HEPRO V
La Plata - 2015

High Energy Processes in Protostellar Jets

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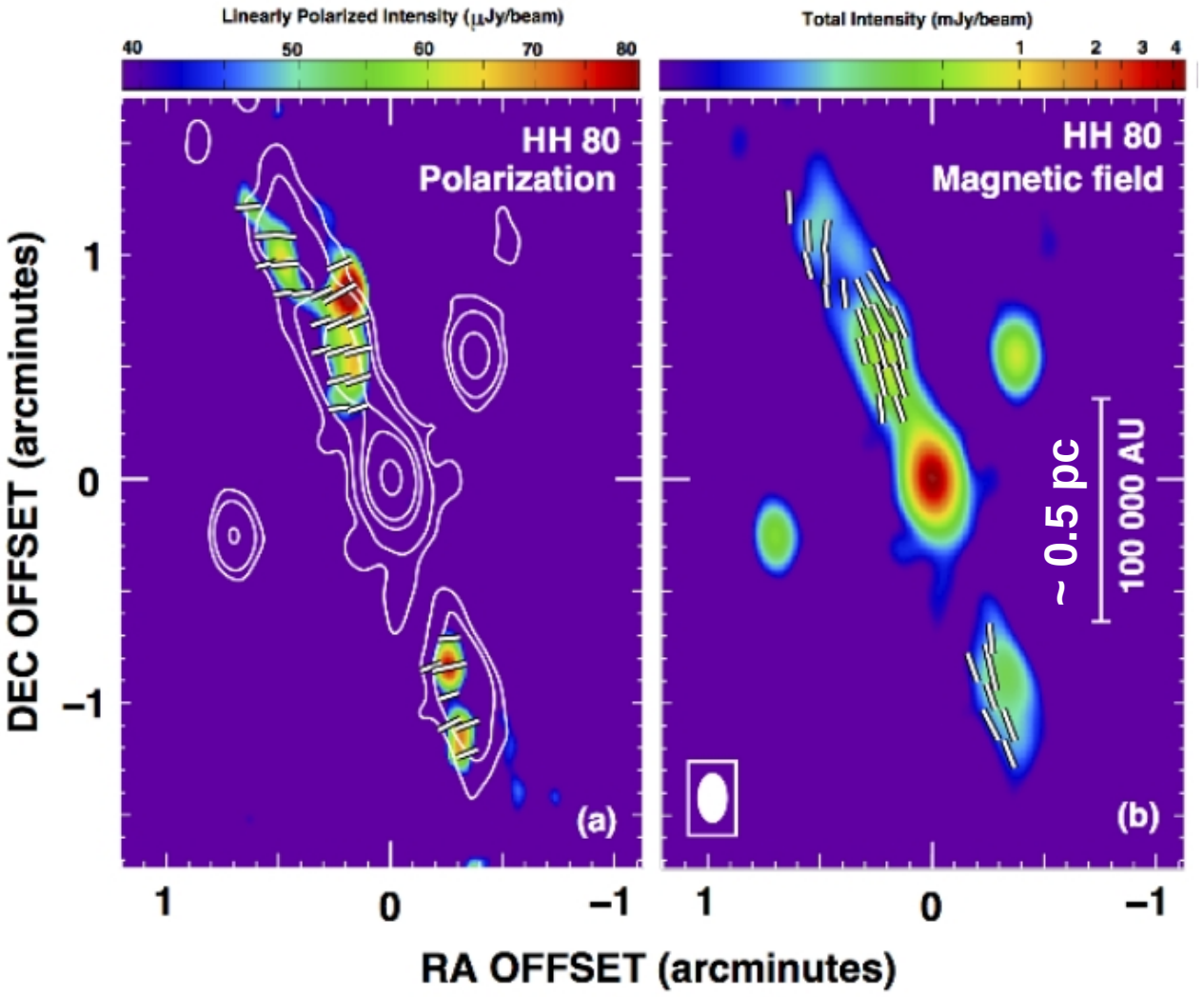
Background:

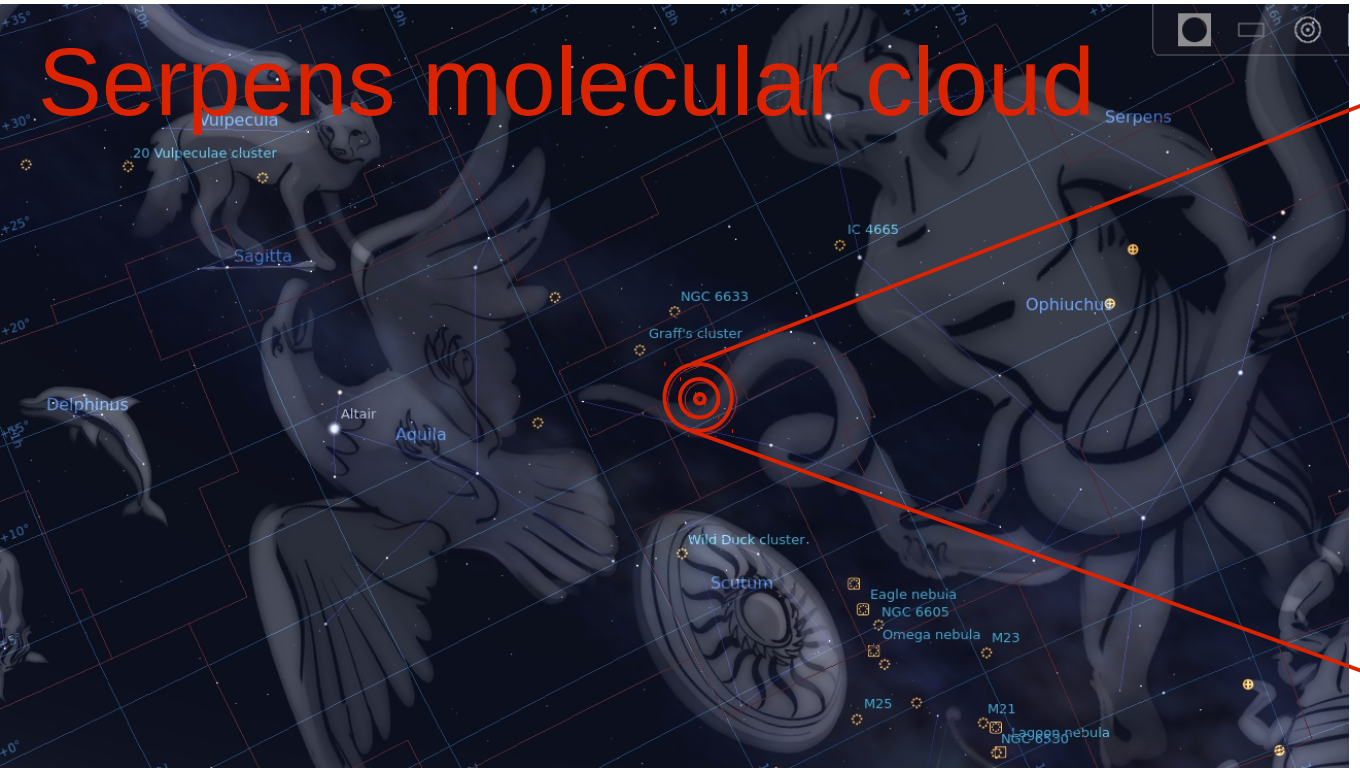
Carrasco-González, C., Rodríguez, L. F., Anglada, G., et al. 2010, Science, 330, 1209

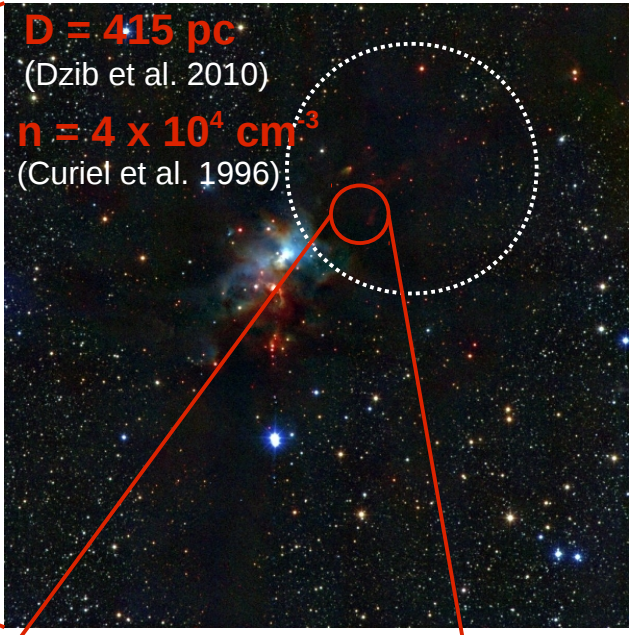


- Linearly polarized emission in HH 80, confirms the synchrotron origin for the radio emission
- Allows the study of magnetic fields in these objects
- There are relativistic particles ---> some particle acceleration mechanism must be taking place

Protostellar jets - - - > low energy limit - - - > particle acceleration

Serpens molecular cloud





The triple radio-continuum source:

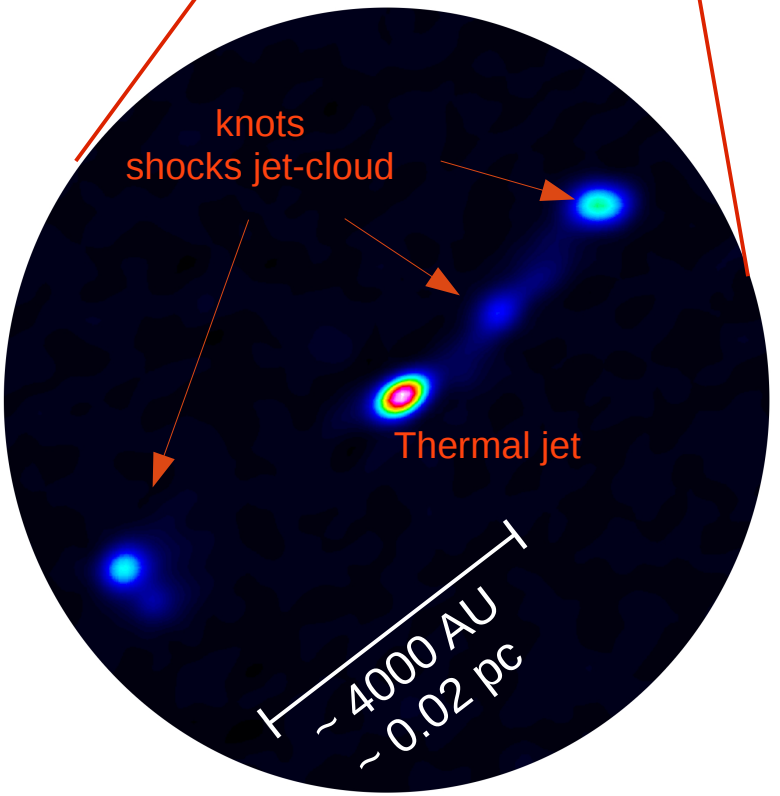
Widely studied since '80

(*Rodríguez et al. 1980; Snell and Bally 1986; Curiel S. et al. 1993*)

L. F. Rodríguez (1989)

Proper motions ~300 km/s (d ~ 500 pc)

Knots NW and SE: α < 0 (non-thermal emission)

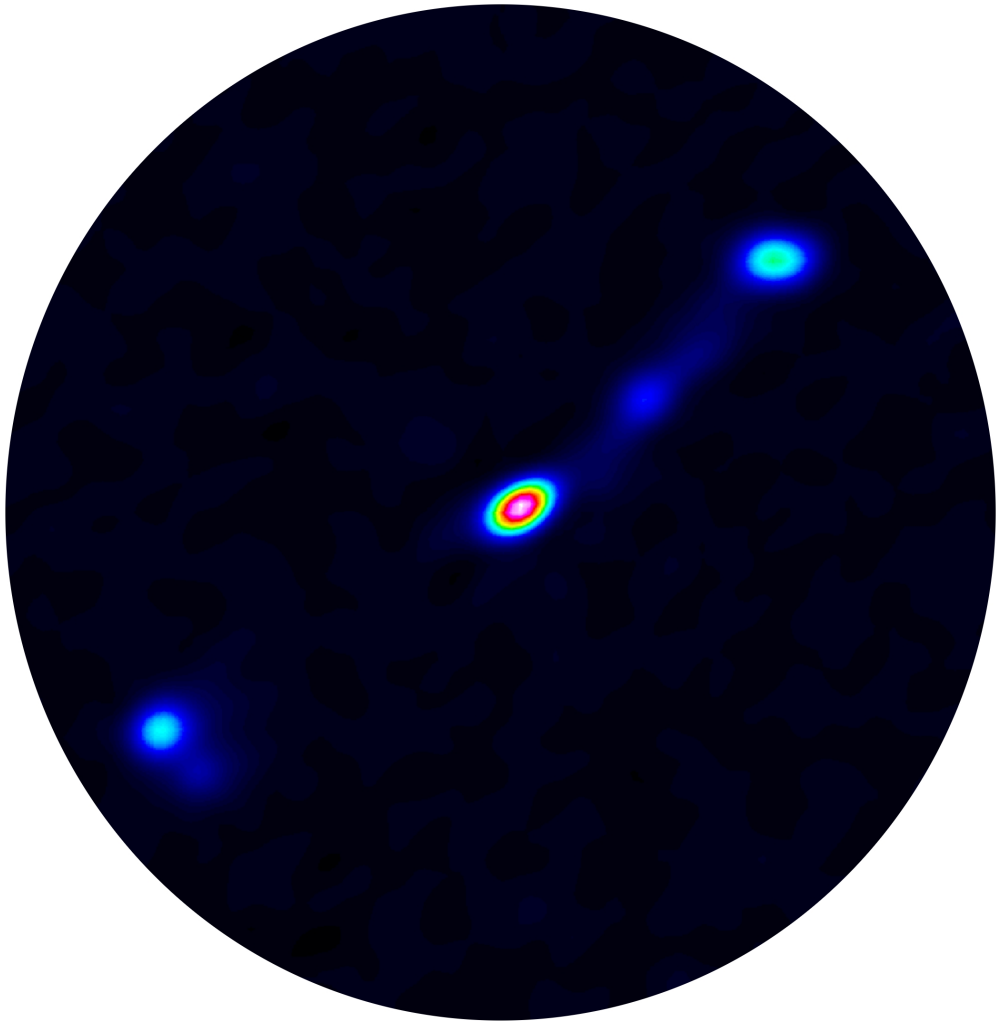


Serpens: Data

Jet kinematics: proper motions of the knots

High resolution images (0.47"):
A configuration – VLA (100 MHz BdW)

C (6 GHz) band, at
1993, 1994, 1995, 1998, 2000 y 2011

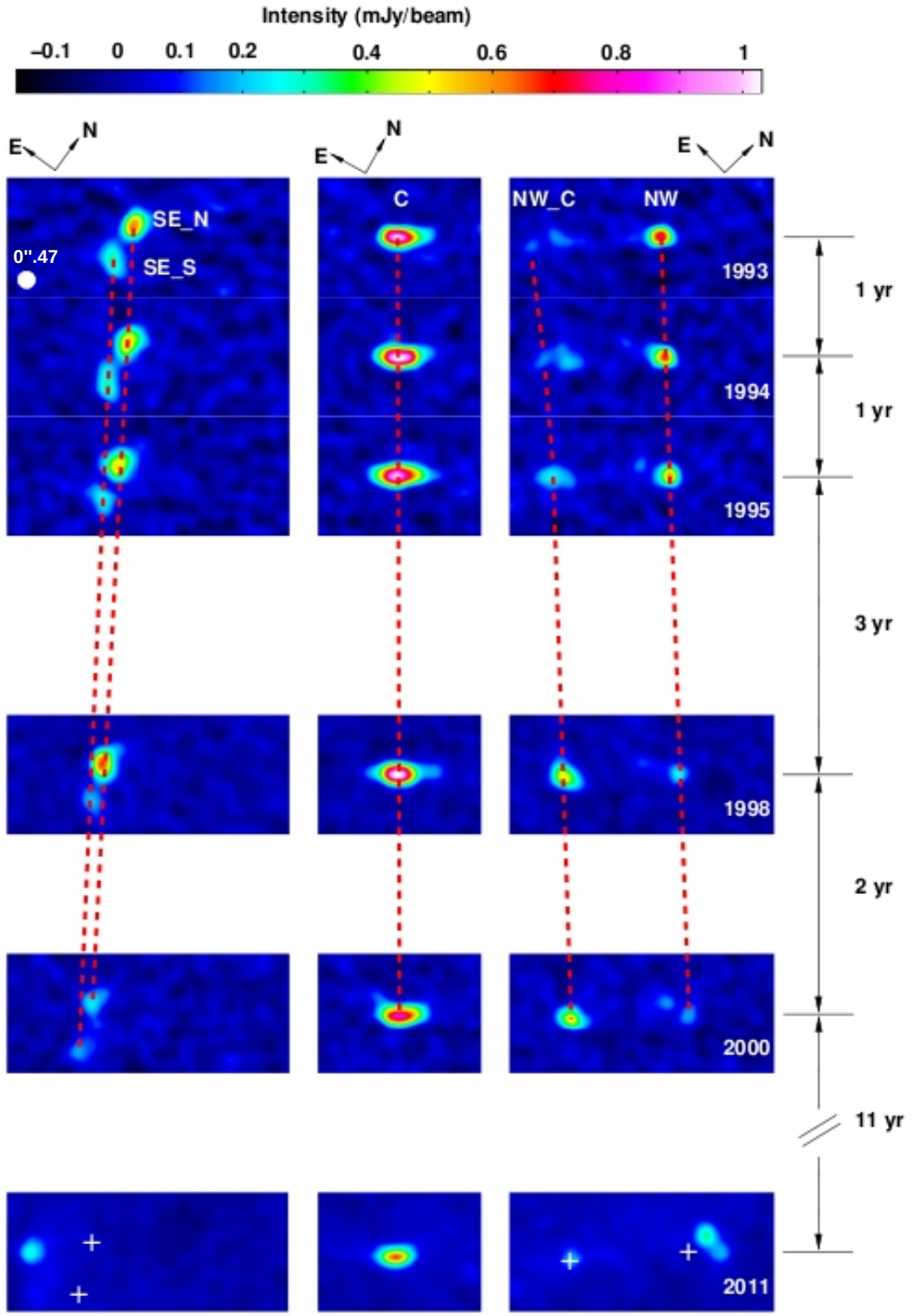


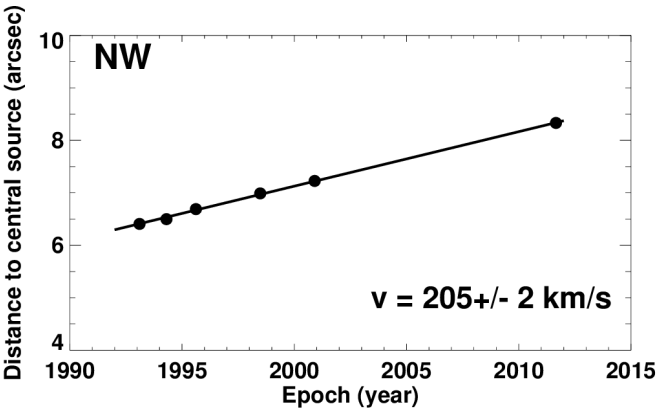
Emission nature:
Spectral Indices. SEDs. Linear polarization.

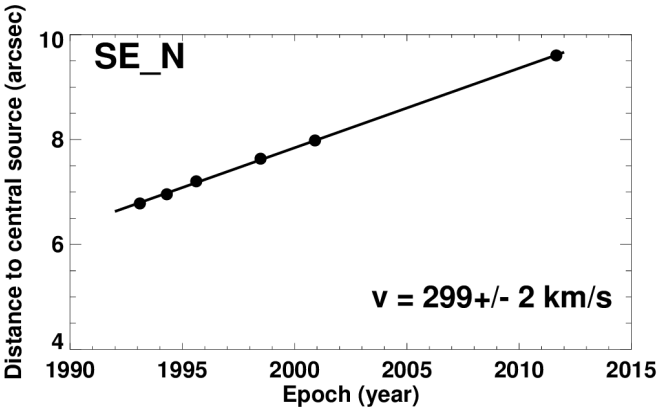
High sensitivity images:
B Configuration – expanded VLA (2GHz BdW)

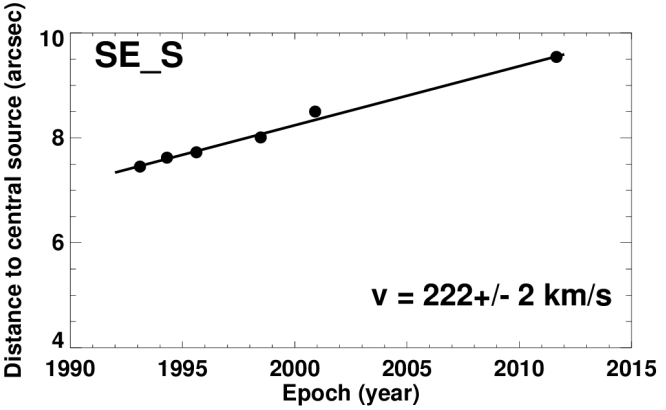
S (3 GHz), C (6 GHz), and X (10 GHz)
bands at 2012

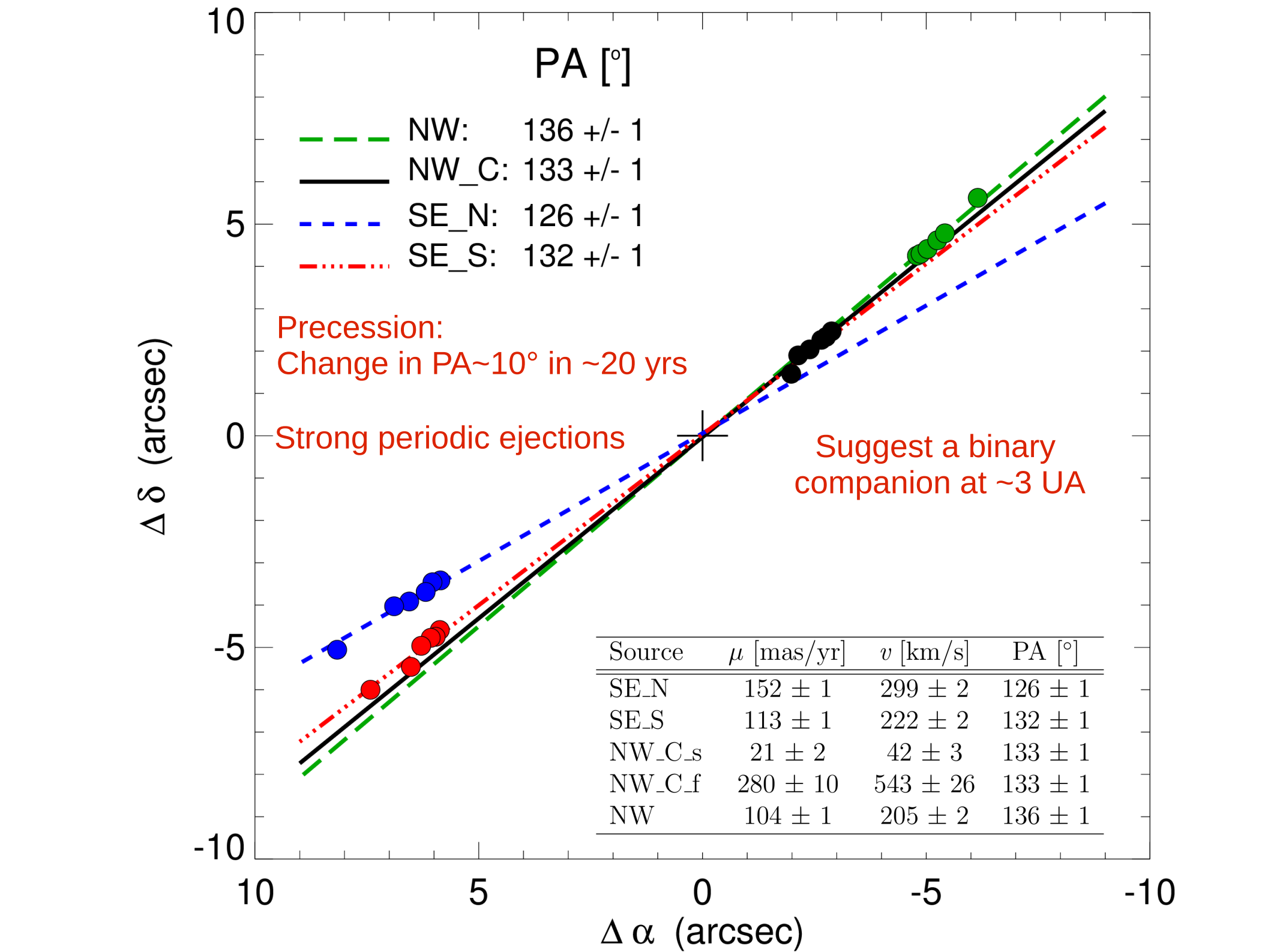
PROPER MOTIONS


Intensity (mJy/beam)
−0.1 0 0.1 0.2 0.4 0.6 0.8 1
E N
SE_N
SE_S
0".47
C
NW_C
NW
1993
1994
1995
1998
2000
2011
1 yr
1 yr
3 yr
2 yr
11 yr


NW
v = 205+/- 2 km/s
Distance to central source (arcsec)
Epoch (year)
10
8
6
4
1990
1995
2000
2005
2010
2015


SE_N
v = 299+/- 2 km/s
Distance to central source (arcsec)
Epoch (year)
10
8
6
4
1990
1995
2000
2005
2010
2015


SE_S
v = 222+/- 2 km/s
Distance to central source (arcsec)
Epoch (year)
10
8
6
4
1990
1995
2000
2005
2010
2015

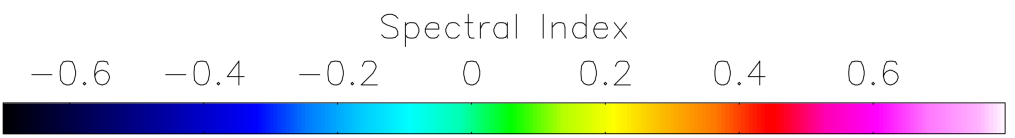


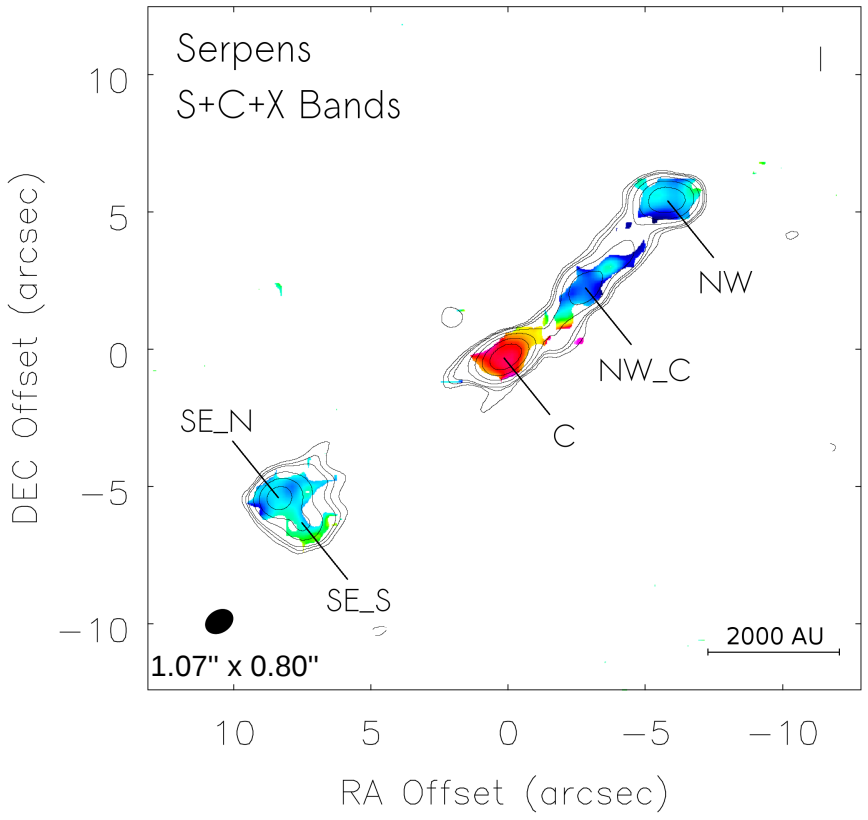
Source	μ [mas/yr]	v [km/s]	PA [°]
SE_N	152 ± 1	299 ± 2	126 ± 1
SE_S	113 ± 1	222 ± 2	132 ± 1
NW_C_s	21 ± 2	42 ± 3	133 ± 1
NW_C_f	280 ± 10	543 ± 26	133 ± 1
NW	104 ± 1	205 ± 2	136 ± 1

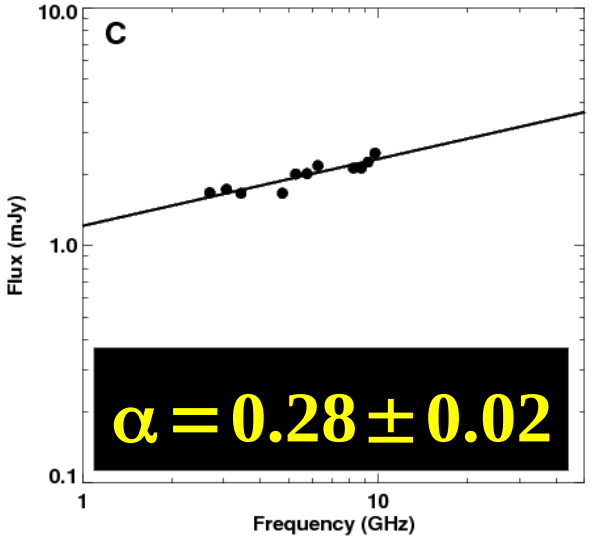
Spectral Indices

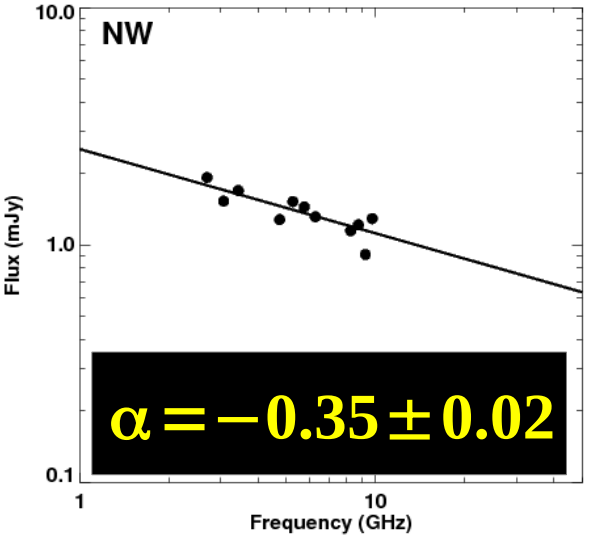
and

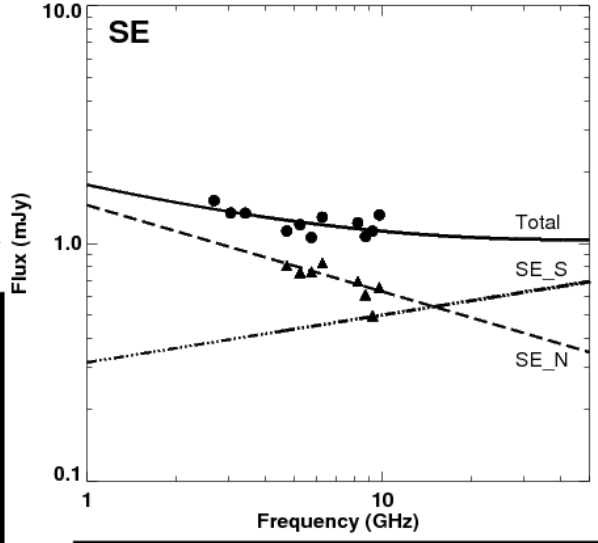
Spectral Energy Distributions

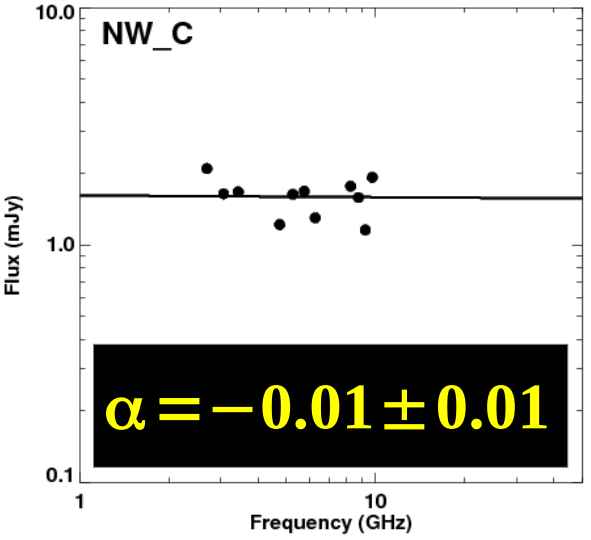












We detect SI < 0 in the knots

- - - > particle acceleration takes place in shocks against the molecular cloud

- - - - - α = −0.36 ± 0.03

· · · · · α ~ 0.2

POLARIZATION

- We searched for linear polarization in high sensitivity data obtained with VLA at S, C, and X bands.
- We give an upper limit for the detected PD of the non-thermal knots

Knot	S Band (%)	C Band (%)	X Band (%)
SE	< 6	< 5	< 7
NW_C	< 6	< 9	< 12
NW	< 5	< 4	< 6

- Very low PD (< 10 %)

➔ Turbulence in the shocks (real effect)

➔ Faraday depolarization (instrumental effect)

(implying high electronic densities in the jet)

Conditions for particle acceleration in Serpens

- Efficient particle acceleration takes place at adiabatic shocks (Blondin et al. 1989)

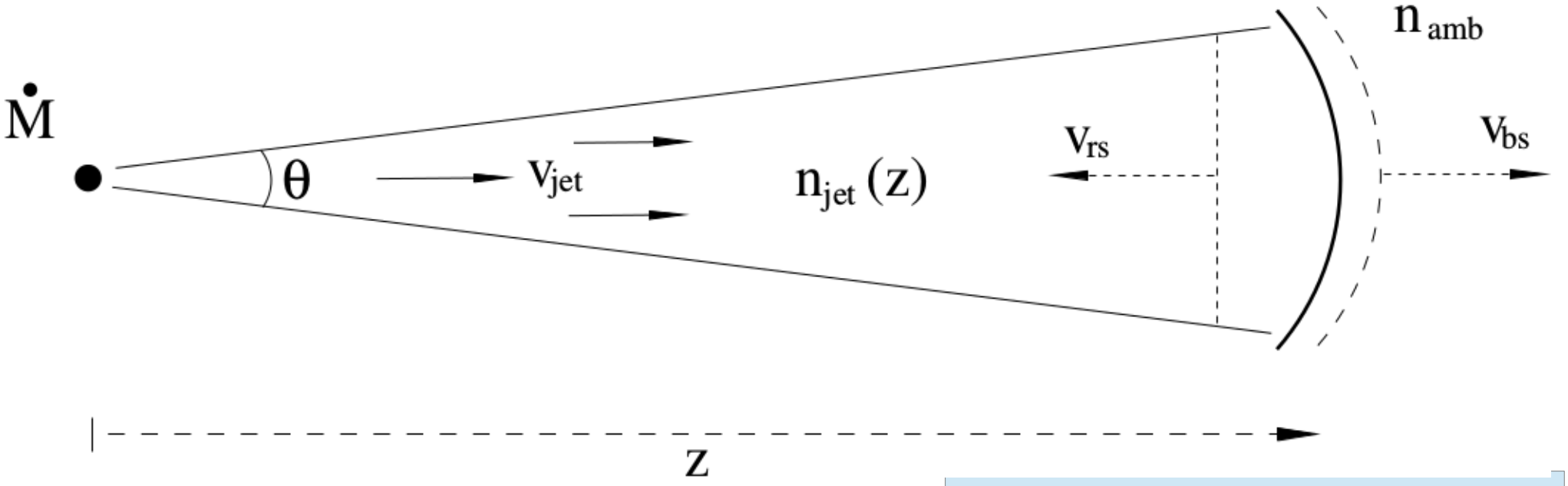
$$\frac{d_{cool}}{r_j} > 1$$

- d_{cool} (thermal), distance to which the shocked material returns to its temperature before the shock

$$d_{cool} \sim 2\,x\,10^{14}\,cm \left(\frac{n_{amb}}{10^4\,cm^{-3}} \right)^{-1} \left(\frac{v_{bs}}{100\,km\,s^{-1}} \right)^{4.43}$$

Gonzalez et al. (2004)

Reverse shocks



$$\frac{v_{jet}}{v_s} = \frac{(1+\beta)}{\beta}, \beta = \sqrt{\frac{n_{jet}}{n_{amb}}}$$ Raga et al. 1998

$$\frac{n_{jet}}{cm^{-3}} = \frac{3.95\,x\,10^{7}}{4\,\pi\,(1-\cos\theta/2)} \frac{\dot{M}}{M_{sun}\,yr^{-1}} \left(\frac{v_{jet}}{km\,s^{-1}}\right)^{-1} \left(\frac{z}{pc}\right)^{-2}$$

Reynolds 1986

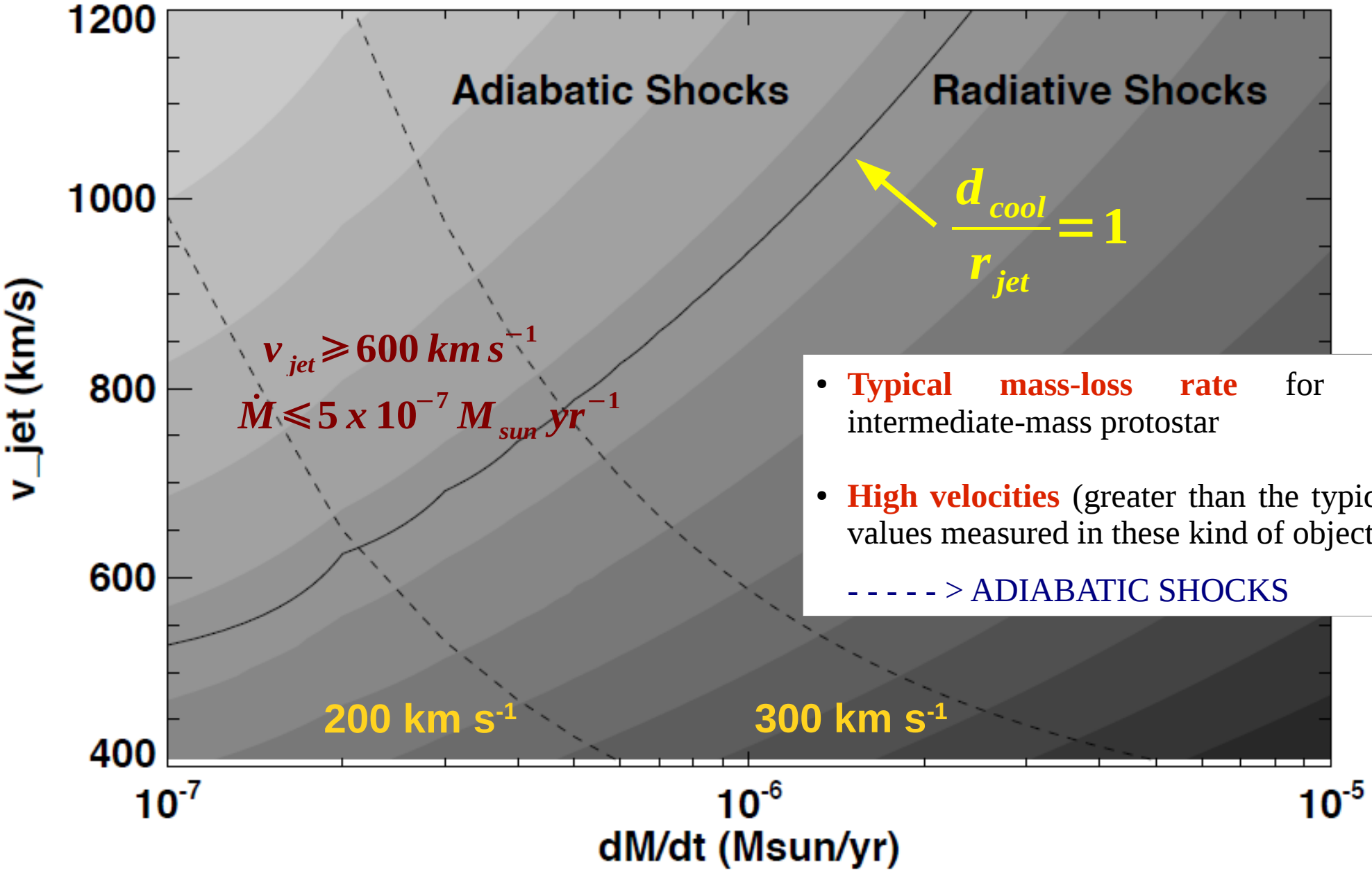
We explore different combinations of

$\dot{M}$, v_{jet}

We solve this two equation system for

n_{jet} y v_{bs}

Reverse shocks



- **Typical mass-loss rate** for an intermediate-mass protostar
- **High velocities** (greater than the typical values measured in these kind of objects)

- - - - - > ADIABATIC SHOCKS

Summary

- We studied the radio emission and kinematics of the Triple Source in Serpens
- We found high proper motions for the knots (tracing shocks), implying jet velocities higher than typical values
- We measured negative spectral indices where the jet impacts against the cloud, suggesting non-thermal emission
- We did not find linearly polarized emission: 1) disordered magnetic fields. 2) Faraday depolarization
- Particle acceleration seems to be efficient in the reverse shock, and no extreme conditions seem to be needed

Mass-loss rate ~ typical value,

but

A fast jet moving in a dense medium


Thanks!