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ABCs of Space

By: John Kraus

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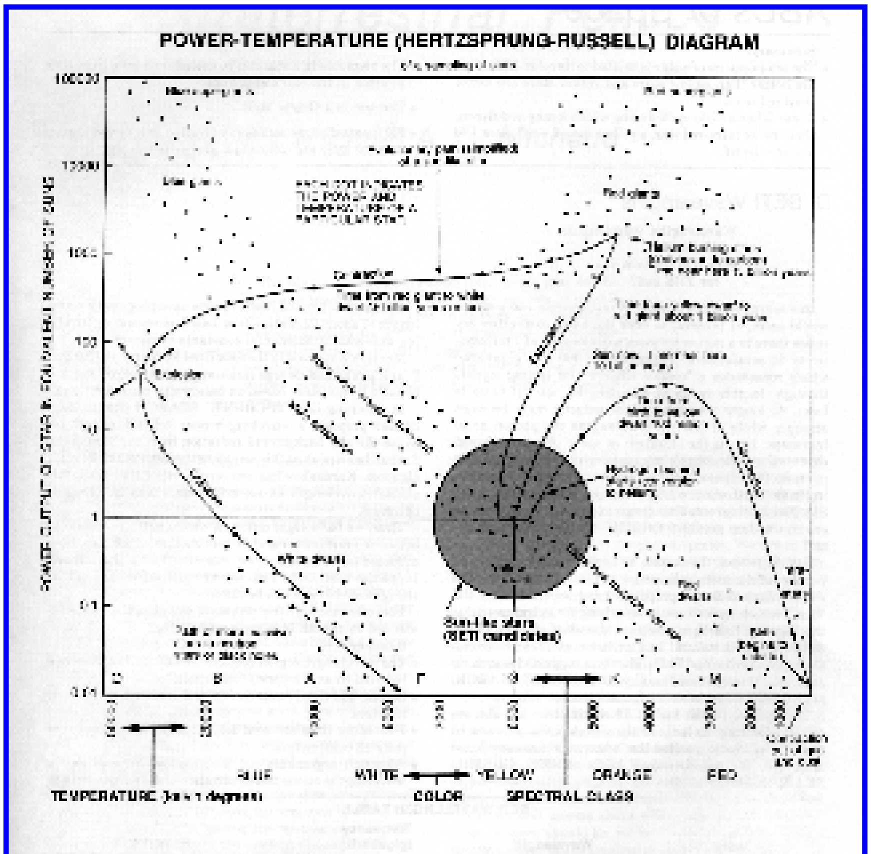
A. Stars and Their Spectra; the Sun-like Stars

Are all stars alike? No indeed, there are many different kinds. The list is long and their names are intriguing. There are red giants, blue giants, white dwarfs, red dwarfs, yellow dwarfs (our sun is one), infra-red stars, neutron stars (or pulsars), black holes and many more. Stars may also be described as old, young or middle aged, first generation or second generation.

At birth a star is an infra-red type. After maturing it may spend a long time, measured in billions of years, in a relatively stable state (the sun is at present in this condition). Growing older it may become unstable and explode as a nova or supernova, its remnant collapsing into a white dwarf, a pulsar or a black hole. During its lifetime a single star may be an infra-red star, a yellow dwarf, a red giant and a white dwarf so that many of the different names simply indicate the age or condition of a star.

It is a remarkable achievement that astronomers have been able to learn so much about the age and evolution of stars because stars live for billions of years while our knowledge of them is very brief. The situation is like that of a mayfly, which lives for a day, trying to comprehend the human life cycle from what it can see of a holiday crowd at a picnic. The mayfly is not able to watch a certain infant grow through childhood to maturity. The mayfly must infer that the different sizes and conditions of the humans, whether active or infirm, are indicative of their age. Like a mayfly, the astronomer has inferred from his brief view of the stars something of their age and evolution.



Star groupings on a *Power-Temperature* or *Hertzsprung-Russell Diagram*. Each dot represents an individual star. The curved line traces the possible evolutionary sequence of a star, such as the sun, from its condensation out of a dust and gas cloud (birth) to its period as a main sequence star where it remains a long time before expanding into a red giant followed by contraction, explosion (nova or supernova) and collapse into a white dwarf. A more massive star might collapse further into a neutron star (pulsar) or even a black hole. The bottom scales give the temperature in degrees kelvin, the corresponding colors and the spectral class letters. The circle centered on the sun (embracing F, G and K stars of the Main Sequence) includes the sun-like stars which are regarded as SETI candidates. A typical star, such as the sun, is about a million kilometers in diameter, a white dwarf about ten thousand kilometers in diameter (earth size), a neutron star or pulsar about ten kilometers and a black hole less than one kilometer in diameter.

One of the great strides towards an understanding of stars was taken by Enjar Hertzsprung of Denmark and Henry Norris Russell of Princeton in the first decade of this century. Working independently, they studied the relation of the power of stars to their temperature. With the aid of a **Power-Temperature Graph**, now called a *Hertzsprung-Russell diagram* [at the left], they found that most stars are in a well-defined region, called the *main-sequence*, extending diagonally from the upper-left to the lower-right of the diagram. But there are also stars at other parts of the diagram. Those at the upper-right are relatively cool (red) but very powerful, so they must be very large. They are called *red giants*. The star Betelgeuse is an example. The stars at the lower-left are relatively hot (white) but weak. Therefore, they must be small. They are called *white dwarfs*. The companion star to Sirius is a white dwarf. The sun, with an intermediate temperature of 6000 kelvin degrees, is a yellow dwarf star which is on the main sequence.

When the light from a star is passed through a prism it is spread out into its spectrum of component colors or wavelengths as in a rainbow. By noting the strongest color of the spectrum an astronomer can determine the star's temperature. Thus, the temperature for a hot blue star may be 20,000 kelvin degrees while the temperature of a relatively cool red star may be only 3000 degrees. In addition to the broad colors (or broadband *continuum radiation*) there may be relatively narrow features called *lines* associated with particular atoms in the star. Each chemical substance has a unique pattern of lines, as distinctive as a finger print. Working like a detective, an astronomer can deduce from these lines what elements are present in a star.

From the spectral colors and spectral lines, astronomers have classified stars into spectral types covering the color range from blue to red by a series of letters: O, B, A, F, G, K, M. Hot blue stars are O or B types, cooler red stars are M types. The sun is an intermediate temperature yellow star of the G type.

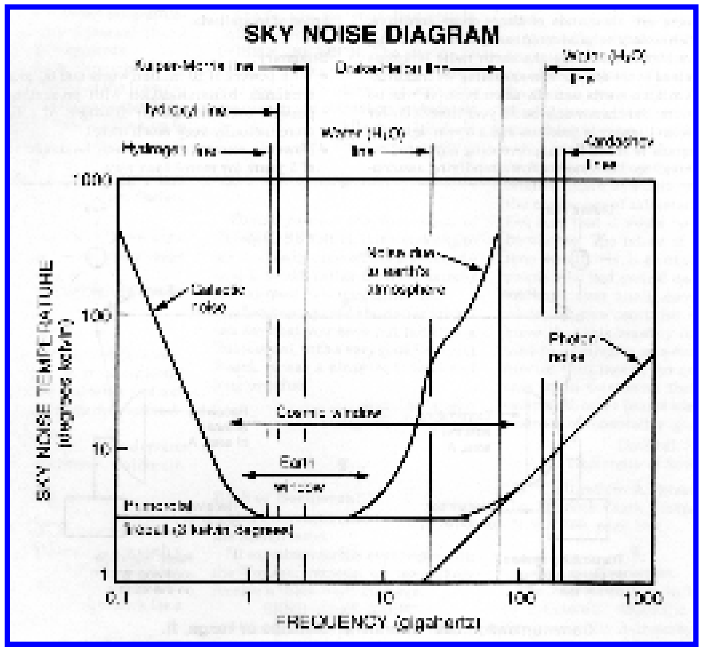
What has all this to do with SETI? Simply that if one G-type star, the sun, has planets one of which, the earth, has intelligent life, we might do better to search for tell-tale signs of life associated with G-type stars than other types. Thus, the nearer G-type stars have been considered as prime candidates for possible beacon signals. The first star at which Frank Drake pointed an antenna in his famous Project Ozma, is a G-type star, Tau Ceti (see **COSMIC SEARCH** for January 1979). Stars of the spectral types F and K are close enough to G to also be considered as likely candidates. The second star at which Drake pointed his antenna is a K-type star, Epsilon Eridani.

Summary:

- The temperature of a star is related to its color. Blue stars are hotter than yellow stars and yellow stars are hotter than red ones.
- A star follows a life-cycle during which it may at different times be an infra-red star, a yellow dwarf, a red giant and a white dwarf.
- The elements in a star can be determined from lines they produce in the star's spectrum.
- The sun is a G-type star.
- SETI searches are commonly directed at F, G and K stars because they are somewhat similar to the sun.

B. SETI Wavelengths

Wavelengths, wavelengths,
  of them all,
Which is the best one
  for THE call?



In a search for extraterrestrial intelligence, radio waves would seem, at present, to offer the best possibilities because there is a region between wavelengths of 1 millimeter to 30 centimeters (frequencies of 300 to 1 gigahertz) which constitutes a "cosmic window" for letting signals through. In this range of wavelengths natural noise is least. At longer wavelengths the galactic noise becomes stronger while at shorter wavelengths the photon noise increases. This is the situation in space. For earth-based observations the earth's atmosphere intervenes and this narrows the window on the short wavelength side, resulting in an "earth window". The situation is illustrated by the **Sky Noise Diagram** [at the right]. This diagram shows a portion of the one in the January 1979 **COSMIC SEARCH** in more detail.

But for either the cosmic or earth window the actual number of channels is enormous and in order to narrow the choice many different proposals have been made for the "best" wavelength to use in searching for extraterrestrial intelligence. Hydrogen, the most abundant element in the universe, has a natural line emission at 21 centimeters. Giuseppe Cocconi and Philip Morrison suggested searching at or near this line (see January 1979 **COSMIC SEARCH**, page 5) and it has been a popular choice.

The hydroxyl (OH) line at 18 centimeters has also received attention. In fact, all the wavelengths between 18 and 21 centimeters, called the "waterhole" are considered attractive for searches (see ABCs of SETI, **COSMIC SEARCH**, March 1979).

Thomas Kuiper and Mark Morris have proposed a wavelength of about 12 centimeters, based on reasoning involving universal fundamental constants of nature.

Mention was made in the SEnTInel for March (1979) that Frank Drake and George Helou suggested a wavelength of about 4 millimeters based on bandwidth considerations.

In a coming issue of **COSMIC SEARCH** Nikolai Kardashev proposes a wavelength near 1.7 millimeters because the sky background radiation from the primordial fireball has a peak at this wavelength which is like a cosmic signpost. Kardashev has reasoned further that a slightly shorter wavelength of 1.5 millimeters may be closer to optimum.

Thus, we have eight different wavelengths in the range between 1 millimeter and 21 centimeters which have been proposed for various reasons. Are some better than others? Is one the best? Or is THE wavelength one we haven't yet thought of? No one can be sure.

For convenience, the proposed wavelengths are summarized in the **SETI Wavelength Table**.

SETI WAVELENGTH TABLE

Name	Wavelength	Frequency (gigahertz)	Remarks
Hydrogen (H) line	21.1 cm	1.420	Most abundant element
Hydroxyl (OH) line	18.3 cm	1.638	Region between H and OH lines, called the "waterhole"
Kuiper-Morris line	11.7 cm	2.5568	Based on universal fundamental constants
Water (H_2O) line	13.5 mm	22.2	Second "waterhole"
Drake-Helou line	4.3 mm	70	Based on minimum bandwidth considerations
Water (H_2O) line	2 mm	150	Third "waterhole"
Kardashev line	1.7 mm	175	Peak of primordial fireball radiation
Kardashev line	1.5 mm	200	Optimal wavelength

Note: cm — centimeter
mm — millimeter

Summary:

- The wavelength region between 18 and 21 centimeters is referred to as the (first) "waterhole."
- Second and third "waterholes" are at near 2 and 14 millimeters.
- Four other lines are near 1.5, 1.7 and 4 millimeters and near 12 centimeters.
- Although arguments can be advanced for each of the wavelengths no one can be certain which one may be best.

C. Radio Telescope Range

How far can a radio telescope reach? Ones no more than 50 meters in diameter detect radio sources known as quasars over ten billion light-year distances or practically to the "edge" of the universe. But quasars are enormously powerful. An extraterrestrial civilization would not necessarily be expected to have such a powerful beacon and be detectible at such great distances.

You may have read that a radio telescope with antenna diameter, for example, of 50 meters could communicate with a twin of itself over interstellar distances. How is this determined? It is a simple, straight forward calculation for any communication engineer. Let's see how it is done.

The basic relation is given by the *Friis transmission formula* expressed originally by Harald Friis, an engineer at the Bell Telephone Laboratories. Friis was Karl Jansky's supervisor at the time Jansky discovered radio waves of extraterrestrial origin (1931). The Friis formula is:

$$\text{Power received} = \frac{\text{Power transmitted} \times \text{Area of transmitting antenna} \times \text{Area of receiving antenna}}{(\text{Wavelength})^2 \times R^2}$$

where R is the distance between the transmitter and receiver. Note that if the distance R is doubled the power received is only one-quarter as much.

Worked example:

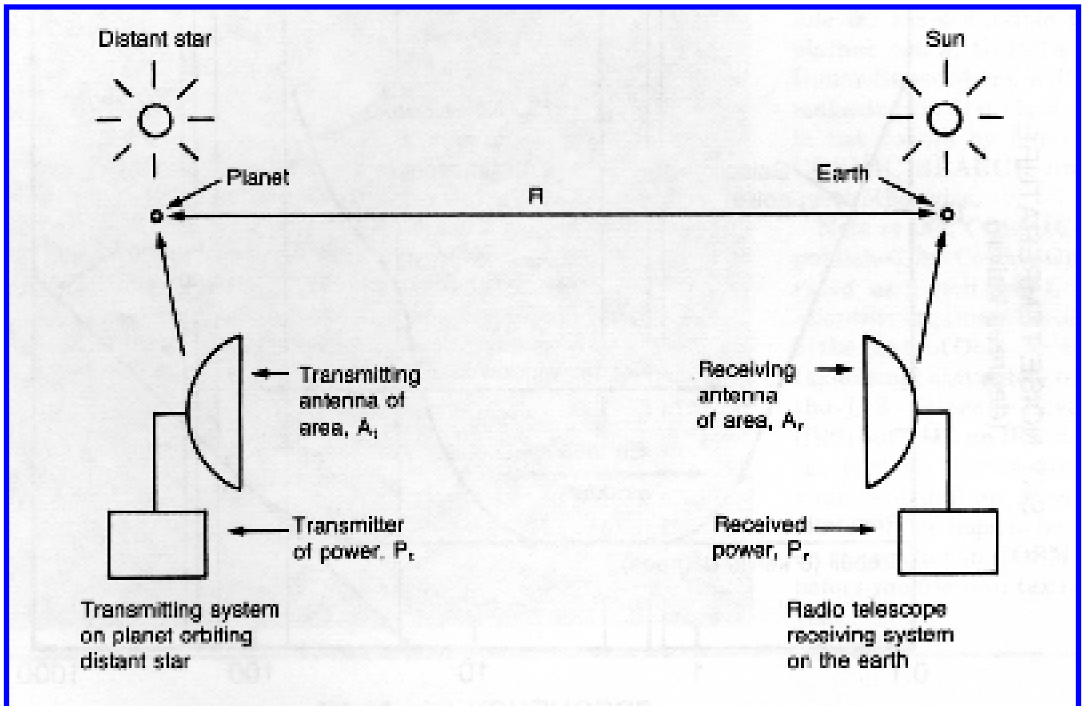
Suppose the alien civilization transmitter power is 10 million (10^7) watts and that its antenna is 50 meters in diameter (area equal to about 2000 square meters). Suppose further that the wavelength used is 21 centimeters (hydrogen line) and that the radio telescope antenna on the earth is also 50 meters in diameter. Then if the alien's star is 5 light-years (or 5 x 10^{16} meters) from our sun, we have

$$\text{Power received} = \frac{10^7 \times 2000 \times 2000}{0.21^2 \times (5 \times 10^{16})^2} = 0.4 \times 10^{-18}\ \text{watts}$$

This received power of 4 tenths of one millionth of a trillionth of a watt is very small but many of our radio telescope receivers are thousands of times more sensitive. Thus, the alien society's signal could easily be detected and, conversely, a signal sent from the earth radio telescope could be received at the distant star assuming we transmitted with 10 million watts and the alien receiver was no better than ours. But there would be a 5 year time delay for the signals from the star to reach us and a 5 year delay for our reply signals to reach them, preventing any rapid repartee. Although we have made a few simplifying assumptions in our calculations (such as 100% percent antenna efficiency) the received power we obtained is of the correct order of magnitude.

Summary:

- With powers of 10 million watts and 50 meter diameter antennas, communication with present technology is possible over interstellar distances of 5 light-years or more (actually very much more).
- However, communication would be subject to time delays of 5 years (or more) each way.



Communication over interstellar distance or range, R.
(Adapted from Kraus and Carver, "Electromagnetics" 2nd ed., McGraw-Hill, 1973.)

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Designed by Jerry Ehman.
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