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P5_12 Putting the JWST in jeopardy

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Abstract

We investigate why the JWST was put at L2, the Lagrange point behind the Earth, instead of L1, the Lagrange point between the Earth and the Sun. We calculate the effects of the Sun's photons on the telescope if it had been put at L1. We find that the photons would exert a force on the telescope of 5.2×10^{-3} N. We also determine that within 1.9 years the telescope would have crashed back down to Earth.

Introduction

Earlier this year (2022) the state of the art James Webb Space Telescope (JWST) was launched. It assumed a heliocentric orbit at the Lagrange point L2 [1]. A Lagrange point is one of dynamic equilibrium for a small mass under the gravitational influence of two massive bodies. In this position, orbiting L2, the JWST will orbit around the Sun with shielding provided by its position behind the Earth. What would happen if the JWST was orbiting the L1 point between the Sun and the Earth instead? Would the force exerted on the telescope by the Sun's photons push it out of its otherwise stable position?

Force Exerted by Photons

Equation 1 represents the force exerted by the photons given by integrating the Poynting Vector $\vec{S}$ over the surface.

$$F_{Photon} = \frac{2}{c}\int \vec{S}\, d\vec{A}, \tag{1}$$

The photons incident on the surface are reflected off the material. This means that the momentum imparted by the photon is double its initial momentum. This explains the factor of 2 in equation 1. An equation for the Poynting Vector can then be substituted in for $\vec{S}$:

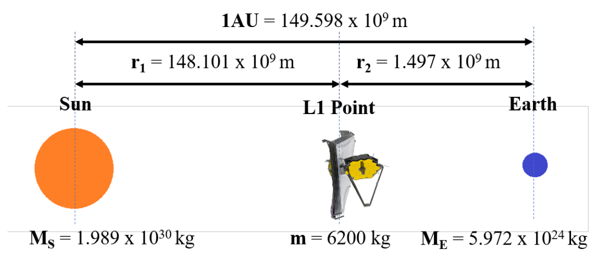

Figure 1: A non-scaled diagram illustrating the relative positions, distances and masses of the JWST, Sun and Earth. We created diagram to help illustrate scenario.

$$F_{Photon} = \frac{2}{c}\int \frac{L(1+a)}{4\pi r_1^2}\hat{r}\, d\vec{A} \tag{2}$$

where a is the reflectivity of the material and L is the luminosity of the Sun. When this is integrated over the surface we find equation 3 where A is the surface area of the spacecraft.

$$F_{Photon} = \frac{2}{c}\frac{L(1+a)}{4\pi r_1^2}A\, cos\theta, \tag{3}$$

Photons from Sun incident on JWST are perpendicular to the sunshield, so $\theta = 90°$. Therefore,

$\cos\theta = 1$ and the equation becomes:

$$F_{Photon} = \frac{2}{c}\frac{L(1+a)}{4\pi r_1^2}A, \qquad (4)$$

The luminosity of the Sun is represented by L and is 3.8×10^{26} W [4]. A represents the surface area of the JWST that would be perpendicular to the direction of force exerted by the photons. This is the sunshield which protects the telescope, which also happen to be the largest area of the telescope. This is 21.197 m by 14.162 m totalling a surface area of 300.19 m^2 [5]. The sunshield of the JWST is made from aluminised kapton which has a high reflectivity of around 0.86 [6]. Using equation 4 and these values we obtained a force of 5.2×10^{-3} N.

Displacement of Orbit

Though this force is very small it would still accelerate the JWST away from its stable orbit around the L1 point and increase r_1. This would lead to an increasingly large imbalance of forces as the JWST moved further from from the Sun and closer to the Earth. The Sun's gravitational force on the telescope would decrease and the Earth's would increase. However, ignoring this effect and only considering the acceleration due to the force exerted by the photons we can calculate how fast the JWST would be pushed.

$$a = \frac{F}{m}, \qquad (5)$$

The JWST has a mass of 6200 kg [7]. The collisions with the Sun's photons would cause the JWST to accelerate away from the L1 point at 8.4×10^{-7} ms^{-2}.

$$t = \sqrt{\frac{2s}{a}}, \qquad (6)$$

Assuming this acceleration away from the L1 point is constant we calculate that it would take 1.9 years for the telescope to reach Earth.

Discussion

This time of 1.9 years does not take into account the changing gravitational forces. In order to account for this numerical methods would need to be used to calculate the changes in forces as the JWST moves closer to Earth. This would mean the telescope would re-enter Earth's atmosphere sooner than calculated. As the telescope moved towards Earth it would also experience less of a force from the Sun's photons due to the inverse square law.

Conclusions

NASA quotes the lifetime of the JWST to be 10 years [7]. We have calculated that without further propulsion the telescope would crash back to Earth within the span of 2 years if it were placed at the L1 point. This is a significant decrease in its lifetime and although not the main reason for the JWST being placed at L2 it would have definitely been a consideration.

References

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