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The evolution of intracluster gas in globular clusters

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Abstract. We have used a 3D hydrodynamics code to trace the evolution of gas as it leaves evolved giant stars and enters the intracluster medium (ICM) of Galactic globular clusters (GC). Mechanisms for removing this ICM gas from the GC potential are investigated.

Key words. Stars: mass-loss – Hydrodynamics – Methods: numerical – (Galaxy:) globular clusters: individual: ICM gas – Galaxy: halo

1. Introduction

A suitable explanation for the dearth of observed gas in globular clusters (GCs) has been sought after for over 50 years.

Analytical work shows that red giant branch (RGB) and asymptotic giant branch (AGB) winds will inject approximately 100 $M_{\odot}$ into the GC intracluster medium (ICM) between Galactic disk crossings (10^8 years) (Tayler & Wood, 1975). The observed limits are 2 to 3 orders of magnitude less than expected (van Loon et al., 2006).
Vandenberg & Faulkner (1977) showed, using 1D hydrodynamical models, that gas can be ejected from the ICM of massive (10^6 $M_{\odot}$) GCs only if RGB wind velocities are $\geq$118 kms^{-1}, typical values being $\leq$20 kms^{-1}. The following additional mechanisms for reducing gas in the ICM have also been investigated, mainly with analytical studies:

- ram pressure stripping due to cluster motion in the hot Galactic halo medium (Frank & Gisler, 1976);
- flaring activity of low mass M dwarfs (Coleman & Worden, 1977);
- hot and highly evolved B-type stars with an ionising flux (Vandenberg, 1978);
- novae (Scott & Durisen, 1978);
- pulsar winds (Spergel, 1991).

For most of these mechanisms, there have been no detailed numerical investigations regards their impact on the overall ICM evolution.

2. Current work

This study employs a sophisticated 3D PPM hydrodynamics code (Ruffert, 1992). It is a Cartesian grid-based scheme, utilising a fixed nested grid architecture to increase the resolution within the central regions of the simulation. We have confirmed that the 3D code correctly reproduces the Vandenberg & Faulkner

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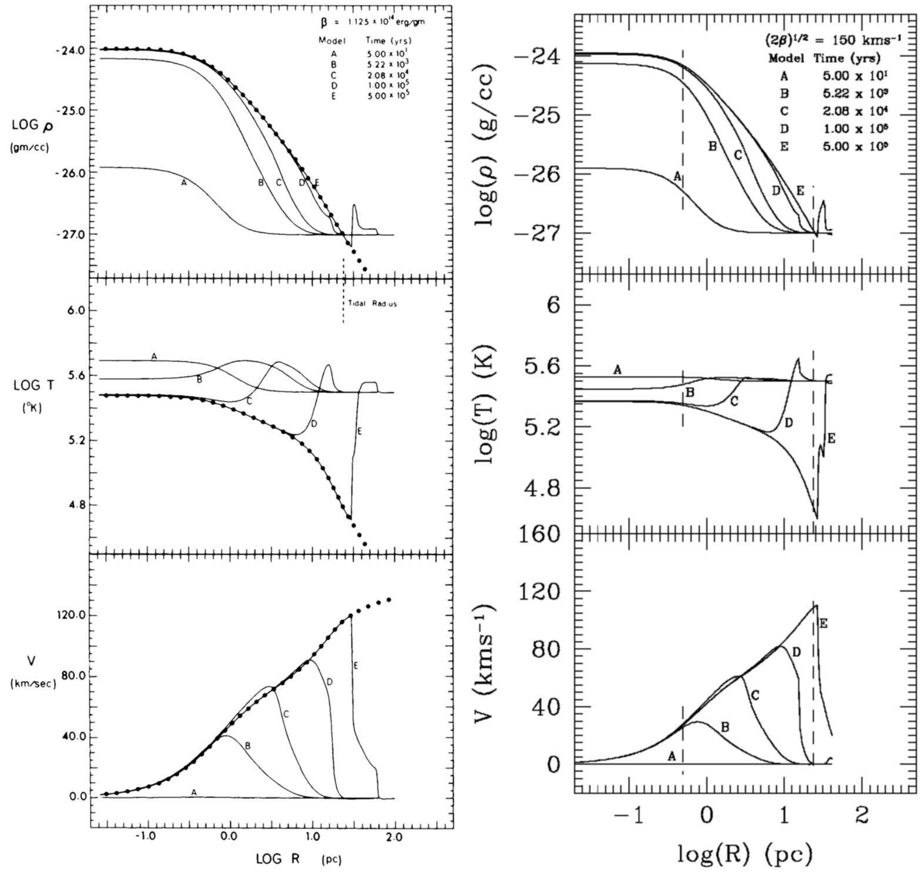

Fig. 1. A comparison of the 3D hydrodynamics code with 1D models: using the 150 kms^{-1} RGB wind model for a 10^6 $M_\odot$ GC. *Left column:* results from Vandenberg & Faulkner (1977). *Right column:* work presented here. The dashed lines in the right column indicate the core and tidal radius. The different curves correspond to different times (in years): A=50; B=5.22×10^3; C=2.08×10^4; D=1×10^5; E=5×10^5

(1977) 1D results in the radial profile of the 3D data, as shown in Fig.1.

We have then progressively increased the level of sophistication of the GC model with the inclusion of:

- a streaming Galactic halo (or disk) medium, simulating an orbiting GC;
- gas ejected from a discrete single-mass stellar population (as opposed to the continuous stellar density distribution used in Vandenberg & Faulkner (1977));
- a discrete 10-component multi-mass stellar population produced from a Kroupa (2001) IMF, including RGB and AGB populations with (η = 0.2) Reimers (1975) and Vassiliadis & Wood (1993) mass loss respectively (as opposed to the usual specific mass loss rate (α) used in single component GC models);
- orbiting discrete mass losing stars in the GC potential.

These changes have yielded encouraging results thus far. Halo streaming on a stationary stellar population truncates the rate of gas accumulation over time (dashed line in Fig.2). Considering a $10^5 M_\odot$ GC with RGB (814 stars) and AGB (2 stars) mass loss, gas injection into the ICM is better described. Orbiting

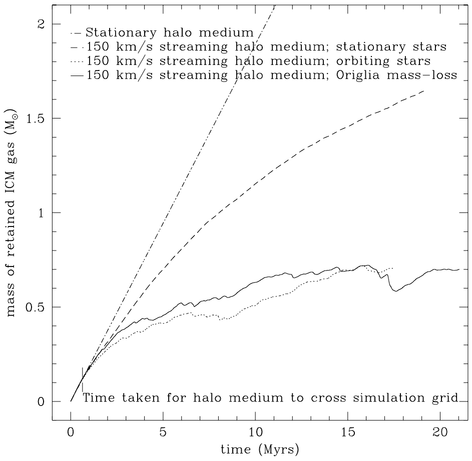

Fig. 2. How increasing GC model sophistication affects the retention of ICM gas in the cluster. A 10^5 $M_\odot$ GC with 10-component multi-mass discrete stellar population with 20 $\mathrm{kms^{-1}}$ RGB and AGB winds is shown: *dot-dashed:* in a stationary halo medium; *dashed:* in a 150 $\mathrm{kms^{-1}}$ streaming halo medium with stationary stars; *dotted:* in a 150 $\mathrm{kms^{-1}}$ streaming halo medium with orbiting stars. *solid:* in a 150 $\mathrm{kms^{-1}}$ streaming halo medium with orbiting stars and episodic Origlia et al. (2007) mass-loss.

the mass losing stars under the GC potential further reduces the amount of ICM gas *in the whole cluster* over time, as shown in Fig.2 (dotted line). Origlia et al. (2007) give a new, shallower, empirical mass-loss law for population II RGB stars. There is also evidence that these higher mass-loss rates occur episodically, with duty cycles of a few Myrs. This new law was included to determine how it affects the predicted levels of ICM gas. To make a meaningful comparison with the Reimers (1975) (with $\eta = 0.2$) RGB stars, the number of active mass-losing RGB stars was limited, making the total mass lost the same. We gave two groups of stars a duty cycle of 2 Myr, in antiphase with each other. The results can be seen in the solid line of Fig.2.

3. Future work

Future work will involve:

- including cooling rates $<10^3$ K to see if the gas can attain lower temperatures;
- investigating the impact of main sequence winds (e.g. Smith, 1999);
- adding a Galactic tidal potential;
- inclusion of a UV-emitting stellar population, X-ray binaries (Vandenberg, 1978) and pulsar winds (Spergel, 1991);
- Bondi-Hoyle accretion by the main sequence stars (e.g. Thoul et al., 2002);
- ascertaining whether infrequent energetic events, such as novae, can dissipate ICM gas in a GC (Scott & Durisen, 1978);
- modelling observational signatures of the ICM gas.

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References

Coleman, G. D. & Worden, S. P. 1977, ApJ, 218, 792
Frank, J. & Gisler, G. 1976, MNRAS, 176, 533
Kroupa, P. 2001, MNRAS, 322, 231
Origlia, L., Rood, R. T., Fabbri, S., et al. 2007, ApJ, 667, L85
Reimers, D. 1975, Memoires of the Societe Royale des Sciences de Liege, 8, 369
Ruffert, M. 1992, A&A, 265, 82
Scott, E. H. & Durisen, R. H. 1978, ApJ, 222, 612
Smith, G. H. 1999, PASP, 111, 980
Spergel, D. N. 1991, Nature, 352, 221
Tayler, R. J. & Wood, P. R. 1975, MNRAS, 171, 467
Thoul, A., Jorissen, A., Goriely, S., et al. 2002, A&A, 383, 491
van Loon, J. T., Stanimirović, S., Evans, A., & Muller, E. 2006, MNRAS, 365, 1277
Vandenberg, D. A. 1978, ApJ, 224, 394
Vandenberg, D. A. & Faulkner, D. J. 1977, ApJ, 218, 415
Vassiliadis, E. & Wood, P. R. 1993, ApJ, 413, 641