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THE SEARCH FOR GRB FROM PRIMORDIAL BLACK HOLE EVAPORATION *

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UCLA-APH0075-4/95

Abstract. The search for high energy γ bursts from primordial black holes (PBH) has continued for the past 20 years. We discuss a very interesting group of γ bursts of very short time duration and an increasing hard spectrum from the published BATSE catalog. We point out that the trend, i.e. anti-correlation of hardness ratio vs. γ burst duration, would be expected if some of the short γ bursts came from black holes evaporation. We discuss the possibility that the onset of the quark-gluon plasma can give rise to such GRB from PBH evaporation.

Key words: PBH - GBH

1. Introduction

Ever since the invention of "Primordial Black Holes" there have been suggestions for the experimental detection of such objects (Page and Hawking, 1976; (Hawking S. 1974). However, the real time detection depends on the final state evolution of the PBH; as the PBH's temperature is rising as it sheds mass, into the region of hadronic interactions and hadronic final states. The most extreme model used to simulate this final state was the Hagedorn model that predicted an explosion lasting $\sim 10^{-7}$ sec, whereas other QCD inspired calculation suggested a final state collapse time of the order of seconds (Carter, B., et al., 1976)(McGibbon, J. and Weber B. 1990). We questioned the validity of the QCD inspired calculations pointing out that final state interactions and non perturbation effects could increase the low energy particle luminosity and even the collapse time, both of which must make detection easier (Cline D. and Hong W., 1992). We note that there are already indications of two classes of GRBs (Konvelioton, et al., 1993). The viewpoint taken here is to see if there are GRBs that could be consistent with PBH evaporation. not to attempt to prove the existence of PBHs at this stage! There are two recent developments:

1. New estimates of the amount of PBH that may occur from the early universe by B. Carr, et al. (Phys. Rev. D50, 4853, 94).
2. A suggestion by W. Hong and the author that some of the BATSE GRB events could have the characteristics expected from PBH evaporation within a specific model of the hadronic interaction (Cline D. and Hong W. 1994).

* TO be published in the Proceedings of the ESA/ESTEC
Meeting on Gamma Ray Bursts, April 1995 - ~~Atene~~

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Fig. 1. The running coupling or density of states factor α showing regions of uncertainty due to the quark-gluon phase transitions (I) or the increase in the number of new elementary particles (II). We also show on the same graph at the top the mass of the black hole and at the bottom the regions in temperature where short GRBs could occur.

Hawking showed the temperature increases as it loses mass during its' lifetime. The black hole loses mass at a rate in the context of the standard model of particle physics:

$$\frac{dM}{dt} = - \frac{\alpha(M)}{M^2} \quad (1)$$

where $\alpha(M)$, the *running constant*, counts the particle degree of freedom in the PBH evaporation. The value of the $\alpha(M)$ is model dependent.

A reasonable model of the running coupling is shown in Figure 1, where we indicate the regions of uncertainty where there could be a rapid increase in the effective degrees of freedom due to the quark-gluon phase transition, leading to a rapid burst in the PBH evaporation or at very high energy, where there could be many new particle types that would also increase the rate of evaporation. We also show, in Figure 1, the regions in PBH temperature where short γ bursts may occur when the PBH mass is 10^{14} or 10^9 grams!

2. The Concept of a PBH & Formation in the Early Universe

Black holes at the evaporation stage at the present epoch can be calculated as

$$M_{\bullet} \simeq [3\alpha(M_{\bullet})\tau_{\text{evap}}]^{1/3} \simeq 7.0 \times 10^{14} \text{g} \quad (2)$$

Fig. 2. Anti-correlation of hardness and GRB time (Cline and Hong 1994)(using T90 BATSE data).

for $\alpha(M_*) \simeq 1.4 \times 10^{-3}$. Thus, the number of black holes with critical mass M_* in their final state of evaporation as

$$\frac{dn}{dt} = \frac{3\alpha(M_*)}{M_*^3} N = 2.2 \times 10^{-10} \text{ N pc}^{-3} \text{ year}^{-1} \quad (3)$$

This rate is directly proportional to the particle emission degree of freedom and is therefore highly model dependent. If they are clustered in the galaxy, the exploding PBH density is estimated as ~ 20 per year pc^3 (Cline and Hong 1992). PBH would be formed in the Early Universe from density fluctuations.

While a detailed model of low energy hadronic interactions does not exist, we note that heavy ion collisions may provide some important insight. At present, these data are described by a limiting hadronic temperature model similar to the Hagedorn type model (Stocker, H. 1983). In the fireball model we would expect the PBH evaporation to give GRBs of time duration of a few hundred milliseconds or less (Cline and Hong, 1994).

3. Survey of GRBs & Unusual Events that Might Signal PBH Evaporation

We have studied many of the experimental papers on GRBs and noticed that there are a short GRBs (few 100ms) that in many cases seem to have a hard γ spectrum (Figure 2)(Cline and Hong 1994). Recently, the BATSE group has recorded a very interesting short (ms) GRB that also has a hard spectrum (Bhat, et al., 1992). Which also has the characteristics consistent with a PBH origin in our model.

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Fig. 3. Plot shows $\log(N)$ vs $\log(C_p)$ distribution for events in Figure 2 with the correction of Petrosian (1993) applied.

Since very short γ -rays from the PBH fireball are expected to be seen at the distance at most parsecs around the earth, we expect the short bursts selected among the BATSE data (Fishman, et al., 1994) to be homogeneous and isotropic distribution of sources in a static, Euclidean space (HISE).

To make any reasonable assessment about the spatial distribution of the short GRB's we need to study the $\log N(C_p)$ vs. $\log(C_p/C_{\text{limit}})$ or $\log(C_p)$. This distribution may contain a bias due to the variable threshold, burst durations as suggested by Petrosian (Petrosian 1993). By following their suggestions we corrected for the bias due to the variability of C_{limit} , obtaining the distribution shown in Figure 3. [The Petrosian analysis is justified due to the expected loss of short-weak bursts.] The corrected distribution is consistent with a slope of $-3/2$, as expected for HISE – of course, the statistical limitation is evident. We note as well that the short bursts observed by PHEBUS (Dezalay, J.P.) also give $V/V_{\text{max}} \sim 1/2$.

4. Conclusions

The search for signals for primordial black holes has been going on since 1975. The traditional very short GRB ($\Delta\tau \sim 10^{-7}\text{sec}$) signature is likely incorrect in current physics theory. However, short GRB's can occur from PBH under the following conditions

- i) $M_{\text{PBH}} \sim 10^9\text{grams}$, QCD Burst (McGibbon and Weber, B. 1990)
- ii) $M_{\text{PBH}} \sim 10^{14}\text{grams}$, Quark-Gluon phase transition (Cline and Hong 1992).

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While no candidates for (i) exist, there are several BATSE events that could be due to (ii). If these events are due to PBH, the density in the galaxy could be $< 10^{10} \text{pc}^{-3}$.

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