High-mass star formation on Galactic scales

The youngest massive clumps revealed by ATLASGAL

Timea CSENGHERI

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, Cesarioni, 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
The first Galaxy scale hunt for high-mass protostars

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Structure formation and dynamics of dense gas

- Filament formation
- Global collapse

Collapse, birth of protostars

- Massive dense cores: >10-100 M$_{\text{Jeans}}$, ~0.1 pc
- High-mass protostars: 10-20 M$_{\text{Sol}}$, ~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

2. **Distances**
   - Kinematic
     - Wienen+ 2012
     - Wienen+ 2015
   - Maser: BesSel
     - (Menten)

3. **Spectroscopy**
   - Astro-chemistry
     - Csengeri+ 2015 (SiO)
     - Leurini+ 2014 (H₂O)
     - Giannetti+ 2014 (CO)

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

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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 \((f_*)\)
- Massive clumps:
  - 75% host star formation
    \[
    \tau_{\text{dark}} \sim (1 - f_*) \times \tau_{\text{bright}}
    \]
    \[
    \tau_{\text{bright}} = 3 \times 10^5 \text{ yr (e.g. Duarte-Cabral+ 2013)}
    \]
    \[
    \tau_{\text{dark}} = 7.5 \times 10^4 \text{ yr}
    \]

- supersonic motions required:
  \[
  v_{\text{rel}} = \frac{D}{\tau_{\text{dark}}} = \frac{0.3 \text{ pc}}{7.5 \times 10^4 \text{ yr}} \approx 3 - 4 \text{ km s}^{-1}
  \]

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

Spitzer, Herschel, 10 pc → 0.1 pc

Molecular line emission

PdBI 3mm continuum
N$_2$H$^+$: cold gas
CH$_3$CN: warm gas
N$_2$H$^+$: cold gas

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

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

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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

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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

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

- 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\(_{\odot}\), ~2000-3000 AU

Where are the youngest precursors to the most massive stars?
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)

MDCs in Cygnus-X @ ~ 5000 AU

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

The first Galaxy scale hunt for high-mass protostars

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Limited fragmentation on 0.1 pc scales

Preliminary results

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

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Precursors of the most massive protostars and clusters

Preliminary results

• Previously known most massive object: SDC335

Peretto et al. (2013)

• Several candidates with $> 1000 \, M_{\odot}$

• 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

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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
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_{\odot}) 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