Spectrum Management for Radio Astronomy

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*NRAO and GBO are operated by Associated Universities, Inc. under a cooperative agreement with the National Science Foundation
SM specifically concerned w/ Radio Astronomy

- NSF Electromagnetic Spectrum Management Unit within the Astronomy Division
  - NTIA and NSF on the IRAC
- NAS Committee on Radio Frequencies (CORF)
  - [http://sites.nationalacademies.org/BPA/BPA_048819](http://sites.nationalacademies.org/BPA/BPA_048819)
- NRAO [https://www.cv.nrao.edu/~hliszt/RFI/](https://www.cv.nrao.edu/~hliszt/RFI/)
- IUCAF (ITU-R) [www.iucaf.org](http://www.iucaf.org), [http://tinyurl.com/yrvszk](http://tinyurl.com/yrvszk)
What do radio telescopes look like?

GBO 100 m Robert Byrd Green Bank Telescope
Green Bank, W. VA 0.3 – 115 GHz
17,000,000 lbs of rolling weight

Arizona Radio Observatory 12m telescope
Kitt Peak, Az 68 – 230 GHz

In some cases a telescope has one antenna
What do radio telescopes look like?

305 m William Gordon Arecibo Radio Telescope
Arecibo, PR 0.3 - 10 GHz
What do radio telescopes look like?

Karl Jansky Very Large Array (VLA)
27 x 25 m antennas on pads near tracks
0.1 – 35 km, Plains of San Augustin NM
7000 ft elevation
58-84, 320-327, 1 000 -50 000 MHz

Atacama Large MM Array (ALMA)
50 x 12 m, 12 x 7m, 4 x 12m antennas
0.2 – 16 km, Chajnantor, Chile
5000 m elevation
32-52, 68 – 950 GHz (with gaps)

A “correlator” takes the signal from each antenna and beats it against the signals of all the others in real time (using short integration periods)
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When these antennas are set down, the positions of their phase centers must be determined to a small fraction of the shortest operational wavelength.

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A certain lack of clutter in the surroundings

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And something more subtle ...
Atmospheric attenuations maybe 10x lower in dB/km than you’re used to seeing

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On larger scales telescopes span the earth

tinyurl.com/yrvszk
NRAO VLBA resolves earth’s orbit on the other side of the Milky Way using emission from the 6.67 GHz line of methanol.
230 GHz VLBI resolves the shadow of a black hole in the center of M87 in Virgo at a distance of 55 Megaparsecs

HST image https://stsci.edu/
VLBI resolves the shadow of a black hole in the center of M87 in Virgo at a distance of 55 Megaparsecs.

This is not glowing gas around the BH, it is radiation behind the black hole focused by gravity into an “Einstein Ring” and the BH is not centered.
The most famous radio astronomy discovery, the Big Bang, origin of the Universe

Bob Wilson (left) and Arno Penzias discovered a mysterious isotropic 3K signal at 8 GHz while trying to separate the noise contributions to a satellite communication link budget in 1964 - this image is from ~1978
μK fluctuations in the mean 2.728K level at mm/sub-mm wavelengths are the basis of modern cosmology.

This is a map from ESA’s PLANCK satellite [http://www.esa.int/ESA](http://www.esa.int/ESA). Brighter and darker regions arise from fluctuations in the mean density of matter in the early Universe, ~ 300,000 y after the Big Bang (13.7 billion years ago).
If you think the L2 point is out of scope, consider

Rec. ITU-R RA.1417-1

RECOMMENDATION ITU-R RA.1417-1

A radio-quiet zone in the vicinity of the L2 Sun-Earth Lagrange point

(1999-2013)
What about spectrum?

- Radio astronomy signals are *places, frequencies or times* when there is more or less cosmic noise
  - Signals are not demodulated, only integrated
    - Noise decreases with $1/\sqrt{\text{time}}$
What about spectrum?

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- Rare, periodic radiators like pulsars are a partial exception

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*Orion SrcI's disk is salty*

Adam Ginsburg, Brett McGuire, Richard Plambeck, John Bally, Ciriaco Goddi and Melvyn Wright

2019ApJ...872...54G

This is a disk of gas and dust emitting room-temperature broadband thermal noise around a protostar, and it may eventually make planets, comets, asteroids, etc.

ALMA mapped this at 215 GHz ... it’s much bigger than our Solar system, more like the Oort belt of comets

NSMA Washington DC May 14-15 2019
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ALMA can observe with fine spectral resolution to resolve the disk’s chemical constituents.
What about spectrum?
What about spectrum?

- Weakest lines have good S/N at ~0.5 mJy/resolution element
- 1 Jy = -260 dBW/m²/Hz so the noise level is -300 dBW/m²/Hz
- 100 dB down from a 1 mW/MHz transmitter at 100 km
- You need suitable conditions across the few hours needed to integrate the signal
What about spectrum management?

Run, hide, fight - what do you do in an active shooter service situation

- RUN, HIDE
  - For RAS this means going to cleaner remote locations
  - You’ve seen that these remote areas can be quite naked. Lush regions aren’t conducive to high frequency work.
  - Mountainside sites create direct upward lines of sight from lower elevations, evading ground clutter there
  - Telescopes not fully robotic, they are accessible by road
What about spectrum management?

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• RUN, HIDE
  – For RAS this means going to cleaner remote locations
  – Some larger and newer telescopes are wrapped in Radio Quiet Zones (~ 13 in world)
The US National Radio QZ Was First, 1958

- 47 CFR 1.924(a)

Areas implicated by this paragraph are those in which it is necessary to restrict radiation so as to minimize possible impact on the operations of radio astronomy or other facilities that are highly sensitive to interference. Consent throughout this paragraph means written consent from the quiet zone, radio astronomy, research, and receiving installation entity. The areas involved and procedures required are as follows:

(a) NRAO, NRRO. The requirements of this paragraph are intended to minimize possible interference at the National Radio Astronomy Observatory site located at Green Bank, Pocahontas County, West Virginia, and at the Naval Radio Research Observatory site at Sugar Grove, Pendleton County, West Virginia.
The US National Radio QZ Was First, 1958

- 13,200 sq miles, ~ 600,000 inhabitants

https://science.nrao.edu/facilities/gbt/interference-protection/nrqz
The US National Radio QZ Was First, 1958

• Prescribes power limits at GBT prime focus at all frequencies whether allocated to RAS or not
• Applies to fixed, licensed transmitters (like others)

**Power Density Thresholds**

Based on a 20 kHz measurement bandwidth, the calculated power density of the transmitter at the reference point should be less than:

- $1 \times 10^{-8} \text{ W/m}^2$ for frequencies below 54 MHz
- $1 \times 10^{-12} \text{ W/m}^2$ for frequencies from 54 MHz to 108 MHz
- $1 \times 10^{-14} \text{ W/m}^2$ for frequencies from 108 MHz to 470 MHz
- $1 \times 10^{-17} \text{ W/m}^2$ for frequencies from 470 MHz to 1000 MHz
- freq$^2$ (in GHz) $\times 10^{-17} \text{ W/m}^2$ for frequencies above 1000 MHz

except for frequencies that reside in the radio astronomy observing bands listed in the US Table of Frequency Allocations, in which case the power densities listed in Table 1 of Recommendation ITU-R RA.769 shall apply. For a comprehensive list, [click here](#).
The US National Radio QZ Was First, 1958

• Many hundreds of transmitter applications are approved each year, only a handful require close coordination

• Geographic area licensing does not relieve an operator of the obligation to coordinate

• The GBT is also protected by the W. VA Radio Astronomy Zoning Act limiting the operation of unshielded electrical apparatus within 10 miles of an observatory
What about spectrum management?

Run, hide, fight - what do you do in an active shooter service situation

• RUN, HIDE
  – The future I see is one where Earth is noisy at all frequencies that don’t knock an airborne or spaceborne service out of or off the air
  – Conversely, the sky will be noisy at all frequencies that don’t disrupt ground operations
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• Fight
  – Spectrum management
  – Passive services go passive-aggressive
Notable things about SM for radio astronomy

1.13  
*radio astronomy*: Astronomy based on the reception of *radio waves* of cosmic origin.

1.58  
*radio astronomy service*: A service involving the use of *radio astronomy*.

1.7  
*terrestrial radiocommunication*: Any *radiocommunication* other than *space radiocommunication* or *radio astronomy*.
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So what you do is only defined by not doing what I do 😊
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1.61 \textit{station:} One or more transmitters or receivers or a combination of transmitters and receivers, including the accessory equipment, necessary at one location for carrying on a radiocommunication service, or the radio astronomy service.

Except as regards harmful interference, sort of

4.6 For the purpose of resolving cases of harmful interference, the radio astronomy service shall be treated as a radiocommunication service. However, protection from services in other bands shall be afforded the radio astronomy service only to the extent that such services are afforded protection from each other.
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Deletion of 2\textsuperscript{nd} sentence of No. 4.6 is on WRC-19 Agenda
Notable things about SM for radio astronomy

• An ITU-R radio service with no (active) branch
• Forced by physical law to unallocated spectrum
  – Frequencies moved by Galactic rotation, Hubble flow
    • Motion away shifts to lower frequency (redshift)
  – RR 4.4 says you can do almost anything you want as long as you don’t interfere or claim protection or (according to RRB) transmit in a passive service band
Notable things about SM for radio astronomy

• We observe all over the spectrum but only seek protection in protected bands
  – Most spectrum below 100 GHz allocated to RAS is in passive bands
    • 1-2% of spectrum below ~30 GHz, more above 86 GHz
    • No passive radio astronomy spectrum 32 – 86 GHz
  – Most recent interference scenarios adjacent band
    • 76 - 81 GHz car radar a notable exception
    • Will be others as mobile etc move to higher frequency
Notable things about SM for radio astronomy

• RAS accepts interference when there should not be any
  – Bands protected by RR. 5.340 where *all* emissions are prohibited
Notable things about SM for radio astronomy

• RAS uses large high-gain instruments to detect weak cosmic signals but does not apply gain to compatibility in static (most terrestrial) scenarios
  – ITU-R Rec. RA. 769 uses 0 dBi gain to calculate thresholds, insensitive to the boresight direction
  – Directivity is no defense against RFI at 0 dBi gain
  – RFI arises in sidelobes away from the boresight, from radiation impinging on the antenna structure
• Standard methodology not accepted by FCC
Let’s look at real RFI

• Satellite interference at the GBT
  – Satellites drift through the antenna pattern in ways not under control and may be seen with gain
  – Compatibility calculations with satellites (and other dynamic scenarios) use epfd simulation
Interference at the GBT – Day 1 (all days are from one week Jan. 2015)
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RR 5.340 (passive)
Primary, shared w/MSS (earth-space)

US246 (passive)

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Interference at the GBT – Day 1
(all days are from one week Jan. 2015)
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50,000 x the protection threshold

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Interference at the GBT – Day 1
(all days are from one week Jan. 2015)

A real HI \( \lambda 21\text{cm} \) line signal

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NSMA Washington DC May 14-15 2019
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- **RR 5.340** (passive)
- **RNSS**
- **MSS (s-e)**
- **US246** (passive)

Primary, shared w/MSS (earth-space)

NSMA Washington DC May 14-15 2019
Interference at the GBT – Day 1 x 10
Interference at the GBT – Day 1 x 100
Interference at the GBT – Day 1 $\times 10^3$
Interference at the GBT – Day 1 x 10³

Mixing in one second of data like this can poison a day’s data
Interference at the GBT – Day 2

RFI gone now
Interference at the GBT – Day 3

Both clean now
### IUCAF Input 6 Documents to CPM-2

<table>
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<th>Date</th>
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<td>Scientific Committee on Frequency Allocations for Radio Astronomy and Space Science</td>
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<td>20</td>
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</table>

**Substantively commented on**

1.6, 1.7, 1.8, 1.9.1, 1.9.2, 1.13, 1.14, 1.15, 9.1.9

**Only 1 AI involves sharing allocated spectrum**

1.6, 1.7, 1.8, 1.9.1, 1.9.2, 1.13, 1.14, 1.15, 9.1.9

**Another AI concerns compatibility at 275 – 450 GHz**

1.6, 1.7, 1.8, 1.9.1, 1.9.2, 1.13, 1.14, 1.15, 9.1.9
Wrap up

• Unique challenges for radio astronomy
• No substitute for on the job training since no one will train you for it beforehand
• It really helps to like Geneva
• The RAS wish list for spectrum issues:
  – Increased recognition of radio quiet zones
  – Decreased risk from illumination by space radars
  – Modernization of ITU-R Recommendations
    • Clarify protection from unwanted emissions
    • Revise RA. 769