Multi-scale view of star formation in IRAS 21078+5211: From clump fragmentation to disk wind

Moscadelli, L.
Beuther, H.
Ahmadi, A.
Gieser, C.
Massi, F.
Cesaroni, R.
Sánchez-Monge, Á.
Bacciotti, F.
Beltrán, M.T.
Csengeri, T.
Galván-Madrid, R.
Henning, T.
Klaassen, P.D.
Kuiper, R.
Leurini, S.
Longmore, S.N.
Maud, L.T.k,
Möller, T.
Palau, A.
Peters, T.
Pudritz, R.E.
Sanna, A.
Semenov, D.
Urquhart, J.S.
Winters, J.M.
Zinnecker, H.

Abstract
Context. Star formation (SF) is a multi-scale process in which the mode of fragmentation of the collapsing clump on scales of 0.1-1 pc determines the mass reservoir and affects the accretion process of the individual protostars on scales of 10-100 au. Aims. We want to investigate the nearby (located at 1.63 ± 0.05 kpc) high-mass star-forming region IRAS 21078+5211 at linear scales from ~1 pc down to ~10 au.

Methods. We combine the data of two recent programs: the NOrthern Extended Millimeter Array large project CORE and the Protostellar Outflows at the Earliest Stages (POETS) survey. The former provides images of the 1 mm dust continuum and molecular line emissions with a linear resolution of ≈600 au covering a field of view up to ≈0.5 pc. The latter targets the ionized gas and 22 GHz water masers, mapping linear scales from a few 103 au down to a few astronomical units. Results. In IRAS 21078+5211, a highly fragmented cluster (size ~0.1 pc) of molecular cores is observed, located at the density peak of an elongated (size ~1 pc) molecular cloud. A small (≈1 km s⁻¹ per 0.1 pc) LSR velocity (VLSR) gradient is detected across the major axis of the molecular cloud. Assuming we are observing a mass flow from the harboring cloud to
the cluster, we derive a mass infall rate of $\approx 10^{-4}$ M$\odot$ yr$^{-1}$. The most massive cores (labeled 1, 2, and 3) are found at the center of the cluster, and these are the only ones that present a signature of protostellar activity in terms of emission from high-excitation molecular lines or a molecular outflow. The masses of the young stellar objects (YSOs) inside these three cores are estimated in the range 1-6 M$\odot$. We reveal an extended (size $\sim 0.1$ pc), bipolar collimated molecular outflow emerging from core 1. We believe this is powered by the compact (size $\lesssim 1000$ au) radio jet discovered in the POETS survey, ejected by a YSO embedded in core 1 (named YSO-1), since the molecular outflow and the radio jet are almost parallel and have a comparable momentum rate. By means of high-excitation lines, we find a large ($\approx 14$ km s$^{-1}$ over 500 au) VLSR gradient at the position of YSO-1, oriented approximately perpendicular to the radio jet. Assuming this is an edge-on, rotating disk and fitting a Keplerian rotation pattern, we determine the YSO-1 mass to be $5.6 \pm 2.0$ M$\odot$. The water masers observed in the POETS survey emerge within 100-300 au from YSO-1 and are unique tracers of the jet kinematics. Their three-dimensional (3D) velocity pattern reveals that the gas flows along, and rotates about, the jet axis. We show that the 3D maser velocities are fully consistent with the magneto-centrifugal disk-wind models predicting a cylindrical rotating jet. Under this hypothesis, we determine the jet radius to be $\approx 16$ au and the corresponding launching radius and terminal velocity to be $\approx 2.2$ au and $\approx 200$ km s$^{-1}$, respectively. Conclusions. Complementing high-angular resolution, centimeter and millimeter interferometric observations in thermal tracers with Very Long Baseline Interferometry of molecular masers, is invaluable in studying high-mass SF. The combination of these twodatasets allows us to connect the events that we see at large scales, as clump fragmentation and mass flows, with the physical processes identified at small scales, specifically, accretion and ejection in disk-jet systems.

Author keywords
ISM: jets and outflows
ISM: molecules
Masers
Radio continuum: ISM
Techniques: interferometric