Star formation in Cygnus X:

Hunting young stellar outflows with UWISH2

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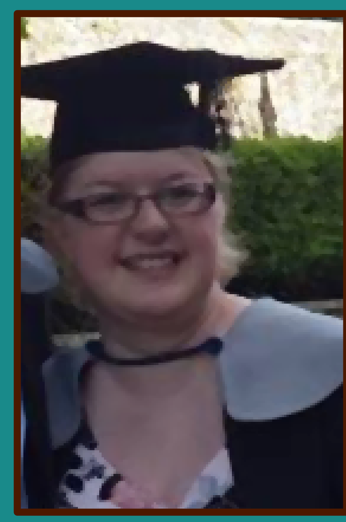
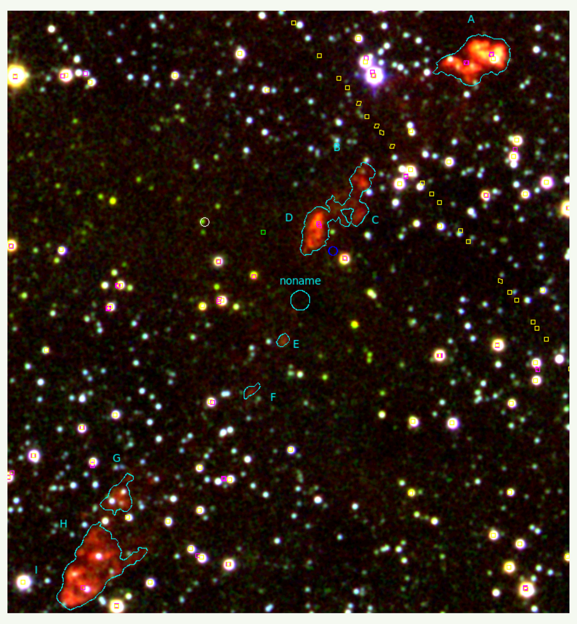


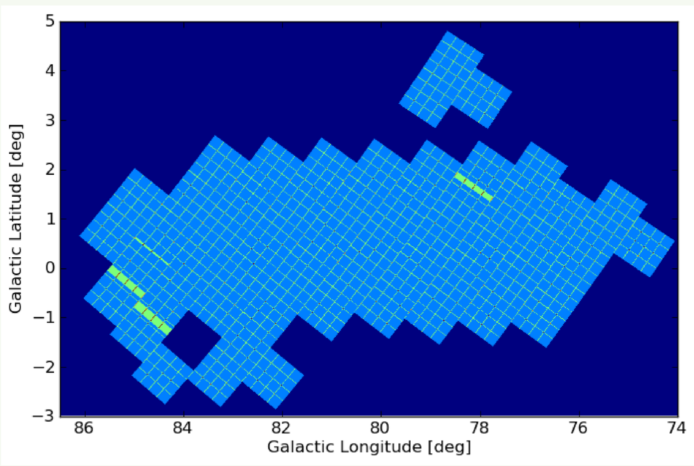
1. Introduction

The UWISH2 survey (Froebrich et al. 2011) traces emission in the H_2 1-0S(1) line at $\lambda = 2.122\mu m$. This line is produced both via shock-excitation and energetic radiation. We can therefore use H_2 emission as a signpost for Young Stellar Objects (YSOs) whose outflows collide with the local environment to produce bright knots as shown in our images to the right.

We are using the UWISH2 data to search for jets in Cygnus X; a high-mass star forming region in the Galactic plane.



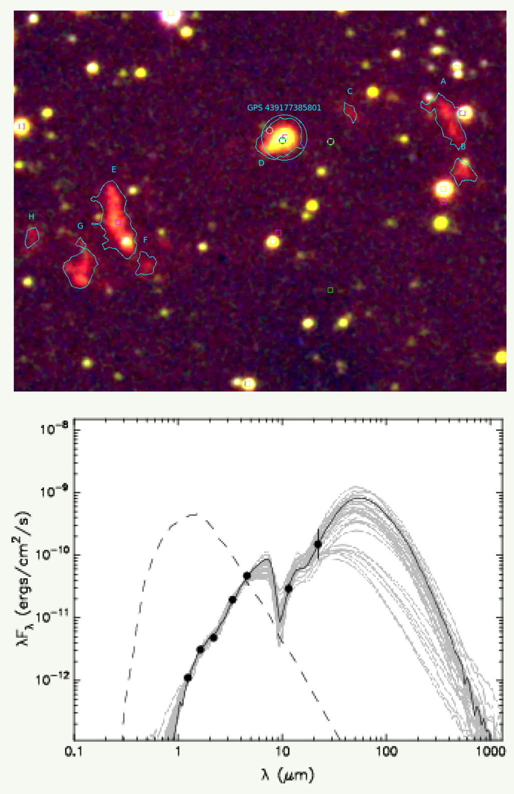
(top) JKH2 image of a newly discovered bipolar, parsec-scale outflow with an embedded driving source in Cygnus X. The majority of our parsec scale jets have an embedded driving source (typically with long-wavelength detections only, or no detections at all).



(left) A map of the UWISH2 coverage of Cygnus X. Each 4x4 block of squares represents a WFCAM tile for a total area of ~41 square degrees.

So far, we have defined 205 Molecular Hydrogen emission-line Objects (MHOs, Davis et al. 2010) in Cygnus X based on the UWISH2 extended emission line source catalogue (Froebrich et al. 2015) and expect at least 200 more, giving excellent statistics. When completed, this survey will allow us to make meaningful comparisons to surveys already done in Orion A, Serpens & Aquila, Auriga and elsewhere in the Galaxy.

2. Methodology



(Top) JKH2 image of one of our MHOs and (Bottom) spectral energy distribution of the star highlighted in the top image, created using the SED fitter of Robitaille et al. (2007). The dashed line shows the best fit for a stellar photosphere.

In Cygnus X we look down one of the spiral arms of the Galaxy, which makes distances uncertain. We have assumed a uniform distance to all objects of 1.4 kpc for the sake of simplicity.

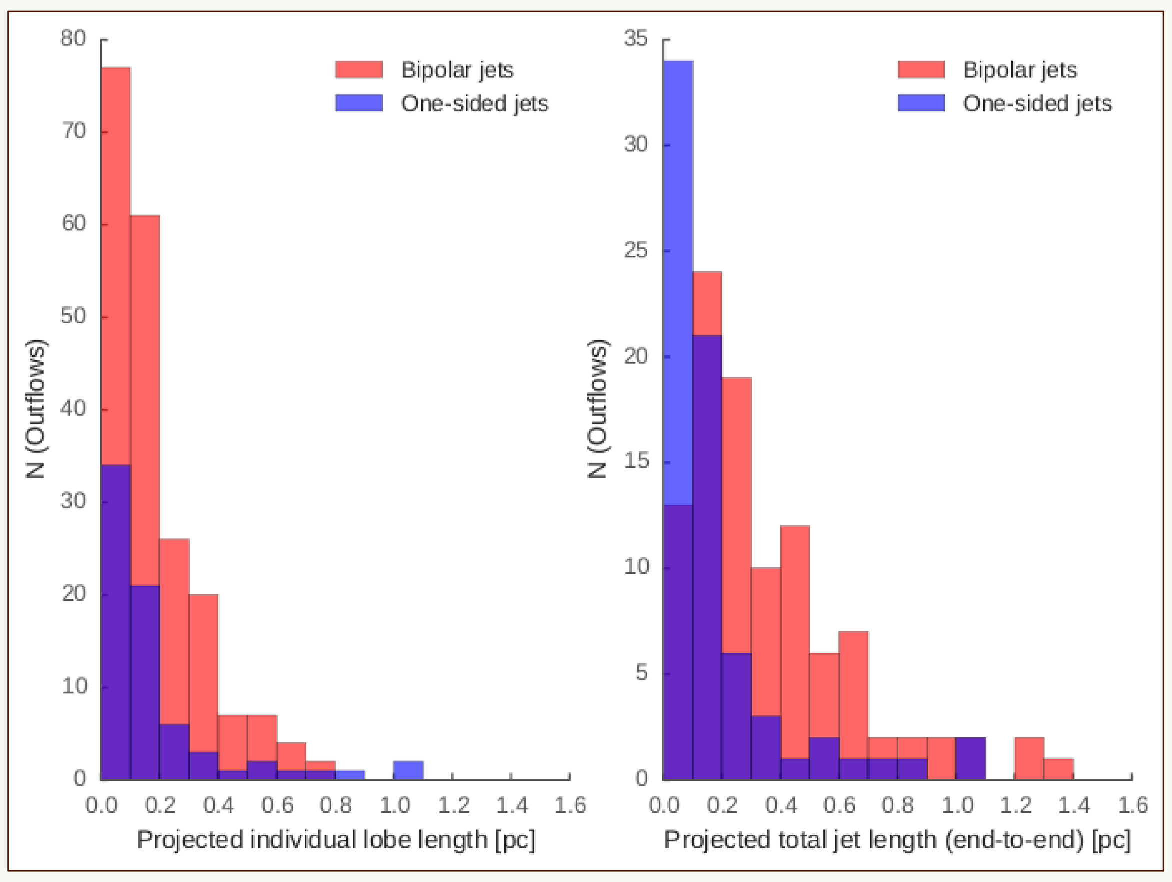
To identify potential outflow driving sources, we choose those aligned with the jet knots. We select sources which are intrinsically red (to account for dusty disks and envelopes) and prefer those which are variable on the assumption that jets are produced as a result of accretion. Colours and variability are generally checked using the Galactic Plane Survey (GPS) or 2MASS. In both cases, this can lead to a risk of contamination from background giants (and even galaxies).

Spectral indices have been calculated for potential driving sources with detections in the WISE survey. The spectral index, α, is calculated by measuring the slope of the spectral energy distribution as per Lada, Adams & Shu (1987):

$$\alpha = \frac{d\log(\lambda F_\lambda)}{d\log\lambda}$$

We assign a probability to each identified source based on our confidence in the selection. Where there are multiple potential sources (e.g., in clusters), the probability is typically very low.

3. Preliminary results



Measuring jet lobes individually vs. end-to-end:

We find that there is a clear difference in the length distribution of our jets depending on how the bipolar jets are measured. Traditionally, jets are measured from end-to-end (right) without distinguishing between the two sides, but we have recorded the lengths of each lobe separately (left). K-S testing shows that when lobe lengths are used, bipolar and single sided jets are not drawn from the same parental distribution (p = 0.11). Furthermore, for the bipolar jets, the lobe length distribution is different from the total length distribution (p = 3E-08).

Random orientation of jets:

K-S testing shows a homogeneous distribution in the orientation of our jets (p=0.98). This is in agreement with Davis et al. (2009) in Orion A, and contradicts Ioannidis et al. (2012) who found a preferential orientation perpendicular to the Galactic plane. If the orientation of the jets is random, then one should expect to see that the single-sided jets follow the same lobe length distribution as the bipolar jets. Since this is not the case the observed differences between single sided and bipolar lobe length distributions are potentially a selection effect or have some so far unknown cause. One explanation could be that the single-sided jets represent objects near cloud edges. We will investigate this further using the brightness of the individual lobes in the 1-0 S(1) line.

Breakdown of jet statistics

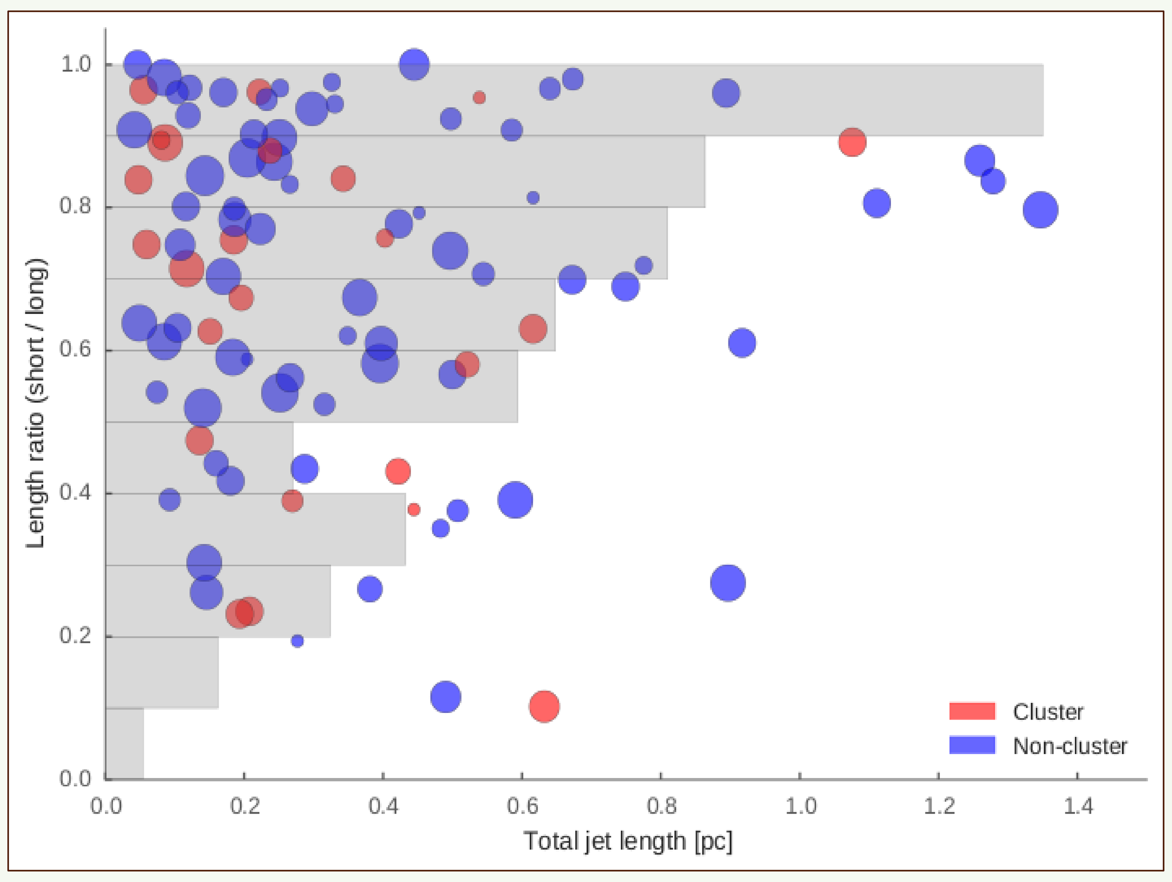
Of the 205 MHOs we have defined so far, ~50% are bipolar, ~35% are single-sided and ~15% are single knots of emission that have been excluded from our statistics.

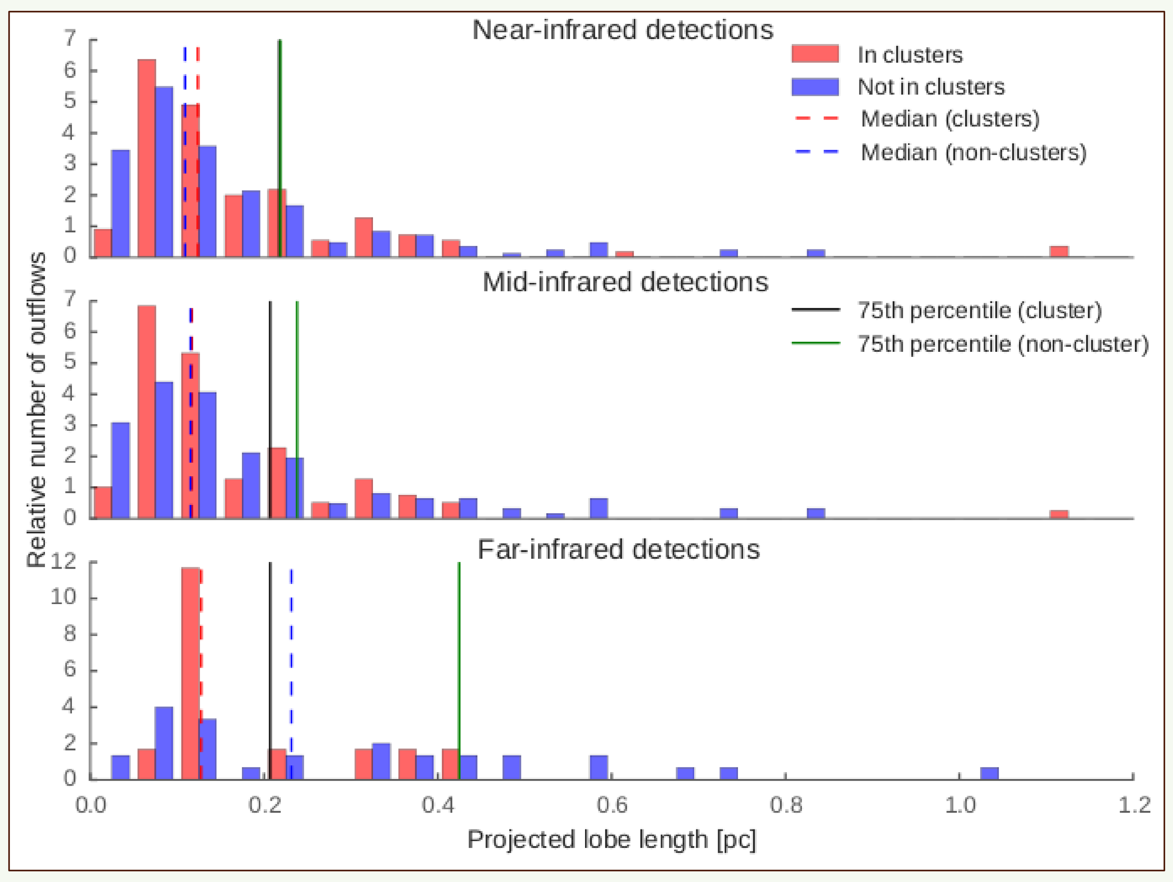
Embedded sources (those with no NIR detection) comprise ~27% of our bipolar jets and only 4% of the single-sided ones.

We have 88 MHOs with sources detected in WISE. For these sources we have calculated spectral indices. Of these ~60% are protostars and ~40% are T-Tauri stars. There is a fraction of Class III-like sources which could point to potential contamination by giant stars. These objects will therefore be investigated in more detail to verify their nature as potential driving sources.

Length ratio distribution of bipolar jets:

(Below) The ratio of the lobe lengths (the shorter over the longer side) shows that the majority of our bipolar jets are short and roughly symmetrical. There seems to be no correlation between the length ratio and whether or not the source is in a cluster. The histogram shows the distribution of the length ratios. The size of the circles represents the probability of the correct allocation of the source, where the larger circles are those with a higher probability, and the colour represents whether or not the jet originates from a cluster.





Projected lobe length/source age progression, according to detection in various infrared surveys:

Here we present the normalised lobe length distributions for jets where the source is detected in near-, mid- and far-infrared (GPS/2MASS, WISE/AKARI-MIR and AKARI-FIS/BGPS respectively). We make the general assumption that younger YSOs (Class 0) will be not be detected at shorter wavelengths. One can consider each panel to contain outflows from sources of decreasing age. We can hence investigate the potential change of the lobe length distribution with evolutionary status of the jet driving source.

In each panel we show the median lobe length (dashed line) as well as the 75th percentile length (solid line, this is the maximum length of the shortest 75% of jet lobes). We indicate on each panel whether or not the jet originates from a driving source in a star forming cluster. It is interesting to note that the very long jets typically seem to be associated with isolated sources in non-clustered environments.

Longer outflows seem to be driven preferentially by younger, protostellar sources whilst the shorter flows are more likely to be associated with slightly more evolved YSOs. This is in agreement with the findings in Orion A of Stanke et al. (2002).

Conclusions & future work

Conclusions:

- It matters how the outflow lengths are measured (lobes vs. total)
- The typical bipolar outflow is not symmetrical (short/long = 0.8)
- There is an age evolution in the length distribution

Future work:

- Finish the identification of MHOs in the entire Cygnus X region (only 50% of the identified jet features have been assigned to MHOs so far)
- Incorporate Spitzer data into the calculation of the spectral indices of the driving sources
- Investigating the surface brightness and total fluxes of the identified outflows
- Comparing our results with other regions in the Galaxy, to investigate if the trends with age and environment in the length distributions are universal, or dependent on the star forming region

References & contacting us

An electronic copy of this poster can be viewed at:
http://astro.kent.ac.uk/~df/vortrag/jetsnetherlands_2015/sally_cygjets.pdf
UWISH2 website: http://astro.kent.ac.uk/uwish2/index.html

Adams et al. 1987, *APJ*, 312, 788
Davis et al. 2008, *MNRAS*, 387, 954
Davis et al. 2009, *A&A*, 496, 153
Davis et al. 2010, *A&A*, 511, A24
Froebrich et al. 2011, *MNRAS*, 413, 480
Froebrich et al. 2015, *MNRAS*, 454, 2586
Froebrich & Makin 2016, *MNRAS*, in prep.
Ioannidis et al. 2012, *MNRAS*, 421, 3257
Robitaille et al. *ApJS*, 169, 328
Stanke et al. 2002, *A&A*, 392, 239

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