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LAE Galaxies at High Redshift: Formation Sites for Low-Metal Globular Clusters

Bruce G. Elmegreen[1], **Sangeeta Malhotra**[2] **and James Rhoads**[2]

[1]IBM Research Division, T. J. Watson Research Center, Yorktown Heights, NY, USA
email: bge@us.ibm.com

[2]School of Earth and Space Exploration, Arizona State University, Tempe, AZ, USA

Abstract. Lyman-α emitting (LAE) galaxies observed at intermediate to high redshift have the correct size, mass, star formation rate, metallicity, and space density to have been the formation sites of metal-poor globular clusters. LAEs are typically small galaxies with transient starbursts. They should accrete onto spiral and elliptical galaxies over time, delivering metal-poor clusters into the larger galaxies' halos as they themselves get dispersed by tidal forces. The galaxy WLM is a good example of a dwarf remnant from a very early starburst that contains a metal-poor globular cluster but failed to get incorporated into the Milky Way or M31 because of its remote location in the local group.

Keywords. globular clusters: general, galaxies: dwarf, galaxies: high-redshift, galaxies: star clusters

1. Introduction

Elmegreen, Malhotra & Rhoads (2012) suggested that Lyman-α emitting (LAE) galaxies at redshifts of $z \sim 2$ to 7 (i.e., $10 - 13$ Gyr ago) are the formation sites of metal-poor globular clusters (GCs). This suggestion followed from four main concepts: (1) metal poor GCs probably formed in dwarf galaxies (Searle & Zinn 1978, Zinnecker *et al.* 1988) and entered the halos of larger galaxies during hierarchical build-up, sometimes producing halo streams such as those observed by Mackey *et al.* (2010) and Romanowsky *et al.* (2012); (2) the low metallicity of these GCs is the result of the mass-metallicity relation (Mannucci *et al.* 2009, Chies-Santos *et al.* 2011) in galaxies at the GC formation redshift, rather than an earlier formation time for metal-poor GCs compared to metal-rich GCs, (3) the most heterogeneous GCs could have been dwarf galaxy nuclei (e.g., Bekki & Norris 2006, Carretta *et al.* 2010), and (4) LAEs are low-mass starburst galaxies with low metallicities (Finkelstein *et al.* 2011) that are observed at the redshifts where metal-poor GCs should have formed.

Clusters with the mass of a young GC probably formed among other clusters and stars having a total mass in excess of $3 \times 10^7\ M_\odot$ with $\sim 10^8 - 10^9\ M_\odot$ in molecules and a star formation rate of $\sim 3\ M_\odot$ yr^{-1} or more. The associated emission would be $10^{10}\ L_\odot$, and in the Lyman-α line, 10^{42} erg s^{-1} if there is ~ 1 mag of extinction to absorb the local Lyman continuum radiation. This is in the range of emission rates for an LAE galaxy. With a more likely 25% escape fraction (Blanc *et al.* 2011, Zheng *et al.* 2012), the Lyα emission is 2.5×10^{41} erg s^{-1}. Integrating the LAE Luminosity function down to this luminosity gives a space density of 0.007 cMpc^{-3} in the GC-forming phase. If this phase lasts 10 Myr (Malhotra & Rhoads 2004), and each such burst makes 1 GC, then the space density of GCs formed is the space density of LAEs multiplied by the ratio of the range of times during which the LAEs are observed (2.5 Gyr from $z = 2$ to 7) to 10 Myr, giving ~ 2 cMpc^{-3}. This is comparable to present day space density of metal-poor GCs with $M > 2 \times 10^5\ M_\odot$. Longer lifetimes for the GC-forming phase that produce the same total young star mass correspond to weaker Lyα galaxies and more of them from the luminosity function, but the duty cycle of this phase increases in proportion, making the total number of GCs produced about the same. Forming more than 1 GC per event also leaves the total GC number unchanged, because each LAE galaxy would be either brighter or it would have been active for a longer time, reducing the number of such galaxies in proportion.

The WLM galaxy is a local dwarf with a metal-poor GC and a distance of ~ 1 Mpc from both the Milky Way and M31. The GC is ~ 14 Gyr old and has Fe/H $= -1.63 \pm 0.14$ and $M_V \sim -8.8$ mag (Hodge *et al.* 1999, Dolphin 2000), which suggests the GC mass is $\sim 10^6\ M_\odot$. The WLM stellar mass is now $1.6 \times 10^7\ M_\odot$ (Zhang *et al.* 2012) but it was $\sim 10^6\ M_\odot$ when the GC formed (Leaman *et al.* 2012). WLM is an example what is likely to be a remnant of an LAE that formed a metal-poor GC at the equivalent of $z \sim 2$ and never got incorporated into a spiral galaxy halo.

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