NOTE ON THE PROBABILITY OF CONTACT WITH SUPERIOR GALACTIC COMMUNITIES

THE FORMATION OF SOLAR SYSTEMS: THEORETICAL DATA

Present theories of stellar mechanics and physics provide, as far as we know, a good approximation of the laws of stellar evolution, and represent well visual and spectral observations. The evolution of the stars in space and time, their variations of color, temperature and chemical composition are described by these models.

Whether stars are formed by gravitational condensation of gas nebulae or by some other process is not yet clear, but it seems fairly well established that each star is not formed independently. Large "associations" are produced during the initial process and their elements move away from a common center. Today, most of the components of these large groups are so far apart that only careful studies of their proper motions can distinguish them from stars in the background and establish their common point of origin. Knowing this point of formation and the annual displacement, one can compute their ages. Stars are still being formed by this process.

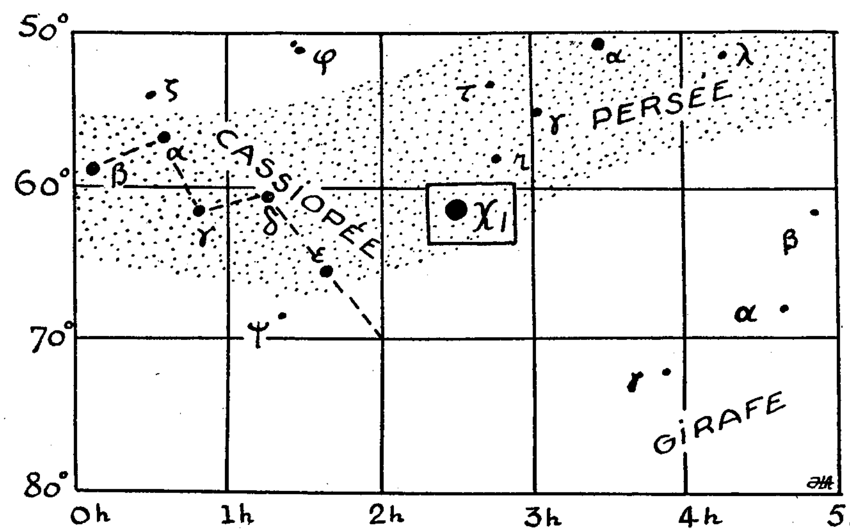
In such associations, stars without companions are not the general case. The original mass of gas will often have distributed its angular momentum between the components of a multiple system and we observe double or triple stars, etc. Planetary systems seem to be generated because of similar physical processes. Angular momenta insufficient to allow the production of a binary system could be distributed between a central mass and a series of smaller condensations. When nuclear reactions start in the center of this mass, the new star radiates and the gaseous material is blown out of the system into space. From that point on, the planets cool

and move freely in more or less definitive orbits, along with their smaller satellites, still integrating some dust material and exchanging small amounts of matter and energy with their environment and the solar corona.

Observation of planetary systems would therefore be a quite common experience if we had means of detecting the very small objects involved. But very often unseen companions of stars, when detected, may well turn out to be small stars of very low luminosity, and not planets.

PLANETARY SYSTEMS: OBSERVATIONAL DATA

The planets of our own system revolve, roughly speaking, in the same plane on elliptic (almost circular) trajectories with the sun as one of the foci. Their mass is small compared with that of the sun. However, the center of gravity of the solar system is situated outside the sun, at about one million kilometers from its center. The sun revolves around this point in about twelve years, about the period of Jupiter, the heaviest planet by far. This phenomenon, as pointed out in (54), could be observed by extraterrestrial beings (for example, inhabitants of a hypothetical system



The sun seen from the nearest star (Proxima Centauri) would appear as a star of the constellation of Cassiopeia. (After *L'Astronomie*, [54]).

around the star Proxima Centauri, the closest to us, would see the sun, as indicated on page 183, from a distance of 4.5 light-years, and could detect an oscillation in its motion, if they possessed advanced astrometric techniques). Although it would probably remain impossible for them to see the earth or even Jupiter, they could discover the existence of our system as a consequence of this "waving" motion of the sun.

In recent years, this method has been used in a survey of neighboring stars and has led to the actual discovery of several unseen companions, among which could be planets. Using very delicate techniques of photometric measurement, P. Van de Kamp has been able to find displacements of the photocenter of these stars leading to the determination of systems in which the ratio of the mass of the companions to that of the central star is generally of the order of ten times the corresponding value in our system.* These discoveries further confirm the words written by F. W. Bessel in 1844: "Light is no real property of mass. The existence of numberless visible stars can prove nothing against the existence of numberless invisible ones." This analysis was justified in 1862 when Alvan G. Clark, using the eighteen-inch refractor now at Dearborn Observatory of Northwestern University, discovered the companion of Sirius.

The fundamental difficulty, according to Van de Kamp, is that "a small perturbation such as would be expected from a planetary companion may be caused also by an unresolved binary whose photocenter falls close to the barycenter." A star is self-luminous, while a planet shines only by reflected light, but only conventional distinctions can be made between heavy planets and very small stars. Generally, an object of a mass of 0.05 solar mass is considered a borderline object (Russell, 1943, 1944); such an object would

* Knowing the distance d from the star to the center of gravity, the period of the revolution T and the magnitude of the star, from which is derived the total mass, the mean distance of the companion to the star is $a = \sqrt[3]{T^2}$ and the ratio of the masses is $\frac{m}{M} = \frac{d}{a}$. This ratio is 1/700 in the case of the solar system; it is much higher in the systems actually discovered (see [57] to [62]). The smallest mass found is one-sixtieth of the solar mass for the third component of the visual binary 61 Cygni, discovered by Strand.

have a surface temperature of 700° K., of the order of some of the measurements taken by Mariner II of the atmosphere of Venus, and would be barely visible in the visual range of the spectrum.

A sphere five parsecs (or sixteen light-years) in radius, with the solar system as its center, contains fifty-six stars composing forty-two systems, of which two are triple, ten double and thirty single. Among these nearby stars, the majority are faint, and less than a dozen are visible to the naked eye (Van de Kamp, 1955). Four of them undergo perturbations indicating the presence of unseen companions. The data relative to these stars are summarized below:

Name	α1950	δ1950	Distance (light-years)	Mass of Unseen Companion*	Period (years)
Barnard's star	$17^H\ 55.4^M$	+04° 33′	6.0		
Lalande 21185	$11^H\ 00.6^M$	+36° 18′	8.2	0.030	1.14
61 Cygni (Strand, 1943)	$21^H\ 04.7^M$	+38° 30′	11.1	0.016	4.90
BD + 20⁰ 2465 = Ci 1244 (Reuyl, 1943)	$10^H\ 16.9^M$	+20° 07′	15.4	0.030	9.00

* solar mass = 1

But these indications must be considered carefully, in view of the fact that the observed perturbations, as mentioned earlier, might be caused by small stars rather than planets in certain cases. This list, however, does give an indication of what number of systems presenting conditions close to those of a planetary system can be expected in a given volume. It seems reasonable, on the basis of existing data, to take four as a probable minimum for the number of planetary-type systems in this standard volume, in addition to our own system, since the perturbations caused by bodies of a size comparable to that of our planets would be unobservable in the present state of astronomical techniques, and since considerations involving the fact that slowly rotating stars are likely to have planetary companions would lead to a higher estimate, possibly more realistic.

CONTACT WITH SUPERIOR GALACTIC COMMUNITIES

If we consider only space-traveling races that might have originated outside our solar system, the restrictions considered in Chapter 2 do not hold. As remarked by Dr. Lipp himself:

> Arguments like those applied to Martians above need not apply to races from other star systems. Instead of being a first port of call, Earth could possibly be reached only after many centuries of development and exploration with space ships, so that a visiting race would be expected to be far in advance of Man.

In our model, we would introduce a number of new parameters. Considering the fraction of eligible systems on which intelligent life has actually developed, we can give a new formula to express the number of races exploring space in a sample volume, and this will give, under our present assumptions, an upper limit of the number of space-traveling races which exist in this volume.

At a given time, one of these races has a certain quantity of information concerning us (possibly only observational data concerning our sun). We define the minimum level of information this particular race should have concerning a point at distance (d) in order to contemplate space travel to this point. From this, we can calculate the radius of the maximum volume of space that race could explore "physically" at a given time.

Obviously, some hypothesis should be made here concerning the levels of intelligence of these races, which need not be constant. However, in this approximation, we will consider that intelligence itself does not increase or decrease as time goes on, and that only the quantity of information or amount of knowledge every race possesses concerning its environment will vary. We can, for example, assume that the knowledge in question, for a given race, varies in proportion to a certain power of time, the coefficient of proportionality defining the type of intelligence of the race, which could be interpreted as an "intellectual development rate." We can then express completely the volume that can be physically explored by the race as a function of time and of this coefficient; similarly, we can calculate the age required for this race to be able to reach a point at a certain distance.

We would then have to take into account the rate of birth and death of such space-traveling races; we cannot expect to make contact with races for which the minimum age required to reach our system is larger than the expected lifetime of scientific civilizations. On the other hand, before we introduce this factor, we should know more about the volume of space to be considered. What physical reality could be attached to the exploration of the whole universe, or even of our galaxy? In the latter case, we would no longer be concerned with spherical volumes, and we should take into account the structure of the galaxy, its stellar population repartition and evolution.

No information on the total volume in which exploration can realistically be considered is given in the literature. Dr. Lipp has only indicated that the probability of finding races occupying higher and higher levels in the intelligence spectrum was increased with the radius of the explored volume, but that the probability for these space explorers to ever find the earth was decreased. From that, we could be tempted to infer that the chance of being "visited" is more or less constant over the distance, the only change being in the "quality" of the visitors; UFO's from very distant places would occur just as often as UFO's from nearby stars, but they would be products of much more highly developed technologies.

We will now try to show another possible approach to this problem.

GALACTIC EXPLORATION IN THE VICINITY OF THE SUN

In (67) Sebastian von Hoerner says he expects "to find either a high activity in communication at shorter distances (200 to 300 parsecs) between civilizations of extremely long time scales, or very little if any activity at greater distances (600 to 1000 parsecs) from civilizations similar to our own." These estimates are justified in the light of an evaluation of the average distance to the ten nearest civilizations, expected to be of the order of 360 parsecs.

Here we do not limit ourselves to communication by radio signals, but consider all means of gaining information, not excluding physical travel (this may be more realistic, since the role of radio techniques as advanced means of communication can be expected to be of an extremely brief duration on our time scale); we can reformulate the problem of the maximum distance as follows:

Each race contained in a shell centered on our system has certain information concerning us that we can compute from considerations explained above. The total knowledge concerning our system and contained in the shell can also be expressed in mathematical terms. We cannot enter here into the details of this model; it is enough to say that as far as galactic exploration in the vicinity of our sun is concerned, it shows that the knowledge gathered by intelligent races situated at a distance (x) from us, and concerning our system, is related to a mean value of the product (age multiplied by development index), and varies in first approximation as the logarithm of the distance.

If we now consider, instead of the ideal "knowledge," the ability of these civilizations to communicate with us, or even to explore physically our system, we have to take into account the fact that such action will cost energy and that the difficulty of the experiment will be proportional to some power of the distance. When we express this idea in mathematical terms, we find that there exists an upper limit above which communication by conventional means with races of intelligence comparable to ours cannot be realistically considered, under our present hypotheses (in which we do not take into account colonies or a process of development of life that would not be random).

This upper limit, for plausible values of the different parameters involved, seems to be small compared to the radius of our galaxy, and this justifies the introduction of simple laws of proportionality and spherical approximations. From this new model we can also compute a new estimate of the average distance to the nearest civilizations. We have already defined the fraction of existing systems which have actually seen the development of races able to travel through space. There is an obvious relation between this

average distance, the upper limit of the volume considered and the total number of stars in this volume. For numerical values of the fraction defined above, ranging from one to one-tenth, the average distance to the six nearest civilizations ranges from five to ten parsecs. This is a more optimistic model than Von Hoerner's estimate in (67), in which the average distance to the ten nearest civilizations is about fifty times larger, and ours is a more pessimistic view than Dr. Lipp's. Dr. S. S. Huang, of Goddard Flight Center, now at Dearborn Observatory, estimates that the number of inhabitable systems is about 3 to 5 per cent of the number of stars; this leads to eight billion inhabitable systems in our galaxy. Our model is close to this estimate.

In the volume of realistic dimensions defined above we find a certain number of races exploring space. We will assume that the only purpose of these explorations is data collection, that both civilizations involved in contacts (if any) are sufficiently different and the duration of the contacts short enough to prevent "feedback" effects which would modify their rates of intellectual development. In order to keep our model free of extrascientific considerations, we will also assume that no colony is established by the visiting race. In this very simplified model, each civilization is allowed only one visit, for scientific purposes, and with limited contact, to another civilization.

We are not making a very restrictive hypothesis if we also assume that as soon as the knowledge a certain race situated in this volume has concerning our system is greater than a certain quantity, the actual sampling takes place. What we are assuming here is simply that exploration of a system is conducted as soon as capability to travel to this point is obtained. The above problem can then be treated as a renewal process.

Consider the birth of a system able to support life. This birth occurs at a certain distance from the sun and a certain time elapses before life actually appears, depending on the physical and chemical conditions in the system, etc. If the system belongs to the total number of planetary systems that actually permit the development of intelligent life, a civilization will eventually develop on one or several planets and, assuming that the technical stage is reached within the lifetime of these civilizations, space travel will be acquired and exploration of space in the vicinity of the system in question will begin.

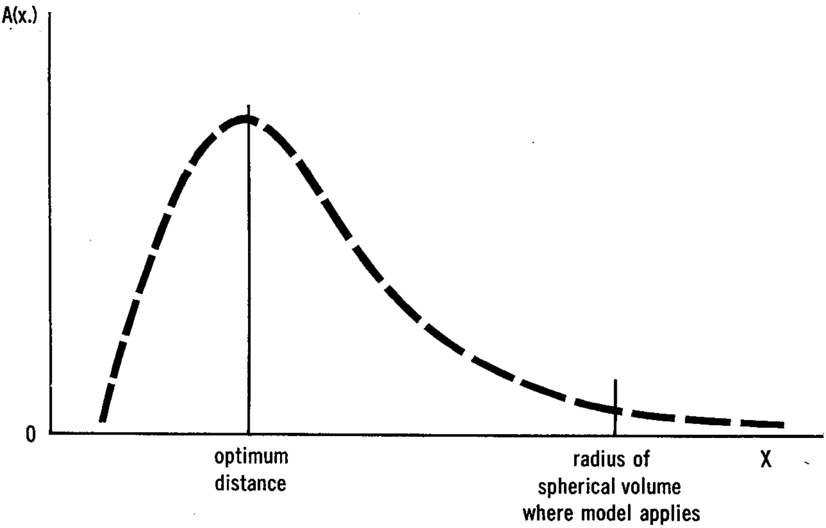
For this technical civilization to acquire sufficient knowledge concerning space travel and concerning our system to be able to sample the earth will require a certain amount of time; this we take as a random variable. During this waiting time other systems may be born and other communities may appear, possibly closer to us, and a new possibility of being visited is to be taken into account. But if we consider on one hand the average time between the birth of systems able to support life, and on the other hand the average time between actual samplings of our system, and if we assume the equilibrium has been reached and that steady-state has been realized, we can show that both average times tend toward the same limit, and this would lead to an estimate of inter-arrival time close to that found by Sagan, namely a visitation every one thousand years (7).

In a complete model, however, one should consider several facts that would increase the probability of visitation after a sufficient time. One would take into account the actual curve of the rate of star-generation for the different types as a function of time, when sufficient data exist from astronomical observations to permit this rate to be estimated. From results obtained through elementary models the expected number of samplings per time period seems to increase very rapidly as soon as the initial stages (during which no race has sufficient knowledge to contemplate travel to the sun) have elapsed. All the considerations involving possible feed-back effects or the foundation of colonies far from the original system, which should be introduced in the discussion but can hardly be formulated in mathematical terms in models of this type, would tend to increase the probability in favor of exchanges between these races.

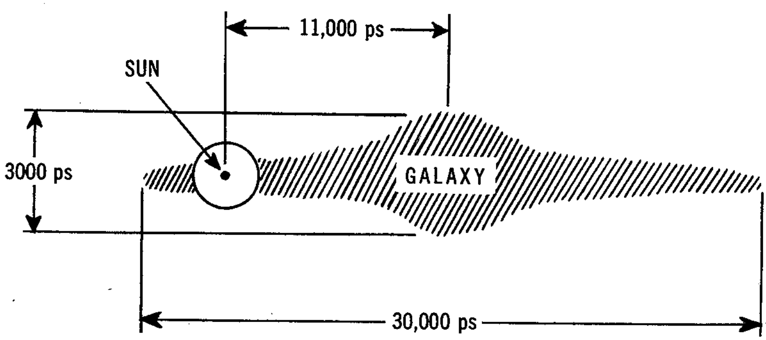
LIMITATIONS OF THIS MODEL

This model is clearly bounded by our ignorance of certain physical laws which might be basic in the technology used by a superior community. In particular, we will point out that the idea of *travel* might undergo considerable variations as knowledge of natural mechanisms is expanded and new physical processes mastered. Most of our ideas about space and time still show the memory of centuries when the wind, the flow of water and the migration of animals and men were the sole illustrations of travel. Only much later was it discovered that physical forces such as electricity (for example, in the form of electrostatic charges) could "travel" in a way which was not easily understandable by *common sense*. Today, we know that people can communicate without actually walking toward each other, without being in visual contact or being connected by material objects such as wires. We can see what goes on in various parts of the world through television; we can even bring back scenes and voices from the past; we have extended our potentiality to travel beyond the immediate material world.

Although space travel as we imagine it (i.e., with some sort of rocket-propelled vehicle) is probably a basic step in the establishment of a technical civilization, it could by no means be considered an ultimate accomplishment. And the *common sense* idea that only propelled vehicles can bridge the gap between adjacent solar systems may well turn out to be as erroneous a view as our fathers' conceptions about the ether. The publicity given to some recent technical feats makes us forget too often that physics, not technology, holds the answer to the problem of space travel. Only when a general solution is found to the very grave questions physicists are debating now will it be possible to formulate satisfactory models for the rational exploration of the universe by scientific communities. The answer to some of the basic problems discussed here undoubtedly lies at this level.



An estimate of the "ability" of a scientific community, situated at a given distance from our sun, to explore physically our system. The optimum distance is large enough to include a number of highly developed technical civilizations, and small enough to allow them to observe our sun and to contemplate actual space travel to our system.



The position of the sun in our galaxy and the dimensions of the spherical volume within which could be situated about four million systems able to support intelligent life. The average distance to the six nearest civilizations would be ten parsecs in this model, in agreement with estimates published by S. S. Huang. The model formulated by S. von Hoerner suggests a larger distance, while the calculations made by J. E. Lipp in the Project Sign report in 1949 were more optimistic.