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2016 Aug 13
How Young Massive Cluster or Globular Cluster Form?

HST Image of 30 Doradus (NGC2070; Credit: NASA, ESA, etc)

The origin of scatterings in the star-formation law

VLT image (I suppose) of antenna galaxies
A Young Massive Cluster

HST Image of 30 Doradus (NGC2070; Credit: NASA, ESA, etc)

Targets: Candidates of Young Massive Cluster in the Making

Red: Spitzer MIPS 24 um (Indicator for HII regions)

Green: Spitzer IRAC 8 um
Herschel 350 um image of a random field in the Galactic plane
Herschel 350 um image

APEX 870 um Galactic Plane Survey
Liu, Haoyu Baobab et al., 2015

2016 Aug. 13 EAO-JCMT seminar
I can understand if she hates me. Lin et al. (2016)
Lin et al. (2016)
They are Different
Nothing is consistent with log-normal distribution. Clearly, we are beyond the central limit theory confusion.
2016 Aug. 13 EAO-JCMT seminar
slope = 0.60
corrcor = 0.89
W49A

G10.2-0.3

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Lu et al. (2014)
2016 Aug. 13 EAO-JCMT seminar
OB Cluster-Forming Molecular Hub-Filament System
An extremely rich astrophysical problem

Within the Centrifugal Radius

On the Large Scale

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A Ring Like Distribution of UC H\,II Region Gave Implication to the Parent Molecular Toroid

The Case of the
Galactic L~10^6 OB Cluster-Forming Region G10.6-0.4

Red : Spitzer MIPS 24 um (Indicator for HII regions)
Green: Spitzer IRAC 8 um

Molecular Gas Distribution
IRAM-30m Telescope OTF Mapping
Observations of ^13^CO 2-1.
Aggressively Zooming-In to the Galactic L~10^6 OB Cluster-Forming Region G10.6-0.4

Target: G10.6-0.4

Central OB Cluster
Satellite OB Cluster

Hot Toroid
Cavity

Aggressively Zooming-In to the Galactic L~10^6 OB Cluster-Forming Region G10.6-0.4

Aggressively Zooming-In to the Galactic L~10^6 OB Cluster-Forming Region G10.6-0.4

VLA CS 1-0 Flux Map
Target: G10.6-0.4

Central OB Cluster
Satellite OB Cluster

Hot Toroid
Cavity


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Progressively Tracing the Rotation Curve From Outer to Inner Region by Observing Multiple Molecular Line Tracers


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Decreasing Specific Angular Momentum in a Toomre Unstable Flattened Rotating Accretion Flow

\[ \text{Specific Angular Momentum (km s}^{-1}\text{pc)} \]

- \( \cdot \circ \) : The \( ^{13}\text{CS} \) (5–4) data
- \( \circ \) : The \( \text{NH}_3 \) data
- \( \times \) : The \( \text{CH}_3\text{CN} \) data

\( \text{NH}_3 \) (1,1) (Keto et al. 1987)
\( \text{NH}_3 \) (1,1) (Ho et al. 1986)
\( \text{CS} \) J=1–0 (Omoda et al. 1992)
\( \text{NH}_3 \) (3,3) (Keto et al. 1987)
\( \text{NH}_3 \) (3,3) (Keto et al. 1987, 1988)

\[ \text{Toomre Q} \]

\[ \text{radius (pc)} \]

G10.6–0.4 stability

Liu 2012, PhD, Thesis

2016 Aug. 13 EAO-JCMT seminar
Showing Significant Asymmetry in Position-Velocity Diagram

Liu 2012, PhD, Thesis

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Now we know that the dominant features are in a flattened rotating structure. Why not look for a “face-on” one?
CSO-SHARC2 0.35 mm imaging resolved the accreting molecular filaments towards the sub-parsec scale, ~3000 Msun OB cluster-forming molecular clumps G33.92+0.11 A and B.

ALMA Cycle-1 observations of 1.3 mm dust continuum showed that the <0.5 pc scale spiraling arm-like structures are cradles to form massive molecular cores.

Liu, Hauyu Baobab et al, 2015
ALMA Cycle-1 observations of 1.3 mm dust continuum showed that the <0.5 pc scale spiraling arm-like structures are cradles to form massive molecular cores.


(Liu et al. 2015)
Gas structure is flattened in the central 0.3 pc radius, and formed spiraling gas arms. These gas arms are indeed the cradles of satellite dense molecular cores and intermediate/high-mass stars.

Numerical Simulation for the Cluster-Formation on the Much Smaller Scale

ALMA Cycle-1 Image of 1.3 mm Dust Continuum Emission (Liu et al. submitted.)
Velocity Maps From Different Tracers

(Liu et al. 2015)
Velocity Gradient: Hot Cores and Massive Molecular Clump

(Liu et al. 2015)
Low-mass Cluster-Forming Region L1287

Juarez & Liu et al. in prep.

Carmen Juarez Rodriguez (IEEC)

Juarez & Liu et al. in prep.
The Case of Intermediate Star-Forming Region NGC6334V

Location of embedded intermediate mass stars

Hashimoto et al. 2007, PASJ, 59, 221

Carmen Juarez Rodriguez (IEEC)
The Case of Intermediate Star-Forming Region NGC6334V

Poloidal Field on large scale

Toroidal Field at the center
Lu et al. (2014); Lin et al. 2016
1. We develop a routine to iteratively fit and yield ~10 resolution dust temperature and column density maps, with little or no loss of extended structures.

2. The high quality, high resolution images are pointing us to a new way of looking at the problem. Molecular clouds form in different physical conditions, may have different geometry/morphology, and the subsequent star-forming activities. (Obvious, since stellar clusters are not all the same either)

3. Very dense, parsec scale molecular gas clumps may only form when there is a highly centrally concentrated molecular cloud structure, which is conducive or is a consequence of cloud global gravitational collapse. Molecular gas in such system seems relatively well self-shielded, and therefore has a better chance to form gravitational bound stellar cluster.
Thank You Very Much