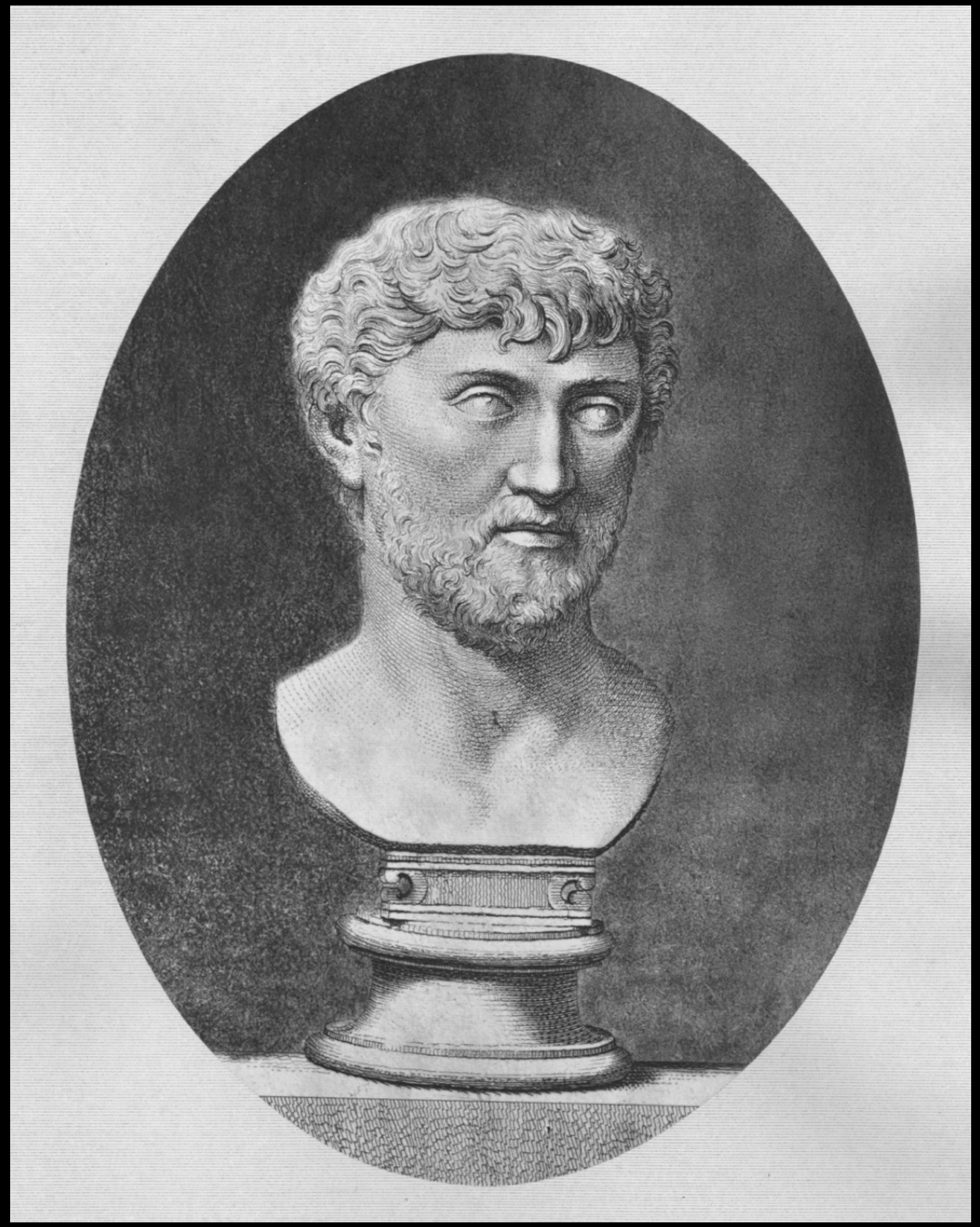
Six Decades of Technosignature Science at Green Bank

STEVE CROFT
scroft@berkeley.edu
Project Scientist for Breakthrough Listen on GBT
Director of Undergraduate Research, BSRC

BREAKTHROUGH
LISTEN

NSF

BERKELEY SETI
RESEARCH CENTER



"Nothing in the Universe is unique and alone, and therefore in other regions there must be other earths inhabited by different tribes of men and breeds of beasts."

Lucretius, c. 60 BCE

"Life, as it exists on Earth in the form of men, animals and plants, is to be found, let us suppose … in the solar and stellar regions. Rather than think that so many stars and parts of the heavens are uninhabited and that this earth of ours alone is peopled … we will suppose that in every region there are inhabitants."

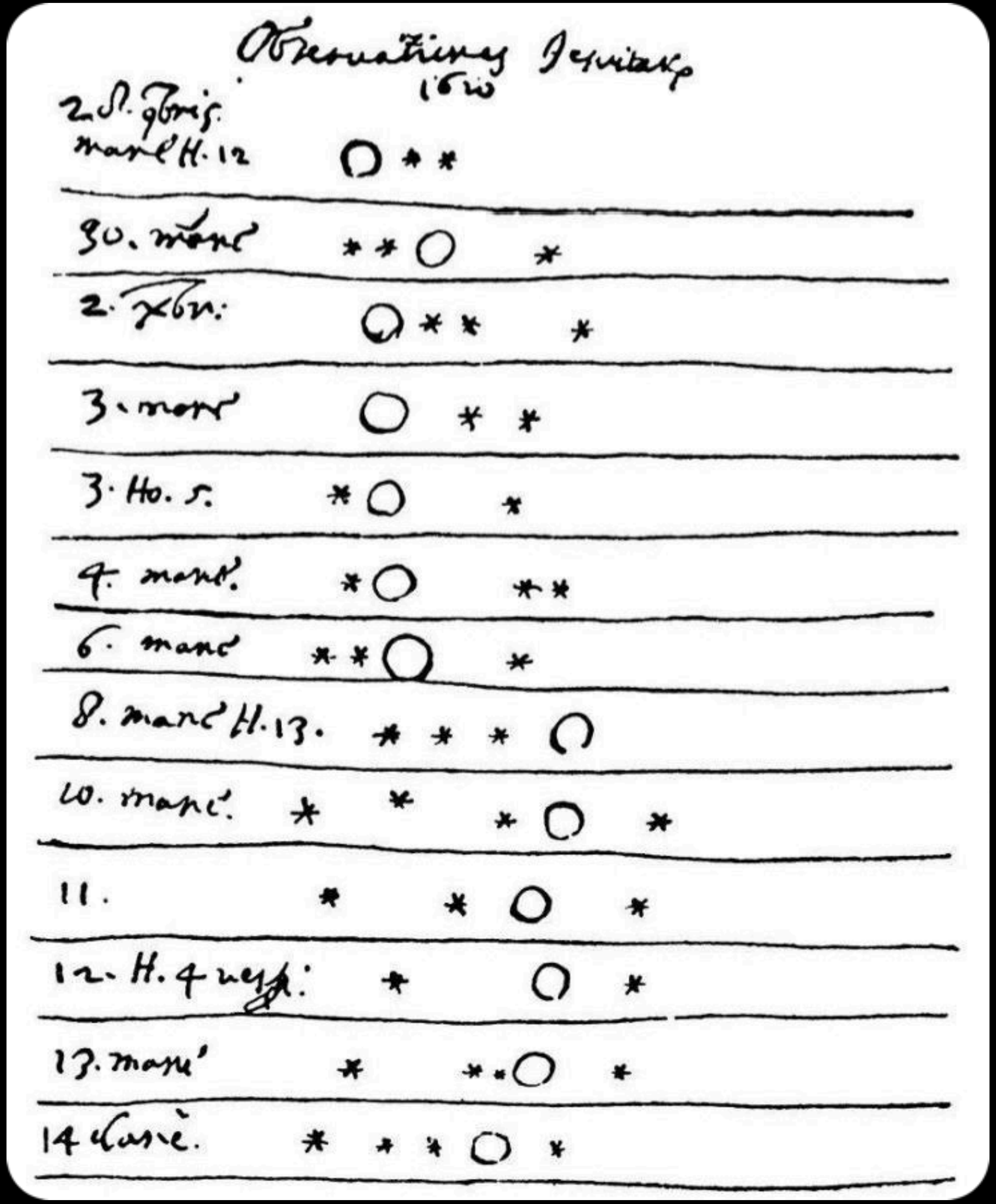
Nicholas of Cusa, 1440

LUNAR ANIMALS

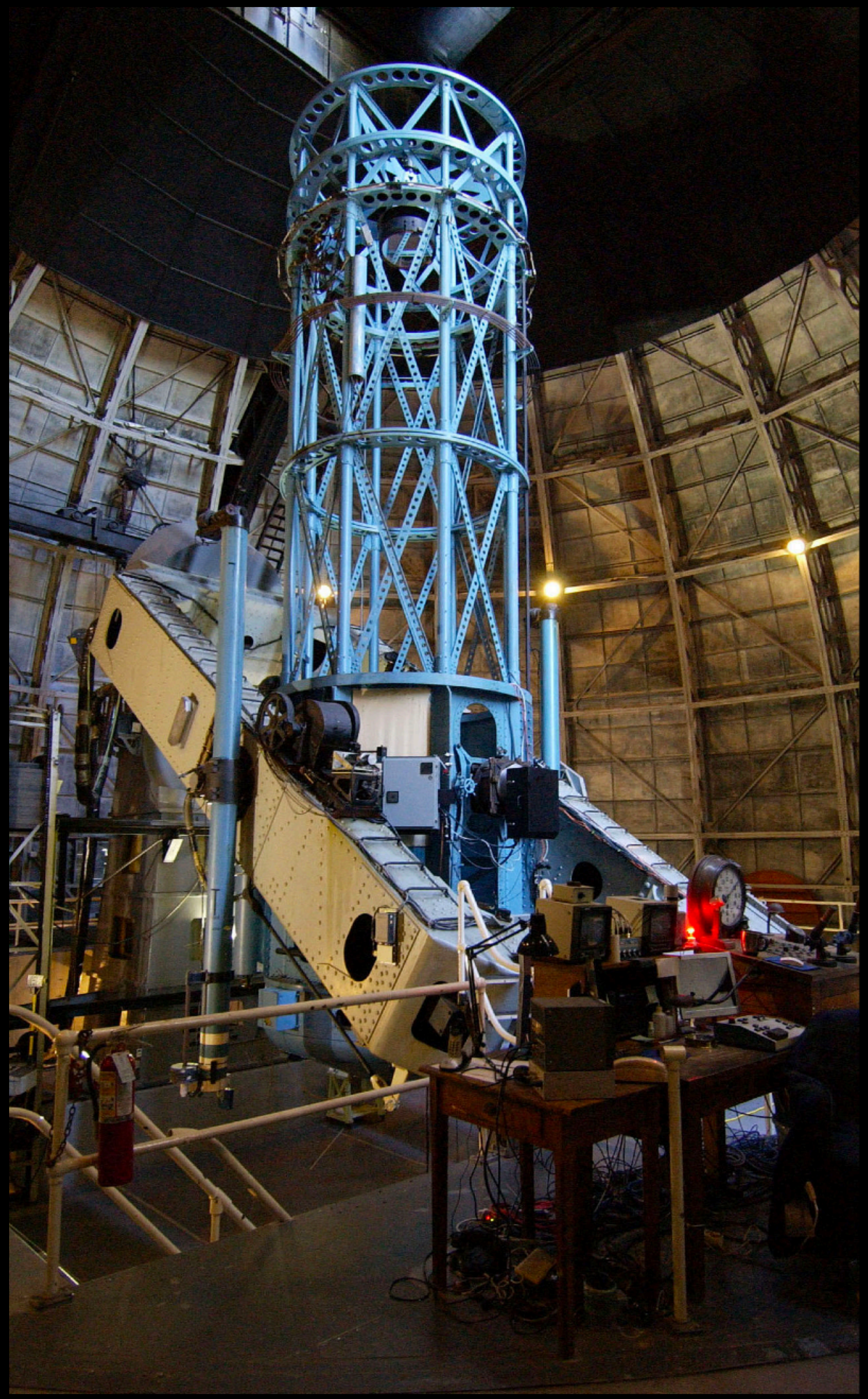
AND OTHER

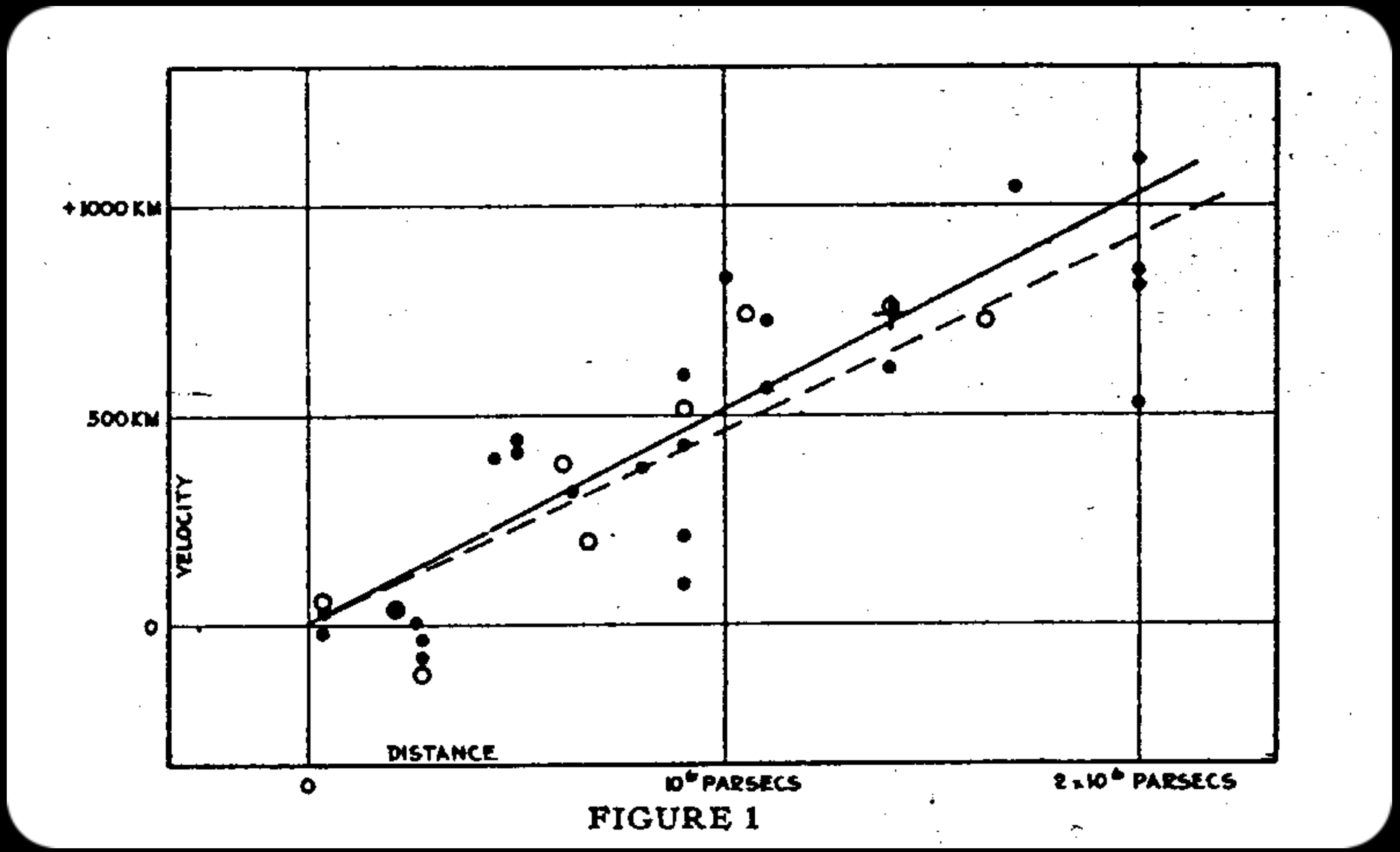
OBJECTS,

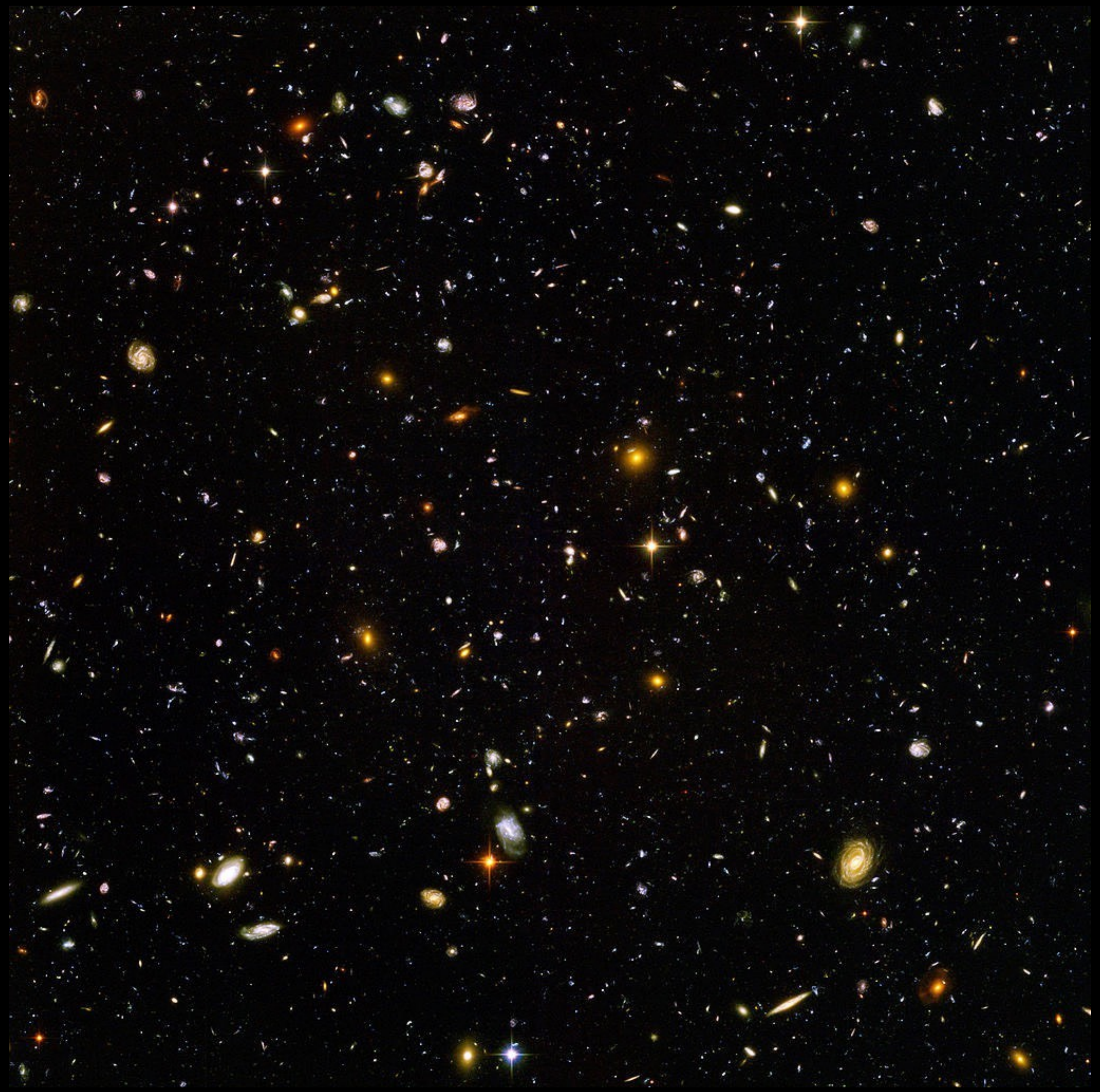
Discovered by Sir John Herschel in his Observatory at the Cape of Good Hope and copied from sketches



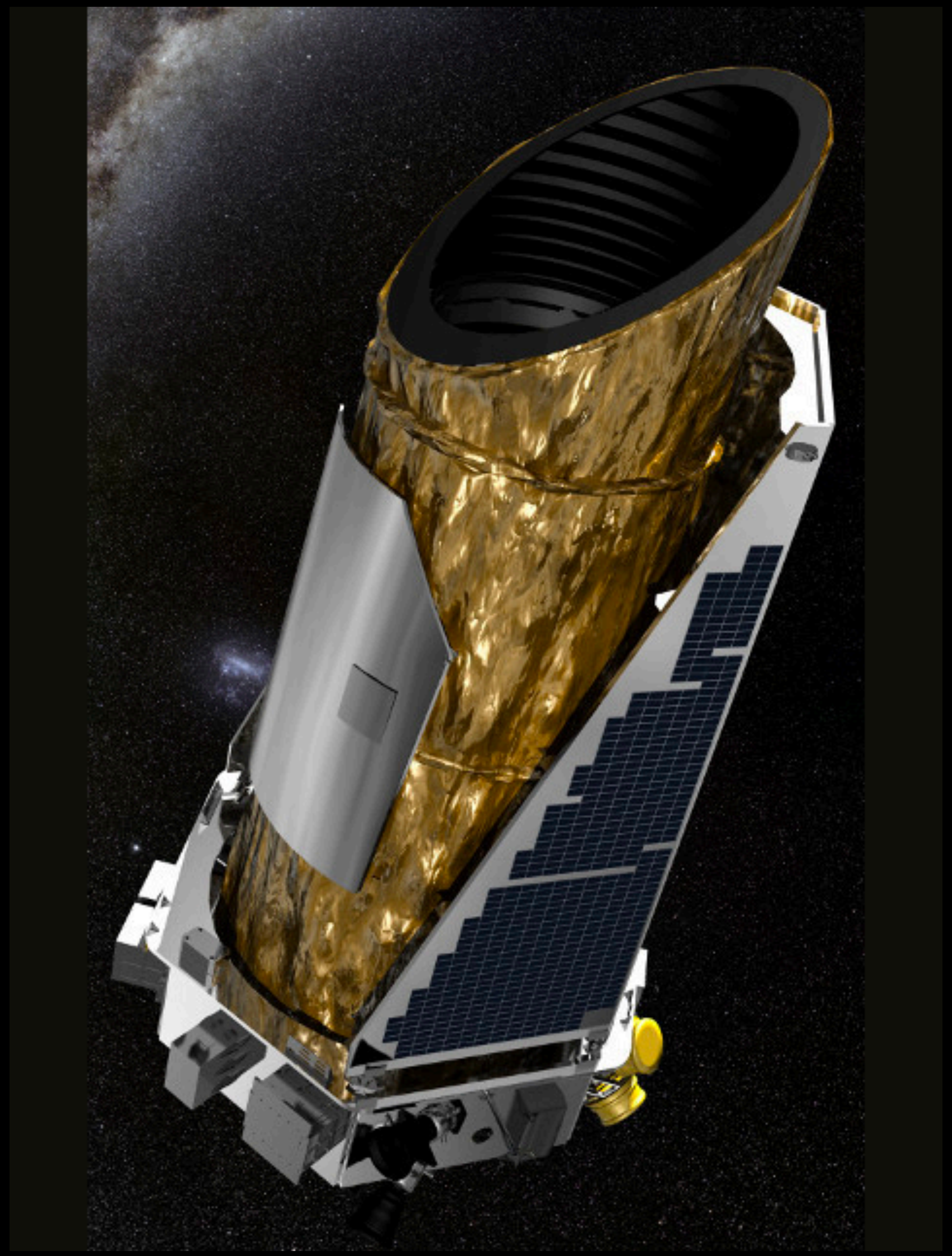
Geocentrism

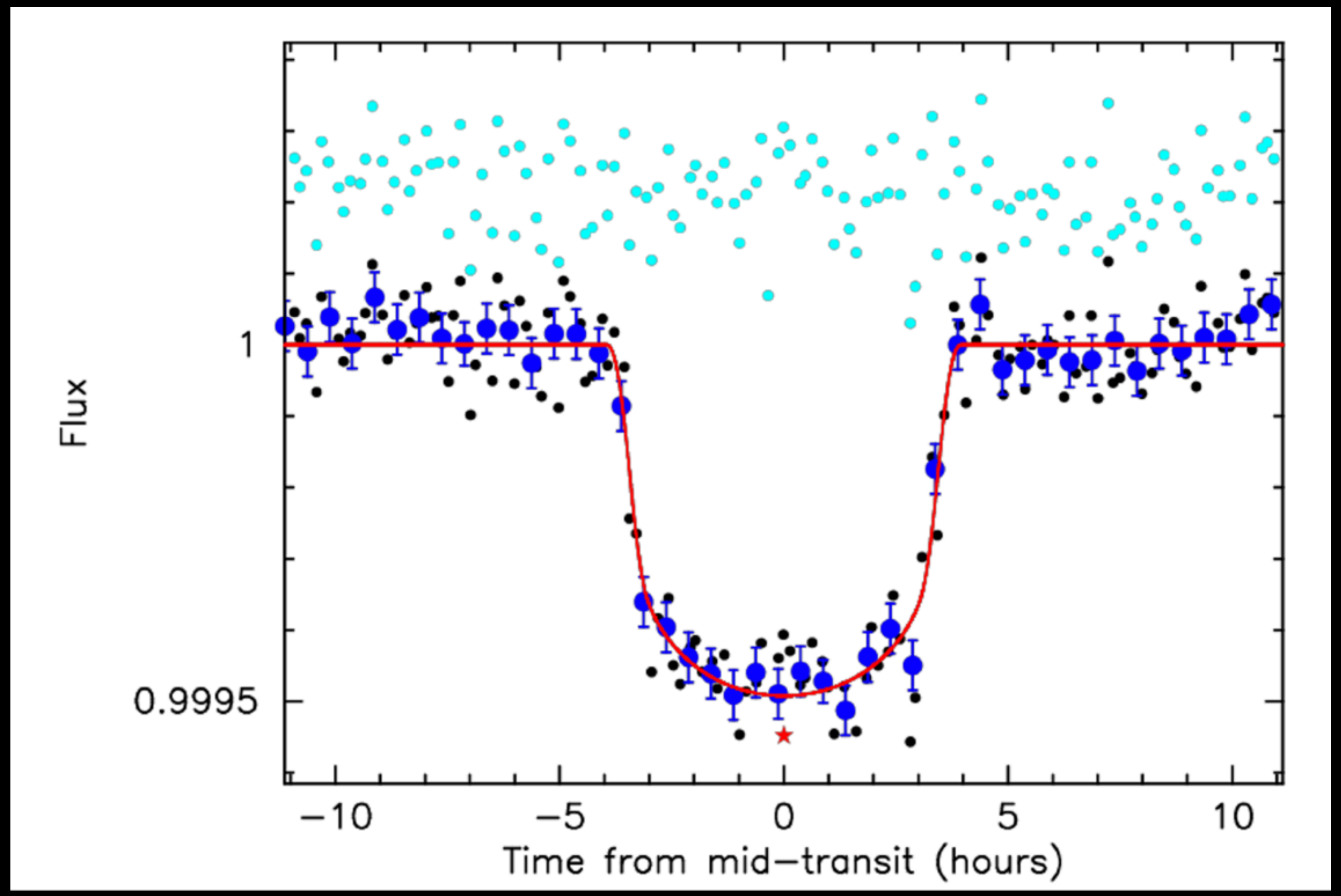




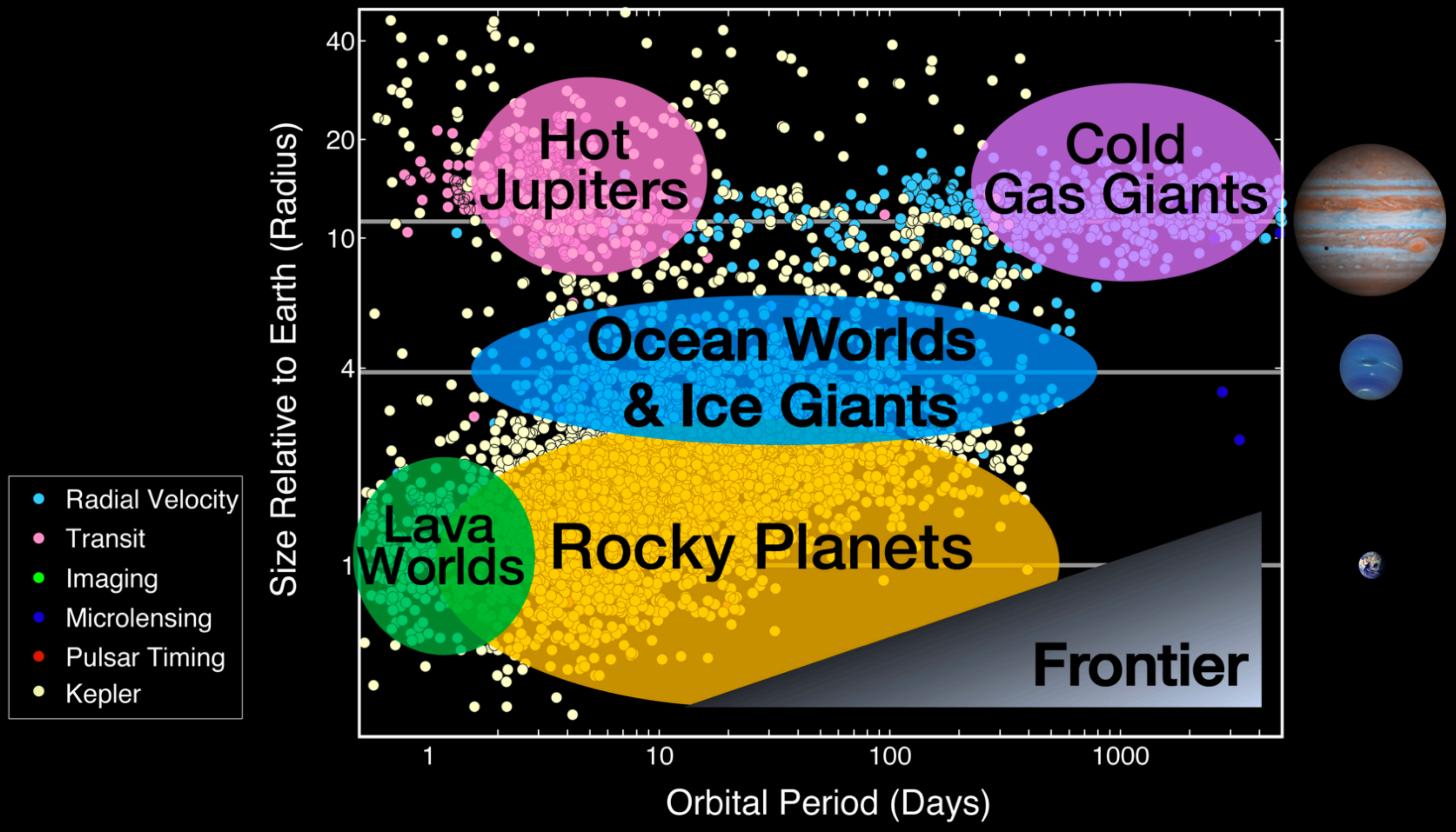


Galactocentrism





Exoplanet Populations



Goldilocks principle

“The Search for Extraterrestrial Intelligence represents the last battle over anthropocentrism.”

Steven J. Dick, 1993

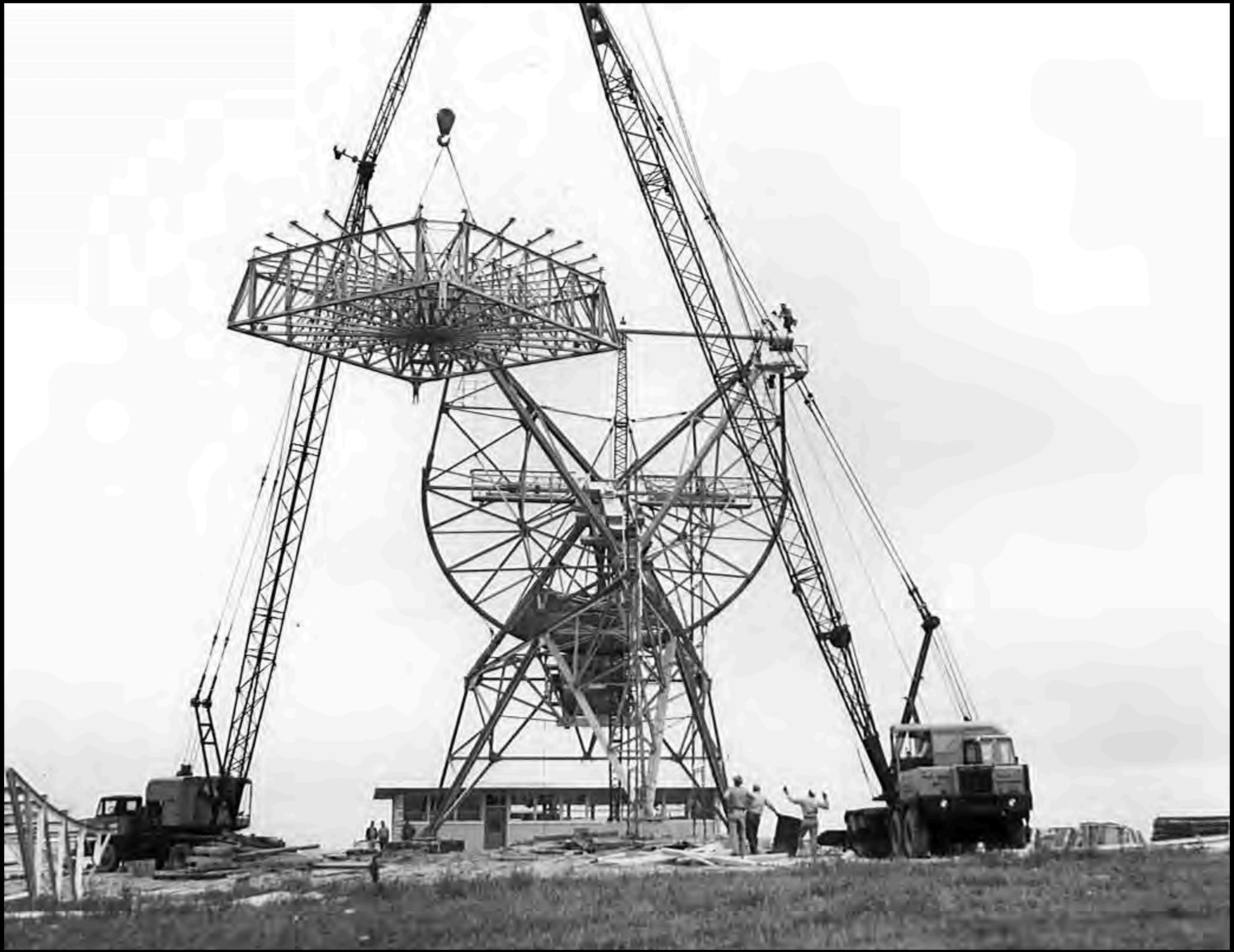
" Undoubtedly there are myriads of planets in the universe which were, are, or will be abodes of life in its highest forms. The same formative principles must be operative in the building up of the bodies of the inhabitants and their perceptions of the external world must be closely similar to ours. It is highly probable that many are as far, or even more, advanced than ourselves. Codes for communication and mutual understanding can be readily formulated on the basis of commonly perceived universal truths.

By my inventions it has become possible to transmit considerable amounts of energy at distances of thousands of light years and if received, it can be easily detected in many ways."

New York July 15. 1937

Nikola Tesla

DEDICATION OF RADIO ASTRONOMY OBSERVATORY
Green Bank, W. Va. - October 17, 1957
L to R: Dr. R. M. Emberson, Dr. L. V. Berkner, G. A. Nay, Dr. J. W. Findlay, Prof. N. L. Ashton, Dr. D. S. Heeschen, H. Hockenberry



Meetings: Problems of Detecting Extraterrestrial Life: Cambridge (Mass)

19-20 Dec 1958

SEE: ADM: ORG: NAS: Space Sc B Requests for Support: Proposals: Stanford U: Extraterrestrial Contamination & Detection of Life on Other Planets: Lederberg 1959: 13 Apr

National Academy of Sciences
2101 Constitution Avenue, N.W.
Washington 25, D. C.

SPACE SCIENCE BOARD

Meeting on the Problems of
Detecting Extraterrestrial Life

Massachusetts Institute of Technology

December 19 and 20, 1958

Participants:

Cowie	Hartline	Miller	Vishniac
Davies	Kamen	Rossi	Billings
Derbyshire	Levinthal	Schmitt	Freeman
Doty	Luria	Sistrom	Young
Gold	MacNichol	Townsend	

NATURE September 19, 1959

SEARCHING FOR INTERSTELLAR COMMUNICATIONS

By GIUSEPPE COCCONI* and PHILIP MORRISON†
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-

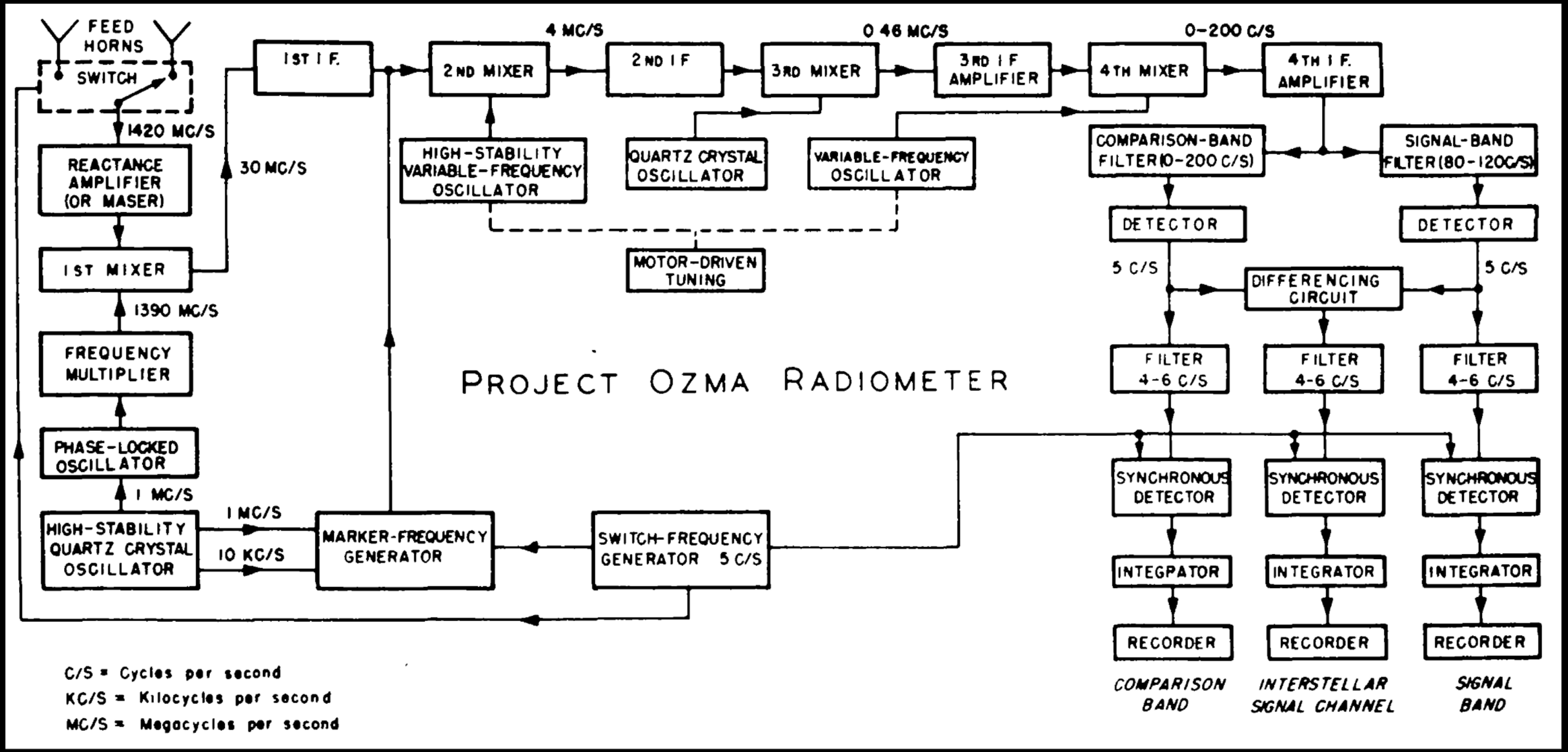
At what frequency shall we look ? A long spectrum search for a weak signal of unknown frequency is difficult. But, just in the most favoured radio region there lies a unique, objective standard of frequency, which must be known to every observer in the universe : the outstanding radio emission line at 1,420 Mc./s. (λ = 21 cm.) of neutral hydrogen. It is reasonable to expect that sensitive receivers for this frequency will be made at an early stage of the development of radio-astronomy. That would be the expectation of the operators of the assumed source, and the present state of terrestrial instruments indeed justifies the expectation. Therefore we think it most promising to search in the neighbourhood of 1,420 Mc./s.

Frank Drake

1930 - 2022

44

DATE	START (EST)	STOP	OP	PROG	RCVR	REMARKS
3 APRIL	1600	1720	RU BLM		ED	WARM-UP AFTER PWR FAILURE
"	1720	1900	RU	HHC	ED	
"	1900	2400	BLM RU	DSH	ED	
4 apr.	0000	0600	AD	DSH	ED	
5 APRIL	2300	2400	R/	FDD	ED	POSI. HORN
6 "	0000	0130	"	"	"	" "
6 April 60	0700	1600	OB			worked on Zeeman RXR!
6 APRIL	1700	2400	"			WORKED WITH MENNON ON ZEEMAN R
7 April	0000	0125	JR			" " " " "
9 APRIL	1600	2400	R/	WORK ON ZEEMAN RXR		
10 Apr. '60	0800	1600	F.C.	work on Zeeman RXRs — Still! It probably		
10 April 60	0800	1500	R.U. F.C.	Menon Zeeman Scan Drive Motor loads + stops		
10 April 60	1500	1600	R.U. F.C.	Drake Flare star		
10 APRIL 60	1600	2400	R/	WORK ON ZEEMAN		
11 " "	0000	0800	G^2	FDD·TKM	East end of Room	
11 April 60	0800	1600	RLU	TKM-FDD	Zeeman-Ozma	
" " "	1600	2400	R/	FDD	OZMA	
12 " '60	0000	0800	G^2	FDD TKM	Flare-Z	
12 april	1700	2400	AD	FDD	OZMA	
13 april	2400	0347	G^2	FDD	"	
"	0530	0800	G^2	TKM	Zeeman	
"	0800	1200	OB FC	TKM	"	
"	1430	1600	OB FC	FDD	OZMA.	
"	1600	1810	AD	FDD	"	
"	1815	2100	AD	FDD		calibrating bandspread dial
"	2100	2400	"	"	Flare Sta	
14 "	0000	0800	G^2	FDD TKM	Flare 4h FDD 4h TKM	
"	0800	1600	OB	TKM	Zeeman-Ozma	
"	1600	1830	AD	FDD	OZMA	
"	1900	2400	"	"	FLARE	
15 April	0000	0800	RLU	FDD/TKM	OZMA-ZEEMAN 4h FDD 4h TKM	Both brake lights
15 APRIL	0800	1300	BLM	TKM	ZEEMAN	
"	1300	1600	BLM	FDD	ZEEMAN	OZMA PROJECT
"	1600	1900	AD	FDD	"	" "
"	1900	2400	"	"	OZMA	FLARE STAR Sandborn recorder
16 April	0000	0400 (~~0800~~)	RLU	FDD	Flare	
	0400	0800	RLU	TKM	Zeeman	
16 APRIL	0800	1300	BLM	TKM	ZEEMAN	
"	1300	1600	BLM	FDD	"	OZMA PROGRAM
~~16 April~~	~~1600~~	~~2400~~	~~AD~~	~~FDD~~	ozma + Flare star	
16 April	1600	2400	AD +	FDD		
17 April	0000	0200	RLU	FDD		



Committees: Exobiology:
Meetings

REC'D USNC-IGY
OCT 18 1961
ROUTED TO:

18 Oct 1961

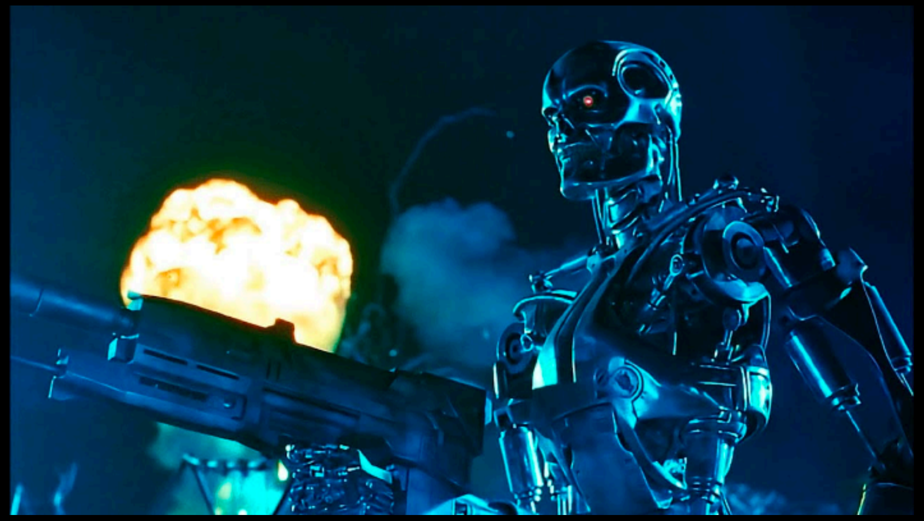
61 J 14/1-

TO: Exobiology Committee 14, Space Science Board, National Academy of Sciences

FROM: Joshua Lederberg, Chairman

Call for Meeting Saturday, October 28, 1961, 9:00 A.M.
Faculty Room, Dean's Office
Stanford Medical Center
Palo Alto, California

	Methods	Relevance to life
I. Atoms and nuclei H C O N P S	γ-ray spectra neutron activation electron-activation x-ray spectra X-ray absorption Mass spectra Conversion to molecules for (2) λ-ray back scattering	Particular (inference from high local concentration and variety): clues to higher complexity abundance: defines habitat.
II. Inorganic Molecules H_2O CO_2 CH_4 NH_3	Mass spectra Gas chromatography volatility and ionization, IR, UV detectors Special methods - hygrometry by conductivity; CO_2 by alkali absorption	Particular - as decomposition products of higher complexity abundance: defines habitat
III. Organic Molecules amino acids sugars nucleins lipids metabolites	Mass spectra IR absorption spectra UV absorption spectra ESR and NMR (Spectro) polarimetry Gas chromatography Special reagents, e.g., specific enzymes	Particular - as evidence of metabolism. Apart from specific identification net optical activity implies asymmetric catalysis.
IV. Macromolecules Proteins Nucleic acids polysaccharides usually determined as agregates with high molecular weight, decomposable to the monomers	Diffusion: dialysis; molecular sieves, ultracentrifugation solubility end group analysis electron microscopy functional tests: enzymes and antigens Special reagents: enzymes and stains	May be reasonably decisive of some stage of life if the identification is adequate
V. Organized Structures (cells, organelles)	Microscopy Decomposition to components analysable by destructive methods Non-destructive methods (spectroscopy) Separation by density	Form alone may or may not be persuasive; more so in combination with other analytical data, e.g, spectra - or with functional evidence: motility, catalysis, metabolism
VI. Artefacts (functional byproducts of life)	Microscopy Photography	Evidence of purposeful activity, e.g., bee hives, bomb shelters
VII. Information	Visual Acoustic Radio	Intelligent communication

$N =$ 5 · 1 · 1/5 · ? · ? · ? · 

$$N = 5 \cdot 1 \cdot 1/5 \cdot 1 \cdot 1 \cdot 1 \cdot L$$


FEB
CALIFORNIA
NEQLS L
UCSC

ICARUS 19, 329–340 (1973)

A Search for Narrow Band 21-cm Wavelength Signals from Ten Nearby Stars

G. L. VERSCHUUR

National Radio Astronomy Observatory, Green Bank, West Virginia 24944

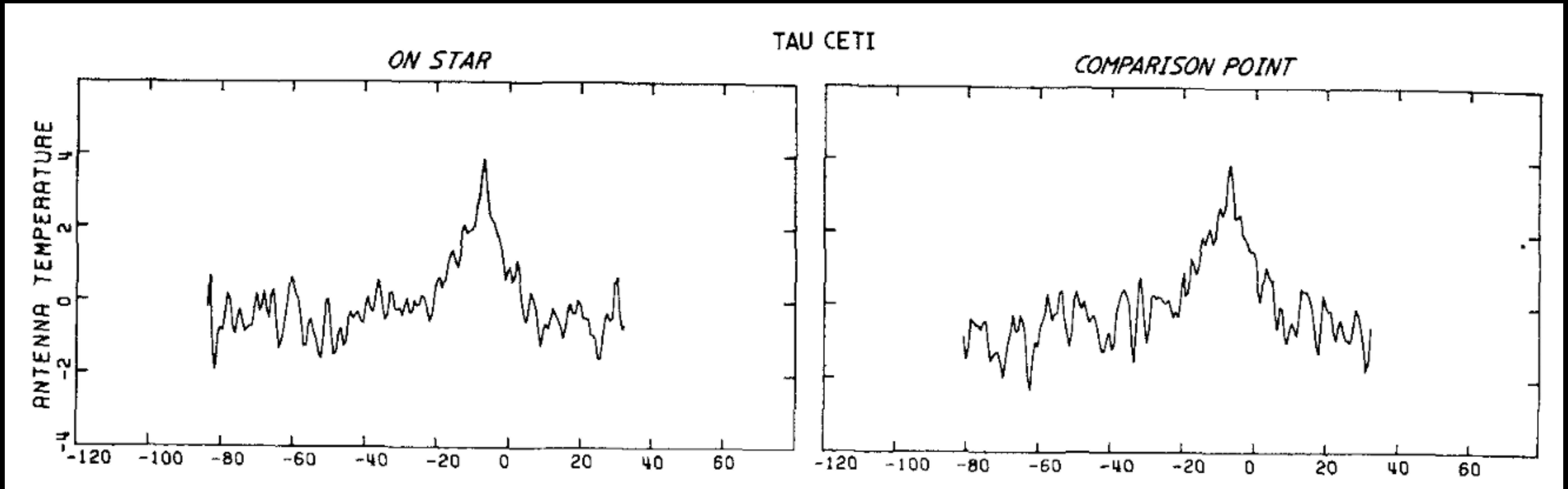
Received February 21, 1973

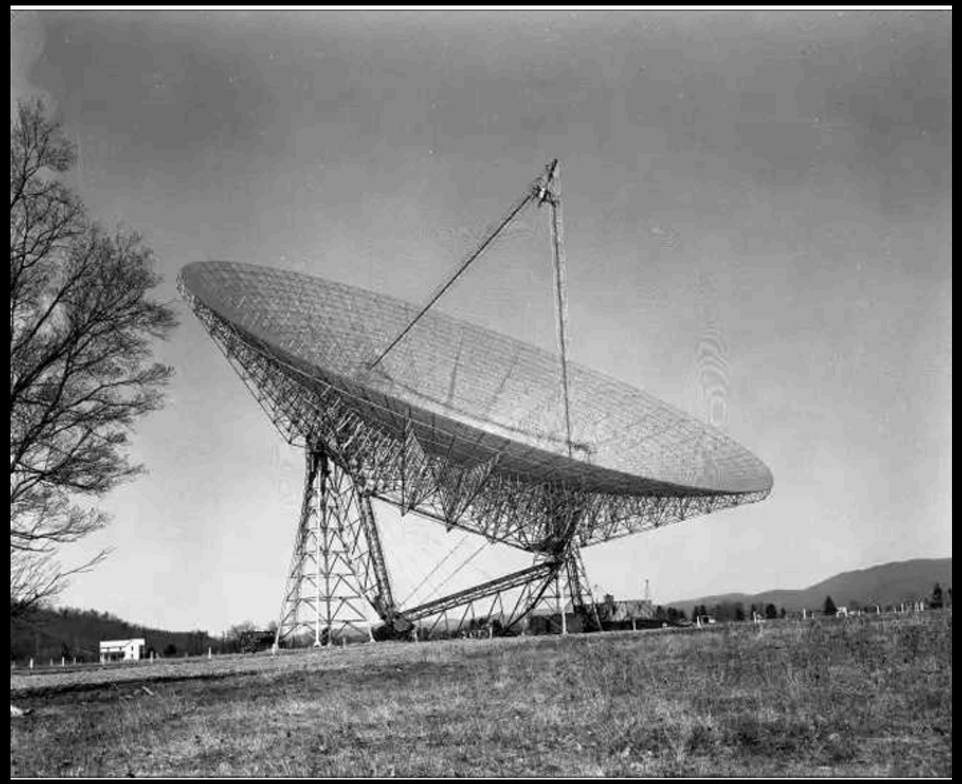
A search for narrow band radio signals, in the 21-cm wavelength band, possibly generated by other civilizations, has been made in the direction of ten stars. No such signals were found and upper limits to the power of possible transmissions toward the Earth are given.

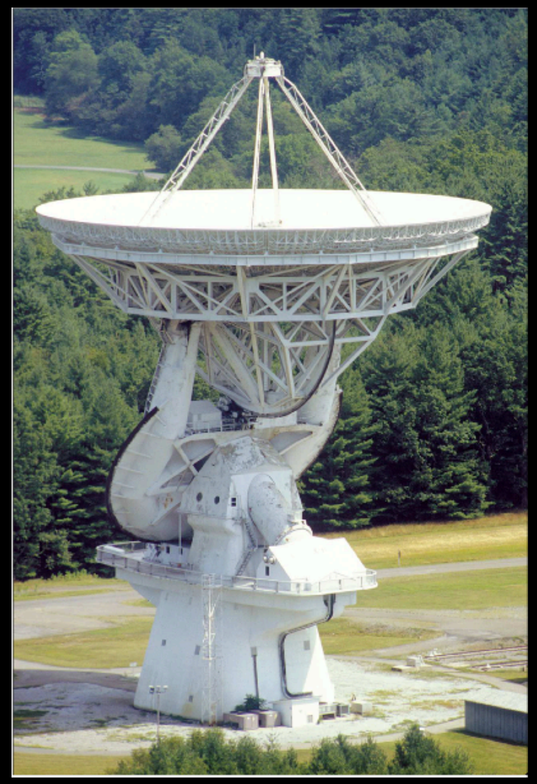
Ozpa, 1971-72

GBO 140′ / 300′

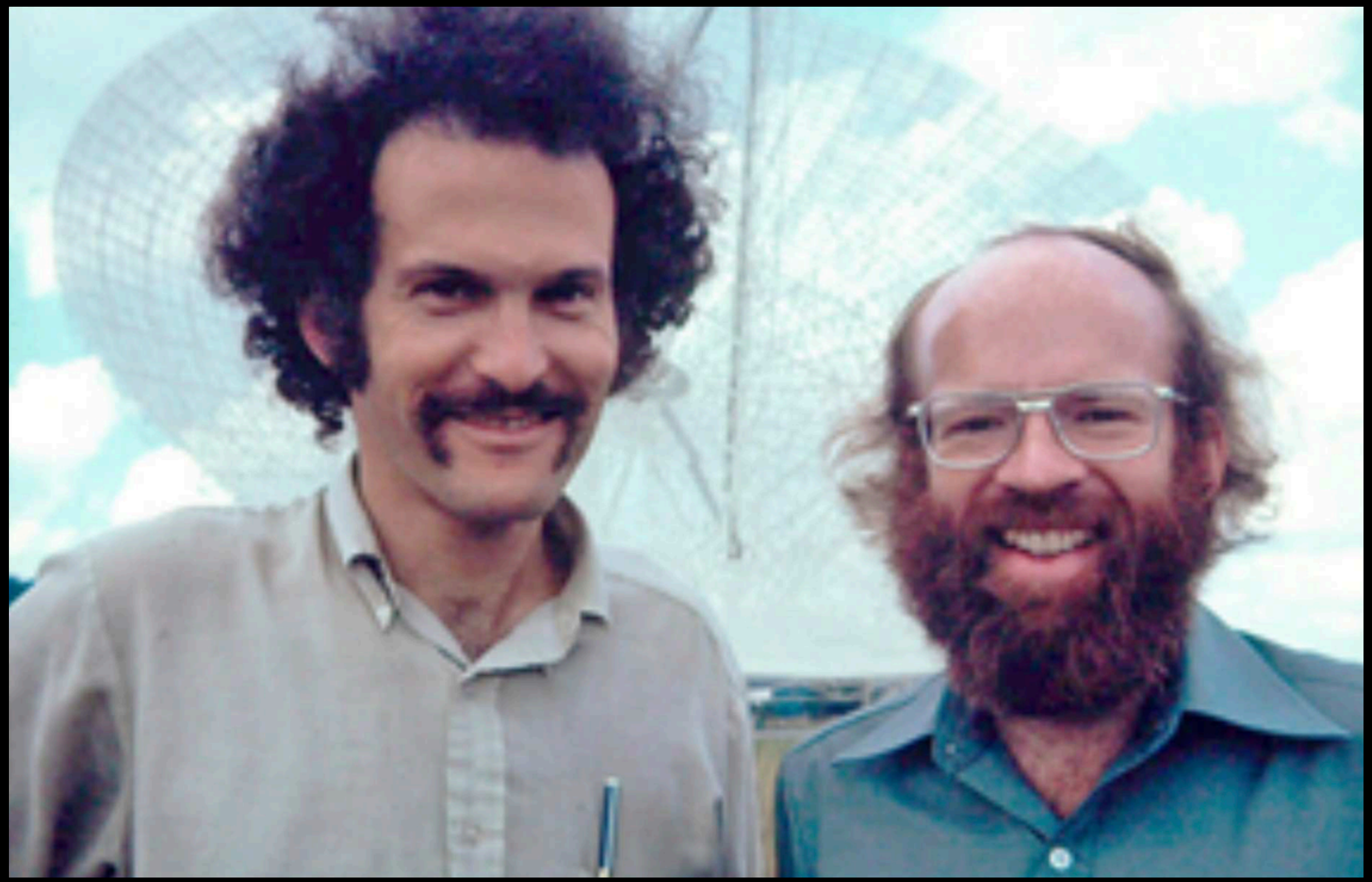
5 mins = 4 days of Ozma







Ozma II - Palmer and Zuckerman



We now have a 400-channel correlator (Frank had a 1 channel scanning radiometer), a 300-foot telescope (Frank used 85-1), and two 50°K 21 cm paramps (Frank's amplifier was typically 500°K). All of these effectively allow us to take data 10,000,000 times faster than in the original Ozma experiment ... We were given a week on the 300-foot telescope to carry out our search. (Palmer and Zuckerman, 1972: 26).

Parameter	Value
Dates	1972–1976
Antenna Diameter	NRAO 91 m
HPBW	10–11 arcmin
Stars	~670 nearby stars
System Temperature	50K
Integration Time	4 minutes day^{-1}
Total Time	500 hr
Spectral Window 1	1420.1–1420.7
Width	625 kHz
Channels	192
Resolution	4 kHz
Sensitivity	10^{-23} W/m^2
Spectral Window 2	1413–1421.5 MHz
Width	10 MHz
Channels	192
Resolution	52 kHz
Sensitivity	3×10^{-24} W/m^2

ICARUS 42, 136–144 (1980)

A High-Sensitivity Search for Extraterrestrial Intelligence at λ18 cm

J. TARTER

Space Sciences Laboratory, University of California, Berkeley, California 94720

J. CUZZI AND D. BLACK

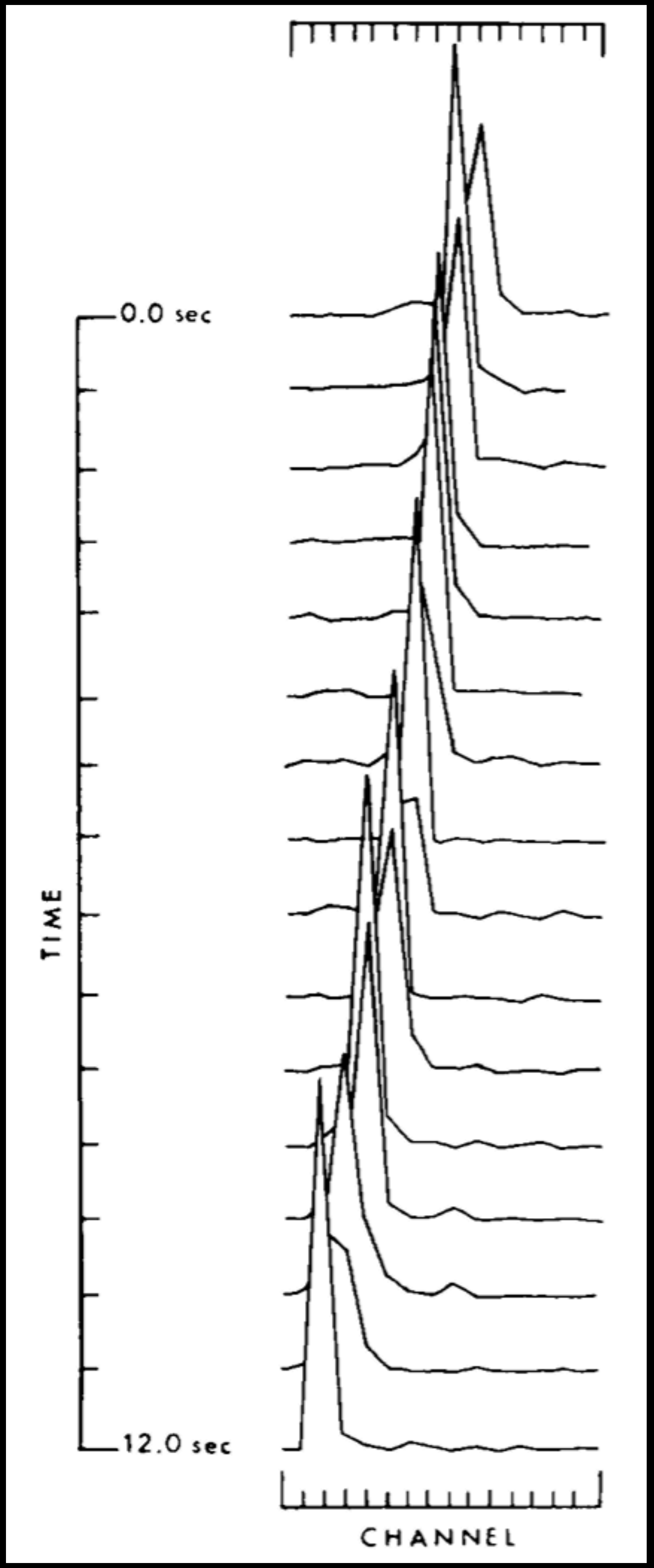
Theoretical and Planetary Studies, NASA–Ames Research Center, Moffett Field, California 94035

AND

T. CLARK

Radioastronomy Branch, NASA–Goddard Space Flight Center, Greenbelt, Maryland 20770

Tarter



300′ telescope

201 stars

65k channels via tape + offline FFT

Comparison scans offset in RA

Much of this project has been supported under NASA Grant NSG 2271 (J.T.) and NASA Interchange NCA2-ORO50-702 (J.C.).

Date	1983
Observer(s)	DAMASHEK
Site	NRAO
Instrument Size (m)	92
Search Frequency (MHz)	382 – 398
Search Wavelength (nm)	
Frequency Resolution (Hz)	2×10^{6}
Other Resolution	
Objects (Hz)	SKY SURVEY (PULSARS)
Flux Limit (W m^{-2})	2×10^{-22}
Total Hours	700
Reference	
Link	
Comments	Sixteen MHz sampled at 60 Hz; 8 contiguous frequency channels. Search for single dispersed pulses and telemetry (bit stream) signals.

THE BERKELEY PIGGYBACK SETI PROGRAM: SERENDIP II

S. Bowyer and D. Werthimer
Space Sciences Laboratory, University of California
Berkeley CA 94720 USA
V. Lindsay
San Francisco State University
San Francisco CA 94132 USA

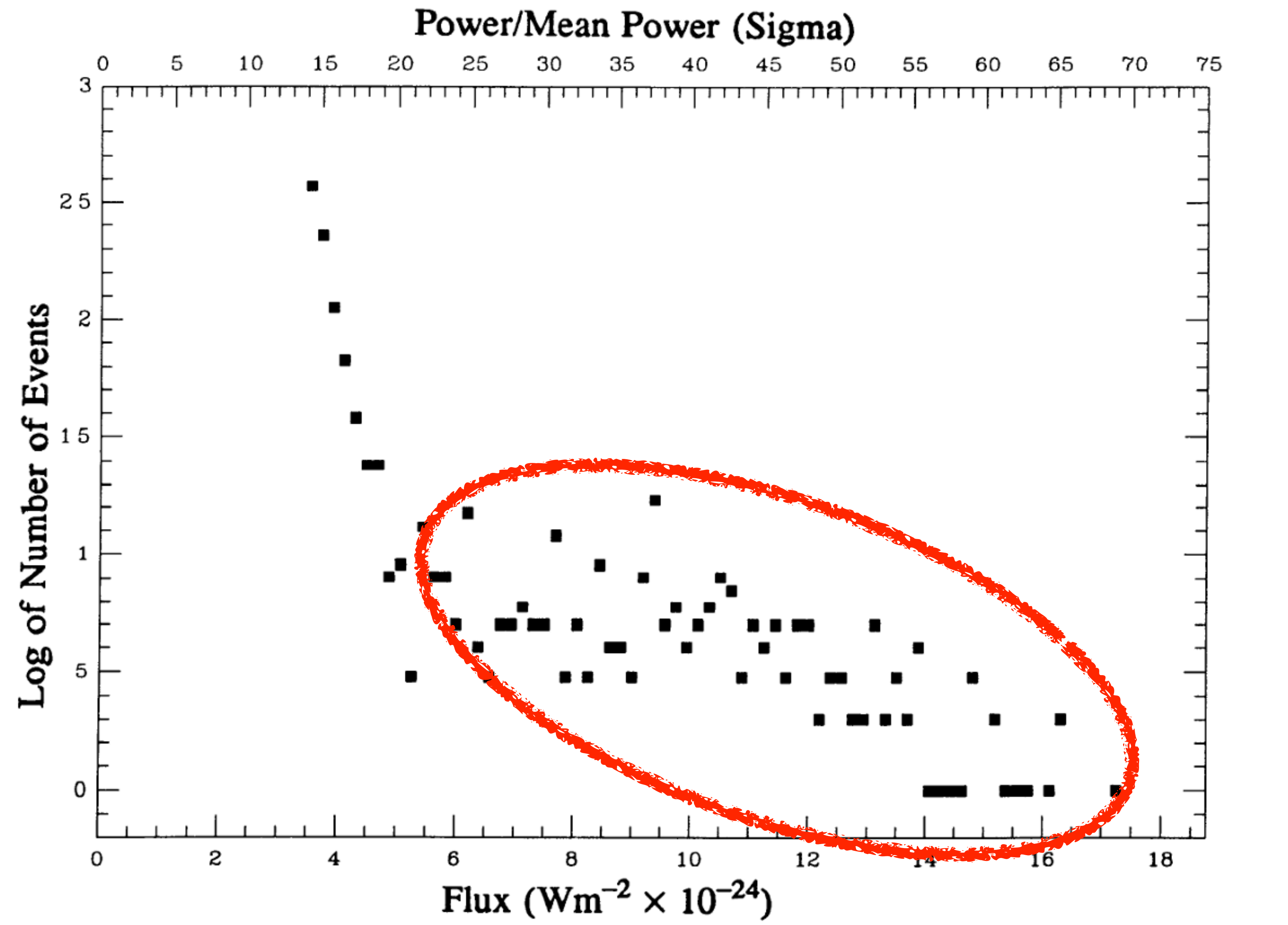


Figure 3. Distribution of events logged by SERENDIP during one day's run.

300′ telescope

Commensal

885 hours in 1986-87

Look for 15-sigma signals that don't occur at more than one sky position

Date	1986
Observer(s)	MIRABEL
Site	NRAO
Instrument Size (m)	43
Search Frequency (MHz)	4829.620 – 4829.776
Search Wavelength (nm)	
Frequency Resolution (Hz)	76
Other Resolution	
Objects (Hz)	GALACTIC CENTER & 33 NEARBY STARS
Flux Limit (W m^{-2})	6 x 10^{-25} to 10^{-24}
Total Hours	144
Reference	
Link	
Comments	Search at H 2 CO frequency. Included star HD170493 located in front of dark “anti-maser” cloud.

SEARCH FOR INTERSTELLAR BEACONS AT THE ^{3}HE$^+$ HYPERFINE TRANSITION FREQUENCY

THOMAS M. BANIA
Department of Astronomy, Boston University, 725 Commonwealth Ave., Boston, Massachusetts 02215

ROBERT T. ROOD
Department of Astronomy, University of Virginia, Box 3818 University Station, Charlottesville, Virginia 22093

31 Aug / 1 Sep 1988

Select 7 stars with 60-micron excess (Dyson spheres?)

Observe at 8.7 GHz with 140′ telescope

6 mins on / 6 mins off

Project Phoenix: A Summary of SETI Observations and Results, 1995 - 2004

Show affiliations

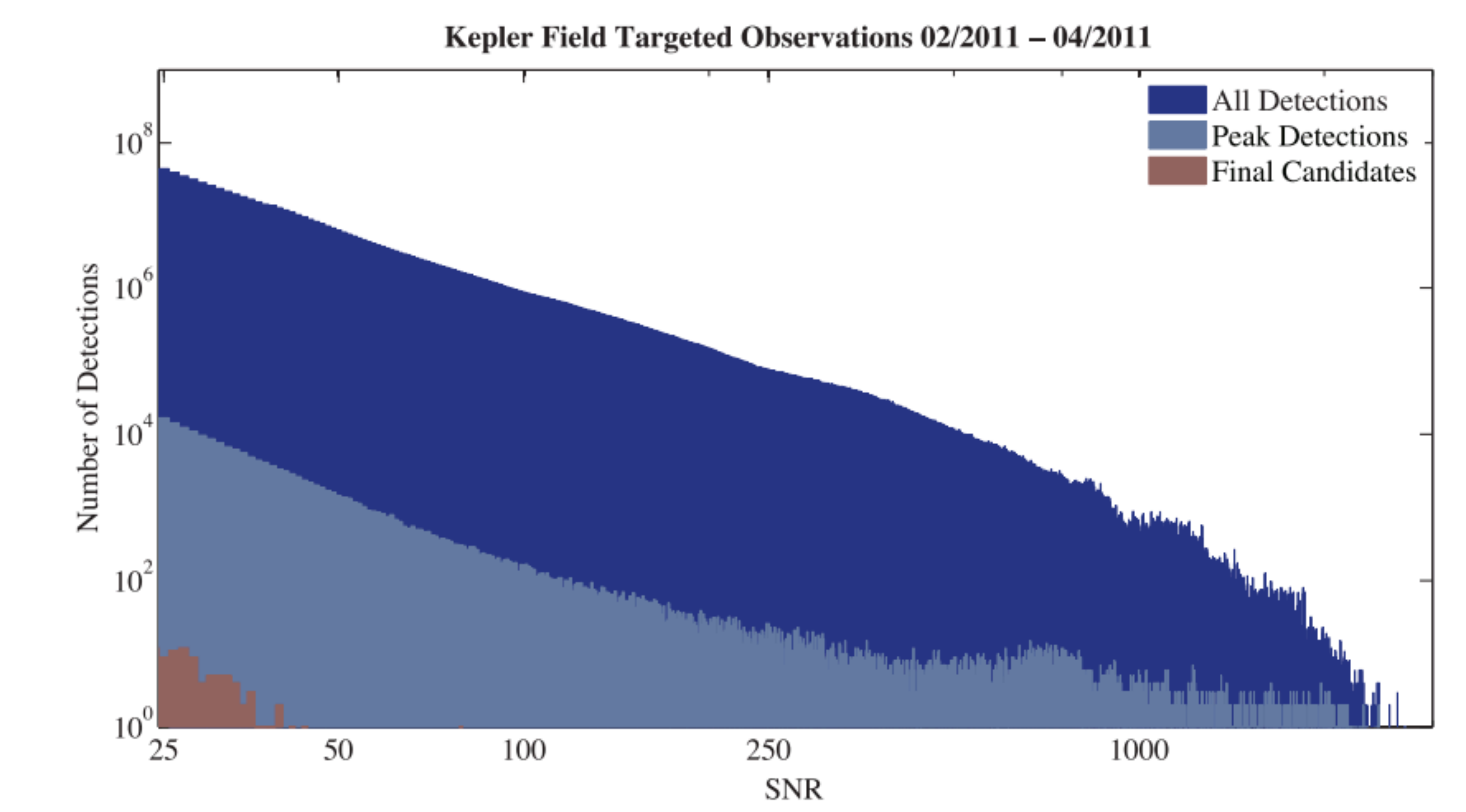
Backus, P. R. ; Project Phoenix Team

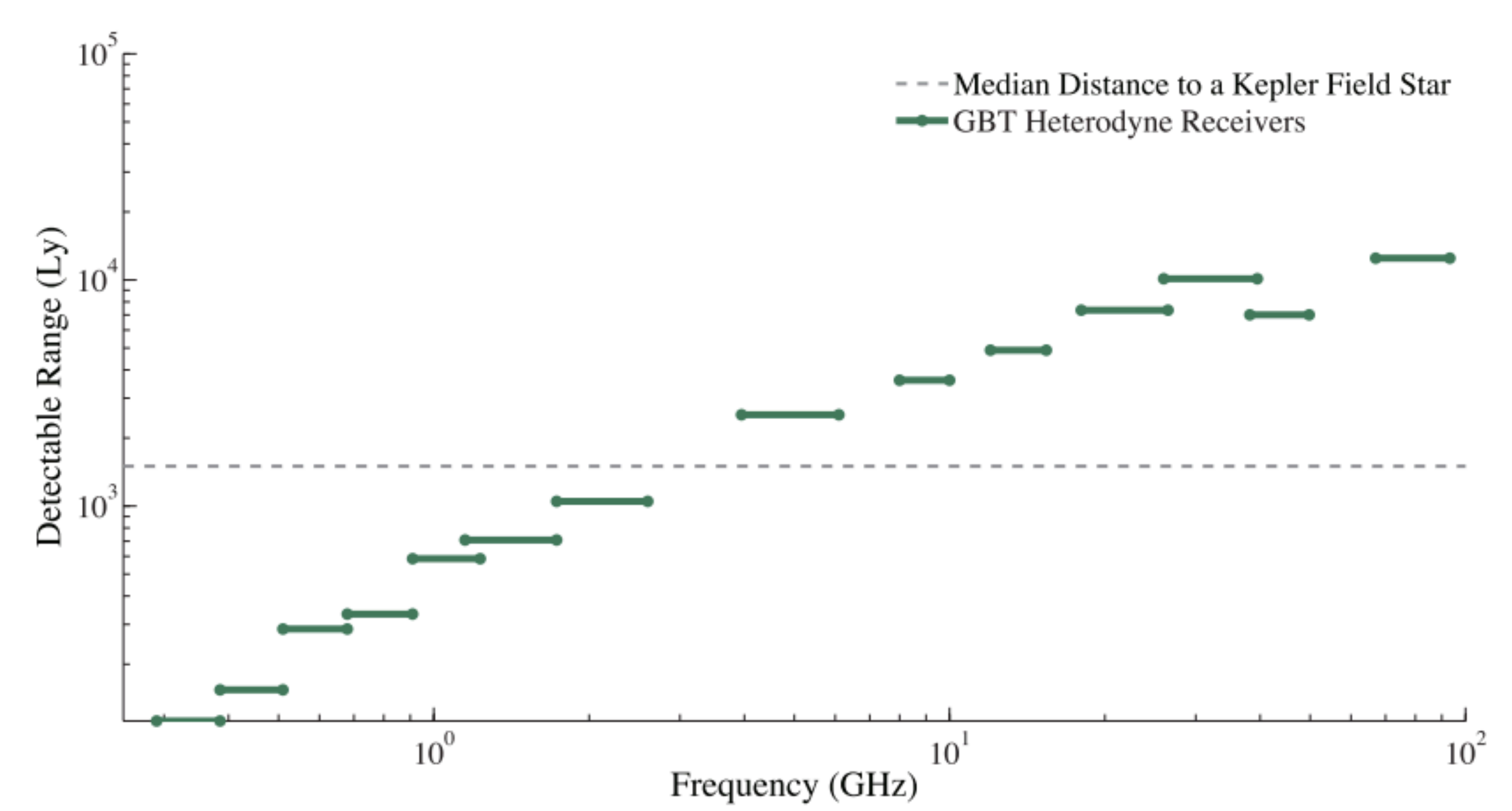
Project Phoenix was a Search for Extraterrestrial Intelligence (SETI) that observed nearly 800 stars within about 80 parsecs over the available frequencies in the microwave spectrum from 1200 to 3000 MHz with a resolution of 0.7 Hz. The search had three major observing campaigns using the Parkes 64 meter, the NRAO 140 Foot, and the Arecibo 305 meter antennas. Phoenix used real time signal detection and immediate verification of possible ETI signals. The search looked for narrowband signals that were continuously present, or pulsed regularly, and allowed for frequency drift rates of up to about 1 Hz per second. A database of terrestrial signals found in the previous week was used to match against detections for each observation. Candidate signals, i.e., those not in the database, were checked immediately with a "pseudo-interferometric" observation using a second, distant antenna, or by simple on-off observations if the second antenna was unavailable. While millions of signals were detected, all proved to be from terrestrial technology. In conclusion, we can set upper limits on the power of narrowband transmitters in the vicinity of nearby stars.

The Astrophysical Journal, 767:94 (13pp), 2013 April 10 doi:10.1088/0004-637X/767/1/94

A 1.1–1.9 GHz SETI SURVEY OF THE *KEPLER* FIELD. I. A SEARCH FOR NARROW-BAND EMISSION FROM SELECT TARGETS

Andrew P. V. Siemion[1], Paul Demorest[2], Eric Korpela[1], Ron J. Maddalena[2], Dan Werthimer[1], Jeff Cobb[1], Andrew W. Howard[3], Glen Langston[2], Matt Lebofsky[1], Geoffrey W. Marcy[1], and Jill Tarter[4]
[1] University of California, Berkeley, 110 Sproul Hall, Berkeley, CA 94720, USA
[2] National Radio Astronomy Observatory, 520 Edgemont Rd Charlottesville, VA 22903, USA
[3] Institute for Astronomy, University of Hawaii, 640 North A'ohōkū Place, #209 Hilo, HI 96720-2700, USA
[4] SETI Institute, 189 Bernardo Ave #100 Mountain View, CA 94043, USA
Received 2012 December 6; accepted 2013 February 3; published 2013 March 28





YouTube

Search

0:40 / 7:50

Visit the Green Bank Telescope in VR (Part One)

4,508 views • Jun 29, 2017

82 3 SHARE SAVE

BerkeleySETI
4.29K subscribers

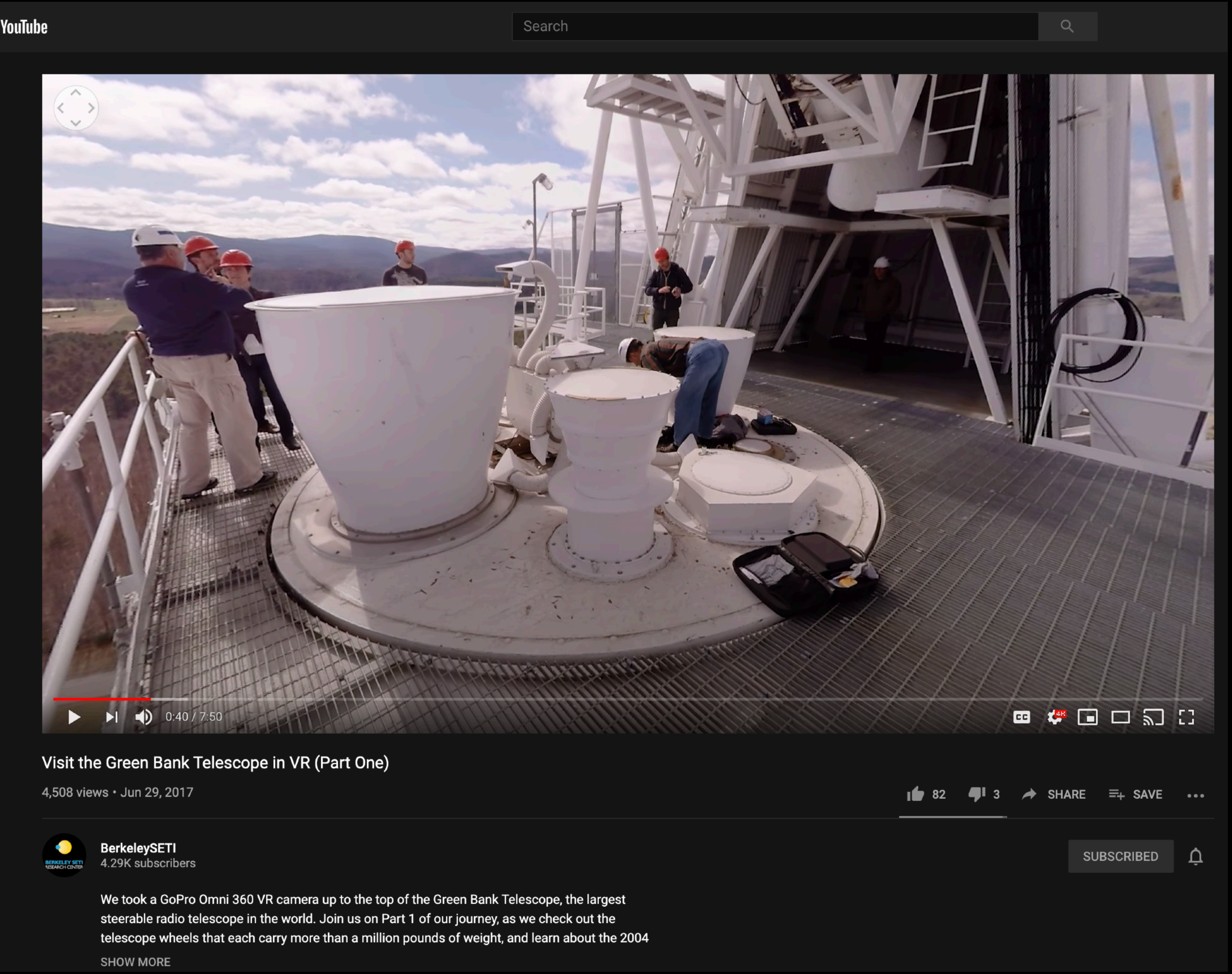
SUBSCRIBED

We took a GoPro Omni 360 VR camera up to the top of the Green Bank Telescope, the largest steerable radio telescope in the world. Join us on Part 1 of our journey, as we check out the telescope wheels that each carry more than a million pounds of weight, and learn about the 2004

SHOW MORE

@BerkeleySETI

SERENDIP VI



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Search
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Visit the Green Bank Telescope in VR (Part One)
4,508 views • Jun 29, 2017
82
3
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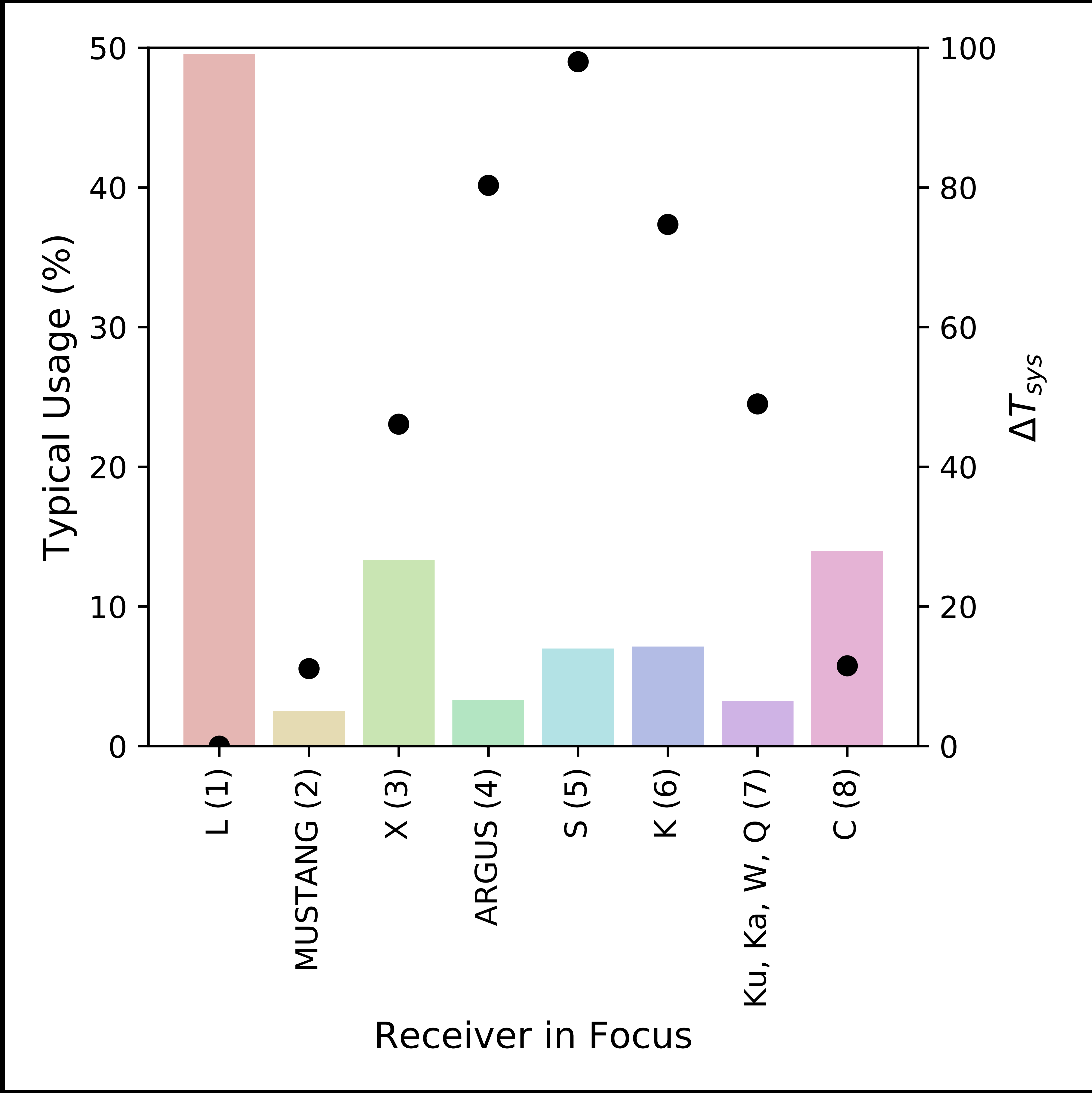
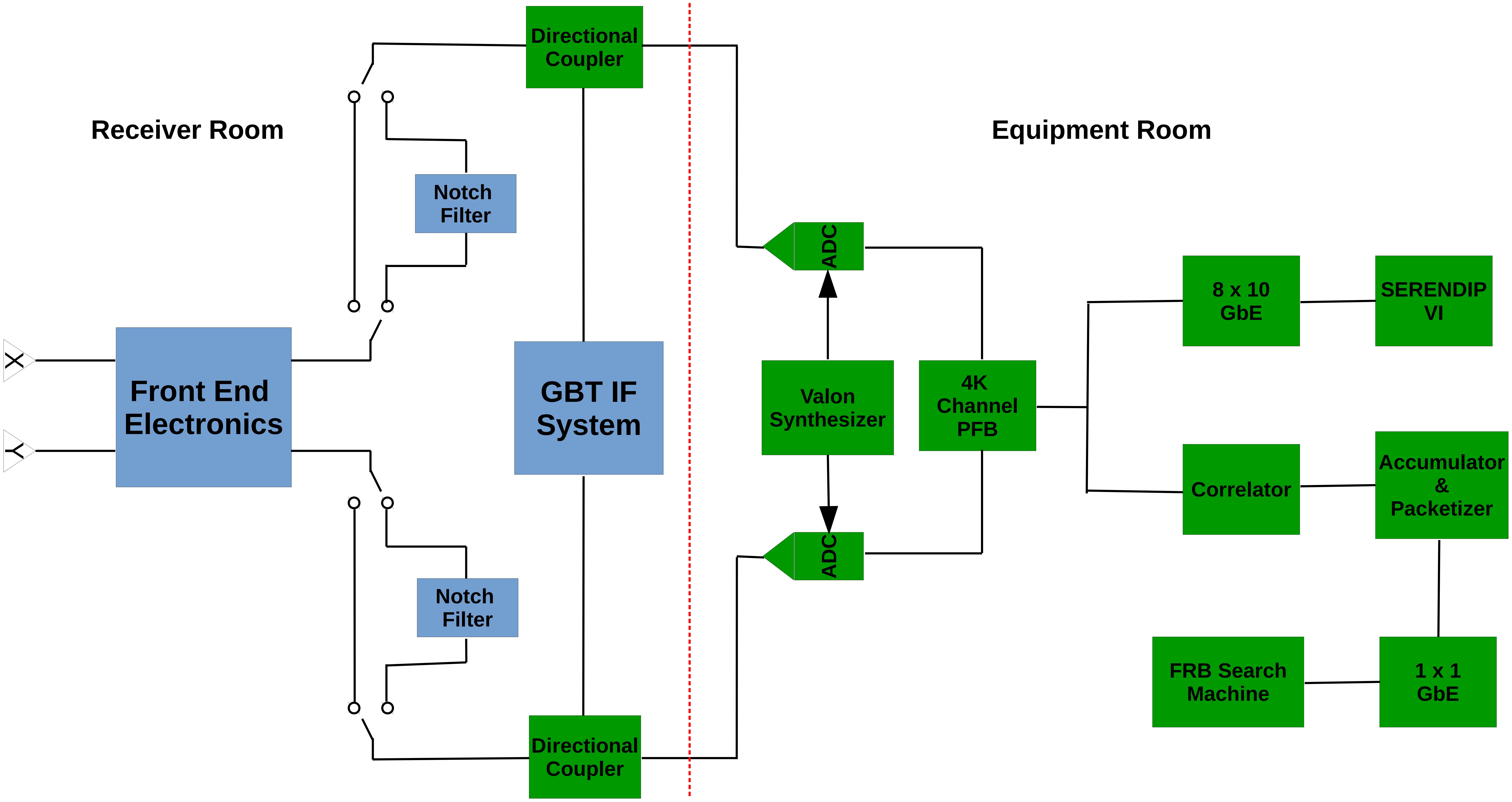
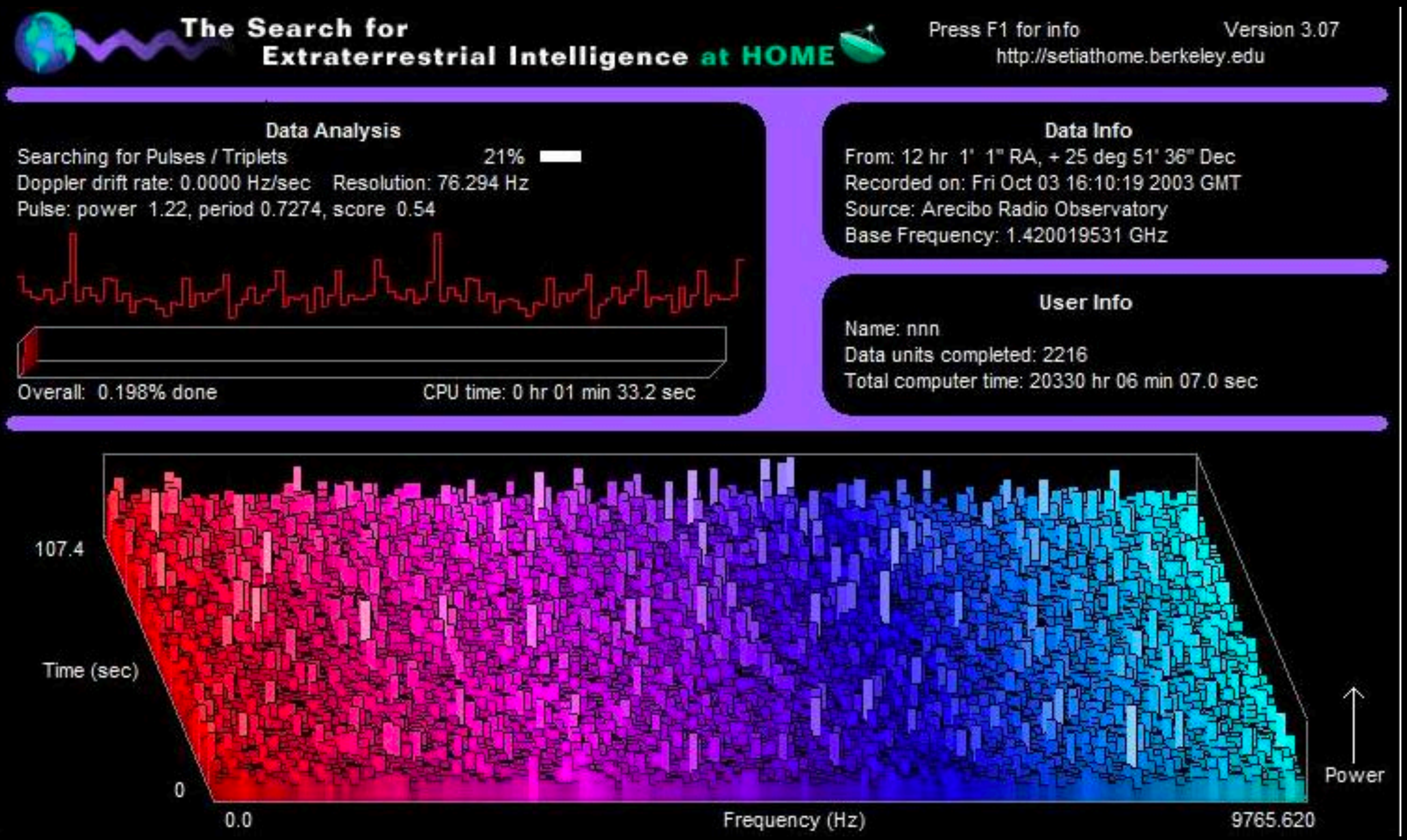
We took a GoPro Omni 360 VR camera up to the top of the Green Bank Telescope, the largest steerable radio telescope in the world. Join us on Part 1 of our journey, as we check out the telescope wheels that each carry more than a million pounds of weight, and learn about the 2004
SHOW MORE



Typical Usage (%)
0
10
20
30
40
50
ΔT_sys
0
20
40
60
80
100
L (1)
MUSTANG (2)
X (3)
ARGUS (4)
S (5)
K (6)
Ku, Ka, W, Q (7)
C (8)
Receiver in Focus


Receiver Room
Equipment Room
X
Y
Front End Electronics
Notch Filter
Notch Filter
Directional Coupler
Directional Coupler
GBT IF System
ADC
ADC
Valon Synthesizer
4K Channel PFB
8 x 10 GbE
SERENDIP VI
Correlator
Accumulator & Packetizer
FRB Search Machine
1 x 1 GbE


The Search for
Extraterrestrial Intelligence at HOME
Press F1 for info
Version 3.07
http://setiathome.berkeley.edu
Data Analysis
Searching for Pulses / Triplets 21%
Doppler drift rate: 0.0000 Hz/sec Resolution: 76.294 Hz
Pulse: power 1.22, period 0.7274, score 0.54
Overall: 0.198% done
CPU time: 0 hr 01 min 33.2 sec
Data Info
From: 12 hr 1' 1" RA, + 25 deg 51' 36" Dec
Recorded on: Fri Oct 03 16:10:19 2003 GMT
Source: Arecibo Radio Observatory
Base Frequency: 1.420019531 GHz
User Info
Name: nnn
Data units completed: 2216
Total computer time: 20330 hr 06 min 07.0 sec
107.4
Time (sec)
0
0.0
Frequency (Hz)
9765.620
Power

BL Backend

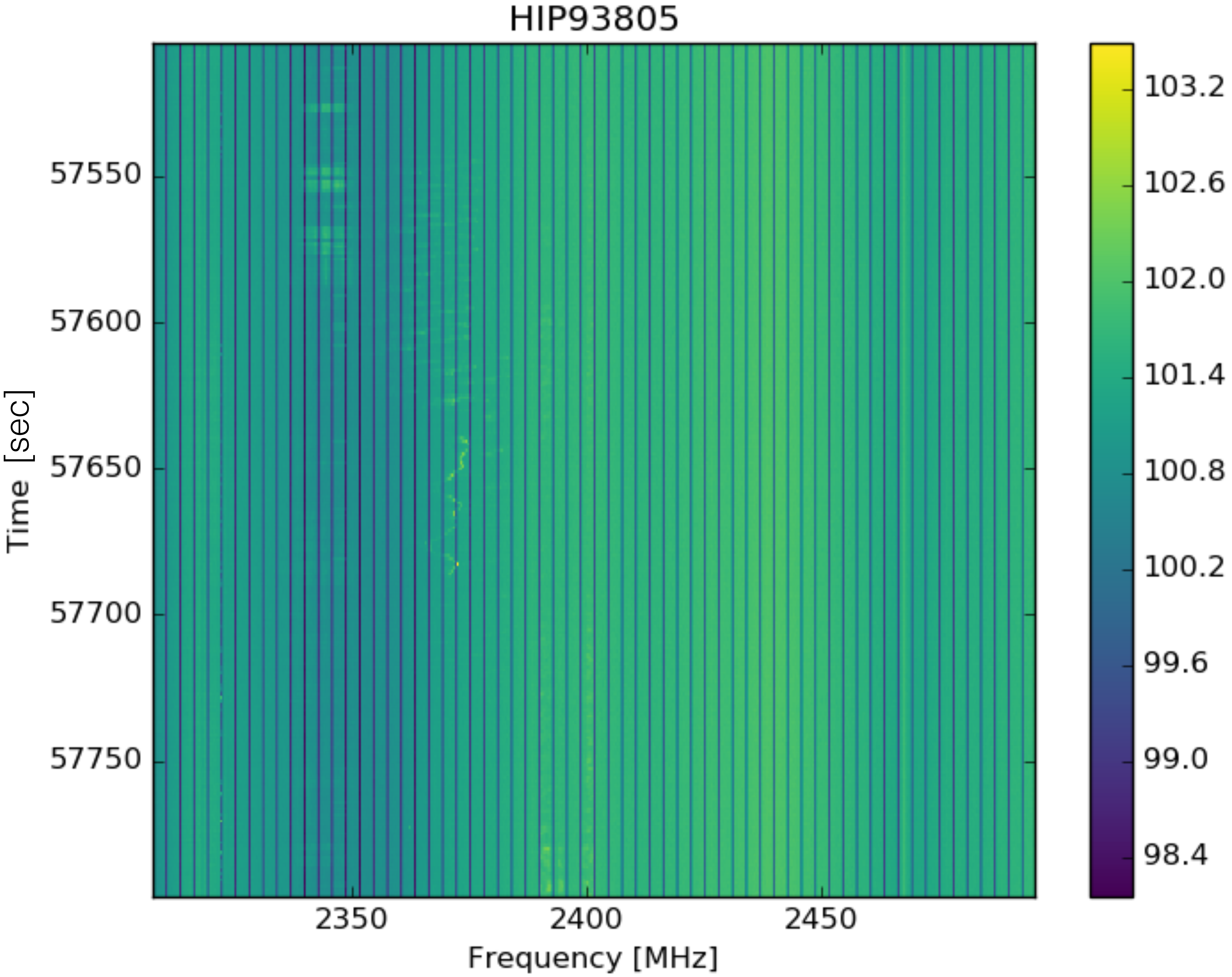
arxiv.org/abs/1707.06024

arxiv.org/abs/1804.04571

- 12 GHz bandwith
- 3 Hz resolution
- 8 PB storage
- 500 TFLOPS
- ~750 MB/sec/compute node complex voltages
- Observing ~5 hours a day (20% time)
- Over 6 PB of GBT data in the archive

Green Bank Data Products

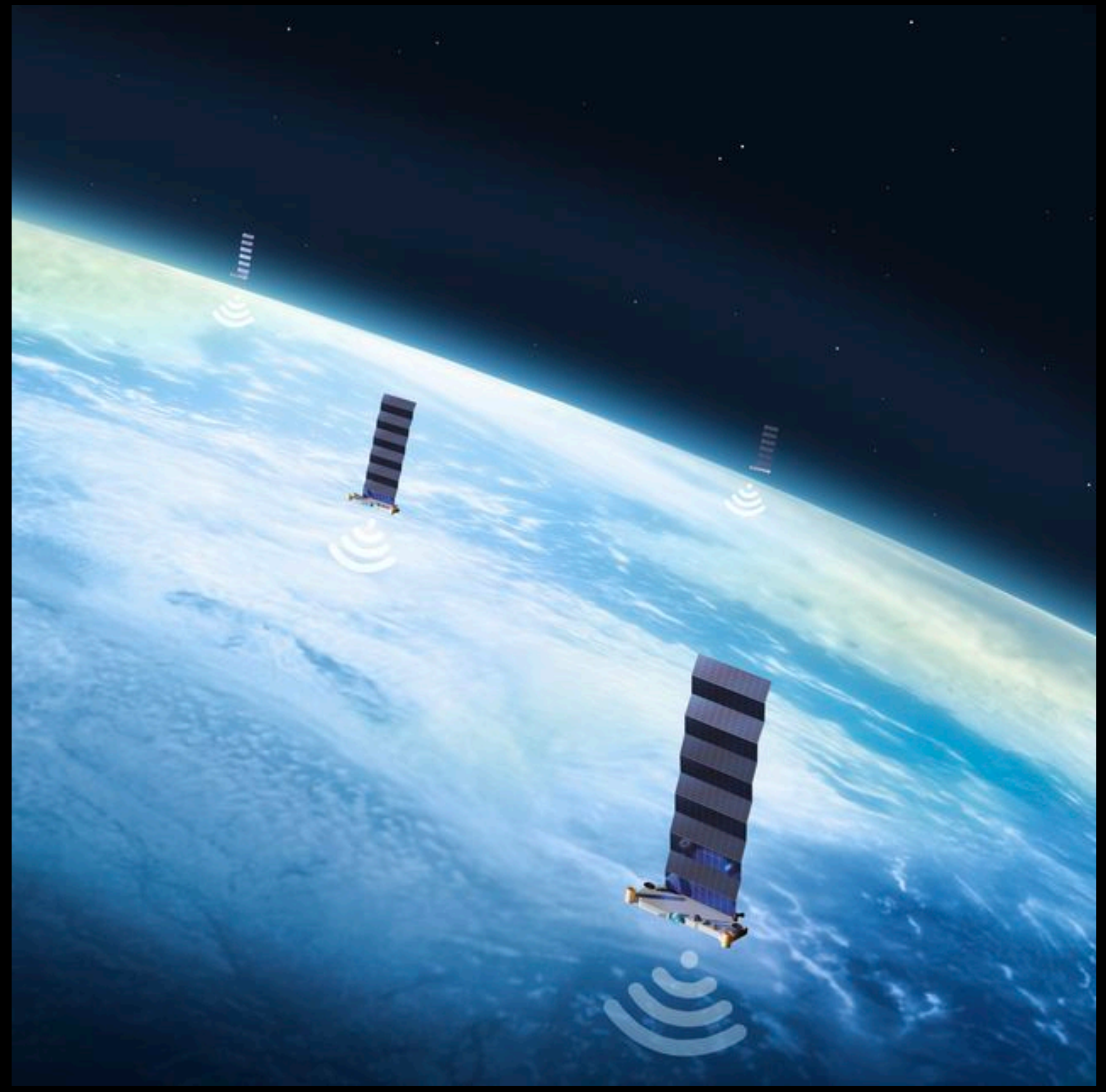
High freq. resolution	~3 Hz frequency bin resolution, ~18 second sample time (SETI)
Medium resolution	~3 kHz frequency bin resolution, ~1 second sample time
High time resolution	~366 kHz frequency bin resolution, ~349 us sample time (pulsar)


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


PAN AM
PAN AM


PAN AM


NETGEAR

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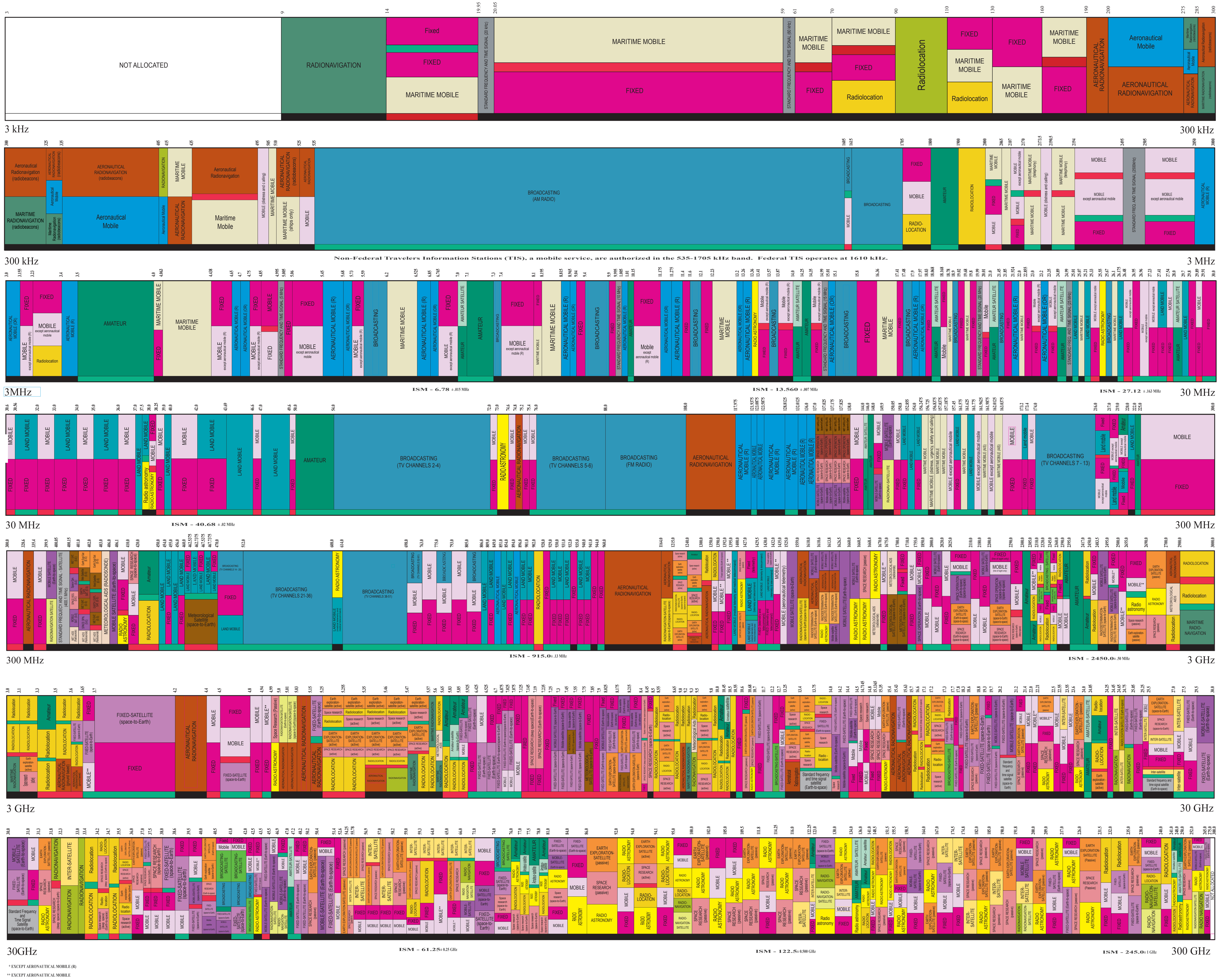
Galanz

UNITED STATES FREQUENCY ALLOCATIONS

THE RADIO SPECTRUM



RADIO SERVICES COLOR LEGEND

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

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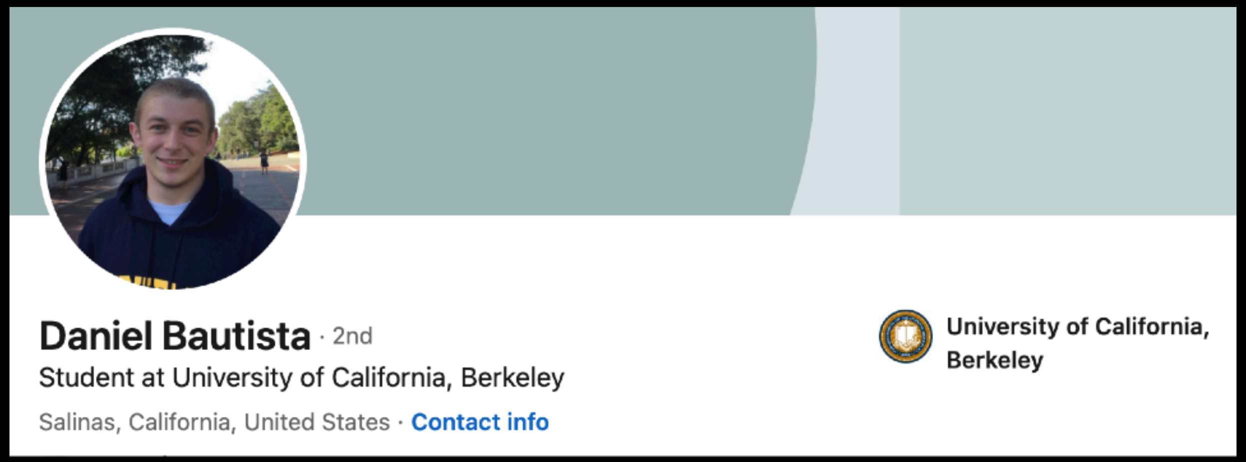
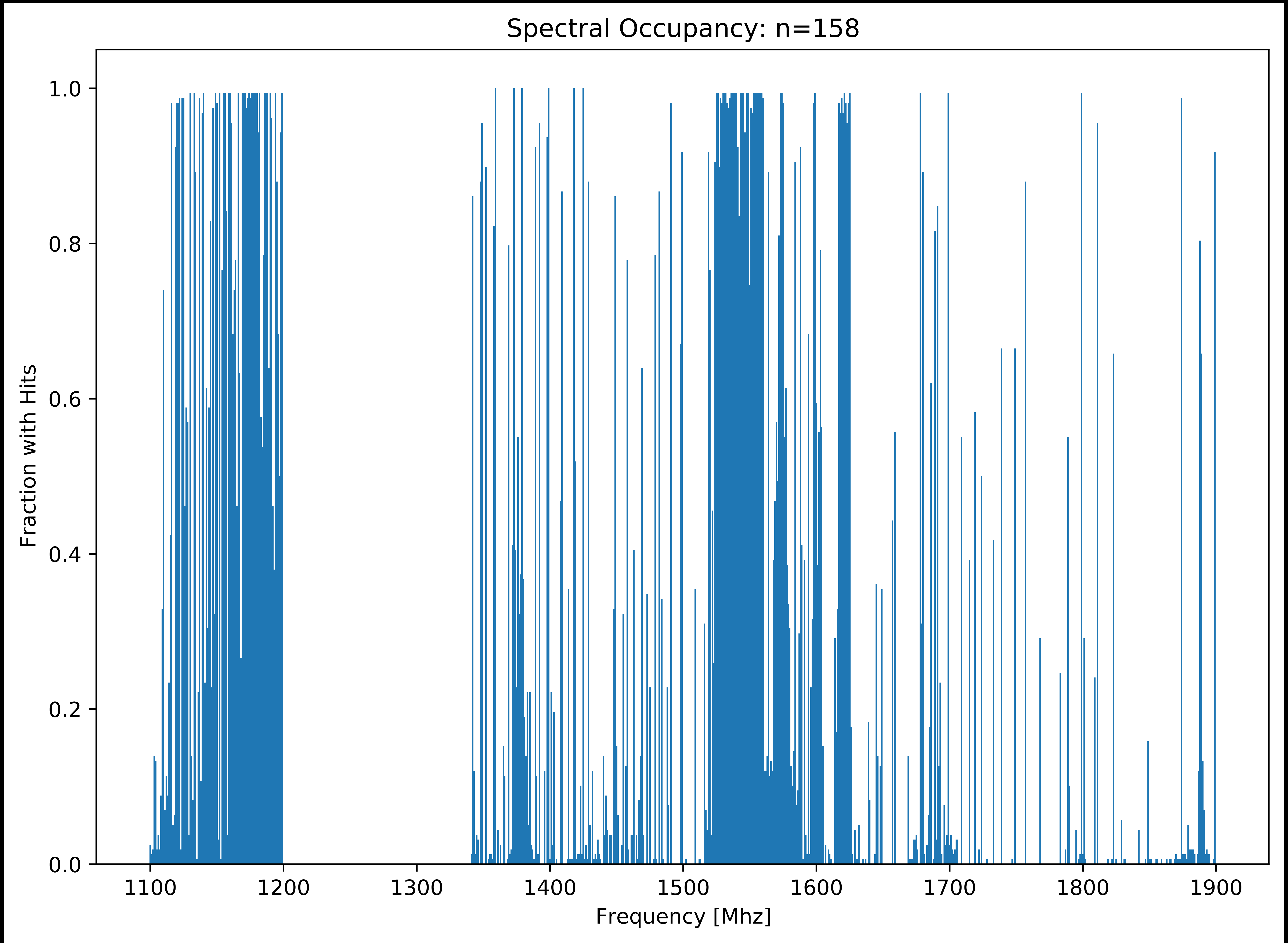
PLEASE NOTE: THE SPACING ALLOTTED THE SERVICES IN THE SPECTRUM SEGMENTS SHOWN IS NOT PROPORTIONAL TO THE ACTUAL AMOUNT OF SPECTRUM OCCUPIED.

L-band


Daniel Bautista · 2nd
Student at University of California, Berkeley
Salinas, California, United States · Contact info
University of California, Berkeley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Fraction with Hits
0.0
0.2
0.4
0.6
0.8
1.0
1100
1200
1300
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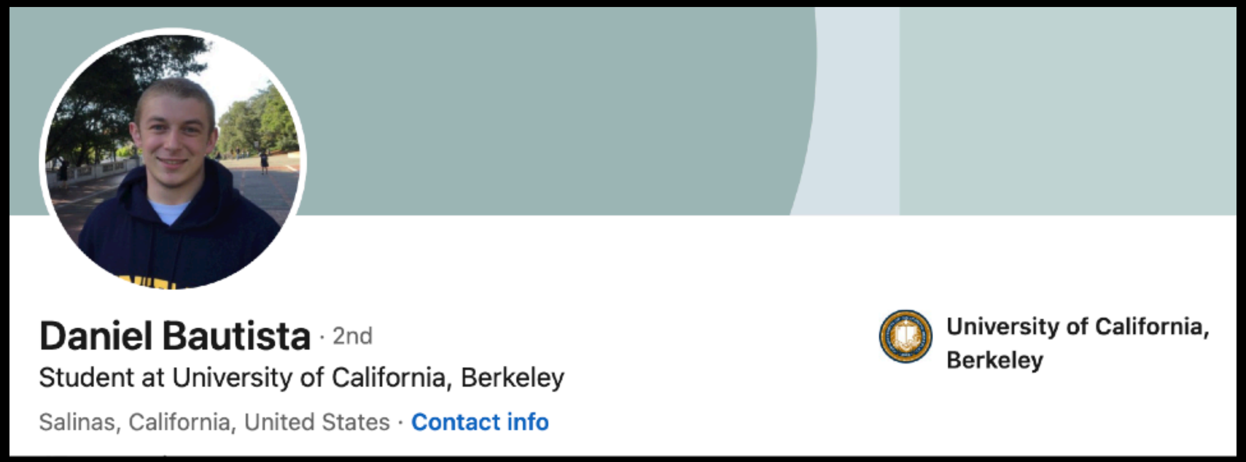
1500
1600
1700
1800
1900
Frequency [Mhz]

X-band



Daniel Bautista · 2nd
Student at University of California, Berkeley
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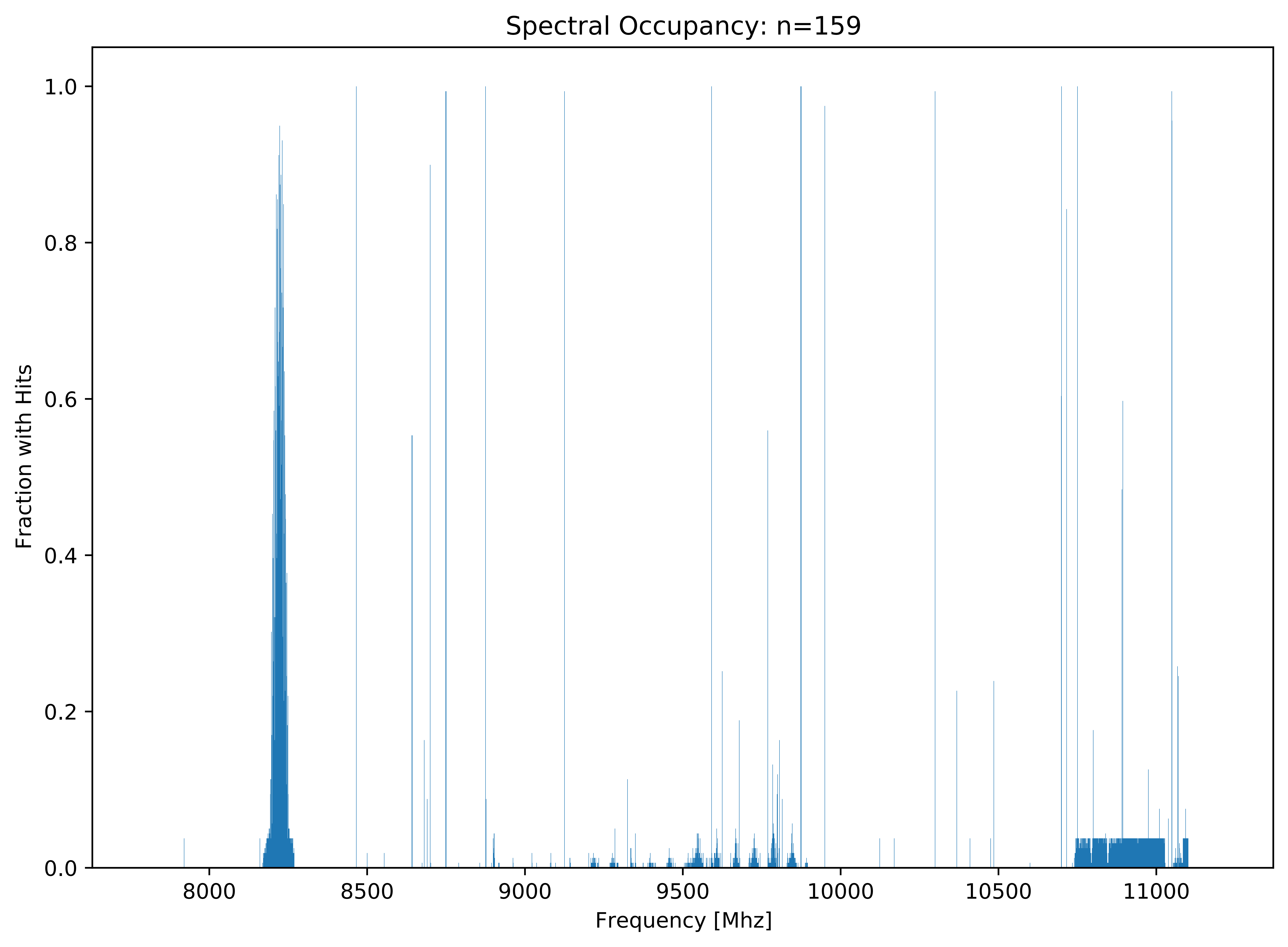
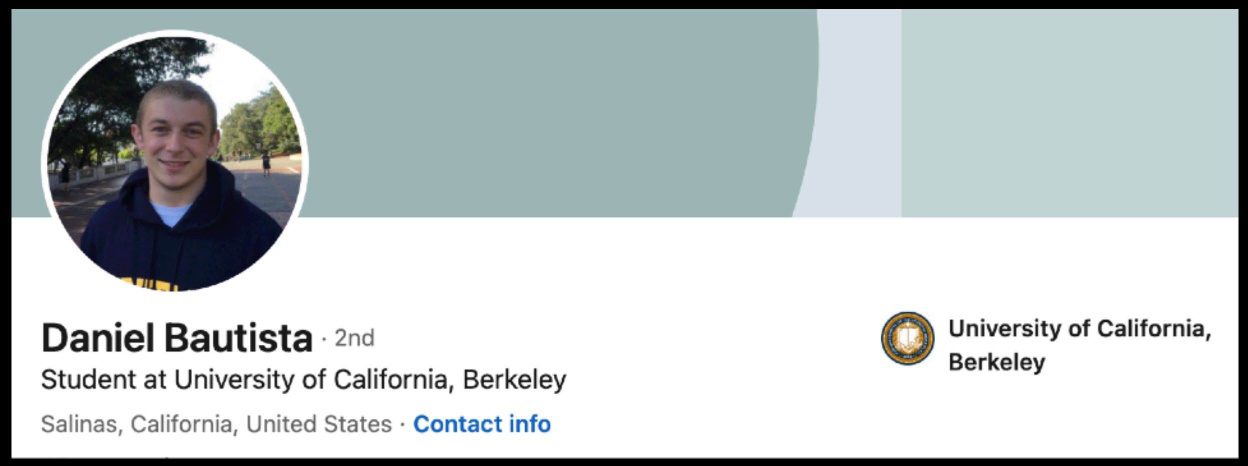
University of California, Berkeley



Spectral Occupancy: n=159
Fraction with Hits
1.0
0.8
0.6
0.4
0.2
0.0
8000
8500
9000
9500
10000
10500
11000
Frequency [Mhz]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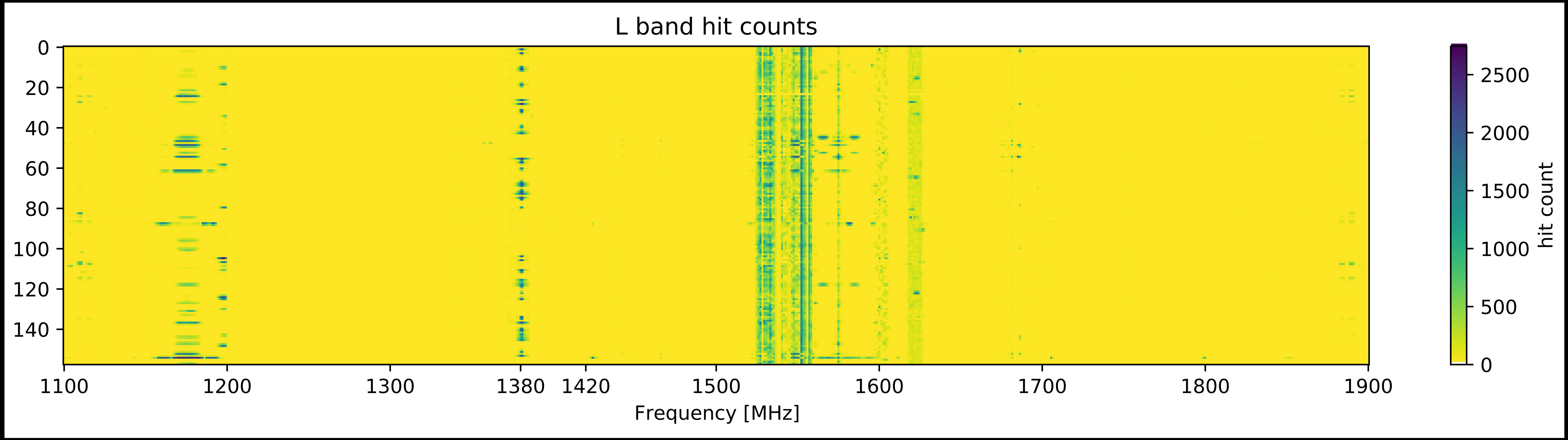
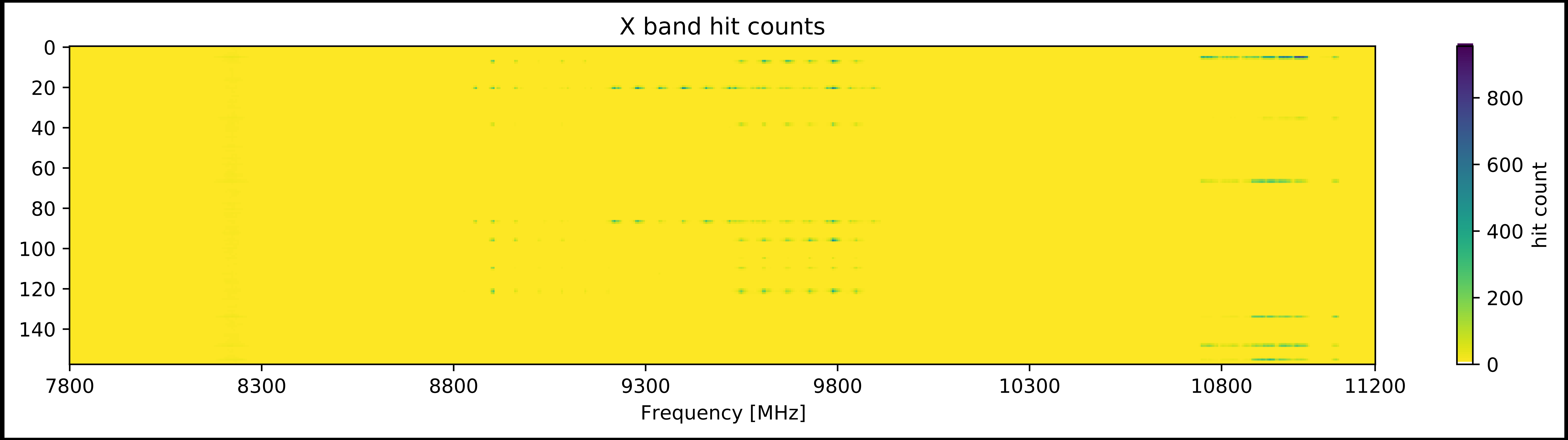
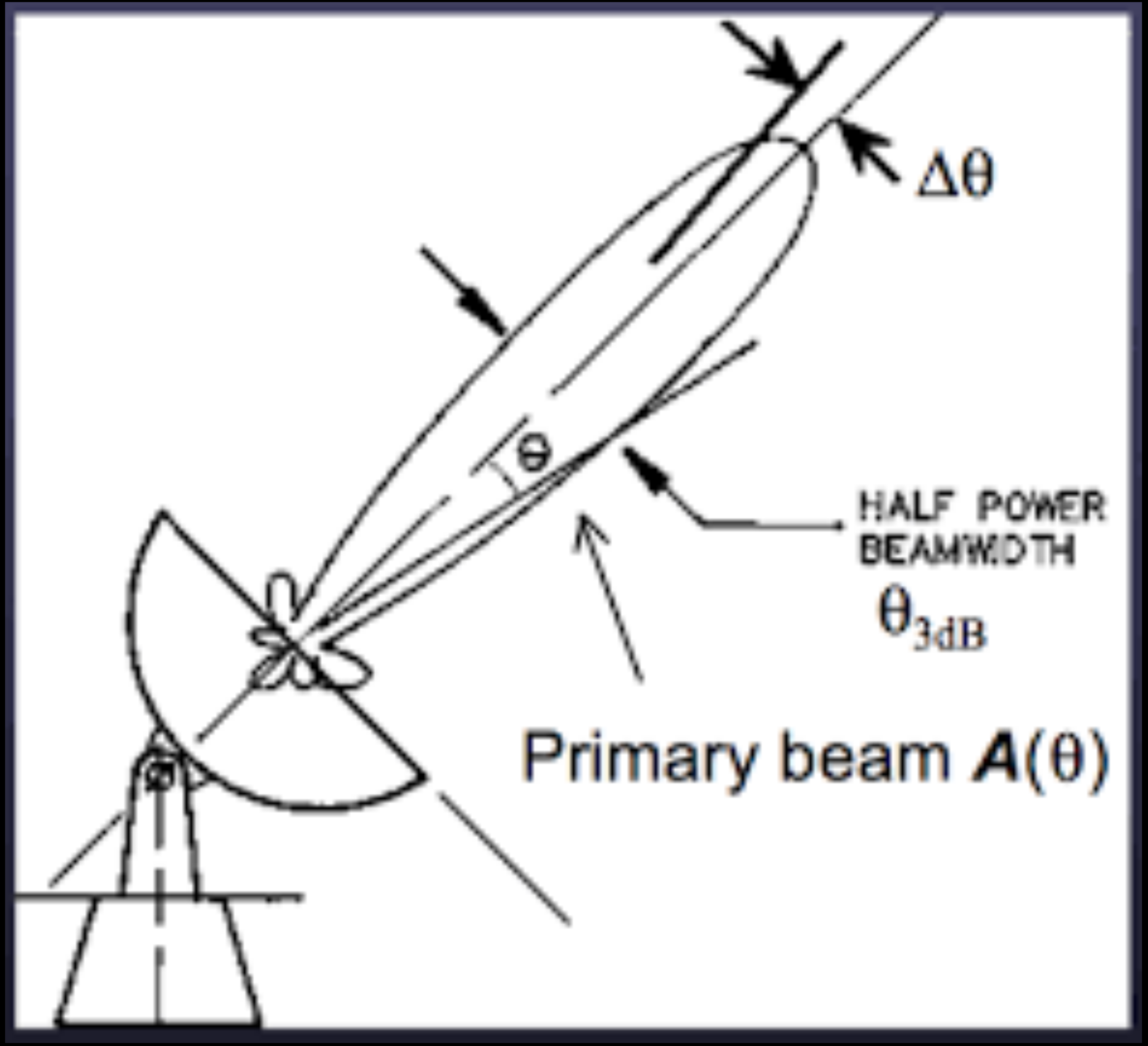
Student at University of California, Berkeley
Salinas, California, United States · Contact info
University of California, Berkeley


L band hit counts
0
20
40
60
80
100
120
140
1100
1200
1300
1380
1420
1500
1600
1700
1800
1900
Frequency [MHz]
2500
2000
1500
1000
500
0
hit count


X band hit counts
0
20
40
60
80
100
120
140
7800
8300
8800
9300
9800
10300
10800
11200
Frequency [MHz]
800
600
400
200
0
hit count

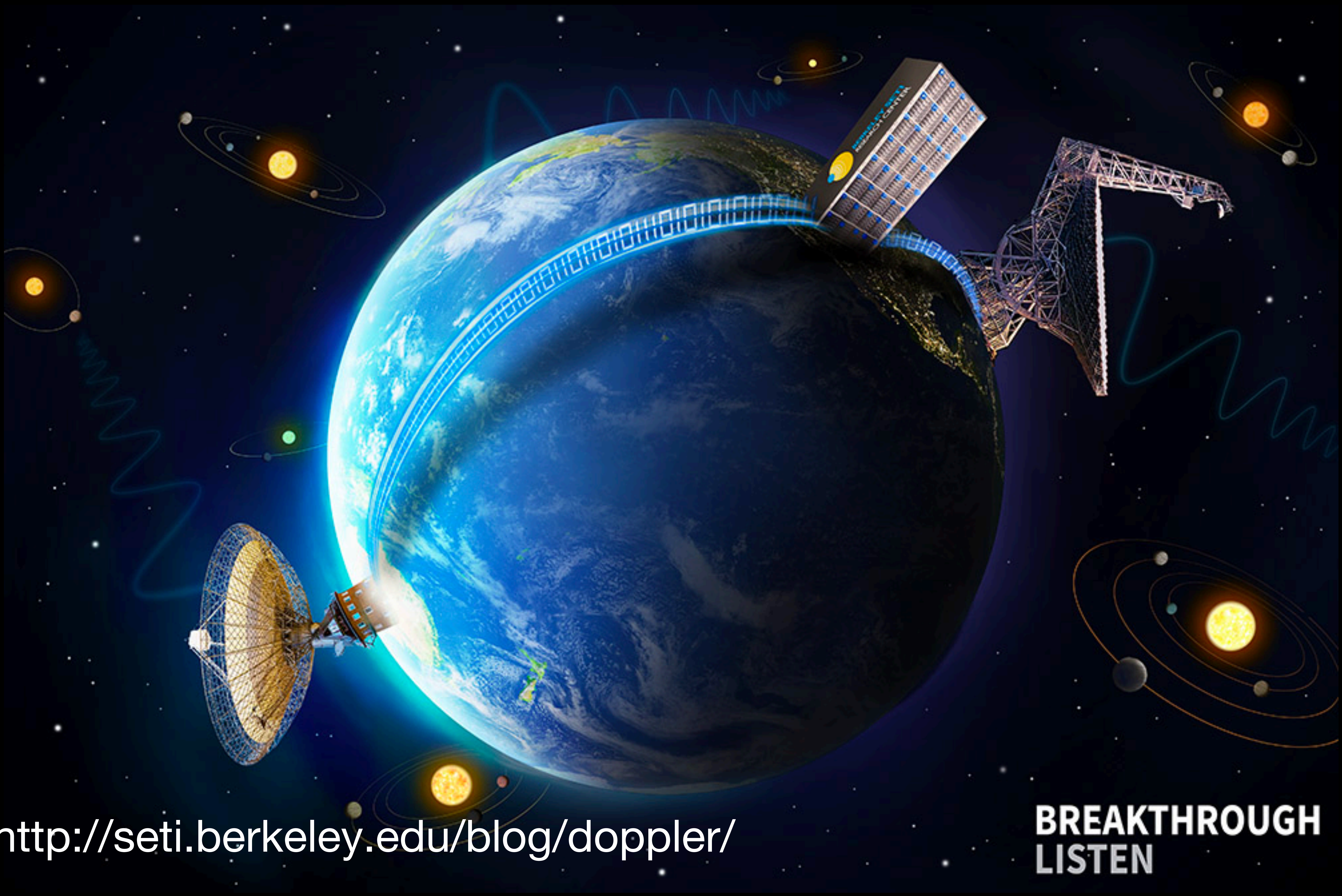

Δθ
θ
HALF POWER
BEAMWDTH
θ3dB
Primary beam A(θ)


Vega (Fidis - Wega)
α Lyr - 3 Lyr - HIP 91262 - SAO 67174 - HD 172167 - HR 7001 - WDS J18369+3846AB
Type: pulsating variable star, double star (DSCTC)
Magnitude: 0.00
Absolute Magnitude: 0.57
Color Index (B-V): 0.00
Magnitude range: -0.02÷0.07 (Photometric system: V)
RA/Dec (J2000.0): 18h36m56.51s/+38°47'08.4"
RA/Dec (on date): 18h37m38.84s/+38°48'15.2"
HA/Dec: 7h33m03.92s/+38°48'15.2"
Az./Alt.: +311°58'43.6"/+15°37'31.9"
Gal. long./lat.: +67°27'01.3"/+19°14'14.7"
Supergal. long./lat.: +35°20'24.9"/+66°35'04.9"
Ecl. long./lat. (J2000.0): +285°19'05.0"/+61°44'05.0"
Ecl. long./lat. (on date): +285°36'35.5"/+61°43'55.9"
Ecliptic obliquity (on date): +23°26'13.2"
Mean Sidereal Time: 2h10m43.8s
Apparent Sidereal Time: 2h10m42.7s
Rise: 10h58m
Transit: 21h28m
Set: 7h57m
IAU Constellation: Lyr
Distance: 25.04 ly
Spectral Type: A1V
Parallax: 0.13023"
Period: 0.19 days
Position angle (2014): 183.00°
Separation (2014): 82.130" (+0°01'22")
Proper motions by axes: 262.3 315.2 (mas/yr)
Position angle of the proper motion: 39.8°
Angular speed of the proper motion: 410.1 (mas/yr)
Aljanah
Sadr
Fawaris
MOLNIYA 3-13
Aldhibah
MOLNIYA 1-87
MOLNIYA 3-31
Athebyne
GSAT0218 (PRN E31)
COSMOS 2464 (736)
Eltanin
Rastaban
MOLNIYA 1-71
POLAR
GSAT0209 (PRN E09)
Vega
Albireo
Sulafat
COSMOS 2457 (733)
FORMOSAT-3 FM1
MOLNIYA 1-69
NOSS 2-2 (C)
Her
Earth, Paris, 42 m
FOV 40°
33.4 FPS
2020-09-05 05:02:35 UTC+02:00
Loading Nebulae

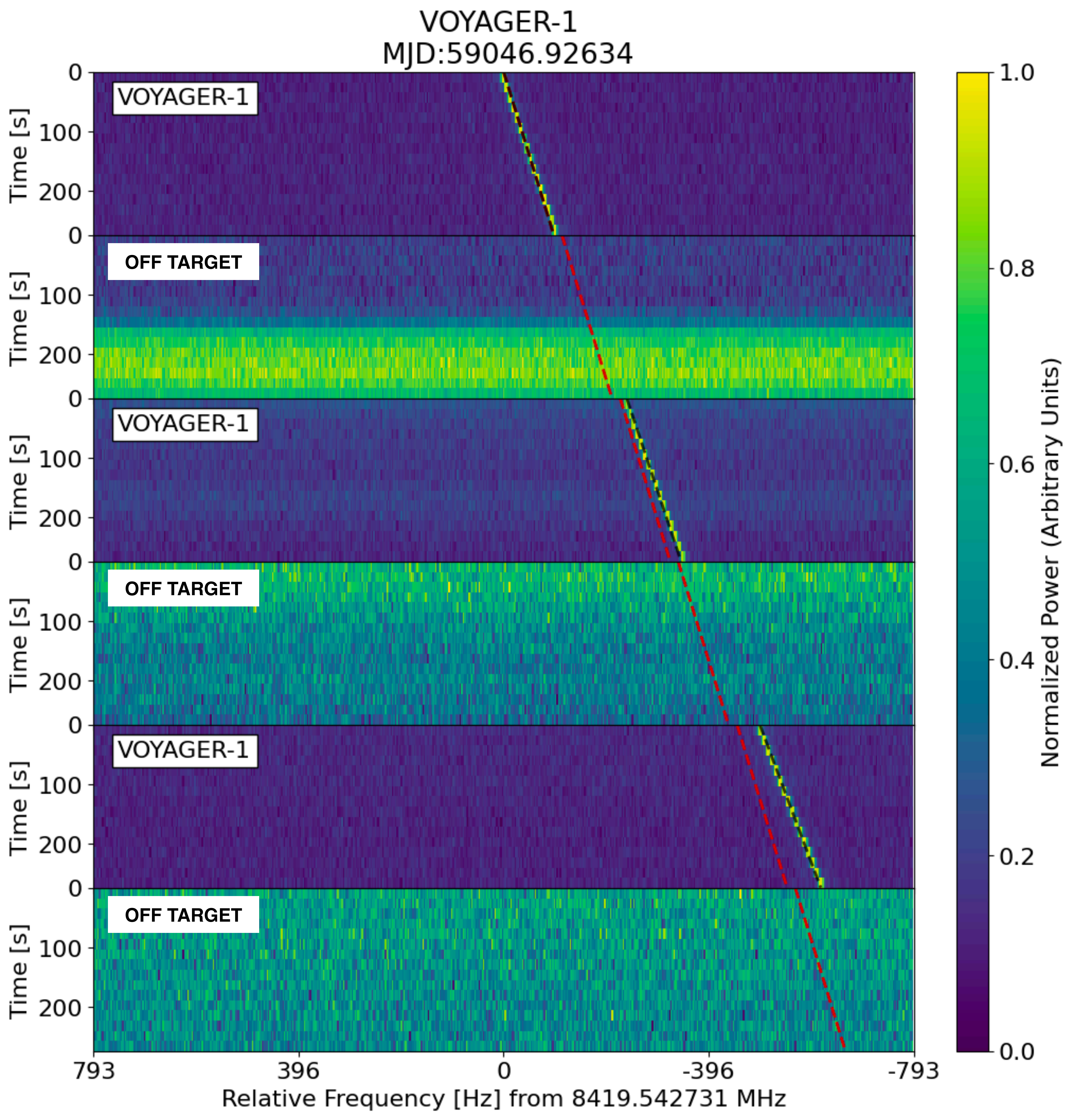
A
HIP93805
57550
57600
57650
57700
57750
Time [sec]
2350
2400
2450
Frequency [MHz]
103.2
102.6
102.0
101.4
100.8
100.2
99.6
99.0
98.4
A
HIP93805
102.5
102.0
101.5
101.0
100.5
100.0
99.5
99.0
98.5
A
HIP93805
104.8
104.0
103.2
102.4
101.6
100.8
100.0
99.2
98.4
B
HIP93805_OFF
102.5
102.0
101.5
101.0
100.5
100.0
99.5
99.0
98.5
C
HIP93805_OFF
103.2
102.4
101.6
100.8
100.0
99.2
98.4
D
HIP93805_OFF
108
107
106
105
104
103
102
101
100
99

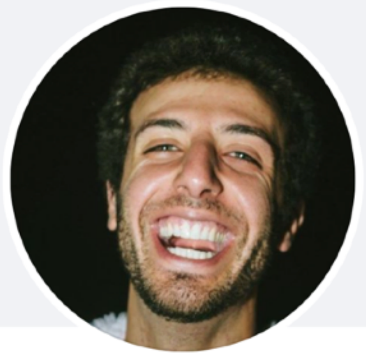

8
AMBULANCE


AMBULANCE



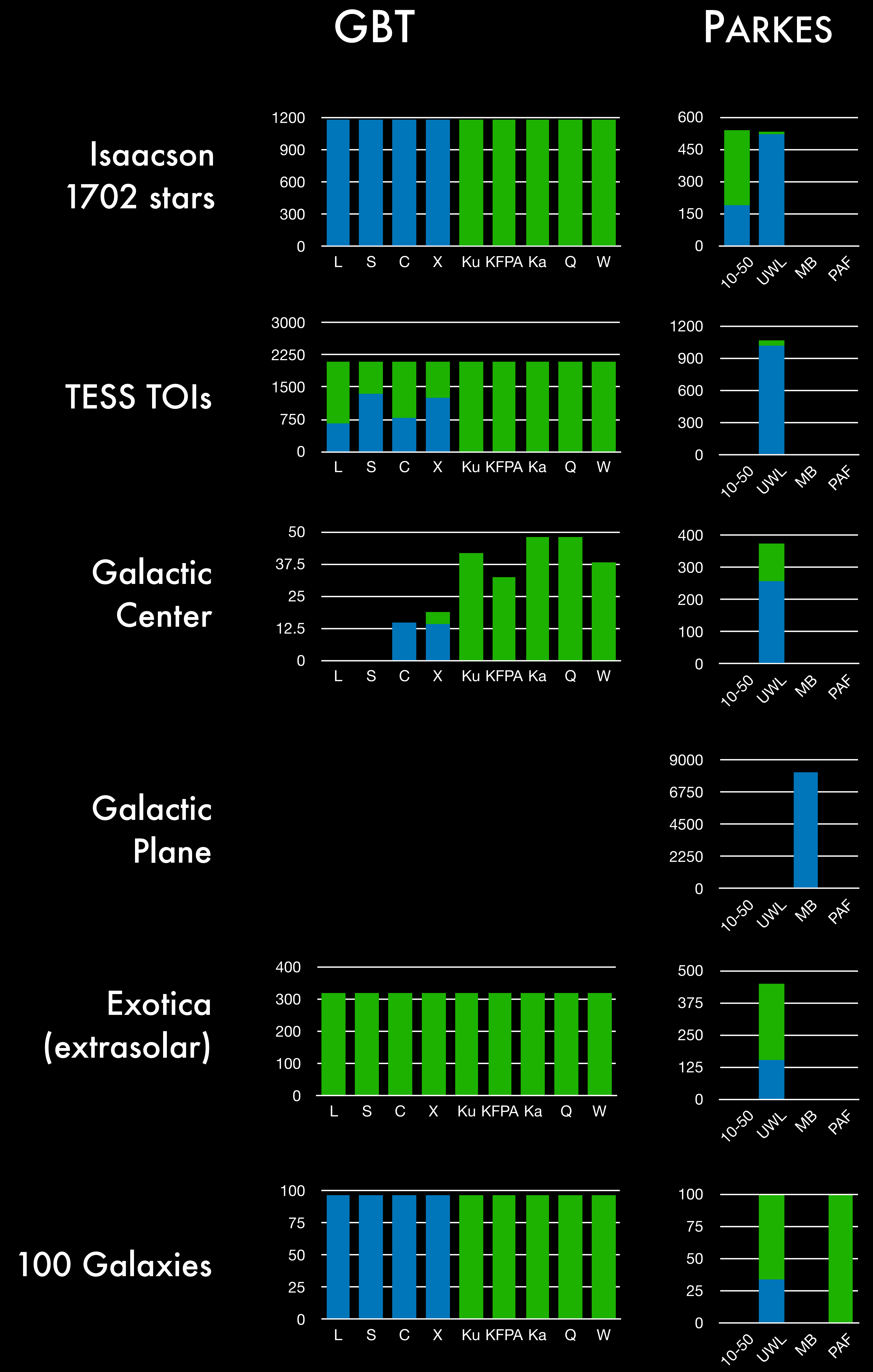
http://seti.berkeley.edu/blog/doppler/

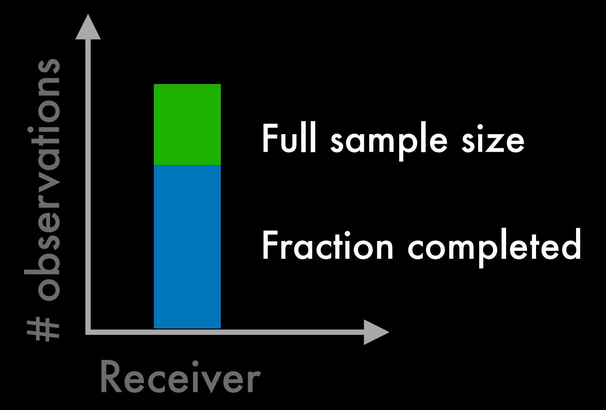


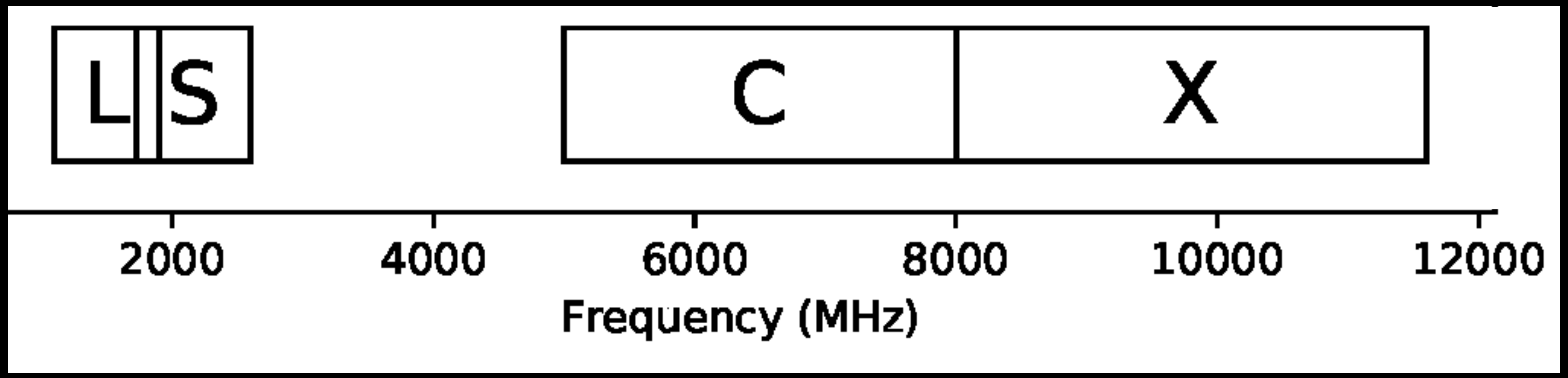


Elan Lavie

http://bit.do/voyager_elan







- Nearby star sample essentially complete to 12 GHz
- Observations of TESS targets underway
- Observations of 97 galaxy centers almost complete
- Mosaic observations of extended galaxies to come
- Galactic Center and Plane observations and analysis underway (K. Perez)
- Exotica sample (B. Lacki) to be added (55 / 625 sidereal targets already observed)
- Observations of other targets (ETZ, Kepler 160, `Oumuamua, etc.)
- Higher frequency receiver observations beginning

GBT | PARKES

Isaacson 1702 stars

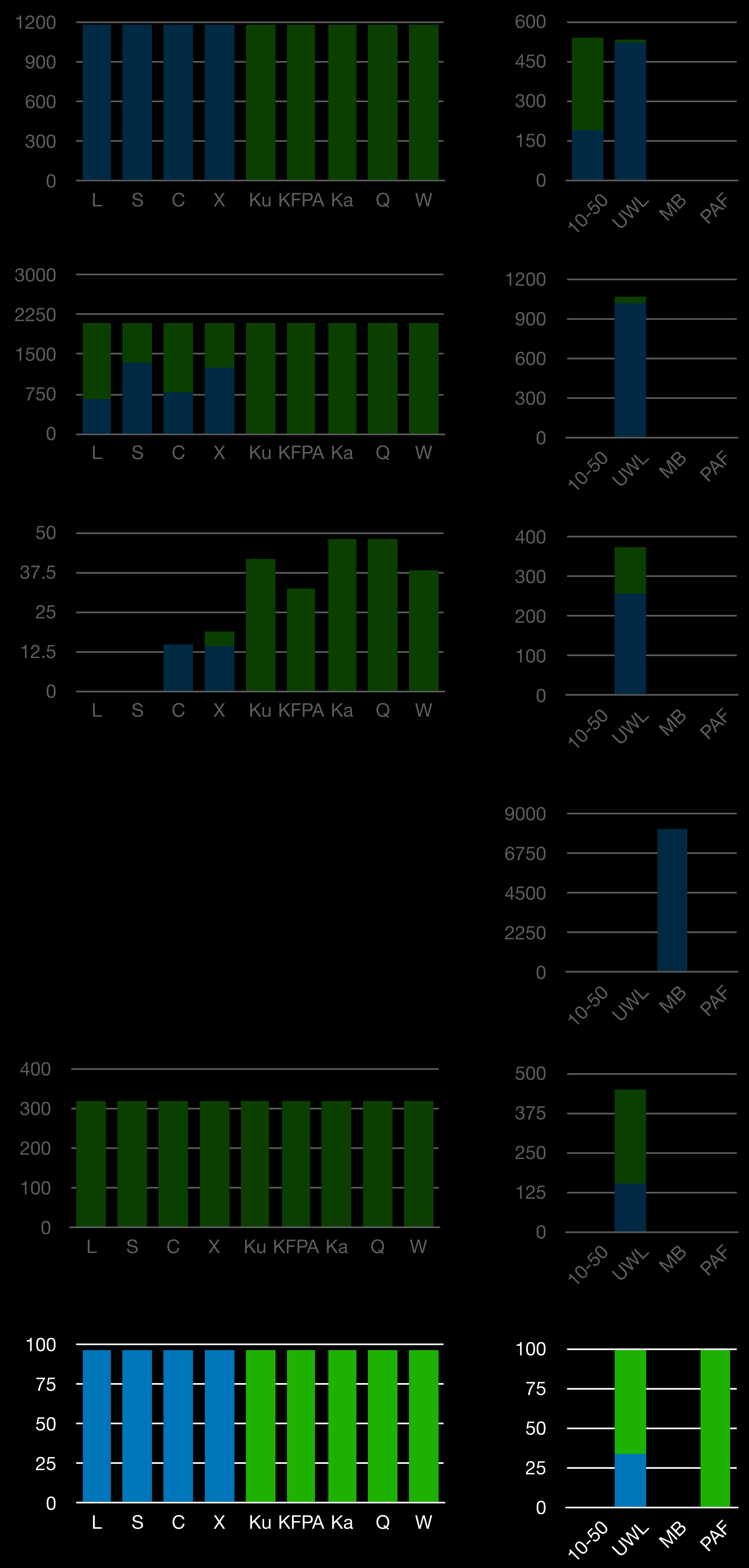
TESS TOIs

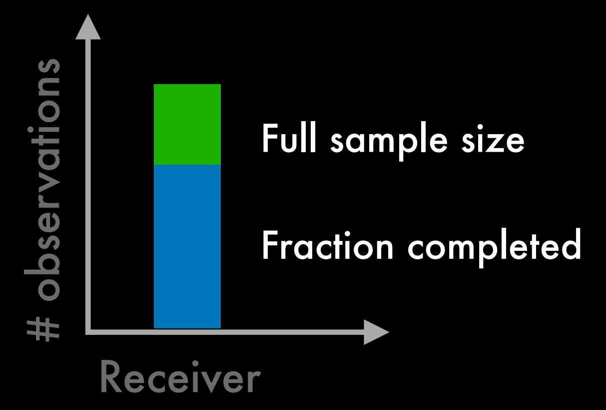
Galactic Center

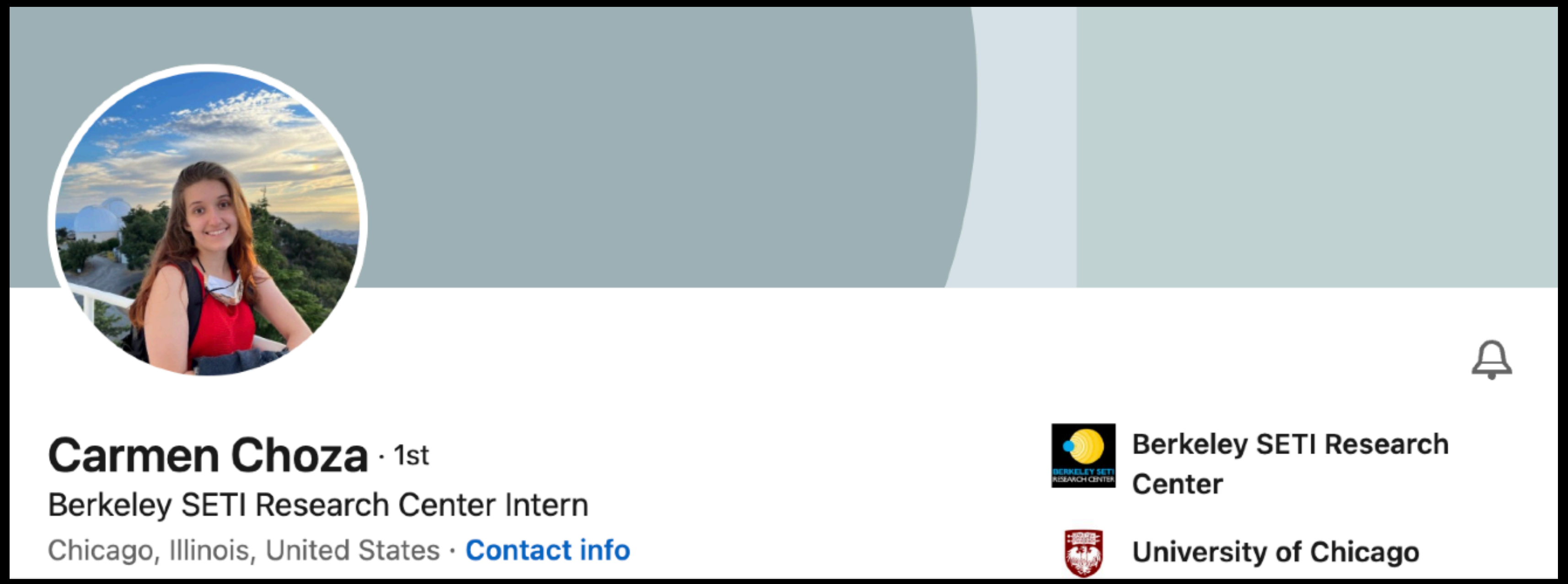
Galactic Plane

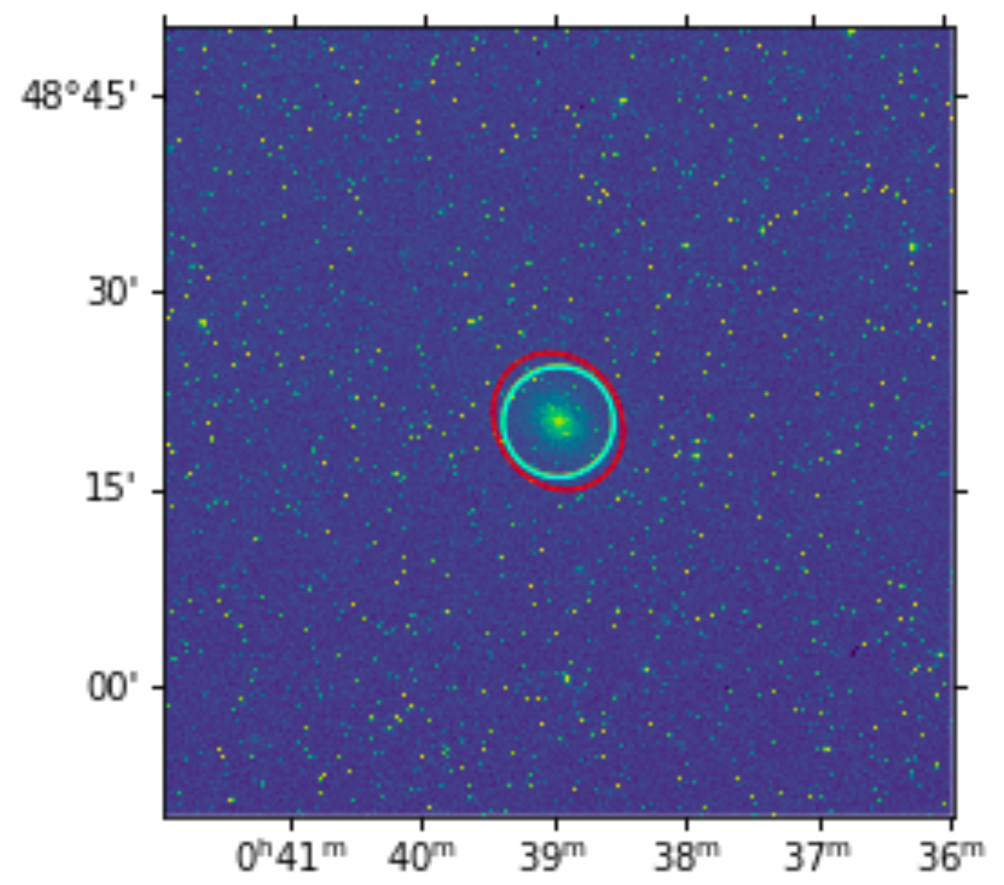
Exotica (extrasolar)

100 Galaxies

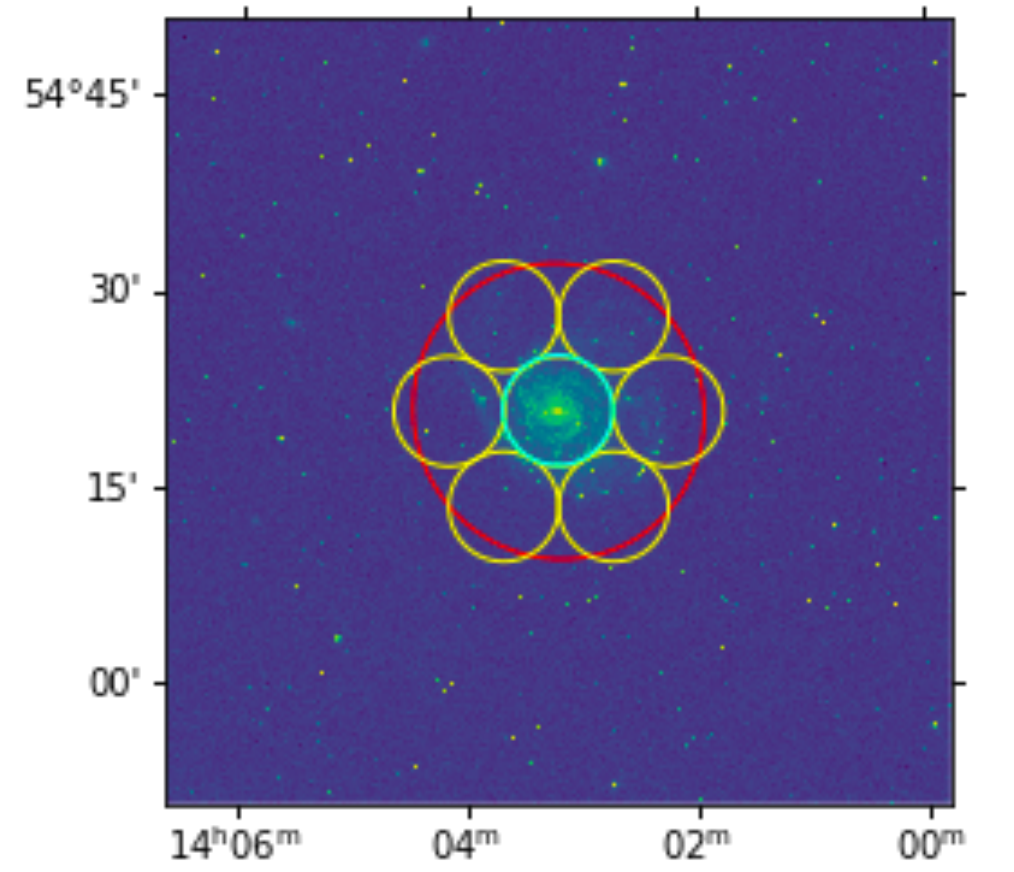




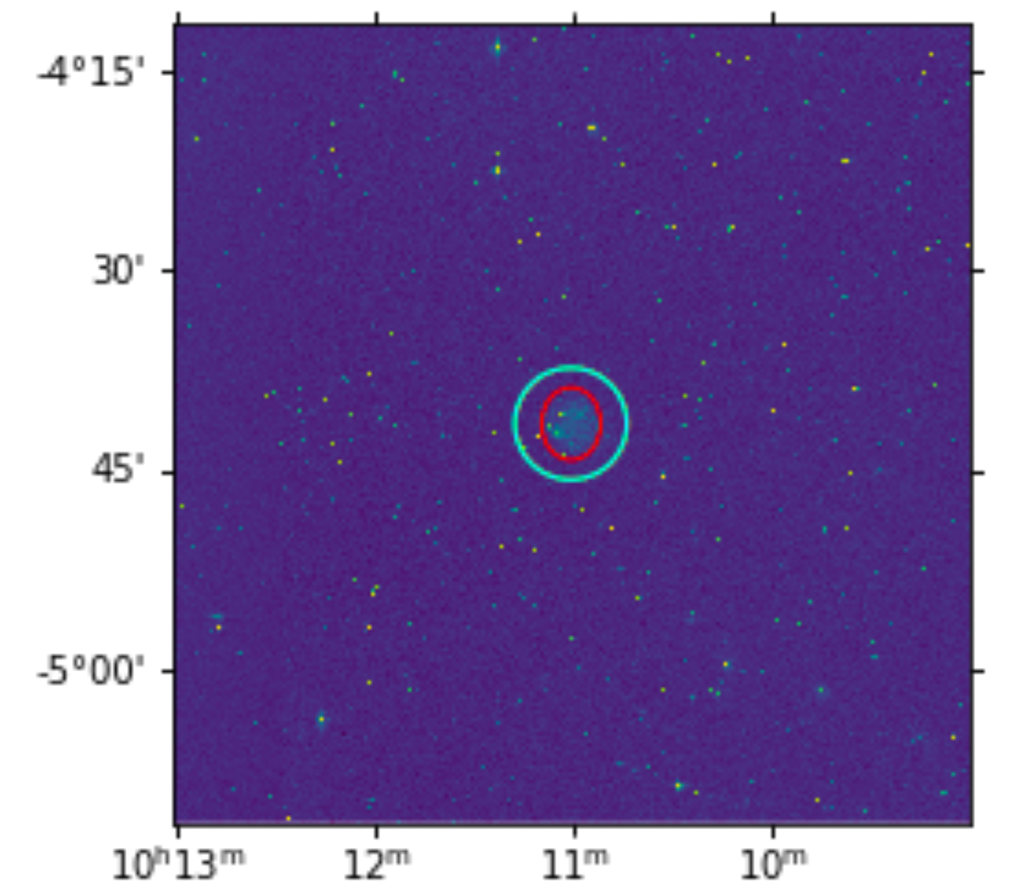




NGC 185



M101



Sex A

SEARCHES OF TESS TARGETS

The Breakthrough Listen Search for Intelligent Life:
Searching for Technosignatures in Observations of *TESS* Targets of Interest

Raffy Traas,[1,2] Steve Croft,[2,3] Vishal Gajjar,[2] Howard Isaacson,[2,4] Matt Lebofsky,[2] David H. E. MacMahon,[2] Karen Perez,[5] Danny C. Price,[2,6] Sofia Sheikh,[7,2] Andrew P. V. Siemion,[2,3,8,9] Shane Smith,[10] Jamie Drew,[11] and S. Pete Worden[11]

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[6]*Centre for Astrophysics & Supercomputing, Swinburne University of Technology, Hawthorn, VIC 3122, Australia*
[7]*Department of Astronomy and Astrophysics, Pennsylvania State University, University Park PA 16802*
[8]*Department of Astrophysics/IMAPP,Radboud University, Nijmegen, Netherlands*
[9]*University of Malta, Institute of Space Sciences and Astronomy*
[10]*Hillsdale College, 33 E College St, Hillsdale, MI 49242*
[11]*The Breakthrough Initiatives, NASA Research Park, Bld. 18, Moffett Field, CA, 94035, USA*

(Received January 28, 2021; Revised January 28, 2021; Accepted XXX)

Submitted to ApJ

ABSTRACT

Exoplanetary systems are prime targets for the Search for Extraterrestrial Intelligence (SETI). With the recent uptick in the identification of candidate and confirmed exoplanets through the work of missions like the Transiting Exoplanet Survey Satellite (*TESS*), we are beginning to understand that Earth-like planets are common. In this work, we extend the Breakthrough Listen (BL) search for extraterrestrial intelligence to include targeted searches of stars identified by *TESS* as potential exoplanet hosts. We report on 113 30-min cadence observations collected for 28 targets selected from the *TESS* Input Catalog (TIC) from among those identified as containing signatures of transiting planets. The targets were searched for narrowband signals from 1 – 11 GHz using the turboSETI (Enriquez et al. 2017; Enriquez & Price 2019) pipeline architecture modified for compatibility with the Google Cloud environment. Data were searched for drift rates of ± 4 Hz / s above a minimum signal-to-noise threshold of 10, following the parameters of previous searches conducted by Price et al. (2020) and Enriquez et al. (2017). The observations presented in this work establish some of the deepest limits to date over such a wide band (1 – 11 GHz) for life beyond Earth. We determine that fewer than 12.72% of the observed targets possess transmitters operating at these frequencies with an Equivalent Isotropic Radiated Power greater than our derived threshold of 4.9×10^{14} W.

Keywords: exoplanets — technosignatures — search for extraterrestrial intelligence

1. INTRODUCTION

1.1. *SETI Methods*

The Search for Extraterrestrial Intelligence (SETI) is the endeavor to discover the existence of intelligent life elsewhere in the universe – one of the longest standing unanswered questions in science. There are three traditional techniques to detecting intelligent life. The first method is *in situ* sampling, where studies are conducted at the site of interest. While this approach would provide us with results containing the least amount of uncertainty, it is infeasible in practice when studying extrasolar objects due to the vast interstellar distances involved. This brings about the need for techniques that can indirectly study sites of interest, which motivates the remaining two strategies: remote *biosignature* and *technosignature* searches. Technosignature searches are

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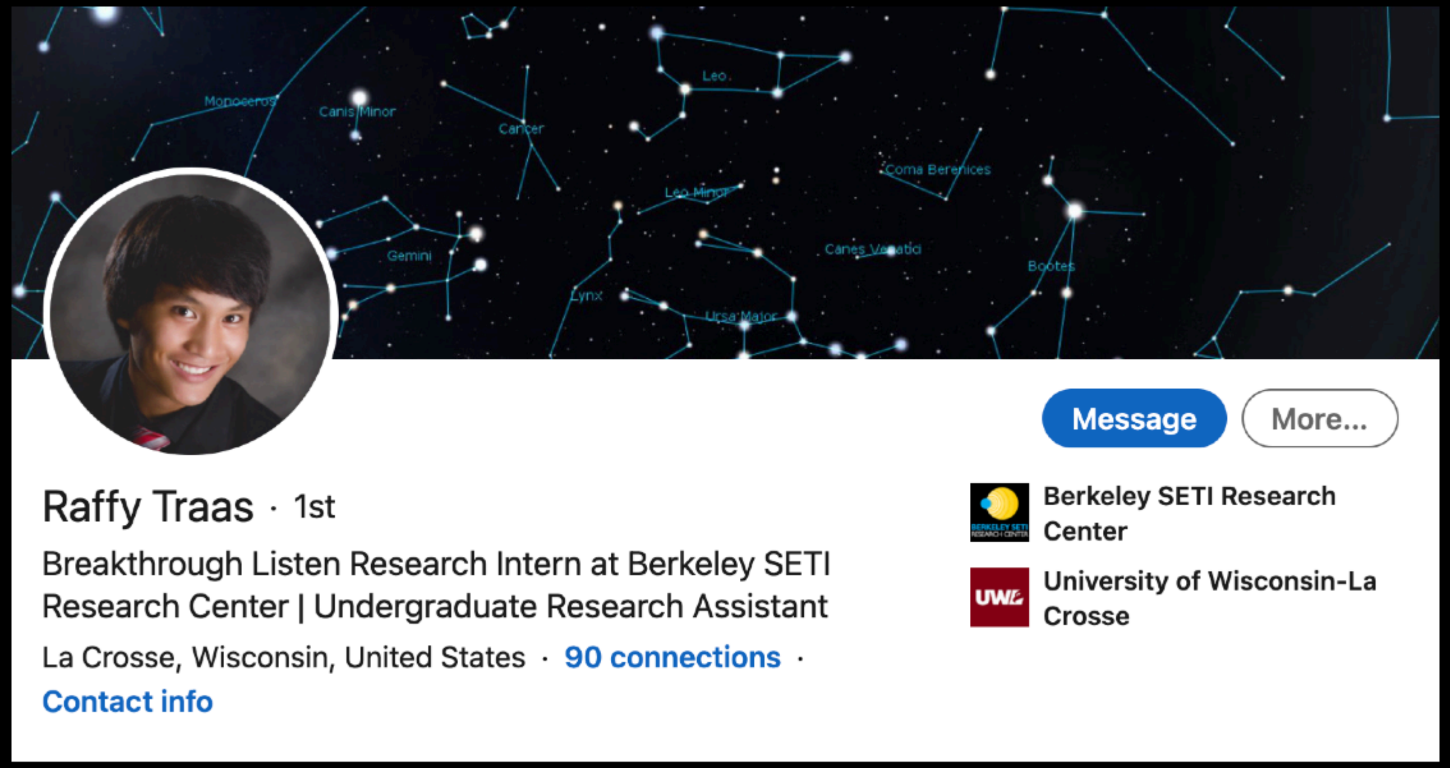
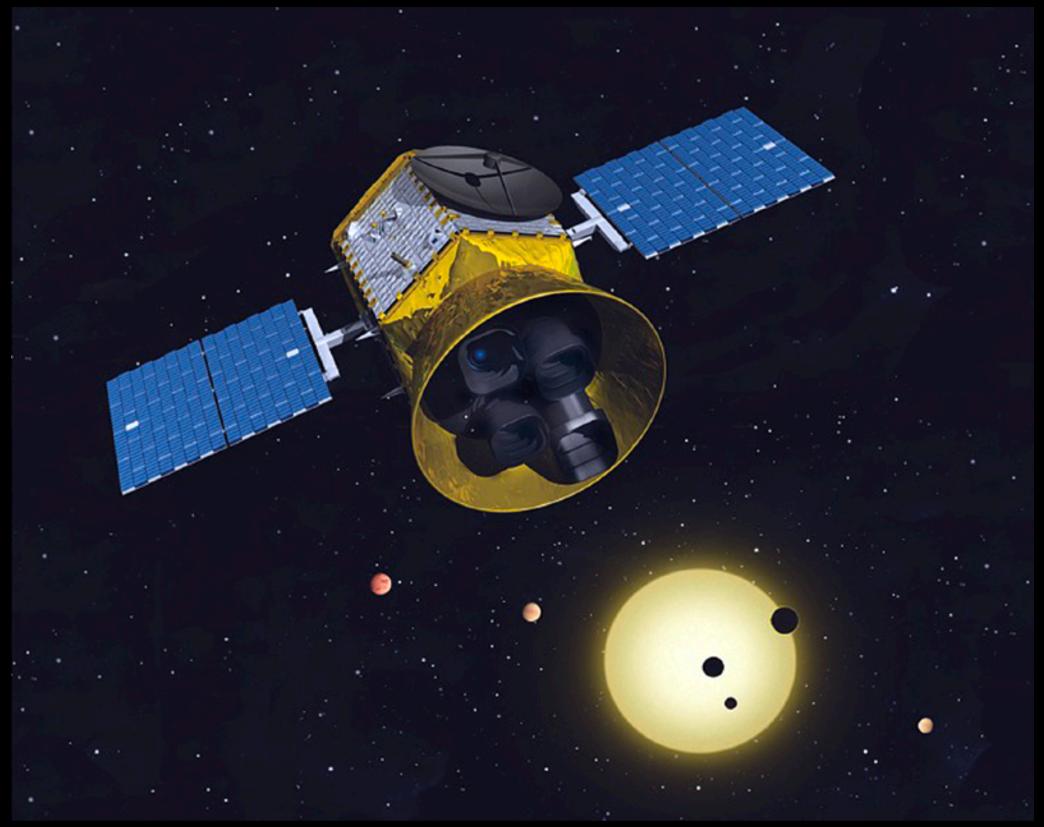




TOIs are viewed in their ecliptic

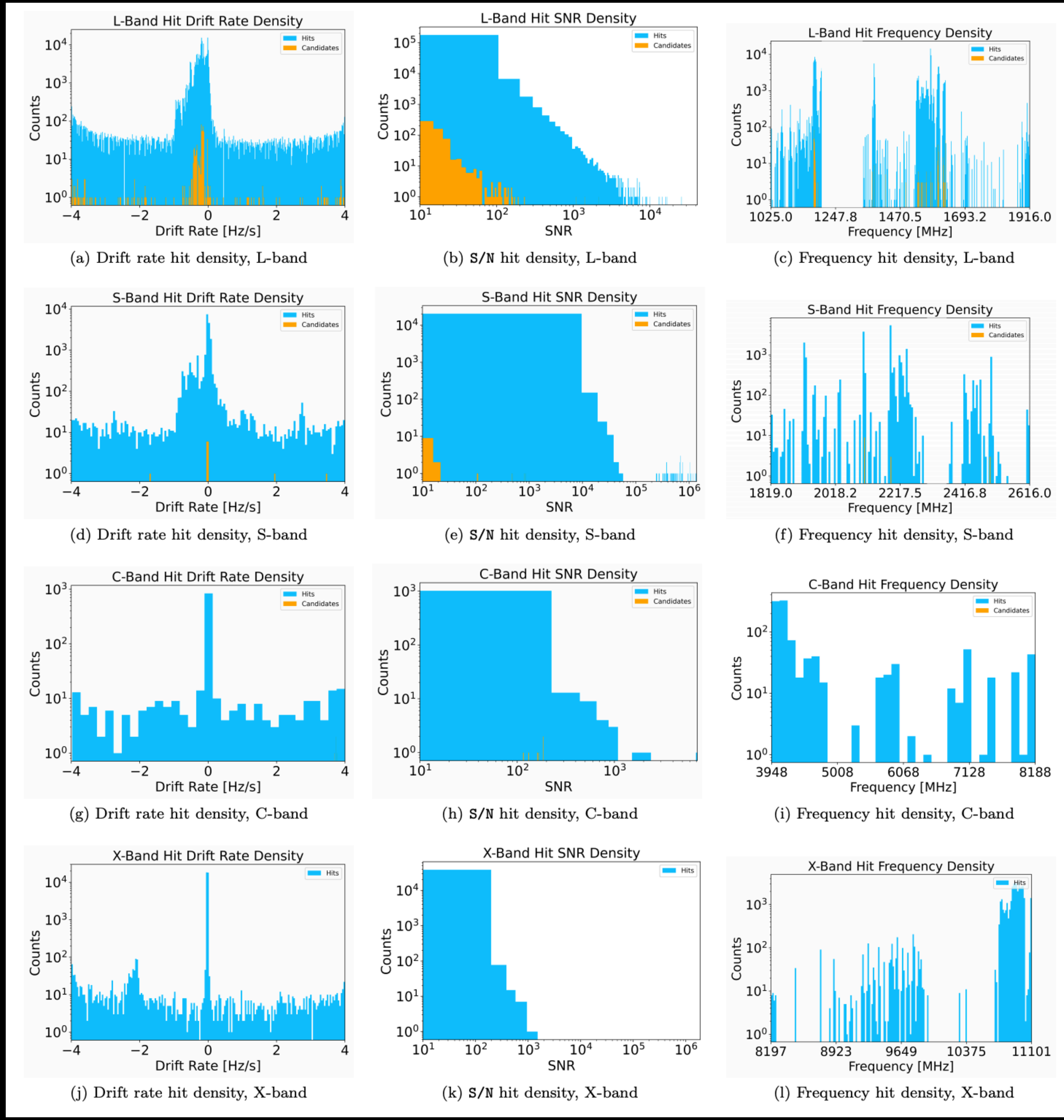
28 TOIs in LSCX (113 cadences)

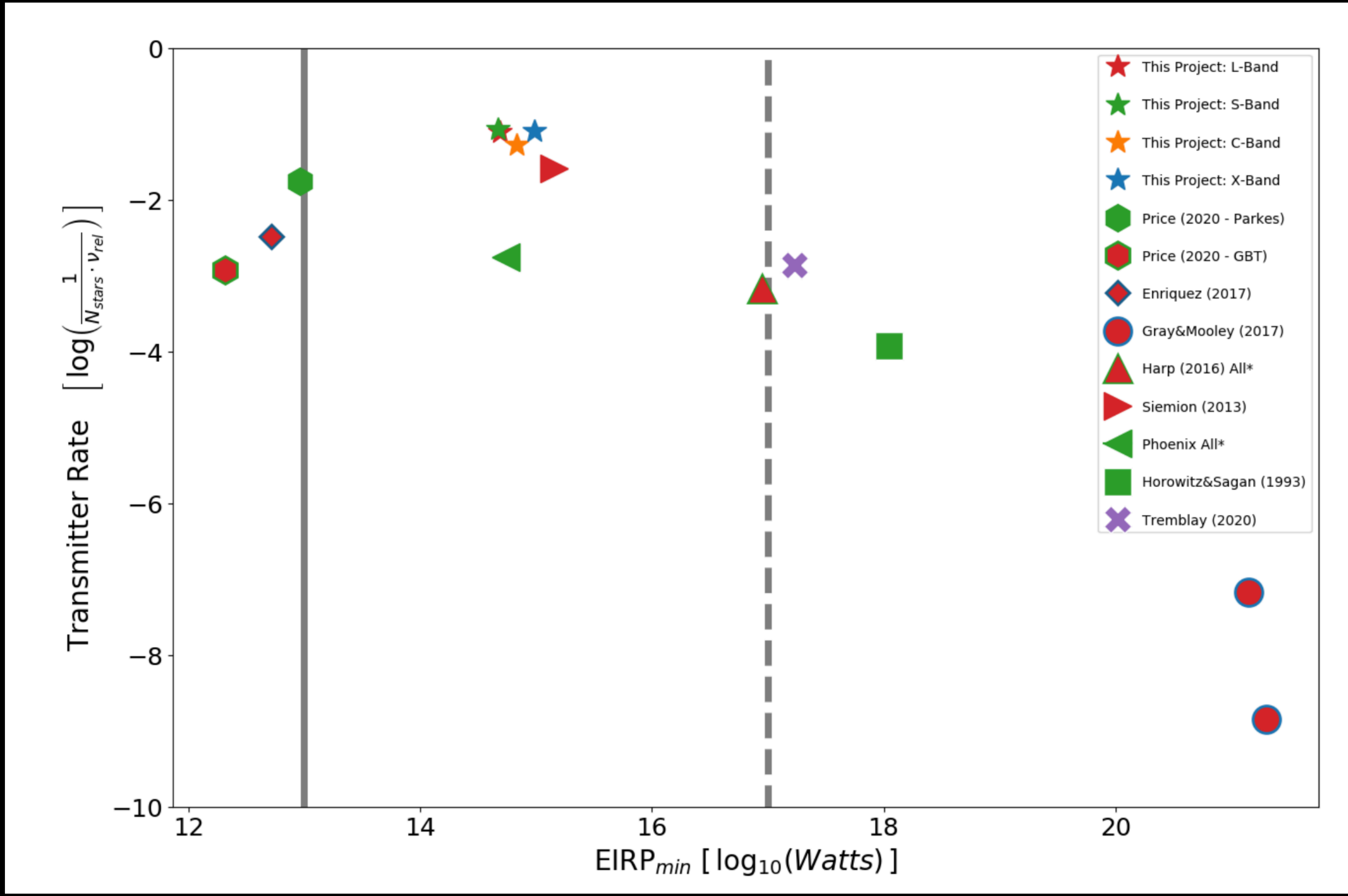
No detections > 5e14 W

Traas et al. (2021), AJ

Searches of TESS Targets

Traas et al. (2021), AJ





Searches of TESS Targets

Draft version September 22, 2021
Typeset using LaTeX **twocolumn** style in AASTeX62

The Breakthrough Listen Search for Intelligent Life: Technosignature Search of Transiting TESS Targets of Interest

Noah Franz,[1,2] Steve Croft,[1,3] Andrew Siemion,[1,3,4] Raffy Traas,[5,1] Matt Lebofsky,[1] David H. E. MacMahon,[1] Danny C. Price,[1,6] Sofia Z. Sheikh,[1] Jamie Drew,[7] and S. Pete Worden[7]

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ABSTRACT

The Breakthrough Listen Initiative, as part of its larger mission, is performing the most thorough technosignature search of nearby stars. Additionally, Breakthrough Listen is collaborating with scientists working on NASA's Transiting Exoplanet Survey Satellite (TESS), designed to search for nearby exoplanets, to examine TESS Targets of Interest (TOI) for technosignatures. Here, we present a $1-11$ GHz radio technosignature search of 61 TESS TOI that were in transit during their Breakthrough Listen observation at the Robert C. Byrd Green Bank Telescope. We performed a narrowband Doppler drift search with a minimum S/N threshold of 10, across a drift rate range of $\pm 4\,\mathrm{Hz\,s^{-1}}$, with a resolution of 3 Hz. We removed radio frequency interference (RFI) by comparing signals across cadences of target sources. After RFI removal, there are no remaining events in our survey, and therefore no technosignature signals-of-interest detected in this work. This null result implies that at L, S, C, and X bands, fewer than 52%, 20%, 16%, and 15%, respectively, of transiting exoplanets possess a transmitter with an equivalent isotropic radiated power greater than a few times $10^{14}\,W$.

Keywords: technosignatures — search for extraterrestrial intelligence — radio astronomy — exoplanets

1. INTRODUCTION

The Search for Extraterrestrial Intelligence (SETI) seeks an answer to the age-old question: Are we alone in the universe? The search for technosignatures, or signs of intelligent extraterrestrial life, began in the 1960s (Drake 1961). Due to the limited technology, this search was across a narrow band of radio frequencies. However, as technology has developed, technosignature searches have become much more advanced.

The Breakthrough Listen (BL) Initiative, launched in 2015, will search over 1 million targets for technosignatures over its 10-year lifetime (Worden et al. 2017). BL searches for technosignatures in both the optical and radio wavelengths, using a wide variety of telescopes including the Robert C. Byrd Green Bank Telescope (GBT), the Automated Planet Finder (APF), and the Parkes Telescope. This work presents a technosignature search of the frequency range $1-11$ GHz using the GBT in West Virginia. The Breakthrough Listen backend on the GBT delivers billions of frequency channels of data across several GHz of bandwidth during every observation. See MacMahon et al. (2018) and Lebofsky et al. (2019) for information about the instrument, data formats, and post-observation data management.

BL employs many strategies for target prioritization: one such strategy is to emphasize targets from NASA's Transiting Exoplanet Survey Satellite (TESS). TESS has found many new exoplanets, some of which may have suitable conditions for life. Traas et al. (2021) recently performed a technosignature search of 28 TESS targets of interest (TOI) using the L, S, C, and X-band receivers at the GBT. Transiting systems are prioritized

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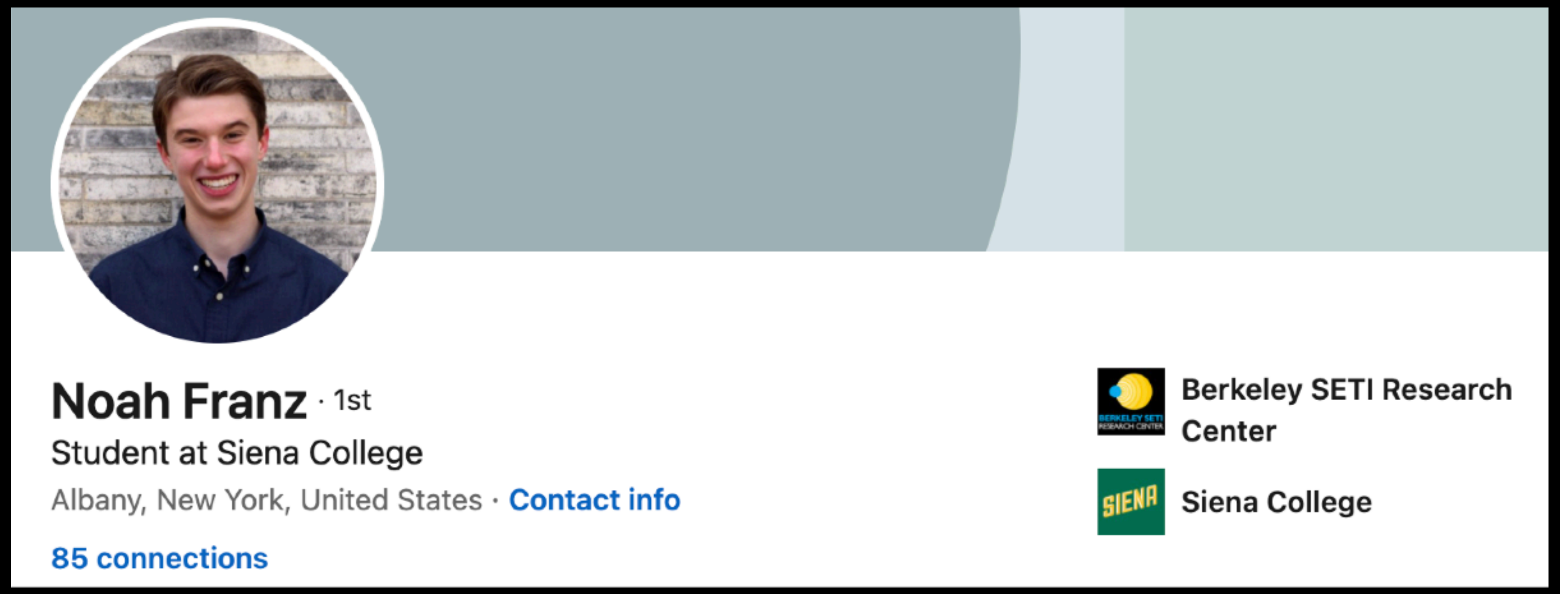
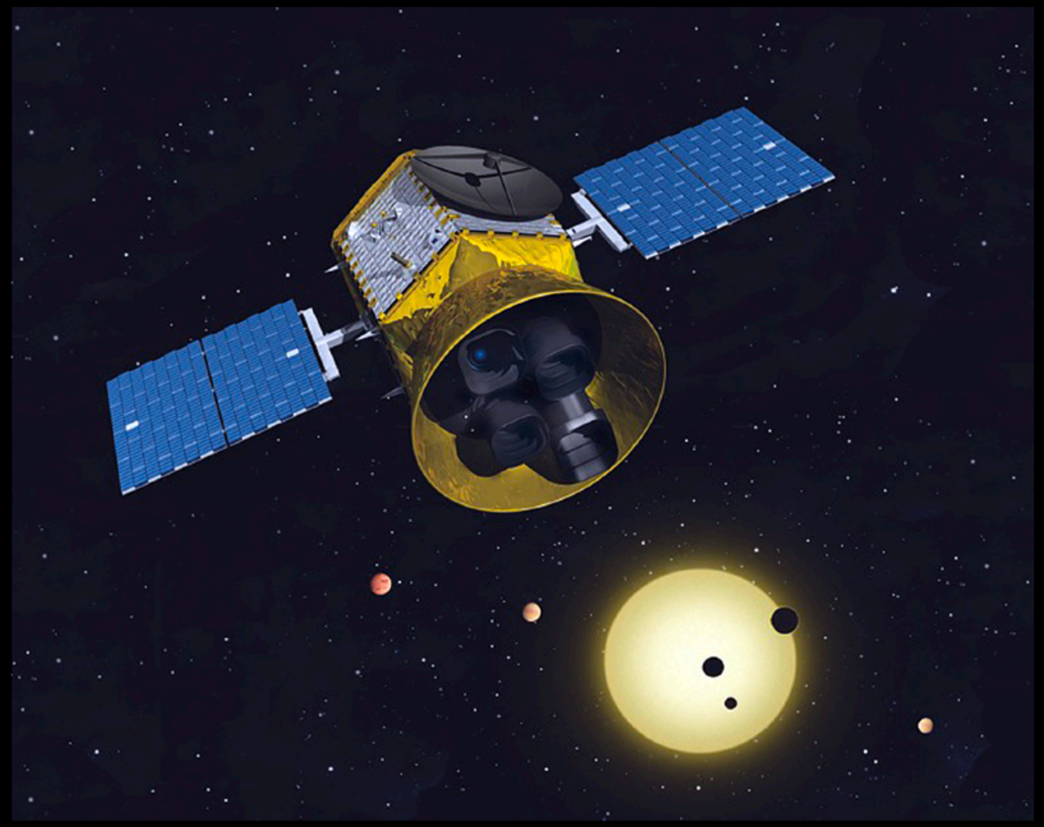


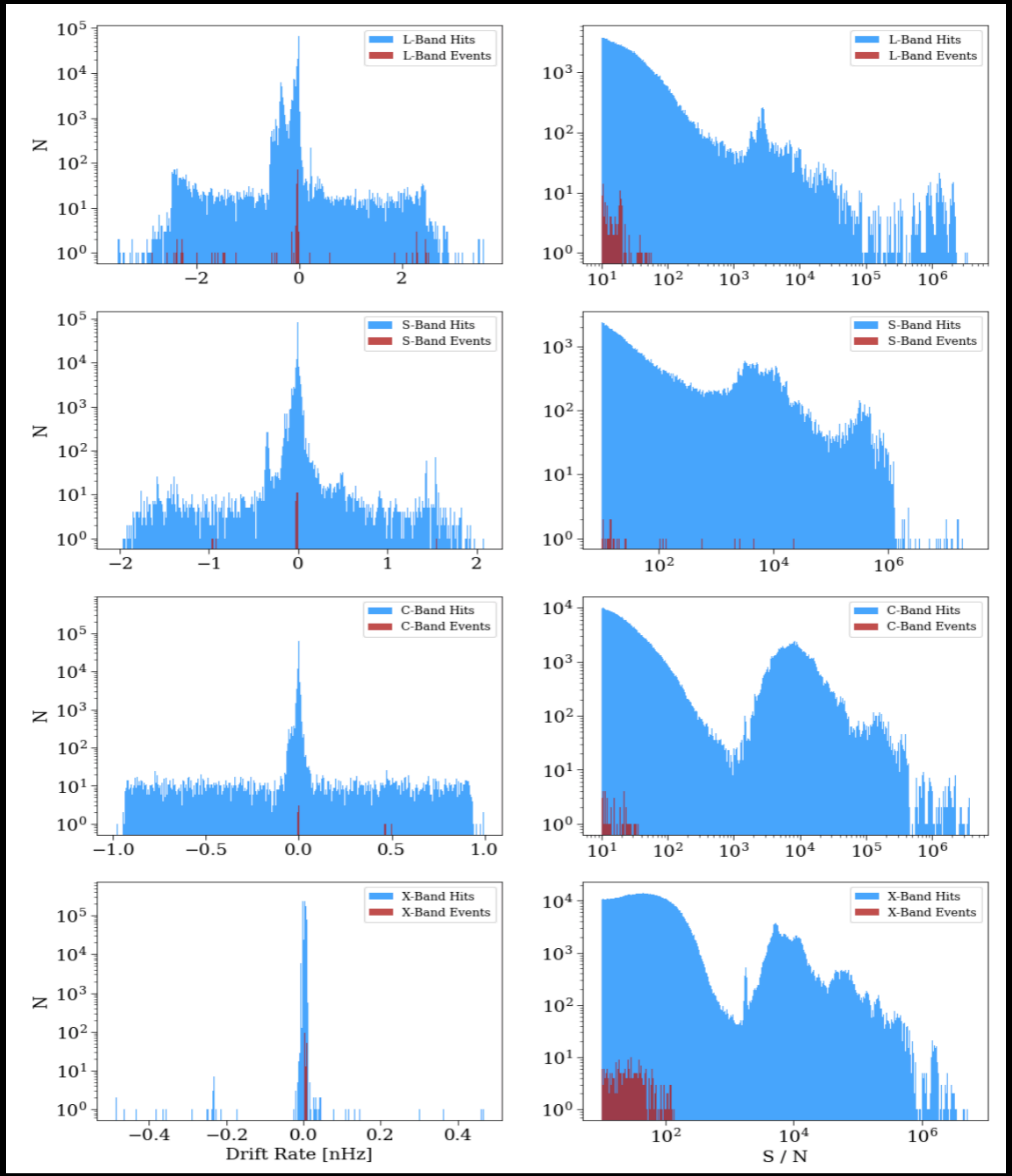


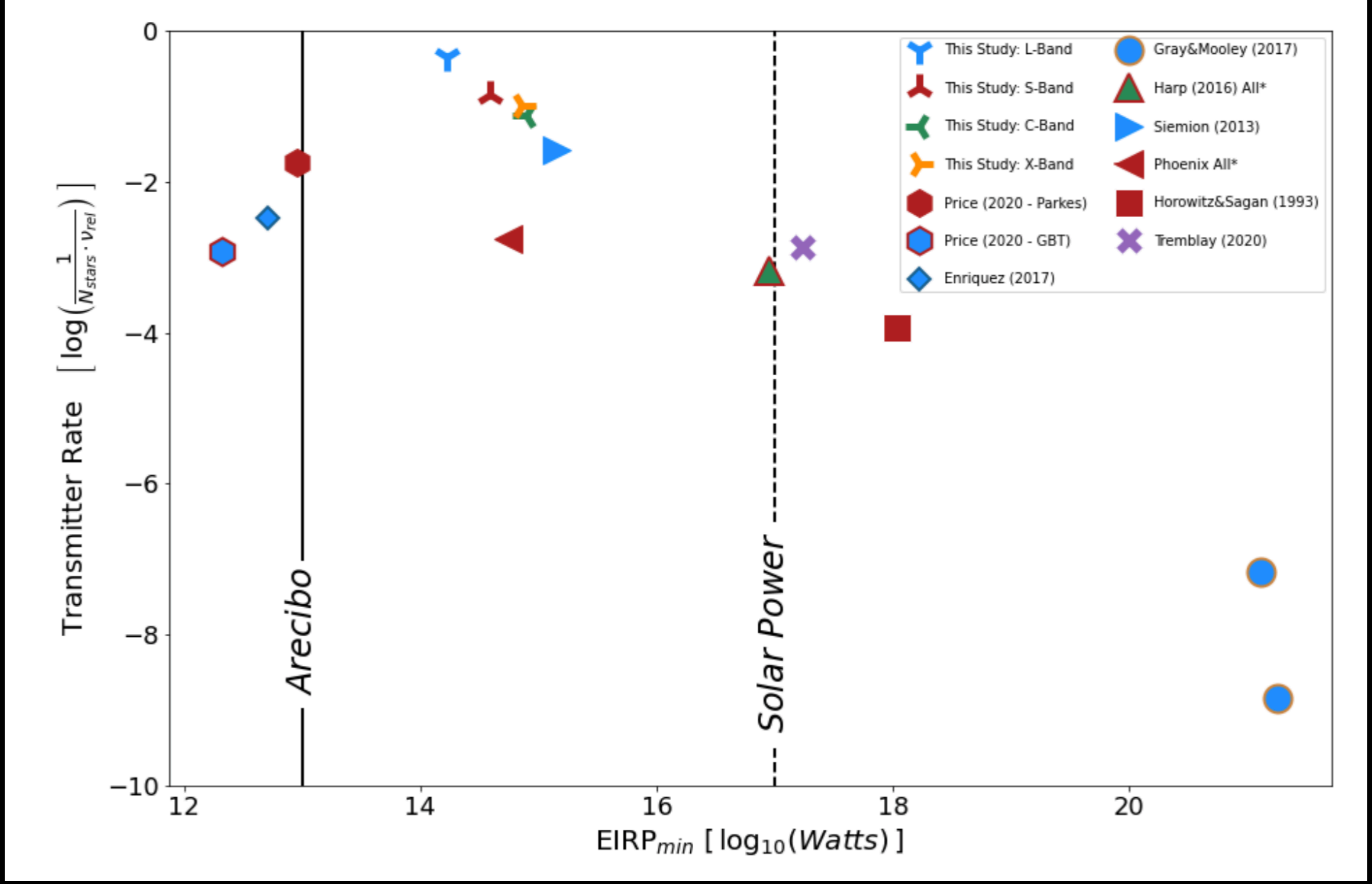
61 TOIs serendipitously observed with GBT during transit in L/S/C/X
No detections > few 1e14 W

Franz et al. (2022), AJ

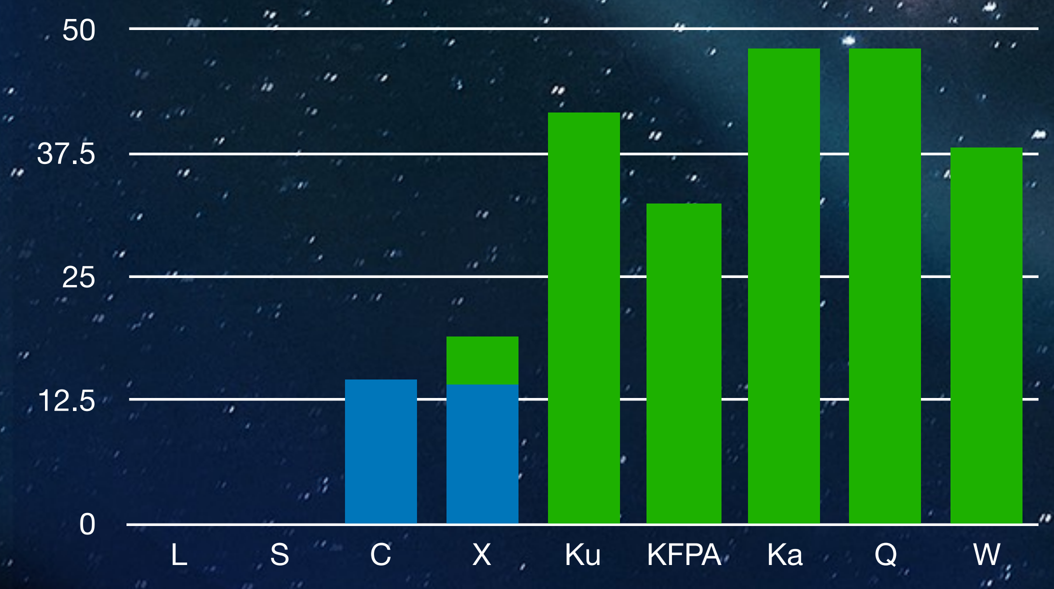
Searches of TESS Targets

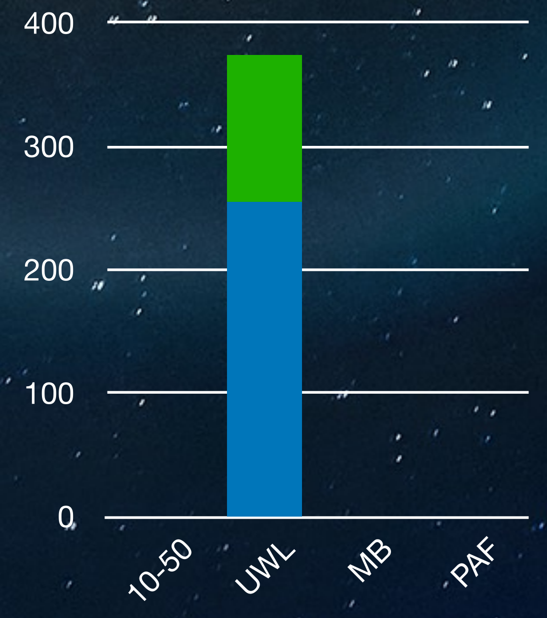
Franz et al. (2022), AJ





Galactic Center Survey





Gajjar, Perez, et al. (2021)
Art: D. Futselaar

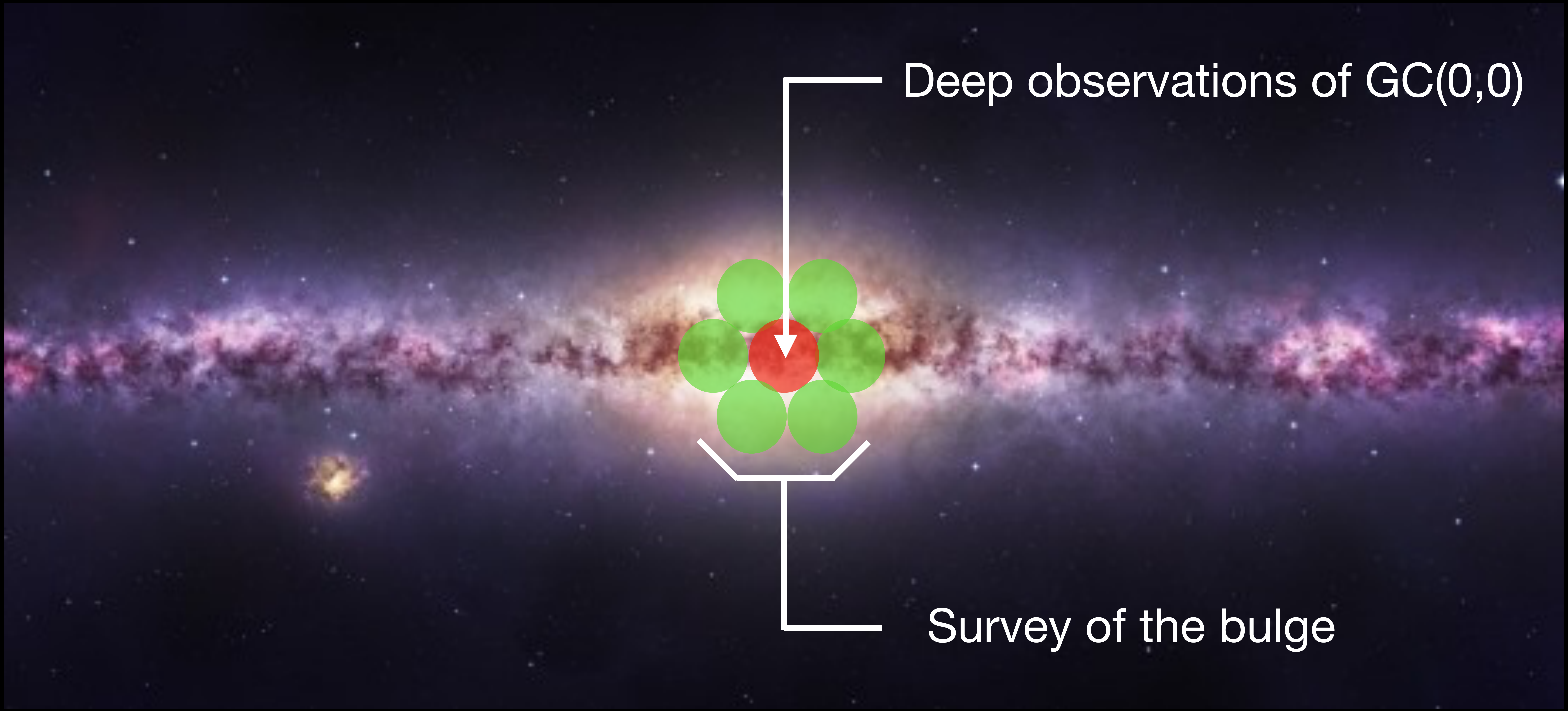
BERKELEY SETI RESEARCH CENTER

SETI.BERKELEY.EDU | BREAKTHROUGHINITIATIVES.ORG

BREAKTHROUGH LISTEN

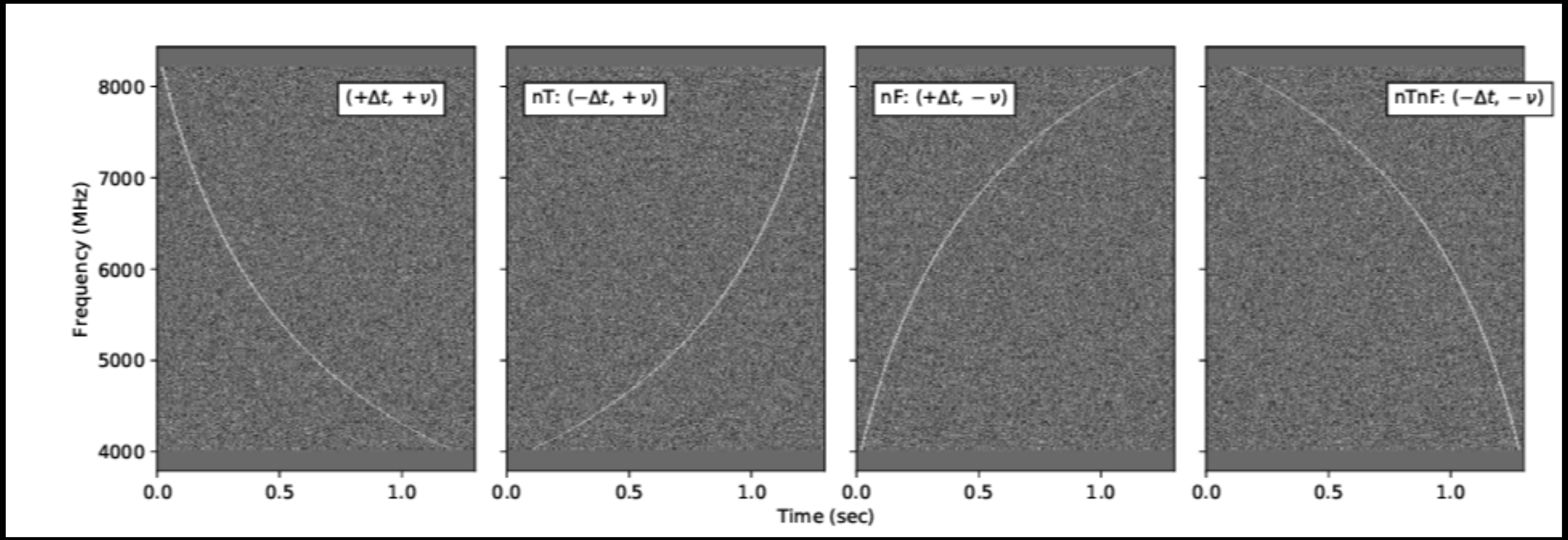
Gajjar, Perez, et al. (2021)

Observation Strategy

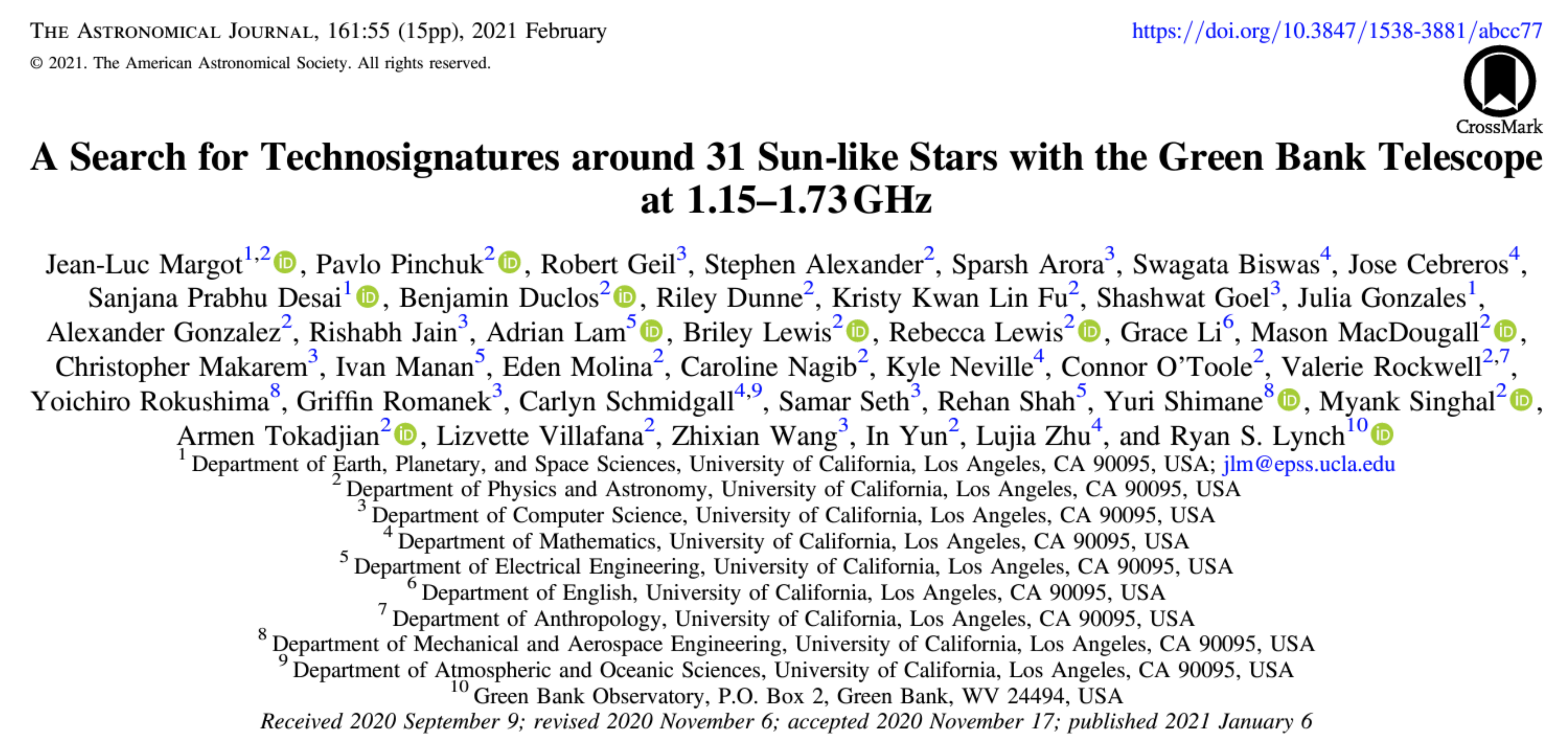


Gajjar, Perez, et al. (2021)

GC Summary



- Comprehensive survey of the GC from 1 - 93 GHz with GBT and Parkes
- Searched for narrowband drifting signals towards 60 million stars across 1 - 4 GHz and 0.6 million stars across 4 - 8 GHz with EIRP limits of 10^{18} W and 10^{17} W, respectively
- Searched for new class of artificially dispersed signals
- Can also search for natural sources such as pulsars and magnetars. Current survey found no transient source with peak luminosity $\geq 10^{31}$ erg/sec and $\geq$0.23 bursts/hr


The Astronomical Journal, 161:55 (15pp), 2021 February https://doi.org/10.3847/1538-3881/abcc77

CrossMark

A Search for Technosignatures around 31 Sun-like Stars with the Green Bank Telescope at 1.15–1.73 GHz

Jean-Luc Margot[1,2], Pavlo Pinchuk[2], Robert Geil[3], Stephen Alexander[2], Sparsh Arora[3], Swagata Biswas[4], Jose Cebreros[4], Sanjana Prabhu Desai[1], Benjamin Duclos[2], Riley Dunne[2], Kristy Kwan Lin Fu[2], Shashwat Goel[3], Julia Gonzales[1], Alexander Gonzalez[2], Rishabh Jain[3], Adrian Lam[5], Briley Lewis[2], Rebecca Lewis[4], Grace Li[6], Mason MacDougall[2], Christopher Makarem[3], Ivan Manan[5], Eden Molina[2], Caroline Nagib[2], Kyle Neville[4], Connor O'Toole[2], Valerie Rockwell[2,7], Yoichiro Rokushima[8], Griffin Romanek[3], Carlyn Schmidgall[4,9], Samar Seth[3], Rehan Shah[5], Yuri Shimane[8], Myank Singhal[2], Armen Tokadjian[2], Lizvette Villafana[2], Zhixian Wang[3], In Yun[2], Lujia Zhu[4], and Ryan S. Lynch[10]

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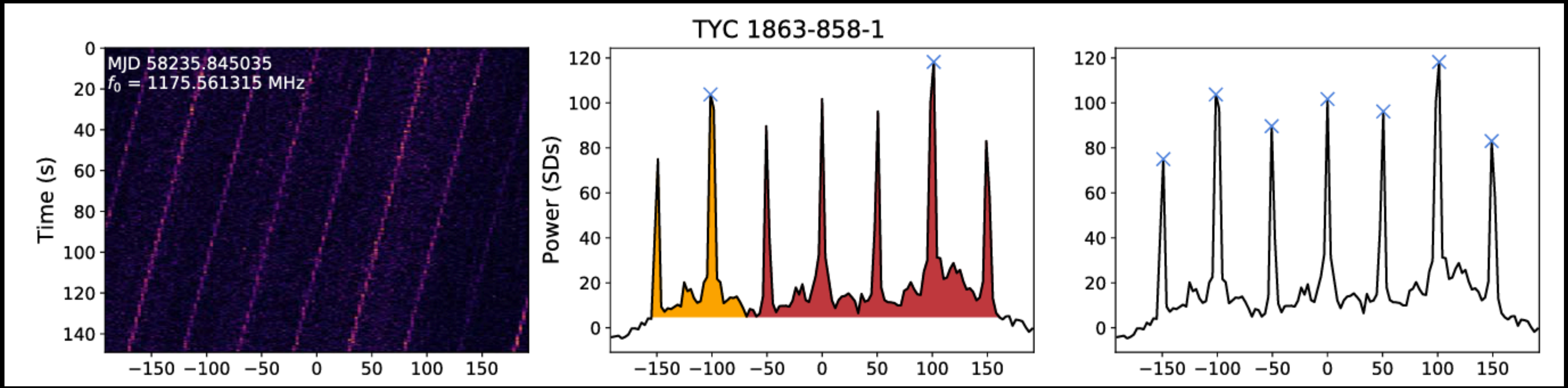
[10] Green Bank Observatory, P.O. Box 2, Green Bank, WV 24494, USA
Received 2020 September 9; revised 2020 November 6; accepted 2020 November 17; published 2021 January 6

- **L-band GUPPI raw**
- **31 stars**
- **ΔT = 1/Δf**
- **200x more signals / s / Hz**



Are we alone? New grant supports citizen science searching for intelligent life with the GBT

Posted on 2022-03-17 at 11:19 am.
Written by Jill Malusky

Photo by Jee Seymour.

The Planetary Society has awarded nearly $50,000 to UCLA Professor Jean-Luc Margot for a new citizen science project using the Green Bank Telescope (GBT), "Are We Alone? A Citizen-Science-Enabled Search for Technosignatures."

THE ASTRONOMICAL JOURNAL, 163:76 (19pp), 2022 February https://doi.org/10.3847/1538-3881/ac426f

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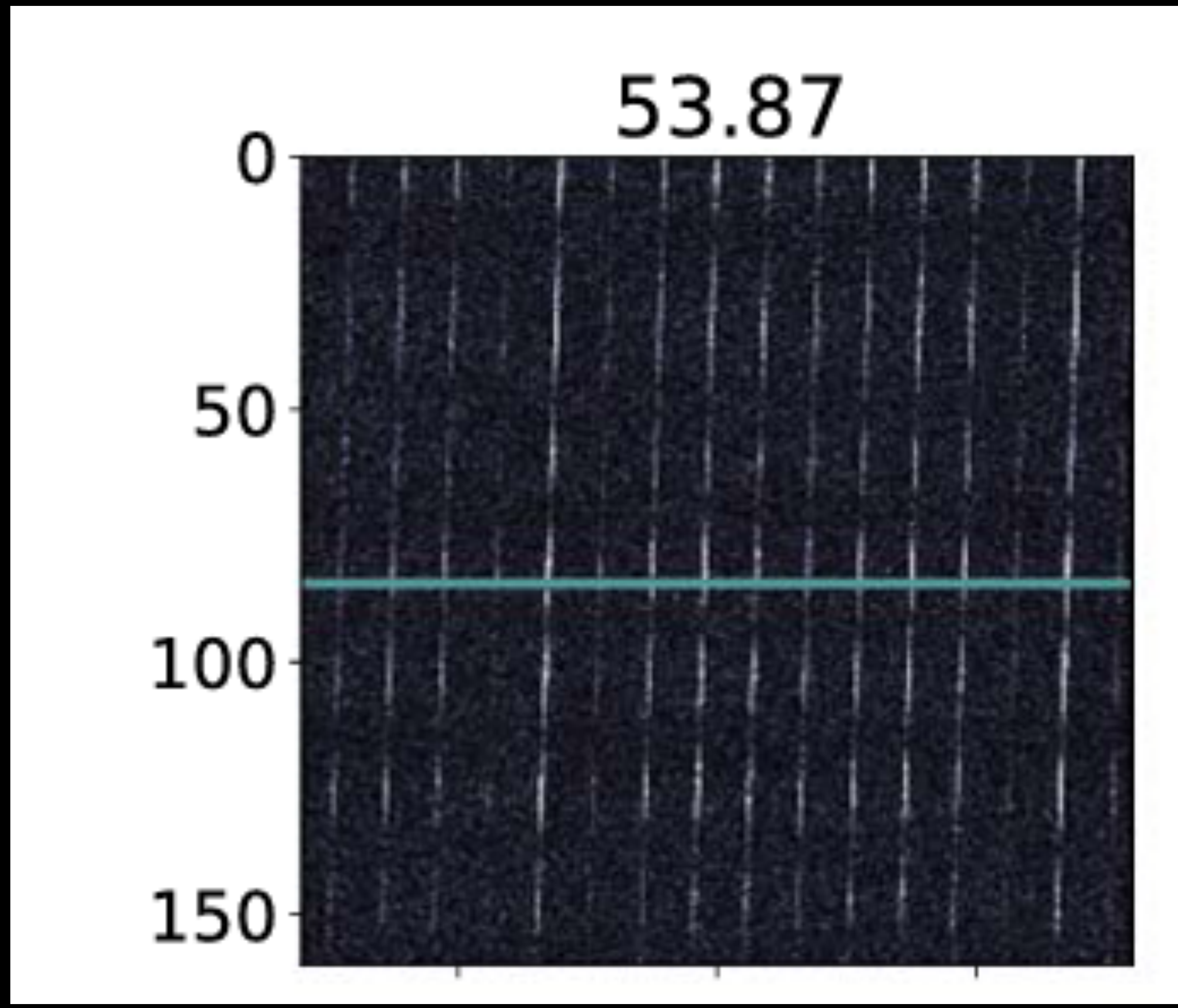
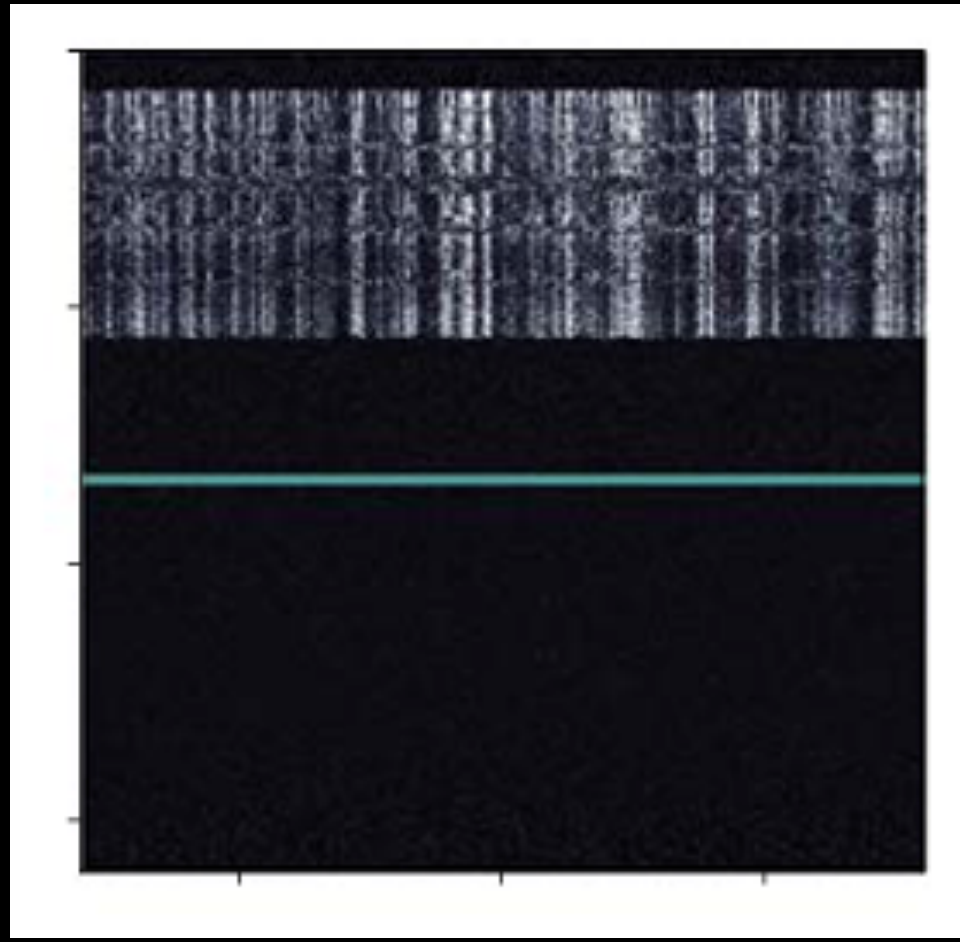
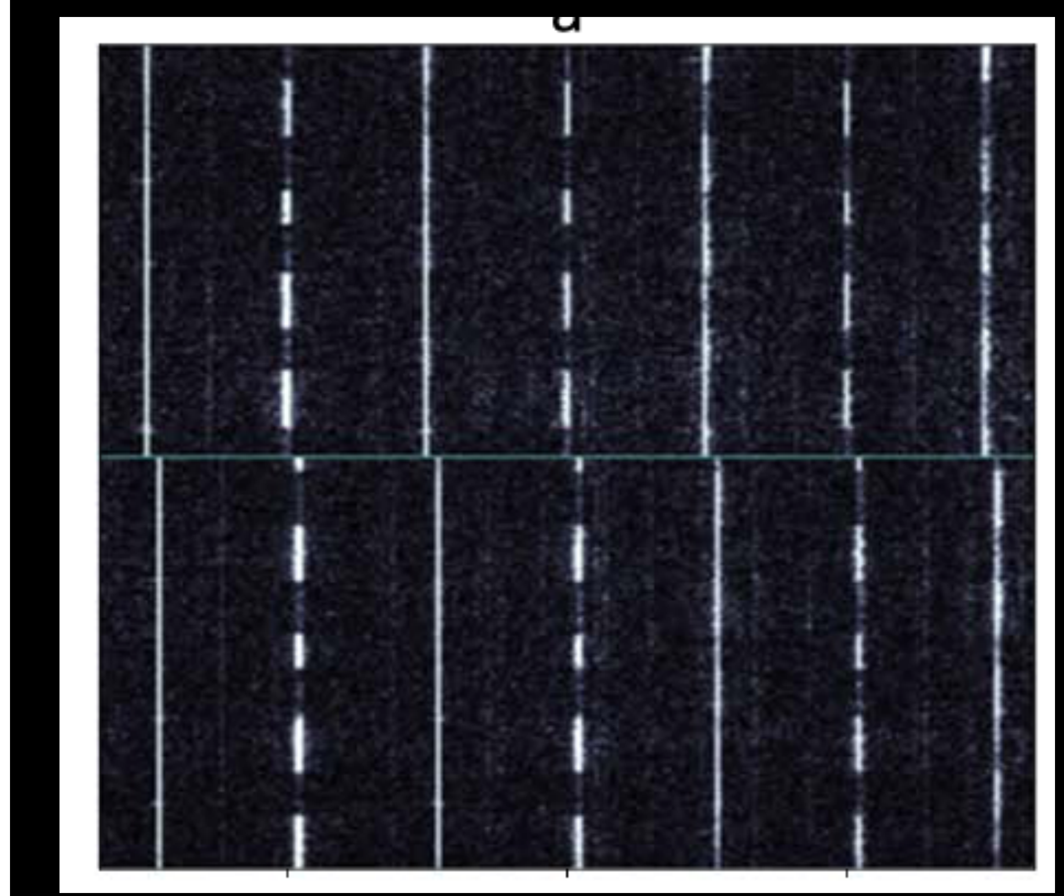
A Machine Learning–based Direction-of-origin Filter for the Identification of Radio Frequency Interference in the Search for Technosignatures

Pavlo Pinchuk[1] and Jean-Luc Margot[2,1]
[1] Department of Physics and Astronomy, University of California, Los Angeles, CA 90095, USA; jlm@epss.ucla.edu
[2] Department of Earth, Planetary, and Space Sciences, University of California, Los Angeles, CA 90095, USA
Received 2021 July 28; revised 2021 December 3; accepted 2021 December 7; published 2022 January 20







A Search for Radio Technosignatures at the Solar Gravitational Lens Targeting Alpha Centauri

Nick Tusay,[1,2,3] Macy J. Huston,[1,2,3] Cayla M. Dedrick,[1,2] Stephen Kerby,[1]
Michael L. Palumbo III,[1,2] Steve Croft,[4,5] Jason T. Wright,[1,2,3] Paul Robertson,[6]
Sofia Sheikh,[5,3]

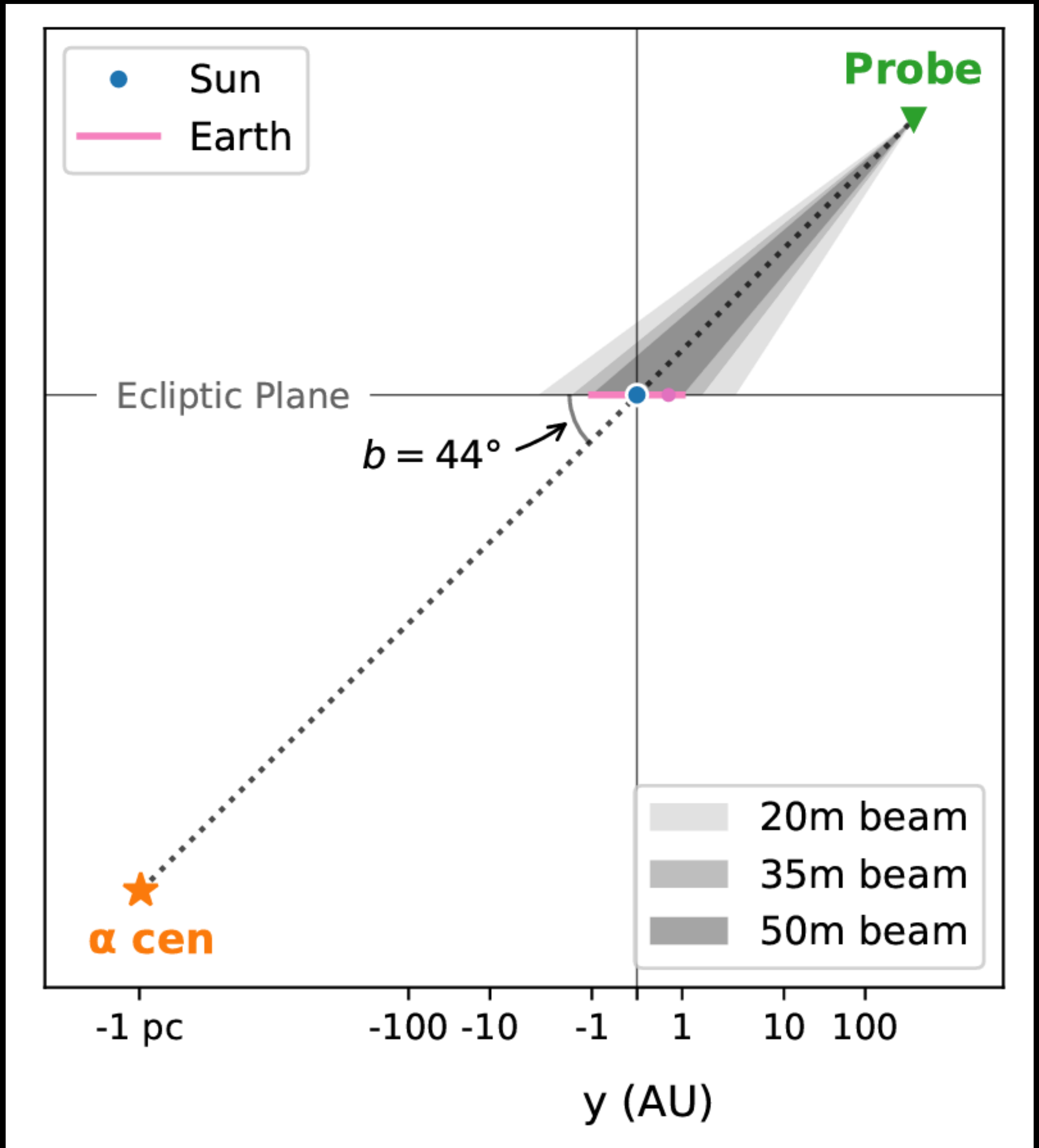
—

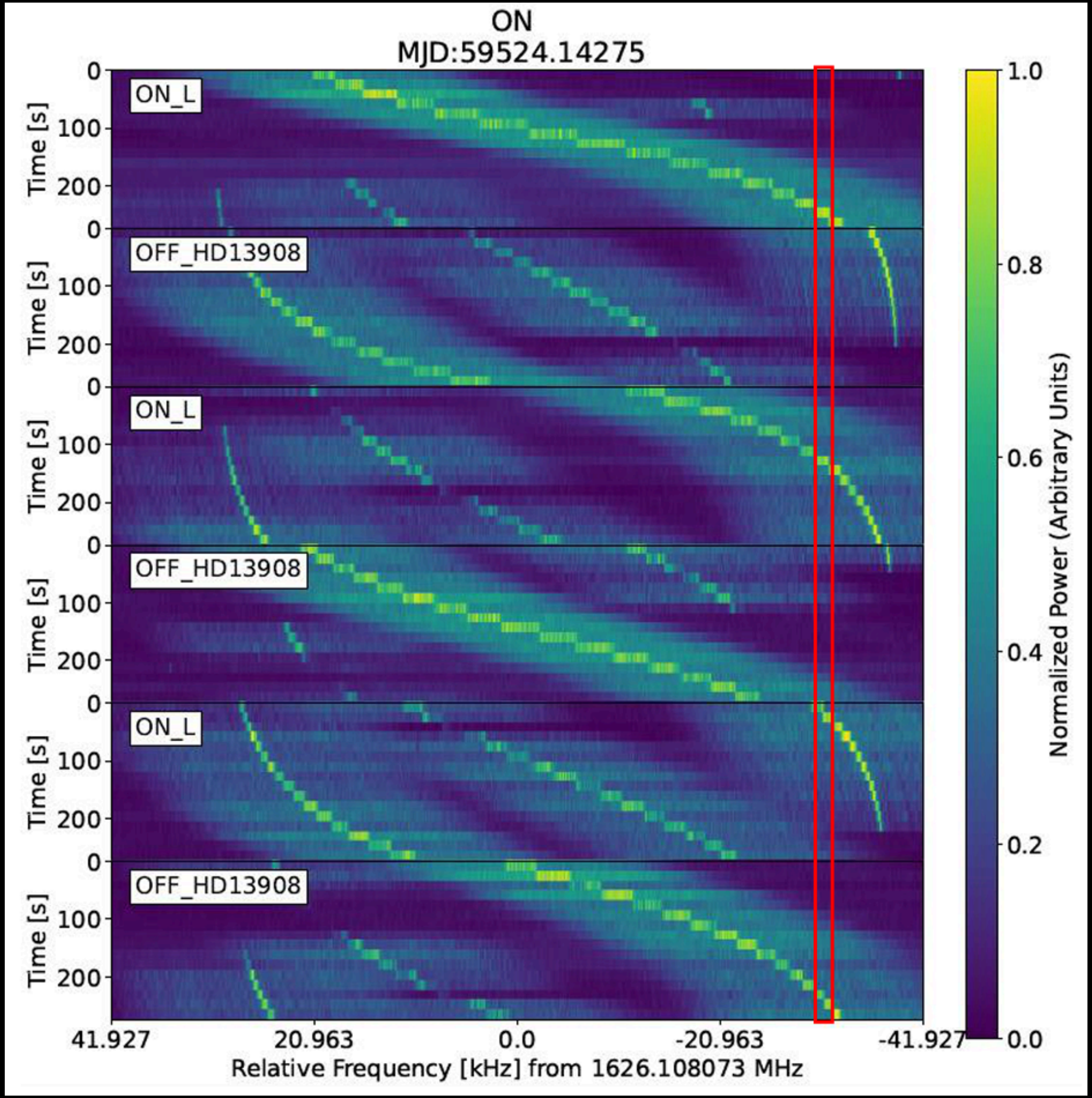
Laura Duffy,[1] Gregory Foote,[7] Andrew Hyde,[8] Julia Lafond,[8] Ella Mullikin,[9]
Winter Parts,[1,2] Phoebe Sandhaus,[1,2] Hillary H. Smith,[8,10] Evan L. Sneed,[3]

Penn State Astro 576 SETI Class, Fall 2020

Daniel Czech,[4] Vishal Gajjar,[4]

Breakthrough Listen

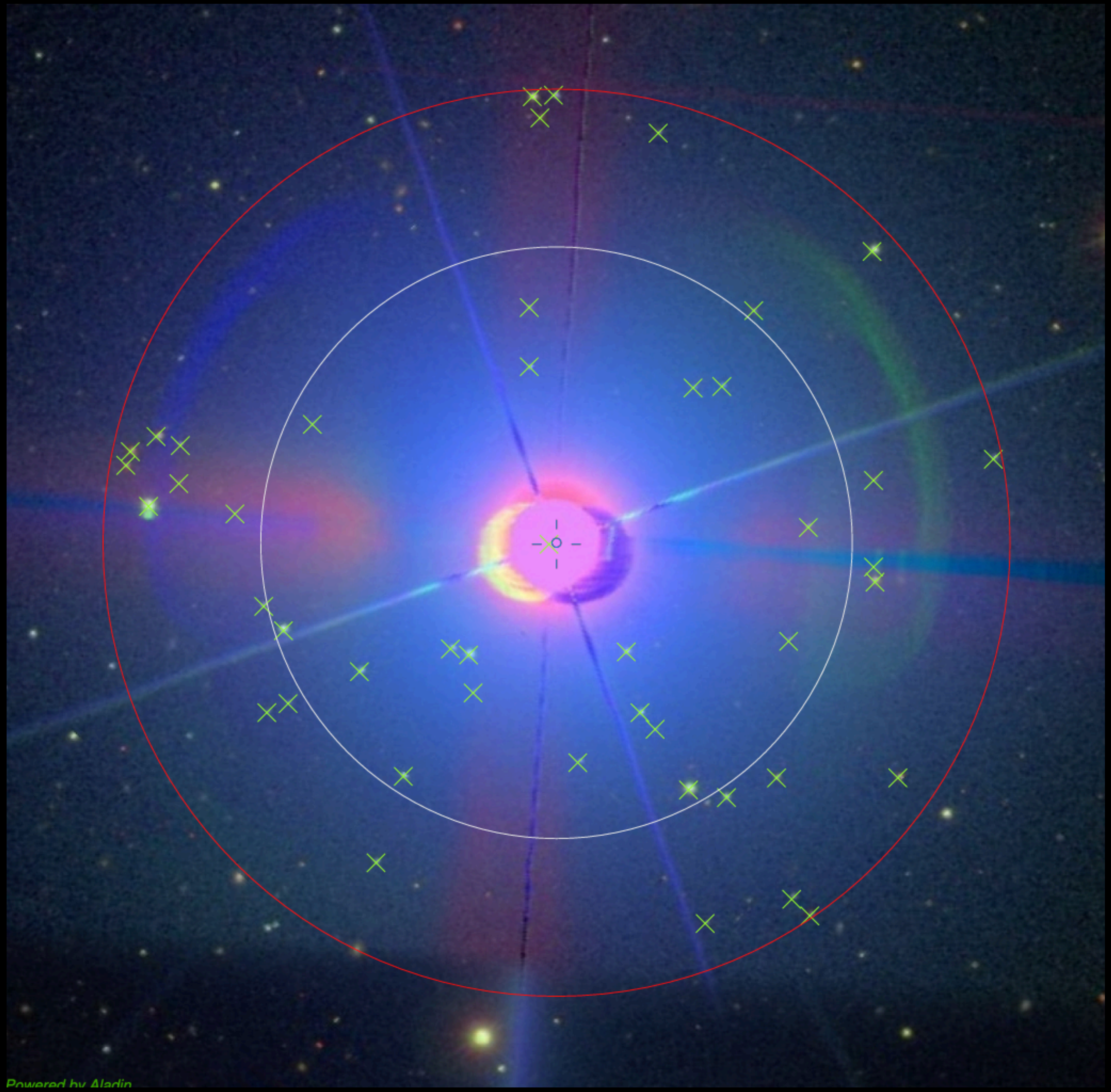


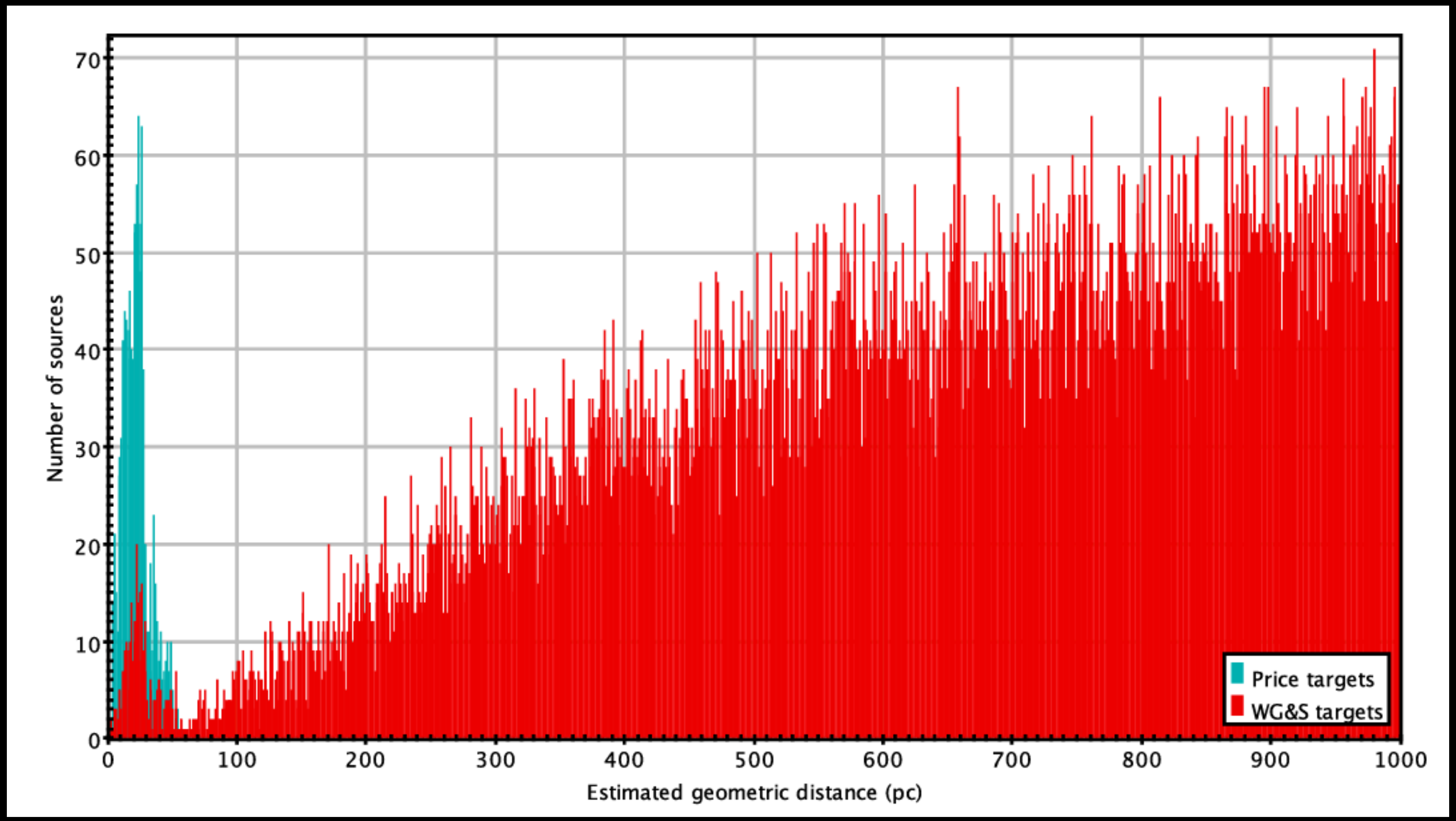


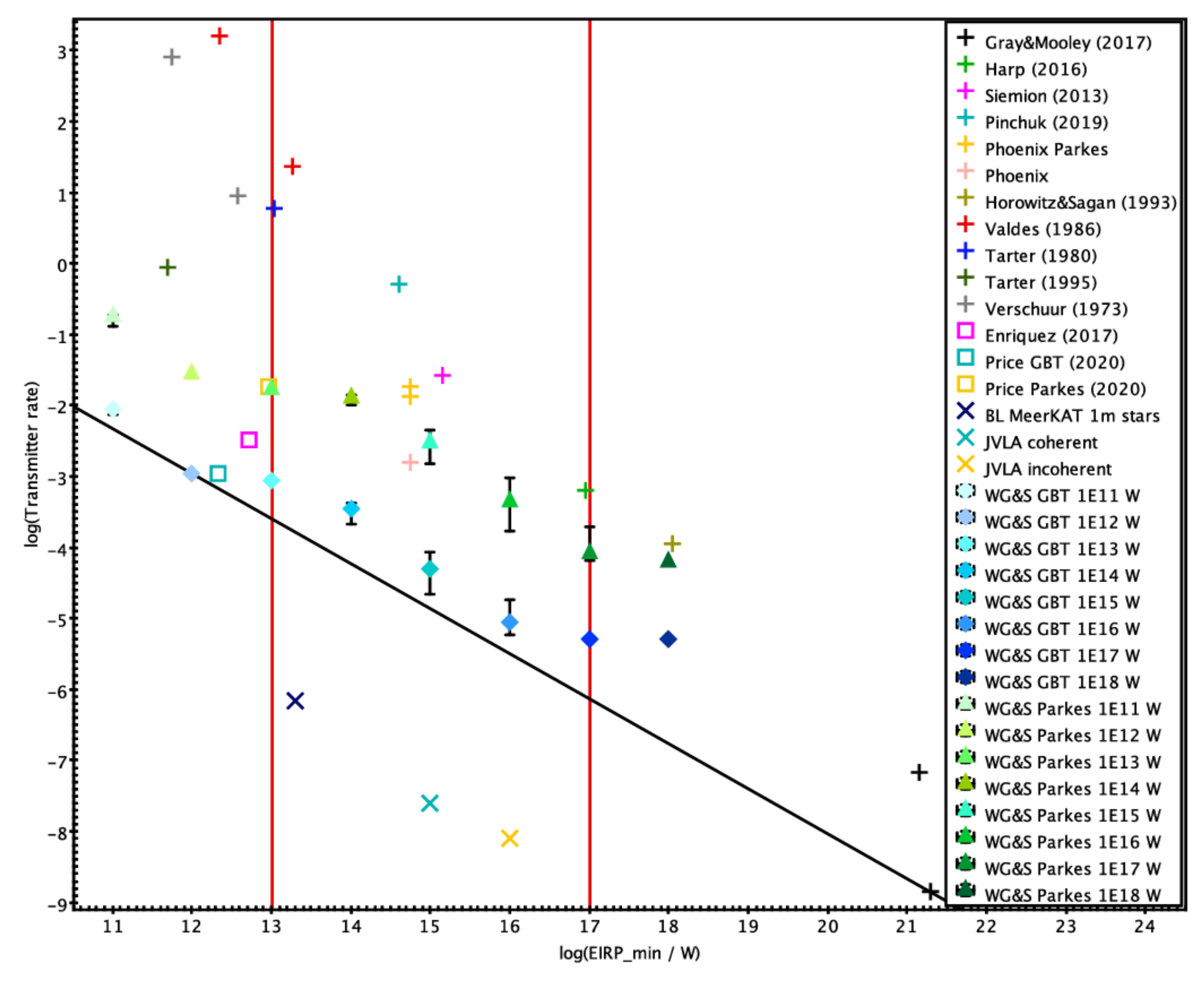
Art: D. Futselaar

Extending the Breakthrough Listen nearby star survey to other stellar objects in the field

B. S. Wlodarczyk-Sroka,[1★] M. A. Garrett[1,2★] and A. P. V. Siemion[1,3]
[1]Jodrell Bank Centre for Astrophysics, Department of Physics and Astronomy, Alan Turing Building, The University of Manchester, Manchester M13 9PL, UK
[2]Leiden Observatory, Leiden University, P.O. Box 9513, NL-2300 RA Leiden, The Netherlands
[3]Department of Astronomy, University of California Berkeley, Berkeley CA 94720, USA







Constraints on extragalactic transmitters via Breakthrough Listen observations of background sources

M.A. Garrett[1,2] and A.P.V. Siemion[3,4,1]
[1]Jodrell Bank Centre for Astrophysics (JBCA), Department of Physics & Astronomy, Alan Turing Building, The University of Manchester, M13 9PL, UK
[2]Leiden Observatory, Leiden University, PO Box 9513, 2300 RA Leiden, The Netherlands
[3]Berkeley SETI Research Center, University of California Berkeley, Berkeley CA 94720, USA
[4]SETI Institute, Mountain View, CA 94043, USA

THE EXTRAGALACTIC ALIEN HUNT

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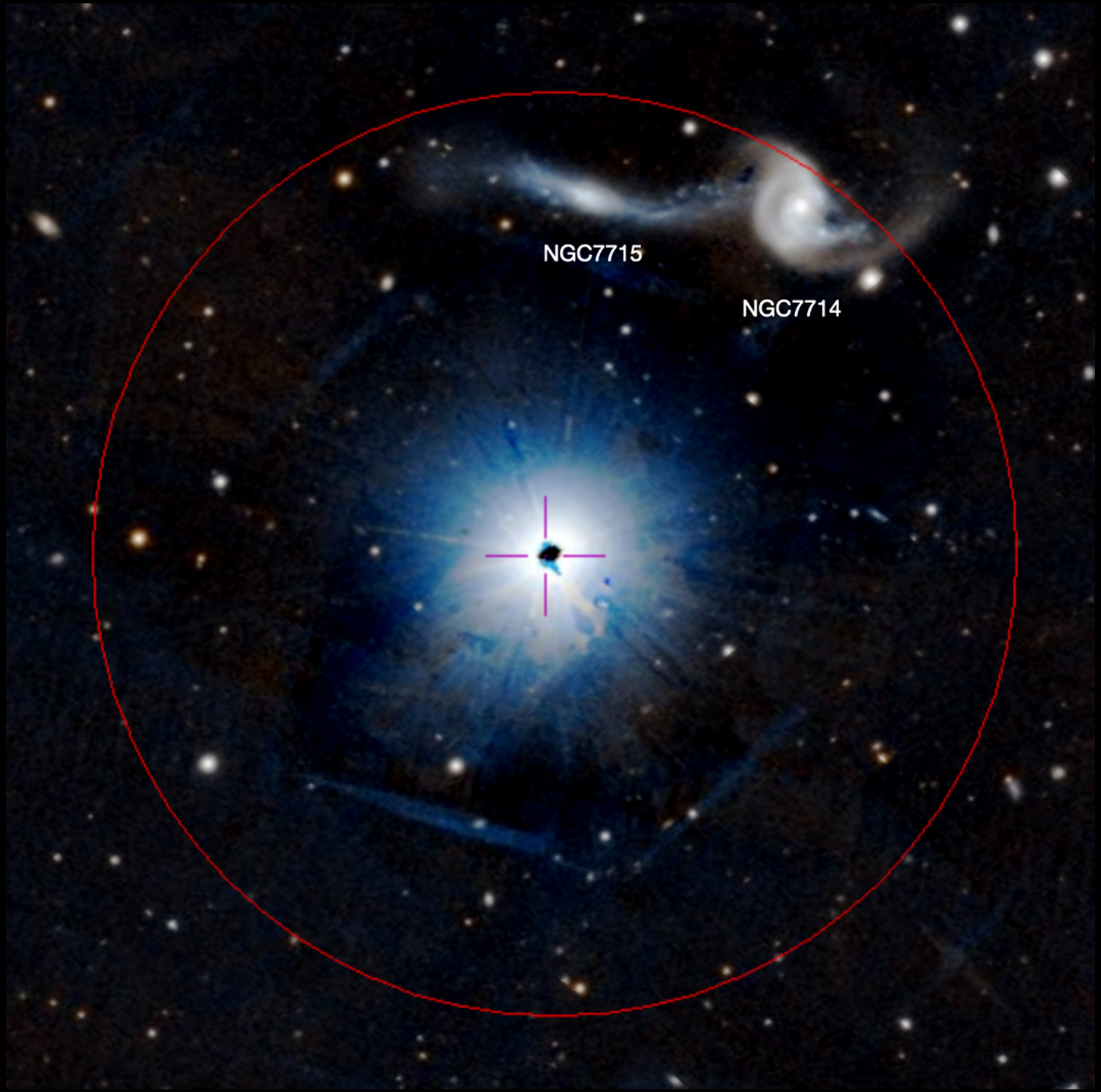
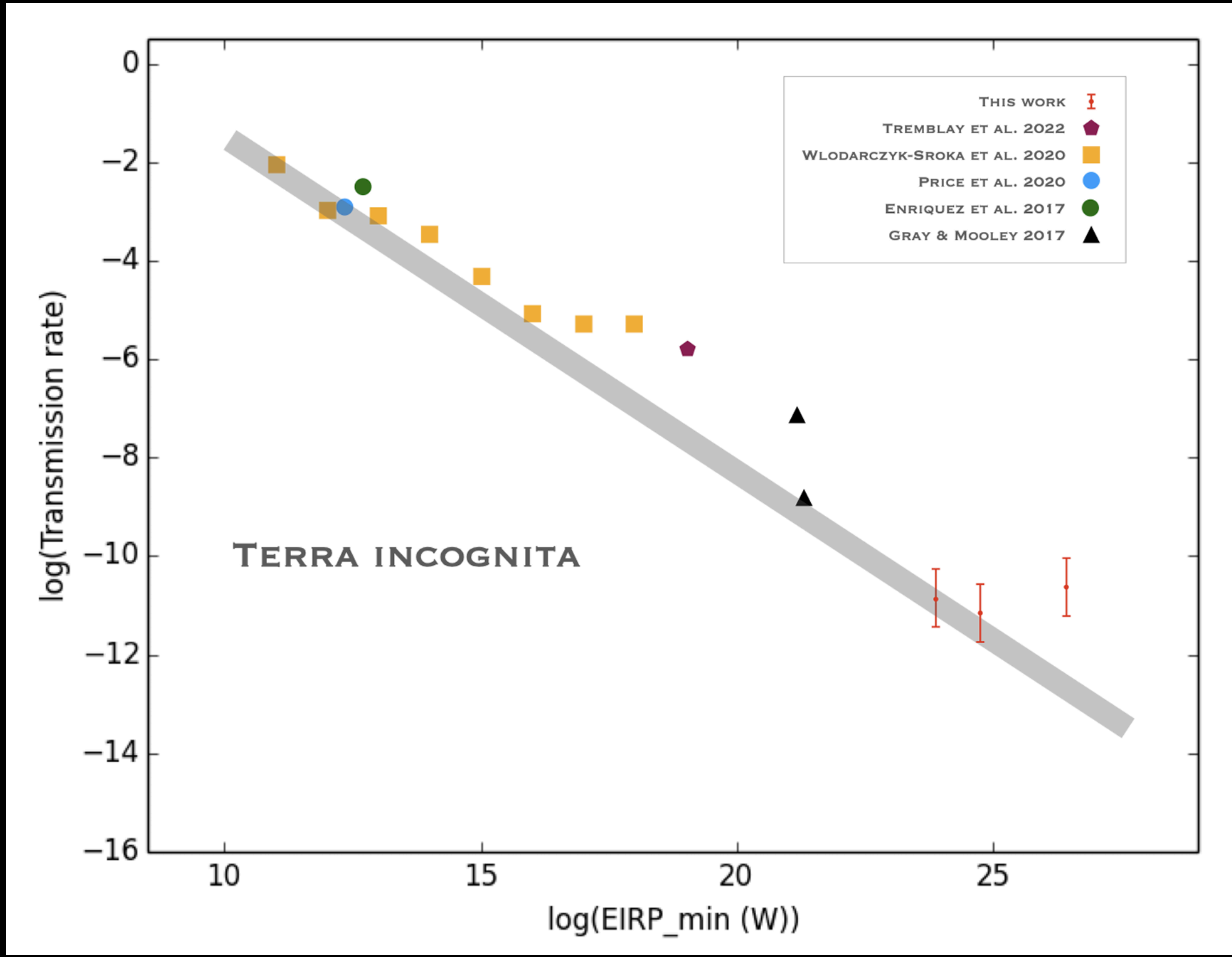
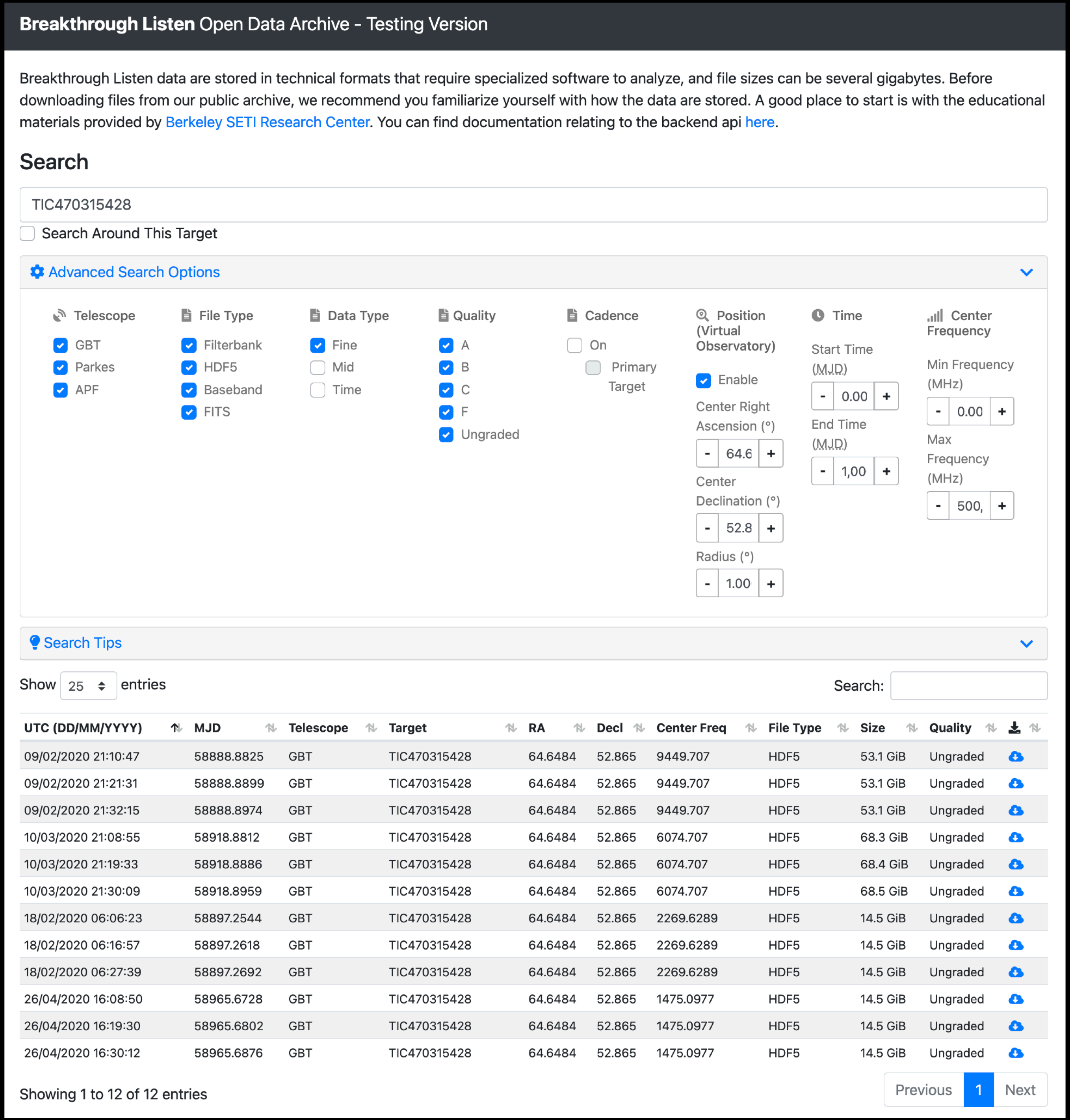




Public Data



Breakthrough Listen Open Data Archive - Testing Version

Breakthrough Listen data are stored in technical formats that require specialized software to analyze, and file sizes can be several gigabytes. Before downloading files from our public archive, we recommend you familiarize yourself with how the data are stored. A good place to start is with the educational materials provided by Berkeley SETI Research Center. You can find documentation relating to the backend api here.

Search

TIC470315428

Search Around This Target

Advanced Search Options

Telescope: GBT, Parkes, APF

File Type: Filterbank, HDF5, Baseband, FITS

Data Type: Fine, Mid, Time

Quality: A, B, C, F, Ungraded

Cadence: On, Primary Target

Position (Virtual Observatory): Enable; Center Right Ascension (°) 64.6; Center Declination (°) 52.8; Radius (°) 1.00

Time: Start Time (MJD) 0.00; End Time (MJD) 1,00

Center Frequency: Min Frequency (MHz) 0.00; Max Frequency (MHz) 500,

Search Tips

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UTC (DD/MM/YYYY)	MJD	Telescope	Target	RA	Decl	Center Freq	File Type	Size	Quality
09/02/2020 21:10:47	58888.8825	GBT	TIC470315428	64.6484	52.865	9449.707	HDF5	53.1 GiB	Ungraded
09/02/2020 21:21:31	58888.8899	GBT	TIC470315428	64.6484	52.865	9449.707	HDF5	53.1 GiB	Ungraded
09/02/2020 21:32:15	58888.8974	GBT	TIC470315428	64.6484	52.865	9449.707	HDF5	53.1 GiB	Ungraded
10/03/2020 21:08:55	58918.8812	GBT	TIC470315428	64.6484	52.865	6074.707	HDF5	68.3 GiB	Ungraded
10/03/2020 21:19:33	58918.8886	GBT	TIC470315428	64.6484	52.865	6074.707	HDF5	68.4 GiB	Ungraded
10/03/2020 21:30:09	58918.8959	GBT	TIC470315428	64.6484	52.865	6074.707	HDF5	68.5 GiB	Ungraded
18/02/2020 06:06:23	58897.2544	GBT	TIC470315428	64.6484	52.865	2269.6289	HDF5	14.5 GiB	Ungraded
18/02/2020 06:16:57	58897.2618	GBT	TIC470315428	64.6484	52.865	2269.6289	HDF5	14.5 GiB	Ungraded
18/02/2020 06:27:39	58897.2692	GBT	TIC470315428	64.6484	52.865	2269.6289	HDF5	14.5 GiB	Ungraded
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26/04/2020 16:19:30	58965.6802	GBT	TIC470315428	64.6484	52.865	1475.0977	HDF5	14.5 GiB	Ungraded
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Showing 1 to 12 of 12 entries

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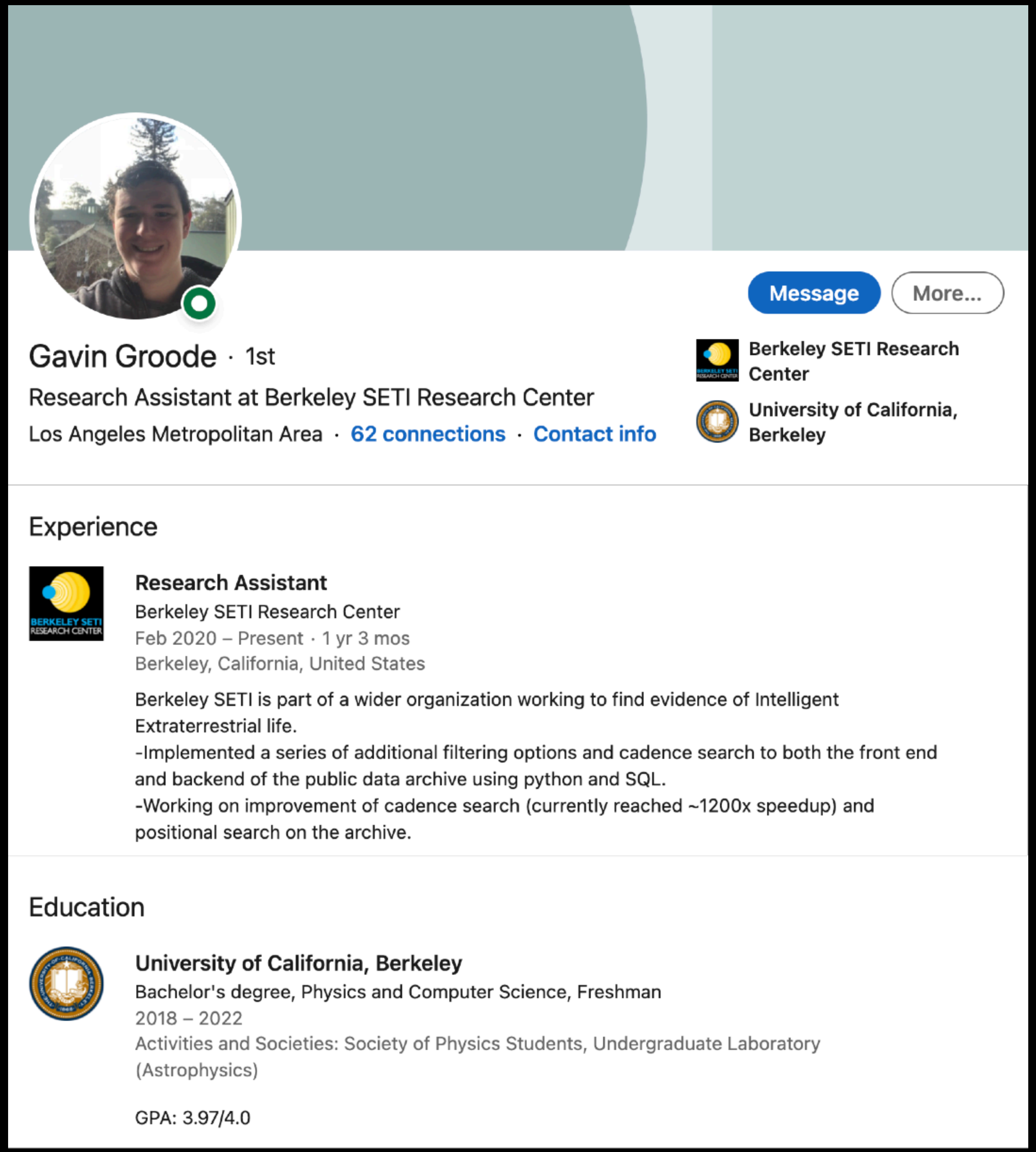
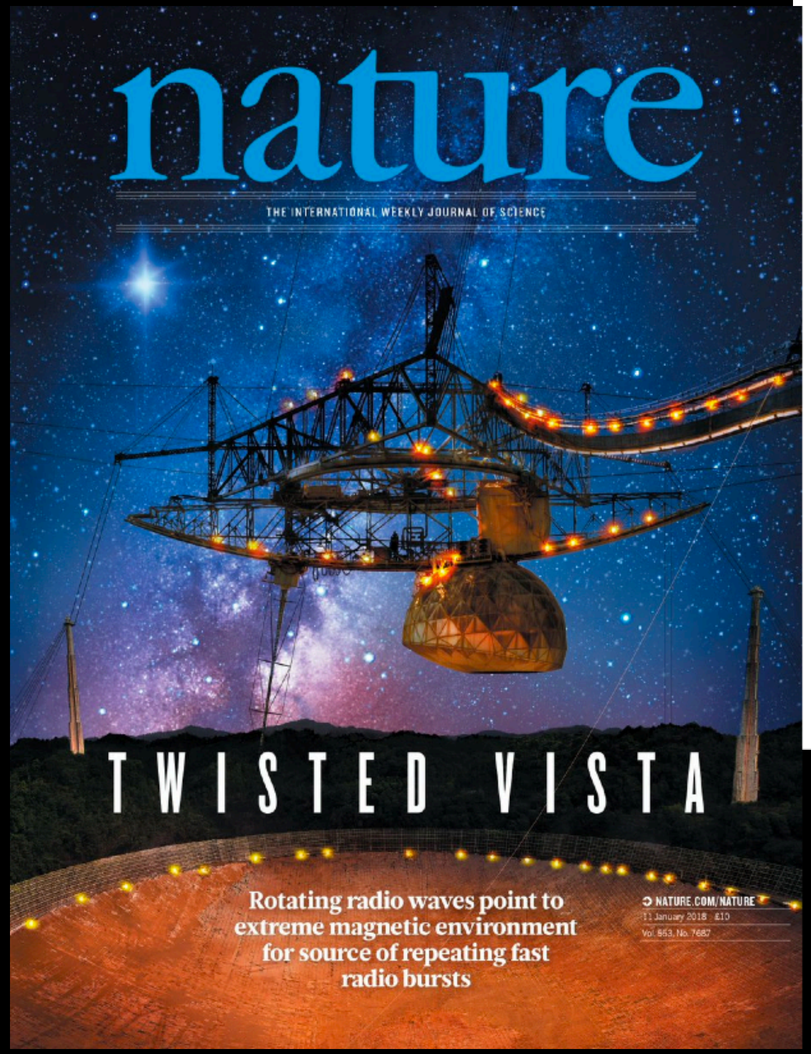
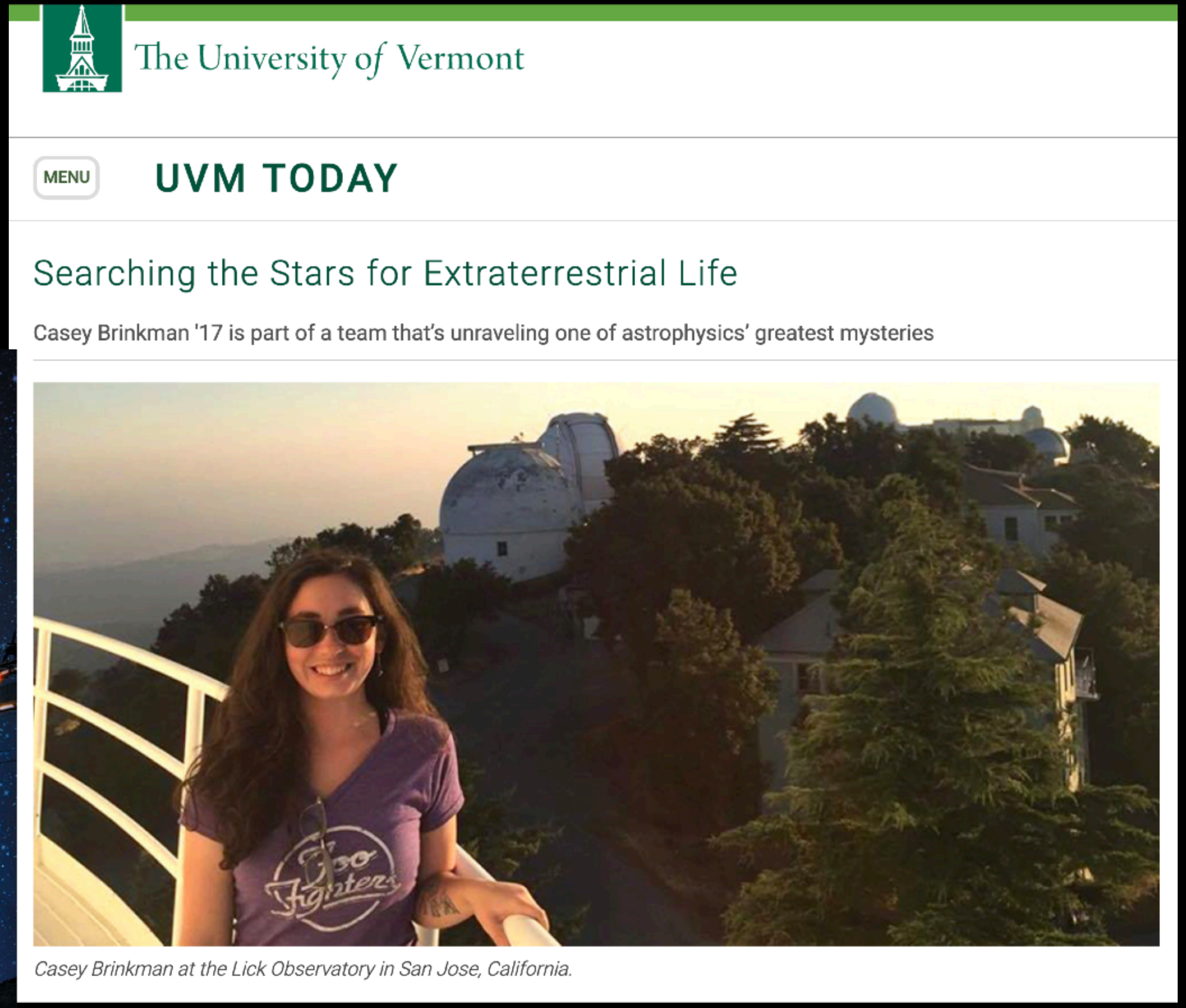


2 PB of public data

https://seti.berkeley.edu/opendata

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Searching the Stars for Extraterrestrial Life

Casey Brinkman '17 is part of a team that's unraveling one of astrophysics' greatest mysteries

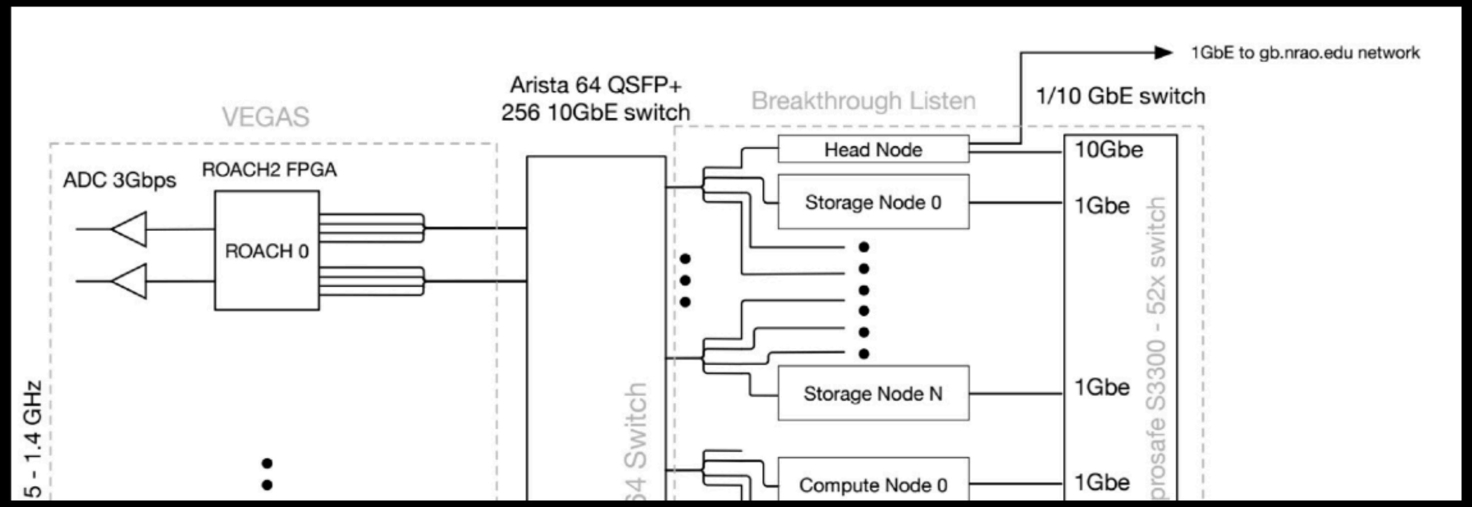
Casey Brinkman at the Lick Observatory in San Jose, California.

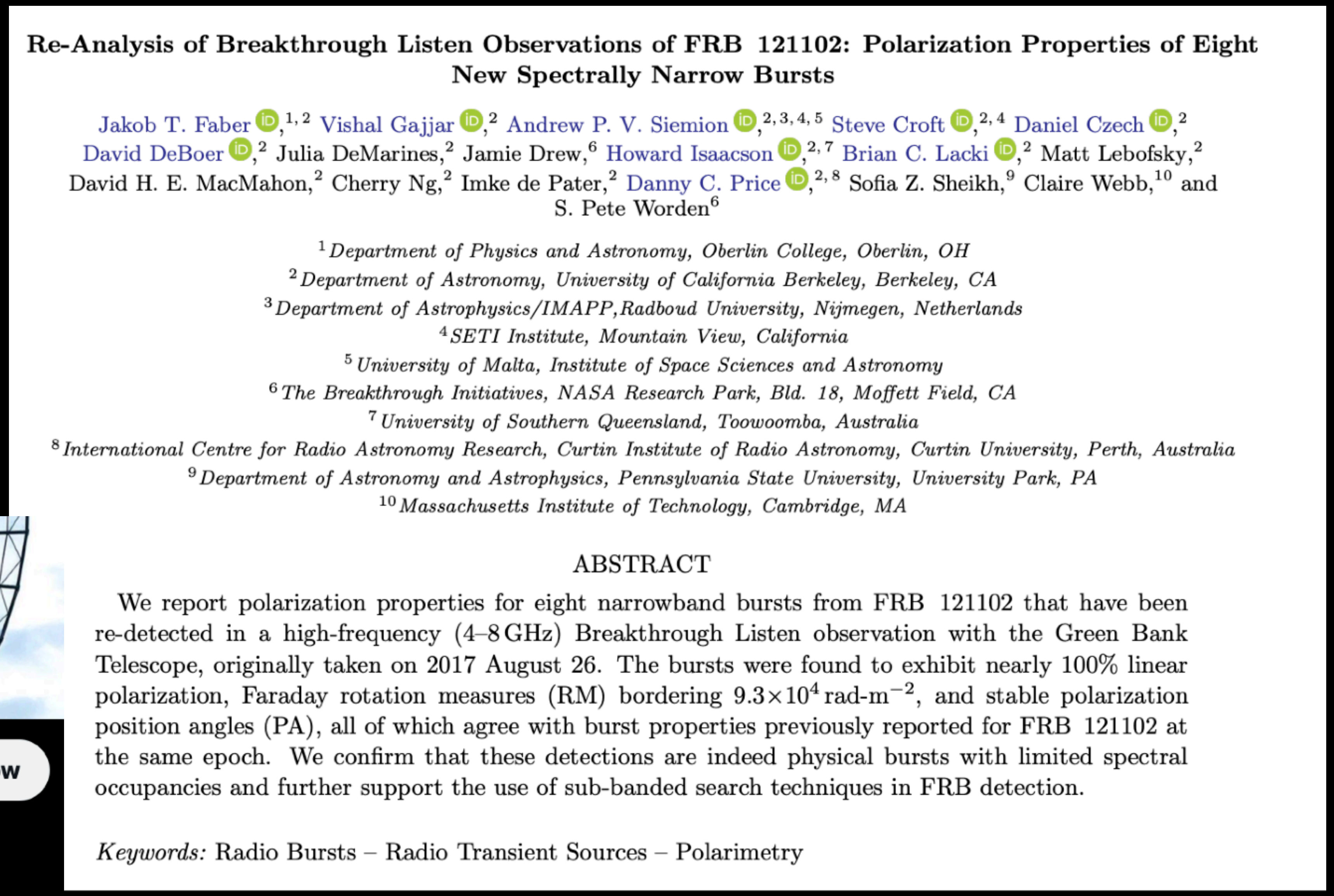
http://seti.berkeley.edu/bl_gbo.html

Breakthrough Listen at the GBO

Shared Risk Observations with the Breakthrough Listen Backend at the Green Bank Telescope

The Breakthrough Listen project is making its digital recorder backend at the Green Bank Telescope available for a minimum of 50 hours of shared-risk observations each semester. The instrument consists of a cluster of 64 Titan X and 1080 GPU-based servers capturing 8-bit baseband voltages over up to 10 GHz of instantaneous bandwidth in two polarizations.




Re-Analysis of Breakthrough Listen Observations of FRB 121102: Polarization Properties of Eight New Spectrally Narrow Bursts

Jakob T. Faber[1,2] Vishal Gajjar[2] Andrew P. V. Siemion[2,3,4,5] Steve Croft[2,4] Daniel Czech[2] David DeBoer[2] Julia DeMarines,[2] Jamie Drew,[6] Howard Isaacson[2,7] Brian C. Lacki[2] Matt Lebofsky,[2] David H. E. MacMahon,[2] Cherry Ng,[2] Imke de Pater,[2] Danny C. Price[2,8] Sofia Z. Sheikh,[9] Claire Webb,[10] and S. Pete Worden[6]

[1]*Department of Physics and Astronomy, Oberlin College, Oberlin, OH*
[2]*Department of Astronomy, University of California Berkeley, Berkeley, CA*
[3]*Department of Astrophysics/IMAPP, Radboud University, Nijmegen, Netherlands*
[4]*SETI Institute, Mountain View, California*
[5]*University of Malta, Institute of Space Sciences and Astronomy*
[6]*The Breakthrough Initiatives, NASA Research Park, Bld. 18, Moffett Field, CA*
[7]*University of Southern Queensland, Toowoomba, Australia*
[8]*International Centre for Radio Astronomy Research, Curtin Institute of Radio Astronomy, Curtin University, Perth, Australia*
[9]*Department of Astronomy and Astrophysics, Pennsylvania State University, University Park, PA*
[10]*Massachusetts Institute of Technology, Cambridge, MA*

ABSTRACT

We report polarization properties for eight narrowband bursts from FRB 121102 that have been re-detected in a high-frequency (4–8 GHz) Breakthrough Listen observation with the Green Bank Telescope, originally taken on 2017 August 26. The bursts were found to exhibit nearly 100% linear polarization, Faraday rotation measures (RM) bordering 9.3×10^4 rad-m^{-2}, and stable polarization position angles (PA), all of which agree with burst properties previously reported for FRB 121102 at the same epoch. We confirm that these detections are indeed physical bursts with limited spectral occupancies and further support the use of sub-banded search techniques in FRB detection.

Keywords: Radio Bursts – Radio Transient Sources – Polarimetry

A Model-independent Radio Telescope Dark Matter Search

Aya Keller[1], Sean O'Brien[1], Adyant Kamdar[1], Nicholas M. Rapidis[1,2], Alexander F. Leder[1], and Karl van Bibber[1]
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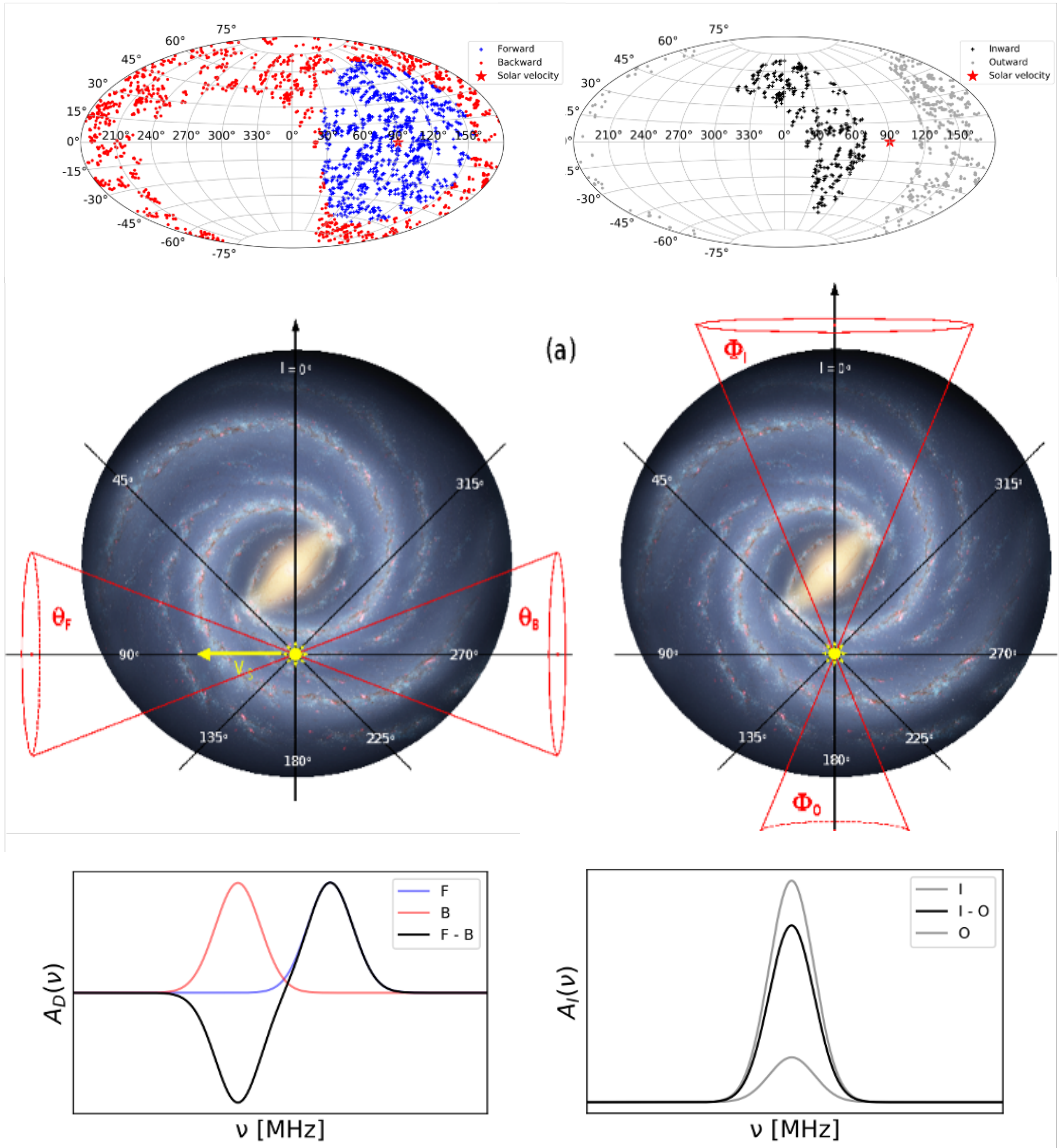
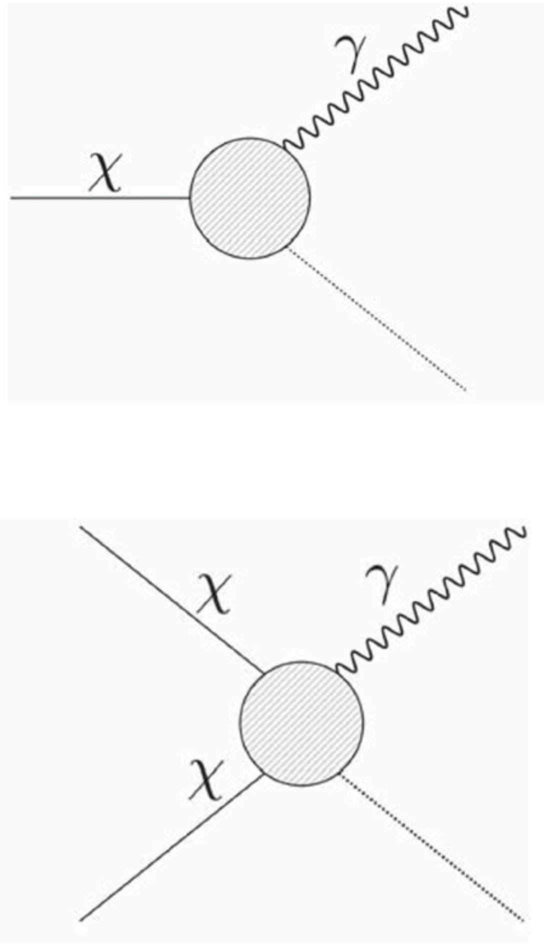
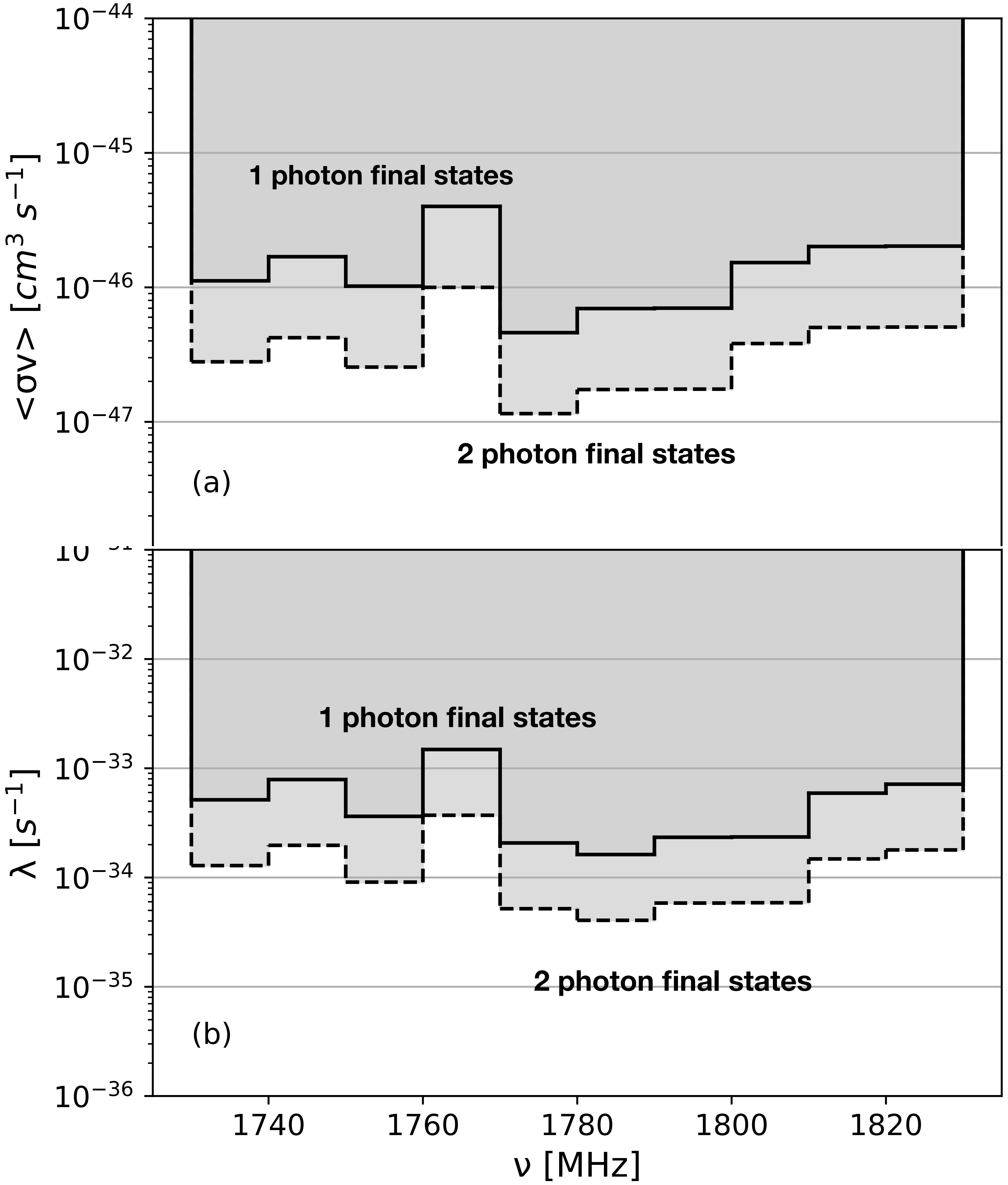
Received 2021 November 30; revised 2022 January 8; accepted 2022 January 18; published 2022 March 7



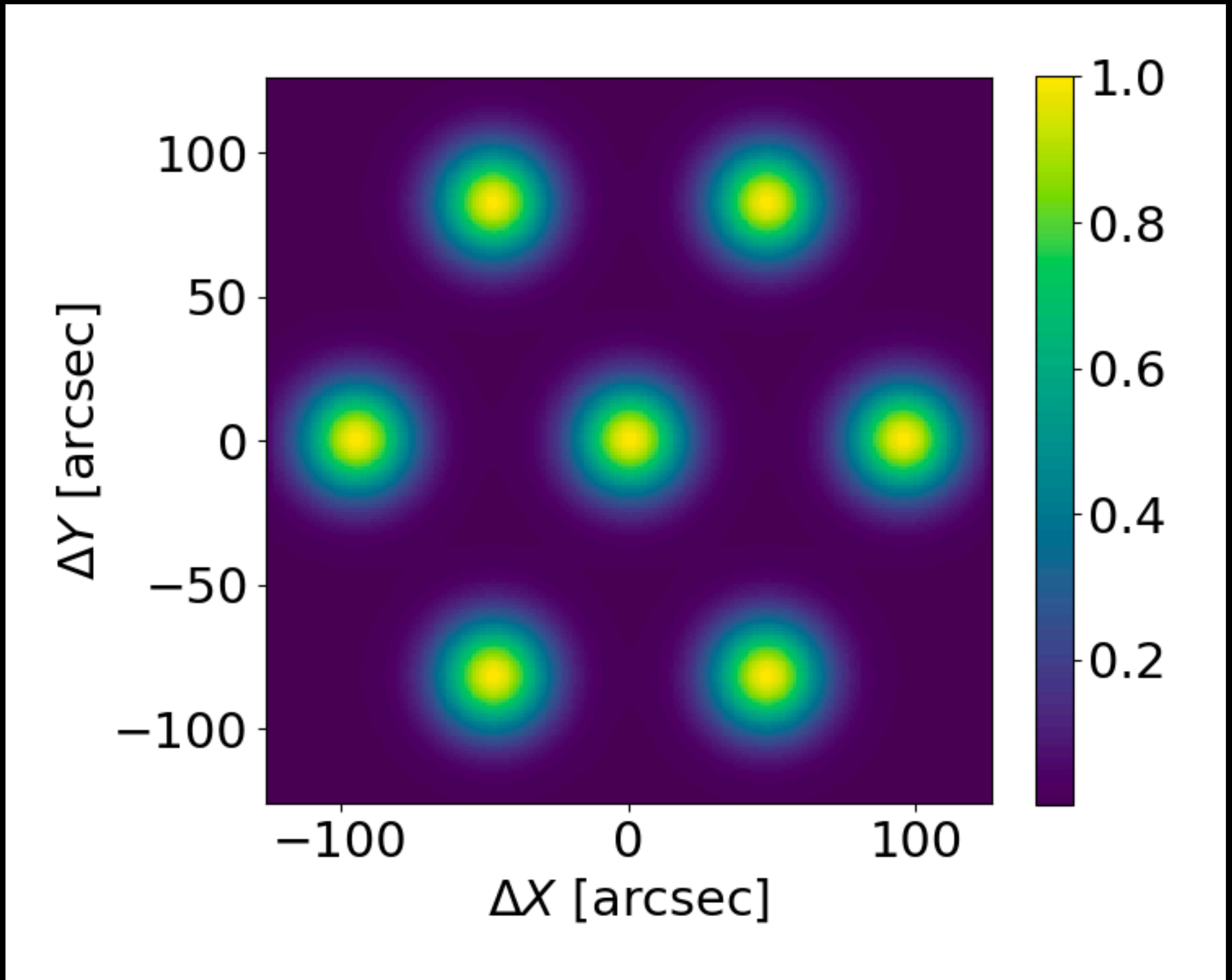


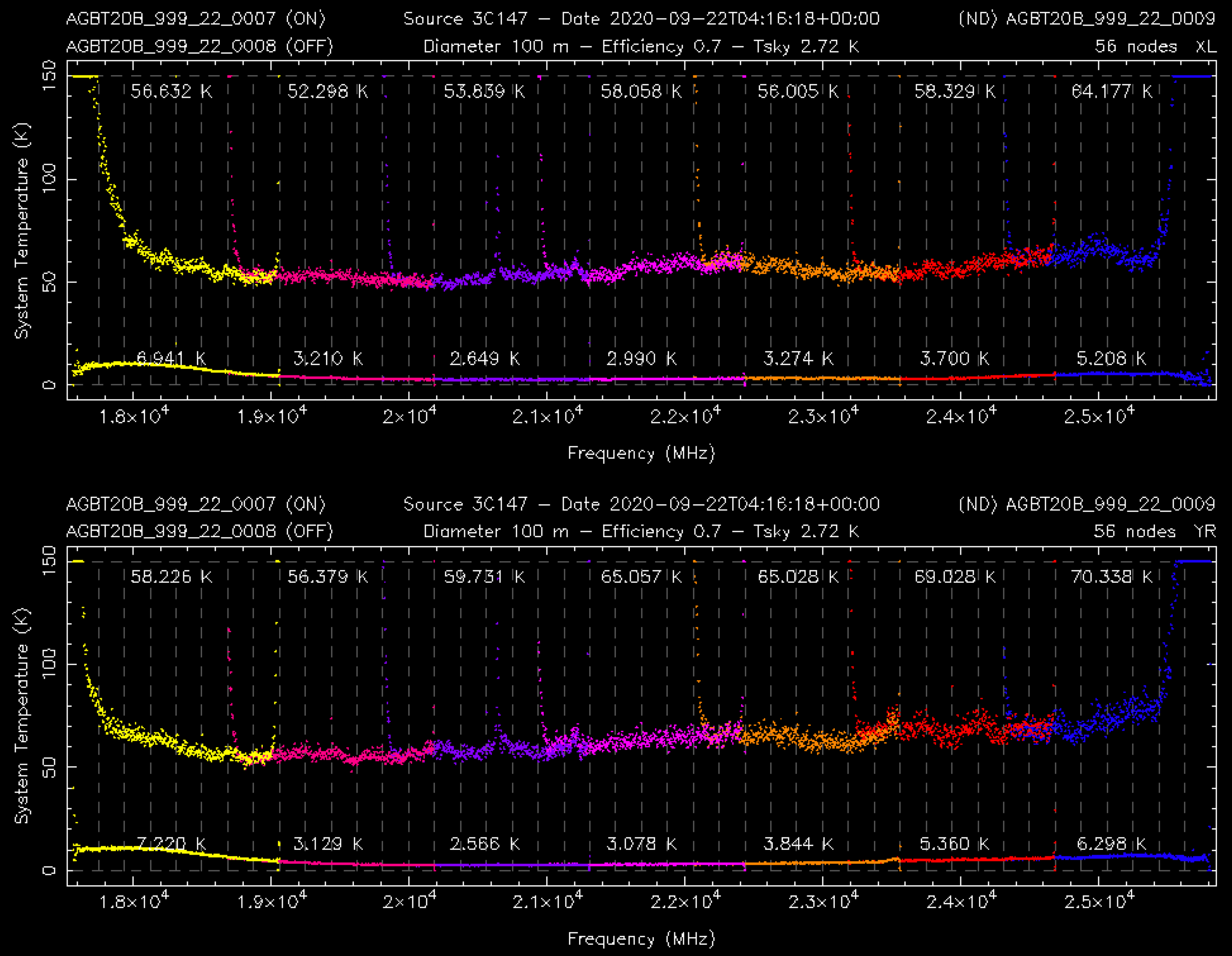


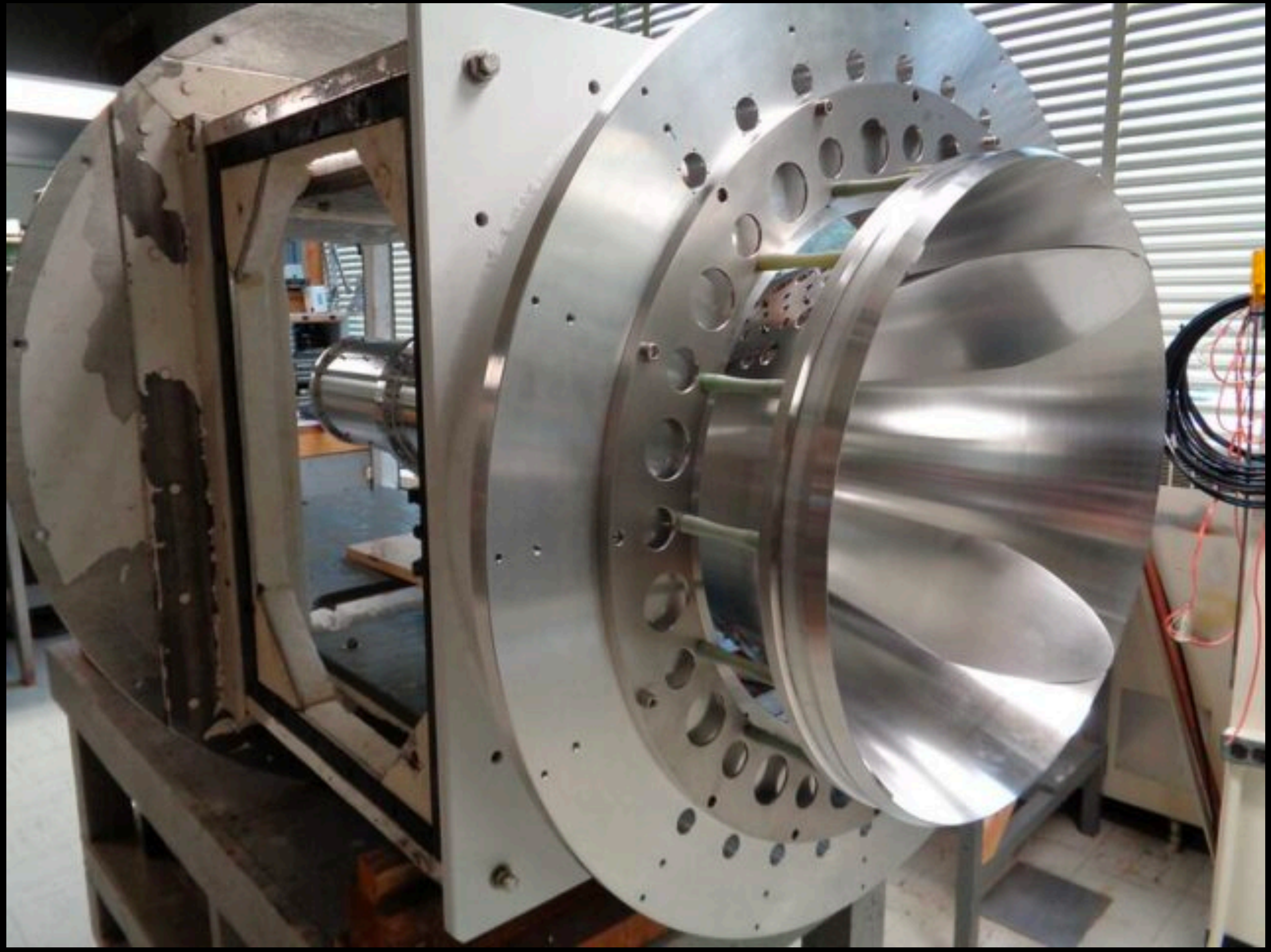
Upcoming Community Zooms

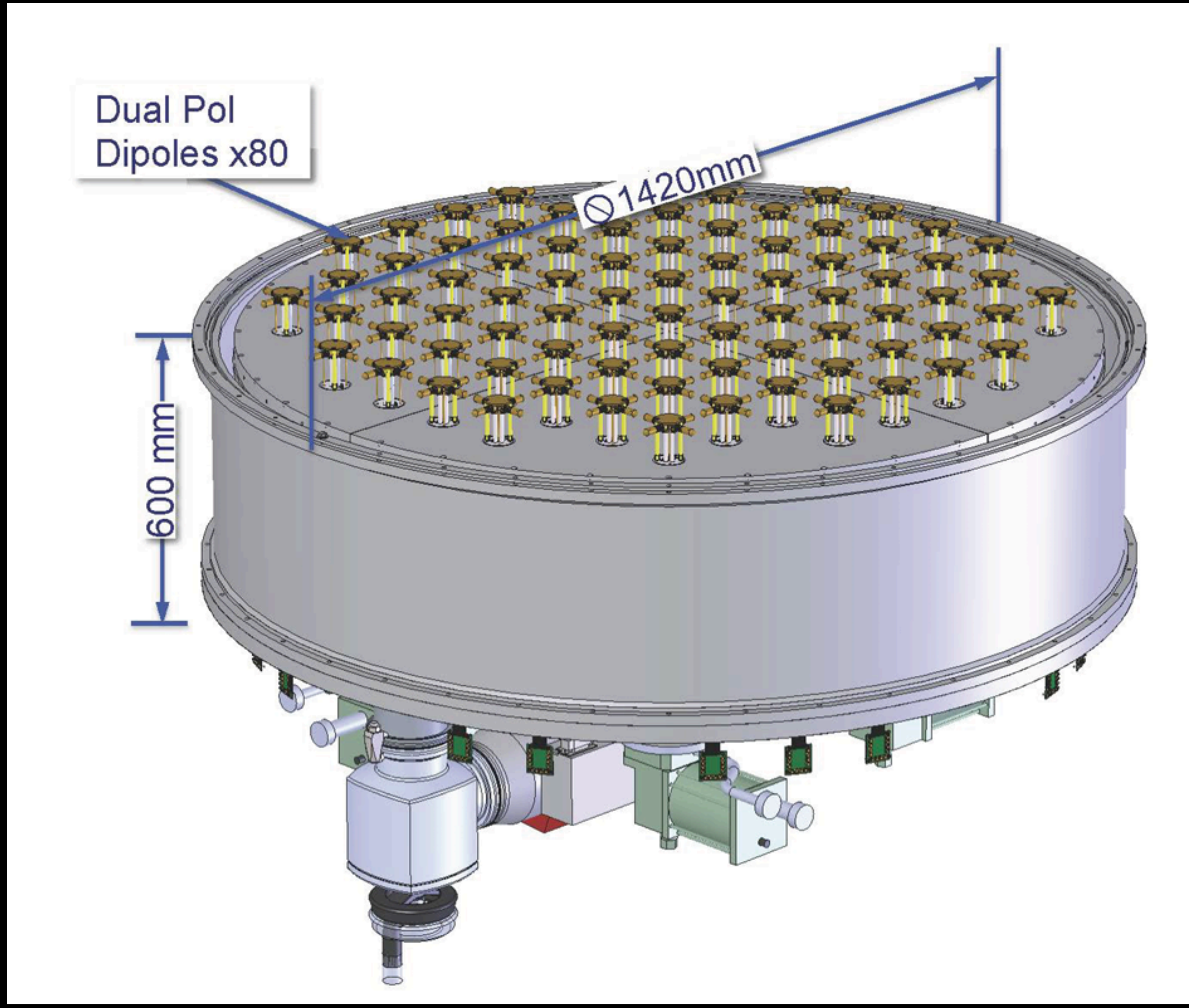
October 26 – Aya Keller (University of California, Berkeley) **A Model-Independent Dark Matter Search Using GBT Data**

KFPA Commissioning





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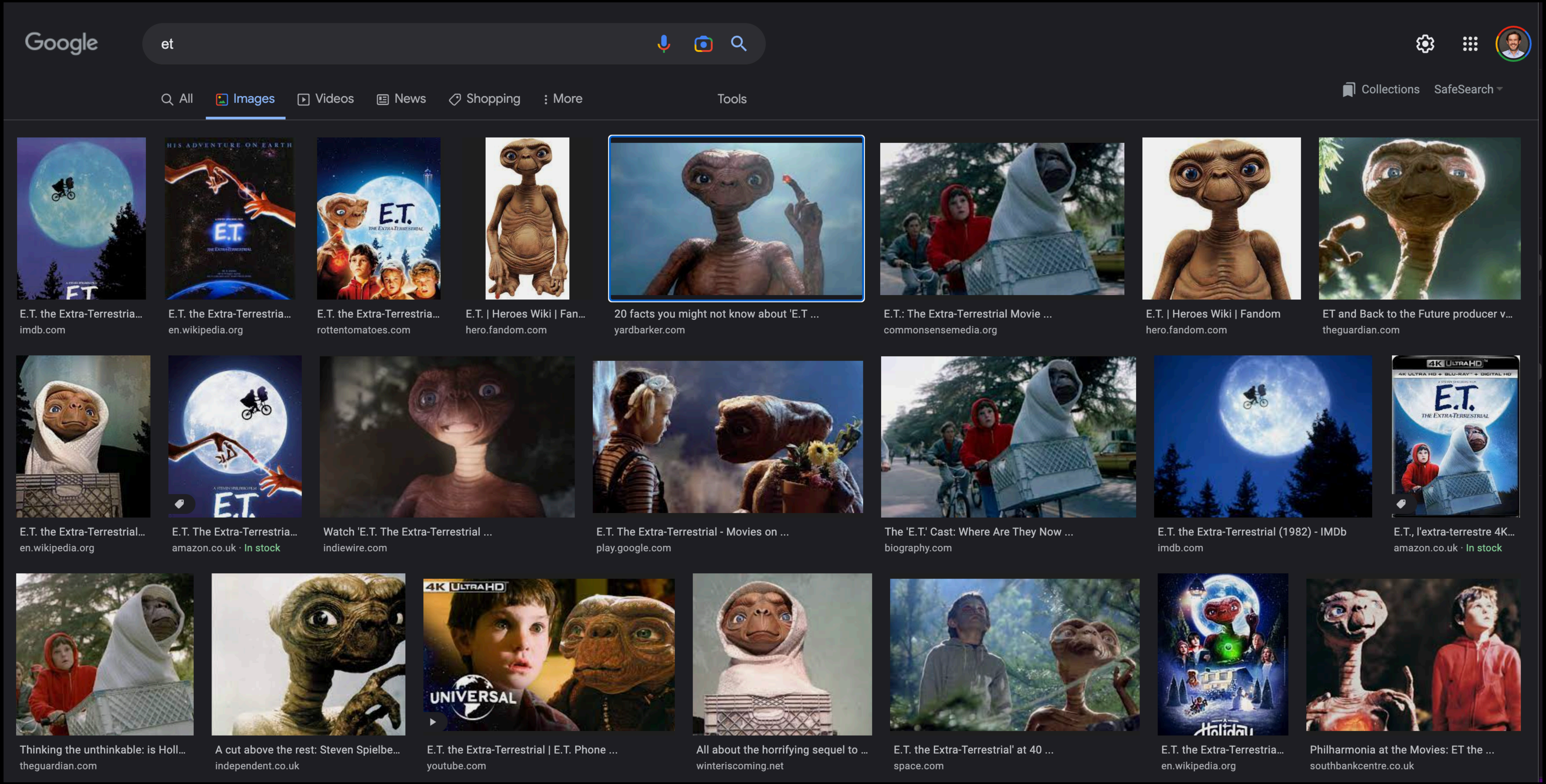
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Machine Learning

The Astronomical Journal, 163:222 (11pp), 2022 May https://doi.org/10.3847/1538-3881/ac5e3d

Setigen: Simulating Radio Technosignatures for the Search for Extraterrestrial Intelligence

Bryan Brzycki[1], Andrew P. V. Siemion[2,3,4,5], Imke de Pater[1], Steve Croft[1,3], John Hoang[1], Cherry Ng[1,3,6], Danny C. Price[1,7], Sofia Sheikh[1], and Zihe Zheng[8]
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[4] Department of Physics and Astronomy, University of Manchester, Manchester, UK
[5] University of Malta, Institute of Space Sciences and Astronomy, Malta
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[8] Goergen Institute for Data Science, University of Rochester, Rochester, NY 14627, USA
Received 2022 January 5; accepted 2022 March 14; published 2022 April 20

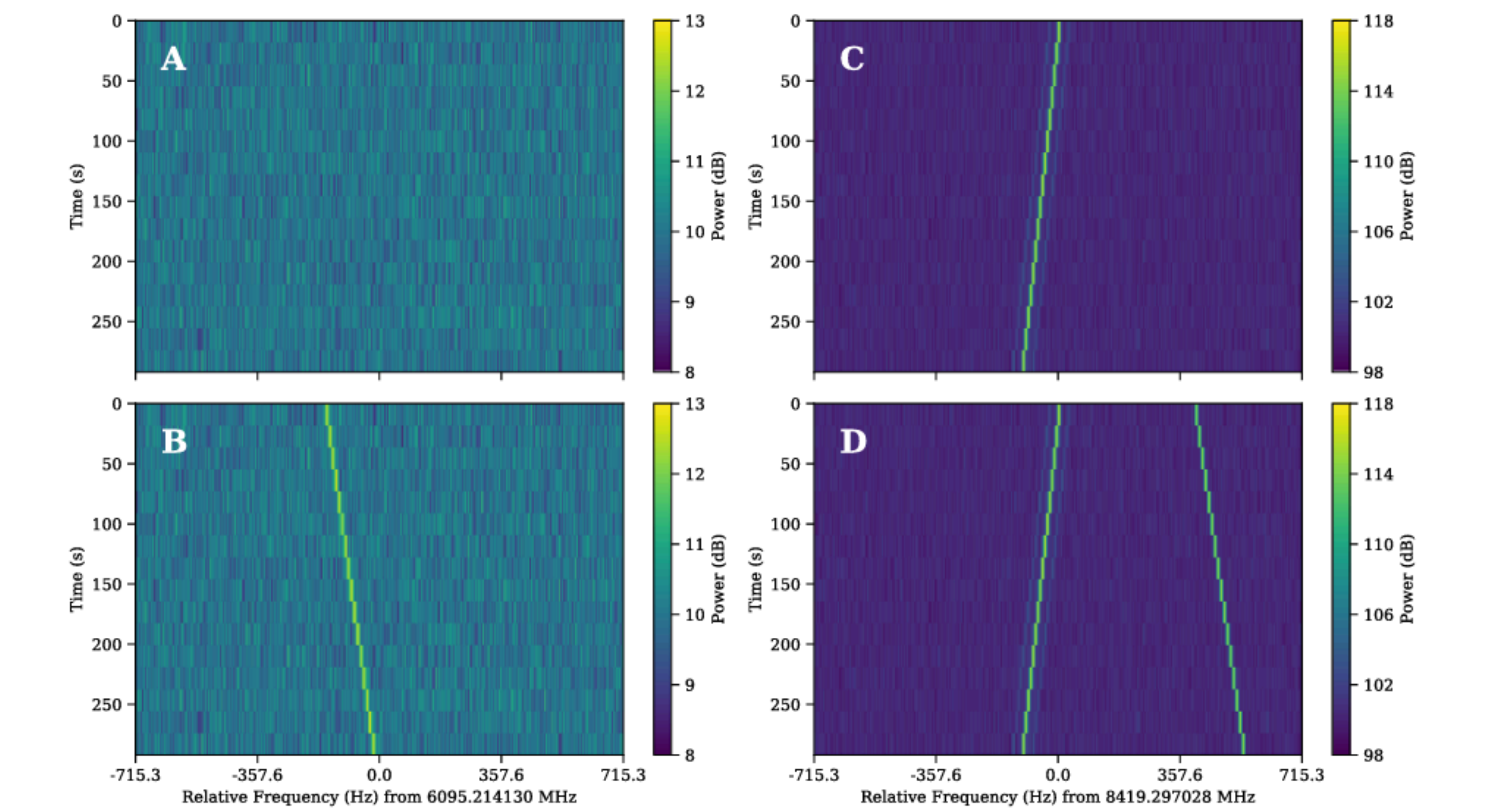

Figure 1. Radio spectrogram plots created from `setigen` frames. A: Frame with only synthetic chi-squared noise. B: Frame from panel (A) with an injected synthetic signal at S/N = 30. C: "Real" GBT observation of Voyager I carrier signal at the *X* band. D: Frame from panel (C) with an injected synthetic signal at S/N = 1000, with the same drift rate as the injected signal in panel (B).

Publications of the Astronomical Society of the Pacific, 132:114501 (12pp), 2020 November https://doi.org/10.1088/1538-3873/abaaf7

Narrow-band Signal Localization for SETI on Noisy Synthetic Spectrogram Data

Bryan Brzycki[1], Andrew P. V. Siemion[1,2,3,4], Steve Croft[1,2], Daniel Czech[1], David DeBoer[1], Julia DeMarines[1], Jamie Drew[5], Vishal Gajjar[1], Howard Isaacson[1,6], Brian Lacki[7], Matthew Lebofsky[1], David H. E. MacMahon[1], Imke de Pater[1], Danny C. Price[1,8], and S. Pete Worden[5]
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[7] Breakthrough Listen, Department of Astronomy, University of California Berkeley, Berkeley CA 94720, USA
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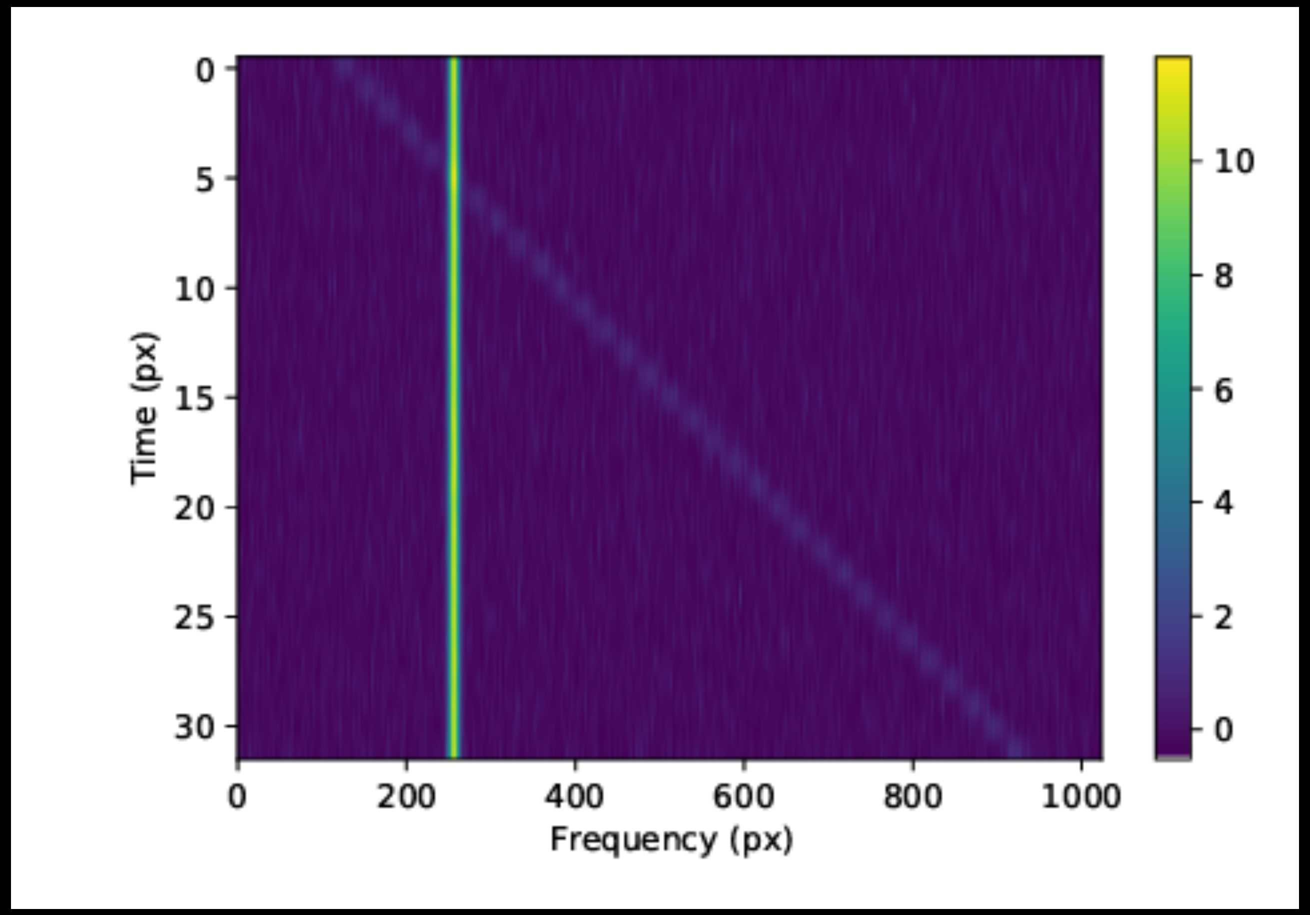
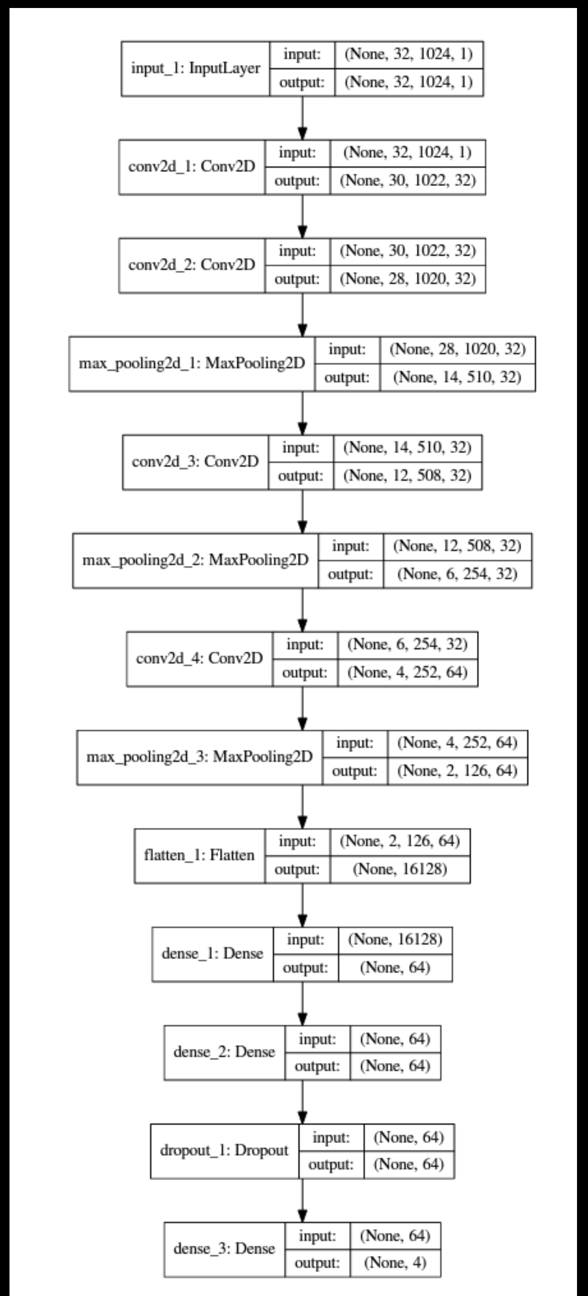
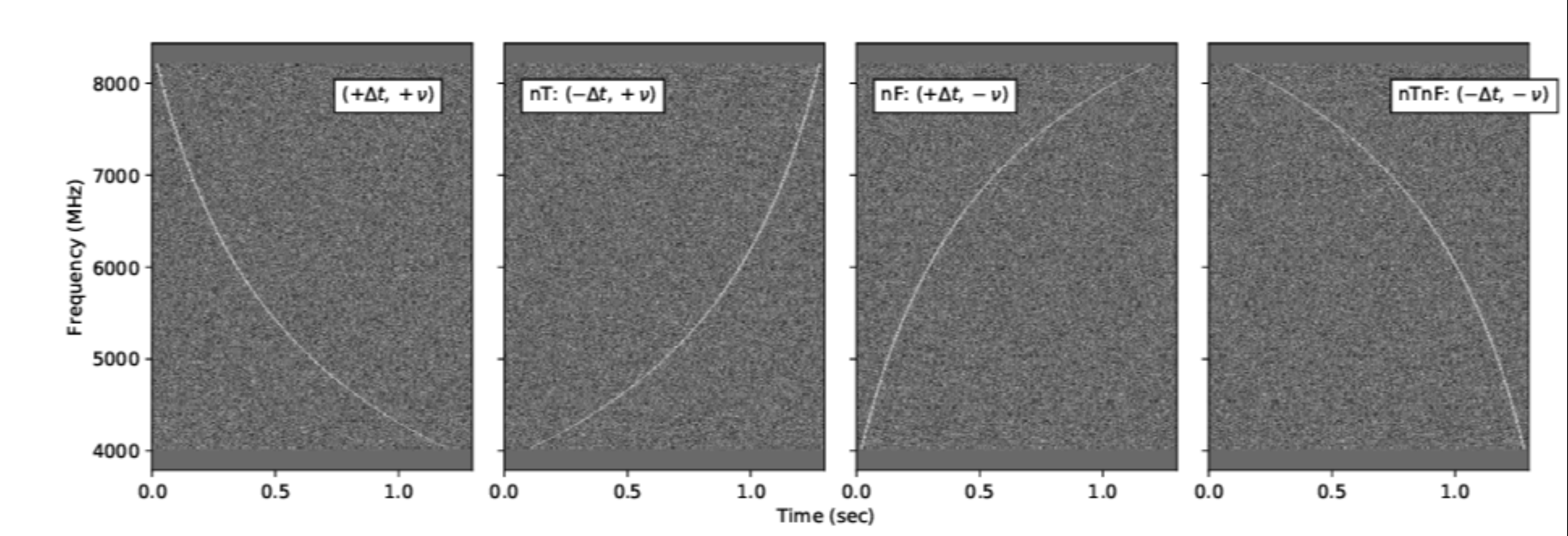
Received 2020 June 7; accepted 2020 July 30; published 2020 September 21

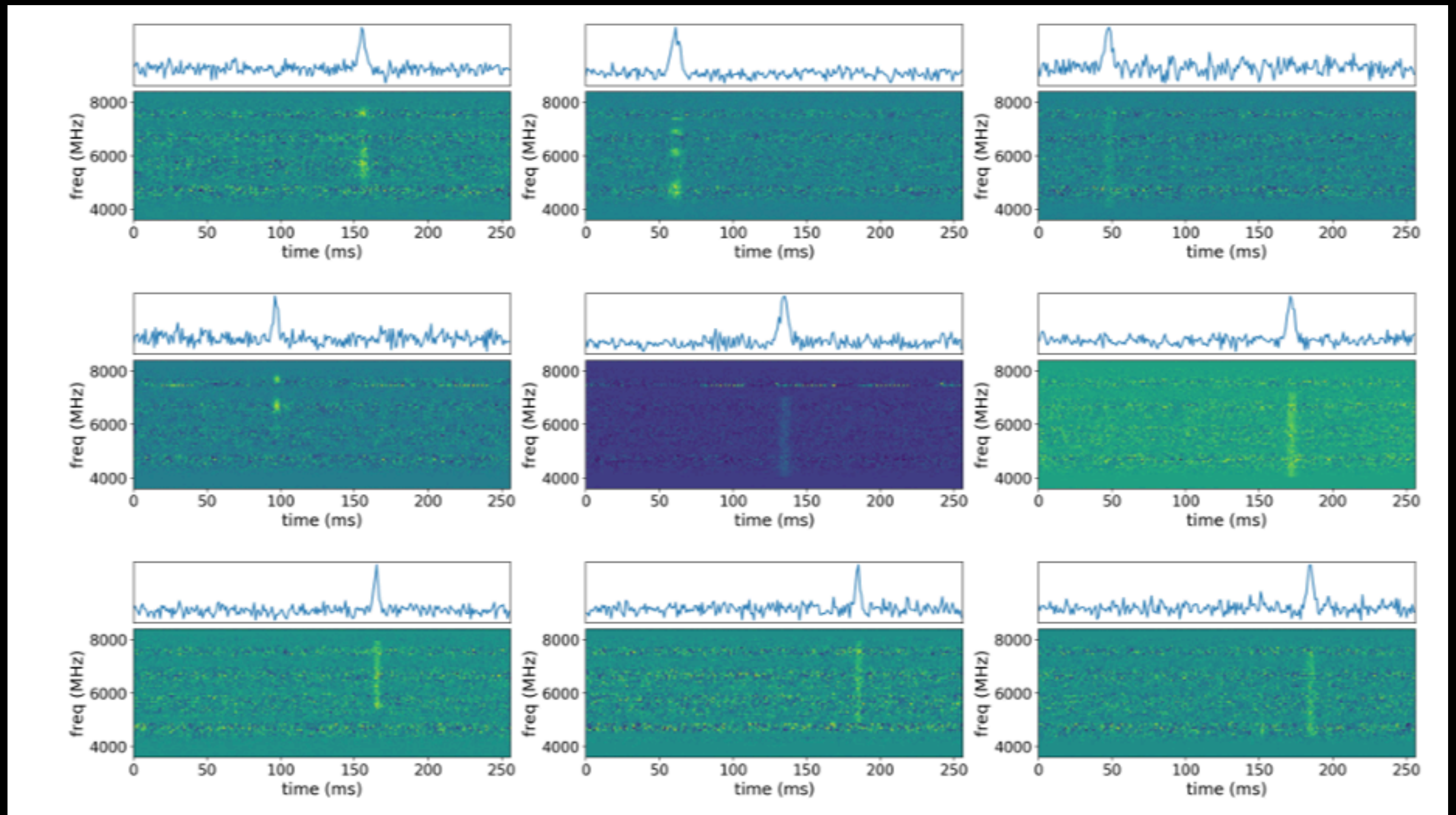




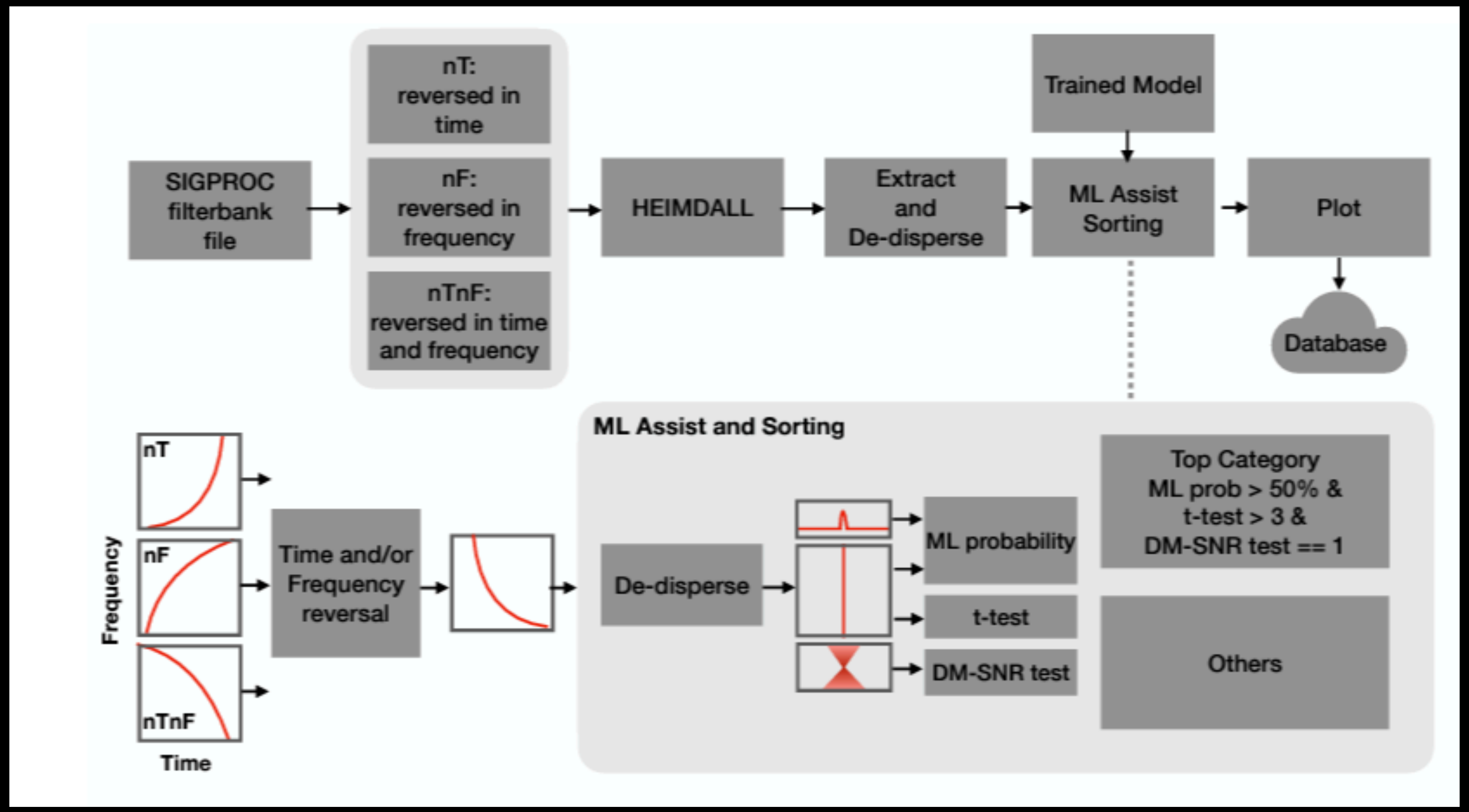
CNN-ASSISTED PULSE SEARCH

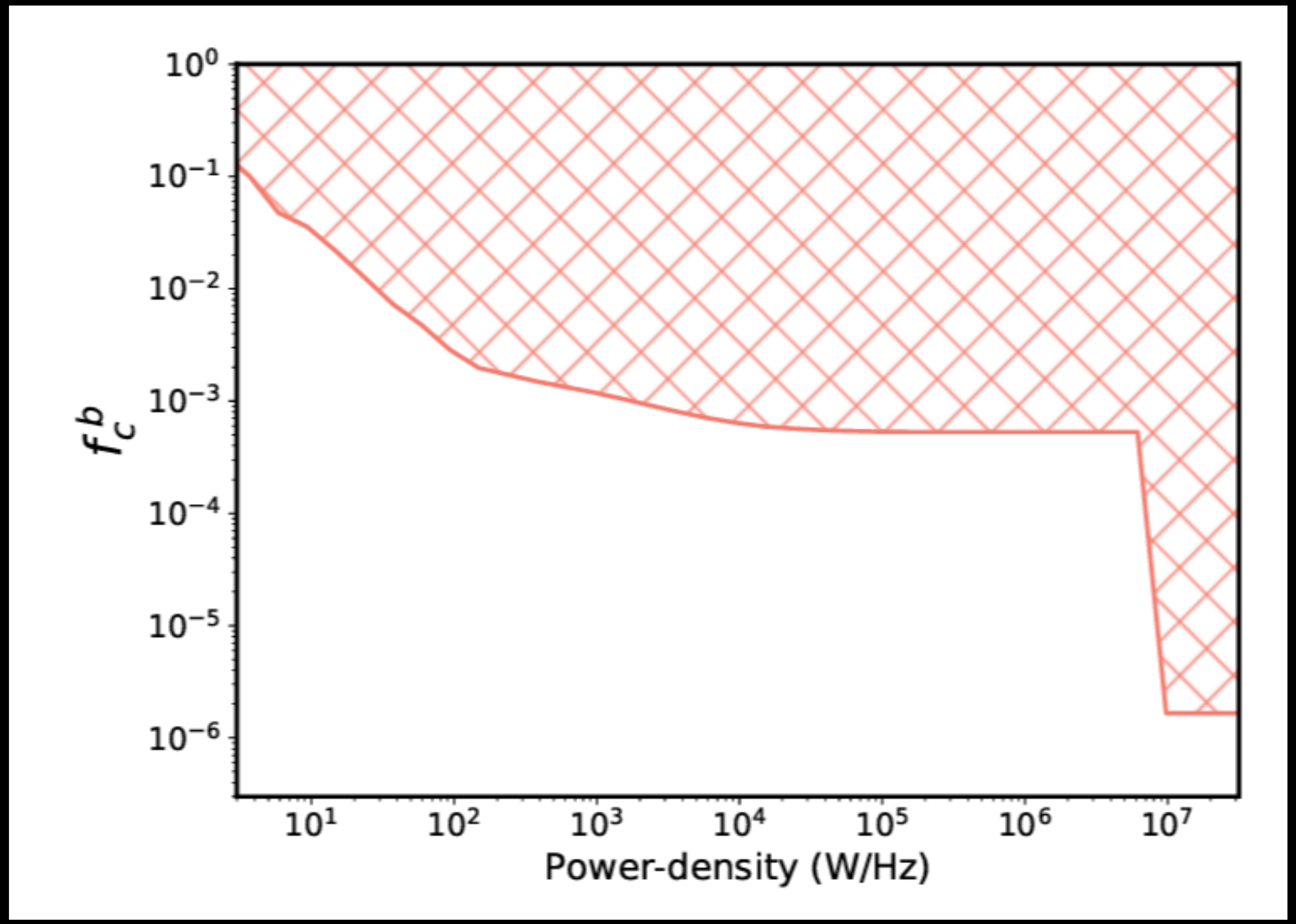
Gajjar et al. (2022)





- 1883 stars at C-band (233 hours)
- Artificial DM search, followed by CNN-based candidate vetting (reducing false signals by factor 50)
- CNN training uses simulated pulses injected into dedispersed spectrograms





Kaggle

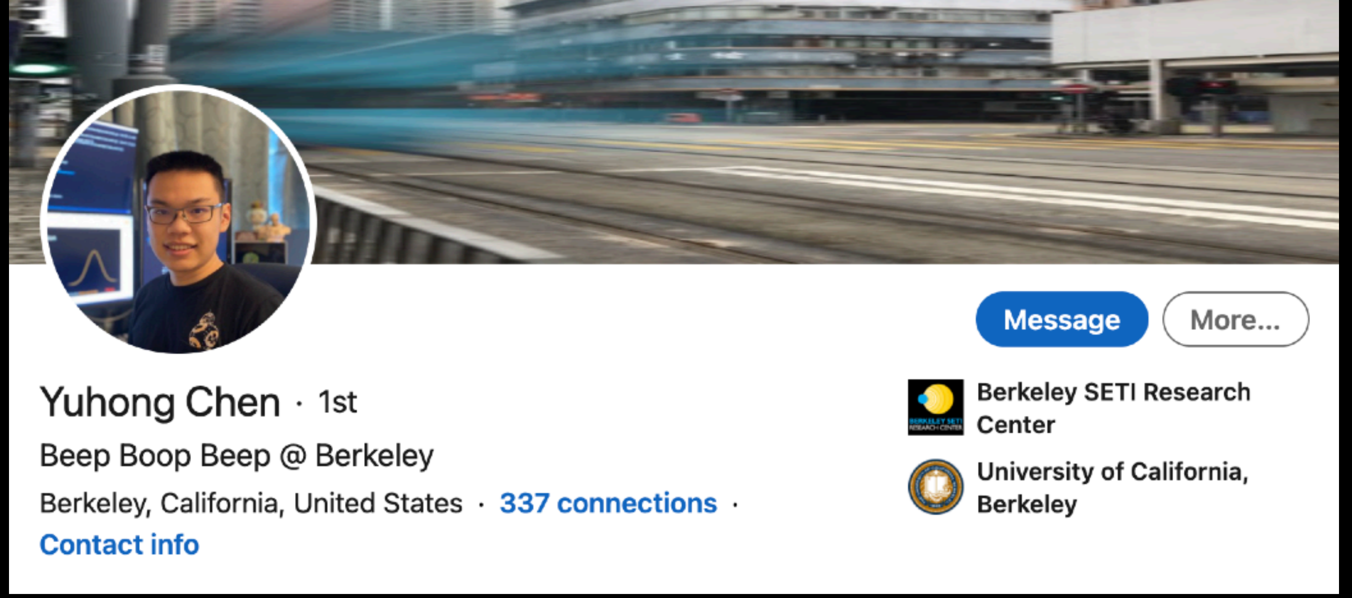
Public Leaderboard | Private Leaderboard

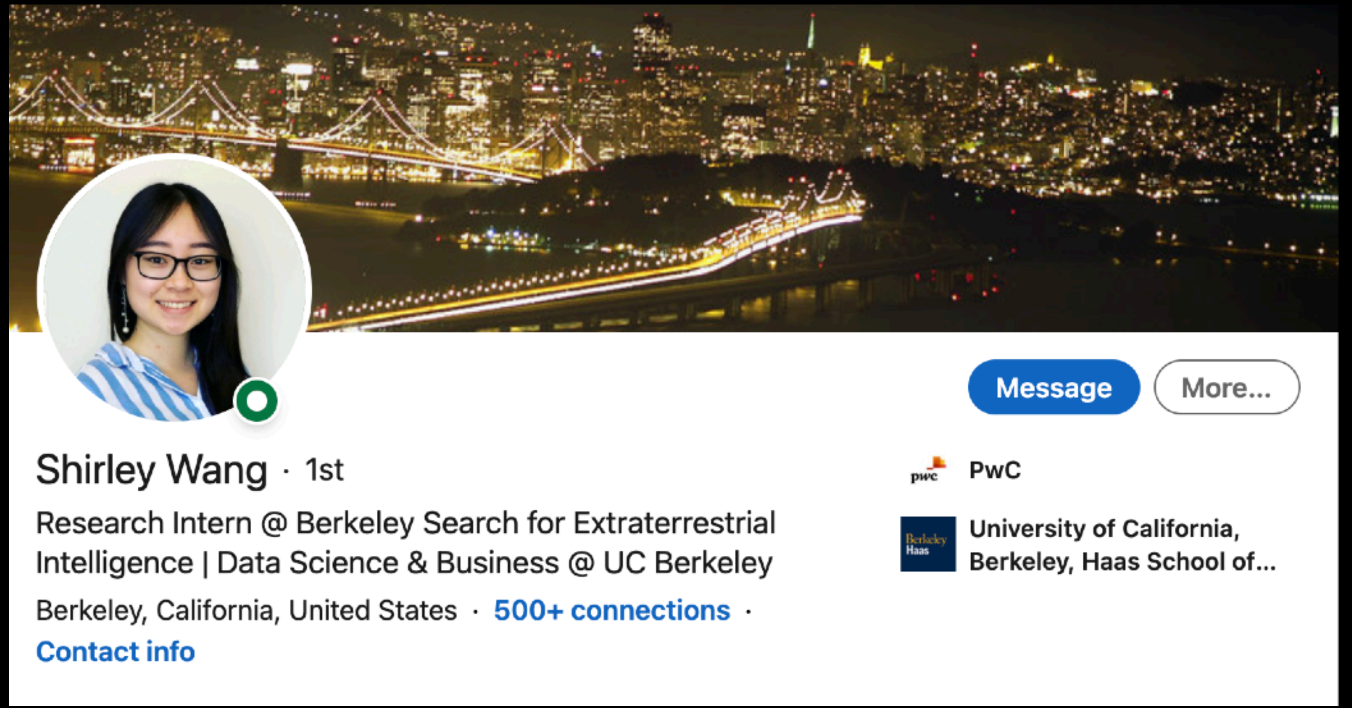
The private leaderboard is calculated with approximately 80% of the test data.
This competition has completed. This leaderboard reflects the final standings.

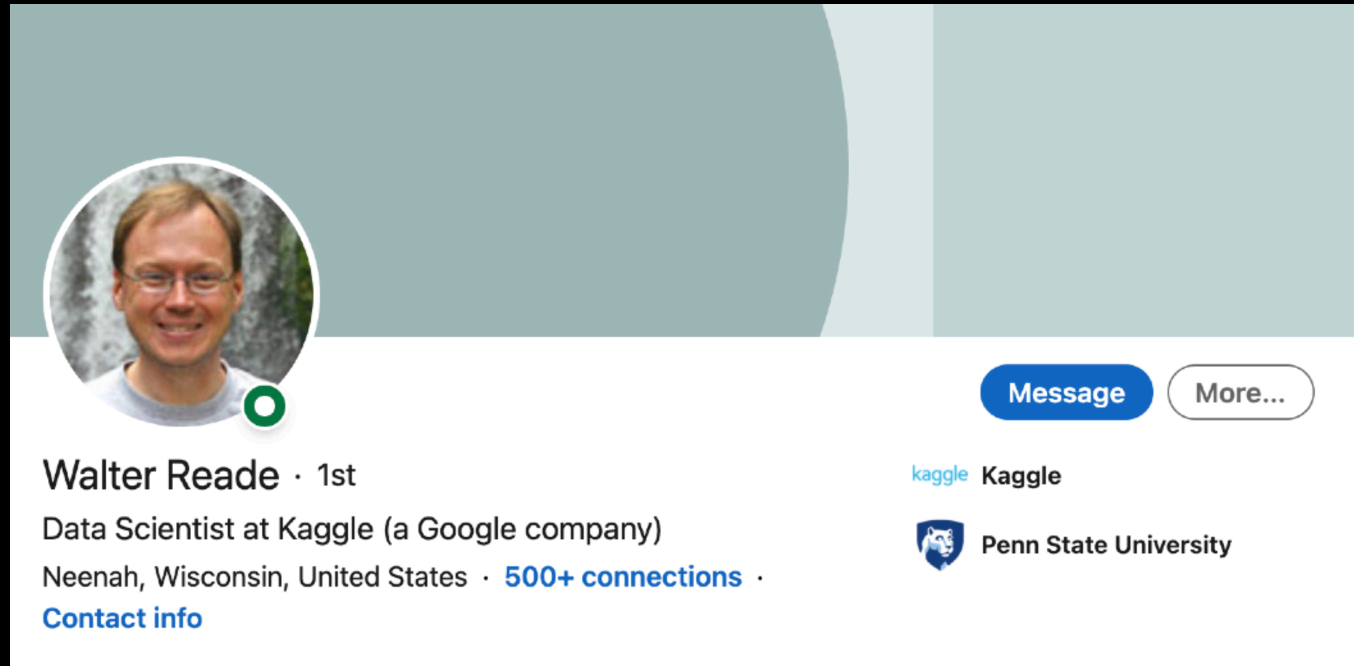
Refresh

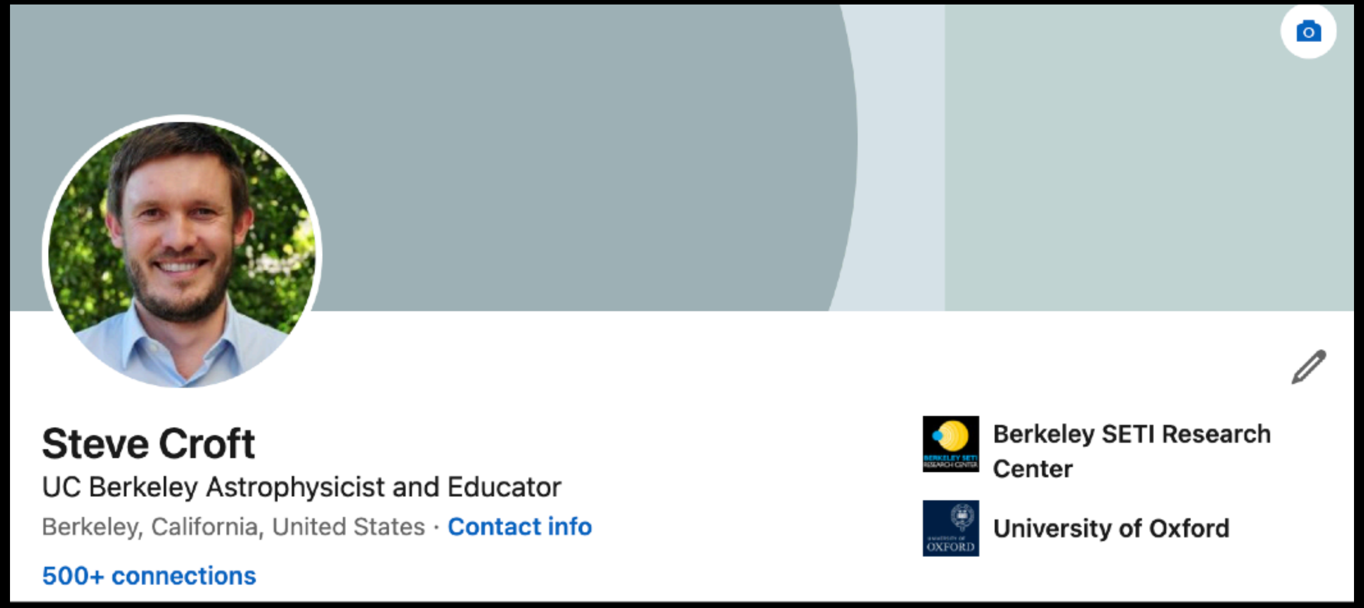
In the money | Gold | Silver | Bronze

#	△pub	Team Name	Notebook	Team Members	Score	Entries	Last
1	—	Watercooled			0.96782	93	1mo
2	—	未知との遭遇			0.81206	85	1mo
3	—	knj			0.80475	77	1mo
4	▲2	Steven Signal			0.80428	92	1mo
5	▲2	SETIの壁			0.80171	168	1mo
6	▲4	James Howard			0.80072	13	1mo
7	▼3	The Unforgiven			0.80036	108	1mo
8	▼3	Ilya Makarov			0.79945	123	1mo
9	—	MPWARE | Giba | CPMP | ...			0.79929	167	1mo
10	▲3	Aliens among us			0.79809	213	1mo
11	▼3	SETIes			0.79806	126	1mo
12	—	A Speck in the Cosmos			0.79698	70	1mo
13	▲1	Melody itni choclatey kyun hai??			0.79668	65	1mo
14	▲3	lookingforgold			0.79581	46	1mo
15	—	Hungry for Gold			0.79483	31	1mo









Research Square

The first deep-learning search for radio technosignatures from 820 nearby stars

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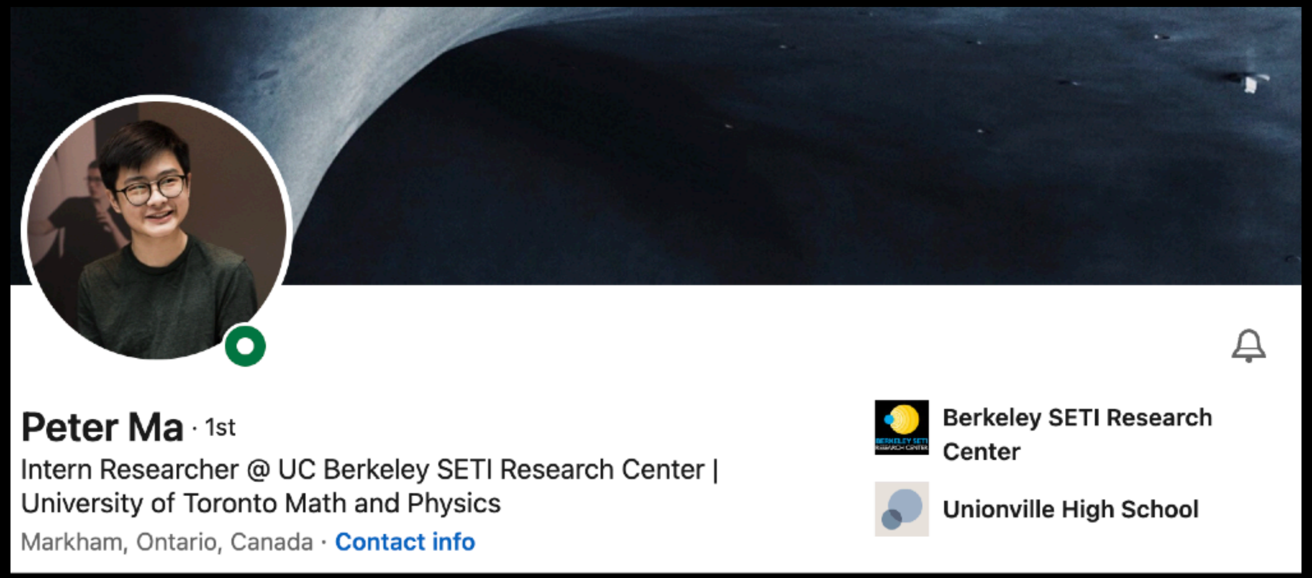
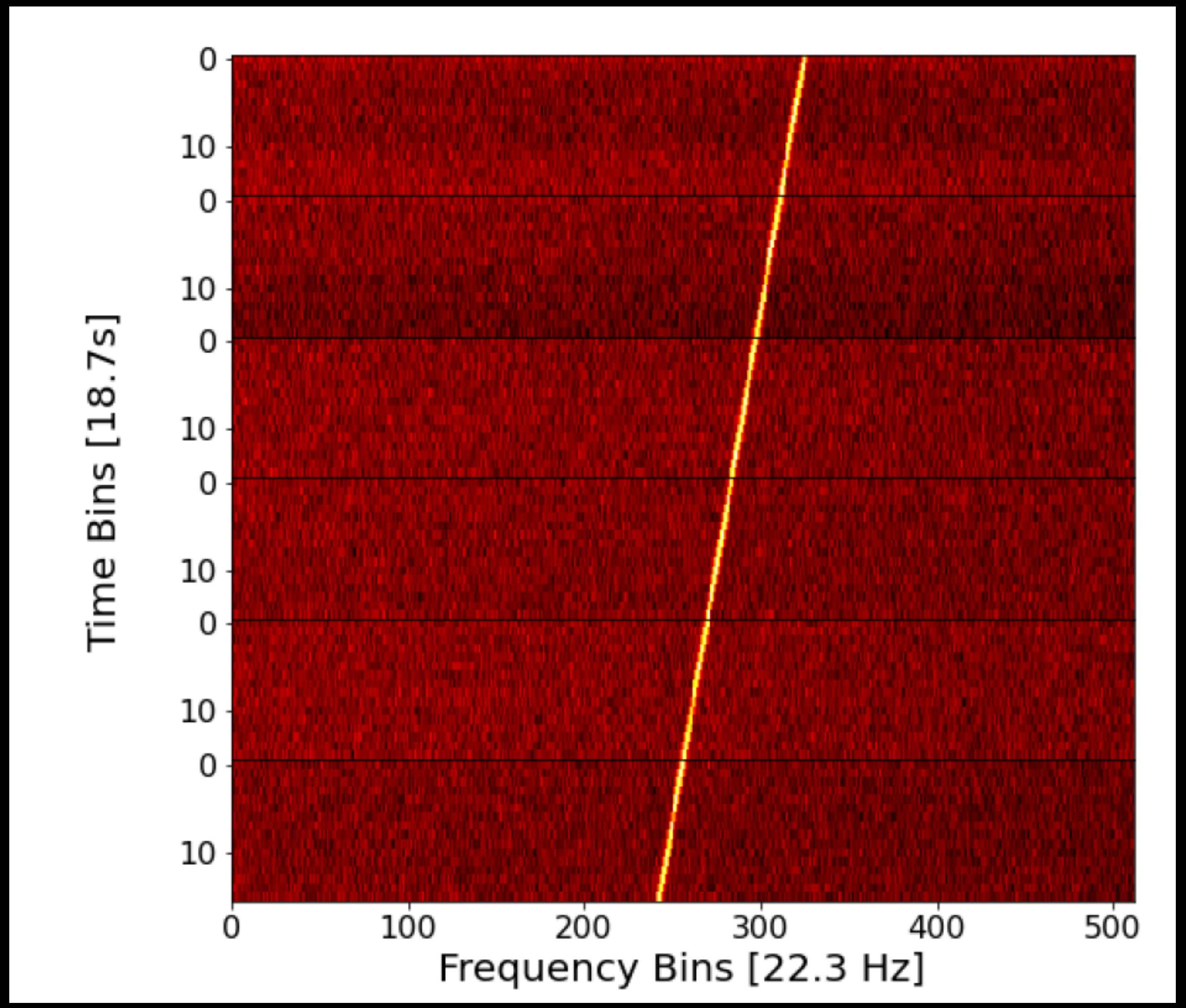
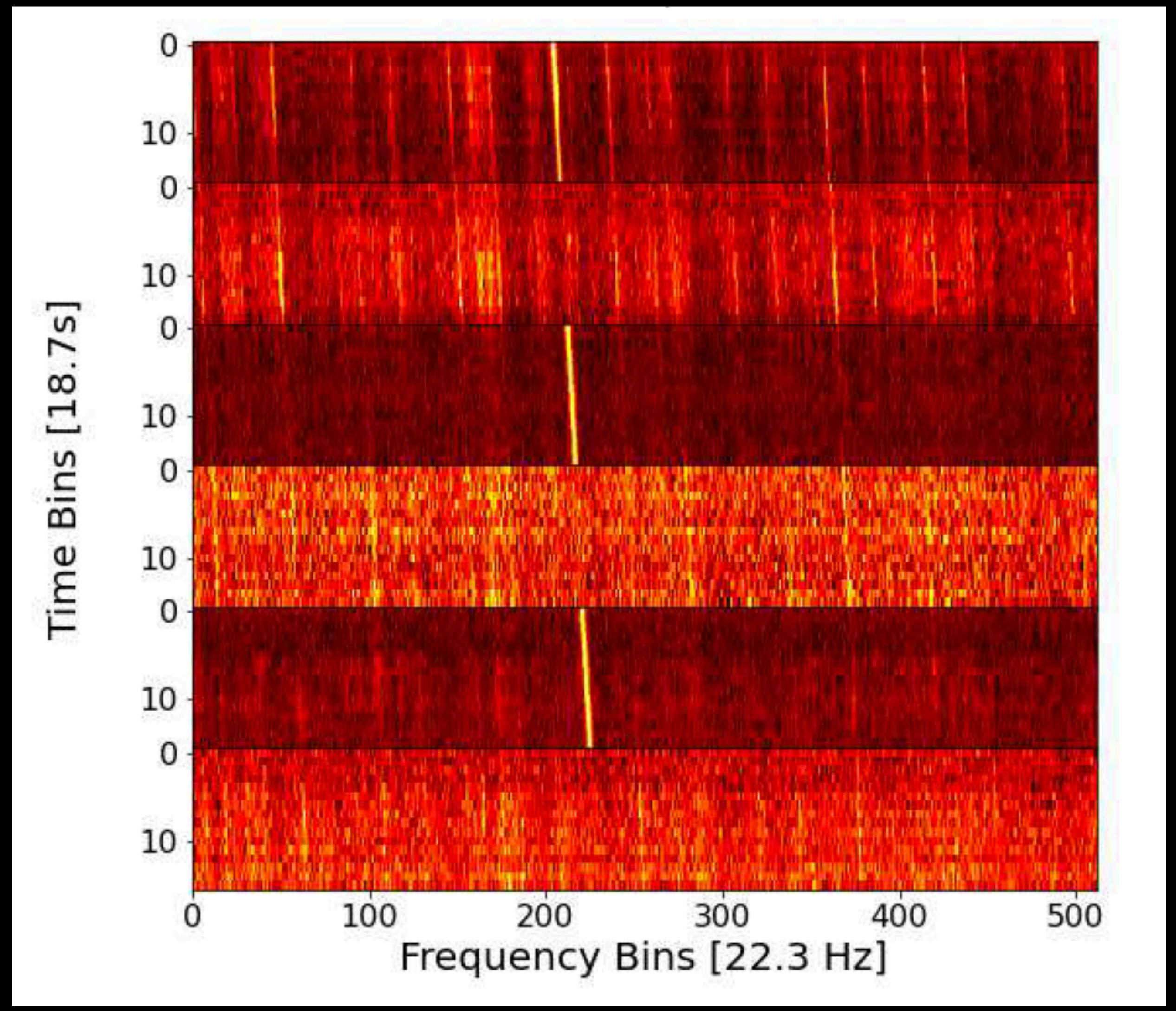
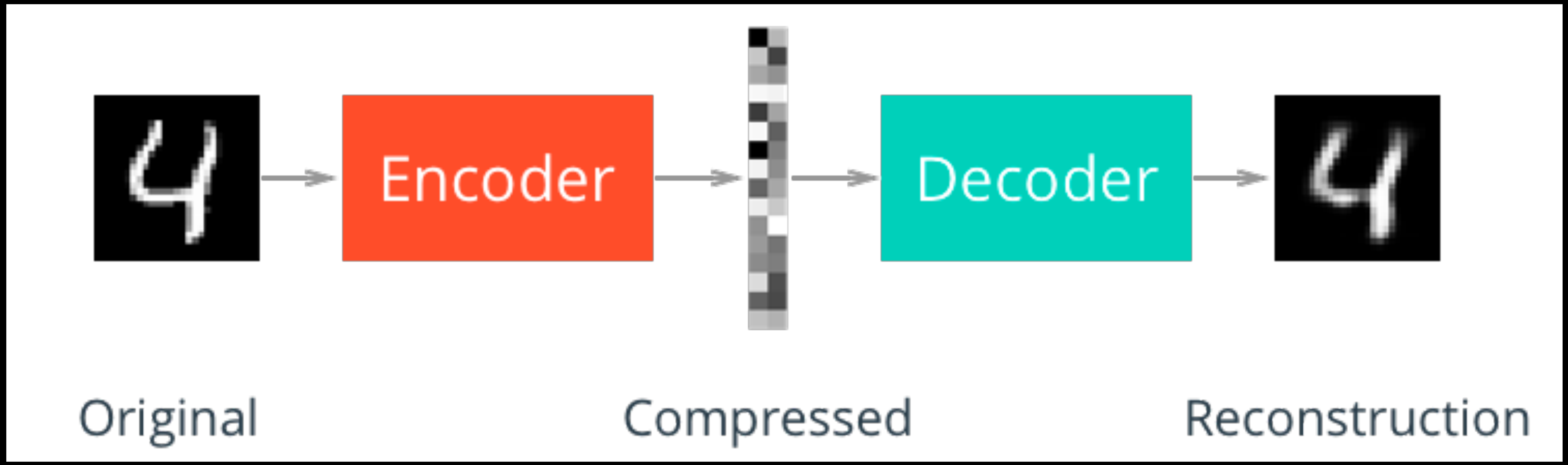
S. Worden
Breakthrough Prize Foundation







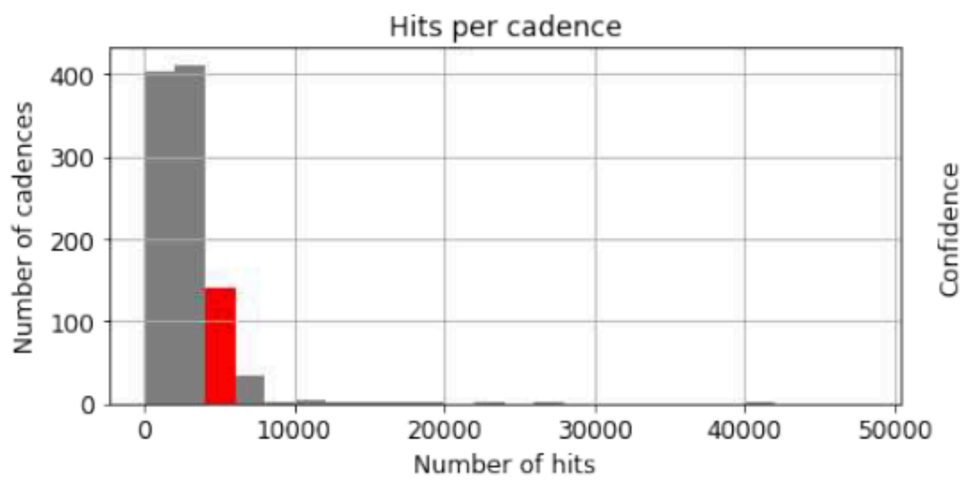


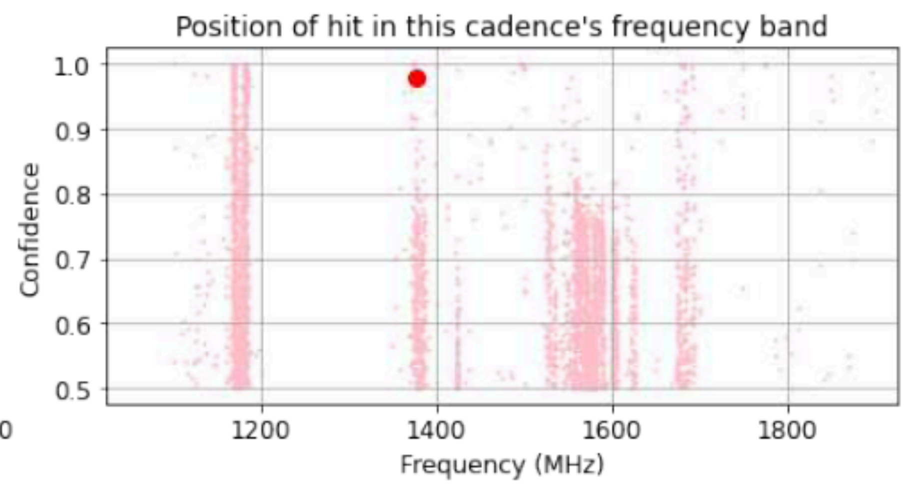
Candidate information

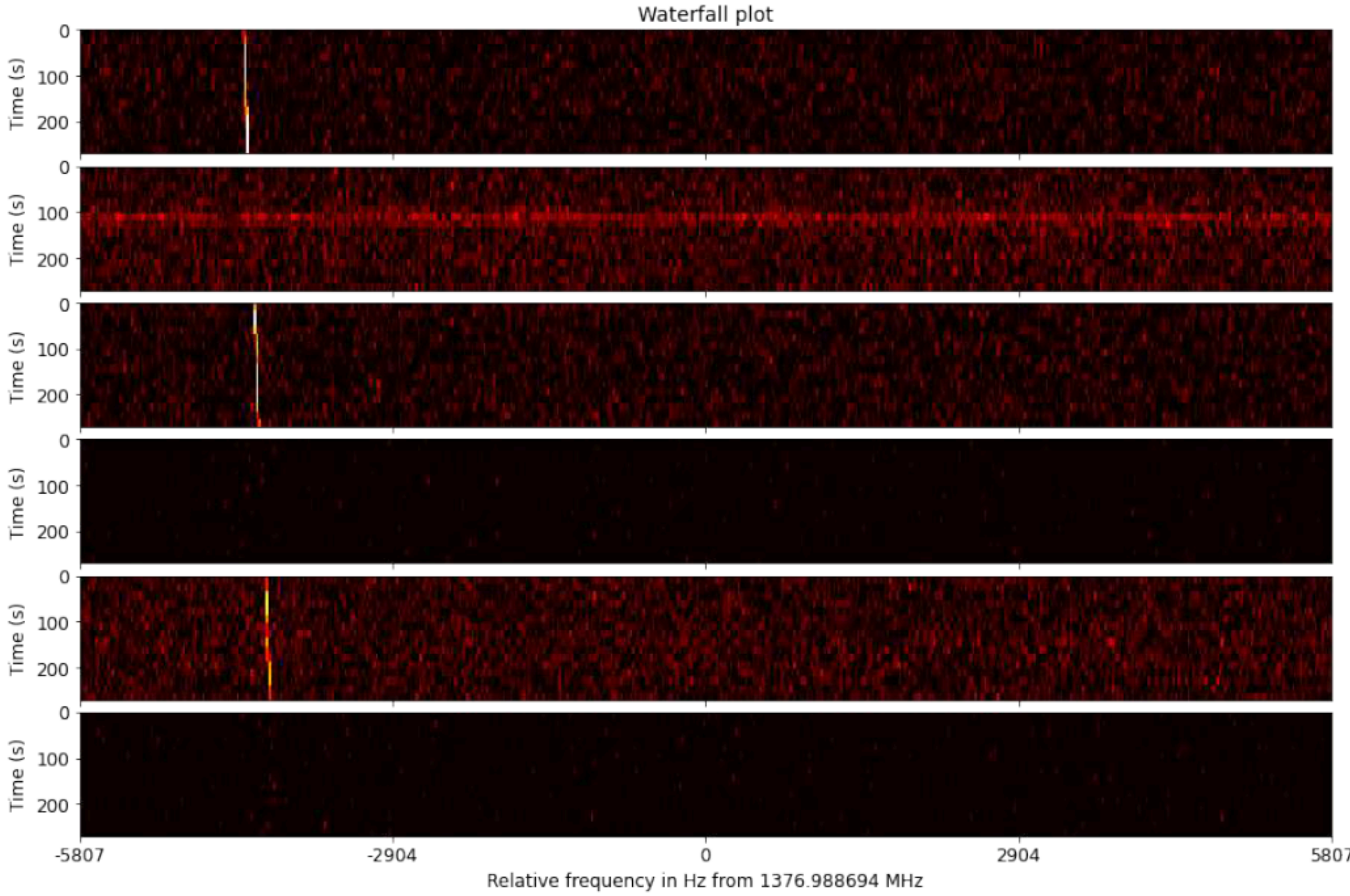
Target name: **HIP54677**
Right ascension: 11h11m33.799s
Declination: -13d41m02.002s
Telescope: GBT
Observation start (MJD): 57517.10172453704
Observation start (ISOT): 2016-05-09T02:26:29.000
Observing time: 300s x 3
Cadence type: ABACAD
Min frequency: 1023.9257840855033 MHz
Max frequency: 1926.26953125 MHz

Number of hits for this cadence: 4202
Average number of hits per cadence: 2906

Hit #1383 of 4202
Start frequency: 1376.98288644388 MHz
End frequency: 1376.994500665882 MHz
Event bandwidth: 11614.222001981034 Hz
Confidence: 97.89999999999999%
Candidate ID: 0262-01383





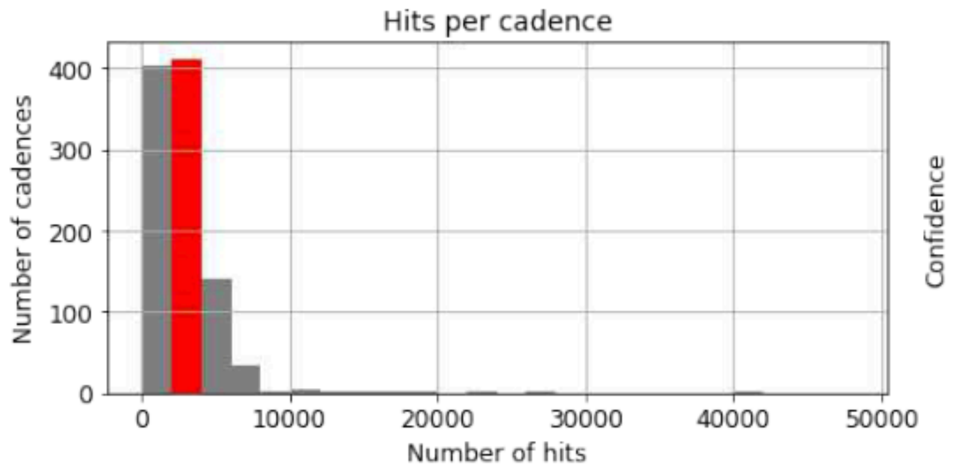


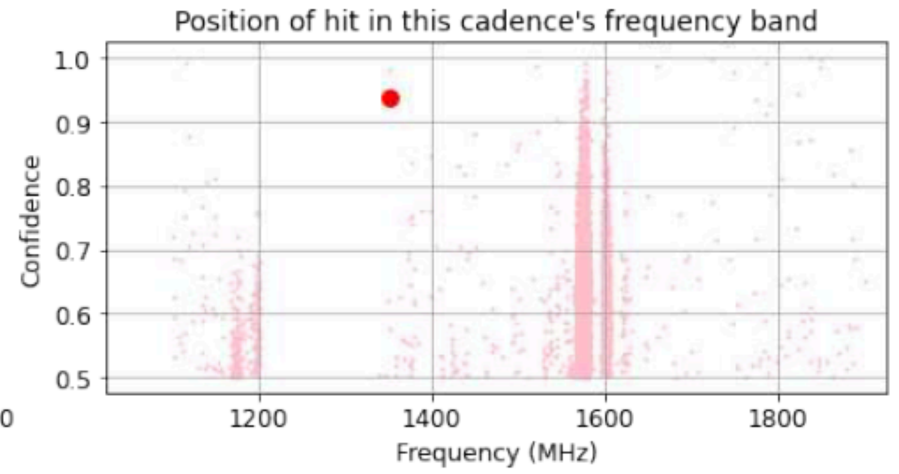
Candidate information

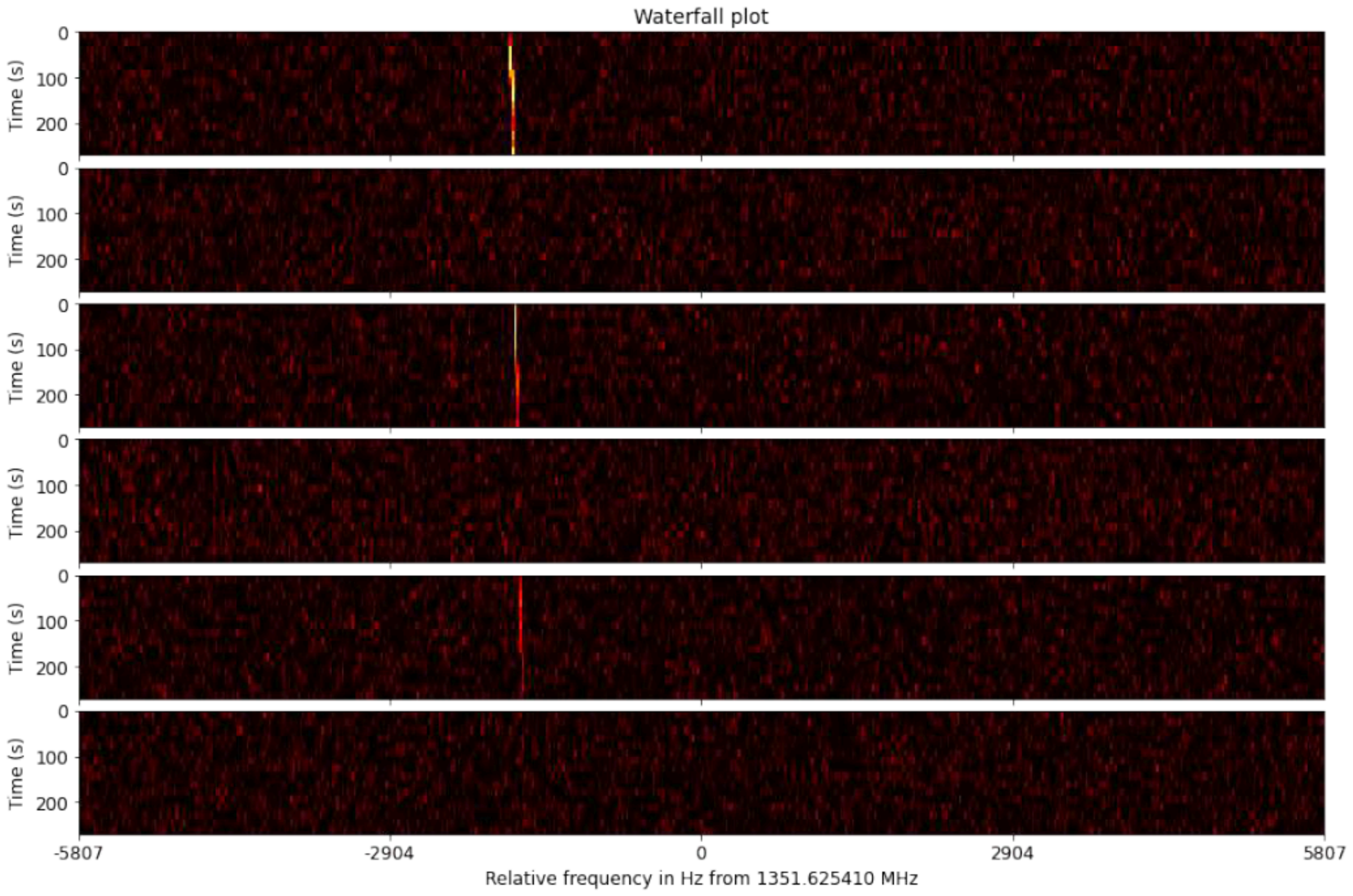
Target name: **HIP62207**
Right ascension: 12h44m58.9s
Declination: 39d16m46.005s
Telescope: GBT
Observation start (MJD): 57543.10008101852
Observation start (ISOT): 2016-06-04T02:24:07.000
Observing time: 300s x 3
Cadence type: ABACAD
Min frequency: 1023.9257840855033 MHz
Max frequency: 1926.26953125 MHz

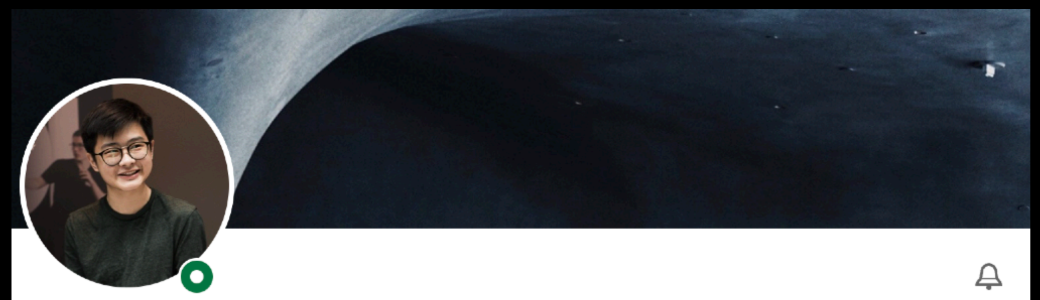
Number of hits for this cadence: 3963
Average number of hits per cadence: 2906

Hit #307 of 3963
Start frequency: 1351.6196032581763 MHz
End frequency: 1351.6312174801783 MHz
Event bandwidth: 11614.222001981034 Hz
Confidence: 93.7%
Candidate ID: 0284-00307









Peter Ma · 1st
Intern Researcher @ UC Berkeley SETI Research Center | University of Toronto Math and Physics
Markham, Ontario, Canada · Contact info
Berkeley SETI Research Center
Unionville High School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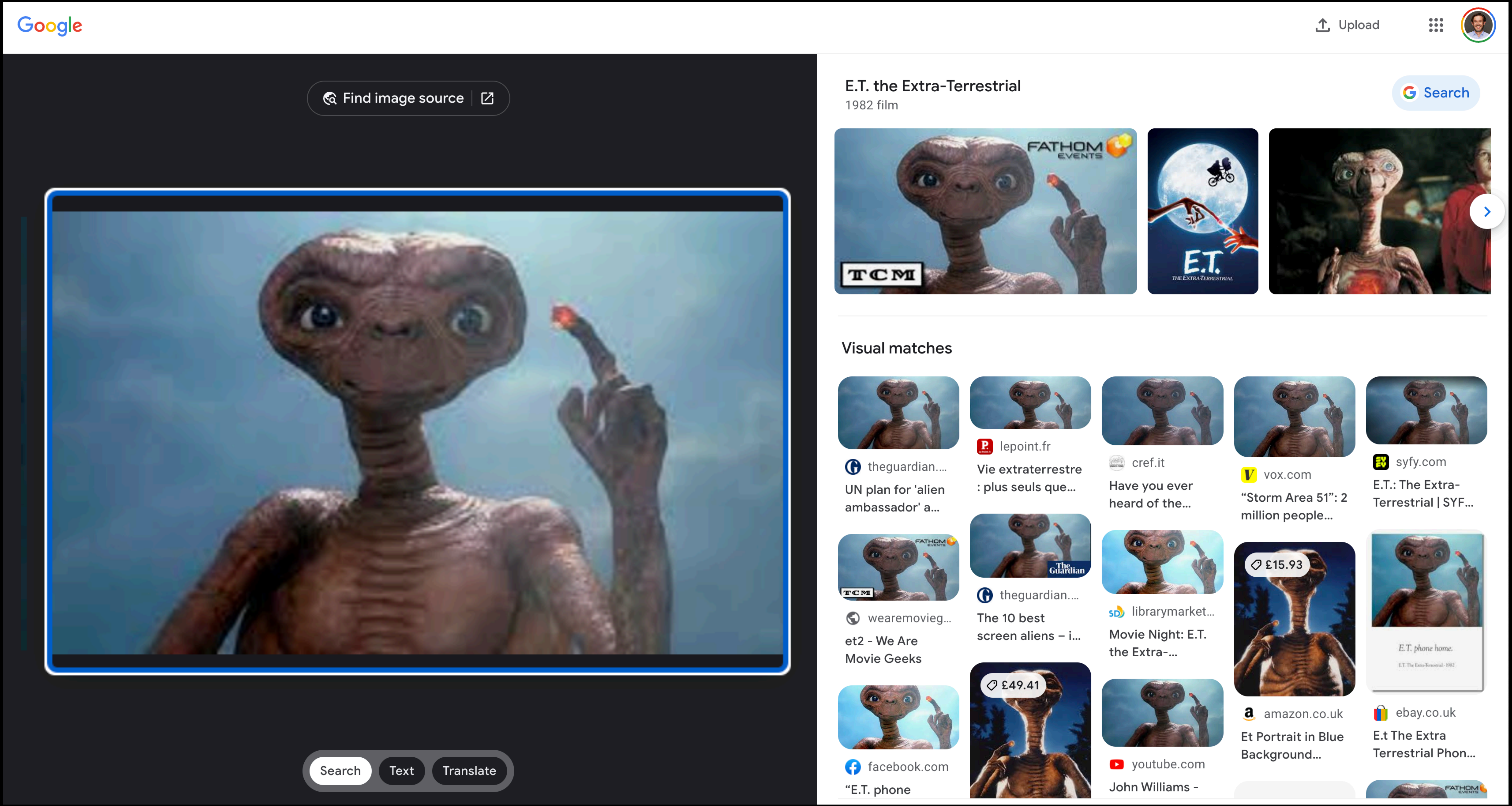
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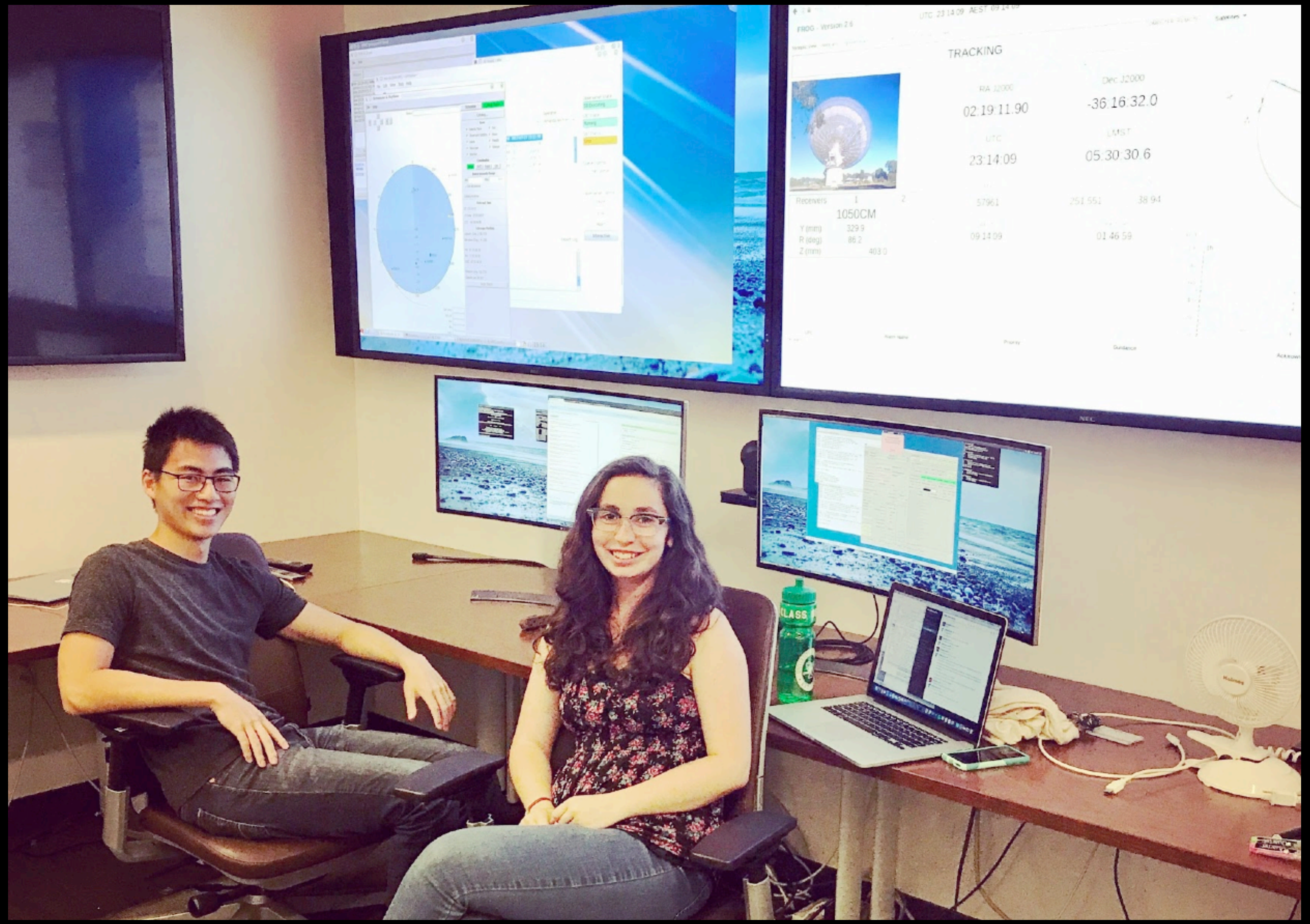

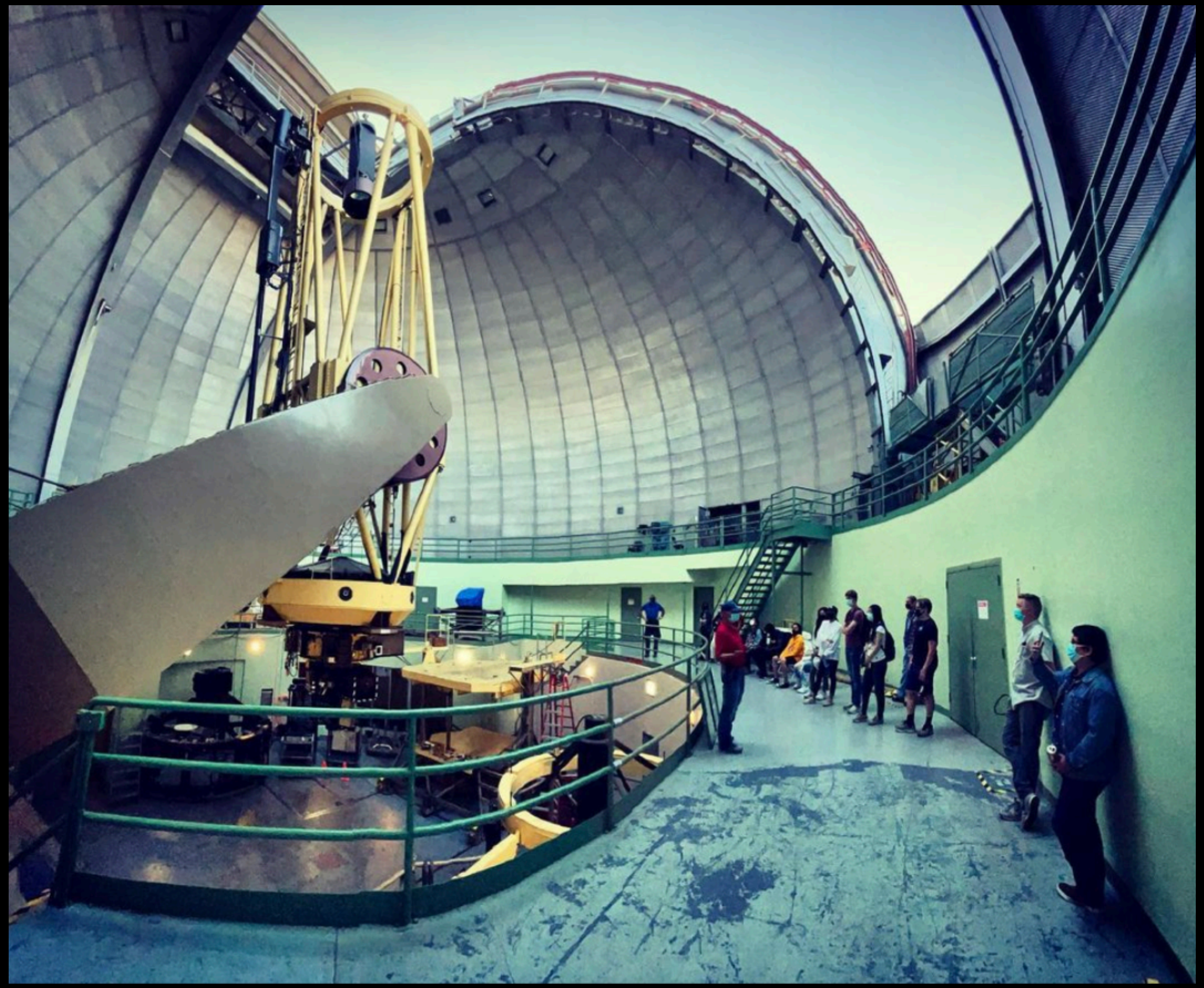

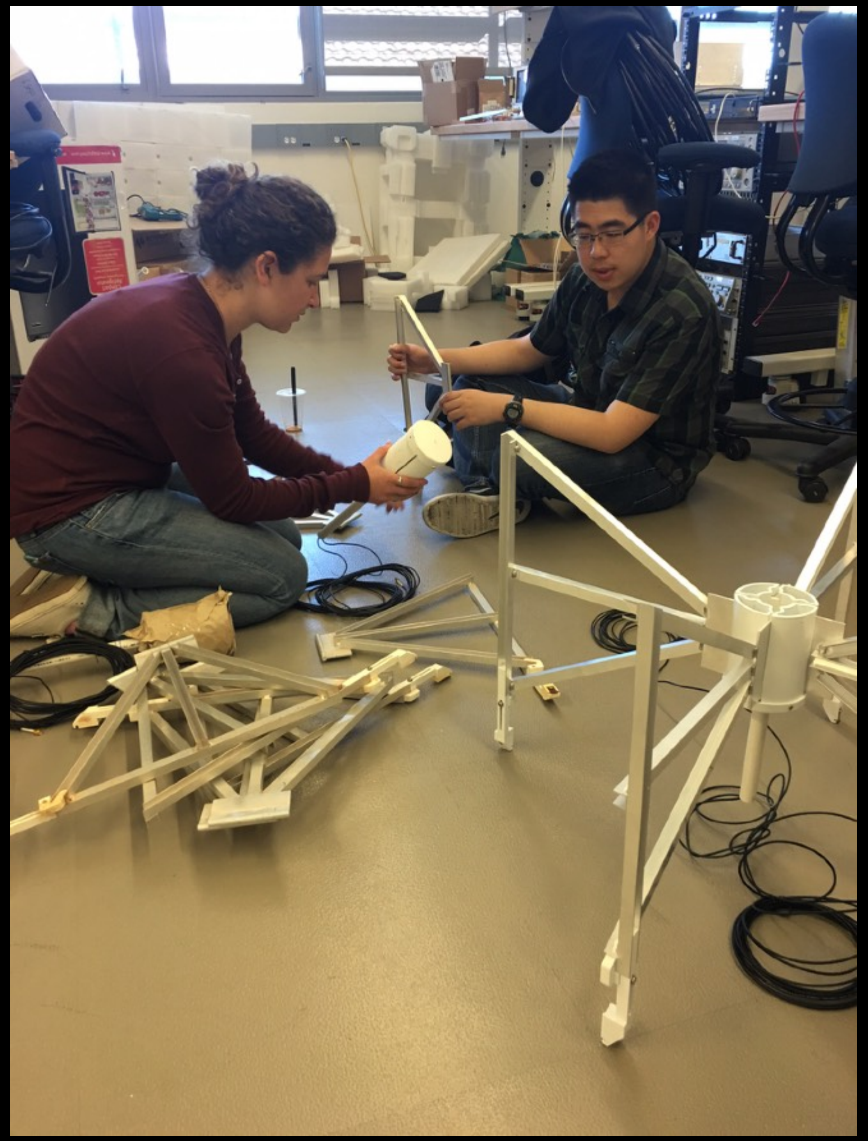

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SETI Institute to Recognize 4 Undergraduate Students at Drake Awards Event

May 2, 2022 — Tags: Press Releases, Education, Research Experience for Undergraduates

The SETI Forward Award encourages students to pursue careers in the search for life in the universe, the REU Award of Excellence honors an outstanding intern

SETI Forward Recipients

Yiwei Chai is a senior at the University of Pennsylvania, majoring in physics. She received the opportunity to undertake a research internship at the Berkeley SETI Research Center in the summer after her junior year. She worked with Dr. Wael Farah to develop a GNU Radio SETI search pipeline for the SETI Institute's Allen Telescope Array (ATA). The internship helped her develop a greater appreciation for data-driven SETI approaches and the observation-to-analysis pipeline. She particularly enjoyed the week she spent on-site at the ATA in Hat Creek, CA, during which she also learned how to drive a buggy! This fall, Yiwei will be headed to Johns Hopkins University to begin a Ph.D. in Astronomy and Astrophysics, where she hopes to pursue questions about exoplanet populations and planetary habitability.


Yiwei Chai

"My experience at the Berkeley SETI Research Center was wonderful," said Chai. "I had the opportunity to learn a lot about how questions are asked and investigated in this field while also being exposed to various hard skills that are important to doing astronomy research in general. The internship also had a great balance of interesting work and interesting experiences—it's not every summer that you get to visit two different observatories and see the instrumentation and the backend where all the professional observing and research happen! I came out of the summer with a better idea of what life as an astronomer might look like and can say that I am very excited to pursue that path."

Raffy Traas is a 4th-year undergraduate studying astrophysics and applied math at the University of Wisconsin-La Crosse. He was adopted from the Philippines at the age of 2. He seeks to use these experiences to someday help advance the visions, missions, and goals of the recently founded Philippine Space Agency as a researcher and science communicator. As an intern at Breakthrough Listen under the mentorship of Steve Croft, Raffy improved its data processing pipeline by enabling it to leverage the computational power of Google Cloud Platform. Using this new processing infrastructure, he analyzed Breakthrough Listen's initial observations of


Raffy Traas

Dr. Sofia Sheikh Awarded National Science Foundation Fellowship for Research & Education at the SETI Institute's Allen Telescope Array

Sep 22, 2021 — Tags: Press Releases, ATA News, Awards, Fast Radio Bursts, SETI


The Allen Telescope Array in Hat Creek, California. Image Credit: Greg Hark. DOWNLOAD.

September 22, 2021, Mountain View, CA – The SETI Institute is announcing that Dr. Sofia Sheikh has been awarded a Mathematical and Physical Sciences Ascending Postdoctoral Research Fellowship (MPS-Ascend) for research and education by the National Science Foundation (NSF). Sheikh's research is focused on fast radio bursts (FRBs) and developing improved technosignature detection methods, specifically by searching higher radio frequencies and in new areas of the sky. She will also mentor underrepresented students in physics and astronomy, helping them build strong networks and providing valuable research experiences. Sheikh's work will leverage the unique qualities of the Allen Telescope Array (ATA), the only radio telescope constructed with SETI as its principal activity.


Dr. Sofia Sheikh. DOWNLOAD.

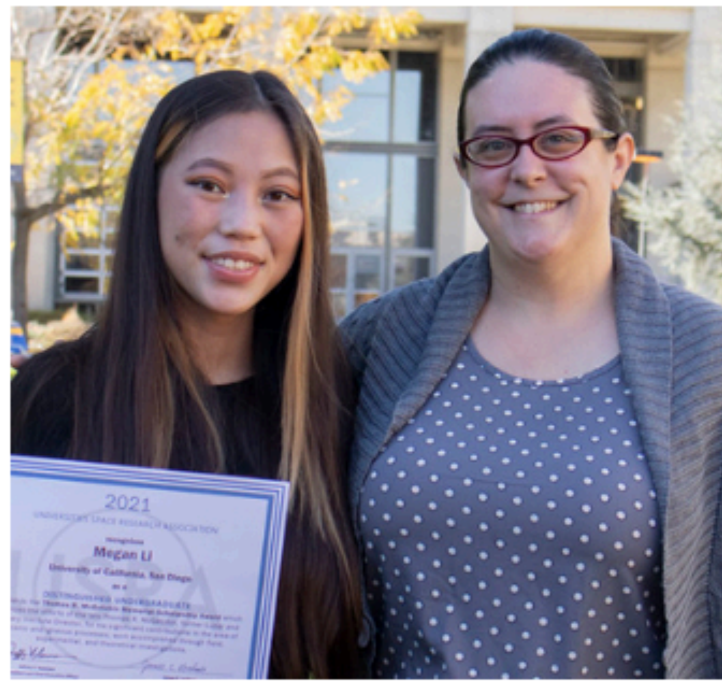
"The combination of Sofia's keen scientific abilities and audacious passion for carving her path is truly remarkable," said Andrew Siemion, Bernard M. Oliver Chair for SETI at the SETI Institute. "Sofia is a world-class scientist who is demonstrating vision, tenacity and academic excellence in researching a profound and challenging topic."

Undergraduate Megan Li Receives Prestigious USRA Award

December 15, 2021 | By Michelle Franklin

Megan Li, majoring in physics with a specialization in astrophysics, has been selected as a 2021 Universities Space Research Association (USRA) Distinguished Undergraduate. Distinguished undergraduates are selected based on their academic record and accomplishments, an essay, and letters of recommendation. Recipients get a certificate and cash award.

USRA's mission is to advance space- and aeronautics-related sciences ... tion ... and ... s, ... you're ... sics, ... geles.


Megan with Assistant Professor of Physics Karin Sandstrom


David Lipman • 1st
Software Engineer Intern at Verily Life Sciences
3w • Edited •

I'm beyond excited to announce that this week I graduated magna cum laude from Princeton University with a Bachelors of Science and Engineering in Computer Science and a certificate in Statistics and Machine Learning. Thank you to all of my family and friends who made this incredible journey possible. I wouldn't have wanted to spend my four years anywhere else and am eternally grateful for all of the memories and relationships I've formed at Princeton. Go Tigers!

With that, I am also excited to announce that beginning this summer I'll be working as a Software Engineer on the Trust and Safety team at Roblox. I'm elated to be starting my career at such an innovative company, and am eager to make the metaverse a safe place for everyone!

Jakob Faber '21 Receives Fulbright Research Fellowship at McGill Space Institute in Montréal

An aspiring astrophysicist, Faber will gain access to the emerging field of Fast Radio Bursts.

JUNE 9, 2021 • Amanda Nagy


Jakob Faber '21
Photo credit: Jonathan Clark '25

The Breakthrough Listen Bibliography

October 17, 2022

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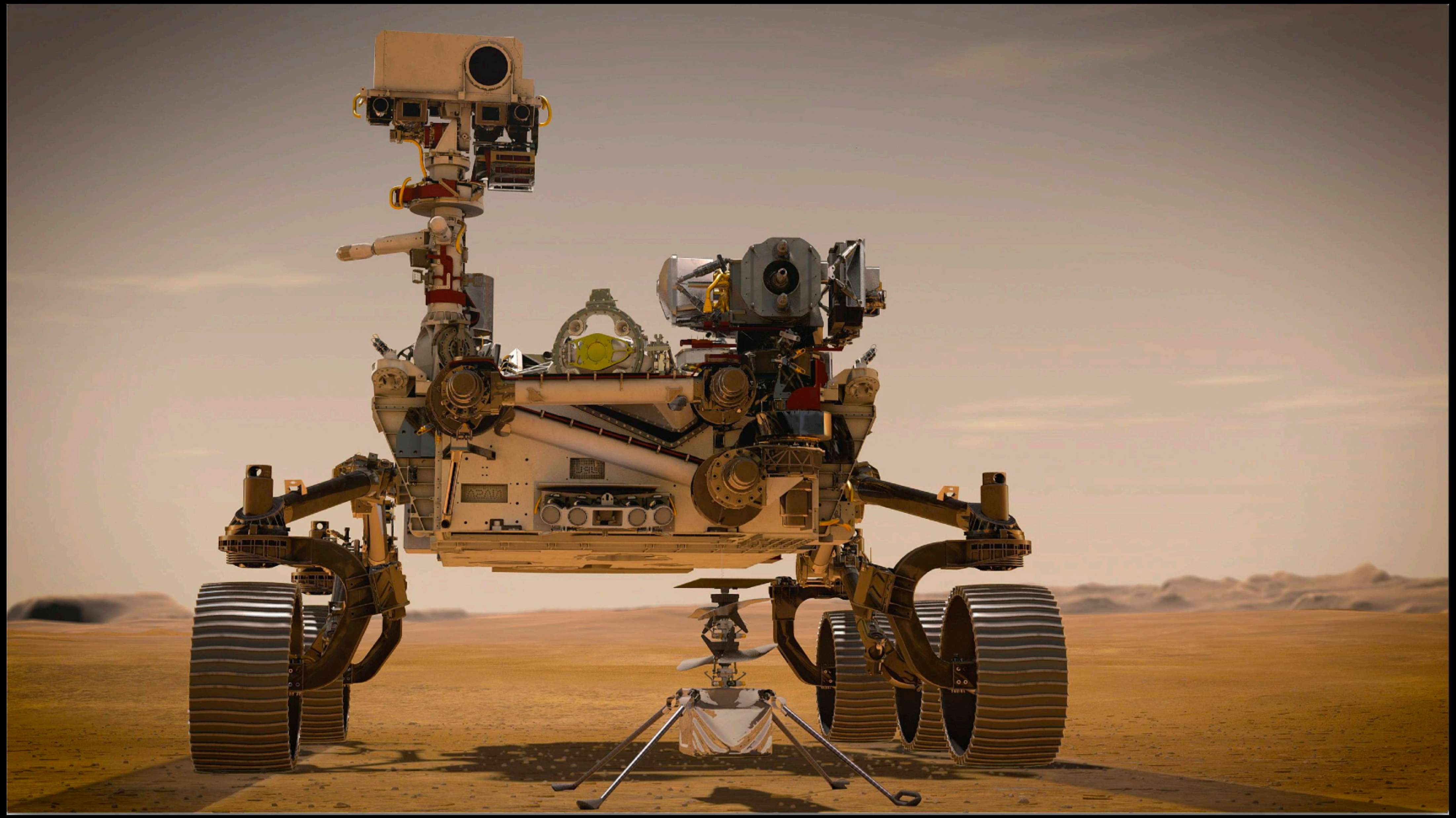


NASA

The Case for Technosignatures: Why They May Be Abundant, Long-Lived, Highly-Detectable, and Unambiguous

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ABSTRACT

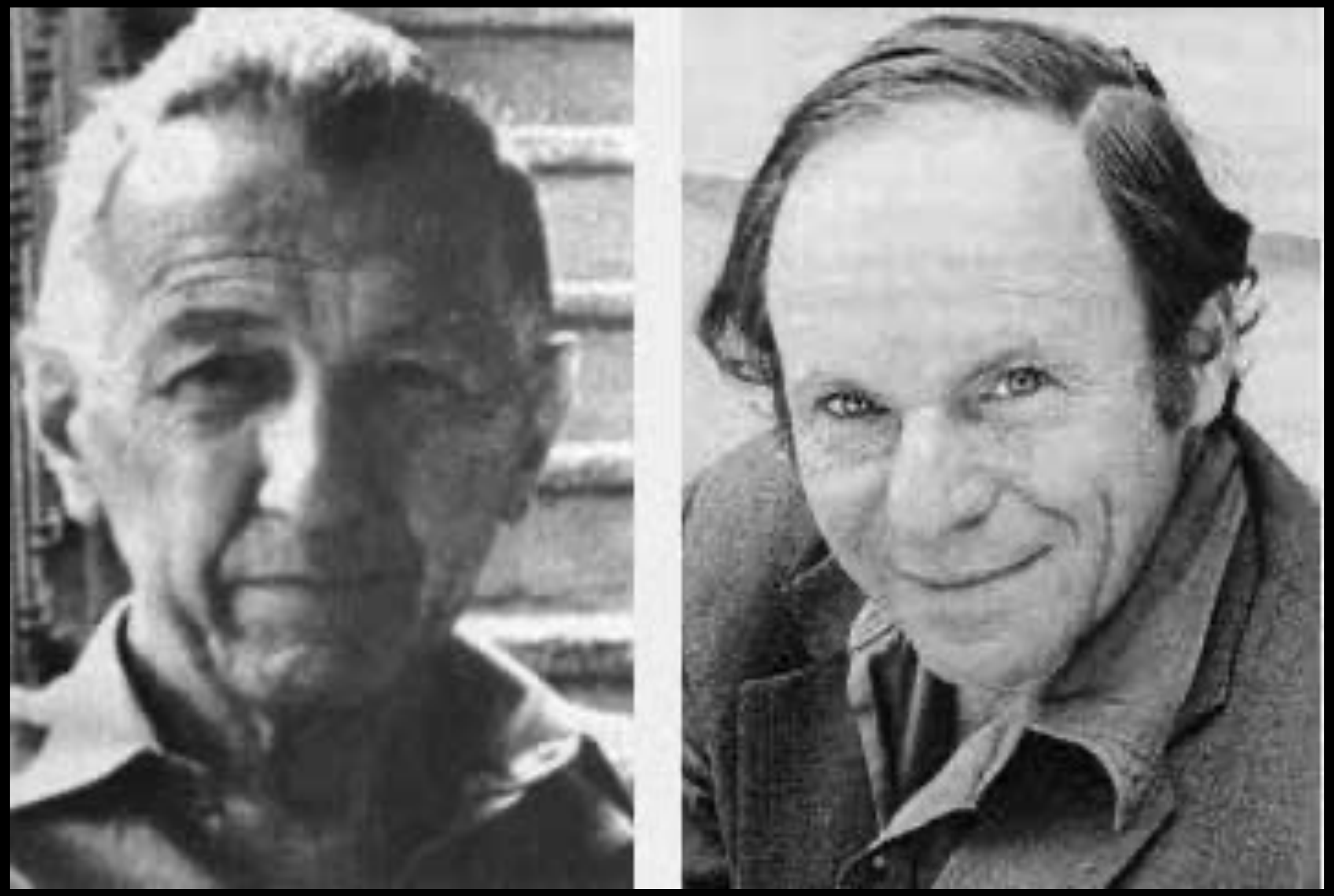
The intuition suggested by the Drake Equation implies that technology should be less prevalent than biology in the galaxy. However, it has been appreciated for decades in the SETI community that technosignatures could be more abundant, longer-lived, more detectable, and less ambiguous than biosignatures.

It is an exciting time in which to practice the astronomical craft, as humanity edges ever closer to being able to answer the age-old question "Are we alone?" It is humbling and exciting to contemplate that the question of whether life exists elsewhere could be answered with the technology humanity now possesses.

2020 Astronomy Decadal Review

“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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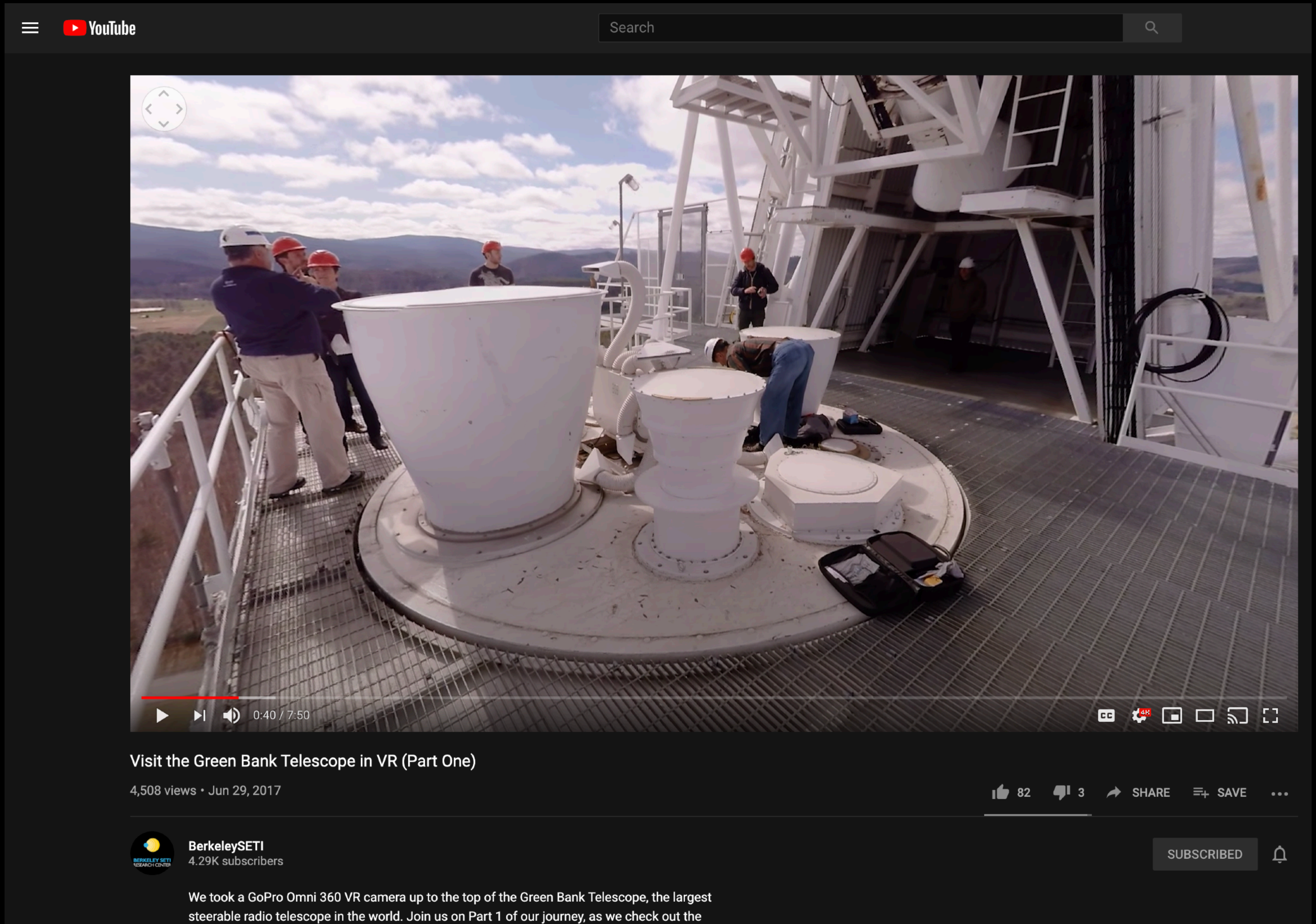

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The blc1 signal is not alien - but it is a huge leap forward for SETI

In October 2020, members of the Breakthrough Listen Initiative performed a standard SETI search of radio observations from Proxima Centauri. Our search algorithm flagged a signal that we couldn't immediately explain. This is the story of that signal, blc1, and the journey to understand its origin.

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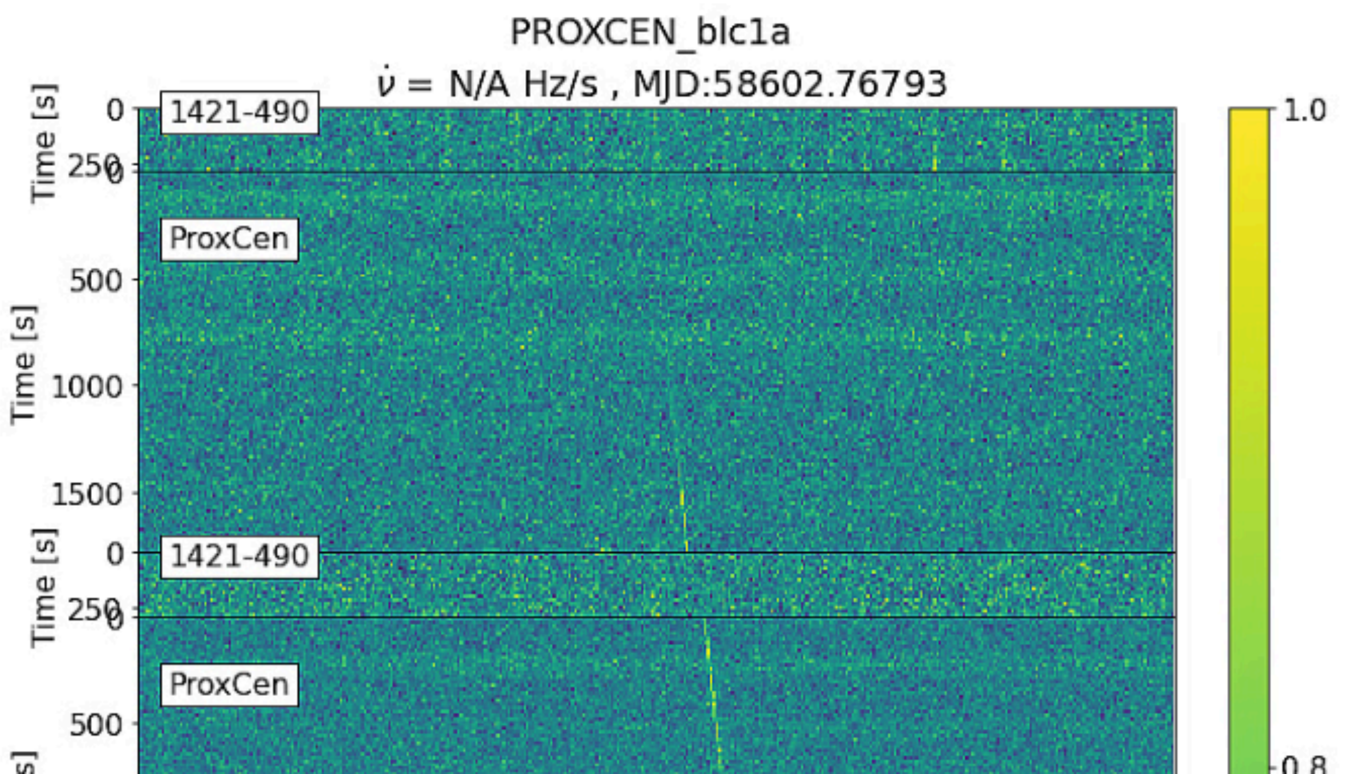
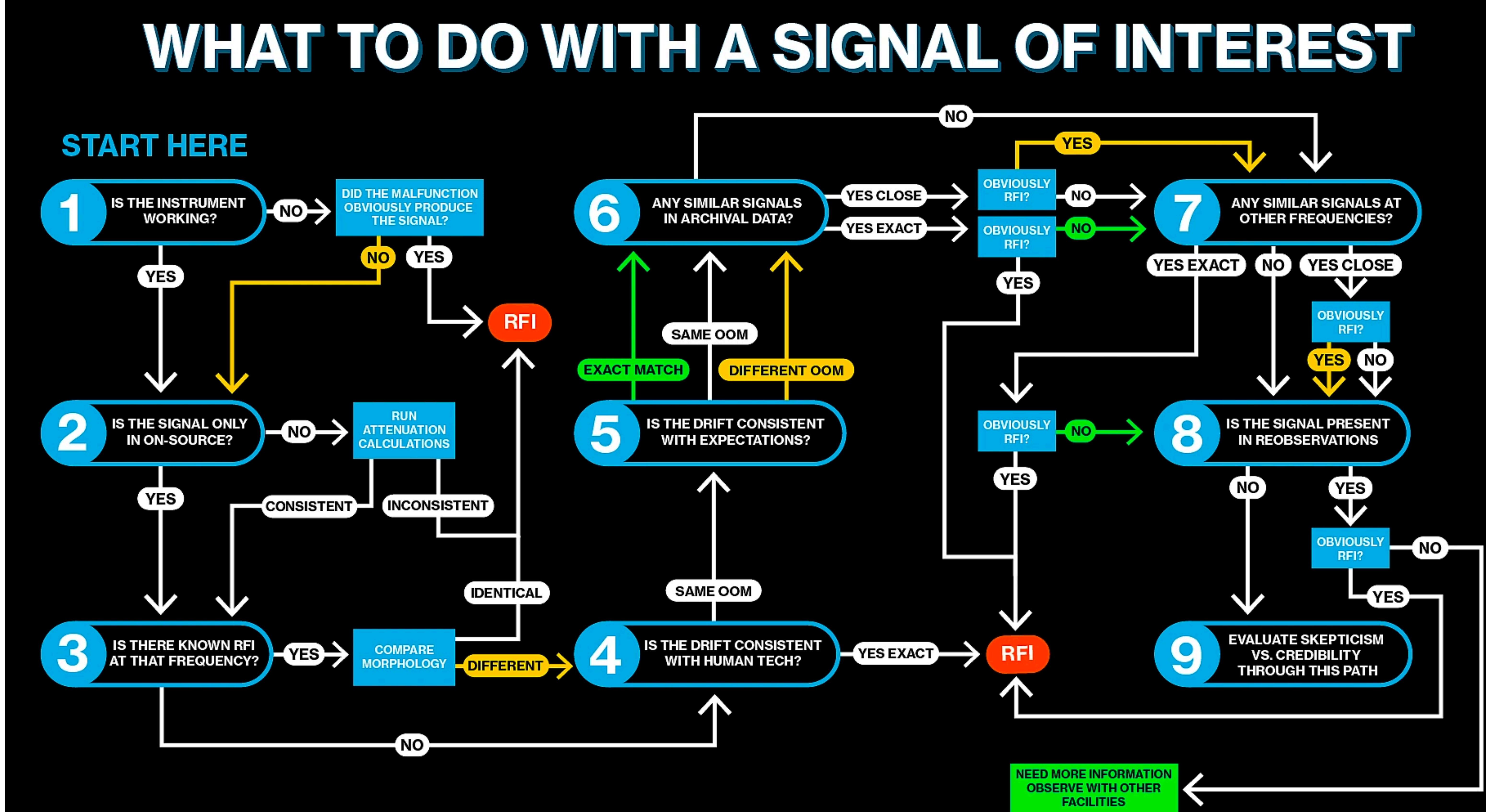
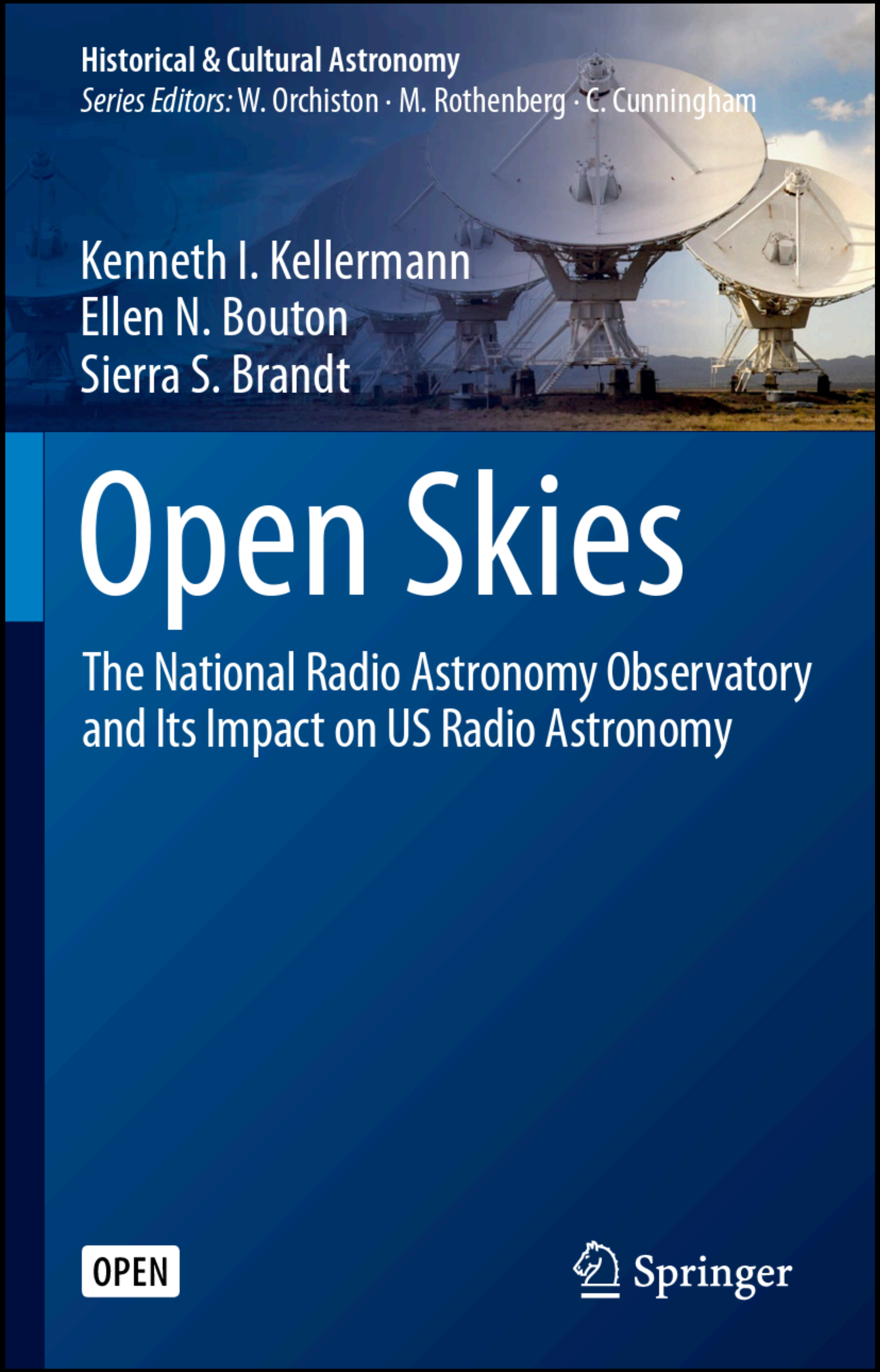
Act I: A Mysterious Signal Is Detected...

In April 2019, the Breakthrough Listen Initiative performed observations of our nearest stellar neighbor, Proxima Centauri (ProxCen), with the Parkes Murriyang telescope in Australia. We were originally searching for stellar flares; learning more about these flares can help us understand the habitability of planets around small, M-dwarf stars like ProxCen. Two years later, the same data were reanalyzed in the context of SETI, the Search for Extraterrestrial Intelligence, looking for technological radio activity from ProxCen. Shane Smith, an REU student working with Breakthrough Listen over the summer in 2020, was the first one to notice that our routine analysis had picked up something unusual. His mentor, Danny Price, posted that plot into our research group's Slack channel. For once, no one in the group had an immediate answer to what could've caused the signal in that plot.

That plot - containing what became known as blc1 - looks like this:







CHAPTER 5

Is Anyone Out There?

In the shadows of the struggles surrounding the construction of the 140 Foot Radio Telescope, Frank Drake, NRAO's newest and youngest scientist, carried out a small observing project to detect radio signals from nearby stars that would indicate the present of extraterrestrial intelligent life. Naming his program "Project Ozma," after the mythical princess of the Land of Oz, Drake observed two nearby stars, Tau Ceti and Epsilon Eridani. This project, the first modern Search for Extraterrestrial Intelligence (SETI), captured the imagination of the public and scientific communities alike. In the following decades, other investigators initiated a variety of SETI programs of ever-increasing capability at NRAO and elsewhere. NASA began a major SETI program, but it became mired in controversy over whether searching for intelligent life in the Universe is a proper scientific pursuit or should be relegated to the realm of science fiction. While no confirmable evidence for extraterrestrial intelligent life has yet been found, the discovery of the widespread existence of other planetary systems combined with the vastly improved sensitivity of radio telescopes has reinvigorated SETI research, and the exciting promise of detection continues to attract the attention of new generations of astronomers and the public.

5.1 Project Ozma

Frank Drake had long been fascinated by the possibility of life on other worlds and more generally by science and engineering. On a Navy ROTC[1] scholarship, he followed these interests by enrolling at Cornell University. Initially

The title of this chapter is taken from the book by Frank Drake and Dava Sobel 1992, *Is Anyone Out There? The Scientific Search for Extraterrestrial Intelligence* (New York, NY: Delacorte Press).

K. I. Kellermann et al., *Open Skies*, Historical & Cultural Astronomy,
https://doi.org/10.1007/978-3-030-32345-5_5

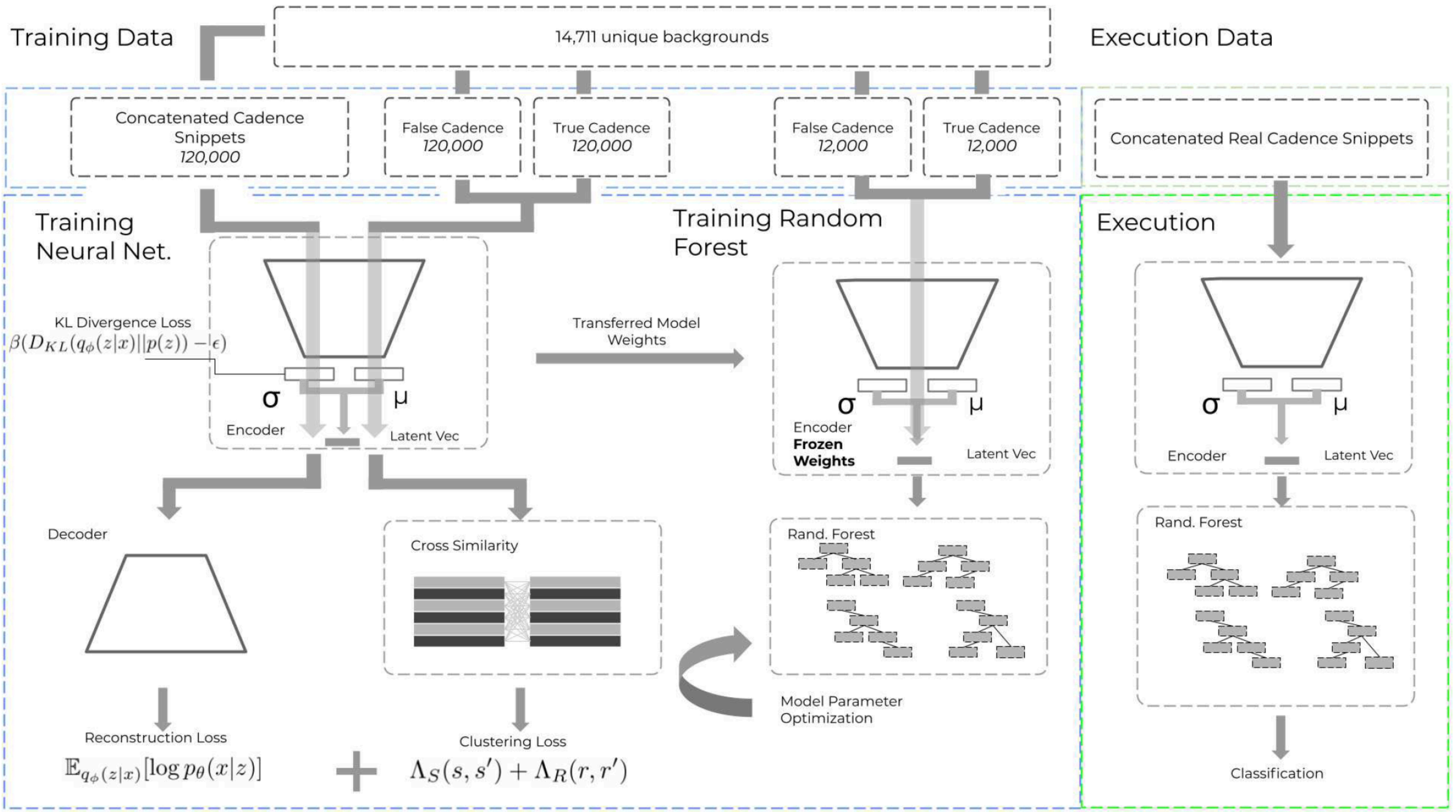


Figure 4. Model training and execution scheme. Backward propagation of the neural network training is not shown for brevity.