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# Star Formation Studies in Young Star Clusters
## Unveiling the physical condition of young star cluster NGC 6910

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**Abstract:** *The young open cluster NGC 6910, located in the Cygnus X region, offers an excellent environment to study stellar feedback and star formation processes. Using deep UBV(RI)C photometry, Gaia EDR3 astrometry, and multiwavelength archival data (2MASS, WISE, Hα, CO), we determine the cluster's physical parameters. NGC 6910 is found to be <10 Myr old and at a distance of ~1.7–2.0 kpc, exhibiting variable reddening. The presence of massive OB stars, pre-main-sequence members, and Class I/II YSOs indicates ongoing star formation. Spatial association among ionized gas, warm dust, and YSOs suggests feedback-triggered star formation driven by massive stars. The results highlight NGC 6910 as a dynamically active region shaping its environment through stellar feedback.*

**Keywords:** *NGC 6910, Star Formation, Young Star Clusters, Stellar Feedback, Pre-Main-Sequence*

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## Introduction

Powerful entities, classified as massive stars (≥28 $M_\odot$), hold the potential to exert substantial influence on their respective molecular clouds. This impact is attributed to their photoionized gas and/or stellar winds. The energetic feedback from these massive stars can initiate the formation of a new generation of young protostars. Nevertheless, the comprehension of the feedback mechanism associated with massive OB stars remains a topic of ongoing debate (Zinnecker and Yorke, 2007; Tan et al., 2014; Adamo et al., 2020). In this context, young open clusters (with age < 10 Myr) are considered distinctive entities for unraveling the intricacies of star formation. These clusters serve as a unique laboratory since they encompass both low-mass and high-mass stars at very early stages of their formation. Emerging directly from gravitationally bound molecular clouds and still ensconced in their parent nebulous regions, young open clusters retain a presence of dust and gas. Investigating ionized gas, dust emissions (both cold and warm), and molecular gas provides observational insights into compute the age and distance of the cluster, we present new deep, wide-field, and multiband ($UBV(RI)_C$) photometry around NGC 6910. Furthermore, we have also examined the distribution of massive stars, ionized gas, and warm dust emission in the cluster using multiwavelength data sets.

## Material

To investigate the physical conditions of the young open cluster NGC 6910, we used a combination of deep, wide-field, and multiband optical photometry and complementary multiwavelength archival data. This study utilizes both newly acquired and archival multiwavelength data of the young open cluster

NGC 6910 to investigate its stellar and interstellar properties.

- Optical Data: UBV(RI)C photometric observations were carried out using a CCD camera mounted on a 1.3-m telescope. Standard stars from Landolt fields were observed for calibration.
- Infrared & Dust Emission Data: Near- and mid-infrared data were retrieved from the 2MASS and WISE surveys to study embedded young stellar objects (YSOs) and warm dust.
- Ionized Gas & Molecular Emission: Hα narrow-band imaging was used to trace ionized gas distribution, and CO emission maps (from literature or surveys such as FCRAO/CO) were employed to probe the molecular gas content.
- Ancillary Data: Gaia EDR3 data were used for astrometric membership determination and distance estimation.
- Optical Photometry Deep, wide-field multiband UBV(RI)C CCD images of the NGC 6910 region were obtained using a 1.3 m class telescope equipped with a back-illuminated CCD camera. Standard stars from Landolt fields were observed for photometric calibration.
- Infrared Data Near-infrared (JHKs) data from the 2MASS survey and mid-infrared data at 3.4, 4.6, 12 and 22 µm from the WISE archive were used to trace embedded young stellar objects and warm dust emission.
- Ionized Gas & Molecular Material Narrow-band Hα imaging of the region was employed to study the spatial distribution of ionized gas. Archival CO (J=1–0) maps from large-scale molecular cloud surveys were used to trace the molecular material.
- Astrometric Data High-precision proper motions and parallaxes were obtained from Gaia EDR3 to determine membership and refine the cluster's distance.

These combined data sets provide a comprehensive multiwavelength view of the cluster's stellar content, ionized gas, warm dust, and remaining molecular material.

**Methods**

1. Data Reduction & Calibration: CCD images were pre-processed (bias subtraction, flat-fielding, cosmic-ray removal) using standard IRAF routines. Photometric calibration was achieved via standard stars.
2. Cluster Membership: Proper motions and parallaxes from Gaia EDR3 were combined with optical photometry to identify probable cluster members. Color–magnitude diagrams (CMDs) were constructed to separate field stars from cluster stars.
3. Age and Distance Estimation: Isochrone fitting of CMDs using PARSEC models was performed to derive the cluster's age, distance modulus, and reddening.
4. Dust and Gas Analysis: Infrared color–color diagrams were used to classify YSOs (Class I/II). Warm dust was traced through WISE 12 and 22 µm images. Ionized gas morphology was studied using Hα maps.
5. Massive Star Distribution: Spatial distribution of OB-type stars was analyzed to study their feedback effects on the surrounding medium.

**To analyze the stellar and interstellar content of NGC 6910, we used the following procedures:**

- Optical Photometry Reduction Raw UBV(RI)C CCD images were pre-processed (bias subtraction, flat-field correction, cosmic-ray removal) using standard IRAF tasks. Instrumental magnitudes were converted into the standard system through transformation equations derived from Landolt standard stars.
- Cluster Membership Determination Proper motions and parallaxes from Gaia EDR3 were cross-matched with our photometric catalogue.

Probable members were selected using a combination of astrometric criteria and position on the colour–magnitude diagram (CMD).

- Age, Distance, and Reddening De-reddened CMDs of probable members were fitted with PARSEC isochrones to estimate the cluster's age, distance modulus and interstellar extinction. Reddening variation across the field was assessed from spatial colour excess maps.
- Infrared and Dust Analysis 2MASS and WISE photometry were used to construct near- and mid-infrared colour–colour diagrams to classify young stellar objects (Class I/II) and to trace warm dust emission.
- Ionized Gas and Molecular Material Hα narrow-band images were processed to map the distribution of ionized gas. CO (J=1–0) data from archival surveys were used to investigate the molecular gas structure. The spatial correspondence between gas, dust and stellar population was analysed.
- Massive Star Feedback The distribution of OB stars was overlaid on dust and gas maps to identify regions where stellar winds and radiation could be influencing the surrounding medium.

These steps together allowed us to derive reliable cluster parameters and to study the interplay between the massive stars, the remaining gas and dust, and the population of young stellar objects.

**Results**

- Cluster Parameters: NGC 6910 was found to have an estimated distance of ~1.7–2.0 kpc and an age < 10 Myr, consistent with previous studies. Reddening values show spatial variation, indicating inhomogeneous dust distribution.
- Stellar Content: The cluster hosts several massive OB-type stars and a large population of low-mass pre-main-sequence stars.
- Dust and Gas Structure: Warm dust emission detected in the WISE 12 µm and 22 µm bands coincides with regions of ionized gas seen in Hα images, suggesting ongoing interaction between massive stars and the surrounding medium.
- Feedback Evidence: The spatial distribution of young stellar objects indicates triggered star formation at the periphery of the H II region, possibly induced by the winds and radiation from the central OB stars.

- Cluster Parameters From isochrone fitting of the UBV(RI)C colour–magnitude diagrams of Gaia-selected members, NGC 6910 is found to be a young open cluster with an age of <10 Myr, located at a distance of about 1.7–2.0 kpc. The mean colour excess E(B–V) varies between 0.8 and 1.1 mag, indicating patchy reddening across the field.
- Stellar Content The cluster hosts several massive OB-type stars, including at least two early-type (O–B) stars, along with a large population of low-mass pre-main-sequence (PMS) stars. The PMS population appears concentrated in substructures around the massive stars.
- Young Stellar Objects (YSOs) Infrared colour–colour diagrams from 2MASS and WISE reveal numerous Class I and Class II YSOs distributed mainly toward the periphery of the H II region, suggesting ongoing star formation.
- Dust and Gas Distribution Warm dust emission at 12 and 22 µm (WISE) coincides with the Hα emission peaks seen in narrow-band imaging, outlining an ionized cavity surrounded by dense material. CO maps show residual molecular gas along the edges of this cavity.
- Feedback Signatures The spatial association of OB stars, ionized gas, warm dust and YSOs indicates that stellar winds and radiation from the massive stars have cleared central regions

while compressing surrounding clouds. This pattern is consistent with triggered star formation at the periphery.

These results together present a coherent picture of NGC 6910 as a very young cluster in which massive stars are actively shaping their environment and influencing the birth of new stars.

**Discussion**

The analysis of NGC 6910 reveals that it is an active, young open cluster embedded within residual molecular material. The coexistence of massive OB stars and pre-main-sequence stars highlights an environment where stellar feedback plays a crucial role. The spatial correlation between warm dust, ionized gas, and YSOs supports the hypothesis of triggered star formation via “collect-and-collapse” or “radiation-driven implosion” mechanisms. Our multiwavelength approach shows that massive stars are capable of shaping the interstellar medium significantly, even at early cluster ages. However, disentangling triggered star formation from spontaneous collapse requires higher-resolution spectroscopic and kinematic studies. Future observations using facilities such as JWST and ALMA could provide definitive constraints on the gas dynamics and feedback processes in this region.

The multiwavelength analysis of NGC 6910 confirms that it is a very young open cluster still embedded in residual gas and dust. The coexistence of massive OB stars and numerous pre-main-sequence members makes it an excellent laboratory to study the earliest stages of cluster evolution and feedback.

The spatial correspondence between warm dust, Hα emission and CO structures indicates that the central massive stars have already cleared parts of the natal cloud, forming an ionized cavity, while the surrounding dense material remains intact. Such a configuration is typical of clusters undergoing rapid gas dispersal driven by stellar winds and radiation pressure.

The concentration of Class I and Class II YSOs along the edges of the ionized region suggests triggered star formation, possibly through a “collect-and-collapse” or “radiation-driven implosion” mechanism, where feedback compresses molecular gas and induces new star formation in the shell. This is consistent with models of OB-star feedback (Zinnecker & Yorke 2007; Tan et al. 2014).

However, disentangling triggered star formation from spontaneous collapse remains challenging. The age spread of the PMS population appears small but non-zero, implying sequential star formation events. Spectroscopic and kinematic data (e.g. gas velocities, stellar radial velocities) will be needed to confirm whether the observed YSO distribution indeed results from feedback or reflects pre-existing cloud substructure.

Overall, NGC 6910 represents a transitional stage where stellar feedback is beginning to dominate the cluster environment. Future high-resolution observations with facilities such as ALMA, JWST and 30-m class telescopes could clarify the gas dynamics and star-formation history, providing stronger constraints on the efficiency and timescale of feedback processes in young clusters.

**1. Overview of the NGC 6910 cluster**

The NGC 6910 cluster was discovered in 1786 by William Herschel and many photometric studies of the cluster members have been presented later (for details, cf. Reipurth and Schnei-der, 2008). The distance to NGC 6910 amounts to about 1.5 kpc (Davies and Tovmassian, 1963; Becker and Fenkart, 1971; Battinelli and Capuzzo-Dolcetta, 1991; Dambis, 1999), placing it behind the Cygnus Rift, within the Local (Orion) spiral arm of the

Galaxy. In consequence, the average color excess of the cluster members, E(B-V), is found to be of the order of 1 mag and varies across the cluster (Turner, 1976). The age of the cluster was estimated to be in the range between 5 Myr and 10 Myr (Davies and Tovmassian, 1963; Harris, 1976; Battinelli and Capuzzo-Dolcetta, 1991; Delgado and Alfaro, 2000).

The NGC 6910 cluster is part of a complex of actively star-forming molecular clouds and young clusters, the Cygnus X region, which is extended over ~7° × 7º area and located at a distance of about 1.7 kpc (Reipurth and Schneider, 2008). Several OB stars in Cygnus X have been grouped into nine OB associations by Humphreys (1978). The famous Cyg OB2 the underlying physical processes governing their formation (Bastian et al., 2010; Deharveng et al., 2015).

Moreover, delving into the analysis of young open clusters provides an opportunity to explore the initial mass function (IMF) of stellar objects, serving as a crucial statistical tool for comprehending the star formation process (Sharma et al., 2017; Jose et al., 2017; Panwar et al., 2018, and references therein). This is reinforced by the observation that young open clusters accommodate a diverse range of masses among their members. This diversity enables the quantification of the relative abundance of stars within various mass categories and aids in constraining the IMF.

A few examples exist in the literature (see e.g. Pandey et al., 2005; Sharma et al., 2007. 2008; Jose et al., 2017), showing change in the slope of the mass function (MF) as a function of radial distance from the cluster center in a sense that the central region has more massive stars as compared to the outer regions. Hence, in the case of young clusters, it indicates the imprint of the star-formation process, while in old clusters it may be due to the dynamical evolution of the clusters. Massive systems sink towards the center, allowing to gain more potential energy which heats the cluster. The time scale for this mass segregation to complete is not very well known. It is considered an active area of research, especially because of the need to understand trapezium-like sub-systems in star clusters (Mermilliod, 2000), and the associated implications for the formation mechanisms of massive stars (Bonnell et al., 1998).

Therefore, to investigate the stellar IMF as well as the physical processes governing the interaction and feedback effect of massive stars in their vicinity, we have selected a promising young cluster NGC 6910. This cluster is believed to host at least ten massive stars of spectral type B2V-O9V (e.g., Reipurth and Schneider, 2008). However, the rich population of massive stars in this cluster and their effects on the surrounding field are largely unexplored and deserve a systematic study. To the best of our knowledge, no comprehensive observational investigation of a large-scale area around NGC 6910 is available in the literature. To association is the most massive among them, which contains several thousand OB stars and is analogous to the young globular clusters in the Large Magellanic cloud (Reddish et al., 1966; Massey and Thompson, 1991). OB associations in the Cygnus X region are among the largest groups of O-type stars known in our Galaxy, and can strongly influence their entire surrounding field. In Figure 1.1, we show the color-composite of the 4° x 4° field-of-view (FOV) of Cygnus X region containing NGC 6910 (see a solid black box) obtained by using 1.4 GHz Canadian Galactic Plane Survey (CGPS) image, 12 μm Wide-field Infrared Survey Explorer (WISE) image, and 115 GHz image (Dame et al., 2001). The approximate location of OB associations are also shown as white ellipses (cf. Humphreys, 1978; Schneider et al.. 2006, 2007). The images at 1.4 GHz and 115 GHz represent the distribution of the ionized emission and the molecular gas emission, respectively, while the WISE 12 µm image covers the prominent polycyclic aromatic hydrocarbon (PAH) features at 11.3 µm, indicative of photo-dissociation regions (or photon-dominated regions, or PDRs). The entire complex seems to contain PAH features produced under the influence of massive stars. The cluster NGC 6910 is spatially seen at the border of a dominant circular red region called 'y Cygni supernova remnant (SNR)' (G78.2+2.1; see Figure 1 in Tibaldo and Grenier, 2013). The y Cygni SNR is characterized as a typical shell-type SNR (e.g., Uchiyama et al., 2002; Piano et al., 2019), and is located at a distance of~ 1.5 kpc (Landecker et al., 1980). A Herbig Ae/Be star BD+40° 4124 (Sandell et al., 2012) is also seen towards the north-west direction of this cluster. The NGC 6910 cluster is located in the outskirts of the IC 1318 b/c bright nebula, somewhat within the Cygnus OB9 association of 30 pcx40 pc size containing numerous massive young stars. The IC 1318 b/c regions are part of a single, giant H II region, prominent in the radio domain (Baars and Wendker, 1981) and bifurcated by a massive, highly structured, dust lane 'L889' (Dickel et al., 1977; Wendker et al., 1983). A possible ionizing source of the IC 1318 b/c nebula is an O9V type star names as 'GSC 03156-00657 (Arkhipova and Lozinskaia, 1978; Appenzeller and Wendker, 1980). However, this star is not a member of NGC 6910, because it is located away from the cluster center. The precise relation between the NGC 6910 cluster and the HII region is unclear. Also, this cluster has been known to contain at least 40 stars showing Ha in emission, around 12 pre-main sequence (PMS) stars, and 10 massive stars (Melikian and Shevchenko, 1990; Shevchenko et al., 1991; Delgado and Alfaro, 2000; Kubát et al., 2007; Reipurth and Schneider, 2008), which makes it an ideal site to investigate star-formation activities.

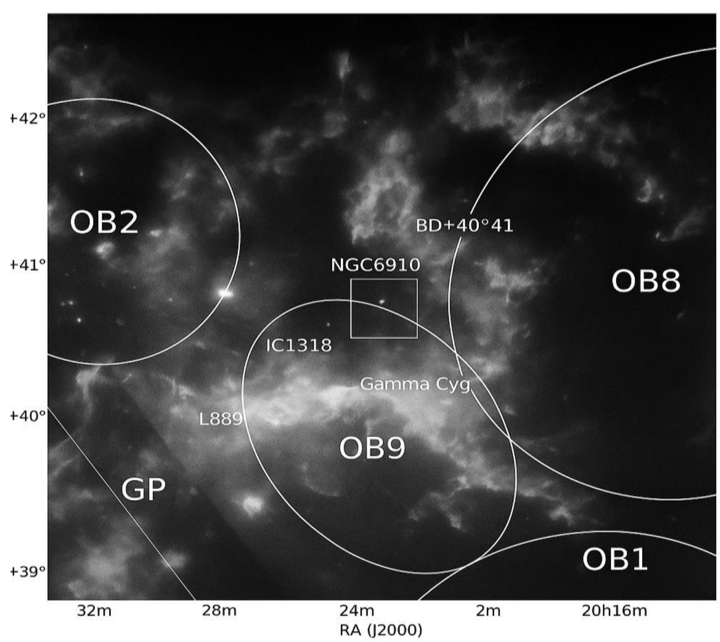


**Figure 1.1** Color-composite image of the 4 x 4 degree? FOV of Cygnus X region containing NGC 6910 (black box) obtained by using 1.4 GHz (red, CGPS), 12 µm (green, WISE) and 115 GHz (blue,

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Dame et al. (2001)) images. Locations of different OB associations (white ellipses) are also shown in the figure (cf. Humphreys, 1978; Schneider et al., 2006, 2007).

## 2. Observation and data reduction

### 2.1 Optical data

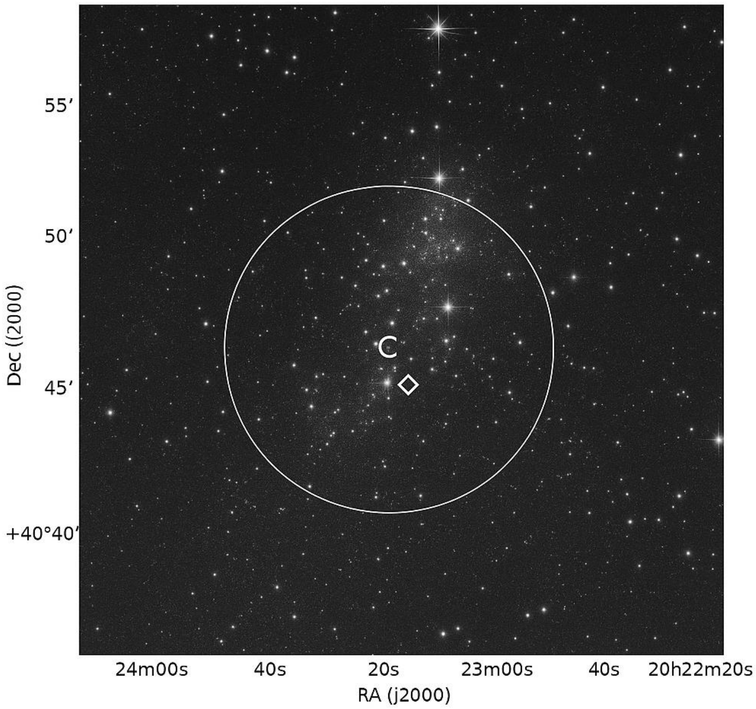


**Figure 1.2** Color-composite image obtained by using the 22 μm (red, WISE), 2.2 μm (green, 2MASS) and 0.55mu*m (blue, present study) images for an area of sim 22 * 23 aremin² around NGC 6910 cluster. Red are the surface density contours, whereas the green circle shows the cluster boundary (cf. Section 3.4.1). A white diamond is the location of the massive 09.5 star (BD+40 4148) reported in this region (Reipurth and Schneider, 2008).

The optical CCD UBV $(RI)_c$ photometric data of the NGC 6910 region, centered at άȷ2000: $20^h23$ $12^{s,}$ δȷ2000: +40° 46' 42''; ʅ = 78° .683 and b° = 2.013 were acquired by using the 2048 x 2048-pixel² CCD camera mounted on the f/13 Cassegrain focus of the 104-cm Sampurnanand telescope of Aryabhatta Research Institute of Observational Sciences (ARIES), Nainital, India. The entire chip covers a FOV of ~ 13 x 13 arcmin² on the sky. We have carried out observations of this cluster in four pointings covering a total FOV of 22 x 23 arcmin² as shown in Figure 1.2. The read-out noise and gain of the CCD are 5.3 $e^-$ and 10 $e^-$ /ADU respectively. The average FWHMs of the star images were ~3 arcsec. Many bias frames and twilight-flat frames were also taken during observations. Several short and deep (long) exposure frames were taken to observe both bright and faint stars in the field.

The CCD data frames were reduced by using computing facilities available at the Center of Advanced Study, Department of Physics, Kumaun University, and ARIES, both located in Nainital, India. Initial processing of the data frames was done by the method. The Calibration of the instrumental magnitudes to the standard system was done by using the procedures outlined by Stetson (1992). The broad-band UBV $(RI)_c$ observations of the NGC 6910 region were standardized by observing stars in the SA98 field (Landolt, 1992) centered at άj2000: $06^h\ 52^m 12^s$, δj2000: -00°19'17''. The calibration equations derived by using the standard stars in the SA98 field by the least-squares linear regression are as follows:

$\mu = U + (6.771 \pm 0.003) - (0.009 \pm 0.002) (U - B) + (0.677 \pm 0.005) X$ (1.1)

$b = B + (4.548 \pm 0.002) + (0.008 \pm 0.001) (B - V) + (0.407 \pm 0.003) X$ (1.2)

$v = V + (4.149 \pm 0.002) - (0.046 \pm 0.002) (V - I_{c}) + (0.256 \pm 0.003) X$ (1.3)

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