Solar Flares Spectrograms

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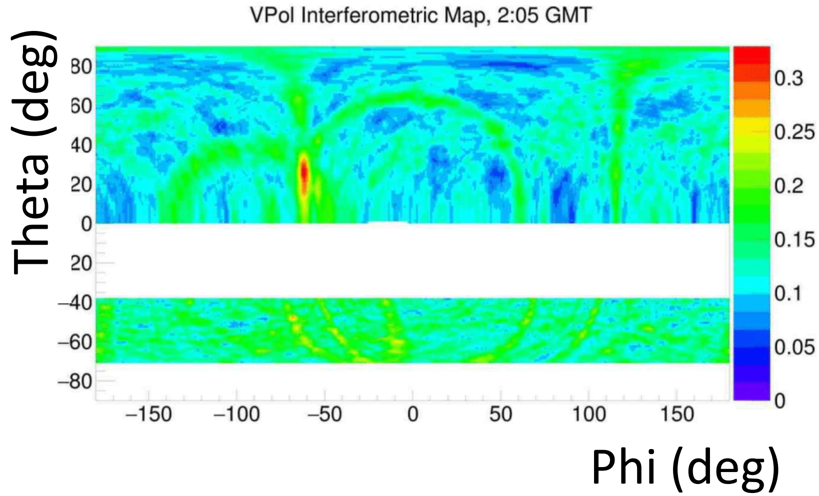
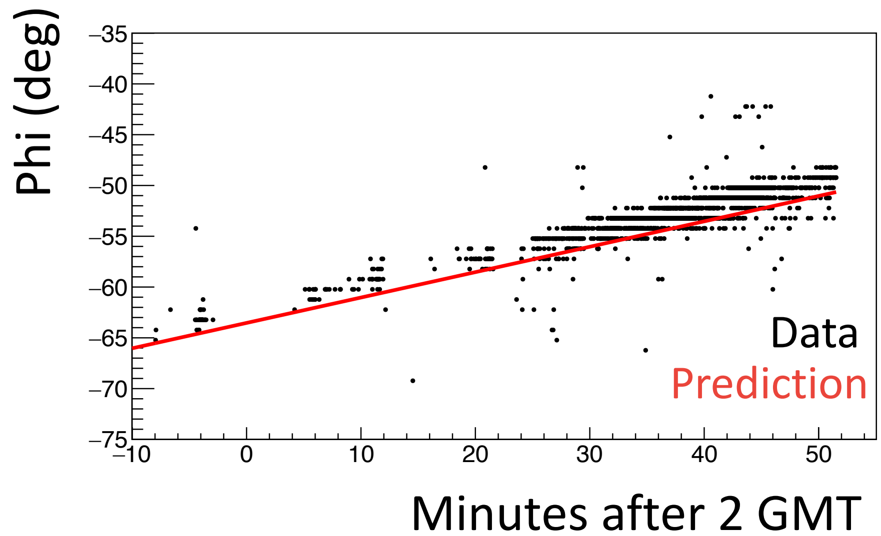
ARA Analysis Call

May 12 2017

Quick Refresher

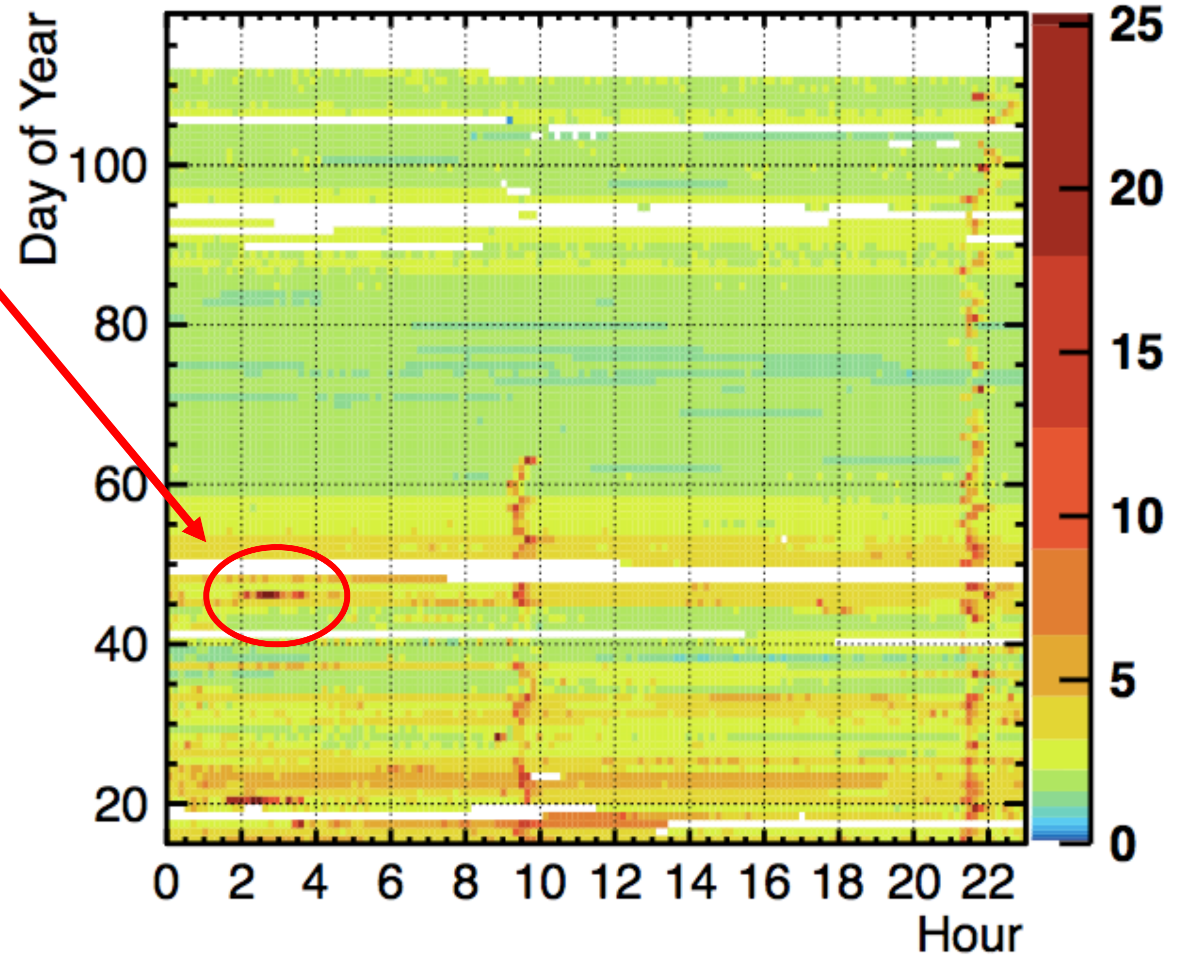
- Testbed saw Solar Flares on Feb 15 2011
  - First studied by Eugene and Carl during the Testbed search in 2014
  - Not the same flare Hagar found / is mentioned in the testbed instrument paper
- Events reconstruct to the direction of the sun over a 1-hour window
- Links to some previous talks (not inclusive):
  - http://ara.physics.wisc.edu/cgi-bin/DocDB/ShowDocument?docid=1353
  - http://ara.physics.wisc.edu/cgi-bin/DocDB/ShowDocument?docid=994
  - http://ara.physics.wisc.edu/cgi-bin/DocDB/ShowDocument?docid=982
  - http://ara.physics.wisc.edu/cgi-bin/DocDB/ShowDocument?docid=980





Quick Refresher (cont.)

- Aside: can be seen in the trigger rate plot from the testbed paper



Why Today's Talk: Summary

- We still don't understand why the solar events reconstruct uniquely
  - CW would reconstruct all over the sky
  - Uncorrelated noise wouldn't reconstruct at all
  - An impulse from the sun would reconstruct, but would have been dispersed in the ionosphere
- Few theories left
  - Correlated noise (HBT)
  - Broadband, nonthermal emission (think broadband single slit diffraction)
  - Chirps
- Starting with the last
  - Figured out the expected frequency evolution of solar radio emission
  - Found it to be on the order of seconds or minutes
  - Going to look for that

About Solar Radio Emission

- Solar radio astronomers have classifications for radio emission
- Largely determined by how the coronal plasma responds to the flares' disruptive influence
- Emission frequency proportional to electron density at the location of the disturbance, which in turn depends on distance from the sun's center[1]:

$$f \propto \sqrt{n_e} \propto 1/R^2$$

- So, as the disturbance (whether shocks, ejecta, etc) exits the sun, get changing frequency with time: df/dt

1: https://swaves.gsfc.nasa.gov/swaves_science.html

Type II vs Type III

- Classified into two types based on df/dt:
- Type III, or "fast"
  - df/dt ~ 10^3 MHz/s
  - Time-scale of ~5-10 s
- Type II, or "slow"
  - df/dt ~ 10^{-1} MHz/s
  - Time-scale of ~5-10 minutes

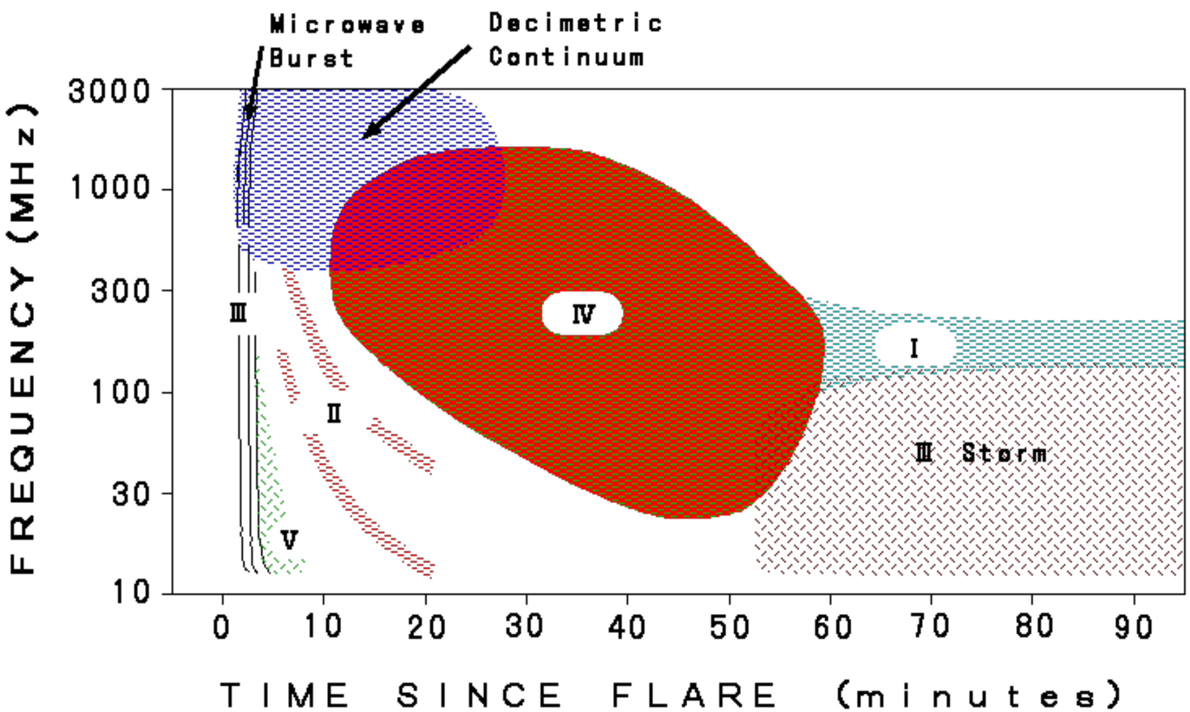


Figure source and some background info: https://web.njit.edu/~gary/728/Lecture11.html

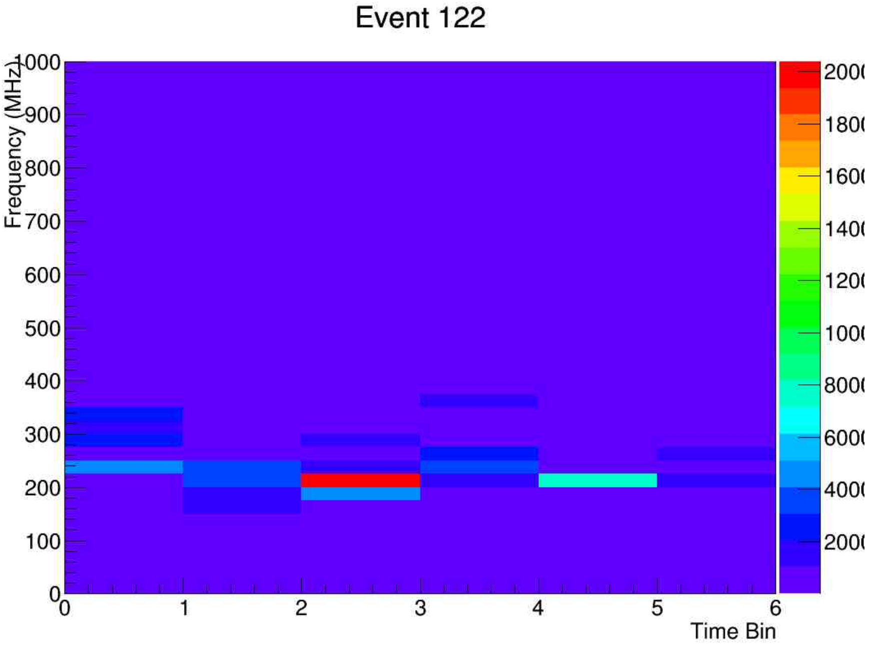
Can df/dt explain the correlation?

- Neither type-II or type-III bursts are fast enough to give a correlation on the timescale of ~250ns
  - Type-III bursts are the fastest, and in the center of our band at 350MHz , people estimate (see Melendez[1]) df/dt ~ 700 MHz/s
  - Over a 250 ns waveform, this Is a 170 Hz of drift
  - To resolve this change, you'd need ~1/170Hz = 6ms of time
  - This is a million times longer than a waveform
- Math suggests no, but we check just to be sure (revisiting Eugene's previous work[2])

1: http://link.springer.com/article/10.1023/A:1005110111620
2: http://ara.physics.wisc.edu/cgi-bin/DocDB/ShowDocument?docid=994

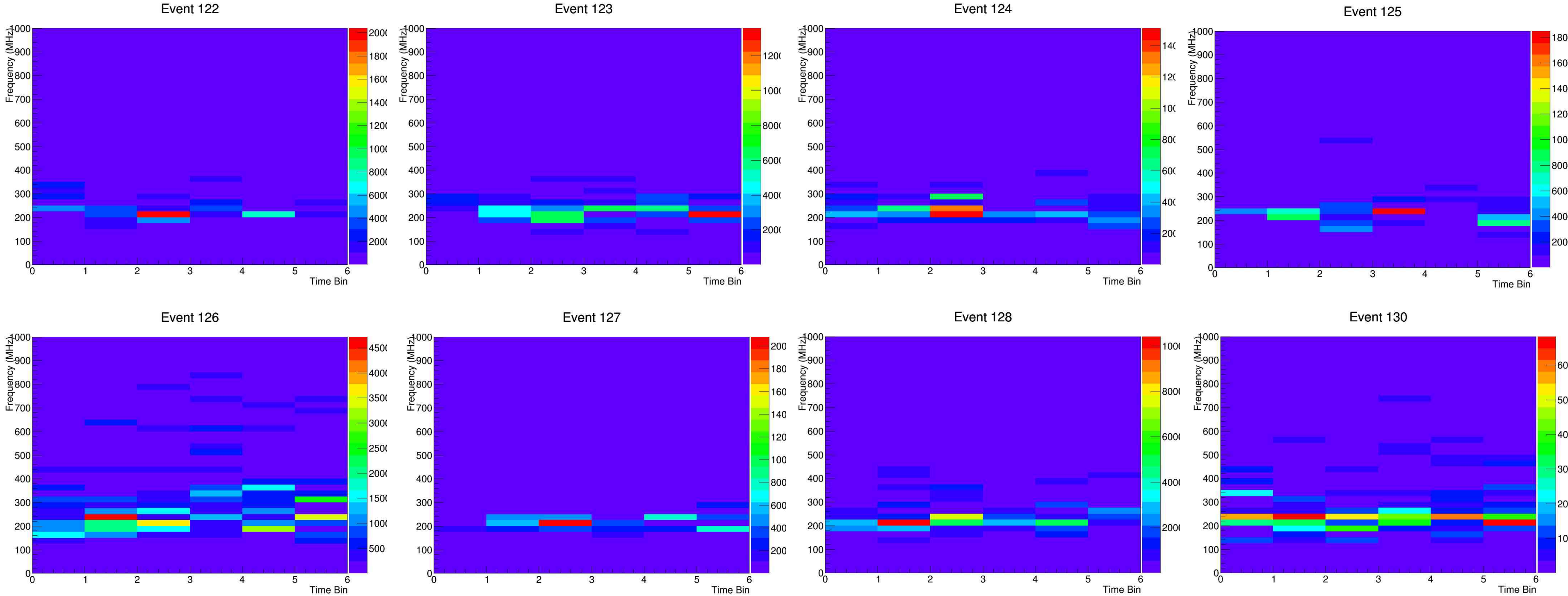
Single Waveform Spectrograms

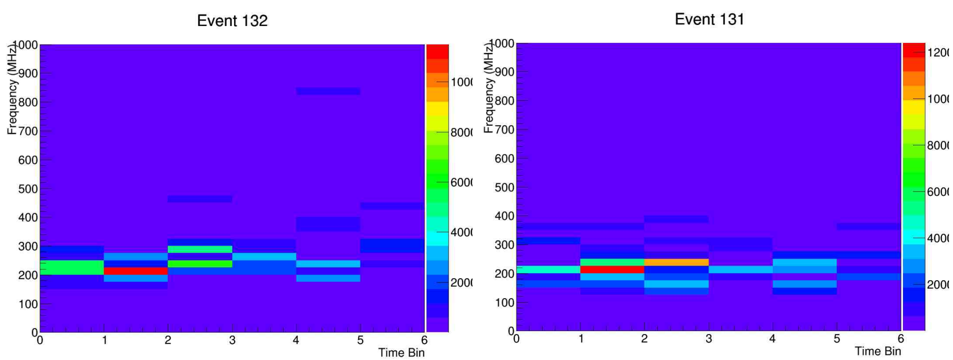
- Procedure (basically a short time fourier transform)
  - Interpolate waveform to 0.5 ns sample spacing
  - Cute waveform into 6 pieces, and FFT each piece
  - Final spectrogram has 40 ns time bins and 25 MHz frequency bins (see backup slides for an explanation)
  - This particular routine by Eugene
- Example from channel 2
- More on next slide
- Reconstruction maps are in backup slides (the ones I show here have good reconstruction)



Single Waveform Spectrograms

- Here are 10, just to give a sampling

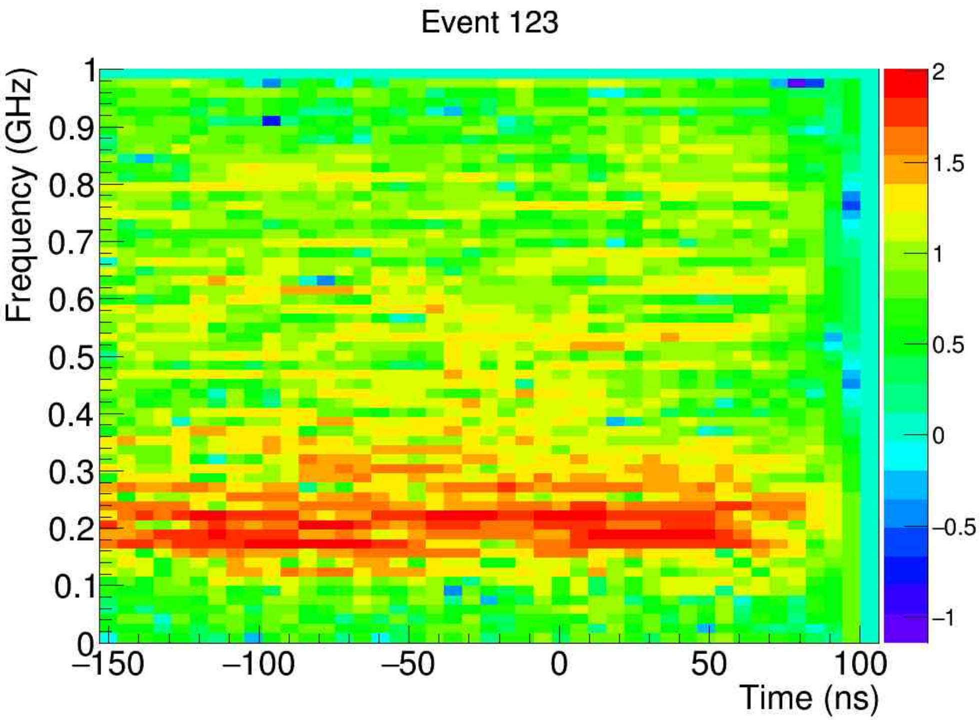




Sometimes get narrow band spike, but nothing chirpish emerges

Single Waveform Spectrograms

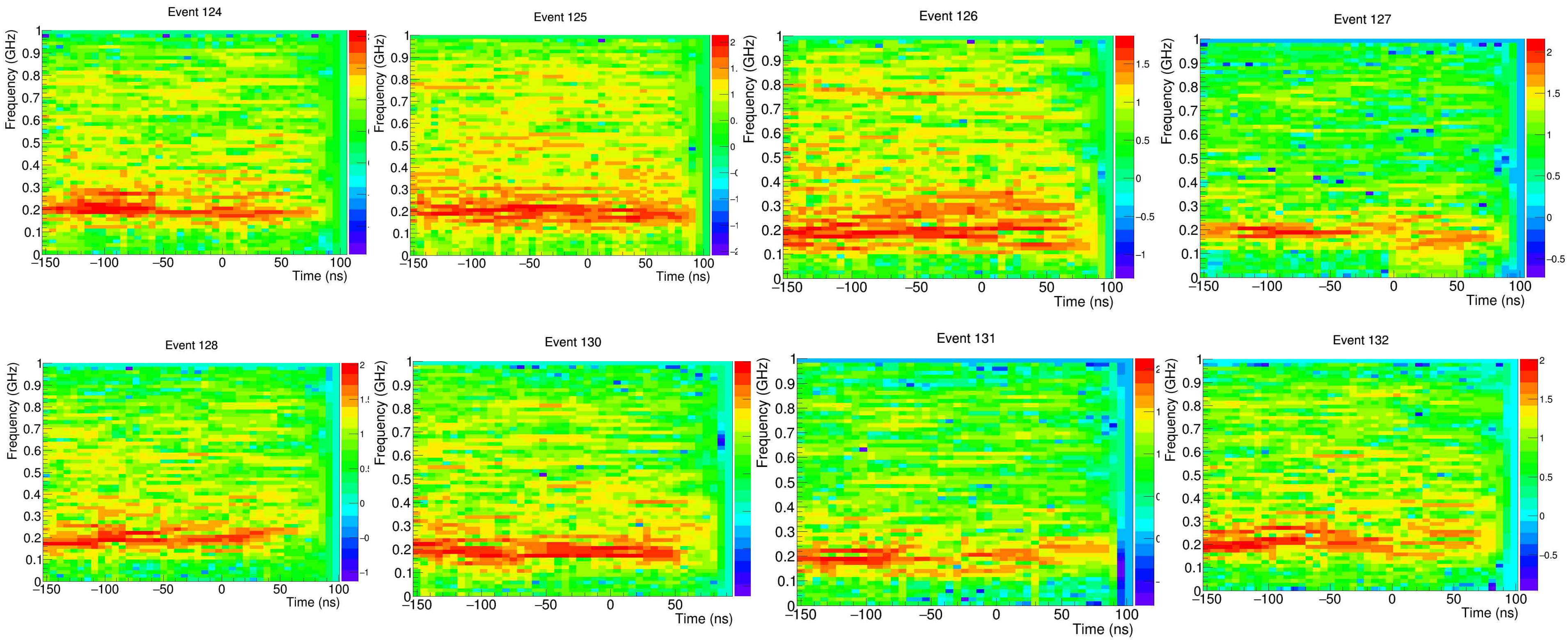
- Can generate more time bins by implementing a "moving window"
  - FFT each in window, then advance it by a "hop size", and FFT again (Jordan wrote the routine I'm suing)
  - Get more time bins, *but*, each time bin is correlated to the neighboring bins
  - The merits/drawbacks are discussed a little here [1,2]



1: https://ccrma.stanford.edu/~jos/parshl/Choice_Hop_Size.html 2: http://www.cs.princeton.edu/~fiebrink/314/2009/week12/FFT_handout.pdf

Single Waveform Spectrograms

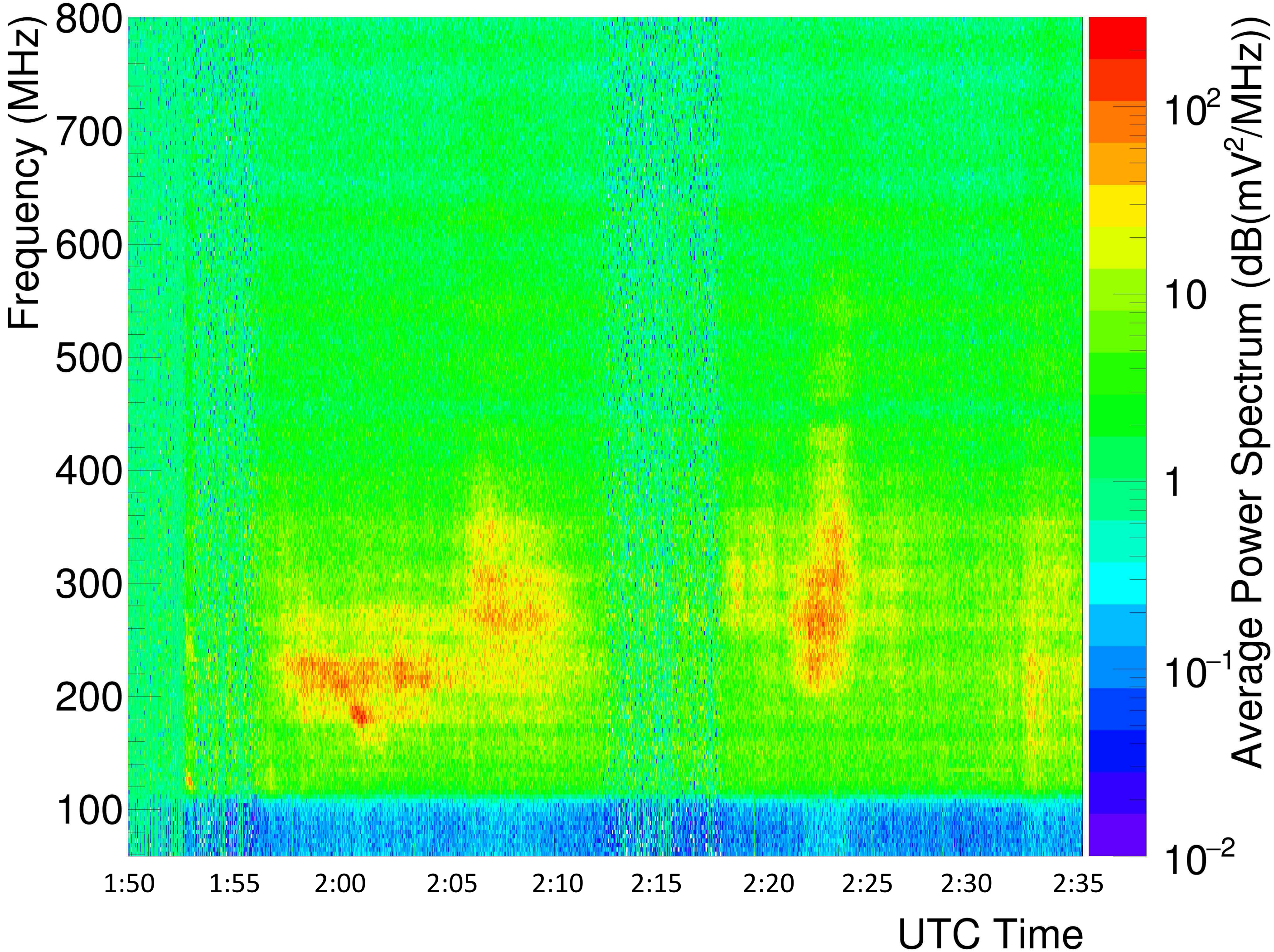
- Here are 8 with the overlapping method



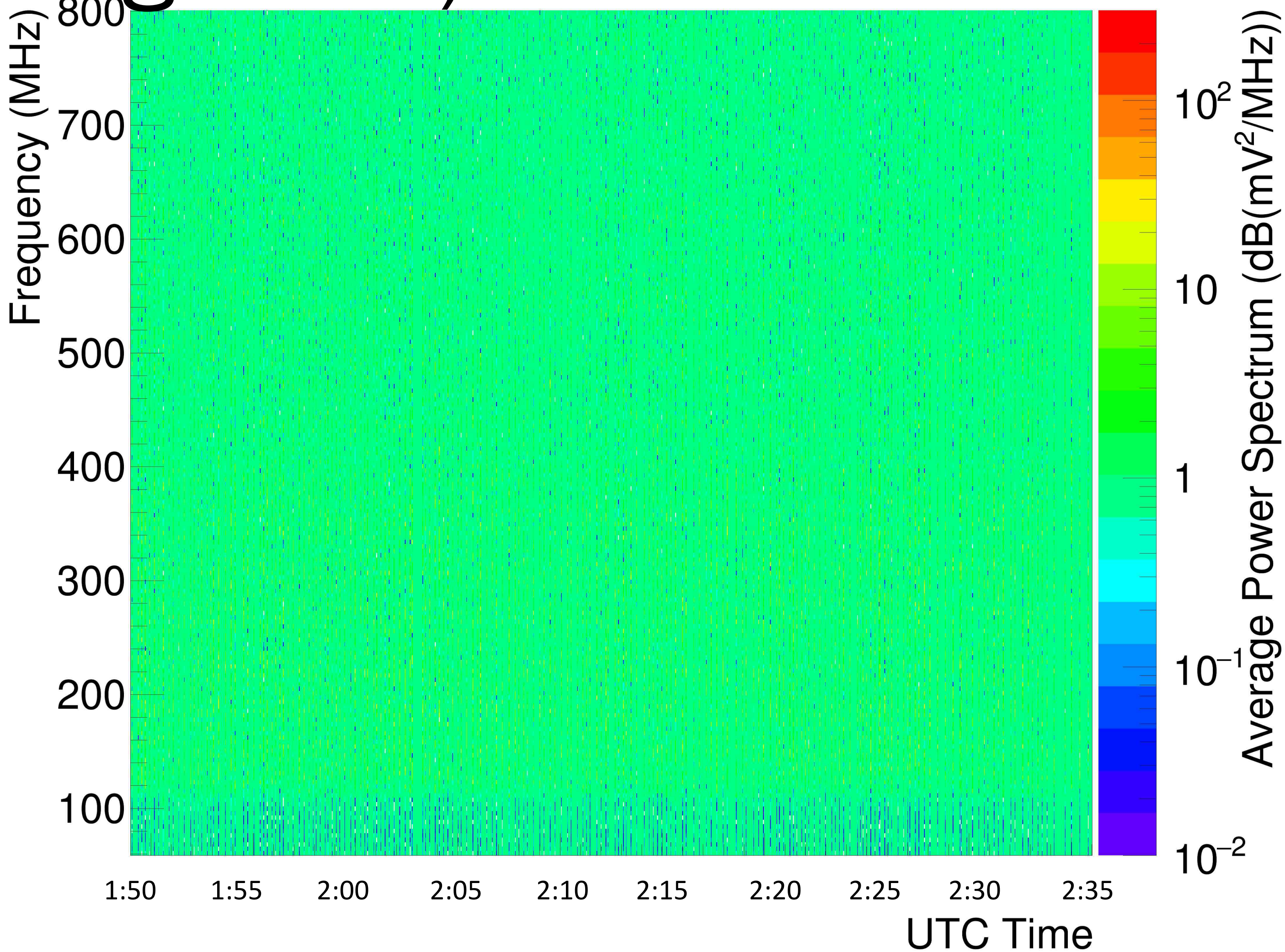
Hour Long Spectrogram

- Compute a background-subtracted spectrogram
  - "Signal" = RF triggered data from Feb 15
  - "Background" = Software triggered data from Feb 11 (quiet sun period)
- Procedure
  - Spectrogram has 2s time bins and 3.9 MHz frequency bins
  - Individual waveforms are padded to a factor of 2 (512 samples) and interpolated (0.5 ns)
  - Each waveform is FFTd and the power for each frequency mode is added to the correct time and frequency bin
- Each time bin is time averaged: I divide the accumulated power by the number of events in that bin

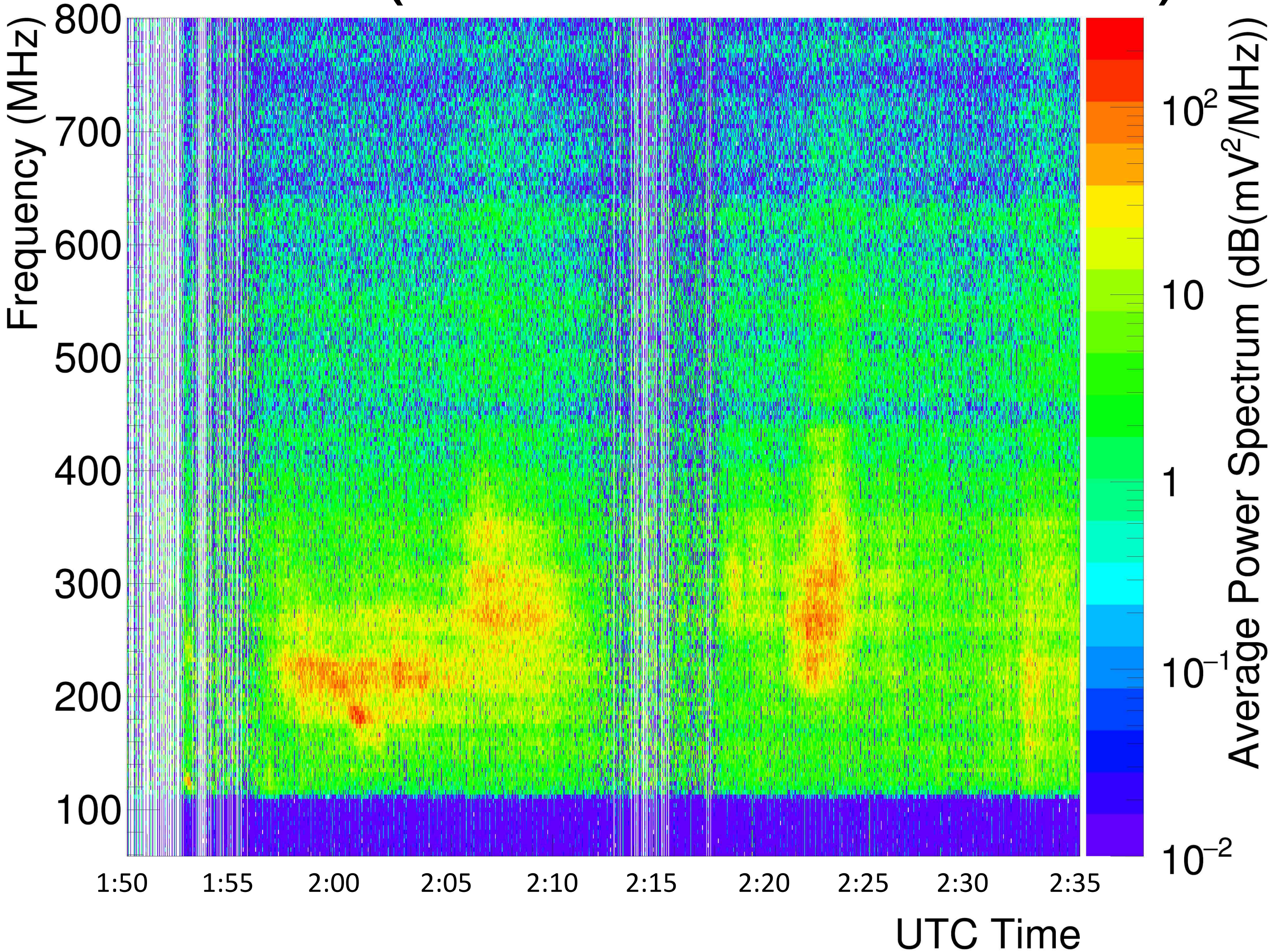
Hour Long Spectrogram: Feb 15



Hour Long Spectrogram: Feb 11 (Background)

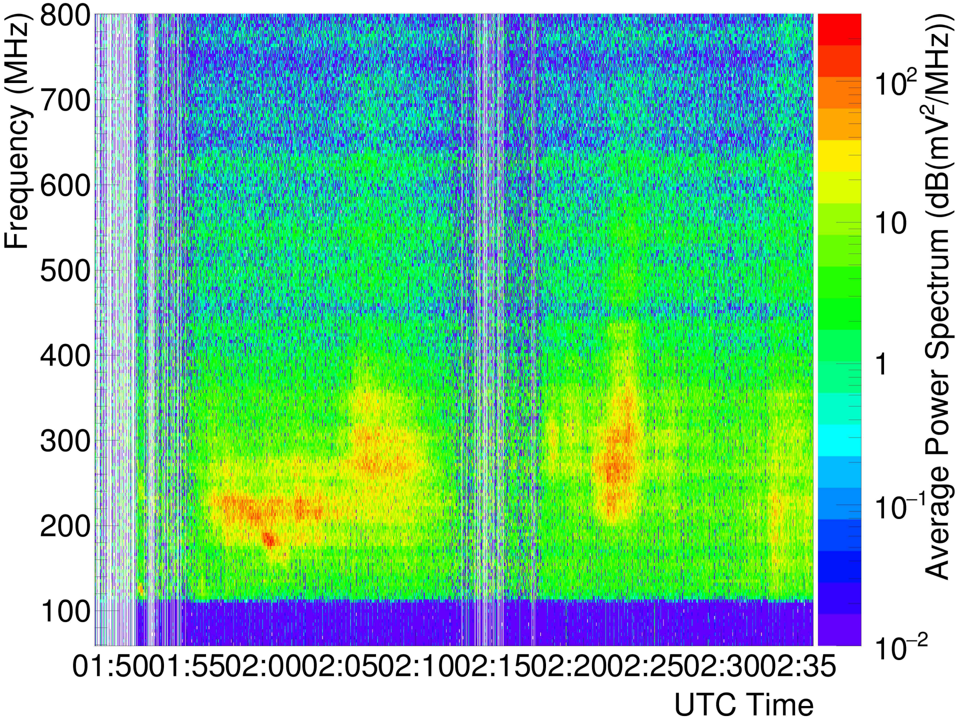


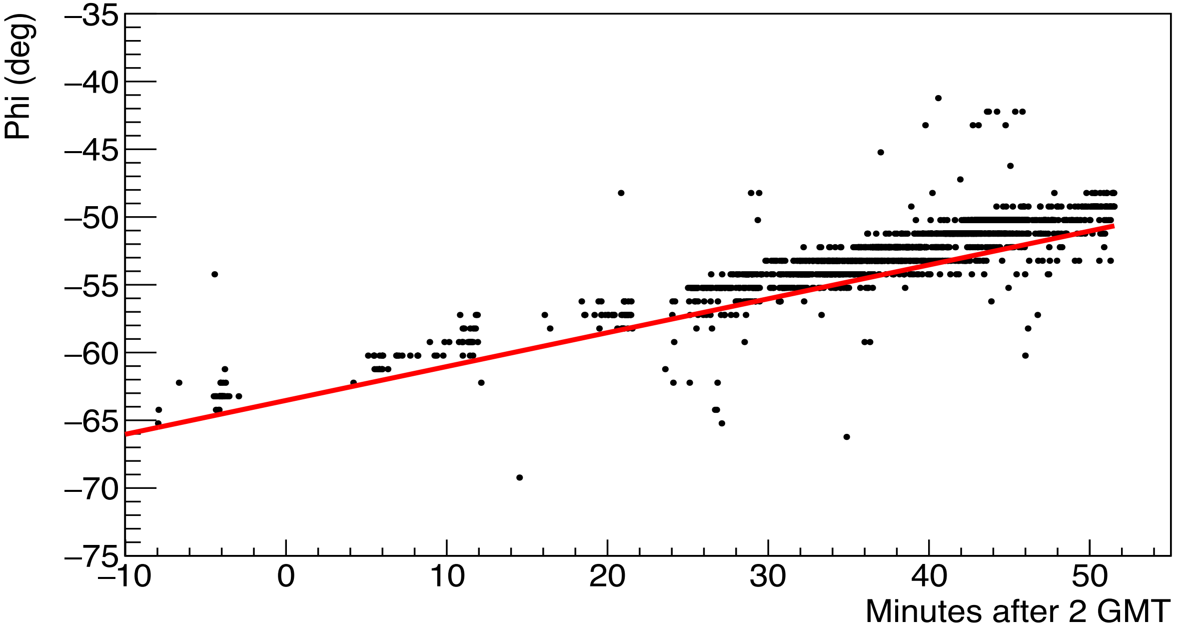
Spectrogram: Background Subtracted (Feb 15 – Feb 11)



Spectrogram Compared with Tracking

- Tracking plot has several analysis cuts applied (slanted cut, reconstruction quality cut, etc) that seem to be eliminating events even during peak flare intensity
- Need to study this more





Reference Spectrogram

- Comparing this to a measurement from the solar radio observatory: Culgoora[1]
- They have a spectrogram of this same flare (same time window, same frequency range)
- They place it in their type-II catalog[2]

Culgoora Observatory

15/02/11 01:52 Type II Event

(last updated 15 Feb 2011 02:38 UT)

```
URASP 85303 10215 57183 ////2 57261 20152 20200
                              57123 40153 1////

PLAIN
PRESTO CULGOORA 15/0205UT FEB 2011


SOLAR RADIO EVENT 1:
   DRIFTING: 260 - 57 MHZ
   START TIME: 0152 UT   END   TIME: 0200 UT
   SPECTRAL TYPE: TYPE II BURST
   IMPORTANCE: MODERATE
   FUNDAMENTAL AND HARMONIC VISIBLE
   ESTIMATED SHOCK SPEED 800 KM/S

SOLAR RADIO EVENT 2:
   DRIFTING: 1200 - 57 MHZ
   START TIME: 0153 UT   END   TIME: -EVENT IN PROGRESS
   SPECTRAL TYPE: TYPE IV
   IMPORTANCE: WEAK
NO OPTICAL OBSERVATION POSSIBLE
NO FADEOUT OBSERVED

HTTP://WWW.IPS.GOV.AU/SOLAR/2/3
_______________________________________________
IPS-CLG-RADIO-SWEEP-EVENT MAILING LIST
IPS-CLG-RADIO-SWEEP-EVENT@IPS.GOV.AU
HTTP://WWW.IPS.GOV.AU/MAILMAN/LISTINFO/IPS-CLG-RADIO-SWEEP-EVENT
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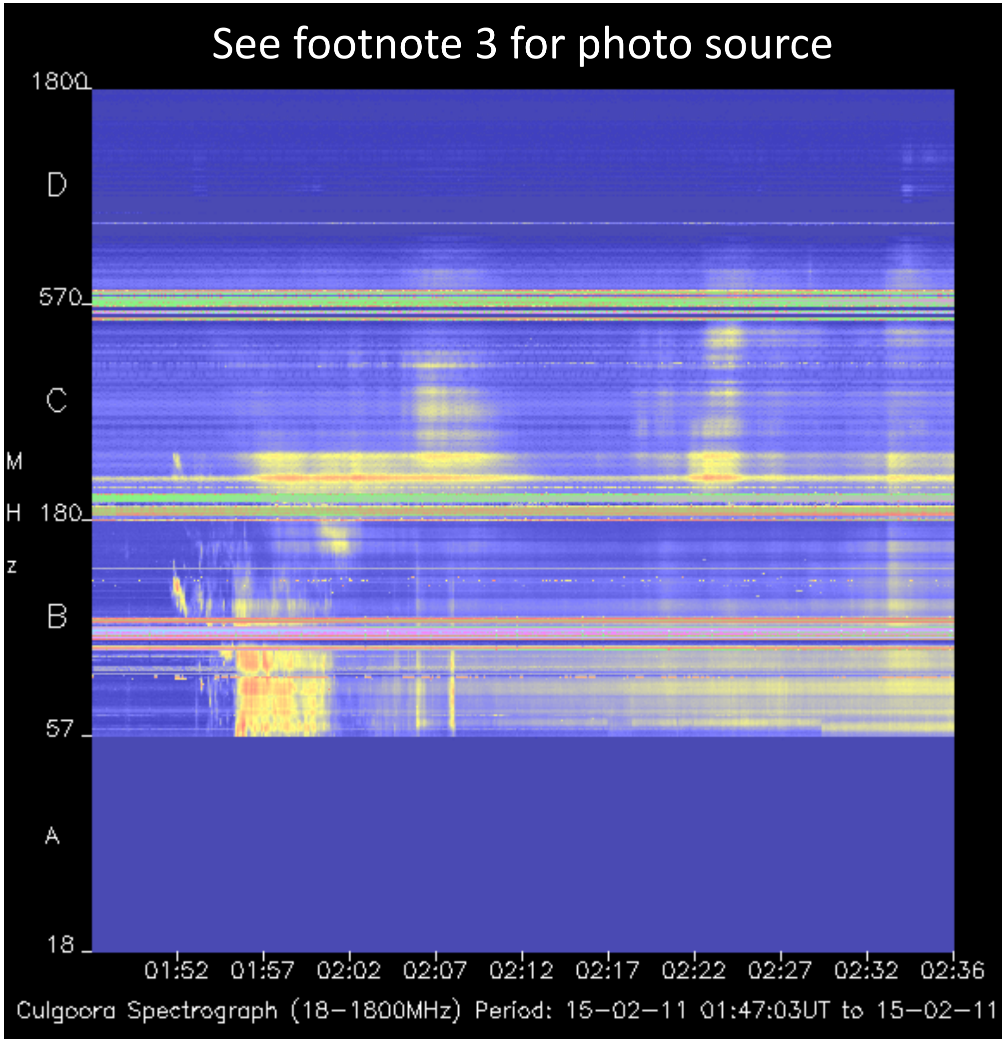
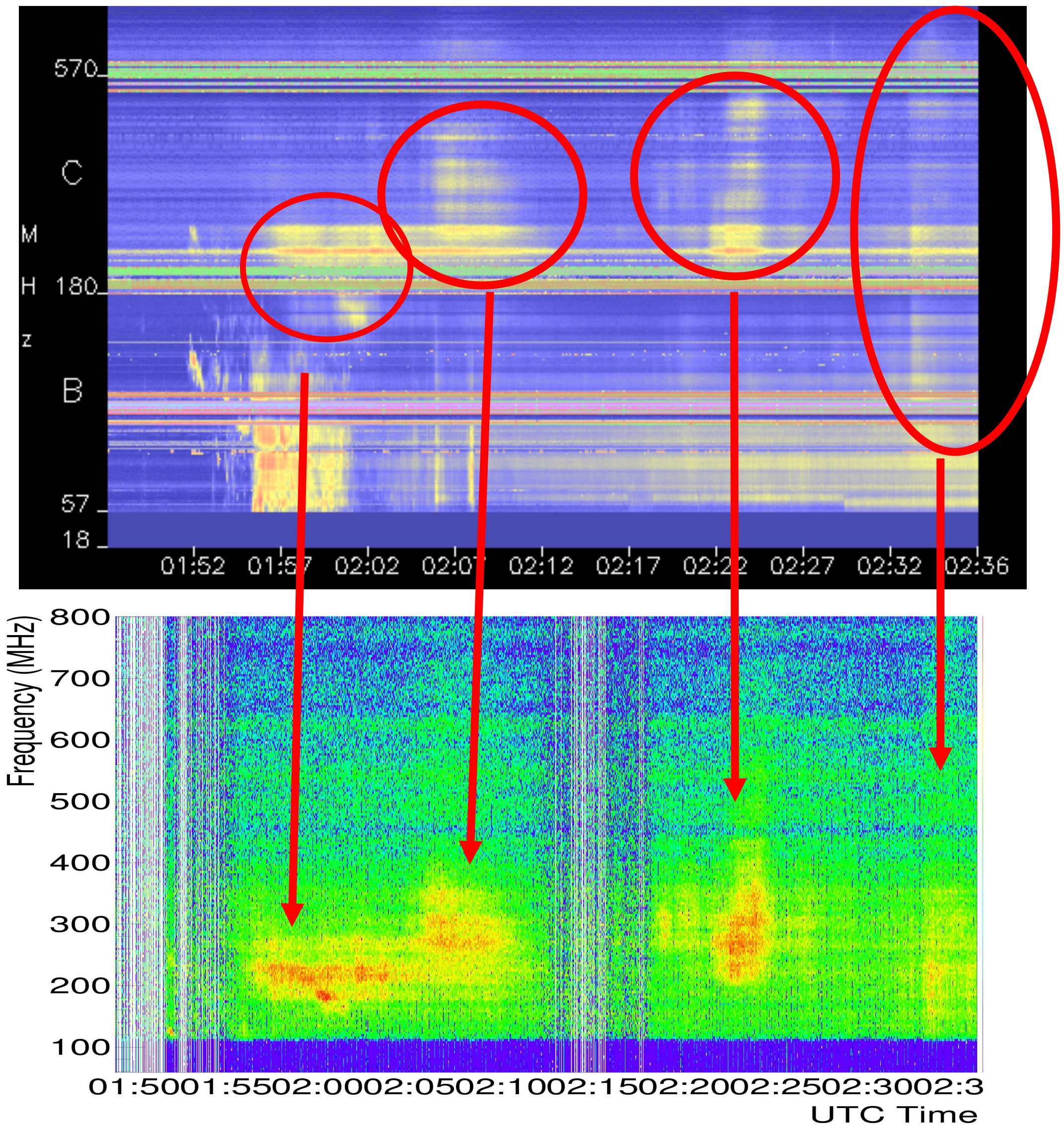


1: http://www.sws.bom.gov.au/Solar/2/1 2: http://www.sws.bom.gov.au/Solar/2/5/1 3: link

Comparison with Culgoora

- Very similar features
- Gives us confidence we're not just seeing noise
- Will try to make this more obvious by plotting the Culgoora data manually (the data is publicly accessible)



Spectrogram Features

- The ARA high-pass filter starts at ~110MHz
- Beginning of flare emission at about 2:56 PM
    - Roughly coincides with the peaking of the soft x-ray emission
        - RHESSI (3-10 keV) says the flare peaks at 1:55AM[1]
        - Fermi GMB (>10 keV) says the flare peaks at 1:50AM[2]
    - This is consistent with expectations: type-II emission usually starts at the peaking of soft x-rays (see White[3])

1: https://hesperia.gsfc.nasa.gov/hessidata/dbase/hessi_flare_list.txt
2: https://catalog.data.gov/dataset/gbm-solar-flare-list/resource/d9b35c16-0621-4f50-8410-562c4b1d2e55
3: https://www.nrao.edu/astrores/gbsrbs/Pubs/AJP_07.pdf

Conclusions

- Chirp behavior can’t explain the correlation on event-by-event basis
- We made a spectrogram that is remarkably similar to one measured by solar radio experts

Paper in Progress

- Writing a paper, first draft taking shape

- Important Points
  - We observe a natural source of radio emission that is reconstructable
  - We measure a spectrogram consistent with an other radio experts, which is verification of instrument behavior
  - Could provide a useful calibration of reconstructions above the ice or measuring n(z) in the firm around each station (still need to look in deep stations!)

Observation of Reconstructable Radio Waveforms from the February 15 2011 Solar Flare with the Askaryan Radio Array Prototype Station

Author list goes here

May 11, 2017

Abstract

An awesome abstract will go here

Contents

Back-Up Slide: Choosing Bin Sizes

- Trade off between spectral and temporal resolution: the finer the frequency binning, the coarser the time binning

Number of points in a waveform chunk →

$$N = \frac{1}{\Delta t \cdot \Delta f}$$

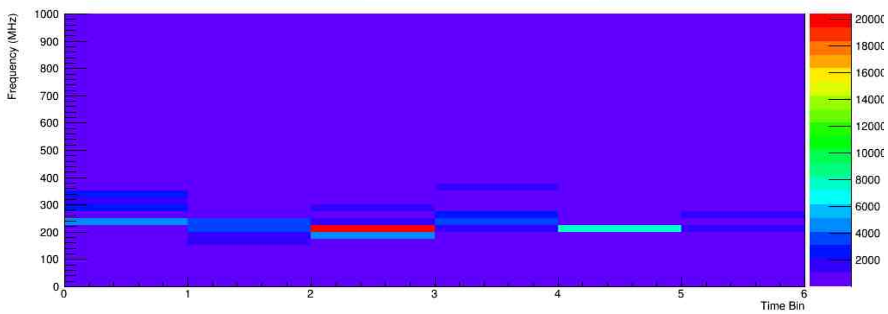
Size of spectral bin (Δf)

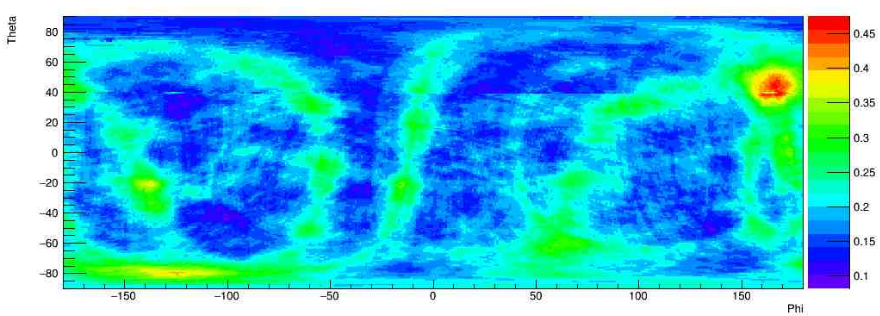
Length of waveform chunk (Δt)

- We only have ~500 data points (after 0.5ns interpolation)
- If I want the waveform to have about 6 time slices (so ~80 samples per slice, or 40ns of data), I can't do better than Δf ~ 25 MHz

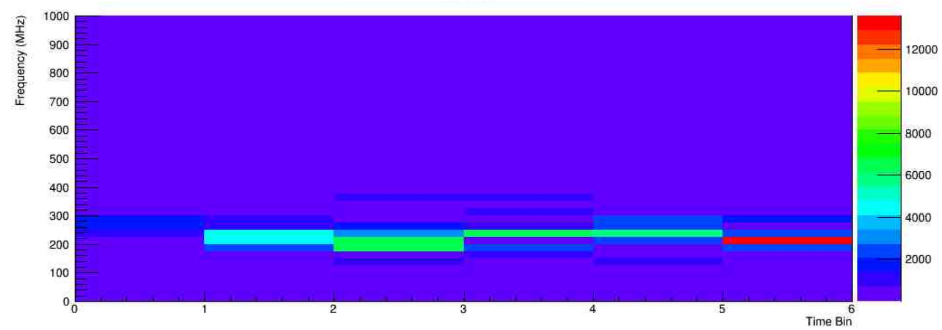
Back-Up Slide: Spectrograms with Reconstruction Maps

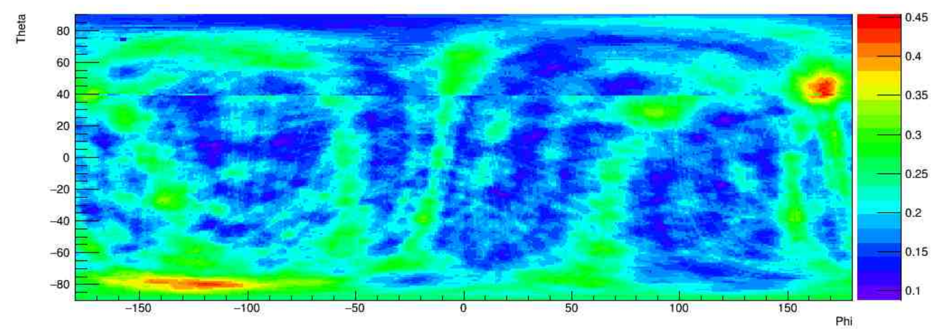
Event 122





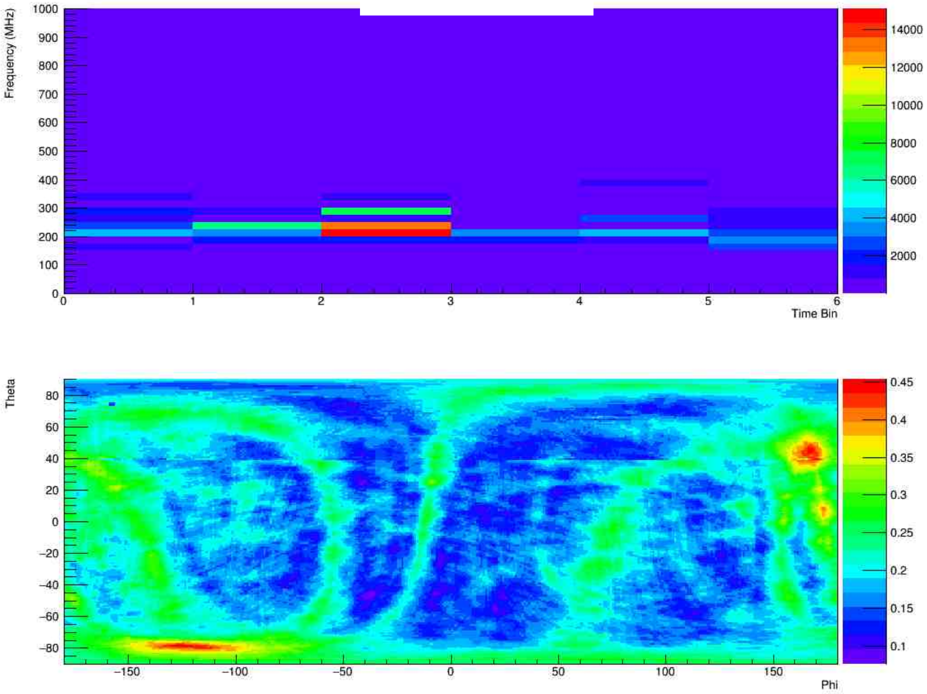
Event 123



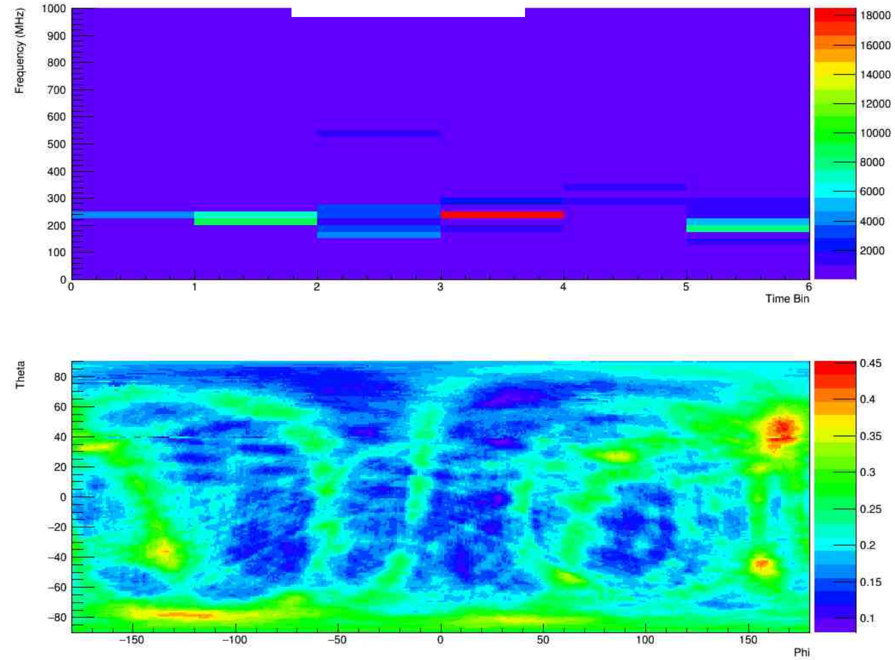


Back-Up Slide: Spectrograms with Reconstruction Maps (cont.)

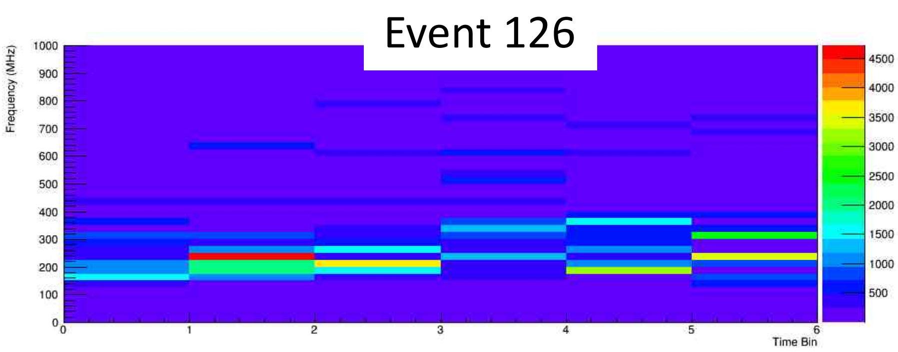
Event 124

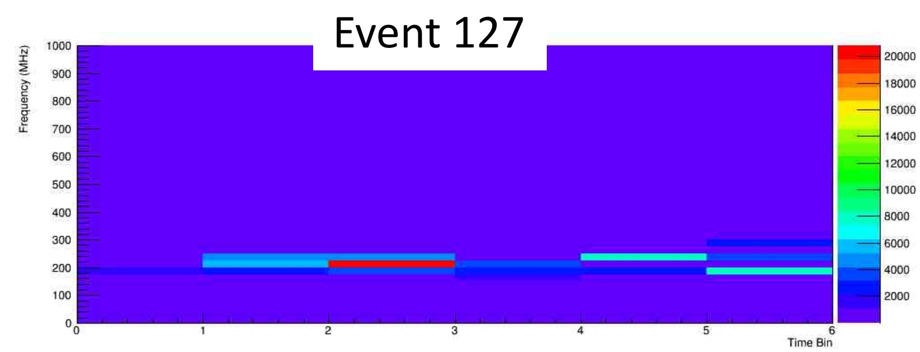


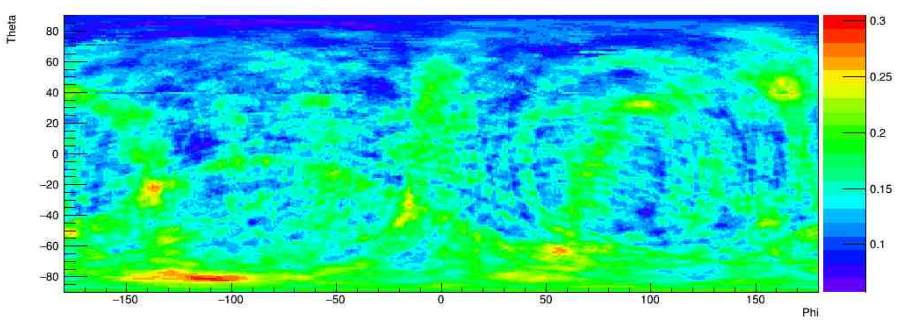
Event 125

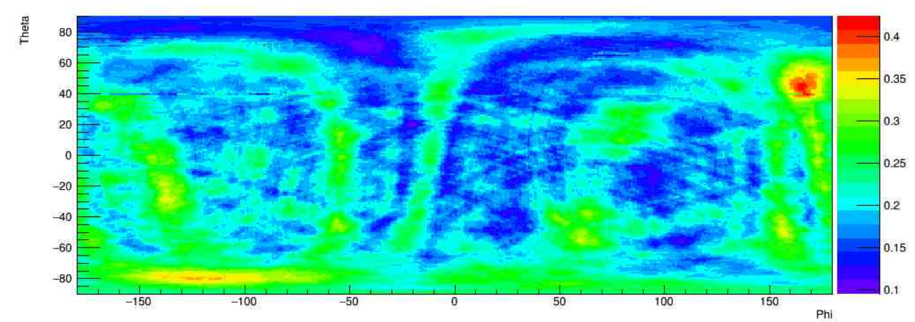


Back-Up Slide: Spectrograms with Reconstruction Maps (cont.)



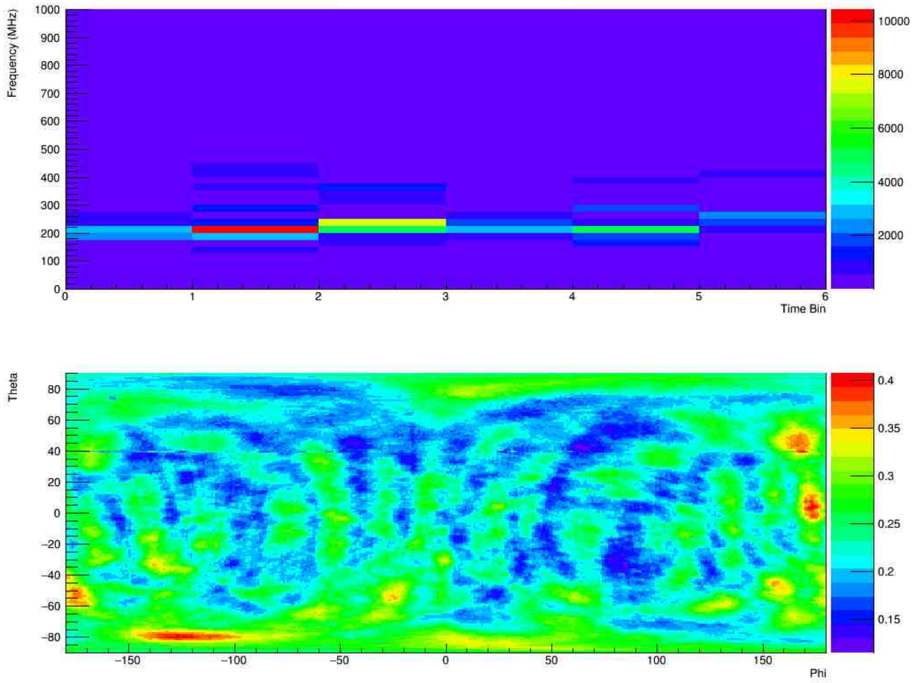






Back-Up Slide: Spectrograms with Reconstruction Maps (cont.)

Event 128



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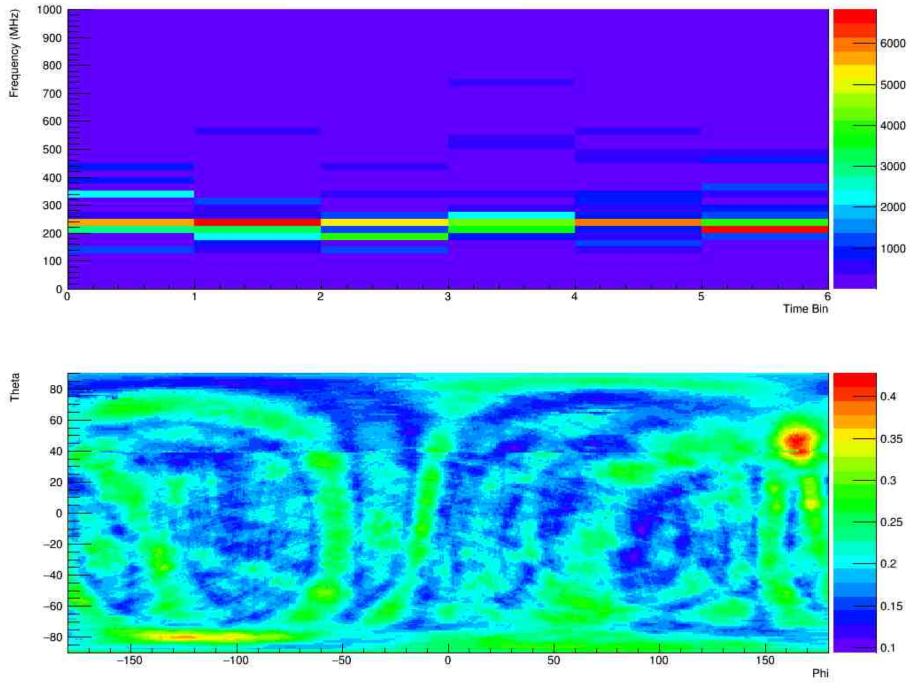
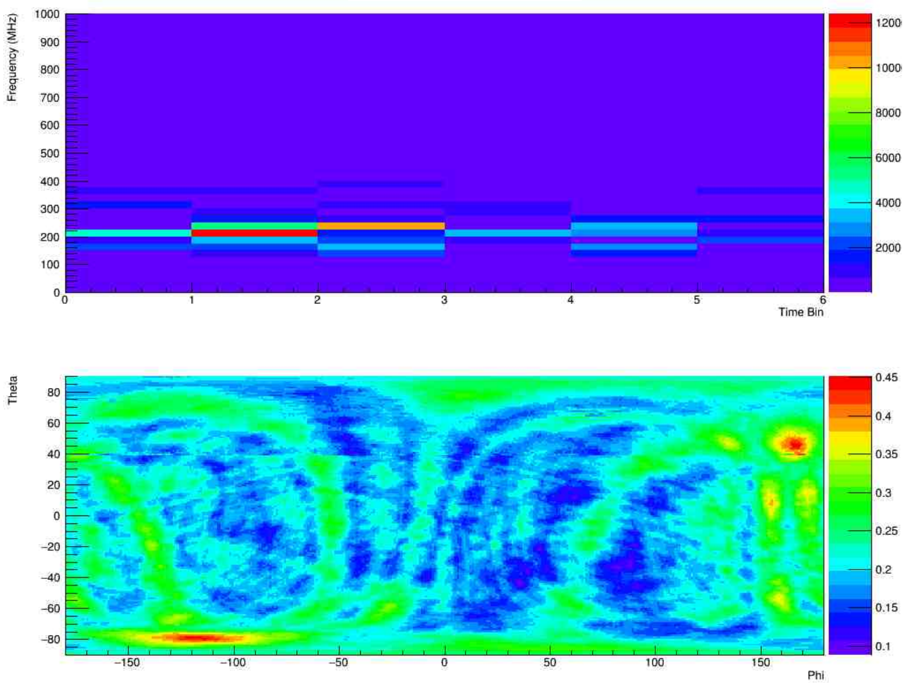


Back-Up Slide: Spectrograms with Reconstruction Maps (cont.)

Event 131



Event 132