2D HD simulations of SSC in a bimodal regime

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Super star clusters:

- observed in variety of starburst galaxies at all redshifts (Ho, 1997)
- masses: \(M_{SC} \sim 10^5 - 10^7 \, M_{\odot}\)
- radii: \(R_{SC} \sim 3 - 5 \, \text{pc}\)
  \(\rightarrow\) very compact
- age: \(< 500 \, \text{Myr}\)
- \(L_{\text{mech}} \sim 10^{40} - 10^{42} \, \text{erg/s}\)
- stellar winds and SN return \(\sim 40\% M_{SC}\) back into ISM
Physical model of SSC wind

- SW and SN energy thermalized (efficiency $\eta$)
- 4 parameters: $\eta$, $R_{SC}$, $L_{SC}$ and $\dot{M}_{SC}$
- $L_{SC}$ and $\dot{M}_{SC}$ coupled:
  \[ v_{a,\infty} = \sqrt{\frac{2L_{SC}}{\dot{M}_{SC}}} \]
  if a stellar population assumed

- Catastrophic cooling: (Silich et al., 2004)
  - energy input rate: $L_{SC} \propto M_{SC}$
  - cooling rate: $\left. \frac{de}{dt} \right|_{\text{cool}} \propto \rho^2 \propto \dot{M}_{SC}^2 \propto M_{SC}^2$
Critical luminosity

- stationary solution for $L < L_{\text{crit}}(R_{\text{SC}}, v_\infty, \eta)$
Quasi-adiabatic and radiative solution

\begin{itemize}
  \itemlog T \_\text{w} \,[K], \log n \_\text{w} \,[pint^{-1}]
  \item velocity
  \item quasi-adiabatic (Chevalier and Clegg, 1985)
  \item temperature
  \item particle density
  \item sound speed
\end{itemize}

\begin{align*}
\log T \_\text{w} & = 8 \\
\log n \_\text{w} & = 6
\end{align*}

\begin{align*}
\text{velocity} & = 1000 \\
\text{temperature} & = 800 \\
\text{particle density} & = 600 \\
\text{sound speed} & = 500
\end{align*}

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Quasi-adiabatic and radiative solution

![Graph showing temperature, velocity, and particle density variations with radius. The graph includes curves for temperature and velocity for quasi-adiabatic and radiative solutions. The curves are labeled with references from Chevalier and Clegg (1985) and Silich et al. (2004).]
Critical luminosity

- bimodal solution for \( L > L_{\text{crit}}(R_{\text{SC}}, v_{\text{a,}\infty}, \eta) \)

![Graph showing critical luminosity and bimodal solutions for different conditions.](image-url)
Bimodal solution
Tenorio-Tagle et al. (2007)
Numerical simulations

- ZEUS, 2D spherical coords, radially scaled, 1 radian
- new cooling (both global time-step control and substeps)
- \( R_{SC} = 10 \text{ pc}, \ L_{SC} = 10^{43} \text{ erg/s} \ v_{a,\infty} = 1000 \text{ km/s}, \ T_{\text{min}} = 10^4 \text{ K} \)
Velocity and "line profile"

- Left: magnitude of velocity of $10^4$ K gas
- Right: column density (projected radius, radial velocity)
- 2 components of outflowing warm material
Mass flux as function of radius

- semi-anl: includes hot/warm wind only
- numerical: includes both hot/warm wind and clumps
- substantial amount of mass stays inside cluster → eventually available for SF

![Graph showing mass flux as a function of radius](image)
Outflow from the cluster for different models

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Conclusions

- 2D simulations confirm bimodal behaviour: outer part of cluster produces the quasi-stationary wind, thermal instability forms dense warm clumps in the inner region
- warm $10^4$ K outflow from the cluster consists of two components: originally hot wind that cools down and ejected clumps formed in the central region
- ejected clumps carry only small amount of inserted mass (10% or less), most of mass inserted below $R_{st}$ stays in the cluster
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References

L. C. Ho 1997, RMxAA, 6, 5