SNBNCBS THESIS COLLOQUIUM

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Thesis Title

A Multiwavelength Study Of Galactic Star-forming Regions

Thesis Abstract

The formation of stars is a continuous and ongoing process observed across the galaxy, enabling investigation of the star forming processes that extend upto the present epoch. Over the last quarter century, advancements in the telescope technology has opened a broad window for the systematic study of physical mechanisms of stellar origin. Despite recent progress in the theoretical and observational frameworks, the complete star formation census is still poorly constrained and requires further exploration. With an aim to strengthen a coherent theory of star formation and early evolution, a few galactic young clusters are undertaken in this thesis. Based on the combination of ground to space facility telescopes, from observed to archival catalogs covering optical to radio wavelengths, a comprehensive picture on the star formation activity has emerged.

The early phases of stellar evolution primarily occur in the dark clouds, consisting of cold molecular hydrogen gas, which significantly hamper observations in the optical bands, a problem practically mitigated in the infrared due to lower dust opacity. Over a timescale of tens of Myrs, the molecular cloud gradually disperses, before producing aggregates of clusters or stellar cores, those bearing the imprints of parental cloud distribution. Such molecular cloud structures coupled with pre/proto-stellar cores involve many complex and diverse physical phenomena, including cloud fragmentation, gravitational collapse, accretion, outflows, etc, mostly traced by the radio mapping surveys. Additionally, harboring massive stars in dense molecular clouds plays an eminent role to shape the surrounding environment by ionizing and creating zones of H ii regions, an efficient birth-site for next generation star formation.

Most stars form in groups and clusters embedded within molecular clouds. The Galactic H ii region Sh2-242, located at a distance of 2.1 kpc in the Taurus constellation, depicts star formation activity in a larger scale (~ 1~×0.~5). The high resolution (1500) extinction map, with sensitivity down to AV ~ 18 mag, leads to identification of three peak extinction complexes (AV up to ~ 17 mag) distributed in a filamentary pattern, moreover demonstrates a spatially variable and modest reddening throughout the region. The infrared photometric data analysis traces the young stellar objects (YSOs) toward an elongated structure (length ~ 26 pc) and the clusters of YSOs exclusively coincide with the peak extinction complexes, revealing an ongoing star formation activity. Supplemented with some 200 young populations, majority of which feature with low-mass (0.1–3.0 M~) range, the region is younger (average age ~ 1 Myr) is nature. Powered by en early B-type (B0.5 V) star, this stellar birth site shows likelihood of triggering star formation activity, possibly induced by propagation of the ionized radiation.

The optically visible emission nebula Sh2-112 is located at a distance of ~ 2.1 kpc in the Cygnus constellation. The H ii complex, 3 pc in radius, is illuminated by the massive star (O8 V) BD+45 3216. The associated molecular cloud extends in angular sizes of 2.~0 × 0.~83, across Sh2-112 along the Galactic longitude. The high resolution (1500) extinction map reveals a chain of dust clumps aligned with the filament-like structure with an average AV ~ 2.24 mag, varying up to a maximum of 6.96 mag. Our analysis led to identification of a considerable number (~ 180) of young (average age ~ 1 Myr) stars, plus roughly twice the sample size (~ 350) of H~ emitters, exhibiting a spatially correlated distribution with the filamentary pattern of the clouds. Located near the edge of the molecular cloud, BD+45 3216 has created an arc-like structure where the ionized radiation encounters with the dense clouds, forming a blister-shaped morphology. We found three distinct young stellar subclusters, all coincident with the densest parts of the molecular cloud complex, signifying active ongoing star formation. Moreover, the cloud filament traced by the CO isotopologues and extending nearly ~ 80 pc are found to be dynamic (median ~ −3.65 km s−1), with the radial velocity, along the long axis of the filament, increasing from the Galactic east to west with a gradient of the order of 1 km s−1.

The star formation and evolution is hardly in isolation, however, the Galactic open cluster M36 presents a tantalizing evidence of multiple stellar population along the same line of sight, stipulating sustained star formation activity. The young (age ~ 15 Myr) cluster, enriched with some 200 member candidates with an estimated contamination rate of ~ 8%, exhibits a distinct proper motion and a distinguishable parallax peak (median distance ~ 1.20 ± 0.13 kpc) from the field distribution. To the south-west of the cluster, we discover a highly obscured (AV up to ~ 23 mag), compact (~ 1.09×1.02) dense cloud, within which three young stellar objects in their infancy (ages . 0.2 Myr) are identified. The molecular gas, 3.6 pc in extent, contains a total mass of (2–3)×102 M~, and has a uniform velocity continuity across the cloud, with a velocity range of −20 to −22 km s−1, consistent with the radial velocities of known star members. In addition, the cloud has a derived kinematic distance marginally in agreement with that of the star cluster. If physical association between M36 and the young stellar population can be unambiguously established, this manifests a convincing example of prolonged star formation activity spanning up to tens of Myrs in molecular clouds.

Publications

- **List of Publications**
- **Alik Panja**, Soumen Mondal, Somnath Dutta, Santosh Joshi, Sneh Lata, & Ramkrishna Das, 2020, *"Census of the Young Stellar Population in the Galactic H ii Region Sh2-242"*, AJ, 159, 153, doi: https://doi.org/10.3847/1538-3881/ab737a
- **Alik Panja**, Wen Ping Chen, Somnath Dutta, Yan Sun, Yu Gao, & Soumen Mondal, 2021, *"Sustaining Star Formation in the Galactic Star Cluster M36?"*, ApJ, 910, 80, doi: https://doi.org/10.3847/1538-4357/abded4
- **Alik Panja**, Yan Sun, Wen Ping Chen, & Soumen Mondal, 2022, *"Star Formation in the Sh2-112 Filamentary Cloud: Stellar Contents, Feedback Mechanisms, and Subclusters"*, ApJ (under review)
- **Alik Panja**, Soumen Mondal, Somnath Dutta, Santosh Joshi, Sneh Lata, Ramkrishna Das, & Siddhartha Biswas, 2019, *"Characterization of pre-main sequence population in H ii region Sh2-242"*, Bulletin de la Société Royale des Sciences de Liège, 88, 270, doi: https://doi.org/10.25518/0037-9565.8959
- *Samrat Ghosh, Soumen Mondal, Somnath Dutta, Ramkrishna Das, Santosh Joshi, Sneh Lata, Dhrimadri Khata, & **Alik Panja**, 2021, *"Fast Photometric Variability of Very Low Mass Stars in IC 348: Detection of Superflare in an M-dwarf"*, MNRAS, 500, 5106, doi: https://doi.org/10.1093/mnras/staa3574

[* Not included in thesis]