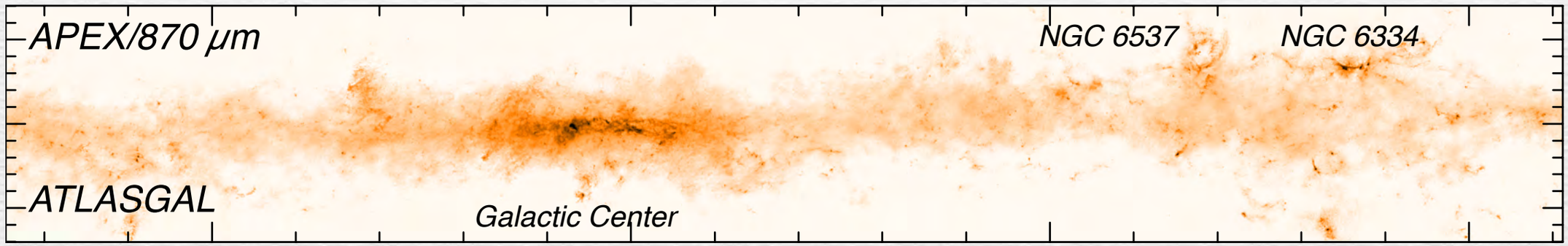
High-mass star formation on Galactic scales

The youngest massive clumps revealed by ATLASGAL

Timea CSENGERI

Max Planck Institute for Radioastronomy



ATLASGAL consortium:
MPG: Schuller (PI, now: ESO), Menten, Wyrowski, Urquhart, Csengeri, (MPIfR) Beuther, Henning, Linz (MPIA), Schilke (now: U-Cologne)
ESO: Walmsley, Bontemps, Cesaroni, Deharveng, Herpin, Lefloch, Molinari, Motte, Minier, Nyman, Reveret, Risacher, Russeil, Schneider, Testi, Zavagno
Chile: Bronfman, Contreras, Garay, Mardones

Co-Is: Bontemps; Wyrowski; Menten; Urquhart; Leurini; Motte; Schuller; Testi; Bronfman; Beuther; Longmore; Commercon; Henning; Palau; Tan; Fuller; Peretto; Duarte Cabral; Traficante

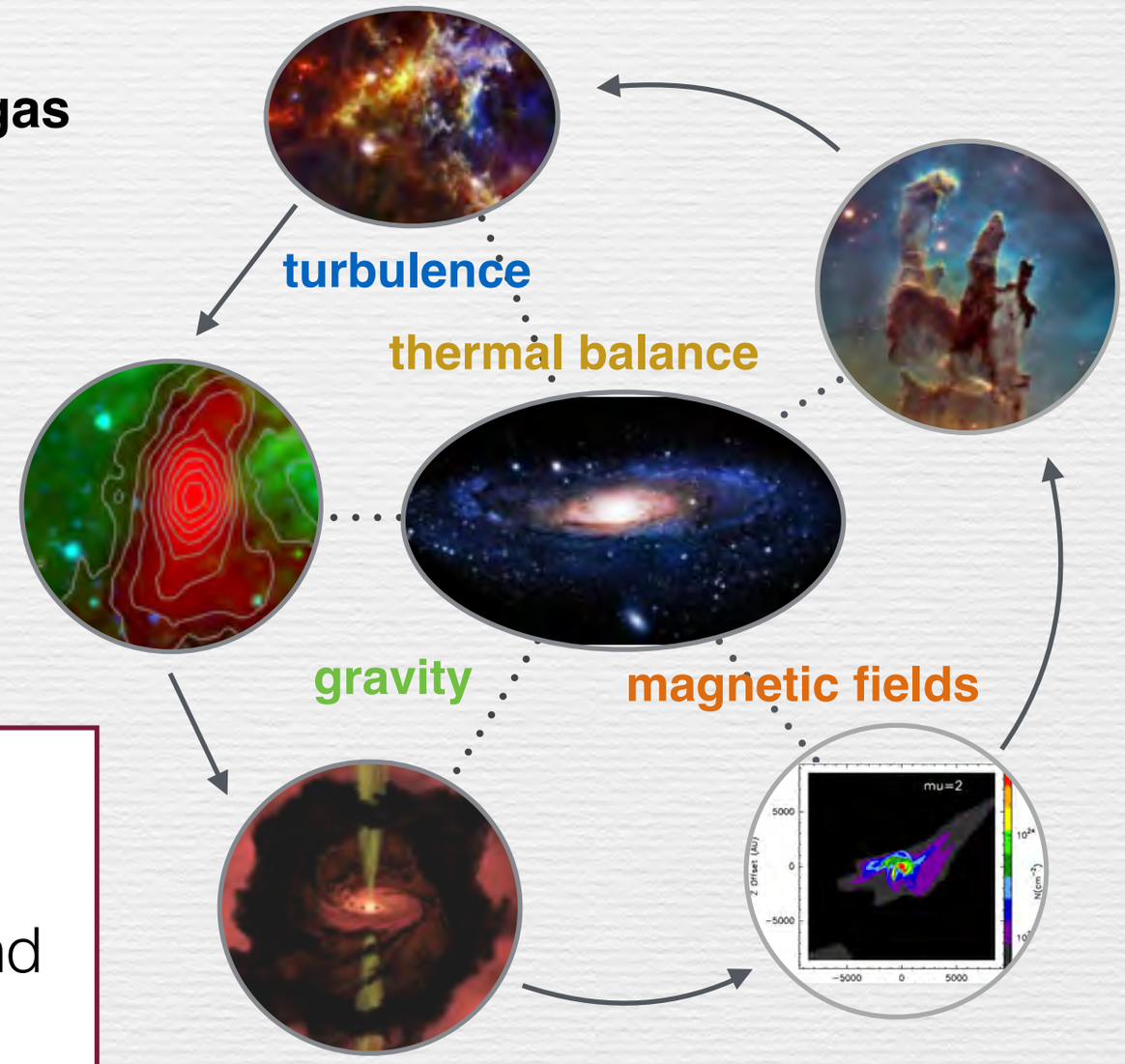
Origin of high-mass protostars ?

Structure formation and dynamics of dense gas

- Filament formation
- Global collapse

Collapse, birth of protostars

- Massive dense cores: **>10-100 M_{Jeans}, ~0.1 pc**
- High-mass protostars: **10-20 M_{Sol}, ~2000-3000 AU**



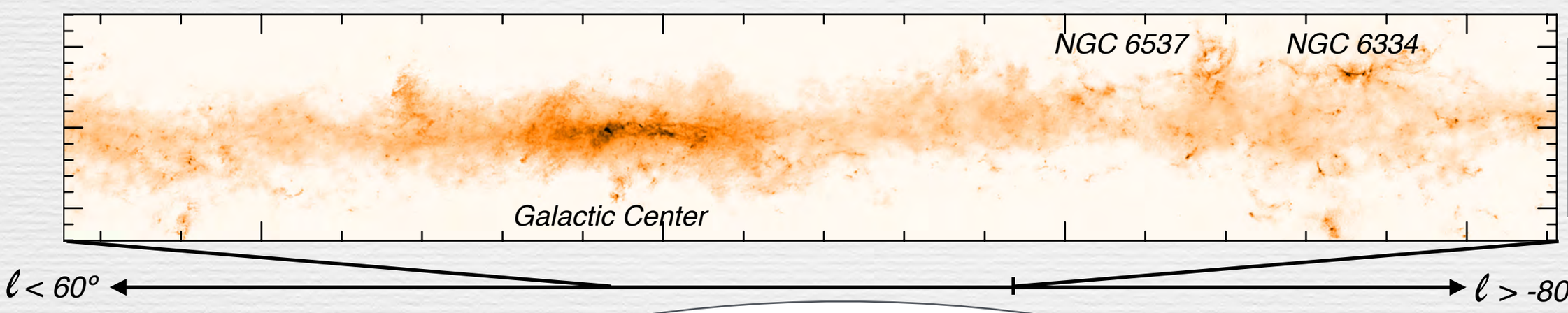
- Where are the precursors of the most massive stars currently forming?
- Which processes control the collapse and on which scales?

- Large samples are needed: Galaxy-wide surveys reveal the best potential targets
- High angular resolution follow-up of selected targets is now feasible with ALMA

ATLASGAL: unbiased view of cold dust in the Galactic Plane

Galactic Plane surveys

- ***APEX Telescope Large Area Survey of the Galaxy:*** *~ 420 sq. degree of the inner Galaxy*



1. Continuum
Statistics: compact sources
Dense gas fraction: uniform,
except Galactic Center
Contreras+2013,
Urquhart+ 2013a,2013b
Csengeri+ 2014,
Urquhart+ 2014
Csengeri, Weiss+ 2015

2. Distances
kinematic
Wienen+ 2012
Wienen+ 2015
maser: BesSel
(Menten)

3. Spectroscopy
astro-chemistry
Csengeri+ 2015 (SiO)
Leurini+ 2014 (H_2O)
Giannetti+ 2014 (CO)

4. Young massive clumps
ALMA follow-up
Csengeri+ in prep
~ 40 sources

> 400 sources
> 3000 sources
> 10 000 sources

Global indication for a fast star formation process

Statistics of massive clumps

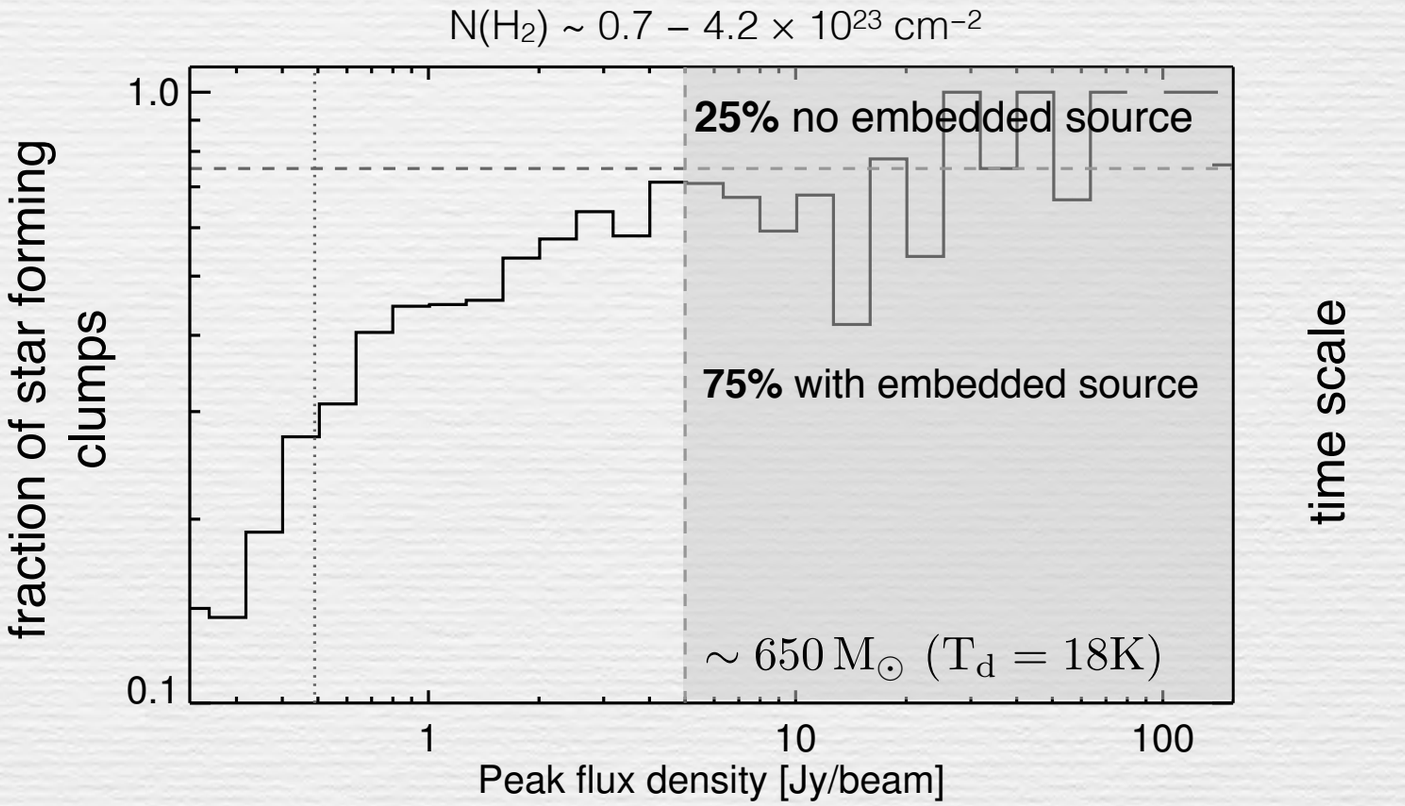
- Extraction of compact sources:
  - > 10 000 sources identified in 420 sq. deg
- MSX & WISE: on average 33% host star formation ($f_\star$)
- Massive clumps:

75% host star formation

$$\tau_{\rm dark} \sim (1 - f_\star) \times \tau_{\rm bright}$$

$$\tau_{\rm bright} = 3 \times 10^5\,{\rm yr}$$ (e.g. Duarte-Cabral+ 2013)

$$\tau_{\rm dark} = 7.5 \times 10^4\,{\rm yr}$$



Csengeri+ (2014)

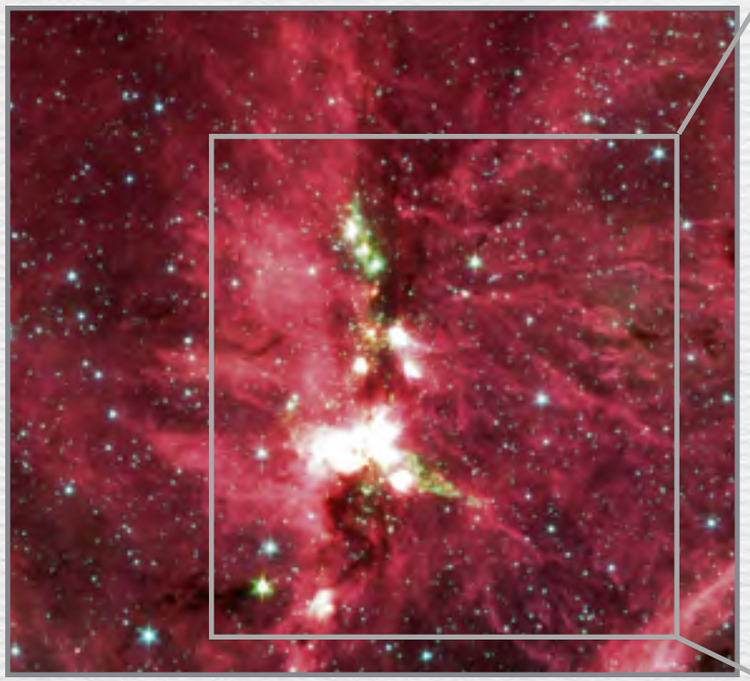
- supersonic motions required: $v_{\rm rel} = \dfrac{D}{\tau_{\rm dark}} = \dfrac{0.3\,{\rm pc}}{7.5 \times 10^4 {\rm yr}} \simeq 3 - 4\,{\rm km\,s^{-1}}$

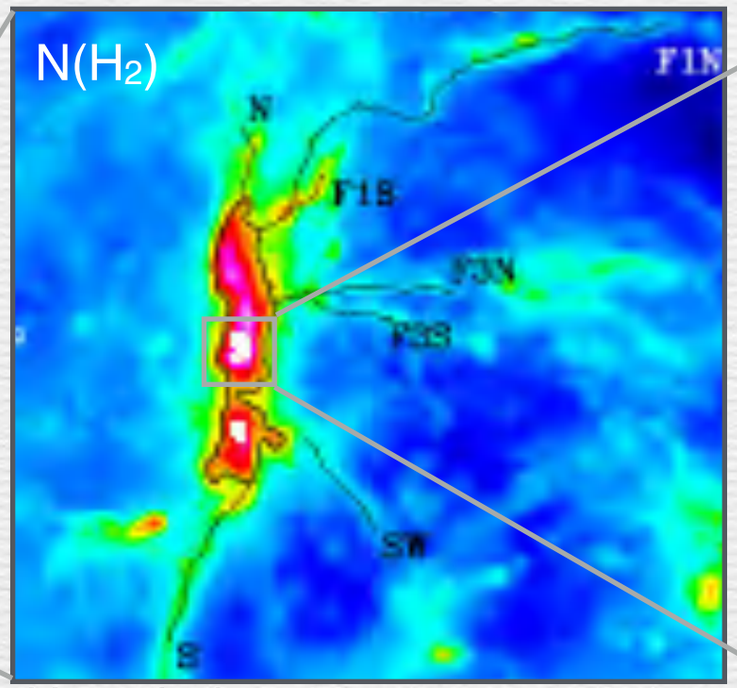
Global statistics of massive clumps suggest short formation time-scale and supersonic motions

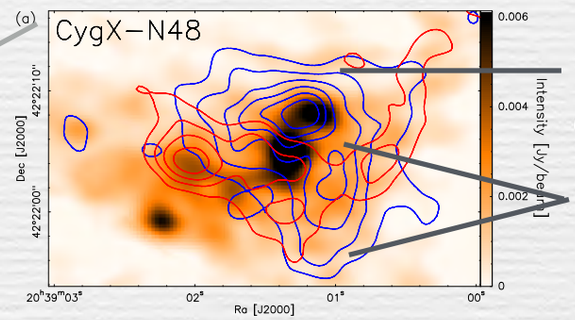
Dynamic scenario for massive star formation in the DR21 filament

- **Dense structures:**
  - filaments, ***ridges***
- **Dynamic processes at the origin of high density filamentary structures:**
  - flows of dense gas and low-velocity shocks observed at high mass protostars

Cygnus-X: nearby massive molecular cloud (1.4 kpc)

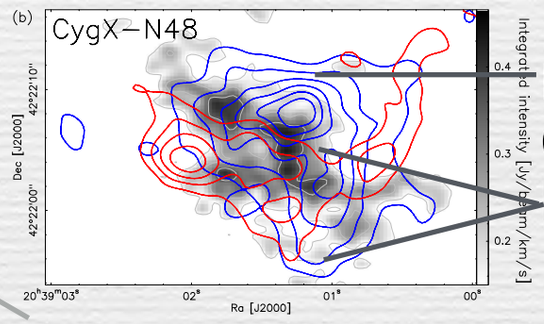






PdBI 3mm continuum

N_2H^+: *cold gas*



PdBI

CH_3CN: *warm gas*

N_2H^+: *cold gas*

Spitzer *Herschel* *10 pc → 0.1 pc* *molecular line emission*

Schneider, Csengeri+ 2010, Csengeri+ 2011a, Csengeri+ 2011b

Flows of dense gas and low-velocity shocks at the origin of high-mass protostars

Global indication for a fast star formation process

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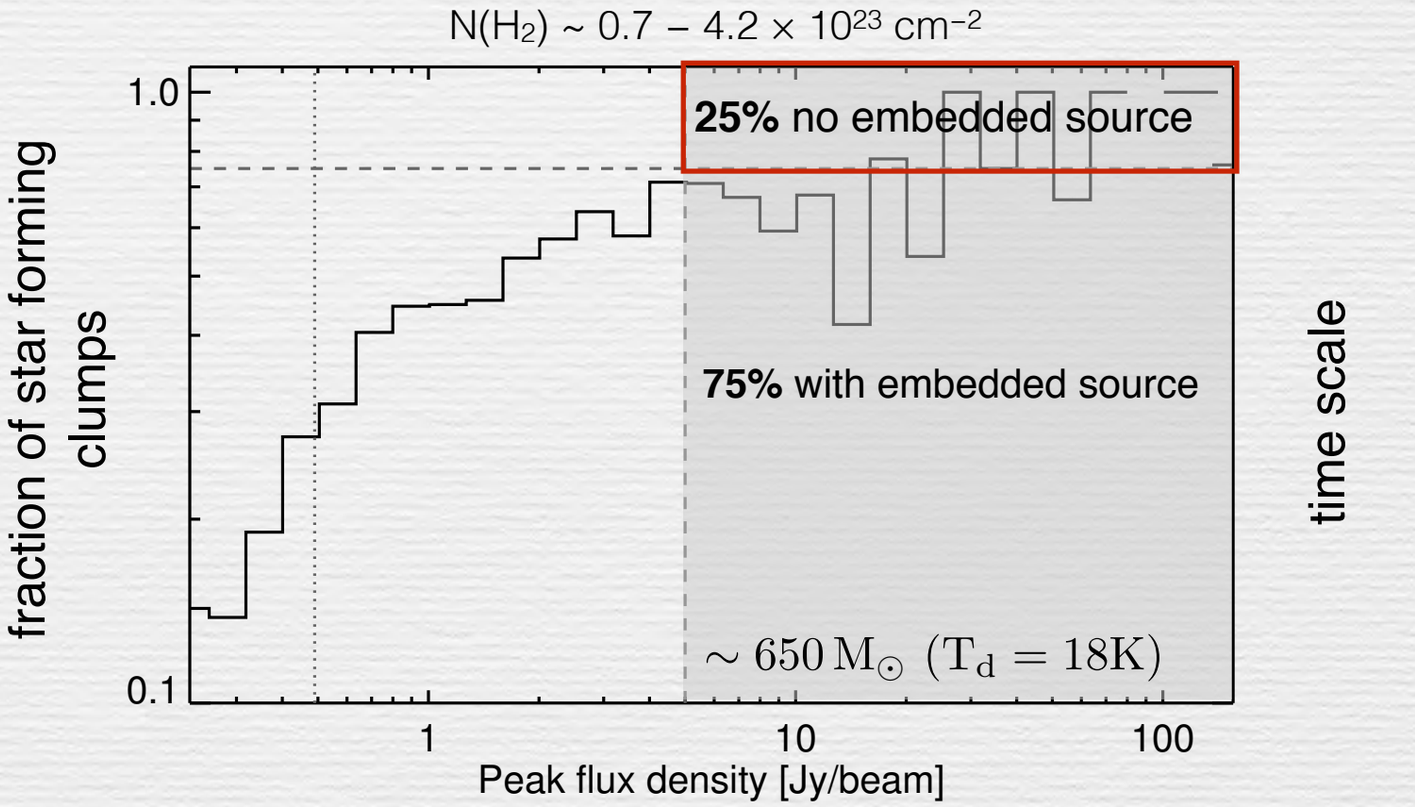

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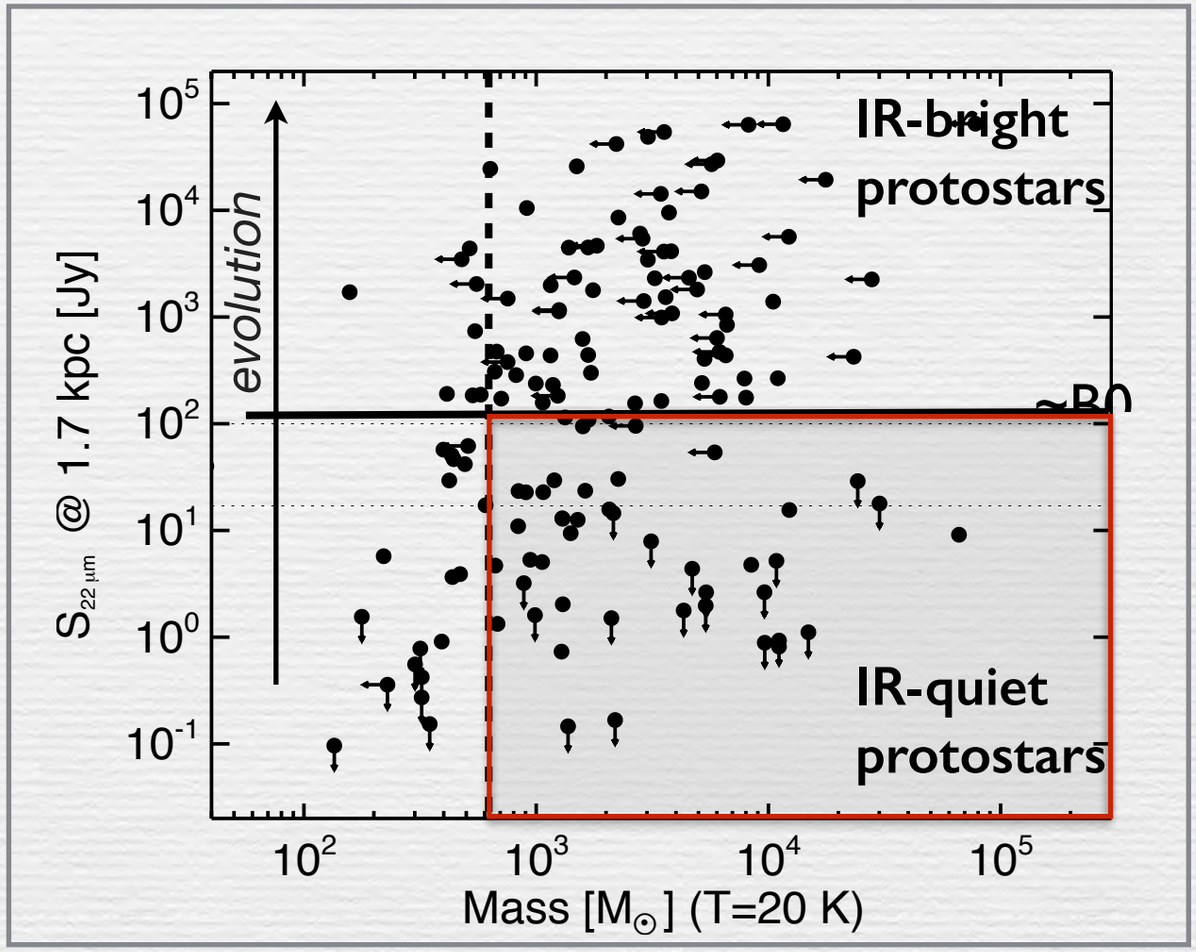
Global statistics of massive clumps suggest short formation time-scale and supersonic motions

Discovery of a sample of pristine massive clumps

A complete sample of IR-quiet massive clumps within 5 kpc

- ➡ maser parallax measurements from the BeSSeL survey (65% for the I[st] quadrant) *Reid et al. (2014)*
- ➡ ATLASGAL + MSX/WISE/Spitzer-MIPS
- ➡ mid-IR flux limit corresponding to early-O type stars
- ➡ ~45 sources: > 650 $M_\odot$ at < 5 kpc (Σ~1 g cm^{-2})



Csengeri, Bontemps+ (in prep)

Initial stages of massive protoclusters:

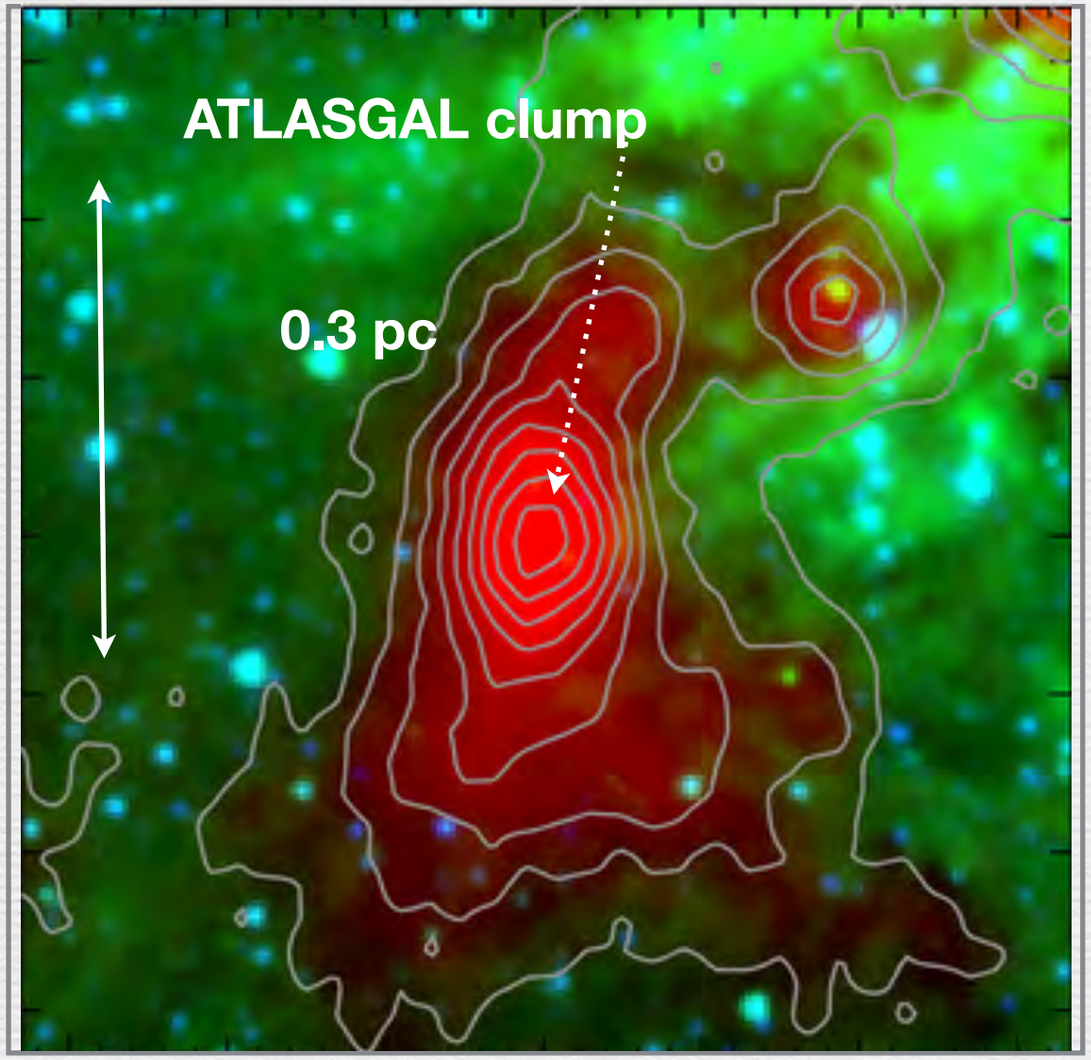
potentially host the most massive protostars currently in formation

- only the high column density hints at the capability to form massive stars

The youngest precursors of massive clusters identified

Discovery of a sample of pristine massive clumps

Initial conditions for massive clumps



- Complete sample includes a few known examples: G28, G14, SDC335
- selection complete for ~1/4th of the Galaxy

Clustering and large distance prevents studies of individual sources!

ALMA follow-up: "*The first Galactic scale hunt for the precursors of the most massive stars in the Milky Way*"

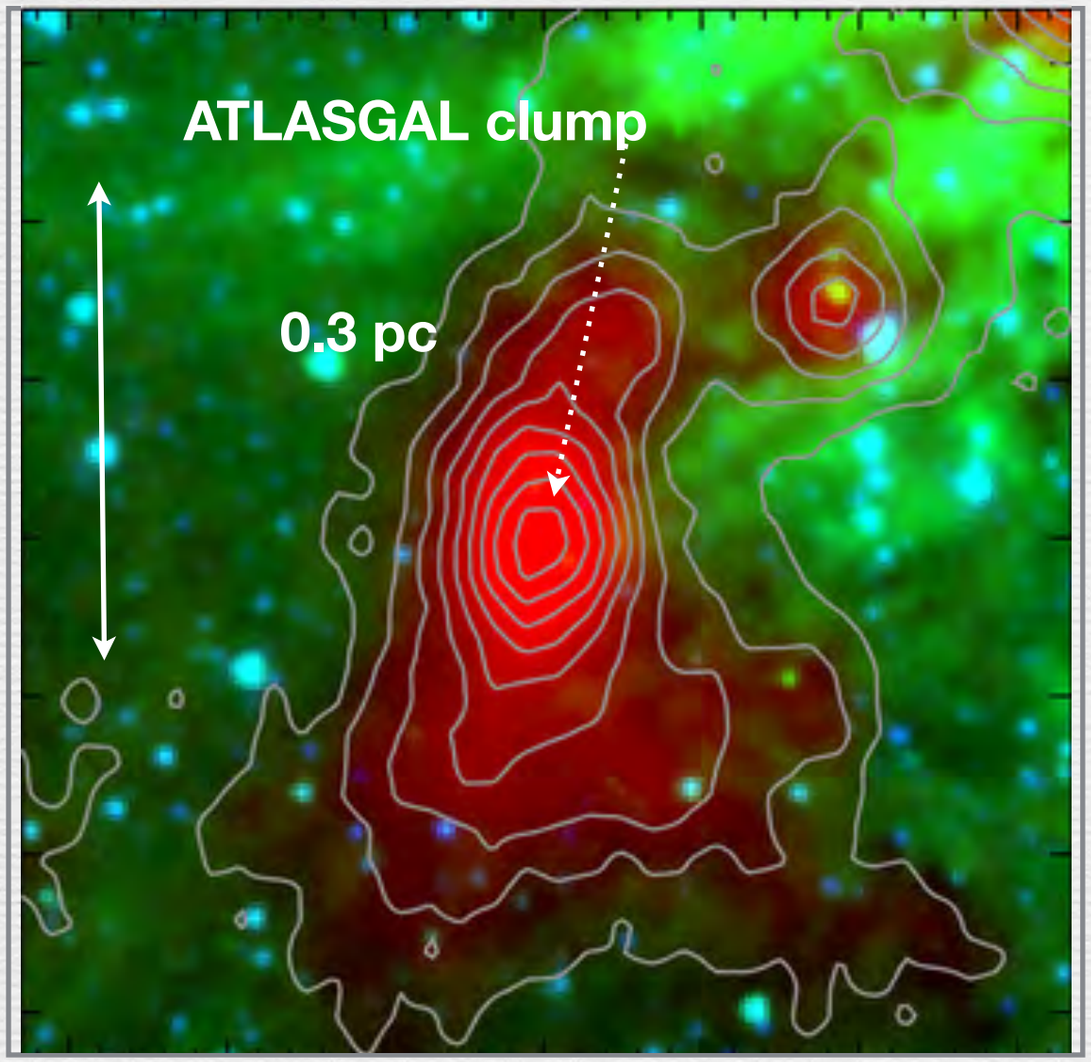
- IR-quiet stage: no hot-core, no ionising emission
- Class 0 -like stage: **10-20 M_{Sol}, ~2000-3000 AU**

Where are the youngest precursors to the most massive stars?

Complete statistics of the most massive and youngest clumps in the inner Galactic plane

The first Galactic scale hunt for the precursors of the most massive stars in the Milky Way

First systematic and comprehensive survey of massive nearby clumps



- **24h** of ALMA time granted! (**6h** with the main array)
- mass assembly process down to 2000-3000 AU scales
- chemistry

ALMA + ACA + APEX
(continuum *and* spectral line)
from 0.6” (-> 2000 AU) to large scales

- Fragmentation, Class 0 like protostars, outflows, kinematics, chemistry on all scales
- 100-150 Class 0-like high-mass protostars
- 10-20 true massive pre-stellar cores?

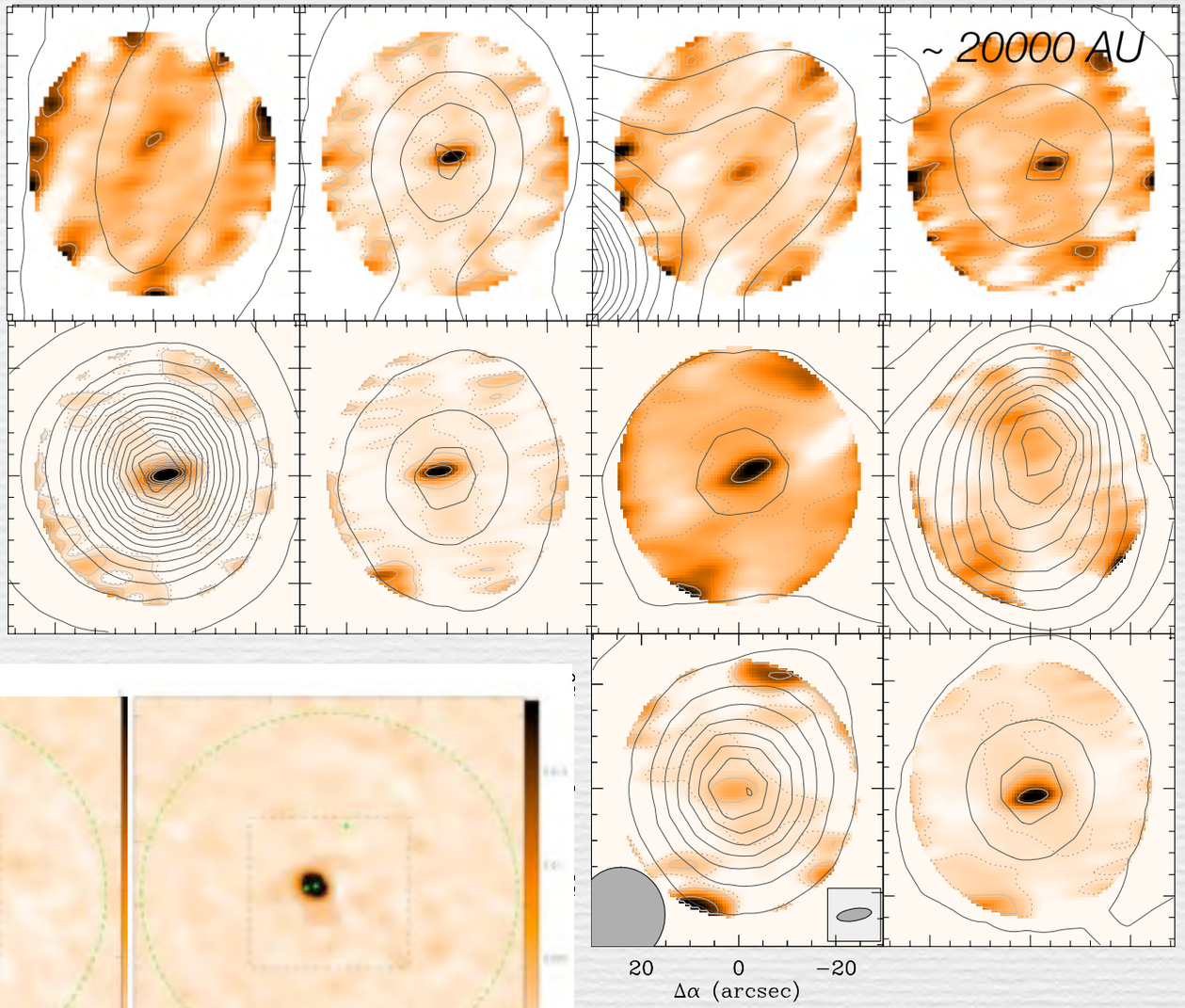
Comprehensive view of the immediate vicinity of high-mass protostars

Limited fragmentation on 0.1 pc scales

Preliminary results

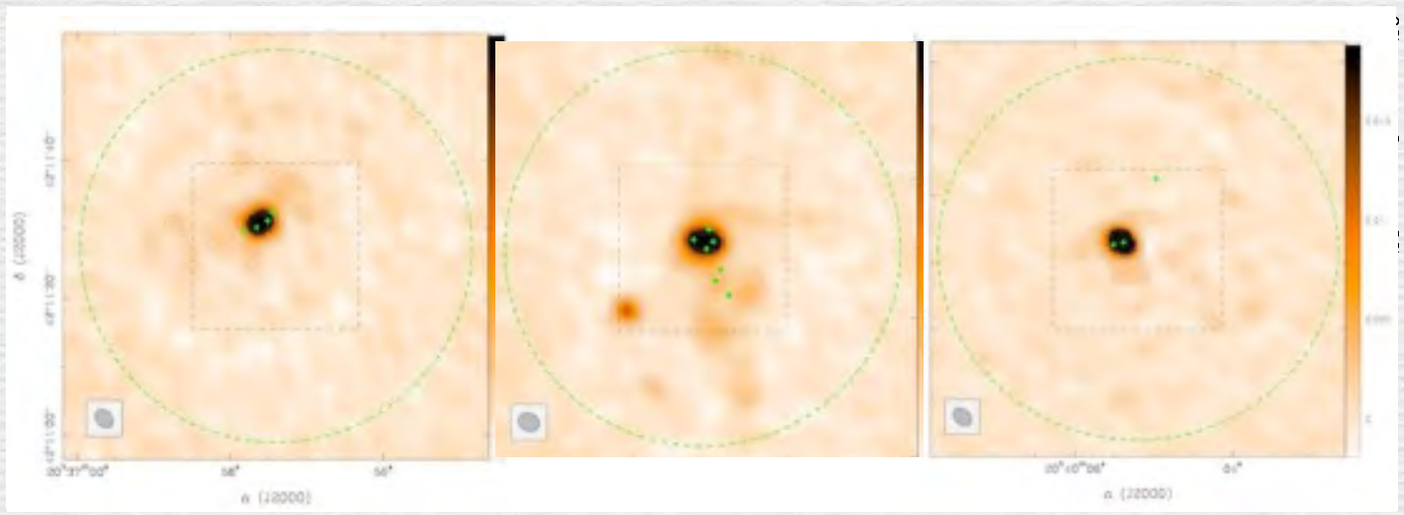
- APEX short-spacings completed
- ACA: 5” resolution for all sources completed (~20 000 AU)

- centrally concentrated emission
- limited fragmentation, compact sources
- (ALMA main array: 0.6” ! ~ 600-3000 AU)



345 GHz continuum (ACA)
contours: ATLASGAL (APEX)

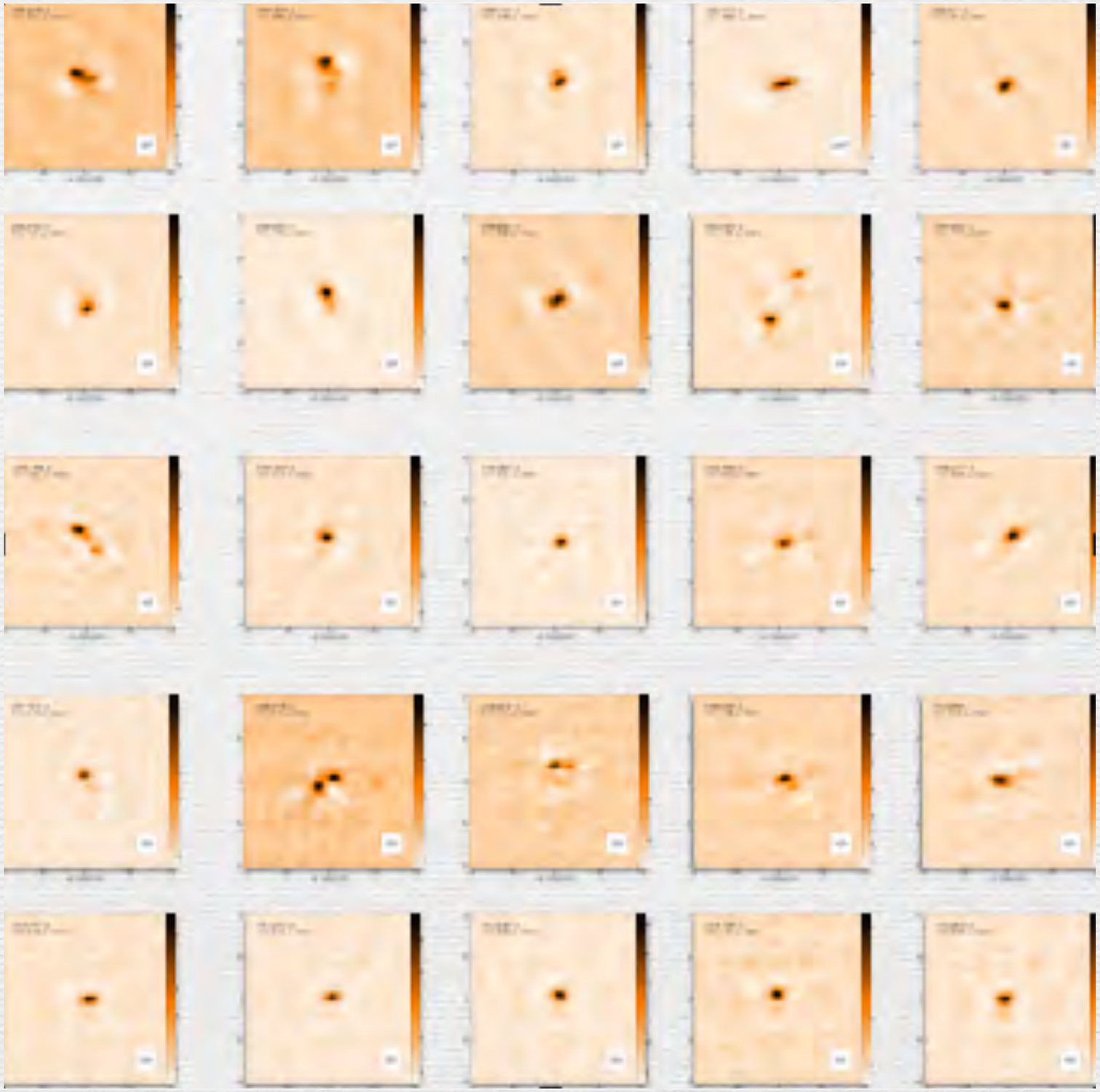
MDCs in Cygnus-X @ ~ 5000 AU



Limited fragmentation on 0.1 pc scales

Preliminary results

- ~ 50% of the targets
- shown here is only continuum



Precursors of the most massive protostars and clusters

Preliminary results

- Previously known most massive object: SDC335

  Peretto et al. (2013)

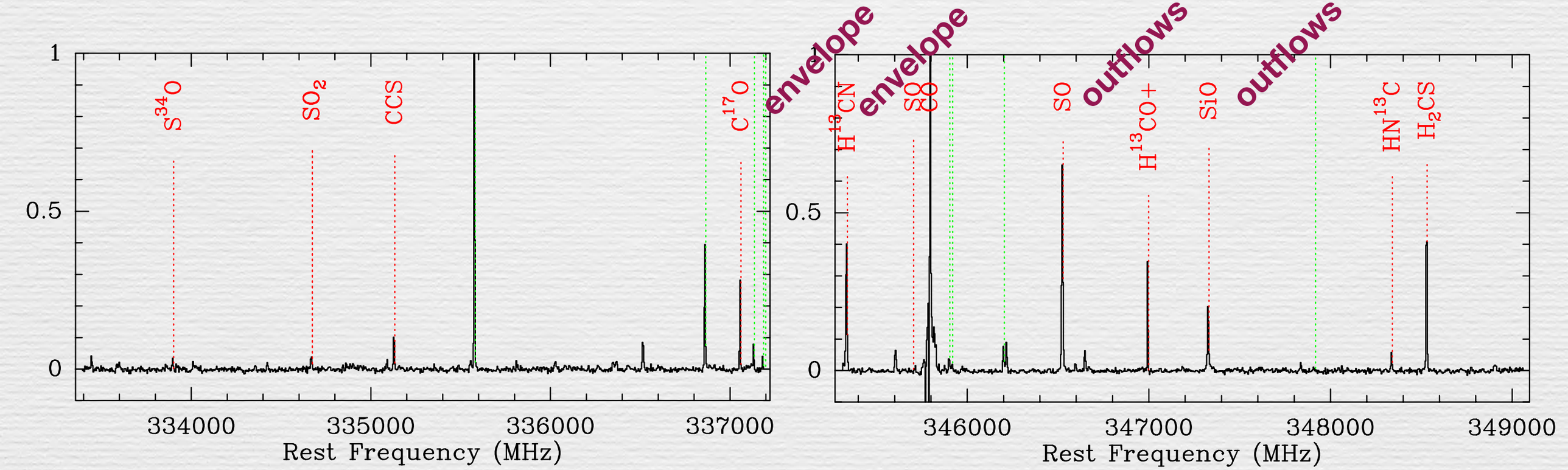
- Several candidates with > 1000 M_{Sun}
- On the 0.1 pc scale:
  strong correlation between the
  clump mass and fragment mass

Strong indication for a correlation between the clump mass and the most massive star forming in a cluster

Chemistry of high-mass protostars

Preliminary results

- ACA: 5” resolution (ALMA main array: 0.6” ! ~ 600-3000 AU)
  - ➡ chemical richness
  - ➡ more species detected than with APEX:
    - ➡ high-density tracers: $H^{13}CN$ (4-3), $HN^{13}C$ (4-3), $H^{13}CO^+$ (4-3)
    - ➡ shock tracers: SiO (8-7), SO
- 10-15% of the sample is dominated by hot-core like emission
- Outflow tracers mostly detected: Class 0-like high-mass protostars

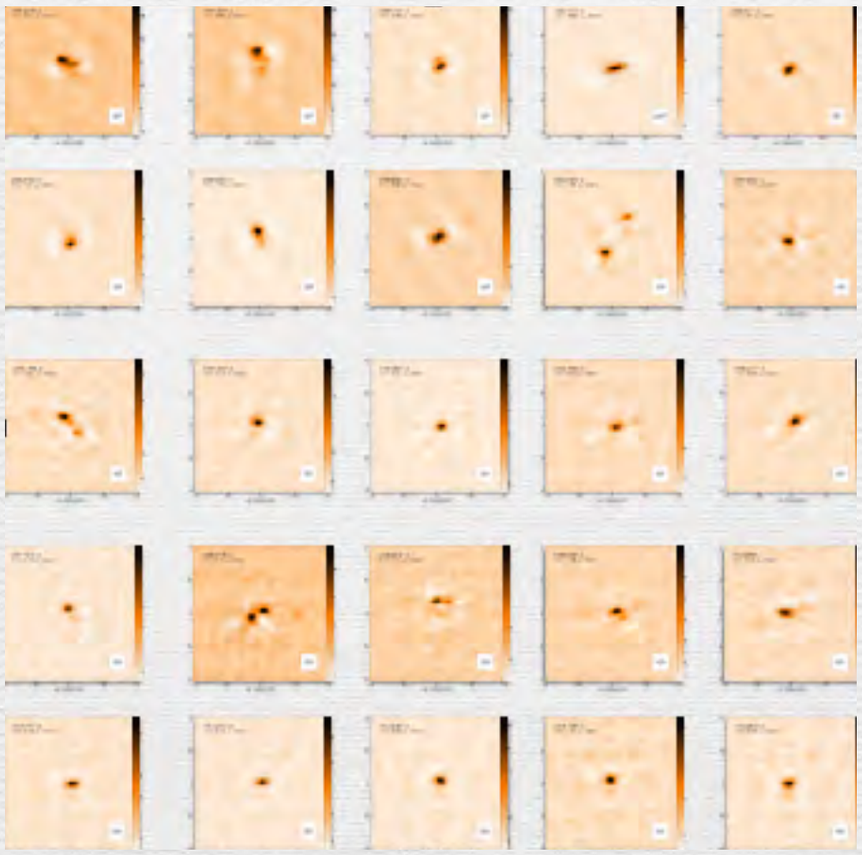


8 GHz instantaneous bandwidth with ALMA

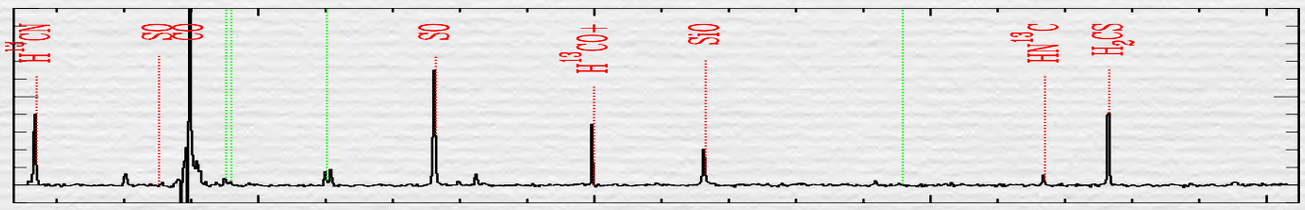
Summary

ATLASGAL selected sample of young proto-clusters :

- ATLASGAL provides a **complete sample** of the youngest massive clumps in the inner Galactic Plane
- **short formation time-scales** implies supersonic motions
- **Galaxy-wide unbiased surveys are needed**
- **ALMA Cycle 2 survey** of the precursors of the highest mass protostars ($M>20M_{Sun}$) and richest clusters currently forming in our Galaxy



- **Preliminary results :**
  - confirms the **existence of Class 0-like high-mass protostars** in the largest sample observed so far
  - **limited fragmentation** on 0.1 pc scales
  - suggests strong self-gravity
  - outflows detected in most cases (Class 0 like protostars)
  - few hot-core like objects revealed



Most comprehensive study to date on the youngest high-mass protostars