JET Simulations, Experiments and Theories

Protostellar jets driven by intermediate- and high-mass protostars: an evolutionary scenario?

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MARIE CURIE ACTIONS

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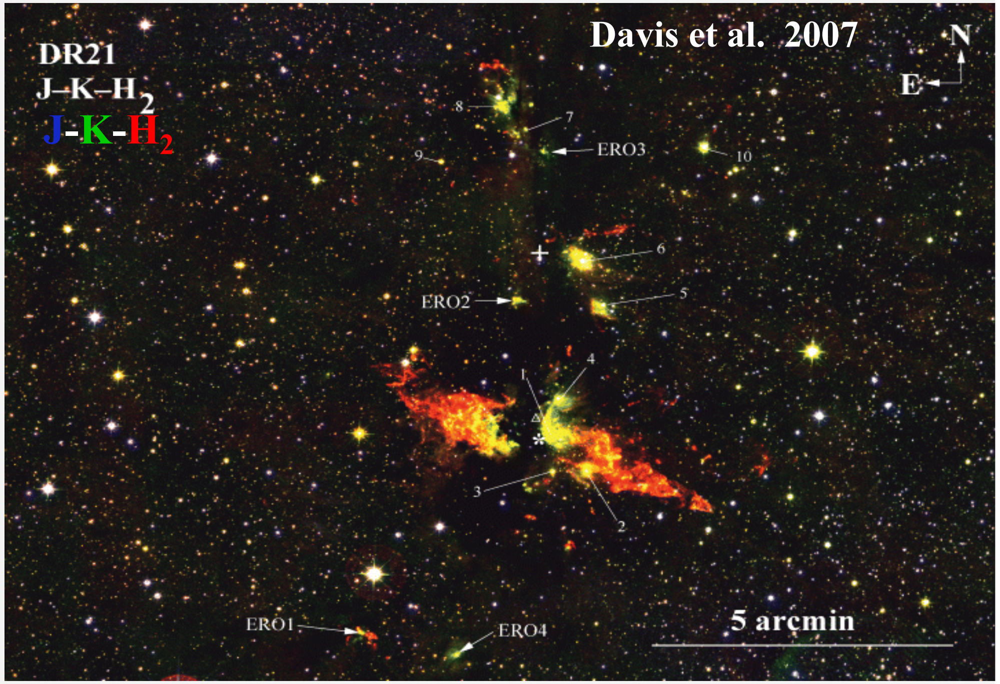
Outline

- **Introduction:**
  - Intermediate- & high-mass jets in context
- **Observations of IRAS 20126+4104 jet**
- **Results**
- **Discussion:**
  - Comparing low-mass & high-mass jets
  - An evolutionary scenario?
- **Conclusions**

High-mass jets in context

Massive outflow & jet study is still in its infancy

- **Observational constraints:**
  - distance
  - clustering
  - high extinction
  - short MYSO lifetime
  - → few HM jets known
  - → surveys needed
    (see Stecklum's poster!)
  - →3 spectroscopically studied
    - → IRAS 18162-2048 (Davis et al.2004), IRAS 11101-1208 (Gredel 2006), IRAS 20126+4104 (Caratti o Garatti et al. 2008)



- **Importance:**
  - insights on high-mass star formation:
    - disc origin or coalescence? higher accretion/ejection rates?

Low- vs high-mass flows

LM jet/outflow characteristics

Morphology:

Collimated & bipolar

Dimension: few AU–some pc

Small precession: ≤ 10°

Velocity: 10-500 km/s

$\dot{P}_{out}$: 10^{-5} $M_{\odot}$/yr

$\dot{M}_{out}$: 10^{-7}-10^{-6} $M_{\odot}$/yr

Density: $10^{2}\div10^{6}$cm^{-3}

Temperature: 10^{2}-10^{4}K

A_v: 0–40 mag

Line emission:

Hα, [SII], H_2, [FeII]

Time evolution: yes

HM jet/outflow characteristics

Morphology:

Not well collimated

Dimension: few AU–few pc

Large precession: up to 45°

Velocity: 10- ? km/s

$\dot{P}_{out}$: 10^{-4}-10^{-2} $M_{\odot}$/yr

$\dot{M}_{out}$: 10^{-5}-10^{-2} $M_{\odot}$/yr

Density: $10^{4}\div10^{6}$cm^{-3} ?

Temperature: 10^{2}-10^{4}K ?

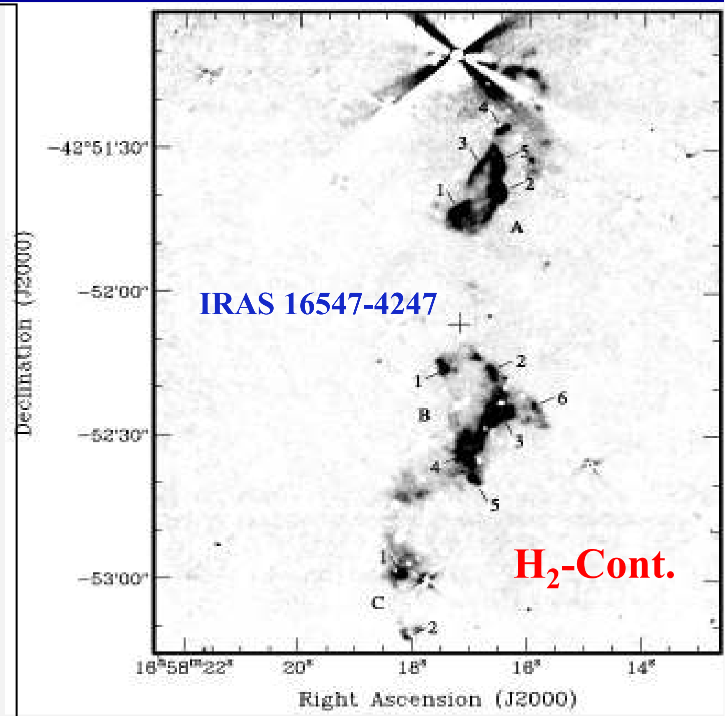
A_v: 10–100? mag

Line emission:

Hα, [SII], H_2, [FeII]

Time evolution: ??

← Beuther & Shepherd 2005



Brooks et al. 2003

I 20126+4104 jet: Observations

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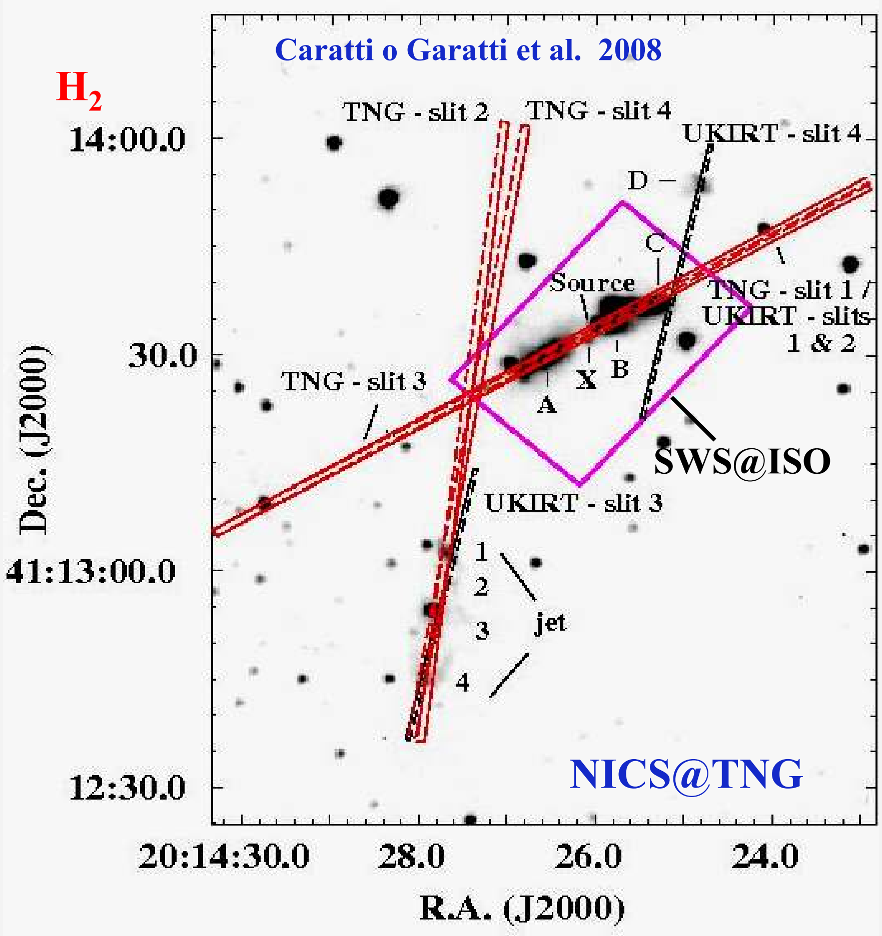
- **IRAS 20126+4104 HMYSO (L_{bol}~10^4 $L_\odot$)**
- **$\dot{M}_{acc}$~$2x10^{-3}$ $M_\odot$ yr^{-1}**
- **Distance 1.7 Kpc. Jet dim. ~ 1pc**
- **Precessing jet ~37°**

- **Imaging :**
  - H_2,K NICS@TNG (5.6’x5.6’, R=0.25”)
  - FeII,H UIST@UKIRT (3.4’x3.4’, R=0.12”)
  - H_2, Br_γ CIAO@Subaru (35”x35”, R=22mas)

- **Spectroscopy :**
  - 0.9-2.5 μm NICS@TNG (R=500)
  - 2.12 μm CGS4@UKIRT (R=18500)
  - 2.38-197 μm SWS/LWS@ISO (R=1000 / 200)



Results: Imaging

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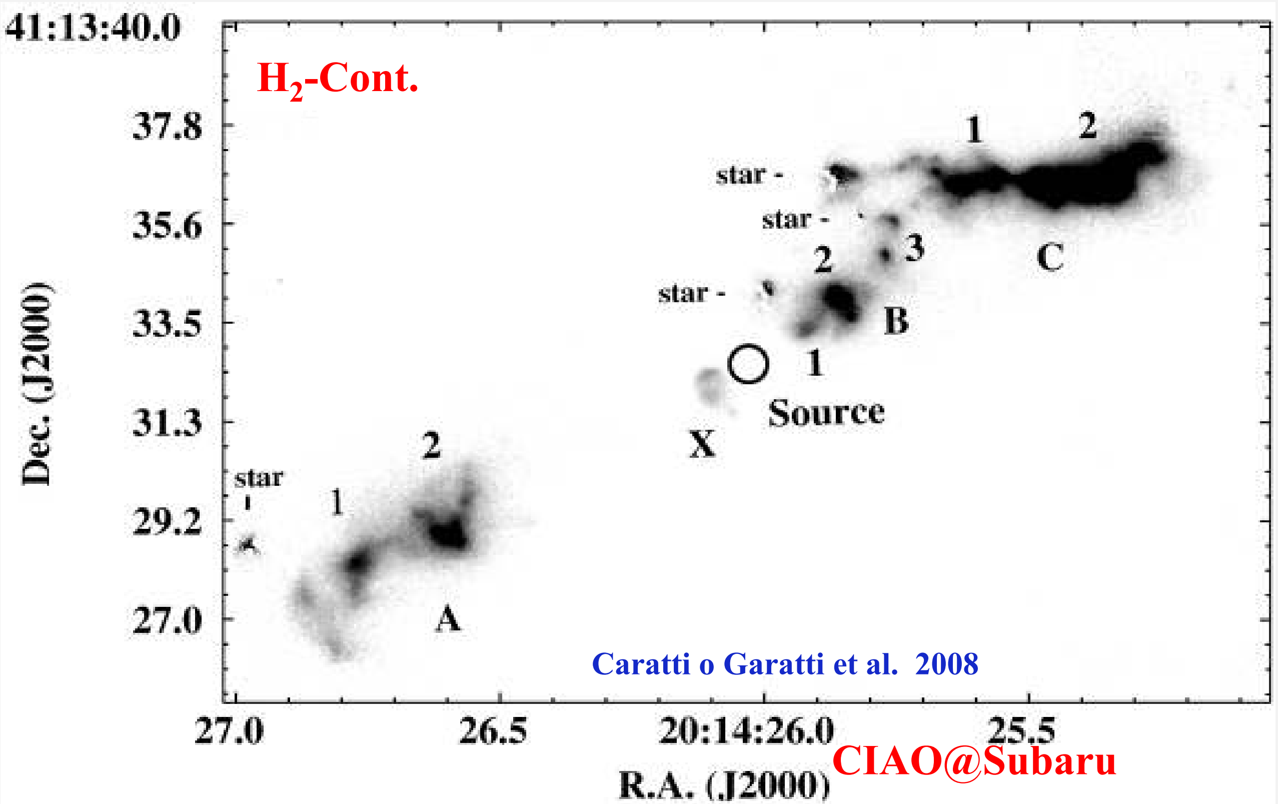
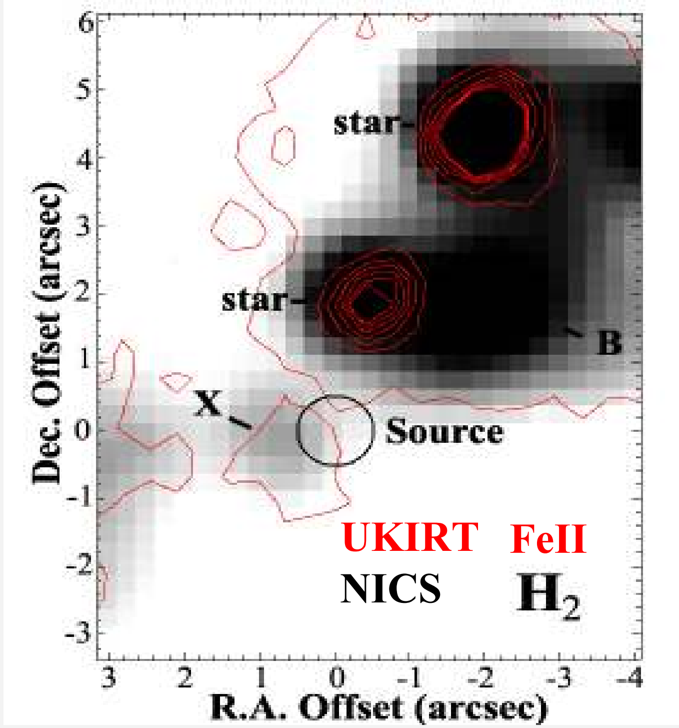
- **Imaging :**
  - Faint FeII emission only close to the Source
  - The jet is mostly molecular!

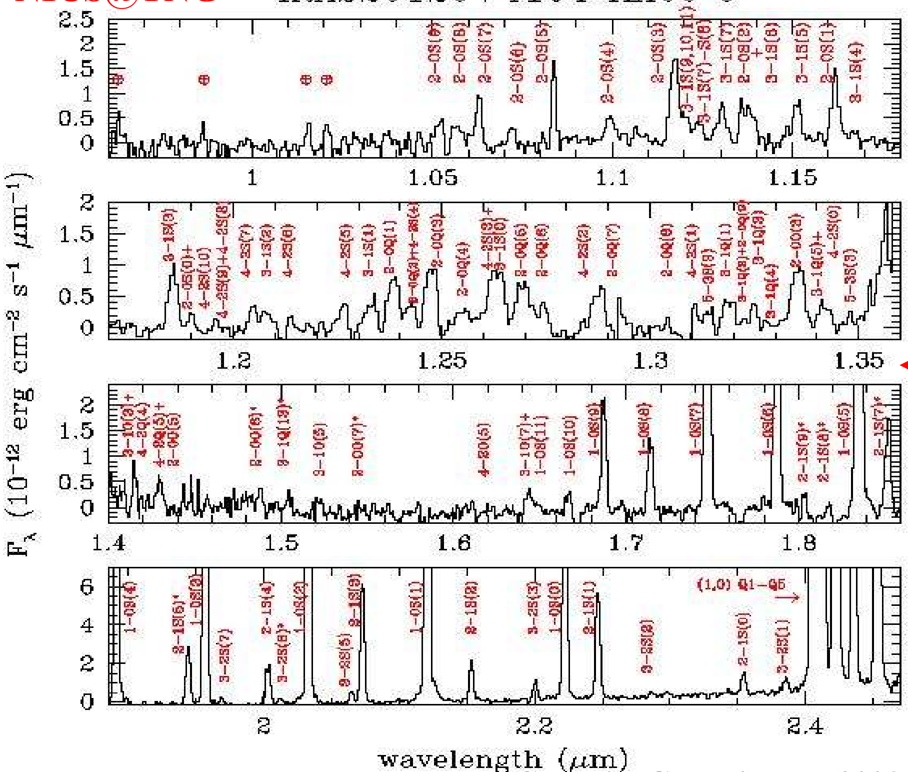




- In addition to the large scale precession, a small-scale one is observed

Low Resolution Spectroscopy

NICS@TNG

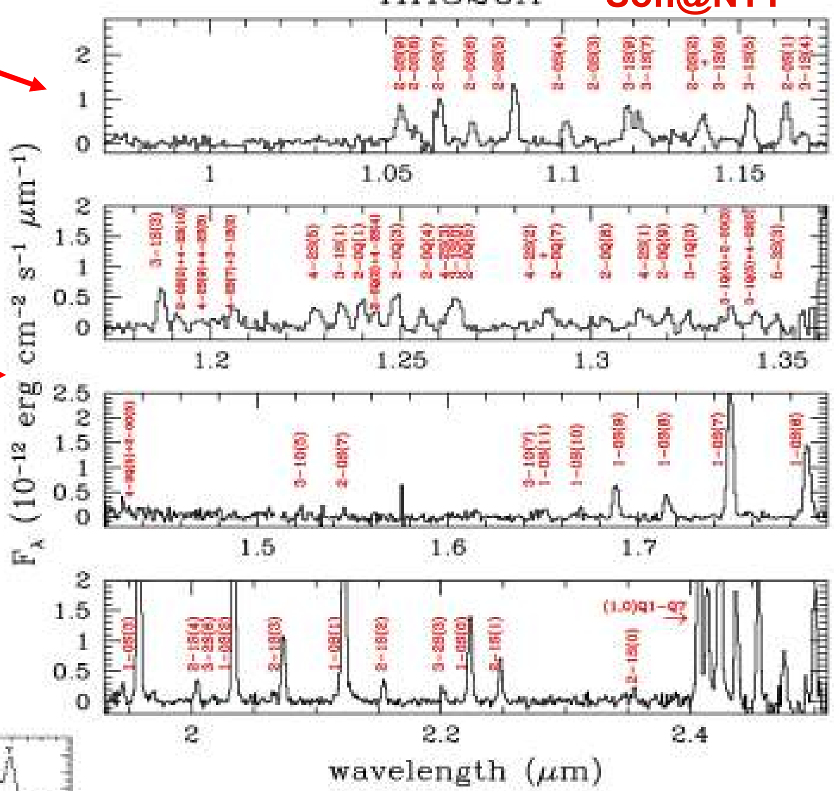


Caratti o Garatti et al. 2008

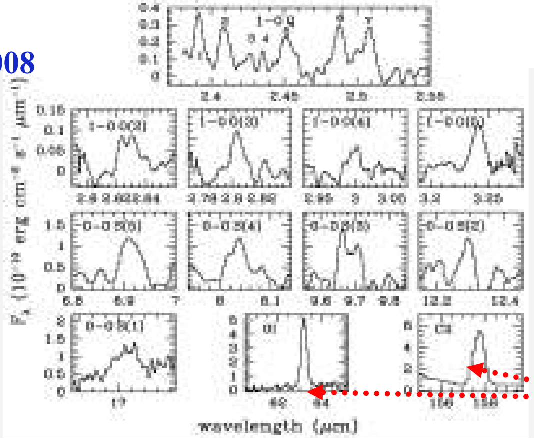
Low mass

Similar!

HH320A Sofl@NTT



Giannini et al. 2004



PDR origin?

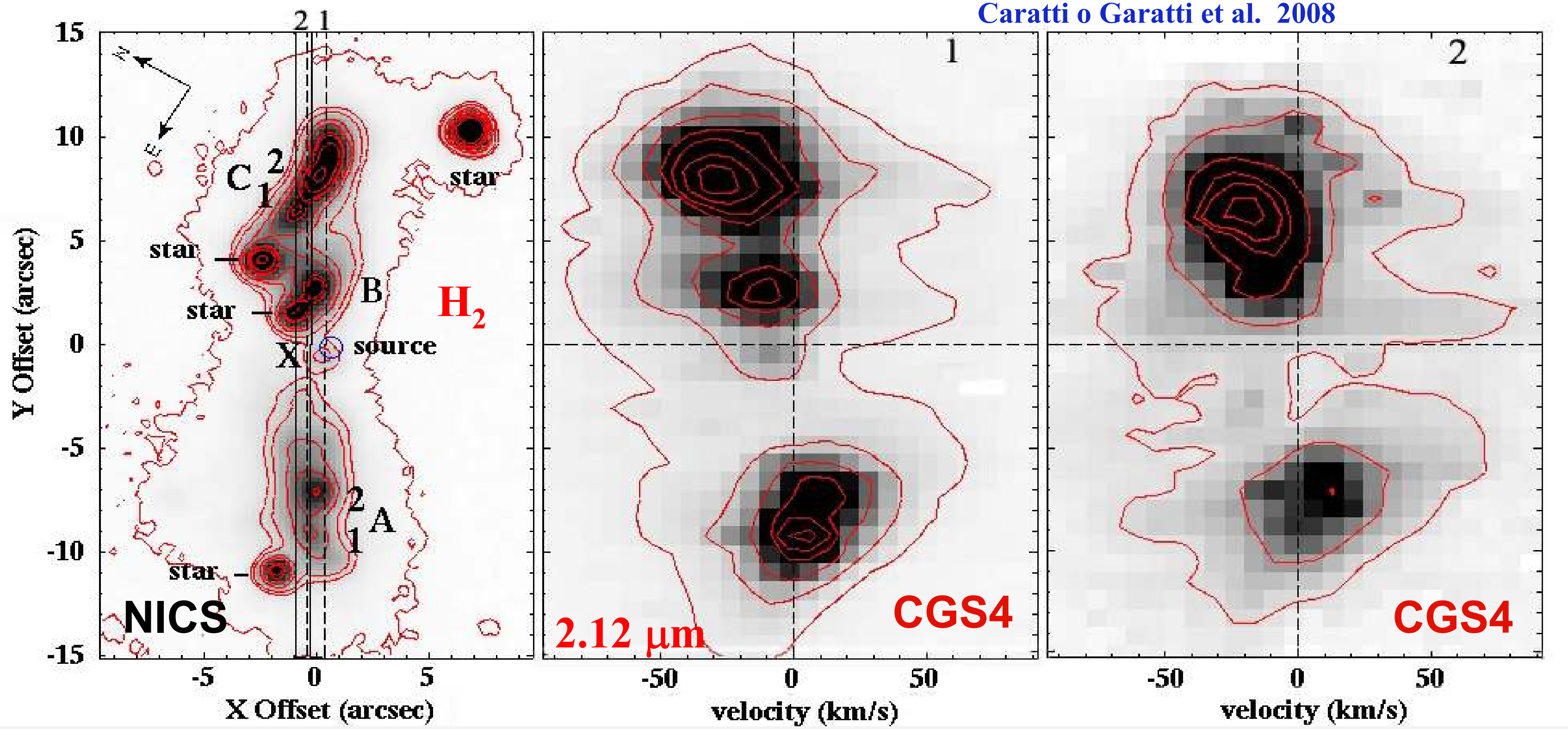
SWS/LWS@ISO

Detected lines:

- NICS: H_2 (red) up to v=5
- faint FeII close to the Source
- SWS: H_2 (1-0 O & Q + 0-0 S)
- LWS: OI (63 μm), CII (158 μm)

Radial velocities

Caratti o Garatti et al. 2008



PV – diagrams close to the Source

- V_{rad}: -14 km/s ÷ -42(blue), -8 ÷ 47 km/s (red)
- Higher velocities found in the outer knots
- FWZI: from ~140 km/s (inner) to ~80 km/s (outer knots) → incl. changes?
- Spatial velocity: between 50 and 80 km/s

Physical Parameters from NIR

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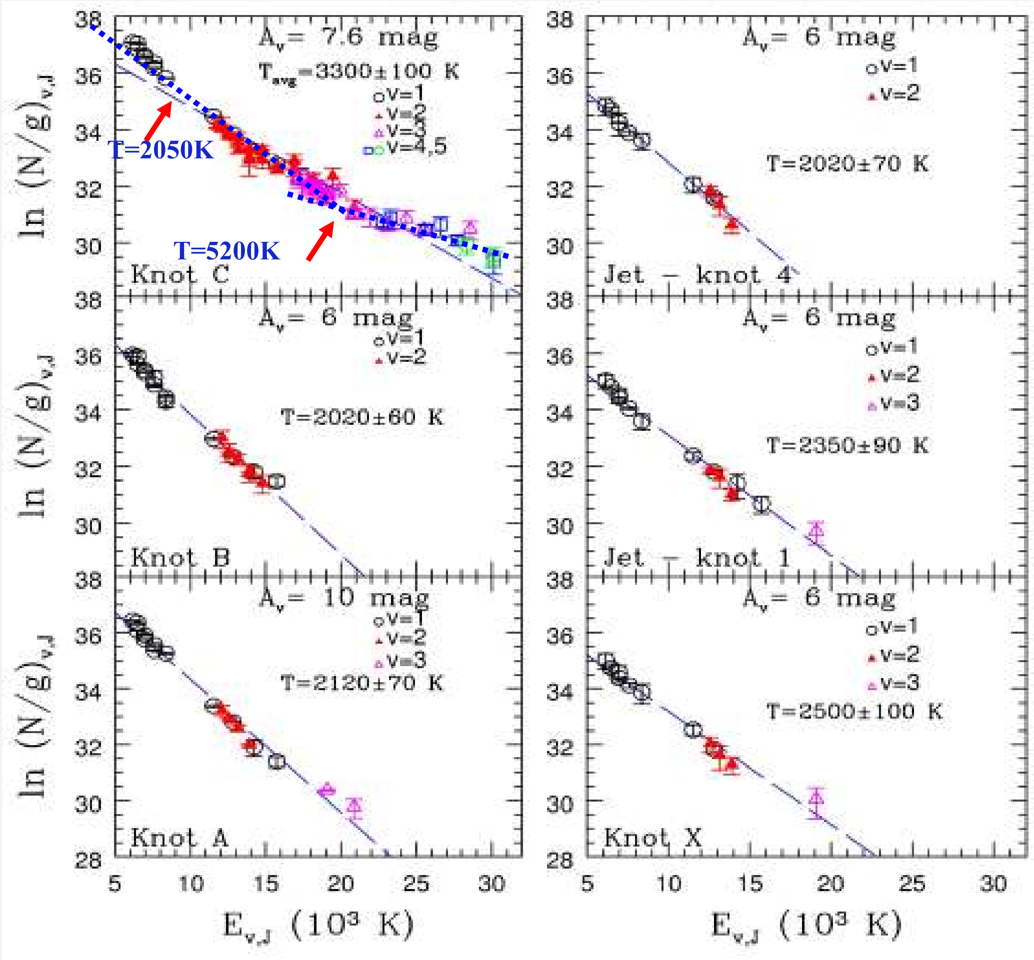
- A_V = 6÷10 mag, $N_{H2}=10^{18}÷10^{19}$ cm^{-2}
- Single T = 2000÷2500 K for all knots, C has 2 comp. T=2050 & 5200 K
  - no evidence of fluorescent excitation in ro-vibrational diagrams
- L(H_2) derived combining A_v, T, and flux 2.12 (imaging) (~3.6 $L_{\odot}$)
- Mass flux rates derived combining N_{H2} and velocity
  - $\dot{M}$: $10^{-8}÷10^{-6}$ $M_{\odot}$/yr - highest value in knot C



Caratti o Garatti et al. 2008

warm component

JeTseT

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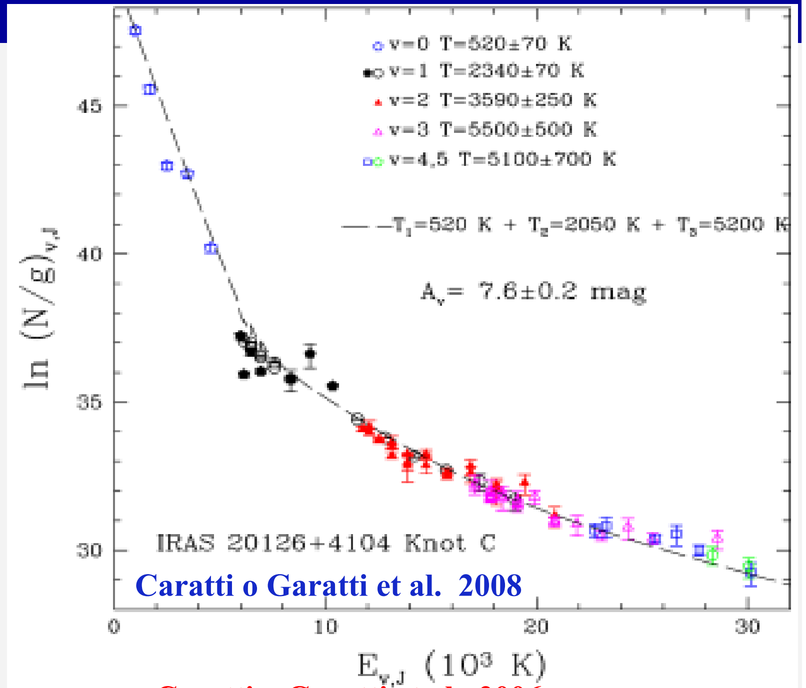
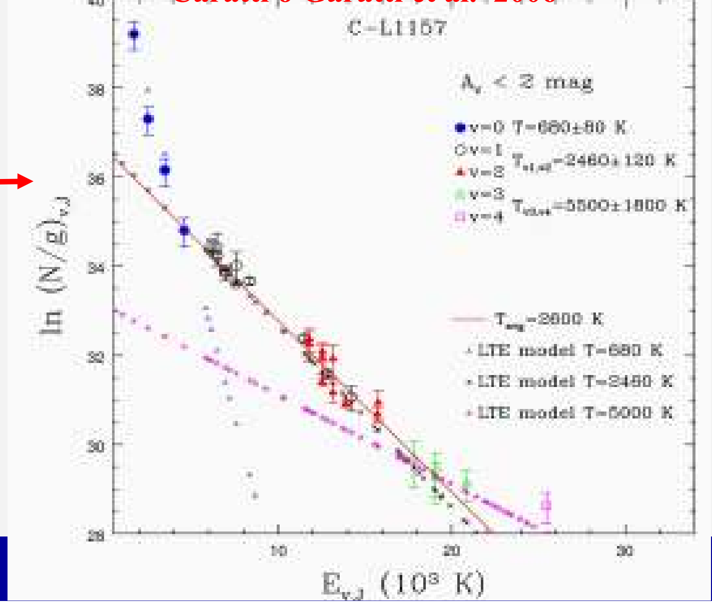
Physical Parameters from MIR

- Pure rotational lines: cold H_2 component $T=520$ K higher $N_{H2}\sim10^{22}$ cm^{-2}
- Assumption: all 0-0 emission observed
  - cold H_2 comp. contributes ~55% to the overall radiated energy ($L_{tot}(H_2)\sim8.1L_\odot$)
- Using N_{H2} of the cold component, v and area of 2.12 → $\dot{M}_{out}\sim7.5\cdot10^{-4}\ M_\odot\ yr^{-1}$



Caratti o Garatti et al. 2006

Low mass



Cold H_2 component has a major role

Does the H_2 jet power the flow?

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- **Observed in low-mass YSOs**

- **Observed in studied HM jets**

- **Comparison between H_2 and CO literature data (Shepherd et al. 2000)**

    – excellent agreement: the jet can power the outflow!

Table 6. Comparison between H_2 and CO physical properties of IRAS 20126+4104 flow.

	H_2	Shep.
Parameter	H_2	CO^a
Mass ($M_\odot$)	0.5	53
v_{red} (km s^{-1})	(-8, 47)	...
v_{blue} (km s^{-1})	(-14, -42)	...
τ_d (10^4 yr)	1.3	6.4
$\dot{M}$ (10^{-3} $M_\odot$ yr)	0.75	0.81
E_k (10^{46} ergs)	3	5.1
P ($M_\odot$ km s^{-1})	40	403
$\dot{P}$ (10^{-3} $M_\odot$ yr^{-1} km s^{-1})	3	6

Notes:
[a] From Shepherd et al. (2000).

Caratti o Garatti et al. 2008

A multiple system?

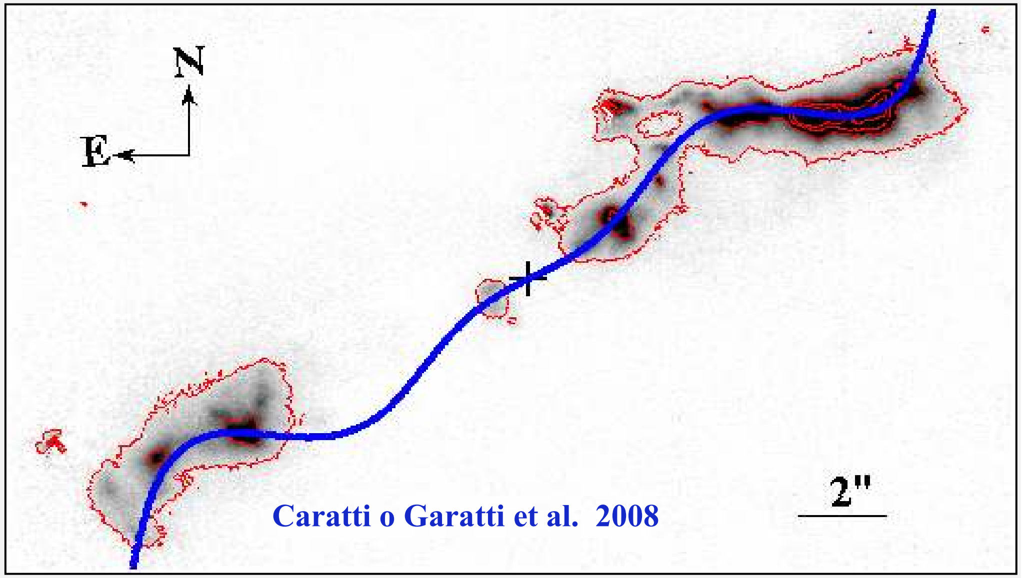
- **Large-scale precession:**
  modelled by Cesaroni et al. (2005)
  t= 64000 yr, 37° prec. angle
  presence of a smaller companion

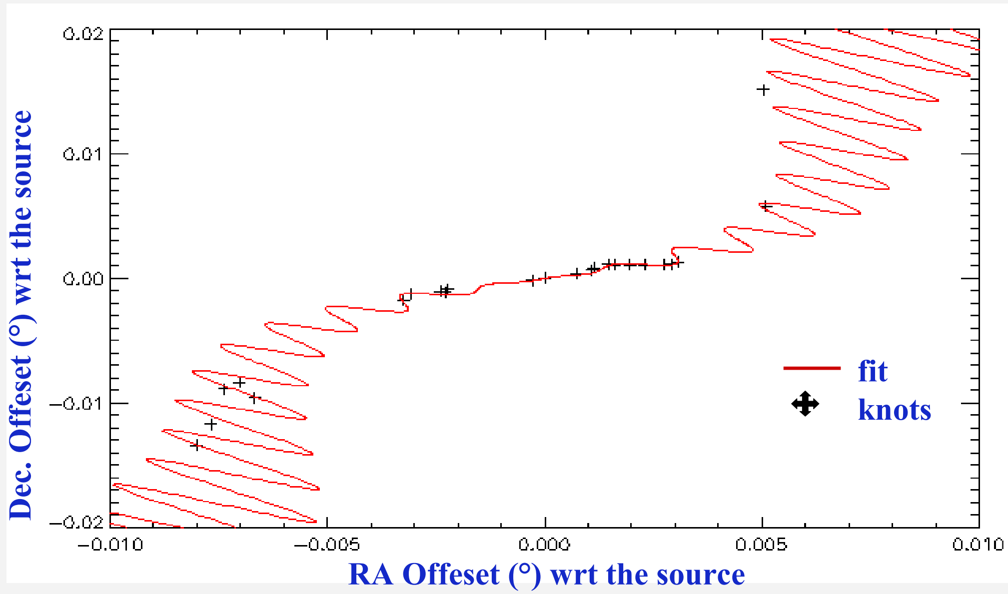
- **Small-scale precession:**
  – simple precessing jet model:

$$\begin{pmatrix}\alpha\\ \delta\end{pmatrix}=\begin{pmatrix}\alpha_0\\ \delta_0\end{pmatrix}+\begin{pmatrix}cos(\psi) & -sin(\psi)\\ sin(\psi) & cos(\psi)\end{pmatrix}\times\begin{pmatrix}\phi l sin(2\pi l/\lambda+\chi_0)\\ l\end{pmatrix}$$

  – t=11000 yr (D=1.7kpc, v =80km/s)
  – 7.6° precession angle

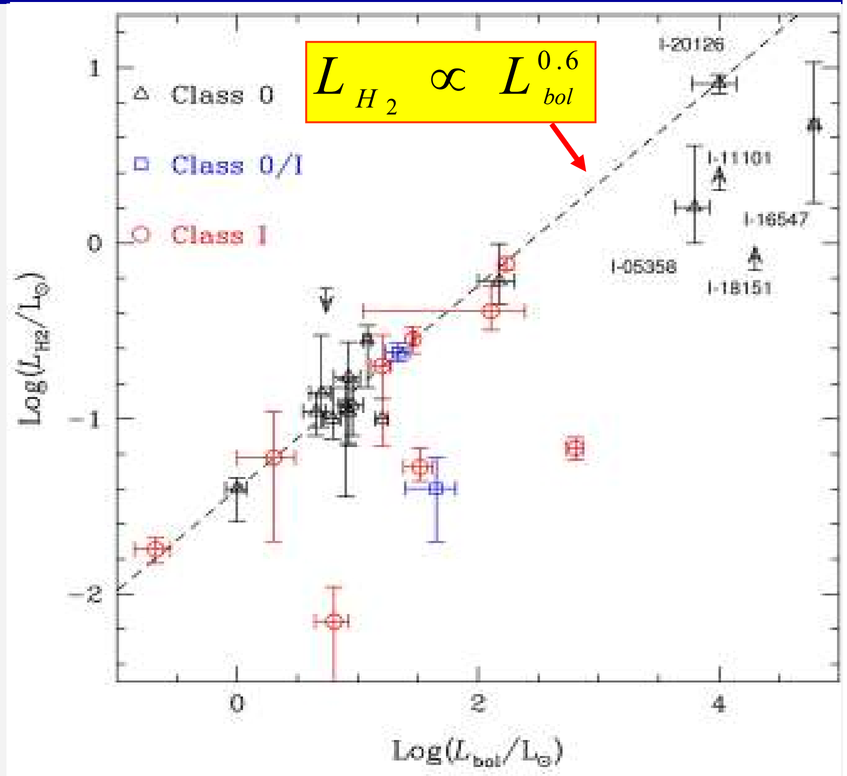
- **Combination of the two precessions**
- **Is it a multiple system?**





Comparing high- & low-mass jets

- L_{H2} vs L_{bol} for I20126 as for low-mass jets!
- What about:
  - **I18162-2048 (Davis et al.2004), I11101-1208 (Gredel 2006), I05358+3543 (Puga et al.2000), I16547-4247(Brooks et al.2003).**
  - **but cold component not studied!**
- **Comparisons:**
  - Spectroscopically low- & high-mass jets are similar (no fluorescence, HH, H_2 jets)
  - Similar velocities & physical conditions
  - Can drive the outflow



Caratti o Garatti et al. 2008

- **but:**
  - involved energies are larger, higher ejection rates→higher accr. rates
  - almost all known high-mass jets are precessing – wider prec. angles → multiple systems, dynamical interactions!!

An Evolutionary Scenario?

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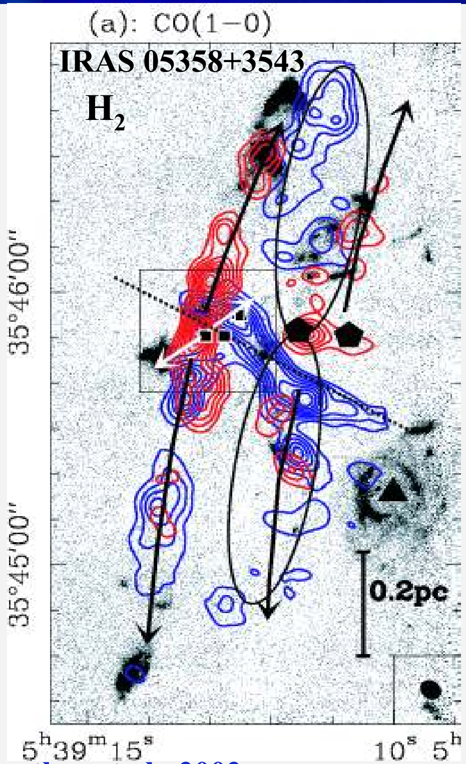
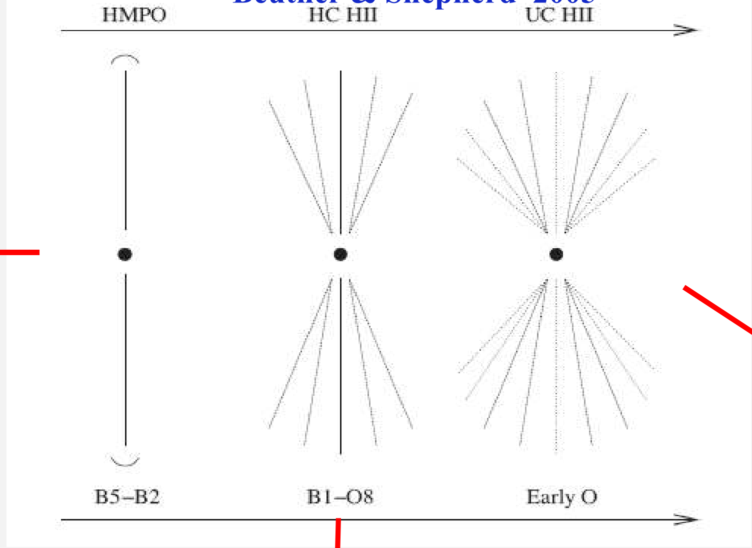
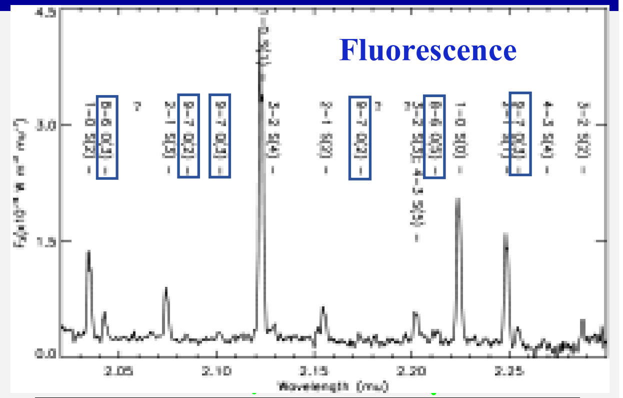


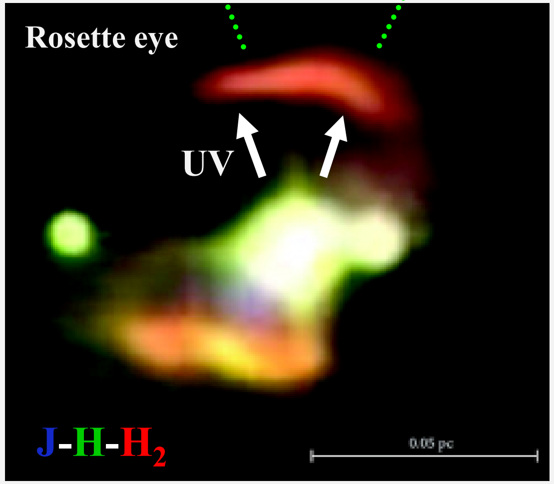
Beuther et al. 2002

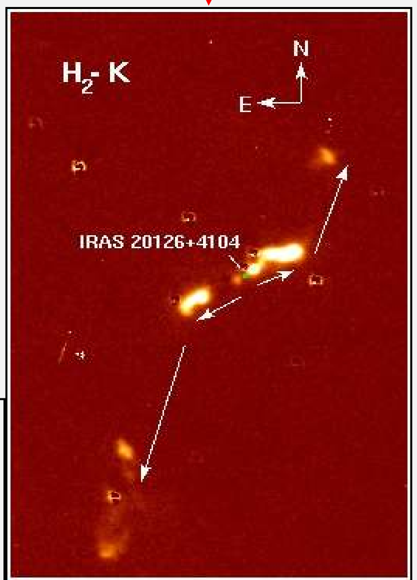
t<10⁴ yr

Beuther & Shepherd 2005









t~10⁴ yr

t~10⁵ yr

Li et al. 2008

I stage: HMPO phase, no HCHII region, collimated outflow/jet, no fluorescence

II stage: HCHII region forms, less collimated outflow&jet + wind, no fluorescence

III stage: UCHII region forms, no outflow/jet, massive wind, UV→fluorescence

Conclusions

High mass protostellar jets:

- Need for more surveys/observations
- HM similar to LM jets but larger energies, higher $\dot{M}_{out}$
- Large precession angles → dynamical interactions

IRAS20126+4104:

- The jet is mostly molecular
- Velocities, extinction, and temperatures as in LM jets, higher column density
- Cold H_2 component strongly contributes to $L(H_2)$ and $\dot{M}_{out}$, larger than in low-mass jets

Thank you!