

Confusion, the sky model and realistic simulations

Randall Wayth (CfA)

with

“team Greenhill” (Greenhill, Mitchell, Sault)

“team MAPS” (Doeleman, Bhat)

Ashes Update:

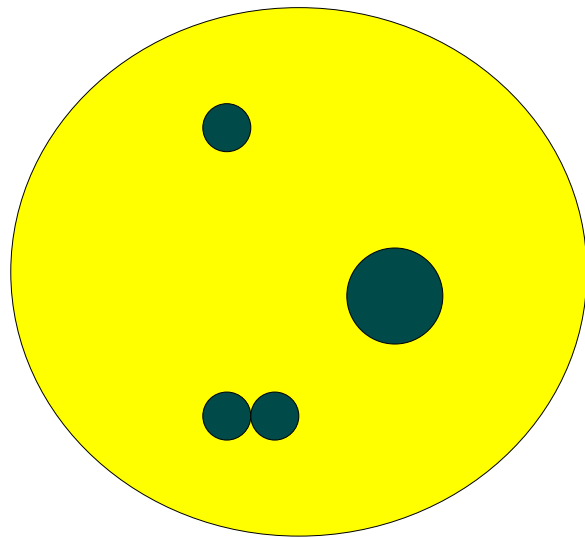
England all out for 350. Australia wins the ashes.

Outline

- Context:
 - What's it going to take to calibrate the MWA?
 - What do we need to test the real-time pipeline?
- Part I: Estimating Confusion
- Part II: Generating realistic simulation data

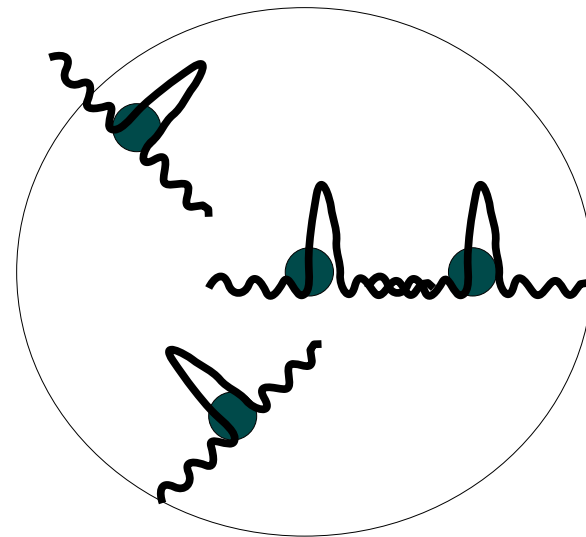
Confusion – basics

- Sources inside *synthesised beam*
 - Depends on size of beam
 - Flux densities add up



~3 arcmin

- Sidelobes of sources out of synthesised beam
 - S = source strength
 - P = pri beam power
 - $\sim P * S / N_{ANT}$ (snapshot)



~20 degrees

Confusion - theory

- Factors of interest:
 - Differential source count distribution: $n(S)$
 - Primary beam: $P(\Omega)$
 - Synthesised beam: $B(\Omega)$.
 - Diffuse emission (not included yet)
- Calculate variance in pixels due to all sources in the sky:

$$\sigma^2 = \int_{\Omega=0}^{2\pi} \int_{S=0}^{S_{MAX}} S^2 n(S) B^2(\Omega) P^2(\Omega) dS d\Omega$$

Confusion - theory

- We want to set a source detection threshold, q , of q sigma, so $S_{MAX} = q\sigma$, $q=5$ (or more)
- Sources in sidelobes of primary beam are attenuated, so $S_{MAX} = q\sigma / |P(\Omega)|$
- For $B(\Omega)$, assume = 1 in beam, $B_{RMS} = 1/N_{ANT}$ outside

$$\sigma^2 = \int_{\Omega=0}^{2\pi} \int_{S=0}^{q\sigma / |P(\Omega)|} S^2 n(S) B^2(\Omega) P^2(\Omega) dS d\Omega$$

Confusion

- For $n(S) = kS^{-\gamma}$, with $P(\Omega)$ and $B(\Omega)$ a “tophat” function with width $\theta_{PB}/2$ and $\theta_{SB}/2$, result is analytic:

$$\sigma = \left(\frac{2\pi k}{3-\gamma} \left[B_{RMS}^2 (1 - \cos \theta_{PB}) + (1 - \cos \theta_{SB}) \right] \right)^{\frac{1}{\gamma-1}} q^{\frac{3-\gamma}{\gamma-1}}$$

Solid angle of primary beam

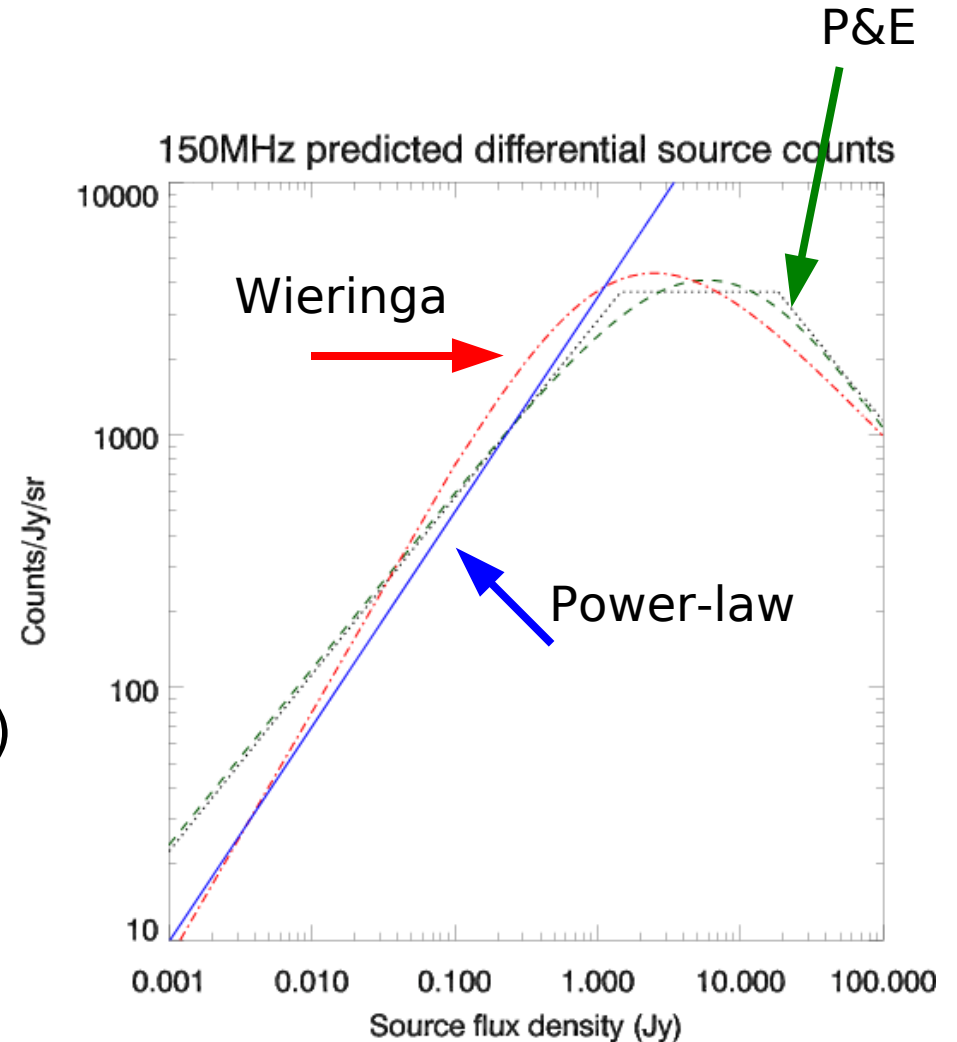
Solid angle of synthesised beam

- This is useful to check numerical integration and is a similar result to Condon (1974), extended to suit synthesis images

Source counts (“logN–logS”)

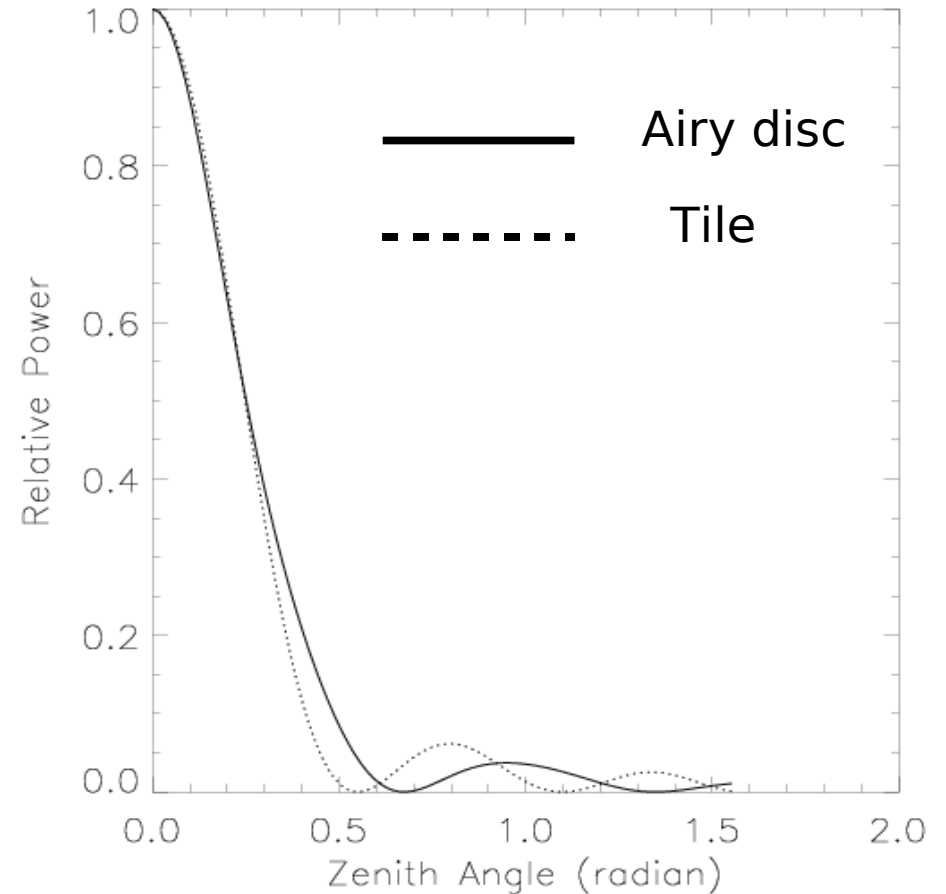
Models for $n(S)$:

- Power law:
 - $n(S) = kS^{-\gamma}$, $\gamma = 1.65$
(not realistic for large S)
- Perley & Erickson:
piecewise linear (VLA
memo 146, after Pearson, 1974)
- Wieringa (1991)
- (Scaled to 150MHz)



Primary Beam

- 150MHz
- Primary beam: 30 deg (FWHM) Airy disc (rotational symmetry)
- Synth beam: 3.4'
- 2π steradian



Results

- This table shows 5σ confusion limits for different contributors, beam models and source counts.
- 150MHz, 30 deg FWHM primary beam (PB)

<i>Model</i>	<i>Synth beam only</i>	<i>Tophat PB only</i>	<i>Real PB only</i>	<i>Synth beam + tophat PB</i>	<i>Synth beam + real PB</i>
Power-law	0.042	0.002	0.038	0.052	0.116
Wieringa	0.078	0.003	0.045	0.095	0.133
Perly + Erickson	0.052	0.005	0.031	0.061	0.089

All values in Jy

Shep's work

- **X** Wieringa total
- **X** Wieringa synth beam only

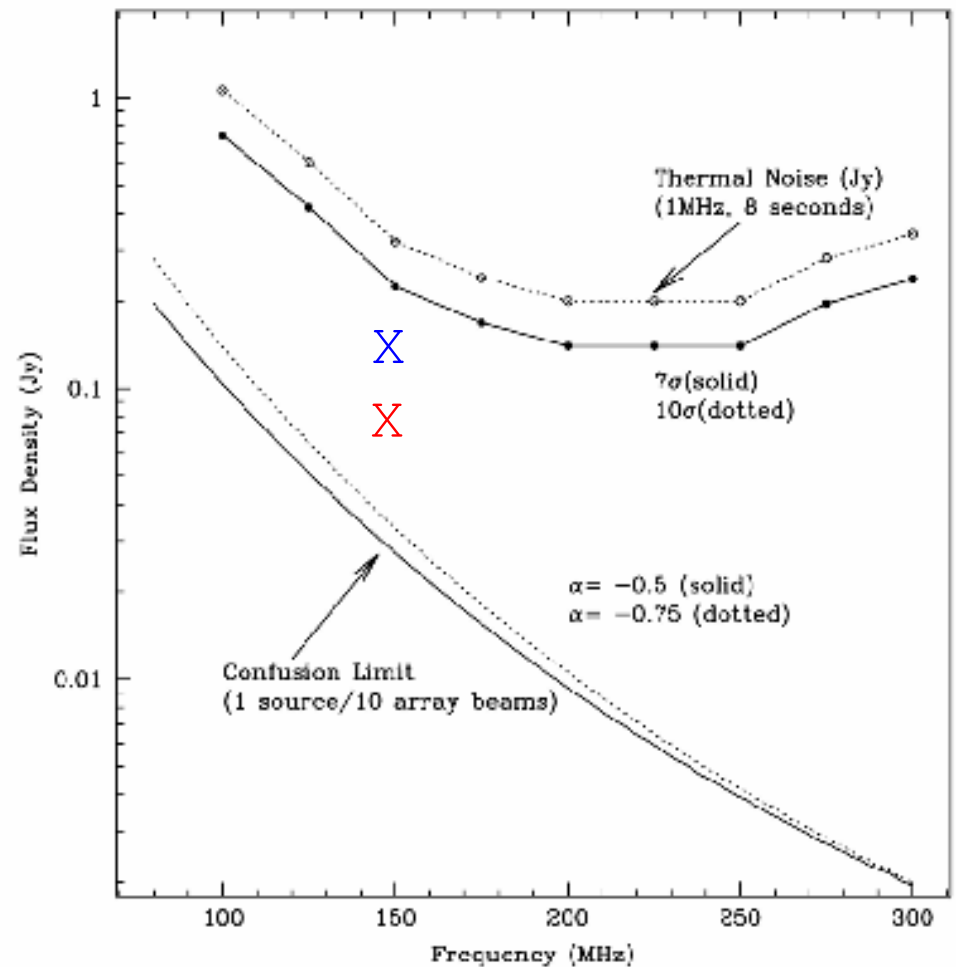


Figure 1: Comparison of continuum confusion limits to thermal noise limits for the MWA. Confusion limits estimated from 327MHz source counts (Wieringa 1991) extrapolated to MWA frequencies assuming the spectral indices shown.

Conclusions – (Part I)

- The confusion limit for the MWA at 150MHz will be around 0.1Jy (with peeling)
 - Results from different approaches agree
- Confusion noise comes partly from sources in synthesised beam and partly from sources in the sidelobes of the tile beams. (does not include diffuse emission!)
 - We can (in principle) reduce the effect of the latter
- Simplified (tophat) models of the primary beam severely underestimate confusion

Part II: GSM & Simulation

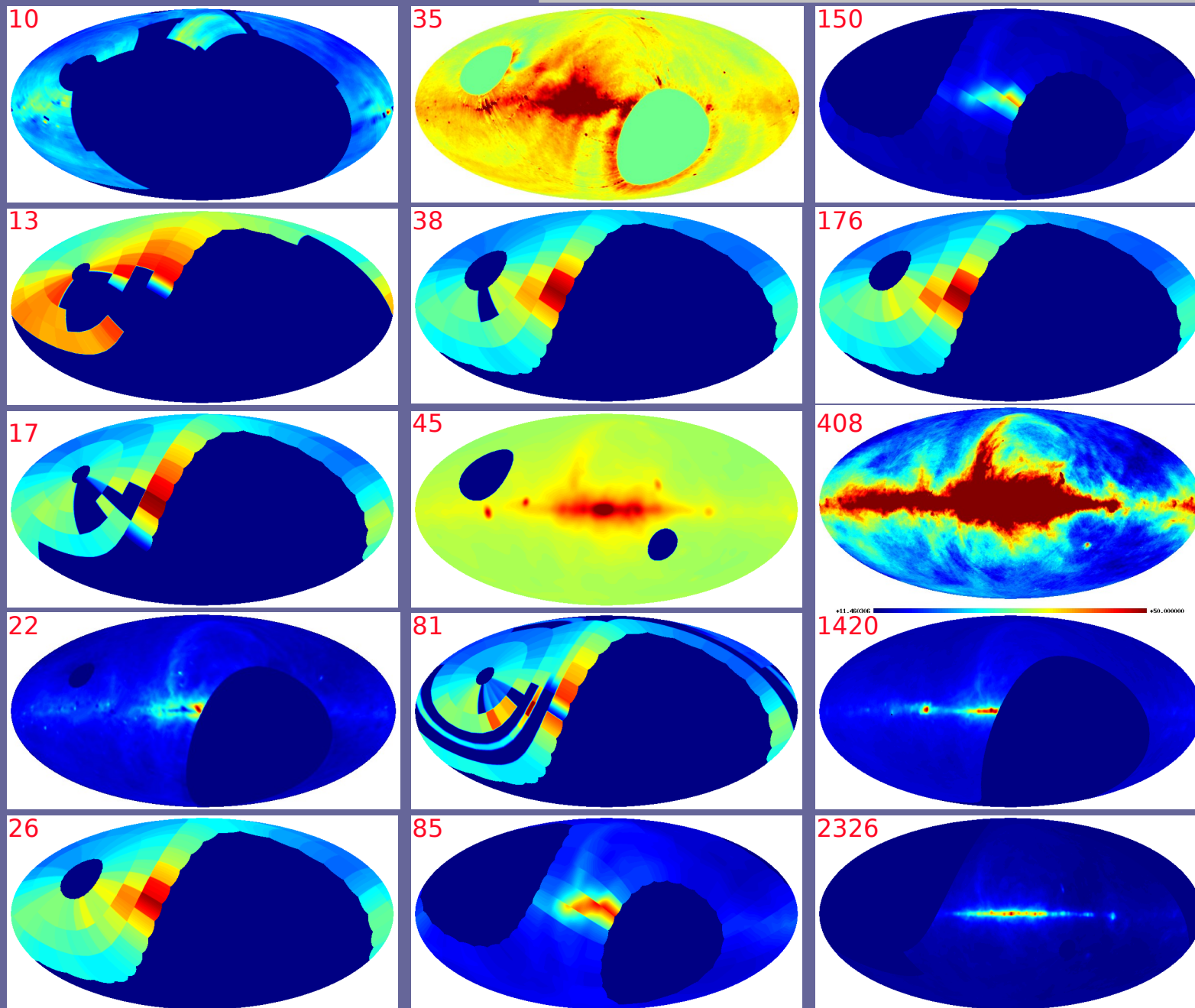
- For simulations
 - We need a “real enough” sky to test the calibration and imaging software
- For the real array: GSM Visibility Predictor
 - Needed to subtract static sky from the data to reduce sidelobe confusion and look for transients

Full sky simulations

- Aim:
 - Realistic model of the sky to test the real-time system including frequency and polarisation
 - Realistic virtual telescope including antenna element (dipole) power pattern, imperfect manufacturing and imperfect gains
- Intermediate goal:
 - Data that are good enough to test the calibration systems
 - Realistic tile response (dipole pattern, gain errors, position errors)

Outline: To improve modeling of foreground emission in the MHz-GHz range.

Work from Angelica de Oliveira-Costa



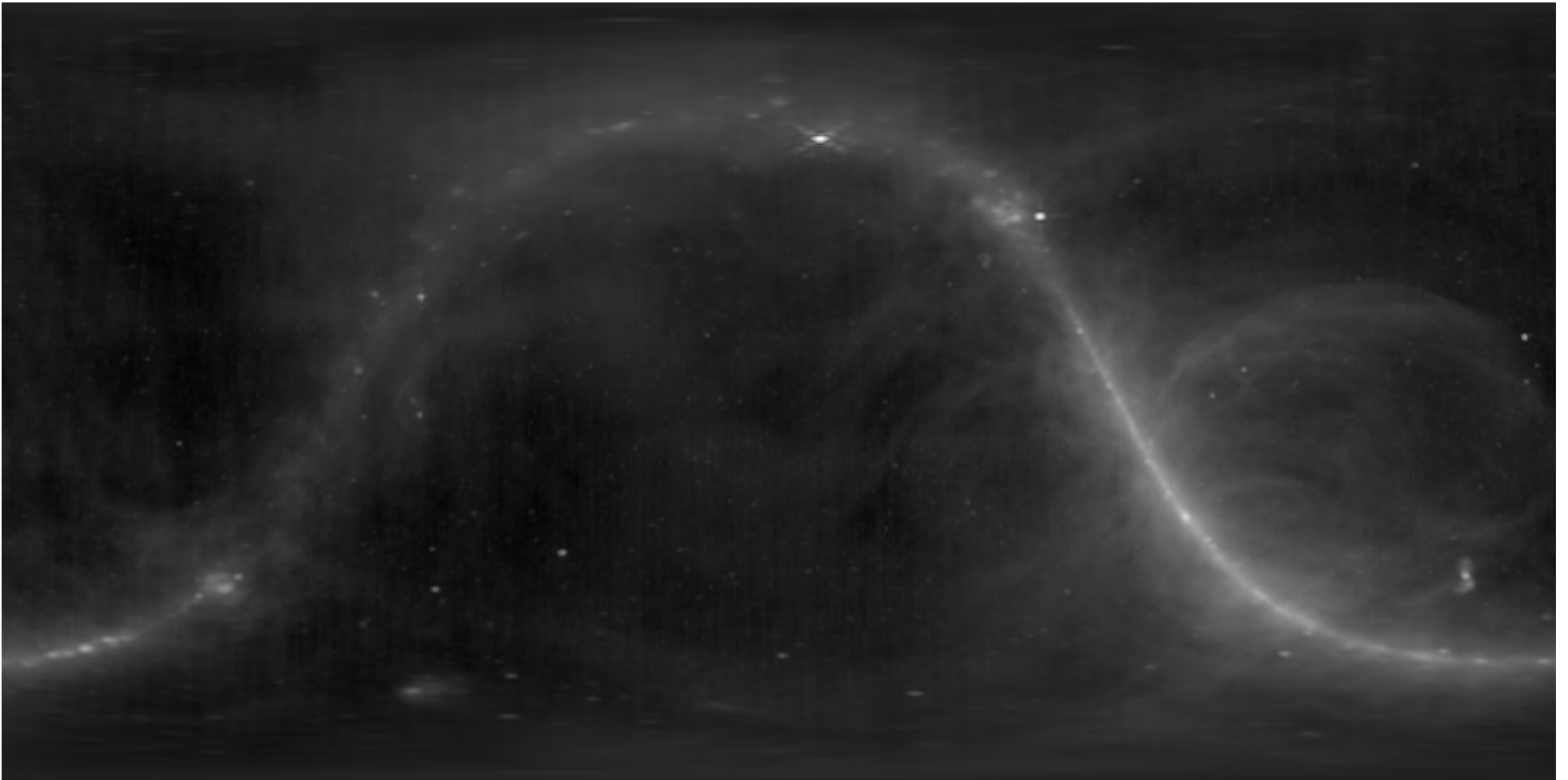
Making Sims

- Ingredients: 1

```
xterm
0000-506 00 00 09.2 -50 41 31 00 02 42.5 -50 24 49 .3 4 1.28 .06 P 321.4 -64.9
0000-307 00 00 12.4 -30 45 09 00 02 45.9 -30 28 27 .2 3 1.49 .06 P 12.6 -78.8
0000-566 00 00 20.4 -56 37 45 00 02 53.5 -56 21 03 .5 5 2.07 .10 P 316.2 -59.5
0000-134 00 00 33.3 -13 24 41 00 03 06.9 -13 07 59 .3 8 .85 .08 81.6 -72.0
0000-149 00 00 36.3 -14 57 12 00 03 09.9 -14 40 30 .2 4 1.99 .10 P 78.4 -73.2
0000-165 00 00 36.6 -16 31 52 00 03 10.2 -16 15 10 .3 4 1.08 .05 P 74.7 -74.4
0000-550 00 00 37.5 -55 01 38 00 03 10.5 -54 44 56 .5 4 2.76 .13 P 317.3 -61.0
0000-362 00 00 39.8 -36 13 16 00 03 13.2 -35 56 34 .2 3 2.44 .08 P 349.3 -76.5
0000-593 00 00 41.1 -59 22 27 00 03 13.9 -59 05 45 .8 7 .82 .07 314.3 -57.0
0000-177 00 00 48.5 -17 43 53 00 03 22.1 -17 27 11 .2 4 6.51 .27 P 71.5 -75.3
0000-673 00 00 53.1 -67 18 11 00 03 25.4 -67 01 29 1.0 7 .85 .07 310.1 -49.4
0000-160 00 00 53.9 -16 03 53 00 03 27.5 -15 47 11 .3 5 1.23 .08 P 76.0 -74.1
0001+128 00 01 07.4 12 49 38 00 03 41.3 13 06 20 .3 6 3.81 .17 P 105.4 -48.1
0001-121 00 01 09.1 -12 08 30 00 03 42.7 -11 51 48 .3 8 1.15 .10 84.4 -71.1
0001-179 00 01 09.4 -17 57 10 00 03 42.9 -17 40 28 .2 4 1.59 .06 71.1 -75.5
0001-114 00 01 10.8 -11 25 09 00 03 44.4 -11 08 27 .3 4 .94 .04* P 85.6 -70.5
0001-237 00 01 14.6 -23 46 24 00 03 48.1 -23 29 42 .2 3 1.77 .06 P 49.0 -78.6
0001-387 00 01 20.7 -38 43 46 00 03 53.9 -38 27 04 .3 5 .90 .05 P 341.3 -74.9
0001-312 00 01 21.8 -31 16 29 00 03 55.1 -30 59 47 .2 3 2.52 .09 P 9.7 -78.9
0001-111 00 01 22.3 -11 09 53 00 03 55.9 -10 53 11 .2 3 1.02 .04 P 86.1 -70.3
0001+058 00 01 26.6 05 50 58 00 04 00.5 06 07 40 .3 7 1.28 .08 102.2 -54.8
0001-233 00 01 29.4 -23 23 39 00 04 02.8 -23 06 57 .2 4 1.23 .05 C P 50.8 -78.6
0001+170 00 01 35.5 17 01 10 00 04 09.5 17 17 52 .2 6 1.61 .06 107.1 -44.1
0001-531 00 01 40.3 -53 10 35 00 04 12.9 -52 53 53 .7 17 1.25 .24 P 318.6 -62.8
0001-224 00 01 43.9 -22 29 36 00 04 17.3 -22 12 54 .4 6 .81 .06 55.0 -78.2
[rwayth@play ~/MWA]$
```


Making Sims

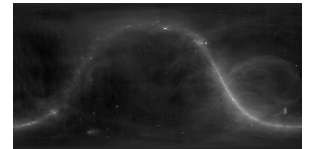
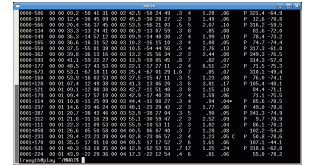
- Ingredients: 2



This is a logarithmic scale

Making Sims

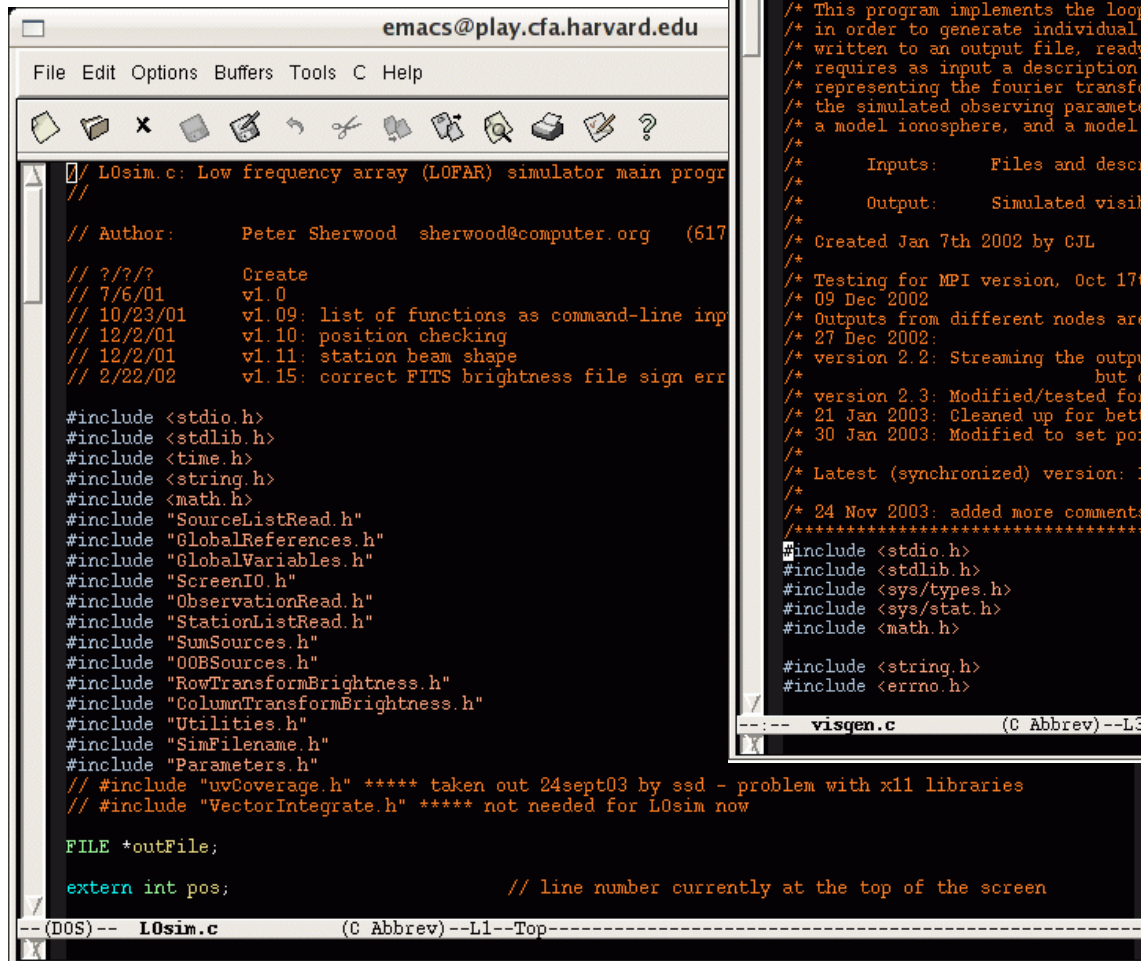
- Ingredients:
 - Molonglo 408 MHz (MRC)
 - Haslam 408MHz all-sky map
 - ~1/3 degree resolution
 - Point sources are not well represented (good)
 - Emission dominated by the Galaxy



Making Sims

visgen

- Ingredients: 3



```
emacs@play.cfa.harvard.edu
File Edit Options Buffers Tools C Help

// L0sim.c: Low frequency array (LOFAR) simulator main program
//
// Author: Peter Sherwood sherwood@computer.org (617
//
// ???/? Create
// 7/6/01 v1.0
// 10/23/01 v1.09: list of functions as command-line inp
// 12/2/01 v1.10: position checking
// 12/2/01 v1.11: station beam shape
// 2/22/02 v1.15: correct FITS brightness file sign err

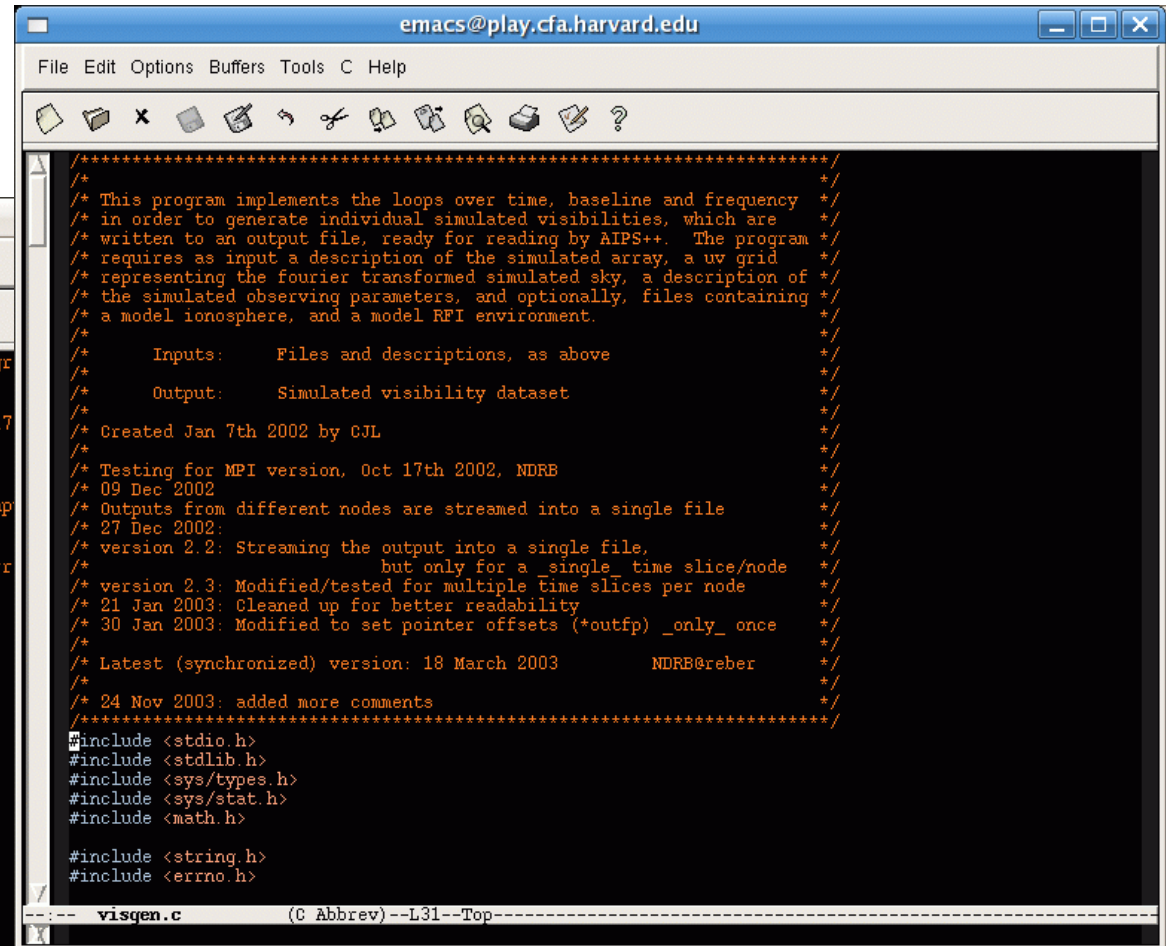
#include <stdio.h>
#include <stdlib.h>
#include <time.h>
#include <string.h>
#include <math.h>
#include "SourceListRead.h"
#include "GlobalReferences.h"
#include "GlobalVariables.h"
#include "ScreenIO.h"
#include "ObservationRead.h"
#include "StationListRead.h"
#include "SumSources.h"
#include "OOBSources.h"
#include "RowTransformBrightness.h"
#include "ColumnTransformBrightness.h"
#include "Utilities.h"
#include "SimFilename.h"
#include "Parameters.h"
// #include "uvCoverage.h" ***** taken out 24sept03 by ssd - problem with x11 libraries
// #include "VectorIntegrate.h" ***** not needed for L0sim now

FILE *outFile;

extern int pos; // line number currently at the top of the screen

--(DOS)-- L0sim.c (C Abbrev)--L1--Top--
```

L0sim



```
emacs@play.cfa.harvard.edu
File Edit Options Buffers Tools C Help

/* *****
/* This program implements the loops over time, baseline and frequency
/* in order to generate individual simulated visibilities, which are
/* written to an output file, ready for reading by AIPS++. The program
/* requires as input a description of the simulated array, a uv grid
/* representing the fourier transformed simulated sky, a description of
/* the simulated observing parameters, and optionally, files containing
/* a model ionosphere, and a model RFI environment.
/*
/* Inputs: Files and descriptions, as above
/*
/* Output: Simulated visibility dataset
/*
/* Created Jan 7th 2002 by CJL
/*
/* Testing for MPI version, Oct 17th 2002, NDRB
/* 09 Dec 2002
/* Outputs from different nodes are streamed into a single file
/* 27 Dec 2002:
/* version 2.2: Streaming the output into a single file,
/* but only for a single time slice/node
/* version 2.3: Modified/tested for multiple time slices per node
/* 21 Jan 2003: Cleaned up for better readability
/* 30 Jan 2003: Modified to set pointer offsets (*outfp) _only_ once
/*
/* Latest (synchronized) version: 18 March 2003 NDRB@reber
/*
/* 24 Nov 2003: added more comments
/* *****
#include <stdio.h>
#include <stdlib.h>
#include <sys/types.h>
#include <sys/stat.h>
#include <math.h>

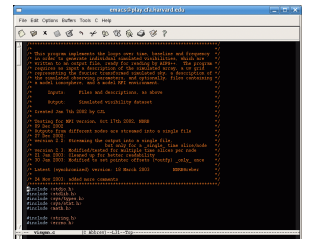
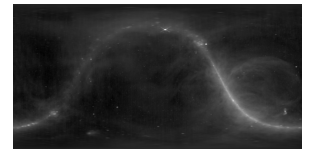
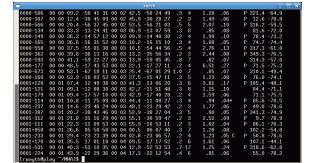
#include <string.h>
#include <errno.h>

--visgen.c (C Abbrev)--L31--Top--
```

MAPS = MIT Array
Performance
Simulator

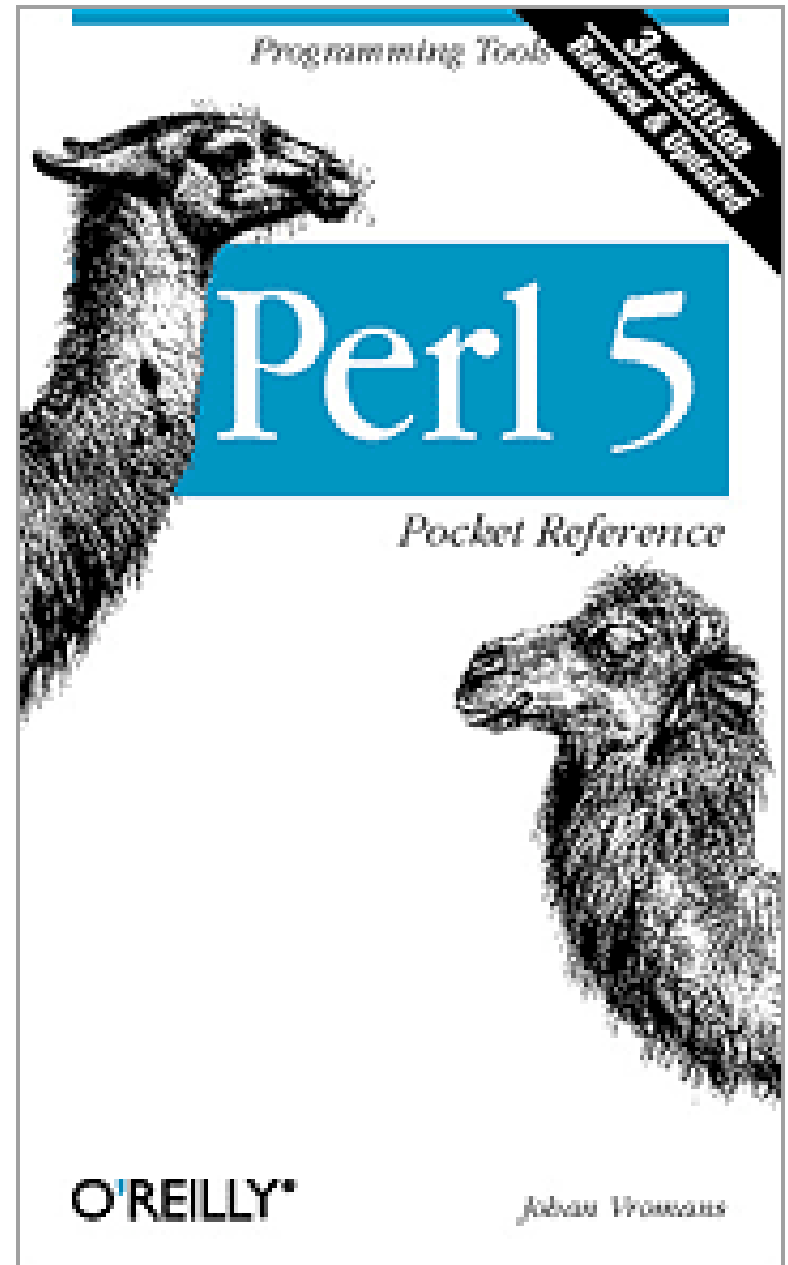
Making Sims

- Ingredients: 3
 - Molonglo 408 MHz (MRC)
 - Haslam 408MHz all-sky map
 - MAPS
 - **In:** sky model, array definition, observing parameters
 - **Out:** visibilities “observed” with a simulated telescope



Making Sims

- Ingredients: 4
 - Plus:
 - CFITSIO
 - FFTW
 - SLALIB/C



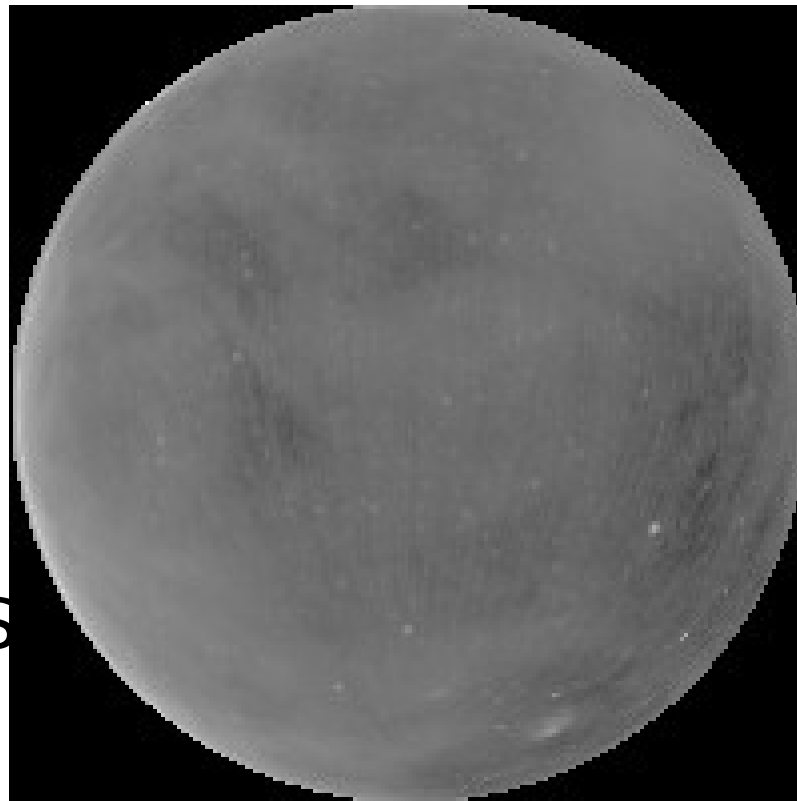
Making Sims

- Ingredients: 4

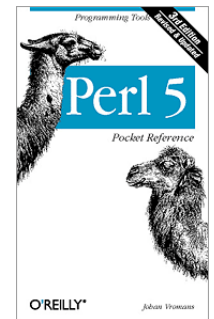
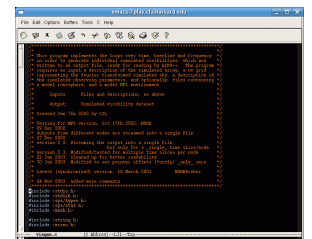
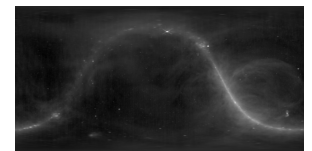
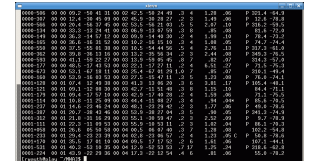
- Molonglo 408 MHz (MRC)
- Haslam 408MHz all-sky map
- MAPS
- Glue

- Method:

- 1) Make sky
- 2) MAPS
- 3) MAPS 2 UVFITS
- 4) miriad

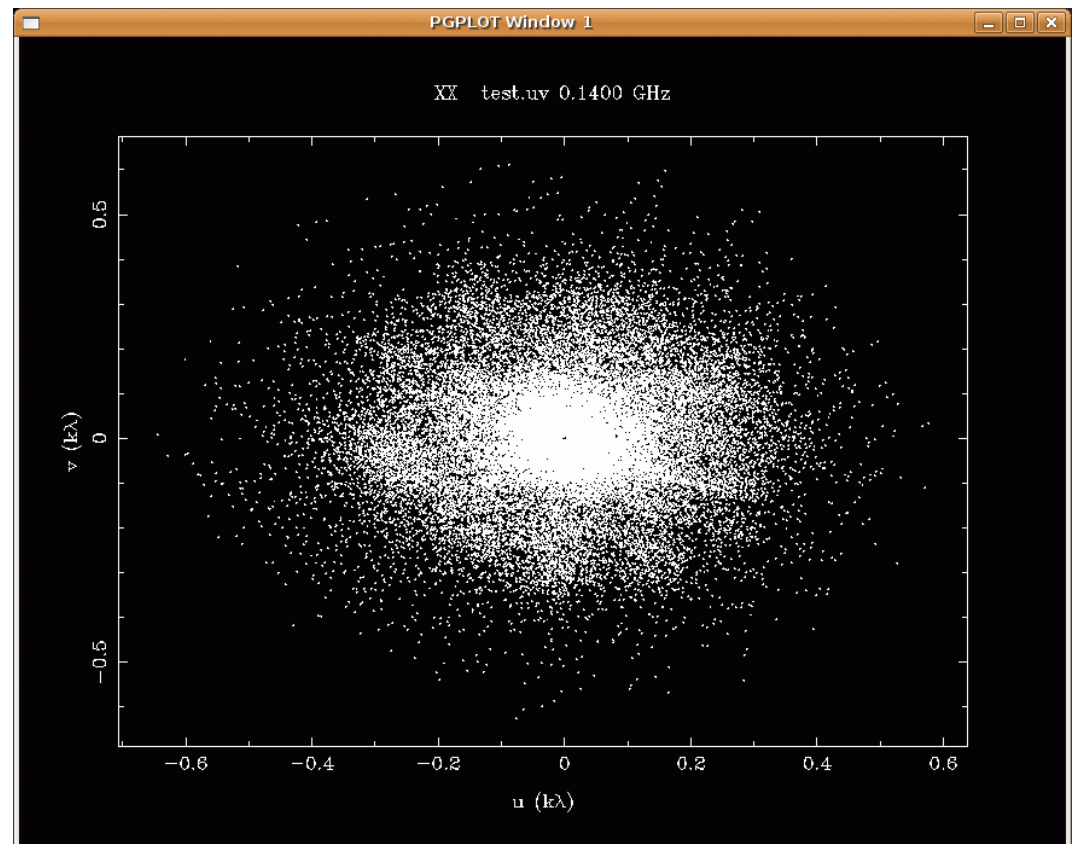


This is a log scale image

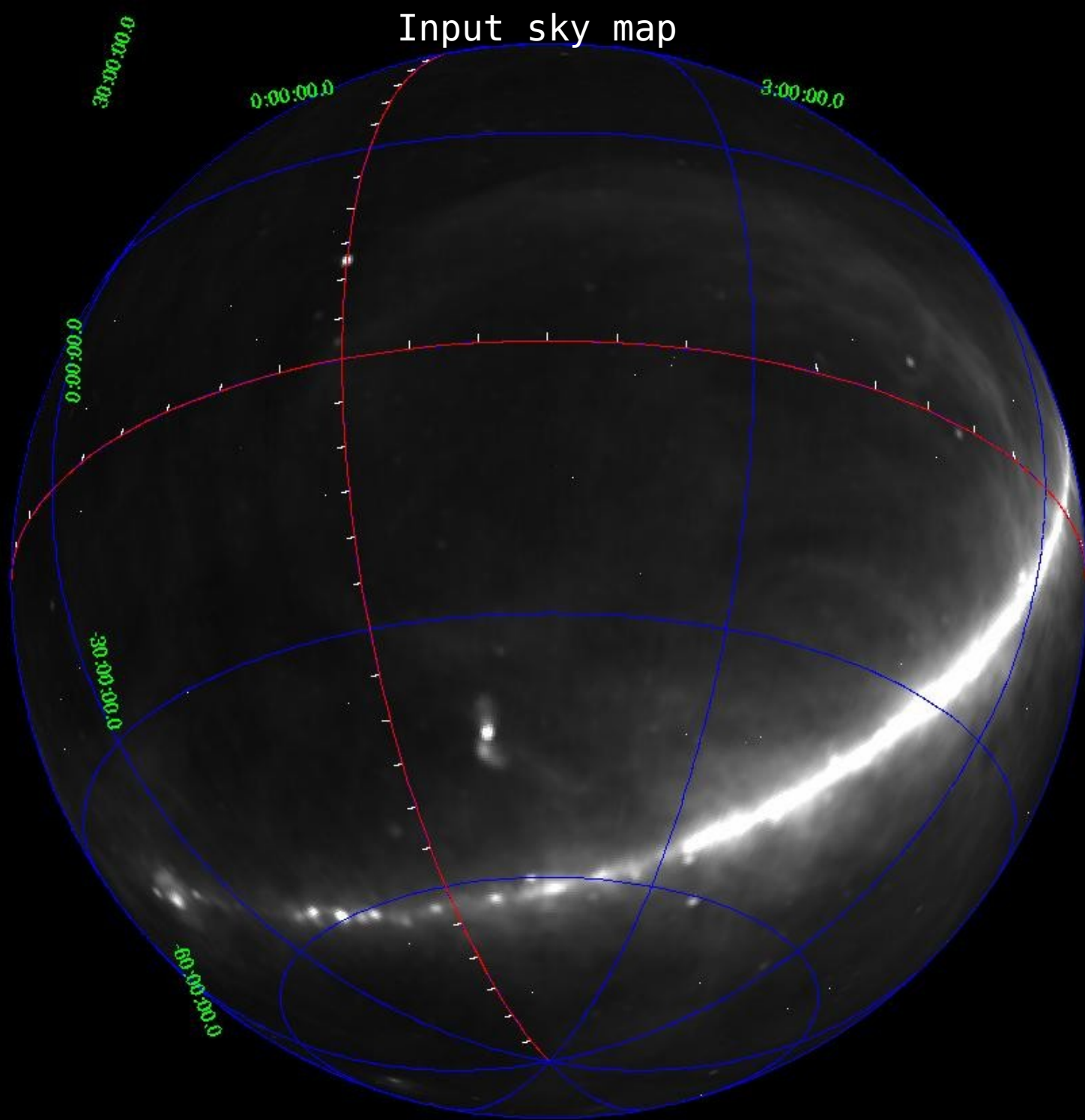


Simulation Specs...

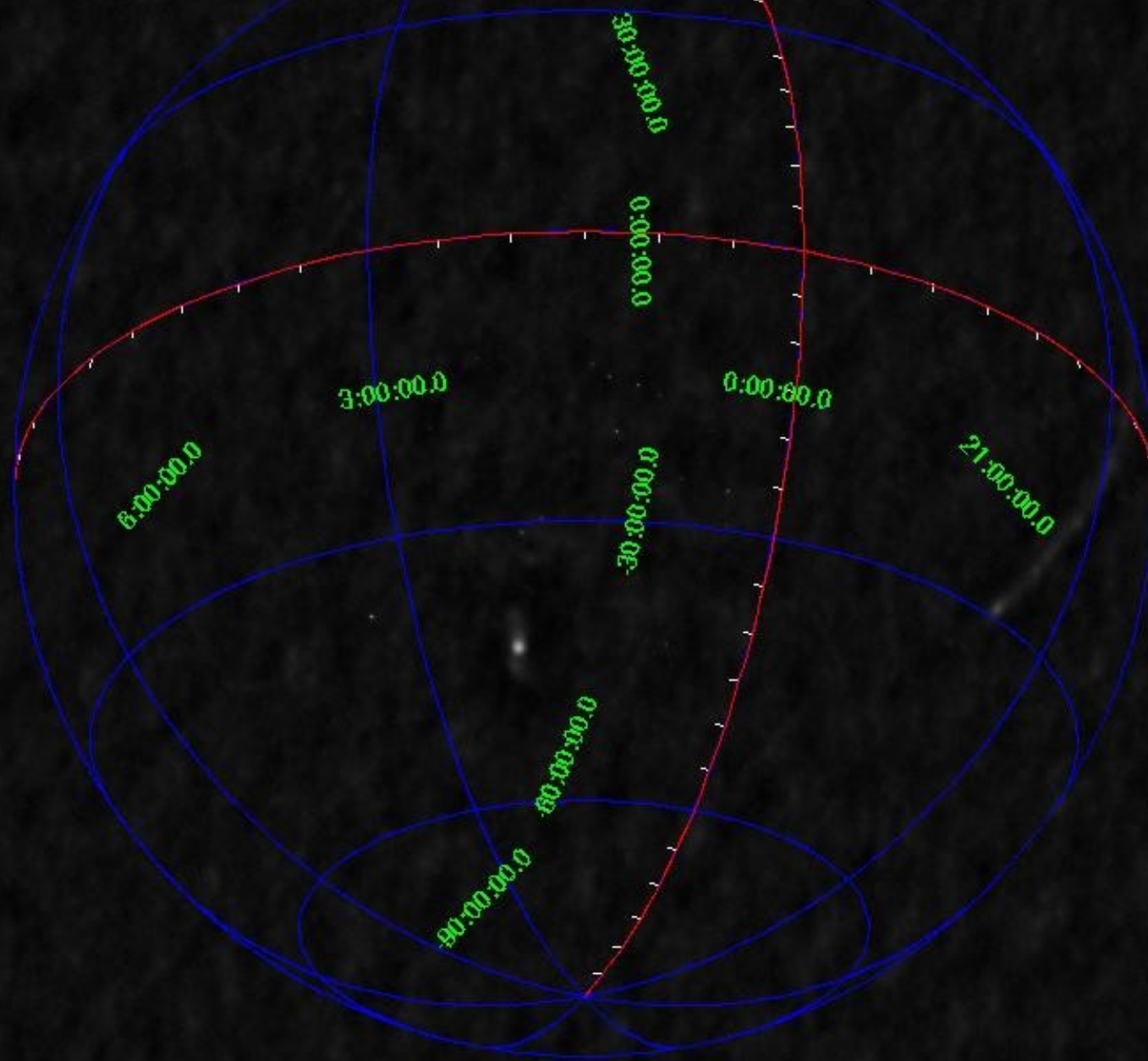
- 250 antennas
- 1.5 km max baseline
- 10m min baseline
- r^{-2} density
- 200 brightest sources from MRC (ex CenA)
- Sky from Haslam
- coplanar
- antennas consisting of 4x4 phased array of isotropic receivers

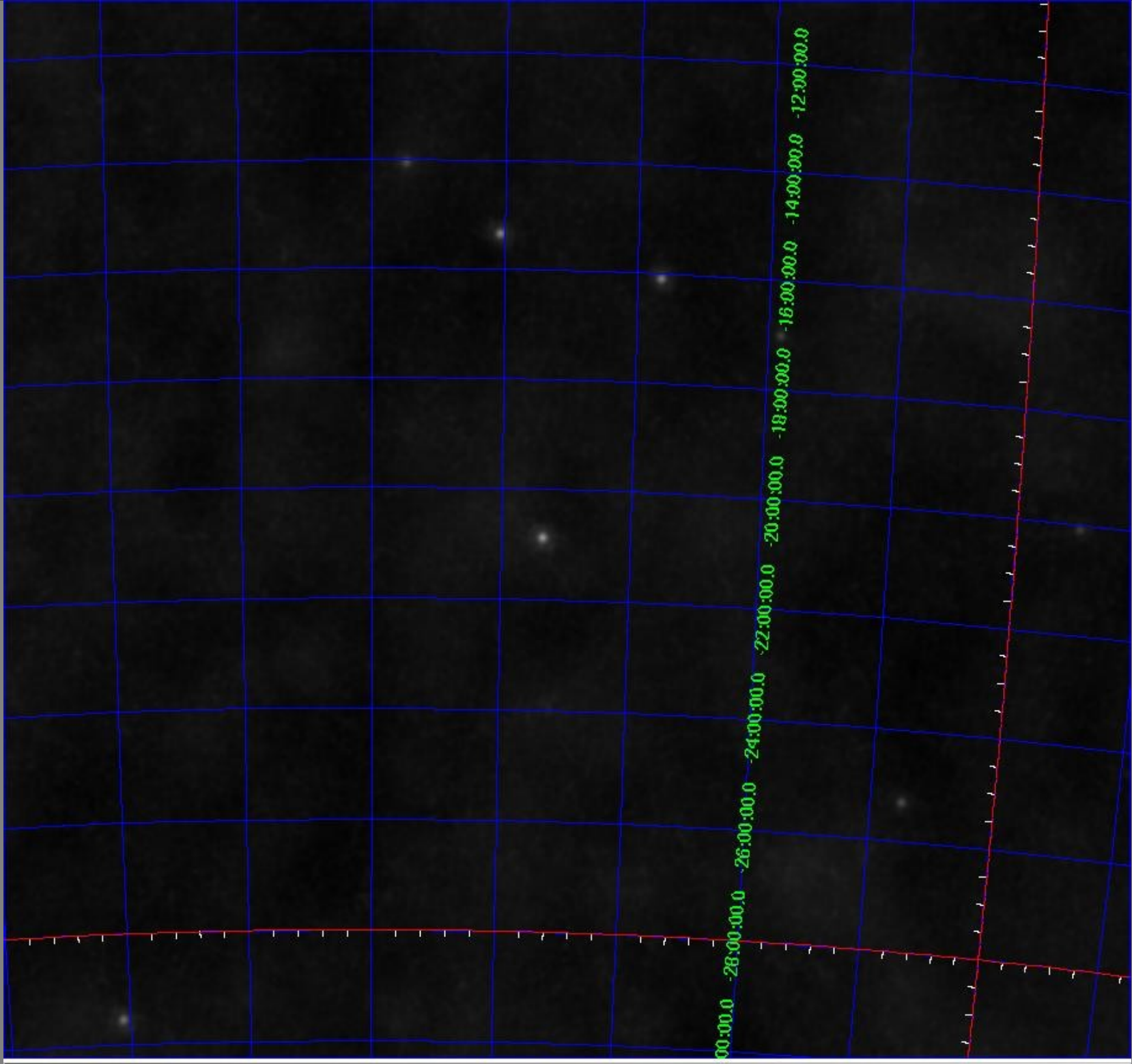


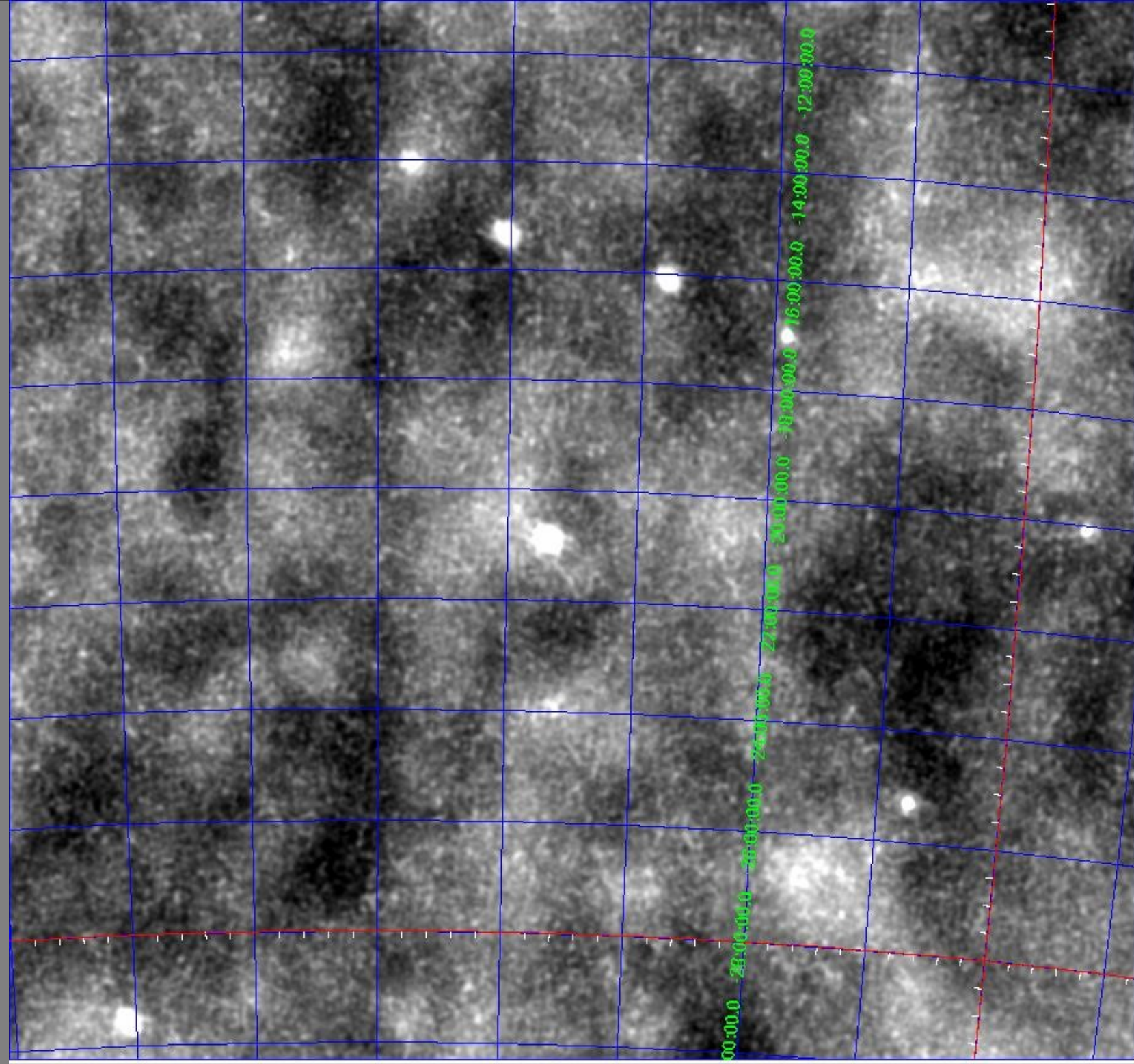
Input sky map



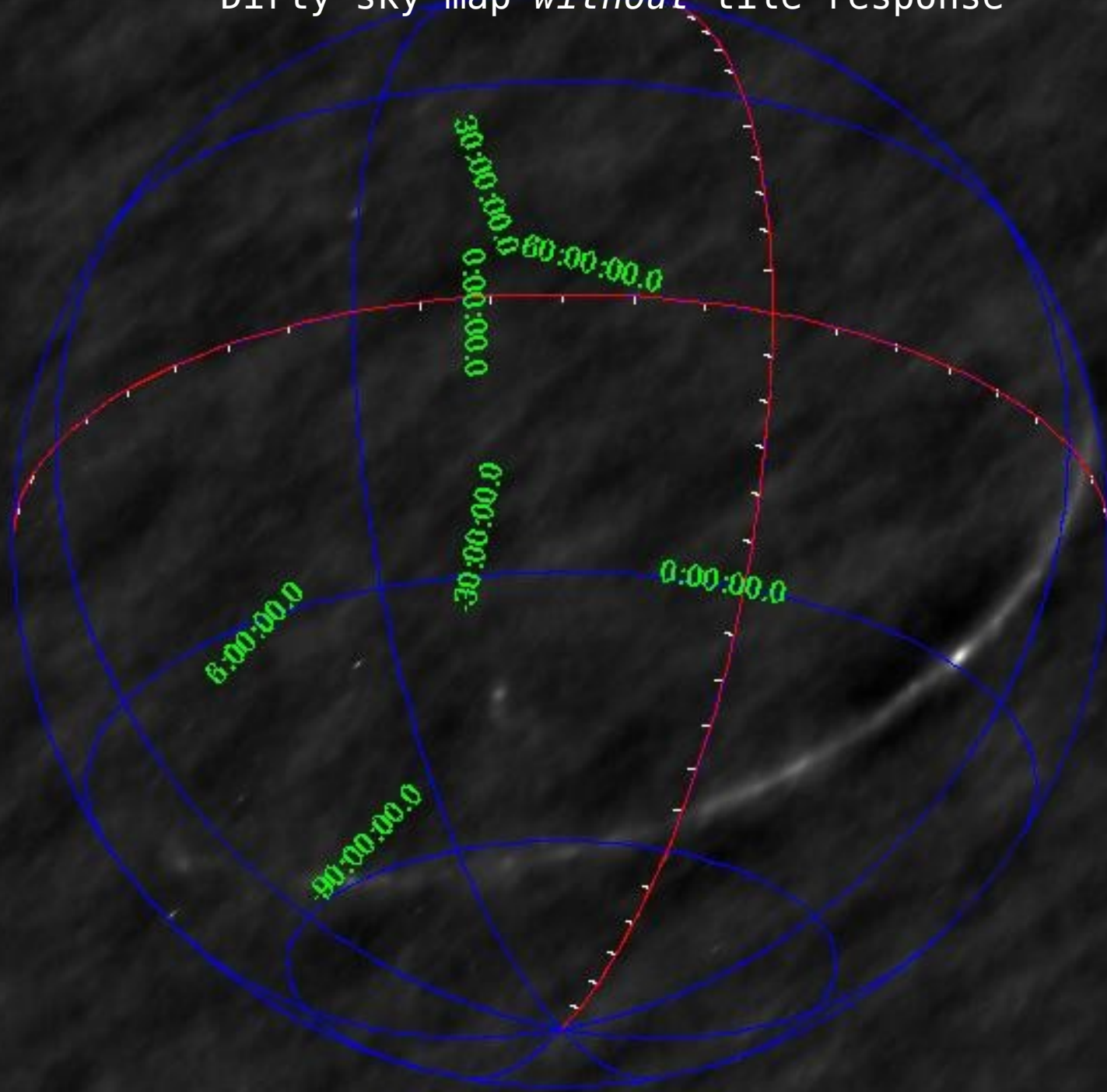
Dirty sky map with tile response
(tile pointing at zenith)







Dirty sky map *without* tile response



Results so far...

- Have generated simulated visibilities for
 - Single freq, single snapshot (any HA, LAT)
 - Takes ~10 mins, requires 2GB memory
 - Pipeline is in place, straightforward to generate long integrations & wide frequencies from here
- Sidelobes from extended sources (gal, Cen A) are significant
 - A few times what was expected from point sources alone
 - caveats: 10m minimum baseline, snapshot, monochromatic
- Data essential for testing, come and get it!

Next . . .

- non-ideal antenna elements
- Spectral indices on sources, sky
- Polarisation on sources
- Polarisation of antenna response

Fin