ВАК 2024 MODERN ASTRONOMY: FROM THE EARLY UNIVERSE TO EXOPLANETS AND BLACK HOLES

# RadioAstron project: calibration of the space radio telescope during the flight in 2011–2018 in the 1.35, 6.2, 18, 92 cm bands using improved primary calibration scales

A. Ermakov[1], V. Vasilkov[1], P. Voitsik[1], Yu. A. Kovalev[1], M. Lisakov[1], and Yu. Yu. Kovalev[2]

[1] Astro Space Center of P. N. Lebedev Physical Institute, 84/32 Profsoyuznaya St., Moscow, 117997 Russia

[2] Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, Bonn, 53121 Germany

**Abstract.** We summarize the results of processing calibration telemetry sessions for the four known primary calibrators of spectral radio flux density—Cassiopeia A, Crab Nebula, Cygnus A, and Virgo A—in the autonomous observation mode with the space radio telescope (SRT) in flight. A new system of automated data processing was used, previously successfully tested in similar processing of the measurements with the SRT in 2015–2018 in the 6.2, 18, and 92 cm bands. The calibration of the SRT intrinsic noise and the internal artificial generators of the noise signal (NG) was performed for two versions of the primary scale of spectral radio flux density: the generally accepted original scale by Baars et al. suggested in 1977 and its improved version based on the results from newer publications. The main differences between the versions are related to the fact that the actual rate of secular variation in the fluxes of astronomical calibrators differs from the extrapolated values in the previously accepted scale. Preliminary results for the SRT calibration with the improved scale coincide within 10–15 percent with the results published earlier.

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## 1 Introduction

The article presents the results of processing the data from the Noise Generator (NG) and the intrinsic noise of the SRT at four wavelengths for the entire flight in 2011–2018 using four astronomical calibrators. The results were obtained with a unified automated data processing system in contrast to the earlier approaches.

## 2 Processing and analysis

Four known astronomical primary calibrators were used: Cassiopeia A, Crab Nebula, Cygnus A, and Virgo A. The data were processed using an automated system that had previously been successfully tested in similar processing of the 2015–2018 SRT measurements in the 6.2, 18, and 92 cm bands, but relative to only Cas A and the Crab Nebula (Ermakov & Kovalev 2020; Kovalev et al. 2020, 2022) in the primary scales by Baars et al. (1977); Perley & Butler (2017).

Each calibration session consists of recording a response to the activation of the noise signal generator, measuring the intrinsic noise of the SRT system, and scanning a calibration source. The resulting values in volts are converted into units of spectral flux density for the NG and the SRT ($F_{\mathrm{ns}}$ and $F_{\mathrm{sys}}$).

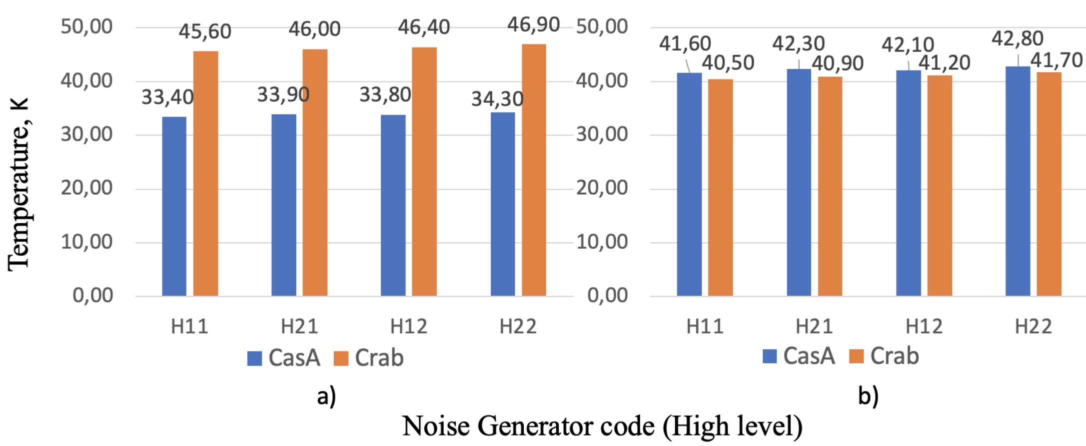


**Fig. 1.** Average values over 2011–2018 in the 18 cm band for four (out of eight) noise generators. The left panel shows the calibration carried out relative to the standard primary scale by Baars et al. (1977). The same NG values from 2011–2018 but calibrated according to the new scale by Perley & Butler (2017) are shown on the right.

The monitoring results for the first half of the SRT flight coincide with the second half: the calibrations of noise generators are stable relative to Crab and Cas A, the average error over 8 years is 2–5%. However, there is still discrepancies in calibrations relative to different astronomical sources: the calibrations according to Crab differ from the calibrations according to Cas A by 25–35%. Figure 1 shows the average values for four out of eight NGs over the entire SRT flight for the 18 cm range. Figure 1a clearly shows how much the NG calibrations differ relative to different calibrators. Recalculating the calibrations to the corrected scale eliminates this difference (Fig. 1b).

In addition to the Crab and Cas A calibrations, the calibrations relative to Cygnus-A and Virgo-A for the entire duration of the SRT flight were also processed. The analysis shows that the calibrations in the new scale also agree well with each other. Figure 2 shows the ratios of the NG calibration between the four calibrators. The ratios in the new scale are close to one and are within an error of 10–15%, which characterizes the accuracy of the spectral flux density scale in which the calibration was performed. Thus, in processing the observations and analyzing the calibrations obtained for the entire SRT flight, we were convinced of the operability of the method for checking the spectral flux density scales and also convinced of the stability of the parameters during the entire operation of the SRT in three wavelength ranges.

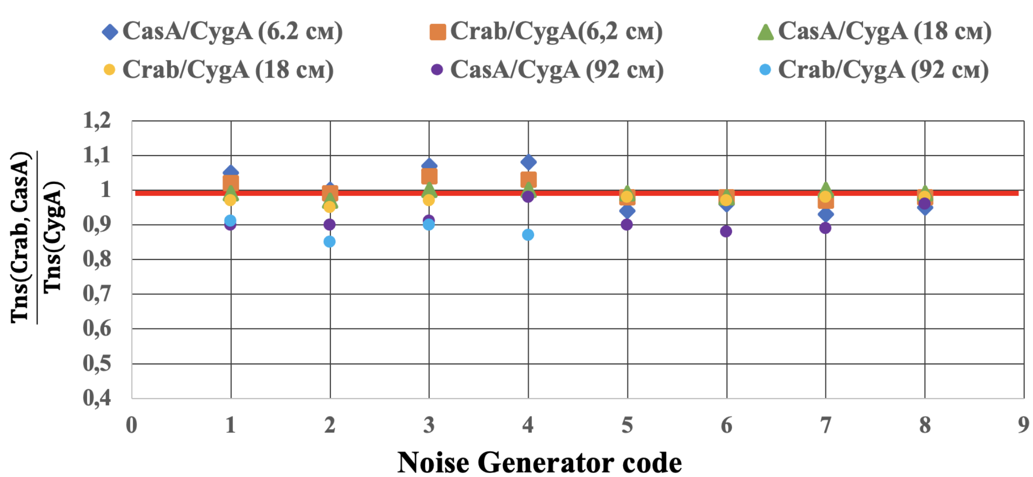


**Fig. 2.** The ratios between the calibrations calculated using different calibrators in the new scale. The values should lie near the red line, around one.

All the observed calibration data at the shortest wavelength of 1.35 cm were also processed using the unified automated data processing system. Figure 3 shows an example of the obtained results. The analysis of the results is in progress.

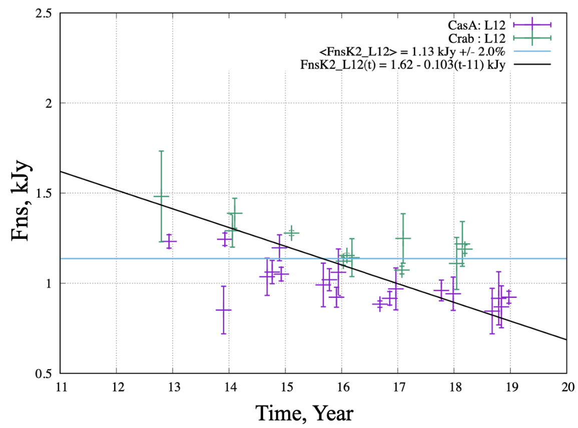


**Fig. 3.** An example of the calibration results for one of eight NGs for 2011–2018 in the 1.35 cm range using Cas A and Crab. The known drift of the NG power can be seen.

# 3 Conclusions

1. The previously tested system for mass automated processing of calibration observations was used to calibrate the observations relative to the Crab Nebula and Cas A during the first half of the SRT flight in 2011–2014 for the bands of 6.2–92 cm.
2. The automated system has processed the observations of Cyg A and Vir A for the entire SRT flight in 2011–2018 in the bands of 6.2, 18, and 92 cm.
3. With a small modification, the system has processed a new range of 1.35 cm for all the years of the SRT flight. The hypothesis about the drift of the NG power over time is confirmed. All the data have been processed, the analysis continues.
4. We have shown that the SRT parameters ($F_{\rm ns}$ and $F_{\rm sys}$—system equivalent flux density, SEFD) are stable within a small error of 2–3% relative to each of the four calibrators at 6, 18, and 92 cm.
5. The transition to the new scale of spectral flux density eliminates the difference in the SRT calibrations calculated relative to different astronomical calibrators. The method has been tested on several new calibration scales.

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