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Breakthrough Listen – A new search for life in the universe

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On July 20, 2015 Stephen Hawking, Yuri Milner, and Lord Martin Rees announced a new scientific initiative – a SETI search called *Breakthrough Listen*. This is the first of several privately-funded *Breakthrough Initiatives*, designed to answer the fundamental science questions surrounding the origin, extent, and nature of life in the universe. The initiatives are managed by the Breakthrough Prize Foundation. With *Breakthrough Listen*, radio SETI observations have begun at the Green Bank Radio Telescope (GBT) and the CSIRO Parkes Telescope, and optical SETI is underway at the Lick Observatory Automated Planet Finder (APF). Other SETI instruments and observations are under consideration. In addition, several other initiatives are under development including an expanded search for life in the universe.

1. Introduction

On July 20, 2015 at the Royal Society in London, UK, Stephen Hawking, Yuri Milner, and Lord Martin Rees announced the launch of the *Breakthrough Listen* (BL) initiative to conduct the most comprehensive and sensitive search for advanced life in history and transform the Search for Extraterrestrial Intelligence (SETI) field. The initial project is slated to be a 10-year, $100 million effort.

The first BL observational campaign commenced in December 2015, when the Lick Observatory 2.4-m Automated Planet Finder (APF) telescope embarked on optical SETI observations of 200 stars nearby to Earth. In January 2016, the 100-m Green Bank Telescope (GBT) began radio-wavelength observations of hundreds of nearby stars and the nearest galaxies. Starting October 2016, the GBT was joined by the Parkes 64-m radio telescope in Australia, to observe stars and galaxies not viewable from the Northern Hemisphere. Work is also underway designing SETI instruments for the next generation of radio telescopes such as the MeerKAT [1], the Murchison Widefield Array (MWA) [2], the Five-hundred-meter Aperture Spherical Radio Telescope (FAST) [3], and the Square Kilometre Array (SKA) [4]. As of this writing, the Breakthrough Listen team has deployed a 2.5 GHz observation system at the GBT, deployed high-resolution multi-mode GPU-accelerated software spectroscopy pipelines, demonstrated detection of synthetic injected signals with radio receivers operating between 1 and 12 GHz, and observed 200 stars with the APF.[1]

2. Breakthrough listen

Breakthrough Listen is a scientific program to search for evidence of advanced life beyond the Earth by searching for technology produced by that life. The effort draws upon decades of work by SETI practitioners from around the world, many of whom serve on BL's scientific advisory committee, including Frank Drake, Jill Tarter, Paul Horowitz, and Dan Werthimer, among others [5–7].

Guidance in SETI can be found in the form of a probabilistic argument utilizing the Drake Equation:

$$N = R^{*} \cdot f_{\mathrm{p}} \cdot n_{\mathrm{e}} \cdot f_{\mathrm{l}} \cdot f_{\mathrm{i}} \cdot f_{\mathrm{c}} \cdot L$$

Nomenclature:
N = Number of civilizations in the Milky Way Galaxy whose electromagnetic emissions are detectable
R^{*} = Rate of formation of stars in the Galaxy
f_{p} = Fraction of those stars with planetary system
n_{e} = Average number of planets, per star that has planets, with an environment suitable for life
f_{l} = Fraction of such habitable planets on which life actually appears
f_{i} = Fraction of such life-bearing planets on which intelligent life emerges

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[1] http://breakthroughinitiatives.org.

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f_c = Fraction of such intelligent civilizations that develop communications technologies that emit detectable signs of their existence into space
L = Length of time such civilizations release detectable signals into space

The first three terms have been measured with increasing precision over the last few decades. Remarkably, recent studies suggest n_e has a value of about 0.2 – roughly one in five stars have a planet about the size of Earth in the "Habitable Zone" [8,9], the region where liquid water could exist on the planetary surface. Such encouraging developments imply that the number of interest to SETI, *N*, may be quite large (given 100 billion stars in the galaxy, the remaining terms would have to be infinitesimally small for *N* to be very small). If alien civilizations are long lived and travel (and settle) among the stars, then N need only be 2 (us and one other civilization) for there to be many signals in the Galaxy for us to detect.

A challenge to SETI is that neither the number of civilizations that might be detected (which could, in principle, be zero), nor the form of their signals, is known. Thus it is important to keep an open mind regarding the motivation, form, and location of any potential signal source.

Nonetheless, physics provides guidance. Radio, optical, and near-infrared communication technologies are the best methods known to efficiently generate high-information-content signals capable of traveling rapidly and readily between stars at strengths that could be easily detectable [10]. If advanced alien civilizations have constructed "beacons" for us to detect [11] then their signals and forms should be obvious to astronomical observations of sufficient sensitivity. Emission from communication technology that is not deliberately beamed towards Earth, or emission from non-communication technology (e.g. from directed energy propulsion systems) [12] might be transient.

For these reasons and others specified in the 'SETI 2020 Roadmap for the Search for Extraterrestrial Intelligence' and other literature [13], Breakthrough Listen will pursue a multi-pronged approach:

- Very sensitive, targeted searches of the nearest several thousand stars of all types, using both radio and near-IR/optical facilities.
- Searches for both continuous narrow-band transmission over a very broad range of frequencies, and for optical and near infrared laser light.
- A shallower radio survey of ~1 million stars.
- Radio and optical searches for signals from several hundred nearby galaxies.
- A comprehensive radio survey of the Milky Way Galactic Plane.
- Exploration of opportunities to conduct searches at other wavelength regimes (sub-mm, infrared, high energy), including the use of data-mining approaches.
- Opportunistic observations of particularly promising sources.

Breakthrough Listen will also explore new technologies that permit all-sky monitoring at radio, optical, and near-infrared wavelengths.

2.1. Radio Observations: The 1-million-star sample

Until recently, observing one million stars at radio wavelengths was daunting. With single dishes, only a few thousand stars can be observed per year, as the telescope must be physically steered toward each new star. However, a new generation of radio array telescopes are being constructed, ultimately leading to the international mega project, the Square Kilometre Array (SKA), that permit thousands or tens of thousands of nearby stars to be observed simultaneously.

The newest of these, the 64-element South African precursor instrument called MeerKAT, is well into its commissioning phase and will be operational in 2017. When complete, MeerKAT will be the most sensitive and capable cm-wave radio telescope in the Southern Hemisphere, and its flexible digital system will allow many simultaneous observations. Eventually, MeerKAT will form the core of the mid-frequency component of the SKA (SKA1-MID). The Murchison Widefield Array [14], the Australian precursor to the low-frequency component of the SKA (SKA1-LOW) has been operational since 2013, and is already extremely scientifically productive, including specifically with respect to SETI [15]. The extremely large field of view, superb site, and flexible digital hardware make it an ideal development platform for the synoptic surveys to be undertaken with the SKA [16].

Unlike single dish telescopes with single-pixel feeds, arrays can use beamforming technologies with small dishes to cover large areas of sky without physically steering and re-pointing the telescope to observe individual objects. These new instruments will make observations of most of the one million nearest stars possible; further, these million stars can be observed as a "commensal" byproduct of other astronomical observations. This means the SETI observations can "piggy−back" on existing observations, requiring no additional observational slots to be scheduled.

The BL and SKA teams are working together to investigate how best a million-star SETI program could be accomplished with the SKA. In the nearer term, a million-star survey using the MeerKAT precursor instrument would be able to detect a directed signal from an extraterrestrial transmitter equivalent in size to the largest radio transmitters on Earth (e.g. a 1-MW transmitter on the 300-m Arecibo dish) located several thousand light years away. As such, a MeerKAT SETI survey would be a compelling test for nearby civilizations comparable to our own. Meanwhile, the latest upgrades to the Voltage Capture System on the MWA will soon allow fully commensal surveys of thousands of square degrees of the sky at frequencies of 80–300 MHz [17]. Dedicated observations in a fly's eye mode (where tile beams are phased in different directions to cover the entire sky) will make use of the latest digital beamforming technologies to pilot all-sky observations in this under-explored frequency band.

2.2. Radio observations: The local sample

More immediately, BL observations currently being undertaken with the GBT and Parkes are focusing on observing the nearest few thousand stars. While this has been done in prior SETI efforts, Breakthrough Listen will be approximately 50 times more sensitive and will cover a vastly larger fraction of radio spectrum. This survey is able to detect not only signals deliberately sent to us, but also some "leaked" radio emissions (for example, from high power radar or communication among planets) from the very nearest stars.

With these telescopes, Breakthrough Listen will have the advantage of being able to integrate signals on these nearest stars for hours at a time, which is not usually possible with commensal observations on array facilities. Additionally, the focus on single targets allows for a broader range of signals to be searched for. Single dishes are also well suited to follow-up observations of viable SETI candidate signals from arrays. In particular, the Chinese FAST 500-m radio telescope, for which construction has recently been completed, would be excellent for post-detection verification and detailed signal study.

2.3. Radio observations: Other samples

In addition to the nearest stars, BL intends to use the GBT and Parkes telescopes to scan the plane of our Galaxy, as well as nearby galaxies, in search of extremely powerful signals produced by more distant civilizations. In this manner, tens of billions of stars will be surveyed.

Finally, it is possible that other galaxies have detectable emission, either because they have been nearly completely settled by space-faring civilizations whose combined transmissions are detectable, or because they transmit extremely powerful beacons at other galaxies for detection. Breakthrough Listen will target a sample of hundreds of galaxies with the GBT and Parkes.

For signals not continuously beamed at us or otherwise inadvertently