Meetings: Problems of Detecting Extraterrestrial Life: Cambridge (Mass)

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Meeting on the Problems of Detecting Extraterrestrial Life

Massachusetts Institute of Technology

December 19 and 20, 1958

Participants:

Cowie	Hartline	Miller	Vishniac
Davies	Kamen	Rossi	Billings
Derbyshire	Levinthal	Schmitt	Freeman
Doty	Luria	Sistrom	Young
Gold	MacNichol	Townsend	

Introduction

Section A describes what is known about the physical conditions of Mars and Venus and, briefly, some of the chemical and biological processes which may occur on these planets. Section B gives a projected time table for planetary probes, satellites or landings on Mars or Venus. Section C contains suggestions and recommendations for use of these launchings for scientific purposes.

A. The Environments of Mars and Venus and Relevant Terrestrial Concepts

It should be noted that observations of spectral absorption features produced by constituents of the atmospheres of Mars and Venus are difficult or impossible when these features are strongly masked by the same constituents in the earth's atmosphere. The figures quoted for percentage of oxygen, water vapor and so forth are all upper limits which, of course, vary from constituent to constituent according to the masking ability (essentially, line widths) and from planet to planet according to the maximum differential radial velocity available to cause doppler-shift of the planet's lines in relation to those of the earth's atmosphere. When a spectroscope with sufficient stability and resolving power can be flown above the earth's atmosphere, it will be possible to fill many of these observational gaps.

1) Mars (cf. Science 128, 89, 1958)

a) Atmosphere CO_2 content is high, about 20m at terrestrial standard temperature and pressure (this may be in error by a factor of 5). Nitrogen is probably present, but the amount is unknown. Oxygen has not been detected but, if present, is less than 1% earth oxygen content.

Water: The polar caps are probably ice. The upper limit of the possible water vapor content of the atmosphere determined spectroscopically is low, but not lower than would be required to account for the transport of water from pole to pole with the seasons.

Trace constituents: Some information on these may already be available or forthcoming (cf. Section C, 1, c).

Clouds: There are three types -

1. Yellow - low altitude, transient and almost certainly dust clouds.
2. White - low to moderate altitude, somewhat more persistent than the yellow, perhaps thin cirri of ice crystals.
3. Blue - high altitude, possibly similar to our high altitude noctilucent clouds to judge from limited spectroscopic observation.

b) Temperature Seasonal and latitudinal variations in temperature occur, in addition to diurnal changes. The mean diurnal range is -100°C to +30°C.

c) Gravity The mass of Mars is .11 times earth; the density is .70 times earth and the surface gravity is .37 times earth.

d) Irradiation Because the atmosphere of Mars is relatively small it is expected that the planet is subject to more intense irradiation in the ultraviolet than is the Earth.

e) Dark patches There are darker areas on the surface which appear to wax and wane with the seasons, becoming darker in the spring. The details and even some fairly gross features of the dark patches change over intervals of time of the order of decades although their locations are more or less permanent. While there is considerable disagreement on the subject, it is possible that the rest of the surface may be covered by a fine sand, some of which is periodically swept up into sand storms. Some scientists feel that since the sand deposited by these storms does not obliterate the dark patches permanently, there must then be an irregularity of surface such as would be provided by vegetation. (cf. Section C. 1. e.)

2) Venus (cf. Science 128, 89, 1958).

a) Atmosphere Because of the heavy and opaque clouds surrounding Venus all information refers to the atmosphere above the clouds. CO_2: This is about 1000 times the amount in the terrestrial atmosphere; this is of the same order as the amount of CO_2 that has been released into the earth's atmosphere and subsequently fixed biologically.

Oxygen and water: Not observed; upper limit is less than 5% of the terrestrial content.

Nitrogen: No evidence available. There is some evidence for an N_2^+ emission spectrum from the night side.

Clouds: The Venerian cloud cover is nearly opaque; as a result, its mass and composition are relatively unknown. A certain amount of structure in the atmosphere of Venus is, however, detectable in UV photographs: regions of slightly greater than average albedo with dimensions of the order of 1000 km.

b) Temperature The temperature has been observed with radiometric devices to be 50°C at the subsolar point outside the opaque part of the atmosphere and -40°C on the dark side. At radio wavelengths the temperature has been observed to be in excess of 200°C. The specific layer from which infrared radiation originates is somewhat open to question, but the radio waves are presumed to refer to the surface of the planet.

c) Gravity Mass .82 times earth, density .89 times earth, surface gravity .86 times earth.

d) Irradiation Because of the unknown nature of the clouds and magnetic field the surface irradiation spectrum is unknown.

3) Evidence for Organic Matter on Mars

Sinton's work: (cf. Astrophys. J. 126, 231, 1957)

All C-H bonds (in compounds heavier than methane) give rise to infrared absorption bands near 3-4 µ. In large organic molecules the resonance occurs near 3-46 µ (the precise wavelength depending on the neighboring atoms) and when two hydrogen atoms are attached to the same carbon atom, the band is a doublet with the mean wavelength again near 3-46 µ. Sinton detected this band on Mars (published data) and showed its association with the dark patches (unpublished data). Most terrestrial plants display a near-infrared reflectivity which is not seen on Mars. Sinton mentions that some lichens show reflection spectra similar to that of the planet and he suggests that if vegetation exists on Mars it may resemble these lichens. A more likely possibility is photosynthetic bacteria, as the following consideration shows.

The high reflectivity in the near-infrared of green plants referred to by Sinton begins at about 750 mµ and extends to about 1500 mµ; it is caused by the absence within plants of compounds absorbing at these wavelengths. Some lichens apparently have absorbing compounds. It can be predicted that photosynthetic bacteria will also have a low reflectivity in this region since bateriochlorophyll (found in purple photosynthetic bacteria) absorbs in the region from 800-900 mµ. The chlorophyll of green plants absorbs in the region 600-700 mµ, that of the green photosynthetic bacteria (Chlorobium) 700-800 mµ. On general biological grounds the photosynthetic bacteria are more likely to be present than lichens.

In the aggregate, Sinton's evidence makes it quite possible that there is organic matter on Mars but leaves open the question of its biological origin.

It is possible, as mentioned previously, that the dark patches are due to vegetation. On earth, vegetation is easily detected by radar and the earth appears perfectly smooth to the radar where vegetation is not present. Since the moon appears completely smooth by radar, Gold concludes that a planet would also be likely to appear smooth in the absence of vegetation. Examination by radar would therefore be useful for revealing the presence of vegetation.

4) Chemical Processes in the Earth's Atmosphere

Miller described the results of experiments in which corona discharges were passed for long periods of time through a reducing atmosphere in the presence of water. Various compounds are found in the residue; most notably amino acids. So far no peptides have been found and the addition of possible catalysts has produced no detectable effects. Similar results were obtained by Abelson under slightly different conditions. The atmosphere and conditions used by Miller were chosen as models for possible reactions on earth and do not refer directly to reactions which may be taking place or have taken place on other planets (cf. Section C, 1, a).

5) A Hypothetical Ecology for Mars

Vishniac described a possible ecology for Mars based on metabolic processes known to be carried out by micro-organisms. In outline, he considered:

a) A carbon-cycle based on:

$CO_2 + H_2S$ + (light) - SO_4 + organic material (sulfate reducing bacteria)

Organic material + SO_4 - $CO_2 + H_2S$ + organic material (photosynthetic bacteria)

This is the anaerobic analog of the carbon-oxygen cycle on earth.

b) A nitrogen cycle would involve the photochemical nitrogen fixation:

$CO_2 + N_2 + H_2S$ + (light) organic nitrogen + SO_4

An experimental demonstration of this kind of ecology is provided by inoculating a medium containing sulfide and carbon dioxide and ammonia with a mixture of the sulfur oxidizing photosynthetic bacteria and sulfate-reducing bacteria. So long as light is supplied and the culture is kept anaerobic it will maintain a constant population; the only input being that of light.

Luria pointed out that this sort of picture, and also less explicit ideas about the nature of Martian life, are based on the assumption of a "closed ecology", that is, one in which the total amount of biological matter remains constant. The earth and Vishniac's mixture of photosynthetic and sulfate-reducing bacteria are examples. It is conceivable, however, that the planets may have an "open ecology", in which the amount of biological material is increasing, or in which there is no cycling of matter between different kinds of living things but a one-way channeling of available organic material into living things. The earth at a time between the first origins of life and the present steady state ecology would serve as an example.

B. Projected Time Table for Planetary Probes, Satellites or Landings on Mars or Venus

1) Davies presented a very rough timetable of planetary satellites:

1960 - 200 lbs. payload in general vicinity of Mars and Venus (perhaps as close as 10^6 miles).

1961 - Soft lunar landing

1962 - An entry or moderately hard-landing on Mars or Venus

1964 - Venus soft-landing, or orbit and return

1965 - Mars soft-landing, or orbit and return

The soft landings in 1964-65 could land about 500 lbs. of instruments. The possibility of landing and return is remote.

2) Balloons and earth satellites

3) Terrestrial experiments and observations

4) Infrared (an ultraviolet) narrow band-pass filters for use on both earth and planetary satellites were discussed.

C. Suggestions and Recommendations for Further Observations and Experiments

For convenience, we list suggested observations and experiments under each of the possible locations or conditions: (1) In the earth; (2) from balloons or earth satellites; (3) from satellites in orbit around the planets; (4) hard-landings; (5) soft-landings.

1) Experiments on earth

a) Extension of Miller's experiments to conditions such as may obtainoon Mars or Venus (different temperatures; various water contents, UV irradiation levels, and atmospheres). These experiments can be designed more effectively when more is known about the atmospheres of the planets. Most of the work done now in this field is concerned with the development of life on earth;

further experiments directed to planetary life should not interfere with current research. (Miller expressed little interest in orienting his research in this direction).

b) Upon soft-landing, a primary need is to photograph the surface of the planet in light of various wavelengths. Hence, control observations should be made on earth to determine the most informative wavelengths. Particular importance is attached to UV light (200-200 mμ peptide bonds; 260 mμ nucleic acids; 280 mμ aromatic amino acids). Of these, 260 mu is probably the most significant. Data are already available for observations at the absorption maximum of chlorophyll and at certain infrared wave (see under A-2)*

c) Re-examination of data on planetary and earth atmospheres with respect to presence of trace components: CO, H_2S, NH_3, etc.

d) Re-examination of the infrared reflection spectroscopy of Martian surface in the region 800-1000 mμ (absorption maximum of bacteriochlorophyll).

e) The use of radar to determine the roughness of the surface of a planet can possibly be done from the earth with a sufficiently large transmitter; it is a technical question if this is better done from a planetary satellite (cf. Section C, 3, d).

f) Calculations of the total amount of information which each of the different kinds of satellites will be able to transmit should be attempted. It is important that biologists, in suggesting possible observations, realize the limited amount of information which can be transmitted.

g) Analysis for biologically important components in suitable meteorites on earth.

2) <u>Observations from balloons and earth satellites</u>

a) Improved spectroscopy of the planets

i. Components of atmosphere, especially O_2, N_2 and trace components.

ii. Surface spectroscopy (extension of Sinton's observations).

b) Control observations of the earth using methods to be used in observations of the planets. The consensus seemed to be that detection of life on earth from observations made at a distance of about one or two radii is improbable.

* A cursory examination of the botanical literature dealing with reflection spectroscopy of leaves, etc., does not seem to support the hope of detecting the presence of chlorophyll by spectroscopy of the surface of a planet. Even a leaf mounted in a totally reflecting sphere does not give a very good reflection spectrum (See Rabideau, French and Holt, Amer. J. Bot. 33, 769) (Sistrom).

3) Observations from near-miss or hard-landing

a) Photographs at various wavelengths to estimate the spatial distribution of any absorption bands found by spectroscopic examination from earth satellite. Narrow-band-pass infrared filters might be very useful.

b) Physical measurements: cosmic ray, magnetic field, temperature, mass spectroscopy of the atmosphere.

c) On a Venerian hard-landing: chemical composition of the cloud.

d) Detection of surface roughness by radar may be easier from a near-miss (extra-atmospheric orbit) satellite than from earth.

e) A hard-landing contamination risk: (see under Section C, 4, a, iv).

4) Observations from a soft-landing

a) Contamination The physical and chemical observations discussed above would be made even apart from any biological interest in the planets. Observations made after a soft-landing will answer more specifically biological questions. It is difficult to suggest observations, because the properties of the possible biological processes are uncertain: a cosmic ray is a cosmic ray, but a Martian organism (if any) may be very different from any terrestrial organism. Before mentioning the kinds of observations that were suggested, we outline the discussion on the problem of contamination, which must be considered in any soft-landing attempt.

i) A variety of possible biological states of the planets can be considered: a. living things essentially identical to those found on earth; b. living things similar in gross metabolic aspects to terrestrial forms with important differences in structure and metabolism; c. living forms basically different from terrestrial forms, for example, anhydrous or silicon-based forms; d. some form of "proto-life", either extensive or marginal; e. the planets are totally sterile; f. the planets, now sterile, may harbor remains of an earlier life.

ii) The demonstration of any one of these states is of extreme importance to biology.

iii) Each state will be very sensitive to contamination from the earth, for example, possibility (d) probably implies the presence on the planet of a rich organic medium (Oparin's "soup"). This may support growth of terrestrial organisms which are marginal by terrestrial standards, but could readily outstrip the "proto-life".

It is also possible that non-living organic contamination from the earth could change the nature of the chemistry of the planets; it seems improbable that this would occur rapidly enough or on a large enough scale to make it necessary to eliminate completely this source of contamination. However, biological contamination would make it unlikely that any useful information could be obtained from later observations.

iv) It was recommended, therefore, that the people designing the vehicles and instruments work in close cooperation with a committee of biologists on dangers of contamination, on means to obtain and to test for sterility, and on possible dangers from chemical contamination. Generally, no non-sterile soft-landing should probably be attempted without prior adequate observation of the uncontaminated planet. This caution would include "entry" vehicles (hard-landings) which may not undergo total combustion in the atmosphere. The inclusion of living organisms in any early soft-landings would be justified only if the information derived from observations on them is commensurate with the extreme danger of gross contamination.

b) Suggestions for observations after a soft-landing

i) Photographic observation The discussion indicated that more thought must be given to the kind of pictures that is most fruitful.

a. Motion of objects; it may be desirable to transmit only changes in a series of pictures.

b. Photographs at different wavelengths: Ultraviolet (see Section C, 1, b), visible light (chlorophyll) and infrared. The wavelengths can be chosen more intelligently after better reflection spectroscopy of the planet surface. The use of "difference-spectrum photographs" was mentioned as an efficient way of transmitting this information.

c. Provisions for moving a camera, or at least for allowing it to rotate. High resolution pictures need be taken only if preliminary scanning revealed the presence of some object.

d. Choice of the most useful magnifications.

ii) Chemical analysis

a. Direct chemical analysis by means of methods such as classical micro-techniques, pyrolytic mass-spectroscopy, and polarimetry to detect optical activity.

Suggestions of compounds to be looked for included: amino acids, purine pyrimidines, phosphates, sulfides, fatty acids and amines. It was recommended that the aid of several analytical chemists be enlisted. The equipment for this analysis could be enclosed in a 'box' and would include devices for sampling the environment.

b. Biochemical analysis. A biochemical analysis can be carried out by inoculating terrestrial organisms of known metabolic patterns into samples of the environment, either alone or mixed with known constituents. For example, if sulfate is added to a sample of the planet surface and the mixture provided with an anaerobic atmosphere and inoculated with a bacterium which can grow by the reduction of sulfate with organic compounds as hydrogen donors, growth of this organism would indicate the presence of organic matter of a particular type. This method may not give any more information than the direct chemical analysis, and involves considerable danger of contamination.

iii) Biological Analysis This could be approached in two ways: first, to see if there occur on the planets any chemical changes that might be ascribed to metabolic reactions; second, to see if organisms exist which are capable of metabolizing in media of known composition: these two approaches may be characterized as analysis by non-intervention and analysis by intervention.

a. Non-intervention. For this a small portion (perhaps of the order of a cubic meter) of the surface would be isolated from the planetary environment and changes in chemical composition looked for. A means of periodically excluding light can also be provided. Compounds which might show changes include: CO_2, O_2, N_2, NH_3, CH_4, H_2S, H_2O, amino acids, fatty acids, etc. An important factor is the time period of observation; this should be longer than the time required on earth, since the metabolic processes may be marginal and very slow.*

b. Intervention. Essentially this is the use of the "enrichment culture" technique. This means providing a variety of known environments and substrates and observing if growth occurs upon the inoculation with samples of the planets surface. Test if simple protection from ultraviolet light (on Mars) and maintenance of different

* A metabolic process is not necessarily a rapid one. Most terrestrial ones are rapid because of the selective pressure under which they have evolved. A micro-organism trying to compete with terrestrial bacteria and having a generation time 100 times longer would not last for very long; but it might be a dominant organism in a place where no great pressure for rapid growth exists. This points up the severity of the danger of contamination of an open ecology.

temperatures (on either Mars or Venus) suffices to change a marginal, barely observable activity into a much more vigorous activity. Vishniac agreed to consider these questions of biological analysis in more detail and to prepare a concrete proposal for the development of an experiment and the instrumentation required.

Since the distribution of life might be spotty, the "boxes" (for photography, chemical analysis, and biological analysis) should be sufficient in number to give a reasonable chance that at least one would land where life is (if any). Some means by which each box could signal its location on the planet might be devised.

iv) Detection of large organisms, as opposed to observing the processes carried out by micro-organisms, seems to reduce to <u>seeing</u> them and, in addition, to luring them and observing their response to stimuli: food, sound, light, etc. More thought is required on the best kinds of stimuli.

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