FILAMENTARY ACCRETION AND MASSIVE STAR FORMATION

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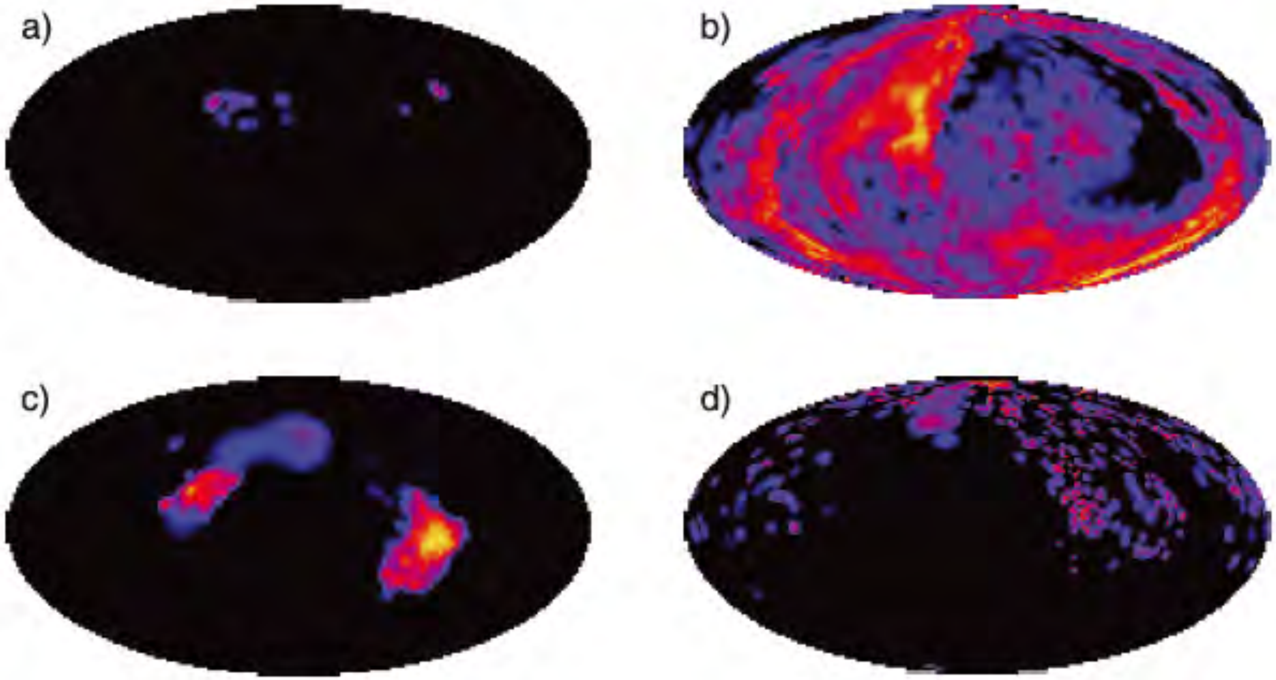
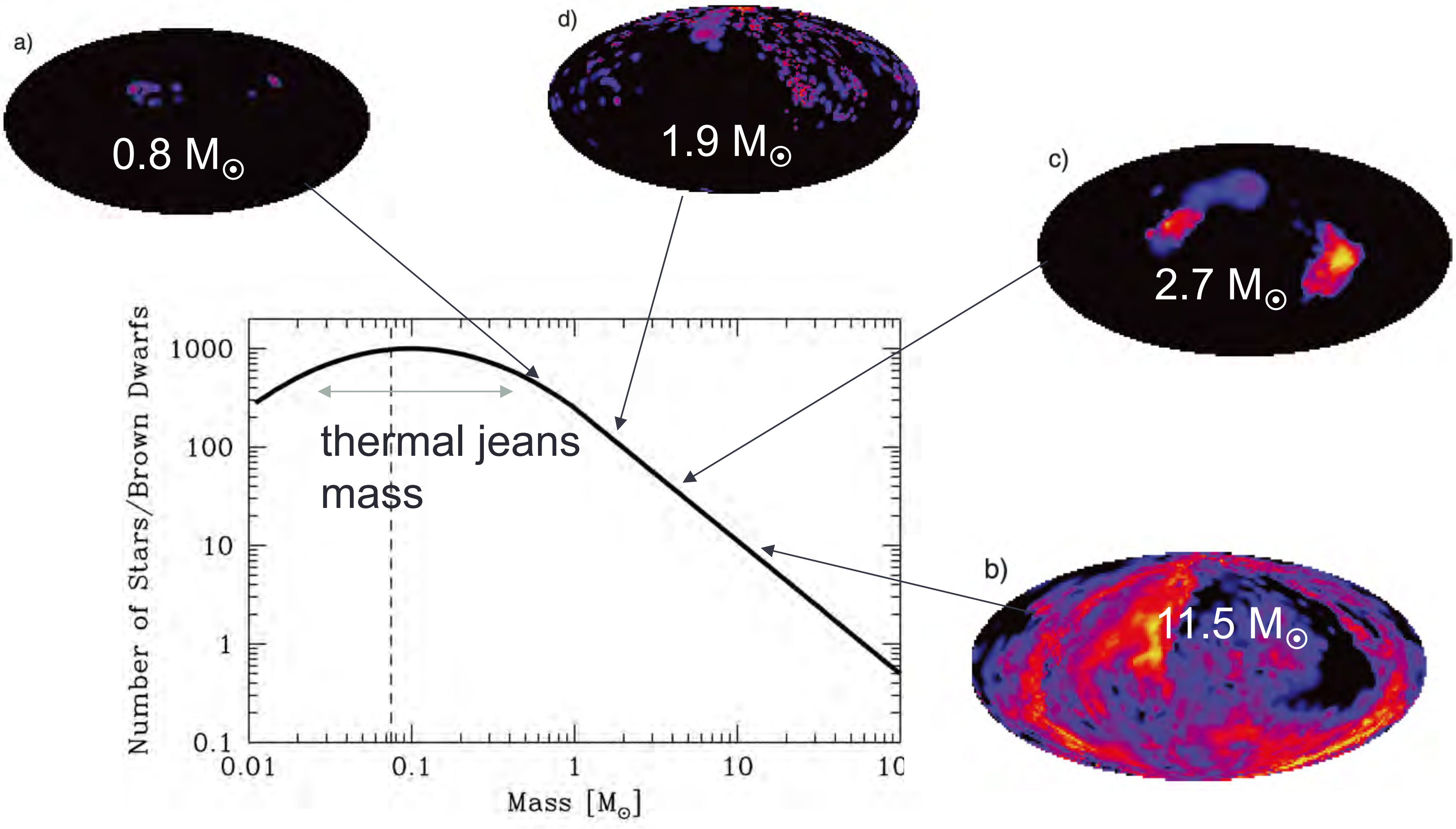
A guessing game…



The positions at which accreted material passes through a shell of radius r = 0.1 pc around a sink over 20,000 yr.

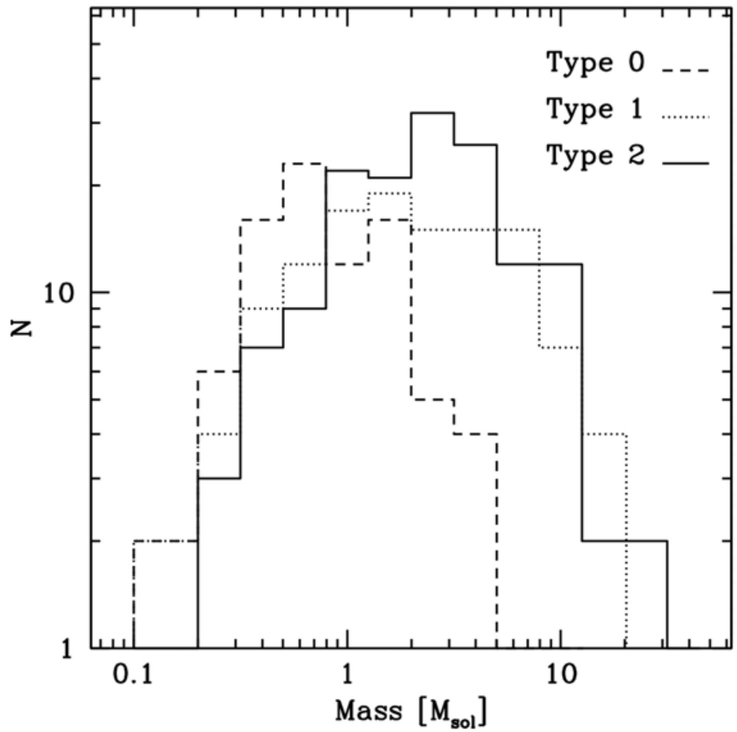
data from the SPH simulations in Smith et al. 2009 in collaboration with Ian Bonnell of a **clustered** star forming region.

Answer:



a)
0.8 M⊙
d)
1.9 M⊙
c)
2.7 M⊙
b)
11.5 M⊙
thermal jeans mass
Number of Stars/Brown Dwarfs
1000
100
10
1
0.1
0.01
0.1
1
10
10
Mass [M⊙]

Filaments and Massive Stars



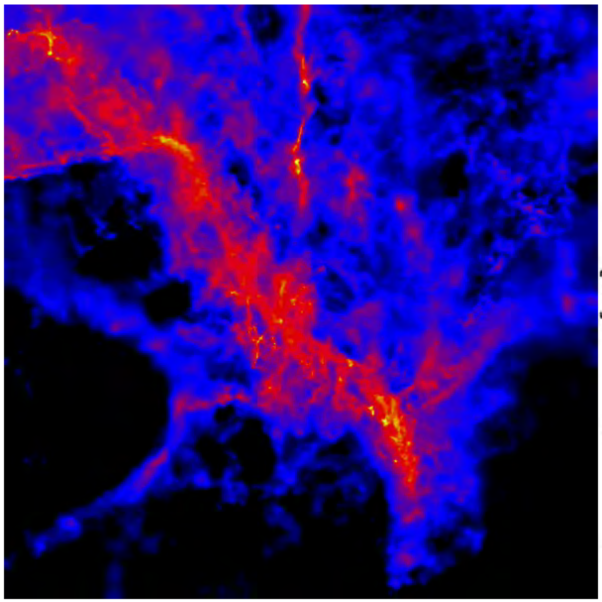
Type	Number	Percentage
0	115	32.3%
1	103	28.9%
2	138	38.8%

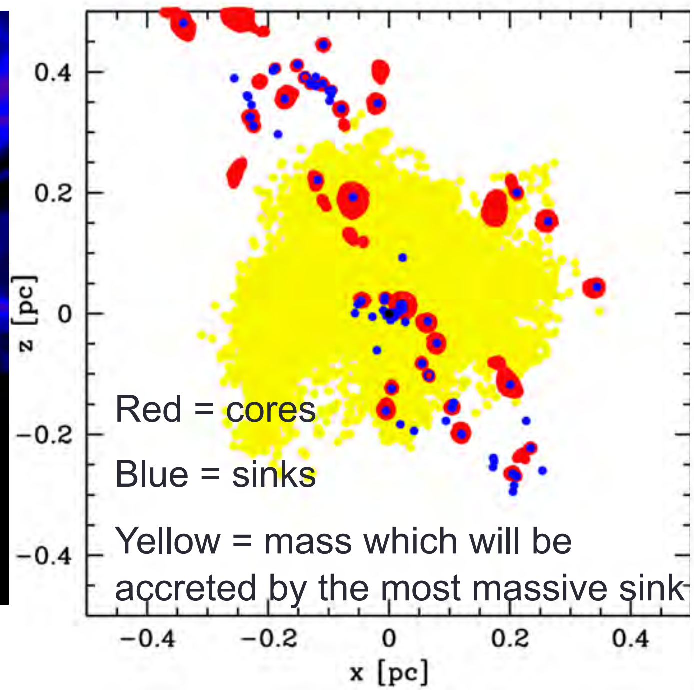
Smith et. al. 2011

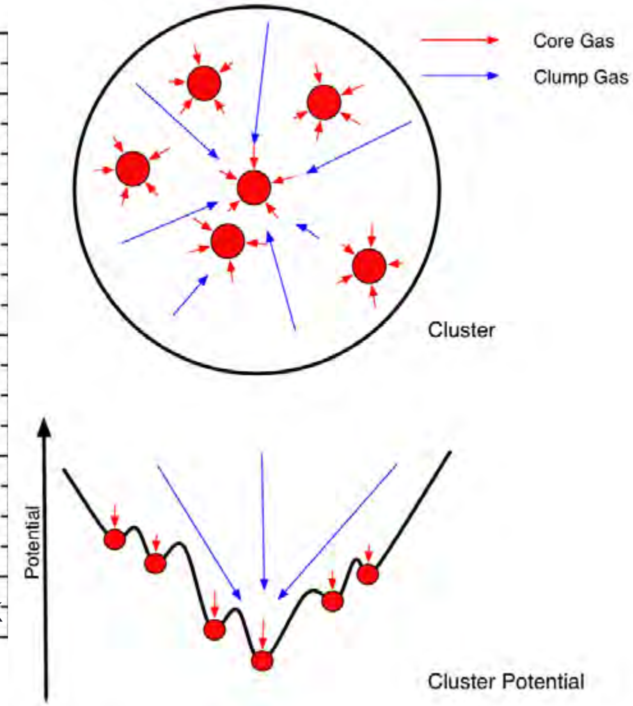
Sinks situated in more filamentary environments are more **massive** at the end of the simulation.

Low mass sinks tend to form from more **spherical** cores.

Gas Evolution





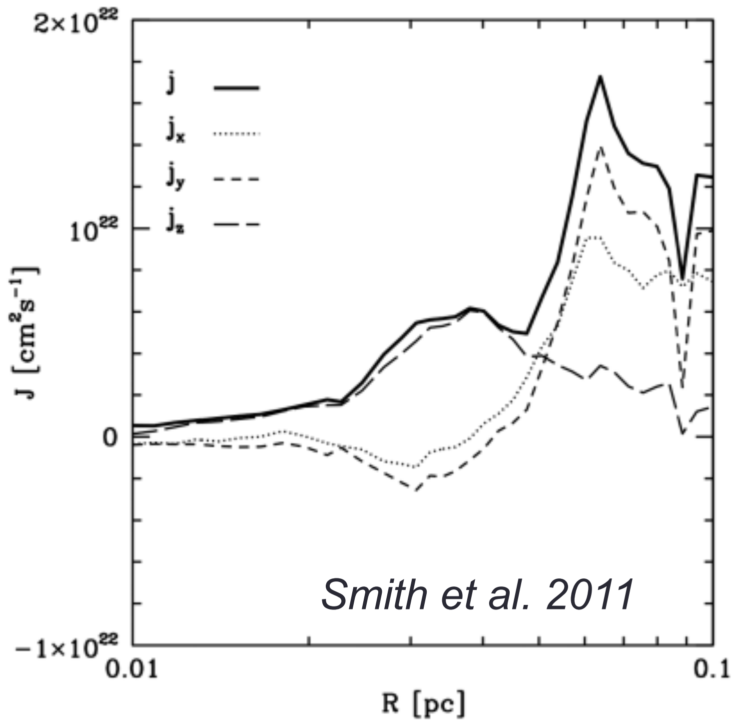


Smith et. al. 2009b

Massive star is mainly built out of gas that initially comes from the surrounding **filament**.

Massive core is built up at the same time as the massive protostar.

Angular momentum



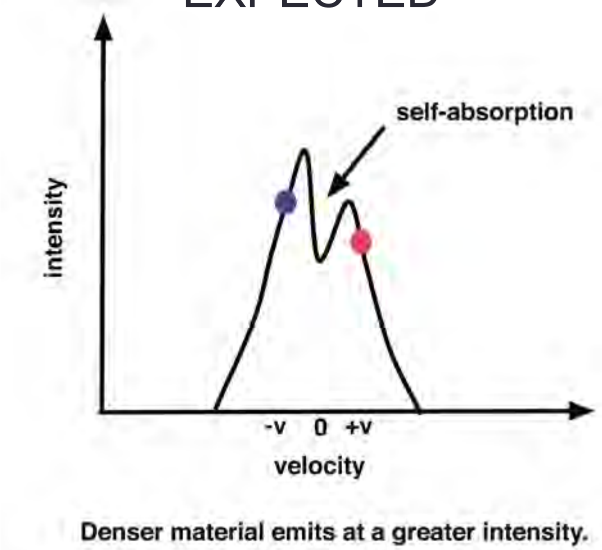
The angular momentum vector of the material accreted onto the core is not coherent.

This may make it more difficult to form a steady state accretion disc, and may change the orientation of jets and outflows over time.

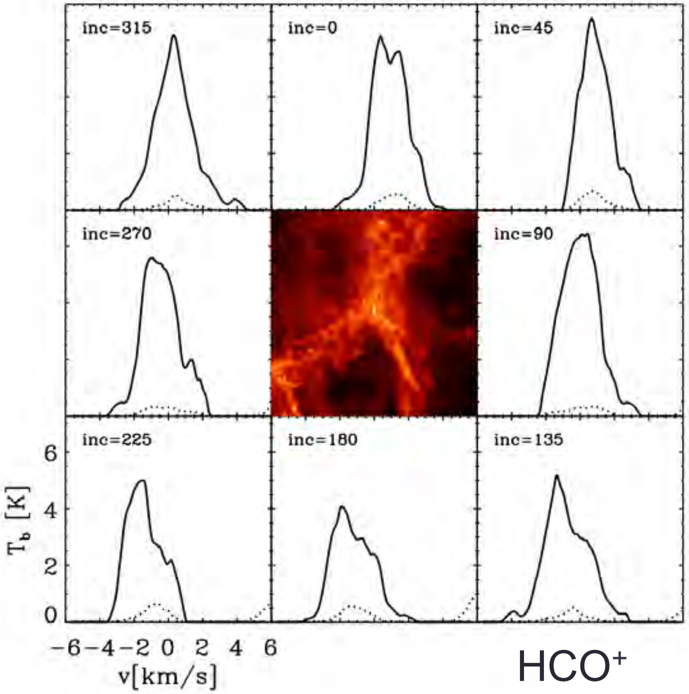
Optically thick line profiles

Post-processing the filamentary massive star forming regions with radmc-3d

EXPECTED



SYNTHETIC OBSERVATION



HCO^+

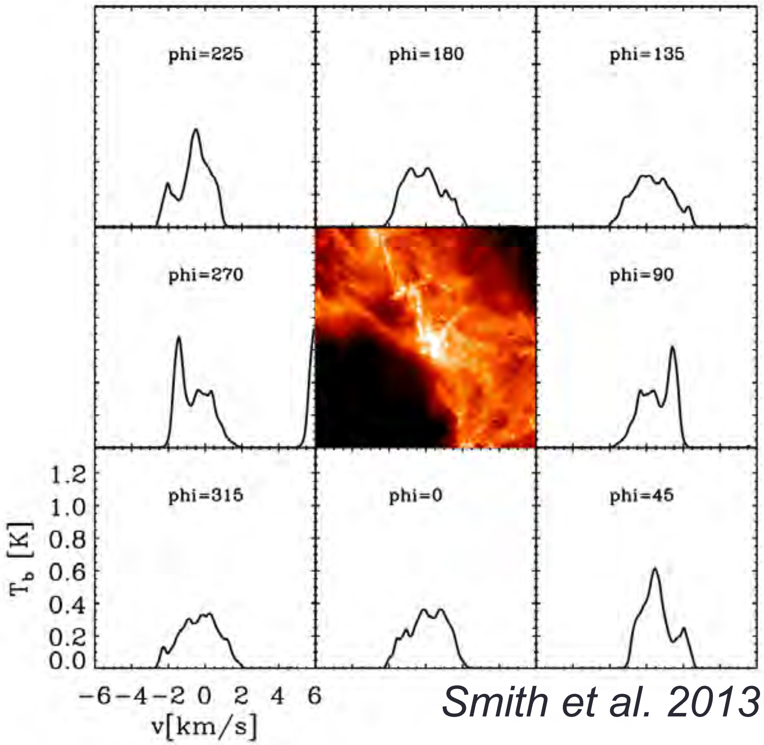
Smith et al. 2013

Filamentary structures means that not all sight-lines are equal.

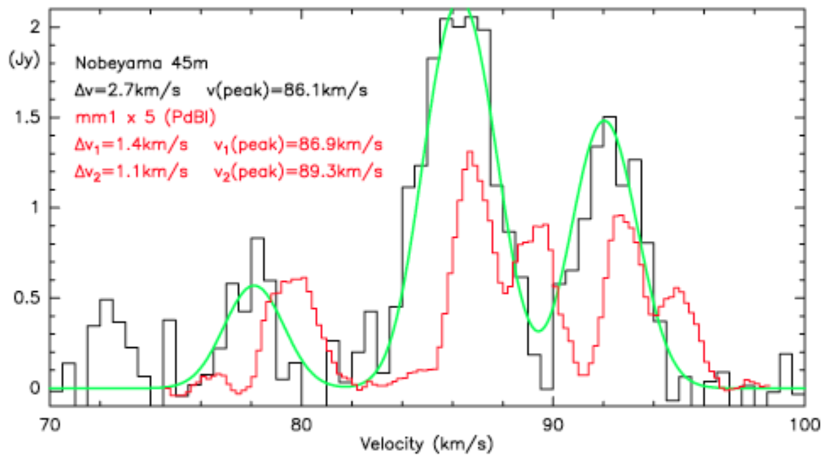
The optically thick line profiles frequently lack self-absorption features as the young massive star is not surrounded by a diffuse stationary envelope.

Optically thin profiles

The N_2H^+ (1-0) isolated hyperfine component observed over 0.06pc HWFM beam



Smith et al. 2013

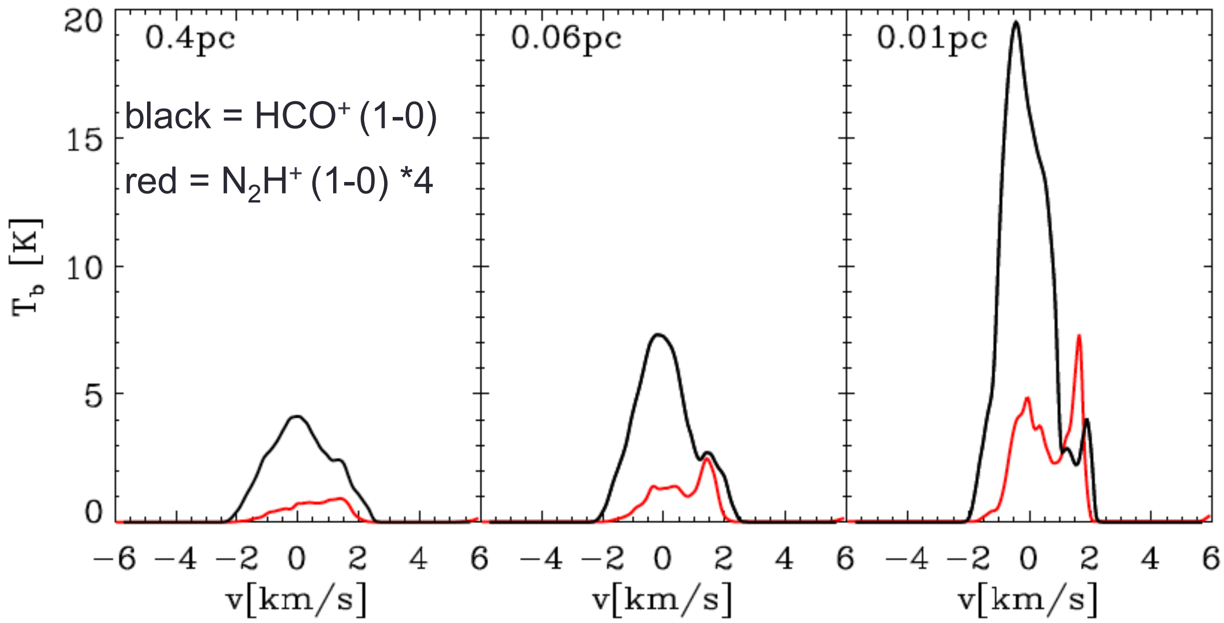


Beuther et al. 2013

The sub-clustering of dense gas within the collapsing clump/filament results in multiple components appearing in the line profiles. This has the potential to be **diagnostic**.

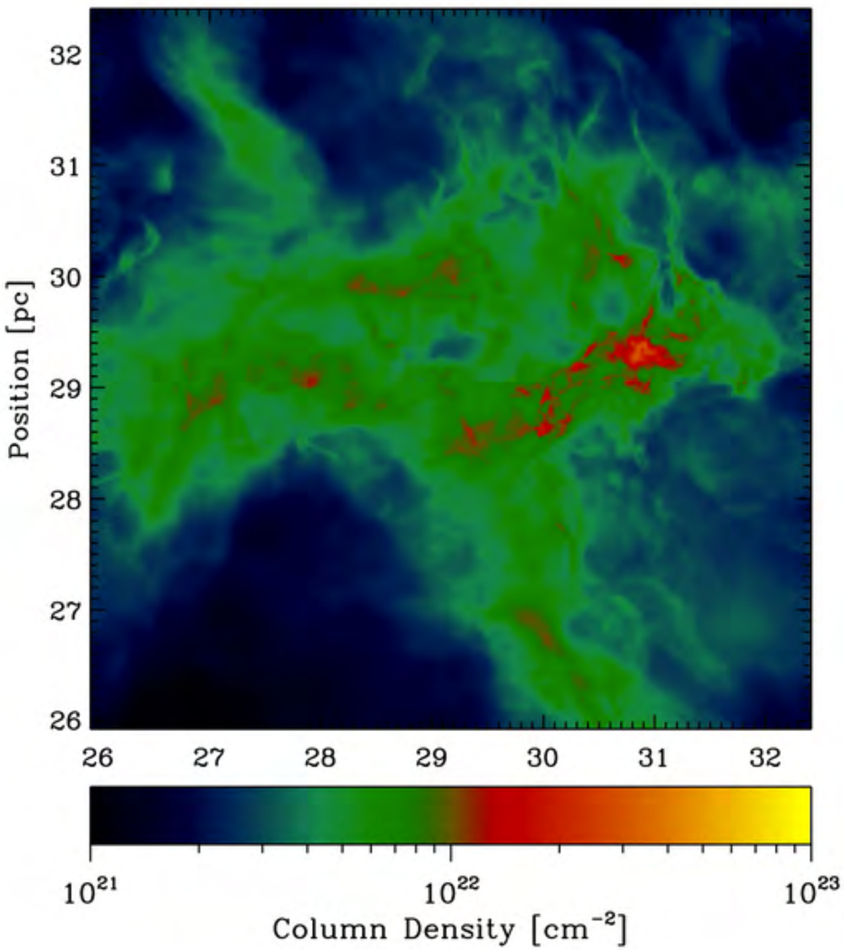
The effect of beam size

N_2H^+ (1-0) isolated hyperfine component observed over 0.06pc HWFM beam



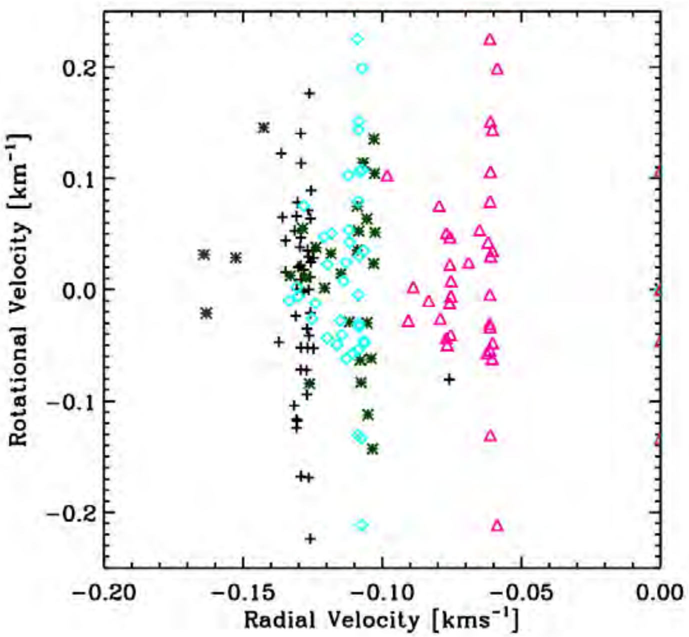
This also becomes more apparent when observed with a narrow beam - implications for ALMA

Filament Formation in Molecular Clouds

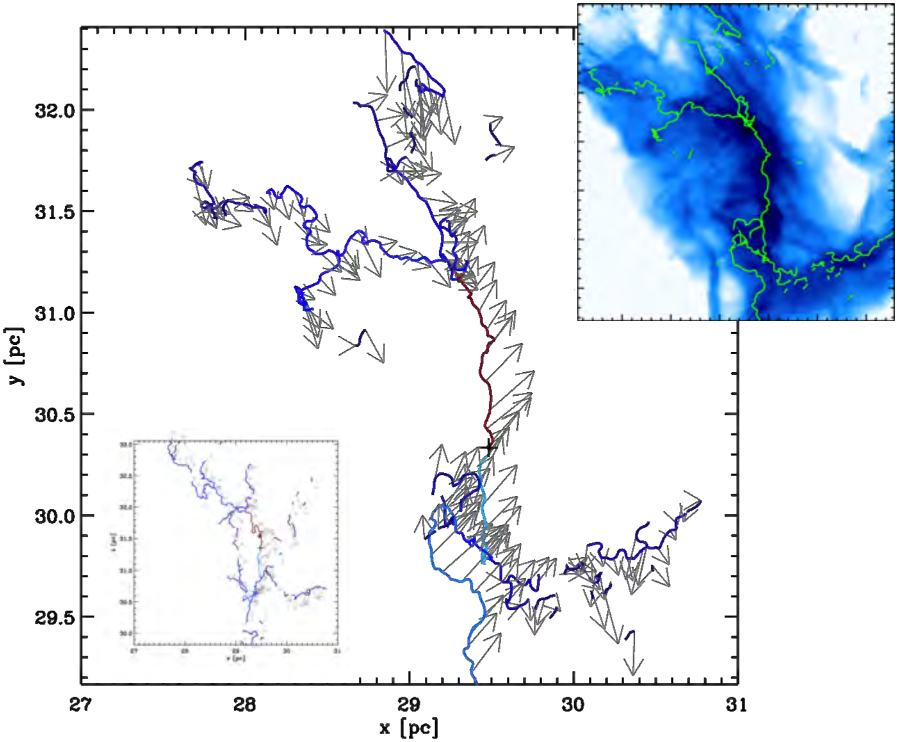


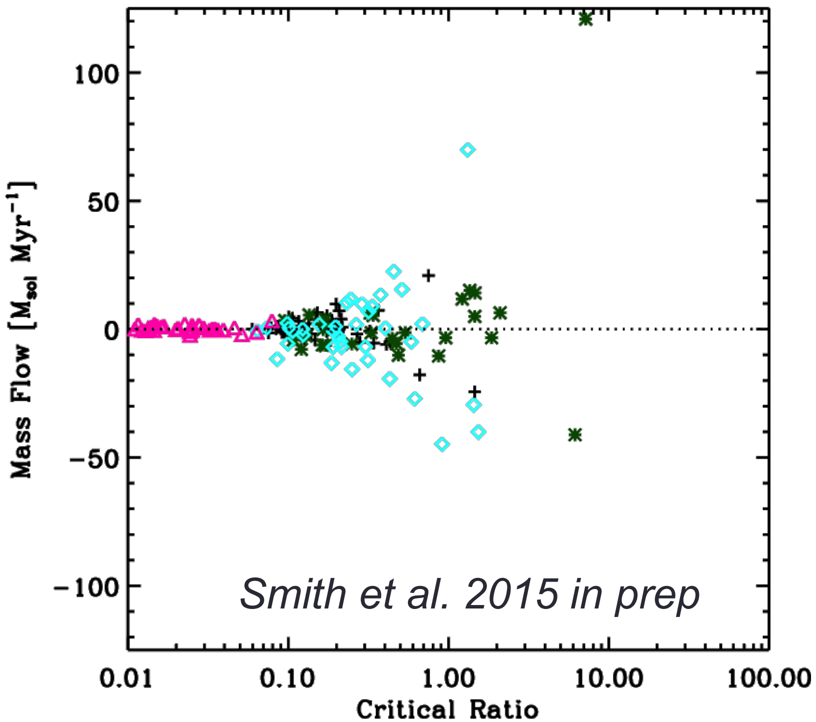
The filament forms from smaller clumpy filaments being **gathered** together by gravitational collapse or large scale turbulent modes.

Coherent structures supported by thermal pressure.



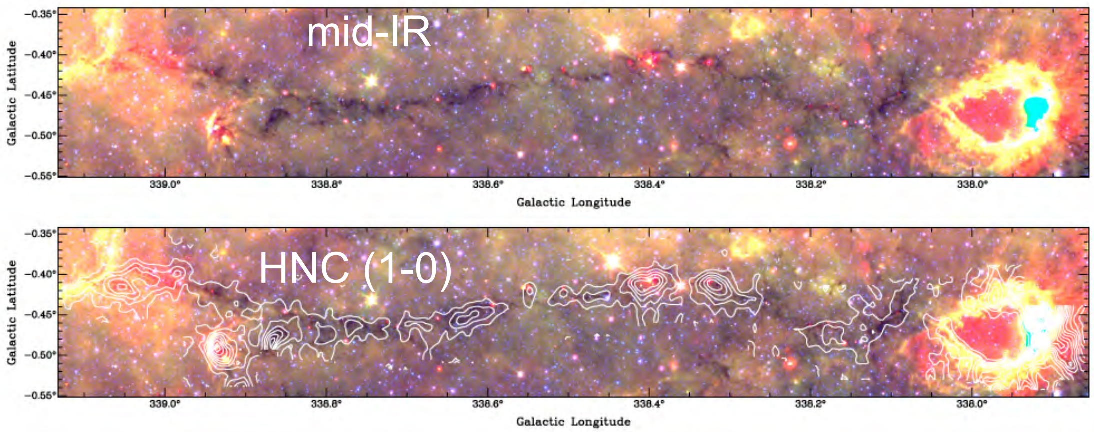
Velocities in Filamentary Flows



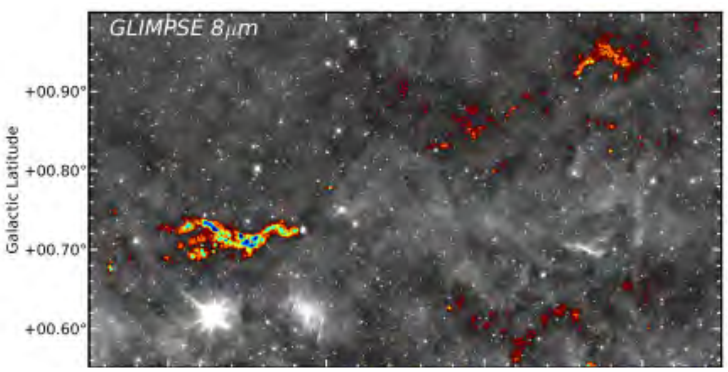


- The filaments are velocity fronts moving perpendicular to their long axis.
- Most filaments are initially stable along their spines (only 0.1 km/s radial motion), super-critical filaments fragment.
- Not all filaments become super critical some are sheared apart.

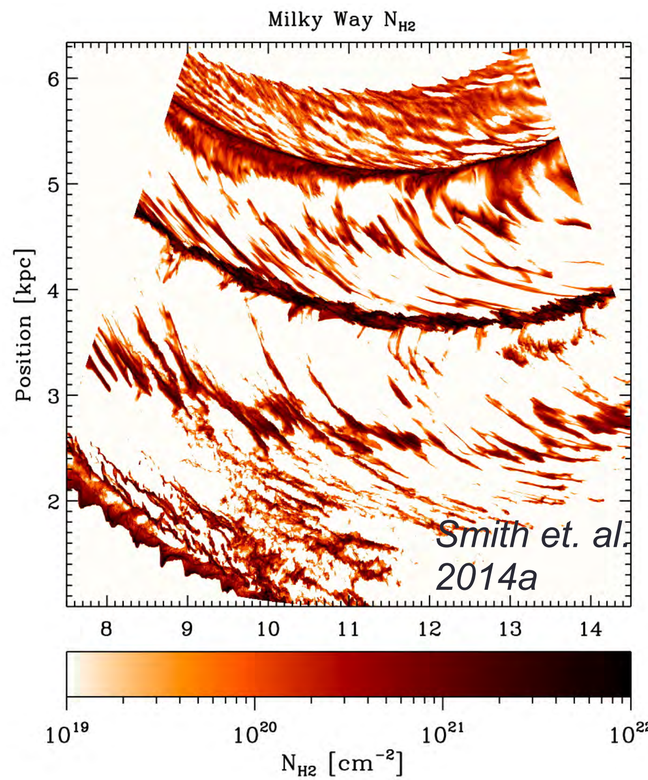
Filamentary Molecular Clouds

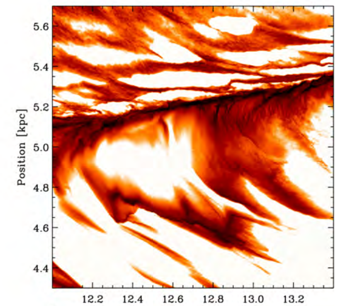


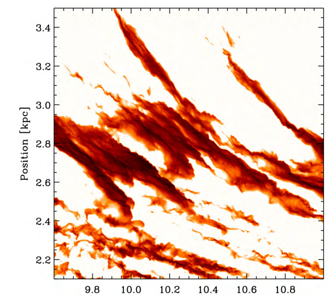
Nessie Nebula: Jackson et al. 2010



Inter-arm filament from Ragan et al. 2014



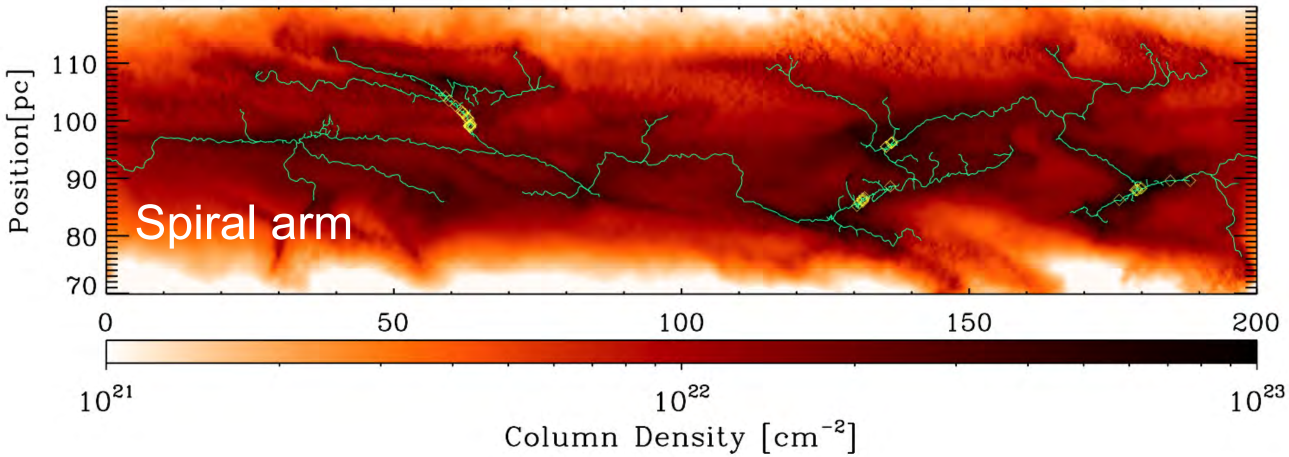


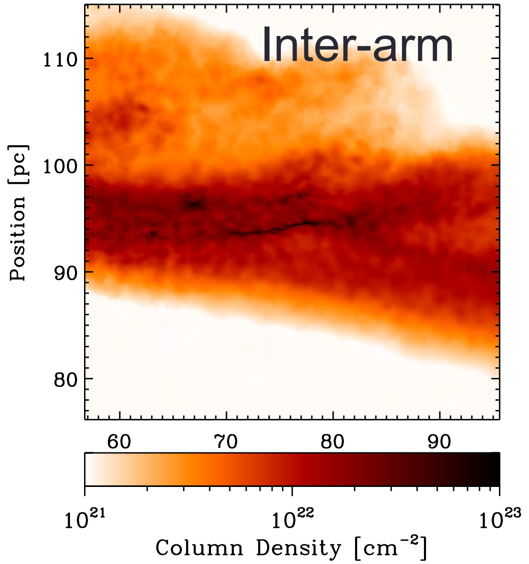


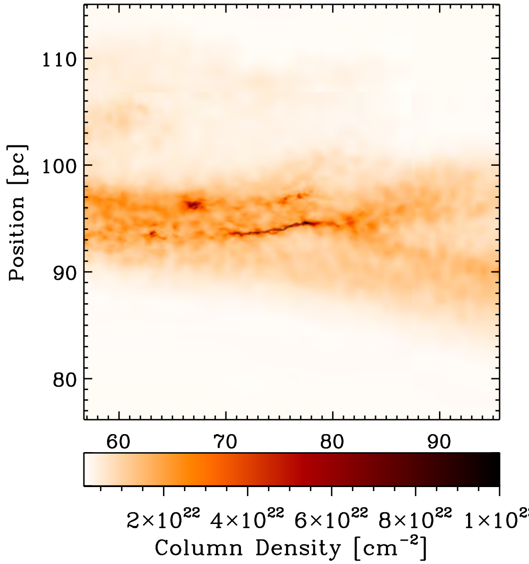
The galaxy is threaded by large-scale dense molecular filaments *(e.g. Schneider & Elmegreen 1979, Jackson et al. 2010, Ragan et al. 2014, Goodman et al. 2014)*

MANCHESTER 1824
The University of Manchester

Star Forming Filaments







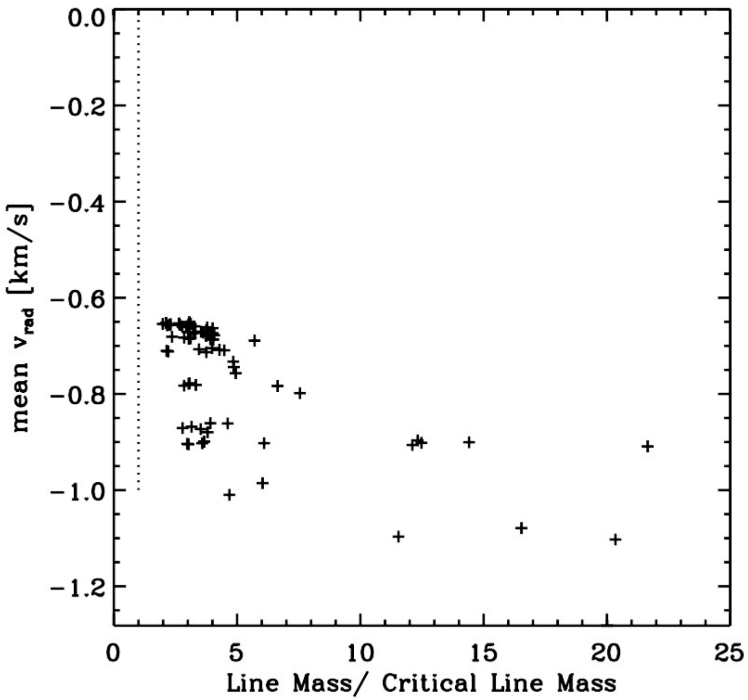
In disc view of two clouds, both have dense filamentary molecular clouds which form stars.

Mass:	Arm:	Inter-Arm:
In IRDCs > 10^{22} cm^{-2}	81%	56%
In gas > 1 g cm^{-2}	0.1 %	0.05%

In both cases there is enough material to form the massive stars in an IMF at surface densities > 1 gcm^{-2}

- BUT must stop it fragmenting into low mass stars.

Radial Contraction of IRDCs

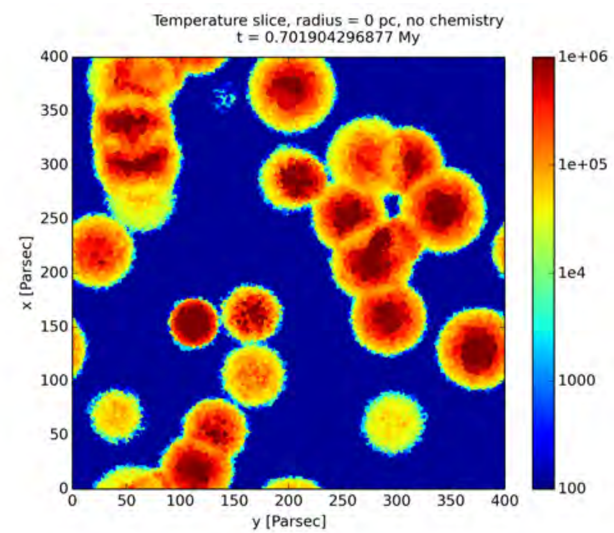


Radial contraction of long filaments can rapidly increase the cloud densities, and the filament will collapse into dense star-forming clumps.

Typical infall speeds are 0.5-1 km/s (within 1pc of the filament centre)

These will form the basis of future work on Massive Stars after more physics is added.

Note: The IRDCs are currently very dense, this may be due to the lack of SN and magnetic fields. We are working on this now in new simulations.



Conclusions

1) Gas flows towards the gravitational centre of a forming cluster along filamentary accretion flows.

2) This can enable the formation of massive stars.

3) When observed using optically thick tracers the massive proto-stellar cores may lack self-absorption features.

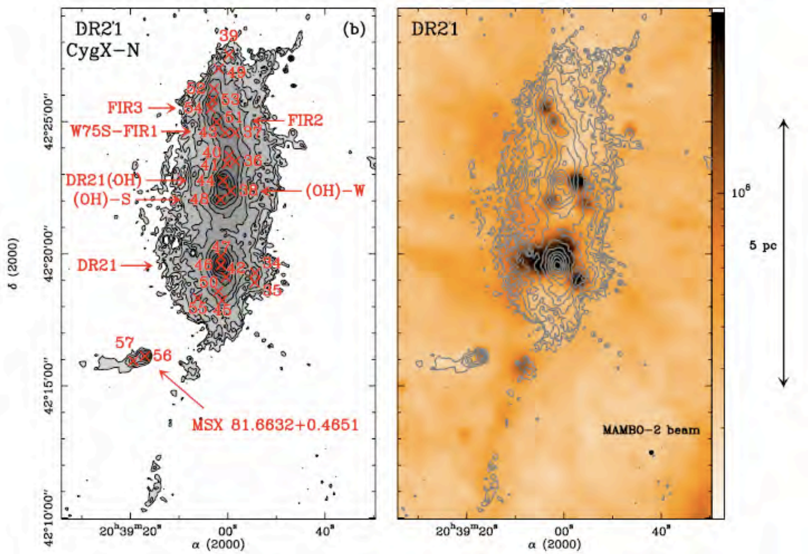
4) Multiple components will be seen in optically thin lines when observed with a narrow beam, this can be used to test how fragmented massive star forming regions are.

5) Not all filaments will go on to form stars.

6) In future we hope to investigate massive star formation in more realistic clouds from galactic simulations.

Extra

Observations: Environment



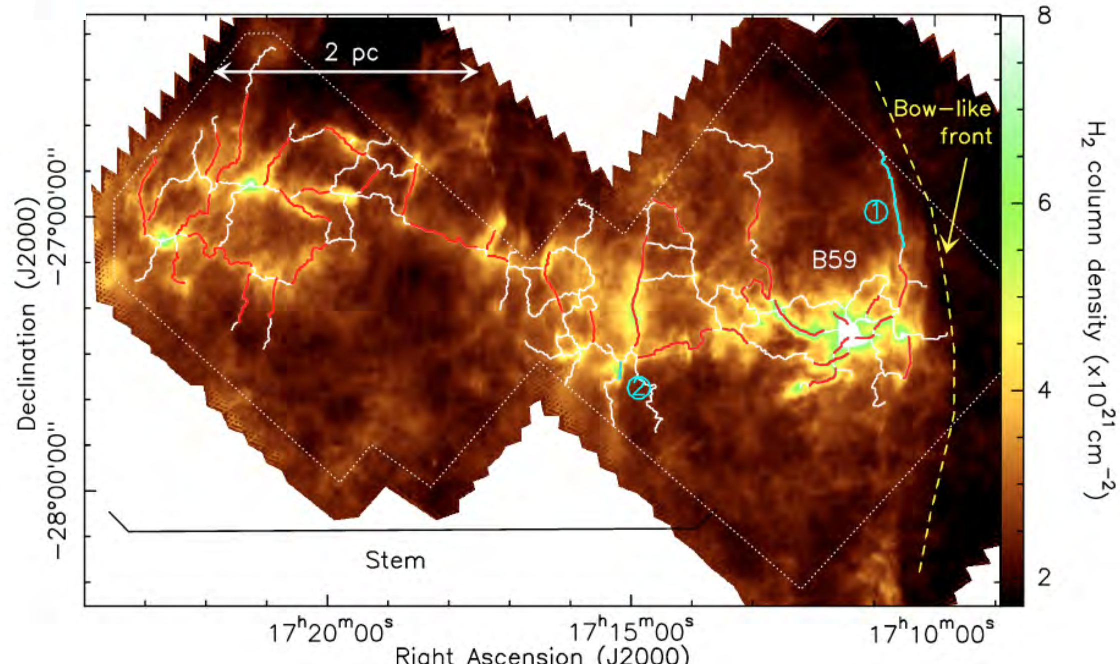
Massive stars usually form at the centre of dense star forming clumps.

Pre-stellar massive cores either extremely short lived or don't exist

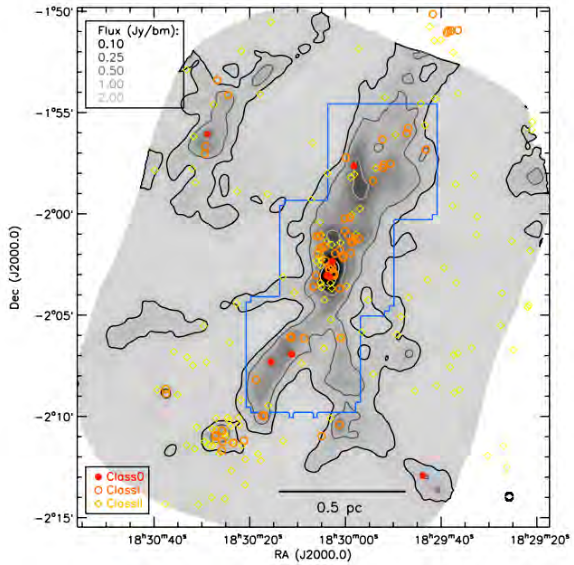
Motte et. al. 2007

Star forming clumps form at the hub points of filaments.

Peretto et. al. 2012, Myers 2009, Schneider et. al. 2012



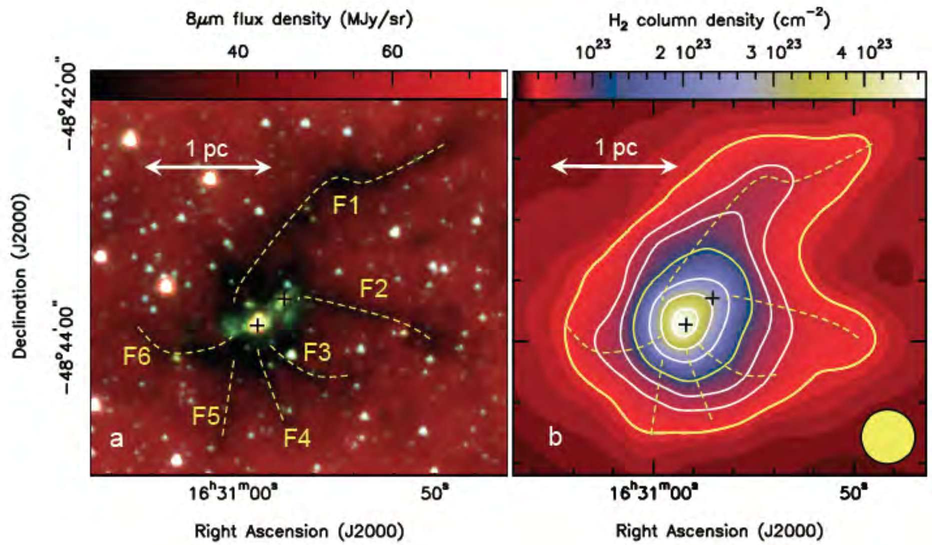
Observations: Inflow



Kirk et al 2013 found infall gradients of ~ 30 M_{sol} Myr^{-1} along the southern filament of Serpens South

-radial contraction onto the filament at ~ 130 M_{sol} Myr^{-1}

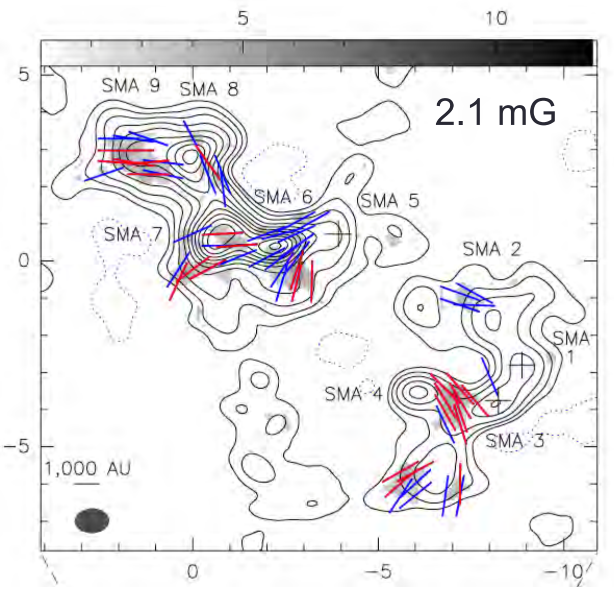
Peretto et al. 2013 found the mass in the central pc of a massive IRDC (SDC335) could be doubled in a million years.



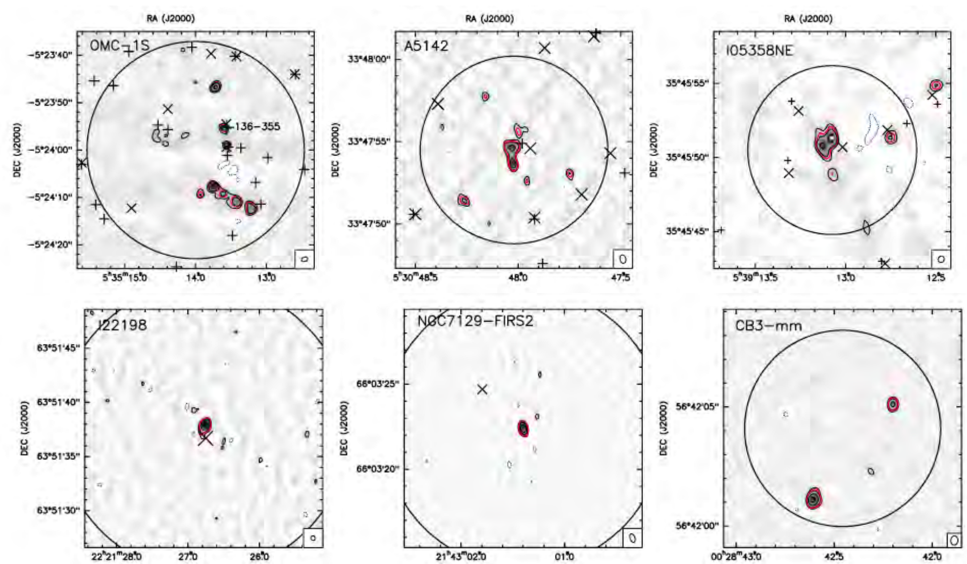
Observations: Fragmentation

Interferometry observations usually (but not always) reveal substructure on core size scales i.e. less than 0.1 pc scale.

see Bontemps et al. 2012, Rodon et al. 2012, Duart-Cabral et al. 2014



Girart et al. 2013



Palau et al. 2013 & 2014

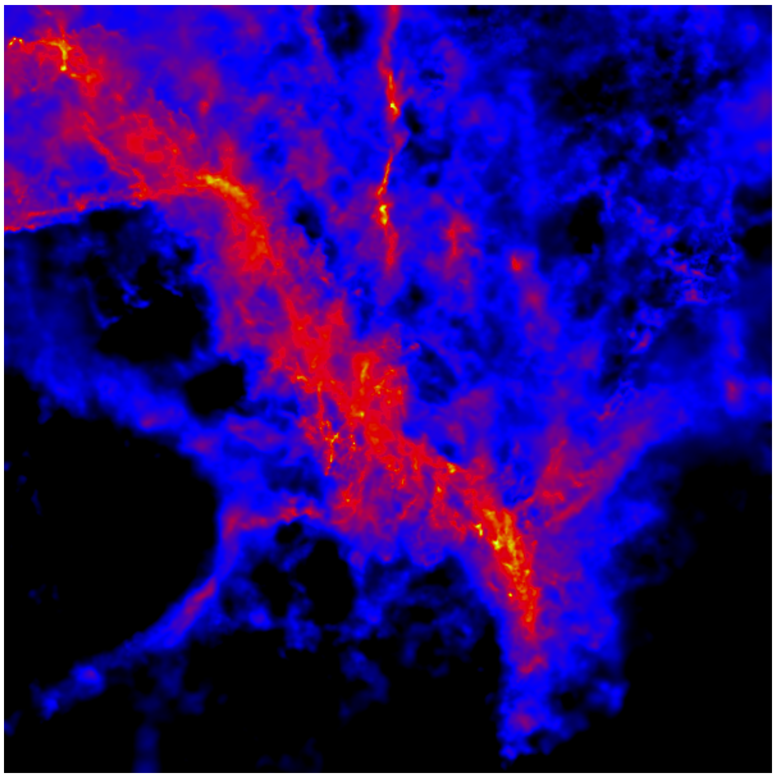
Fragmentation with an entrained magnetic field.

18 massive dense ~0.1 pc cores

5 one dominant source, 9 many (>4) sources

low fragmentation = stronger magnetic field

Gas Evolution

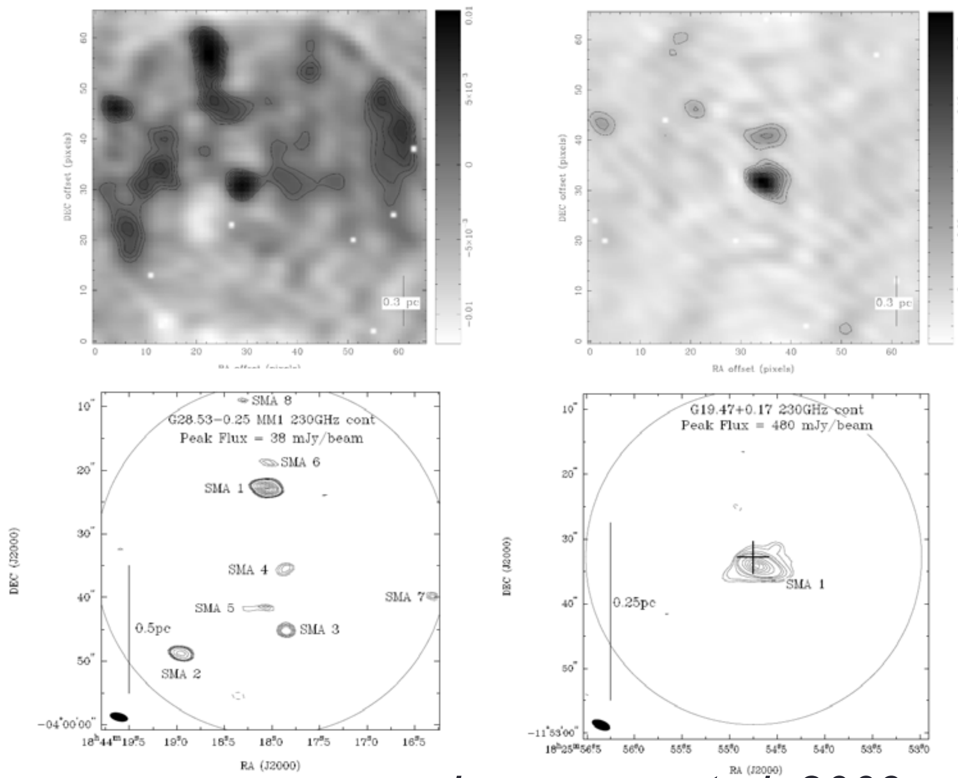


Clump Alpha
in column density
blue: 0.05 gcm^{-2} yellow: 5 gcm^{-2}

Smith et al. 2009

Filament collapsing along its axis

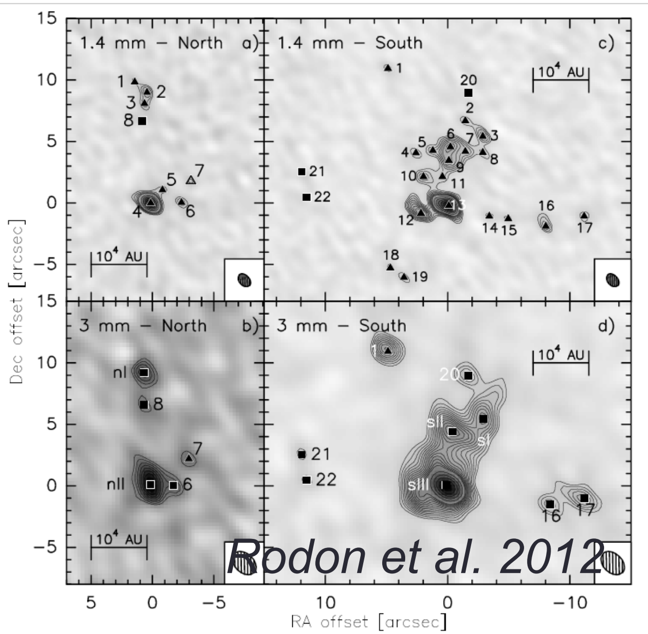
- evolves to a more compact state with less sub-structure

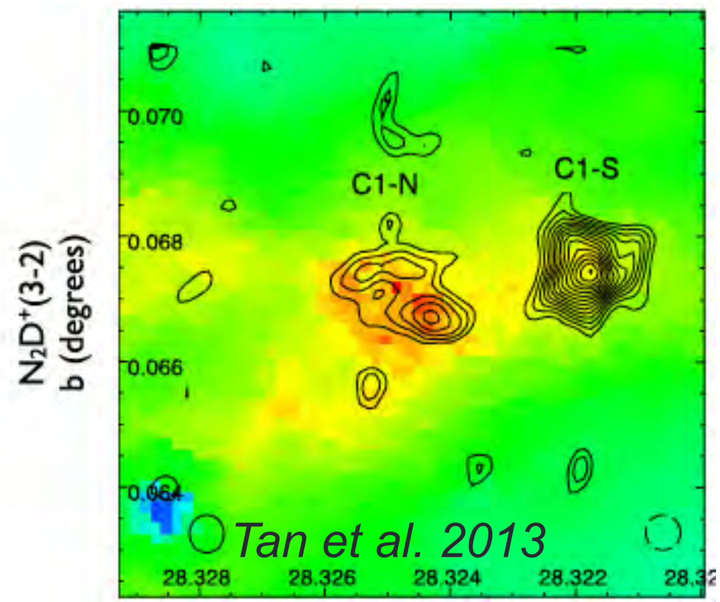


Longmore et al. 2009

Massive Starless Cores

Generally massive condensations exhibit some sub-structure consistent with the predictions of these simulations.



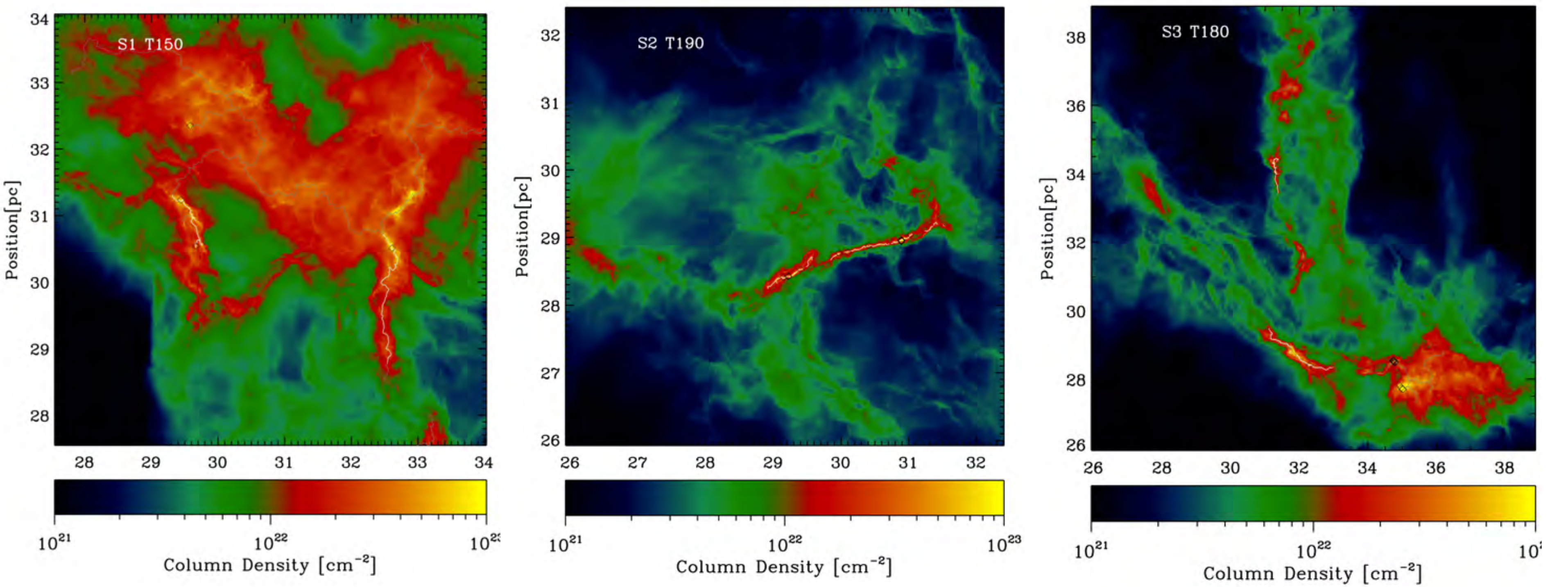


Caveats:

My simulations lack magnetic fields (see *Myers et al. 2013*)

It is important to see what such regions would look like in actual observations.

AREPO clouds

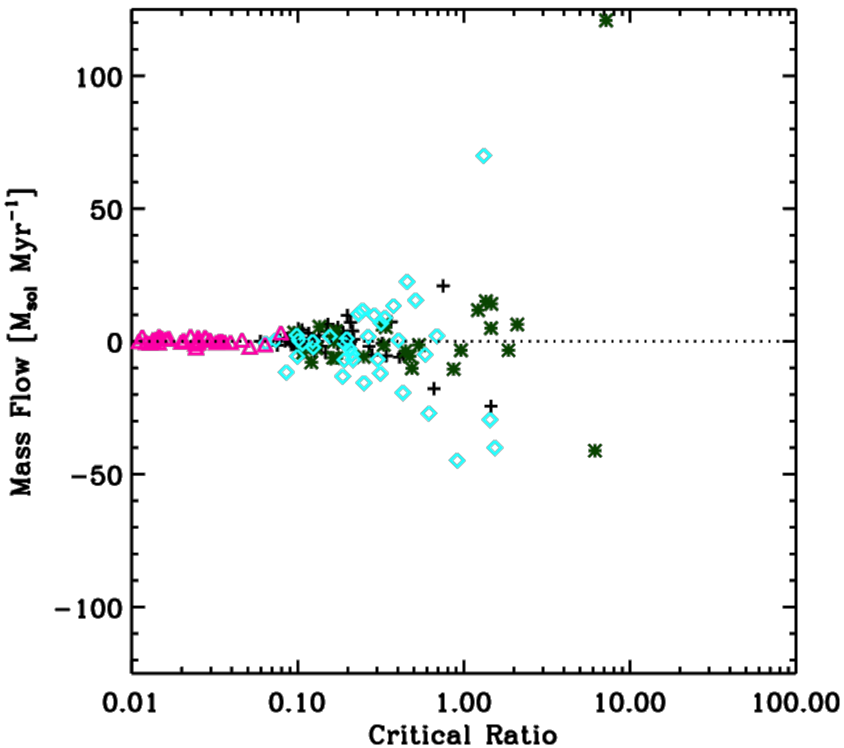


10^4 solar mass initially spherical clouds embedded in a hot medium.

- Turbulent clouds with $P(k) = k^{-4}$ and different turbulent mixes and seeds.
- Chemistry, self-gravity, and chunky sinks.
- Jeans length always refined by at least 16 cells.

Smith et. al. 2014b

Velocities in Filamentary Flows



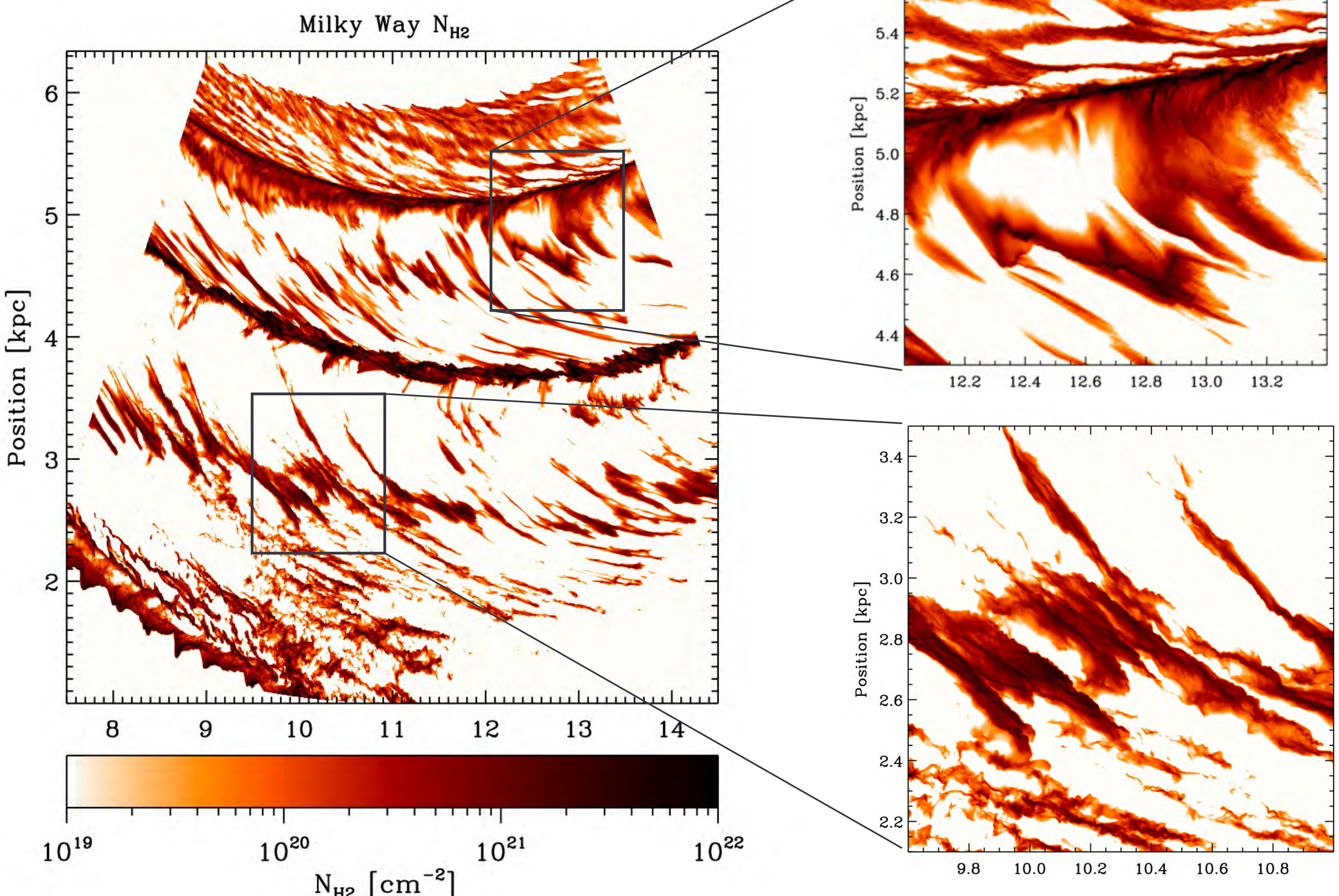
There may also be a net mass flow along the filament.

- Positive or negative, many filaments are shearing flows
- Up to 50 solar masses per Myr increase in this simulation.
- Most filaments are stable and supported by thermal pressure.

Simulation	$Nfil$	Mass [$M_\odot$]	v_{front} [kms^{-1}]	$\mid v_{flow} \mid$ [kms^{-1}]	v_{rad} [kms^{-1}]	v_{rot} [kms^{-1}]	$crit$	$\mid \frac{v_{front}}{v_{flow}} \mid$	$\mid \frac{v_{rad}}{v_{rot}} \mid$
S1F1T140	47	4.13 (8.83)	0.75 (0.175)	0.36 (0.25)	-0.13 (0.008)	-0.005 (0.084)	0.22 (0.23)	6.22 (11.92)	44.32 (195.9)
S2F1T180	28	9.48 (9.04)	0.82 (0.26)	0.36 (0.22)	-0.11 (0.018)	0.014 (0.071)	1.04 (1.70)	5.39 (13.74)	6.34 (15.96)
S1F2T140	38	5.16 (7.05)	1.25 (0.39)	0.49 (0.42)	-0.11 (0.008)	0.012 (0.088)	0.37 (0.36)	7.12 (11.52)	5.67 (10.46)
S2F2T100	35	1.81 (2.18)	1.29 (0.67)	0.37 (0.42)	-0.07 (0.011)	0.003 (0.069)	0.03 (0.02)	6.75 (11.50)	3.17 (3.87)

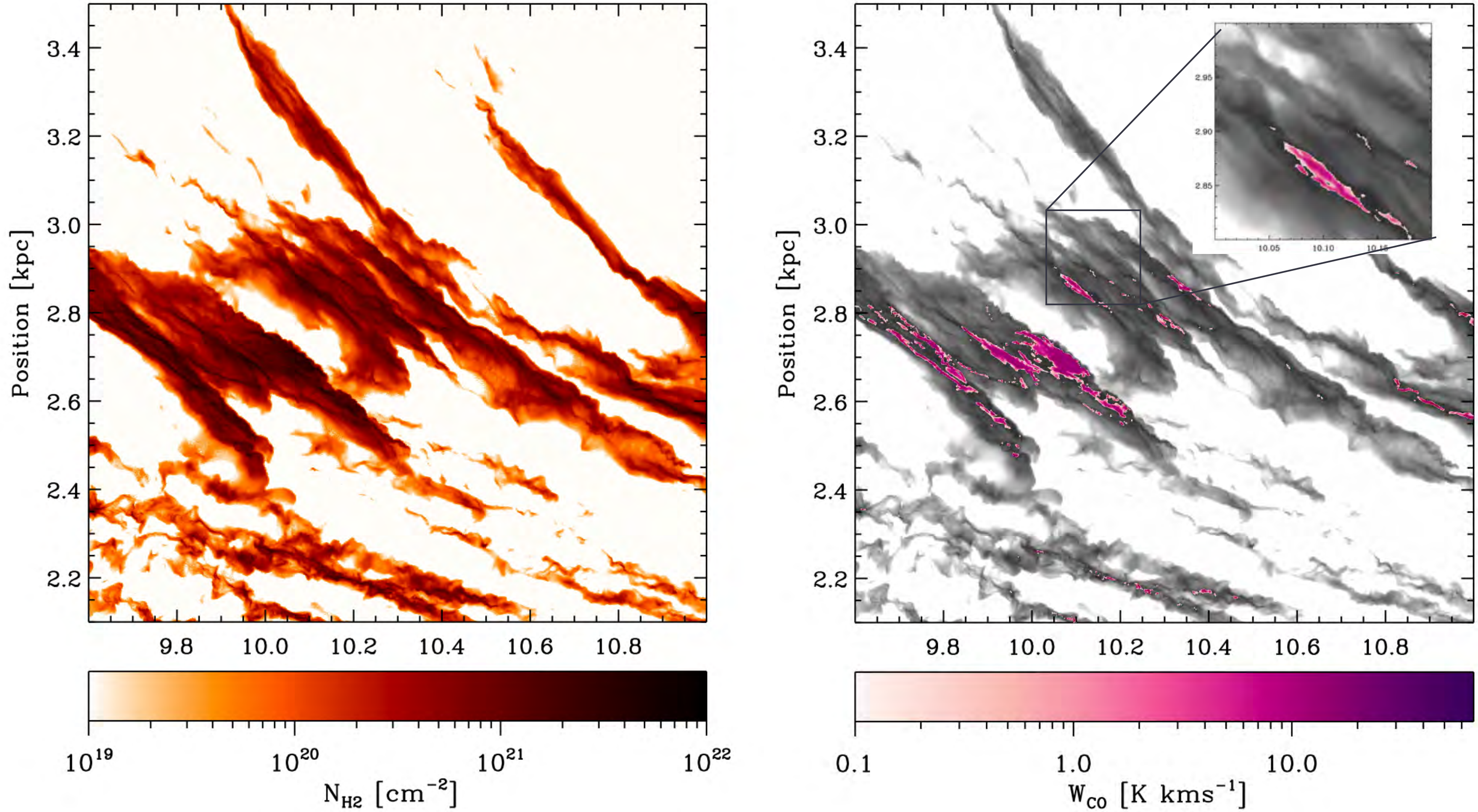
Smith et. al. 2015 in prep

Galactic H_2



Smith et. al. 2014a

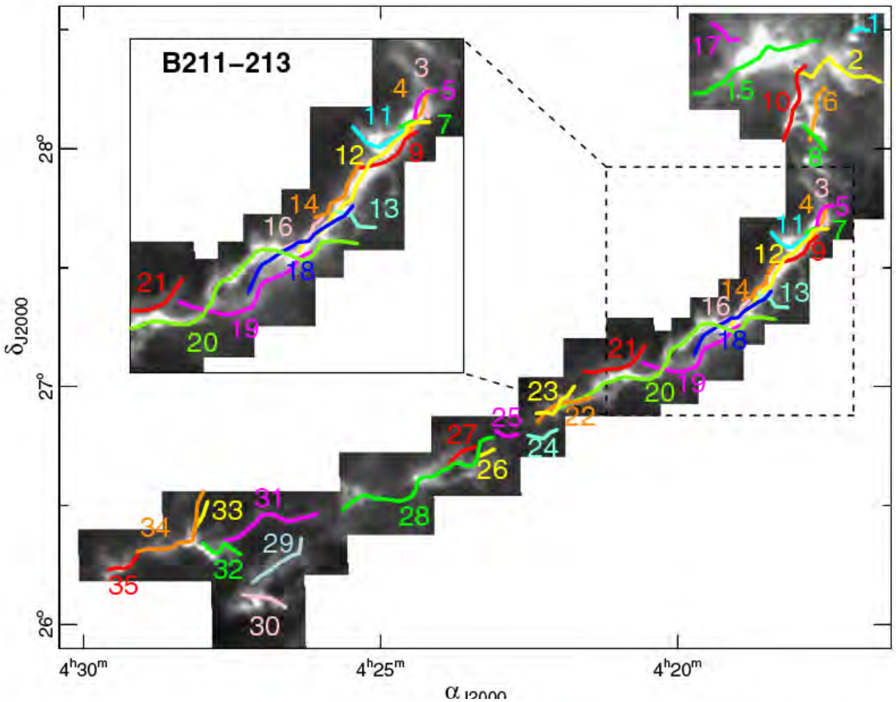
Morphology

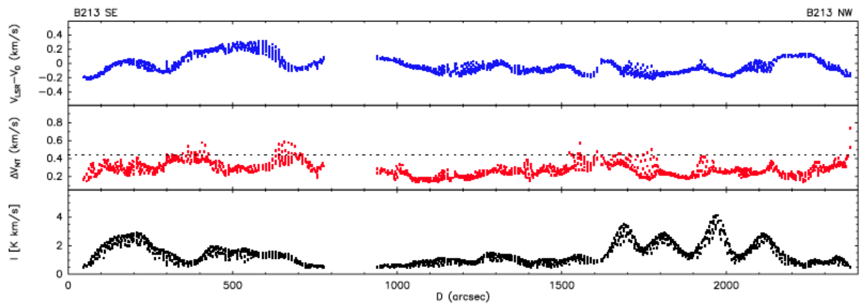


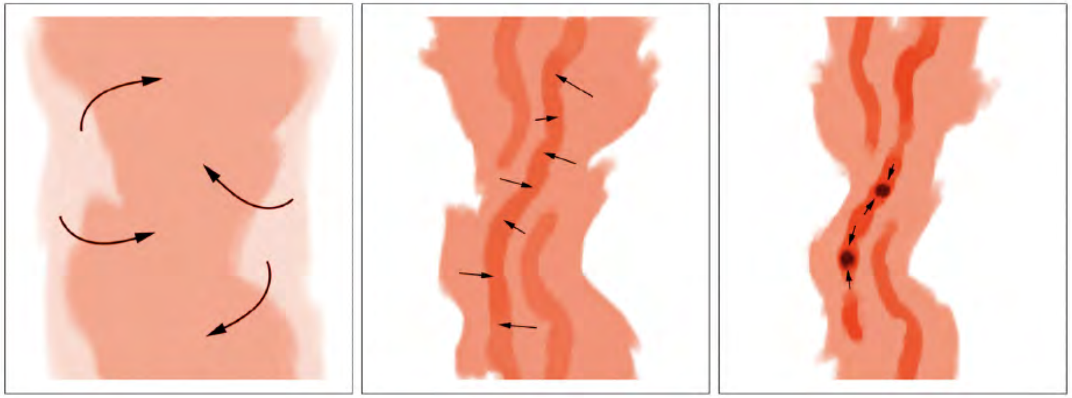
Filamentary molecular clouds in inter-arm regions are likely only the observable parts of much larger structures.

Bundles of fibres

Hacar & Tafalla 2013 showed that in the Taurus the main filament breaks up into many "fibres" when identified in ppv space.

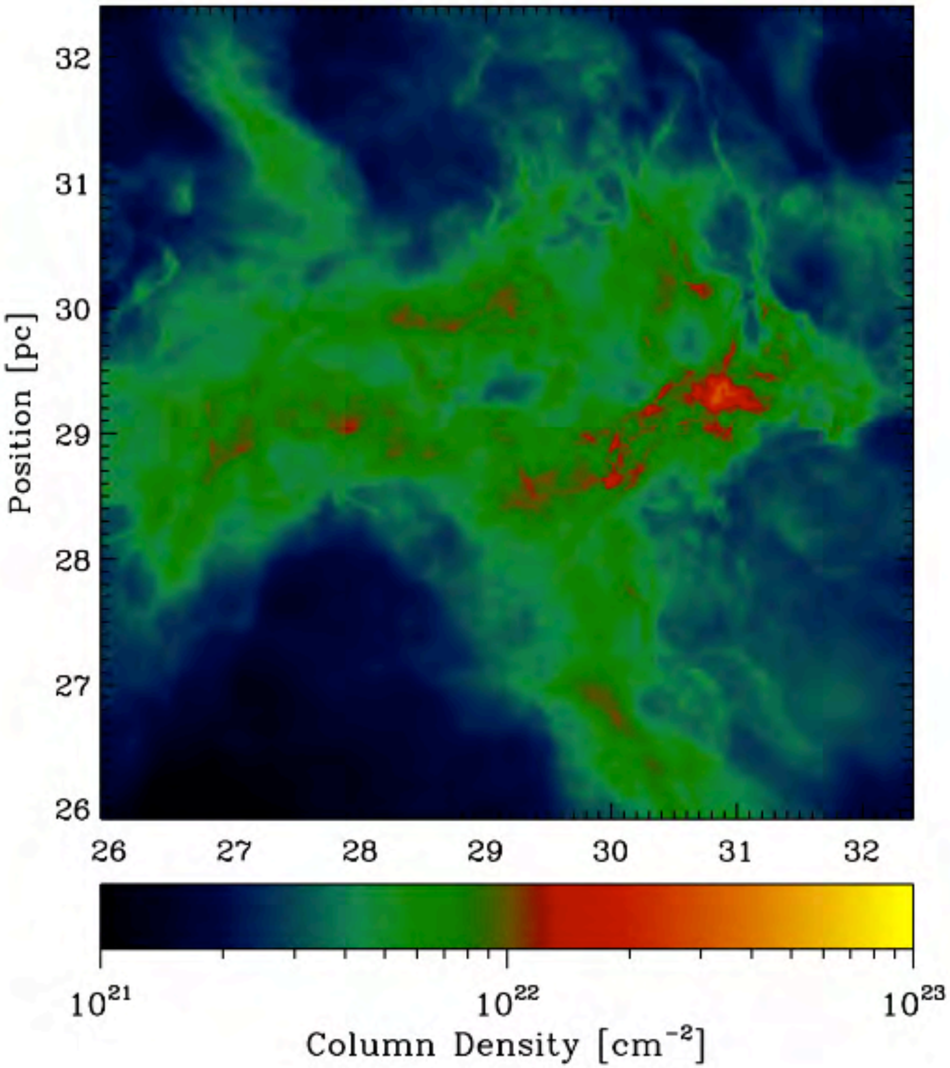






They propose a "fray and fragment" scenario *(Tafalla & Hacar 2015).*

Filament Formation



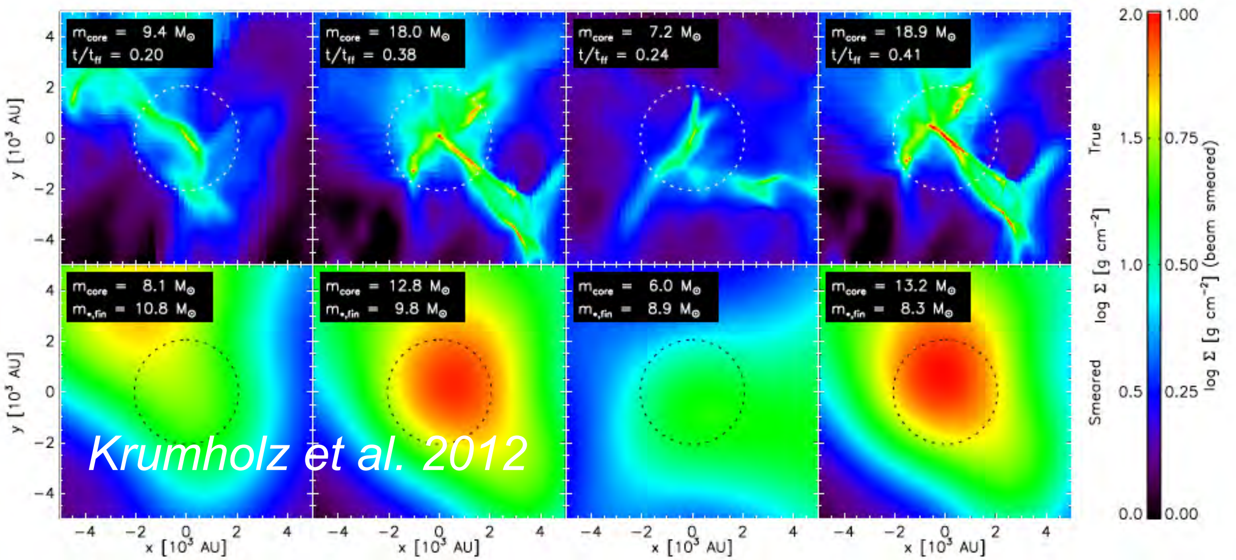
The filament forms from smaller clumpy filaments being collected together by gravitational collapse.

The sub-filaments begin to form before the larger structure not by subsequent fragmentation as proposed in Hacar et al. 2013 .

A comment

Competitive Accretion vs. Turbulent Cores -> Probably both wrong

1) What we see in the simulations (*Smith+ 2009, Wang+ 2010)* is **not** competitive accretion in the original Bondi-Hoyle sense. The gas and cores are well coupled. It is the global collapse of the cloud that feeds the proto-stars.



2) Supersonic turbulence is not an isotropic pressure and so it cannot support a core without also inducing fragment in regions that have been compressed.