Astrobiology and the Search for Life Beyond Earth in the Next Decade

Statement of

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Chairman Smith, Ranking Member Johnson and Members of the Committee, thank you for the opportunity to testify today.

Overview

Nearly 14 billion years ago, our universe was born from a swirling quantum soup, in a spectacular and dynamic event known as the "big bang." After several hundred million years, the first stars lit up the cosmos, and many hundreds of millions of years later, the remnants of countless stellar explosions coalesced into the first planetary systems. Somehow, through a process still not understood, the laws of physics guiding the unfolding of our universe gave rise to self-replicating organisms – life. Yet more perplexing, this life eventually evolved a capacity to know its universe, to study it, and to question its own existence. Did this happen many times? If it did, how? If it didn't, why?

SETI (Search for ExtraTerrestrial Intelligence) experiments seek to determine the distribution of advanced life in the universe through detecting the presence of technology, usually by searching for electromagnetic emission from communication technology, but also by searching for evidence of large scale energy usage or interstellar propulsion. Technology is thus used as a proxy for intelligence – if an advanced technology exists, so to does the advanced life that created it. Although natural astrophysical sources produce a diverse array of electromagnetic, gravitational and high energy particle emission, there are particular types of emission that, as far as we know, could only be generated by an advanced technology. For example, technology constructed by human beings has been producing radio emission for more than 100 years that would be readily detectable at dozens of light years using receiving technology only moderately more advanced than our own. Some emission, including that produced by the planetary radars at Arecibo Observatory and the NASA Deep Space Network, would be detectable across our galaxy.

Technologies far more advanced than our own could potentially produce even more dramatic evidence of their presence. Large stellar-scale structures could cause apparent modulation in starlight as they orbited their host, and massive energy usage by a super advanced civilization might be revealed by its thermodynamic signature, even from millions of light-years away.

Although we know of only one example of life anywhere in the universe, we have reasons to be optimistic about the possibility of life beyond Earth. Earth-like planets, water and complex chemistry have now been found in abundance throughout our galaxy. Everything that we believe was necessary for life to begin on Earth is now known to be ubiquitous throughout our galaxy and beyond. Knowing that extraterrestrial life could exist, the race is on to discover whether or not it, in fact, does exist. Yet more compelling is the possibility that extraterrestrial life may have followed a similar developmental process as life on the Earth, and given rise to a life form possessing intelligence and a technological capability similar to, or perhaps far exceeding, our own. Conducting direct searches for advanced extraterrestrial life is the sole means of determining the prevalence of such life in the universe, and answering one of our most fundamental questions: Are we alone?

Radio and Optical SETI

The motivation for radio searches for extraterrestrial intelligence can be summarized as follows: 1. coherent radio emission is commonly produced by advanced technology (judging by Earth's technological development), 2. electromagnetic radiation can convey information at the maximum velocity currently known to be possible, 3. radio photons are energetically cheap to produce, 4. certain types of coherent radio emissions are easily distinguished from astrophysical background sources, 5. these emissions can transit vast regions of interstellar space relatively unaffected by gas, plasma and dust. These arguments are unaffected by varying assumptions about the motivation of the transmitting intelligence, e.g. whether the signal transmitted is intentional or unintentional, and can be applied roughly equally to a variety of potential signal types or modulation schemes. Modern radio SETI experiments have been ongoing for the last 55 years, but for the most part they have searched only a small fraction of the radio spectrum accessible from the surface of the Earth and have probed only a few nearby stars at high sensitivity.

Large national radio telescopes in the United States, such as the Green Bank Telescope in West Virginia and the Arecibo Observatory in Puerto Rico are superb facilities for a wide range of astronomy, including pulsar studies that could lead to the detection of low-frequency gravitational radiation, mapping the atomic and molecular content of nearby galaxies, and probing the earliest epochs of the universe. In addition, these facilities are among the world's best at searching for the faint whispers of distant technologies. Figure 1 illustrates the natural low noise portion of the radio spectrum between $1-10$ GHz, and the approximate locations in the radio spectrum where several different types of terrestrial transmitters produce emission. The Green Bank Telescope and Arecibo Observatory can conduct observations across this entire range of the radio spectrum.

Earlier this year, a group of astronomy, engineering and physics students and staff from our team at UC Berkeley, working with our colleagues from the National Radio Astronomy Observatory, installed a new instrument at the Green Bank Telescope that enables us to conduct SETI observations in parallel with other astronomers, a technique we call "piggy-back" observing. This project was funded by a combination of support from the NASA Astrobiology Program, the National Science Foundation and the John Templeton Foundation, but *NASA no longer provides funding for SETI experiments.*

In addition to the Green Bank Telescope, other radio SETI programs are underway in the United States at Arecibo Observatory and the private Allen Telescope Array in Northern

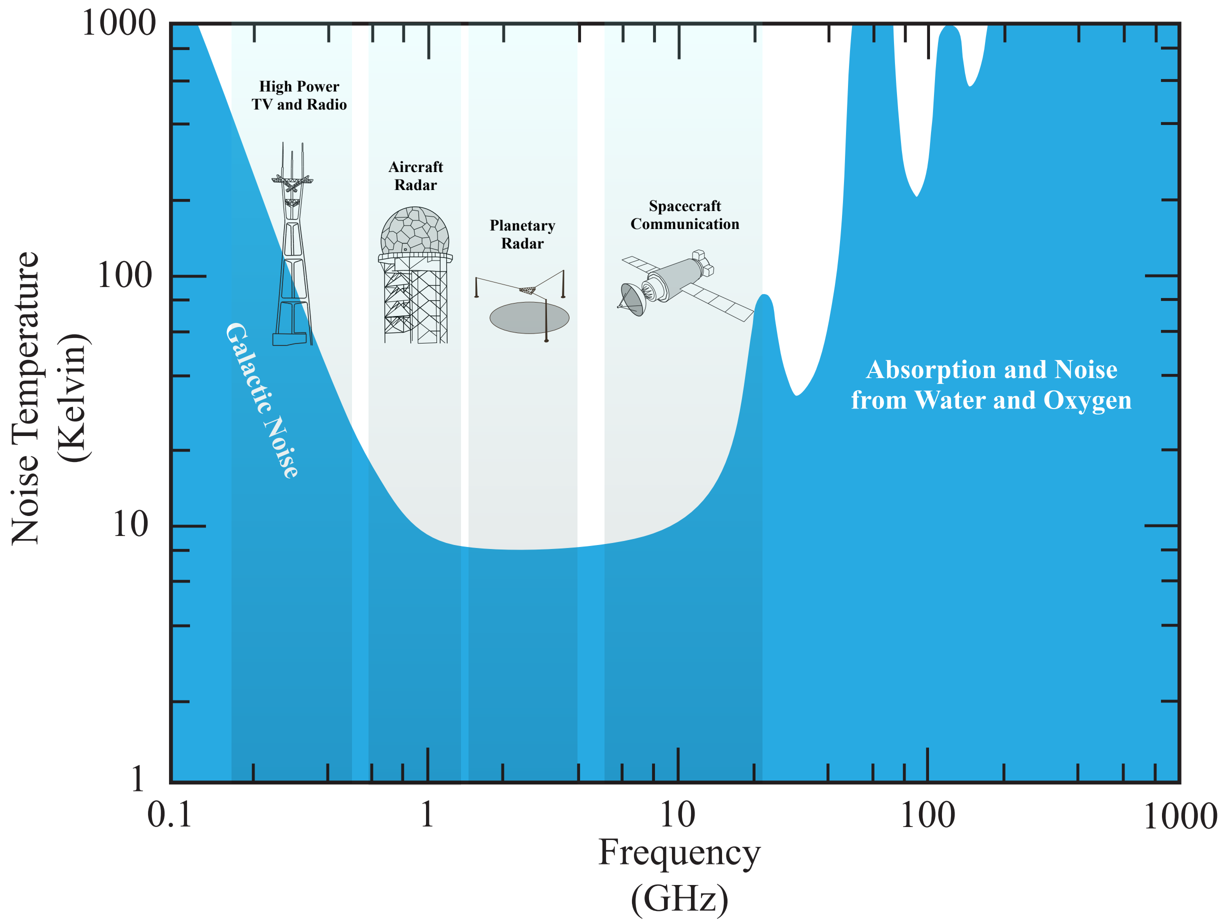


Figure 1: The centimeter-wavelength portion of the electromagnetic spectrum, showing the natural relatively low-noise region between 1-10 GHz. At low frequencies, background radiation from our own galaxy produces significant noise. Above 15 GHz, the oxygen and water in the Earth's atmosphere both attenuates incoming radiation and produces noise. Also indicated in the figure are the approximate locations in the radio spectrum where terrestrial transmitters produce emission.

California. Many international radio telescopes are also currently being used for radio SETI searches, including the Low Frequency Array (LOFAR) in Europe, the Murchison Widefield Array (MWA) in Australia and the Lovell Telescope at Jodrell Bank Observatory in the United Kingdom.

While the dominant paradigm in SETI research involves searching the radio portion of the electromagnetic spectrum, other wavelengths possess merit as well. Similar to our consideration of radio emission from human technology as an example of a potentially detectable signal from extraterrestrial intelligences, we can conceive of ways in which human technologies operating at other wavelengths could produce signatures detectable at interstellar distances. For example, laser technology already developed on Earth could be used to produce a signal that could outshine the sun by many orders of magnitude at a distance of more than 1000 lightyears.

These optical and infrared SETI experiments come in two varieties, searches for pulses of light of short duration and searches for light emission at a single wavelength using a spectrometer. Relative to radio transmissions, optical signals could potentially convey much more information content and are more easily focused for directed signaling or communication.

At one of the world's premier optical telescopes, the Keck Observatory on Mauna Kea, Hawaii (Figure 2), students and faculty at UC Berkeley are pursuing a search for continuous artificial lasers, using optical spectra that are collected for the primary purpose of searching for and characterizing extrasolar planets. In an additional effort, a group led by students and faculty at UC San Diego are using the Lick Observatory, near San Jose, California, to conduct a search for pulsed lasers in the near-infrared part of the electromagnetic spectrum (Figure 3), wavelengths just a hair longer than optical light − the first SETI experiment ever to operate at this wavelength. Other optical SETI experiments are currently operating or under development at Harvard University and several research institutes in France and Italy.

Ensuring that facilities like the Green Bank Telescope, Arecibo and Keck Observatory continue to exist as world class astronomical observatories is critical to their continued availability for SETI experiments.

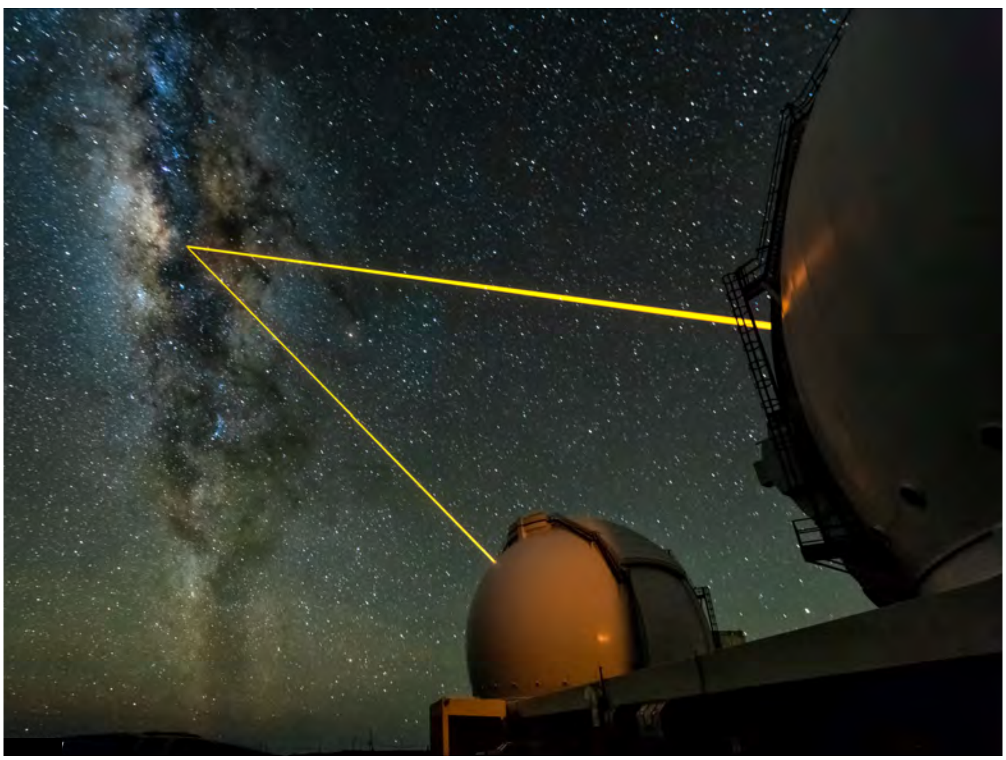


Figure 2: Optical SETI, searches for laser emission from advanced civilizations, are conducted at the Keck Observatory on Mauna Kea, Hawaii.

Data Mining SETI

The era of the "virtual observatory" has arrived. Many astronomers no longer need to travel thousands of miles to a telescope and command an instrument to perform observations.

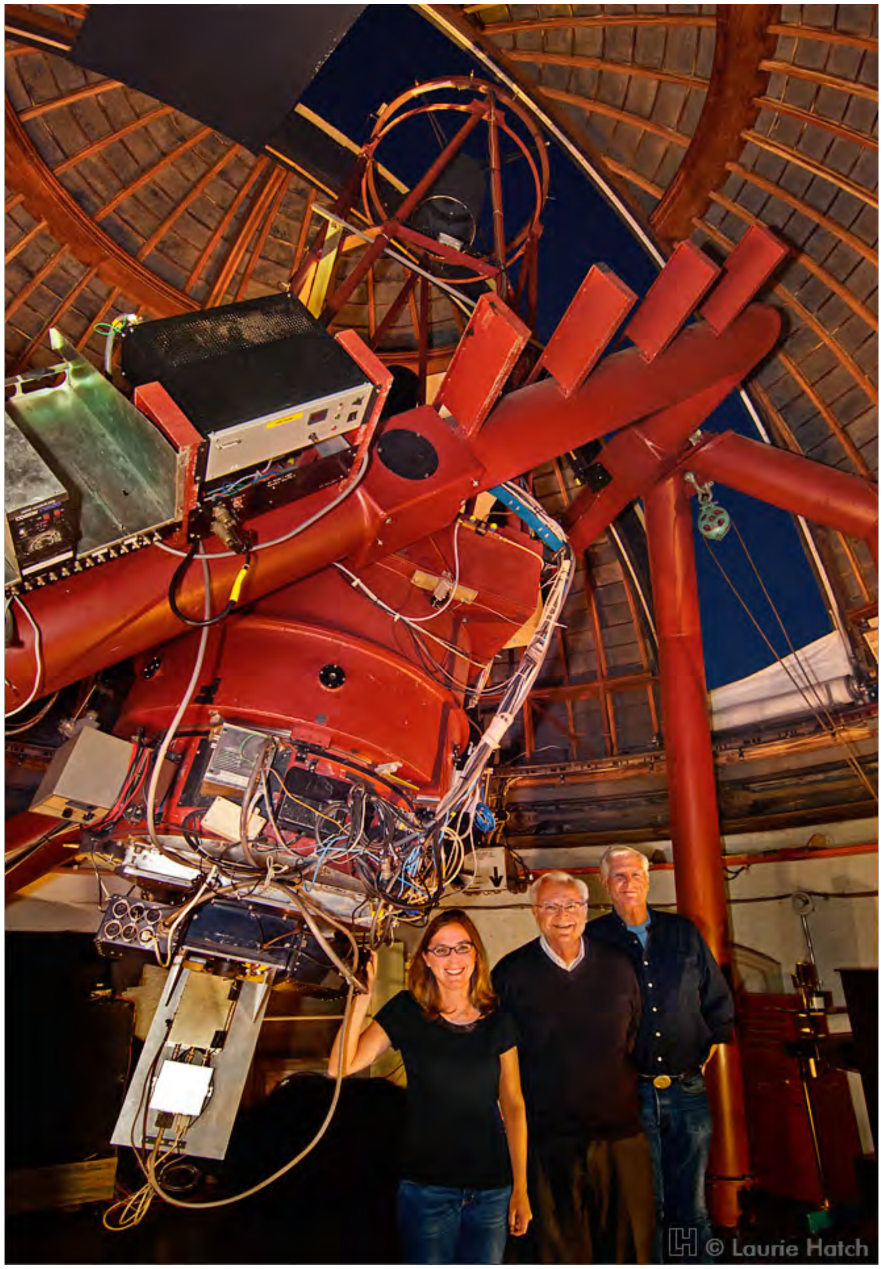
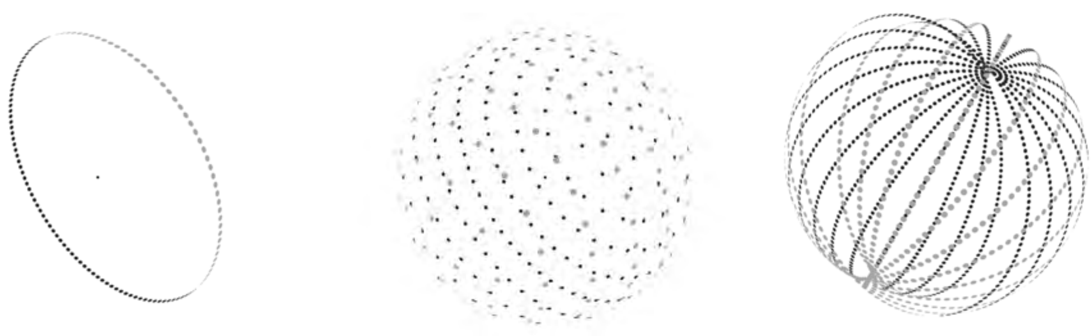


Figure 3: Near-Infrared "Optical" SETI at Lick Observatory. Professor Shelley Wright from UC San Diego (left) leads a team that includes Professor Frank Drake (middle) and Remington Stone (right) using the "Nickel" telescope to search for short pulses of near-infrared light that might originate from an advanced technology.

Hundreds of terabytes of astronomical data, collected with billion dollar telescopes, are now freely available. In many cases, these data are made available to the entire astronomical community the instant they are collected. These data undoubtedly contain many astronomical discoveries that are as yet uncovered. Perhaps, if looked at very closely in a novel way, some of these data contain evidence of an extraterrestrial intelligence.

The astronomical literature is rife with speculation that very advanced intelligences may produce signatures detectable by traditional astronomical observations. Massive "Dyson" structures, so named after they were first proposed by physicist Freeman Dyson, might be be built to harvest the energy of hundreds of Suns and could be detected in the latest generation of infrared sky surveys. Figure 4 shows three hypothetical configurations of these Dyson structures orbiting a parent star. A very advanced civilization using a naturally bright astronomical source as a pseudo-artificial beacon, such as modulation of a naturally expanding and contracting star or interference with a pulsar, could be discovered through careful analysis of variable star or pulsar observations.



(a) (b) (c)

Figure 4: Three hypothetical Dyson structures, a ring (left), and more numerous configurations (middle and right). Such a collection of solar collectors could allow a very advanced civilization to harvest a large fraction of the energy from their star.

Researchers at Penn State University, led by Prof. Jason Wright, have recently undertaken a significant effort to search for evidence of massive energy usage by very advanced civilizations using data from NASA's *WISE* space telescope. Although so far this work has produced only negative results, it has placed significant constraints on the presence of extremely advanced galactic-scale civilizations. Additional work led by Dr. Erik Zackrisson in Sweden and Prof. Michael Garrett in the Netherlands has come to similar conclusions regarding the rarity of super-advanced civilizations, but this collected work represents a promising and growing new area of SETI research.

"Open science" and "open data" policies are incredibly important for enabling innovative SETI research using archive data from national facilities.

The Next Ten Years

It is undoubtable that the next decade will be an incredibly exciting time for astrobiology. Data provided by missions like the Transiting Exoplanet Survey Satellite (TESS) and the James Webb Space Telescope (JWST) virtually guarantee dramatic new insights into exoplanet science, including identifying and characterizing some of the nearest exoplanets to the Earth. At the same time, we will continue to learn more about the development of life on Earth and the potential for life elsewhere in our own Solar System. If history is any guide, these discoveries will only heighten our imagination about the possibilities for advanced life elsewhere in the Universe. Two of the most exciting prospects for advances in SETI research are described below.

The Breakthrough Prize Foundation[1] has recently announced the Breakthrough *Listen* and *Message* Initiatives[2] − two programs that will investigate the possibility of life beyond Earth and the relationship between humanity and life in the universe. *Breakthrough Listen* is a \$100M 10−year effort to conduct the most sensitive, comprehensive and intensive search for advanced intelligent life on other worlds ever performed. Figure 5 shows the three facilities that will be employed in the *Breakthrough Listen* Initiative, the Green Bank Telescope (GBT) in West Virginia (Figure 5a), the Parkes Telescope in New South Wales, Australia (Figure 5b) and the Automated Planet Finder (APF) at Lick Observatory, Mount Hamilton, California (Figure 5c).

Using the GBT and Parkes, *Breakthrough Listen* will conduct deep observations of 1,000,000 of the nearest stars to the Earth that will be at least 10 times more sensitive than ever performed and will cover at least 5 times more of the radio spectrum. *Breakthrough Listen* will also conduct an unprecedented complete survey of the entire plane of the Milky Way Galaxy, as well as surveys of more than 100 other galaxies, including all galaxies in the Milky Way's Local Group. The sensitivity of the Green Bank, expressed as the luminosity (power) detectable as a function of the transmitter distance, is shown in Figure 6. As shown, the Green Bank Telescope could detect an extraterrestrial radio transmitter with the same luminosity as our own most powerful radar (the Arecibo Planetary Radar), in 1 minute each, for more than 1 million nearby stars.

Using a robotic optical telescope at Lick Observatory, the APF with its "Levy Spectrometer," *Breakthrough Listen* will observe 1000 nearby stars and 100 galaxies searching for artificial laser emission. These observations will be performed over wavelengths from 374−950 nm, including the near ultraviolet, the entire visible, and near infrared portion of the electromagnetic spectrum. *Breakthrough Listen* will detect lasers with any power above 100 Watts from the nearest stars and above 1000 Gigawatts from the nearest galaxies.

(a) (b) (c)

Figure 5: The three facilities to be used in the *Breakthrough Listen* Initiative. From left to right, (a) The Green Bank Telescope, Green Bank, West Virginia (b) The Parkes Telescope, New South Wales, Australia (c) The Automated Planet Finder, Lick Observatory, Mount Hamilton, California

The *Square Kilometre Array* (SKA) project is an international partnership that seeks to construct the world's largest radio telescope operating at meter and centimeter wavelengths,

[1] http://breakthroughprize.org
[2] http://breakthroughinitiatives.org

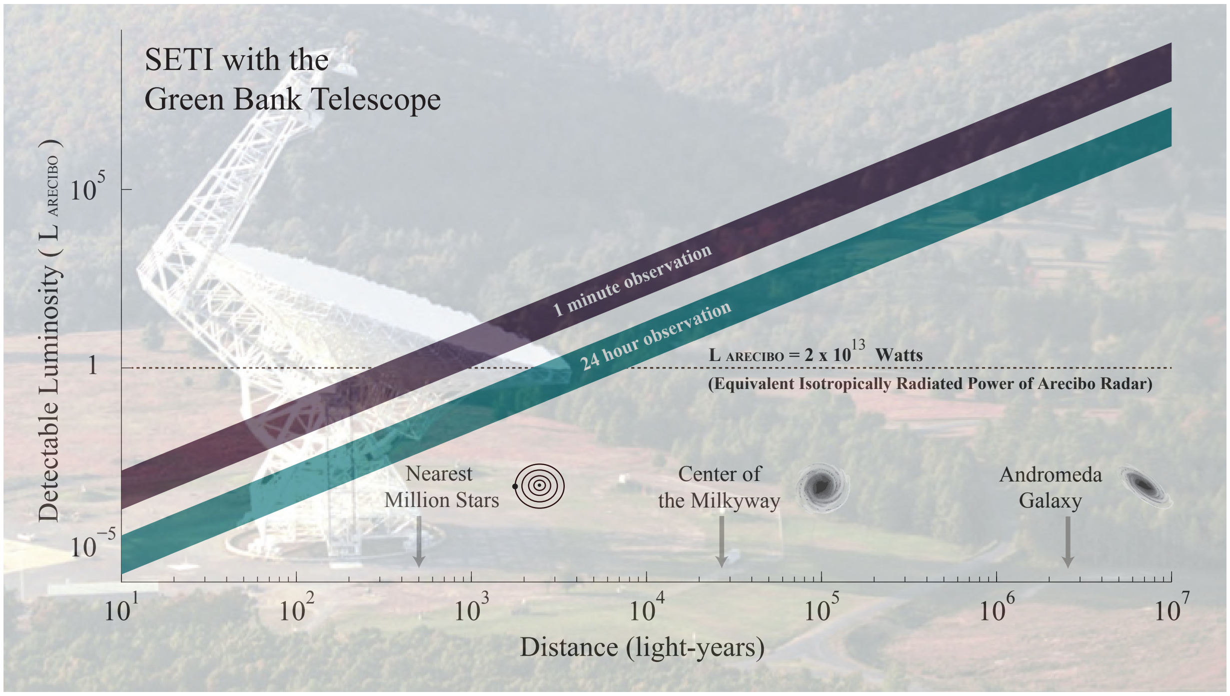


Figure 6: The sensitivity of the Green Bank Telescope expressed as the luminosity detectable as a function of the transmitter distance. Both 1 minute and 24 hour observation durations are indicated. The detectable luminosity is indicated in units of the luminosity of the Arecibo Planetary Radar − the most powerful radio transmitter on Earth. As shown, the Green Bank Telescope could detect a radio transmitter with the same luminosity as the Arecibo Planetary Radar, in 1 minute each, for more than 1 million nearby stars.

eventually achieving a full square kilometer (1 km^2) of collecting area for some components. Such a telescope, as envisioned, would be the most powerful radio telescope in the world, surpassing all current facilities by an order of magnitude or more in sheer sensitivity. Phase I of the SKA is expected to be built in Southern Africa and Southern Australia, with the mid-frequency (centimeter-wave, SKA1-MID) and low frequency (SKA1-LOW, meter-wave) components split between the two sites respectively. The SKA Headquarters is located at the Jodrell Bank Observatory near Manchester, UK. There are 10 SKA member countries, and approximately 100 organizations from 20 countries participating in its development. The United States is not currently an SKA member country.

The SKA will offer revolutionary new observational capabilities for SETI, allowing sensitive targeted SETI observations to be performed alongside other astronomical research. Rather than simply "piggy-backing," SETI observers will be able to independently point the telescope at targets of interest using high speed digital beamforming. SKA construction is expected to be completed in two phases. SKA Phase 1 will include a low frequency (SKA1-LOW, 50 350 MHz) array component made up of 130,000 dipole antennas sited in Southern Australia (Figure 7a) and a 200-dish mid-frequency (SKA1-MID, 350 14000 MHz) component sited in Southern Africa (Figure 7b). SKA Phase 2 will complete telescope construction at both sites and could include augmentation with new mid-frequency aperture array technology that could dramatically expand the telescopes primary field of view.

SKA may be the first telescope capable of detecting truly Earth−like leakage radiation from nearby stars, allowing us our best chance at detecting another civilization with an artificial radio signature similar to our own.

(a) (b)

Figure 7: Artist impressions of the two components of the first phase of the Square Kilometre Array (SKA): SKA1-LOW (left) is a low frequency facility operating from 50−350 MHz sited in Southern Australia. SKA1-MID, operating from 350−14000 MHz will be built in South Africa.

Dr. Andrew P. V. Siemion

Short Narrative Biography

Dr. Andrew Siemion is an astrophysicist at the University of California (UC), Berkeley and serves as Director of the UC Berkeley Center for Search for Extraterrestrial Intelligence (SETI) Research. He is jointly affiliated with The Netherlands Institute for Radio Astronomy (ASTRON) and Radboud University, Nijmegen, Netherlands. Dr. Siemion's research interests include studies of time-variable celestial phenomena, astronomical instrumentation and SETI. Dr. Siemion is one of the leaders of the "Breakthrough Listen Initiative" – a 10 year, 100 million dollar effort, sponsored by Yuri Milner's Breakthrough Prize Foundation, that is conducting the most sensitive, comprehensive and intensive search for advanced extraterrestrial life in history.

Dr. Siemion was a recipient of the Josephine De Kármán Fellowship for Undergraduate Studies at UC Berkeley, the UC Berkeley Dorothea Klumpke Roberts Prize for outstanding scholarship as an undergraduate major in astrophysics and the UC Berkeley Mary Elizabeth Uhl PhD Dissertation Prize for his work on searches for exotic radio phenomena. Dr. Siemion is an elected member of the International Union of Radio Science, in which he serves as an Early Career Representative for the Commission on Radio Astronomy, and the International Academy of Astronautics' SETI Permanent Committee, in which he serves as Committee Secretary. Dr. Siemion also serves on the Science@Cal Advisory Board, Co-Chairs the Cradle of Life Science Working Group for the forthcoming Square Kilometer Array telescope and is a member of the Board of Directors of the Foundation for Investing in Research on SETI Science and Technology (FIRSST).