IS THERE A MASSIVE BLACK HOLE AT THE GALACTIC CENTER?

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1. INTRODUCTION

During the past 10 years an hypothesis about the presence of a massive black hole at the center of our Galaxy (Lynden-Bell, 1969) has been an object of many exciting speculations. This hypothesis is based, firstly, on attempts to explain the nature of the "point radio source" at the galactic center (as well as a presumed much more powerful activity of the galactic nucleus in the remote past), and, secondly, on the opinion that the conditions in the course of dynamical evolution of galactic nuclei are favorable for the formation of massive black holes. However, both these approaches did not succeed in predicting with any confidence the black hole mass at the center of the Galaxy. The estimates available are based on indirect arguments and range from 10^7-10^{11} $M_\odot$ (Novikov and Thorne, 1973) to 10^4 $M_\odot$ (Shklovskii, 1976). A recent dynamical approach using NeII infrared observations of the galactic center (Wollman et al., 1977) has indicated that the black hole mass does not exceed 5×10^6 $M_\odot$ (Oort, 1977), although this value may well be due to a very dense star cluster whose brightest members only are seen in the infrared.

Black hole models are usually based on at least two arbitrary parameters: the black hole mass M_h and the accretion rate $\dot{M}$. As for the galactic center, the situation is fortunately much more definite. Taking into account such an inevitable process as disruption of stars in the vicinity of the black hole by its tidal forces, it is possible to obtain a lower limit on $\dot{M}$ and then (invoking available observational constraints on the luminosity or mass of the point source) an upper limit to the black hole mass M_h.

2. CONSTRAINTS ON M_h FROM LUMINOSITY DATA

The rate of tidal disruption of stars surrounding a black hole at the center of a compact star system has been calculated recently by a number of authors (Hills, 1975; Ozernoy, 1976; Bahcall and Wolf, 1976; Frank and Rees, 1976; Lightman and Shapiro, 1977; Dokuchaev and Ozernoy, 1977a) and may be considered as rather well established. Recently the

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present author has investigated the character of accretion of gas released from the disrupted stars. Applied to a presumed black hole surrounded by the conditions pertaining in the nucleus of the Galaxy (defined by a core radius $R_c \gtrsim 1$ pc, a stellar concentration inside the core of density $n_c \gtrsim 10^7$ pc^{-3}, and a velocity dispersion v = 200 km s^{-1}) the overall picture is as follows.

As long as the mass of a black hole is comparatively small (less than, say, 3×10^7 $M_\odot$), then the feeding of the hole can be provided by stars from unbound orbits which are disrupted by the tidal forces of the hole with a rate $\dot{N} \gtrsim 10^{-2}$ $(M_h/10^6 M_\odot)^{4/3}$ yr^{-1}. After 10-100 stars are disrupted, their remnants, forming gaseous disks inclined to each other under different angles, will form as a result of their collisions a more or less spherical cloud which will provide an effective accretion of the gas onto the hole. Afterwards accretion will produce, in addition to a flare (intermittent) component, a steady component of the luminosity. The value of the latter is determined by the rate of star disruption and is equal to

$$L = \varepsilon \dot{M} c^2 \gtrsim 10^{42}\ \varepsilon_{0.1}\ M_6^{4/3}\ n_7 V_{200}^{-1} \text{ ergs s}^{-1}. \qquad (1)$$

Here ε is the efficiency of mass-to-energy production during accretion and is hardly much smaller than 0.1; the quantities are normalized to 0.1, 10^6 $M_\odot$, 10^7 pc^{-3}, and 200 km/s, respectively.

Although an appreciable part of the luminosity of a massive black hole will be in the optical, UV, and very soft x-ray bands, the spectrum will differ significantly from that in the standard disk accretion model. First of all, dust does re-radiate optical and UV emission into the infrared band. By comparing the recent upper limit to the infrared radiation of the point source, $L \lesssim 10^7$ $L_\odot$ (Gatley <u>et al</u>., 1977), with eq. (1) it is easily seen that the black hole mass is constrained by the value $M_h < 3\times10^4$ $M_\odot$ (<u>cf</u>. Ozernoy, 1976).

This upper limit may be lowered farther to a much smaller value if one takes into account that an appreciable part of the emission of a massive black hole is in the energy range 1 keV $\lesssim$ E $\lesssim$ 100 keV, according to an "optically thin model" by Payne and Eardley (1977) which is appropriate for the case of interest. Meanwhile the recent high resolution observations of x-ray sources at the galactic center by Cruddace <u>et al</u>. (1977) reveal no x-ray emission from the point source in Sgr A West, which yields an upper limit of 1.5×10^{36} ergs/s (2-10 keV) on its x-ray luminosity. Comparing this limit with the x-ray emission of the optically thin model (Eardley <u>et al</u>., 1978), one obtains $L/L_{Edd} < 10^{-4}$, where L_{Edd} is the Eddington luminosity of a black hole. The inequality obtained, together with eq. (1), give an extremely low upper limit to the black hole mass

$$M_h < 1\ \varepsilon_{0.1}^{-3}\ n_7^{-3}\ V_{200}^{-3}\ M_\odot. \qquad (2)$$

Evidently, the numerical coefficient is arguable, but the qualitative result seems to be rather significant. True, a confrontation with observational data needs time-dependent models of accretion which

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should be elaborated to determine details of gas flow near a hole. Because this has not been done, we present in the next Section another method to obtain an upper limit to the black hole mass, without invoking the luminosity arguments.

3. CONSTRAINTS ON M_h FROM SECULAR GROWTH OF A BLACK HOLE

Let us consider the inevitable growth of the black hole mass in the course of tidal disruption of stars surrounding the assumed hole at the galactic center. The calculations of secular growth of the black hole formed presumably 10^{10} years ago in the galactic nucleus were made by Dokuchaev and Ozernoy (1977b) under the following assumptions: (i) stars in the nucleus have a Maxwellian velocity distribution, and the rotation of the nucleus is negligibly small; (ii) most of the gas from disrupted stars is accreted eventually onto the hole; (iii) the main parameters of the galactic core (its radius $R_c \gtrsim 1$ pc and the star density $n_c \gtrsim 10^7$ pc^{-3}) do not change appreciably during secular evolution of the black hole.

The character of the growth of the black hole mass is shown in Figure 1. As long as the black mass is comparatively small, its tidal forces disrupt neighboring stars with a rate $\dot{N} \gtrsim 6 \times 10^{-7} (M_h/10^3 M_\odot)^{4/3}$ yr^{-1} (Hills, 1975; Dokuchaev and Ozernoy, 1977a). When the mass $M_h \sim 3 \times 10^7 M_\odot$ is reached, disruption of stars due to collisions begins to prevail over tidal disruption. Finally, when the black hole mass becomes comparable with the mass of the core (*i.e.*, when the concentration of stars diminishes noticeably), tidal disruption will again become dominant over star collisions, but will proceed now at the lower rate $\dot{N} \gtrsim 4 \times 10^{-3}$ yr^{-1} (Dokuchaev and Ozernoy, 1977c).

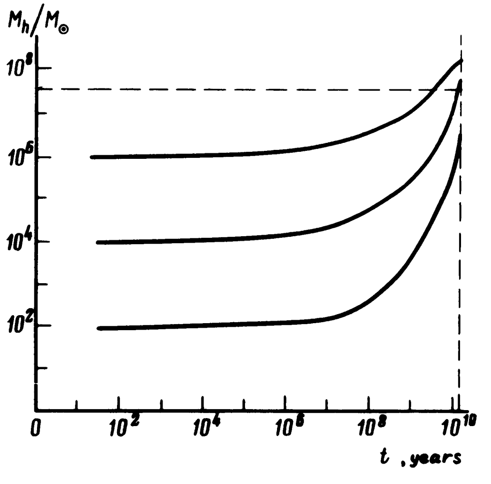

Figure 1. Secular growth, a black hole mass at the Galactic nucleus.

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As seen in Figure 1, an appreciable growth of the black hole mass during 10^{10} yr is possible only if the initial mass was greater than $\sim 10^2$ $M_\odot$. An important additional feature is shown in Figure 2, which gives the relation between the initial black hole mass $M_h(0)$ and its expected present value $M_h(10^{10}$ yr) caused by accretion. As one can see, the mass increases during 10^{10} yr to a value $M_h \sim (4\times10^6-10^8)M_\odot$ which depends weakly on the initial mass provided that the latter exceeds 10^2 $M_\odot$ only slightly.

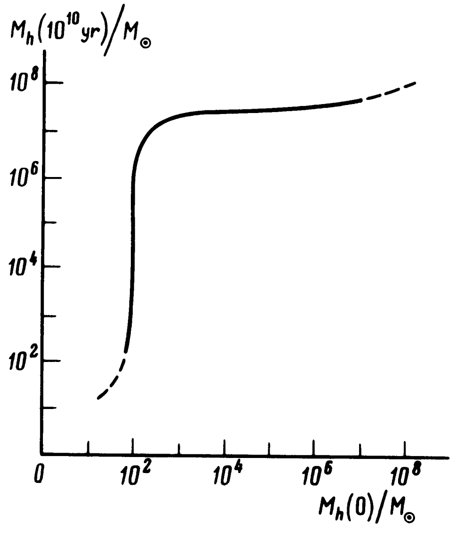

Figure 2. Final mass of a black hole vs its initial mass.

Even the minimal value of the final black hole mass is only marginally consistent with the above-mentioned observational upper limit to the black hole mass 5×10^6 $M_\odot$ (Oort, 1977), if $M_h(0) \gtrsim 10^2$ $M_\odot$. Of course, there is a possibility that a black hole in the galactic center was formed so recently that its present mass lies within the interval $10^2-4\times10^6$ $M_\odot$. However this possibility seems to be rather artificial.

Let us discuss briefly the other assumptions and simplifications listed above which could change the upper limit obtained.

(i) Repopulation of the "loss-cone" by stars due to diffusion of their orbits could depend on the rotation of the core only at a large anisotropy of star velocities. As for the situation in the nucleus of M31 (whose dynamical parameters are very similar to our own), its rotational velocity is much smaller than the velocities of chaotic motions of stars (e.g., Ruiz, 1976). This makes it quite reasonable to neglect rotation, in a first approximation, in estimates of the tidal disruption rate.

(ii) The possibility of partial ejection of gas from disrupted stars out of the sphere of its spreading, as a result, e.g., of thermal flares induced by the tidal forces (Lidskii and Ozernoy, 1978) was not taken into account. On the other hand, the interaction of stars with elongated gas clouds (remnants of disrupted stars) was neglected also. Their collisions lead to a decrease of the orbital angular momentum of the stars and, consequently, to a more rapid filling of the loss-cone. These processes work in opposite directions and compensate each other partially.

(iii) Although the assumption that the main dynamical parameters of the nuclear core are constant during its life is an oversimplification, a detailed analysis indicates (Dokuchaev and Ozernoy, 1977c) that it is not too bad.

4. SOME INFERENCES

A stringent upper limit $M_h \lesssim 10^2\ M_\odot$ to the black hole mass in the galactic center raises an interesting question: Why did the dynamical evolution of the nucleus lead to a small, if any, mass of the black hole? A possible answer, according to results of Dokuchaev and Ozernoy (1977d) may lie in the formation of a large number of close binary systems which may be the main factors preventing both collapse of the core and the formation of a massive black hole there.

Regardless of the eventual explanation of its low value, the upper limit to the black hole mass in the nucleus of the Galaxy appears to be in contradiction

(1) with the hypothesis that nuclei of normal galaxies are dead quasars (Lynden-Bell, 1969);

(2) with the hypothesis that massive black holes serve as sources of activity for Seyfert galaxies unless the Seyfert nuclei belong to some peculiar galaxies rather than to normal giant spirals;

(3) with the hypothesis that relic black holes may be the main factor of galaxy formation, because the mass of a relic black hole must have grown to $\sim 10^7\ M_\odot$ by the present time if it served as a center for the formation of the Galaxy (Ryan, 1972).

These negative results are, in fact, rather positive in the sense that they impose very informative constraints on the dynamical history of the galactic nucleus and, possibly, on the nature of an "engine" in the nuclei of Seyfert galaxies.

5. SUMMARY

During recent years many authors have become so convinced that black holes do exist that they adhere to the statement "Black holes are everywhere until their presence is disproved". Clearly, this claim violates the principle of "presumption of failure to prove". Nevertheless the galactic center appears to be the place where the existence of a <u>massive</u> black hole seems to be inconsistent with observational data coupled with theory, which together impose rather severe constraints on its mass.

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DISCUSSION

Ostriker: Quite without regard to the ability of the rotating black hole to find and eat stars, the limit on the x-ray luminosity observed sets a rather low limit on the local gas density. Even a 10^6 $M_{\odot}$ black hole emitting with an efficiency of 10^{-4} would produce too much luminosity if the surrounding gas density were as much as the solar neighborhood value of 1 particle per cm^2.

Trimble: Ozernoy would undoubtedly agree with you, as, of course, do I, provided that the x-rays are emitted isotropically, and not perpendicular to a thick disk which we see edge-on. A creative imagination could probably come up with one or more plausible processes to clear gas out of the immediate black hole environment.