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# An Instrument-Based Method to Search for Extraterrestrial Interstellar Robotic Probes

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Technological advancements have allowed us to build robotic space probes to remotely explore the solar system. Interstellar robotic missions are under serious consideration. Advanced extant extraterrestrial civilizations within the galaxy, if they exist, are very likely exploring with robotic probes as well, some of which may have reached our solar system and taken an interest in life on Earth. Recent technological advances make it possible to conduct a scientific search for evidence of extraterrestrial interstellar robotic probes. Modern solid-state sensing devices and scientific instruments, combined with high-speed computer hardware, can be used in an effort to detect the physical presence of a probe. The SETV (Search for Extraterrestrial Visitation) model is new and an offspring of SETA (artifacts) and SETI. SETV includes the construction of passive autonomous data acquisition platforms using “commercial off-the-shelf” hardware, to collect reliable and unambiguous data on anomalous observational phenomena that may be ETI probes. The SETV hypothesis and experimental methods will be described. The SETV hypothesis can be experimentally tested and attempts to statistically reject a *null* hypothesis which states that ETI probes do not exist. SETV Pre and Post-detection protocols are necessary and will be examined. SETV is a timely, results-oriented, method worthy of serious consideration in our continuing desire to answer the question "Are we alone?"

**Keywords:** SETI, Interstellar robotic probes, SETV, SETA, COTS, Instruments, Sensors, automated smart surveillance

## 1. Introduction

Those aware of the technological achievements in the fields of theoretical physics, astrophysics, computer engineering and electronics miniaturization know that the ability to explore the environment extending into the solar system is rapidly advancing. In the time since the USA Pioneer IV launch and the Russian inauguration of the Luna [1] moon probe series beginning in 1959 (fig. 1), our civilization has sent robotic space probes to study nearly every planet in our solar system – an impressive feat for a forty year time span. It is clear that robotic exploration is an invaluable tool in achieving first-hand scientific knowledge that would otherwise be nearly impossible to attain. Whenever possible, active techniques, as opposed to passive ones need to be engineered because the information return is much richer. One example of an especially successful robotic probe was the NASA Magellan mission. Using cloud penetrating radar it brought us a view of the Venusian surface that was breathtaking and scientifically invaluable. Magellan provided about twelve times better resolution than the planetary radar system in use by the Deep Space Network (DSN). Also within this 40 year time period there are other examples of exploration that required *actively going there* for a direct investigation. Space scientists, in general, hold a positively reinforced realization that active space exploration is the method of choice; remote-sensing is cost effective and a proven success.

Ronald Bracewell [2,3] and Robert Freitas [4] have rationally argued it’s reasonable to believe that advanced technologically-based extraterrestrial civilizations having the urge to explore would engage in active space exploration. Given the age of the galaxy and its star systems compared to ours, very ancient and fully-developed ETI programs of active space exploration may exist. Given extensive timescales [5], such extraterrestrial exploration programs are likely to have deeply probed the surrounding cosmos. Besides testing the premise that ETI probes exist, there are other reasons to search for them. Detecting an ETI probe will not only answer the question about the existence of ETI, but also prove to us that active robotic interstellar exploration can be achieved. Also, if a probe is detected and verified, remotely observing its features and behaviour would provide insight into alien thought processes and technological engineering. The purpose of this essay is the introduction of a contemporary observational method to search for extraterrestrial interstellar probes that may be actively exploring the solar system [6] and planet Earth.

## 2. Autonomous ETI Probes and their Missions

The first thing to consider is the ETI probe itself and the various reasons it might be present. Using our own technological capabilities and achievements as a guide we must examine the likely range of ETI probe missions to our solar system. This is important because it will help in determining what probe features, manifestations and behaviors to search for, and the observational strategies to use.

Remote-sensing missions to unlock the secrets of our solar system involve the construction of robotic machines. Currently our civilization has a remote presence in the solar system that includes nine active space probes. More than 100 exploratory probes have been successfully launched since 1959. These probes are not sufficiently independent and need to communicate with Earth frequently during their missions. The goal is to build self-sufficient, autonomous robotic probes that manage their own navigation, stability, control and systems maintenance. These futuristic "smart probes" will be part of a network of remote sentinels that occasionally contact Earth to relay data and telemetry. NASA recently launched the Deep Space 1 probe (formally Space Technology 1 – ST1) with an ambitious goal of testing numerous new technologies including autonomous spacecraft operation. In July 1999 ST1 passed by an asteroid. In 2000 it should pass a comet with a goal of collecting data and relaying it back to Earth all with a reduced amount of radio contact. Toward the end of the ST1 primary mission phase a milestone was met when NASA engineers successfully demonstrated and technologically validated an experiment called the "remote agent" (RAX). RAX tested an autonomous mode of operation in which the spacecraft had decision-making control of its systems. With this mission autonomous spacecraft operation has been proven possible, and this justifies building more advanced autonomy into future robotic voyagers.

Autonomous missions of the future will ease the burden on DSN telecommunications resources because of the growing number of probes launched. Only requiring communication with a probe on yearly or longer intervals has strategic value. For extended duration missions, not requiring contact for long periods of time is all but mandatory. Consider a hypothetical 0.1C velocity interstellar mission to the nearest star system that takes about 50 years to get there. For the majority of its mission the probe is coasting and primarily just maintaining its health. During the cruise phase of this mission there is no point expending energy frequently communicating with the probe when nothing is happening. One exception to this limited-communication policy is with spacecraft emergencies. Because of this possibility, resources need to be allocated to scan for emergency beacon service requests. If a probe diagnoses a systems anomaly it can't resolve and places itself in a "safe mode", it will need assistance from ground controllers to help solve the problem. These considerations emphasize the point that very long interstellar robotic missions demand spacecraft autonomy.

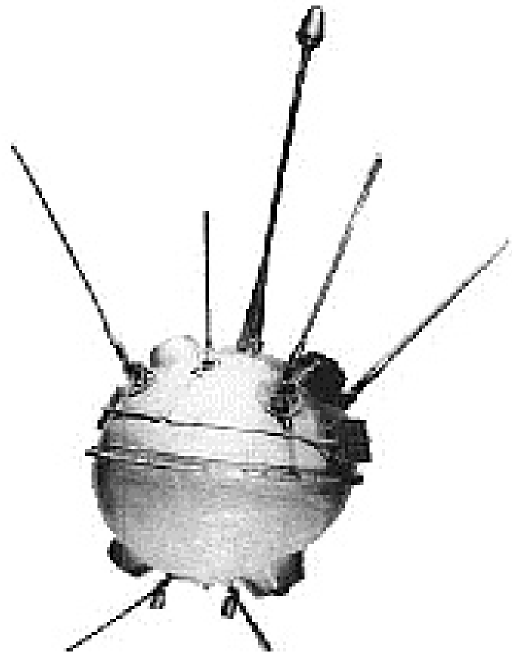

Fig. 1 Russian Luna 1Space Probe (circa 1959). (Michael Nagel)

The hardware and software needed to build completely autonomous, artificially intelligent flight systems is remarkably complex and depends on the existence and use of a number of advanced technologies. Two of these advancements are micro/nano-technology [7] and an embedded software co-design programming language [8]. These are critical paths to achieving probe autonomy and involve a tight coupling and integration of software and re-configurable or evolvable hardware. Furthermore, the use of more densely packed hardware structures with embedded data processors leads to smaller volume, lower mass, lower power, increased diversity, and improved reliability [9]. Effectively applying these technologies will lead to superior space probe designs. This is the desired trend in probe design, and extending this progression out to several decades, the majority of the probes launched will be small, smart and fully autonomous [10]. Throughout the years our robotic probes have noticeably evolved, will continue to evolve, and have a wide range of shapes and sizes. Because probe configurations can vary so much, we must not allow subjective views about what ETI probes should look like cause us to dismiss certain shapes as not being probes–they will not all look like Pioneer 10. Consequently we should expect highly advanced robotic probes from ETI civilizations to exhibit a wide range of physical features, some of which may even be organic in nature. Therefore the SETV method shall include a search for probes that are intelligent autonomous machines, having a wide range of sizes and shapes

Once an advanced ETI civilization has overcome certain major technological challenges, like practical interstellar travel, what might the probe missions involve and what behaviors might be observed? There are many reasons why ETI probes may be sent to explore the galaxy, but for brevity let's consider the following four types of ETI interstellar probe missions:

(1) Scientific exploration and discovery.

(2) Military or colonization reconnaissance.

(3) Remote tourism and sight-seeing.

(4) Establishing contact.

Until a comprehensive set of incontrovertible observational data on robotic ETI probes exists, determining the likelihood of these missions remains a matter of conjecture. However, a brief examination of how our civilization would conduct the different missions will aid in defining certain observational parameters. The four mission types require the approaching object to decelerate a substantial amount before it reaches our solar system unless it is a relativistic flyby. Probes can enter the solar system from any direction. They will likely want to approach from above or below the ecliptic plane where collisions with particles or space debris would be minimal. The flight path and desired length of stay within the solar system depends on the probe's trajectory, the prevailing alignment of the planets and any decision to study a specific body. Scientific probe missions will involve complicated trajectories, including gravity assists, especially if the desired survey includes visiting all the major planetary bodies. Once here, some robotic probes may place themselves into a heliocentric orbit. Remarkably, a telescopic observation of an object in 1991 may be a defunct or dormant robotic ETI probe in heliocentric orbit [11]. Some missions will involve more than one probe. The first arriving probe might carry out a long and extensive reconnaissance of the solar system. Decades or centuries later a rendezvous probe would pass though the solar system, establish a communications link with the first probe, collect its data and head back to the originating solar system. Or, a large mother-probe may arrive and deploy an array of smaller probes each having specialized functions. ET colonization and military mission profiles are fairly self-evident. Based on our own history, this type of mission is considered a low probability because of the incredible expenses, logistics and enforcement burdens required [12]. ETI probe tourism is a distinct possibility. To an advanced Kardashev Type II civilization [13] remote tourism may be an easily affordable luxury not unlike remote-controlled submersibles here on Earth. If observational data is collected on anomalous objects which exhibit intentional, yet inconsistent behavior, or of no discernable purpose, that may represent a tourist visit. Lastly, probes may be sent here exclusively to make contact with our civilization. How and when a messenger probe chooses to make contact, and the preferred method is unknown. This uncertainty means existing communication technologies should be considered in the search for possible signs of probe contact. Aside from being able to search far outside the solar system, microwave and optical SETI is presently capable of searching within the solar system for signs of ETI probe telecommunications activity. The ideas of one author [14] regarding using the Internet and other strategies to encourage contact are worthy of serious consideration.

Some authors [15,16] have postulated that ETI probes wanting to explore Earth up close, and not immediately seeking contact, may find it necessary to conceal themselves from detection until they have assessed our threat potential, biological, social and technological levels, and level of preparedness for contact. For defensive purposes our civilization's military establishment designs and builds craft that are stealth and *low observable* (LO). Because LO ETI probes are a distinct possibility, added difficulty arises in defining practical detection strategies. If zero emission stealth is required then ETI probes should be able to avoid all earth-based detection attempts. Physics mandates there are only so many stealth strategies that can be used, even by ETI probes. Cloaking devices to mask a probe spatially, thermally, optically, or from radar, as often depicted in science fiction, may not be necessary. Simple camouflage through mimicry works well in nature and may be a technique used by visiting ETI probes which possess some *experience* in surveillance. One possible LO technique may be for a probe to remain stationary over a certain geographic region appearing as a pseudostar. Unless one was exceedingly familiar with stellar positions, magnitudes and motions the probe would go unnoticed. Another LO technique may be to enter the atmosphere with either the look or trajectory of a meteor, or hidden within a meteor shower. The observed phenomena of "dark meteors" [17,18] may be a technique used by ETI probes to pass through the lower atmosphere on a meteoric trajectory, with a minimal optical train or signature. Yet another technique, while engaged in close surveillance, may be to mimic the aggregate features of commercial or civilian aircraft (flashing red-green anti-collision lights, engine sounds, speeds, motions) with just enough thinly veiled accuracy to only draw a quick and disinterested glance [19]. If mimicry is not employed, ruse tactics may be used to confuse or distract eyewitnesses to keep them from observing any meaningful probe features. The possibility that probes may conceal themselves using active or passive techniques requires that the detection strategy include observational instruments that are diverse, broadband, sensitive and fast responding.

Scientific missions involving extended environmental surveys are considered low-risk to a probe if it confines itself to isolated, sparsely inhabited regions like jungles, deserts or poles where little or no evidence of civilization or terrestrial technology is found. In these regions LO may be unnecessary, but the probe would still be expected to employ adaptive multi-level risk techniques to avoid danger. Avoiding clear and present dangers involves minimal physical interaction with the local environment and indigenous lifeforms. This means probe landings would rarely take place. Behaviors employing hazard avoidance, learned through previous surveillance or encounters, will make ETI probes appear intelligently controlled. The mere act of illuminating a probe with a powerful spotlight, laser, or radiating it with pulsed radar may be enough to invoke an immediate hazard avoidance reaction. To avoid accidentally causing this type of reaction, and risk losing an opportunity to collect detailed observational data, demands the use of *only* passive detection devices and non-threatening strategies.

This anthropic discussion of ETI probe missions has presumed that our civilization would be the object of interest. If the primary interest is our civilization, then one can argue that humanity can be safely observed and studied in detail from orbit. Highly advanced probes must be able to collect large amounts of data in a few polar orbits, so there is no reason to expect a probe to repeatedly investigate any particular civilized region. If this is true, close up observations of our civilization would occur very rarely and be of transient duration, minutes perhaps. Arguments favoring repeated visitation are: certain places on Earth are so compelling as to attract probes more than once; repeated visits are actually probes from different ET civilizations; ongoing intercommunication, or limited contact, is occurring between ETI probes and certain humans requiring repeated and close visits. If our civilization is not the subject of study then clearly something more interesting, or possibly more fundamental that escapes our awareness, is what attracts a probe. Only after an in depth observational study will science be able to determine if our civilization is the attraction to ETI probes or not.

ETI probes are expected to be highly advanced robotic machines; of mechanical, organic or combined construction; autonomous; having various sizes and shapes; on missions of scientific discovery, tourism or contact; employ LO and hazard avoidance behaviors; minimize risk by avoiding civilization; favor visiting relatively safe unpopulated areas; may or may not be interested in our civilization with few good reasons to return. In the next section the SETV experiment is defined and shows how it addresses the observational challenges

## 3. The SETV Experiment

SETV is a collection of observational experiments having three main goals. The first is to demonstrate that automated search platforms capable of detecting ET probe manifestations can be built and operated. The second is to actually carry out the experiments to collect data. The third is performing follow-on experiments that involve probe contact. The SETV method inherits some of the best features of the SETA (Search for Extraterrestrial Artifacts) [20] experiment and the radio/optical SETI methods.

Here are the two predominant hypotheses for SETA and SETI:

The SETA Artifact Hypothesis states:

> A technologically advanced extraterrestrial civilisation has undertaken a long-term program of interstellar exploration via transmission of material artifacts. [21]

The SETI Energy Hypothesis states:

> A technologically advanced extraterrestrial civilization has recognized the use of electromagnetic energy, at certain universally known and/or practical wavelengths, as a means to remotely explore the universe, and to detect, signal or communicate with other advanced civilizations.

Both hypotheses express the assumption that advanced ETI exist, are technologically mature, and using that technology as a tool to explore the cosmos, search for life and signs of intelligence. SETV's strength lies in combining the ideas contained in the SETA and SETI models into one that maximizes the possibilities of producing experimental results.

The SETV Hypothesis states:

> Technologically advanced extraterrestrial civilizations have deployed interstellar exploratory probes, and there is a non-zero probability that functioning probes have reached our solar system and are detectable or contactable using existing terrestrial technologies.

The SETV hypothesis is testable like that of SETA and SETI, and can be used to reject a *null hypothesis* which stipulates there is a probability of 1 that ETI probes do not exist and have not reached our solar system. Within the SETV model, a *visitation* is defined as the presence of *any* functioning extraterrestrial robotic probe within a heliocentric sphere of radius 50 Astronomical Units (AU). A probe artifact that lies outside the 50 AU sphere, or flies past is not considered an active visitation nor part of the search. The presence, features and behavior of a probe are to be measured in a permanently recorded form. Hard data is defined as sensor data from calibrated scientific instruments. There is no requirement to determine the origin, age, internal contents of the probe, or if intelligent organisms are involved. Furthermore, defunct artifacts, such as ones that may have impacted a moon or are floating space junk, do contain physical evidence of past visitation but are beyond the SETV strategy as it is defined herein. The SETV *near* search space, inherited from SETA, involves scanning for evidence of active ETI probes whose primary function is a study of Earthly features. The *far* search space, inherited from SETI, involves a broadband radio/optical frequency search within the solar system for evidence of ETI probe telecommunications activity. SETV *far* is a research topic unto itself intended to augment the radio/optical SETI effort, and will not be expanded upon in this paper. By methodically searching *near* and *far* within the $5.2x10^5$ $AU^3$ heliocentric volume, it's possible to collect enough observational evidence to statistically test the SETV hypothesis and attempt rejection of the *null* hypothesis.

## 3.1 Placement of an Experimental Platform

SETV involves passive detection experiments that include building autonomous computer-controlled data acquisition systems (DAS) which include specific types of instruments. The SETV DAS is a carefully engineered platform using as much commercial off-the-shelf (COTS) hardware and software as possible. This platform is called the ETP – Experimental Tactical Platform. The ETP operation is based on the concept of automated smart surveillance. Conceptually, an ETP, or array of ETP's, is deployed into a carefully chosen location and left to operate unattended for months or years at a time. To increase the probability of getting useful data, several of these platforms will have to be deployed worldwide.

The decision where to place the ETP is not random and must be based on anticipated ETI probe interests. A valid question therefore is 'how do we determine where to place these platforms?' One such procedure begins by accepting the *null hypothesis* as being valid–i.e. there exists no empirical evidence of any anomalous observations which suggest that extraterrestrial visitation has ever occurred or where to start searching. Using this postulate, the study of Earth must be approached from the perspective of an advanced exploratory probe coming here for the first time. Logically a probe would first make an examination of Earth's surfaces safely from orbit. If Earth's darkside were imaged hyperspectrally in the UV, visible and IR regions with 1 meter resolution, and integrated over a few periods of Earth's rotation, a probe could accurately map all the areas with artificial lights, sources of energy and civilized activity. Obviously ocean surfaces are dark, and the majority of energy sources are on landmasses. Of the landmass regions there are certain locations where artificial light and heat are scarce indicating minimal civilized activity. A similar survey of the solar illuminated regions of Earth would reveal the extent of civilized constructions. The larger the area without energy emissions or structures, the safer it will be for a probe to study up close. Of the areas where civilization is non-existent or sparse, do there exist any interesting geophysical features? Areas with significant amounts of geomagnetic, seismic or volcanic activity might be attractive to a probe and should be weighed in the selection process. By mapping Earth's day and nightside surfaces as a probe might do, and considering unusual geographic features (like those recorded by the SRTM, AIRS, SPOT, Landsat 5 and 7 satellites), a prioritized list of regions can be made suggesting where platforms should be deployed. Possible candidates based on remoteness and geographic features are locations in South America–areas in Brazil such as Planalto De Mato Grosso or the Pampas region of Argentina. The Australian desert region of the Nullarbor Plane is a candidate. The Great Plains region of North America from Montana to Oklahoma should be considered. The sparsely populated inner Mongolia region of China is also an acceptable candidate. If the oceans are deemed more interesting than landmasses, then an ETP could be located on a small island or a coastal region. Other criteria for platform placement, like a requirement for "good seeing", and accessibility also exist and should be studied before the first ETP is deployed.

If a probe is mainly interested in civilized areas, then the problem arises of determining which areas are altogether interesting, "non-threatening" and relatively safe to explore. Every modern city is a risky place to explore, but places that are heavily populated while having few concentrations of energy producing facilities would be the first places to explore. Many such places exist in underdeveloped areas in South America, Africa and Central Asia. If these location requirements are adopted then it is expected that some platforms will have to be established in remote areas.

## 3.2 Description of an Experimental Platform

Before any ETP is set up and operated, a careful regional field survey must be conducted first to understand the local geophysical environment to determine what forms of natural "background noise" or interference are present. The background magnetic, radio, seismic, gravimetric and meteorologic effects need to be well understood and included in the platform calibration process. The calibration process involves the optical and mechanical alignment of the platform instruments, loading the ETP with relevant environmental data, various instrument adjustments and system self-tests. For traceability purposes, every step of the field survey, on-site platform assembly, setup and equipment calibration must be documented. Once the survey and platform calibrations are complete the deployment team leaves the area and remotely activates the DAS, which runs autonomously.

Platforms placed in remote areas will have no access to commercial electrical power. Therefore the ETP will require a combination of batteries, solar panels or wind generators for energy. Batteries and solar cells can power the ETP during the day, which can also recharge "AGM—Absorbed Glass Mat" batteries used to run the platform after sunset. Wind generators can provide added power at night when solar is not available. The ETP must be rugged, designed for all-weather operation and have many self-maintenance features. Besides a weather station, each ETP must include a GPS receiver to update its system clock, provide a frequency reference for the data acquisition hardware, and to determine the location and elevation of the platform. Differential GPS (DGPS) should be implemented to more accurately determine the platform's location and elevation. DGPS bias corrections can be made on ETP coordinates either before or after the platform is set up. Measured data is locally archived in either a "data logger", RAID (Redundant Array of Independent Disks) or solid-state storage system. Sensor data is downloaded periodically or when the system records anomalous events. Recorded data is retrieved either manually, or transferred to a central file server via Ethernet, satellite RF link using VSAT (Very Small Aperture Terminal) or equivalent telecommunications technology like wireless T1.

One crucial aspect of the ETP implementation is that people *are not* part of the remote data acquisition process. Why? First, waiting in the field for particular observations or transient events to occur will eventually become so tedious and boring for the researcher that their enthusiasm for the project will vaporize. More productive work can take place elsewhere while the researchers wait for the desired ETP instrument data to come in. Second, subjective human observations usually conflict with more reliable computerized instrumentation–a computer system doesn't subjectively rationalize its observations. Third, the physical presence of people combined with "experimenter effects" may interfere with the operation of the ETP and spoil the measured data. Fourth, observer confusion over the interpretation of perceived coincidental side effects is eliminated. Lastly, during times of excitement, stress or fatigue, people's reactions are generally unpredictable and memories fallible or fragmented [22]. If it ever becomes necessary for human observers to be present during any data acquisition event, these participants must be connected—instrumented—to physiological monitoring equipment such as a Quantitative Electroencephalograph (QEEG), Infrared Photoplethysmograph (IRPPG), Electrodermal Activity (EDA) monitor and Electrooculograph (EOG). Even though it's not required, physiological reaction data from observers does have objective value, and can be collected in controlled "single blind" experiments. However, because these experiments include a human variable they will require much more planning, more than is necessary for the early phases of the experiment. Designing an ETP that operates autonomously solves many of the problems associated with "spontaneous" human-generated observational data that is labeled: "too subjective", "overly interpretive" or "anecdotal" and easily refutable by well-meaning skeptics. The collection of high-quality instrument data lends itself to repeated and varied analysis by independent researchers, the formation of alternate theories, refinement of the working hypotheses and experimental methods. Building autonomous instrumentation platforms follows the overall trend toward robotic observatories as outlined by Bode [23] and the preferred observing methods for the 21st century [24]. An abbreviated semi-technical description of one possible ETP implementation will now be made.

The types of instruments used on the ETP depend on the kinds of environmental *effects*, physical interactions, or manifestations to be detected and recorded. Specific instruments are matched to anticipated probe energy features, like ionization plasmas, thermal emissions, or secondary effects that may cause weak low frequency ground vibrations (infrasonics) or small changes in the local geomagnetic field. The exact instrument types also depend on the ETP deployment phase. The search effort needs to be carried out incrementally and in phases. There are two basic development phases:

**Phase A** – Is the design, construction and deployment of an automated weather station. This is an absolute minimum. A weather station is required to regularly monitor the local meteorologic environment during the experiment. Without an intimate knowledge of the local weather, added frustration will arise in separating the local natural meteorologic effects (lightning, etc.) from the important sensor data [25]. The weather station includes a host computer and data recorder interfaced to electronic versions of air/ground temperature sensors, barometer, hygrometer, anemometer, rain gage, dew sensor, a lightning detector (with direction finding capability), and a cloud sensor. Additional sensors may include a passive microwave radiometer, a seismometer, or a geophone used to record local ground vibrations. The phase A SETV DAS is the design and implementation of a reliable autonomous weather station to measure the local meteorologic and geophysical activity.

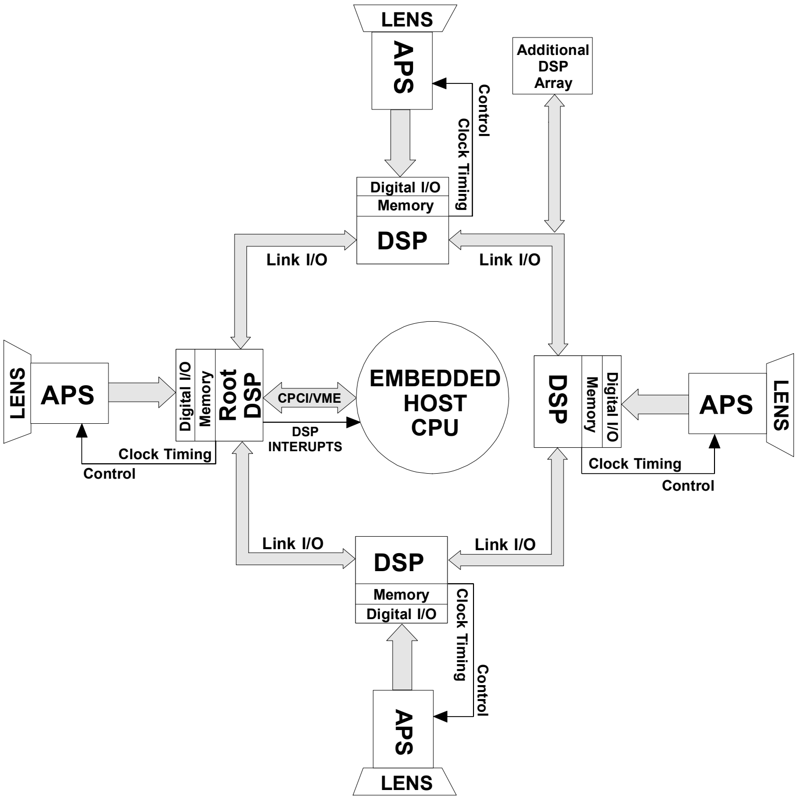


Fig.2 Scanning Polycamera System Block Diagram.

**Phase B** – Is a Phase-A weather station combined with a passive DAS platform using various combinations of instruments called *sub-phases*. One such configuration uses a fixed-position grid of CMOS Active Pixel Sensor (APS) focal plane arrays (FPA) [26] to optically scan a hemisphere having an azimuth angle (AZ) of 360° and elevation (EL) of 90°. This arrangement is known as a *polycamera*, *chipixel array* [27] or *omni-directional* imager. For coordinate reference purposes the sensor system is aligned to true North. Each FPA is assigned a compass heading and its lens covers a 90° by 90° field of view (FOV) yielding a possible resolution of 10.6′/pixel for a 512x512 pixel sensor. Scan rates for each FPA can be independently programmed from 1 to 60 frames per second. Each COTS APS includes on-chip A/D conversion allowing it to interface directly to the memory of a dedicated digital signal processor (DSP) [28] or Field Programmable Gate Array (FPGA). Each DSP is programmed to perform a first-order image analysis of the data from the APS to detect motion (trigger events) within its FOV. Once a trigger is detected an interrupt is generated by the particular DSP. The host computer, under the control of an embedded "hard real-time" OS, like VxWorks™ or RTLinux, processes the interrupt and instructs the array of processors to stop scanning and perform a more in depth image processing/analysis of the motion and object features using the combined multi-processing computational speed of the four, or more DSP's (see fig. 2). Notably, a few companies now offer COTS image processing boards that use multiple DSP's and local high-speed memory.

Using a "staring array" scanning arrangement offers a passive, no-moving-parts, all-sky method to search for changes in the optical environment (from $\lambda$=300 nm to $\lambda$=1000 nm) indicating motion. The motion detection sensitivity of the platform depends on the dynamic range of the sensors and a need to scan for the motion of relatively bright objects (> -2 magnitude) against a dark background. The dynamic range and anti-blooming features of CMOS APS allows the system to operate in full sunlight and still be able to detect targets. Obviously false trigger events like aircraft lights, lightning, star scintillation, birds, insects, intermittent sunshine or moonshine through clouds, and so on are expected to occur. False triggers from these and other optical transients can be simulated in the laboratory and added to a trigger signature database loaded into the host computer. All recorded triggers are analyzed in "real-time" and compared with this database; possible false positive data are tagged accordingly. Tagging false positives will help simplify data post-processing. Trigger events are weighted between a high or low priority. Depending on their weighting, a data collection mode is invoked which mathematically corrects lens curvature distortions, timestamps and stores the raw and corrected images, calculates the Right Ascension and Declination of the "region of interest" (ROI) in a spherical coordinate system and sends the ROI target angles to an Object Tracker APS, or OTAPS. The OTAPS uses a color CMOS APS megapixel FPA, with a ~±1.0° (300 mm) FOV catadioptric lens. The OTAPS is mounted on a precision, high slew rate, pan & tilt gimbal positioner. After initial acquisition and target lock, the positioner's angular coordinates are controlled [29] by the tracker APS [30] in a closed loop using a "center of response" (COR) pointing technique [31]. Implementing a COR technique with position control feedback [32] under the control of an embedded processor allows visible tracking of the phenomena under observation to, among other things, produce a 2D trajectory map, and a complete series of ROI images of the target. Besides supporting the OTAPS, the positioner would also support other sensors optically aligned with the OTAPS system. Furthermore, additional gimbaled positioners with various other sensor arrays whose pointing is coupled to the OTAPS' could also be used to record data on the phenomena while it is tracked. This allows stereo image data to be collected and permits 3D range and track calculations. The design of the ETP's passively-based, single-target-tracking, system is modeled after modern tracking systems [33] which utilize state and error estimations, prediction algorithms, filtering (e.g. Kalman, etc.), multi-sensor registration, data fusion and sensor management techniques [34].

The selection of the phase-B sensors depends not only on the stimuli to be measured but also on the sub-phase deployed. For example, sub-phase B.1 may contain a spectroradiometer, LWIR imager, Geiger counter, ultrasonic microphone and ozone/ion sensor. Sub-phase B.2 may be B.1 plus a fixed-position flux-gate magnetometer, solid state x-ray gamma burst sensor and gravimeters. To improve data reliability, and estimate errors it is necessary to always record the internal operation of the platform during the entire data collection process. This is done by instrumenting-the-instruments. Engineering telemetry from internal current, voltage, temperature and vibration sensors (accelerometers) are recorded along with UTC time-coded primary sensor and weather data. The states of software error and fault-protection flags are also recorded. Instrumenting the DAS in this manner allows the identification of faulty or failed sensors, detecting interference induced in the instrumentation, and some knowledge of how the DAS actually malfunctioned. The phase B SETV DAS is a configurable autonomous scanning instrument platform combined with a phase A weather station.

When operating a phase B ETP, what information might an instrument like a spectroradiometer be able to collect? A spectroradiometer is used to measure the spectral concentration of radiant energy from a light source. It spectrally characterizes any optical radiation source completely by measuring the absolute spectral distribution of radiant flux or intensity. The data format is usually a table or plot of radiant intensity ($W/m^2 \cdot nm$) versus wavelength (nm). The instrument's response function is calibrated using a metrology standard that outputs a known spectral power distribution. The "unknown" spectra that is measured is compared against the radiant intensity reference or standard. For example, after the initial lab calibration of the ETP spectroradiometer, measurements of several commercial and military aircraft exterior and anticollision avoidance lamps are made. These spectra, along with many others can be digitally recorded and placed into a spectra signature database. The recorded "unknown" spectra can be digitally compared on-site to the known spectra to see if there is a match (e.g. tungsten filament light). Spectra that do not match any known sources in the database are tagged and require additional analysis to determine if they can be identified as a natural or manmade source. Any spectra that remains unknown after further investigation is grouped with other unknown spectra collected previously and eventually analyzed as a set. This is just one example of how valuable the right instruments are for the SETV experiment.

The initial SETV experimental phases (A and B) must be attempted first and then expanded upon in subsequent sub-phases if justified. It is illogical to attempt building elaborate scanning platforms without first trying to verify the functionality of simpler ones. Not to be overlooked are the added benefits of the ETP to other scientific studies. Its ability to collect scientific data in fields relating to seismology, climatology, astronomy, meteor studies and exploring natural atmospheric anomalies, provides commercial and scientific value beyond that of just searching for evidence of ETI probes.

## 3.3 Related Observational Experiments, AOP and Data Analysis

Compared to just 10 years ago, a large variety of COTS electronic instruments are now available with embedded microprocessors, high-capacity solid-state memory, giga-flop single board computers, DSP's, integrated A/D (analog-to-digital) converters and built-in parallel, serial or Ethernet data communications ports. It is the recent advances in computing (especially DSP's and FPGA's), software, miniaturization, passive and active sensor technologies that makes the instrumentation aspect of this method so attractive, feasible and affordable. Using mainly COTS components adds flexibility, reduces cost, design time and customization. Using COTS also makes it possible for other researchers to more readily build and repeat the same field experiments. There is an experimental platform called ROTSE (Robotic Optical Transient Search Experiment) that uses a significant amount of COTS hardware and has been in operation for well over a year [35]. There is a considerable and ongoing effort to complete the Automated Astrophysical Site Testing Observatory (AASTO) in the Antarctic [36,37]. Also of note is the "Project Hessdalen" [38] experiment in Norway that is field testing platform semi-autonomy. The SETV DAS is very similar conceptually to these examples of multi-sensor working systems.

Employing multiple instruments during an observation provides the necessary corroborating data. The corroborating data need not be photographic. When collecting unambiguous data on any kind of Anomalous Observational Phenomena–AOP [39,40] still photographs and movie footage alone can't stand on their own, or be used to draw firm conclusions. Photos and video of AOP only confirm something was visible on the film. The subjective interpretation of photographs, thought to portray "objective reality", combined with naked-eye observations was played out during the protracted "Martian Canals Controversy" [41]. A collection of hundreds of low resolution photos of Mars could not have halted that controversy. A similar controversy about the basis of AOP can be avoided by bringing multiple instruments to bear on the problem from the beginning. Optical astronomy has used photography in combination with spectroscopy, photometry, IR, UV, *x*-ray, γ-ray, cosmic-ray and radio astronomy observations to better understand the physical properties of galaxies and other stellar objects. In the case of galaxies, visible photographs alone cannot reveal much more than outward aggregate features. While aesthetic, these *snapshots* tell little about the physical properties of the specific galaxy. Similarly, photographic snapshots alone are inadequate when studying the effects of AOP events, of which visiting ETI probes are definitely classified. From the onset, detailed resolution from multiple sensor data of AOP features must be sought. Reliable field data collected from several corroborating instruments of a *single* transient AOP event may reveal tantalizing features, but cannot be allowed to stand alone as hard evidence or proof of an ETI visitation. Because of the data-rich, yet possibly transient nature of AOP, verification of ETI probe visitation will depend on the statistical analysis of multiple observations made over months, years or decades. Data mined from additional ETP sites will further aid in verification. SETV researchers must be patient since it will take time, effort and a sizeable volume of data to reject the *null hypothesis*. Admittedly, it is a distinct possibility that the data collected may not be statistically strong enough to support the SETV hypothesis or any other hypothesis regarding ETI. Rather, that data may more strongly argue in favor of manmade or natural origins which would effectively support the *null hypothesis*. Regardless of the experimental outcome, we must try because as the adage goes: "Nothing ventured, nothing gained."

The problem of analyzing AOP data to show a convincing causal relationship with ETI is a difficult one. Due to the nature of the SETV hypothesis, if researchers are not careful "expectancy effects" may creep into certain data analysis techniques and bias the results. Analyses that involve unbiased or "blind" examinations must be applied whenever possible. Since it is desired to show the probability of the *null hypothesis* is low (< p=0.05) then statistical analysis techniques are required. Certain techniques, like *Bayesian Inference* or *Meta-analysis* may be used on the data if it can be organized or coded properly. One possible data coding technique can be borrowed and adapted from the biological sciences [42]. It is the method of Cladistics [43]. Cladistics is presently the best method available for phylogenetic analysis, for it provides an explicit and testable hypothesis of organism relationships. The Cladistic method is more objective, and requires a minimal amount of subjective judgement when applied to AOP data. The Mixed Method parsimony algorithm with the Wagner option in PHYLIP [44], with global branch-swapping, is applicable to the identification of a robotic/mechanical "species." The algorithms can be input with a matrix of discrete characters, coded as 0, 1, and X (missing or indeterminate information), and attempt to find the tree(s) requiring the smallest number of character state differences (steps). The coding is compared against specific character states (e.g. presence of specific emission spectra or its absence) for robotic/mechanical entities in order to group (nest) the data sets according to their highest probability of identification. AOP may share certain characteristics or features with known conventional aircraft or natural phenomena, but that does not mean they are related or derived from the same source. AOP groups will be recognized to share unique features which are not present in the more mundane observational data. In Cladistics, shared characteristics are called synapomorphies, and choosing the right characteristics to measure is one of the most important steps when using the Cladistic approach. Cladistics makes certain basic assumptions. These can be modified and applied to the analysis of AOP and possible ET Visitation (ETV) observational data.

(1) Any group of AOP are related by distinct observational characteristics (data sets) according to similar templates and behaviors (functions).

(2) There is a bifurcating pattern of AOP data when applied to ETV.

(3) Changes in ETV characteristics (data sets) occur according to the level of technological advancement or evolution of the originating extraterrestrial species.

Once enough reliable AOP data are collected, the information can be coded into a Cladogram. Figure 3 depicts a hypothetical branching sequence of observed lineage’s leading to the entity under consideration. The points of branching within a Cladogram are called nodes. The Cladogram is hierarchical in the way the nodes are organized in the tree. All entities, be they natural, manmade, unknown or ETI will occur at the endpoints of the Cladogram. Ordinary data (e.g. helicopters, weather balloons, meteors, etc.) is handled somewhat subjectively because it is known where it goes on the Cladogram. Statistical analysis on the crown (aggregate endpoints) of the Cladogram follows once it has sufficiently blossomed. For these or any other alternate analysis techniques, like standard clustering and ordination methods, to work they must be included in the SETV experiment from the beginning and not be an afterthought once the data starts coming in. SETV researchers need to produce data products that are not only amenable to database coding and statistical testing but also discourage unnecessary speculation and controversy about the SETV experimental results.

### 3.4 SETV Protocols

The SETV experiment, like SETI, must include a well documented set of Pre and Post-detection protocols. The derivation of these protocols is based on certain preliminary assumptions about detectable probe energy manifestations, behaviors, and simple ETI contact scenarios. It is not befitting to statistically prove an ETI probe has been verified and then do nothing more. Furthermore, it is reckless science to proceed beyond detection without a set of documents that define not only a Declaration of Principles, but also Post-detection protocols. Every ETI search strategy must be conscious of and sensitive to the body of international laws pertaining to the exploration and use of outer space, the security of our world, the UN position on SETI activities and the SETI Declaration of Principles Concerning Activities Following Detection of Extraterrestrial Intelligence. Governing documents, written for SETV experiments, should be modeled after those of NASA SETI, and the IAA SETI Committee. The SETI documents focused on a Declaration of Principles, Pre-Detection protocols and a draft for Post-Detection protocols [45]. Although there have been calls to have approved Post-Detection protocols ready just in case [46], there is no immediacy whatsoever for traditional radio SETI to have *any* contact protocols. Following the detection of a faint radio or optical signal, a protracted multi-year UN or UNESCO debate on the content of a reply would be miniscule compared to the light-years taken for the alien signal to arrive. Furthermore, once the announcement is made there is nothing to prevent individuals or groups, with the necessary technology, from sending their own Active-SETI (ASETI) replies. A lack of global consensus, combined with bureaucratic and political delays, paves the way for multiple and confusing ASETI radio transmissions to be sent. Sending conflicting ASETI messages is a very risky prospect especially if the destination is a robotic probe located in our solar system. Clearly, for SETV, if an alien probe is verified then the next logical step is to cautiously attempt radio or optical communication. For any ETI probe contact experiment, a real need exists for immediacy, one which demands that approved Post-detection protocols are written, ready and diligently followed. Post-detection protocols must include strict rules for verification, confirmation and syntax for communicating with an ETI probe. Work on these protocols involves a detailed look at the following aspects of probe contact: presence, recognition, position, mimicry, orientation, and intention. If, by chance, a probe desires to communicate in some way, optically for instance, a protocol must be in place to respond intelligently with something deemed interesting to the probe. The task of devising these protocols will rest with those who sponsor and implement the SETV experiments. At the moment, the UN and world governments have no interest in devising such Post-detection protocols, not even for mainstream SETI, so those who actually perform the SETV experiments must do it themselves. This is unfortunate because contact and communication with ETI probes should be done by those persons capable of representing the entire human civilization. But, since no such global representation presently exists, minority groups which undertake post-detection contact must do so responsibly with the good of humanity at the forefront. If a group is unwilling or unable to write and follow acceptable Post-detection protocols then they must concentrate only on the detection and verification aspects and not attempt the phases of any SETV experiment that involve contact.

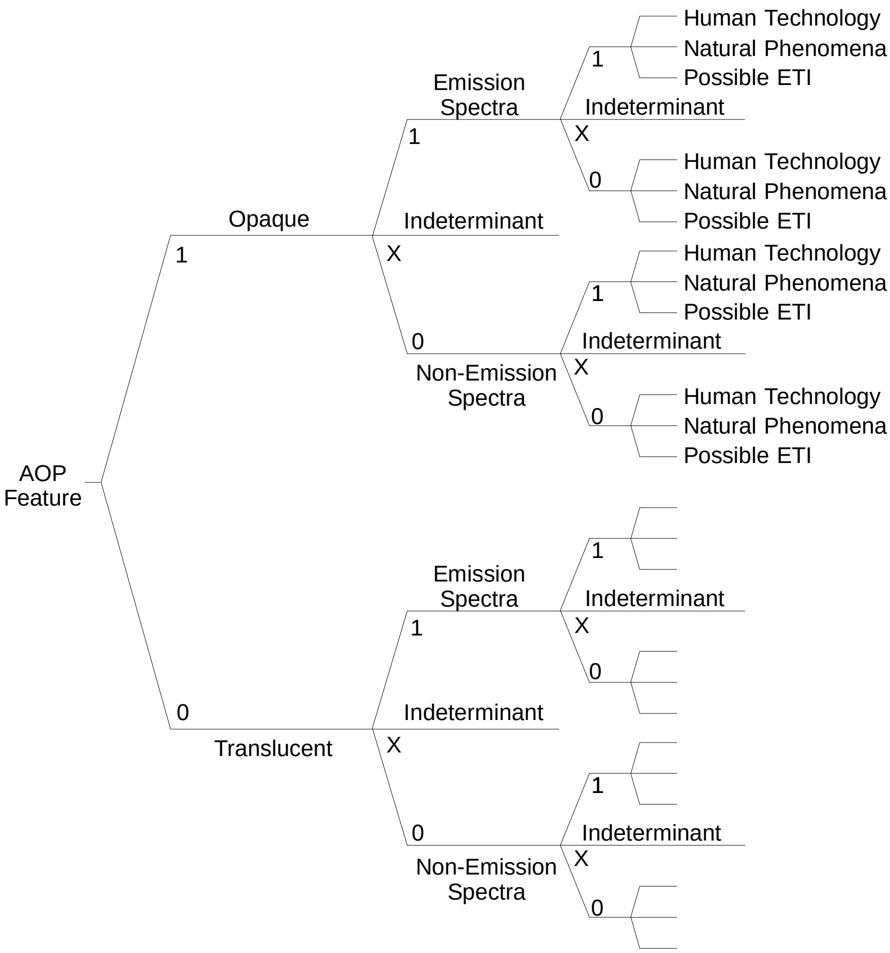


Fig. 3 Hypothetical Cladogram.

## 4. Conclusion

The excellent scientific discoveries made using our civilization's robotic space probes has been acknowledged. Continuing technological advancements make it possible to build better and more autonomous space probes to explore the solar system. These same advancements have been shown to enable systematic searches for visitation from advanced interstellar robotic probes of suspected ETI origin. The SETV approach includes certain key features inherited from SETA and SETI. This observational strategy uses established scientific methods and experimentation with a goal of detecting and verifying evidence of ETI probe visitation to our world. It has been shown that hypotheses can be devised to address search parameters in terms of detectable probe features and platform location. Ground-based autonomous platforms can be designed and constructed using available COTS instruments to collect detailed observational data and test these hypotheses. AOP data can be organized and coded by adapting existing methods, like Cladistics, from other scientific disciplines. Careful statistical analysis of AOP data can be used to aid in the rejection of the ETI probe *null hypothesis*. For SETV experiments involving possible contact with a robotic probe, it is argued that a set of Pre and Post-detection ETV protocols must be written and followed.

Modern Exobiology and Astrobiology studies now being sponsored by NASA, with participation by other nations and academia, are doing more than just ponder the probabilities of extraterrestrial life. Technological and human resources are being invested in remote-sensing efforts like the Terrestrial Planet Finder and robotic probe missions to search, in-situ, for clear signs of ET life on Mars, Europa and other promising solar system bodies. To further enhance and broaden the search for ETI, it's now time to invest in methods, such as SETV, which search for clear evidence of extraterrestrial intelligence *locally* to aid in proving we are not alone in the universe!

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