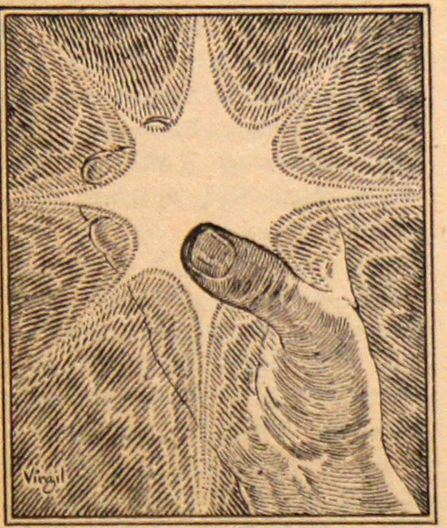
No. IV of a series on the possibilities of Extra-terrestrial Life*



LIFE AMONG THE STARS

By BEN BOVA

Illustrated by FINLAY

WITHIN this generation, Earthmen will explore the Moon and nearer planets, and many of our speculations about extraterrestrial life will be either confirmed or destroyed. But the solar system is only one tiny corner of the observable universe. Beyond distant Pluto lie the remote and beckoning stars. Do they possess planetary systems? If so, do those planets bear life?

Remember that we are operating under the assumption that the stars are essentially similar to the Sun. Astronomers now believe that the Sun and planets coalesced out of a primeval cloud of interstellar gas and dust. The evolution of the solar system to its present condition—including the existence of life on one or more of the planets—is considered to be a completely natural sequence of events. Nothing unusual is necessary to explain the solar system's evolution. Granted the same conditions elsewhere (and these conditions, as we will shortly see, may be quite ordinary throughout interstellar space) a similar development would eventually lead to the formation of a star and, perhaps, a system of planets.

Looking for the Unseeable

THE best way to illustrate the frustrations of searching for planets circling other stars is to

*Previous articles appeared in June, July and September AMAZING imagine, for the moment, that we have been magically transported to Alpha Centauri A, the brightest component of the triple-star Alpha Centauri system, and a star that is almost identical to the Sun. Let us further suppose that we have at our disposal the best astronomers and astronomical equipment currently available on Earth.

Now we look back at the Sun, 4.3 lightyears away, and try to find the planets that we know are there. To make things easier on ourselves, we shall try to find only Jupiter, the largest and most easily-visible of Sol's nine planets.

Even through a 200-inch telescope, we can see nothing. The Sun appears to be a first-magnitude star; but Jupiter, the astronomers' computations reveal, should be a twenty-third magnitude object at this distance. That is, Jupiter should appear some *one billion* times fainter than the Sun!

A 200-inch telescope can pick up twenty-third magnitude stars —under good conditions. But Jupiter is very close to the bright Sun, and is drowned out in glare. If the planet were further away from Sol, the glare problem would be reduced, but Jupiter would become even dimmer, since its only light is that which it reflects from the Sun. Conversely, if Jupiter were closer to the Sun it would be brighter, but the increased brightness would be more than offset by the glare effect, which becomes worse as the faint object comes closer to the bright one.

So visual detection seems to be out.

However, astronomers have been able to find several objects in the sky that at first were invisible to them. Objects such as the faint dwarf stars accompanying Sirius and Procyon were originally detected through the gravitational perturbations that they induced in the motions of their bigger, brighter partners.

Sirius, for example, was observed in 1844 to be bobbing back and forth through space for no apparent reason. A star, like any body in a frictionless vacuum, should move through space in a straight line—unless some outside force is deflecting it.

Sirius was weaving through the sky in corkscrew fashion; something was pulling at it, gravitationally. When a good-enough telescope was turned on the Dog Star, the dim dwarf Pup was visually discovered. The same tactics led to the discovery of Procyon's dwarf companion, and also to the planets Neptune and Pluto.

Can we detect the presence of Jupiter by its gravitational pull on the Sun? Every body in the


Virgil Finlay

solar system exerts a gravitational pull on all the other bodies. This pull is directly proportional to the mass of the bodies concerned. The Sun, with a mass of 2.24 x 10^{27} American tons, keeps all the planets, comets, etc., gravitationally bound to itself.

JUPITER, the biggest body in the solar system except for the Sun, has a mass of slightly less than 0.001 times Sol's. Its gravitational influence on the Sun is minute. Jupiter deflects the Sun's forward motion through space by less than one-hundreth of a second of arc (1/36,000 of a degree of arc—about the size of a twenty-five cent piece, seen from 300 miles away!). This heartbreakingly-small motion is just a shade under the amount of deflection that astronomers can detect with their present instruments. So it appears that Jupiter would be undetectable by this means also from Alpha Centauri.

Obviously the same problems confront us here on Earth when we attempt to determine if there are planets near any of the three Alpha Centauri stars. We cannot see such planets, even if they are there. We cannot detect gravitational perturbations from a planet even as massive as Jupiter.

The immense distances between the stars, and the practically infinitesimal mass and brightness of planets as compared to stars, is an almost impassable barrier.

The Mysterious Companions

Almost impassable. A few of the nearest stars have shown perturbations due to companions that are too faint to be picked out visually.

For example: of the three stars closest to the Sun, two of them—Barnard's Star, 6.1 light-years away, and Lalande 21185, 7.9 lightyears—are accompanied by invisible companions.

While we cannot see these companion objects, either because they are too dim or too close to their primary stars, we can compute their masses by measuring the perturbations they cause on their respective stars. In both cases, the masses work out to be slightly less than 0.1 times the Sun's—about 100 times larger than Jupiter. This is an immense mass for a planet, but quite a small mass for a star.

The orbital periods ("years") are 11 months for Barnard's Star's companion and 14 months for Lalande 21185's. The dark "fellow travellers" are both estimated to be less than 1 AU from their respective stars—closer than the Earth is to the Sun.

Several other stars near the Sun are known to have unseen companions. Among them are

Epsilon Eridani, Tau Ceti and the double star 61 Cygni, each of which will be significant parts of the story to follow. The suspicion is that there are myriads of stars with small, dark companions. We cannot detect any but the very closest from Earth, though, since these objects become increasingly difficult to find with distance.

Stars vs. Planets

NOW then, are these unseen companions truly planets? Or are they very small, very dim stars?

Most astronomers have accepted a rule of thumb first proposed by the American, Henry Norris Russell, in 1944. He suggested that any invisible companion of a star that is estimated to be smaller than 0.05 times the Sun's mass should be arbitrarily designated a planet. More massive companions should be classified as dwarf stars, until evidence is available to settle the question definitely.

According to this convention, the companions of Barnard's Star and Lalande 21185 are both technically labelled as stars. However, the double star 61 Cygni (a pair of small reddish stars, 11.1 lightyears away) has an invisible third component with a mass of about 0.017 times the Sun's. Thus 61 Cygni C, as it is called, can be termed a planet even under Russell's conservative system.

What kind of a planet might 61 Cygni C be? If the estimation of its mass is accurate, it is about 170 times larger than Jupiter. A giant among giant planets; probably much like Jupiter in chemical composition—an atmosphere of hydrogen, helium, ammonia and methane; crushing gravity. Totally alien.

And yet, this is precisely the type of planet we should expect to find, considering how limited our information-gathering equipment is. A small planet orbiting close to its parent star—like Earth—would be impossible to observe or even detect. Our chances of finding a planet increase as we consider larger, heavier planets. There may be a multitude of Earth-type planets virtually next door to us, but they are totally undetectable as long as we are Earthbound.

However, there is another aspect to consider.

We have been operating under the assumption that, since the Sun is an average Main Sequence star, our planetary system represents a rather ordinary condition for most stars. Hence, there should be almost as many planetary systems as there are stars. But many astronomers have pointed out that the Sun is a single star in a galaxy that seems to show a preference for double and multiple stars. Of the 12 stars nearest the Sun, eight of them are double or multiple. Of these eight, four have unseen companions that may well turn out to be small stars, not planets.

These astronomers go on to conjecture that stars "prefer" to exist in double or multiple groups, and that the Sun and its planetary system represents an extreme case where there was not enough building material available in the original gas cloud to create two stars. Hence, a single star and some cosmic rubble—the planets—resulted.

Of course, in the case of 61 Cygni we see a formation that clearly has at least two stars, and probably one giant planet. There might even be more planets in the system, undetectable from Earth. So we could conclude that it is not impossible for double or multiple stars to evolve with planets.

Moreover, the history of astronomy has repeatedly shown that attempts to consider the conditions closest to us as unique or extreme, are usually hopelessly incorrect. Our planet is not unique, neither is our Sun. Is it reasonable to conclude that our solar system is?

The Conditions for Life

EVEN the pessimists, though, agree that there must be literally hundreds of millions of stars that possess planetary systems. What requirements must be met to make these planets possible abodes of life?

Dr. Si-Shu Huang, of Princeton University's Institute for Advanced Study, has given this problem considerable thought. He concludes that two major conditions must be met:

1. The star around which the planets orbit must be stable in life span and luminosity;
2. The planets must have stable orbits that lie within a "thermally habitable" zone.

A Stable Star: The first condition is simply a recognition that, on the one hand, stars change and evolve (in some cases comparatively rapidly); while, on the other hand, it takes a good deal of time to develop life.

Figure 1 (page 71) illustrates this point graphically. Earth and the Sun developed, presumably, out of the same interstellar gas cloud and at the same time—some five billion years ago. It is believed that life first appeared on our planet some 2.5 billion years ago, although the earliest known fossils are less than one billion years old.

Assuming that life on Earth is 2.5 billion years old, this means that it took an additional 2.5 billion years for "chemical evolution" to build up molecules of sufficient complexity to become living. So, in the solar system's five-billion-year history, it took 2.5 billion years for the first life to appear on Earth, and an almost equal time for intelligent life to evolve. During all this time, the Sun has been a Main Sequence star, and has beamed out a practically unvarying stream of energy.

If the Sun's output had changed as little as a few percent, our atmosphere might have been boiled away, or our seas might have been frozen. The Sun is destined to remain on the Main Sequence for another five or six billion years, so we have a long future of solar stability to look forward to. But, eventually, our star will enter its death throes of expansion, explosion and extinction.

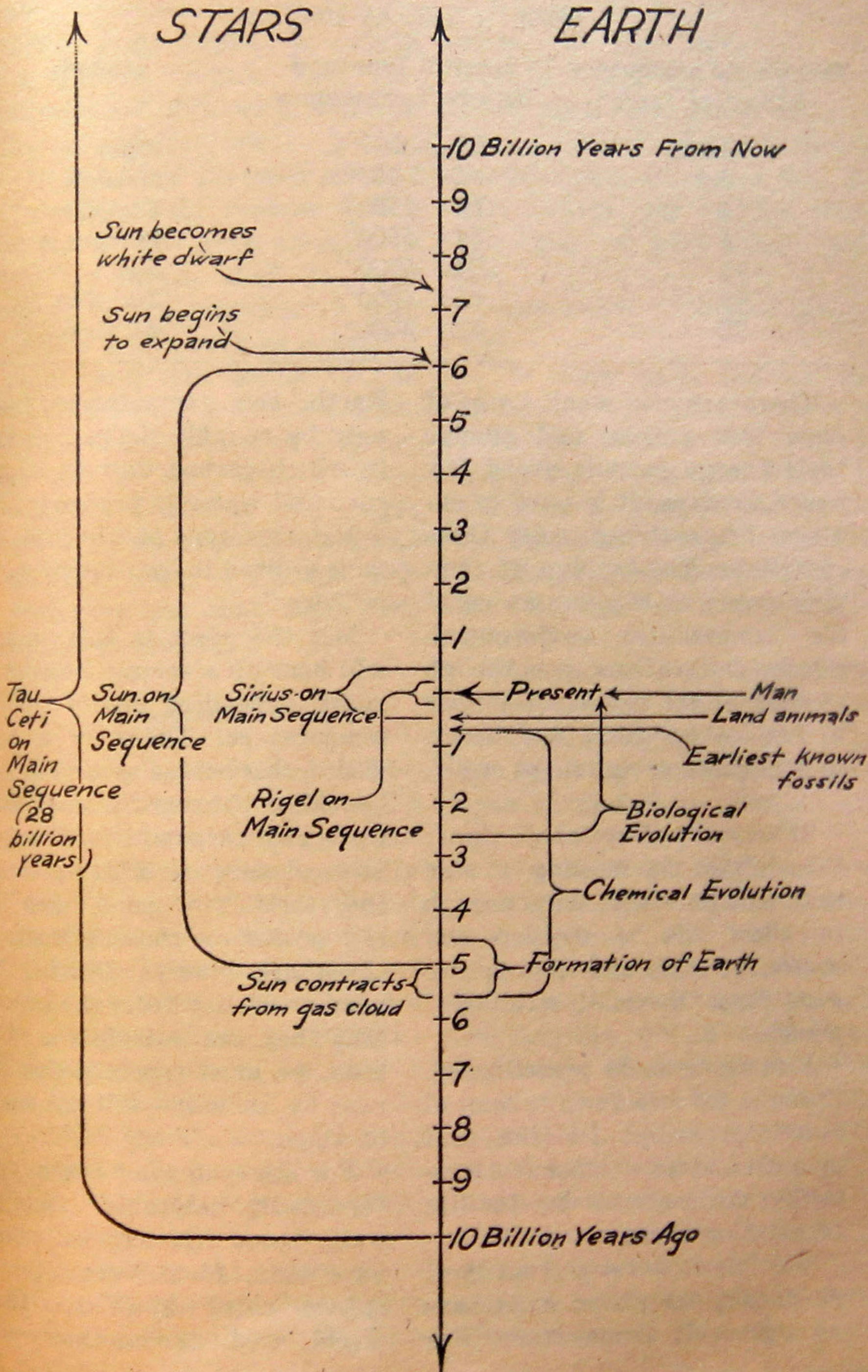
Not all stars are as marvelously constant as the Sun. As Figure 1 shows, Sirius probably became a Main Sequence star well after the first life forms evolved on Earth. And Sirius' lifespan is so short that one-half of this double star has already gone into white dwarfdom, the inevitable fate of all stars. The blue giant Rigel, it has been deduced, cannot be older than 10 million years! Born yesterday, on an evolutionary time scale.

MEANWHILE, small, dim dwarf stars like Tau Ceti will age so slowly, and remain on the Main Sequence for so long, that they make the Sun seem prodigal. Table 1 (page 72) shows the expected life-spans of several different types of stars.

As can be seen by comparing Table 1 with the time spans on Figure 1, planets circling the fast-living B- and A-type stars would not have enough time to develop life before their stars headed for extinction. Even F0 types apparently evolve too quickly to allow life sufficient time to get started. The "break-even" point comes at about spectral class F5, which is on the Main Sequence for about six billion years—long enough to allow chemical evolution and perhaps even the evolution of intelligence.

Figure 1, opposite page, shows life span of stars contrasted to time necessary for development of life. Sun has been on Main Sequence (and hence stable) for some five billion years. During that time, chemical evolution has led to living forms and eventually to intelligent life. Fast-living stars such as Sirius and Rigel apparently are not stable long enough to allow life sufficient time for development. In contrast, smaller, fainter stars—such as Tau Ceti—will remain on Main Sequence even after Sun has expanded, exploded and become dwarf star.

FIGURE 1



STARS
EARTH
10 Billion Years From Now
9
8
7
6
5
4
3
2
1
Sun becomes white dwarf
Sun begins to expand
Tau Ceti on Main Sequence (28 billion years)
Sun on Main Sequence
Sirius on Main Sequence
Present
Man
Land animals
Earliest known fossils
1
Rigel on Main Sequence
2
Biological Evolution
3
Chemical Evolution
4
5
Formation of Earth
Sun contracts from gas cloud
6
7
8
9
10 Billion Years Ago

TABLE 1: STELLAR LIFESPAN

Time on Main Sequence (Billions of Years)	Spectral Type and Surface Temperature	Example
0.002	B5-20,000°C	Rigel
0.4	A0-10,000°	Sirius A
4	F0 - 7500°	Canopus
6	F5 - 6500°	Procyon A
11	G0- 6000°	Sun
28	K0- 4900°	Tau Ceti
70	K5- 4000°	61 Cygni

There are also many types of stars that pulsate and change their energy outputs every few hours, or days. It is hard to envision life evolving under these conditions. The buildup of complex molecules requires an equable temperature environment. Sudden fluctuations, even though regular, might well be a fatal bar to chemical evolution (and, hence, to biological evolution as well).

"Thermally Habitable" Zone: In addition to needing a star that will be stable long enough to allow life to develop and evolve, we must add the requirement for a "thermally habitable" planet.

Life seems to be planet-based. Space is too cold for biochemical reactions, except for the first primitive steps of chemical evolution; stars are too hot for life to exist on them.

For life to develop from inert chemicals, the planet must have an agreeable temperature. For Earth, this temperature range may be roughly defined as that in which carbon dioxide is gaseous and water is predominantly liquid. Our type of life could not have evolved in ice—either water or "dry."

But the point is this: a star will heat up a certain amount of space, depending on its surface temperature. There is a zone within this heated space that can be called "thermally habitable" for a given type of life. If one or more planets are orbiting within the star's "t-h" zone, then life can evolve on those planets. If there are planets orbiting too near or too far from the star, so that they are outside the "t-h" zone, we must conclude that life —as we know it—will not evolve on them.

For our own solar system, the "thermally habitable" zone for water-based life extends, as we have seen, from Venus (atmosphere only) to Mars; there might well be another "t-h" zone, for ammonia-based life, extending from Jupiter to Saturn (it appears unlikely that ammonia-based life could exist on Uranus and Neptune).

To be a good prospect for life, a planet should remain within its star's "t-h" zone permanently. This means that its orbit cannot be too eccentric. A long elliptical orbit, such as a comet's would carry the planet in and out of the zone constantly, making the development of life improbable, at best. Also, a planet bound to a double star might have a highly unusual orbit, and two "t-h" zones to contend with —complications that might well bar life-chemistry.

The Question of Spin

WE have seen that stars hotter than spectral class F5 probably evolve too quickly, and are on the Main Sequence for too short a time, for life to develop near them. Also, in considering "thermally habitable" zones, we should realize that the dim, cool dwarf stars—such as Proxima Centauri—can heat up only a very small amount of space; therefore the chances of having a planet within such a star's "t-h" zone are correspondingly small.

Apparently, the stars most likely to harbor life lie between spectral classes F5 and K5. This rules out the brightest, largest stars; it also rules out the dwarfs, which are probably the most numerous single type of star. However, if we seriously consider ammonia-based life, the cool dwarfs may sponsor more life than we give them credit for.

Now comes a curious discovery.

The stars spin, just as the planets do. But stellar spins vary from 200 miles per second, or more, for a star like Rigel, to about three miles per second for the Sun and similar stars. The question occurs, why should some stars spin so fast and others so slowly?

The answer is intriguing. The Sun's spin has been absorbed by the wide-swinging planets. The fast-spinning stars presumably have no planets to absorb their spin.

So a star's spin might indicate whether or not the star possesses planets! And what do we find when we follow this clue? It is precisely at spectral class F5 that the spin of stars shows a strange change. Stars hotter and larger than F5 rotate rapidly. But at F5 and below, the stars' spins suddenly slow down to speeds like the Sun's. Indications are that this is precisely what would happen if planetary systems were accompanying such stars.

Statistics, OZMA, and Faith

CONSIDER the statistics. Of the 40 stars nearest the Sun, there are seven unseen companions. All but three of them are heavier than Russell's arbitrary figure of 0.05 times the Sun's mass, so we must reject them as possible planets.

The three remaining objects are orbiting around Tau Ceti, Epsilon Eridani, and 61 Cygni. Since the orbit of a planet tied to a double star is apt to be highly eccentric, we should reject 61 Cygni C as a possible life-bearing planet. That leaves the companions of Tau Ceti and Epsilon Eridani. Both these stars are very stable, spectral classes K0 and G5, respectively.

Two possible life-bearing planets out of 40 stars. A ratio of one in 20. If one of every 20 of the Milky Way's 100 billion stars harbors a potentially life-bearing planet, that means there are five billion possible homes for life in this galaxy.

Now, statistics are not proof, and speculation is not evidence. But there is enough information available to make the questions intriguing.

Scientists have become comfortable enough with the possibilities of extra-solar-system life to begin listening for intelligent radio signals from Tau Ceti and Epsilon Eridani. This is Project OZMA, underway at the National Radio Astronomy Observatory at Greenbank, West Virginia.

The chances of picking up intelligent signals from these two nearby stars are, frankly, astronomical. The statistics work against us here. For if the stars in fact do possess planets, they might be Earth-type planets. Even if they are, intelligent life might well not have developed on them. And even if intelligent beings are there, a cultural difference of a scant century below or beyond us could mean that they either have not yet developed radio telescopes or they are so far beyond them that they cannot conceive of intelligent creatures having to use them for interstellar communication.

Worst of all, they might be *exactly* like us, and doing precisely what we are doing—listening, but not transmitting.

But regardless of this first adventure in interstellar communication, we have established that: (1) the forces that created the solar system can, and probably do, create other stars and planetary systems just as easily; (2) the physical and chemical processes that build stars and planets also lay the groundwork for the evolution of life; (3) given the proper conditons of a stable star with sufficient heat-energy output, there is no reason to assume that life will not develop and evolve.

Intelligent life? Humanoid life? That's another story, depending on different lines of evidence and deduction.

The important point, however, is that man is finally reaching out into the universe. The laws of statistics tell us that, for any given star, the chances are always 50-50 that life will be there; but for a large enough sampling of stars, it appears inevitable that we will find life. Disappointments will be plentiful, of course, but since when has that stopped the human race?

No, the solar system and even the stars will be inspected by man's instruments, his rockets, and eventually by man himself. Earth is not the only abode of life and intelligence. Those of us who have the faith—scientists and science fictioneers, dreamers and technicians—realize full well that *this* is the only adventure worthy of a civilized man.

THE END