SETI Researchers Sift Interstellar Static for Signs of Life

The raw computational power of Xilinx FPGAs in ganged arrays drives the international search for extraterrestrial intelligence at 10^{15} ops per second.

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You don't have to leave Earth to find intelligent life on other worlds. All you have to do is tune in ... at the right time ... on the right frequency ... in the right direction ... with the right spectrometer ... using the most powerful supercomputer on this planet.

With the support of the Xilinx University Program (XUP), the University of California at Berkeley has emerged as the world leader in the search for "ET" [pronounced EE-tee, as in the popular fantasy motion picture *E.T.*]. UC Berkeley operates about a half-dozen different SETI (Search for Extraterrestrial Intelligence) projects under the umbrella of the SERENDIP (Search for Extraterrestrial Radio Emissions from Nearby Developed Intelligent Populations) Program.

"When we started 25 years ago, we built a machine that could listen to a hundred channels at once. We thought that was amazing," says Dan Werthimer, Ph.D., director of the SERENDIP SETI Program at UC Berkeley. "That was called SERENDIP I. Then we went to 65,000 different channels with SERENDIP II – and then Xilinx technology allowed us to go to four million channels with SERENDIP III." And in 1997, "We went to 168 million channels with SERENDIP IV."

Later this year, SERENDIP V will go online at the Arecibo Observatory in Puerto Rico with the capability of simultaneously processing data from five billion channels (Figure 1), using several hundred Virtex™-II XC2V6000 and XC2V1000 platform FPGAs populating dozens of racks of spectrum analyzer boards.

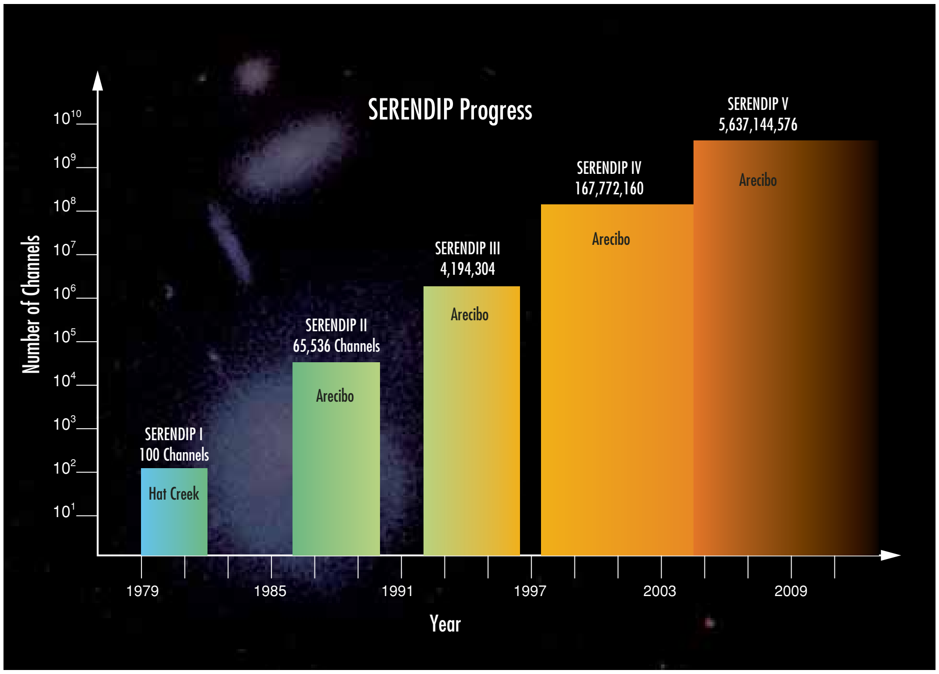

Figure 1 – SERENDIP DSP growth follows Moore's Law

With such an awesome capability to collect massive amounts of data, the SERENDIP scientists need far more computing power than they could possibly have with the high-end Sun Microsystems™ workstations at the Berkeley Space Sciences Laboratory. That's where you and I come in. SETI@home volunteers comprise the largest supercomputer on the planet.

Meanwhile, in the next few years, UC Berkeley's Radio Astronomy Laboratory and the SETI Institute of Mountain View, Calif., will build the Allen Telescope Array, a bold innovation in radio telescope design – and a powerful new tool for SETI research. As with SERENDIP, Xilinx will provide the core technology to enable real-time digital signal processing (DSP) at the unprecedented speed of 10^{15} ops per second.

And what happens if we do find ET? Virtually all of the world's scientific community of SETI researchers have endorsed a United Nations treaty that requires the free and open disclosure of everything discovered and deciphered. How the rest of humanity will react is anybody's guess. A lot of it depends, says Werthimer, on whether the ET signal is accidental or intentional.

Tuning In to ET

Radio waves (including television, radar, cell phones, and other microwave telecommunications) are considered the optimum band of the electromagnetic spectrum for interstellar communication. Radio wavelengths are relatively free of the absorption and noise that afflict other areas of the spectrum. Additionally, stars are generally quiet in the radio wavelengths. This makes radio frequencies a natural candidate for intentional interstellar communications – or "leakage" of local transmissions.

Just as the "local transmissions" of American television shows, such as "I Love Lucy" and "The Honeymooners," leaked out into space 50 years ago (and now have passed thousands of star systems), it is conceivable that we could someday intercept an extraterrestrial situation comedy show.

Anatomy of Arecibo

Operated by Cornell University and the National Science Foundation, the National Astronomy and Ionosphere Center Arecibo Observatory is the largest radio telescope on this planet (Figure 2).

The spherical reflector dish measures 1,000 feet (305 meters) across and covers 20 acres. In what is considered a valid scientific calculation, Werthimer says the dish could theoretically hold 10 billion bowls of cornflakes. Milk, however, would quickly drain out the almost 40,000 perforated aluminum panels that make up the dish.

Suspended 450 feet (137 meters) above the dish is a 900-ton (816 metric tons) platform that can be placed with millimeter precision anywhere up to 20 degrees from the vertical. A "Gregorian dome" on the platform contains two subreflectors (secondary and tertiary) to further focus deep space radio emissions.

The platform also houses ultra-sensitive radio receivers cooled with liquid helium (to reduce electron noise) so the infinitesimally weak signals from outer space can be picked up amidst all the interstellar static and radio interference generated on Earth, orbiting satellites, and probes launched from Earth.

Figure 2 – Arecibo Observatory, Puerto Rico

> "… the name of the game in SETI is to search through as many frequencies as possible." – Aaron Parsons, SERENDIP V design engineer

Piggyback SETI

While most radio astronomers are lucky to get a day or two a year to use the Arecibo Observatory, "We figured out how to use the telescope 24 hours a day all year round by having our own feed antenna," Werthimer says with a certain amount of glee.

"The problem with that is that we don't get to point the telescope, but that's okay, because we don't know where to look anyway," he grins.

"We call it piggyback SETI."

Spectacular Spectrometers

Although radio telescope antennas are visually impressive and quite essential, they are useless without the instruments that receive and process the signals. The real guts of radio telescopes are spectrometers, or spectrum analyzers, such as SERENDIP IV.

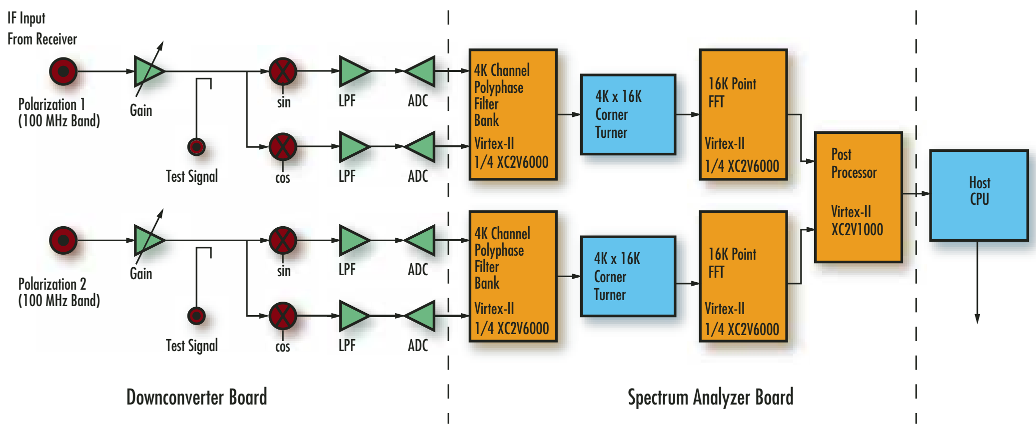

Figure 3 – SERENDIP V spectrometer module

SERENDIP IV

The SERENDIP IV spectrometer at Arecibo consists of 120 Xilinx FPGAs on 40 spectrum analyzer boards working in parallel to scan 168 million narrow-band (0.6 Hz) channels every 1.7 seconds.

Each SERENDIP IV board computes a four million point Fast Fourier Transform (FFT). This four million point FFT is broken down into three smaller FFTs (128, 128, and 256 points each). Xilinx chips comb the resulting power spectra for strong narrow-band signals and report their findings to the back-end computers at Berkeley for subsequent analysis, Werthimer says.

SERENDIP V

"We don't know what frequency ET will be transmitting at, so the name of the game in SETI is to search through as many frequencies as possible," explains Aaron Parsons, a design engineer at the Berkeley Space Sciences Laboratory. Parsons is designing SERENDIP V, the next-generation spectrometer that will be able to process five billion channels simultaneously.

As of press time, SERENDIP V was still on the drawing board, but it is on schedule to be installed at Arecibo later this year.

The whole spectrometer will consist of 40 spectrum analyzer boards, each performing a pair of 64 million point FFTs to handle a real-time signal bandwidth of 100 MHz, Parsons says. Because Xilinx platform FPGAs have the capability of interfacing with double data rate DRAM memory chips, SETI engineers will be able to fit this 64 million point FFT onto a single Virtex-II XC2V6000 FPGA.

Spectrum Splitting

"We did this by first cutting the spectrum into coarse frequency bins using the characteristic frequency response of a 4,096-channel polyphase filter bank," Parsons explains (Figure 3). "The output data were then re-ordered using 256 MB of DRAM and broken into 16,384 smaller bins using a dual flow-through FFT we developed. It uses one-fourth of the space of a traditional FFT, he says with pride.

Finally, information about the best signals will be passed to a CPU over a compact PCI backplane using a Virtex-II XC2V1000 running a Xilinx PCI core, according to Parsons.

Xilinx Chief DSP Architect Chris Dick, Ph.D., consulted on the design of SERENDIP V. "The signal processing requirements in the SETI program present significant computational and I/O challenges that can only be met using Xilinx FPGAs," Dick asserts. "Traditional processor-based approaches just cannot deliver the performance required for this challenging application.

"The highly parallel compute fabric and I/O capability of the FPGA, however, are well suited to support the computational requirements of the filter banks and FFTs used in the polyphase transform channelizer," Dick says.

Key aspects of SERENDIP V were realized using a recent generation design flow from Xilinx called System Generator for DSP. This visual programming development environment is based on The MathWorks Simulink® interactive tool for modeling, simulating, and analyzing dynamic, multidomain systems. It provides a natural framework for rapidly specifying and verifying complex signal processing systems, according to Dick.

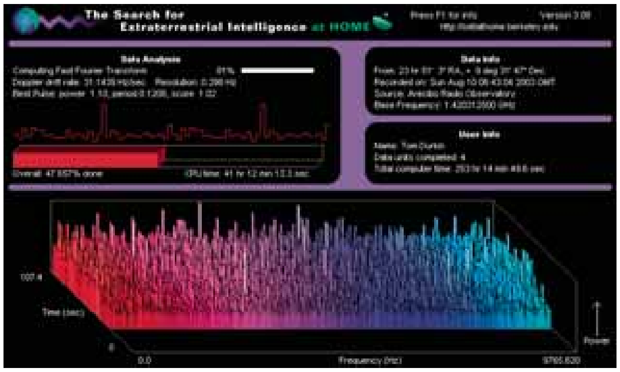

Figure 4 – SETI@home "screen saver" data analysis program

SETI@home Wants You

As fast and as efficient as "ganged" (parallel) FPGAs are, the real-time data processed by SERENDIP IV still needs much further analysis. After the DSP algorithms in SERENDIP IV break down the incoming signal into 168 million channels, some of the outgoing data is recorded onto high-density digital linear tape – about one 35 GB tape per day.

The tapes are shipped to the Berkeley Space Sciences Laboratory. Even with high-end Sun workstations, the amount of data far exceeds the lab's ability to crunch the data. Thus, the SETI@home project was born. The SERENDIP scientists decided to farm out the massive computing task to idle computers all over the Internet (distributed grid computing), so they created SETI@home "screen saver" software.

Calling the SETI@home data analyzer software a screen saver is a misnomer. The only resemblance the data analyzer has to real screen savers is that it only works when your computer is idle – and the graphical display of the data analysis in action is semi-hypnotic (Figure 4).

If you want to join the hunt for ET, you can download the free SETI@home data analysis software at *http://setiathome.berkeley.edu*. There are versions for Windows, Macintosh, Unix, Linux, BeOS, OS/2, OpenVMS, and other operating systems.

Once you've got the software loaded, the SETI@home server at Berkeley sends you a 0.34 MB "work unit." This is a very small chunk of data from the Arecibo tapes. The SETI@home data analyzer performs anywhere from between 2.4 trillion and 3.8 trillion floating point calculations – including FFTs, de-chirping, and baseline smoothing, among others.

Once the data is processed, the SETI@home program notifies you that it wants to report its results back to Berkeley and acquire another work unit. The only time the SETI@home data analyzer needs to be online is when the data is being transferred.

"When we get the data back from the participants, we comb through the strong signals looking for ET," Werthimer says.

Super Computing

The SETI@home project is an awesome display of the power of distributed grid computing. Starting with a base of 1,500 volunteers in 1998, SETI@home has grown to more than 4.7 million participants in 226 countries, with 2,000 new volunteers signing up daily, Werthimer reports.

"The SETI@home volunteers have formed the planet's largest supercomputer, averaging 60 teraflops [60 trillion floating point operations per second] and donating about 1,200 years of CPU time daily," he says. "The search for ET is truly an international effort."

Allen Telescope Array

While the SETI research will continue at Arecibo, the SETI Institute and the Radio Astronomy Laboratory at UC Berkeley have begun to build the Allen Telescope Array at the Hat Creek Observatory near Mt. Lassen in Northern California.

Underwritten by a large donation from Paul Allen, co-founder of Microsoft, the Allen Telescope Array will eventually grow to be a huge, expandable antenna farm (Figure 5) of as many as 350 20-foot (6.1-meter) offset Gregorian dishes with 8-foot (2.4-meter) secondary antennas. This innovative telescope design will cost much less than an equivalent single dish telescope, according to Werthimer.

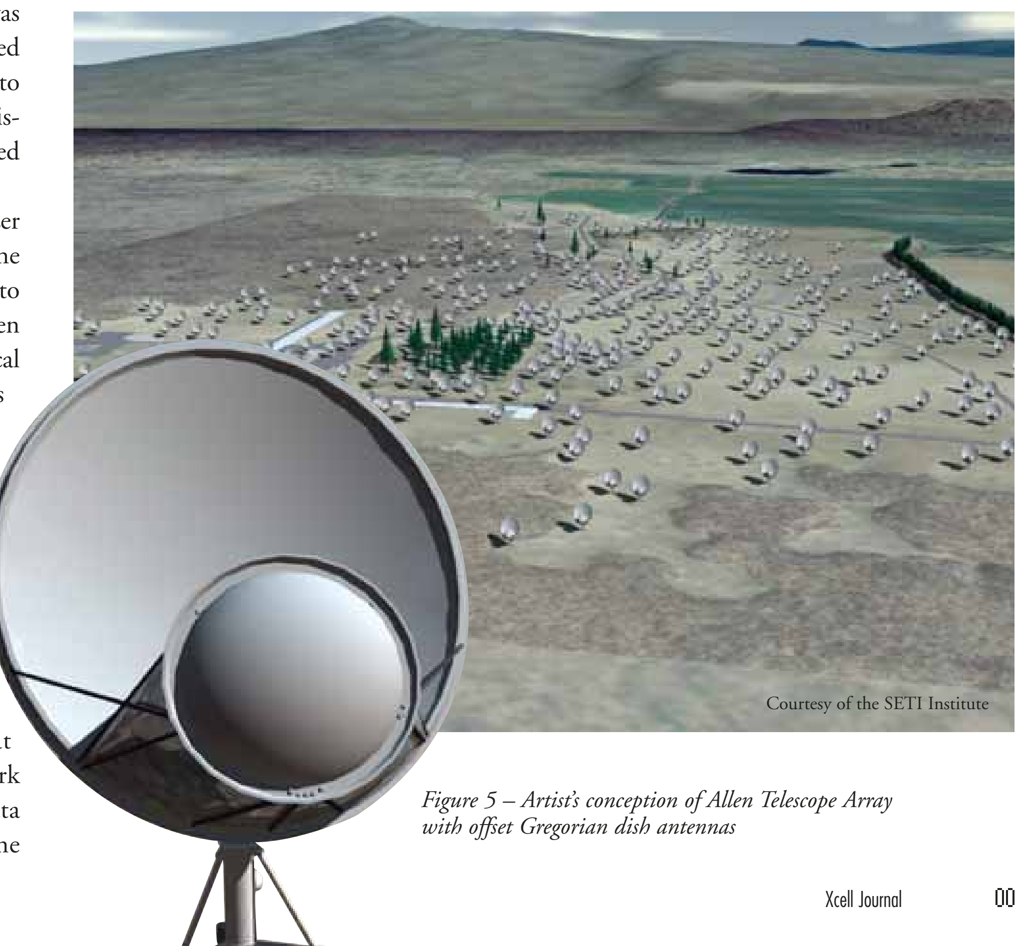

Figure 5 – Artist's conception of Allen Telescope Array with offset Gregorian dish antennas

Employing the same piggyback strategy used at Arecibo, SETI researchers will scan for ET wherever other radio astronomy research projects aim the array.

Although these dishes can be "stamped out like hot tubs" very cheaply, Werthimer says, no one has ever attempted to build a giant telescope from so many small dishes before. The costs of the electronics and signal processing technology required to manage such an array were prohibitively high. The signal processing computation grows as the square of the number of antennas, he explains. But, "Thanks to Virtex-II Pro™ and Spartan™-3 chips, the peta-op per second signal processing costs will comprise only a tiny fraction of the total system costs."

Each telescope (Figure 6) will have an extremely wide-band dual polarization feed, covering 0.5 GHz to 11.2 GHz. This feed will drive a pair of wide-band, low-noise amplifiers that output their signals to a pair of analog optical fiber laser modulators. All telescope fibers will be routed to the central electronic lab where the SETI signal processors and image processors will be located.

To make maps of the radio sky, the FPGA-based "imager" for the antenna array must process real-time data at the rate of one terabit per second (10^{12} bits/sec) and compute one peta-op per second (10^{15} ops/sec) – that's 20 times faster than the SETI@home supercomputer, Werthimer declares.

First, each telescope signal will be digitized and broken up into 1,024 spectral components by means of a polyphase filter bank. The resulting data from each telescope will then be sent to a "corner turner" that will re-order this data by frequency channel.

Next, each telescope "pair" will be cross-correlated and integrated (there are N*(N-1)/2 "pairs" of telescope signals to correlate). Then the data will be "2D Fourier transformed" to produce an image. All signal processing and data routing will be implemented using several thousand Virtex II-Pro platform FPGAs in Rack 2 and Spartan-3 FPGAs in Rack 4, Werthimer says.

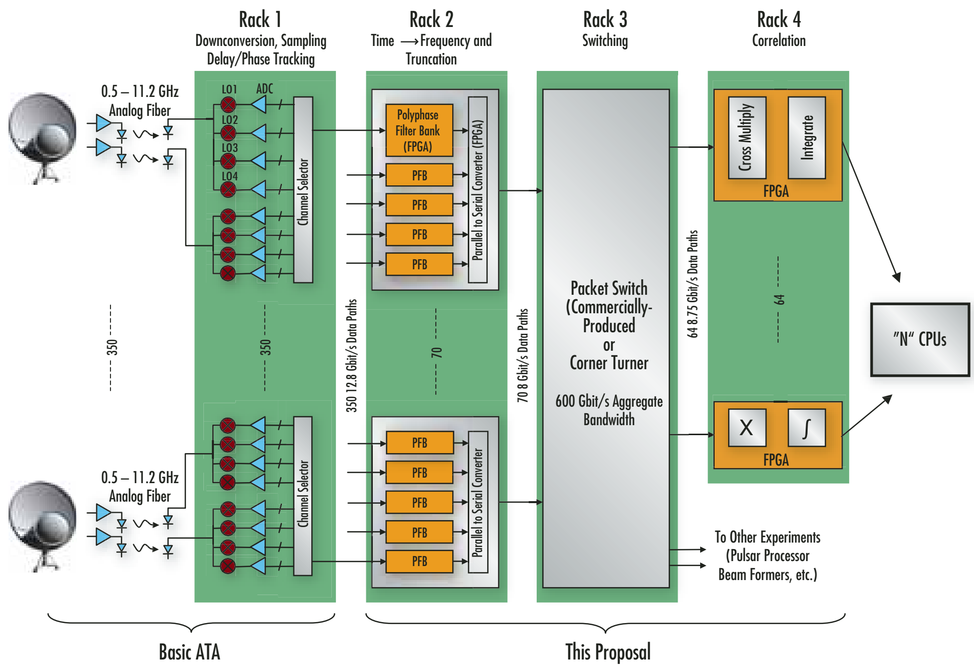

Figure 6 – Proposed Allen Telescope Array image former

Turning Science Fiction into Fact

SETI scientists operate on the assumption that there are other intelligent civilizations "out there." Otherwise, why look? So, the question is not "if," but "how many?" And where? And when will we find them?

Xilinx University Program

Xilinx donations to SETI research date back to 1988. Patrick Lysaght, senior director of Xilinx Research Labs, which includes the Xilinx University Program (XUP), reports that within the past five years, Xilinx has donated more than $1.5 million in hardware, software, and technical support to UC Berkeley's SETI research.

"The search for extraterrestrial intelligence is a tremendously exciting adventure at the frontiers of science," Lysaght says. "Xilinx FPGAs are uniquely suited to the huge computing demands of projects such as SETI."

Werthimer is unrestrained in his gratitude to XUP: "The Xilinx University Program has really made this whole thing possible. Not only did you guys develop the core technology that we needed to process 168 million channels simultaneously, but you have this generous program that gives us the software and the chips to build SERENDIP V."

Werthimer's gratitude goes beyond words. In a memo to XUP last year, he wrote: "We'd like to reciprocate as best we can for all the wonderful stuff you've donated." For example: "We have a flow-through dual FFT and polyphase filter design that Xilinx and its customers are welcome to use. It uses one-fourth of the memory that the Xilinx FFT IP core uses, and it calculates two complex FFTs simultaneously at 240 million samples per second."

"The Xilinx University Program has really made this whole thing possible."

– Dan Werthimer, director, SERENDIP SETI Program

Contact

Why are companies like Xilinx, Sun Microsystems, Intel™, Toshiba™, Hewlett Packard™, Quantum™, Network Appliance™, Fujifilm™ – as well as non-profit organizations like the SETI Institute, the SETI League, and The Planetary Society – contributing millions of dollars worth of technology and expertise to support the search for ET? Xilinx CEO Wim Roelandts puts it this way: "You can say, well, maybe it is science fiction, but to prove it isn't, you need state-of-the-art technology. This is probably the ultimate science problem we must solve. The intellectual challenge is enormous. And that is what is exciting."

Within the SETI community, the word "excited" has become almost a code word for the discovery of ET. Pretty much everybody uses the word "excited" when they describe how they'll feel when a signal from ET is scientifically confirmed. That means replicated results from other, independent observatories, such as those in Australia, Italy, France, and Argentina.

"We actually want to look at the sky many, many times," Werthimer explains. "One of our most robust algorithms is: Did you see the signal again, in same place, when the telescope comes back to the same place in the sky? Do we see it in the same place at the same frequency? – that's what gets us really excited."

Unfortunately, in the last 44 years of serious, scientific research, nobody's found anything to get all that excited about.

"I'm optimistic," Werthimer says. "I think we might find ET in our lifetimes, but I think, right now, we'd be very lucky to find ET. So, I'm sort of counting on Moore's Law. If Moore's Law keeps going, and if Xilinx keeps on making faster and better chips, the better the chances we have of finding an extraterrestrial radio signal."

Two Scenarios

"There are sort of two scenarios for contact with ET," Werthimer reasons. "One is that we find a signal, and we aren't really able to decode it. It could just be a navigational beacon – there's no information. All we would know is that they're out there.

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>
> – Dan Werthimer

"The more scary scenario to me," Werthimer continues, "is that we might receive a direct broadcast with a huge amount of information content in the ET signal – and that could be used in good ways or bad ways."

To prevent the potential abuse of extraterrestrial intelligence, virtually all SETI research organizations – including the SETI SERENDIP Program, the SETI Institute, the SETI League, and The Planetary Society, to name just a few – have endorsed Article XI of the United Nations Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space. In part, Article XI decrees that the discoverers of ET must "... inform the Secretary General of the United Nations, as well as the public and the international scientific community, to the greatest extent feasible and practicable, of the nature, conduct, locations, and results ..." of the discovery.

Furthermore, the treaty calls for a transnational decision on whether to reply to ET – and if so, what to say.

Conclusion

We may discover ET any time from now to never. And it's impossible to predict exactly how humanity will react to scientifically validated proof that life as we know it – isn't.

For many years, the late astronomer-philosopher Carl Sagan was the standard-bearer for SETI research. He gave as much thought to the implications of finding ET as he did to the technology of the search for ET. In a 1978 essay, he wrote: "The search for extraterrestrial intelligence is the search for a generally acceptable cosmic context for the human species. … It is difficult to think of another enterprise within our capability, and at relatively modest cost, which holds as much promise for the future of humanity."

Hyperlinks to SETI Research

Allen Telescope Array:
www.seti.org/science/ata.html

Arecibo Observatory:
www.naic.edu/bigtable.htm

Origins: Astrobiology: The Search for Life:
www.exploratorium.edu/origins/arecibo/

SETI@home:
setiathome.ssl.berkeley.edu

SETI at the University of California, Berkeley:
seti.berkeley.edu

SETI Institute:
www.seti.org

SETI League:
www.setileague.org

The Planetary Society:
seti.planetary.org

"The Quest for Extraterrestrial Intelligence" by Carl Sagan:
www.bigear.org/vol1no2/sagan.htm

Xilinx University Program:
www.xilinx.com/univ/

Protocols for Contact with ET

Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space:
www.oosa.unvienna.org/SpaceLaw/outersptxt.htm

SETI Institute:
www.seti.org/science/principles.html

SETI League:
www.setileague.org/general/protocol.htm

The Planetary Society:
seti.planetary.org/Contact/AfterTheDetection.html