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Dear Dr. Anders:

Thank you for your letter and manuscript on "The Moon as a Collector of Biological Material." I am sorry I have delayed in replying but I have only just returned from ten days in Pasadena and Santa Monica on business of the Planetary Atmospheres Study Group of the Space Science Board.

Since our conversation in New York in December, I have also been thinking about the integration of cosmobiota contributions from the distribution of stars in the Galaxy, and have obtained an expression slightly different from yours. The Galaxy can be considered a shpere of radius R_1 surrounding the Sun, imbedded in a disk of radius R_2 and thickness R_1. In this way the contribution of biological material from the solar neighborhood is explicitly taken into account. Transcribing to your notation, I obtain

$$N = \frac{8\sigma}{2\rho R_1 + \beta \ln (R_2/R_1)}$$

where is the expected lunar surface density of cosmobiota, and

ρ is the volume number density of stars in the solar neighborhood. With $\rho = 0$, the expression essentially reduces to your eq. (2). If we take R_1, the thickness of the galaxy at the Sun's distance from the galactic center, to be of the order of 100 pscs, the two terms in the denominator are of equal magnitude. This decreases your value of W by at most a factor of 2. However, it does point out that if the stars in the solar neighborhood were ever very much closer together than they are today, W can have been much smaller. Many current ideas on star formation suggest that there was a sudden condensation of clusters of stars in the remote past. The clusters then dissipate; open clusters and multiple star systems are thought to be the remnants of this process. If for 10^8 years, the stars in the solar neighborhood were ten times closer together, the effective W would be smaller by a factor of 100. Life would have to arise very rapidly in these early times, but this may not be impossible. There is some evidence that life arose very rapidly on the primitive Earth.

If we set $\beta = 0$, ρ take as the mean density of stars in the universe, and R_1 as the effective radius of the universe, we obtain $W = 4 \times 10^{-16}/10^{-28} \times 10^{-33} \times 10^{28} = 4 \times 10^{17}$ gm, or about a factor of ten less than the previous estimate. If the big-bang cosmogony is correct, then ρ was once very much greater. It therefore seems that if appropriate ejection and acceleration and survival mechanisms exist, the lunar cosmobiota population -- if any -- may be predominantly intergalactic, rather than interstellar in origin.

I wonder if the values of W are as prohibitive as you suggest. If $W = 10^{18}$ gm, this corresponds to an average ejection flux during geological time, for a terrestrial planet, of about 10^{-19} gm cm^{-2} sec^{-1}. Current estimates for the infall flux of meteorites on the Earth are 10^5 to 10^6 times larger. Put another way, the escape flux would be about 1 micro-organism per square centimeter per year. Suppose a one-ton meteorite ejects into interplanetary space upon impact a mass of surface material equal to 1% of its mass (is this a reasonable assumption?). One kg of soil may contain about 10^{10} micro-organisms, so the meteorite ejects 10^6 gm x 10^{-2} x 10^{-5} = 10^{-1} gm of micro-organisms = 10^{11} micro-organisms into space. Therefore, to give the required escape flux, 10^{-2} of the Earth's surface must have been hit by a one-ton meteorite once during geological time. Isn't it plausible that such is the case?

Finally, I would object to your revised statement of the need for sterilization of lunar impact vehicles, as contained in the copy of your reply to Dr. Lederberg, which you kindly sent to me. As I attempted to suggest in my paper on biological contamination of the Moon, a copy of which is enclosed, there are four other reasons for sterilization besides the possible confusion of terrestrial micro-organisms with cosmobiota. These are:

(1) a confusion between deposited terrestrial micro-organisms and relics of primitive lunar indigenous organisms

(2) a confusion between deposited terrestrial organic matter and prebiological lunar organic matter

(3) an explosive reproduction of deposited terrestrial micro-organisms in prebiological lunar organic matter, and

(4) interaction or confusion between deposited terrestrial micro-organisms and indigenous contemporary lunar organisms.

To this can now be added the very exciting suggestion of Dr. Turkevich, which you quote, namely,

(5) interaction or confusion between deposited terrestrial micro-organisms and ancient terrestrial organisms, or their remnants, ejected to the Moon in early times.

In my paper, I conclude that the likelihoods of (1) and (2) occurring are very small, but the probabilities of (3), (4), and (5), while remote, are non-negligible. Even if it were certain that the Moon had been previously contaminated through meteoritic ejection, I would argue for sterilization of impacters to keep the Moon safe for paleomicrobiologists. But as you point out, we are not certain. Since the information to be gained from an investigation of lunar prebiological organic matter, indigenous lunar organism, or ancient terrestrial micro-organisms, are so important, despite the fact that the probabilities of making these discoveries are low, I feel that rigorous sterilization should be supported. The engineers are anxious to be rid of the burdensome chore of sterilization, and I know they will seize upon your statement. I would therefore urge you to reconsider your comments on lunar sterilization.

Thank you again for sending me your fascinating manuscript. I hope we will have the opportunity of discussing these topics again soon.

Sincerely,

Carl Sagan

CS:mr
Enclosure - 1
cc: Dr. Lederberg