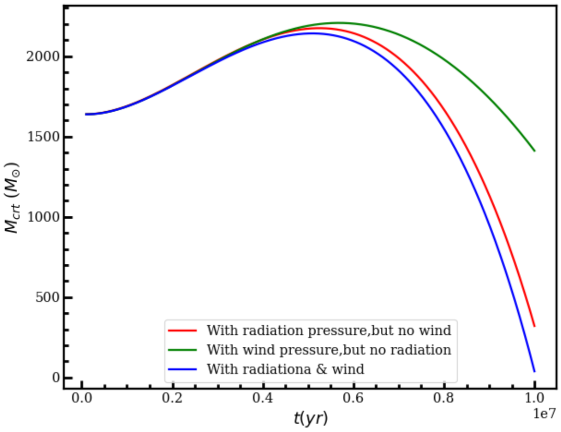

Figure 6. The MC's response to the influence of OB stars varies under different conditions throughout the system's lifetime. This figure demonstrates that the impact of radiation and wind pressure becomes pronounced after approximately 0.4 million years. Prior to this point, the critical mass of the cloud rises over time due to these pressures; however, as the system continues to age, the critical mass begins to decline.

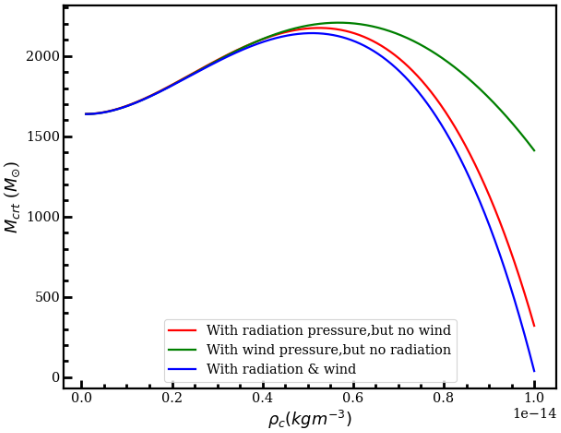

Figure 7. The critical mass of the cloud expossed to OB star at different conditions vs the intial density of the MC. The MC's response to the influence of OB stars varies under different conditions in relation to its density. This figure demonstrates that the critical mass begins to decrease after reaching a specific density threshold. As the density of the MC increases, the critical mass diminishes beyond a certain point, primarily due to the complex interactions of dynamic factors such as stellar winds and radiation pressures.

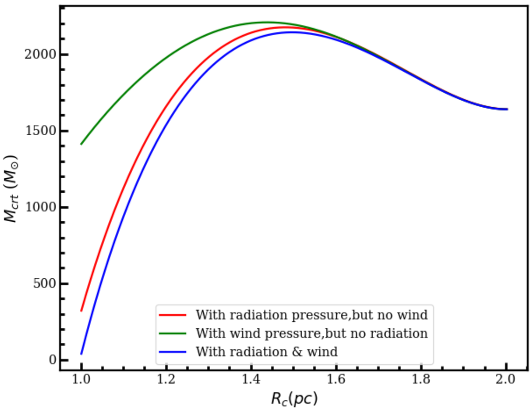

Figure 8. The relationship between the critical mass of the MC (MC) subjected to the pressure exerted by an O-type star in various scenarios and the initial radius of the MC is illustrated in this figure. It demonstrates that as the size of the cloud increases, the influences of radiation and wind pressures begin to converge. This phenomenon occurs because a larger cloud can better withstand external pressures.

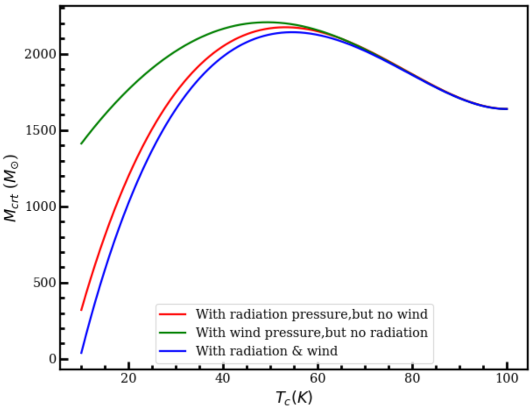

Figure 9. The relationship between the critical mass of the MC (MC) subjected to the pressure exerted by an OB-type star varies under different conditions in relation to the initial temperature of the MC. When the temperature of the O-type star is comparatively low, the mass of the cloud required for gravitational collapse increases. Conversely, as the temperature of the OB-type star rises, the necessary mass for collapse diminishes due to the increase in external pressure, which compresses the cloud. Nevertheless, if the temperature continues to escalate, there is a possibility that the cloud may begin to disperse.

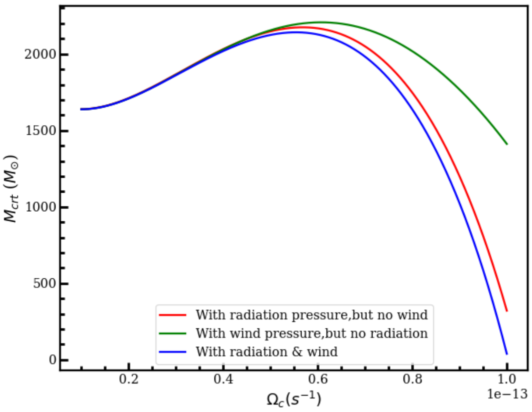

Figure 10. The relationship between the critical mass of the MC (MC) exposed to the pressure from an O-type star and the angular velocity of the MC varies under different conditions. As the rotational speed of the cloud increases, the critical mass also tends to increase; however, at higher rotational velocities, the impact of other parameters becomes more significant than that of rotation itself. Consequently, beyond a certain threshold of rotational speed, the critical mass begins to decrease despite the rising angular velocity of the MC.

6. Conclusions

This study examines the impact of radiation and wind pressure from OB stars on MCs that are forming stars. The results reveal that stellar feedback can exert both positive and negative influences on these clouds. Specifically, as the radiation and wind intensity from the OB star escalates, the critical mass necessary for star formation diminishes. In contrast, a decrease in the pressures applied by the OB star results in an increase in the critical mass. This indicates that the external pressures affecting star-forming MCs can either facilitate or obstruct the star formation process. Furthermore, if the radiation and mass ejection from the OB star are excessively intense, the MC may not be able to endure this external force, leading to its eventual dispersion and hindering star formation. Consequently, it is essential to maintain optimal levels of external radiation for successful star formation within the MC. Additionally, the inherent characteristics of the MC play a significant role in determining the minimum mass required for collapse and subsequent star formation. For instance, larger clouds may experience less pronounced effects from radiation and wind pressures, while those located nearer to the OB star may be more vulnerable to dispersal due to these forces. Thus, the interplay between the properties of the star-forming MC and the pressures exerted by OB stars is vital in regulating the star formation process within these clouds.

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