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INTERGALACTIC TRAVEL WITH MOND ROCKETS

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ABSTRACT

An attractive interpretation of MOdified Newtonian Dynamics (MOND) as an alternative to dark matter, changes the inertia of matter at accelerations $a \lesssim a_0 \approx 1.2 \times 10^{-8}$ cm s^{-2}. I show that if inertia is modified at low accelerations, this suppresses the exponential factor for the required fuel mass in low acceleration journeys. Rockets operating at $a \ll a_0$ might allow intergalactic travel with a modest fuel-to-payload mass ratio.

1. INTRODUCTION

MOdified Newtonian Dynamics (MOND) was proposed by Milgrom four decades ago (Milgrom 1983) to explain the flat rotation curves of galaxies and the baryonic Tully-Fisher relation (Milgrom 2020; McGaugh 2012; McGaugh et al. 2021). An attractive interpretation of MOND is that at accelerations of magnitude, $a \ll a_0 = 1.2 \times 10^{-8}\ \mathrm{cm}^{-2}$, the inertia of an object of mass m satisfies a modified equation of motion in response to a force F (Milgrom 2011, 2015),

$$m\frac{a^2}{a_0} = F. \tag{1}$$

Below I consider the implications of modified inertia for a rocket whose fuel burns so as to produce a steady low-acceleration, $a \ll a_0$.

The force (momentum delivered per unit time) acting on a rocket, is given by the mass ablation rate, $\dot{m}$, times the exhaust speed of the ablated gas relative to the rocket, $v_{\rm exh}$,

$$F = -\dot{m}v_{\rm exh}. \tag{2}$$

For a constant acceleration, the solution to equations (1) and (2) is,

$$\left(\frac{m_{\rm initial}}{m_{\rm final}}\right) = \exp\left\{\left(\frac{a}{a_0}\right)\left(\frac{v_{\rm final} - v_{\rm initial}}{v_{\rm exh}}\right)\right\}, \tag{3}$$

where the subscripts 'initial' and 'final' refer to the initial and final values of the rocket mass and speed. This result differs from the standard Tsiolkovsky solution to the rocket equation (Tsiolkovsky 2000) by the suppression factor (a/a_0) in the exponent. Whereas the amount of fuel that needs to be carried grows exponentially with terminal speed in the standard Tsiolkovsky solution, a modified inertia offers the prospects of reaching high speeds by carrying much less fuel. This allows for intergalactic travel at a modest fuel-to-payload mass ratio.

2. NUMERICAL EXAMPLE

As a concrete example, consider an intergalactic journey at a final speed of $v_{\rm final} \sim 300\ \mathrm{km\ s^{-1}}$, an order of magnitude faster than the rockets launched so far by humans. For standard chemical fuel, this terminal speed exceeds the exhaust speed by a factor $(v_{\rm final}/v_{\rm exh}) \sim 10^2$ (Gilster 2004). Thus, in order to achieve this terminal speed through an average acceleration magnitude $(a/a_0) \sim 0.01$ in free space, the required fuel mass would be comparable to the payload mass, $(m_{\rm initial} - m_{\rm final}) \sim 1.7m_{\rm final}$. At this acceleration, the above terminal speed is obtained over a timescale, $t \sim 8$Gyr, comparable to the remaining lifetime of the Sun. During this time, the rocket would be able to traverse a distance $\frac{1}{2}at^2 \sim 1.2$ Mpc, all the way to the edge of the Local Group of galaxies. Of course, additional fuel would be needed to overcome the binding energy of the Earth, the Sun and the Milky-Way galaxy.

3. IMPLICATIONS

The validity of the modified rocket equation can be tested by launching our own low-acceleration rocket or by finding low-acceleration rockets which arrived to our vicinity from great distances. It is unclear which approach is more likely to bear fruit as the first direct test of the modified inertia interpretation of MOND.

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