Episodic ejection in massive young stellar objects: S255IR-SMA1 and AFGL 5142 MM1

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Introduction

Massive star formation is deeply embedded in issues of theory and observation. Presently, it is unclear if massive stars undergo a distinct formation mechanism, or if they follow a scaled-up version of low mass star formation. Theory suggests the former on account of the intense radiation pressure emitted by the star which is thought to limit accretion. However, observationally there are several common traits which suggest some degree of likeness.

Outflow driving in MYSOs

Massive young stellar objects (MYSOs) produce bipolar molecular outflows. However, whether these are driven in a similar manner those that seen in low mass stars i.e. a narrow disk-launched jet entraining a wider molecular outflow, is still uncertain.

Episodic accretion

Since ejection events are thought to trace accretion episodes the study of outflows in massive stars also reveals their accretion history. Thus outflows stand as an accessible and valuable point of comparison between low and high mass star formation models.

Target MYSOs

This work targets S255IR-SMA1, a 20 Mo MYSO, and AFGL 5142 MM1, a 10 Mo MYSO – both of which exhibit traits common to both massive star formation (6.7 GHz methanol masers, L > 1000 Lo, centimeter emission) and low mass star formation (bipolar outflows perpendicular to a rotating disk).

Observations

We observed 22 GHz water masers in S255IR-SMA1 over 12 epochs (covering 2.5 years) using VERA (VLBI Exploration of Radio Astrometry) in Japan. Using VERA's dual beam capabilities we simultaneously observed the quasar, J0613+1708, which was used as phase reference – employing the inverse phase referencing technique.
Data reduction was done by hand in AIPS.

Observations: S255IR-SMA1

Epoch number	Observation date	Modified Julian date	Number of features
1	23rd Nov 2008	54793	15
2	1st Feb 2009	54863	15
3	18th May 2009	54969	10
4	28th Aug 2009	55072	12
5	15th Sep 2009 †	55089	12
6	27th Sep 2009 †	55101	14
7	24th Oct 2009 †	55128	13
8	13th Dec 2009	55178	14
9	28th Jan 2010 †	55224	-
10	10th Feb 2010	55237	12
11	4th Apr 2010	55290	8
12	11th Aug 2010	55419	9

† These epochs were not used in parallax determination.

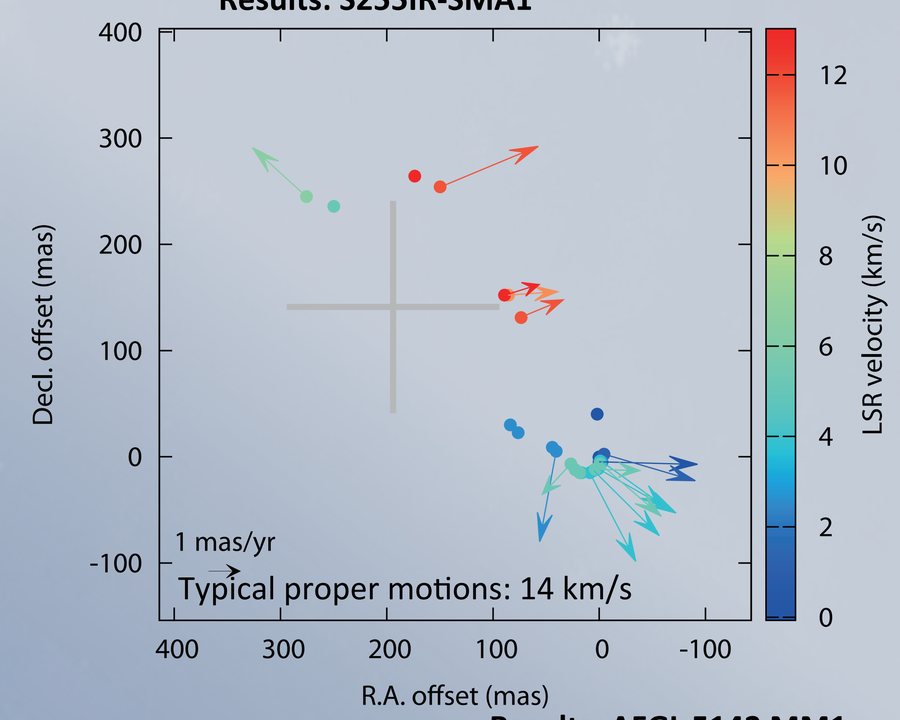
Observations: AFGL 5142 MM1

Epoch number	Observation code	Modified Julian date	Number of features
1	r14080as	I	will
2	r14140bs	do	this
3	r14275b	later	later
4	r14329b	later	later
5	r15031a	later	later
6	r15088a	later	later
7	r15149d	later	later

VLBI Results

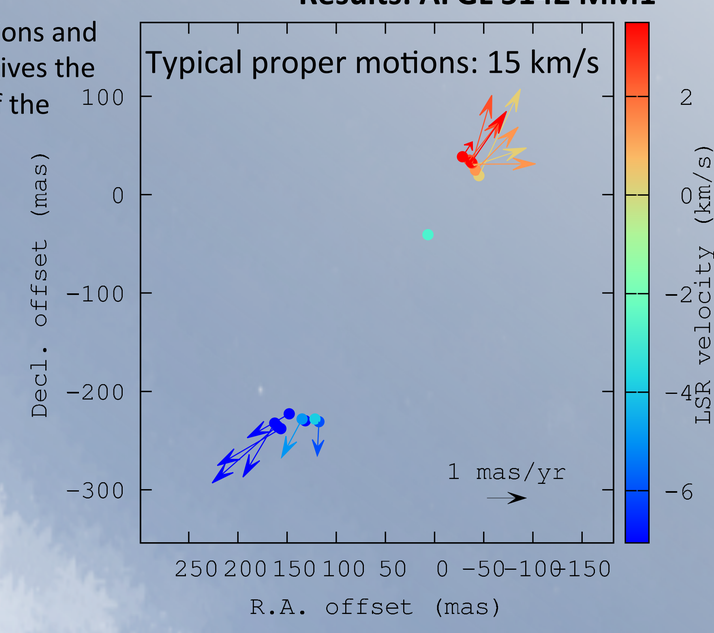
In both targets water masers trace the leading edges of protostellar ejections. Masers are shown as spots, coloured to indicate line of sight velocity and arrows represent velocity vectors from the measured maser proper motions (astrometry)

Results: S255IR-SMA1



Combining proper motions and line of sight velocities gives the 3D velocity structure of the ejections from these MYSOs

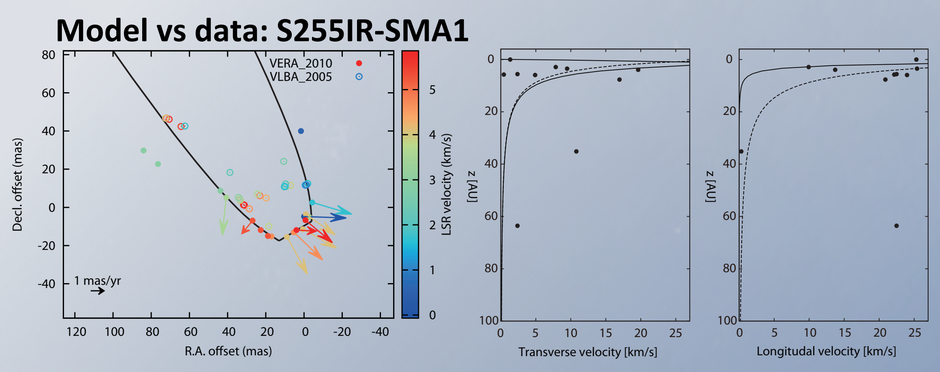
Results: AFGL 5142 MM1



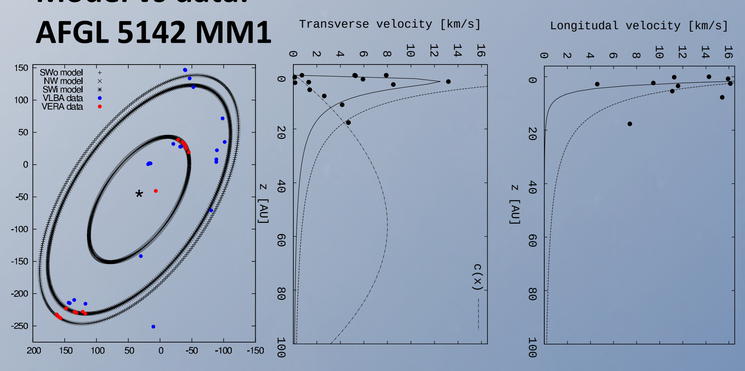
Launching outflows from massive stars

We compared the maser distribution and proper motions in our targets to hydrodynamic models (lee et al., 2001; Ostriker et al., 2001) describing a wind driven outflow and a jet-bowshock driven outflow (pictured in Fig. 3) for the case of low-mass YSOs.

Model vs data: S255IR-SMA1



Model vs data: AFGL 5142 MM1



Our VLBI observations clearly show that both MYSO outflows are primarily driven by bow-shocks with some contribution from a disk wind. This is evidence that the ejection mechanisms seen in low-mass star formation appear similar at masses of at least 20 Mo.

Episodic ejection (episodic accretion) in a massive young stellar object

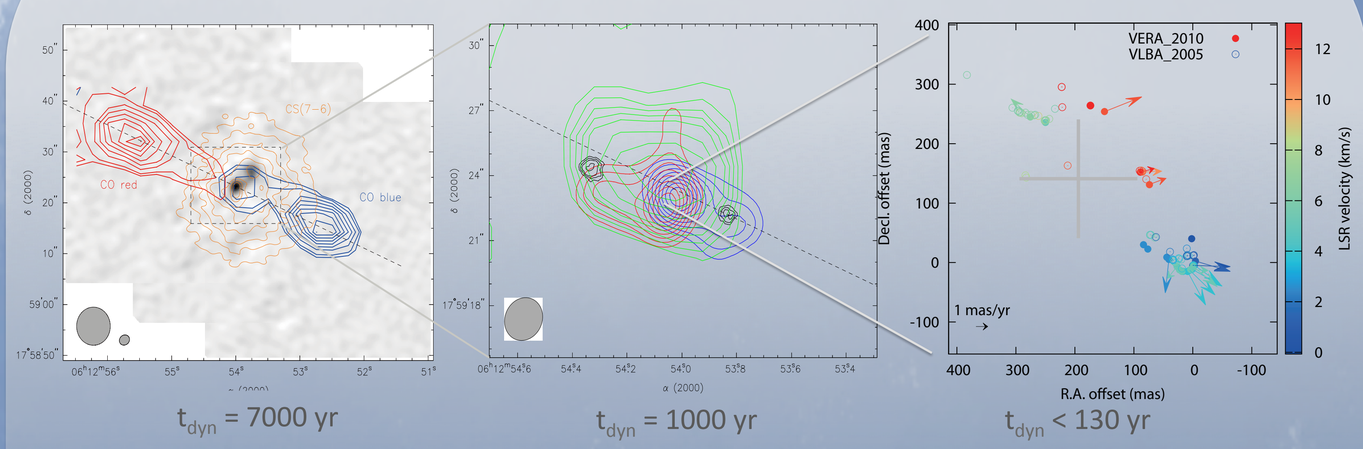


Fig 4. Multi-scale collimated ejections from S255IR-SMA1, showing: (Left) CO molecular outflow with a dynamic timescale of 7000, yrs from Zinchenko et al. (2015). (Middle) HCO+ emission (blue and red) and FeII bow shocks (black) tracing the 1000 yr old outflow from Wang et al. (2011). (Right) Combined (VERA + VLBA) view of water masers tracing the 130 yr old jet.

The intimate relationship between accretion and ejection in young stellar objects reveals a history of episodic accretion bursts in S255IR-SMA1 working on timescales of a few thousand years. Here we supplement VERA data with VLBA data from Goddi et al. (2007).

Episodic accretion is rarely studied with regard to massive stars (contact me if you do!). Simulations by Hosokawa at al. 2015 discuss a mechanism whereby episodic accretion could suppress radiation pressure – allowing stars to be built up to 100s of Mo.
The prospect of circumventing radiation pressure, along with evidence of episodic accretion could suggest the presence of a yet undefined 'massive FUOri' type stage of star formation.

Episodic ejection is also seen in AFGL 5142 MM1, I will discuss it during my talk at Thursday 13:30.

References
S255IR-SMA1: Burns, R. A. et al., 2016, MNRAS, 460, 283
AFGL 5142 : Burns, R. A. et al., 2016, in prep.
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Ostriker, E. C. et al., 2001, ApJ, 557, 443
Goddi C. et al., 2007, A&A, 461, 1027
Zinchenko I. et al. 2015, ApJ, 810, 10
Wang Y. et al, A&A, 527, A32
Hosokawa T. et al., 2015, ArXiv e-prints, arXiv:1510.01407