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IDEAL BLACK HOLE FLUID

Larry L. Smalley

Space Science Laboratory
Science and Engineering Directorate

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I. INTRODUCTION

The concept of primordial black hole creation in the early universe has been a common theme in early cosmological scenarios [1]. This report puts forward the concept of a primordial black hole fluid with intrinsic spin density and its consequence for supercluster-sized, i.e. large-scale voids, and the missing mass question [2].

It has been hypothesized that the mass of primordial black holes [3] range as far down as the Planckian mass limit of about 10^{-5} g. On the other extreme, primordial black holes with a mass of about 10^{15} g should now be in the final stages of Hawking evaporation [4]. At one time, it was thought that these latter black holes were candidates for gamma ray and X-ray bursts. However, it appears more likely that these events are associated with the dynamics of solar remnants [5]. Thus, it would be likely, within the original scenario, that these relic black holes were not created with sufficient mass to survive until the present epoch. There is, however, the supposition that the life-time of the inflationary era is associated with the evaporation time for the primordial black holes. This would mean that the primordial black holes would have been created with masses consistent with the evaporation time scale [6]. What follows does not, in principle, conflict with this hypothesis although it probably modifies the time scale somewhat and makes the model more difficult to construct. On the other hand, quantum mechanical arguments have been put forth which suggest that the ultimate remnant of an evaporating black hole is a degenerate gas (fluid) of Planck mass black holes called planckons which are stable against further decay due to the onset of quantum stability of the "lowest" state of a black hole [7]. If this is the case, the model would be more natural. Presumably, this planckon gas would be in thermal equilibrium with the background radiation field. However, the consistency between the temperature of evaporating black holes and that of the planckons seems to contradict the principle of Hawking evaporation and the existence of the planckons themselves. That is, the planckons must be relatively cool, or they would interfere with the big bang relic 3 K black body radiation. It is not known how this can be overcome, but the thermodynamic description must somehow be replaced with a quantum mechanical decay process especially in the latter stages of evaporation. In either case, what is presented here is far from the planckian limit and, thus, well within the classical realm.

Recent observations support the existence of significant large-scale structures [8] with extent greater than 80 Mpc. It is, in fact, likely that some of these objects may not even be visible, such as the recently discovered object in the constellation Leo which, it is conjectured, supposedly lenses a quasar over 1.6 Gpc distant [9]. The existence of large-scale voids with diameters on the order of 100 Mpc seems to be consistent with this structure [10]. The general features of the universe show a vast network of clusters, filaments, and voids as is evident in the analysis of the Shane-Wirtanen survey [11]. Combined with these general features is the question of the missing mass which is usually attributed to massive neutrinos [12], axions [13], strings [14], Higgs boson decay [15] or other generally unspecified cool or even hot dark mass [16]. The existence of large quantities of dark matter seems to be indicated for instançe by an infall of visible matter in the Virgo cluster [17]; however, this dark matter is probably not composed of baryons [18]. Here, it is proposed that this missing mass be attributed to an ideal black hole gas or fluid with sufficient intrinsic spin density to avoid collapse and be collocated with the large scale voids and perhaps galactic centers.

II. IDEAL BLACK HOLE FLUID

In order to avoid confrontation with the 3 K black body background radiation field, which appears from experimental measurements to be highly isotropic with quadrapole or higher multipole moments consistent with zero [19], it is assumed that the temperature of objects within the "voids" has an average close to the background black body temperature. This hypothesis says that the matter in the voids has evolved to present day in equilibrium with the relic radiation of the big bang. This imposes two constraints on a black hole fluid which must be met: the fluid temperature itself must be in equilibrium with the background radiation field, and the surface temperature of the mini black holes must also be near 3 K [20]. This is an unusual constraint on a gas since, classically, one does not associate an intrinsic temperature with a "particle" in a classical gas.

It is assumed that during the early stages of the big bang, mini black holes, with possibly some intrinsic spin, will be formed. Thereafter, the black holes can eventually either evaporate in the Hawking manner or grow by accretion of other black holes. During the accretion process, the spin of the black holes will tend to increase both through the union of individual spins and the absorption of the relative orbital angular momentum of colliding black holes (and perhaps ordinary matter). The intrinsic spin of the product black holes tends to increase because of the randomness of both the initial spin distributions and the collisions between pairs of black holes (presumably due to the spherically symmetric initial conditions at the time of the big bang). This means that the random walk absorption of the intrinsic spin of the newly-formed black holes after each union will statistically favor an increase in spin angular momentum in the accretion process.

Consider a large scale, supercluster-sized void with diameter 100 Mpc. If one assumes that the initial matter density in the void is the same as elsewhere in the universe, with a density close to the critical density $\rho_c \sim 10^{-29}$ g cm^{-3}, then the mass in the void would be approximately 8.2×10^{50} g. This assumption follows closely the results of a recent measurement by Loh and Spillar of the mass density of the universe based upon the redshift and fluxes of 1000 field galaxies. They find that the density of matter is 0.9 (+0.7, −0.5) the critical mass density at the 95 percent confidence level. Their method is supposedly sensitive to <u>any</u> matter, dark or luminous [21]. It is interesting to note for later comparison that if all this matter had coalesced into a single gigantic Schwarzschild black hole, it would have a radius 1.2×10^{23} cm (or about 40 kpc) with an "internal density" of about 1.1×10^{-19} g cm^{-3}

The surface temperature of a black hole is given by [4,22],

$$T = (8\pi M)^{-1} = 1.225 \times 10^{26} \text{ g K}/M \qquad (1)$$

where M is given in grams. (In what follows, this should be taken as only approximately since the mass should be corrected for rotation [22]. The temperature and mass could be iterated in what follows, but this would not change our qualitative conclusion. Additionally, any statistical distribution of the masses of the black holes is ignored.) For a surface temperature of 3 K, the mass would be $M_{3K} = 4.1 \times 10^{25}$ g with radius $R_{3K} = 6.1 \times 10^{-3}$ cm with internal density 4.2×10^{31} g cm^{-3}. Note that this radius is larger than the radius of a nucleus. Thus, if all the mass of the cluster were concentrated in such black holes, there would be 2.0×10^{25} of them in the black hole fluid!

III. AVOIDANCE OF COLLAPSE

It has been hypothesized that the spin of matter could give rise to a repulsion (or bounce) during the "final" collapse of the universe towards a singularity [23]. If, indeed, spin of matter is effective against the collapse of matter to a singularity, the same process would hold for any fluid with sufficient spin density. Thus, at some point in the growth of the black holes, they will have sufficient spin so that they would be stable against further coalescence. This repulsion then avoids the further growth problem even for stiff matter [24]. Suppose that the relaxation process has continued until the black hole fluid has attained a density comparable with nuclear density, $\rho_n \sim 7 \times 10^9$ g cm^{-3}. This assumption is not crucial, but it provides a consistent reason for our assumption of the thermodynamic condition for stiff matter. The 3 K black holes would have a relative separation on the order of 1.1×10^5 cm and a root mean square fluid velocity of 1.7×10^{-21} cm s^{-1}. (Such numbers give new meaning to the concept of "stiff" matter used below!) At nuclear density, the close-packed "radius" of the fluid would be about 3.0×10^{13} cm, and thus the fluid could be contained in a region within the orbit of Jupiter. This mini black hole fluid should be compared with the gigantic supercluster-sized black hole mentioned above.

Although such a large black hole is possible, the surface temperature is far below the background 3 K black body radiation and, thus, may give rise to some detectable nonuniformity in the uniform black body radiation. Experimental data, however, seems to exclude this possibility [19]. Outside the voids, it is presumed that the primordial black holes either coalesced into large black holes or perhaps into a smaller version of the ideal black hole fluid hypothesized above. This latter is an interesting case which could yield exciting consequences for galactic structures. Nonetheless, there is now reasonable evidence that something like massive black holes on the order of 10^{6-8} solar masses are contained in the nuclei of galaxies [25]. Such masses are consistent with previously observed mass distributions in spiral galaxies providing the massive object is less than 10 percent of the mass of the galaxy [26]. If these objects are large black holes, then within the context of the arguments here, the spin was not able to prevent coalescence. The second consequence will be discussed briefly in Section V.

IV. BLACK HOLE FLUID MODEL

How spin can prevent the fluid from collapsing will now be investigated. It can be shown that for a fluid with randomly oriented spin density, the renormalized pressure and energy density is given by

$$p' = p - 2\pi G\, s^2/c^2 \tag{2}$$

and

$$\rho' = \rho - 2\pi G\, s^2/c^4 \tag{3}$$

where G is the gravitational constant, c is the speed of light, and s is the spin density. Assume the following: (1) the renormalized density is of the order of nuclear density, (2) the fluid is ideal, and (3) the fluid obeys a stiff equation of state. Then

$$p - (2\pi G/c^2)s^2 = \rho_n\, kT/M_{3K} \tag{4}$$

For a stiff fluid, $p = \rho_n c^2$, then

$$\rho_n c^2 - (2\pi G/c^2)s^2 = \rho_n\, kT/M_{3K} \tag{5}$$

and

$$s^2 = (\rho_n c^3/2\pi G)\,[1 - kT/M_{3K}c^2] \tag{6}$$

For $T = 3K$ and $M_{3K} = 4.1 \times 10^{25}$ g, it is noted that

$$kT/M_{3K}c^2 = 1.1 \times 10^{-62} \tag{7}$$

and the spin density

$$s = 1.2 \times 10^{29}\ \mathrm{g\ (cm\ s)^{-1}} \tag{8}$$

This is the spin density that gives an energy density comparable with the nuclear energy density and, thus, prevents collapse of the fluid into a larger black hole.

It is noted that the "fine tuning" of the energy associated with the internal energy of the fluid at a temperature of 3 K compares to that of the rest mass energy of the fluid "particles" to one part in 10^{62}. Such fine tuning between present epoch astronomical data, compared with initial conditions in the big bang, has been noticed consistently before [27].

V. GALACTIC MATTER

Experimental evidence indicates that large compact objects are contained in the cores of some galaxies. Thus, galaxies (and necessarily clusters) may have passed beyond fluid state so that they contain a large black hole core or even a small black hole fluid core. This is precisely what one would expect on the average for a system so finely tuned. Thus, for galaxies the initial state was also a black hole fluid; however the "particle" mass of the fluid did not grow sufficiently to avoid the Hawking evaporation up to the present epoch. For black hole fluids with particle masses of the order of $10^{14\text{-}16}$ g, one now has a possible mechanism and source for the emission of energy by a quasar. Since the black hole fluid is much more concentrated than a single black hole of comparable mass, the size of the emission regions would no longer be a source problem for quasar emission. If this hypothesis is correct, then some quasars could be relatively close, provided the particle masses were initially large enough. The recently reported apparent correlation observed between bright (i.e., near) galaxies and quasars [28] is noted. For example, quasars with $z < 0.2$ are known but are rare compared with those with $z > 1$. This seems to indicate that quasar redshifts may depend on the compactness of the object. Black hole fluid cores would, therefore, give a larger redshift which could be mistaken as a distance indicator. It is interesting to speculate that the most spectacular event that might be observed would be the "turning on" of a quasar, or even a galactic nucleus, e.g., the brightening by a factor of 2 of 3C147 over a period of 6 years although this is normally attributed to relativistic motion within the core [29]. Also note that the spin axes of the black hole fluid would be aligned since, as indicated above, anti-alignment during the accretion period of the fluid would favor particle coalescence which would destroy the stability of the black hole fluid. Consistent with the estimated mass of galactic cores discussed above, the total spin (not including any overall orbital angular momentum) of the black hole fluid would then be $S = V_{3K}s = 1.4 \times 10^{60}$ g cm^2 s^{-1}. The observed angular momenta of large spiral galaxies lies within the range 10^{73}–10^{75} g cm^2 s^{-1}. Smaller or less evolved galaxies can have angular momenta six orders of magnitude smaller [30]. Thus, the total spin of the black hole fluid falls well within the observed angular momentum range for galaxies. It is speculated that this implies that local black hole evaporation may provide the seed perturbation for the angular momentum imparted to the galaxy as a whole. Also, the fluid would represent, in its mature (i.e., evaporating) stages, a compact polarized medium (object) which could explain the directionality and perhaps the strength of jets (radio lobes) from quasars.

VI. CONCLUSIONS

The concept of a black hole fluid has been developed and shown to have consequences for both large scale voids as well as galactic structures. It is then considered that collocated, with the voids, there is a primordial relic, called an ideal black hole fluid, that formed from the initially created primordial black holes and their subsequent coalescence before they were able to individually evaporate. Galactic-sized objects of 10^{6-8} solar masses could be formed in the following manner. Suppose that in some regions the coalescence of most of the primordial black holes did not occur fast enough to avoid evaporation. In one case, the coalescence of the small black holes in the fluid did not occur fast enough, for the most part, to avoid collapse, due to spin repulsion, into a large-sized black hole. Alternately there is the possibility that some of the mini black holes coalesced sufficiently fast with enough spin to avoid collapse and, thus, formed a small version of the black hole fluid. It has already been argued, on the basis of angular momentum considerations, that the black hole fluid objects would be associated with the cores of galaxies and, therefore, would be consistent with the limits on compact galactic objects mentioned also for large black holes in the cores of galaxies.

It is interesting to speculate for the case of small black hole fluid cores that the mass of the fluid particles could be near the Hawking mass for the onset of evaporation. Such a fluid could represent the enormous energy sources seen in quasars for large redshifts. The lifetime of such an object is very dependent on the mass of the "particles" making up the fluid, i.e., the temperature of the early epoch when the objects condensed. For example for particles of 10^{16} g, this would be at a temperature of 10^{10} K. For this mass, "decay" would occur much later and could explain the quasar mechanism.

Finally, the overall consequence is that the dark matter in the universe which is concentrated in the "voids" should be of the same order of magnitude as visible matter in the universe. On the basis of this model, one would predict that the universe is closed.

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APPROVAL

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By Larry L. Smalley

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

E. Tandberg-Hanssen

E. TANDBERG-HANSSEN
Director, Space Science Laboratory

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16. ABSTRACT

The concept of a primordial black hole fluid is introduced and its consequence for super-cluster-sized (i.e., large scale voids) and the missing mass question are discussed.

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