Outflows from Young Stars and the Interstellar Medium

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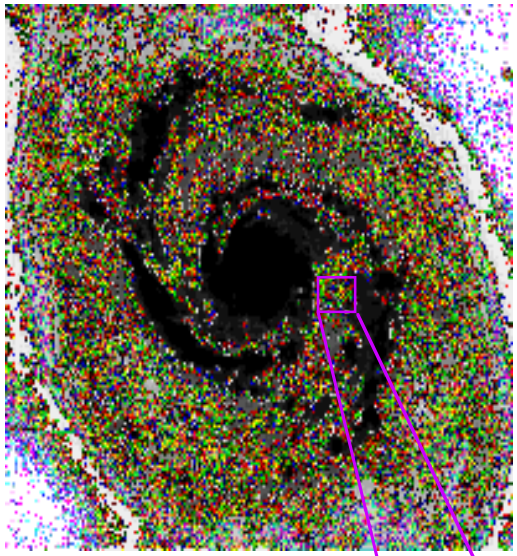
Note: This talk is a special "preview" of Héctor Arce's thesis, to be completed Summer 2001.

Galaxy



Star Formation
v. 2000

Stars

time

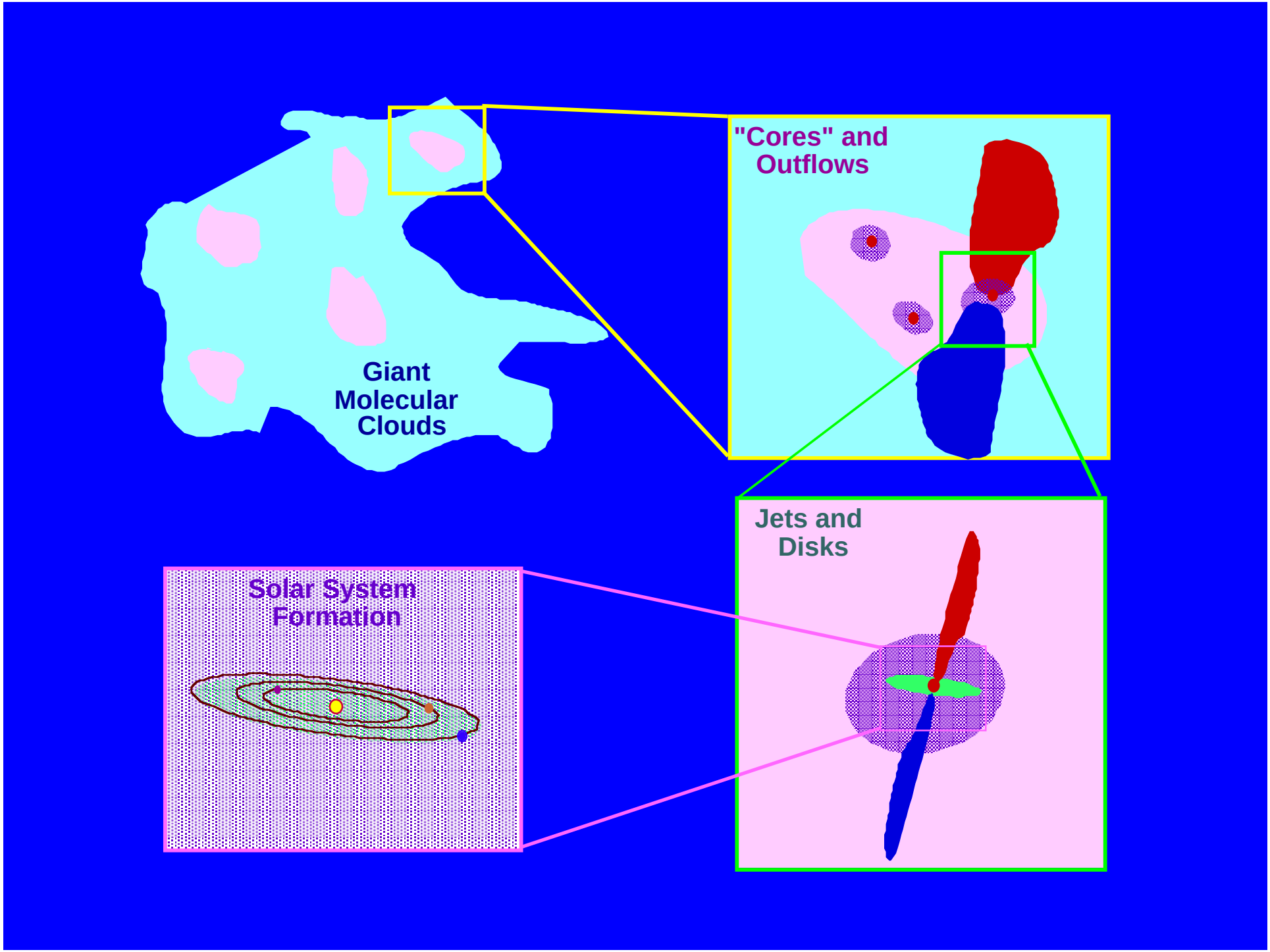
Young Stellar
Object +Outflow

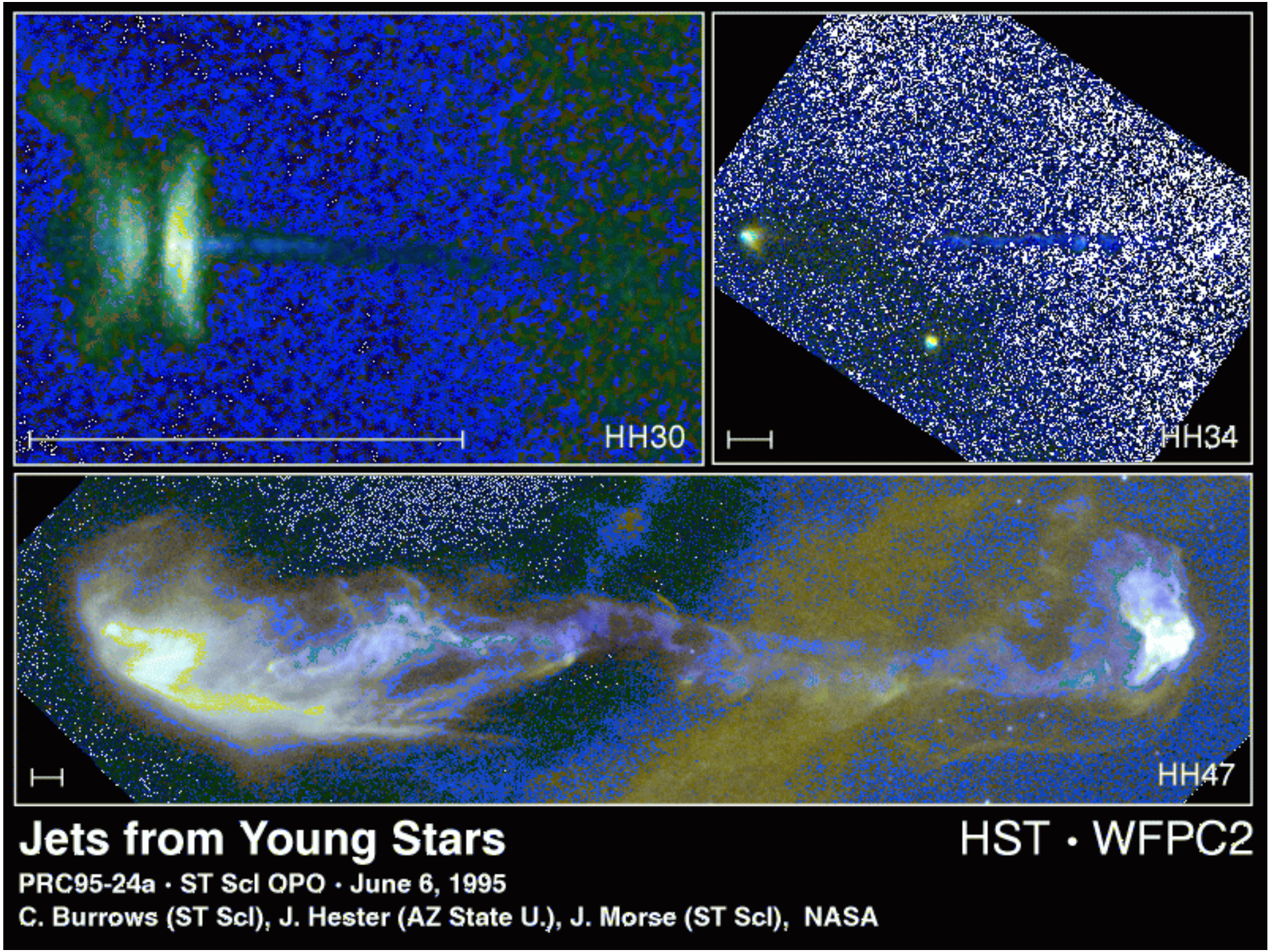
"Velocity Coherent"
Dense Core

Self-Similar, Turbulent,
"Larson's Law" Clouds
(a.k.a. GMC or Cloud Complex)

Star Formation v. 2000: The Bare Essentials

1. Stars form in molecular cloud complexes which range in size from ~10's to 100's of pc.
2. Molecular clouds can be characterized as turbulent, definitely supersonic, and perhaps super-Alfvénic.
3. Select "coherent" pieces of molecular clouds collapse and fragment to form stars.
4. Every star produces an outflow for during some (significant) fraction of its pre-main-sequence life.
5. Outflows can, and apparently often do, extend for several pc.


Giant
Molecular
Clouds
"Cores" and
Outflows
Jets and
Disks
Solar System
Formation

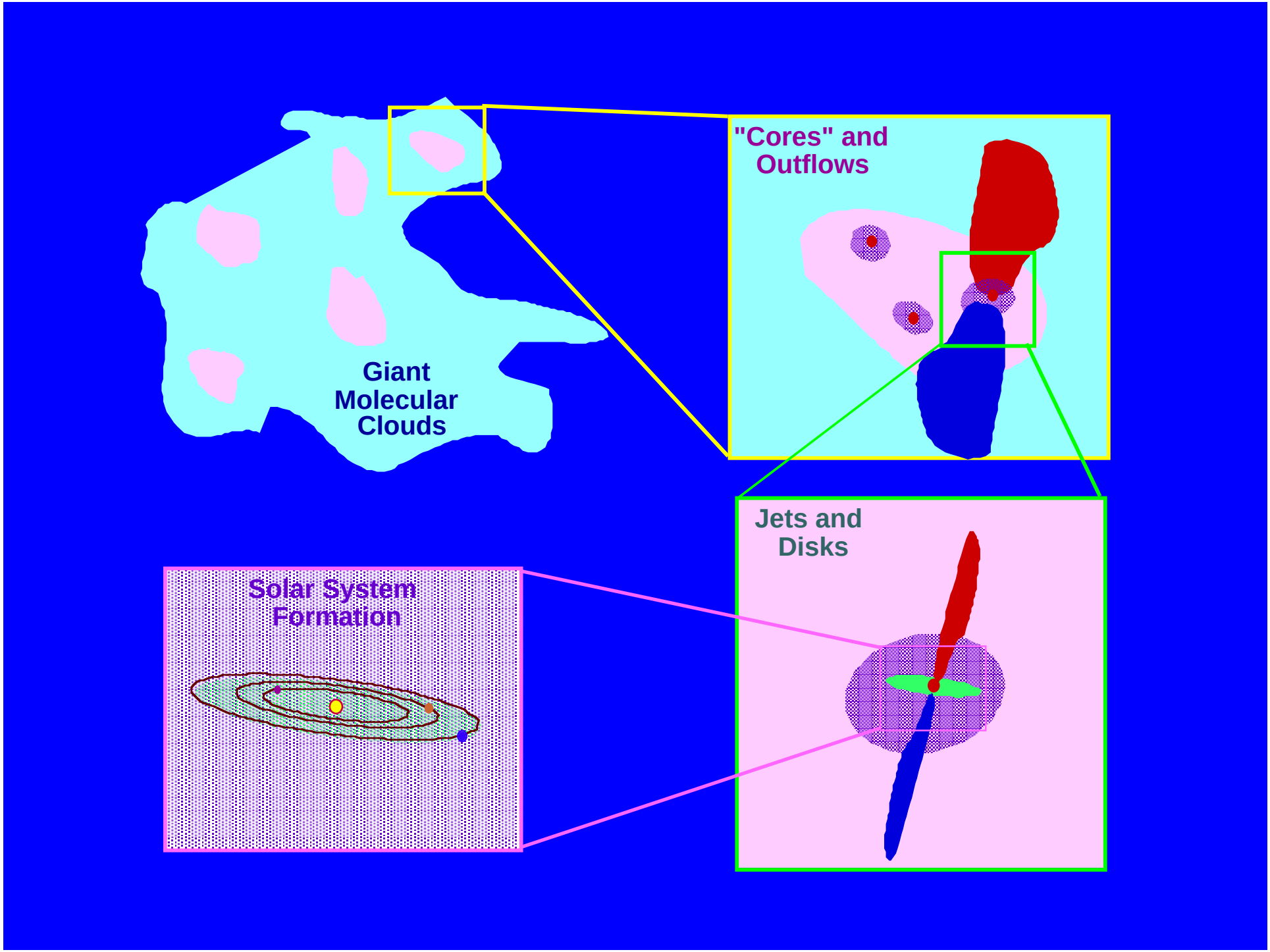


Jets from Young Stars

HST • WFPC2

PRC95-24a · ST ScI OPO · June 6, 1995

C. Burrows (ST ScI), J. Hester (AZ State U.), J. Morse (ST ScI), NASA


Giant
Molecular
Clouds
"Cores" and
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Jets and
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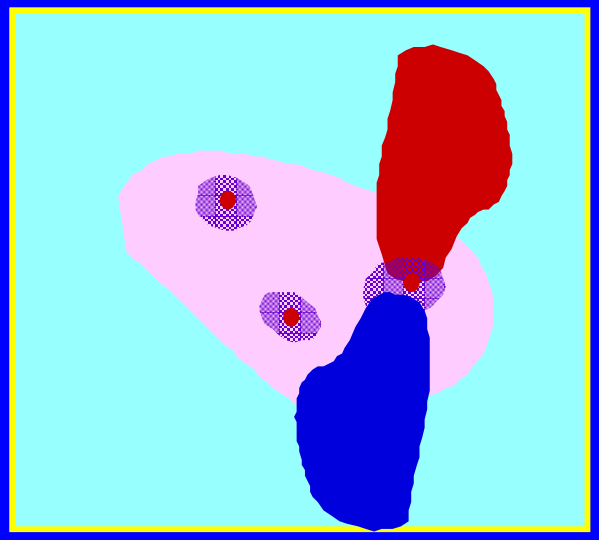
Solar System
Formation

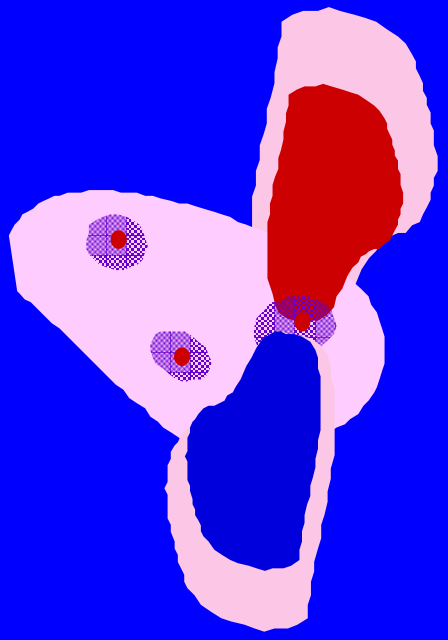
Do Outflows Ever "Create" Cloud Structures?

If so, how does this effect future star formation & the "clump mass spectrum"?

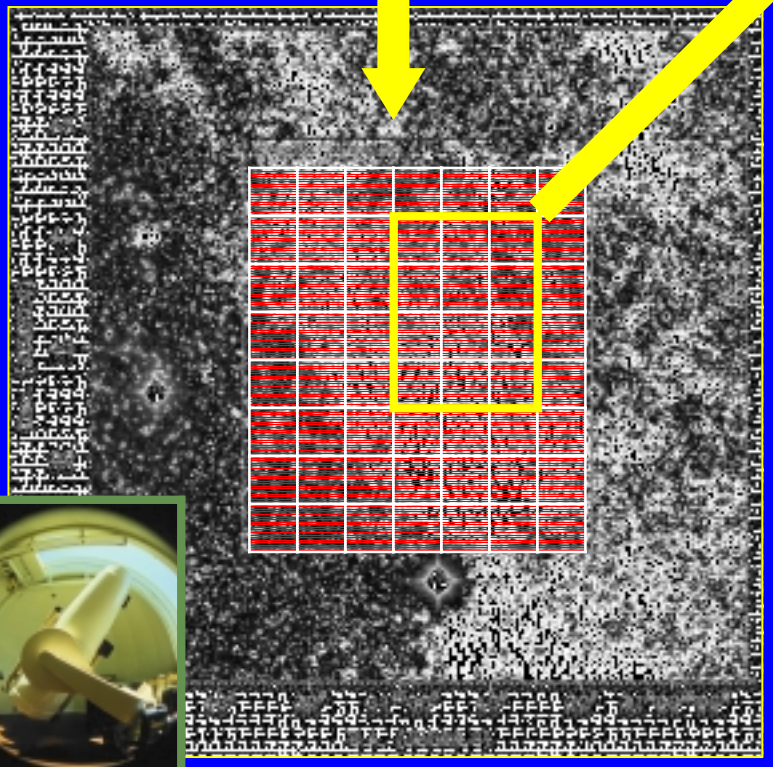
The "Standard Model"

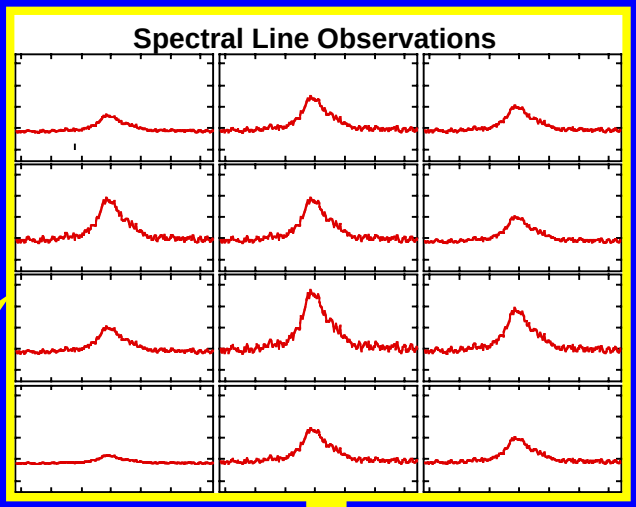


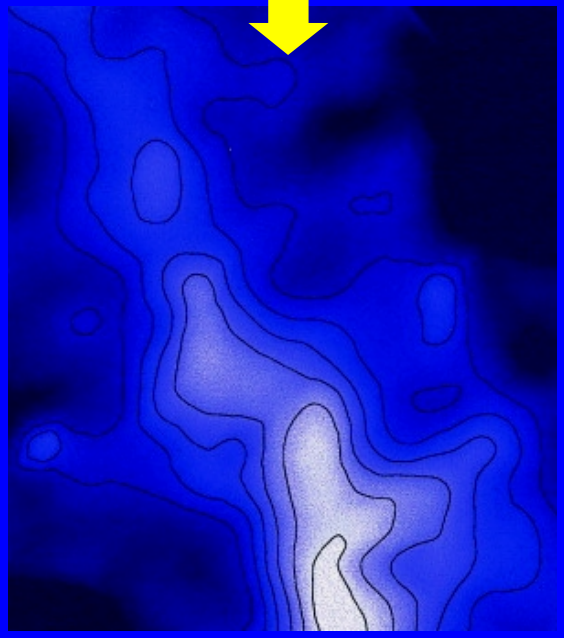
Today's Proposal



Radio Spectral-line Observations of Molecular Clouds

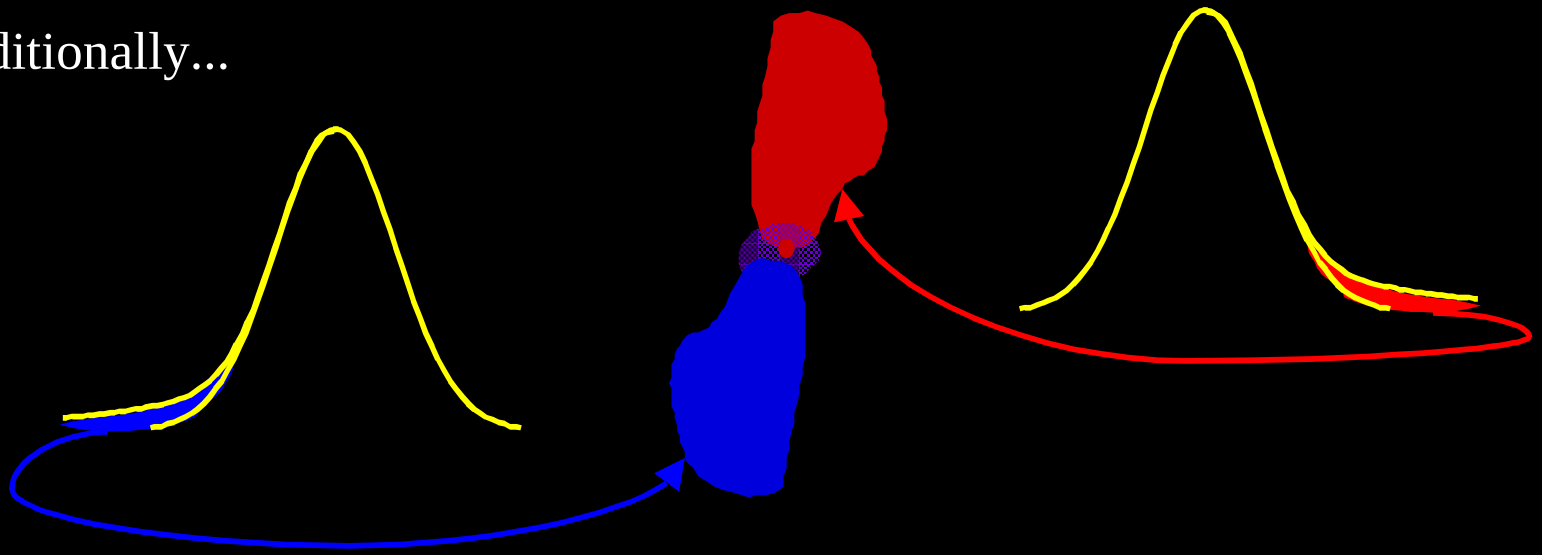




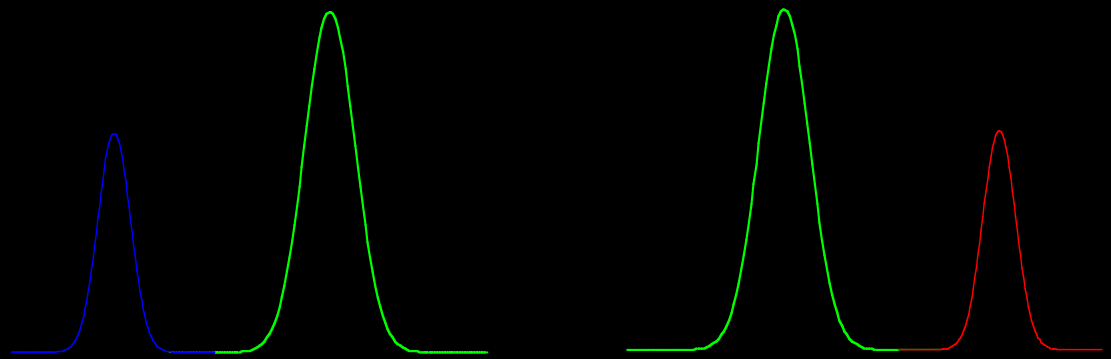


“Outflow” Spectra

Traditionally...

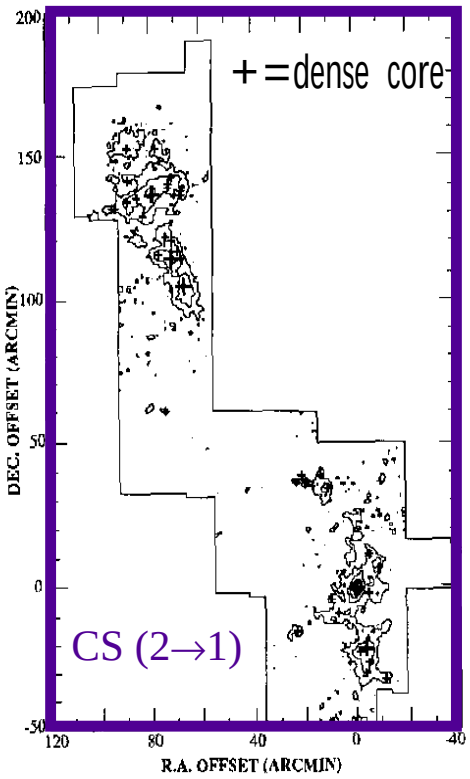


Today...



"Clump" Mass Distribution

What is a clump?



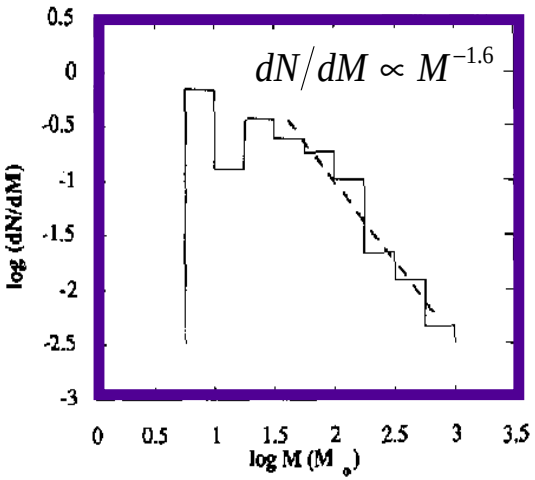
E. Lada 1992

Typical Stellar IMF

$$dN/dM \propto M^{-2.5\pm0.3}$$

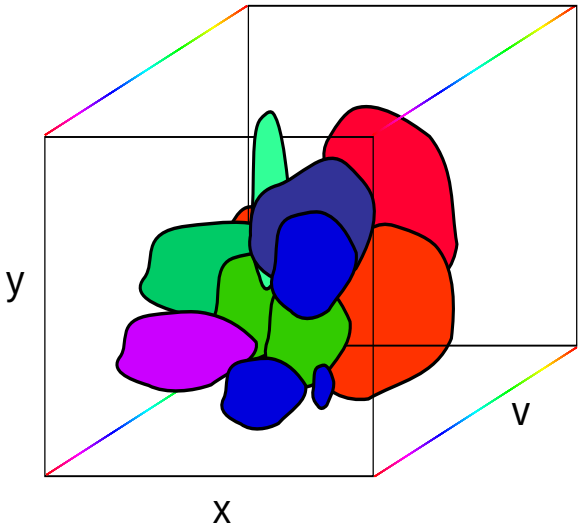
Salpeter 1955
Miller & Scalo 1979

What does the clump "IMF" look like?



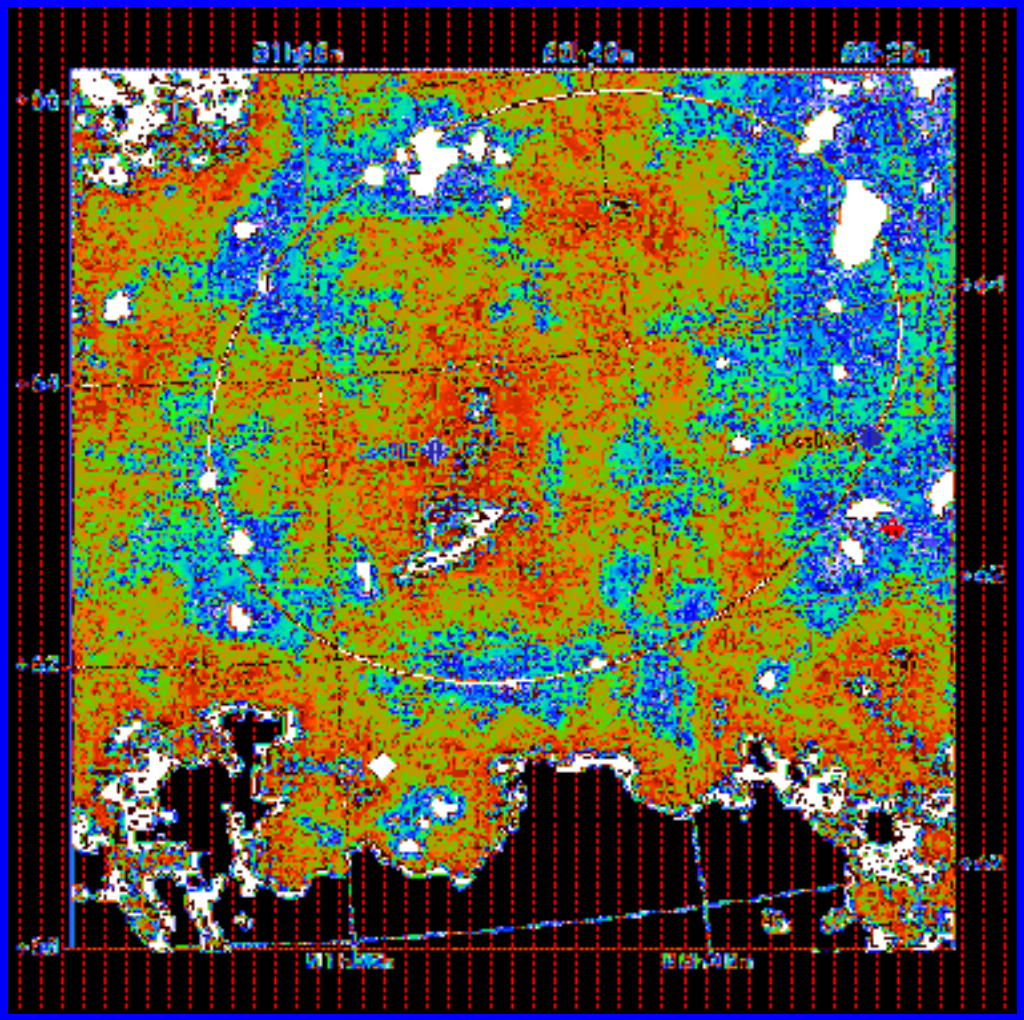
E. Lada et al. 1991

Structure-Finding Algorithms



- CLUMPFIND (*Williams et al. 1994*)
- Autocorrelations (e.g. *Miesch & Bally 1994*)
- Structure Trees (*Houlahan & Scalo 1990,92*)
- GAUSSCLUMPS (*Stutzki & Güesten 1990*)
- Wavelets (e.g. *Langer et al. 1993*)
- Complexity (*Wiseman & Adams 1994*)
- IR Star-Counting (*C. Lada et al. 1994*)
- PCA (Heyer & Schloerb 1997)
- Spec. Corr. Function (Rosolowsky et al. 1999)

Keep in Mind...
Molecular Clouds "Created" by Supernovae



100 μm Emission in Cassiopeia

Tóth et al. 1995

Examples that might convince you that YSO Outflows Move More Gas than You Thought

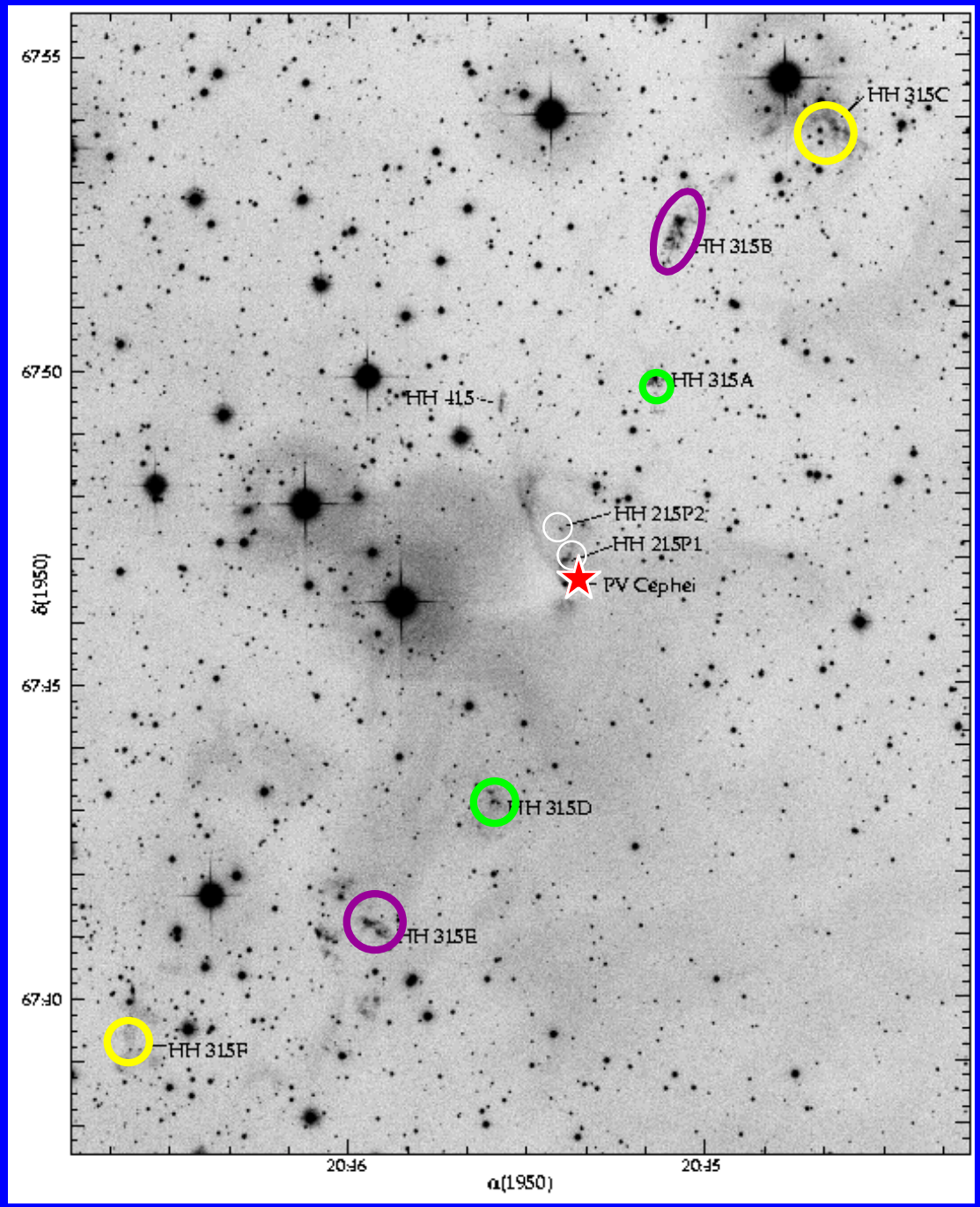
1. "Giant" Herbig-Haro Flows
PV Cephei

2. The Effect of Outflows on their host Cores
B5

3. Are Some Dark Clouds Created by Outflows?
HH300

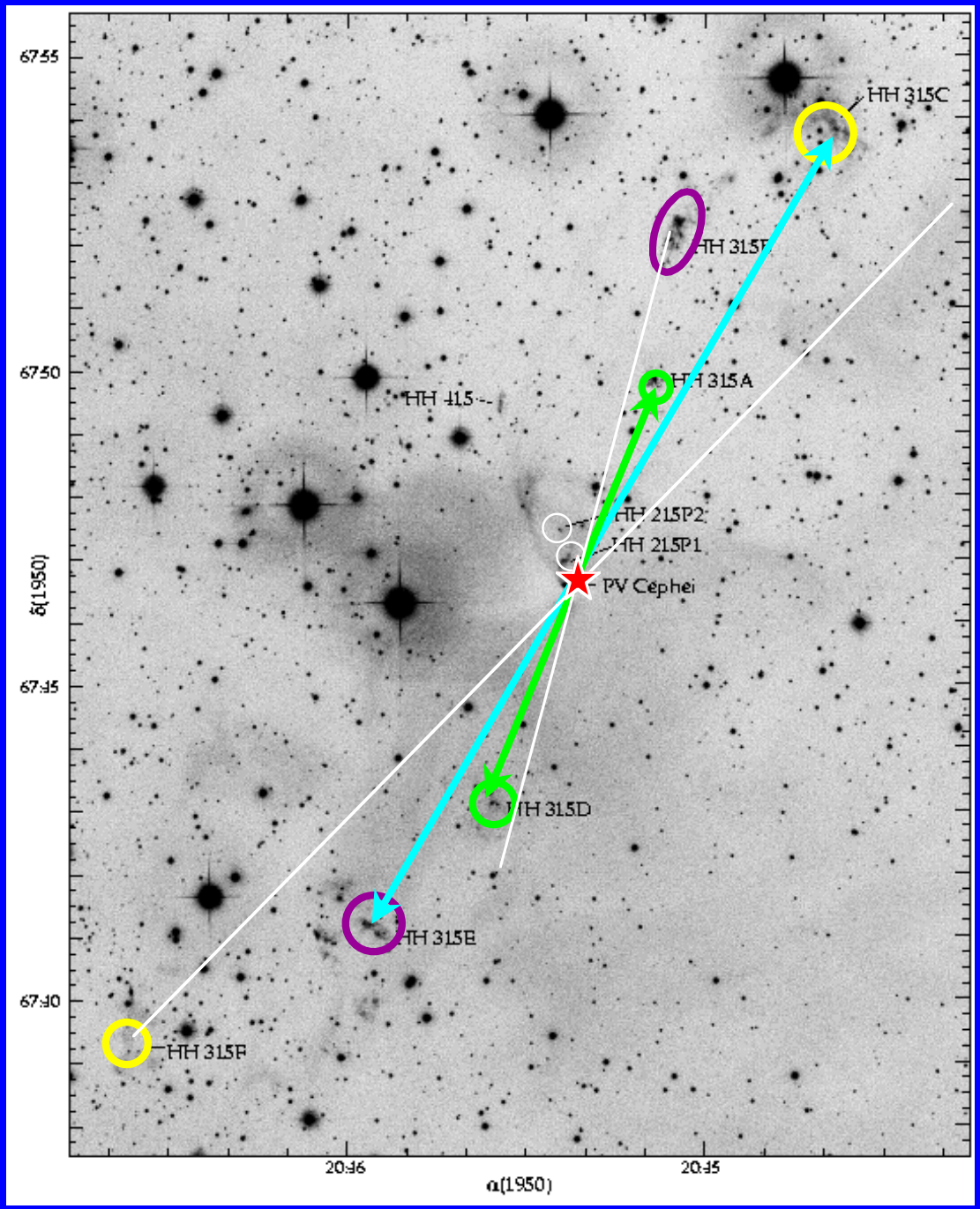
4. How much of a molecular cloud complex was "moved" to its present location by an outflow?
Taurus

“Giant” Herbig-Haro Flows: PV Ceph

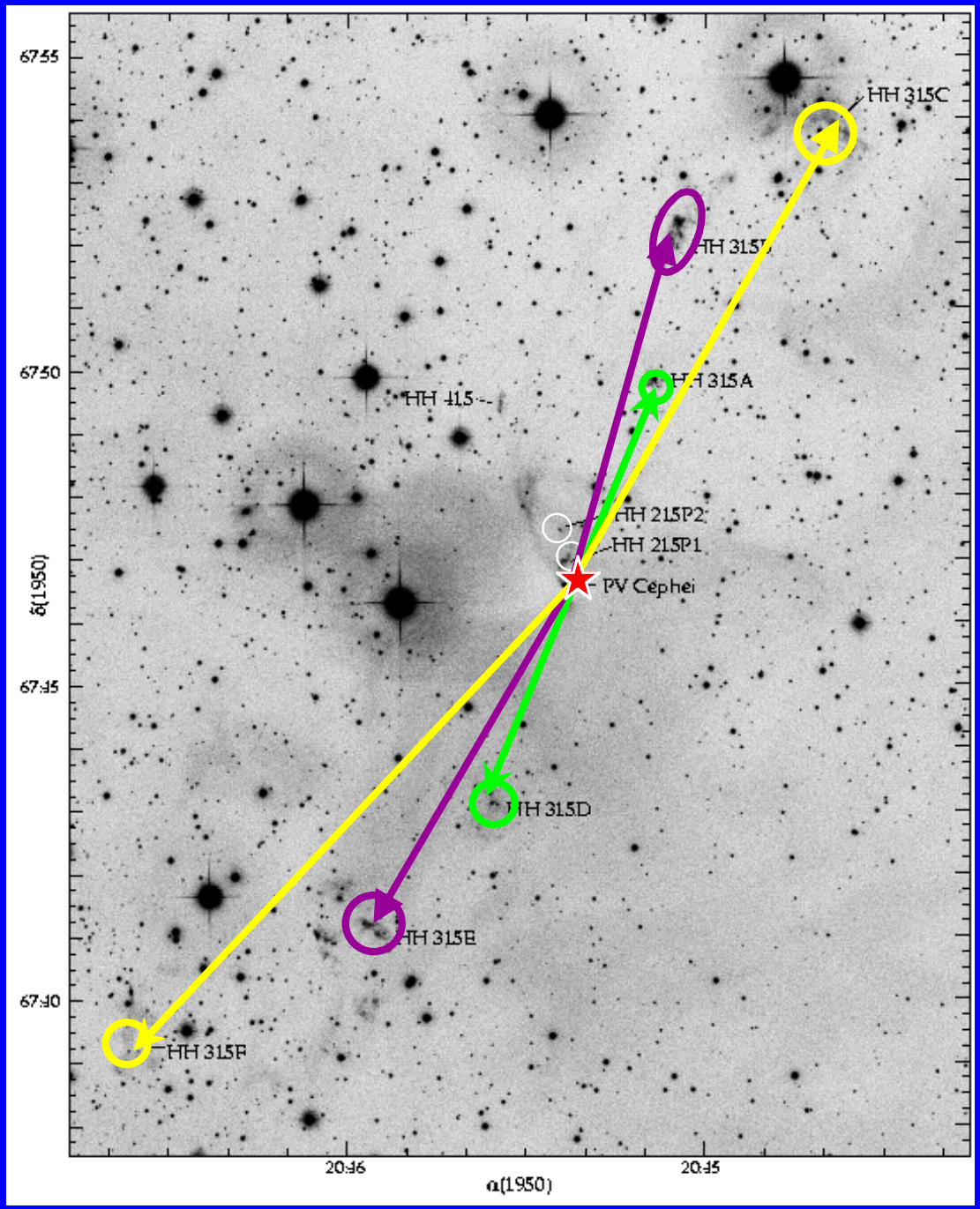


Reipurth, Bally & Devine 1997

Matching Ejection Angles (assumes episodic ejections from precessing or wobbling stationery source)



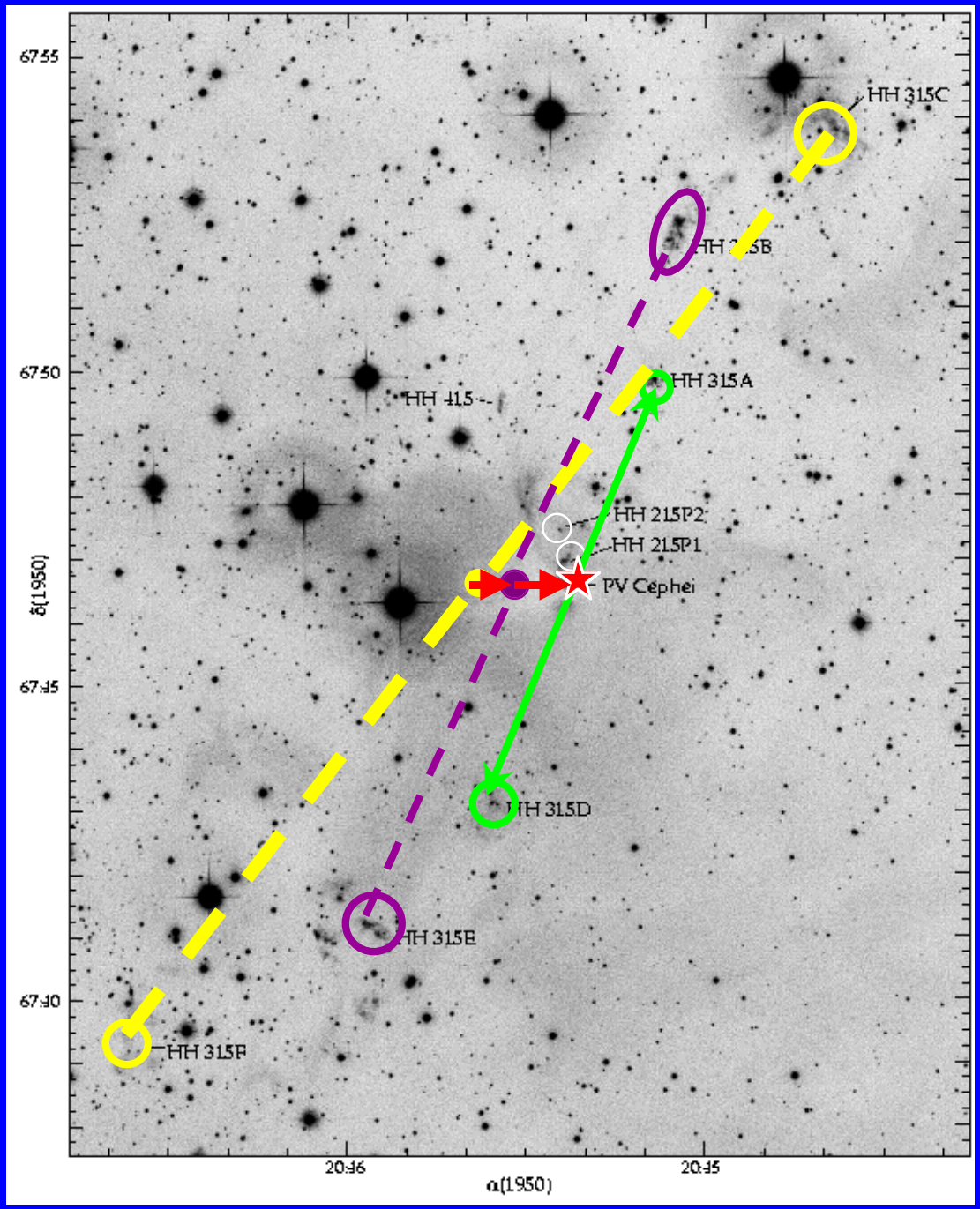
Matching Ejection Distance (preferred by Reipurth)



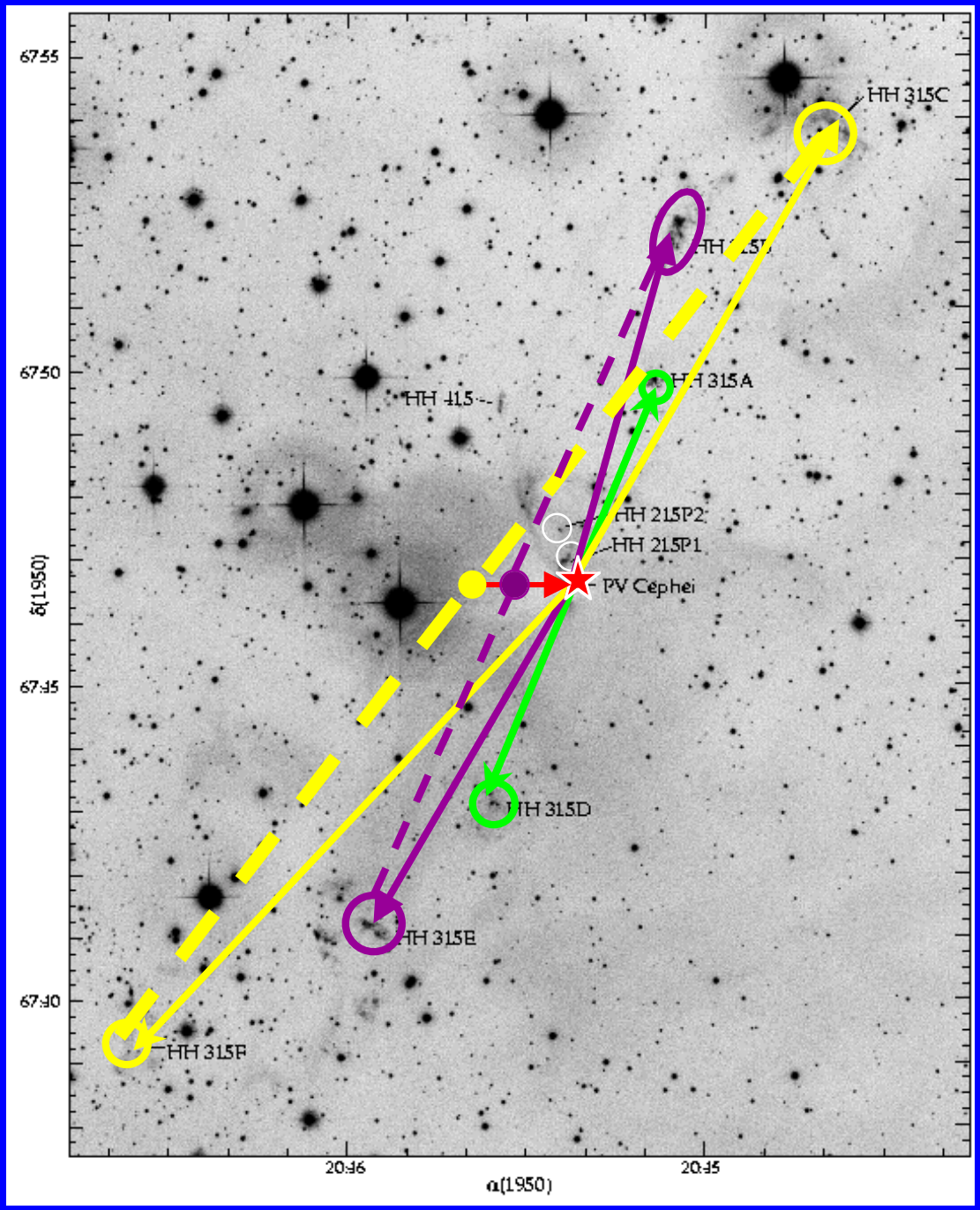
A New Proposal:

Episodic ejections from precessing or wobbling moving source

Required motion of 0.25 pc (e.g. 2 km s^{-1} for 125,000 yr)



“Giant” Herbig-Haro Flows

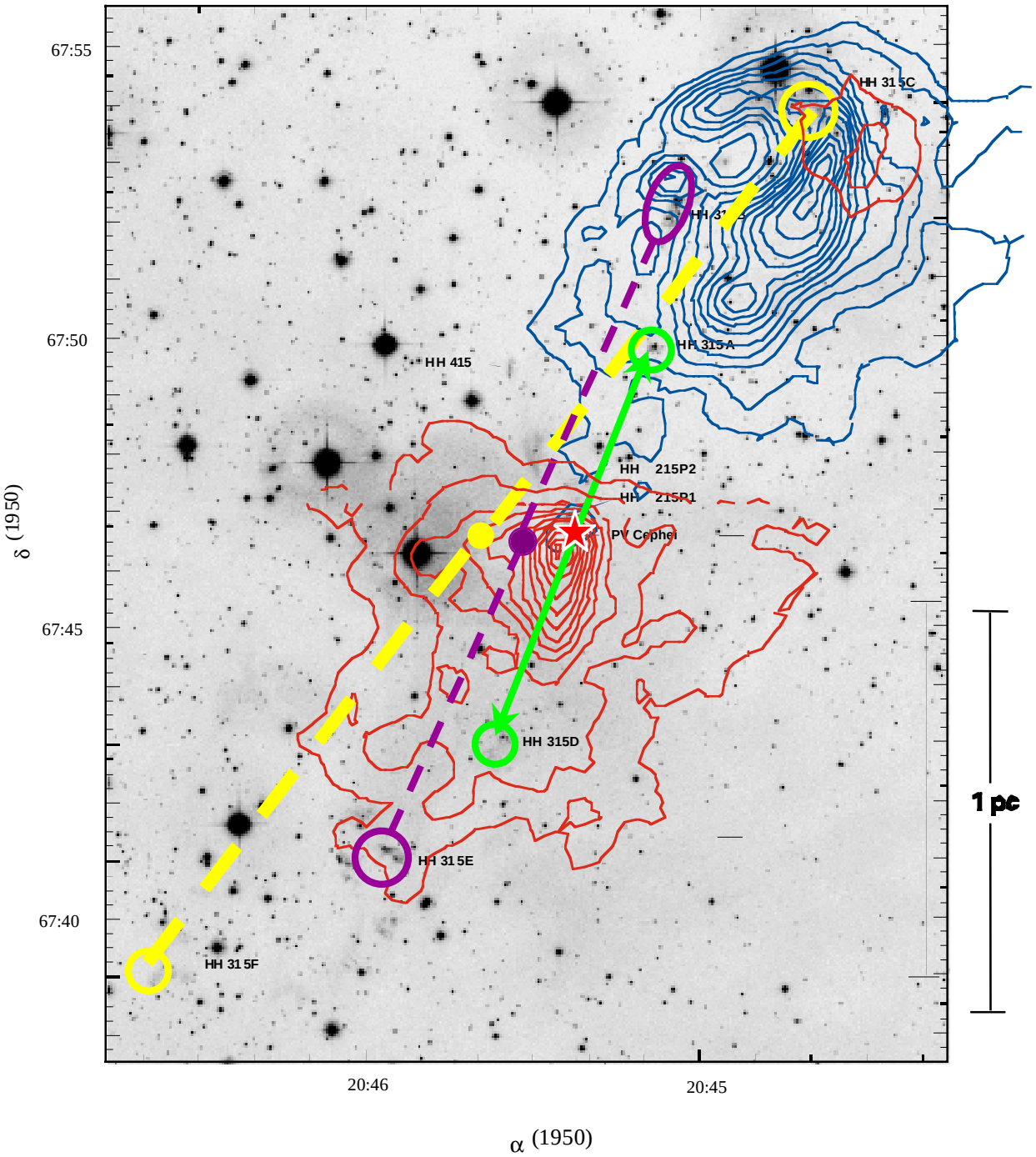


PV Ceph

^{12}CO (2-1) OTF
*Map from **NRAO 12-m***

Red: 3.0 to 6.9 km s^{-1}
Blue: -3.5 to 0.4 km s^{-1}

Arce & Goodman 2000



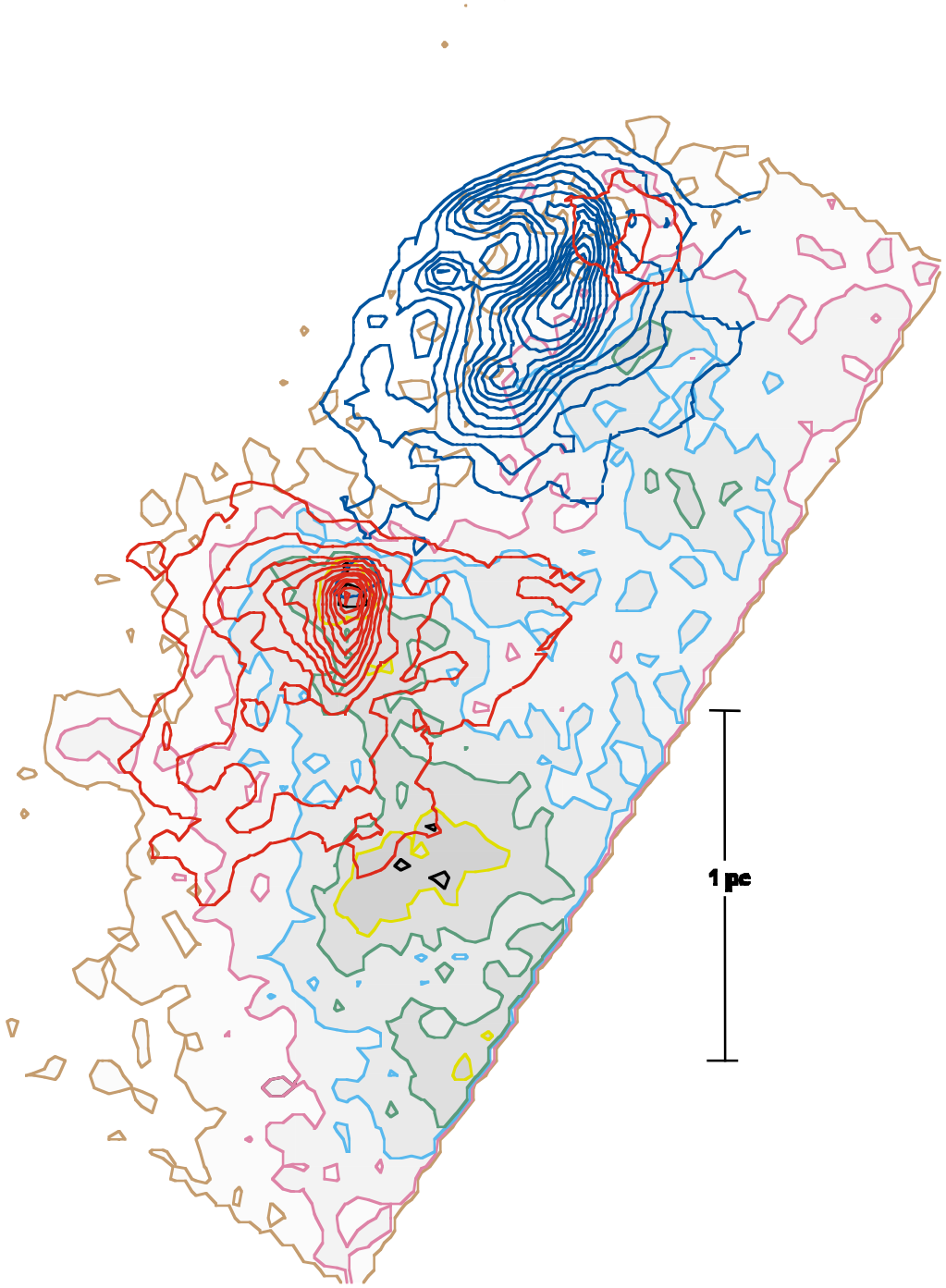
"Ambient" Gas in PV Ceph

^{13}CO (1-0) SEQUOIA
Map from FCRAO

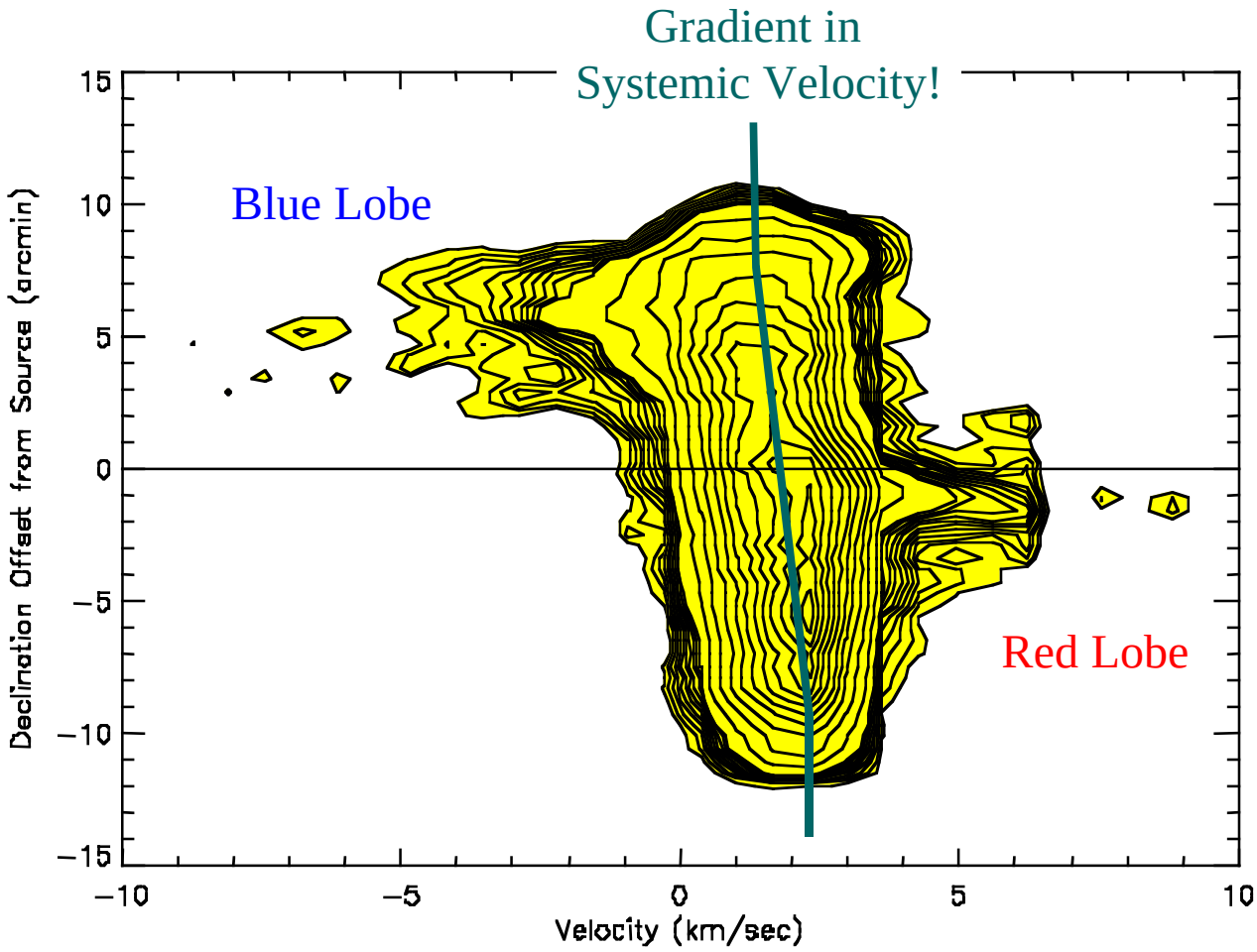
Integrated over all velocities.

Arce & Goodman 2000

PV Ceph ^{12}CO (2-1) Outflow Contours on ^{13}CO (1-0) Map



Position-Velocity Diagram for PV Ceph Outflow



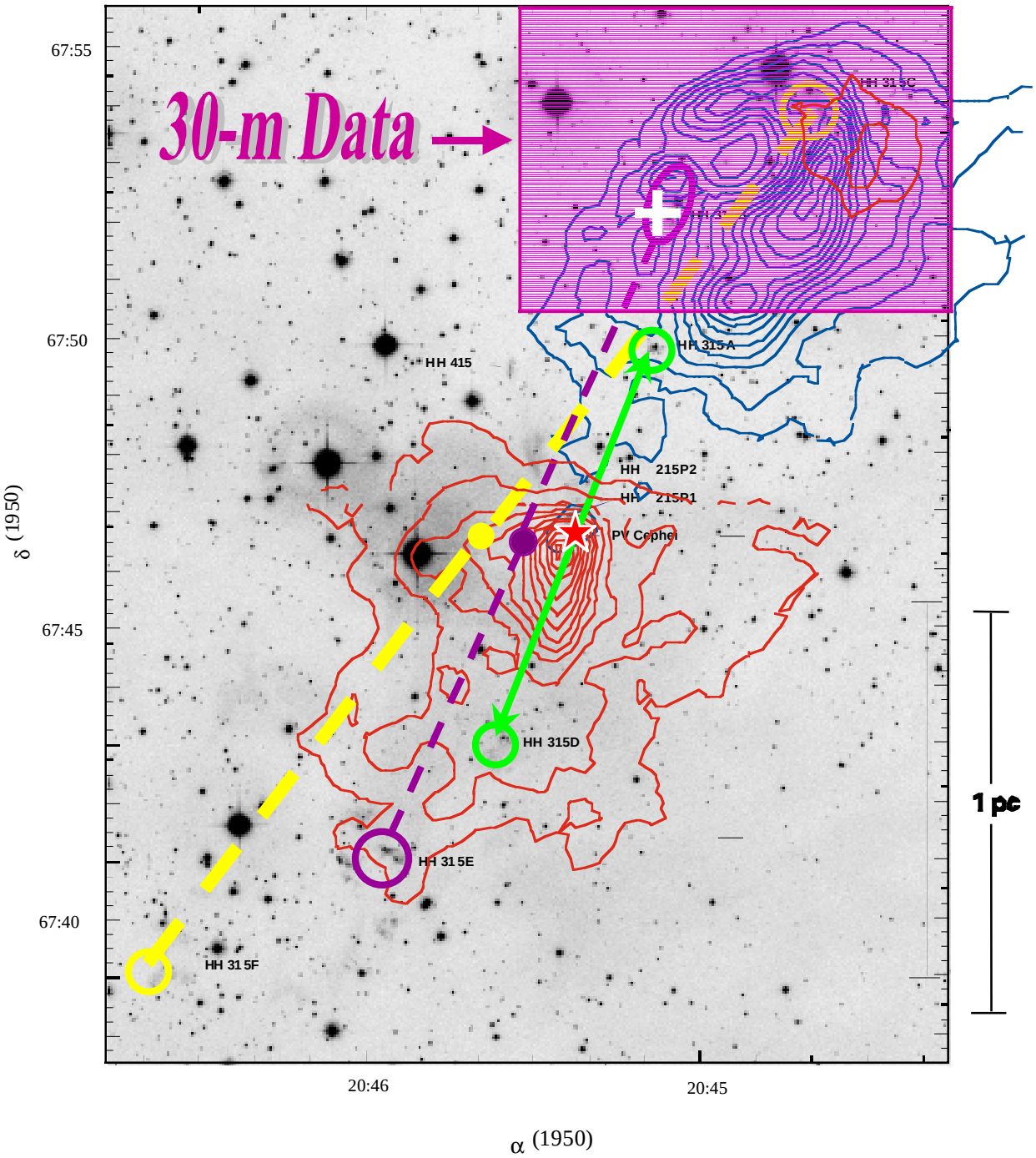
^{12}CO (2-1) data from NRAO 12-m (Arce & Goodman 2000)

Zooming in on the "Blue Lobe" of PV Ceph

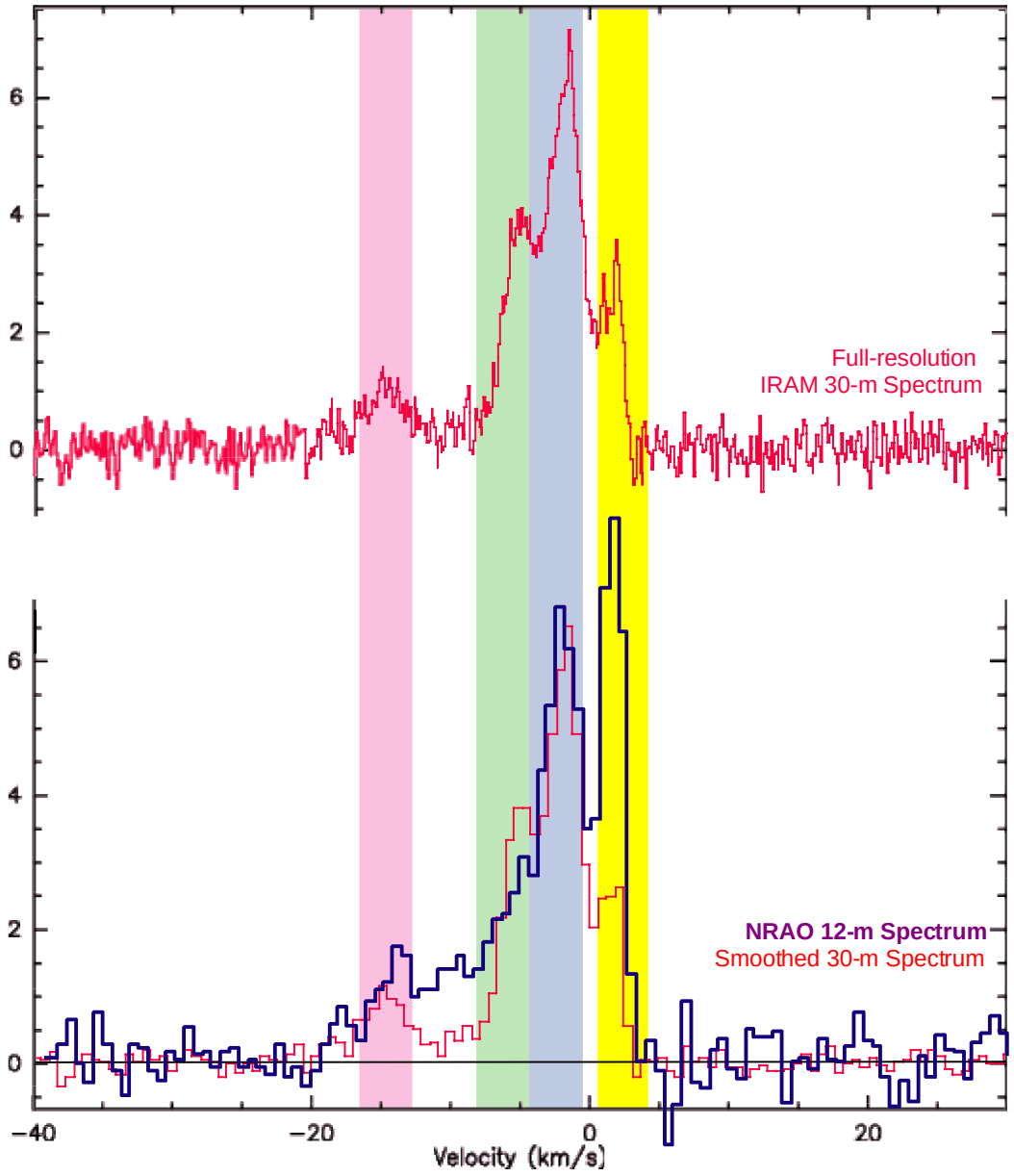
^{12}CO (2-1) OTF
*Map from **NRAO 12-m***

Red: 3.0 to 6.9 km s^{-1}
Blue: -3.5 to 0.4 km s^{-1}

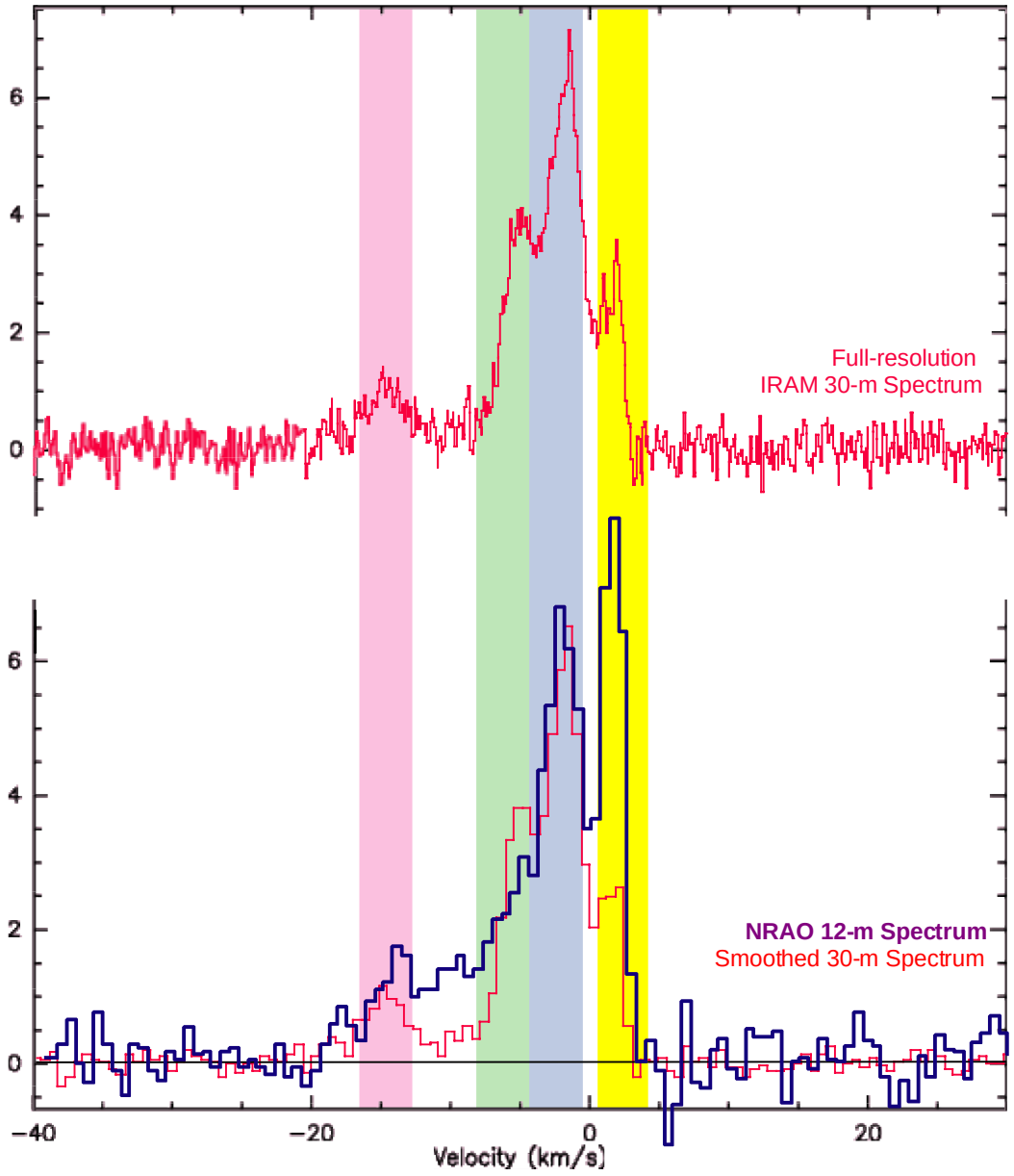
Arce & Goodman 2000



PV Ceph: CO (2-1) Spectra Near HH315 B



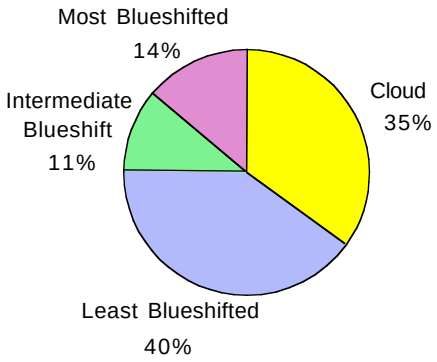
PV Ceph: CO (2-1) Spectra Near HH315 B

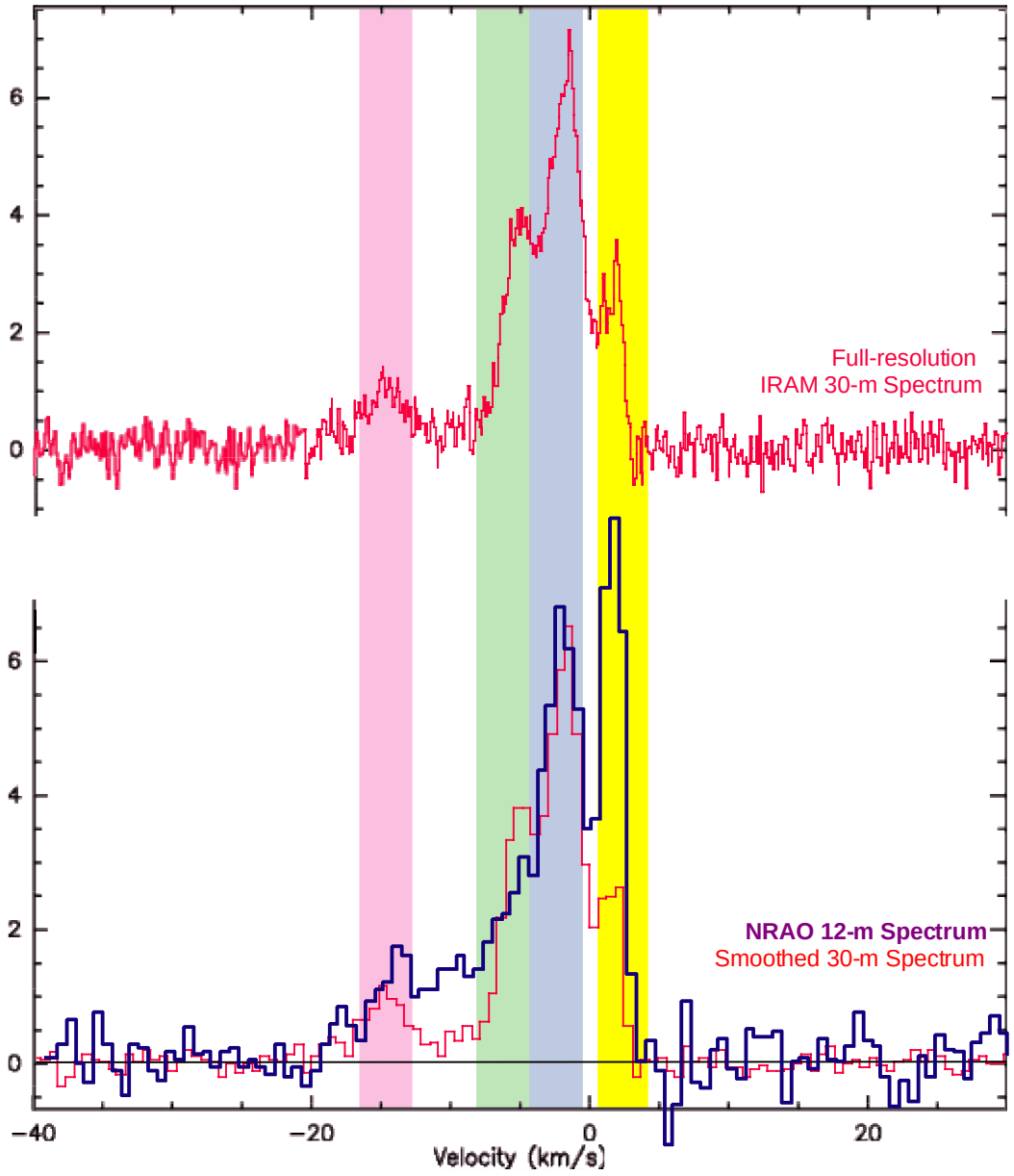


Note: Higher spatial resolution gives higher velocity resolution!

Arce & Goodman 2000

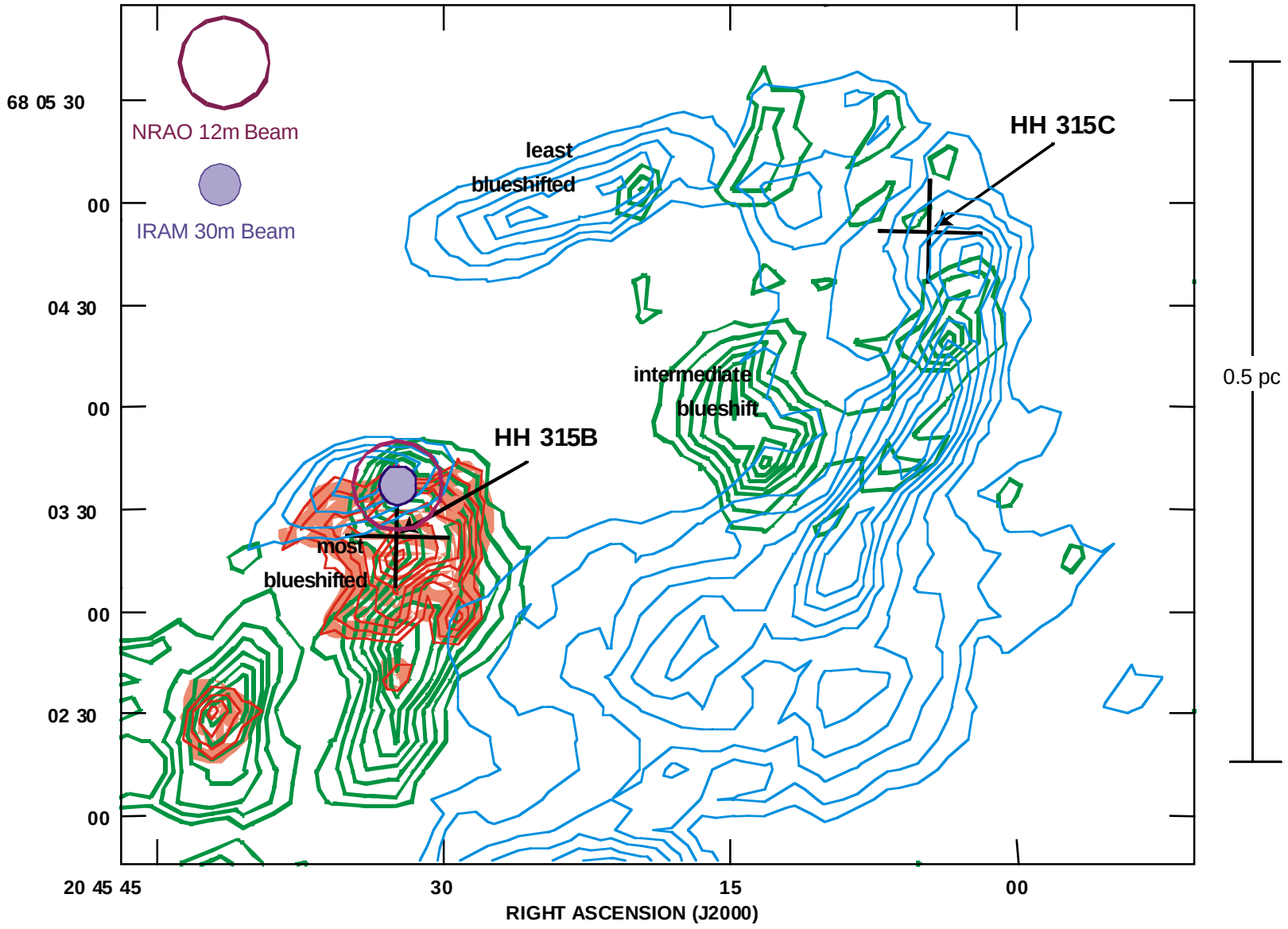
PV Ceph: CO (2-1) Spectra Near HH315 B





Arce & Goodman 2000

The "Blue" Lobe of the PV Ceph Outflow



^{12}CO (2-1) data from IRAM 30-m (Arce & Goodman 2000)

Giant HH Flow: PV Ceph

- Ejection is almost surely episodic, and gas from >1 episode present along some lines of sight
- Souce may travel in addition to precessing or wobbling
- Both Velocity and Density Structure of "Cloud" bear resemblance to Outflow

2. The Effect of Outflows on their host Cores

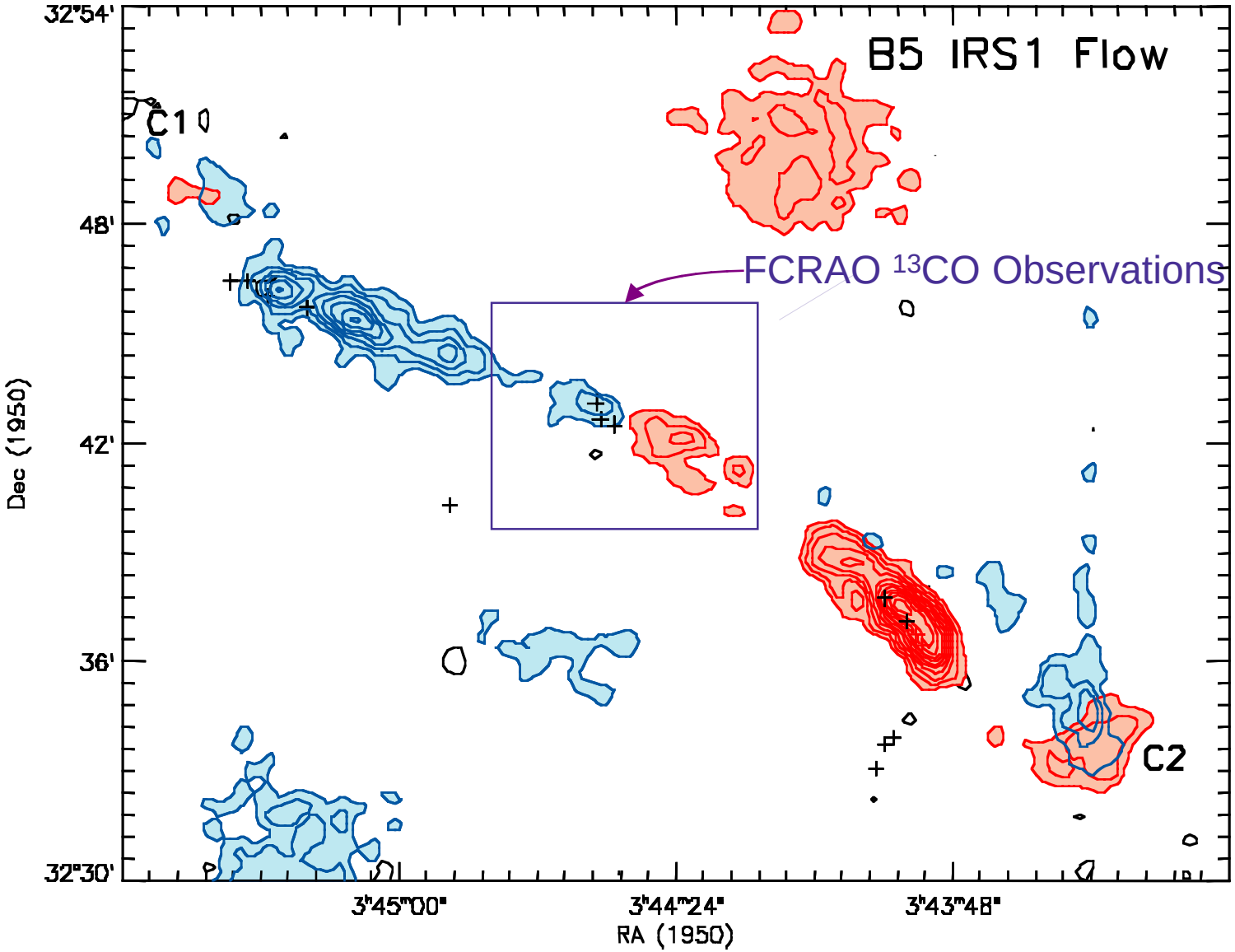
Previous Suggestions

- Increased Turbulence (in the area of the core coexisting with outflow)
- Core Dispersal by Outflows

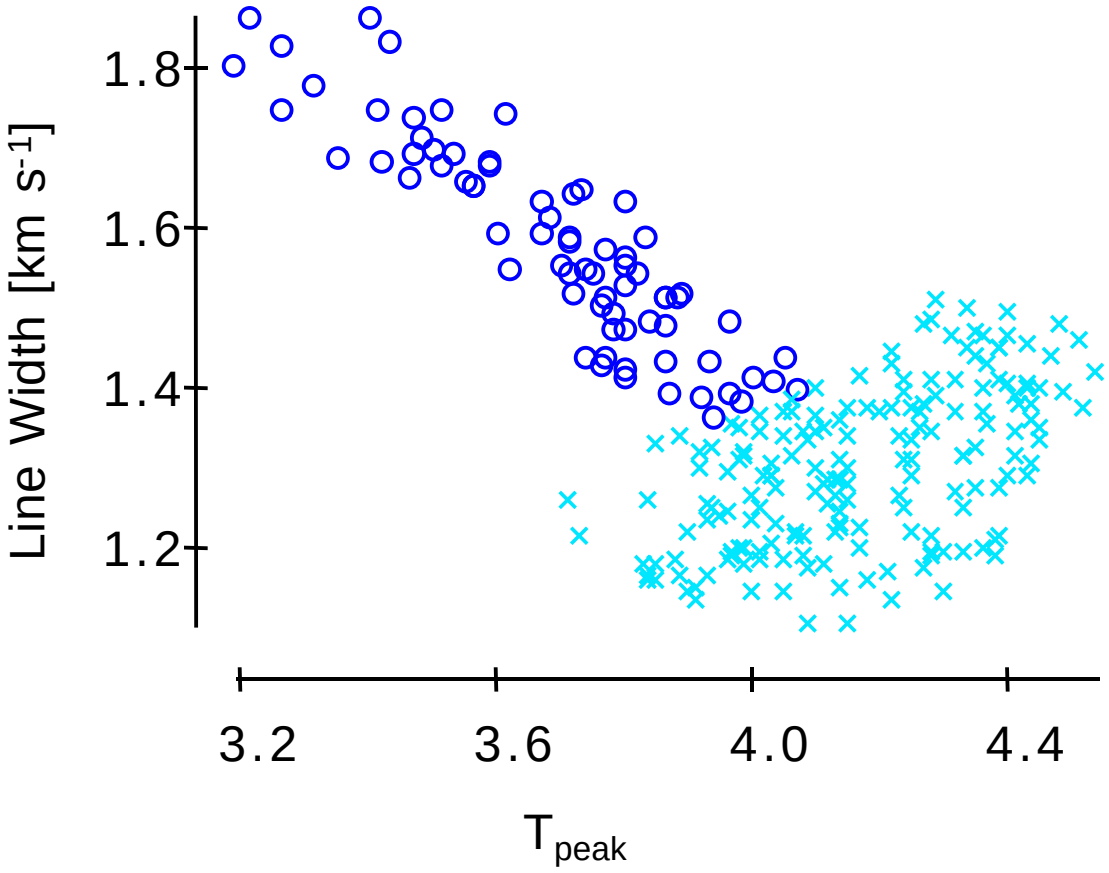
New Slightly Radical Suggestion

- Outflow Gas May Be a Significant Volume of a Core (accounts for increased line widths & can lead to core dispersal)

Yu et al. (2000) ^{12}CO (2-1) Observations,

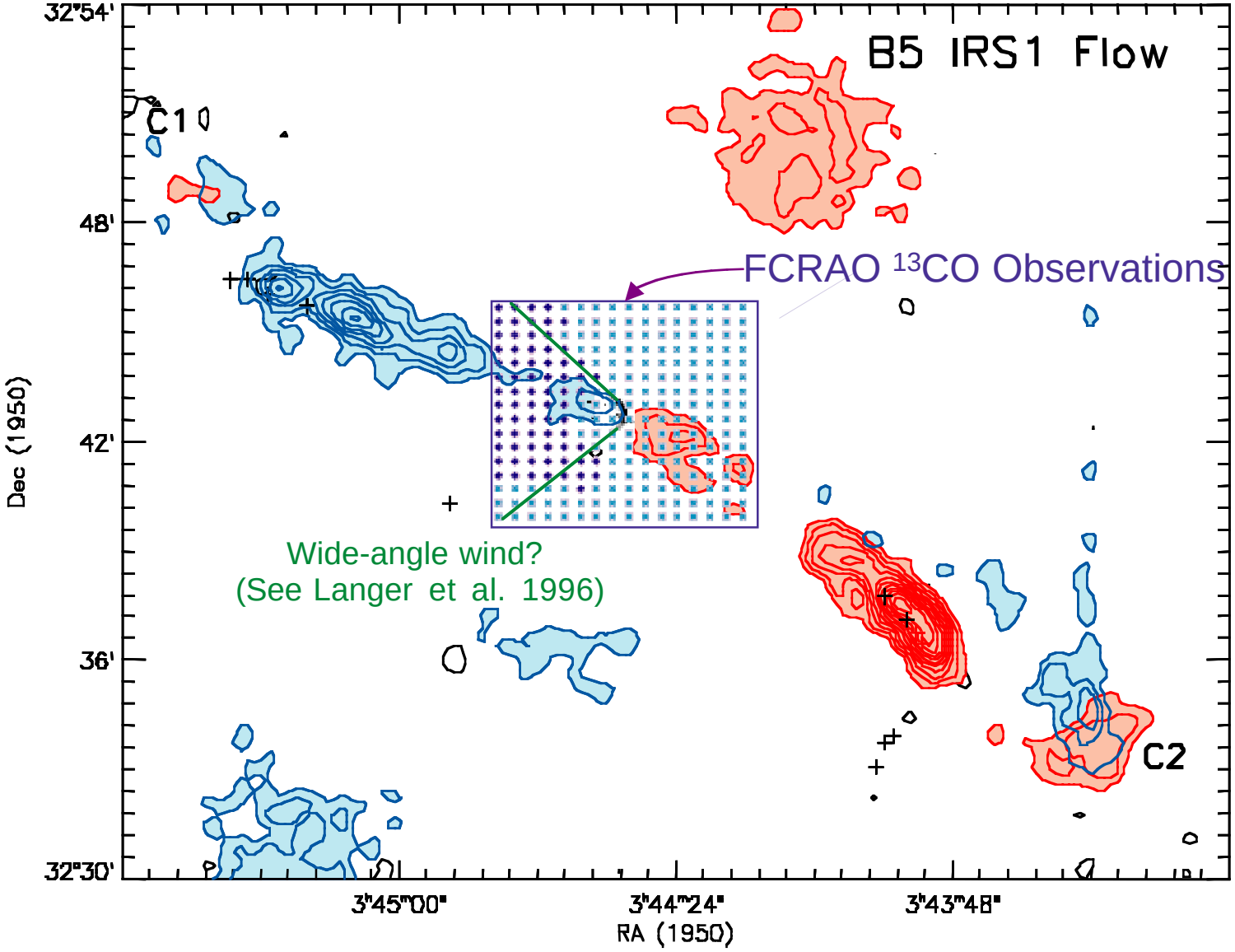


B5 “Line Width-Intensity Plot”

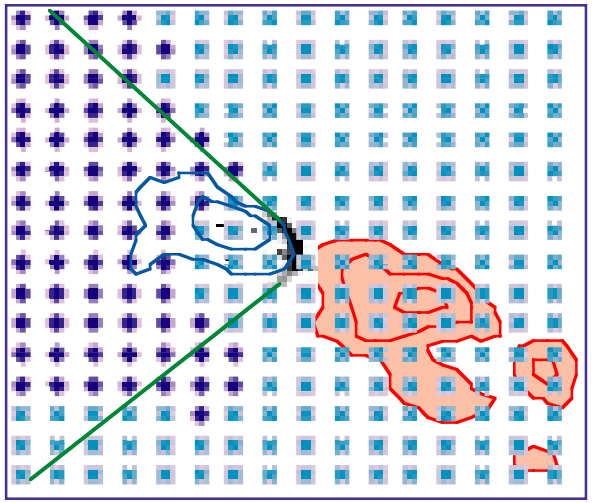


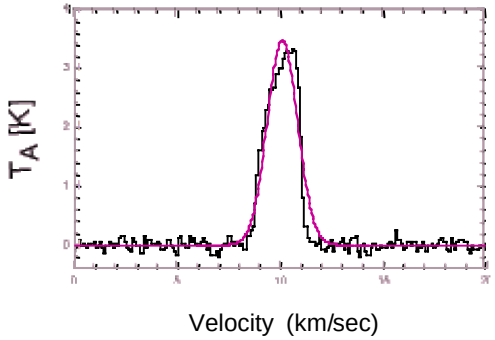
Arce & Goodman 2000

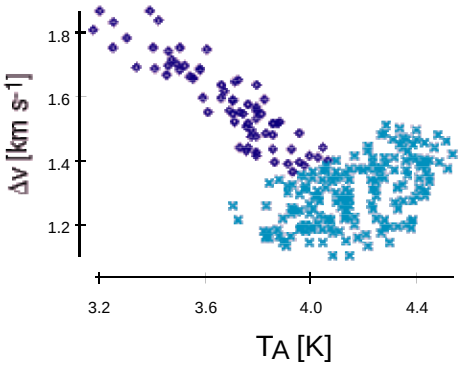
Yu et al. (2000) ^{12}CO (2-1) Observations,
with Heyer et al. (1990) IR nebulosity superimposed near source



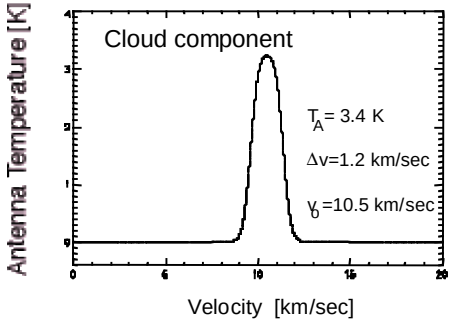
B5-IRS 5: An "Outflow" Component?

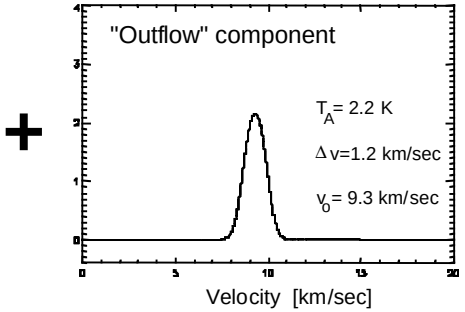


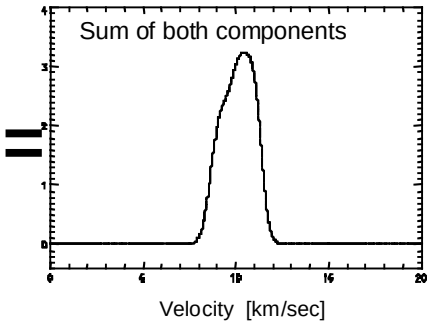


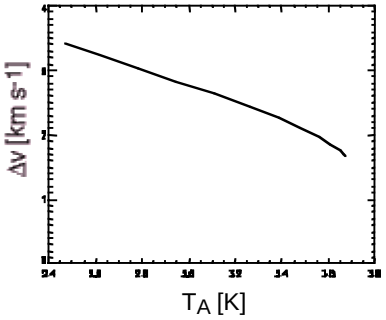


Model:



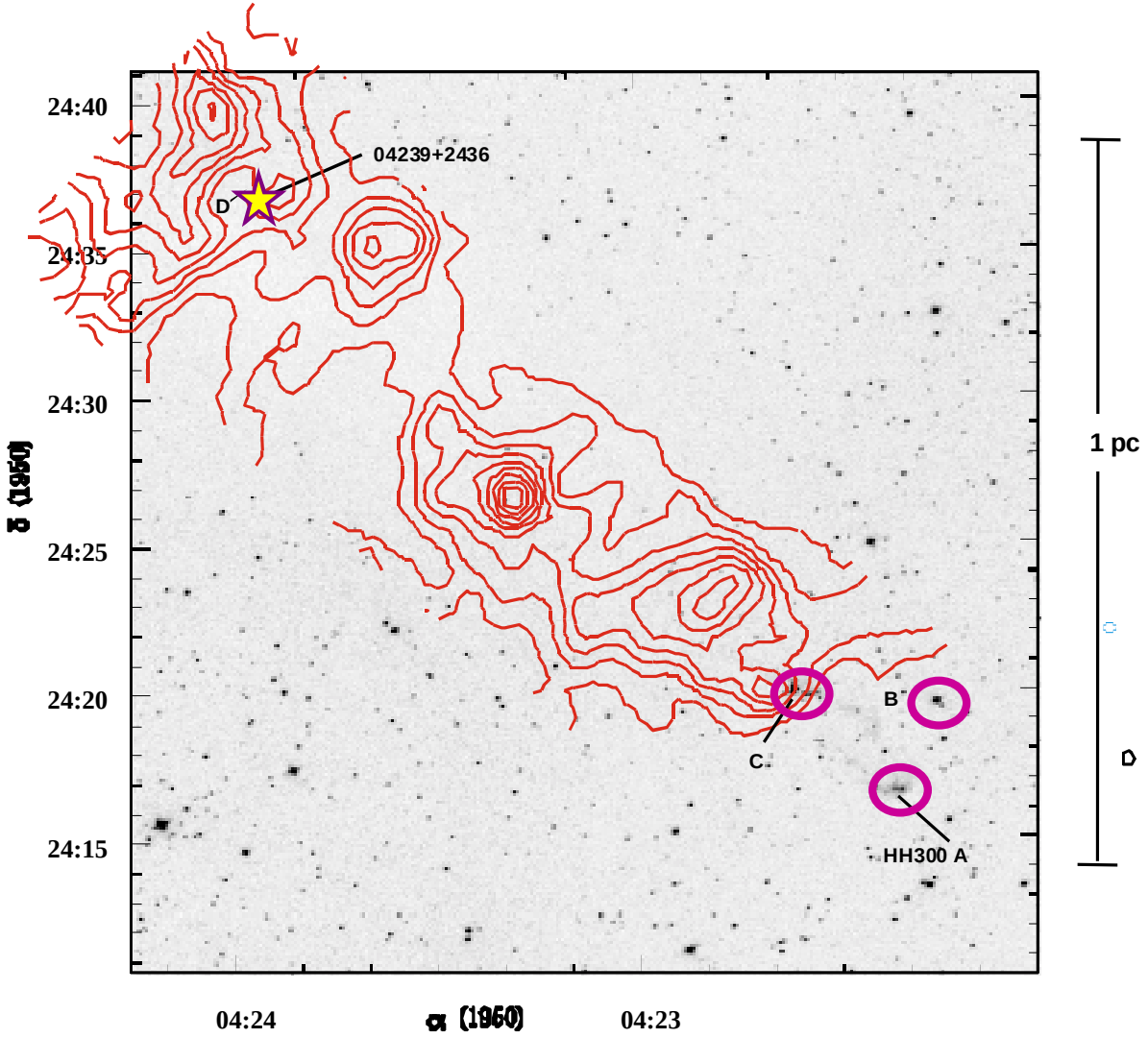




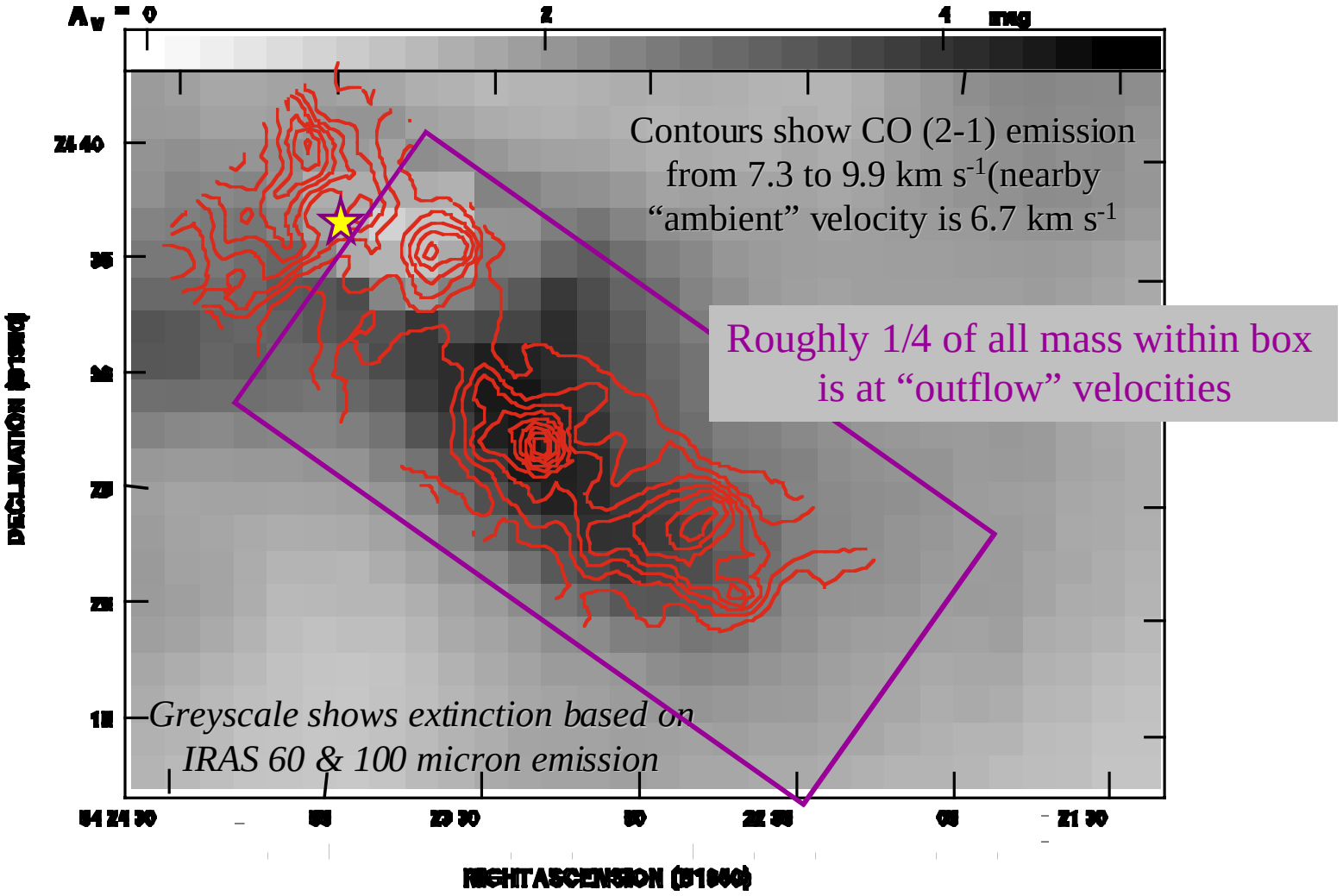


^{13}CO(1-0) Data from FCRAO to appear in Arce & Goodman 2000

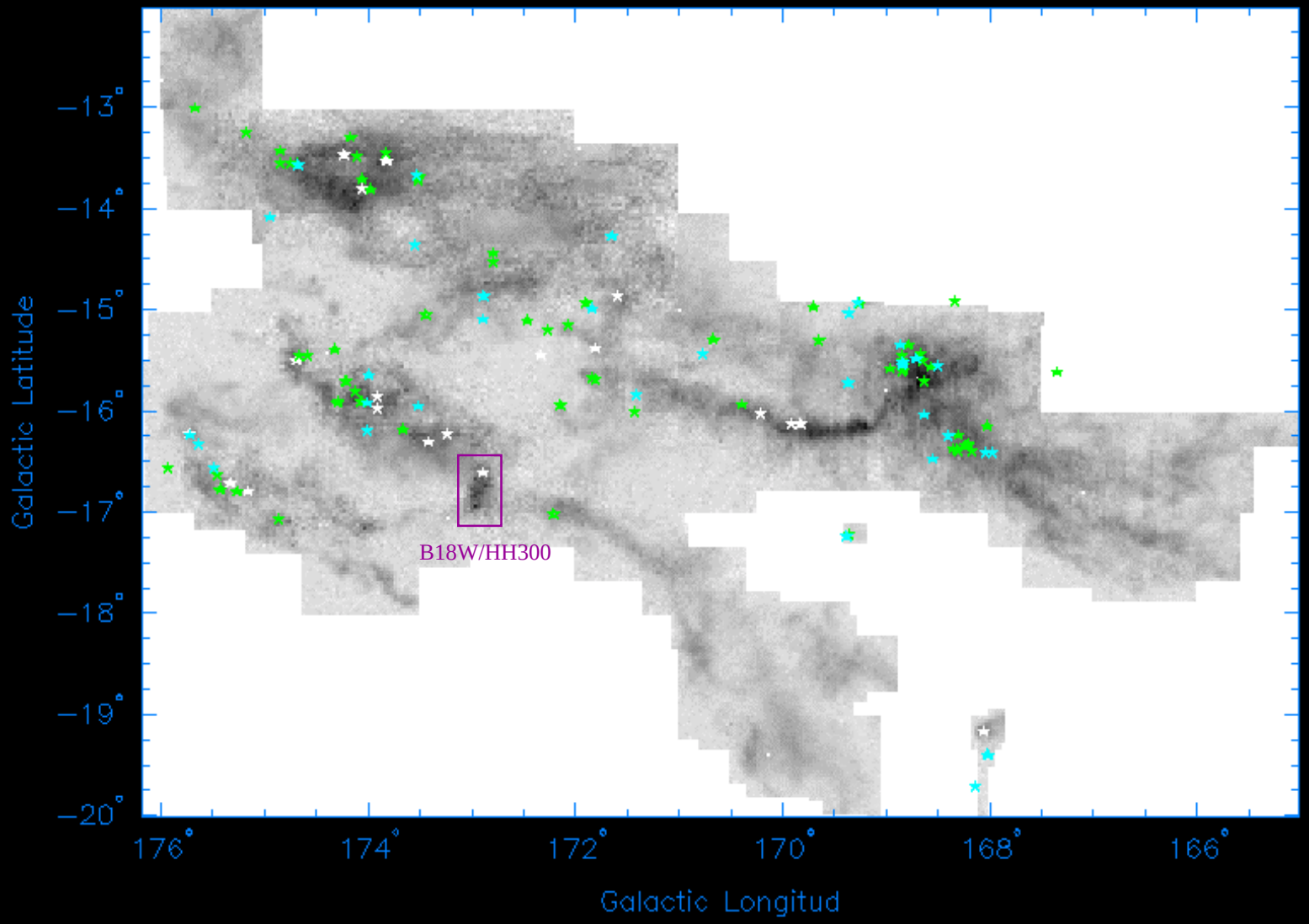
3. Are Some Dark Clouds Created by Outflows?



HH300 & B18w in Taurus



The Taurus Dark Cloud Complex



Mizuno et al. 1995 $^{13}CO(1\text{-}0)$ integrated intensity map from Nagoya 4-m

4. How much of a molecular cloud complex was "moved" to its present location by an outflow?

- Movie of Taurus, Gas Only
- Movie of Taurus, with Stars

Key:

Blue	34%
"Cloud"	56%
Red	10%

(by mass)

YSO Outflows Move More Gas than We Thought

1. "Giant" Herbig-Haro Flows
   PV Cephei shows density & velocity structure--at least at low density--controlled by flow.

2. The Effect of Outflows on their host Cores
   B5: Evidence for a "Core" Component in ^{13}CO

3. Are Some Dark Clouds Created by Outflows?
   HH300: Is B18w an Outflow Lobe?

4. How much of a molecular cloud complex was "moved" to its present location by an outflow?
   Taurus: A Lot