Recent SETI Results With Observations at the ATA. G. R. Harp,[1] P. R. Backus, [1] T. N. Kilsdonk,[1] J. C. Jordan [1] J. C. Tarter[1]. SETI Institute, 515 N. Whisman Rd. Mountain View, CA, 94043.

Introduction: In the cm-wavelength range, an extraterrestrial electromagnetic sine wave beacon is an excellent choice for beacon signal type because 1) it is minimally affected by interstellar / interplanetary dispersion or scattering, 2) compared to other matched filter searches, searching for sine waves is among the most computationally efficient (scales as N log(N)). On the down side, sine wave beacons contain no information (Shannon entropy = 0) apart from their existence. Simple pulsed signals, with a bandwidth defined by the pulse duration are also detectable with relative ease beacons with low information content. We call these algorithms "conventional" SETI.

Here we present results from multiple conventional and unconventional SETI at the Allen Telescope Array (ATA).

The Telescope: The Allen Telescope Array (ATA) is an array of 42 antennas, each 6.1 meters in diameter. The array spans an area of roughly 300 by 150 meters. The array can image an area 2.5 degrees in diameter in the traditional SETI "Waterhole" frequency band (1.4-1.7 GHz) and has a pixel resolution of about 9x3 arcminutes. The ATA is built and operated through a partnership between SETI Institute and the Radio Astronomy Lab of U.C. Berkeley. The design of the ATA allows for simultaneous "commensal" SETI and radio astronomy observations.

ATA SETI Projects: SETI projects generally adopt one of two basic strategies: 1) a "sky survey" covering large areas of the sky with modest sensitivity, or 2) a "targeted search" dwelling on the position of selected stars or astronomical objects to achieve higher sensitivity. We have used both approaches as well as a third approach which examines time and frequency domain of radio images.

Galactic Center Survey: The region near the center of our galaxy has the greatest density of stars and so provides a rich opportunity for SETI. We are surveying 20 square degrees (galactic longitude 357 to 7 and latitude -1 to + 1) over the 1.42 -1.72 GHz Waterhole with a resolution 0.7 Hz. We observed two positions simultaneously in the same 24 MHz frequency band with a pair of synthesized beams. The positions are separated by 20 -30 arcminutes and serve as an "off-source comparison for each other. Any signal detected in both beams is deemed to be terrestrial. The survey area is mapped in a grid of about 3500 positions. In order to avoid disruption of signals due to the solar wind, we observe the region only from March through October. While we search the ~40 billions stars within 25,000 light years, our UC Berkeley colleagues examine the region for transient radio sources.

Cygnus X-3 Survey: From November through February we examine a region of the galaxy in the constellation of Cygnus. The exact position for this SETI program was determined by the potential for commensal astronomy. We selected a region of four square degrees (~800 grid positions) that includes the x-ray binary star Cygnus X-3. This search also covered the Waterhole frequency band.

Exoplanet Search: Life as we know it evolved on a planet so stars known to host planets are attractive targets for SETI. We have observed 146 stars with planets in the Waterhole band. This is an ongoing search that will all exoplanet stars visible to the ATA.

HabCat Search: Turbull and Tarter [2] compiled lists of stars that could be suitable hosts for habitable planets. We observe these stars in the traditional Waterhole band and "two times the Waterhole" (2.84-3.44 GHz) The later is a type of "magic frequency" search starting with the universal frequencies of Hydrogen and Hydroxyl and multiplying by a "magic" number, in this case the number 2.

These first four search projects have used the conventional signal detection algorithms for very narrow band continuous (sine) waves and simple pulses.

PiHI Search: Our fifth project is a small-scale conventional search near the magic frequency of 4.462 MHz (magic number π times the HI line frequency of 1.421 GHz). Suggested by Carl Sagan in his book Contact, we choose this frequency because 1) recently, little conventional SETI has been done in this range (exception: [1]). This relatively small size of this search (100 stars) is offset by the fact that a blind search on 2500 independent pixels near each star (2.5 million points) was carried out commensally with the ATA spectral imaging correlator. This second mode of observing can (and has) be carried out commensally with the conventional observations.

The conventional observations use a high resolution spectrometer which focuses on a single point in the sky, while the spectral correlator produces images of an area approximately 50x50 pixels on a side with the target star at image center. Images are formed with frequency resolution from 100 down to 3 kHz, and the images are compared in sequence for to look for exceptionally strong pixel values indicating a signal localized in both frequency and in space.

The conventional PiHI observations showed no persistent narrowband signals (10 Hz to less than 1 Hz) for any the 100 targets. The spectral imaging mode is still in the development stages and multiple signals were found with 4σ significance (e.g. Figure 1). No persistent signals were found, but the signals do not appear to have a statistical distribution consistent with a Gaussian distribution.

Lastly, we consider an "unconventional" class of beacon signals that may contain vast quantities of information yet are still resistant to dispersion and scattering during the voyage from transmitter to receiver. Here is one example: An arbitrary signal (e.g. encyclopedia galactica) is initiated, and after a relatively short delay, the same signal is sent again on the same channel. This beacon can be received with ¼ the sensitivity of that for a sine wave beacon (in some scenarios, sensitivity is equal). This disadvantage is traded off against the fact that the signal contains information which humans may parse. An simple N log(N) implementation of the search algorithm is known (see poster by Harp), and takes less than 2x the compute time for a sine wave beacon search.

Following the lead of Weisberg et al [2]., we prototype our unconventional search with strong masers, which could act as amplifiers for extraterrestrial signals. Presently we are expanding the range of targets to include many "oddballs" of the galaxy such as the Crab pulsar, and extragalactic oddballs with short time duration amplitude variations. Since "oddballs" are by definition rare or unique, we do not have a sufficient sampling of such sources to be fully confident that the physics of their origin is understood. This leaves open the possibility that these sources might be intelligently manipulated to send information.

We will summarize recent results from all of the above mentioned survey and demonstration observations.

References:

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[2] Weisberg, J.M., Jonston, S, Koribalski, B., Stanimirović, S., *Discovery of Pulsed OH Maser Emission Stimulated by a Pulsar.* Science, 2005. **309**: p. 106-110.

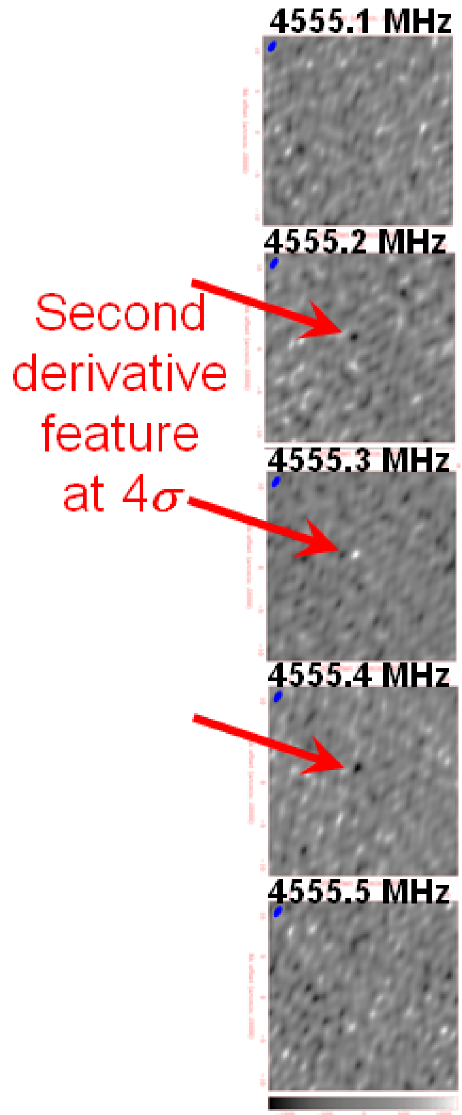

Figure 1: Spectral imaging candidate signal appears at 4 σ above the background level (images on linear scale, color bar at bottom. In this second derivative display, the candidate appears positively in the central frame and negatively in the frequency frames above and below the candidate frequency.