ESTIMATION OF THE MASS AND THE SPECIFIC MOMENT OF ROTATION OF A BLACK HOLE IN THE CENTER OF SPHERICAL CLUSTER M15

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ABSTRACT. Using dispersions of radial velocities of stars, being near to the center of spherical cluster M15, and having applied integral of energy, we have estimated the minimal mass of the central body as 2×10^3 masses of the Sun. The estimation of kinetic energy of outflow of substance of the area surrounding a black hole in M15 also is fulfilled, and the size of the specific angular moment of rotation of a black hole a/M_{BH} is determined.

1. Introduction

Astrometric observations of double and multiple stars and stars with invisible satellites are conducted in Pulkovo observatory for many years on a Zeiss refractor ($D = 65$ cm, $F = 10.4$ m).

Using a technique of determination of orbits and masses of double stars we have taken part in an estimation of mass of the central object in the center of our Galaxy (Kisselev et al., 2007), using those data of observations of stars near to the center which were accessible from publications. The observations of ESO, (VLT) (Genzel et al. (2003) and Keck (Ghez et al., 2005) are available in view.

We managed to show, that with knowing of precise parameters of movement is possible to determine orbital elements and to estimate the mass having not on all visible ellipse, but by means of a small part of an arc. Also using the solution of a problem of two bodies we applied our methods to the estimation of mass of a supermassive black hole in the center of our Galaxy.

In the further in work (Kisselev et al., 2008) we have estimated mass of the central object of spherical cluster M15 by means of astrometric method using the energy integral which has been applied to the value of average space velocity, and also by means of astrophysical data.

2. Determination of mass of central object M15

For the astrometric approach we used radial velocities of 13 stars nearest to the dynamic center of a cluster in the field of $r < 1''$ (see fig.2 in work Kisselev, 2008) which have been received by means of Space Telescope Imaging Spectrograph (STIS) and are published in the article by Gerssen et al. (2002).

We have considered stars with a negative and positive dispersion of radial velocities from the list [5]. The dynamic analysis of these velocities has been carried out on the basis of a problem of two bodies as there were concrete objects with individual velocities for this solution.

We were limited to consideration of movements of stars only in small central area of a cluster ($r < 1''$), because the distribution of stars velocities has come to light in this area appeared not casual.

In the distribution of residual radial velocities

$$\Delta \bar{V}_r = V_r - \bar{V}_r \tag{1}$$

there is a rotational movement of this group of stars relatively of an axis, whose projection on a picture plane is the axis with positional angle near to 130°.

For more general case (accidental distribution of velocities) we had been used also statistical properties of distribution of movements of stars according to theorem of Kleiber.

In our work (Kisselev, 2008), we used estimations of average distance up to a cluster: Cox et al.(1983); Harris (1996), MacNamara et al. (2004), which give on the average 10 kps.

Recently the study by Lugo et al. (2007) has been published, where the distance is determined by means of V and R photometry on stars RR Lirae available in a cluster. It has appeared equal 8.67 ± 0.41 kps.

Thus, at the account of new distance the area considered by us $r < 1''$ in the center of a cluster was reduced in the linear sizes from 10^4 a.u. up to 8.67×10^3 a.u. Radial velocities and their dispersion have not changed.

Accordingly, we receive following estimations of mass of a black hole in the center of a cluster.

Table 1: Data about spherical cluster M15.

$\alpha_{(2000.0)}$	$\delta_{(2000.0)}$	$l_{(2000.0)}$	$b_{(2000.0)}$	Size
$21^h27^m.6$	$+12°10'$	$65°05'$	$-27°00'$	19'×19'

In the case when the observed dispersions of velocities of stars near the center of a cluster we consider as a projection of the circular movements in a plane, parallel to a line of sight with velocity $V_r = 3.0$ a.u./year, the mass (M) of the central body in the field of $r = 1''$ ($r = 8.67 \times 10^3$ a.u.) is estimated according to integral of energy:

$$V^2 = 4\pi^2 M \left(\frac{2}{r} - \frac{1}{a}\right) \tag{2}$$

$$if\ r = a\ and\ V = V_r\ \ M_1 = \frac{rV^2}{4\pi^2} = 1.98 \times 10^3 M_\odot;$$

$$if\ \rho = 0.''5\ \ M_1 = 10^3 M_\odot \tag{3}$$

In the second case, if observed velocities of stars one can consider as a projection to a line of sight of velocities of stars chaotically moving about the center of a cluster, then according to theorem Kleiber: $|V_r| = 1/2\bar{V}$, $\bar{V} = 6$ a.u./year.

The mass M_2 determined by us for the second case will be equal:
$M_2 = 7.89 \times 10^3 M_\odot$, if $\rho = 1''$
and
$M_2 = 3.95 \times 10^3 M_\odot$, if $\rho = 0.''5$.

Thus, our former estimations of mass of the central body (a black hole) in the center of the cluster M15 received in Kisselev et al. (2008):

1) $M_1 = 2.28 \times 10^3 M_\odot$ and $M_1 = 1.14 \times 10^3 M_\odot$
2) $M_2 = 9.11 \times 10^3 M_\odot$ and $M2 = 4.56 \times 10^3 M_\odot$

have changed only proportionally to change of distance, because the basic observational data for research, namely, the relative radial velocities of stars, expressed in an absolute measure - have not changed.

Thus, if the dispersion of radial velocities $\{\Delta V_r\}$, is real, but it is not consequence of mistakes of measurements, then this dispersion is possible to explain an attraction of a supermassive star in the center of a cluster which mass is estimated according to integral of energy and makes from 1000 up to 8000 masses of the Sun.

It is necessary to notice also, that, the given estimations take place only in the event that observed stars of the central area really belong to cluster M15, but are not projected to a cluster, being placed, thus, on uncertain distance from the observer.

3. Astrophysical analysis

In the given work also we consider the specific angular moment of rotation of a black hole, which is key parameter and criterion of an belonging of an object or to metrics Kerr (if this object is a rotating black hole), or to metrics Schwarzschild (if rotation is absent).

The analysis of available black holes has shown, that the most probable value for a rotating black hole is $a/M_{BH} = 0.5$, however it is accepted to account, that if $a/M_{BH} > 0$ the object also corresponds to metrics Kerr.

Discovery of some supermassive black holes on greater cosmological distances has allowed to consider black holes of intermediate masses as initial stage of supermassive black holes.

Such objects at which mass M is in following limits: $10M_\odot < M < 10^5 M_\odot$ are considered as black holes of intermediate masses. According to new data such objects can be in the central areas of spherical clusters.

Astrophysical research of M15 gives a weak inconsistent results concerning mass of the central object. However authors of these researches recognize, that the black hole can exist in the center of a cluster.

It is revealed now, that in M15 there is no essential X-ray flux, which it would be possible to expect as a result accretion of gas on a black hole. But it does not contradict the possibility of existence of other mechanisms of extraction of energy from a rotating black hole.

The scientific explanation of process of extraction of energy from a black hole is one of the central problems of modern astrophysics.

Straumann (2007) and Blanford (1977) have suggested electromagnetic process of energy extraction from a rotating black hole. Here the essential role plays the magnetic field captured by a black hole amplified by rotation of a black hole near to horizon of being events. As a result of such process from a vicinity of a black hole there is a strong expiration of plasma both in the form of magnetic wind, and in the form of relativistic jet.

Other variant of this process is process of magnetic coupling between the central rotating black hole and a accretion disk surrounding it (see, for example, Blanford, 1999). In this case energy and the angular moment are taken from accretion on a black hole of substance.

We have stopped on last variant. At first the power of energy L_{BZ} from a rotating black hole in view of metrics Kerr has been obtained. Then the strength of magnetic field B_H near to horizon of events according to a relation between the strength of magnetic field B_H on horizon of events and magnitude of mass of central massive black hole M_{BH} by means of following formulas has been obtained:

$$L \equiv L_{BZ} = (1/32)\omega_F^2 B_H^2 R_H^2 c(a/M)^2 \quad (4)$$

$$\omega_F^2 = \Omega_F(\Omega_H - \Omega_F)/\Omega_H^2 \quad (5)$$

Here L is the power of energy, Ω_H and Ω_F are angular velocity of rotation of a black hole and magnetic power lines accordingly, $\omega_F^2 = 1/2$.

$$R_H = \frac{GM_{BH}}{c^2}\left(1 + \sqrt{\left(\frac{a}{M_B H}\right)^2}\right) \quad (6)$$

Following step was determination of the angular moment of rotation a/M_{BH} with use of equality of kinetic energy L_{kin} and L_{BZ}.

It has appeared that $a/M_{BH} = 0.08$. Thus, it is possible to make the conclusion of that the given object can be considered within the limits of Kerr metric.

4. Conclusions

For small sample inside of a cluster ($r \leq 1''$) distribution of radial velocities which can be interpreted as reflection of rotary movement of the given subsystem as the whole is revealed. Having accepted average velocity of the rotation as 14 km/s, (3 a.u./year), the mass of the central kernel of a cluster at the assumptions mentioned above cannot be less than 2.0×10^3 masses of the Sun. The size of the specific angular moment of rotation of a black hole a/M_{BH} in view of value of the mass received by an astrometric method is determined.

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