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Fast rotating Blue Straggler Stars in Galactic Globular Clusters

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Introduction

Blue Straggler Stars (BSSs) are an exotic stellar population formed from mass transfer activity in binary systems (McCrea, 1964), or from direct collisions between two or more stars (Hills & Day, 1976). They are routinely observed in Globular Clusters (GCs) and other environments, and they are powerful tools to measure the level of internal dynamical evolution reached by the host system (e.g., Ferraro et al., 2012). Unfortunately, however, their physical properties are still badly understood and poorly constrained by observations.

In particular, theoretical models predict large rotational velocities at birth for both mass-transfer BSSs (Sarna & De Greve, 1996) and collisional BSSs (Benz & Hills , 1987), but some braking mechanisms (such as magnetic braking and disk locking) should then intervene to slow down these stars with unknown timescales and efficiencies (Leonard & Livio, 1995; Sills et al., 2005). To shed new light on this topic, here we present the results of a dedicated spectroscopic survey, from which **we measured the rotational velocity of ~300 BSSs in 8 Galactic GCs** with different structural parameters (concentration and central density): **47 Tucanae** (Ferraro et al., 2006), **M4** (Lovisi et al., 2010), **NGC 6397** (Lovisi et al., 2012), **M30** (Lovisi et al., 2013a), **NGC 6752** (Lovisi et al., 2013b), **ω Centauri** (Mucciarelli et al., 2014), **NGC 3201** (Billi et al., 2023) and **M55** (Billi et al., in prep.).

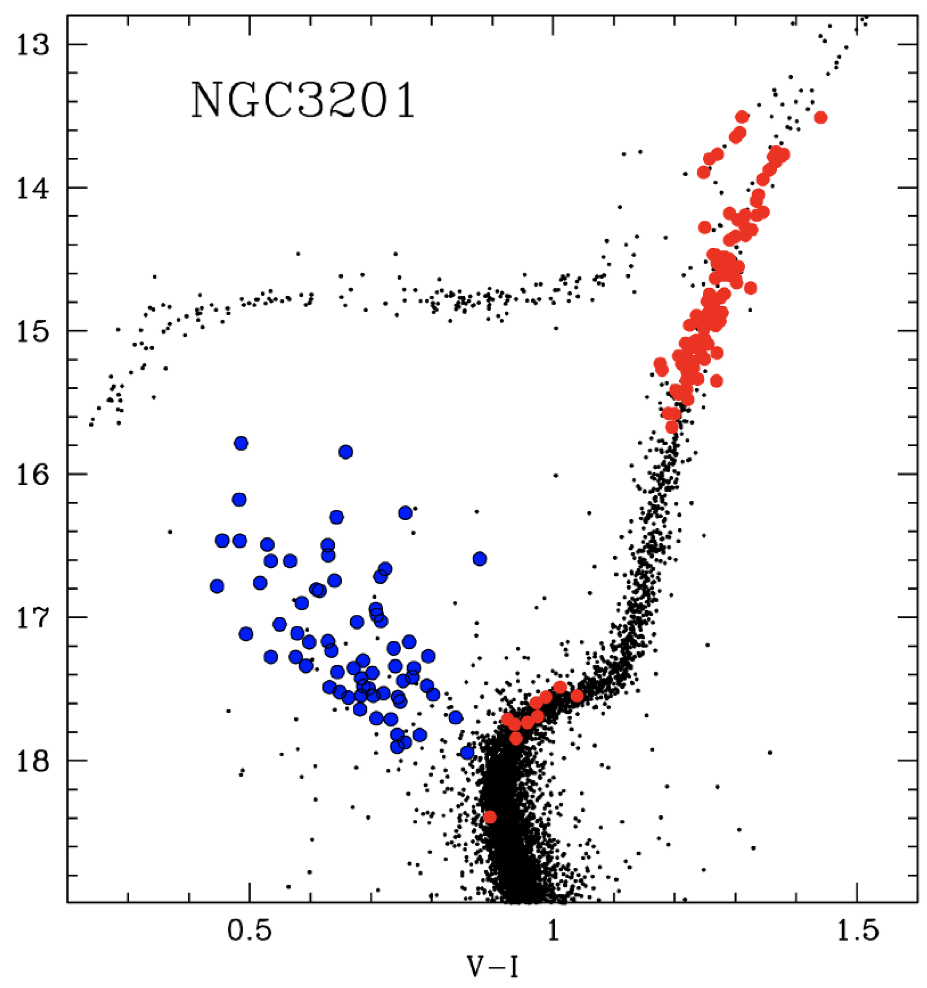

Figure 1. Proper motion selected and differential reddening corrected CMD of NGC 3201 (black dots), with the spectroscopic targets highlighted as filled colored circles: the 67 BSSs are marked in blue, while the reference sample of MS, SGB, RGB and AGB stars are plotted in red.

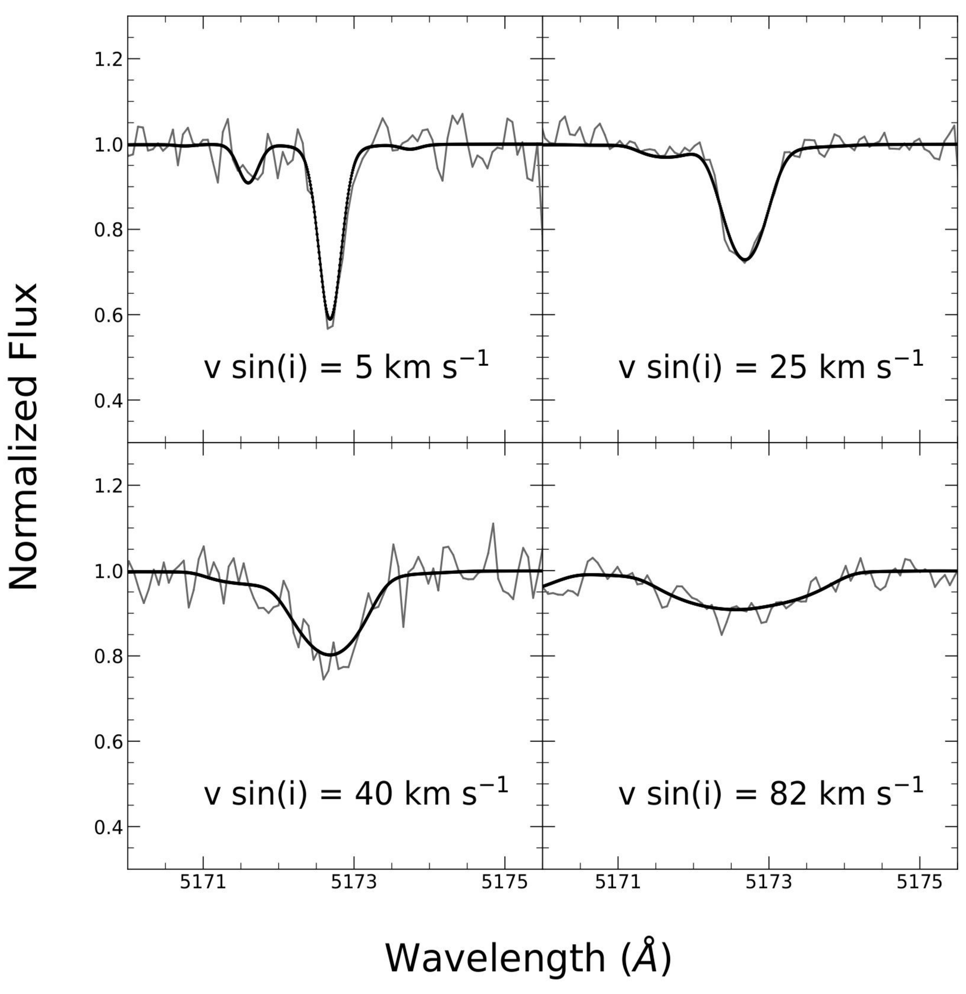

Figure 2. Comparison between the observed spectra (grey lines) and the best-fit synthetic spectra (black lines) for 4 BSSs with different rotational velocities, ranging from 5 to 82 km s^{-1}.

The case of NGC 3201

To illustrate the adopted methodological approach, we show the case of NGC 3201 (Billi et al., 2023). We used high resolution spectra (R=18000) acquired at the Magellan Telescope to measure the rotational velocity of 181 stars (see their CMD position in **Figure 1**): 67 BSSs, and 114 reference stars in different evolutionary stages (main sequence turn-off, sub-giant, red giant and asymptotic giant branches).

The rotational velocities projected on the plane of the sky, v sin(i), have been calculated by using a χ2 minimization procedure between the observed spectra, and a grid of synthetic spectra calculated by assuming different values of v sin(i). **Figure 2** shows the comparison between the observed spectra (grey lines) and the best-fit synthetic spectra (black lines) for four BSSs with different rotational velocities. As can be seen, the FWHM of the absorption line at 5172.6 Å strongly depends on the rotation of the star, thus providing reliable measures of v sin(i).

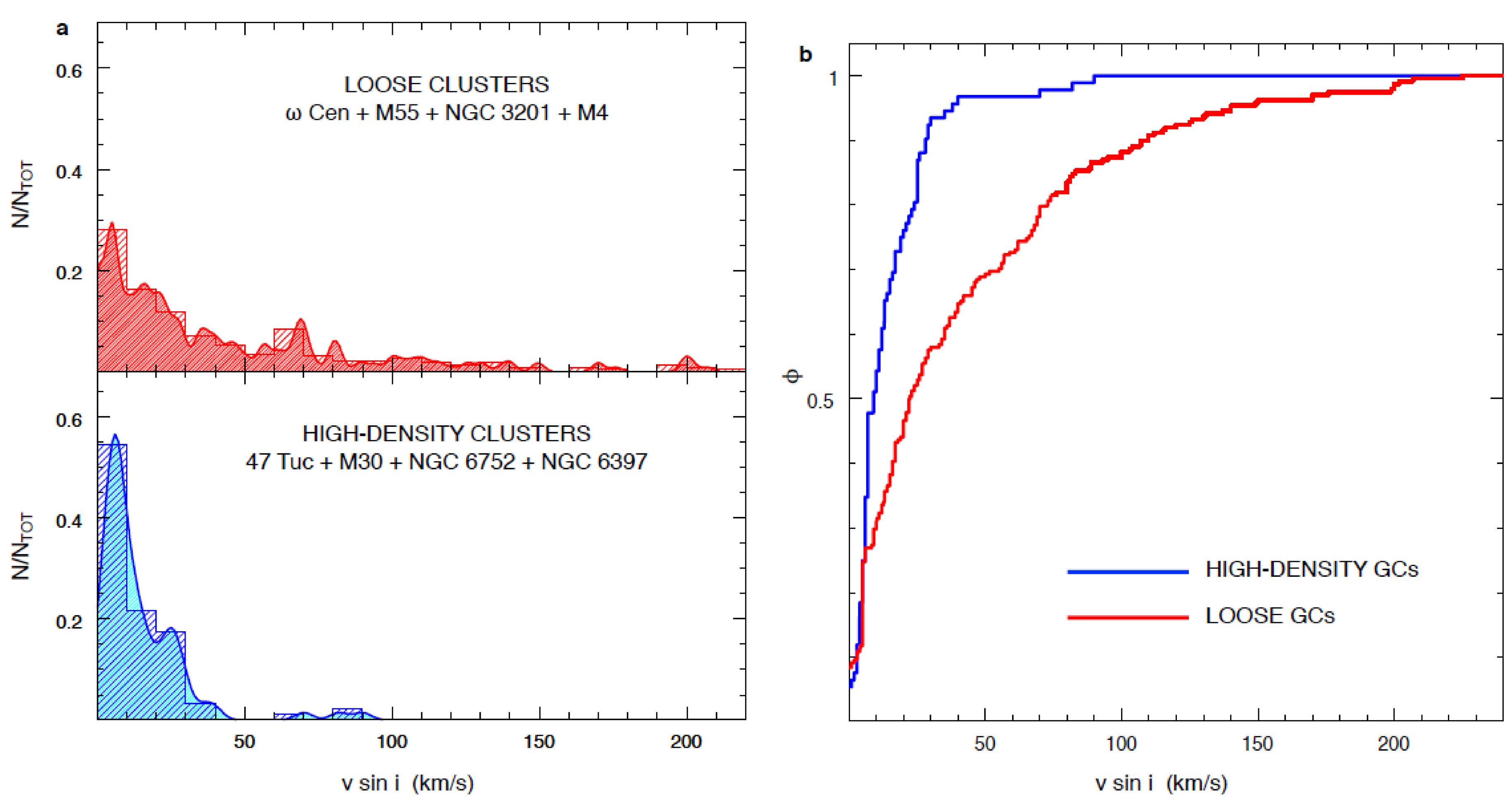

Figure 3a. BSS rotational velocity distribution for loose clusters (namely, ω Centauri, M55, NGC 3201 and M4), compared to that of high-density clusters (namely, 47 Tucanae,M30, NGC 6752 and NGC 6397), in the top panel (red histogram) and in the bottom panel (blue histogram), respectively. In both cases, the fraction is referred to the total number of BSSs observed in each sample.
Figure 3b. Comparison between the normalized cumulative distributions of BSS rotational velocities in low-density (red line) and high-density (blue line) clusters. A Kolmogorov–Smirnov test applied to the two distributions confirms that they are different at more than a 5 σ significance level.

The survey of 8 GCs

In all the surveyed GCs, we found that the reference stars have v sin(i) < 10 km/s, while BSSs show a very wide range of values.

Surprisingly, the BSS rotational velocity distributions mirror the grouping of clusters in terms of their structural parameters (**Figure 3a**): ~96% of the BSSs observed in dense clusters have v sin(i) < 40 km/s, while all loose clusters show a long tail at high rotational velocities (up to 200 km/s). Using a Kolmogorov-Smirnov test we quantify that the probability that these two distributions (**Figure 3b**) are extracted from the same parent family is 10^{-8} (more than 5σ significance).

By defining as "Fast rotating blue straggler stars (FR-BSSs)" those with v sin(i) > 40 km/s, we found a strong anti-correlation between the fraction of FR-BSSs and the parent cluster central density (see **Figure 4**). This suggests that loose environments are the ideal habitat for highly rotating BSSs.

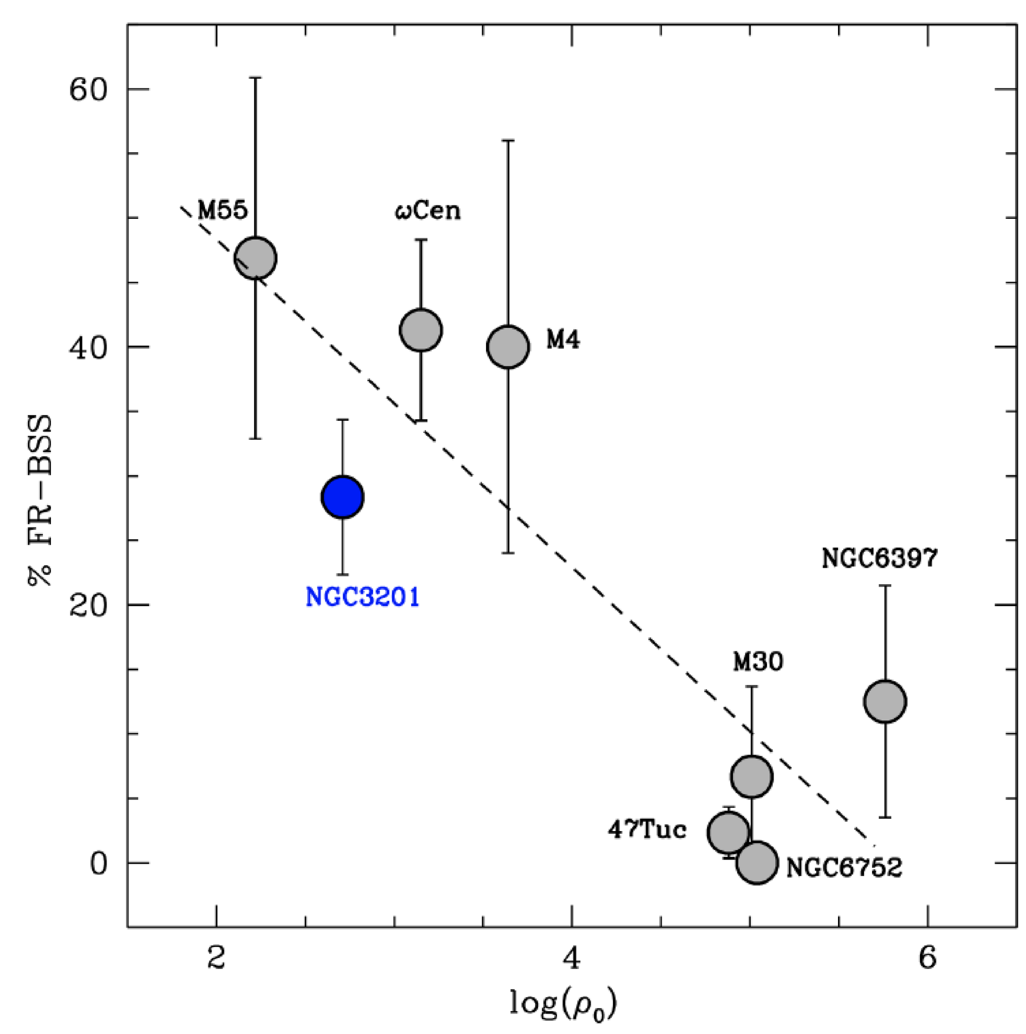

Figure 4. Percentage of FR-BSSs (i.e., number of FR-BSSs over the total number of surveyed BSSs) as a function of the central density of the parent cluster, for the sample of eight Globular Clusters. NGC 3201, the more recent paper, is represented with a blue circle.

Conclusions

A large rotational velocity can be considered as the signature of the early phase of BSS evolution, and the percentage of FR-BSSs therefore provides information about the recent BSS formation activity in the host cluster. On the other hand, stellar collisions are expected to be negligible in low-density environments, where the main BSS formation channel likely is mass transfer in binary systems. Indeed, the fraction of FR-BSSs has been found to also correlate with the fraction of binaries (Ferraro et al. 2023b).

Hence, the significantly larger fraction of FR-BSSs measured in loose clusters likely is the **evidence of recent BSS formation from the evolution of primordial binaries**, which are instead subject to the destructive action of multiple dynamical interactions in high-density environments.

For more information see

⇨ Ferraro, F. R., Mucciarelli, A., Lanzoni, B., et al. 2023, Nature Communications, 14, 2584, doi:10.1038/s41467-023-38153-w

⇨ Billi A., Ferraro F. R., Mucciarelli, A., et al. 2023, ApJ, accepted. doi:10.48550/arXiv.2309.01442

References: Benz, W., & Hills, J. G., 1987, ApJ, 323, 614; Ferraro, F. R., Sabbi, E., Gratton, R., et al., 2006, ApJL, 647, L53; Hills, J. G., & Day, C. A., 1976, ApL, 17, 87; Leonard, P.J.T., & Livio, M., 1995, ApJL, 447, L121; Lovisi, L., Mucciarelli, A., Ferraro, F. R., et al., 2010, ApJL, 719, L121; Lovisi, L., Mucciarelli, A., Lanzoni, B., et al., 2012, ApJL, 754, 91; Lovisi, L., Mucciarelli, A., Dalessandro, E., Ferraro, F. R., & Lanzoni B., 2013a, ApJ, 778, 64; Lovisi, L., Mucciarelli, A., Lanzoni, B., et al., 2013b, ApJ, 772, 148; McCrea, W. H., 1964, MNRAS, 128, 147; Mucciarelli, A., Lovisi, L., Ferraro, F. R., et al., 2014, ApJ, 797, 43; Sarna, M. J., & De Greve, J.-P., 1996, QJRAS, 37, 11; Sills, A., Adams, T., & Davies, M. B., 2005, MNRAS, 358, 716