Guide to Planning OTF Maps with the upGREAT Array in SSpot

1. Introduction

The upGREAT Low Frequency Array (LFA) is a 2x7-beam (H and V polarization) heterodyne array arranged in a hexagonal pattern with a central beam. The spacing between the pixels is approximately 2 beam widths (about 33"). For efficient mapping, the array is rotated by -19.1° relative to the scan direction, resulting in a projected pixel spacing of 11" (see Fig. 1). In SSpot, the array rotation is handled automatically for on-the-fly (OTF) mapping.
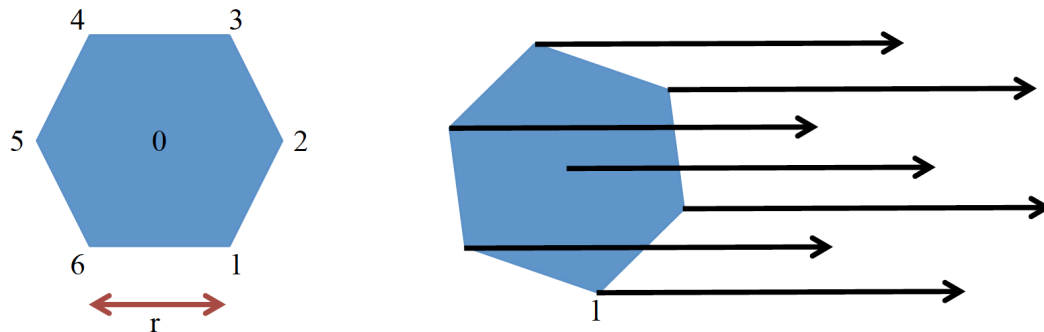

Figure 1. *Left*: The configuration of the upGREAT LFA. The numbers 0-6 mark the pixel numbers of the array, and the separation between the pixels, r, is 33". *Right*: The upGREAT array, rotated by -19.1° (pixel 1 is labeled) with arrows indicating the scan direction. The projected pixel spacing perpendicular to the scan direction is 11".

2. upGREAT Array Mapping

Map Coordinates

Because upGREAT maps can be rotated relative to standard sky coordinates (e.g., J2000), upGREAT maps have their own coordinate system. The two coordinates in the upGREAT array mapping frame are x and y. With a map rotation of 0 degrees, the +x axis is aligned with the +RA axis, and the +y axis is aligned with the +Dec axis (Fig. 2). Map rotation increases in the counter-clockwise direction, and the map angle can range from 0° to 360°. Scans in the x-direction are parallel to the x-axis, and scans in the y-direction are parallel to the y-axis.
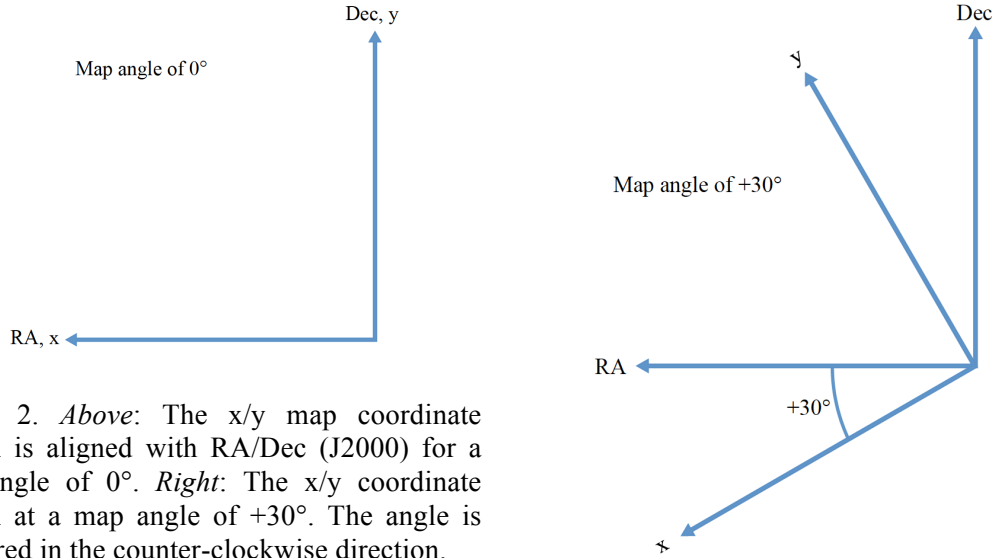
Figure 2. *Above*: The x/y map coordinate system is aligned with RA/Dec (J2000) for a map angle of 0°. *Right*: The x/y coordinate system at a map angle of +30°. The angle is measured in the counter-clockwise direction.

Map Blocks

The basic unit of the upGREAT array mapping scheme is called a 'block,' which consists of a single or multiple scans of the same length, in the same direction (Fig. 3). As stated above, the projected pixel spacing for a single scan is 11". Because the SOFIA/upGREAT beam at 1.9 THz is 14", a single scan results in an under-sampled map. To create a fully sampled map, it is necessary to make at least one more scan to fill in the 11" gap. The default behavior is to step the array by 11"/2=5.5" and make a second scan, creating a fully sampled map and completing the block. It is possible, however, to scan only a single time (creating an under-sampled map with 11" spacing between rows), or more than two times (creating an oversampled map), depending on the goals of the project. The lengths of blocks (scans) are integer multiples of the rotated array width (76").
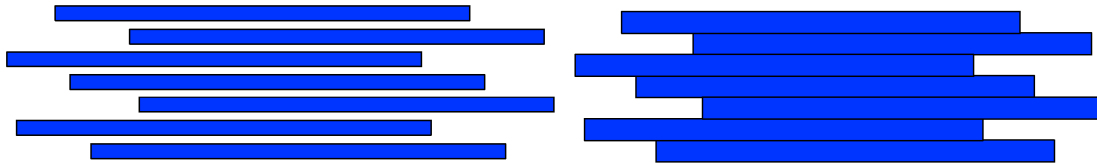

Figure 3. *Left*: A block that consists of a single scan of the rotated array. The gaps between the scans indicate an under-sampled map. *Right*: A block that consists of two scans separated by 5.5". This block is fully sampled in the direction perpendicular to the scan direction. The second scan fills in the gaps in the single-scan block.

Constructing a Map

A single map can consist of any number of blocks, and can scan in the x- or y- direction, or both. The parameters of the x- and y-direction scans are independent, but can be used in concert to create fully sampled maps of a region, scanning in both directions (Fig. 4). Scanning in both directions helps to minimize the striping effects that can be caused by the different system temperatures of the array pixels.
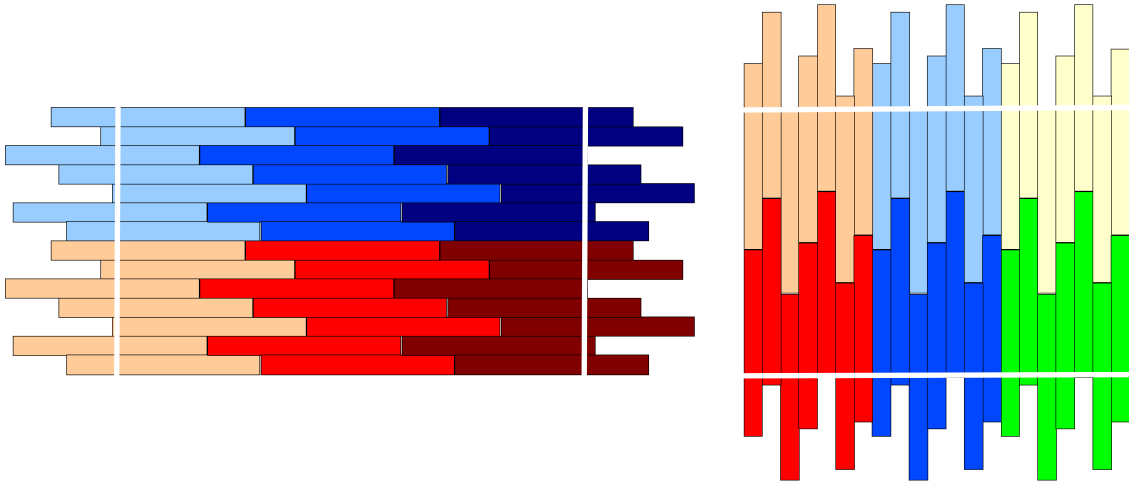
Figure 4. *Left*: A map composed of six blocks scanning in the x-direction. There are 3 blocks along the scan direction, and 2 blocks perpendicular to the scan direction. The region interior to the two vertical white lines shows the inner coverage region. *Right*: A map composed of six blocks scanning in the y-direction. There are 2 blocks along the scan direction, and 3 blocks perpendicular to the scan direction. The region interior to the two horizontal white lines shows the inner coverage region. Maps scanning in both directions can be set up to align the inner coverage regions of the two maps.

To calculate the size of the inner coverage region along the scan direction:
  inner coverage = [(block length) * (# of blocks in scan direction) – 1] * 76",
where block length is in units of the array size.
To calculate size of the inner coverage region perpendicular to the scan direction:
  inner coverage = (# of blocks perpendicular to scan direction) * 76"

Because of the flexibility of the mapping scheme, there can be multiple ways to observe the same region. For example, the two setups in Figure 5 both fully cover the same area. Some important factors in determining the proper setup between these two options are the desired integration time per point, the step size between the points, and the duration of a single scan.
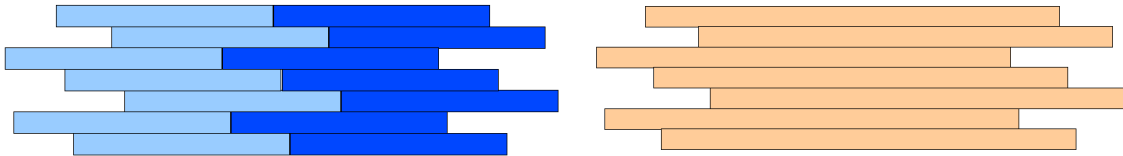

Figure 5. *Left*: A map consisting of two blocks, each one 2*76" long. *Right*: A map consisting of a single block that is 4*76" long. The total inner coverage for both maps is 228".

3. upGREAT Array Mapping Parameters in SSpot

The OTF Array Mapping AOT in SSpot contains three subsections: Config, Mode, and Map (see Fig. 6). The Config and Mode subsections are identical to those of other GREAT AOTs and are not discussed here. The Map subsection contains all of the parameters necessary to design a map with the LFA. The parameters are listed and described below.
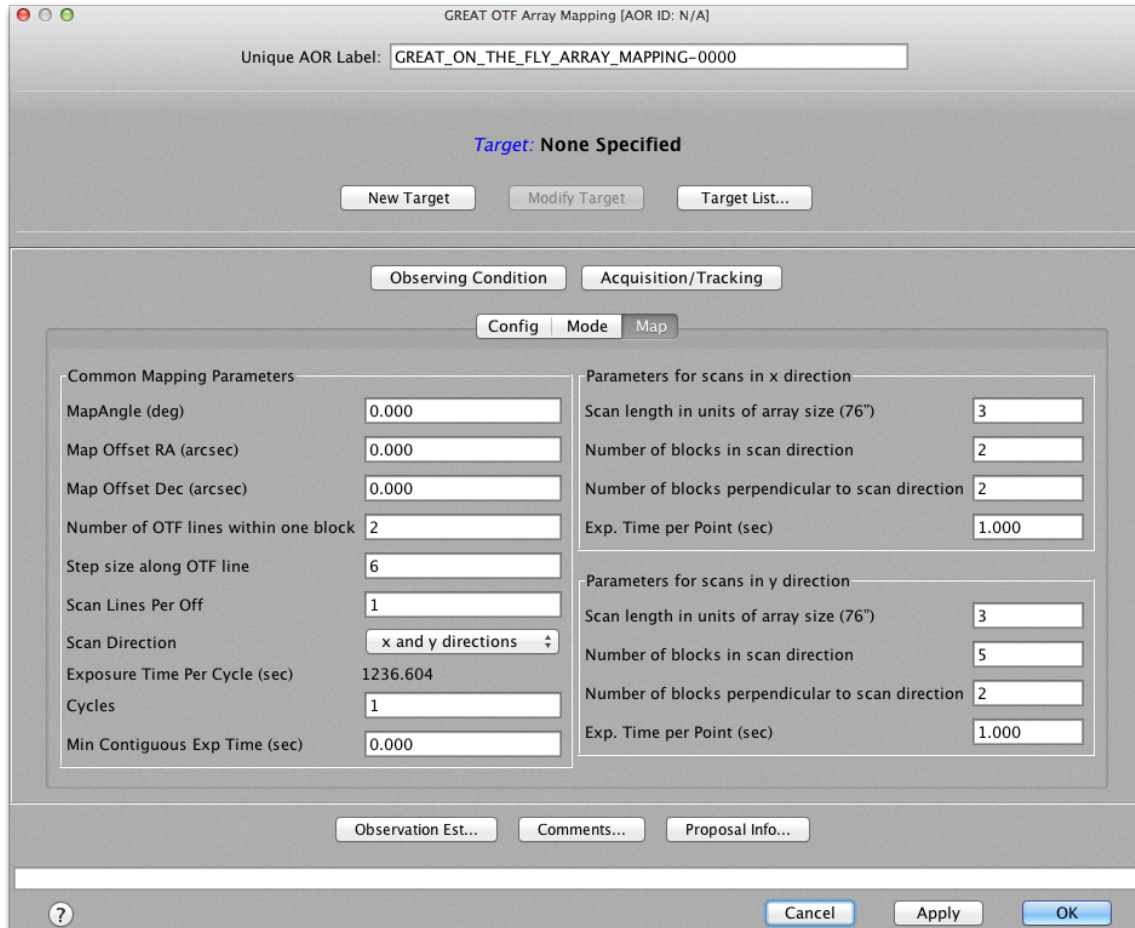
Figure 6. A screenshot of the Map subsection of the GREAT OTF Array Mapping AOT in SSpot. Each of the parameters is described below.

Common Mapping Parameters

These parameters pertain to the entire map, regardless of scan direction(s).

- MapAngle (deg): The angle of the x/y map coordinate system relative to the RA/Dec coordinate system (see Fig. 2). MapAngle is measured in the counter-clockwise direction. The map is rotated around the map center, as defined by the target and map offsets. The allowed values for MapAngle range from 0° to 360°.
- Map Offset RA(arcsec): The offset in Right Ascension of the map center from the specified target position.

- Map Offset Dec (arcsec): The offset in Declination of the map center from the specified target position.
- Number of OTF lines within one block: The number of scans that make up a single block. A value of 1 will result in an under-sampled map, a value of 2 is the minimum required for a fully sampled map, and a value greater than 2 will result in an over-sampled map (see 'Map Blocks' section above).
- Step size along OTF line: The spacing between individual spectra (dumps) along the scan row (in arcseconds). The default value of 6" results in fully sampled maps.
- Scan Lines Per Off: The number of map scans performed for each observation of the reference position. If the duration of a single scan is close to 30 seconds, this number should be 1. If the duration of a single scan is very short (e.g., 10 seconds), this can be increased to 2. Note, however, that longer scan durations result in higher on-source observing efficiency.
- Scan Direction: The scan direction(s) that will be used in the map. The selection here (x and y directions, x direction, y direction) will determine the available fields in the 'Parameters for scans in x/y direction' sections of the AOT.
- Exposure Time per Cycle (sec): The time, including overhead, to complete one repetition of the map. This is calculated automatically.
- Cycles: The number of repetitions desired for the map.
- Min Contiguous Exp Time: The minimum amount of time needed for the AOR. This is typically one repetition of the map.

Parameters for scans in x/y direction

These parameters specify the size and number of blocks in each scan direction.
- Scan length in units of array size (76"): The scan length of a single block, in integer values of the 76" array size.
- Number of blocks in scan direction: For the *left* example in Figure 4, this is 3.
- Number of blocks perpendicular to scan direction: For the *left* example in Figure 4, this is 2.
- Exp. Time per Point (sec): The amount of on-source integration time for each dump, in each scan. This value is typically between 0.3 and 2.0 seconds.

Scanning Duration

The maximum scanning duration for each observation of the reference position is 30 seconds. Scanning duration is calculated as follows:

$$scanning\ duration = \frac{(Scan\ length\ in\ units\ of\ array\ size) * 76'' * (Exp\ time\ per\ point)}{(Step\ size\ along\ OTF\ line) * (Scan\ lines\ per\ off)}$$

If the maximum duration exceeds 30 seconds, then one or more of the parameters in the above equation needs to be adjusted.