Catastrophic cooling in super star cluster winds

positive feedback on star formation

(R. Wünsch, J. Palouš, G. Tenorio-Tagle, S. Silich)

Super star clusters:

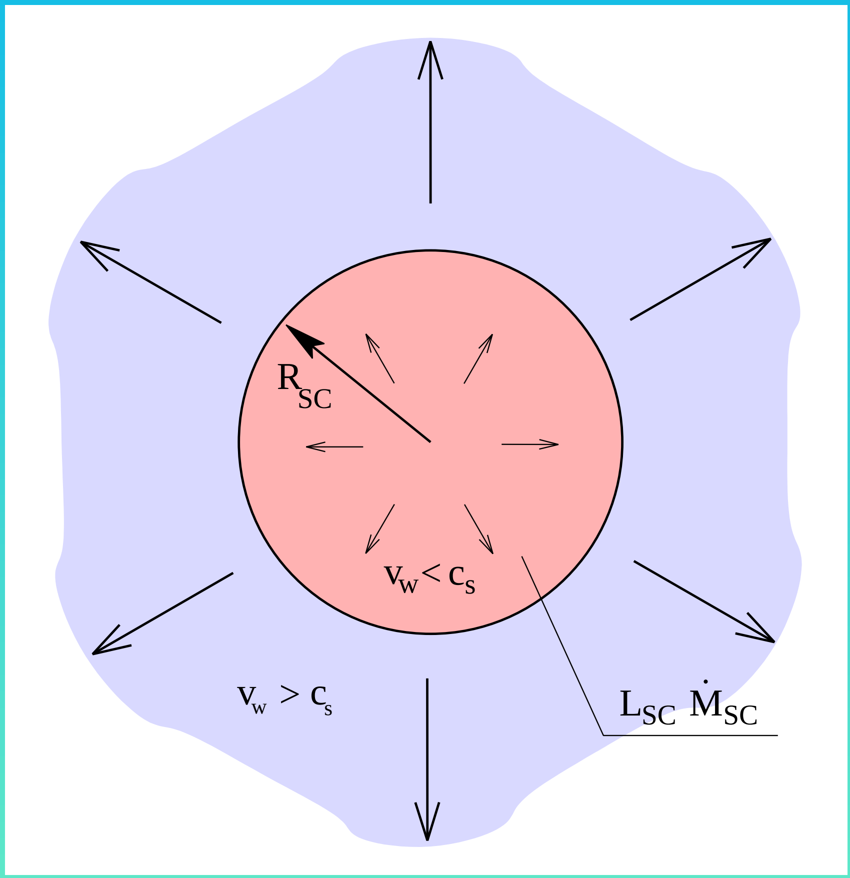
- observed in variety of starburst galaxies at all redshifts (Ho, 1997)
- masses: $M_{\rm SC} \sim 10^5$–10^7 M$_\odot$
- radii: $R_{\rm SC} \sim 3 - 5$ pc
  $\rightarrow$ very compact
- age: < 500 Myr
- $L_{\rm mech} \sim 10^{40} - 10^{42}$ erg/s
- stellar winds and SN return $\sim 40\% M_{\rm SC}$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

Physical model of SSC wind

- SW and SN energy thermalized
- 3 parameters: R_{SC}, L_{SC} and $\dot{M}_{\mathrm{SC}}$
- L_{SC} and $\dot{M}_{\mathrm{SC}}$ coupled:

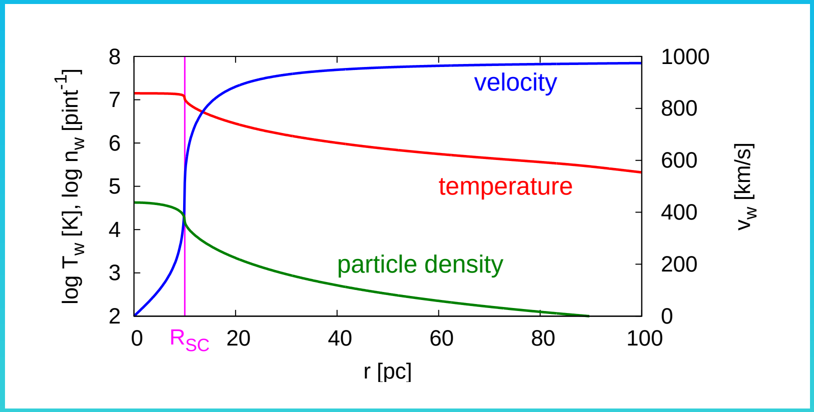
$$v_{a,\infty} = \sqrt{\frac{2L_{\mathrm{SC}}}{\dot{M}_{\mathrm{SC}}}}$$

if a stellar population assumed



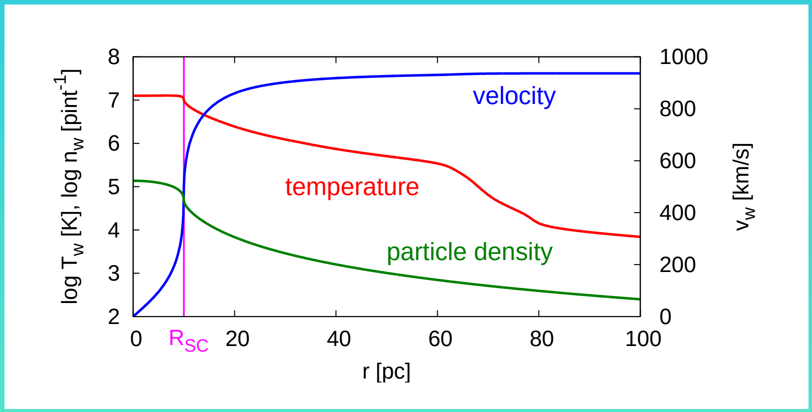
- Catastrophic cooling:
  energy input rate: $L_{\mathrm{SC}} \propto M_{\mathrm{SC}}$
  cooling rate: $\frac{de}{dt}\Big|_{\mathrm{cool}} \propto \rho^2 \propto \dot{M}_{\mathrm{SC}}^2 \propto M_{\mathrm{SC}}^2$

Wind solution types



Quasi-adiabatic (Chevalier & Clegg, 1985)

- low L_{SC}, $\dot{M}_{SC}$; large R_{SC}
- too high X-ray flux

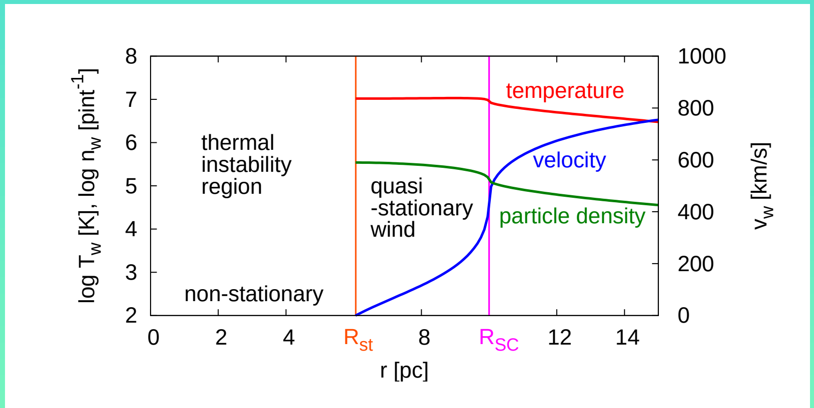


Radiative (Silich et al., 2004)

- moderate L_{SC}, $\dot{M}_{SC}$ and R_{SC}
- T_w drops outside the cluster

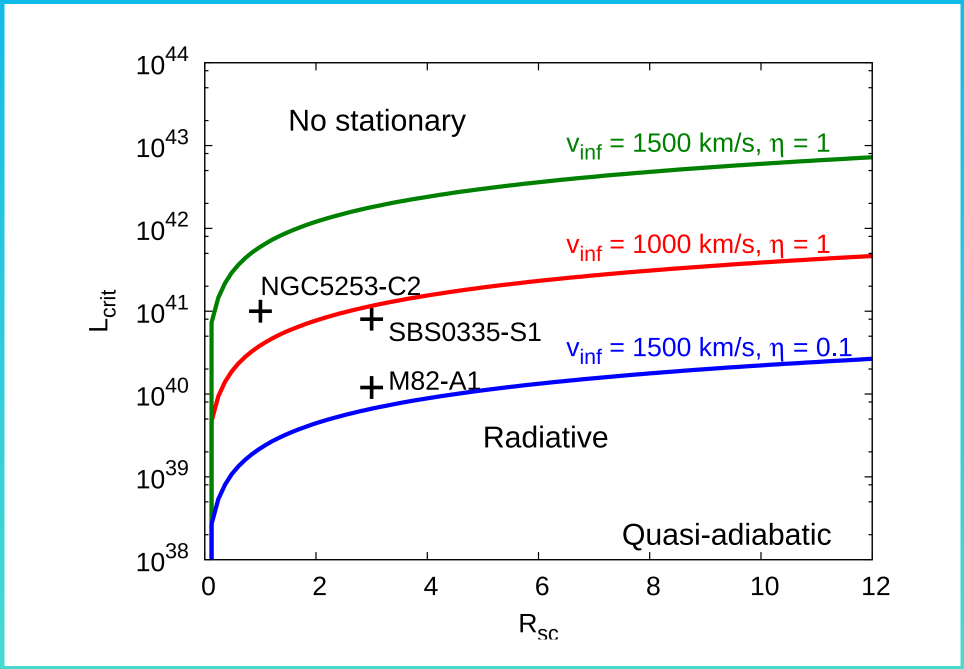
Bimodal (Wünsch et al., 2007)

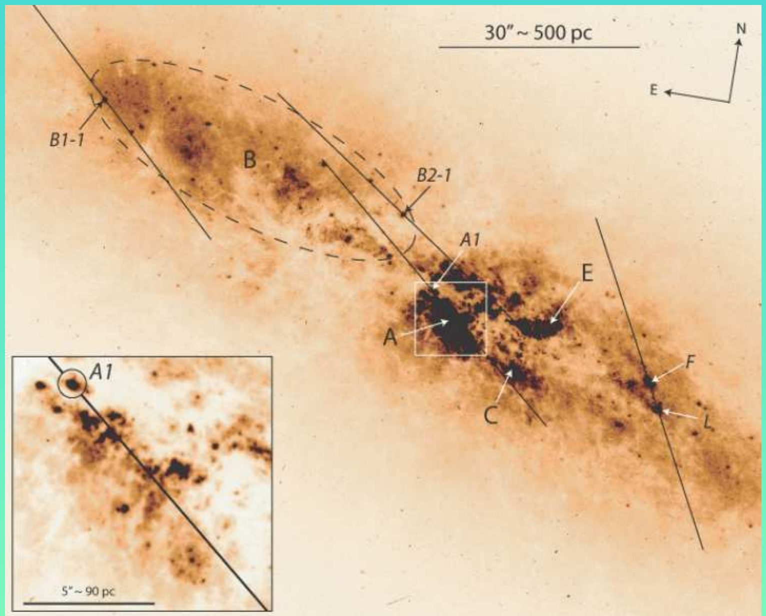
- high L_{SC}, $\dot{M}_{SC}$; small R_{SC}
- $r < R_{st}$: thermal instability region
  $r > R_{st}$: quasi-stat. wind region



Critical luminosity

- bimodal solution for $L > L_{\rm crit}(R_{\rm SC}, v_{a,\infty}, \eta)$
- uncertainty in $v_{a,\infty}$ and η - thermalization efficiency
- clusters with $L \sim L_{\rm crit}$ observed





- M82-A1 associated with HII region:

$R_{SC} = 3$ pc

$L_{SC} = 10^{40}$ erg/s

$R_{HII} = 4.5$ pc

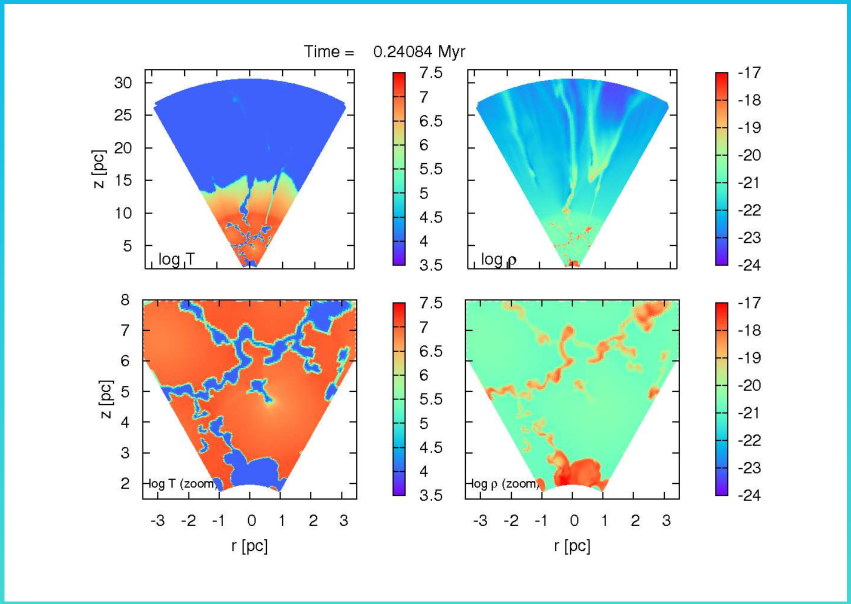
$n_{HII} = 1800$ cm^{-3}

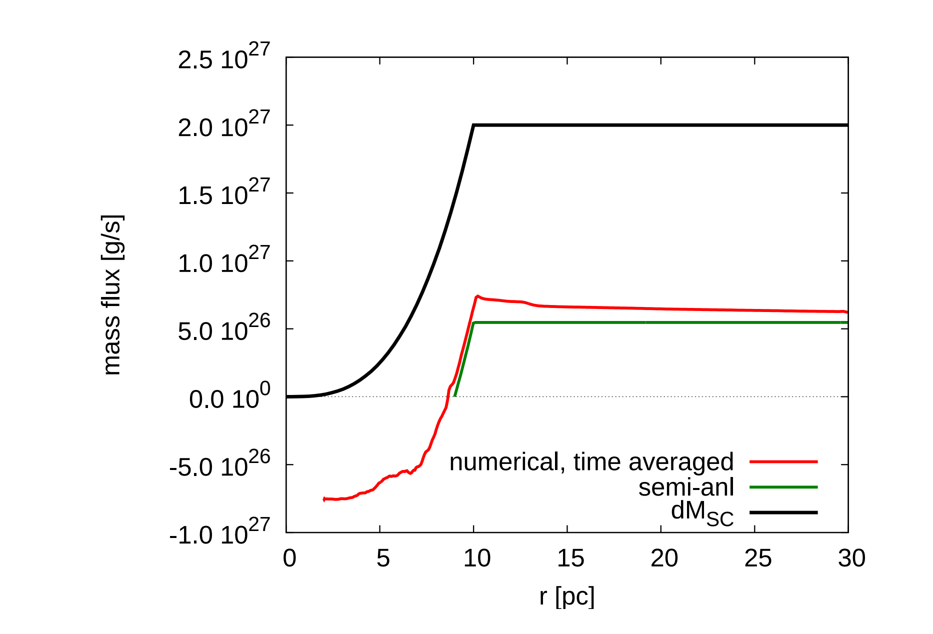
FWHM$_{HII} = 62$ km/s

(Smith et al., 2006)

Numerical simulations

- ZEUS, 2D or 3D RTP, new cooling mechanism (both global time-step control and substeps)
- $R_{\rm SC} = 10$ pc, $L_{\rm SC} = 10^{43}$ erg/s $v_{a,\infty} = 1000$ km/s, $T_{\rm min} = 10^4$ K





- time-averaged mass out-flow close to semi-anl. value

$$\frac{\dot{M}_{\rm out}}{\dot{M}_{\rm SC}} \approx \left(\frac{L_{\rm SC}}{L_{\rm crit}}\right)^{-0.46}$$

- most of clumps fall into the center, few ejected from the cluster

Computed models

$L_{\rm SC}$ [erg/s]	dim	grid	$M_{\rm SC}$	$\dot{M}_{\rm IB}/\dot{M}_{\rm SC}$	$\dot{M}_{\rm OB}/\dot{M}_{\rm SC}$
10^{42}	1	semi-anl.	0	-22%	78%
10^{42}	1	1200	0	-21%	77%
10^{42}	2	150x56	0	-12%	76%
10^{42}	2	300x112	0	-11%	78%
10^{42}	2	600x224	0	-14%	77%
10^{42}	2	150x56	10^6	-14%	78%
10^{42}	2	300x112	10^6	-15%	80%
10^{42}	3	150x56x56	10^6	-15%	70%
10^{43}	1	semi-anl.	0	-73%	27%
10^{43}	1	1200	0	-21%	31%
10^{43}	2	300x112	10^6	-42%	31%
10^{44}	1	semi-anl.	0	-91%	8.8%
10^{44}	1	1200	0	-53%	8.7%
10^{44}	2	300x112	10^6	-33%	13%

Summary

- three qualitatively different types of SSC wind solution: quasi-adiabatic, radiative (temperature drops outside the cluster), and bimodal (thermal instability, non-stationary)
- bimodal regime: outer part of cluster produces the quasi-stationary wind, thermal instability forms dense warm clumps in the inner region
- most of the clumps tend to stay inside the cluster $\rightarrow$ SF, few of them ejected from the cluster

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References

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