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Session 19. Future SETI: Technologies, Techniques, and Strategies

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The vast range of the electromagnetic spectrum and the wide range of potential signaling methods make comprehensive searches for extraterrestrial signals difficult. Perhaps because of this, in nearly five decades of SETI searches no indications of extraterrestrial civilization have been seen. Expanding technologies and new instruments can help close the gaps in the SETI search space. New techniques, such as detecting extraterrestrial artifacts, or atmospheric modification on extrasolar planets, could result in success where searches for signals fail. Creative search strategies increase the probability of a detection by focusing on likely targets or regions of the Galaxy where communicating civilizations are more likely to exist. In this session we will explore new technologies and techniques and discuss strategies for increasing the probabilities of detecting an alien civilization.

19-01-O. SonATA: SETI on the Allen Telescope Array

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The Allen Telescope Array (ATA) is a large N small D array (large number of small dishes) now being commissioned at the Hat Creek Radio Observatory in Northern California by the SETI Institute and University of California Berkeley Radio Astronomy Lab. The array uses digital technology to synthesize multiple simultaneous large radio telescopes or "Äúbeams," Äù. Using relatively small (6.1 meter) dishes has the advantage of providing a wide field of view in which the much smaller beams are pointed. The multi-beam capability of the array and the ability to form and position nulls are prominent features in new observing strategies and RFI mitigation techniques for the Search for Extraterrestrial Intelligence (SETI). These techniques will be used in both sky survey and targeted star observations. New wide-band receivers will expand the search to cover the frequency range from 1 GHz to 10 GHz. Software signal processing will examine the spectrum at resolutions ranging from 1 Hz to 1 kHz. Using open software and commercial-off-the-shelf technology wherever possible creates a new data distribution and processing architecture that will allow new search techniques and increased capability to be added over time.

The first phase of the ATA was funded through generous grants from the Paul G. Allen Family Foundation. UC Berkeley, the SETI Institute, the National Science Foundation (Grant No. 0540599), Sun Microsystems, Xilinx, Nathan Myhrvold, Greg Papadopoulos, and other corporations and individual donors contributed additional funding.

19-02-P. Extended IRAS-Based Whole-Sky Upper Limit on Dyson Spheres and the Implication for Future Dyson Sphere Searches

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A Dyson Sphere is a hypothetical construct of a star purposely cloaked by a thick swarm of broken-up planetary material to better utilize all of the stellar energy flux. A clean Dyson Sphere identification would give a significant signature for intelligence at work. An earlier search has now been extended to a sample of more than 1500 sources drawn from the extended Calgary Low Resolution Spectrometer data set. The Calgary data is used to search for fits to blackbody spectra. Searches have been conducted for both pure (fully cloaked) and partial Dyson Spheres in the blackbody temperature region $100 \leq T \leq 600$ K. Most sources can be linked to other infrared stellar signatures that resemble a Dyson Sphere. When these signatures are used to eliminate sources that mimic Dyson Spheres very few candidates remain and even these are ambiguous. Upper limits are presented for both pure and partial Dyson Spheres. The sensitivity of the LRS was enough to find solar-sized Dyson Spheres out to 400 pc, a reach that encompasses more than a million solar-type stars. The utility of extending this search by using other databases such as 2MASS and the Spitzer GLIMPSE survey will be discussed. The relationship of this search to other ETI searches will be reviewed.

19-03-O. TPF-SETI

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Previously enacted methods for communicating with and detecting extraterrestrial civilizations have involved attempts to send/receive information via modulated electromagnetic waves. Unfortunately, sending a signal this way requires the receiving civilization to examine the relevant wavelengths of light at the time the signal arrives. Fortunately, as our ability to do astronomy increases, so does our ability to send and receive signals. Here we propose a new way of detecting extraterrestrial civilizations with a TPF-style mission, and an advanced calling card to civilizations that are doing TPF-level astronomy. We first propose to look for terraformed planets around other stars. In principle, a terraforming effort involves the intentional alteration of a planet's radiative budget, and as such should leave a large fingerprint on a planet's spectrum. Our second proposal is to modulate the moon's albedo to create a calling-card detectable by any civilization pointing a TPF-like telescope in our direction. This signal would be created by placing panels on the moon that have mirrors on one side, solar cells on the other, and a pivot for flipping between the two sides. By simultaneously flipping these panels in a clearly artificial pattern, the albedo of the Earth-moon system would serve as evidence of our existence. Both of these signals are omni-directional in nature, as they would be sent from the surface of a planetary body, covering the entire sky in the case of a terraformed planet, or half the sky in the case of mirrors on the moon.

19-04-P. Targets & SETI: Refining the Thinking Behind Identification of Targets

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SETI can be divided into two basic schemes for assigning resources. One scheme is to search everywhere—to scan the heavens for "likely emissions". The commensal data-gathering in the 21 cm band, at Arecibo, feeding the SETI@home project, illustrates this. Using the 21 cm band is commonplace but needs reflection (ET's astronomers will want to protect this band for their astronomy).

The alternative approach is to identify targets and allocate resources to surveying just those. Identifying a target means at least reasoning about habitable zones and star types, detected exoplanets, distance limitations on weakness of signals, use of microwave versus optical detectors, and etc. The nature of the signal sought in such surveys needs characterization (as it does for scans).

I will argue that current targeting is poorly conceived. Todd's use of the US army Signal Corps operators in 1924 ("listening to Mars") was more sensible! Why?—because they assumed Earthlings were being targeted. The crucial point about targeting in SETI is to understand that our job is to identify targets which could host communities which could have identified us as a target for their transmissions.

This sounds impossible—but is not. The delivered paper will review the thinking behind the use of pulsars as SETI beacons—both for target identification and signal characterization—and will report on progress with the analysis of data gathered at Arecibo in 2005 using targeting as specified by Edmondson and Stevens (2003).

Reference: Edmondson, W.H. and Stevens, I.R. 2003. The utilization of pulsars as SETI beacons. *Int. J. Astrobiology* 2 (4): 231, 271 (2003).

19-05-P.Advanced Detection Algorithms for Pulsed Optical SETI

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Pulsed optical SETI searches look for short bursts of photons in the visible and near-IR spectrum from a variety of astrophysical sources. These experiments use two or three photon-counting detectors (typically PMTs), digitize the detector outputs, and trigger when all detectors measure multiple photons arriving simultaneously. The fixed voltage thresholds on the detector outputs are set to maximize sensitivity (*i.e.*, detect the smallest pulses) while minimizing false alarms from stellar photon pileup and a variety of detector pathologies. While computationally simple, this detection algorithm is not the optimal balance of sensitivity and false alarm rate. We show that improved algorithms can improve search sensitivity. These algorithms take the digitized photodetector outputs (with data rates measured in giga-samples per second) and and perform arithmetic operations on combinations of the data streams to search for correlated pulsed signals. Simply thresholding the sum or product of the data streams (while also vetoing events from a single detector) are two such algorithms. Fast-folding and arrival time correlation algorithms also allow us to detect a new class of signals—weak, repeating signals with individual pulses below the detection threshold. Our poster will compare the sensitivity and false alarm rate of these and previous algorithms, and discuss their implementation in hardware from the CASPER group. These new algorithms are a small step in the direction of computationally intensive astronomy, and emerging aspect in the field that is exemplified by the Allen Telescope Array (ATA), SETI@home, and Large Synoptic Survey Telescope (LSST).

19-06-O. The Low-Down on SETI

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LOFAR (the Low Frequency Array) is an innovative sparse aperture array being constructed in the Netherlands. It is the first of a new generation of so-called "software telescope" in which the low-cost antenna elements have access to the entire sky and all the complexity (and cost) is associated with the "back-end," *i.e.*, commercial digital electronics, advanced signal processing hardware, and novel (high-bandwidth) computer resources (both hardware and software). LOFAR is capable of imaging large, multiple and distinct areas of the sky simultaneously and with unprecedented sensitivity. In addition to its huge field of view and high spectral/spatial/time resolution, LOFAR uniquely spans a largely unexplored range of the e-m spectrum—from 30–220 MHz. So far most radio based SETI programmes have focused on the "water-hole"—LOFAR could extend such searches to much lower frequencies where we know that some civilizations (this one!) are "radio bright".

The huge field of view accessed by LOFAR, together with the software being developed by both the Survey and Transient key science programmes, makes it an interesting instrument with which to broaden and enhance conventional radio SETI programmes.

19-07-P. Searching Gravitational Waves for Intelligent Messages

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Gravitational waves, like EM waves, can be used to transport intelligent signals. Alien civilizations may be advanced enough to know how to generate (and/or modulate) gravitational waves. Gravitational waves would probably be the preferred method of extraterrestrial communication for the following reasons:

1. Advanced alien civilizations would use gravitational waves to ensure that only civilizations that have sufficiently advanced knowledge would receive their signal.
2. Gravitational waves can be monitored 24 hours a day, 365 days a year, regardless of weather conditions.
3. In order to detect light or radio waves, one must look at the source directly. This involves the tedious task of continuously scanning the sky. And the signal would be missed if the observer is not looking in the right direction at the right time. Gravitational waves are more like sound waves, which can be detected (or heard), regardless of the orientation of the detectors.
4. Local interference should not be a problem since no one on our planet is transmitting gravitational waves.

Gravitational Wave Detectors (such as LIGO) are currently in production, but their outputs are being analyzed for astronomical events, such as coalescing black holes and supernova explosions. In addition to this, SETI could start analyzing the data for intelligent messages.

19-08-P. Sustainability and the Fermi Paradox

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The Fermi Paradox leads some to conclude that humans formed the first advanced civilization in the galaxy. A popular class of solutions assumes rarity for the evolution of life in the Universe, with other inhabited planets in the Universe too far away for interaction or detection. If life is commonplace in the galaxy, though, and if the evolution of intelligence is common, then there is hope for projects that search for signs of technology and communication. No present observations suggest that a technologically advanced extraterrestrial intelligence (ETI) has spread through the galaxy, with this absence of evidence often taken to imply the lack of ETI in this galaxy. The Fermi Paradox, though, cannot logically conclude the uniqueness of humans as the only advanced intelligence in the galaxy. Instead, the absence of evidence for ETI colonization of the galaxy suggests that no ETI successfully formed a galactic civilization, not for lack of technology but because of the unsustainable positive feedback in the mechanism of civilization itself. Assumptions about intelligence often imply that civilization necessarily arises as a consequence of intelligence, but even if this were true the ecological instability of civilization renders any galactic civilization short-lived. This absence of ETI civilization does not preclude the search for life through remote detection of spectral biosignatures, and the possibility that a sustainable ETI exists within the galaxy remains. Unnecessary anthropocentric assumptions, though, make it difficult to conceive of the life we do not know.

19-09-O. Initial Plans for the First Pulsed Infrared SETI Instrument

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We present plans for the first pulsed infrared SETI instrument. This yet-to-be-built device will observe a variety of astrophysical targets for nanosecond flashes of near-infrared photons. Like current pulsed optical SETI instruments that are sensitive at visible wavelengths, this instrument will use multiple photon-counting detectors and fast electronics to digitize, detect, and record short bursts of photons that momentarily exceed the background from astrophysical and instrumental sources. It will likely use InGaAs/InP avalanche photodiodes, which have a linear response and low noise in the 900–1700 nm range. The outputs of these photodetectors will be digitized at 1–2 giga-samples per second and the resulting data streams will be processed in real time using new, advanced algorithms (see Foster *et al.*, this volume) on FPGA-based hardware developed by the CASPER group. The new instrument will use the 30-inch telescope at Leuschner Observatory, and may be cloned for the 1-m Nickel Telescope at Lick Observatory. Despite the fact that pulsed, beamed near-IR lasers are a completely plausible interstellar communications scheme with no known pulsed astrophysical backgrounds, this experiment will be the first to search for such signals. Near-IR wavelengths may even be preferable over the visible spectrum because of reduced interstellar extinction and stellar background.

19-10-O. "Who's Looking at You, Kid?": SETI Advantages Near the Ecliptic Plane

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Recent knowledge about real extrasolar planets, and about telescopes needed to see more of them, can affect our approaches to SETI. This knowledge implies that ETI following technology paths like ours for observing planets may find us more easily if they are located in particular directions. Our SETI efforts should perhaps concentrate on those directions where ETI will most likely have an idea we are here and can then send us efficiently focused communications signals we can detect.

We expect to first observe terrestrial exoplanets by seeing them transiting their host stars. The COROT and Kepler missions may soon find these planets out to 1 kpc. The advantage in distance over other methods, more than 30 times, puts nearly 20,000 times as many stars in range of our earliest (transit) instruments for detecting Earths. We must reside in a stripe of sky 0.5 degree wide centered on the ecliptic of another Earth to see it transiting its sun. That stripe occupies just 1/230 of the whole sky, but for observers like us the transit method could still find 20,000/230 = 90 times as many Earths as any other method yet proposed.

Therefore, distant ETIs first finding our planet are 90 times more likely to be in the narrow stripe straddling our own ecliptic than in all the rest of the sky. SETI searches over that stripe could be 90 times more efficient in detecting signals than are whole-sky searches. Similarly, active SETI transmissions toward that stripe may reach suitable targets best.

19-11-O. The Drake Equation Generalized to Statistics

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We give the statistical generalization of the Drake equation from a simple product of seven positive numbers into the product of seven positive random variables. This new equation we call the "Statistical Drake Equation".

Our mathematical proof, given in this paper, is based on the Central Limit Theorem (CLT) of Statistics.

In particular, we prove that:

1) The new random variable yielding the number of communicating civilizations in the Galaxy is log-normally distributed. The mean value of this log-normal is N in the ordinary Drake equation. The standard deviation of this N log-normal random variable is given also.

2) The seven factors in the ordinary Drake equation now become seven positive random variables. The probability distribution of each random variable may be, in general, arbitrary, because the CLT allows for that. Even a higher number of random variables may be compatible with the CLT, so our theory allows for a generalization of the ordinary Drake equation to many more factors that will be added in the future as long as more refined scientific knowledge about each factor is obtained by researchers.

This capability to allow for more future factors in the statistical Drake equation we call the "Data Enrichment Principle" and it is the key towards more profound mathematical and physical analyses in the field of Astrobiology.

3) Finally, as a practical example of application of our statistical Drake equation, we work out in detail the case when each of the seven random variables is uniformly distributed around its own mean value and with a given standard deviation. For instance, the number of stars in the Galaxy is assumed to be uniformly distributed around (say) 300 billions with a standard deviation of (say) 100 billions. Then, the resulting log-normal distribution of N is computed numerically by virtue of a MathCad file that the author has written and is given in the paper. This shows that the mean value of the log-normal random variable N is actually of the same order as the classical N given by the ordinary Drake equation, as one might expect from a good statistical generalization.

19-12-P. Wide-Band and Low-SNR SETI by the KLT

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The KLT acronym for Karhunen-Loève Transform is a mathematical algorithm superior to the classical FFT in many regards:

1) The KLT can filter signals out of the background noise over both wide and narrow bands. That is in sharp contrast to the FFT that rigorously applies to narrow-band signals only.

2) The KLT can be applied to random functions that are non-stationary in time, *i.e.*, whose autocorrelation is a function of the two independent variables t_1 and t_2 separately. Again, this is a sheer advantage of the KLT over the FFT, inasmuch as the FFT rigorously applies to stationary processes only, *i.e.*, processes whose autocorrelation is a function of the absolute value of the difference of t_1 and t_2 only.

3) The KLT can detect signals embedded in noise to unbelievably small values of the Signal-to-Noise Ratio (SNR), like 10^{-3} or so. This particular feature of the KLT is studied in detail in this paper.

An excellent filtering algorithm like the KLT, however, comes with a cost that one must be ready to pay for, especially in SETI: its computational burden is much higher than for the FFT. In fact, it can be shown that no fast KLT transform can possibly exist and, for an autocorrelation matrix of size N, the calculations must be of the order of N^2, rather than N*log(N). Nevertheless, for moderate values of N (in the hundreds) the KLT dominates over the FFT, as we show in this paper with mathematical details.

19-13-P. Spectroscopic Optical SETI at Lick Observatory

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Technological artifacts in an astronomical signal are an unmistakable sign of intelligent origin. Signal characteristics such as energy concentration in frequency or time beyond the limits imposed on natural sources, or an embedded non-random pattern, betray an extraterrestrial source. We plan to search one plausible and eminent domain of this SETI search space—monochromatic laser emission lines between 360–900 nm from spatially unresolved sources. We have applied for observing time on the 3-m Shane Telescope and Hamilton spectrometer at Lick Observatory for an initial reconnaissance. We will survey a diverse set of astrophysical environments that implicitly sample a vast range of habitats and possible luminosity functions for ET laser power—'aligned binaries', open and globular clusters, nearby galaxies, the Hubble Deep Field, as well as some nearby stars lacking high-resolution spectra and candidate stars from previous SETI searches. Many of these objects have never been observed optically at high spectral resolution. Besides the laser lines we seek, the resulting spectra may reveal astrophysical surprises. Our poster will describe our observing strategy, target list, and any observations completed at the time of the conference.

19-14-O. Re-observation of Harvard Allsky Optical SETI Events Using an Imaging Cherenkov Telescope

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Imaging Cherenkov telescopes have been noted for their near ideal mix of elements for receiving pulsed optical signals, large collecting areas, fast photon detectors, and high-speed signal-capture electronics. Relatively little actual use has been made of these astronomical instruments for optical SETI (OSETI) purposes. We present the results of a short targeted SETI survey using the Whipple 10 m air Cherenkov telescope. Twelve events from Harvard's Allsky Optical SETI Survey database of possible detections were selected for re-observation on the Whipple 10-meter. The sky position of each of these events was observed for a minimum of 28 minutes. Potential OSETI sources were discriminated from the cosmic ray background by characterizing each trigger image based upon radius, ellipticity, and ADC counts (Holder *et al.* (2005) *29th Int. Cosmic Ray Conf. Pune*, 101–106). Eleven events were observed from five candidate locations, using analysis cuts appropriate for an unresolved pulsed source; this rate is consistent with expected cosmic ray events at the observing declinations.

19-15-P. Alien Laser Transmitter Features to Maximize Signal Detection on Targeted Planets

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A rationale is presented showing that a laser with certain features can sucessfully cover thousands of targeted star systems that may have intelligent life. Knowledge of desired features from the transmitting society viewpoint can help design a receiving system that maximizes the chance to detect the laser signal. The important features desired include short pulse, low duty cycle transmitter to overcome the star's background light, agility to move rapidly to point at other star systems, have a minimum useful beamwidth to hold power needs down and insure privacy, ability to point ahead with great accuracy, and enable simple detection by the receiver that requires no knowledge of the transmitting wavelength. A complete design is included for both transmitter and receiver that incorporates stop, stare, and scan-search strategies compatible with each other. The time frames are arranged such that the receiver at some point has to be looking at the transmitter when the transmitter is looking at the receiver. The details and rationale are presented in the paper.

19-16-P. Interstellar Communication: The Quantum Connection

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It has often been suggested in the SETI literature that any message we might receive from a distant solar system would be a message from a more advanced civilization than our own.

This is so because we have only recently learned to search for signals from other civilizations. Given the exponential growth rate of technological development, civilizations only a few centuries ahead of us would have probably developed truly exotic means of signal search and signal transmission.

In this paper it is suggested that a truly advanced extraterrestrial civilization might be able to utilize one of our nascent-state technologies to provide a way around speed-of-light limitations on interstellar communications. Drawing upon recent developments in communications via quantum entanglement, this hypothesis is examined.

If successfully developed, communication via quantum entanglement could lay to rest the argument that interstellar communications are impractical because of the immense time delays involved in exchanges of messages between interstellar civilizations.

19-17-P. Drake Equation Issues

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We discuss the Drake equation, first in its historical context, in both time-independent and time-dependent forms and then as it pertains to present-day searches for extraterrestrial life. We present our suggestions for modifying the structure of the time-dependent equation to include further time-dependences, both for the time for a communicating civilization to arise and for the duration of a communicating civilization. We address several issues relating to the Drake Equation, including that of differing "habitable zones" for the origin of life and for the development of communicating civilizations. The number of habitable sites in the Galaxy is estimated by star spectral type. Estimates are made for the times to develop communicating life and for the duration of a communicating civilization. The relevance to bounds on N that can be inferred from the Fermi Paradox and Bayes' rule is assessed.

19-18-O. New SETI and Transient Radio Sky Surveys

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We review six Berkeley SETI programs at IR, visible, and radio wavelengths, concentrating on two new Arecibo-based radio sky surveys: Astropulse and multibeam SETI. The announcement by Lorimer *et al.* of the detection of an extremely powerful dispersed radio pulse originating at a cosmological distance has renewed interest in the study of short duration radio transients. Such pulses could come from exploding primordial black holes, RRATs (rotating radio transients), pulsars, or perhaps from extraterrestrial civilizations.

Using the 7-beam, dual polarization Arecibo L-band Feed Array (ALFA), and the SETI@home multibeam data recorder, we are conducting a high sensitivity survey of the entire sky visible to Arecibo, searching for μs to ms time scale dispersed pulses.

These data are transferred via the internet to the computers of millions of volunteers. These computers perform a coherent de-dispersion analysis faster than the fastest existing general purpose supercomputer.

The results of this survey will allow us to characterize the spatial, power, and dispersion measure distributions of these pulses. Overall, this survey will be 14 times more sensitive than the best previous searches.

Simultaneously, we are performing a search for artificial narrowband signals in a 300~MHz band surrounding 1420~MHz using the SERENDIP~V spectrometer and SETI@home public resource distributed computing platform. The observations will be 10 times more sensitive and up to 500 times more comprehensive than existing SETI large-area surveys (SERENDIP~IV and SETI@home).

19-19-P. Spinoffs and Catalysis of SETI@home and Other Berkeley SETI Programs

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Although no extraterrestrial signal has yet been detected by the SETI@home and other Berkeley SETI observations, there have nevertheless been several achievements resulting from the work done by our group. We can categorize these successes into three broad areas: computational, technological, and scientific.

Under the auspices of the Berkeley Open Infrastructure for Network Computing (BOINC), the SETI@home program has spawned a new computing paradigm called Volunteer Computing, where noteworthy scientific projects requiring significant computing resources can tap into a large base of volunteers' computer systems. Our expertise in correlator and spectrometer development has led to the establishment of CASPER, the Center for Astronomy Signal Processing and Electronics Research, where we are involved in creating backend instruments for many of the world's major radio telescopes. Additionally, the SETI@home data have been used for several scientific projects, including the mapping of Galactic atomic neutral hydrogen (SETHI) and a search for short-timescale bursting phenomena (AstroPulse).