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Central bodies' masses of selected globular clusters

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We present estimations of masses of central bodies for selected globular clusters with a predicted black hole in the center. We proposed our approximate dynamic method and compared our results with other ones and, in particular, with modern radio observations. As the result, the masses obtained by our method correspond to the range of intermediate mass for black holes. The exception is the situation with ω Cen (in our Galaxy) and G1 (in M31) whose estimations of central masses have some differences depending on several methods and take place near the lower end of masses of the central bodies of galaxies.

Keywords: Globular clusters; Intermediate-mass black hole; ω Cen, G1

1 Introduction

One of the very interesting problems in modern astronomy is the search for the existence of black holes of intermediate masses (IMBH) that are in the range of 10^2 to 10^5 $M_\odot$.

Globular clusters are the most suitable targets for this purpose as they can contain such objects in the central regions. Now the intensive study of possibility of their existence is carried out by means of various astronomical methods (see, for instance, a detailed review by Safonova and Shastri (2010)). But this problem is rather disputable, and it is noted in many papers (see also Ting Ni-Lu and Kong (2011)) that observational evidence of such masses is limited. On the other hand, theoretical works provide possibilities of IMBH existence, see also the paper by Safonova and Stalin (2010), where the principle mechanisms of IMBH formation are considered: the core collapse of massive BH and the merging of BH with small masses, and also some exotic scenarios are mentioned. In our work we used information on six clusters (see Table 1), for which recent radio continuum observations have been fulfilled (Ting Ni-Lu and Kong 2011) and which are considered as clusters with reported central black holes.

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2 Selected objects

We have made earlier our estimations of the central body masses (Kiselev et al. 2008, 2011) using dispersion σ of radial velocity $V_{\rm r}$ from Safonova and Shastri (2010) and Safonova and Stalin (2010). For M15 (NGC 7078) we have used the results of HST observations with STIS for individual stars in region $1'' \times 1''$ according to Gerssen et al. (2002). For NGC 104 and NGC 6397 we have used the dispersions σ, which was pointed in Safonova and Shastri (2010). Now new objects have been added, where an opportunity of the existence of a black hole in their central region was explored. We have included for our analysis ω Cen (NGC 5139), NGC 6388 – the globular clusters in the Milky Way and G1 in Andromeda galaxy. We have chosen clusters with the predicted central BH. Observations of these clusters have a very long and interesting history, but in the framework of the present article we can give only a short information about them. The clusters ω Cen and G1 differ from other objects, because they are considered to be the cores of galaxies stripped by tidal forces (see Safonova and Shastri (2010), Mackey and van den Bergh (2005) and references therein), and it was interesting to estimate the mass of their centers.

1. ω Cen is the brightest and largest globular cluster known to date. The cluster belongs now to our Galaxy, but it is assumed that in the past it was a dwarf galaxy absorbed by the Milky Way. One can track the debate concerning the mass of the central body in the cluster ω Cen in the most topical publications presented today, see, for instance, van der Marel and Anderson (2010) and Noyola et al. (2008, 2010).

2. Under the initiative of an author of this work – Yu.N. Gnedin – we have made an attempt to estimate the scale of additional spatial measurement l. Taking into account the age and calculated mass of the globular cluster NGC 6397 we have estimated the size of l in connection with the new theory of gravitation. The value of l has been found in the range of 0.02–0.14 mm (Kiselev et al. 2011).

3. We applied our method first for M15 (Kiselev et al. 2008) and now we compared our results with radio observations and with other methods.

4. The globular cluster 47 Tuc (NGC 104) is also of interest for researchers, because it contains a large number of X-ray stars, but the evident presence of a black hole with a very large mass in the center has not been proved (Ting Ni-Lu and Kong 2011).

5. There are various estimations of the mass of a black hole in the center of cluster NGC 6388 from $5.7 \times 10^3\ M_\odot$ (Lanzoni et al. 2007) up to no more than $1.5 \times 10^3\ M_\odot$ (Cseh et al. 2010).

6. It is proposed also that G1 can be the remains of a dwarf galaxy absorbed by the galaxy of Andromeda at the previous stage of evolution. From the analysis of observations we can see that the mass of the central body estimated by different authors differs significantly, for instance, $4.5 \times 10^3\ M_\odot$ (Ulvestad et al. 2007) and $1.8 \times 10^4\ M_\odot$ (Gebhardt et al. 2002).

All of these clusters have been subjected to research by different methods of observations and procedure. We tried to compare our results with limits of masses given in reviews (Safonova and Shastri 2010; Ting Ni-Lu and Kong 2011) which have been obtained by several authors.

3 Method and processing

We have fulfilled the estimation of masses of the central bodies for selected globular clusters on the basis of σ dispersions of their radial velocities $V_{\rm r}$, taken according to the astronomical data, and with the use of our method, which is described in detail in Kiselev et al. (2008, 2011). We made an assumption that stars of a cluster with corresponding σ are on a short distance relatively of the predicted black hole and they are revolving it as planets around the Sun, according to laws of Newton, and thus their masses are near to the mass of the Sun, but the mass of the central body can be more by a factor of 10^3. We considered dispersions of radial velocities of stars near to the center of the cluster for two prospective extreme cases:

1) regular rotation of stars around the center in the plane parallel to the line of sight, and

2) rotation on the orbits with accidental orientation.

We have estimated a mass of the system: the central body + a star (Σm), proceeding from the integral of energy, as in a problem of two bodies at determination of masses of double stars. Here the integral of energy has the following form:

$$V^2 = k^2 \left(\frac{2}{r} - \frac{1}{a}\right), \tag{1}$$

where $k^2 = 4\pi^2(M_1 + M_2)$ or $k^2 = 4\pi^2 \Sigma M$.

Corresponding dimensions: $[k^2]$ = a.u.^{3}/year^2; $[V] = \dfrac{V km/c}{4.74}$ or $[V]$ = a.u./year; $[r]$ = a.u.; $[M] = 1M_{\odot}$.

It was supposed that stars rotate around the black hole on circular orbits parallel to the direction of the line of sight. Then we used the formula:

$$\sum M = \frac{rV^2}{4\pi^2} = \frac{rV^2}{39.48} = 0.0253\ rV^2, \tag{2}$$

where $\sum M \simeq M_c$ – a mass of the central body and instead of space velocity V we use dispersion σ.

In the case of chaotic movement we used the integral of energy and Kleiber relation between absolute differences of space and radial velocities: $\Delta\overline{V} = 2|\Delta\overline{V}_r|$ and then we applied the following formula:

$$M_c = 0.101r(|\Delta\overline{V}_r|)^2, \tag{3}$$

where

$$|\Delta\overline{V}_r| = \sqrt{\frac{2}{\pi}}\ \sigma_{(V_r)} = 0.798\ \sigma_{(V_r)}. \tag{4}$$

We proposed that the semi-axis mayor a of the random orbits in the middle is equal to r and the mass of the stars is small in comparison with the central body mass.

4 Results

The results are given in Table 1, where the name of a cluster is given in column I; D – the distance from the Sun – in column II; dispersion σ – in column III; the values of masses estimated by our method are in column IV; the masses from Safonova and Shastri (2010) are given in column V. For references on each cluster, see also Safonova and Shastri (2010). The values of masses collected in Ting Ni-Lu and Kong (2011), based on recent radio continuum observations of globular clusters of several authors and quoted therein (Ting Ni-Lu and Kong (2011)), are given in column VI.

Estimation of the central body masses based on observations by means of HST and VLT and using velocities and proper motions of individual stars is in column VII. The references for papers according to each cluster for columns VI–VII are also given in Ting Ni-Lu and Kong (2011). The results given in column VII have been obtained by means of some dynamic methods including the statistical approach described in Safonova and Shastri (2010) using the $V_{\rm r}$ dispersions σ.

For our estimations of the masses we used formulas (2) and (3). Results for NGC 104, NGC 6397, NGC 6388, NGC 7078 are given as a fraction, where the numerator is the value for proposed regular orbits and the denominator − for accidental orbits. For other clusters we give results only with suggestion of regular rotation of stars.

For NGC 104, NGC 6397, NGC 6388 and NGC 7078 (as in Kiselev et al. 2011) we proposed that the radius r in formulas (2) and (3) is one thousandth part relative to the tidal radius $R_{\rm t}$, and also we used σ from Safonova and Shastri (2010) for the first three clusters and σ calculated according to the data by Gerssen et al. (2002) for NGC 7078.

We pay our attention on globular clusters ω Cen and G1 for which various methods give different results. Our estimation of the mass for ω Cen is close to the results of Noyola et al. (2008, 2010), which consists of $4{\times}10^4$ $M_\odot$ and more than the mass estimation by van der Marel and Anderson (2010), which is estimated as $1.8{\times}10^4$ $M_\odot$. For ω Cen we took σ from van der Marel and Anderson (2010) equal to 23.0 km/s or 4.85 a.u./year. The distance from the center of the cluster r has been adopted as $14''$ or 74200 a.u. also according to van der Marel and Anderson (2010). With these parameters we obtained the mass equal to $4.4{\times}10^4$ $M_\odot$. But with $\sigma = 18.6$ km/s and with $r = 5''$ we obtained a mass equal to $2.8{\times}10^4$ $M_\odot$.

We analyzed the HST and Keck's data for G1 given in Gebhardt et al. (2005). We compared the dispersions corresponding to different radii from the center of cluster. In Table 1 we give masses for relatively small distances r: $8.5{\times}10^3$ $M_\odot$ and $4{\times}10^4$ $M_\odot$ for r which are equal to $0''.01$ and $0''.05$, respectively.

However our method has shown a failure at a greater distance from the center of G1, where the values of masses obtained are larger in order than IMBH.

5 Conclusion

We applied our astrometric method to estimate the masses of central bodies of globular clusters, using our practice of observations of double stars. We consider this method to be approximate, because we did not take into detailed account the features of clusters and stars forming them, but our approach may be considered as an addition to similar research.

Table 1 The masses of the central bodies of globular clusters.

Name	D kps	σ, km/s	$M{\cdot}10^3\ M_\odot$, (this issue)	$M{\cdot}10^3\ M_\odot$, (*)	$M{\cdot}10^3\ M_\odot$, (**) radio	$M{\cdot}10^3\ M_\odot$, (**) dynamic
I	II	III	IV	V	VI	VII
NGC 104 (47 Tuc)	3.8	11.6	1.1/4.4	1.0	9–0.5	1.5
NGC 5139 (ω Cen)	5.3	23.0	28–44	40	5.2–1.1	12.0
NGC 6388	9.9	18.6	1.6/6.4	5.7	1.5–0.73	5.7
NGC 6397	2.3	4.5	0.03/0.13	0.02	4.3–0.9	0.05
NGC 7078 (M15)	10.4	14.1	2.4/9.6	2.5	2.4	1.0
G1	780	30.0	8.5–40	18	4.5	18

*Safonova and Shastri (2010)
**Ting Ni-Lu and Kong (2011)

We compared our results with those obtained by means of the statistical method with a logarithmic dependence between σ and M, by the method of fundamental plane (Ting Ni-Lu and Kong 2011) and by some others.

In most cases our results are in the range reported by other authors. We detected some limits in the use of our method. We revealed that in some cases the masses of central bodies are similar to massive BH masses corresponding to galactic cores.

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