NEWS & FEATURES

NEWS

Using Natural Event Synchronizers with Near-Infrared Spectrometry in Remote Sensing

Last Updated: 25 June 2001

Colleen Scherer and Robert A. Lodder*, Department of Chemistry, University of Kentucky, Lexington, KY 40506, USA
* Author to whom correspondence should be addressed.

Astrobiology is the study of the origin, evolution, distribution, and destiny of life in the universe. The field uses many scientific disciplines and spectrometric technologies to address these important issues. While questions about life in the universe have existed as long as man has looked up at the stars, advances in science and spectrometry in the past few decades make it possible for us to begin to find answers to such questions. Using imaging and spectrometric techniques, more planets have been discovered outside our solar system than exist in it. There are now more than 50 planets known to exist beyond our solar system (1,2). More stars are known to have planetary systems than are known to lack them. This observation, coupled with the fact that life has been found to exist on earth under conditions and in places previously thought impossible, suggests that life in some form may exist on other planets. For example, life has been discovered deep in the ocean around hydrothermal vents, where conditions may resemble those on Europa, a moon of Jupiter (3). The discovery of life on Europa or Mars would increase the importance of the search for Earth-like planets orbiting the other 100 billion or more stars in our galaxy (4), and even the search for extraterrestrial civilizations.

Astrobiological research generally falls into one of three categories: (a) searching for planets in a livable zone around a star, (b) recreating conditions in the laboratory that might exist on a remote planet, to study what might live there, and (c) searching for communication signals that might be emitted by intelligent life. Spectroscopists have a role to play in all three categories of study. The analytical methods employed in studies in these categories are analogous to fluorescence or absorbance spectroscopy. The first two categories are similar to absorbance spectroscopy in that they seek a small analytical signal in a large background. For example, there are many planets in the universe and it is difficult to establish which are in the livable zone and might support life. Likewise, recreating the atmosphere of a planet in the laboratory requires knowing the temperature, pressure and exact composition of the atmosphere. Many different chemical reactions might occur in that atmosphere, making discernment of the reactions that are related to life problematic. However, discernment of deliberate communication signals is more like fluorescence spectrometry, in that it seeks an analytical signal in a small background. Deliberate communication beacons are likely to be high in power, narrow in spectral bandwidth, polarized, spatially

Thermo Nicolet
www.thermonicolet.com

Innovative Solutions
Specac

MS Prediction
www.acdlabs.com

Essential
Authoritative...
Comprehensive

E-mail a colleague

localized, and drifting in frequency due to Doppler shift. All of these characteristics combine to make deliberate communications signals stand out prominently against the background noise. While the frequency with which we encounter interstellar communications signals has been lower than the rate with which we find planets in the livable zone, the possibility of improved signal-to-noise ratio in detection of communications samples continues to suggest that spectrometric searches for communications beacons might one day bear fruit.

The goal of Project Argus is to create a continuous all-sky spectrometric survey with thousands of telescopes designed to detect deliberate communication beacons (5). Project Argus will ultimately deploy and coordinate 5,000 small radio telescopes around the world (6). When fully operational, Project Argus will provide the first ever continuous monitoring of the entire sky, in all directions in real time. Project Argus, which is named after the all-seeing Greek guard-being with 100 eyes, is coordinated by The SETI League, Inc., a U.S. educational and scientific corporation. The SETI League was established in 1994 to help privatize the scientific Search for Extra-Terrestrial Intelligence (SETI), formerly conducted by NASA. The spectra collected by Project Argus form a distributed database that can also be "mined" continuously for transient signals from other interesting astronomical sources, including Mira variable stars, pulsars, and comets, and "synchronizers" for communications (such as supernovas and gamma ray bursts). Continuous all-sky surveillance in real-time would enable detection of these and other outburst phenomena in real time. Such transient sample signals could be detected in sky surveys using microwave, infrared, visible and x-ray telescopes (7).

Project Cyclops (8), an early 1970's design study headed by Dr. Bernard M. Oliver, compared the potential effectiveness of various interstellar communications technologies, and concluded that interstellar communications could best be accomplished in the microwave spectrum. For years, the Cyclops arguments were used to discourage optical and infrared spectral searches.

In fact, the search for signals in the optical spectrum had been proposed by Schwartz and Townes as early as 1961 (9). Townes, the physicist honored in the development of the maser and the laser, has subsequently maintained that short gigawatt pulses of coherent light could propagate readily through the interstellar medium, outshining nearby stars briefly by a factor of up to one billion. These pulses, if they exist, should be visible to Earth's most powerful optical telescopes using suitable photon-counting pulse detectors.

Historically, the most frequently voiced objections to searching in the optical spectral regions have dealt with perceived limitations in human technology. In other words, optical communications were deemed incapable of traversing interstellar distances, based upon calculations predicated on old Earth technology. As our instrumentation has improved, those arguments have become dubious. Significant advances in Earth's optical communications capabilities were announced at previous SPIE meetings (10,11), and no doubt, more will be announced in the future.

Organizing and querying a large distributed spectral image database is no small task. Spectral data collected from the telescope network vary in frequency coverage, resolution, digitization rate, the programs and instruments used to collect the data, the data processing, and more. In addition, completing the all-sky surveillance network and the distributed database will take some time. Until the network is complete, efforts are being made to focus the spectrometric telescopic resources presently available in a way that maximizes their effectiveness.

The "search-space" for signals is often referred to as being five-dimensional, with three spatial dimensions, one frequency dimension, and one time dimension. Detecting a signal requires looking in the right physical location at the right frequency and at the right time (12). Consequently, it makes sense to look for "synchronizers" that might be used to mark spatial coordinates, time and frequency for a beacon. Synchronizers fix the three spatial coordinates and the time coordinate, leaving only frequency as an unknown in the search. An intelligent life form might select a natural synchronizer signal (e.g., a gamma ray burst or a supernova explosion) on which to "piggy-back" a beacon to other intelligent life forms, knowing that the synchronizer would attract the attention of other intelligent life. When a synchronizer event is monitored in one direction, the beacon signal would be transmitted in the opposite direction, so the two would appear nearly coincident from the perspective of the distant observer (see Fig. 1).

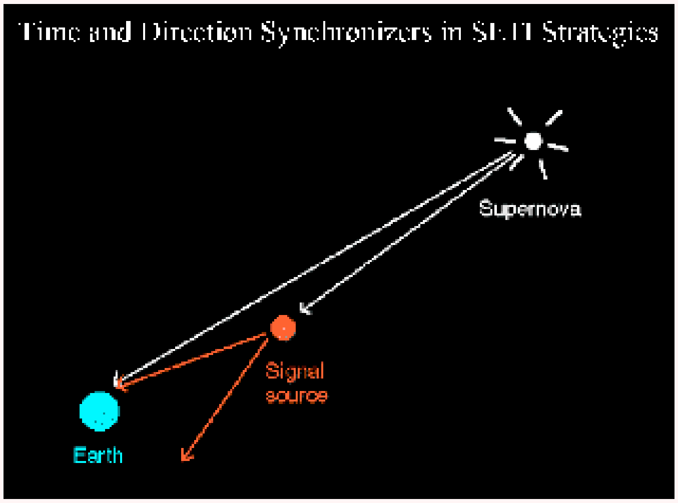

Figure 1. A beacon signal from a distant source could be synchronized with emission from an even more distant supernova. In this way, the beacon could take advantage of the enormous power of the natural signal to attract attention, and fix the three spatial coordinates and the time coordinate in the search space, leaving only frequency as the unknown spectral variable.

Type IA supernovas are used astronomically as "standard candles" for measuring distances (13-15). These stars, which accrete matter from a nearby companion star until they reach a critical mass and then explode, are all believed to have similar brightness and decay profiles. The similarity of the explosions enables their distance to be gauged by their brightness, and this feature has been used to make important new discoveries, including the discovery that the expansion of the universe is actually accelerating.

A supernova emits an immense amount of light that is visible not only across this galaxy, but in other galaxies as well. Approximately 70 new supernovas are now monitored every year, and with brightness decay occurring over a period of days, a new one is available as a synchronizer almost continuously. Supernovas last longer than gamma ray bursts, making it easier to detect an explosion and set up equipment in time to monitor radiation from the direction of the exploding star.

Several different types of equipment are used to observe the sky in astrobiology. A radio telescope is used to detect narrow-band microwave signals, which have traditionally been thought of as best suited for galactic communications (8). A conventional optical telescope will detect visible-light signals, which can be more easily generated in higher peak-power pulses and tightly beamed toward a target. A near-infrared telescope will detect signals even better than a visible-light telescope, because near-infrared light penetrates the dust in galaxies much better than visible light (see Figure 2).

Fig. 2 - click to enlarge

Figure 2. Star Forming Region G45.45 + 0.06 Gemini North Image, June 1999. (a) Image at "J", 1250 nm, (b) Image at "K", 2200 nm. Resolution = 0.12 arcseconds FWHM.
Photo Credit: Gemini Observatory, US National Science Foundation, and University of Hawaii Institute for Astronomy. (Click on image to enlarge).

Optical and near-IR communications might be accomplished by methods such as pulse position modulation (PPM). In PPM, the information is encoded in a pulse series by varying the time intervals between the pulses (16). For example, sending a pulse in the third, first and then twentieth interval of three consecutive frames can spell the word "cat" (see Figure 3). A typical pulsed near-IR laboratory laser emits about 10 pulses per second. These pulses are approximately a nanosecond in duration, giving 100 million possible intervals per frame (ignoring temporal dispersion in the galactic medium). The potential efficiency of information transfer by PPM is large. Applying more information compression, a message could be sent using only one pulse per word, because the entire English language comprises just 2-3 million words, and each entry in the dictionary could be assigned a pulse position. Sending the message "Let’s be friends" would only require three pulses. The intensity of each individual pulse is far above the background noise, making it easily visible even though the average power of the whole signal is not higher than the background noise (17).

Fig. 3 - click to enlarge

Figure 3. Pulse-position modulation (PPM) varies the time delay between pulses to encode information on a pulsed laser signal. In this figure, placing a pulse in the third, and first, and then twentieth intervals of three consecutive frames spells the word "cat." (Click on image to enlarge).

The current near-infrared telescope at the University of Kentucky is based on a "light bucket" design in which image resolution is traded for capture area (18). The telescope is based on an infrared/near-infrared/visible Fresnel lens, a compound parabolic concentrator, tunable interference filter, a CCD camera for maintaining star lock, x-y-z translation stage for tracking and detector dithering, and Dewar and detectors (PbS, InSb, or InGaAs) as shown in Figure 4. Data collected from the telescopes are placed online and can be downloaded from the web at http://www.pharm.uky.edu/ASRG/CURRENT/J94/argus.htm.

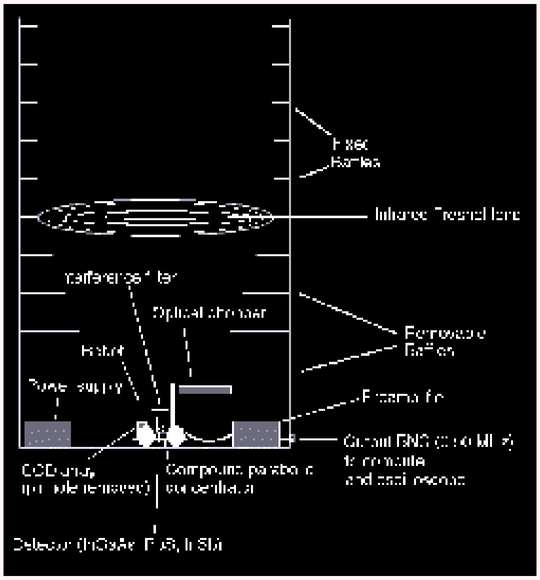

Figure 4. Diagram of a near-IR telescope based on a one-meter Fresnel lens and compound parabolic concentrator. (Click on image to enlarge).

The compound parabolic concentrator (CPC) collects skew rays that enter the telescope over a large solid angle by directing them onto the detectors, reflecting each ray once from off-axis parabolic surfaces. The earliest use of CPCs was in concentration of the diffuse blue glow of Cerenkov radiation. The concentration of light from a Fresnel lens is also possible using CPCs. A one-meter imaging mirror would produce the same point of concentrated light from a distant source, but it is far more economical to use a Fresnel lens and the CPC (18).

In initial experiments, our laboratory used the telescope to monitor the area around the star Deneb. Deneb is one of the brightest stars of its kind in the galaxy and is located about 2500 light years from Earth (19). A spectrum from the initial experiment is shown in Figure 5.

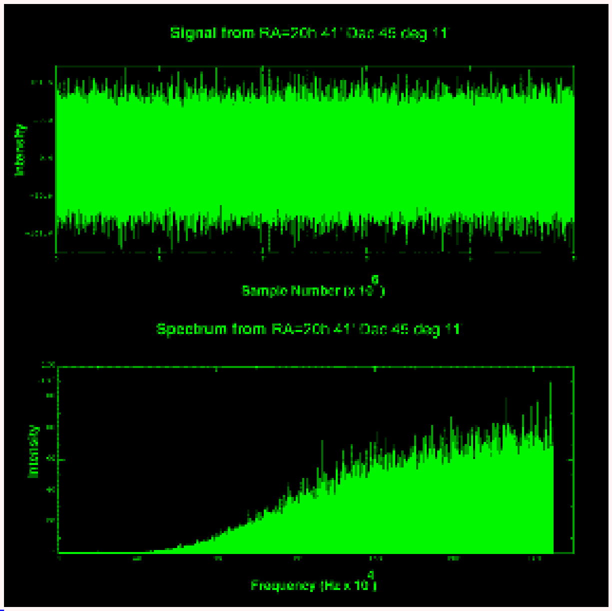

Figure 5. Light intensity (1-2.2 μm wavelength) as a function of time and

frequency, using the near-IR telescope on data recorded from the vicinity of Deneb. (Click on image to enlarge).

The data can be analyzed using many methods, and different volunteers on the web project have employed different methods. Among the simplest methods are autocorrelation and crosscorrelation. Autocorrelation at all possible lag times is used to improve the signal-to-noise ratio (S/N) without *a priori* knowledge of the incoming signal. However, crosscorrelation can improve the S/N even more, but only if very good guesses are made about the frequency, shape, and phase of the incoming signal. The signal correlation between two detectors is employed to determine which signals are generated internally (for example, by thermal noise) and which are not.

The near-IR telescope rapidly collects a large amount of data. In one day 4.3 Tb of data can be collected using the 50 MHz preamplifier and A/D. For this reason, studies utilizing the telescope are often kept short (60-180 sec). Our laboratory began searching for signals synchronized with supernovas in 2001. By mid-February no signals had been detected in this first set of very preliminary data (see Table 1).

Supernova	Date	Result
SN2001A	06 Jan 2001	negative
SN2001B	06 Jan 2001	negative
SN2001C	06 Jan 2001	negative
SN2001G	14 Jan 2001	negative
SN2001P	02 Feb 2001	negative
SN2001Q	02 Feb 2001	negative
SN2001T	11 Feb 2001	negative

Table 1. Two types of searches were conducted: (1) a search for PPM pulses of 20 nsec duration anywhere within 60 seconds, 10 SDs over noise. (2) a search for regularly spaced (unmodulated) beacon pulses, correlated between 2 detectors over 60 seconds, 7 SDs over noise, at least 10 evenly spaced pulses.

When a supernova can be observed continuously for two weeks following its initial outburst, the likelihood of detecting a signal will be greatly increased. However, the data storage and processing capacity of this instrument must be greatly increased before such extensive observations can be made. Furthermore, a network of telescopes will be required to keep the supernova in view as the earth rotates. Project Argus is building this network.

Telescopes provide an excellent way for spectroscopists to discover new planets and to determine whether they orbit in the nominally livable zone around a central star. Project Argus is creating a distributed spectrometric database that can be used by astrobiologists, astronomers and other scientists to study many phenomena in the sky. Eventually, a distributed database will provide data in a way that makes it simple to determine what type of event happened where and when. Some of these events, like supernova explosions, can be used as synchronizers to fix the three spatial coordinates and the time coordinate in searches for beacon signals. The reduced dimensionality of the search space (which then includes only photon frequency as an unknown) may increase our chance of finding a deliberate beacon signal.

Copyright © 2001 John Wiley & Sons, Ltd. All rights reserved.
Terms & Conditions **Privacy Policy** **Contact Webmaster**