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Change in Internal Energy of Non-Spinning Black Holes in AGN

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***Abstract*—This research paper calculates the change in internal energy of non-spinning black holes of different test non-spinning black holes existing in Active galactic nuclei on the basis of equation $dU = R_{bh}dR_{bh}/4M$ as proposed by Mahto et al.(December, 2013).**

***Index Terms*—Internal energy, Entropy and AGN.**

I. INTRODUCTION

The laws of black hole mechanics describe the behaviour of a black hole in close analogy to the laws of thermodynamics relating mass to energy, area to entropy, and surface gravity to temperature.The analogy was completed when Hawking, in 1974, showed that quantum field theory predicts that black holes should radiate like a black body with a temperature proportional to the surface gravity of the black hole [1]. Hernandez et al. showed that if the total internal energy of a black hole is constructed as the sum of N photons all having a fixed wavelength chosen to scale with the Schwarzschild radius as $\lambda = \alpha R_s$, then N will scale with R_s^2 and also studied the behaviour of a classical black body photon gas as it is compressed into a black hole, and proposed a simple model for such a system using only photons confined to the Schwarzschild radius at their lowest possible momentum level[2]. Dipo Mahto et al. have derived the formula for both the changes in energy (δE) and entropy (δS) represented by eq^n (i) $\delta E = \frac{\delta R_{bh} \cdot c^2}{4M}$ and (iia) $\delta S_{bh} = \frac{2\pi}{k \cdot c^2}\delta E$ (iib) $\delta S_{bh} = 2\pi(\delta R_{bh})$ taking account the first law of black hole mechanics and mass-energy equivalence relation [3]. In 2012, Dipo Mahto et al. have derived a formula for the change in entropy of the non-spinning black holes with respect to change in the radius of event horizon ($\delta S_{bh}/\delta R_{bh} = 2\pi R_{bh}$), applying the first law of black hole mechanics with the relation for the change in entropy $\delta S = 8\pi M \delta M$. They have extended this work with proper operation, Bekenstein-Hawking formula for the entropy of black holes ($S_{bh} = A/4$) is obtained [4]. Dipo Mahto et al. discussed the derivation for internal energy of the non-spinning black holes using the first law of black hole thermodynamics and calculated their values of different test non-spinning black holes existing in X-ray binaries and Active galactic nuclei [5]. Dipo Mahto et al. derived expression for the change in internal energy and enthalpy of the black holes using first law of thermodynamics and showing that the change in internal energy and enthalpy are the manifestations of same thing at constant pressure and volume [6]. Dipo Mahto et al. have derived an expression for change in internal energy of the non-spinning black holes using the entropy change((δS) as proposed by Mahto et. al.(2011) and also calculated their values for different types of the test non-spinning black holes existing in X-ray binaries[7]. In the present research paper, we have calculated the change in internal energy of different test non-spinning black holes existing in Active galactic nuclei using the formula $dU = R_{bh}dR_{bh}/4M$ as proposed by Mahto et al.(Dec, 2013).

II. FORMULA USED

The change in internal energy of non-spinning black holes due to corresponding change in the radius of event horizon is given by eq^n (1) [7].

$$dU = R_{bh}dR_{bh}/4M \qquad (1)$$

The above expression shows the change in internal energy of non-spinning black holes which is the exactly the same to the expression for the change in internal energy as in the reference [6]. It may be supposed that there is negligible change in the radius of the event horizon due to change in internal energy of non-spinning black holes. Hence in the numerical calculations, the radius of event horizon (R_{bh}) can be taken into consideration instead of δR_{bh} . Here, we have calculated the change in internal energy (dU) using eq^n (1) for different test non-spinning black holes as listed in the table given below.

III. DATA IN THE SUPPORT OF MASS OF THE BLACK HOLES

There are two categories of black holes classified on the basis of their masses clearly very distinct from each other, with very different masses M ~ 5- 20 $M_\odot$ for stellar – mass black holes in X-ray binaries (XRBs) and M ~ $10^6 - 10^{9.5} M_\odot$ for super massive black holes in active galactic nuclei[8].

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IV. TABLE

Change in internal energy of non-spinning black holes in AGN.

Sl. No.	Mass of BHs (M)	R_{bh}=1475x (M/ $M_{\odot}$) (in metre)	log(R_{bh}) (in metre)	Change in internal energy of non-spinning black holes (δU) in Joule	log (δU)
1	$1 \times 10^6 M_{\odot}$	1.475×10^9	9.1687	5.439×10^{11}	11.7355
2	$2 \times 10^6 M_{\odot}$	2.950×10^9	9.4698	1.087×10^{12}	12.0362
3	$3 \times 10^6 M_{\odot}$	4.425×10^9	9.6459	1.631×10^{12}	12.2124
4	$4 \times 10^6 M_{\odot}$	5.900×10^9	9.7708	2.175×10^{12}	12.3374
5	$5 \times 10^6 M_{\odot}$	7.375×10^9	9.8677	2.719×10^{12}	12.4344
6	$6 \times 10^6 M_{\odot}$	8.850×10^9	9.9469	3.263×10^{12}	12.5136
7	$7 \times 10^6 M_{\odot}$	1.032×10^{10}	10.0136	3.803×10^{12}	12.5801
8	$8 \times 10^6 M_{\odot}$	1.180×10^{10}	10.0718	4.351×10^{12}	12.6385
9	$9 \times 10^6 M_{\odot}$	1.327×10^{10}	10.1228	4.891×10^{12}	12.6893
10	$1 \times 10^7 M_{\odot}$	1.475×10^{10}	10.1687	5.439×10^{12}	12.7355
11	$2 \times 10^7 M_{\odot}$	2.950×10^{10}	10.4698	1.087×10^{13}	13.0362
12	$3 \times 10^7 M_{\odot}$	4.425×10^{10}	10.6459	1.631×10^{13}	13.2124
13	$4 \times 10^7 M_{\odot}$	5.900×10^{10}	10.7708	2.175×10^{13}	13.3374
14	$5 \times 10^7 M_{\odot}$	7.375×10^{10}	10.8677	2.719×10^{13}	13.4344
15	$6 \times 10^7 M_{\odot}$	8.850×10^{10}	10.9469	3.263×10^{13}	13.5136
16	$7 \times 10^7 M_{\odot}$	1.032×10^{11}	11.0136	3.803×10^{13}	13.5801
17	$8 \times 10^7 M_{\odot}$	1.180×10^{11}	11.0718	4.351×10^{13}	13.6385
18	$9 \times 10^7 M_{\odot}$	1.327×10^{11}	11.1228	4.891×10^{13}	13.6893
19	$1 \times 10^8 M_{\odot}$	1.475×10^{11}	11.1687	5.439×10^{13}	13.7351
20	$2 \times 10^8 M_{\odot}$	2.950×10^{11}	11.4698	1.087×10^{14}	14.0362
21	$3 \times 10^8 M_{\odot}$	4.425×10^{11}	11.6459	1.631×10^{14}	14.2124
22	$4 \times 10^8 M_{\odot}$	5.900×10^{11}	11.7708	2.175×10^{14}	14.3374
23	$5 \times 10^8 M_{\odot}$	7.375×10^{11}	11.8677	2.719×10^{14}	14.4344

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24	6 x 10^8 $M_\odot$	8.850 x 10^{11}	11.9469	3.263 x10^{14}	14.5136
25	7 x 10^8 $M_\odot$	1.032 x 10^{12}	12.0136	3.803 x10^{14}	14.5801
26	8 x 10^8 $M_\odot$	1.180 x 10^{12}	12.0718	4.351 x10^{14}	14.6385
27	9 x 10^8 $M_\odot$	1.327 x 10^{12}	12.1228	4.891 x10^{14}	14.6893
28	1 x 10^9 $M_\odot$	1.475 x10^{12}	12.1687	5.439 x10^{14}	14.7355
29	2 x 10^9 $M_\odot$	2.950 x10^{12}	12.4698	1.087 x10^{15}	15.0362
30	3 x 10^9 $M_\odot$	4.425 x 10^{12}	12.6459	1.631 x10^{15}	15.2124
31	4 x 10^9 $M_\odot$	5.900 x 10^{12}	12.7708	2.175 x10^{15}	15.3374
32	5 x 10^9 $M_\odot$	7.375 x 10^{12}	12.8677	2.719 x10^{15}	15.4344

V. GRAPH

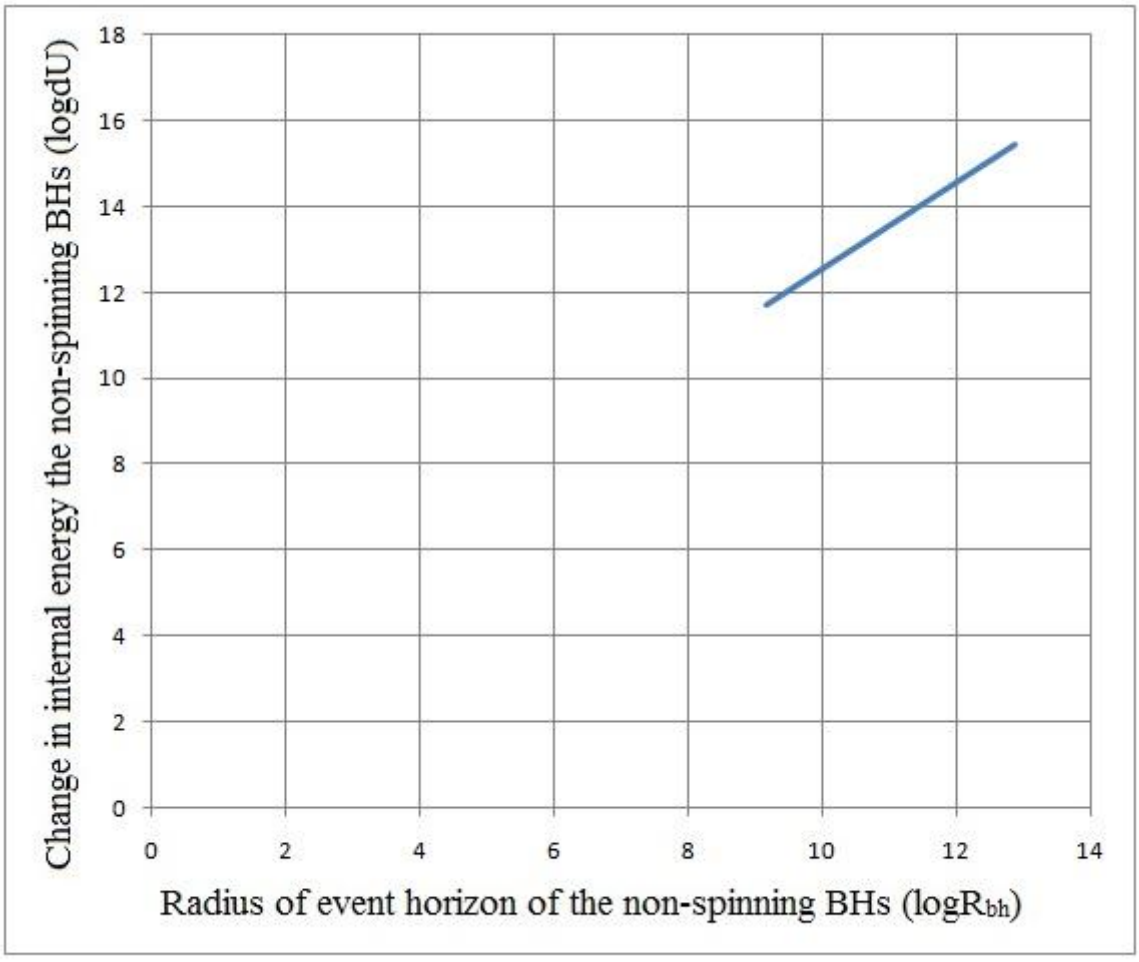

Fig 1: The graph plotted between the radius of event horizon and change in internal energy (in joule) of the different test non-spinning black holes in AGN.

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VI. RESULT AND DISCUSSION

In the present work, we have used the expression for the change in internal energy of non-spinning black holes as proposed by Mahto et al.(December, 2013) to calculate the values of change in internal energy of different test non-spinning black holes existing in Active galactic nuclei. To discuss the relation between the radius of the event horizon of non-spinning black holes and change in internal energy in AGN, the graph is plotted between the of different test non-spinning black holes radius of the event horizon and their corresponding values of change in internal energy using logarithmic scale (Fig.1) The graph plotted for AGN is in a straight line and shows that there is a uniform variation between the radius of the event horizon of different test non-spinning black holes and their corresponding values of change in internal energy. The straight line also shows that there is a definite relation between the radius of the event horizon of non-spinning black holes and change in internal energy and gives the validity of the equation(1). When we compare the nature of graph in present work with that of the same work for X-ray binaries (XRBs), we see that the characteristics of the non-spinning black holes for both XRBs and AGN are approximately the same.

VII. CONCLUSION

In the study of present research work, we can draw the following conclusions:

(i)There is uniform variation in the change in internal energy due to increasing the radius of the event horizon of different test black hole candidates in AGN which shows a definite relation between the change in internal energy and radius of the event horizon of non-spinning black holes.

(ii)Larger the radius of the event horizon, greater is the change in internal energy of black holes and vice-versa.

(iii) The characteristics of the non-spinning black holes for both XRBs and AGN are approximately the same.

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