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# Large Scale Use of Solar Power May be Visible Across Interstellar Distances

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Solar power, if used on a large scale, it has two characteristics that may make it visible across interstellar distances. First, by design it intercepts a large amount of the sun's radiation. Second, the orientations of the panels, chosen to achieve maximum power, will also concentrate the reflection of the sun into a relatively small subtended angle. Combined, these effects make the reflections visible across large distances for those observers aligned with the reflection. For example, if the Earth's current electrical capacity was supplied by solar power, and flat plate tracking collectors were used, then the reflections from the panels are brighter than the reflection from the rest of the planet, more than doubling its brightness when viewed from angle within a few degrees of the sun. The effect will be strongest at or near the secondary eclipse of transiting planets, so many suitable systems are already under study. It may also be visible near superior conjunctions in systems which do not transit. Estimates show that under favorable conditions, proposed exoplanet characterization missions (such as Darwin and Terrestial Planet Finder) could see evidence of solar power developments similar to those proposed for Earth.

## INTRODUCTION

Energy from the sun provides a very large and renewable source of energy.[1] Great efforts are being made to make this technology cheaper and more efficient.[2] These structures may cover a substantial fraction of a planet's surface, and hence intercept a large amount of solar radiation. To maximize output for a a given cost, the arrays are oriented roughly normal to the incoming solar radiation. Since the sun subtends a small angle as seen from a planet, the position, and hence reflections, of all these solar panels are highly correlated. This is shown in Fig 1. This results in very bright reflections, though obviously only in some directions, as total energy is conserved.

The world's total energy usage is about 15 TW. Suppose a civilization generates this power by photovoltaic panels. Assuming a 10% efficiency for collection, storage, and transmission, this means that about 150TW would need to fall on the solar collectors. This is entirely feasible since about 172 PW falls on the Earth's surface, so it would require covering roughly 0.1%, or one part in 1000, of the Earth's surface.[1] Raising the entire world population to US standards requires about an order of magnitude more area, still quite practical. (Compare to farming, which uses about 15% of the Earth's surface.)

A very simple estimate of the brightness of the reflection uses only the fraction of the celestial sphere into which the reflection is concentrated. The inverse of this will be the approximate gain. Much more sophisticated models are of course posssible, but probably not worthwhile given the uncertainty of the other assumptions.

As an example, if we assume all panels have orientations within 0.05 radians of each other, then the reflection is concentrated into $0.0025\pi$ steradians of the $4\pi$ steradians available. This results in a gain of more than 1600 in brightness, compared with an equal area of non-directional reflector such as a textured surface. When

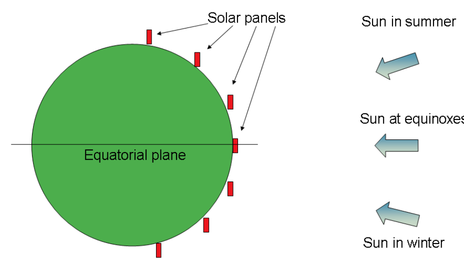


FIG. 1: Why solar panel orientations are correlated. For maximum power production, each user tries to set their panel normal to the incident radiation. Since the incoming rays are almost parallel, this results in all reflections lining up.

combined with a solar cell area of 1/1000 of the planet, the reflection from the solar cells might be as bright as the planet itself, if the observer is within the reflection.

The albedo of solar cells must be low in the visible region (the cell absorbs this to generate power) but is very high in the infrared for current Earth technology - see Fig 2. This is because infrared light goes right through the cell, since it has less energy/photon than the bandgap. It then reflects off the substrate and goes back through the cell.[4][3]

On a rotating planet with a tilted axis, the sun moves across the sky each day, and changes in elevation with the seasons. Photovoltaic systems are most efficient when facing normal to the incident sunlight. The decision of what tracking, if any, to employ is a compromise between simplicity and performance, and many solutions are possible.

Can this be observed? Since the power of the reflection

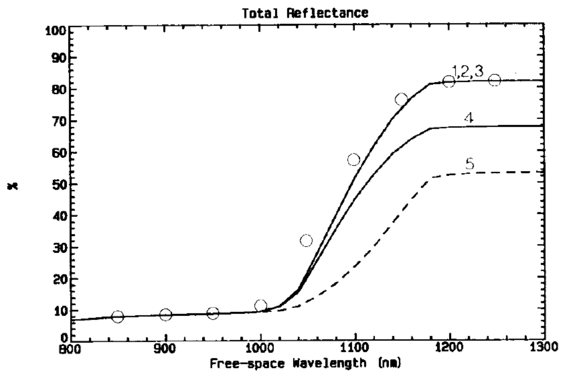


FIG. 2: Solar cell reflectance as a function of wavelength, from [3]. Case 1 represents a real solar cell, with the circles as experimental data. The other cases are predictions for possible variants.

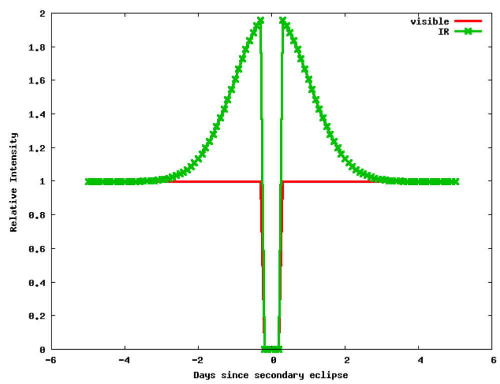


FIG. 3: Example of how a secondary eclipse of an Earthlike planet might look like in two wavelengths, assuming two-axis tracking panels covering 0.1% of the surface.

is conserved, if the reflection in one direction is increased by a given factor, the area of the sky covered by the reflection must be decreased by at least the same amount. Since the gain for an Earth-like planet would be about 1000, only 1 in 1000 planets will have the reflection aimed our way at a given time. However, since the reflection is always aimed at the sun, as the planet orbits its star the reflection sweeps out a band around the plane of the planet's orbit. Using the 0.1 radian figure above, this covers about 5% of the sky at some point.

Exoplanet characterization missions, such as *Darwin* and *Terrestial Planet Finder*, will examine the reflections and emissions of extra-solar planets. Furthermore, some of these systems where we would expect strong reflections have already been selected for intensive study since at least one planet in the system transits its sun. In particular, exoplanets can be characterized by looking at the loss of light during the secondary eclipse where the planet goes behind its star.[5][6] This is exactly where the specular reflections would be most visible. Since solar cells absorb in the visible but not the infrared, a possible diagnostic is to observe this ratio. (Here visible should be thought of as the peak emission wavelengths of the parent star; presumably extraterrestial engineers would tune their solar cells to their peak wavelengths as we do.)

For an earth type planet moving in its orbit about 1 degree per day, a 0.05 radian accuracy means the intensity will start to rise about 3 days before the transit. With plausible values (0.1% coverage, gain of 1000) the brightness will roughly double. Then, both the planet and the solar reflection will drop to zero as the planet goes behind its star. Both of these would be superimposed on the roughly sinusoidal variation expected from the reflected light of the planet.[7] Since the details are unknown, assuming a gaussian distribution of mirror orientations gives the light curve in Fig. 3. The effect should also be measureable in cases of near-transits, where it is manifested as a several day bump in the infrared brightness. Using the previous assumptions of a 0.1 radian cone and an Earth-like 0.5 degree subtended sun, the reflection should be about 14 times more common than the transit.

Perhap the main point is that astronomers should be careful with baseline subtraction - it might throw out some interesting data. And as earth builds more solar panels and better telescopes, over the next few decades we will reach the point where we can potentially detect civilizations that are no more developed than we are.


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