RFI and How to Deal with It

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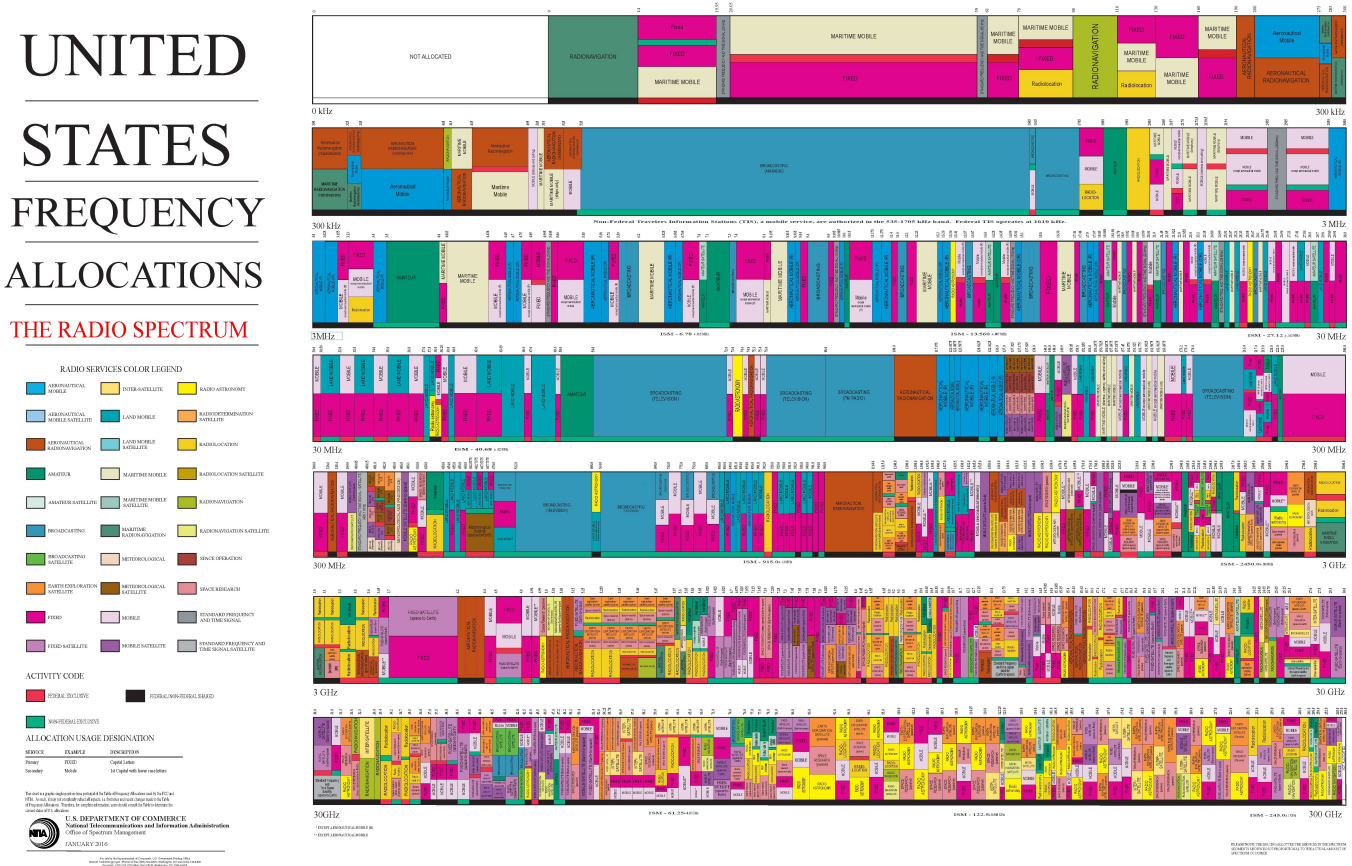
Spectrum Management

US Government has set aside parts of the spectrum for astronomy….

But the parts of the spectrum are few and far between.



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The Spectrum and Radio Astronomy

- Observations often use wide-bandwidths
- Sources can be red-shifted
- May be observing spectral lines that are “not protected”
- A majority of the spectrum radio astronomy uses is “shared”

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Why care about spectrum management?

- There are three ways to handle unwanted radio frequency signals:
  - Legal Protection
  - Community agreement
  - Excision

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Why care about spectrum management?

- There are three ways to handle unwanted radio frequency signals:
  - Legal Protection
  - Community agreement
  - Excision
- Spectrum management includes:
  - Legal Protection
  - Community agreement

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Spectrum Management

- Legal Protection
  - International/Federal agreements regarding spectrum allocation
  - Federal protection for geographic regions
  - Local protection for geographic regions

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Spectrum Allocation

- Spectrum bands are allocated to ‘services’
  - Service = purpose or application
  - Most services are ‘active’ - they transmit
- Radio astronomy and Earth-sensing are ‘passive’
  - RAS and EE-SS (passive) only listen
  - Radar astronomy and EE-SS (active) also transmit but are distinct
  - Concept of ‘use’ elusive for passive services
- Examples of ‘services’
  - Radiolocation = radar
  - Radionavigation/Radio Navigation Satellite Service = GPS
  - Fixed-satellite service (space-earth, earth-space)
  - Fixed service (terrestrial point to point)
  - Cellular service

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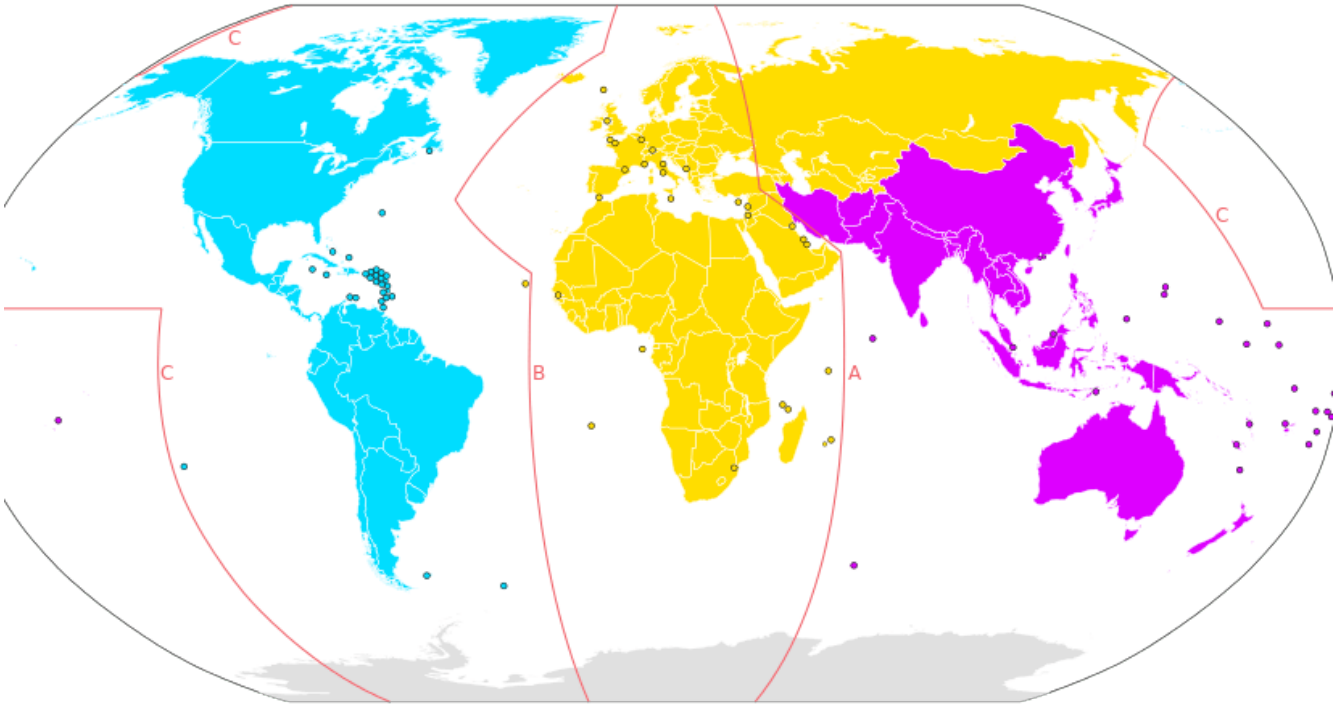
How is the spectrum allocated?

- Three ITU-R regions (International Telecommunications Union - Radiocommunications)



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How is the spectrum allocated?

- Three ITU-R regions (International Telecommunications Union – Radiocommunications)
  - All countries are sovereign inside their border
    - Assumes radio waves stop at borders
  - No country can operate a satellite transmitter without ITU-R permission
    - Border issues are often important
    - Not all countries participate in ITU-R regulations
  - Most general set of rules
    - Renegotiated every 4-5 years through the UN http://www.itu.int/ITU-R/

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How is the spectrum allocated?

- Radio Astronomy and Space Sciences represented through IUCAF:

  (Scientific Committee on Frequency Allocations for Radio Astronomy and Space Science)
- Chartered for International Astronomical Union (IAU), Committee on Space Research (COSPAR), International Union of Radio Science (URSI)

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How is the spectrum allocated?

- Within the United States:
  - Federal Communications Commission (FCC)
    - businesses
  - National Telecommunications and Information Administration (NTIA)
    - Federal government’s use of spectrum
    - Includes NSF

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Legal Protection

- Radio Quiet Zones
  - Legal protection against some/all forms of radio frequency interference
  - Located around a geographic region

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Puerto Rico Coordination Zone

- Established in late 1990s
- Entire territory of Puerto Rico
- All new and upgraded transmitters

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National Radio Quiet Zone

- Established in 1957
- 13,000 square miles
- All new fixed, license transmitters

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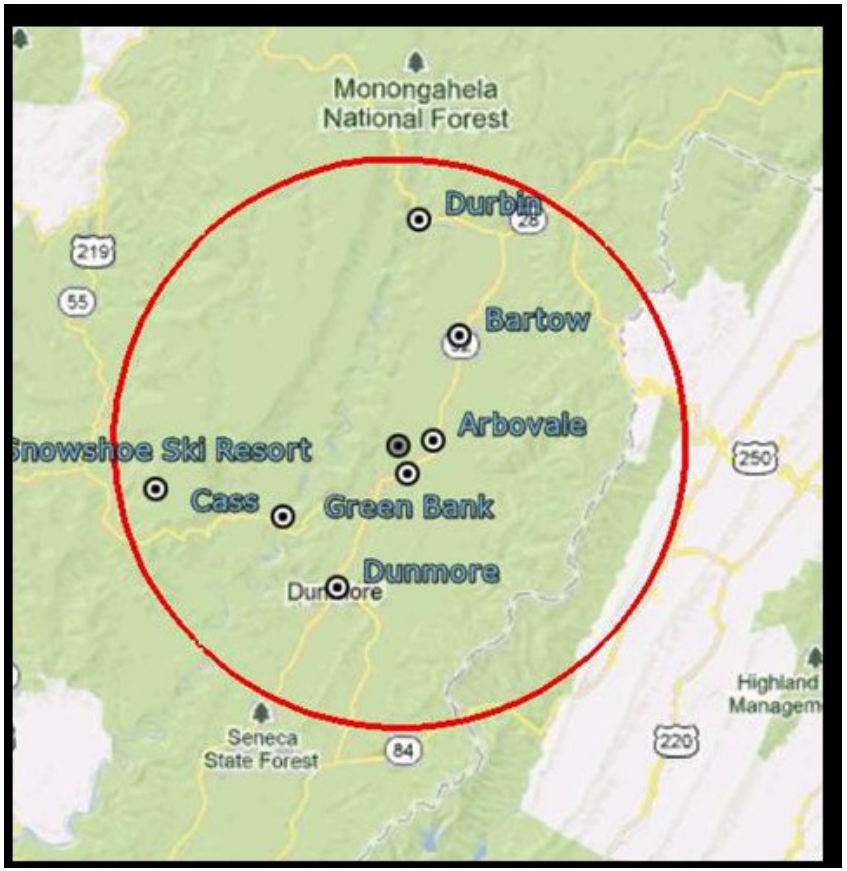
WV Radio Astronomy Zone

- Established in 1956
- 10 mile radius
- All transmitters
  - Intentional
  - Unintentional



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Legal Protection

- Radio Quiet Zones
  - Legal protection against some/all forms of radio frequency interference
  - Located around a geographic region
- Enforcement is a major challenge
  - Must balance law and radio astronomy needs against community opinion

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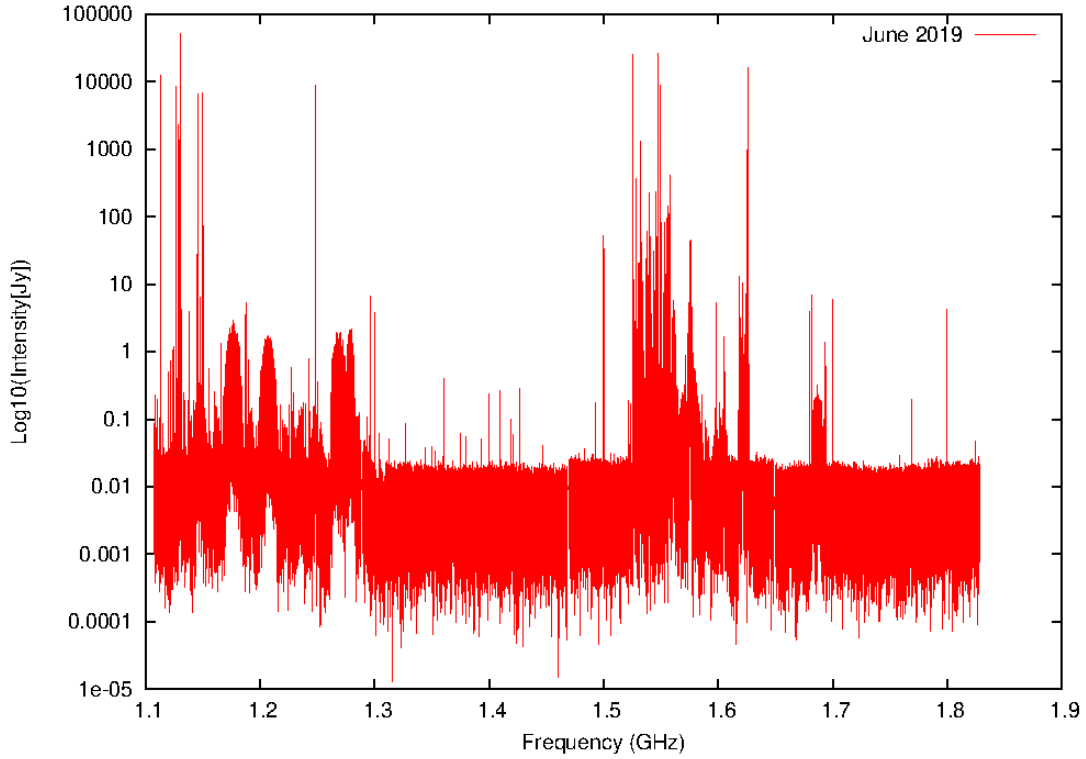
Community Agreement

- Even with legal agreement community agreement is vital
  - Radio Astronomy must work with the community and not against it
- Continuous challenge with outreach, education and help
  - Teach the community who you are why you need the protection
  - Show the community the value of radio astronomy locally and scientifically
  - Help the community to mitigate the effects of Quiet Zones
- This is a difficult challenge that is never finished and must always be considered

Radio Frequency Interference (RFI)

- Where is the RFI?



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The RFI “Myth” - a legal viewpoint

- Interference is:
  - ***not*** any unwanted signal
- Interference is:
  - Emission out of designated frequency band
  - If applicable: intensity above allowed limits

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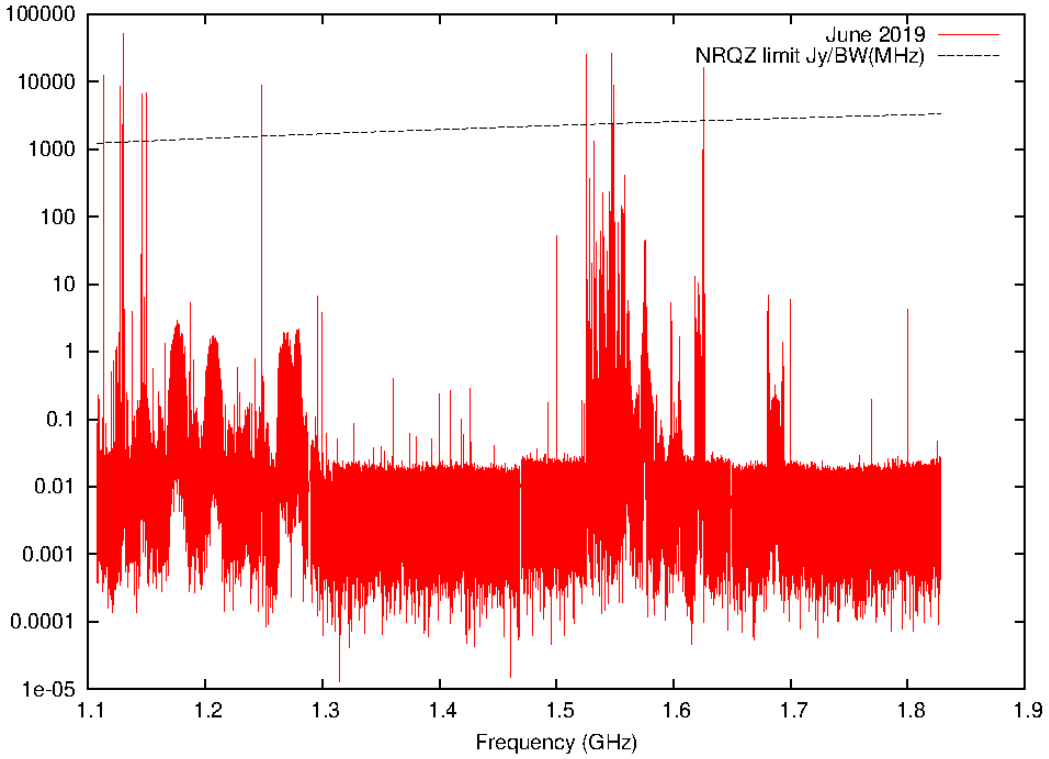
Radio Frequency Interference (RFI)

- Where is the RFI?



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Radio Frequency Interference (RFI)

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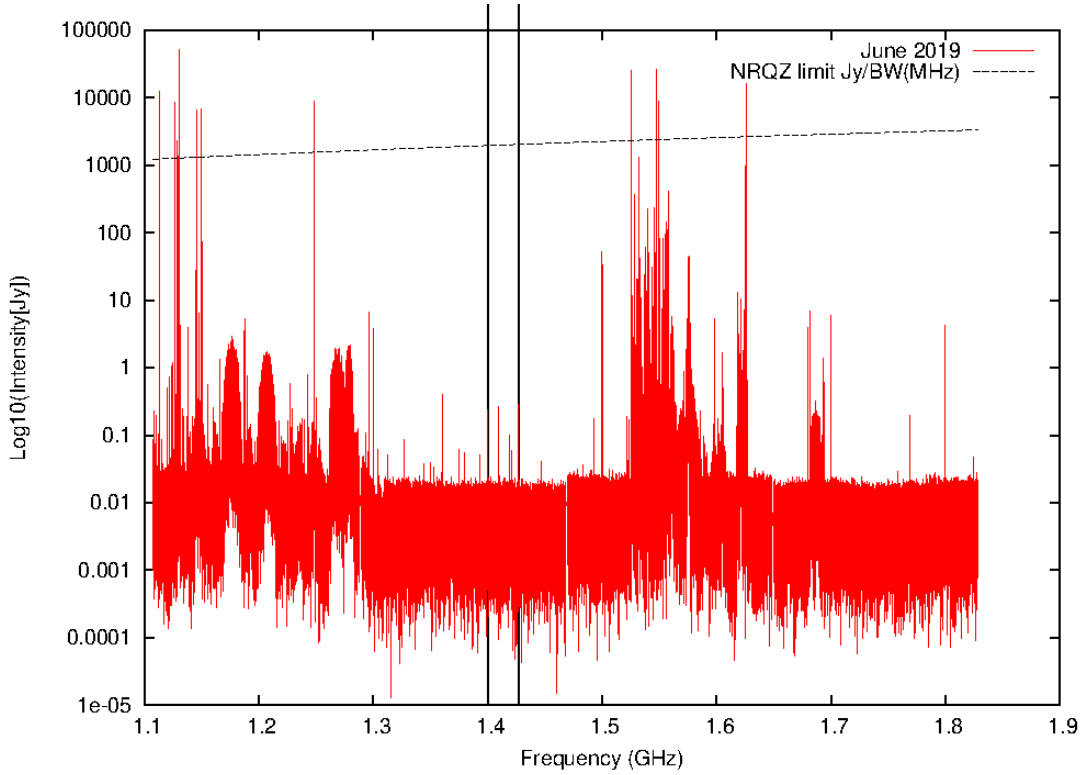

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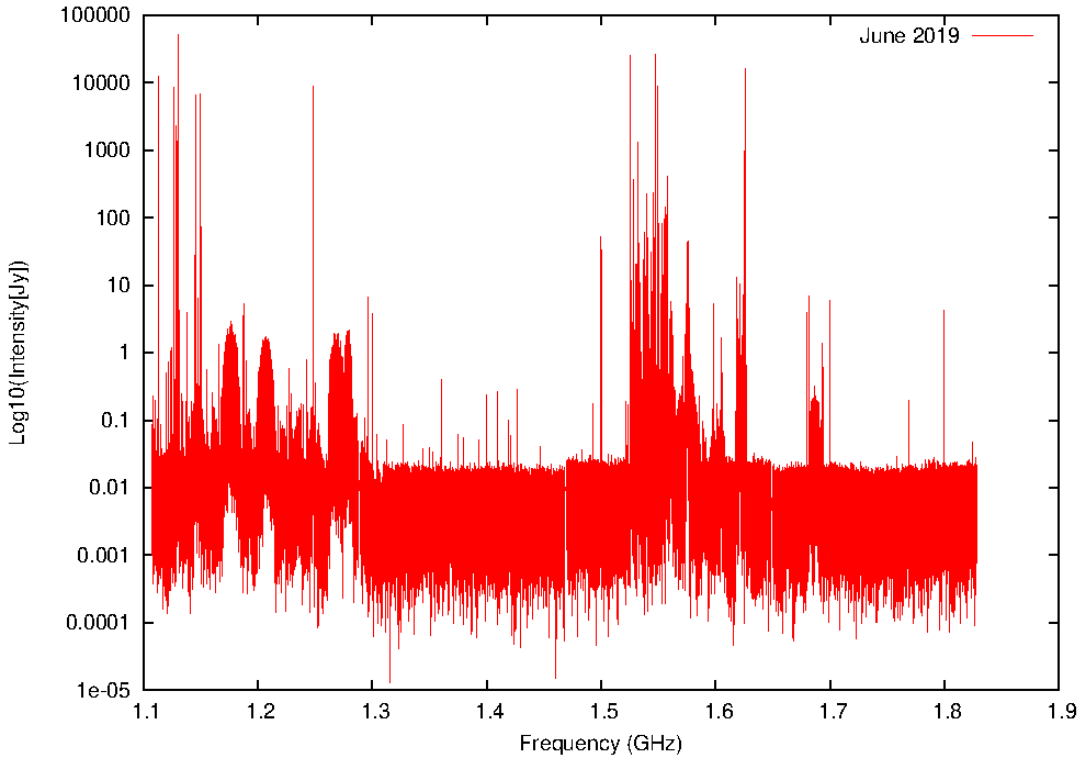
RFI excision

- Prior to observing
- During the observation
- Post observation

Planning prior to observing

- Understand the RFI environment
  - RFI plots



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Planning prior to observing

- Understand the RFI environment
  - RFI plots
    - A bandpass shift can save an observation
  - How often does RFI appear
    - Post observing flagging produces better results if data sampled faster than RFI changes
- Can a mitigation solution be found?

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RFI excision during observing

- Adaptive Cancellation
- Filters/spectral channel suppression
- Blanking
- Future
  - Non-Guassian statistics, e.g. Spectral Kurtosis
  - AI/Deep Learning

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Adaptive Cancellation

- Uses 2nd antenna to measure RFI
- “Matches phases” between antennas to cancel RFI signal
- Works well in cases of single strong RFI signal
  - ATNF has canceled signal from TV repeater
- Multiple interferes and multi-path are issues

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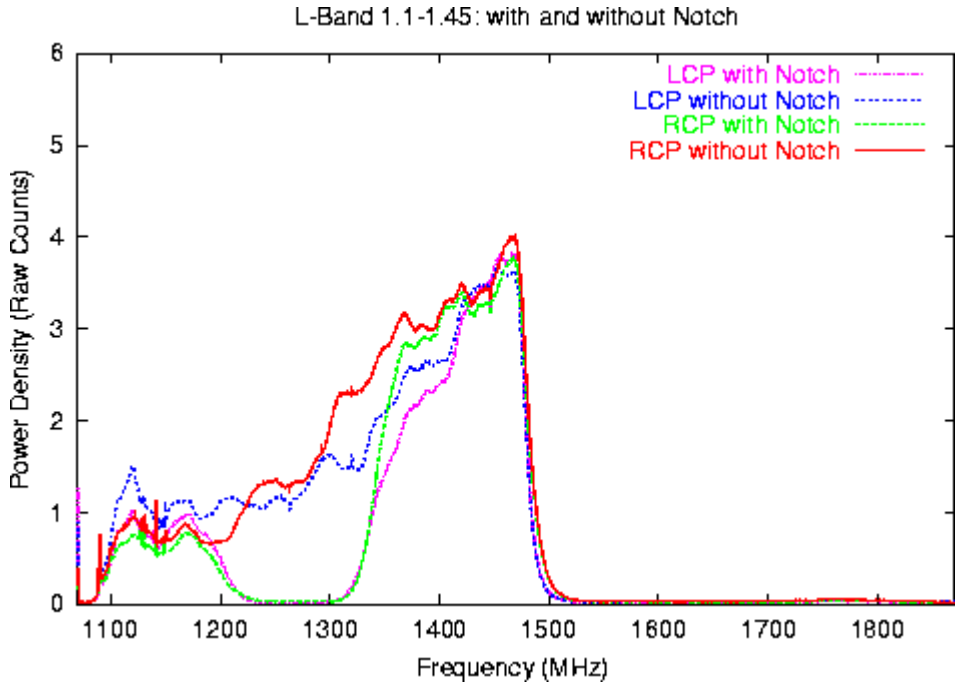
Filters/spectral channel suppression

- GBT has a notch filter
  - 1250-1350 MHz
  - Covers FAA radar and Aeronautical Nav. Signals



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Blanking

- Former Arecibo radar pulse blanker
  - Known time of arrival
  - Known frequency
  - Known phase
- Can avoid integrating when radar signal present
- Radar is now frequency agile so blanking no longer works

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Future of RFI Cancellation

- Non-Guassian Statistics
  - Signals from space are random and have Gaussian profiles
  - RFI is not random or Guassian
  - Spectral Kurtosis
    - Kurtosis measures how Gaussian data are
    - Can blank time series of raw voltages above a given threshold
  - Cyclic Spectroscopy
    - Filters “repeating” patterns

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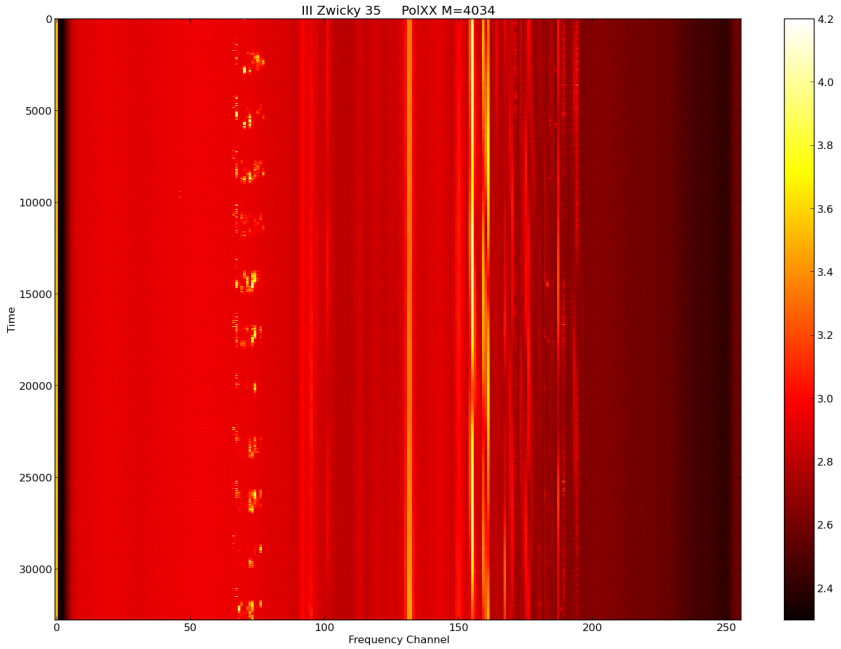
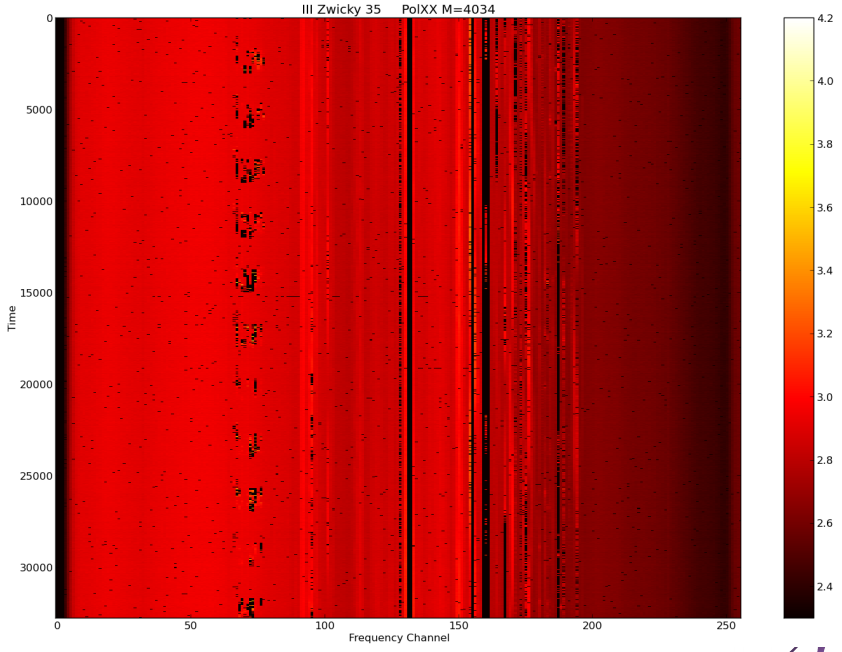
Future of RFI Cancellation





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Future of RFI Cancellation

- Spectral Kurtosis
  - Signals from space have Gaussian profiles
  - RFI does not
  - Kurtosis measures how Gaussian data are
  - Can blank time series of raw voltages above a given threshold
- Expect problems once >50% of signals are RFI

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Future of RFI Cancellation

- Artificial Intelligence/Deep Learning
  - Research into this method has begun
  - Shows promise

Flagging

- Time domain
  - Looks for anomalously bright voltages
  - Replaces values above a threshold
- Spectral domain
  - Flag specific spectral channels vs time

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RFI excision Pros/Cons

- Prior to observing
  - 100% efficiency in observing
  - May rely on kindness of other
- During the observation
  - Self contained
  - > 50% of data may need to be flagged in 5-10 years, depending on frequency
- Post observation
  - Less data volume
  - Greatest amount of flagged observing time

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State of RFI

- Automobile Collision Avoidance Radar
  - Sep 1, 2021 required on 99% of new cars in US
  - 76-81 GHz
- Space based internet
  - Some companies cooperating, some are not
  - Many bands 12-50 GHz will be used
- 5G
  - Many bands ~700 MHz to 50 GHz
- Communication companies want to move to 70-120 GHz
- Many “clean” observing bands will begin to have RFI over the next few years

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State of RFI

- **“Shared Spectrum”**
  - expected to become the new normal
- Radio Astronomy bands above 60 GHz are shared with other users
- National Radio Dynamic Zones
  - Investigating how different (industry) users can share spectrum
  - Requires monitoring of spectrum to know how it is being used
  - Technologies have strong overlap with Radio Astronomy

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What can you do?

- Spectrum management is a challenging issue which must be tackled for radio astronomy to flourish
- Crowding of the spectrum is increasing and will continue to do so
  - Space for radio astronomy is shrinking
- How you can help:
  - Report RFI as soon as possible
  - Be conscious of using electronic devices near radio telescopes
  - Take an active role in spectrum management
    - ***Without action the spectrum will disappear***

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