Microlensing in globular clusters: the first confirmed lens

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Microlensing observations toward globular clusters could be very useful to probe their low mass star and brown dwarf content. Using the large set of microlensing events detected so far toward the Galactic centre we investigated whether for some of the observed events the lenses are located in the Galactic globular clusters. Indeed, we found that in four cases some events might be due to lenses located in the globular clusters themselves. Moreover, we discuss a microlensing event found in M22. Using the adaptive optics system NACO at ESO VLT it was possible to identify the lens, which turned out to be a low mass star of about 0.18 solar masses in the globular cluster M22 itself.

1. Introduction

A sizable fraction of the mass of globular clusters could be in form of brown dwarfs and low mass stars. This is still an open issue and a possible way to test this is to use microlensing observations, see Refs. 1–3. The idea is to monitor Galactic Globular Clusters (hereafter GGCs) in front of rich background fields of stars of the galactic bulge. In this case, when the lens belongs to the cluster population, its distance and velocity are roughly known. This way it is possible to get a more accurate estimate for the lens mass. Such a study has already been performed [2,3] and some events were found which might be associated with lenses in globular clusters, see Refs. 2–4,6.

We analysed the possible microlensing events in a large set of GGCs some of which are highly aligned with a non negligible number of microlensing events detected toward the Galactic Centre (hereafter GC). The data set included 4697 microlensing events detected in the last years by the MACHO, OGLE, and MOA collaborations in direction of the GC. In our analysis we focused on the configuration in which the lens is hosted in a GGC and the source is located either in the Galactic disc or bulge.

For a microlensing event which occurred in the year 2000 toward the cluster M22, observed against the dense stellar field of the Milky Way Bulge, we made a new observation in 2011. Using the adaptive optics system NACO at ESO VLT it was possible to identify the lens, which turned out to be a low mass star of about 0.18 solar masses in the globular cluster itself.[6]

2. Results

In order to discriminate among events due to lenses hosted either in GGCs or in the Galactic bulge/disc, we first made a rough selection of events being aligned with a GGC. In particular, for every given GGC, we considered a sphere of radius r_t (corresponding to its tidal radius), centred at the GGC centre, and we selected, as a first step, only the events being included in one such contour. By doing so, out of the considered 4697 events, we were left with 118 only.

Due to the GGC structure, we expect the predicted number of events to be largest toward their centres and to decrease as we move toward their borders. Since the alignment between an event and a projected cluster contour does not assure that the deflector belongs to the GGC, this alignment possibly being accidental, we made a further, rough selection and considered only the events being included in the projected contour of a sphere centred at a GGC centre and of radius $r_i = 2 \times r_t/5$ (this including on average 90% of the total cluster mass). We then distinguished between *inner* and *outer* events, the former being inside r_i and the latter being included in the circular ring of internal

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radius r_i and outer radius r_t. Furthermore, we assumed all the outer events to be due to Galactic bulge/disc deflectors (this possibly underestimating the events due to GGC lenses), whereas we left open the possibility that among the inner events some could still be attributed to bulge/disc deflectors. At the end we are left with 28 inner events, among which 7 (17/4) have been detected by the MACHO (OGLE/MOA) collaboration.

Table 1.   GGCs with inner events. For each of them N_{in} is the number of events inside a projected radius $r = 2 \times r_t/5$ and, for this subset of aligned events, $< t_E >$ is the mean Einstein time (in days) and $< m >$ is the average predicted lens mass in units of solar masses. N_{GGC} (N_{BD}) is the number of events, out of N_{in}, that we expect to be due to GGC (Galactic bulge/disc) lenses. Γ_{exp} is the expected event rate in units of $f \times \mu_o^{-1/2} \times 10^{-3}/year$.

Cluster ID	N_{in}	$< t_E >$	$< m >$	N_{BD}	N_{GGC}	Γ_{exp}
NGC 6522	8	13.1	1.63	4.1± 2.0	3.9	0.66
NGC 6528	7	13.0	2.98	4.9± 2.2	2.1	0.09
NGC 6540	7	17.2	0.06	4.2± 2.0	2.8	1.56
NGC 6553	4	35.7	0.62	0.6± 0.8	3.4	0.08

An estimate of the predicted number of events, N_{GGC}, due to low mass stars in a given GGC, can be roughly made as follows. Assuming that all the outer events are due to Galactic bulge/disc lenses, we calculate how many such events, N_{BD}, are expected in the inner region of a GGC contour assuming that the number of events is proportional to the covered area and that the background source distribution is uniform inside every GGC contour. Thus we assume that the microlensing rate for Galactic bulge/disc events is constant over the entire small area within the tidal radius of the considered globular cluster. Thus N_{BD} is simply proportional to the monitored area. Clearly, also with these assumptions, which are reasonable, given the very small area considered, one expects fluctuations in the number of events in a given area. We assume the fluctuations to follow Poisson statistics, in which case they are given by $\sim \sqrt{N_{BD}}$. By doing so, for every GGC considered, N_{GGC} turns out to be around 2-4 per cluster (see Table 1) and in two cases (NGC 6522 and NGC 6553) this number is larger than the estimated fluctuation of N_{BD}. Given these numbers we cannot claim for any clear evidence of lenses hosted in GGCs. Nonetheless, it is remarkable that for the 4 cases considered the value of N_{GGC} is positive and most probably underestimated, since the assumption that all the events lying in the outer ring are due to bulge/disc deflectors possibly overestimates N_{BD}.

Assuming that the deflector is a GGC low mass star or brown dwarf, we can estimate its mass through the relation $R_E/t_E = v_r$, where v_r is the lens-source relative velocity orthogonal to the l.o.s., t_E is the event Einstein time and R_E is the Einstein radius. For v_r we adopt the value of the proper motion of the considered globular cluster as given in the literature. As reported in Ref. 5, the mean GGC tidal radius is of the order of tens of pc, this making the GGC extension relatively small compared to the average lens distance from Earth or the source distance (of the order of kpc), since we are assuming Galactic bulge/disc sources and the GGCs are kpcs away from the Sun. For this reason, we make the simple assumption that in a given GGC the objects acting as lenses are all at the same distance from the Sun. Table 1 shows, for the whole subset of inner events, the predicted deflector mass in units of solar masses, $< m >$, obtained with these assumptions. The resulting average lens mass are values in the range $\{10^{-2}, 10\}$, suggesting that the involved deflectors are possibly either brown dwarfs, M-stars or stellar remnants. Moreover, Jupiter-like deflectors are not definitively excluded, since, already a small increase on D_{os} can substantially reduce the predicted lens mass.

The average expected lens mass has been drawn from the set of inner events, some of

which being possibly not due objects located in the GGC. This source of contamination should be removed before one makes any prediction, but since we are not able to do such a distinction, the average values on the overall inner sample can be taken as a first crude approximation.

Also given in Table 1 is the number of expected events toward the GGC centres, Γ_{exp}, as calculated through formula (36) of Ref 3, where it is assumed that all the lenses have the same mass μ_o, in units of solar masses, and that their distribution is very narrow with respect to that of the source population. Γ_{exp} is given in units of $f \times \mu_o^{-1/2} \times 10^{-3}/year$, f being the fraction of matter in form of brown dwarfs, dim stars or stellar remnants in the cluster. For a typical value of $10^2 - 10^3$ monitored source stars behind a GGC (this number depending also on the GGC extension) and an observation period of ~ 5 to 10 years, we expect at most between an event and a couple of events toward each GGC depending also on the value of f, in reasonable agreement with the number of events N_{GGC} reported in the Table 1.

In 2000 July/August a microlensing event occurred at a distance of 2.33 arc minutes from the centre of the globular cluster M22 (NGC 6656), observed against the dense stellar field of the Milky Way bulge. In order to check the hypothesis that the lens belongs to the globular cluster we made a dedicated observation, using the adaptive optics system NACO at the ESO Very Large Telescope to resolve the two objects - the lens and the source - that participated in the event. The position of the objects measured in July 2011 was in agreement with the observed relative proper motion of M22 with respect to the background bulge stars. Based on the brightness of the microlens components we found that the source is a solar-type star located at a distance of 6.0 ± 1.5 kpc in the bulge, while the lens is a 0.18 ± 0.01 $M_\odot$ dwarf member of the globular cluster M22 located at the known distance of 3.2 ± 0.2 kpc from the Sun,[6] therefore being the first confirmed microlens in a globular cluster.

3. Conclusions

Given these very promising preliminary results, nicely supported by the first confirmed event, it would be desirable to get more observations of globular clusters. Indeed few events could already help very much to constrain the low mass star and brown dwarf content and thus to get a clear mass budget and information on the stellar mass function of globular clusters. Clearly, the expected number of events, and thus the rate, is certainly quite small, which would require to develop an appropriate strategy for a systematic survey during many years of the lines of sight comprising several globular clusters, in particular the ones we analysed and for which we found some evidence of possible candidates and also toward M22, which is a rather massive globular cluster for which we expect a higher event rate as compared to the other clusters.

References

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