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P5_6 Defrosting Mars with "a Few" Mirrors

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Abstract

The minimum power that can be redirected to the Martian surface by a '3M VM2000' concave reflector, with a diameter of 8 km, is of the order 10^{10} W, from which 1000 satellites in orbit would be able to melt, at least, the 5 million km^3 of known surface polar ice sheets, in under 10^5 years, but the manufacturing of such reflectors were found to be financially infeasible.

Background

A different strategy on orbital mirror heating from Grant el al. 2011 is investigated [1].

The Martian surface pressure is only 0.655 kPa [2], which means that the boiling point of water is lower than its melting point, where ice transitions directly to vapour at higher temperatures, as liquid water can only exist at pressures of around 1 kPa. In the realm of Martian terraforming, we can assume that there are already systems in place on Mars that are increasing the global pressure to at least 10 kPa, where the boiling point $\gg$ the melting point of water.

Melting the Ice Sheets

Higher latitudes around Mars contain at least 5×10^{15} m^3 of ice, V_i [3] and polar surface temperatures during winters can reach a minimum of -150 °C [4].

$$E = mc\Delta T + mL_f = \rho_i V_i (c\Delta T + L_f) \qquad (1)$$

Eq.(1) finds the minimum energy required to melt the ice, $E = 2.97 \times 10^{24}$ J, where the density of ice, $\rho_i = 917$ kg m^{-3}, the latent heat of fusion for water, $L_f = 334$ kJ kg^{-1}, and the specific heat capacity of ice, $c = 2.093$ kJ kg^{-1} K^{-1}.

Redirecting Solar Radiation

Consider a satellite in a sun-synchronous polar orbit with a giant circular concave reflector (primary) facing towards the sun, with its foci, F, at a significantly smaller secondary reflector, directed towards the target surface, connected by a rod of insignificant relative mass, as drawn in Figure 1. The reflector will be made of 3M VM2000 radiant mirror film with a reflectivity, $R_r = 0.98$ [5].

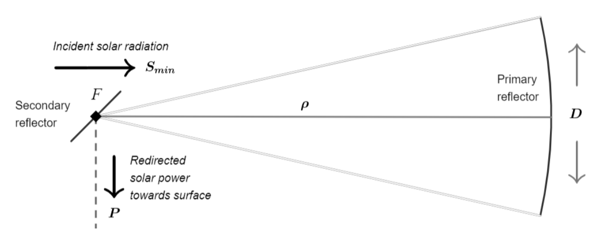

Figure 1: Reflector focusing solar irradiance towards surface

$$D = 2\rho \sin\left(\frac{\theta}{2}\right) = 2\rho \sin\left(\frac{90l}{\pi\rho}\right) \qquad (2)$$

Eq.(2) shows the chord length as the diameter of the primary reflector, D, with a radius of curvature, ρ and an arc length, l, where $\pi\rho \geq l$. We can see that the diameter is maximised at

$\pi\rho = l$, so when $\rho = 4.00$ km and $l = 12.57$ km, D = 8.00 km. Given the relatively large heliocentric distance, if the area covered by the secondary reflector across sunward direction is $\frac{1}{100}^{\text{th}}$ of the primary, the surface area covering the solar irradiance, minus the eclipsing area of the secondary reflector is $0.99\frac{\pi D^2}{4}$.

$$S = \frac{L_\odot}{4\pi a^2} \tag{3}$$

Eq.(3) finds the solar constant at a planet, but as Mars has an aphelion and perihelion of 206 and 249 million km respectively [6], the minimum solar irradiance, at perihelion, is $S_{min} = 492$ Wm^{-2}, where the solar luminosity, $L_\odot = 3.83 \times 10^{26}$ W, and the heliocentric distance, $a = 2.49 \times 10^{11}$ m.

$$P = 0.99R_r^n(1 - R_t)(1 - A)S_{min}\frac{\pi D^2}{4} \tag{4}$$

Eq.(4) gives the solar power redirected towards the surface of Mars, where the bond albedo, $A = 0.16$ [7], the reflectivity of the target surface (ice), $R_t = 0.5$ [8] and the number of on-board reflectors, $n = 2$, producing a redirected power, $P = 9.88 \times 10^9$ W.

$$t = 9\frac{E}{NP} \tag{5}$$

Eq.(5) provides the maximum time taken to melt the ice sheets, where N is the number of orbiting satellite reflectors. The factor '9' comes in as polar regions are only accessible to the reflector at co-latitudes $\leq 10°$, so only $\frac{1}{9}$th of the power is incident at the poles. If 1000 satellites were used, 2.71×10^{12} s $\approx$ 85,800 Earth years would be needed to theoretically melt all of the known surface ice on Mars.

On the scale of planetary lifetimes, this change is quite rapid in comparison to the billions of years it took for Venus to lose its oceans [9]. When using the average heliocentric distance, $a = 229 \times 10^{11}$ m, and average night surface temperatures of -70 °C [10], the redirected power increases by a factor of 1.18 and so the time to melt decreases by $\sim$10,000 years to 72,600 years.

Conclusion

A maximum time scale of $\sim 10^5$ Earth years, using 1000 orbiting reflectors, to produce only 0.3% of the ocean water on Earth seems quite mundane, but could provide enough atmospheric heating and the release of frozen CO2 to begin the terraformation of Mars. The redirected power, P changes over the course of the seasons, so the variation, about the average, is given by $\pm$18%. The value of the mirror film plus UV coating is US$ 1.55 per square foot [5], so a reflector of diameter l would cost about US$ 2.1 billion, where 1000 reflectors would push this above the trillion mark. So unless huge breakthroughs are made in reflective material construction, the inability to fund and manufacture just the reflective film makes this project highly infeasible.

References

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