RFI Simulation and Mitigation for the DSA-2000

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DSA-2000

The Deep Synoptic Array (DSA-2000) is a planned innovative radio telescope made of 2000 antennas located in the Nevada (USA) desert (projected construction in 2024). Its design is centered around the concept of Radio Camera, involving a streamlined data processing pipeline - including array data correlation, calibration, Radio Frequency Interference (RFI) flagging, and gridding - to achieve a real-time production of fully sampled radio images every 15 minutes. As any radio telescope, the DSA-2000 will be sensitive to active spectrum users and will embed a multi-layer protection against RFI including real-time flaggers at both the individual antenna level and cross-correlation level.

RFI environment

Goal : keep 700 MHz – 2GHz as free as possible (fig 1)

- Air and space transmissions are unavoidable
- Commercial cellular downlink spans 617 MHz – 6 GHz
  - 183 MHz (sparse) allocated and utilized in DSA-2000 band
  - Mostly utilized at lower frequencies in rural areas
- Digital TV broadcast spans up to 186 MHz
- Administrative protections:
  - Locally allocate cellular downlink bands below 700 MHz
  - Change cellular / DTV towers radiation patterns
  - NRDZ : Dynamically utilize free bands given telescope operation
  - NRDZ : Dynamic satellite avoidance

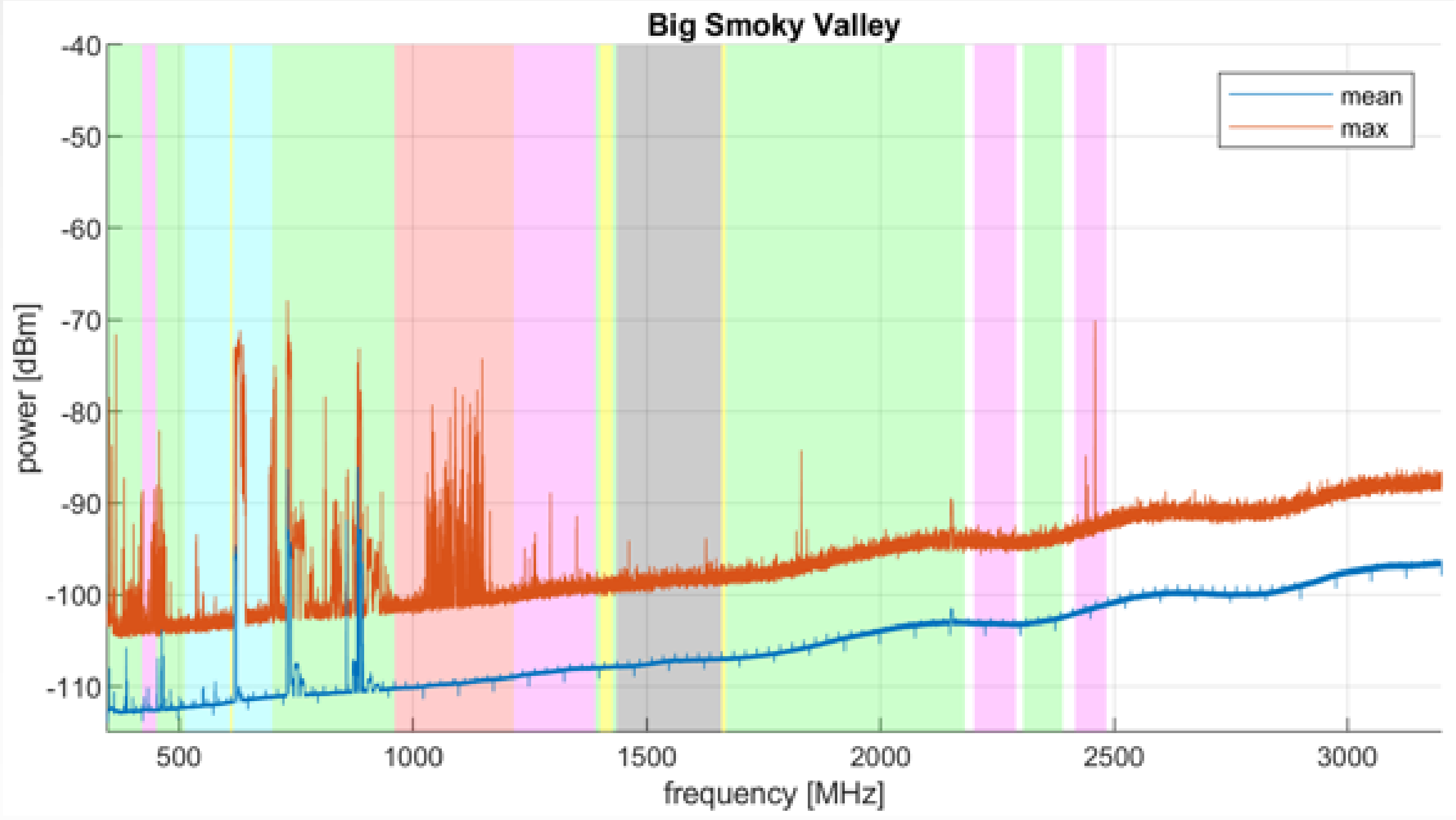

Figure 1

🟩 Mobile comm

🟪 Radio location

🟦 DTV broadcast

🟥 Aeronautical

🟨 Radio astro

⬜ Sat comm

RFI simulation

Assessing the impact of RFI to the telescope data is crucial to estimate the resources needed to achieve the targeted sensitivity of the instrument. This assessment requires an accurate modelling of the potential sources of RFI the future telescope will eventually have to face (and based on a preliminary site survey). To this end, we developed a framework allowing the generation of realistic synthetic sources of RFI and the production of an associated ``RFI-only" DSA-2000 dataset. The generated dataset can then be added to a forward modelling dataset to evaluate the impact of the RFI on the telescope data products, as well as the performance of the real-time RFI mitigation.

The current sources of RFI available for injection in a DSA-2000 data set include a continuous wave (single carrier signal), a white noise, and a Long-Term Evolution (LTE) 4G telecommunication signal. Figure 2 shows an example of a 1.5 s-long baseband 4G LTE signal generated with the Matlab LTE Waveform generator toolbox. The modulation parameters can be set to model a realistic emitter near the pre-selected observatory sites.
The baseband signal is then further processed with quantization and channelization. These steps model the effect of the telescope Analog-to-Digital converter and Polyphase Filter Bank. The channelized version of the RFI signal is shown in red in the figure 2.

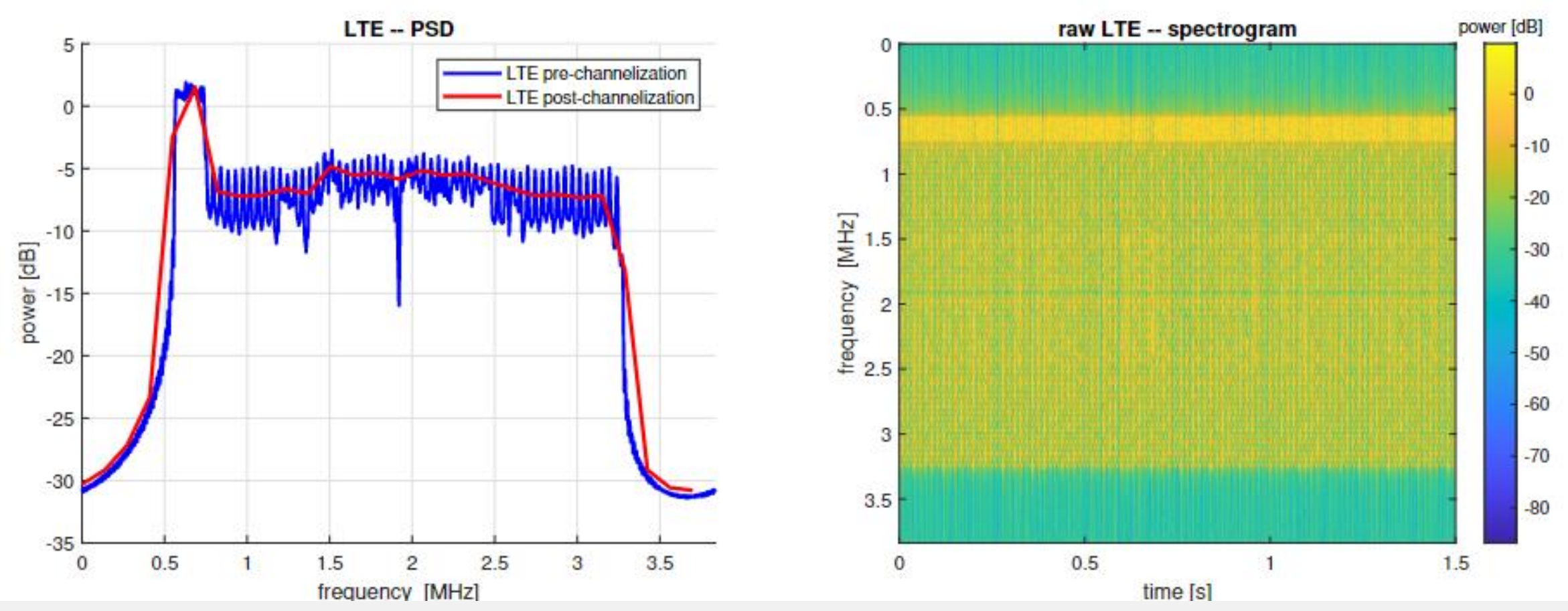

Figure 2

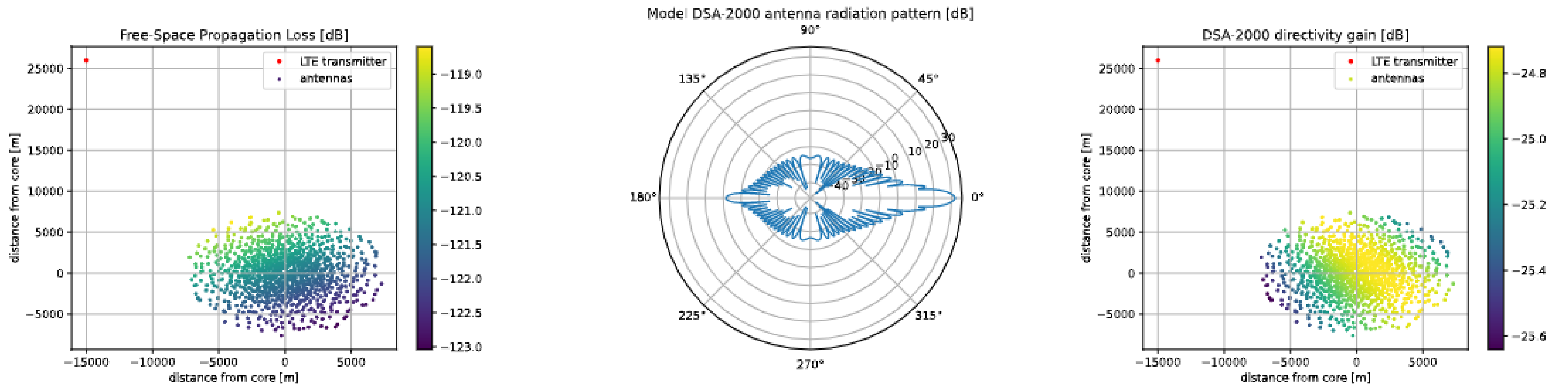

Figure 3

Figure 3 shows the telescope array and a base station emitter (red star) located 30 km away from the telescope center and 30° away from the north direction.
Using free-space propagation loss (FSPL), we evaluate the attenuation of the 4G signal at each antenna :
FSPL = $(\lambda/4\pi d)2$, where d is the distance between antennas and λ is the signal center frequency. Loss from the clutter in the environment of the LTE transmitter and multipath effects are neglected due to the large distances between the transmitter and the telescope.

Figure 3 shows the “RFI-only” visibilities magnitudes plotted in the UV domain. The shape of the autocorrelation function can be inferred as coming from the 30° angle.

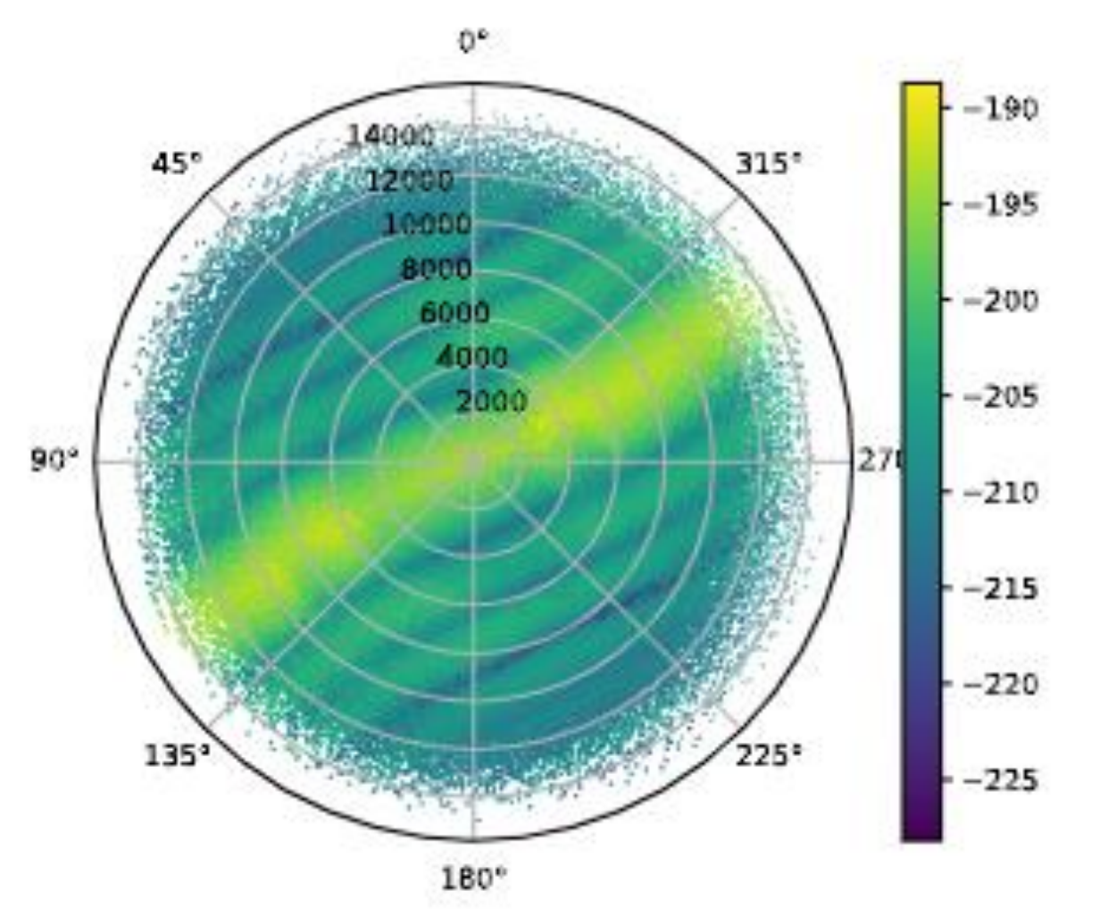

Figure 3

RFI flagging

The aim for the DSA-2000 flagger is to detect corrupted data at the native resolution of 1.5 s and 135 kHz. This is achieved in two stages:

- The digitization and channelization boards access data from a limited number of antennas for the whole frequency range of the telescope. Access to the full spectrum for each antenna permits the detection of the strongest sources of RFI using a standard peak finding algorithm.

However, the sensitivity of a single array element is limited, this approach will only be sensitive to the strongest sources of RFI.

- Post-correlation, the GPU servers will now access the visibility data of all antennas over a reduced set of frequencies. The large number of visibilities allows for accurate statistics measurements and sensitive RFI detection at a low interference-to-noise ratio (INR).

The visibility-level flagger exploits the fact that the telescope system noise and astronomical sources can be approximated as white Gaussian noise, independently and identically distributed across time, frequency, and antennas. The presence of an additional RFI term, which is deterministic in nature, leads the data distribution to diverge from a Gaussian distribution. The proposed approach consists in running a Kurtosis estimator on clustered visibilities.

To evaluate the performance of the Kurtosis flagger, we generated a noise only visibility matrix as well as an RFI + noise matrix. We ran the flagger for both hypotheses (interference and noise vs. noise only) over 500 trials, and the results can be seen on Figure 4. The Signal-to-Noise Ratio (SNR) is defined a SNR =< ri,i > / < ni,i >, where < . > is the average operator applied over all antennas. The flagger detects RFI down to SNR = -71 dB. This performance is due to the large number of visibilities the Kurtosis is computed over. The threshold of the Kurtosis flagger can be set independently of the noise scale factor.

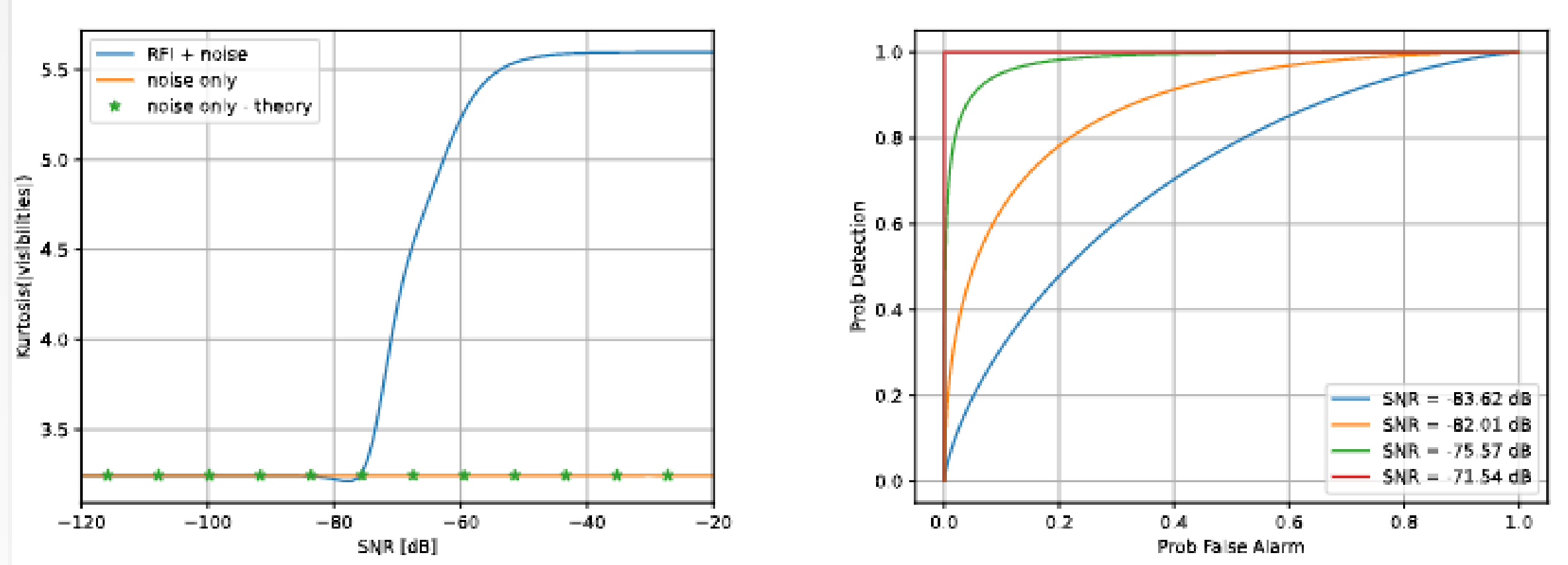

Figure 4

Conclusion

We surveyed candidate sites for the future DSA-2000, and provided an RFI simulation framework to assess the impact of RFI on the sensitivity of the telescope. We also developed a Kurtosis-based flagger for real-time corrupted visibility excision.