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A new Method for Verification of Astronomical Spectral Flux Density Calibrators based on SRT Data

A.N. Ermakov,[a,*] **Yu.A. Kovalev,**[a] **V.I. Vasilkov,**[a] **V.A. Soglasnov,**[a] **M.M. Lisakov**[a,b] **and Y.Y. Kovalev**[a,b]

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

[b] *Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, Bonn, Germany*

E-mail: ermakov.a@list.ru, ykovalev@asc.rssi.ru

The RadioAstron is an international project of a ground-space VLBI at the wavelengths 92, 18, 6.2 and 1.35 cm. The SRT has a paraboloid antenna with a 10 m diameter. It had been launched on July 18, 2011 and worked in flight up to January 10, 2019 together with many ground-based radio telescopes. The base of the VLBI reached 250 000 km. The results of mass processing of radiometric observations obtained with the RadioAstron Space Radio Telescope (SRT) are presented. A new complex for automated processing of SRT calibration sessions in the single telescope mode has been designed. The main and backup noise signal generators as secondary calibration standards in the wavelength ranges of 6.2, 18 and 92 cm in the calibration sessions for the 4 years of SRT flight in 2015–2019 are calibrated relative to the known primary flux density standard sources - Cassiopeia-A (Cas A) and the Crab Nebula (Crab). Calibration was carried out using the 1977 generally accepted spectral flux density scale. One of the most important and unexpected results of processing is the detection of a 25–35% discrepancy between the noise generator calibrations relative to Crab and Cas A. The analysis showed that the reason for this discrepancy is a real long-term variability of Cas A and Crab, which does not correspond to the known extrapolated flux densities in the standard scale of 1977. The transition from the generally accepted flux density scale of 1977 to the new corrected scales of 2017 and 2014 eliminates the discrepancy found. Based on the analysis above the report proposes a new method for verifying astronomical spectral flux density calibrators. A noise generator of a telescope is used as an indicator. The SRT calibration example is extended to most ground-based radio telescopes, also possibly including the RATAN-600.

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[*] Speaker

1. Introduction

The work is devoted to the processing of SRT calibration observations for the second half of the space telescope flight in 2015-2019. SRT calibration sessions for 4 years (2015-2019) were automatically processed in three wavelength ranges of 6, 18, 92 cm in two polarization channels.

2. Processing and analysis

Each observation consists of 4 responses to 4 Noise Generators (NG) at the beginning, the same 4 responses to NG at the end of an observation, and several responses to Cassiopeia A or Crab Nebula calibrators. All responses are measured in Volts and then calibrated to NG in the spectral flux density, in Jy, via the astronomical calibrator. Figure 1 shows the result of processing the Noise Generator over 4 years (for convenience, all results are in Kelvin).

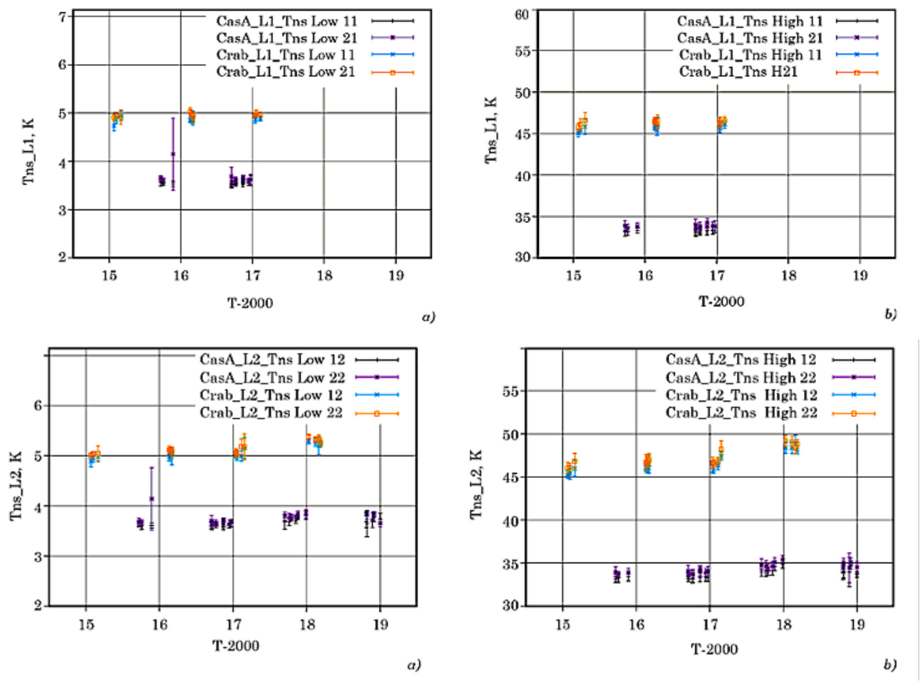

Figure 1: Results of processing the 8 main and backup internal Noise Generators (NG or NS) of SRT calibrated relative to Crab Nebula and Cassiopeia A in the left (top) and right (bottom) circular polarization channels — for the Low (a) and High (b) power level of NGs. These are the examples at 18 cm only [1, 2]. The temperatures $T_{NG} \equiv T_{NS}$ for each NG have to be $T_{NG}(Crab) = T_{NG}(Cas\ A)$ in ideal cases.

Analysis of the results showed that the calibrations of the Noise Generator are stable with respect to each calibrator, the average error over 4 years was 2-3% [1, 2]. But at the same time, an unexpected result was discovered - the NG calibrations according to the Crab differ from the calibrations according to Cassiopeia by 25-35%. One can clearly see the difference between the calibrations in Figures 1 - 3. It is important to note that the calibration of the Noise Generator was carried out according to the generally accepted standard 1977 spectral flux density scale.

Ideally, a Noise Generator calibrated to any of two or more accurate calibration sources should have the same value.

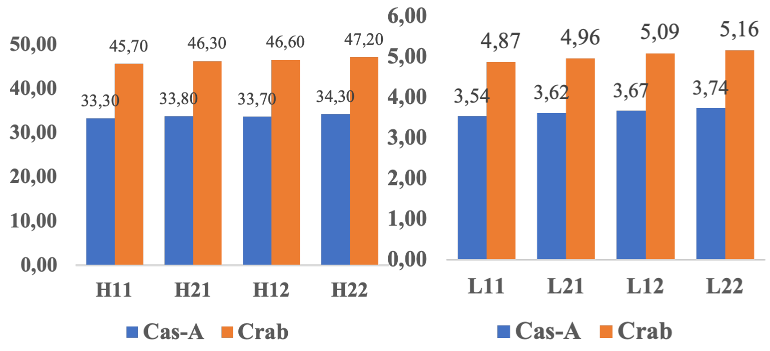

Figure 2: A comparison of the calibration for the Noise Generators (NG), in K. Blue color - NG calibrated by Cas A, orange one - by Crab: on the left — comparison of the High Power NG calibrators (Index H); on the right — the same but for the Low Power NG calibrators (index L).

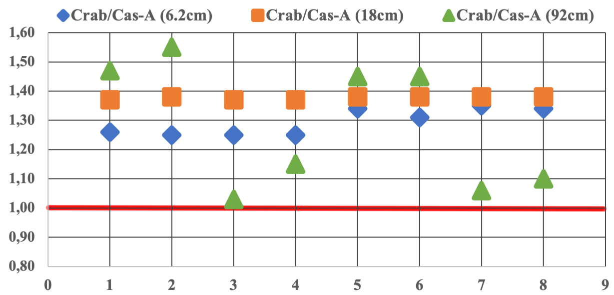

Figure 3: The 1977 flux density scale: Crab to Cassiopeia A calibration ratios for each type of Noise Generator at the wavelengths of 6.2, 18 and 92 cm. The values should be near the red line, around 1.00.

We considered several reasons for this difference in calibrations. First of all, we tested the hypothesis about a secular change in the spectral flux density of the astronomical calibrators used for NG and SRT calibration. To check this, it is necessary to use a spectral flux density scale and recalculate the NG calibrations accordingly. We found two new astronomical flux scales: for 2014 [5] and 2017 [4], and recalculated the calibrations to these scales. Figure 4 shows the result of the recalculation, where each value is the ratio of the calibrated values of the Noise Generators measured relative to Crab Nebula and to Cassiopeia in the 2017-scale.

It can be seen that the ratio has become close to 1.00. A similar result, but with a slightly larger error, was also obtained in the 2014-scale. We concluded that the 2017-scale is better suited for calibration measurements, thereby confirming our hypothesis about the incorrect extrapolation of the spectral density change in flux calibrators indicated for the generally accepted 1977-scale. As a result, a new method for verification of calibration sources was formulated.

The essence of the new technique is that one first needs to observe two or more calibration sources together with the Noise Generator (NG), then calibrate the Noise Generator relative to each of these calibrators. If the NG calibrations are equal to each other within the measurement error, then the calibrators are matched. Otherwise a correction of the spectral flux density of one of the calibration sources is required. This technique requires two conditions to be met: 1) the antenna

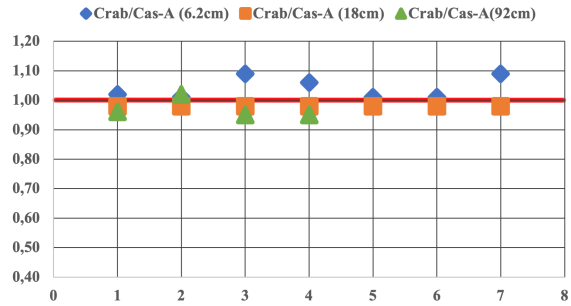

Figure 4: The 2014 and 2017 flux density scales: Crab and Cassiopeia calibration ratios for each type of NG for three wavelength ranges. The ratios are close to 1.00, which is a good indicator.

temperature of the NG has to be stable, and 2) the effective area of the antenna has to be constant. For SRT, these two conditions are met. For ground-based antennas, the NG temperature is stable, but the effective area varies with height as a rule. Nevertheless, this technique can also be applied to ground-based telescopes if the calibration sources are observed at the same height.

3. Conclusions

1. A new system of mass automated processing was developed and applied to the calibration observations of SRT relative to the Crab Nebula and Cassiopeia A for 2015–2019. The analysis showed that SRT parameters are stable with typical errors of 2–3% relative to each calibrator.

2. The spectral equivalent flux density of internal Noise Sources or Noise Generator (NS or NG) $F_{NS}(Crab)$, in Jy, measured relative to the Crab Nebula and averaged over 4 years differ by 25–35% from $F_{NS}(CasA)$ measured relative to Cassiopeia A. But these F_{NS} should be equal within the measurement errors, since F_{NS} does not depend on the calibration source.

3. The transition from the generally accepted 1977-scale to two new scales — 2017 and 2014 — practically eliminates these detected differences. But the standard 1977-scale can be also used, if the F_{NS} averaging between Crab and Cas A is performed. This discrepancy was a result of a real secular variability of Crab and Cas A, which differed in the generally accepted extrapolated data.

4. Such analysis of F_{NS} can be applied to the verification of the astronomical spectral flux density calibrators and scales for the data from both space-based and most ground-based telescopes.

References

[1] A. N. Ermakov & Yu. A. Kovalev *Transactions of IAA RAS, 2020*, 54, 21

[2] A. N. Ermakov, Yu. A. Kovalev and V. I. Vasilkov, *In: Proc. XVIII Young Scientists Conf. on Fundamental and Applied Space Researchers, Moscow, Russia, 2021, Ed. by A. M. Sadovski, pp. 31–45 (IKI RAS, Moscow, 2021)*

[3] J. Baars et al. *A&A, 1977*, 500, 135

[4] R. A. Perley & B. J. Butler *ApJS, 2017*, 230, 7

[5] E. N. Vinyaikin *Astronomy Reports, 2014*, 58, 626