DE GRUYTER Open Astron. 2018; 27: 91–94

Research Article

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The strange hot horizontal-branch binary star in NGC 6752

https://doi.org/10.1515/astro-2018-0016
Received Oct 06, 2017; accepted Dec 31, 2017

Abstract: M5865 is the only so-far confirmed close binary found in the extreme horizontal branch (EHB) of a globular cluster. A detailed study has recently proposed that this object could be a close system (period P=1.61 days) comprising a EHB and a main-sequence star of mass M≈0.6 $M_\odot$. Such a system has never been found among hundreds of known EHB binaries in the field, and it results in a very interesting, unique object. In this contribution, we resume the previous literature results on M5865, we discuss the reasons of interest on it, and we present some very preliminary results obtained from new observations.

Keywords: close binaries, horizontal branch, globular cluster

1 Introduction

1.1 High spectroscopic masses in globular clusters

Extreme horizontal-branch stars (EHBs) in globular clusters (GCs) are evolved stars of low initial mass currently burning helium in the core, found at the hotter end ($T_{\rm eff}$ > 20000 K) of the horizontal branch (Hoyle & Schwarzschild 1955; Faulkner 1966; Heber 1986). While the mass of their burning core must match the critical value required for helium ignition under degenerate conditions (0.45 $M_\odot$), the high effective temperature indicates that most of their envelope was lost during evolution, leaving only a thin ($< 0.02\ M_\odot$) external layer. Thus, the total mass of EHB stars is precisely determined by theoretical models.

The fit of Balmer and helium lines in low-resolution spectra is a classical method to derive the temperature, gravity, and surface helium abundance of hot horizontal-branch stars (*e.g.*, Saffer *et al.* 1994; Moehler *et al.* 1995). When the distance modulus and the reddening are independently known, as in the case of members of globular clusters, spectroscopic masses can be derived from these parameters, the apparent magnitude, and basic equations (see, *e.g.*, Moehler *et al.* 2000).

Moni Bidin *et al.* (2007) analyzed the spectra of nineteen EHBs in the globular cluster NGC 6752, and found that the spectroscopic mass of eight of them ($\sim$ 40% of the sample) was of the order of $\sim 0.65\pm0.05$ $M_\odot$. These values are far too high compared to the expectations of canonical models. The authors interpreted these results as unphysical, likely originating from some inadequacy of the synthetic models used to fit the observed spectral lines. However, the same models and software were used for all the stars, hence these stars should be intrinsically different from the rest of the sample, whose spectroscopic masses are in line with expectations. In addition, the authors showed that the photometric properties of these eight stars might be peculiar, as they appear fainter and redder than the bulk of clusters EHB stars. Later studies found similar objects with anomalously high spectroscopic mass in other clusters also, suggesting that this might be a common feature in these ancient systems (Moni Bidin *et al.* 2009, 2012). A systematic search is however still missing, as well as a comprehension of the phenomenon, and an estimate of the incidence of these stars in the EHBs of GCs.

Moni Bidin *et al.* (2007) detected a faint but clear MgIb in the spectrum of one (and only one) of the eight EHBs with anomalously high spectroscopic mass. This feature is not typical of hot horizontal-branch stars, and it suggested the presence of a faint main-sequence star, possibly physically related to the hotter object. The target was later named M5865 from its entry number in the catalog of Momany *et al.* (2002). One year after, Moni Bidin *et al.* (2008) detected small (≈16 km s^{-1}) but significative (10σ) radial velocity (RV) variations for this object. Thus, M5865 became the first, and so far the only, spectroscopically-confirmed close EHB binary in a GC. The authors could not estimate the orbital period due to the poor temporal sam-

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pling of their survey, but they could argue that it was most likely shorter than 5 days.

1.2 Close binaries in cluster EHBs

Extensive surveys in the early 2000's revealed that close binaries are extremely common among field EHBs (*e.g.*, Maxted *et al.* 2001; Morales-Rueda *et al.* 2003; Kawka *et al.* 2015). The estimated binary fraction varied from one study to another, probably due to selection effects, but they all indicated that close binaries could represent approximatively 40% or more of the field EHB population. These results confirmed the scenario of a binary origin of EHBs stars (Han *et al.* 2002, 2003). However, similar studies in GCs found a lack of close binaries in cluster EHBs (Moni Bidin *et al.* 2006, 2008). It was proposed that this difference is caused by the age of the parent population, because GCs are ancient systems where the merging of two white dwarfs might be the most efficient channel to create a (single) EHB star (Moni Bidin *et al.* 2008; Han 2008). However, this scenario was questioned by the discovery of multiple stellar populations in GCs, which led to the proposition that EHB objects are the progeny of second-generation, He-enriched stars (*e.g.*, D'Antona *et al.* 2002; Chung *et al.* 2011).

While further studies confirmed that EHB close binaries were very rare in GCs (Moni Bidin *et al.* 2009, 2011), the properties of the only case known, M5865, is of special interest. The faint MgIb in its spectrum was even more intriguing, suggesting that it could be an unique close system composed by a hot EHB and a close late-G to early-K type main sequence (MS) companion. Nevertheless, this idea was not the most probable explanation for the observations (Moni Bidin & Piotto 2010). In fact, stellar blends are common in the crowded environment of GCs, and the MgIb feature could be the result of light contamination by a nearby, physically unrelated object. In addition, M5865 could be a hierarchical triple system, where a main-sequence third object in a wide orbit does not interfere the evolution of the inner pair. Such systems are rare, but known among field EHBs (Heber *et al.* 2002).

2 A peculiar system

2.1 The nature of M5865

Seven years after its discovery, Moni Bidin *et al.* (2015) gathered and analyzed all the archival photometric and spectroscopic data available for M5865, in order to clarify its properties. From 21 high-resolution spectra centered on the H_β line, they could determine the orbital period of the close binary $P = 1.61$ days, with a RV semi-amplitude $K_{\mathrm{EHB}} = 7.2 \pm 0.7$ km s^{-1}. The small RV variations point to a high inclination of the orbital plane with respect to the line of sight, *i.e.* the system is seen nearly face-on. The mass of the cool component was estimated fitting the photometric (position in the color-magnitude diagram) and spectroscopic (MgIb feature) properties of M5865 with synthetic models. The two independent estimates returned identical results, revealing an early-K type MS objects of mass $M_{\mathrm{MS}} = 0.63 \pm 0.05\ M_\odot$, temperature $T_{\mathrm{eff,MS}} = 5310 \pm 20$ K, and apparent magnitude $V_{\mathrm{MS}} = 19.6 \pm 0.1$ (while the system has V=17.20).

Moni Bidin *et al.* (2015) could prove that the probability of a chance alignment with a foreground MS star is negligible ($< 0.2\%$), and therefore the MS star is indeed physically related to the EHB. The authors could also detect significative (3.8σ) RV variations of the MgIb triplet within $\sim$3 days, that would not be expected for a third object in a wide orbit. They could not derive a RV curve for the MS star due to the scarcity of spectra where its Mg feature was observable. However, when their five RVs measurements were phased with the known solution for the EHB, they were found in anti-phase with the RV of the hotter component, as expected if the MS star was its close companion. In addition, time-series photometry showed tiny light variations, whose periodicity matched the orbital period or its first overtone, as expected from a EHB+MS close system (Heber *et al.* 2004; Geier *et al.* 2012) on a nearly face-on orbital plane. Gathering all the aforementioned independent pieces of evidence, the authors concluded that M5865 is likely a EHB star with a close, K-type MS companion. Such a unique system has never been found in the Galactic field, among the more than 180 EHB binaries known (Østensen 2006; Wade *et al.* 2014). All the close systems known so far comprise either a compact, unseen companion such as a white dwarf or a neutron star, or very low-mass MS stars with $M<0.3\ M_\odot$ (*e.g.*, Maxted *et al.* 2001; Morales-Rueda *et al.* 2003). MS companions with $M>0.5\ M_\odot$ have been found only in long-period systems (*e.g.*, Vos *et al.* 2013).

2.2 A close EHB+K system

The coincidence that the only to date confirmed close EHB binary in a GC could be a system never found in the Galactic field is particularly intriguing. It might be indicating that either field studies has so far missed an entire class of objects, or that different dominant formation mechanisms make them much more common in GCs than in the field. The theoretical models predict the formation of very few such close binaries after the first common-envelope (CE) phase (Han *et al.* 2003; Yungelson & Tutukov 2005), although they should be very rare. Basing on the results of Han *et al.* (2003) and Han (2008), Moni Bidin *et al.* (2015) argued that, while they could be more frequent in an old stellar population such as a GC, they should be present in younger populations also. It might simply be that field surveys has so far missed this kind of objects due to some selection effect, for example the well-known GK bias (Han *et al.* 2003). On the other hand, GCs are very different and peculiar environment due to the high stellar density, and it is well known that dynamical interactions can have relevant effects on the evolution of binaries (*e.g.*, Heggie 1975). Companion exchanges, orbit alterations, expulsion of a component, are common results of these interactions (*e.g.*, Hills 1975a,b). Hence, M5865 could have largely been affected, and its current status should not necessarily be compared to the expected product of the evolution of an isolated system.

Very interestingly, M5865 offers the unique opportunity to precisely measure the dynamical mass of a EHB star in a GC for the first time. In fact, as the mass of the companion is determined from independent methods, the semi-amplitude of the RV curves of the two components $\frac{K_{EHB}}{K_{MS}}$ would directly return the mass of the EHB. A part from spectroscopic measurements, which suffer from large uncertainties and heavily rely on models and assumption, the mass of these objects is so far only theoretically known. This task unfortunately results very challenging. The only feature characteristic of the MS component detected so far in the spectrum of M5865 is the MgIb triplet, but due to the large magnitude difference ($\Delta V \approx 2.5$ magnitudes), it is very faint. A high accuracy is required, *i.e.* high-resolution and/or high-S/N spectra, because RV variations are small for this nearly face-on system. However, large exposures are prevented by the relatively short orbital period. The data set analyzed by Moni Bidin *et al.* (2015) is too scarce to this end, because they could measure the RV of the MS companion in only five spectra. However, their Figure 2 suggests that K_{MS} could be of the order of K_{EHB}, which would imply $M_{EHB} \approx M_{MS} \approx 0.65\ M_{\odot}$. This value is unacceptably high compared to the expectations of theoretical models, but no conclusion could be drawn from these poor data. More precise and systematic studies are needed to obtain more reliable results.

3 New observations

To further study M5865 and better clarify its properties, we collected new intermediate-resolution ($R \approx 6000$) spectra with the MagE spectrograph, mounted at the 6.5 Baade telescope, Las Campanas Observatory. Nineteen one-hour exposures were acquired during two nights of observations (on 2016, July 5 and 6) with the 0.75" slit. The spectra covered the whole optical range, and they were reduced with the dedicated MagE pipeline. A portion of one of these spectra is shown in Figure 1, where the faint MgIb triplet from the MS star can be seen at ≈ 5180 Å.

These spectra are the first one for M5865 covering a wide wavelength range. Our preliminary search for new spectral feature from the cooler star failed to detect new lines in addition to the MgIb triplet, except probably the NaI doublet at ≈5890 Å. Unfortunately, this feature seems blended with interstellar absorption lines, and they will likely result useless for RV estimates. Preliminary measurements of the RVs of the MS component based on the MgIb triplet are affected by too high uncertainties, and any possible RV modulation results hidden behind too largely scattered results. On the contrary, RV measurements of the Balmer lines match the solution obtained by Moni Bidin

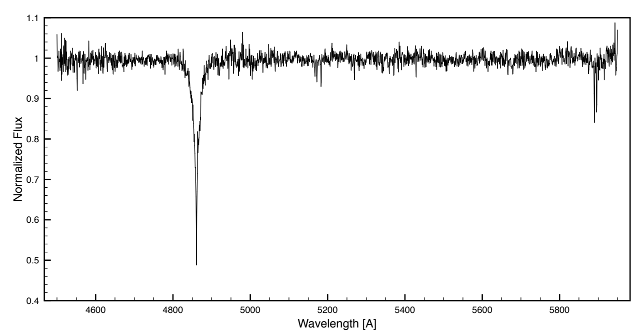

Figure 1. Portion of a MagE spectrum of M5865.

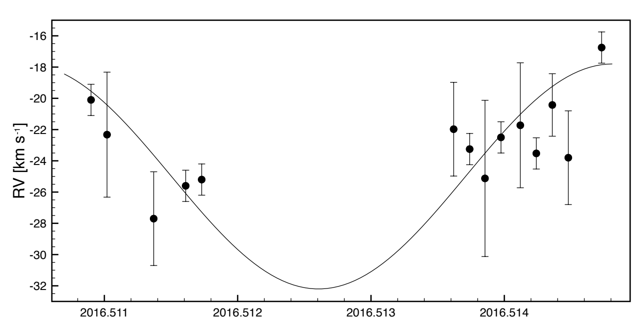

Figure 2. Preliminary results for the RV of the EHB star in the M5865 system. The curve indicates the solution found by Moni Bidin *et al.* (2015).

et al. (2015), as shown in Figure 2. Hence, as a first preliminary result, we confirm the parameters previously obtained for the RV curve of the hotter component. Further analysis is needed on these data.

Acknowledgment: The author acknowledges support from FONDECYT through regular project 1150060. Based on observations at Las Campanas Observatory (program ID CN2016A-71).

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