YSO jets in Vulpecula OB association

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INTRODUCTION

Jets and outflows are one of the first signposts of stellar birth. Jets are narrow, highly collimated ejections comprising of atomic and/or molecular gas. The outflows are the entrained ambient medium surrounding the jets. Jets/outflows are believed to be channels for removal of excess angular momentum in an accreting protostar and speculated to provide feedback to the parent cloud. Jets/outflows are ubiquitous,yet we do not understand the launching mechanisms of jets, factors affecting jets properties, and their role in the growth of protostars.

H_2 1-0S(1) ro-vibrational transition at 2.122μm is a powerful tracer of shock excited regions associated with protostellar jets. We present an analysis of the Vulpecula OB association (l ~ 60.2°, b ~ -0.2°) located at a distance of 2.3 kpc (Billot et. al. 2010) for jet-bearing young stellar objects (YSOs) using data from the UKIRT Widefield Infrared Survey for H_2 (UWISH2), covering a total of 8 square degrees. 43 individual jets/-knots have been identified in the complex. Outflow properties such as length, luminosity, and ejected mass are measured and radiative transfer models are fitted to the spectral energy distribution (SED) to obtain the physical properties of the candidate driving sources.

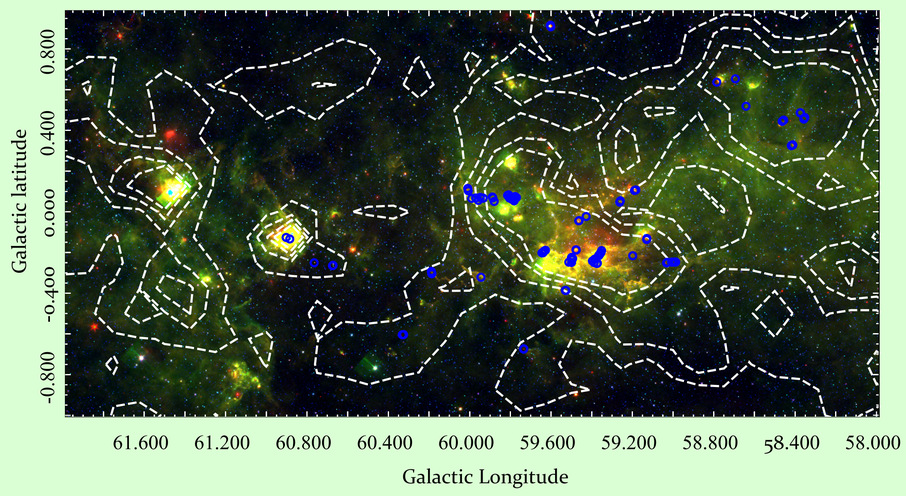

Fig 1: Spitzer IRAC & MIPS band (24 (R) ,8.0 (G) and 4.5μm (B)) color composite image for Vulp OB1. The H_2 line-emission sources are shown by blue circles. The CO velocity integrated map (integrated from 20-40 km/s) from Dame et al. (2001) is shown by white contours.

METHODOLOGY

- Jets are identified using the H_2 1-0S(1) line-emission sources from the catalog of Froebrich et al. (2015).
- Multi-band images are used to associate candidate driving sources based on jet alignment and location.
- The SED of candidate YSOs in the wavelength range 1.2 - 70μm are fitted using the radiative transfer models of Robitaille et al. (2007).
- The derived physical parameters are listed in Table 1.
- For sources with detection only at 70μm, the luminosities of the sources are obtained using the correlation found by Dunham et al. (2008):

$$L_{bol} = 3.3\times10^{8}\ F_{70}^{0.94}(d/140pc)^2\ L_{\odot}$$

where F_{70} is in cgs (erg cm^{-2} s^{-1}).

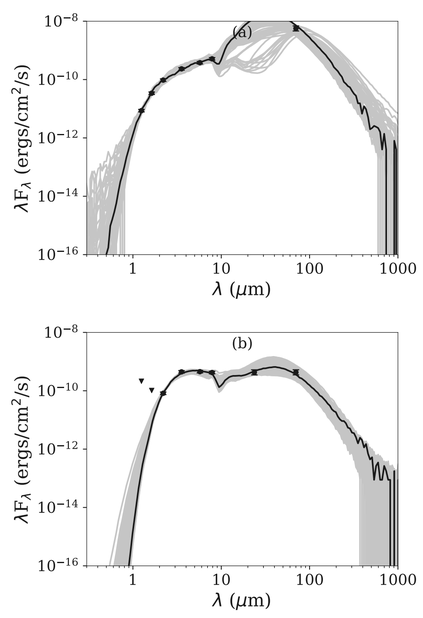

Fig 2: SED fits obtained for sources (a) and (b) in Fig 3. The black line shows the best fit model and the grey lines correspond to models satisfying the goodness-of-fit criteria:

$$\chi^2 - \chi^2_{min} \geq 2\,N_{data}$$

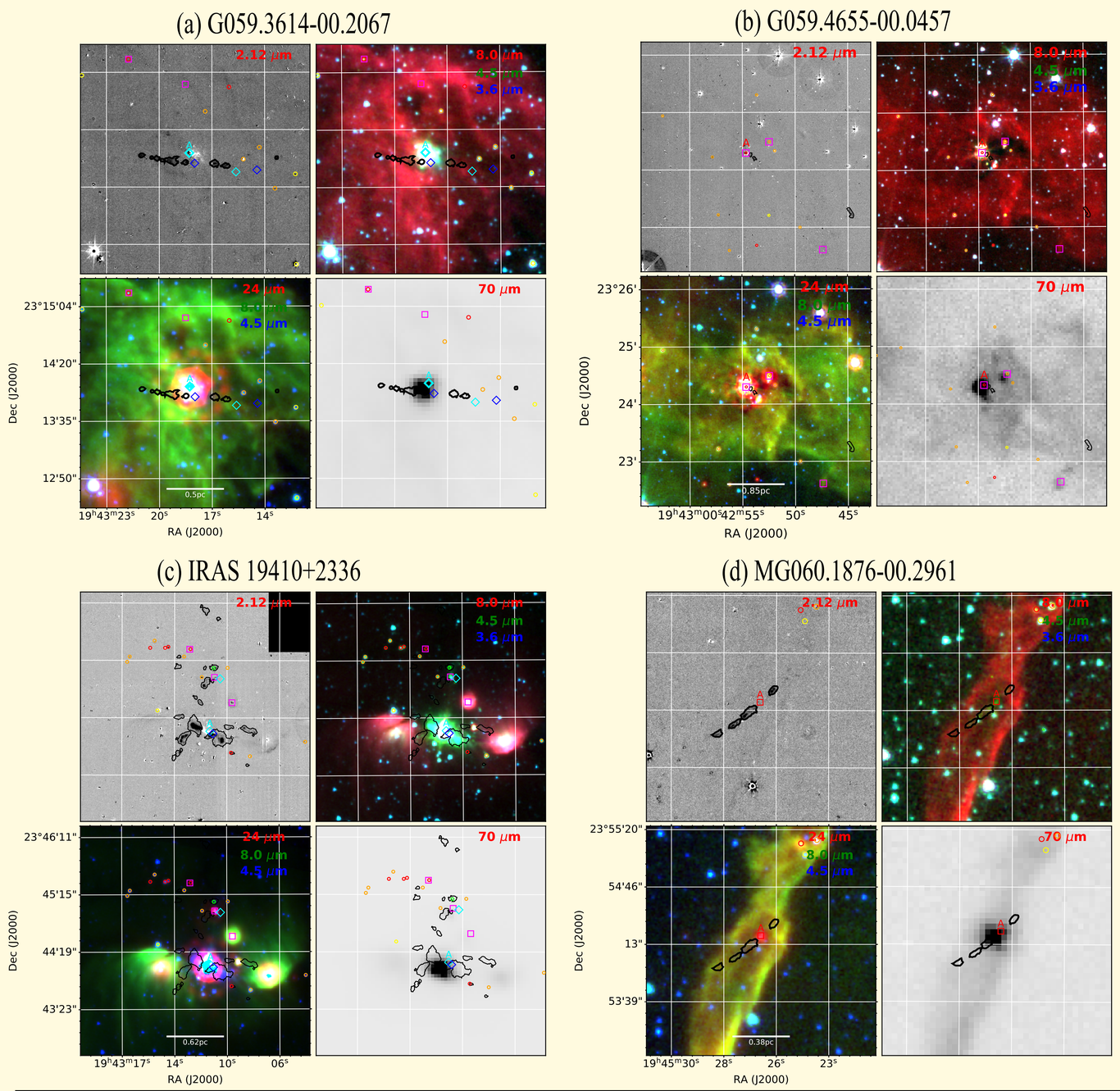

Fig 3: Multi-band images of various targets in Vulp OB1. The subfigures shown (in a clockwise manner from top left) are: Continuum subtracted (H_2-K) image, Spitzer IRAC band (8.0 (R), 4.5 (G) and 3.6μm (B)) color-composite image, Spitzer IRAC and MIPS band (24 (R), 8.0 (G), 4.5μm (B)) color-composite image, Herschel PACS (70 μm) image. The black regions show the H_2 line-emission sources. The square regions show the YSOs identified based on 24 and 70 μm color criteria. The red square shows the PACS bright red (PBR) source (early class 0 source). The YSOs identified by Billot et. al. 2010 are shown by circles (red, orange & yellow corresponding to class 0/I, II and III respectively). The cyan diamond shows SiO emission from Csengeri et al. 2016, and the blue diamond shows the sources from ATLASGAL compact source catalog (Urquhart et al. 2014)

PROPERTIES OF JETS AND DRIVING YSOS

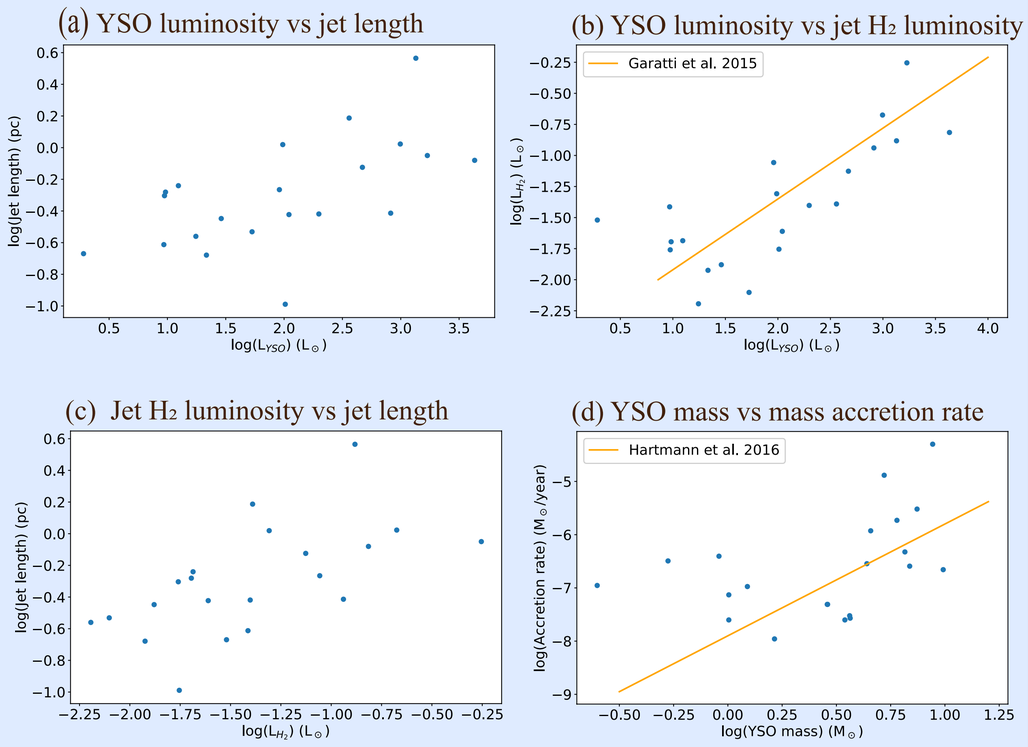

Fig 4: Variation of properties of jets with the physical properties of the physical properties of the driving YSO. In subfigure (b) and (d), the straight line correspond to known correlations from literature.

RESULTS

- The length of the jets were found to be between 0.1 to 3.67 pc.
- We obtained the following physical parameters for the driving sources:

Property	Min. Value	Max. Value
M_{YSO} ($M_\odot$)	0.3±0.2	10.3±0.7
L_{YSO} ($L_\odot$)	1.9±3.8	4368±2329
$\dot{M}_{disk}$ (10^{-7} $M_\odot$ /year)	0.1±0.1	501±198
Jet length (pc)	0.1	3.67

Table 1: Physical propeties of the jets and the associated YSOs.

- The physical properties of the jets appear to be associated with the properties of the driving sources.
- The trends observed in YSO mass vs mass accretion rates are consistent with the study of Hartmann et al. 2016.
- The slope of H_2 luminosity vs YSO luminosity plot for jets in our region is consistent with the stellar population studied by Garatti et al. 2015.
- Our results corroborate with the general idea that bigger, massive YSOs drive longer and more energetic jets.

CONCLUSION

- 43 H_2 jets were identified in the Vulp OB1.
- We have identified the driving source candidates for most of the jets and fitted their spectral energy distributions to obtain the physical properties of the YSOs.
- Most of the jets in the region are driven by intermediate mass stars.
- Corrleations between the physical properties of the jets and outflows are observed.
- Various targets in the region are ideal for follow-up studies. These include multiple EGOs and sites of possible triggered star formation.

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