A thesis of

6.7 GHz methanol masers and the early phases of massive star formation

submitted by

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Abstract

Methanol masers at 6.7 GHz are the brightest of Class II methanol masers and have been found almost exclusively towards massive star forming regions. These masers can thus be used as an ideal tool to probe the early phases of massive star formation. The primary goal of this thesis was to investigate the evolutionary stage of the young stellar objects that excite 6.7 GHz methanol masers. Even though there have been several studies in this regard, they were either limited by small sample size or lack of data in the far-infrared. This work has made use of the entire sample from the Methanol Multibeam Survey (MMB) – the largest unbiased Galactic plane survey for 6.7 GHz methanol masers, FIR data from the Herschel Infrared Galactic plane survey (Hi-GAL) and millimetre wave spectroscopic data from the MALT90 survey. We investigated the evolutionary states of 6.7 GHz maser hosts from two perspectives: (1) studying the physical properties of the methanol maser sources (2) probing the chemical environments of maser hosts. For the first case, we obtained the spectral energy distributions (SEDs) from 870 to 70 μm for 320 6.7 GHz methanol maser sources, and used the best-fit parameters of the SED fits to derive the maser clump properties. A comparison of the mass–luminosity diagram of the sample with evolutionary tracks from the turbulent core model suggests that most methanol masers are associated with massive young stellar objects, with over 90 percent in early evolutionary stages where they are accreting matter. However, there also appears to be a small population of sources that are likely to be associated with intermediate- or low-mass stars, suggesting that the association between high-mass star formation and methanol maser emission is not exclusive.

We also studied the chemical properties of the sources associated with the masers using the molecular line observations from the MALT90 survey. This study was carried out for a sample of 68 out of the 320 methanol masers of the first study, with the selection based on data availability and the signal-to-noise ratio of the molecular lines. We used the line intensities and abundances of four molecular transitions: N_2H^+(1-0), HCN(1-0), HNC(1-0) and HCO^+(1-0) since they are bright and are good tracers of dense gas. The molecular spectra were modelled using radiative transfer under the assumption of local thermodynamic equilibrium (LTE). The excitation temperatures and column densities were compared to models that solve for time dependent astrochemistry in star forming cores. The molecular abundances and integrated line intensities agree well with the typical values

found towards high-mass star forming regions. The HCN/HNC, N_2H^+/HCO^+, HNC/HCO^+ and N_2H^+/HNC ratios of column density and integrated intensity suggest that methanol masers are at an earlier evolutionary state than H II regions, but more evolved than the quiescent phase – much in agreement with previous dust continuum studies. This thesis work thus gives strong evidence that along a timeline for massive star formation, the 6.7 GHz methanol maser phase originates in massive young stellar objects that are more evolved than infrared dark clouds, and is quenched by the time the sources evolve into ultracompact H II regions.