New Tools for RFI

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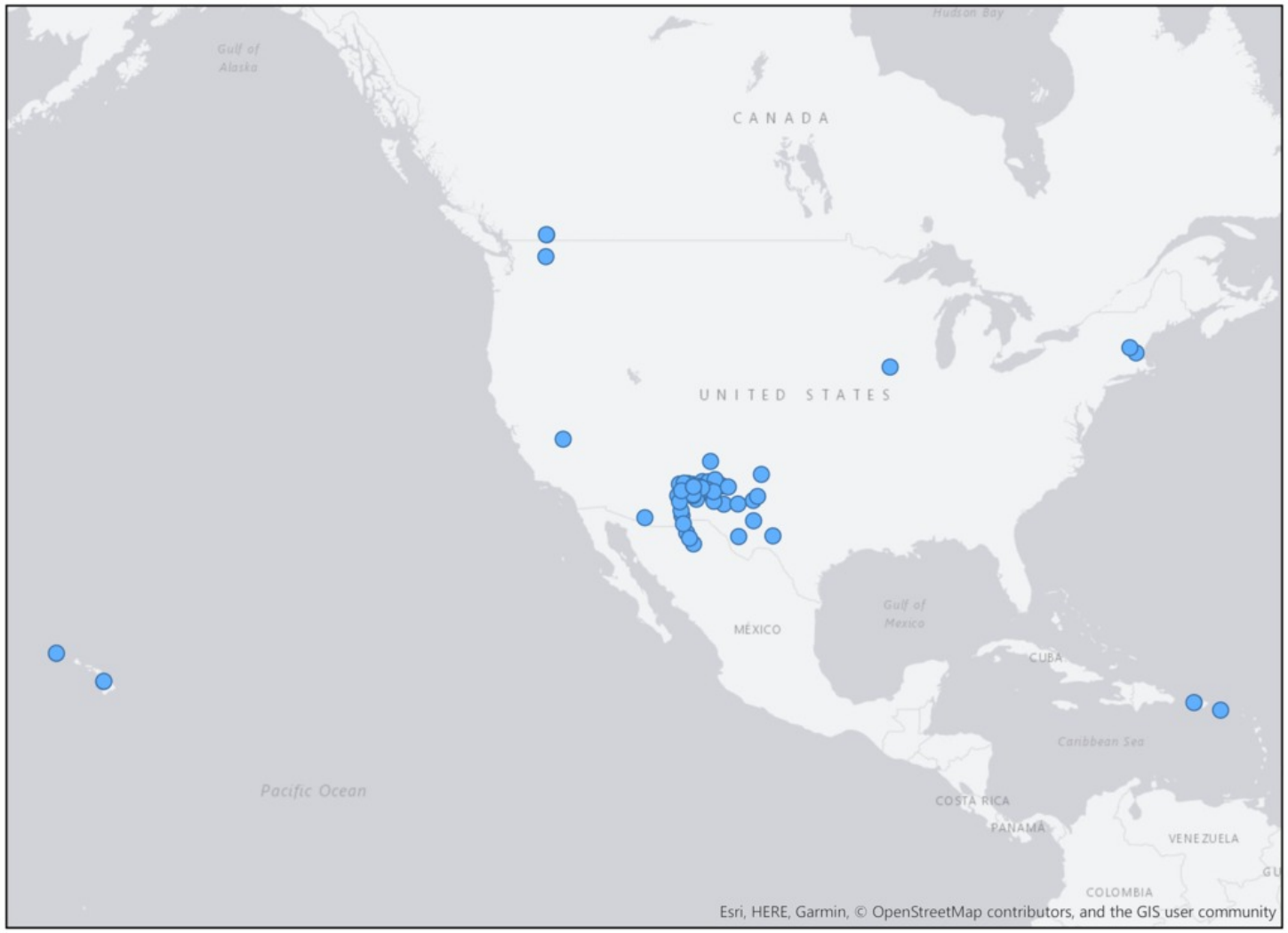
ngVLA overview

- 214 main antennas, 18m
- 30 long-baseline antennas
- 1.2 – 116 GHz
- Water vapor radiometer (18 – 26 GHz) on each antenna


Hudson Bay
Gulf of Alaska
CANADA
UNITED STATES
MÉXICO
Gulf of Mexico
CUBA
Caribbean Sea
Pacific Ocean
COSTA RICA
PANAMÁ
VENEZUELA
COLOMBIA
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ngVLA overview

- Geographically dispersed
  - populated areas
  - wide longitude range
  - very different environments: inland, maritime, var. climates, military
- Wide frequency range
- Water vapor radiometers (K-band)

RFI Coexistence is Possible

- See and avoid
- Be notified and avoid
- Predict and avoid
- Avoid in many dimensions: time, frequency, polarization, ...
- Reduce data corruption algorithmically

ngVLA RFI Goals

- Create cohesive, system-level, RFI-aware design for ngVLA.
- Allow RFI research to be continued through the life of the telescope.
- Ensure new techniques can be incorporated with minimal impact.
- Adapt to changing RFI with minimal impact.

Problem Breakdown

- RFI has many dimensions, e.g. time, frequency, polarization, ...
- Identify dimensions to allow matching available tools to RFI.

Time

Domain	Scale	
time	ps – ns	raw samples
pre-integration	ms	pre-integration
post-integration	s	post-integration

Frequency

Domain	Scale	
Receiver	1 – 50 GHz	Analog electronics
Digitizer	1 – 10 GHz	Digitized bandwidth in a receiver
Window	1 – 100 MHz	Range of frequencies within digitized bandwidth
Channel	Hz - MHz	Smallest frequency quantum for instrument/observation

Location

Domain	
Antenna	Affects single antennas at any one time
Group	Affects a group of antennas
Array	Affects most of the array simultaneously

Prediction

Domain	
Forecast	• scheduled occurrence • predictable, e.g. orbit parameters • notification by service, agency, or partner • all timescales – microseconds to decades
Non-forecast	• not predicted • unannounced • modified schedule, e.g. orbit change • repeating but asynchronous, e.g. radar

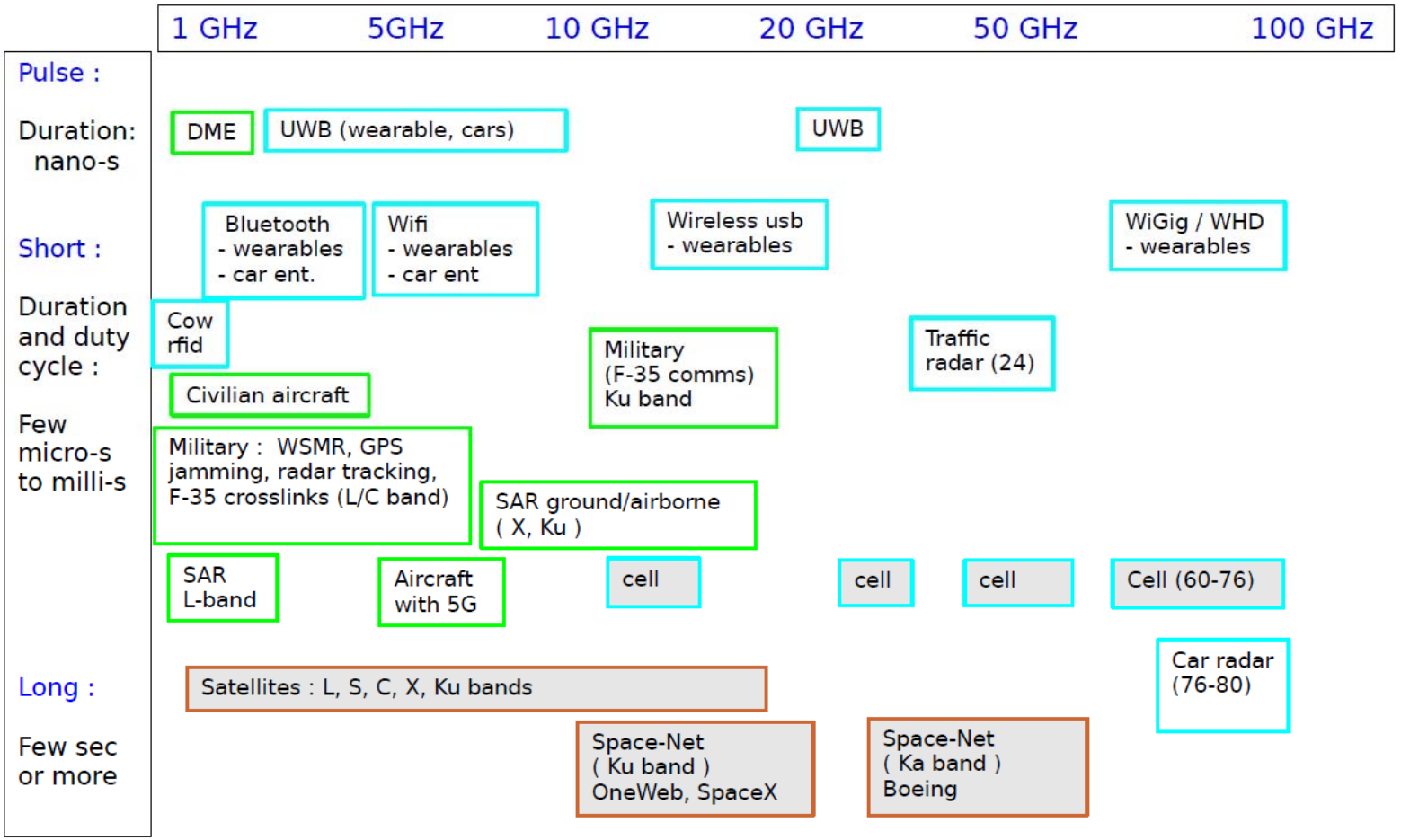
- Requires prior knowledge, i.e. RFI database
- Likely requires external databases, e.g. orbital parameters

Character

Domain	
Fingerprinted	• matches known characteristics in the set of domains relevant to this RFI • likely non-Boolean
Non-fingerprinted	• does not match a known set of characteristics

- Requires prior knowledge, e.g. RFI database
- Database can be shared with collaborators

Future RFI Landscape (1-100 GHz)



Color : Local RFI (~ few antennas) RFI on large fraction of array(airborne) RFI on entire array (satellite)
Shading : White : Seen for a small fraction of observing time. Grey : Seen for most/all observations

Examples

RFI	Data	Frequency	Location	Prediction	Character
meteorological radar	t, pre	window	group	no	yes
commercial satellite	pre, post	channels	group, array	yes	yes
cell tower	pre, post	channels	antenna, group	no	yes
vehicle radar - nearby	pre, post	receiver	antenna, group	no	yes
vehicle radar - distant	t, pre	channels	antenna, group	no	yes
new dark satellite	pre, post	window	array	no	no
drone, advance notice	pre	channels		yes	partial

Domains

One can then group these dimensions into domains, e.g.

- Regular pulse emitters (radars)
- Intermittent pulse emitters (DME, UWB transmitters)
- Continuous-transmission, fixed (cell towers)
- Continuous-transmission, mobile (satellites, aircraft)
- Receiver-saturating (automotive radar)

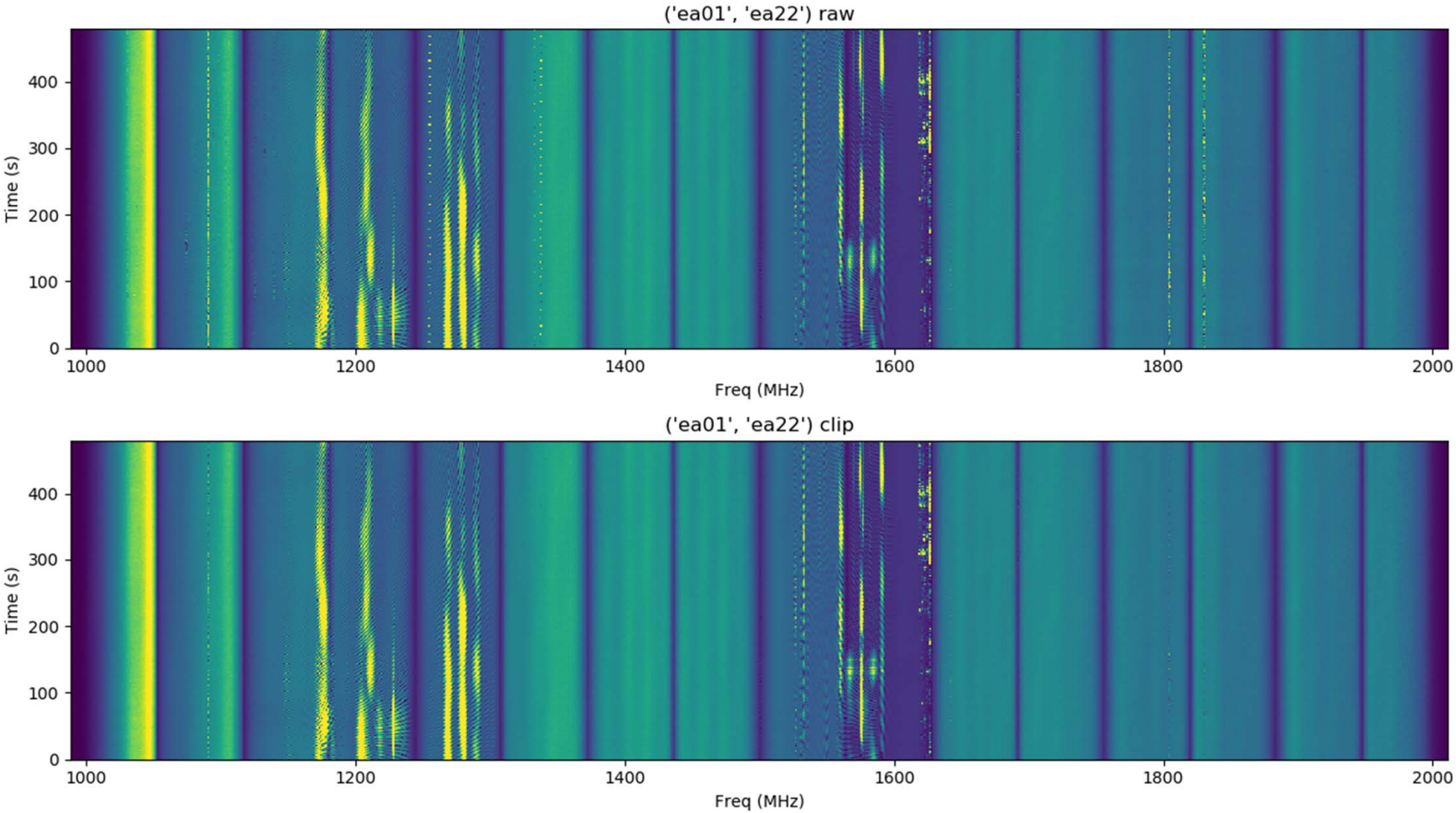
For each domain, many technologies are being developed.

RFI Detection/Mitigation Tools

- Blanking
  anticipate time of occurence and eliminate data
- Thresholding
  remove data over an amplitude threshold
- Compressive Cyclic Analysis (UIUC)
  detect modulated signals
- Median Absolute Deviation (GMRT and others)
  detect statistical markers of RFI and replace affected samples

VLA WIDAR example

- One of the simplest methods: threshold
- Trigger on voltage threshold
- Excise samples in t domain, mean- or zero-fill


('ea01', 'ea22') raw
Time (s)
0
100
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300
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1200
1400
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Freq (MHz)
('ea01', 'ea22') clip
Time (s)
0
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200
300
400
1000
1200
1400
1600
1800
2000
Freq (MHz)

RFI Detection/Mitigation Tools

- Edge thresholding (UvA)
  detect transients via fast-rising edges
- Fourier-domain excision (ASTRON)
  excise periodic signals
- RFI Novelty Detection (NRC)
  machine learning, detect changes in channel properties
- High bit-count ADCs
  up to 12b widely available

RFI Detection/Mitigation Tools

- CYCLONE Cyclic Imager (ICRAR)
  integrate around periodic signals
- Spectral kurtosis
  detect non-stochastic signals
- U-Net (ETH Zurich) and RFI-Net (FAST)
  convolutional neural networks
- Sub-Space Projection (BYU)
  synthesize a null in the direction of the emitter

RFI Detection/Mitigation Tools

- Prediction
  - Orbital parameters + antenna location/pointing
  - Time of day for vehicular, visitor, maintenance traffic
  - FAA flight filings, flight tracking
- External notification
  - Military exercises, Navy frequency-sharing notifications
  - Pilot NOTAMs
  - Weather
  - Space launch
  - Collaborator detection

Multiple Techniques

- No one tool solves all RFI.
- Multiple RFI sources will likely be present in any observation.
- Use input from many tools.
- Exemplar: ZenithalBlue GRDS (Earth observation)
  Imagery, kurtosis, threshold, patterns
- Resulting strategy to deal with RFIs can be complex.

Strategy

All telescope systems work together dynamically to deal with RFI.

- Scheduling system
- Data processing pipeline
- Automated diagnostics
- Receiver parameters
- Maintenance reports
- Operator interface

Strategy

Inputs to create a strategy include:

- Observation properties
- RFI databases
- Satellite parameters
- FCC database
- Notifications
- Weather

Strategy

Outputs include:

- Possible set of RFI excisors
- Observation metadata
- Actions to take, e.g. reschedule observation, collect RFI data, ...
- Expected results, e.g. impact on data
- RFI incident record

Summary

- There are lots of tools available and under development to detect and reduce the impact of RFI.
- Telescopes should develop an architecture that can easily be expanded to include new tools and strategies.
- Employ a large zoo of RFI detector, predictor, and excisor tools.
- Let the tools inform the observation parameters.
- Create strategies to deal with expected and detected RFI.
- ngVLA will employ these methods to reduce its RFI cross-section.

Links

ngVLA website	https://ngvla.nrao.edu/
ngVLA Memo 38 Subarray Processing for Projection-Based RFI Mitigation in Radio Astronomical Interferometers	http://library.nrao.edu/public/memos/ngvla/NGVLA_38.pdf
ngVLA memo 70 RFI Mitigation for the ngVLA : A Cost-Benefit Analysis	https://library.nrao.edu/public/memos/ngvla/NGVLA_70.pdf
ngVLA memo 71 RFI Mitigation in the ngVLA System Architecture	https://library.nrao.edu/public/memos/ngvla/NGVLA_71.pdf