7

LIGHTWAVE (LASER) COMMUNICATION

Optical SETI (OSETI) communication can be best compared to the light signals used to send coded messages between ships at sea. The equipment used to generate the coded flashes of light is more sophisticated, and the flashes of light are much more brief (billionths versus fractions of a second). However, the basic concept is not all that different from the communication technique employed by mariners for generations. This chapter discusses the techniques used to generate light signals that can be detected across interstellar distances, as well as the systems used to detect these signals on the receiving end.

Just as we can use radio waves to transmit information, we can do the same thing with visible and infrared light. While the basic principle is the same (we're using photons to convey information), the equipment we use to generate and detect these signals is different than what we use to transmit and detect radio waves.

Interstellar semaphores

OSETI currently looks for two types of laser signals: a pulsed beacon, or a steady, continuous signal. The approach is fairly straightforward. The transmitting civilization aims a tightly focused laser beam at a distant star. Because lasers can be turned on and off within an extremely short period of time (billionths of a second or less), they can be focused into a very tight beam, which can outshine an entire star, if only for an instant. A pulsed beacon would flash, in strobe-light fashion, at the target star. A continuous (always on) beacon works a bit differently. This type of laser is tuned to shine at a very precise wavelength (color).

In both cases, the light from the laser beam focuses on a very small region of the sky, so even at great distances, it's apparent strength is detectable to an observer within the focus of the beam. Either type of signal can be detected over interstellar distances and used to transmit large amounts of information.

The physics of starlight

The light emitted by stars (also known as *starlight*), carries an incredible amount of information. We can learn a great deal about a distant object by studying its spectrum (the color of its light). By shining the star's light through a prism, we can split its light into a rainbow of individual colors. Then, by analyzing the different colors of light emitted by a star, we can learn:

- The chemical composition of the star
- The temperature of the star's surface (which allows us to infer its size and weight)
- The approximate age of the star (which can be inferred from a star's temperature and chemical composition)
- Whether the star is orbited by large planets or a dim companion star (brown dwarf)

We can also detect an intelligent civilization that is attempting to communicate with us via a laser beacon.

Photographing chemistry

Since each chemical element absorbs light at a specific wavelength, we can determine the chemical composition of the star's outer atmosphere by examining the color content of a star's light (see Figure 7-1). In a sense, a star transmits its own chemical "bar code," enabling astronomers to measure the chemical composition of a star.

One of the things we're interested in learning is distant stars' metal content. By analyzing a star's spectrum, we can determine how much carbon, nitrogen, oxygen, iron, and other heavy elements it has. If the star is rich in heavy elements, the star may have a greater chance of developing rocky, Earth-like planets and carbon-based life.

Taking a star's temperature

Since the color and intensity of light closely correlates with temperature, we can measure a star's surface temperature by analyzing the color and intensity of its light. The light emitted by a star follows the rules that govern blackbody radiation, which varies according to temperature. As an object's

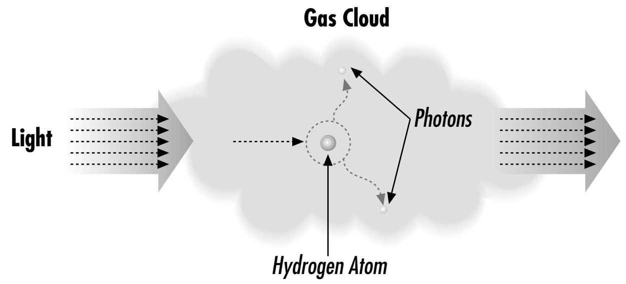

Figure 7-1: *Atoms in a gas cloud absorb specific colors of light. This light is re-emitted, but usually in a different direction.*

temperature rises, it emits more light overall, and peak intensity occurs at shorter (bluer) wavelengths.

When an object reaches a temperature of several hundred degrees Fahrenheit, it emits nearly all of this energy as infrared (invisible) light. As its temperature increases above this threshold, the object emits some of its energy as red light, which is why molten steel glows red. As the temperature increases to several thousand degrees, its color will shift from red to yellow to white, and eventually to blue. If the object gets hot enough (millions of degrees), it will emit most of its light as ultraviolet or X-ray radiation.

To measure a star's temperature, we must look at its spectrum to find the wavelength (color) where light intensity is highest (brightest), as shown in Figure 7-2.

Weighing a star

Since a star's surface temperature and brightness are closely related to the rate at which the star burns its fuel, and the burn rate is, in turn, directly related to a star's mass, once we know a star's brightness, temperature and chemical composition, we can estimate its mass (similar to its weight). Massive stars burn their nuclear fuel at a much faster rate than do smaller stars. As a result, they emit much more light than their less massive counterparts.

We're primarily interested in stars whose mass is similar to that of our sun. These stars belong to the *main-sequence* category of stars, and have a life span of several billion years. A star's mass is a critical factor in determining its ability to host life, primarily because its life span directly correlates with its mass. Stars that have more than 10 times the mass of our sun will burn much more brightly (which is not necessarily a problem since their habitable zones

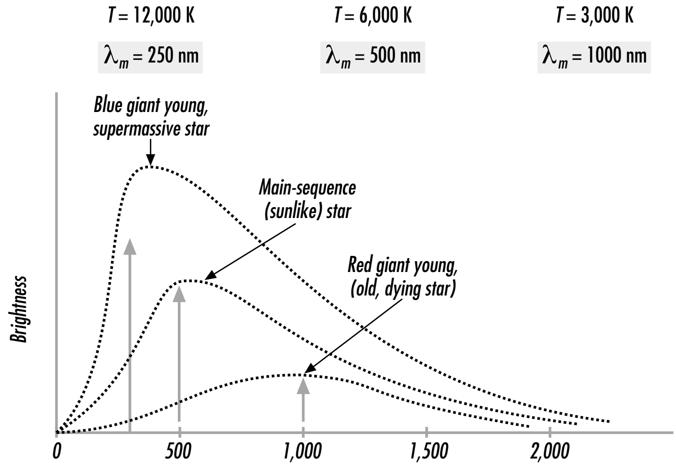

Figure 7-2: *The peak in this graph indicates the color at which a star is emitting most of its energy. This directly correlates with its temperature. This graph depicts several stars with different temperatures.*

will simply be further out). They also have a much shorter life span—a billion years (or less) compared to about 10 billion years for our sun. This shorter life span is a problem because life takes time to evolve from single-celled bacteria to animals. Conversely, stars that are much less massive than our sun, although they have extremely long life spans, have tiny or non-existent habitable zones.

Measuring a star's age

The chemical composition of a star tells us where it is in its life cycle. For example, if a star is rich in hydrogen and has relatively little helium, we know that it is a fairly young star. If a star is poor in hydrogen and has large quantities of helium and heavier elements, this tells us that the star is nearing the end of its life cycle. As a sun-like star ages and depletes its hydrogen fuel, it begins burning helium and heavier elements. When this happens, the star expands and cools to become a red giant. The star becomes redder in color as it cools, a signature that can easily be detected with an ordinary telescope.

Taking the star's size, brightness, and estimated age into account, we can determine whether the star is a likely site for life or not. We're most interested in stable, main-sequence stars that are rich in heavy elements such as carbon and iron, and that are several billion years old. Very young stars aren't good candidates since it takes hundreds of millions of years for planets and life to form; massive stars aren't good candidates since they tend to burn out much more quickly than do main-sequence stars.

Detecting planets

In Chapter 3, *The Drake Equation*, we discussed the technique used by astronomers to indirectly detect planets orbiting other stars. What we're looking for is a wobble in the star as it moves across the sky. Large planets in orbit around a star will exert a large enough gravitational pull to cause the star to wobble back and forth as its planets orbit.

The technique used to detect this wobble is based on the Doppler effect (also known as the *train whistle effect*). An object's motion affects the color of its light. When an object moves toward you, it's light shifts slightly toward the blue (a shorter wavelength) end of the spectrum. When an object retreats from you, it's light shifts toward the red (a longer wavelength) end of the spectrum. A large planet orbiting a star tugs the star, causing it to wobble toward and away from an observer. This wobble can be detected by looking for a cyclical Doppler shift in the star's light.

Detecting ET

It is also possible for an extraterrestrial civilization to use a laser to introduce an obviously artificial signature to a star's spectral fingerprint, one that can be detected by ordinary optical telescopes trillions of miles away.

The basic premise behind OSETI, much like microwave-based SETI programs, is to look for patterns that are obviously different from naturally occurring phenomena. When looking for alien radio signals, we look for signals tuned to a very precise frequency. A signal tuned to a precise frequency is the signature of an engineered device (and is also easier to detect at great distances).

The same principle applies to visible light. Stars emit tremendous amounts of energy as visible light. As an example, our own sun produces 10^{26} Watts (W) of energy, or the equivalent of about 1 septillion 100 W light bulbs (or $10^{24}\times100$). However, this energy is spread across many colors of the spectrum. The yellow-white light our sun produces is actually a composite of many different colors. So, while a star's total energy output is quite large, it spreads this energy across many colors in a predictable pattern.

Monochromatic (single color) light is the signature of an artificial device. Naturally occurring light emitted by a star will always blur across many colors. The yellow-white light we see from our sun is actually a composite of red, orange, yellow, green, blue and violet light (plus ultraviolet and infrared light, which we cannot see). When we look at the sum of these colors together, the light is white. The laws of blackbody radiation, which we discussed previously as a way to measure temperature, govern this pattern.

By understanding these natural patterns, it is possible to engineer artificial signals that stand out against them; lasers are perfect tools for this. We can use lasers to generate an extremely strong and focused source of light tuned to a very precise wavelength (color). We can also use lasers to transmit extremely brief, but bright, pulses of light. The trick is to generate obviously artificial signals that stand out against the type of light normally emitted by a star.

Knowing how starlight usually behaves, it is possible to build an artificial beacon that, while it is weak compared to a star as a whole, shines brightly at a specific color or for very brief periods of time. The receiving party can then look for evidence of this type of artificial signal by splitting the light into thousands of individual colors, or by measuring the intensity of the light during very short (billionths of a second) timeframes.

Continuous beacons

Even a powerful laser will be very weak compared to its planet's sun. However, a laser transmits its energy into a very precisely focused beam, while a star emits its light equally in all directions (Figure 7-3). One type of laser signal we're looking for is a continuous beacon. This type of beacon can aim at a targeted star continually, giving the signal a greater chance for detection.

For every doubling in distance from the star, its light will grow four times weaker. In looking at the figure, you can see how the intensity of the starlight drops off rapidly as distance increases (e.g., increasing distance by 5× decreases light intensity by 25×).

When viewed from a distance, the laser and starlight merge into a single point of light. Therefore, as shown in Figure 7-4, a distant observer sees the starlight and laser light combined, and would probably have a difficult time determining which light is from which source. However, when viewed close in, the laser light and starlight originate from two different points in the sky.

The apparent brightness of light produced by a star decreases by a factor of 100 for every 10-fold increase in distance. We can simplify this to say that signal strength varies in proportion to distance squared. A laser beam does not distribute its energy uniformly in all directions. It concentrates its energy into a beam shaped like a very narrow cone (Figure 7-5).

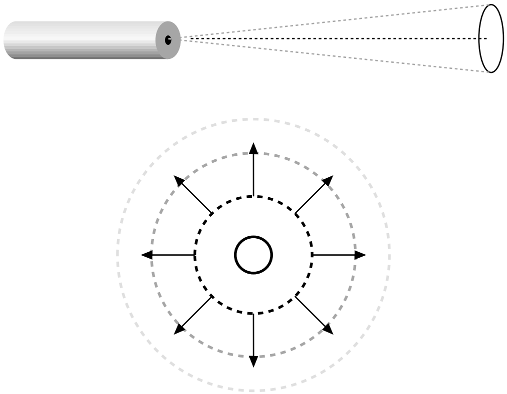

Figure 7-3: *A laser (at top) can be trained, in a tightly focused beam, on a distant target, whereas a star (bottom) shines equally brightly in all directions.*

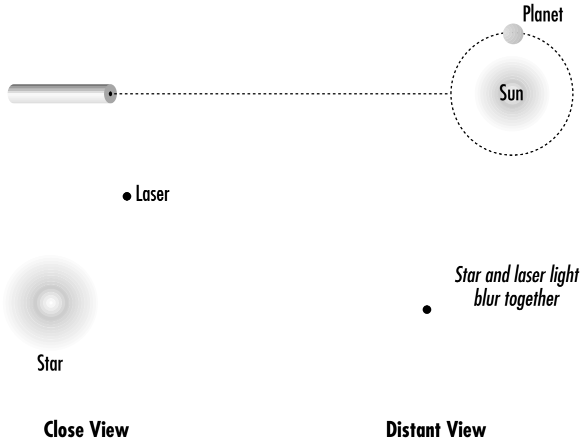

Figure 7-4: *A laser light source and its star depicted close up and at a great distance.*

The formula used to estimate the intensity (*I*) of the signal at a distance (*d*) can be expressed as follows:

$$I = P / (\pi \times r^2)$$

or:

$$I = P / (\pi \times (d \times \text{tangent}(\phi))^2)$$

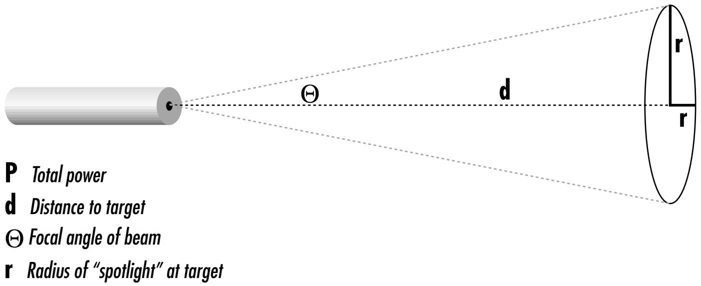

Figure 7-5: *Geometry of a laser light beam (r, radius, is exaggerated).*

The elements in this equation are defined as follows:

I	Intensity
P	Total laser power output
d	Distance from the laser to the target
Θ	Focal angle of the laser beam
r	Radius of the laser beam's "spotlight" when it reaches its target

This formula tells us that we can boost the apparent strength of the signal by tightly focusing the beam. The angle, Θ, describes how tightly focused the beam is. The smaller we make the angle, the more the intensity of light is boosted at a given distance, compared to an omnidirectional source of light (e.g., a star or incandescent light bulb).

As an example, let's compare two identical beams. Each beam transmits at the same power level, however, beam A has an angle of 1°, and beam B has a much narrower angle of 0.01°. When observed from an equal distance, beam B will appear to be roughly 10,000 times brighter than beam A.

The trick to maximizing the efficiency of a laser beacon is to adjust the angle Θ so that the most intense part of the beam passes within about 100 to 200 million miles of the targeted star. This target radius may extend out as far as one billion miles, depending on the type of solar system. This means that most of the transmitted energy focuses on the region in which habitable planets are likely to exist.

As we transmit to more and more distant stars, we would reduce the angle of the beam to match the desired target radius. There are limits to how tightly we can focus a laser beam. Vibration, atmospheric instability, and the long-term motion of distant stars all impose limits on the accuracy with which the beacon can target distant stars. Vibrations in the device will cause the beam to smear across a larger patch of sky. Atmospheric instability, although not an issue for space-based transmitters, degrades the performance of ground-based lasers by causing the beam to bend and disperse slightly as it passes through the atmosphere (this same effect causes stars to twinkle). In addition, uncertainty about the future position of distant stars also places a limit on the transmitter's efficiency, as the solar system may drift away from the beam by the time the laser light arrives.

Detecting continuous laser beacons

The key to detecting a continuous beacon is to analyze the spectrum of a star's light in great detail. The trick is to analyze the star's light not just at a few wavelengths, but at thousands or even millions of wavelengths. A laser emits nearly all of its energy in a single, precisely tuned wavelength, whereas the star shining behind it blurs its energy across many different wavelengths (Figure 7-6). By measuring the intensity of light at very specific wavelengths, we improve the chances of detecting a laser against the background glare of the star. This is the same strategy used to detect radio signals, except here we're applying it to visible light.

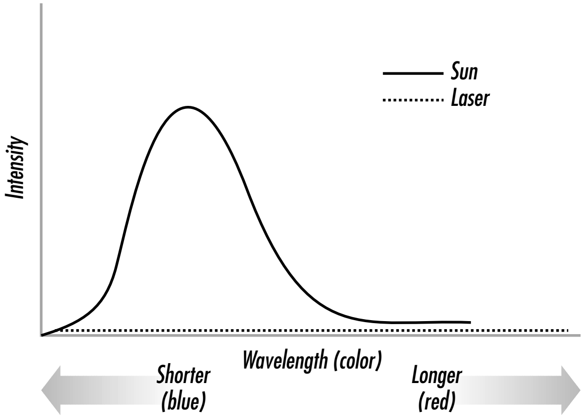

Figure 7-6: *A star emits its energy across a wide range of wavelengths (solid line), whereas a laser (dotted line) is tuned to a precise wavelength.*

If we look at a wide range of colors, the laser beam's net contribution to the measured light will be hidden in the background glare of its star. This is best illustrated by example. The first step is to graph the intensity of the incoming light from a star as a function of its color (Figure 7-7).

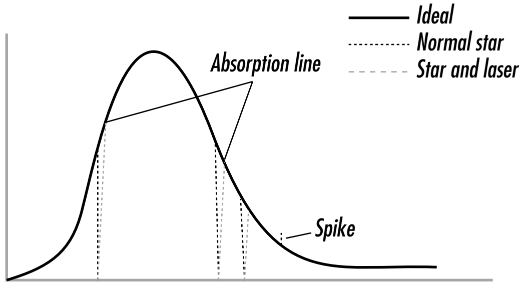

Figure 7-7: *Graph of light intensity as a function of color for a perfect blackbody source, for normal starlight, and for starlight with an embedded laser beacon.*

Figure 7-7 depicts three curves. The solid line is the curve we expect to see from a perfect source of blackbody radiation. Notice how the intensity of the light peaks at a specific color and then tapers off. The solid dashed line is the graph we expect to see from a normal star. Notice how it's similar to the perfect curve. The main difference we notice is the sharp drops in intensity at specific wavelengths. These sharp drops represent the absorption lines caused when light is absorbed by chemicals in the star's outer atmosphere. The dotted line represents the curve we would see if a strong laser beam were embedded in the incoming starlight. It is identical to the other two curves, except for a slight increase in intensity at a specific wavelength. This *spike* above the ideal intensity curve is a red flag indicating something unusual about the star (especially if the spike has an unusual color not typically emitted by known elements).

Continuous beacons will not be easy to spot; however, they can be detected if we know what to look for. Even a very strong, and very well aimed laser will be weak compared to its background starlight. The signature we're looking for will be subtle—and definitely invisible to the human eye—but it may be visible to telescopes equipped to analyze a star's spectrum in detail.

Pulsed beacons

Since we don't really know which signaling method is the *de facto* choice of extraterrestrials (if there are any), we shouldn't assume that any particular method of laser light communication is the sole method that will be used. This is why we're looking for signals in many parts of the electromagnetic spectrum. As mentioned earlier, another type of signal we'll look for is a *pulsed laser beacon*.

Pulsed laser beacons are based on a different strategy. They use strobe-like flashes of light to outshine an entire star for an instant. This is fairly easy to do because lasers can be turned on and off very quickly, and can emit flashes of light measured in billionths or even trillionths of a second. By concentrating their power into such a short period of time, they can generate extremely bright flashes of light without requiring extraordinary amounts of power.

The basic setup for sending and receiving pulsed laser signals is similar to the strategy used for continuous beacons. The main difference is on the receiving (detection) end of the line. The transmitting laser will be off for a majority of the time, emitting its light in brief, but very bright flashes of light. As with a continuous laser beam, the light from a pulsed beacon will also be tuned to a precise wavelength.

On the receiving end, an optical telescope feeds the light it collects into a *photon detector* or *photomultiplier (PMT)*. A photon detector is a sensitive instrument that counts each incoming photon (or light particle) that enters the telescope. This device allows the observer to count each incoming photon one by one, and to do so within very short time intervals (billionths of a second)

On a simplistic level, you can visualize the photon detector as a device that, when a light is shined on it, lights up an indicator. This detector then feeds data to a display. If the detector were seeing a pulsed light signal, the receiver would see something similar to the graph in Figure 7-8.

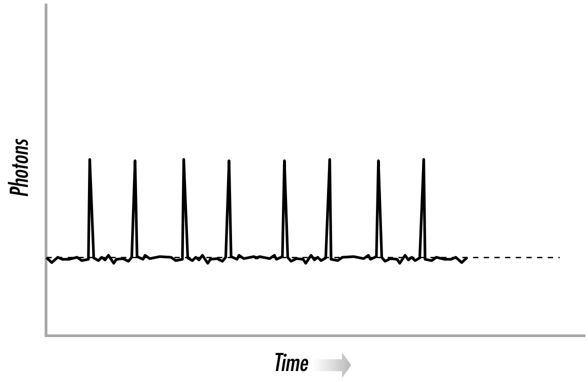

Figure 7-8: *Light intensity (photons captured per second) over time. A pulsed signal will produce a graph like this with regularly spaced spikes coinciding with each light pulse.*

While normal incandescent light might take a tenth of a second to go to full brightness, lasers can flash brightly for billionths of a second, allowing the sender to concentrate the laser's power into a very short period of time. During this brief period of time, the laser will shine thousands, or even millions of times, more brightly than a star. The laser is turned off most of the time, and when averaged out, does not consume an extraordinary amount of power.

Pulsed OSETI transmitter

The key component in an OSETI transmitter is a laser beam that can be cycled on and off very rapidly. This laser beam is aimed at the center of another solar system (at its primary star), and is focused such that the majority of its energy falls into a region within 200 million to 1 billion miles of the target star (Figure 7-9).

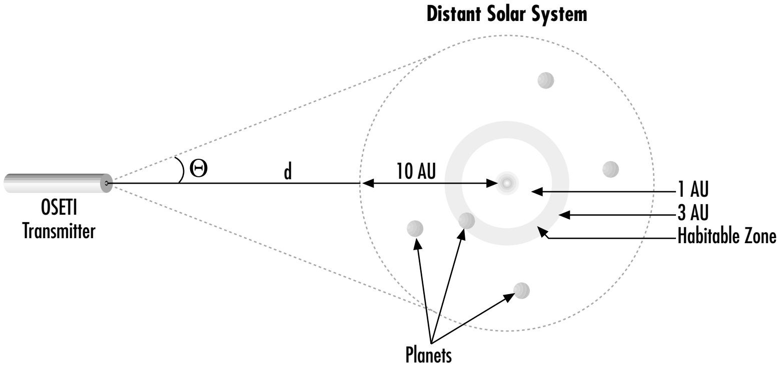

Figure 7-9: *An OSETI transmitter will be aimed such that most of the laser light traverses a target area with a radius of about 1 billion miles around a target star.*

This configuration makes it likely that the signal will traverse any potentially habitable planets in the system.

When we combine this pulsing technique with a well-aimed and tightly focused beam, we can emit light pulses that briefly outshine a nearby star when viewed from a distant solar system.

Pulsed beacon detection system

Detecting this light pulse is surprisingly simple, actually quite a bit simpler than detecting a microwave radio transmission. A simplified OSETI detector will consist of the following basic components:

- An optical telescope
- Two or more physically separated photon detectors
- A spectrometer, which is used to split light into different wavelengths, further increasing detector sensitivity
- Computers and signal processing software (unlike radio-based SETI programs, OSETI searches do not require high-speed supercomputers)

The first item, the optical telescope, is easily understood. We use an optical telescope to focus on a specific region of the sky so that we can limit the light we receive to that from a single target star. The telescope feeds the light it collects to two or more photon detectors.

PHOTON DETECTORS

A photon detector generates an electrical impulse every time it is struck by a light particle (photon). The nice thing about photon detectors is that they respond instantaneously when they capture a photon. Instead of counting the number of photons received per second, we count the number of photons received during much smaller slices of time (i.e., per microsecond, per nanosecond, etc.).

Photon detectors take advantage of the *photoelectric effect*. Albert Einstein discovered the photoelectric effect, and for his work in this area, received the Nobel Prize (though many people mistakenly assume the prize was awarded for his theory of relativity). Einstein discovered that when light strikes a surface, it knocks negatively charged electrons free from the atoms to which they are bound, causing an electrical current to flow. This same basic principle is employed in solar cells, digital cameras, and other light-sensing devices.

You can think of a photon detector as a pile of sand that has been stacked so high it is on the verge of collapsing. All it takes is one minor disturbance (adding or subtracting a single grain of sand) to trigger an avalanche. In the case of a photon detector, the arrival of a single photon triggers a cascade of events that ultimately triggers the release of a large number of electrons (Figure 7-10). This event is measured as a brief spike in electrical current. So, while the incoming photon has nearly zero energy all by itself, its impact can be magnified to make it an easily detected (and counted) event. This doesn't mean that you can get something for nothing; the device requires an outside power source to amplify the effect of the initial photon's impact to a level that can be detected by an electronic counter.

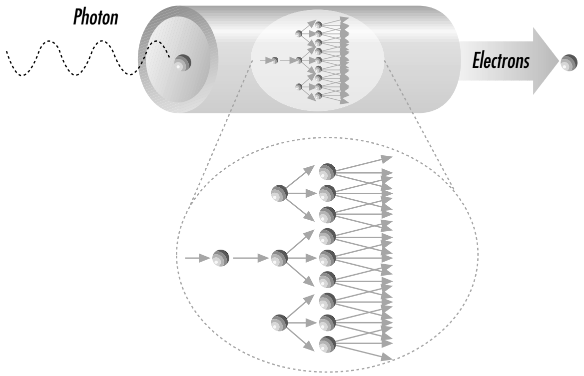

Figure 7-10: *Simplified depiction of a photomultiplier. A single photon triggers a cascade (a chain reaction). This triggers the release of a large number of electrons, which can be measured as a brief electrical current.*

What happens if we look at the output from the photon detector at an interval of once every 10 billionths of a second? If there is no pulsed beacon, the only light we will see is the background light from the star. The photons will arrive at random intervals, with no obviously repeating spikes.

If we add a pulsed beacon to the mix with a transmission time of one pulse once every 3 nanosecond (ns), the receiving telescope will capture photons emitted by the background star at a steady rate (Figure 7-11). During the brief *on* time, the photon detector will detect photons at many times the usual rate. If we average this over an entire second, the photons contributed by the laser will be insignificant compared to the total number of photons emitted by the star.

Output from the photon detectors is fed into a computer that analyzes this data using sophisticated software to look for short duration spikes in the number of photons received compared to the background noise level. A spike might be caused by a laser from an extraterrestrial civilization, but is more likely caused by stray photons entering the detector. One major source of noise is photons generated by the radioactive decay of material in the detection equipment itself.

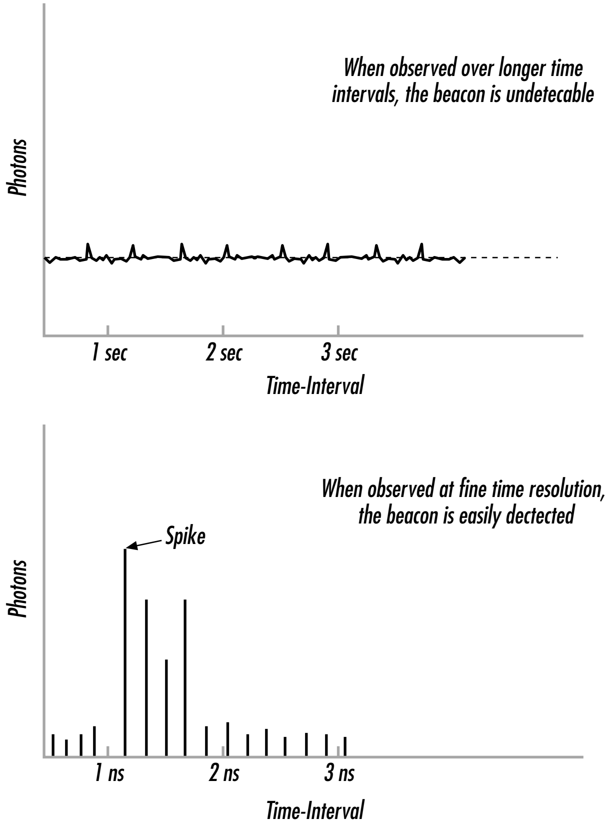

Figure 7-11: *Photons captured per second (top) and photons captured per nanosecond (bottom). The flashing beacon is overwhelmed by background radiation from the star when observed over a long time frame, but is easily seen when observed over a short (i.e., nanosecond) time frame.*

The detector's sensitivity can be further enhanced by splitting the incoming light through a prism, as shown in Figure 7-12. In a simplified form, the detector would split light into four buckets for red, yellow, green, and blue/violet light so the device has a total of eight photon detectors (two for each color of light). This allows us to identify incoming photons by their color, enabling us to improve our chances of detecting a beacon.

Figure 7-12 shows a simplified diagram of an OSETI detection system that breaks incoming light into different color bands. The incoming light passes through a prism and splits into different colors. An array of photon detectors behind the prism counts individual photons as they arrive. This type of arrangement allows the detector to differentiate according to color.

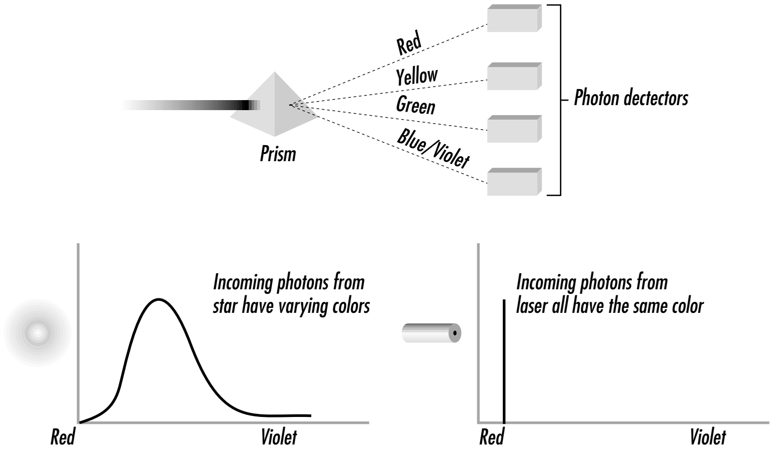

Figure 7-12: *Diagram of a multi-wavelength OSETI detector.*

Incoming light from the target star is a composite of many different colors. For example, some of the star's photons are green while others are red. Since the detector is set up to isolate different colors of light, it will count green photons in one bucket, and red photons in a different bucket. Hence, the intensity of the starlight, at a specific color, is reduced.

Incoming light from a pulsed laser, on the other hand, will concentrate all of its energy at a single precisely tuned wavelength. A single photon detector in the array will count all of the photons from the laser. So, instead of seeing incoming light spread across many wavelengths, the detector sees incoming photons that are precisely tuned to a specific color (e.g., deep red).

This technique can be used to build OSETI detectors that are many times more sensitive compared to the basic setup described earlier. For example, if the detector splits light into 100 different detectors, the apparent intensity of the background light from the star decreases by a factor of 10 to 100 within each color band, while the apparent intensity of the beacon remains the same.

Future OSETI technology

One of the biggest advances in OSETI technology will come in the next 10 to 20 years when we launch the Terrestrial Planet Finder space telescope, which uses interferometers instead of traditional mirrors for imaging. The interferometers, which will primarily search for Earth-sized planets, could also be used to detect laser beacons.

Space-based interferometers will enable astronomers to distinguish between light that is coming from a star and light that is coming from a site in close proximity to the star (e.g., light reflected from a planet, or light emitted by a laser beacon). These telescopes reduce the glare from a star by a factor of 100,000 or more, further improving our chances of seeing the signature from an extraterrestrial laser beam. Astronomers will be able to use the same basic techniques presently used to search for pulsed and continuous beams. The advantage, however, is that they will be able to reduce the background glare from the stars they observe, making it easier to see the nearby beacon.

Technical challenges and limits of OSETI

While transmitter power is important, is not the primary limiting factor in the detection range of an optical or infrared signal. Other factors conspire to impose limits on the detection range for a laser beacon. Among them are:

Pulse duration

By concentrating the laser's power into the shortest time interval possible, we maximize its apparent intensity during its *on* cycle. By using shorter pulses, we can increase the detection range for a pulsed signal, but only up to a certain point.

Aiming accuracy

While the stars in the night sky appear to be stationary, they are in constant motion. The effect of this motion is negligible over a short period of time. However, if we aim a laser beam at a star that is 1,000 light years away, it will be in a different location by the time the light beam arrives (see Figure 7-13). (When we look at a star that's 1,000 light years away, we see is the position of that star 1,000 years ago because its light took 1,000 years to reach us.)

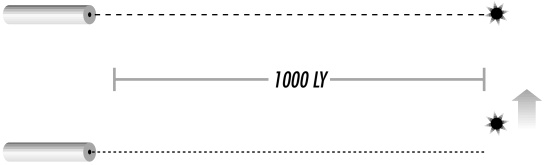

Figure 7-13: *When aiming a laser at a distant star, we need to aim at the star's predicted position when the light beam arrives, not at its current position as seen in our sky.*

Vibration and atmospheric interference will also limit aiming accuracy. As we lower the value of the lasers' angle (Θ), we become more and more susceptible to aiming errors caused by mechanical vibration and atmospheric interference. Even minute vibrations will be enough to cause the laser beam's aiming point to drift off center. Likewise, atmospheric instability (similar to the effect seen when looking at a stretch of asphalt on a hot day) also causes aiming errors. While less of a problem for nearby stars, this becomes a major problem when aiming at more distant sites. Moving the laser to a space-based platform can minimize these issues.

Extinction

Extinction refers to the attenuation (weakening) of the beam due to absorption by interstellar medium. While interstellar space appears to be empty, it is not a perfect vacuum. Interstellar space contains trace amounts of hydrogen, helium, oxygen, and other basic elements. When light transmits over short distances, the chance that an individual photon will collide with a molecule in transit is extremely remote. However, when the light beam traverses a distance of hundreds to thousands of light years, a significant percentage of the photons will be absorbed in transit, making the signal weaker and weaker as it travels.

At long wavelengths (i.e., infrared light), a signal can travel long distances with little attenuation. At shorter, visible wavelengths, attenuation limits communication range to a few dozen light years. We get the best results by using red or infrared light. One of the reasons that microwave (radio) signals are favored for very long-range communication is that microwave band signals are not as susceptible to extinction as infrared and visible light signals.

Dispersion

Dispersion is a particularly important phenomenon that affects pulsed laser beams. As illustrated in Figure 7-14, as a light pulse travels over a long distance, it spreads out over time.

Dispersion imposes a limit on the time resolution we can use to detect a signal. Think of this as being like the frame-rate for a movie projector. If dispersion introduces a 10 ns error into the arrival times for incoming photons, then the smallest time slice we can use to count incoming photons is about 10 billionths of a second. This effect is largely a function of the distance between stars. The farther away the other star is, the greater the effects of dispersion. Dispersion cancels out the benefits of using shorter-duration light pulses once the distance of the target becomes great enough.

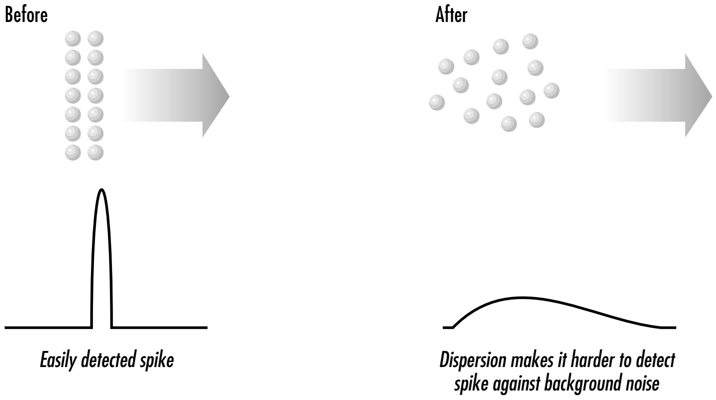

Figure 7-14: *As a result of dispersion, a light pulse blurs over time.*

Optical versus microwave SETI

Sir Arthur C. Clarke made an excellent observation once when he commented on the debate over the relative merits of optical and microwave SETI programs. He compared the debate to arguing over whether the inhabitants of a remote island should use smoke signals or beat on their drums to make contact with the inhabitants of nearby islands. Clarke's point was that our modern technology might be quite crude compared to that of an advanced civilization.

The one thing that we do know is that it is possible to communicate over very long distances using electromagnetic radiation. But will an extraterrestrial civilization use microwave radiation, visible light, or infrared light to establish contact with nearby civilizations? We really don't know. What we do know is that either method—optical or microwave—can be used to transmit coded information across interstellar space.

The main advantage of using microwave signals is economy. Microwave signals can be generated cheaply, and can travel longer distances with less degradation than optical signals. The downside of microwave signaling is the size and complexity of the detection systems. While a pulsed laser beacon can be detected by a modified optical telescope, detecting a microwave signal requires high-speed computers and sophisticated signal processing hardware and software.

Which method is best? This most likely depends on two factors: the senders' ability to cheaply generate energy, and whether or not the location of the receiving site(s) is known.

If the senders have developed advanced energy production technology (e.g., nuclear fusion power plants), the cost of the electricity needed to operate a powerful transmitter will be negligible. In this case, the senders will likely use signal formats that are easiest to detect (e.g., optical beacons). On the other hand, if the senders' energy production technology has reached a plateau similar to ours, they will have a strong incentive to minimize the transmitter's power budget. Microwave signaling is cheaper in this situation, although the signal will be harder for the receiving party to detect.

Next, if the location of the receiving party is known, the senders will want to focus most of the transmitted signal on that part of the sky. In this situation, the senders can use either optical or microwave technology, since both types of signals can be focused into a narrow beam. On the other hand, if the senders do not know where the other sites are, they will want to use a loosely focused beam or an omnidirectional beacon. Lasers are a poor choice in this situation, and so the senders will probably be biased in favor of microwave signaling.

So, what method will another civilization use to contact us? It could be either of these, or perhaps something we haven't even thought of yet. People on both sides of the optical-versus-microwave debate have made convincing arguments that their approach is best. The most likely answer is that both technologies have their advantages and disadvantages, depending on how they are applied. Since we don't know anything about the location or technological sophistication of other civilizations, we should look for both types of signals.