Addendum to ''Mathematical structure of quantum superspace as a consequence of time asymmetry''

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In this paper we improve the results of Sec. VI of a previous paper [M. Castagnino, Phys. Rev. D **57**, 750 (1998)] by considering that the main source of entropy production is the photospheres of the stars. [S0556-2821(99)05904-4]

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A ROUGH COINCIDENCE BECOMES MORE PRECISE

In Ref. [1] one of us reported a rough coincidence between the time where the minimum of the entropy gap $\Delta S = S_{\rm act} - S_{\rm max}$ [2] takes place and the time where all the stars will exhaust their fuel. The time where the minimum of ΔS is located was

$$t_{\rm cr} \approx t_0 \left(\frac{2}{3} \frac{\omega_1}{T_0} \frac{t_{\rm NR}}{t_0} \right)^3. \tag{1}$$

The following numerical values were chosen: $\omega_1 = T_{\rm NR}$, the temperature of the nuclear reactions within the stars (that was considered as the main source of entropy), $t_{\rm NR} = \gamma^{-1}$ the characteristic time of these nuclear reactions, t_0 the age of the universe, and T_0, the cosmic microwave background temperature, and making some approximations the rough coincidence was obtained.

Now we reconsider the problem and conclude that, even if nuclear reactions within the stars are a source of entropy, the parameters $T_{\rm NR}$ and $t_{\rm NR}$ are not the best ones to define the behavior of the term $e^{-\gamma t/2}\rho_1$ of Eq. (100) of Ref. [1], since they do not correspond to the main unstable system that we must consider. In fact the main production of entropy in a star is not located in its core, where the temperature is almost constant (and equal to $T_{\rm NR}$), but in the photosphere where the star radiates. The energy radiated from the surface of the star is produced in the interior by fusion of light nuclei into heavier nuclei. Most stellar structures are essentially static, so the power radiated is supplied at the same rate by these exothermic nuclear reactions that take place near the center of the star [3]. We can decompose the whole star in two branch systems [2], as explained in Sec. VII of Ref. [1], where a chain of branch systems was introduced. We have two branch systems to study: the core and the photosphere. The core gives energy to the photosphere and in turn the photosphere diffuses this energy to the surroundings of the star, namely, in the bath of microwave radiation at temperature T_0. In this way, we have two sources of entropy production, the radiation of energy at the surface of the star and the change of composition inside the star (as time passes we have more helium and less hydrogen). Since the core of a star is near thermodynamic equilibrium, we neglect the second and we concentrate on the first: the radiation from the surface of the star (related with the difference between the star and the background temperatures). So the temperature of the photosphere and not the one of the core must be introduced in our formula. Thus it is better to consider the photosphere as the unstable system that defines the term $e^{-\gamma t/2}\rho_1$ of Eq. (100) of Ref. [1]. So we must change $T_{\rm NR}$ and $t_{\rm NR}$ to T_P, the temperature of the photosphere and t_S the characteristic lifetime of the star. Then we must change Eq. (1) to

$$t_{\rm cr} \approx t_0 \left(\frac{2}{3} \frac{T_P}{T_0} \frac{t_S}{t_0} \right)^3. \tag{2}$$

As 90% of the stars are dwarfs with photosphere temperature $T_P = 10^3$ K [4] and the characteristic lifetime $t_S = 10^9$ [5] if we take these values we reach again

$$t_{\rm cr} \lesssim 10^4 t_0, \tag{3}$$

but now with no approximation. The order of magnitude of $t_{\rm cr}$ is a realistic one. In fact, $10^4 t_0 \approx 1.5 \times 10^{14}$ yr after the big-bang the conventional star formation will end [6] and it is also considered that all the stars will exhaust their fuel [7] so it is reasonable that this time would be of the same order as the one where the entropy gap stops its decreasing and begins to grow [8]. So the rough coincidence is now a precise order of magnitude coincidence and therefore the comprehension of Ref. [1] is improved.

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