Search for Extra-Terrestrial Intelligence

Geographically-spaced Synchronized Signal Detection System

West

Deep Space Exploration Society
60 Foot Plishner Telescope
Haswell, Colorado

Simultaneous SETI observations:
Oct.2017 through Oct.-Nov. 2018

East

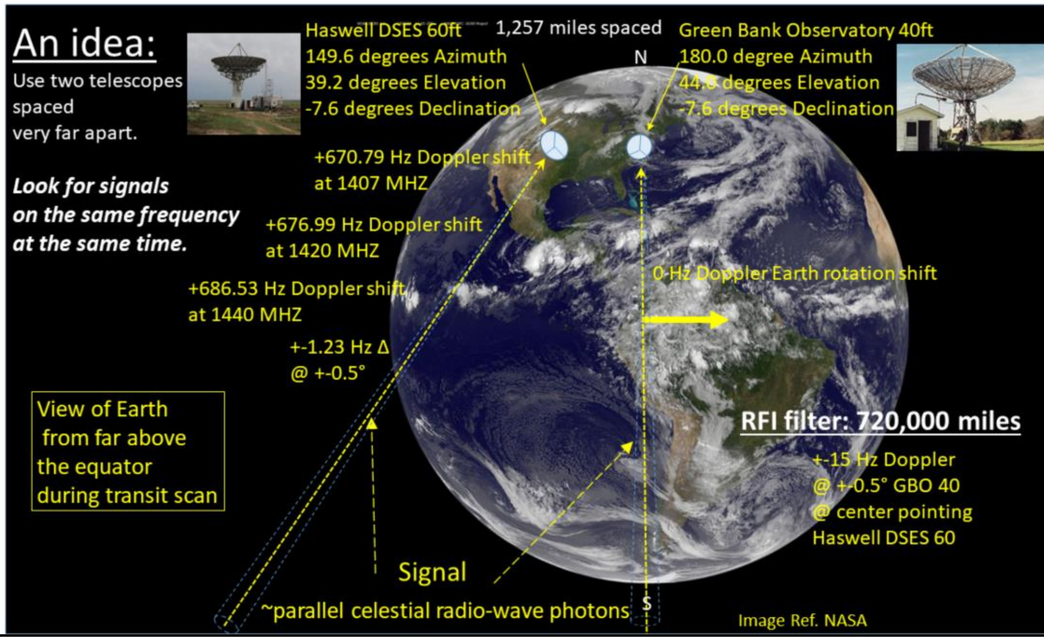
Green Bank Observatory
Forty Foot Telescope
West Virginia

Prepared for Deep Space Exploration Society
by Skip Crilly revised Nov. 8, 2018

Abstract: A system has been designed and implemented that makes simultaneous geographically-spaced time-and-frequency-synchronized measurements of hypothetical extraterrestrial narrowband signals in the 1405-1448 MHz band. One radio telescope is the Deep Space Exploration Society sixty foot Plishner Telescope in Haswell, Colorado, and another radio telescope is the Forty Foot Telescope at the Green Bank Observatory in Green Bank, West Virginia. A GPS-signal-locked reference oscillator and a digital back-end is used at each site to permit differential Doppler measurements of radio pulses to a RF frequency resolution of 3.73 Hz. This presentation will describe signal search strategy, the receiver system, observations of simultaneous close-frequency pulses, a working hypothesis, and plans to enhance capabilities of the measurement system.

Topics

- Description of Haswell and Green Bank Observatory telescope sites
- Search strategies
- System design
- Observations and measurement results
- Working hypothesis
- Plans

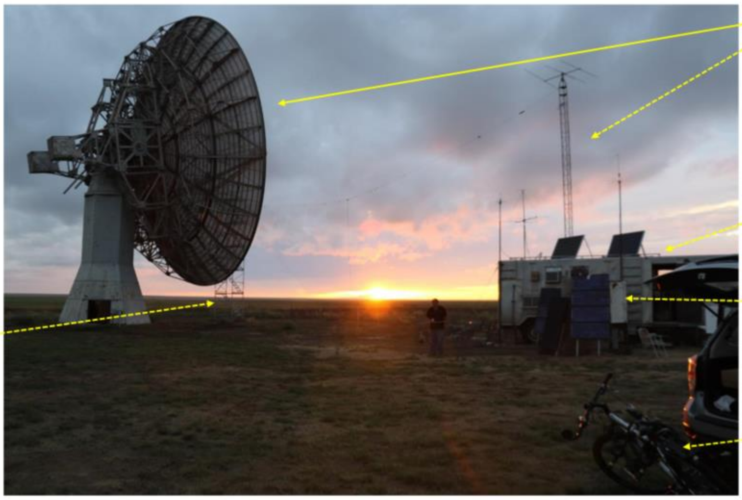

An idea:
Use two telescopes spaced very far apart.
Look for signals on the same frequency at the same time.
Haswell DSES 60ft
149.6 degrees Azimuth
39.2 degrees Elevation
-7.6 degrees Declination
1,257 miles spaced
Green Bank Observatory 40ft
180.0 degree Azimuth
44.0 degrees Elevation
-7.6 degrees Declination
N
+670.79 Hz Doppler shift at 1407 MHZ
+676.99 Hz Doppler shift at 1420 MHZ
+686.53 Hz Doppler shift at 1440 MHZ
+-1.23 Hz Δ @ +-0.5°
0 Hz Doppler Earth rotation shift
View of Earth from far above the equator during transit scan
RFI filter: 720,000 miles
+-15 Hz Doppler @ +-0.5° GBO 40 @ center pointing Haswell DSES 60
Signal
~parallel celestial radio-wave photons
S
Image Ref. NASA

Deep Space Exploration Society   Plishner Telescope near Haswell, Colorado

Haswell simultaneous observations were made by Steve Plock, President of DSES

60 foot diameter telescope

40 foot high stand to access feed LNAs, RF over fiber



Amateur radio, astronomy and SETI antennas

Communications trailer

Solar backup power

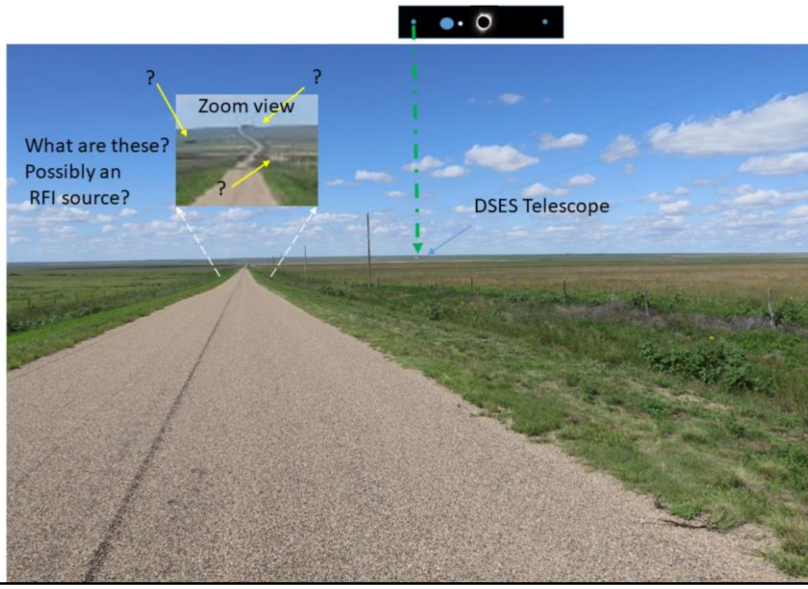
Transport having low radio frequency interference

The DSES telescope is remote.

Intelligently-designed
celestial radio transmitter here

Photo courtesy of Gary Agranat

Looking at the 60 Foot Telescope from another direction

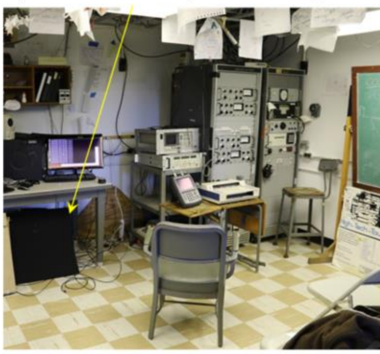


Lesson for SETI:
Know your RFI sources.

Green Bank Observatory
Forty Foot Telescope
West Virginia
Primary Activity:
Education and Public Outreach
Thousands of students,
educators and amateur astronomers observe per year

This is where I work part time

SETI computer surrounded by RFI absorbing foam



Forty Foot Telescope

Green Bank Telescope
In background
100m x 110m;
~100 dBi gain @120 GHz
world's largest fully steerable telescope

Third SETI telescope site, 28 foot diameter paraboloid under construction
on New Hampshire farm, 5 pixels of dual polarization,
surrounded on all sides by deep forests

Proposed prime prerequisite of transmitter (ETI) and receiver (human) entities

Understand communication theory, i.e. math : e.g. Shannon's Law

Examples:

Energy per communicated bit limitations

Bandwidth available for communication

Data rate possible

Detectability functions

Two telescope site signal search strategy

Filtering methodology
What are the signal requirements to be significant?
SNR = Signal to Noise Ratio

1. SNR > 12 dB (15.8) at distant locations, e.g. Haswell and Green Bank, and
2. Measured close frequency (post Doppler + correction) at the same time at two distant telescope sites

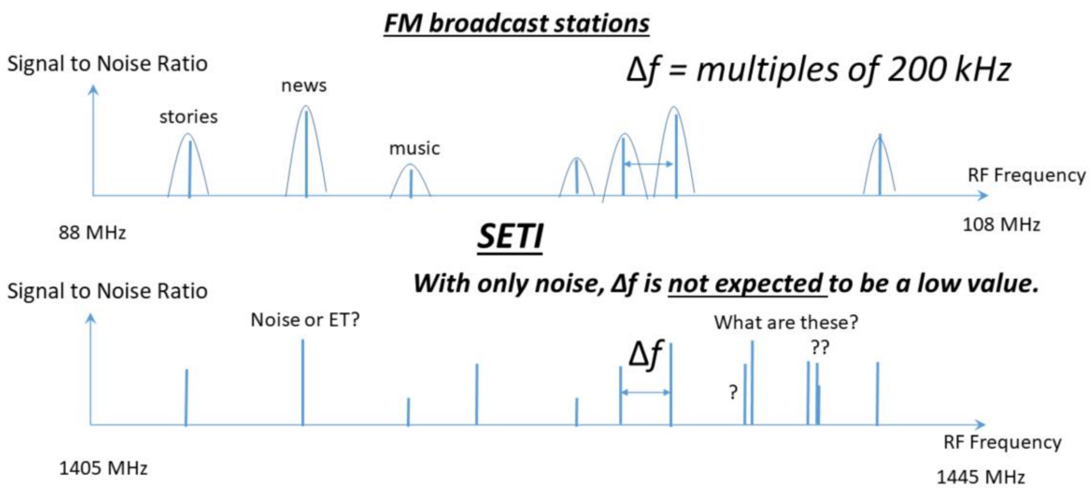
or many close frequency spaced tones at both sites

Open squelch

followed by

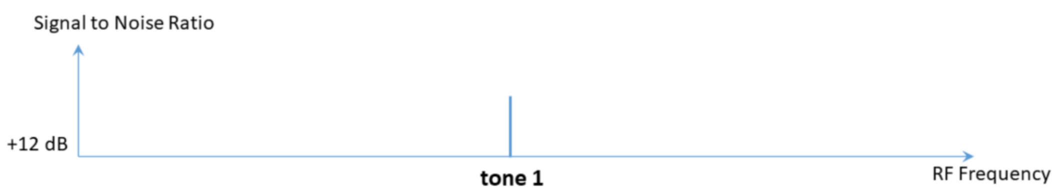
Post-squelch information-containing signal analysis

Signals carrying information use frequencies example: FM broadcast band



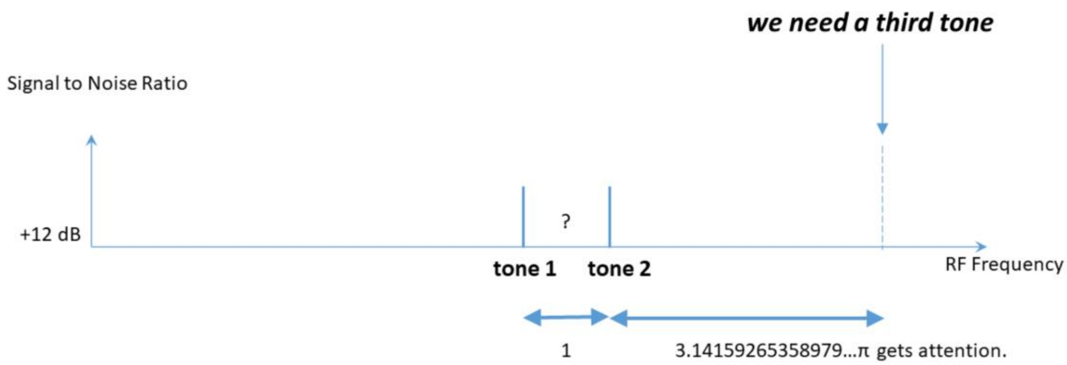
Frequency Triplets: Why search for triplets?

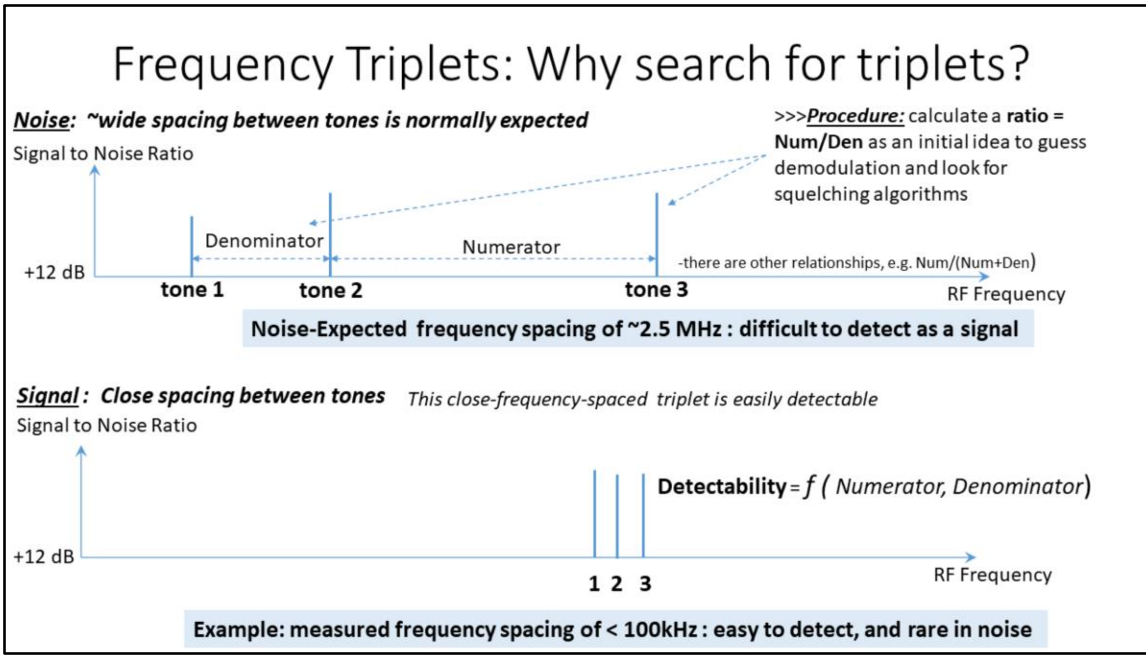
Difficult to encode / decode information in one tone



Idea: It seems preferable to search for information content in one dimension, e.g. frequency, at a time.

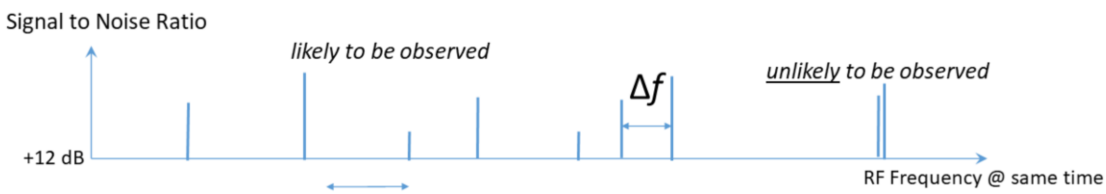
Difficult to encode / decode information in two tones




Frequency Triplets: Why search for triplets?
Noise: ~wide spacing between tones is normally expected
>>>Procedure: calculate a ratio = Num/Den as an initial idea to guess demodulation and look for squelching algorithms
Signal to Noise Ratio
Denominator
Numerator
+12 dB
-there are other relationships, e.g. Num/(Num+Den)
tone 1
tone 2
tone 3
RF Frequency
Noise-Expected frequency spacing of ~2.5 MHz : difficult to detect as a signal
Signal : Close spacing between tones
This close-frequency-spaced triplet is easily detectable
Signal to Noise Ratio
Detectability = f (Numerator, Denominator)
+12 dB
1 2 3
RF Frequency
Example: measured frequency spacing of < 100kHz : easy to detect, and rare in noise

Likelihood of close-spaced tones due to noise

Detectability = f (*Numerator, Denominator*)



Median spacing: Δf_{50} ; i.e. 50% of $\Delta f < \Delta f_{50}$, due to noise

$$Likelihood(\Delta f) = 1 - e^{-\ln 2 \ (\Delta f / \Delta f_{50})}$$

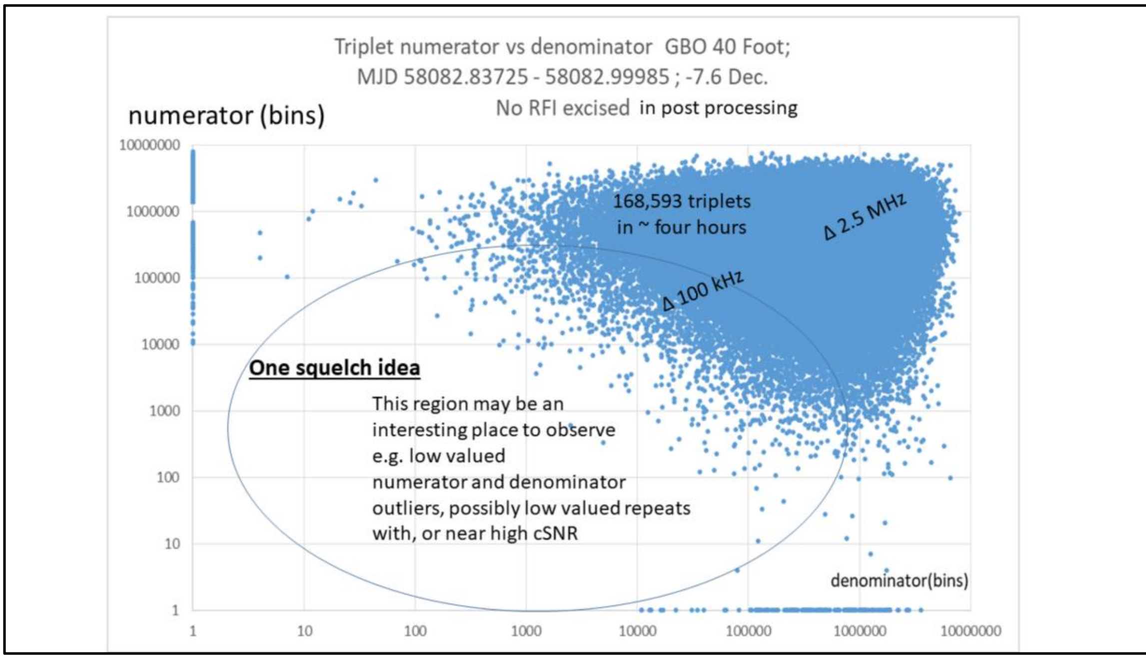
$$Likelihood(\Delta f) \approx \ln 2 \ (\Delta f / \Delta f_{50}) \quad \text{if } (\Delta f / \Delta f_{50}) \ll 1$$

derived from Poisson Point Process model; notebook #16 page 68; tested in simulation

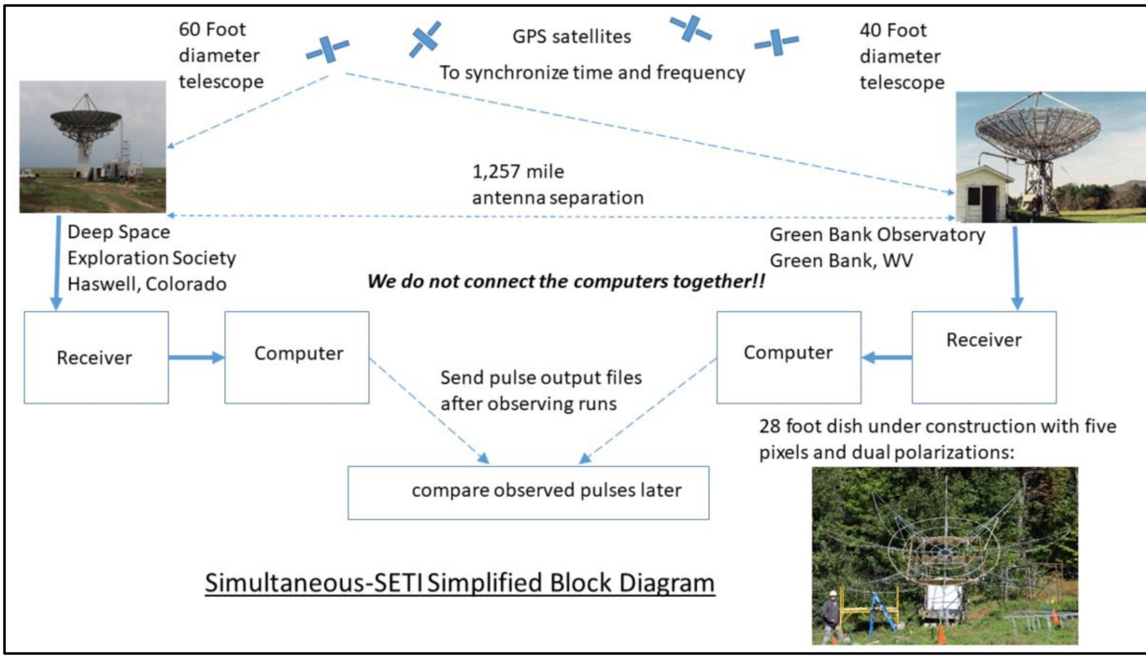
The likelihood of tone spacing was derived from the concept that tones, expected to be due to noise, occur at frequencies uniformly distributed within a given interval of frequency. A first order differential equation results from the analysis of multiple trials having various tone spacings, resulting in an exponential solution to a probability density function. The cumulative probability is then obtained from an integral of the probability density function.

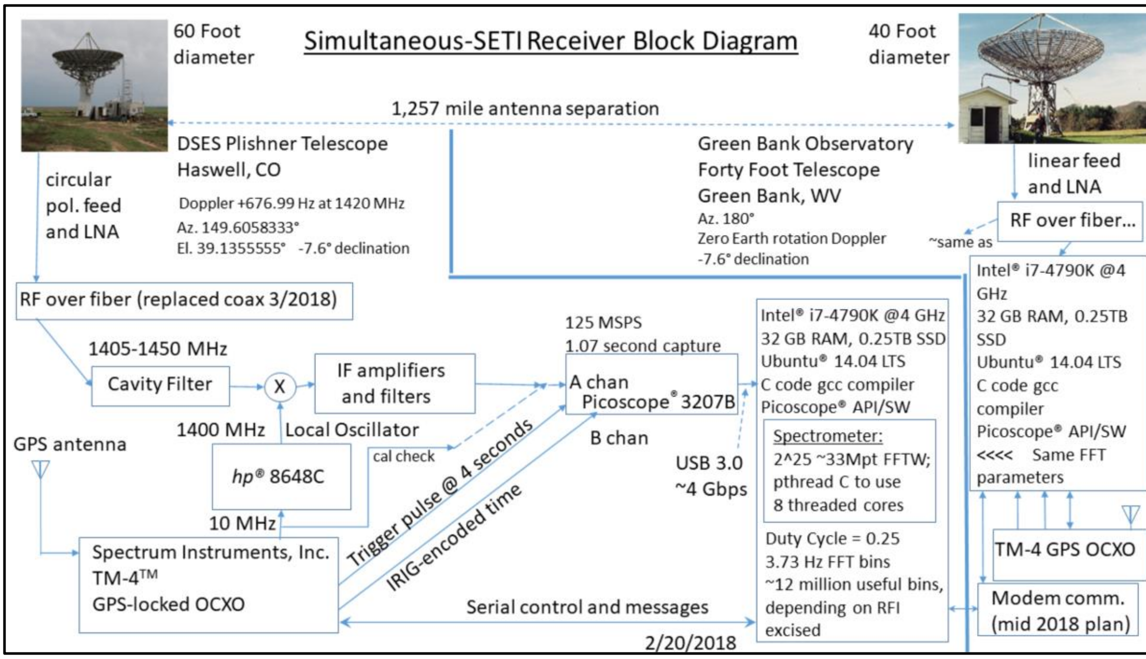
The calculation above is referred to as a likelihood, as the calculation is most commonly used in the observations, in this work, to calculate the probability of an event a posteriori.

The calculation above is an *estimated* likelihood due to noise, as RFI can affect the determination of an estimate of Δf_{50}. Δf_{50} is estimated from an observation of tone spacings, expected to be due to Rayleigh IQ amplitude distributed noise, that exceed the 12.0 dB composite one second signal to noise ratio measurement. Composite SNR is implemented to reduce noise-caused false positives that exceed a lower 11.2 dB threshold in a single 0.26 s interval of the time samples that are applied to the uniform windowed FFT. The 11.2 dB threshold and the 12.0 dB threshold must both be exceeded to record a pulse to the output file. The combination of the two SNR thresholds has not been used in a stochastic process to rigorously derive Δf_{50} .


Triplet numerator vs denominator GBO 40 Foot;
MJD 58082.83725 - 58082.99985 ; -7.6 Dec.
No RFI excised in post processing
numerator (bins)
168,593 triplets
in ~ four hours
Δ 2.5 MHz
Δ 100 kHz
One squelch idea
This region may be an
interesting place to observe
e.g. low valued
numerator and denominator
outliers, possibly low valued repeats
with, or near high cSNR
denominator(bins)
10000000
1000000
100000
10000
1000
100
10
1
1
10
100
1000
10000
100000
1000000
10000000

System Design

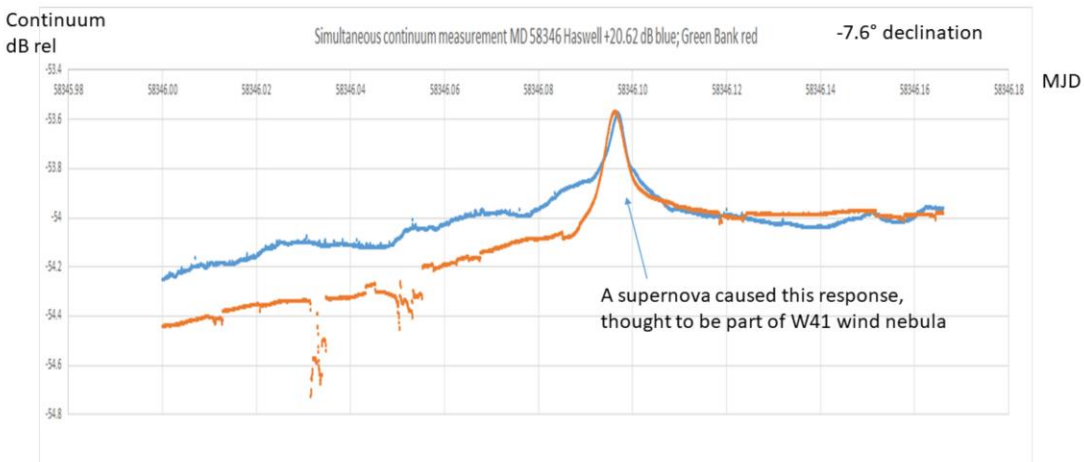

60 Foot diameter telescope
GPS satellites
To synchronize time and frequency
40 Foot diameter telescope
1,257 mile antenna separation
Deep Space Exploration Society Haswell, Colorado
Green Bank Observatory Green Bank, WV
We do not connect the computers together!!
Receiver
Computer
Computer
Receiver
Send pulse output files after observing runs
28 foot dish under construction with five pixels and dual polarizations:
compare observed pulses later
Simultaneous-SETI Simplified Block Diagram


Simultaneous-SETI Receiver Block Diagram
60 Foot diameter
40 Foot diameter
1,257 mile antenna separation
DSES Plishner Telescope
Haswell, CO
Doppler +676.99 Hz at 1420 MHz
Az. 149.6058333°
El. 39.1355555° -7.6° declination
Green Bank Observatory
Forty Foot Telescope
Green Bank, WV
Az. 180°
Zero Earth rotation Doppler
-7.6° declination
circular pol. feed and LNA
linear feed and LNA
RF over fiber…
~same as
RF over fiber (replaced coax 3/2018)
1405-1450 MHz
Cavity Filter
X
IF amplifiers and filters
125 MSPS
1.07 second capture
A chan
Picoscope® 3207B
B chan
1400 MHz
Local Oscillator
hp® 8648C
cal check
10 MHz
GPS antenna
Spectrum Instruments, Inc. TM-4™ GPS-locked OCXO
Trigger pulse @ 4 seconds
IRIG-encoded time
USB 3.0
~4 Gbps
Intel® i7-4790K @4 GHz
32 GB RAM, 0.25TB SSD
Ubuntu® 14.04 LTS
C code gcc compiler
Picoscope® API/SW
Spectrometer:
2^25 ~33Mpt FFTW; pthread C to use 8 threaded cores
Duty Cycle = 0.25
3.73 Hz FFT bins
~12 million useful bins, depending on RFI excised
Serial control and messages
2/20/2018
Intel® i7-4790K @4 GHz
32 GB RAM, 0.25TB SSD
Ubuntu® 14.04 LTS
C code gcc compiler
Picoscope® API/SW
<<<< Same FFT parameters
TM-4 GPS OCXO
Modem comm. (mid 2018 plan)

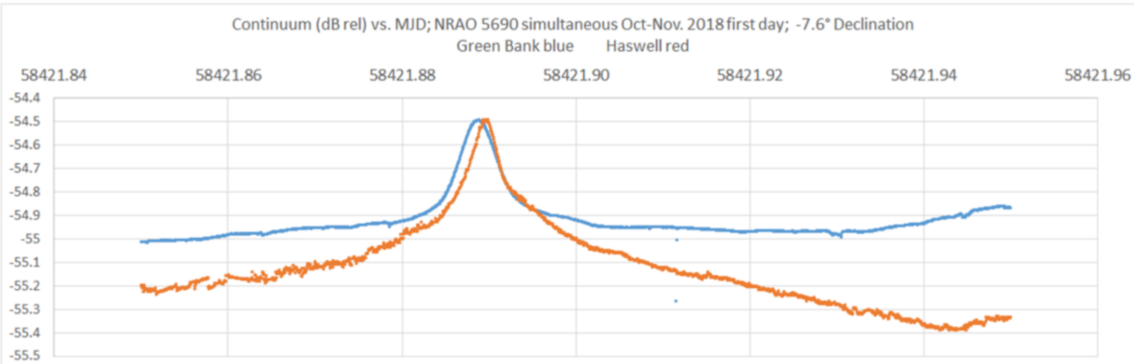
System Pointing Validation

Are the Haswell and Green Bank telescopes pointing at the same Right Ascension & Declination?

August 16, 2018 NRAO 5690 simultaneous Green Bank & Haswell observation



Oct. - Nov. 2018 NRAO 5690 transit
Haswell and Green Bank pointing verification



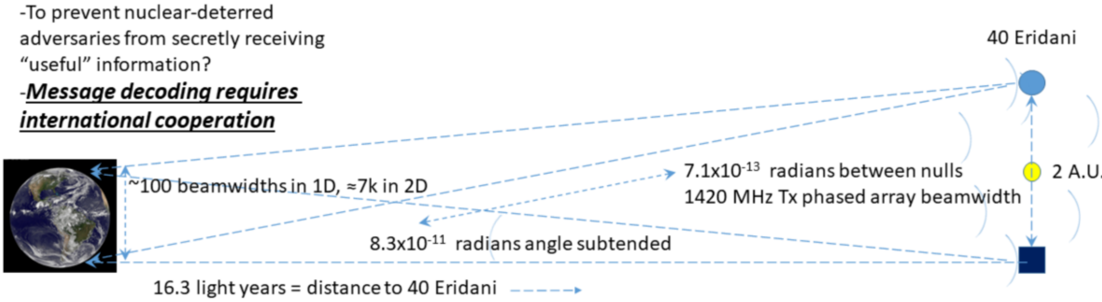
Geo-multiplexing….the same signal may not be received at all locations on Earth

Is there a message in a message?

Why send geo-multiplexed information?
-For higher channel capacity?
-To prevent nuclear-deterred adversaries from secretly receiving "useful" information?
-***Message decoding requires international cooperation***

To open squelch :

One, or a few, tones of many simultaneously transmitted tones need(s) to be at close frequency at two telescope sites. After squelch opens, associated pulsed tones observed at each receive site contain a subset of a message.



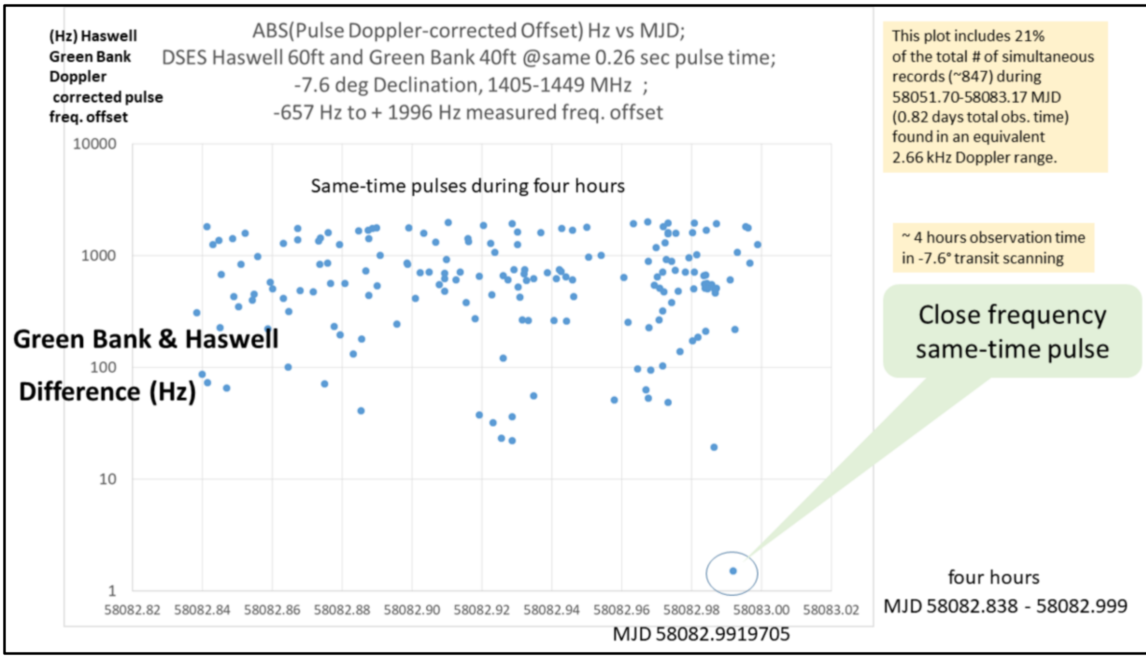
Observations, measurements and calculations

Observations that are described here occurred during Haswell and Green Bank simultaneous transit scan pointing to -7.6° declination on November 25, 2017, (MJD 58082) April 10-11, 2018, (MJD 58219) and Green Bank standalone June 7-9, 2018, (MJD 58276-8), and August 15-16, 2018 (MJD 58345-6).

Notes:

1. Some pulse observations, described in this presentation, calculate to be highly unlikely to be noise-caused.

2. The following is not a *claim* of detection of an extra-terrestrial intelligent signal.


(Hz) Haswell
Green Bank
Doppler
corrected pulse
freq. offset
ABS(Pulse Doppler-corrected Offset) Hz vs MJD;
DSES Haswell 60ft and Green Bank 40ft @same 0.26 sec pulse time;
-7.6 deg Declination, 1405-1449 MHz ;
-657 Hz to + 1996 Hz measured freq. offset
Same-time pulses during four hours
Green Bank & Haswell
Difference (Hz)
10000
1000
100
10
1
58082.82
58082.84
58082.86
58082.88
58082.90
58082.92
58082.94
58082.96
58082.98
58083.00
58083.02
MJD 58082.9919705
This plot includes 21% of the total # of simultaneous records (~847) during 58051.70-58083.17 MJD (0.82 days total obs. time) found in an equivalent 2.66 kHz Doppler range.
~ 4 hours observation time in -7.6° transit scanning
Close frequency same-time pulse
four hours
MJD 58082.838 - 58082.999

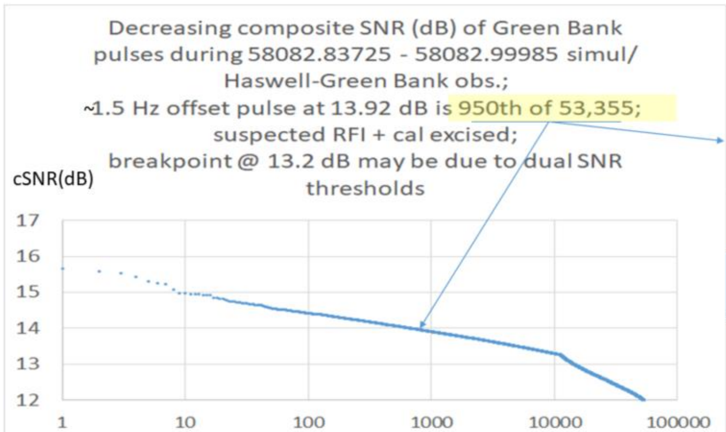
Simultaneous pulse observed at time 58082.9919705

≈1.5 Hz difference after Doppler at center of beam and sample clock offset correction

Triplet tone frequencies and cSNR un-postprocessed

	Haswell		Green Bank	
Tone 1	1429.535342 MHz	12.186 dB	1429.534683 MHz	**13.92 dB**
	Δ ≈73 kHz measured (expected ≈2.5 MHz)		Δ ≈80 kHz measured (expected ≈2.5 MHz)	
Tone 2	1429.461417 MHz	12.474 dB	1429.454120 MHz	12.675 dB
Tone 3	1414.049824 MHz	12.819 dB	1428.671384 MHz	**13.261 dB**

13.92 dB composite 1 s SNR of Green Bank & Haswell simultaneous ~1 Hz offset pulse



i.e. the simultaneous measurement is presumed to be unlikely to be due to noise;

Likelihood(Pr. noise at 13.92 dB) calculated at ~0.017

Estimated Likelihood of simultaneous ~1 Hz offset Haswell & Green Bank pulsed tones, due to noise

Likelihood function uses **an idea** that "un-squelching" the receiver requires:

1. 12.0 dB threshold-crossing composite 1 s signal-to-noise ratio at Haswell & Green Bank
2. 13.92 dB threshold at Haswell **or** Green Bank
3. adjacent tone bin spacing ≤ 21626 at Haswell and Green Bank (i.e. < 80 kHz)

- ~1 Hz offset during the same 0.26 s interval (expected ~once per day)

AND (

1. 13.92 dB composite 1s SNR Green Bank likelihood ~ 0.017 * 2 (GB or Haswell)
2. 21626 bins(Δ 80 kHz) Green Bank numerator tone spacing likelihood ~ 0.03
3. 19844 bins (Δ 73 kHz) Haswell numerator tone spacing likelihood ~ 0.03 **)**

Combining three AND factors in Likelihood function:

- 0.017 * 2 * 0.03 * 0.03 ≈ **0.000031 = 31 ppm**

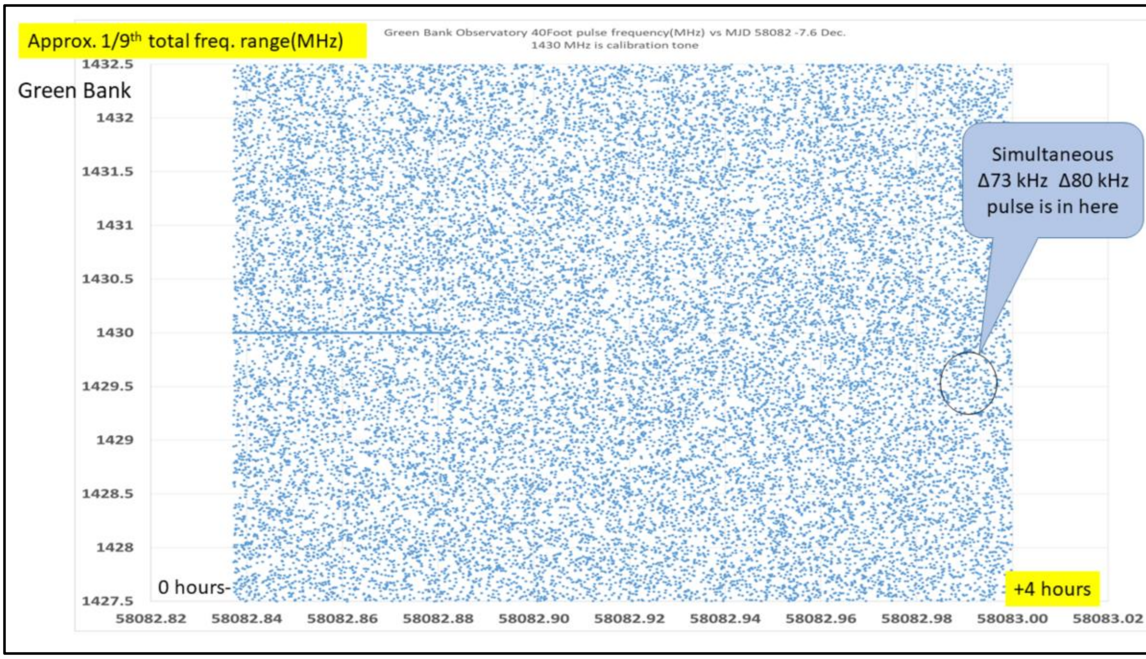
i.e. event is expected 31 times per million simultaneous Haswell-Green Bank pulses,

if squelch conditions are independent, and noise is the anomaly's suspected cause.

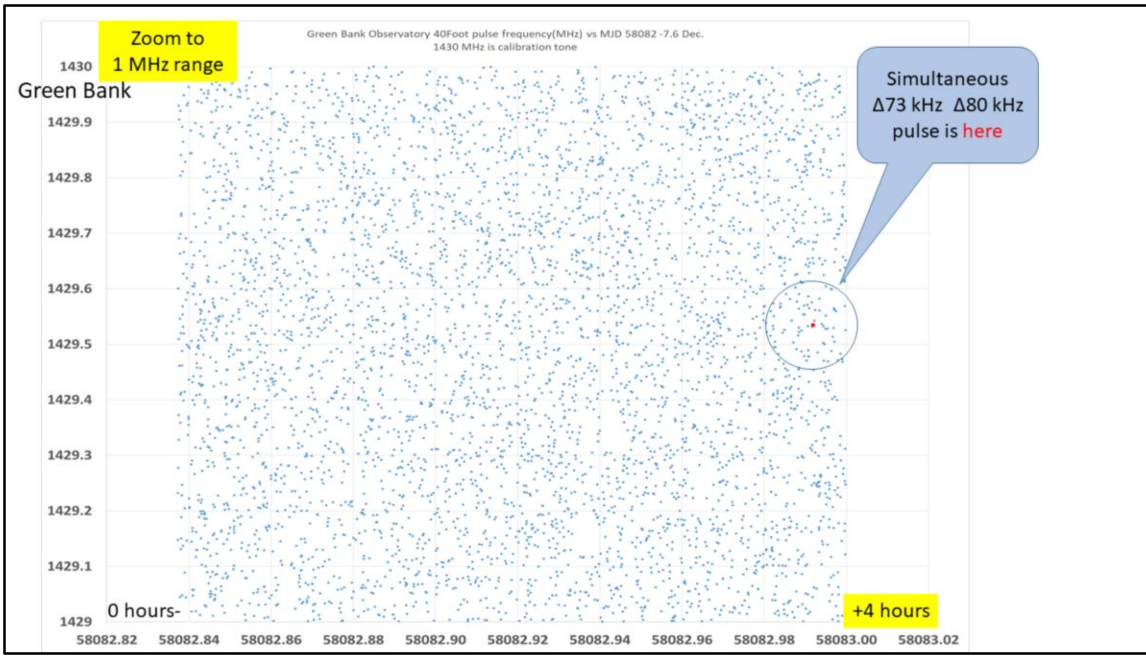
Squelch has opened

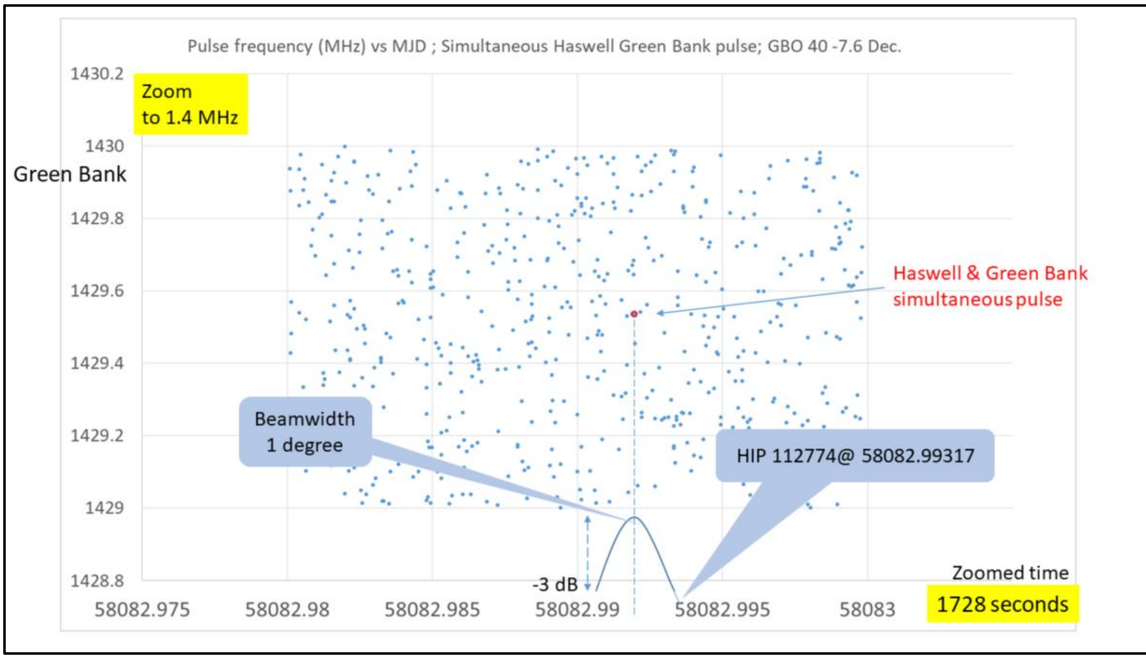
Post-squelch information-containing signal analysis

Did other anomalous pulses appear
near the time & frequency of the simultaneous pulse?

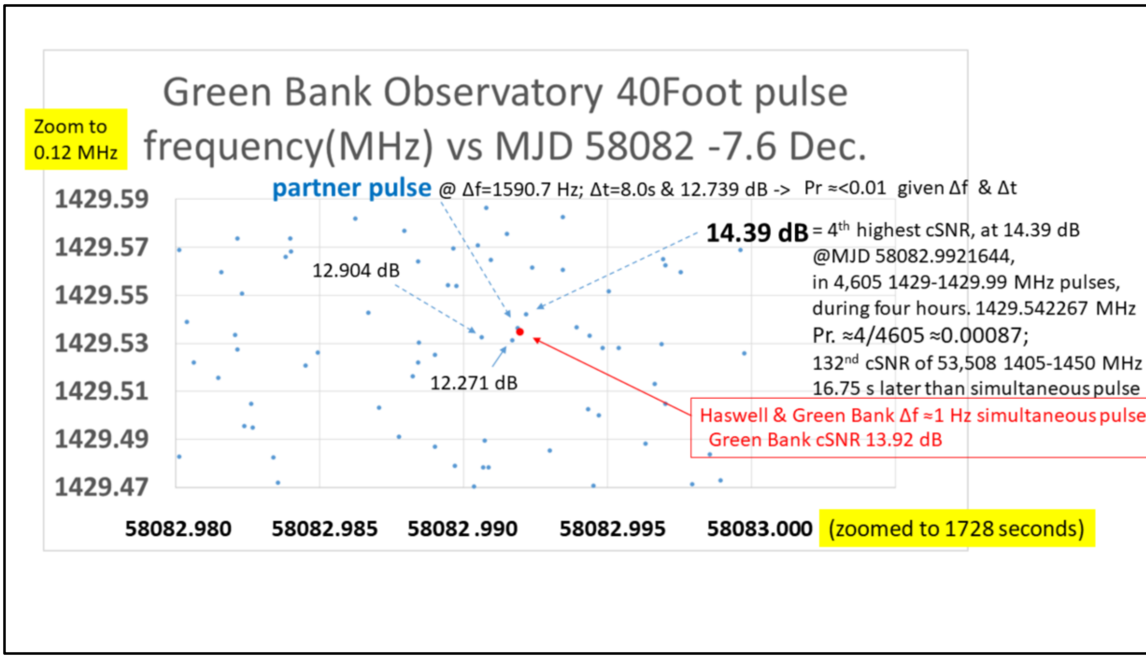


Approx. 1/9th total freq. range(MHz)
Green Bank Observatory 40Foot pulse frequency(MHz) vs MJD 58082 -7.6 Dec.
1430 MHz is calibration tone
Green Bank
1432.5
1432
1431.5
1431
1430.5
1430
1429.5
1429
1428.5
1428
1427.5
Simultaneous
Δ73 kHz Δ80 kHz
pulse is in here
0 hours-
+4 hours
58082.82
58082.84
58082.86
58082.88
58082.90
58082.92
58082.94
58082.96
58082.98
58083.00
58083.02


Zoom to
1 MHz range
Green Bank Observatory 40Foot pulse frequency(MHz) vs MJD 58082 -7.6 Dec.
1430 MHz is calibration tone
Green Bank
Simultaneous
Δ73 kHz Δ80 kHz
pulse is here
1430
1429.9
1429.8
1429.7
1429.6
1429.5
1429.4
1429.3
1429.2
1429.1
1429
0 hours-
+4 hours
58082.82
58082.84
58082.86
58082.88
58082.90
58082.92
58082.94
58082.96
58082.98
58083.00
58083.02



Pulse frequency (MHz) vs MJD ; Simultaneous Haswell Green Bank pulse; GBO 40 -7.6 Dec.
Zoom
to 1.4 MHz
Green Bank
1430.2
1430
1429.8
1429.6
1429.4
1429.2
1429
1428.8
Haswell & Green Bank
simultaneous pulse
Beamwidth
1 degree
HIP 112774@ 58082.99317
-3 dB
Zoomed time
1728 seconds
58082.975
58082.98
58082.985
58082.99
58082.995
58083



An unusual partner pulse was observed. A high composite SNR pulse was observed.

1.1 58082.992 **58082.991878** -53.32536 30971 7928583 **1429.536273 MHz**
-54.18 11.925 -3.058 -2.118 3.231 **12.739 dB** 17.127 292847 1815684 2108531 2.64559
2.75343 2.82148
6.200111320928676066341809887074e+00 11
4.928038974273873767492193268345e+02 2
1.051994121804501204928973163956e+214 5
S

Green Bank partner pulse measured data
associated triplet of the partner of the simultaneous Haswell-Green Bank pulse

1.1 58082.992 **58082.991878** -53.32536 31112 7964918 **1429.671632 MHz**
-54.27 11.38 -7.632 -0.897 3.564 **12.304 dB** 17.173 1815684 36335 1852019
ratio Shannon Entropy = 2.37878 2.64559 2.89629
2.0011742131340034940000057278689e-02 20 **0123479 *late 5 6 8***
1.0202133194352154400085210805420e+00 10 **0123459 digits late 6 7 8**
2.773786403406941519449065953088e+00 14
S

Close tone spacing
Expect: ~2.5 MHz
Measure: 135, 195 kHz

1.1 58082.992 **58082.991878** -53.32536 31317 8017156 **1429.866234 MHz**
-54.23 11.538 -1.471 -0.267 -1.115 **12.221 dB** 17.199 **36335 52238 Σ =88573**
ratio Shannon Entropy = 2.35988 2.69951 2.69951
tone spacings in FFT bins
1.437677170771982936562543002615e+00 **01346789 *late 2 5*** 14
4.210903239036432115141323885143e+00 **5 01234569 late 7 8**
6.741740635061165008466862357335e+01 37 late 239
S

Bin Σ event rank 1652 / 216711 = 0.0076

It was surprising to observe that the 1590.7 Hz offset pulse partnered to the simultaneous pulse, is itself a triplet with a low predicted likelihood due to noise. The rank of the combined tone spacing was calculated at 1,652 of 216,711 combined triplet tone spacings.

This tones comprising the triplet, and the high cSNR pulse described in the previous slide are referred to as ***associated pulses***, as the pulses appear to be associated with a simultaneous pulse.

If a transmitting entity is attempting to reduce the noise-likelihood of transmitted pulses measured at the receiver, then it seems natural that the transmitting entity will transmit low noise-likelihood pulses, at close to the same time and frequency as a simultaneous pulse.

Likelihood analysis of three triplets containing seven tones close in time and frequency

close partner to GB Haswell pulse

Tphase.site	MJD time	Freq. before corrections	composite1sSNR	denominator(bins)	numerator(bins)	
		B. Δ 1.6 kHz				
1.1 GB	58082.99187790	**1429.536273 MHz**	**12.739 dB**	292847	1815684	
1.1 GB	58082.99187790	**1429.671632 MHz**	12.304 dB	1815684	36335	
1.1 GB	58082.99187790	**1429.866234 MHz**	12.221 dB	**36335**	**52238**	**C.** 0.3299601 MHz total
8.0 second time difference; seven 0.26 s intervals separating .9918779 and .9919705						
1.2 HA	58082.99197050	1414.049824 MHz	**12.819 dB**	360460	14389	
1.2 HA	58082.99197050	**1429.461417 MHz**	12.474 dB	14389	4137018	
1.2 HA	58082.99197050	**1429.535342 MHz**	12.186 dB	4137018	**19844**	**A.** Δ 73.3 kHz
Simultaneous Haswell&Green Bank pulse ~1 Hz difference with Haswell Doppler corrected						
1.1 GB	58082.99197050	**1428.671384 MHz**	**13.261 dB**	251301	760778	
1.1 GB	58082.99197050	**1429.454120 MHz**	12.675 dB	760778	210114	
1.1 GB	58082.99197050	**1429.534683 MHz**	**13.920 dB**	210114	**21626**	**A.** Δ 80.5 kHz

Likelihood Function: (receiver squelch function)

A. Meas. noise average frequency difference between adjacent tones = 2.50 MHz; 80.5 kHz / 2.5 MHz = 0.032 ; 73.3kHz /2.5 MHz = 0.029
B. <1.6 kHz / 2.50 MHz = 0.00064 @ 8 tries = 0.005
C. Likelihood of <(36335+52338) = 0.0076

Estimated Pr.(A. AND B. AND C.) = 3.6 x 10^{-8}

Three pairs of Haswell close frequency spaced pulses (MHz) at time of simultaneous Green Bank & Haswell 11/25/2017 pulse event @ 58082.9919705; expect ~ 2.5 MHz spacing

Pr. (A&B&C) =0.0003

1.2 58082.9919705 **1429.461417 MHz** 11.238 2.82 1.657 0.004 12.474 19.16 14389 4137018
3.03915 3.16825 0 2.8751254430467718395996942108 56e+02 19
7.33012649869083310998029656661 9e+124 9 2.0985787164673876924043581168 84e+323228496 3 S **Pr.A= 0.029**

1.2 58082.9919705 **1429.535342 MHz** 11.224 -8.965 0.571 3.05 12.186 17.272 4137018 **19844**
2.89629 2.69951 2.52164 4.7966917233620931791933223399 08e-03 6
1.00480821426510015512280153545 0e+00 31 2.7313833822209080585388105395 40e+00 14 S

1.2 58082.9919705 **1430.617684 MHz** 11.582 -2.303 -1.345 -1.11 12.173 17.051 19844 290539 2.89629 3.03915
0 1.46411509776254787341261842370 5e+019 2.28334259467811082896898873703 4e+069 1.22790101080819012905236378330 2e+991643 5
S

1.2 58082.9919705 **1434.062058 MHz** 11.237 4.155 -9.143 1.912 12.449 17.042 290539 924592
2.4956 2.64559 2.69951 3.1823335249312484726663201842 09e+00 11
2.41029327733076158936809142814 8e+01 6 2.9360990406277570489400128816 33e+10 2 S **Pr.B= 0.084 x2**

1.2 58082.9919705 **1434.27273 MHz** 11.556 6.051 -1.538 -2.675 12.917 17.295 924592 **56552** 2.69951
2.6645 2.64559 6.1164275702147541834668697111 81e-02 27 1.0630735369953847338319670099 90e+00
11 2.8952560045029402479261269429 76e+00 3 S

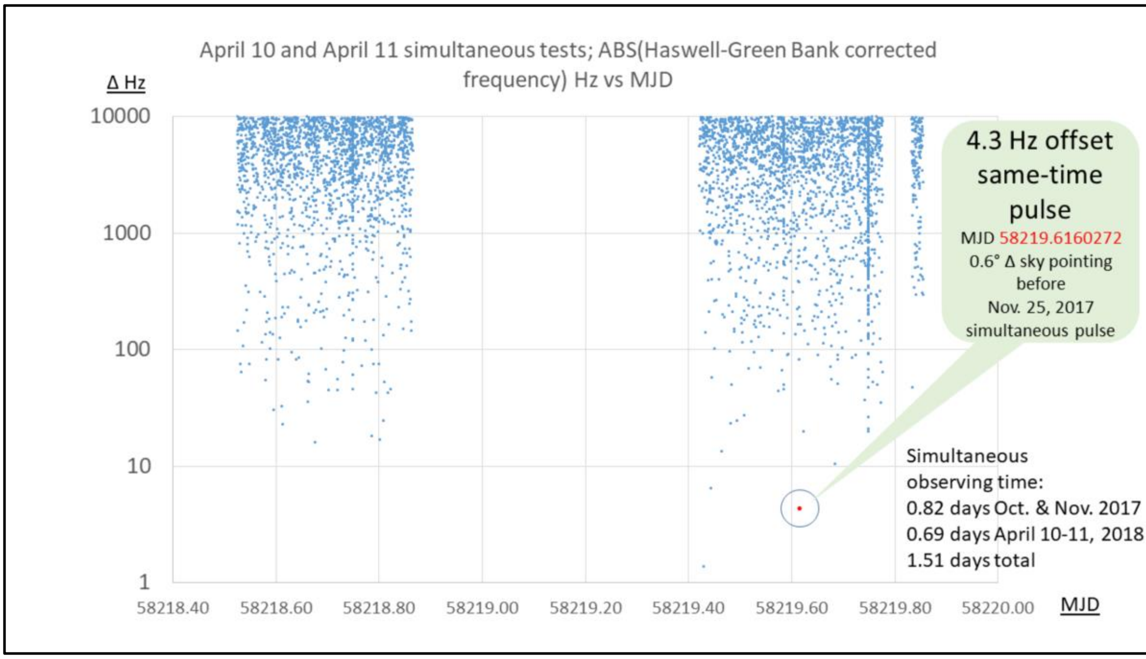
1.2 58082.9919705 **1439.466836 MHz** 12.093 -19.73 1.911 -0.514 12.706 17.466 56552 1394282 2.89629 2.84237
0 2.46548663177252793888810298486 3e+0117 5.09885185433663172328525491703 5e+103 2.09857871646738769240435811688 4e+323228496 3
S

1.2 58082.9919 RF |**1440.219452 MHz** 18.374 17.343 16.86 18.83 23.943 26.471 143126 58903 2.54952 2.89629 2.95021
4.11546469544317594287550829339 2e-0110 1.50914983568418743556650712945 1e+004 4.52288396477593833338103163969 9e+008 S

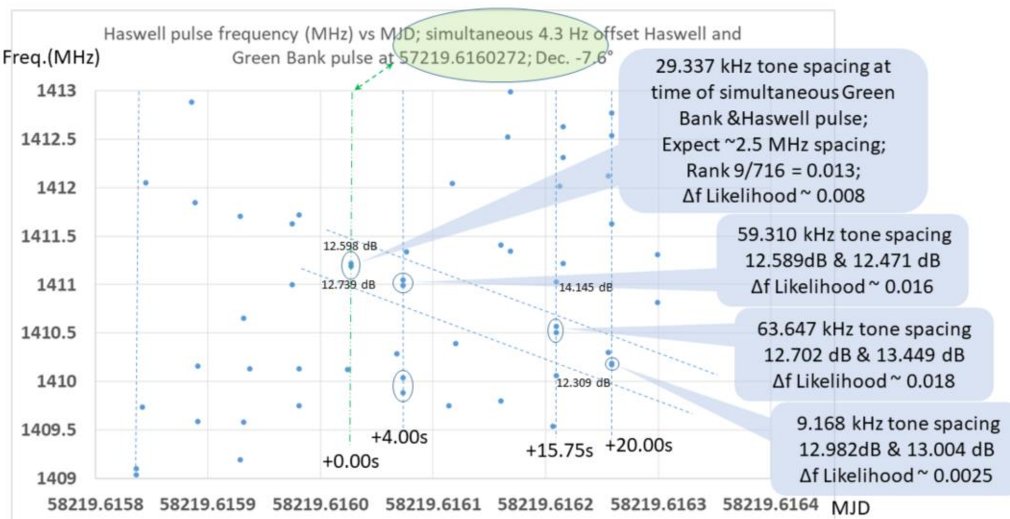
1.2 58082.9919705 **1441.339032 MHz** 12.238 -2.56 1.098 -4.519 12.773 26.473 58903 300535
2.30596 2.75343 2.73967 5.1022019251990560752423475884 08e+00 8
1.64383469190816657807505315305 7e+02 9 2.4594250134135919789853763474 36e+71 4 S **Pr.C= 0.030 x2**

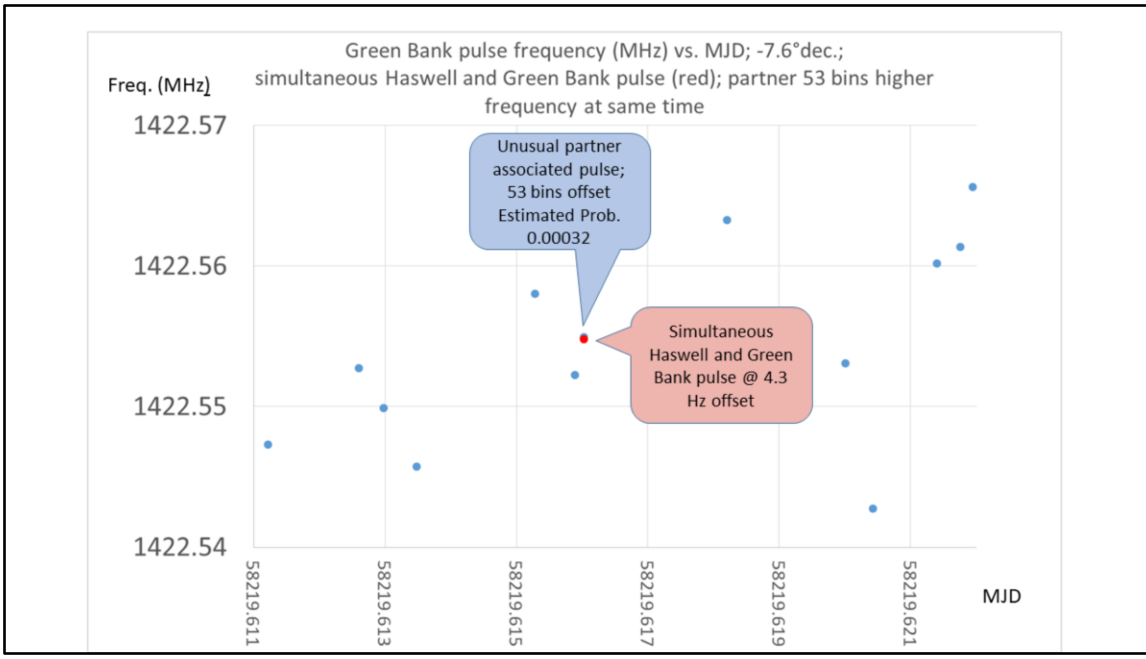
1.2 58082.9919705 **1441.414321 MHz** 11.542 -3.914 -4.162 1.319 12.15 24.522 300535 **20210**
2.46772 2.69951 2.89629 6.7246743307767814064917563678 11e-02 23
1.06955935223110616705565032712 4e+00 4 2.9140951275035676802638188336 28e+00 2 S

April 11, 2018 simultaneous Green Bank & Haswell close frequency pulse

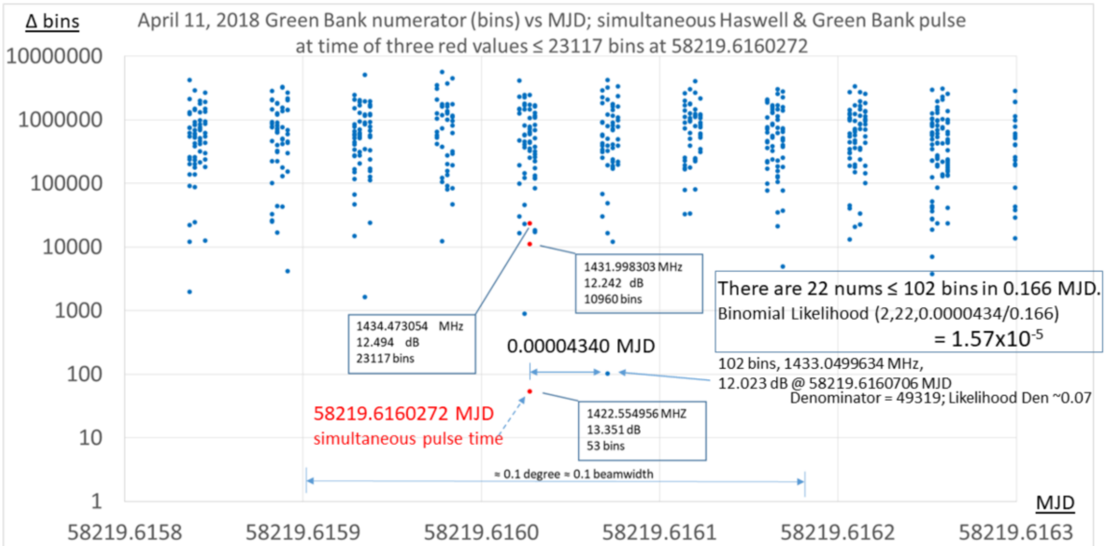

April 10 and April 11 simultaneous tests; ABS(Haswell-Green Bank corrected frequency) Hz vs MJD
Δ Hz
10000
1000
100
10
1
58218.40
58218.60
58218.80
58219.00
58219.20
58219.40
58219.60
58219.80
58220.00
MJD
4.3 Hz offset same-time pulse
MJD 58219.6160272
0.6° Δ sky pointing before
Nov. 25, 2017 simultaneous pulse
Simultaneous observing time:
0.82 days Oct. & Nov. 2017
0.69 days April 10-11, 2018
1.51 days total

Haswell close-frequency spaced pulses at & near time of simultaneous April 11, 2018 Haswell & Green Bank pulse




Green Bank pulse frequency (MHz) vs. MJD; -7.6°dec.;
simultaneous Haswell and Green Bank pulse (red); partner 53 bins higher frequency at same time
Freq. (MHz)
1422.57
1422.56
1422.55
1422.54
Unusual partner associated pulse; 53 bins offset Estimated Prob. 0.00032
Simultaneous Haswell and Green Bank pulse @ 4.3 Hz offset
58219.611
58219.613
58219.615
58219.617
58219.619
58219.621
MJD

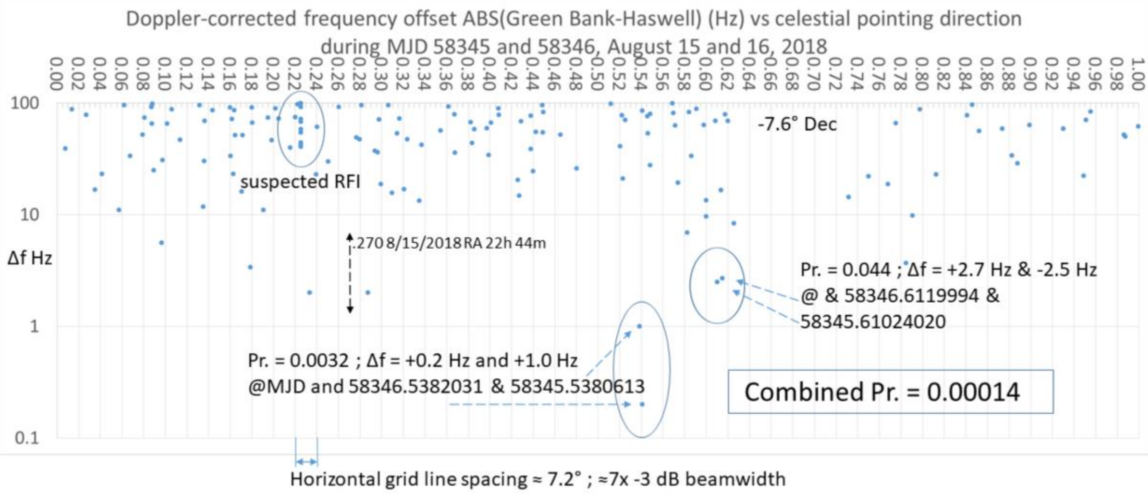
Other Green Bank closely spaced pulses at or near time of simultaneous Haswell and Green Bank pulse?

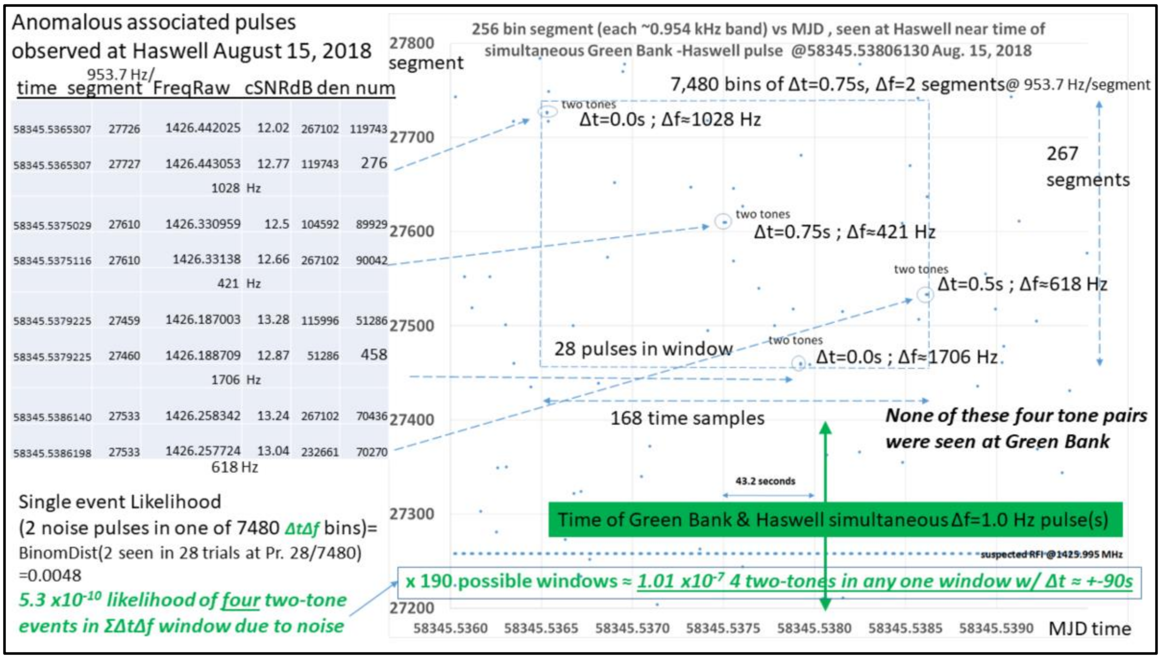


August 15 and 16, 2018
simultaneous Haswell and Green Bank pulses
amd associated pulses

August 15 and 16, 2018 simultaneous Haswell and Green Bank observations

Search for simultaneous anomalous pulses with RFI excision, close to the time of these simultaneous pulses.



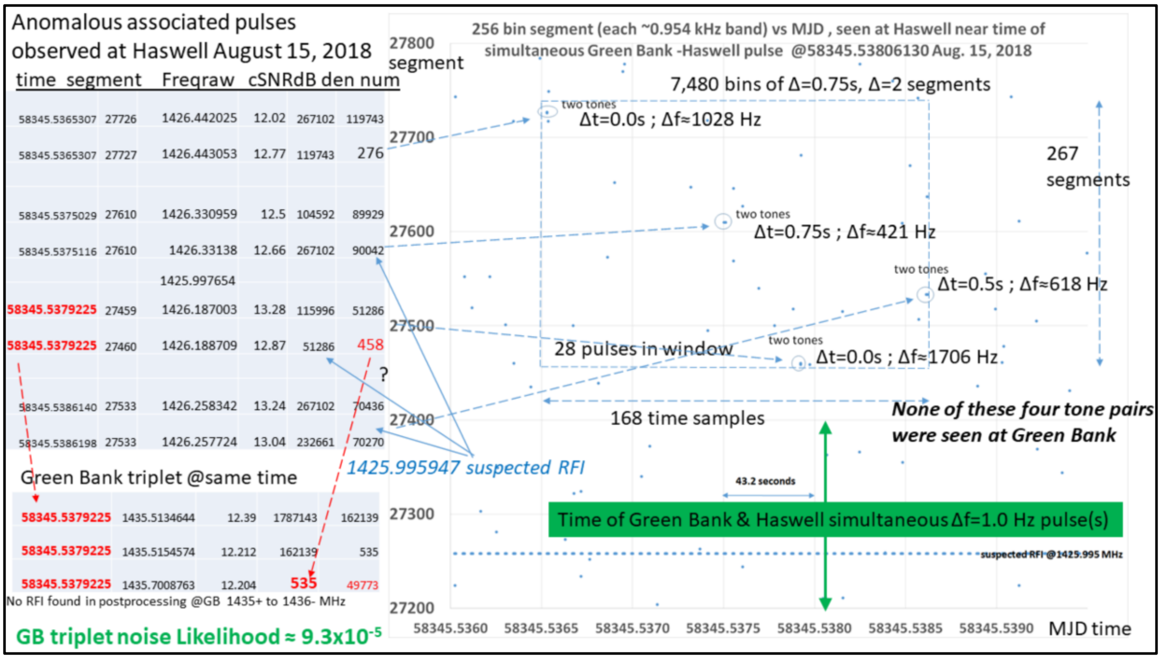


One glaring very difficult problem is raised in the data and diagram in ***Anomalous associated pulses observed at Haswell August 15, 2018***.

It seems difficult to explain why the time-frequency window's event, comprising four close-frequency tone pairs, a calculated 5.3×10^{-10} noise-likelihood event, should be captured at Haswell within -140 s and +50 s of a simultaneous same FFT bin, 1.0 Hz offset frequency pulse, Doppler-corrected, observed in the same 0.26 s interval at Haswell and Green Bank. The Doppler-corrected one FFT bin overlap of a simultaneous Haswell and Green Bank pulse is expected to result from a source distance four times the Earth-Moon distance. If the signal's source is human RFI, it seems that the RFI source needs to be quite distant.

If the suspected RFI source transmits common signals to Green Bank and Haswell, then it would seem likely that some of the anomalous associated tones seen at Haswell should appear at Green Bank. However, none of the eight signals of the four two tone pairs exceeded the SNR threshold at Green Bank. There is a possibility that the suspected signal source has a design that results in one pulsed signal appearing at both sites, and many pulsed signals not appearing at both sites. This possibility leads to the idea that the transmitter uses an antenna with multiple beams in its pattern.

The Haswell and Green Bank computers running the FFTs do not communicate with each other, and are not connected to the Internet. Standalone computers, connected to the Green Bank Forty Foot Telescope and Haswell Sixty Foot Telescope, observe the same location in the sky, have local oscillators and have ADC trigger time synchronized by GPS satellites, yet the systems otherwise measure telescope signals separately. However, the system behavior appears to be unusually correlated between Green Bank and Haswell. To make the problem more inexplicable, in the same sky pointing direction, a simultaneous Green Bank&Haswell pulse 0.2 Hz offset from each other, occurred the next day, shown in the plot of August 15 and 16 pulses on the previous slide. The problem appearing in these slides, and other observed anomalies, lead to the hypothesis stated below in ***Conclusion from pre-hypothesis observations***.



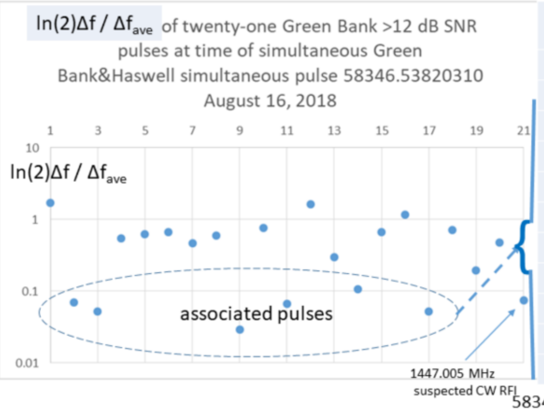
At the time 58345.5379225, a triplet was captured at Haswell having three tones spaced by 51,286 and 458 bins, from 1425.997654 to 1426.188709. These are raw data, not Doppler corrected frequencies. The noise likelihood of this and the other three close spaced tones is described on the previous slide. The driving interest in these two tones is that the tones' capture time was within the pointing beamwidth of a simultaneous Green Bank Haswell pulse at a Doppler corrected Green Bank to Haswell measured frequency difference of 1.0 Hz.

Upon examining the Green Bank file, a close-tone-spaced triplet was found to occur at the same time, i.e. 58345.5379225. Statistical analysis indicates that the likelihood of seeing this Green Bank triplet in the presence of only noise is 9.3×10^{-5} .

There was suspected RFI observed at Haswell at 1425.995947 MHz. No RFI was seen at Green Bank between 1435 and 1436 MHz. There is a possibility that the first tone in the Haswell triplet, at 1425.997654 MHz, is due to the suspected RFI approximately 2 kHz lower in frequency. The other two tones in the Haswell triplet do not correlate with known or suspected RFI.

The existence of the two triplets further seem to correlate Haswell and Green Bank measurements, countering attempts to falsify the working hypothesis.

Normalized Noise-Likelihood calculations of Green Bank associated pulses observed **at the same 0.25 s interval time**, 58346.5382031 MJD, i.e. the time of the **August 16, 2018 Green Bank & Haswell Δf=0.2 Hz simultaneous pulse**



MJD IRIG	Frequency MHz	>12dB SNR dB		Δf FFT bins	$\ln(2)\Delta f/\Delta f_{50}$
58346.53820310	1407.4044988	12.16		1987630	1.564402
58346.53820310	1407.7067725	12.183	1	**81141**	**0.063864**
58346.53820310	1407.9347268	12.854	2	**61191**	**0.048162**
58346.53820310	1420.4539560	13.213		690637	0.543579
58346.53820310	1420.5810294	12.674	3	**34111**	**0.026848**
58346.53820310	1423.8617770	12.038		Δf_{50} =880669	0.693147
58346.53820310	1424.1481364	12.278	4	**76869**	**0.060501**
58346.53820310	1432.5168036	12.361		343015	0.269976
58346.53820310	1432.9764746	12.651	5	**123392**	**0.097118**
58346.53820310	1440.8468805	12.045		1339655	1.054401
58346.53820310	1441.0708897	12.265	6	**60132**	**0.047328**
58346.53820310	**1447.3290980**	12.495		86917	***simult. 8/16/2018***

$$(\mathrm{Product}_{i=1..6} \text{ of } (\ln(2)\Delta f_i/\Delta f_{50})) / 0.5^6 = \boxed{1.47\text{x } 10^{-6}}$$

August 15, 2018 simultaneous pulse @GB: **1440.928669** MHz **7.542**dB **11.325**dB **3.027**dB -10.342dB **13.293dB composite**
-1 0 +1 +2 sample time intervals

In the 0.25 s interval time of the 0.2 Hz offset simultaneous Green Bank and Haswell pulse(s), a high rate of doublets and triplets were observed at Green Bank.
The median Δf in likelihood calculations was obtained from the frequency offsets thought to be due to noise. The average Δf during the four hour run was used in the plot above, after suspected RFI was excised. Almost all of the RFI that was excised in post-processing were suspected RFI tones close in frequency to a subset of harmonics of 1 MHz. The table above lists tones that are thought to comprise the doublets and triplets for which likelihood calculations have been performed.

Haswell doublet and triplet in August 16, 2018 Δf = 2.7 Hz simultaneous pulses

Noise likelihood ≈ 0.000398 = Binom.dist(1 in 9 trials @ 0.0036) * 0.0417 * 0.1531 * 2 combinations

time MJD	frequency MHz	t-2 SNR dB	t-1 SNR dB	SNR dB	t+1 sNR dB	comp. SNR dB	denom. bins	num. bins	**Pr. = ln(2) Δf/Δf$_{50}$**
58346.61199940	1407.80719150	2.395	3.438	11.257	-3.249	12.498	1880533	215194	0.4531
58346.61199940	1407.81349840	0.51	-2.982	11.482	-1.977	12.13	215194	**1693**	**0.0036**
58346.61199940	1409.83315330	-3.362	6.469	11.332	4.528	**13.289**	1693	542147	1.1416
58346.61199940	1411.45493240	-7.382	-3.789	12.534	-0.44	12.884	542147	435343	0.9167
58346.61199940	1419.76942640	3.468	1.3	11.895	-4.385	12.88	1073232	476058	1.0025
58346.61199940	1436.13574800	-0.326	-8.894	11.222	2.754	12.093	1073726	303503	0.6391
58346.61199940	1436.40655060	-4.564	6.034	11.423	2.756	**13.038**	303503	**72693**	**0.1531**
58346.61199940	1436.48034860	3.032	-11.591	12.323	0.835	**13.089**	72693	**19810**	**0.0417**
58346.61199940	1442.14771460	-2.098	1.874	11.486	-9.713	12.133	19810	1521322	3.2035
58346.61199940	1445.09125280	-3.125	4.204	11.258	1.347	12.515	1521322	790150	1.6639
58346.61199940	1447.40744830	6.028	-6.921	11.254	-6.148	12.504	513699	108050	0.2275

Green Bank	58346.61199940	58083.33375170	0.00450	1.62 ° RA	12.606	1328642	2.7
Haswell	58346.61199940	58083.33375170			**13.038**	72693	2.7
Green Bank	58345.78468750	58083.50417475			12.225	166709	3.7
Haswell	58345.78468750	58083.50417475			**13.096**	1046784	3.7

center tone of Haswell triplet is simultaneous 2.7 Hz off at Green Bank

November 25-August 16 summary of simultaneous pulses

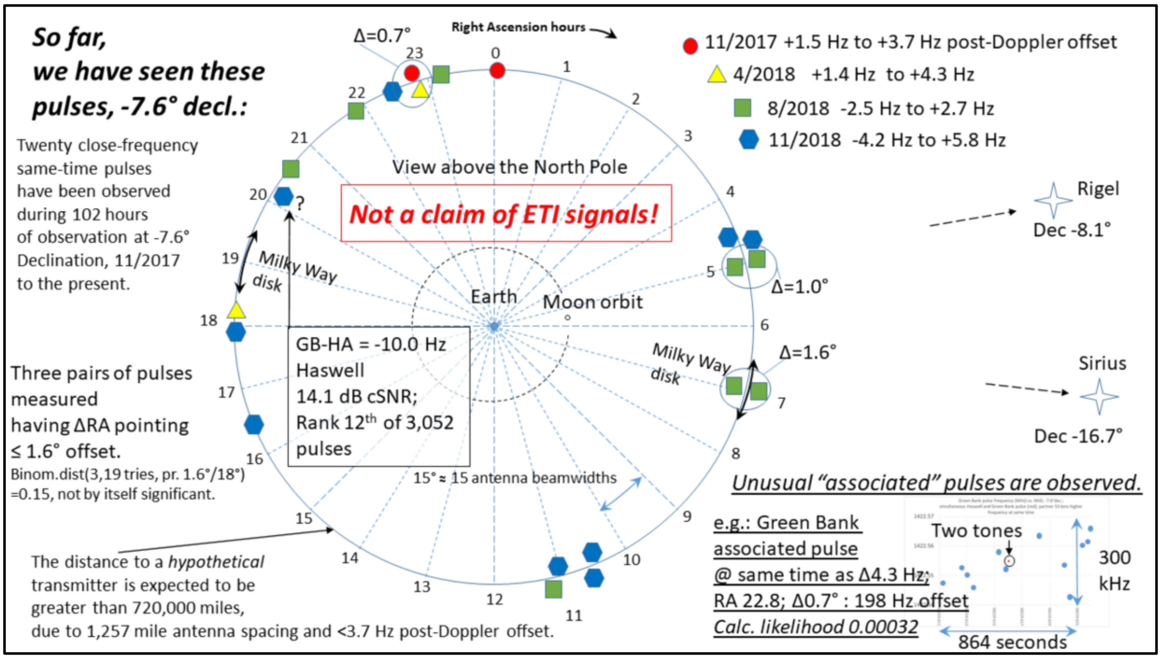
Radio Telescope Location	Recorded IRIG MJD	IRIG Ref. to 58082.9919705	MJD time diff.	RA Angle Diff.	Likelihood simulated	SNR/bin /s	Num bins	Δf Hz
November 25 & 26, 2017								
Green Bank	58082.99197050	58082.99197050		**0 ref ° RA**		**13.92**	21626	1.5
Haswell	58082.99197050	58082.99197050				12.186	19844	1.5
Green Bank	58083.04392	58082.04406584				12.516	673691	3.7
Haswell	58083.04392	58082.04406584				12.449	1879417	3.7
April 10 & 11, 2018								
Green Bank	58219.42857350	58082.80211656				**13.003**	547800	1.4
Haswell	58219.42857350	58082.80211656	1st try to match .99197050			12.716	650423	1.4
Green Bank	58219.61602720	58082.99008348	-0.00189	**-0.68 ° RA**	**1 in 93+-4 trials**	12.469	1715899	4.3
Haswell	58219.61602720	58082.99008348	2nd try to match .9919705		to match any RA twice in April 11 range	12.941	1104425	4.3
August 15 & 16, 2018					91+-3 when 2-attempt match to 0.99197050			
Green Bank	58345.17852430	58082.89635196				12.352	40796	-3.4
Haswell	58345.17852430	58082.89635196				**13.116**	215602	-3.4
Green Bank	58345.61024020	58083.32924984		0 ref ° RA		12.305	573351	-2.5
Haswell	58345.61024020	58083.32924984				12.001	183726	-2.5
Green Bank	58346.23070310	58082.95141147				12.312	781038	-2.0
Haswell	58346.23070310	58082.95141147				12.239	1145777	-2.0
Green Bank	58345.28731770	58083.00544322				12.245	80565	-2.0
Haswell	58345.28731770	58083.00544322				12.425	56068	-2.0
Green Bank	58346.53820310	**58083.25975336**		**0 ref ° RA**		12.495	86917	0.2
Haswell	58346.53820310	**58083.25975336**				12.335	87197	0.2
Green Bank	58345.53806130	**58083.25687332**	-0.00288	**-1.04 ° RA**	**1 in 107+-5 trials**	**13.293**	2131096	1.0
Haswell	58345.53806130	**58083.25687332**				12.75	340430	1.0
Green Bank	58346.61199940	58083.33375170	0.00450	1.62 ° RA		12.606	1328642	2.7
Haswell	58346.61199940	58083.33375170				**13.038**	72693	2.7
Green Bank	58345.78468750	58083.50417475				12.225	166709	3.7
Haswell	58345.78468750	58083.50417475				**13.096**	1046784	3.7

9,951 11/25-8/16 simulated trials required

HIP 24472 73 ly red dwarf 0.3° offset

In ***November 25-August 16 summary of simultaneous pulses***, the post-processing results are summarized to post the apparent received signals that matched at Green Bank and Haswell. Three sky pointing directions each have a pair of simultaneous pulses, at 0.68, -1.04 and 1.62 degree difference in pointing Right Ascension between the repetitions. Frequency offset ranges from -4.3 Hz to +2.7 Hz. The 1.62 degree RA pointing difference is significantly outside the approximate 1.0 degree antenna beamwdiths, and is not considered as significant as the other two repetitions of simultaneous pulses.

Summary of simultaneous pulses observed, including October-November 2018 observations


So far,
we have seen these pulses, -7.6° decl.:
Twenty close-frequency same-time pulses have been observed during 102 hours of observation at -7.6° Declination, 11/2017 to the present.
Three pairs of pulses measured having ΔRA pointing ≤ 1.6° offset.
Binom.dist(3,19 tries, pr. 1.6°/18°) =0.15, not by itself significant.
The distance to a *hypothetical* transmitter is expected to be greater than 720,000 miles, due to 1,257 mile antenna spacing and <3.7 Hz post-Doppler offset.
Right Ascension hours
Δ=0.7°
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
?
View above the North Pole
Not a claim of ETI signals!
Milky Way disk
Earth
Moon orbit
GB-HA = -10.0 Hz
Haswell
14.1 dB cSNR;
Rank 12th of 3,052 pulses
15° ≈ 15 antenna beamwidths
Δ=1.0°
Δ=1.6°
Milky Way disk
11/2017 +1.5 Hz to +3.7 Hz post-Doppler offset
4/2018 +1.4 Hz to +4.3 Hz
8/2018 -2.5 Hz to +2.7 Hz
11/2018 -4.2 Hz to +5.8 Hz
Rigel
Dec -8.1°
Sirius
Dec -16.7°
Unusual "associated" pulses are observed.
e.g.: Green Bank associated pulse @ same time as Δ4.3 Hz; RA 22.8; Δ0.7° : 198 Hz offset
Calc. likelihood 0.00032
Two tones
300 kHz
864 seconds

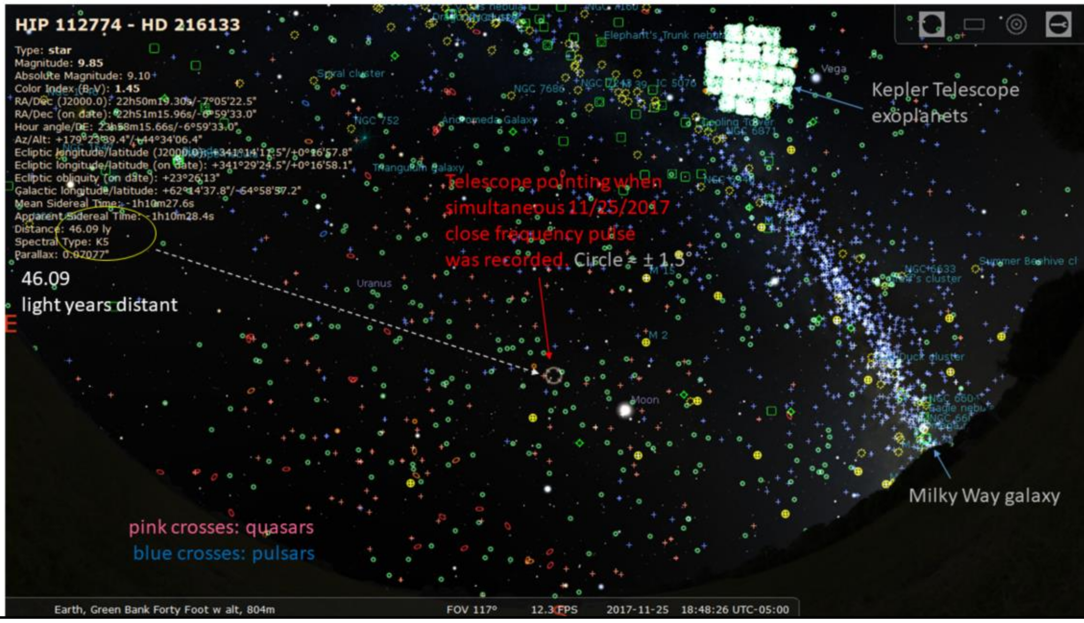
Center beam antenna pointing at times
of the Green Bank & Haswell 11/25/2017, 4/11/2018 simultaneous pulses and June 7-9 Green Bank pulses

date	MJD	RA hr	RA min	RA s (J2000)
6/9/2018	58278.45422	22	44	50
4/11/2018	58219.61603	22	45	53
6/7/2018	58276.46042	22	45	55
6/8/2018	58277.45839	22	46	54
11/25/2017	58082.99197	22	48	37

Δ = 63 RA seconds
Δ = 2 RA seconds
Δ = 59 RA seconds
Δ = 103 RA seconds
Σ = 227 RA seconds

Green Bank Forty Foot -3 dB beamwidth @ -7.6° Dec. ≈ 266 RA seconds

Green Bank Observatory sky view November 25, 2017 at time of simultaneous Haswell - Green Bank pulse



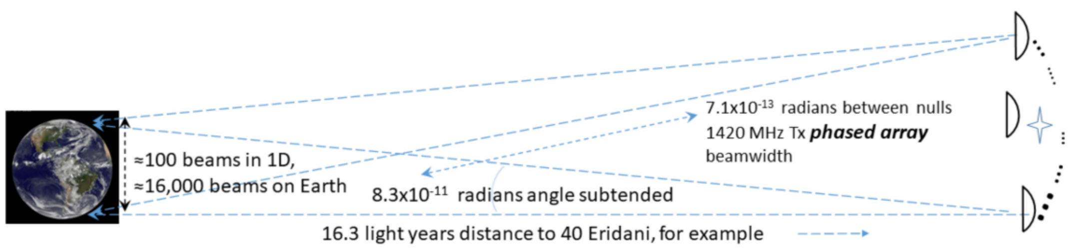
Unexpected observations compel a hypothesis, leading to an experiment to ***falsify, not "prove".***

Summary of hypothesis:

Anomalous ***telescope-to-telescope similar*** "simultaneous" pulses are predicted.

Anomalous ***telescope-to-telescope different*** "associated" pulses are predicted.

Idea: ETI may transmit certain types of high capacity signals to Earth ***to compel human cooperation and readily indicate transmission motive.***



Conclusion from pre-hypothesis observations

The observed anomalies compel a hypothesis with tests.

Working Hypothesis:

1. Close-time (+- 0.1s) close-frequency (+-5 Hz) 1404-1445 MHz narrowband (<5 Hz) pulses are predicted to be observed at distant-separated (>1000 km) radio telescope sites.
2. Anomalous pulses, associated with pulses 1., are predicted to be observed close in frequency to each other, and close in time (+-200 s) to the observation of the simultaneous close frequency pulses 1.
3. The simultaneous pulses 1., and associated pulses 2., are predicted to be observed at an indication rate at least two orders of magnitude higher than the rate due to the likelihood of pulses caused by known noise processes.
4. The simultaneous pulses 1. are predicted to have multi-site measurement attributes explained by a distant (>10^6 km) source.
5. The associated pulses 2. are predicted to have multi-site measurement attributes explained by a distant (> 10 ly) large (>1 AU) phased array.
6. The pulses are predicted to be observed to repeat when pointing in fixed (+- 1 degree RA Dec.) celestial pointing directions.

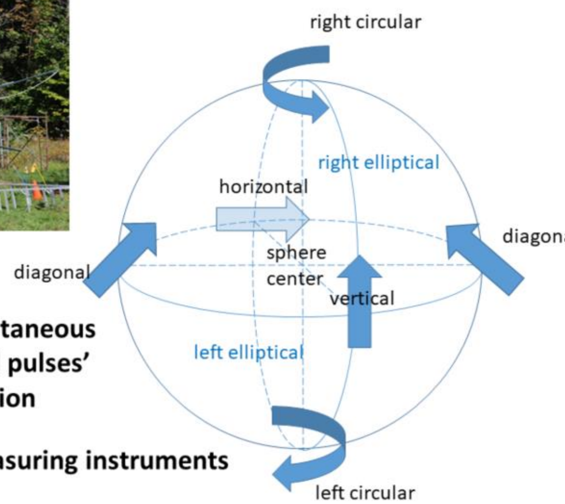
Known alternate hypotheses: Noise sources, natural objects, terrestrial RFI and reflections, clandestine satellites, equipment characteristics, calculation errors, hoaxes.

SETI simultaneous telescope improvements underway

<u>More telescopes:</u>
A third simultaneous telescope under construction in New Hampshire

<u>More pixels per antenna</u>

Measure simultaneous and associated pulses' wave polarization



<u>More computers</u>, faster computers, better measuring instruments

Plans for system improvement

- Add computer communication between sites? *Risk: corrupting data*
  - Store raw data at both sites if SNR threshold is simultaneously crossed in Doppler corrected frequency window and/or close tones seen – increases post-trigger sensitivity by ~10x.
- Follow up HIP 112774 and 40 Eridani with low Δf & low SNR squelch algorithms
- Verify Doppler calculations
- Post-process raw data to search at lower SNR; cross-correlate; measure time delay
- Calculate likelihoods using apriori and aposteriori scenarios
- Non-contiguous triplet search
- Long term unattended simultaneous searches
- Adjust declination during observation to “hop” to nearby stars
- Telescope metrology, pointing accuracy, beamwidth, sensitivity
- Polarization measurements and Poincare Sphere search
- Two sites: ~one same-T same-f per day ➔ **Three sites ≈10^6 days @ 12 dB threshold**
  - **Third site plan: ~continuously observing, eight meter paraboloid antenna under construction in NH**

Thank you (It is difficult to acknowledge all who helped me and gave me advice)

Steve Plock, Ed Corn, Rich Russel, Pasha Roberts, Paul Berge, Glenn Davis
Adam Beardsley of ASU, Richard Prestage of GBO,
Jay Lockman of GBO, Ron Maddalena of GBO, Ken Kellerman of NRAO, Duncan Lorimer of WVU,
Scott Ransom of UVA and NRAO, Dan Reichart of UNC, Sandy Weinreb of Caltech,
Jon Richards of SETI Institute, Jill Tarter of SETI Institute, Robert Gray,
and many other very helpful friends.
Online Arbitrary Precision Calculator :Thanks Mikko Tommila
Equipment vendors and SW and HW engineers
Thanks to folks of Green Bank Observatory, Breakthrough Listen,
Berkeley SETI Research Center, SETI Institute, Deep Space Exploration Society
and Society of Amateur Radio Astronomers folks, hams, friends and family.

Thank you for listening and your advice during preparation of ideas.

Reference: "Getting Ready for SETI", SARA Journal, December 2017

Thank You!
Questions?

Other topics, further detail, artifacts

8.2 meter diameter paraboloid, on Az-El mount, under construction in New Hampshire

Dual polarized
five pixels
Az-El mount

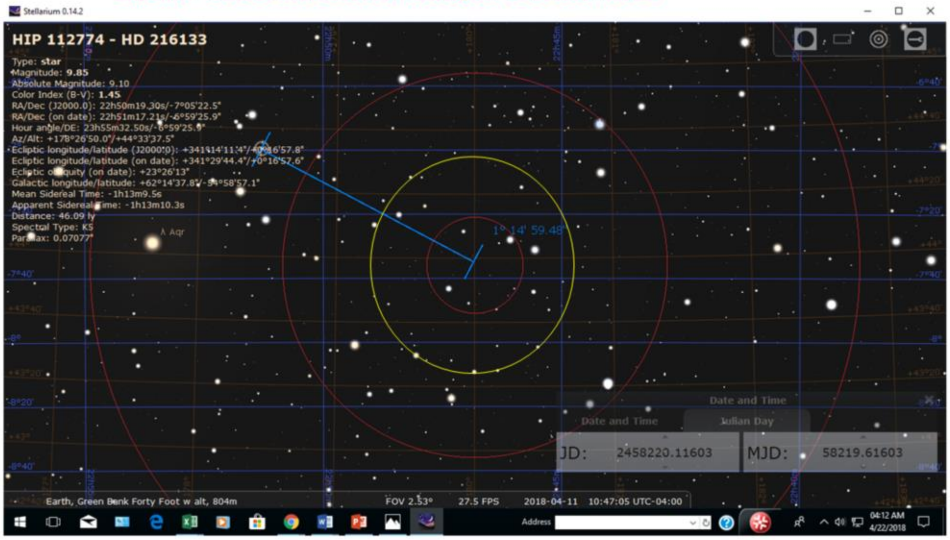
Where were the telescopes pointing
when the simultaneous pulse occurred?

Are there nearby stars or objects in the direction?
(< 100ly)

Green Bank field of view of HIP 112774 at the time of the simultaneous pulse; response -5.75 dB with Gaussian 1.1 degree -3 dB beamwidth

Green Bank field of view of HIP 112774 at the time of the April 11, 2018 simultaneous pulse;

response -15.8 dB with Gaussian 1.1 degree -3 dB beamwidth



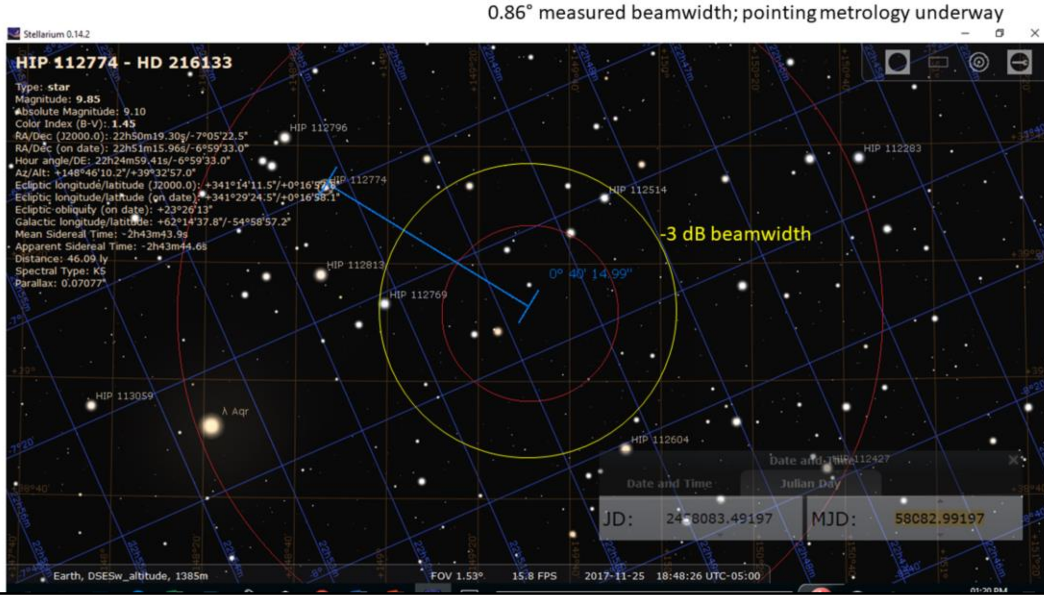
April 11, 2018 Green Bank sky view at time of simultaneous 4.3 Hz offset pulse

Green Bank HIP 112774 on Stellarium during closest MJD 58082 transit;
GBO Forty Foot pointing is 36 arc minutes south ~½ FHPBw
HIP 112774 is the 805th closest star of 119,615 stars in HYGv3 database.

GBO 40 Foot has ≈18,000 1.5° non-overlapping pointing directions

Haswell DSES field of view at 58082.99197; at occurrence of simultaneous ~1 Hz offset pulse

0.86° measured beamwidth; pointing metrology underway



June 7-9 , 2018 Green Bank 40 Foot standalone close frequency pulses

Green Bank

April 11, 2018 (simultaneous w/ Haswell)

58219.6160272 MJD

1422.554759 MHz

12.021 dB

Δf = 1.0692 kHz

Green Bank

June 7, 2018 (GB 40 Foot standalone)

58276.4604225 MJD

1422.5536898 MHz

12.571 dB

June 7, 2018 Green Bank low Δf pulses, at same time as June 7, 2018 1422.5536898 MHz pulse

MJD	Frequency	composite 1s SNR	Den(Δbins)	Num(Δbins)	Num+Den(Δbins)	Likelihood≈ ln(2)*Num.(Δbins) /549485
58276.46042250	**1413.5711245** MHz	**13.863 dB**				
58276.46042250	**1413.7422457** MHz	12.799 dB	958612	45935	1004547	**0.058**
58276.46042250	**1413.7898698** MHz	12.229 dB	45935	12784	58719	**0.016**
58276.46042250	**1413.8526000** MHz	12.048 dB	12784	16839	29623	**0.021**
58276.46042250	**1413.9137693** MHz	12.763 dB	16839	16420	33259	**0.021**
58276.46042250	**1414.0745975** MHz	12.072 dB	16420	43172	59592	**0.054**

Product of Likelihoods = 2.2 x 10^{-8}

Green Bank
April 11, 2018 (simultaneous w/ Haswell)
58219.6160272 MJD
1422.554759 MHz
12.021 dB

Δf = 22.82 kHz →

Green Bank
June 8, 2018 (GB 40 Foot standalone)
58277.4583912 MJD
1422.577580 MHz
12.065 dB

June 8, 2018 Green Bank low Δf pulses, *0.75 s before* June 8, 2018 1422.57758 MHz pulse

MJD	Frequency	composite 1s SNR	Den (Δbins)	Num (Δbins)	Num+Den(Δbins)	Likelihood ≈ **ln(2)*Num. (Δ bins) /479423**
58277.45838250	**1444.2654788** MHz	12.168 dB				
58277.45838250	**1444.6393527** MHz	12.695 dB	349050	100361	449411	**0.145**
58277.45838250	**1444.6530879** MHz	**13.556 dB**	100361	3687	104048	**0.005**
58277.45838250	**1444.7444357** MHz	12.004 dB	3687	24521	28208	**0.035**
58277.45838250	**1444.7740406** MHz	12.426 dB	24521	7947	32468	**0.011**
58277.45838250	**1444.8213480** MHz	**13.079 dB**	7947	12699	20646	**0.018**
58277.45838250	**1444.9525341** MHz	12.736 dB	12699	35215	47914	**0.050**

Product of Likelihoods = 1.7×10^{-9}

June 9, 2018 Green Bank observations

MJD	Frequency (MHz)	1s Composite SNR(dB)	Den (Δbins)	Num (Δbins)		Likelihood ≈ ln(2)*Num. (Δ bins) /507447
58278.45421590	1411.2440325	12.127 dB	1558035	1460262		
58278.45421590	1411.2445056	12.437 dB	1460262	**127 bins**	**rank 10/64376 = 0.00016**	**0.00017**
58278.45421590	1411.2869218	12.596 dB	127	**11386 bins**	**rank 974/64376 = 0.015**	**0.016**
58278.45421590	**1429.8427790**	12.228	1601523	1239291		

Product of Likelihoods = 2.7×10^{-6}

Δf = 23.455 kHz ; expect ≈ 2.5 MHz

November 25, 2017 Green Bank partner pulse; Δf=1590.7 Hz; Δt=8.0s from Green Bank & Haswell simultaneous pulse

58082.99187790	1429.536273	12.739 dB
58082.99187790	1429.671632	12.304 dB
58082.99187790	**1429.866234**	12.221 dB

What was telescope pointing
during the simultaneous November 25, 2017, April 11, 2018 and June 7-9 events?

File records of the April 11, 2018 simultaneous pulse

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Green Bank 3.1 58219.61847 **58219.6160272** -52.81719 23650 6054497 **1422.554759 MHz** -53.45 -12.056 -22.148

12.021 dB = 0.26 second SNR **2.204 dB**

12.469 dB=one second composite **17.199 dB**=three tone triplet composite 431036 1715899 2.69951 2.37878 3.11432

ratio = 3.980871667331730992306907079687e+00 <**no 4 5 digits**

2 5.3**563**70361505369432941860001498e+01 16 1.8298728**365**05673582862742297708e+23 4 S **0.0000043 MHz**

ratio = 3.98087166733173099230690707968707950148015478985513970990822112306164682300318302879573863899999072

$\Pr(digits\ a, b\ \in \{0,1..9\}\ \notin \{\ 34\ digits\ of\ ratio\}\ ) = 0.0228$

Haswell 3.2 58219.61732 **58219.6160272** -69.19056 23651 6054673 **1422.555415 MHz** -69.09 -1.73 -0.252

11.315 dB 6.563 dB

12.941 dB=one second composite **17.378 dB**=three tone triplet composite 1938800 1104425 2.64559 2.75343 2.69951

ratio = 5.696435939756550443573344336703e-01 <**no 1 2 8**

digits 4 1.767636942697898176067335706809e+00 8 5.856996577113111722342559352924e+00 5 S **0.0000043 MHz**

ratio = 5.696435939756550443573344336703115329069527542809985558077161130596245100061893955023726016092428306e-1

$\Pr(digits\ a, b, c\ \in \{0,1..9\}\ \notin \{\ 31\ digits\ of\ ratio\}\ ) = 0.00189$

Signal to Noise Ratio approximately 16

Approximately 12 dB