1. Jets from Young Stars

Young stellar objects (YSOs) exhibit prominent accretion and outflow features such as accretion disks and bipolar outflows. The Magnetohydrodynamic (MHD) models propose that jets act to remove angular momentum from the star, slowing their rotation and enabling further accretion from the surrounding envelope. Sz102 possesses a bipolar jet that has been well studied. Seeing was good during the observations which act as diagnostic measures of physical conditions within the jet and are particularly important. Classical binary systems like MWC 297, Taurus class (Tutukov and Viyoga 1991) associated with young, actively accreting stars which frequently possess jets. They offer particularly good targets for study due to their close proximity and low inclination making it easier to observe jet features. The techniques of integral field spectroscopy (IFS) and broadband spectroscopy have proved to be especially useful for studying jets. Both allow diagnostic studies to be carried out. With IFS images of the jets in different outflow tracers can be extracted and therefore maps of the physical conditions in the jets constructed (Maury et al. 2014). With broadband spectroscopy numerous emission lines are available for diagnostic studies and accretion and outflow activity can be investigated contemporaneously (Whelan et al. 2016). Here we present results of the integral field observations of the TH 28 jet carried out with the Multi Unit Spectroscopic Explorer (MUSE) and X-Shooter respectively. Both MUSE and X-Shooter are IFS instruments. The broader spectral coverage and better spatial resolution of X-Shooter enables more precise measurement of emission line ratios across a much broader spectral range, making it complementary to observations taken with MUSE.

2. TH 28

The focus of this study will be on the CTTS TH 28 (also named HR 322), which is located in the Lupus 3 cloud, approximately 185 pc distant. This is thought to be a G-K type dwarf with an estimated mass of 2.3 solar masses and an age < 5 Myr (Louvet et al., 2016). HR 322 possesses a bipolar jet that has been well-researched in previous optical and infrared studies and has a total length of 0.32 pc (Comezra & Fernandez 2011). TH 28 is significantly underestimated existing edge-on view of the accretion disc which obscures the star itself. This makes it a useful object for study by enabling a view of both red- and blue-shifted jets to be observed close to the star. Previous studies have reported signatures of jet rotation from an optical study with HST STS (Coffey et al., 2004). Recent ALMA observations detected a counter-rotation between the disk and the optical jet for TH 28 (Louvet et al., 2016).

3. Observations and Data Reduction

The MUSE observations were made on 25th June 2014. The average seeing was 0.9” during which the observations and MUSE had a field of view of 3”x3”. The observations were taken so that the long axis was aligned with the jet axis and the red-shifted jet can be observed within the frame. The total integration time was 600 s. The pixel scale was 0”2, the spatial resolution being 30 km/s. The wavelength range was 5500-9150 Å with a wavelength dependent spectral resolution of between 170 km/s (5710 Å) and 75 km/s (9150 Å). The X-Shooter observations were taken on 17th April 2015 in nodding mode. The single exposure time was 1200 s, yielding a nominal exposure time of 1.4 hour with a 2 × 2 ABBA sequence. The average seeing was 1”2 during the observations. The slit was aligned with the jet axis at a position angle of 170°. The red and blue-shifted jets were observed at 0”5, 0”4 and 0”4 respectively. This choice of slit width yields spectral resolutions of 3900, 1990 and 1200 for each arm respectively. The pixel scale is 0”16 for the UVB and VIS arms and 0”11 for the NIR arm. The data were reduced using the ESO pipelines.

4. Data Analysis

The X-Shooter data was analyzed using the usual IRAF routines for spectral analysis. For the MUSE data reduction we have been able to obtain images in a given line at a chosen velocity. This allows us to trace different components of the jet as well as to measure line ratios using similar velocity ranges when obtaining important line ratios. Position-velocity diagrams can be obtained using a line extraction routine to construct a slice of the data along the jet axis. This shows the distribution of emission as a green line in terms of velocity and distance from the star. This is a valuable tool for examining the variations in emission and velocity components as the jet moves outward from the star. To account for systemic errors in the wavelength calibration, we extracted two-dimensional slices from regions of the field of view containing no visible background stars. We then compared a number of skylines visible in the data with wavelength values obtained from a UVES catalogue (Hansch, 2002) in order to estimate the wavelength offset in each region of the MUSE spectrum. The maximum offset for any line was determined to be approximately 45 km/s, which is significantly better than the resolution of the detector at any wavelength.

5. Results to Date and Future Work

Results to date include:

In Figure 2 the MUSE and X-Shooter spectra are shown. By measuring the flux of emission traces in both spectra we have estimated the emission line ratio. The emission line ratio is shown in Figure 1. We have followed the method of Alcala et al. (2014). The next steps in the analysis of the X-Shooter data, are to correct for log(N_H2) for the sub-luminous nature of the source and to carry out the diagnostic analysis including estimating the mass outflow rate (M放弃了). The main results are described in Whelan et al. (2015) and will be followed up in a future paper.

In Figure 4 the PV plots extracted from the jet in 1 Hα, [N II] λ2058 and [O II] λ3727 lines are shown. These are taken from the X-Shooter spectra. One advantage of the X-Shooter data is that it allows us to also study the jet in the near-infrared. Some extensions is seen in the Fe II lines while the near infrared Hα line is very weak. The redshifted Hα jet is brighter in [N II] λ2058 compared to [O II] λ3727. The near infrared Hα jet is also much more collimated than the near infrared Hα jet which is associated with Hα emission lines from the redshifted jet. All of the lines shown here are important for the diagnostic method. The next step in this study will be to apply the diagnostic method of Bacciotti & Isella to the data (Maury et al., 2014).

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