Abstract

Massive stars ($M \geq 8$ M$_\odot$) play a pivotal role in shaping the interstellar medium and influencing the evolution of galaxies through their intense radiation, stellar winds, and supernova explosions. These stars are the primary sources of ionizing radiation, producing large quantities of ultraviolet photons that ionize the surrounding gas and create H II regions. Studies of H II regions are critical for understanding how massive stars impact their environments and how the interstellar medium is chemically enriched and dynamically shaped over time.

Despite the importance of H II regions in tracing high-mass star formation, there remain some gaps in our understanding of their structure and evolution. A long-standing problem is the discrepancy between the ionizing photon rates inferred from radio and infrared observations. While infrared observations suggest higher ionizing photon rates, radio observations often detect significantly lower values, raising questions about the processes that govern the evolution of H II regions and how ionizing radiation interacts with the surrounding gas and dust. In particular, compact and ultracompact H II regions are known to exhibit this discrepancy, which has been a source of debate for several decades.

In this work, we explore the hypothesis that extended, arcminute-scale radio emission surrounding compact H II regions may account for this discrepancy. Using high-sensitivity radio observations from the *upgraded Giant Metrewave Radio Telescope* and complementary data from the GLOSTAR survey, we conducted a detailed multi-wavelength analysis of eight Galactic H II regions. Additionally, mid-infrared and far-infrared data from the Hi-GAL, MIPSGAL, and GLIMPSE surveys were utilized to assess the ionizing photon rates through spectral energy distribution fitting and other radiative transfer models.

Our findings reveal the presence of significant extended emission surrounding all eight target H II regions, which dramatically increases the radio-estimated ionizing photon rates, bringing them into closer alignment with the infrared estimates. The velocity field of the ionized gas, traced through radio recombination lines, is seen to be continuous across the compact and extended regions, suggesting a common source of origin for both regions. This extended emission, often undetected in earlier high-resolution studies due to sensitivity limitations, provides crucial missing flux that significantly reduces discrepancies in ionizing photon rates.

Our observations show the presence of hierarchical structure in compact and ultracompact H II regions, which may help resolve the "age problem" of ultracompact H II regions. In the context of hierarchical structure, the extended emission is likely to arise from the leakage of ionizing photons into regions of lower density, as opposed to the classical picture of expansion of a bubble of uniform density. Thus, ultracompact H II regions with associated extended emission may not be as young as that inferred from the size of the compact emission alone.

We find the presence of multiple ionizing sources in all eight sources of our sample. We find good agreement between the rate of Lyman continuum photons as inferred from the radio emission and the overall rate from the different ionizing stars. The luminosity of the nebular emission from the H II region is also found to be in good agreement with the total luminosity of the ionizing stars. These confirm the clustered nature of massive star formation and provide further support for a common origin for the compact and extended emission components.

In addition, we have found signatures of a cloud-cloud collision in a multi-wavelength study of an ultracompact H II region, G18.148−0.283. The velocity distribution map of the ionized gas reveals the presence of a velocity gradient of approximately 10 km s^{-1} across the radio continuum peaks. The ^{12}CO (J=3−2) molecular line data also shows the presence of two velocity components (corresponding to two molecular clouds) that overlap with the ionized gas velocities. Besides, the spectrum and position-velocity diagram generated from the CO emission reveal intermediate-velocity molecular gas bridging those velocity components, a very important signature of a cloud-cloud collision. These bridging features are also visible in the position-velocity diagram created from the radio recombination line emission from the ionized gas, which could be a first-of-its-kind discovery. Furthermore, the mid-infrared absorption and far-infrared emission maps establish the presence of a filamentary infrared dark cloud, which may have formed due to a collision.

In sum, the broader implications of this research highlight the importance of accounting for large-scale diffuse emission in radio observations of H II regions. Our findings emphasize the need for high-sensitivity surveys, such as the forthcoming *Square Kilometre Array*, which will further enhance our understanding of how ionizing feedback from young massive stars influences the interstellar medium and drives galactic evolution. By shedding light on the dynamics of ionized regions and their surrounding environments, this work provides a critical step forward in unraveling the complex processes that govern massive star formation and feedback in the Galaxy.