

# The Launch Region of the SVS13 Outflow



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## Abstract

We present the results of Keck Telescope laser adaptive optics integral field spectroscopy with OSIRIS of the innermost regions of the NGC1333 SVS13 jet that drives the system of Herbig-Haro objects 7-11. We find a 0.4" long micro-jet traced by the emission of shock-excited [FeII]. Beyond the extent of this jet, we find a series of near-spherical bubbles traced in the lower excitation H<sub>2</sub> 1-0 S(1) line. While this most recent outflow activity is directed almost precisely (PA 170°) to the south of SVS13, the older bubbles show a different direction of motion and orientation more towards the south-east, connecting the recent outflow activity to the well-known, poorly collimated HH 7-11 system of Herbig-Haro objects. We postulate that the creation of a series of bubbles and the changes in outflow direction are indicative of a precessing disk. Our velocity-resolved observations of the microjet in the [FeII] emission line at 1.644μm, as well as the HI12-4 and 13-4 (Brackett series) emission lines originating from the accretion disk or jet launch region clearly show the kinematic signature of disk and jet rotation.

## Observations

The adaptive optics data in the H and K bands reported here were obtained at the Keck I and II telescopes in 2011 and 2012, using laser guide star adaptive optics with the OSIRIS integral field spectrograph (Larkin et al. 2006). The resulting data cubes contain the atomic hydrogen 12-4 (1.641μm) and 13-4 (1.611μm) Brackett lines, the shock-excited [FeII] 1.644μm line, and the low-excitation shock-excited H<sub>2</sub> 1-0 S(1) line at 2.122μm. Outside of emission lines, SVS13 appears as an unresolved source. Continuum images of SVS13 were used as the PSF for Lucy-Richardson (Lucy 1974) deconvolution of the data.

## Morphology

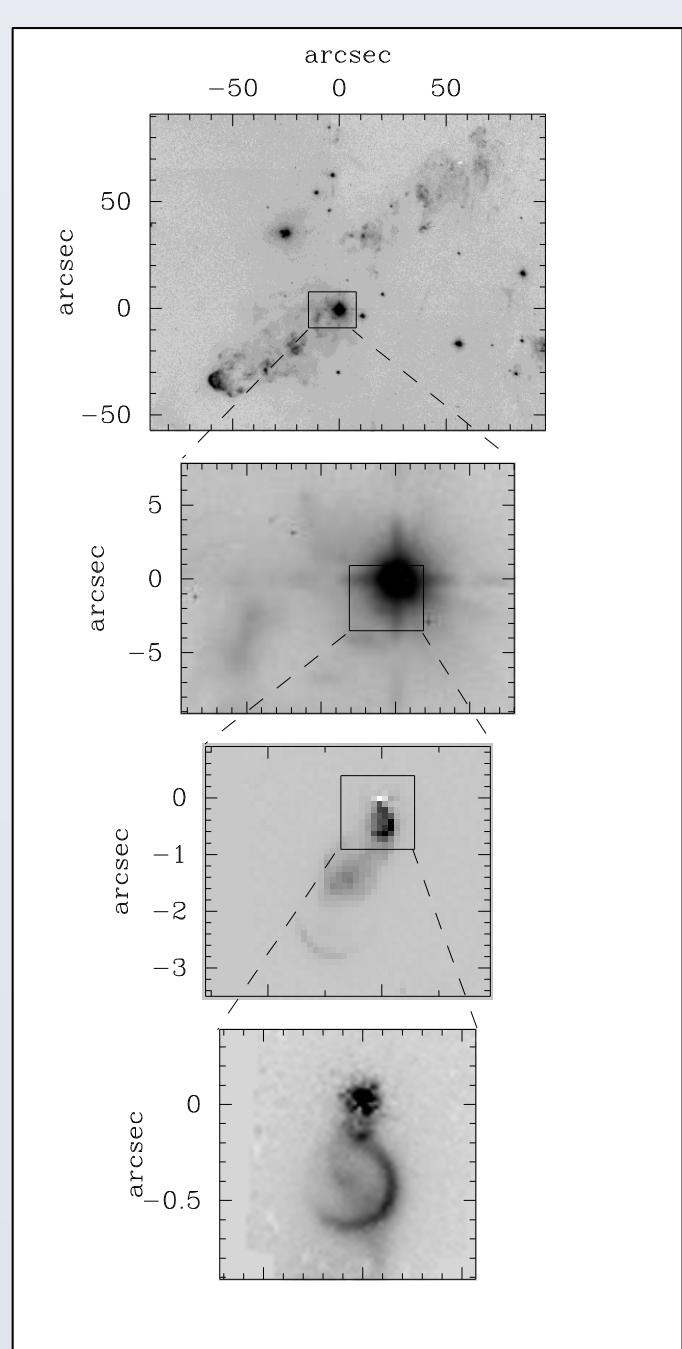


Fig. 1: Zooming towards SVS13: The SVS13 (Strom, Vrba, Strom, 1976) outflow at different spatial scales in K band, from seeing-limited (top) to the OSIRIS H<sub>2</sub> S(1) image (bottom).

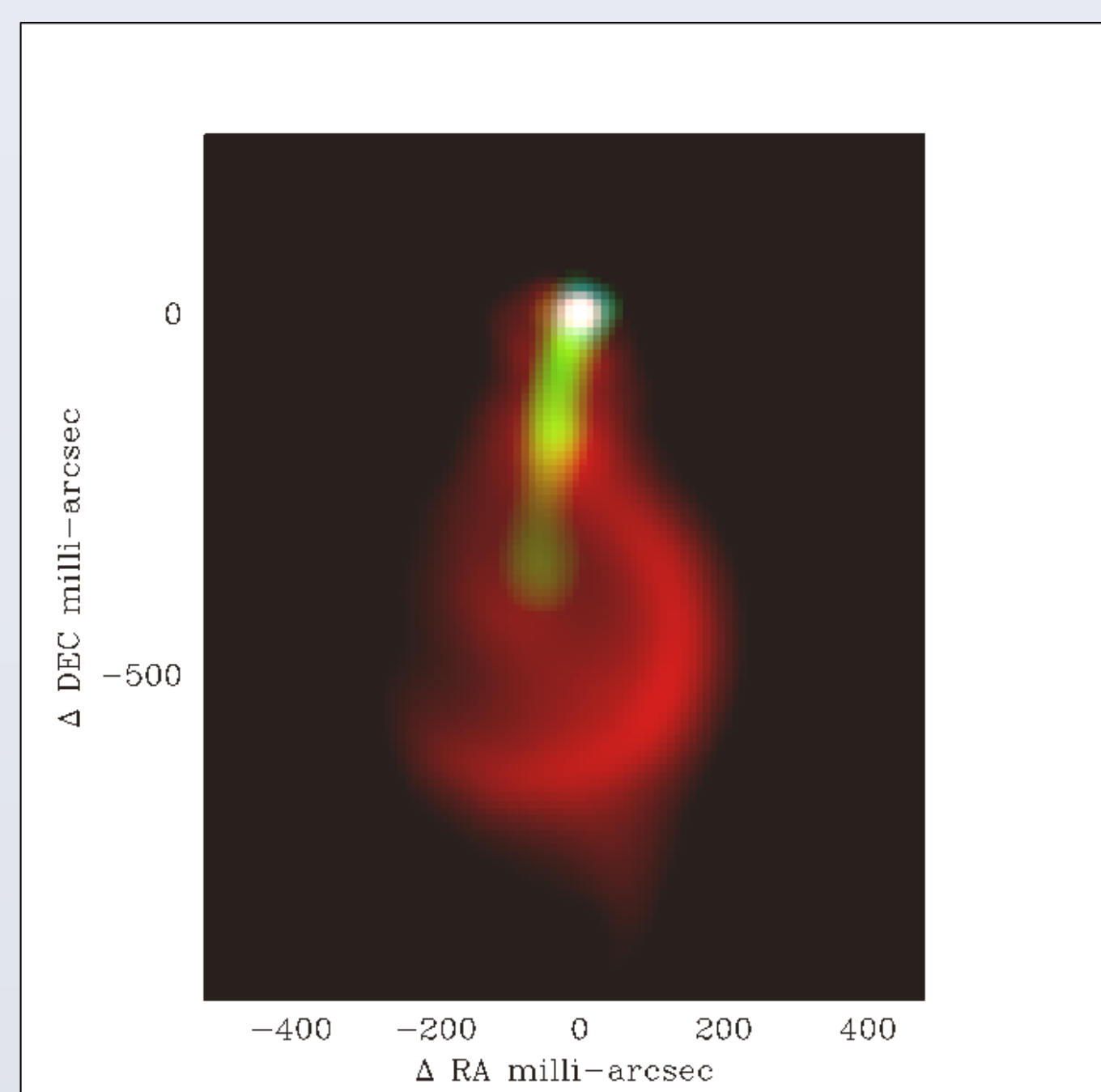


Fig. 2: Color Composite of the SVS13 jet and bubble, based on the deconvolved OSIRIS data cubes. Green is [FeII] and red is H<sub>2</sub> S(1). A scaled down continuum image of the stellar object SVS13 was added to show its position. At the distance of SVS13 of 235pc (Hirota et al. 2008), the bubble has a diameter of 95AU.

## Molecular Hydrogen S(1) Line Kinematics

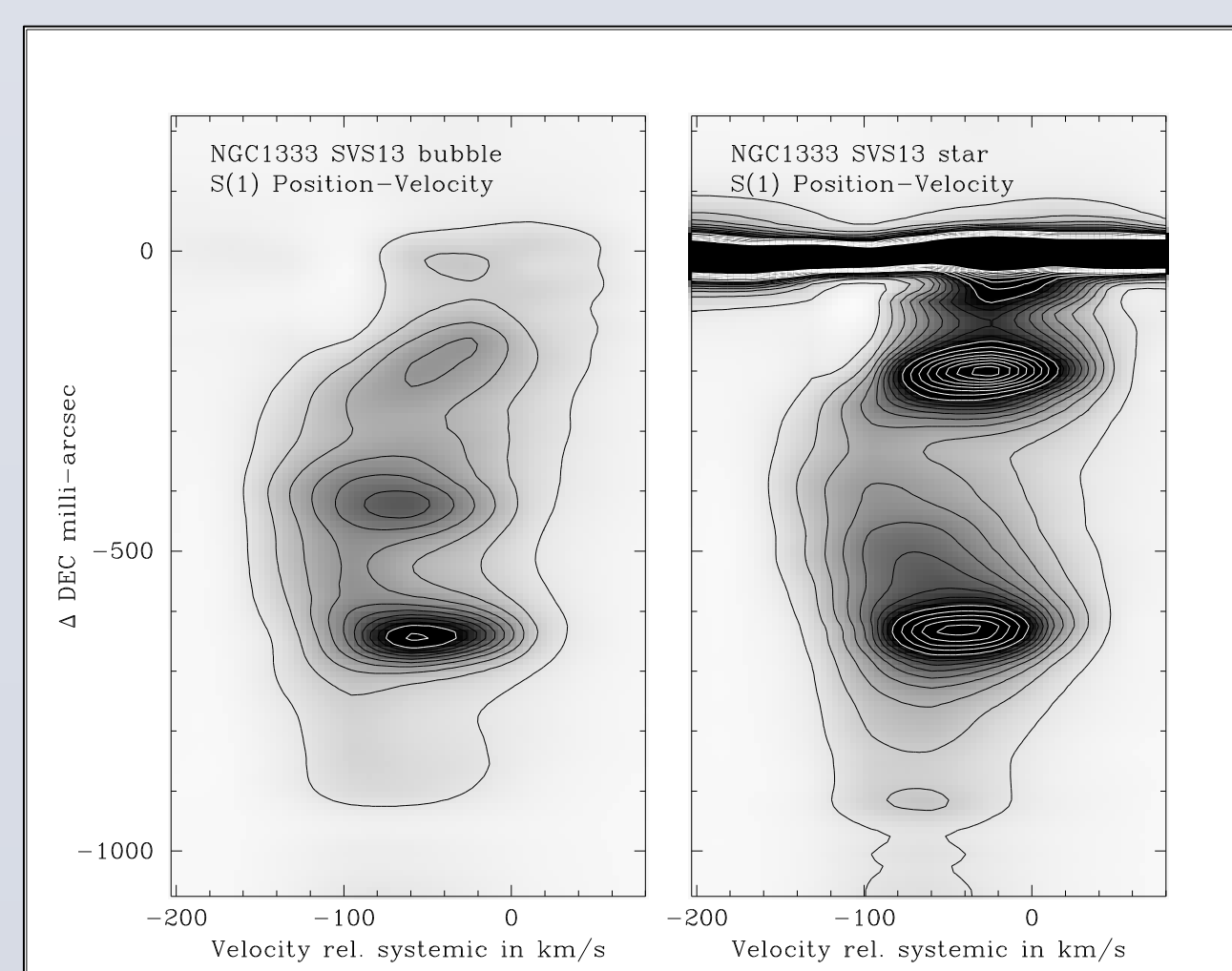
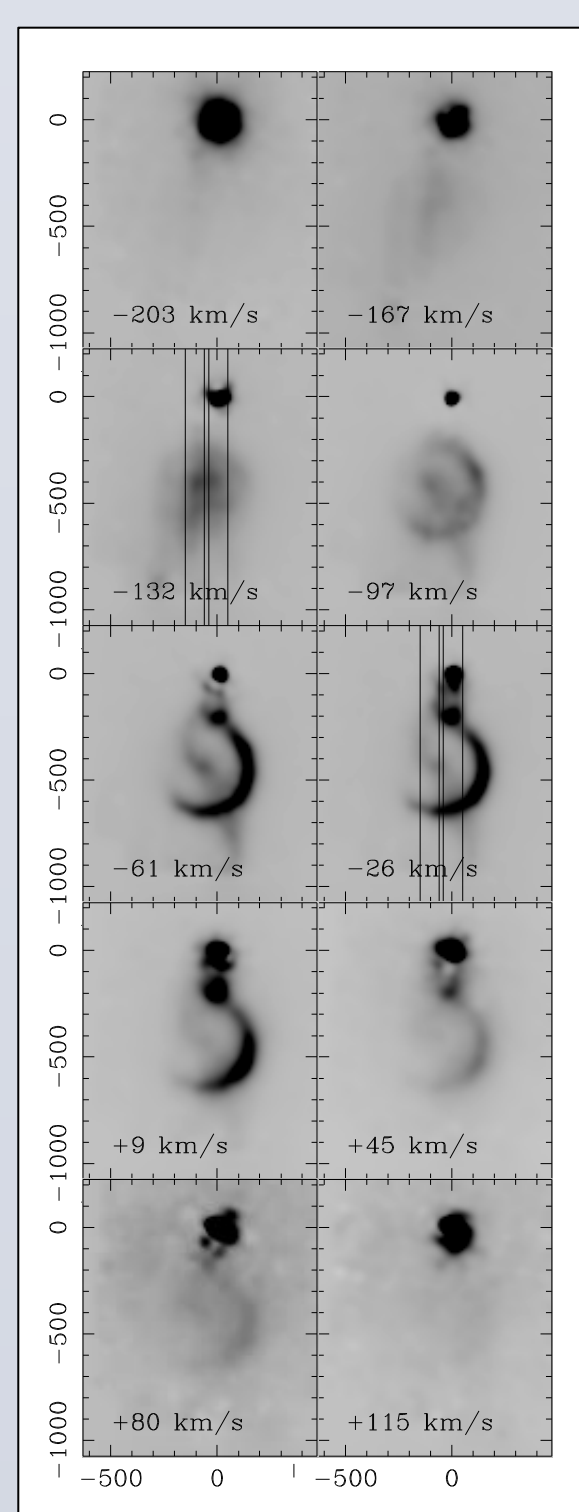


Fig. 3 (left) and Fig. 4 (above): Velocity channels (relative to the SVS13 systemic velocity) of the H<sub>2</sub> S(1) line emission (left Figure). The position of the two slits where the position-velocity diagrams in the top figure were derived are indicated. The bubble is a thin shell with emission from the front surface being visible, but with no emission from the receding (red-shifted) back surface being detectable.

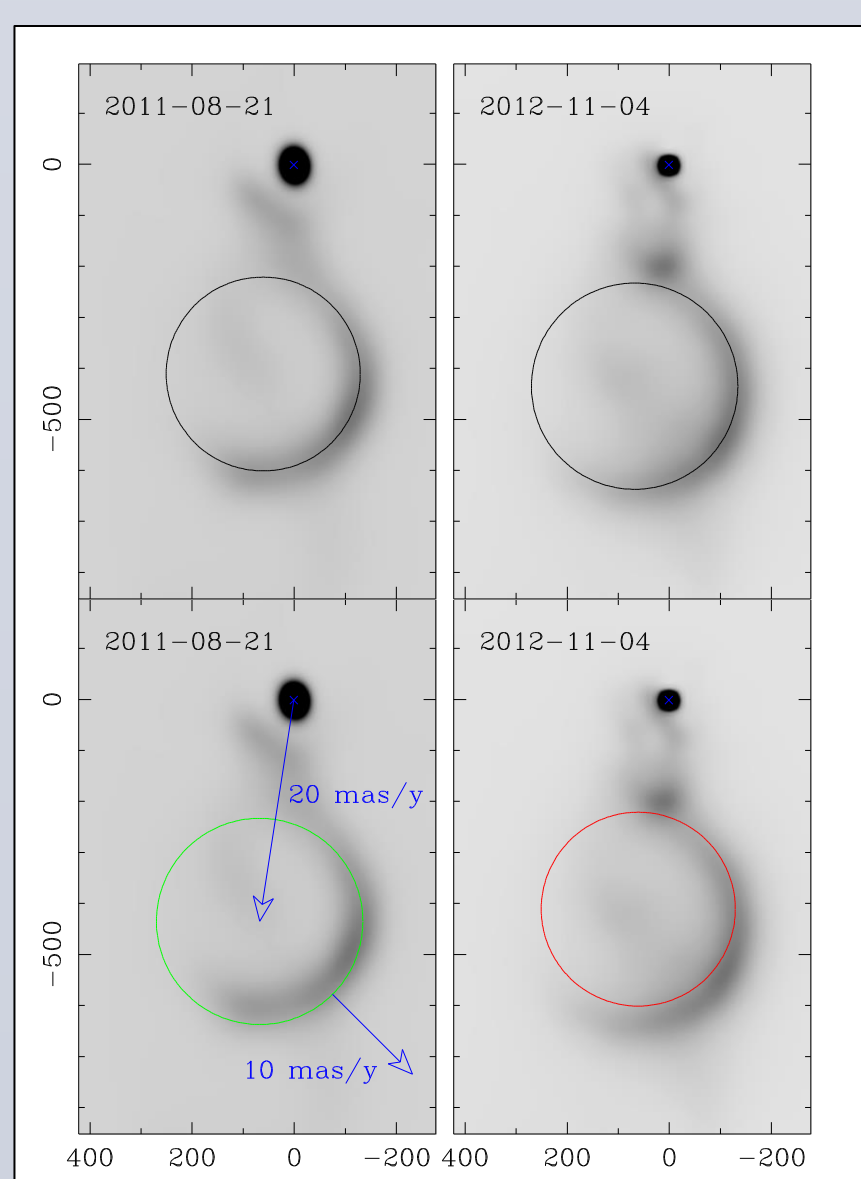


Fig. 5: The left panels show the integrated 2.122μm line image from 2011 Aug. 21, the right panels show the same line on 2012 Nov. 4. Both images were scaled to 1mas/pixel and registered on the unresolved image of the stellar source SVS13. The black circles in the top panels are the best visual fit of a circle to the image of the bubble. The green circle in the 2011 image (left panel) shows the fitting circle in 2012, while the red circle in the 2012 image (right panel) shows the fit to the 2011 data. These lower panels demonstrate clearly that a significant motion and expansion of the bubble has occurred over the 441 days separating the epochs of these images.

## [FeII] Jet Rotation

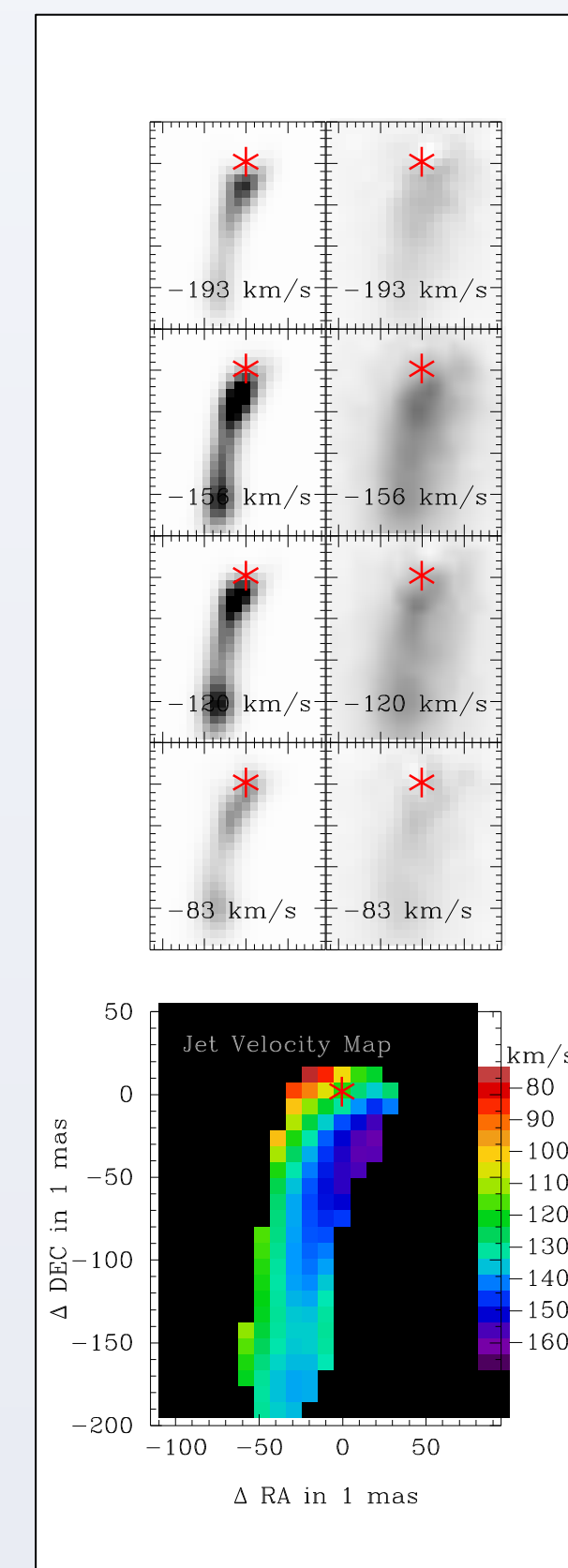


Fig. 6: Continuum-subtracted [FeII] 1.644μm images of the SVS13 jet, original on the right and deconvolved using the Lucy-Richardson algorithm on the left. The bottom panel shows the centroid velocity for each spaxel in the deconvolved image in a color-coded representation. It clearly shows that all the line emission from the jet is blue-shifted relative to the systemic velocity of SVS13. On top of the dominant blue-shift, the eastern edge of the jet is relatively red-shifted while the western edge is relatively blue-shifted.

This is the characteristic pattern of jet rotation in addition to the jet motion.

## Indications of Disk Rotation

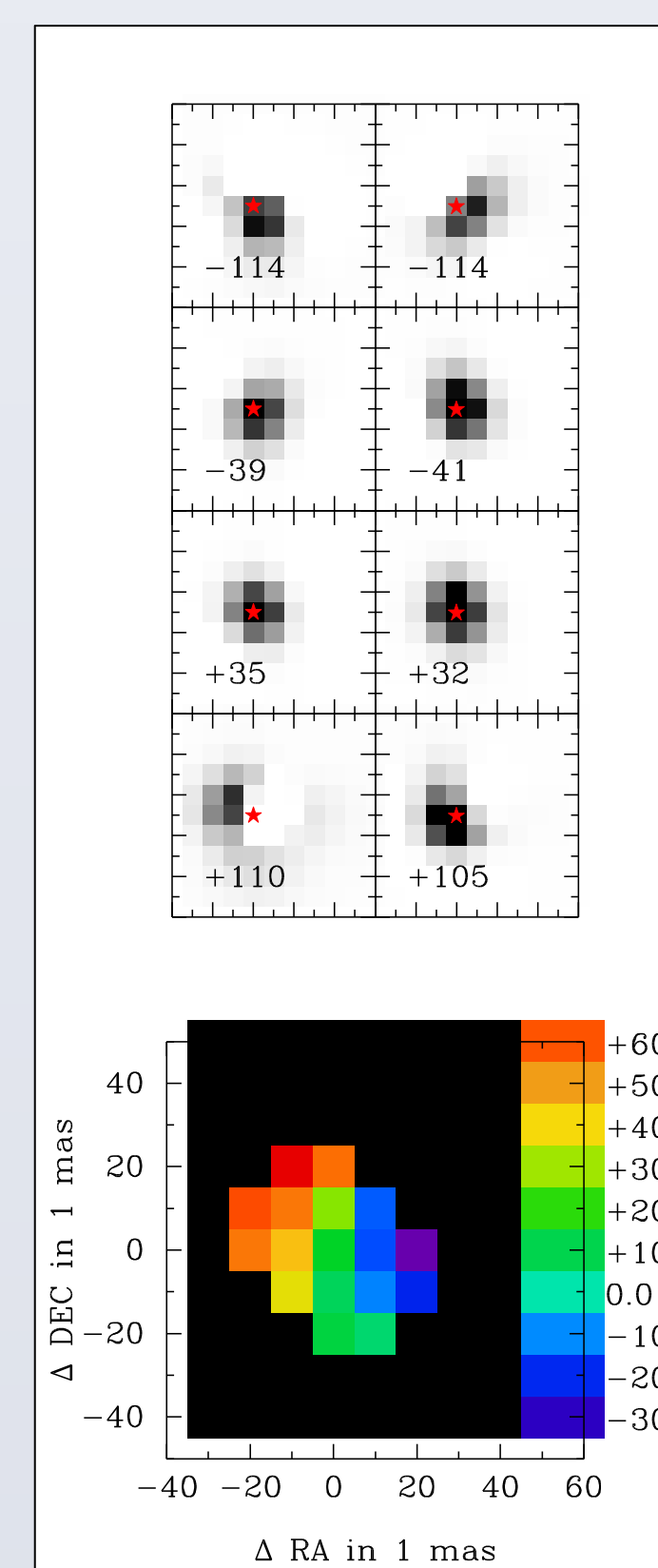


Fig. 7: The individual panels in the top part show every other of the Lucy-Richardson-deconvolved and continuum-subtracted images of the Brackett 13 (left) and Brackett 12 (right) emission. The centroid of the continuum component of each image is indicated by a star. For each spaxel in the deconvolved image, the centroid of the velocity was computed and averaged over the two lines. The panels cover 24x24AU.

The result is shown in the lower (color) panel and clearly indicates a shift in the velocity centroid across the line emission in a direction perpendicular to the jet orientation.

This is the expected kinematic signature of a rotating accretion disk.

## Conclusions

- The HH7-11 outflow, at present, originates from SVS13 as a micro-jet of ~0.4" length, detectable in [FeII] and oriented at P.A. 170° (Fig. 2).
- From the driving source to the first bubble, the [FeII] emission traces a nearly straight micro-jet. Beyond that, the H<sub>2</sub> S(1) emission outlines a curved path of the jet (Fig. 2).
- This present jet orientation is consistent with the orientation of outflowing material in the counter-jet found by Bachiller et al. (2000) in CO.
- An instability in the [FeII] microjet has generated an internal shock front that manifests itself as an expanding, moving bubble seen in H<sub>2</sub> S(1) emission (Fig.1,2,3).
- The formation of this bubble can be traced back to the ~1990 "Exor" outburst of SVS13 reported by Eisloffel et al. (1991) (Fig. 5).
- Recent K-band photometry (not shown here) indicates that this outburst is not over, but that SVS13 remains substantially above its pre-outburst brightness.
- Two other, older bubbles have been unambiguously observed whose orientation indicates that past internal shock fronts have propagated in slightly different directions closer to the 123° P.A. of the HH7-11 chain of Herbig-Haro objects (Davis et al. 2001). This indicates precession of the accretion disk and driving jet (Fig. 1).
- A clear velocity gradient, interpreted as the signature of jet rotation, is detected along the first 200 mas of the micro-jet (47 AU). Beyond this, at the point where the [FeII] jet interacts with the expanding H<sub>2</sub> S(1) bubble, the rotation signature becomes confused (Fig. 6).
- Atomic Hydrogen emission in the HI12-4 and HI13-4 (Brackett series) lines is detected around the continuum position of SVS13 and shows the kinematic signature of accretion disk rotation (Fig. 7).

## References

- Bachiller, R., Gueth, F., Guilloteau, S., Tafalla, M., Dutrey, A. 2000, AAP, 362, L33  
 Davis, C. J., Ray, T. P., Desroches, L., & Aspin, C. 2001, MNRAS 326, 524  
 Eisloffel, J., Günther, E., Hessman, F.-V., Mundt, R., Poetzel, R., Carr, J. S., Beckwith, S., & Ray, T. P. 1991, APJL, 383, L19  
 Hirota, T., Bushimata, T., Choi, Y. K. et al. 2008, PASJ, 60, 37  
 Larkin, J., Barczys, M., Krabbe, A., et al. 2006, Proceedings SPIE, 6269, 42  
 Lucy, L. B. 1974, AJ, 79, 745  
 Strom, S. E., Vrba, F. J., & Strom, K. M. 1976, AJ, 81, 314

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