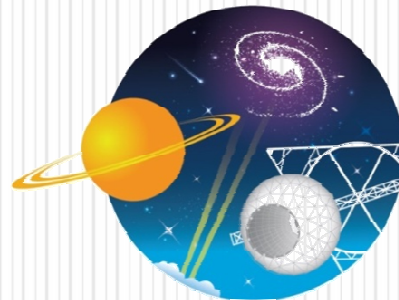


**UPRM RFSMW (Radio Frequency Spectrum Management Workshop)**  
**May 23-27, 2016**

# RFI Issues at the Arecibo Observatory

**Luis Quintero, [lquintero@naic.edu](mailto:lquintero@naic.edu)**  
**(Phil Perillat, [phil@naic.edu](mailto:phil@naic.edu))**



**ARECIBO OBSERVATORY**  
PUERTO RICO  
SRI • UMET • USRA

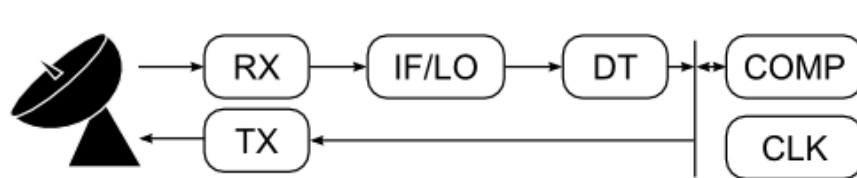
# Talk outline

- AO Radio-Telescope Systems
- Spectrum Management, RFI Monitoring and Prevention
- L-band Interference
  - Radars, global navigation satellites
  - Light squared 1670-1675
- S-band Interference
  - 2390 ism cheaters, low level rfi at 2380, AT&T at 2370
- S-band Wide: 2130 notched filter for pulsar observers
- C-band Interference: 5150 U-NII band cheaters
- Miscellaneous things



# AO Radio-Telescope Systems

305m – Passive & Active



12m – Passive



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# AO Receiver Coverage

Receiver	Freq. Range (GHz)	Native Pol
CH 47	-	Dual Circular
327	0.312 - 0.342	Circular with Hybrid
CH 430	0.425 - 0.435	Dual Circular
GD 430	0.422 - 0.442	Dual Circular
ALFA	1.225 - 1.525	Dual Linear
LBW	1.15 - 1.73	Dual Linear
SBL	1.80- 3.10	Dual Linear
SBN	2.33 - 2.43	Dual Circular
SBH	3.00 - 4.00	Dual Linear
CB	3.85 - 6.00	Dual Linear
CBH	5.90 - 8.10	Dual Linear
XB*	7.80 - 10.2	Dual Circular

\* Also used for bi-static radar



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# AO Transmitters

Transmitter	Freq/Peak Power (MHz/kW)	Application
HF	~ 5 & 8MHz / 600 CW	Atmospheric
47	47 / -	-
Incoherent Scatter Radar	430 / 1500 Pulsed	Atmospheric / Planetary
Planetary Radar	2380 / 1000 CW	Planetary / “Atmospheric”

- Receivers Protection - Shutters
- Electro-Magnetic Compatibility (EMC) with
  - Radio-Telescope electronics
  - Simultaneous transmitter operation

# Spectrum Management and Monitoring at AO

- **Local** (e.g., Puerto Rico Spectrum Users Group)
- **National** (e.g., GPS/Iridium/GlobalStar, Committee on Radio Frequencies - CORF)
- **International** (e.g., World Radiocomm. Conf. -WRC)
- People involved
  - Collaborators, Int. mostly, **Murray L., Mike D.**
  - Spectrum Manager / PRCZ – FCC applications, **Angel V.**
  - Lab RFI checks, **Luis Q., Felix F.**
  - RFI chasing / site test, Angel V., **Phil P., Felix F., Dana W.**
  - RFI checks with 305m Radio-Telescope, Phil P.
  - RFI Group include scientist, **Chris S., Robert M.**



# *Puerto Rican Coordination Zone (PRCZ)*

- Covers Puerto Rico, Desecheo, Mona, Vieques, and Culebra
- “Before establishing a repeater **within 16 km (10 miles)** of the Arecibo Observatory or before changing the transmitting frequency, transmitter power, antenna height or directivity of an existing repeater, the station licensee **must give notification thereof at least 20 days in advance of planned operation** to the Interference Office, Arecibo Observatory, ... [prcz@naic.edu](mailto:prcz@naic.edu)”
- **If an objection** to the proposed operation is received by the FCC from the Arecibo Observatory, Arecibo, Puerto Rico, within 20 days from the date of notification, **the FCC will consider all aspects of the problem and take whatever action is deemed appropriate.** The licensee will be required to **make reasonable efforts** in order to **resolve or mitigate** any potential interference problem with the Arecibo Observatory.



# *Puerto Rican Coordination Zone (PRCZ)*

- We do not recommend **radio links crossing** the 10 mile radius





# RFI Monitoring

## X111 Telescope Time for RFI Test

- Data available for users or response to users

## Hilltop Monitoring System

- Runs 24/7/365
- Setup:
  - Omni Dir. Ant. 0 to 1450 MHz
  - Log periodic 1.8 GHz to 10 GHz
  - Filter bank, amplifiers, spectrum analyzer
  - Peak hold 60 secs, dump, then next band
    - 20 steps to cover 0 to 10GHz.

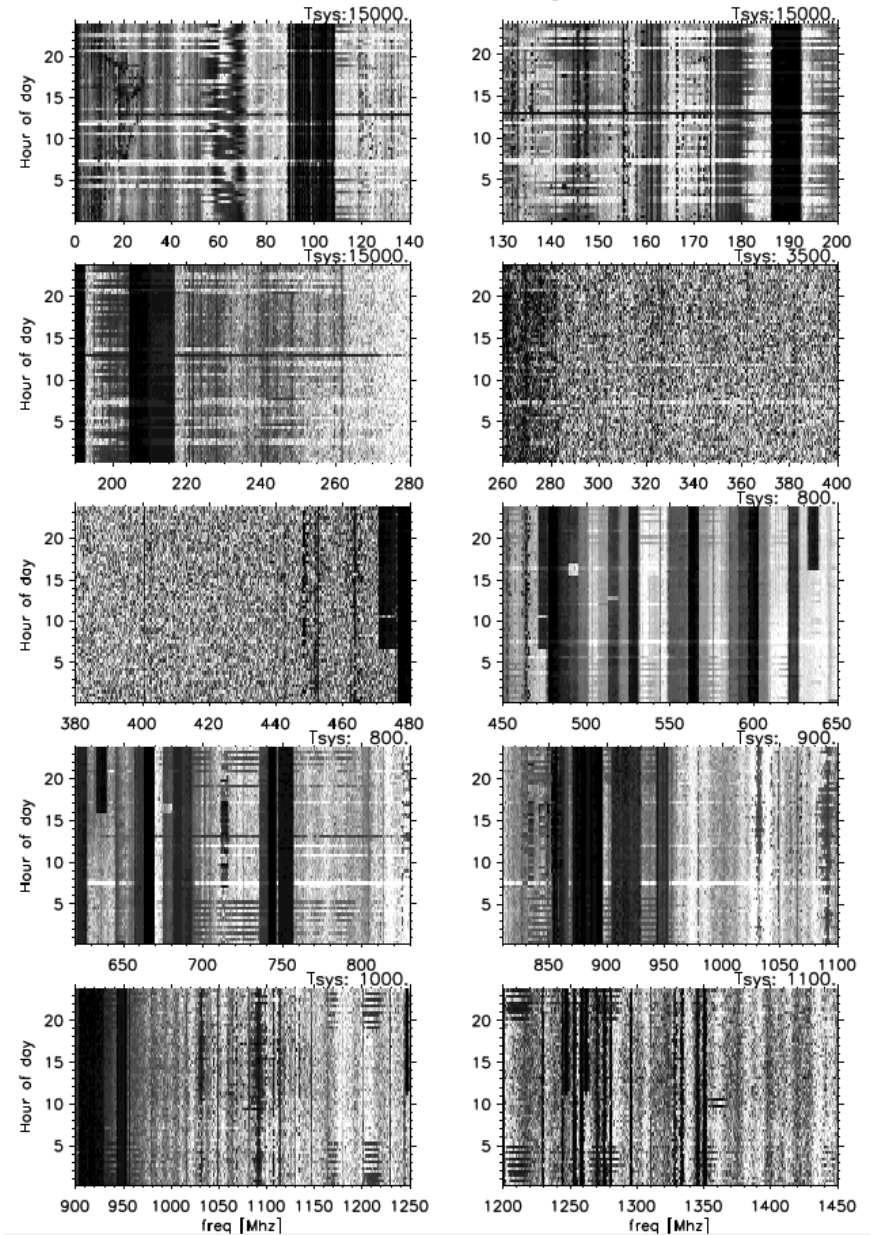


# RFI Monitoring

## Hilltop Monitoring System

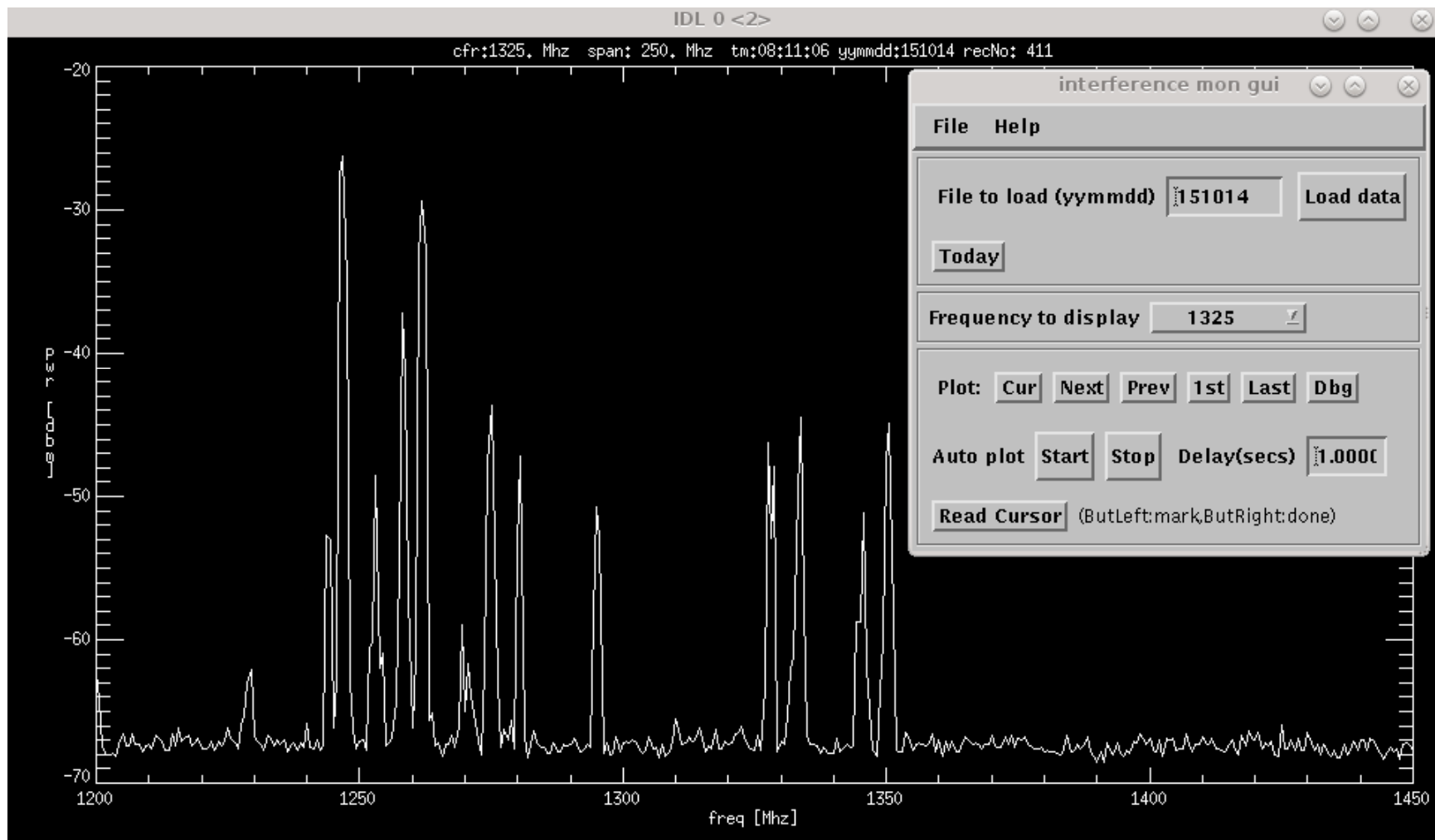
- Daily web output
  - 24 hour avg over each band:
  - Images: spectral density vs time
  - Rms/mean by channel for a day.
- Usage:
  - Good for strong, wide ( $>100\text{KHz}$ ) signals
  - $T_{\text{sys}} > 1000\text{K}$ , 401 chan over 100Mhz to 1Ghz
  - Looks at the horizon. Hard to see satellites
  - Lets you see when signals appeared.

Arecibo Obs RFI time/freq Images for 151010



# RFI Monitoring

- Interactive tool to access 1 minute records



# RFI Chasing at the Field

- Portable/ **Handheld spectrum analyzers**:
  - Anritzu MS2713E 6GHz
  - Keysight N9916A 14Ghz
- **Antennas / Probes**
  - 7405 E & H Near Field Probe Set
  - Log-periodic
  - Helical
- Looking for **interference at AO**: new equipment, defective shielding, mal functioning equipment
- Looking for **interference outside** from our neighbors



# RFI Prevention

- **RFI checks** at the Lab + **shielding/filtering**
  - Agilent E4445A Spectrum Analyzer up to 13.2 GHz
- **RFI ON/OFF checks** with telescope for new equipment and **AO Buildings**: A/C Units are major offenders
- **No RFI policy**:
  - **No wireless** communications, **fiber optic for long connections**
  - **No microwave ovens, no power tools** during obs or tests
  - **No unshielded electronics** close to the telescope during obs
  - **Incandescent lights** only and **approved LED lights**
  - **Use linear power supplies**, instead of switching
  - **Coordinating with contractors**, e.g. CCTV, Fire Alarms, Kronos, vending machines



# L-band Interference

- L-band Radars in Puerto Rico
- Global navigation satellites
- Light squared 1670-1675 and the 1665/1667 OH lines



# L-band radars seen by AO

Radar	Info
FAA radar Pico del Este	Old 1330,1350 – no blanking New:1252,1258,1344,1350 (CARSR) blanks 4 deg in AO direction
Punta Borinquen radar	Old : 1270 or 1290 New:1269,1276,1327,1333 (CARSR) Blanks 4 deg in AO direction
Punta Salinas radar	Frequency agile radar Old:1232,1247,1242,1256 (ModeA) New:1228,1243,1279,1294 blanks 22 deg in AO direction
Aerostat radar balloon	1246,1261 line of site to dish makes it extremely strong. They blank +/-21 deg in AO direction



# L-band radars seen by AO

## Punta Borinquen





# L-band radar – CARSR

- The **FAA** and **PuntaBorinquen** radars were replaced by **CARSR** (Common Air Route Surveillance Radar) in 2013
  - Run by FAA but only used by DOD, DHS.
  - They are blanking the radars +/- 2 degrees toward AO.
  - We needed a memo from DoD, DHS to get the blanking.

Radar	Freq. (MHz)	BW (MHz)	Duty cycle (%)	Sector Blanking	Dist. (Nmi)
Old FAA	1330,1350	0.2	0.5	no	57
CARSR FAA	1252.4,1257.6 1344.4,1349.6	1.0 Chirped	9.0	Yes (01nov14) +/-2 deg	57
Old Punta Borinquen	1270 or 1290	0.2	0.5	no	24
CARSR PuntaBor.	1269.4,1274.6 1327.4,1332.6	1.0 Chirped	9.0	Yes (01oct13) +/- 2 deg	24



# L-band radar – CARSR

- How the **upgrades made things worse:**
  - Went from **3 freq. to 8 freq.** More interference, more **intermods** (if radar pulses overlap in time).
  - **Lower power, but duty cycle went 0.5% to 10%**
  - **Multiple ipps** so there are many more periods to **interfere with pulsar observing.**
- **Positive: they blank in our direction.** Old ones didn't.
  - We could use a few more degrees of blanking, to lessen intermods.



# L-band radar – Punta Salinas

- Punta Salinas is a **freq. agile** phased array radar
- Apr 15 upgraded from 18 to **100 dual freq channels**.
- **They will no longer transmit freq. close to other radars on the island**
- MOU: when AO uses L-band, they use 2 dual freq channels (called Mode A).
  - We've had some trouble with this, especially during their upgrades

Radar	Info
Punta Salinas radar	Frequency agile radar Old:1232,1247,1242,1256 (Mode A) New:1228,1243,1279,1294 (Mode A) blanks 22 deg in AO direction



# L-band Radars from Hilltop Monitor

- Compare radar frequency usage in next slide:
  - Top: 29may09 pre CARSR, pre PuntaSalinas upgrade
  - Middle: 27apr15: CARSR, new PuntaSalinas (ModeA)
  - Bottom: 14oct15: CARSR, new PuntaSalinas, all channels

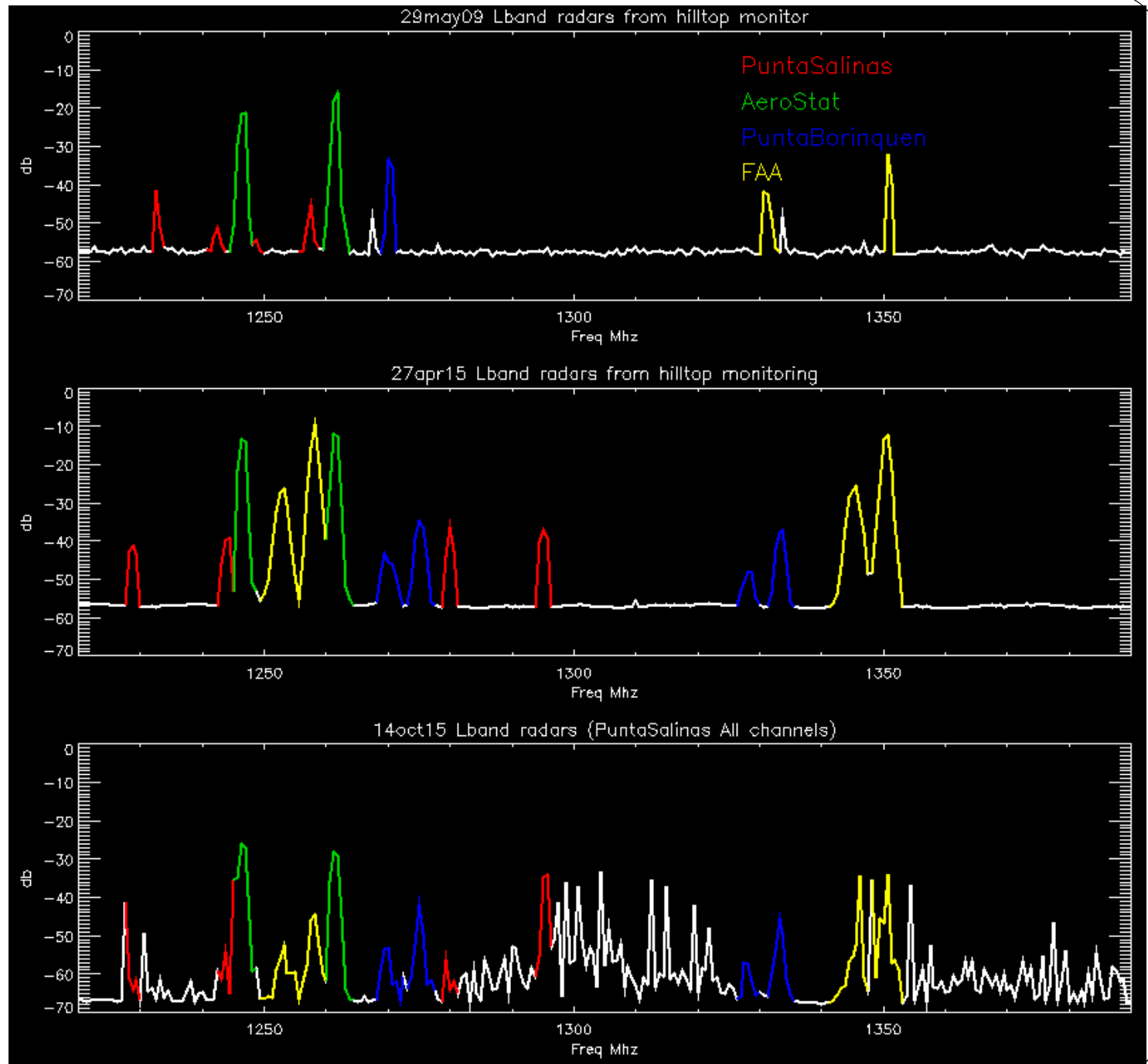


### Old Freq. Ch.

PS, 1232, 1247  
1242, 1256  
AS, 1246, 1261  
PB, 1270, 1290  
FAA, 1330, 1350

### New Freq. Ch.

PS, 1228, 1243  
1279, 1294  
AS, 1246, 1261  
PB, 1269, 1276  
1327, 1333  
FAA, 1252, 1258  
1344, 1350



# Punta Salinas coordination to Radar Operators

- If the coordination fails, then the L-band experiment is wiped out.

## Arecibo Observatory Telescope Schedule

May 20 - June 3, 2016

### TRANSMITTERS

2380	430	HF
------	-----	----

Opt	47	System Checks
-----	----	---------------

### VISITORS

(or PIs)

- A. R. Taylor
- V. Ravi
- E. Fonseca
- M. Brozovic
- P. Taylor
- L. Magnani
- J. Deneva
- S. Ransom
- K. Stovall
- J. Hessels
- P. Demorest
- D. Nice
- A. Wolszozan
- B. Cabrinella
- N. Tang
- D. Li
- J. Rankin
- M. Route
- V. Kaspi
- R. Ferdwan
- A. Archibald
- L. Qian
- Y. Haan

COMBENSAL PROJECTS:  
 A2772; A2763  
 P2030; A2754, A2757  
 ALFA Rx; A2774  
 A2048; A2763  
 VER 7.0 - 20 May 16

Revision (2.5) May 20, 2016.

AST	20 FRI	21 SAT	22 SUN	23 MON	24 TUE	25 WED	26 THU	27 FRI	28 SAT	29 SUN	30 MON	31 TUE	1 WED	2 THU	3 FRI	LST
2	X114	X114	X114	X111 to	X111 to	P2945	P2825 ks	X111	P2825	A2772 art	P2780	P2780	P2945 ef	X111	T2689	19
4	A2048	A2048	A2048	A3023 vr	A3023 vr	P3031 jr	P3029 ym	P2789 rf	P2780	P2030 vk	pd/dn	pd/dn	P2030 vk	P2030 vk	(DB)	19
6	A3023 vr	A3023 vr	A3023 vr	(d)	(d)	LBW	(d)	P2945	PALFA	PALFA	Grav	Grav	A3021 lm	A3021 lm	(DB)	0
8	P2910 ar	P2945	X111	P2910 ar	A3021 lm	A3021 lm	A3021 lm	A3026 aw	NANO	A3021 lm	NANO	NANO	P2945	(b)	A3021 lm	(DB)
10	MAINT	(b)	(b)	MAINT f/ut	MAINT elec	MAINT elec	MAINT	X140 elec	(d)	P2945	(b)	X114	MAINT	MAINT		0
12	f/ut	X111 to	X111 to		RC008 eEVN jh	RC008 eEVN jh		f/ut	A2766 cs	X111	X111	X110 elec	f/ut	elec	T2565	0
14	P3094 jh	P3094 jh	P3094 jh	P3094 jh	rFRB	rFRB	X110 elec	P3094 jh	P2825	A3025 nt dl	A3025 nt dl	MAINT				12
16	MAINT	X111 to	X111 to	MAINT	MAINT elec	A3026 aw	MAINT	MAINT elec	NANO	X111	P1693 jd		MAINT	X110		12
18	X111	R2954 mb	R2954 mb	R2954 mb	R2954 mb	R2954 mb	R2954 mb	R2954 mb	X111	P3031 jr	X111	P3031 jr	X113	X111	T2881	12
20	R2954 mb	R2954 mb	R2954 mb	R2954 mb	R2954 mb	R2954 mb	R2954 mb	R2954 mb	P2905	A2772 art cs	P3033 aw	pd/dn	A3024 mr	A3024 mr	(DB)	12
22	R3037 pt	R3037 pt	R3037 pt	P3033 aw	A2935 lq	(a)	A2935 lq	A2935 lq	A2772 art cs	P3033 aw	Grav	Grav	A3018 bc	A3018 bc	(DB)	12
24	DL46	DL46	DL46	A3018 bc	A3018 bc	A3018 bc	A3018 bc	A3018 bc	GALFA	A3018	Grav	NANO	A3018 bc	A3018 bc	(DB)	12
	X111	X111													(DB)	12

Mode (A) Only.



# L-band Radars from Hilltop Monitor

- Example of Punta Salinas coordination (**next slide**)
  - April 2016 we were painting the platform until **21 Apr 2016**
  - During this time Punta Salinas was allowed to run using **all 100 channels**.



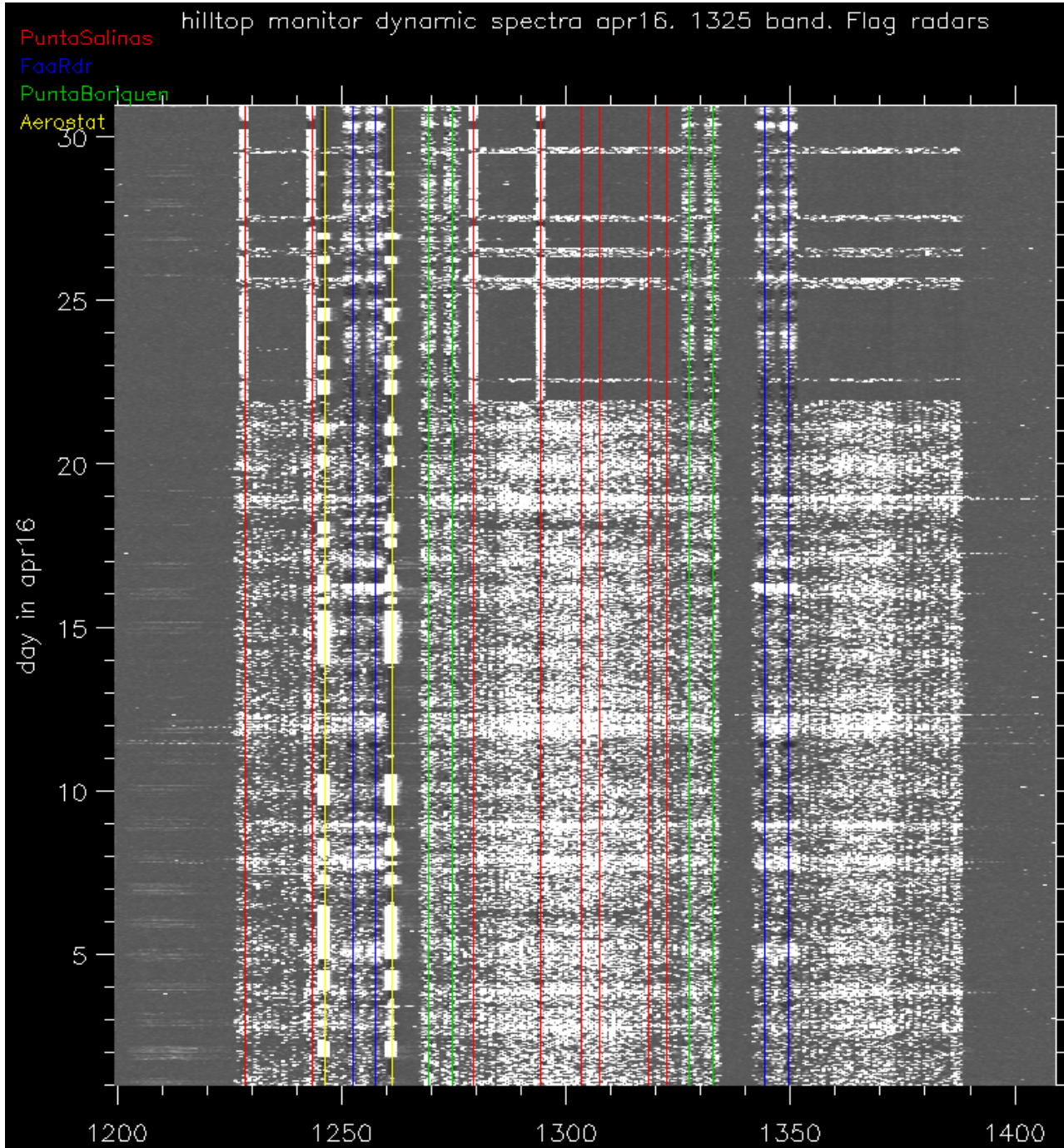
Freq. Ch. (MHz)

PS, 1228, 1243  
1279, 1294

AS, 1246, 1261  
PB, 1269, 1276  
1327, 1333

FAA, 1252, 1258  
1344, 1350

PS Coordination  
Mode A  
Starting Apr 21.



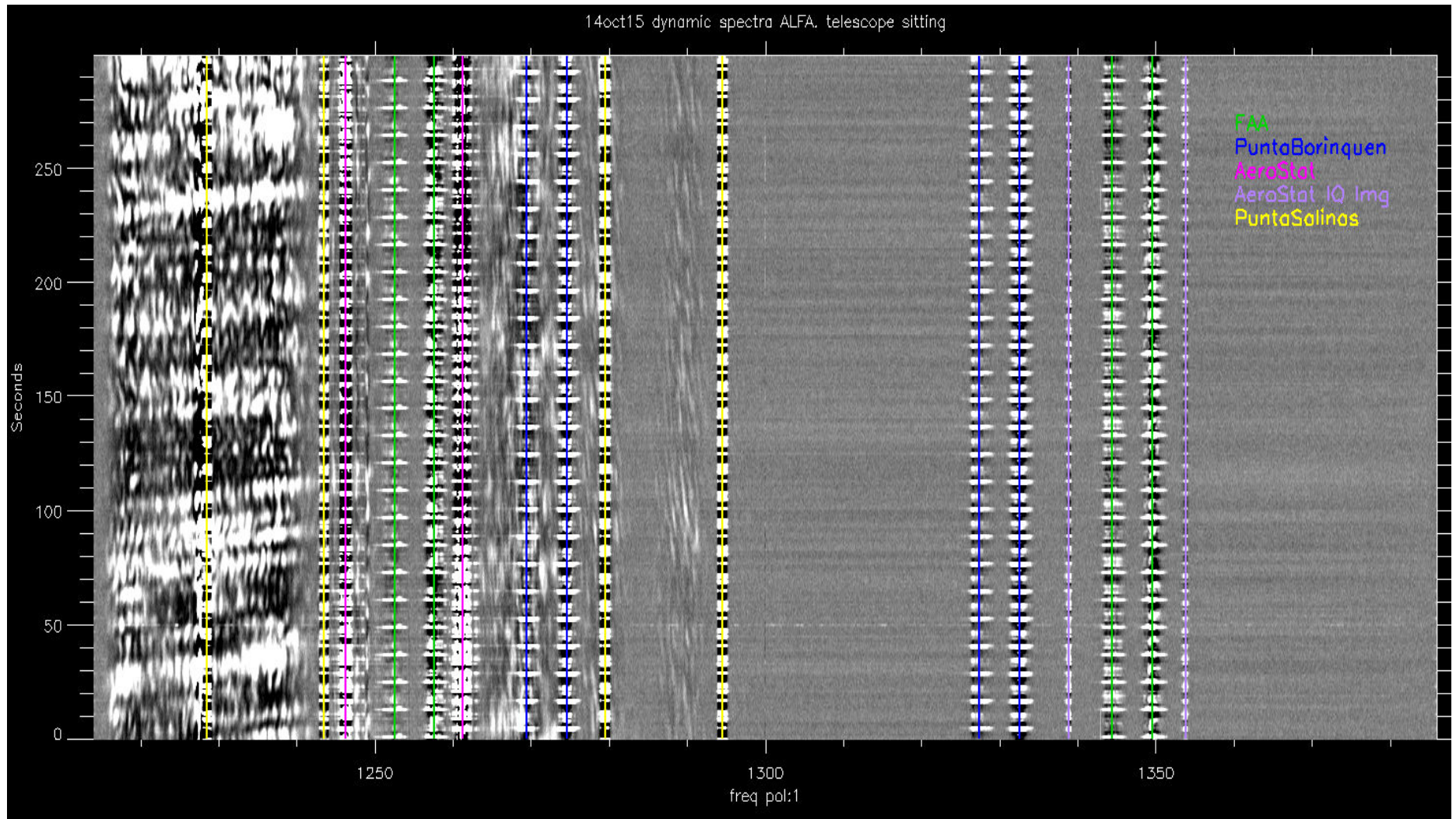


# L-band Radar RFI in ALFA receiver

- 300 x 1 **sec** integrations with ALFA receiver (**next slide**)
  - 1220 to 1390 MHz band
  - **Telescope sitting**, sky drifting
  - Dynamic spectrum (flattened by median)
- Image shows:
  - Radars, **12 sec rotation periods**
  - IQ image of aerostat
  - GPS L2, Glonass, probably Galileo

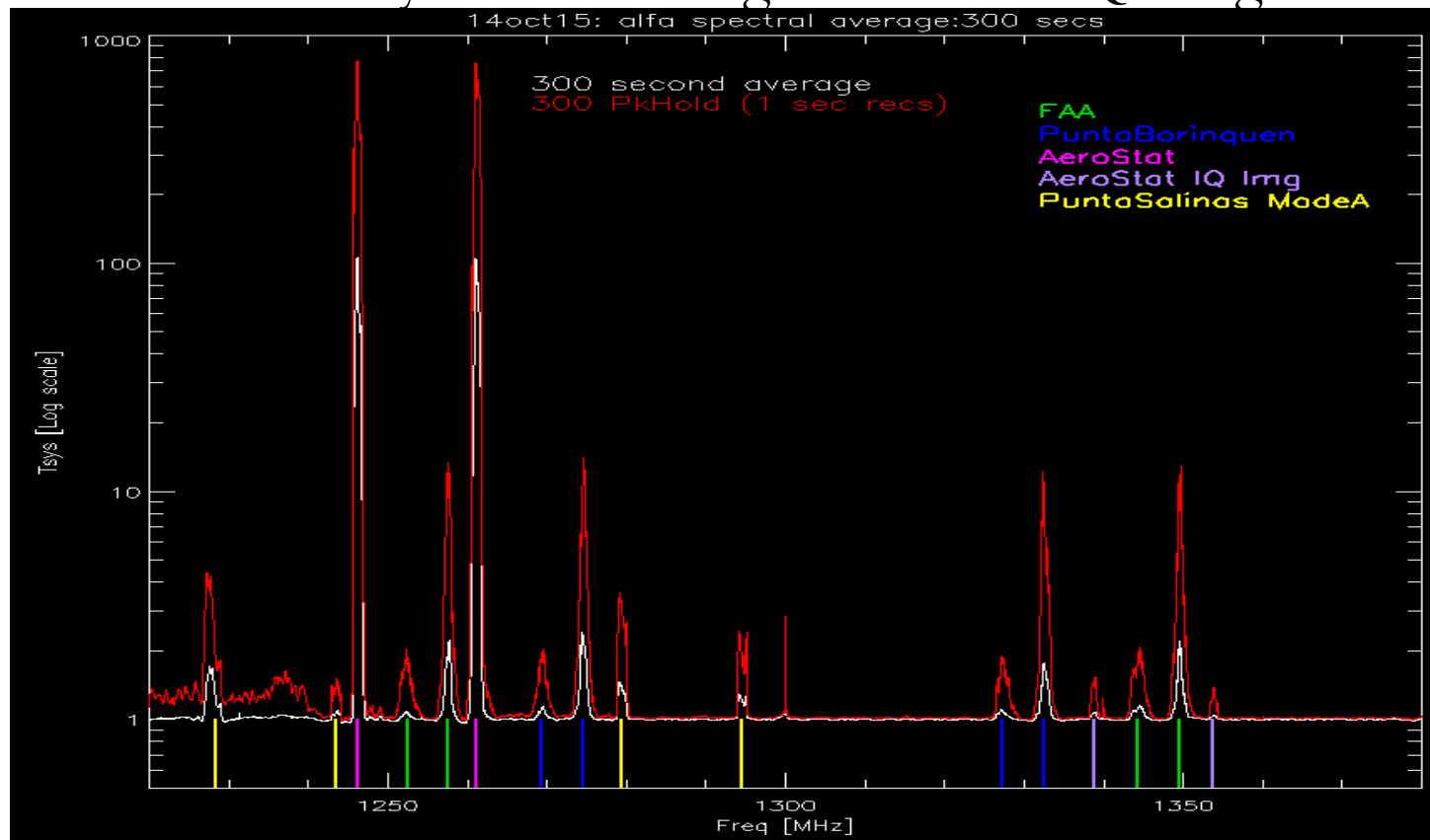


# L-band Radar RFI in ALFA receiver



# L-band Radar RFI in ALFA receiver

- 300 second average and 300 second peak hold.
- The peak value has been decreased by the radar duty cycle (10%). Instantaneously it is 10 times stronger.
- You can see why the aerostat generates an IQ image...



# LightSquared: 1670-1675

- Using 1670-1675 band (after GPS fiasco)
- Too close to 1665/1667 OH line
- Their transmitter met the FCC out of band spec by only .4 dB ( $43 + \log(P)$ )



# LightSquared: 1670-1675

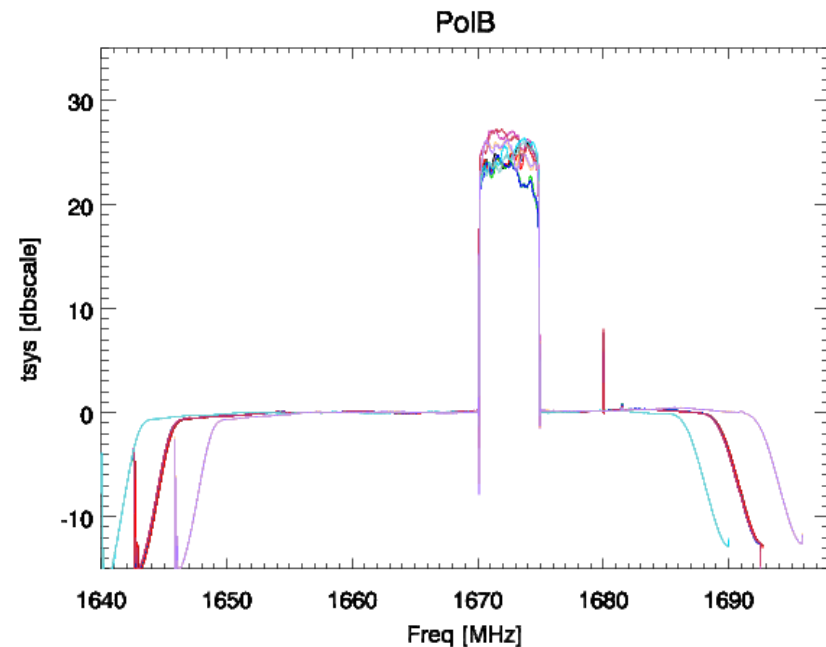
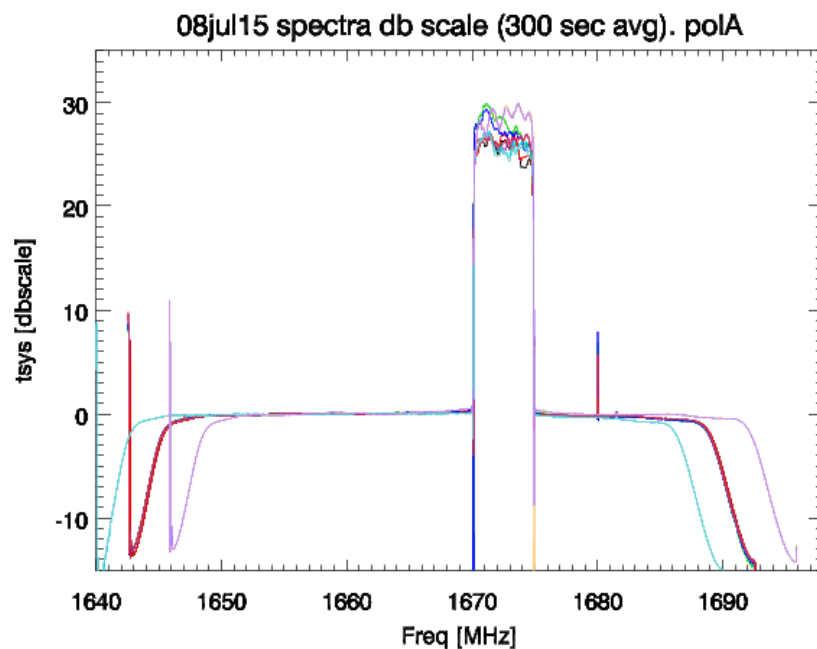
Tower ID	Distance to AO (miles/km)	Losses (dB)		
		Terrain	Freespace	Total
TMUSPRSNJN0001	43.9/70.5	-57.8	-133.9	-191.7
TMUSPRSNJN0002	11.5/18.63	0	-122.3	-122.3
TMUSPRSNJN0004	26.0/41.84	0	-129.4	-129.4
TMUSPRSNJN0005	51.2/82.51	-70.4	-135.3	-205.6
TMUSPRSNJN0006	27.4/45.27	-77.7	-130.1	-207.8

[http://www.naic.edu/~phil/rfi/lband/rfi1670\\_1675/rfi1670\\_1675.html](http://www.naic.edu/~phil/rfi/lband/rfi1670_1675/rfi1670_1675.html)



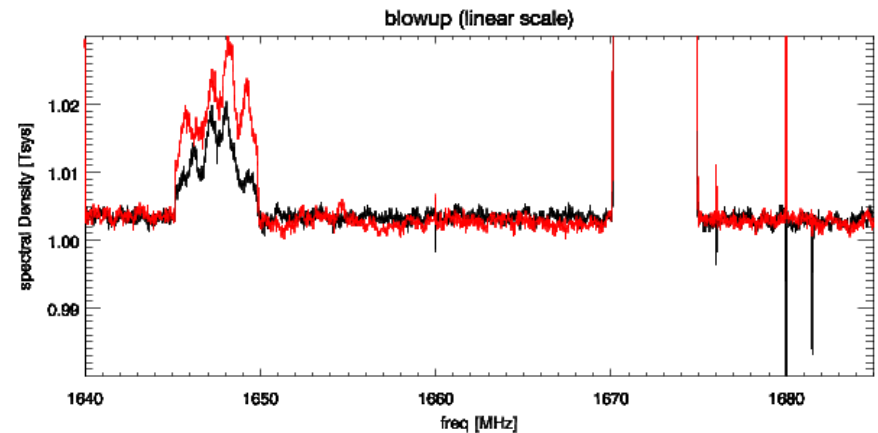
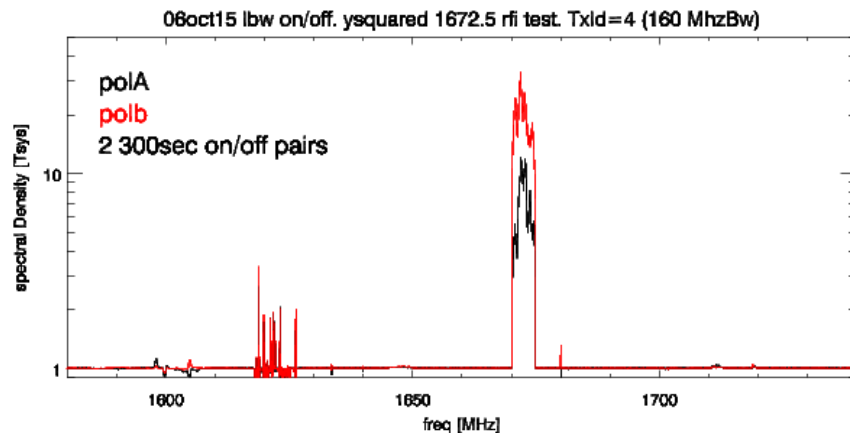
# LightSquared: 1670-1675

- 5 Towers, 2 are line of sight (LS) to AO
- Jul15 LS testing with Tower ID 2 (11.5 miles)
  - They hadn't put in their PRCZ request before testing.



# LightSquared: 1670-1675

- 06oct15: LS testing with AO
  - Decided they didn't need Tower ID 2
  - Tower ID 4 is line of sight, 26 miles
- 14oct15 LS decided they will not use Tower ID 4
- Towers 1,5,6 are 0.5 to 1% of  $T_{\text{sys}}$  in 1670 – 1675



# LightSquared: 1670-1675

- If they leaked into the 1667 line, we need a **super conducting filter** to not affect the OH line
- AO has a VLBI agreement with Radio Astron
  - They use 32Mhz about OH
  - Strong 1670-1675 RFI could wipe out these observations.
  - With towers 2 and 4 no longer in use, the VLBI operations will probably be ok
    - Towers 1,5,6 are .5% to 1% of  $T_{\text{sys}}$  In 1670-1675 band.



# S-band Issues – 2345-2350MHz

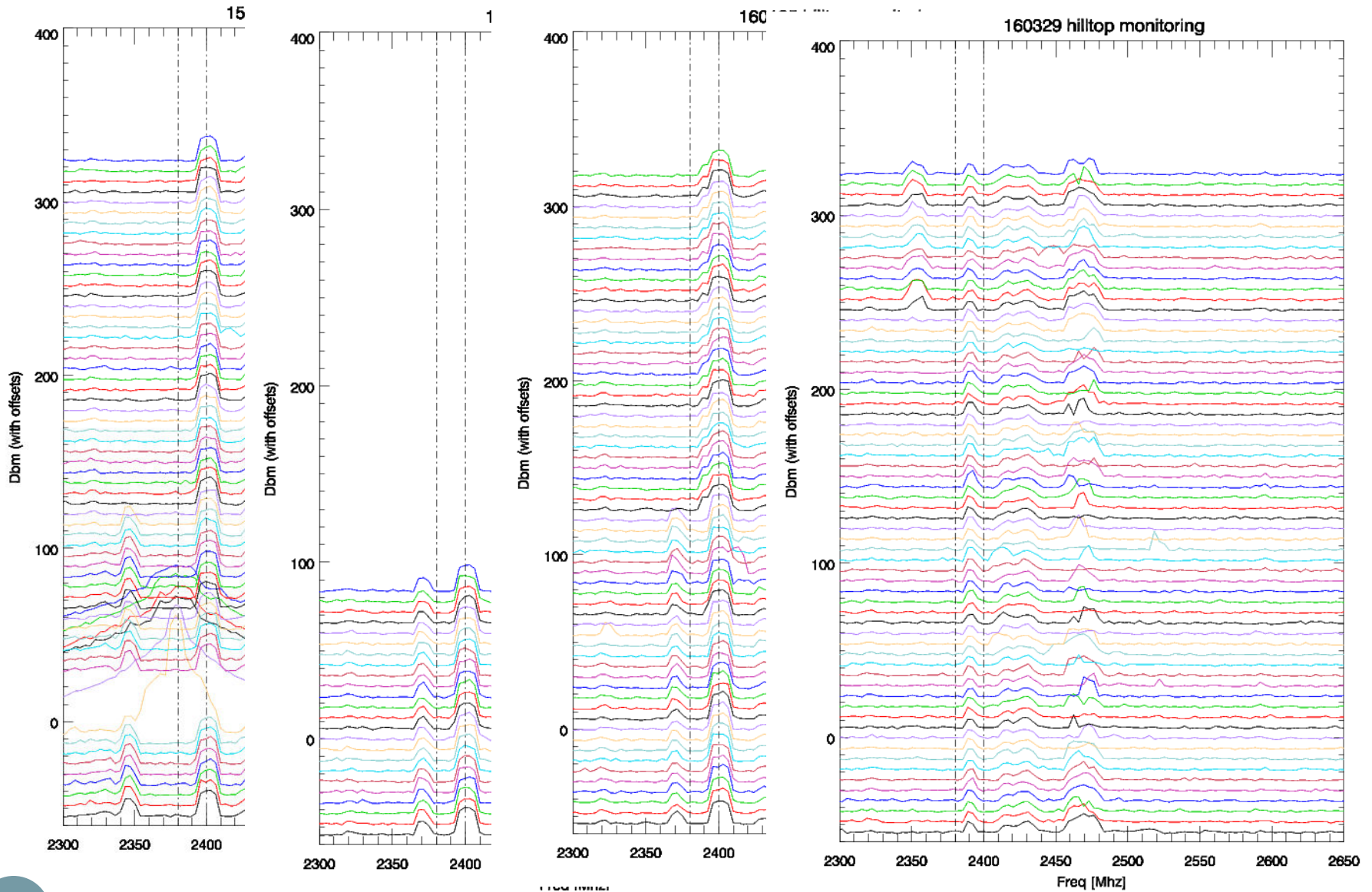
- 1997 WCS auction #14, Coloma wireless bought blocks A-D and then sold them to AT&T

BlockName	LowerFreqBlock	UpperFreqBlock
A	2305-2310	2350-2355
B	2310-2315	2355-2360
C	2315-2320	
D	2345-2350	

- The 2345-2350 band status:
  - 28dec15 went off the air
  - 31dec15 came back on at 2370-2375
    - This is inside our S-band transmitter band
  - 25jan16 went off the air.
    - they were at 2370-2375 for almost a month.
  - 29mar16: back on the air at 2350.



# S-band Issues – 2345-2350MHz



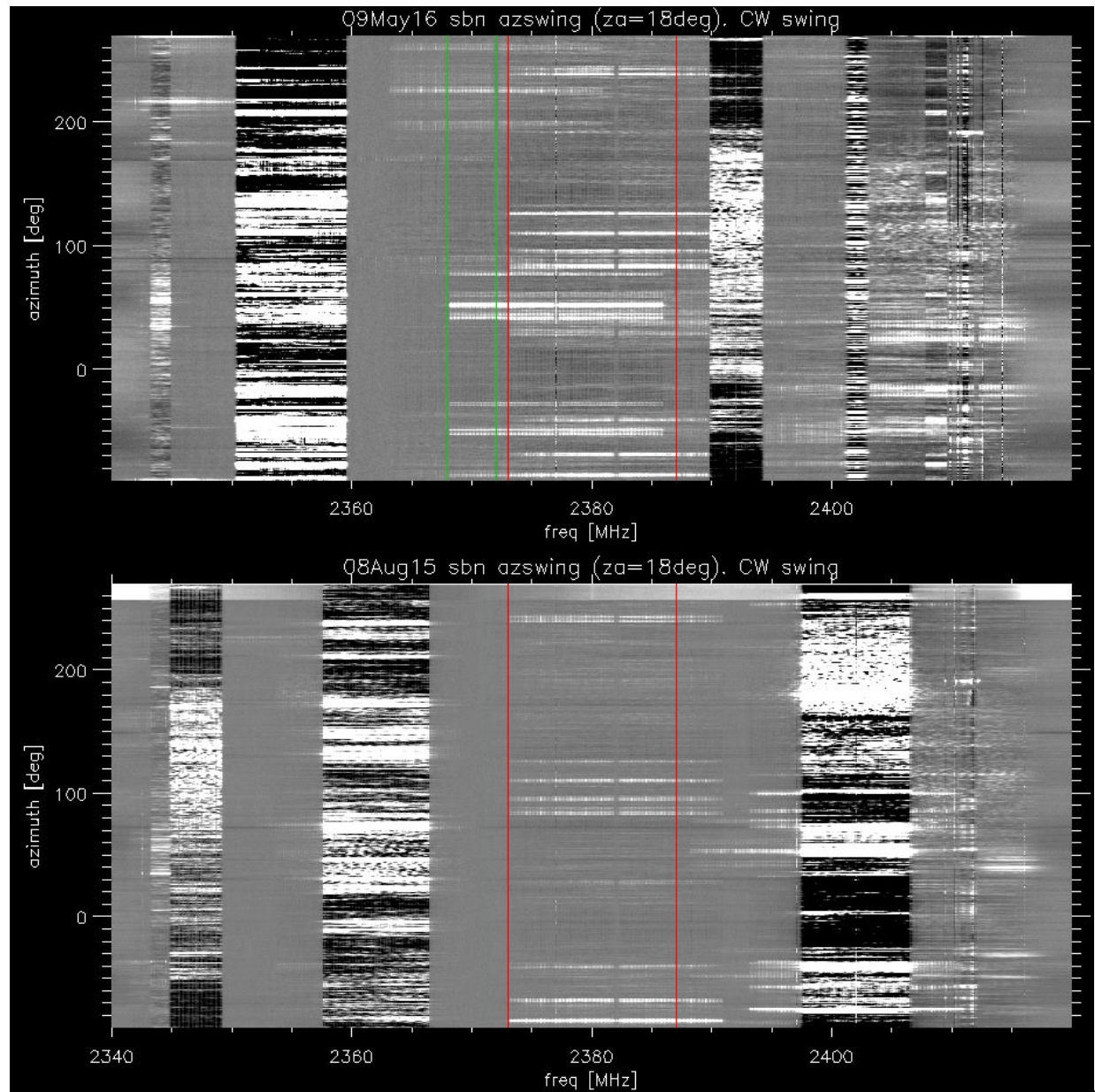
# Planetary Radar Interference – 2380MHz

- Frequency allocations
  - 2360-2390: mobile medical body networks, aviation flight, missile testing
  - The planetary radar:
    - Covers 2370 to 2390 MHz
    - Center frequency 2380
  - The unregulated ISM band starts at 2400 MHz



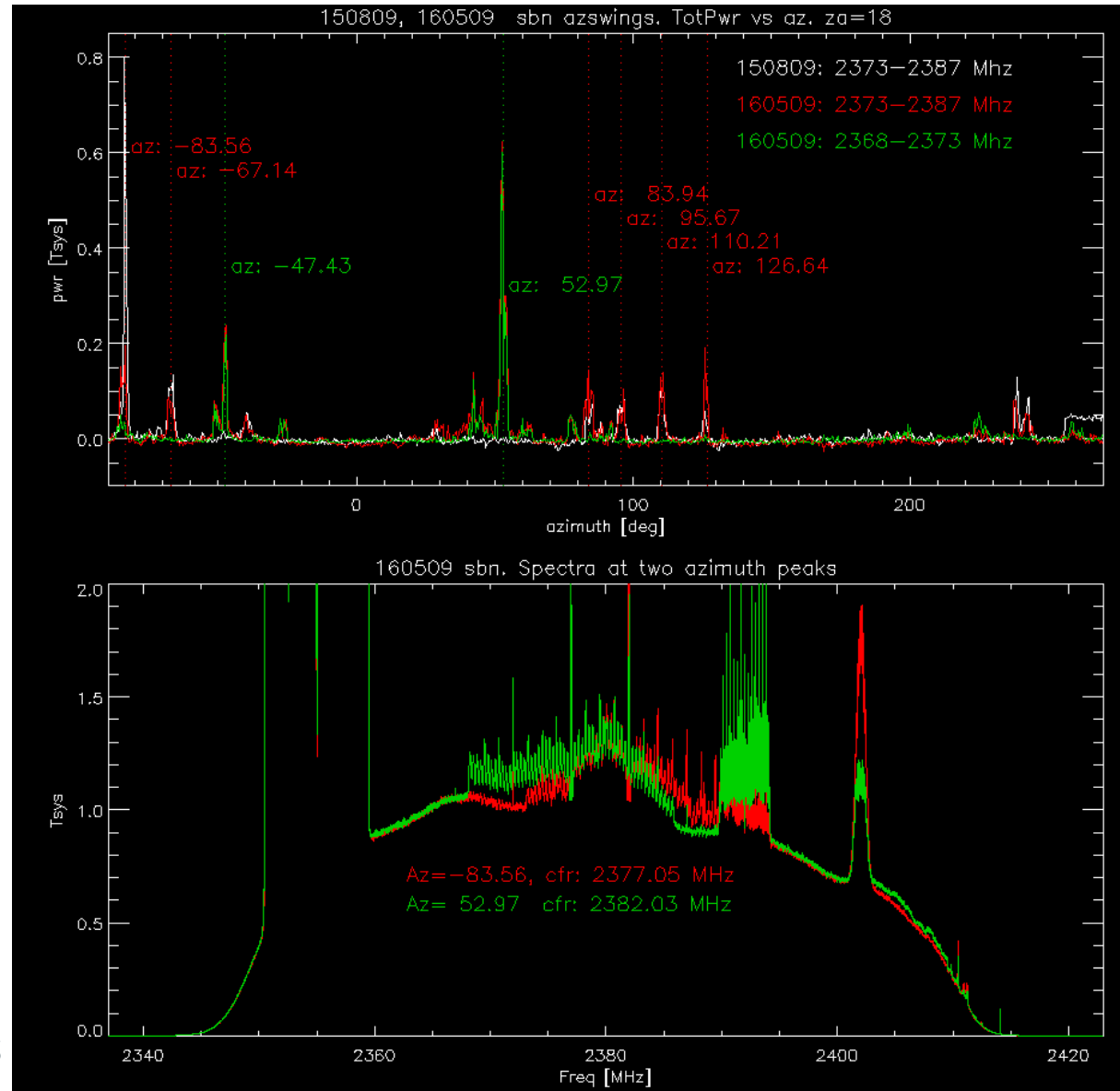
# Planetary Radar Interference – 2380MHz

- Azimuth swings
  - Aug15: 2350-2360 band at 2358-2367
  - Aug15, May16: 2372-2392 interference (weak)
  - May16: 2367-2387
  - May16: 2390-2395. very strong
  - Aug15: 2398-2408



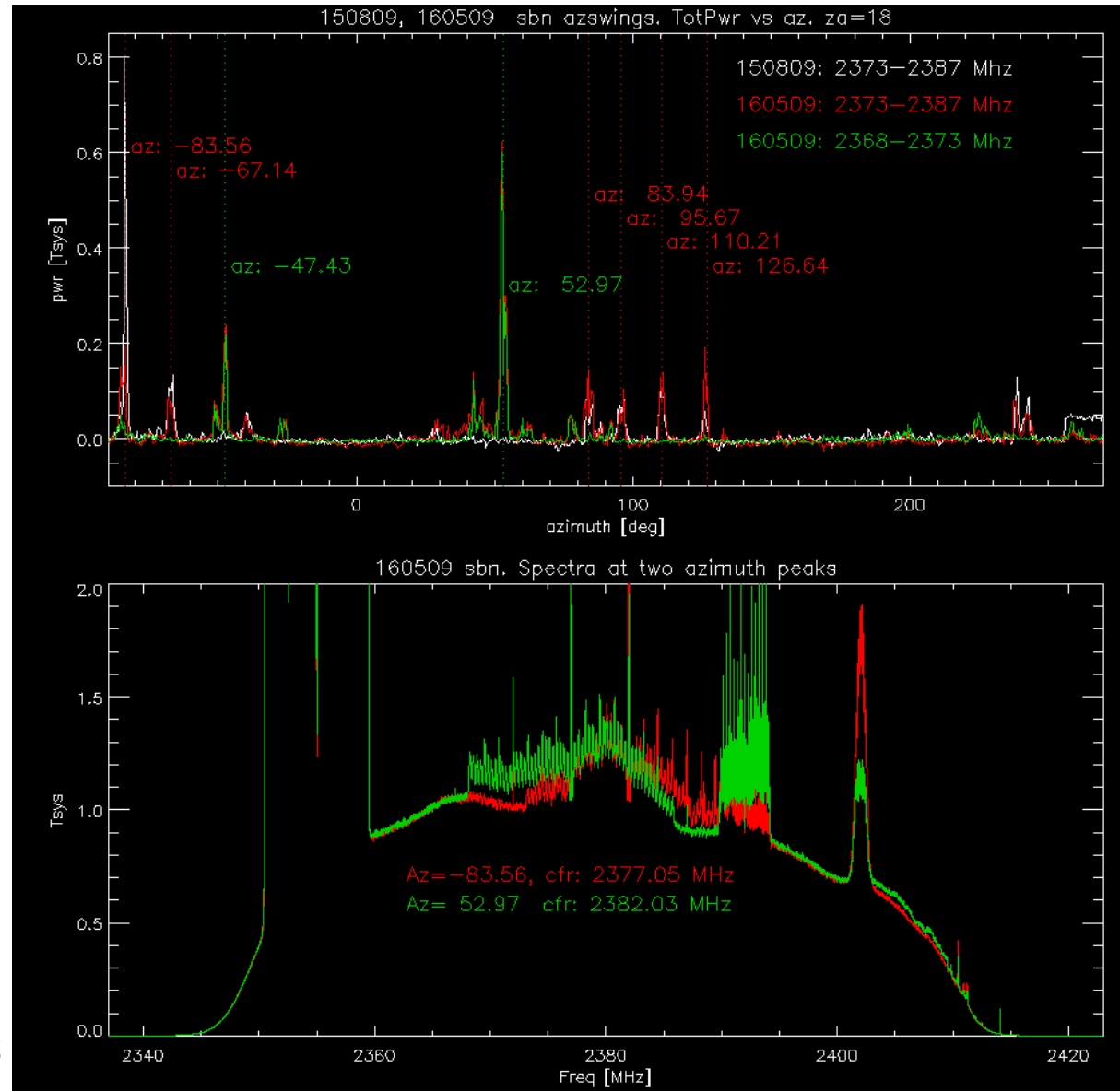
# Planetary Radar Interference - 2380MHz

- Average the power within the red, green lines of the image and then plot versus azimuth angle.
- The 2373-2393 pks (white/red) are stationary in azimuth aug15 and may16. Pk at -84 degrees.
  - They show peaks separated by 180 degrees. Direction is probably parallel or perpendicular to azimuth direction.



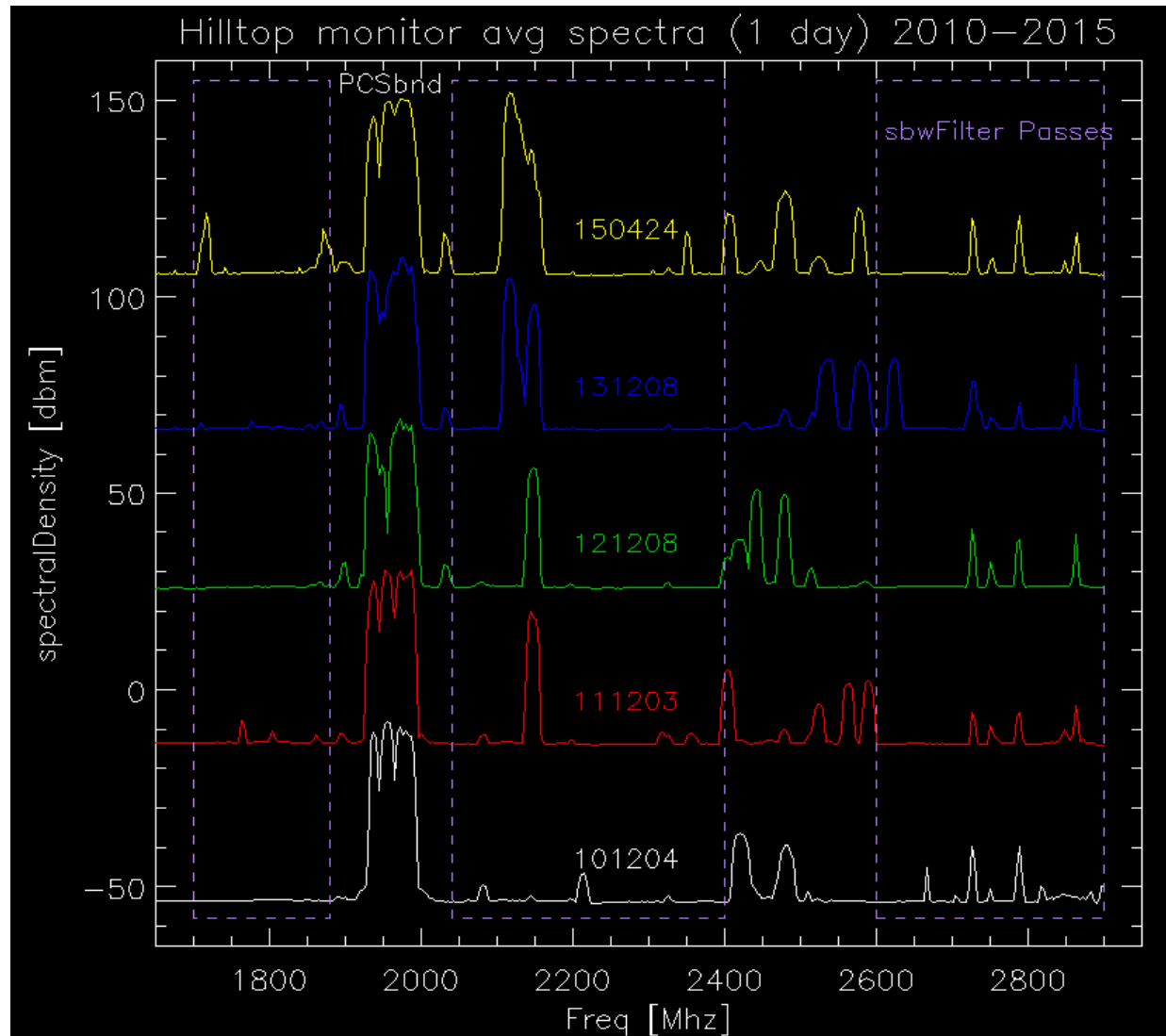
# Planetary Radar Interference - 2380MHz

- The 2368-2388 is new may16. peaks at az=53 deg.
- Moving the LO showed that they are not intermods.
- Bottom plot shows 1sec spectra at the two peaks.
- Dana & Phil went looking for this in jan16.. No luck.
- Looks like OFDM from an ISM internet provider (or user)



# S-band Wide & AWS 2130 Notched Filter

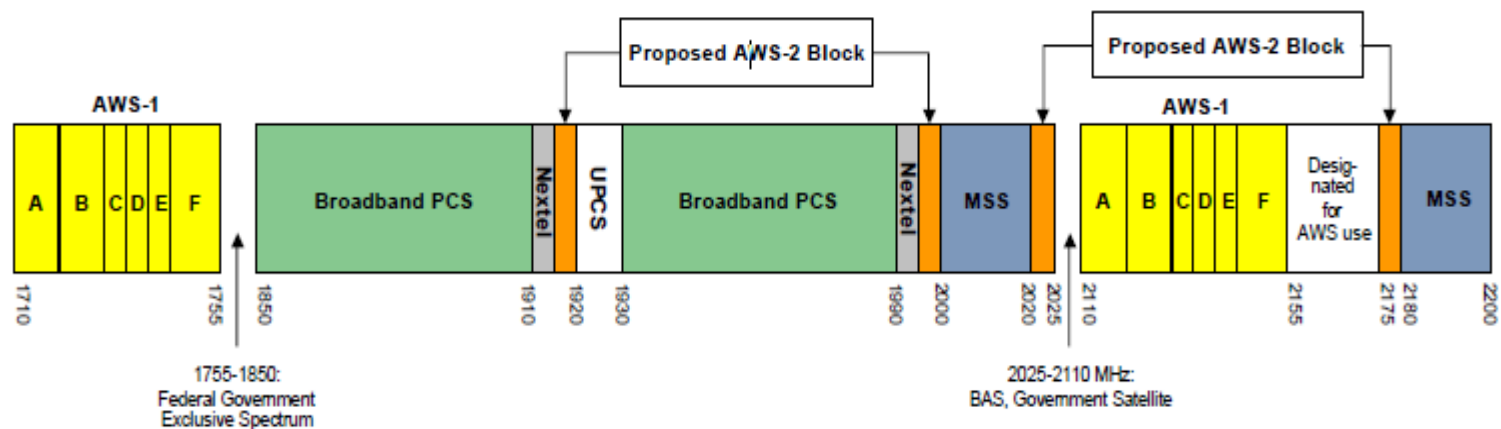
- S-band Wide –SBW
- 1700-3100 MHz has a selectable RFI filter bank:
  - 1770 – 1880
  - 2040 – 2400
  - 2600 – 3100
- Hilltop monitor data shows evolution of S-band RFI:
  - 2110-2150 RFI appeared after filter bank installed.



# S-band Wide & AWS 2130 Notched Filter

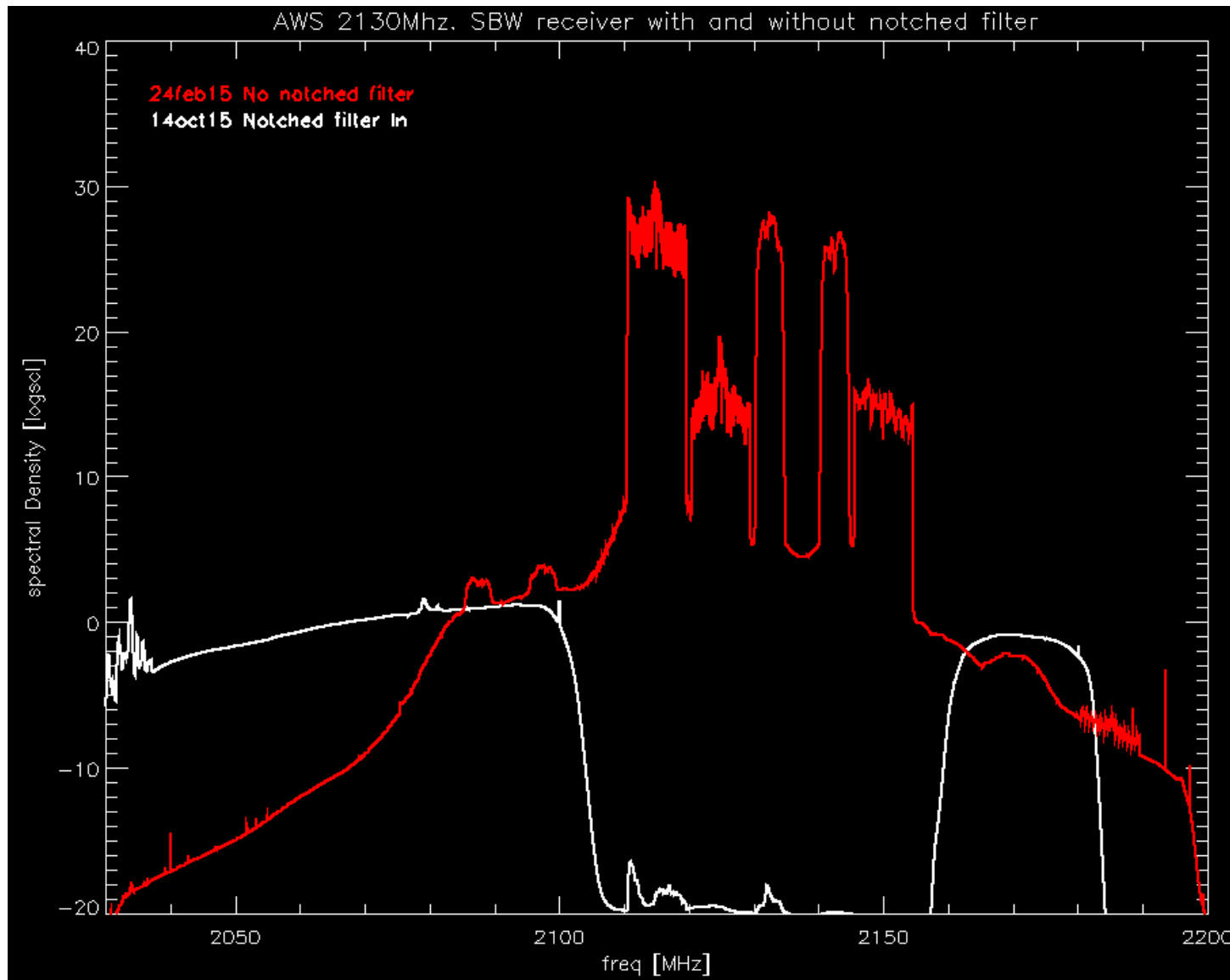
- AWS Band
  - AWS1 2110 – 2150 was causing problems with pulsar observing
  - In oct15 installed a permanent notched filter.
    - Cuts down on intermods that were spreading outside the band.

## Advanced Wireless Services (AWS) Band Plan





# S-band Wide & AWS 2130 Notched Filter

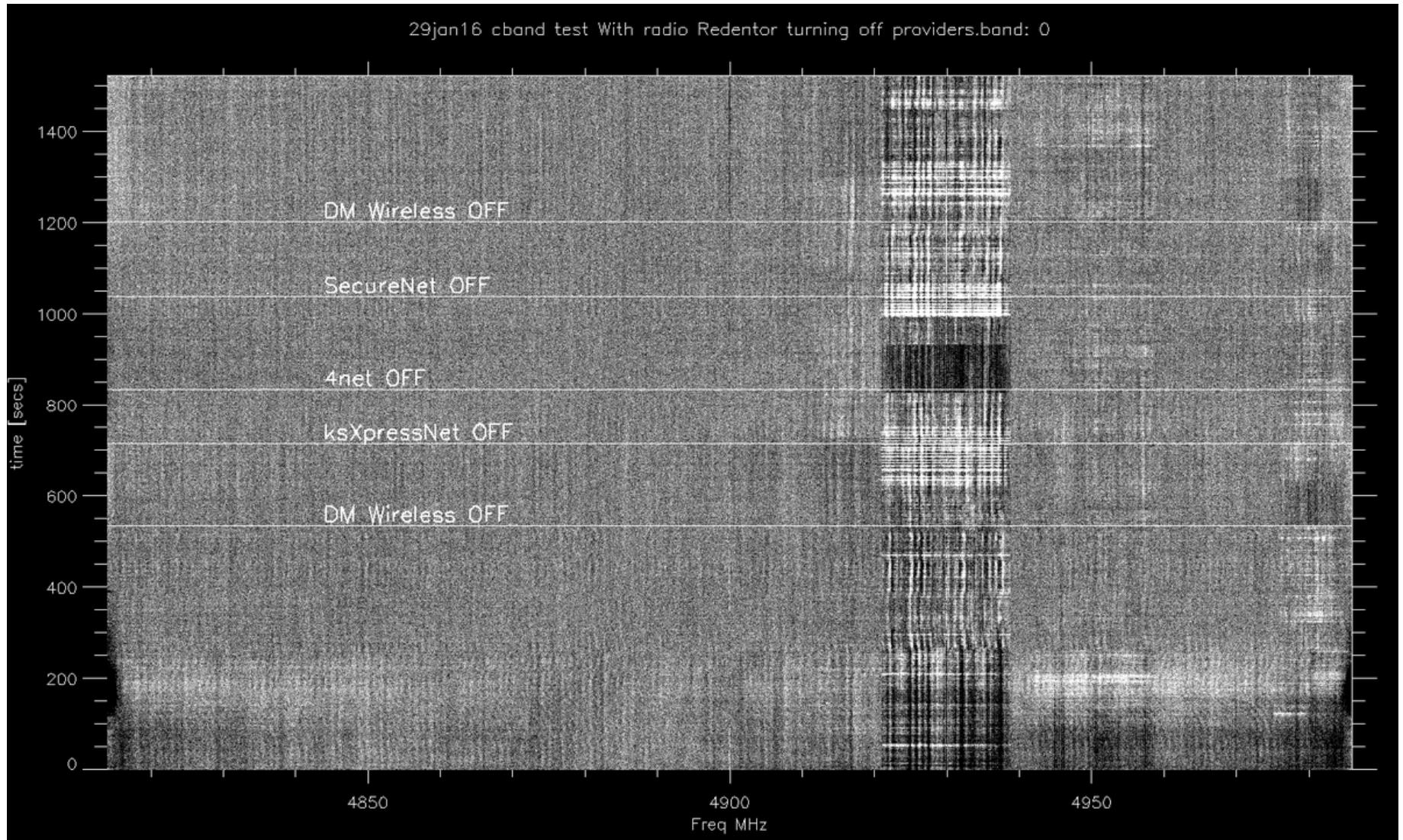


# C-band Interference

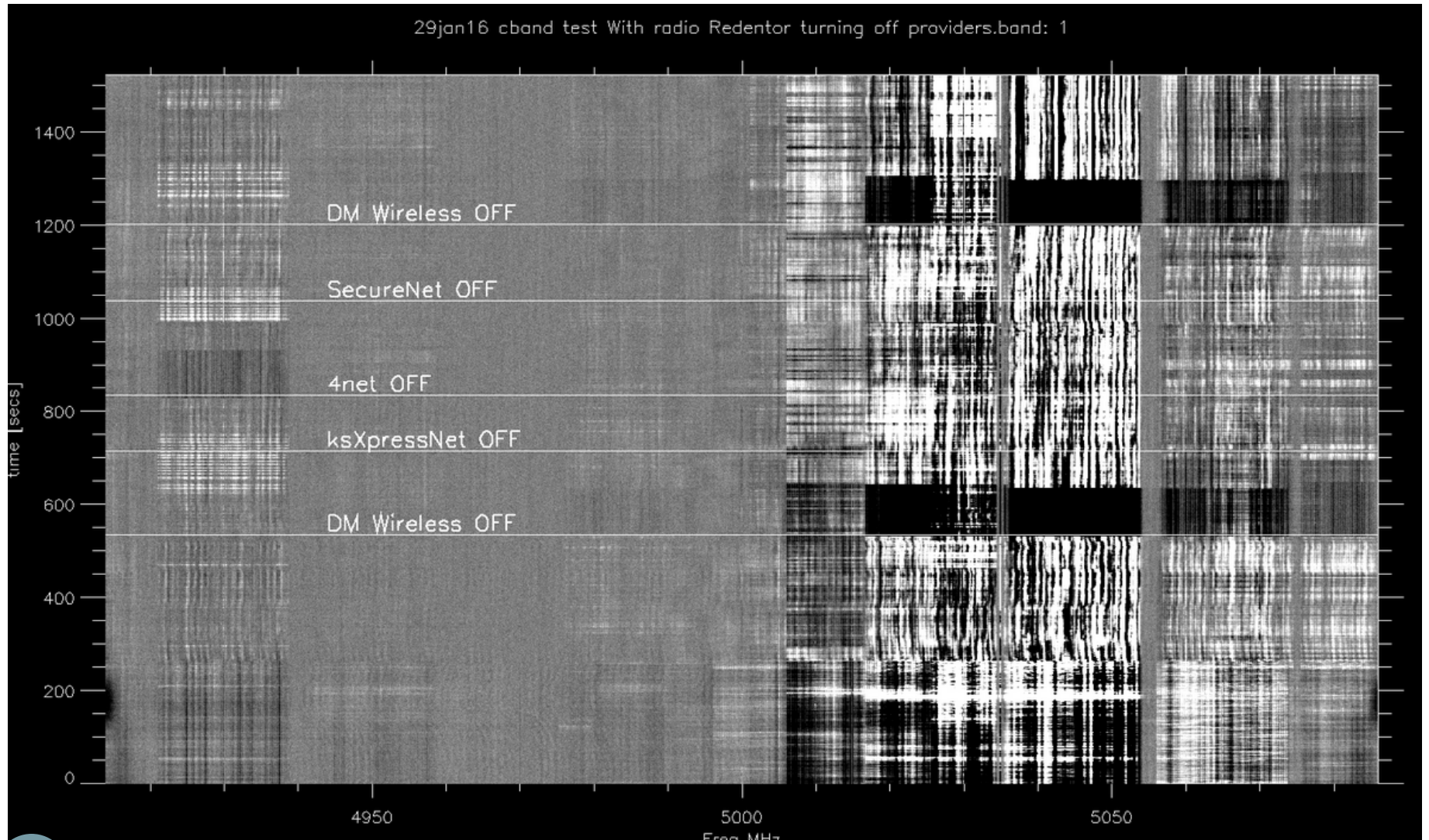
- U-NII (Unlicensed National Information Infrastructure)
  - Used by internet providers (801.11a/h/j/n/ac)
  - **Supposed to be above 5150 MHz...**
- **19Jan16** road trip found **Radio Redentor** tower in Utuado had out of band transmissions.
- **29jan16** tower operator cycled users ON/OFF while we took data:
  - Dynamic spectra during test showed who was illegal
  - **4Net, and DM wireless** were out of band
  - There was more than 1 user some freq bands (maybe from another tower).



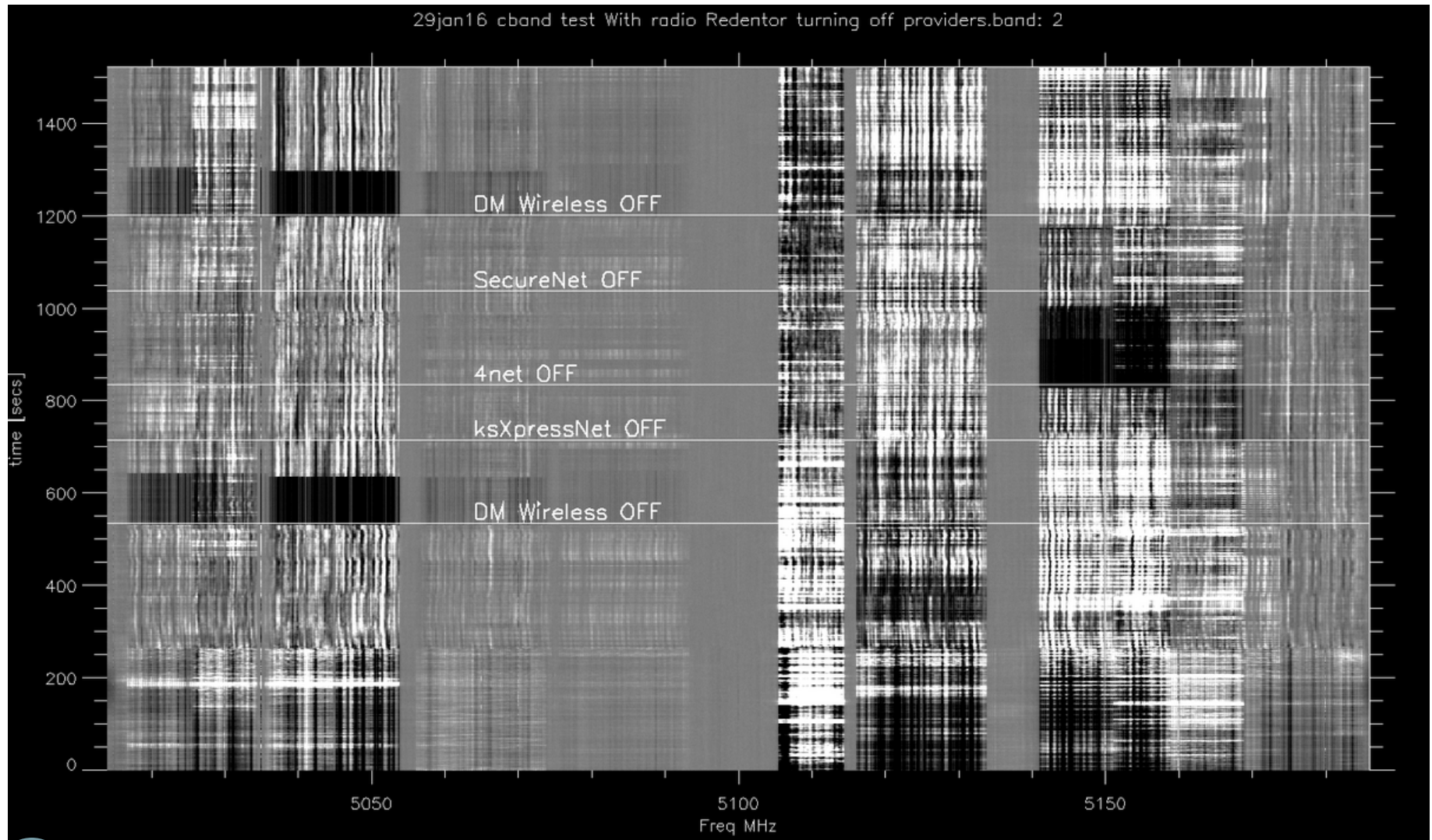
# C-band Interference



# C-band Interference

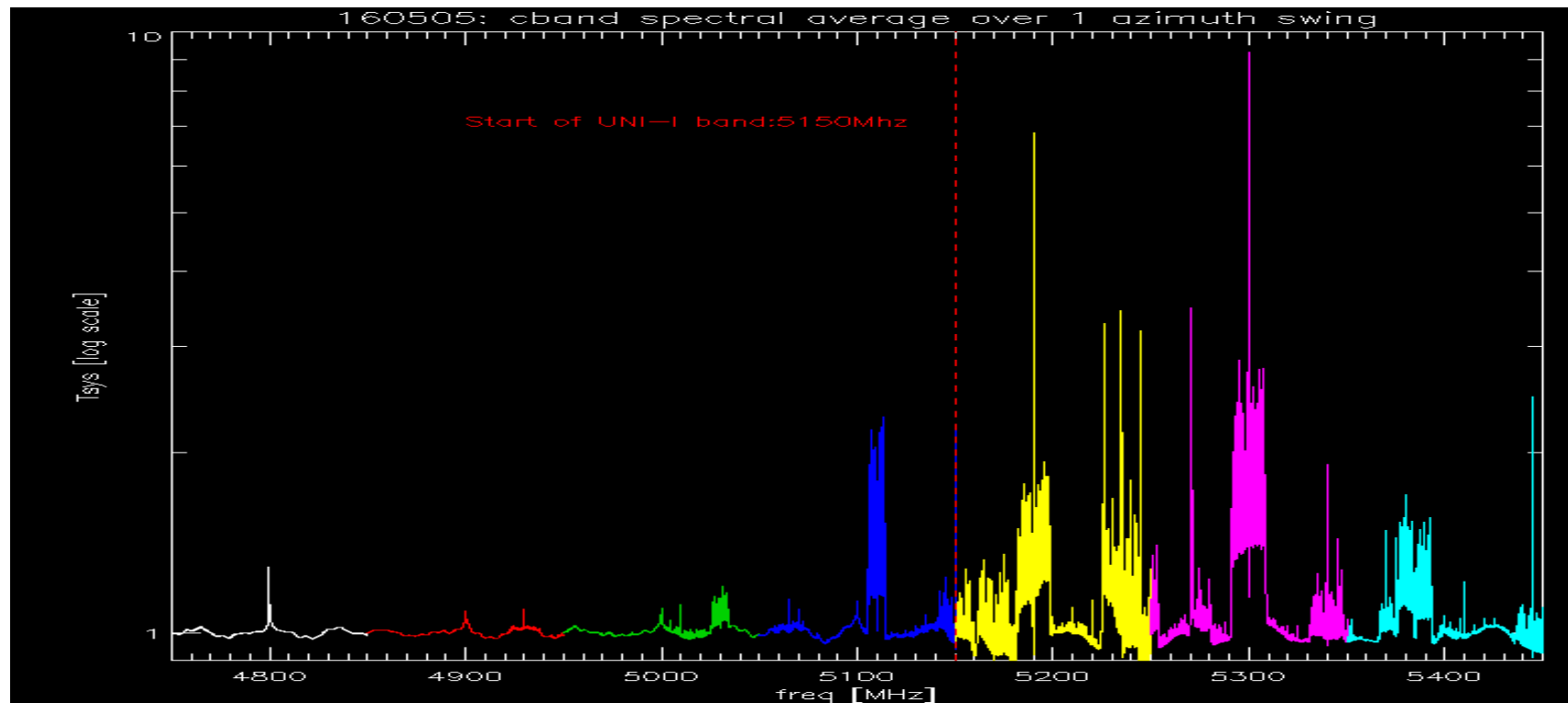


# C-band Interference

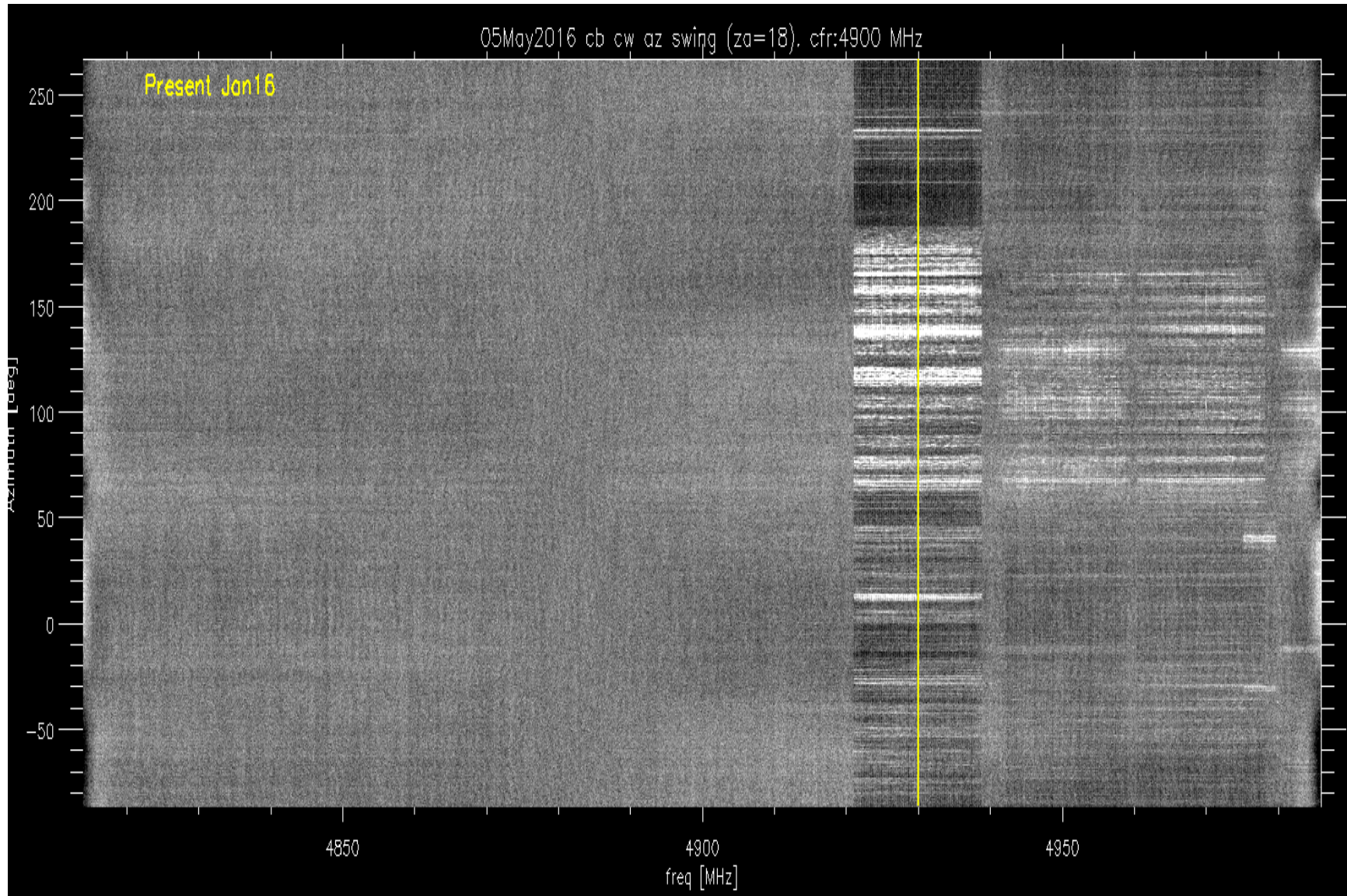


# C-band Interference

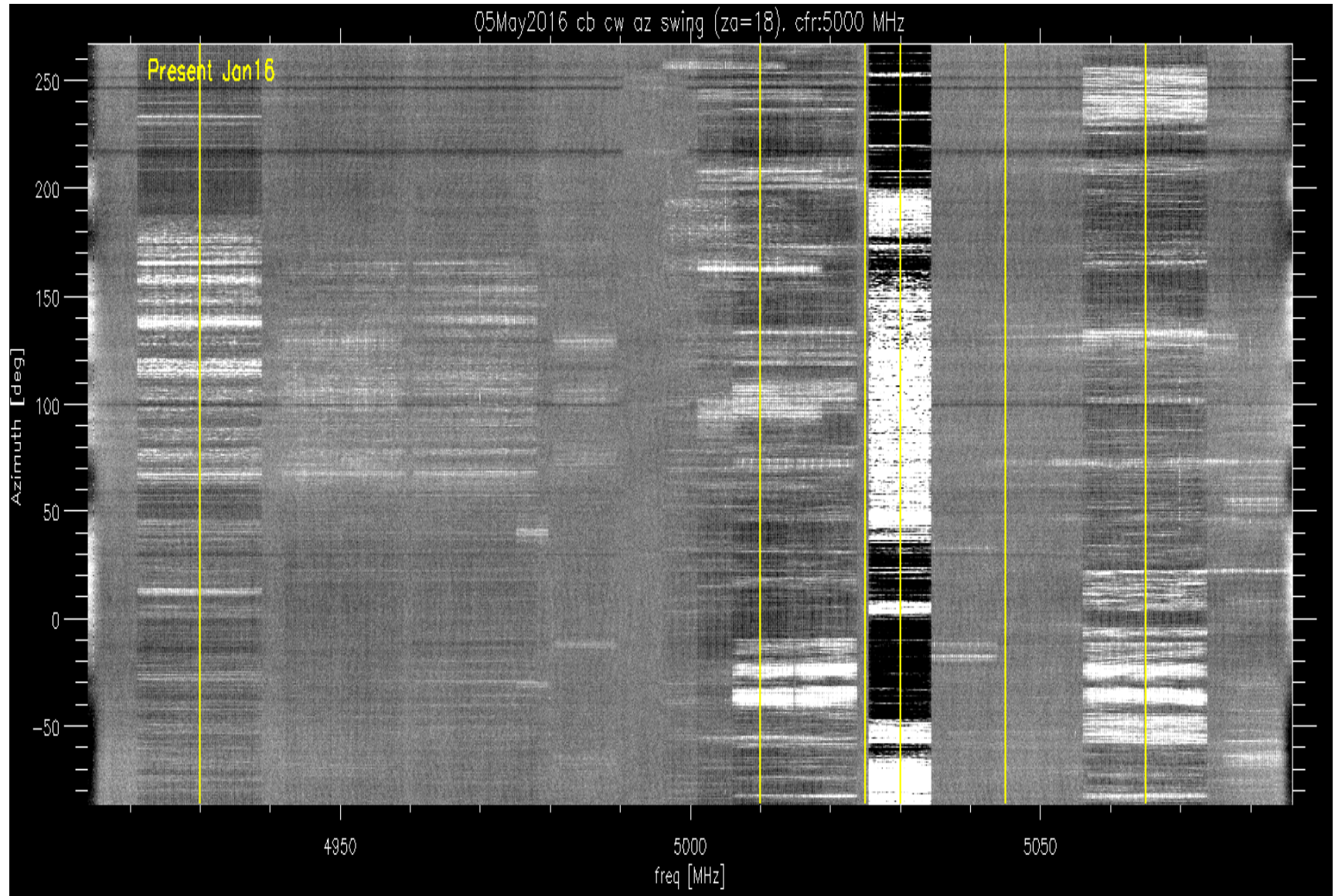
- DM wireless moved it's illegal freq up above 5150...but
- 05may16: another set of azimuth swings at cband:
  - Average spectra over entire 360 degrees still shows transmissions below 5150 MHz



# C-band Interference

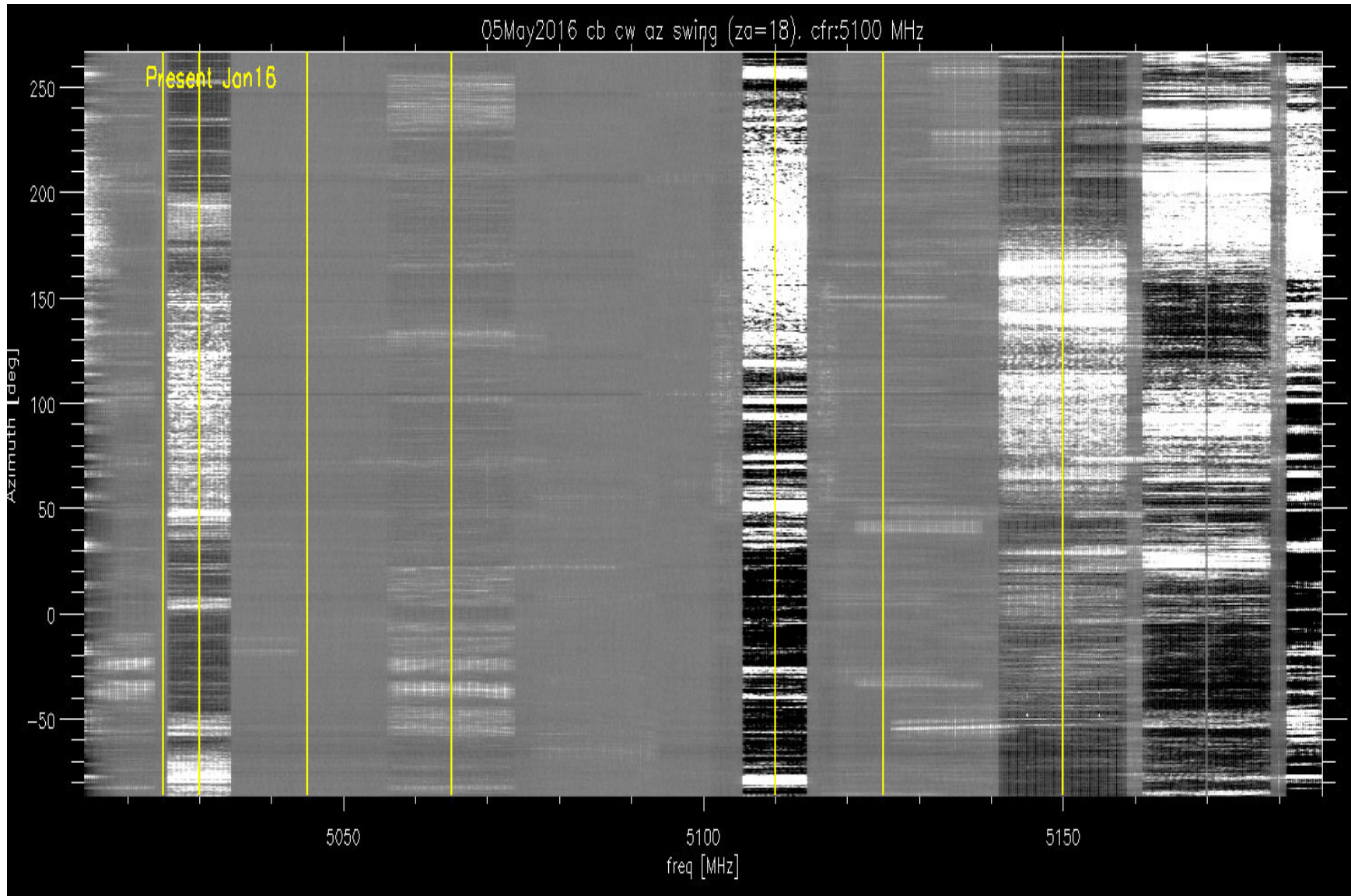


# C-band Interference





# C-band Interference



# Miscellaneous

- 327MHz Receiver:
  - 2<sup>nd</sup> harmonic of FM stations are getting into the band
    - Also seeing intermods between the two FM transmitters in Utuado (Radio Redentor and HQ. The towers are within 50 meters of each other).
    - We purchased a calibrated log periodic antenna that can cover 100 and 327 MHz simultaneously. Need to go near the transmitters to see if their 2<sup>nd</sup> harmonics are legal.
  - Lots of the other spikes in the 327 band are coming from our equipment. Partially fixed improving shielding.
- New Exhibits at the Visitor Center
  - Took data with spectrum analyzer, and some data from the 305m Data reduction finished. Now we have to figure out how to shield the displays



# Questions?

**Thank you!**



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