RFI Mitigation for Radio Interferometry

RFI Landscape

- Current + Future
- Estimated data loss

Mitigation Options

- Algorithms
- Data Processing Stages
- Cost vs Benefit

RFI Avoidance and Regulation

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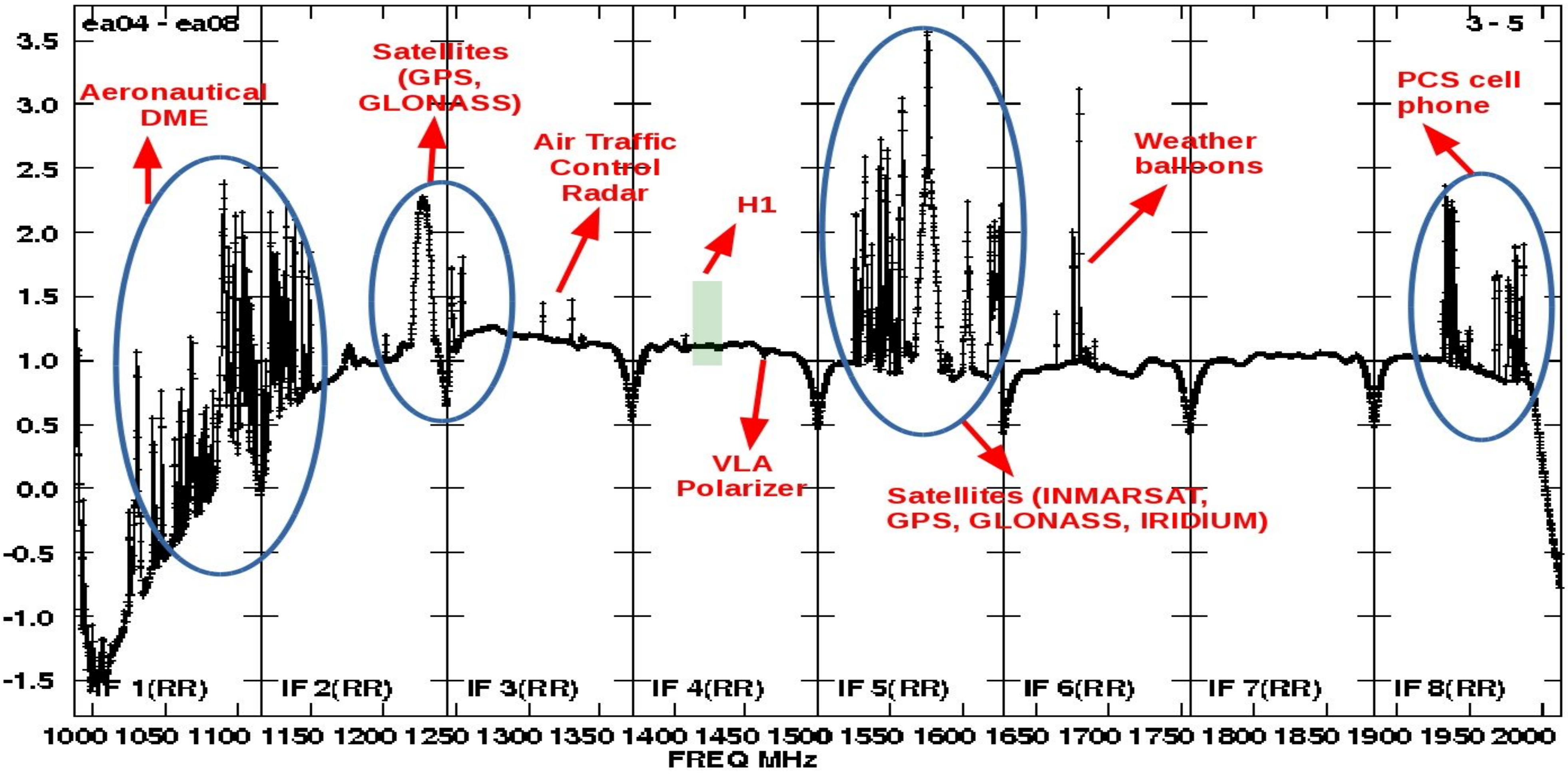
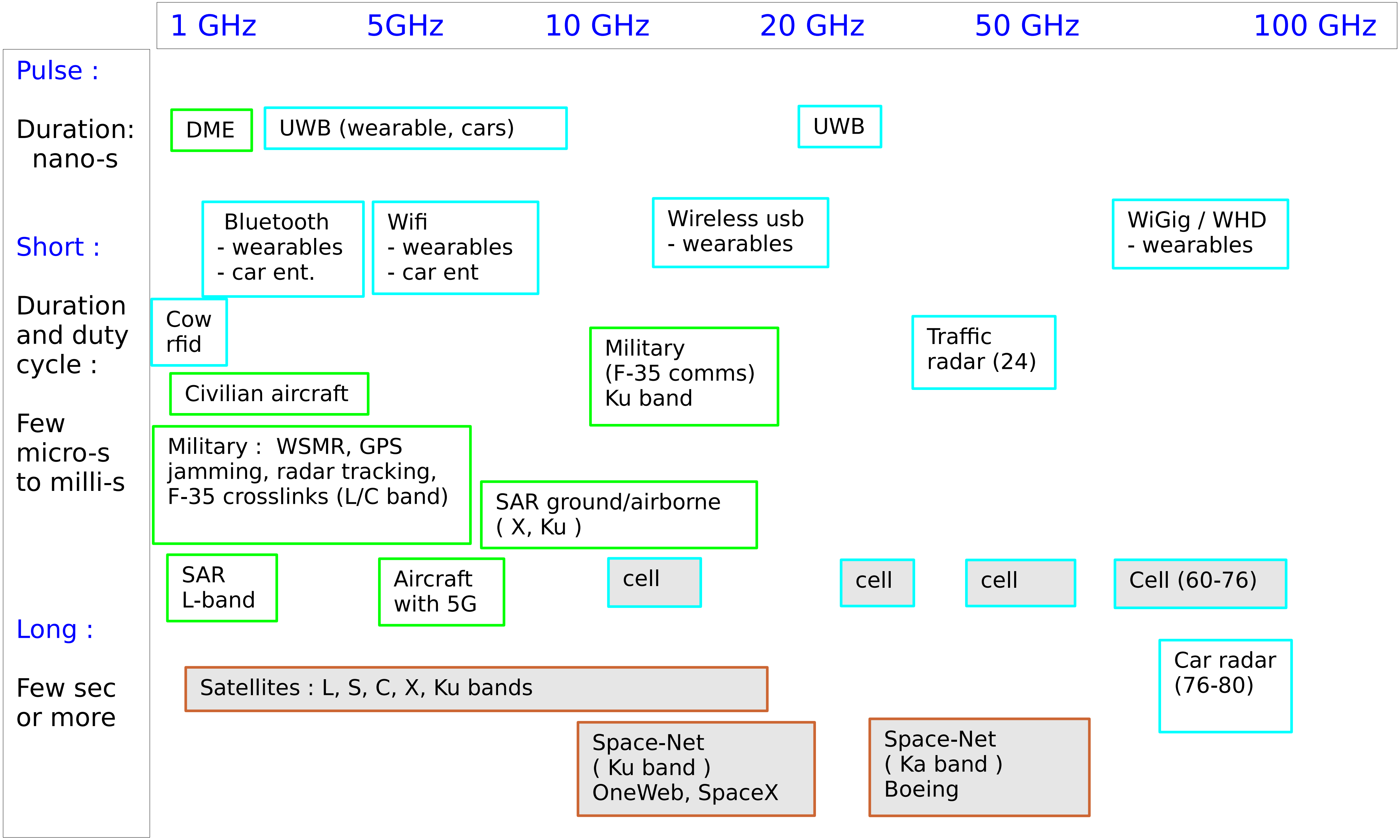
Meeting of the Committee on Radio Frequencies
National Academies of Sciences, Engineering, Medicine
Sept 17, 18 2019

Example of current RFI at L-Band (1-2 GHz)

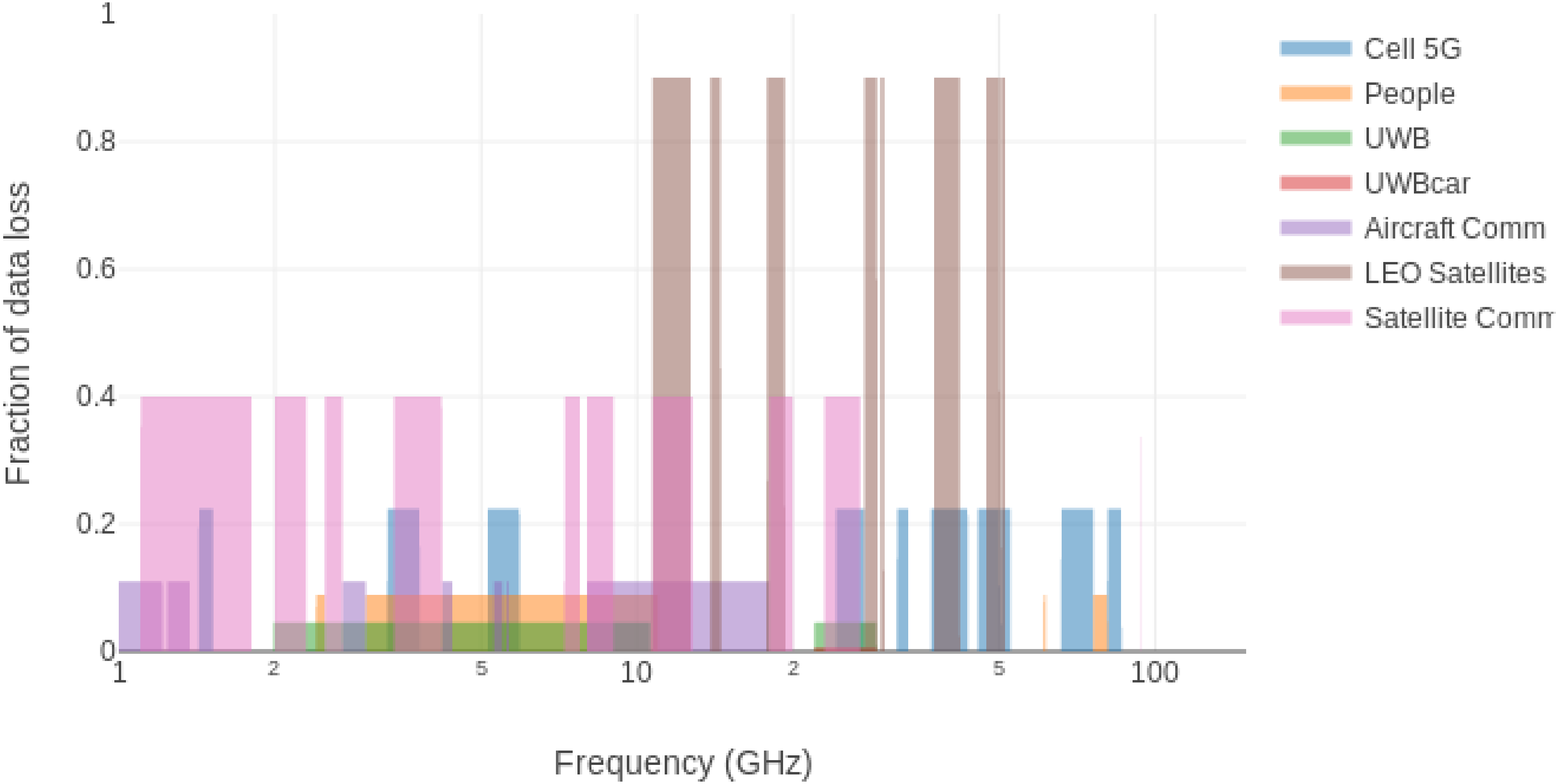


Future RFI Landscape (1-100 GHz)



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

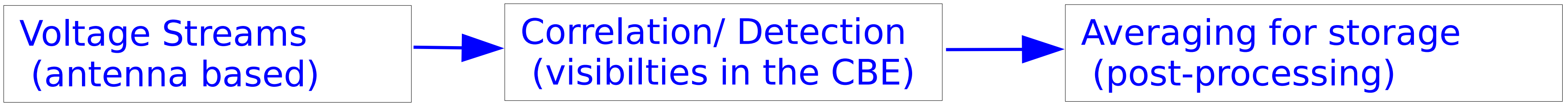
Estimated fraction of data loss – status quo



Assumptions : Multiple types of RFI with different footprints in frequency, time, and antennas.
Calculations : Affected antennas and baselines, effect of RFI decorrelation and uncorrelated RFI

RFI mitigation : Only post-processing flagging (i.e. current operations)

RFI mitigation options



RFI mitigation options

Voltage Streams (antenna based) → **Correlation/ Detection (visibilties in the CBE)** → **Averaging for storage (post-processing)**

Voltage Streams (antenna based)

- Detect strongest RFI in real time

- Best for local RFI

- Catch impulsive broad-band RFI before the FFT (UWB, DME)

Correlation/ Detection (visibilties in the CBE)

- Intermittent RFI
  - micro-s to milli-sec on/off
  (communication protocols)

- RFI phase structure is preserved in visibilities (airborne, satellite, etc...)

Averaging for storage (post-processing)

- Time-persistent RFI that requires analysis along some other axes.

- Weak RFI that becomes visible only after averaging

RFI mitigation options

Voltage Streams (antenna based)

- Detect strongest RFI in real time

- Best for local RFI

- Catch impulsive broad-band RFI before the FFT (UWB, DME)

Detection :
Median / MAD / MoM / Kurtosis / Threshold...
w/wo FFT.

Action :
- Remove/mask/flag samples containing RFI

- Add to RFI monitoring database

Correlation/ Detection (visibilties in the CBE)

- Intermittent RFI
  - micro-s to milli-sec on/off
  (communication protocols)

- RFI phase structure is preserved in visibilities (airborne, satellite, etc...)

Detection :
- Autoflag on visibilities
- Use prior information
- Matrix decomposition (PCA)
- Imaging and Peeling
(– RFI source location)

Action :
- Mask/flag samples that go into the next integration step

- Subtraction (subspace projection / PCA methods)

Averaging for storage (post-processing)

- Time-persistent RFI that requires analysis along some other axes.

- Weak RFI that becomes visible only after averaging

Detection :
- Look at plots of data (no more)

- Autoflag on visibilities (rflag, tfcrop, uvbinflag)

- Use prior information for deterministic flags and tuning of autoflag methods

Action :
- Remove from further processing (flagging).
- Imaging and decorrelation

Smart Scheduling

How effective are these solutions ?

(1) Do the mitigation approaches work ?

- 1D statistical filters : Reasonably well
- Auto-Flagging correlated data : Reasonably well
- Modeling and subtraction of continuous signals : Experimental
- Attenuation due to decorrelation during imaging : Maybe

(2) Is the RFI environment well-matched to the algorithms ?

- Pulsed RFI : Sparse enough at nano-s timescales : Don't know
- Micro-s to milli-s duty cycles : Usable gaps in time/freq : Don't know
- Long RFI : Can we handle many interferers at once : Unlikely
  Are signals long enough to decorrelate effectively : Don't know
  Can we schedule around satellite orbits : Maybe

(3) Cost versus benefit ….

- If nothing is done : 25%-40% data loss (80% at LEO)
  - Some continuum science is possible with longer observation times.
  - Spectral line science is lost in all satellite bands.

- If solutions are implemented : Data loss depends on answers to (2)
  - Extra operational cost of RFI mitigation at high data rates.

How can regulation help ?

(1) LEO satellites : A quiet zone (footprint) above the telescope

– Main Goal : To avoid saturating entire receiver bands.

=> Data loss is confined to LEO bands only.

(2) 5G Cell Towers :

– No new 5G towers near the ngVLA array core.

- Data loss will be similar to that from LEO satellites (at diff freqs) if cell 5G is active near the core.

– Band-selection for cell 5G towers near ngVLA antennas.

(3) Other (hard to regulate, but what most of our solutions depend on) :

– The presence of RFI gaps in time and frequency (current situation)