Is Optical SETI a Viable Option for Independent Researchers?

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After a few years of research, developing hardware and considering this issue, the following discourse makes a fair case for answering the question in the affirmative. But before getting into the basis for the "yes" answer, it will be helpful to go over a few of the rudiments of Optical SETI.

Several papers over the past decade have described mega-joule scale pulsed lasers as being capable of outshining a parent star by several orders of magnitude at distances up to 1000 light years. While those assertions are well founded, for anyone who has not yet done their homework they can be misleading. What is meant is that during the brief period of a laser pulse there can be several orders of magnitude more laser photons passing through a distant unit of area than photons from a parent star. For example, if the rate of detected stellar photons is 10^6 per second and a laser pulse length is 5 nanoseconds, then on average during that very brief interval one could expect only about 0.005 stellar photons, but there could be tens or even thousands of photons from a laser pulse and these would be sufficient for detection. We also know that a laser signal can have a nearly constant total flux out to 1000 light years (Howard, A.W, et al[4]). That is, there is little in the interstellar medium to degrade or disperse the signal.

The independent researcher may well hold the trump card for detecting ETI laser signals. Large institutional telescopes are few in number and fewer still have allocated significant blocks of time to Optical SETI searches. OSETI funding is also dearly held. It will be seen that Optical SETI needs many telescopes looking all the time; not just a few large telescopes looking only rarely, albeit with high end equipment.

Laser Signal Detection. Recently, for another paper, I was tasked with comparing the sensitivity of the Boquete Observatory's system to laser signals with that of other Optical SETI projects. Prior to this, I was aware of most of those comparisons, but when the whole picture was laid out a new appreciation was formed for the potential contributions independent researchers can make. The Boquete telescope has only a 0.5 meter (20") aperture compared with institutional optical SETI instruments ranging at present from 0.9 meters to 1.8 meters. How can the Boquete system compare favorably with these? Other SETI laser signal detection schemes have typically employed two or more photo-detectors (photomultipliers or avalanche photodiodes) whose outputs are compared to reveal photoelectron pulses that are coincident in time (piled up). This method requires fussy design and precise construction using beam splitters to divert portions of the incoming starlight to the photo-detectors. It is expensive, somewhat complicated and not so simple to calibrate and maintain. Using this method, positive detections, false and otherwise, create a time consuming requirement to explain each and every one. Thus, the desire to minimize false positives appears to have driven the experimenters to make sensitivity compromises.

Alternatively, coincident (piled up) photons can be detected using a single photo-detector, but that method has generally been dismissed because of the propensity for false positive signals caused by gamma rays, corona and a few other distracting phenomenon. Sorting out a large number of false positives can be a burden, and if it can't be done timely and unambiguously, the whole experimental effort becomes a useless exercise. So it is clear that the needs for credibility and a reasonable experimental workload have, until the last few years, limited detector designs to multiple photo-detector configurations.

The Boquete photometer uses only a single photomultiplier in combination with a number of unique steps that result in a detection method having improved sensitivity and without concerns for false positive detections. The later is exemplified with the observation of more than 4000 stars during which only a single (presumed) false positive event was experienced. In addition to coincident pulse detection, the photometer is also sensitivity to non-coincident pulsed signals, i.e. photoelectron pulses spread out in time to 50 nanoseconds or more. The single detector photometer is described in more detail in the appendices.

The Boquete Observatory instrument's minimum detectable limit of 67 photons m^{-2} compared well with most of the larger systems having apertures up to about 1 meter. More recently, improvements to the photometer have reduced that limit down to about 60 photons m^{-2} for stars of magnitude 11 and greater. Thus, we can see that a 0.5 meter telescope and detector can have performance that nearly matches that of current larger systems. It must also be appreciated that telescopes having apertures larger than about 1 meter have the disadvantage of gathering too much background starlight; reducing the ability to detect laser signals. The range of stellar magnitudes actually favors small telescopes for optical SETI. For example, candidate stars most often include magnitude extremes of ~2 to 14. The 0.5 meter telescope is limited to stars no brighter than about magnitude 6 without the use of an aperture mask or a neutral filter in the photometer. Larger telescopes would be even more constrained without an appropriate light limiting feature. Thus, a small telescope with a single detector can have a sensitivity advantage over a larger one with multiple detectors. A large telescope aperture does have a clear advantage for stars of magnitude ~10 and greater, but only if compromises aren't made with detection sensitivity. Furthermore, telescopes with apertures as small as 10"- 14" can be applied to SETI searches involving bright stars within ~100 light years such as Rigil Kent, Eps. Iridani, Tau Ceti, etc.

Next it will be useful to review the primary aspects of laser transmissions and to bracket what may be considered a range of expectations regarding the intensity of laser signals at various target distances. The parameters to be considered are the laser pulse energy, the transmitting telescope's aperture and the distance to the targeted star. The calculation details of these aspects may be found in the appendices. For our purposes, and staying clear of what might now be considered transmission equipment extremes, we will see that a small telescope, 16" aperture for example, can detect laser pulses at distances out to 300 light years or more. Of course a more powerful laser using a very large transmitting telescope can extend that distance well beyond 500 ly, but there are practical aspects that argue against these extreme cases; not the least of which is, " what is the point"? It is beyond this author's imagination why any civilization would consider making blind targeted transmissions for which the earliest chance of contact confirmation might be a thousand years. Even attempting an 800 year round trip communication seems a highly unlikely enterprise. In my opinion, the probability of being targeted is inversely proportional to distance - and more probably to some power of the distance, e.g. $1/r^3$.

The primary advantage of very large (>5m) telescopes for SETI is in searches for chance signals from deep space; those not targeting our solar system but whose beam has, over a great distance, diverged to a relatively large degree. Deep space signal detection requires a different approach with the intention only to establish that something somewhere has sent a signal. Any acquired signal would likely be too brief to establish periodicity and the chances of it being replicated later nearly nonexistent. The criteria to determine such a signal's authenticity is an entirely different matter and not part of this discussion.

These arguments suggest that the greatest likelihood of being targeted would originate from nearby stars, i.e. out to <400 ly. The number of K, G and M type stars in our neighborhood is very roughly:

Distance (ly)	Total Quantity of K,G,M Stars
100	3,500
200	27,000
300	90,000
400	215,000
500	420,000

A discussion regarding the probability of being targeted and coincidentally detecting that signal here on earth can be depressing to say the least. Although scientific endeavors disdain the need for luck, there can be little disagreement that a large dose of fortunate happenstance would be most welcome in this case. Presently and worldwide, there may be only one full time OS observatory (Boquete). By the summer of 2018 the Owl Observatory in Michigan will be going full time and the dependence upon luck will have been cut in half. Is it worth mentioning that more are needed?

Laser Transmission Characteristics. A laser's beam divergence angle is inversely proportional to the waist of the beam. For our purposes the waist is the radius of the transmitting telescope's aperture. Tables 1 and 2 will help provide some insight here.

Table 1

Illuminated Disk Diameter (AU)

Distance (ly)	Transmitting Telescope Aperture 2m	4m	8m	16m
100	2.2	1.1	0.5	0.3
200	4.4	2.1	1	0.5
300	6.6	3.2	1.6	0.8
400	8.8	4.3	2.2	1.1
500	11	5.4	2.7	1.5

It may be seen in Table 1 that at less than 200 ly, a very large aperture telescope could confine a beam too greatly and possibly prevent the illumination of a planetary system's entire habitable zone. At 200 ly, for example, a 2 or 4 meter telescope appears to have reasonable targeting characteristics, but Table 2 indicates that the pulsed energy requirements for those apertures may be excessive. Therefore, a 6 to 8 meter telescope seems a reasonable choice for this example. (Take special notice that the tabular data in table 2 is for a received photon flux of 100 photons m^{-2}.) Advanced civilizations could, however, have precise knowledge of a targeted planet's habitability and position. In such case and with the same results, a very large transmitting telescope may be precisely aimed and operate with substantially reduced beam pulse energy.

Table 2

Laser energy required to present 100 photons m^{-2} at the target

Distance (ly)	Transmitting Telescope Aperture **2m**	**4m**	**8m**	**1 6**
100	3 MJ	750 kJ	200 kJ	50 kJ
200	13 MJ	3 MJ	750 kJ	200 kJ
300	-	7 MJ	1.7 MJ	450 MJ
400	-	13 MJ	3 MJ	800 kJ
500	-	-	5 MJ	1.3 MJ

Conclusions. A fair case has been made that small receiving telescopes have sufficient sensitivity to detect laser beacons from nearby stars. Needed now are many small optical SETI observatories. How can this be achieved? The single photo-detector photometer may be an important step in that direction.

Independent of the sensitivity issue, the multiple photo-detector photometer option probably involves the need for a greater range of technical competence and higher costs than may be expected of many independent SETI researchers. On the other hand, the single photo-detector photometer can be produced relatively inexpensively and used competently by those who have only a minimal background in instrument development. Also, for simplicity, some of the features that are under computer control at the Boquete facility may be set/adjusted manually with some loss in observing time productivity.

Appendices

I. Detector design: coincidence and pulse group detection using a single photomultiplier. For telescopes having 16 to 20 inch apertures, the typical photomultiplier background detection rates for stars having visual magnitudes of 14 to 6 is approximately 10^3 to 10^6 photoelectron pulse counts per second (cps or pps) respectively. For clarity, note that a detected photon and a pmt or apd photoelectron output pulse are used interchangeably.

Within the stellar background, we seek to detect 1+ pmt photoelectron pulse(s) that arrive during intervals from a few nanoseconds up to ~50 ns and which have a long but precise pulse period, i.e., 0.005 to 0.5 seconds. We now apply conditions to the 50 ns intervals such that the photometer will only generate an output pulse when more than 1 photoelectron pulse (i.e., 2, 3, 4) occurs within the interval. This number is often referred to as n, and it is a fundamental factor of the applicable Poisson statistics. Thus, when n = 2, there must be at least two photoelectron pulses detected within the detection interval. For coincidence, the interval is generally something less than 5 ns and for group detection less than 100 ns. The goal was to design a total system that differentiates low rate periodic pulses (signal) from a higher rate of individual random background pulses (noise).

Many of the multiple photo-detector photometers have attempted to do all of the signal differentiation within the photometer. But to accomplish the desired result of a very low rate of false positive detections, the threshold criterion was that 2, 3 or more photons, coincident in the time interval, were required to be detected by *each* detector before the photometer would generate an output pulse. That is, a minimum of 4 detected photons were needed for a two detector system, 6 for a three detector system, and so on. This technique works well, but it is complicated, expensive and sacrifices sensitivity to achieve a low rate of false positive detections.

During the first two years of SETI observations at the Boquete Observatory, two embodiments of the multiple photo-detector type of photometer were used. But because these were difficult to calibrate and suspected of having insufficient sensitivity it was decided to put time and effort into the design of a photometer and system having only a single photomultiplier and that used a combination of methods to extract periodic signals from the stellar background. It was also decided that the arbitrary limit of detecting coincident events occurring in less than 5 ns may be too restrictive. That is, longer laser pulse durations may have embedded data and other technical advantages. Thus, the new photometer should be capable of detecting unusual temporal photon densities occurring within intervals as great as 100 ns. Over a few years, the single detector photometer and downstream processing methods have evolved into a sensitive means of signal detection and differentiation from a wide range of stellar backgrounds.

The following paragraphs describe the current embodiment of the Boquete optical SETI system.

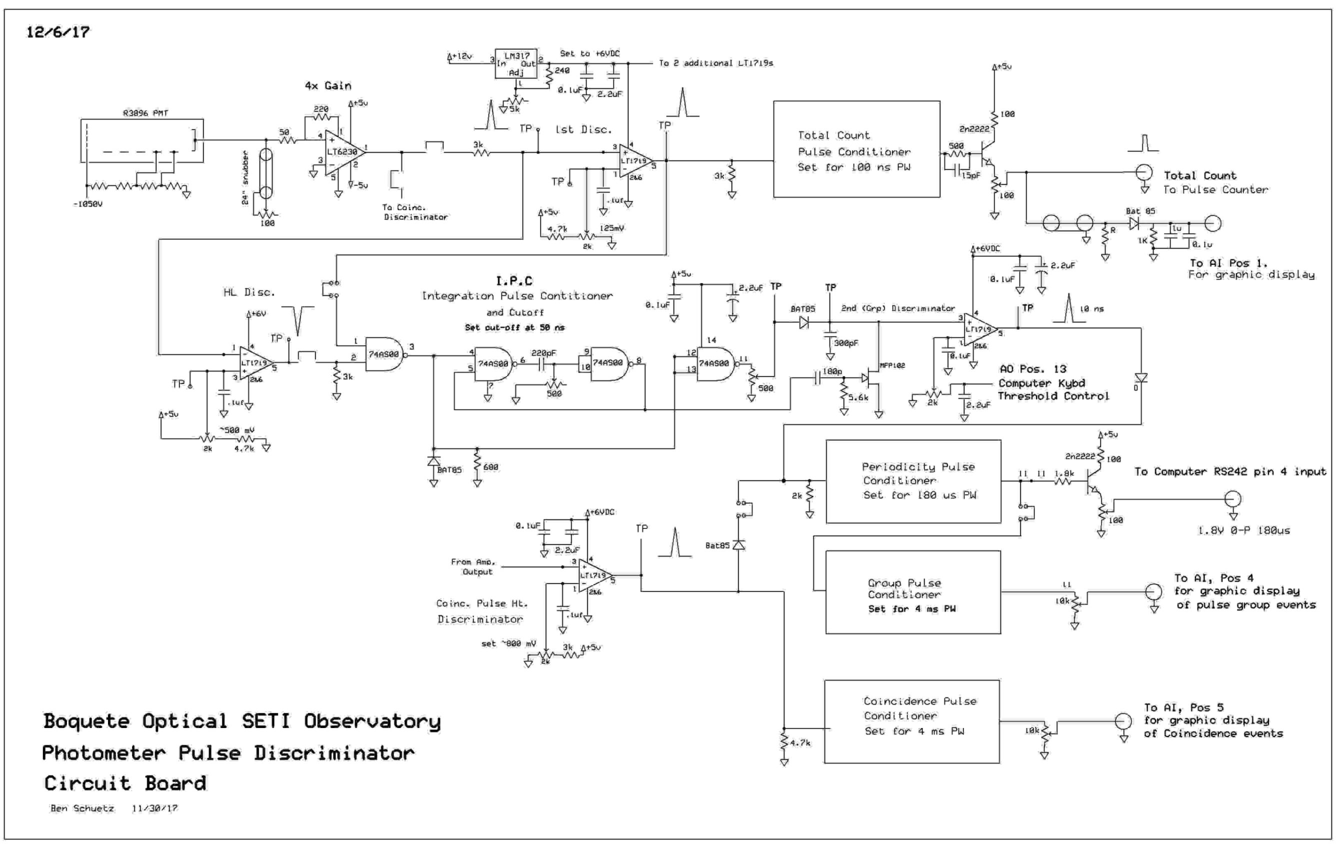

Figure 1

Referring to Figure 1, the photomultiplier output pulses are amplified and inverted then fed to a low level discriminator (comparator) and an adjacent high level discriminator. The high level discriminator passes only those pulses that are greater than about 1.8 times the photomultiplier's pulse amplitude for single photon detection, i.e. coincident photon events and other large amplitude pulse phenomena. The output of the high level discriminator is then conditioned to provide 180 usec, 1 volt output pulses to the downstream process for the detection of periodic signals.

The output of the low level discriminator follows two circuit paths. In one path pulses from the low level discriminator are conditioned and counted as a measure of the total photon flux incident upon the photomultiplier photocathode. A second circuit path performs the following functions:

the pulses are processed for uniform pulse height and width,
the pulses are integrated and subsequently threshold discriminated,
the discriminator output pulses are conditioned to 180usec at 1 volt amplitude and are fed to a computer to detect any pulse periodicity.
A field effect transistor terminates and resets integration after 50 ns.

The integrator/discriminator functions in a way that, dependent upon the threshold level, detects any two, three or four photoelectron pulses that occur within ~50ns. That is, pulse trains of much longer lengths will be detected so long as the 50ns criterion is met. The second discriminator threshold level is adjusted by the computer to maintain the highest level of sensitivity consistent with the noise level for stellar magnitudes within the acceptable range, i.e. 3 to 14. Note that it is possible to detect periodic events where two photons are only intermittently detected, i.e. a marginal signal level.

A means of testing the photometer was a key element in establishing the functionality and true sensitivity. That need has been satisfied by placing two LEDs in the photometer. One LED is energized by pulses that are variable in amplitude, width and repetition rate. The second LED may be energized to provide simulated stellar background count rates from 0 to 1 million counts per second. Importantly, the light output of both LEDs must undergo at least two reflections (with large angular dispersions) off of flat black surfaces before entering a small aperture and ultimately reaching the photomultiplier's photocathode. Thusly, it is a simple matter to demonstrate the detection of 2, 3, 4 photons within the 50 ns time frame. Combining this with the detection of pulse periodicity and a wide range of simulated stellar backgrounds one can appreciate that photometer characterization can be done with a high degree of precision. The LED pulser is described in detail in another section of this website.

A custom computer program analyses the time stamped photometer output pulses and displays any periodic signal found in the range of 0.005 to 2 Hz.

In addition to improvements in the overall photometer sensitivity, the other advantages of the detector are that it: works equally well with coincidence and longer duty cycle pulse detection, is less complicated and less expensive than multiple pmt or apd photometers, is relatively simple to calibrate, has optimized sensitivity over the range of stellar backgrounds, eliminates signal losses related to beam splitters and simplifies pmt or apd cooling (if required).

In the development works is a new photometer board utilizing ECL ICs for the front end. The higher speed chips are a next step toward further photometer improvements.

II. Laser Transmission Relationships

The total photon flux emitted by a device such as a laser is:

$$\Phi_t = E_o/E_p \qquad \text{(photons per pulse)} \tag{1}$$

E_o= single pulse energy output of a laser (J)
E_p= $h\cdot c/\lambda$ energy per photon (e.g., $3.6\text{x}10^{-19}$Joules/photon @ λ = 550nm)
h = Planck's constant ($6.626\cdot10^{-34}$ m^2kg/s)
c = speed of light ($3\cdot10^8$ m/s)
λ = laser output wavelength (m)

And, the flux of a beam confined to a uniformly illuminated disk at a distance z is:

$$\Phi = (E_0\cdot\lambda / \pi\cdot\omega^{2}\cdot h\cdot c) \tag{2}$$

ω_z is the radius of the illuminated disk.

Next, it is useful to examine the elements that characterize laser beam divergence. The parameters needed are the beam waist ω_0, (the radius of the beam where it is at a minimum) and the Raleigh length Z_r, (the distance from the beam waist to where the beam radius has increased by a factor of the square root of two). A laser can be coupled to a telescope via a weak negative lens to match the telescope optical characteristics. Where a transmitting telescope is used for beam collimation, the beam waist becomes the diffraction limited telescope aperture radius (ω_0) and the Raleigh length is:

$$Z_r = \pi\cdot\omega_0^2/\lambda.$$

From this it is a simple matter to calculate the radius of a beam (ω_z) at any distance (z) from the diffraction limited transmitting telescope.

$$\omega_z = z\cdot\omega_0/z_r \qquad (\omega_z >> \omega_0) \tag{3}$$

and

$$z = \pi\cdot\omega_0\cdot\omega_z/\lambda \tag{4}$$

An expression equivalent to (2), but perhaps having more convenient terms is:

$$\Phi = \pi\cdot\omega_0^2\cdot E_0 / z^2\cdot\lambda\cdot h\cdot c \quad (\text{photons m}^{-2}). \tag{5}$$

Some of the tabular data found in the body of the text were determined from these relationships.