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Production and Detection of Relic Dilatons in String Cosmology

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Abstract

This paper summarizes the contribution presented at the *IX Marcel Grossmann Meeting* (Rome, July 2000). It is stressed, in particular, that a non-relativistic background of ultra-light dilatons, produced in the context of string cosmology, could represent today a significant fraction of cold dark matter. If the dilaton mass lies within the resonant band of present gravitational antennas, a stochastic dilaton background with a nearly critical density could be visible, in principle, already at the level of sensitivity of the detectors in operation and presently under construction.

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PRODUCTION AND DETECTION OF RELIC DILATONS IN STRING COSMOLOGY

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The main purpose of this paper is to point out that the relic dilatons produced in the context of the pre-big bang scenario [1] could provide a significant contribution to the present fraction of dark matter density and, if light enough, could be detectable even by present gravitational antennas [2], provided their coupling to macroscopic bodies is not too far from the present experimental upper limits.

The spectrum of the relic dilatons, produced from the vacuum through the parametric amplification of quantum fluctuations, differs from the graviton spectrum because of the mass of the dilaton, and contains in general three branches [3], corresponding to

- relativistic modes, with proper momentum $p = k/a > m$;
- non-relativistic modes, with $p_m < p < m$, which were still relativistic at the time of horizon crossing;
- non-relativistic modes, with $p < p_m$, which were already non-relativistic at the time of horizon crossing.

The last two branches are separated by the limiting frequency $p_m = p_1(m/H_1)^{1/2}$ of a mode that becomes non-relativistic, $p \simeq m$, just at the time of horizon crossing, $p \simeq H$ (here $p_1 = H_1 a_1/a$ is the maximal amplified momentum scale, and H_1 the curvature scale at the time $t = t_1$ of the inflation-radiation transition).

At the present time t_0, the "minimal" dilaton spectrun can thus be written as follows [3]:

$$\begin{aligned}
\Omega_\chi(p,t_0) &\simeq \left(\frac{H_1}{M_p}\right)^2 \Omega_\gamma(t) \left(\frac{p}{p_1}\right)^\delta, && m < p < p_1, \\
&\simeq \left(\frac{H_1}{M_p}\right)^2 \left(\frac{m^2}{H_1 H_{\rm eq}}\right)^{1/2} \left(\frac{p}{p_1}\right)^{\delta-1}, && p_m < p < m, \\
&\simeq \left(\frac{H_1}{M_p}\right)^2 \left(\frac{m}{H_{\rm eq}}\right)^{1/2} \left(\frac{p}{p_1}\right)^{\delta}, && p < p_m,
\end{aligned} \tag{1}$$

where M_p is the Planck mass, $H_{\rm eq} \sim 10^{-55} M_p$ is the curvature scale at the epoch of matter-radiation equilibrium, and $\Omega_\gamma(t) = (H_1/H)^2 (a_1/a)^4$ is the energy density (in critical units) of the radiation that becomes dominant at the end of inflation (today, $\Omega_\gamma(t_0) \sim 10^{-4}$). Finally, δ is a slope parameter depending on the kinematics of the pre-big bang phase ($\delta = 3$ for dilaton-dominated inflation [1], while $\delta < 3$ for modes crossing the horizon during the high curvature string phase).

Let us suppose now that the dilaton mass is small enough to fall inside the sensitivity band of present gravitational detectors, so that $m \ll p_1$, and assume $\delta > 0$, to avoid infrared divergences. It follows that the relativistic branch of the spectrum is growing, and it is bounded today by the peak value $\Omega_\chi^{\rm rel} \sim (H_1/M_p)^2 \Omega_\gamma \lesssim 10^{-6}$, where we have used the fact that the final inflation scale is controlled by the string mass scale $H_1 \simeq M_s \sim (0.1 - 0.01) M_p$.

The non-relativistic part of the spectrum, on the contrary, is only constrained by the critical density bound,

$$\int^m d \ln p \Omega_\chi^{\rm non-rel}(p) \lesssim 1. \tag{2}$$

Let us suppose that $\delta < 1$, so that the above integral is dominated by the peak of the spectrum at $p = p_m$, and leads to the constraint

$$\Omega_\chi(p_m) \simeq \left(\frac{H_1}{M_p}\right)^2 \left(\frac{m}{H_{\rm eq}}\right)^{1/2} \left(\frac{m}{H_1}\right)^{\delta/2} \lesssim 1. \tag{3}$$

If this constraint is saturated, i.e. if the dilaton mass satisfies

$$m \simeq (H_{\rm eq} M_p^4 H_1^{\delta-4})^{1/(\delta+1)}, \tag{4}$$

then the non-relativistic branch dominates the dilaton spectrum, and the relic dilatons might represent a significant fraction of the present cold dark matter density. It is important to stress that, for a nearly flat spectrum ($\delta \to 0$), this may occurr even for very low masses, lying in the sensitivity range of gravitational antennas. If we take, for instance, $m \sim 1$ kHz $\sim 10^{-12}$ eV, and $H_1 = M_s \sim 10^{-1} M_p$, then the condition (4) is satified for $\delta \simeq 11/39 \simeq 0.28$.

It is not impossible, therefore, that the very weak (much smaller than gravitational) coupling to the detectors of ultra-light dilatons [4] may be compensated by a very high (almost critical) relic energy density (much higher than for relic gravitons). If this is the case, an analysis of the signal-to-noise ratio produced by a non-relativistic stochastic background of scalar particles [2] shows that the detection of a dilatonic dark matter component is in principle compatible with the expected sensitivity of the gravitational antennas in operation and presently under construction.

References

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