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Ejection of massive black holes from galaxies

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Abstract. Gravitational recoil of a gigantic black hole ($M \sim 10^{8-9} M_{\odot}$) formed in the nonspherical collapse of the nuclear part of a typical galaxy can take place with an appreciable speed as a consequence of the anisotropic emission of gravitational radiation. Accretion of gaseous matter during its flight through the galaxy results in the formation of a glowing shock front. The accompanying stellar captures can lead to the formation of an accretion disk-star system about the hole. Consequently, the hole can become "luminous" enough to be observable after it emerges out of the galaxy. The phenomenon seems to have an importance in relation to the observations of quasar-galaxy association in a number of cases.

Keywords. Nonspherical collapse; recoiling black holes; quasar-galaxy association.

1. Introduction

Arp (1972, 1973, 1974 and refs. therein) has from time to time presented evidence of the quasar-peculiar galaxy association in a number of cases; in many cases the pairs are joined by luminous intergalactic matter. The nucleus of the galaxy appears eruptive, as if material were ejected with considerable speeds from there in roughly opposite directions, in the form of a coherent massive object and gaseous lumps. According to Arp, the redshift of the ejected object which also happens to be a radio source exceeds that of the peculiar galaxy. Particularly whenever the radio source is a quasar, it shows up with a much larger redshift and is dynamically or evolutionarily younger. A few BL Lacertae type objects too have been seen associated with certain galaxies. Had the associations been chance juxtapositions, no disturbance in the parent galaxy and luminous bridges would have been seen. We therefore, consider ejection to be real.

Now, the question of the cause of ejection and the anomalous redshift remains unsettled. Only a few mechanisms are known which could eject different kinds of objects. According to Shklovsky (1972), a magnetoid from the nuclear regions of a galaxy might be ejected because of anisotropic emission of particles, whereas, Saslaw (1975) has conjectured the possibility of a gravitational sling-shot effect to be operative. Herein, we propose yet another possibility of ejection, *viz.*, gravitational recoil of a huge black hole. This can occur as a result of anisotropic emission of gravitational radiation in the nonspherical collapse of a supermassive star in the nucleus of a certain galaxy. The ejected black hole may capture gaseous matter and stars on its way and thus become luminous enough at the time of emergence out of the galaxy (Kapoor 1976). It is then natural to expect some observational prospects and the only question is, can we identify such a phenomenon with an observed quasar-galaxy association?

Which galaxies would be promising for ejecting massive compact objects? Naturally, to be able to eject a massive black hole, with $M \sim 10^{8-9} M_\odot$ considered here, the galaxy must be comparatively a massive one. The possible seats of this kind of activity might be the nuclei of spiral, elliptical and Seyfert galaxies. Ellipticals, having a mass to light ratio (~ 70) larger than a normal galaxy, appear with violent explosions and might breed central black holes with masses $\lesssim 10^{10} M_\odot$ (Wolfe and Burbidge 1970).

How can a huge black hole form in a galactic nucleus? It is known from the works of Lynden-Bell and Wood (1968) and Spitzer (1969) that a galaxy may develop a dense nuclear region as a consequence of a thermal runaway or a lack of energy equipartition between light and massive stars. Such a supermassive body may collapse to the stage of black hole because of the instability against radial pulsations after a stage of as high a redshift as 0·51–0·73 has been reached (Ipser 1969; Fackerell 1970, Gerlach 1970). In general, the collapse would be nonspherical. In nonspherical gravitational collapse, there is an emission of gravitational waves in an anisotropic manner which carry away not only energy and angular momentum but linear momentum also. Consequently, the body (black hole or an object with its surface very close to its event horizon) must recoil in order to conserve linear momentum in the frame of reference in which the collapsar was originally at rest. The stellar case has been dealt with by Bekenstein (1973). Here, we outline the basic idea applicable to the nonspherical gravitational collapse of a supermassive star in the nucleus of a certain galaxy and the subsequent recoil of a gigantic black hole through the galaxy. The order of magnitude estimates show that the recoil effect has something interesting to offer.

2. The recoil of a supermassive black hole

The collapse would be nonspherical owing to rotation, magnetic field and the asymmetric nature of the nuclear regions of the galaxy. The collapsar emits gravitational waves anisotropically during the collapse at a rate (Misner *et al* 1973):

$$\frac{dE}{dt} \sim \frac{1}{G}\left(\frac{cR_s}{R}\right)^5 \text{ erg sec}^{-1}, \tag{1}$$

where $R_s = 2GM/c^2$ is the Schwarzschild radius of the collapsing mass M (in gms), R its instantaneous radius, c the velocity of light and G the gravitational constant. According to Arp (private communication), the observed speeds are 10^2 km sec^{-1} $\lesssim v \lesssim 10^4$ km sec^{-1}. Such large speeds of recoil can be achieved only when the collapse is considerably nonspherical and proceeds up to the black hole stage, as most of the gravitational radiation is spewed out only during collapse between radii $R = 3R_s$ and $R = R_s$. As this happens, the total energy emitted in the form of gravitational waves over a dynamical time of the order $\tau \sim R_s/c$ can be as high as $E = \alpha Mc^2$, with $\alpha = 0\cdot01$–$0\cdot9$. The linear momentum carried by the waves in this process is αMc. Because of the anisotropic emission, the black hole recoils in a direction of minium radiation flux in order to conserve linear momentum. Its net momenum is βMc and recoil speed $v = \beta c$. The nonspherical gravitational collapse is not well understood so that an exact range of β cannot be adjudged.

It depends, among other things, on the geometry of the collapsar. For our estimates, we have chosen β in the range $0 < \beta c \lesssim 10^4$ km sec^{-1}.

The maximum frequency of emitted gravitational waves is

$$\nu_{max} \sim \frac{1}{\tau} \sim 10^{-5} \text{ Hz for } M \sim 10^9 \text{ M}_\odot \tag{2}$$

with a bandwidth $\Delta\nu$ of the same order. Since the gravitational energy E ($\sim GM^2/R$) of the collapsar changes as $dE/dt \sim -E/R\ (dR/dt)$, in view of eq. (1) the radius at time t can be approximated by

$$R(t) = R_0 \left[1 - \frac{t}{T(R_0)}\right]^{\frac{1}{4}}; \qquad T(R_0) = \frac{2R_0^4}{cR_s^3} \tag{3}$$

where, $T(R_0)$ is the collapse time, R_0 the initial radius and $T \sim \tau$ corresponding to $R_0 \sim R_s$. Since asymmetry enhances with the collapse, the stars in the nuclear regions may acquire some angular momentum but those with an impact parameter $R_s\beta^{-1}$ can get captured. The flux F_ν of gravitational radiation received at the earth in the case of ejection of the hole along the direction away from the observer is maximum and in the case of ejection toward the observer at the earth it would be minimum. Therefore

$$F_\nu \lessgtr \frac{aMc^2}{4\pi d^2 (1+z')^2} \simeq 10^9\, a \text{ erg cm}^{-2} \text{ sec}^{-1} \text{ H}_z^{-1} \tag{4}$$

for $d \sim 100$ *Mpc* and $M \sim 10^9$ M$_\odot$. In eq. (4), $d(1+z_0)$ is the luminosity distance to the ejecting galaxy and z' is the mean frequency shift of the pulse of gravitational waves which consists of cosmological redshift, doppler shift and gravitational redshift. The lower sign in eq. (4) refers to the case of ejection away from the observer. However, in this case of ejection, the 'object' may well be eclipsed by the ejecting galaxy; one can imagine the occurrence of such an event from the eruptive look of the nucleus of the galaxy, partly due to the ejection of matter toward the observer and partly due to the fact that passage of strong gravitational waves through matter disturbs it. For arbitrary directions of ejection, one might hope to see the lumps of gaseous matter and the 'object' roughly in opposite directions joined to the galaxy by a luminous bridge (formed as a consequence of tidal interaction). The motions of the 'object' and the gaseous lumps are damped due to tidal effects they suffer within the galaxy and therefore the structure of the gaseous lumps may change appreciably. In this model, therefore binary associations (galaxy-object) would be more probable rather than a multiple system.

3. Flight of the hole through the galaxy

The collapse of the supermassive body and the subsequent recoil of the huge black hole may change the structure of the galaxy itself quite a bit. For, let us assume that the collapse takes place in an elliptical galaxy. The density distribution of stars in the elliptical galaxies is considered almost isothermal and, herein, we assume a simple exponential density law without taking into account the high energy cut off and angular momentum which make the density fall more steeply in the outer regions:

$$n(r) = n_0 \exp\left[-\frac{U(r)}{kT}\right], \tag{5}$$

n_0 being the central star density, $U(r)$ the potential of a star at a distance r from the center, T the temperature of the system and k the Boltzmann constant. While an assumption of spherical symmetry in the stellar distribution is self-contradictory because it staves off the possibility of nonsphericity in the galactic nucleus responsible for the gravitationl recoil effect, it has been adopted for the sake of simplicity to make order of magnitude estimates.

When the collapse has proceeded sufficiently, the gravitational field of the stars in the galaxy and the supermassive collapsar both have to be taken into consideration. This is important especially when the collapse is more or less spherical resulting in so slow a recoil that the hole is unable to move sufficiently away from the center of the galaxy. Then we can write

$$U = U_1(r) + U_2(r). \tag{6}$$

From the theory of isothermal gas spheres (Chandrasekhar 1943)

$$\psi = \frac{U_1}{kT} = \frac{1}{6}\xi^2 - \frac{1}{120}\xi^4 + \cdots, \qquad \xi = \frac{r}{a}, \tag{7}$$

corresponds to the smooth density distribution of stars with an average mass μ, where a is the scale height

$$a = \left(\frac{kT}{4\pi G\mu n_0}\right)^{\frac{1}{2}} = \left(\frac{\langle V^2 \rangle}{4\pi G\mu n_0}\right)^{\frac{1}{2}} \tag{8}$$

and $\langle V^2 \rangle$ the mean square velocity of stars. $U_2(r)$ can be found out by considering the potential of a star at a distance $r = x + R(t)$ from the center of the collapsar with radius $R(t)$ at a time t after the onset of the collapse:

$$U_2(r) = \frac{-GM}{x + R(t)}. \tag{9}$$

When $R(t) \ll r$, $x \simeq r$ and

$$U_2(r) \cong -\frac{GM}{r}\left(1 - \frac{R(t)}{r}\right) \tag{10}$$

so that we get an expression for the density distribution similar to that of Wolfe and Burbidge (1970)

$$n(\xi, t) = n_0 \exp\left[-\psi(\xi) + \frac{a'}{a\xi}\right],$$

$$a' = \frac{GM}{\langle V^2 \rangle}\left[1 - \frac{R_0\left(1 - \frac{t}{T(R_0)}\right)^{\frac{1}{2}}}{a\xi}\right]. \tag{11}$$

Thus a time dependent scale height due to a central collapsing mass may change the rms velocity and the velocity distribution of the stars in the nuclear regions.

The recoiling black hole accretes gas and stars from the surroundings. The cross-section for accretion varies as β^{-2} and hence, different structures can develop depending on the values of β. However, the outgoing hole is subject to deceleration due to (1) attraction by a galactic mass $\mathcal{M}(\xi)$ within radius ξ, and (2) the cumulative effect of stellar encounters. These decelerations are given by

$$\left.\frac{d\beta(\xi)}{dt}\right|_1 = -\frac{G\mathcal{M}(\xi)}{a^2\,\xi^2\,c} \tag{12}$$

and

$$\left.\frac{d\beta(\xi)}{dt}\right|_2 \cong -\frac{2\pi G^2\,n(\xi)\,\mu M}{\beta^2(\xi)\,c^3}\ln(1+x_1^2) \tag{13}$$

respectively, where

$$\mathcal{M}(\xi) = 4\pi\mu n_0\,a^3\,\xi^2\,\frac{d\psi}{d\xi},\quad x_1 = \frac{\beta^2\,c^2\,p_1}{GM},$$

and p_1 is the maximum impact parameter (Ogorodnikov 1965). When p_1 is chosen to be of the order of mean stellar distance, $x_1 \gg 1$. In the very beginning, the damping of motion due to a galactic mass $\mathcal{M}(\xi)$ is not significant compared to that due to the encounters. But as the hole moves out, the contribution of encounters relative to that due to $\mathcal{M}(\xi)$ diminishes according to

$$\frac{\left.\frac{d\beta}{dt}\right|_2}{\left.\frac{d\beta}{dt}\right|_1} \cong \frac{\langle V^2\rangle\,R_s\ln x_1\zeta^2}{2\beta^2(\xi)\,G\mathcal{M}(\xi)}\,e^{-\psi(\zeta)} \tag{14}$$

The retardation due to the gravitational attraction of the galactic mass $\mathcal{M}(\xi)$ overtakes once the hole has moved beyond a few parsecs from the center (for, say $\beta \sim 10^{-2}$). Hence, in the first approximation, we have

$$\left.\frac{d\beta}{dt}\right|_1 \gg \left.\frac{d\beta}{dt}\right|_2 .$$

Equation 12 can now be written as

$$\beta(\xi)\frac{d\beta(\xi)}{d\xi} = -\frac{\langle V^2\rangle}{c^2}\frac{d\psi(\xi)}{d\xi} \tag{15}$$

which, upon integration, gives

$$\beta(\xi) = \pm\beta\,[1 - K^2\psi(\xi)]^{\frac{1}{2}};\qquad K^2 = \frac{2\langle V^2\rangle}{\beta^2 c^2}. \tag{16}$$

Here, β is the initial speed and K measures the strength of the recoil. Different structures (compact object–galaxy) can be expected depending on whether K is large or small with respect to unity. The former case, *viz.*, $K \gtrsim 1$, can be called the failed recoils which reproduce Wolfe and Burbidge (1970) model of a massive black hole in the center of the galaxy. In this case, $\beta(\xi)$ falls short of the escape velocity, which in general is given by

$$\beta_{esc}(\xi) = \left[\frac{2\langle V^2\rangle}{c^2}\,\xi\,\frac{d\psi}{d\xi}\right]^{\frac{1}{2}} \tag{17}$$

before the object can emerge out of the galaxy. It may eventually execute damped oscillations about the centre to give rise to a peculiar structure. The solution of the isothermal equation, given in Chandrasekhar (1943), can be used to determine variation in $\beta(\xi)$. A comparison with $\beta_{esc}(\xi)$ suggests that only those black holes which have initial ejection speeds $\beta c \gtrsim 1500$–$2000\ \mathrm{km\ sec^{-1}}$ can manage to come out of the galaxy. It is convenient to define a function

$$F(\xi) = \frac{\beta_{esc}(\xi)}{\beta(\xi)} = K\left[\frac{\xi \frac{d\psi}{d\xi}}{1 - K^2\psi(\xi)}\right]^{\frac{1}{2}} . \tag{18}$$

Figure 1 shows $F(\xi)$ *vs.* ξ, K being the parameter. For the black hole to be able to emerge out of the galaxy $F(\xi)$ must be less than unity over the range of ξ considered, *i.e.*, $0 < \xi < R_g/a$ where R_g is the radius of the galaxy. That is to say that, the object can reach infinity if and only if $\beta_{em} > \beta_{esc}(R_g/a)$, or

$$\beta > \beta_{esc}\left(\frac{R_g}{a}\right)\left[1 + \frac{2\langle V^2\rangle}{\beta^2_{esc}\left(\frac{R_g}{a}\right)c^2}\,\psi\left(\frac{R_g}{a}\right)\right]^{\frac{1}{2}} \tag{19}$$

For $\xi \gg 1,\ \beta_{esc} = \left(\frac{2\langle V^2\rangle}{c^2}\right)^{\frac{1}{2}}$. Let, for instance, $\psi(R_g/a) \simeq 5$, so that $\beta_e \gtrsim 2500\ \mathrm{km\ sec^{-1}}$.

Actually, black holes with still lesser speeds might come out and escape to infinity since the escape velocity predicted by eq. (17) for $\xi \gg 1$ is independent of ξ and higher than the observed.

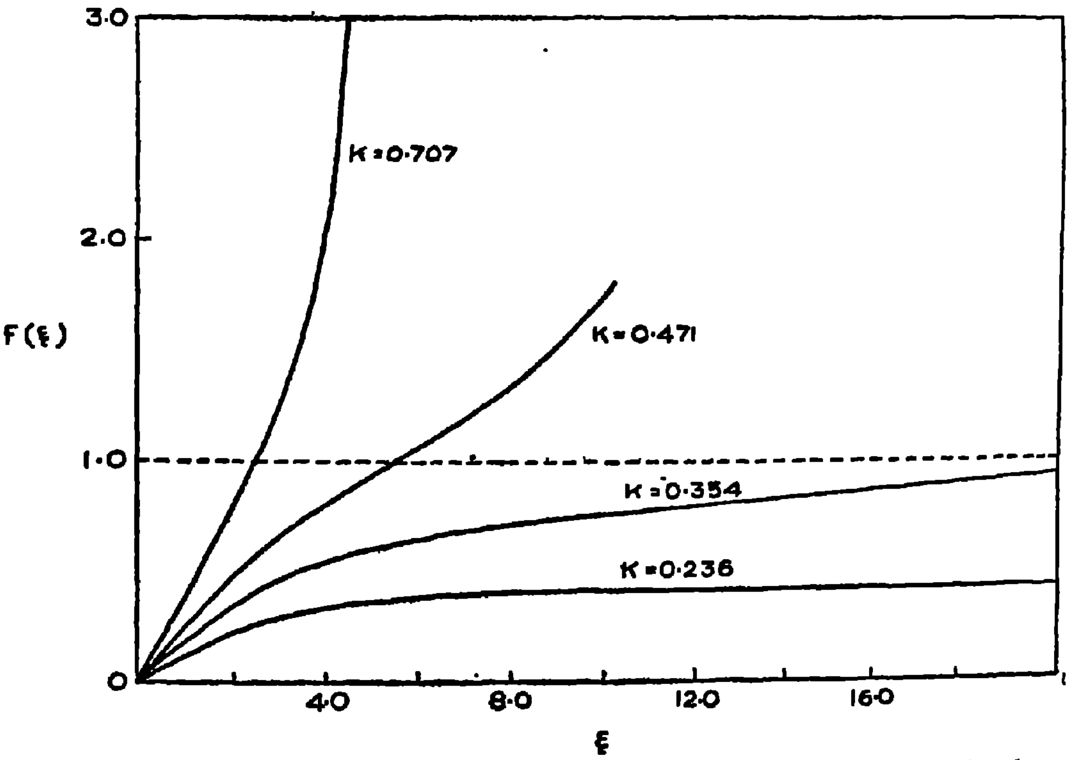

Figure 1. Plot of $F(\xi)$ *vs.* ξ for various values of K. The recoiling black hole would be able to emerge out of the galaxy, if $F(\xi)$ remains less than unity over $0 < \xi < R_g/a$

The black hole captures stars of the galaxy at a rate

$$\frac{dN(\xi)}{dt} = n(\xi)\beta(\xi)c\sigma(\xi); \qquad \sigma = \pi l_{\pm}^2 \tag{20 a}$$

where $l_{\pm}$ is the impact parameter (Godfrey 1970)

$$l_{\pm} = \frac{2GM}{\beta(\xi)c^2} f_{\pm}(\epsilon); \qquad f_{\pm}(\epsilon) = [1 + (1 \pm \epsilon)^{\frac{1}{2}}]. \tag{20 b}$$

Above, $\epsilon = a_1/m$, a_1 the specific angular momentum of a Kerr black hole, $m = GM/c^2$ and ϵ has the range $0 \leq \epsilon \leq 1$. The + sign in eq. (20 *b*) refers to capture in the counter-rotating manner and − sign to that in the corotating manner. Hence, number of stars captured over the distance range $0 \leq \xi \leq \xi_1$ is

$$N = \pi \left[\frac{2GM}{c^2} f_{\pm}(\epsilon)\right]^2 \frac{n_0 a}{\beta^2} \int_0^{\xi_1} \frac{e^{-\psi(\xi)}\, d\xi}{[1 - K^2\psi(\xi)]} . \tag{21 a}$$

Most of the stars are captured in the flight between $0 < \xi \lesssim 1$ and eqs (20) then lead to

$$N \simeq \frac{\pi R_s^2 n_0 a}{\beta^2} . \tag{21 b}$$

Using $\beta \sim 10^{-2}$, $n_0 \sim 10^6$ stars pc^{-3}, $a \sim 500$ pc and $M \sim 10^9\, M_\odot$, one has $N \sim 10^5$. As we shall see later, these stars ultimately lead to an accretion disk–star system about the hole with dimensions

$$l_+ = \frac{2GM}{\beta_{em} c^2} f_+(\epsilon) \tag{22 a}$$

where β_{em} is the speed of the object at the time of its emergence out of the galaxy

$$\beta_{em} = \beta \left[1 - K^2 \psi\left(\frac{R_g}{a}\right)\right]^{\frac{1}{2}} ; \qquad \beta c \gtrsim 1500\text{–}2000 \text{ km sec}^{-1} \tag{22 b}$$

The time of flight of the object through the galaxy can be given as

$$t_f = \frac{\Delta\beta}{\langle d\beta/dt \rangle} \tag{23}$$

where $\Delta\beta$ is the total change in the speed of the hole, *i.e.*, $\beta - \beta_{em}$ and,

$$\langle d\beta/dt \rangle = \frac{a}{R_g} \int_0^{\frac{R_g}{a}} \frac{d\beta}{dt}\, d\xi . \tag{24}$$

Using eq. 15 we get

$$\langle d\beta/dt \rangle = \frac{\langle V^2 \rangle}{R_g c} \psi\left(\frac{R_g}{a}\right). \tag{25}$$

The kinetic energy lost by the object,

$$\Delta E = \frac{1}{2} Mc^2 (\beta^2 - \beta_{em}^2) = M \langle V^2 \rangle \psi\left(\frac{R_g}{a}\right), \tag{26}$$

is $\sim 10^{58}$ ergs, which is comparable to the internal energy of the galaxy. This energy goes into increasing the rms speed of the stars; the galaxy may expand and evaporation of stars might take place. The time over which this energy is dissipated is the flight time $t_f \sim 10^7$ yrs, obviously much smaller than the relaxation time of the galaxy. Disturbances in the galaxy along the direction of flight of the object would not decay soon. It would therefore be interesting to study the change in the structure of the galaxy in detail.

During its flight through the galaxy, the asymmetrical nature of the galactic structure can impart some orbital angular momentum to the recoiling hole also and deflect it from its original direction of ejection depending on the asymmetry and β. Moreover, deflection would be greater should the ejection take place in a spiral. This problem has recently been considered by Saslaw (1975).

Should ejection of a massive object be the answer to the observed quasar-galaxy associations, then as suggested by the present model, it would be worthwhile to look for the disturbances in the galactic structure in approximately the direction of ejection, because the observed speeds of emergence of the quasars suggest flight times far smaller than the relaxation time of the galaxies. Formation of a luminous bridge in the wake of the outmoving object as a consequence of tidal effects is quite likely in this model. Recent work by Arp and coworkers (Arp *et al.* 1974) on the isophotal tracings of a few galaxies near quasars does reveal disturbances in the inner isophotes extended fairly close in the direction of the quasar which can be interpreted as due to an event which occurred in the galaxy at a time of the order of $\sim 10^7$ yrs previously.

4. A qualitative model of the object

The luminosity of the 'object', while within the galaxy, is contributed by the captured stars as well as by the glowing shock front that is formed due to the accretion of interstellar gas during the flight through the galaxy. Outside the galaxy, the contribution of the shock front luminosity dwindles (the object moves in a low density medium). Inside the galaxy, the supersonic motion of the object through the interstellar medium leads to the formation of a shock front where a large fraction of the kinetic energy released in the shock is radiated away. Novikov and Thorne (1973) have shown that the shock front is located at a distance $\sim R_g \beta^{-2}$ from the center of hole; it glows with a luminosity

$$L \simeq 10^{24} \left(\frac{M}{M_\odot}\right)^2 \rho_{-24} (\beta c|_{10})^{-2} \, \text{erg sec}^{-1} \tag{27}$$

where ρ_{-24} is the gas density in units of 10^{-24} gm cm^{-3} and $\beta c|_{10}$ is the speed of the object in units of 10 km sec^{-1}. For $\beta \sim 10^{-2}$, $M \sim 10^9 \, M_\odot$ and $\rho_{-24} \sim 10^{-2}$, in case of ellipticals considered here, $L \sim 10^{40-41}$ erg sec^{-1}.

We have seen that a total number of more or less $\sim 10^{4-5}$ stars could be captured by the black hole. The average star density, $\gtrsim \beta^3 N/R_g^3$, in a volume of radius $\sim l_+$ turns out to be $\sim 10^{10}$ stars pc^{-3}. A cluster with such a high density of stars cannot survive because stellar collisions, coalescences and tidal interaction among stars themselves as well as stars and the black hole become important soon after the recoil. This happens as most of the stars are captured during the early stage of the flight of the hole. In addition, the interstellar gas trapped in the shock front goes in circular orbits to form ultimately an accretion disk which also contributes to damp out the motions of the stars about the hole. This further enhances the probability of stellar collisions and close encounters. As a result, the stars closer to the hole lose energy and move in orbits still closer to the hole. The whole system tends to be axisymmetric and most of the stars tend closer to the orbital plane (dragging of inertial frames) which brings the stars closer to the disk too. The disk and the star system is very much disturbed because a number of 'tube of tooth paste' effects may occur. The supersonic motion of the stars in high energy oribts about the hole through the gas itself has interesting consequences: Shocks formed in the high energy collisions of stars, when most of the stellar matter interacts supersonically, convert much of the kinetic energy of stellar motion into thermal energy to be radiated away. During the flight of the hole, some captured stars may gather enough material to evolve within a time $< t_f$ and produce supernova explosions leaving behind collapsed stars (if they do not become runaway objects due to gravitational recoil).

Thus the model that suggests is one of a supermassive Kerr black hole at the center of an accretion disk and a number of stars, including perhaps collapsed stars too, moving around in low energy orbits. The gas in the accretion disk is expected to carry a magnetic field which would get sheared and tangled because of the motions in the gas. Synchrotron radiation and thermal bremsstrahlung can, therefore, be expected to be the mechanisms contributing to the luminosity of the object when it emerges out of the galaxy. The net radiation is expected to have a power law spectrum, resembling that from quasars.

Thus, it seems reasonable to attach a significance to the gravitational recoil phenomenon which is natural to happen, especially in view of the observations of association of quasars and BL Lacertae type objects with galaxies. This mechanism has the advantage over that suggested by Rees and Saslaw (1975) that the hole, given an appropriate initial speed, moves always out of the galaxy and can collect vast amount of matter whereas in the latter case, the object ($\sim 10^6$ $M_\odot$) can collapse during its flight and one is never sure whether it will undergo gravitational recoil in any direction except that of its motion. It may fail to leave the galaxy or become too faint to be observable at the time of its emergence.

The observed anomalous redshifts of quasar-galaxy systems remain unexplained in all the models of ejection of massive objects. The only explanation that seems feasible in the present model is regarding the total redshift of the object as partly gravitational (z_g), partly peculiar Doppler (z_d) and partly cosmological (z_c) common to the quasar and galaxy:

$$1 + z = (1 + z_g)(1 + z_d)(1 + z_c). \qquad (28)$$

Several attempts (Lynden-Bell 1969; Wolfe and Burbidge 1970) have been made to see whether the quasar-like activity of the nuclei of certain galaxies can be explained by considering gigantic black holes swallowing matter from their surroundings. The present model would suggest that in these systems one is actually looking at the objects which failed to recoil gravitationally. One wonders whether or not in the case of field quasars on one hand, and in the case of quasars associated with galaxies and active galactic nuclei on the other, different seats of activity are at work. We already have seen, $t_f \sim 10^7$ yrs, *i.e.*, quasars ejected from the galaxies have a life time of at least $\sim 10^{7-8}$ yrs. This is larger than that of the field quasars by an order of magnitude or two and implies that over its life time an ejected quasar emits $\sim 10^{55-56}$ ergs or so. The field quasars are, on the other hand, highly luminous objects ($L \sim 10^{46-47}$ ergs sec^{-1}) and live for $\sim 10^{5-6}$ yrs only. Thus two classes of quasars can be suggested where the Class A consists of the field quasars whose seat of activity is not known and the Class B consists of the ones found associated with or in the nuclei of galaxies. They are comparatively nearby, subluminous ($\sim 10^{40-41}$ ergs sec^{-1}), live longer than the field quasars and possibly involve supermassive black holes.

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