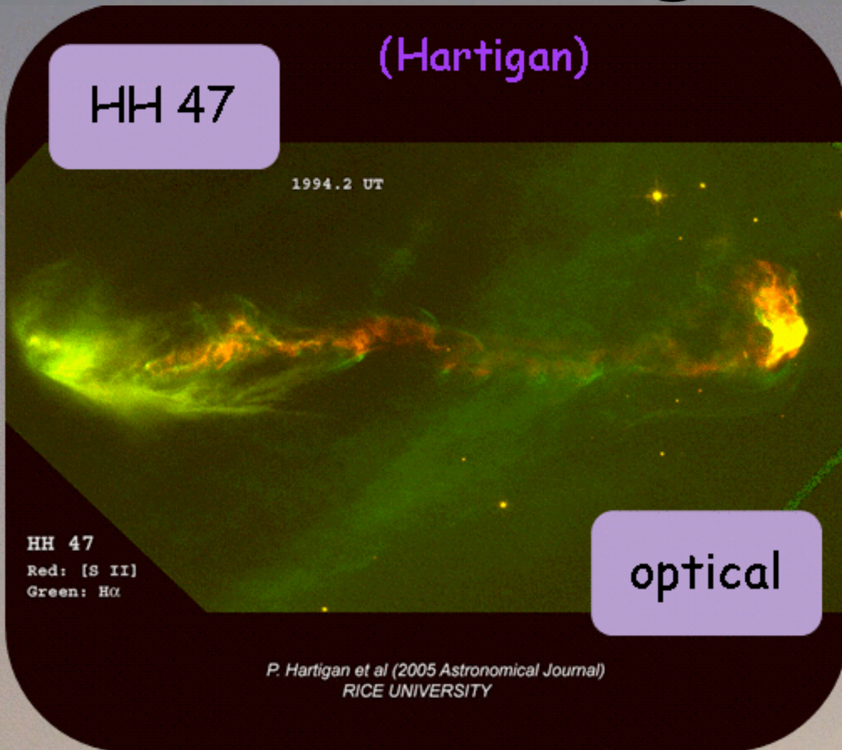
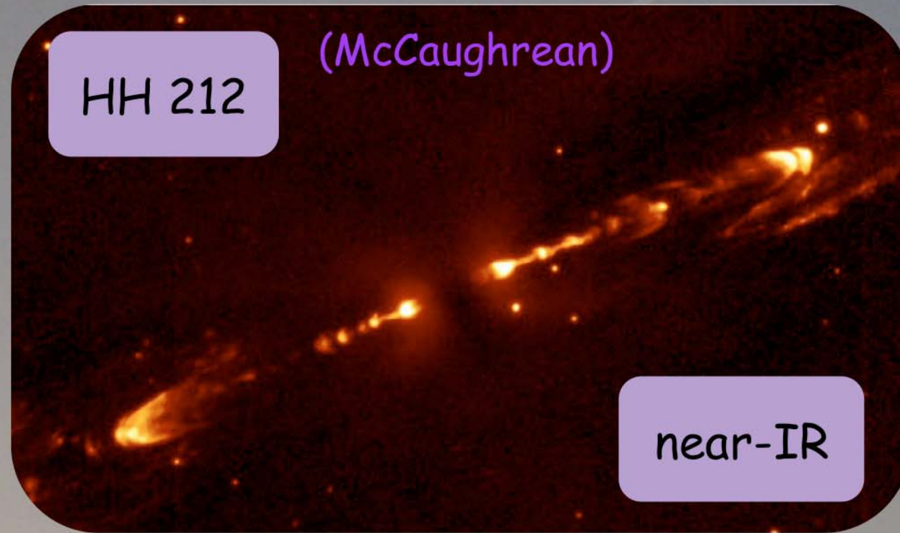
Modeling the X-ray emission from jets observed with Chandra

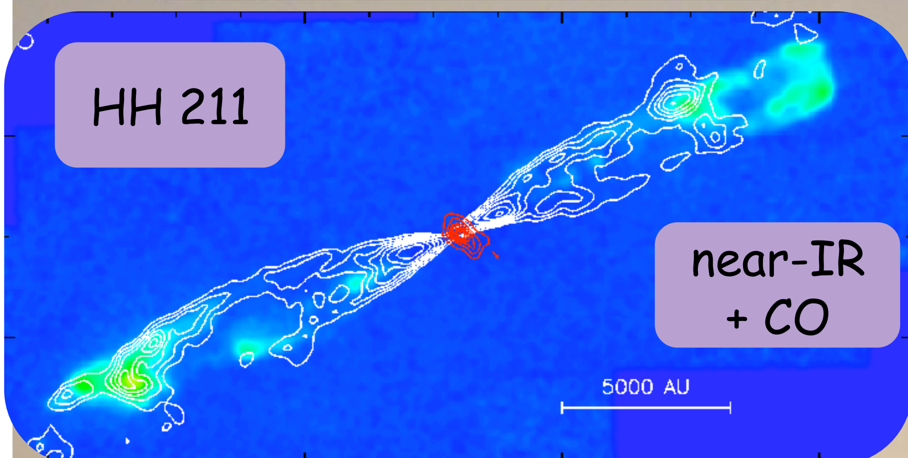
Rosaria (Sara) Bonito
Dip.S.F.A., Universita' di Palermo
INAF - Osservatorio Astronomico di Palermo

S. Orlando, INAF - Osservatorio Astronomico di Palermo
G. Peres, Dip.S.F.A., Universita' di Palermo
F. Favata, ESA, Community Coordination and Planning Office, Paris
M. Miceli, Dip.S.F.A., Universita' di Palermo, INAF - Osservatorio di Palermo
J. Eisloffel, Thüringer Landessternwarte, Tautenburg

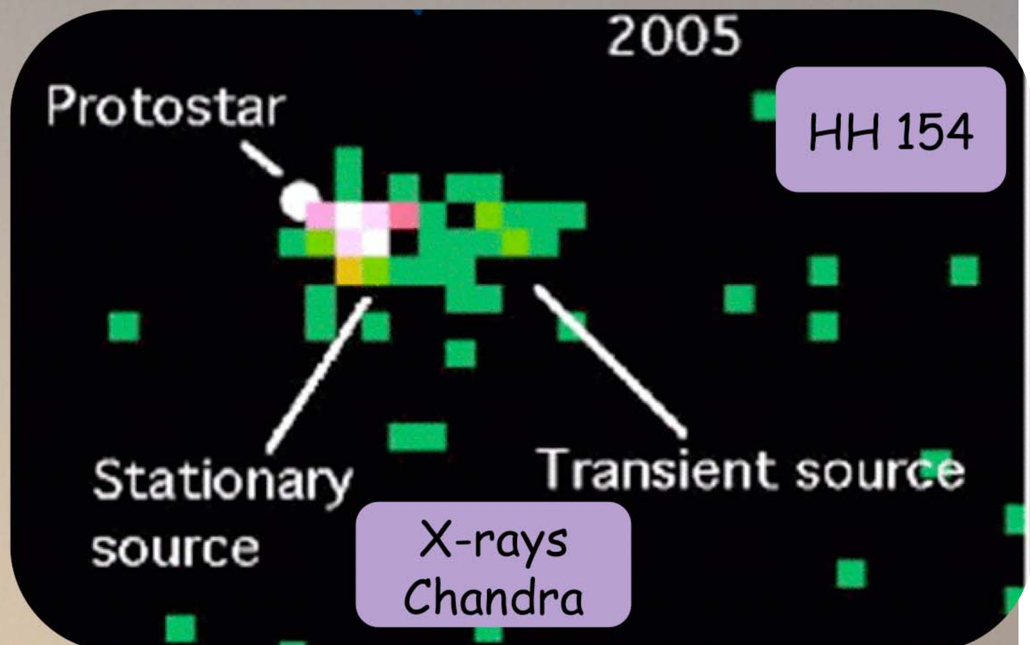
Herbig - Haro objects







Gueth & Guilloteau (1999)



Favata, Bonito et al. (2006)

First observations of the X-ray emission from protostellar jets

(Pravdo & Marshall,1981)

X-ray emission

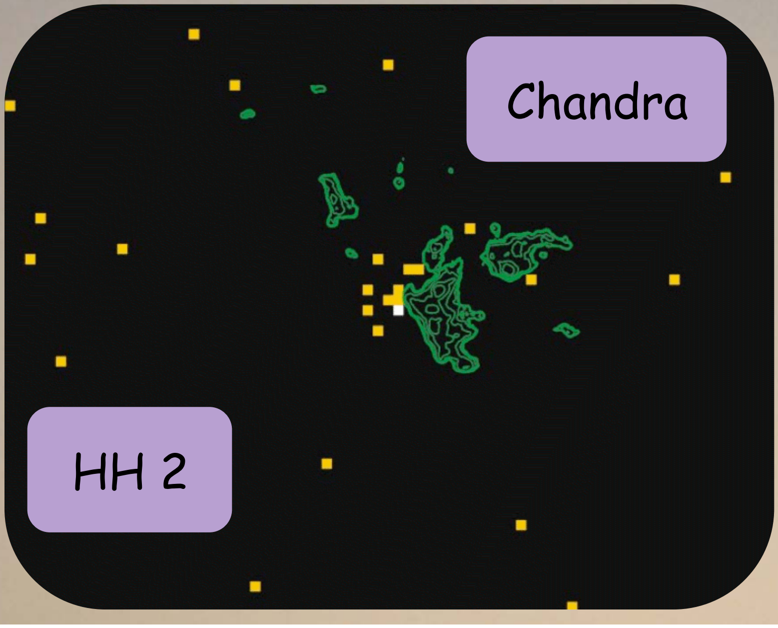
discovered from few HH objects since 2000

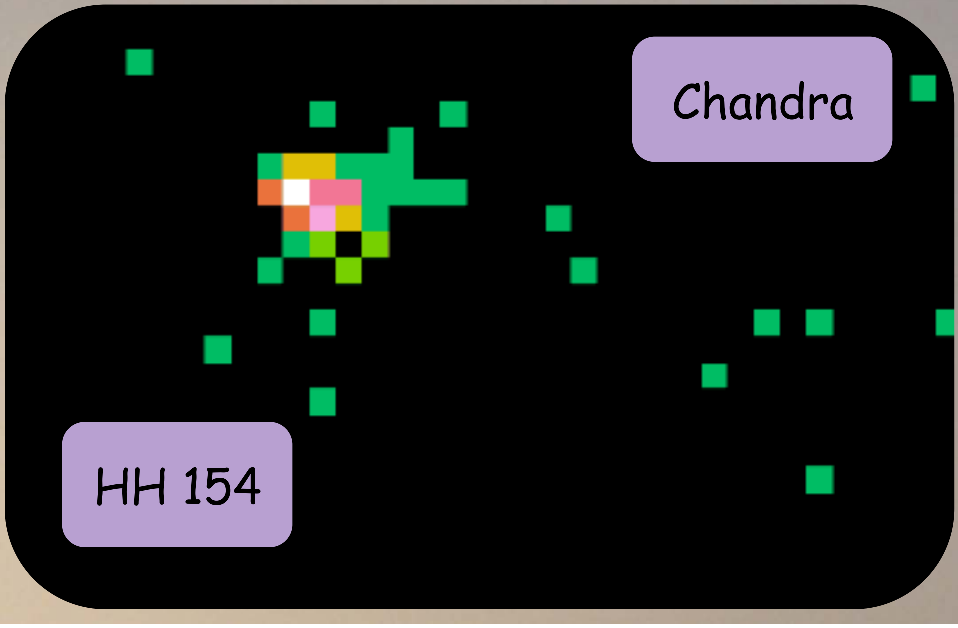
the first 2

HH 2 (Pravdo et al., 2001)

HH 154 (Favata et al., 2002; Bally et al., 2003)

$$T_{psh} = \frac{\gamma - 1}{(\gamma + 1)^2}\left(\frac{m v_{sh}^2}{k_B}\right)$$





X-ray emitting HH jets (few examples)

- Observed with both XMM and Chandra: 2000, 2001, 2005
- No contamination from the stellar corona: A_V (star/jet)= (150/ 7) mag
- The nearest most luminous jet: > 60 cnts in ~ 100 ks (single exposure)

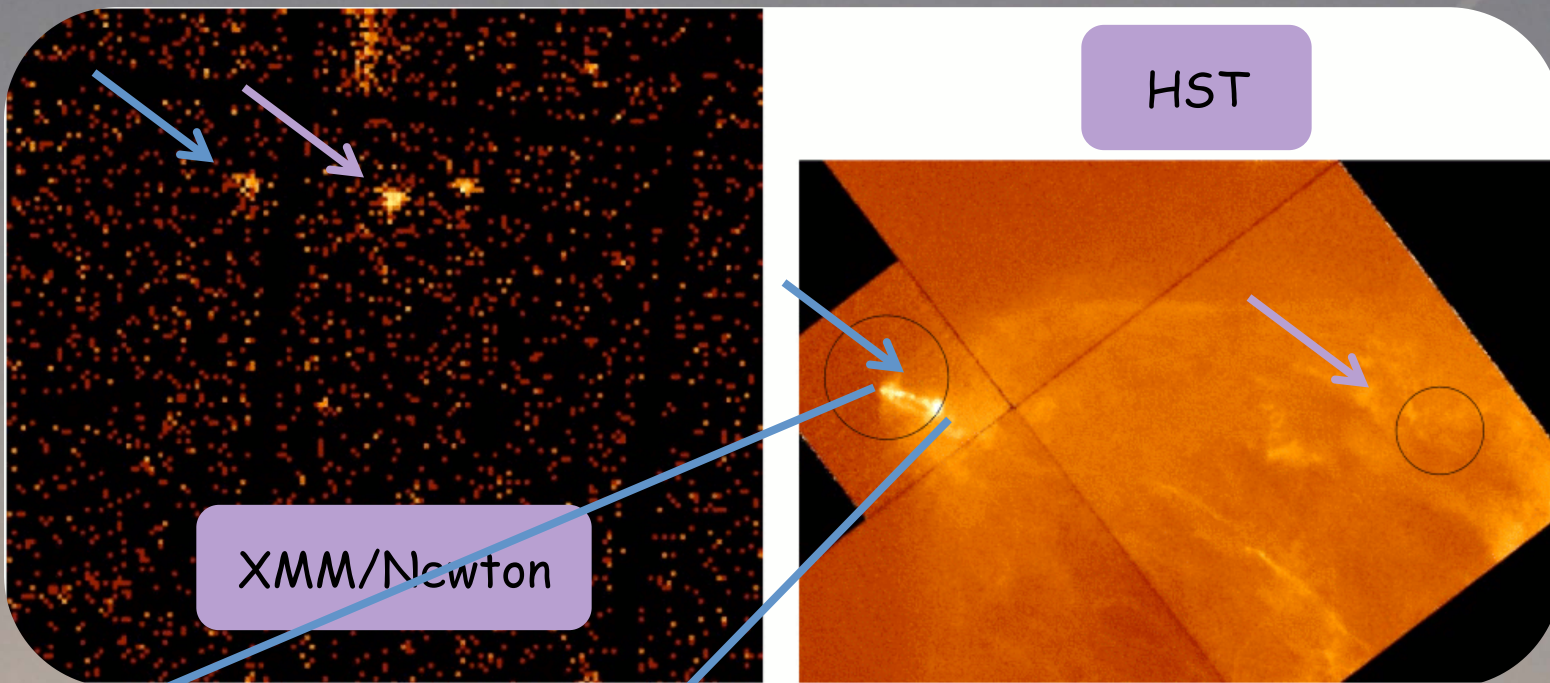
object	L_X (10^{29} erg/s)	T (MK)	N_H (10^{22} cm^{-2})	D (pc)	references
HH 2	5.2	1.2	< 0.09	480	Pravdo et al. (2001)
HH 154	3.0	4.0	1.40	140	Favata et al. (2002; 2006) Bally et al. (2003)
HH 80/81	450	1.5	0.44	1700	Pravdo et al. (2004)
HH 168	1.1	5.8	0.40	730	Pravdo & Tsuboi (2005)
HH 210	10	0.8	0.80	450	Grosso et al. (2006)
DG Tau	0.12	3.4	0.3	140	Guedel et al. (2008)

HH 1 (?) Pravdo & Marshall (1981); HH 540 Kastner et al. (2005);

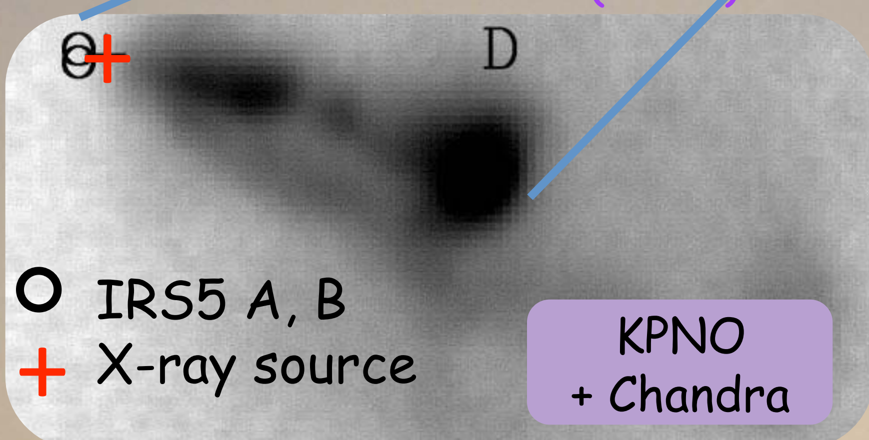
Tsujimoto et al. (2004); Stelzer et al. (2009)

Bonito et al. (2007)

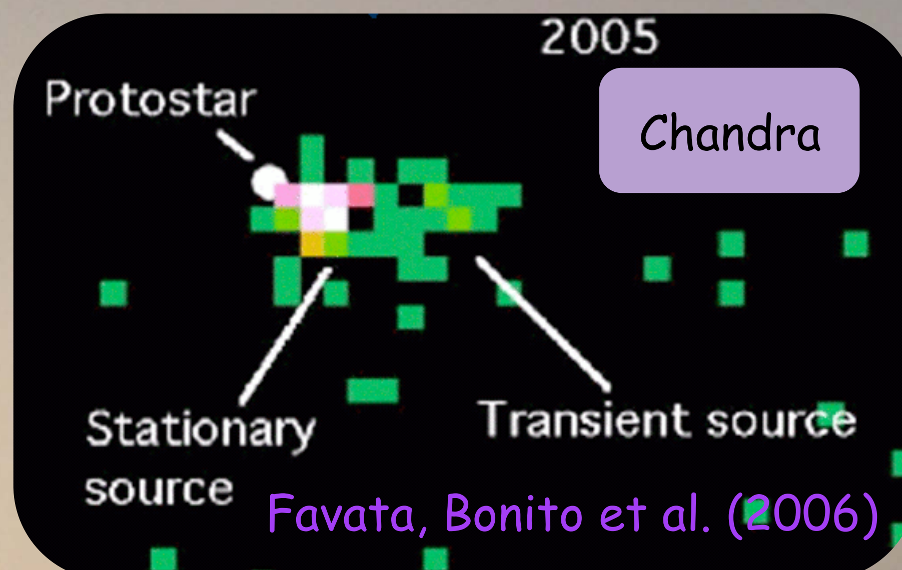
Why Chandra (HH 154)



Favata et al. (2002)



Bally et al. (2003)



Favata, Bonito et al. (2006)

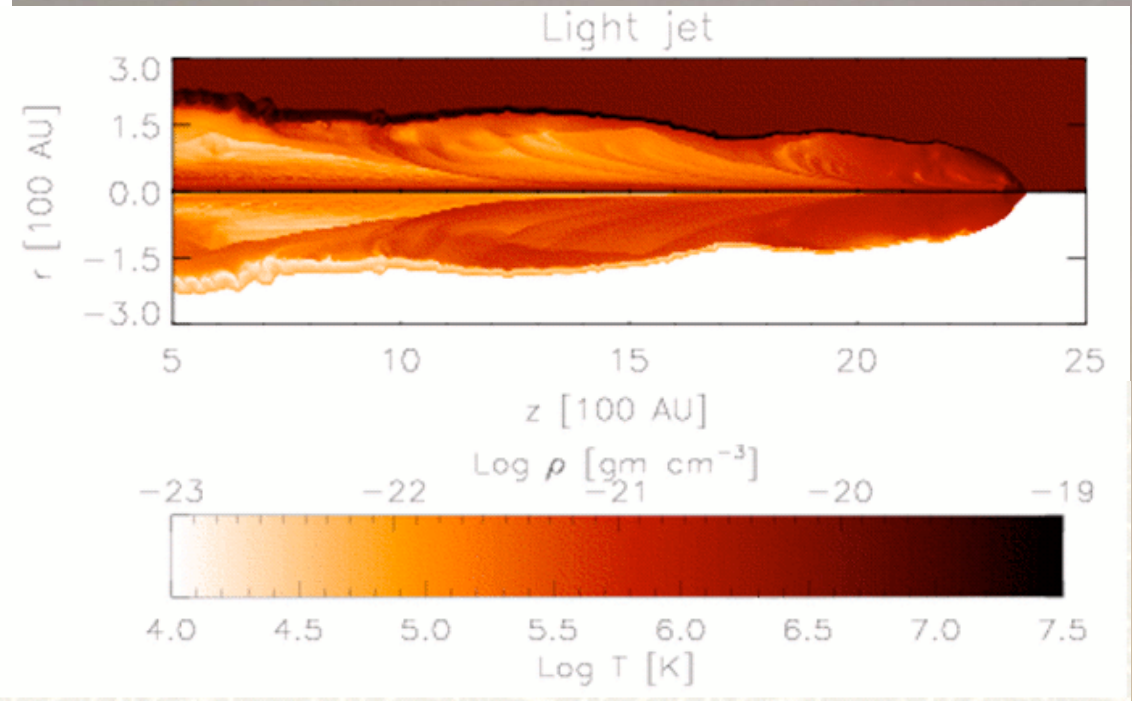
Hydrodynamic model: continuous jet

solving the hydrodynamic equations

(with radiative losses and thermal conduction effects)

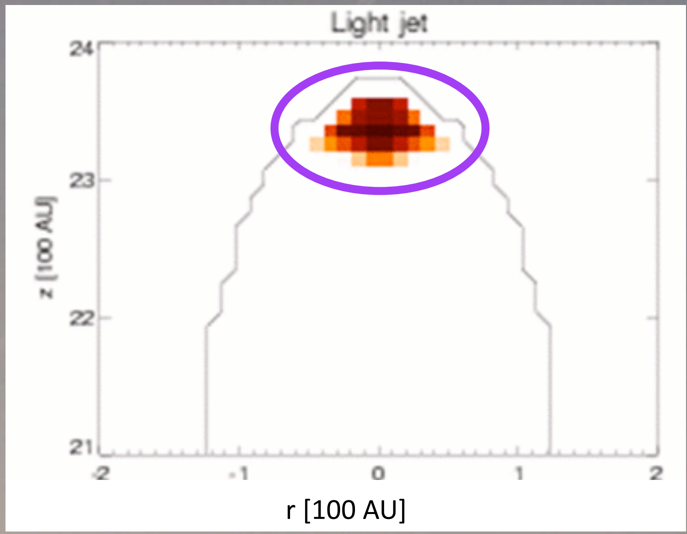
with the FLASH code

model	ν	M	v_j [km s^{-1}]	n_a [cm^{-3}]	T_a [10^4 K]
light	10	300	1400	5000	0.1



Bonito et al. (2004; 2007)

(Chandra/ACIS-I)



X-ray synthesis from numerical model of protostellar jets

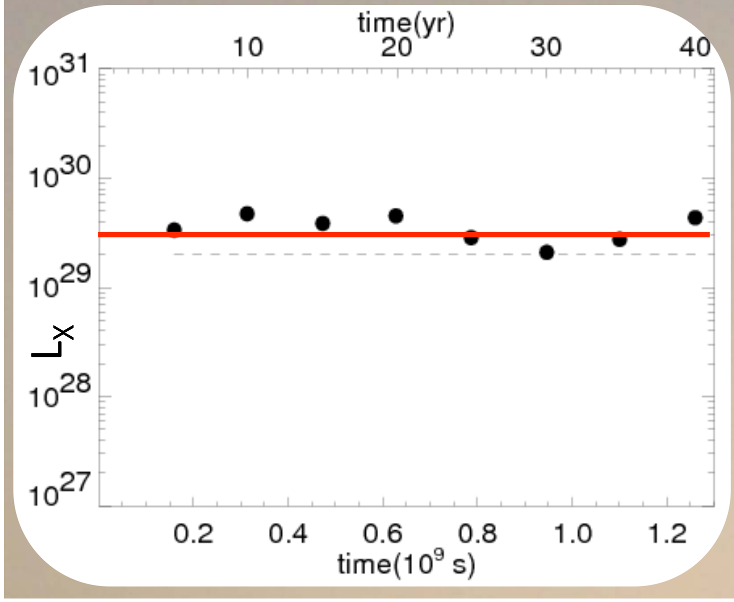
proper motion of the X-ray source:

$v_{sh} \approx 500$ km/s

Hydrodynamic model: continuous jet

Model
(Bonito et al. 2004):
count rate = 1.2 cnts/ks
T = $(3.4 \pm 1.2) \times 10^6$ K
Fx = 1.4×10^{-13} erg/cm^2/s

Observations
(Favata et al. 2002):
count rate = 1.0 cnts/ks
T = $(4.0 \pm 2.5) \times 10^6$ K
Fx = 1.3×10^{-13} erg/cm^2/s

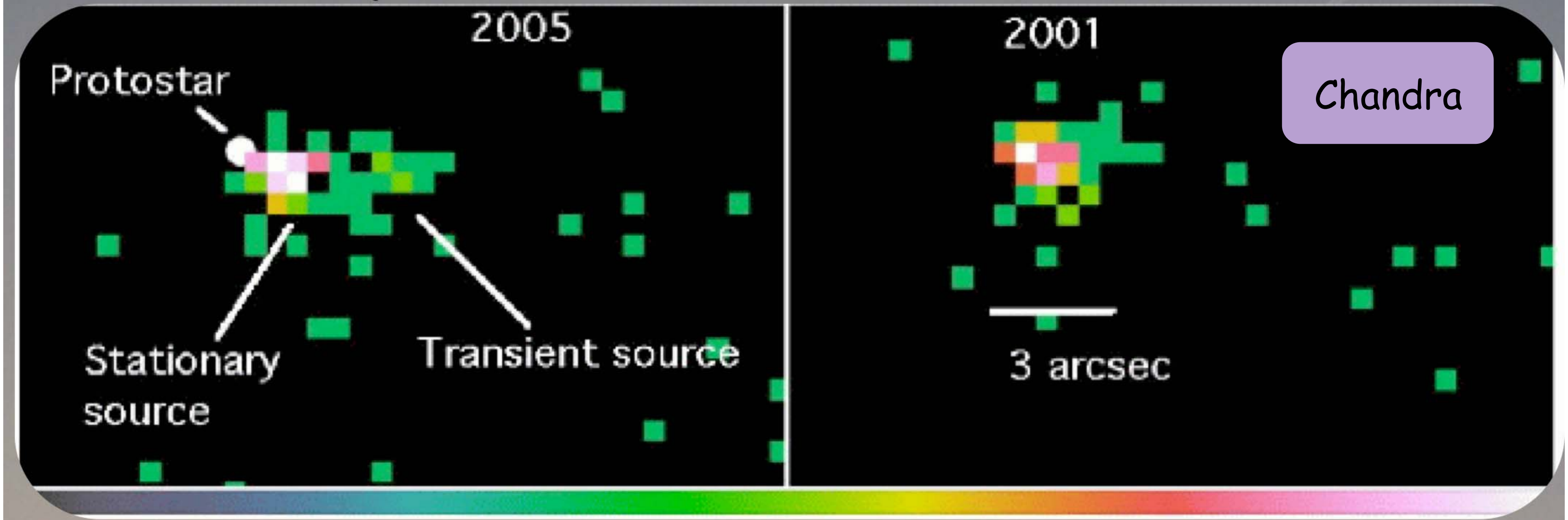


Shocks from supersonic jets:
reproduce in a natural way
the observed L_X and $(EM, T)_{best\text{-}fit}$
predicts proper motion

Natural candidate to explain the physical mechanism of the X-ray emission from protostellar jets

Bonito et al. (2004; 2007)

X-ray emission: observations



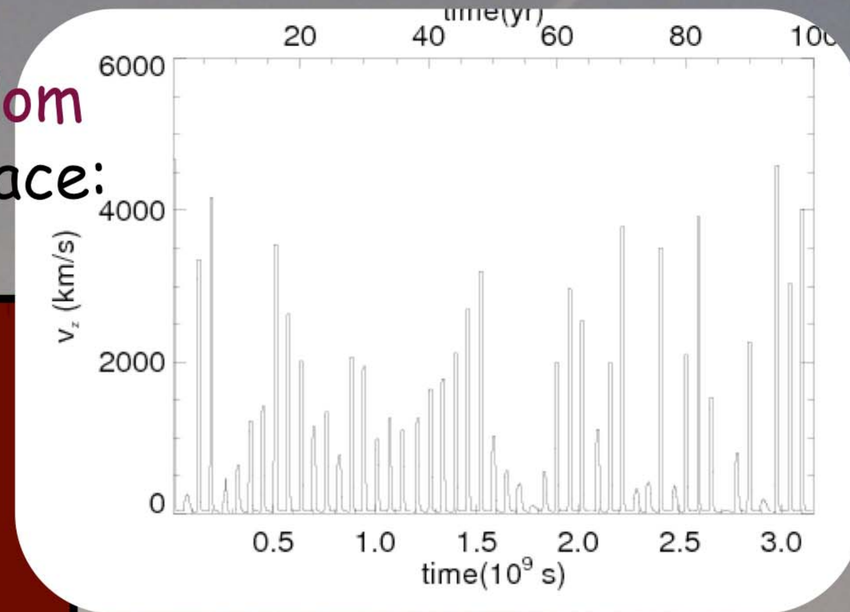
- ⌗ Complex morphology: two components
  1) point-like, stationary (over 4 yr)
  2) elongated
- ⌗ Proper motion elongated X-ray source (component 2): as predicted by the model
  powerful diagnostic discriminate models:
  validate the moving shock model
  detected for the first (and only) time
- ⌗ Speed consistent with model's results: 460 km/s

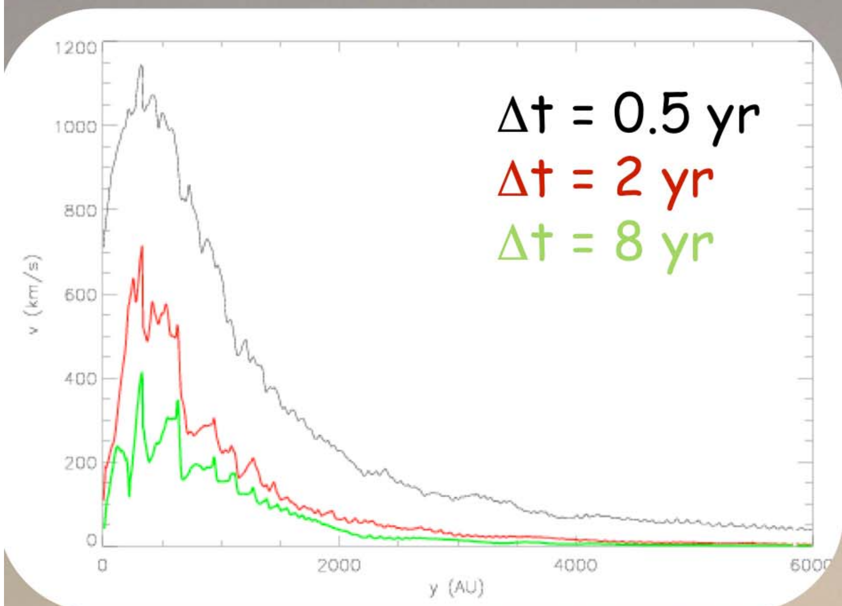
Favata, Bonito, Micela, Fridlund, Orlando, Sciortino, Peres (2006)

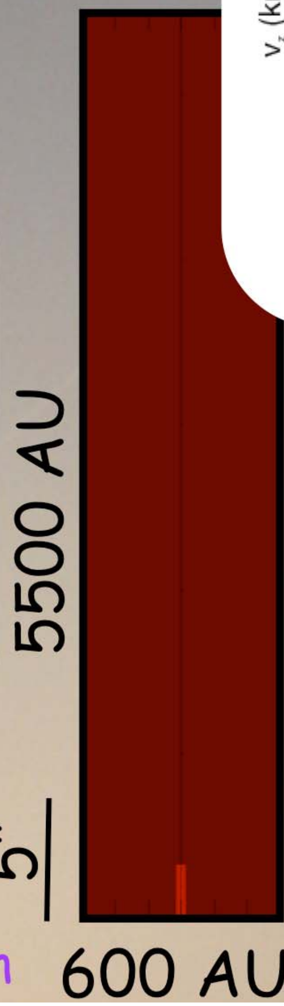
to verify the model
use Chandra

The pulsed jet scenario

- Basic physics = continuous jet
- Improved model: blobs, v(t) random
- Exploration of the parameter space: M, ν, n_j, v(t), ejection rate (Δt)







- Few blobs at high speed
- Most of the blobs at low speed

Mutual-interaction between blobs

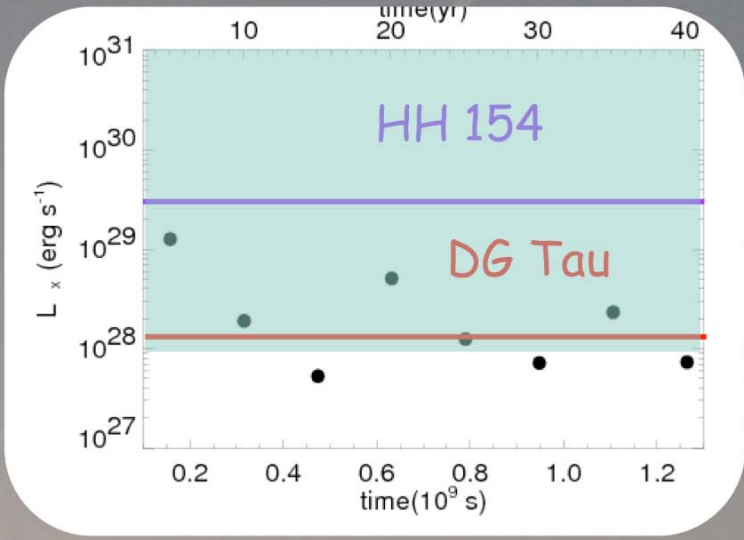
Bonito et al. (2009) in preparation

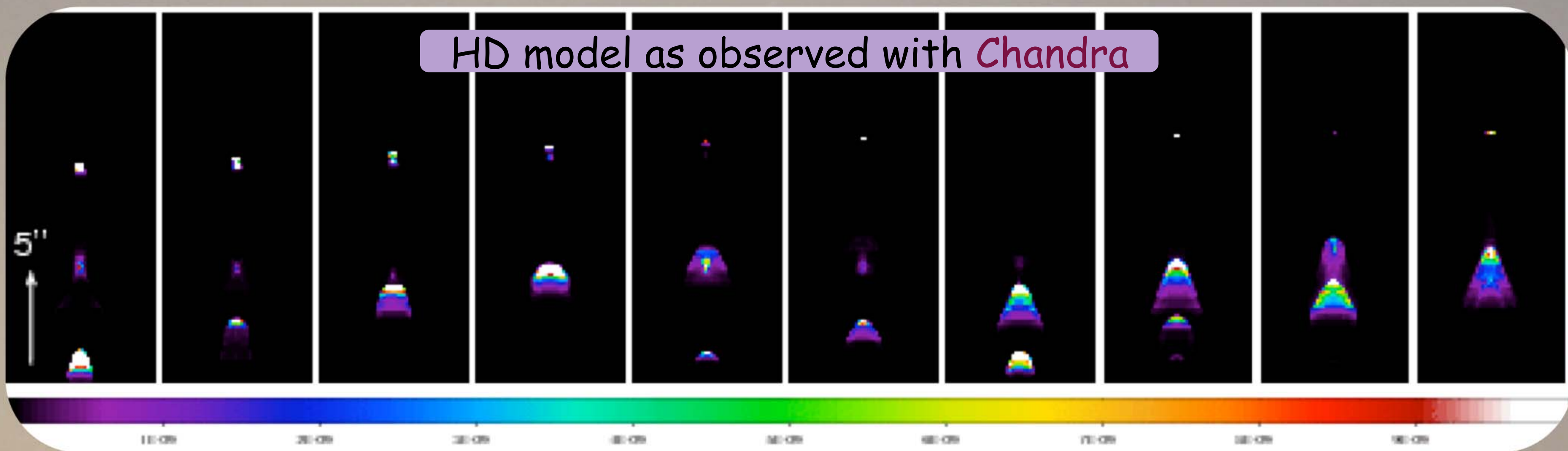
The pulsed jet scenario

cnts	$n_H \pm \Delta n_H$ (10^{22} cm^{-3})	$T \pm \Delta T$ (10^6 K)	$EM \pm \Delta EM$ (10^{52} cm^{-3})	χ^2	Prob.[a]
100	1.4 ± 0.2	3.3 ± 0.8	7.0 ± 17.3	0.29	0.957
9667	1.40 ± 0.02	3.8 ± 0.1	4.8 ± 1.2	0.80	0.991

[a] Null hypothesis probability.

ν	M	v_j [km s^{-1}]	n_a [cm^{-3}]	T_a [10^4 K]
10	500	2300	5000	0.1

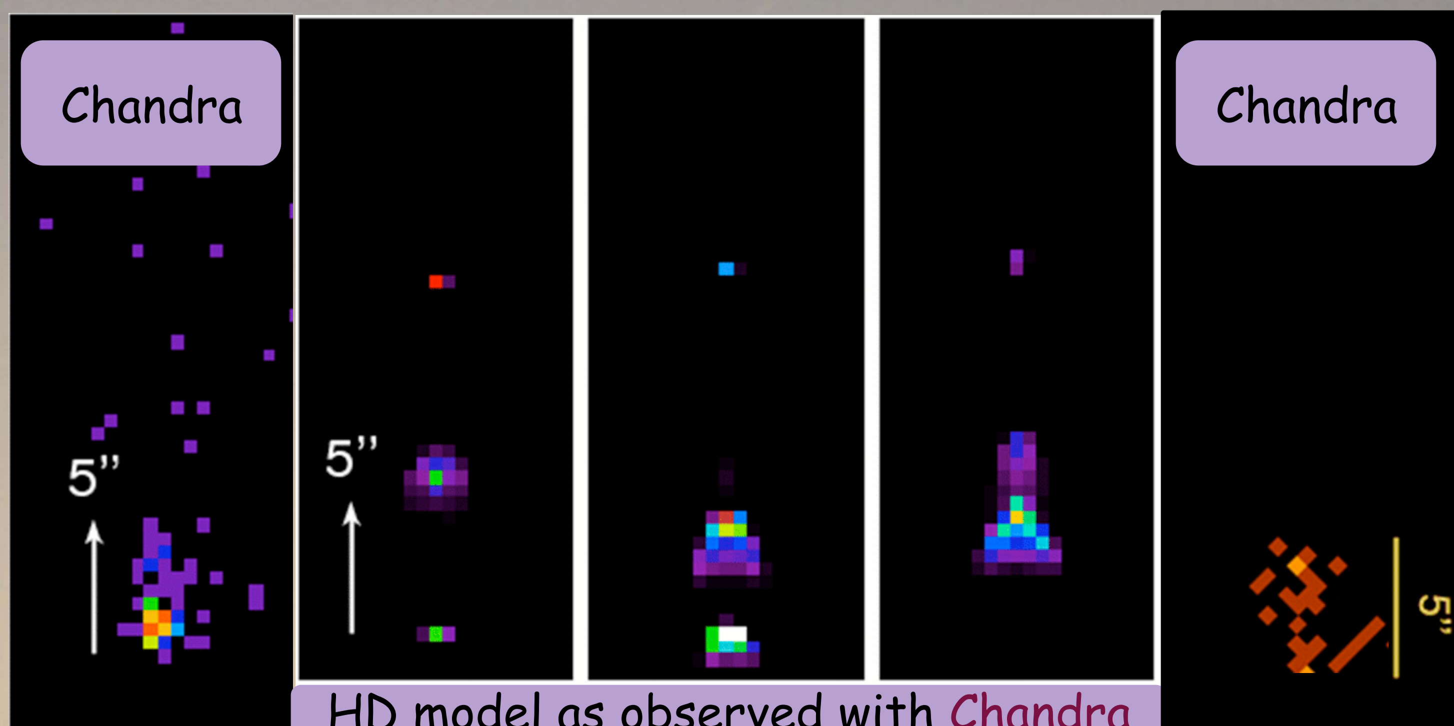




Bonito et al. (2009) in preparation

The pulsed jet scenario

- X-rays from the base of the jet (e.g.: HH 154, DG Tau)
- Complex morphology
- Variability
- Size of the X-ray source

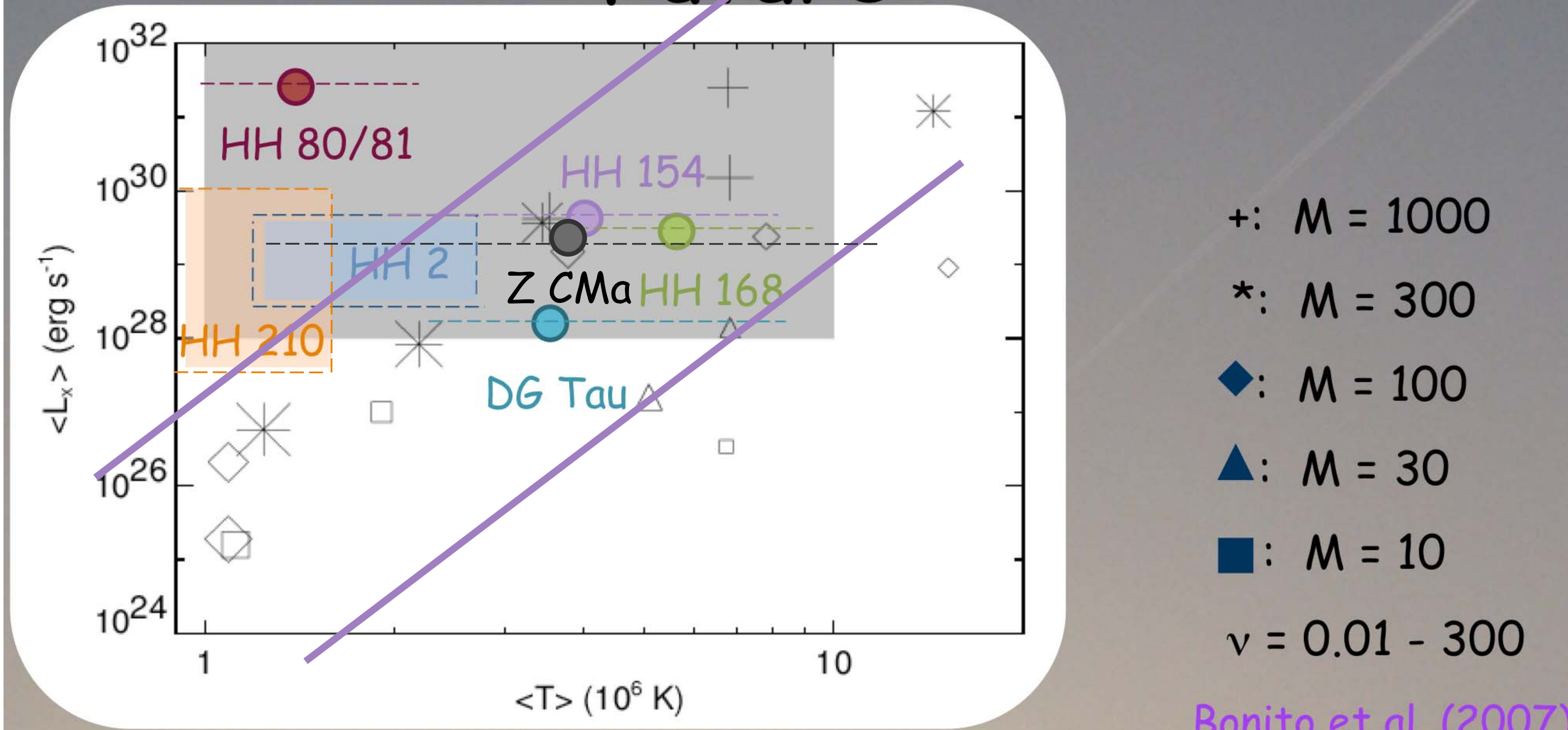


HH 154

Bonito et al. (2009) in prep.

DG Tau

Future



comparison between the model's predictions

and the observations

- Our model results can be extended to all the X-ray emitting HH jets
- New Chandra observations of near jets (e.g.: HH 154): proper motion and morphology

Conclusions

- $T \sim 10^6$ K
- $L_X \sim (10^{28} - 10^{31})$ erg/s
- $v_{sh} \approx 500$ km/s
- X-rays from the base of the jet (e.g. HH 154, DG Tau, ...)
- Complex morphology
- Variability

(*)

- HD model continuous jet:
  reproduces in a natural way the X-ray emission (T, L_X, v_{sh})
  does not explain (*)
- Improved model to explain (*): blobs, v(t) random
- Exploration of the parameter space:
  M, ν, n_j, $v(t)$, ejection rate
- Results:
  (*) + size in nice agreement with HH 154 and DG Tau
  promising model