ALMA'S FIRST VIEW OF STAR FORMATION IN THE NEAREST SUPER STAR CLUSTER 30 DORADUS

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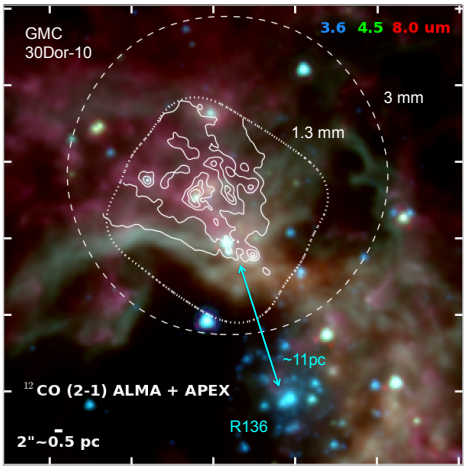

Fig. 1: 3-Color mid-IR image of the 30 Doradus region of the LMC. The fields of view of the Band 3 (3 mm) and Band 6 (1.3mm) ALMA Cycle 0 data are shown by the dashed and dotted lines respectively. The ^{12}CO (2-1) integrated intensity from combining ALMA and APEX data are shown in white contours.

Abstract: As the nearest super-star cluster 30 Doradus in the Large Magellanic Cloud presents a truly unique opportunity to study star formation in an extreme environment. We present ~2" (about 0.5pc) resolution ALMA observations of the molecular cloud North of R136 in the 3mm lines of HCO+, HCN, and CS and 1.3mm lines of CO (2-1) and its isotopologues. The sensitivity of ALMA allows us to spatially resolve the dense gas that actually participates in star formation for the first time in a reduced metallicity extragalactic starburst. These observations reveal filamentary cloud structures as well as dense clumps about 1pc in size coincident with embedded near-IR sources. The results from this study will be invaluable for extrapolation to unresolved observations in the distant Universe.

Overview: The R136 super-star cluster contains > 10^6 stars within a few parsec with a metallicity ~ 0.5 Solar. We observed the GMC 30Dor-10 located ~11pc north of R136 in ALMA Cycle 0 including CO (2-1) and its isotopologues (Band 6), along with HCO+ (1-0), HCN (1-0), and CS (2-1) using Band 3. Fig. 1 shows the region observed. The spatial and spectral resolution of the Band 3 data is 2.5" x 2.0" and 1 km/s.

Interesting results from our recent paper (Indebetouw et al., 2013, ApJ, 774, 73) on the Band 6 CO data combined with total power data from APEX include:

- The GMC (30Dor-10) is resolved into ~100 molecular clumps with CO derived masses of 100-1000 $M_\odot$, radii < 1pc, n(H2) densities 10^3 – 10^5 cm^{-3}, Tex ~ 40K, and line widths 1-3km/s.
- Compared to Milky Way SFRs, the filling fraction is low, with 2/3 the CO line flux contained in <15% of the area.
- Velocity dispersion vs. size shows that clumps in 30Dor-10 have large linewidths for their size similar to the relation found for larger sized clumps (~10pc) in the Central Molecular Zone of the Milky Way and for Infrared dark clouds with sizes < 1pc.
- We find $M_{virial}/M_{H2} = 35 M_\odot\ M_{mol}^{-0.6}$ (see Fig 2), suggestive of pressure confinement of magnetized clumps (Bertoldi & McKee 1992), but this interpretation is not unique.
- Clumps in 30Dor-10 extend to higher surface densities for the same linewidth-size parameter, but many lack SF in the near to mid-IR also suggesting magnetic support.
- The X-factor is consistent with simple scaling by the average LMC metallicity without correction for the extreme radiation field.

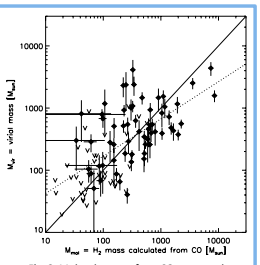

Fig. 2: Molecular mass from CO compared to virial mass. The solid line indicates the M_{vir} = M_{mol} line, while the dotted line shows the best fit to the data: $M_{vir}/M_{mol} = 35\ M_\odot\ M_{mol}^{-0.6}$.

Below we describe preliminary results for the ALMA Band 3 high density tracers HCO+ (1-0), HCN (1-0), and CS (2-1).

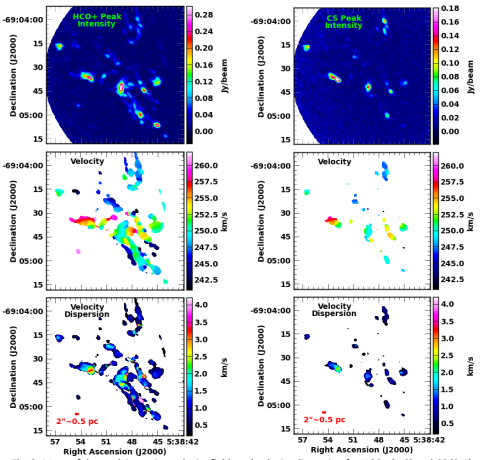

Fig. 3: Maps of the peak intensity, velocity field, and velocity dispersion for HCO+ (1-0) and CS (2-1). While there is excellent kinematic agreement between the two species, no systematic trend with distance from the ionization front is observed. Most of the high velocity dispersion regions in HCO+ are due to the superposition of multiple clumps

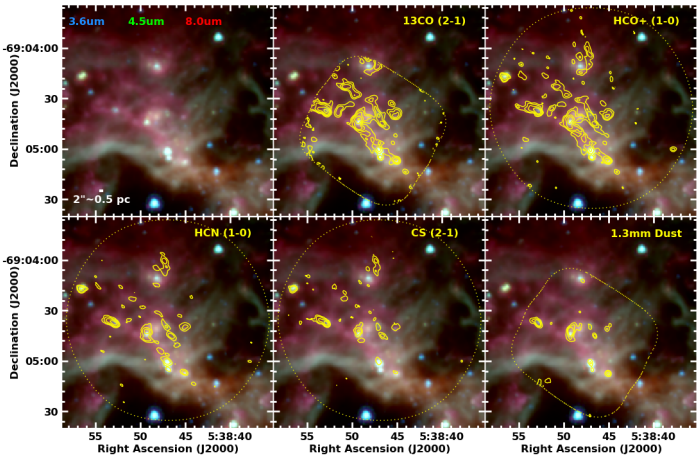

Fig. 4: Zoomed in mid-IR image of the 30Dor-10 region of 30 Doradus with the indicated contours overlaid in yellow. There is excellent morphological agreement between 13CO(2-1) and HCO+(1-0). In contrast, the HCN, CS and the dust emission are more compact. The 1.3 mm "dust" image was created by subtracting the scaled 6 cm ATCA emission from Lazendic et al. (2002).

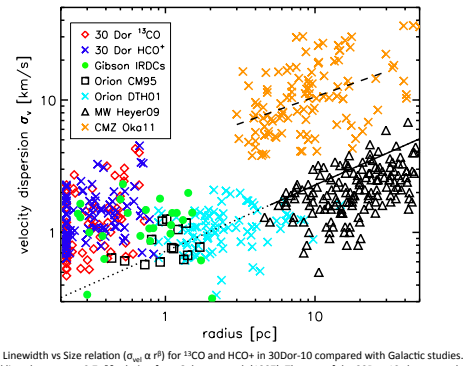

Fig. 5: Linewidth vs Size relation (σ_{vel} α r$^\beta$) for ^{13}CO and HCO+ in 30Dor-10 compared with Galactic studies. The dotted line shows $\sigma_{vel} = 0.7\ r^{0.5}$ relation from Solomon et al. (1997). The σ_{vel} of the 30Dor-10 clumps are larger for a given size than predicted by the Solomon et al. (1997) relation and the observed relation for large-sized clumps (> 1pc) in "normal" Milky Way GMCs like Orion. However, the large linewidth vs size is consistent with that measured for large-sized clumps in the Central Molecular Zone (~10pc) of the Milky Way and for comparable size clumps in Infrared Dark Clouds (Oka et al. 2011; Gibson et al. 2009). The measurements for 30Dor-10 are derived from the 3-D clump finding algorithm "cprops" (Rosolowsky & Leroy 2006). Where the size could not accurately be deconvolved from the 2.5"x2" beam it has been set to ½ half the beam in both dimensions. The results for ^{13}CO and HCO+ in 30Dor-10 are in excellent agreement with each other.

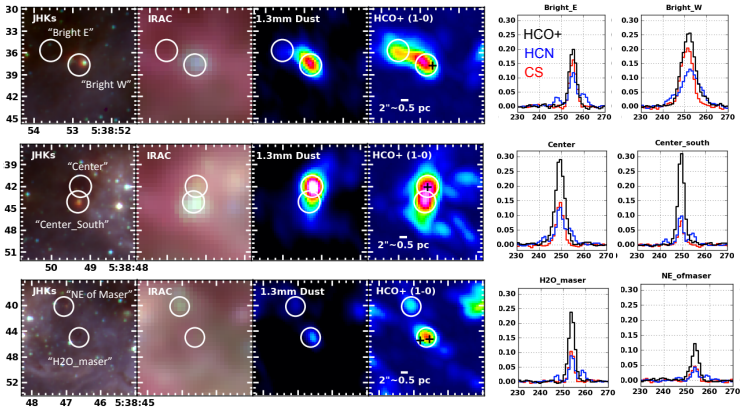

Fig. 7: Multi-wavelength images of selected clumps demonstrating the diversity in SEDs observed. The black crosses show H_2O maser locations from Imai et al. 2012. In particular some of the brighter HCO+ clumps ("Bright E", "Center", "H2O_maser") do not have near or even mid-IR detections though the latter two are sites of H2O maser emission – a signpost for active star formation. Clearly some of the most active regions are still very deeply embedded or at an earlier evolutionary stage. With typical sizes of 0.5 pc, these clumps should be regarded as massive protoclusters rather than individual massive protostars.

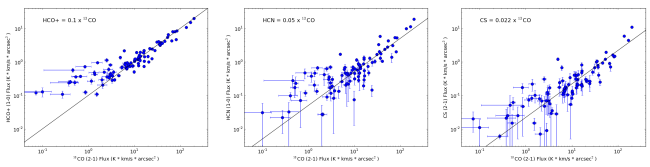

Fig. 6: Comparisons of the line flux measured from the high density tracers with that of ^{13}CO (2-1). The solid line indicates the approximate relation between the flux of the species on the y-axis and that of ^{13}CO (2-1). The correlation at high S/N is quite good.