ALMA’s view of the initial conditions within a massive protocluster

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CMZ as an analogue for galaxies in the early Universe

- Molecular clouds in the CMZ are indistinguishable from high-red-shift galaxies
- CMZ is \sim 1000 times closer than the nearest star-burst Galaxy
- Extrapolate our knowledge of the detailed physics in CMZ molecular clouds to the most extreme conditions in the early Universe
- Molecular gas reservoir in the CMZ provides a template for studying star formation across cosmological time-scales

Characterize the small-scale fragments within a high-mass protocluster in the CMZ

- Reveal the conditions for star formation in this extreme environment
- Compare to low-mass clouds in the solar neighbourhood
The Galactic Centre: Feeding and Feedback in a Normal Galactic Nucleus

Herschel 70μm image
Molinari et al. 2011
G0.253+0.016: a cold, dense, high-mass clump

Its low dust temperature, large masses, and high density combined with its lack of star-formation, makes it an excellent candidate for a cluster in a very early stage of formation.

Its location in the Central Molecular Zone makes its detailed study relevant for understanding star-formation in galaxies in the early Universe.
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MALT90: hot, dense gas and shocks

See poster by Yanett Contreras

Image: Spitzer/GLIMPSE
Contours: Mopra 90GHz (38")
G0.253+0.016: hierarchical fragmentation?

JCMT 450 μm (image, 0.3pc), MALT90 dense gas (contours, channel maps, 1.2pc)

Sub-structure on smaller scales – hierarchical fragmentation?
We require a significant improvement in the spatial resolution of the dust and kinematics of the gas
ALMA cycle 0 observations

- 90 GHz (3mm) line and continuum emission
  - reveal the location, mass, and kinematics of its small-scale fragments
- 13 point mosaic (primary beam 69")
- Excellent uv-coverage (25 antennas)
  - Synthesized beam 1.7” (0.07 pc)
  - Missing zero spacing information
- Velocity resolution of 3.5 kms^{-1}
- Continuum emission : rms of 20 $\mu$Jy/beam
- Line emission : rms of 0.7 mJy/beam per channel

- Images of 3mm continuum emission (ALMA + SD*)
  - Use 450$\mu$m continuum scaled to 3mm assuming $\nu^{-4}$
- Line integrated intensity images and channel maps (ALMA + Mopra)
  - HCO$^+$, HCN, H$^{13}$CO$^+$, H$^{13}$CN, HNCO, C$_2$H, H$_2$CS, SiO, SO
The Galactic Centre: Feeding and Feedback in a Normal Galactic Nucleus
Column density Probability Density Function

Log-normal with a small excess at high column densities
→ quiescent gas with a small region of active star formation
→ turbulence dominates the initial gas structure

σ = 0.831 ± 0.006
peak = 0.568 ± 0.011
Complex morphology, chemistry

SiO
HNCO
C₂H

The Galactic Centre: Feeding and Feedback in a Normal Galactic Nucleus
The Galactic Centre: Feeding and Feedback in a Normal Galactic Nucleus
Complicated substructure: filaments, shocks

\( \text{H}^{13}\text{CN} \)  \hspace{2cm} \text{H}_2\text{CS} \hspace{2cm} \text{SO}
Intricate network of filaments and arcs

HNCO three colour image
\[ r = v_{\text{channel}} + 1 \]
\[ g = v_{\text{channel}} \]
\[ b = v_{\text{channel}} - 1 \]
Shocked gas

SiO three colour image

\[ r = v_{\text{channel}} + 1 \]
\[ g = v_{\text{channel}} \]
\[ b = v_{\text{channel}} - 1 \]
Cold absorbing filaments

HCO+ three colour image
\[ r = v_{\text{channel}} + 1 \]
\[ g = v_{\text{channel}} \]
\[ b = v_{\text{channel}} - 1 \]
Filaments tracing the magnetic field?

Vectors: 350 $\mu$m polarization
Contours: 350 $\mu$m continuum (CSO)
Dotson et al. 2010
Summary

Identified an extreme cold, dense, high-mass clump that may be a precursor to an Arches-like massive cluster.

Testing cluster formation models can only be achieved with the order of magnitude improvement in sensitivity, angular resolution, and dynamic range provided by ALMA.

ALMA data are magnificent and reveal a wealth of information about the distribution and kinematics of its small-scale fragments.
Thank you

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MALT90: kinematics
Dust column density vs gas column density

Image: dust-derived H$_2$ column density
Contours: Gas H$_2$ column density
Hot skin, cold interior, molecules depleted in centre.
G0.253+0.016: A Baked Alaska?

Dessert: ice-cream surrounded by meringue, baked in a very hot oven for a few minutes. Coined in 1876. February 1 is Baked Alaska Day in the United States.

Herschel dust temperature → externally heated

Optically thick emission systematically red-shifted wrt optically thin tracers → collapsing

Kinematics and an anti-correlation between the gas/dust column density profiles → gas is depleted in cold interior

Hot skin, Cold interior, Molecules depleted in centre