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DISCOVERY AND STUDY OF THE PHYSICAL PROPERTIES OF HIGH-MASS PRESTELLAR AND PROTOSTELLAR CORES

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Abstract. The question of how sufficient mass can be accumulated to form high-mass stars ($M > 8\,M_{\odot}$) remains open, and a comprehensive investigation of the earliest stages of high-mass star formation is required to address it properly. Here, we take advantage of the large statistics provided by the ALMA-IMF dataset to investigate the physical properties of a sample of high-mass prestellar and protostellar cores. This analysis enables us to obtain more reliable estimates of the lifetime of high-mass prestellar cores, and to probe the different types of support competing with gravity during the collapse of high-mass cores.

Keywords: ISM : outflows, stars : formation, stars : prestellar and protostellar cores

1 Introduction

While the formation of low-mass stars follows a relatively well-established sequence (Pineda et al. 2023), the processes leading to the formation of high-mass stars remain far less understood, mainly because of the complex interplay between turbulence, magnetic fields, and large-scale dynamical events. Constraining the physical conditions that regulate mass accretion and fragmentation in such environments requires probing the earliest evolutionary phases of massive cores, when the initial balance between gravity, turbulence, and magnetic support is first established. Investigating these young, deeply embedded objects is therefore crucial to distinguish between competing scenarios of high-mass star formation, such as core accretion (McKee & Tan 2003) versus competitive accretion (Bonnell et al. 2001), and to better assess the timescales and mechanisms that govern the birth of the most massive stars in our Galaxy. We use here the ALMA-IMF Large Program (Motte et al. 2022) data to study a sample of high-mass prestellar and protostellar cores.

2 A systematic method to detect protostellar outflows

In order to separate prestellar from protostellar cores, we developed a new systematic method to search for protostellar outflows in large datasets such as ALMA-IMF, using CO(2–1) and SiO(5–4) lines (usual outflow tracers). This method consists of a combination of a spectral and a spatial tool (Valeille-Manet et al. 2025). We compare the spectra on the source (On, computed in its ellipse) with the spectra of its environment (Off, computed in an annulus around the source) to search automatically for blue and red-shifted line wings, representative of a protostellar outflow. We use the On-Off spectra to detect the protostellar outflows systematically, which is the best spectra to trace the emission from the source as the contribution of the environment has been retrieved. In addition, we also build moment 0 maps of the blue- and red-shifted CO(2–1) and SiO(5–4) lines, overlaid on the environment, to complement the spectral tool. Molecular outflow maps are commonly used in several studies to trace protostellar outflows (Duarte-Cabral et al. 2013; Nony et al. 2020; Avison et al. 2021; Nony et al. 2023). In Fig. 1 we show the spectra and the molecular outflow maps for one specific protostellar core.

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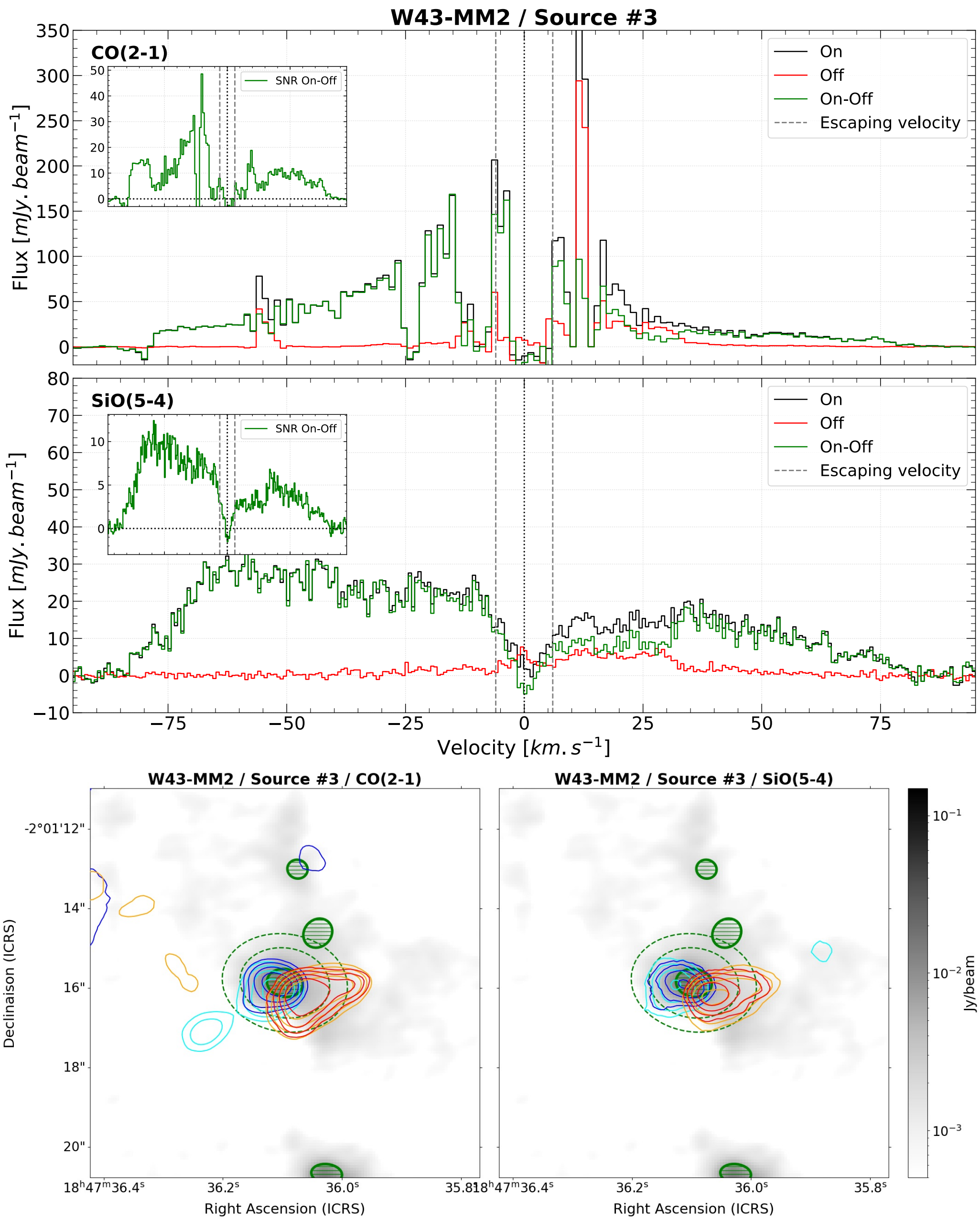

Fig. 1. Top: CO (2–1) and SiO (5–4) On (black), Off (red) and On-Off (green) spectra of the protostellar core #3 of the W43-MM2 region which shows clear line wings representative of its bipolar outflow. Sub-panels present the signal-to-noise ratio of the On-Off spectra. **Bottom:** Molecular outflow maps of the CO (2–1) and SiO (5–4) lines for the same core. Cyan and blue contours show the low- and high-velocity blue-shifted outflowing emission, while orange and red contours show the low- and high-velocity red-shifted emission. A clear bipolar outflow is driven by core #3.

3 A new sample of high-mass prestellar cores

Using the method described above, we identified a sample of 30 prestellar cores within 14 protoclusters of the ALMA-IMF survey (Valeille-Manet et al. 2025), among which 12 can be classified as high-mass with $M > 16\,M_{\odot}$. These cores span a mass range of 8-54 $M_{\odot}$ and have sizes between 1400 and 4200 au (see Fig. 2). Based on this sample of prestellar cores, complemented with the protostellar core population, we estimated the lifetime of the high-mass prestellar phase above 8 $M_{\odot}$. We find lifetimes as short as $\sim$50 kyr towards the most massive cores (see Fig. 3), which is significantly shorter than the $\sim$1000 kyr typical lifetime of the low-mass prestellar phase

(Könyves et al. 2015). This result suggests that the formation of massive cores proceeds in a much more dynamic manner, as it is already observed in high-mass star-forming regions (see, e.g., Schneider et al. 2010; Peretto et al. 2013). However, when comparing these lifetimes with the free-fall times of the cores, we consistently find values exceeding 10 free-fall times, suggesting that strong support mechanisms (e.g., turbulence or magnetic fields) could act against pure gravitational collapse.

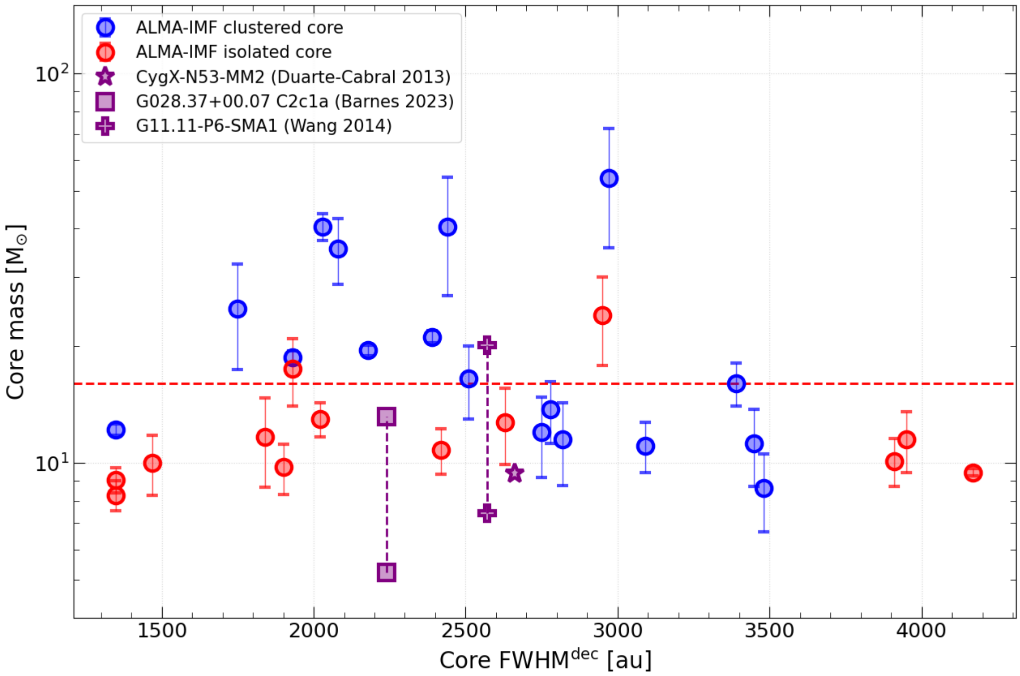

Fig. 2. Mass and size distribution of the sample of prestellar cores. Purple points correspond to previous high-mass prestellar cores that were known. The red dashed line displays the threshold of 16 $M_\odot$.

4 Turbulence and magnetic fields in high-mass cores

We then investigated the level of turbulence within the 12 high-mass prestellar cores of the Valeille-Manet et al. (2025) sample by measuring the velocity dispersion in dense gas tracers. We find that all cores exhibit supersonic turbulence. However, a virial analysis shows that in about two-thirds of the cases, turbulence alone is insufficient to provide stability against gravitational collapse. This strongly suggests that magnetic fields could play a key role in supporting these cores. We also observe a trend in which cores embedded within massive clumps display higher levels of turbulence. An ongoing study in W43-MM1 (Valeille-Manet et al., in prep.) aims to quantify both turbulence and magnetic field strengths in all cores of this protocluster, with particular emphasis on the high-mass regime.

5 Conclusions

This work has led to the identification of the first statistical sample of high-mass prestellar cores, providing a crucial step toward constraining the initial conditions of high-mass star formation. These cores are of particular importance as they represent the earliest, and most elusive, phase of the formation of massive stars. Our study uncovered the most massive prestellar cores detected to date and showed that they preferentially reside in clustered environments. From the combined sample of prestellar and protostellar cores, we estimate that the lifetime of the massive prestellar phase is significantly shorter than that of their low-mass counterparts, yet still exceeds ten free-fall times. This implies the presence of additional forms of support against gravitational collapse. An analysis of turbulence in the 12 most massive prestellar cores reveals that, while supersonic motions are ubiquitous, turbulence alone cannot stabilize most of the cores. This points toward a key role for magnetic fields in the regulation of core evolution. Ongoing investigations of turbulence and magnetic field strength in

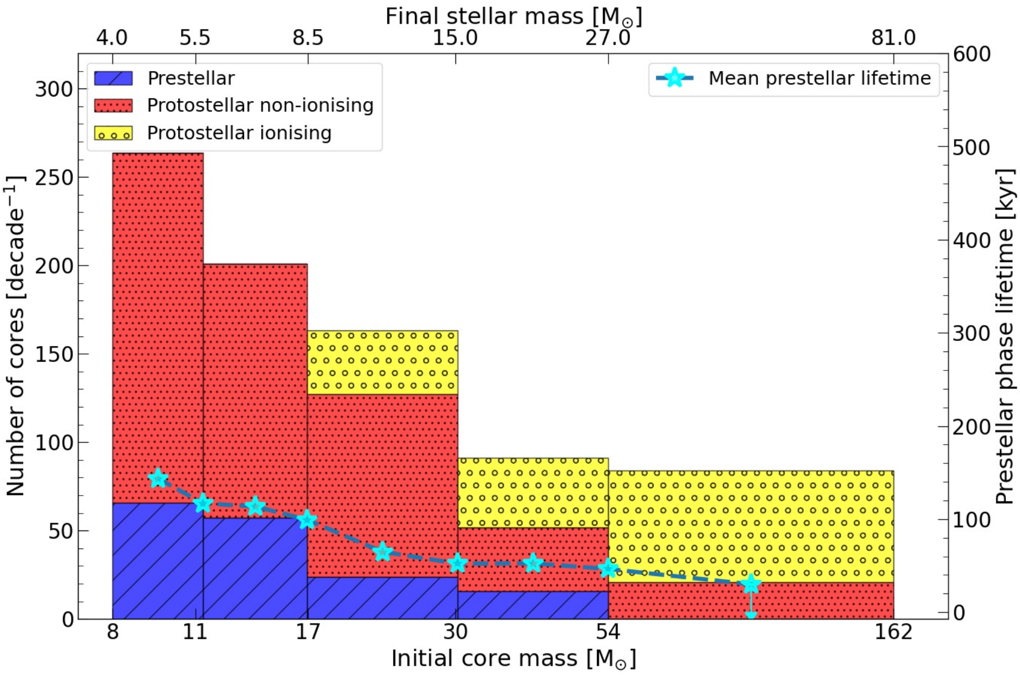

Fig. 3. Weighted histogram of the number of prestellar and protostellar cores per bin and lifetime of the (massive) prestellar phase for each bin (points).

the cores of the W43-MM1 protocluster will provide new insights into the physical processes that govern the formation of high-mass stars.

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