Catastrophic cooling in super star cluster winds

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Abstract:

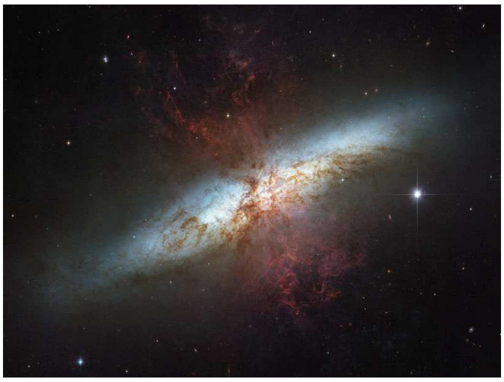
An extremely intensive star formation takes place in the so called starburst galaxies. The best known example is probably the nearby Cigar Galaxy (M82). The stars are formed there in massive compact clusters which consist of approximately million of stars each. A significant fraction of the star mass is released into the interstellar medium, either in a form of the stellar winds or during the supernova explosions. The mechanical energy carried by this mass is quickly thermalized in shock-shock interactions. It leads to a cluster filled by the very hot ($\sim 10^7 K$) high pressure gas resulting in a powerful wind blowing away from the cluster with the velocity of an order 1000 km/s.

In this project we study the so called thermal instability which causes that some regions of the wind may cool down to 10^4 K very quickly thanks to the radiation emitted by heavy elements. Such regions collapse into dense clumps in which new stars may form. This mechanism may be important for understanding the formation of globular clusters where the high star formation efficiency is needed. We perform numerical models of winds driven by super star clusters taking into account radiative cooling. The importance of the cooling for the wind dynamics depends on the properties of the central cluster, that are the energy and mass deposition rates $\dot{E}$ and $\dot{M}$, and the cluster radius R_{sc}. The low energetic clusters are almost adiabatic, and the wind is described by solution discovered earlier by Chevalier & Clegg (1985). However, as the $\dot{E}$ and $\dot{M}$ grow and/or R_{sc} decreases, the cooling starts to be important, and the wind enters the radiative regime in which the wind temperature quickly drops at certain distance from the cluster (Silich et al., 2004). For even higher values of $\dot{E}$ and $\dot{M}$ no stationary wind solution exists.

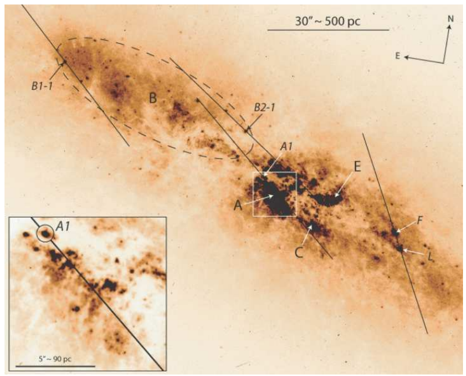
We use hydrodynamic code ZEUS for which we develop the new cooling procedure which is able to treat extremely fast cooling regions. We test our numerical model against semi-analytical solution of the wind in both adiabatic and radiative regimes, and continue exploring properties of the wind in more complicated cases with energy input above the critical value where the outflow starts to be non-stationary. Our 2D simulations suggest that another non-stationary regime of the wind exists in which dense cold clouds are formed inside the cluster and eventually accelerated by the surrounding wind and ejected from the cluster.

Observations:

Left: The Hubble Space Telescope view of the M82 galaxy unveils a huge amount of the red-glowing outwardly expanding gas. This powerful galactic super-wind is formed by combining winds of more than 100 super star clusters concentrated in the galactic central region. **Right:** Super star clusters are seen as bright dots in the M82 central region. Spectroscopic observations (Smith et al. 2006) found that cluster A1 ($r = 3$ pc) is associated with HII region of the radius 4.5 pc. It suggests that there must be a substantial amount of relatively cold ($T = 10^4$ K) gas close to the cluster center. This gas may result from the catastrophic cooling instability.



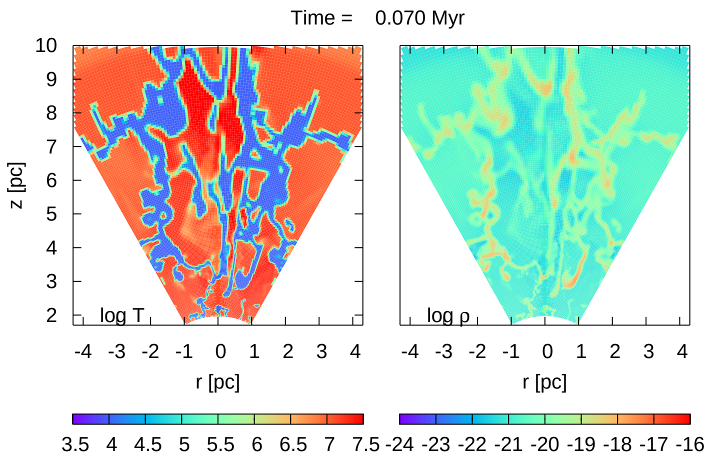
M82 - the nearby starburst galaxy
Credit: NASA, ESA, The Hubble Heritage Team

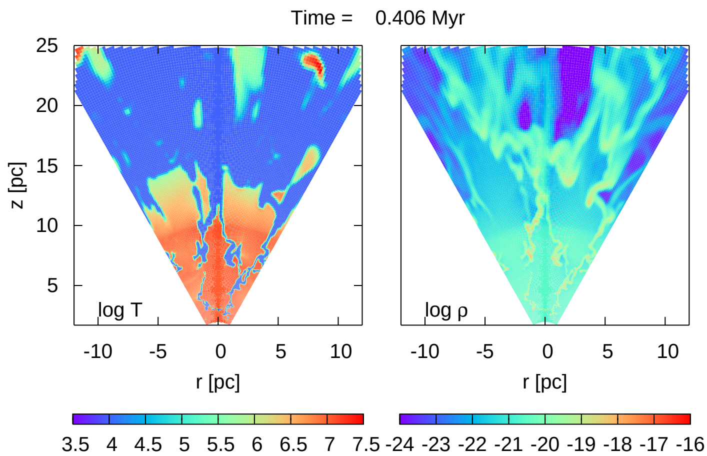


HST + ACS/WFC F814W image of M82
Smith et al. (2006)

Numerical models:

2D numerical simulation of the extremely energetic cluster with $R_{SC} = 10$ pc, $\dot{E} = 10^{43}\ \mathrm{erg\,s^{-1}}$, and $\dot{M} = 2 \times 10^{27}\ \mathrm{g\,cm^{-3}}$ (which corresponds to the adiabatic wind terminal velocity $v_\infty = 1000\ \mathrm{km\,s^{-1}}$). **Left:** The cluster central region where the thermal instability quickly forms the two-phase medium: dense cold clumps surrounded by hot rarefied gas. **Right:** Later stage of the cluster evolution: some clumps are accelerated by the surrounding wind and ejected from the cluster. (See Tenorio-Tagle et al., 2007 for details.)





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