SOME IMPLICATIONS OF ESCAPE OF SUPERMASSIVE BLACK HOLES FROM GALACTIC NUCLEI DUE TO PLASMOID EJECTION

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Abstract. Shklovsky (1982) has hypothesized escape of accreting supermassive black holes from galactic nuclei as a consequence of asymmetric ejection of plasma clouds from their accretion disks and their subsequent defunction for explaining evolutionary effects in quasars. It has been argued here that such an interpretation must accomodate the possibility of substantial capture of stars and gas by the black hole on its way out – which can prolong the life of the quasar – unless the mass of the black hole is less than $\sim 10^7 M_\odot$ and a large enough initial recoil velocity is achieved.

1. Introduction

Shklovsky (1968) has suggested an interpretation of one-sided jets of active galactic nuclei as a relativistic ejection of compact plasma clouds (the plasmoids) from the nucleus of a galaxy at a small angle to the line-of-sight. In addition, the powerful radio emissions of quasars and radio galaxies are conjectured to be caused by ejection of plasmoids originating in supercritical accretion on to massive black holes (Shklovsky, 1982). If successive ejections of plasmoids from thick accretion disks forming around massive black holes (the object) take place in an asymmetric manner, the object can attain a recoil velocity enough for it to escape from the nucleus. This phenomenon offers a possibility for explaining a number of evolutionary effects and an approach to solving the problem of dead quasars.

The purpose of this paper is to point out a significant aspect of the hypothesis, namely, substantial mass accretion by the escaping black hole, a point which has not been stressed by Shklovsky (1982) but would have a bearing on an interpretation of certain observations based on the recoil hypothesis.

2. The Model and the Implications

We briefly recall the main points of Shklovsky's (1982) hypothesis. This is based on the assumption that a supercritically accreting black hole of mass $M_H \sim 5 \times 10^8 M_\odot$ located in a galactic nucleus is responsible for its activity. This black hole, however, is likely to radiate below rather than above the Eddington limit (corresponding to critical accretion) for its mass if one goes by the standard picture of accretion onto supermassive black holes located in galactic nuclei (Rees, 1978). Depending on fuel supply and mass, subcritical accretion onto supermassive black holes can produce higher luminosities (Young *et al.*, 1977) and mass ejection also is possible (Rees, 1982).

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In the following discussion, we confine ourselves to the figures adopted by Shklovsky (1982): namely, a supermassive black hole of mass $M_H \sim 5 \times 10^8 M_\odot$ which is pushed out of a galactic nucleus having been accelerated to a velocity $V_H = \Sigma_i \Delta V_i = 10^4$ km s^{-1} as a consequence of asymmetric ejection of plasmoids each imparting an increment in velocity ΔV_i. As suggested by Shklovsky (1982), the fuel carried by the black hole would not last for the time of flight $\tau = R/V_H$ (R being the dimension of the Galaxy) and therefore the quasar, interpreted as an accreting black hole, must be extinguished even before it comes out of the Galaxy. Evolutionary effects imply that almost every galactic nucleus contains a defunct quasar which cannot be detected. According to Shklovsky (1982), if the quasar has been pushed out of the Galaxy, the problem of explaining evolutionary effects is decisively solved.

In what follows, we demonstrate that due to mass accretion by the supermassive black hole, escaping from a galactic nucleus as a consequence of gradual plasmoid emission in an asymmetric manner, the quasar would not be extinguished soon. The black hole, while at the center of the Galaxy, should have an accretion disk and a dense cluster of stars around it. The distribution of stars is given by the standard power law of the form $\sim r^{-7/4}$ (Bahcall and Wolf, 1976). Stars contained within a volume of dimension of the order of accretion radius of the black hole, $r_a \sim 2GM_H/\langle V^2 \rangle$ where $\langle V^2 \rangle$ is the mean-square velocity of stars at the center of the Galaxy, are bound to it. These will be carried along when the recoil takes place. The number of stars so carried is related to the density of stars n_0 in the center of the Galaxy by

$$N \approx \frac{16\pi}{5} n_0 r_a^3 . \tag{1}$$

Hence, if we assume that the density in the innermost par sec of the Galaxy exceeds $\sim 10^6$ pc^{-3}, $N \gtrsim 10^8$. Next, there would be gas accretion from the interstellar medium. When the motion is supersonic, a shock front forms around the black hole which glows with a luminosity $\sim 10^{42-43}$ erg s^{-1} falling off as the black hole gradually picks up speed (Novikov and Thorne, 1973). Furthermore, a black hole of mass $\sim 5 \times 10^8 M_\odot$ starting, as we stress later, with a speed $> \langle V^2 \rangle^{1/2}$ can capture roughly a hundred million stars from the Galaxy while on its way out. This happens soon after the recoil takes place (Kapoor, 1976, 1983). The rate of capture decreases as the recoil builds up, and although the black hole loses a substantial number of captured stars in its wake, it still would carry a very large number along. The star system bound to the black hole in a region of dimension $R_H \sim 2GM_H/(\langle V^2 \rangle + V_H^2) \approx 0.1$ pc would be very compact where the stellar density becomes large enough to trigger violent physical processes such as stellar coalescences, disruptions and consumption of stars in toto by the black hole. If we compare the rate of stellar collisions with that of consumption of stars in toto by the black hole, expressed by the equation

$$\frac{\dot{N}_{\text{coll.}}}{\dot{N}_{\text{const}}} \approx 4N \left(\frac{R_*}{R_s} \right)^2 , \tag{2}$$

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where R_s is the Schwarzschild radius of the black hole and R_* the radius of a typical star ($\approx R_\odot$), we find that for $N \gtrsim 10^6$, rate of stellar collisions predominates over that of consumption of stars in toto by the supermassive black hole. If, in each collision an average mass $\langle \mu \rangle$ is released, it can be shown (Kapoor, 1979) that the entire system liberates mass at a rate

$$\frac{\mathrm{d}M}{\mathrm{d}t} \approx \frac{3\pi^2 G M_H n_0^2 \alpha^2}{V_H} \langle \mu \rangle \approx 0.1 M_\odot \,\mathrm{yr}^{-1}, \tag{3}$$

α being a scale length attributed to the Galaxy and $\langle \mu \rangle \approx 0.1 M_\odot$ (Sanders, 1970). In due course, one expects an accretion disk to be maintained which at 10% efficiency would radiate at $\sim 10^{44}$ erg s^{-1} for a period $\gtrsim 10^7$ yr (greater than flight time). Larger masses and lower velocities can produce higher luminosities. Obviously, the disk cannot be the conventional quiescent type even if the disk is thin and the violent physical processes allow for random ejection of gaseous matter in the interstellar and intergalactic medium at very high velocities. It is not clear to what extent stellar captures and subsequent mass ejections interfere with the recoil mechanism. Therefore, assuming that the quasar *is* eventually pushed out of the Galaxy, we find that it is not extinguished so soon even though its luminosity may be somewhat below the Eddington limit for the mass of the accreting black hole. Thus an extra-galactic energetic source that has an associated jet to start with (relativistic ejection) must eventually show up paired with a luminous object; the jet probably having fizzled out in the meanwhile.

In view of a large velocity of the escaping black hole, one should examine whether any significant rampressure stripping of the accreting material due to the gas in the interstellar medium (of density ρ_{I}) takes place. The momentum transferred per unit time to the gaseous contents (of mass M_g) of the system around the black hole is $\rho_{\mathrm{I}} V_H^2(\pi R_H^2)$. Stripping takes place when this quantity exceeds the gravitational attraction of the black hole which keeps the gaseous contents bound to it.

Therefore

$$\rho_{\mathrm{I}} V_H^2(\pi R_H^2) > \frac{G M_H}{R_H^2} M_g, \tag{4}$$

where we have neglected the attraction due to the stars bound to the black hole. Writing $M_g \equiv f M_\odot$ we have

$$\rho_{\mathrm{I}} > f M_\odot R_H^{-3} \approx 10^{-18} f \,\mathrm{g\,cm}^{-3}, \tag{5a}$$

if $V_H \sim 10^4$ km s^{-1}; and

$$\rho_{\mathrm{I}} > 10^{-24} f \,\mathrm{g\,cm}^{-3} \tag{5b}$$

if $V_H \approx \langle V^2 \rangle^{1/2}$. This is contrary to the general expectation where rampressure stripping becomes more effective with increasing velocity. Thus, be it elliptical or a spiral the black hole moves through, rampressure stripping is insignificant. The passage of the 'object' through the Galaxy causes perturbations along the path. Its track would be delineated

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by a wake of stars and gas, ionizing effects on the interstellar medium, bursts of star formation and hotspots (plasma thrown out at large velocities from the object).

Keeping in mind the coherent scattering off the fluctuations in the stellar density produced by the black hole in its wake (Saslaw, 1975a) one infers from the rocket equation describing the motion of the black hole through the Galaxy which takes into account the gravitational attraction due to a galactic mass $M(r)$ (probably $10^9 M_\odot$ within the innermost 10 pc region of the Galaxy), the stellar captures and the mass ejection that the initial recoil velocity ΔV_1 should much exceed $\langle V^2 \rangle^{1/2}$. The cases of failed recoil, namely, when $V_H \lesssim V_{\rm esc}$ cannot be ruled out. These can give rise to noticeable consequences from astrophysical point of view since the black hole falls back and oscillates through the Galaxy (Valtonen, 1976; Kapoor, 1976; Harrison, 1977; see also Rees, 1982). The object must finally settle down at the center of the Galaxy due to dynamical friction which becomes more pronounced at lower velocities. Each time it passes through the nucleus it may be stripped off its gaseous contents but would capture another hundred million stars or so. The activation can thus be recurrent for an appropriate black hole mass and the recoil velocity (Kapoor, 1979). For $M_H \gtrsim 10^9 M_\odot$ and $V_H \sim 10^3$ km s^{-1}, higher luminosity results but tidal influence on galaxy's structure would be appreciable.

3. Conclusions

In this paper, we have discussed a hypothesis of Shklovsky (1982) according to which asymmetric ejection of plasmoids from the accretion disks causes supermassive black holes to escape from galactic nuclei leading to the extinguishing of the quasar and that this phenomenon offers a possibility to interpret a number of evolutionary effects and to solve the problem of defunct quasars. We have demonstrated that rampressure stripping of the gaseous contents of the 'object' while passing through the interstellar or intergalactic medium is insignificant, so that a prolonged activity due to substantial gas and stellar accretion by the supermassive black hole is a definite possibility. This must be taken into consideration while interpreting evolutionary effects in terms of escape of supermassive black holes from galactic nuclei. For instance, if recoil is a general occurrence, this would tend to produce a steeper luminosity function for flat spectrum sources. To circumvent this, one must place an upper limit on the mass of the black hole, say $\lesssim 10^7 M_\odot$, to be pushed out of a galactic nucleus. Unless plasmoid ejection imparts large enough initial recoil velocity, coherent scattering, substantial accretion of gas and stars and the gravitational attraction of the Galaxy can arrest the escape of the supermassive black hole. The scope of a hypothesis of ejection of supermassive black holes from galaxies is perhaps larger in view of many observations as possible areas of its application. These relate to galaxies with displaced nuclei (Burbidge, 1970), asymmetric location of some BL Lac objects and quasars with respect to the underlying nebulosity (Saslaw, 1975b; Hutchings *et al.*, 1981, 1982; see also Readhead *et al.*, 1983) nonrelativistic jets produced by oscillating black holes (Rees, 1982), quasars and BL Lac objects seen in association with galaxies (Burbidge, 1981; Sulentic *et al.*,

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1979; Sulentic, 1983), compact companions to quasars (Stockton, 1982), and even in relation to theories invoking ejection of matter or coherent massive bodies to explain peculiar spiral patterns of galaxies (see, e.g., Clairemidi and Clairemidi, 1980), etc.

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