IGRINS-2 SV Observation Evaluation Form

Title: Near-IR kinematics and physics of the collimated outflows from intermediate-mass young star

Program ID: GN-2024B-SV-114

Authors: Heeyoung Oh et al.

Description of the primary goals and the main findings

Science goal

Mass accretion and outflows are essential processes in the formation of stars and planets, as they remove the angular momentum of the infalling material (Hartigan et al. 1995). It is believed that the formation mechanism and evolution pattern are different depending on the mass of the star (e.g, low-, intermediate, and massive star). In Particular, massive star formation is not understood well (Zinnecker & Yorke 2007) but they are thought to form in multiple systems and in filamentary structures in molecular clouds.

LkHα 233 is a Herbig Ae/Be star of intermediate mass, with around 4 solar masses. Usually, low-mass stars have good collimation and outflow, but this object is a rare case of such a phenomenon among medium-mass stars. It is also known as one of the special examples of driving parsec scale outflow with a distribution spanning over 3 parsecs (McGroarty et al. 2004).

Optical spectroscopic observations have shown jets over 100 km/s near the central star Lkhα 233 with various emission lines (e.g., Corcoran and Ray 1998), while there is a lack of study in the infrared region. IFU observations conducted using OSIRIS/Keck detected 1.64 um [FeII] emission at a speed close to 200 km/s (Perrin et al. 2007). In the case of the 2.12 um H2, it was detected very weakly, possibly because it was at the edge of the filter's coverage, or because it was actually weak. With IGRINS-2, multiple lines can be observed simultaneously with wider spatial and wavelength coverage, and more detailed velocity structures can be revealed with high spectral resolution. Since past observations (e.g., Oh et al. 2018) have proven that IGRINS is a very powerful tool for studying the kinematics and physics of outflow, we will also test this possibility with IGRINS-2.

Name	Object type	RA	Dec	K (mag)	Time (hr)
LkHα 233	YSO Outflow	22 34 40.99	+40 40 04.25	8.92 (central star)	1.05

========= **Total time request: 1.05 hr** ============

OFF - (ON x 8) - OFF sequence with 180s including overheads → 0.72 hr

20 min for observing a A0V standard star → 0.33 hr

==

Summary of observation

- 20240718 (UT)
- Science: 42.5 min, standard star: 8 min
- Sky condition
  - Requested: IQ 70 / CC 50
  - Observed: IQ 20 / CC 50 (measured FWHM 0.5–0.6)
- Data reduction using IGRINS PLP v3.0 igrins-2 branch
- plotspec (Kaplan et al.): optimized tool for 2d IGRINS spectra
  - continuum subtraction, position velocity maps

Main findings

With the benefit of wide simultaneous wavelength coverage, 7 forbidden iron lines, 13 molecular hydrogen lines, and 7 Brackett series were detected.
Especially, the exposure time estimation aimed to detect weaker [Fe II] lines such as [Fe II] 1.600 μm with S/N > 10, and it has been achieved.

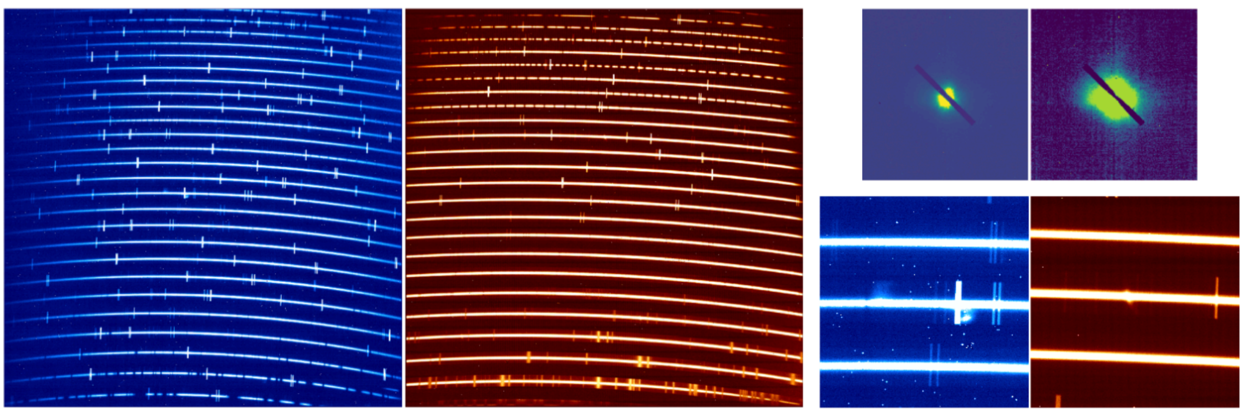


Figure 1. Raw spectra of each H (blue colored) and K (orange colored) channel. The zoomed-in image in the lower right shows the major lines in each band which are [Fe II] 1.644 μm and H_2 2.122 μm emission. The upper right picture shows the central area of the slit view camera in Ks band. By varying the scale of the two images, the scattered features of the envelope around YSO are visible in the case on the right.

Table 1. List of detected emission lines

[Fe II] lines	H_2 lines	HI Br series
[Fe II]1534	1-0 S(7)	H I 4-14
[Fe II]1600	1-0 S(6)	H I 4-12
[Fe II]1644	1-0 S(3)	H I 4-11
[Fe II]1664	1-0 S(2)	H I 4-10
[Fe II]1677	2-1 S(3)	H I 4-9
[Fe II]1712	1-0 S(1)	H I 4-8
[Fe II]1810	1-0 S(0)	H I 4-7
	2-1 S(1)	
	1-0 Q(1)	
	1-0 Q(2)	

	1-0 Q(3)	
	1-0 Q(4)	
	1-0 Q(5)	

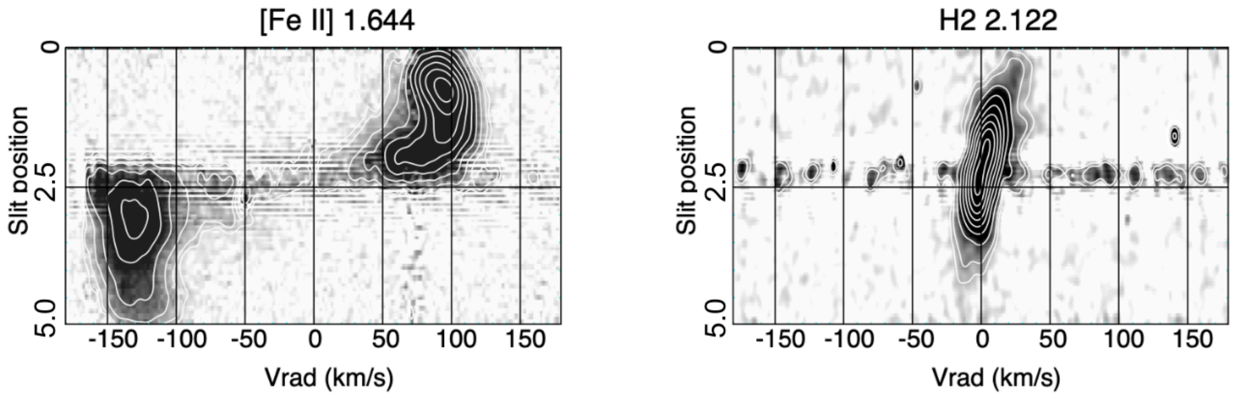


Figure 2. Continuum subtracted position-velocity maps of the [Fe II] 1.644 μm and H2 2.122 μm emission lines detected from the outflow of the LkHa 233. Among the 7 [FeII] lines and the 13 H2 lines detected, the two lines were the brightest. The horizontal axis of the plot is the V_LSR velocity, and the vertical axis is the spatial distribution in the direction of the slit length with a total length of 5 arcseconds. The upward direction in the plot is the position angle of 69°. In the central region of this intermediate-mass YSO, strong and narrow hydrogen molecular lines were **confirmed for the first time**.

The velocity distribution seen in the [Fe II] line is very similar to that seen in Perrin et al. (2007). In the case of molecular hydrogen lines, it shows a slow and narrow velocity component. This intermediate-mass YSO shows the typical outflow structure seen in low-mass stars as reported in studies such as Pyo et al. (2003): [Fe II] lines with fast, wide opening angle, and molecular hydrogen lines slow, narrow velocity width.

Additional comments on IGRINS-2 performance:

The referred previous study with OSIRIS/Keck (Perrin et al. 2007) was an IFU observation with medium-resolution, AO (angular resolution of 0.06″). Although the spatial resolution was lower in this program, high spectral resolution made it possible to distinguish velocity components, and multiple lines could be detected through wide simultaneous wavelength observation. In particular, strong molecular hydrogen lines were detected with signal to noise ratio over 100, which had not been detected or very weak as located at the edge of the filter in Perrin et al. (2007).

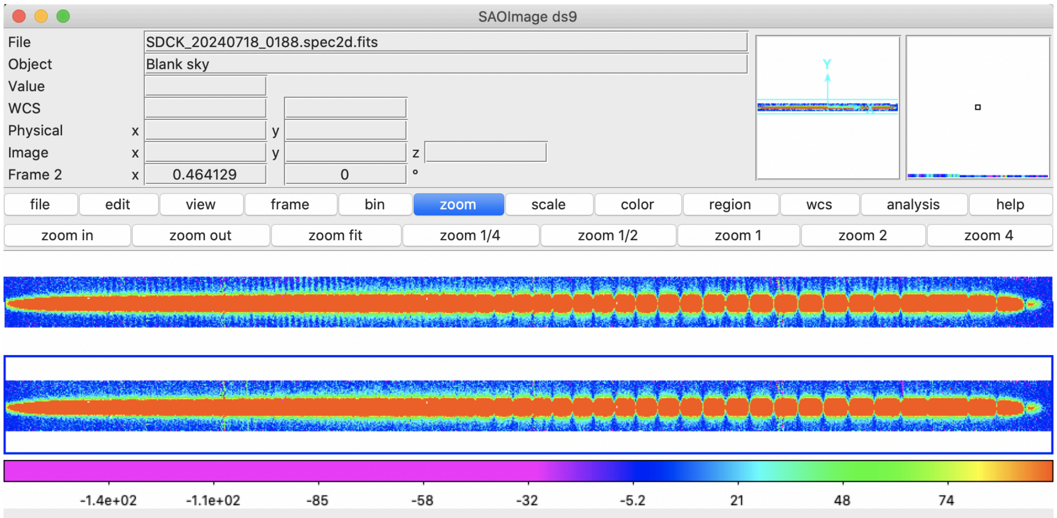
Suggestions for improvements:

An optional feature applied to the pipeline to reduce vertical noise patterns associated with coldhead power, which is currently being investigated from the hardware side, was tested and performed well in noise removal.

Pipeline version: igrins2-dev

`--remove-vertical-pattern`

In the figure below, the upper and lower images shows the result without and with the option, respectively.



Any additional comments about IGRINS-2 SV

N/A