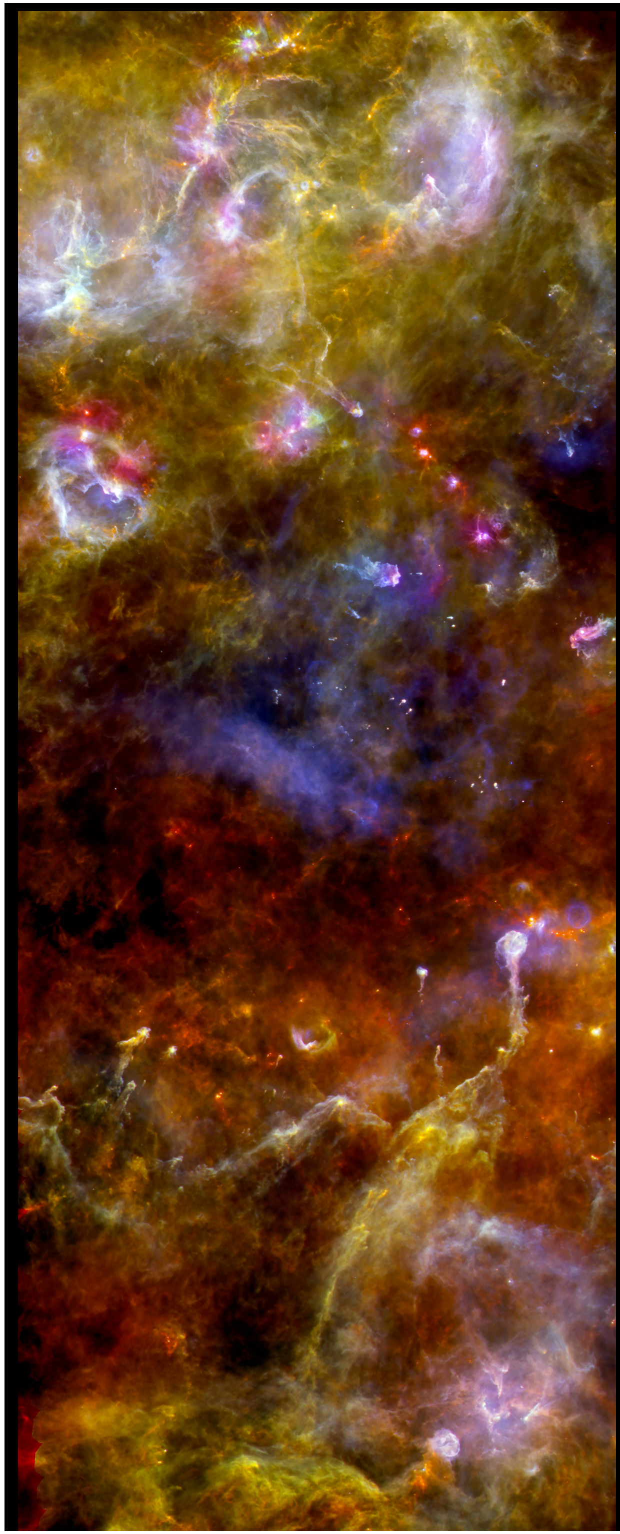


Herschel HOBYS

70 - 500 μm

High-mass star formation
The observer point of view

Sylvain Bontemps

Laboratoire d'Astrophysique de Bordeaux

CNRS – Université de Bordeaux

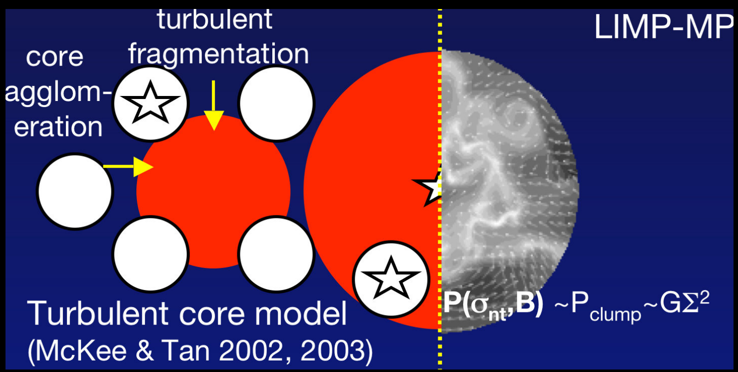
with T. Csengeri (Bonn), F. Motte (Grenoble), N. Schneider (Cologne), and the HOBYS, SPARKS, ALMA-IMF consortia.

Nafplio - June 13, 2019

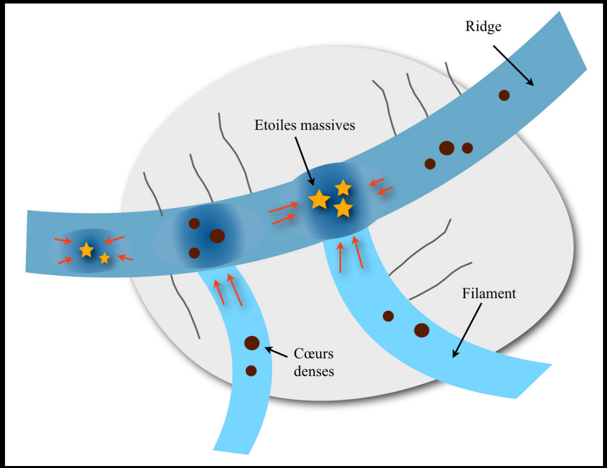
How high-mass stars form (in the filament paradigm)?

- Filaments are the locations for Jeans fragmentation.
- Jeans masses (in filaments) are not in the high-mass regime (even considering some effective Jeans masses).

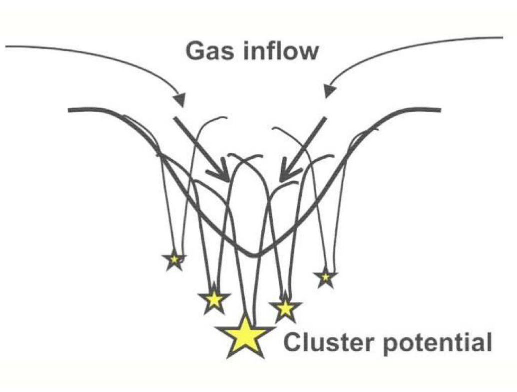
→ An additional process required to explain High-mass stars?



McKee & Tan 2002
... controled by pressure equilibrium (BE-like evolution).



Myers 2009; Schneider et al. 2012; Peretto et al. 2014



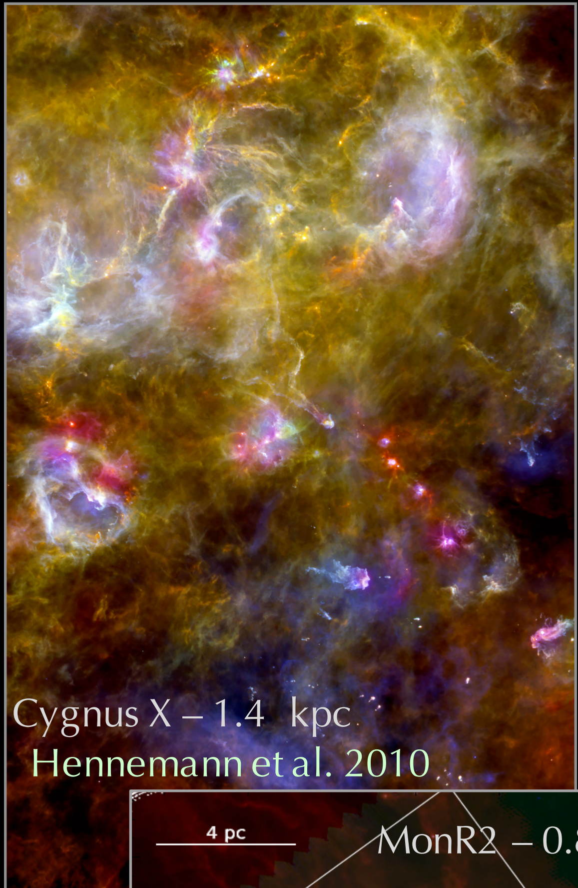
Bonnell et al. 2007; Myers 2011

Dynamical (supersonic motions) evolution

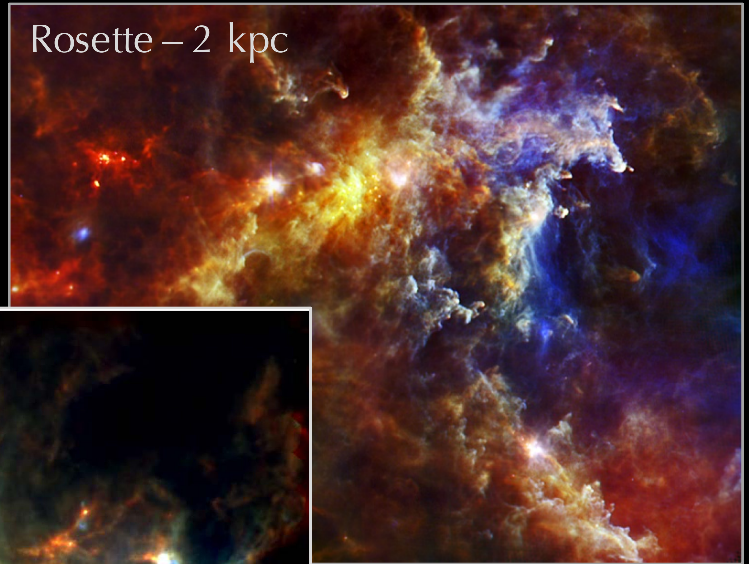
High-mass star and cluster formation?

- What links high-mass stars with cluster formation?

2. What observations tell us?

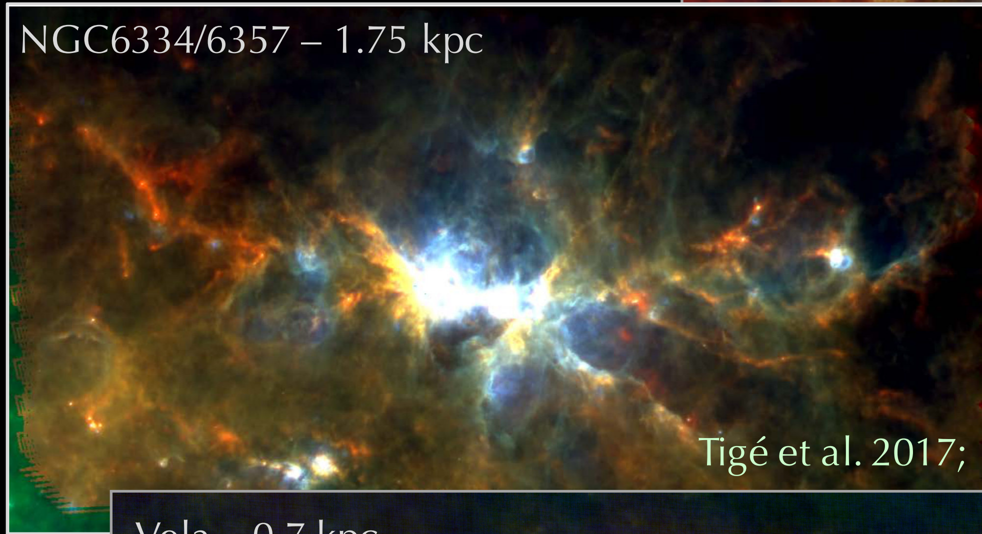


Cygnus X – 1.4 kpc
Hennemann et al. 2010



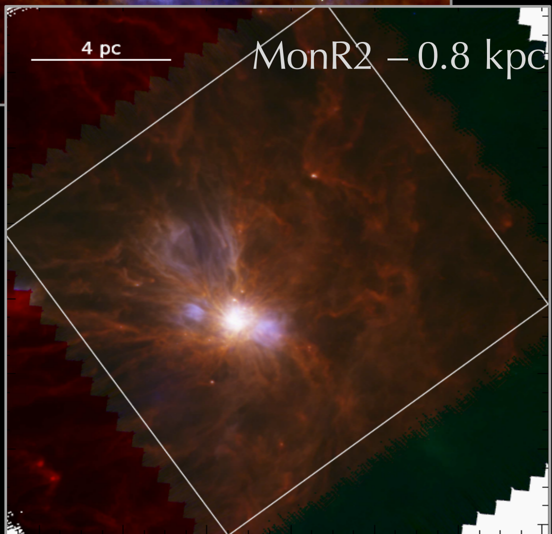
Rosette – 2 kpc

Motte et al. 2010



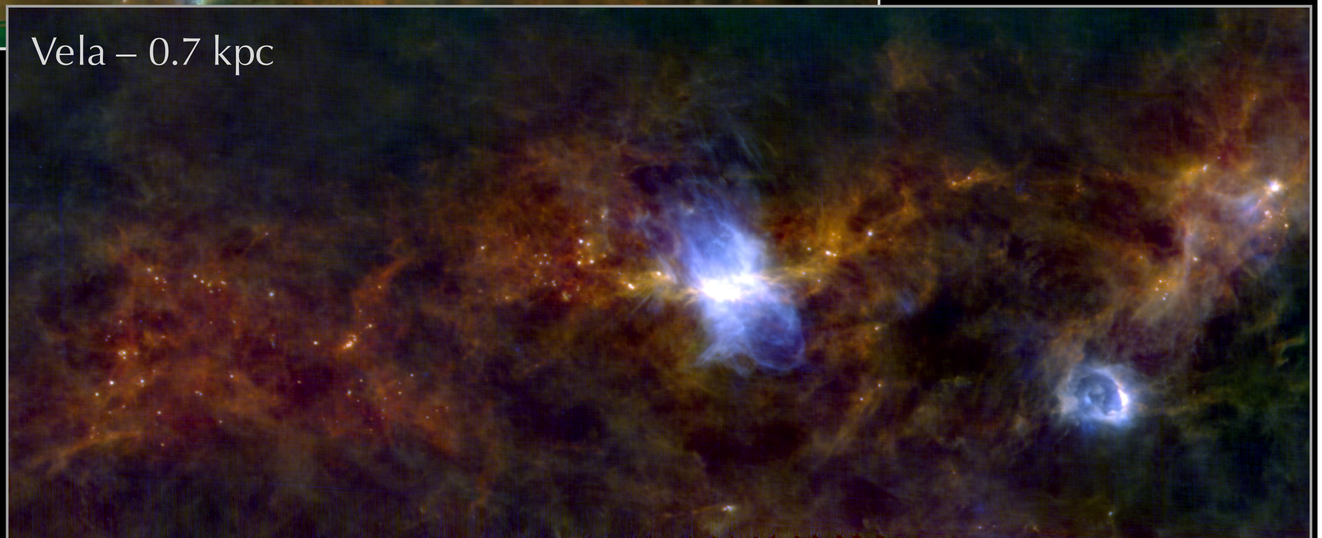
NGC6334/6357 – 1.75 kpc

Tigé et al. 2017; Russeil et al. 2019



MonR2 – 0.8 kpc

Didelon et al. 2015

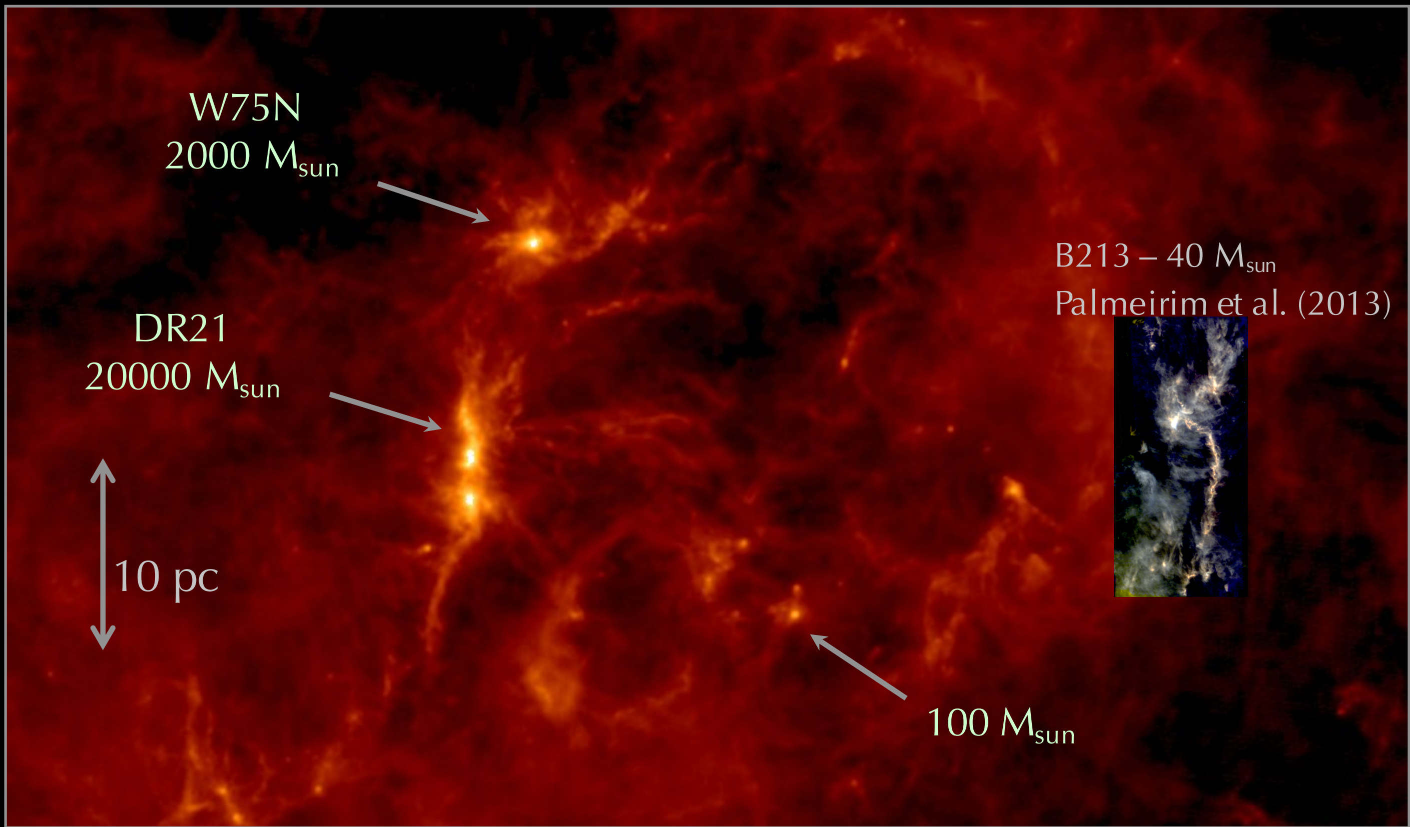


Vela – 0.7 kpc

Hill et al. 2011, 2012

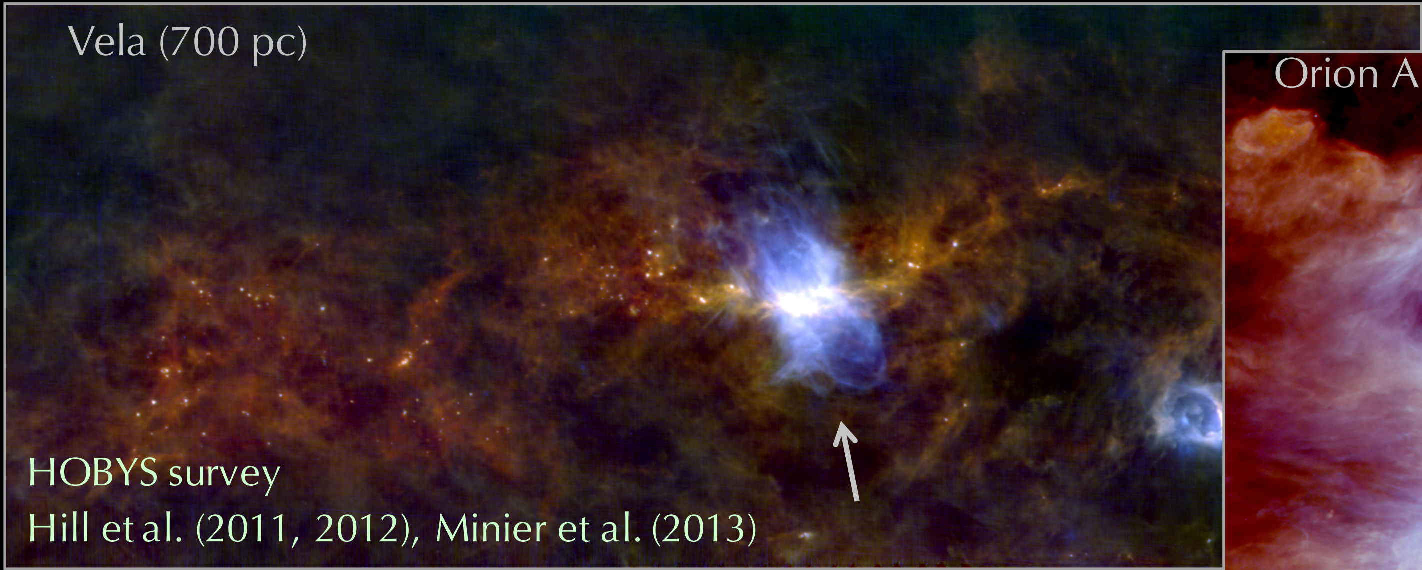
High density regions in GMCs

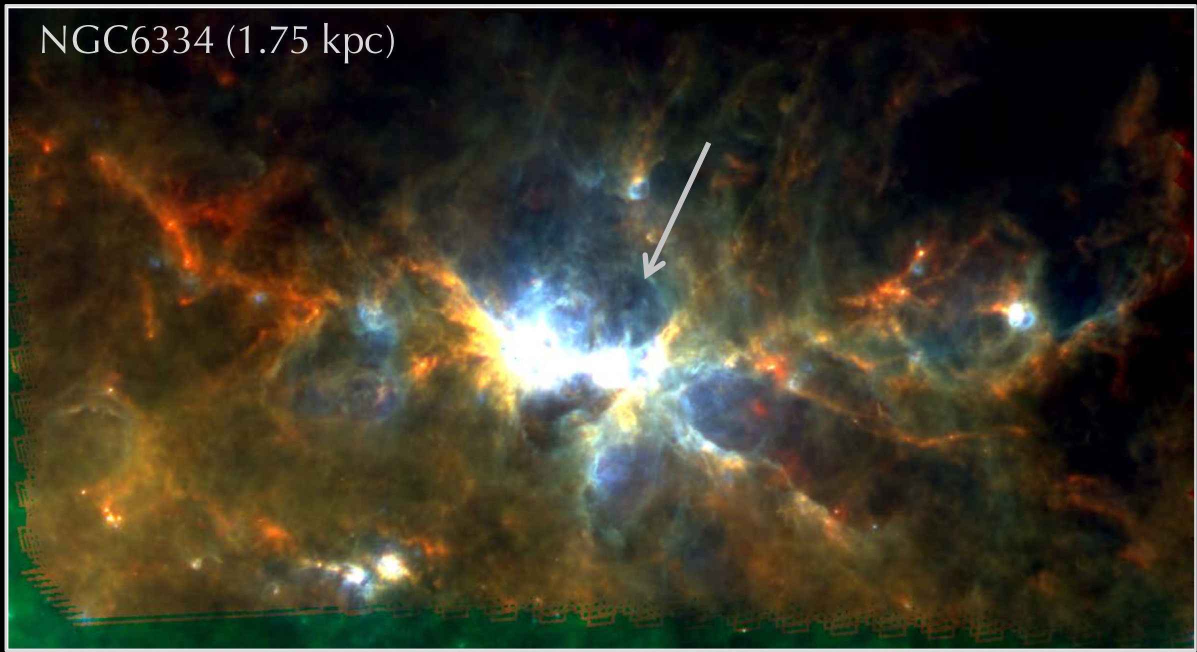
- Hubs, ridges, Massive Dense Cores (MDCs)
- A snapshot view for Cygnus X



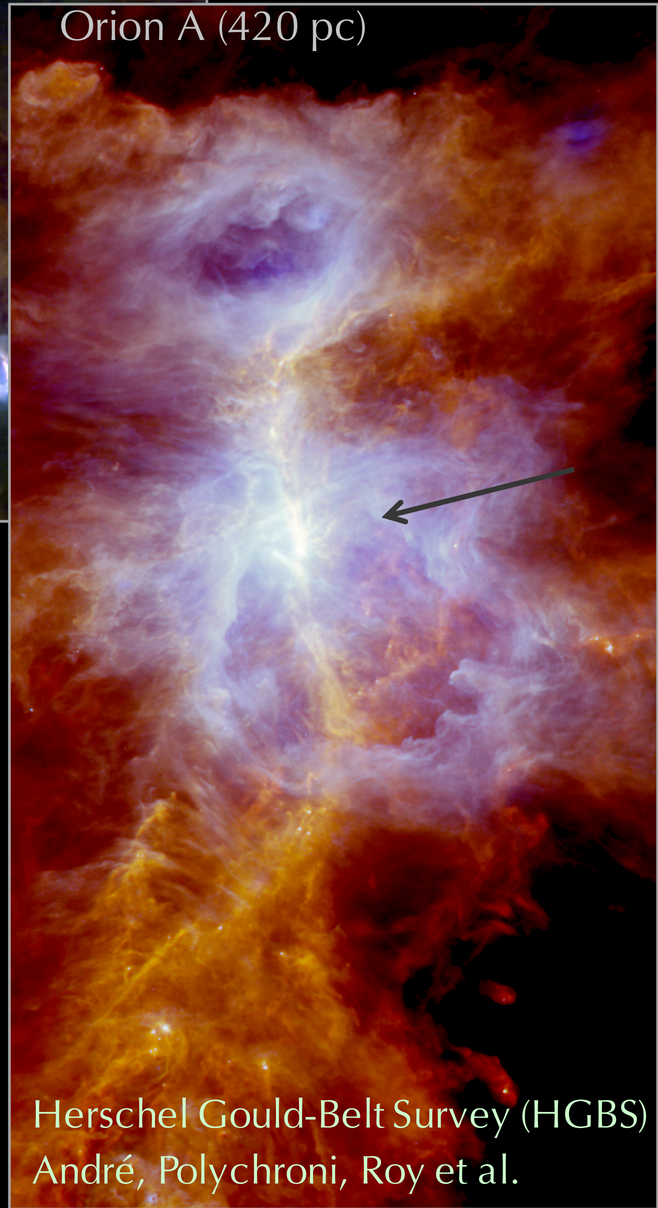
HOBYS survey (Motte et al.) – Herschel 250μm
Hennemann et al. (2012)

Ridges in nearby GMCs

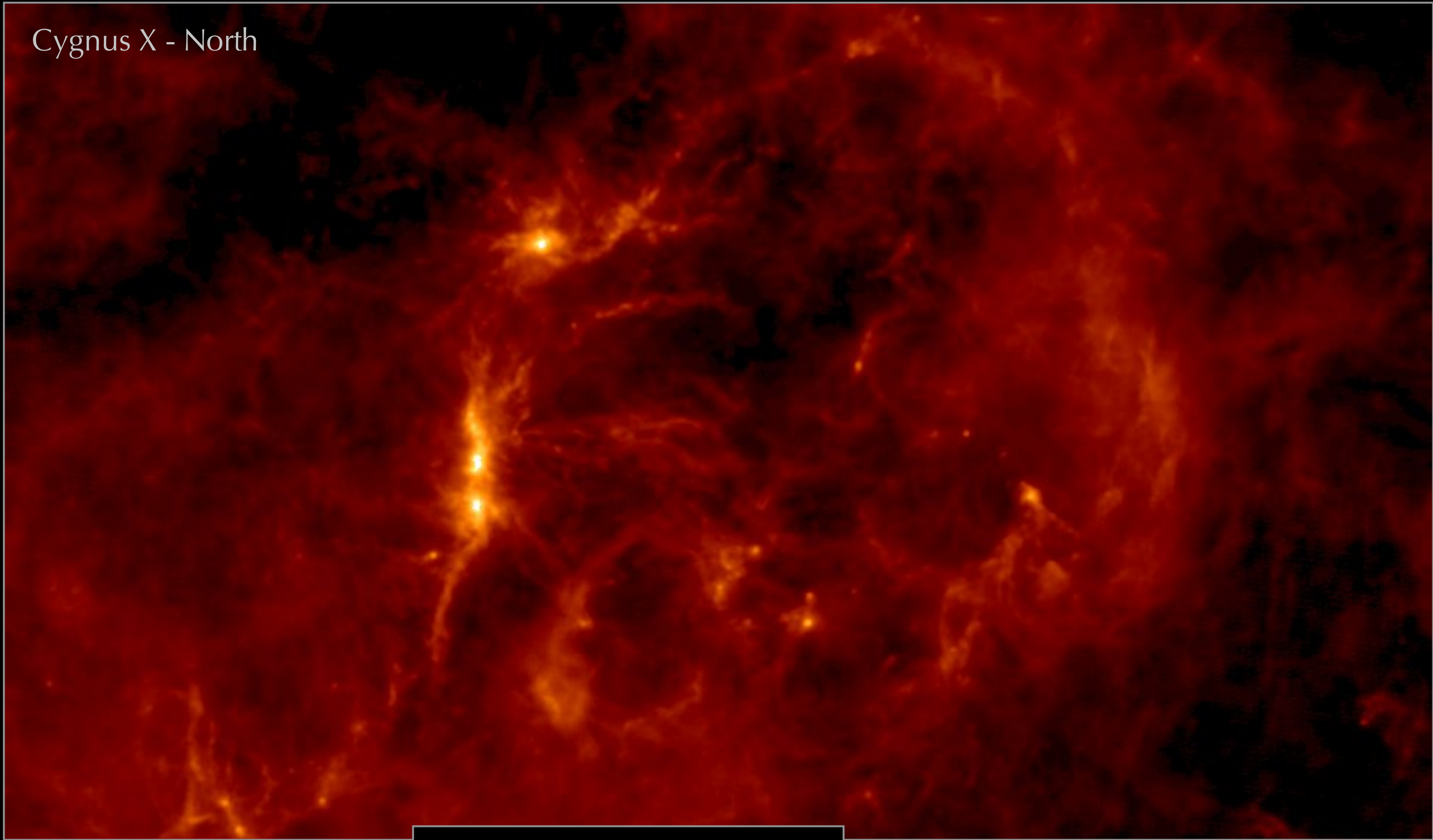




Tigé et al. 2017



Massive dense cores

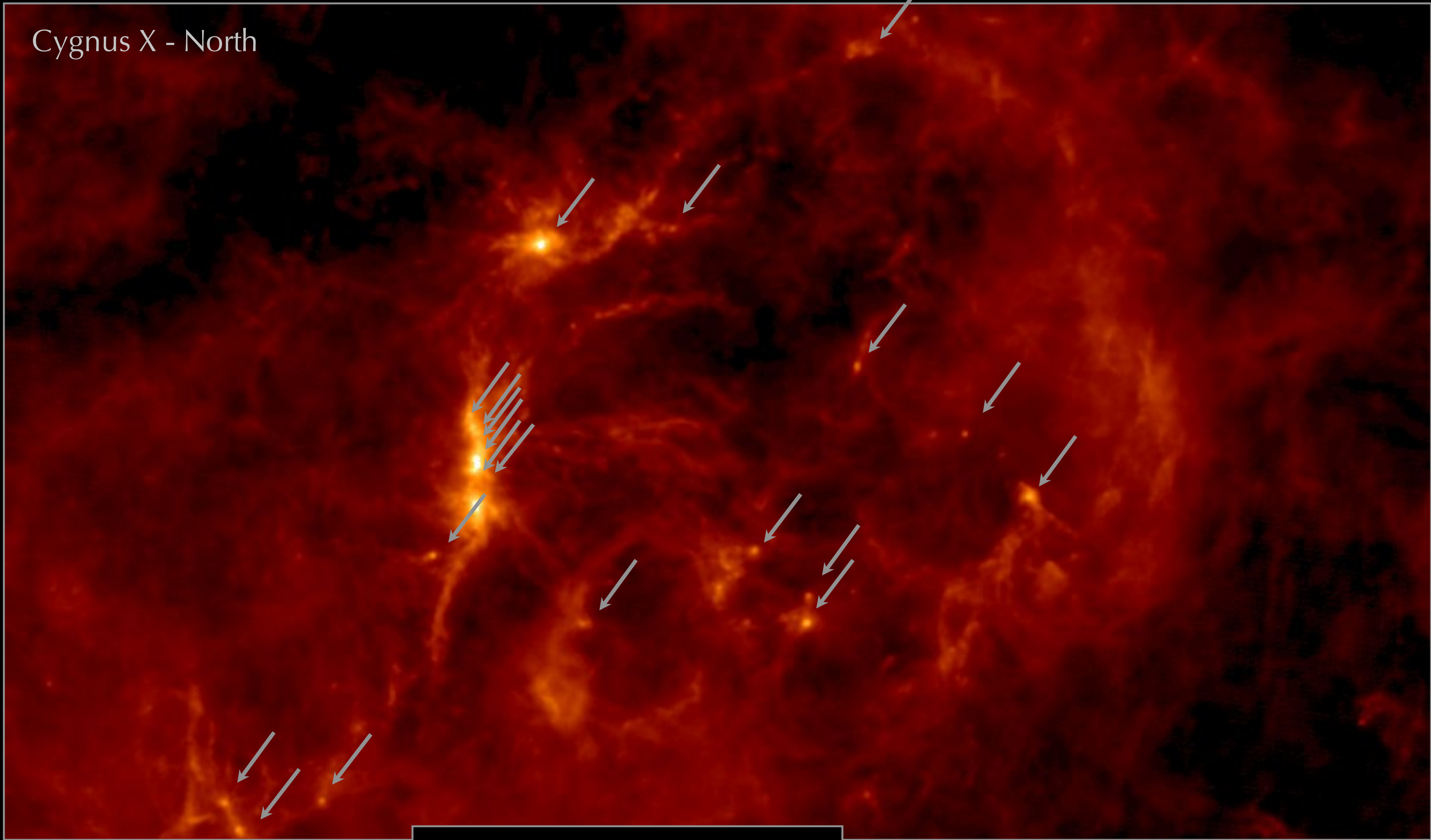


HOBYS - SPIRE consortium

Massive Dense Cores:
0.1 to 0.2 pc

Herschel/PACS 250 μm

Massive dense cores



HOBYS - SPIRE consortium

Massive Dense Cores:
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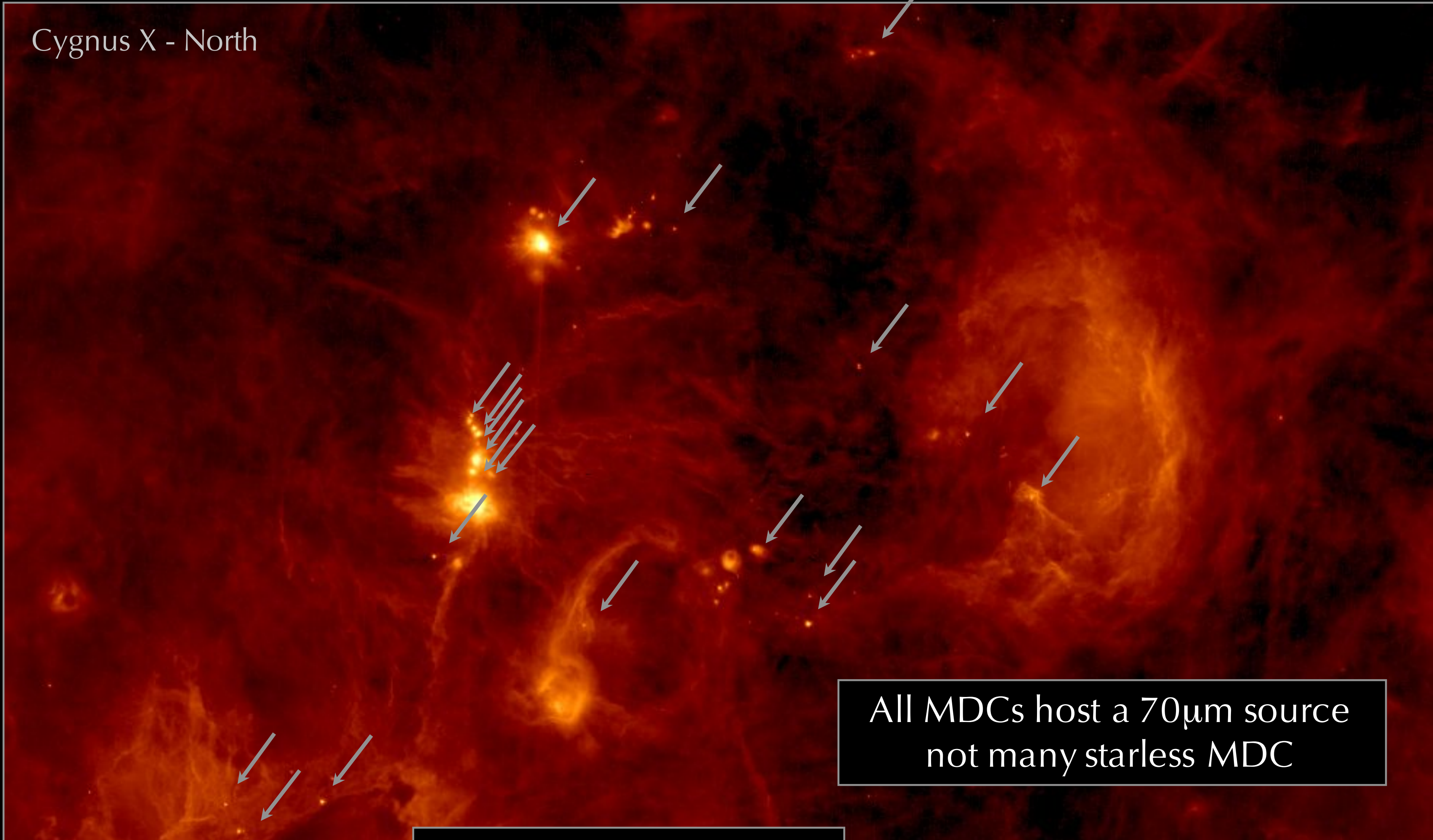
Herschel/PACS 250 μm

Massive dense cores



HOBYS - SPIRE consortium

Massive Dense Cores:
0.1 to 0.2 pc

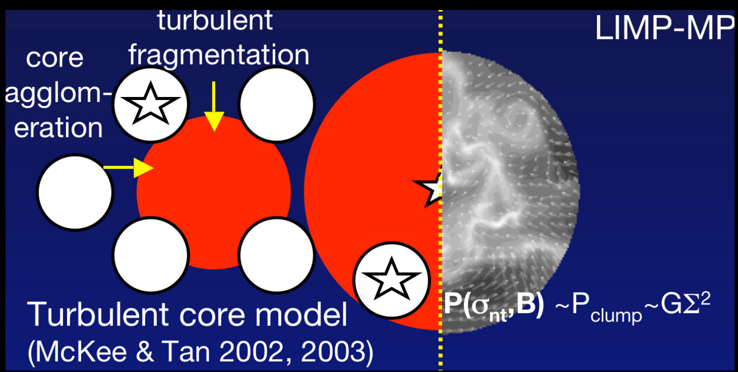
Herschel/PACS 70 µm

Three types of massive dense structures:

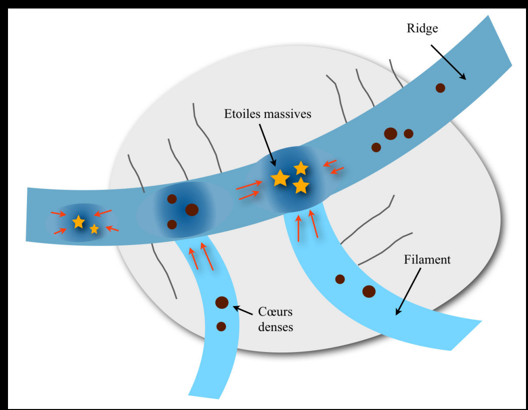
- Massive Dense Cores (e.g. Motte et al. 2007):
  40 to 100-200 M_{sun}, 0.1-0.2 pc diameter.
- Hubs (~spherical, dense massive) (e.g. Myers 2009):
  1000 to 3000 M_{sun}, 0.3-0.5 pc diameter.
- Ridges (massive, dense elongated structures):
  in the 10000s M_{sun} range, 2 - 10 pc x 0.3 - 0.5 pc.

Sequence in age? In mass inflow?

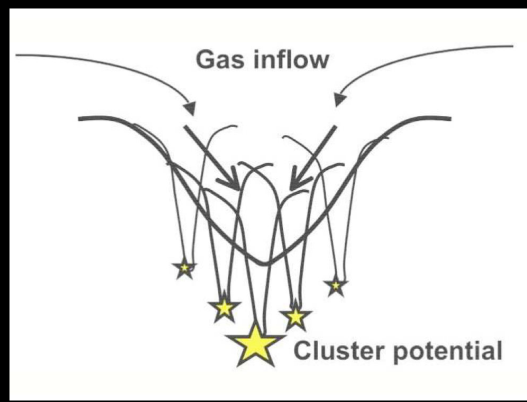
Hubs = filament crossing/collision, or formed by longitudinal flows? or "big" MDCs? or evolved ridges?



McKee & Tan 2002
... controled by pressure equilibrium (BE-like evolution).



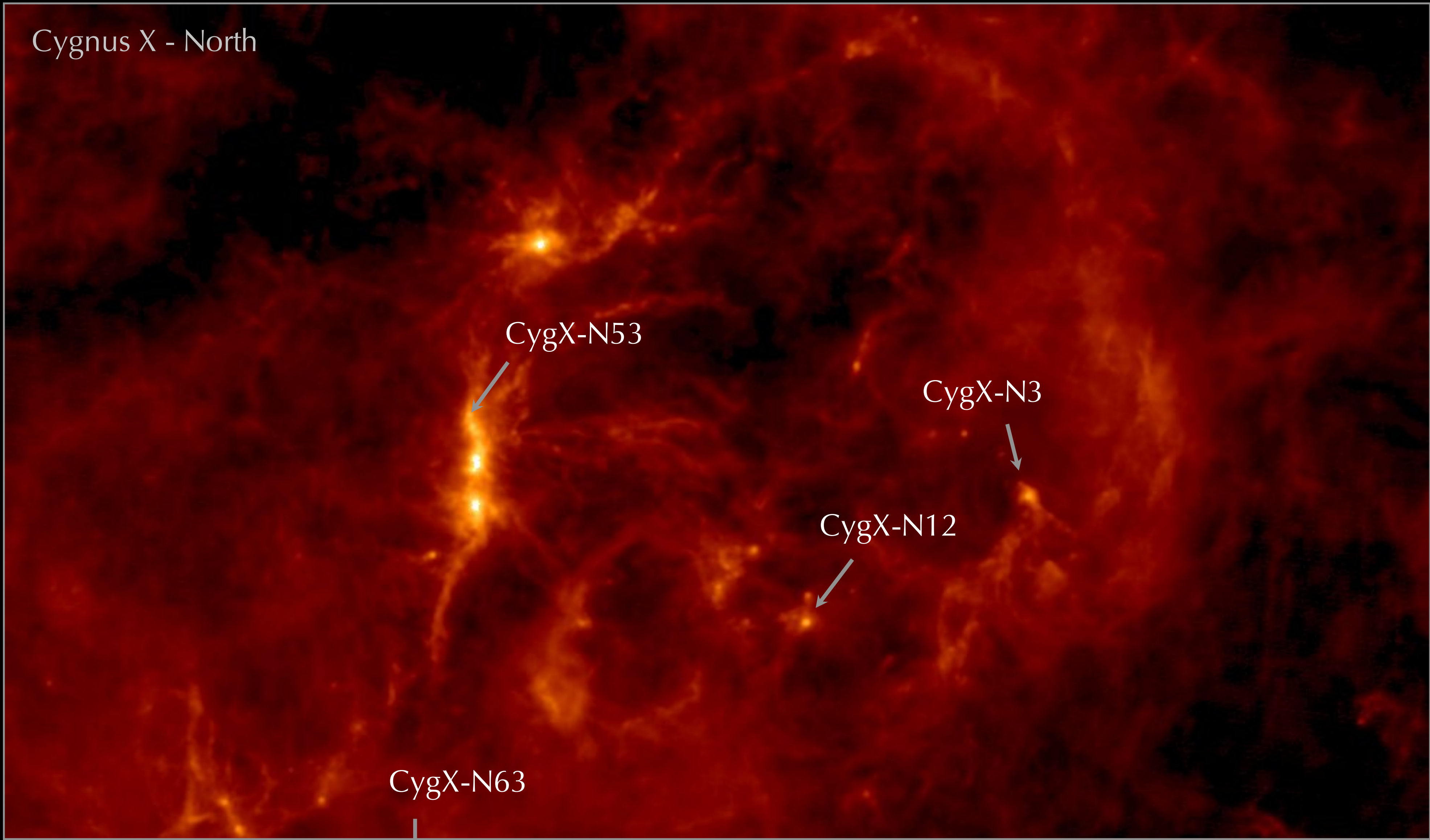
Myers 2009; Schneider et al. 2012; Peretto et al. 2014



Bonnell et al. 2007; Myers 2011

Dynamical (supersonic motions) evolution

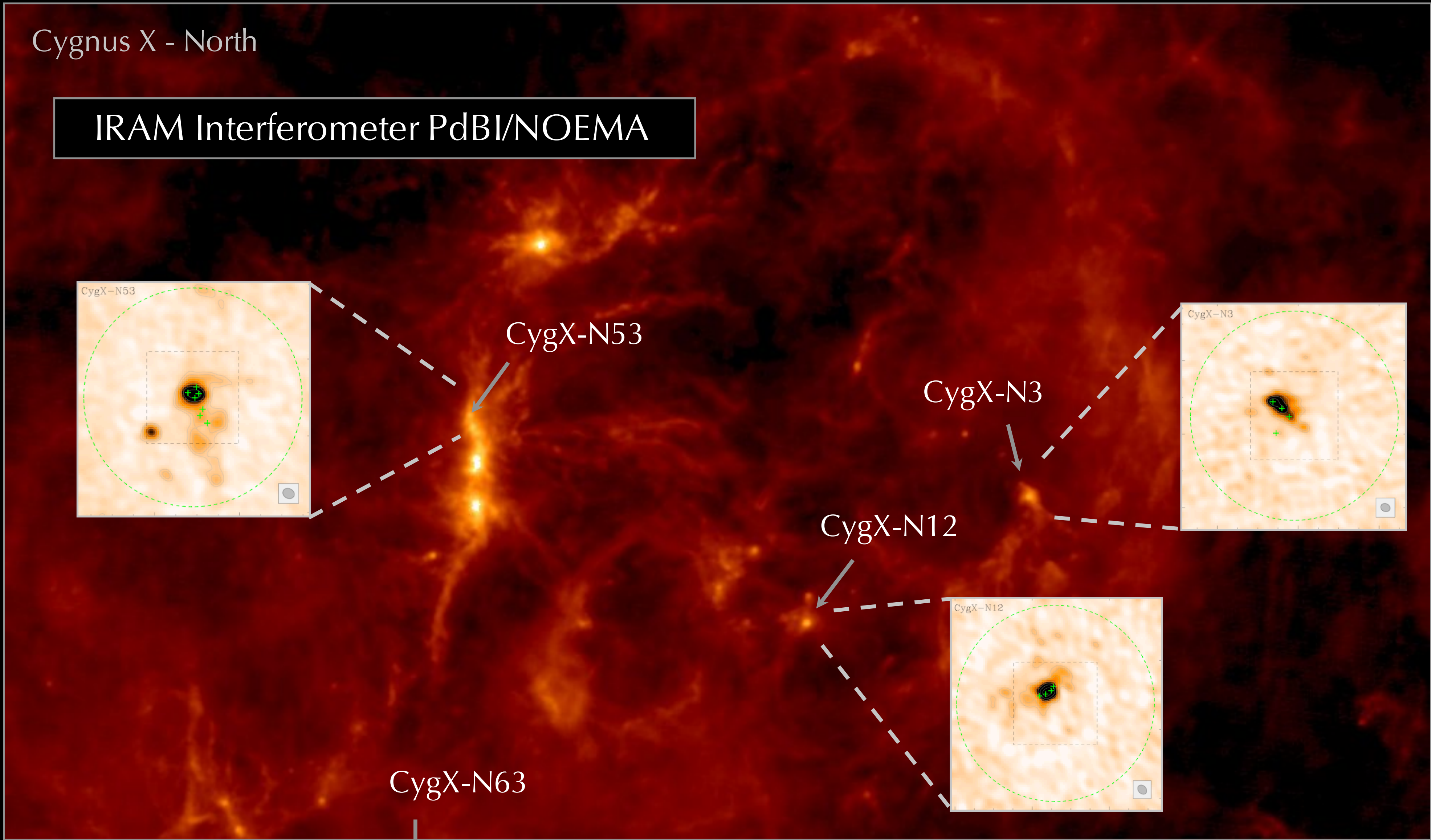
Massive Dense Cores as individual cores?



HOBYS - SPIRE consortium

Herschel/PACS 250 μm

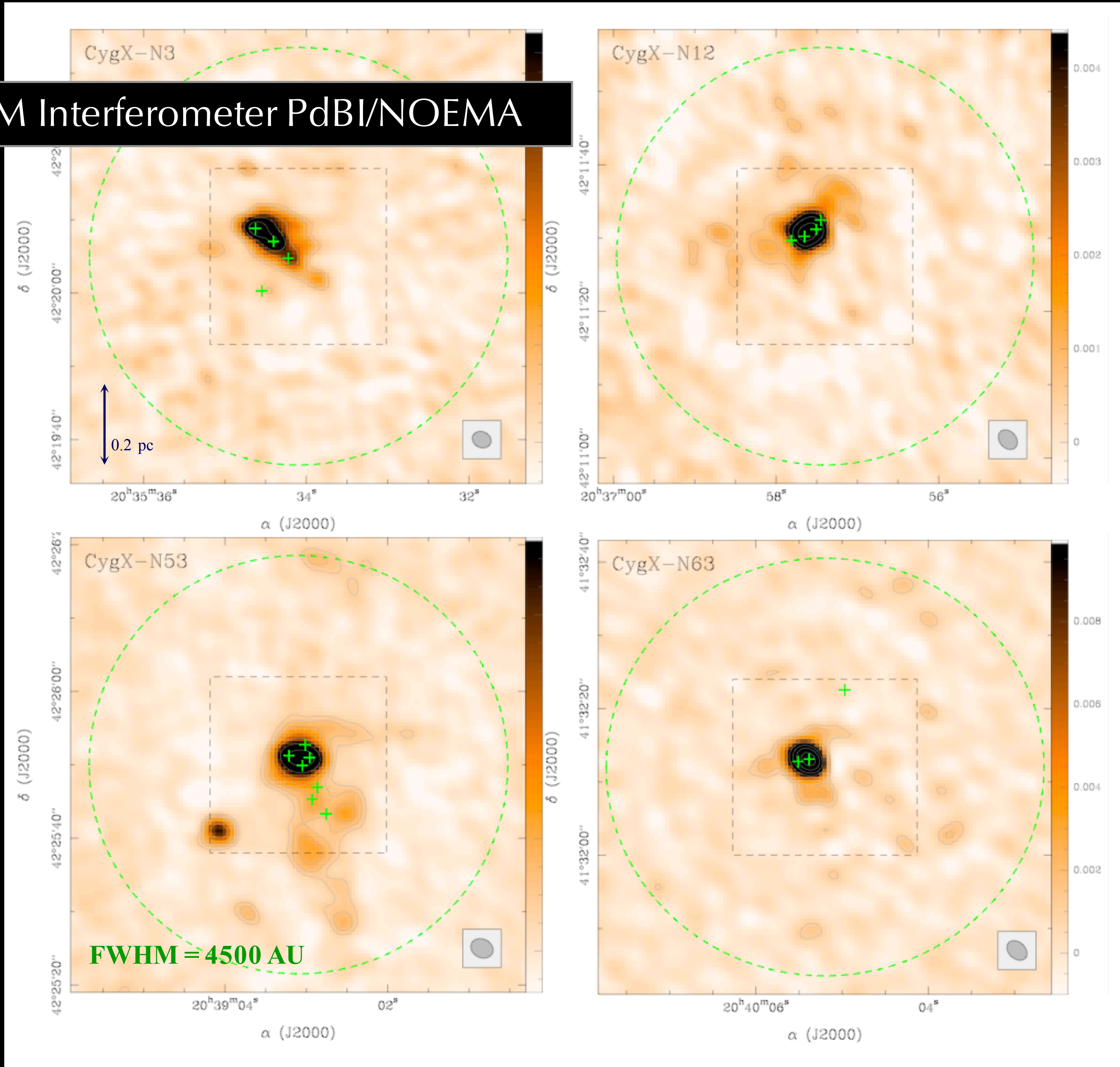
Massive Dense Cores as individual cores?



HOBYS - SPIRE consortium

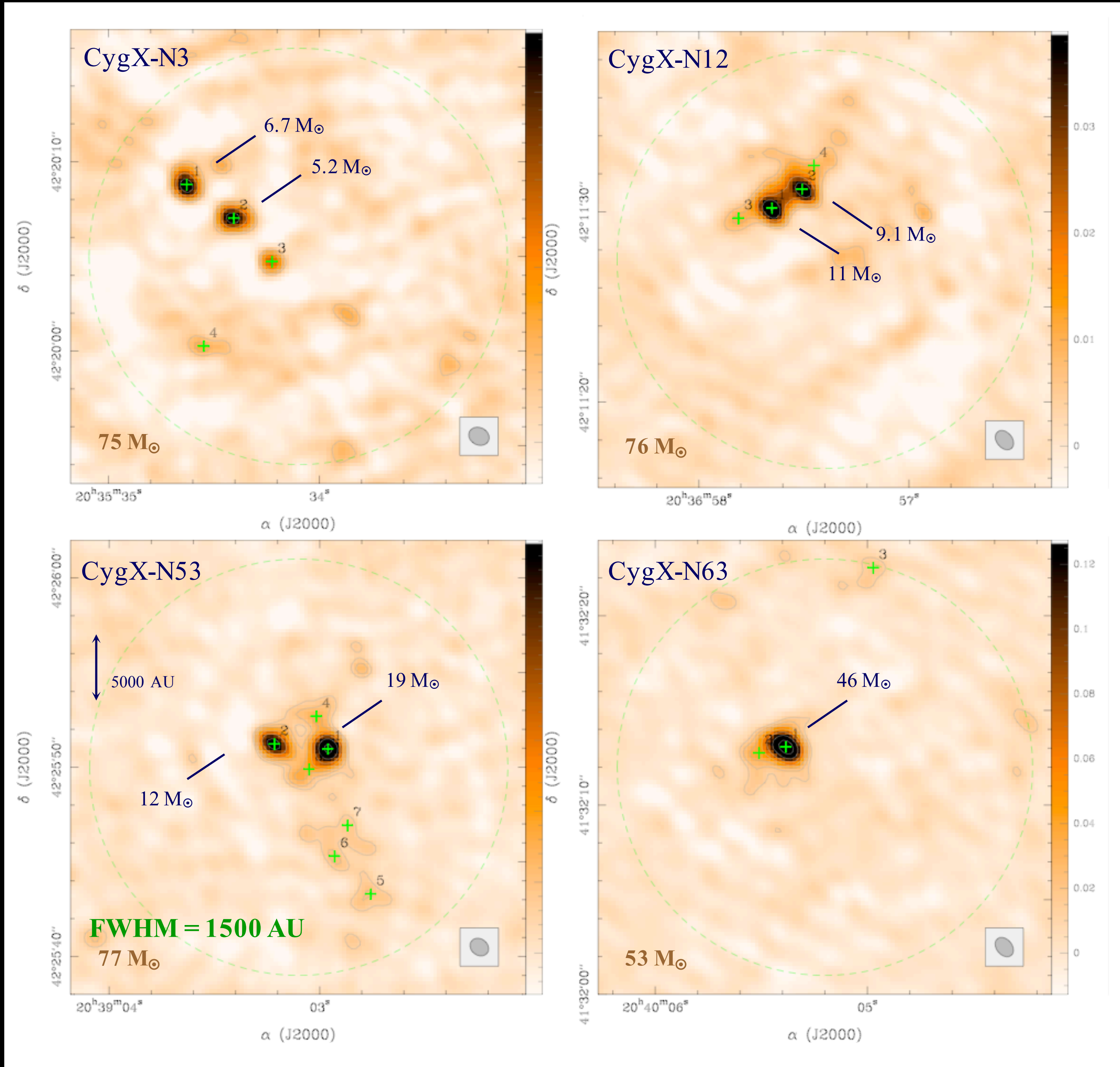
Herschel/PACS 250 µm

IRAM Interferometer PdBI/NOEMA



Bontemps et al. 2010

PdBI 3.5 mm
3.2'' res. (4500 AU)



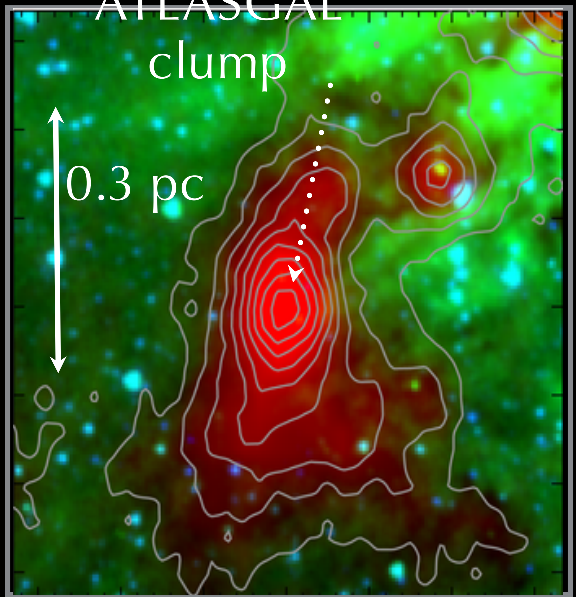
PdBI 1.3 mm
1.1′′ res. (1500 AU)

Bontemps et al. 2010

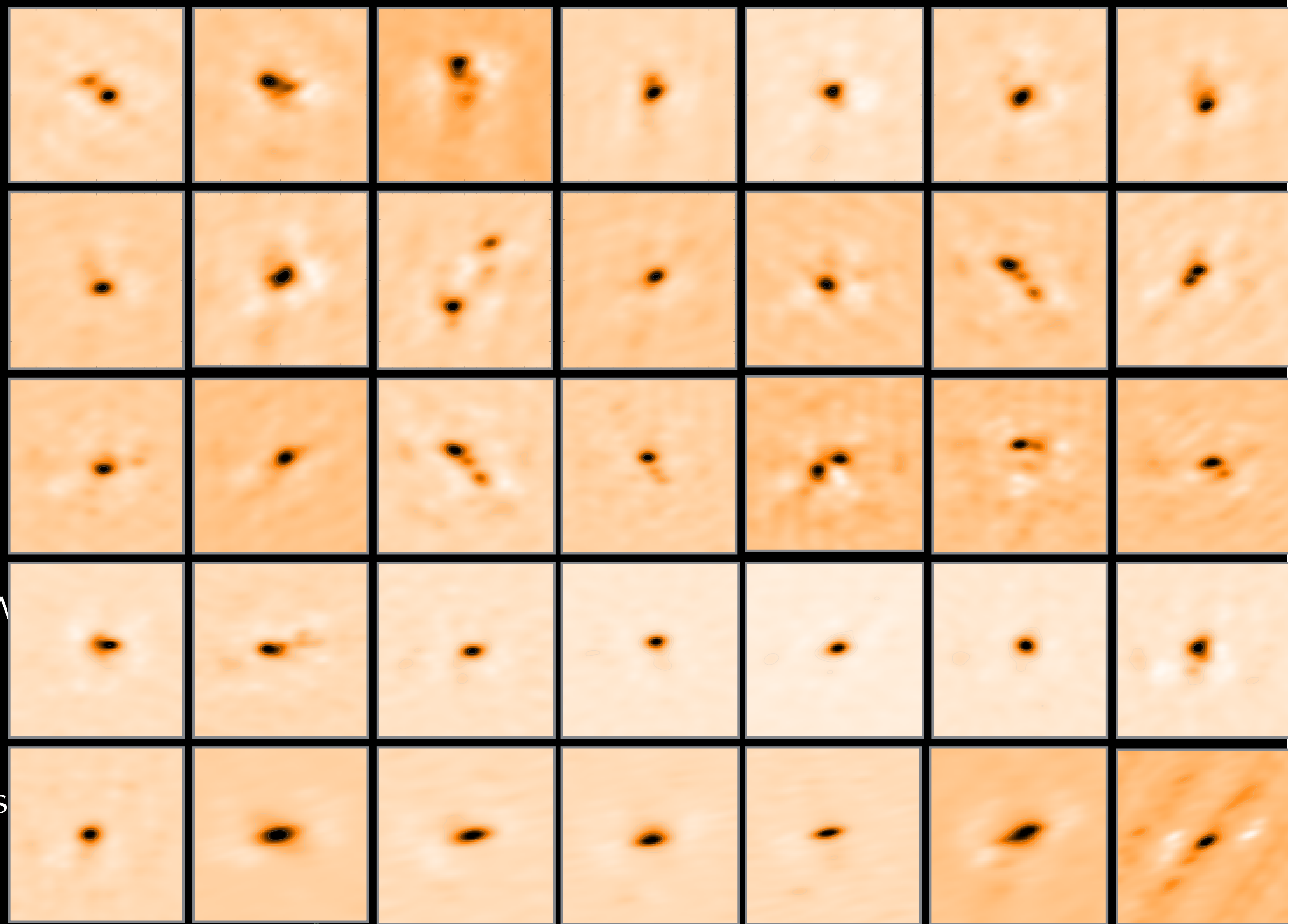
Fragmentation of Hubs

SPARKS project (Csengeri et al.)

SPARKS: Search for high-mass Protostars with **ALMA** up to kilo-parsec scales



870 µm (ATLASGAL) ; 22 µm ; 3.4 µm (W



1-3 MDCs per Hub

Only one source with >90% flux loss

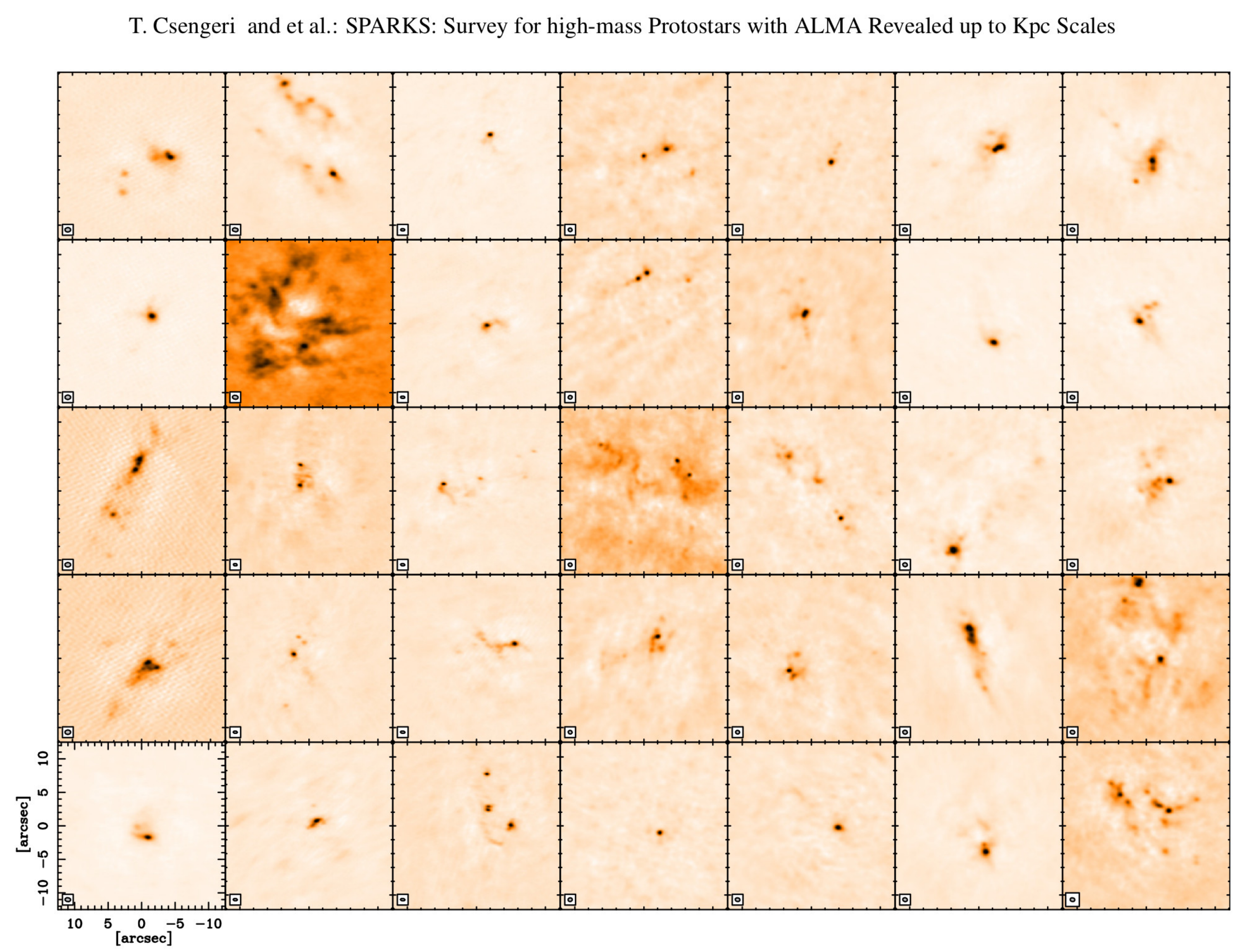
123 fragments are identified above

Csengeri, Bontemps, et al. 2017

ACA-only; 870 µm line free-continuum

Fragmentation of Hubs

SPARKS project (Csengeri et al.)

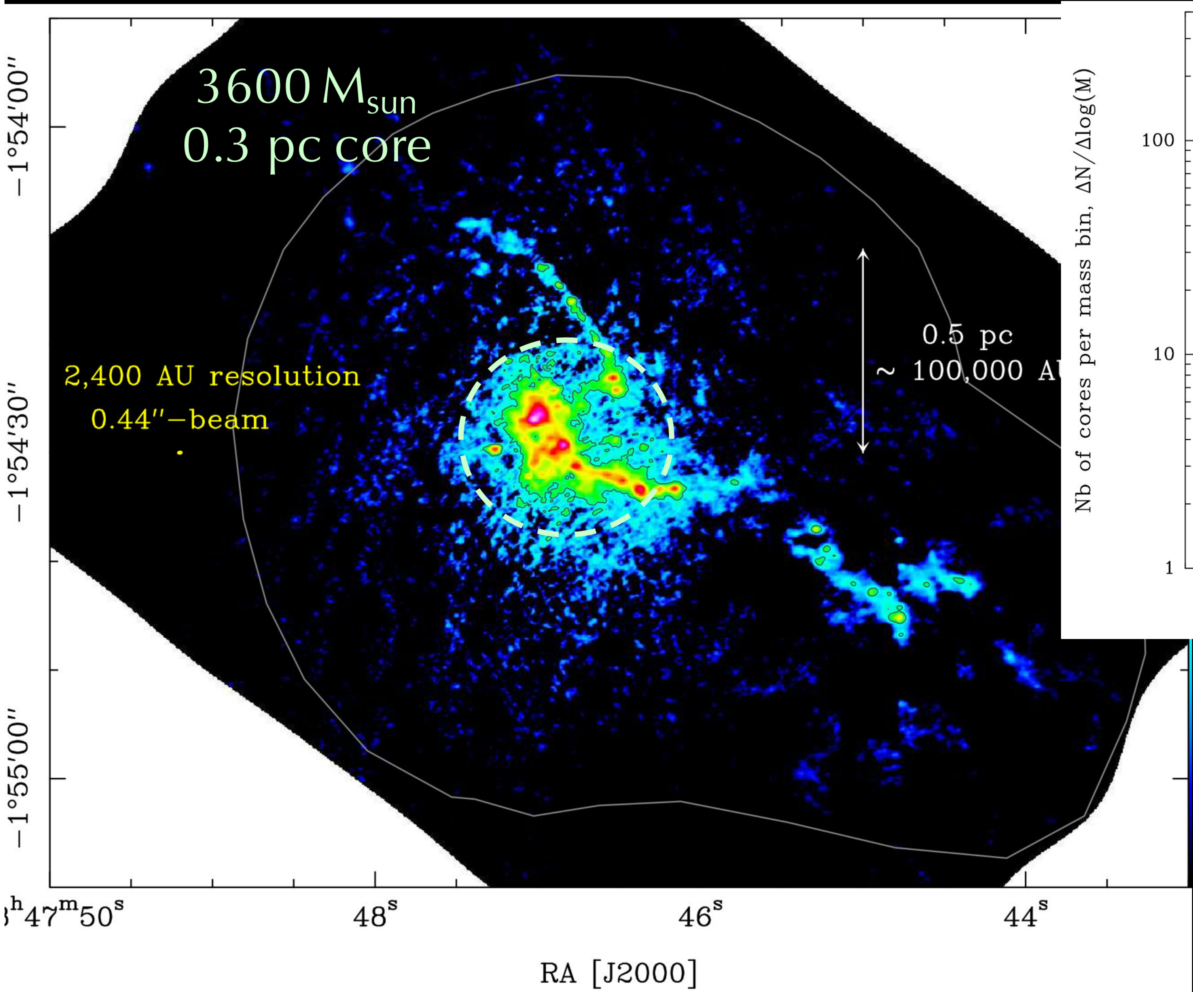


- > 100 high-mass Class 0 YSOs inside the hubs (less than 4.5 kpc from ATLASGAL catalog).
- Csengeri et al. (2018).

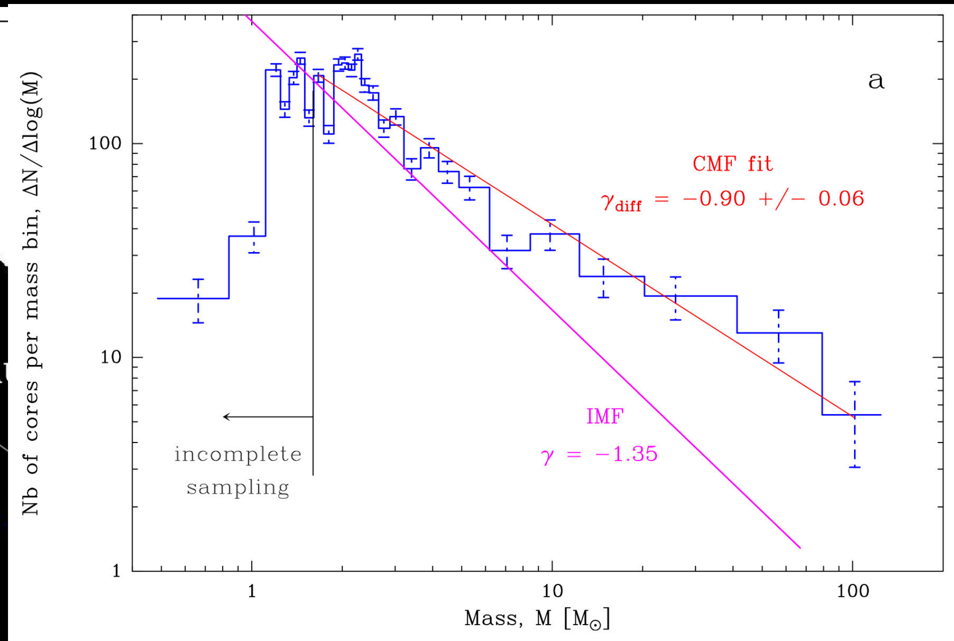
ALMA 12m+ACA; 870 μm line free-continuum

Fragmentation of Hubs

The IR-quiet Hub W43-MM1



ALMA dust 230 GHz emission
Motte et al. 2018, Nature



Motte+2018, Nature

Filaments from global collapse?
Top heavy core mass function
Central regions of Hubs/MDCs
are High-Mass biased.

Three types of massive dense structures:

- Massive Dense Cores:
  40 to 100-200 M_{sun}, 0.1-0.2 pc.
- Hubs (~spherical, dense massive):
  1000 to 3000 M_{sun}, 0.3-0.5 pc.
- Ridges:
  in the 10000s M_{sun} range,
  2 - 10 pc x 0.3 - 0.5 pc.

MDCs, Hubs, Ridges:

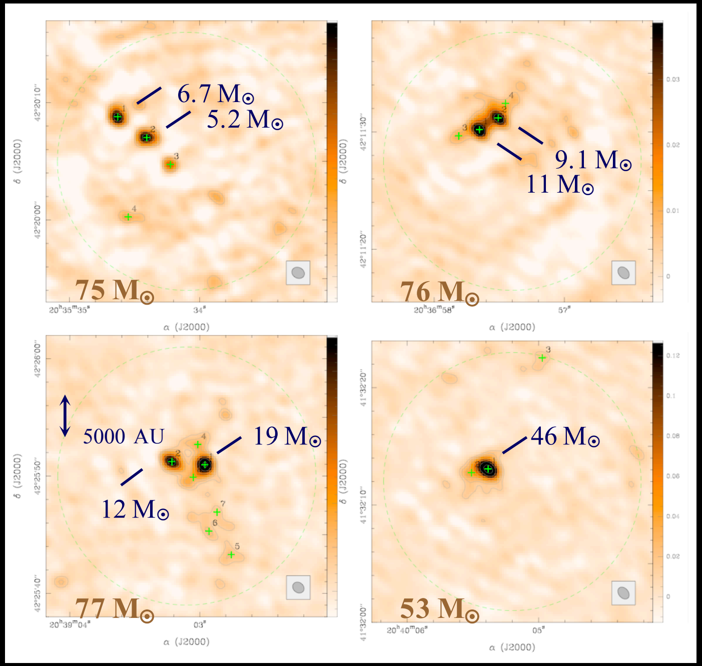
- They are forming high-mass stars.
- Top-heavy CMF - Mass segregation of clusters?

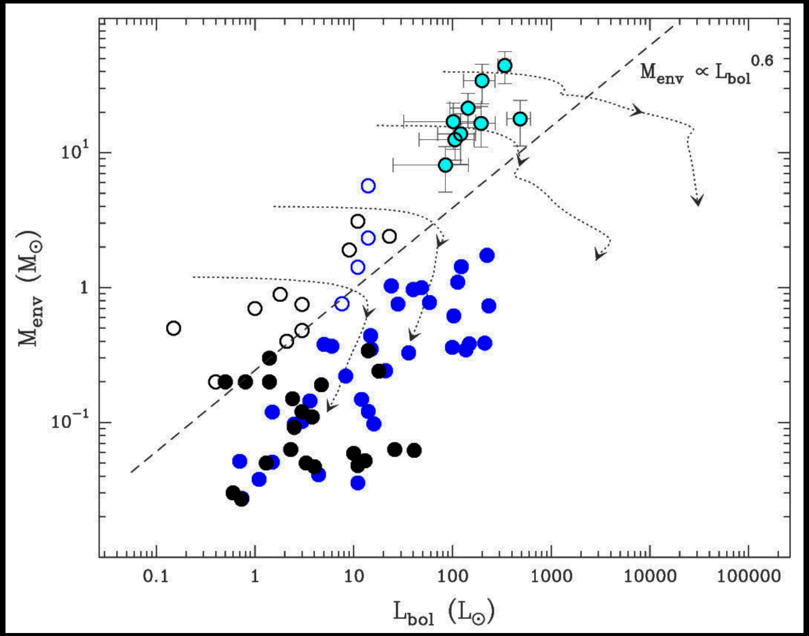
Fragmentation:

- MDCS: rarely individual cores, but limited fragmentation.
- Hubs: Few to tens of protostars.
- Ridges: Tens of protostars.

Timescale for High-mass star formation

- CO Outflows to estimate the typical accretion rates.
- In Cygnus X for Bontemps et al. (2010) cores.

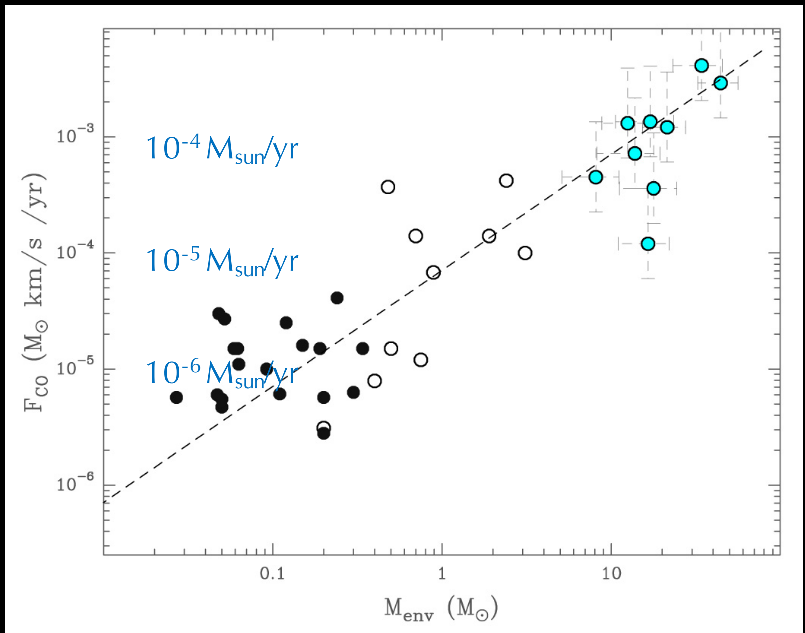


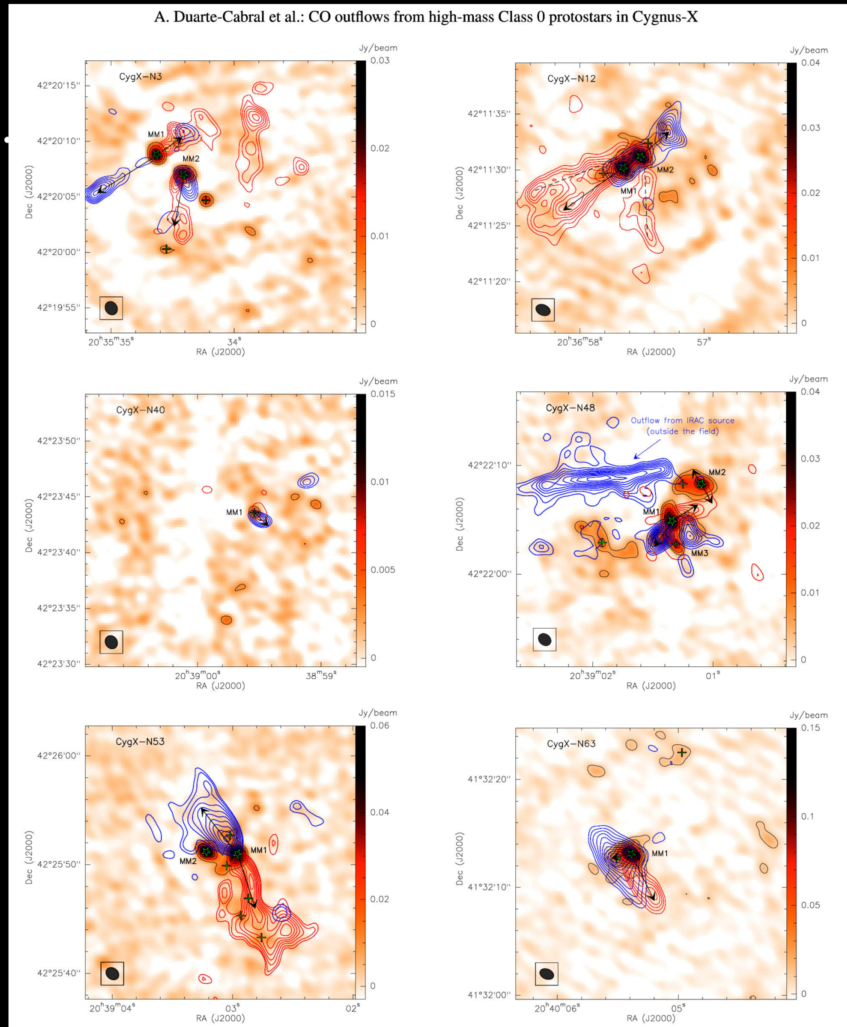


Duarte-Cabral, Bontemps et al. 2013

Timescale for High-mass star formation

- Powerful outflows.
- Linear correlation - Accretion rates vs Masses.
- One expects F_{CO} in $M_{env}^{1.5}$.
- Collapse at ~0.1 pc instead of 0.03 pc?
- Equal Accretion time (~2 x 10^5 yr) for low and high-mass SF.





Duarte-Cabral, Bontemps et al. 2013

A dynamical (gravity driven) evolution of MDCs, Ridges, and Hubs

Indirect evidences

- Starless MDCs/hubs are rare (short formation time) (Motte et al. 2007; Csengeri et al. 2014).

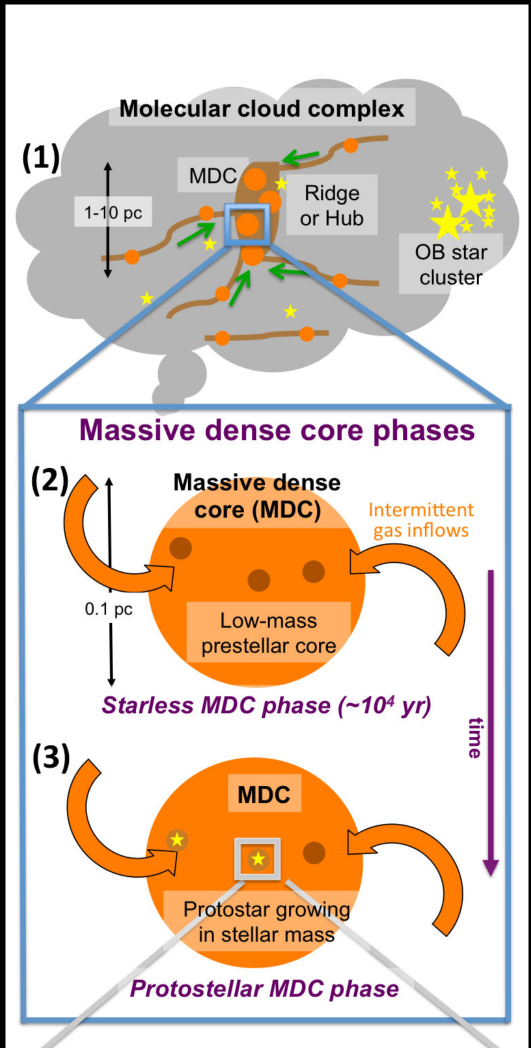
Massive dense cores are indeed out of equilibrium

- Turbulent support too small for MDCs; Small-scale convergent flows (gravity driven?) (Csengeri et al. 2011).

Ridges/hubs are dynamical structures in global collapse

- Short global dynamical time.
- Collapse directly observed (inverse P-cygni profiles). (Motte et al. 2003; Hartmann & Burkert 2007; Schneider et al. 2010; Peretto et al. 2013).
- Filament feeding is not dominant (in DR21; Schneider et al. 2010).

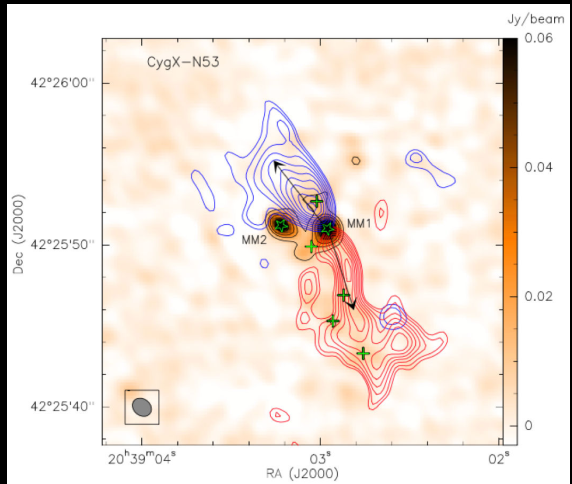
A scenario to explain the rare occurrence of high-mass pre-stellar cores?



Motte, Bontemps, Louvet 2018, ARA&A 56, 41

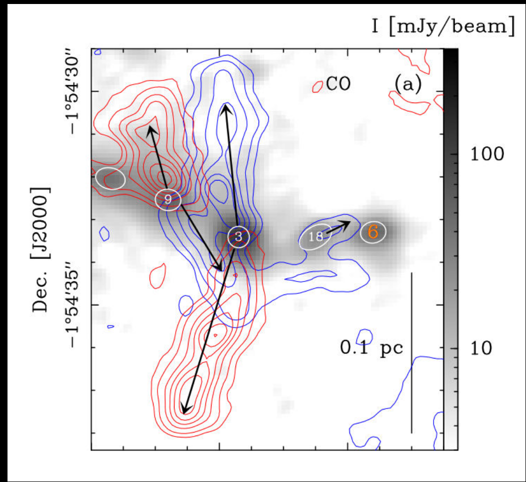
Very good candidates to be high-mass pre-stellar cores:

CygX-N53-MM2 12 Msun



Duarte-Cabral, Bontemps et al. 2014

W43-MM1-core#6 56 Msun



Nony et al. 2018; Molet et al. 2019

See Talk by Jordan Molet

Direct formation of HM PSC in massive dense structure?

A top heavy CMF in the central region of Hubs/Ridges/MDCs

- Where are the low-mass stars?
- Do they form before/after high-mass stars?
- Do they form more in the outskirts of densest structures?

A large ALMA program to progress on these critical issues:

- ALMA-IMF (Motte et al.) France, US, Japan, Chile.
- 15 highest mass protoclusters at d < 5 kpc at different evolutionary stages.
- Mosaics at 1 and 3 mm to get SF at larger scale, and to get both low and high-mass cores, and with cold gas tracers.

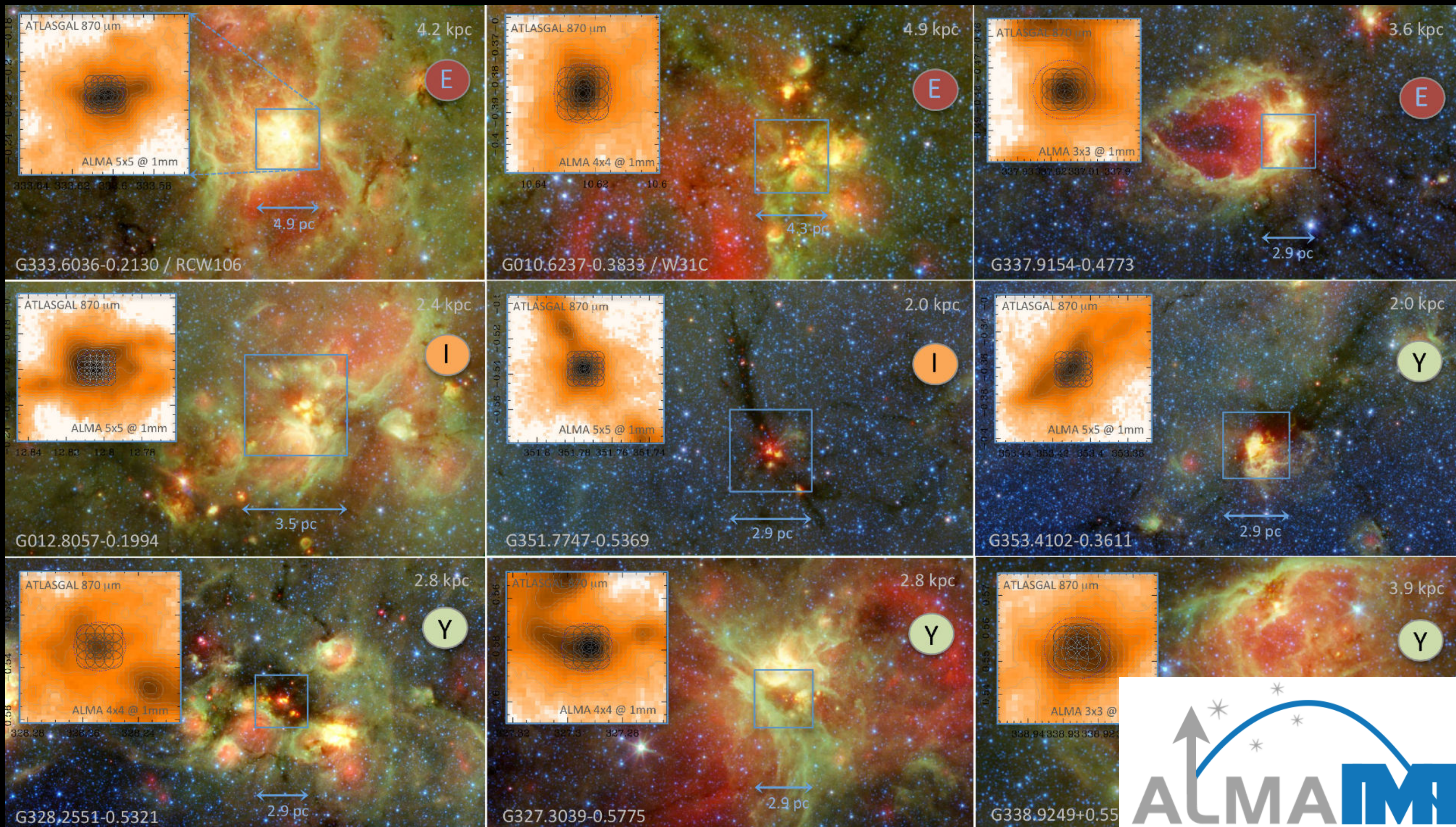
In a nutshell :

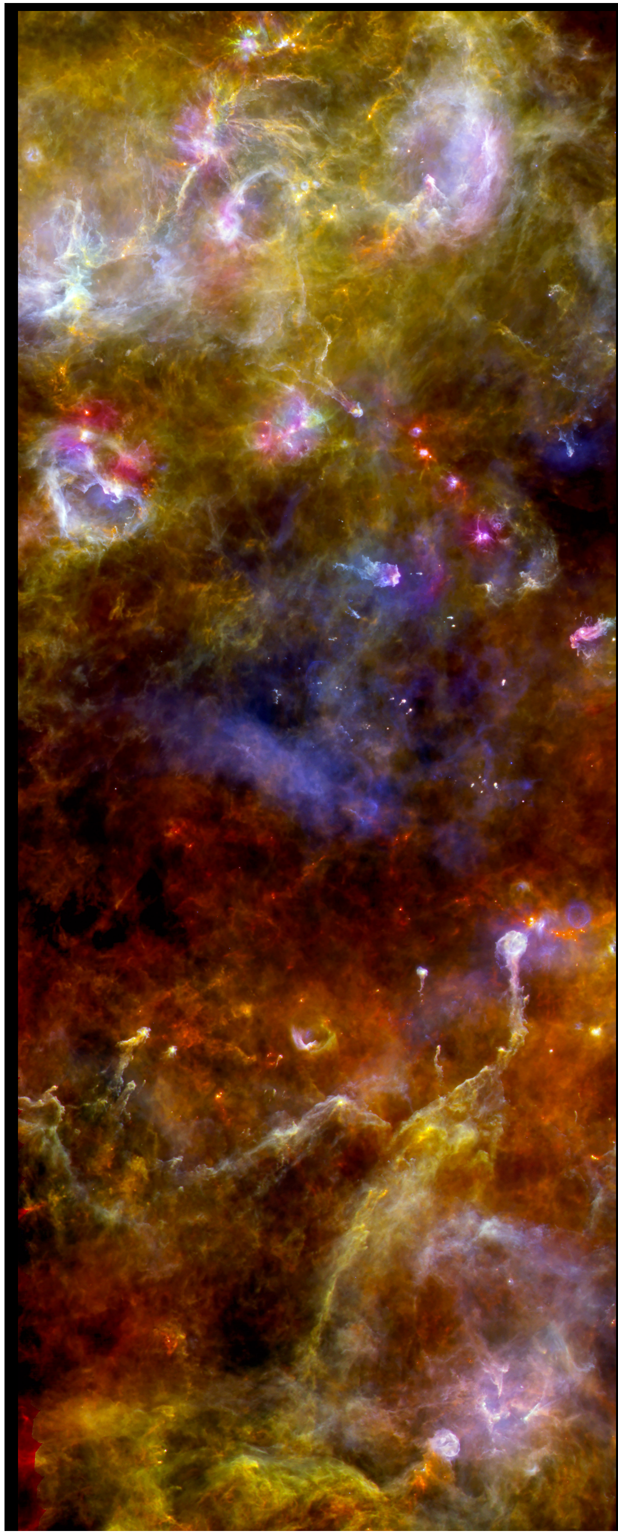
- 15 proto-clusters
- 65 hrs of 12m
- 1+3 mm mosaics; 2000 AU spatial resolution; 100s of LM, IM and HM Class0s.

7. What next?

ALMA large Program - ALMA-IMF

F. Motte; Ginsburg; Sanhueza; Louvet; Cengeri; Bontemps; Nony; Lopez-Sepulcre, Galvan-Madrid; Ohashi, Rosolowky; Menten; Sakai; Guzman; Herpin, Lu; Marsh; Molet; Braine; di Francesco; Nakamura; Battersby; Stutz; Bally; Bronfman; Gursdorf; Ladjelate; Nguyen Luong; Hennebelle; Gomez; Chen; Svoboda





Summary

1. Three types of massive structures: Ridges, Hubs and MDCs.
2. They are the birth place for high-mass stars.
3. Top heavy CMF in all these structures.
4. High-mass accretion time = low-mass SF. (accretion rates proportional to mass).
5. Clear dynamical formation, self-gravity driven evolution of Ridges, hubs and MDCs.
6. Some (a very few) good candidates of high-mass pre-stellar cores.
7. What next? ALMA-IMF.