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Dual-Beam Rastering and Deconvolution Techniques for SCUBA

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Abstract. With the advent of large format submillimetre arrays such as SCUBA, mapping of large areas of sky (several square degrees) becomes a feasible proposition. This paper discusses the dual-beam rastering technique used at the JCMT with particular emphasis on the data reduction algorithms used to deconvolve the chopped signal and remove the effects of sky-noise fluctuations. Direct deconvolution techniques (Fourier deconvolution) and non-linear methods (Pixon) are discussed.

1. Introduction

The Submillimetre Common User Bolometer Array (SCUBA) (Holland et al. 1999) consists of two arrays of bolometers (or pixels); the Long Wave (LW) array has 37 pixels operating in the 750 μm and 850 μm atmospheric transmission windows, while the Short Wave (SW) array has 91 pixels for observations at 350 μm and 450 μm. Each of the pixels has diffraction-limited resolution on the telescope (approximately 14.5 and 8 arcsec FWHM respectively), and are arranged in a closed-packed hexagon. Both arrays have approximately the same field-of-view on the sky (diameter of 2.3 arcmin), and can be used simultaneously by means of a dichroic beamsplitter.

2. Scan Mapping

The observing technique for scan mapping is to raster the SCUBA arrays over the map area, using the secondary chopper to measure the difference signal between points a short distance apart. The hexagonal configuration means that the array can only produce fully-sampled data at 6 different Nasmyth angles and it is therefore not possible to scan in pure Azimuth, RA or Dec and generate fully-sampled images.

For SCUBA, we normally scan the telescope at a rate of 24 arcsec per second with a chop frequency of 7.8 Hz, giving 3 arcsec sampling along a scan length.

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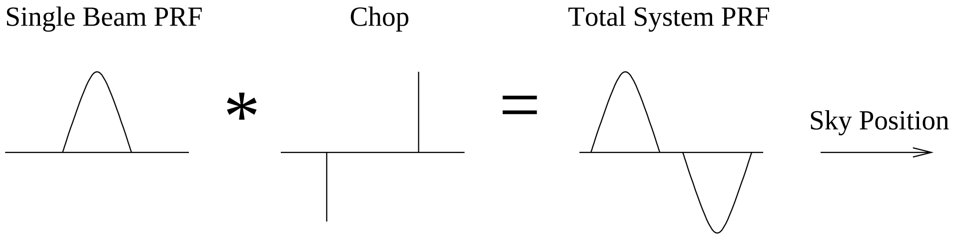

Figure 1. Diagram showing how the source profile is modified by the chop function.

If only the long-wave array is required the scanning speed can be increased to 48 arcsec per second resulting in 6 arcsec sampling.

Chopping removes the DC offset due to sky emission and diminishes the effect of sky variability on the signal. Unfortunately, it also results in a map that has the source profile convolved with the chop (Figure 1).

3. Emerson II Observing Technique

The traditional method of raster-mapping involves scanning and chopping in the same direction (Emerson, Klein & Haslam 1979) (EKH), resulting in a map that has the source profile convolved with the chop. However, restoring the source data by deconvolving the chop from the measured map produces problems at spatial frequencies where the Fourier transform (FT) of the chop (a sine wave) is low or near-zero. This introduces noise into the restored map. To minimize these effects, data are currently acquired using a revised method first described by Emerson (1995) where maps of the same region are taken with several different chop throws and directions (usually three throws, chopping in both RA and Dec). This ensures that the zeroes of one chop FT do not coincide with the zeroes of another. This is known as the "Emerson II" observing technique. The usual chop throws are 20, 30 and 65 arcsec when scanning with both arrays.

4. Data Reduction

Once the dual-beam images have been generated they are combined and the chop function is deconvolved in Fourier space[1]. For a single chop this involves simply dividing the Fourier transform of the data by the Fourier transform of the chop function and then inverting the Fourier components:

1. Calculate the Fourier transform of each input image,
2. Calculate the Fourier transform of the corresponding chop function,
3. Divide the FT of each input image by the FT of the corresponding chop function,
4. Combine the deconvolved FTs by using a weighted average where the square of the chop FT is used as the weight,

[1] Reduction software is available in the SURF package (Jenness & Lightfoot 1998).

5. Remove all frequencies that are larger than the highest frequency that can be measured by the telescope,
6. Perform an inverse Fourier transform.

In reality steps 3 and 4 are combined such that the division by the chop FT and the multiplication by the weights are performed in one step so that the data are never divided by the FT of a single chop (and hence do not suffer from noise amplification at nulls in the sine wave). The Emerson II deconvolution can therefore be represented as:

$$I = \mathcal{F}^{-1}\left[\frac{\sum_{j=1}^{N} \frac{\mathcal{F}(D_j)\mathcal{F}(C_j)^2}{\mathcal{F}(C_j)}}{\sum_{j=1}^{N} \mathcal{F}(C_j)^2}\right]$$

Where N is the total number of independent chops available, D is the data and C is the chop function.

The ability to combine all the bolometer data into separate chop images provides some immediate advantages over EKH since any problems with individual scans (e.g. spikes) will be much less significant when all scans are combined into an image before deconvolution. For example, if the observer finds that the scanned region does not cover the source (a major problem with EKH where the positive beam must be associated with a corresponding negative in each scan) a new map at an offset position can simply be combined with the original.

5. The Future: Pixon?

While the Emerson II data reduction technique works well it suffers from a number of shortcomings related to the use of a linear inversion technique:

- The data must first be rebinned before the algorithm can be applied,
- Each of the chopped images must cover the same area,
- The chop must be fixed for the duration of the observation.

These issues can only be resolved by using an image reconstruction technique. Recently we have been investigating the use of the Pixon image reconstruction technique (Puetter & Yahil 1999). This is an iterative technique which has a number of advantages over Emerson II:

- The raw samples are used (no rebinning),
- Full knowledge of the chop beam positions are used,
- Each data sample can be from a different chop throw and direction (for example, jiggle maps with 3 position chopping or chopping in Azimuth which rotates on the sky),
- There is also the possibility of super-resolution by deconvolving the beam pattern in addition to the chop function.

Currently, we have been able to use successfully the Pixon method and software to deconvolve chop functions for scan and jiggle map data but no progress has yet been made on super-resolution (Chapin 1999). An example reconstruction can be seen in Figure 2.

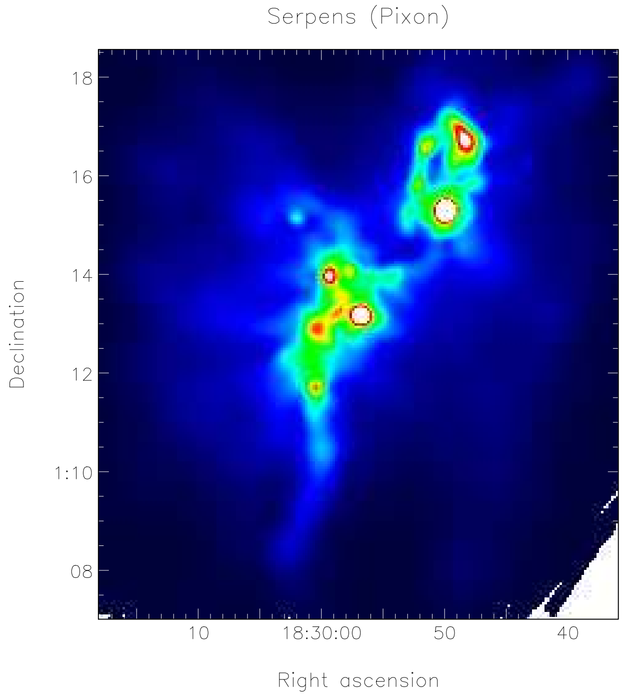

Figure 2. Pixon image reconstruction from SCUBA scan map data of the Serpens star-forming region (data courtesy of C. J. Davis (Davis et al. 1999)).

References

Chapin, E. L. 1999, "Pixon Image Reconstruction of SCUBA Data", JCMT Technical Report TR/001/80/EC

Davis, C. J., Matthews, H. E., Ray, T. P., Dent, W. R. F., & Richer, J. S. 1999, MNRAS, 309, 141

Emerson, D. T. 1995, in ASP Conf. Ser., Vol. 75, Multi-feed Systems for Radio Telescopes, ed. D. T. Emerson, & J. M. Payne, (San Francisco: ASP), 309

Emerson, D. T., Klein, U., & Haslam, C. G. T. 1979, A&A, 76, 92

Holland, W. S., Robson, E. I., Gear, W. K., Cunningham, C. R., Lightfoot, J. F., Jenness, T., Ivison, R. J., Stevens, J. A., Ade, P. A. R., Griffin, M. J., Duncan, W. D., Murphy, J. A., Naylor, D. A. 1999, MNRAS, 303, 659

Jenness, T., 1998, & Lightfoot, J. F., in ASP Conf. Ser., Vol. 145, Astronomical Data Analysis Software and Systems VII, ed. R. Albrecht, R. N. Hook, & H. A. Bushouse (San Francisco: ASP), 216

Puetter, R. C., & Yahil, A. 1999, in ASP Conf. Ser., Vol. 172, Astronomical Data Analysis Software and Systems VIII, ed. David M. Mehringer, Raymond L. Plante, & Douglas A. Roberts (San Francisco: ASP), 307