ALMA Observations of the Large Magellanic Cloud: Molecular Filament Collisions Causing Massive Star Formation in N159 West

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Paper: High-mass star formation triggered by collision between CO filaments in N159 West in the Large Magellanic Cloud (submitted)

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Why Study the Large Magellanic Cloud?

- Distance ~ 50 kpc (one of the nearest)
- Face-on view
- Active Star Formation
  - Massive star formation
  - SAGE survey (Meixner et al. 2006) used to find YSOs
- Different environment than Milky Way
  - Low dust-to-gas ratio (1/3 of MW)
  - Low metallicity (0.5 solar)
  - SFR of 0.1 solar mass/year
- Unbiased Survey

Meixner et al. (2006)
R: MIPS 24, G: IRAC 8.0, B: IRAC 3.6
Why study the N159 GMC?

- One of the largest
  - Mass: \(10^5 M_{\text{sun}}\)
  - Size: \(220 \, pc^2\)
  - Strongest CO peak
  - Actively forming stars

![Map of N159 GMC with CO(J=1-0), CO(J=3-2), and CO(J=4-3) emissions with HPBW 45"

(MOPRA, ASTE, NANTEN)
HST versus. ALMA 13 CO (2-1): Filaments!

R: Spitzer 8 micron, G: HST F555W, B: 13CO(2-1)

HST PI: R. Indebetouw
ALMA PI: Y. Fukui
Filaments Revealed in ALMA 12 m Array 13CO (2-1)

White Crosses: YSOs (Chen et al. 2010)
Red Crosses: 1.3mm continuum peak

Beam Size: 1.1"
Formation of Massive Cores

- Filamentary collisions lead to massive star formation
First Extragalactic Outflows Detected

- Colliding Filaments
  - Velocity difference: 2-5 km/s
- Massive YSO in the center of collision
Fitting the SED to Derive Stellar Parameters of Stage 0/I YSOs

\[
\begin{align*}
YSO - N \\
M_{\text{star}} &= 33 \pm 5 \, M_{\odot} \\
t_{\text{star}} &= (40 \pm 4) \times 10^3 \, \text{yr}
\end{align*}
\]

\[
\begin{align*}
YSO - S \\
M_{\text{star}} &= 36 \pm 4 \, M_{\odot} \\
t_{\text{star}} &= (38 \pm 8) \times 10^3 \, \text{yr}
\end{align*}
\]

Photometry From: IRSF JHK, Spitzer IRAC, Spitzer MIPS, Herschel PACS, and Herschel SPIRE

Other photometric points extracted from Spitzer IRS spectrum

SED fitter by Robitaille et al. (2006, 2007)
YSO-N is More Evolved

- $N_e = 2.5 \times 10^3 \, cm^{-3}$
- $M_{ionized} = 350 \, M_{sun}$
- $EM = 6.3 \times 10^5 \, pc \, cm^{-6}$
- $U = 170 \times 10^3 \, pc \, cm^{-2}$
- $N_c = 1.5 \times 10^{50} \, s^{-1}$
- Spectral Type = O3
Conclusions

• We detect filaments
• Colliding filaments create massive stars
• We detect outflows associated with massive star formation for the first time outside our own Galaxy
• Difference between YSO-N and YSO-S shows evidence for evolution of environment
• Look for Fukui et al paper (coming soon)
• These are early results, more exciting things to come!
ALMA 12CO(2-1)

 Flux density (Jy km/s)

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<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
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<tbody>
<tr>
<td>A</td>
<td>196</td>
<td>48.4</td>
<td>65.8</td>
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<tr>
<td>B</td>
<td>785</td>
<td>151</td>
<td>168</td>
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ALMA 12m Array Image of 13CO(1-0)

Image made by: T. Onishi