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Black Holes Associated with Galaxies

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A small and a large black hole are naturally associated with a galaxy of total mass M and spherical halo radius R. Also of mass M, the large black hole is a spatial contraction of the galaxy down to its Schwarzschild radius, $\mathbf{r} \to \lambda\mathbf{r}$, with $\lambda = 2GM/c^2R$, where $G/c^2 = 4.78 \times 10^{-17}$ kpc/$M_\odot$ is Newton's gravitational constant divided by the speed of light squared. The small black hole is the $\mathbf{r} \to \lambda\mathbf{r}$ contraction of the large hole, i.e., the iterated double contraction of the galaxy itself, with the resulting mass $m = \lambda M = 2GM^2/c^2R$. In the case of the Milky Way ($M = 7.0 \times 10^{11} M_\odot$ and $R = 15$ kpc) the latter equation for the small black hole mass yields $m = 3.1 \times 10^6 M_\odot$, which is close to the observed value for the mass of the black hole at the center of the Milky Way. Black holes of the small type may evolve to the large by mass accretion, perhaps during a quasar phase. Vast regions of the universe may in fact be populated by large black holes—"missing mass"—which validates the cosmological principle and effects the closure of the universe.

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1. INTRODUCTION

While extensive regions in the universe appear to be devoid of galaxies, the "Great Wall" (Geller and Huchra, 1989) and "Great Attractor" (Dressler and Faber, 1990) are remarkable concentrations of galaxies that overpopulate spatial regions with cosmic extensions of about 170 Mpc ($\cong 5.5 \times 10^8$ light-years) and 80 Mpc, respectively. Additional recent observations (Broadhurst *et al.*, 1990) also suggest large-scale inhomogeneity in the distribution of radiation-emitting galaxies out to distances of at least 2000 Mpc. These new findings do not necessarily clash with the *cosmological principle* (Tolman, 1950; Einstein, 1955)—the conjecture that a nearly homogeneous and approximately uniform distribution of mass should be present throughout the universe—because black holes (Wheeler, 1980) and other

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nonradiating structures may populate the dark regions and provide the "missing mass" for closure of the universe.

Numerical simulations framed in a big bang context do in fact generate the observed inhomogeneities in the distribution of galaxies, provided that the galaxy formation mechanism works efficiently in regions of very high initial mass density (Park, 1990). Since a very high initial mass density also favors the development of black holes, the latter are a likely concomitant to galaxy formation. In this regard, two black holes—the natural associates of a galaxy of total mass M and spherical halo radius R by spatial contraction—are of considerable interest. The purpose of the present paper is to discuss the salient features of these black holes.

2. BLACK HOLES DIRECTLY ASSOCIATED WITH GALAXIES BY SPATIAL CONTRACTION

Having the same mass M as the galaxy itself, the *large black hole* is a spatial contraction of the galaxy down to its Schwarzschild radius $2GM/c^2$, the event horizon radius of the black hole. Under this spatial contraction, every point mass moves radially toward the center of the galaxy, $\mathbf{r} \to \lambda\mathbf{r}$, with $\lambda = 2GM/c^2R$, where $G/c^2 = 4.78 \times 10^{-17}$ kpc/$M_\odot$ is Newton's gravitational constant divided by the square of the speed of light. Thus, mass that is originally just within the galaxy's "surface" $|\mathbf{r}| = R$ is mapped by the radial contraction to lie just within the large black hole's event horizon. By using the Milky Way total mass and spherical halo radius values (Townes, 1989; Reid, 1989; Sanders, 1989; Genzel, 1987; Freeman, 1987; Schmidt, 1985), $M = 7.0 \times 10^{11} M_\odot$ and $R = 15$ kpc, one finds that the associated large black hole has the contraction factor $\lambda = 4.5 \times 10^{-6}$ and the radius $2GM/c^2 = 0.067$ pc. Figure 1 shows the large black hole to the right of a galaxy of total mass M and spherical halo radius R.

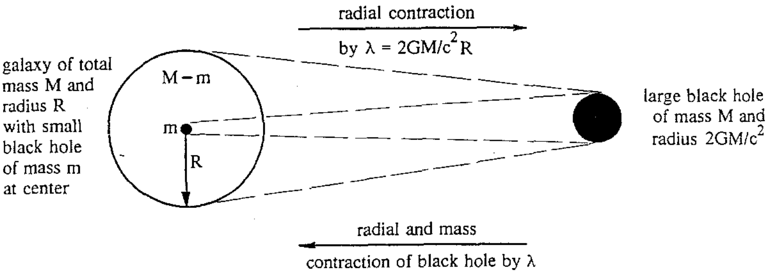

Fig. 1. Schematic drawing of galaxy with total mass M, spherical halo radius R, and associated black holes, obtained by successive spatial contractions $\mathbf{r} \to \lambda\mathbf{r}$. Mass of the small black hole is thus $m = \lambda M = 2GM^2/c^2R$.

The *small black hole* is the $\mathbf{r} \rightarrow \lambda\mathbf{r}$ contraction of the large hole, or equivalently, the iterated double contraction of the galaxy itself. Owing to the fact that the event horizon radius is directly proportional to a black hole's mass, the small black hole must have the mass $m = \lambda M$ with $\lambda = 2GM/c^2R$, and hence

$$m = 2GM^2/c^2R \tag{1}$$

If equation (1) is evaluated for the Milky Way, one obtains

$$m = 3.1 \times 10^6 M_\odot \tag{2}$$

The latter mass is close to the observed value for the black hole at the center of the Milky Way (Genzel, 1987; Townes, 1989), $m \cong 3 \times 10^6 M_\odot$, as indicated by infrared and radiofrequency observations. Formula (1) may also yield correct mass values for the black holes that are conjectured (Rees, 1990) to reside at the center of the giant elliptical galaxy M87, the Andromeda M31, and the Sombrero NGC4594; however, improved observational estimates for these m and M are required in order to check the accuracy of equation (1).

It should be noted that small black holes associated with galaxies are only "small" in a relative sense. For example, the radius of the black hole with the mass shown in equation (2) is $2Gm/c^2 = 9.3 \times 10^6$ km, which is about 13 times the radius of the Sun. Figure 1 shows the small black hole at the center of a galaxy.

Black holes of the small type may evolve to the large, $m \rightarrow M$, by mass accretion (Hills, 1975; Ozernoy, 1977: Sanders and van Oosterom, 1984), perhaps during a quasar phase (Rees, 1990). Quasars, now at cosmic distances of the order 1000 Mpc and beyond, may have featured the (small black hole) → (large black hole) transition during the time interval $2\text{–}3 \times 10^9$ years after the big bang. The extremely large emission rates of quasars may relate to electromagnetic phenomena that accompany the accretion of mass $(M - m) > 10^9 M_\odot$ by a black hole in transition.

Large black holes may have formed along with sibling galaxies of roughly the same mass in regions of very high initial mass density. Such regions might grow dark in time with mass accretion to the population of large black holes. Due to close approaches to the holes, electromagnetic radiation from distance quasars would undergo a characteristic *gravitational aberration* stemming from multiple gravitational deflections (i.e., ray bending) in traversing a vast dark region populated by many large black holes. Observations of this characteristic gravitational aberration would in turn confirm the existence of extensive populations of large black holes—"missing mass" which validates the cosmological principle and effects the closure of the universe.

Note Added in Proof. The recently discovered ultramassive ($\sim 10^{11} M_\odot$) dark core in the luminous infrared galaxy NGC6240 [Bland-Hawthorn, J., Wilson, A. S., and Tully R. B. (1991). *Astrophysical Journal Letters*, **371**, 19–21] may indeed be the first *large black hole*, in the projective sense introduced in the present paper, to be detected by observation.

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