PUBLICATIONS OF THE KOREAN ASTRONOMICAL SOCIETY
12 : 145 ~ 148

PRIMORDIAL BLACK HOLES CANNOT GROW TO BECOME GALACTIC BLACK HOLES

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(*Received May 7, 1997; Accepted July 16, 1997*)

ABSTRACT

In this letter we will investigate the possibility whether primordial black holes can grow to become galactic black holes or not. We find that even a primordial black hole with the probable maximum mass cannot grow in a short timescale. Only a hole with the initial mass of order $\sim 10^4 M_\odot$ can significantly grow to become a galactic hole.

I. INTRODUCTION

Now most astronomers believe the black hole hypothesis, namely that essentially all the galactic nuclei contain supermassive black holes in their nuclei and that those objects together with their accretion disks and tori are the central engines for the most of the powerful activity.

The fast variability is one of the reasons of the black hole hypothesis. For example, rapid variability with timescales as short as a few minutes is observed in low power Seyfert galaxies. The associated light travel time across the source can be as small as the Schwarzschild radius of a $\sim 10^7\ M_\odot$ black hole.

If t is the shortest period of variability,

$$t \sim \frac{GM}{c^3} \tag{1}$$

implies that there must be a hole with mass $M\sim$. There are other good reasons why we support the black hole hypothesis, but we will skip them in this letter. Now the mass of the central black holes turns out to be $10^6 \sim 10^{10}\ M_\odot$. Their existence, therefore, cannot be explained through the stellar evolution theory. Their formation is also one of the most fundamental tasks to be solved to complete the evolution scenario of their host galaxies.

Numerical relativists (e.g., see Shapiro and Teukolsky 1985) have shown that supermassive black holes may have been formed through the gravitational collapse of well-developed clusters. Collapsing of stellar clusters, however, needs time for several billion years. This contradicts with the recent observational results of highly-redshifted QSOs.

In this letter we will investigate the possibility whether primordial black holes can grow to become galactic black holes or not. Much time is saved in this way if possible. It is not a simple problem and it is strange that nobody has considered this problem seriously before.

II. ANALYSIS AND DISCUSSION

It has been suggested that there could be a large number of primordial black holes (hereafter, PBHs) which were formed in the early universe (Zel'dovich and Novikov 1967 ; Hawking 1971). Hawking (1974) showed that, because of the quantum effects, any black hole of mass M should emit particles like a blackbody with the associated time scale τ

$$\tau \sim 10^{10}\left(\frac{M}{10^{15}g}\right) yr. \qquad (2)$$

Equation (2) shows that PBHs of less than mass $\sim 10^{15}g$ would have exploded by now. The mass spectrum of PBHs had been widely investigated in 70's and 80's (e.g. see Hayward and Pavon 1989 and references therein), but no specific results came out. The maximum mass of PBHs is known to be order of $\sim 1M_{\odot}$ (Freese et al. 1983).

PBHs in the early universe must accrete matter hydrodynamically. They cannot grow in the radiation-dominated era (Carr and Hawking 1974), but that era is too short to disturb our discussion in this letter. If the density and temperature of the early universe are ρ and T, respectively, the mass accretion rate $\dot{M}$ is given by

$$\dot{M} \sim 10^{11}\left(\frac{M}{M_{\odot}}\right)^2\left(\frac{\rho}{10^{-24}\ g/cm^3}\right)\left(\frac{T}{10^4 K}\right)^{-3/2} g\ s^{-1} \qquad (3)$$

in this case (Novikov and Thorne 1973). If the hole grows early enough, we can conclude that a PBH can grow to become a supermassive black hole at the center of a galaxy.

For this analysis we have to investigate the evolution of ρ and T in the early universe. In the Friedmann-Robertson-Walker (hereafter, FRW) cosmology the Hubble constant H and the size of the universe R play the main roles and the present values are denoted by the suffix 0. If we define the scale parameter a as

$$R(t) \equiv R_0\, a(t) \qquad (4)$$

the radiation-dominated era satisfies

$$\rho a^4 = \rho_0 a_0^4 \tag{5}$$

while the matter-dominated era does

$$\rho a^3 = \rho_0 a_0^3 \tag{6}$$

respectively. Applying equation (5) to FRW solution with curvature constant 0, we get

$$a \propto t^{1/2}, \quad T \propto t^{-1/2} \tag{7}$$

and applying equation (6), we get

$$a \propto t^{2/3}, \quad T \propto t^{-2/3} \tag{8}$$

respectively. If we set $H_0 = 50\ km/s/Mpc$ and assume that the transition from the radiation-dominated era to the matter-dominated era at $t = t_*$, we have

$$t_* \sim 10^4\ yr, \quad \rho \sim 5.2 \times 10^{-18}\ g/cm^3, \quad T \sim 2.7 \times 10^4\ K \tag{9}$$

in this case. We set this as the initial condition of the growth of a PBH. This condition with equation (8) gives us

$$\rho \sim 4.5 \times 10^5\, t^{-2} \tag{10}$$

$$T \sim 1.2 \times 10^{12}\, t^{-2/3} \tag{11}$$

in CGS units. We also get the age of the universe as

$$t_0 \sim 1.3 \times 10^{10}\ yr \tag{12}$$

in this case. Since no confusion would occur, we set the initial mass of our model PBH as M_0 at $t = t_*$. Substituting equations (10) and (11) into equation (3), we get

$$\begin{aligned} \int_{M_0}^{M} \frac{dM}{M^2} &= 8.6 \times 10^{-39} \int_{t_*}^{t} \frac{dt}{t} \\ \frac{t}{t_*} &= \exp\left[1.2 \times 10^{38}\left(\frac{1}{M_0} - \frac{1}{M}\right)\right]. \end{aligned} \tag{13}$$

If the PBH grows to become a galactic black hole, the relation $M_0 \ll M$ holds and t is dependent only on M_0. Here we find that, even in the maximum mass $M_0 \sim M_\odot$ cannot give a small value of t/t_* .

Equation (13) gives meaningful values only at least $M_0 \sim 10^4 M_\odot$, which cannot be expected in the PBH formation theory. Our conclusion, therefore, must be that PBHs cannot grow to become galactic black holes.

ACKNOWLEDGEMENT

The author thanks to R. D. Blandford and E. T. Vishniac for their helpful comments. This work was supported in part by the project 97-5100-000 of Korea Astronomy Observatory.

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