



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.







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"





Why care about spectrum management?

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





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- Spectrum management includes:
 - Legal Protection
 - Community agreement





Spectrum Management

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





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





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







- 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 with ITU-R permission
 - Border issues are often important
 - Most general set of rules
 - Renegotiated every 4-5 years through the UN http://www.itu.int/ITU-R/





 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)





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





Legal Protection

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





Puerto Rico Coordination Zone

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





National Radio Quiet Zone

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







WV Radio Astronomy Zone

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







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





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?







The RFI "Myth" - a legal viewpoint

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





Radio Frequency Interference (RFI)



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Radio Frequency Interference (RFI)







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?





RFI excision during observing

- Adaptive Cancellation
- Filters/spectral channel suppression
- Blanking
- Future
 - Spectral Kurtosis
 - Al/Deep Learning





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





Filters/spectral channel suppression

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







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





- 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











- 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





- 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



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





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





RFI and How to Deal with It





