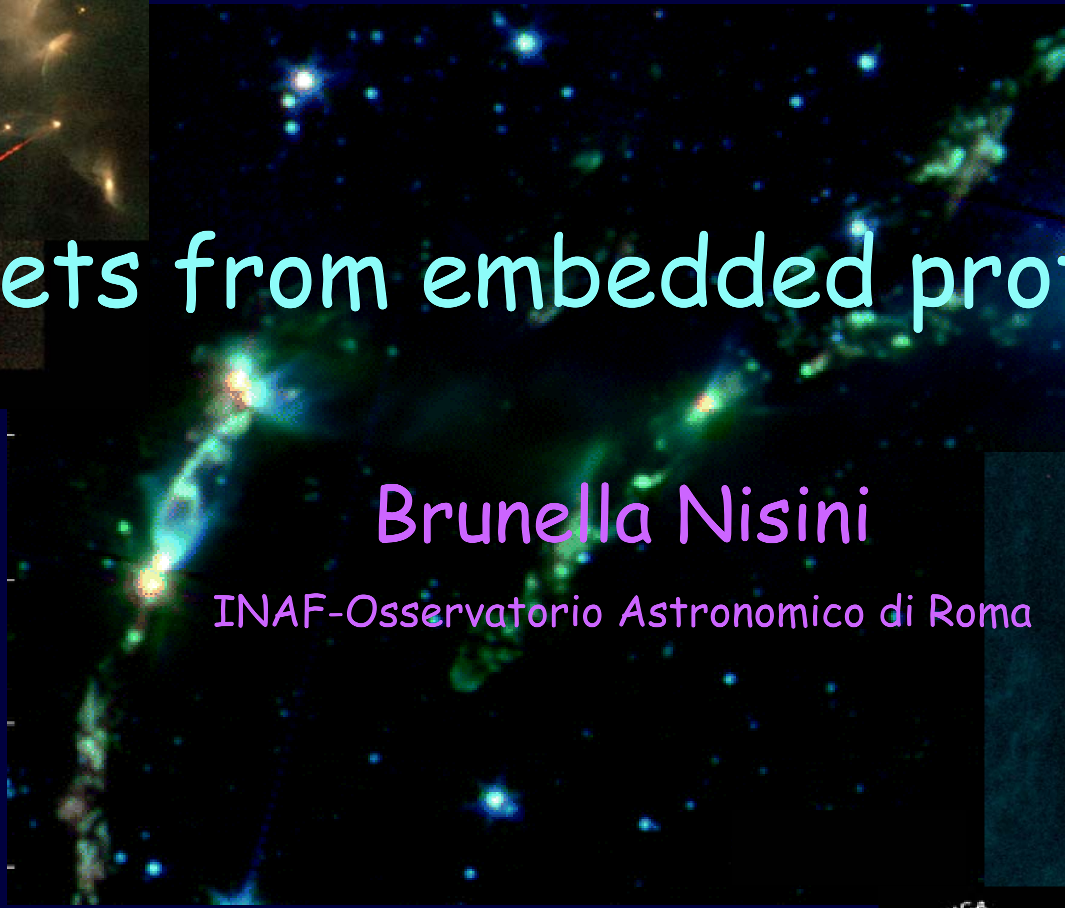
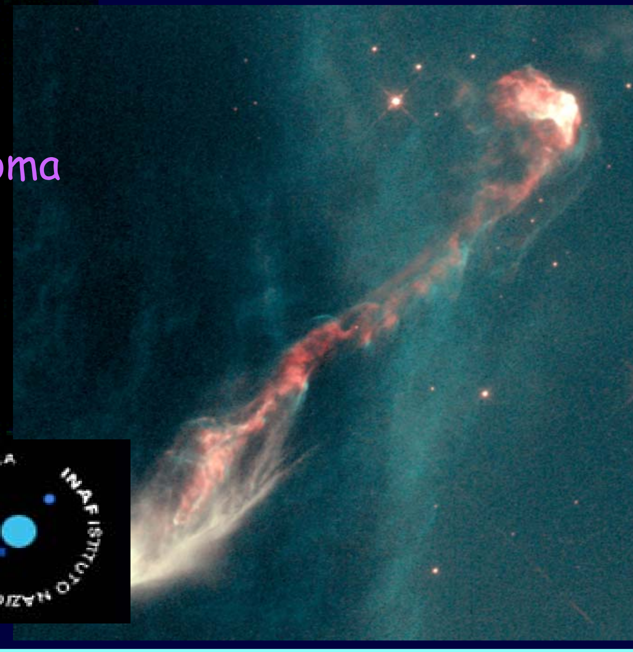
Jets from embedded protostars

Brunella Nisini

INAF-Osservatorio Astronomico di Roma

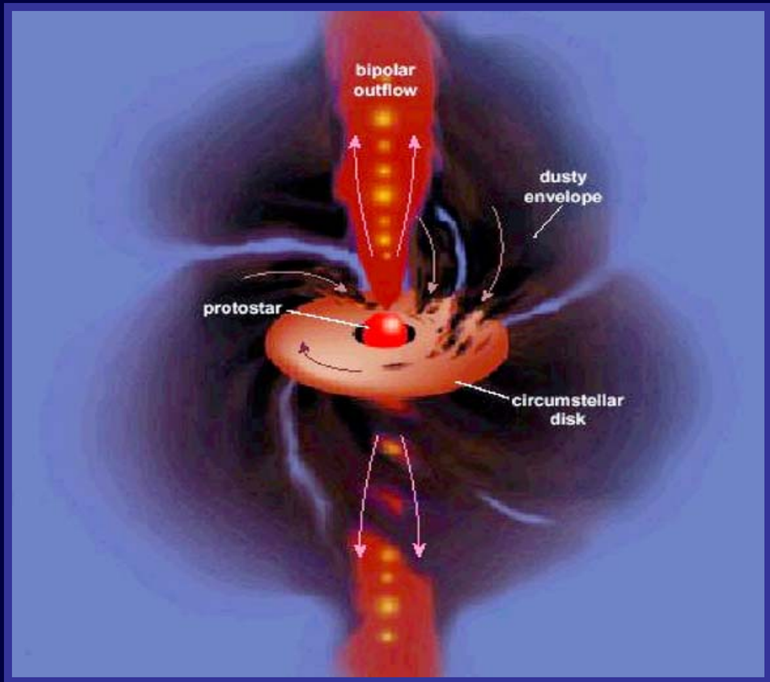




Outline

- Embedded protostars: putting them in an evolutionary context
- Class 0/I jet beams physical properties from NIR spectroscopy
- Class I micro-jets
- Submm molecular jets: SiO, CO and Spitzer observations
- Future prospects

Class 0/I embedded sources



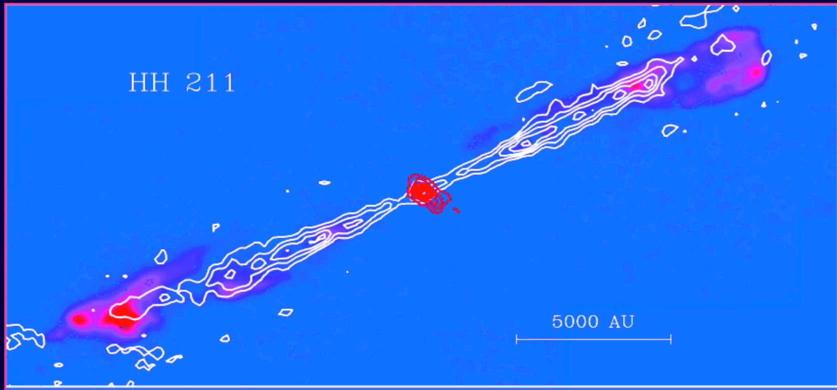
Embedded in a dusty envelope
→ high extinction (optically invisible)

Evolutionary time 10^4 - 10^5 yr

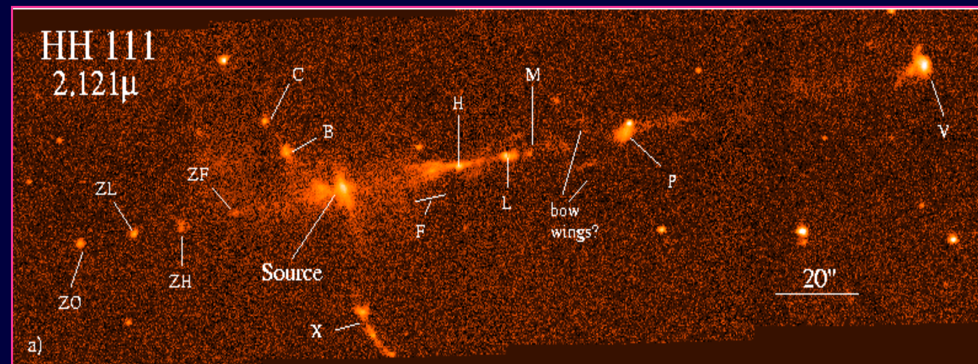
Accretion dominated luminosity

- Classification may be limited by disk inclination effects and scattering (e.g. 2D SED models by Whitney et al. 2003)

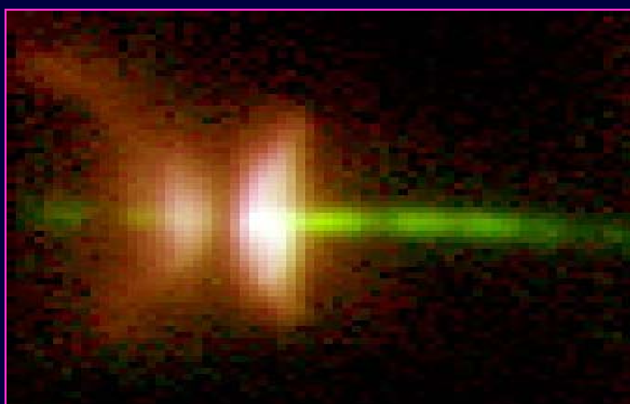
Jets from Young Stellar Objects



Class 0: ~10^4 yr
- molecular flows
-highly energetic
-- tracers: CO, SiO, H_2



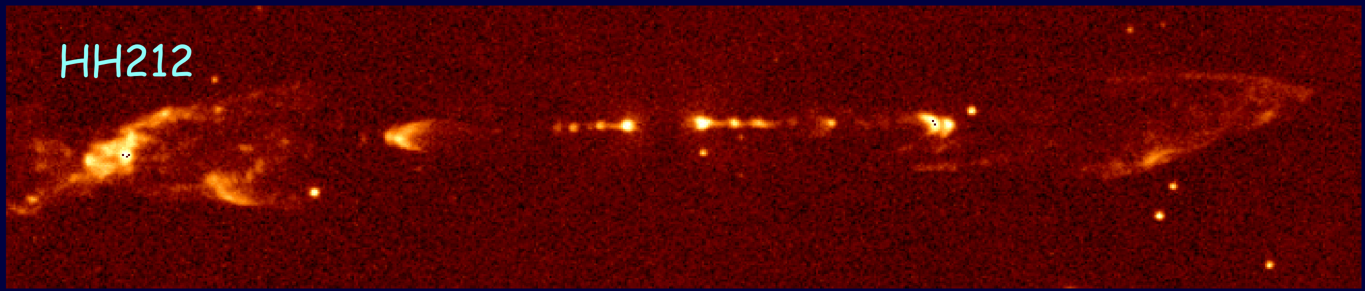
Class I: ~10^5 yr
- molecular and atomic flows
- tracers: H_2, FeII, SII



Class II: ~10^6 yr
- atomic flows
- tracers: SII, Hα..

Open questions in the study of Class 0/I jets

- Is the mass ejection mechanism and the $\dot{M}_{jet}/\dot{M}_{acc}$ ratio evolving with time ?
- How much the physical properties differ from optical T Tauri jets ?
- What is the origin of class 0 sub-mm collimated jets ?

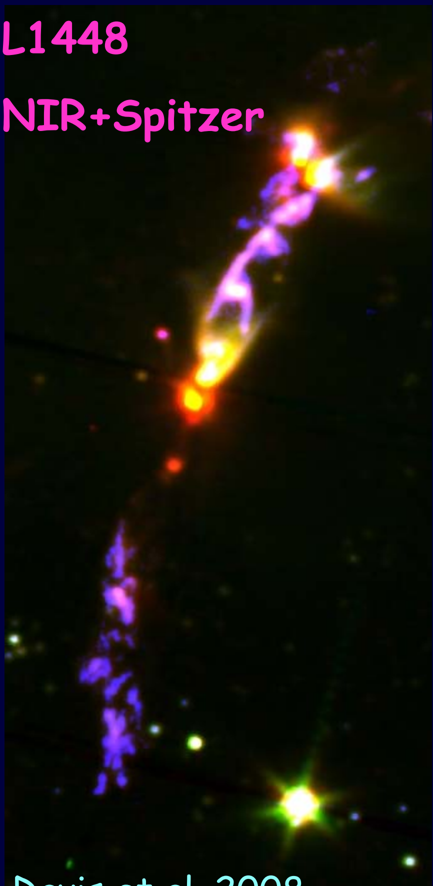


➔Driving star not optically visible and veiled

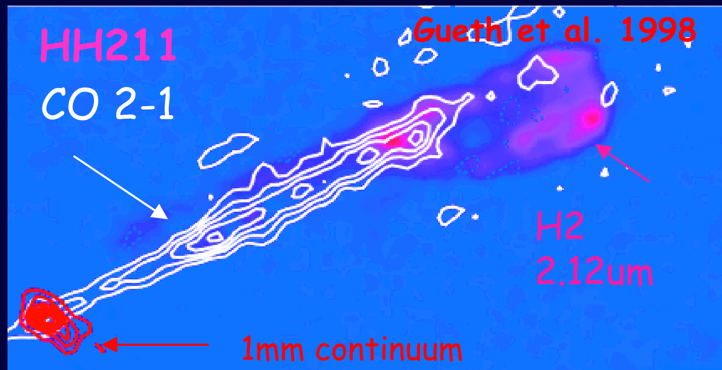
➔Few info on source parameters

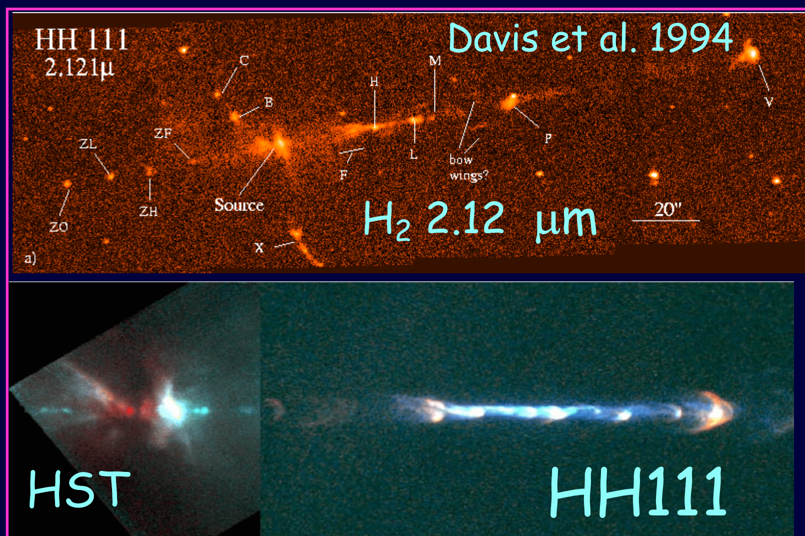
Observational tracers

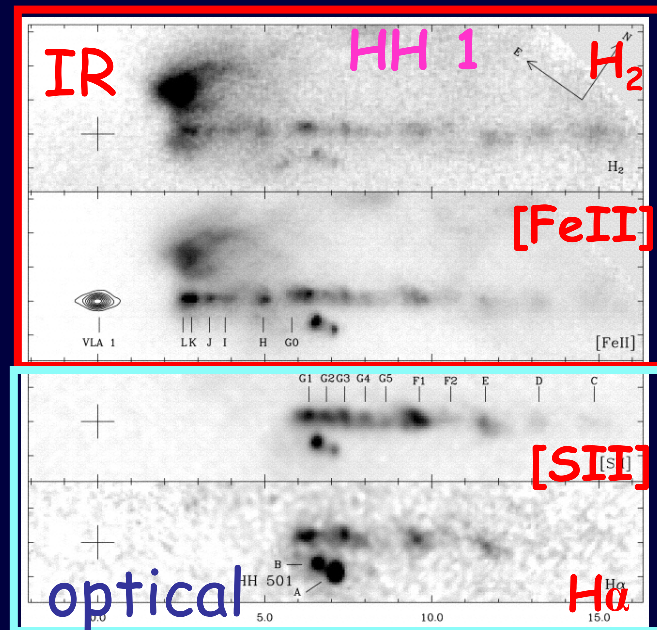
- Wavelengths from near-IR to sub-mm
- Ground-based and space facilities



Davis et al. 2008

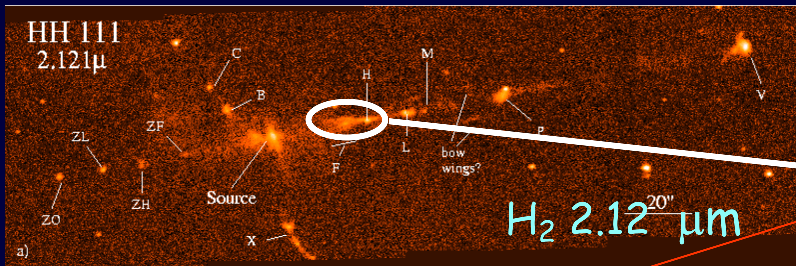


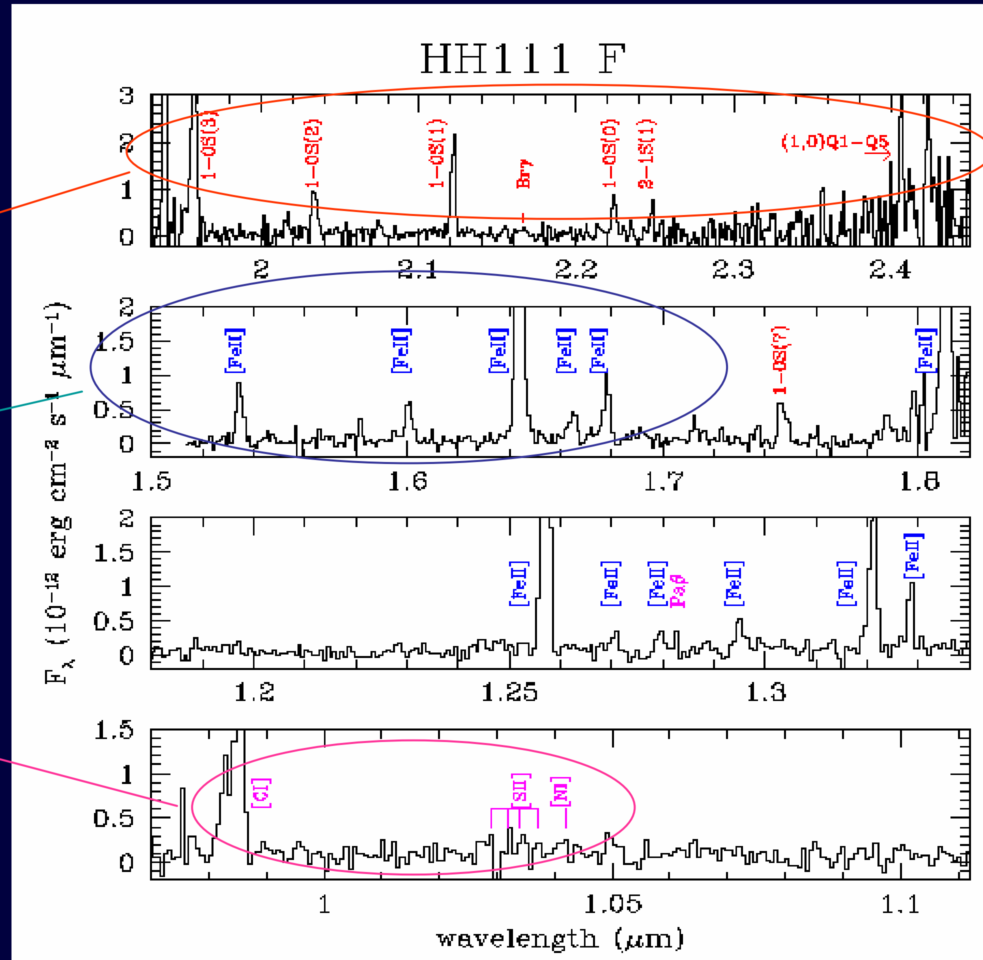




Reipurth et al. 2000

Jets: diagnostics from IR spectroscopy





H2 ro-vibrational lines

[FeII] lines

[CI], [SII], [NI] lines

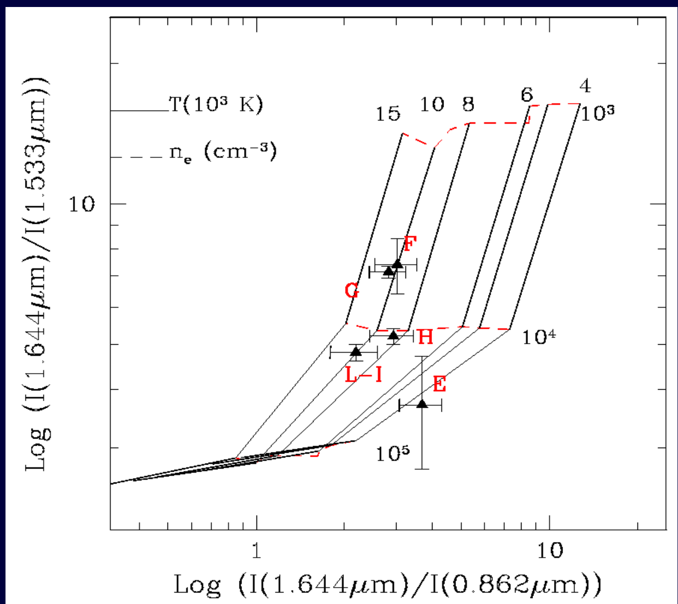
Near IR spectra provide diagnostics on both ionized and molecular gas excited in jets

(Nisini et al. 2002)

The ionized gas: diagnostics with [FeII] lines

•NIR lines: T_e ~ 8-15 10^3 K

n_e ~ 10^3 - 10^5 cm^{-3}

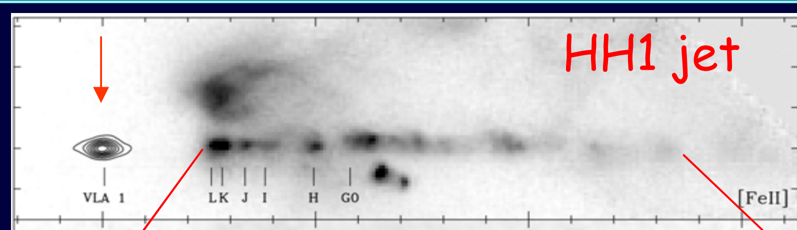


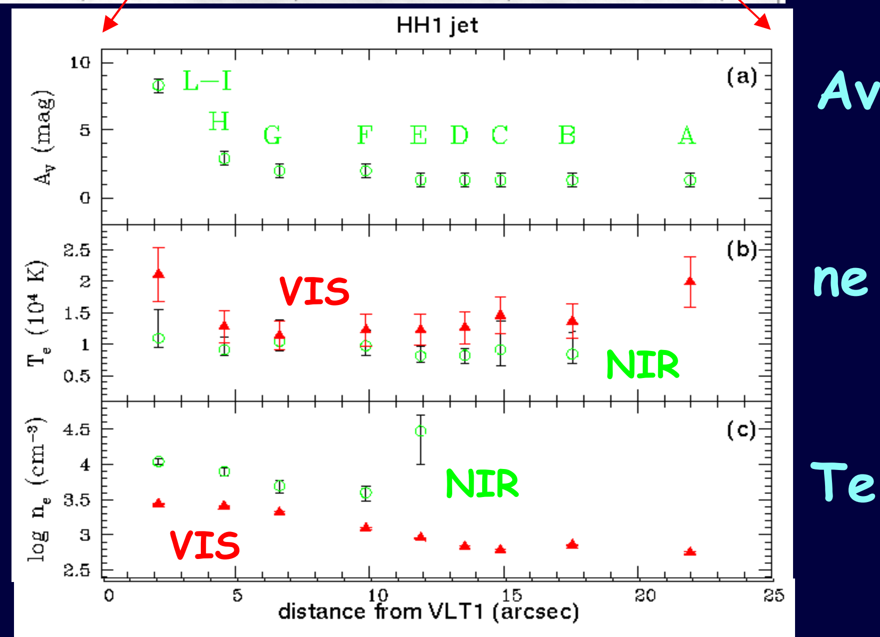
Nisini et al. 2005

The HH1 jet case

- Optical diagnostics from Bacciotti & Eislöffel (1999)

- IR diagnostics: [FeII] lines





Class 0/I atomic jet properties vs T Tauri

Analysis combining optical and IR lines

From optical SII/OI/NII lines — From FeII lines

	Jet	n_e (10^3 cm^{-3})	x_e	T_e (10^3 K)	n_H (10^3 cm^{-3})	n_e (10^3 cm^{-3})	T_e (10^3 K)
Class 0/I	HH 111	1.0	0.10	13.0	11.3	2.6	7.3
	HH 34	0.8	0.04	13.8	16.2	1.8	5.8
	HH 1	2.0	0.05	12.0	36.6	5.7	9.8
T Tauri	HH 83	0.5	0.38	17.5	0.9	-	-
	HH 73	0.6	0.31	17.5	1.7	-	-
	HH 24 C/E	0.4	0.32	19.3	1.3	-	-

(Podio, Bacciotti, Nisini et al. 2006,
Nisini,Bacciotti, Giannini et al. 2005)

Class I jets are heavier and less excited than T Tauri jets

Mass flux

If $\dot{M}_j/\dot{M}_{acc}$ ~ const. during evolution

$\dot{M}_j$ of class 0/I expected to be higher than in T Tauri

Mass flux measured from the luminosity of optically thin infrared lines

•From [FeII]1.64um line

Following Hartigan et al. 1995

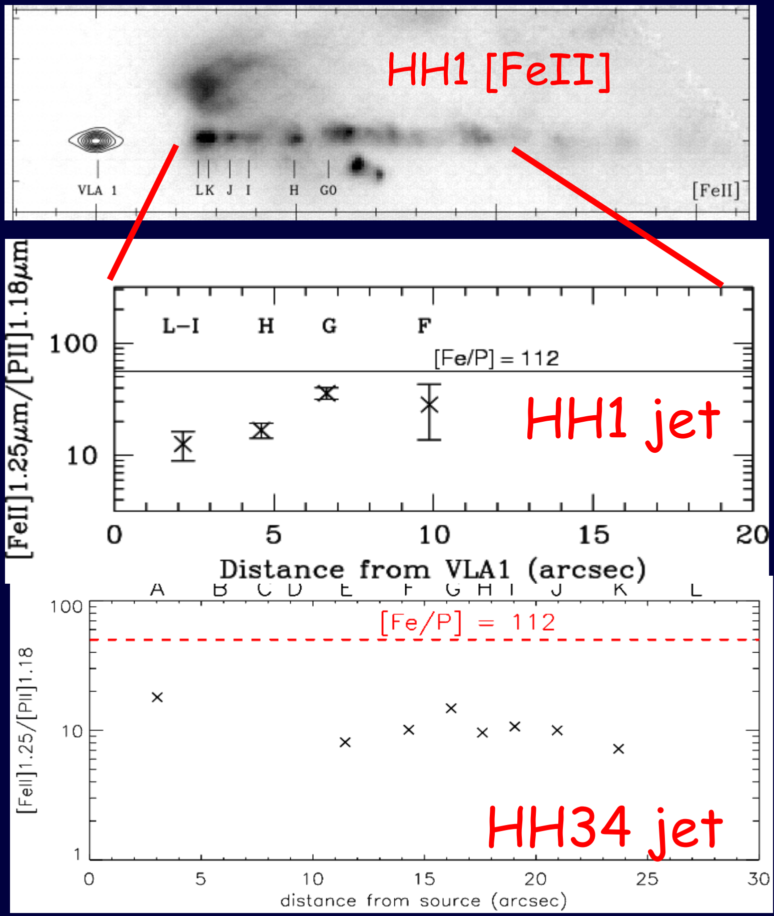
$$\dot{M}_{jet} = \mu m_H \cdot (n_H V) \cdot v_t / l_t$$

$$n_H V = L_{1.64\mu m}/(\varepsilon_{1.64\mu m}(ne,Te) \cdot X(Fe))$$

Values in the range 10^{-8} - 10^{-6} Mo/yr

(Nisini et al. 2005, Podio et al. 2006, Davis et al. 2003, Garcia Lopez et al. 2008)

Fe abundance in jets



(Nisini et al. 2005, Podio et al. 2006)

X(Fe) critical parameter in mass flux calculations

→Iron is usually depleted on grains

→abundance in gas-phase of refractory elements depend on the **amount of dust in jets, shock velocity and grain composition**

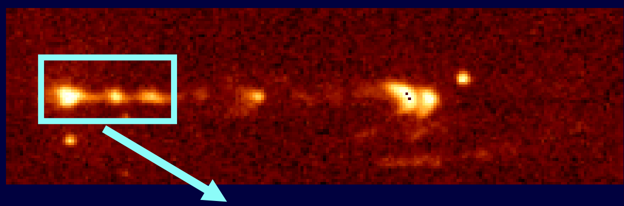
in the NIR a very sensitive ratio is [FeII]1.25um/[PII]1.18um (Oliva et al. 2001)

[FeII]1.25um/[PII]1.18um ~X(Fe/P)/2 =56

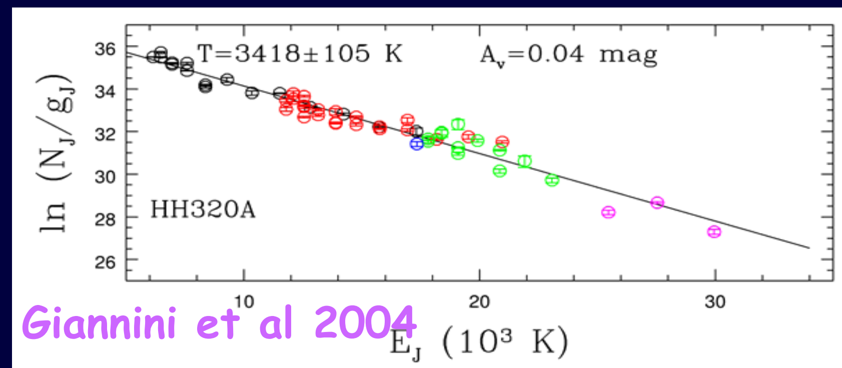
Up to 80% of Iron may be depleted in jet beams

Mass flux from H_2 emission

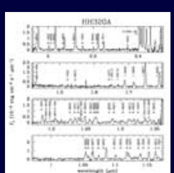
If the jet is fully molecular..



$N(H_2)$ derived from the Boltzman diagram



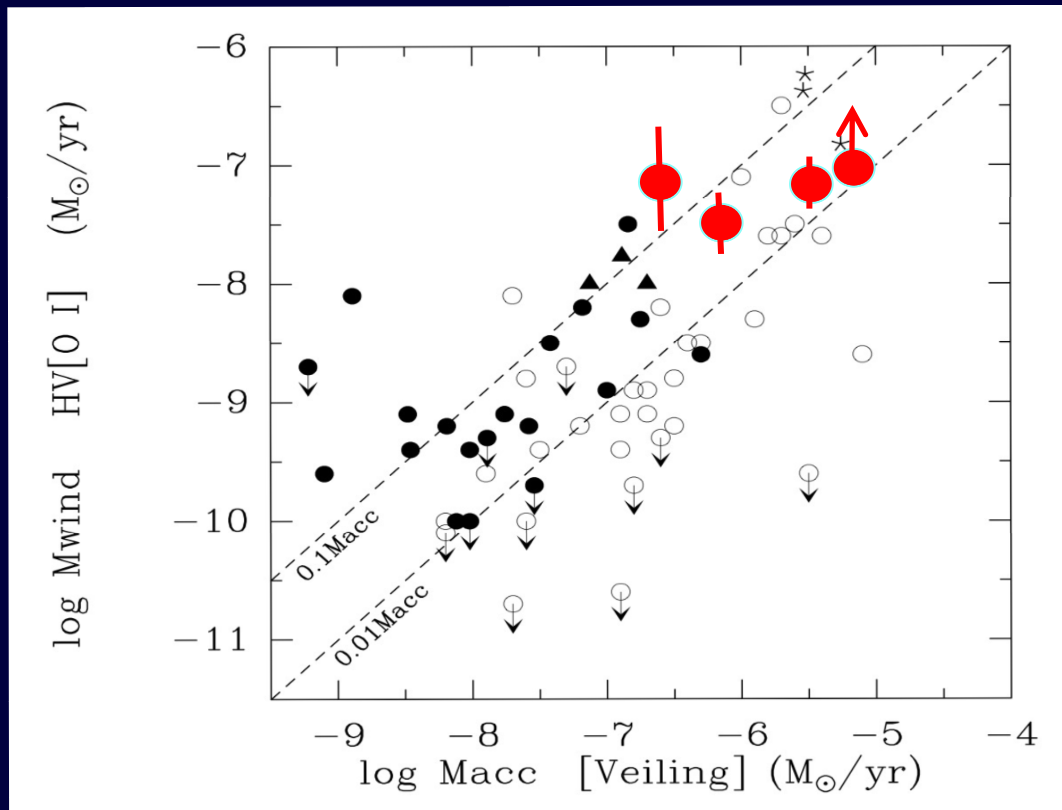
From $N(H_2) \rightarrow M_{jet} = M_{H2} * v_t / l_t$



Limits: underestimate M_{jet} if a colder molecular component dominates

Accretion vs ejection mass flux

Cabrit, 2002

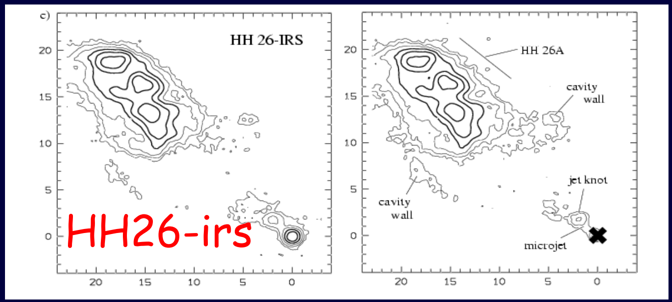


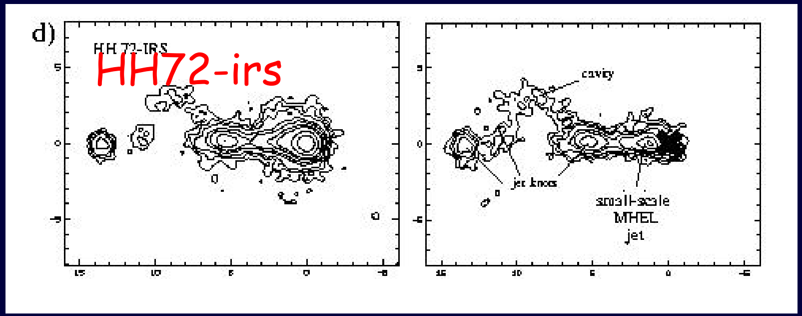
Class I accretion rates from Antoniucci et al. 2008

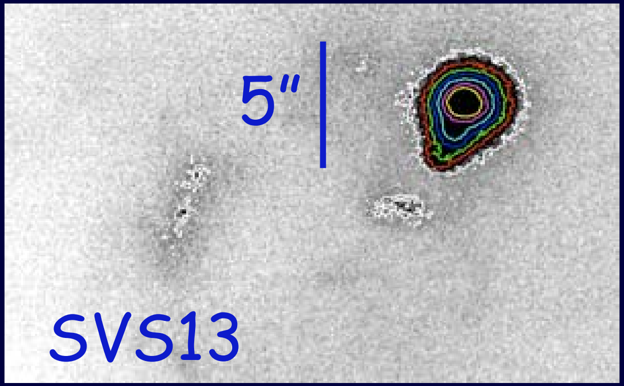
T Tauri data from Gullbring 1998, Hartigan 1995

Getting closer: Class I micro-jets

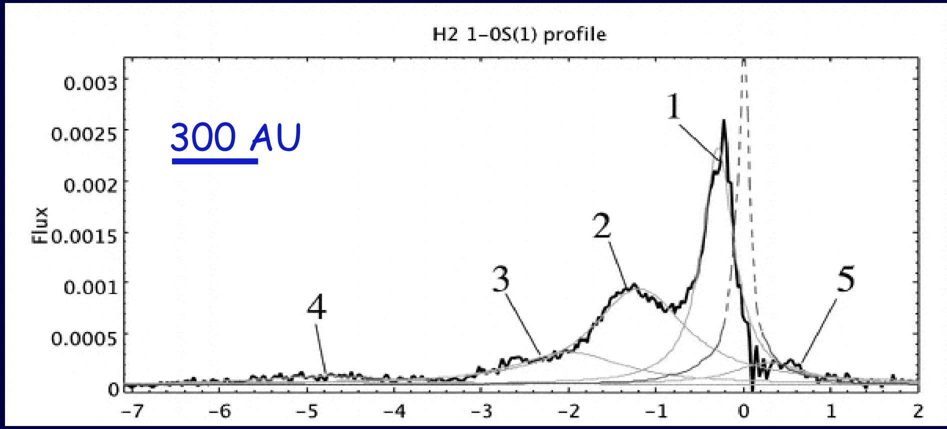
Molecular Hydrogen Emission Line (MHEL) regions : H2 microjets
Davis et al. 2001





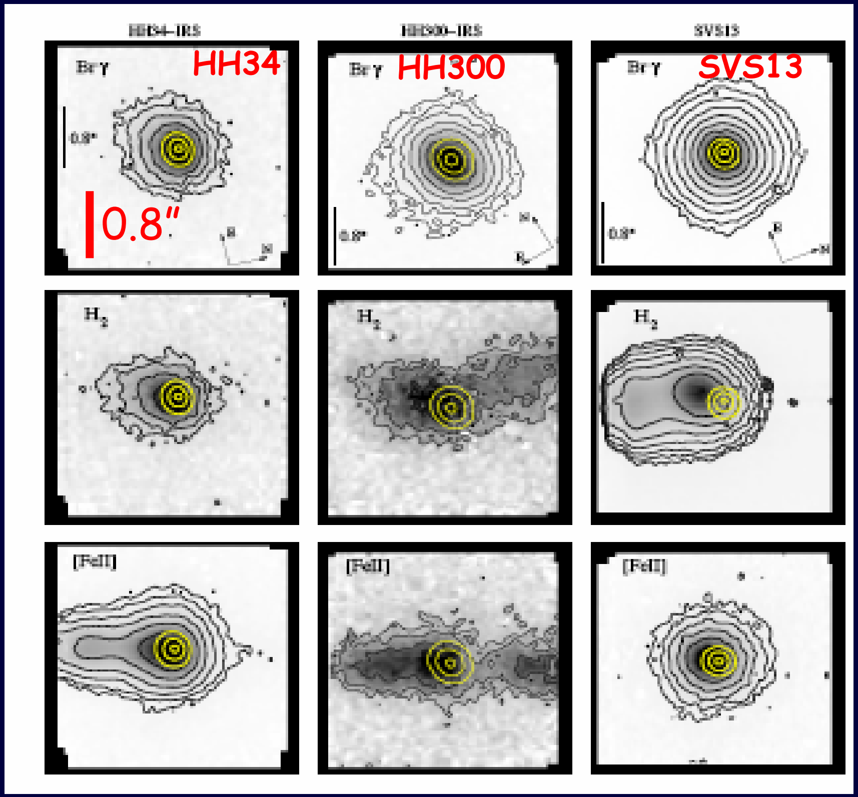


Intensity profile from AO assisted NACO observations



Davis, Nisini, Takami et al. 2005

Show up in both atomic and molecular components

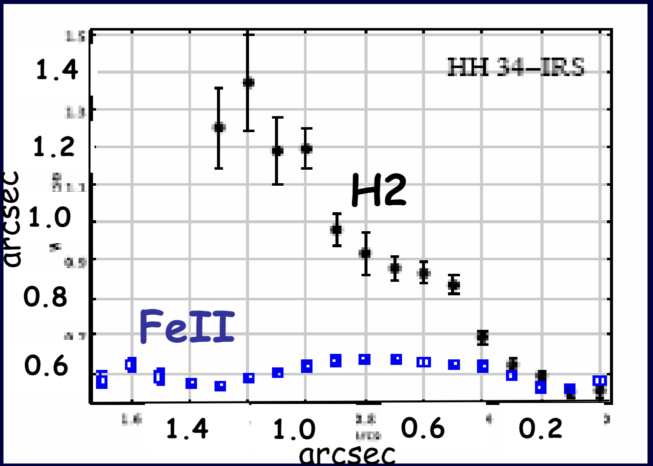


IFU Sinfoni seeing limited observations

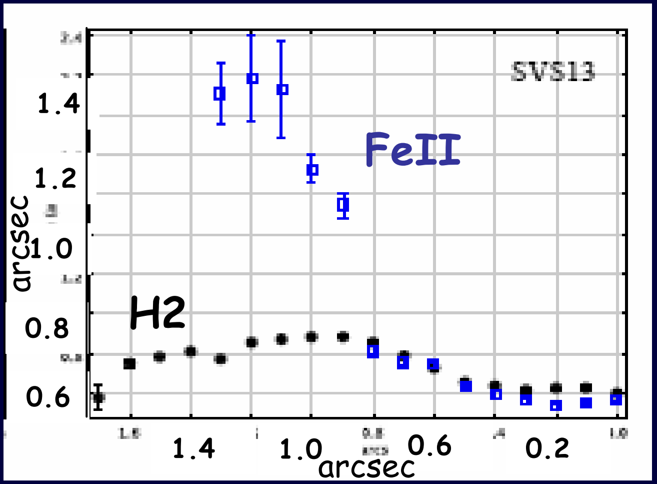
(Davis et al. in prep.)

Jet diameter

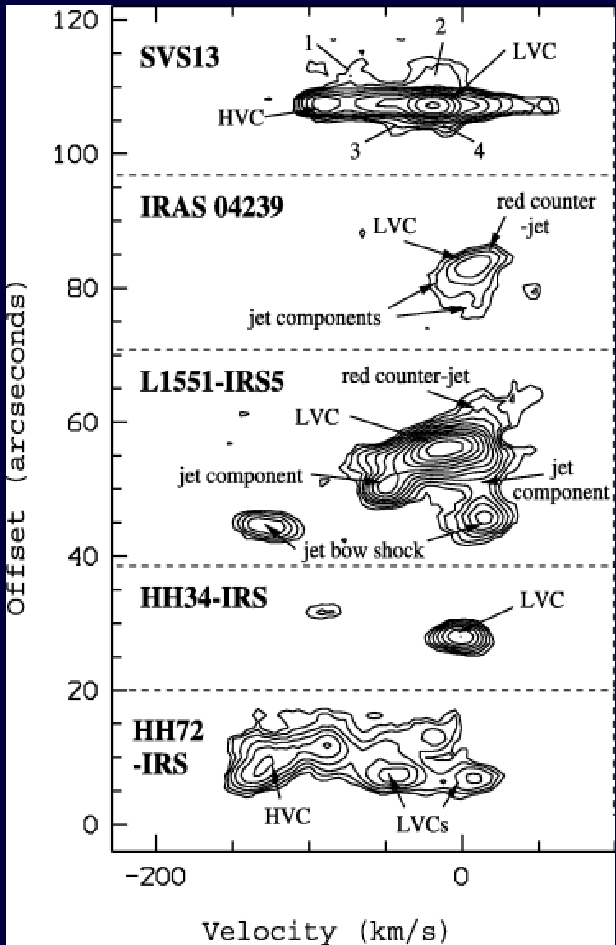
HH34



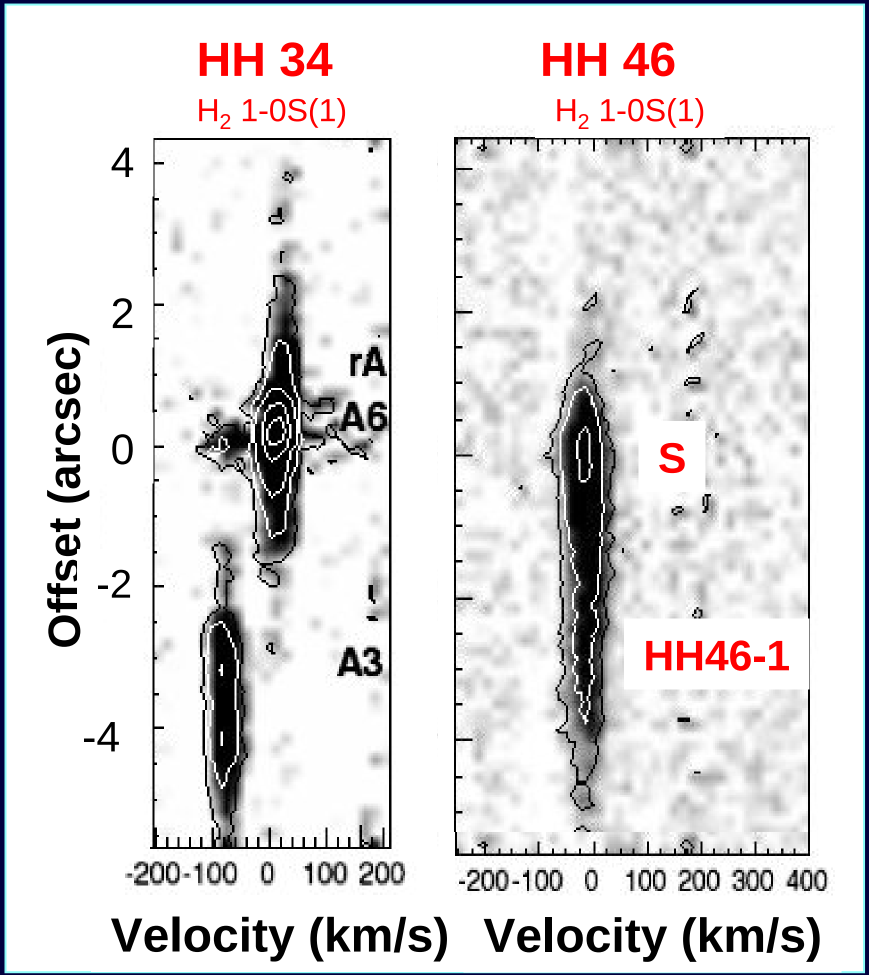
SVS13



Micro-jets kinematics



Davis et al. 2001



Garcia Lopez et al. 2008

NOT CLEAR ORIGIN:

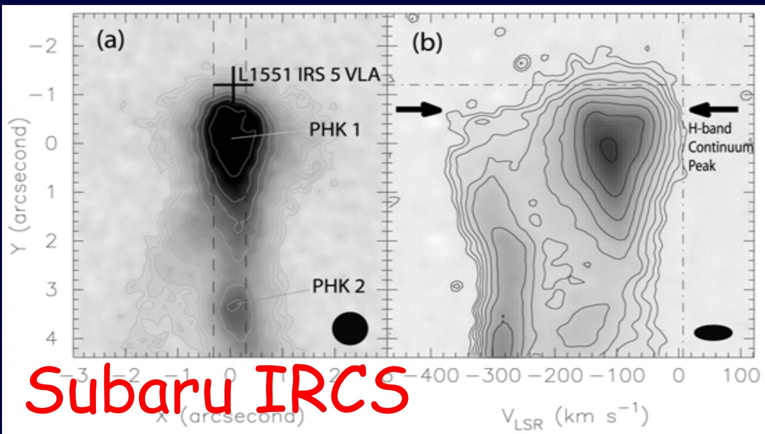
- MOLECULAR SURVIVAL IN DISK-WINDS
- ENTRAINMENT OF AMBIENT MATERIAL
- SHOCK INTERACTION

➔LACK OF MODELS FOR MHEL REGIONS

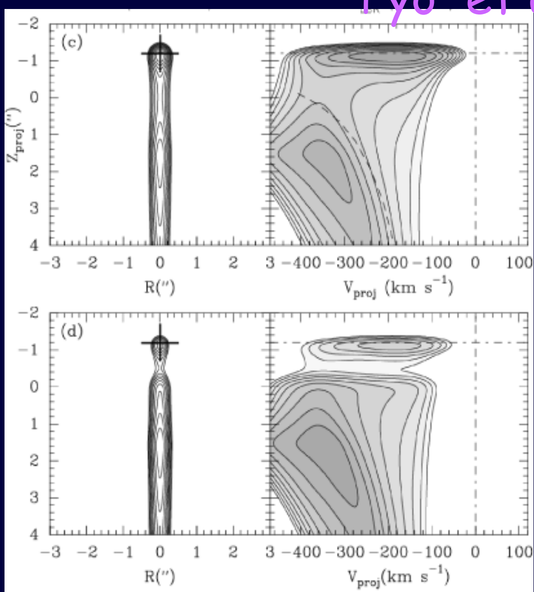
Atomic jet kinematics

L1551 IRS5 jet

[FeII]1.64um



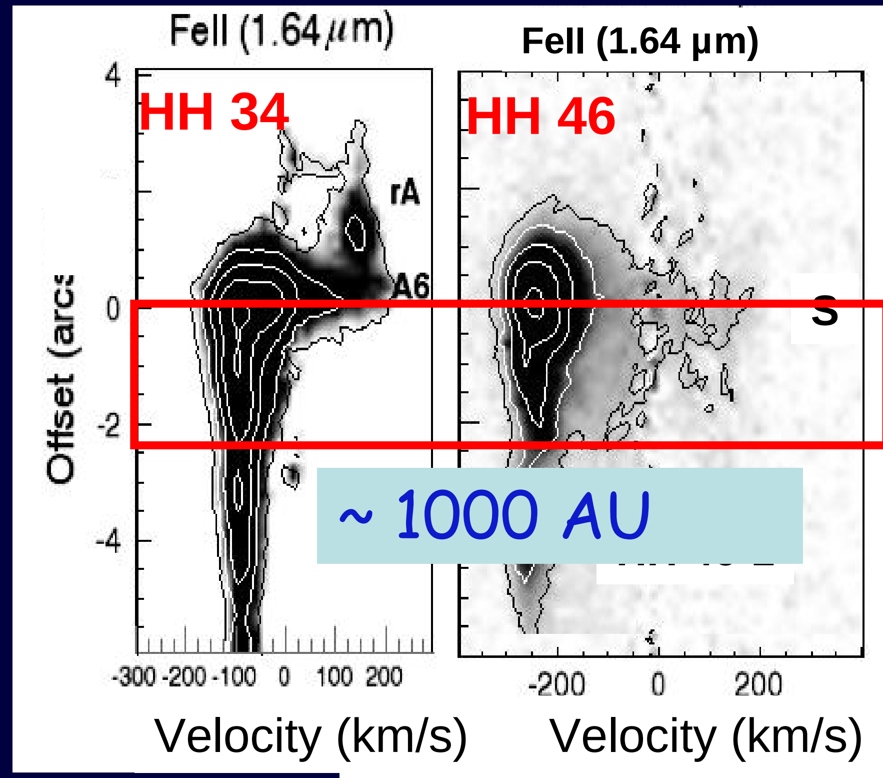
Pyo et al. 2002



Pesenti et al. 2003

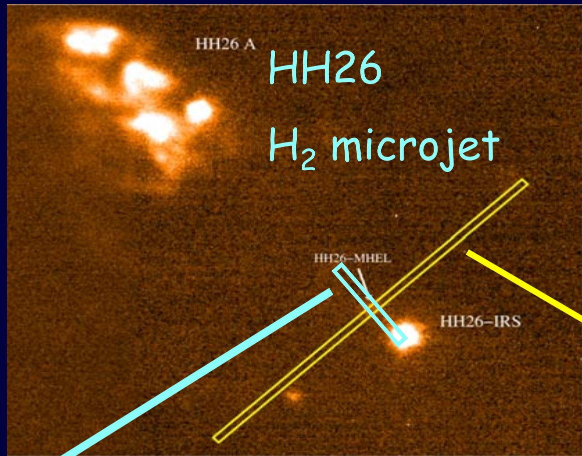
Disk-wind FeII synthetic PV

Garcia Lopez et al. (2008)
VLT-ISAAC obs.



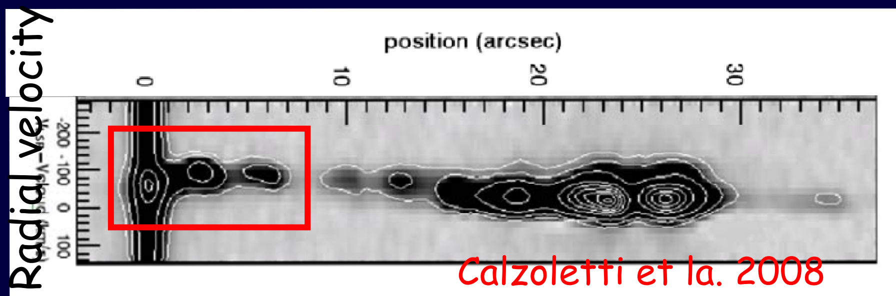
n_e (LVC) > n_e (LVC)

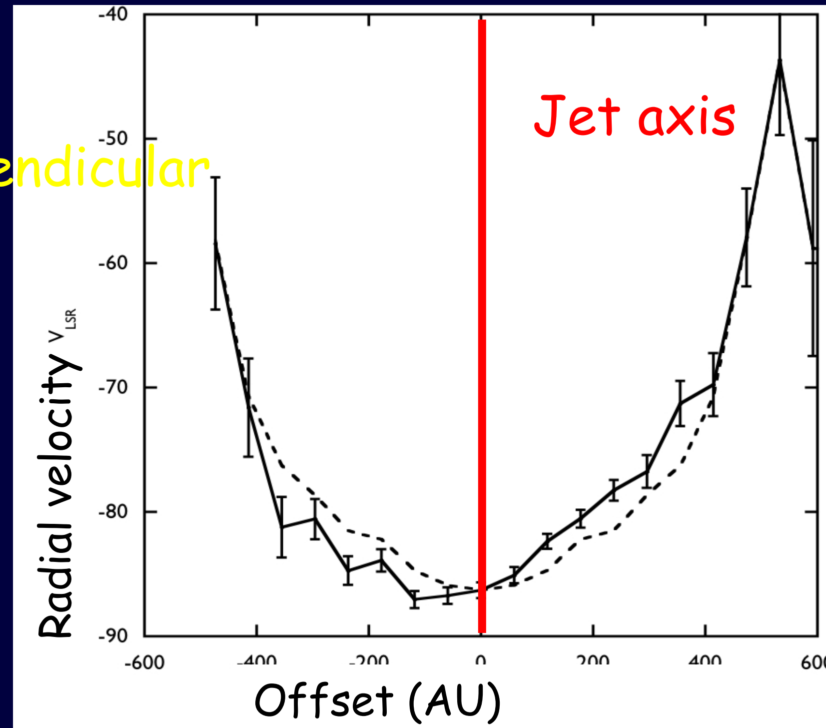
Do jets from Class I rotate ?



Slit parallel to axis

Slit perpendicular to axis





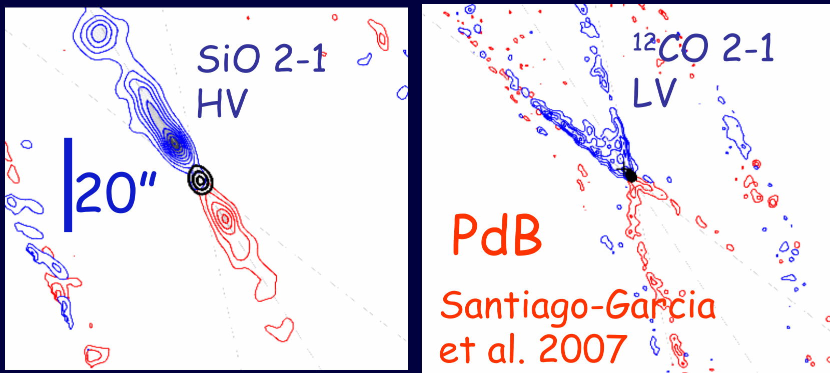
Crysostomou, Bacciotti, Nisini et al. 2007

- $v\phi \sim 2\text{-}4$ km/s
- taking $\dot{M}_{acc}$ and $\dot{M}_{ej}$ rates from Antoniucci et al. (2008)

$\dot{L}jet \sim 70\%$ of the excess angular momentum for disk accretion

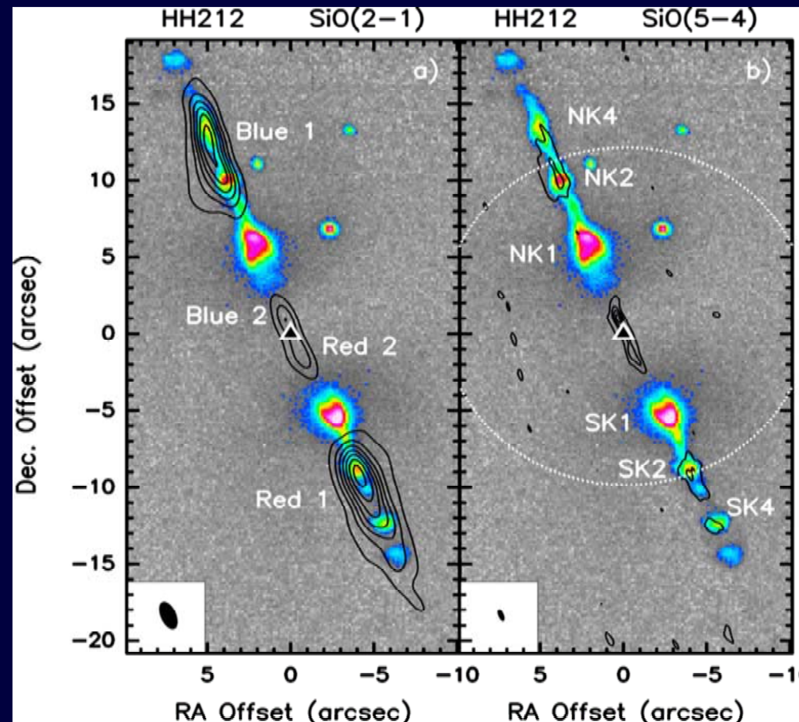
Class 0 SiO jets

IRAS04166+2706

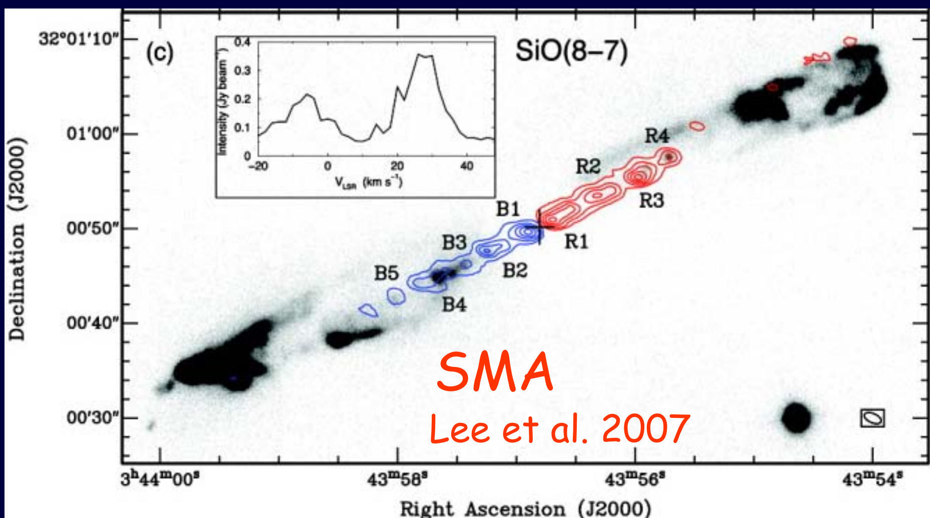


HH212

PdB Codella et al. 2007

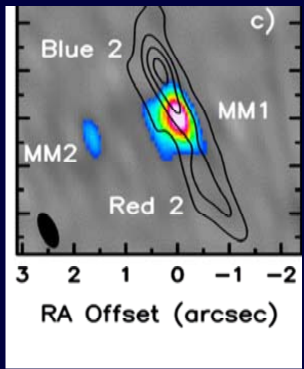


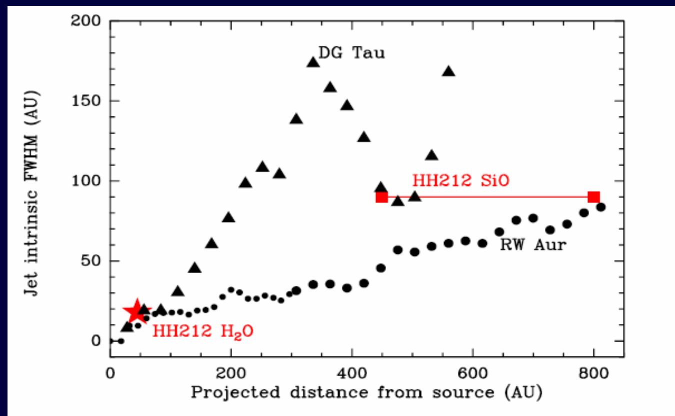
HH211



- Jet diameter less than ~0.3"
- Dynamical times of the inner knots only 20-30 yrs

SiO jets:similarities with ClassI/II micro-jets





HH212 Cabrit et al. 2007

•Collimation

Jet diameter at 500 AU ~ 100 AU, I.e. similar to those found in T Tauri jets

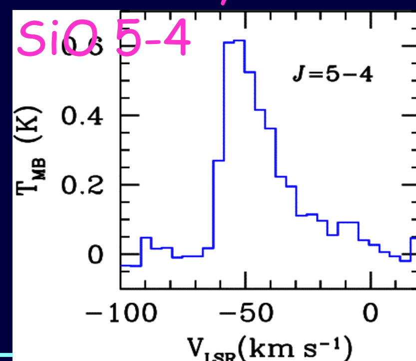
•Kinematics

Typical velocities of ~ 150-200 km/s, I.e. half of those in T Tauri. Consistent with the lower escape speed in less massive sources

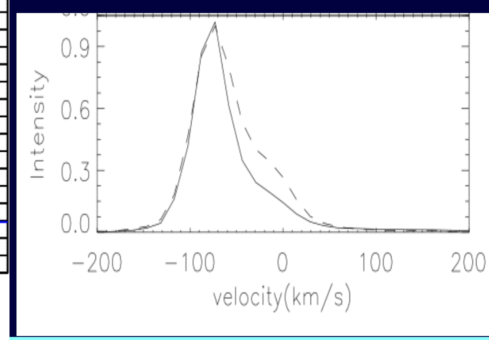
•Line profile

High velocity peak and lower velocity wings

L1448 B1, SiO 5-4



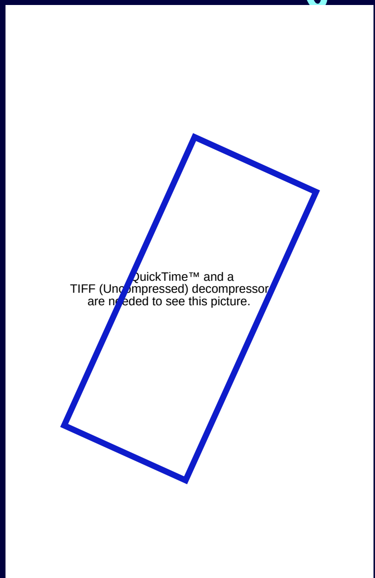
HH34 FeII 1.64um



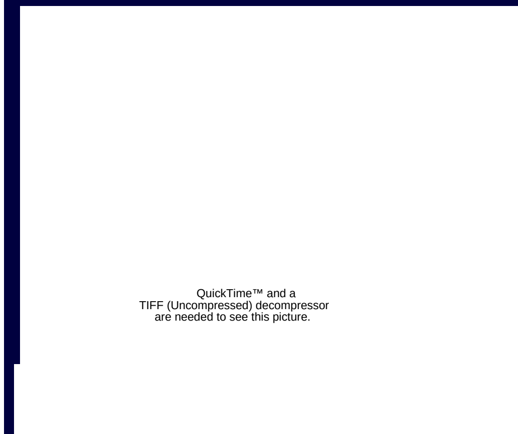
SiO and CO excitation

L1448-mm jet

Multi-transition LVG analysis



(Guilloteau et al. 1992)



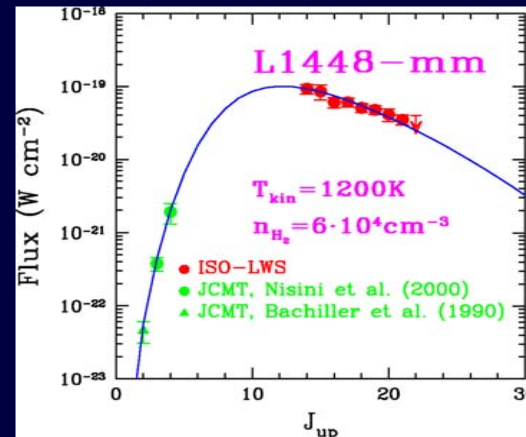
Nisini et al. 2007

IRAM, JCMT

SiO J=2 to J=11

ISO-LWS

CO up to J=22



Nisini et al. 2000

T_{kin} ~ 300-1200 K, n(H2) ~ 10^5-10^6 cm^{-3}

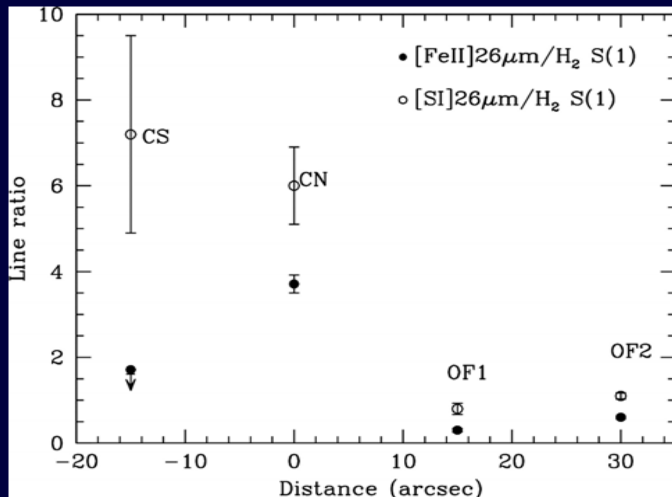
- gas excitation in the jet due to shocks with v ~ 30-50 km/s (Gusdorf et al. 2008)

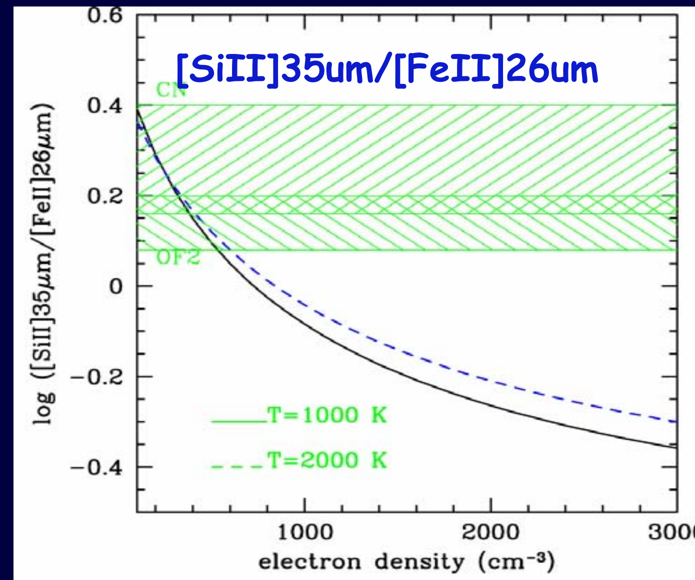
Excitation: Spitzer

L1448 (Bally et al. 1993)

(Dionatos et al. 2008)

Atomic jet at low excitation embedded in the molecular jet

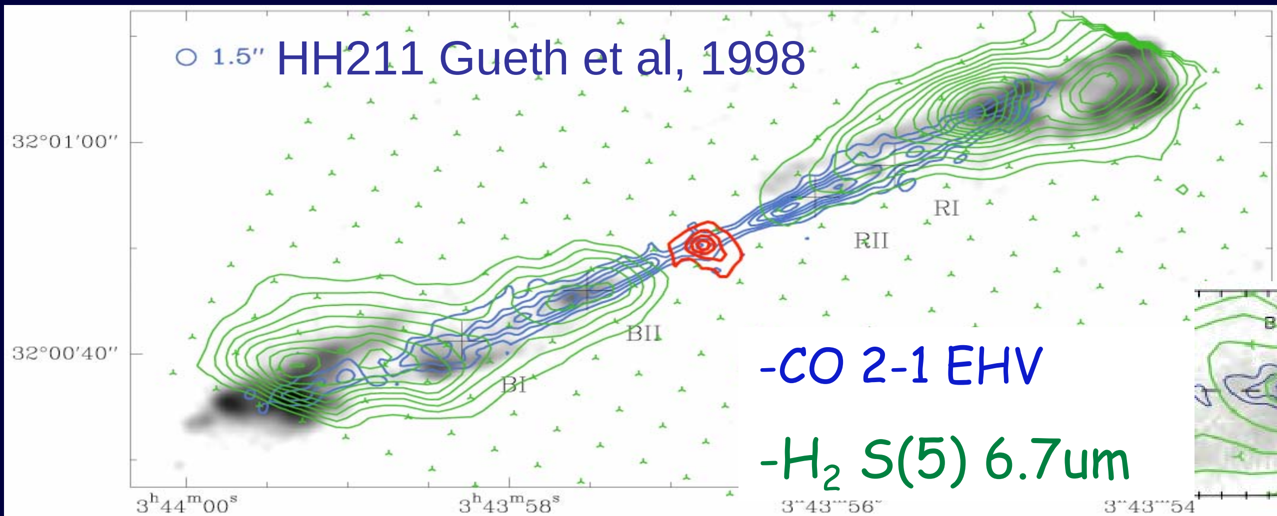




- T < 2500 K
- Ne ~ 300-500 cm^{-3}
- Xe <~ 5 10^{-3}

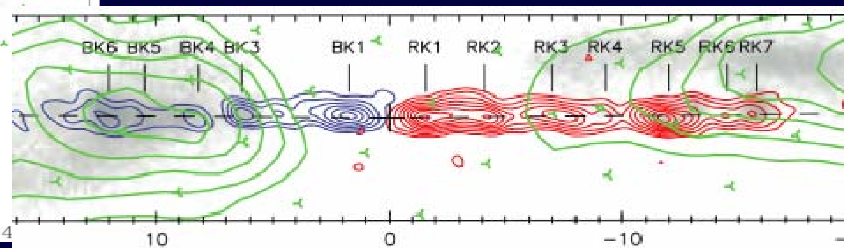
Mass flux carried by the atomic component ~ 10^{-6} Mo/yr

Excitation: Spitzer

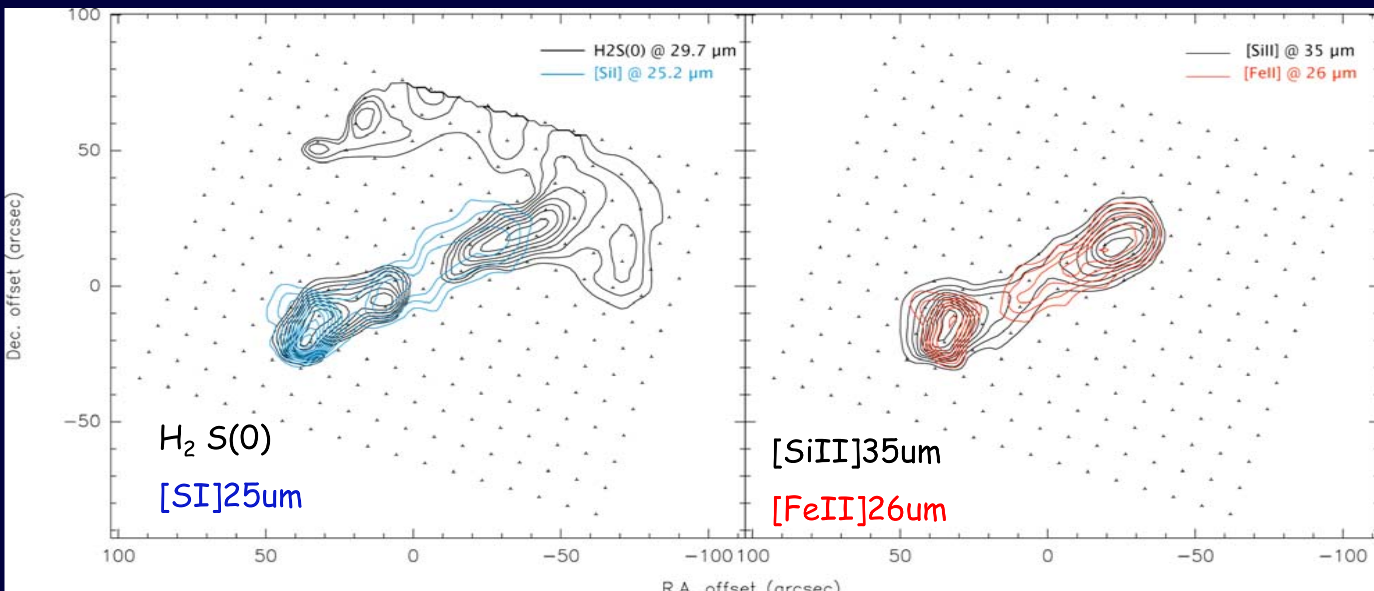


IRS 5-35um maps of the HH211 jet

Dionatos et al. in prep.



Lee et al., 2007 SiO



Future prospects

- Enlarge the statistics: only an handfull of class 0/I jets are so far studied

- Probe the jet base with high-angular resolution IR observations
  - Problem to apply AO systems in embedded sources!
  - SINFONI with LGS
  - JWST
  - ALMA
- Probe the missing components:
  - Herschel: [OI] 63um line

- Needs for model predictions to be observationally tested !