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A2_4 You May Fire When Ready

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Abstract

In this paper we consider the energy requirements of the Death Star to destroy the Earth and offer two other options for planetary destruction to compare energy usage. We estimate that blowing up the planet would take 2.24×10^{32} J and deorbiting the Earth into the sun would take 1.11×10^{36} J. But the most energy efficient method is to bring all water on Earth to boiling point, requiring 1.1×10^{30} J of energy.

Introduction

The Death Star is a superweapon operated by the Empire in the fictional universe of Star Wars [1]. In one scene, we see the weapon being used to completely destroy the planet of Alderaan. In this paper, we estimate the energy required to destroy Earth in such a way. We also considered using the weapon as a decelerant to deorbit the Earth, and using the energy of the weapon to bring the all the oceans to boiling point.

In this paper, we make a number of assumptions to make calculations simpler. We believe this is justified since the objective of this paper is just to provide a comparison of energy requirements.

Gravitational Binding Energy

Our first calculation used Earth's binding energy. This best represents the destruction seen in the movie. The gravitational binding energy of a sphere of constant density is given by (1):

$$|U| = \frac{3GM^2}{5R}, \tag{1}$$

where M and R are the mass and radius of the sphere, respectively [2]. $|U|$ is the energy required to overcome the sphere's own gravity and move all the mass out to infinity. Using earth's appropriate values for mass and radius, we calculated a required energy of 2.24×10^{32} J.

We used the approximation of a constant density sphere, instead of a more realistic model. We also assumed that there is no material binding energy, the only gravity to be overcome. Both of these assumptions would increase the actual total energy required but we recognise our calculation is an estimate and that a planet would be considered destroyed long before the calculated energy is reached.

Deorbit

An alternative method that we considered is deorbiting the Earth into the Sun by using the Death Star's energy as a purely decelerating force. To do this, we used the vis-viva equation, (2):

$$v^2 = GM_\odot \left(\frac{2}{r} - \frac{1}{a}\right), \tag{2}$$

where v is the orbital speed of the earth, r is the orbital radius at a given point, a the semi-major axis of the orbit that can be expressed as

$a = (r_{\min} + r_{\max})/2$, half the sum of periapsis and apoapsis radii of the orbit, respectively. We first calculated v_1 by approximating earth's current orbit as a perfectly spherical orbit. In this case all r values are equal to 1 AU.

Since we are modelling the decelerating force as an impulse, we can calculate the instanenous orbital velocity v_2 the earth requires so that it's periapsis is at the radius of the sun - plunging it straight in.

The difference of v_1 and v_2 is the required instanenous change in velocity, substituting this into the equation for kinetic energy gives us equation (3), allowing us to calculate the required energy:

$$E = \frac{GM_{\odot}M_{\oplus}}{2r_{\max}}\left(\frac{2r_{\min}}{r_{\min} + r_{\max}} - 1\right)^2. \quad (3)$$

With this, we have an equation for the required energy E. With $r_{\min}$ the radius of the Sun and $r_{\max}$ as 1 AU, we calculated the required energy to be 1.11×10^{36} J.

For this calculation we had to assume that all energy emitted from the Death Star arrives anti-parallel to Earth's velocity and that it slows the earth with 100% efficiency. We also assume that there are no heating effects and we don't consider the effect of sudden deceleration.

Boiling Point Oceans

We also estimated the energy required to bring all water of a planet to boiling point. We started with equation (4) that allowed us to calculate the energy required,

$$Q = mc\Delta T, \quad (4)$$

where m is the mass of water on Earth, c the specific heat capacity of seawater (3850 $\mathrm{Jkg^{-1}K^{-1}}$) and ΔT the required changed in temperature.

The mass of water on Earth is about 1.4×10^{24} kg [3]. To calculate an upper limit for the energy required, we assumed the lowest average temperature for life to be around the freezing point of water, so that $\Delta T = 100$ K. With these values, we calculated Q as 5.39×10^{29} J.

However, we also considered that water only covers 70% of Earth's surface [4] so only 70% of incident energy heats up the ocean water; and that Earth's albedo is ~ 0.3 [5], so 30% of incident energy is immediately reflected. Due to this, we divide our Q value by 0.7^2 to account for this. Our final required energy is 1.1×10^{30} J.

This is a basic estimation with some large assumptions - we assumed that all incoming energy is absorbed and heats all water evenly. We also assume this is on a short-timescale where cooling effects are negligible.

Conclusion

We determined that for Earth, whilst not conventionally destroying it, bringing the oceans to boiling point is least energy intensive method, less than 1% of the first gravitational calculation. The energy cost of deorbiting a planet required a million times more energy than evaporating the oceans and should not be considered as a useful method of planetary destruction.

The calculations made in this paper are all heavily approximated in idealised scenarios, but we believe these values to be useful estimations for comparing magnitudes of energy required.

References

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