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ORIGINAL ARTICLE

The Pioneer anomaly and the holographic scenario

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Abstract In this paper we discuss the recently obtained relation between the Verlinde's holographic model and the first phenomenological Modified Newtonian dynamics. This gives also a promising possible explanation to the Pioneer anomaly.

Keywords Modified Newtonian dynamics · Cosmology · Pioneer anomaly

1 The phenomenological version of MOND

The Modified Newtonian dynamics theory (MOND) was introduced by Milgrom to solve the galaxies rotation curves problem as an alternative to the dark matter. The MOND can be implemented by a modification of the Newton's second law or the Newton's law of gravity.

In particular Milgrom (in the formulation where the Newton's second law is modified) allowed for an inertia term not to be proportional to the acceleration of the object but rather to be a more general function of it. More precisely, it has the form

$$m_i \; \mu(a/a_0)\, \mathbf{a} = \mathbf{F},$$

where $\mu(x \gg 1) \approx 1$, and $\mu(x \ll 1) \approx x$ and $a = |\mathbf{a}|$, replacing the classical form $m_i \; \mathbf{a} = \mathbf{F}$. Here m_i is also the inertial mass of a body moving in an arbitrary static force field $\mathbf{F}$ with acceleration $\mathbf{a}$, see Milgrom (1983). For accelerations much larger than the acceleration constant a_0, we have $\mu \approx 1$, and Newtonian dynamics is restored. However for small accelerations $a \ll a_0$ we have that $\mu = a/a_0$. In this case if $\mathbf{F}$ is the gravitational force of a central mass M, then the modulus of the acceleration is $a = \sqrt{a_0 GM}/r$. This acceleration gives a constant velocity $v = \sqrt[4]{GMa_0}$ in a circular orbit and the correct value of the galactic rotational curves. However, it has been shown that Milgrom theory, while solving a few difficulties, gives rises to other fresh problems, see for instance Felten (1984); Sanders (2006). The fundamental objection to a modification of the inertia is that it violates the equivalence principle, tested to an accuracy of 10^{-13} kg, see Baeßler et al. (1998), and the energy conservation. The version of MOND presented is not a consistent theory and it is only a phenomenological approach. To solve these problems Bekenstein and Milgrom (1984) proposed a nonrelativistic potential theory for gravity which differs from the Newtonian one. In Famaey and Binney (2005) simple analytical forms of $\mu(x)$ are analyzed and satisfactory fits to the observationally determined terminal velocity curve are obtained. A theoretical argument that supports a certain form of $\mu(x)$ against other is still not known. In Giné (2009) we made a first approximation to the problem and deduced the following form of $\mu(x)$, in the context of the Mach's principle

$$m_i \left(\frac{a}{a + a_0} \right) \mathbf{a} \; = \mathbf{F}. \tag{1}$$

This simple form of $\mu(x)$ yields very good results in fitting the terminal velocity curve of Milky Way and others, see Famaey and Binney (2005). Moreover, in Giné (2010) a new form for the $\mu(x)$ appearing in the Milgrom formula was obtained:

$$m_i \left(\frac{|\mathbf{a}|}{|\mathbf{a} + \mathbf{a_e}|} \right) \mathbf{a} \; = \mathbf{F}, \tag{2}$$

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