ALMA observations: Researchers reveal dynamic view of massive protocluster evolution

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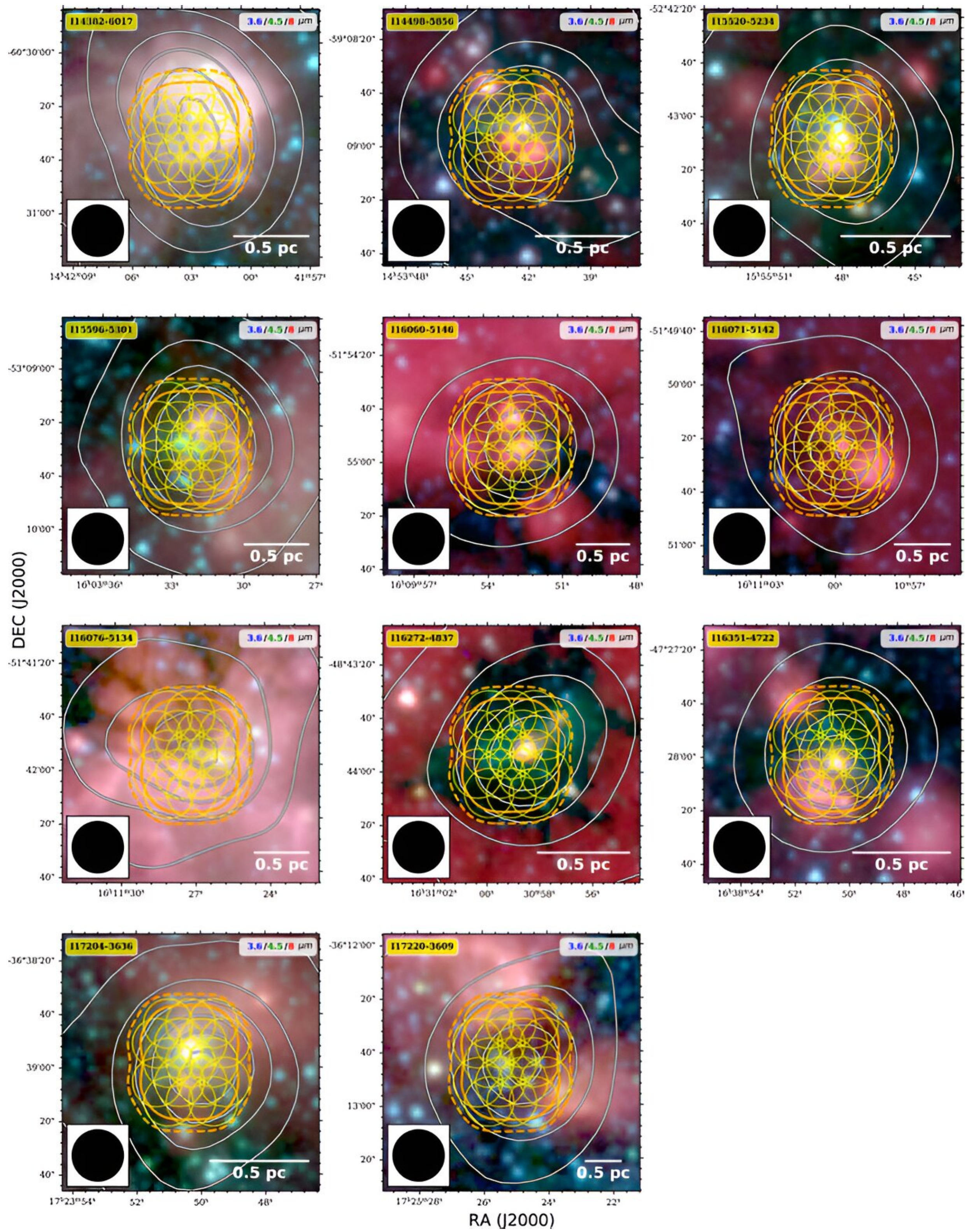

Showcase of the ASSEMBLE sample. Credit: *The Astrophysical Journal*

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A team of researchers has jointly launched the ALMA Survey of Star formation and Evolution of Massive Protoclusters with Blue-profiles (ASSEMBLE) project. They revealed the growth in mass and density of cluster members, along with increasing proximity and mass segregation as the clusters evolve, and proposed a comprehensive formation and evolution scenario for these massive protoclusters.

Their findings are published in *The Astrophysical Journal Supplement Series*.

Understanding mass assembly, including fragmentation and accretion processes, is challenging due to the time dependent and therefore dynamic nature of these processes. Observations offer only a series of snapshots of the entire lifetime of massive protoclusters. The predictions of theoretical models and numerical simulations with observations of massive clumps across a wide range of evolutionary stages have been compared. Research focusing on specific cases or stages has offered valuable insights.

The new study was conducted by scientists from Shanghai Astronomical Observatory of the Chinese Academy of Sciences (CAS), National Astronomical Observatory of CAS, Peking University, Yunnan University, Guangzhou University, and other institutions.

ASSEMBLE utilized the Atacama Large Millimeter/submillimeter Array to observe 11 massive star-forming regions with a deep integration and a large mosaic. Eleven massive clumps with Ultra-compact (UC) HII regions served as the pilot sample. These clumps are thought to harbor massive protoclusters in a late stage, as evolved versions of 12 massive starless infrared dark clumps in another project called ALMA Survey of 70-um Dark High-mass Clumps in Early Stages (ASHES).

"We're excited to find highly consistent angular resolution, sensitivity, and field of view between two surveys, which is the best for comparative studies," said Xu Fengwei, the first author of the paper.

The ASSEMBLE team made a census of 248 dense cores in the 11 protoclusters and found that late-stage ASSEMBLE protoclusters show systematic increment in dense core mass and surface density compared to the early-stage ASHES protoclusters. The team also found a clear correlation in the ASSEMBLE sample, between the clump mass and the most massive core mass, but not seen in the ASHES sample, which indicates a co-evolution regulated by continuous mass accretion from clump to core scale.

Additionally, the ASSEMBLE team discovered that the dense cores in the ASSEMBLE protoclusters exhibit significantly closer proximity compared to those in the ASHES protoclusters.

This finding aligns with the predictions of a theoretical dynamic model where dense cores are driven inwards by gravitational potential of parent massive clump.

"Such model anticipates rapid mass accretion on the clump scale, exactly as viewed from our APEX HCN (4–3) and CO (4–3) line survey," said Liu Tie from Shanghai Astronomical Observatory.

In star clusters, stars frequently exchange kinetic energy through binary interactions, leading to an equal distribution of this energy. As a result, larger mass stars lose energy and sink towards the center of the cluster, while smaller mass stars, gaining energy, are distributed more on the periphery.

This phenomenon is referred as mass segregation. Debate persists over whether mass segregation is purely a dynamical effect or is inherited from the primordial protoclusters. Only a limited number of research teams have sought the so-called "primordial mass segregation."

Recently, the ASHES team reported no discernible primordial mass segregation in the initial stage of massive star cluster formation. However, it reported that a significant number of the ASSEMBLE protoclusters exhibit evident mass segregation.

More interestingly, such dynamic evolution of mass segregation, observed by both ASHES and ASSEMBLE, cannot be explained by a pure dynamical effect since the dynamical relaxation timescale of the system is far longer than the lifetime of these protoclusters.

In contrast, the observed mass segregation aligns well with the "competitive accretion" model where cores tend to accumulate more mass within deeper gravitational potentials.

"The observed primordial mass segregation shed light on the mass segregation problem in star clusters, and it also changes the traditional view of the origin of mass segregation," said Xu.

Based on the above findings, the ASSEMBLE team proposed a comprehensive dynamic perspective on massive protocluster evolution. At the initial stage, the protocluster originates from thermal Jeans fragmentation, with wide separation and no mass segregation. Subsequently, filamentary structures act as "conveying belts" and facilitate mass transfer towards the cores, by which the connection between the clump and core is gradually established.

Concurrently, protostars form from dense cores, leading to the heating of gas and dust, and clump transitioning into infrared weak state. Due to the effects of persistent global gravitational collapse and contraction, the protocluster becomes even tighter with narrower core separations and the mass segregation builds up in the late stage.

This study offers a more comprehensive understanding of the evolutionary trajectory of massive protoclusters. The ASSEMBLE team is embarking on a path to capture every moment in the life of protoclusters.

More information: Fengwei Xu et al, The ALMA Survey of Star Formation and Evolution in Massive Protoclusters with Blue Profiles (ASSEMBLE): Core Growth, Cluster Contraction, and Primordial Mass Segregation, *The Astrophysical Journal Supplement Series* (2023). DOI: 10.3847/1538-4365/acfee5

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