



## **VLASS Project Memo # 4**

### **VLASS Pilot Scheduling Block Creation**

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#### ***1 Introduction***

This memo describes the code and procedures for creating scheduling blocks (SBs) in the Observing Preparation Tool (OPT) for the VLASS Sky Survey Pilot observations. The goal for the full survey is a process that is largely automated with little or no manual intervention. The procedure used during the Pilot required manual input at various stages. Many lessons learned during scheduling of the Pilot will improve the procedure for the full survey.

The VLASS survey speed is approximately 20 square degrees per hour, and the fiducial SB length for the Pilot was roughly 4 hours in length, surveying 80 square degrees. For VLASS on-the-fly observing, the telescope scans in the direction of Right Ascension (RA) covering roughly 10 degrees in RA per scan. We informally used the term “tile” to refer to a  $10^\circ \times 8^\circ$  contiguous region, and “mini-tile” to refer to a  $10^\circ \times 4^\circ$  contiguous region. A 4-hour SB would cover one tile or two mini-tiles. A longer SB (e.g., 6 or 8 hours) would cover a combination of multiple tiles and/or mini-tiles. The decision to observe one tile vs two mini-tiles is largely driven by scheduling constraints in order to avoid high-elevation transits, or to avoid the satellite belt at  $\delta \sim -5^\circ$ .

A typical VLASS SB begins with setup scans (including allowance for a long initial slew), a flux calibration scan, and then a series of loops: phase calibrator — OTF scans — phase calibrator. Tweaks are needed for certain variations; for example: if the flux calibrator is observed at the end of the observation instead of at the beginning, if multiple phase calibrators are used (i.e., for multiple tiles or mini-tiles), or if extra leakage calibration scans are needed to provide sufficient parallactic angle coverage.

## 2 Pilot SB creation procedure

The main steps for creating VLASS Pilot SBs are:

1. Gather necessary metadata/input for the tile(s) and SB.
2. Use *Python* modules `OTF_scans_from_tile` and `scanrows2opt_slew` to create the source and SB files to be imported into the Source Catalog Tool (SCT) and OPT. Two modules are used instead of one owing to an optional intermediate step to fine-tune the LST start range based on standard output from the first module.
3. Import the files into the SCT and OPT.
4. Verify SB, then submit.

### 2.1 A-priori metadata

#### 2.1.1 Tile boundaries

The first step is to determine or decide the [mini-]tile boundaries to be observed in the SB. Tiles are “rectangular” in RA and Dec meaning they appear as trapezoids on the sphere given that RA width varies with  $\cos(\text{Dec})$ . For the Pilot, we determined the boundaries for each SB manually. For the full survey, we intend to tile the sky and store all [mini-]tile boundaries in a database.

Motivation for observing combinations of mini-tiles is to restrict the hour angle coverage, and/or to avoid high-elevation transits. Therefore, it is advantageous when observing multiple mini-tiles in an SB to select mini-tiles that are spaced roughly two LST-hours apart on the sky— after observing the 1st mini-tile for two hours, the 2nd mini-tile will have moved into the same position as was the 1st mini-tile at the start of the SB.

#### 2.1.2 Phase calibrator(s)

The next step is to choose or determine the phase calibrator for each [mini-]tile. This is a manual step for the Pilot observations, with calibrators identified using the *Advanced Search* option in the SCT. This is a non-trivial task because the VLA calibrator list is not up-to-date, and the parameter indicating source structure (P or S) can be unreliable. At the time of Pilot observations, there is no S-band information in the VLA catalog database, so finding an appropriate calibrator for S-band involves identifying a calibrator with good qualities in both the L- and C- bands (bracketing S-band). An ideal calibrator has a structure code “P” (point source) in L and C, is close to 1 Jy or brighter in both bands, and is within 5–10 degrees of the tile center. When no “ideal” calibrator is available, it is necessary to juggle between the various goals: e.g., a point-source vs a bright source vs a nearby source.

For the Pilot, each [mini-]tile is assigned a single phase calibrator. A possible implementation in the code is the option to assign multiple phase calibrators to a tile, allowing the script to choose whichever is closest at the end of an OTF scan. This could be an option for the full survey.

*Lesson learned:*

For the full survey, potential calibrators should be observed ahead of time to verify their quality. Resources for potential calibrators include the known calibrator list, the VLBA calibrator list, and AT20G (Massardi, M. et al. 2008, *MNRAS*, 384, 775), and SUMSS (Mauch, T. et al. 2003, *MNRAS*, 342, 1117).

### **2.1.3 Leakage calibrator**

The following applies to polarization leakage (D-term) calibrators with unknown polarization; this is not the only possible approach to leakage calibration, but it is the one we have used throughout the Pilot.

The requirements for such a calibrator are that it be bright ( $> 1$  Jy is ideal,  $> 0.5$  Jy is okay); unresolved; and observed at least 3 times, covering a wide range of parallactic angle ( $> 60^\circ$  is ideal,  $> 30^\circ$  is okay). Note that the combination of a smaller parallactic angle range ( $> 30^\circ$ ) with a brighter source ( $> 1$  Jy) is fine, and the combination of a fainter source ( $> 0.5$  Jy) with a larger parallactic angle range ( $> 60^\circ$ ) is fine.

Thus the next step is to select a source to use as the polarization leakage calibrator. Almost always, this will simply be a phase calibrator of the tile or tiles to be observed in the SB. In rare cases, a separate source may be needed if none of the phase calibrators is sufficient owing to, e.g., LST range and elevation constraints. (See below for details.)

For much of the sky, 4 hours generally provides sufficient parallactic coverage for leakage calibration if the calibrator is observed both at the beginning and end of the SB (and at least once more within the SB). Thus a standard VLASS setup of a 4-hour SB with one phase calibrator usually provides the required parallactic angle coverage “for free”. However, a 2-hour observation of a single mini-tile typically does not provide sufficient parallactic angle coverage; the solution is to add an “extra” leakage calibration scan at either the beginning or end of the SB as needed to increase the time range of the calibrator observations to 4 hours. The `scanrows2opt_slew` script to create SBs handles this by ensuring that a leakage calibrator scan is obtained before and after each [mini-]tile, as long as the calibrator is within the allowed elevation range. Note that this scan happens by default when the leakage calibrator is actually the phase calibrator for that [mini-]tile.

The exception from assigning one of the phase (complex gain) calibrators as the leakage calibrator source will likely occur for tiles/sources near  $\delta = 34^\circ$ , the latitude of the VLA. Such sources see only a small range of parallactic angle over 4 hours, unless they are observed on both sides of transit. It is generally not desirable to observe  $\delta \sim 34^\circ$  sources at both sides of transit during a 4-hour SB, because this requires observations very close to transit at high elevation, and thus long (azimuthal) slew times. Possible solutions are to arrange for  $\delta = 34^\circ$  tiles to be observed in 8-hour blocks (so the leakage calibrator can be observed before and after transit but not close to transit), or to select an entirely different source as the leakage calibrator, to be observed at the beginning and end of the SB, and once more about halfway through the SB. (During every VLASS Pilot SB, the leakage calibrator was also a complex gain calibrator.)

*Lesson learned:*

SBs made of multiple mini-tiles will use more than one phase calibrator. The better leakage calibrator choice is generally the one that is more point-like and brighter. However, scheduling constraints can also play a role in choosing a leakage calibrator. If the mini-tiles are to be observed rising, then it is best to use the phase calibrator of the 1st mini-tile, as the calibrator of the 2nd is likely to be at low elevation at the start of the SB. Conversely, if the mini-tiles are to be observed setting, then the phase calibrator of the 2nd mini-tile should be chosen, as the phase calibrator of the 1st is likely to have set by the end of observations. Conversely, absent other scheduling constraints, the choice of leakage calibrator (from the 1st or 2nd mini-tile) can drive the choice of whether to observe the mini-tiles rising or setting.

*Alternative approach:*

Another typical approach to leakage calibration is to observe a source that is known to be unpolarized, in a single scan (rather than a source with unknown polarization observed at least three times over a range of hour angles). F. Schinzel has pursued VLA observing tests under the code TPOL0003 to look for suitably unpolarized sources using targets from the COINS sample (Peck & Taylor, 2000, *ApJ*, 534, 90) and the VIPS sample (Tremblay, S.E. et al. 2016, *MNRAS*, 459, 820). These tests will also be used to quantify upper limits on polarization fraction (*e.g.*,  $<0.5\%$ ) and/or absolute polarized flux density (*e.g.*,  $\sim$ few mJy) for a source to qualify as suitably unpolarized. (See, *e.g.*, VLASS memo XX.)

#### **2.1.4 Flux calibrator**

It is necessary to select a flux calibrator, which will also serve as the bandpass calibrator and the polarization angle calibrator. For the Pilot, we used one of 3C286 or 3C48 for every SB. The preferred approach is to start the SB with the flux calibrator as the setup source and for the first non-setup scan. Such an approach mitigates the risk of being absent the flux calibrator scan in the event that an SB is interrupted. However, because these two sources do not quite cover the full LST range from 0-24 hours (given the elevation limits), it was occasionally necessary to observe 3C286 or 3C48 at the end of the SB rather than at the start.

The “best” choice is determined by the LST range of the SB to be observed; conversely, the choice of flux calibrator restricts the LST range of the SB. 3C286 should be chosen for start-time LSTs in the approximate range 07:45–12:35 or 14:10–19:00. 3C48 should be chosen for start-time LSTs in the approximate range 19:45–00:35 or 02:15–07:15. At all other LST ranges (00:40–02:10, 07:20–07:40, 12:40–14:05, 19:05–19:40), the two sources are either below  $20^\circ$  or above  $80^\circ$  elevation. SBs that must start in the approximate range 01:00–02:00 or 13:00–14:00 are good candidates for observing the flux calibrator at the end of the SB.

### 2.1.5 Starting declination

It may be necessary to decide whether to survey each [mini-]tile from low to high declination (the default option) or from high to low. It is desirable to perform the OTF scans between  $30^\circ$  and  $80^\circ$  in elevation, and the choice to observe rising vs setting may be motivated by LST pressure, or by the location of the chosen flux calibrator. Therefore we typically wish to:

1. observe  $\delta < 34^\circ$  tiles high-to-low if rising, low-to-high if setting.
2. observe  $\delta > 34^\circ$  tiles low-to-high if rising, high-to-low if setting.

### 2.2 Python script: `OTF_scans_from_tile`

The *Python* code `OTF_scans_from_tile.py` creates a source list and a list of OTF scans for one contiguous rectangular (in RA and dec) region, i.e. for a single tile or mini-tile. For SBs covering multiple tiles or mini-tiles, `OTF_scans_from_tile` must be run once for each of the tiles/mini-tiles. The resulting source list comprises the OTF “sources” that represent the starting and ending positions of the OTF scans. The script determines the appropriate positions for these “sources”, staying within the input boundaries; each OTF scan constitutes a “row” at constant declination. In line with VLASS parameters, it also determines the number of phase centers per OTF scan.

The declination grid is globally (for VLASS) defined as having a row at  $\delta = 0^\circ$  and a separation of 7.2 arcmin (a VLASS parameter) between rows. The declination values for each OTF scan will be consistent with the global declination grid. For tile boundaries that coincide with a value on the declination grid, the tile will *include* the lower tile boundary and *exclude* the upper tile boundary. To illustrate: a tile with declination boundaries of  $\delta_{\min} = 0^\circ$  and  $\delta_{\max} = 14.4$  arcmin would have two OTF rows: one at  $\delta = 0^\circ$  and one at  $\delta = 7.2'$ .

There must be an integral number of phase centers per row, and the exact number is chosen so as to ensure a scan rate as close as possible to the fiducial VLASS scan rate of  $3.31'/s$ . Tiles are rectangular in RA/Dec and thus trapezoidal on the sky; the number of phase centers per row varies as  $\cos(\text{Dec})$ . The RA edges of OTF rows are defined such that they start and end  $1/2$  of a phase center distance inside the RA boundaries of the tile. The latter option ensures uniform coverage when data from adjacent tiles will be combined.

#### 2.2.1 `OTF_scans_from_tile` usage

The inputs are: name of the [mini-]tile; and boundaries in dec and RA (minimum and maximum in Dec, east-most and west-most in RA allowing for a wrap around RA=0). With input from R. Hiriart, the script for the Pilot already has the capability to obtain tile boundaries from a VLASS database. However, for creation of Pilot SBs all the tile boundaries were provided manually at the command line. The script also accepts an optional input parameter that designates whether the SB will start its scans at the the minimum (the default) or the maximum declination of the tile.

To run the script:

```
OTF_scans_from_tile.py [-h] [--use_database] [--rawest RAWEST] [--raeast RAEAST]
  [--decmin DECMIN] [--decmax DECMAX] [--decstart DECSTART] tile_name
```

- `-h`: shows help for the module
- `--use_database`: get boundaries from the database instead of from standard input?
- `--rawest`, `--raeast`, `--decmin`, `--decmax`: input in decimal degrees. (N.B. `rawest` < `raeast`, unless the tile wraps around  $RA = 0^\circ$ )
- `--decstart`: can be “high” or “low” (in future, could implement this functionality in `scanrows2opt_slew` instead of in `OTF_scans_from_tile`)

## 2.2.2 OTF\_scans\_from\_tile *output*

The main code output is as follows:

- a file containing the source list of OTF scan start/stop positions. The naming scheme uses “west” and “east” for RA boundaries; sources numbered “000” correspond to the lowest declination of the tile. File will be named `<tile_name>_sources.txt`
- a file containing the scan list in execution order (i.e., low-to-high or high-to-low), with the two endpoints of each OTF scan and the number of OTF phase centers for each scan. Each scan is listed with the western endpoint first, eastern endpoint second. Actual scan directions for the SB will be determined in `scanrows2opt_slew`. File will be named `<tile_name>_scans.txt`

The header of each output file includes:

- the `OTF_scans_from_tile` command that created the files.
- the total number of OTF phase centers and OTF observing time (i.e., excluding SB overhead).
- a report of any starting LSTs (in steps of 5 minutes) when the elevation for any non-setup scan would be outside of the  $30^\circ$ – $80^\circ$  elevation range.

The LST report is useful for fine-tuning the LST starting range that will be used as input to `scanrows2opt_slew`.

## 2.3 *Second module*: `scanrows2opt_slew`

The *Python* script `scanrows2opt_slew.py`<sup>1</sup> uses the output files from `OTF_scans_from_tile`, and the metadata discussed in Section 2.1, to create an SB file that can be uploaded directly into the OPT.

This section describes the high-level usage of this module. Details of the internal workings of the script are given in the Appendix.

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<sup>1</sup>The script is based on code and input provided by L. Sjouwerman, with modifications incorporating slew times, and in various ways made specific for VLASS.

### 2.3.1 `scanrows2opt_slew` *usage*

Input parameters are:

- name of the SB (will also be the name of the source catalog in the SCT)
- one or more scanlist files (“rowfile”) output from `OTF_scans_from_tile`
- name of a phase calibrator for each of the scanlist files (in respective order)
- name of the flux calibrator
- (optional) whether to observe the flux calibrator at the beginning (default) or end of the SB
- (optional) name of the leakage calibrator; may be omitted if there is only one phase calibrator and it will also serve as the leakage calibrator
- LST start range to use (which may be modified in the OPT later if necessary)

To run the script:

```
scanrows2opt_slew.py [-h] SB_NAME --rowfile ROWFILE1 ... ROWFILEn
  --phasecal PHASECAL1 ... PHASECALn --fluxcal FLUXCAL --lstrange LSTRANGE
  [--leakage LEAKAGE] [--fluxpos FLUXPOS]
```

- Multiple rowfiles can be provided; will result in a combined SB.
- Rowfiles will be observed in the same order as they are input.
- Must input one phasecal per rowfile, or exactly one (to be used for all rowfiles).
- Leakage calibrator is not required to be one of the phase calibrators.
- If only one phase calibrator provided, and no leakage calibrator, phase calibrator will be used as leakage calibrator.
- LST start range must have format `hh:mm-hh:mm`.
- (optional) `fluxpos`: when to observe flux calibrator; can be `beg` (beginning) or `end`

### 2.3.2 `scanrows2opt_slew` *output*

This script produces an SB file (named `<SB_name>.4opt`) that can be directly uploaded into the OPT. The file header contains a record of the `scanrows2opt_slew` command that was used to create the file. It reports progress to standard output, for example: for each rowfile, the number of scan loops and the amount of OTF time in each loop (roughly, the calibration cycle time); the starting source (east or west) for each loop; times when it will skip an “extra” leakage calibration scan because the calibrator could be at too high or low elevation; the minimum possible range in parallactic angle for the polarization leakage calibrator. The code issues a warning for each LST start time (in 5-minute increments) that would result in a parallactic angle range of less than  $60^\circ$ . This can be useful in determining whether to modify the input start range.

## 2.4 SB checking and verification

The SB can be created in the OPT using the following steps:

1. If multiple mini-tiles in the SB, concatenate all source files into a single file [this step could be automated in `scanrows2opt_slew` in the future]
2. Import source file into the SCT. Change catalog name from “Unnamed\_Catalog” to match SB name [I have requested a modification to the SCT software, such that it may import directly to a named catalog in order to eliminate this step]
3. Upload SB file into the OPT

The next step is to verify the SB using the Block Checker tool. If the scripts have worked correctly, all scans should be the correct length for any LST time in the starting range, and the required manual checking should be minimal. Particular verification steps which were performed manually for every Pilot SB (but could potentially be automated in the future) include: for the full LST starting range (using 5-minute increments), ensuring that there is enough time on source for the OTF scans; and determining the LST start range where the OTF scans and calibrators remain inside the desired elevation range. Here are some verification steps:

- The overall on-source time for the flux calibrator should be at least 2 minutes.
- The on-source time for the phase calibrators should be at least 30 seconds for every scan.
- The Block Checker will automatically report if any OTF scans do not have enough on-source time. When this happens, it is often because the problematic scan has gone above 80° elevation. Note that I have determined slew/settle time for OTF scans in an attempt to reduce overhead. Errors of this type may indicate that the slew/settle time value used in `scanrows2opt_slew` needs to be increased.
- OTF scans (named like “rowXXX”) should be between 30° and 80° in elevation. Calibrators should be between 20° and 80° in elevation. This often requires restricting the LST start range more than the original estimate. These “shoulds” are only guidelines— for very low declination tiles or constrained start times, it may not be possible to stay within this ideal elevation range.
- If needed, change the LST start range, re-verifying with the Block Checker. For ease of scheduling, it is best to keep the LST start range at least 30–40 minutes wide. Ideally, use an LST start range of at least one hour. If no errors show up, try extending the LST start range in the Block Checker. However, note that shorter LST start ranges generally require less slew time. So for a significant change in LST start range (whether shorter or longer), consider remaking the SB file with a new call to `scanrows2opt_slew`, and see whether the overhead changes significantly.
- For tiles at declinations near the Clark Belt ( $-15^\circ \lesssim \delta \lesssim 5^\circ$ ), it is desirable to avoid observing at transit. A final check for such SBs might be to use the Reports tab of the OPT to examine the range of hour angles as a function of declination for OTF scans. It will likely be necessary to observe at very low elevations (high hour angles) in order to avoid transit.



## **Appendix: Under the hood of scanrows2opt\_slew.py**

### **A.1 Scan duration**

Scan duration is based on the type of target (scan intent) and slew time:

- minimum of 2 minutes on source for the flux calibrator and up to 3 minutes on source if it is observed at the beginning (depending on the length of the initial slew); this should suffice for polarization angle calibration for both 3C286 and 3C48
- minimum of 30 seconds on source for phase and leakage calibrators
- OTF on-source time must be at least  $(N + 1) \times t_{\text{phase}}$  where  $N$  is the number of phase centers and  $t_{\text{phase}} = 0.9\text{s}$  is the time per phase center for VLASS. The script currently adds 7.6 seconds to this value to get the OTF scan duration. Seven seconds is the telescope’s “settle” time; trial and error suggest 0.6 is the right amount of extra slewing overhead to add (unless the OTF scans are at high elevation).
- slew time (see below)
- the scan duration (on-source time + slew time) is increased so that the scan is divisible by 0.45 seconds (the dump time used for VLASS)

The slew time is calculated based on the `EvlaTelescopeMotionSimulator.java`<sup>2</sup> algorithm with possible slew start/stop positions determined from the LST start range (and calculated using 5-minute increments across the LST range); the maximum possible slew time is used (added to on-source time to determine scan duration).

### **A.2 Setup procedure**

The default behavior is to use the flux calibrator as the setup source. If the flux calibrator is to be observed last, then the polarization leakage calibrator is next in line to be used as the setup source. However, for long SBs (e.g., 6 or 8 hours), the polarization leakage calibrator may not have risen by the SB start time. The script determines whether the polarization leakage calibrator is above a limiting elevation (currently hard-coded as  $15^\circ$ ); if at any point in the LST start range the leakage calibrator would be below  $15^\circ$ , the script instead uses the first [mini-]tile’s phase calibrator as the setup source.

The first three scans of the SB are the following setup scans:

1. a long dummy scan at X-band tuning (with 0.45s dump time) for the initial slew
2. a 60.3s scan in the VLASS S-band tuning for attenuator setting
3. a 30.15s scan to allow for requantizer setting (for commensal P-band observing)

Based on whether the setup source will be rising or setting at the mid-point of the LST start range, the code determines whether to use clock-wise or counter-clockwise wrap preference for the setup procedure. (Wrap preference is only used for the setup scans and first calibrator scan.) The code calculates the longest possible starting slew time to the setup source, based on the wrap preference and assuming the antennas start at the azimuthal

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<sup>2</sup><https://svn.aoc.nrao.edu/repos/shared/sss-model/trunk/src/main/java/edu/nrao/sss/model/resource/evla/EvlaTelescopeMotionSimulator.java>

extreme of the opposite wrap. Typical “worst slew” times are about 9.5 minutes. The duration of the first setup scan is set such that the length of the first three setup scans is a maximum of 8 minutes long; for shorter initial slew times, the first scan is 1 minute shorter than the worst slew. The duration of the first calibrator scan is one minute longer than the minimum on-source time. This procedure ensures that the attenuator setting will occur while the antennas are either tracking the first calibrator source, or are close to it in the sky. We expect it will be rare for the initial slew to actually take the full “worst slew” calculated time; therefore the first calibrator scan will have as much as one minute of extra on-source time.

If the flux calibrator was used as the setup source (default procedure), then the next scan after the flux calibration scan will be the leakage calibrator, unless the leakage calibrator would be outside of the desired elevation range (if  $<15^\circ$  or  $>80^\circ$ ). The `EvlaTelescopeMotionSimulator.java` algorithm is used to determine the slew time from one calibrator to another. For each new scan to be added to the SB, potential slew times are calculated for the full range of LST start times (in 5 minute increments). The longest potential slew time is added to the minimum on-source time to determine the scan duration.

### ***A.3 Loop length (Calibrator cycle time)***

The script determines how many OTF scans (rows) to put into a single loop, aiming for a calibration cycle time of approximately 18–20 minutes. It does this by calculating the OTF time per row (without accounting for slew time between adjacent rows). Using the total OTF time for the tile, the script determines the average number of rows per loop that results in an average loop time of 17.5–19 minutes<sup>3</sup> That value is used to estimate the number of loops needed. The script then assigns an actual number of rows to each loop, aiming for each loop to have a time close to the average loop time. Because the duration of OTF scans is roughly proportional to  $\cos(\text{Dec})$ , the time per scan as well as the time per loop will vary. After assigning rows to loops based on the original estimate of number of loops, there are often remain unassigned (leftover) rows. If the number of leftover loops is “large” (more than half of the “average” number per loop), then a short extra loop is added, containing the leftover rows. However, if the number of leftover rows is “small”, then the code will add a row to the loop that has the shortest duration, and continue to do so until all leftover rows have been assigned to the original loops. At this stage, if any single loop results in a total OTF time longer than 21 minutes, then the assignment of rows to loops is cleared, the number of loops expected is increased (with a corresponding shorter average time per loop, and the assignment of rows to loops starts over.

Note that in the case of multiple tiles/mini-tiles in an SB, the assignment of rows for the Pilot was performed individually per tile/mini-tile. This process should be modified for the full survey, as we are already aware that some mini-tiles will be assigned to the same phase calibrator and combined into a single SB.

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<sup>3</sup>The actual cycle time will be 1-2 minutes longer, once slew time accounted for.

#### **A.4 Loops (bulk of the SB)**

Once the assignment of the number of OTF rows to loops is complete, the script stores the scans for the [mini-]tile as a series of “calibrator — OTF scans — calibrator” loops. Upon completion of the loops for a [mini-]tile, the script ensures that there is a scan of the leakage calibrator. If the leakage calibrator doubles as the complex gain calibrator of the just-completed set of loops, or the calibrator for the next set of loops, then this step is superfluous and is skipped. Otherwise, it is skipped if the leakage calibrator would be outside of the desired elevation range at this stage in the SB for any LST start time in the input LST start range.

Within the SB, each time the telescope would change source to or from a calibrator scan, the script calculates all potential slew times given range of LST start times; the longest slew time is used in determining the scan duration. For any calibration scan to be followed by an OTF scan, the script calculates the range of possible slew times to the east edge and to the west edge of the OTF row. The edge with the shorter slew time is used as the starting position of the OTF row, determining the scanning direction (east to west or vice-versa) for the row. Thereafter the scanning direction of each row is reversed until the completion of that loop, when another calibration scan is added. Thus the telescope will scan back and forth within each loop of OTF scans. Note: the input file of OTF scans must be listed with all rows starting at the same (east or west) edge of the [mini-]tile in order for this to work correctly; `OTF_scans_from_tile` produces appropriate scan lists for this purpose.

A leakage calibrator scan is included each time the SB switches to a new [mini-]tile, as well as at the very beginning and very end of the SB, unless the leakage calibrator would be outside of the desired elevation range (below  $15^\circ$  or above  $80^\circ$ ). When a leakage scan is “skipped” due to elevation, the script reports a warning to standard output. The user should double-check the parallactic angle coverage (also reported to standard output), in case a modification needs to be made to the LST start range to avoid skipping a necessary leakage calibration scan.

#### **A.5 End of SB**

If the SB did not setup on the flux calibrator, then the final source in the SB will be the flux calibrator. Instead of a single scan, this scan will be split into two scans in case the final scan of the SB is dropped. The second of the two scans will have a duration of 54 seconds. The first of the two scans will incorporate the slew time and the remaining on-source time.

## A.6 Standard output

The full information printed to standard output includes:

- name of output file: <SB\_name>.4opt
- report of the flux calibrator, phase calibrators, leakage calibrator, and LST start range parsed from the input parameters
- starting wrap and longest possible starting slew time (typically  $\sim 9.5$  minutes)
- for each of the input scan lists (“rowfile”):
  - name of the accompanying source list file (used to determine source positions for calculating slew times)
  - number of OTF rows read from the input scan list
  - total time of OTF coverage (excluding overhead)
  - goal for average loop length (time) and average number of rows per loop
  - the starting source (east or west) for each OTF loop
  - the actual number of rows per loop and actual OTF time per loop upon final assignment of rows to loops
- a warning if any “extra” leakage calibrator scan is skipped (owing to elevation limits)
- LST start times (in increments of 5 minutes) where the parallactic angle coverage of the leakage calibrator would be  $< 60^\circ$  (excludes setup scans)
- the minimum possible parallactic angle range for the leakage calibrator
- finally: the SB duration, total OTF time, total phase/leakage calibrator time, total “dummy” time (time in OTF scans that amounts to overhead time), and the overhead percentage

The information in the last bullet point above is also included via comments at the end of the SB file.

## ***Revision History***

<b>Revision</b>	<b>Date</b>	<b>Author(s)</b>	<b>Description</b>
1.0	2016-08-30	Amy Kimball	Original