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Analyzing the Upper Mass Boundary of Main Sequence of Stars

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Abstract:

This study explores the upper mass boundary of main sequence stars, a fundamental aspect of astrophysics that shapes our understanding of stellar evolution, galactic dynamics, and cosmic chemical enrichment. The maximum stellar mass is not a fixed limit but depends on various factors, including stellar winds, metallicity, and the properties of molecular clouds. Historical estimates range from 120 to 300 solar masses, reflecting the intricate interplay of environmental conditions and initial formation parameters. Massive star formation begins with the gravitational collapse of gas clumps within giant molecular clouds, leading to protostar formation. This early stage involves non-homologous collapse, heavily influenced by magnetic fields and accretion dynamics. As mass accumulates, radiation-driven winds shape the surrounding medium, ultimately determining whether the star will reach supernova or collapse into a black hole. This research critically examines key formation mechanisms—monolithic collapse, competitive accretion, and stellar mergers—each governed by interstellar medium (ISM) properties. Through analysis of contemporary simulations and observational data, the study aims to refine our understanding of the factors regulating high-mass star formation and their implications for the initial mass function (IMF). It also investigates the balance between mass accretion and stellar winds, which can limit a star's growth, as well as the role of metallicity in influencing radiation pressure and the upper mass boundary. Ultimately, this study underscores the complexity of high-mass star formation and its pivotal role in cosmic evolution, highlighting the need for further research to unravel the mechanisms governing stellar mass limits.

Keywords: Stellar Mass Limits, Main Sequence, Maximum Mass, Stellar Formatting, Stellar Winds, Metallicity, Molecular Cloud.

1.Introduction:

The upper mass boundary of main sequence stars is a pivotal topic in astrophysics, with profound implications for our understanding of stellar evolution, galactic dynamics, and the chemical enrichment of the universe. Despite extensive research, the maximum mass a star can attain remains a subject of debate, with estimates ranging from approximately 120 to 300 solar masses. This variability arises from factors such as stellar winds, metallicity, and the initial conditions of the molecular clouds from which stars form. Massive star formation begins with the gravitational collapse of gas clumps within giant molecular clouds. As material accumulates, mechanisms such as monolithic collapse, competitive accretion, and stellar mergers determine the final mass of the star. Understanding these processes is essential for grasping the broader implications of massive star formation on galactic evolution. A key challenge in defining the upper mass boundary lies in the role of stellar winds and radiation pressure. High-mass stars generate intense

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radiation that counteracts gravitational forces, driving mass loss through powerful stellar winds. This interplay between mass accretion and mass loss establishes a delicate balance that constrains a star's maximum possible mass. Additionally, metallicity significantly impacts stellar evolution; higher metallicity increases opacity, enhancing radiation pressure and potentially lowering the upper mass limit. Magnetic fields also play a crucial role in the formation and evolution of massive stars. Recent magnetohydrodynamic simulations indicate that magnetic fields influence the collapse of molecular clouds, affecting the conditions necessary for high-mass star formation. Theoretical models and computational simulations continue to explore these complex interactions, offering deeper insight into the mechanisms governing massive star formation. The concept of an upper mass cut-off has been a subject of theoretical inquiry for over 50 years, with proposed values varying depending on the conditions under which stars form. Studying massive stars not only advances our understanding of stellar evolution but also provides valuable insights into the early universe, particularly through Population III stars. The remnants of massive stars significantly shape the interstellar medium (ISM), influencing star and planet formation. Currently, the dominant mechanism for massive star formation involves gravitational collapse, which creates optically thick regions within molecular clouds, ultimately forming protostars. According to Zinnecker and Yorke, this process is non-homologous, meaning the material distribution changes rather than collapsing in a self-similar manner. For lower-mass stars, accretion ceases before hydrogen fusion begins, but for high-mass stars, accretion continues into the hydrogen-burning phase, leading to the development of radiation-driven winds. These winds, along with strong outflows and radiation, profoundly affect the surrounding medium, with many high-mass stars culminating in supernovae within approximately three million years. This study aims to refine our understanding of the factors governing the upper mass boundary of stars, addressing the interplay between accretion, radiation pressure, magnetic fields, and environmental conditions. By integrating theoretical models with observational data, it seeks to enhance our comprehension of massive star formation and its role in shaping the cosmos [5, 8-9].

2.Literature Review

The upper mass boundary of main-sequence stars, or the theoretical maximum mass at which stars can remain stable in the main sequence, is a fundamental concept in astrophysics. It explores how massive stars evolve, their stability mechanisms, and the role they play in the life cycle of galaxies. Understanding the upper mass boundary has implications for stellar evolution theory, supernova research, and galactic feedback models. This literature review examines key theoretical and observational advancements, covering the physical constraints that define this boundary, the effects of mass loss and stellar winds, and recent findings from observational data.

2.1 Theoretical Background on Stellar Mass Limits

Main-sequence stars exist in a state of hydrostatic equilibrium, where the outward pressure from nuclear fusion balances the inward pull of gravity. However, there is a limit beyond which this balance becomes unsustainable due to increased radiation pressure. Historically, early studies by Eddington in the early 20th century provided a foundational understanding of radiation pressure's role in massive stars. He proposed that radiation pressure dominates over gas pressure in very massive stars, leading to instability once a certain mass is reached [1]. Subsequent research has refined this limit, suggesting an approximate boundary between 100 and 200 solar masses. Recent computational models have allowed for more precise simulations, exploring factors such as metallicity and stellar rotation, which influence the upper mass limit. For example, high metallicity increases opacity, leading to greater radiation pressure and thus lowering the maximum stable mass [2]. Additionally, rotation can support more massive stars by providing additional centrifugal force, which helps counteract gravitational collapse [3].

2.2 Role of Mass Loss and Stellar Winds

Massive stars experience significant mass loss through stellar winds, which strongly influence their evolution and impact the upper mass boundary. As stars increase in mass, their luminosity and radiation pressure also rise, leading to stronger stellar winds. The "Eddington limit," named after Arthur Eddington, describes the point at which radiation pressure exceeds gravitational force, causing stars to shed their outer layers [4,13]. This effect is particularly pronounced in high-mass stars, where mass loss mechanisms such as radiation-driven winds expel large amounts of material. Observational data from telescopes like the Hubble Space Telescope (HST) and the Very Large Telescope (VLT) confirm that massive stars in high-metallicity environments exhibit greater mass loss [15]. These findings align with theoretical models suggesting that high-metallicity stars experience enhanced stellar winds due to increased opacity from heavy elements. This feedback mechanism can reduce a star's mass over time, preventing it from exceeding the upper mass limit [9,16].

2.3 Observational Evidence and Mass Distributions

Directly observing and identifying the upper mass boundary remains challenging due to the rarity and short lifetimes of massive stars. However, observations of young star clusters provide valuable data for determining this limit. For instance, the Arches Cluster near the Galactic center contains some of the most massive stars known, with initial masses estimated to approach or exceed 100 solar masses. Observations of such clusters suggest a possible cutoff in stellar mass distributions, supporting theoretical upper limits [7,11,15]. Studies using infrared and X-ray observations have also provided insights into the behavior of massive stars nearing the upper mass limit. X-ray binaries, in which a massive star orbits a neutron star or black hole, offer clues about the evolution and mass loss of high-mass stars, as X-ray emissions are generated by accretion processes linked to mass shedding [8]. Additionally, high-resolution infrared studies of the 30 Doradus region in the Large Magellanic Cloud—home to some of the most massive stars, such as R136a1—suggest that stars exceeding 200 solar masses are extremely rare or potentially unstable [4,7].

2.4 Effects of Metallicity on the Upper Mass Boundary

Metallicity, or the abundance of elements heavier than helium, plays a significant role in determining the upper mass limit of main-sequence stars. Higher metallicity increases opacity, which enhances radiation pressure and accelerates mass loss. As a result, high-metallicity stars may reach the Eddington limit sooner, leading to a lower maximum stable mass [12,14]. In contrast, stars with lower metallicity—such as those in early-universe environments—are theorized to reach higher masses before becoming unstable due to reduced opacity and weaker stellar winds. Studies of Population III stars, the first stars to form after the Big Bang, suggest that these metal-poor stars could have grown to masses potentially exceeding 300 solar masses—a threshold unlikely in the modern universe [8,9]. Research based on simulations and observational data from metal-poor regions in nearby dwarf galaxies supports this hypothesis, showing that low-metallicity environments favor the formation of more massive stars compared to high-metallicity regions [7,11].

2.5 Stellar Rotation and Its Implications for the Upper Mass Boundary

Stellar rotation is another crucial factor influencing the upper mass boundary of main-sequence stars. Rotating stars experience an outward centrifugal force that counteracts some of the gravitational force, allowing them to maintain stability at higher masses. Models incorporating rotation suggest that stars could theoretically exceed the conventional mass limits proposed for non-rotating stars. However, excessive rotation can lead to mass loss from the equatorial region, gradually reducing the star’s mass and limiting its lifespan [13,17]. Observations of massive stars with high rotational velocities indicate that they are often surrounded by circumstellar material, which may result from this equatorial mass loss. For example, massive stars in the Tarantula Nebula exhibit significant rotation and associated circumstellar disks, supporting the idea that rotation influences mass retention and stability [7,5]. Studies have also shown that rotationally induced mixing in a star's core can prolong nuclear fusion, allowing massive stars to sustain fusion processes for extended periods and potentially increasing the effective upper mass limit for rotating stars [12,6].

2.6 Implications of the Upper Mass Boundary on Stellar Evolution and Supernova Mechanisms

Understanding the upper mass boundary has significant implications for stellar evolution and supernova mechanisms. Stars near or exceeding this boundary are candidates for rare phenomena such as pair-instability supernovae, which occur when photons in the star's core produce electron-positron pairs, leading to gravitational collapse and an explosive release of energy. Observations of supernovae in distant galaxies suggest that stars in the 100–150 solar mass range may undergo this type of explosion, providing empirical evidence for theoretical mass limits [8]. Furthermore, stars at the upper mass boundary contribute significantly to the enrichment of the interstellar medium, dispersing elements produced during their short lifespans into surrounding space through supernovae and stellar winds. This feedback effect influences the formation of subsequent generations of stars, impacting the metallicity and mass distribution in young star clusters [15,18]. Understanding the upper mass boundary is thus crucial for developing accurate models of galaxy evolution and star formation cycles.

The formation of a high-mass star begins with a core or a clump of molecular gas in a massive molecular cloud. Cold, dense filaments may be created by turbulent gas within these clouds. Turbulent and pressurized clouds can allow sufficient material to accumulate for high-mass star formation. An alternative theory suggests that this scenario is more transient due to the random motion in the cloud. Simulations using smoothed particle hydrodynamics have demonstrated the collapse and fragmentation processes that initiate high-mass star formation. The primary difference between these models is whether or not the protostellar object must compete for material. A crucial factor driving this collapse is the influence of magnetic fields on the molecular cloud. Magnetohydrodynamic simulations indicate that without magnetic fields, the necessary cores are unlikely to develop. These simulations assume driven turbulence rather than decaying turbulence. The outflows of these massive protostars help maintain virial equilibrium rather than turbulence.

The implications of this research are significant, as the initial mass function (IMF) may be influenced by these outflows. However, no conclusive observations determine whether high-mass star formation follows a gradual or rapid process. Regardless of the formation mechanism, some gas within these filaments becomes gravitationally bound, initiating the collapse necessary for star formation. This gravitational force must overcome magnetic forces, rotational effects, and other forms of pressure to proceed. The densest regions collapse first, while less dense layers contain a lower mass density. This causes the Jeans mass to decrease during the collapse. As the densest parts become optically thick, the gas heats up, significantly increasing pressure. Rotational forces also increase due to the conservation of angular momentum, forming accretion disks. This phenomenon is not unique to high-mass stars, but it does suggest that the mass of the forming star is influenced by both inflows and outflows of material. Eventually, the temperature reaches a critical point at which hydrogen within the cloud fragment dissociates, and a secondary core forms within the initial core. This core continues to grow in mass until it reaches the density and temperature required for hydrogen fusion.

The evolution of a massive star occurs in four largely independent stages: the formation of the initial core, the accretion of material onto the disk, the inward movement of material within the disk, and the transfer of material from the disk to the core. The overall formation process is similar for both high- and low-mass stars, except that each of these components is assumed to act independently in high-mass star formation. Due to complex geometries, the precise mechanism for accreting material onto the disk remains an active area of theoretical research. One crucial factor in high-mass stellar accretion, as discussed by Zinnecker, is dust destruction. At a certain temperature, dust dissociates, reducing the opacity of the surrounding material. Hydrostatic simulations assuming spherically symmetric accretion suggest that stars can form with masses up to 150 solar masses [11–17]. A reduction in effective opacity may also occur as radiation escapes through low-density gaps between shocks driven by the radiation flux of the forming star.

Several possible mechanisms have been proposed to explain the formation of massive stars. Naturally, these processes depend on the initial conditions of the molecular cloud and the properties of the interstellar medium (ISM). The most prominent theories include monolithic collapse, competitive accretion and runaway growth, and stellar collisions or mergers. Zinnecker notes that the work of Yorke and Sonnhalter has modeled the collapse of rotating, non-magnetic massive molecular cores up to 120 solar masses using frequency-based radiation hydrodynamics simulations. Their research highlights the significant impact of frequency on opacity and flux within the accretion disk, lending support to this approach. While this does not necessarily define an upper mass limit for stars, conditions could arise in which denser flows within filaments or fragments produce even more massive stars. Speculations have been made regarding the impact of outflows on accretion in these star formation processes. Researchers are studying magnetized disks to better understand the vertical radiation flux within the disk, which may explain super-Eddington accretion in highly luminous systems, such as extremely massive stars. Efficient angular momentum transfer can also result from weak magnetic fields in the disk and from turbulence driven by gravitational instabilities in both magnetized and non-magnetized disks. Ultimately, whether a molecular cloud is magnetically subcritical or supercritical may determine whether massive stars form in isolated environments or within clusters. Additionally, tidal effects from nearby stars could also induce gravitational instabilities, influencing the formation of massive stars [6–10].

3. Methodology of Study

3.1 Research Design

This study employs a multi-faceted approach to analyze the upper mass boundary of main sequence stars. The research design integrates theoretical modeling, computational simulations, and observational data analysis. By combining these methods, we aim to provide a comprehensive understanding of the factors influencing the maximum mass limit of stars on the main sequence.

3.2 Theoretical Framework

To establish the theoretical basis for our study, we utilize various stellar evolution models that simulate the life cycles of stars. Key models include:

- **Standard Stellar Evolution Models:** These models track the evolution of stars from the protostar phase through the main sequence and post-main-sequence stages. They help determine the mass limits at which stars can sustain hydrogen burning.

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- **Non-Standard Models:** In addition to standard models, we incorporate effects such as rotation, magnetic fields, and mass loss due to stellar winds. These factors are crucial in determining the upper mass limit.

3.3 Mass Accretion Theories

We explore several mass accretion theories that describe how stars gain mass during their formation:

- **Monolithic Collapse:** This theory posits that a single molecular cloud fragment collapses under its own gravity, forming a massive star. We analyze the conditions under which this process can yield stars exceeding 100 solar masses.
- **Competitive Accretion:** In this scenario, stars form in clusters and compete for surrounding gas. We investigate how the density and dynamics of the environment influence mass accretion rates.
- **Stellar Mergers:** We examine the effects of stellar collisions and mergers in dense star clusters, assessing their contribution to the formation of supermassive stars.

3.4 Computational Simulations

3.4.1 Numerical Methods

To simulate stellar formation processes, we implement state-of-the-art numerical techniques:

- **Hydrodynamic Simulations:** We employ smoothed particle hydrodynamics (SPH) to model the collapse of molecular clouds and the birth of stars. This method enables the study of dynamics such as turbulence and angular momentum transfer.
- **Magnetohydrodynamic (MHD) Simulations:** To incorporate the influence of magnetic fields, we utilize MHD models. These simulations help us understand how magnetic forces affect star formation and mass limits.

3.4.2 Parameter Space Exploration

We systematically vary key parameters to evaluate their effects on stellar formation:

- **Metallicity:** We analyze how different metallicity levels in the initial molecular cloud influence the maximum mass of the resulting stars.
- **Density and Temperature:** By adjusting the initial density and temperature of the gas, we observe their impact on the star formation process.

4. Observational Data Analysis

4.1 Data Collection

We gather observational data from various sources, including:

- **Telescopic Surveys:** Large-scale surveys such as the Sloan Digital Sky Survey (SDSS) and the Hubble Space Telescope (HST) provide extensive data on high-mass stars and their distributions.
- **Spectroscopic Studies:** We analyze the spectra of massive stars to determine their mass, luminosity, and chemical composition. This information is essential for validating our theoretical models.

4.2 Statistical Analysis

Using the collected observational data, we perform statistical analyses to identify trends and correlations:

- **Initial Mass Function (IMF) Analysis:** We examine the IMF of stellar populations to understand the relationship between stellar mass distributions and the upper mass limit.

5. Synthesis of Results

5.1 Comparative Analysis

We compare the results of our computational simulations with observational data through:

- **Model Validation:** We assess the accuracy of our theoretical models by comparing predicted mass limits with observed data.

- **Parameter Sensitivity Analysis:** We examine how variations in key parameters influence our results, identifying the most significant factors that determine the upper mass limit.

5.2 Implications for Galactic Evolution

The final step involves synthesizing our findings to draw broader conclusions about the role of massive stars in galactic evolution:

- **Role in Chemical Enrichment:** We discuss how high-mass stars contribute to the chemical enrichment of the interstellar medium through supernova explosions.

- **Impact on Star Formation Rates:** We analyze how massive stars influence the formation rates of subsequent stars in their vicinity, emphasizing the feedback mechanisms at play.

6. Discussion

The upper mass boundary of main sequence stars is a profoundly intricate topic that encapsulates various astrophysical phenomena and processes. Understanding this boundary is essential for unraveling the complexities of stellar evolution and its implications for galactic dynamics and chemical enrichment in the universe. One of the most compelling aspects of this investigation is the role of mass accretion mechanisms in the formation of massive stars. Theoretical models, such as monolithic collapse and competitive accretion, highlight the diverse pathways through which stars attain significant masses. Monolithic collapse suggests that a single gas clump collapses under its own gravity, leading to the formation of a massive star. However, in environments where stars form in clusters, competitive accretion becomes a crucial factor. This process posits that stars compete for surrounding gas, with those located centrally in a cluster having an advantage due to their gravitational influence. Observational evidence supports this notion, demonstrating that massive stars often exist in clusters, reinforcing the idea that environmental dynamics significantly influence stellar mass outcomes.

The impact of stellar winds and radiation pressure cannot be understated. High-mass stars generate substantial radiation, which counteracts the gravitational forces pulling material inward. This process leads to mass loss through strong stellar winds, a crucial factor that can prevent a star from reaching its theoretical maximum mass. The balance between accretion and mass loss remains delicate— as mass accumulates, the resulting radiation pressure increases, which can trigger enhanced mass loss. Understanding this interplay is key to explaining why we observe fewer stars at the extreme upper end of the mass spectrum.

Metallicity is another fundamental parameter influencing the upper mass boundary. Higher metallicity enhances the opacity of stellar material, increasing radiation pressure and leading to a lower maximum mass limit. This effect is particularly relevant in high-metallicity environments, where stars may not reach the mass limits observed in lower-metallicity regions, such as those populated by Population III stars. The existence of these early, metal-poor stars suggests that the conditions of the early universe allowed for the formation of exceptionally massive stars, potentially exceeding 300 solar masses. Additionally, the role of magnetic fields in star formation dynamics is gaining recognition. Recent magnetohydrodynamic simulations indicate that magnetic fields influence the collapse of molecular clouds, thereby affecting the conditions under which massive stars form. The presence of magnetic fields regulates the rate of mass accretion and facilitates the formation of dense cores necessary for high-mass star creation. This interaction between magnetic fields and the accretion process remains a burgeoning area of research that warrants further exploration.

6.1 Competitive Accretion and Stellar Growth

Competitive accretion is another viable mechanism for the formation of massive stars. Bonnell et al. presented 3D simulations of stellar mass growth through competitive accretion in small young clusters. In this model, mass growth is influenced by the size and composition of a star's accretion domain. As mass increases, its gravitational reach expands, allowing it to accrete more material. This suggests that stars born in the center of a cluster have a greater opportunity to attain higher masses. This phenomenon occurs because gas in a molecular cloud tends to settle into the deeper gravitational wells at the cluster's core. Protostars located at the periphery of the cloud are constrained by the local availability of gas, whereas those near the center can draw from a larger reservoir. Competitive accretion models also predict that accretion domains will eventually overlap, meaning that stars in clusters or dense regions will compete for the same material, making the formation of the most massive stars a rare occurrence. However, a key assumption in early simulations was that these clouds were strongly gravitationally bound, with negligible turbulence. Krumholz, McKee, and Klein argued that such an environment would prevent significant protostellar mass growth. More recent simulations have incorporated improved turbulence models, revealing that protostars move with their surrounding gas in a correlated manner until they encounter uncorrelated material, allowing for continued accretion.

6.2 Mass Accretion Rates and Eddington Limit

Omukai and Palla examined mass accretion rates as a key factor in massive star formation. Their results indicate that the earliest stages of stellar evolution are independent of accretion rates. However, at later stages, there is a critical mass accretion rate that brings a star's luminosity to the Eddington limit before nuclear burning begins. The critical mass accretion rate (McritM_{crit}Mcrit) is approximately 4×10−3M⊙4 \times 10^{-3} M_{\odot}4×10−3M⊙ per year. When this limit is reached, rapid stellar radius expansion can occur, potentially reversing the accretion flow. If accretion rates fluctuate significantly over time, they can have dramatic consequences on the final mass of the star. This study primarily focused on environments with extremely low metallicity (ZZZ), such as those of Population III stars. In such cases, lower gas temperatures lead to smaller variations in accretion rates, allowing for higher mass accumulation. However, at slightly higher metallicities (Z≈0.01Z⊙Z \approx 0.01 Z_{\odot}Z≈0.01Z⊙), increased radiation pressure limits the amount of material that can be accreted. Palla and Omukai also highlighted the impact of strong stellar winds in blowing off envelope material, reducing the final mass of the star and allowing it to enter the main sequence at a lower mass than its initial accretion would suggest.

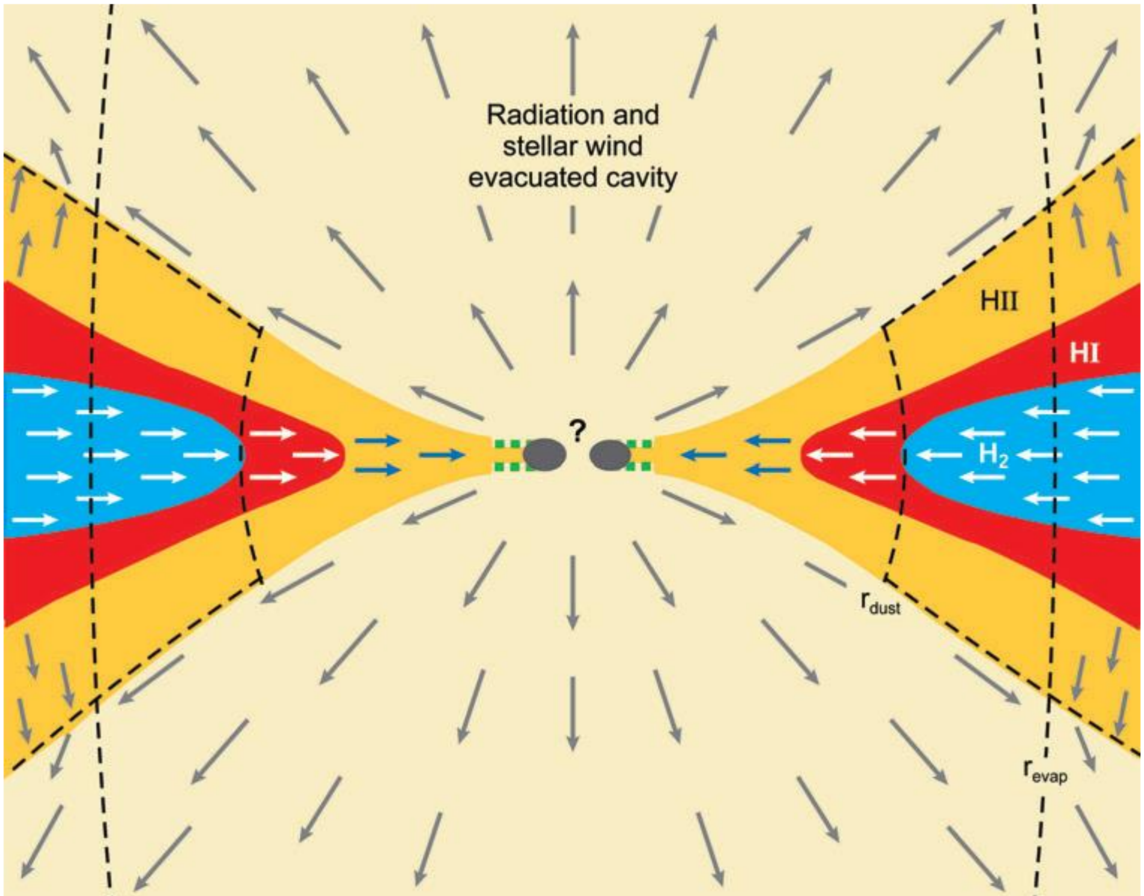

Figure-1 An example of a close binary pair and the associated inner accretion disk

6.3 Stellar Mergers and Cluster Density

Stellar mergers provide another potential explanation for the formation of high-mass stars. A significant concern with this model is that massive stars would need to be packed tightly into dense clusters, where collisions could occur frequently enough to form supermassive stars. However, observations indicate that many high-mass stars exist in OB associations rather than in highly compact clusters. This suggests that stellar mergers are rare and only relevant in the densest and youngest star clusters.

6.4 The Initial Mass Function and Maximum Stellar Mass

One of the fundamental goals of theoretical astrophysics is to understand the parameters governing star formation. A key aspect of this understanding is the Initial Mass Function (IMF), which describes the distribution of stellar masses at birth. Since its introduction by Salpeter in 1955, the IMF has been refined through observational studies. Recent modeling suggests that the Salpeter slope of -1.35 provides a reasonable approximation for the IMF. Figure 2 illustrates that the expected maximum stellar mass (MmaxM_{max}Mmax) could be higher than the commonly cited 100–120 M⊙M_{\odot}M⊙ range. However, analysis by Oey et al. suggests that this estimate is highly dependent on the assumed Salpeter slope. For the standard value of the Salpeter slope, the upper mass cutoff is estimated to be in the range of 120–200 M⊙M_{\odot}M⊙.

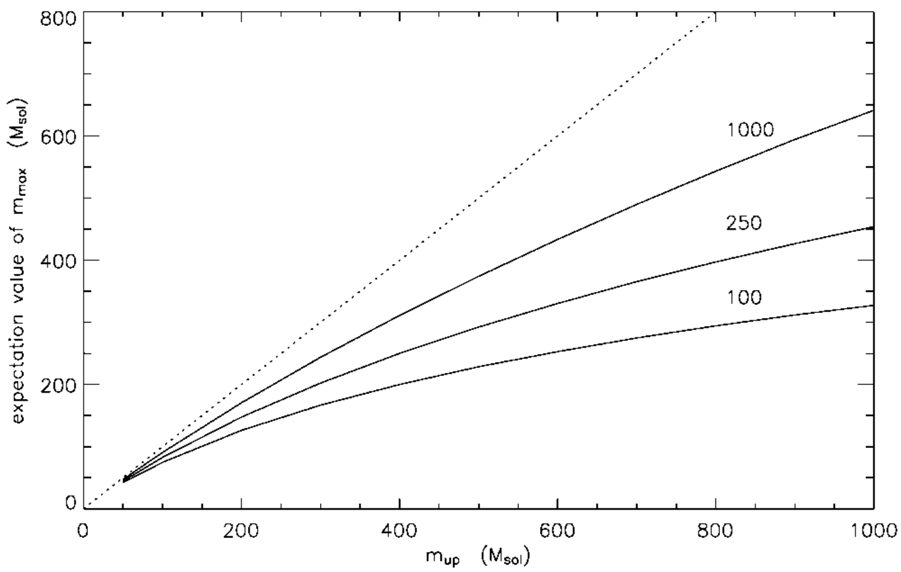

Figure-2 Graph of the expectation value of mmax vs. upper limit mass mup for N = 100, 250, and 1000 stars.

The Graph assumes a Sal peter IMF and a minimum mass limit of $10M_{solar}$ [1-5]. paintings done by using Greenbelt includes an exponential decrease to the IMF with the intention of simulating the competition for materials in denser turbulent clouds. There should be a turn down for stars of mass extra than 100Msolar for numerous motives. the principle argument for this restriction is the plain structure of the universe on kilo parsec scales. without this dilemma, one may want to count on that the cloud is only a small a part of a large fuel shape that may be used for stellar formation. This commentary by way of Greenbelt shows that the energy-law IMF drops extra rapidly than the Sal peter slope at loads close to numerous hundred sun hundreds [2]. Parent four shows a excessive mass turn-down that would account for the lack of great massive stars underneath regular big name-formation situations. This statistics also has the same opinion with the commentary of the Salpeter slope to out to a fee of approximately 100-one hundred thirty solar hundreds in paintings by using Massey et al. [5][2]. nonetheless, issues are that it's miles viable to get one hundred thirty Msolar stars in dense clusters, but not having any stars of three hundred Msolar in the entire galaxy.

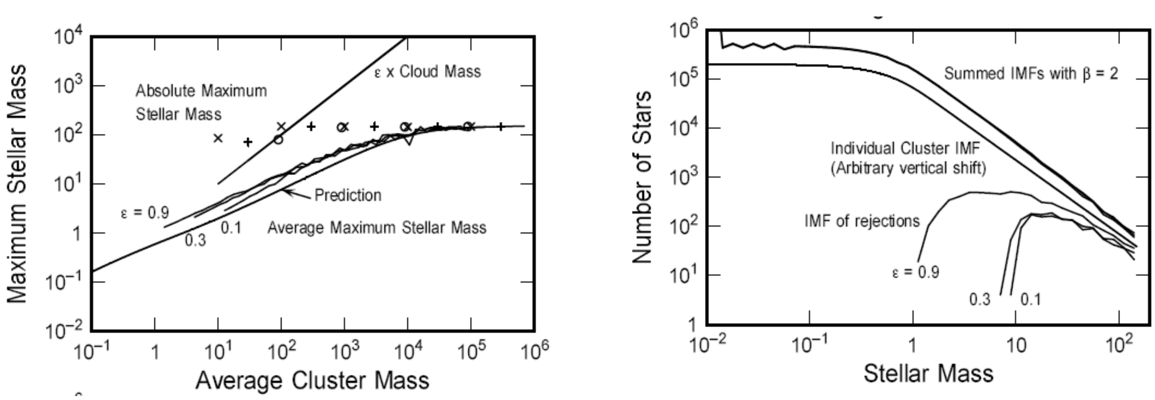

Figure-3 Data from a Monte Carlo IMF model. The bottom panel shows different star-formation efficiencies, ε, as well as the cluster IMF. The top panel shows average maximum

stellar mass in a cluster and the cluster mass. The "x", "+", "o" represent the cases ε = 0.1, 0.3, and 0.9 respectively with the theoretical prediction [3].

Figure-3 indicates that the summed IMF could be very similar to the cluster IMF with the simulations selected parameters. The distinction is slope is ~0.1 for masses greater than 10 Msolar. The efficiency, ε, contributes minimally in these outcomes. within the top panel of determine three, the common maximum stellar follows Elmegreen's predictions, as does the absolute most. The value of absolute maximum mass holds consistent with the exception of the lowest mass clusters. usual, this confirms Elmegreen's analytical results that the summed IMF of the cluster populace is nearly indistinguishable from the individual cluster IMF parameters. From this work, the conclusion is that stars form with little apparent bodily connection between mass and cluster mass. A statistical connection is made to the sample length impact, with extra large stars created in greater huge clusters on average. This statistical connection apparently has no affect at the summed IMF outcomes. parent three suggests that, inside the Monte Carlo simulation, statistically any number of clusters of a particular mass will produce most size stars close to the same cutoff cost. in the end, the most effective brief-coming of this result is that clusters and clouds aren't nicely defined entities and a statistical evaluation is the most dependable paintings that can be finished.

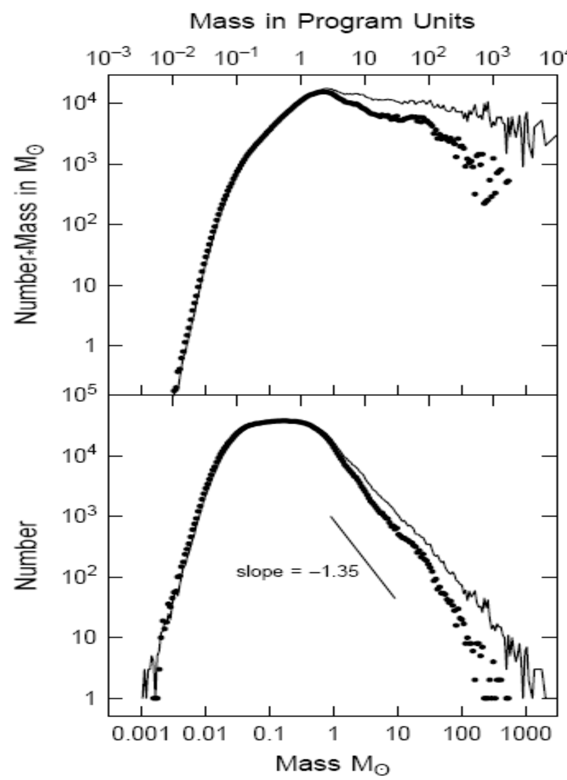

Figure-4 The bottom panel shows IMF simulations for two cases; the solid lines the model without timing constraints, and the dotted line is the model with timing constraints. The top panel shows the product of mass with IMF [2].

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7. Conclusion

Determining the true maximum mass of a star is an extraordinarily complex challenge. The upper mass limit of main sequence stars is influenced by numerous factors, including the properties of their birth environment, such as composition, age, and proximity to other astrophysical bodies. High-mass stars form under a specific set of conditions that involve the characteristics of the interstellar medium (ISM), the chemical makeup of their natal cloud, and the influence of nearby objects. If these initial conditions are met, theoretical models suggest that the maximum stellar mass falls within the range of 120–300 solar masses ($M_\odot$). However, this upper limit varies depending on the population of stars in question. Population I stars, which form from the enriched material of previous generations, tend to have the lowest upper mass limit due to their higher metallicity. The presence of heavy elements increases radiation pressure, making it more difficult for stars to accrete large amounts of mass. Population II stars, which originate from more pristine material, can reach slightly higher masses because of their lower metallicity. The most massive stars are theorized to belong to the hypothetical Population III stars, which formed in the early universe. These stars, composed almost entirely of hydrogen and helium, may have reached extreme masses in the range of 300–600 $M_\odot$ due to the absence of metal-driven radiation pressure. Ultimately, the upper mass boundary of stars remains an area of active research, requiring further observational data and improved theoretical models. Advancements in high-resolution simulations and next-generation telescopes will play a crucial role in refining our understanding of massive star formation and the physical processes that govern their limits.

Abbreviations

- **IMF**: Initial Mass Function
- **HST**: Hubble Space Telescope
- **VLT**: Very Large Telescope
- **ISM**: Interstellar Medium
- **MHD**: Magnetohydrodynamic
- **SPH**: Smoothed Particle Hydrodynamics
- **Myr**: Million Years
- **Z**: Metallicity

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Author Contributions

- **Diriba Gonfa Tolasa**: Conceptualization, Data Curation, Formal Analysis, Funding Acquisition, Investigation, Methodology, Resources, Software, Visualization, Writing—Original Draft, Writing—Review & Editing.
- **Adugna Terecha Furi**: Software, Project Administration, Validation.

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Conflicts of Interest

The authors declare no conflicts of interest.

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