MANCHESTER 1824

The University of Manchester

Towards Understanding Massive Star & Cluster Formation

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ALMA

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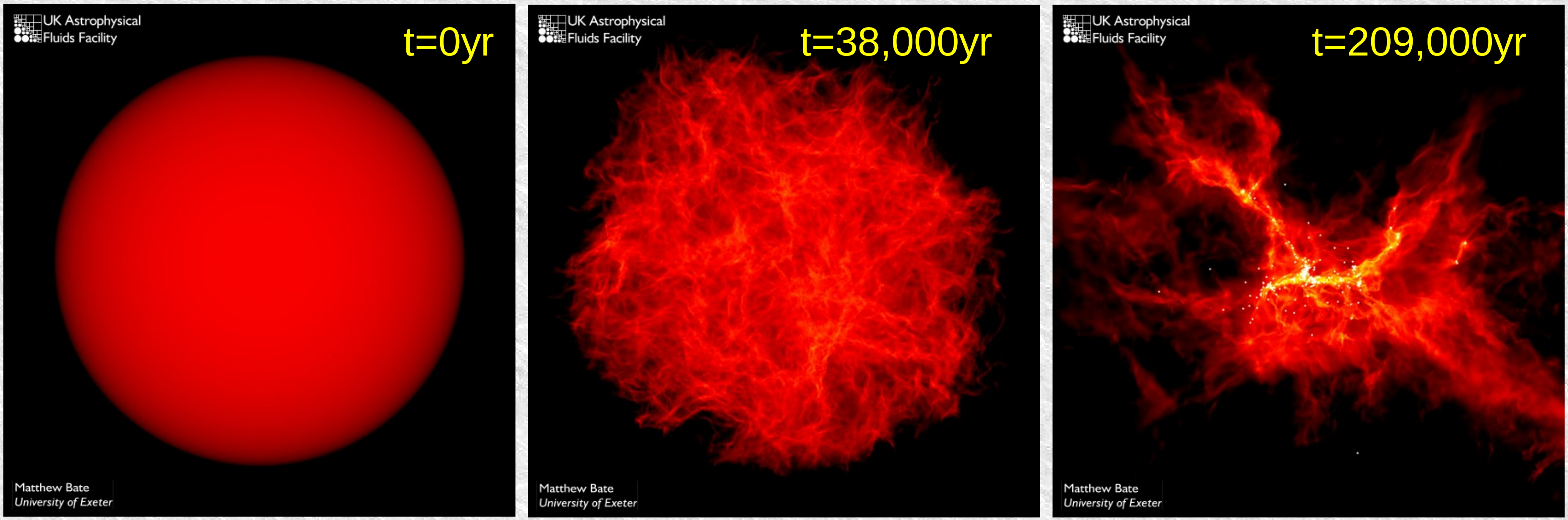
A Complex, Multiscale Process

- Large dynamic range
  - 10^{24} factor increase in density, 10^{8} decrease in volume
  - Diffuse/HI clouds, l~100 -1000 pc, n~1-10 cm^{-3}
  - GMCs, l~10-100 pc, n~10-100 cm^{-3}
- Inefficient
  - 1-3% of mass of GMC turns in to stars
- Products sensitive to environment
  - External & internal factors
- Fast
- High mass stars are rare but important
- Complex flows of gas

Model for the collapse of a cluster forming clump

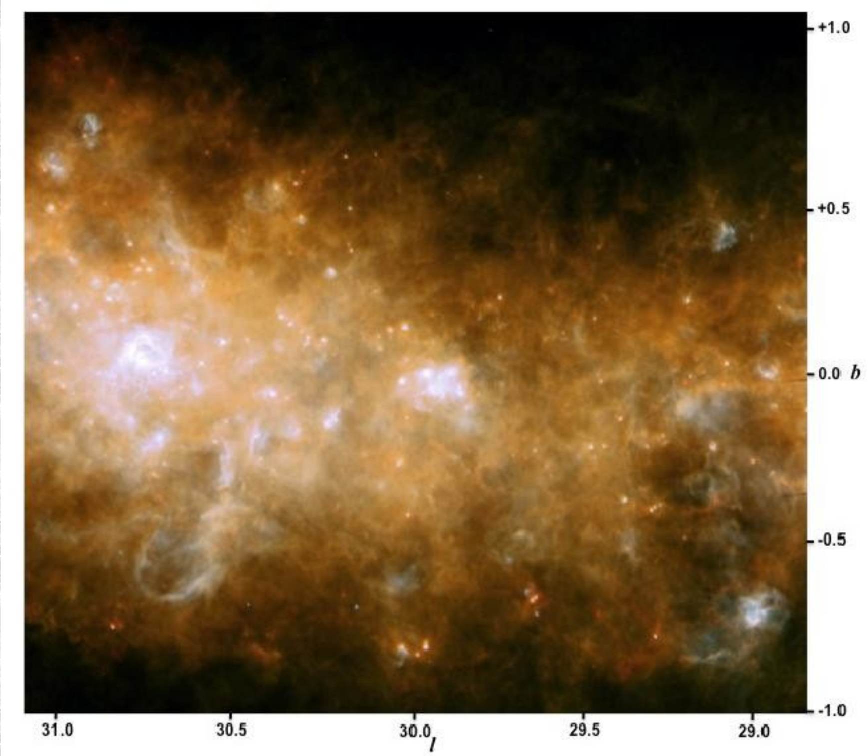


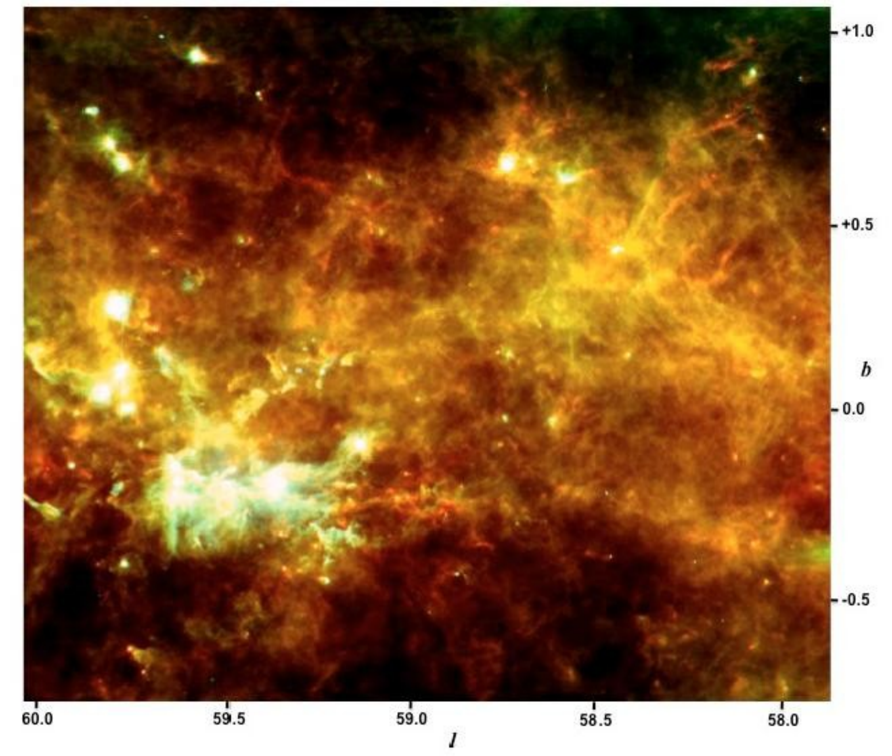
1pc (1' at 4kpc), $500M_o$ (Model by M. Bate)

- Highly structured
- Fast collapse

HiGAL Survey

(Molinari et al 2010)





- 5 band (70,160,250,350,500μm) survey
- Full plane: $0^o < l < 360^o$, $|b| < 1^o$
- Full census of ***dust*** in the plane

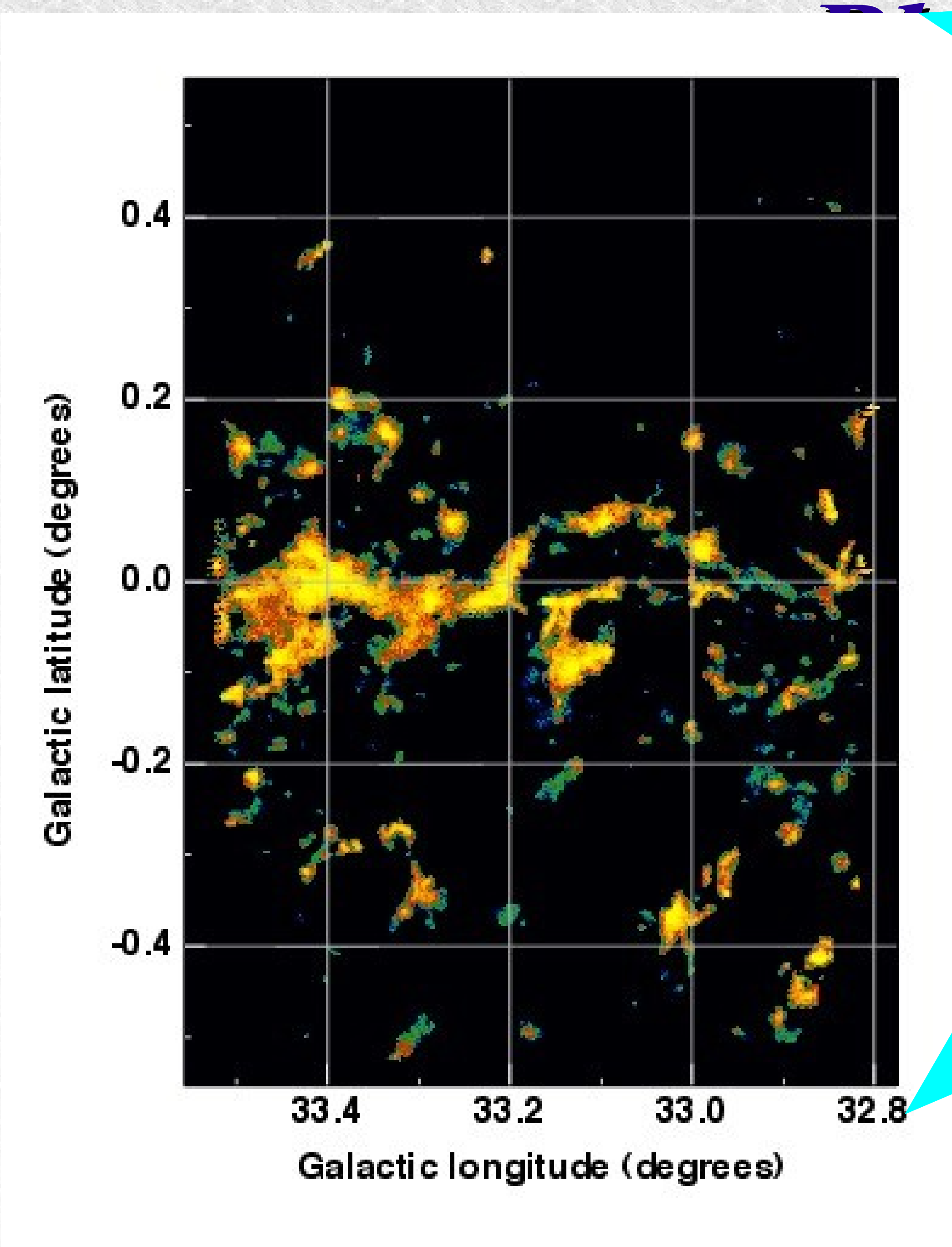
But poor angular resolution at long wavelengths 36'' at 500μm

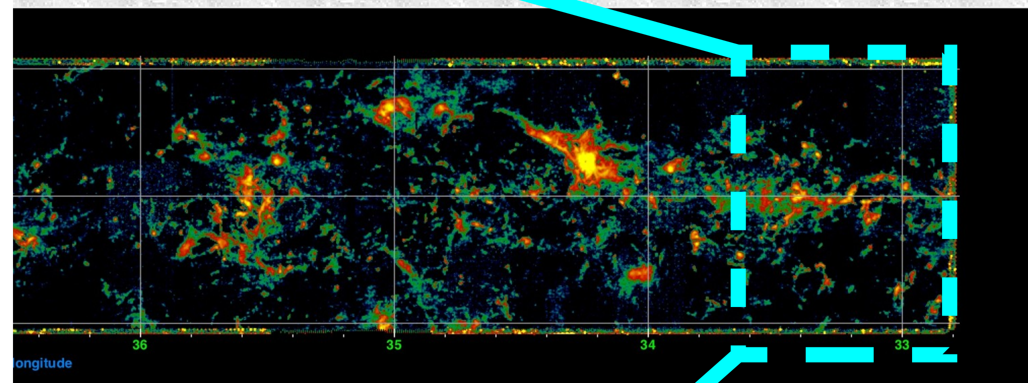
No coverage > 500μm

SCUBA2 survey

Gas Across The Galactic Plane

(Moore et al.)

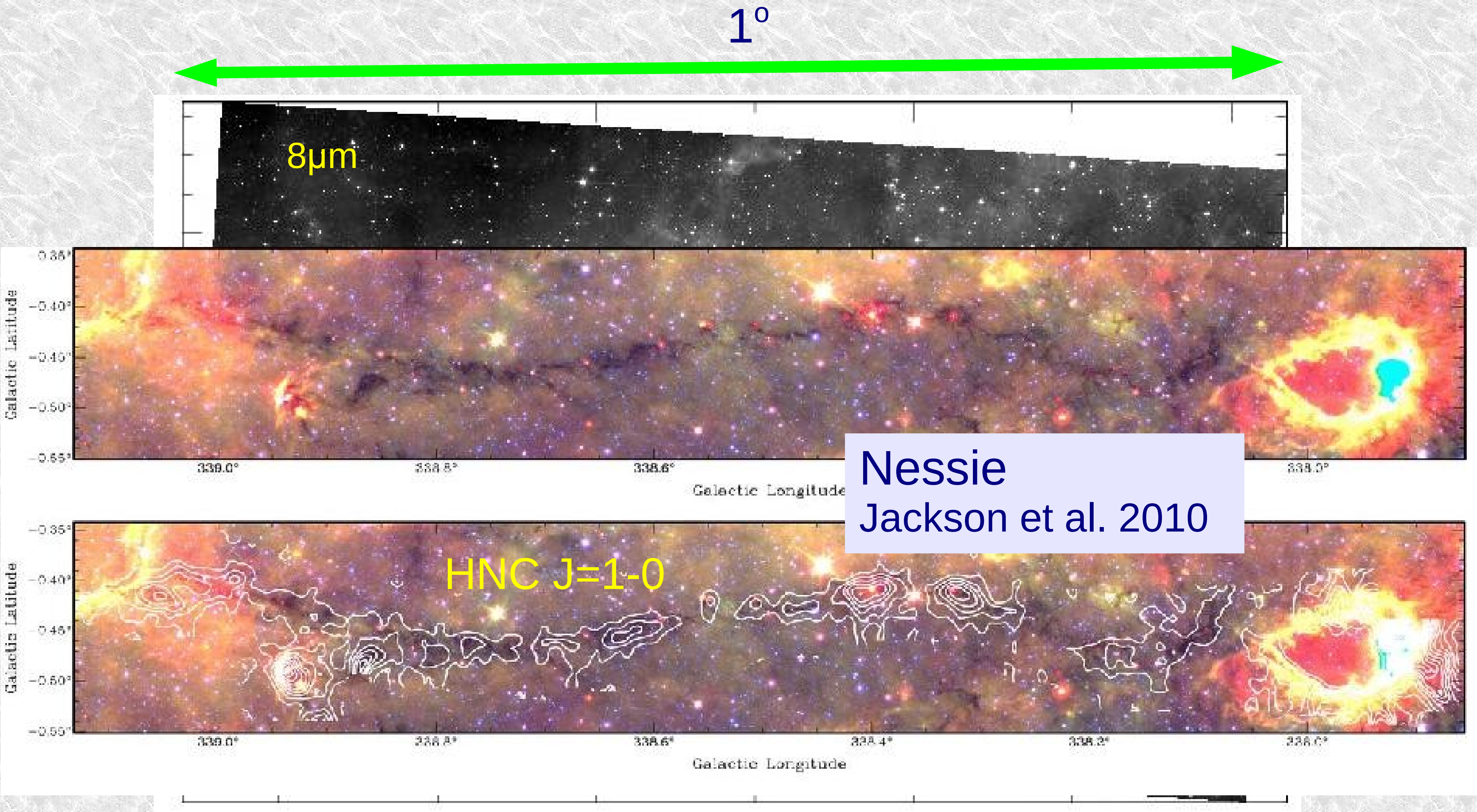




JCMT ^{13}CO J=3-2 survey HARP

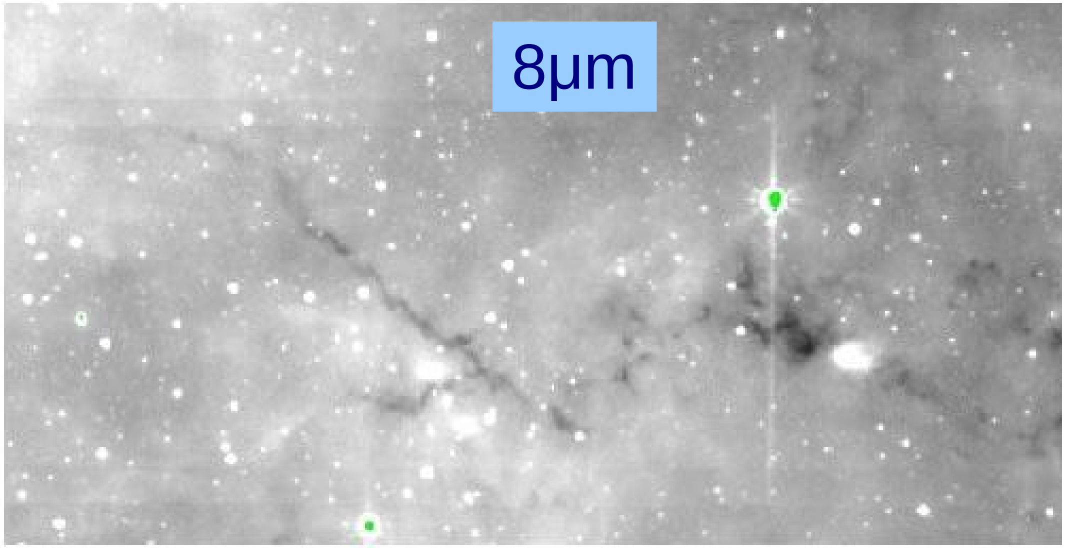
- T_{peak} image
- Less diffuse emission (SNR, excitation)
- Optically thick heated surface of clouds
- Not the dense gas forming stars

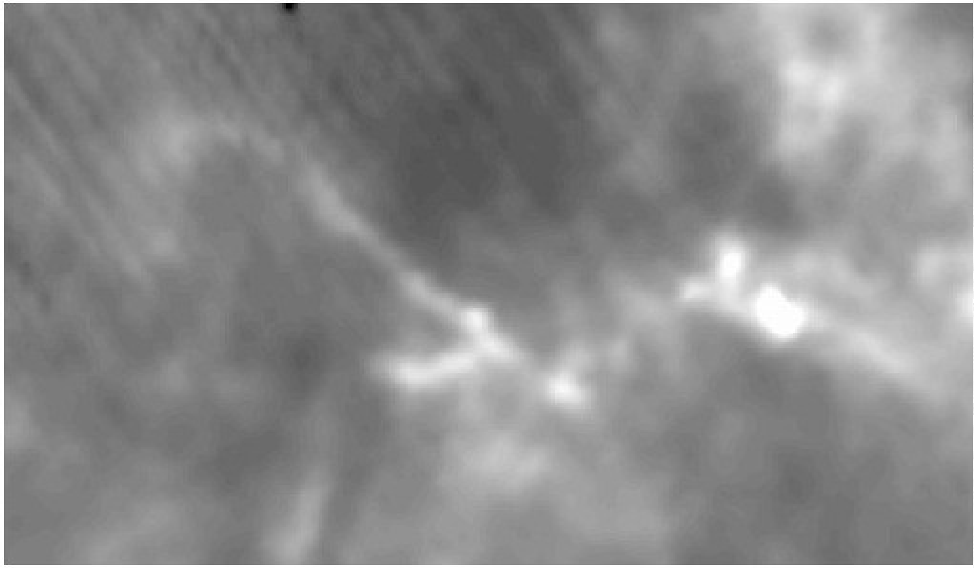
Filaments Of Clouds



- Minimum spanning tree
- ~100 filaments of different morphologies
  (Lenfestey, Peretto & Fuller 2012)
- Some Nessie-like (Jackson et al 2010)

Filaments in HiGAL



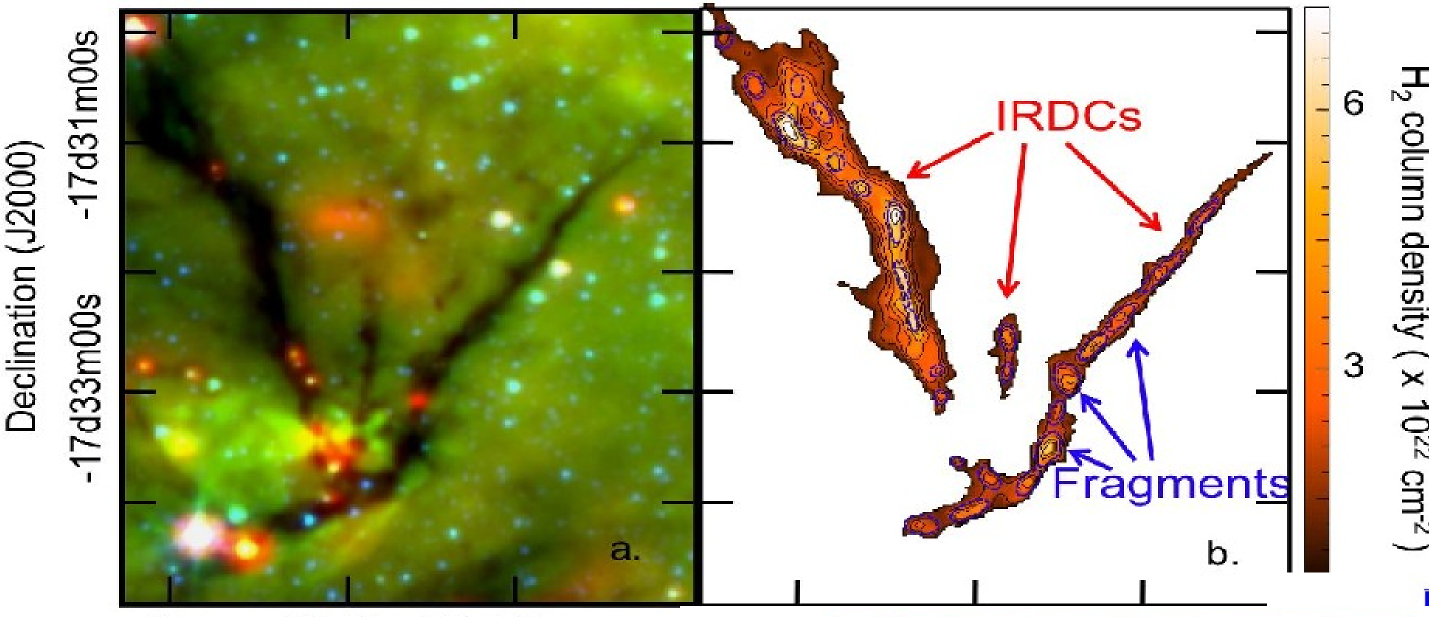


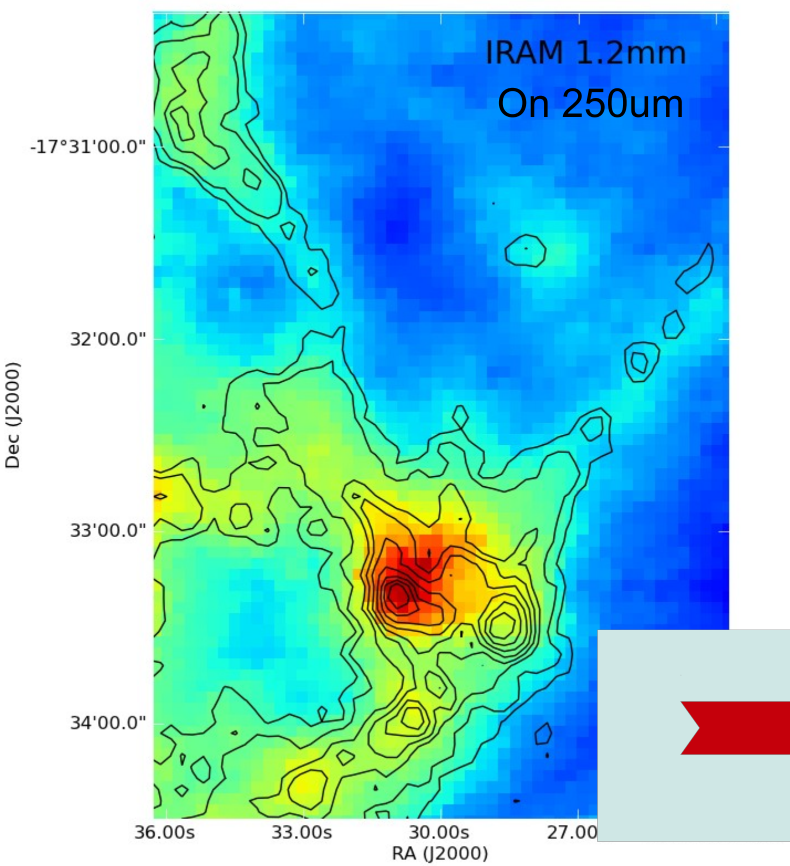
Herschel column density

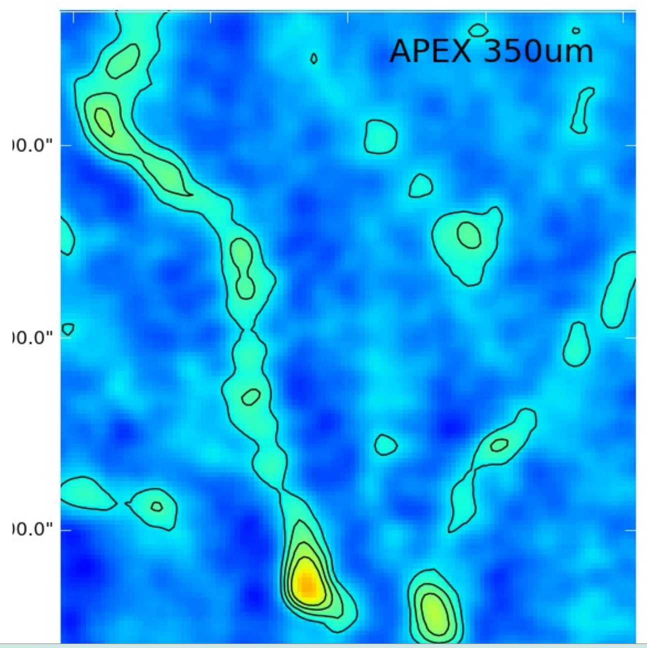
- Good correspondence in column density between absorption and HiGAL emission
- But poor angular resolution

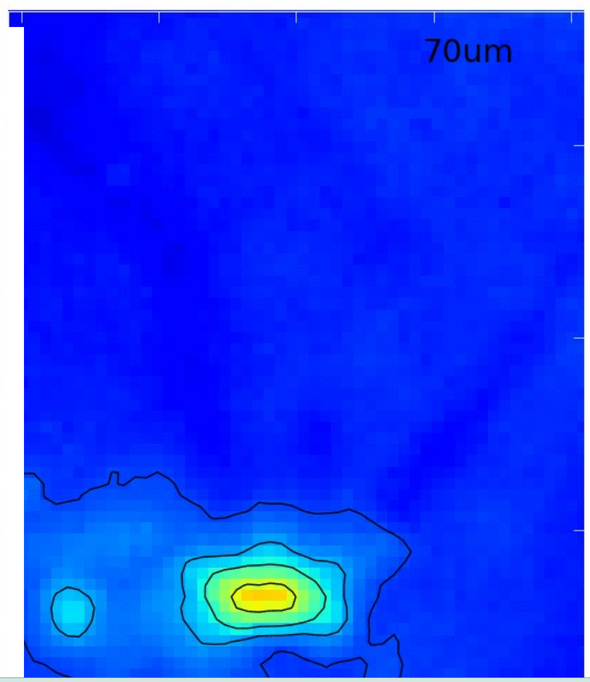
Fragments & Filaments: Absorption & Emission

(Peretto et al. 2012)









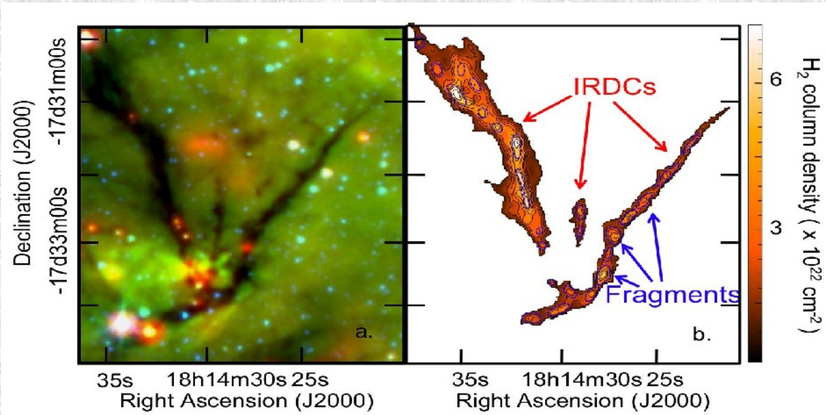
➡ Herschel follow-up requires sensitivity & resolution.

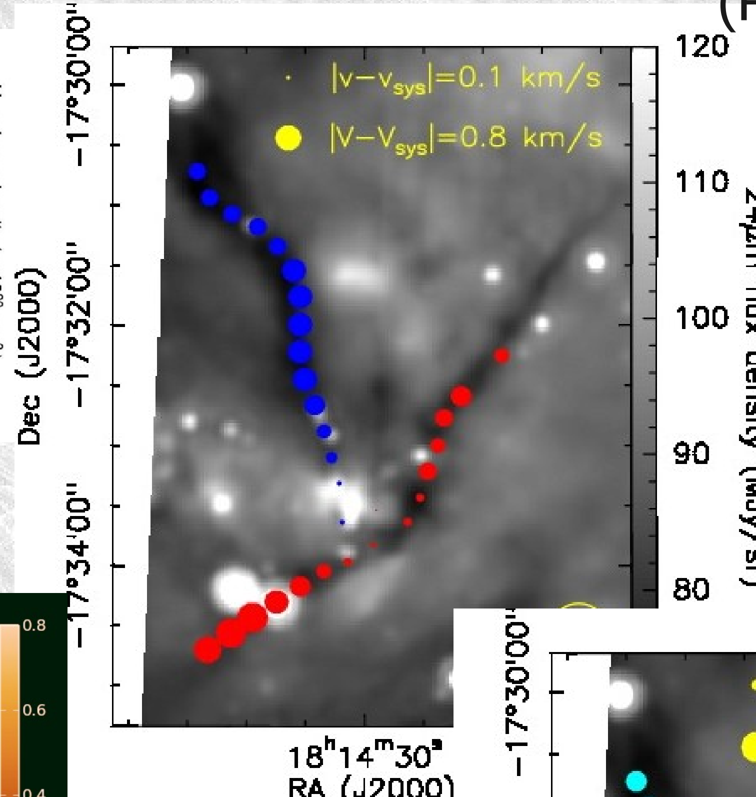
Kinematics are essential

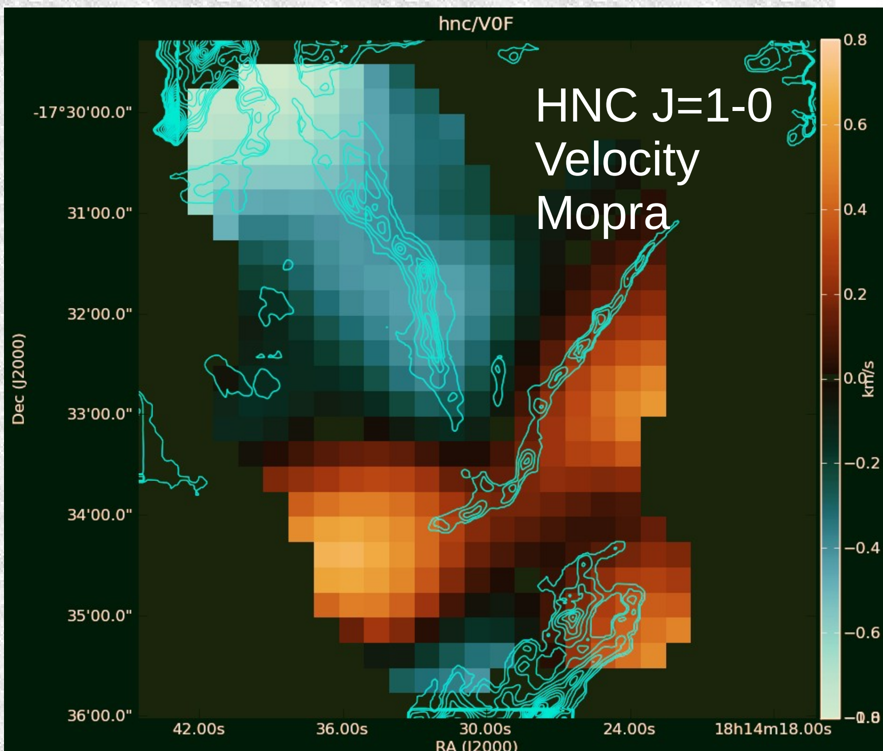
(Peretto et al. 2012)

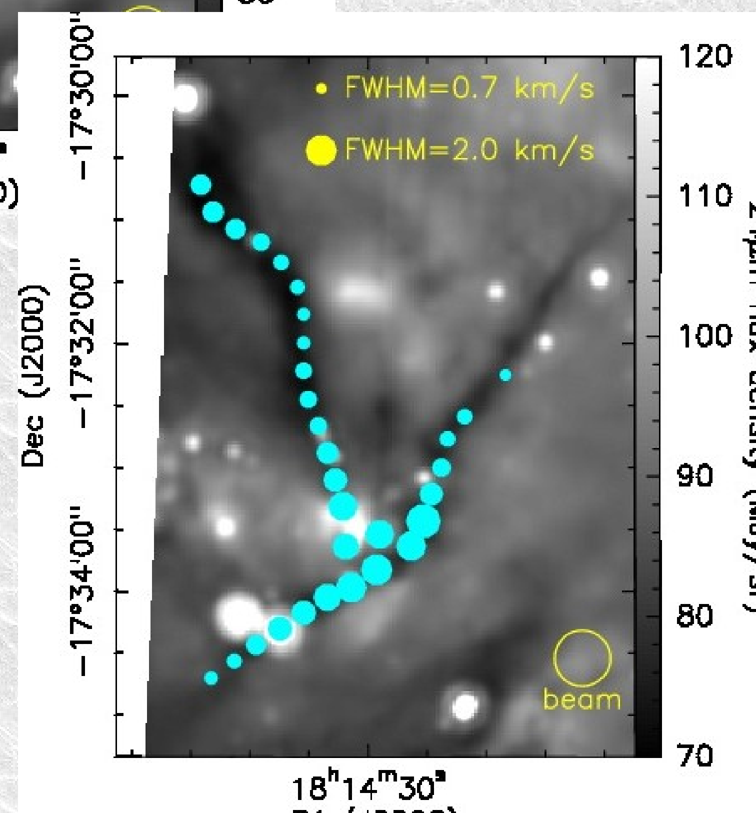
N_2H^+ J=1-0

IRAM 30m

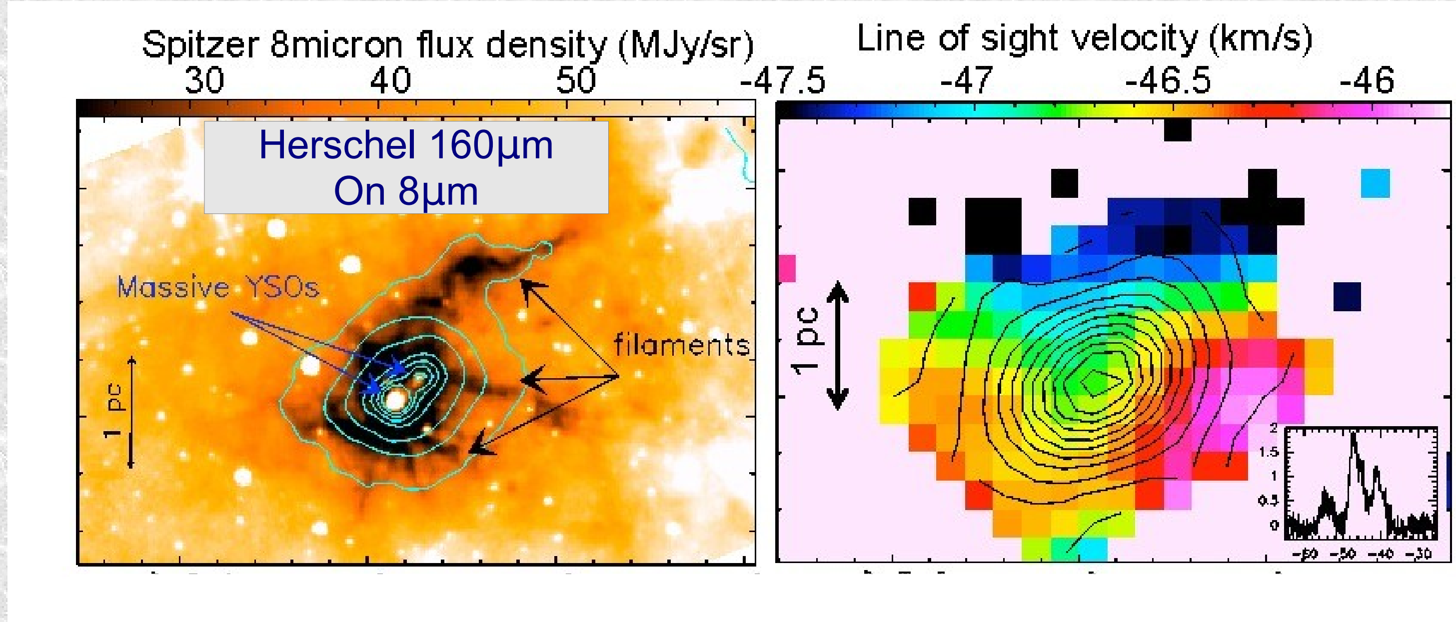


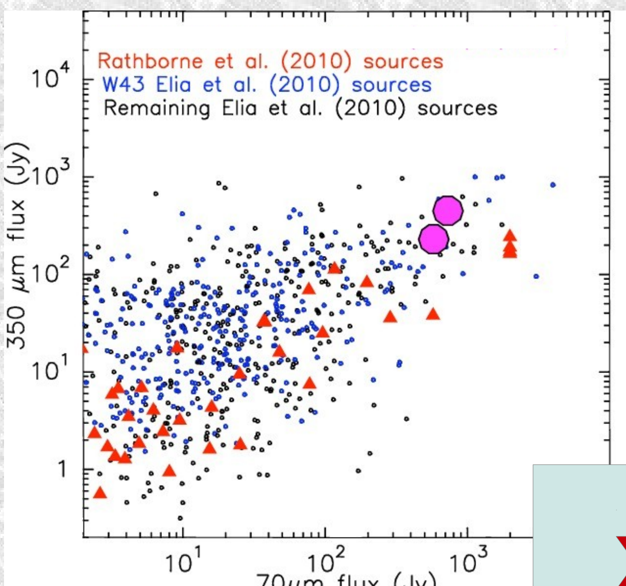


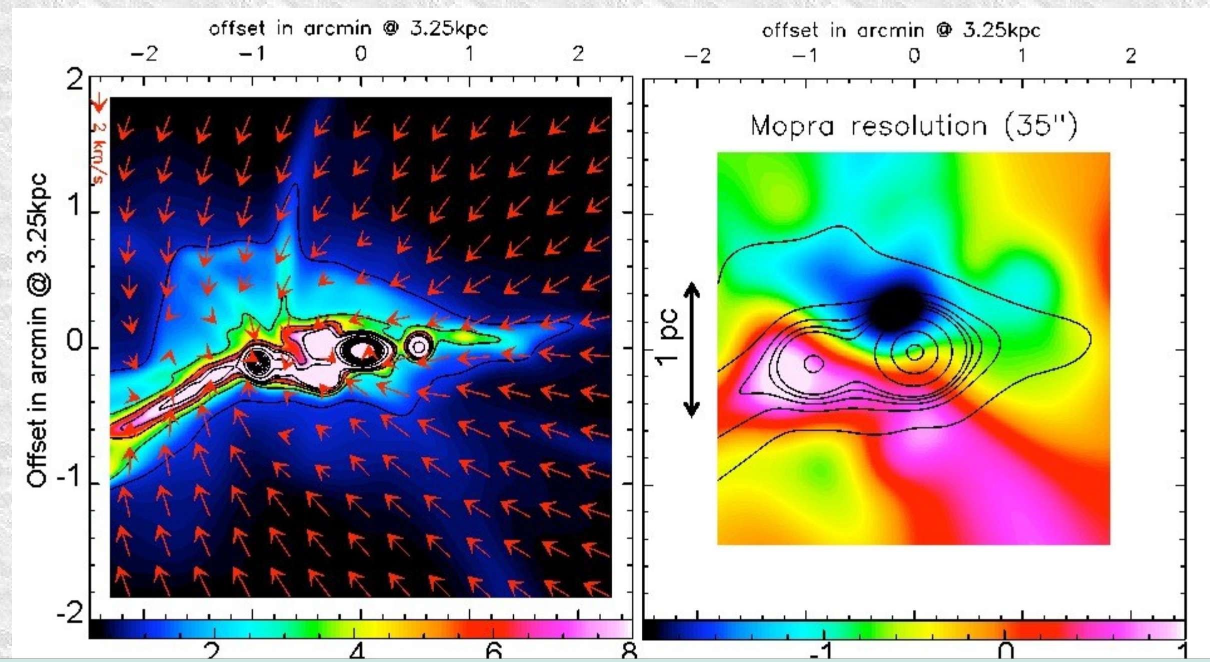




A Massive Core Formed by Inflow?

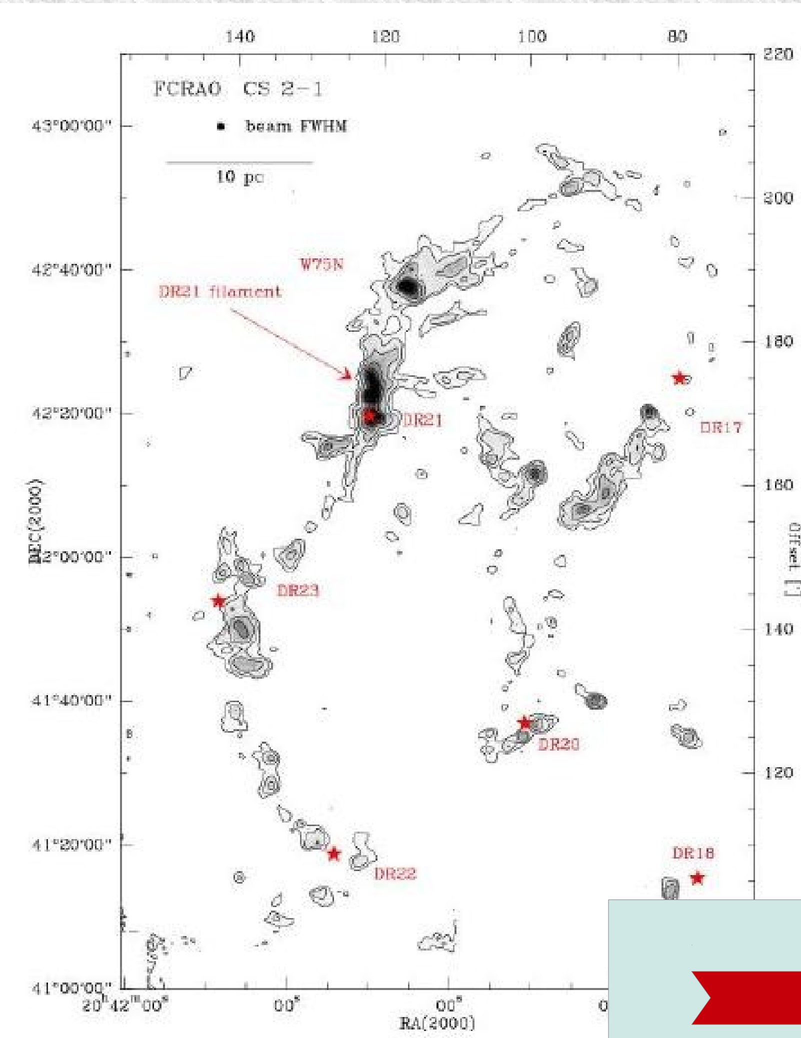






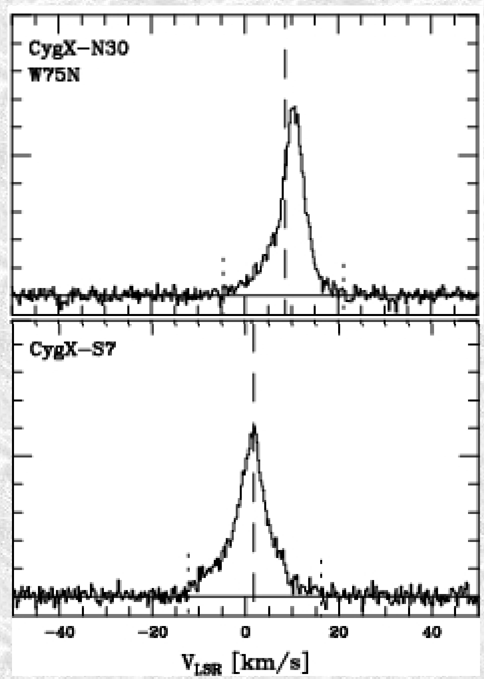
Kinematics are essential and potential discriminators between models

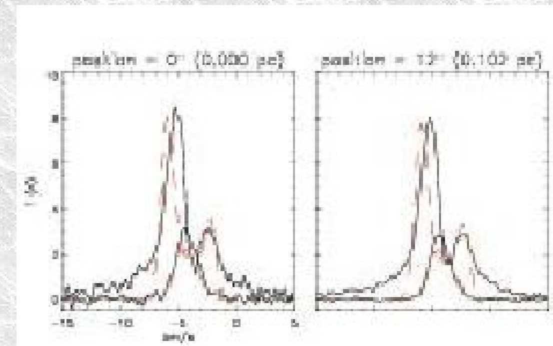
A Nearby Filament



(Schneider et al

Outflow - SiO



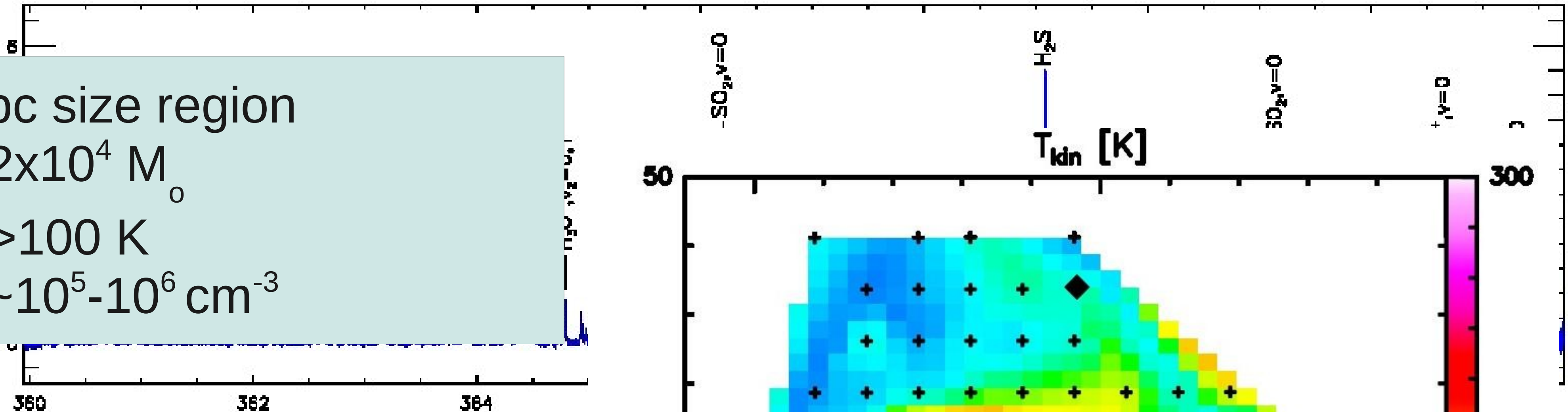


HCO^+ & $H^{13}CO^+$ J=1-0

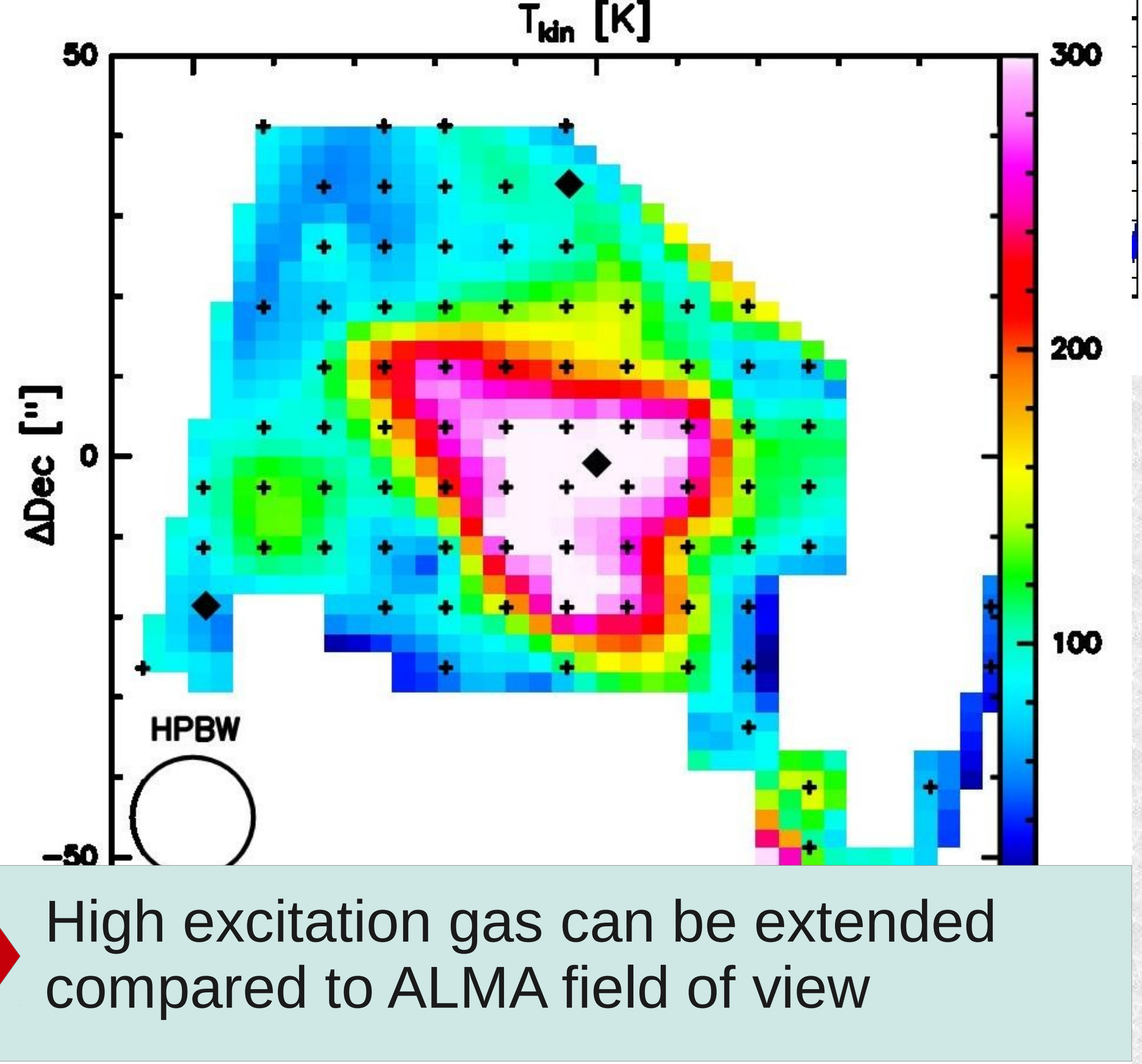
- Infall asymmetry
- 3300 M_o clump
- 0.6 pc in size
- V_{infall}~0.5 km/s

Following the flow needs high spectral resolution.

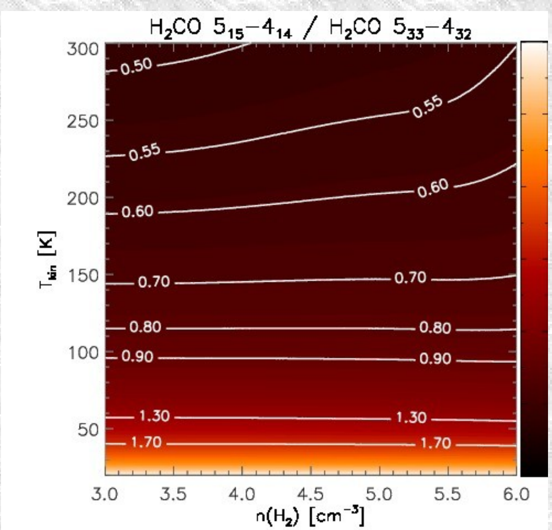
More than just kinematics



1pc size region
~2x10^4 M_o
T>100 K
n~10^5-10^6 cm^{-3}

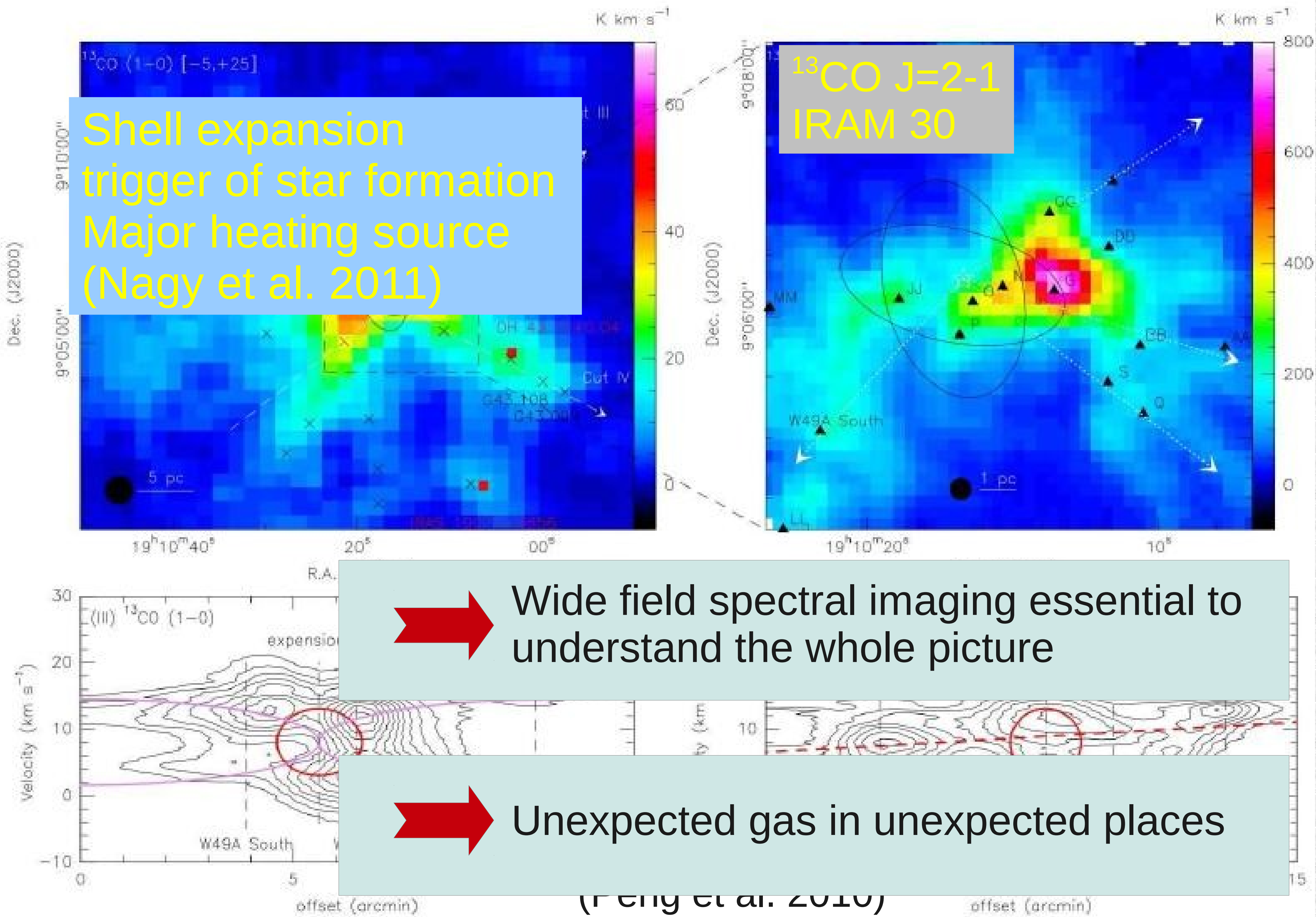


JCMT Spectral Legacy Surv
(Nagy et al 2011)



High excitation gas can be extended compared to ALMA field of view

Heating in W49



Wide field spectral imaging essential to understand the whole picture

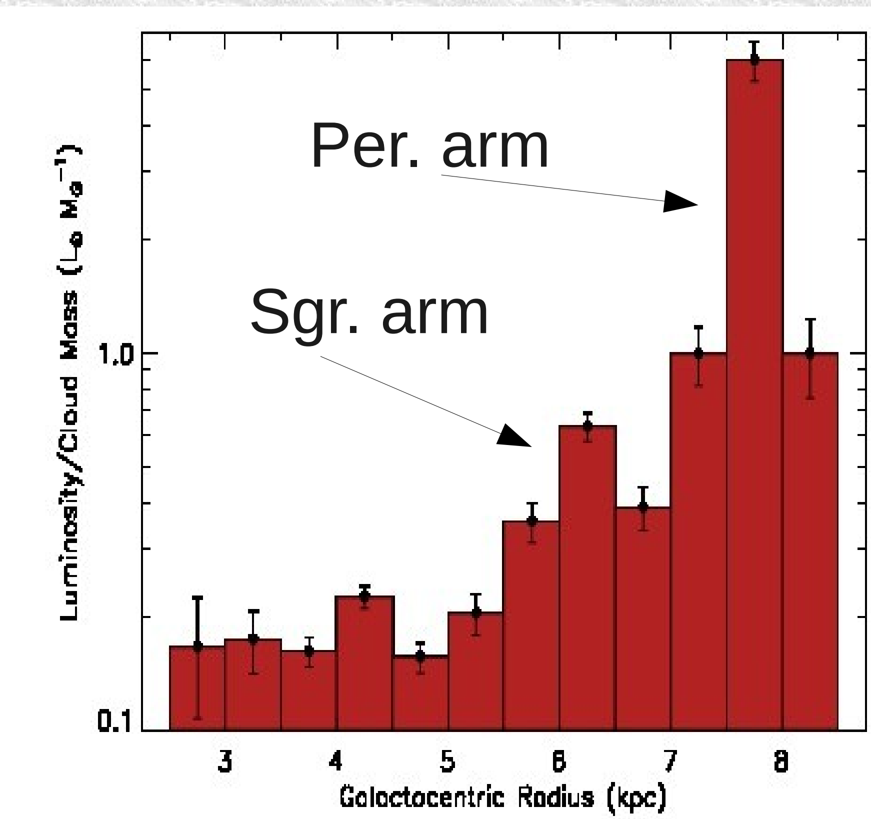
Unexpected gas in unexpected places

(Peng et al. 2010)

Nurture or Nature?

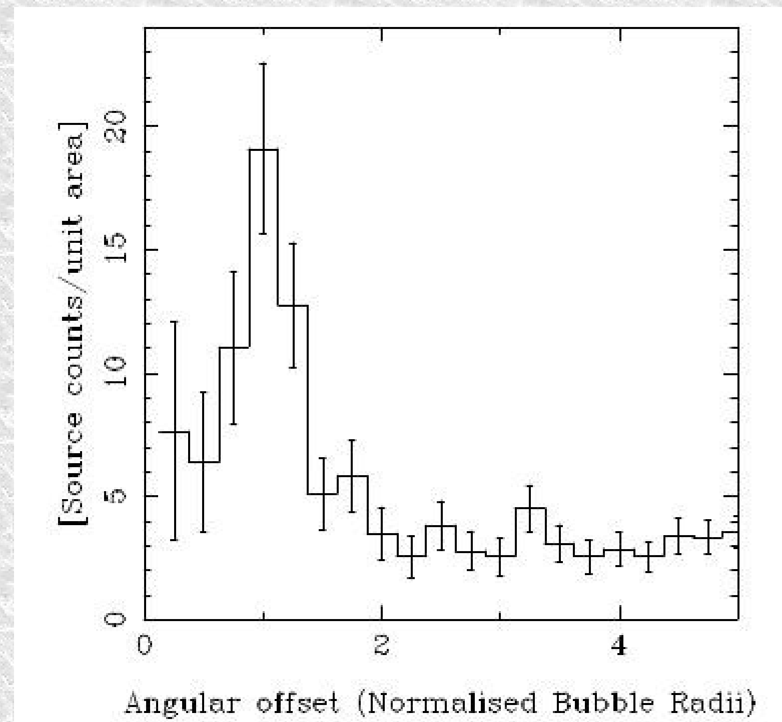
Need to probe full range of environments

Higher sf efficiency in spiral arms



(Moore et al. 2011)

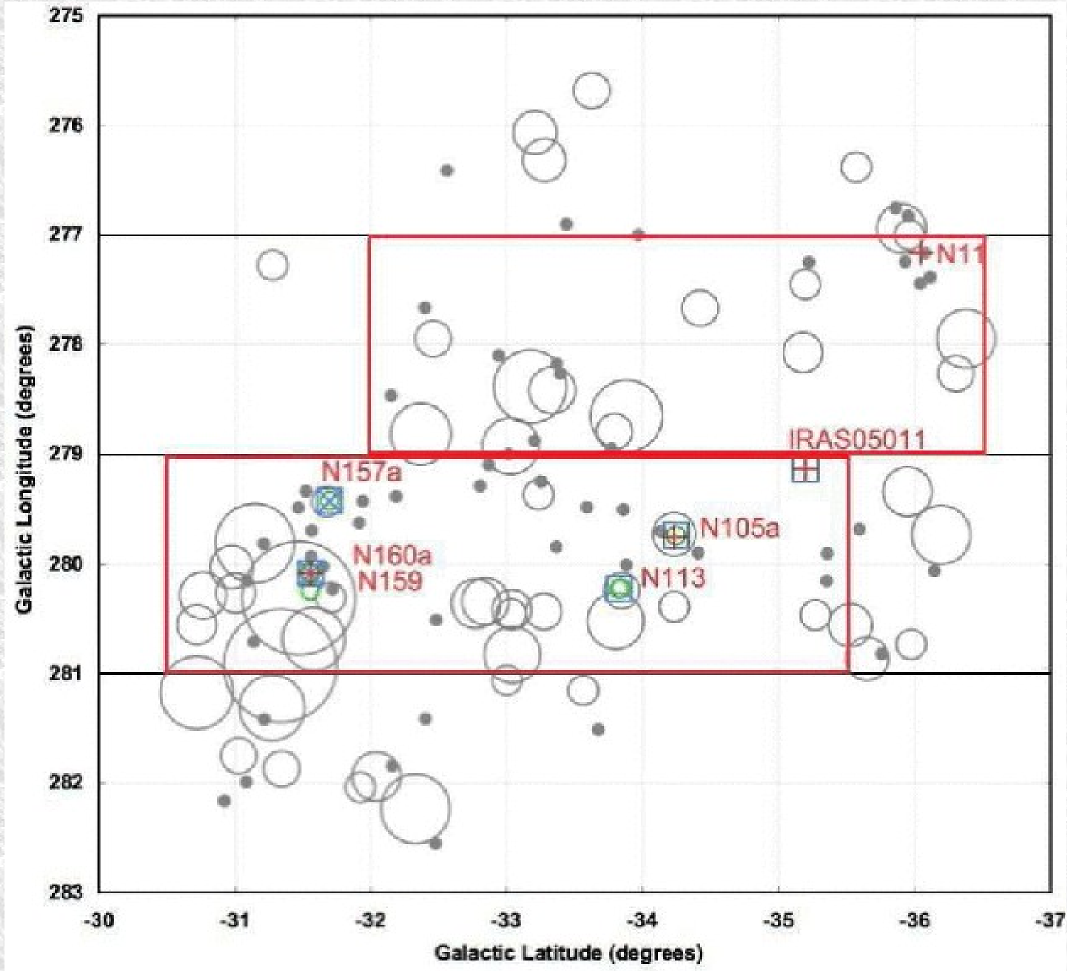
Higher density of sources around bubbles



(Thompson et al 2011)

High Mass Protostars in The LMC

- Nested noise coverage
  - rms = 0.22 Jy, 0.09 Jy, 0.06 Jy
- Masers less abundant in LMC (and SMC) than in our Galaxy
  - CH_3OH ~5 less common even accounting for SFR
- Pin point (sub-arcsec accuracy) young massive stars in another galaxy (Green et al 2008)



LMC Maser Population Statistics

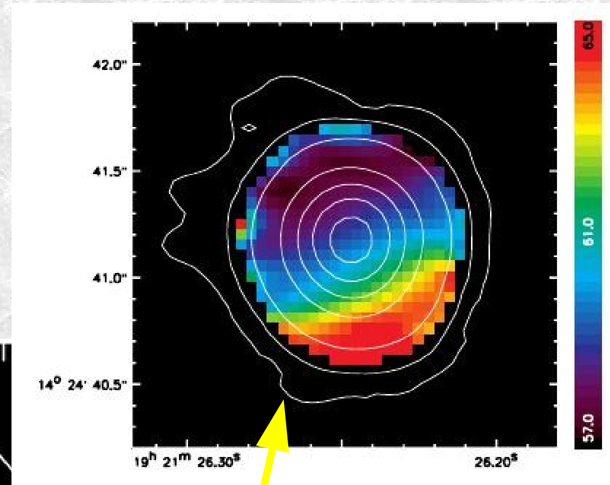
Molecule	Transition (MHz)	Luminosity Cutoff (Jy kpc^2)	LMC Pop.	Galactic Pop.	Pop. Ratio (Gal/LMC)
OH	1665	500	$\geqslant 4^g$	60^a	$\leqslant 15$
OH	6035	500	$\geqslant 2^{e,j}$	2^e	$\leqslant 1^\dagger, \leqslant 10^*$
CH_3OH	6668	500	$\geqslant 4^{c,d,f,j}$	$186^{i,k}$	$\leqslant 47^\dagger$
H_2O	22235	2500	$\geqslant 7^h$	88^b	$\leqslant 13$

- Chemistry ?
- Environment: UV/IR field?
- Evolution?

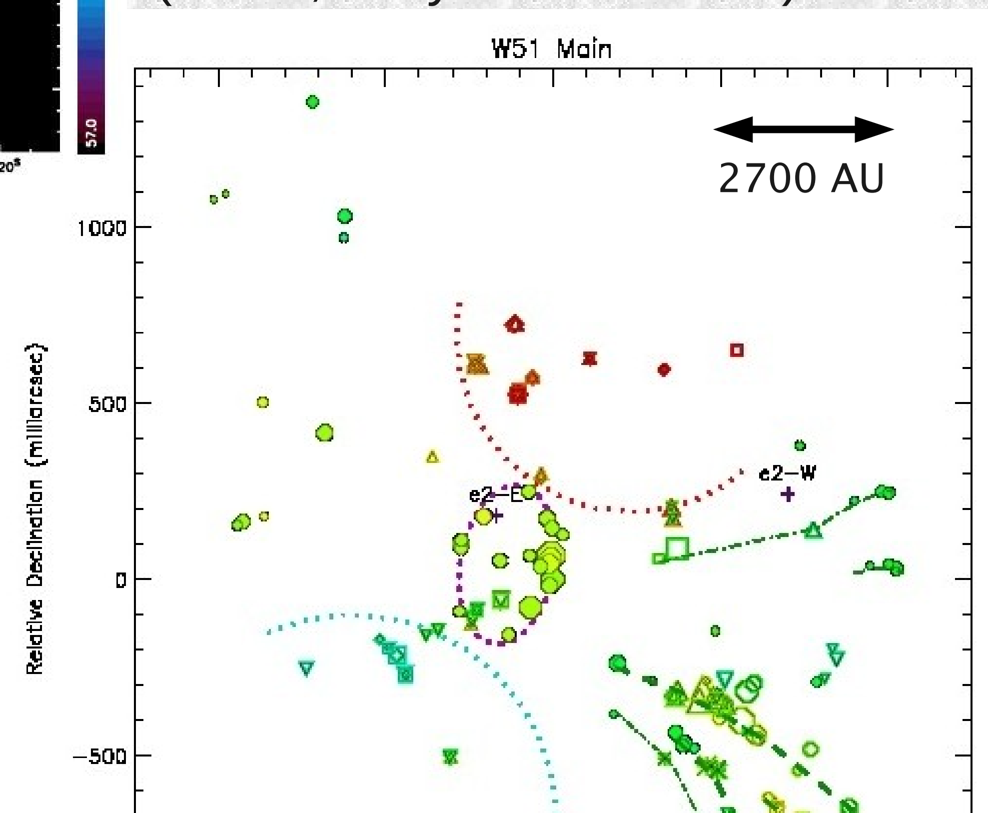
The inner most regions

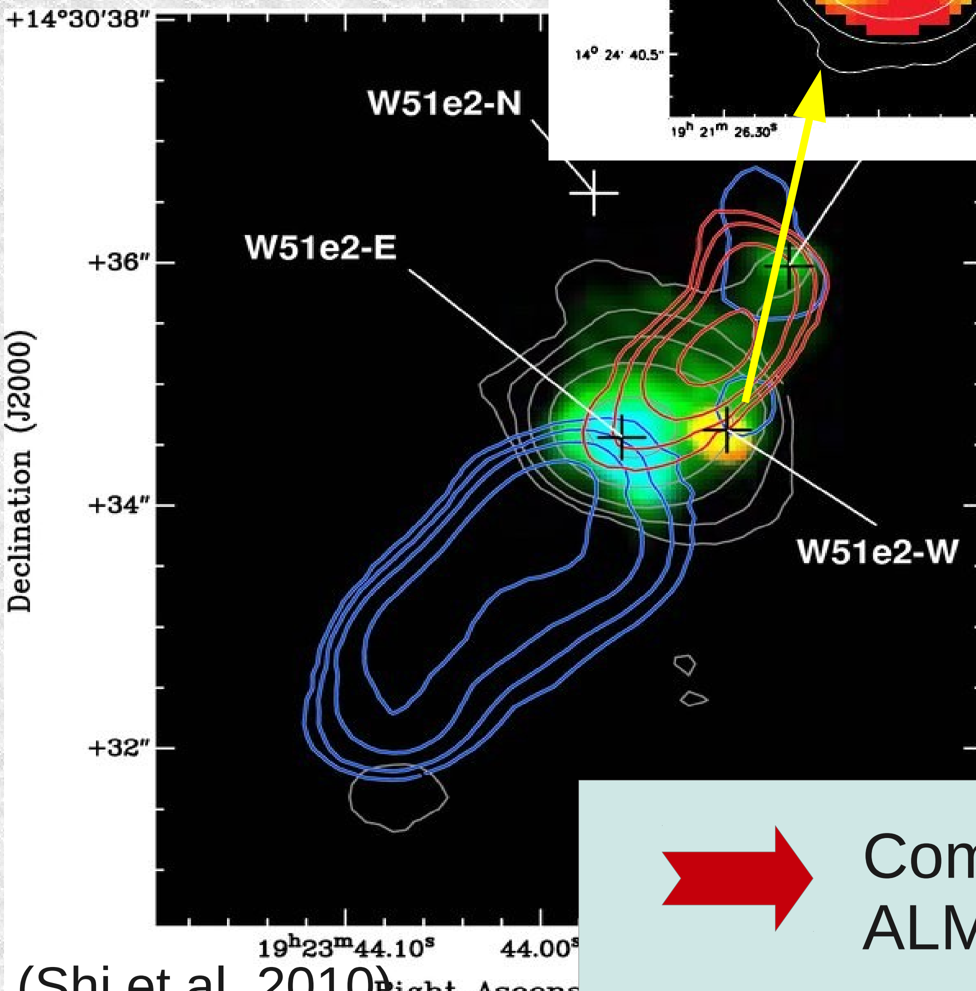
W51e2
Outflow
dv~200 km/s

HII recomb. Line velocity gradient
(Keto & Klaassen 2008)



Methanol & OH masers
(Etoka, Gray & Fuller 2011)





(Shi et al. 2010)

Complex circumstellar environments: ALMA

Questions

- Do massive pre-cluster/pre-massive star cores (e.g. Tan & McKee) exist or is global infall important?
- How, where and why do the seeds for massive stars & clusters form?
- How and when do these seeds fragment?
- How and when does accretion stop?
- How does gas flow from HI clouds to circumstellar disk and then onto the protostar?
- What determines the structure and evolution of filaments?
- What is the nature and effect of stellar feedback on various size scales?

Massive Cores?

- Myers & Fuller, Tan & McKee – Distinct centrally condensed self gravitating entities
- Bonnell et al – Competition between protostars for intra-cluster gas
- Myers – Thermal kernels + intra-kernel gas
- Peretto et al – Inflow + core merging

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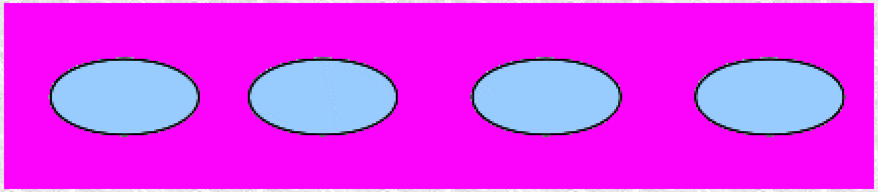
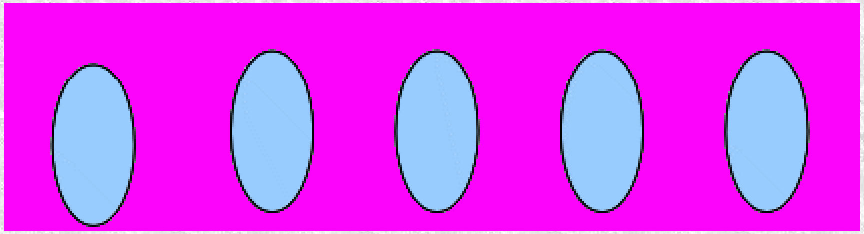
Properties of Filaments

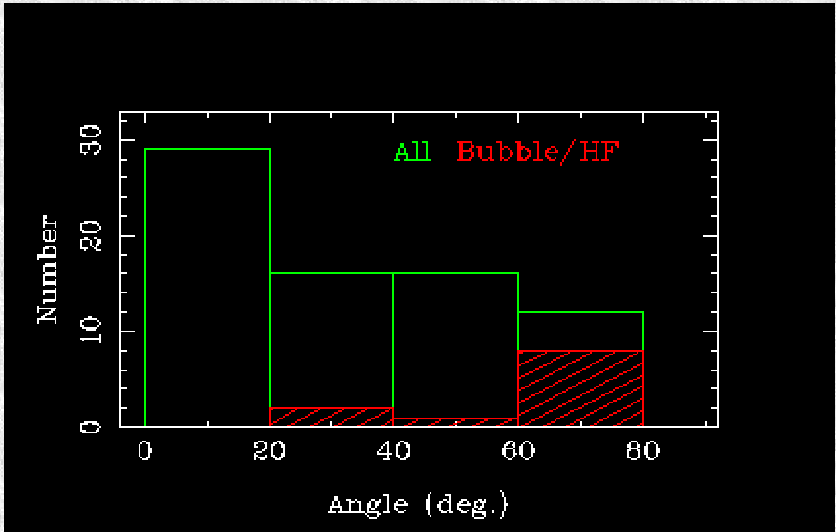
- Spacing of clouds within filaments?
- Direction of elongation of clouds wrt filament?



or



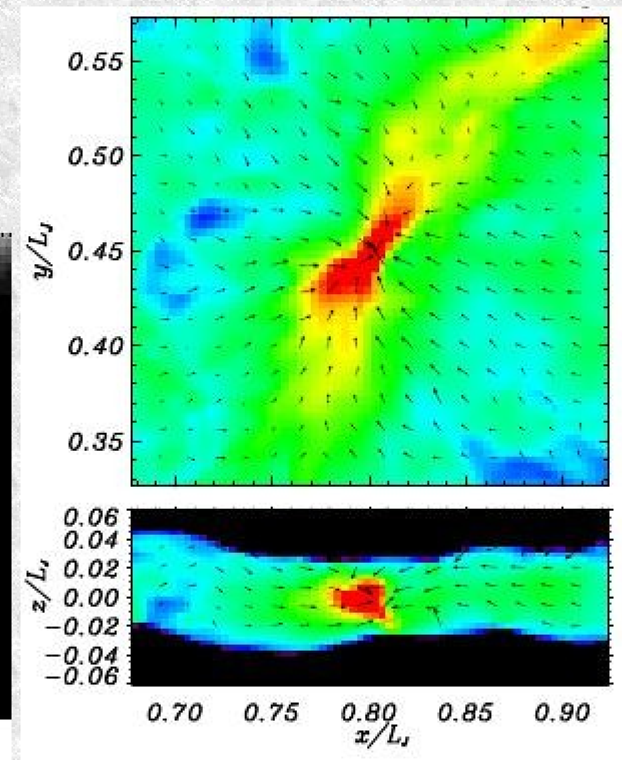
- Connection to galactic structure?
  - Generally parallel to plane
- Location of most massive clouds?
- Which are real structures?
  - Velocity structure of gas



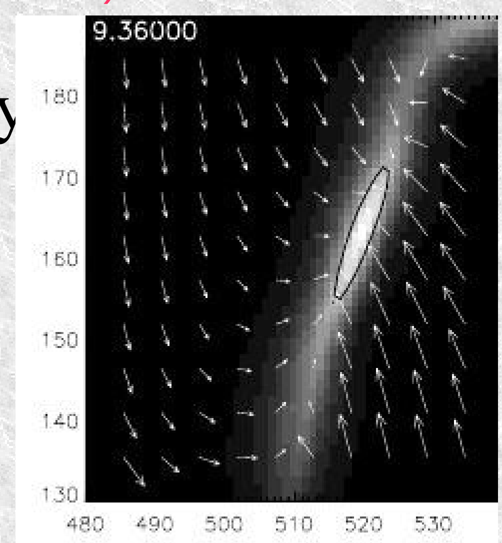
Origin & Evolution?

- Origin
  - Compression in spiral density waves
  - Swept-up shells
  - Colliding flows
- Evolution
  - Transition to self-gravity
  - Flow
  - Fragmentation

(Gong & Ostriker 2011)



(Ballesteros-Paredes et al 1999)



Wide field, high spectral resolution imaging of the gas - CII – CI – CO isotopologues - high density tracers

"Tracing the flow"

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Tools to Provide Answers

- ALMA
  - Resolution & sensitivity
- SCUBA2
  - Resolution compared to Herschel, mapping speed & frequency coverage
- Wide field heterodyne imaging
  - Kinematics & physical properties
  - Telescopes: JCMT, CCAT, LMT & APEX