CRT Simulation

The simulation described here will create 3D pixel maps of observed flux, for various models of the sky, telescope, and electronics.

These data are used by analysis modules, prototypes of the "final" scientific analysis.

We will use these results to optimize CRT design.

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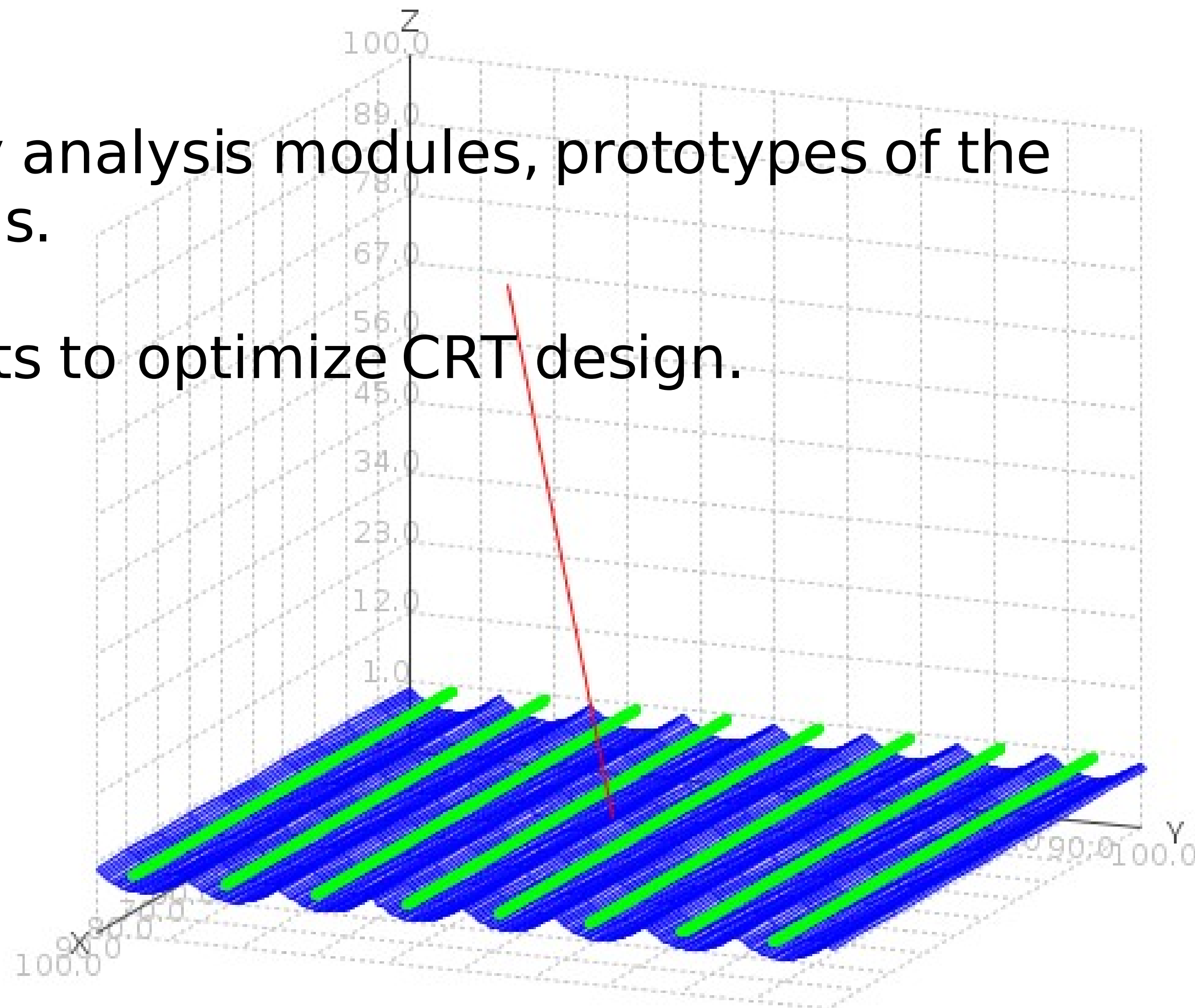


Purpose

- Measuring BAO signal is not trivial
- We need a detailed model of the sky and instrument:
  - Reasonable foregrounds and signal;
  - antenna and receiver models;
  - firmware options (zero padding, windowing, etc.)
- Begin with identical antennas and receivers, then evaluate impact of variations on the BAO analysis.

General Approach

- It is not feasible to simulate the time domain in detail – that would be 1 Tbyte/sec. Rather, we simulate the results of the DFTs.
- We will calculate the power spectrum: average power and rms fluctuations.
- The instrument is modeled as a linear transformation of power (T) on the sky.
- One ”exposure” yields 3D pixel map of T
  - coadd these to form the intensity map
  - this is input to the BAO analysis

Indices and Coordinates

Conjugate Variable Indices:

x: reciever number along cylinder ↔ m: θ parallel to cylinder

$N_X = N_m = 2^{10}$

y: cylinder number ↔ n: φ around cylinder axis

$N_Y = N_n = 2^3$

t time sample ↔ f frequency bin

$N_t = N_f = 2^{16}$

Sample bins in physical space by $N_{SAMPLE} = 2^3$

$N_\Theta = 2^{13}$ $N_\mu = 2^6$ $N_\upsilon = 2^{19}$

Coordinates: $\mathbf{k}=(k_X,k_y,k_z)$; $k=|\mathbf{k}|=\omega/c$

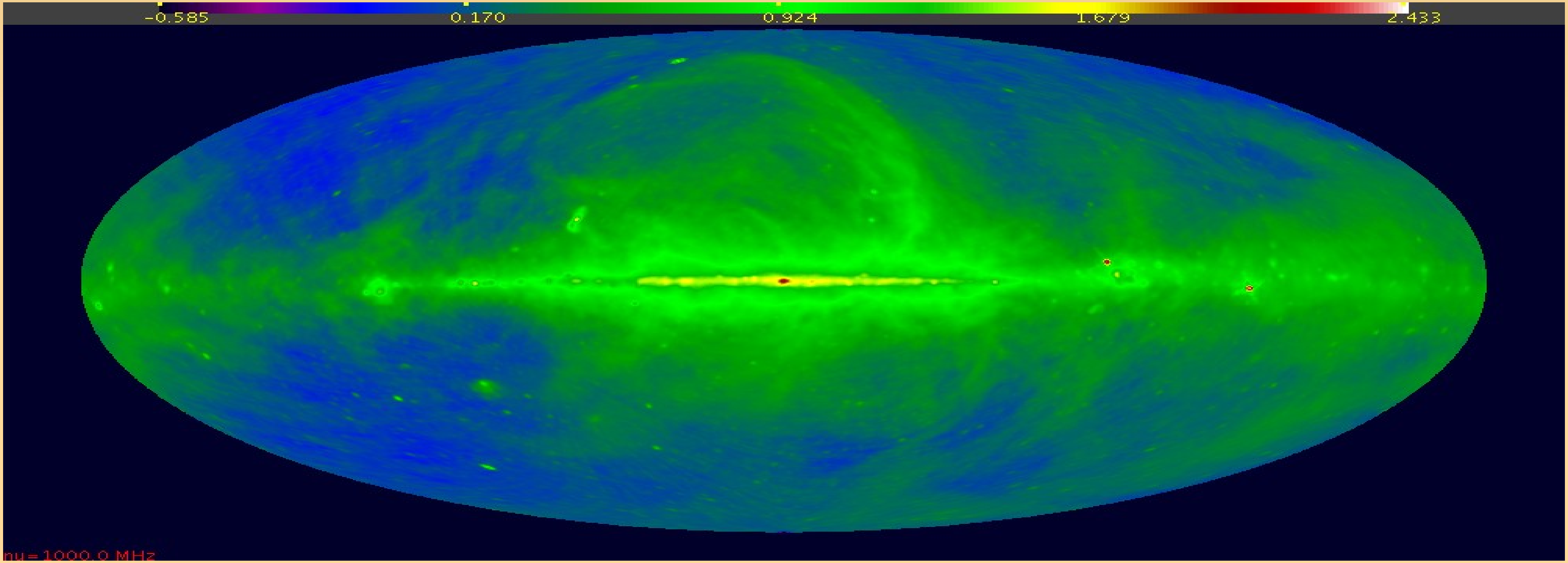
$k_X = k\sin(\theta)$ $k_y = k\cos(\theta)\sin(\varphi)$ $k_z = k\cos(\theta)\cos(\varphi)$

Define $\omega_f = 2\pi f/N_f\Delta t$, and angular size of pixels Δθ, Δφ

$\theta \in (-\pi/2, \pi/2)$ $\varphi \in (-\pi/2, \pi/2)$ $\upsilon \in (750, 1000)$ MHz

Sky Model T(ra,dec,omega)

~~back~~foreground: Global Sky Model
  http://space.mit.edu/home/angelica/gsm/
HI signal: N-body simulation, or discrete sources.



$$I(k) = \frac{2k_B T(f, \theta, \varphi)}{\lambda^2}$$

$$\sigma(k) = \sqrt{I(k)}$$

Constant Sky

$$F_\nu = F_0(\nu/\nu_0)^\alpha \quad \alpha=-0.6$$

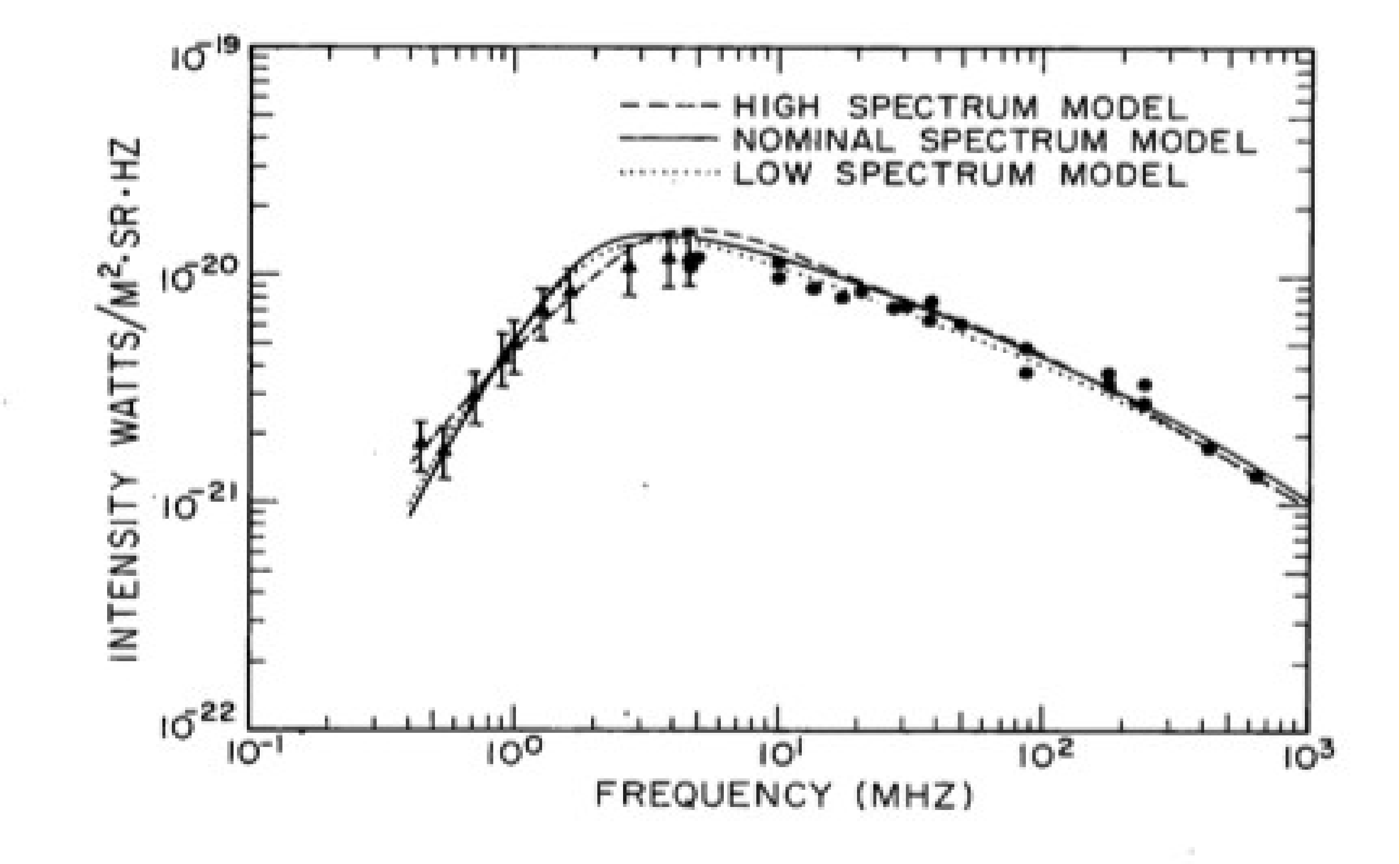


Figure from Cummings, Stone and Vogt,
13th International Cosmic Ray Conference, Denver, 1973.

Signal Options

- No signal
- delta-function with one ”pixel” at constant temperature
- real bao signal from Nick Gnedin n-body simulation

Telescope Model

- Array of receivers with regular spacing
- $N_x = 2^{10}$ $D_x = 0.10$ m
- $N_y = 2^3$ $D_y = 12.5$ m
- Antenna model (simple, no polarization):

$$A_{xy}(\boldsymbol{k}) = \sqrt{d_x d_y}\,\frac{\sin(k_x d_x)}{k_x d_x}\,\frac{\sin(k_y d_y)}{k_y d_y}$$

Electronics Model

- Receiver bandwidth: 750 to 1000 Mhz (z from 0.4 to 0.9) constant gain: $G_{xy}(\omega) = 1$
- Constant noise T 50 K: $\eta_{xy}(\omega) = \sqrt{k_B T_{Nxy}(\omega)}$
- Digitize voltage with $\Delta t = 2$ ns for $N_t = 2^{16}$ samples
- ”exposure time” = 131 micro-sec.
- Front-end electronics; DFT to calculate 3D intensity pixel map.
- We simulate the results of the DFT for one exposure.

Simulate One Exposure

For each pixel in fmn (frequency, x-angle, y-angle) for the sky an instrument model, calculate mean power and its rms variation.

John Marriner's write-up describes how to calculate the mean power per pixel h_{fmn} and its variance δh_{fmn}.

For one exposure, in each pixel fmn, calculate h_{fmn} and δh_{fmn}. Choose a random number from a normal distribution with this mean and sigma.

Change the random number seed for the *next* exposure.

Status

- We have code in place to calculate the mean power seen in each receiver and the detected power in each pixel.
- Confirming that the normalization is correct.
- Scans of intensity vs l, m, and n make sense.
- It is slow.