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ORIGINAL ARTICLE

Entanglement entropy of acoustic black hole in Bose–Einstein condensate

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Abstract We study the entanglement entropy associated to the phonons generated via the Hawking mechanism of acoustic black holes in a Bose–Einsten condensate. The lowest energy allowed for the radiated phonons is found to be a function of space coordinate. Based this, we calculate the entanglement entropy, which contains three parts: a leading term, which is a constant of value $1/6$, a logarithmic correction term and some series terms. We discuss the convergence of the series terms.

Keywords Acoustic black holes · Entanglement entropy

1 Introduction

Black hole thermodynamics tells us that a black hole has an entropy proportional to its horizon area and a temperature proportional to its surface gravity at the horizon. Black hole mass, entropy, and temperature obey the first law of thermodynamics. In black hole thermodynamics, general relativity, quantum mechanics, and statistical physics are entangled with each other. Therefore the black hole is a crucial window through which one can probe the quantum properties of gravity. Hawking radiation, an important ingredient of black hole thermodynamics, is an important predication of general relativity together with quantum mechanics (Hawking 1975; Damour and Ruffini 1976; Robinson and Wilczek 2005; Iso et al. 2006; Parikh and Wilczek 2000; Zhao et al. 2009). However, it is almost impossible to detect the Hawking radiation of an astronomical black hole in the universe at present because its Hawking temperature is much lower than the temperature of the cosmic microwave background radiation. For example, the Hawking temperature of a black hole with a solar mass is just 10^{-7} K. Thus it becomes quite interesting to detect the Hawking radiation associated with some analogue black holes in laboratory (Unruh 1981; Belgiorno et al. 2010a, 2010b, 2011; Faccio et al. 2010; Zhang et al. 2011; Barcelo et al. 2011).

Unruh (1981) proposed the concept of acoustic black hole and pointed out that the “Hawking radiation” from the acoustic black hole may be detected in laboratory. Acoustic black holes possess many of the fundamental properties of black holes in gravity. Later on it has been found that various analogous black holes could be realized in real material systems, see for example, works of Barcelo et al. (2005), Fabbri and Mayoral (2011), Mayoral et al. (2011), Carusotto et al. (2008). Most of these studies pay attention to the Hawking radiation associated with analogue black holes. As we know, entropy is another important quantity in black hole thermodynamics; it measures the correlation of degrees of freedom between inside and outside of a black hole. The entanglement entropy of a black hole in gravity has been intensively studied in the literature. However, there has not been much work on the entanglement entropy associated with analogue black holes. More recently such studies have been initiated. Giovanazzi (2011) has calculated the entanglement entropy and the rate of entropy radiated by stationary one-dimensional acoustic black holes. It has been found that the rate of entropy production is given by $\dot{S} = \kappa/12$, where κ is the sound acceleration on the sonic horizon. This entropy production is accompanied by a corresponding for-

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