ON THE NON-ACCELERATION ORIGIN OF THE HIGEST ENERGY COSMIC RAYS

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ABSTRACT

The Hawking radiation from primordial black holes in their near terminal stages of evaporation can produce ultra high energy (UHE) particles spontaneously. The contribution from such objects to the highest energy cosmic rays observed is estimated. Comparison is made with the UHE particle production from cosmic topological defects such as strings and monopoles.

1. INTRODUCTION

It is well known that there are many difficulties[1] in finding suitable acceleration mechanisms to explain the existence of cosmic ray (CR) particles observed up to energies $E > 10^{20}$ eV. For instance supernova blast wave shock acceleration mechanisms typically give 10^{15} -10^{16} eV, while surface acceleration from polar caps of neutron stars may at most give 10 - 10^{18} eV for Fe nuclei . Thus it may be necessary to look for mechanisms which could produce such high energy particles ($\sim 10^{20}$eV) spontaneously without the need to invoke complex acceleration schemes. One possibility is the Hawking radiation from evaporating primordial black holes (BH's) in their terminal stages of evolution. Virtual particles can tunnel to the outside near the event horizon of a black hole which thus emits Hawking radiation as if it were a black body with temperature:

$$T \simeq 10^{20} \left[\frac{10^{2}\mathrm{gm}}{M} \right] \mathrm{eV} \qquad \text{....(1)}$$

with M being black hole mass. Thus evaporating primordial BH's when they reach down to a mass $\sim 10^{2}$g or less, radiate predominantly particles with energies 10^{20} eV, i.e. a gien particle of energy E is emitted with half the full power when the B.H threshold mass of

$$M \simeq 3 \times 10^{2} \left[\frac{10^{20}\mathrm{eV}}{E} \right] \mathrm{g} \quad \text{is reached} \qquad \text{....(2)}$$

There is a slight spin dependence, M increases by 1.4 for emission of spin-one particles. The evaporation rate is $\dot{M} = -p(M)M^{-2}$, which if one includes all the gauge bosons and 3 fermion generations increases by at least a factor of 10 and by another factor of two if one considers shadow states of E(8) x E'(8) superstrings. Particles of energy E in eq. (2) are suppressed by $\exp[-E/MC^{2}]$. However if one includes the Hagedorn spectrum with number of states growing exponenetially with mass as $\sim m^{-3}$ exp (m/160 MeV), this offsets the exponential decrease of the black body tail. In the case of topological relics (TR), like cosmic strings, formed in big bang phase transitions, at say GUT scale ~10 GeV, when they annihilate at late epoch or are destroyed can also release high energy particle with energies upto 10 GeV abinitio.

2. ESTIMATES OF UHE CR'S PRODUCED BY PBH'S AND TR'S

With $\rho(M) \sim 10^{-3}$, black holes with $M \simeq 5 \times 10^{14}$g are just in their final stages of evaporation. The stage with $M \approx 10^{2}$g which spews out UHE's with E 10 eV, lasts for just a burst of $\sim 10^{-12}$ sec; in which a maximum of ~10 ergs of energy i.e. $\sim 10^{15}$ UHE particles are released. BH's with M M contribute to a gamma background close to T ~ 20 MeV. Satellite γ - ray measurements can be used to update the Hawking-Page bound at about ~10 terminal explosions per PC^{-3} per year of such BH's assuming they have clustered in galaxies. Integrating this to red shifts upto z≃5, gives finally the estimate of the flux of UHE's with $E > 10^{20}$ eV of: (i.e. combining eqs. (1), (2) (along with in $\dot{M} = -(\rho(M)(M^{-2})$

and $Ho^{-1} \int_0^5 \frac{dz}{(1+z)^2} \frac{}{[1+\Omega z]^{\frac{1}{2}}}$

($\Omega = 1$, $H_o \approx 60$ km/s/MPC)

$$\phi\ (E > 10^{20}\ eV) \approx 3 \times 10^{-19}\ cm^{-2}\ sec^{-1} \quad ....(3)$$

Of course here the distinct signature is that we should have only protons of energies $> 10^{20}$ eV (no other heavier nuclei are allowed in this process) and more importantly one should have almost equal numbers (allowing for CP violating processes) of antiprotons. Moreover, the spectrum can extend all the way to $E > 10^{28}$ eV.! However the observed CR UHE spectrum is subject to the GZK cut off at 5×10^{19} eV due to interactions with the 3° K microwave background. Here the spectrum continues to extend much higher (for instance the flux of $E > 10^{25}$ eV, can be estimated as $\phi\ (E > 10^{25}\ eV) \sim 5 \times 10^{-26}$ cm sec) However, such high energy protons would not be subject to GZK cut off owing to decrease (with rising E) of photopion energy loss. So the spectrum flattens or recovers at E $E > 10^{21}$ eV. Again one has equal numbers of antiprotons but no heavier nuclei. However, if the Hagedorn hadronic spectrum prevails, the final stage releases $\sim 10^{25}$ ergs in $\sim 10^{-6}$ s in γ-rays of average energy ~200 MeV.

CONCLUSION

Both PBH's and TR's are capable of spontaneously generating UHE CR's with $E > 10^{20}$ eV. In both cases the flux would be of particles and antiparticles (i.e. both P and $\bar{P}$'s) with no heavier nuclei. In both cases UHE neutrinos and high

γ/P ratios are expected. For PBH case the spectrum can extend till 10^{28} eV, whereas for TR's it has terminates at $\sim 10^{24}$ eV, TR's give significant contributions at $E > 10^{19}$ eV, whereas PBH's can contribute to the whole range of particle and γ-ray energies. If the Hagedorn spectrum prevails, PBH's have a very different spectra. The injection spectrum has different power laws in the two cases, the PBH having a black body tail. Future observations of UHE CR's can in principle discriminate between these pictures as well as the nature of the non-acceleration mechanisms.

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