EVLA Memo No. 232 - VLA Dynamic Scheduling Statistics

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Table of Contents

Abstract

The objective is to quantify some of the VLA observation characteristics by looking at its dynamic scheduling history. The Scheduling Blocks are classified according to their resource parameters (sub-arrays, pulsar, received bands). As a novelty, the characteristics of each scan are also investigated. The established quantities are fundamental for planning and improvements in VLA Operations.

Introduction

The VLA observations are defined as Scheduling Blocks (SBs) and are classified here as follows. Each SB contains a list of *scans* to provide instructions for the antenna positions (i.e., source positions), receiver band, scan duration (length of scan including slew and on source time), and data mode ("regular" or "pulsar" mode). The SB can have up to three parallel scan lists, using subgroups of antennas (or *sub-arrays*).

This is the fourth memo of a series analyzing the OST logs data. The initial memos are numbers 220, 221, and 225. The VLA band definitions are reproduced at the end of the Appendix for convenience.

Data summary

The VLA observation history is based on the OST (Observation Scheduling Tool) logs. I considered all the scheduled SBs from 2012-01-01 to 2023-12-31 (12 full years). The observations were classified based on the SB information stored in the `evlaopt` database on 2024-05-16. Some SBs may have changed since their execution, but I am assuming these are not significant for the analysis made here.

No distinction is made between "science" and "test" SBs. This ensures that the derived values are representative of the functioning of the observatory as a whole.

The OST logs contained a total of 36,805 scheduled SBs for the period. Valid SBs are the ones that have started execution and have a valid configuration as currently read by the OST (version 1.33.05). Valid SBs account for 97.6% (35,938) of the data set, while 2.4% (604) had invalid configurations and 0.7% (263) did not start

Among the valid SBs that started, 96.8% (34778) reached the end. In terms of array time, 72,702.3 hrs were used for valid SBs, and of these 71,024.3 hrs (97.7%) for completed SBs. In other words, only 2.3% (1,678.0 hrs) of the dynamic time was spent on scans of incomplete SBs (or "time lost").

It is recalled that the observatory underwent extensive electrical work in mid-2018.

Results

I chose to move all graphs and tables generated to the Appendix to improve readability. Therefore, this section only contains the discussion and highlights for each of the topics.

Sub-arrays and Pulsar modes

Sub-arrays were present in 129 SBs (0.4%). The array time of these SBs was 352.4 hrs (0.5%), with a total scan time of 786.4 hrs (1.1%). That corresponds to an average of 2.23 sub-arrays per SB.

Pulsar was present in 213 SBs (0.6%). The array time of these SBs was 321.5 hrs (0.4%), with a total scan time of 303.8 hrs (0.4%).

The above values indicate that sub-array and pulsar are uncommon observing modes, corresponding to approximately 0.5% of the total. However, for a long period, sub-array and pulsar modes were not regularly offered in the dynamic schedule (or at least could not be run using the OST). The first record of OST execution of sub-arrays is from 2017, while pulsars started in 2019.

If we estimate the maximum use of sub-arrays by the years 2019 and 2023, we have about 100 hrs of the 6500 hrs observed annually. That's 1.5% of the total. For pulsars, the highest usage was in 2022 and 2023 with 125 hrs observed each. Therefore the upper limit for the pulsar mode usage is 1.9%.

Receiver bands

Very low-frequencies (4- and P-bands) are marginally used, with less than 1% of total usage metrics.[1]

Intermediate low frequencies (L-, S-, C-, and X-bands) correspond to three quarters of the total. L-band accounts for 30% of the observed hours, while the S-, C-, and X-bands each account for about 15%.

High-frequencies (Ku-, K-, Ka-, and Q-band) account for approximately 25% of the used time (approximately 6% for each band).

The minimum percentage of single-band SBs is 26%. This can be derived from the 1.74 average of requested bands, assuming that all other SBs would be using 2 bands. Thus, the number of single-band SBs is likely higher, since many SBs make use of 3 or more bands.

Although X-band is used by almost half of the SBs (49%), it accounts for only 10% of the number of scans. This reflects the preference for setup and pointing scans with this band.

The configuration of VLA observations from 2012 to 2023 displays a stable pattern. The sole exception of a shift from C-band to S-band use after 2017. This change likely coincides with the Very Large Array Sky Survey (VLASS).

Scan lengths and single-tracking

Each scan has a specific target (also called a "source") and duration. The median scan length is 1.33 minutes, while its average is 2.34 minutes. This bigger average indicates that a considerable number of scans have a long duration.

Pulsar scans are considerably shorter than average (1.3 minutes), while very low frequency scans are the longest ones (approximate average of 4 minutes). This change in duration per band is expected, since lower frequencies have longer calibration cycles[2].

The average number of scans per SB is 52 (total duration of 121 minutes), which matches the mean SB duration found in the EVLA Memo 220.

We define *single tracking* as scans executed continuously on the same sidereal target. Although almost one-third (32.3%) of the scans share the same sidereal target as the previous one, the single tracking length does not change considerably from the individual scans. The median and average single tracking duration are 1.82 and 3.33 minutes, respectively.

I do not report the maximum scan or single tracking duration values since these edge cases are test SBs.

Slew

Slew times were also computed using the VLA kinematic model of the OST. These are the additional times the OST considers for *on source* scans (instead of the default *duration*). For the first scan, the position of the antennas is unknown. It is then assumed that the antennas are in the middle of the Azimuth and Elevation ranges.

The definition of "slew time" in this document also considers changes in the subreflector. A fixed time of 20 seconds is considered when receiver bands change between scans[3]. The reported slew time is therefore the longest between slew and the considered subreflector movement.

The median and average slew times are 0.24 and 0.40 minutes, respectively. When comparing the total slew with the scan times, it is found that the average fraction of the scan duration spent in slewing is 17.0% (740,586.7 versus 4,362,136.2 minutes). For an average SB with 52 scans (2 hours long), this corresponds to 20.6 minutes spent on slewing.

This is a lower limit since I did not consider the extra time required for the initial setup scan, whose recommended value is 11 minutes. Nevertheless, the values above are representative of the slew time between scans after the first one.

[1] A single SB using the "4_P" band was found.

[2] For details on calibration cycles, see https://science.nrao.edu/facilities/vla/docs/manuals/obsguide/calibration#section-15

[3] The actual duration varies from 10 to 37 seconds, depending on the receivers in transition. For more details, see https://science.nrao.edu/facilities/vla/docs/manuals/propvla/determining#section-8

Sources

A total of 483,414 sources were used by the 35,938 SBs. This is an average of 13.5 sources per SB. The median (typical) number of sources in an SB is 3.0. This allows inferring that many SBs are composed of a complex gain calibrator, a flux calibrator, and the science target.

The average number of scans is 3.86 per source (total of 1863786 scans). Regarding duration, the median time on a given source is 3.07 minutes per SB. The average is 9.02 minutes.

Note that some SBs are from surveys with a high number of sources (like those from VLASS) and that we did not make a distinction.

Pointing

Area bins, rather than raw coordinates, were chosen to represent target counts. That avoids the need for a specific accuracy criterion for comparing coordinates, which would depend on observed wavelengths (higher frequencies lead to better pointing accuracy).

To create equal area elements (solid angle), I divided the equatorial longitude into 100 bins (0.24 hr intervals) and latitude into 100 bins with finer spacing near the equator (arcsin(0.02) intervals).

Two major peaks in Right Ascension (RA) were found: one at 17–19 hrs (Galactic Center and its east plane[4]), and another at 13–14 hrs (basically 3C286). A minor peak at 5–6 hrs can be associated with reference targets (e.g., 3C48, 3C147, and 3C138). Very few targets were found in the following RA ranges: [6–8, 15–16, 21–22] hrs. At these intervals, the count was 30,000 or less, well below average (roughly 78,500 per hour).

In Declination, three pronounced peaks can be found: one at -30 deg (Galactic Center), another around the equatorial plane (0 deg), and the preferred peak around VLA's latitude (+34 deg; corresponding to reference targets 3C286, 3C48, and J0336+3218).

Queue anticipation

[5] Dynamic scheduling at the VLA typically creates observation queues lasting 24 sidereal hours. We analyzed this queue history to assess the lead time for Scheduling Blocks (SBs) between entering the queue and their observations starting. This analysis is crucial because the queue is updated frequently - at the end of each SB execution - incorporating fresh weather data (API and wind speed, and its forecast).

For the 4 years analyzed (mid-2023 – mid-2019):

- 67.7% of the SBs were set more than 20 minutes in advance;
- 32.3% of the SBs were defined in up to 20 minutes;
- 17.3% of the SBs were defined in up to 10 minutes.

Dynamic scheduling at the VLA creates gaps to accommodate high-priority observations. To mitigate RFI, these gaps could be strategically rescheduled to match satellite reconfiguration time. VLA Memo 225 suggests that the schedule gaps account for roughly 2.7% of scheduled time. With a typical Scheduling Block (SB) length of 121 minutes, this translates to 3.2 minutes per SB. Requiring all SBs to wait for favorable satellite configuration before commencing would significantly impact VLA operations if such configuration takes longer than 3.2 minutes. This is a point to be better evaluated in the future, as two-thirds of the observations are fixed more than 20 minutes in advance, and not all SBs use bands subject to RFI emission from satellites.

[4]The conversion to Galactic coordinates from equatorial J2000 was done using the Gaia DR2 recipe at https://gea.esac.esa.int/archive/documentation/GDR2/Data_processing/chap_cu3ast/sec_cu3ast_intro/ssec_cu3ast_intro_tansforms.html#SSS1

[5]This section was originally published on June 07, 2023 at https://open-confluence.nrao.edu/display/Arch/VLA+data+sender+description

Final remarks

This work aims to quantify various aspects of Very Large Array (VLA) observations to characterize observatory operations. It does not include an analysis of the scientific impact of observations, such as publications or citations generated per band or observing time.

While VLA Utilization Reports can provide information on observed Scheduling Blocks (SBs), this work offers novel insights into scan characteristics (coordinates, slew, total duration).

This work is based on some hypotheses: 1) the OST logs correctly record all SBs that had an execution started in dynamic scheduling; 2) the SBs as defined in the database on 2024-05-16 did not change since their observation; 3) the 2.4% of SBs that could not be reconstructed did not significantly alter the results. Although representative, the values derived here should not be taken as absolute ones.

The data from this work can be used as a reference for more detailed operational assessments and improvements, such as:

- *Smoother Scheduling*: Prioritizing proposals with targets in low-pressure Right Ascension (RA) intervals can facilitate dynamic scheduling.
- *Maintenance Planning*: Knowing receiver band usage can help optimize maintenance windows and user availability.
- *RFI Mitigation*: Anticipating the observation queue, band usage, and duration are important factors in mitigating Radio Frequency Interference (RFI) from sources like satellites.

Acknowledgments

The author would like to thank P. Beaklini, K. Gibson, D. Medlin, and H. Medlin for the discussions.

Appendix

Scheduling Blocks summary

Table 1: *Summary of SBs in OST logs from 2012-01-01 to 2023-12-31.*

SB type	count	perc.	hrs
Total	36805	100.0%	–
Valid	35938	97.6%	72702.3
Bad configuration	604	1.6%	–
Not started	263	0.7%	0
Completed	34778	96.8%	71024.3

Table 2: *Summary of SBs parameters by receiver band. Note that "SBs" column accounts for the band presence in the block (resulting in an average of 1.74 bands per SB), while "scans" and "hours" are exclusive to the band.*

band name	SBs	scans	hours
4	272	6569	509.7
4_P	1	5	0.0
C	11277	462522	11456.1
K	3966	177246	4548.1
KA	4615	192440	6379.4

. . . continued on next page

Table 2: *Summary of SBs parameters by receiver band. Note that "SBs" column accounts for the band presence in the block (resulting in an average of 1.74 bands per SB), while "scans" and "hours" are exclusive to the band.* (... continued)

band name	**SBs**	**scans**	**hours**
KU	3277	108097	2920.9
L	12750	337035	22032.3
P	258	7846	520.4
Q	2404	132872	3158.6
S	5826	247975	11696.4
X	17720	191179	9480.3
(total)	62366	1863786	72702.2

Scheduling Blocks parameters

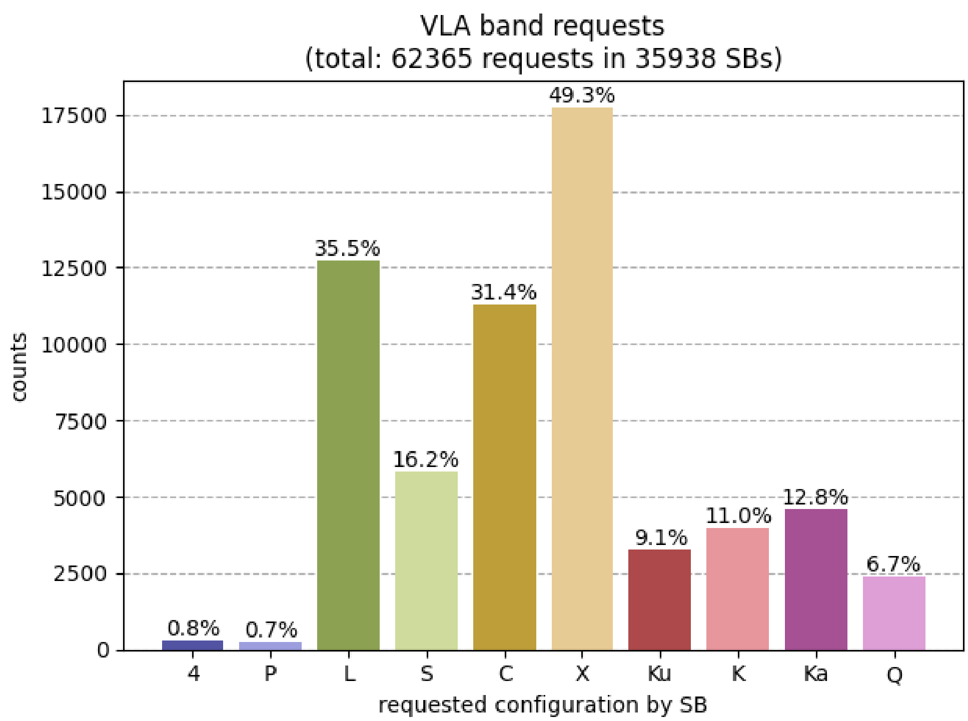

Figure 1: *Receiver bands used by SBs. Note that this is the presence of bands in the block, resulting in an average of 1.74 bands per SB.*

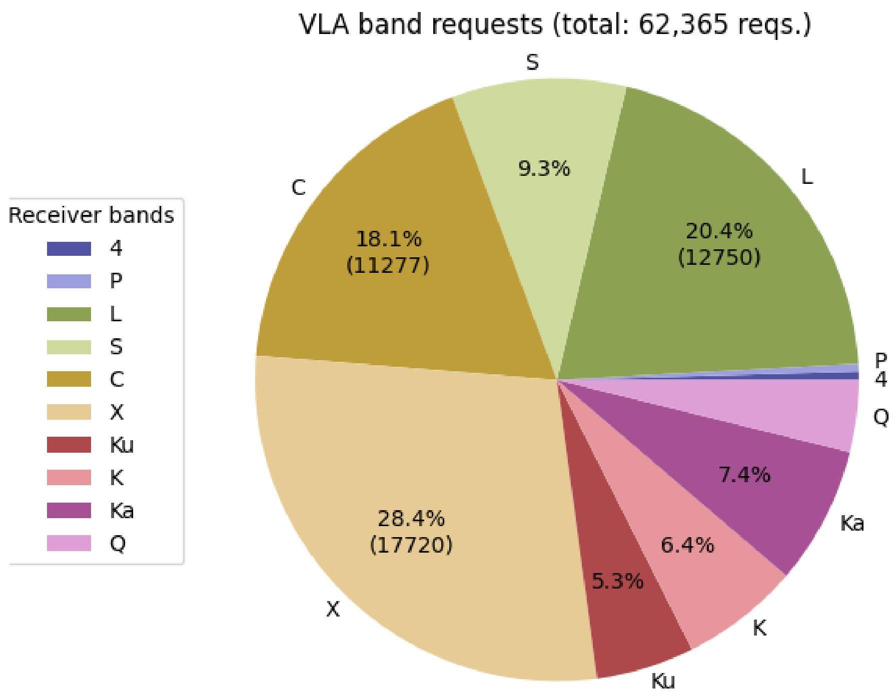

Figure 2: *Receiver bands used by SBs. Additional percentages are: 4 = 0.4%; P = 0.4%; Q = 3.9%.*

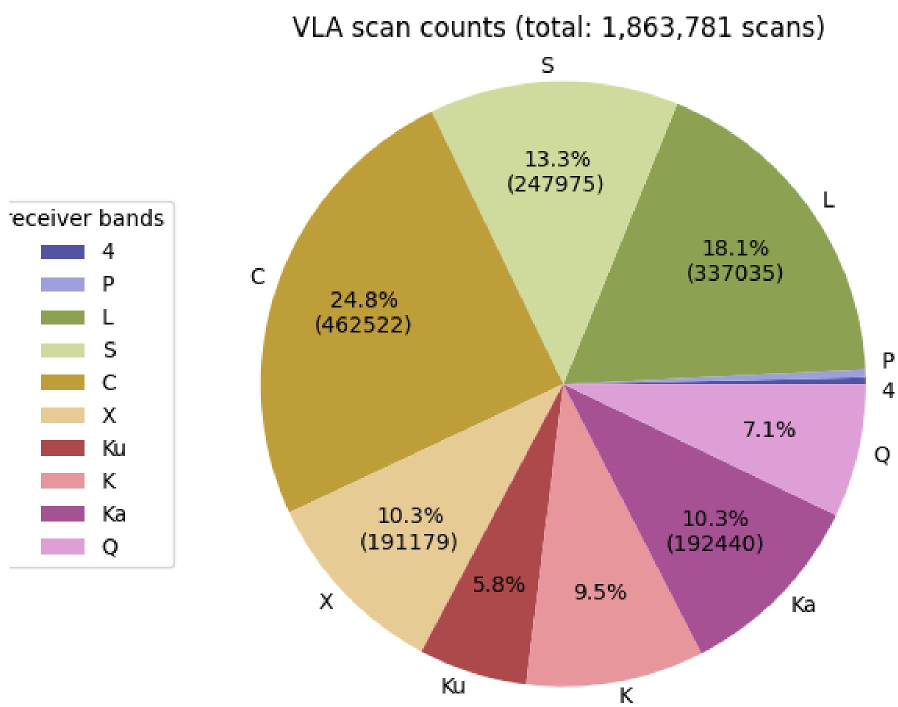

Figure 3: *Number of scans observed at each band. Additional percentages are: 4 = 0.4%; P = 0.4%.*

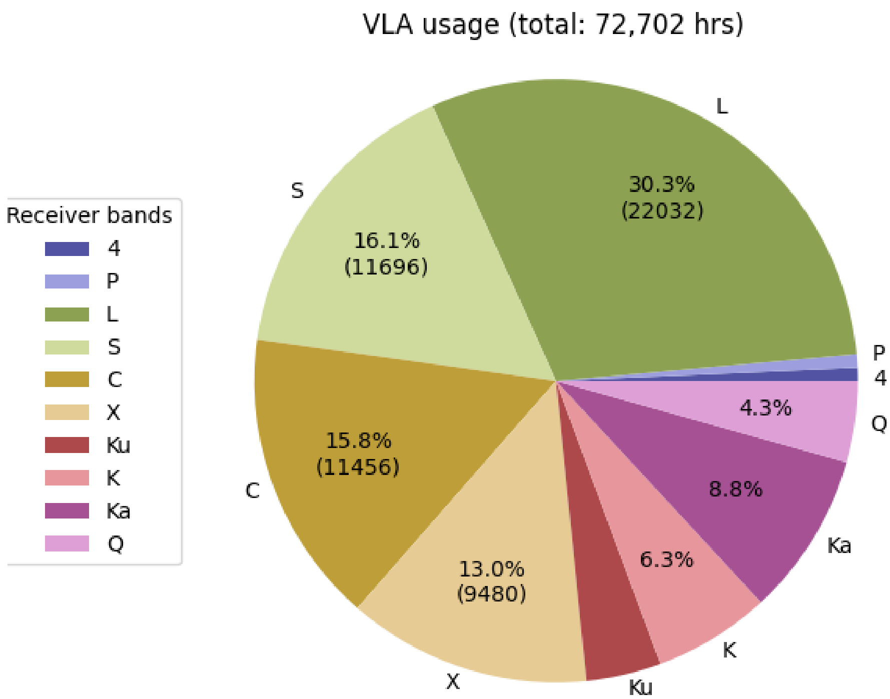

Figure 4: *Time observed at each band. Additional percentages are: 4 = 0.7%; P = 0.8%; Ku = 4.0%.*

Sub-arrays and Pulsar modes

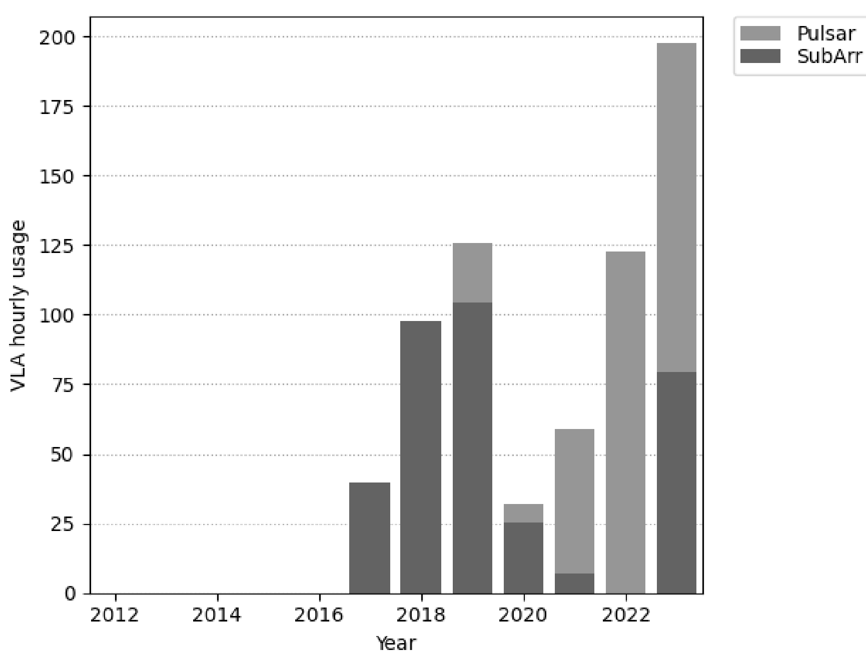

Figure 5: *Time observed with sub-arrays and pulsar modes by year.*

Scan lengths

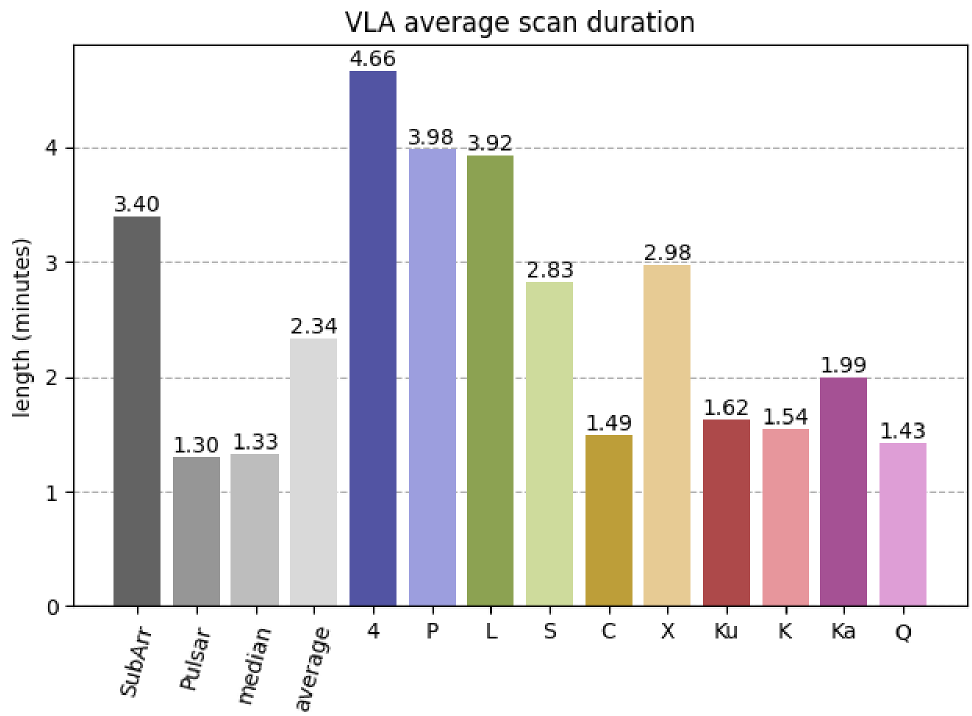

Figure 6: *Average scan duration at each band, and by sub-array ("SubArr") and pulsar modes. Total median and average values are also displayed.*

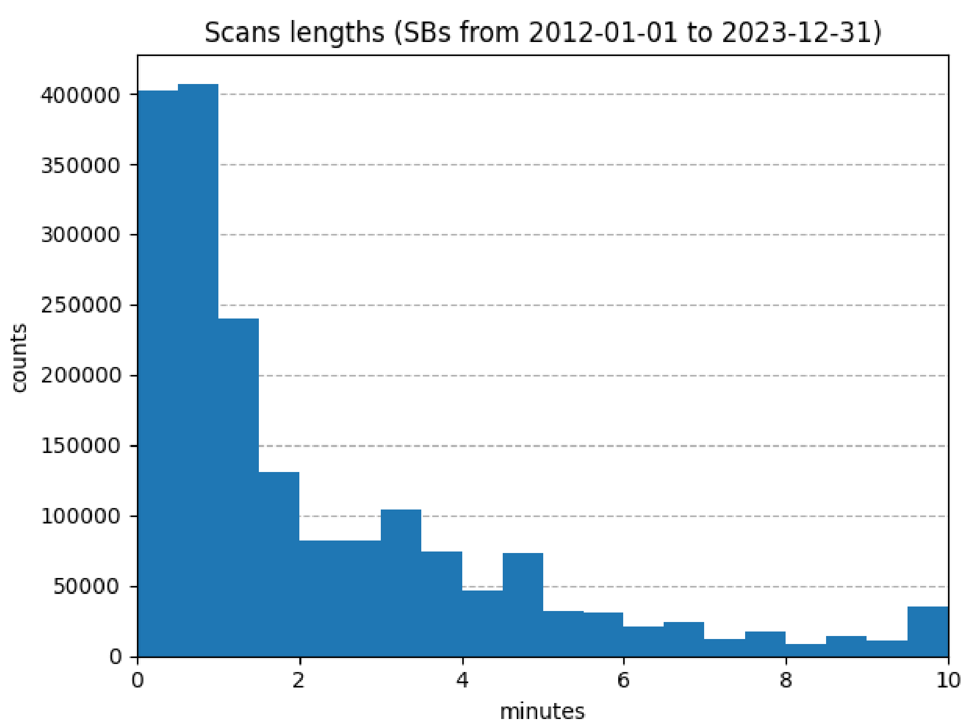

Figure 7: *Histogram of scan duration up to 10 minutes.*

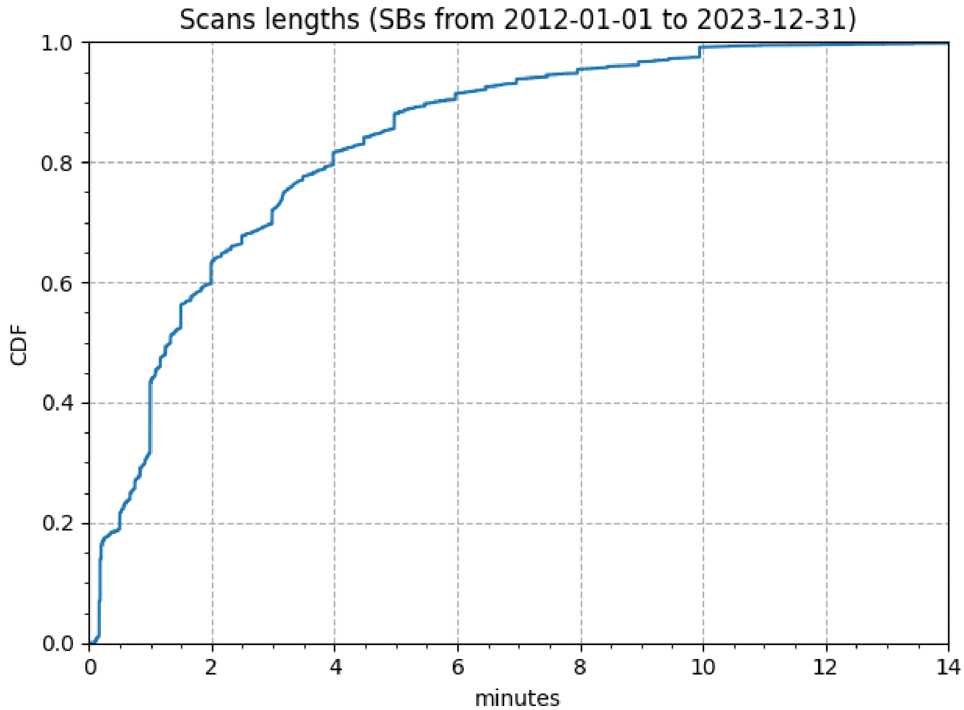

Figure 8: *Cumulative Distribution Function of scan duration up to 14 minutes.*

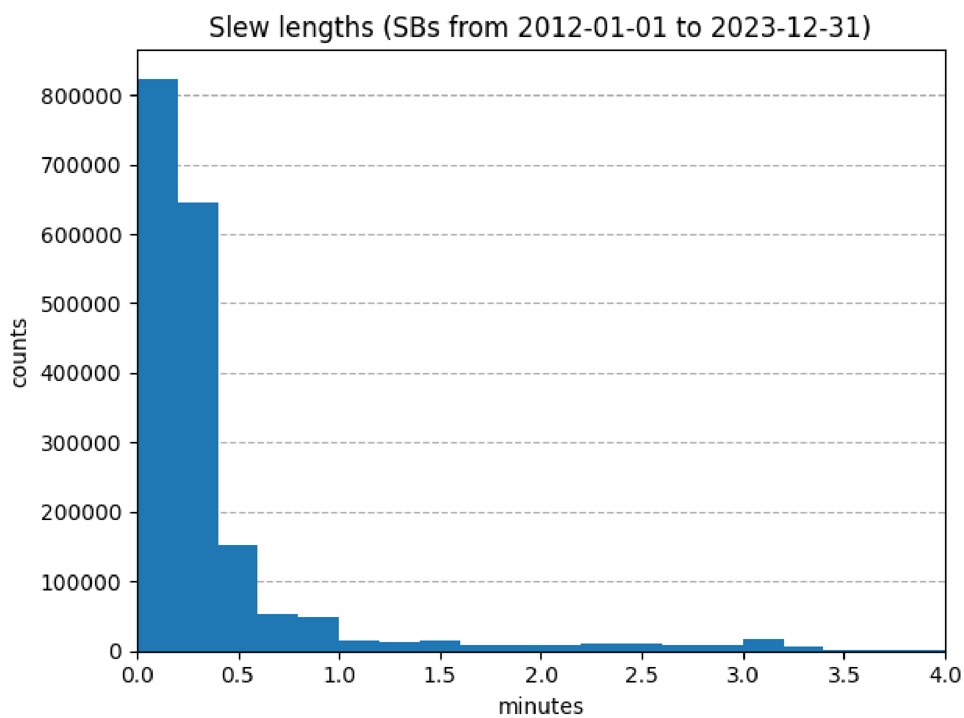

Figure 9: *Histogram of slew duration up to 4 minutes.*

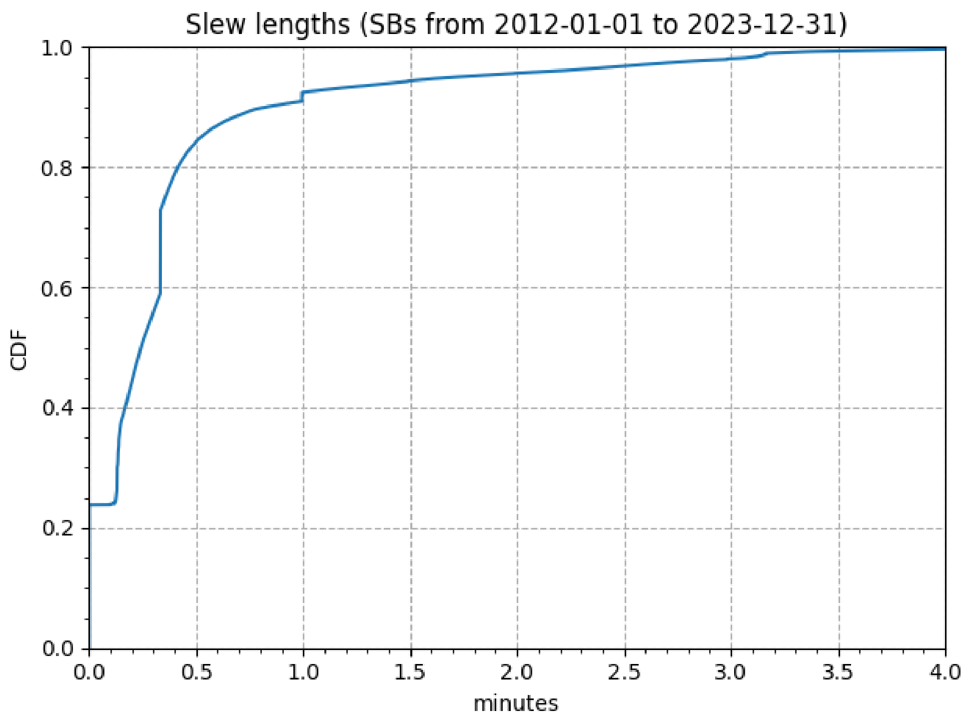

Figure 10: *Cumulative Distribution Function of slew duration up to 4 minutes.*

Single tracking length

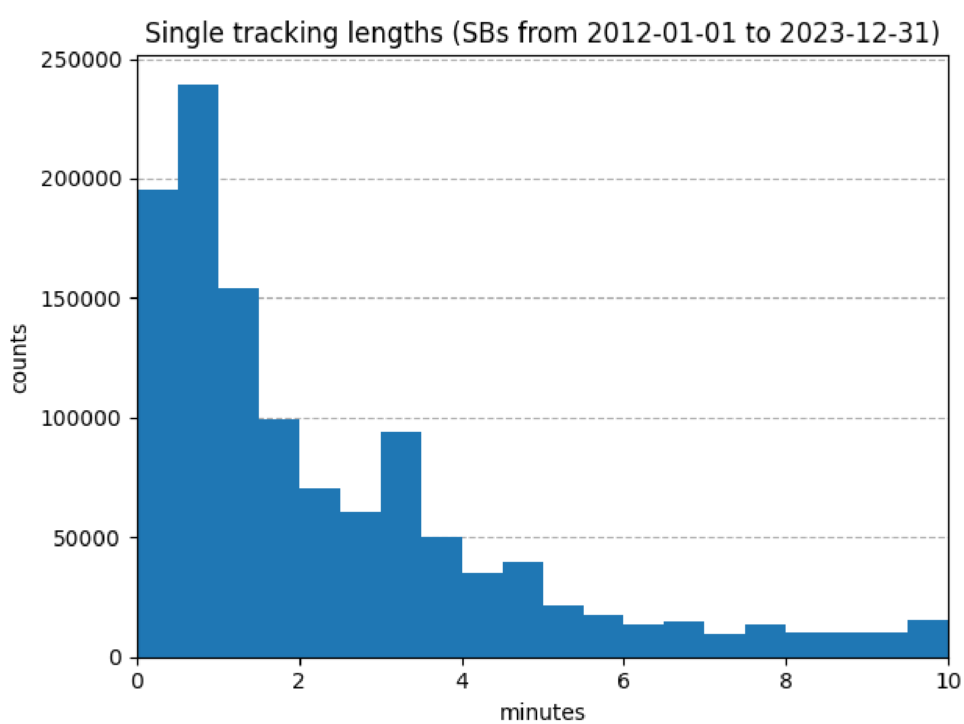

Figure 11: *Histogram of slew duration up to 10 minutes. "Single tracking" is defined as scans executed continuously on the same sidereal target.*

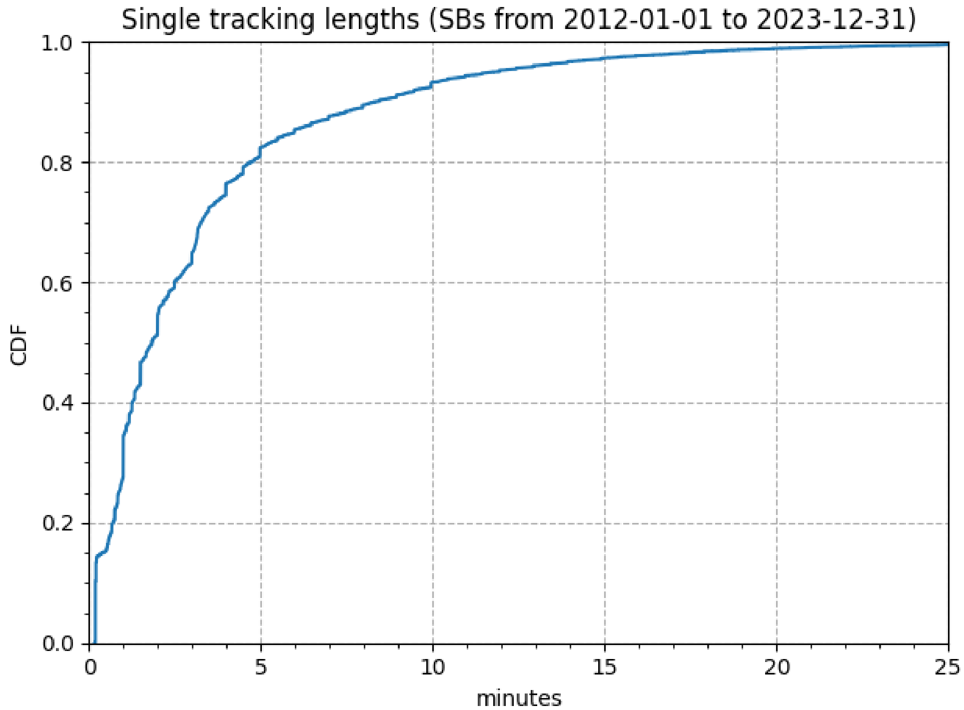

Figure 12: *Cumulative Distribution Function of slew duration up to 25 minutes.*

Queue anticipation

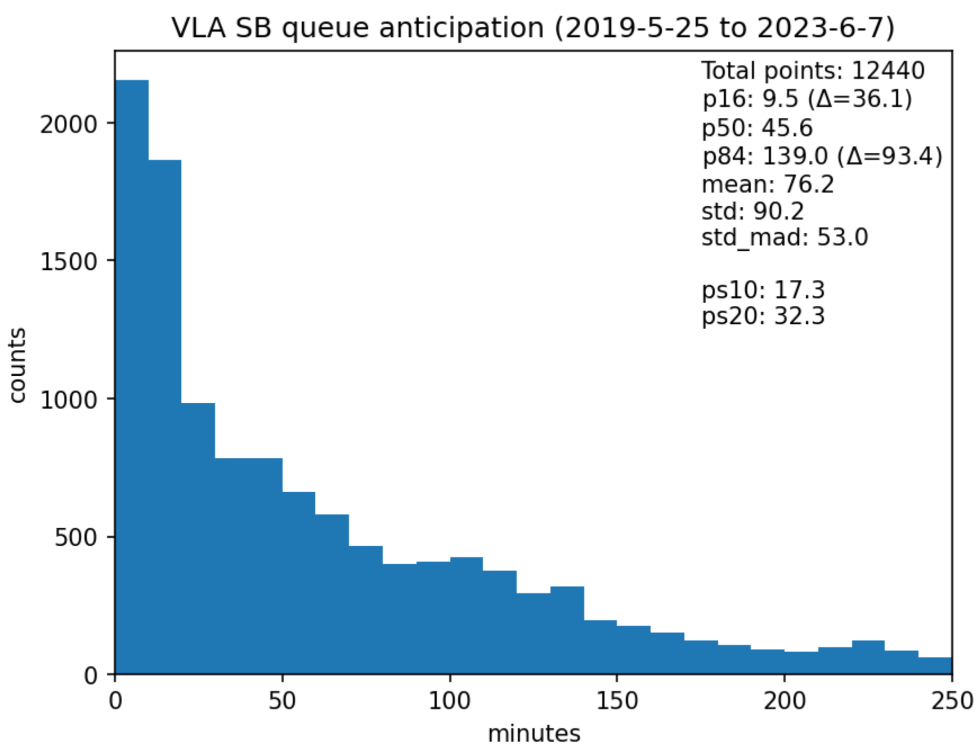

Figure 13: *Histogram of SB queue anticipation up to 250 minutes.*

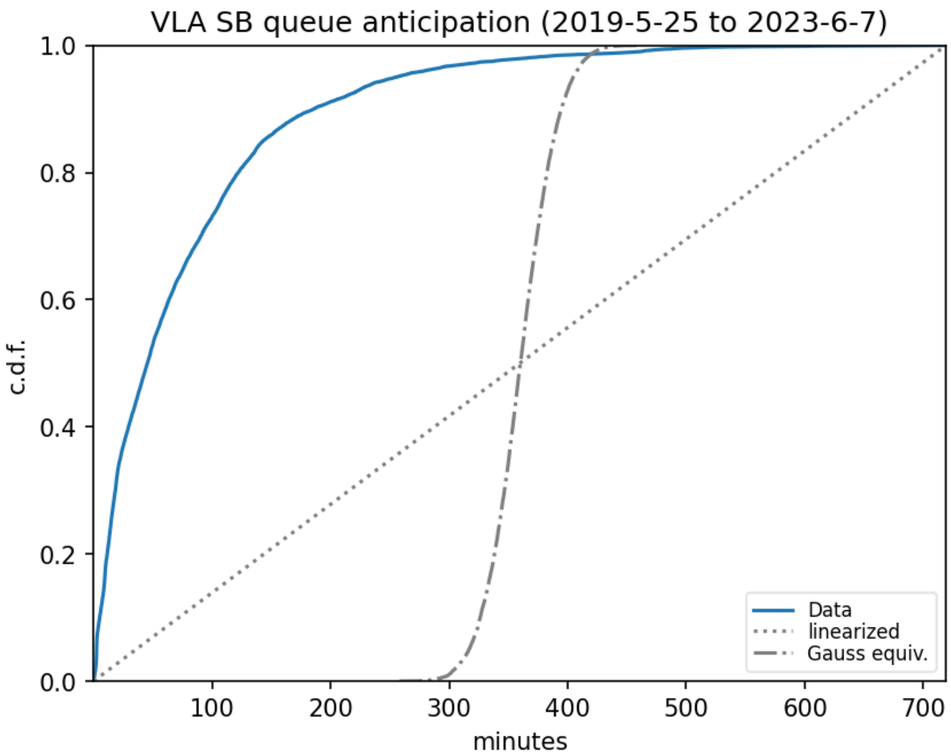

Figure 14: *Cumulative Distribution Function of SB queue anticipation.*

Sources

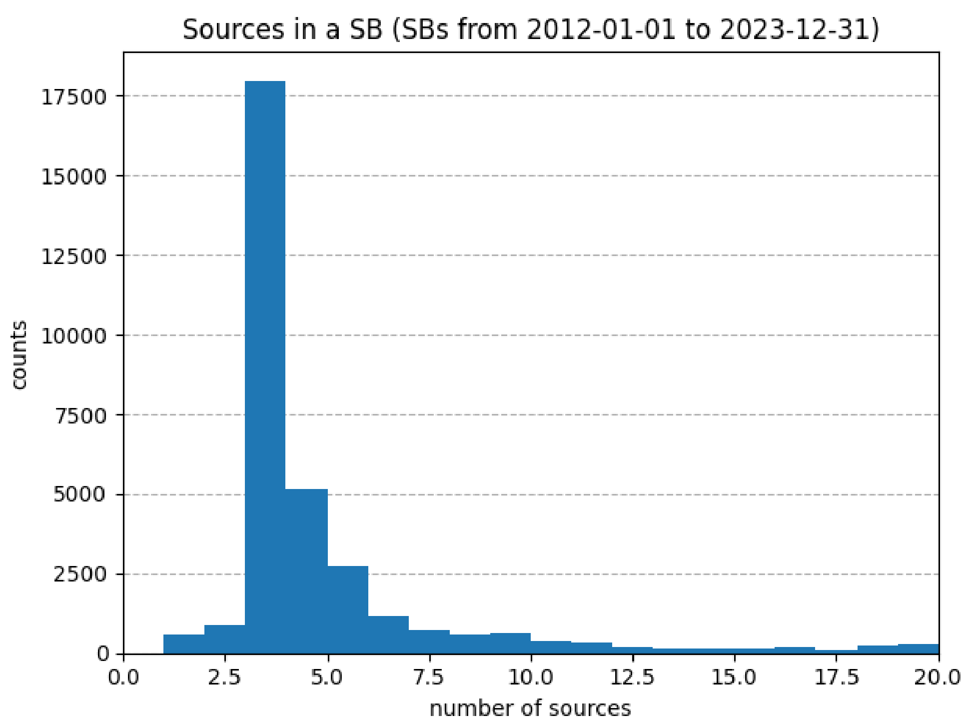

Figure 15: *Histogram of the number of sources in an SB (up to 20).*

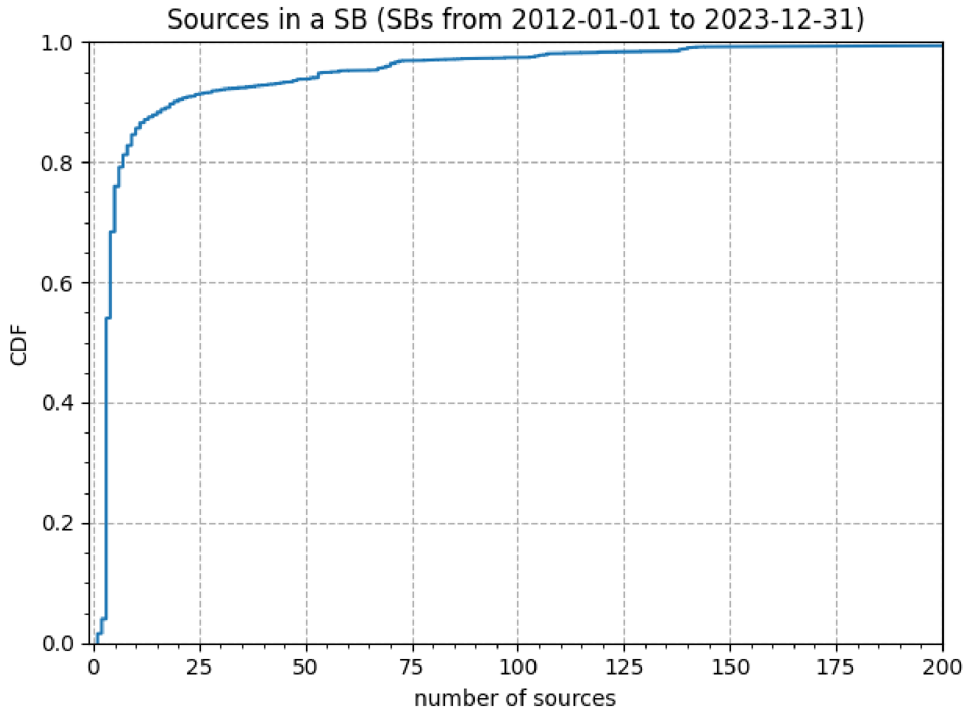

Figure 16: *Cumulative Distribution Function of number of sources in an SB.*

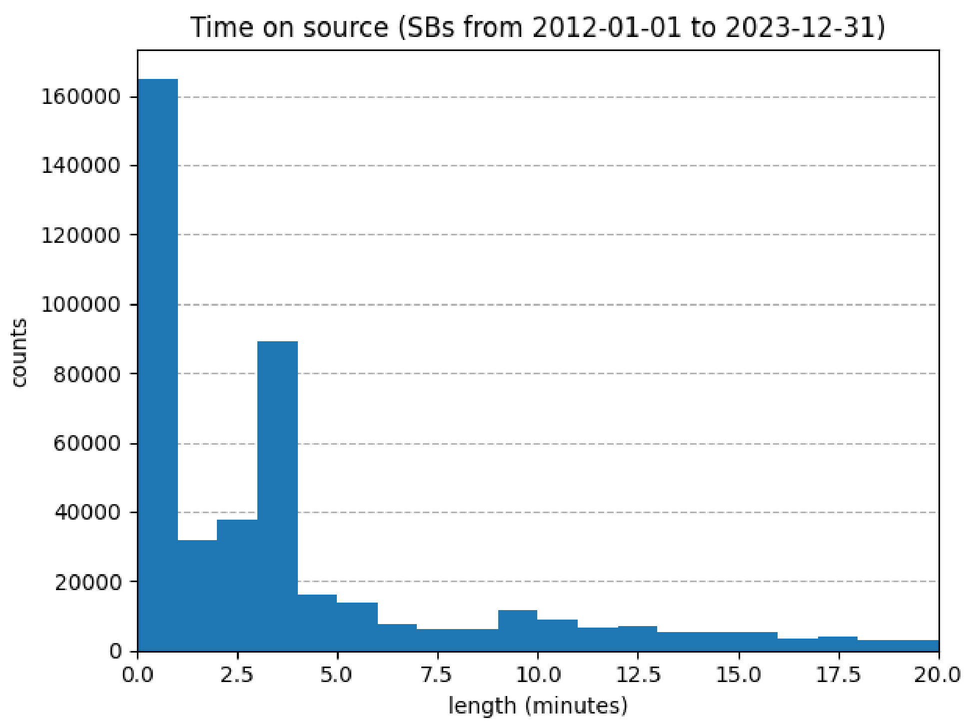

Figure 17: *Histogram of time on source per SB (up to 20 minutes).*

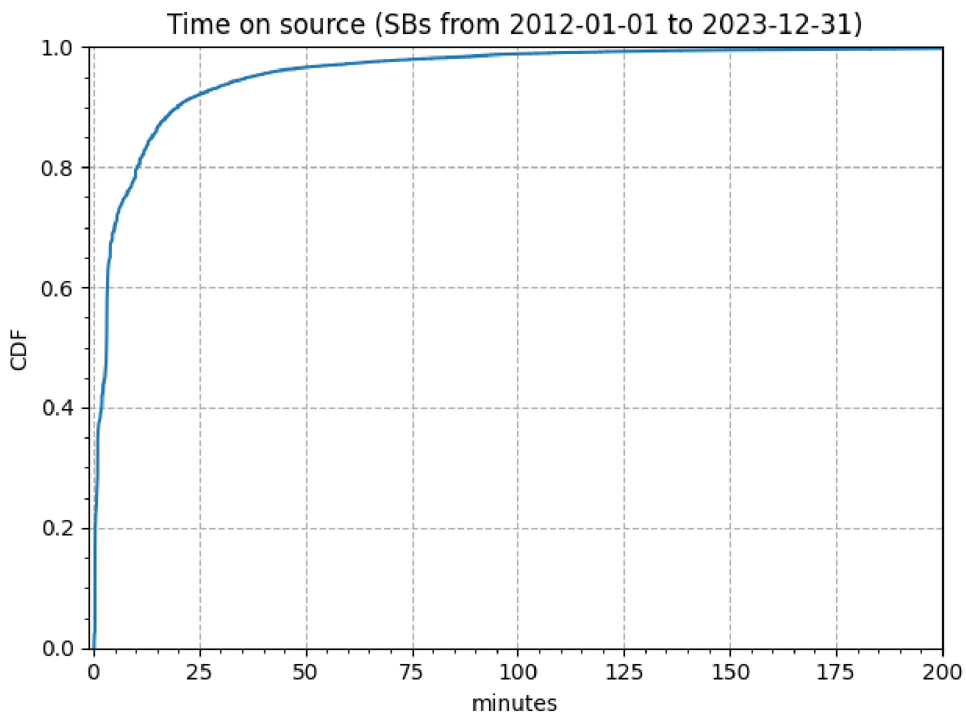

Figure 18: *Cumulative Distribution Function of time on source.*

Pointing

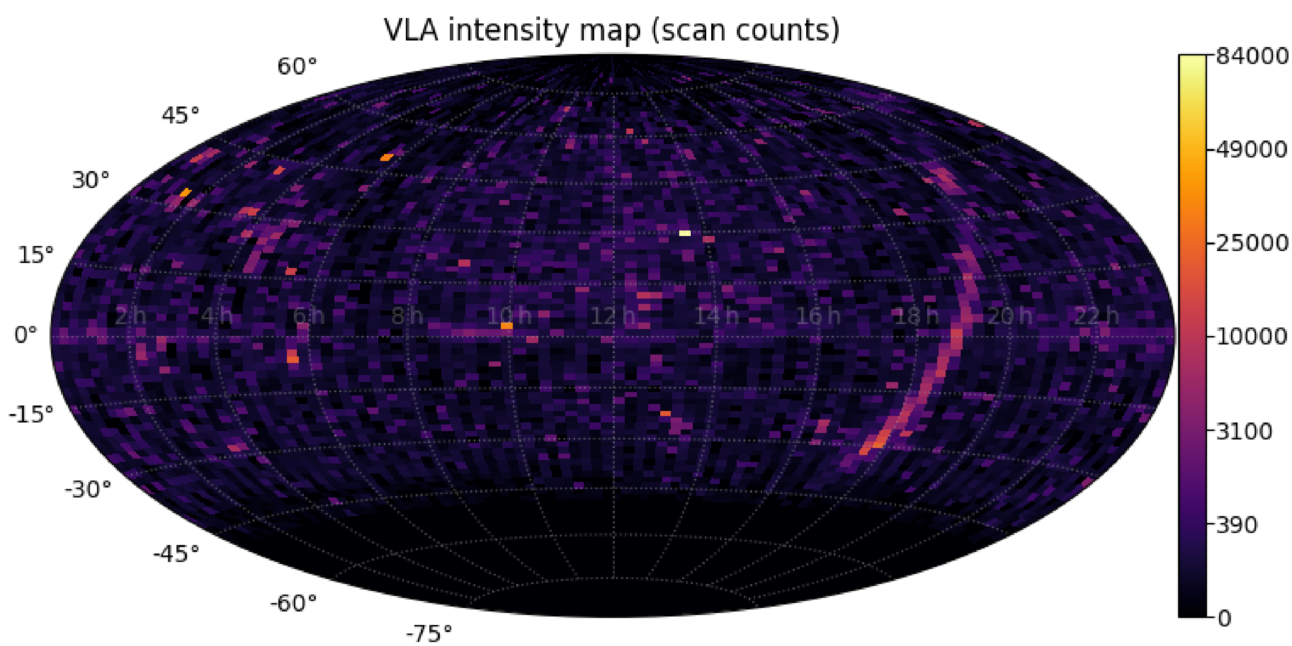

Figure 19: *Intensity map of the scan's pointing history using cube root normalization in the Equatorial coordinate system (J2000) and Hammer projection.*

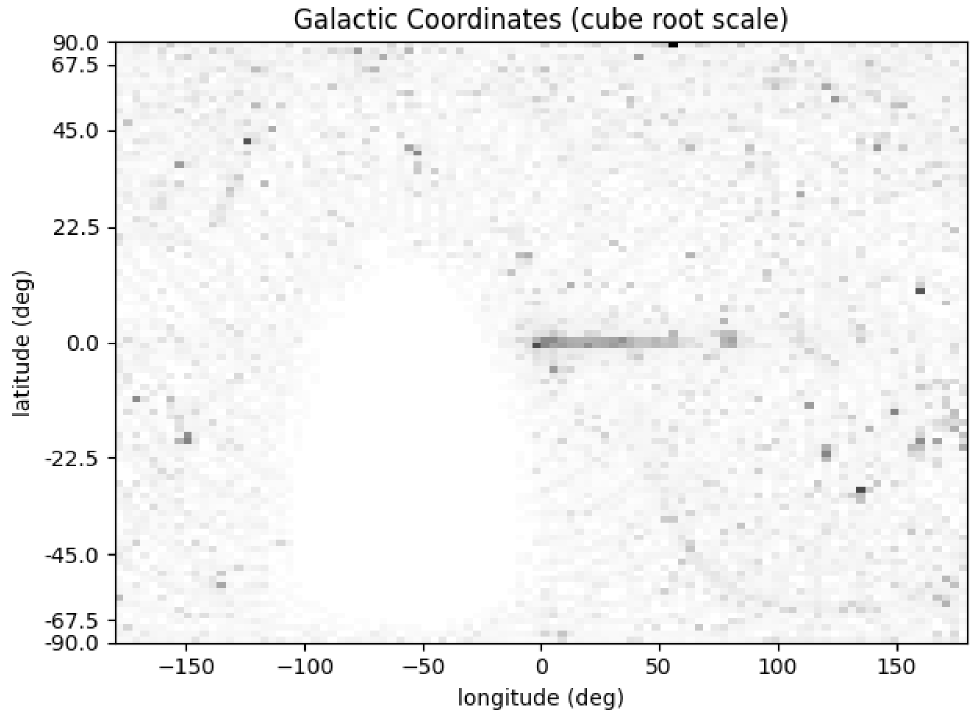

Figure 20: *Same as previous one, in the Galactic coordinate system.*

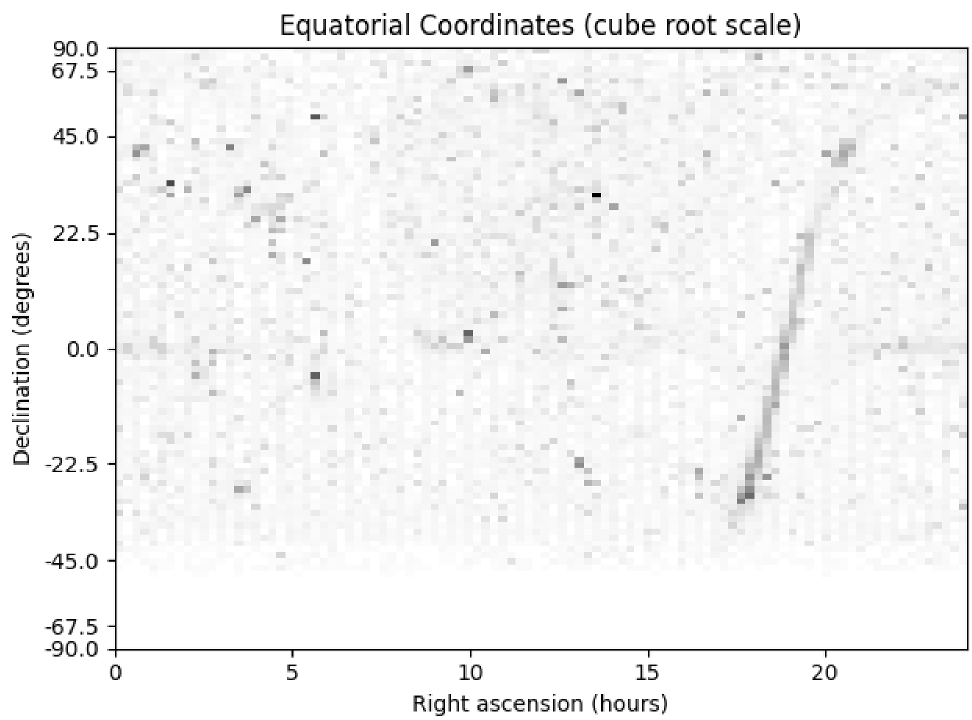

Figure 21: *Same as previous one, without projection.*

Most observed areas

Table 3: *Areas with the highest target counts and their respective central coordinates (leftmost columns). The most frequent target of each area is also shown (rightmost columns). For definition of area bins, see text.*

counts	RA (hr)	dec (deg)	most frequent target	Ra (hr)	dec (deg)
82269	13.56	30.6638	3C286	13.5190	30.5092
38556	1.56	33.3670	3C48	1.6281	33.1598
31841	5.64	50.3539	3C147	5.7100	49.8520
27667	5.64	-5.1636	J0541-0541	5.6939	-5.6971
26440	9.96	2.8660	CHILES deepfield	10.0233	2.3500
23470	17.88	-29.3406	Galactic Center (GC)	17.7611	-29.0078
17154	17.64	-30.6638	Surronding GC	17.7399	-31.2767
15366	3.24	42.0671	3C84/J0319+4130	3.3300	41.5117
13716	3.72	32.0055	J0336+3218	3.6084	32.3082
13186	5.40	16.8580	3C138/J0521+1638	5.3527	16.6395

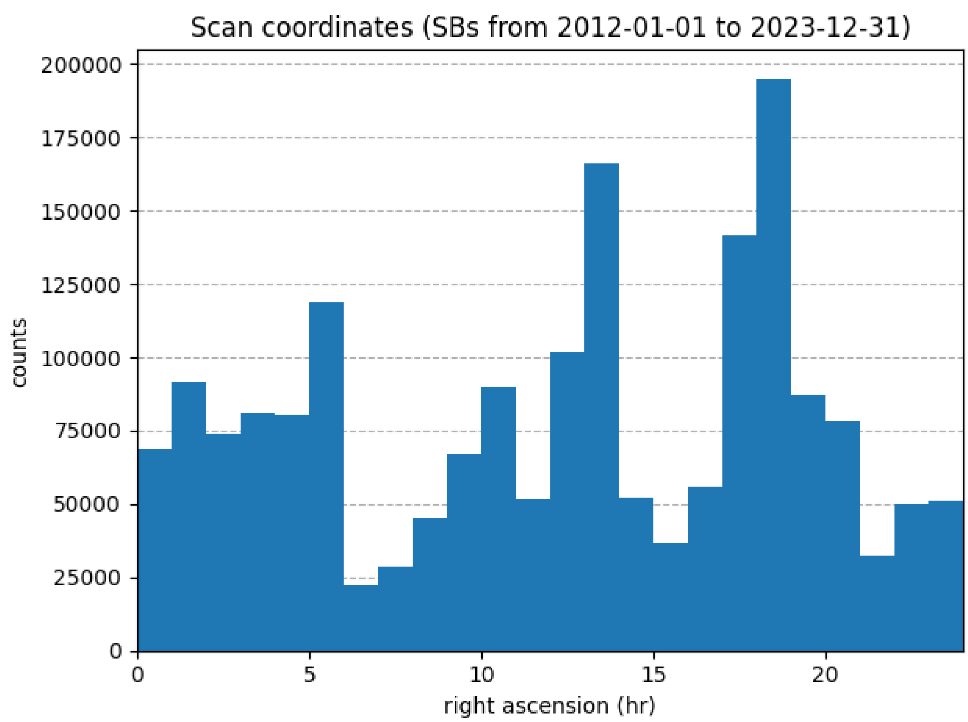

Figure 22: *Scan's Right Ascension (J2000) distribution of the VLA Scheduling Blocks (SBs).*

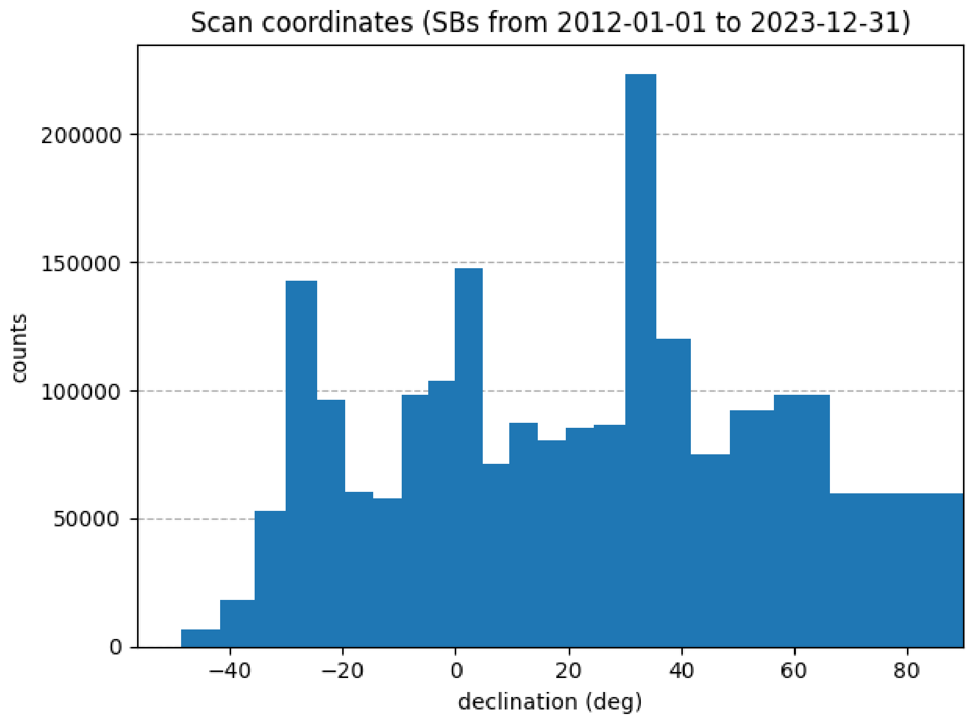

Figure 23: *Same as previous one, for Declination. The histogram bins were defined in uniform arcsine spacing.*

Time variations

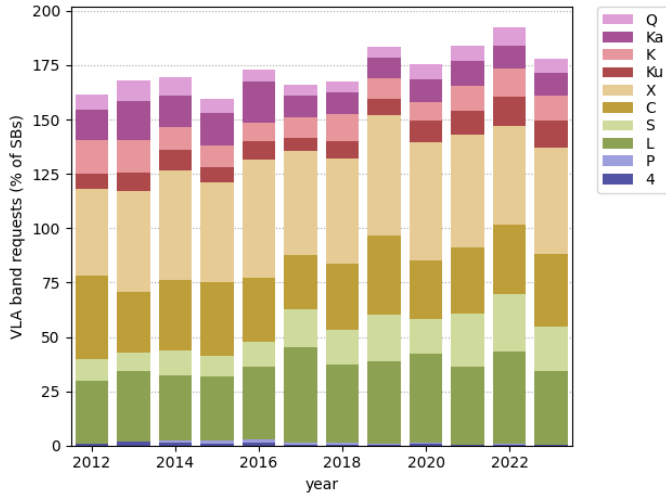

Figure 24: *Fraction of receiver bands used by SBs each year. Note that this is the presence of bands in the block, resulting in an average of 1.74 bands per SB.*

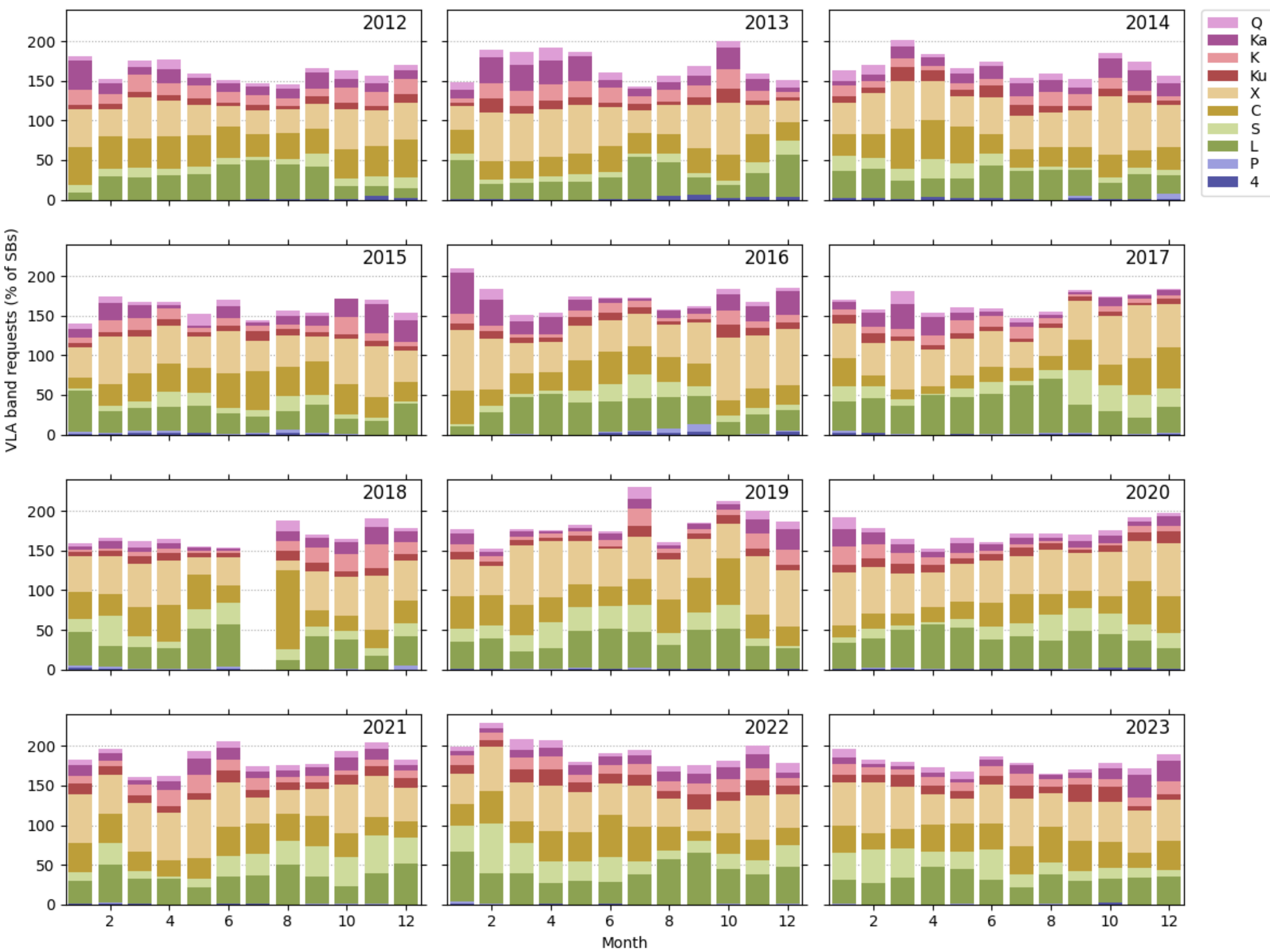

Figure 25: *Fraction of receiver bands used by SBs each month. Note that this is the presence of bands in the block, resulting in an average of 1.74 bands per SB.*

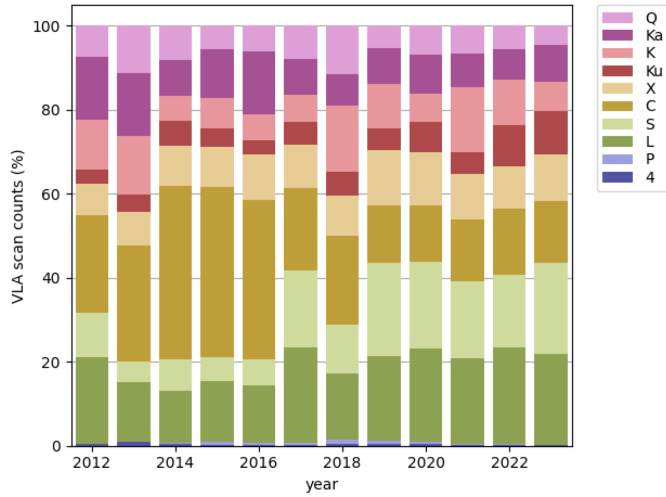

Figure 26: *Normalized number of scans observed at each band by year.*

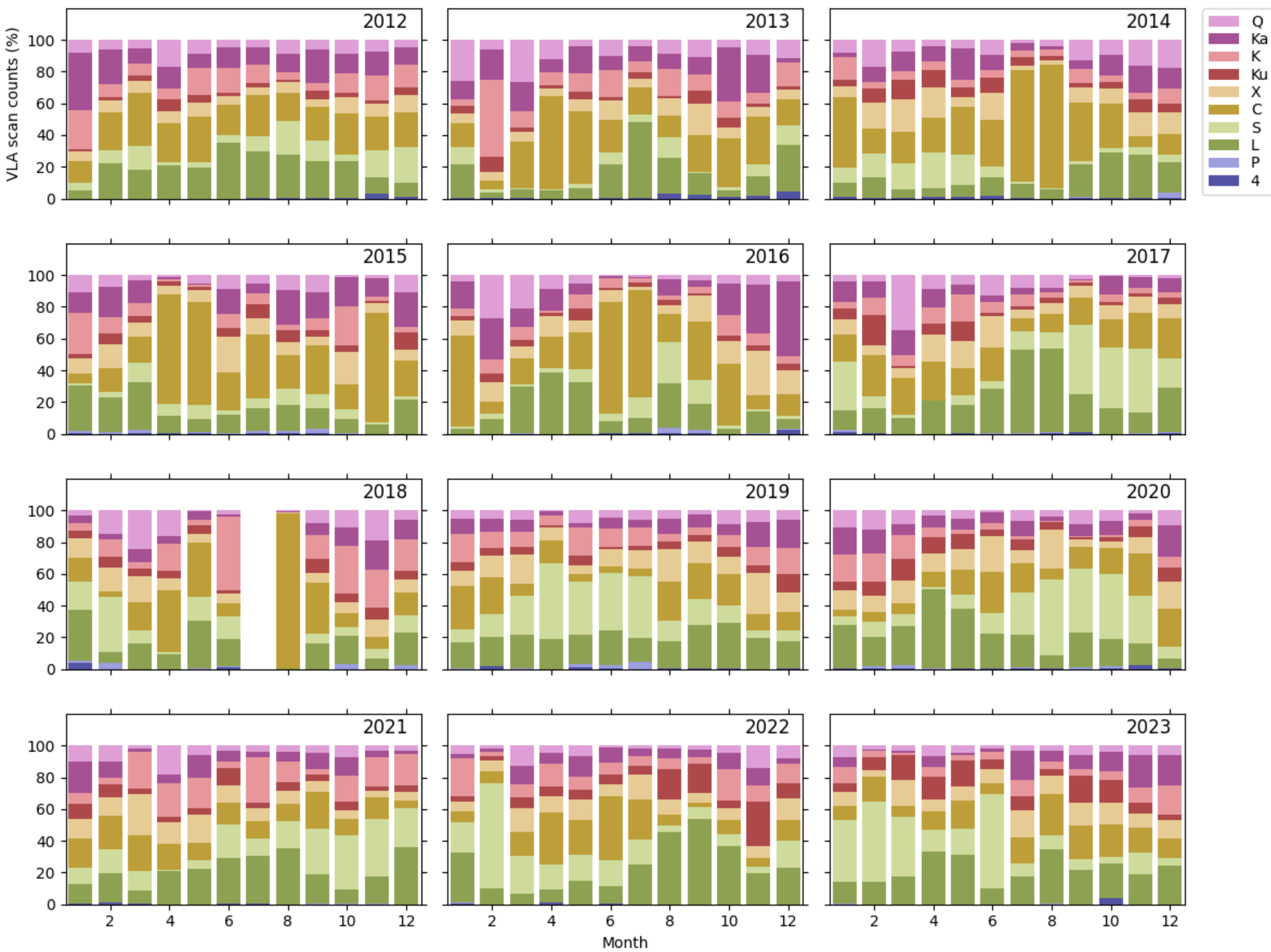

Figure 27: *Normalized number of scans observed at each band by month.*

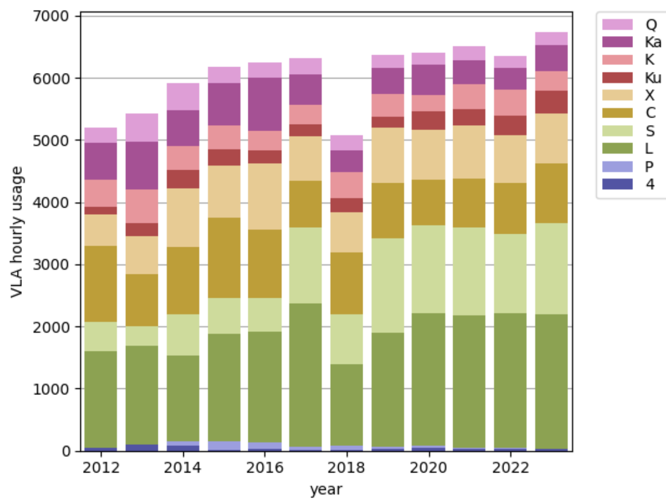

Figure 28: *Time observed at each band by year.*

Figure 29: *Time observed at each band by month.*

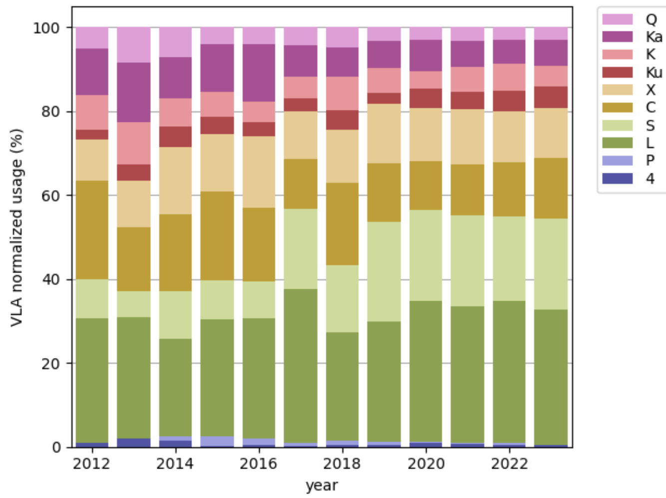

Figure 30: *Normalized band usage by year.*

Figure 31: *Normalized band usage by month.*

Band definitions

Table 4: Bands used by the VLA.

band name	lambda	freq (GHz)	cont. bandwidth
4	4 m	0.075	–
P	90 cm	0.33	0.2
L	20 cm	1.5	0.6
S	13 cm	2.3	1.5
C	6 cm	5.0	3.0
X	3 cm	10.0	3.5
Ku	2 cm	15.0	5.25
K	1.3 cm	23.0	7.2
Ka	1 cm	30.0	7.2
Q	0.7 cm	43.0	7.2

Bands ranges ordered alphabetically (1 GHz or higher frequency):

- C band: 4-8 GHz
- K band: 18-26 GHz
- Ka band: 26-40 GHz
- Ku band: 12-18 GHz
- L band: 1-2 GHz
- Q band: 40-50 GHz
- S band: 2-4 GHz
- X band: 8-12 GHz

More at https://science.nrao.edu/facilities/vla/docs/manuals/oss/performance/vla-frequency-bands-and-tunability .