Revealing a clustered region of massive star formation through NIR jets using VLT instruments

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The formation of massive stars ($M_* > 8\,M_\odot$) is a process that is not yet clearly understood. There are many observational challenges preventing us from uncovering the mechanisms behind their birth, such as the limited number of high-mass young stellar objects (HMYSOs), their location at large distances (typically a few kiloparsecs), and high visual extinction [see, e.g. 1, 2, for recent reviews]. We do know that, similarly to their low-mass counterparts, HMYSOs eject great amounts of material in the form of bipolar outflows and jets [e.g. 3, 4]. These outflows are intrinsically related to the process of accretion onto the protostellar surface [5, 6, 7]. Thus, jets and outflows are crucial for pinpointing the location of massive protostars and providing insights into the physical processes unfolding in the extinguished regions.

When observing in the near infrared (NIR) regime, the driving source is usually not accessible as it is very often totally obscured. However, it is possible to observe the jets driven by massive young stars in the NIR and these can provide a wealth of information about the star-forming complex. Moreover, the excellent angular resolution usually achieved in this regime allows us to probe the collimated jet and individual knots. Molecular hydrogen (H_2) is a particularly good shock tracer as it is the primary coolant in the NIR and its emission can be extended over spatial scales of several parsecs [8, 9, 10, 11, 12], displaying numerous strong emission lines. In the K-band ($1.9-2.5\,\mu$m) in particular, the strongest transition is the H_2 $1-0$ S(1) at 2.12 μm, which has been used in many studies to probe the jet morphology in massive protostellar environments [13].

HMYSO accretion is indeed revealed by their outflows, extending parsecs away from the star, but also through reflected light in their outflow cavity walls [14]. This reflected light emission can further reveal the YSO nature when no clear association can be done with their outflows. In particular, the Brγ at $2.16\,\mu$m is an excellent tracer of young protostars as it probes phenomena occurring very close to the YSO. The Brγ line has been detected at the base of powerful jets driven by a HMYSO [15], as well as in accretion discs in a sample of HMYSOs [16].

When NIR is combined with other (usually longer) wavelengths, one can tell the different parts of the story. Figure 1 top panel (a) shows an RGB image from the Hubble Space Telescope where the jet driven by the massive protostar G35.2-0.74N is clearly seen. In the bottom panel (b), a multi-wavelength composite is shown where the NIR traces the shocked material as revealed by H_2 2.12 μm and [FeII] at 1.64 μm and the free-free radio emission at 6 cm from the powerful outflow.

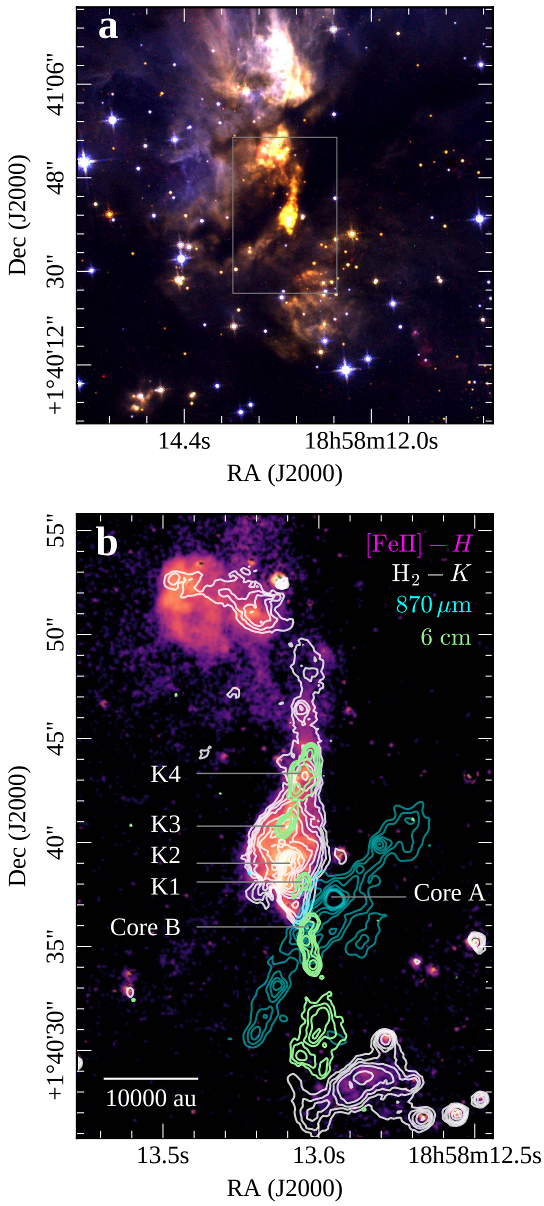

Figure 1: G35.2-0.74N star formation complex. **a** Three colour composite HST image, revealing the jet from the massive protostar. Red channel is the [Fe II] 1.644 μm, green channel is the H 1.600 μm, and blue channel is the J 1.100 μm. **b** Composition of the HST/WFC3 (violet) image, VLT/ISAAC (white contours), ALMA (cyan), and VLA (green) datasets. In both panels, north is up and east is left. Taken from Fedriani et al. [17].

The morphology of the IRAS 18264-1152 region.

We aim to probe the IRAS18264-1152 high-mass star-forming complex in NIR through H_2 jets to analyse the morphology and composition of the line emitting regions and to compare with other outflow tracers [18].

We observed the H_2 NIR jets via K-band (1.9 μm - 2.5 μm) observations obtained with the integral field units VLT/SINFONI and VLT/KMOS. VLT/SINFONI provides the highest NIR angular resolution achieved so far for the central region of IRAS18264-1152 ($\sim 0.2''$). We compared the geometry of the NIR outflows with that of the associated molecular outflow, probed by CO (2−1) emission mapped with the Submillimeter Array. Figure 2 shows a radial velocity map using the IFU KMOS where the different outflows are outlined.

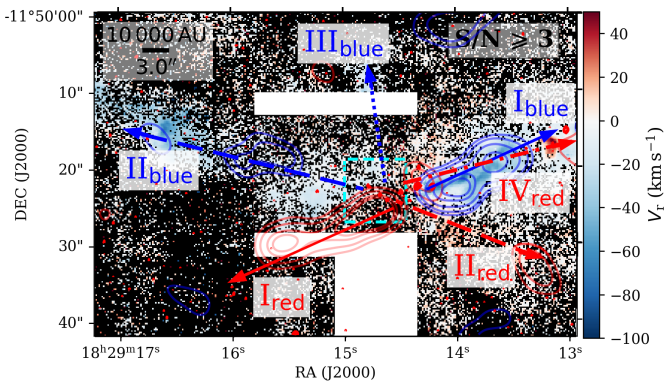

Figure 2: Velocity map for IRAS18264-1152. Taken from Costa Silva et al. [18].

We identify nine point sources in the SINFONI and KMOS fields of view. Four of these display a rising continuum in the K-band and are $Br\gamma$ emitters, revealing that they are young, potentially jet-driving sources. The spectro-imaging analysis focusses on the H_2 jets, for which we derived visual extinction, temperature, column density, area, and mass. The intensity, velocity, and excitation maps based on H_2 emission strongly support the existence of a protostellar cluster in this region, with at least two (and up to four) different large-scale outflows, found through the NIR and radio observations. We compare our results with those found in the literature and find good agreement in the outflow morphology. This multi-wavelength comparison also allows us to derive a stellar density of $\sim$4000 stars pc^{-3}. We also measure and fit its spectral energy distribution (SED) using the python package sedcreator [19]. Figure 3 upper panel shows the best fit for this source while the logo of the package is shown on the lower panel.

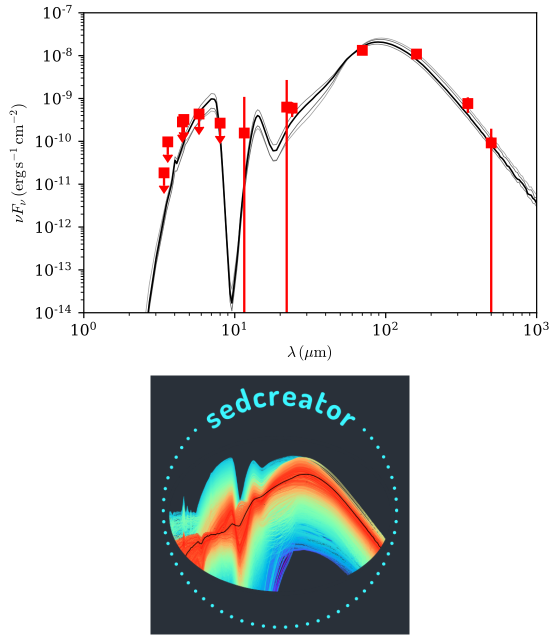

Figure 3: Upper: Velocity map for IRAS18. Lower: Best SED fit and logo for sedcreator. Taken from Costa Silva et al. [18].

Conclusions

Our study reveals the presence of several outflows driven by young sources from a forming cluster of young, massive stars, demonstrating the utility of such NIR observations for characterising massive star-forming regions. Moreover, the derived stellar number density together with the geometry of the outflows suggest that stars can form in a relatively ordered manner in this cluster.

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