Reports

Search for Artificial Stellar Sources of Infrared Radiation

Abstract. If extraterrestrial intelligent beings exist and have reached a high level of technical development, one by-product of their energy metabolism is likely to be the large-scale conversion of starlight into far-infrared radiation. It is proposed that a search for sources of infrared radiation should accompany the recently initiated search for interstellar radio communications.

Cocconi and Morrison (*1*) have called attention to the importance and feasibility of listening for radio signals transmitted by extraterrestrial intelligent beings. They propose that listening aerials be directed toward nearby stars which might be accompanied by planets carrying such beings. Their proposal is now being implemented (*2*).

The purpose of this report is to point out other possibilities which ought to be considered in planning any serious search for evidence of extraterrestrial intelligent beings. We start from the notion that the time scale for industrial and technical development of these beings is likely to be very short in comparison with the time scale of stellar evolution. It is therefore overwhelmingly probable that any such beings observed by us will have been in existence for millions of years, and will have already reached a technological level surpassing ours by many orders of magnitude. It is then a reasonable working hypothesis that their habitat will have been expanded to the limits set by Malthusian principles.

We have no direct knowledge of the material conditions which these beings would encounter in their search for lebensraum. We therefore consider what would be the likely course of events if these beings had originated in a solar system identical with ours. Taking our own solar system as the model, we shall reach at least a possible picture of what may be expected to happen elsewhere. I do not argue that this is what *will* happen in our system; I only say that this is what *may have* happened in other systems.

The material factors which ultimately limit the expansion of a technically advanced species are the supply of matter and the supply of energy. At present the material resources being exploited by the human species are roughly limited to the biosphere of the earth, a mass of the order of 5×10^{19} grams. Our present energy supply may be generously estimated at 10^{20} ergs per second. The quantities of matter and energy which might conceivably become accessible to us within the solar system are 2×10^{30} grams (the mass of Jupiter) and 4×10^{33} ergs per second (the total energy output of the sun).

The reader may well ask in what sense can anyone speak of the mass of Jupiter or the total radiation from the sun as being accessible to exploitation. The following argument is intended to show that an exploitation of this magnitude is not absurd. First of all, the time required for an expansion of population and industry by a factor of 10^{12} is quite short, say 3000 years if an average growth rate of 1 percent per year is maintained. Second, the energy required to disassemble and rearrange a planet of the size of Jupiter is about 10^{44} ergs, equal to the energy radiated by the sun in 800 years. Third, the mass of Jupiter, if distributed in a spherical shell revolving around the sun at twice the Earth's distance from it, would have a thickness such that the mass is 200 grams per square centimeter of surface area (2 to 3 meters, depending on the density). A shell of this thickness could be made comfortably habitable, and could contain all the machinery required for exploiting the solar radiation falling onto it from the inside.

It is remarkable that the time scale of industrial expansion, the mass of Jupiter, the energy output of the sun, and the thickness of a habitable biosphere all have consistent orders of magnitude. It seems, then, a reasonable expectation that, barring accidents, Malthusian pressures will ultimately drive an intelligent species to adopt some such efficient exploitation of its available resources. One should expect that, within a few thousand years of its entering the stage of industrial development, any intelligent species should be found occupying an artificial biosphere which completely surrounds its parent star.

If the foregoing argument is accepted, then the search for extraterrestrial intelligent beings should not be confined to the neighborhood of visible stars. The most likely habitat for such beings would be a dark object, having a size comparable with the Earth's orbit, and a surface temperature of 200° to 300°K. Such a dark object would be radiating as copiously as the star which is hidden inside it, but the radiation would be in the far infrared, around 10 microns wavelength.

It happens that the earth's atmosphere is transparent to radiation with wavelength in the range from 8 to 12 microns. It is therefore feasible to search for "infrared stars" in this range of wavelengths, using existing telescopes on the earth's surface. Radiation in this range from Mars and Venus has not only been detected but has been spectroscopically analyzed in some detail (*3*).

I propose, then, that a search for point sources of infrared radiation be attempted, either independently or in conjunction with the search for artificial radio emissions. A scan of the entire sky for objects down to the 5th or 6th magnitude would be desirable, but is probably beyond the capability of existing techniques of detection. If an undirected scan is impossible, it would be worthwhile as a preliminary measure to look for anomalously intense radiation in the 10-micron range associated with visible stars. Such radiation might be seen in the neighborhood of a visible star under either of two conditions. A race of intelligent beings might be unable to exploit fully the energy radiated by their star because of an insufficiency of accessible matter, or they might live in an artificial biosphere surrounding one star of a multiple system, in which one or more component stars are unsuitable for exploitation and would still be visible to us. It is impossible to guess the probability that either of these circumstances would arise for a particular race of extraterrestrial intelligent beings. But it is reasonable to begin the search for infrared radiation of artificial origin by looking in the direction of nearby visible stars, and especially in the direction of stars which are known to be binaries with invisible companions.

FREEMAN J. DYSON
Institute for Advanced Study, Princeton, New Jersey

Instructions for preparing reports. Begin the report with an abstract of from 45 to 55 words. The abstract should *not* repeat phrases employed in the title. It should work with the title to give the reader a summary of the results presented in the report proper.

Type manuscripts double-spaced and submit one ribbon copy and one carbon copy.

Limit the report proper to the equivalent of 1200 words. This space includes that occupied by illustrative material as well as by the references and notes.

Limit illustrative material to *one* 2-column figure (that is, a figure whose width equals two columns of text) or to *one* 2-column table or to *two* 1-column illustrations, which may consist of two figures or two tables or one of each.

For further details see "Suggestions to Contributors" [*Science* **125**, 16 (1957)].

References

1. G. Cocconi and P. Morrison, *Nature* **184**, 844 (1959).
2. *Science* **131**, 1303 (29 Apr. 1960).
3. W. M. Sinton and J. Strong, *Astrophys. J.* **131**, 459, 470 (1960).

13 May 1960

Automatic Tonometer with Exact Theory: Various Biological Applications

Abstract. Methods for externally measuring pressure within body cavities exist. In tonometer form they are fast and gentle not requiring anesthetics for the cornea of the human eye. Readings are accurate and independent of tissue tension, corneal stiffness, astigmatic curvatures, and surface tension. There are also separate indications of corneal rigidity and relaxation, and tonographic fluid expression. Other applications include monitoring blood pressure, uterine contractions, and infant intracranial pressure.

The classical methods for measuring the pressure within the human eye have involved a measurement of the force required to flatten a given area or a measurement of the corneal indentation produced by a given weight-loaded rod (*1*). Though ophthalmologists learn to make clinical evaluations from such readings, these procedures are somewhat cumbersome and inaccurate. Inexactness is introduced into the readings by corneal effects such as rigidity and the tension in the tissues tending to resist indentation. The magnitude of this effect seems to be rather variable, and thus an uncertainty is introduced into any reading. On the other hand, the surface tension of the tears tends to pull the probing member toward the eye. In the diagnosis of glaucoma it is desirable to observe intraocular pressure alone: this is made possible by the new tonometer that we have devised and demonstrated, since the aforementioned and other extraneous factors are eliminated (*2*). Besides this increased accuracy, the readings are taken more quickly, more gently, and from any position, without the help of expensive auxiliary equipment such as slit lamps.

In Fig. 1 the principle of one form of our device is illustrated. The end of a small, hand-held probe is pressed against the eye. The tip of the probe carries a pressure-sensitive area approximately 1 mm across. If the eye is momentarily flattened to beyond this sensitive area, then, according to first-order theory, the only pressure that will be recorded is the intraocular pressure of the eye. It will be seen from the figure that a high pressure will press down upon the force transducer, which can be a ferrite core that can move toward or away from a coil, thereby varying the coil's inductance. This variation in the position of the core is detected and amplified, causing a variation in current in a coil whose purpose is to exert a restoring force on a small permanent magnet also coupled to the moving system. Thus an increase in pressure will cause an increase in restoring force which will maintain the pressure-sensitive area rather accurately in the plane of the surrounding plate. The measure of force is the current that is recorded as passing into the restoring-force coil. The sensitivity of the detector is 100 mv/μ, and the deflection of the plunger is 0.6 μ for an intraocular pressure of 40 mm-Hg.

The force required to bend the cornea is exerted beyond the sensitive region and is not recorded. For this reason astigmatism and eye size do not enter: the device can be applied with accurate results to the eye of rabbit or man. Tensions in the tissues are tangential forces that are not recorded by the pressure-sensitive area. Surface tension merely pulls the whole probe against the eye a bit harder and does not influence the reading. The end of the probe can be covered by a thin, disposable, sterilizable, rubber membrance without invalidating the reading, but this membrane must be thin, for its presence slightly decreases the sensitivity of the instrument.

The measurement can be recorded or stored electronically in a number of ways. The most convenient and reliable is simply to record the current that measures the force on the sensitive area, as a function of time, on a strip-chart recorder. A representative recording is shown in Fig. 2. As the hand advances the probe against the eye, the indicated reading increases as the flattened region gradually expands to cover the sensitive area. Once the sensitive area is covered, a further increase in total force applied to the probe will cause expansion of the flattened region out over the surrounding plate which then sustains the bending forces which previously acted on the sensitive region. Thus the increasing reading rises to a crest and then drops down into a trough. A further increase in flattened area will raise the intraocular pressure and thus cause a new rise. The crest amplitude is the result of both pressure and bending forces and thus is the reading that is obtained by the classic aplanation tonometers such as that of Goldmann. The reading at the trough is the true pressure reading for the given flattening without the effect of bending forces. Thus the crest-trough difference is a measure of corneal rigidity. It should be mentioned that minor decentering of the sensitive area with respect to the cornea can result in degrading the maximum into a plateau at trough height. In either circumstance measurement from the baseline to the height of the trough or plateau is a measure of intraocular pressure that is absolute and relatively independent of extraneous factors. As the probe is withdrawn the sequence of events reverses itself. The traced out pattern is essentially symmetrical about its center except that the second trough is generally lower than the first. It is assumed that this results from corneal relaxation and a decreased intraocular pressure during the reduction of aplanation following the expression of some fluid. A comparison of dip height advancing and receding measures corneal relaxation, while comparison of trough height advancing and receding measures the rate of expression of fluid during the interval. The height of the central bump in the tracing is a measure of the elevation in pressure due to the tonometric observation. Measurement of the rate of advancement of the probe against the cornea gives the rate of change of volume of the eye which, in conjunction with the rate of change of pressure, yields more information than classical tonography; we call this metrotonometry.

In developing this instrument there was some question about the ideal size for the central pressure-sensitive area. Other workers trying to make various extraneous factors effecting the aplanation tonometers cancel out had settled upon a flattened area of 3 mm. Thus our first experiments made use of a

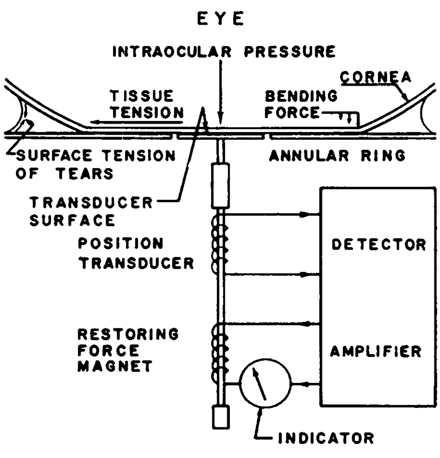

Fig. 1. If the cornea of the eye is flattened against a probe to beyond the pressure sensitive region then the only force that will be recorded will be intraocular pressure, since such factors as corneal rigidity exercise their force beyond the periphery of the sensitive region. Any tendency towards motion in the displacement transducer is detected and amplified to produce a restoring force that holds the pressure sensing piston coplaner with the surrounding region. The restoring-force current is recorded as a measure of intraocular pressure.