Super Star Clusters and Their Emission Lines

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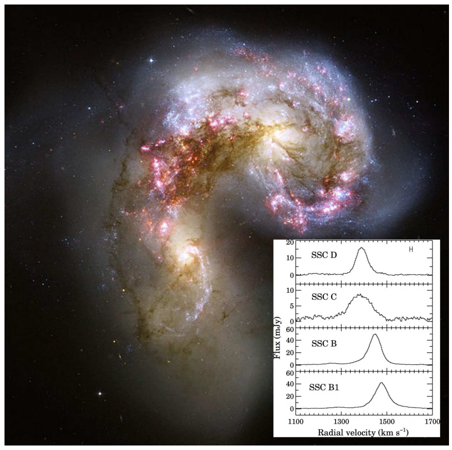
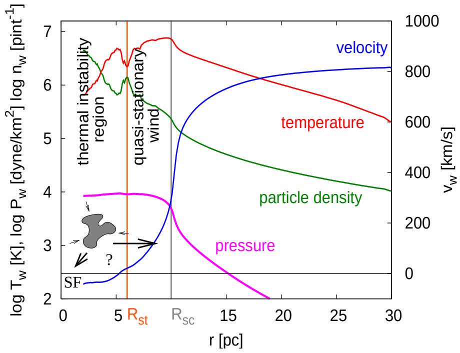
Super Star Clusters (SSCs) are young massive objects typically observed in starburst galaxies. They consist of millions of stars occupying volumes only several parsecs across. Recent infrared observations of SSCs reveal strong emission lines with moderately super-sonic widths (FWHM $\sim 50-100$ km s^{-1}). An additional much broader and weaker line component is present in some cases.
Using 2D and 3D hydrodynamic simulations, we study models of SSCs in the so-called *bimodal regime* which occurs if the stellar density inside the cluster exceeds a certain limit. We confirm the existence of the bimodal solution predicted analytically and suggest an explanation for double component line profiles: the narrow component is formed close to the cluster center by *repressurizing shocks* compressing the rarefied gas cooled down due to the thermal instability into dense cold clumps; and the broad component is created by the wind which cools down at a certain distance from the cluster.

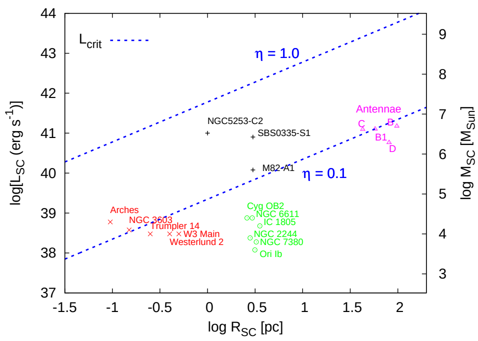


Credit: NASA, ESA, Hubble Heritage Team
Br-γ lines of SSC: Gilbert & Graham (2007)

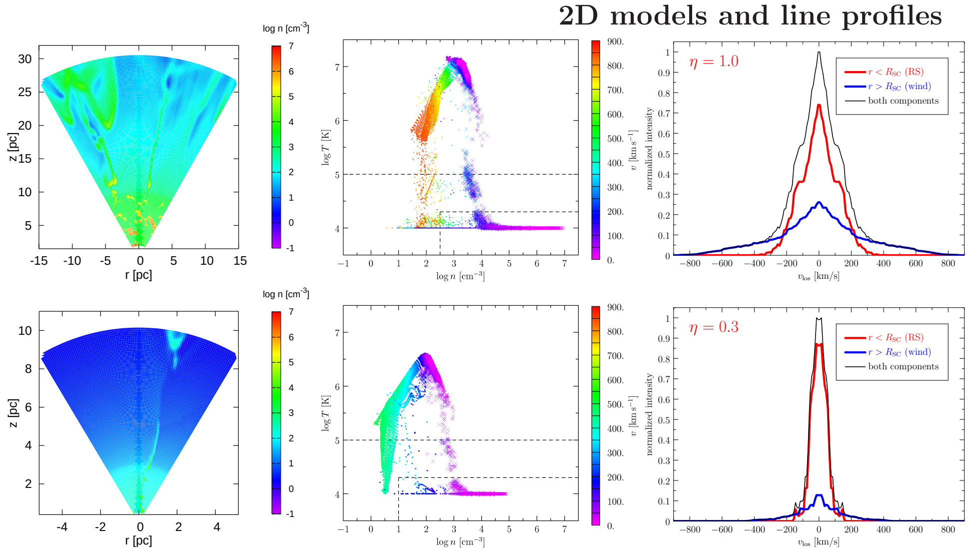
Bimodal regime

In the bimodal regime, the outskirts of the cluster remain hot and drive the cluster wind. However, in the central region the gas becomes thermally unstable and certain areas quickly cool down from $\sim 10^7$ K to $\sim 10^4$ K. Consequently, repressurizing shocks propagating from the rarefied ambient hot gas compress the cooled areas into dense clumps, which may either feed secondary star formation or be ejected from the cluster (first Figure on the right). The second Figure on the right shows positions of several clusters in the parameter space L_{SC} vs. R_{SC} (cluster luminosity vs. radius). Dashed lines provide for given R_{SC} the critical luminosity L_{crit} above which the bimodal regime occurs. Its value depends on the heating efficiency η, a fraction of the mechanical energy of stellar winds which is converted into heat inside the cluster.





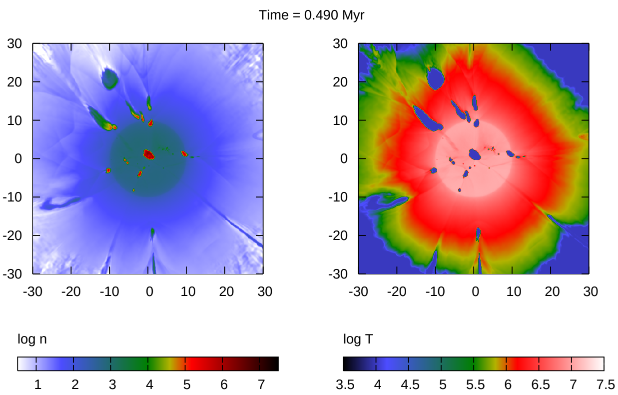
2D models and line profiles



Models based on the ZEUS hydrocode enable us to simulate the thermal instability inside the cluster and determine the line profiles. We present two simulations with heating efficiency $\eta = 1$ (top Figures on the left) and $\eta = 0.3$ (bottom Figures on the left). The simulations show that line widths strongly depend on η, and therefore provide a useful means of measuring η in observed clusters.
Figures (from left to right) show particle density across the computational domain, the distribution of grid cells in log n vs log T plane, and the line profiles consisting of two components: the narrow one formed by repressurizing shocks inside the cluster and the broad one created by the wind (see Wünsch et al. 2008 and Tenorio-Tagle et al. 2009). On the middle Figures, the color denotes magnitude of velocity, and dashed lines bounds the area which was considered for the line computation.

3D model and future

We develop a new model based on the MPI-parallel AMR code Flash which enables us to simulate clusters in the bimodal regime in 3D. It will also allow us to include new physical processes like transport of ionizing radiation (the surfaces of clumps are maintained at 10^4 K, but their interior cools further), which is necessary to follow subsequent phases of mass concentration in the thermally unstable clumps leading to secondary star formation and/or eventually to formation of a central black hole. The Figures on the right shows the 3D simulation ran on 256 processors of the ARCCA HPC facility at the Cardiff University.



Conclusions

- bimodal regime of SSCs is confirmed and explored by 2D and 3D hydrodynamic simulations
- profiles of recombination lines are computed; observed double component profiles are interpreted in terms of the bimodal model
- comparisons of observed and computed line profiles show that SSC have a heating efficiency $\eta < 0.3$

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