URSI GASS 2021, Rome, Italy, 28 August - 4 September 2021

Sky modeling for correction and calibration of a single VHF antenna system for interferences monitoring

B. Censier*, I. Thomas, G. Auxepaules, B. Flouret, P. Renaud

Abstract

Using a VHF dipole antenna built for the 10-100MHz band and used for RFI monitoring of the Nançay radioastronomy station site, we investigate the influence of the sky signal on the observed power. The latter is seen as a power modulation at a period of one sideral day in long term monitoring data. By use of a sky and antenna model, a simulated receiver temperature due to sky only is estimated. That model fits the time modulation very well and is used it fot excision of the sky signal and calibration of the power scale in Kelvin units. An example application of calibration and correction is shown on an observed spectrum.

1 Introduction

The Nancay Surveillance Antenna (NSA in the following) is a set of antennas and receivers dedicated to radio frequency interferences (RFI) monitoring between 10 MHz and 4 GHz for radio astronomy observations held on site. The 10-100MHz band is monitored by a Nenufar antenna and front-end electronics [1], it has to be calibrated in flux or temperature. Those are the lowest frequencies accessible to ground-based telescopes, their detection with sensitive antenna arrays being one of the important challenge of today's radioastronomy. That observation window implies several observational specificities concerning low angular resolution, high sky temperature, ionospheric disturbances or RFI mitigation. Qualifying that instrumentation chain with usual controlled environment techniques is made very difficult by the large wavelengths implied, and the corresponding lack of absorbers and highly diffractive nature of the waves. On the other hand, the high sky temperature is far bigger than the noise temperature of any state of the art electronics. While detrimental to most high sensitivity astronomical observations, the sky background signal show sufficient strength and characteristic features to be measured, corrected for, and even used as an external source for calibration.

2 Sky signal modeling and excision

The periodic signal induced by the sky, rotating above and integrated in the large antenna main lobe, is clearly seen when plotting data as a function of sidereal time (see Figure 1, blue points). That characteristic signal may be fitted with e.g. a polynomial function for excision. That requires to mitigate the influence of RFI outliers over the sky background, and to sample the signal over at least one sidereal day. Nevertheless it can also be modeled taking into account both a sky model and an antenna model. We used the Global Sky Model (GSM [2]) and a NEC2 modeling of the antenna radiation pattern to simulate the temperature signal to be expected at the amplifier input. The obtained model fits the observed signal very well (see Figure 1, red line), with a single normalization free parameters determined from the data. As an example, while the original sky signal induces a variation amplitude in time of about 2.5 dB around the baseline in the 40-45 MHz, the corrected signal has only 0.15 dB residual variations. Concerning frequency dependence, the model used (see figure 4) is mainly set by the major synchrotron emission of the sky in this frequency range, and the characteristics of the antenna. We found that over a period of one sidereal day, a 6^{th} order polynomial modulating the simulated signal from GSM may still lower those residuals down to 0.06 dB without loosing any signal of interest. It may indicates some second order differences between simulations and observations due to antenna environment (e.g. attenuation of the incoming power by the surrounding trees).

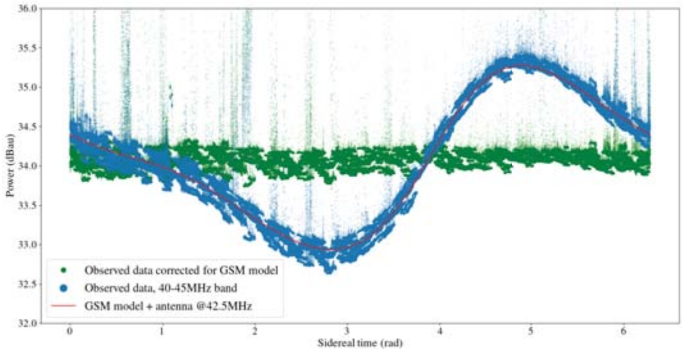

Figure 1. : Observed power over several months vs. sidereal time in the 40-45MHz band (blue), simulated power profile adjusted by a dB offset (red), and correponding residuals after substraction (green)

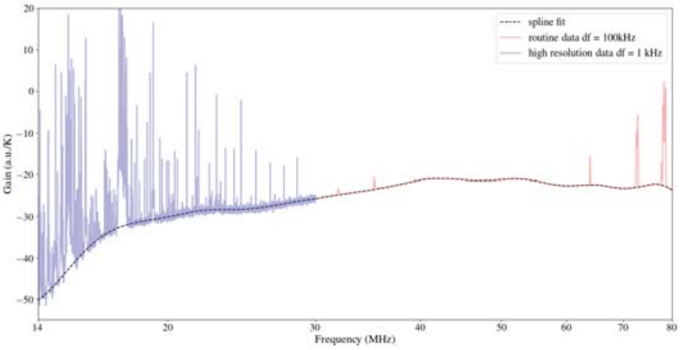

Figure 2. : Gain in arbitrary unit per Kelvin, computed as the ratio of observed power to simulated temperature. Above 30 MHz, routine data at 100 kHz resolution are used. Below 30 MHz the band is crowded with RFI emission lines, we thus used higher resolution 1kHz data to mitigate emission lines pile-up that prevents determining a baseline signal. Final gain vs. frequency baseline curve is determined by an iterative spline fitting method, alternatively rejecting RFI outliers far from the baseline model and refining the spline model on non-outliers samples.

3 Amplitude calibration and correction based on sky signal

The normalization parameter is a ratio between observed power in arbitrary units, and simulated noise temperature from the GSM and antenna model. We neglect any offset in temperature caused by system noise, which is far smaller than sky temperature in this low frequency band. It is computed in each subband over the 14-80MHz band. As a result, we get a quantity that is homogenous to a gain in arbitrary units (a.u.) per Kelvin (see Figure 2).

That quantity allows to convert the arbitrary units at digitizer output to Kelvin units, therefore to calibrate the system, at least relatively by monitoring gain variations over time, and over period as short as one day. The precision of an absolute calibration using this scheme is difficult to assess. Main discrepancies are expected to come from poor modeling of antenna at lowest frequencies and for sources near the horizon, ionospheric effects or uncertainties about the direct environment of the antenna. While the latter is not taken into account in the simulation, we already state an additional polynomial modulation seems to help correcting those effects, and the quality of the fit indicates the potential distorsion introduced by the environment is small. Concerning ionospheric effects, they are much attenuated by the very low angular resolution and the averaging over long periods. If we take a typical 10% potential systematic error on the GSM and antenna modeling, then this model should be able to be precise at the few hundreds of Kelvins level, which is sufficient given the high noise temperature of most RFIs NSA has to monitor.

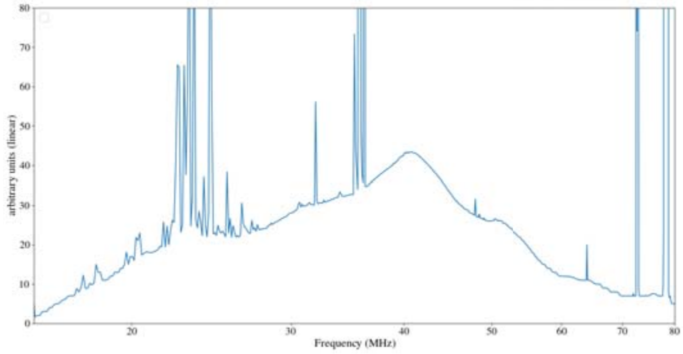

Figure 3. : Example of observed power spectrum in arbitrary units, linear scale.

4 Example application

An example application is shown in figure 4. The calibrated spectrum (blue line) is obtained by dividing the raw spectrum (see figure 3) by the computed gain (see figure 2). The orange line shows the sky model to be substracted, and the residuals of that substraction is the green line. Above 50 MHz, the residuals are well centered around zero with a maximum offset of the order of 10 Kelvins, and a dispersion of about 100 K mainly due to the low integration time used (0.1s). Between 30 and 50 MHz and as frequency decreases, there is an increasing residual baseline temperature up to 500 K, the knee around 30 MHz shown in the model is well corrected but a residual power seems to remain. Below 30 MHz the band is crowded with RFI lines piling up, the baseline temperature seems to go back to zero below 19 MHz, but with a larger dispersion than for higher frequencies (negative residuals of up to 500K). That may indicate the baseline model has to be refined at the lowest frequencies, whether for RFI pollution in the baseline estimation, precision of the antenna model or of the sky model itself.

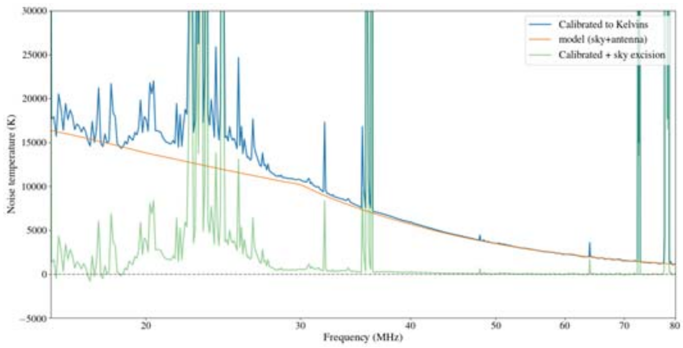

Figure 4. : blue: Observed power spectrum converted to Kelvins using the computed gain (see text, to be compared to raw spectrum shown in figure 3), orange: Noise temperature model as simulated with GSM and antenna radiation pattern, green: Residual power spectrum in Kelvins after sky model substraction.

5 Conclusion

The correction for and calibration on sky signal has proven effective for RFI applications. At frequencies below 20 MHz, the uncertainty is bigger and the low gain data together with a crowded RFI environment makes the baseline model more difficult to define. There are nevertheless several perspectives of improvemen, and the application of that method and its monitoring on longer time scale should help precising the picture. For example, the possible correction of the gain model with an additional polynomial modulation during a sidereal day may reveal systematic errors in the model that can be corrected for. Concerning potential RFI pollution, we may refine the baseline model by using the fact that some emitters seem to be far lower in certain parts of the day. Another antenna geometry on the same receiver is also under investigation for higher gain measurements. Also the antenna simulation used here were done with the moment methods, a confirmation of the low frequency part results with another simulation method like finite element could help improving the model. Finally the simple proportionality relations between arbitrary units and Kelvins used here can be refined using an additional parameters, namely electronic noise temperature. At the lowest frequencies the electronic gain drops and the observed sky power may fall to the order of magnitude of the electronic noise power, a model including both a gain term and an offset term may thus improve the method in that frequency range.

References

[1] P. Zarka et al., “The low-frequency radio telescope NenuFAR”, URSI GASS 2020, Rome, Italy, 29 August - 5 September 2020.

[2] A. De Oliveira-Costa et al., “A model of diffuse Galactic radio emission from 10 MHz to 100 GHz”, Monthly Notices of the Royal Astronomical Society, Volume 388, Issue 1, pp. 247-260.