BREAKTHROUGH
LISTEN

Humanity’s largest search for cosmic company

Steve Croft, UC Berkeley

with Andrew Siemion and colleagues
and support from the Breakthrough Prize Foundation

BERKELEY SETI RESEARCH CENTER
UFO Sighting? No, Just Google's 'Rogue' Balloon

By Nola Taylor Redd, Space.com Contributor  I  May 28, 2014 02:02pm ET

Two years ago, a Google balloon launched to test the feasibility of delivering the internet to people around the world achieved notoriety when it was identified as a UFO in Pike County, Kentucky.

Turns out, the balloon responsible for the mass UFO sightings was not only a prototype, but one that wasn't following the plans of its designers.

"This is a balloon that went rogue," said Google X Rapid Evaluation team leader Rich DeVaul at Smithsonian magazine's "The Future is Here" festival in Washington, D.C., on May 17. "No one outside Google X knows this," DeVaul added. [Where to Spot 'UFOs' (Infographic)]

Do you believe alien life exists elsewhere in the universe?

- Yes - We may not have found them yet, but they're out there.
- No - Aliens are just part of science fiction.

Launched in California in 2012, the now Falcon 11 model was supposed to take a short-duration test flight. However, while in the air, the balloon malfunctioned, and controllers were unable to land it, leading to its cross-country trip.
I DON'T KNOW

THEREFORE ALIENS.
TRAPPIST-1 System

Illustration
Where is everybody?
Biosignatures

VENUS

EARTH

MARS

WAVELENGTH (MICRONS)
Technosignatures
“...THE ONLY SIGNIFICANT TEST OF THE EXISTENCE OF EXTRATERRESTRIAL INTELLIGENCE IS AN EXPERIMENTAL ONE.”

- CARL SAGAN + 69 SIGNATORIES, SCIENCE MAGAZINE
NooElec NESDR Mini+ AI - 0.5PPM TCXO USB RTL-SDR Receiver (RTL2832 + R820T) w/ Antenna and Remote Control, Installed in Aluminum Enclosure

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BL Radio Infrastructure

ARXIV.ORG/ABS/1707.06024
ARXIV.ORG/ABS/1804.04571

- 6 GHz bandwidth
- 4 PB storage
- 200 TFLOPS
- ~750 MB/sec/compute node
- Observing ~5 hours a day (20% time)
- Hundreds of TB/day raw data per day since 1/1/16 - reduced to dynamic spectra at 0.5 TB / hr
## Green Bank Data Products

Some GUPPI raw (IQ) data, some hdf5 / filterbank spectrograms publicly available - working on more

<table>
<thead>
<tr>
<th>High Freq. Resolution</th>
<th>~3 Hz frequency bin resolution, ~18 second sample time (SETI)</th>
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<td>High Time Resolution</td>
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MULTIPLE HIT EVENTS (ENRIQUEZ ET AL. 2017)

HTTPS://SETI.BERKELEY.EDU/LBAND2017
Alien shock as scientists reveal 11 mysterious ‘signals’ hailing Earth are probed for UFOs

ALIENS could be hailing Earth say scientists hunting for life as 11 signals from space were discovered.

By Henry Holloway / Published 24th April 2017

ALIENS: SETI scientists revealed a string of signals detected by Breakthrough Listen project

The Breakthrough Listen project, an £80 million experiment to try and track down aliens, has revealed they have detected 11 promising signals.

Scientists running the giant listening scheme base dolled out the data to experts for analysis.

Nearly 700 stars have been buzzed by the Green Bank Telescope in West Virginia, US.
HEIMDALL (GPU-ACCELERATED TREE DEDISPERSION)
ARXIV.ORG/ABS/1804.04101
Scientists say ‘MONSTROUS’ energy bursts from space may be from ALIENS

MYSTERIOUS radio bursts may be being beamed to Earth by aliens, according to experts.

By Anders Anglesey / Published 11th January 2018

Flying saucer in Mexico sky proves ALIENS are here

Boffins at Breakthrough Listen, a scientific research centre dedicated to finding intelligent life in the universe, confirmed it picked up the strange signals this week.

Radio bursts are not rare, but the FRB 121102 frequency is the only one that has been known to repeat itself.

The stunning details were revealed at this week’s meeting of the American Astronomical Society in Washington DC.

Researchers said the burst releases a “monstrous” amount of energy each millisecond.
BL ML WITH CNNS (GERRY ZHANG)

ARXIV.ORG/ABS/1809.03043

seti.berkeley.edu/frb-machine
TSNE FOR MODULATION CLASSIFICATION

(GERRY ZHANG AND MORAD SHEFA)
Breakthrough Listen: Voyager 1 Observations

Voyager 1 is the most distant man-made object from Earth. Launched by NASA in 1977, it has travelled at fantastic speed (roughly 17,000 m/s), past the outer boundaries of our Solar System and into interstellar space (>12.5 billion miles from the Sun).

Remarkably, 38 years on, Voyager 1 is still sending telemetry data from the depths of interstellar space. This makes it a great systems test for the Breakthrough Listen signal processing pipeline.

In this tutorial, we load, read, and plot some Breakthrough Listen (BL) observations of Voyager 1. The data were taken using the Robert C. Byrd Greenbank Telescope in West Virginia.

About this tutorial

This tutorial introduces you to BL filterbank data. It is intended for intermediate to advanced users, who have experience with Python, Numpy and basic astronomy. You'll need to have Jupyter installed, along with a scientific Python installation (numpy, scipy, matplotlib, and astropy).

About the data

We used the Greenbank X-band receiver (8.0-11.6 GHz) on December 30, 2015, to observe the known position of Voyager 1. The BL digital signal processing system saves digitized data in a 'raw' format, which we have converted into 'filterbank' format using our gpuspec code (see guppi2spectra.c in https://github.com/UCBerkeleySETI/gbt_seti/tree/master/src). For advanced users who want to start from scratch, the specific command is:

```bash
    time /gbt_seti/bin/gpuspec -i ./blc3_2bit_guppi_57386_Voyager1_0004.0000.raw \
        -B 2 -f 1032192 -t 15 -V -o /datax2/scratch/dprice/
```

For the purposes of this tutorial, we suggest that you download the 504 MB file voyager_f1032192_t300_v2.fil from the BL data archive.

Filterbank format

The voyager data is stored in filterbank format, a simple binary file format that is detailed in the SIGPROC user guide. For this tutorial, we've provided a simple Python class to load and interpret the filterbank file into a numpy array.

Let's get started!

Firstly, let’s setup the notebook and import the Filterbank() class to read the data.

```python
In [1]: %matplotlib inline

In [3]: import pylab as plt
from filterbank import Filterbank
```

Now, let's read the observation data using Filterbank():
`Oumuamua
We conducted a search of the data for narrow-band (3Hz resolution) drifting sinusoids as described by Enriquez et al. (2017), over a drift rate range of $\pm 2$ Hz/s. This range includes any acceleration in the geocentric and barycentric frames, as well as accommodating a transmitter located anywhere on the body itself. Our preliminary results show no narrow band radio emission from the direction of 1I/'Oumuamua at any rotational phase.

The object was at $\sim 2$ AU when observed, and given an approximate SEFD of 20 Jy, with a 300 s observation, and a 5$\sigma$ threshold, these observations were sensitive to a hypothetical transmitter with an EIRP of $\sim 0.08$ W ($\sim 3,000$ times weaker than the Dawn spacecraft communication down-link.).

Based on the possibility that 1I/'Oumuamua could be in fact a dormant comet with delayed outgassing, we also searched for any indication of hydroxyl emission at the four transitions between 1612 MHz and 1720 MHz. We searched the L-band data taken during quadrant Q2 by stacking the three 5-min observations. No emission was detected, confirming previous observations during closer approach that the nature of the object is consistent with an asteroid-like composition (Park 2017 in prep).

No transmitters brighter than 0.1 W between 1 - 12 GHz
Mystery ‘cigar’ asteroid in our solar system probed for ‘ALIEN technology’ THIS WEEK

ALIEN-hunting scientists are set to examine a “peculiar” 1,300ft-long asteroid hurtling through our solar system for signs of extraterrestrial technology this week.

By Joshua Nevett / Published 11th December 2017

The mysterious cigar-shaped object, dubbed "Oumuamua" by astronomers, soared past Earth last month after entering our solar system.

Astronomers spotted the strange object – the size of New York’s Empire State Building – through the Pan-STARR telescope in Hawaii on October 19.

As Oumuamua, the first interstellar object in our solar system, sped away through space, researchers gathered as much data as possible.
How to get access to the data

Some, but not all, of the data are available in the BL archive at http://breakthroughinitiatives.org/OpenDataSearch

To access GBT data, select "BL at Green Bank" from the projects drop-down, and optionally a target name. Note that this will return large numbers of files with filetype listed as "baseband data". These are the raw voltage files. Until you already have extensive experience using filterbank files, it would be best to avoid these baseband files at first, and stick to some of the example filterbank files (those with a .fil extension) at http://setiathome.berkeley.edu/~mattl/ml/

If you are developing pipelines to compare features between filterbank files, you may wish to test these with a larger set of data. We've made a subsample of the filterbank files from our analysis in Enriquez et al. (2017) available at http://blpd0.ssl.berkeley.edu/Lband/ - there's a total of 16 TB of high frequency resolution filterbanks here. We recommend only downloading these if you have fully explored a smaller subset of the filterbank data. We can provide more filterbank data where these came from on request, and will be making more of the data available online in due course.

How to read in a filterbank file

As noted above, the file format is pretty simple, a header plus a data array. We are moving towards HDF5 for data storage, which, among other things, makes it easier to access portions of a file without reading the whole thing into memory. You can read both filterbank and HDF5 files using https://github.com/UCBerkeleySETI/blimpy

There's also a fun Jupyter notebook that uses blimpy to read in and display one of our observations of the Voyager I spacecraft. Despite being 20 million kilometers from Earth and having a transmitter that only uses the same power as a refrigerator light, it's clearly detectable by our observations: https://github.com/UCBerkeleySETI/breakthrough/blob/master/GBT/voyager/voyager.ipynb

This is a nice illustration of the capabilities of our instruments to detect signatures of technology even for very distant targets, and observations like the ones of Voyager, or others with artificially inserted "birdie" signals, could be used as a training set for machine learning or other approaches.
Towards an All-Sky Radio SETI Telescope

29-31 October 2018
University of Manchester

Towards an All-Sky Radio SETI Telescope

Monday 29 October - Wednesday 31 October 2018
Jodrell Bank Centre for Astrophysics
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