SUPER STAR CLUSTERS AND THEIR X-RAY EMISSIION

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ABSTRACT

The diffuse X-ray emission from the hot thermalized plasma resulted from the collisions of individual stellar winds and supernovae ejecta inside massive, compact star clusters is discussed. A simple analytical formula that relates the diffuse component of the X-ray emission with the global star cluster parameters and temperature of the X-ray plasma is proposed. The predicted X-ray luminosity is then compared with that expected from the interstellar bubbles generated from the mechanical interaction of the high velocity outflows with the ISM and with the X-ray emission from the HMXB population.

Key words: LaTeX; Super star clusters; X-rays.

1. SUPER STAR CLUSTER WINDS AND THEIR X-RAY EMISSION

In many starburst, interacting and merging galaxies a substantial fraction of the star formation is concentrated in a number of compact, young and massive stellar clusters or super star clusters (SSCs). Their typical masses are $10^4 - 10^6$ $M_\odot$ and radii $3 - 10$ pc. The extremely high stellar densities, the large energy and mass deposition rates, provided by stellar winds and supernovae explosions, suggest that SSCs are potentially strong X-ray emitters. Indeed the X-ray emission from the local analogies to the low mass SSCs: Arches cluster, Quintuplet cluster, R136 and several others, has been detected. However the origin of this emission, its dependence on global star cluster parameters and the X-ray appearance of the SSCs in distance galaxies remain under debate.

Random collisions between nearby stellar winds and supernova ejecta in compact star clusters lead to the thermalization of the ejected material and thus produce the high temperature plasma whose central pressure exceeds that of the interstellar gas around the cluster and thus accelerates the ejected material and eventually results in a high velocity outflow that continuously removes the oveabundant (particularly with $\alpha-$elements) ejected material

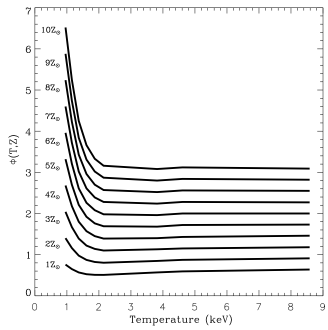

Figure 1. The normalization function $\Phi(T, Z)$ plotted as function of the X-ray plasma temperature measured in keV units. Different lines are marked with the assumed gas metallicity.

from the star cluster volume. The interection of such outflows with the outside gas generates strong shocks which heat the ISM and shape it into interstellar bubbles filled with a high temperature mixture of the ejected and swept-up material. Both, the SSC and the superbubble, plasmas should be detected in the X-ray regime. One can calculate the expected X-ray luminosity if the density and the temperature distributions are known from the hydrodynamical model.

In Silich et al., 2005 we have found that the diffuse X-ray emission associated with the hot, high velocity outflow may be well approximated by a simple analytic expression:

$$L_X = 3.25 \times 10^{34} \Phi(T, Z) \frac{L_{38}^2}{R_1 T_{keV}^3} \, erg \, s^{-1}, \qquad (1)$$

where L_{38} is the mechanical luminosity of the SSC measured in units of 10^{38} erg s^{-1}, R_1 is the star cluster radius measured in units of 1 pc and T_{keV} is the temperature of the plasma measured in keV units. The normalization function, $\Phi(T, Z)$, depends on the plasma temperature and its metallicity and is presented in Figure 1.

2. RESULTS AND DISCUSSION

We compared our formula (1) with that proposed by Chu et al. (1993) for interstellar bubbles and found that the total, $(0.3 - 0.8)$ keV, luminosity is regularly dominated by the bubble plasma. However the temperature of the hot plasma ejected from the star cluster (10^7K - 10^8K), is much higher, than that of the superbubble plasma (few times 10^6K). Therefore the hard component, $(2.0 - 8.0)$ keV, of the X-ray emission is regularly dominated by the plasma accommodated inside the star cluster and in the free wind region.

Several more complications should be taken into consideration when comparing the results from equation (1) to the observed X-ray emission. In particular, the fraction of the kinetic energy supplied by SNe and stellar winds that is converted into the thermal energy and eventually drives the outflow (the thermalization factor or heating efficiency ϵ) is a badly known parameter whose value depends on the proximity of the sources depositing energy, metallicity of the ejected material and the relative velocity at local encounters. The impact of ϵ on the star cluster diffuse X-ray emission may be taken into consideration by replacing the energy deposition rate in equation (1) with its effective value, $L_{eff} = \epsilon L_{38}$. Because the temperature of the plasma, $T \sim L_{eff}/\dot{M}$, and the rate of the mass ejection, $\dot{M}$, does not depend on ϵ, the X-ray luminosity scales as $L_x \sim \epsilon^{-1}$.

The X-ray emission associated with the SSCs should be also contaminated by the X-ray binary population (Van Bever & Vanbeveren, 2000). The HMXB component begins to contribute when the star cluster reaches ≈ 4 Myr. It is essential that the contribution from the X-ray binaries scales linearly with the star cluster mass whereas the luminosity from the star cluster plasma is a quadratic function of the mass of the cluster. This implies that for the most massive clusters the diffuse component associated with the ejected material may be comparable or dominate over the HMXB population (see Figure 2).

The justification of the proposed theory requires a comprehensive study of the SSCs which have been detected in the X-rays and have optical or IR counterparts. Then the star cluster parameters (radii and masses) can be derived from the optical or IR observations and the temperature of the X-ray plasma from the X-ray spectra. The only problem that remains is how to separate the contributions from the diffuse emission associated with the star cluster plasma and that from the binary population in distant galaxies.

The theory predicts that the X-ray emission associated with the HMXBs does not depend on the star cluster radii and scales linearly with the star cluster mass whereas the diffuse component associated with the thermalized supernovae ejecta and stellar winds should be in inverse proportion to the star cluster radii and scale quadratically with the star cluster mass. Thus the dominant of the two components may be revealed if the dependence of the detected X-ray luminosity on the star cluster parameters is known.

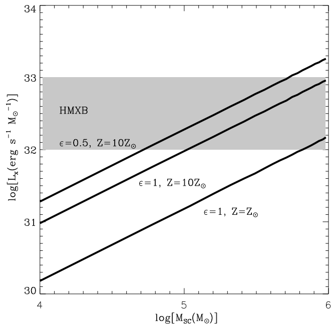

Figure 2. Comparison of the diffuse X-ray emission normalized per unit stellar mass with that from the HMXB population for different star cluster masses and heating efficiencies. The temperature of the plasma, $T = 2.1$ keV, for the cases with $\epsilon = 1$.

3. CONCLUSIONS

We proposed a simple analytic expression that indicates how the diffuse X-ray emission associated with the thermalized star cluster plasma depends on the global cluster parameters. We have also compared the predicted X-ray emission with that expected from the hot bubbles and from an HMXB population.

We have found that compact and massive star clusters in distant galaxies should be detected as point-like hard X-ray sources embedded into extended regions of soft diffuse X-ray emission associated with the interstellar bubbles. In the most massive clusters the diffuse X-ray emission may be comparable or even larger than that expected from the HMXB population. The last two components may be distinguished by their dependence on the star cluster parameters $-$ their radii and masses.

ACKNOWLEDGMENTS

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