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Investigating episodic accretion in a very low-mass young stellar object

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ABSTRACT

We investigate accretion and ejection processes, as well as variability of IRS54, a Class I VLM protostar with a mass of $M_* \sim 0.1$ - $0.2\ M_\odot$. Spectroscopic and photometric data were obtained with VLT/ISAAC and VLT/SINFONI in the NIR across four epochs (from 2005 to 2013). Accretion-tracing (Paβ and Brγ) and outflow-tracing lines (H_2 and [FeII]) are used to study physical properties of the object. Through continuum-subtracted emission maps of H_2 emission and [FeII] jet, the molecular and atomic emission from the jet has been found to be asymmetric, with the H_2 mostly red-shifted and the [FeII] mostly blue-shifted. A large increase in luminosity was found between the 2005 and 2013 epochs, of over 2 mag in the K-band. Also increasing between 2005 and 2013 was the mass accretion rate M_{acc}, which increased by an order of magnitude from $\sim 10^{-8}\ M_\odot\ yr^{-1}$ to $\sim 10^{-7}\ M_\odot yr^{-1}$. The visual extinction (A_V) derived from the [FeII] line has increased from ~15 mag in 2005 to ~24 mag in 2013. This increase in A_V in tandem with the increase in M_{acc} is explained by the lifting up of a large amount of dust from the disk, due to the violent accretion and ejection activity in the YSO. Due to the strength and timescales involved, this event is believed to have been an accretion burst similar to EXor bursts, making IRS54 the lowest mass outbursting protostar so far observed.

IRS 54 (YLW 52)

IRS54 is in its main accretion phase and an asymmetric jet had been previously speculated *(Garcia Lopez et al. 2013)* making it a good candidate to study further for its accretion/ejection dynamics and variability.

- Very low-mass YSO, 0.2 $M_\odot$
- $L_{bol} \sim 0.78 L_\odot$
- Class I
- Spectral type M *(Garcia Lopez et al. 2013)*
- Located outside main clouds in Ophiuchus star-forming region (d ~ 120pc)

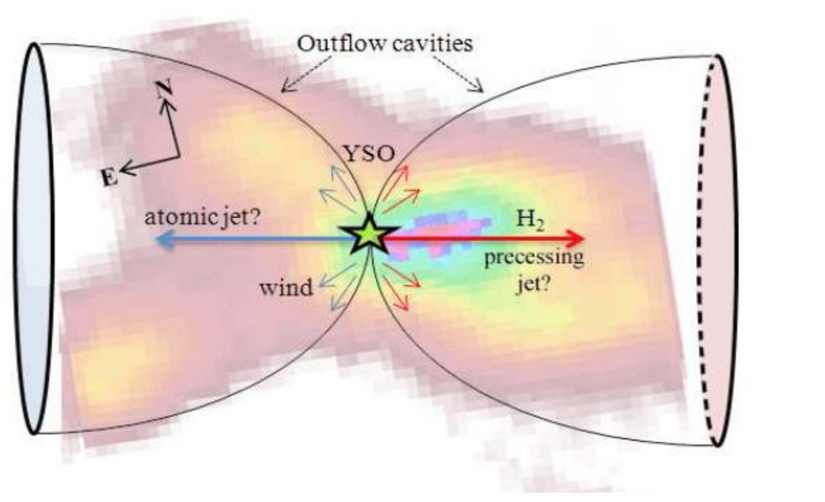

Figure 1. A sketch of the IRS54 morphology. This was generated with the 2010 SINFONI data. *(Garcia Lopez et al. 2013)*

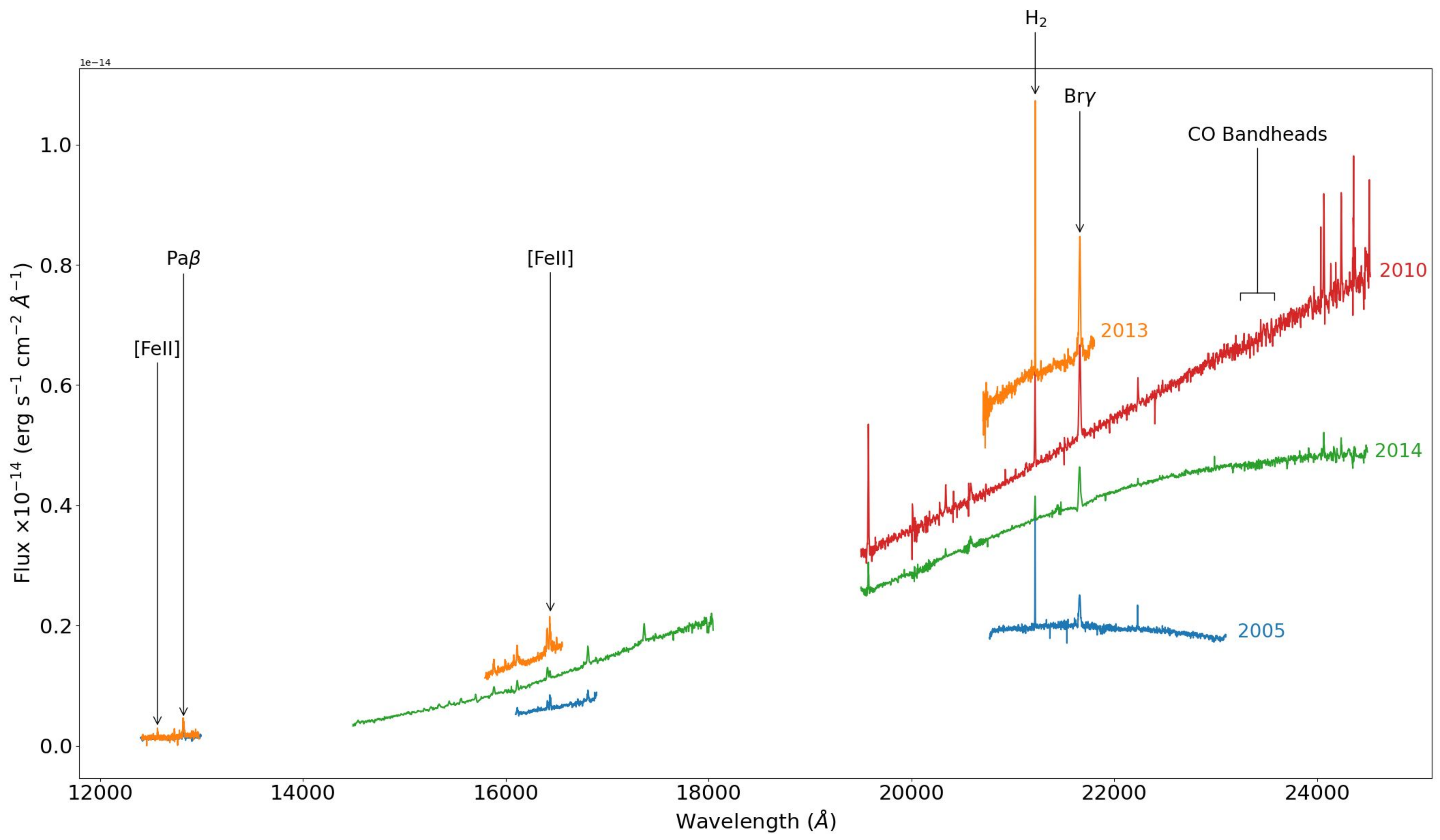

Figure 2. Spectral Energy Distribution (SED) of J, H, and K bands over the four epochs (2005, 2010, 2013, and 2014). We note that the J band has two overlapping spectra from 2005 (blue) and 2013 (orange).

Our results indicate that the change in SED shape observed is not due solely to an accretion or extinction (A_V) phenomenon, but to a combination of the two.

We see an increase in steepness in the slope with increased A_V, but also an increase of flux in the H and especially the K bands.

This combination of both accretion and extinction is representative of the complex processes at work and how they are related to one another in IRS 54. The combined effect of these two processes is quite unique, because it tends to flatten the light curves more at shorter wavelengths.

This can be seen qualitatively in Fig. 3, where the J band light curve is much flatter with respect to the K-band, WISE bands.

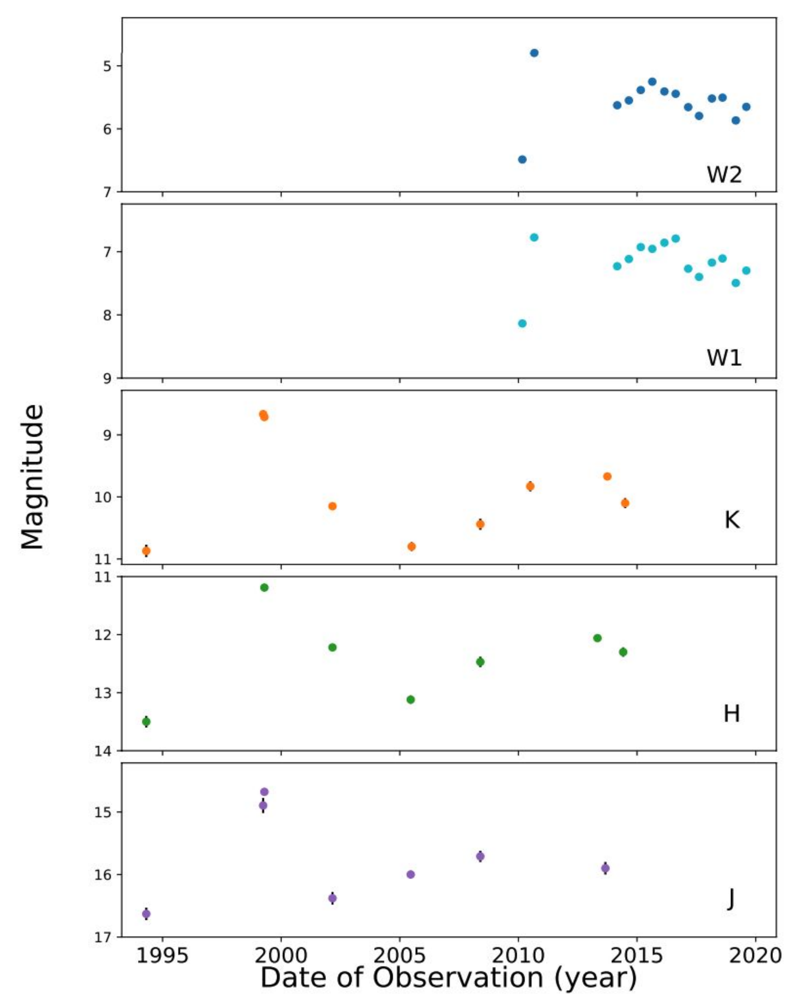

Figure 3. Photometry of IRS 54. Our data from *VLT/ISAAC* and *VLT/SINFONI* are complemented by archival data *KPNO/SQIID, DENIS, 2MASS, IRTF/NSFCAM, AAT/IRIS2, WISE, and NEOWISE.*

ACCRETION AND OUTFLOW VARIABILITY

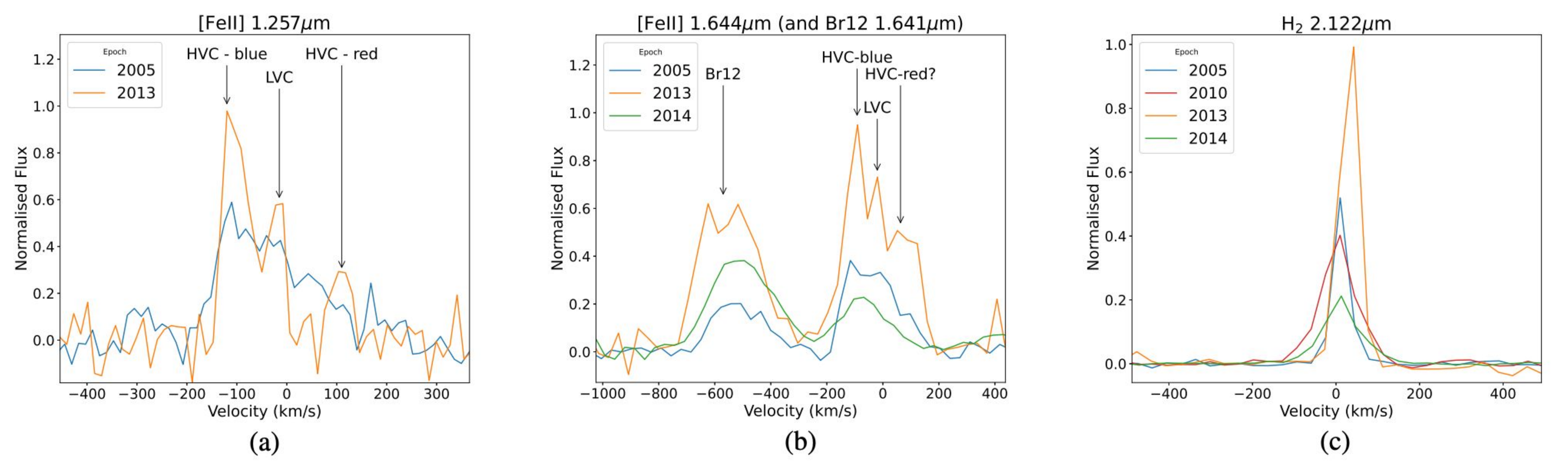

Figure 4 - Outflow-tracing Lines. Panels a and b: line profiles of [Fe II] at 1.257 μm and 1.644 μm. **Panel c:** line profile of molecular hydrogen (H_2) 2.122 μm. Different velocity components are present. In (b) the Br12 (1.641 μm) line is also shown to highlight how the 2014 epoch (green line) changes differently in the outflow-tracing [Fe II] emission from the accretion-tracing Br12 line.

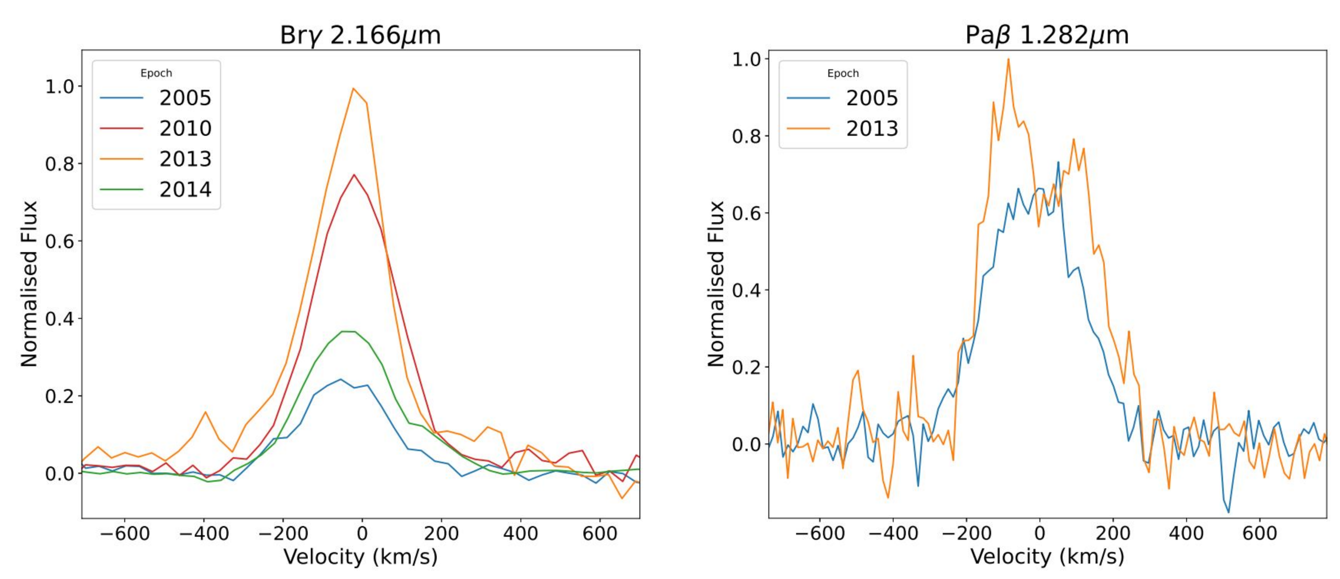

Figure 5 - Accretion-tracing Lines. Line profiles of the Brγ 2.166 μm (panel a) and Paβ 1.282 μm (panel b) hydrogen-recombination lines.

	A_V	$L_{acc,\mathbf{Br\gamma}}\ (L_\odot)$	$\dot{M}_{acc,\mathbf{Br\gamma}}\ (M_\odot yr^{-1})$	$L_{acc,\mathbf{Pa\beta}}\ (L_\odot)$	$\dot{M}_{acc,\mathbf{Pa\beta}}\ (M_\odot yr^{-1})$	$\dot{M}_{acc,\mathbf{avg}}\ (M_\odot yr^{-1})$
2005	15 ± 1	0.039 ± 0.007	$(2.1 \pm 0.4) \times 10^{-8}$	0.023 ± 0.009	$(1.2 \pm 0.5) \times 10^{-8}$	$(1.7 \pm 0.5) \times 10^{-8}$
2013	24 ± 1	0.68 ± 0.09	$(3.6 \pm 0.5) \times 10^{-7}$	0.29 ± 0.08	$(1.5 \pm 0.4) \times 10^{-7}$	$(2.6 \pm 0.5) \times 10^{-7}$

Table 2. Visual extinction (AV) values calculated using the ratio [Fe II] 1.644/1.257 μm and mass accretion rates (M_{acc}) calculated from the Brγ and Paβ line luminosities using the relation from Alcalá et al. (2017).

The M_{acc} between 2005 and 2013 (Table 2) increases by a factor of ~ 20, while A_V increases by nine magnitudes (flux increases by ~ 4000 in the V band and by ~ 2.4 in the K band). While both of these are significant changes, it is clear that the accretion burst appears to have the larger effect on the SED of IRS 54 between this time period because we see an overall increase in luminosity, especially in the K band where the continuum flux increases by a factor of approximately six. The photometry also reflects this increase in flux (Fig. 3), supporting the idea of an accretion burst.

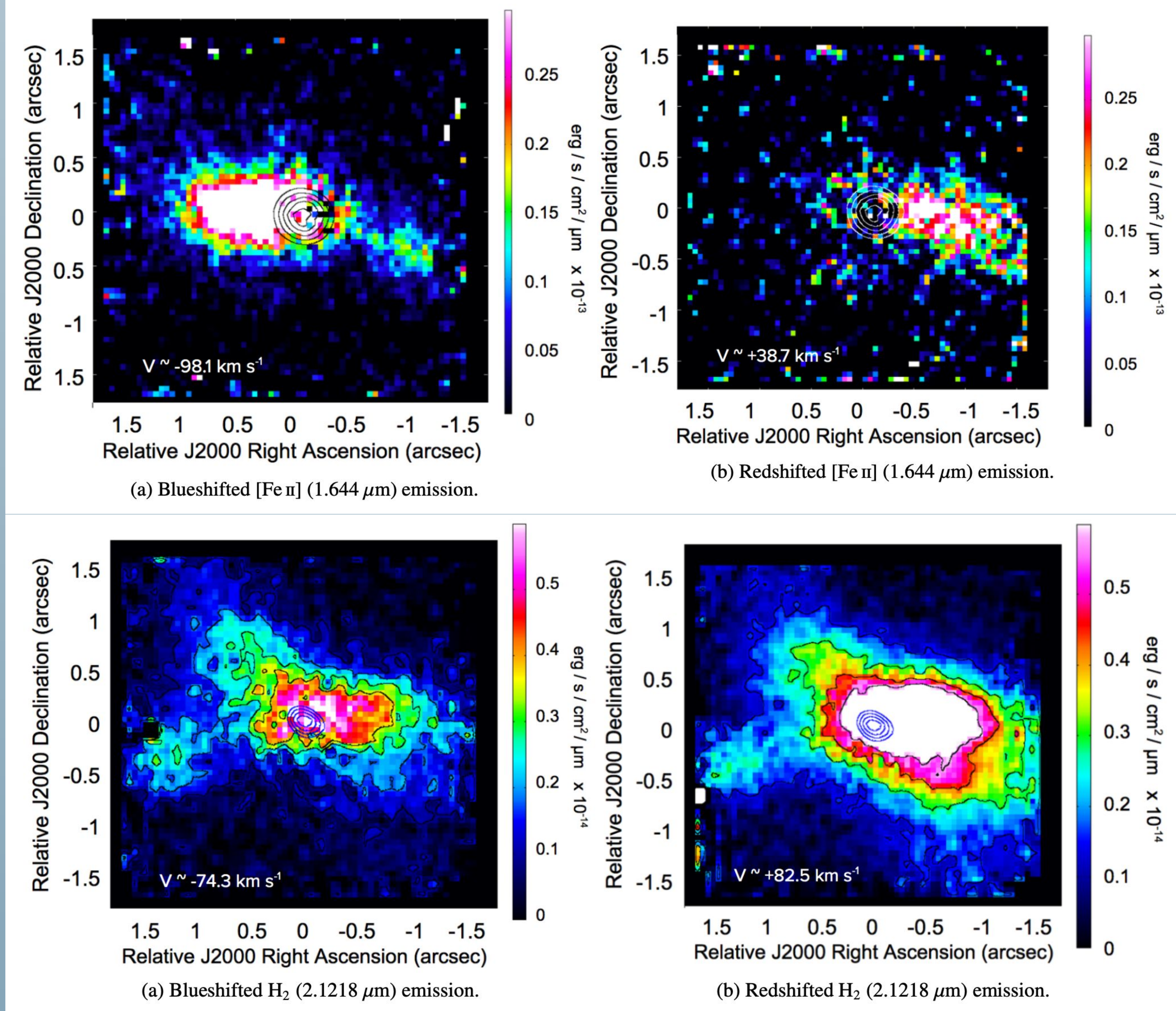

Figure 6. Top panel: Blueshifted and redshifted components of the [Fe II] emission in the H band in IRS 54 from the SINFONI 2014 data. Four spectral channels were averaged. **Bottom panel:** Blueshifted and redshifted components of the H_2 emission in the H band in IRS 54 from the SINFONI 2014 data. Four spectral channels were averaged. For reference, there are contours representing the continuum of the source taken at levels of 0.1, 0.3, 0.5, 0.7 and 0.9.

Our results clearly show that the jet of IRS 54 has both an atomic and a molecular component, as seen in Fig. 6 where the H_2 line emission is predominantly redshifted and the [Fe II] line emission is predominantly blueshifted.

This implies different excitation conditions and possibly different velocities of the jet material ejected in the two lobes. This asymmetry could be due in part to the inhomogeneity of the interstellar medium (ISM) in the region, or is potentially an effect of a misalignment in the magnetic fields of the protostar.

CONCLUSIONS

- IRS54 underwent an accretion burst between 2005 and 2013
  - ~2 mag (K-band) change in brightness
- Both accretion and extinction increased during this time period
  - A_V increase from 15 to 24 mag
  - M_{acc} increase from 1.21×10^{-8} to $1.90 \times 10^{-7}\ M_\odot yr^{-1}$ *(more than an order of magnitude)*
- Increase in A_V is possibly due to the lifting up of material during the accretion burst, obscuring the line-of-sight
- IRS54 is potentially an EXor because of the timescales (lasting ~1-2 yrs) and mass accretion rates measured
- This study provides further evidence on the importance of accretion bursts in young stars

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