

THE INFRARED DETECTABILITY OF DYSON CIVILIZATIONS

In a very stimulating paper, Dyson (1960) has suggested that technical civilizations considerably in advance of our own may rearrange the matter in their planetary systems into spherical shells, so that the emission of the local suns into all 4π steradians may be gainfully employed. Dyson showed that the mass available for exploitation in a possibly typical planetary system, the luminosities of main-sequence stars of solar spectral type, and the minimum thickness of a habitable biosphere have mutually consistent orders of magnitude. If such solar system re-engineering is a tractable—if, for us, remote—solution to problems of energy acquisition and overpopulation, it may have been attempted by many advanced technical civilizations on planets of other stars.

Whether natural or artificial in origin, a spherical shell a few astronomical units in radius, at a temperature of a few hundred degrees Kelvin, will be a detectable source of

TABLE 1
DETECTABLE RANGE FOR $R = 5.2$ a.u., $\lambda = 8\text{--}13\ \mu$

P_n	10 ⁻¹¹ Watts			10 ⁻¹² Watts			10 ⁻¹⁴ Watts		
D (inches)	20	61	200	20	61	200	20	61	200
r (pc)	10 8	32 9	108	34 2	104	342	342	1040	3420
N (mag.)	— 1 8	0 63	3 2	0 69	3 1	5 7	5 7	8 1	10 7

TABLE 2
DETECTABLE RANGE FOR $R = 1$ a.u., $\lambda = 8\text{--}13\ \mu$

P_n	10 ⁻¹¹ Watts			10 ⁻¹² Watts			10 ⁻¹⁴ Watts		
D (inches)	20	61	200	20	61	200	20	61	200
r (pc)	2 06	6 46	20 6	6 58	20 1	65 8	65 8	201	658
N (mag.)	— 1 8	0 63	3 2	0 69	3 1	5 7	5 7	8 1	10 7

infrared emission, seen through the 8–13- μ window of the Earth’s atmosphere, provided that the shell is close enough to us. It is clearly very difficult to estimate from first principles the number of advanced technical civilizations in the Galaxy, and, therefore, the mean distance to the nearest such civilization. Recent estimates for this distance which at least explicitly state the assumptions invoked are 200–1000 pc (von Hoerner 1961), 50–300 pc (Sagan 1963), ~ 90 pc (Cameron 1963), and 3–300 pc (Pearman 1963). The distance to the nearest 300° K protostar is likely to be less than the distance to the nearest Dyson civilization.

It is possible to determine the range at which detection is feasible of large opaque spherical shells emitting black-body radiation at a temperature $\sim 300^\circ$ K. We are interested in ascertaining whether a Dyson civilization, or an equivalent natural object, can be detected with existing infrared systems at a distance comparable to the foregoing range estimates. The noise equivalent power, P_n , realized with the cooled mercury-doped germanium detector of Westphal, Murray, and Martz (1963) was about 10^{-12} watts; the authors indicate that this may ultimately be improved to 10^{-14} watts. Similar values are achievable with germanium bolometers at liquid helium temperatures (see, e.g., Low and Johnson 1964; Low 1965).

Using the instrumental response of Murray and Wildey (1964), based on the atmospheric transmission data of Sinton and Strong (1960*a, b*) for the 8–13- μ window in the terrestrial atmosphere, we derive the results of Tables 1 and 2, which present, for various values of P_n , of the telescope aperture, D , and of the radius, R , of the Dyson sphere, the maximum detectable range, r , of the Dyson civilization. A signal-to-noise ratio of 9 was considered the minimum criterion for detection, and the optical efficiency of the telescope was assumed to be unity. The magnitude, N , of the object as estimated from the data of Low and Johnson (1964) is also given.

Table 3 presents similar calculations for a highly idealized lead sulfide detector operated at liquid nitrogen temperatures, and for square band-pass filters 1 μ wide, centered at the wavelengths 2.2 and 3.6 μ . R was here assumed to be 5.2 a.u. The magnitudes K and L (see Johnson 1962) are also presented, as estimated from the data of Walker and D'Agati (1964) and of Johnson (1964).

It is easily shown that for, e.g., a source at 300° K, the background at 200° K, an integration time of 1 sec., and an instantaneous field of view of 6'', the detection range is not limited by photon noise.

Inspection of Tables 1–3 demonstrates that, while the 2.2- and 3.6- μ atmospheric windows with PbS detectors are ineffective for this problem, existing detectors in the

TABLE 3
DETECTABLE RANGE FOR $R = 5.2$ a.u., PbS DETECTOR

λ	2.2 μ			3.6 μ		
D (inches)	20	61	200	20	61	200
r (pc)	0 58	1 8	5 8	3 7	11	37
K (mag.)	7 2	9 6	12 2	· 5 ·	· 9 ·	· 15 ·
L (mag.)	·	· ·	· ·	2 5	4 9	7 5

8–13- μ window can detect Dyson civilizations at their estimated distances, with relatively modest apertures. With the largest apertures, there is the prospect of detection at $r > 1000$ pc and, therefore, of encompassing at least several advanced technical civilizations or equivalent natural objects.

Of course, the detection of some infrared source at 8–13 μ in itself carries no implication of intelligent origin. From existing stellar luminosity functions and current views of stellar evolution, there is reason to believe that great numbers of large, faint objects are in the pre-main-sequence contraction phase. Some of these should be at temperatures $\sim 300^\circ$ K and therefore not distinguishable from Dyson civilizations even after an estimate of the slope of the object's emission intensity with wavelength is obtained. Very recently infrared observations have been made of cool objects with temperatures as low as 800° K (Neugebauer, Martz, and Leighton 1965).

After the positions of 300° K infrared sources have been plotted, a search for intelligible monochromatic emission at microwave or other frequencies from these objects could be carried out. Only then could the intelligent origin of these infrared sources be demonstrated. An infrared search for Dyson civilizations serves, then, only to narrow the range of objects to be investigated by other methods. But the number of objects within a radius of 300 pc of the Sun is so great that such a simplification can be very useful.

In summary, the circumstellar shells of Dyson civilizations—at temperatures $\sim 300^\circ$ K and radii ~ 1 a.u.—can be detected with existing telescopes and state-of-the-art infrared detectors in the 8–13- μ window out to distances of several hundred parsecs. But dis-

crimination of Dyson civilizations from naturally occurring low-temperature objects is very difficult, unless Dyson civilizations have some further distinguishing feature, such as monochromatic radio-frequency emission.

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THE PHOTOMETRIC PROPERTIES OF MERCURY

It has been known for some time that the photometric properties of the planet Mercury are very similar to those of the Moon. The geometric albedos, p , in the blue, yellow, red, and near-infrared, and the visual phase integral in the yellow of Mercury and the Moon are compared in Table 1 and are seen to have a striking parallelism. The consequent visual Russell-Bond albedo of Mercury is 0.056, and of the Moon, 0.067. The polarization of sunlight reflected from Mercury has been measured by Lyot (1929). At inferior conjunction the Mercurian polarization-curve agrees within observational error with that of the Moon; near quadrature it is intermediate between curves obtained for waxing and waning phases of the Moon. These detailed agreements in reflectivity as a function of wavelength, in polarization, and in phase dependence are likely to have a common cause.

TABLE 1

COMPARISON OF GEOMETRIC ALBEDOS AND PHASE INTEGRALS
OF MERCURY AND THE MOON (HARRIS 1961)

	$p(B)$	$p(V)$	$p(R)$	$p(I)$	$q(V)$
Mercury ..	0 076	0 100	0 145	0 179	0 563
Moon . .	0 088	0 115	0 16	0 17	0 585