# Studying the Origin of the Outflows/Jets from YSOs with Subaru and Gemini

Tae-soo Pyo & Masa Hayashi

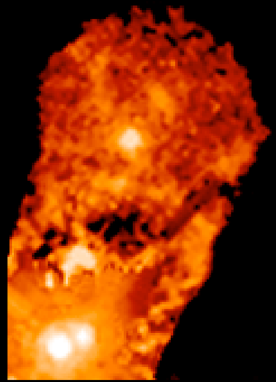
Subaru Telescope

*May 21, 2009*

# Agenda

- Introduction about Outflows/Jets
- The Observations & Results from [Fe II] 1.644 um emission
- On-Going Plan with NIFS/GEMINI

# Outflows/Jets are Ubiquitous



- Outflows/Jets are ubiquitous phenomenon from BD to AGN.
- They are related to accretion disks and magnetic field.

**Common Launching Mechanism for All Outflows/Jets !?**

Introduction:

# Outflows/Jets from YSOs

- **They are close to us.**
  - **TMC : d=140 pc, 0.1" = 14 AU**
  - **→ studying detail structure in a few AU scale.**
- **Closely related to the accretion of disk material onto central star ($dM_{outflow}/dM_{acc.}$ ~ 0.01)**
- **Important role for Angular momentum removal from star-disk system**

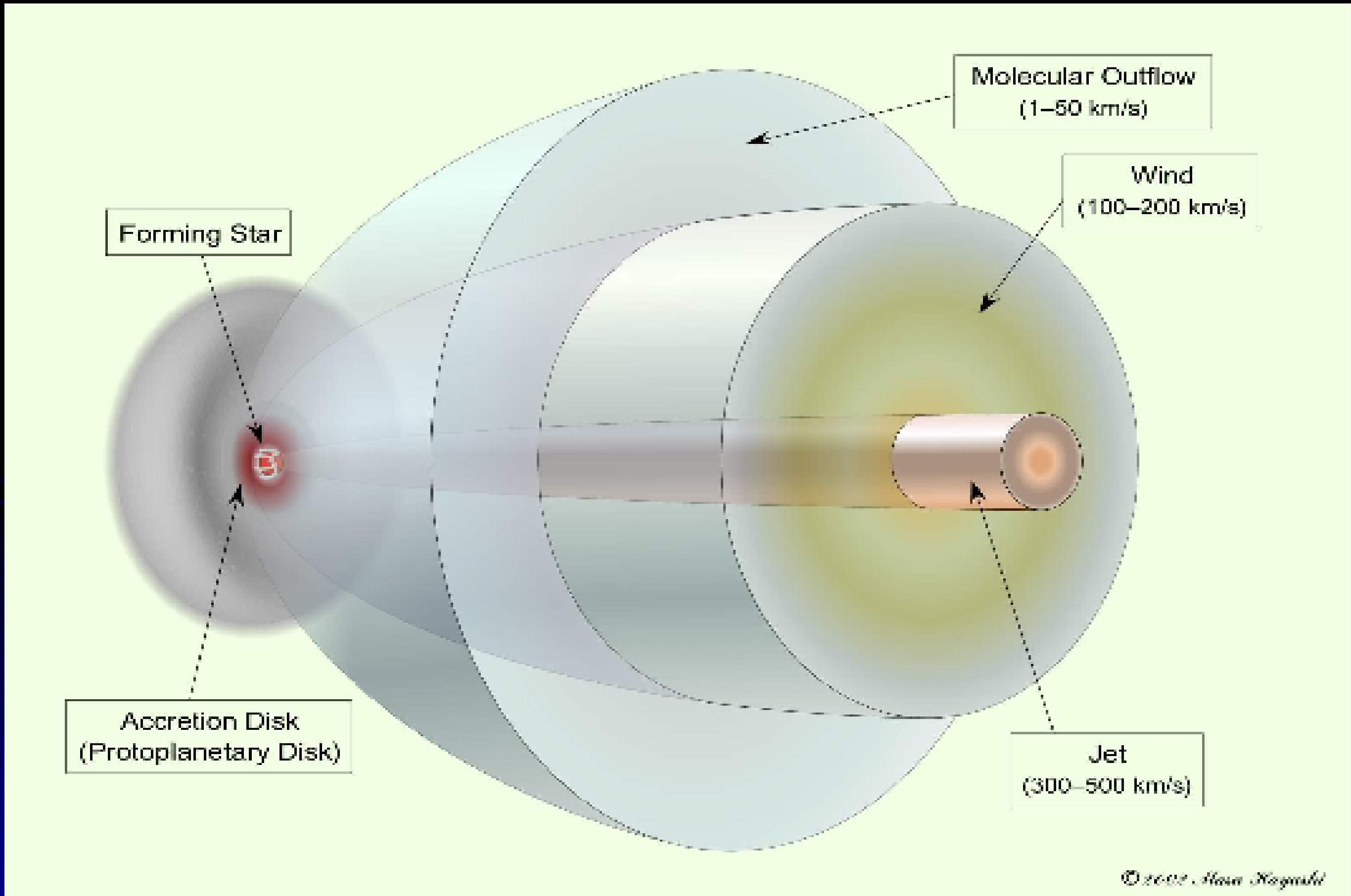
Introduction:

# Classification of YSO's Outflow

| | V (km/s) | Collimation | Remark |
|---|---|---|---|
| HH jet | 100 – 400 | Well | (PI) gas (HVC) |
| Radio jet | --- | Well | PI gas |
| T Tauri FEL | 5 – 20 (LVC)<br>50 – 100 (HVC) | Unresolved | PI gas<br>LVC & HVC |
| T Tauri Wind | 50 – 200 | Unresolved | (Neutral?) Cold Gas |
| HVNW | 50 – 200 | Moderate | Neutral Gas |
| 'Classical' CO | 1 – 30 | Poor | Entrained Gas |
| EHV | 40 – 150 | Moderate | Neutral Gas |

Introduction:

# Structure of YSO's Outflow




Molecular Outflow:
Cavity structure
Slow velocity
Entrained Gas

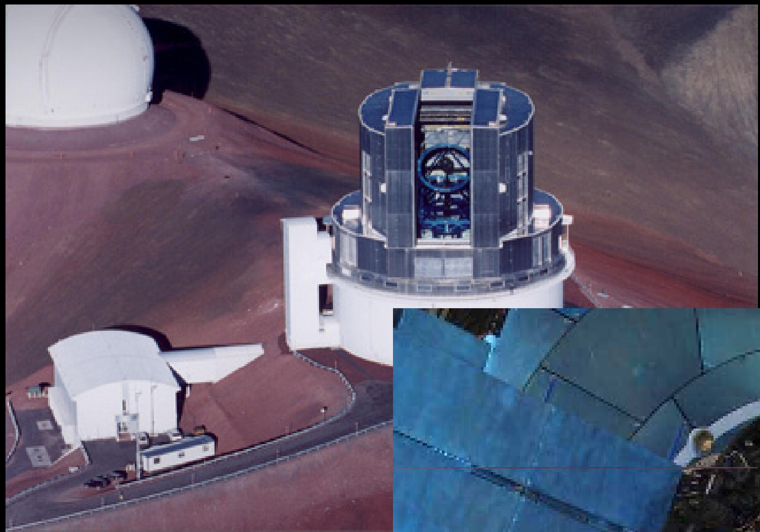
Wind:
Unseen outflow
Widely opening angle

Jet :
Well collimated
High velocity

Main concern: Launching Mechanisms of directly driven winds and Jets

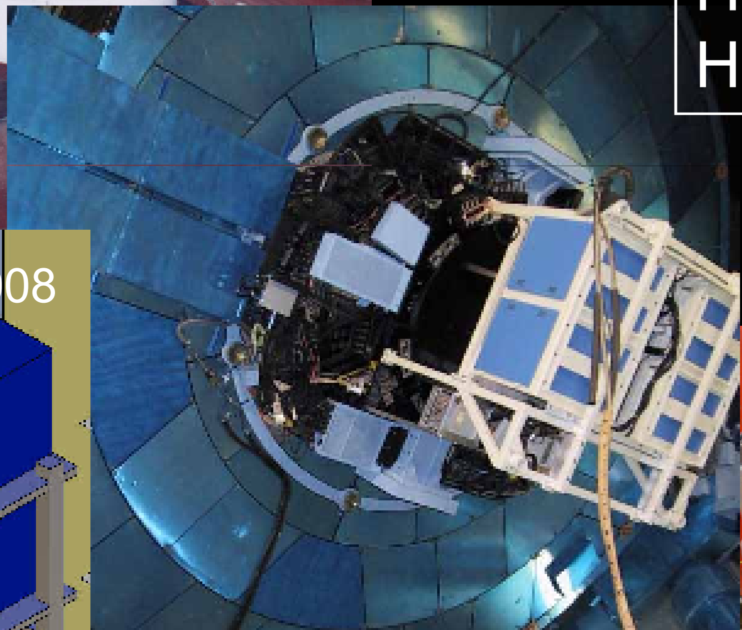
# Observations and Results by IRCS+AO/SUBARU

# Telescope & Instruments

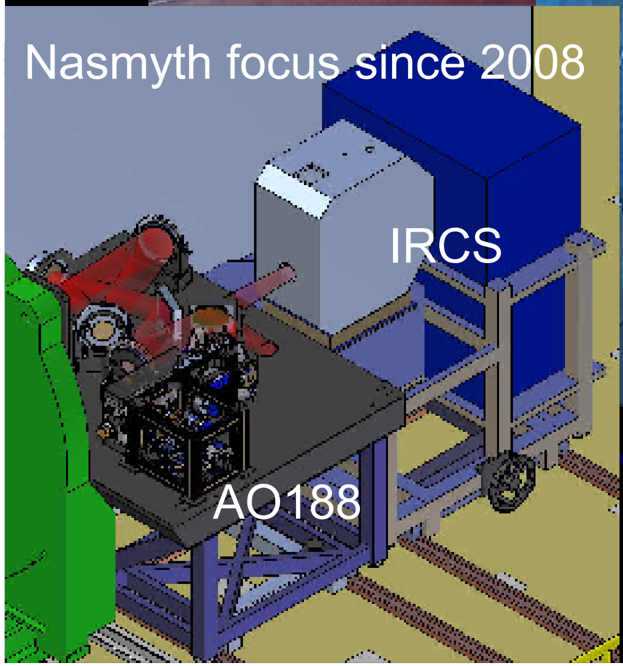


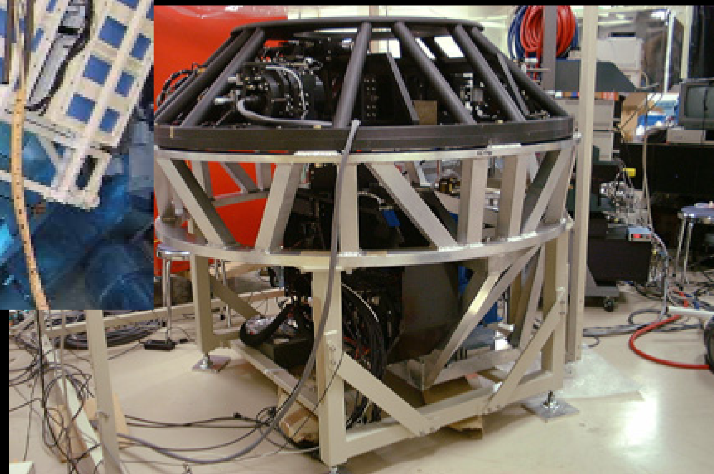
Subaru Telescope

NIR [Fe II] emission
High spatial resolution
High velocity resolution



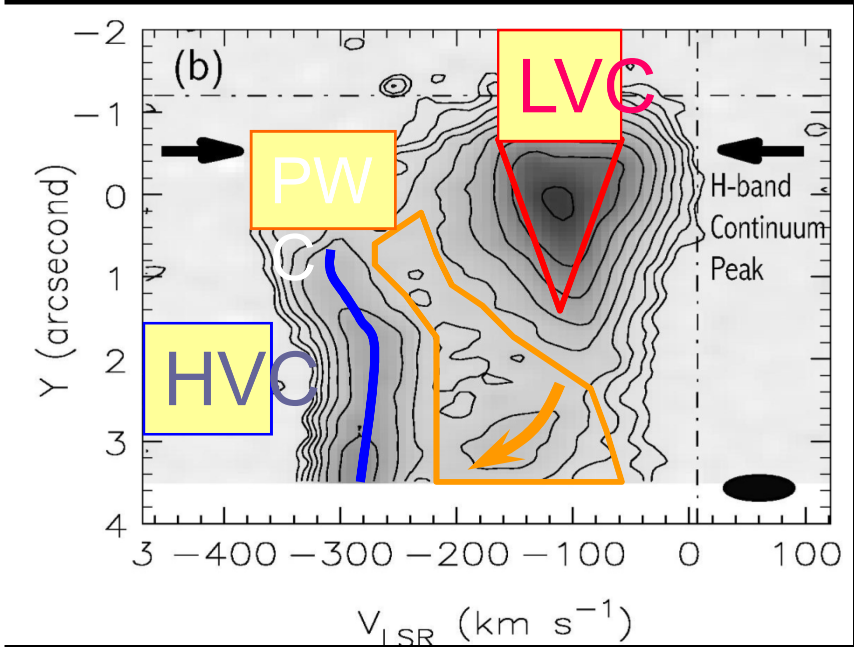
IRCS (~2005)

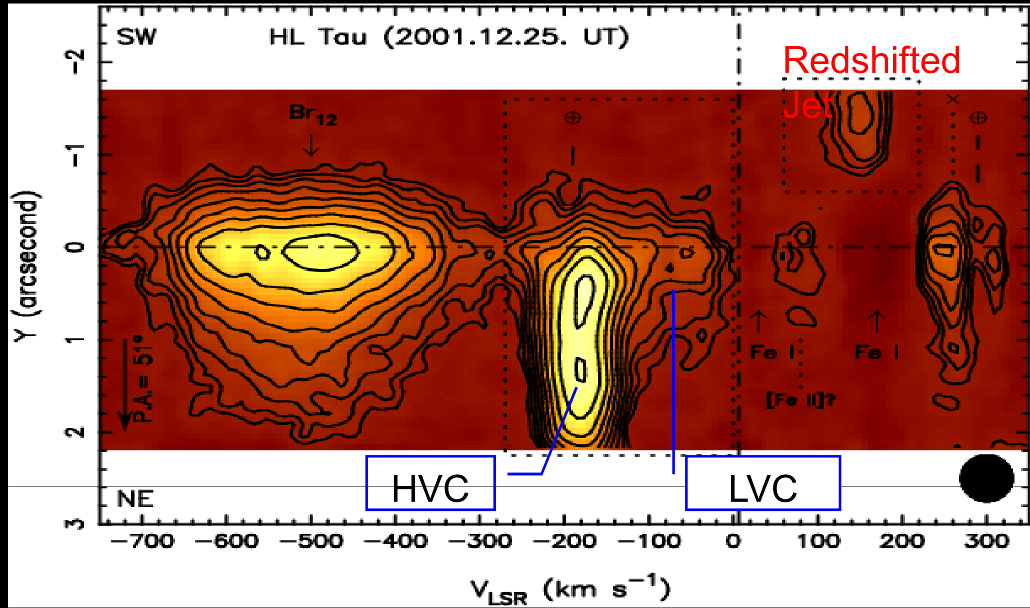


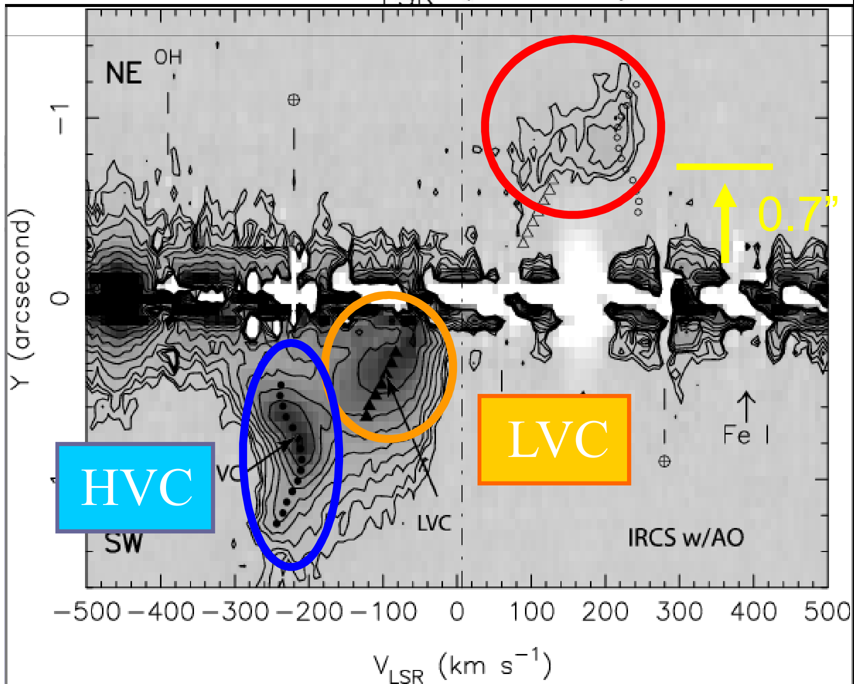



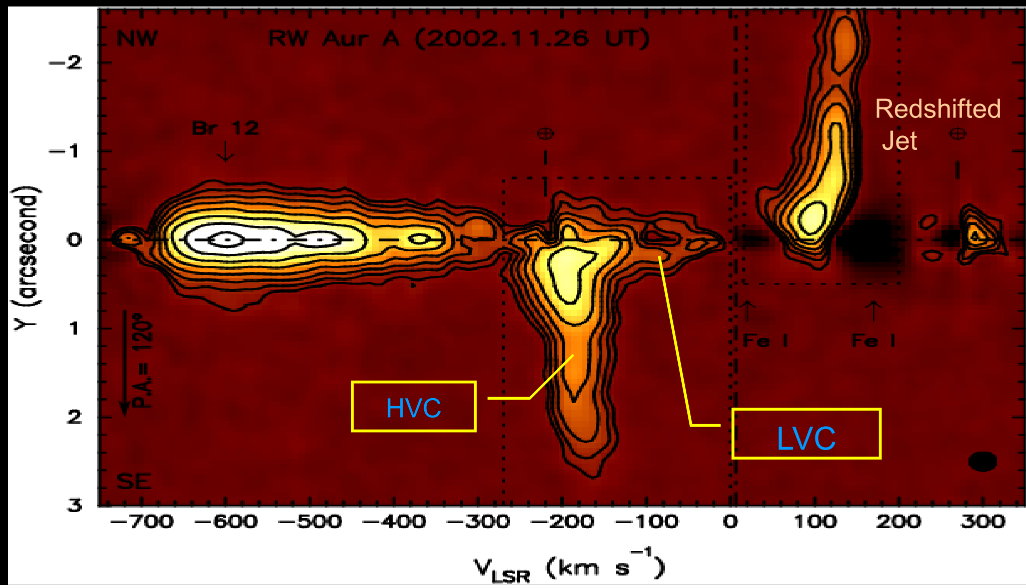
AO36 system (~2008)

# Two Velocity Components



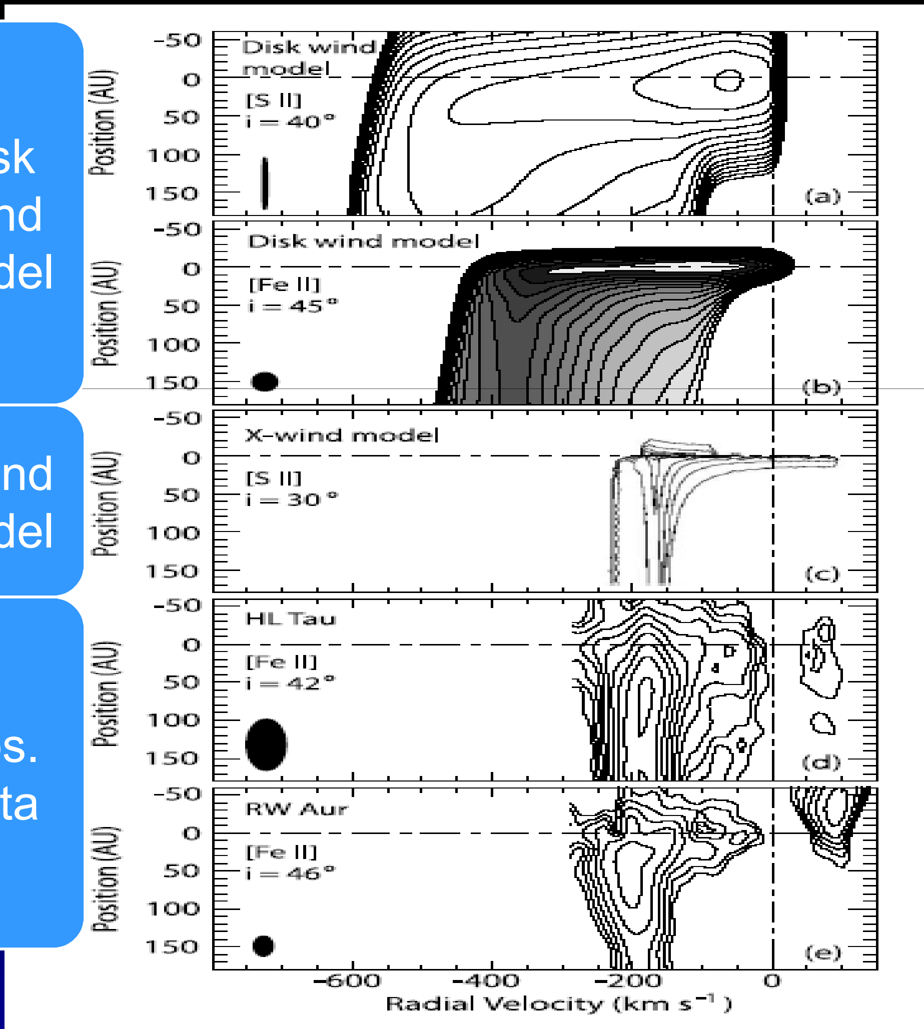

(Pyo et al. 2002, 2003, 2006, ApJ)

# Comparison with Model PVDs

Disk Wind Model

X-wind Model

Obs. Data




(Pyo et al. 2007)

HVCs well match X-wind Model.

Extended LVCs can be explained by Disk wind model.

Why?

(1) Launching Region

Disk wind : wide area

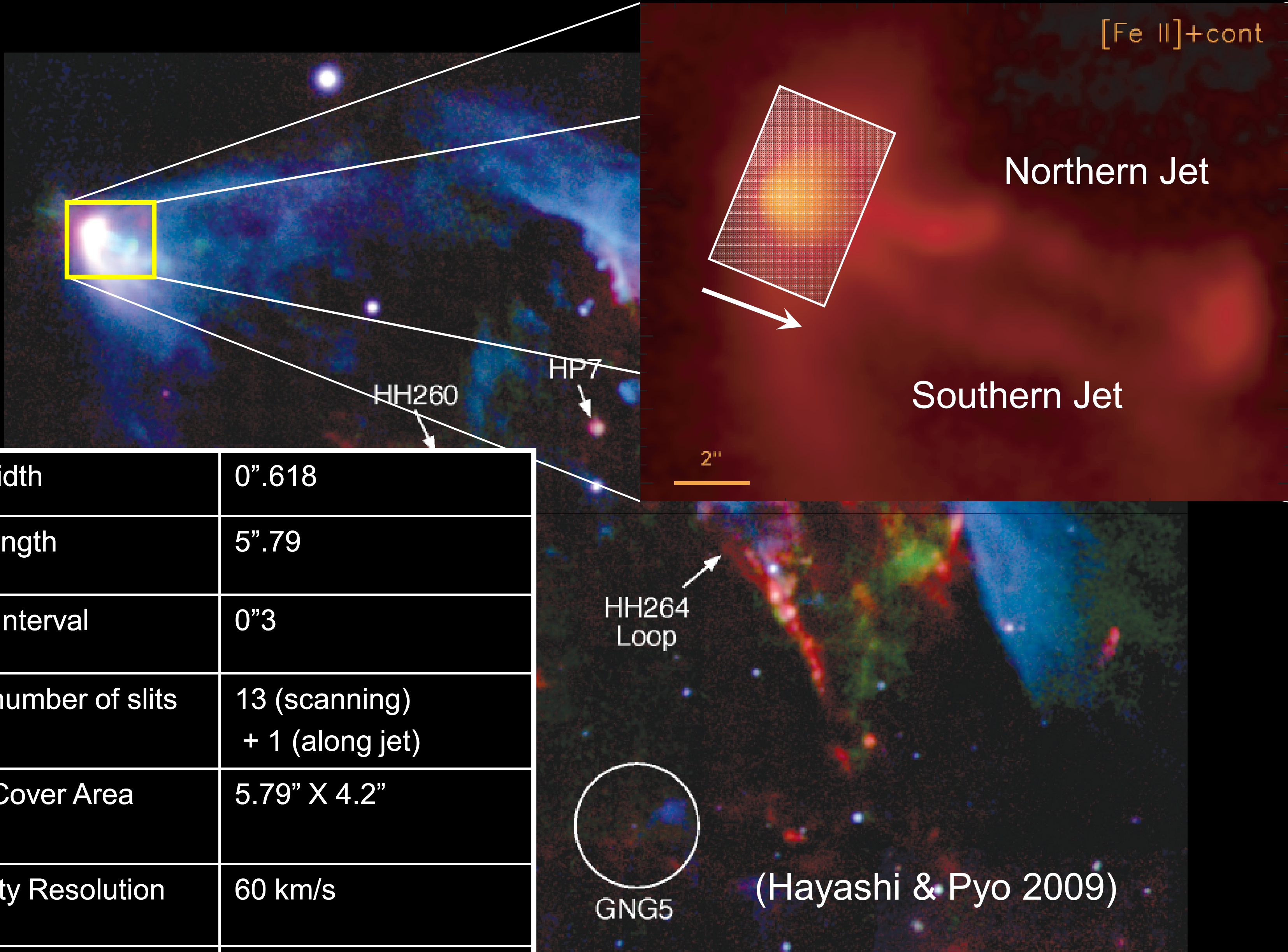
X-wind : inner disk edge (narrow)

(2) Collimation of Wind

Disk wind : Yes

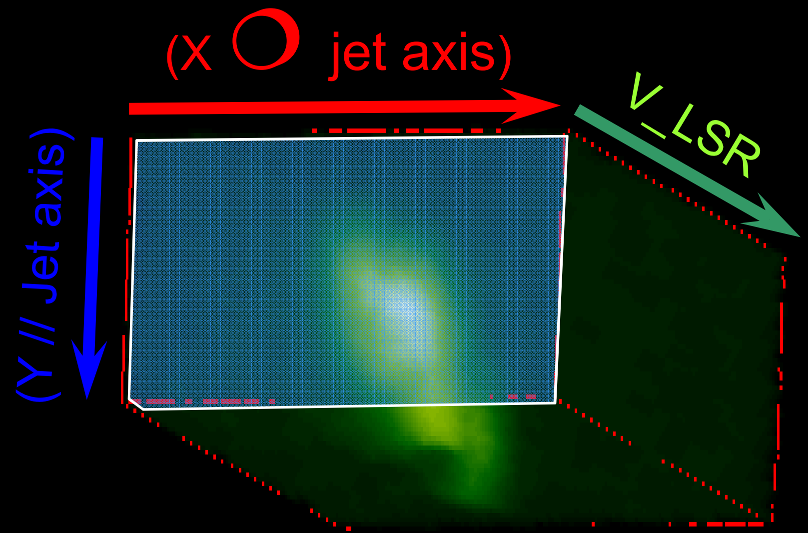
X-wind : No

# SlitScan Observation toward L1551 IRS 5 Jets

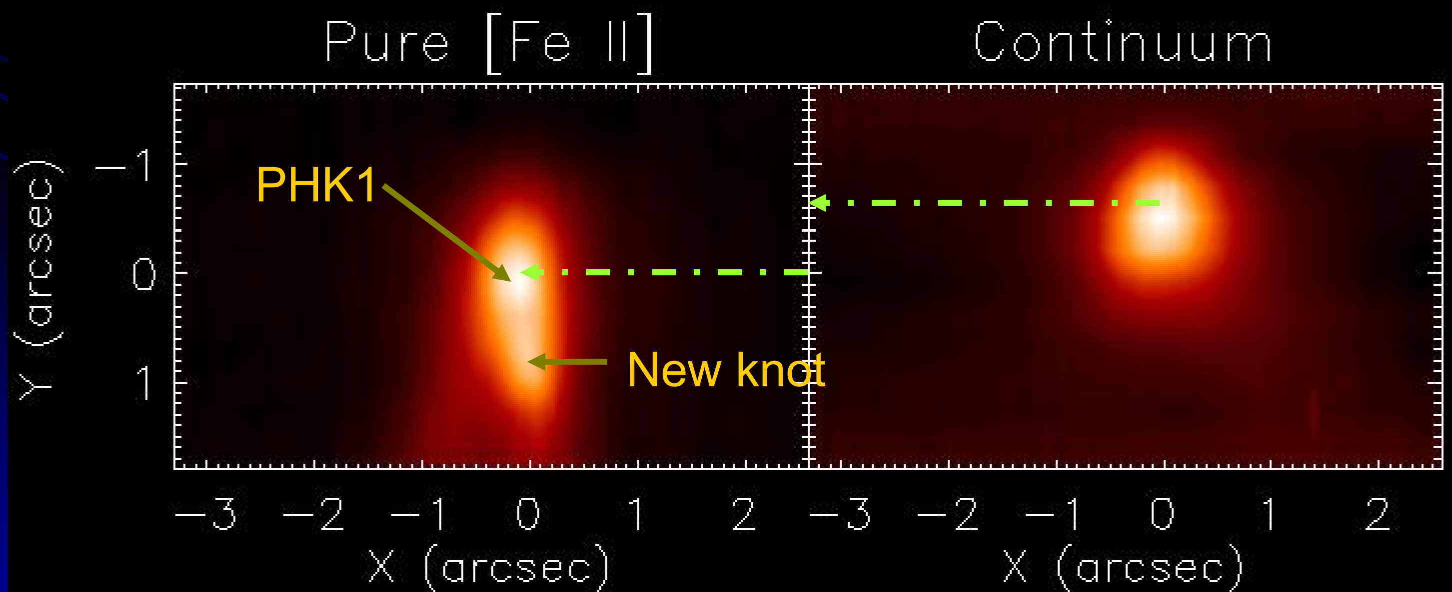



| | |
|---|---|
| Slit Width | 0”.618 |
| Slit Length | 5”.79 |
| Scan Interval | 0”3 |
| Total number of slits | 13 (scanning)<br>+ 1 (along jet) |
| Total Cover Area | 5.79” X 4.2” |
| Velocity Resolution | 60 km/s |
| Spatial Resolution | ~0.5” |
| Pixel scale | 0.06” |

# Integrated pure [Fe II] Image

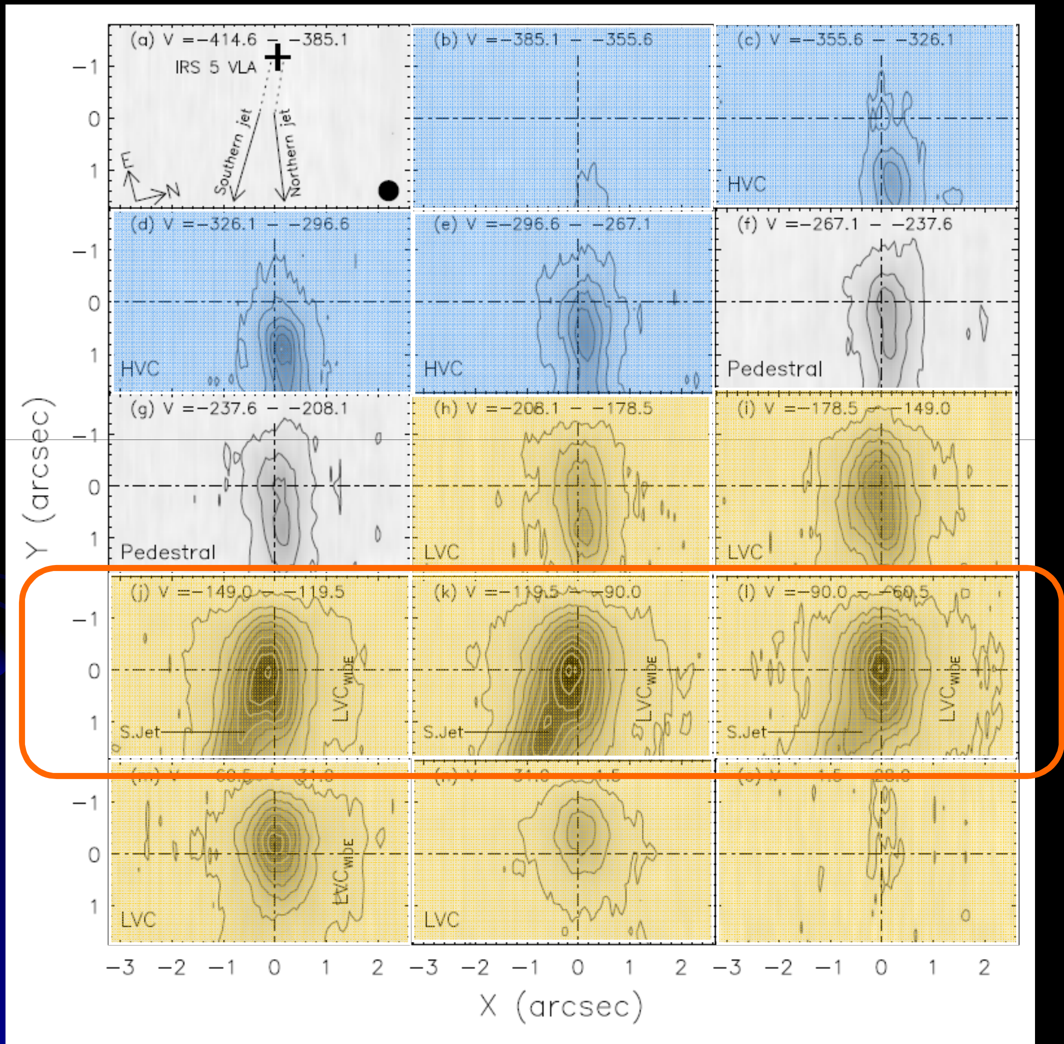



- ~ 0.7” offset: outflow origin
- PHK1 peak is stationary for 4 yrs + strong X-ray emission
  → Strong shock (dV~500 km/s) with stationary material.



# Channel Maps of [Fe II]

dV = 29.5



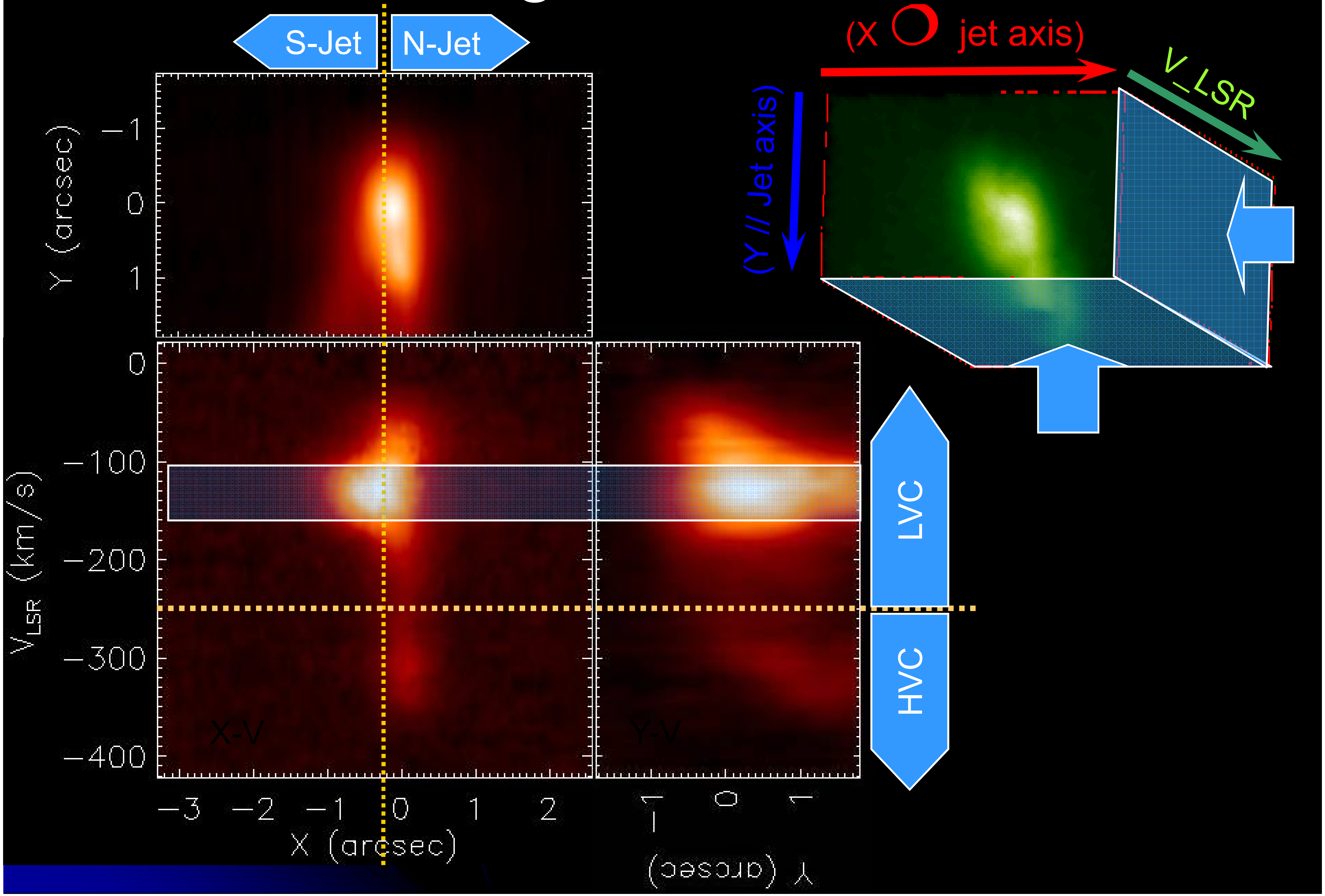

HVC: narrow spatial width

LVC : narrow → wide

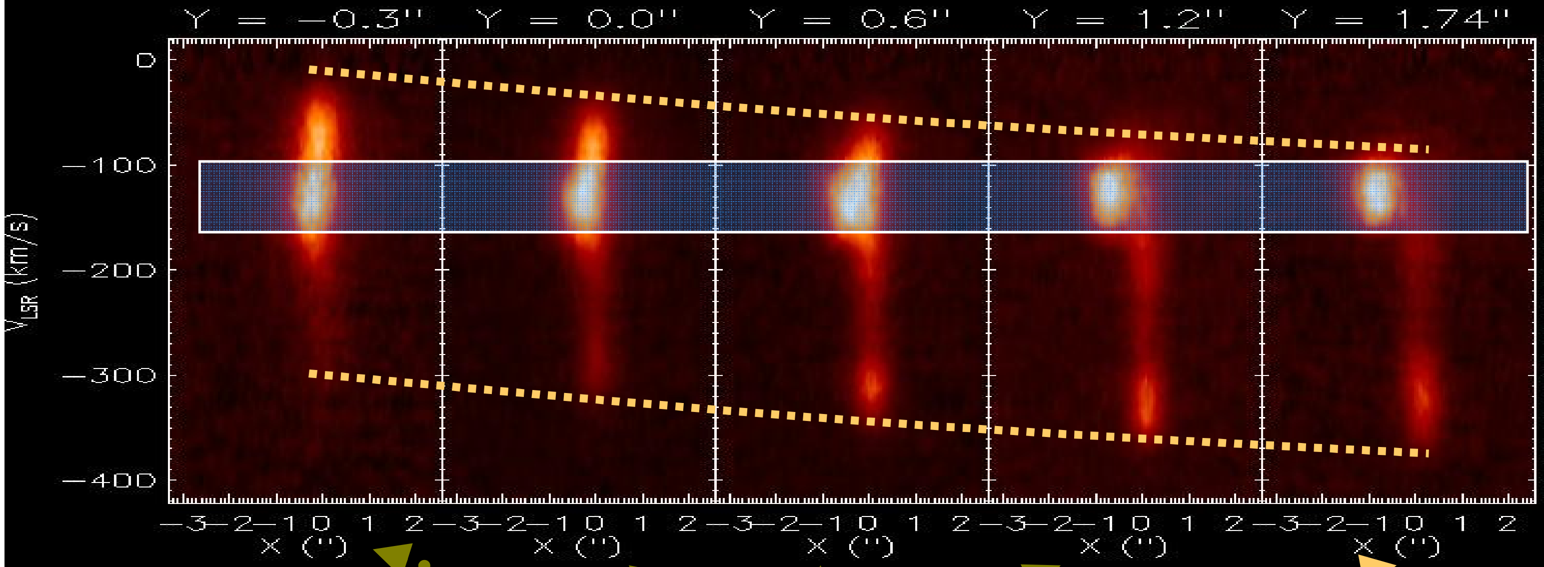
S-jet appears in just 3 channel maps

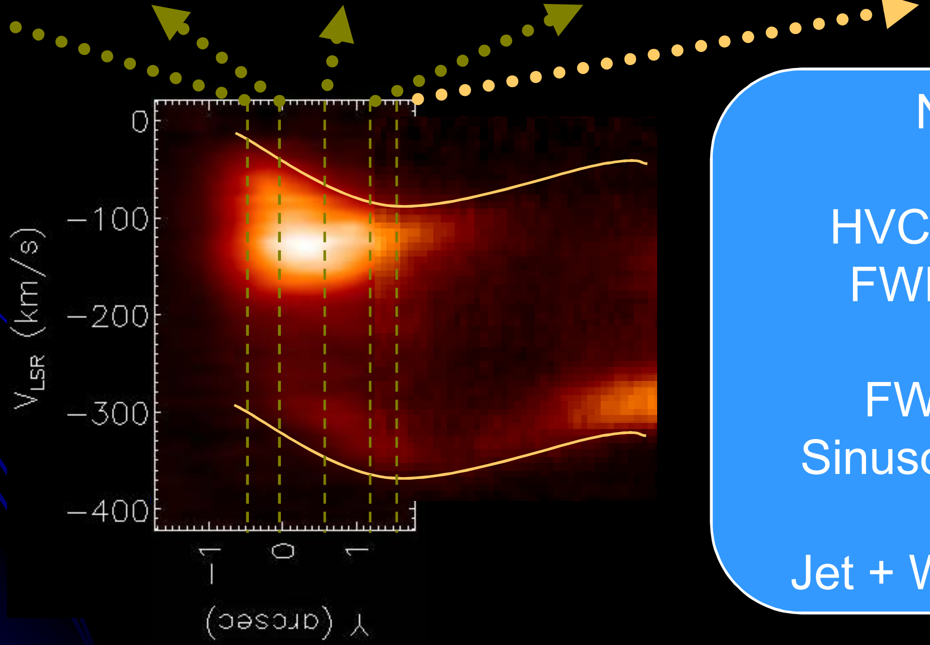
Pyo et al. 2009

# Integrated PVDs



# PVDs variation along the jet direction




Southern Jet

V ~ -130 km/s
FWHMv = 60 km/s
(= V resolution)
Constant V.

Well Collimated Jet

Northern Jet

HVC > |V|=240 km/s
FWHMv ~ 60 km/s
With LVC
FWZI ~ 300 km/s
Sinusoidal Pattern in V.

Jet + Wind+Entrainment

# Summary

Table 2. Deconvolved velocity widths (FWHM) of the HVCs and LVCs for [Fe II] Jets

| Jet | HVC Width (km $s^{-1}$) | HVC Remark | LVC Width (km $s^{-1}$) | LVC Remark | Reference |
|---|---|---|---|---|---|
| L1551 IRS 5 Northern Jet | 40 | Extended | 150–180 | Extended | Present work |
| DG Tau | 50 | Extended | $\sim$100 | Extended | Pyo et al. (2003) |
| RW Aur | 50 | Extended | 100 | Compact | Pyo et al. (2006) |
| HL Tau | 40 | Extended | $\gtrsim$100 | Compact | Pyo et al. (2006) |
| L1551 IRS 5 Southern Jet | 53 | Extended | N/A | Not Detected | Present work |

Narrow Wide

The velocity of the outflow is order of the Keplerian rotation velocity at its launching radius. Thus narrow velocity width implies a narrow launching radial region and wide velocity width implies a wide launching radial region.