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Studies of pre-stellar evolution with the ngVLA interferometer

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1 Introduction

Radio-wavelength spectral line observations are a central tool in studies of the interstellar medium (ISM) and the star formation (SF). Observations need to provide both high sensitivity and high angular resolution, in order to be able to trace the full evolution from molecular clouds to gravitationally unstable filaments and further to the actual birth of protostars. In the case of high-mass star formation, large optical depths and line-of-sight confusion pose additional challenges.

The Next Generation Very Large Array (ngVLA) is the planned extension of the VLA radio interferometer, which will consist of some 250 18-m antennas with baselines up to thousands of kilometres. The ngVLA array will enable very sensitive observations at 1.2-116 GHz frequencies and sub-arcsecond resolutions. The ngVLA community study "Ultra-high-resolution studies of pre-stellar evolution with ngVLA" (PI M. Juvela) is studying the possibilities that ngVLA offers for SF research, to image ISM structures from filaments (0.1-10 pc) down to the scale of the smallest pre-stellar core fragments (1000 au or 0.005 pc) so far detected with the Atacama Large Millimeter Array (ALMA).

As part of the community study, we have examined synthetic observations of a massive filamentary molecular cloud. The cloud model is based on magnetohydrodynamic simulations, combined with radiative transfer modelling. The properties of the cloud (3000 solar masses, 15×40 arcsec projected size for a distance of 4 kpc) are similar to many infrared dark clouds, known birth-places of massive stars. The emphasis is on the molecular tracers available to ngVLA, including the ground transitions of NH_3 and N_2H^+ molecules and different HCO^+ and CO isotopomers. To study the extended cloud structures, observations were simulated for the ngVLA antenna configurations "core" (94 antennas, up to 1.3 km baselines) and "core+ plains" (168 antennas, up to 36.5 km baselines). The nominal observing time was six hours.

The analysis of the simulated ngVLA observations shows that the small-scale density structure can be mapped accurately with different spectral lines. At high frequencies, the measurements are affected by interferometric filtering. Because of the lower frequencies (23.7 GHz), the NH_3 column-density maps show only small systematic errors, even without the help of additional single-dish data. With NH_3, also the kinetic temperatures could be measured with $\sim$1 K accuracy over most of the cloud area. The model cloud contained two main cores and small-scale kinematic features (e.g. "streamers") that are connected to the core-level mass accretion. For the assumed 4 kpc distance, these are at the resolution limit of the simulated observations (1 arcsec or below) but could be partly detected. However, line-of-sight confusion can make the interpretation of the kinematics challenging, even in the case of perfect observations.

Our study shows that the sensitivity and resolution of the ngVLA interferometer will be an important asset for future SF studies. The ngVLA interferometer will have capabilities comparable to and partly exceeding those of the ALMA interferometer. It will also complement ALMA by covering the northern hemisphere and frequencies below 100 GHz. This frequency range includes low-lying transitions of many key molecules, especially deuterated species, and is thus crucial for studies into the physics of the cold ISM and the initial stages of the star-formation process.