

Limits on Primordial Black Holes evaporation with H.E.S.S.

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Abstract. Primordial Black Holes (PBHs) are hypothetical black holes that could have formed in the early stages of the Universe. According to Hawking’s prediction, PBHs loose mass over cosmological time scales by emitting a blackbody particle spectrum. With decreasing PBH mass, this process becomes increasingly fast, eventually leading to an explosive final evaporation accompanied by bursts of very high-energy (VHE) particles. In this paper, a search for PBH bursts of VHE γ -rays in the H.E.S.S. data set is presented and preliminary limits on the local PHB evaporation rate are derived.

Keywords: gamma-rays, bursts, primordial black holes

I. INTRODUCTION

PBHs are black holes that may have been created in the early stages of our Universe [1]. PBHs formation mechanisms include the gravitational collapse of density fluctuations [2], cosmic phase transition [3], [4], [5] or the collapse of cosmic strings [6], [7]. Such black holes are predicted to have masses ranging from 10^{-5} g upwards and to produce energetic radiation as black bodies [8] with a temperature:

$$T_{\text{BH}} = \frac{M_{\text{p}}^2}{8\pi M}, \quad (1)$$

where M_{p} and M are the Planck mass and the PBH mass, respectively. For black holes of stellar masses or higher, Hawking radiation is quite negligible but for small enough PBHs, it becomes the predominant process that governs the black hole evolution. Black holes lose their mass at a rate inversely proportional to their squared mass:

$$\frac{dM_{\text{BH}}}{dt} = -\frac{\alpha(M)}{M^2}, \quad (2)$$

where $\alpha(M)$ is a parameter counting the number of degrees of freedom available to the radiated particles. The parameter α is an increasing function of the black hole temperature and strongly depends on the particle physics model at high energies [9]. Since the particle emission rate increases with the black hole temperature, PBH evaporation is a runaway process that could lead to a violent explosion and bursts of particles. PBHs can evaporate more or less rapidly depending on the number

of available particle species that can be produced. In a Friedman universe and in the standard model of particle physics, PBHs whose initial mass does not exceed 5×10^{14} g are expected to have fully evaporated in the 10^{10} years of our Universe history. Consequently, PBHs a little more massive than this will still be emitting particles at a rate large enough so that they would be detectable.

The poster reports on the search for bursts of TeV γ -rays that would be the signature of such PBHs evaporation with the High Energy Stereoscopic System H.E.S.S.. Different methods of background bursts determination are presented and have been cross-checked against each other. Limits on the local PBHs evaporation rate are then derived in the framework of the standard model of particle physics.

II. METHODS

A. Data set

The data set comprises all targeted and survey observations made with H.E.S.S. from March 2004 through January 2009. Observations are organized in runs of approximately 28 min duration. Each run has passed the quality criteria which ensure that data have been collected under good weather and instrumental conditions. The total data set amounts to 2791 hours of live time, after corrections for the instrument dead time.

B. Data analysis

The data are analysed using the combination of two independent techniques. The first technique computes the “Hillas geometrical moments” of the shower image [10] and the second one is based on a semi-analytical model of showers, which predicts the expected intensity in each pixel of the camera [11]. Arrival time and geometrically reconstructed arrival direction in the RA-Dec (J2000) coordinate system of all selected γ -like events are then stored in event lists.

C. Searching for bursts of TeV γ -rays

Assuming the standard model of particle physics, the final stage of a PBH evaporation is expected to give bursts of γ -rays with second timescales [9]. Here, the event lists are searched for bursts of duration $\tau = 1$ second. As this time scale is much shorter than the duration of a single run, all runs can be analyzed individually.

Evaporating PBHs are point sources. The events of a physical burst are then expected to be distributed in a region not larger than the H.E.S.S. angular resolution of $\theta = 0.1^\circ$. The burst search procedure is the following. Each of the N_{ev} γ -like events i stored in the run's event list marks a possible start time t_i of a burst that possibly including additional γ -like events reconstructed within the time interval $[t_i, t_i + \tau]$. From all events lying within the time interval $[t_i, t_i + \tau]$ the burst search algorithm finds the maximal subset that fits in a circle in the RA-Dec plane with radius θ . The found subset is said to be a burst of a size b where b is given by the number of events participating in the burst. In the course of finding burst each list event gets assigned the size of the maximal burst it has participated in. To prevent multiple counting of bursts, the number $N(b)$ of detected bursts of size b is defined as the number of events $N_{ev}(b)$ that have been assigned the burst size b divided by b :

$$N(b) = \frac{N_{ev}(b)}{b} \quad (3)$$

Using this convention the following intuitive normalization relation holds:

$$N_{ev} = \sum_b N_{ev}(b) = \sum_b bN(b) \quad (4)$$

D. Background estimation

Most of the γ -like events contained in the event lists result from the residual cosmic ray background, whose statistical fluctuations may cause fake bursts. Estimating the contribution of this background is essential to extract a possible VHE gamma-ray burst signal. The background estimation procedure aims to eliminate any physical bursts in the data in order to properly estimate the number of statistical bursts. The procedure is performed following three methods which have been cross-checked against each other. The first method is the "scrambling" method where a new simulated data set is created by keeping the arrival direction of each event and randomly scrambling their arrival times. The distribution of the time difference between two consecutive events in a single run shows an exponential behavior (figure 1). Thus, a second method consists in keeping the arrival directions unchanged and simulating the arrival times according to this distribution. Finally, the third method simulates both the arrival directions, according to the camera response for γ -like events over the field of view (figure 1), and the arrival times according to the exponential time difference distribution (figure 2). The same burst search algorithm is then applied to 10 simulated data runs and the averaged result is taken as the background.

III. CALCULATING THE LIMITS

No significant excess are found in the H.E.S.S. data, and limits on the PBH explosion rate can be derived. The expected number of physical bursts of TeV γ -rays originating from PBH evaporations are computed

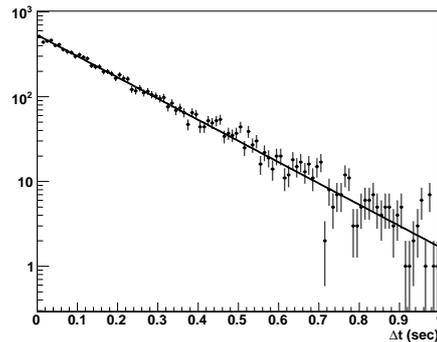


Fig. 1. An example of the time difference distribution between two consecutive events in a single run. The distribution follows an exponential behavior.

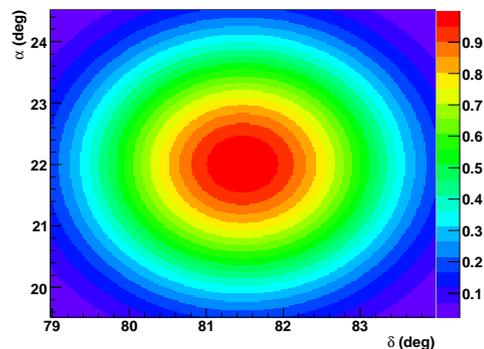


Fig. 2. An example of the camera response for γ -like events over the field of view. The camera response is supposed to be rotationally symmetric with respect to the center of the field of view.

within the standard model of particle physics, using the parametrisation of [9] for the γ -ray spectrum emitted by an evaporating PBH.

The number of expected bursts (the estimated background bursts + the predicted number of physical bursts) are compared to the total number of counted bursts in the H.E.S.S. data set following a likelihood approach. Upper limits on the PBH explosion rate (in $\text{pc}^{-3} \text{yr}^{-1}$) are then derived at the 99 % C.L.

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