CAN A MODERATELY MASSIVE BLACK HOLE REVERSE CORE COLLAPSE?

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Direct N-body simulations show that the heat flux from the cusp of stars surrounding an object of mass M $\sim$ 10-100 $M_\odot$ has a profound effect on the evolution of a cluster of N stars of mass m $\sim$ 1 $M_\odot$. A cluster containing an object which is $\gtrsim$5% of its total mass expands, transferring most of the cluster binding energy to a few stars deep in the cusp within several central relaxation times. The results, together with analytic estimates, suggest that core collapse in a globular cluster will be reversed when the core mass is reduced to $\sim$10 M. As is discussed below, this result does not depend on whether or not stars are disrupted by the black hole.

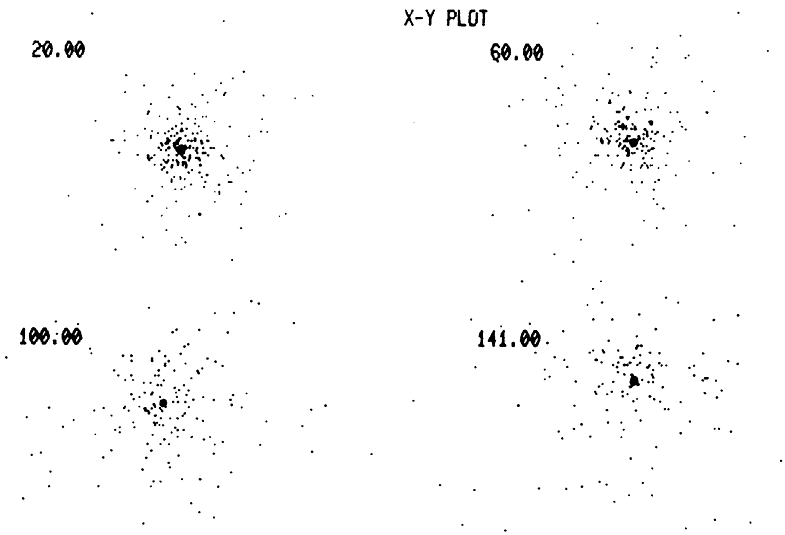

Figure 1. The evolution of a cluster of 240 stars with central object of mass = 10. Initial core mass = 60, disruption radius = 0, unit of time = core crossing time, core relaxation time $\sim$10 crossing times.

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In these proceedings, Stu Shapiro has summarized Monte Carlo simulations of the dynamical effect of a very massive black hole ($\sim 10^2$-10^4 $M_\odot$) in a star cluster. In order to check the validity of the approximations used in these simulations (e.g. orbit-averaging in E-J space, small angle scattering) and to extend them to smaller M, a comprehensive series of direct N-body simulations has been completed for systems of N $\sim$200-500 stars containing a black hole of mass M $\sim$10-500. Stars are assumed to be consumed by the hole if they come within a distance r_D (so that setting $r_D = 0$ eliminates consumption). The simulations are described in detail elsewhere (Duncan 1984 a,b).

The results show that a cusp of bound stars with density profile $n(r) \propto r^{-7/4}$ develops within $\sim$ one central relaxation time, t_r, as suggested by the Fokker-Planck calculations of Bahcall and Wolf (1976). The consumption rate of stars is in rough agreement with Monte Carlo calculations (Marchant and Shapiro 1980, Duncan and Shapiro 1982). However, for cases in which $M \gtrsim mN$, the stars beyond the half-mass radius tend to have highly eccentric orbits with density profile $\propto r^{-3.5}$ (cf. Spitzer and Shapiro 1972). In all cases studies ($.05 < M/mN \lesssim 1$) the bulk of the cluster expanded on a timescale $\sim t_r$, leaving a few tightly bound stars (especially when $r_D = 0$).

When the number of cusp stars is large, Bahcall and Wolf (1976) have shown that the $r^{-7/4}$ solution implies a net outward conduction of energy through the cusp, with a "zero-flow" diffusion of stars inward on a timescale $\propto r^{-1}$. The analysis of Duncan (1984b) suggests that for cusps containing $\lesssim$10 stars, the bound stars may be approximated as black hole-star "binaries" which interact with each other and the unbound population. Stars in orbits with semi-major axes $a > r_a/3 \equiv M/v^2$ (where v is the rms velocity dispersion in the core) are soft binaries. However, those with $a < r_a/3$ are hard binaries which are formed either by the cascade inward of a fraction of the soft binaries or by three-body encounters involving the black hole and two unbound stars. A lower limit to the heating per hard binary is the heating rate due to encounters with unbound stars, $0.5\ mv^2/(t_r \ln\Lambda)$, which is a "zero-flow" result <u>independent of</u> <u>r</u> and <u>M</u>. Neglecting consumption, the useful lifetime of a hard binary is $\sim 10\ t_r \ln\Lambda$ after which point it ejects unbound stars from the core and the heating efficiency is reduced. Hard binaries form from unbound-unbound reactions at the rate $\sim 3(M/mN_c)^3 N_c/(t_r \ln\Lambda)$. In steady-state, then, the lower limit to the heat input is

$$\dot{E} = (30/\ln\Lambda)(M/mN_c)^3(0.5N_c mv^2)/t_r$$

The rate at which the core energy decreases during core collapse is $\sim 0.01\ N_c mv^2/t_r$, which suggests that $M \sim 0.1\ mN_c$ is sufficient to reverse core collapse. This simple analysis of course neglects bound-bound interactions which may lead to ejection or consumption of one of the participants, but the actual number of hard binaries is of order unity. As a result changes in stellar orbits will be highly stochastic and the "loss-cone" theory of the rate of consumption can at best be valid in a statistical sense and at worst may be unreliable. If the latter is true, it is not obvious that the black hole will increase in mass at the dramatic rate indicated by Monte Carlo calculations. It is clear that further N-body and/or Monte Carlo simulations (or a hybrid thereof) will be required to study the re-expansion phase when a moderately massive black hole is present, especially when there is a spectrum of stellar masses.

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