Three-telescope synchronized narrow bandwidth pulse observations

Report of Observations: December 2019

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Introduction

Background: August 2019 system and observation report [Ref. 1]

Radio Frequency Interference (RFI) is a confounding problem in radio SETI, as false positives are introduced into receiver signals. Various methods exist to attempt to excise suspected RFI, with a possibility that true positives are rejected, and that un-excised RFI remain as false positives. Uncertain far side-lobe antenna patterns add to the uncertainty. To ameliorate the RFI problem, a system having geographically-spaced simultaneous and synchronized pulse reception has been implemented. A radio telescope at the Green Bank Observatory in Green Bank, West Virginia has been combined with a radio telescope of the Deep Space Exploration Society, near Haswell, Colorado to implement a spatial filter having a thrice-Moon-distance transmitter rejection. Approximately 135 hours of simultaneous synchronized pulse observations have been captured from November 2017 through February 2019 and another 45 hours captured in April 2019. The observations are described in a paper presented August 4, 2019 at the annual conference of the Society of Amateur Radio Astronomers at the Green Bank Observatory. [Ref 1] This paper describes the problem, observation system, observed results and proposed hypotheses to be subjected to attempts at refutation and relative inference, through further experimentation, and RFI and ETI transmitter signal model development. The August 2019 paper describes anomalous simultaneous pulses observed in the pointing direction near HIP 24472, near 5.2 hours RA and -7.6° declination.

February 2020 update
The report contained in this present paper describes additional observations, made in December 2019, using a three-telescope synchronized telescope system. The third telescope is a 26 foot diameter parabolic dish antenna in New Hampshire. A GPS receiver is used to synchronize New Hampshire frequency and acquisition time to those of the telescopes in Green Bank and Haswell.

Paper organization
The purpose of this paper is to report post processed results of the December 2019 observations.

This paper is organized as follows. Figure 1 and text describe the system and reference to previous observations [Ref. 1]. Figure 2 and text is an overview of the simultaneous pulses recorded in the December 2019 observations, at all Right Ascension values. Figure 3 and text describe calculations to estimate the likelihood of the December 2019 observed anomalous events, given a noise hypothesis and prior 5.2 hours RA direction of interest. Figure 4 and text describe methods and estimates of multiple telescope system pointing direction calibration. Figure 5 and text describe further observation details and other anomalies in six simultaneous pulses observed in December 2019. Conclusions and further work are proposed.

Geographically-spaced Synchronized Signal Detection System

Transit scan observations at -7.6° declination using overlapping antenna beams

Time and frequency are synchronized using GPS.
Receivers: 1395-1455 MHz; 3.7 Hz Δf channels

New Hampshire 26 foot

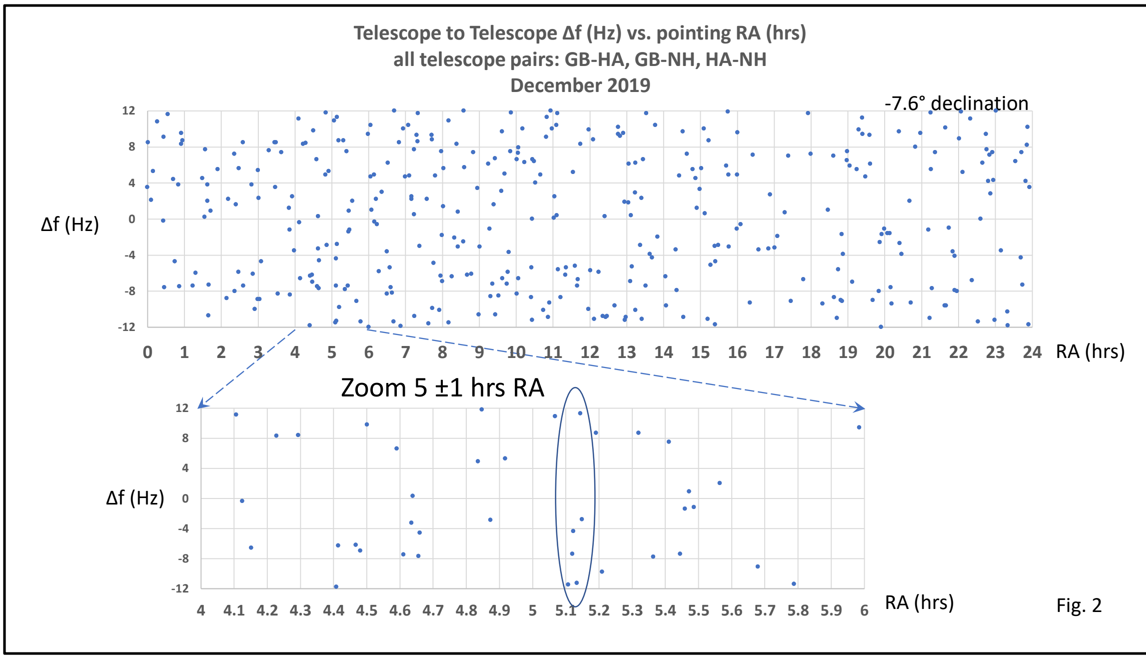
Haswell, Colorado 60 foot

Green Bank, West Virginia 40 foot

Fig. 1

Geographically-spaced Synchronized Signal Detection System (Fig. 1)
The synchronized telescope system currently comprises three telescopes. The New Hampshire telescope has orthogonal circular polarization receivers, Haswell has one circular polarization receiver, Green Bank has one linear polarized receiver. The telescopes operate independently during observations, i.e. are not networked and are not communicating with one another. Similar hardware and software operates at each telescope site. The GPS satellite constellation synchronizes frequency and time using locked oscillators. Narrow bandwidth pulse measurement files are captured during observations, and post processed after observation runs are complete. Details of signal processing and RFI excision are included in the August 2019 SARA Green Bank paper [Ref. 1 Fig 2 text and Fig 17 text] All multi-telescope observations since late 2017 have been conducted when pointing to -7.6° declination, and transit scanning. -7.6° declination was chosen primarily due to anomalies observed using two radio telescopes in New Hampshire, during several years of transit scans prior to 2017.

Automatic RFI excision has been added in December 2019 signal post-processing. 1 kHz bandwidth spectrum segments having an anomalously large number of bin hits are suspected to be RFI, and are excluded from post processing. Spectrum segments that contain the number of bin hits expected in noise are included to search in post processing for simultaneous pulses. Other RFI excision methods are described in the August 2019 Green Bank paper. [Ref. 1 Figs 17,18 text].



Anomalous number of simultaneous pulses in the approximate target pointing direction (Fig. 2)

An RA pointing direction of approximately 5.2 hours, at a declination of -7.6° appears, in past work, to be related to anomalous indications of simultaneous pulses at two distant synchronized radio telescopes. Details of three anomalous simultaneous pulses and associated pulses are described in the August, 2019 presentation at the Green Bank SARA Annual Conference [Ref. 1 Figs. 5-18].

Observations in December 2019 indicate statistically significant anomalous pulses in approximately the same pointing direction, i.e. approximately 5.2 hrs RA and -7.6° declination, pointing.

The plot in Figure 2 captures the simultaneous pulses within ±12 Hz at each telescope pair, after accounting for site-to-site Doppler shift and receiver metrology. ±12 Hz is chosen as a search limit due to estimated metrology residuals and other reasons, explained as follows. In post processing, limiting the simultaneous pulse Δf search range to an overly low value can create a tendency to overlook important experimental aspects and unknowns, e.g. Doppler calculation errors, GPS constellation induced offsets, RFI mechanisms, and transmitted communication signals intentionally offset in frequency, spatially, to increase Shannon channel capacity. The details of the latter process, multibeam phased array MIMO, (Multiple In – Multiple Out) are described in the August 2019 Green Bank paper. [Ref. 1 Fig 22a text describing multiple transmit and receive antennas in modern communication systems].

Δf within ±12 Hz is chosen in this present work to balance experimental and hypothetical source uncertainties with the unavoidable increase in calculated likelihood of events in noise. Further, a wider search range is helpful to search for anomalies among differing data populations using statistical methods, e,g, Cohen's d analysis, [Ref 1 Fig. 7].

An RA region in the vicinity of 5.2 hours RA, within the full RA range, is isolated, as a prior, to examine for anomalous events, due its apparent significance in prior simultaneous pulse observations. [Ref 1] Statistical significance calculations are simplified if such a prior is used to limit analysis to a closely examined data set. Measurements of this RA range are further detailed below.

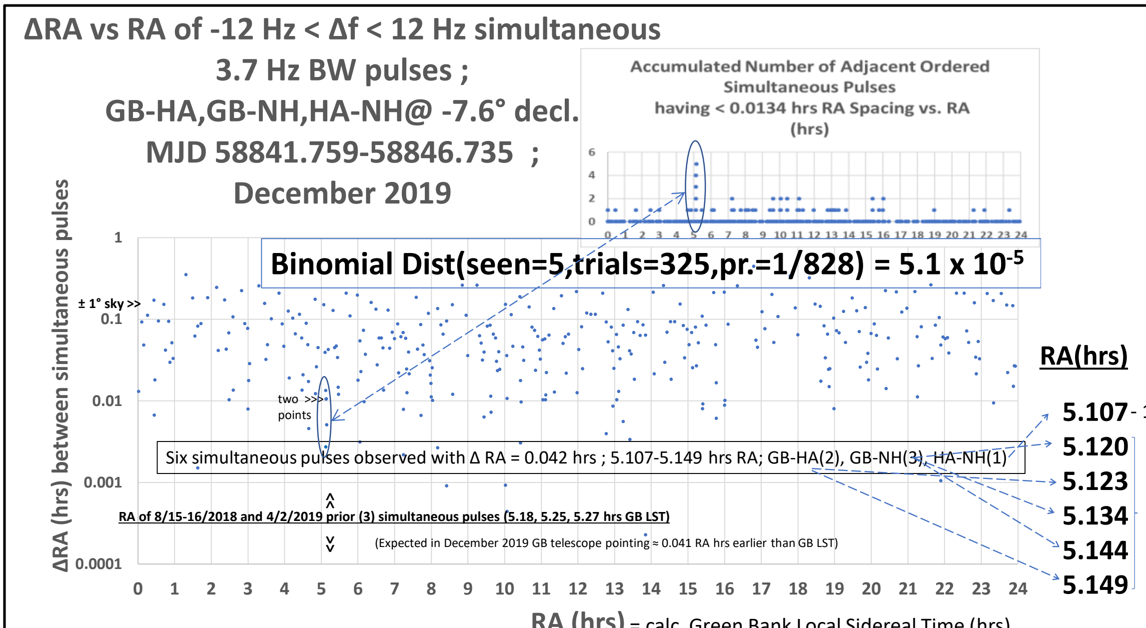


Fig. 3

Simultaneous pulses observed near the 5.2 hours RA pointing direction (Fig. 3)

Six anomalous simultaneous pulses were observed in the approximate prior established pointing direction, among 325 candidate simultaneous pulses observed over all RAs during the December 2019 observation run. These six simultaneous pulses add to the three anomalous Green Bank-Haswell pulses observed in prior observations, two simultaneous pulses in August 2018 and one simultaneous pulse in April 2019. [Ref 1].

An assumption is made that close-time spaced pulses are significant to study. Reasoning implies that intermittent communication, noise, a natural object, or RFI source may transmit pulses that have components primarily restricted to a relatively low event time spacing and consequent Right Ascension range at an event MJD. Given this assumption, the difference in recorded RA of increasingly ordered RA values is plotted against RA. A sub-diagram in Figure 3 accumulates the number of simultaneous pulses captured, on all three pairs of telescopes, within a given delta RA pointing.

An apparently anomalously low RA-spaced set of six simultaneous pulses, having five RA differences, appear to be present in the plotted post-processed data.

The five pulses following the first pulse at 5.107 hrs RA, increasing in value ordered in RA, have a binomial distribution in noise likelihood, of presence in one of 828 RA bins, at 5.1 in 100,000 tries of multi-day assays, each assay having 325 simultaneous pulses, i.e. the number observed in December 2019. The 828 RA bins are established from the observed close RA spacing of the first and last of the five RA-ordered simultaneous pulses at RA values above the 5.107 hrs RA pulse, i.e. 0.029 hours, with RA bin = 24/828. The chosen bin is significant due to previous observations in the approximate pointing direction. Uncertainty in the significant pointing direction by a factor of 3, i.e. 3 of 828 bins, increases the noise likelihood of the five pulse event to 1.5 in 10,000 tries.

The estimate of significant RA range depends on calibration of telescope pointing and is described in the next section.

December 2019 Telescope Pointing Calibration using source NRAO 5690

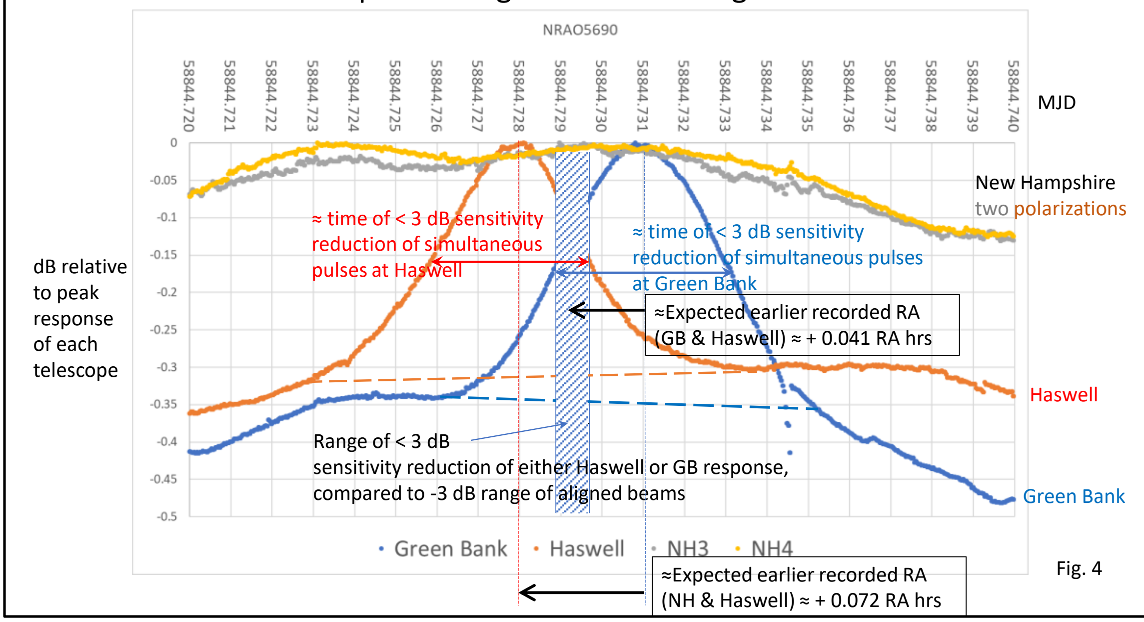


Fig. 4

Calibration of telescope pointing (Fig. 4)

A Right Ascension pointing estimate is calculated using the MJD of the recorded narrowband pulse time, establishing the Local Sidereal Time of the Green Bank 180° azimuth Forty Foot telescope pointing. Corrections are then applied as necessary due to observed pointing offsets of the telescopes. Simultaneous pulses are searched, from raw telescope data, in post processing software that posts the simultaneous pulse's Local Sidereal Time of the Green Bank Forty Foot Telescope, pointing to an azimuth of 180 degrees. A simultaneous pulse data post of Green Bank and New Hampshire telescopes, will, for example, estimate the Right Ascension of an object hypothetically in the center of the Green Bank antenna beam-width. The estimates made in this way are subject to the residuals resulting from Rician amplitude fading, FFT bin scalloping, hypothetical transmitter power variations, receive antenna response, and declination offsets.

Astronomical object NRAO 5690 is observed to calibrate the RA pointing of the New Hampshire and Haswell telescopes relative to the Green Bank Forty Foot telescope. An apparent azimuth offset of the Haswell telescope was observed in the December observations. This offset reduces the peak sensitivity of the detection of simultaneous pulses at Haswell and Green Bank, while not significantly affecting simultaneous pulses at New Hampshire and either Haswell or Green Bank. The peak sensitivity of simultaneous detection using the Haswell and Green Bank telescope pair occurs due to a hypothetical source at a Right Ascension pointing earlier in time, thus higher in RA value, compared to an estimated RA without the azimuth pointing offset.

Given the Haswell pointing offset to the east, the estimated Right Ascension of an object in both Haswell and Green Bank beams increases by approximately 0.041 hours of RA, relative to the RA value set by the LST of Green Bank at the time of the simultaneous pulse observation. Similarly, given the Haswell pointing offset to the east, the estimated Right Ascension of an object in both Haswell and New Hampshire beams increases by approximately 0.072 hours of RA, relative to the RA value set by the LST of Green Bank at the time of the simultaneous pulse observation. Simultaneous pulses observed in Green Bank and New Hampshire are estimated to have an RA pointing equal to the calculated Green Bank Local Sidereal Time.

These calculated offsets are used to provide subsequent estimates of RA pointing during December 2019 simultaneous pulses.

Six simultaneous pulses captured pointing ≈ 5.16 hours RA during December 2019 observation run; 3 close in time

Telescope pair	Pulse MJD	Δt (seconds)	Δf (Hz)	Green Bank LST (hrs)	Estimated RA pointing (hrs)	composite 0.75s SNR (dB)	FFT bin posted frequency (MHz)
Haswell	58845.16694730	ref	-11.5	5.10700590	5.17900590 ≈±0.06 hrs	12.328	1426.39906260
NH4	58845.16694730	ref	-11.5	5.10700590	5.17900590	12.335	1426.39816480
NH4	58845.16750290	48.00	-7.4	5.12037680	5.12037680 ≈±0.06 hrs	11.925	1401.26299410
Green Bank	58845.16750290	48.00	-7.4	5.12037680	5.12037680	12.188	1401.26322140
Green Bank	58845.16761570	9.75	-4.4	5.12309140	5.16409140 ≈±0.06 hrs	11.953	1431.88035410
Haswell	58845.16761570	9.75	-4.4	5.12309140	5.16409140	12.174	1431.88104330
NH4	58843.17350980	2 days previous	-11.3	5.13351740	5.13351740 ≈±0.06 hrs	12.948	1400.95421970
Green Bank	58843.17350980	2 days previous	-11.3	5.13351740	5.13351740	11.884	1400.95444320
NH3	58842.17667820	3 days previous	11.3	5.14405740	5.14405740 ≈±0.06 hrs	12.578	1413.93182720
Green Bank	58842.17667820	3 days previous	11.3	5.14405740	5.14405740	11.845	1413.93208430
Haswell	58844.17142940	1 day previous	-2.8	5.14916100	5.19016100 ≈±0.06 hrs	11.901	1435.83954800
Green Bank	58844.17142940	1 day previous	-2.8	5.14916100	5.19016100	12.225	1435.83885880

57.75 s

Pr. .0024

Number of pulse pairs seen during MJD 58845, ±12 Hz, all RAs, 3 telescope pairs = 89
Number of pulse pairs seen during 57.75 s = 3
Probability (in noise) of one pulse pair in 57,75s if uniform/day = 57.75 s / 86400 s = 0.00067
(Span=4)*Binomial distribution (3 seen, 89 tries, pr=0.00067) = 0.00013

Mean RA composite pointing (hours)
5.1552 hrs

Δf = 175 Hz associated pulse

HIP 24037 @ 5.183 hours RA
G0 175 ly -7.05° dec.

Fig. 5

Estimate of RA pointing during the six observed simultaneous pulses (Fig. 5)

An estimate of RA of a hypothetical source object may be calculated, given the simultaneous pulse times in MJD, and the telescope calibration methods described above. The nearest star that fits the observations is speculated to be HIP 24037, a G0 type star at 175 lyr distance. There are other candidates, e.g. HIP 24472, red dwarf at 73 lyr. Metrology work and further observations are planned to help narrow down these possibilities.

This current speculation is not a claim of the existence of signals from sources near these stars. Much experimental work, multiple hypotheses developments and observations are required before one can reach confidence of one hypothesis over another.

Simultaneous pulses contain additional anomalies

Three of the simultaneous pulses indicated event close-in-time occurrences, during one day. Three simultaneous pulses, one observed on each of the three pairs of telescopes, occurred within a 57.5 second time interval. The likelihood of this close in time event, due to noise, calculates at 1.3 x 10^{-4} , using a method described in Figure 5. The Span=4 value roughly accounts for the possible occurrence of the event within the larger RA range of the six simultaneous pulses.

One simultaneous pulse is observed to contain a rare associated pulse
In past work, close frequency spaced pulses have been observed to be apparently associated with simultaneous pulses. [Ref 1]. These pulses are referred to as associated pulses, and are apparently anomalous, given a noise hypothesis. Details of associated pulses and their likelihood calculation methods, given a noise hypothesis, are detailed in the August 2019 Green Bank paper. [Ref 1]

A close RF frequency pulse was observed, paired with a simultaneous pulse, the sixth pulse pair in Fig. 5. The median spacing in RF frequency between adjacent frequency SNR threshold-crossing pulses in data sets is measured at approximately 1.2 MHz, a value approximately expected in noise. One of the simultaneous pulses indicated a partner pulse at 175 Hz offset. In a Poisson process, the likelihood of such an event, due to noise, on either side of the pulse, associated with either of the simultaneous pulses within the pair, calculates to:

$4\ (\ln(2)^*\Delta f\ /\ \Delta f_{50\%}\ ) = 4.0 \times 10^{-4}$, $\ln(2) = 0.693\ldots$, [using equation in Ref 1. Fig. 8]

and calculates to approximately 2.4 x 10^{-3} when considering the likelihood of the presence of the close tone among any of the six simultaneous pulses observed in December 2019, listed in Figure 5.

Preliminary scans of the other of the six simultaneous pulses, in a search for associated pulses, while indicating a possibility of some anomalies, are not detailed in this paper.

Conclusion
The observed anomalies compel further observations. A known noise hypothesis, e.g. Additive White Gaussian Noise (AWGN), explaining the anomalies, appears unlikely to explain the observations. In Bayesian Inference, [Ref. 1, Fig 21], assuming high probability that experimental data is valid, and assuming high probability that the AWGN noise and Poisson process models are valid in the experiment, the AWGN noise model's calculated probability as an explanation, i.e. a Bayesian likelihood given December 2019 observations, tends to refute the AWGN noise model's explanation as a cause of the observed anomalous simultaneous and associated pulses. Further work is required to refine the conclusion regarding the AWGN hypothesis. Further work is required within each family of hypotheses.

Further work

Additional observations are planned to seek and refute various hypotheses, e.g. RFI, noise, natural object, ETI, equipment, using Bayesian Inference calculations. Two additional approximate 28 foot diameter antennas are under construction, planned to be operated around the clock, and synchronized with the New Hampshire 26 foot antenna. One of the two antennas under construction is planned to be transported to the Pacific Northwest and operated almost continuously. Another is planned to be located at the New Hampshire telescope site, operated almost continuously together with the current New Hampshire telescope. Telescopes at Green Bank and Haswell will be added to produce a five antenna system, when observation time on these two telescopes is available. Metrology, the use of different telescopes, system hardware and software, and seeking independent post processing of raw telescope data are additional tasks underway.

References:

1. Details of the synchronized telescope SETI project and observations are in a paper presented in August 2019, in Green Bank, West Virginia:
http://dses.science/wp-content/uploads/2019/08/SARA_2019_GreenBank_Crilly_73_f.pdf

2. Close frequency tones observed and described in Fig. 9 of the August 2019 paper are played in the following WAV file:
http://dses.science/wp-content/uploads/2019/02/Fig_7_tones.wav

3. The Deep Space Exploration Society Publications page is:
http://dses.science/deep-space-exploration-society/dses-publications

Thank you!

Thank you

Steve Plock

Deep Space Exploration Society team

Green Bank Observatory team

family and friends