PANSPERMIA - A MODERN ASTROPHYSICAL AND BIOLOGICAL APPROACH

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ABSTRACT. For the first time a laboratory simulation of the effect of the interstellar environment has been used to provide quantitative estimates of bacterial spore survival in the space between the stars. In the diffuse regions between clouds ten percent survival is limited to at most hundreds of years although one in ten thousand may survive for several thousand years. Within common dense clouds the ten percent life expectancy is extended to tens of millions of years because of the severely reduced ultraviolet within these clouds as well as because of the accretion of ultraviolet absorbing mantles on the spores. The random motion of molecular clouds is shown to provide a possible vehicle for transport of spores from one solar system to another. The most hazardous times in such a journey are at the start and finish and, although the requirements for survival during these periods are quantified here, the possibility or probability of their being satisfied remains pure conjecture.

1. INTRODUCTION

Starting with the classic work of Oparin [1] and the experimental foundation provided by Miller and Urey [2], the chemical basis for the origin of life has become the most widely accepted doctrine in the scientific community. The modern concept of spontaneous generation has been pursued with vigor both experimentally and theoretically. Although the results have been encouraging no one can yet claim to have achieved a complete solution. This has left the door open to some who wish to doubt that life can have started from chemical building blocks alone. Additional impetus to the suggestion of panspermia has come from the fact that evidence for life on the earth takes us back to times which may appear to be uncomfortably close to that when the crust cooled. The time available for the origin of life may have been as short as 300 million years [3]. Actually, if one tries to argue that in this time the probability for random aggregation of atoms to lead to life forms is "infinitesimal" the fact must then be faced that even going back to the beginning of the universe, some 2×10^{10} years ago, only provides an

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improvement of a factor of 100 on this "infinitesimal" probability. This would seem to imply either that life has a non-natural origin or has "always" existed. Inverting this argument, and accepting the basic premise of a natural origin of life, one must conclude that 300 million years is not an unreasonably short time after all and that a purely probabilistic argument is not relevant [4].

However, even though life has a natural chemical origin somewhere (perhaps almost everywhere) in the universe - and actually we shall limit ourselves to our own milky way galaxy - the possibility that some already existing life form may be successfully transported across space is not automatically excluded from providing the beginnings elsewhere.

The effects of various hostile environments on bacteria survival have been investigated before, but there have not been experiments which can be related to the interstellar environment. Irradiaton of spores under simulated interstellar conditions will be used in the following to provide a quantitative basis for discussing the possibility for survival of living organisms over astronomical distances. We shall use the transportation mechanism provided by the pick up and sweeping along within molecular clouds whose random velocities are $\sim$ 10 km s^{-1} with respect to the stars (solar systems).

2. BACTERIA IN SPACE

There is both a similarity and an essential difference between interstellar grain evolution and interstellar effects on living organisms. In the former, the effects of ultraviolet radiation lead to the formation of complex organic molecules from simple molecules [5]; while in the latter the ultraviolet radiation leads to the destruction and rearrangement of already existing complex molecules. In either case the process is initiated by the breaking of a molecular bond or the ionization or excitation by an ultraviolet photon.

The three basic factors in interstellar space which are hostile to microbes are: vacuum, ultraviolet photons, low temperature (of solid particles). The experimental setup which has been designed in the Leiden Astrophysics Laboratory as a simulation of interstellar conditions [6] for the study of chemical evolution of interstellar grains has been used to study the inactivation of bacteria (See Fig. 1). Although inactivation of bacterial spores by ultraviolet radiation has been studied for years under a variety of conditions these conditions have never simulated that of the interstellar medium [7]. We chose to consider Bacillus subtilis spores both because of their resistance to vacuum exposure and the existance of a large body of experimental data on inactivation. We have chosen two strains, one of which is relatively radiation resistant, wild type 168 (WT 168, Nester, Marburg), and the other, TKJ 6323 (kindly provided by Prof. Munakata), which is sensitized to irradiation as a result of repair deficiences. Although we confirm this relative sensitivity to the Hg 254 mm resonance line radiation at room temperature for both vacuum and 1 bar pressure, we find that at 10 K, TKJ 6323 is as strongly resistant to radiation as WT 168

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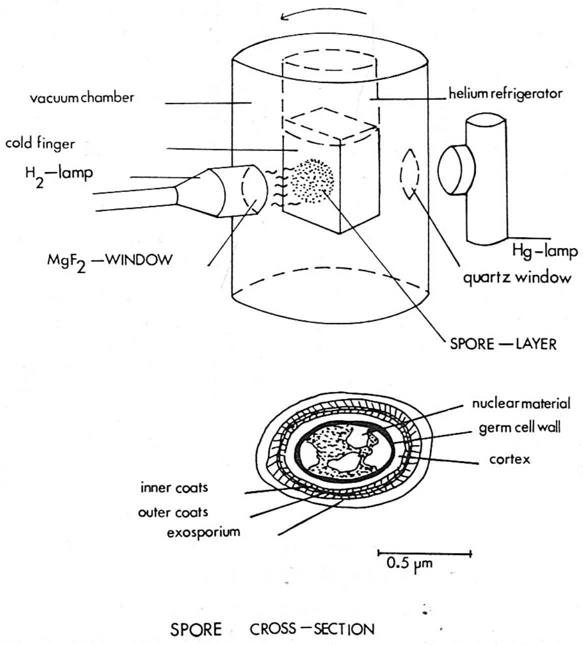

Figure 1: Diagram of apparatus used to irradiate spores. The cold finger on which the spores are deposited is maintained at either 10 K or room temperature. The quartz window is also used with the H_2-lamp.

(Figs. 2a, 2b). This trend to less ultraviolet sensitivity of spores at very low temperatures is consistent with the prediction of Ashwood-Smith, et al [8]. As we shall see, if the interstellar radiation consisted only of the Hg resonance line, spores would survive for very long times indeed.

In order to simulate the ultraviolet flux in interstellar space we use the microwave powered H_2-discharge lamp which is regularly used in the interstellar dust experiments. At wave lengths shortward of 2000 Å (VUV) the emission of this source is peaked at 1600 Å and at 1215 Å (Lyman α) and in this region the mean flux is ~ 1.5 x 10^{15} quanta $cm^{-2}s^{-1}$ as compared with 10^8 quanta $cm^{-2}s^{-1}$ in the diffuse interstellar medium. Between 2000 Å and 3000 Å there is a substantial rise in flux resulting from the fact that the energy output in this region is about 5 times as high as in the VUV. In the interstellar medium this ratio is ~ 1. Our first suspicion was that the higher energies would be more deleterious than the lower ones. To our

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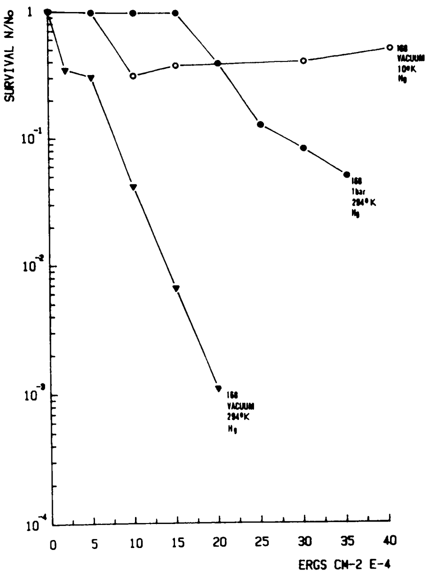

Figure 2a: Inactivation curves for Bacillus subtilis strain WT 168 at 10 K and at 294 K.

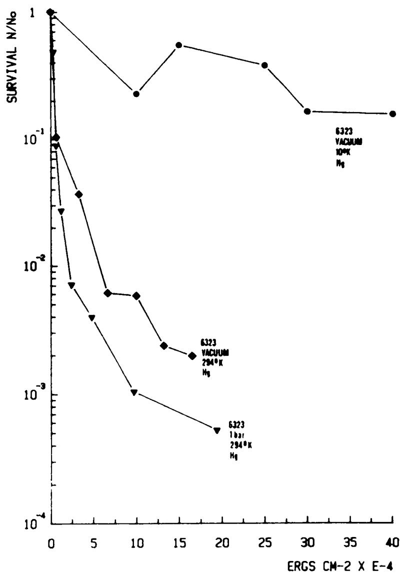

Figure 2b: Inactivation curves for Bacillus subtilis strain TKJ at 10 K and at 294 K.

surprise this was not at all the case. In fact (see Fig. 3) we found, by using various filters in the VUV and cutting the VUV off entirely (using a quartz rather than a MgF_2 window), that the major damage to our cells was produced by the longer wavelengths (but obviously not λ 254 nm).This result seems to be explainable and will be included in a later report where we examine relative penetration of ultraviolet photons of different energy in spores and variation in chromophores at different depths.

3. SURVIVAL OF SPORES IN THE ISM

According to our survival data with the H_2 lamp, using a linear regression on the top curve of Fig. 4, it takes a dose of 1 Kj m^{-2} of VUV to inactivate spores to F_{10} (10% survival) at 10 K. Using the full spectrum and noting the fact that the H_2 lamp emits 5 times as much energy in the 2000-3000 Å range as in the VUV implies that for the diffuse interstellar medium a dose of F_{10} occurs in about 150 years. To derive this result we have used the fact that the flux of VUV by the lamp is

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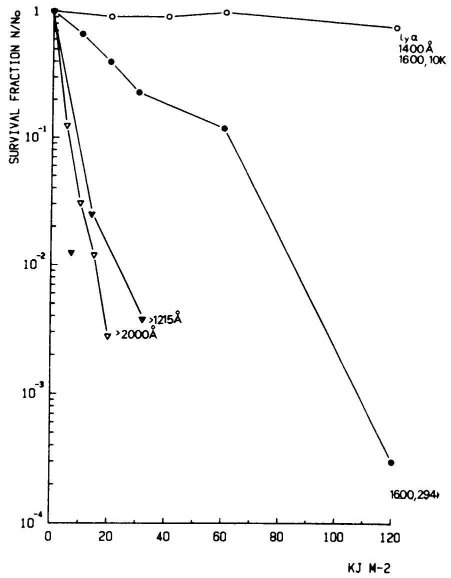

Figure 3: Inactivation curves for Bacillus subtilis as a function of ultraviolet wave length using the H_2-lamp. The two lowest curves show the small difference at 10 K between using the full spectrum ($\lambda > 1215$ Å) and only the long wavelength portion ($\lambda > 2000$ Å).

such that 1 hour in the laboratory corresponds to about 1000 years in space [6] and the ratio of energy flux in space between 2000 Å and 3000 Å is about equal to that at $\lambda < 2000$ Å rather than being 5 times as large. To inactivate spores to $F_{0.1}$ requires a dose equivalent to 2500 years in the diffuse interstellar medium. At such doses the spores may be presumed to be really dead.

Thus the mean survival time for spores in the diffuse regions of space is exceedingly short compared with the relevant astronomical time required for transport of a spore from one solar system to another within a molecular cloud. If a spore is caught up in a cloud and carried along with the rest of the material over the distance between neighboring stars of ~ 0.1 to 1 parsec (0.3 to 3 light years) [9], this corresponds to a passage time of 10^5 to 10^6 years. If we assume that one star in a thousand possesses a solar system we require a survival time of 10^6 to 10^7 years. The next question is: "Can a spore survive as long as a million or ten million years in a molecular cloud?". Two possibilities exist for increased survival time in clouds relative to the diffuse cloud medium:

1) ultraviolet radiation within clouds is generally less by a factor of 10^3 - and more likely 10^4 - than in the diffuse cloud medium.

2) Accretion of atoms and molecules which occurs on spores just as on grains provides a mantle of material which attenuates the ultraviolet radiation. In ~ 10^5 years a 0.15 μm mantle is accreted on a spore in a

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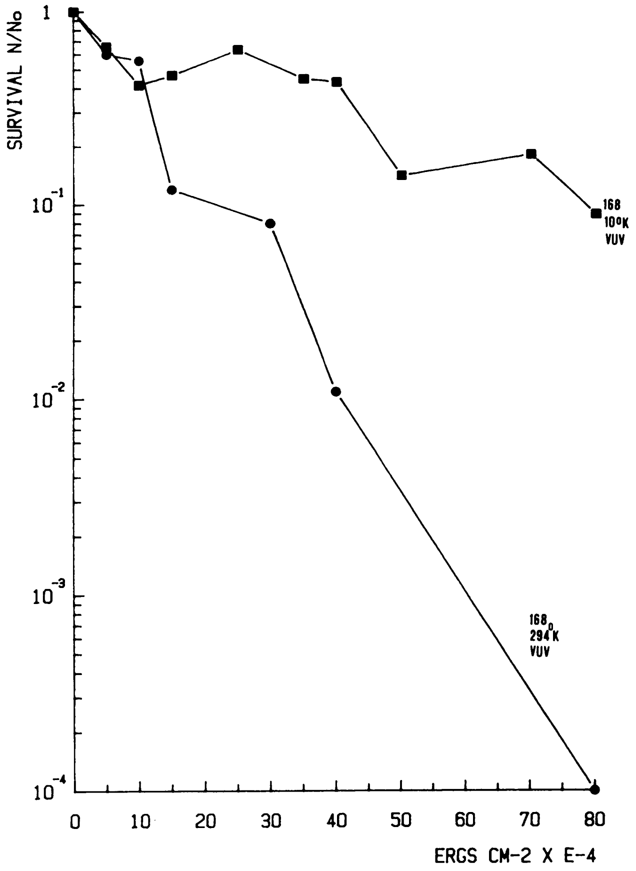

Figure 4: Comparison of inactivation of Bacillus subtilis strain WT 168 by the H_2-lamp full spectrum at 10 K and 294 K.

cloud of density $n_H = 10^4$ cm^{-3} [10] leading to an ultraviolet attenuation by at least a factor of 10 for moderate mantle absorptions.

Thus, spores within a dense cloud have F_{10} values in equivalent interstellar times of the order of 150 x $10^{3.5}$ x 10 ≃ $10^{6.6}$ years which is just about adequate for viability. Of course, should a spore become part of a comet along with the other interstellar matter it could then be protected indefinitely.

Note that we have not yet discussed the question of how surviving spores got into a molecular cloud from a planet. In order for this to

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occur, the spore must first be injected into the upper atmosphere. Since the effective ultraviolet radiation from the sun is (above the earth's atmosphere) $> 10^{10}$ times that of the diffuse I.S.M. [9] the spore must arrive there with a mantle thick enough to provide protection while it is first captured by the cloud and then during the time it takes to be removed from the solar ultraviolet environment to the interstellar ultraviolet environment in the cloud. This gives a distance from the sun of ~ 3000 a.u. and a passage time of $\sim 10^3$ years. An absorbing mantle which attenuates the solar UV by a factor of $\sim 10^9$ should be more than adequate not only while the spore is at the earth but also during its removal. A mantle of ~ 0.9 micron thickness will do this if the imaginary part of its index of refraction is $m'' = 0.5$.

Finally, with respect to "reentry" of a spore on a non-hostile planet, we have to postulate again a rather thick protective mantle during its sojourn in the new solar system. One may presume that this could have been accreted in the molecular cloud. Another possibility is that the spore is imbedded in cometary debris (interplanetary dust) which penetrates the earth's atmosphere without being overheated just as is observed for sufficiently small particles collected in the upper atmosphere [11].

4. CONCLUSIONS

By studying the effects of ultraviolet radiation on bacterial spores under simulated interstellar conditions we have been able to put quantitative limits on the survival of a spore in interstellar space. We have demonstrated the fact that the exceedingly low temperature reached by interstellar particles provides a substantial degree of protection against effects of the ultraviolet but that, even with this, the life expectancy (measured as a 10% survival) of an unprotected spore in the average diffuse regions is a mere 150 years. However, we have used the observed properties of dense molecular clouds to show that spores in such environments are not only subjected to far less ambient ultraviolet radiation but also accrete ultraviolet absorbing molecular mantles. Taken together, enough protection is provided that a substantial percentage of spores may survive for tens of millions of years which is the kind of time for passage of a molecular cloud from one solar system to another.

The survival of a living organism from the time it emerges from a planet like the earth and passes through the hostile environment of the inner solar system to the time it reaches the shelter of a passing molecular cloud requires conditions which can only be speculated on.

We conclude that the limits for survival of spores in the interstellar medium are not inconsistent with the concept of panspermia. Survival during the very short time spores are subjected to an exceedingly hostile solar environment remains a major problem. Panspermia is like flying - the most dangerous times are during take-off and landing.

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