A Message from Earth
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Reports

A Message from Earth

Pioneer 10 is the first spacecraft that will leave the solar system. Scheduled for a launch no earlier than 27 February 1972, its 630- to 790-day-long flight will take it within two planetary radii of Jupiter, where, in a momentum exchange with the largest planet in the solar system, the spacecraft will be accelerated out of the solar system with a residual velocity at infinity of 11.5 km/sec. The spacecraft is designed to examine interplanetary space between the earth and Jupiter, perform preliminary reconnaissance in the asteroid belt, and make the first close-up observations of Jupiter and its particles and fields environment.

It seemed to us appropriate that this spacecraft, the first man-made object to leave the solar system, should carry some indication of the locale, epoch, and nature of its builders. We do not know the likelihood of the Galaxy being filled with advanced technological societies capable of and interested in intercepting such a spacecraft. It is clear, however, that such interception is a very long term proposition. With a residual interstellar velocity of 11.5 km/sec, the characteristic time for Pioneer 10 to travel 1 parsec (pc)—slightly less than the distance to the nearest star—is some 80,000 years. From the simplest collision physics, it follows that the mean time for such a spacecraft to come within 30 astronomical units (1 A.U. $= 1.5 \times 10^{13}$ cm) of a star is much longer than the age of the Galaxy. Consequently there is a negligible chance that Pioneer 10 will penetrate the planetary system of a technologically advanced society. But it appears possible that some civilizations technologically much more advanced than ours have the means of detecting an object such as Pioneer 10 in interstellar space, distinguishing it from other objects of comparable size but not of artificial origin, and then intercepting and acquiring the spacecraft.

But if the intercepting civilization is not within the immediate solar neighborhood, the epoch of such an interception can only be in the very distant future. Accordingly, we cannot see any conceivable danger in indicating our position in the Galaxy, even in the eventuality, which we consider highly unlikely, that such advanced societies would be hostile. In addition we have already sent much more rapidly moving indications of our presence and locale: the artificial radio-frequency emission which we use for our own purposes on Earth.

Erosional processes in the interstellar environment are largely unknown, but are very likely less efficient than erosion within the solar system, where a characteristic erosion rate, due mainly to micrometeoritic pitting, is of the order of 1 Å/year. Thus a plate etched to a depth $\sim 10^{-2}$ cm should survive recognizably at least to a distance ~ 10 pc, and most probably to $>> 100$ pc. Accordingly, Pioneer 10 and any etched metal message aboard it are likely to survive for much longer periods than any of the works of man on Earth.

With the support of the Pioneer Project Office at NASA's Ames Research Center in Mountain View, California, and of NASA Headquarters in Washington, D.C., it was agreed to prepare a message on a 6- by 9-inch surface of 6061 T6 gold-anodized aluminum plate, 50/1000 inch thick. The mean depth of engraving is 15/1000 inch. The plate is mounted in an exterior but largely protected position on the antenna support struts, behind the ARC plasma experimental package, on the Pioneer 10 spacecraft.

The question of the contents of such a message is not an easy one. The message finally agreed upon (Fig. 1) is in our view an adequate but hardly ideal solution to the problem. A time interval of only 3 weeks existed between the formulation of the idea of including a message on Pioneer 10, achieving NASA concurrence, devising the message, and delivering the draft message for engraving. We believe that any such message will be constrained, to a greater or lesser degree, by the limitations of human perceptual and logical processes. The message inadvertently contains anthropocentric content. Nevertheless we feel that an advanced technical civilization would be able to decipher it.

At top left is a schematic representation of the hyperfine transition of neutral atomic hydrogen. A transition from antiparallel nuclear and electronic spins to parallel nuclear and electronic spins is shown above the binary digit 1. So far the message does not specify whether this is a unit of length (21 cm) or a unit of time [(1420 Mhz)$^{-1}$]. This fundamental transition of the most abundant atom in the Galaxy should be readily recognizable to the physicists of other civilizations. As a cross-check, we have indicated the binary equivalent of the decimal number 8 along the right-hand margin, between two tote marks corresponding to the height of the human beings shown. The Pioneer 10 spacecraft is displayed behind the human beings and to the same scale. A society that intercepts the spacecraft will of course be able to measure its dimensions and determine that 8 by 21 cm corresponds to the characteristic dimensions of the spacecraft.

With this first unit of space or time specified we now consider the radial pattern at left center. This is in fact a polar coordinate representation of the positions of some objects about some origin, with this interpretation being a probable, but not certain, initial hypothesis to scientists elsewhere. The two most likely origins in an astronomical interpretation would be the home star of the launch civilization and the center of the Galaxy. There are 15 lines emanating from the origin, corresponding to 15 objects. Fourteen of these objects have a long binary number attached, corresponding to a 10-digit number in decimal notation. The large number of digits is the key that these numbers indicate time intervals, not distances or some other quantity. A civilization at our level of technology (as evinced from the Pioneer 10 spacecraft itself) will not know the distances to galactic objects useful for direction-finding to ten significant figures; and, even if we did, the proper motion of such objects within the Galaxy would render this degree of precision pointless. There are no other conceivable quantities that we might know to ten significant figures for relatively distant cosmic objects. The numbers attached to the 14 objects are therefore most plausibly time intervals. From the unit of time, the indicated time intervals are all ~ 0.1 second. For what objects might a civilization at our level of advance know time periods ~ 0.1 second to ten significant figures? Pulsars are the obvious answer. Since pulsars are running down at largely known rates

Table 1. The 14 selected pulsars.

Pulsar	Period (1970/1971 epoch) (second)	Period (units of H hyperfine transition)
0328	$7.145186424 \times 10^{-1}$	$1.014906390 \times 10^{9}$
0525	3.745490800	$5.320116676 \times 10^{9}$
0531	$3.312964500 \times 10^{-2}$	$4.705753832 \times 10^{7}$
0823	$5.306595990 \times 10^{-1}$	$7.537519468 \times 10^{8}$
0833	$8.921874790 \times 10^{-2}$	$1.267268227 \times 10^{8}$
0950	$2.530650432 \times 10^{-1}$	$3.594550429 \times 10^{8}$
1240	$3.880000000 \times 10^{-1}$	$5.511174318 \times 10^{8}$
1451	$2.633767640 \times 10^{-1}$	$3.741018705 \times 10^{8}$
1642	$3.876887790 \times 10^{-1}$	$5.506753717 \times 10^{8}$
1727	$8.296830000 \times 10^{-1}$	$1.178486506 \times 10^{9}$
1929	$2.265170380 \times 10^{-1}$	$3.217461037 \times 10^{8}$
1933	$3.587354200 \times 10^{-1}$	$5.095498540 \times 10^{8}$
2016	$5.579533900 \times 10^{-1}$	$7.925202045 \times 10^{8}$
2217	$5.384673780 \times 10^{-1}$	$7.648421610 \times 10^{8}$

they can be used as galactic clocks for time intervals of hundreds of millions of years. The radial pattern therefore must indicate the positions (obtained by us from the observed dispersion measures) and periods at the launch epoch of 14 pulsars, plus one additional object which is the most distant.

The problem thus reduces to searching the astronomical records to find a locale and epoch within the galaxy at which 14 pulsars were in evidence with the denoted periods and relative coordinates. Because the message is so overspecified, and because the pulsar periods are given to such precision, we believe that this is not an extremely difficult computer task, even with time intervals $>> 10^6$ years between launch and recovery. The pulsars utilized, with their periods in seconds and in units of the hydrogen hyperfine transition, are indicated in Table 1. The hyperfine period of $(1.420405752 \times 10^9 \text{ sec}^{-1})^{-1}$, a fraction of a nanosecond, is just small enough so that all the known digits of the pulsar periods can just be written to the left of the decimal point. Accordingly decimals and fractions are entirely avoided with no loss of accuracy and without many noninformative digits. The presence of several consecutive terminal zeros (Table 1), particularly in pulsars 1240 and 1727, imply that, for these two pulsars, we have given a precision greater than we now have. The problem of which end of a number is the most significant digit is expressed automatically in this formulation, since all binary numbers start with a 1 but end in a 1 or a 0. The binary notation, in addition to being the simplest, is selected in order to produce a message that can suffer considerable erosion and still be readable. In principle, the reader only need determine that there were two varieties of symbols present, and the spacings alone will lead to a correct reconstruction of the number.

Those radial lines for which the earth-pulsar distance is not accurately known are shown with breaks. All three spatial coordinates of the pulsars are indicated. The (r, θ) coordinates are given in the usual polar projection. The tick marks near the ends of the radial lines give the z coordinate normal to the galactic plane, with the distances measured from the far end of the line. The reconstruction of pulsar periods will indicate that the origin of (r, θ) coordinates is not the center of the Galaxy. Accordingly the long line extending to the right, behind the human beings, and which is not accompanied by a pulsar period, should be identifiable as the distance to the galactic center. Since the tick mark of this line is precisely at its end, this should simultaneously confirm that the ticks denote the galactic z coordinate, and that the longest line represents the distance from the launch planet to the galactic center. The tick marks were intended to be asymmetric about the radial distance lines, in order to give the sign of the galactic latitude or z coordinate. In the execution of the message this convention was inadvertently breached. But the sign of the z coordinate should be easily deducible without this aid. There is an initial ambiguity about whether the (r, θ) presentation is from the North or South Galactic Pole, but this ambiguity would be resolved as soon as even one pulsar was identified.

The 14 pulsars denoted have been chosen to include the shortest period pulsars which give the greatest longevity and the greatest luminosity; they are, therefore, the pulsars of greatest use in this problem where interception of the message occurs only in the far future. They are also selected to be distributed as evenly as possible in galactic longitude. Included are both pulsars in the vicinity of the Crab Nebula; the second (PSR 0525) has the longest known period. Fourteen pulsars were included to provide redundancy for any position and time solutions, but also to allow for the good possibility that pulsar emission is highly beamed and that not all pulsars are visible at all view angles. We expect that some of the 14 would be observable from all locales. In addition a very advanced civilization might have information on astronomy from other locales in the Galaxy. If the spacecraft is intercepted after only a few tens of millions of years (having traveled several hundred parsecs), all 14 pulsars may still be detectable.

The reconstruction of the epoch in which the message was devised should be performable to high precision: With 14 periods, almost all of which are accurate to nine significant figures in decimal equivalent, a society which has detailed records of past pulsar behavior should be able to reconstruct the epoch of launch to the equivalent of the year 1971. If past records of pulsar "glitches" (discontinuities in the period) are not kept or reconstructable from the physics it should still be possible to reconstruct the epoch to the nearest century or millennium.

Fortuitously, two of the pulsars are very near Earth. If either is correctly identified, it can be used to place the position of our solar system in the galaxy to approximately 20 pc, thereby specifying our location to approximately 1 in 10^3 stars.

To specify our position to greater accuracy, we have included a schematic solar system at the bottom of the diagram. Because of the limited plate dimensions, the solar system was engraved with the planets not in the solar equatorial plane. (If this were an accurate representation of our solar system it would identify it very well indeed!) Relative distances of the planets are indicated in binary notation above or below each planet. The serifs on the binary "ones" are presented to stress that the units are different from those of pulsar length and period. The numbers represent the semimajor axes of the planetary orbits in units of one-tenth the semimajor axis of the orbit of Mercury, or 0.0387 A.U., approximately. There is no way for this unit of length to be deciphered in the message, but the schematic sizes and relative distances—given to three significant figures in decimal equivalent—of the planets in our solar system, as well as the schematic representation of the rings of Saturn seen edge-on, should easily distinguish our solar system from the few thousand nearest stars if they have been surveyed once. Also indicated is a schematic trajectory of the Pioneer 10 spacecraft, passing by Jupiter and leaving the solar system. Its antenna is shown pointing approximately back at Earth. The cross-correlation between this stage of solar system exploration and the instrumentation and electronics of the Pioneer 10 spacecraft itself should specify the level of contemporary human technology with some precision.

The message is completed by a representation at right of a man and woman drawn to scale before a schematic Pioneer 10 spacecraft. The absolute dimensions of the human beings are specified in two ways: by comparison with the Pioneer 10 spacecraft and in units of the wavelength of the hyperfine transition of hydrogen, as described above. It is not clear how much evolutionary or anthropological information can be deduced from such a sketch drawing. Ten fingers and ten toes may provide a clue to man's arboreal ancestry, and the fact that the distance of Mercury from the sun is given as 10 units may be a clue to the development of counting. It seems likely, if the interceptor society has not had previous contact with organisms similar to human beings, that many of the body characteristics shown will prove deeply mysterious. We rejected many alternative representations of human beings for a variety of reasons; for example, we do not show them holding hands lest one rather than two organisms be deduced. With a set of human representations to this degree of detail, it was not possible to avoid some racial stereotypes, but we hope that this man and woman will be considered representative of all of mankind. A raised outstretched right hand has been indicated as a "universal" symbol of good will in many human writings; we doubt any literal universality, but included it for want of a better symbol. It has at least the advantage of displaying an opposable thumb.

Among the large number of alternative message contents considered and rejected were radioactive time markers (rejected because of interference with the Pioneer radiation detectors), star map position indicators (rejected because of stellar proper motions and serious data-handling problems in decoding), and schematic representations of the vascular, neurological, or muscular apparatus of human beings or some indication of the number of cortical neural connections (rejected because of the ambiguity of the envisioned representations). It is nevertheless clear that the message can be improved upon; and we hope that future spacecraft launched beyond the solar system will carry such improved messages.

This message then is a first attempt to specify our position in the Galaxy,

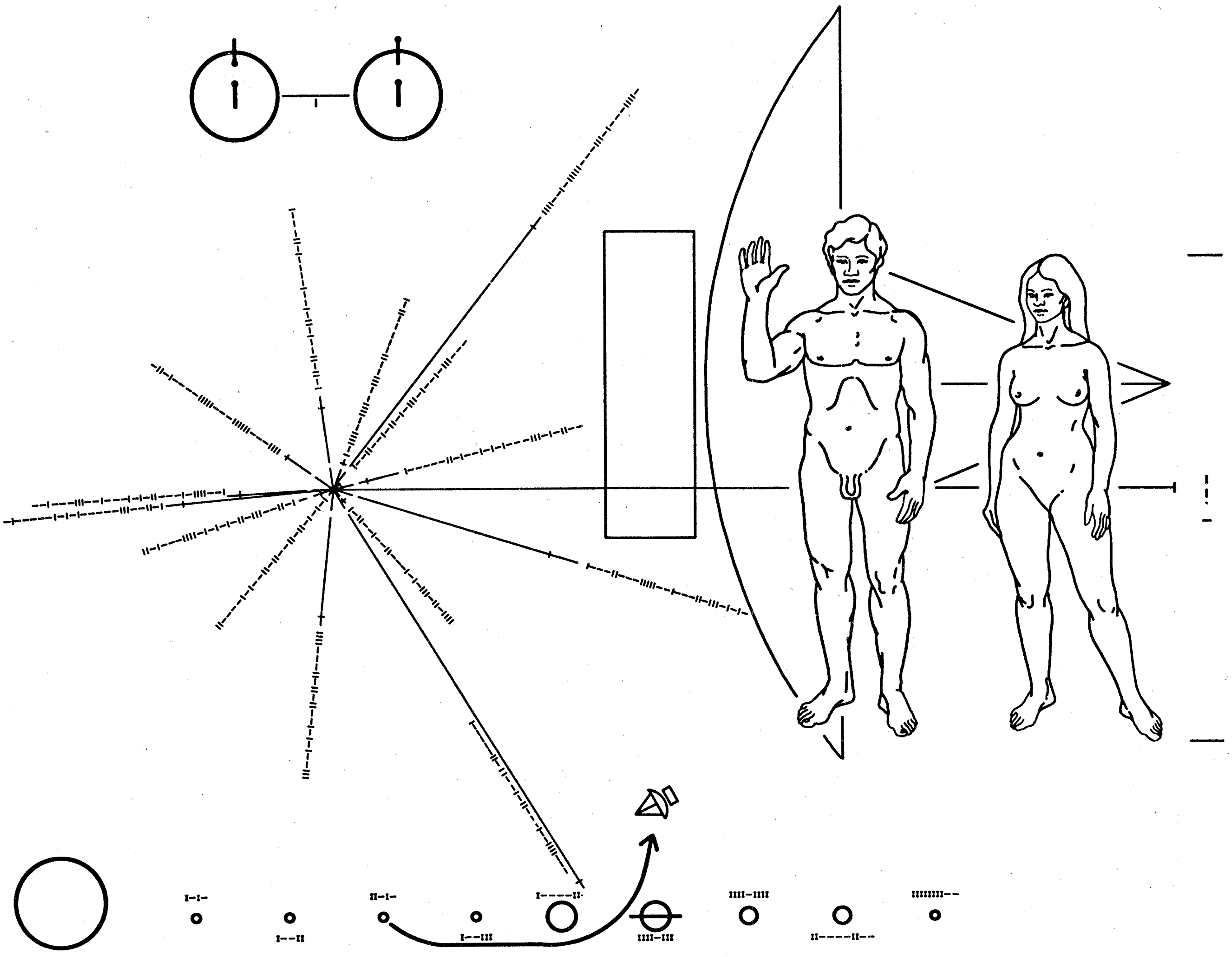

Fig. 1. The engraved aluminum plate carried aboard Pioneer 10. It contains information on the position, epoch, and nature of the spacecraft.

our epoch and something of our nature. We do not know if the message will ever be found or decoded; but its inclusion on the Pioneer 10 spacecraft seems to us a hopeful symbol of a vigorous civilization on Earth.

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Note

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Superconductivity of Double Chalcogenides: $Li_xTi_{1.1}S_2$

Abstract. *Lithium titanium sulfides, $Li_xTi_{1.1}S_2$ ($0.1 < x \leqq 0.3$), become superconducting over the temperature range from 10° to 13°K. They have the hexagonal Ti_3S_4 structure and should not be considered intercalation compounds. This is the first class of noncubic compounds with high transition temperatures.*

We here report the discovery of new superconducting compounds $Li_xTi_{1.1}S_2$ ($0.1 < x \leqq 0.3$) whose properties are quite remarkable. After annealing at 600°C these compounds exhibit superconducting transition temperatures very much higher than those that have been reported in sulfides. Although none of the binary compounds of the constituents, Li-S, Li-Ti, or Ti-S, becomes superconducting above 1°K, the new ternary compounds do so over the temperature range from 10° to 13°K with "onset" temperatures as high as 15°K. The new compounds are also noteworthy in that such high transition temperatures are achieved for the first time in a hexagonal rather than cubic structure. It is also important to point out that the compounds with the composition $Li_xTi_{1.1}S_2$ are very unstable between 77°K and about 600°K.

When held for even a few hours at room temperature, the transition temperature drops a few degrees and the compounds no longer show a bulk effect. Subsequent annealing, however, completely restores the superconductivity as a bulk effect at the high transition temperatures mentioned above. These compounds can be prepared by melting together the appropriate amounts of Li metal and titanium sulfide, $Ti_{1.1}S_2$, having the CdI_2 structure. The double sulfides $Li_xTi_{1.1}S_2$ ($0.1 < x \leqq 0.3$) have the hexagonal Ti_3S_4 structure. A comparison of the interplanar spacings and the observed intensities is given in Table 1 for $x = 0.3$.

Many different phases exist in the Ti-S phase diagram, each one having a large homogeneity range (*1*). Titanium monosulfide, TiS, can crystallize with the NiAs structure, whereas the disulfide, TiS_2, crystallizes with the CdI_2 structure. Even though it is possible to bring about a continuous change from a NiAs structure to a CdI_2 structure, titanium sulfides with the composition $Ti_{1+x}S_2$ ($0.1 < x \leqq 0.5$) have a different hexagonal structure (*2*). They belong to space group $P6_3mc$ with $a \simeq 3.42$ Å, $c \simeq 11.42$ Å, and two molecules per unit cell. The atoms are in the following positions: 2Ti(1) in special positions $2b$ ($\frac{1}{3}, \frac{2}{3}, z$; $\frac{2}{3}, \frac{1}{3}, \frac{1}{2} + z$) with $z \simeq \frac{3}{4}$; xTi(2) in $2b$ with $z \simeq 0$; 2S(1) in $2b$ with $z \simeq \frac{3}{8}$; and 2S(2) in the special positions $2a$ ($0, 0, z$; $0, 0, \frac{1}{2} + z$) with $z = \frac{1}{8}$. The S atoms in $Ti_{1+x}S_2$ are in alternate hexagonal and cubic close-packing, whereas in both TiS and TiS_2 they are all hexagonal close packed. The Ti atoms occupy the octahedral sites in the close-packed array of the S atoms, in such a way that they form alternate completely filled and partly occupied sheets of metal atoms. The limiting composition is Ti_3S_4, because the partly filled sheets can only be half filled. The S octahedrons around the atoms forming the filled sheets share faces, perpendicular to the *c* axis, with the octahedrons of the partially filled sheets. There are two crystallographically independent S atoms in the structure. They have different environments: S(1) is at the center of a trigonal prism of Ti atoms, whereas S(2) is at the center of the octahedron. The compounds $Li_xTi_{1.1}S_2$ with $0.1 < x \leqq 0.3$ crystallize with this structure. They do so because the ratio of metal to S is within the limit of existence for the sulfide $Ti_{1+x}S_2$ with $0.1 < x \leqq 0.5$ and also because the effective radii of Li and Ti are nearly the same. It is not possible, on the basis of the x-ray data available at present, to determine which octahedral sites are occupied by the Li atoms. Neither before nor after annealing at 600°C did we find any evidence of superlattice reflections corresponding to a multiple *a* axis; therefore the metal atoms and the vacancies are not ordered in the half-filled layers. This disorder has also been reported for the titanium sulfides which have the same structure (*2*), whereas complete order has been shown to the exist for the isostructural Cr_2S_3 (*3*). Although we have not refined the structure of any of the $Li_xTi_{1.1}S_2$ compounds, we can estimate the metal-metal separation across the shared octahedral face to be approximately 2.88 Å for $x = 0.3$. The Ti-Ti distance in Ti metal is 2.90 Å; therefore some strong metal-metal

Table 1. Crystal data for $Li_{0.3}Ti_{1.1}S_2$ (hexagonal structure, $a = 3.439 \pm 0.003$ Å, $c = 11.511 \pm 0.009$ Å); *d*, interplanar spacing; strong, s; medium, m; weak, w; very weak, vw; very very weak, vvw.

Intensity	*hkl*	d_{obs} (Å)	d_{calc} (Å)
m	002	5.772	5.756
w	100	2.961	2.978
w–m	004 101	2.887	2.883 2.878
s	102	2.642	2.645
m–s	103	2.351	2.353
w	104	2.070	2.069
vw	006	1.906	1.919
w	105	1.825	1.821
s	110	1.717	1.719
vw	112	1.646	1.648
w	106	1.615	1.613
vvw	201	1.480	1.477
w–m	202	1.441	1.442
w	203	1.387	1.388
vw	204	1.324	1.323
vvw	116	1.279	1.280
vw	205	1.250	1.250
vw	206	1.175	1.176
m	212	1.105	1.105
w	213	1.080	1.080
vw	214	1.048	1.048
vw	215	1.011	1.011
w	300	0.993	0.993
vw	216	.971	.971
w	220	.859	.860
w	312	.818	.818
vw	313	.808	.808