

# TEMPORAL VARIABILITY IN LOW-FREQUENCY RADIO INTERFERENCE



## Insight from High-Cadence Monitoring at a Candidate RNZ in Malaysia

Affan Adly Nazri<sup>1\*</sup>, Zamri Zainal Abidin<sup>1\*\*</sup>, Mohamad Ridhaudin Mat Sabri<sup>1</sup>, Zulfazli Rosli<sup>1,2</sup>, Mohd Shaiful Rizal Hassan<sup>1</sup>, Mohd Shazwan Mohd Radzi<sup>1</sup>, Ahmad Najwan Zulkiplée<sup>1</sup>, Dalilah Nur Fathiah Hanim Razak<sup>1</sup>, Norsyazwani Asmi<sup>1</sup>, Jinsong Ping<sup>3</sup>, Mingyuan Wang<sup>3</sup>, Liang Dong<sup>4,5</sup> \*affanadly.astro@gmail.com \*\*zzaa@um.edu.my

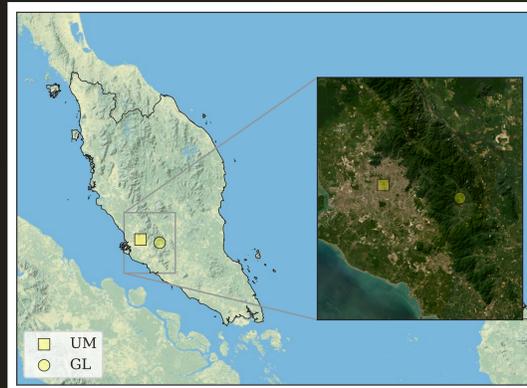
<sup>1</sup> Radio Cosmology Research Laboratory, Center for Astronomy and Astrophysics Research, Department of Physics, Faculty of Science, Universiti Malaysia, 50603 Kuala Lumpur, Malaysia  
<sup>2</sup> Centre of Foundation, Language and Malaysian Studies, Universiti Malaysia-Wales, 50480 Kuala Lumpur, Malaysia  
<sup>3</sup> National Astronomical Observatories, Chinese Academy of Sciences, Beijing, 100012, People's Republic of China  
<sup>4</sup> Yunnan Astronomical Observatory, Chinese Academy of Sciences, Kunming, 650216, People's Republic of China  
<sup>5</sup> Yunnan Sino-Malaysian International Joint Laboratory of HF-VHF Advanced Radio Astronomy Technology, Kunming, 650216, People's Republic of China

### Introduction

Radio astronomy relies on access to radio frequency bands that are increasingly threatened by terrestrial radio frequency interference (RFI) from telecommunication, broadcasting, and other human-made sources. Low-frequency bands i.e. LH - VHF (30 kHz - 300 MHz) are particularly important for solar monitoring, pulsar timing, fast radio bursts, and deep-sky surveys, yet are highly susceptible to contamination. In Malaysia, RFI monitoring has shown a strong link between population density and interference levels, with rural regions generally providing cleaner conditions<sup>1,2</sup>. However, earlier studies relied on long-averaged measurements with less sensitive equipment, which limits the detection of transient and narrowband signals. Establishing suitable low-RFI sites is not only essential for local radio astronomy but also aligns with Malaysia's long-term goal of joining regional VLBI networks, where its equatorial location could serve as a critical link between (South-)East Asian<sup>3</sup> and Australian arrays. This work addresses existing gaps by applying high-cadence monitoring and advanced statistical detection at both urban and rural candidate sites for future facilities.

### Method

We conducted RFI observations at two contrasting locations in Peninsular Malaysia: Universiti Malaysia (UM) in Kuala Lumpur, representing a densely populated urban environment (population density: 8235 km<sup>-2</sup>); and Glami Lemi (GL) in Jelebu, a rural region (population density: 35 km<sup>-2</sup>) proposed as a candidate radio notification zone<sup>4</sup> (RNZ). Observations used a dual-polarization log-periodic antenna connected to a Liquid Instruments Moku:Lab spectrum analyzer, recording spectra from 0 - 250 MHz with a 244 kHz channel spacing every 0.3 seconds for an entire day. We implemented a modified generalized spectral kurtosis (GSK) method for RFI detection<sup>5</sup>, incorporating a median-based shape factor to reduce bias from heavily contaminated channels.



RFI contamination was significantly higher at UM (99.9%) compared to GL (45.85%), confirming strong population-density dependence even at LF - VHF frequencies. Five main groups of RFI were identified: Three persistent (P) and two transient (T) signal groups, each corresponding to their respective spectral allocations.

### Results and Discussion

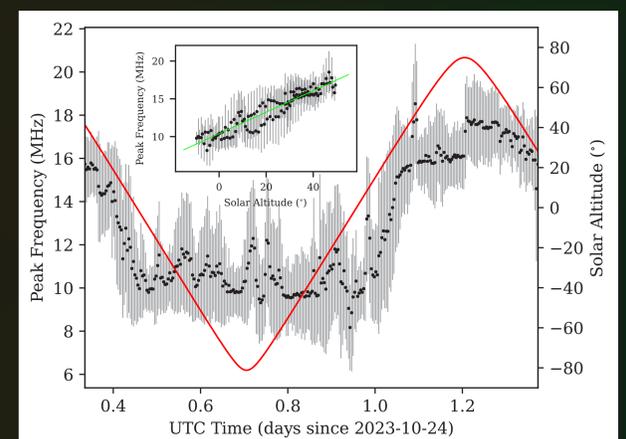
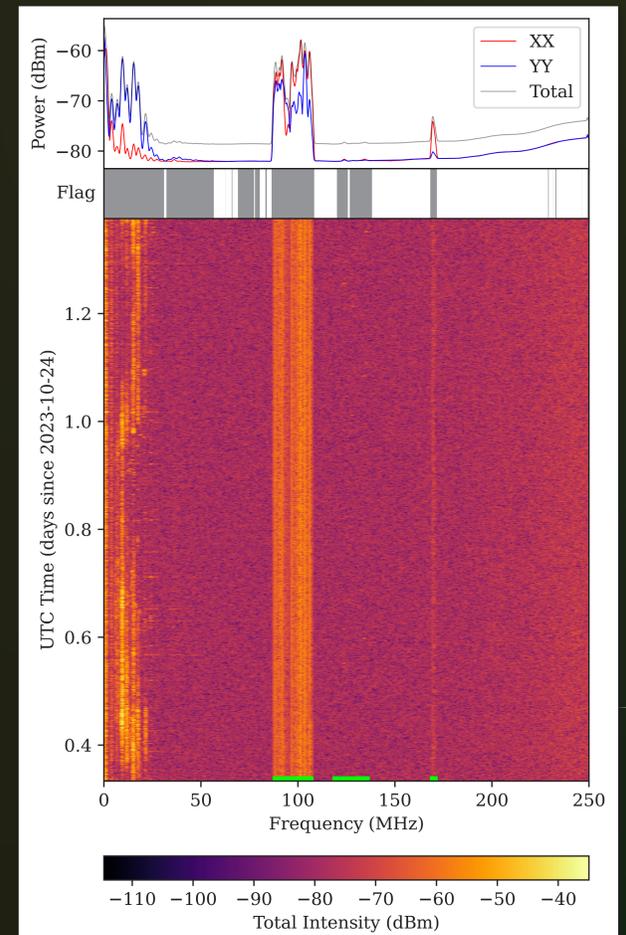
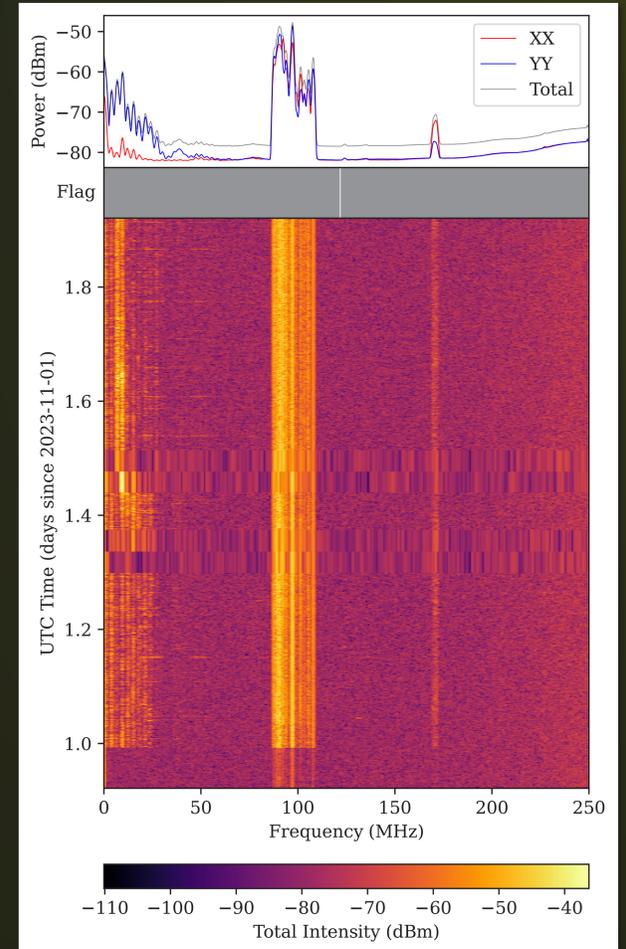
RFI Type	Frequency (MHz)	Source/Allocation	Characteristics
RFI-P1	0 - 31	Various	Two components: Steady ground-wave signals below 5 MHz, and diurnally varying emissions above 5 MHz due to solar radiation affecting ionospheric skywave propagation <sup>6</sup>
RFI-P2	86 - 108	FM analogue broadcast	Strong, stable signals with sub-band structure
RFI-P3	168 - 172	Government mobile services (MLA14)	Narrow, continuous single-band signal
RFI-T1	32 - 57	Various	Random bursts: Includes a new 50 MHz digital VHF signal enhanced by equatorial ionospheric anomalies (EIA) <sup>7</sup>
RFI-T2	120 - 138	Aeronautical mobile (airband and ATC)	Intermittent AM voice transmissions, including distress signals

Detection of these RFI groups highlights the dual challenge of persistent emissions from communication services and natural contributions driven by ionospheric effects. We tested several mitigation techniques, including post-observation methods e.g. statistical (MAD) and autocleaning (DWT), as well as physical suppression methods e.g. band-stop filters, each with distinct strengths and limitations. Ultimately, the most effective strategy will combine these approaches: Constructing telescopes in low-RFI environments, applying statistical or machine-learning-based flagging, and implementing FPGA-based real-time suppression.

### Summary

Our high-cadence, low-frequency monitoring shows that rural RNZ sites like GL experience substantially less RFI at low-frequencies than urban environments, making them suitable for sensitive radio astronomy observations. GSK effectively characterized both persistent and transient signals, with natural ionospheric effects. By combining RNZ siting with post-processing and physical suppression techniques, Malaysia has potential to host research-grade radio facilities for various astronomy purposes. Our future work will expand the temporal coverage to capture seasonal variations, expand the frequency range to enclose other important radio astronomy windows, and deploy more spatially distributed monitoring stations to characterise environmental effects.

**Captions - Left:** A map of Peninsular Malaysia with the two radio observation stations. The main map represents the Natural Earth physical map, while the inset shows a zoomed-in satellite image around the two stations, depicting their respective urban and rural environments. The GL station can also be seen to be surrounded by the Titiwangsa Mountains which provides shielding from urban radio signals. **Top right:** Overall monitoring result plot for UM data. The top panel shows the time-averaged power spectra for both linear polarization and total intensity, the middle panel shows the SK flags (gray lines denote the flagged frequencies), and the bottom panel shows a waterfall plot of the total intensity for the entire observation period. **Center right:** Similar plot to the middle figure, but for GL data. The green markers within the plot represents RFI-P2, RFI-T2, and RFI-P3 (left to right) respectively. **Bottom right:** Summary plot of the diurnal pattern in RFI-P1 of the GL data. The main plot shows the evolution of the peak emission frequency for emissions between 0 and 31.25 MHz, with the black markers and grey error bars representing binned data over every 5-min interval with their 1 $\sigma$  respectively, and the red line representing the solar altitude. The inset shows the correlation fit between the peak emission frequency in the GL data and the solar altitude, with the green line representing a linear fit to the data. Note that only the data for solar altitudes between -10° and 50° are considered for the fitting due to the constant darkness from dusk to dawn and the saturation of the formation of the ionospheric D layer near noon.



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<sup>1</sup>Abidin Z. Z. et al., 2013, *PASA*, 30; <sup>2</sup>Umar R. et al., 2014, *RAA*, 14(2), 241-248; <sup>3</sup>Abidin Z. Z. et al., 2021, *JATIS*, 7(2); <sup>4</sup>Sugiyama K. et al., 2022, *Proc. IAU*, 18(S380), 461-469; <sup>5</sup>Nita G. M. & Gary D. E., 2010, *MNRAS*, 406(1), L60-L64; <sup>6</sup>Wagner L. S. et al., 1995, *Radio Sci.*, 30(3), 659-676; <sup>7</sup>Lin C. H. et al., 2007, *Geophys. Res. Lett.*, 34(19)