Open Sourcing the Search for Extraterrestrial Intelligence

Steve Croft

UC Berkeley / SETI Institute

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

BERKELEY SETI RESEARCH CENTER

BREAKTHROUGH LISTEN

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Sale

Zoom

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NooElec NESDR Mini+ 0.5PPM TCXO-based RTL-SDR USB set installed in a special edition black aluminum enclosure. R820T tuner is guaranteed.

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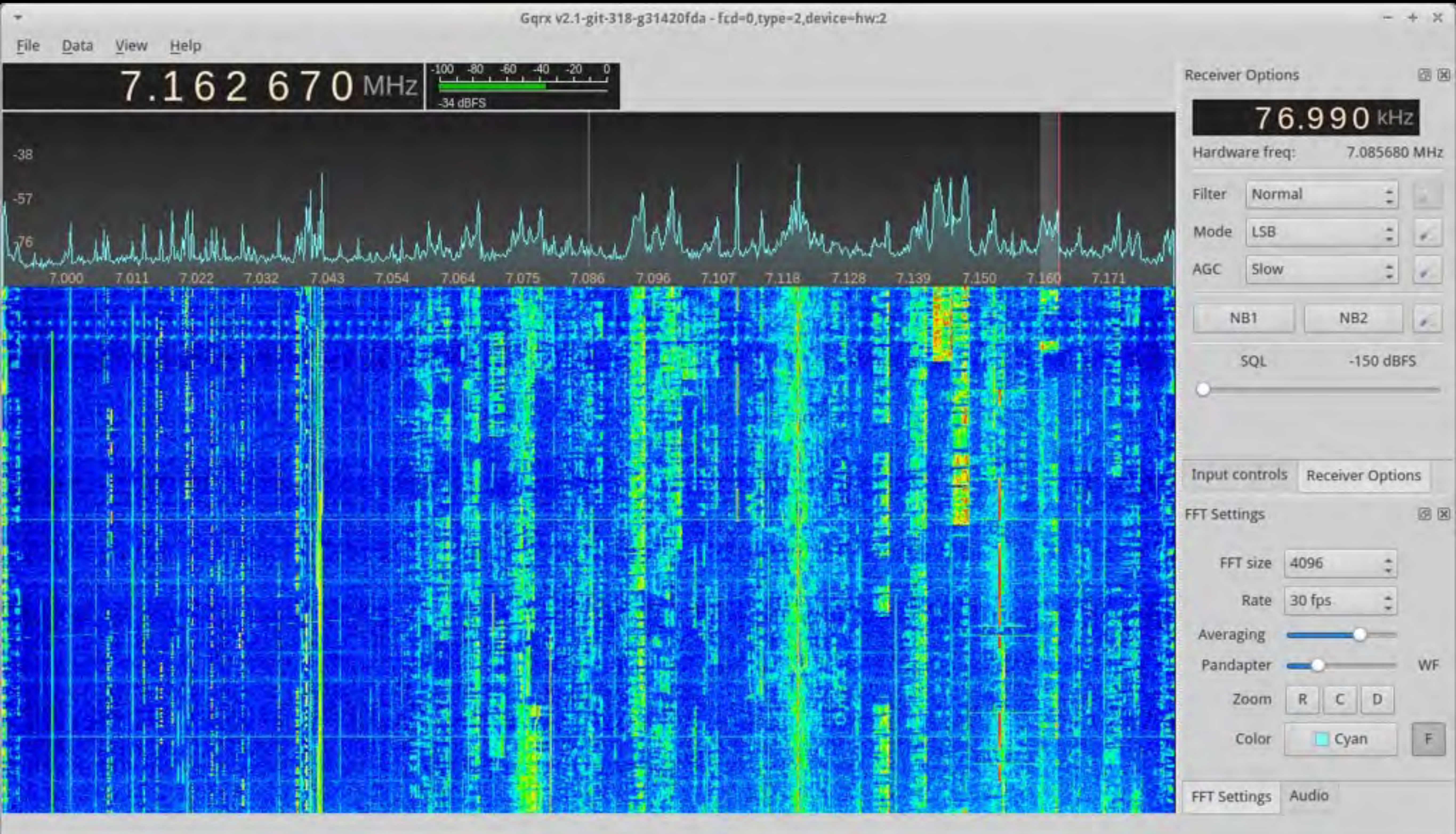
US$42.95



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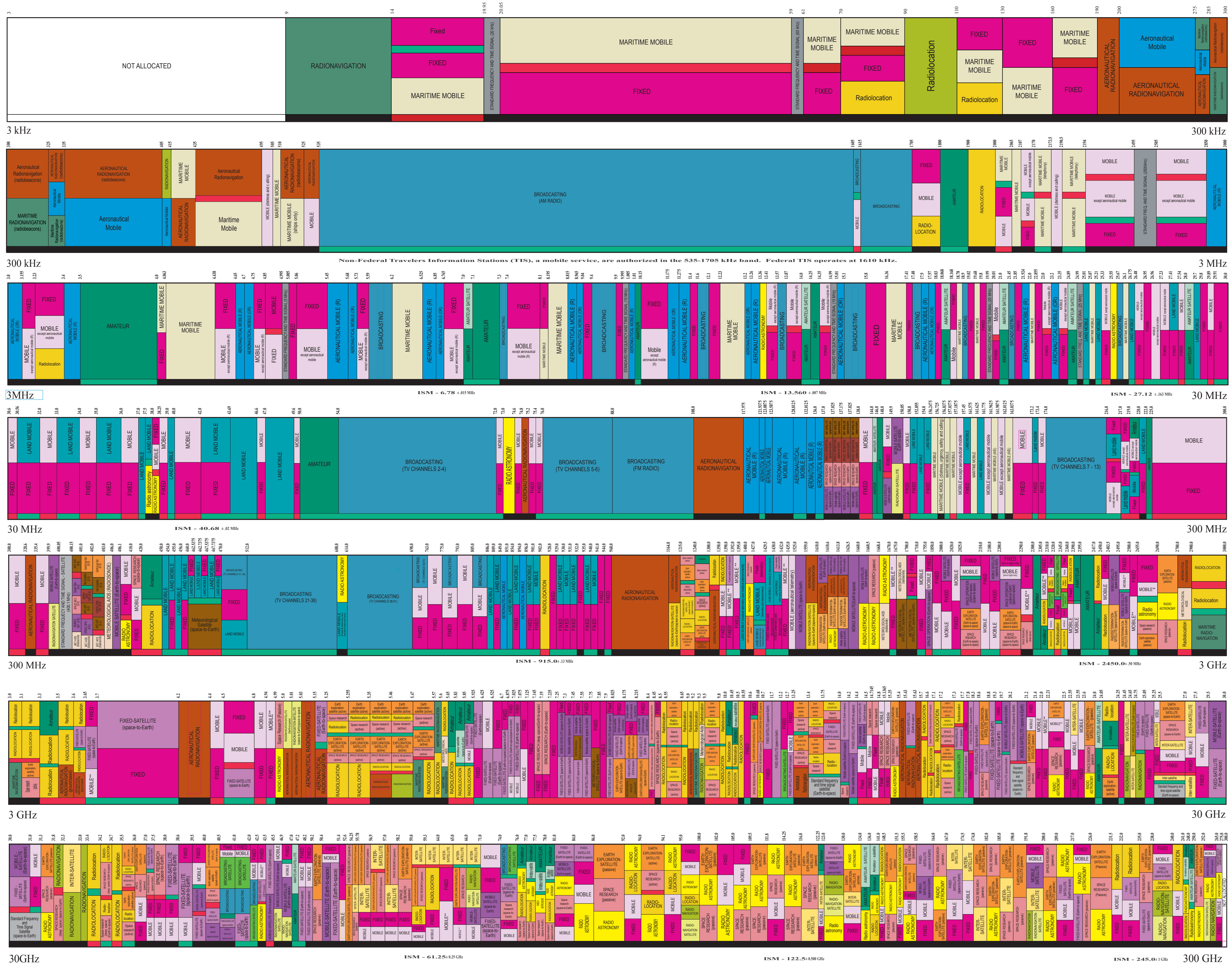
UNITED STATES FREQUENCY ALLOCATIONS

THE RADIO SPECTRUM



* EXCEPT AERONAUTICAL MOBILE (R)

** EXCEPT AERONAUTICAL MOBILE

PLEASE NOTE: THE SPACING ALLOTTED THE SERVICES IN THE SPECTRUM SEGMENTS SHOWN IS NOT PROPORTIONAL TO THE ACTUAL AMOUNT OF SPECTRUM OCCUPIED.

RADIO SERVICES COLOR LEGEND

- AERONAUTICAL MOBILE
- AERONAUTICAL MOBILE SATELLITE
- AERONAUTICAL RADIONAVIGATION
- AMATEUR
- AMATEUR SATELLITE
- BROADCASTING
- BROADCASTING SATELLITE
- EARTH EXPLORATION SATELLITE
- FIXED
- FIXED SATELLITE
- INTER-SATELLITE
- LAND MOBILE
- LAND MOBILE SATELLITE
- MARITIME MOBILE
- MARITIME MOBILE SATELLITE
- MARITIME RADIONAVIGATION
- METEOROLOGICAL
- METEOROLOGICAL SATELLITE
- MOBILE
- MOBILE SATELLITE
- RADIO ASTRONOMY
- RADIODETERMINATION SATELLITE
- RADIOLOCATION
- RADIOLOCATION SATELLITE
- RADIONAVIGATION
- RADIONAVIGATION SATELLITE
- SPACE OPERATION
- SPACE RESEARCH
- STANDARD FREQUENCY AND TIME SIGNAL
- STANDARD FREQUENCY AND TIME SIGNAL SATELLITE

ACTIVITY CODE

- GOVERNMENT EXCLUSIVE
- GOVERNMENT/NON-GOVERNMENT SHARED
- NON-GOVERNMENT EXCLUSIVE

ALLOCATION USAGE DESIGNATION

SERVICE	EXAMPLE	DESCRIPTION
Primary	FIXED	Capital Letters
Secondary	Mobile	1st Capital with lower case letters

This chart is a graphic single-point-in-time portrayal of the Table of Frequency Allocations used by the FCC and NTIA. As such, it does not completely reflect all aspects, i.e. footnotes and recent changes made to the Table of Frequency Allocations. Therefore, for complete information, users should consult the Table to determine the current status of U.S. allocations.

U.S. DEPARTMENT OF COMMERCE
National Telecommunications and Information Administration
Office of Spectrum Management

August 2011

For sale by the Superintendent of Documents, U.S. Government Printing Office
Internet: bookstore.gpo.gov Phone toll free (866) 512-1800; Washington, DC area (202) 512-1800
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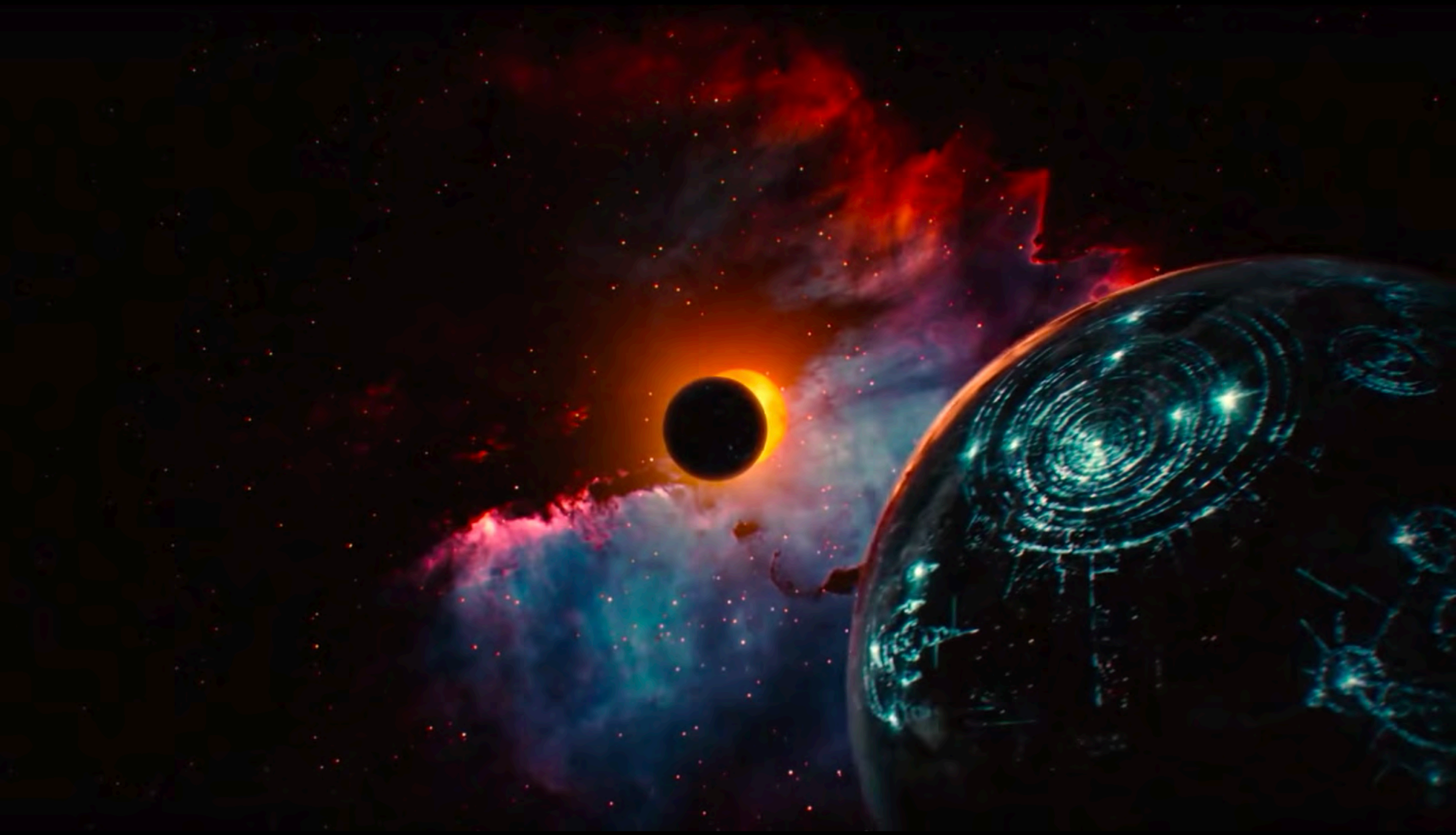
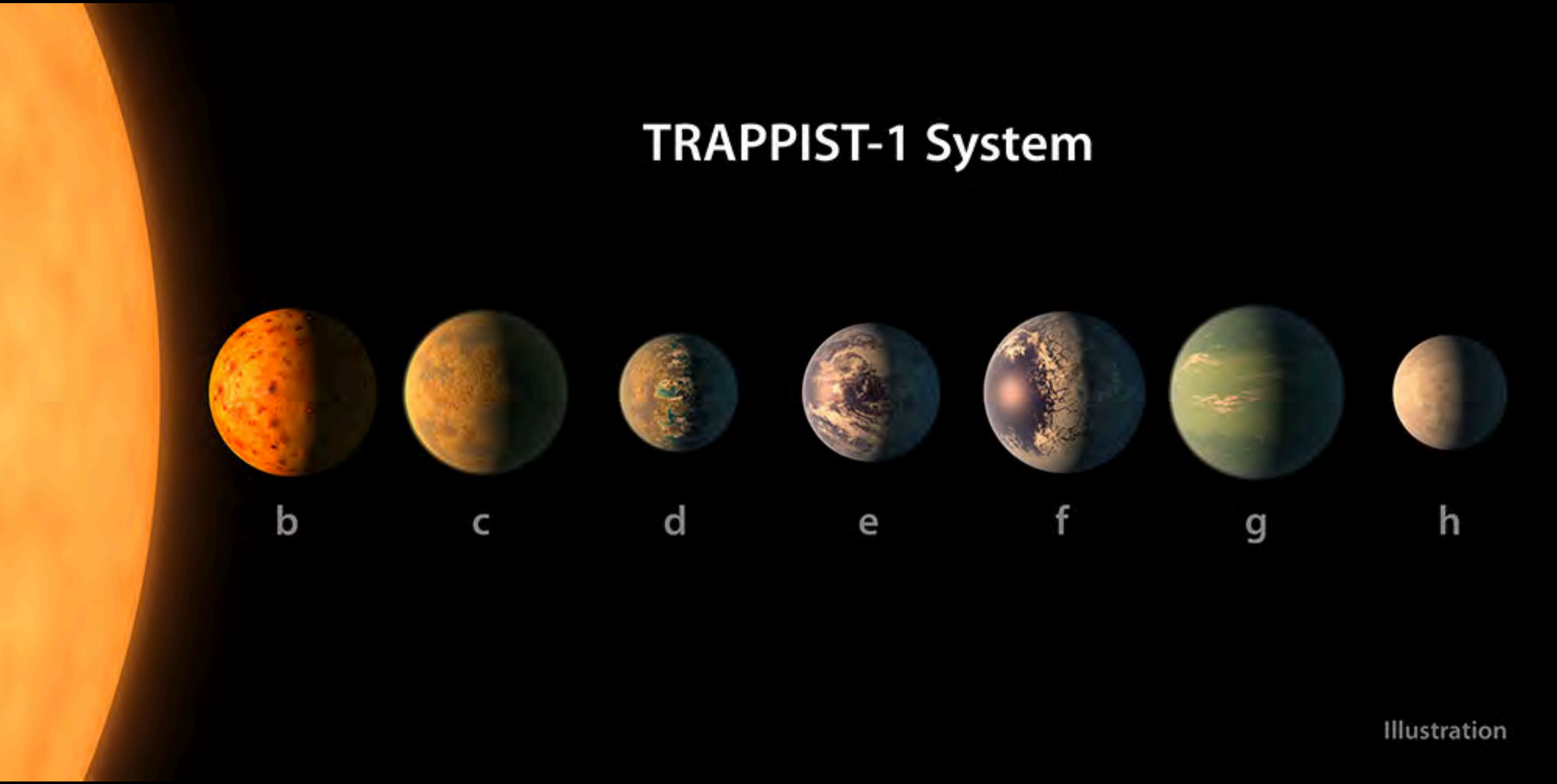


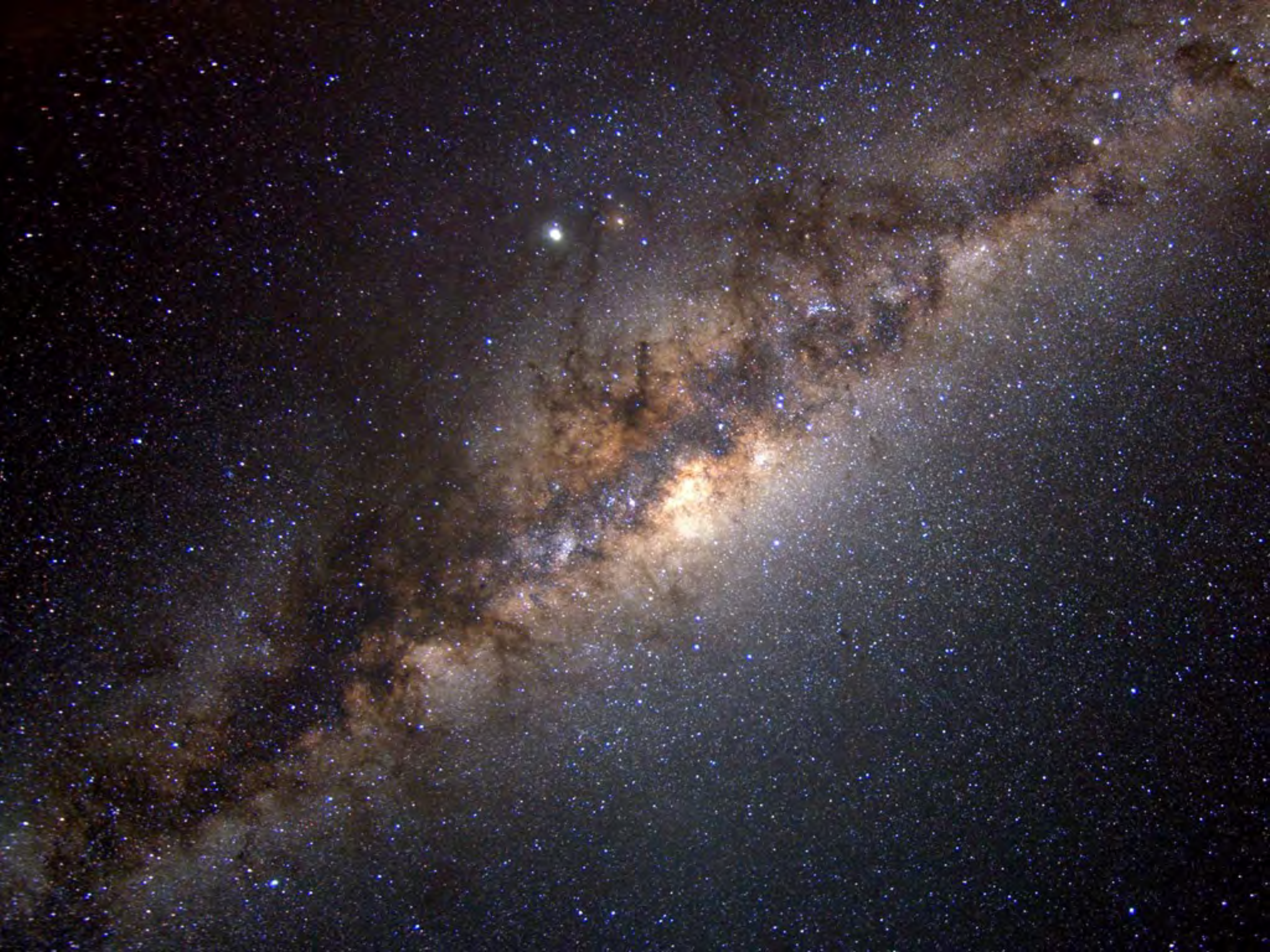
Mundos esse innumerabiles

"… he posits many worlds, many Suns, necessarily containing similar things in kind and in species as in this world, and even men …"

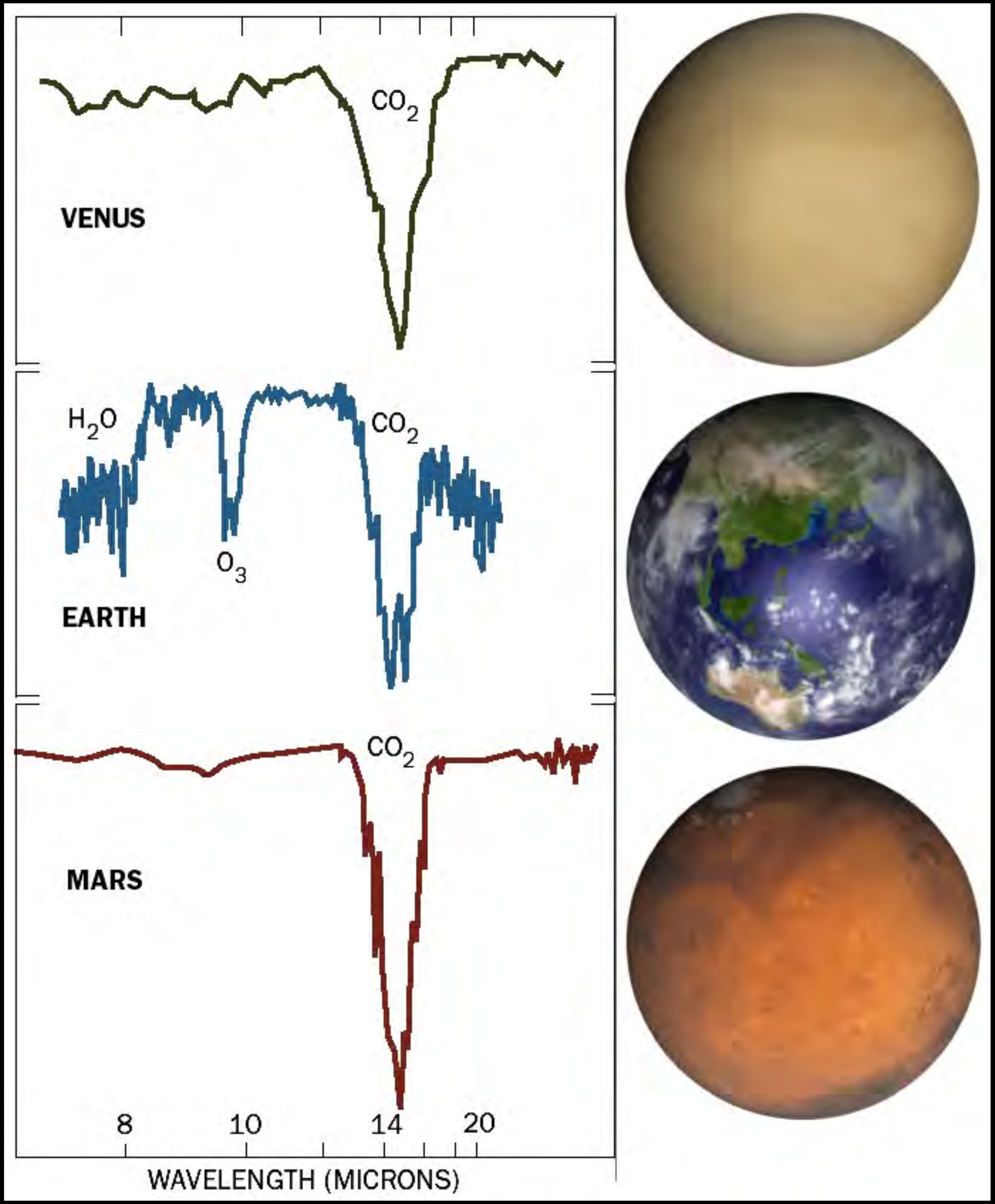
Summary of the heresy trial of Giordano Bruno


© Lynette Cook
http://extrasolar.spaceart.org

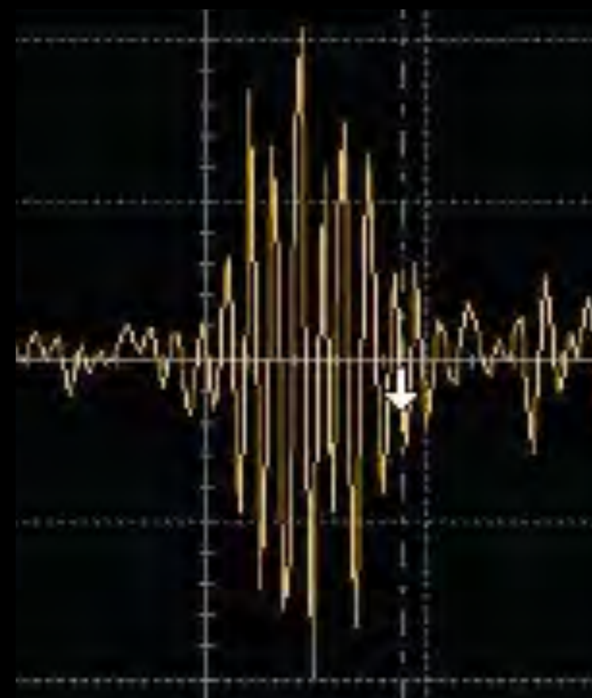

TRAPPIST-1 System
b
c
d
e
f
g
h
Illustration

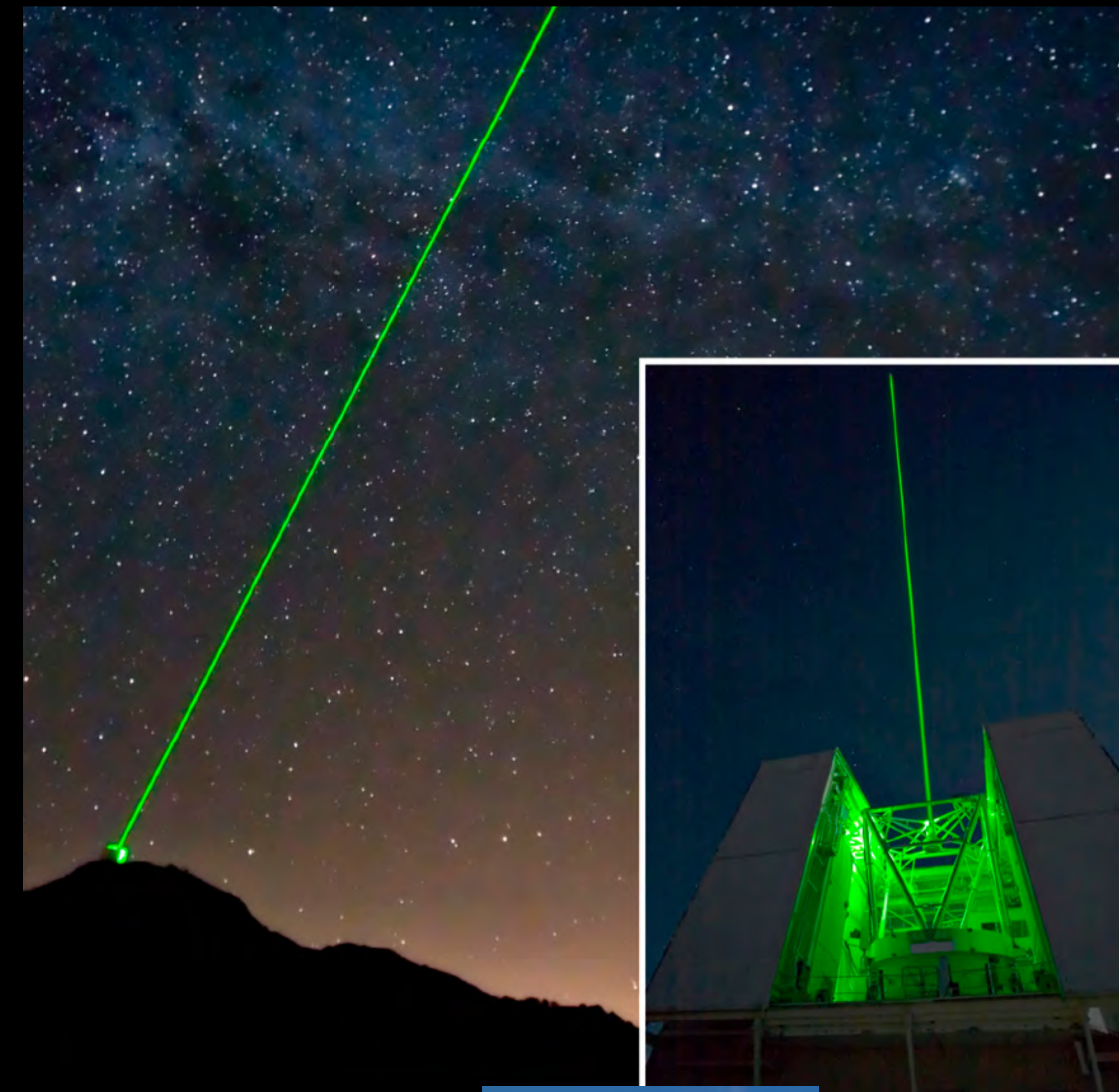


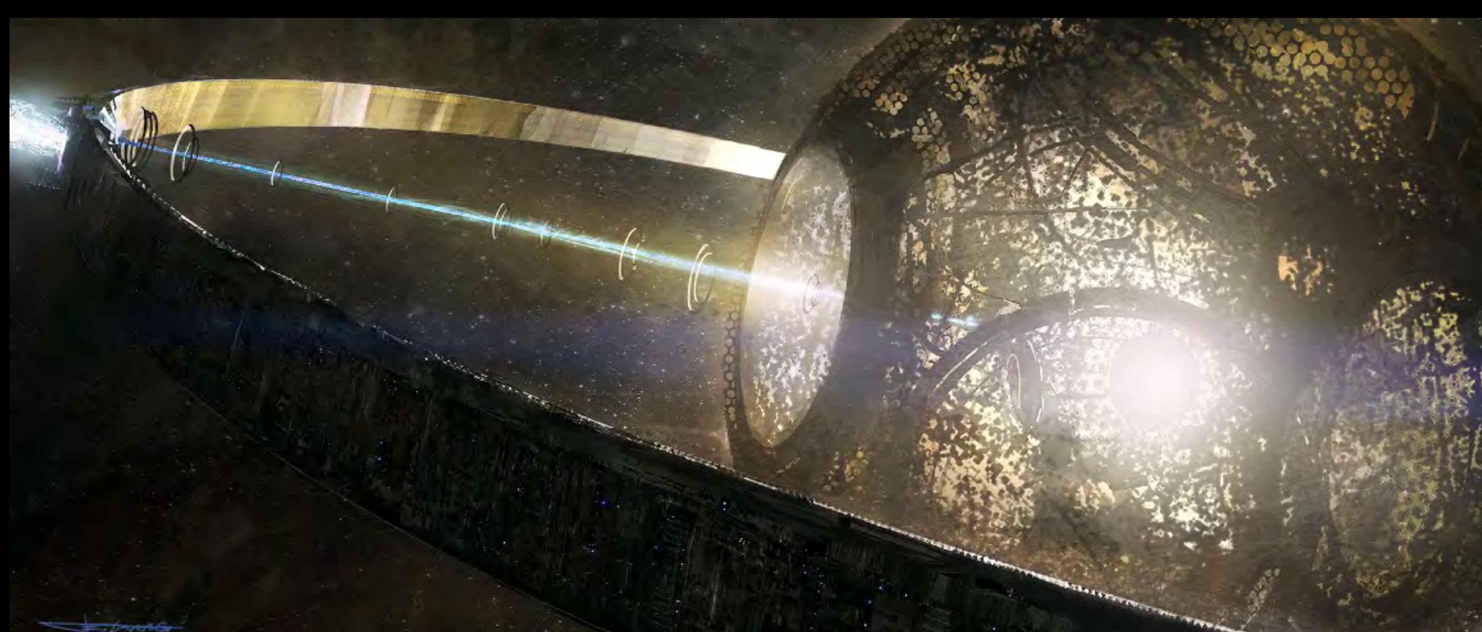
Biosignatures



Technosignatures







SEARCHING FOR INTERSTELLAR COMMUNICATIONS

By GIUSEPPE COCCONI* and PHILIP MORR'SON†
Cornell University, Ithaca, New York

NO theories yet exist which enable a reliable estimate of the probabilities of (1) planet formation ; (2) origin of life ; (3) evolution of societies possessing advanced scientific capabilities. In the absence of such theories, our environment suggests that stars of the main sequence with a lifetime of many billions of years can possess planets, that of a small set of such planets two (Earth and very probably Mars) support life, that life on one such planet includes a society recently capable of considerable scientific investigation. The lifetime of such societies is not known ; but it seems unwarranted to deny that among such societies some might maintain themselves for times very long compared to the time of human history, perhaps for times comparable with geological time. It follows, then, that near some star rather like the Sun there are civilizations with scientific interests and with technical possibilities much greater than those now available to us.

* Now on leave at CERN, Geneva.

† Now on leave at the Imperial College of Science and Technology, London, S.W.7.

To the beings of such a society, our Sun must appear as a likely site for the evolution of a new society. It is highly probable that for a long time they will have been expecting the development of science near the Sun. We shall assume that long ago they established a channel of communication that would one day become known to us, and that they look forward patiently to the answering signals from the Sun which would make known to them that a new society has entered the community of intelligence. What sort of a channel would it be ?

The Optimum Channel

Interstellar communication across the galactic plasma without dispersion in direction and flight-time is practical, so far as we know, only with electromagnetic waves.

Since the object of those who operate the source is to find a newly evolved society, we may presume that the channel used will be one that places a minimum burden of frequency and angular discrimi-

https://rdcu.be/bRju2

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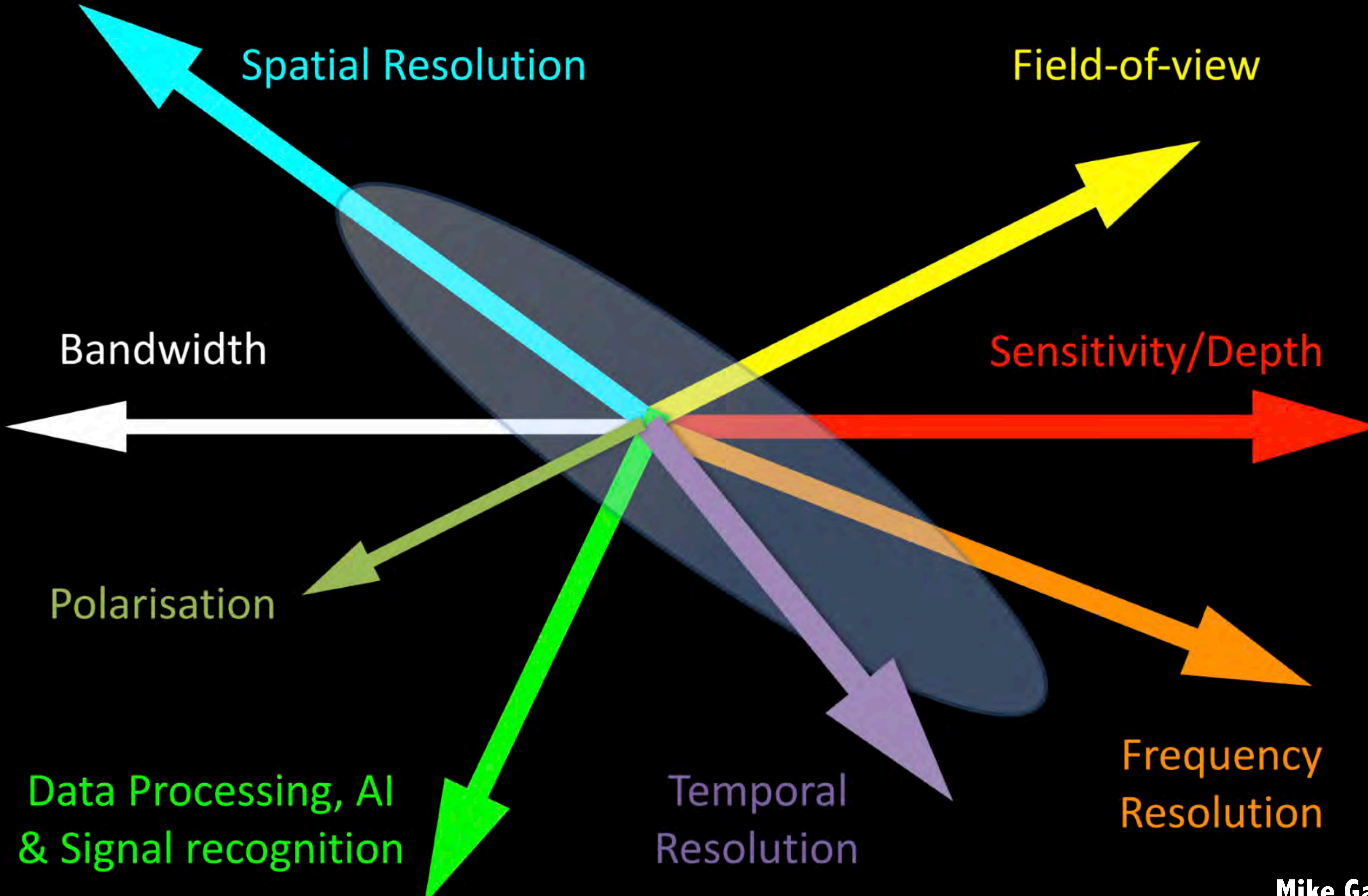
SETI Success



Mike Garrett

Breakthrough Listen



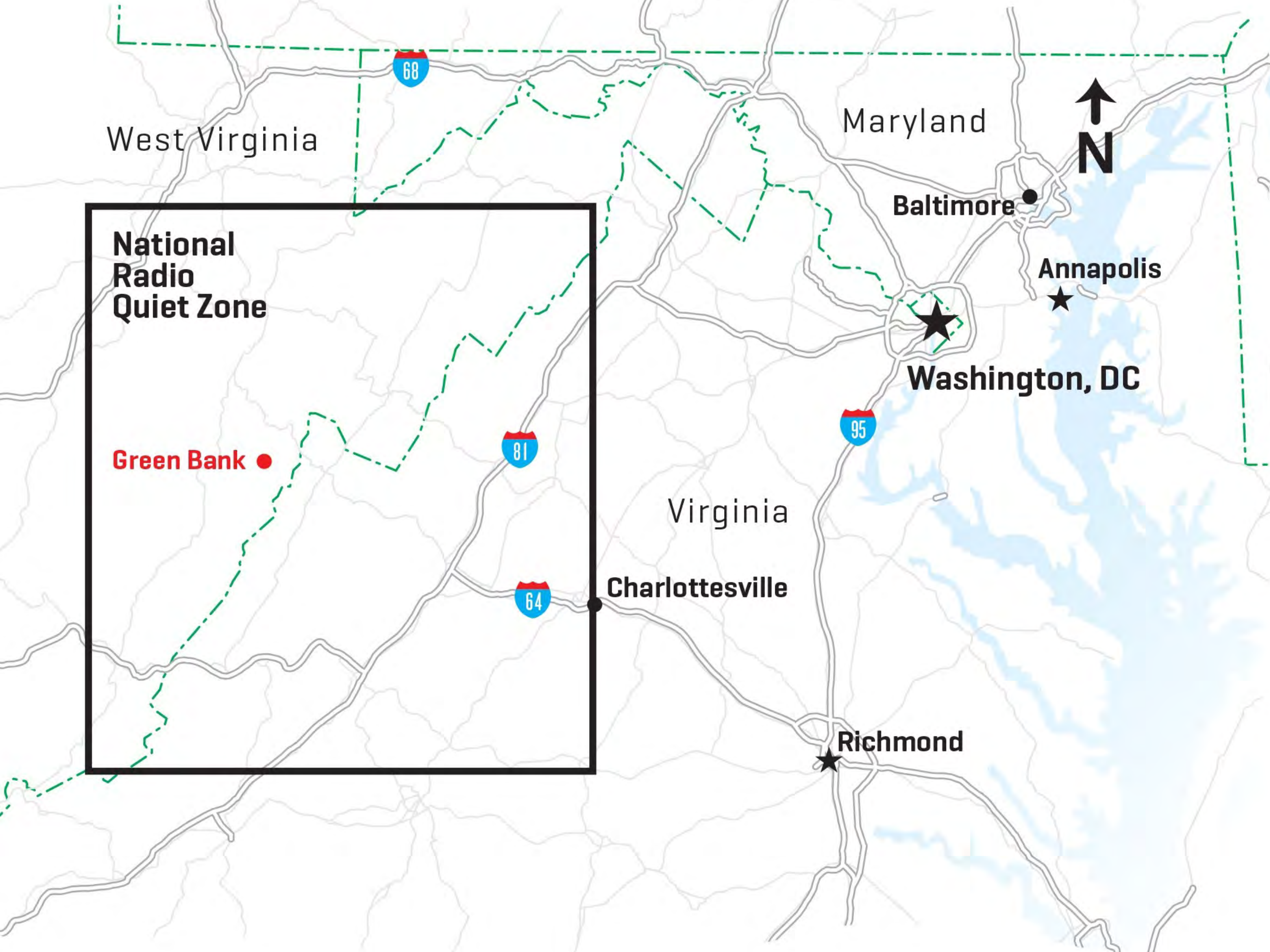








SKA



West Virginia
Maryland
N
Baltimore
Annapolis
National Radio Quiet Zone
Washington, DC
68
95
81
Green Bank
Virginia
Charlottesville
64
Richmond

BL Radio Infrastructure

arxiv.org/abs/1707.06024

arxiv.org/abs/1804.04571

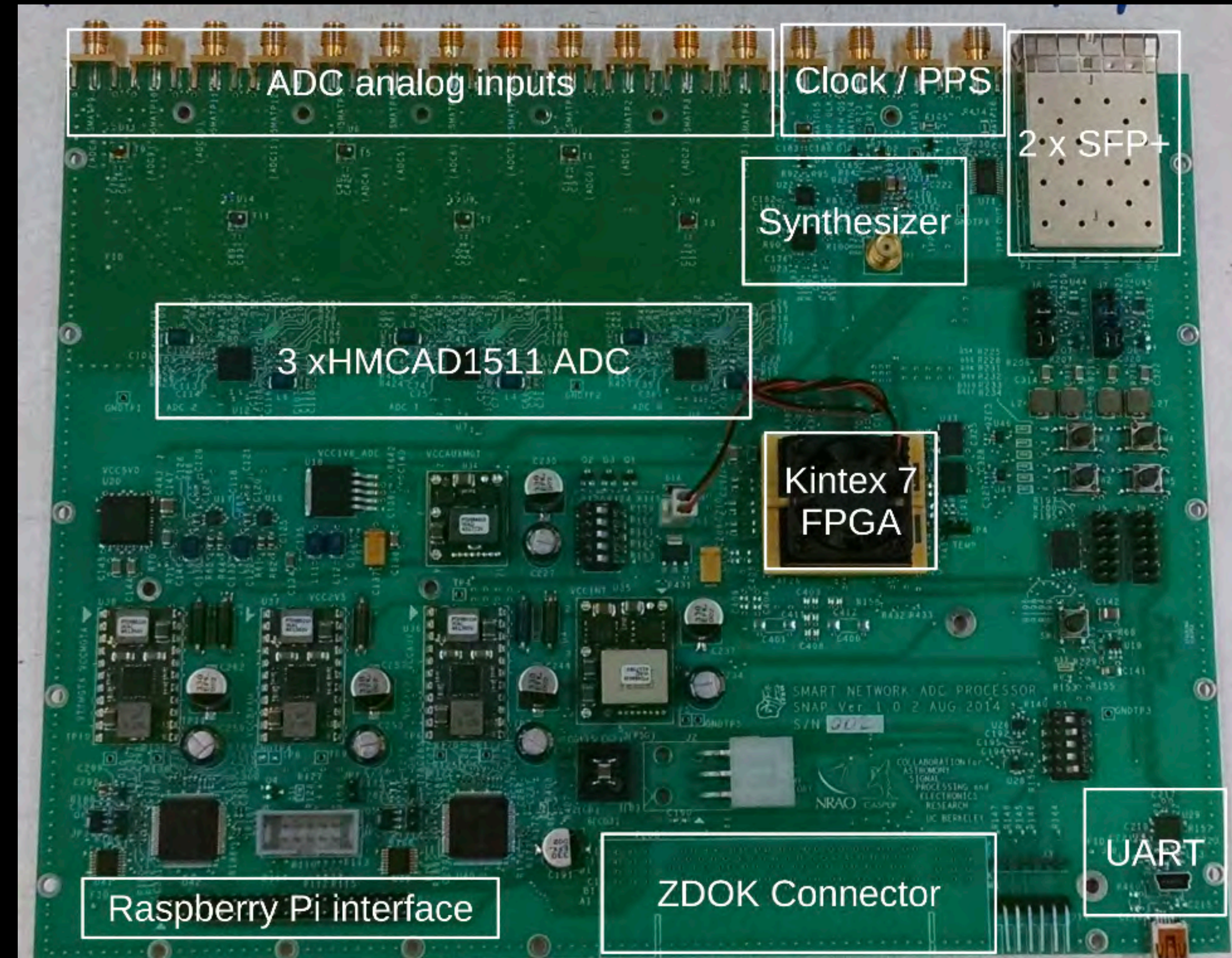
arxiv.org/abs/1906.07391

- 12 GHz bandwith
- 8 PB storage
- 400 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

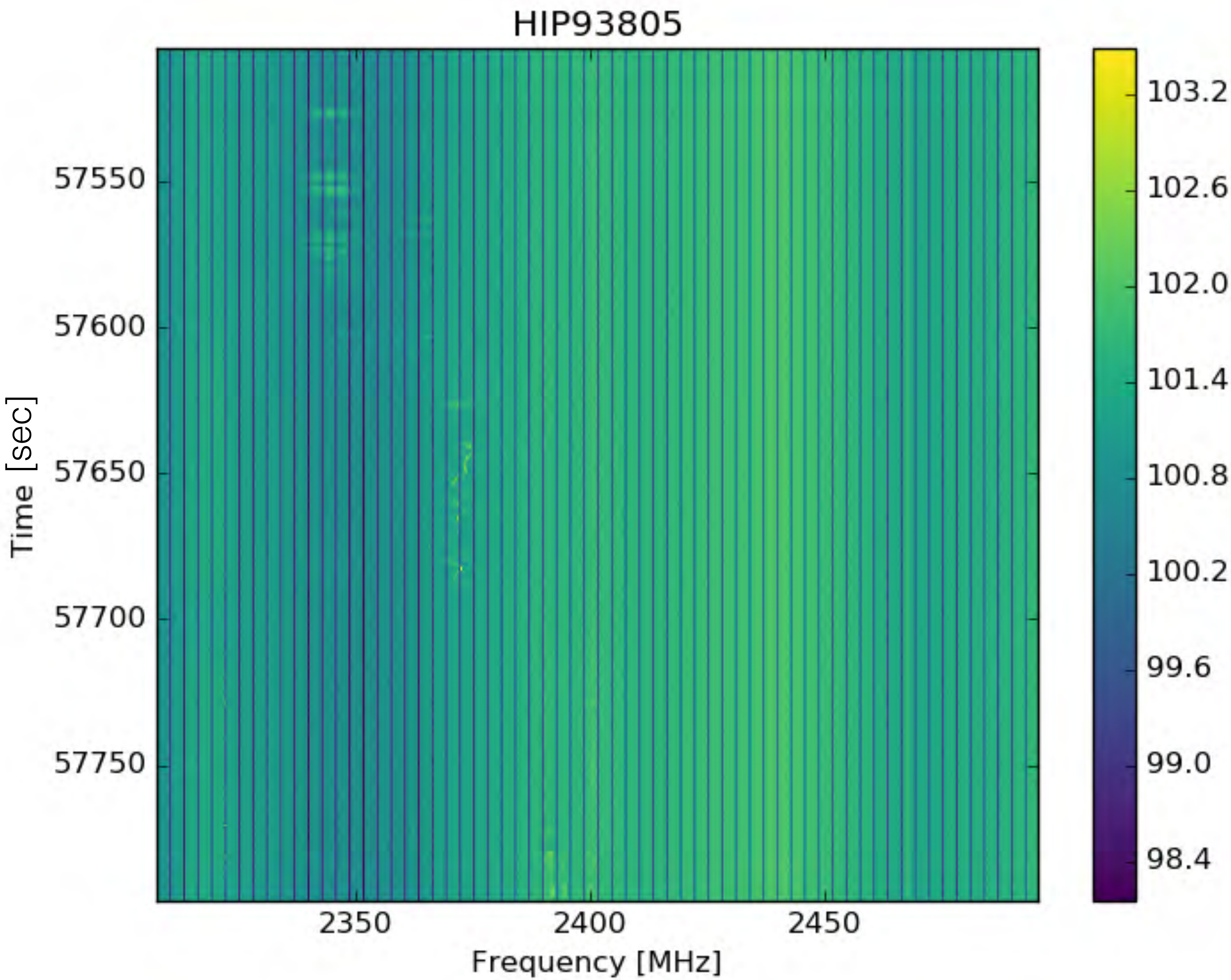
Green Bank Data Products

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

High freq. resolution	~3 Hz frequency bin resolution, ~18 second sample time (SETI)
Medium resolution	~3 kHz frequency bin resolution, ~1 second sample time (spectral line)
High time resolution	~366 kHz frequency bin resolution, ~349 us sample time (pulsar)



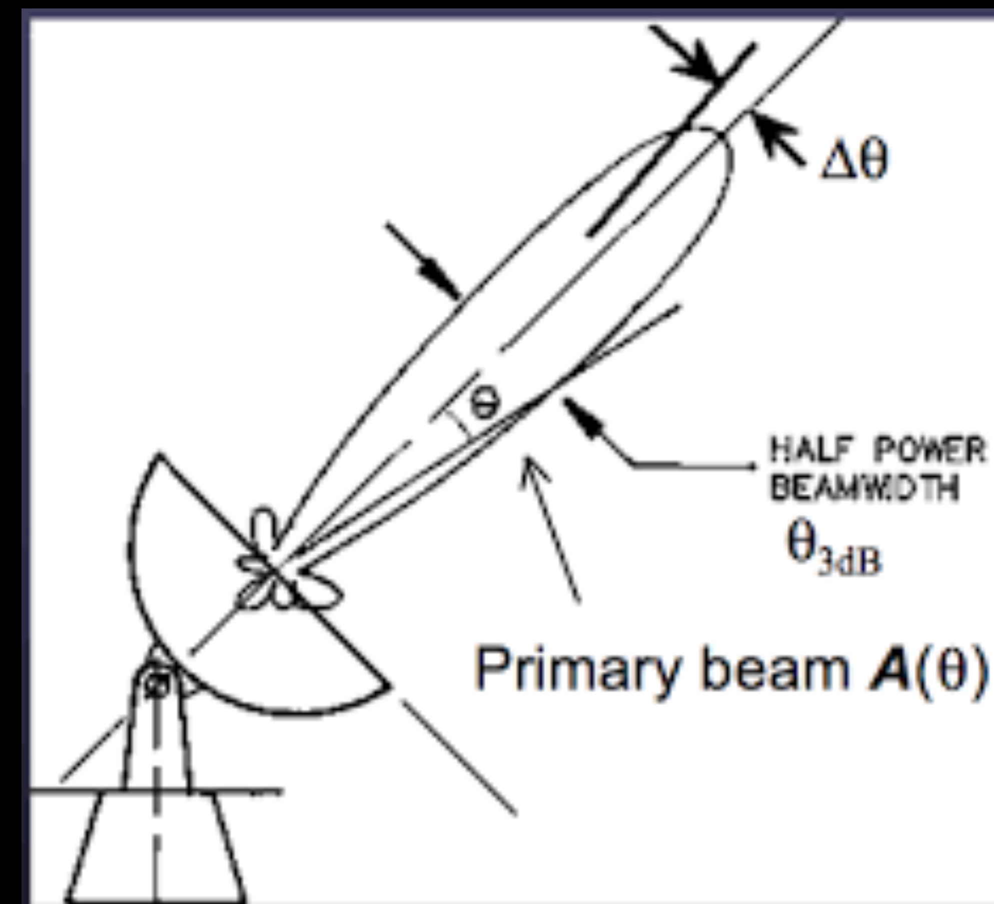
The primary goal of CASPER is to streamline and simplify the design flow of radio astronomy instrumentation by promoting design reuse through the development of platform-independent, open-source hardware and software. CASPER hardware and software now powers over 45 radio-astronomy instruments worldwide including some of the largest, most advanced telescopes ever built.


HIP93805
Time [sec]
57550
57600
57650
57700
57750
2350
2400
2450
Frequency [MHz]
103.2
102.6
102.0
101.4
100.8
100.2
99.6
99.0
98.4

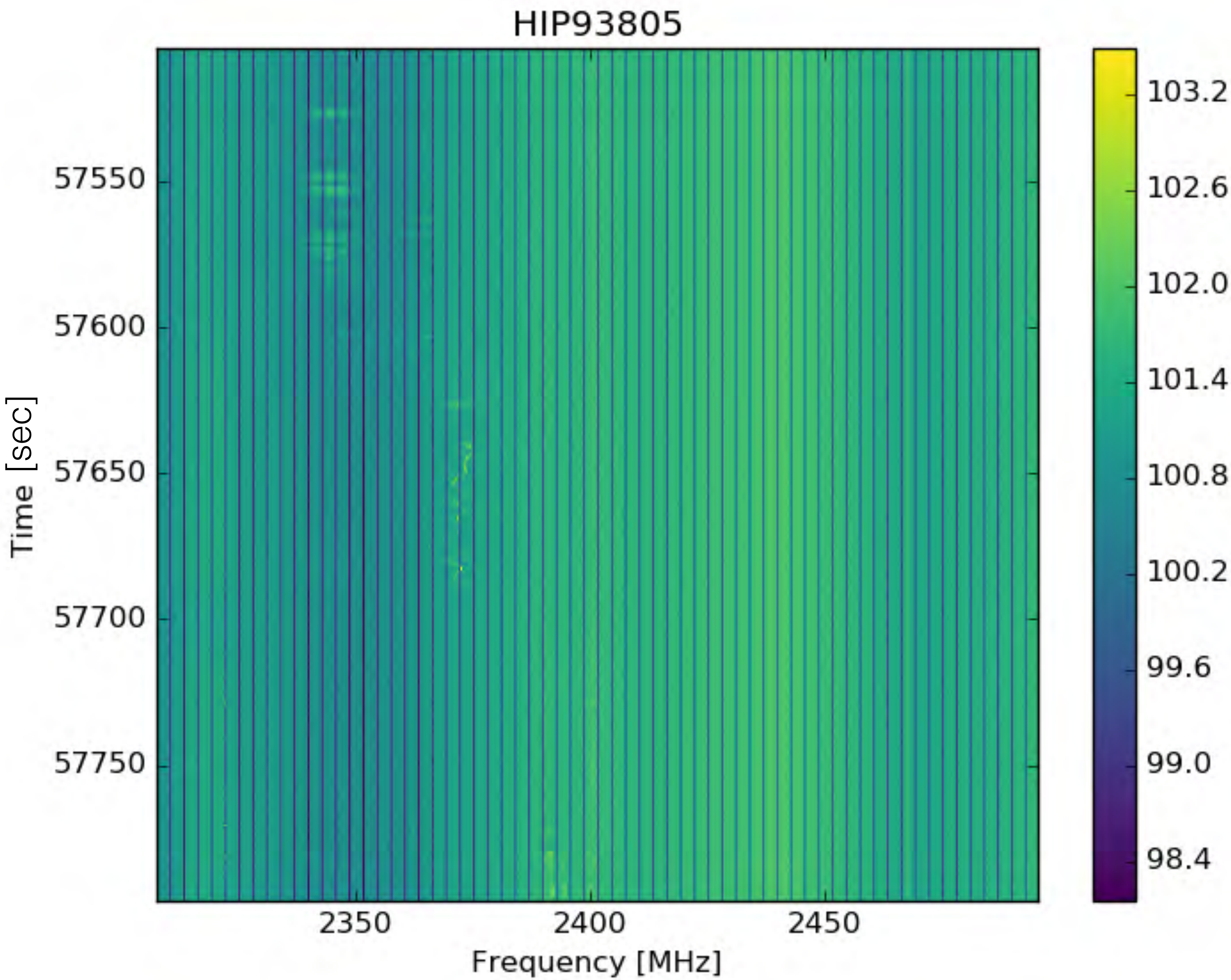

NETGEAR
GEAR


9:41
Tuesday, September 12


12:08
Galanz



Δθ
θ
HALF POWER
BEAMWIDTH
θ_{3dB}
Primary beam $A(\theta)$


HIP93805
Time [sec]
57550
57600
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57750
2350
2400
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Frequency [MHz]
103.2
102.6
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101.4
100.8
100.2
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99.0
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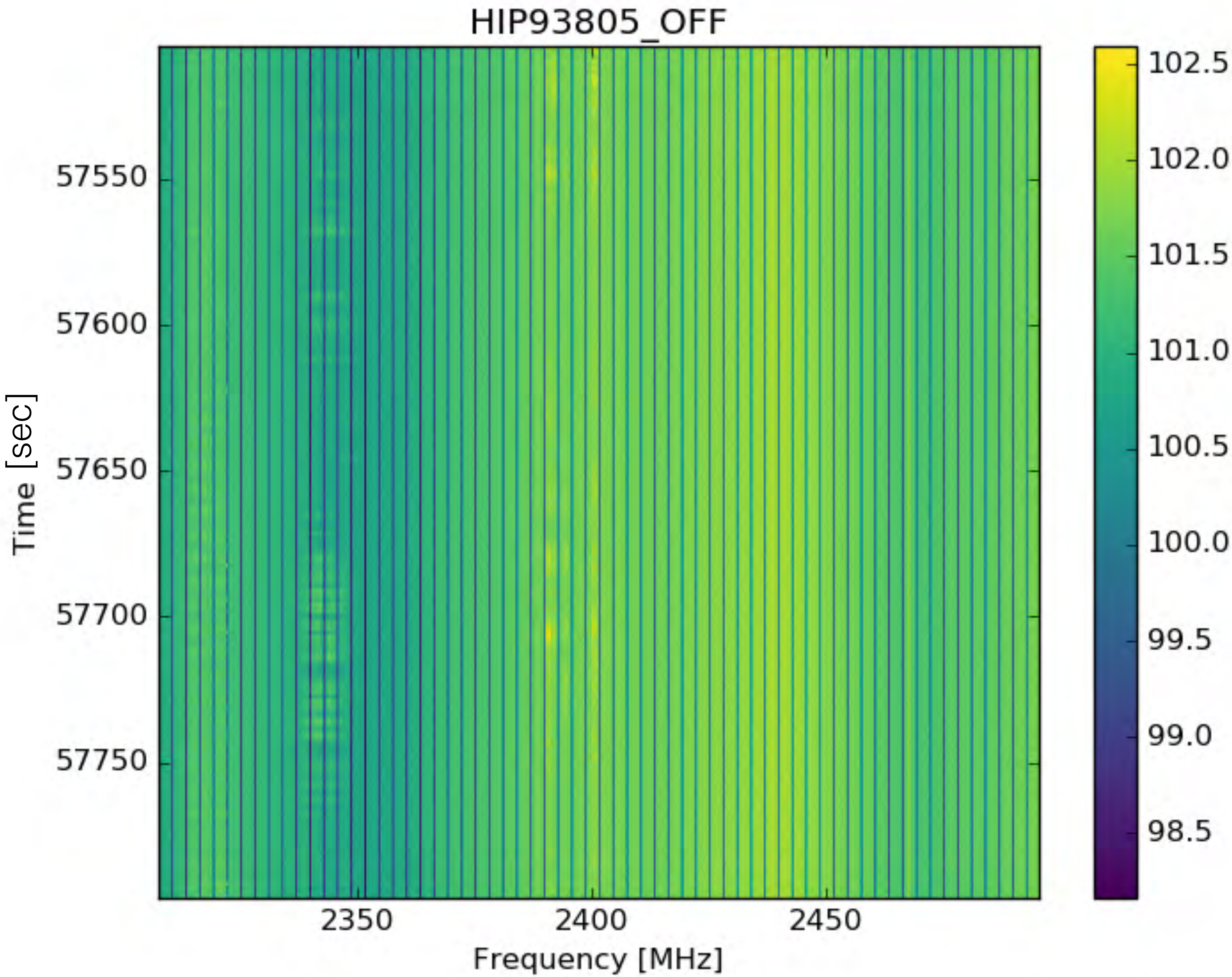

HIP93805_OFF
57550
57600
57650
57700
57750
Time [sec]
2350
2400
2450
Frequency [MHz]
102.5
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101.5
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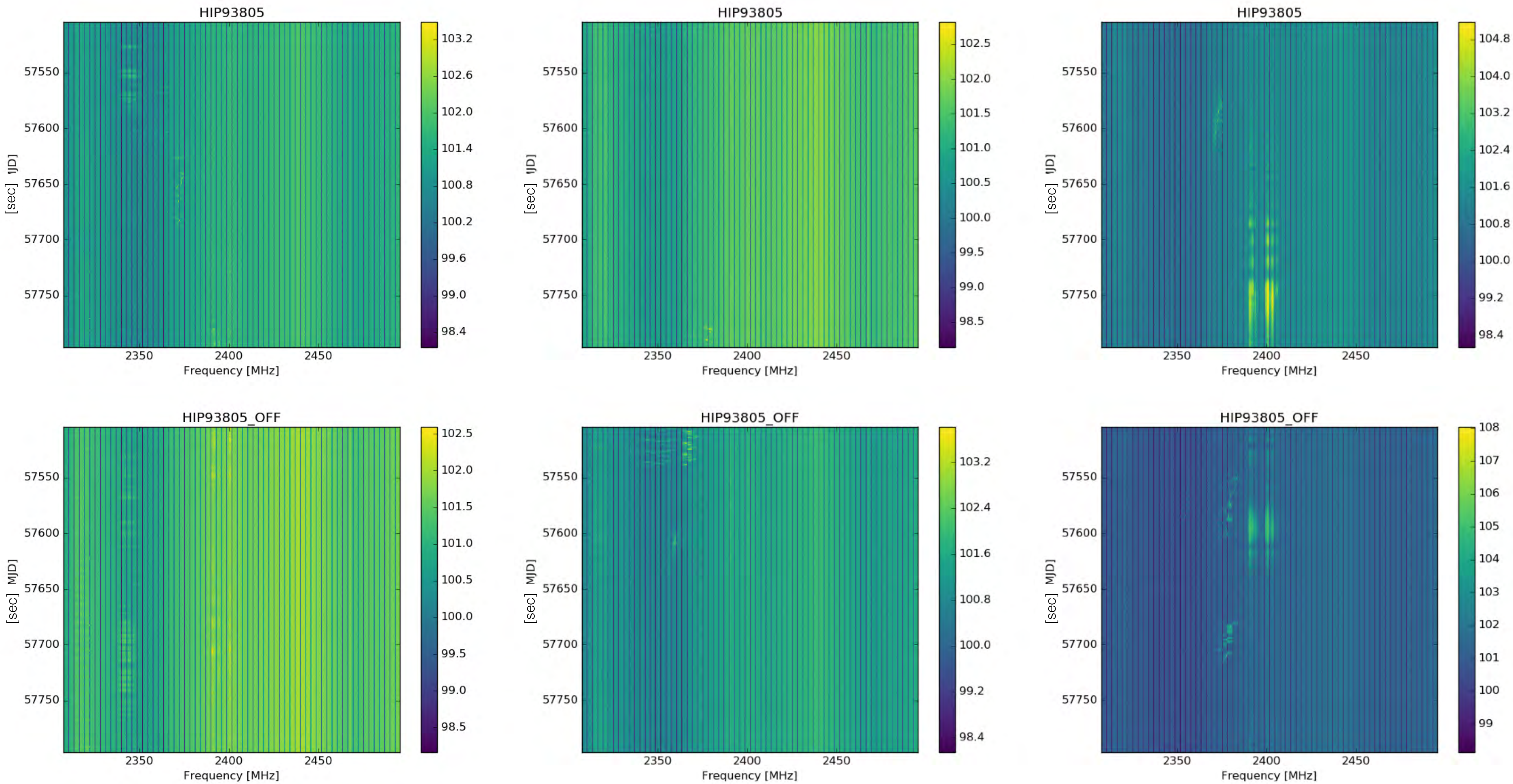
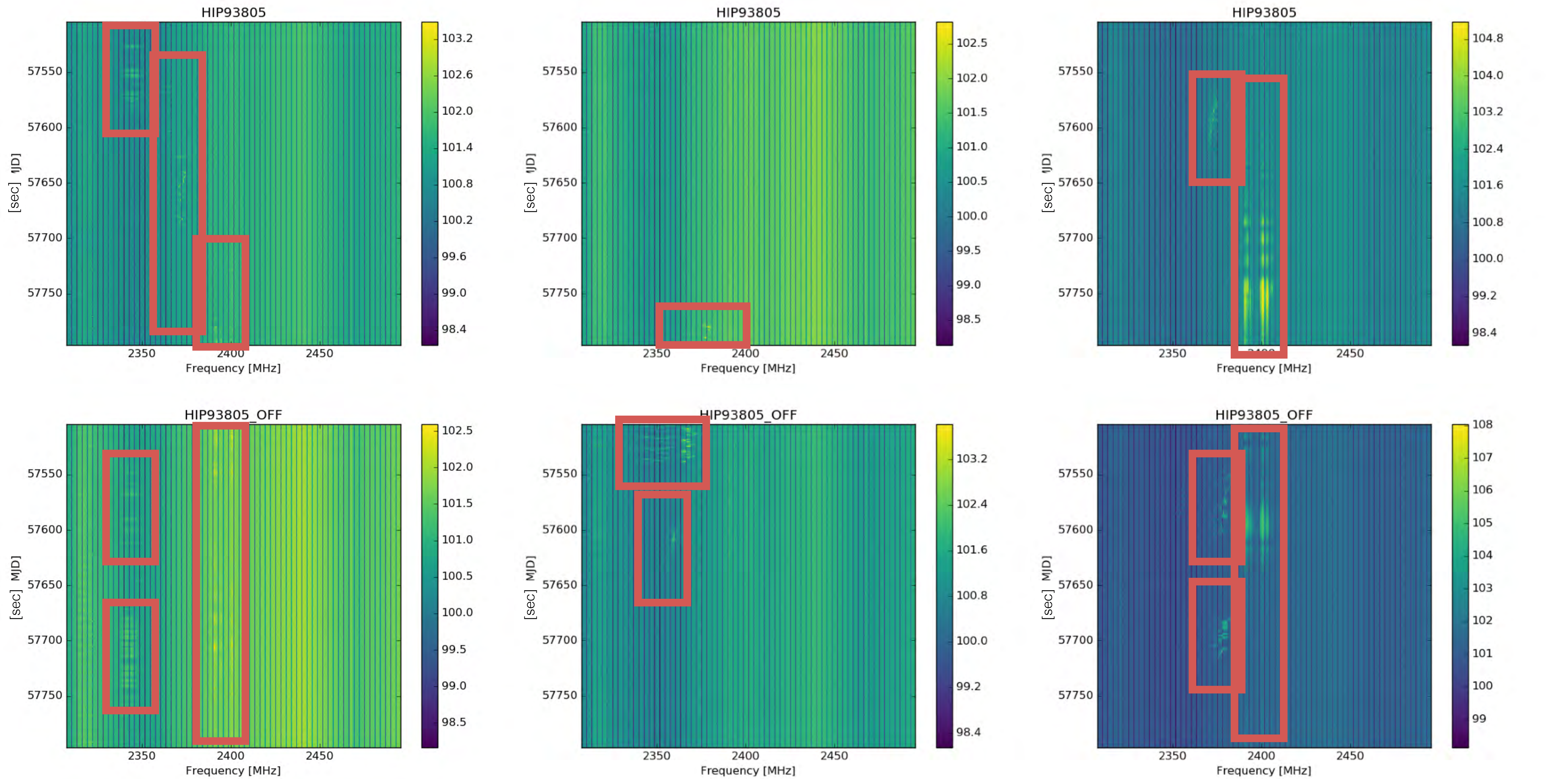
100.5
100.0
99.5
99.0
98.5


HIP93805
HIP93805
HIP93805
HIP93805_OFF
HIP93805_OFF
HIP93805_OFF
Frequency [MHz]
[sec] MJD



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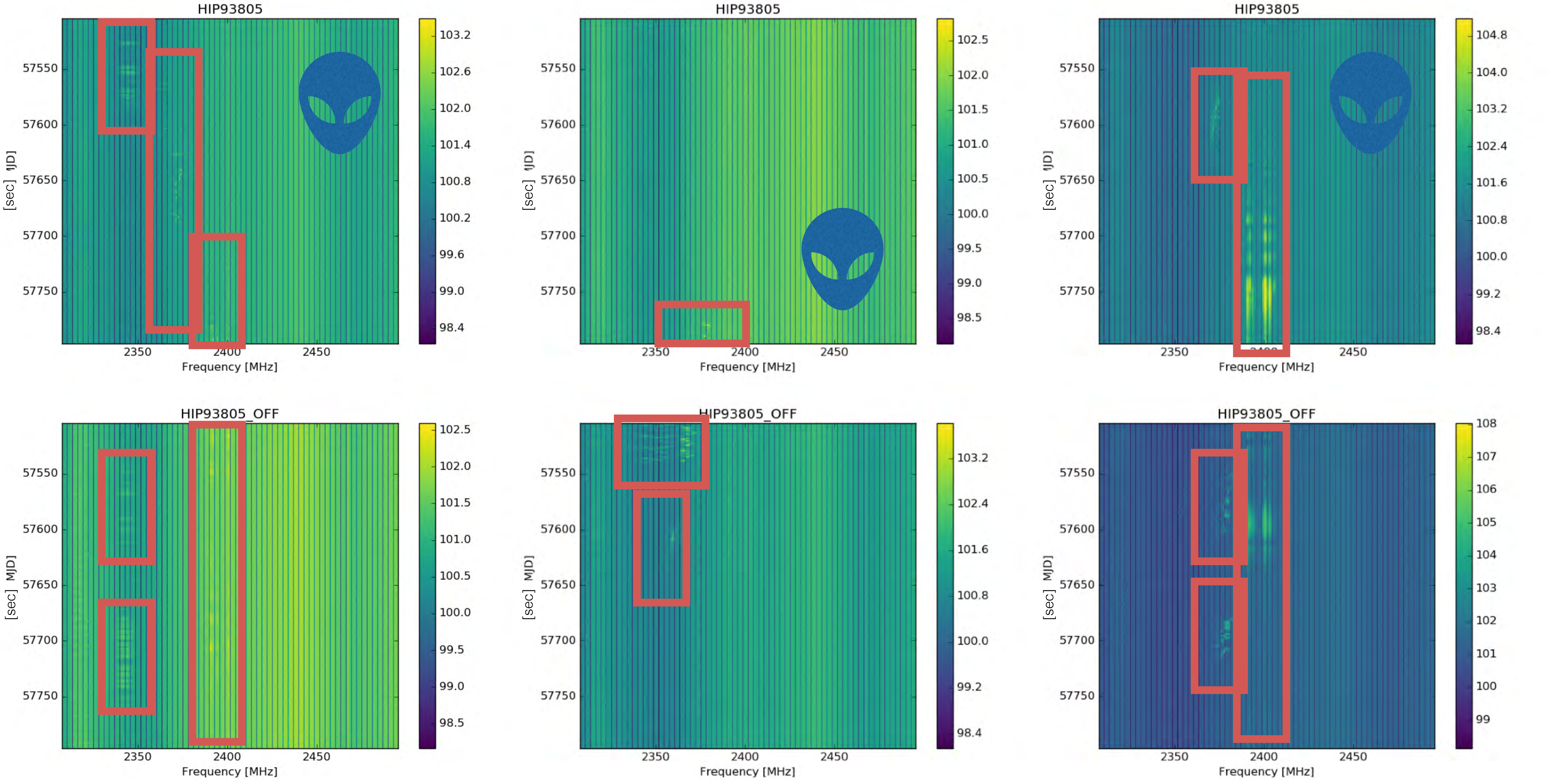
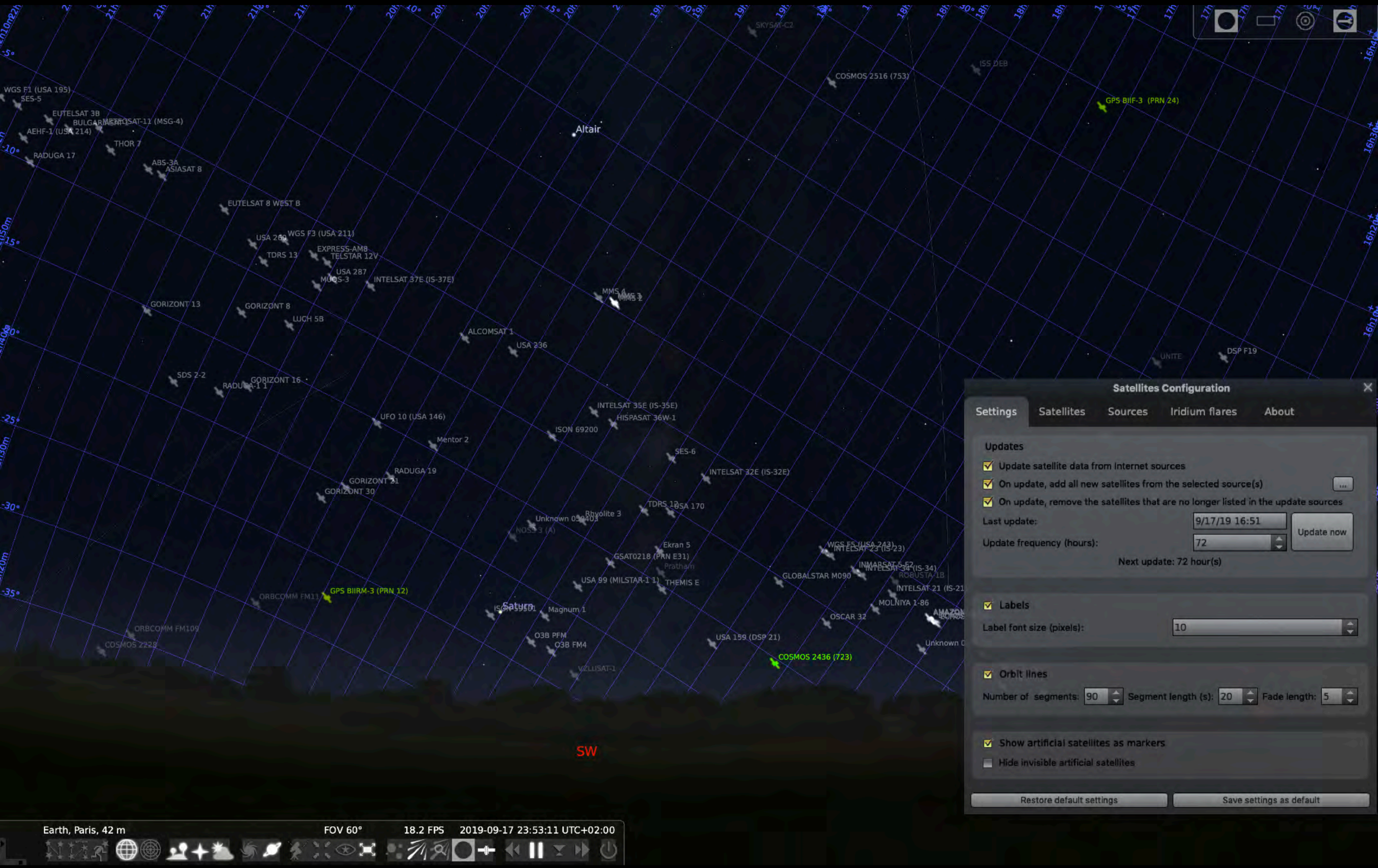

HIP93805
HIP93805
HIP93805
HIP93805_OFF
HIP93805_OFF
HIP93805_OFF
Frequency [MHz]
[sec] MJD
2350
2400
2450
57550
57600
57650
57700
57750



stellarium.org

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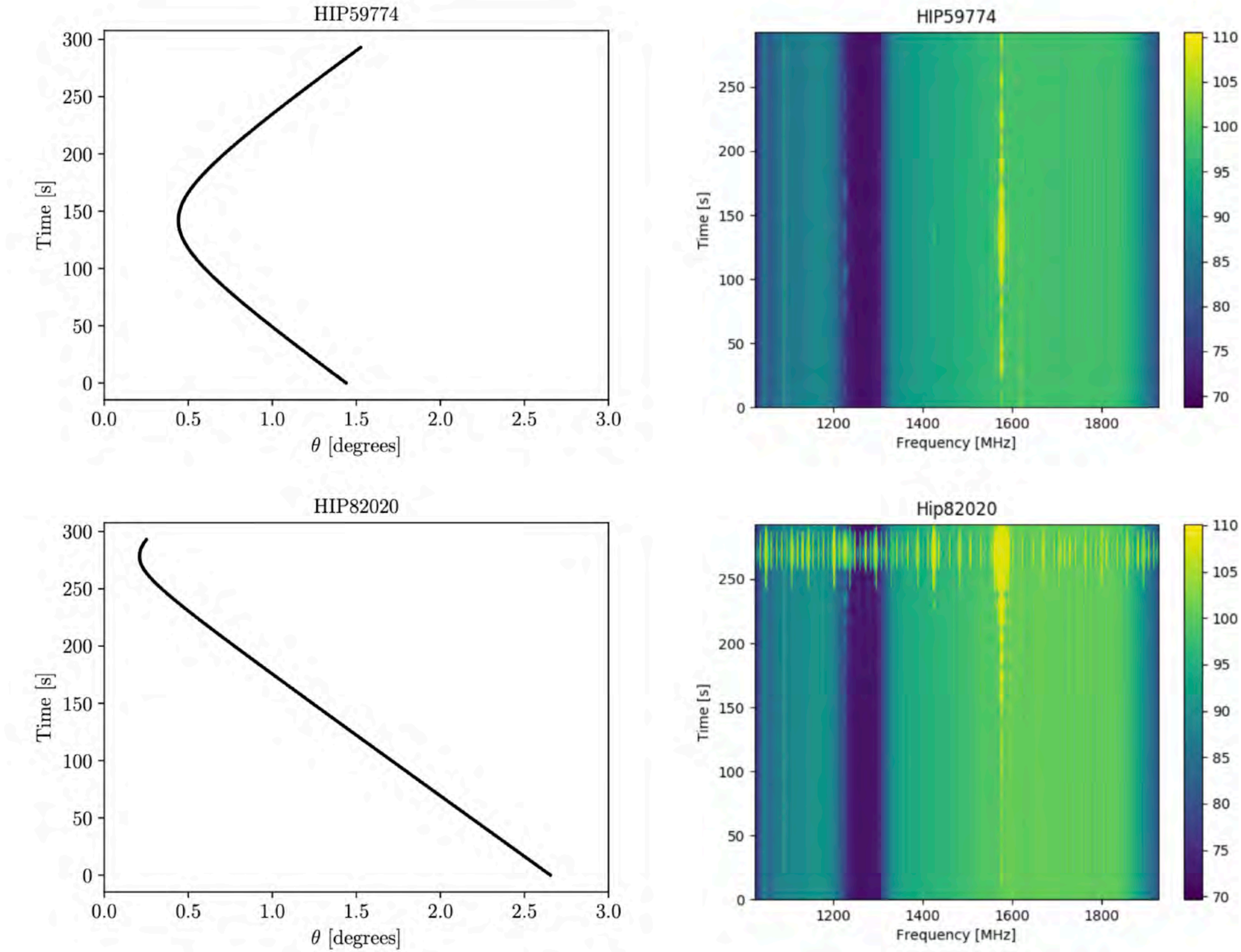


Figure 11. GPS Hits

Breakthrough Listen: 1327 Star Analysis and Public Data Release 1

- Overview
- Open Data
- Press Release

Overview

This page presents the results of our analysis of 1327 nearby stars observed as part of the Breakthrough Listen program with the Green Bank Telescope and the Parkes Telescope. With these new results, Breakthrough Listen has completed the most comprehensive and sensitive radio search for extraterrestrial intelligence (SETI) in history. We also present Breakthrough Listen Data Release 1.0, consisting of almost 1 PB of data, including the datasets used in the 1327 star analysis.

We invite the public to read the two papers accompanying the data release and the scientific analysis, and for those with technical skills, to download some of the datasets, to explore them, and to perform their own analyses.

Much of our software is publicly available, including blimpy, a tool for loading filterbank, hdf5, and raw format data files, and turboSETI, a tool for performing Doppler drift searches.

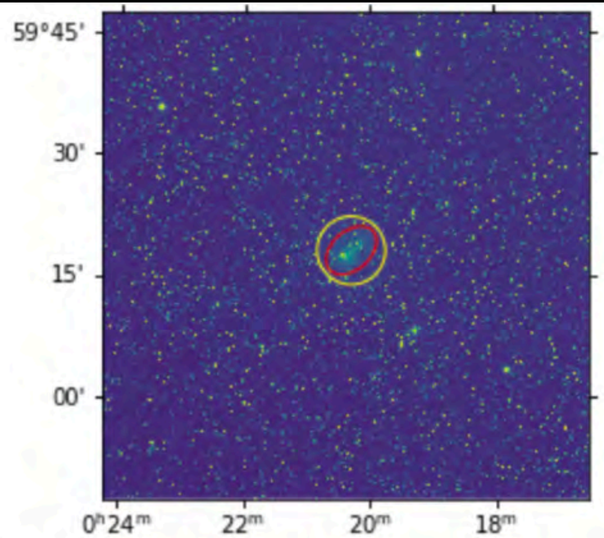
Download the background art seen here (Credit: Breakthrough Listen / Danielle Futselaar - also available as high resolution tif or pdf).

Papers:

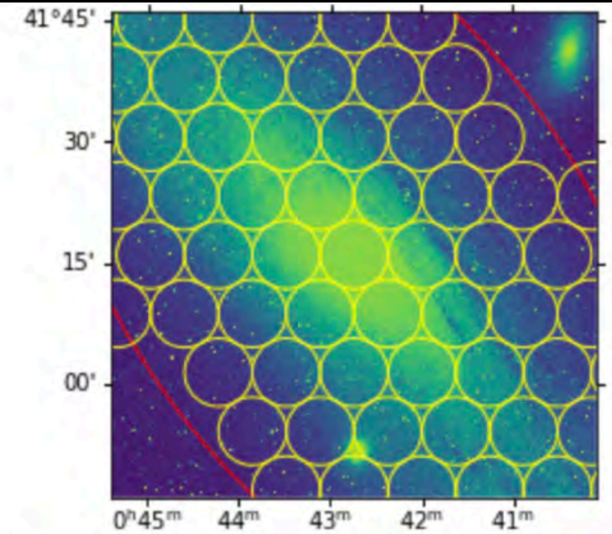
- "The Breakthrough Listen Search for Intelligent Life: Observations of 1327 Nearby Stars over 1.1-3.4 GHz" - Price, et al. Supplementary tables
- "The Breakthrough Listen Search for Intelligent Life: Public Data, Formats, Reduction and Archiving" - Lebofsky, et al.

1 PB of public data (spectrograms & IQ)

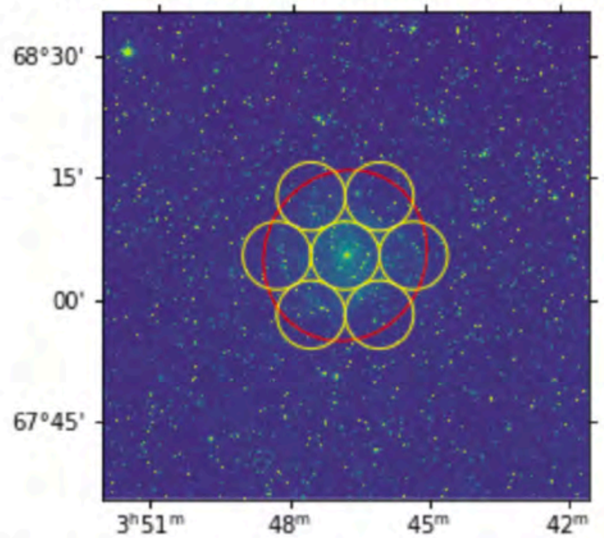
http://seti.berkeley.edu/listen2019



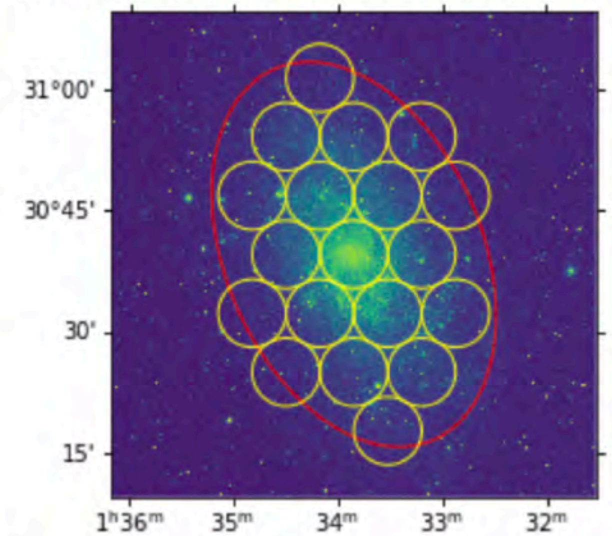
IC 0010 5.072250 59.303780 429.800000 284.990000 132.000000 1



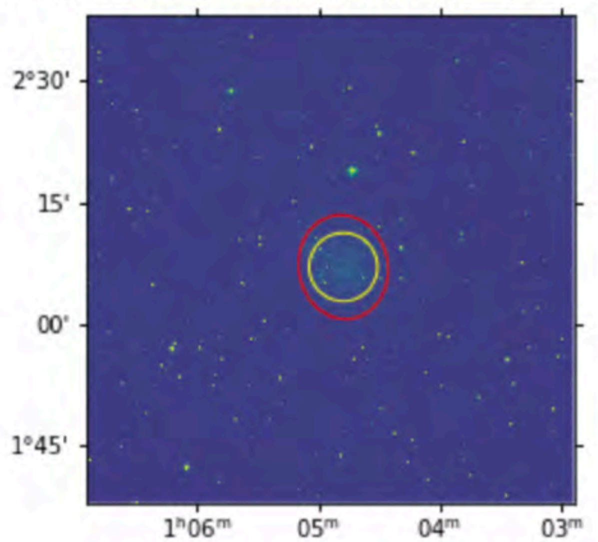
MESSIER 031 10.684790 41.269060 6200.000000 3478.200000 35.000000 77



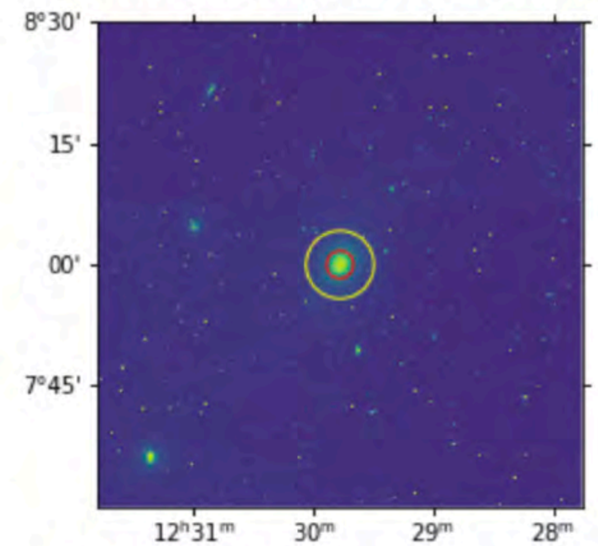
IC 0342 56.702090 68.096370 1282.800000 1185.860000 153.000000 7



MESSIER 033 23.462040 30.660220 2995.300000 1910.240000 23.000000 19



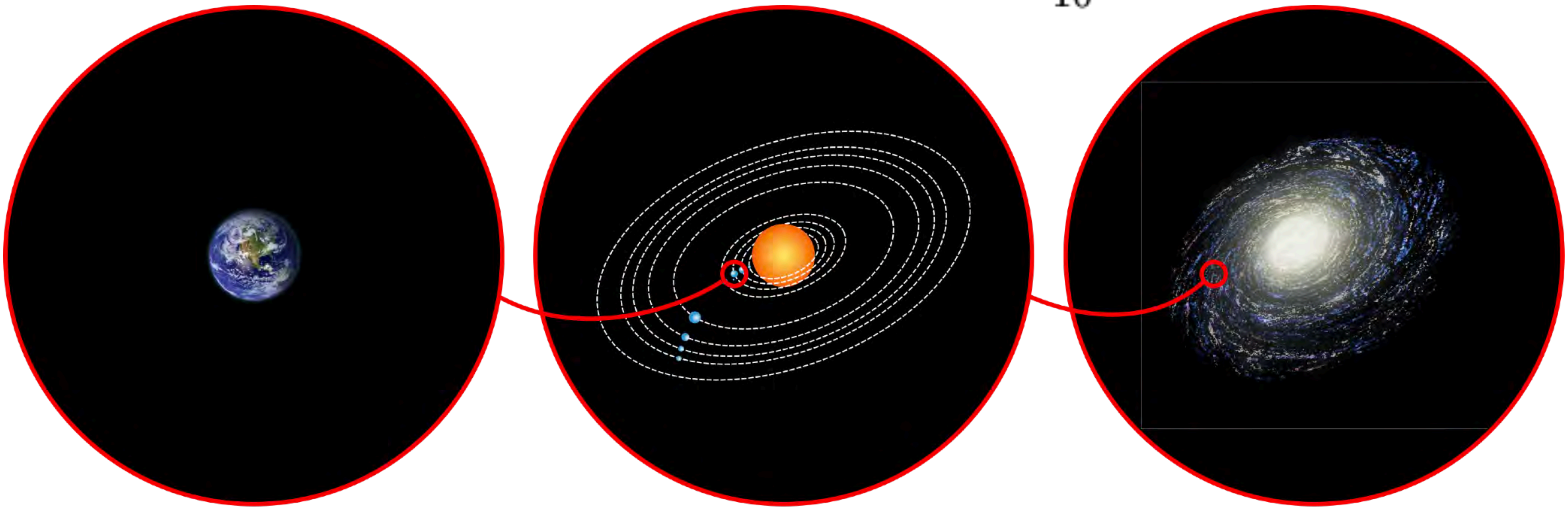
IC 1613 16.199130 2.117780 772.900000 660.000000 10.000000 1



MESSIER 049 187.444840 8.000480 208.000000 199.150000 155.000000 1

Kardashev Scale

$$K = \frac{\log_{10} P - 6}{10}$$



Type I : 10^{16} W

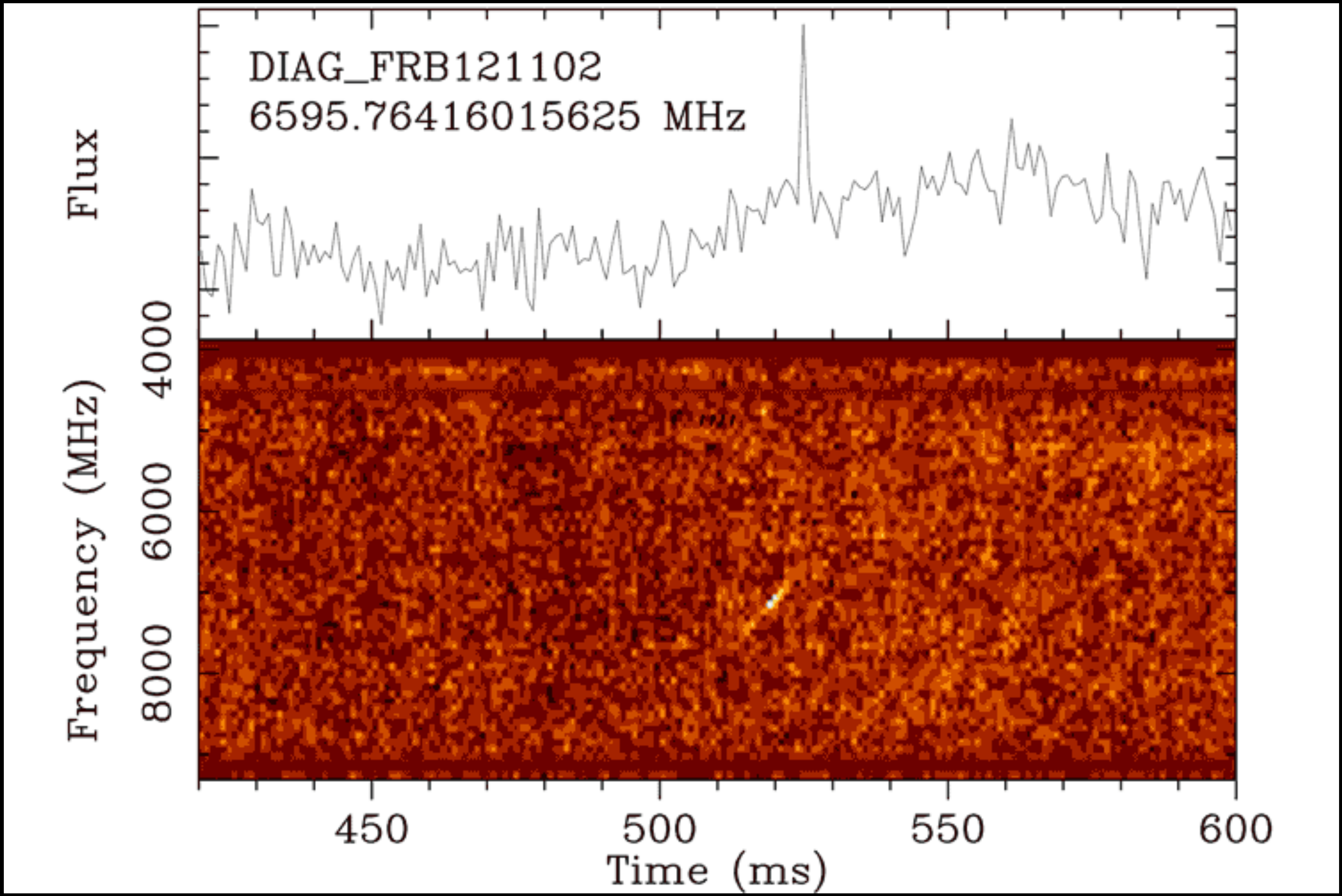
Type II : 10^{26} W

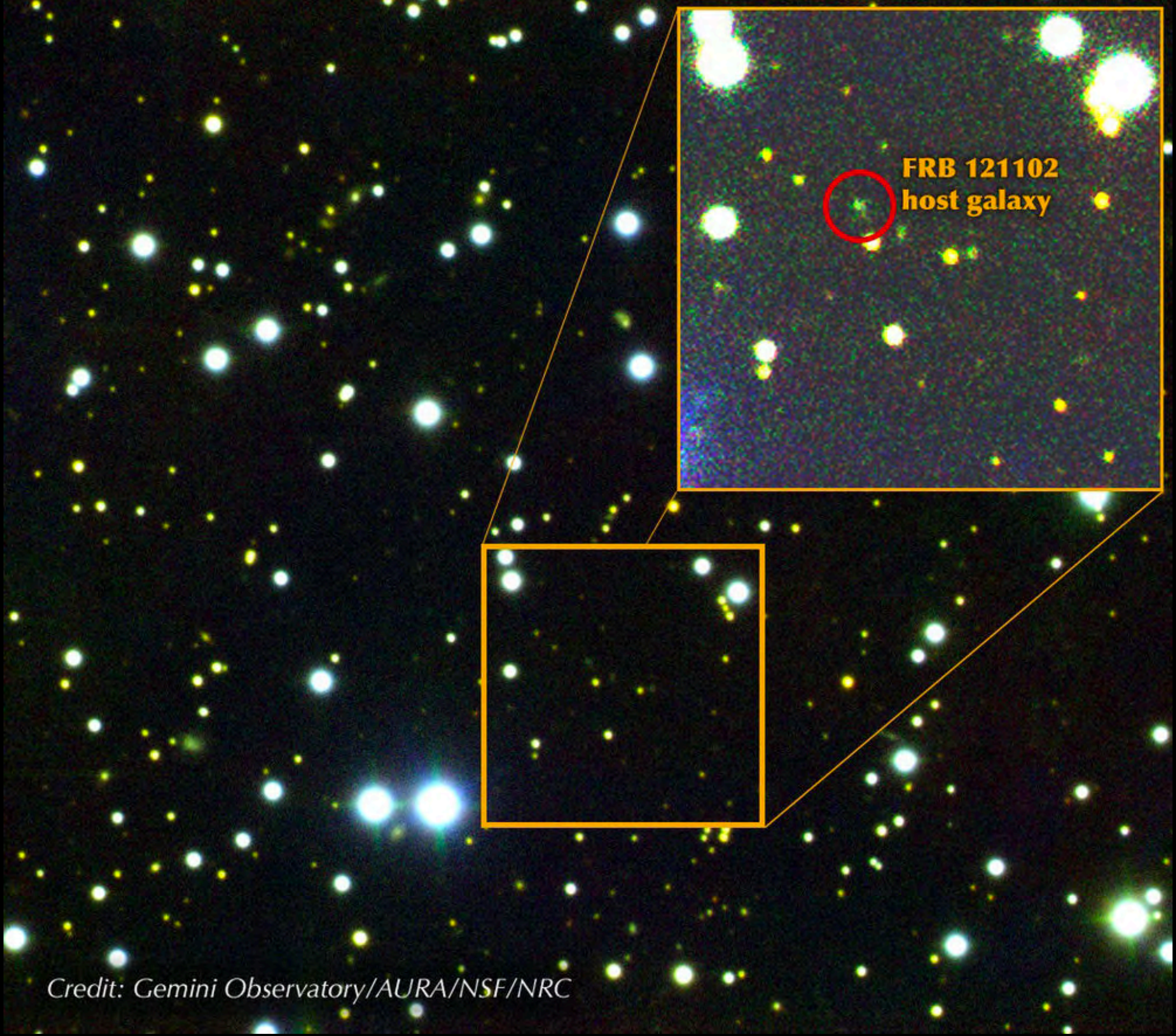
Type III : 10^{36} W

Wikipedia: Indif

HEIMDALL (GPU-ACCELERATED TREE DEDISPERSION)

ARXIV.ORG/ABS/1804.04101



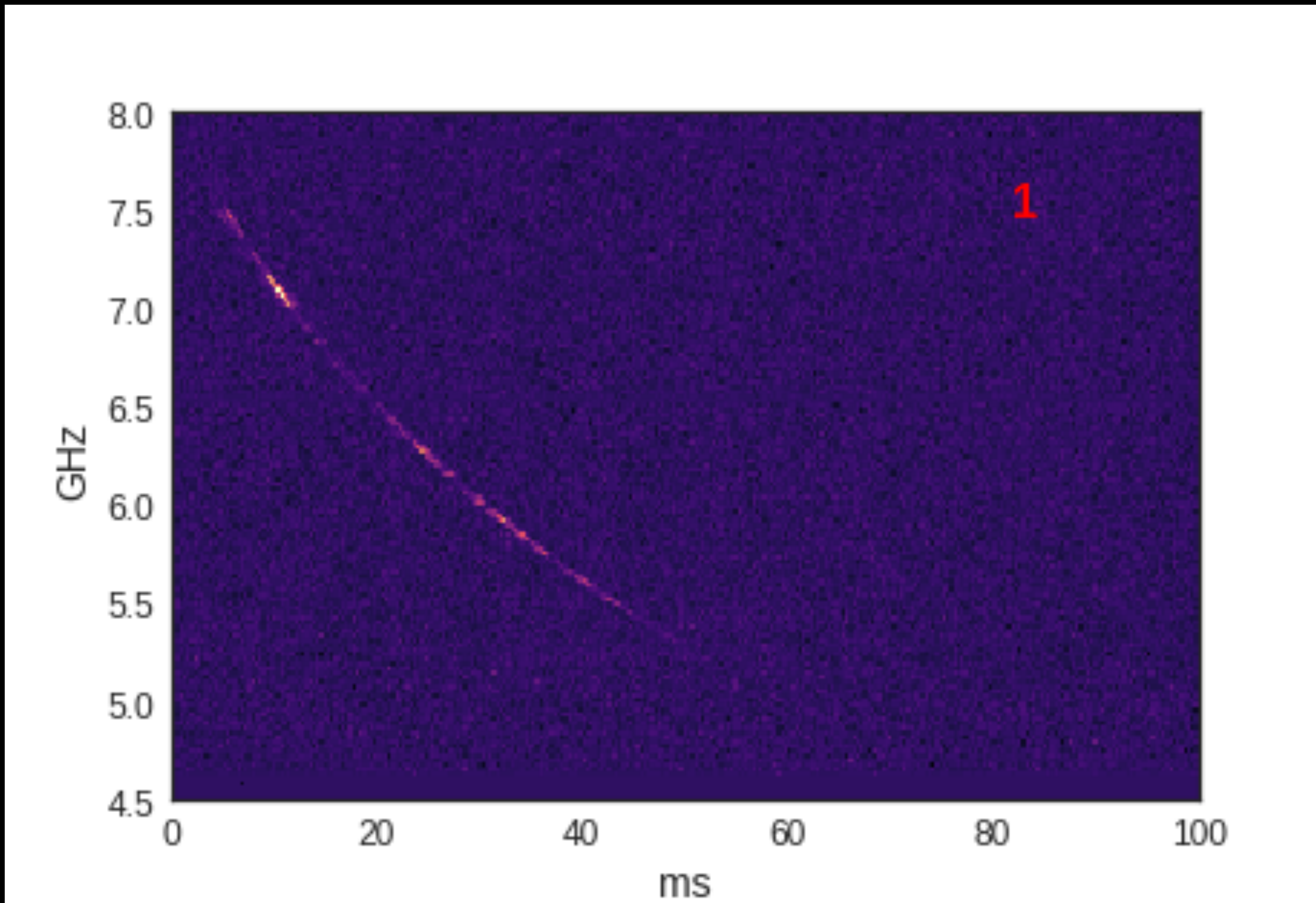

FRB 121102
host galaxy
Credit: Gemini Observatory/AURA/NSF/NRC


BREAKTHROUGH
LISTEN

BL ML WITH CNNs (GERRY ZHANG)

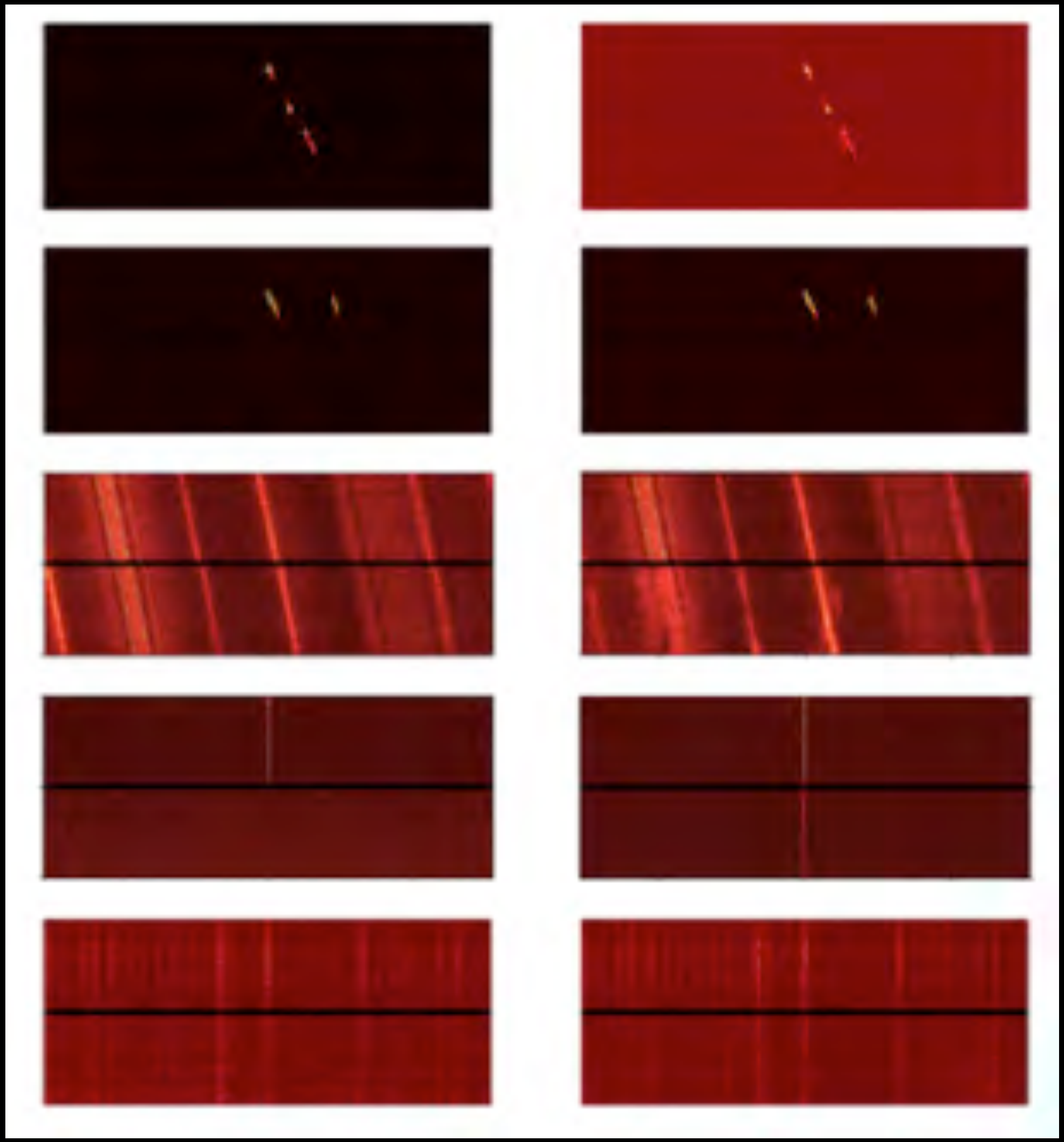
ARXIV.ORG/ABS/1809.03043

seti.berkeley.edu/frb-machine

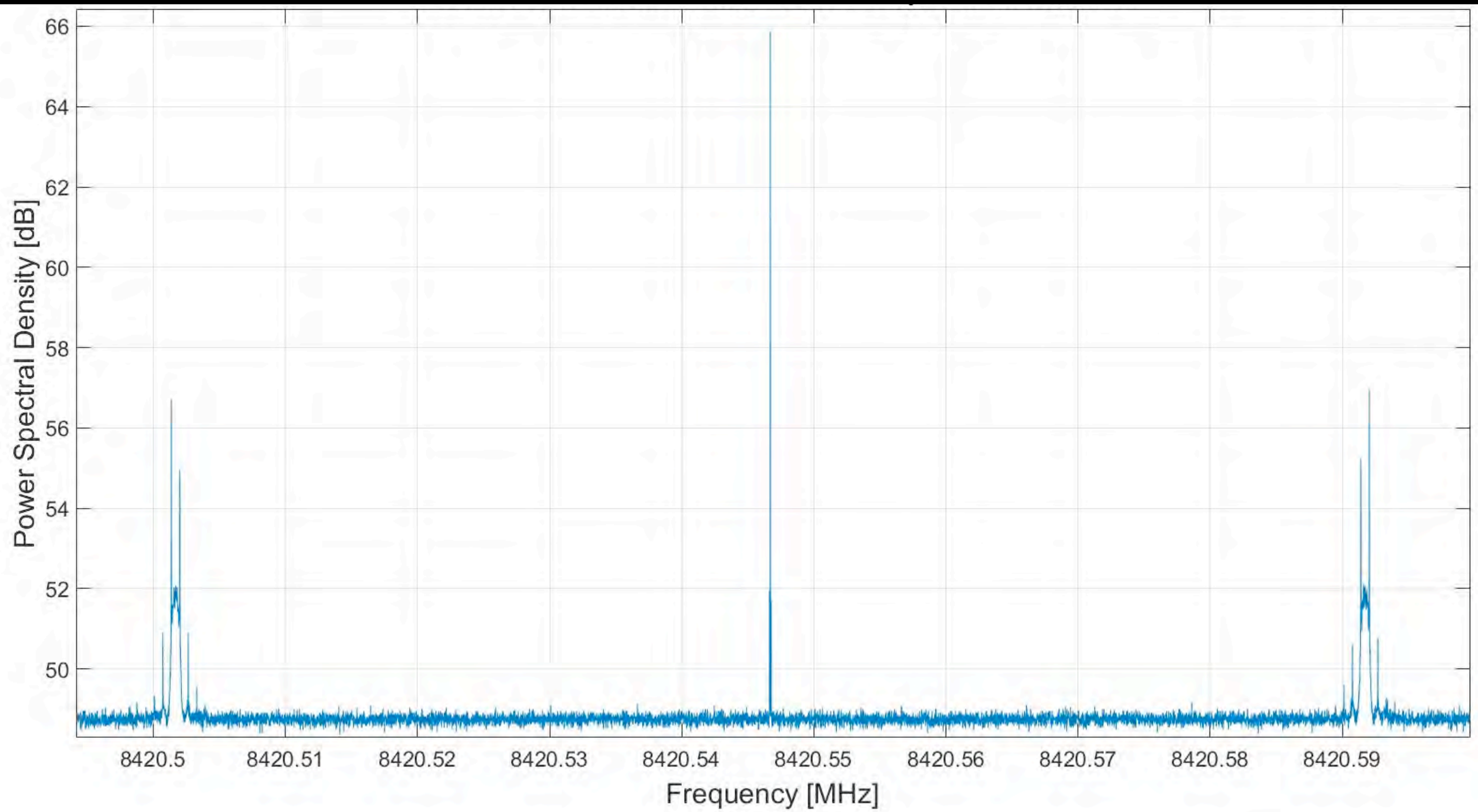


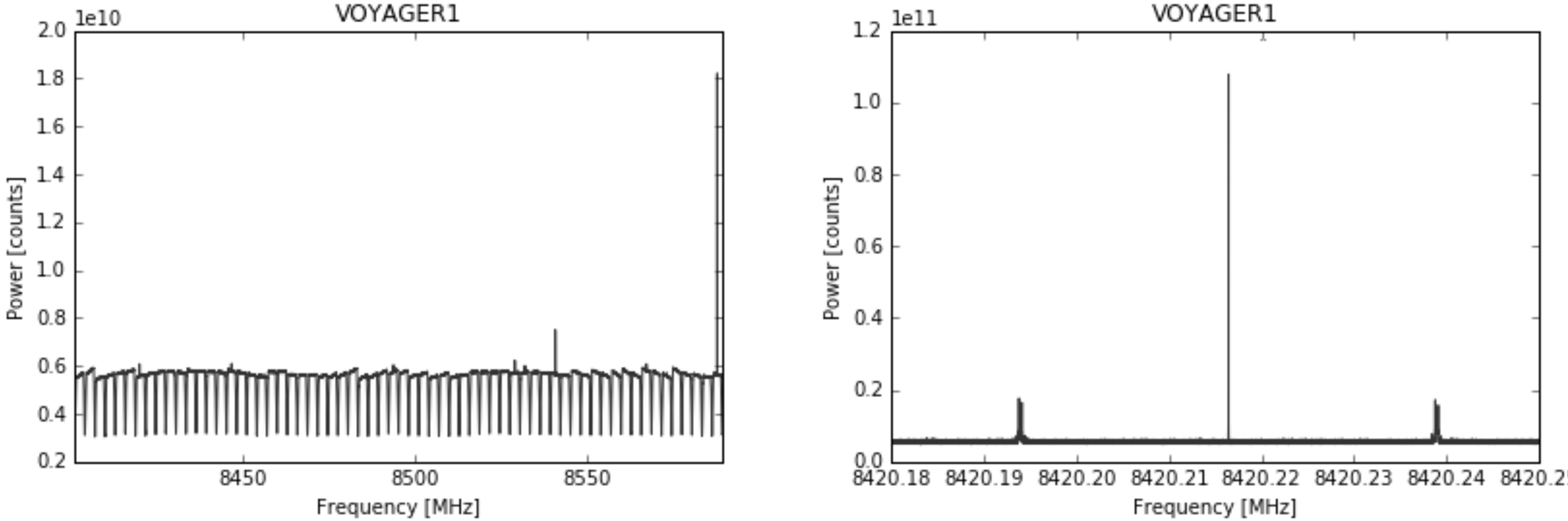
“We’d love to build an anomaly detector or serendipity machine”

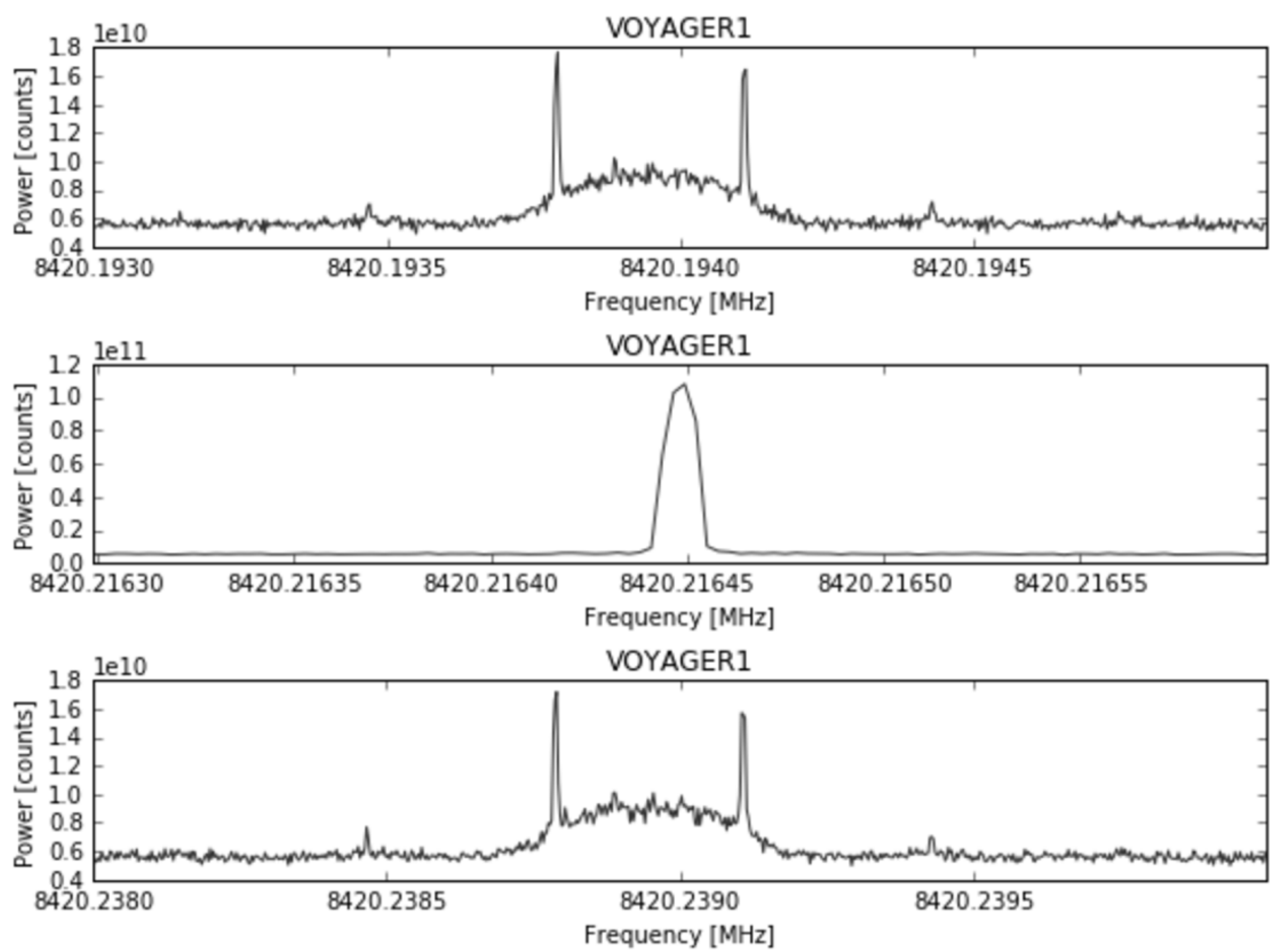
– Andrew Siemion



Zhang et al. (2019)
http://seti.berkeley.edu/blog/conv-lstm/


66
64
62
60
58
56
54
52
50
Power Spectral Density [dB]
8420.5
8420.51
8420.52
8420.53
8420.54
8420.55
8420.56
8420.57
8420.58
8420.59
Frequency [MHz]





http://bit.do/BL_voyager

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:

```
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.

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

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

Now, let's read the observation data using `Filterbank()`:

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.

bit.do/HowToFindET

For Media

Qualcomm Founder Franklin Antonio Funds Allen Telescope Array Upgrade Program

Sep 16, 2019 Tags: Press Release , SETI , ATA News

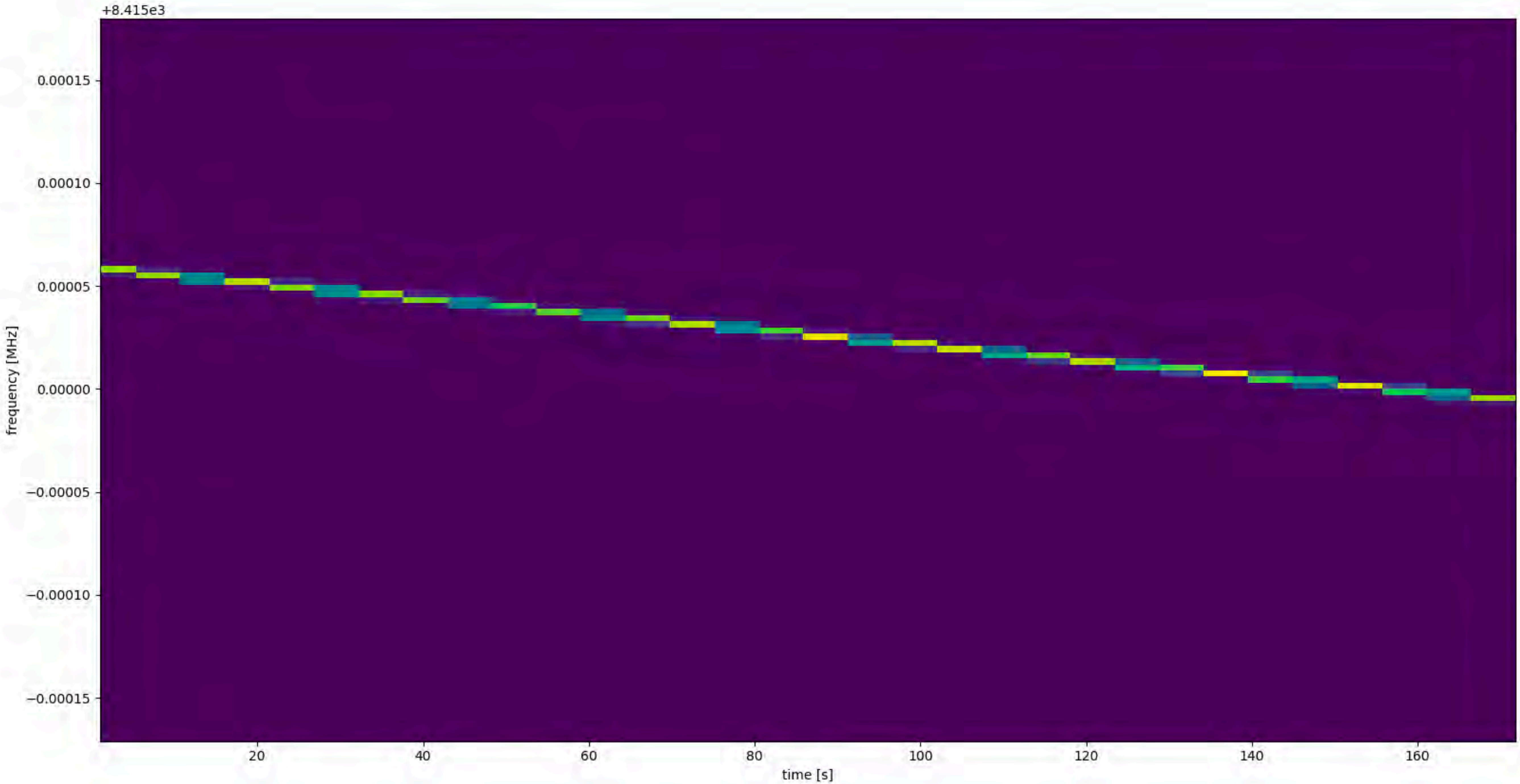
The Allen Telescope Aray (ATA) Located in Hat Creek, CA. The SETI Institute.

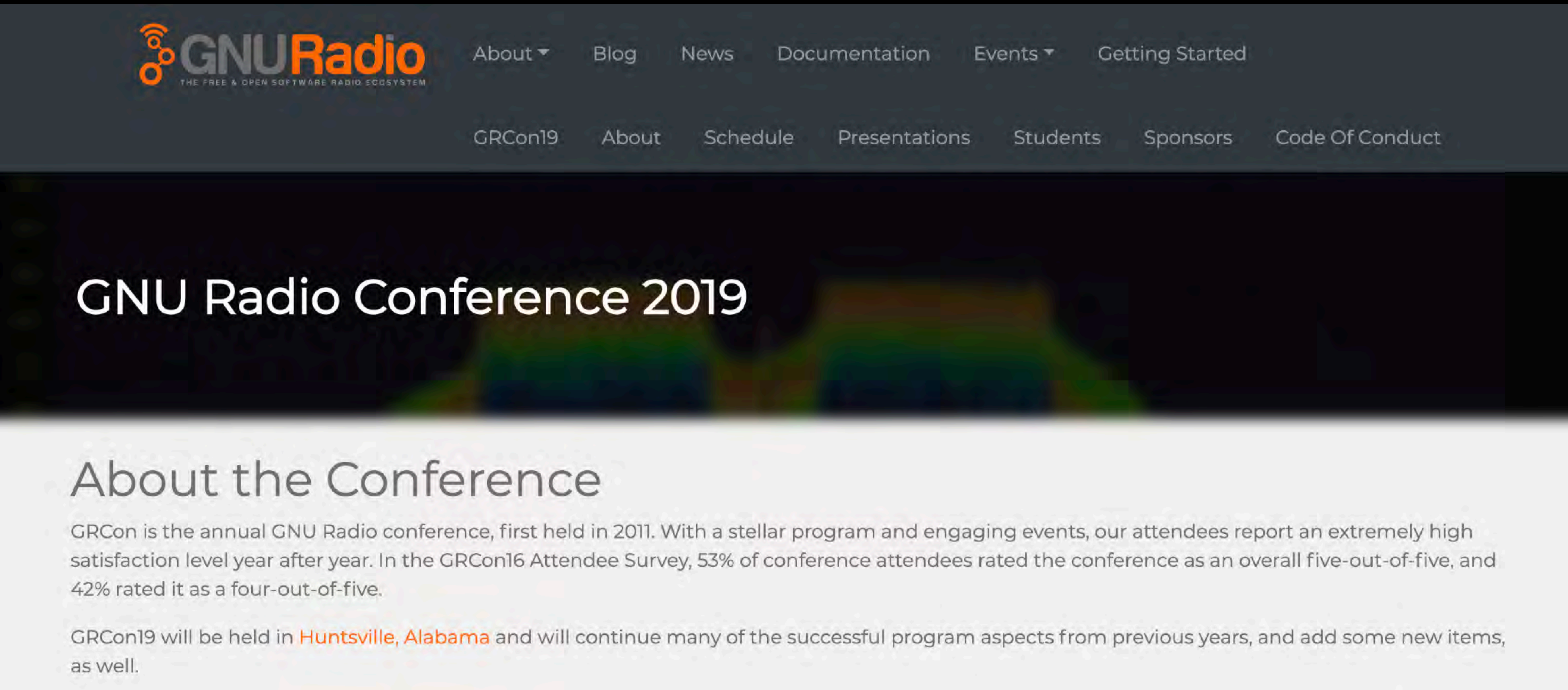
September 16, 2019, Mountain View, CA – The SETI Institute announced a new gift by Qualcomm founder Franklin Antonio that funds the first phase of a 3-year initiative to revitalize the Allen Telescope Array (ATA). These upgrades will significantly increase the sensitivity of ATA's receivers and permit the development of a new digital processing system that will bring enhanced capabilities.


Photo: Arash Roshanineshat
seti.org/hacking-seti
github.com/SETIatHCRO/gr-ata

Data from ATA & GBT in SigMF format

seti.berkeley.edu/blog/open-data/





GNURadio
THE FREE & OPEN SOFTWARE RADIO ECOSYSTEM

About Blog News Documentation Events Getting Started

GRCon19 About Schedule Presentations Students Sponsors Code Of Conduct

GNU Radio Conference 2019

About the Conference

GRCon is the annual GNU Radio conference, first held in 2011. With a stellar program and engaging events, our attendees report an extremely high satisfaction level year after year. In the GRCon16 Attendee Survey, 53% of conference attendees rated the conference as an overall five-out-of-five, and 42% rated it as a four-out-of-five.

GRCon19 will be held in Huntsville, Alabama and will continue many of the successful program aspects from previous years, and add some new items, as well.

Next year, in collaboration with SETI Institute / Breakthrough Listen / Berkeley Seti

Undergrad internships

seti.berkeley.edu/Internship.html

Deadline: February 2020







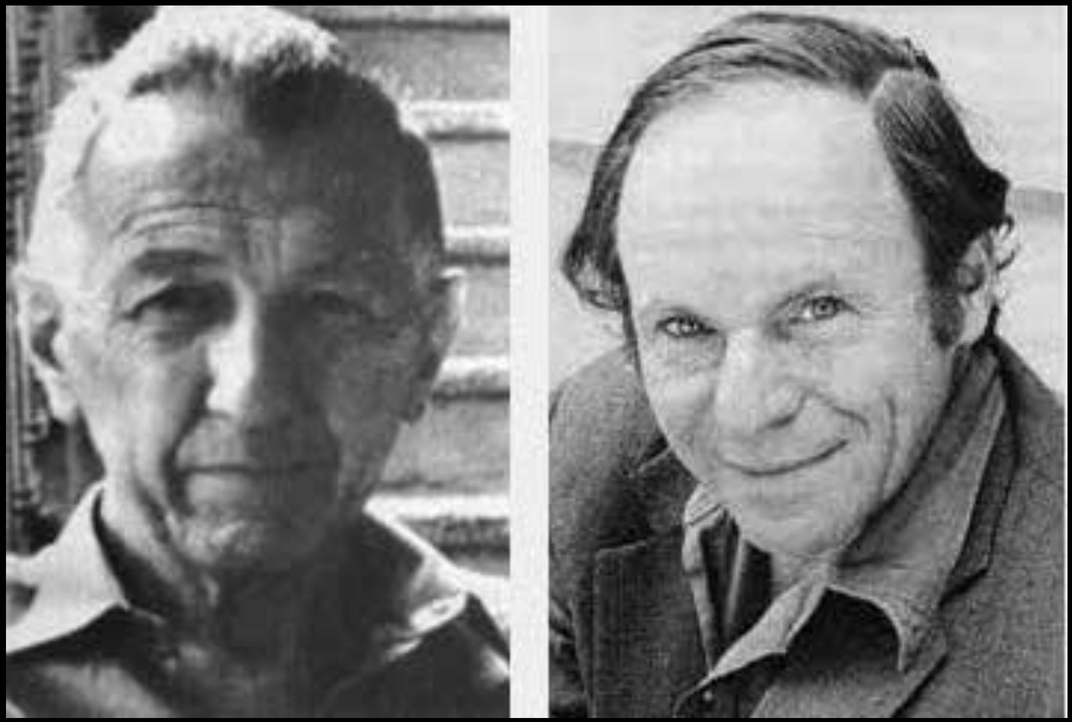

Watch @BerkeleySETI for jobs or join our Slack (email scroft@berkeley.edu)

Steve Croft - UC Berkeley / Breakthrough Listen / SETI Institute - GNURadio Conference 2019

Steve Croft - UC Berkeley / Breakthrough Listen / SETI Institute - GNURadio Conference 2019

“The probability of success is difficult to estimate; but if we never search, the chance of success is zero.”

Cocconi & Morrison, September 19, 1959



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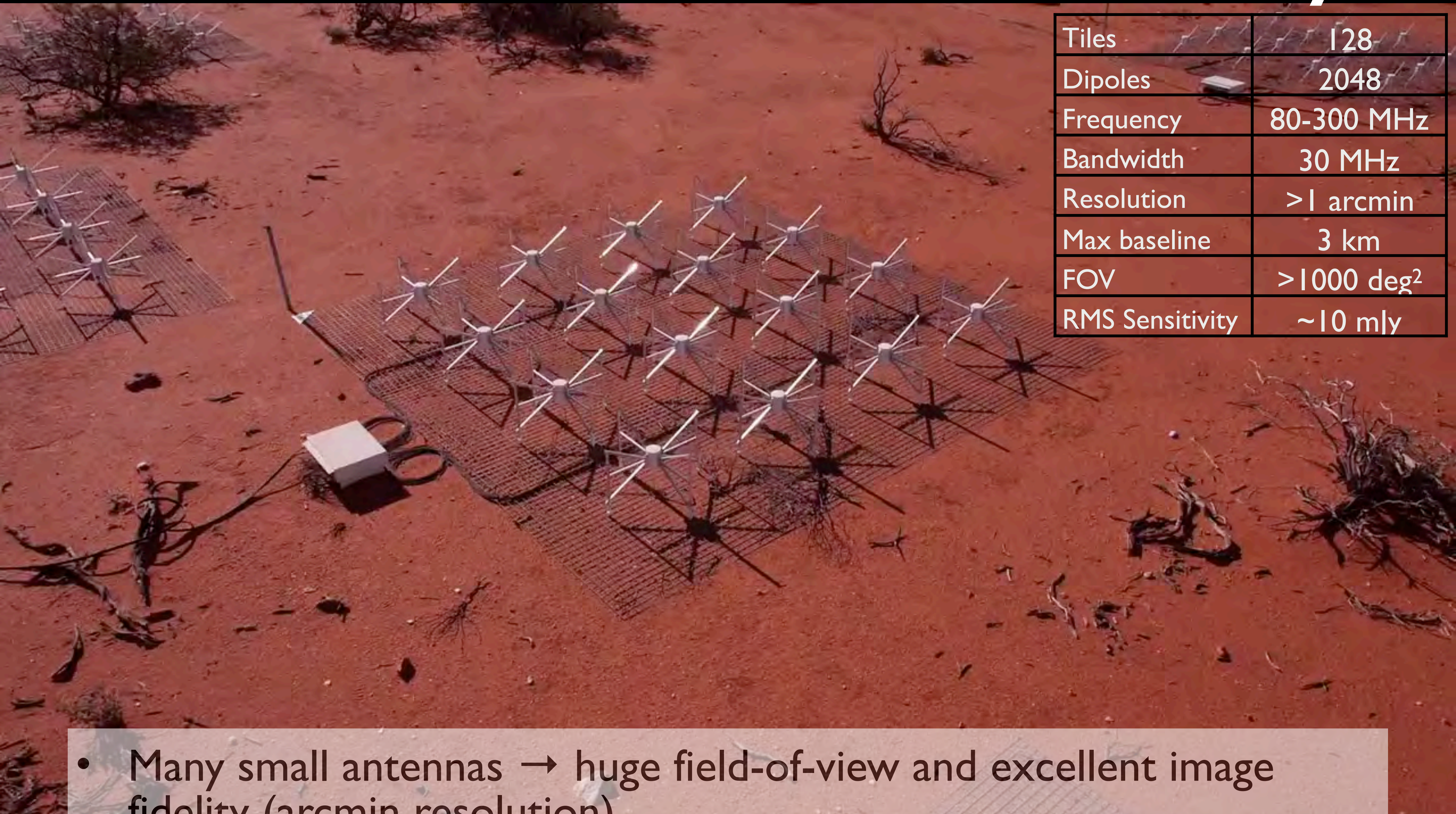
seti.berkeley.edu
bit.do/HowToFindET

@BerkeleySETI

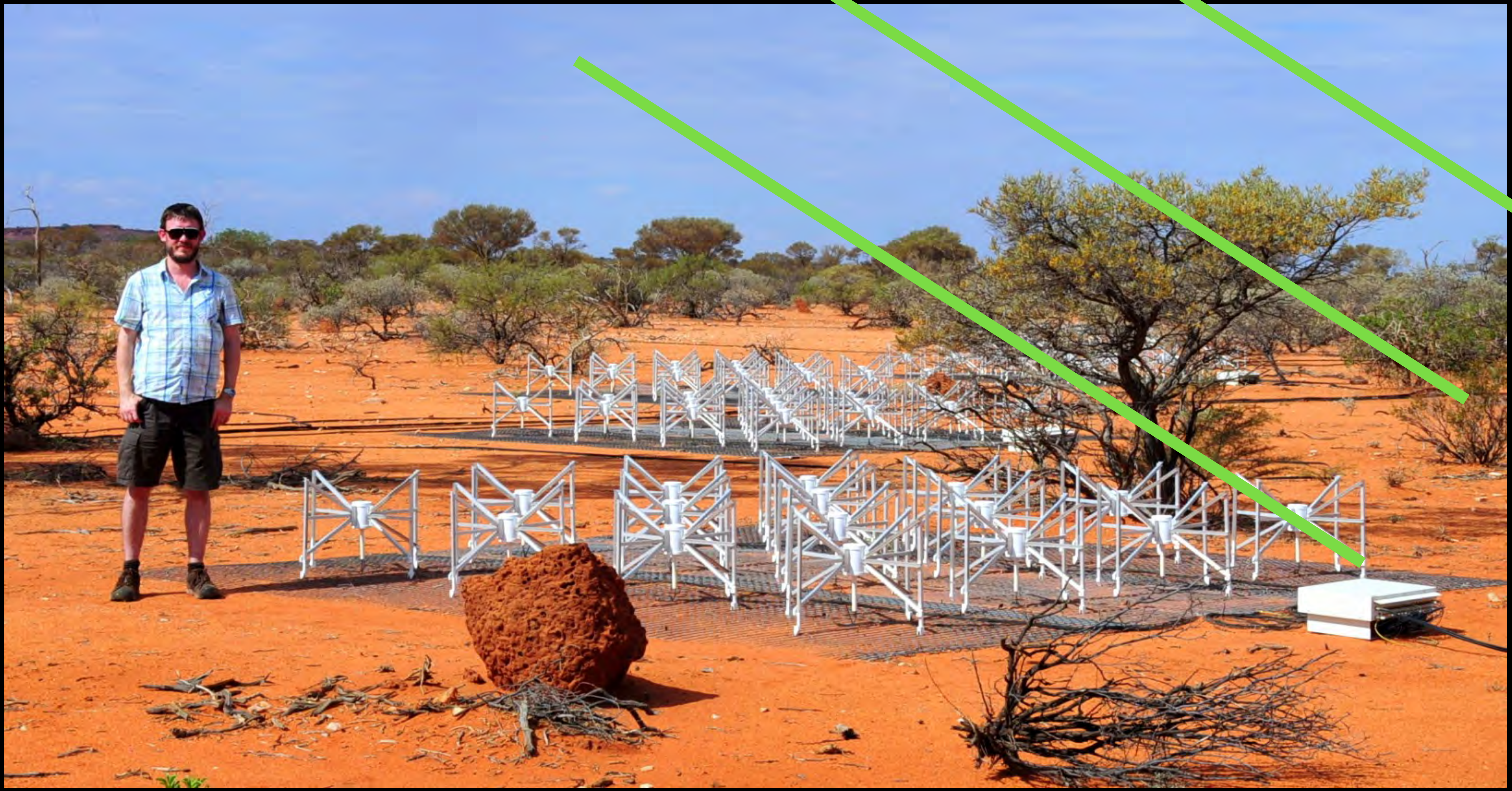
Murchison Widefield Array



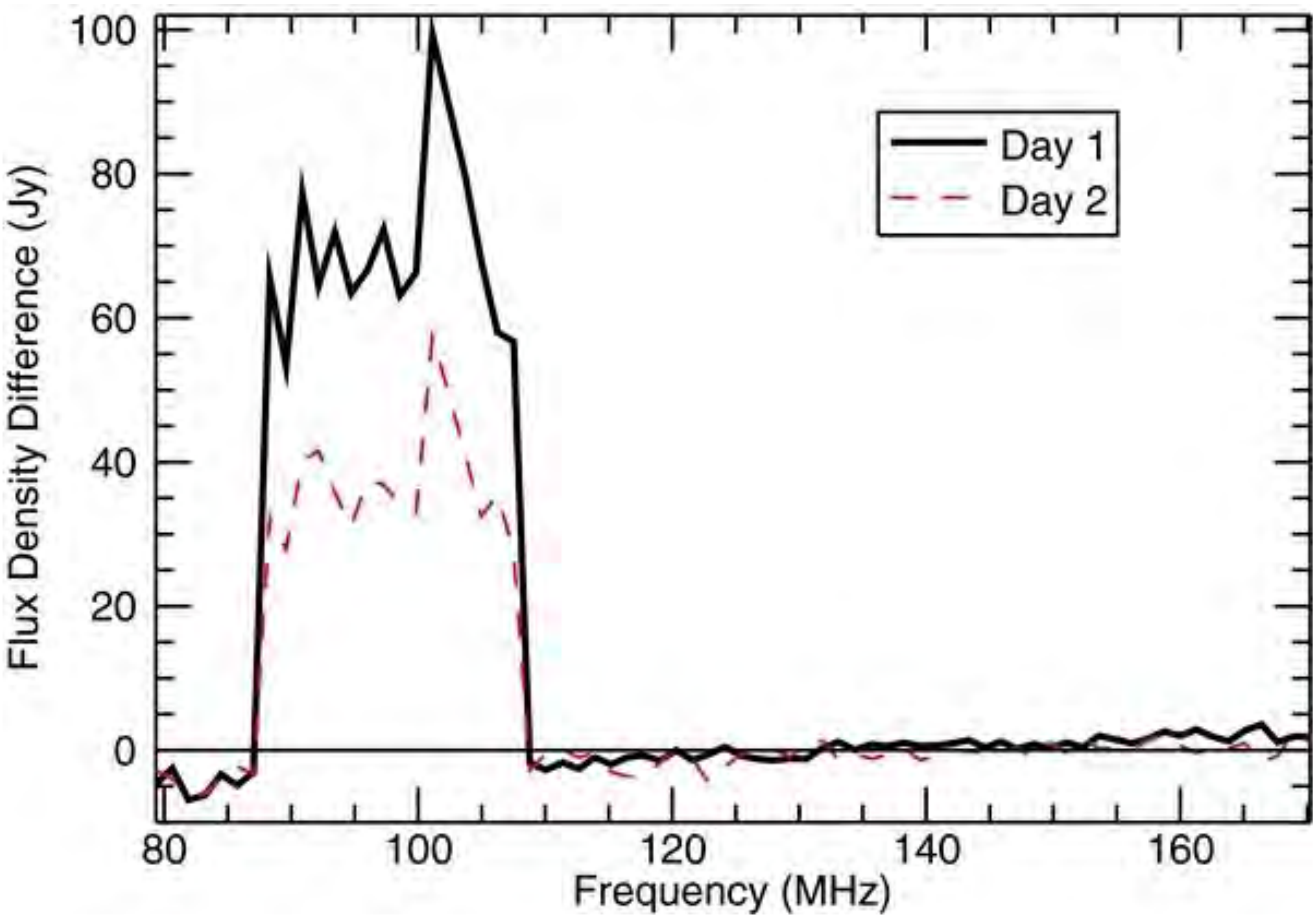
Tiles	128
Dipoles	2048
Frequency	80-300 MHz
Bandwidth	30 MHz
Resolution	>1 arcmin
Max baseline	3 km
FOV	>1000 deg^2
RMS Sensitivity	~10 mJy

- Many small antennas → huge field-of-view and excellent image fidelity (arcmin resolution)
- *MWA phase 2 upgrade*. Doubles number of antennas and array diameter


Murchison Shire Boundary
MRO (operated by CSIRO)
On site: data rate into central building ~60 Gbps
41,000 sq. km = The Netherlands
Population density = 0.002 people/sq. km
Geraldton
Off site: data rate into science archive was ~3 Gbps, now 100 Gpbs
~200 km
Perth
Pawsey Centre 9 PB storage for MWA



FM radio from the moon, detected with MWA



From McKinley et al., 2013