Time-Series Position-Velocity Diagrams of the Jet and Low-Velocity Components in HH 444

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Motivation for the Study

Located in Orion, HH 444 is a highly collimated jet that is particularly important for studying how gas becomes heated and entrained in outflows within a few thousand AU of their sources. HH 444 has a bright, well-defined low-velocity component (LVC) that merges with a high-velocity component (HVC) a few arcseconds away from the star. A high-quality position-velocity diagram[1] taken in 2000 shows both the jet and the low-velocity component in the red lines of [S II], Hα and [N II]. Enough time has now passed since the previous observations to measure proper motions, and thereby learn which features in the position-velocity map of the jet evolve dynamically, and which are static. We can also use new analysis methods developed in the last few years to infer ionization fractions, temperatures and densities when multiple line ratios are present[2].

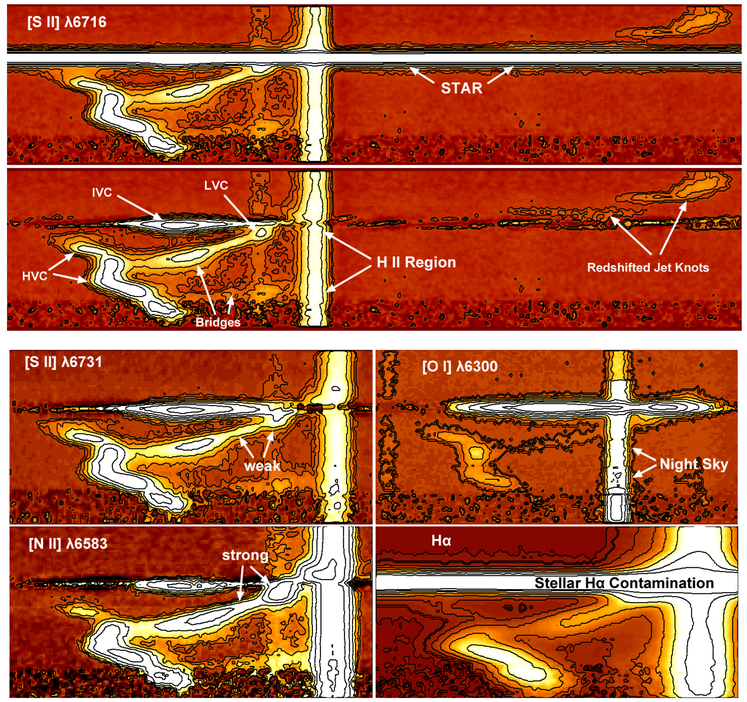
Main Results

Using the two epochs of data, we created position-velocity diagrams that represent the most thorough exploration of the phase space of stellar jets to date. The data allow us to examine both the emission line ratios and their associated diagnostics as well as the temporal, spatial, and radial velocity data for each point in the flow. We observe where ambient material is heated along the jet, and see it get ionized as it is dragged along the flow. Some parts of the flow move, and others are quasi-stationary.

Observations

- New HIRES Keck longslit echelle spectra taken Dec 23, 2010. 14”x1.148” slit, dithered to increase spatial extent. Spectral coverage 3700 – 8000 A.
- Existing HIRES longslit echelle spectrum from Andrews et al.[1] Dec 18, 2000, one slit position and spectral coverage that includes [O I] 6300 through [S II] 6731.

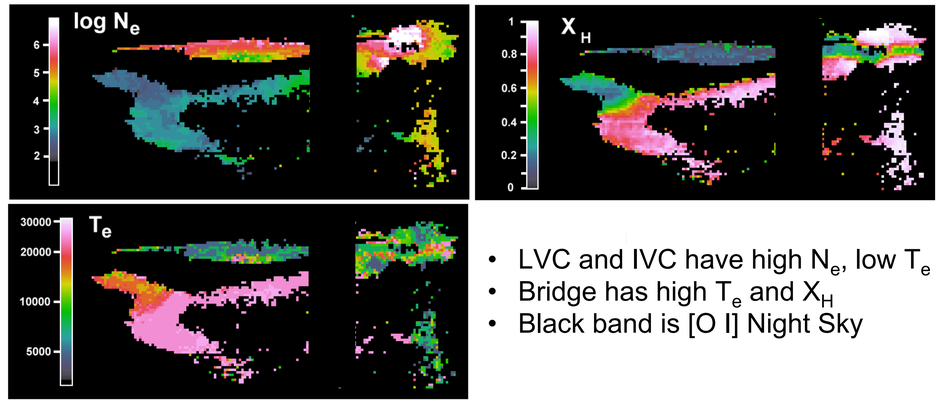
Subtracting the Star



Things to Note in the Data

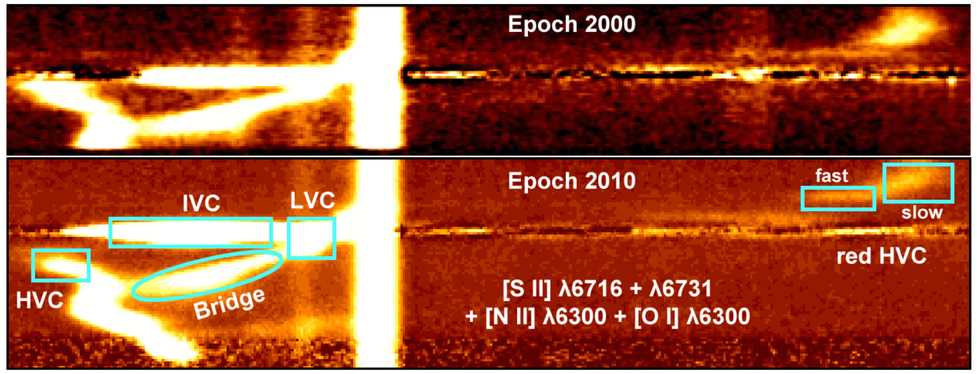
- Morphology differences in emission line maps caused by differing physical conditions in the components
- Exceptionally strong [N II] along the `bridges’ between LVC and HVC indicating high ionization there
- Fainter second bridge
- HVC slows when bridges appear
- Faint background emission at velocity of LVC
- Strong, broad Intermediate velocity component (IVC) near the star, especially in [O I] indicating high density and mostly neutral gas
- Hα is smoother – thermal line width is resolved
- Refer to image: where the jet grazes its surroundings and drags along material it becomes *less* collimated
- Velocity asymmetry of a factor of two between red and blue sides of flow

Electron Density, Hydrogen Ionization Fraction and Electron Temperature



- LVC and IVC have high N_e, low T_e
- Bridge has high T_e and X_H
- Black band is [O I] Night Sky

Proper Motions



FEATURE	Line(s)	Proper Motion (km/s)	Critical Density
LVC	[S II]	25 +/- 8	Low
	[N II]	13 +/- 4	Intermediate
	[O I]	-1 +/- 2	High
	average	13 +/- 5	
IVC	[S II] 6731	14 +/- 4	Low
	[O I]	-4 +/- 5	High
	average	7 +/- 3	
Bridge	[S II], [N II]	21 +/- 5	
HVC	[S II], [N II]	242 +/- 19	
red HVC	[N II], [S II]	205 +/- 19 (fast)	
	[N II], [S II]	135 +/- 28 (slow)	

The highly-ionized ‘bridge’ is quasi-stationary, and must define an interface where the jet entrains ambient material. This result has broad implications as to how jets propagate as they emerge from their sources.

References:
1. Andrews, S., Reipurth, B., Bally, J., & Heathcote, S. 2004, AJ 606, 353
2. Hartigan, P., & Morse, J. 2007, ApJ

System Overview