Bowshocks and Non-Linear Motions Seen in the H2O Masers of AFGL 5142

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In this contribution we present new VLBI observations of 22 GHz H_2O masers in the well-known massive star forming region, AFGL 5142. The masers exhibit prototypical well-defined symmetric bowshocks about a central driving source, in addition to revealing the presence of episodic ejection. One water maser located close to the central accreting star shows clear non-linear motion in the sky-plan, possibly indicating the influence of forces near the star/disk. These phenomena (episodic ejection and disk-jet systems) highlight similarities in the processes of low- and high-mass star formation.

Keywords: Masers, Astrometry, Massive Star Formation, AFGL 5142.

1 Introduction

Revealing the formation mechanisms of massive stars is often approached with observational comparisons of young low- and high-mass stars with regards to their accretion and ejection mechanisms. Characterising accretion is key to understanding massive star formation, however the small physical scales and large dynamic timescales involved make direct observation of accretion almost impossible. On the other hand, protostellar ejections — which are launched during accretion phases — are observationally accessible, and provide a tapestry of the accretion history of the host star. With this in mind we observed the massive young stellar object (MYSO), AFGL 5142 MM1, to investigate its ejection activity and use this to infer properties of the central object and its accretion activity.

Water maser emission at 22 GHz predominantly traces shocked gas associated with protostellar feedback (jets, outflows and expanding shells). VLBI observations of emission at this transition provides the locations, distribution and line of sight velocities of the shocked gas near MYSOs, while multi-epoch observations unlock proper motion information, thus giving the 3D kinematics of the masers. As such maser VLBI is an excellent observational approach to revealing the physical properties of young protostellar ejections.

AFGL 5142 was chosen for this study because it exhibits properties associated with both high-mass star formation (centimeter continuum and 6.7 GHz methanol maser emission) an low-mass star formation (circumstellar disk with a collimated bipolar jet), making it ideal for a comparative observational study of massive star formation.

2 Observations

Seven evenly spaced epochs of phase referenced observations of AFGL 5142, and the reference source J0533+3451, were made with VERA (VLBI exploration of radio astrometry) between April 2014 and May 2015. VERA employs a unique dual-beam VLBI observation mode [1] in which the target and reference sources are observed simultaneously, bypassing the need to slew during phase referencing, thus providing excellent solution of the dynamic tropospheric phase fluctuations.

Sixteen baseband channels (BBCs) of 8 MHz bandwidth were recorded at the 4 VERA stations in Japan. Fifteen BBCs recorded continuum data from J0533+3451 while one BBC recorded spectral line data from AFGL 5142. Data were correlated at the Mitaka FX correlator [2] with a velocity spacing of 0.12 km s^{-1} for the line data. Data were reduced using AIPS (Astronomical Image Processing System), developed and maintained by the National Radio Astronomy Observatory. We used the *inverse phase-referencing* procedure, customised to the dual-beam system of VERA (*see* [3, 4]) to derive the proper motions of masers in AFGL 5142, after subtracting of motions associated with the source's annual parallax (*see* [5] for details).

3 Results

Masers in AFGL 5142 MM1 associate with bipolar bowshocks which exhibit symmetric expansion (Fig. 1). Three bowshocks are seen in the VERA data; the N. W., S. E. inner and S. E. outer. At the source distance of D=$2.14^{+0.051}_{-0.049}$ kpc [5] the average magnitude of proper motion velocity vectors indicate expansion motions in the sky plane direction of 15 km s^{-1}, while line of sight velocity differences in the N. W. and S. E. bowshocks are smaller; only ±5 km s^{-1} about a central velocity of -1.8 km s^{-1}. Maser feature 'A' was detected at an intermediate position and velocity between the bowshocks. Its proper motion could not be determined since it exhibited a clear non-linear trajectory in the sky-plane.

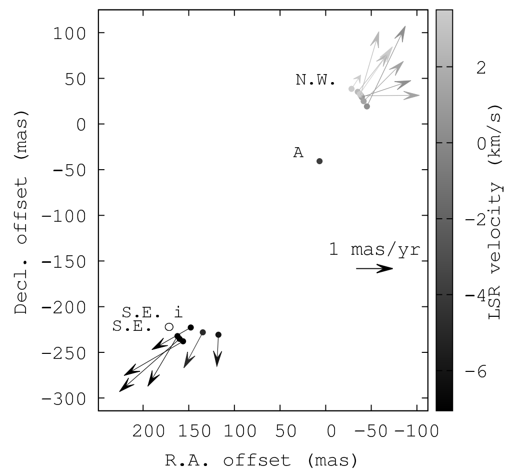

Fig. 1. The distributions and internal proper motions of water masers around AFGL 5142 MM1. Vectors indicate proper motions while greyscale indicates line of sight velocities

4 Discussion

4.1 Episodic, jet-driven outflow from an MYSO

Sky-plane proper motions of masers can be used as a diagnostic for distinguishing whether a protostellar outflow is driven by a jet-driven bowshock or a momentum driven wind [6,7]. The large velocity dispersion at the leading edge of the maser traced bowshock suggests a that the jet in AFGL 5142 MM1 is driven by a bow-shock. Furthermore, the jet position angle ($-35°$) is offset from the axis of the disk ($-8°$) [9]. Such an offset is inconsistent with jet launching via an extended disk wind, and instead favours scenarii where the jet is launched from the inner radii which could exhibit a warp/axis offset, or precession, with respect to the wider disk.

Narrow, collimated jets are better known from observations of low-mass protostars. The masers in AFGL 5142 demonstrate that similar jets are also present in some MYSOs. Furthermore, we note that the ejections from AFGL 5142 appear to be episodic [5], operating on $\sim 10^4$ year timescales, consistent with recent simulations [8]. The literature on massive star formation is seeing a gradual increase in observational evidence that several processes and physical features are common to both low- and high-mass star formation. However, whether the Galaxy's massive stars formed via a 'scaled-up' version of low-mass star formation is yet to be confirmed.

4.2 Non-linear motions

Maser feature A showed clear non-linear proper motions (Fig. 2). Since the astrometries presented in this section are *relative motions*, they are unaffected by systemic, positional uncertainties which show up in multi-epoch parallax measure-

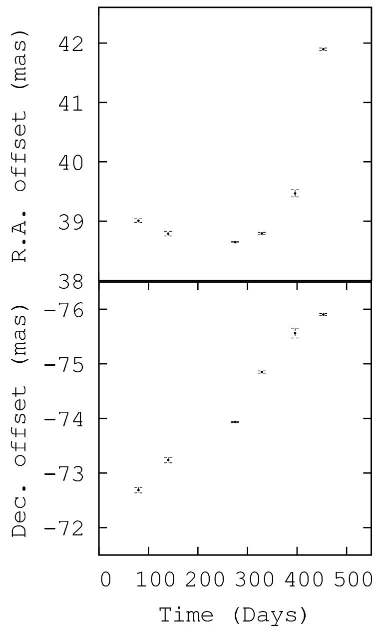

Fig. 2. Astrometric positions of Feature A in R.A. (*above*) and Dec. (*below*) as a function of days, starting on the 1st of January 2014. Positions are relative to the reference maser. Error bars are determined from 2D Gaussian fits to the data in AIPS, added in quadrature with those of the reference maser

ments. Careful inspection of the maser maps confirm that the structure and line of sight velocity of feature A remained constant over the 6 epochs in which it was detected — confidently ruling out misidentification.

The proximity of Feature A to the circumstellar disk [9] raises the possibility that this motion arises from the influence of local force, possibly gravitational or magnetic, or whether its apparent motion comes from changes in position of the physical conditions capable of sustaining maser emission; perhaps introduced by a precessing ejection from the central object. An alternative interpretation is that the maser emission amplifies a background continuum source orbiting near to the MYSO. Such a scenario would not require any movement on the part of the masing gas. The intriguing behaviour of this maser source certainly warrants further investigation.

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