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Steps towards an absolute-based flux density scale at meter wavelengths

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Abstract. The VLA's new Lowband system has been employed to measure the flux densities of seven proposed standard flux density calibration sources between 220 and 460 MHz, based on the Baars et al. (1977) expression for Cygnus A. Using these data, legacy VLA 74 MHz data, and the results of Perley and Butler (2013), we generate interim polynomial expressions for the spectral flux densities of 3C123, 3C196, 3C286, and 3C295 valid between 50 MHz through 50 GHz.

Keywords : VLA lowband receivers, low frequency flux scale

1. Introduction

The flux density scale most widely used in radio astronomy for the past 35 years has been that of Baars et al. (1977), which provided convenient polynomial expressions for the spectral flux densities of thirteen relatively compact radio sources, based on the absolute observations for Cygnus A, Cassiopeia A, Virgo A, and Taurus A. Of these thirteen, three – 3C48, 3C147, and 3C286 are compact enough to be utilized as flux density standards for high-resolution radio interferometers, including the GMRT and the VLA. However, the Baars et al. (1977) scale for these compact sources was only defined for frequencies between 400 MHz and 15 GHz, so their expressions are not valid for the new low-frequency arrays now built or under construction. The high frequency flux density scale has recently been updated by Perley and Butler (2013), who provide accurate (better than $\sim 3\%$) polynomial expressions for the non-variable radio sources 3C123, 3C196, 3C286 and 3C295 from 1 to 50 GHz. These are tied to the absolute WMAP scale through observations of the planet Mars.

By contrast, the flux density scale below 400 MHz is much less well established,

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with many proposed scales and standards, which are in disagreement at the level of 5 to 10%, or more, as described in Baars et al. (1977). Scaife and Heald (2012) recently proposed a unified scale spanning 30 to 300 MHz for six compact sources, based on a Bayesian analysis utilizing a number of the older scales. However, this is a weighted scale utilizing older work, and is not directly tied to an absolute standard nor utilizes any new observations.

To put this, or any other low-frequency scale on an absolute standard requires measuring accurate ratios between the proposed calibrator sources and the primary sources Cygnus A, Taurus A, or Virgo A, whose absolute spectral flux densities are believed to be known. Of these three sources, the best standard is Cygnus A, as it is the strongest and the most compact. Making these ratio measurements is not trivial, as the flux density of Cygnus A is more than two orders of magnitude higher than that of the calibrator objects, and, for a 25-meter antenna, observing Cygnus A more than quadruples the system power. Both effects place strong demands on receiver and interferometer linearity.

The old Very Large Array could not accurately measure the ratios between proposed calibrator sources and the standard Cygnus A, as both the analog and digital portions were not designed for such high power and flux density ranges. The recently-completed Jansky Very Large Array has been designed for high linearity in its analog and digital components. Hence, it is capable of accurately measuring the flux density ratios between Cygnus A and standard calibrator sources.

2. VLA's new low-band system

The old VLA's low frequency receivers ('4' band and P-band) were incompatible with the Jansky VLA's electronics, and have now been replaced with a single wideband (50 – 500 MHz) receiver, funded with a \$270K grant by the US Naval Observatory. See Huib Intema's contribution in these proceedings for a more thorough description. All VLA antennas are now equipped with these new receivers, and commissioning tests are ongoing.

3. Observations and results

3.1 Observations

As part of the commissioning effort of the LowBand receivers, we have taken observations of seven proposed low-frequency calibrator sources – 3C48, 3C123, 3C147, 3C196, 3C286, 3C295, and 3C380, plus the absolute standard 3C405 (Cygnus A), in seven short sessions between October 2013 and January 2014, while the array was in the **B** configuration (providing ∼15 arcseconds resolution). Six of these soruces (excluding 3C123) are Scaife and Heald (2012) sources, and five of these (excluding 3C196 and 3C380) are Baars et al. (1977) sources. Included in the observations were

Table 1. Results from old and new VLA.

	286/296	196/295	196/123	196/286	123/286	123/295
Old VLA	0.430	0.776	0.322	1.81	5.61	2.41
Jansky VLA	0.432	0.775	0.320	1.80	5.61	2.42

Table 2. New flux densities.

	3C48	3C123	3C147	3C196	3C286	3C295	3C380
New	45.1	149.9	55.0	46.8	26.8	62.6	43.2
S&H	44.2		55.4	47.8	24.2	60.7	43.3
Ratio	1.02		1.03	0.98	1.11	1.03	1.00
Baars	45.4	140.5	53.8		27.1	61.1	
Ratio	0.99	1.07	1.02		0.99	1.02	

The top line gives the newly derived flux density, based on Cygnus A. Below this is the Scaife and Heald (2012) value, under which is the ratio of our value to that of Scaife and Heald. Next is the Baars et al. (1977) value, followed by its ratio.

Taurus A and Virgo A. However, these sources were largely resolved out by the array, and the derived flux densities are not reliable. We observed between 216 and 472 MHz, utilizing 16 subbands, each of 16 MHz width.

3.2 Calibration

RFI is a significant factor in this frequency band, with two of our 16 subbands so heavily contaminated that the data were abandoned. The remaining subbands are sufficiently free of RFI that a simple clipping operation was sufficient to allow accurate gain calibration. As some of the targeted objects are partially resolved (notably Cygnus A, 3C123, and 3C380), and as confusing background sources are always present, spectral flux densities were determined through imaging of each field in each subband. The accuracy in our process is difficult to determine at this time, as we have not yet had enough observations to determine the scatter. An encouraging initial indication comes from the observations of 3C380 and Cygnus A, which were both observed on four of the seven sessions. The resulting ratios were in agreement at the $\sim$1 – 3% level.

3.3 VLA Comparison

Table 1 shows the ratios of the four non-variable sources from Perley and Butler (2013) using old VLA and Jansky VLA data. The old VLA data were taken from 1990 through 2008.

Table 3. Polynomial coefficients.

Source	A0	A1	A2	A3	A4
3C123	1.810	-0.810	-0.105	-0.004	0.000
3C196	1.295	-0.875	-0.150	0.0014	0.009
3C286	1.254	-0.465	-0.184	0.055	-0.008
3C295	1.480	-0.790	-0.280	0.000	0.026

The similarity of the ratios with the new system to that of the old gives us confidence in our results.

3.4 Flux Densities for Calibrators

Using these new ratios, and the Baars et al. (1977) values for Cygnus A, we derived new flux density values for the seven calibrator sources, as shown in Table 2.

The agreement between our values and the old scales is quite good, with the only notable errors being with 3C123 (Baars et al. (1977) is 7% high) and 3C286 (where Scaife and Heald (2012) is 11% low).

4. Polynomial fits

We have utilized our new data, the Perley and Butler (2013) values for the 1 – 50 GHz range, and unpublished values from the VLA's old 74 MHz system for the four non-variable sources, 3C123, 3C196, 3C286, and 3C295, to derive tentative polynomial expressions of the form $\log(S) = A_0 + A_1 \log(\nu_G) + A_2(\log(\nu_G))^2 + A_3(\log(\nu_G))^3 + A_4(\log(\nu_G))^4$ for the spectral flux densities of these objects, valid over the range 50 MHz through 50 GHz. In this expression, S is in Jy, and ν_G is the frequency in GHz.

5. Discussion

These are preliminary results, as the VLA's new Lowband system is still undergoing testing, and the array configuration utilized **'B'** significantly resolved the primary standard, Cygnus A. We plan to utilize the upcoming **C** configuration at the end of this year to re-observe these sources, including Cassiopeia A, Taurus A and Virgo A, and a selected set of proposed southern declination sources.

References

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