Enhanced Momentum Feedback from Clustered Supernovae

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11 Aug 2016 --- UCSC Galaxy Workshop

arXiv:1606.01242
Why SNe feedback models?

\[(t - t_{SN}) = 3.38 \times 10^6 \text{ yr}\]

Diagram showing the density [g cm\(^{-3}\)] as a function of radius [pc]. The graph indicates efficient cooling at certain points. The time difference \(t - t_{SN}\) is marked as 3.38 million years.
Momentum-driven rather than Energy-driven feedback model

Single SN simulations
Momentum-driven rather than Energy-driven feedback model

Single SN simulations

- Energy remnant keeps decreasing over time.
- Asymptotes reached in the plot.
Momentum-driven model

\( p \approx 3000 \quad (100 \, M_\odot) \, \text{km s}^{-1} \)

Ostriker & Shetty (2011)
Momentum-driven model

\[ p \approx 3000 \left( \frac{n_H}{1 \text{ cm}^{-3}} \right)^{1/7} \ (100 \, M_\odot) \, \text{km s}^{-1} \]

Ostriker & Shetty (2011)
Cioffi+98
What about non-isolated SNe?

R136 in 30 Dor
50 pc

>70 O stars
Within inner 5pc
Our simulations
$$t - t_{\text{first SN}} = 9.10 \times 10^5 \text{ yr}$$

Gentry+16 (in prep.)
$t - t_{\text{first SN}} = 1.09 \times 10^7 \text{ yr}$

$\rho \left[ \text{g cm}^{-3} \right]$ vs. $R \left[ \text{pc} \right]$ and $t \left[ \text{Myr} \right]$

$E_{R, \text{tot}} \left[ \text{ergs} \right]$ and $\frac{\rho}{100 M_{\odot}} \left[ \text{km s}^{-1} \right]$
\( (t - t_{\text{first, SN}}) = 5.01 \times 10^7 \, \text{yr} \)
Our simulations

- Hydro: 1D Lagrangian Riemann solver (Duffel+16)
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• Realistic IMF, stellar lifetimes, SN ejecta (Kroupa+02, Ekström+12, Woosley&Heger+07)
  • Fixed: $E / N_{SN} = 10^{51}$ ergs
Our simulations

- Hydro: 1D Lagrangian Riemann solver (Duffel+16)
- Cooling: GRACKLE
- Realistic IMF, stellar lifetimes, SN ejecta (Kroupa+02, Ekström+12, Woosley&Heger+07)
  - Fixed: $E / N_{SNe} = 10^{51}$ ergs
- Evolved until momentum reached a maximum
Results
Key results

Only showing simulations with $Z = Z_\odot$, $\rho = 1.33 \, m_H \, \text{cm}^{-3}$
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Each SN is in lower density background.
Key results

Only showing simulations with $Z = Z_\odot$, $\rho = 1.33 \, m_H \, cm^{-3}$

Predicted:
\[ \frac{p}{N} \sim N^{-0.08} \]

Data:
\[ \frac{p}{N} \sim N^{-0.07 \pm 0.02} \]
Uncertainties

• 2 phase media?
  (CG Kim & Ostriker+15, CG Kim et al. in prep.)
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• Disk shear?
• Galactic gravity?
• Disk breakout?

Mac Low +89
Summary & Case Study

- Clustered SNe in R136 could increase momentum budget by 10x

- Bubble would grow to 1 kpc over 150 Myr
  - LMC size: 4 kpc
  - Bubble evolution not easily separable from galactic evolution

- SNe momentum budget remains quite uncertain
Additional Slides
\[ (t - t_{\text{first SN}}) = 0.00 \times 10^0 \text{ yr} \]

\( \rho \quad [\text{g cm}^{-3}] \)

\( E_{R,\text{tot}} \quad [\text{ergs}] \)

\( \frac{\rho}{100 M_\odot N_{\text{SNe}}} \quad [\text{km s}^{-1}] \)

\( R \quad [\text{pc}] \)

\( t \quad [\text{Myr}] \)

Gentry+16 (in prep.)
\[(t - t_{\text{first SN}}) = 3.15 \times 10^7 \text{ yr}\]
More momentum than expected!

Peak: 30,000

Expected: 3,000

\[
\frac{dN_{\text{cluster}}}{dN_{\text{SNe}}} \propto N_{\text{SNe}}^{-2}
\]

\[
\frac{dN_{\text{cluster}}}{dM_{\text{cluster}}} \propto M^{-2}
\]

\[
\frac{dN_{\text{cluster}}}{d \log N_{\text{SNe}}} \propto N_{\text{SNe}}^{-1}
\]

\[
\left< \frac{p}{N_{\text{SNe}}} \right> = 25,000 \pm 1,000 \frac{100 M_\odot \text{ km}}{s}
\]

\[
\left( \left< N_{\text{SNe}} \right> = 6 \right)
\]
Effects of 3D vs. 1D?

Low Res. (2.5 pc)
Low resolution leads to overcooling

Eulerian (2.5 pc)  

Lagrangian (0.06 pc)
Comparison to Keller+14

\[ \frac{p}{(100 M_{\odot} N_{\text{SNe}})} \text{ [km s}^{-1}] \]

Keller+14
Comparison to Keller+14
Other stellar feedback: Pre-SN HII Regions

Ionizing radiation from massive stars creates HII regions

HII regions expand, adding momentum and decreasing the gas density

This directly adds momentum
- \( p_{HII} \approx 50\% p_{SNe} \)

This changes effective density
- Changes momentum by a few percent
Other stellar feedback:
Type Ia SNe

Type Ia SNe can have an impact,
But that impact is smaller than the model’s uncertainties