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Evolution of high-mass star-forming regions

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Abstract Observational identification of a coherent evolutionary sequence for high-mass star-forming regions is still missing. We use the progressive heating of the gas caused by the feedback of high-mass young stellar objects to prove the statistical validity of the most common schemes used to observationally define an evolutionary sequence for high-mass clumps, and identify which physical process dominates in the different phases.
From the spectroscopic follow-ups carried out towards the TOP100 sample between 84 and 365 GHz, we selected several multiplets of CH_3CN, CH_3CCH, and CH_3OH lines to derive the physical properties of the gas in the clumps along the evolutionary sequence.
We demonstrate that the evolutionary sequence is statistically valid, and we define intervals in L/M separating the compression, collapse and accretion, and disruption phases. The first hot cores and ZAMS stars appear at $L/M \approx 10\ L_\odot\ M_\odot{}^{-1}$

1. Introduction

Making use of the unbiased nature of the ATLASGAL survey, we selected the TOP100, a representative and statistically significant sample of high-mass star-forming clumps covering a wide range of evolutionary phases (Giannetti et al. 2014; König et al. 2017). In our effort to define an evolutionary sequence for high-mass star formation, extensive molecular line surveys were carried out for this sample, covering more than a 120 GHz of bandwidth between 84 GHz and 365 GHz, as well as specific lines. One of the expected effects of the feedback from massive YSOs, is the progressive heating of the surrounding gas. We use this effect to statistically validate the evolutionary schemes based on the L/M ratio and on the IR and radio-continuum emission, and compare different tracers to identify intervals in L/M within which distinct physical processes (compression, collapse, accretion, disruption) characterise the current star formation activity.

2. Data and results

To reveal the progressive warm-up of the gas, we rely on efficient thermometers. From the spectroscopic follow-ups, we selected several multiplets of CH_3CN, CH_3CCH, and CH_3OH to derive the physical properties of the gas via MCWeeds (Giannetti et al. 2017); we additionally compare them with those from previous studies (Wienen et al. 2012; Giannetti et al. 2014; König et al. 2017).

We find that all probes indicate a progressive warm-up of the gas with evolution, to different degrees. CH_3CCH and CH_3CN are

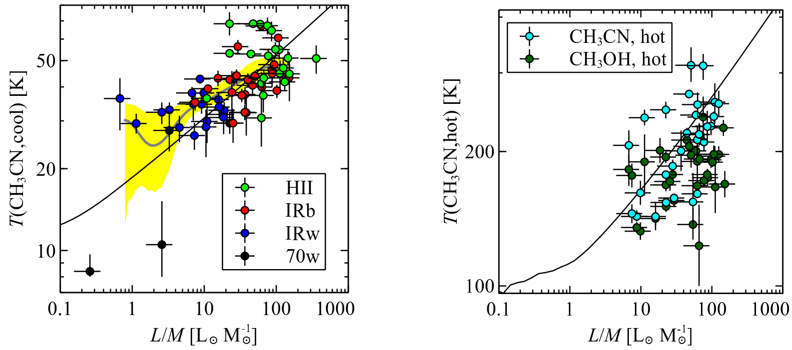

Figure 1. Temperatures vs. L/M. Predictions from the toy model are shown by the black line.

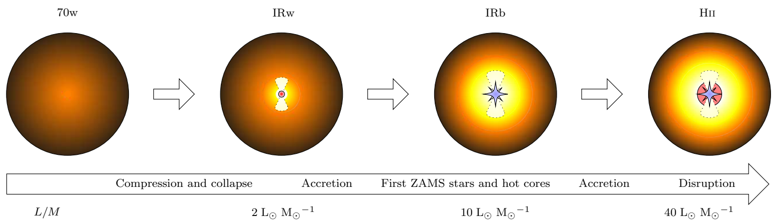

Figure 2. Sketch of the TOP100 evolutionary classes; the dominating process per L/M interval is indicated.

the most sensitive to the this process, whereas CH_3OH and NH_3 (using the two lowest inversion transitions) show only a marginal increase in T. A toy model was constructed, considering a spherical clump with power-law density and temperature profiles. This model is able to reproduce the trend in L/M vs. T for CH_3CN and CH_3CCH, and the hot-core properties as traced by high-excitation lines (Fig. 1).

The detection of torsionally-excited methanol and high-excitation CH_3CN lines ($J = 19 \rightarrow 18$) implies temperatures in excess of 150 K, and reveal the presence of a hot core. CH_3OH $v_t = 1$ levels are pumped by IR radiation, whereas the CH_3CN (19–18) line series is excited by collisions. The negligible contamination of cold and warm gas make these transitions suitable to study the kinematics of the hot gas in the immediate surroundings of high-mass YSOs. We conclude that both the L/M ratio and the classification based on the continuum properties of the source define a statistically valid evolutionary sequence, demonstrated by the progressive warm-up of the gas, as well as the increase in linewidths and volume density of H_2. Figure 2 shows a sketch of the different phases. In the horizontal arrow we indicate the physical process that characterises the ongoing star formation activity in each interval of L/M, giving a first point of contact between the empirical classifications and theory.

It is now possible to identify virtually all massive star-forming regions in the inner Galaxy (Urquhart et al., subm.) and classify them in terms of evolution, estimating the timescale of the process and the statistical lifetime of each phase.

References

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