ezRA - Easy Radio Astronomy - ezCon

- Jan-2-2023

ezRA - Easy Radio Astronomy
https://github.com/tedcline/ezRA

The ezCon program is a data CONdenser, which reads one or more frequency spectrum data .txt files, processes the data to better reveal the Galactic hydrogen information, and creates one condensed data .ezb file, and perhaps one Galaxy data *Gal.npz file. Along the way, ezCon creates many plot image files and perhaps 2 text files to study.

.ezb Data File Column Numbering

That human-readable .ezb condensed data output file has a few header lines, followed by one long line for each recorded data sample. Each long line has 20 ragged columns of numbers, separated by one space character.

The “coordinate” columns 0 through 9 are unrelated to the radio of the sample:
TimeUtcMjd, RAH, DecDeg, GLatDeg, GLonDeg, VLSR, Count, Spare1, Spare2

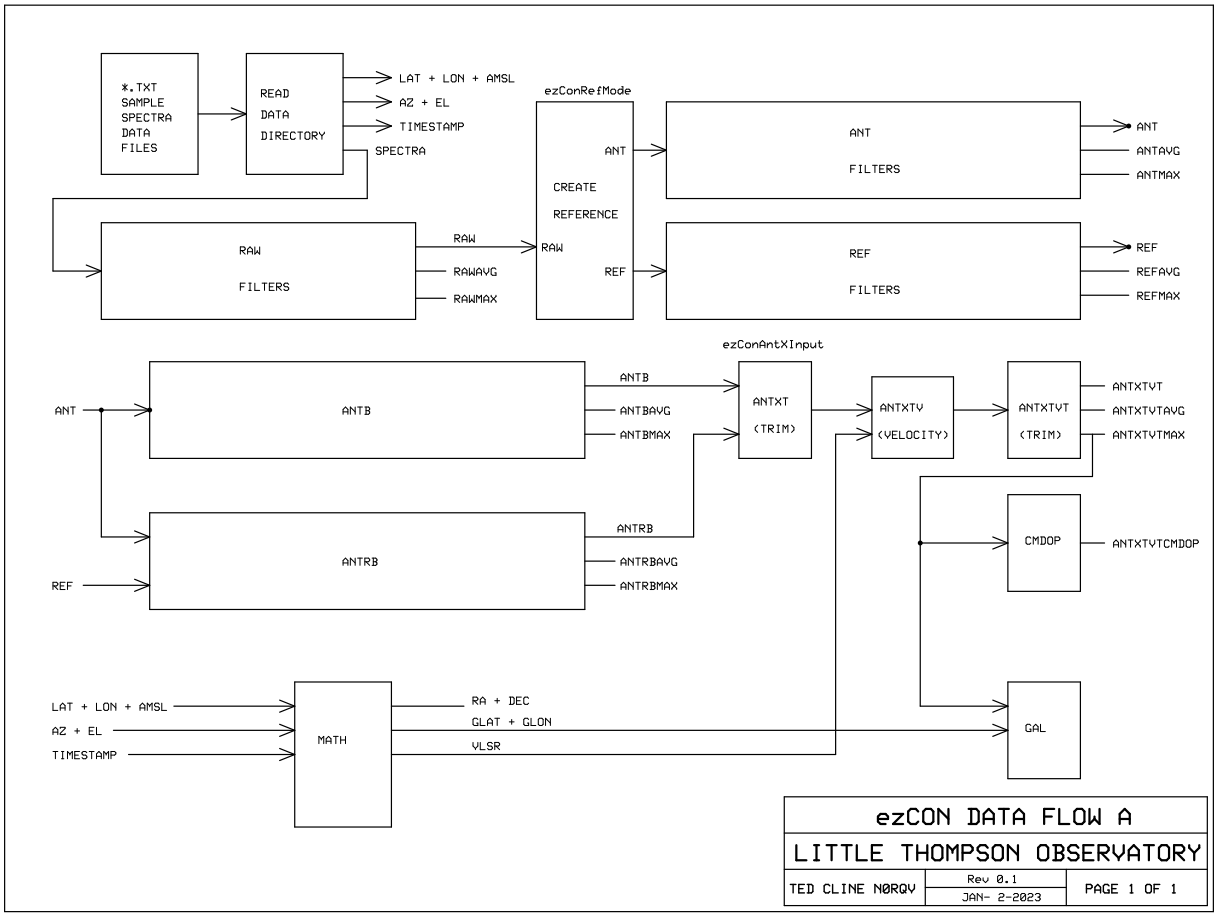
Spare1 and Spare2 are experimentally redefined as Azimuth and Elevation.

The remaining 11 “signal” columns document the processing of the radio samples. The last 10 “signal” columns are 5 signal pairs of the signal sample’s average value, followed by its signal sample’s maximum value. The 2 unprocessed (maybe filtered) signals are in columns 10 through 13:
AntAvg, AntMax, RefAvg, RefMax
The 3 processed signals are in columns 14 through 19:
AntBAvg, AntBMax, AntRBAvg, AntRBMax, AntXTVTAvg, AntXTVTMax
Throughout ezRA, these 10 signals use this order, and are conveniently numbered using 0 through 9. Each of the 5 signals use its own color for plot traces.

And then there is column 9 with the unusual processed signal, AntXTVTCmDop, which tracks the center-of-mass of the Doppler shift of the AntXTVT signal.

ezCon Data Flow

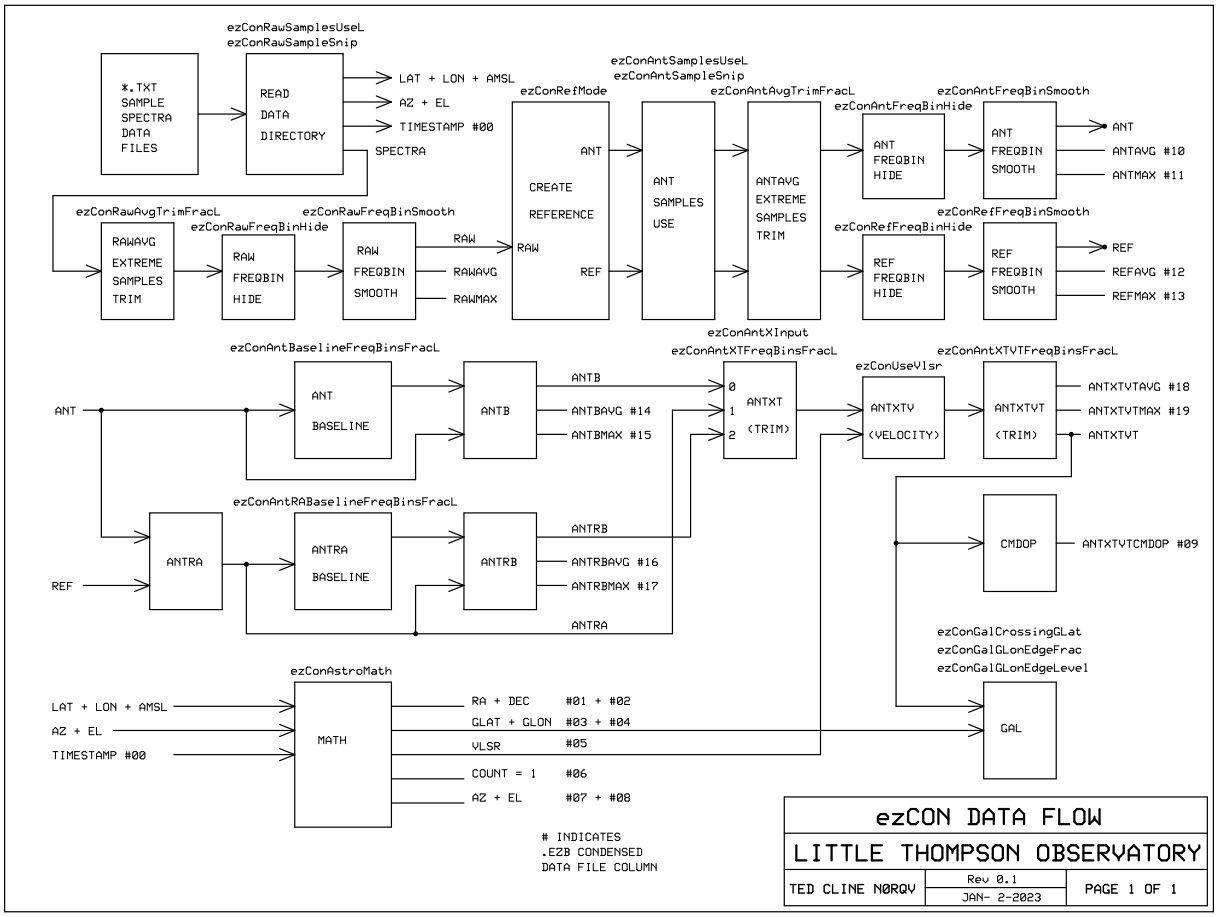
Here is simplified diagram of the data flow inside the ezCon program.



Starting at the top left, ezCon reads .txt data files, filters the Raw data samples, and separates them into Antenna (Ant) samples and Reference (Ref) samples.

Continuing at center left, ezCon uses those Ant and Ref samples to create the AntB and AntRB signals. It then selects AntB (default) or AntRB, to create AntXT, AntXTV, and AntXTVT signals. All to better reveal Galactic hydrogen emission and the information it contains. Default values for the many command line options (“arguments”) provide guidance.

Here is a more complete diagram of the data flow inside the ezCon program.



This ezCon program diagram reveals more program controls, and the output .ezb file column numbers.

ezCon Plot File List

Each ezCon plot image filename starts with “ezCon”, followed by a 3-digit number, followed by a brief description, followed by “.png” . The first plot filename is “ezCon001raw.png”.

The ezCon plot files are organized into groups. The groupings allows the -ezConPlotRangeL arguments to speed execution by creating only the related plots that are wanted.

The ezCon0Nx plot files are colorful heatmaps of frequency spectra, using color to indicate relative power values, where N is the 0-9 signal number (plotting sample spectrum frequency by sample number). The Max plots also mark each vertical sample’s maximum value with a green dot, and mark the maximum value of all those maximums with a yellow dot. Ideally, those green maximum dots track the weak hydrogen signal, but sometimes they mark stronger noise.

ezCon000rawRaw.png	- only if any Raw filtering, Ant and Ref samples mingled, before any filtering
ezCon001raw.png	- Ant and Ref samples mingled, after any Raw filtering
ezCon002antRaw.png	- only if any Ant filtering, just Ant samples, after any Raw filtering, before any Ant filtering
ezCon007ant.png	- just Ant samples, after any Raw and Ant filtering
ezCon017antMax.png	- just Ant samples, after any Raw and Ant filtering, with dots on spectrum maximum
ezCon022refRaw.png	- only if any Ref filtering, just Ref samples, after any Raw filtering, before any Ref filtering
ezCon027ref.png	- just Ref samples, after any Raw and Ref filtering
ezCon037refMax.png	- just Ref samples, after any Raw and Ref filtering, with dots on spectrum maximum
ezCon047antB.png	- AntB sample spectra: Ant samples divided by their AntBaseline values
ezCon057antBMax.png	- AntB sample spectra, with dots on spectrum maximum
ezCon061antRA.png	- AntRA sample spectra: Ant sample spectra divided by their Ref sample spectra (calculation step toward AntRB)
ezCon067antRB.png	- AntRB sample spectra: AntRA samples divided by their AntRABaseline values
ezCon077antRBMax.png	- AntRB sample spectra, with dots on spectrum maximum
ezCon081antXT.png	- AntXT sample spectra: AntB or AntRA or AntRB samples, then frequency Trimmed
ezCon082antXTV.png	- AntXTV sample spectra: AntXT samples, then VLSR Velocity corrected
ezCon087antXTVT.png	- AntXTVT sample spectra: AntXTV samples, then frequency Trimmed
ezCon097antXTVTMax.png	- AntXTVT sample spectra, with dots on spectrum maximum

The ezCon1NN plot files are 2-dimensional plots of values related to samples, where NN is generally the output condensed data .ezb file 0-19 column number (plotting value by sample number). These include coordinate values (such as time, declination, or VLSR), and signal values (such as Ant, Ref, or AntRB). Identify problem samples with the ezConStudy*.txt file, which records the samples that have the maximum, minimum, and greatest change values, for each of 10 signals.

ezCon100timeUtcMjd.png - UTC MJD time of sample (fractional days)

ezCon101raH.png - Right Ascension of sample (hours)
ezCon102decDeg.png - Declination of sample (degrees)

ezCon103gLatDeg.png - Galactic Latitude of sample (degrees)
ezCon104gLonDeg.png - Galactic Longitude of sample (degrees)

ezCon105vlsr.png - VLSR (Velocity from the Local Standard of Rest) of sample (km/sec)

ezCon110antAvg.png - filtered Ant sample spectrum average values
ezCon111antMax.png - filtered Ant sample spectrum maximum values

ezCon112refAvg.png - filtered Ref sample spectrum average values
ezCon113refMax.png - filtered Ref sample spectrum maximum values

ezCon114antBAvg.png - AntB sample spectrum average values
ezCon115antBMax.png - AntB sample spectrum maximum values

ezCon116antRBAvg.png - AntRB sample spectrum average values
ezCon117antRBMax.png - AntRB sample spectrum maximum values

ezCon118antXTVTAvg.png - AntXTVT sample spectrum average values
ezCon119antXTVTMax.png - AntXTVT sample spectrum maximum values

ezCon191sigProg.png - Signal Progression: summary of ezCon110 through ezCon119 plots

ezCon198azimuth.png - Azimuth sample values (degrees)
ezCon199elevation.png - Elevation sample values (degrees)

ezConStudy*.txt - text max, min, and fastest-changing value, sample number, for 10 signals

The ezCon2Nx plot files are 2-dimensional plots of values related to samples, revealing the processing of the Galactic hydrogen information, where N is generally the output condensed data .ezb file 0-19 column number (plotting value by sample number). These include raw, separated, and processed data (such as time between Raw or Ant samples, Ant, Ref, AntRA, AntXT). Some of these ezCon2xx plots present the same information as some of the ezCon1xx plot files.

ezCon200rawRawAvg.png - only if any Raw filtering, Ant and Ref sample spectrum average values mingled, before any Raw filtering

ezCon201ArawAvg.png - Ant and Ref sample spectrum average values mingled, after any Raw filtering

ezCon201CrawAvgRecentFrac.png - for ezConRefMode 20 Ref creation, RawAvgRecentFracTrig in red, RawAvgAvgRecentFrac in connected green

ezCon201DsampleRef.png - for ezConRefMode 20 Ref creation, unfiltered Raw sample spectrum average values, with Ant and Ref dots

ezCon201EsampleRefAgain.png - for ezConRefMode 20 Ref creation, true for consecutive Ref samples

ezCon201FsampleBad.png - for ezConRefMode 20 Ref creation, true for sample should be rejected

ezCon201GrawAntRef.png - display of Raw, MaskRawAnt and MaskRawRef

ezCon201HtimeUtcMjdDBetweenRaw.png - time since last Raw sample (seconds)

ezCon201ItimeUtcMjdDBetweenAnt.png - time since last Ant sample (seconds)

ezCon201JtimeUtcMjdDBetweenRef.png - time since last Ref sample (seconds)

ezCon202antRawAvg.png - only if any Ant filtering, just Ant samples,
after any Raw filtering, before any Ant filtering

ezCon207antAvg.png - Ant sample spectrum average values,
after any Raw and Ant filtering (like ezCon110 plot)

ezCon217antMax.png - Ant sample spectrum maximum values (like ezCon111 plot)

ezCon222refRawAvg.png - only if any Ref filtering, just Ref samples,
after any Raw filtering, before any Ref filtering

ezCon227refAvg.png - Ref sample spectrum average values,
after any Raw and Ref filtering (like ezCon112 plot)

ezCon237refMax.png - Ref sample spectrum maximum values (like ezCon113 plot)

ezCon241antBaseline.png - average of non-hydrogen Ant sample spectrum frequencies
(calculation step toward AntB)

ezCon247antBAvg.png - AntB sample spectrum average values (like ezCon114 plot)

ezCon257antBMax.png - AntB sample spectrum maximums values (like ezCon115 plot)

ezCon261antRAAvg.png - AntRA sample spectrum average values

ezCon262antRABasAvg.png - average of non-hydrogen AntRA sample frequencies
(calculation step toward AntRB)

ezCon267antRBAvg.png - AntRB sample spectrum average values (like ezCon116 plot)

ezCon277antRBMax.png - AntRB sample spectrum maximum values (like ezCon117 plot)

ezCon281antXTAvg.png - AntXT sample spectrum average values
(after frequency Trim)

ezCon282antXTVAvg.png - AntXTV sample spectrum average values
(after VLSR Velocity corrected)

ezCon287antXTVTAvg.png - AntXTVT sample spectrum average values
(after frequency Trim) (like ezCon118 plot)

ezCon297antXTVTMax.png - AntXTVT sample spectrum maximum values (like ezCon119)

The ezCon3Nx plot files are 2-dimensional plots of values by frequency, averaged or maximized across all samples, where N is generally the 0-9 signal number (plotting value by frequency). These include raw and separated and processed signal data (such as rawRaw, filtered Raw, Ant, Ref, AntRA, AntXT).

ezCon300rawRawByFreqBinAvg.png	- only if any Raw filtering, average of all Raw sample spectra, Ant and Ref samples mingled, before any filtering
ezCon301rawByFreqBinAvg.png	- average of all Raw sample spectra, Ant and Ref samples mingled, after any Raw filtering
ezCon302antRawByFreqBinAvg.png	- only if any Ant filtering, averages of all Ant sample spectra, after any Raw filtering, before any Ant filtering
ezCon307antByFreqBinAvg.png	- averages of all Ant sample spectra, after any Raw and Ant filtering
ezCon317antByFreqBinMax.png	- maxima of all Ant sample spectra, after any Raw and Ant filtering
ezCon322refRawByFreqBinAvg.png	- only if any Ref filtering, averages of all Ref sample spectra, after any Raw filtering, before any Ref filtering
ezCon327refByFreqBinAvg.png	- averages of all Ref sample spectra, after any Raw and Ref filtering
ezCon337refByFreqBinMax.png	- maxima of all Ref sample spectra, after any Raw and Ref filtering
ezCon347antBByFreqBinAvg.png	- averages of all AntB sample spectra
ezCon357antBByFreqBinMax.png	- maxima of all AntB sample spectra
ezCon361antRAByFreqBinAvg.png	- averages of AntRA sample spectra (step toward AntRB)
ezCon367antRBByFreqBinAvg.png	- averages of all AntRB sample spectra
ezCon377antRBByFreqBinMax.png	- maxima of all AntRB sample spectra
ezCon381antXTByFreqBinAvg.png	- averages of AntXT sample spectra
ezCon388antXTByFreqBinAvgRfi.png	- rotated ezCon381 to easily identify RFI freqBin values
ezCon382antXTVByFreqBinAvg.png	- averages of AntXTV sample spectra
ezCon387antXTVTByFreqBinAvg.png	- averages of AntXTVT sample spectra
ezCon397antXTVTByFreqBinMax.png	- maxima of AntXTVT sample spectra

If the data includes Galactic plane crossings, the ezCon5xx plot files are various plots of Galactic plane hydrogen gas velocity information. Many ezCon690 plot files are possible, each displaying a spectrum for a particular 1-degree Galactic Longitude. The ezCon511velGLonCount.txt file is a scorecard of which 1-degree Galactic Longitude Galactic plane spectra are recorded.

ezCon510velGLon.png - gas velocity vs 1-degree Galactic Longitude
ezCon511velGLonCount.png - data count of gas velocity vs 1-degree Galactic Longitude
ezCon511velGLonCount.txt - text of data count of velocity vs 1-degree Galactic Longitude

ezCon520velGLonPolar.png - gas velocity vs Galactic Longitude, Polar
ezCon521velGLonPolarCount.png - data count of gas velocity vs Galactic Longitude, Polar

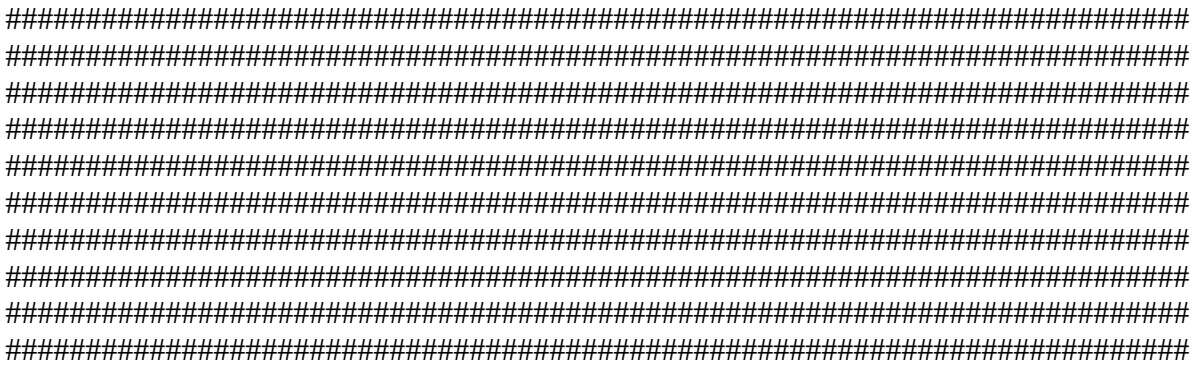
ezCon530galDecGLon.png - data count, Declination vs Galactic Longitude

ezCon541velGLonEdges.png - min and max freq of Galactic crossing spectrum vs Glongitude, using ezConVelGLonEdgeFrac and ezConVelGLonEdgeLevel argument settings

ezCon550galRot.png - Galactic rotation speed vs Galactic radius

ezCon560antXTVTMaxIdxGLon - index of antXTVTMax vs Galactic Longitude

ezCon690gLonDegP180_*ByFreqBinAvg.png - spectrum for one Gal crossing at a 1-degree GLon where the "*" is nnn, which is the Galactic Longtitude in degrees plus 180, such as:
ezCon690gLonDegP180_000ByFreqBinAvg.png - spectrum for Gal crossing at -180 degrees GLon
ezCon690gLonDegP180_001ByFreqBinAvg.png - spectrum for Gal crossing at -179 degrees GLon
ezCon690gLonDegP180_002ByFreqBinAvg.png - spectrum for Gal crossing at -178 degrees GLon
...
ezCon690gLonDegP180_180ByFreqBinAvg.png - spectrum for Gal crossing at 000 degrees GLon
ezCon690gLonDegP180_181ByFreqBinAvg.png - spectrum for Gal crossing at +001 degree GLon
ezCon690gLonDegP180_182ByFreqBinAvg.png - spectrum for Gal crossing at +002 degrees GLon
...
ezCon690gLonDegP180_359ByFreqBinAvg.png - spectrum for Gal crossing at +179 degrees GLon
ezCon690gLonDegP180_360ByFreqBinAvg.png - spectrum for Gal crossing at +180 degrees GLon

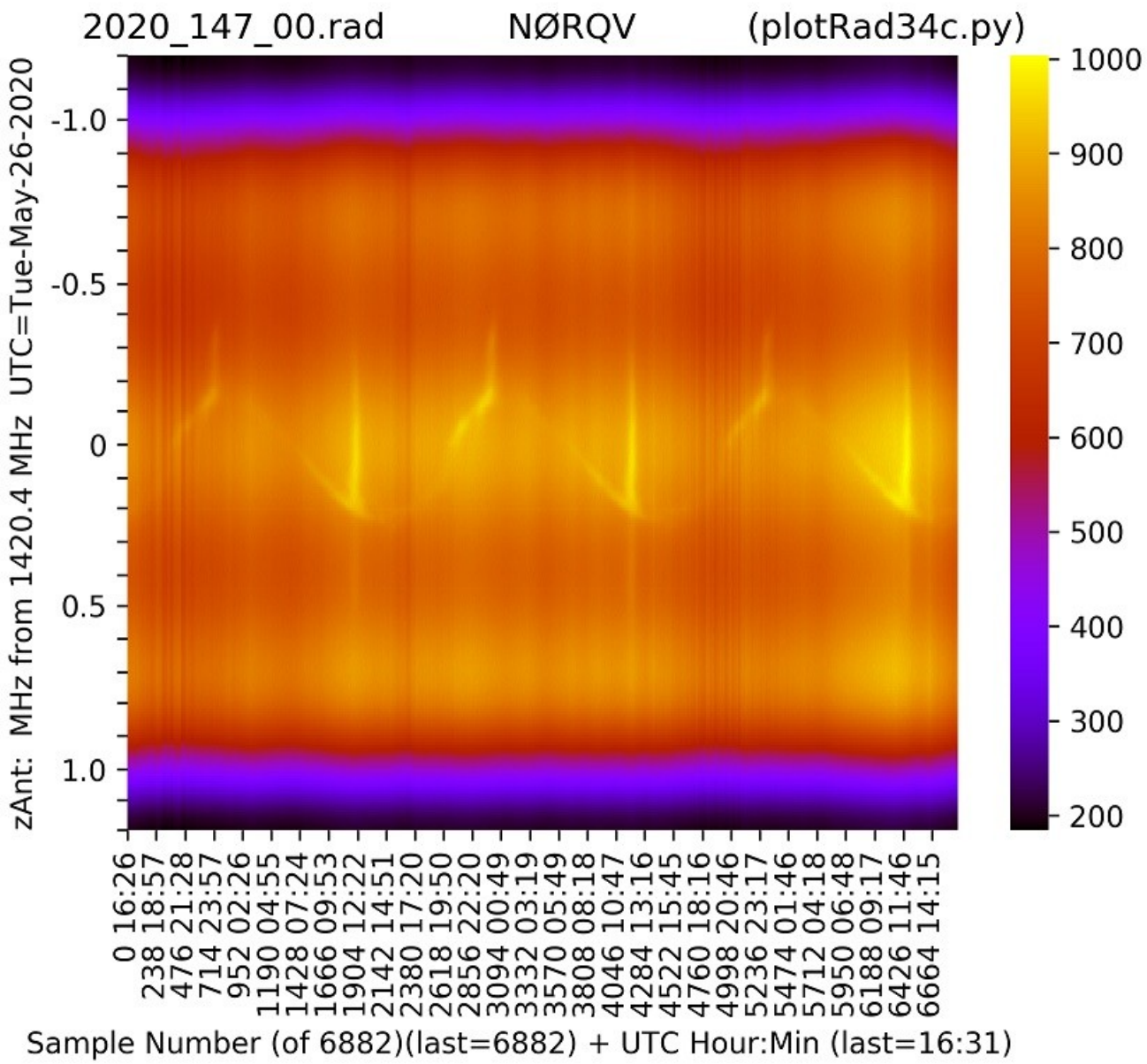


Blah, blah, blah …

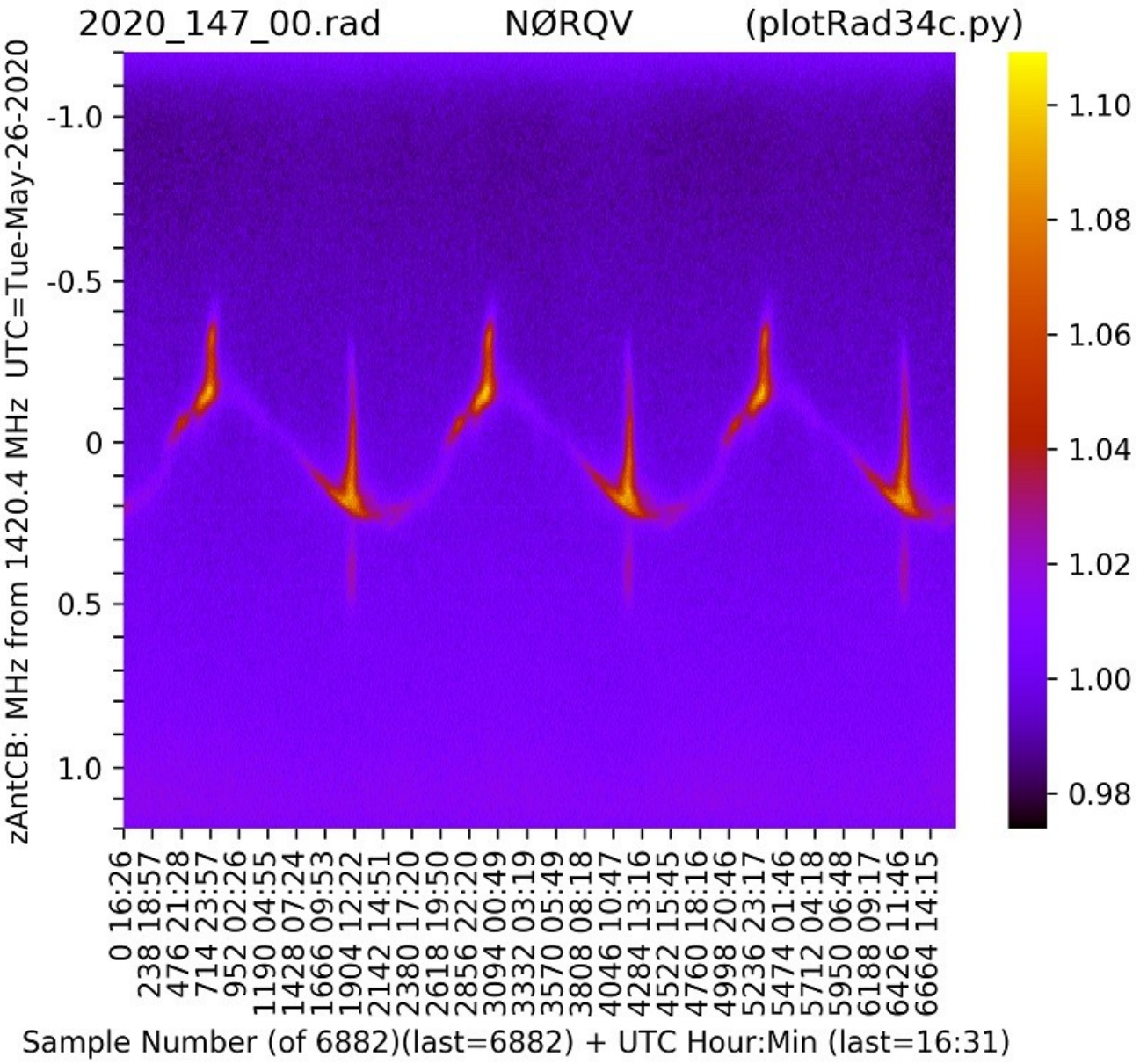
I continue exploring how to reduce the pesky day-to-day and minute-to-minute gain variation of our Radio Astronomy data.

My May-5-2020 “RA Status #15” talked about needing 3 inputs: Antenna signal, Calibrator signal, and local Temperature data. Within 3 hours of emailing that, I found I did not need the Temperature data.

My simpler system can record a noisy dish antenna signal,



and post-process it to something cleaner, with much less gain variation,

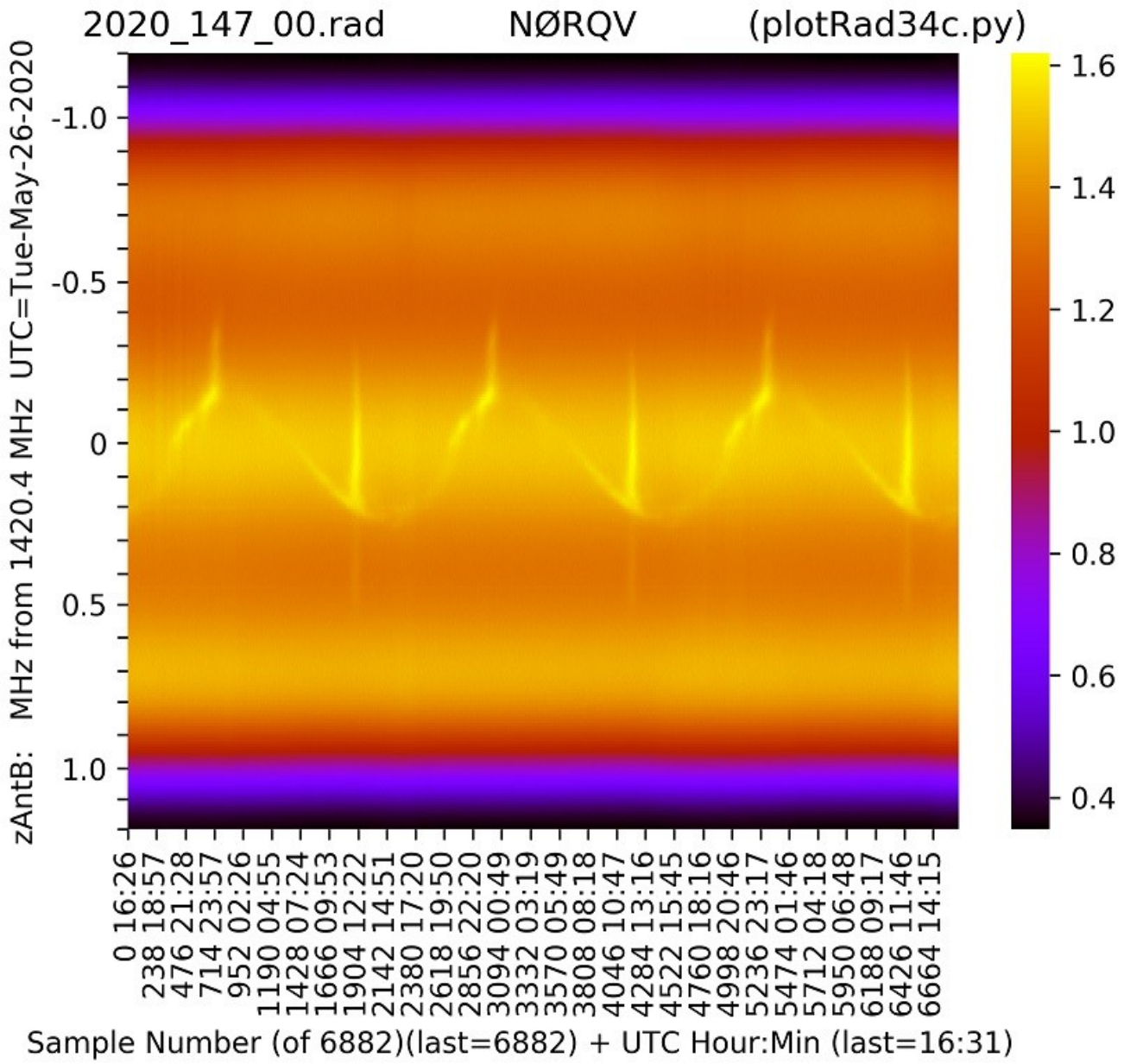

2020_147_00.rad
NØRQV
(plotRad34c.py)
zAntCB: MHz from 1420.4 MHz UTC=Tue-May-26-2020
-1.0
-0.5
0
0.5
1.0
1.10
1.08
1.06
1.04
1.02
1.00
0.98
0 16:26
238 18:57
476 21:28
714 23:57
952 02:26
1190 04:55
1428 07:24
1666 09:53
1904 12:22
2142 14:51
2380 17:20
2618 19:50
2856 22:20
3094 00:49
3332 03:19
3570 05:49
3808 08:18
4046 10:47
4284 13:16
4522 15:45
4760 18:16
4998 20:46
5236 23:17
5474 01:46
5712 04:18
5950 06:48
6188 09:17
6426 11:46
6664 14:15
Sample Number (of 6882)(last=6882) + UTC Hour:Min (last=16:31)

AntB

AntB is Ant minus the average of those dull (unused) top 60 Ant frequency bins and bottom 60 Ant frequency bins as a baseline in time.

AntB(f, t) = Ant(f, t) - AntBaseline(t)

AntB is interesting, but needs more processing,



Note how that removes the time (horizontal) variability.

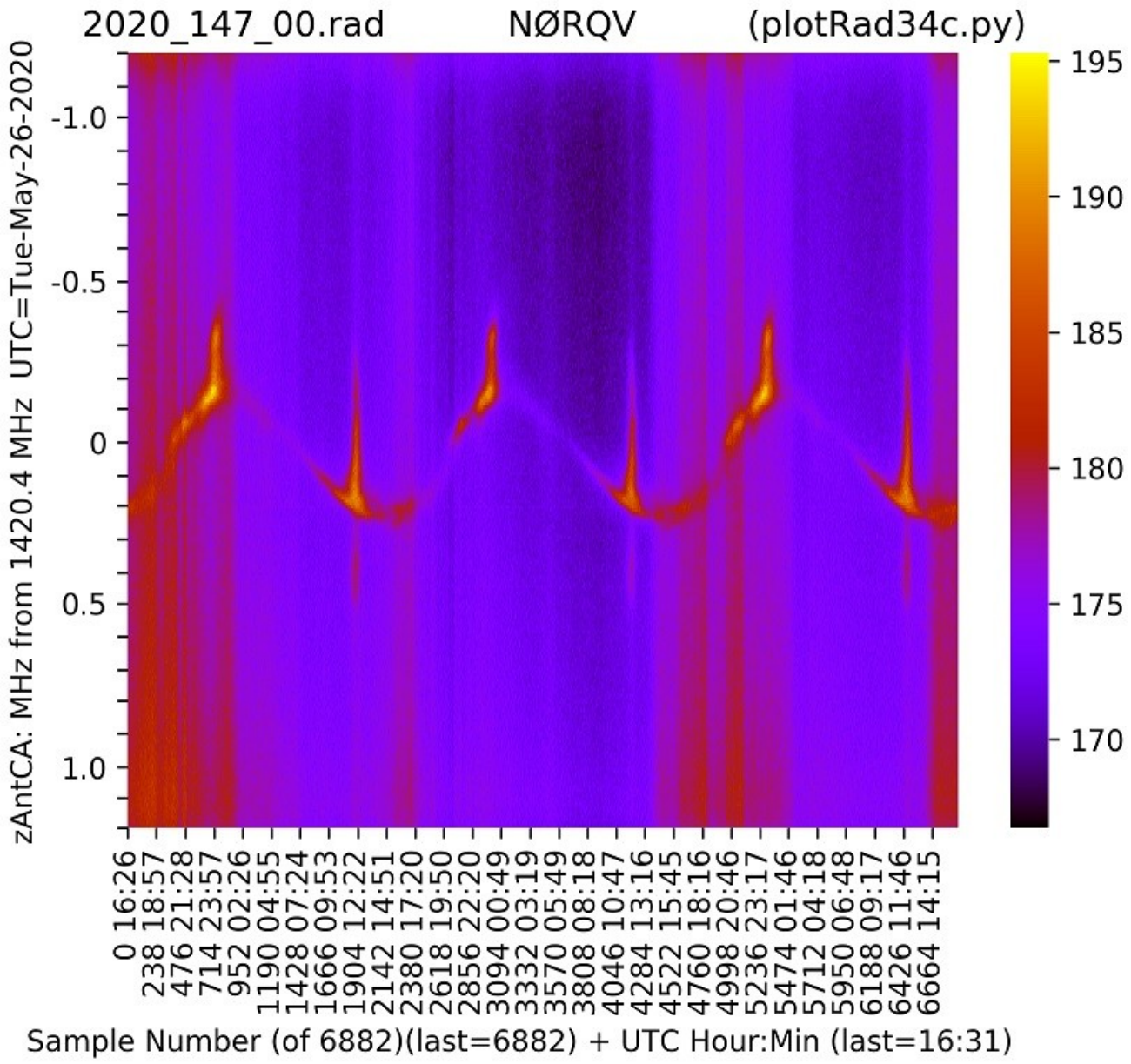
AntCA

AntCA is Ant divided by Cal, for each frequency and time.

The Feed-Calibrator resistor is about 290 Kelvin hot, so I multiply by 290.

AntCA(f, t) = 290 * Ant(f, t) / Cal(f, t)

AntCA is a stepping stone for AntCB later,



Note how that removes much of the frequency (vertical) variability.

AntCB

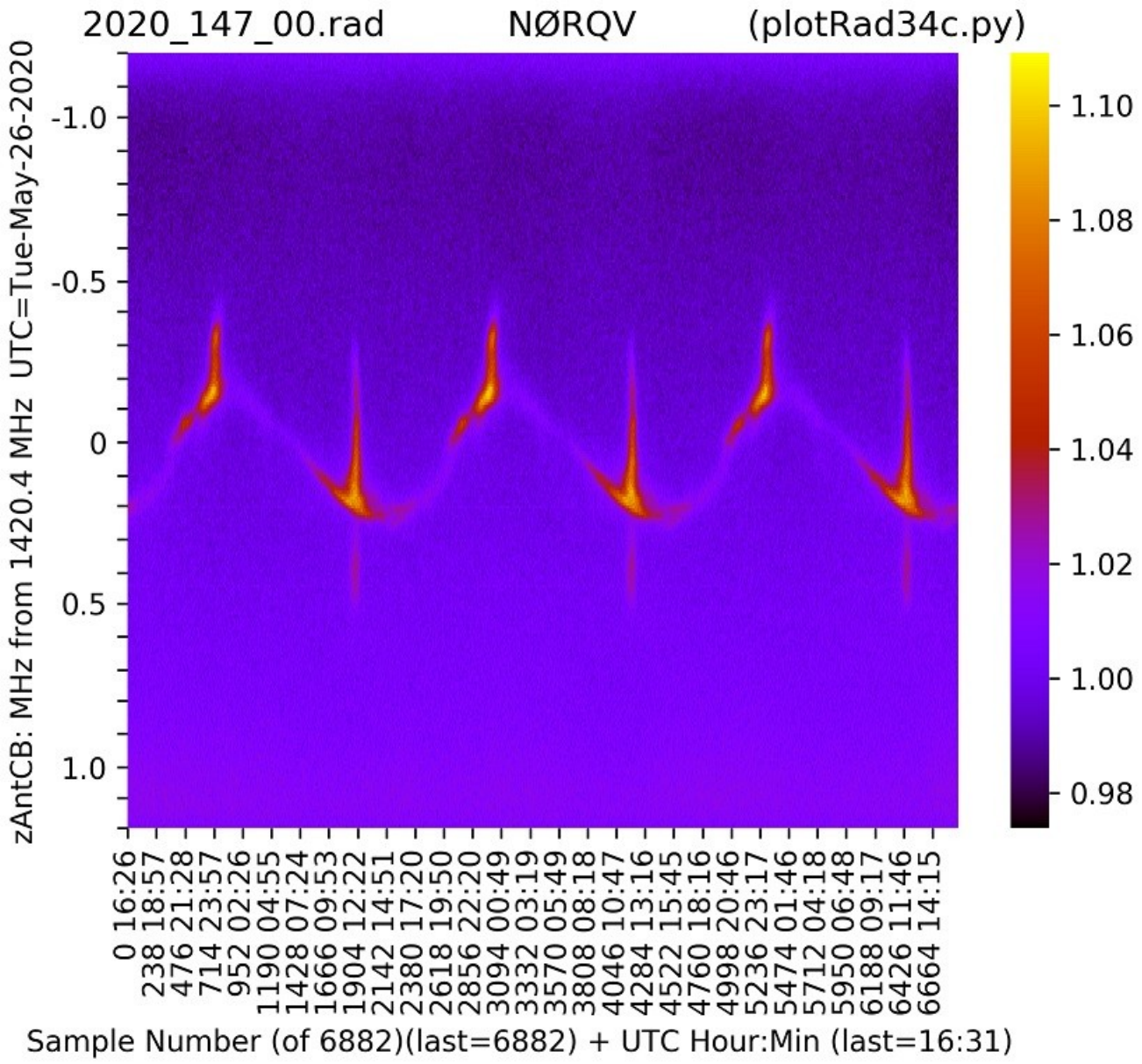
AntCB is combination of the methods above.

AntCB is AntCA minus the average of those dull top 60 AntCA frequency bins and bottom 60 AntCA frequency bins as a baseline in time.

AntCB(f, t) = AntCA(f, t) - AntCABaseline(t)

= 290 * Ant(f, t) / Cal(f, t) - AntCABaseline(t)

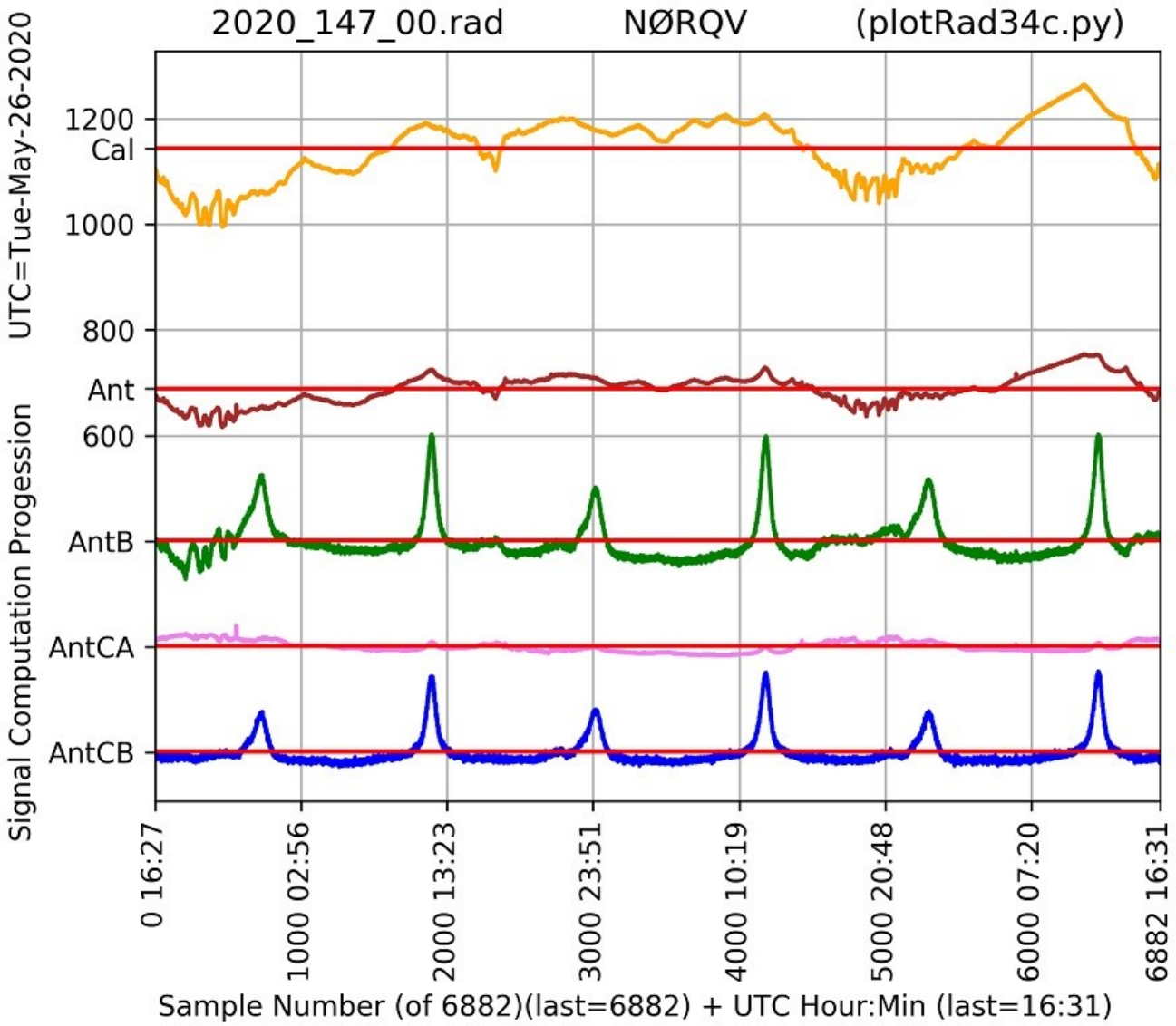
AntCB looks good,



Much better, at least for the interesting 1420 MHz hydrogen signal in the middle frequencies.

But to plot the radio sky, I want signal strength as a function only of time.

Averaging the frequency bins in the plots above, as a function of time yields,



In this 3 day drift scan example,

At the top, the ORANGE Cal input data of the warm feed calibrator averaged about 1144.

Next, the BROWN Ant input data of the cold sky (Azimuth=227.9, Elevation=38.9, Declination= 0.6) averaged about 689.

The bottom BLUE AntCB output line (not the same scale) has more signal, and less gain variation than the brown Ant input. Note the galactic outer and inner arm signal peaks, repeating 3 times.