Resolved CO filaments in N159; Evidence for filament-filament collision triggering high-mass star formation

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Filamentary Structures in Molecular Clouds
Charlottesville, October 10-11, 2014
Large scale observations

CO: NANTEN
40 pc resolution
(Fukui et al. 2008)

Spitzer survey of the LMC
SAGE: Surveying the Agency
of the galaxy’s evolution
(Meixner et al.)

GMCs, HI, dust, YSOs, HII regions, SNRs, ...
throughout the galaxies.

3.6μm
8.0μm
24μm
1” - 8”
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N159
N159: Most active on-going star formation in the Local Group: Resolving filaments and cloud cores in the LMC

Y. Mizuno et al. 2010

Fukui [PI]
Yamamoto
Ohama
Onishi
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Long filaments in N159W

ALMA Band6 12m-array 13CO J=2–1
Star formation in N159W [ALMA cycle1]

Filaments dominate the CO distribution
• Filaments are massive 1000Mo
• Filaments are colliding to form high-mass stars
  ---First discovery of molecular outflows outside the Galaxy
  ---Inflow along the filaments?
• Collision amplifies turbulence and B field
  ---MHD numerical simulations (Inoue Fukui 2013)
• Large dM/dt 1e-3 Mo/yr rapidly forms high-mass stars
  (Tan McKee 2003; Wolfire Cassinelli 1987)

Evidence for cloud-cloud collisions in the Galaxy
• Four super star clusters: Westerlund 2, NGC3603, RCW38 and DBS[2003]179
  (Furukawa+2009; Ohama+2010; Fukui+2014)
• Star burst regions: NGC6334, NGC6357
• Spitzer bubbles: RCW120, M20 (Torii 2011; 2014)
- **left**
  - **color**: $^{12}$CO(2-1) integrated intensity
  - **contour**: continuum

- **right**
  - **color**: continuum
  - **white contour**: continuum
  - **blue**: $^{12}$CO(2-1) integrated intensity (Blue)
  - **red**: $^{12}$CO(2-1) integrated intensity (Red)
• left
  
  color: 12CO(2-1) integrated intensity
  contour: continuum

• right
  
  color: continuum
  white contour: continuum
  blue: 12CO(2-1) integrated intensity (Blue)
Long filaments in N159W

ALMA Band6 12m-array 13CO J=2–1

223.0 - 247.5 km/s

05°39'45" 35°

Right Ascension (J2000)

05°39'44" 40°

Right Ascension (J2000)

-69°46'30"

Declination (J2000)

Jy/beam km/s

5 pc

blue

red
Inoue & Fukui 2013

$z = 7.992 \text{ pc}, \ \text{Time} = 0.900 \text{ Myr}$
Filament-filament collision
Cloud-cloud collision rapidly triggers formation of massive dense cores: MHD simulations

Inoue and Fukui 2013

Fig. 1.—Schematics of the gas stream before (left) and after (right) the interaction between a shock and a dense blob. Because the deformed shock wave leads to a kink of stream lines across the shock, stream lines are headed toward convex point of the deformed shock wave.
Collision amplifies turbulence and B field

\[ M_{J,\text{eff}} \equiv \frac{\langle c_s \rangle^3 + \langle c_A \rangle^3 + \langle \Delta v \rangle^3}{G^{3/2} \langle \rho \rangle^{1/2}} \]
Lesson on the Galactic mini-starburst: NGC3603

◇ one of SSC in the Milky Way

◇ Carina arm 
(l, b) = (291.6, -0.5)

◇ Distance: 6-8 kpc 
(e.g. Russeil 2003)

◇ Total mass of stars: >10^4 M_{\odot} 
(Harayama et al. 2008)

◇ Age : 1-3 Myr 
(e.g. Sung & Bessell 2004)

◇ O type Star: more than 30 
(Moffat et al. 2004)

◇ WR: 1-4 
(Schmutz W. et al. 1999)

◇ Star formation in progress 
(Stolte et al. 2004)

WISE&HST credit: NASA/JPL-Caltech/UCLA
NGC3603 star formation is quick, in $10^5$ yrs

Fukui et al. 2014

Kudryavtseva et al. 2012

Figure 4. Normalized $L(t)$ for NGC 3603 YC at DM = 14.1 mag. The most probable age is 2.0 Myr. The red curve is a fitted Gaussian function.
Star formation in N159W [ALMA cycle1]

Filaments dominate the CO distribution
- Filaments are massive 1000Mo
- **Filaments are colliding to form high-mass stars**
  --- First discovery of protostar outflows [1e4 yrs] in the LMC
  --- Inflow along the filaments? perhaps “no time”
- **Collision amplifies turbulence and B field**
  --- Numerical simulations (Inoue Fukui 2013)
- **Large dM/dt 1e-3 Mo/yr rapidly [1e5 yrs] forms high-mass stars**
  (Tan McKee 2003; Wolfire Cassinelli 1995)

Evidence for cloud-cloud collisions in the Galaxy
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