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# Holographic considerations on a Machian Universe

Everton M.C. Abreu [a,b,*], Jorge Ananias Neto [b]

[a] Grupo de Física Teórica e Matemática Física, Departamento de Física, Universidade Federal Rural do Rio de Janeiro, BR 465-07, 23890-971, Seropédica, RJ, Brazil

[b] Departamento de Física, ICE, Universidade Federal de Juiz de Fora, 36036-330, Juiz de Fora, MG, Brazil

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ABSTRACT

MOND theory explains the rotation curves of the galaxies. Verlinde's ideas establish an entropic origin for gravitational forces and Tsallis principle generalizes the theory of Boltzmann–Gibbs. In this work we have promoted a connection between these recent approaches, that at first sight seemed to have few or no points in common, using the Mach's principle as the background. In this way we have used Tsallis formalism to calculate the main parameters of the Machian Universe including the Hubble parameter and the age of the Universe. After that, we have also obtained a new value for the Tsallis parameter via Mach's principle. Using Verlinde's entropic gravity we have obtained new forms for MOND's well established ingredients. Finally, based on the relations between particles and bits obtained here, we have discussed the idea of bits entanglement in the holographic screen.



## 1. Introduction

One of the great mysteries of general physics at current times is to explain dark matter, which composes the great majority of the matter of the Universe. Therefore, there are several reasons to derive alternatives to dark matter, following [1] we will name three good reasons. The first one is

* Corresponding author at: Grupo de Física Teórica e Matemática Física, Departamento de Física, Universidade Federal Rural do Rio de Janeiro, BR 465-07, 23890-971, Seropédica, RJ, Brazil.

*E-mail addresses:* evertonabreu@ufrrj.br, everton.abreu@gmail.com (E.M.C. Abreu), jorge@fisica.ufjf.br (J. Ananias Neto).

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a kind of alternative just in case our understanding of gravity on astronomical scales, in which the concept of dark matter is based, is not correct. The second one would be based on the fact that dark matter has not been identified directly yet. In other words, it was not identified through gravitational experiments. And the last reason, the simpler one, is that it is always good to have other paradigms of it in order to be able to confront them, since the dark matter paradigm is not fully understood yet.

Besides, another challenge comes from the well known fact that classical Newtonian dynamics does not work on galactic scales. Measures taken through observations on the rotation curves showed that galaxies are not rotating in the same way as the Solar system. The velocity of rotation versus the distance from the galactic center is visualized through the so-called galactic rotation curves. However, the last one cannot be understood through only the visible matter. This fact leads us to consider the possibility, among others, that the Newtonian dynamics is not valid universally speaking.

One explanation came with Zwicky [2,3] that considered dark matter, in addition to the matter of the known galaxies, taking part in the galactic scale by its gravitational action. However, nowadays we know that dark matter is not only an exotic feature of clusters. It can also be found in single galaxies to explain their flat rotation curves.

To explore this problem, Milgrom [4–6] proposed a second explanation which results in the so-called modified Newtonian dynamics, MOND, as a phenomenological theory. The basic ingredient in MOND is to modify the force expression to adapt it to the case of extremely small accelerations, that occurs at the scale of galaxies.

Concerning both the force expression and gravitation we know that recently E. Verlinde [7] brought an idea that the gravitational force appears as the result of entropic and holographic concepts. Through these first principles Verlinde was able to obtain Newton's gravitation law but he did not deal with extremely small accelerations.

The holographic screen, formed by bits of informations, on the other hand can be considered as the causal sphere that encompasses the two-body interaction and all other matter that affects this two-body, which agrees with Mach principle. Concerning Mach's ideas [8,9], in the scenario of gravitational interaction of closed objects, one can substitute the far Universe by a spherical shell of effective mass $M$ and radius $R$. This spherical shell, in our point of view, can be seen as the holographic screen. Hence, the mass inside, according to Mach's principle, has a constant gravitational potential which will be described latter.

It is our objective in this work to analyze the connection between Mach's and Verlinde's ideas in the light of MOND formalism. Moreover, we derived Mach's underlying ingredients as functions of Tsallis' nonextensive parameter [10,11].

The organization of this paper follows a structure where Sections 2 and 3 are dedicated to introductory explanations of Verlinde's and MOND formalisms, respectively. In Sections 4 and 5, after a very brief introduction of the important ingredients of Mach and Tsallis principles that will be used here, respectively, we will calculate the value of the MOND parameters through Tsallis parameter in Section 6. After that, in Section 7 we will make a connection between Verlinde's bits-holographic-screen ideas and Mach's particles-horizon concepts. In Section 8 we will introduce new values for some MOND ingredients in a Machian model. In Section 9 we will discuss the results and conclusions obtained in this the work.

## 2. A brief review of Verlinde's formalism

The objective of this section is to provide the reader with the main tools that will be used in the following sections. Although both formalisms are well known in the literature, these brief reviews can emphasize precisely that there is a connection between both ideas and that it was established recently [12–14].

The study of entropy has been an interesting task through recent years thanks to the fact that it can be understood as a measure of information loss concerning the microscopic degrees of freedom of a physical system, when describing it in terms of macroscopic variables. Appearing in different scenarios, we can conclude that entropy can be considered as a consequence of the gravitational framework [15,16].