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# Star Formation Studies in Young Star Clusters

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**Abstract:** *Young Star Clusters (YSCs), primarily located in the spiral arms of the Galaxy, are key tracers of star formation on both local and galactic scales. Formed in compact embedded clusters, stars within YSCs share a common origin and age, providing ideal laboratories for testing stellar evolution theories through color-magnitude diagrams. YSCs contain statistically significant samples spanning a wide range of stellar masses, enabling robust determination of the stellar initial mass function (IMF), which is critical for understanding galaxy formation, interstellar medium properties, and unresolved stellar populations. These clusters also host massive stars whose feedback can regulate star formation in surrounding regions, offering insights into the formation and early evolution of high-mass stars. Despite theoretical and observational progress, the universality of the IMF, ongoing star formation processes, and clustered massive star formation remain open questions. This study, "Star Formation Studies in Young Star Clusters", examines YSC structural morphology, stellar mass distribution, massive star feedback, mass segregation, environmental influences, and star formation modes, advancing our understanding of stellar and galactic evolution.*

**Keywords:** *Young Star Clusters, Star Formation, Initial Mass Function, Massive Stars, Stellar Evolution*

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## Introduction

The Young Star Clusters (hereafter, YSCs) are predominantly distributed in the spiral arms of the Galaxy. They, therefore, are important tracers of the star formation processes on the local and Galactic scale. According to observations of nearby Giant Molecular Clouds (GMCs) (Lada and Lada, 2003), most stars originate in compact embedded clusters. By studying these clusters, several fundamental astrophysical issues can be directly addressed. Observations of cluster's color-magnitude diagrams (CMDs) have been used to provide classic tests of stellar evolution theory since stars in such clusters have the same ancestry of being born more or less simultaneously from the same progenitor molecular cloud (Lada and Lada, 2003). Thus, YSCs can significantly contribute to the understanding of star formation or stellar evolutionary theories (Shu et al., 1999; Pandey et al., 2005). The YSCs encompass statistically significant samples of stars with a range of stellar masses in a relatively small space area. Additionally, YSCs provide a substantial extent across which it is possible to consciously determine the stellar initial mass function (IMF), the distribution of stellar masses at formation. The IMF is the most significant distribution in stellar and galactic astrophysics. Almost all models of Galaxy formation and the interstellar medium (ISM). as well as almost all conclusions of physical parameters for unresolved star populations, rely on an assumed form of the IMF (Kroupa and Boily, 2002; Offner et al., 2014). The spatial distribution of clusters has also played a crucial role in our understanding of galactic structure (e.g., Pandey et al., 2005; Sharma et al., 2008, 2017, 2020).

There are numerous physical processes related to star formation occurring in the Pre Mains Sequence (PMS) stars (age <3 Myr) in the YSCs. These processes may be found both inside and outside of the stars. YSCs containing YSOs allow astronomers to study the evolution of young stars and their properties. Massive stars are mostly formed in a clustered environment (Zinnecker and Yorke, 2007; Tan et al., 2014) and evolve rapidly to the MS phase, even when they are still deeply embedded (Zinnecker and Yorke, 2007; Dewangan et al., 2015). The massive stars of the YSCs can further stimulate or impede star formation in their surroundings (Deharveng et al., 2005; Panwar et al., 2014) due to their tremendous energy feedback. Therefore, the YSCs allow to study the formation and earlier evolution of the massive stars (Portegies Zwart et al., 2010; Schneider et al., 2020).

Despite the significant theoretical and observational advancements, the physics behind the universality of IMF, the ongoing star formation process, and the formation of massive stars in clustered environments are not completely understood.

This thesis work entitled, "Star Formation Studies in Young Star Clusters", includes the structural morphology of YSCs, distribution of stellar masses in cluster regions, feedback of massive stars, mass segregation in YSCs, the large-scale environment of YSCs, and mode of star formation present in YSCs. This chapter incorporates a brief introduction about YSCs, a literature review, and existing scientific problems in the field of star formation studies in YSCS.

## MATERIALS AND METHODS

This section outlines the data sources, observational techniques, analysis methods, and tools employed in the study of Young Star Clusters (YSCs), focusing on their structure, stellar content, and star formation processes.

### Data Sources

To investigate the properties of YSCs, multi-wavelength data were collected from both space-based and ground-based observatories:

- Infrared and Optical Photometry: Data from surveys like 2MASS, Spitzer, WISE, and Gaia were used to identify young stellar objects (YSOs) and to construct color-magnitude diagrams (CMDs).
- Archival Catalogs: Pre-existing catalogs of known star-forming regions and young clusters were utilized to select suitable clusters based on age, richness, and spatial distribution.
- Supplementary Observations: In some cases, optical or near-infrared observations were conducted from ground-based telescopes to enhance spatial resolution and depth.

**Cluster Selection Criteria**

Clusters were selected based on the following parameters:

- Age < 10 Myr, preferably < 3 Myr to include Pre-Main Sequence (PMS) stars.
- Availability of high-quality photometric data across multiple bands (optical, near-IR, mid-IR).
- Well-defined boundaries and identifiable YSO populations.
- Minimal foreground/background contamination.

**Photometric Analysis**

- CMDs were constructed using (V, V-I) and (J, J-H) to identify PMS stars and estimate stellar parameters like age and mass.
- Isochrone fitting using models from Siess et al. (2000) and PARSEC tracks were employed to determine stellar ages and masses.
- Extinction Correction: Reddening and extinction values were calculated using color-color diagrams and were corrected using standard extinction laws (e.g., Rieke & Lebofsky, 1985).
- Age and Mass Estimation: Stellar ages and masses were estimated by fitting isochrones from models such as Siess et al. (2000) and PARSEC evolutionary tracks to the CMDs.

**Structural and Spatial Analysis**

- Surface density maps and nearest neighbor (NN) methods were used to study spatial distributions.
- Radial density profiles were derived to estimate the core and cluster radii using King's profile fitting.

**Initial Mass Function (IMF) Estimation**

- Masses derived from isochrones were binned logarithmically to estimate the IMF slope.
- The observed IMF was compared with the Salpeter slope (-1.35) and the Kroupa (2001) IMF.

**Mass Segregation Analysis**

- Mass segregation was assessed using the minimum spanning tree (MST) method and ΛMSR parameter.
- Cumulative radial distributions of massive and low-mass stars were compared using the Kolmogorov-Smirnov (K-S) test.

**Feedback and Environment Analysis**

- The feedback effect of massive stars was studied via infrared and Hα imaging, tracing ionized gas and heated dust.
- The spatial distribution of YSOs relative to HII regions was analyzed to investigate triggered star formation.

**RESULTS**

**Cluster Morphology and Structure**

- Most YSCs exhibit centrally concentrated or hierarchical substructures, indicating ongoing or sequential star formation.
- Cluster cores typically show higher stellar densities and younger stellar populations.

3.2. Stellar Mass Distribution and IMF

- The derived IMFs for the studied clusters closely follow the Kroupa IMF, although slight deviations are observed in low-mass or high-mass ends.
- The majority of clusters show a flattened slope for masses $< 0.5\ M_\odot$, indicating possible incompleteness or environmental effects.

**Mass Segregation**

- Clear evidence of mass segregation is seen in several clusters, where massive stars are more centrally concentrated.
- Some younger clusters show primordial mass segregation, suggesting it may arise early during cluster formation.

**Massive Star Feedback**

- Regions around massive stars display ionized gas bubbles and bright-rimmed clouds, supporting feedback-driven triggering.
- Several YSOs are found near the edges of these feedback zones, indicating possible triggered star formation.

**Large-Scale Environment and Star Formation Mode**

- Clusters located near molecular cloud filaments exhibit hierarchical structures, consistent with turbulent fragmentation.
- Both monolithic and sequential star formation modes are present, often influenced by local environment and stellar feedback.

**DISCUSSION**

The study of Young Star Clusters (YSCs) provides key insights into the fundamental processes of star formation, stellar evolution, and the structure of our Galaxy. Based on the observational data and analyses, several important conclusions and interpretations have emerged:

**Role of YSCs in Star Formation Studies**

Young star clusters serve as ideal laboratories for studying star formation. Since the stars within a YSC are generally coeval (formed at the same time) and originate from the same molecular cloud, they offer a controlled environment to test:

- Stellar evolutionary models
- Star formation efficiency
- The nature of the initial mass function (IMF)
- Dynamical interactions and cluster evolution

This study reinforces the importance of YSCs in tracing recent star formation activity and in understanding the physical conditions of the interstellar medium.

**Universality of the Initial Mass Function (IMF)**

One of the central discussions in star formation research is whether the IMF is universal across different environments. The findings of this work show:

- The IMF in most clusters follows the Kroupa or Salpeter-like slope, particularly for intermediate-mass stars.
- Variations in the low-mass end may arise due to observational incompleteness, dynamical evolution, or local environmental effects (e.g., density, turbulence).

This suggests that the IMF is generally consistent but may not be strictly universal, especially in regions of high stellar density or strong feedback.

**Mass Segregation in YSCs**

The analysis reveals that many clusters show evidence of mass segregation, where massive stars are more centrally concentrated. This can occur via two main mechanisms:

- Primordial segregation: Massive stars formed in the center due to initial gas density peaks.
- Dynamical segregation: Result of gravitational interactions over time.

In very young clusters (<3 Myr), segregation is likely primordial, suggesting that the formation process itself may favor the central concentration of high-mass stars.

**Feedback Effects of Massive Stars**

Massive stars play a dominant role in shaping their environment through radiation, stellar winds, and ionizing feedback. The study highlights:

- Presence of ionized gas bubbles, shock fronts, and pillars near massive stars.
- Spatial distribution of YSOs near the edges of these features supports triggered star formation, consistent with models like:

- Collect and Collapse
- Radiation-Driven Implosion (RDI)

This demonstrates that while massive stars can disperse surrounding gas, they can also initiate new generations of stars, influencing the mode and efficiency of star formation.

**Cluster Morphology and Star Formation Modes**

The observed structural morphology of clusters — whether centrally condensed or hierarchically fragmented — provides clues about the star formation process:

- Centrally concentrated clusters likely result from rapid, localized gravitational collapse.
- Hierarchical structures point to turbulent fragmentation across molecular clouds.

Furthermore, the presence of both spontaneous and triggered star formation within the same region suggests that multiple formation modes can operate simultaneously, depending on local physical conditions.

4.6. Implications for Galactic Structure and Evolution

The spatial distribution of YSCs in the Galactic plane, especially in spiral arms and molecular cloud complexes, contributes to our understanding of:

- Large-scale Galactic star formation history
- Location of spiral density waves
- Stellar feedback on galactic-scale ISM regulation

YSCs are thus essential for tracing the ongoing dynamical processes that govern the evolution of the Milky Way.

**Summary of Key Interpretations**

| Topic | Key Findings |
|---|---|
| IMF | Generally consistent with standard forms but may vary locally. |
| Mass Segregation | Present even in young clusters, indicating primordial origin. |
| Feedback | Massive stars can trigger or suppress nearby star formation. |
| Star Formation Mode | Both spontaneous and feedback-induced modes coexist. |
| Cluster Structure | Varies from centrally condensed to fragmented, reflecting formation environment. |

**Conclusion of Discussion**

In conclusion, this study underscores the complex interplay of gravity, radiation, turbulence, and environmental feedback in shaping the birth and evolution of stars in YSCs. While many theoretical models explain aspects of these processes, observational studies like this one are vital to validate and refine our understanding of star formation in real Galactic environments.

**Significance of YSCs in Star Formation Studies**

The results reinforce the role of YSCs as crucial laboratories for understanding star formation. Their rich stellar populations and varied environments provide insight into fundamental processes such as IMF, feedback, and cluster evolution.

**On the Universality of IMF**

While the IMF generally conforms to canonical slopes, observed variations at the low-mass end may reflect environmental effects, data incompleteness, or dynamical evolution. This supports ongoing debates on the non-universality of IMF, especially in dense, high-radiation regions.

**Mass Segregation Origins**

The presence of mass segregation in very young clusters points to primordial origin, possibly linked to the initial conditions of molecular cloud collapse. However, dynamical evolution may enhance segregation over time.

**Massive Star Feedback and Triggered Star Formation**

Massive stars significantly impact their surroundings via UV radiation, winds, and ionization fronts. Observations indicate that this feedback may stimulate star formation in adjacent gas clumps, consistent with the collect and collapse and radiation-driven implosion models.

**Mode of Star Formation**

The coexistence of different star formation modes (isolated, clustered, triggered) in the studied YSCs indicates a complex interplay between initial cloud conditions, feedback, and large-scale dynamics.

**Understanding stars and star clusters**

Stars are formed through gas and dust compressed together by gravitational collapse. Star clusters are groups of physically associated stars. Stars are huge nuclear furnaces, converting their hydrogen supplies to helium and eventually to heavier elements. This process takes place over the millions and billions of years of the star's life cycle.

**The Star Birth**

Stars form within massive accumulations of molecular gas called molecular clouds. Molecular clouds are much larger than stars and usually have masses $10^4$-$10^6$ times the

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mass of the Sun. These clouds have normal number densities of n~100 $cm^{-3}$ and typical temperatures (T) in the range of 10-35 K, making them significantly denser and colder than the surrounding interstellar gas. The cores of molecular clouds are collapsed to generate stars. These core areas, which are tiny sub-condensations inside the much larger molecular clouds, are partially supported by magnetic fields. Such fields act as a pressure source to support the cores against gravitational collapse. The magnetic fields gradually diffuse outward while the inner parts of the core become more centrally concentrated during a process known as ambipolar diffusion that causes the cores to evolve. The core is supported against its gravity by thermal pressure alone as the magnetic contribution to the pressure support declines over time. The core is in an unstable equilibrium state, the precursor to the ensuing dynamic collapse. A small pressure-supported object, or the forming star itself, develops at the center of the collapse flow as a core collapses. A significant amount of angular momentum is present in the rotating cloud cores. A circumstellar disc is produced by the infalling material with a greater specific angular momentum accumulating around the developing star. Thus, the existence of this disc is a logical consequence of the law of conservation of angular momentum. Thus, this stage of evolution (commonly referred to as the proto stellar phase) is characterized by a core star and disc encircled by a flux of gas and dust descending inwards towards the center object. The features of the radiation that the object emits during this stage of evolution are substantially determined by the properties of this infalling envelope.

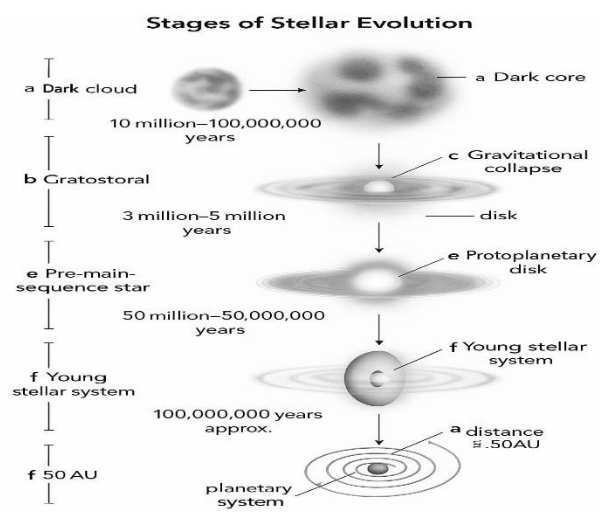


Figure 1.1 The different Phases of star birth (Credit: Stee et al. (2017))

A protostar gains mass and luminosity as it develops. After some time, the protostar grows a powerful stellar wind that eventually escapes via the infall at the rotating poles of the system and produces a bipolar outflow. The bipolar outflow phase is the term used to describe this stage of evolution. The inflow occurs throughout most of the solid angle centered on the star for most of this phase, and the outflow occurs over a very small portion of the angular extent. The column density of the material infalling gradually diminishes, and the outflow gradually spreads to an angular extent. In other words, as time passes, the star gets less firmly anchored to the center of the molecular cloud. Eventually, the outflow removes the developing star/disk systems from their parental core, and the object develops as a young star.

The T-Tauri phase or pre-main sequence (PMS) phase is the name given to this later phase of evolution. The system often keeps its circumstellar disc during this phase of evolution. During this stage of evolution, planets might form inside the disc. The entire phase of star birth is illustrated in Figure 1.1. Despite being optically visible, the freshly formed star does not have the proper internal structure to produce energy through hydrogen fusion. Instead. the star generates most of its energy through gravitational contraction. The core temperature of a star rises as it compresses, eventually allowing for hydrogen fusion. The star is entirely formed when hydrogen ignites.

**Evolutionary stages of stars**

Observations of the protostar's mass distribution and non-stellar radiative flux can be used to infer its growth. Simulating the continuum's spectral energy distribution (SED) makes it possible to deduce the distribution of mass and/or temperature on both small and large spatial scales. The star radiation heats the circumstellar disc or envelope, which is cooled by radiating the energy primarily at infrared wavelengths. The circumstellar structure's temperature and density profiles significantly impact the shape of the infrared SEDs. Conventionally. protostellar SEDs are categorized into classes 0, I, II, and III, which are thought to follow an evolutionary path. A brief description of these classes is as follows:

Class 0: These sources are cloud cores in the early stages of proto-stellar collapse. They have a typical age of $10^4$ year. These sources typically emit relatively little energy below 10 um and exhibit dust continuum emission at sub-millimeter wavelengths (≥100 μm).

Class I: These sources are encased in an "accreting envelope" of surrounding material falling into a thick disc and being directed towards the star. These sources have outflow characteristics and frequently exhibit 10 µm silicate absorption patterns in the spectra. The peak of the SED moves towards far-infrared (FIR) wavelengths (≤100 µm). The typical age of Class I sources are ~ $10^5$ years.

Class II: These sources are virtually fully constructed stars just undergoing disc accretion, while a small amount of envelope material may be present. Their average age is between $10^6$ and $10^7$ years. The SED typically peaks at 2µm, which corresponds to 1000-2000 K temperatures. A dusty disk emerging infrared excess is seen at longer wavelengths.

Class III: These sources have a very weak thin disc and are in the post-accretion phase, although they are nevertheless referred to be pre-man-sequence (PMS) stars. At longer wavelengths, a bit of infrared excess is still visible. The SED has a peak at optical or infrared wavelengths and resembles a stellar black body. Their average age is $10^6$-$10^7$ years old or higher.

The Class II and Class III sources are also known as Classical T Tauri Stars (CTTSs) and Weak line T Tauri Stars (WTTSs), respectively.

Strong Ha emission from CTTSs (EW > 10Å), which comes primarily from the circumstellar disc and infrared excess, is brought on by material accreting onto the central star. The primary characteristic of WTTSs is their weak Ha line (EW < 10Å), which results from chromospheric activity. In the case of WTTSs, a reduced IR excess indicates a smaller or depleted disc and envelope. Because of the magnetic activity on the chromospheric surface, WTTSs exhibit significant X-ray emission. The Class 0, Class I, Class II, and Class III sources are also called YSOs.

Understanding stellar evolution can be accomplished with the help of the Hertzsprung-Russell diagram, commonly known as the H-R diagram. On the Kelvin-Helmholtz time scale, the stars are initially in the contraction stage when they emerge from the molecular cloud. The star is fully convective at this stage and is located on the right side of the H-R diagram. The Hayashi track shows the location of stars entirely convective in the H-R diagram.

**Stellar evolution on H-R diagram**

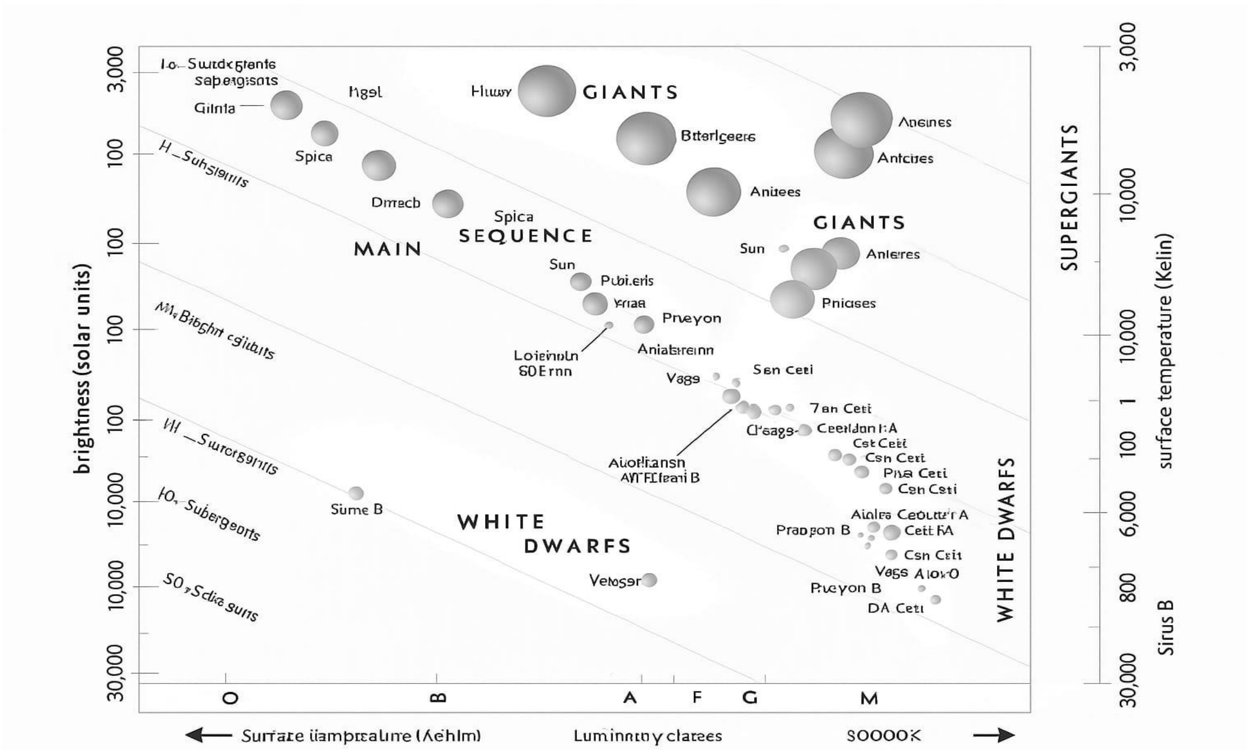


Figure 1.2 The Hertzsprung-Russell (HR) diagram. (Credit: NASA)

Low mass stars migrate immediately to the left of the Hayashi line on the color-magnitude diagram (or H-R diagram), with a modest temperature rise, until it achieves (for example, after roughly $10^7$ years for $1M_\odot$) the practically horizontal evolutionary track for radiative equilibrium. At first, along its pathway, gravitational energy suffices to meet its energy needs.
which the energy generated by nuclear reactions in the star core completely offsets the energy lost due to radiation from the stellar photosphere. The time required to reach the MS is often quite short compared to the MS lifetime of the star. An illustration of H-R is given in Figure 1.2. The contraction time scale for high-mass stars ($\geq 8M_\odot$) is very short ( $\sim 10^6$ years), whereas it is longer ( $> 10^7$ years) for low-mass stars ( $\geq 3M_\odot$). The MS lives of low-mass stars are significantly longer than those of high-mass stars.

Astronomers are always looking for ways to study and classify astronomical objects. One of the best ways to classify stars is by their spectra, divided into various spectral types or colors. This classification system was developed at Harvard Observatory to help astronomers classify and understand the different types of stars. The types are O, B, A, F, G, K, and M. where, O stars are the hottest, and the M stars are the coolest among them.

**The Star Clusters**

The first question that must be addressed in any discussion of star clusters is how to define and distinguish a star cluster from multiple systems (Trumpler, 1930). Recently, Portages Zwart et al. (2010) defined a star cluster as a set of stars The well-known nuclear reaction begins before reaching the main sequence (MS). The zero-age main sequence (ZAMS) is where the PMS evolved. The evolutionary track's culmination marks the first instance in

gravitationally bound to one another. Whereas, according to an earlier review by Lada and Lada (2003), a cluster is defined as a group of stars with a mass density large enough (<~1 M⊙ $pc^{-3}$) to withstand tidal disruption in the solar neighborhood conditions and numerous enough to prevent N-body evaporation for at least 100 Myr. As per McKee et al. (2015), clusters can alternatively be defined as groups of stars whose mass density considerably surpasses the average in their galactic neighborhood ( ~0.1 M⊙ $pc^{-3}$ close to the Sun). For our purposes, a star cluster is a group of gravitationally bound stars (to clearly distinguish it from a multiple star system; Trumpler, 1930)) with a mean density which is at least a factor of a few times the background density (same as constraint adopted by Lada and Lada, 2003).

Star clusters are traditionally classified into two main categories: open clusters and globular clusters. Open clusters are typically young, with ages below 1 Gyr, and they typically consist of 100 to $10^4$ stars. In contrast, globular clusters are characterized by their advanced age, exceeding 10 Gyr, and their high density, surpassing 100 M⊙ $pc^{-3.}$ Open clusters are also referred to as Galactic clusters as they are distributed within the disk of our Galaxy. Open clusters exhibit a broad age range, spanning from a few Myr to Gyr. Younger open star clusters, also known as YSCs, with ages up to 10 Myr, are often associated with the molecular clouds and dust from which they originated. An example of an embedded cluster is shown in Figure 1.3.

sites of active star formation. Due to the short lifetimes of massive stars, OB associations are transient structures. The massive stars exhaust their nuclear fuel relatively quickly and eventually end their lives as supernovae, disrupting the association over time.

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Stellar associations or 'OB' associations are large groups of young and massive stars that share a common origin and are gravitationally bound to each other. OB associations are primarily composed of young stars. The name 'OB' is derived from the spectral classifications of these stars, where O and B-type stars are among the most massive and luminous in the stellar population. 'OB' associations are often of massive stars, OB associations are transient structures. The massive stars exhaust their nuclear fuel relatively quickly and eventually end their lives as supernovae, disrupting the association over time.

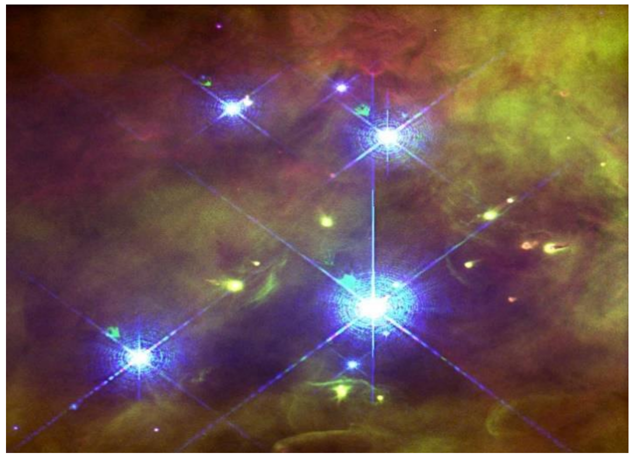

**Figure 1.3** Example for an embedded cluster - The Trapezium cluster associated with the famous Orion Nebula. (a) is Optical, and (b) is an infrared view of this cluster. (Credit: Lada and Lada (2003))

Therefore, the parent molecular cloud's structure might determine the cluster's initial stellar distribution. Internal gravitational interactions between member stars alter the stellar distribution as the cluster evolves. The cluster would disintegrate due to Galactic tidal forces, differential rotation, and impact with molecular clouds. Therefore, star clusters are foremost in studying stellar dynamics. The structure of the youngest cluster is particularly marked by its formation history. It sheds important light on the fragmentation processes during the gravitational collapse of molecular clouds.

**Morphology of Star Clusters**

Based on a thorough analysis of star clusters (Lada and Lada, 2003; Pandey et al., 2005; Sharma et al., 2008), it is determined that they are composed of two primary regions:

(a) Core (nucleus) - The core is the densest part of the star cluster. It contains bright massive ($\geq 3M_\odot$) stars.

(b) Corona (halo) - The corona is extended outer region of the cluster. It is comparatively less dense than the core region and contains many cluster members. This region comprises a large number of faint and low-mass stars ($\leq 1\ M_\odot$)

Internal (mass loss during the star's evolution, mass segregation, and evaporation) and external (tidal interactions with the Galactic disk/bulge and collision with GMCs) forces drive star clusters to evolve dynamically. Clusters undergo substantial structural alterations as they age, and most of them either disintegrate entirely into the Galactic stellar field or remain as sparsely inhabited leftovers.

The spherical shape of the stellar distribution is because of the internal interaction of two-body relaxation resulting from interactions among member stars. Due to relaxation, high-mass stars gradually recede towards the cluster center, while low-mass stars may acquire sufficient kinetic energy via interactions to escape the cluster boundary (stellar evaporation).

This results in mass segregation in these massive stars, preferentially distributed towards the cluster's center.

**Properties of Young Star Clusters**

YSCs are groups of stars that form from the same molecular cloud and are relatively young. typically having ages less than a few million years. YSCs have typical radii ranging from 0.3 to 1 pc and masses ranging from 20 to 1000 solar masses ($M_\odot$). These clusters provide valuable insights into the stages of stellar evolution and the processes involved in star formation. The stars are closely packed (density ~10 to 1000 $M_\odot\ pc^{-3}$) within the cluster, leading to strong gravitational interactions and dynamics. The YSC Westerlund 2 is an excellent example of high stellar density, shown in Figure 1.4. This embedded cluster is formed within the Carina star-forming region about 2 Myr ago. One can see that stellar winds and pressure produced by the radiation from the hot massive stars within the cluster are blowing and sculpting the surrounding gas and dust. The nebula still contains many globules of dust. Star formation continues within the denser globules and pillars of the nebula. YSCs can vary widely in mass. Some YSCs are relatively small, with a few hundred solar masses, while others can be more massive, containing thousands of solar masses worth of stars.

The H-R diagram for YSCs typically shows a well-defined MS. This MS represents the evolutionary stage where stars burn hydrogen in their cores. YSCs allow studying the early stages of stellar evolution as stars progress through various phases. Observing a cluster over time allows one to track the changes in the cluster's H-R diagram and understand how stars evolve. The stars within YSCs share similar kinematic properties, as they inherit the motion of the molecular cloud from which they were formed. This kinematic coherence can be studied to understand the dynamics of star formation regions.

The stellar birth rate for embedded (young) clusters has been discovered to be around one order of magnitude higher than that of classical open clusters. This suggested that most embedded clusters disperse to populate the Galactic field instead of surviving their emergence from molecular clouds. According to Lada and Lada (2003), less than 4-7% of the clusters formed in molecular clouds in the solar neighborhood can age beyond 100 Myr, and less than 10% of them endure for more than 10 Myr. The majority of clusters have the potential to disintegrate before they reach the age of 10 Myr. Haisch et al. (2001) has demonstrated that the near-infrared (NIR) excess fraction in YSCs declines with the mean cluster age. According to Lada et al. (2007), there seems to be an increase in internal cluster structure with age, which could be further an evidence of the beginning of cluster expansion and disruption. YSOs can be observed across different wavelengths, from optical to infrared and radio. Infrared observations are particularly useful for studying young stars embedded in dusty regions.

**Bibliography**


- Deharveng, L., Zavagno, A., & Caplan, J. (2005). Triggered massive-star formation on the borders of Galactic H II regions. *Astronomy & Astrophysics, 433*(2), 565–577.
- Dewangan, L. K., Ojha, D. K., & Zinchenko, I. (2015). Star formation in massive clumps associated with the W42 complex. *Monthly Notices of the Royal Astronomical Society, 446*(3), 2640–2661.
- Haisch, K. E., Lada, E. A., & Lada, C. J. (2001). Disk Frequencies and Lifetimes in Young Clusters. *The Astrophysical Journal Letters, 553*(2), L153–L156.
- Kroupa, P., & Boily, C. M. (2002). On the mass function of star clusters. *Monthly Notices of the Royal Astronomical Society, 336*(4), 1188–1194.
- Lada, C. J., & Lada, E. A. (2003). Embedded Clusters in Molecular Clouds. *Annual Review of Astronomy and Astrophysics, 41*, 57–115.

- Lada, C. J., Muench, A. A., Rathborne, J., Alves, J. F., & Lombardi, M. (2007). The Nature of the Dense Core Population in the Pipe Nebula. *The Astrophysical Journal, 672*(1), 410–422.
- McKee, C. F., Parravano, A., & Hollenbach, D. J. (2015). Stars, Gas, and Dark Matter in the Solar Neighborhood. *The Astrophysical Journal, 814*(1), 13.
- Offner, S. S. R., Clark, P. C., Hennebelle, P., Bastian, N., Bate, M. R., Hopkins, P. F., Moraux, E., & Whitworth, A. P. (2014). The Origin and Universality of the Stellar Initial Mass Function. *Protostars and Planets VI*, 53–75.
- Panwar, N., Pandey, A. K., Samal, M. R., Chauhan, N., Jose, J., & Ogura, K. (2014). Star formation activity around the young cluster Be 59. *Monthly Notices of the Royal Astronomical Society, 443*(2), 1614–1632.
- Pandey, A. K., Sharma, S., Ogura, K., Ojha, D. K., Chen, W. P., Bhatt, B. C., Ghosh, S. K., & Chauhan, N. (2005). Young open clusters and star formation regions: Tr 37 and IC 1396. *Monthly Notices of the Royal Astronomical Society, 358*(4), 1290–1304.
- Portegies Zwart, S. F., McMillan, S. L. W., & Gieles, M. (2010). Young Massive Star Clusters. *Annual Review of Astronomy and Astrophysics, 48*, 431–493.
- Schneider, F. R. N., Ramírez-Agudelo, O. H., Tramper, F., Bestenlehner, J. M., Castro, N., Fossati, L., Gräfener, G., et al. (2020). The VLT-FLAMES Tarantula Survey. *Astronomy & Astrophysics, 618*, A73.
- Sharma, S., Pandey, A. K., Ojha, D. K., & Chen, W. P. (2008). Stellar content and star formation in the young open cluster NGC 1893. *Astronomy & Astrophysics, 489*(3), 1153–1169.
- Sharma, S., Pandey, A. K., Ojha, D. K., Panwar, N., Chen, W. P., & Eswaraiah, C. (2017). A multiwavelength study of the star formation region Sh 2-311. *Monthly Notices of the Royal Astronomical Society, 467*(3), 2943–2962.
- Sharma, S., Pandey, A. K., Ojha, D. K., Chen, W. P., & Jose, J. (2020). A multiwavelength view of star formation in the H II region Sh 2-288. *Monthly Notices of the Royal Astronomical Society, 498*(3), 3703–3721.
- Shu, F. H., Allen, A., Shang, H., Ostriker, E. C., & Li, Z. Y. (1999). Star formation in molecular clouds:

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Observation and theory. In *NATO Advanced Science Institutes (ASI) Series C* (Vol. 540, p. 193).

- Tan, J. C., Beltrán, M. T., Caselli, P., Fontani, F., Fuente, A., Krumholz, M. R., McKee, C. F., & Stolte, A. (2014). Massive Star Formation. *Protostars and Planets VI*, 149–172.
- Trumpler, R. J. (1930). Absorption of Light in the Galactic System. *Publications of the Astronomical Society of the Pacific, 42*(249), 214–227.
- Zinnecker, H., & Yorke, H. W. (2007). Toward Understanding Massive Star Formation. *Annual Review of Astronomy and Astrophysics, 45*, 481–563.

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