Mem. S.A.It. Vol. 88, 584

Memorie della

CORE: fragmentation and disk formation in high-mass star formation

An IRAM NOEMA large program

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Abstract. Fragmentation, disk formation, outflow and chemical processes lie at the heart of understanding high-mass star formation. We present an IRAM NOEMA (Northern Extended Millimeter Array) large program addressing these questions using high-spatial-resolution observations (0.3″ − 0.4″) at 1.3 mm in both line and continuum emission. After introducing the survey outline and goals, initial results from the dust continuum data about the fragmentation processes are presented. A dichotomy of structures is found, varying from regions dominated by a single high-mass fragments to highly fragmented regions with up to 20 sub-structures. Core separations derived with a minimum-spanning-tree analysis are roughly consistent with thermal Jeans fragmentation, and the influences of turbulence, magnetic field and initial density structure are discussed.

Key words. Stars: formation – Stars: massive – Stars: rotation

1. Introduction

Central questions in the field of high-mass star formation include the topics of fragmentation and cluster formation as well as the properties of massive accretion disks. Related processes are the driving of molecular outflows and the chemical evolution of the associated gas cores. Since the formation of the most massive stars takes place in cold dark clouds at typically >0.5 kpc distance, interferometers at (sub-)mm wavelengths are the tools of choice to address these questions. With these goals in mind we have embarked on an IRAM large program employing the Northern Extended Millimeter Array (NOEMA, formerly PdBI) together with the 30 m telescope to study 20 high-mass star-forming regions at high spatial resolution (∼0.3″ – 0.4″), enough to probe the (sub-)1000 AU scales in line and continuum emission at 1.3 mm wavelengths. In the following we will briefly outline the goals and specifications of the survey (for more details see also the project webpage at http://www.mpia.de/core and Beuther et al. in prep.). Furthermore, we will show initial results from the dust continuum analysis. Additional results from the spec-

* http://www.mpia.de/core

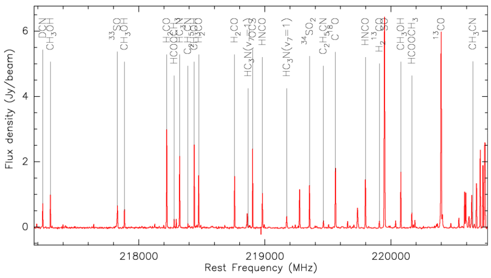

Fig. 1. Example spectrum extracted toward the peak position of AFGL2591.

tral line analysis are presented in accompanying contributions to this volume by Ahmadi et al. and Mottram et al.

2. Survey design and specifications

Our sample is selected to have luminosities $>10^4\,L_\odot$, to be closer than 6 kpc, and to have high declination, ensuring good uv-coverage with northern interferometers. While the 1.3 mm continuum data will be used for the fragmentation analysis, the spectral line data allow us to investigate the turbulence, the kinematic and physical properties of the rotating gas and outflow structures, as well as the chemical properties of the regions. Our spectral setup encompasses lines from dense gas tracers like CH_3CN, less dense environmental gas like H_2CO, and molecular lines suitable to trace outflows like ^{13}CO. Fig. 1 presents an example spectrum. The sample has been observed with NOEMA in three different array configurations (A, B and D) as well as with the 30 m telescope. This setup allows us to study small spatial scales (∼1000 AU), and to tie them to the larger-scale environment. The three configurations ensure an excellent uv-coverage and image fidelity, and result in a continuum rms typically below 0.5 mJy beam^{-1}. While the combination with the single-dish data allows us full flux recovery for the spectral line observations, the continuum data suffer still from the interferometric missing flux. Typically 50 to 80% of the single-dish continuum flux is filtered out by our interferometer observations.

3. Initial results

While we be able to address a diverse set of scientific questions, here we will concentrate on the results from the NOEMA 1.3 mm continuum study only. Spectral line investigations dealing with the small-scale rotating disk-like structures as well as the larger-scale kinematics are presented separately in this volume (Ahmadi et al., Mottram et al.). Figure 2 presents a compilation of the 1.3 mm continuum data for the whole sample. While the actual angular spatial resolution varies between $\sim 0.3'' - 0.4''$, we present the data in linear units over an area of 40000 AU to better outline the relative differences between the regions.

The spatial fragmentation structures in this sample exhibit large variations from regions that are dominated by single massive cores to those that fragment to up to 20 sub-cores. Assuming optically thin dust continuum emission, we estimate masses, column densities and volume densities of the regions. While the masses vary between ∼0.1 to ∼40 $M_\odot$, the column densities are very high, typically in excess of the 10^{23} cm^{-2}, going up to a few times 10^{25} cm^{-2}. Because of the missing flux, mass and column density estimates are lower limits. The estimated average volume densities are also high, varying between 10^6 and 10^8 cm^{-3}.

What are the main agents that determine the fragmentation of these high-mass star-forming regions? How strong are the influences of turbulence, magnetic field properties or initial density structures? To quantify the spatial separation between the cores, we conducted a minimum-spanning-tree analysis. The minimum core separation is typically on the order of a few 1000 AU. This is around or even below the thermal Jeans fragmentation scales of high-mass star-forming regions. Since adding a turbulent contribution to such a Jeans analysis would only increase the separations, this is indicative that thermal Jeans fragmentation is important whereas turbulent contributions may be of lower importance in this context (see also Palau et al. 2015). Furthermore, many of the observed core separation values cluster around the spatial resolution limit of our observations. This indi-

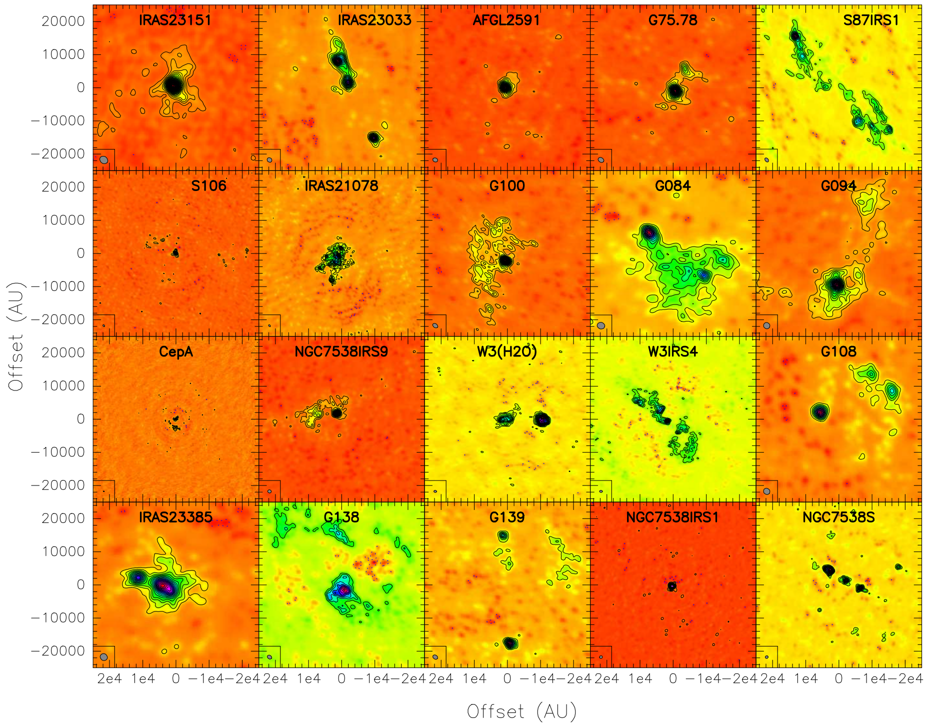

Fig. 2. Compilation of 1.3 mm continuum images for CORE sample converted to linear resolution elements. The contouring is done always in 4σ steps. The sources are labeled in each panel, and the synthesized beams are shown at the bottom-left of each panel.

cates that higher spatial resolution could reveal more fragmentation on even smaller scales. Regarding the importance of initial density profiles or magnetic fields, this is difficult to estimate. While one may naively expect that different initial density structures would result in different fractions of missing flux during the interferometric observations, no such signature is found. For two low-fragmentation regions, magnetic field investigations exist (Chen et al., 2012; Frau et al., 2014), and in both cases high values between 2 and 17 mG are found. Such high magnetic field strengths are consistent with magnetic fields reducing the fragmentation of the star-forming gas (e.g., Commerçon et al. 2011). Future studies of the magnetic field and density structure will further reveal the relative importance of the two effects.

In the coming winter semester, a subsample of five regions will be observed with NOEMA at even higher spatial resolution (0.2″) in the 345 GHz band. In addition to the better resolution, higher excitation/density gas tracers and a radio recombination line to study the ionized gas will be covered.

Acknowledgements. HB, AA, JM and FB acknowledge support from the European Research Council under the Horizon 2020 Framework Program via the ERC Consolidator Grant CSF-648505.

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