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thermodynamics in (2+1) -dimensional cosmology**

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# Holography and the generalized second law of thermodynamics in (2+1)-dimensional cosmology

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## Abstract

The Fischler-Susskind entropy bound has been studied in (2+1)-dimensional universes with negative cosmological constant. As in all contracting universes, that bound is not satisfied. Furthermore, we found that the Fischler-Susskind bound is not compatible with a generalized second law of thermodynamics in (2+1)-dimensional cosmology, neither the classical nor the quantum version. On the other hand, the Hubble entropy bound has been constructed in (2+1)-dimensional cosmology and it is shown compatible with the generalized second law of thermodynamics.

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Motivated by the well-known result in black hole theory that the total entropy of matter inside a black hole cannot exceed the Bekenstein-Hawking entropy, a conceptual change in our thinking about gravity has recently been put forward by the so called "holographic principle" [1,2]. According to this principle, all the degrees of freedom inside a volume is expressed on its boundary, implying that the entropy of a system cannot be larger than its boundary area. A specific generalization of the holographic principle to cosmology was realized by Fischler and Susskind (FS) [3]. A remarkable point of their proposal is that the holographic principle is valid for flat or open universes with the equation of state satisfying the condition $0 \leq P \leq \rho$. However, for closed universes the principle is violated. The problem becomes even more serious if one investigates the universe with a negative cosmological constant [4]. In that case the holographic principle fails, independently of whether the universe is closed, open or flat. Various different modifications of the FS version of the holographic principle have been raised recently, such as replacing the holographic principle by the generalized second law of thermodynamics [5,4], using the cosmological apparent horizon instead of the particle horizon in the formulation of holographic principle [6], changing the definition of "degrees of freedom" [7] etc. A very recent result claimed that the holographic principle in a closed universe can be obeyed if the universe contains strange negative pressure matter [8]. The study of the cosmic holography has also been extended to Pre-big-bang string cosmological models [9]. All these studies have concentrated on (3+1)-dimensional (4D) cosmology.

In our previous work, we have considered the investigations on cosmic holography in (2+1)-dimensional (3D) cosmological models [10]. Analogously to the 4D counterpart, the holographic principle is satisfied in all 3D flat and open universes, but breaks down for 3D closed universes. Attempts to uphold the holographic principle by introducing negative pressure matter as well as matter with very unconventional high pressure failed, because they cannot accomodate any classical description after the big bang. It is of interest to generalize our discussions to 3D universes with a negative cosmological constant. There has been many successful applications of the holographic principle for 3D pure Anti-de Sitter (AdS) space from string theory [11-14]. Thus we have the motivation to investigate whether the holographic principle holds in 3D AdS cosmology.

Recently a generalized second law (GSL) of thermodynamics in 4D cosmologies has been put forward [15], and its relation to the Hubble entropy bound (HE) suggested by

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