Spatially resolved atomic and molecular emission from the VLMS YLW52

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Abstract: Molecular outflows from very low-mass stars (VLMSs) and brown dwarfs (BDs) have been studied very little, and only a few objects have been directly imaged. Using VLT SINFONI K-band observations, we spatially resolved, for the first time, the H_2 emission around YLW52, a ∼0.1-0.2 $M_\odot$ Class I source. The molecular emission shows a complex structure delineating a large outflow cavity and an asymmetric molecular jet. In addition, new [Fe II] VLT ISAAC observations at 1.644 μm allowed us to discover the atomic jet counterpart which extends down to the central source. The outflow structure is similar to those found in low-mass Class I young stellar objects (YSOs) and Classical TTauri stars (CTTSs). However, its L_{acc}/L_{bol} ratio is very high (∼80%), and the derived mass accretion rate is about one order of magnitude higher than in objects with similar mass, pointing to the young nature of the investigated source.

Outflow and jet morphology:

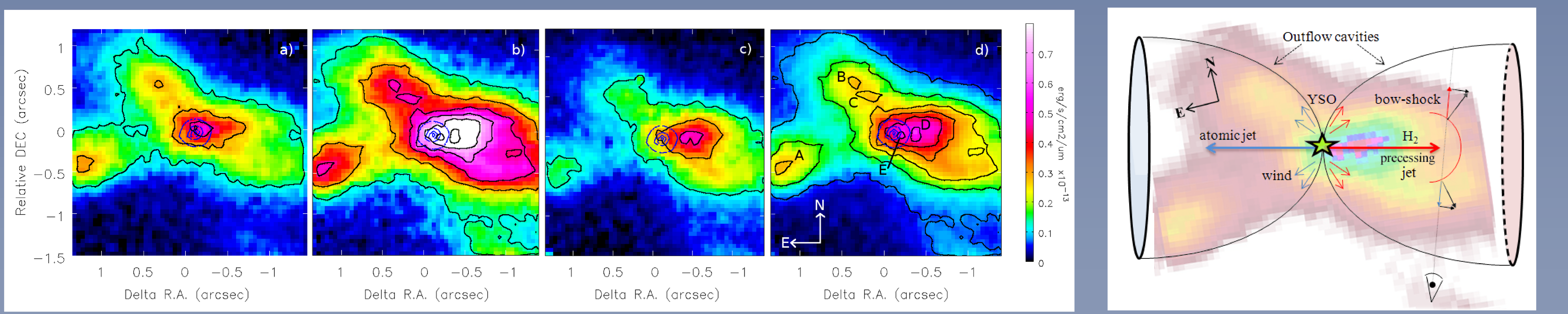

Figure 1: **Left:** Continuum-subtracted H_2 1-0S(1) images of YLW52. Panels **a** and **c**: average over two spectral channels at −64 kms^{-1} and -30 kms^{-1} (panel *a*), and +40 kms^{-1} and +75 kms^{-1} (panel *c*). Panel *b*: Single spectral channel at +6 kms^{-1}. The velocities are corrected from an average cloud velocity of 3.5 kms^{-1} (wouterloot+ 05; Andre+ 07) and measured with respect to the local standard of rest (LSR). Panel **d**: average H_2 1-0S(1) emission over the previous velocity channels. Overplotted are the locations of six spatial regions where spectra were extracted. For reference, contours of the continuum (near the H_2 2.122 μm line) down to the FWHM size have been overplotted at the centre of every image (dashed-blue contours). **Right:** Sketch showing YLW52 outflow/jet morphology. .

- Complex H_2 morphology mainly composed of:
  X-shaped distribution + "jet-like" structure
- The "jet-like structure" is only detected westward of the source: H_2 gas excited along the outflow cavity?

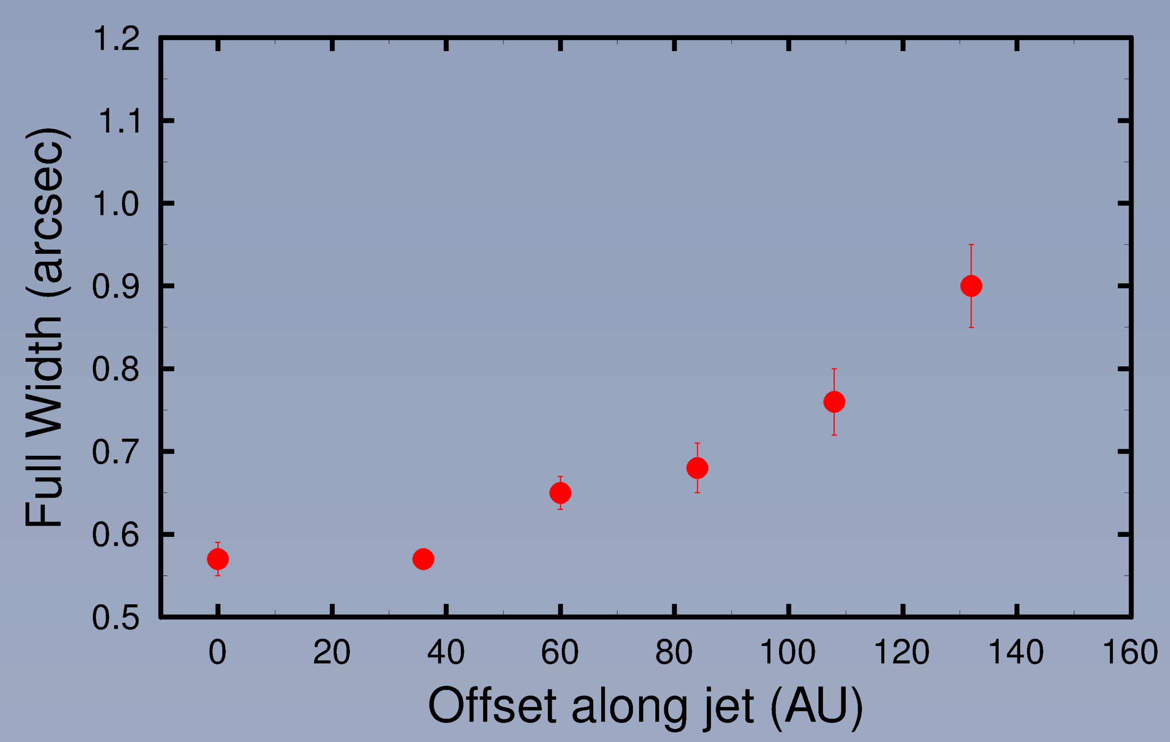

Figure 2: Width of the H_2 1-0S(1) jet-like structure as a function of the distance from the source.The jet width has been estimated fitting a single Gaussian function to vertical cuts across the H_2 emission.

- Full opening angle of the flow ($\theta \sim 23^o$; Fig. 2) very similar to those found in jets from low-mass Class I sources and CTTSs ($\theta \sim 20^o$-42^o; Davis+ 2011) suggesting the "jet-like" structure is the H_2 jet.

- Asymmetric jet with different lobe velocities: new [Fe II] 1.644 μm ISAAC observations supports the presence of an asymmetric jet in which the eastern lobe (likely blue-shifted) is faster and dissociates the H_2 component.

[Fe II] 1.644 μm

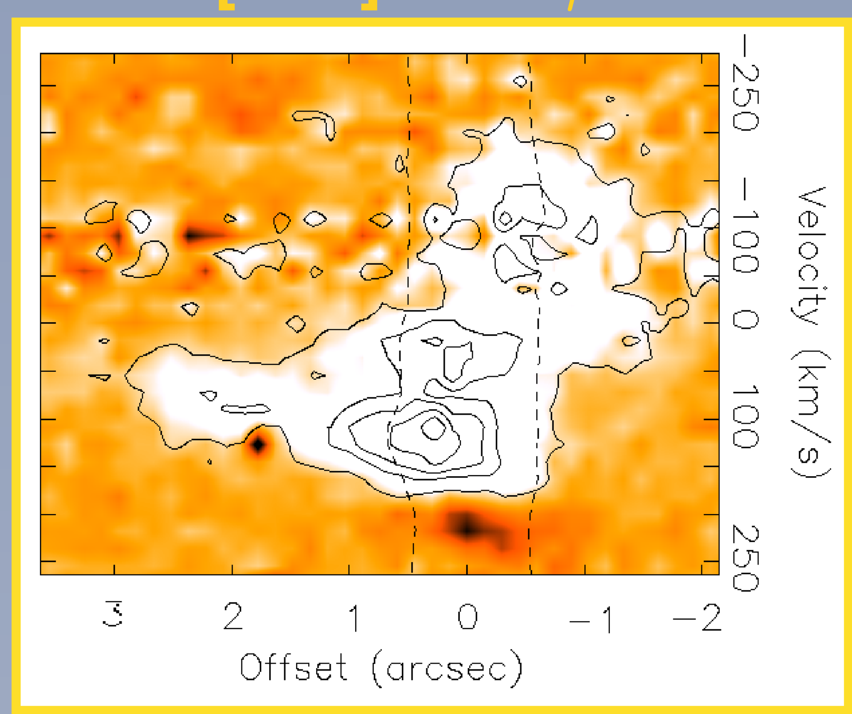

Figure 3: Continuum-subtracted position velocity diagram of the [Fe II] 1.644 μm line along YLW52. The slit was centred on-source encompassing positions E and D (i.e., with position angle ∼ 90°). Radial velocities are measured with respect to the LSR and corrected for the cloud velocity. As a reference, contours of the continuum were overplotted (dashed lines).

Accretion and ejection properties:

- Accretion luminosity (L_{acc}) derived from the luminosity of the Br γ line (Calvet+ 2004). The accretion luminosity is very high (L_{acc}/L_{bol}∼80%) consistent with a young and active YSO.

stellar parameters

d (pc)	K (mag)	A_V (mag)	L_*^a ($L_\odot$)	L_{bol} ($L_\odot$)	R_* ($R_\odot$)	M_* ($M_\odot$)	L_{acc} ($L_\odot$)
120	8.7	30	0.14	0.78	2.0	0.1-0.2	0.64

$^a L_{bol} = L_{acc} + L_*$

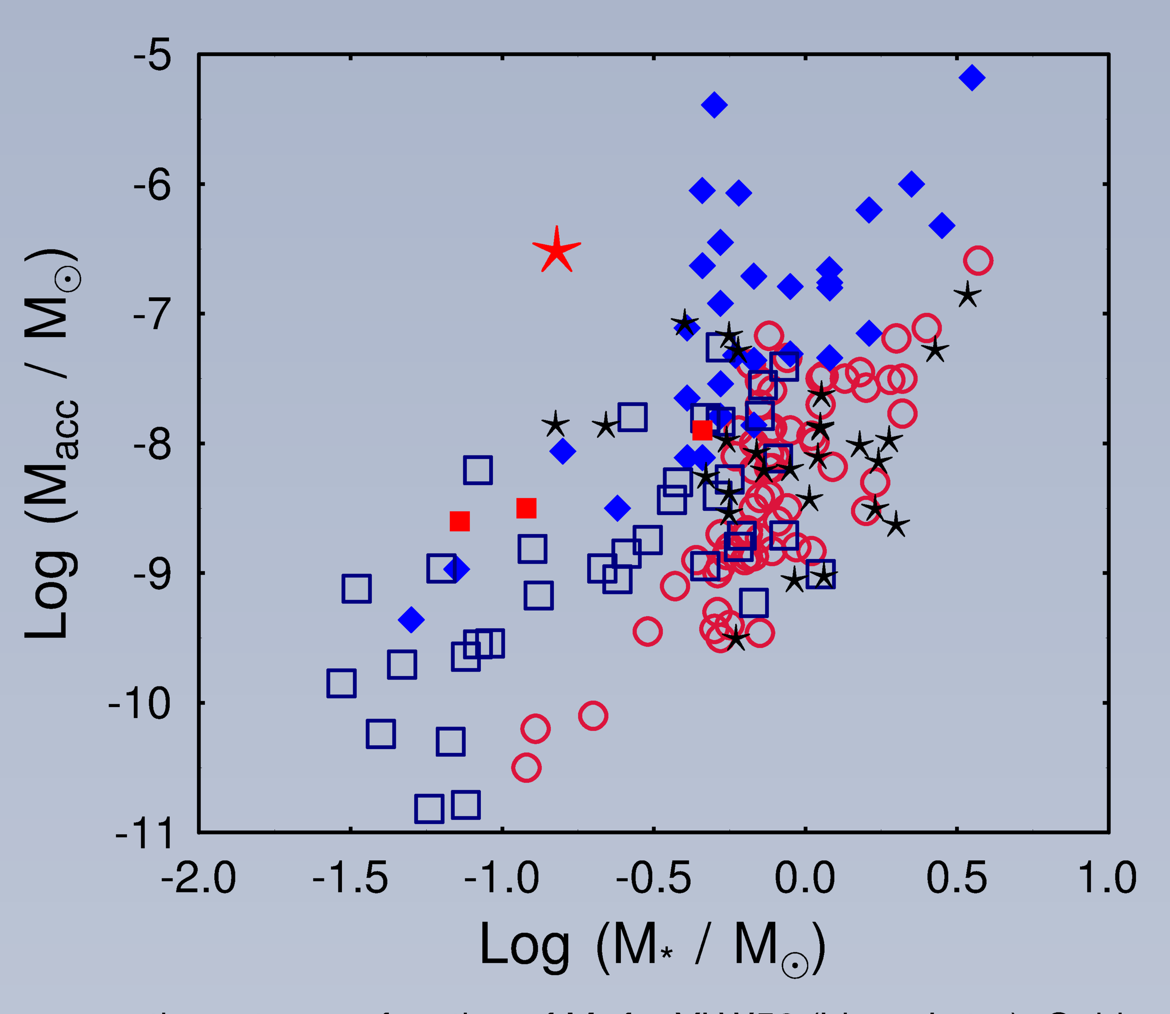

Figure 4: Mass accretion rate as a function of M_* for YLW52 (big red star); Ophicus, Taurus-auriga and L1641 Class II objects (open squares, open circles and stars; Natta+ 06, White+ 01, Calvet+ 04, Caratti o Garatti+ 12); very low-mass stars and brown dwarfs in Taurus-auriga (filled squares; White+ 03); and Class I sources (filled diamonds; White+ 04, Antoniucci+ 08).

- Mass accretion rate ($\dot{M}_{acc}$) derived from L_{acc} and stellar parameters (Gullbring+ 1998).
  The $\dot{M}_{acc}$ value is higher than those found in objects of roughly the same mass (Fig. 4), pointing again to the young nature of this source.
- The mass transported by the jet was computed form the K-band H_2 lines and the [Fe II] 1.644μm (Garcia Lopez+ 10).

Mass ejection rate

	$\dot{M}_{[FeII]}$	$\dot{M}_{H_2}$
	$M_\odot$ / yr	
VLM-YLW52	2.0×10^{-8}	1.6×10^{-10}
LM Class I	10^{-5}-10^{-6}	10^{-7}-10^{-8}

- $\dot{M}_{[FeII]} \sim 2\times \dot{M}_{H_2}$
  Similar results are found in low-mass Class I sources (Davis+ 11).
- $\dot{M}_{[FeII]}/\dot{M}_{acc}$∼0.1

- The outflow/jet morphology in YLW52 is very similar to the one observed in low-mass Class I sources
- Our results indicate a smooth transition from low-mass to VLM jets and outflows.

References: Andrè et al. 2007, A&A, 472, 519; Antoniucci et al. 2008, A&A, 479, 503; Davis et al. 2011, A&A, 528, A3; Calvet et al. 2004, AJ, 128, 1294; Caratti o Garatti et al. 2012, A&A, 538, A64; Garcia Lopez et a. 2010, A&A, 511, A5; Gullbring et al. 1998, ApJ, 492, 323; Natta et al. 2006, A&A, 452, 245; White et al. 2001, ApJ, 556, 265; White et al. 2003, ApJ, 582, 1109; White et al. 2004, ApJ, 616, 998; Wouterloot et al. 2005, A&A, 430, 549.