Infrared Dark Clouds & Massive Star Formation

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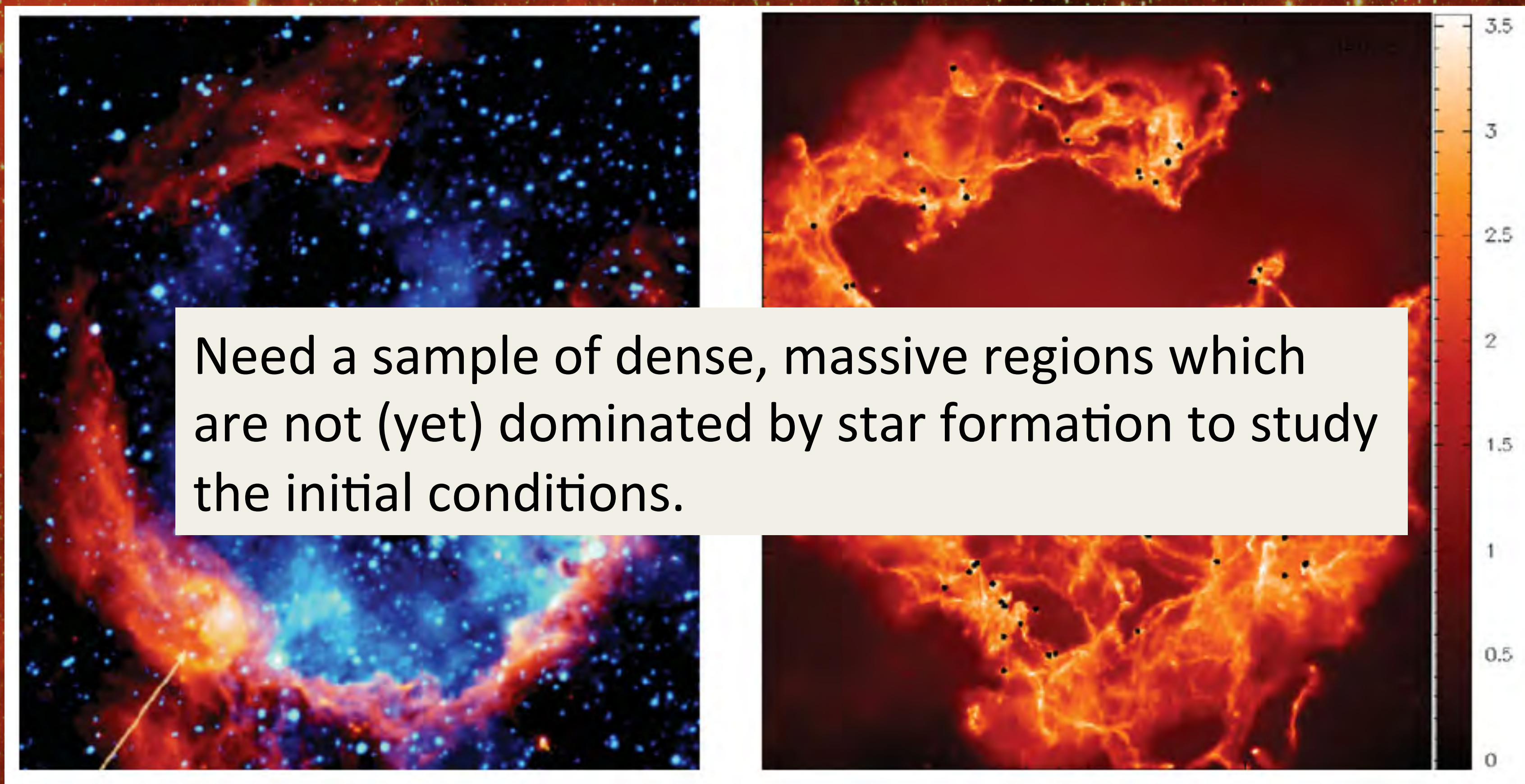
Why Are Massive Stars Important?

- Drive the chemical and physical evolution of the Galaxy
- Massive stars ($M>8M_o$, $L>10^4\ L_o$) rapidly dominate their environment
  - Radiation
  - Winds
- Most stars form in clusters (Lada & Lada 2003)
  - Many clusters contain massive stars
  - Positive or negative feedback on current and future star formation?
- Most difficult to form
  - Time scales
  - Feedback

Stellar Feedback



Need a sample of dense, massive regions which are not (yet) dominated by star formation to study the initial conditions.

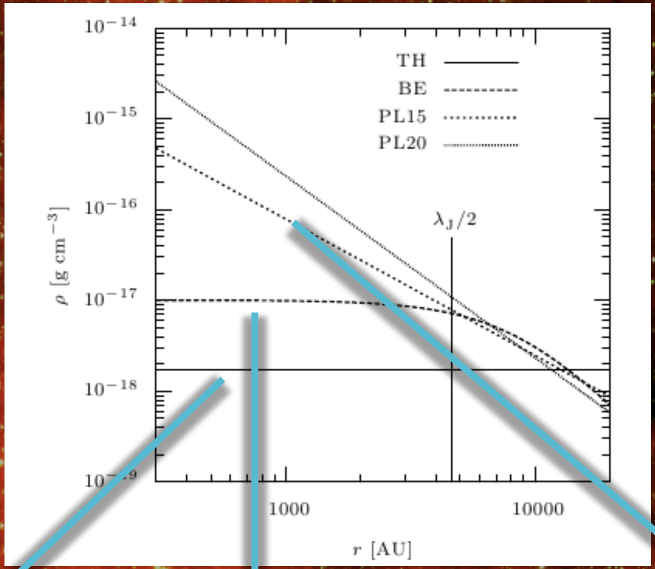
RCW79

(Walch et al. 2011)

“Star formation is a messy, complex process.” I. Smail, RAS meeting 2010

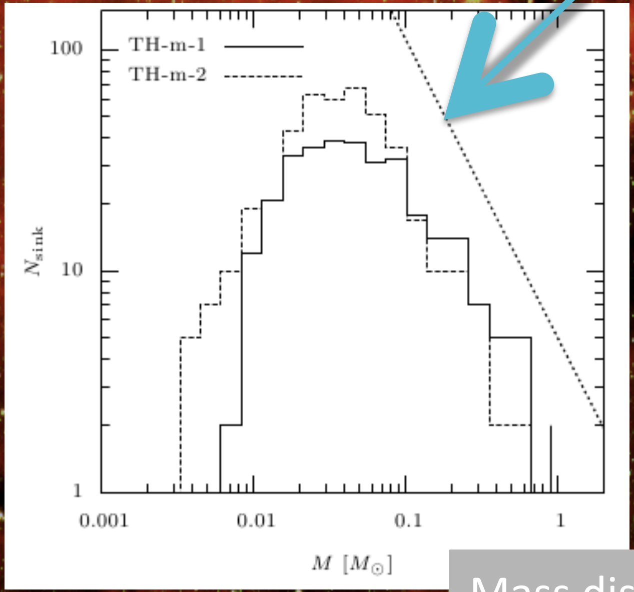
Initial Conditions Are Important

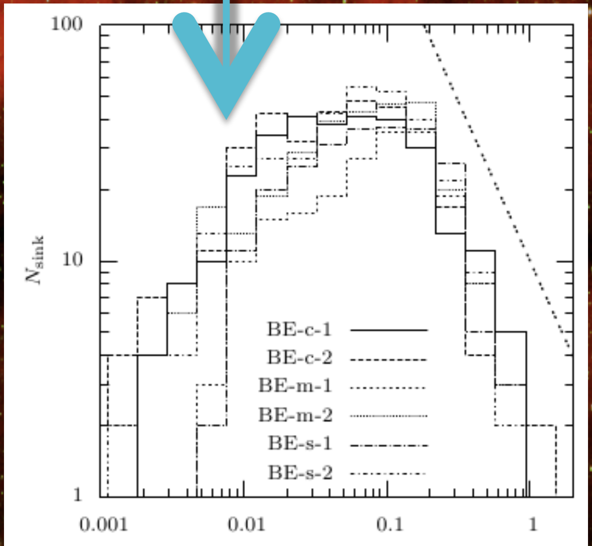
Girichidis et al 2011
100 M_o core
0.2 pc diameter

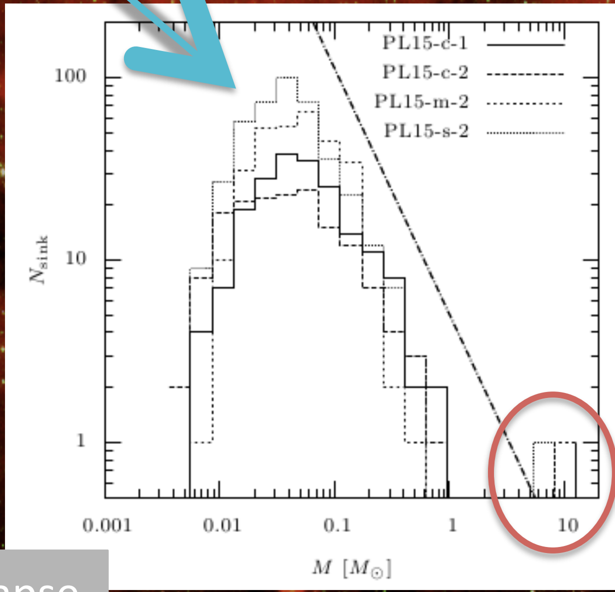


Initial density profile in core

$$\rho \propto r^{-2}$$







Mass distribution of fragments after collapse

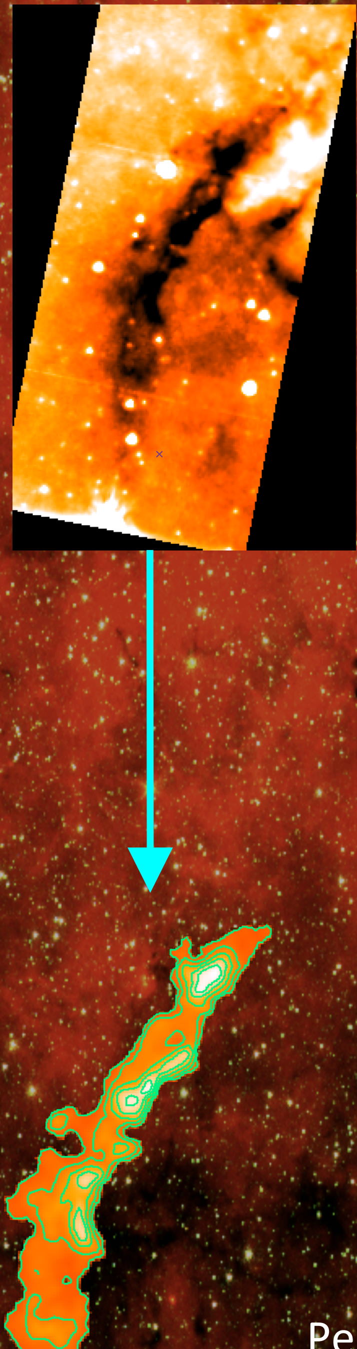
Look where the light isn't

- Look for quiescent gas where there isn't (much) emission
  - Dark clouds seen in absorption against the diffuse IR

- IRDCs first seen with ISO (Perault et al. 1996)
  - First extensive catalogue MSX

(Carey et al. 1998, 1999, 2000; Teyssier et al. 2002; Schuller et al. 2009; Vasyunina et al 2009; Teyssier et al. 2002; Ragan et al. 2006; Pillai et al. 2006, 2007; Beuther & Sridharan 2007; Chambers et al 2009; Jackson et al. 2008; Simon et al. 2006a,b; Rathborne et al 2007/2008; Wang et al. 2008; Zhang et al. 2009; Butler & Tan 2009; Ragan et al. 2009)

Spitzer GLIMPSE provided an opportunity for a higher sensitive, higher resolution survey



Spitzer Dark Cloud Catalogue
An New IRDC Catalogue

Spitzer GLIMPSE & GLIMPSE II 8µm data.

- Construct maps of Spitzer Dark Clouds (SDC):

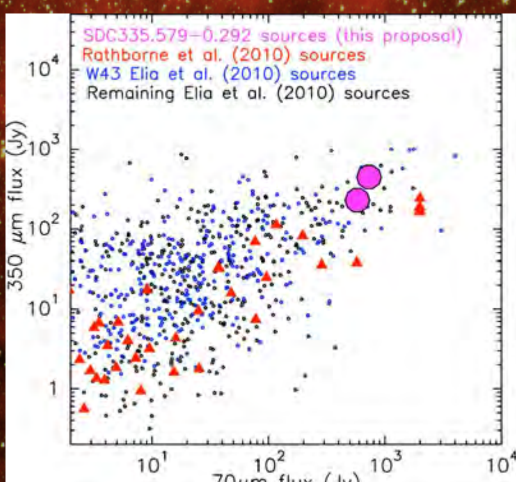
$$\tau_{8\mu\mathrm{m}} = -\ln\left(\frac{I_{8\mu\mathrm{m}} - I_{\mathrm{fore}}}{I_{bg}}\right)$$

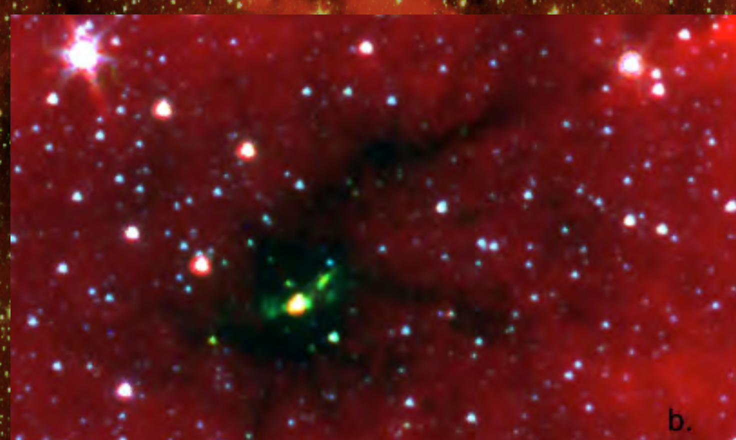
  - connected regions of tau(8um)>0.35 with peak > 0.7
  - $N(H_2)>10^{22}$ cm^{-2} with peaks $N(H_2)>2x10^{22}$ cm^{-2}
  - d>4" (0.1 pc at 5 kpc)
  - 15,000 clouds in region $295^o<l<65^o$, $-1^o<b<1^o$
  - Masses from few M_o to $\sim10^4$ M_o
  - Sizes 0.1 to 6 pc

Peretto & Fuller 2009; Lenfestey, Peretto & Fuller 2015; Peretto & Fuller 2010

SDCs & Massive Star Formation

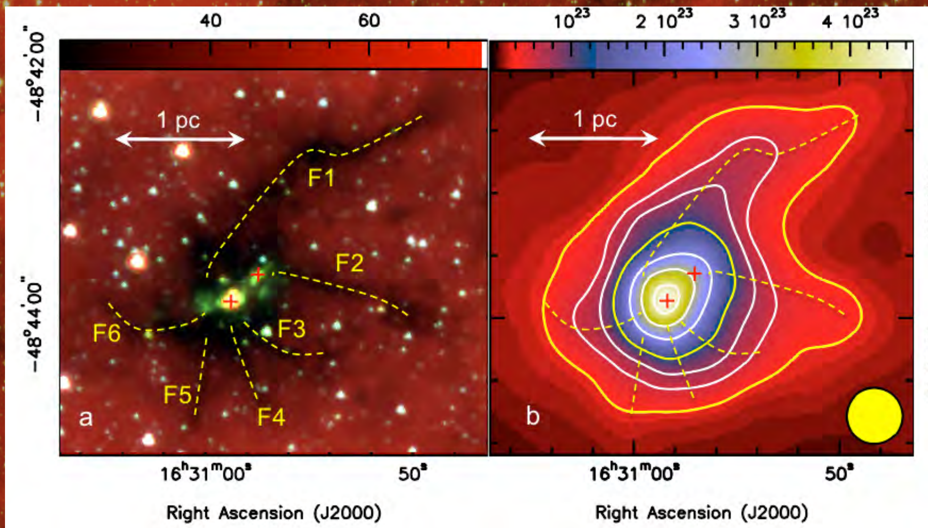
- Some SDCs are forming massive stars
- ~800 SDCs associated with bright 24m sources
- 200 associated with 6.7 GHz methanol masers. (33% of 630 masers)
- 248 associated with EGOs (84% of 297 EGOs).
- Average properties: 1.7pc radius, $700M_o$ mass

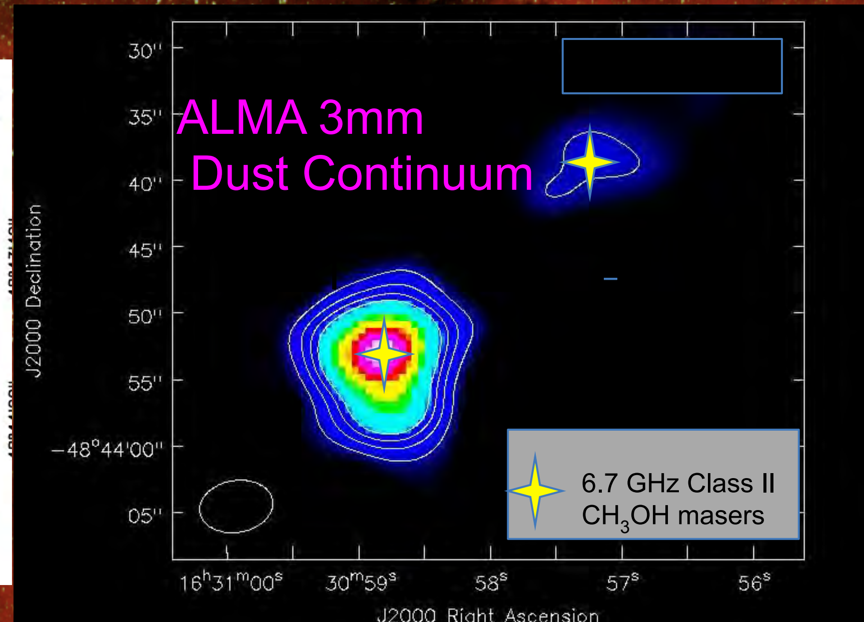




ALMA Cycle 0 target

ALMA Dust Continuum Emission

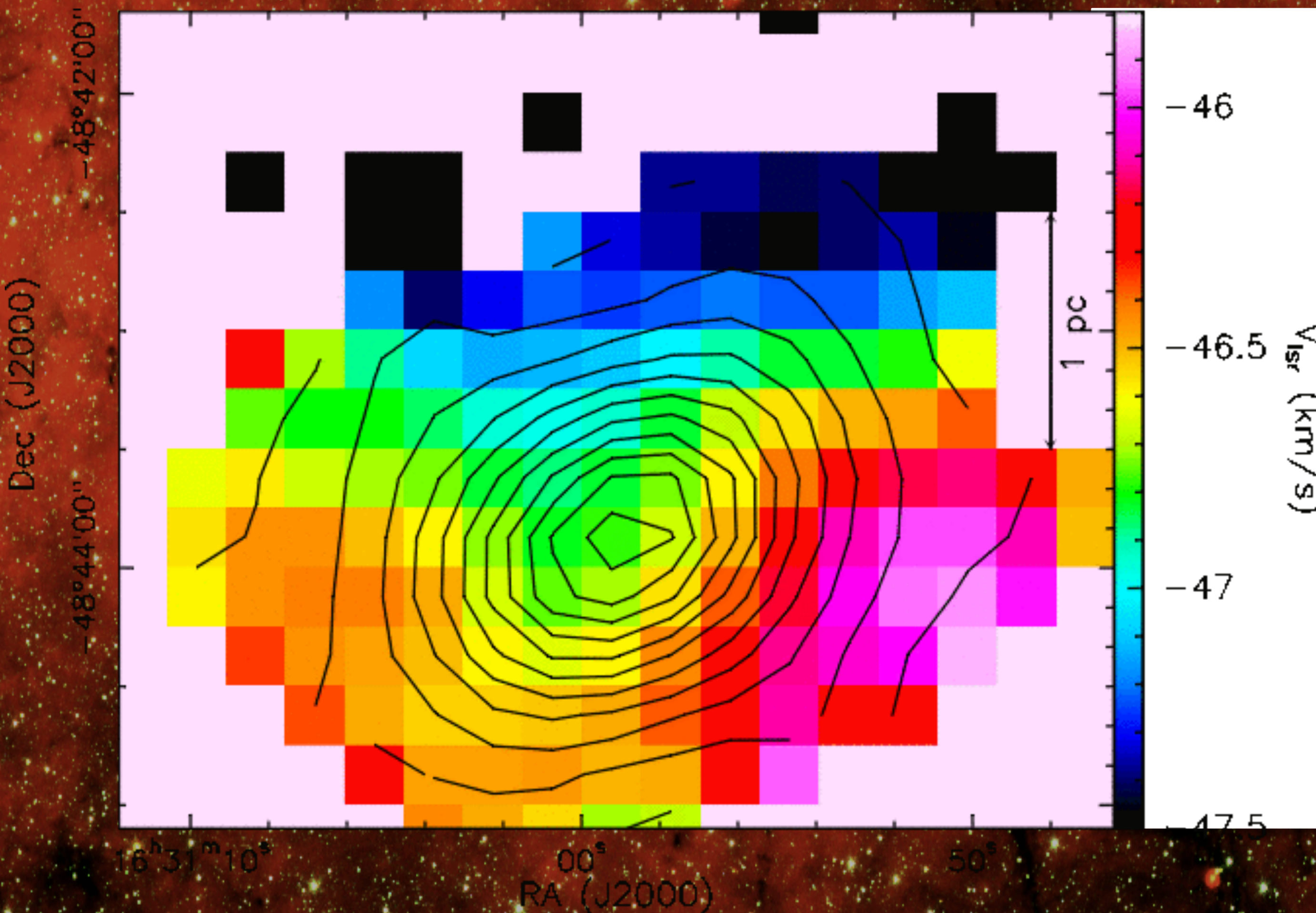




- Dust Continuum Emission
- Both 8/24μm sources detected
- MM1 Peak flux ~0.1 Jy
  - ~10% of mass of cloud
- within 0.1 pc sized region.
  - $n \sim 10^7 - 10^8\ cm^{-3}$

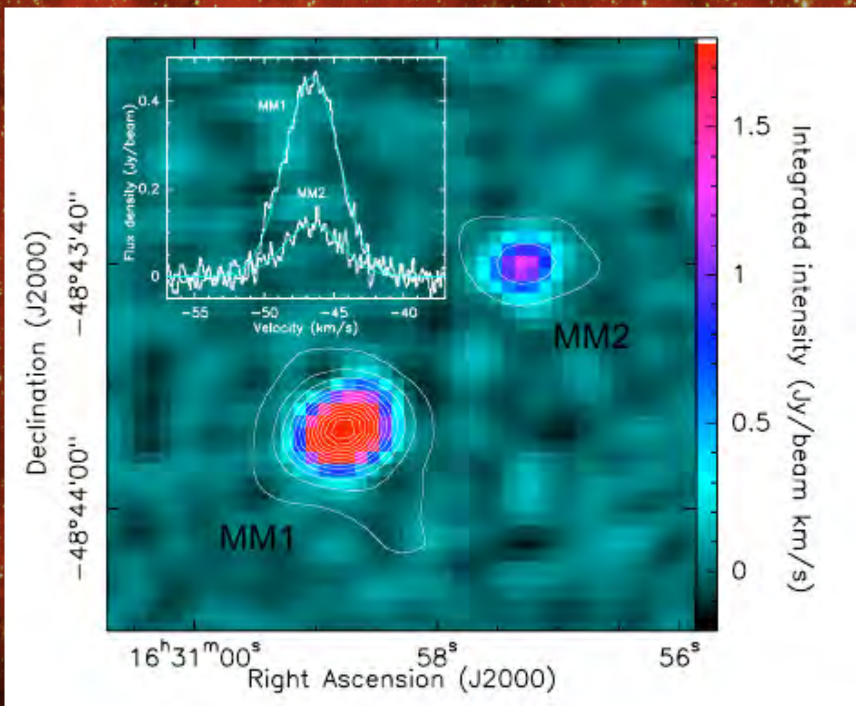
Region	Size (pc)	Mass ($10^3\ M_{sun}$)
SDC335	2.4	5.5
Centre	1.2	2.6
F1	0.3x2.0	0.4
F2	0.3x1.3	0.2
MM2	0.057	65 M_{sun}
MM1	0.054	550 M_{sun}

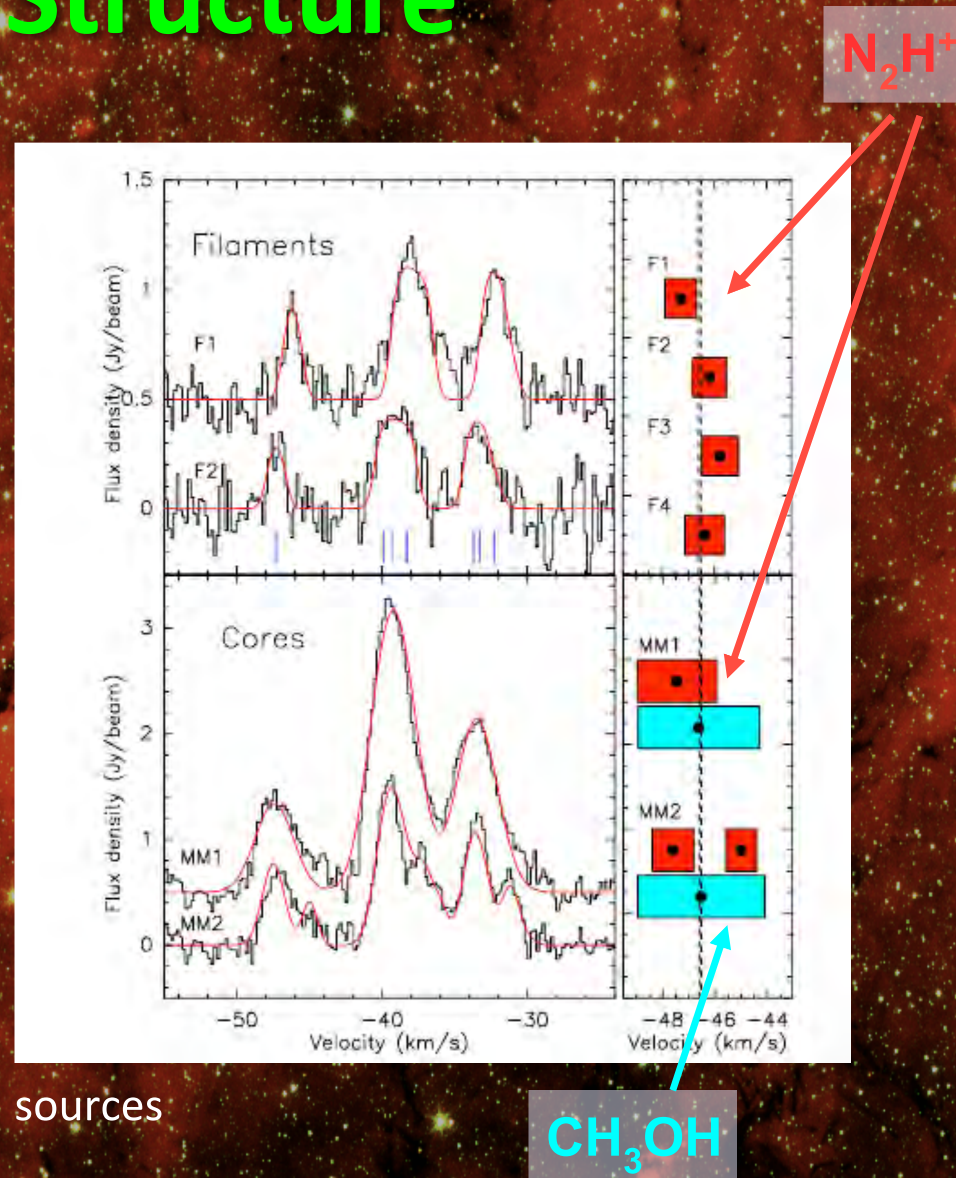
Dense Gas Velocity: ALMA N_2H^+ J=1-0



Velocity Structure

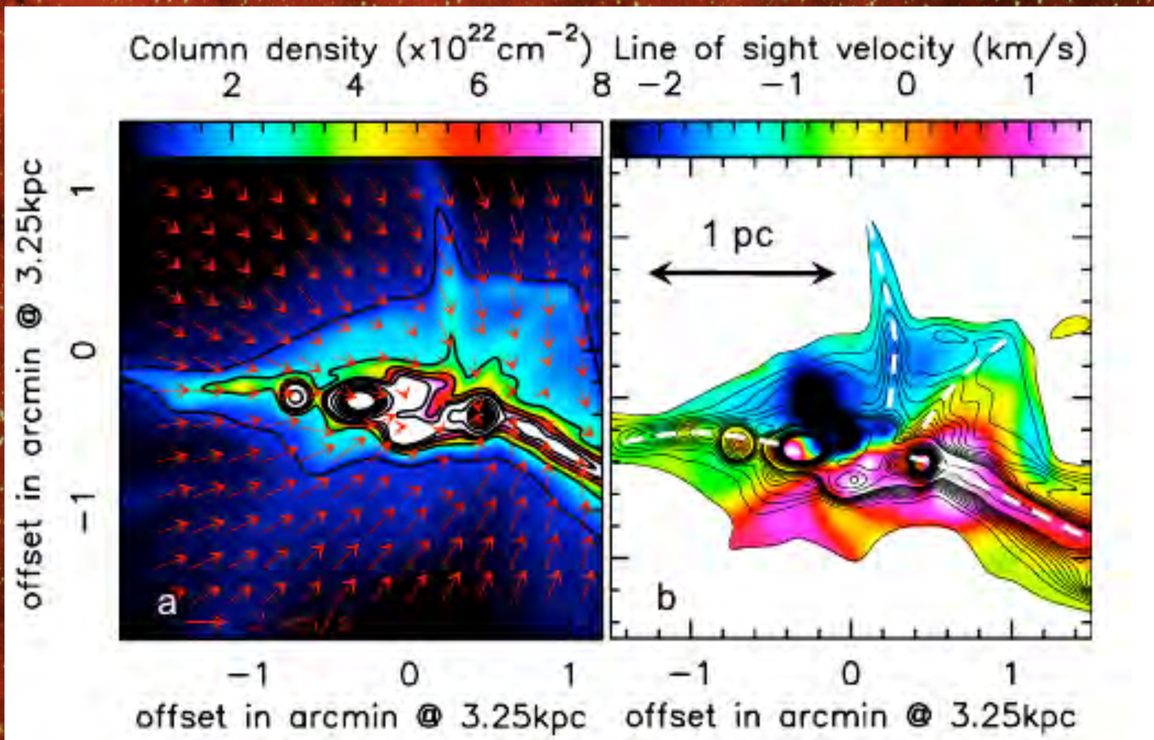
Methanol line (E~200K) peak on sources → source velocity





Increase in linewidth towards the central sources
- Blending of filament velocities?

Simulations Show Uniform Velocity Filaments



10^4 M_{sun}

Ellipsoidal cloud ($z_0=2r_0$)

Initial density at 5pc =500 cm^{-3}

$n(r,z) = n_0/(1+(r/r_0)^2+(z/z_0)^2)$

- Highly centrally condensed

(Hennebelle; Schneider et al 2010)

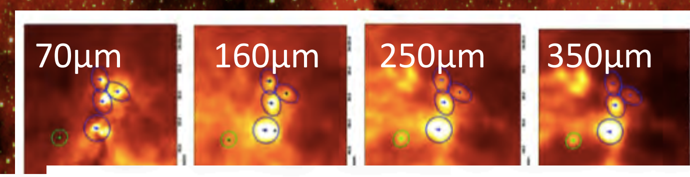
SDC335 is already forming 3 massive stars - Can we find similar objects before they form (massive) stars?

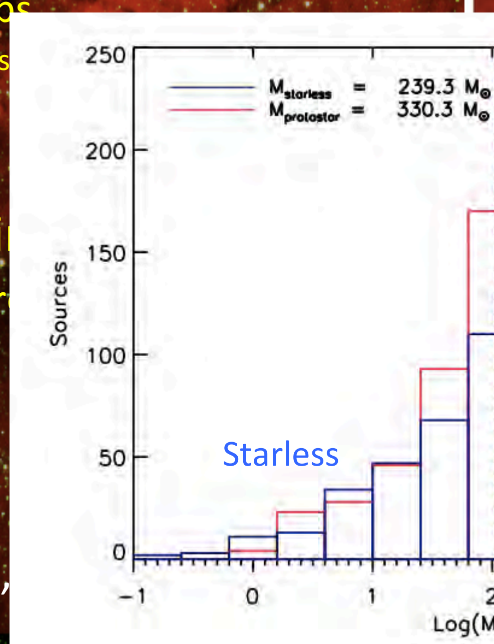
Are they centrally condensed or fragmented?

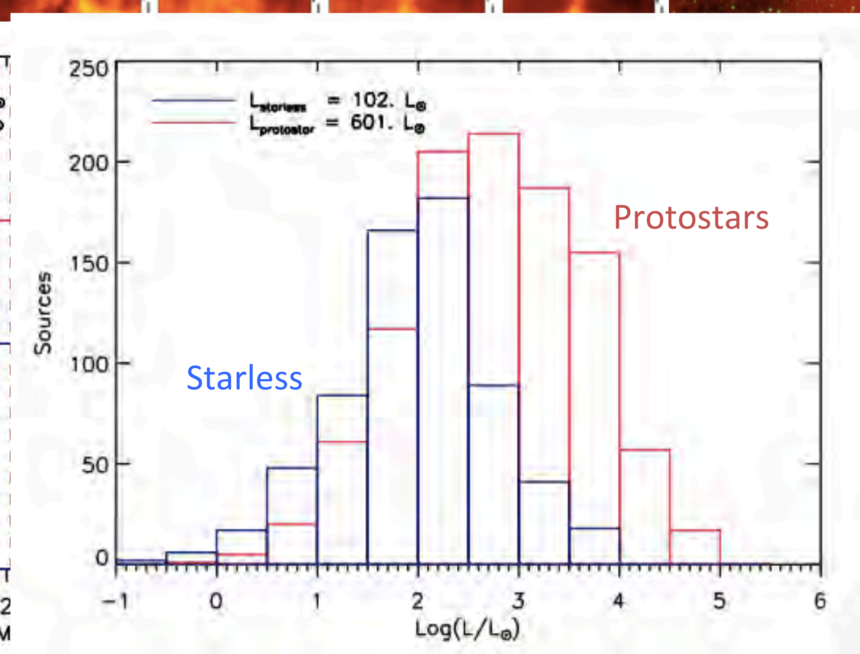
What is their velocity & ‘turbulent’ structure?

Compact Sources In The SDCs

- Extract and cross-match compact sources from Hi-GAL data associated with SDCs in 15°<*l*<50° region with kinematic distances
  - 3500 SDCs
- Using new elliptical aperture photometry routine *Hyper* (Traficante et al 2014)
- Merged catalogue of sources detected at 160, 250 and 350 μm
  - 1723 clumps in 764 SDCs
- Associate 70μm sources
  - Protostellar clumps
    - 1056 in 586 SDCs
  - Starless clumps
    - 667 in 389 SDCs
- Greybody SED fitti
  - Mass, temperatur

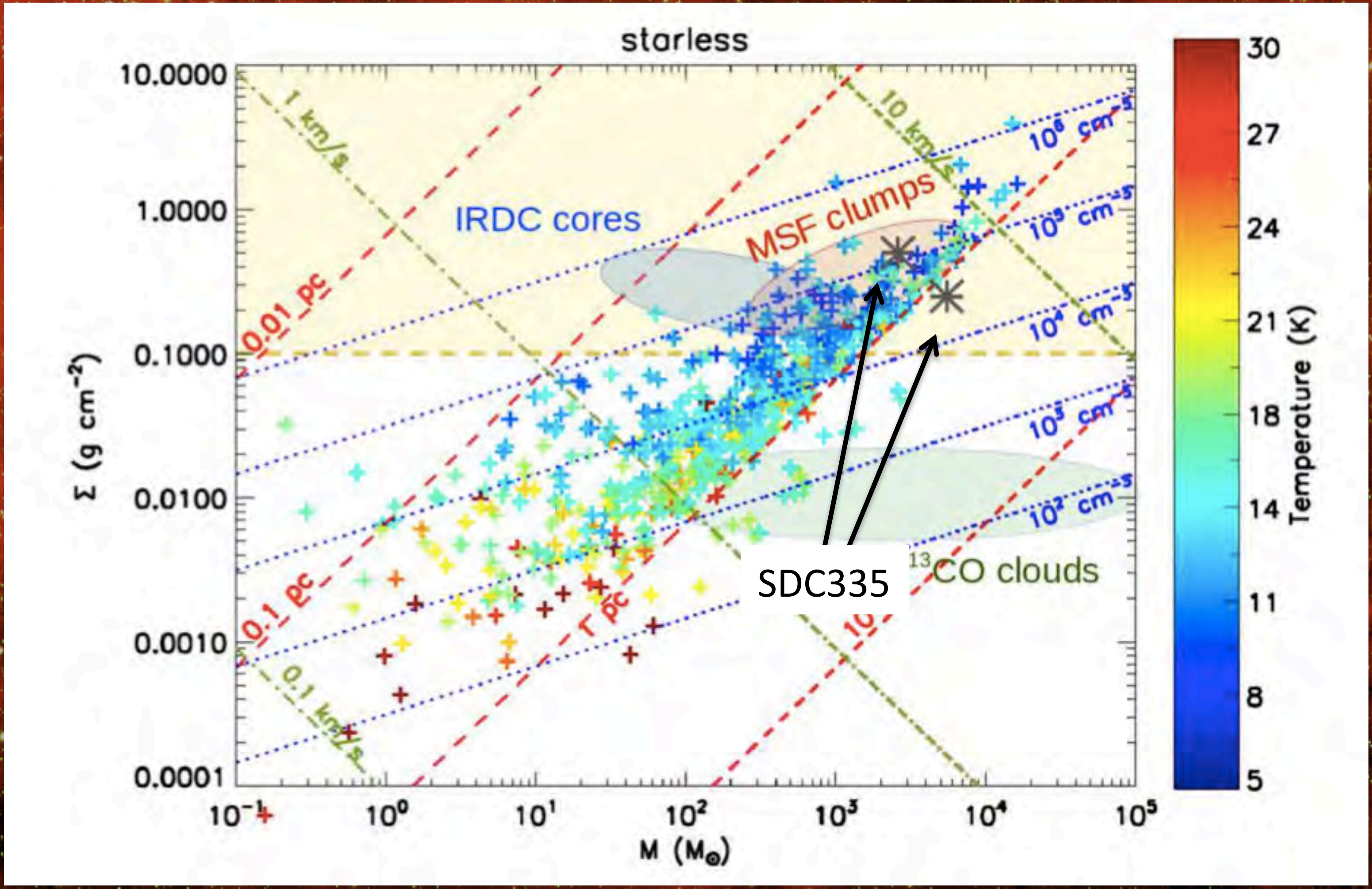






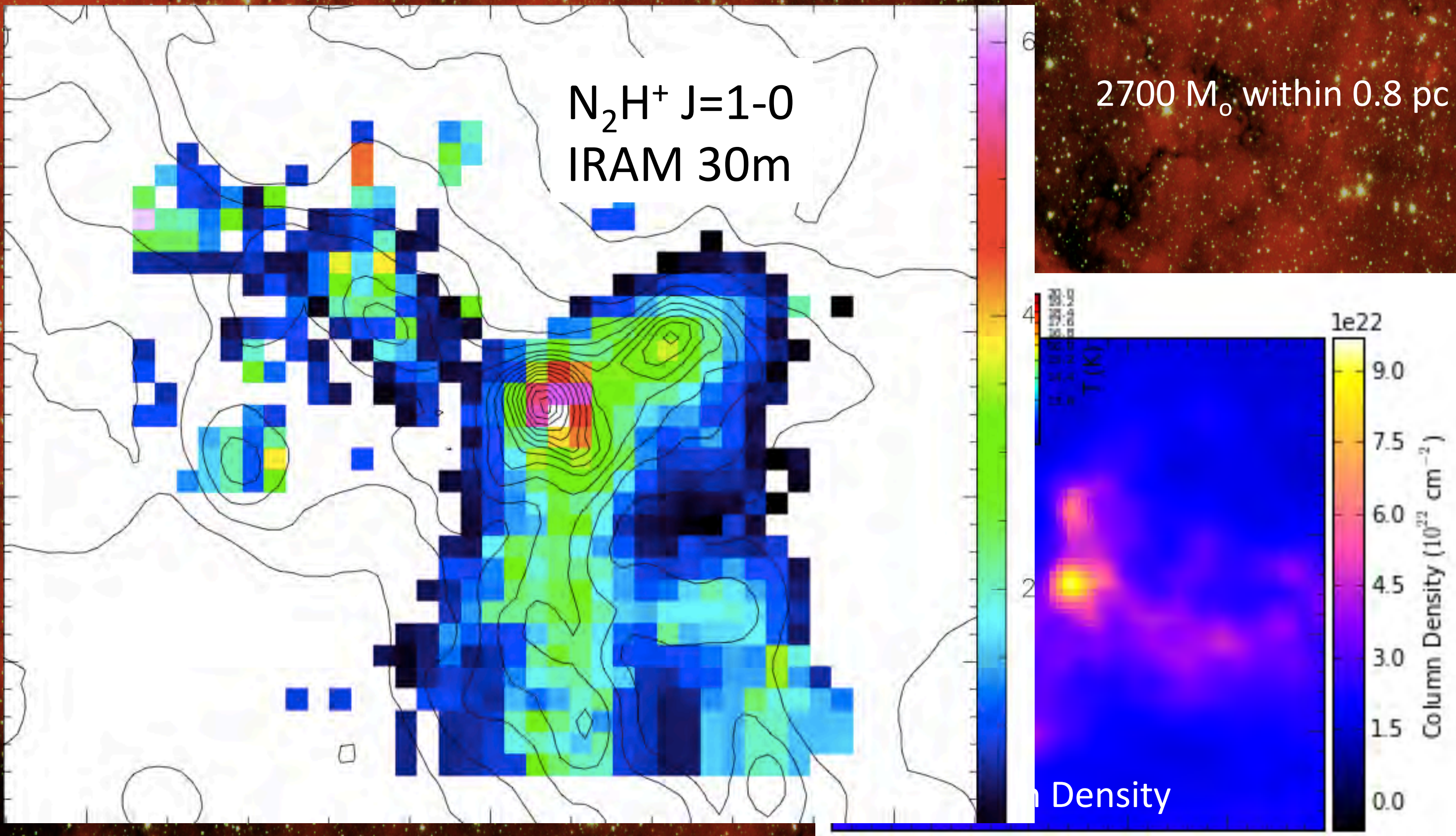
Traficante, Fuller et al 2015a,

Potentially Massive Star Forming?



Currently following up a sample of 18 SDC335-like starless cores

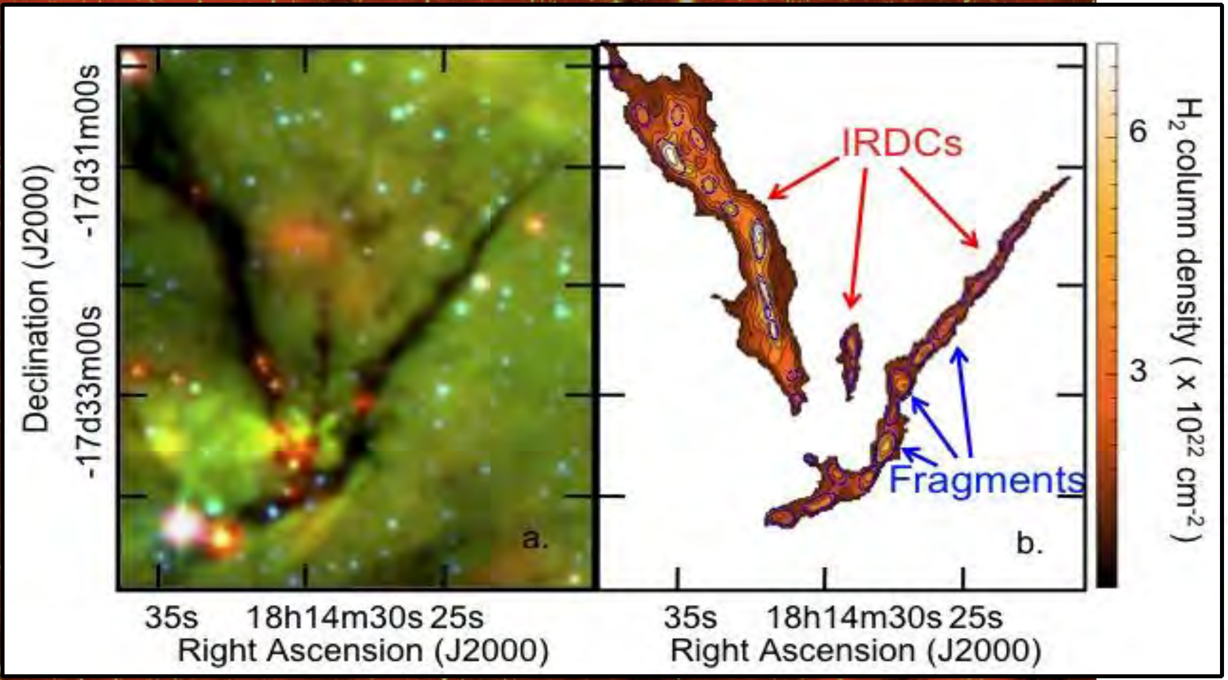
A Massive Starless Core

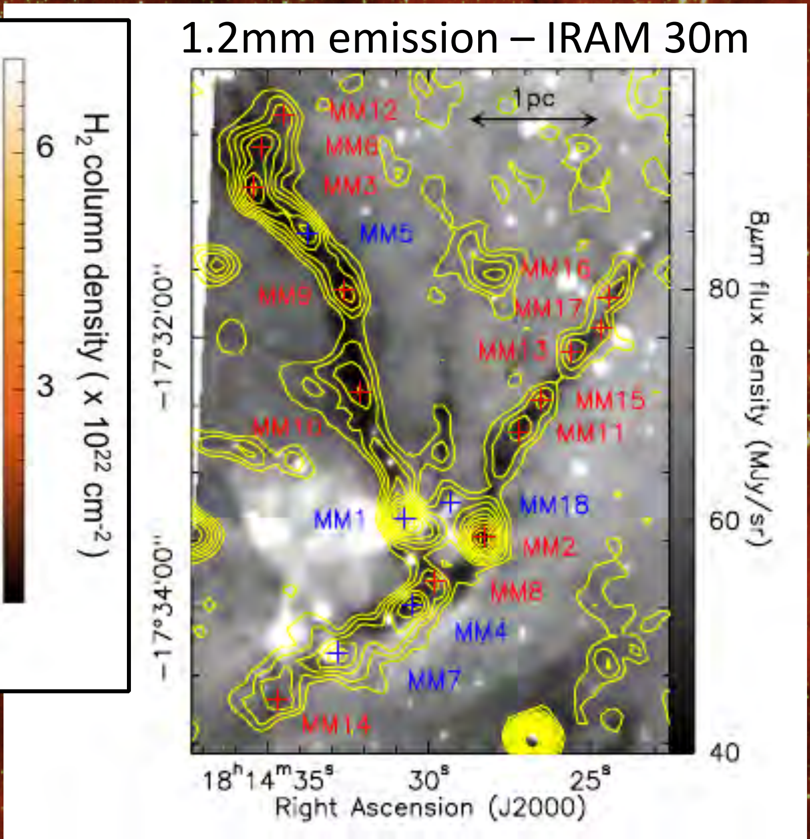


2700 M_o within 0.8 pc

Traficante, Fuller et al 2015b, in prep.

SDC13: Infalling Filaments





100 M_o in each of MM1 & MM2

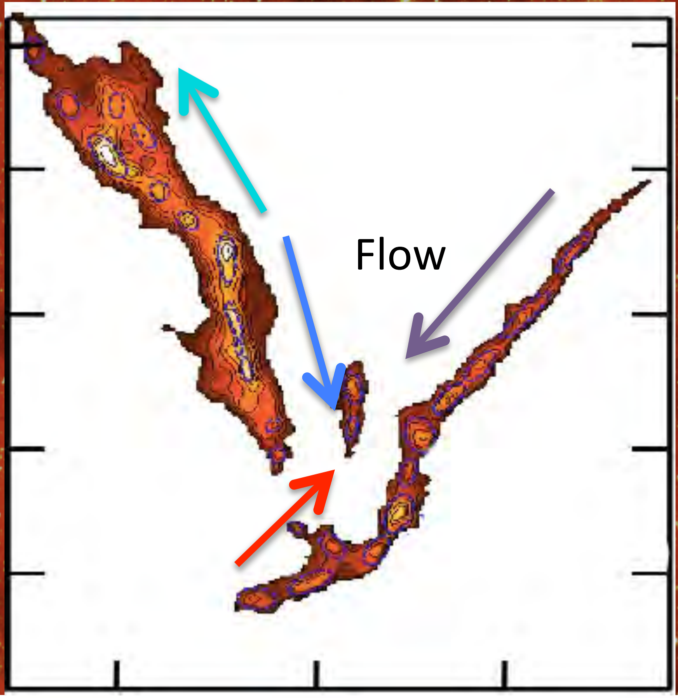
One star forming, the other starless

200 M_o in each of the two filaments

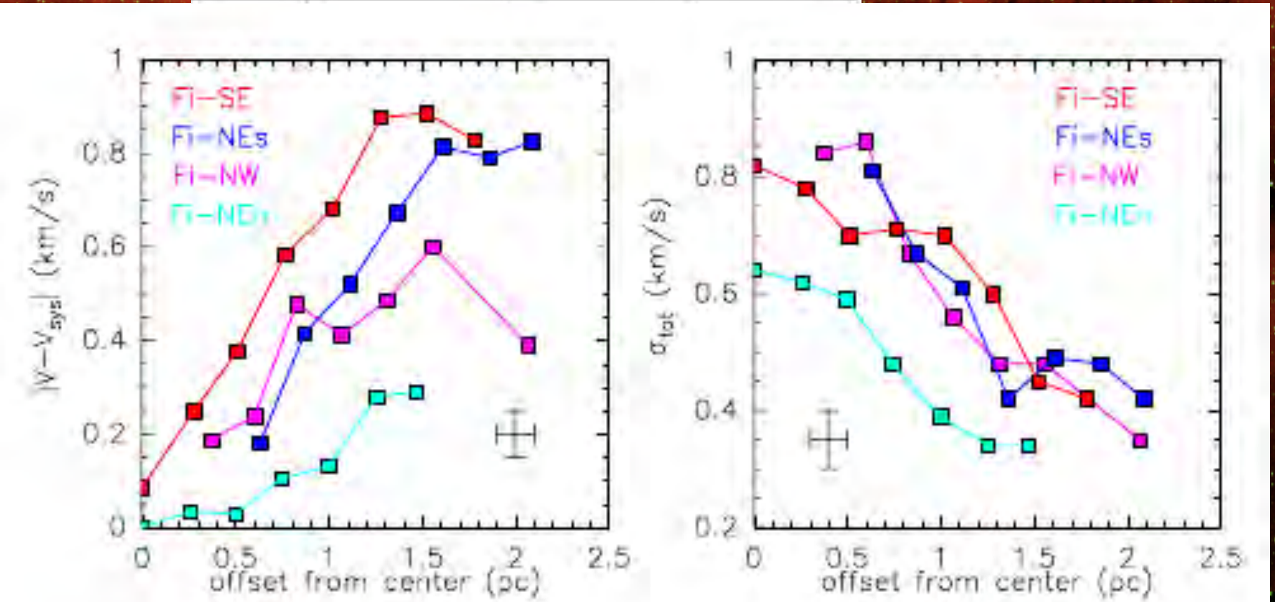
Line mass 4-8x larger than maximum stable mass for 12 K – unstable to fragmentation

(Peretto,Fuller et al. 2014)

SDC13: Infalling Filaments



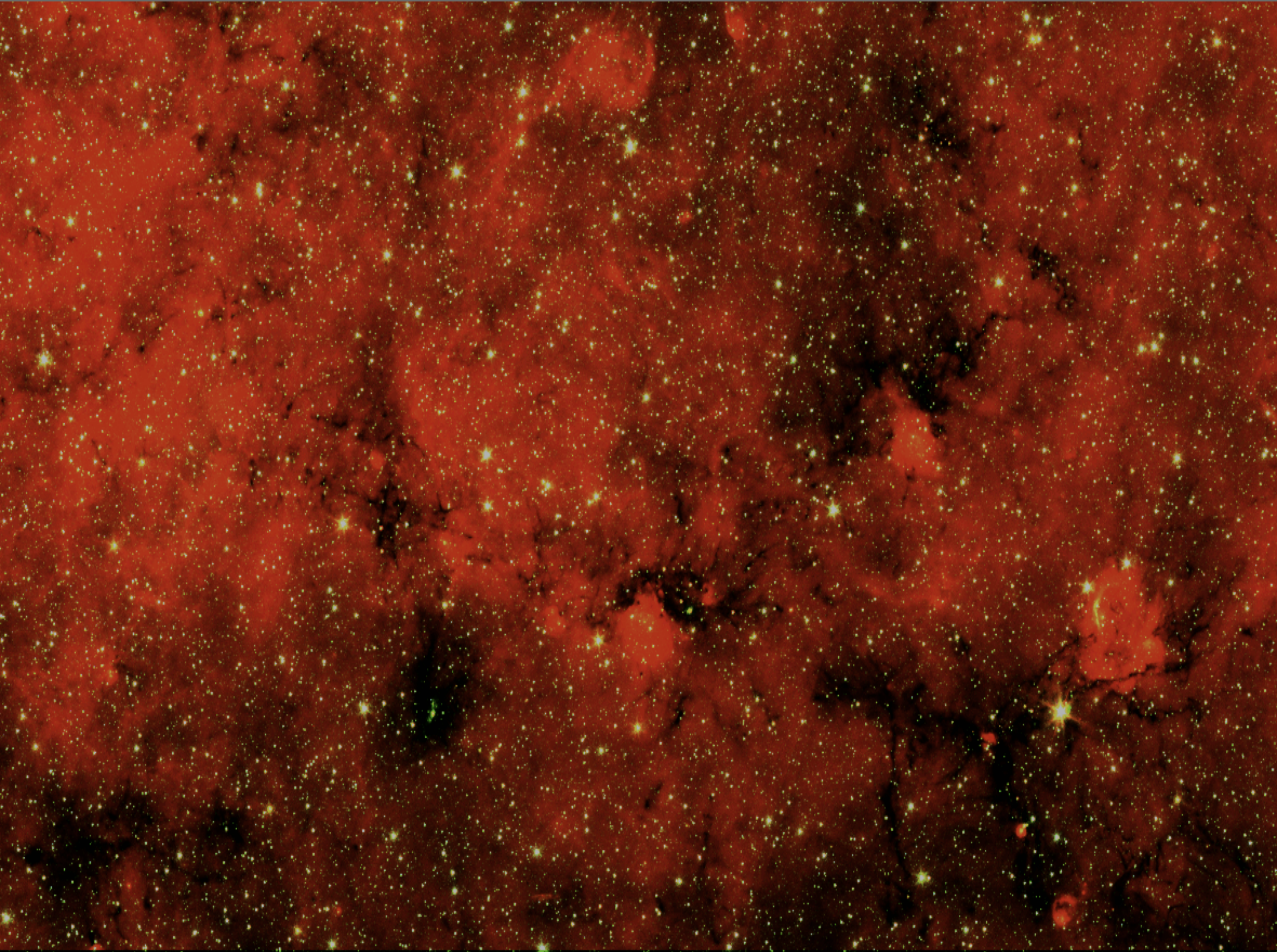
- IRAM 30m N_2H^+ J=1-0
- Linear velocity gradient along filaments
- Consistent with infall/contraction
- Anti-correlated increase in linewidth
- Gravitationally driven turbulence?
- Increasing local Jeans mass?



Summary

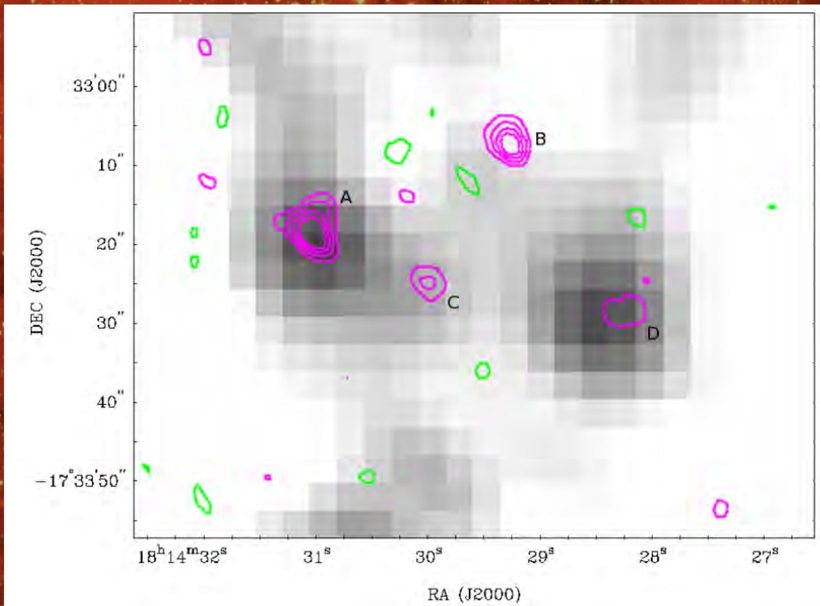
- SDC catalogue excellent resource for finding young potential cluster and massive star forming regions
- SDC335 contains one of the most extreme cores known and is likely to go on to form a Trapizium-like cluster
- Identified a sample of massive starless clumps with masses and sizes similar to SDC335
- Interesting kinematic signatures – dv(R), velocity gradients – but with different origins

www.irdarkclouds.org



Structure of MM1 & 2

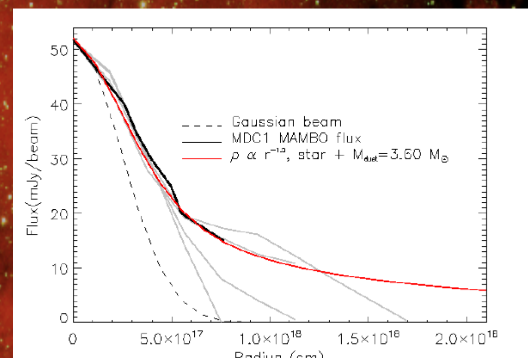
1.2mm Dust Continum,



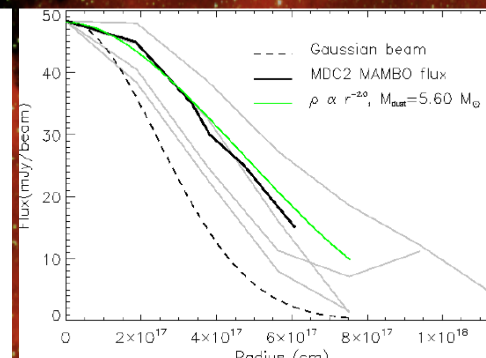
IRAM 30m MAMBO (grey)
SMA (purple contours)

- MM2 much weaker than MM1
- Model

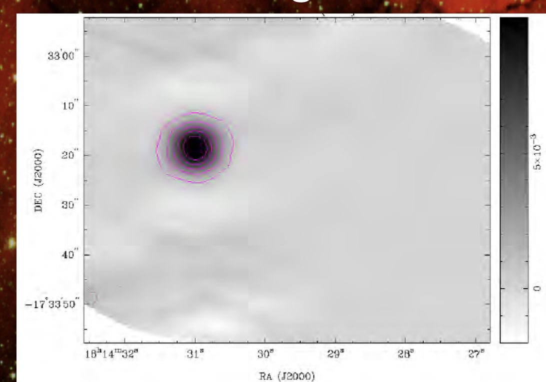
MM1 $\rho \propto r^{-1.5}$



MM2 $\rho \propto r^{-2.0}$



Model image at 1.2mm



Evolution from steep SIS density profile to shallower infall profile?