



# The International Heating Experiments (HEX) Campaign at Arecibo

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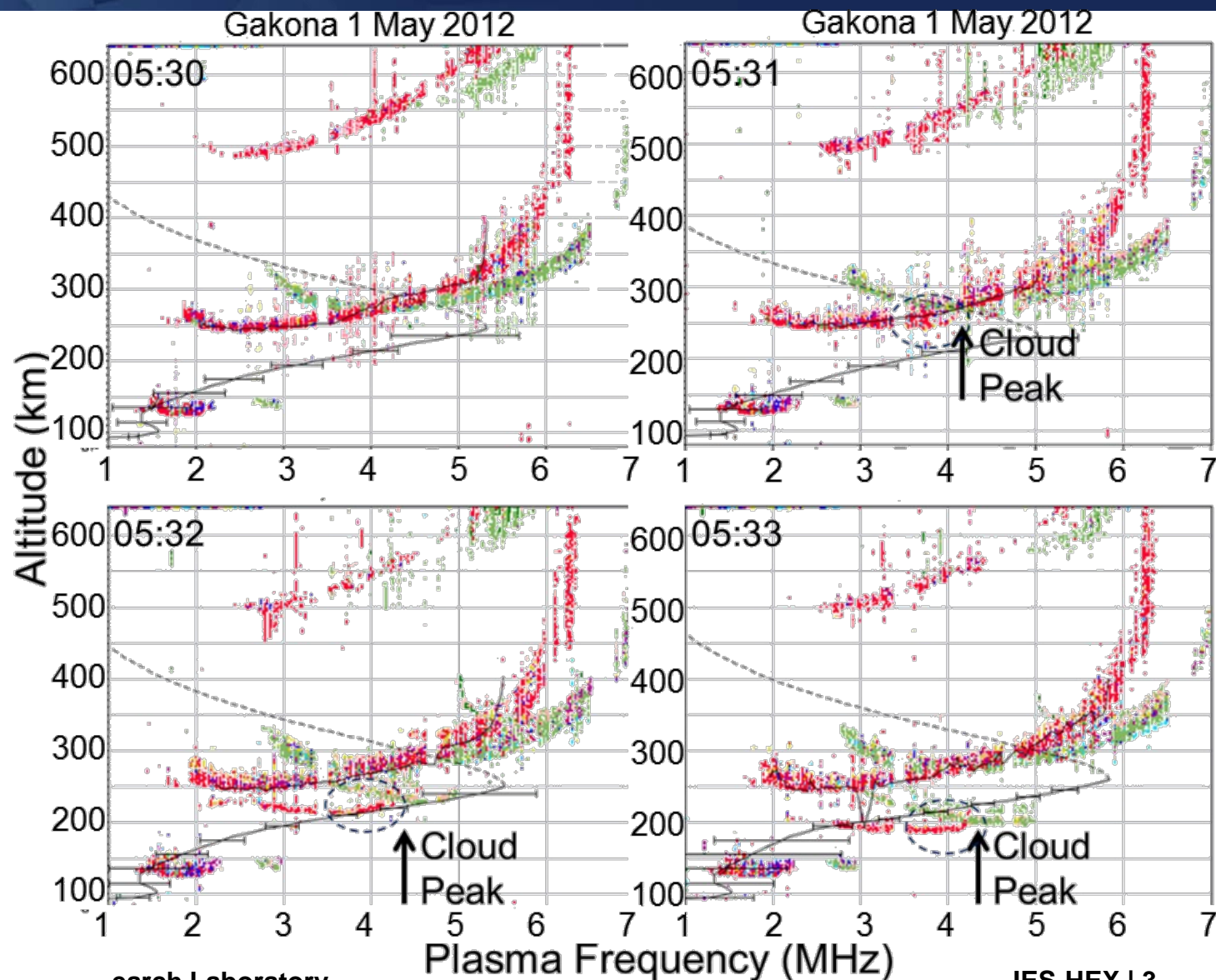
**Ionospheric Effects Symposium, Alexandria VA**

10 May 2017

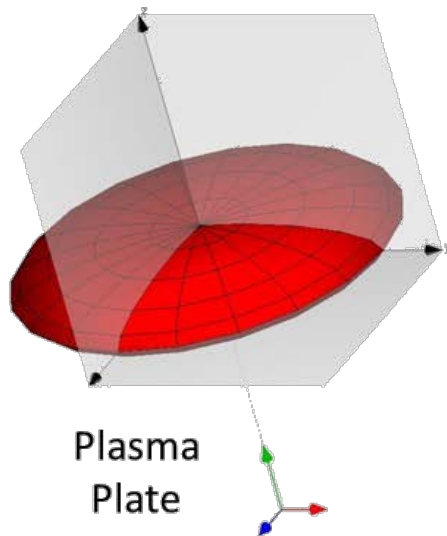
# March 2017 Arecibo Experiments

- **HAARP Observations with 3.6 MW Transmitter**
  - Artificial Ionization
  - Descending and Stable Pancake Ionization Clouds
- **Overview with Arecibo 600 kW Transmitter**
  - 13-19 March HF Campaign at Arecibo
  - ROTHF HF Radar Backscatter (Virginia and Texas)
  - UHF Incoherent Scatter Radar (Ion and Plasma Line Profiles)
  - HF Oblique Sounders Between ROTHF VA/TX/PR and Ground HF Receivers
  - ePOP HF Radio Receiver Instrument (RRI)
  - Ground SEE Receivers
  - GPS TID Receivers
- **Objective**
  - Detect Artificial Ionospheric Irregularities
  - Generate Plasma Pancakes

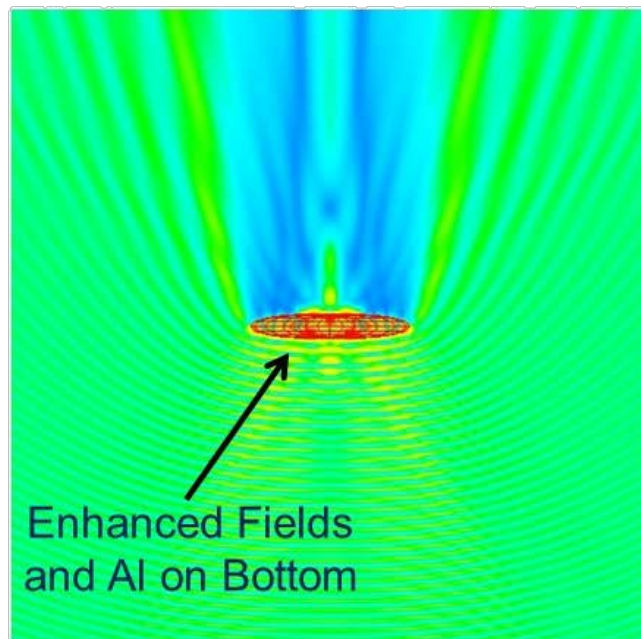
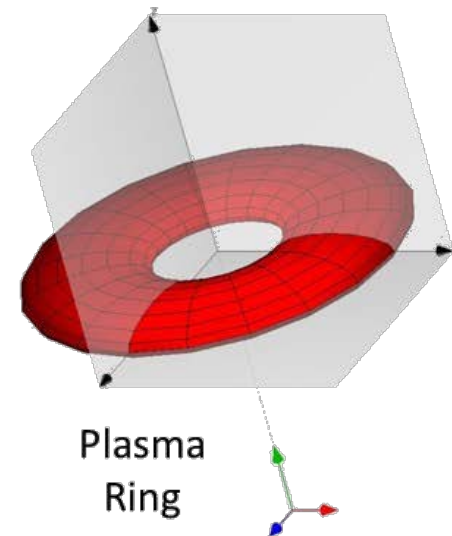
# HAARP Artificial Ionization Cloud Formed with 4.325 MHz Pump



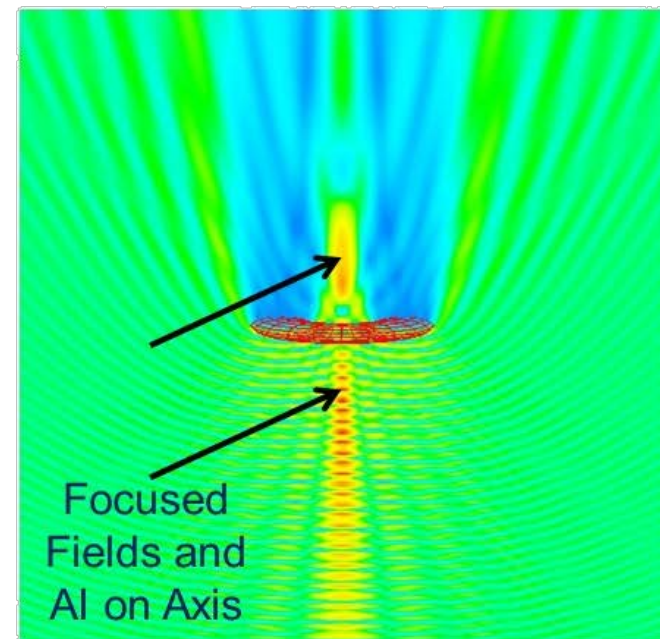
# Simulations of Plane EM Wave Interactions with Plasma Plate and Ring



3 MHz Pump  
0.9 km Diameter Cloud



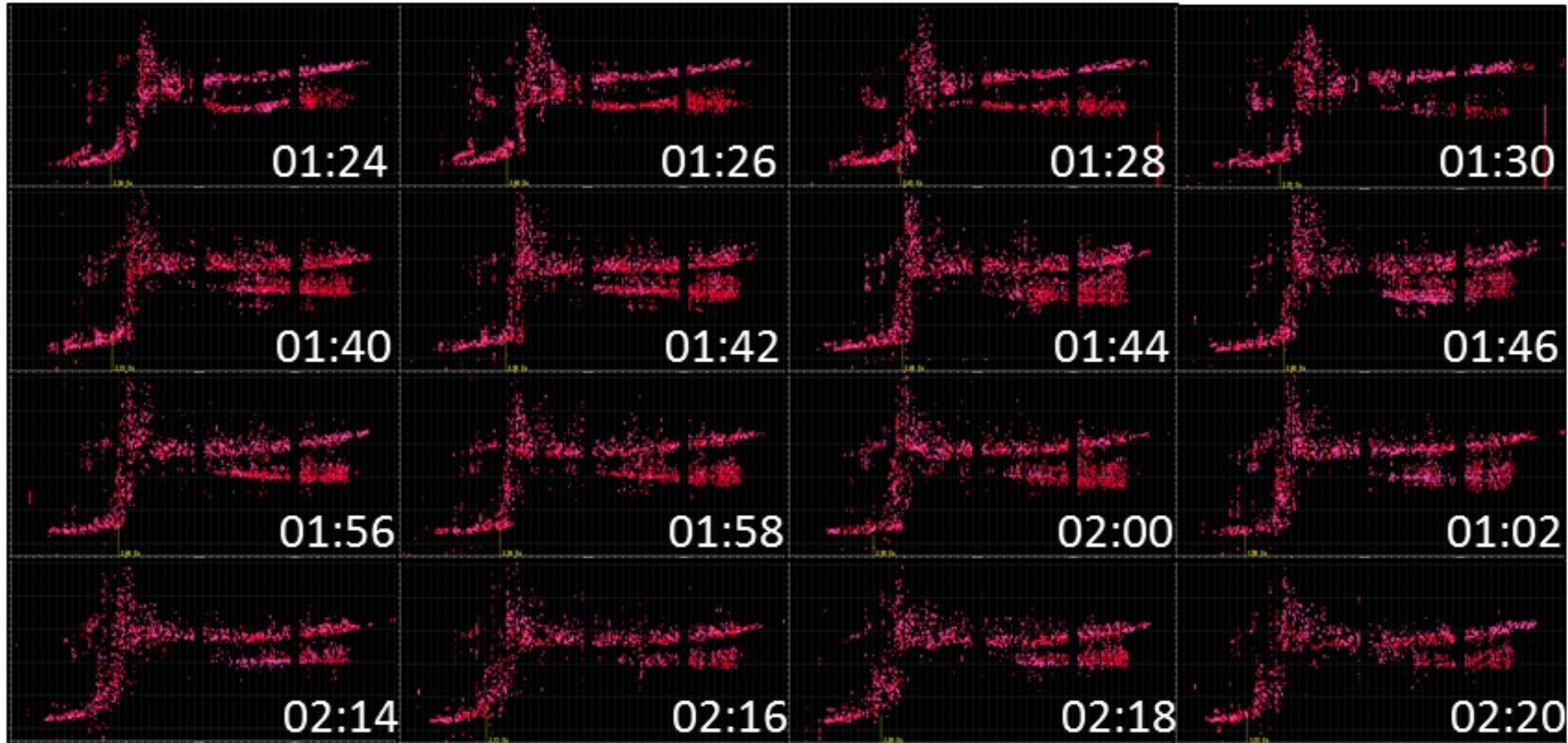
$|E|$  (V/m)



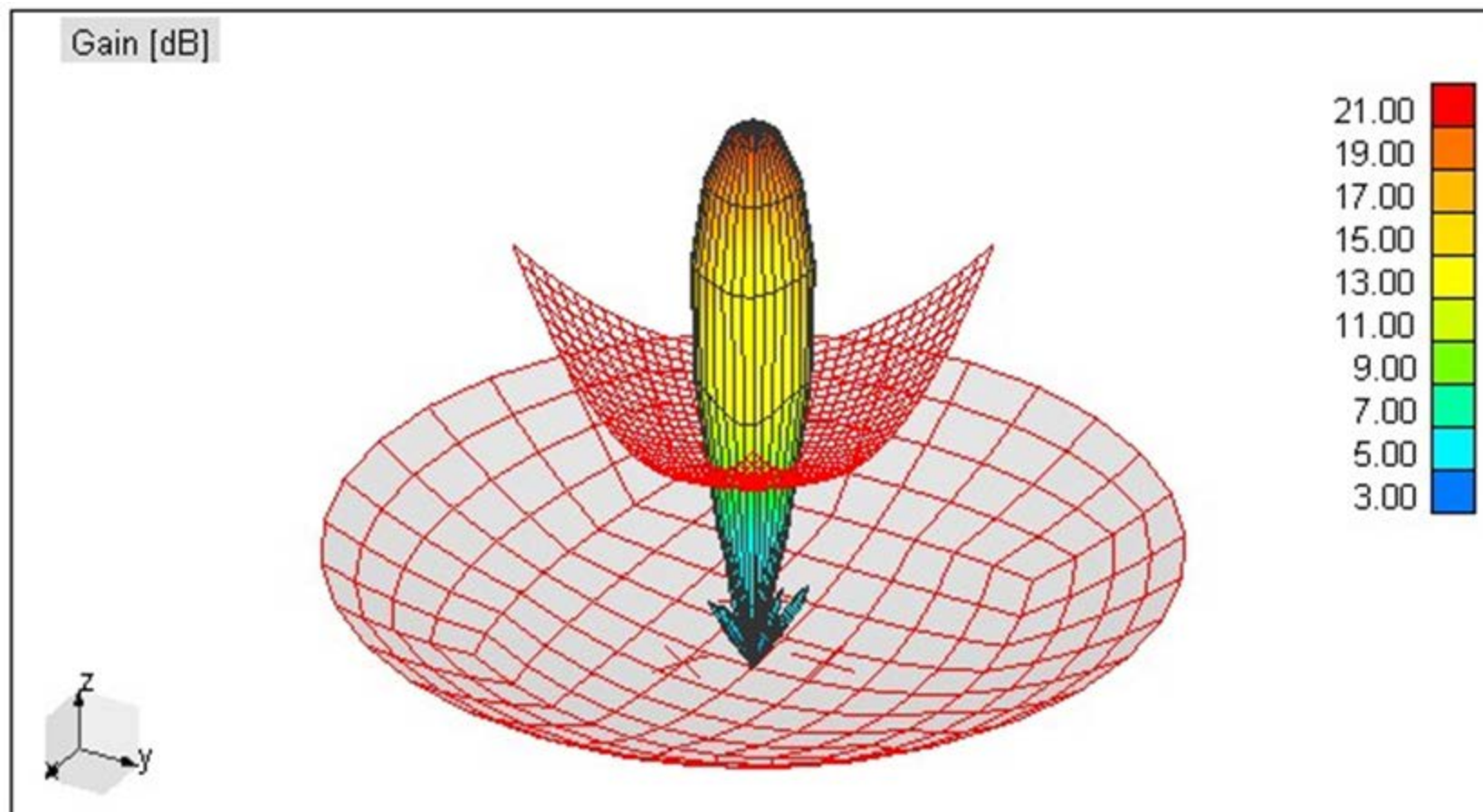


# 14 March 2013 01:00 to 01:20 GMT Artificial Ionization with 5.8 MHz Twisted Beam

Stable Artificial Ionization, HAARP Digisonde 13 March 2013



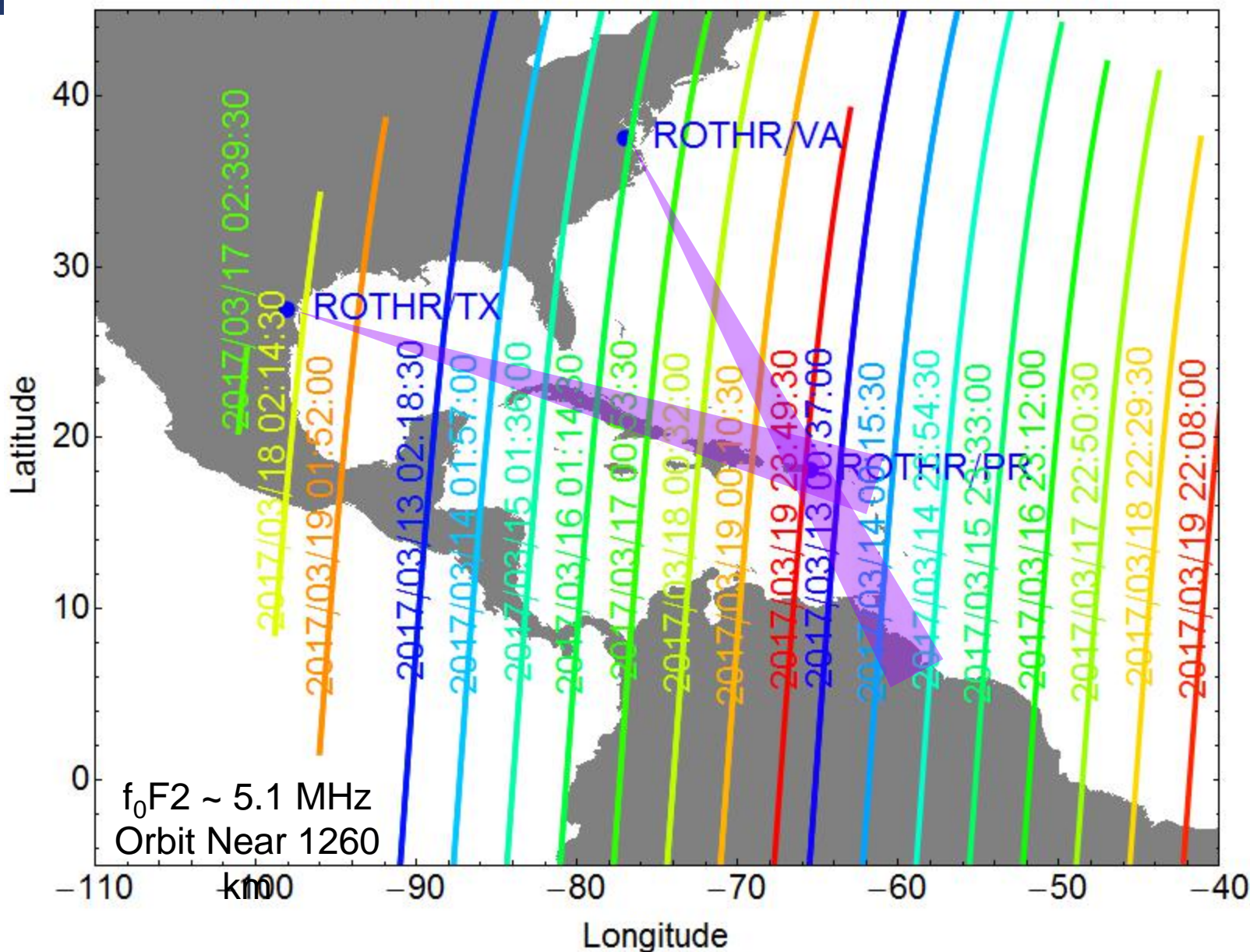
# Arecibo HF Facility Antenna Gain at 5.1 MHz with 110 MW ERP





# 2200 to 0300 AST ePOP Satellite Passes

Arecibo and ROTHR Transmitters with ePOP Orbit



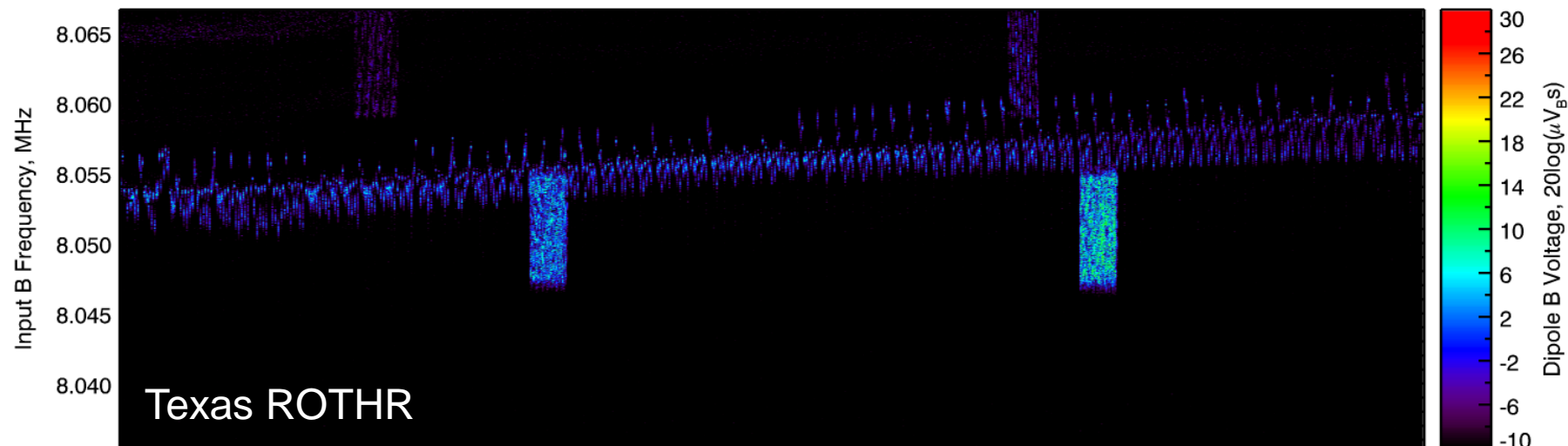
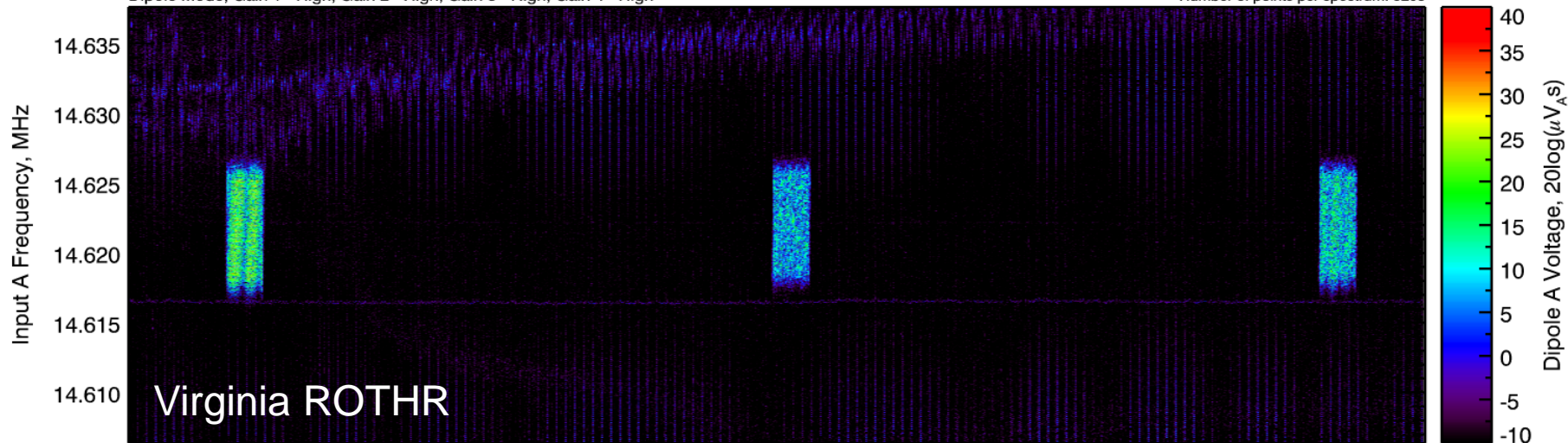


# e-POP RRI

Mar 18, 2017

Inputs: Channel 1 - I1, Channel 2 - Q1, Channel 3 - I3, Channel 4 - Q3  
Dipole Mode, Gain 1 - High, Gain 2 - High, Gain 3 - High, Gain 4 - High

Number of points per spectrum: 5208



UT	11:17:14.61	11:17:26.47	11:17:38.33	11:17:50.20	11:18:02.06	11:18:13.92	11:18:25.78
Geo. Lat, °	31.92	31.16	30.31	29.59	28.75	27.92	27.15
Geo. Lon, °	-62.45	-62.34	-62.22	-62.10	-61.98	-61.86	-61.74
Altitude, km	328.20	327.29	326.47	325.74	325.09	324.54	324.06
Mag. Lat, °	41.19	40.35	39.51	38.79	37.95	37.16	36.40
Mag. Lon, °	11.75	11.86	11.99	12.00	12.12	12.25	12.30
MLT	7.08	7.10	7.11	7.11	7.12	7.13	7.14



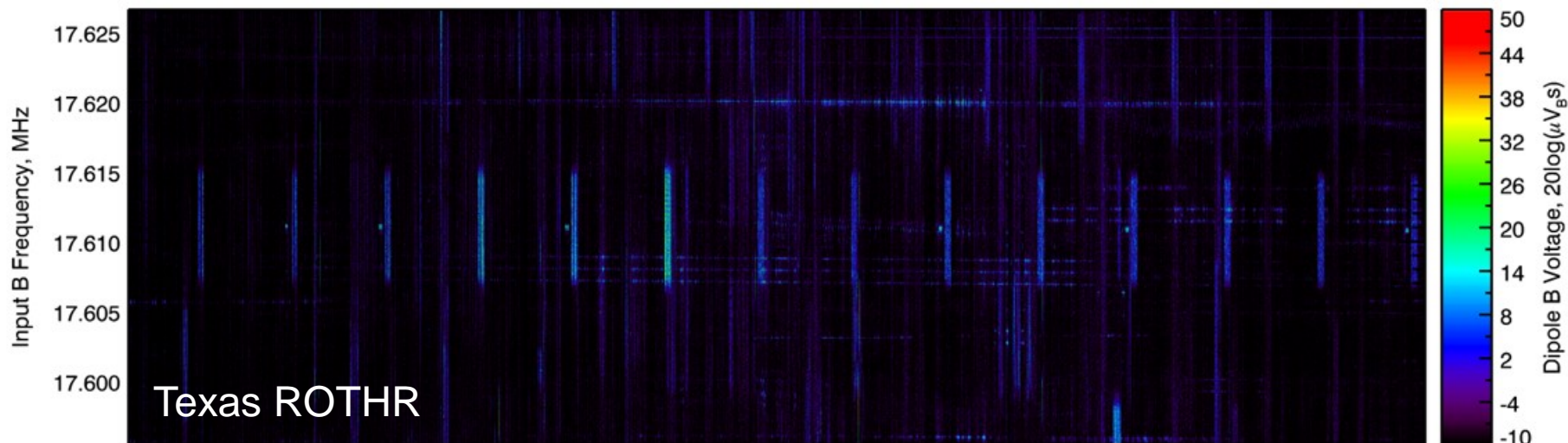
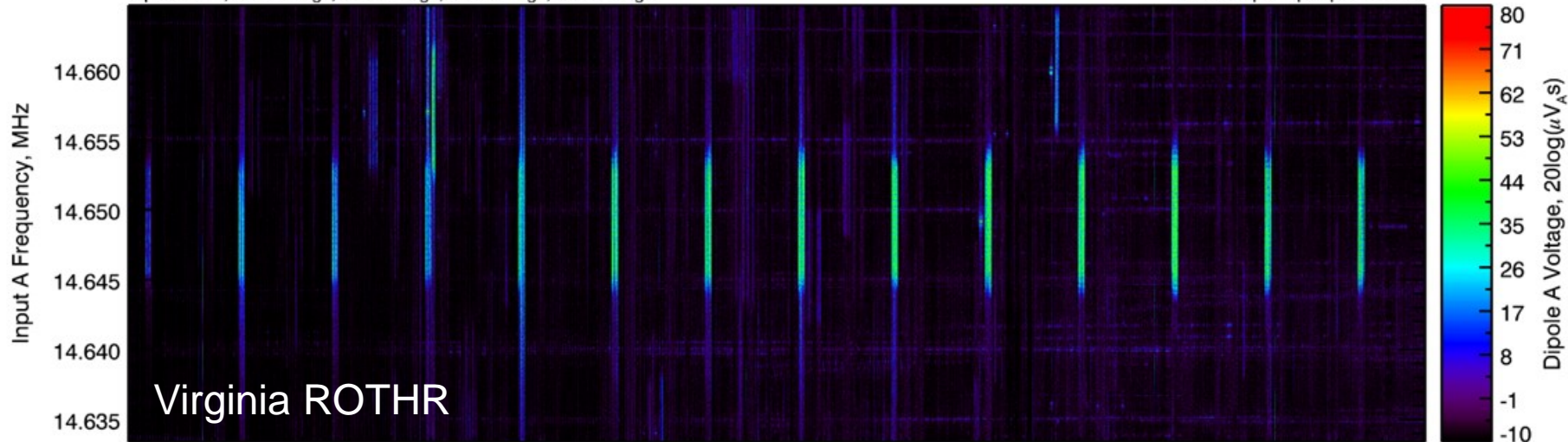


# e-POP RRI

Mar 19, 2017

Inputs: Channel 1 - I1, Channel 2 - Q1, Channel 3 - I3, Channel 4 - Q3  
Dipole Mode, Gain 1 - High, Gain 2 - High, Gain 3 - High, Gain 4 - High

Number of points per spectrum: 5208



UT	00:09:14.55	00:10:24.05	00:11:33.54	00:12:43.03	00:13:52.53	00:15:02.02	00:16:11.52
Geo. Lat, °	6.92	10.59	14.27	17.98	21.72	25.51	29.28
Geo. Lon, °	-69.85	-69.56	-69.26	-68.90	-68.50	-68.10	-67.69
Altitude, km	1226.42	1205.66	1183.19	1159.08	1133.45	1106.35	1077.93
Mag. Lat, °	16.47	20.09	23.78	27.44	31.15	34.91	38.68
Mag. Lon, °	3.09	3.43	3.83	4.22	4.73	5.22	5.82
MLT	19.36	19.39	19.44	19.48	19.53	19.59	19.65



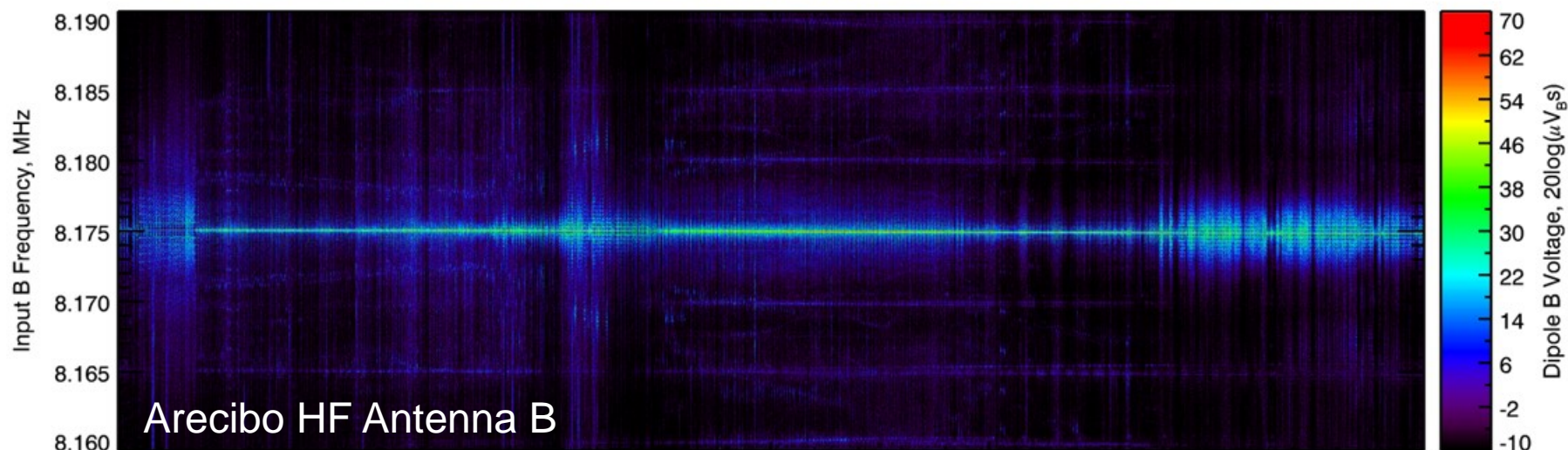
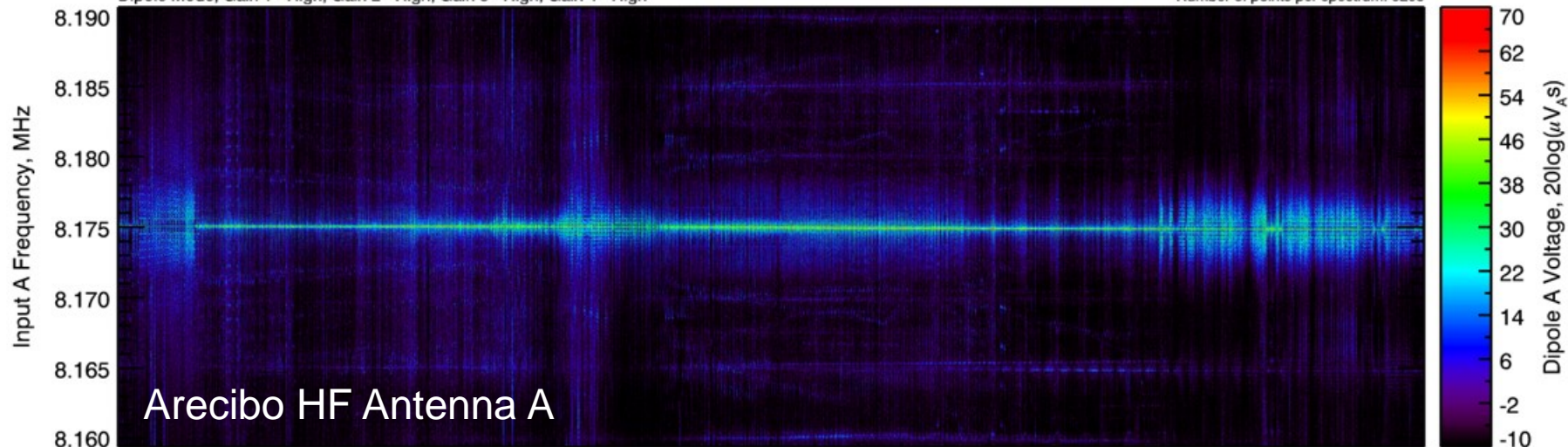


# e-POP RRI

Mar 19, 2017

Inputs: Channel 1 - I1, Channel 2 - Q1, Channel 3 - I3, Channel 4 - Q3  
Dipole Mode, Gain 1 - High, Gain 2 - High, Gain 3 - High, Gain 4 - High

Number of points per spectrum: 5208

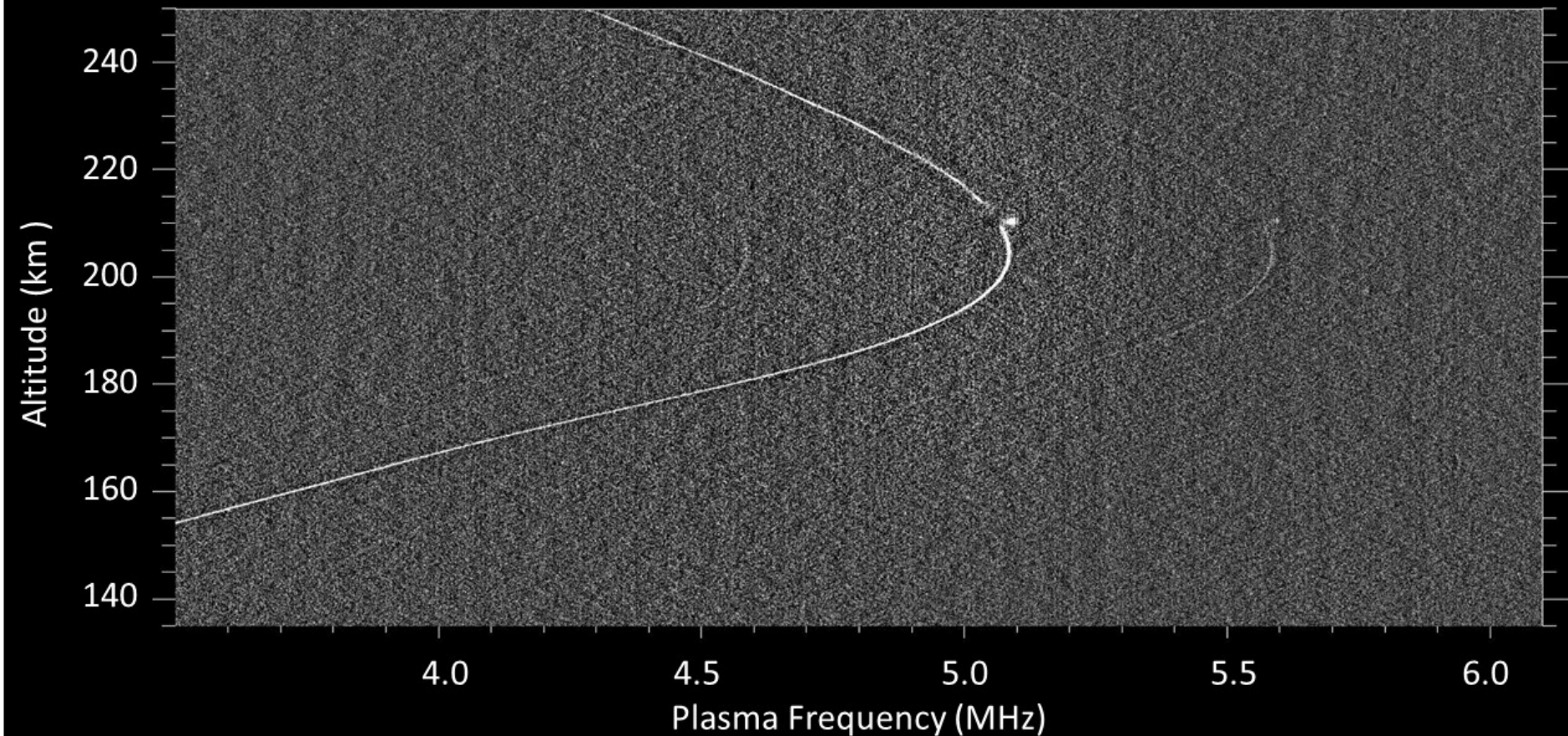


UT	23:47:44.64	23:48:54.13	23:50:03.63	23:51:13.12	23:52:22.62	23:53:32.11	23:54:41.61
Geo. Lat, °	6.63	10.30	14.02	17.77	21.46	25.22	29.09
Geo. Lon, °	-66.50	-66.20	-65.90	-65.57	-65.17	-64.77	-64.30
Altitude, km	1212.45	1190.39	1166.69	1141.42	1114.69	1086.57	1057.19
Mag. Lat, °	16.14	19.75	23.42	27.17	30.82	34.62	38.39
Mag. Lon, °	6.53	6.94	7.32	7.84	8.33	8.92	9.52
MLT	19.23	19.29	19.33	19.38	19.43	19.49	19.55



# Descending Artificial Plasma Pancake Layers

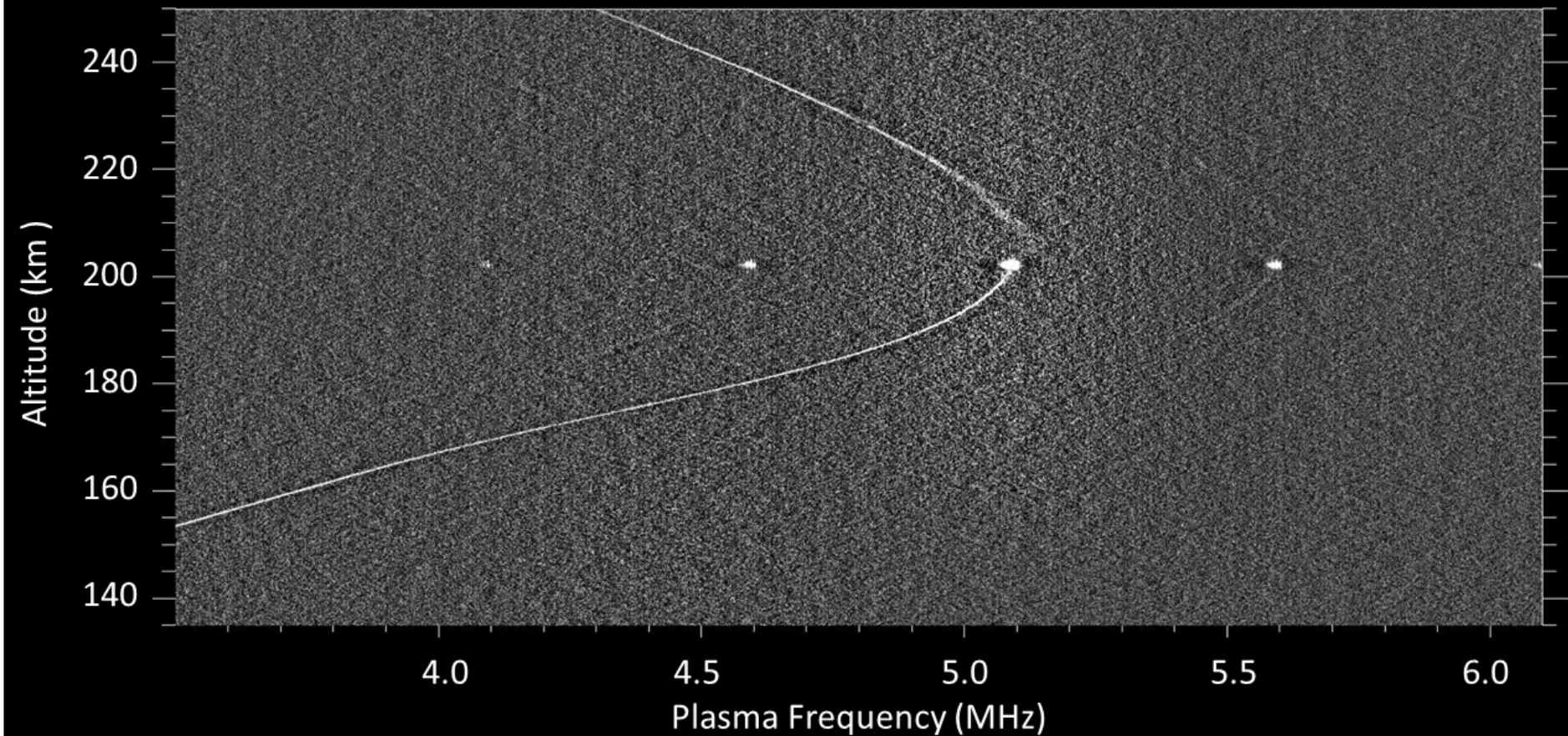
15 March 2017 08:04:44 AST





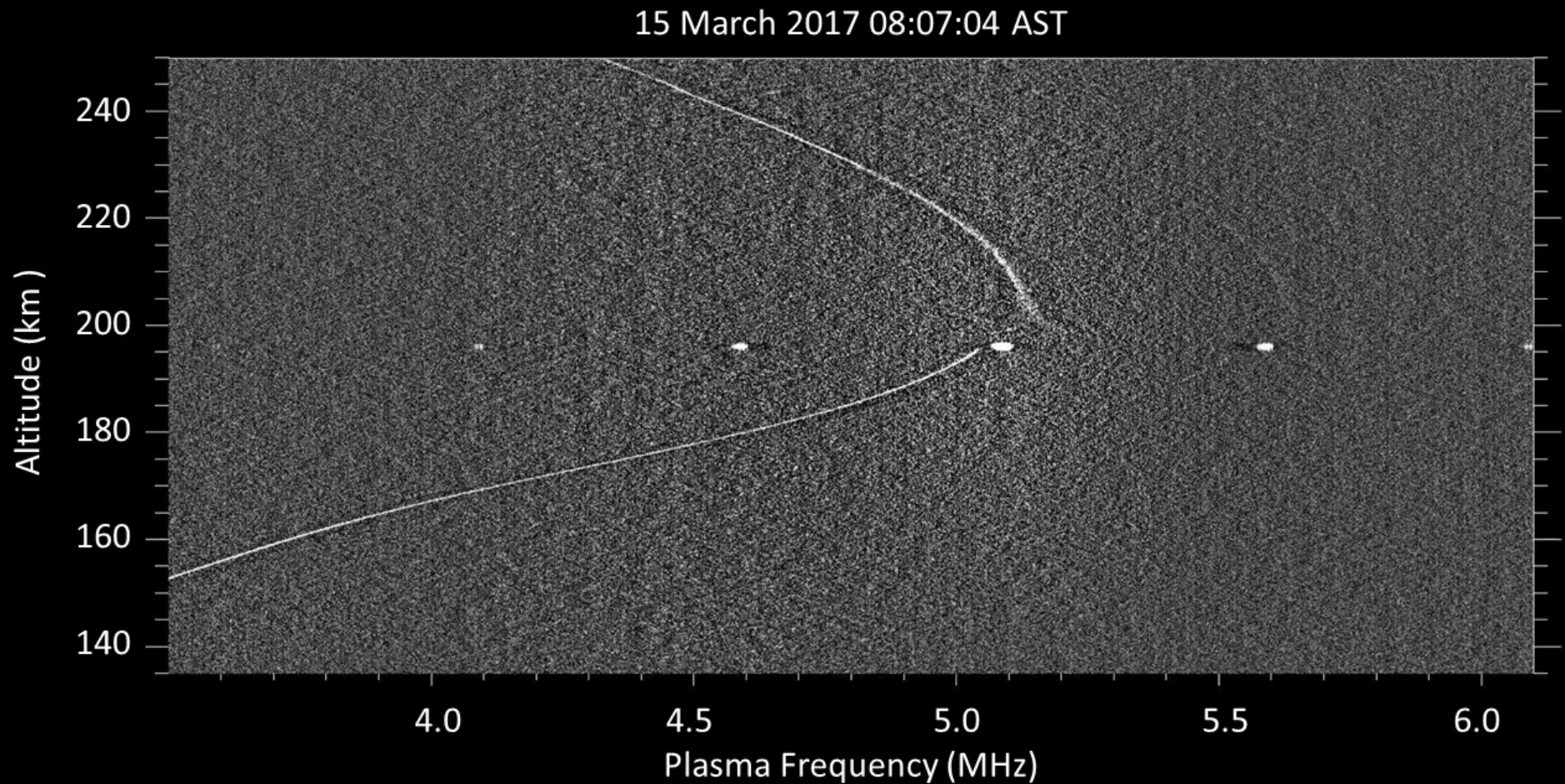
# Descending Artificial Plasma Pancake Layers

15 March 2017 08:05:44 AST





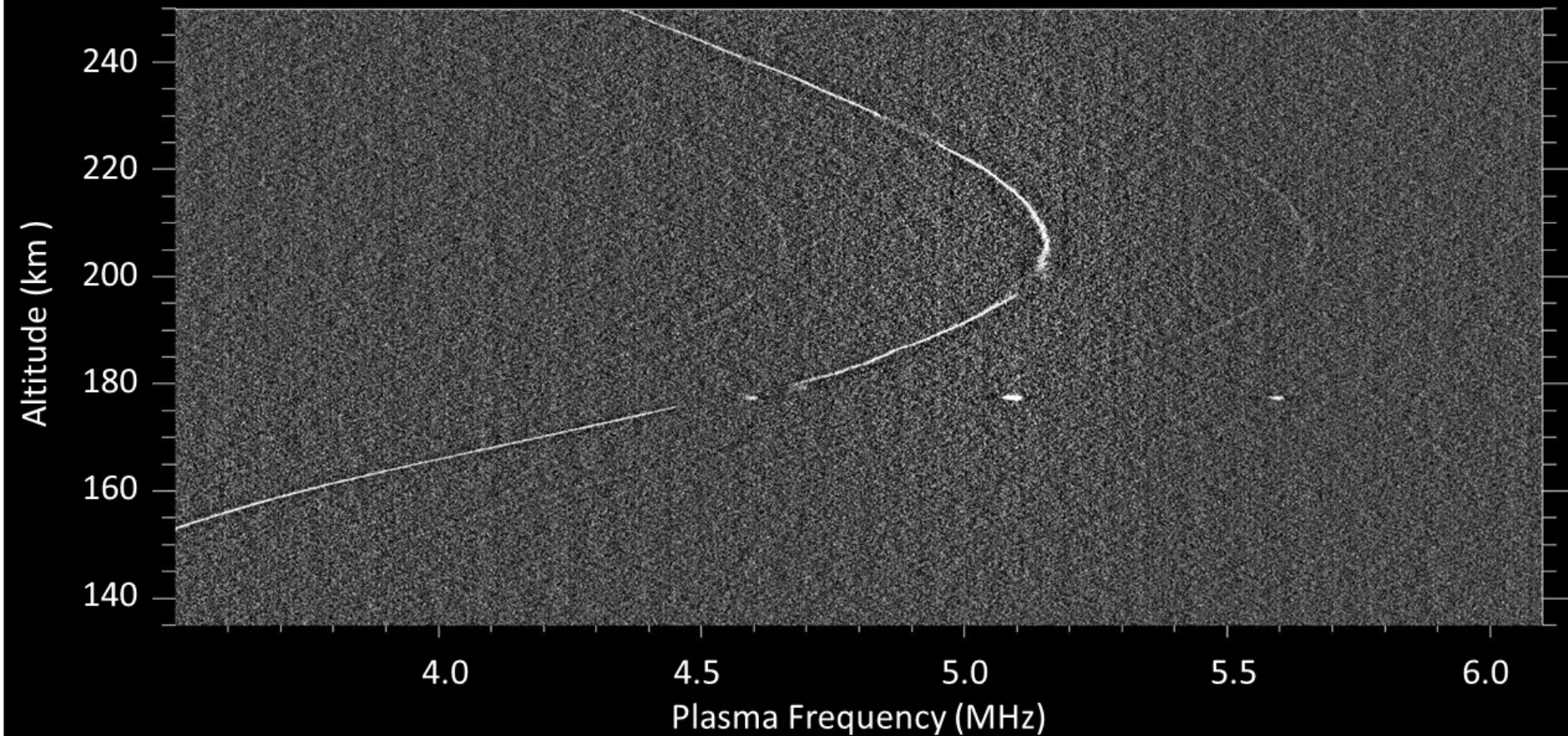
# Descending Artificial Plasma Pancake Layers





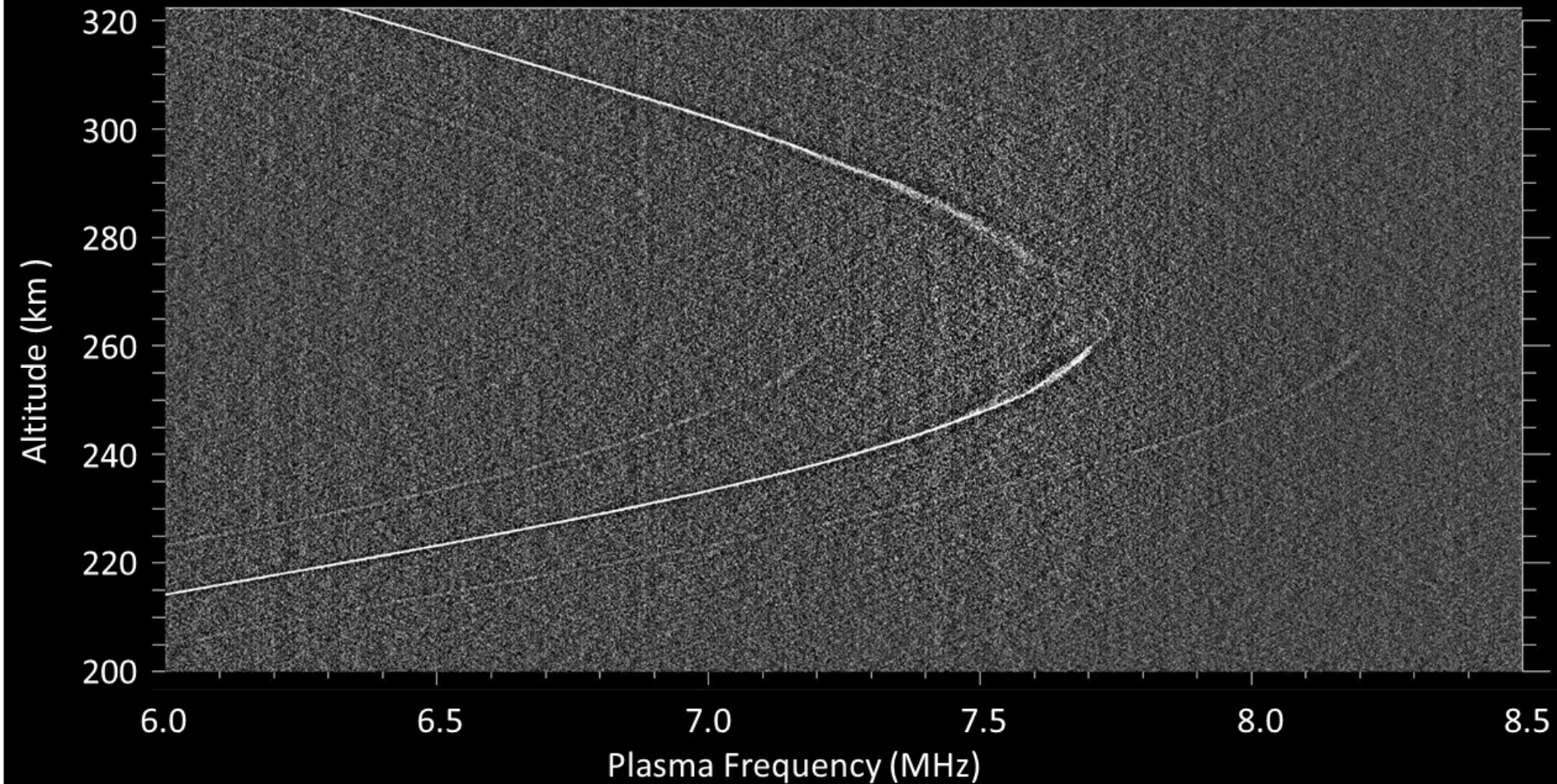
# Descending Artificial Plasma Pancake Layers

15 March 2017 08:13:24 AST

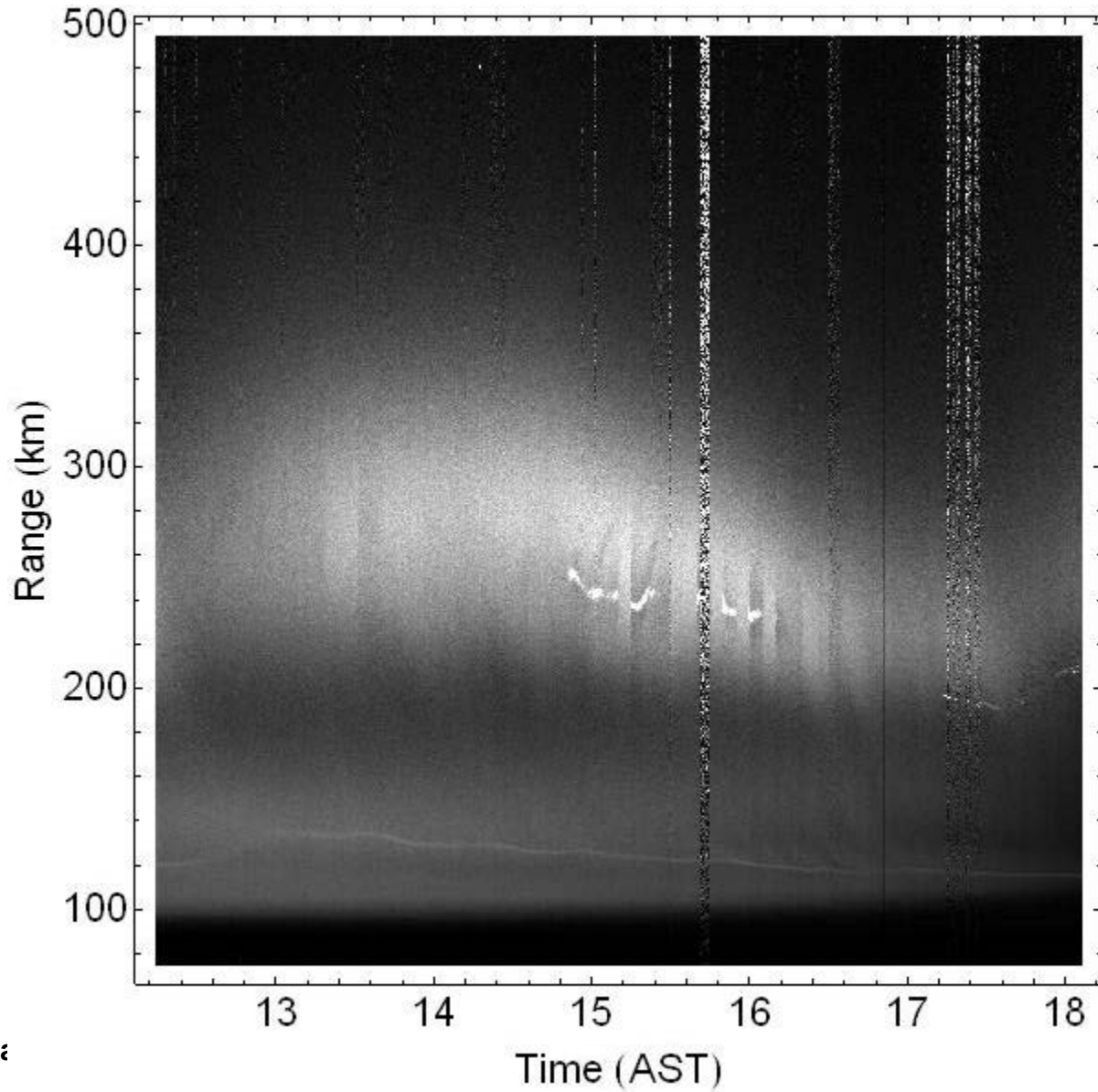




18 March 2017 13:35:25 AST



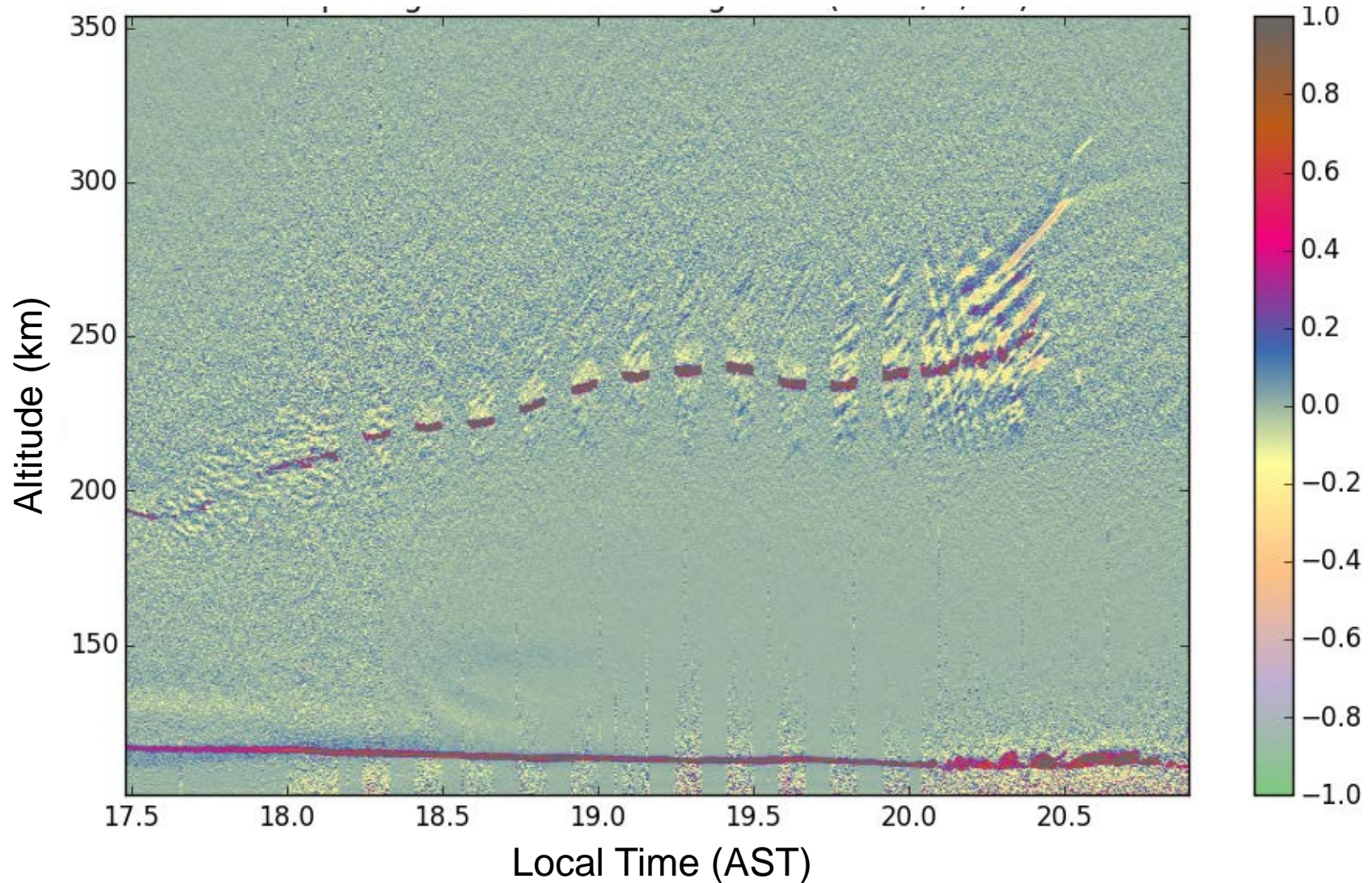
# Artificial Layer Disturbance Seen in Ion Line Data Arecibo 430 MHz Radar, 18 March 2017





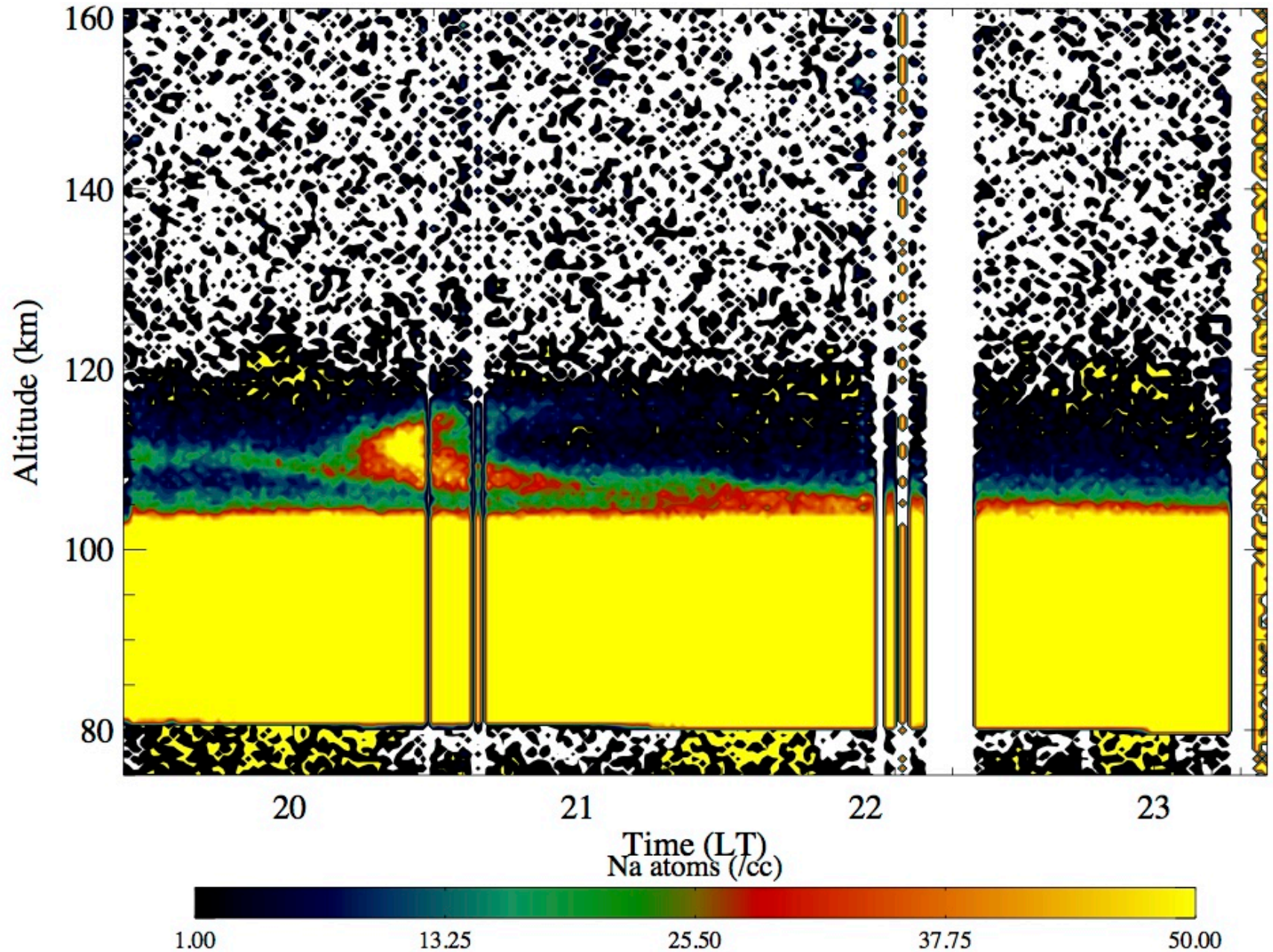
# Ion Line Data Over Arecibo

## 18 March 2017 AST

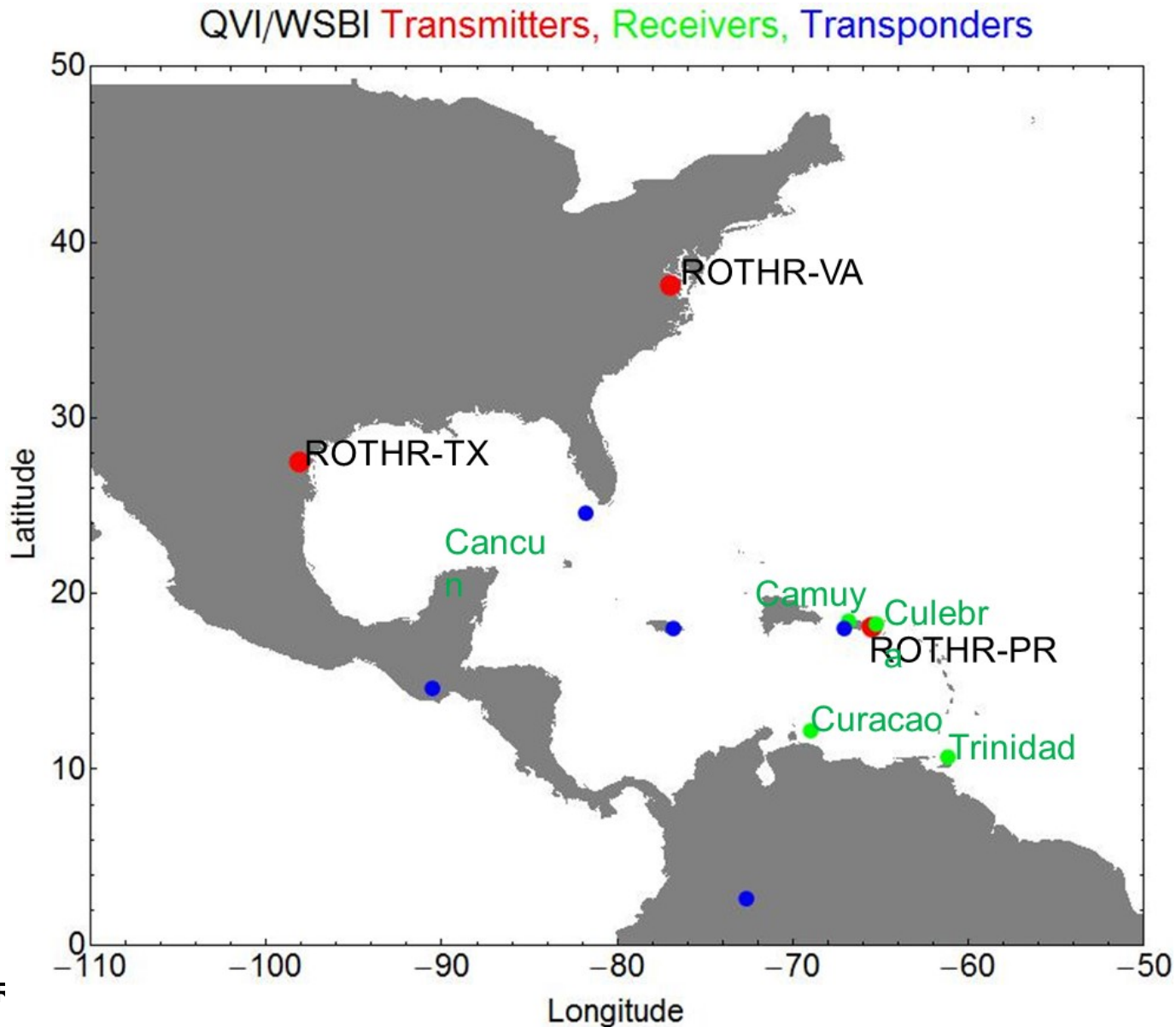




# Sodium Neutrals Over Arecibo, 18 March 2017



# Ground HF Instruments for Caribbean

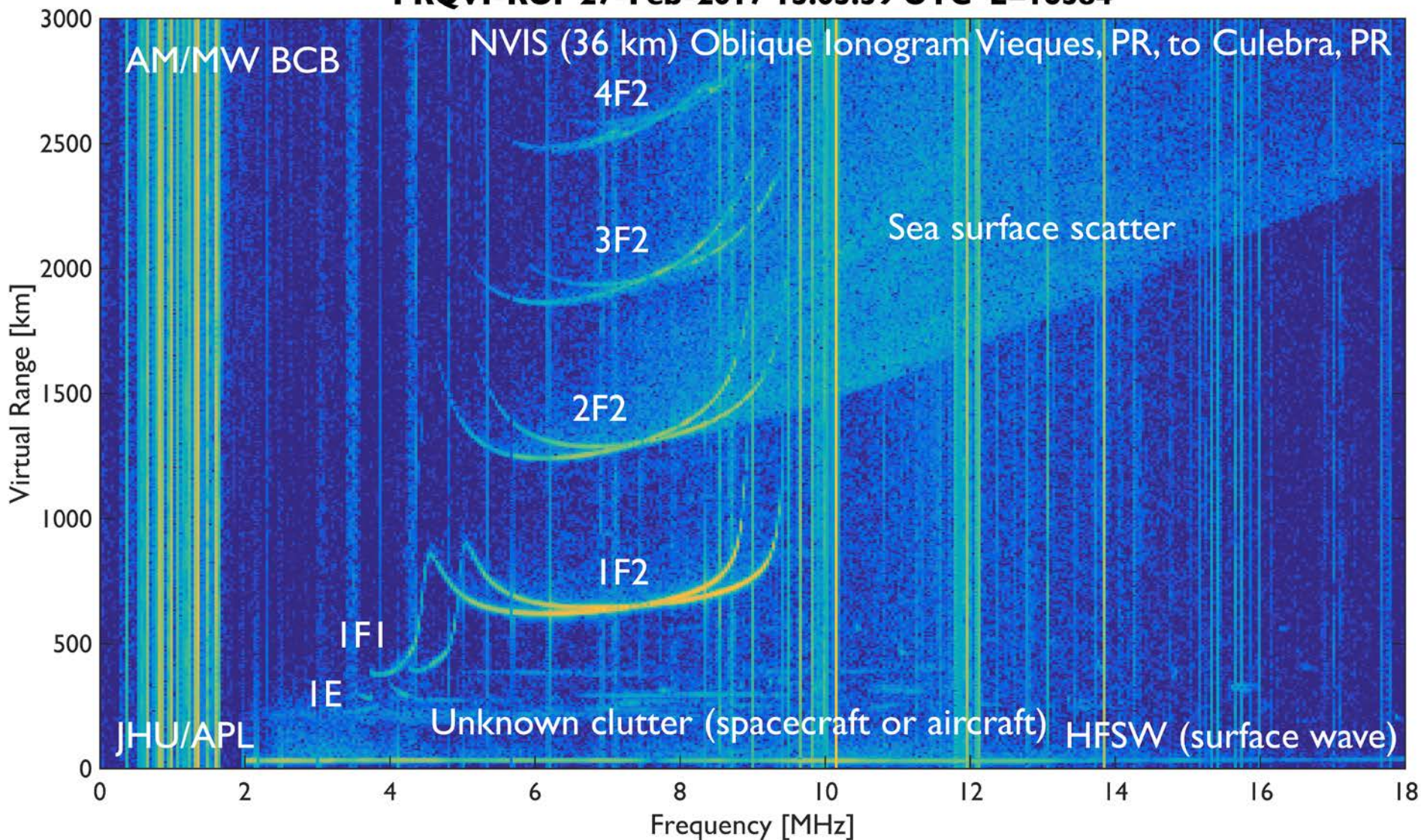




# Vieques to Culebra PR Oblique Ionogram

Ethan Miller, APL

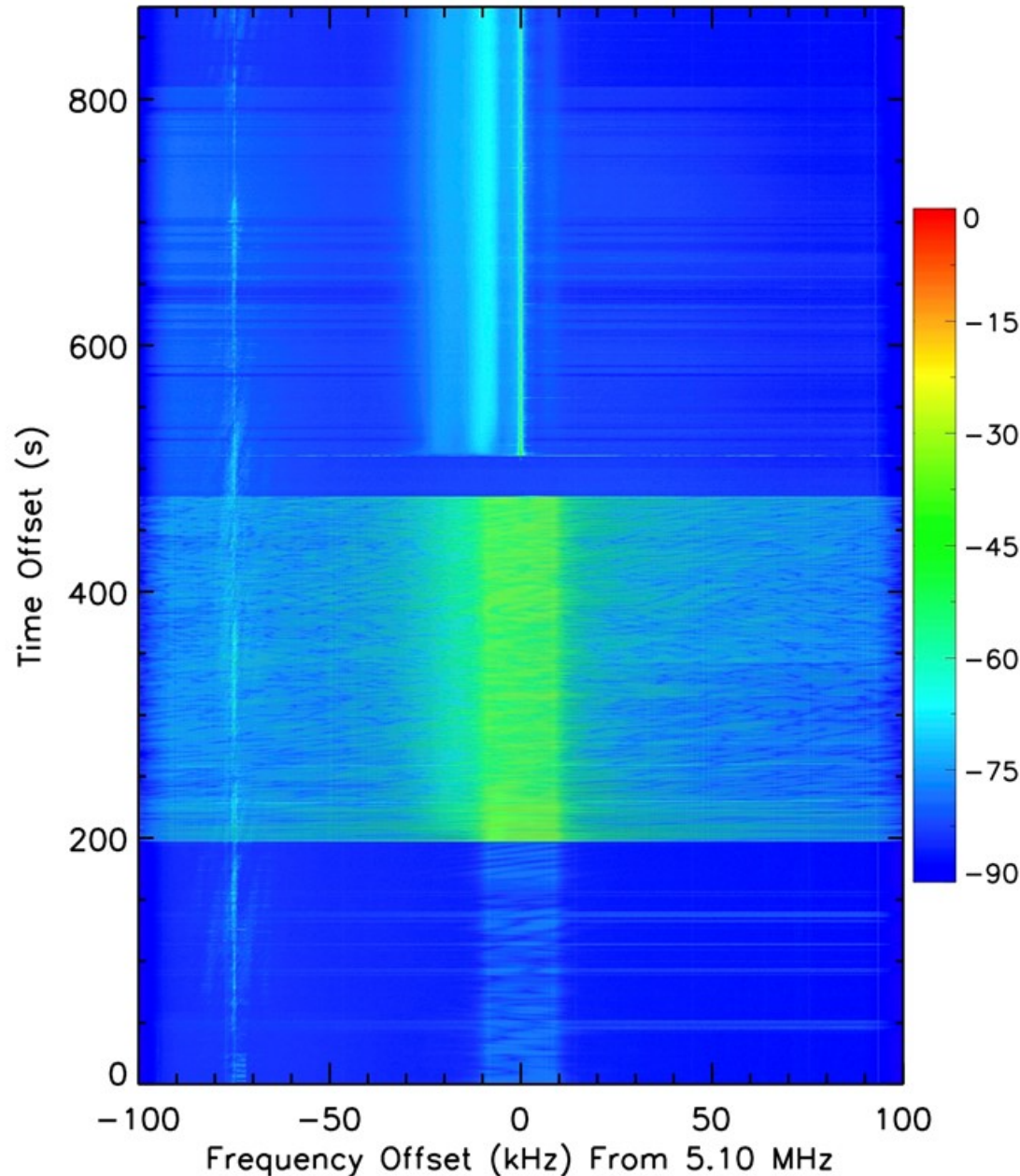
PRQVI-ROF 27-Feb-2017 15:05:39 UTC L=16384





# Camuy HF Receivers for SEE

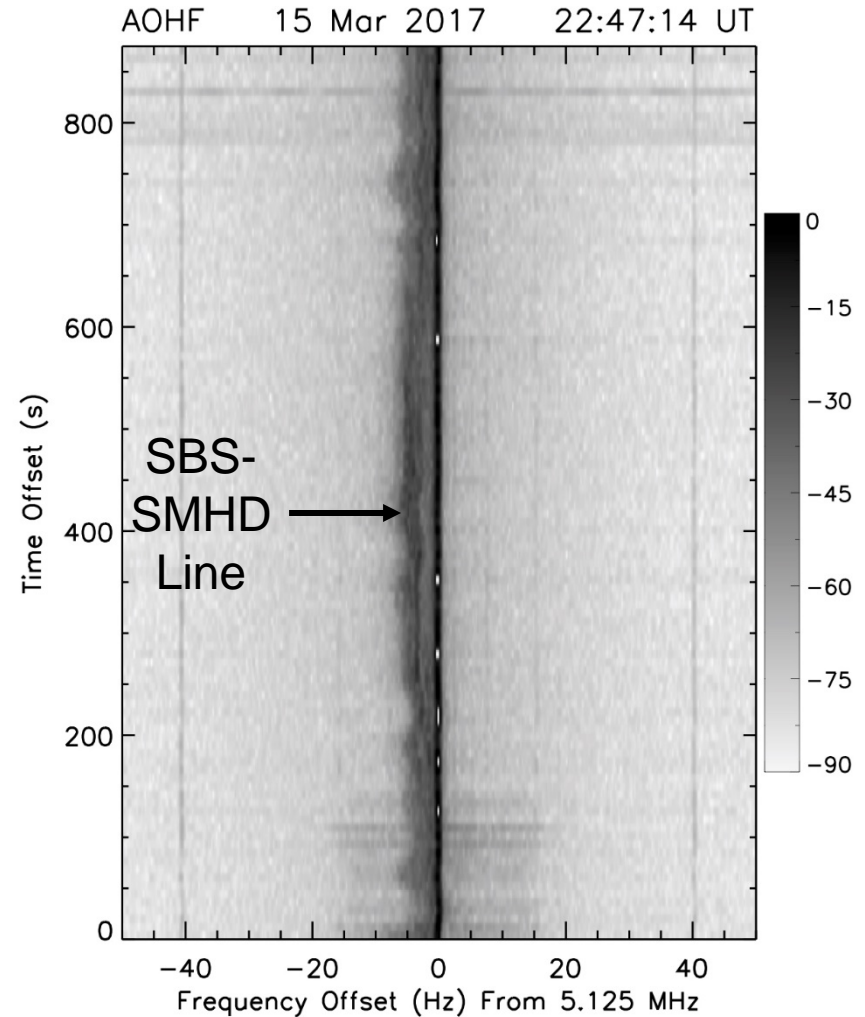
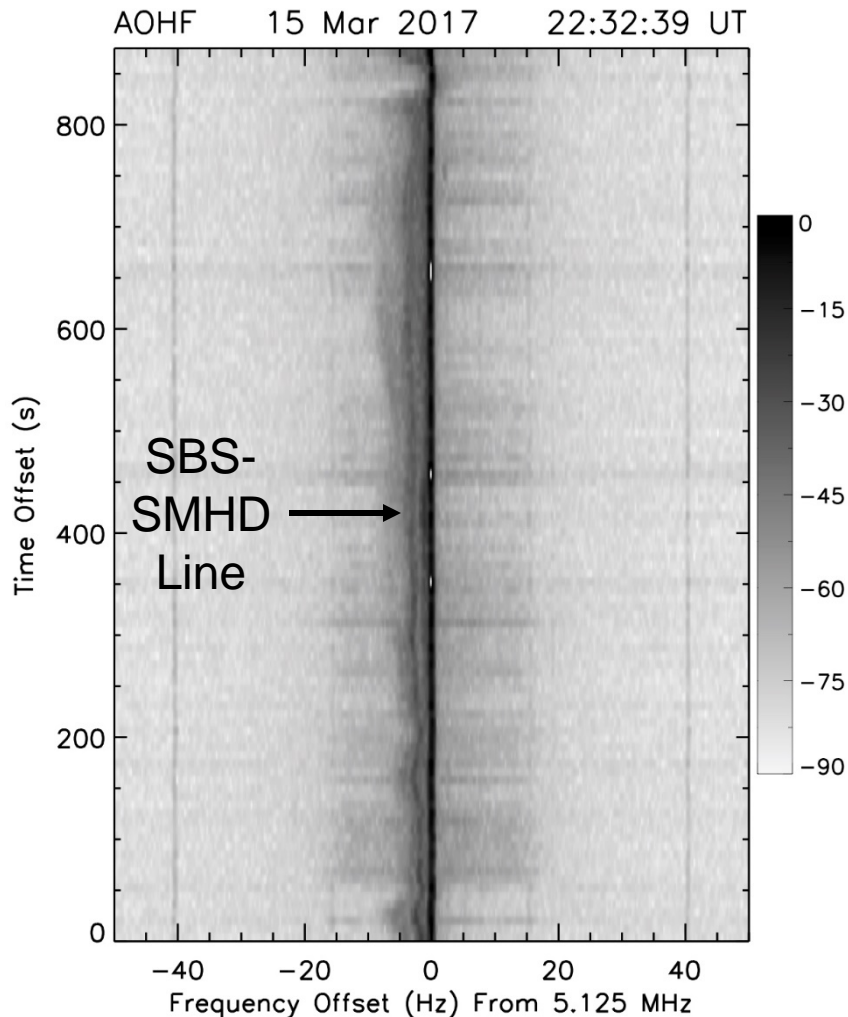
AOHF 14 Mar 2017 13:51:44



200 Hz WRF  
20 kHz BW  
5.1 MHz Pump  
FMCW and CW  
14 March 2017

Downshifted  
Spectral Features  
Represent  
Irregularities

# Low Frequency Stimulated Brillouin Scatter from Slow MHD Waves



Strongest Effects Involve Direct Parametric Decay in EM Waves



- The Arecibo HF Facility
  - Produces Artificial Ionization at Much Lower Power than HAARP
    - Different Ionosphere and Magnetic DIP Angle
    - Better UHF Radar Diagnostics (300 meter dish at 430 MHz)
  - Artificial Irregularities Impact HF Propagation
    - Useful for Spread Doppler Clutter Mitigation
    - Useful of Determine Area of HF Effects
  - Needed Improvements to Arecibo HF Facility
    - Frequency License to Cover 2 to 10 MHz
    - HF Feeds for Broad Band and Ring-Beam Transmissions
    - Proximity to ROTHF Virginia and Texas Beams Should be Emphasized
- ROTHF HF Radar
  - Puerto Rico QVI Ionograms Needed to Detect Arecibo HF Effects
  - Future Experiments: Multiple Transmit Beams to Cover 50 Degrees Azimuth