

A2_2 Thawing of Europa by a stellar Jupiter

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Abstract

Jupiter's moon Europa could have primitive life existing beneath its surface of ice. The book *2010: Odyssey Two* by Arthur C. Clarke proposes that transforming Jupiter into a star would melt the ice on Europa, providing conditions suitable for advanced life forms. This paper assesses the effects on Europa should Jupiter's mass increase suitably to cause ignition. It is found that igniting Jupiter would cause orbital problems which would need to be managed, if these problems could be solved the radiation output of the new star would be more than sufficient to thaw Europa. Additional changes would need to be made to the moon for conditions to be fully suitable for advanced life, these are also discussed.

Introduction

Europa is an ice covered moon orbiting Jupiter, it is slightly smaller than Earth's moon. There is evidence for a liquid water ocean beneath the moon's frozen surface which could potentially contain life [1].

In the book *2010: Odyssey Two* by Arthur C. Clarke, aliens discover life forms on Europa whose evolution is hindered by the outer layer of ice [2]. To increase the rate of evolution, the aliens thaw the ice on Europa by transforming Jupiter into a star, which is achieved by increasing its mass. Previous work by Barker et al. has assessed the additional mass required to ignite Jupiter, and the luminosity of the resulting star. The paper concludes that a stellar Jupiter would need to be at least 80 times its original mass, M_J , to ignite and the resultant luminosity would be $P_{SJ} = 2.24 \times 10^{24}$ W [3]. This paper uses these figures to study the effect on Europa.

Orbital analysis

An increase of Jupiter's mass to $80M_J$ would drastically alter the orbits of its moons. Europa's orbit is approximately circular and therefore the orbital radius will be approximately constant, so $r_o \approx r_{0a} \approx r_{0p} \approx 6.71 \times 10^5$ km [4] where r_o is the orbital radius and r_{0a} and r_{0p} are the original orbit's apoapsis and periapsis. Assuming that Jupiter instantaneously gains mass, the apoapsis of Europa's new orbit will be the distance between Europa and Jupiter at the time of the increase, which is equal to the original orbit's radius. The new periapsis can be found using the definition

$$r_a + r_p = 2a, \quad (1)$$

where a is the semimajor axis of the elliptical orbit. The value of a can be determined using Newton's *vis viva* equation [5]:

$$v_1^2 = G(M_{SJ} + M_E) \left(\frac{2}{r_o} - \frac{1}{a} \right), \quad (2)$$

where $M_{SJ} = 1.52 \times 10^{29}$ kg [6] and $M_E = 4.80 \times 10^{22}$ kg [4] are the masses of the stellar Jupiter and Europa respectively and $v_1 = 13.7$ km s⁻¹ [4] is the velocity of Europa. The M_E term can be ignored since $M_{SJ} \gg M_E$, hence rearranging for a and substituting into Eq. (1) gives

$$r_p = 2 \left(\frac{2}{r_o} - \frac{v^2}{GM_{SJ}} \right)^{-1} - r_a = 4.19 \times 10^3 \text{ km}. \quad (3)$$

The radius of Jupiter is 6.99×10^4 km [6], so assuming that the stellar Jupiter is of a similar size or larger, Europa will collide with the new star.

Assuming they have the required technology, the aliens would need to accelerate the moon to keep it in the original orbit. For the new orbit, Eq. (2) becomes

$$v_2 = \sqrt{\frac{GM_{SJ}}{r_o}} = 123 \text{ km s}^{-1}. \quad (4)$$

where v_2 is the new velocity of Europa. The energy required to accelerate Europa is

$$E = \frac{1}{2} M_E (v_2^2 - v_1^2) = 3.59 \times 10^{32} \text{ J}. \quad (5)$$

Given that the Sun's luminosity is 3.85×10^{26} W [7], the energy required is equal to the power output of the sun over 11 days, which is a considerable problem. To save the other moons of Jupiter from destruction, similar amounts of energy would be required for each.

Assuming the aliens have access to the technology to keep Europa in the same orbit, the effect of increased radiation incident on the moon can be analysed.

Thermal analysis

The behaviour of the thermal system on Europa once Jupiter is ignited is complex, as such it is beyond the scope of this paper to determine the rate at which the ice on Europa may melt. However, the approximate

temperature of the moon once the system reaches equilibrium can be determined by evaluating the balance between incoming radiation from the stellar Jupiter and the outgoing blackbody radiation. Radiation incident on Europa from the Sun is ignored as the flux is negligible compared to that from the stellar Jupiter.

The power absorbed by Europa is the radiation flux at the distance of its orbit, $P_{SJ}/4\pi r_o^2$, multiplied by the area of Europa's disk as seen from Jupiter, πr_E^2 , multiplied by the fraction of radiation absorbed, $(1 - \alpha)$, where α is Europa's albedo. This is expressed as

$$P_{in} = \frac{P_{SJ} r_E^2 (1 - \alpha)}{4r_o^2}. \quad (6)$$

The blackbody radiation power for a body at a given temperature is given by the Stefan-Boltzmann law

$$P_{out} = A\varepsilon\sigma T^4, \quad (7)$$

where A and T are the surface area and temperature of the body, ε is the emissivity of the surface and $\sigma = 5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$ is Stefan's constant [8]. For Europa the power output is therefore

$$P_{out} = 4\pi r_E^2 \varepsilon \sigma T^4. \quad (8)$$

After a period of time the moon will reach thermal equilibrium where the power output will be equal to the power input. The equilibrium temperature can then be found by equating Eqs. (8) and (6) and rearranging for T to give

$$T = \left(\frac{P_{SJ}(1 - \alpha)}{16\pi\varepsilon\sigma r_o^2} \right)^{1/4} \quad (9)$$

Due to Europa's surface of ice, it has a high albedo $\alpha = 0.67$ [9]; however, as the ice melts the albedo will change depending on the surface properties. Liquid water has a negligible reflectivity at low angles of incidence [10], therefore assuming the albedo of the moon at thermal equilibrium is between the value for water and Europa's current value, $\alpha = 0 - 0.67$. The emissivity of liquid water and ice are 0.98 and 0.96 respectively, the eventual emissivity of Europa may be lower than this, which would increase the temperature, the emissivity is assumed to be $\varepsilon \approx 1$ to give a lower limit for temperature. Using Eq. (9) gives the range $T = 871 \text{ K to } 1149 \text{ K}$.

Discussion

The purpose of evaluating the equilibrium temperature of Europa is to determine whether an improved environment for life would be created should Jupiter be ignited. At any temperature within the range calculated (which is a lower limit), assuming the atmospheric pressure would not be excessively larger than on Earth, liquid water would be unable to exist on the surface [11], making the conditions non-ideal for advanced life.

The solar radiation incident on Earth is $(1360 \text{ W m}^{-2})\pi(6371 \text{ km})^2 = 1.73 \times 10^{17} \text{ W}$ [8, 12], comparing this to P_E , Europa would have 20 times the incident radiation as Earth. Assuming that Earth has an ideal radiation flux for life, it could be beneficial to move Europa to a larger orbit.

Once Europa is thawed, several problems remain which would make the moon's surface unsuitable for life. Atmospheres are important for life as they provide protection from meteors and radiation, among other reasons. Europa has a very thin atmosphere, so for life to develop in a similar manner to that on Earth an atmosphere would need to be created. Europa also passes through Jupiter's powerful radiation belt, to protect against this a large magnetic field would need to be created, this may not be necessary if Europa were moved to a larger orbit.

To fully evaluate the usefulness of transforming Jupiter into a star, the thermal model would need to be extended significantly; however, that is beyond the scope of this paper.

Igniting Jupiter would clearly be effective in terraforming Europa. The resulting problems such as the change to Europa's orbit would require dealing with, as would the other issues which are not corrected by the increased incident radiation. However, any alien race with the technology to greatly multiply Jupiter's mass should have little difficulty solving these problems.

References

- [1] M. G. Kivelson, Science 289, 1340-1343 (2000).
- [2] A. C. Clarke, *2010: Odyssey Two* (Granada Publishing Ltd, 1982).
- [3] J. Barker, J. Coxon and T. Conlon, *A4-2 A Bright Night*, PST 9, (2010).
- [4] http://solarsystem.nasa.gov/planets/profile.cfm?Object=Jup_Europa (Retrieved 26/10/2011).
- [5] T. Logsdon, *Orbital Mechanics: Theory and Applications* (Wiley-IEEE, 1998), p. 30.
- [6] <http://solarsystem.nasa.gov/planets/profile.cfm?Object=Jupiter> (Retrieved 26/10/2011).
- [7] <http://nssdc.gsfc.nasa.gov/planetary/factsheet/sunfact.html> (Retrieved 27/10/2011).
- [8] P. A. Tipler and G. Mosca, *Physics for Scientists and Engineers*, 6th ed. (W.H. Freeman and Company, New York, 2008), p. AP-3; p. 683.
- [9] http://ssd.jpl.nasa.gov/?sat_phys_par (Retrieved 15/11/2011).
- [10] <http://scubageek.com/articles/wwwatw.html> (Retrieved 27/10/2011).
- [11] <http://www.lsbu.ac.uk/water/phase.html> (Retrieved 23/11/2011).
- [12] <http://eesc.columbia.edu/courses/eesc/climate/lectures/radiation/> (Retrieved 28/10/2011).