Influence of a Photonic Drag Effect on the Solar Galactic Orbit

This was a theoretical senior-level undergraduate physics research project I participated in from the fall semester of 2018 to the spring semester of 2019 with Dr. Kevin Haglin.

The goal of the project was to derive and construct a mathematical model that would incorporate a drag-like effect on the orbit of the Sun as it traversed the galactic disk and determine if this could serve as a replacement to other models that incorporate dark matter. More specifically, we wanted to explore the following question:

If this drag effect is applied to the solar galactic orbit, and if the force of gravity acting on the Sun is only due to visible (baryonic) matter only, will the galactic orbital radius of the Sun remain constant?

Simplifying conditions that we used to answer this question were the following:

- Assume the Sun's galactic orbit is circular, rather than elliptical
- Assume that the Sun never deviates from the plane of the galactic disk
- Consider a time-frame of only a single orbital revolution of the galaxy ($\approx$ 230 million years)

For the drag effect, the following force was to be applied to the Sun in the direction of the its orbital motion:

$$\vec{F}_{drag} = \frac{Pv}{c^2}\hat{e}_\theta$$

Where P is the power of the Sun, v is the Sun's orbital velocity, c is the speed of light, and $\hat{e}_\theta$ is the azimuthal basis vector in a spherical coordinate system following the standard mathematics convention.

Upon adding the drag term to Newton's 2nd Law applied to the Sun and simplifying the spherical coordinates using $\phi = \pi/2$ and $\dot{\phi} = 0$, the general form was the following:

$$(-\vec{F}_{gravity})\hat{e}_r - (\vec{F}_{drag})\hat{e}_\theta = m\vec{a} + \dot{m}\vec{v}$$

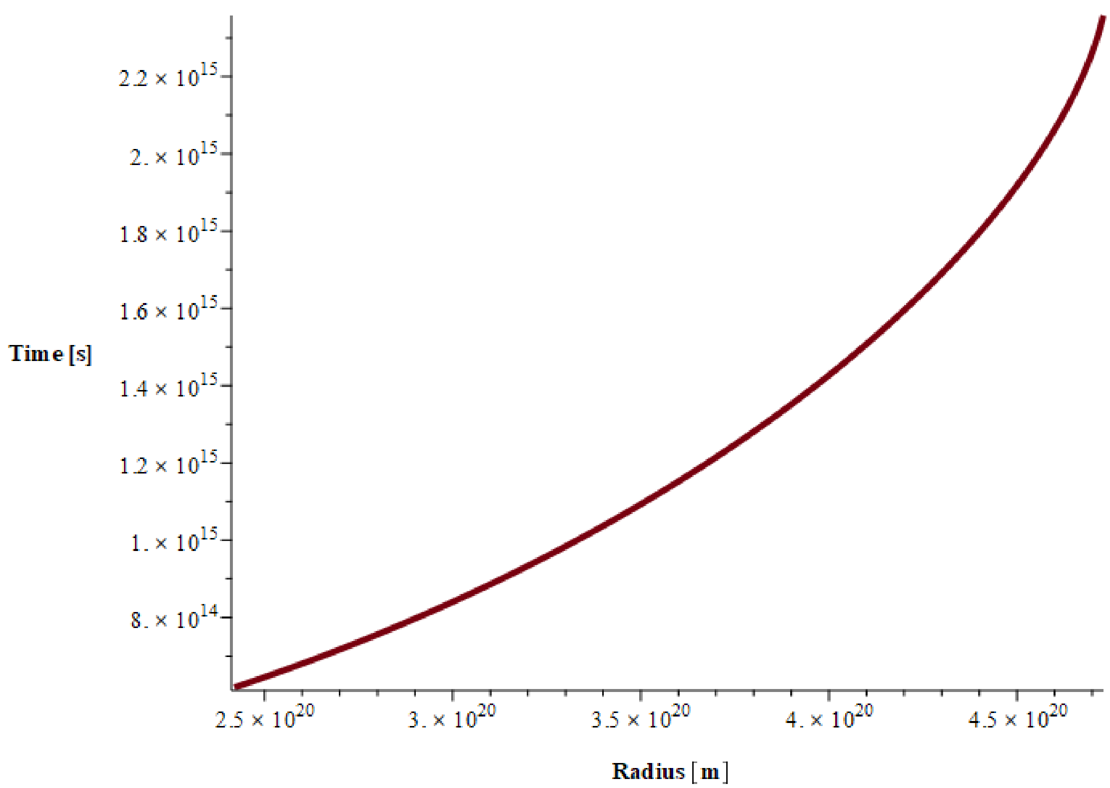
Given that the Sun loses a negligible amount of mass over the period of a galactic revolution, $\dot{m}$ was assumed to be zero. Thus, the full form of Newton's 2nd Law was:

$$\Big(-\frac{GMm}{r^2}\Big)\hat{e}_r - \Big(\frac{Pv}{c^2}\Big)\hat{e}_\theta = m[(\ddot{r} - r\dot{\theta}^2)\hat{e}_r + (r\ddot{\theta} + 2\dot{r}\dot{\theta})\hat{e}_\theta]$$

Where G is the gravitational constant, M is the mass of the Milky Way assuming no dark matter, m is the mass of the Sun, and r is the solar galactic radius.

The mathematical heavy-lifting was mainly performed in Maple 2017 due to the extensive and complicated nature of the expressions involved. From Newton's 2nd Law, we derived an expression for time as a function of orbital radius.

The expectation was that, if the orbital radius of the Sun remains constant, then a vertical line should appear on a plot of t vs. r at $r = 0$. Otherwise, it was thought that the drag effect would slow the Sun's orbital velocity, causing it to spiral into the galactic core. What we found was a different outcome entirely:



This plot reveals that the orbital speed of the Sun *increases* under the influence of this drag effect, causing the orbital radius to continually increase. Within a period of $2.4 \cdot 10^{15}$ seconds ($\approx$ 76 million years) the Sun is gradually pushed to the edge of the galaxy.

Obviously, this conclusion does not conform with well-established astronomical observations. An azimuthal drag force (under the following conditions and assumptions) is clearly not a suitable substitute.