# Optical SETI Observatories in the New Millennium: A Review

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## ABSTRACT

The Optical Search for Extraterrestrial Intelligence is now 40 years old. However, it was only during the closing years of the 20th Century, after a 25-year hiatus, that the optical search has regained respectability in the SETI community at large. The quarter-of-a-century delay in American Optical SETI research was due to a historical accident and not for the lack of any enabling technology. This review paper describes aspects of past, present and future Optical SETI programs. Emphasis is placed on detecting fast, pulsed attention-getting laser beacon signals rather than monochromatic, continuous wave beacons. Some examples of commercial detection equipment that may be employed for either type of OSETI are given.

It is expected that in time, some of the great telescopes of the world will be employed in this optical search for ETI signals. This may take the form of either dedicated observations or a type of Optical SERENDIP program, as had been done with Microwave SETI. There will also be large observatories built dedicated only to the optical search. Just as the microwave SETI@Home project has proved very popular with the public, the time has come for its optical equivalent. This paper also speculates on the eventual need to move Optical SETI observatories into space with high altitude balloons and space-based telescopes. It is expected that by the end of the first decade of the Third Millennium, the electromagnetic search for extraterrestrial intelligence on planet Earth will be dominated by SETI of the optical kind.

**Keywords:** Optical, lasers, SETI, ETI, extraterrestrial, intelligence, observatories, space-based, review, millennium.

## 1. INTRODUCTION

The Search for Extraterrestrial Intelligence in the Optical Spectrum III marks a turning point in Optical SETI (OSETI) and also the 40th anniversary since Robert Schwartz and Charles Townes first proposed the idea in *Nature*.[1,2] This paper reviews some aspects of OSETI, with which the author has been involved for over ten years,[3,4,5,6,7,8,9,10,11] and looks to see where OSETI may be going, now that several major organizations that had previously opposed the optical approach have become actively involved themselves.

**Figure 1. The Columbus Optical SETI Observatory - the first dedicated Optical SETI observatory in North America (www.coseti.org/webcam0.htm). The observatory employs a Meade LX200 SCT (www.meade.com).**

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In 1992, when the author was constructing his own observatory[6] (Figure 1), he suggested that by 2001 the SETI community would have begun to reevaluate the rationale for the microwave approach.[12] This was illustrated in Figure 2, where just a few of the milestones along the microwave and optical roads were shown. Note that the diagram, which was shown as an inverted pyramid, is really a very lop-sided one, with a predominance of microwave activities. Underlying the then sum total of our knowledge was the original assumptions about the Effective Isotropic Radiated Powers (EIRPs) that ETIs could be expected to produce from their transmitters. If the High Resolution Microwave Survey (HRMS), which was soon to be cancelled and then reborn as the privatized Project Phoenix, continued to produce negative results, serious questions would start to be asked by 2001 concerning the prevailing microwave SETI rationale.

The change in thinking about the electromagnetic rationale for SETI came about in 1998. However, it has been suggested that Optical SETI research could not have previously been carried out effectively because of the lack or immaturity of certain key enabling technologies. This excuse will be shown not to be true. More detailed accounts of Optical and Microwave SETI over the past four decades may be found in the two previous SPIE proceedings on Optical SETI[5,8] and on the COSETI Web site.[b]

Before going any further we should perhaps briefly mention Von Neumann/Bracewell Probes.[13,14,15] These probes may be in our solar system monitoring this planet, and they are likely to communicate back to their home star system or systems with lasers rather than with radio waves. This is for the same underlining reasons why lasers are superior for interstellar communications of the electromagnetic kind and are likely to be employed by ETIs to signal emerging civilizations. Clearly, we will do this ourselves with our own non-relativistic interstellar probes when we send then out to our nearest star systems within the next 50 years.[16,17] That said, we are unlikely to accidentally intercept these free-space ETI laser probe links on Earth but might with space-based observatories. Thus, Optical SETI or OSETI is mainly about searching for artificial extrasolar laser signals, but it should not be discounted that non-terrestrial laser signals transmitted from within our solar system may be detected.

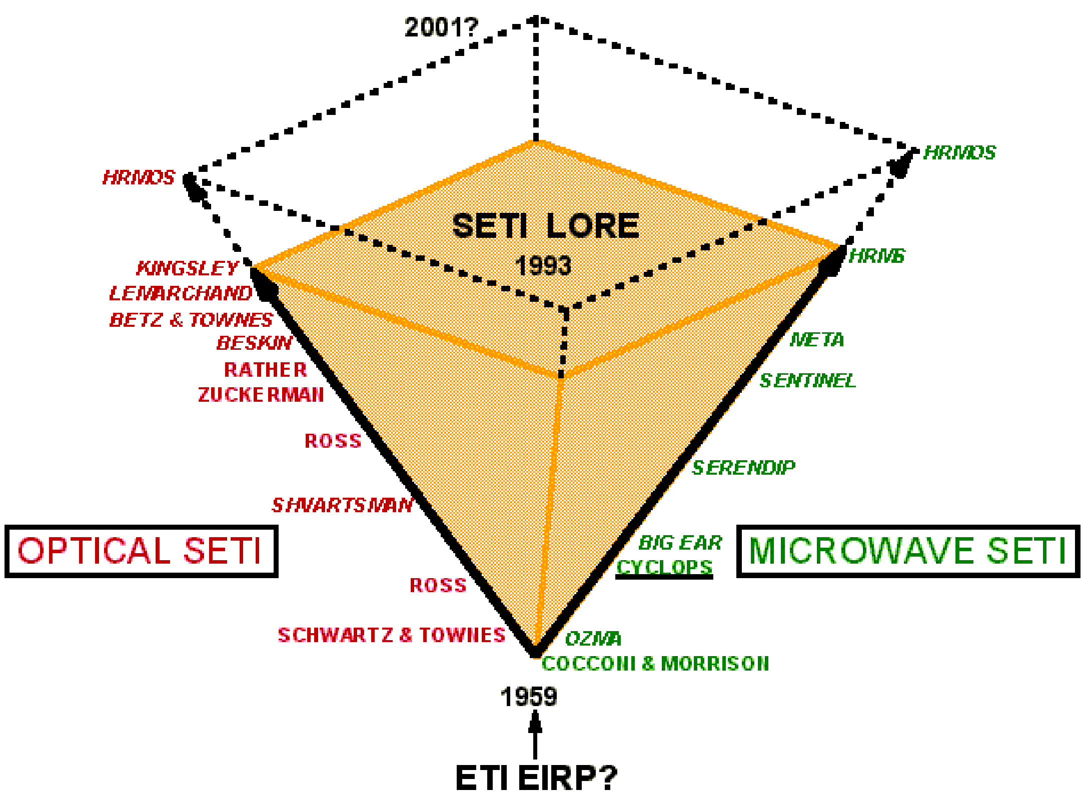


**Figure 2. The SETI lore time pyramid. To the right are listed a few milestones in microwave SETI, while to the left are listed most of the optical SETI research activities up to 1993. The predominance of the present microwave SETI lore has been caused by mistaken assumptions about the transmitter gains and resulting Effective Isotropic Radiated Powers (EIRPs) available to ETIs.**

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[b] www.coseti.org

## 2. THE PAST

The Cyclops Report[c] bears considerable responsibility for the quarter of a century hiatus in American Optical SETI research. To understand how this came about one needs to look at Table 1, which is part of a table from the Cyclops Report that compares the efficacy of the Optical (read visible and near infrared), Infrared and Microwave approaches to SETI.

Of particular interest are the assumptions that went into the transmitter part of the table, which is reproduced below. What's very odd about the table is the entries for the ETIs' transmitting aperture in the near infrared. Here the optical uplink aperture is stated to be 22.5 cm in diameter. Why were these numbers so small? The main reason is that the principal architect of NASA's Cyclops Report, the late Dr. Barney Oliver, did not believe that ETIs would have the technical prowess to overcome the point-ahead targeting problems associated with tightly focused laser beams.[18,19] So to overcome this so-called problem, he used very small apertures, thus throwing away all the uplink gain advantage of a laser transmitter. It seems reasonable to suggest that a mature ETI civilization, perhaps a million or more years in advance of our own, would not waste energy in empty space, but would spatially multiplex their highly directional transmitter beams over many suitable targeted star systems. For more information about this, visit the COSETI Web site.[b]

### Table 1. The Cyclops Report – Transmitter Side

| | OPTICAL | | INFRARED | | MICROWAVE | |
|---|---|---|---|---|---|---|
| PARAMETER | A | B | A | B | A | B |
| Wavelength | 1.06 µm | 1.06 µm | 10.6 µm | 10.6 µm | 3 cm | 3 cm |
| TRANSMITTER | | | | | | |
| Antenna Diameter | ***22.5 cm*** | ***22.5 cm*** | 2.25 m | 2.25 m | 100 m | 3 km |
| No. of Elements | 1 | 1 | 1 | 1 | 1 | 900 |
| Element Diameter | 22.5 cm | 22.5 cm | 2.25 m | 2.25 m | 100 m | 100 m |
| Antenna Gain | $4.4 \times 10^{11}$ | $4.4 \times 10^{11}$ | $4.4 \times 10^{11}$ | $4.4 \times 10^{11}$ | $1.1 \times 10^{8}$ | $9.8 \times 10^{10}$ |

**Data taken from Table 5-3, page 50, July 1973 revised edition (CR 114445) of the Project Cyclops design study of a system for detecting extraterrestrial life. This study was prepared under Stanford/NASA/Ames Research Center 1971 summer faculty fellowship program in engineering systems design.**

This table was the cause of some correspondence between this author and Barney Oliver. A copy of this historic correspondence may be found on the COSETI Web site.[d] One of the other objections was that it was impossible to conduct a diffraction-limited "All-Sky Survey" at optical wavelengths so that only a targeted search would be possible in the optical spectrum. Information about the list of stars for both the microwave and optical targeted searches may be found on the Project Phoenix[e] and COSETI[f] Web sites.

[c] Copies of this report are available from the SETI Institute (www.seti.org) and the SETI League (www.setileague.org).
[d] www.coseti.org/oliver.htm.
[e] www.seti.org/science/gb-starstab.html
[f] www.coseti.org/greentab.htm

Of course, we have no idea whether ETIs would come down to our level and use “crude” free-space laser communications in an attempt to contact emerging technical civilizations, like ourselves. Perhaps the light-speed limitations of any type of electromagnetic communications would prevent such technology from being employed. All that we can say at present is that from our standpoint, at the beginning of the 21st Century, lasers look superior for point-to-point communications over a range of a few thousand light years, both in terms of signal-to-noise ratio and modulation bandwidth.

## 3. THE PRESENT

When Charles Townes and Robert Schwartz first suggested Optical SETI 40 years ago, only the search for continuous wave cw laser beacons at the $CO_2$ wavelength of 10.6 μm was considered. In recent years, as the optical approach to SETI has received greater acceptance by the SETI community at large, the general approach has been to look for short pulses, as first suggested by Monte Ross in 1965.[20] This is reflected in the emphasis in this paper and elsewhere in these proceedings. However, that is not to suggest that ETIs would not use cw beacons. So it is worthwhile to continue to search for monochromatic laser beacon signals, which initially is likely to be the dominant form of space-based Optical SETI. So before concentrating on the pulsed laser approach, a brief description of some of the technology available for monochromatic OSETI will be presented.

### Enabling Technologies

As with all scientific research, there are certain key technologies that need to be of sufficient maturity in order for measurements to be taken. Figure 3 is a diagram showing some major technology milestones and their timing in relation to key developments in the SETI field. Of particular note is the timing of the development of fast Photomultipliers Tubes (PMTs) and the various SETI activities.

The ubiquitous 931A PMT was developed by RCA in 1948, shortly after the Second World War. This is the same year that the transistor was invented. The relatively fast 56AVP (2 ns response time) photomultiplier made its appearance in 1956. In 1958, the first proposal for an Optical Maser was made by Schawlow and Townes[21], which was also the same year that the first integrated circuit was produced. In 1959, Cucconi and Morrison[12] ushered in the era of Microwave SETI, rapidly followed by Frank Drake’s Project Ozma[22] in 1960. In 1960, Maiman[23] demonstrated the first laser action in a synthetic ruby crystal, while in 1961, as already mentioned, Schwartz and Townes[24] proposed monochromatic (cw) Optical SETI.[25,26] In 1965, Monte Ross proposed the use of very short pulses for Optical SETI type communications.[20] By that time, fast, sub-nanosecond PMTs were becoming available. In 1973, the late Barney Oliver produced the famous “Cyclops Report”, which is now often referred to as the “SETI Bible”. This attempted to show conclusively that radio waves were far superior to lasers for SETI purposes. By the mid 1970’s, fast ECL logic was commercially available. In the late 1970’s, Shvartsman and Beskin had started their pulsed OSETI work in the former Soviet Union[27], later replicated by Guillermo Lemarchand.[28]

Fast, Low Noise Avalanche Photodetectors (APDs) became available in 1988. The COSETI Observatory was formed in 1992, two years after the author’s initial involvement on the theoretical side of OSETI. Initially, the work of the observatory concentrated on looking for cw laser beacons. Around that time, Townes and Betz had a small $CO_2$ optical heterodyne receiving project piggybacked onto observing black holes at the center of the galaxy.[29,30] John Rather[31,32] and Ben Zuckerman[33] had been writing about cw OSETI was some time. The first SPIE Optical SETI Conference (OSETI I) was held in 1993, the OSETI II Conference in 1996, Optical SETI programs were started in Australia by David Blair[34] and Ragbir Bhathal[35], and The SETI Institute/Planetary Society commenced their own OSETI programs in 1998[36]. This OSETI III conference was held in January 2001. The first decade of the new Millennium can be considered as marking the start of the new “Optical SETI Age”.

It should now be clear that there were fast enough optical detectors and photon counters available since the first demonstration of the laser in 1960. There was never any “missing” technology, which failed to enable the search for fast optical pulses. Rather, as far as the lack of US-driven observational OSETI activities, that was determined solely by the conclusions of the Cyclops Report[37] and not by the lack of suitable optical detector technology. As far as to the availability of very high power lasers, they have been obtainable for a long time now, so since the late 1970’s it has not been too much of a stretch of the imagination to postulate on ETIs employing extremely high peak laser powers. In 1992, it became possible to generate peak powers on the tabletop in excess of 10 TW![38] Lawrence Livermore’s NOVA and new NIF (National Ignition Facility) are examples of what we can do today.[39,40] NIF will produce pulses of about 1 ns duration at peak powers of about

$10^{15}$ W, albeit only a few pulses per day. Over a period of 40 years, terrestrial lasers have gone from peak powers of a few milliwatts to 1,000 Terawatts![41]

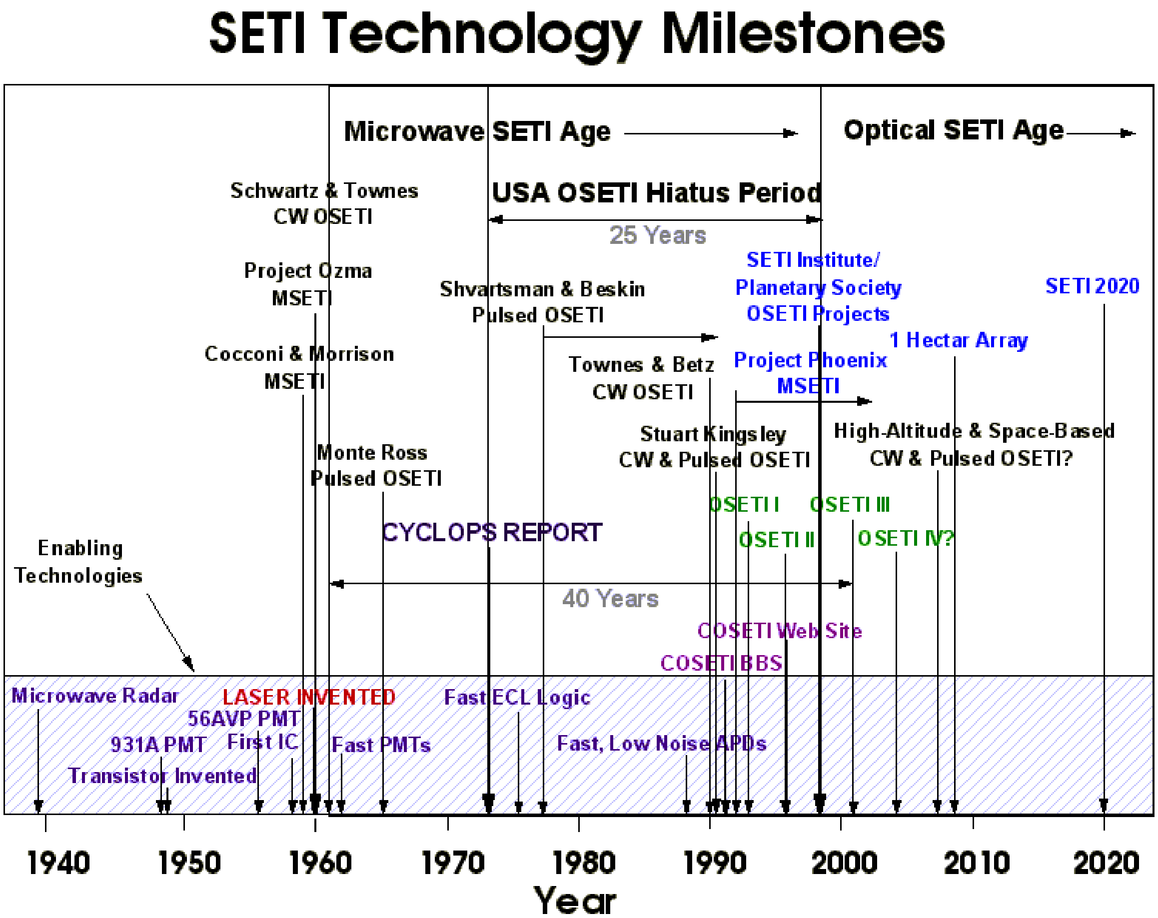
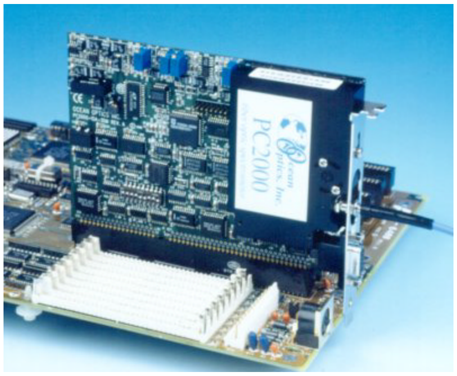



**Figure 3. SETI Technology Milestones showing major Microwave and Optical SETI activities and inventions enabling these approaches to SETI. Of particular note is that fast PMTs were available in the mid 1960's, so there wasn't anything lacking in available technology that would have prevented dynamic American OSETI programs during the last several decades of the 20th century. When complete, the new National Ignition Facility (NIF) laser system at Lawrence Livermore Laboratories will be capable of producing peak powers of 1,000 Terawatt in nanosecond bursts, once or twice a day.**

## Monochromatic CW Beacons

Continuous wave (cw) OSETI is an approach that can probably be accommodated by various planned space-based telescopes with little overhead in the way of additional instrumentation and payload cost. This will be mentioned again later. Searching for continuous wave beacons is straightforward spectral analysis. This can be done with a convention spectrograph strapped onto the back of the telescope or attached to the telescope via a fiber optic cable. Ocean Optics manufactures a variety of small fiber-based spectrometers, such as the S2000 shown in Figure 4. Alternatively, a more conventional spectrograph can be attached to a CCD camera. Figure 5 illustrates a relatively new product by Santa Barbara Instrument Group (SBIG) that produces spectrographs similar to that produced by conventional professional (classic) spectrometers.

Given sufficiently intense pulsed beacons, it might be possible to detect them while searching for monochromatic cw beacons, by integrating long enough, but the frequency search space is huge. It is far better to employ dedicated ultra-fast photon counting systems for pulsed OSETI observations.



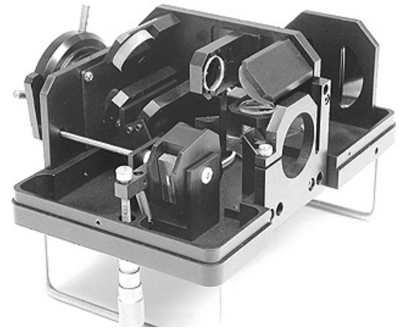


**Figure 4. Ocean Optics Fiber Optic Spectrometer.**[g]

**Figure 5. Santa Barbara Instrument Group's (SBIG) Self-Guiding Spectrograph for use with their ST-7E CCD camera.**[h]

## Pulsed Beacons

As previously noted, Monte Ross[20] was the first to suggest looking for very short laser pulses, rather than monochromatic cw beacons, since it can be shown that such pulses can easily outshine the brightness of a star, enhancing their detectability. The other major advantage was that it was not necessary to guess a "magic optical wavelength or frequency", one just had to be looking in the right wavelength regime. Most of today's and future OSETI activities concern the detection of pulsed laser ETI beacon signals, so we will now take a few moments to review the essentials of the pulsed beacon OSETI rationale.

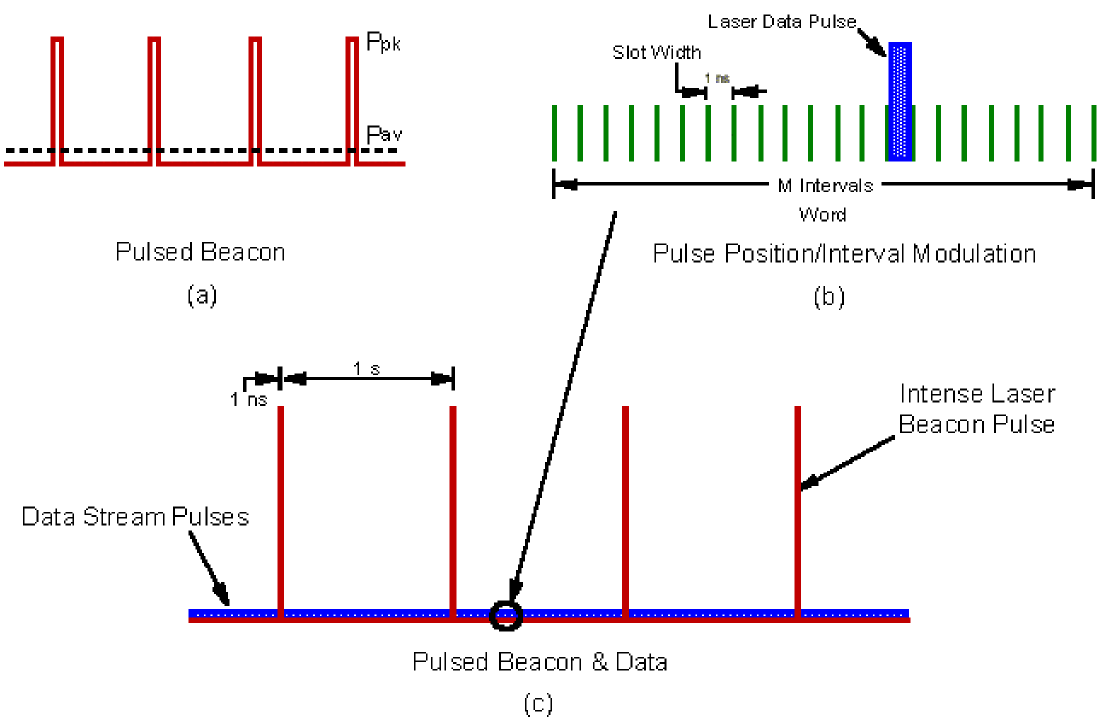



**Figure 6. A scenario for pulsed laser beacons and wideband data signals that might be produced by an ETI civilization. This would make for easier detection in the presence of stellar background radiation, and the precise "magic laser wavelength" need not be known.**

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[g] www.oceanoptics.com
[h] www.sbig.com

Figure 6 illustrates how a wideband data channel can be immersed within an attention-getting beacon signal. The diagram shows a regular pulsed beacon with a duty cycle of only 1 part in $10^9$. This allows the peak transmitter power $P_{pk}$ to be $10^9$ as large as its mean power $P_{av}$, making detectabilty in the presence of stellar background noise much easier. Indeed, it was shown in the EJASA[42] publication, that Optical SETI can be done during the day "under a clear blue sky"! The weaker wideband channel may have sufficient capacity to transmit 1 Gbps, while the stronger beacon channel would be encoded.with low bandwidth data – perhaps providing the "Rossetta's Stone" for decrypting the wideband channel.

This author has also suggested that while the beacon signal may be sufficiently intense to be detectable with amateur-sized telescopes, it would probably take the "great telescopes" of the world to collect sufficient signal photons to reliably detect the weaker wideband channel.

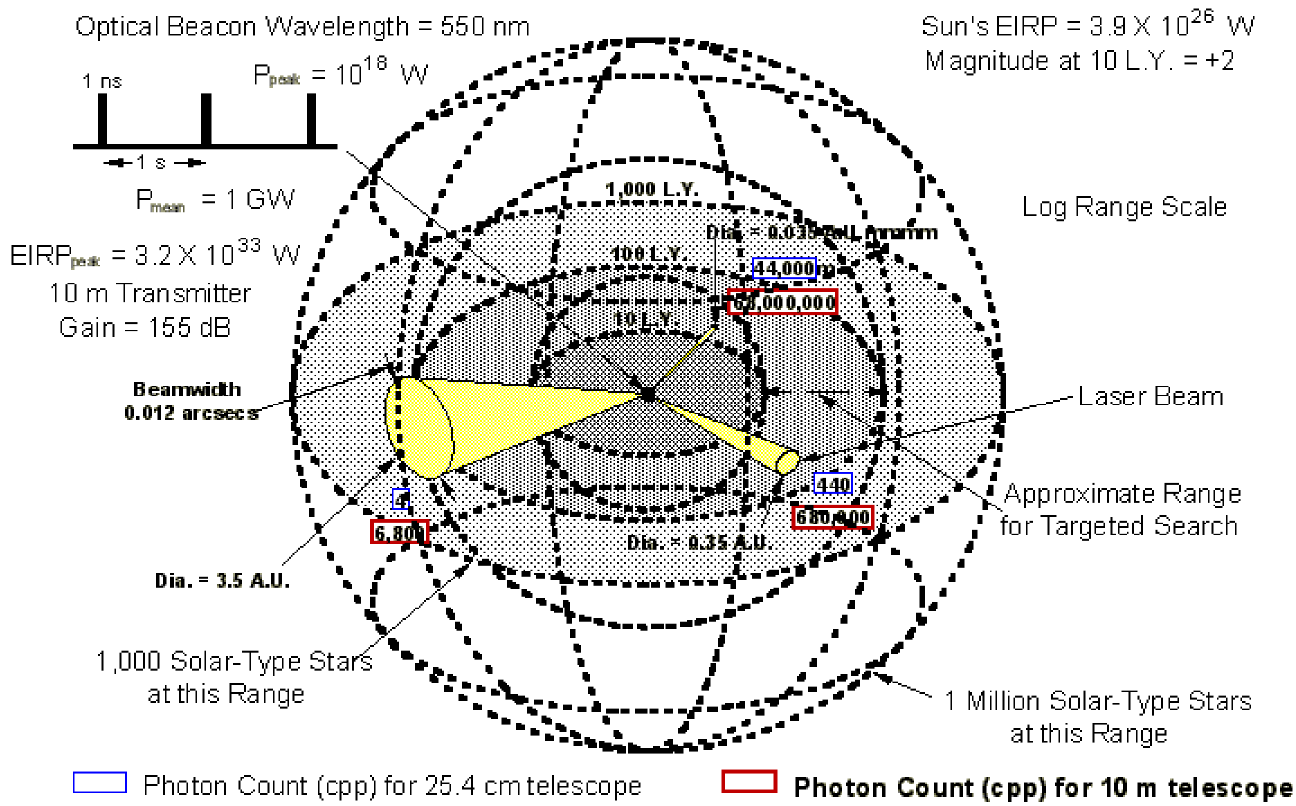


**Figure 7. Signal photon detection rate for small and large ground-based telescopes assuming a very conservative overall photon detection efficiency of one percent. Under this scenario, there would be no problem for amateur telescopes in detecting 1 ns laser pulses of $10^{18}$ W peak power over a range of 1,000 light years.**

Figure 7 illustrates the number of photons that can be detected by both large and small telescopes at ranges of 10, 100 and 1,000 light years. The major assumption is that the ETI transmitter can send out peak EIRPs of 3.2 x $10^{33}$ W. Such a signal could be produced by the diffraction-limited equivalent of a 10-meter diameter transmitting telescope (probably a phased array). This array would have an uplink gain of about 153 dB. A visible wavelength laser system putting out a total mean power of 1 GW, would produce 1 ns peak powers of $10^{18}$ W with a duty cycle of $10^{-9}$. At a range of 100 light years, a 10-meter ground-based telescope could detect a burst of photons or flash consisting of over 680,000 photons, so that 680,000 photons would be counted per pulse. Over 1 ns, this beacon flash would outshine the brightness of the ETIs' star by about 10 million times but be invisible to the naked eye. A 25.4 cm amateur telescope would detect a flash of about 440 photons. Clearly, there is a lot of room to "play" with the numbers here, but it should be apparent to the reader that such signals are easily detectable, given the right fast photon-counting equipment in the focal plane of even relatively small telescopes. Conversely, if we assume the use of large ground or space-based receiving telescopes, then very low transmitter powers are detectable across hundreds of light years, whether the beacon consists of short pulses or a continuous wave optical carrier.[42]

Figure 8 illustrates how an ETI civilization might spatially time multiplex their transmitter beams to different targeted star systems. In this particular diagram, the duty cycle for a targeted star system is 1 in 60. If the beacon pulse train does not consist of a significant number of pulses, then the low-bandwidth data, which may be expected to be encoded onto the beacon signal, would be very low bandwidth indeed. This would unnecessarily reduce the data rate for the beacon signal. It makes more sense to send out bursts of beacon pulses rather than solitary pulses every hour or so. As previously indicated, the beacon pulses within a burst might have a repetition rate of say, 1 pulse per second, making them more noticeable in each of the star systems targeted by the ETIs. This issue is taken up again in at the end of this section with regard to the photon counting technology employed in the telescope focal plane, such that the signal is easily discernable from the stellar background and detector noise.

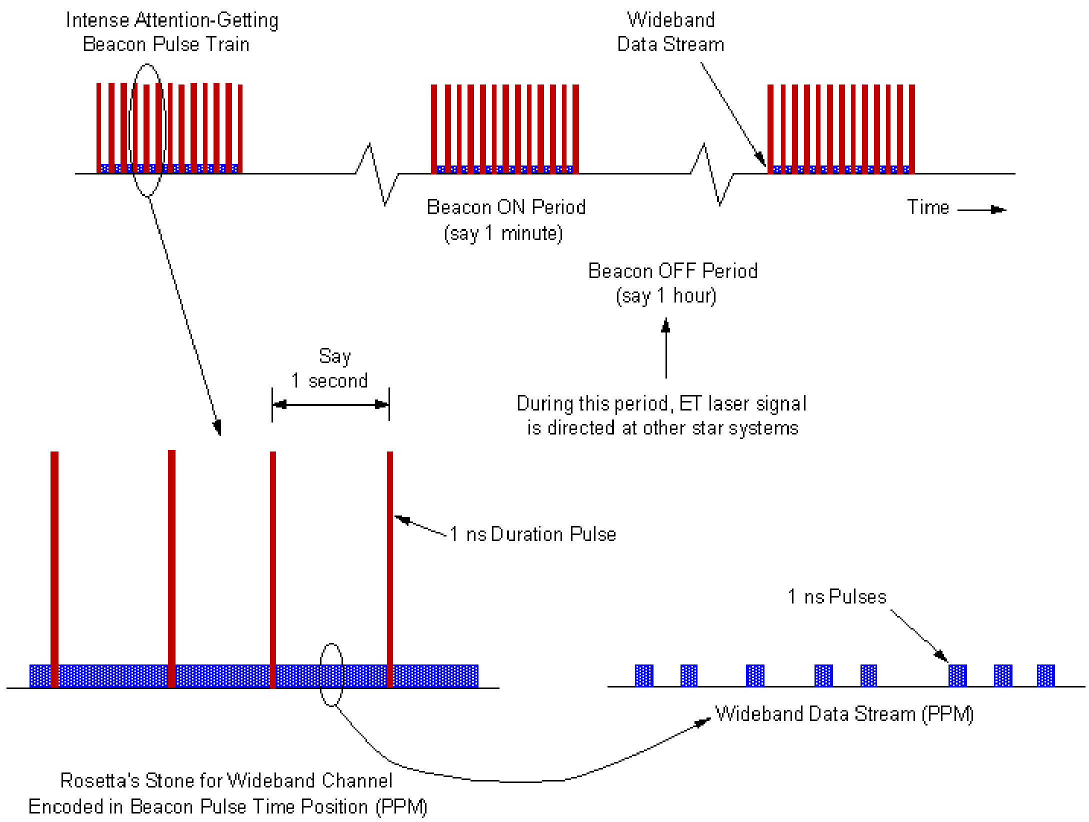


**Figure 8. Spatial multiplexing of attention-getting ET laser signals. In order to be most effective in getting out attention and making discrimination from receiver noise easier, ETIs would likely send a burst of pulsed beacons of significant time duration, say a minute or so, before directing their beam to another star system. To each target, the off period may be one or more hours before the cycle begins again. When the burst of repetitive beacon pulse are received, there will be no doubt that they are of artificial origin.**

Figure 9 is based on an earlier schematic by Monte Ross. In this variation, we have shown a combined system producing both the attention-getting beacon and the main wideband channel. Each laser produces a mean power of 1 GW at its target. Although separate transmitting phased arrays are shown for the combined beacon and wideband data channel, in practice the final stage of the ETI transmitter may consist of a common optical amplifier for both signals. The phased array could spatially time multiplex the combo signal to many targeted star systems in sequence, dwelling on each target for a short period of time. The numbers shown above are for the 1 GW mean power scenario for both the bean and wideband channel, with peak beacons powers of $10^{18}$ W. As previously mentioned, the peak beacon EIRP of nearly 3 x $10^{33}$ W has an instantaneous intensity that is about 10 million times greater than that of our Sun at the range of the transmitter.

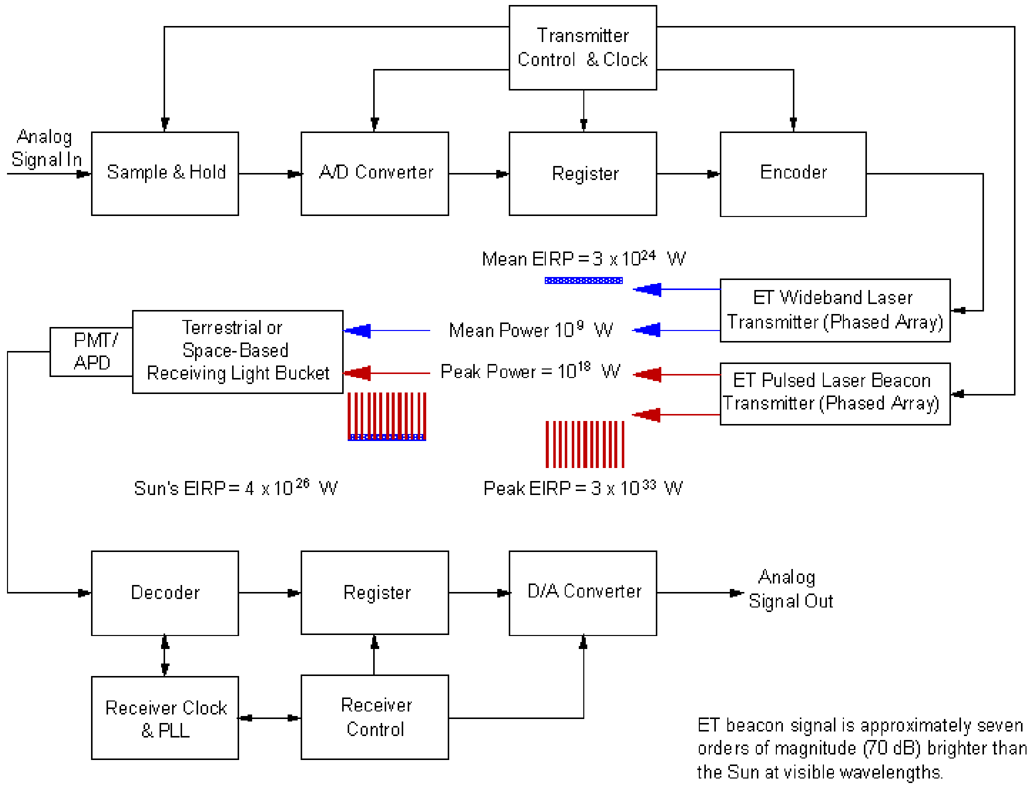


**Figure 9. This illustration is loosely based on a block diagram by Monte Ross.[20]**

## Photon Counting

At some point, photon counting receivers will need to be constructed for OSETI that have insignificant pulse-pair resolution, so that every photon or burst of photons arriving in adjacent nanosecond intervals can be counted. This may also involve a significant amount of data storage capability. However, for the moment, the issue is only about detecting the attention-getting beacon signal or flash, so that small amounts of "dead time" for single detector systems, i.e., 30 to 80 ns, is not important. Figure 10 illustrates the effect of raising the counting threshold for a photon counter such that less received background photons are counted. For a photomultiplier optical front-end, the high voltage can be backed off to reduced saturation effects during received pulses, and the discriminator threshold can be increased. For this technique to work, it is assumed that the beacon pulses to be detected will consist of regular large burst of photons - not just one or two occasional photons, i.e., the laser pulses, if they are there, will be relatively powerful.

As more sophisticated signal processing and extensive data storage facilities become available, the sensitivity of the laser beacon pulse receiver can be improved by increasing the photodetector gain and lowering the discriminator threshold, thus allowing more stellar and sky background noise photons to be counted. Eventually, the optical front-end receiver will be operated in the true photon-counting mode, i.e., where every photon detected produces an electrical output (TTL or ECL) pulse from the photon-counter discriminator. Today's Microwave SETI experiments are 14 orders of magnitude more sensitive than Project Ozma.[22] Similarly, the initial OSETI activities will be far less sensitive than ones to come later. If it was all right for Microwave SETI researchers to use, what today would be termed "crude" equipment, then it could be said that it is all right for Optical SETI researchers today. One has to learn to walk before one can run!

Figure 11 shows how the background count rate can be substantially reduced without lowering the sensitivity of the photon-counter. This is done by the use of two identical optical detectors and coincidence detecting their outputs. This technique has been employed by Werthimer[43], Horowitz[44] and others to essentially "eliminate" the background noise count problem.

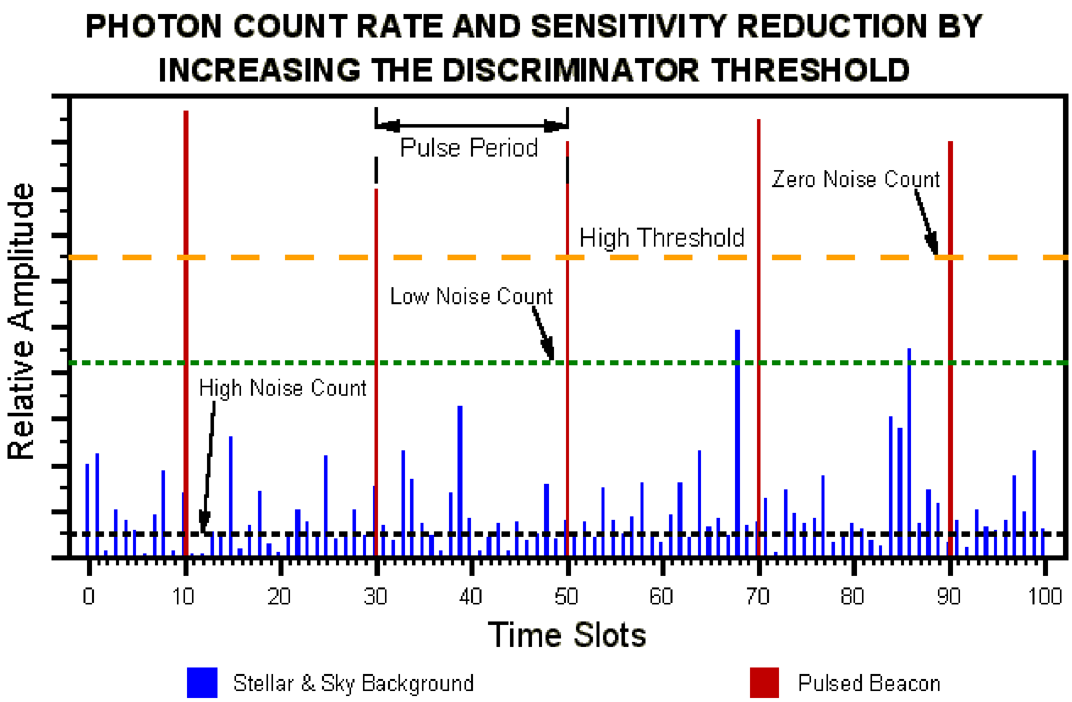


**Figure 10. When employing a single photon-counter, the background noise can be reduced by setting the descriminator level higher than normal. This amount to a desensitization of the receiver, but if the ETI beacon pulses are expected to be relatively intense, then this is a reasonable approach for substantially reducing the background count. If a burst of beacon pulses is expected, then this simple and lower cost form of receiver could be adequate for the task.**

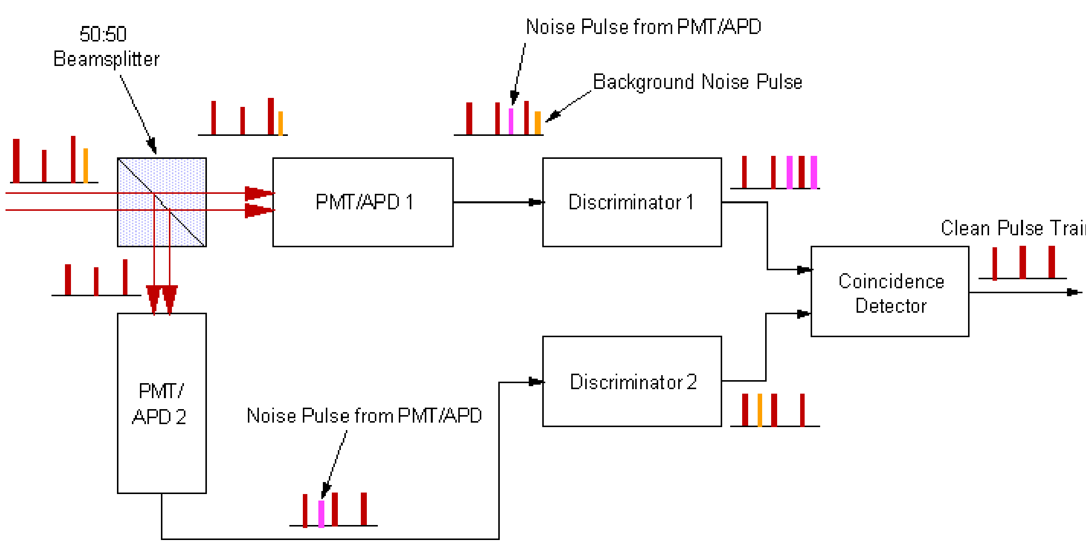


**Figure 11. Background and internal noise count reduction by the use of two PMT or APD photon detectors and coincidence detector. Based on ideas originally employed in the nuclear particle counting industry and later extended to OSETI by Werthimer and Horowitz. The noise reduction technique works because the probability of receiving a 1 ns-duration background noise photon in each receiver <<1, whereas a burst of beacon photons will be instantaneously detected by both detectors as a simultaneous event.**

It could be argued that only if an emerging civilization like our own attempts Optical CETI (Communications with ETIs), will the signal strength be so low as to require big receiving telescopes for their successful detection. That, since advanced technical civilizations are bound to be very rare indeed, we should develop receivers that are better matched to the signals produced by these advanced civilizations, rather than ones just above our level of technical accomplishments.

## The Latest Photon Counting Technology for the Visible and Near Infrared

At this time there are two main contenders for the title of best commercial photon-counting modules. They are the Hamamatsu H7421-40 PMT system[i] and PerkinElmer SPCM-AQR solid-state system[j]. Both turnkey systems employ Peltier coolers and have high quantum efficiencies. One of the major disadvantages of these modules is that they use relatively slow discriminators. If two or more units are required for coincidence detection, then a faster 1-ns external discriminator should be employed with the analog version of the detector. The analog version of the Hamamatsu H7421-40 PMT is the H7422.

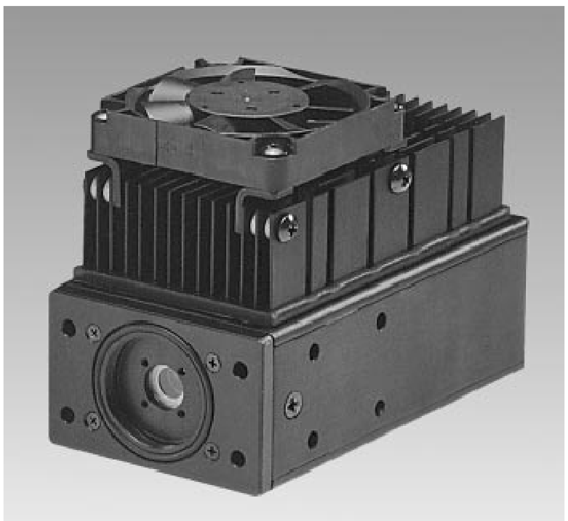

**Figure 12. Hamamatsu H7421 PMT Photon Counter.**

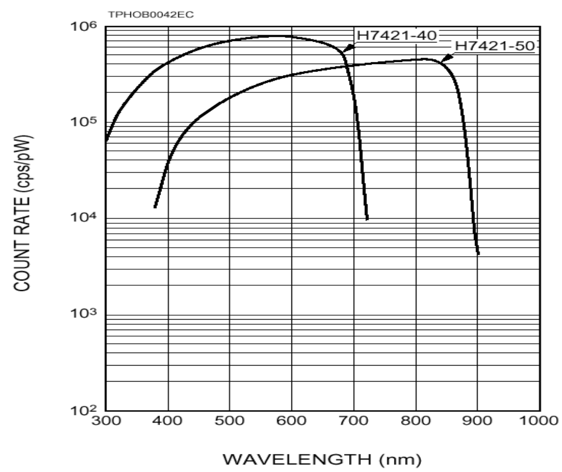


**Figure 13. Spectral response for the Hamamatsu H7421 PMT Photon Counter.**

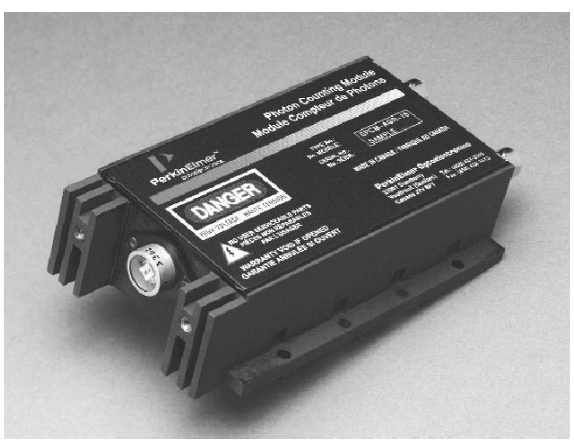


**Figure 14. PerkinElmer solid state Single Photon Counter Module (SPCM).**

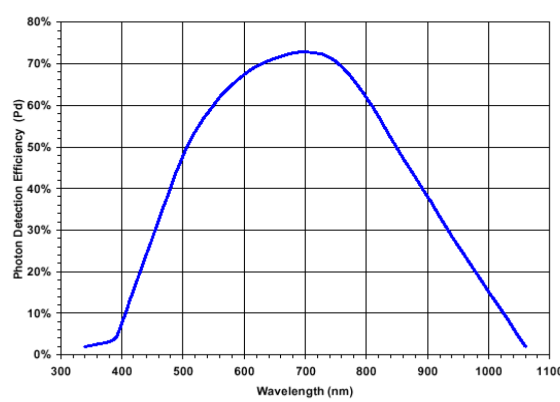


**Figure 15. Spectral response for PerkinElmer SPCM.**

[i] Hamamatsu: www.hamamatsu.com
[j] PerkinElmer: www.perkinelmer.com

The quantum efficiency for the Hamamatsu H7421-40 Photon Counter peaks at 580 nm around 30%, while the quantum efficiency for the PerkinElmer Photon Counter peaks at 630 nm at 70%. Both have dark counts less than 100 cps. The Hamamatsu module uses a very delicate GaAsP photocathode. The PerkinElmer module (formerly an EG&G product) uses a specially selected low-noise GaAs APD in the Geiger mode. Even though both the Peltier-cooled modules are small and can be mounted directly at the rear of most small telescopes, they come with fiber optic pigtail options that allow for mounting to the telescope support structure, if required. Unfortunately, these Cadillacs of the photon counter world are very expensive, typically $3,500 to $4,500 each, and they are also rather delicate with respect to being damaged or destroyed by excess optical input.

Of course, there is not necessary to use such state-of-the-art photon counters, other low-cost analog PMTs with modest 10 to 20% quantum efficiencies can be employed with external faster discriminators. Note that PMT dark current is normally negligible with respect to stellar background radiation, and if a coincidence discriminator is employed, can be reduced to insignificant levels.

## Pulsed Beacon Optical SETI Rationale Revisited

In a paper in these proceedings by Shelley Wright, et. al., a super sensitive photon counter is described which employs three or more PMTs to suppress the background noise count.[45] The basic idea was illustrated in Figure 11, and Figure 16 is an extension of this concept. It would perhaps be in order to make some comments regarding the sensibility of doing this for we may be in danger of losing track of why ETIs would transmit attention-getting pulsed beacons and making our photon-counting receivers unnecessarily complex, to the point where the law of diminishing returns sets in. Particularly if expensive, high quantum efficiency, low noise photon counters are being employed, as described above, the utility of using more than two needs to be questioned on a cost-benefit basis.

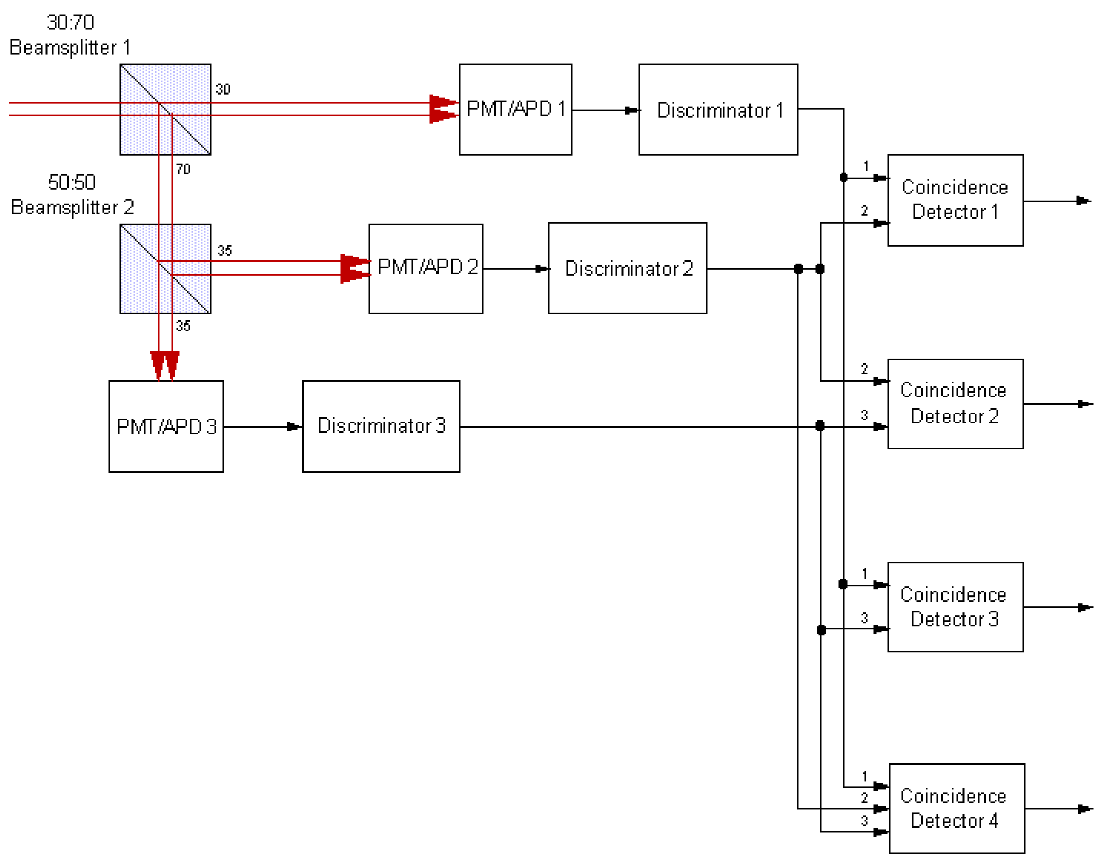


**Figure 16. An extension of the coincidence system of Figure 11, but employing three photon detectors. This system is described elsewhere in these proceedings.[44] A system based on this technique is being installed at the Lick Observatory.**

As mentioned earlier, the original idea to use coincidence detection to suppress the unwanted background noise count and thus mitigate the data collections requirements and signal processing complexity, was first employed by Dan Werthimer and subsequently used by Paul Horowitz. There is little doubt that the use of a coincidence detector photon-counter system consisting of two PMTs or APDs is very beneficial. More coincident detectors aimed at reducing noise may not be!

First we need to ask ourselves "What might be the format of such signals and how might ETIs send the "Rosetta Stone" to decode the main wideband channel? This was covered earlier in this paper. The idea was represented that an "attention-getting" laser beacon would have the form of a regular, very short pulse of very high EIRP. ETIs would try and make their beacon easily detectable. There would be no doubt that when such a signal was detected that it was artificial in nature, and that it probably conveyed a low data-rate message.

Although the acceptance by main stream SETI researchers that the optical approach to SETI is a promising avenue of investigation is fairly recent, we may already be seeing the beginning of the process adopted in Microwave SETI in assuming that failure to detect an ETI signal immediately means that we need to increase our receiver sensitivity. This may not be the case! It is more likely that, in these early days, failure so far is due to not yet observing targeted stars systems that are transmitting, when they are transmitting in our direction, or not observing in the correct part of the optical spectrum. This may require high-altitude or space-based observatories. As previously mentioned, if a reasonably rapid pulse train of attention-getting beacon pulses is not employed by ETIs, then the low data rate channel will be constrained unnecessarily to be of extremely low bandwidth. Why would the sending ETI civilizations do this?

Using the data provided by Shelley Wright[45], Table 2 has been constructed. It shows the predicted coincidence detected background photon count rate in counts per second (cps) as a function of the optical background arrival rate (photons per second) for 2, 3 and 5 sets of coincidence detectors (see Figure 16). If the system time resolution is short, i.e., 1 ns, the probability of a single photon counter with a quantum efficiency of 25% detecting a background noise photon when the background flux is $10^6$ photons per second, leads to a count rate of 250,000 cps. A background radiation level of $10^6$ photons per second is what would be obtained from a small telescope and a typical bright star. The ratio of $10^6/10^9 = 0.001$. Two such detectors feeding a coincidence gate will produce a noise count of 250,000 x 0.001, or 250 cps.

With three such detectors, the detected count it falls to $3.6 \times 10^{-2}$ counts per second and for five such detectors, it falls to $3.9 \times 10^{-6}$ counts per second. Clearly, the twin detector system produces a major improvement in detected background noise. However, even in the presence of the background radiation from a bright star, the detected noise count is now so low, that 3 or more coincidence detectors do not really improve matters. If there was a bright ETI laser beacon pulse present in that flux that repeated once every second, its effect could easily be separated from the 250 cps detected background count by simply doing an FFT on the count, and looking for energy piling up at certain frequencies (the pulse repetition rate), and/or slightly increasing the PMT thresholds to cut down the background count. As the detected background drops (dimmer targeted stars) or the receiver aperture is reduced, the detected background count drops significantly, so that the amount of data (signal and noise) that needs to be stored becomes rather modest. A noise count of 250 cps is not too different from the dark current count produced by a single PMT or APD.

**Table 2. Based on the table presented in Shelley Wright's paper[45] and converted to detected photon counts per second (cps)**

| Numbers of Detectors Used | | | |
|---|---|---|---|
| Photon Flux | 2 Detectors | 3 Detectors | 5 Detectors |
| $10^3$ | $2.5 \times 10^{-4}$ | $3.6 \times 10^{-11}$ | $3.9 \times 10^{-18}$ |
| $10^4$ | $2.5 \times 10^{-2}$ | $3.6 \times 10^{-8}$ | $3.9 \times 10^{-14}$ |
| $10^5$ | 2.5 | $3.6 \times 10^{-5}$ | $3.9 \times 10^{-10}$ |
| $10^6$ | 250 | $3.6 \times 10^{-2}$ | $3.9 \times 10^{-6}$ |

Thus, if we assume a strong regular pulsed laser beacon then there may be no point in having more that one pair of coincidence detectors. Even a single photon-counter with raised threshold (Figure 10) should be adequate to detect a pulsed

ETI beacon since the characteristics of the signal will be unique and should differentiate itself from random background and internal PMT/APD noise sources.

Now it can be argued that by suppressing the background noise count, it means that only simple threshold detection need be applied on the fly, so that if we do detect any "count" it is more likely that it is a real ETI signal. Essentially, what has been done here is to trade off post-detection electronic simplicity with more pre-detection optical complexity and cost. This will be of particular concern for amateur observatories on tight budgets. One might pay $4,000 for a single state-of-the-art, very low noise, high quantum efficiency photon counter. Adding several more identical photon counters and their associate beamsplitters and electronics may not be performance and cost effective. What might be desirable for a professional facility with a large budget, hanging onto the back of a large, expensive telescope, may not make sense for the amateur, particularly with regard to the rapidly falling costs of post-detection signaling processing hardware and storage.

## Multichannel/Multiscaler Analyzers

At some time in the future, an OSETI observatory will need to collect and process all the data in 1 ns slots to "understand" the message in the wideband channel. Processing on the fly and not storing the data just delays the need to demodulate the "message". For the moment, while the search is only about finding ETI laser beacons signals and demodulating its low bandwidth message, this is not a major problem.

For counting short pulses, the types of instruments previously developed for the nuclear industry may be appropriate. During the '90's, The Ortec Turbo MCS Multichannel Analyzer[k] (Figure 17) might have been appropriate for the job. Today, for an ultimate PC-based counter, FastComTec[l] (Figure 18) makes one of the fastest PC cards. Of course, there is not much point in having such a high-speed counter if the pulse-pair resolution for the photon-counting system is poor (many tens of ns). This is the case for the Hamamatsu and PerkinElmer "digital" photon-counting systems described earlier, with their somewhat limiting integral discriminator performances, particularly with respect to the PMT systems. Faster discriminators would use ECL logic, rather than TTL. Using an "analog" PMT or APD photon counting head with external discriminators is often required for fast recovery and short pulse-pair resolution, though the costs will be higher.

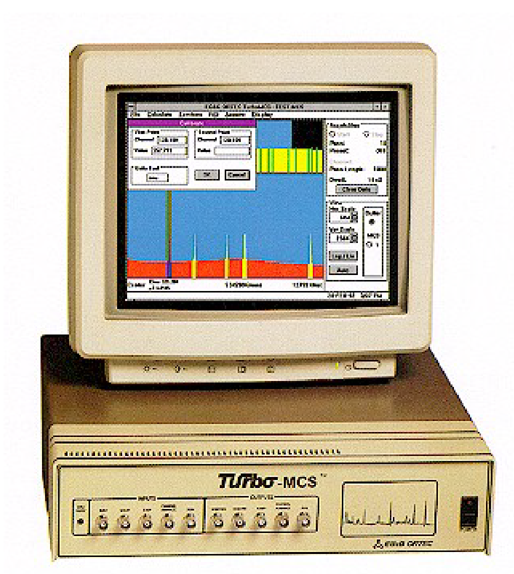

**Figure 17. PerkinElmer's Ortec Turbo MCS Multichannel Analyzer.**

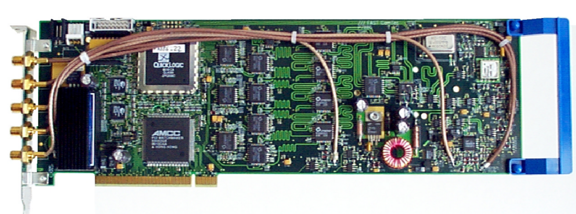

**Figure 18. FastComTec ultra-fast P7886 2 GHz Time-of-Flight/Multiscaler.**

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[k] www.perkinelmer.com
[l] www.fastcomtec.com

## 4. THE FUTURE

The Columbus Optical SETI Observatory is believed to be the world's first observatory dedicated just to Optical SETI.[46] Up to now, other OSETI observatories have employed existing telescopes and have shared time with other projects. Now the time has come for large dedicated observatories to be built, for optical type SERENDIP projects on the world's largest telescopes, and for space-based Optical SETI.

### The Planetary Society

On the first day of the OSETI III Conference, The Planetary Society announced that with Harvard University, they are going to build the largest dedicated OSETI observatory to date.[44] The new All-Sky Optical SETI Survey will use a 1.8 meter (72 inch) diameter optical telescope dedicated exclusively to SETI. When this "light-bucket" telescope is completed, it will be the largest in the eastern United States. This new Optical SETI telescope will be located in Harvard, Massachusetts and should see first light early in 2002.

### The PhotonStar Project

In another paper in these proceedings, Monte Ross describes an optical version of the P2P (Peer-to-Peer) SETI@Home, but with a difference.[43] This concept should appeal to many amateur optical astronomers who already possess a well-equipped observatory. Basically, the idea is to use GPS technology to obtain precise location and time information for amateur Optical SETI observatories scattered over a continent. Each observatory would employ a standard photon counting detector head, a PC interface card, and some software. Clearly, for this endeavor to have great appeal to the amateur astronomy community, a low-cost and rugged photon counting turnkey module needs to be developed with nanosecond response time.

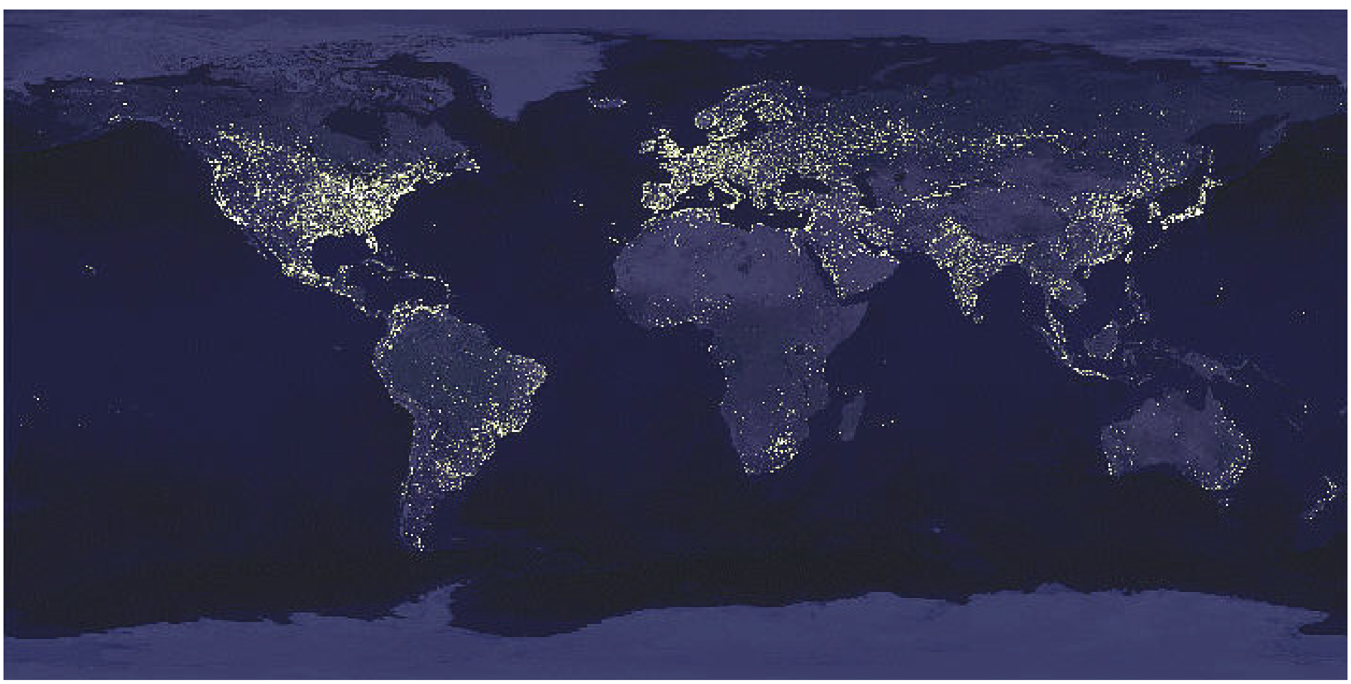

**Figure 19. Composite photo of the Earth at Night.[m]**

The data collected over the Internet from each observatory would be integrated, after making time adjustments for each data set to account for the location of each observing site. This would be equivalent to using a single huge telescope. Each week there would be a "star of the week" which would be observed at certain designated UTC times, continent by continent.[47] Even in light-polluted areas (Figure 19), Optical SETI is practical as long as the participant uses imaging devices that allow

[m] Air Force's Defense Meteorological Satellites Program: http://antwrp.gsfc.nasa.gov/apod/image/0011/earthlights_dmsp_big.jpg.

the correct identification and location of the designated targeted star. For more information about the PhotonStar Project, visit: www.photonstar.org.

## The World's Largest Optical Telescopes

In recent years there has been an explosion in construction of new "great" ground-based optical observatories, using new technologies to construct larger mirrors and improve "seeing" by the use of adaptive optics.[48] In time, it is possible that some of these observatories will be employed for OSETI research, either for dedicated observations or as a kind of Optical SERENDIP. Indeed, Geoff Marcy[43,49] has been doing just that as he and his colleagues search for extrasolar planets. Table 3 is a list of great and large telescopes located throughout the world (not every large telescope is listed here).

There are also a significant number of large optical telescopes around the world that have fallen out of use because of light pollution. Many of these latter 'scopes could be brought back into service for Optical SETI, at low cost. Some might even be employed for daylight OSETI!

It may well take one of these great telescopes listed at the top of the table to be able to gather a sufficient number of photons per second to ensure low bit error rate (BER) of the expected weaker wideband channel. Of course, these expensive diffraction-limited telescopes could be considered to be overkill for OSETI. For all that is needed are large, non-diffraction-limited light buckets.

**Figure 20. A narrow laser beam transmitted by a large terrestrial telescope.**

**Figure 21. The Starfire Optical Range at Kirkland Air Force Base.**

The photograph of Figure 20 illustrates the appearance of a laser beam leaving a large aperture telescope. To date, most such laser experiments have involved work on adaptive optics and laser guide stars[48] (Figure 21), shooting down dummy missiles, and communicating with experimental satellites[50]. This is not to suggest that ETIs would use ground-based uplinks. The author has long assumed that ETIs would employ stellar or nuclear-pumped space-based laser transmitter phased-array uplinks in orbit about their star or constructed on an inner planet lacking an atmosphere.[31,32,42]

# Table 3. The World's Largest Optical Telescopes[n]

| | Name | Location | Latitude | Longitude | Aperture |
|---|---|---|---|---|---|
| 1. | Very Large Telescope (VLT) | Cerro Paranal, Chile | 24° 38′ S | 70° 24′ W | 4 x 8.2 m |
| 2. | Keck Telescopes (Keck I and II) | Mauna Kea, HI | 19° 49′ N | 155° 28′ W | 2 x 9.82 m |
| 3. | Large Binocular Telescope (LBT) | Mount Graham, AZ | 32° 42′ N | 109° 51′ W | 2 x 8.4 m |
| 4. | Gran Telescopio Canarias (GTC) | La Palma, Canary Islands | 19° 49′ N | 17° 54′ W | 10.4 m |
| 5. | Hobby-Eberly Telescope (HET) | Mount Fowlkes, TX | 30° 41′ N | 104° 01′ W | 9.1 m |
| 6. | Southern African Large Telescope (SLAT) | Sutherland, South Africa | 32° 23′ S | 20° 49′ E | 9.1 m |
| 7. | Subaru Telescope | Mauna Kea, HI | 19° 50′ N | 155° 29′ W | 8.2 m |
| 8. | Gemini Telescope (north) | Mauna Kea, HI | 19° 49′ N | 155° 28′ W | 8.1 m |
| 9. | Gemini Telescope (south) | Cerro Pachón, Chile | 30° 14′ S | 79° 43′ W | 8.1 m |
| 10. | MMT Observatory 6.5-m Telescope | Mount Hopkins, AZ | 31° 41′ N | 110° 53′ W | 6.5 m |
| 11. | Magellan I and II | Las Campanas, Chile | 29° 00′ S | 70° 42′ W | 2 x 6.5 m |
| 12. | Bolshoi Teleskop Azimutal'ny (6-m BTA) | Mount Pastukhov, Russia | 43° 39′ N | 41° 26′ E | 6.0 m |
| 13. | Large Zenith Telescope (LZT) | Maple Ridge, BC, Canada | 49° 17′ N | 122° 34′ W | 6.0 m |
| 14. | George Ellery Hale Telescope (200-inch) | Palomar Mountain, CA | 33° 21′ N | 116° 52′ W | 5.08 m |
| 15. | William Herschel Telescope (WHT) | La Palma, Canary Islands | 28° 46′ N | 17° 53′ W | 4.2 m |
| 16. | SOAR 4-m Telescope | Cerro Pachón, Chile | 30° 21′ S | 70° 49′ W | 4.2 m |
| 17. | Victor M. Blanco Telescope (CTIO 4-m) | Cerro Tololo, Chile | 30° 10′ S | 70° 49′ W | 4.001 m |
| 18. | Anglo-Australian Telescope (AAT 3.9-m) | Siding Spring Mtn., Australia | 31° 17′ S | 149° 04′ E | 3.893 m |
| 19. | Nicholas U. Mayall Reflector (Kitt Peak 4-m) | Kitt Peak, AZ | 31° 58′ N | 111° 36′ W | 3.81 m |
| 20. | United Kingdom Infrared Telescope (UKIRT 3.8-m) | Mauna Kea, HI | 19° 50′ N | 155° 28′ W | 3.802 m |
| 21. | Advanced Electro-Optical System Telescope (AEOS 3.6- | Haleakala, Hi | 20° 42′ N | 156° 15′ W | 3.67 m |
| 22. | Canada-France-Hawaii Telescope (CFHT 3.6-m) | Mauna Kea, Hi | 19° 49′ N | 155° 28′ W | 3.58 m |
| 23. | Telescopio Nazionale Galileo (Galileo 3.6-m) | La Palma, Canary Islands | 28° 45′ N | 17° 54′ W | 3.58 m |
| 24. | ESO 3.6-m Telescope | La Silla, Chile | 29° 15′ S | 70° 43′ W | 3.57 m |
| 25. | 3.5-m Telescope | Calar Alto, Spain | 37° 13′ N | 2° 33′ W | 3.5 m |
| 26. | New Technology Telescope (NTT 3.5-m) | La Silla, Chile | 29° 16′ S | 70° 44′ W | 3.5 m |
| 27. | Astrophysics Research Consortium Telescope (ARC 3.5- | Apache Point, NM | 32° 47′ N | 105° 49′ W | 3.5 m |
| 28. | Wisconsin-Indiana-Yale-NOAO Telescope (WIYN 3.5-m) | Kitt Peak, AZ | 31° 57′ N | 111° 36′ W | 3.5 m |
| 29. | Starfire Optical Range 3.5-m Reflector | Kirkland Air Force Base, NM | 34° 58′ N | 106° 28′ W | 3.5 m |
| 30. | C. Donald Shane Telescope (120-inch) | Mount Hamilton, CA | 37° 21′ N | 121° 38′ W | 3.05 m |
| 31. | NASA Infrared Telescope Facility (IRTF) | Mauna Kea, HI | 19° 50′ N | 155° 28′ W | 3.0 m |
| 32. | 3-m Liquid Mirror Telescope (NODO) | Cloudcroft, NM | 32° 58′ N | 105° 44′ W | 3.0 m |
| 33. | Harlan J. Smith Telescope (107-inch) | Mount Locke, TX | 30° 40′ N | 104° 01′ W | 2.72 m |
| 34. | Shajn 2.6-m Reflector (Crimean 102-inch) | Nauchny, Ukraine | 44° 44′ N | 34° 00′ E | 2.64 m |
| 35. | Byurakan 2.6-m Reflector | Mount Aragatz, Armenia | 40° 20′ N | 44° 18′ E | 2.64 m |
| 36. | Nordic Optical Telescope (NOT) | La Palma, Canary Islands | 28° 45′ N | 17° 53′ W | 2.56 m |
| 37. | Irenee du Pont Telescope (100-inch) | Las Campanas, Chile | 29° 00′ S | 70° 42′ W | 2.54 m |
| 38. | Isaac Newton Telescope (98-inch) | La Palma, Canary Islands | 28° 46′ N | 17° 53′ W | 2.54 m |
| 39. | Hooker Telescope (100-inch) | Mount Wilson, CA | 34° 13′ N | 118° 03′ W | 2.5 m |
| 40. | Stratospheric Observatory for Infrared Astronomy | Airborne | --- | --- | 2.5 m |
| 41. | Sloan 2.5-m Reflector | Apache Point, NM | 32° 47′ N | 105° 49′ W | 2.5 m |
| 42. | Hubble Space Telescope (HST) | Earth Orbit | --- | --- | 2.4 m |
| 43. | Hiltner Telescope (2.3-m) | Kitt Peak, AZ | 31° 95′ N | 111° 62′ W | 2.34 m |
| 44. | Vainu Bappu 2.3-m | Kavalur, Tamil Nadu, India | 12° 35′ N | 78° 50′ E | 2.33 m |
| 45. | Bok Telescope (90-inch) | Kitt Peak, AZ | 31° 57′ N | 111° 36′ W | 2.3 m |
| 46. | Mount Stromlo 2.3-m (Advanced Technology Telescope) | Siding Spring Mtn., Australia | 31° 16′ S | 149° 03′ E | 2.3 m |
| 47. | Wyoming Infrared Telescope | Jelm Mountain, WY | 41° 06′ N | 105° 59′ W | 2.29 m |
| 48. | 2-meter Telescope (Tautenberg Schmidt) | Tautenberg, Germany | 50° 59′ N | 11° 43′ E | 1.34 m |
| 49. | Oschin 48-inch Telescope | Palomar Mountain, CA | 33° 21′ N | 116° 51′ W | 1.24 m |
| 50. | United Kingdom Schmidt Telescope Unit (U.K. Schmidt) | Siding Spring Mtn. Australia | 31° 16′ S | 149° 04′ E | 1.24 m |
| 51. | Kiso Schmidt Telescope | Kiso, Japan | 35° 48′ N | 137° 38′ E | 1.05 m |
| 52. | 3TA-10 Schmidt Telescope (Byurakan Schmidt) | Mount Aragatz, Armenia | 40° 20′ N | 44° 30′ E | 1.00 m |
| 53. | Kvistaberg Schmidt Telescope (Uppsala Schmidt) | Kvistaberg, Sweden | 59° 30′ N | 17° 36′ E | 1.00 m |
| 54. | ESO 1-meter Schmidt Telescope | La Silla, Chile | 29° 15′ S | 70° 44′ W | 1.00 m |
| 55. | Venezuela 1-meter Schmidt | Mérida, Venezuela | 8° 47′ N | 70° 52′ W | 1.00 m |
| 56. | Telescope de Schmidt (Calern Schmidt) | Grasse, France | 43° 45′ N | 6° 56′ E | 0.90 m |
| 57. | Telescope Combine de Schmidt | Brussels, Belgium | 50° 48′ N | 4° 21′ E | 0.84 m |
| 58. | Schmidt Telescope | Riga, Latvia | 56° 47′ N | 24° 24′ E | 0.80 m |
| 59. | Calar-Alto-Schmidtspiegel | Calar Alto, Spain | 37° 13′ N | 2° 33′ W | 0.80 m |

[n] Adapted from Sky & Telescope, Vol. 100, No. 2, pp. 46-48, August 2000.

## Space-Based Optical SETI

Over the next two decades, many optical telescopes will be launched into space. Indeed, Steven Kilston and David Begley address this issue elsewhere in these proceedings.[51] Andrew Howard and Paul Horowitz[52] have recently published a paper on *Optical SETI with NASA's Terrestrial Planet Finder*. This author long ago proposed that at some point, the Hubble Space Telescope (HST) should be retrofitted for OSETI and that the Next Generation Space Telescope (NGST) be designed from the start to be capable of doing pulsed type OSETI. Table 4 lists a number of the major space-based optical telescopes that are planned or proposed for the coming decades. See Kilston's paper for a couple of space-based telescopes not included in this table. In the meantime, high-altitude balloons could enable the search to be extended further into the near infrared, early in this decade.

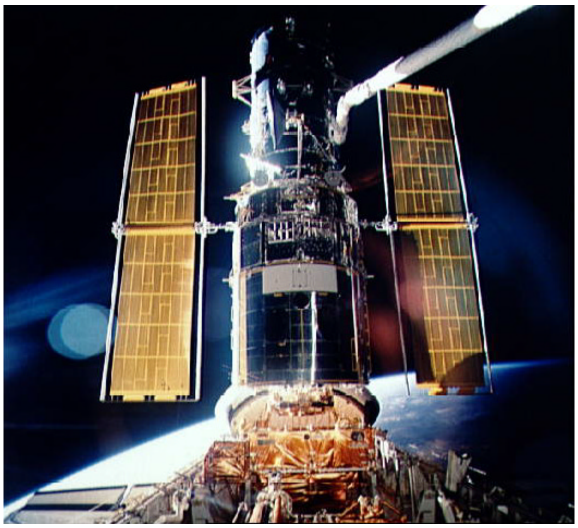

**Figure 22. The Hubble Space Telescope (HST).**

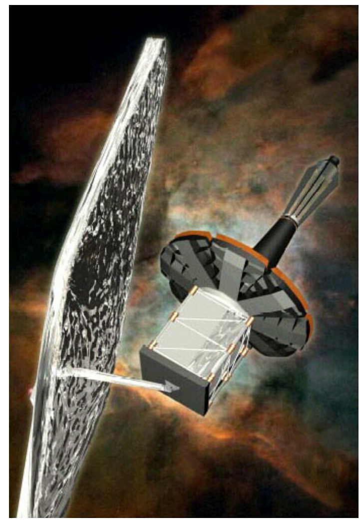

**Figure 23. The Lockheed Martin design for the Next Generation Space Telescope (NGST).**

### Table 4. Planned & Proposed Major Space-Based Optical Telescopes

| | Name | Wavelength Range | Agency | Launch Year | Aperture |
|---|---|---|---|---|---|
| 1. | Hubble (HST) | 0.11 – 1.10 µm | NASA[o] | 1990 | 2.4 m |
| 2. | Space Infrared Telescope Facility (SIRTF) | 3 – 180 µm | NASA | 2002 | 0.85 m |
| 3. | Infrared Imaging Surveyor (IRIS) | 2 – 200 µm | NASA | 2003 | 0.70 m |
| 4. | Full-Sky Astrometric Mapping Explorer (FAME) | 0.4 – 0.9 µm | NASA | 2004 | 2 x 0.6 m x 0.25 m |
| 5. | Kepler | 0.4 – 0.85 µm | NASA | 2006 | 0.95 m |
| 6. | Far Infrared and Submillimeter Telescope (FIRST) | 60 – 670 µm | ESA[p] | 2007 | 3.5 m |
| 7. | Space Interferometry Mission (SIM) | 0.4 – 0.9 µm | NASA | 2009 | 2 x 0.3 m |
| 8. | Next Generation Space Telescope (NGST) | 1 – 20 µm | NASA | 2009 | 8.0 m |
| 9. | Global Astrometric Interferometer for Physics (GAIA) | 0.28 – 0.92 µm | ESA | 2011 | 1.7 m x 0.7 m |
| 10. | Terrestrial Planet Finder (TPF) | 3 – 30 µm | NASA | > 2015 | 4 x 3.5 m |
| 11. | Darwin InfraRed Space Interferometer (IRSI) | 5 – 30 µm | ESA | > 2015 | 5 x 1.5 m |
| 12. | Life Finder (LF) | Visible to Infrared | NASA[51] | > 2018 | 2 x 12.5 m, 2 x 25 m |
| 13. | Planet Imager (PI) | Visible | NASA[51] | > 2022 | N* x 40 m |

*A small number.

[o] www.jpl.nasa.gov
[p] www.esrin.esa.it

The need for OSETI observatories in space is clear, since we do not know the favored wavelength bands in the optical spectrum that might be used for a SETI communications channel. There may be good reasons why a laser transition is chosen for which the terrestrial atmosphere is not transparent. On the other hand, sensitive, low noise optical detectors suitable for photon counting have only been developed for the visible and near-infrared regions of the spectrum. If this continues to be a limitation, perhaps we do not need to move far into the infrared to hit on the "magic" region of the optical spectrum.

**Figure 24. Space Interferometer Mission (SIM). JPL artistic impression.**

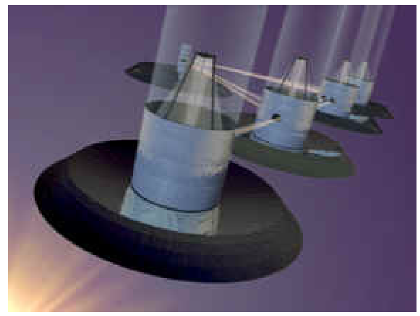

**Figure 25. Terrestrial Planet Finder (TPF). JPL artistic impression.**

Most of these planned space-telescopes will already feature high-resolution spectrometers that can search for cw beacons. Adding fast photon-counting instrumentation is another matter. As with the great telescopes of the world, an optical type of SERENDIP program is probably in order. Don't just look for extrasolar planets; see if there are Alien laser transmitters on or near these planets!

## 5. CONCLUSIONS

This author has long maintained that it is only an historical accident that on this planet, the Search for Extraterrestrial Intelligence in the Electromagnetic Spectrum has taken on a radio frequency bias. It is now clear that the first decade of this new Millennium will witness a major redirection of SETI research effort from the radio spectrum to the optical spectrum. This effort will be both professional and amateur based. By 2005, most professional SETI observatories on this planet will be of the optical variety. By 2010, most of the SETI funding will be for Optical SETI. By the end of the first decade of the Millennium, monochromatic cw SETI observations will have been conducted by space-based observatories. Hopefully, by that time or shortly thereafter, space-based OSETI of the pulsed kind will also be underway and we will be truly in "The Age of Optical SETI".

Because of the large established base of amateur optical observatories, amateur astronomers will make major contributions to SETI. This has never been "conveniently" possible in the radio regime to any major degree. If the radio frequency SETI@Home was able to find a huge number of participants (approaching 3 million at this time of writing), how much more so would an optical version that allowed amateur optical astronomers the ability to contribute their own observational data!

Even if by 2020 we have not yet had a confirmed detection of a laser-based ETI signal, it is likely to be many more years before sufficient target observing time has been accumulated to come to a definite conclusion about the lack of attention-getting ETI transmitter beacons. A large part of the optical spectrum will have to be searched and different detection techniques implemented before we can come to any such conclusion. In the meantime, research data from other areas of astrophysics, such as the detection of earth sized extrasolar planets, will help us better understand how formidable is the task of detecting electromagnetic signals of any kind from transmitting ETI civilizations.[q]

[q] This paper may be downloaded in PDF and HTML formats from: www.coseti.org/4273-06.htm. Both formats contain active hypertext external links.

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