

Communication

How Clumpy Star Formation Affects Globular Cluster Systems

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Abstract: There is now clear evidence the metallicities of globular clusters are not simple tracers of the elemental abundances in their protocluster clouds; some of the heavy elements were formed subsequently within the cluster itself. It is also manifestly clear that star formation is a clumpy process. We present a brief overview of a theoretical model for how self-enrichment by supernova ejecta proceeds in a protocluster undergoing clumpy star formation, and show that it predicts internal abundance spreads in surprisingly good agreement with those in observed Milky Way clusters.

Keywords: globular clusters; star formation; abundances; stellar halos

1. Introduction

Globular clusters (GCs) are critical tracers of galactic stellar halos. It is only very recently that heroic observations have been able to detect diffuse stellar components around galaxies beyond the Local Group (see, for example, the excellent work done by many other authors in this special edition); for most galaxies, GCs are the only easily-identifiable halo components.

GCs are almost uniformly old, and trace the early stages of galaxy formation. Observationally, they mainly differ from each other by their luminosity and colour, which more-or-less correspond to stellar mass and total metallicity. Metallicity is particularly valuable, because heavy elements were formed by previous generations of stars, implying that the metallicity of a GC traces the history of the gas cloud from which it formed.

However, this assumes that the only contribution to the metallicity of present-day GC stars is from the metallicity of the protocluster cloud. Two major pieces of evidence point towards a more complicated picture: (1) the “blue tilt”, a tendency for the most massive metal-poor GCs around a large galaxy to be more metal-rich than the less-massive GCs (e.g., [1]); and (2) internal abundance spreads within GCs, especially of intermediate elements like oxygen and sodium, but sometimes also including iron (e.g., [2]). Both pieces of evidence suggest that some of the metals in GCs come from *self enrichment* (i.e., they were formed by stars within the GC itself).

In [3] (BH09), we presented a model in which protocluster clouds are able to gravitationally hold onto a fraction of core collapse supernova ejecta that depends on the balance between supernova kinetic energy and the depth of the protocluster potential well. The metals from this ejecta were then assumed to mix evenly among the low-mass slow-forming stars, increasing the total metallicity of the GC. The BH09 model reproduced the blue tilt qualitatively, and provided a decent quantitative match with reasonable modifications to the model’s free parameters [4,5].

However, the BH09 model was deficient in one major way—it assumed that star formation and metals were well-mixed. This flies in the face of patently clumpy star formation regions that are observed [6] and cannot reproduce the *internal abundance spread* that is one of the main motivations for considering self-enrichment. In this contribution, I give an overview of a new extension to the BH09 model that is explicitly clumpy.

2. Materials and Methods

In brief, the model assumes that each protocluster cloud begins with a pre-enriched level of metallicity due to its history up to that point. During star formation, the cloud fragments into clumps, which undergo individual star formation events spread out over time. Parameters of the number and structure of the clumps have been calibrated using the Bolometric Galactic Plane Survey [7,8]. Supernovae from each clump can pollute later-forming clumps with metals to the degree that the gravitational potential of the entire cloud can contain them, meaning that each clump has an individual metallicity and there can be a metallicity spread within the final cluster. Full details of the model are presented in [9].

3. Results

More massive GCs both fragment into more pieces, and also are able to hold onto a larger fraction of their supernova ejecta, resulting in larger internal metallicity spreads. This is shown by the black dots in Figure 1, which shows the spread in internal iron abundances as a function of cluster mass. Observations of Milky Way GCs from [10] are overplotted. Although GCs are generally considered to have “no” iron spread (in contrast to dwarf galaxies) the measured spreads are small but non-zero. Note that the observations have been corrected to the estimated initial cluster mass using [11], in order to make them directly comparable to the model GC masses. Given that there was *no fine tuning* of the model parameters, the agreement is remarkable (in fact, the goodness of fit is probably to some degree a coincidence).

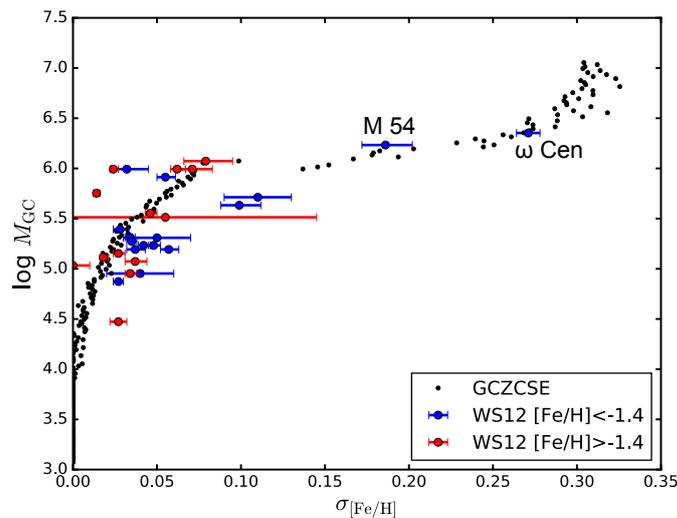


Figure 1. Internal iron abundance spread as a function of globular cluster (GC) mass. Black points denote model GCs, while blue and red data points indicate observed Milky Way metal-poor and metal-rich GCs, respectively, from [10]. Observed GCs are plotted using the estimated initial mass of [11].

4. Discussion

The agreement between the new clumpy self-enrichment model that we have presented and observations of Milky Way GCs suggests that we are indeed capturing an important facet of GC formation. Since the parameters of the model were calibrated entirely on local star formation regions, this implies that the high-intensity star formation that occurred at high redshift—when these GCs formed—was not qualitatively different from local star formation, but simply acted as a scaled-up version of processes we observe locally.

The model predicts that sufficiently massive GCs should have substantial iron spreads, and in particular matches observations of ω Cen and M 54—two objects that have often been speculated to be stripped dwarf galaxies rather than true GCs. One of the pieces of evidence that is often cited for such an identification is the iron spread, but our model predicts that GCs with these masses ought to have precisely so large of an iron spread. Therefore, the iron spread cannot be used as a piece of evidence that these high-mass GCs are not true GCs.¹

Finally, we note that the same self-enrichment that causes internal abundance spreads also increases the total metallicity of the cluster (hence the blue tilt). If we want to use GCs as probes of the history of their natal gas cloud, we want to know the unpolluted initial metallicity of the cloud before self-enrichment occurred. The magnitude of internal abundance spread may give us a calibration of how much self enrichment has occurred, allowing us to correct GC metallicities and use them as better galaxy formation probes. This is an avenue of current research we are actively pursuing.

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Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

GC Globular Cluster

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¹ We are not arguing that these objects are necessarily GCs, simply that other evidence must be used to make the argument.

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