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ORIGINAL ARTICLE

Universe models with negative bulk viscosity

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Abstract The concept of negative temperatures has occasionally been used in connection with quantum systems. A recent example of this sort is reported in the paper of S. Braun et al. (Science 339:52, 2013), where an attractively interacting ensemble of ultracold atoms is investigated experimentally and found to correspond to a negative-temperature system since the entropy decreases with increasing energy at the high end of the energy spectrum. As the authors suggest, it would be of interest to investigate whether a suitable generalization of standard cosmological theory could be helpful, in order to elucidate the observed accelerated expansion of the universe usually explained in terms of a positive tensile stress (negative pressure). In the present note we take up this basic idea and investigate a generalization of the standard viscous cosmological theory, not by admitting negative temperatures but instead by letting the bulk viscosity take *negative* values. Evidently, such an approach breaks standard thermodynamics, but may actually be regarded to lead to the same kind of bizarre consequences as the standard approach of admitting the equation-of-state parameter w to be less than -1. In universe models dominated by negative viscosity we find that the fluid's entropy decreases with time, as one would expect. Moreover, we find that the fluid transition from the quintessence region into the phantom region (thus passing the phantom divide $w=-1$) can actually be reversed. Also in generalizations of the ΛCDM-universe models with a fluid having negative bulk viscosity we find that the viscosity decreases the expansion of the universe.

Keywords Viscous cosmology · Negative viscosity

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1 Introduction

The absolute temperature T is in usual physics bound to be a positive quantity. Under special conditions, however, such as when high-energy states are more occupied than low-energy states, the temperature calculated from the thermodynamical formula

$$\frac{1}{T}=\left(\frac{\partial S}{\partial U}\right)_N, \tag{1}$$

can be a negative quantity. A striking example of this kind of system has recently been found experimentally, in the form of an attractively interacting ensemble of ultracold bosons; cf. Braun et al. (2013).

This is, however, not the first example of a negative-temperature system. Thus negative temperatures are associated with the properties of paramagnetic dielectrics; cf. for instance, Landau and Lifshitz (1980), a key factor being here that the "magnetic spectrum" has to lie within a finite interval of energy. It is to be observed generally that the region of negative temperatures lies not "below absolute zero" but rather "above infinity", implying that negative temperatures are in some sense "higher" than positive ones.

An interesting idea suggested by Braun et al. (2013) is that the negative-temperature model may be helpful for the construction of a theory of dark energy in cosmology. As is commonly accepted by now, the expansion of the universe