Imprints of cosmic strings on the cosmological gravitational wave background

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The equation which governs the temporal evolution of a gravitational wave (GW) in curved space-time can be treated as the Schrödinger equation for a particle moving in the presence of an *effective potential*. When GWs propagate in an expanding universe with *constant* effective potential, there is a *critical value* (k_c) of the comoving wave number which discriminates the metric perturbations into oscillating ($k > k_c$) and nonoscillating ($k < k_c$) modes. As a consequence, if the nonoscillatory modes are outside the horizon they do not *freeze out*. The effective potential is reduced to a nonvanishing constant in a cosmological model which is driven by a *two-component fluid*, consisting of radiation (dominant) and cosmic strings (subdominant). It is known that the cosmological evolution gradually results in the *scaling* of a cosmic-string network and, therefore, after some time ($\Delta\tau$) the Universe becomes radiation dominated. The evolution of the nonoscillatory GW modes during $\Delta\tau$ (while they were outside the horizon), results in the *distortion* of the GW power spectrum from what it is anticipated in a *pure* radiation model, at present-time frequencies in the range 10^{-16} Hz $< f \lesssim 10^5$ Hz.

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I. INTRODUCTION

The so-called cosmological gravitational waves (CGW) represent small-scale perturbations to the Universe metric tensor [1]. Since gravity is the weakest of the four known forces, these metric corrections decouple from the rest of the Universe at very early times, presumably at the Planck epoch [2]. Their subsequent propagation is governed by the space-time curvature, encapsulating in the field equations the inherent coupling between relic GWs and the Universe matter content; the latter being responsible for the background gravitational field [3].

In this context, we consider the coupling between CGWs and cosmic strings. They are one-dimensional objects that can be formed as linear defects at a symmetry-breaking phase transition [4,5]. If they exist, they may help us to explain some of the large-scale structures seen in the Universe today, such as gravitational lenses [6]. They may also serve as *seeds* for density perturbations [7,8], as well as potential sources of relic gravitational radiation [9].

In the present article we explore another possibility: A fluid of cosmic strings could be responsible for the constancy of the effective potential in the equation which drives the temporal evolution of a CGW in an expanding universe. As we find out, a constant effective potential leads to a critical comoving wave number (k_c), which discriminates the metric fluctuations into oscillating modes ($k > k_c$) and nonoscillatory ($k < k_c$) ones. As long as the latter lie outside the horizon, they do not freeze out, resulting in the departure of the inflationary-GW power spectrum from scale invariance. This would be the case, if there is a short period after inflation where the cosmological fluid is made out of radiation and a subdominant component of cosmic strings. As regards the space-time geometry itself, the spatially flat Friedmann-Robertson-Walker (FRW) model appears to interpret adequately both the observational data related to the known thermal history of the Universe and the theoretical approach to cosmic-string configurations [4]. Consequently, we will assume our cosmological background to be a spatially flat FRW model.

This paper is organized as follows: In Sec. II we summarize the theory of CGWs in curved space-time. In Sec. III we demonstrate that, in a radiation model *contaminated* by a fraction of cosmic strings, the effective potential in the equation which governs the temporal evolution of a CGW in curved space-time is constant. In Sec. IV we explore the characteristics of a potential contribution of cosmic strings to the evolution of the Universe and in Sec. V we study the propagation of the nonoscillatory GW modes during this stage. We find that, if the Universe evolution includes a *radiation-plus-strings* stage, then, although it could last only for a short period of time, its presence would lead to a distortion of the stochastic GW background from what it is anticipated in a pure radiation model, at present-time frequencies in the range 10^{-16} Hz $< f \lesssim 10^5$ Hz.

II. GRAVITATIONAL WAVES IN CURVED SPACE-TIME

The far-field propagation of a weak CGW ($|h_{\mu\nu}| \ll 1$) in a curved, nonvacuum space-time is determined by the differential equations [10]

