Analysis of Fast-Scanning data from ALMA

Benjamin Gill

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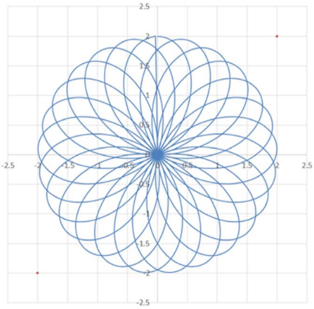
Atacama Large Millimeter/sub-millimeter Array

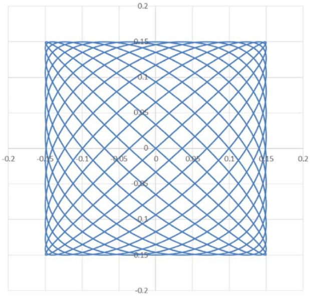
- 66 telescopes of 7 and 12 metres in diameter used as an interferometric array.

- Angular resolutions of tens of milliarcseconds are possible.
- Structure above a few tens of arcseconds is resolved out.

Fast-Scanning

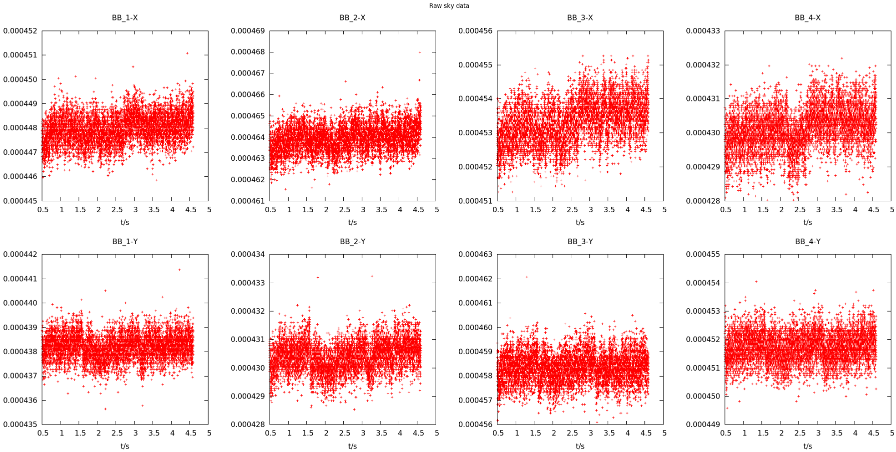
- Fast-scanning is the practice of scanning a single telescope over the region of interest to observe large-scale structure.
- Using a 'clover-leaf' or Lissajous pattern, an area of up to 100 square arcminutes can be scanned in five minutes.



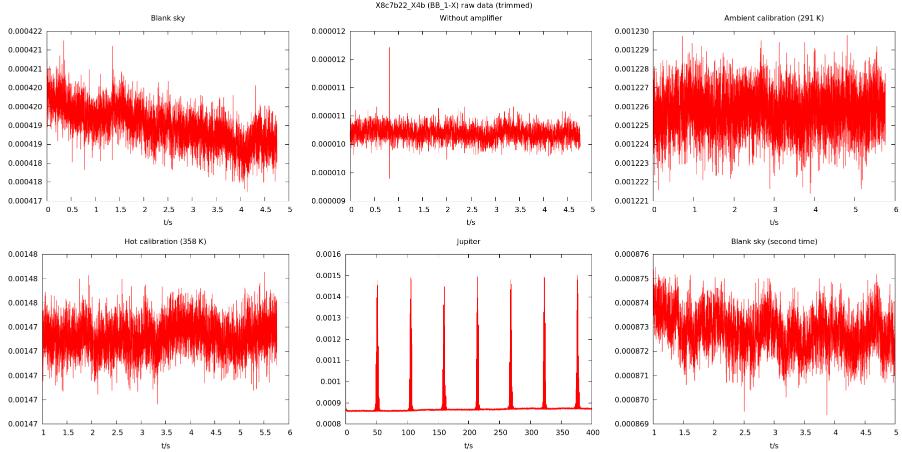


Data

- Two polarisations and four frequency channels give eight channels worth of data.



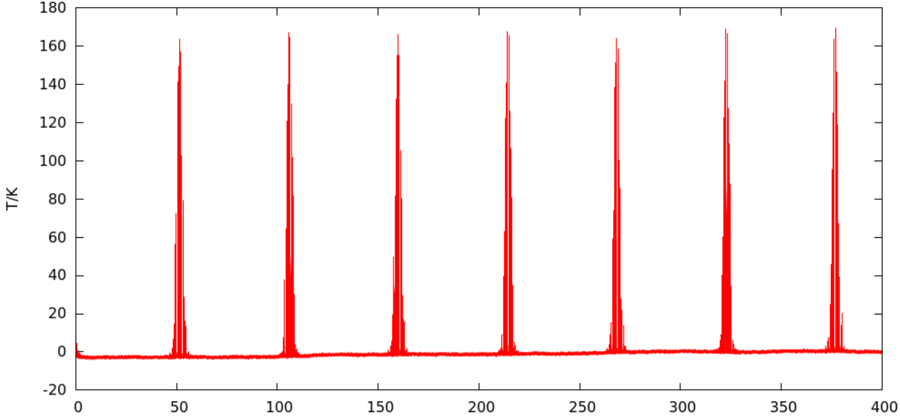
- Calibration uses two reference sources at known temperature and a patch of ‘blank’ sky.



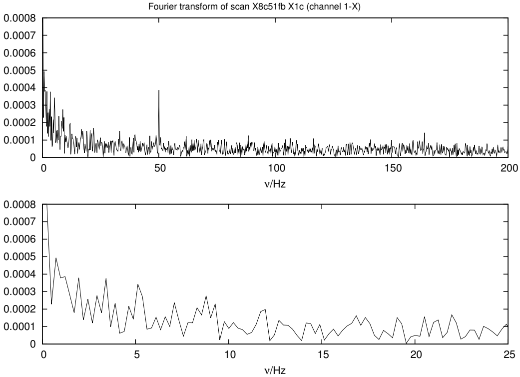
Temperature Conversion (II)

$$S = (T_{\text{obs}} + T_{\text{CMB}} + T_{\text{atm}} + T_{\text{sys}})\, G + O$$

- Inverting the equation to get T_{obs} yields a sensible result for Jupiter – 170 K



Noise Characterisation



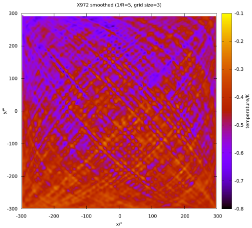
- White noise at high frequency. Probably electronic noise.
- Chilean mains at 50 Hz.
- Excess at low frequency due to atmospheric noise.

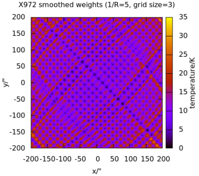
Map making

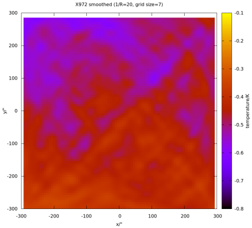
- Direct parameter estimation preferable, but computationally expensive.
- Map making attempts to remove the noise added by scanning over the true sky.
- It can be a useful intermediate step, with low computational requirements, and has been studied in similar contexts.
- With the correct algorithm, can limit information loss.

Map making (II)

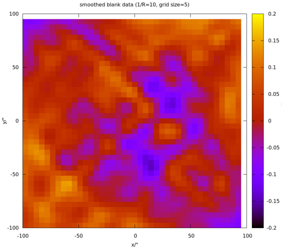
- Convolve each data point with a smoothing kernel.
- Kernel is a Gaussian or Bessel function with width of the telescope beam (20 arcseconds).
- Wide kernel needed to avoid gaps in weights.

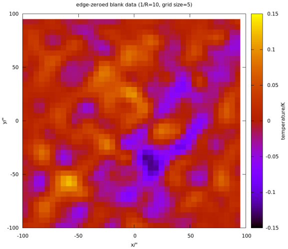


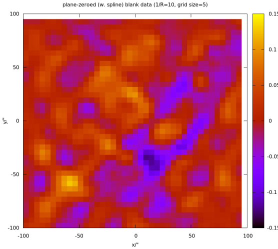




- Let each edge-to-edge run be a ‘scan’.
- Move the scan to set the edges to zero.







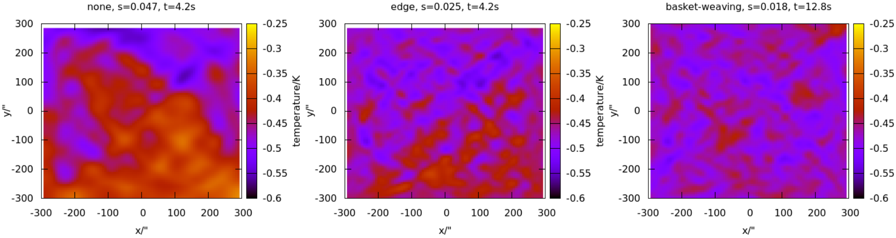
- Fast methods which remove some of the atmospheric noise.

Basket-Weaving

- The data is divided in half.
- Then, each scan is offset (by P_i) to minimise the difference between the two halves (D_i).
- Requires finding a least-squares solution to $A\mathbf{P} = \mathbf{D}$, with the constraint that $|\mathbf{P}| = 0$.
- A is a matrix where each column is formed from mapping the weights of one of the scans.
- Can extend to a polynomial offset, but risk loosing signal and getting very expensive for $n > 1$.

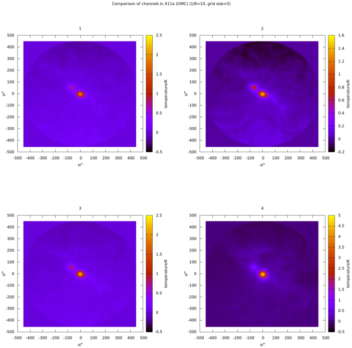
Comparison

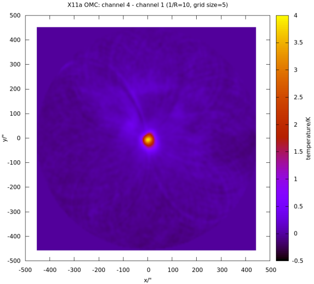
Comparison of noise removal methods for X972 with standard deviations and run-time (1/R=20, grid size=7)



- Basket-weaving produces lowest standard deviation and removes gradient in sky.

Orion Molecular Cloud





- Channel four contains a spectral line.

Future Work: Inference

- Inference methods would be preferable since they preserve more information and can be tuned to the noise present.

$$T_{\text{obs}}\left(t_i\right) = \sum_j A_{ij} T_{\text{map}}\left(x_j\right) + \sum_q E_q f_q\left(t_i\right) + N_i$$

- Mathematically similar to basket weaving, but the matrix will be 100 times larger.
- However, it will be at least 95% sparse, so should be solvable with access to greater computational power.

Conclusions

- Fast-scanning is a good means of mapping a large area of sky relatively rapidly.
- Basket-weaving has proven to be the most effective technique for removing atmospheric noise, reducing the standard deviation ~ 2.5-fold.
- Further improvements will require inference techniques.

Acknowledgements and Questions

- I would like to thank Prof Hills for a great deal of help and support.
- Any questions?