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P1_3 Out-Run the Sun

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Abstract

In this paper, we calculate the time taken in order for the Earth's kinetic energy to reach that of the gravitational potential energy between the Earth and the Sun, and so 'escape' the system, if the Earth was using lights placed equally on its surface and use radiation pressure for propulsion. The lights will provide an energy flux in the direction of the Sun of the same magnitude of that of the current average solar flux. The time required was found to be $4.28 * 10^{10} s$.

Introduction

It has long been known that energy is carried by traveling photons, and that these photons can impart a force on an object when they are absorbed and re-emitted, due to the conservation of momentum and radiation pressure. This would mean that the electromagnetic radiation (EM) emitted by the Sun would impart a force on the Earth by the same mechanism, and any light emitted would push the emitting medium backwards similar to that seen in the recoil of a gun. So what if we wanted to use momentum of photons to escape the Sun's gravitational orbit? One option to achieve this which will be explored in this paper is using lights mounted on the Earth, along with the radiation pressure provided by the Sun. To do this the assumptions were made that the Earth could be approximated as a blackbody, the Sun is immovable (due to large mass difference of the Sun and Earth), the lights are 100% efficient and constructed from on Earth materials, the Earth is kept at a constant temperature, the space environment is a perfect vacuum with no other bodies present and that all relativistic effects will be negligible. The assumption was also made that the lights could be powered by some unknown method throughout the Earth's trip escaping the Sun's gravitational field.

Method and Results

In order to escape the Sun's gravitational orbit, the gravitational potential of the Earth in the gravitational field of the Sun would have to be zero, which involves the input of energy into the Earth's orbit. The energy value needed to do this is given my following equation:

$$-U = \frac{GM_S M_E}{r_{orbit}} \quad (1)$$

Where U is the gravitational potential energy between the Earth and the Sun, G is the gravitational constant, M_S is the mass of the Sun, M_E is the mass of the Earth and r_{orbit} is the current average radius of the Earth's orbit around the Sun. In this scenario, some of the energy required will be provided from lights mounted on the Earth. The lights will cover the entire surface of the Earth and will only be lit on the Sun facing side. The power distribution of the lights will be such that the EM flux caused by the lights in the direction of the Sun, will be that of the Sun's current solar flux on the Earth in the Earth's current average orbit.The components of the force produced by the lights in the directions perpendicular to the vector between the Earth and the Sun can be ignored due to the spherical symmetry of the Earth and opposite perpendicular vectors canceling each-other out. The other contributor to the addition of energy into the Earth's orbit, will be the solar flux density incident on the Earth (F_0). This currently is at a value of approximately $1373Wm^{-2}$ [1], but will change as the Earth travels away from the Sun with the inverse square of the distance between the two bodies. The Equation for the solar energy density (L_*) a particular solar radius (r), in Wm^{-2} is:

$$L = \frac{L_*}{4\pi r^2} \quad (2)$$

Where L_* is the total solar luminosity of the Sun in W, and r is the separation distance between the orbiting body and the Sun. In order to find the total energy imparted on the Earth over its whole journey, the cross-sectional area of the Earth multiplied by the integration of equation (2) is needed, with respect to the variable r, multiplied by the time taken to complete the journey, t, between the limits of r_{orbit} and r_{final}. This gives the provided energy (in J) by the Sun's luminance as:

$$E = \frac{tL_*A_E}{4\pi} * (\frac{1}{r_{orbit}} - \frac{1}{r_{final}}) \quad (3)$$

Where A_E is the cross sectional area of the Earth. Therefore the energy needed to escape the gravitational well of the Sun will be:

$$U = A_E F_0 t + E \quad (4)$$

With F_0 being the solar flux density being currently incident on the Earth. Re-arranging equation (4) for t and substituting equations (1) and (3) for U and E respectively then gives:

$$t = \frac{\frac{GM_S M_E}{r_{orbit} A_E}}{\frac{L_*}{4\pi} * (\frac{1}{r_{orbit}} - \frac{1}{r_{final}}) + F_0} \quad (5)$$

with r_{earth} being the average radius of the Earth. Inputting into (5) the known values from literature and replacing r_{final} by using the equations of motion ($1au + 1.68 * 10^{-5}t$ metres)will then give the time taken to complete the journey. L_* is $3.85{*}10^{26}W$[3], the average radius of the Earth is $6371km$[2], r_{orbit} is $1.5{*}10^{11}m$ ($1Au$), the mass of the Sun is $1.99 * 10^{30}kg$ and the mass of the Earth is $5.97 * 10^{24}kg$. This gives a time value of $4.28 * 10^{10}s$ for the Earth to be able to escape the gravitational field of the Sun.

Conclusion

In conclusion, it was found that the timescale in order for the lights to de-orbit the Earth was $4.28 * 10^{10}s$. Its application to reality is limited however due to approximating earth as a black-body whereas in reality the Earth has an albedo of about 0.3. Furthermore, the temperature on Earth isn't constant when incident with EM radiation, and the heating caused by EM radiation is spread and re-released over the surface of the Earth, not just in the direction it came from, effecting the result. To get a more accurate time value, a more complex and accurate model would need to be considered taking into account reflection of light, light scattering and the thermal properties of the Earth.

References

[1] `https://www.sciencedirect.com/topics/earth-and-planetary-sciences/solar-flux` [Accessed 23/10/2020]

[2] `https://nssdc.gsfc.nasa.gov/planetary/factsheet/earthfact.html` [Accessed 24/10/2020]

[3] `https://link.springer.com/referenceworkentry/10.1007%2F1-4020-4520-4_374` [Accessed 24/10/2020]