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P1_4 Solar Radiation: the radiative force on orbiting bodies

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Abstract

Stars, such as the Sun, radiate power in the form of photons and create an effect in the bodies around it. We have calculated the effect of the power radiated on those bodies, such as the Parker Probe and a dust particle, by calculating the ratio between the gravitational and the radiation acceleration in each case; 5.62×10^{-6} for the probe and 8.40×10^{-6} for the dust particle. These small numbers show that the Radiation Pressure does not have a significant effect on the orbits or the acceleration of those particular bodies. Therefore, we also studied the size that these object should have to experience a strong enough Solar Radiation to be expelled from the Sun's orbit.

Introduction

The Sun radiates large amounts of energy in the form of photons, those photons have a momentum associated with them and therefore they apply a force on the radiative the bodies.
The Parker Probe is an active mission to the Sun, which aims to explore the solar activity by orbiting 88 times at the closest distance of 6 million kilometres from the Sun[1]. At such small distances, the heat and the radiation incoming from the Sun will be very high and might affect the trajectory of the mission. In this paper, we will investigate how the radiation from the Sun affects orbits of the bodies around it.

Theory

The bodies orbiting around the Sun are subject to the force of gravity, which pulls them towards the centre of the Solar system and creates a positive acceleration on the bodies, centripetal acceleration,

$$a_{cen} = GM/r^2. \tag{1}$$

Where G is the gravitational constant 6.67×10^{-11} kgm^3s^{-2}, M is the mass of the Sun 1.99×10^{30} kg and r is the bodies' distance from the Sun.

Also, the radiation pressure applies a force to the bodies in the opposite direction of the gravitational force and as a consequence, this radiation force counteracts the gravitational acceleration, the radiation acceleration,

$$a_{rad} = (L_oAQ)/(4\pi mr^2c).[2] \tag{2}$$

Where L_o is the luminosity of the Sun, which we assume to be constant, $L_o = 3.83 \times 10^{26}$ W [3], A is the cross-sectional area of the object, c is the speed of light, m is the mass of the object and Q is the ratio of the light absorbed by the body, which is 5.00×10^{-2} for the dust particle and9.80×10^{-1} for the Parker Probe[1]. We have also assumed that we are in a closed system, the Sun's radiates equally in all directions, neglecting variations in the incident radiation due to different angles.
Taking the ratio between (a_{rad}) and (a_{cen}) gives a relationship that is not r dependant;

$$B = (L_or_p^2Q)/(4cGMm), \tag{3}$$

where r_p is the radius of the body in question.

If $B > 1$, the radiative acceleration will be bigger than the gravitational acceleration, therefore the object will be expelled from the orbit. If

$B < 1$ the radiative acceleration will counteract the gravitational acceleration slowing down the acceleration of the object around the Sun.

Calculations and Discussion

To calculate the effect of the radiation power of the Sun on the Parker Probe and on a dust particle, we calculated the ratio (B) for each body; also the minimum size that those objects should have to be expelled from the Sun's orbit. To calculate a value for B, we have used $Equation(3)$, the mass is 5.55×10^2 kg and the radius of the circular radiation shield of the probe is 1.15 meters [1]. We can then substitute those values into the equation and calculate a value for B, 5.62×10^{-6}. As the ratio B is very small, we know that the radiation force acting on a satellite is very small compared with the gravitational force. Therefore, the radiation would not affect the trajectory of the probe around the Sun, being able to complete the 88 flybys without the danger of being altered.

However, radiation has larger effects in small dust particles, due to their small mass and smaller radius. Those particles going at very high speeds can seriously affect the satellites and probes orbiting the solar system, so it is essential to study them.
An average dust particle has a mass of 5.73×10^{-10} kg, and an average radius of 2.00×10^{-6} m[4]. To calculate the ratio B for those particles we need to use $Equation(3)$ and substitute the values for the radius and mass for a dust particle. Which gives a value for B of 8.40×10^{-6}. This value for the ratio B is very small, which shows that solar radiation does not affect the trajectory of dust particles.

However, we are going to calculate the minimum radius of the probes shield and the radius of the dust particle required to be expelled from the Sun's orbit, assuming the mass is constant. By rearranging $Equation(3)$ in terms of its radius, we can obtain an equation;

$$r_p = \sqrt{\frac{4cm_pGM}{L_oQ}}, \tag{4}$$

to calculate how big the radius of those bodies needs to be to make the ratio $(B) = 1$ and therefore, be expelled from the orbit.Where m_p is the mass of the dust particle.
This gives a value of 6.90×10^{-4} m for the radius of the particle, and 4.85×10^4 m for the Parker Probe, any of those bodies with higher radius than the one calculated will be expelled from the Sun's orbit.

Conclusion

The Sun's radiative power and its effect on a space probe and on a dust particle is not as powerful as we thought it would be at the beginning of the study. We found that the ratios between the two accelerations to be 5.62×10^{-6} for the probe and 8.40×10^{-6} for the dust particle. This is due to the fact the Sun's mass is large and consequently, the gravitational force pulling the bodies together is proportional to its mass, making the radiative acceleration negligible.

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References

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