Minimally Invasive CMB Mapmaking

Gil Holder

McGill

Canadian Institute for Advanced Research

Collaborator: ***Tom Crawford***
(Chicago)

Outline

- What is the problem?
- Single detector scanning sky
  - Space = time
- Finite array
  - Array timestreams in Fourier space are simple
  - Signal moving through array shows up as a thin plane in Fourier space
- Implications:
  - "1/f" noise not so scary
  - cross-linking requirements depend on science

WARNINGS:

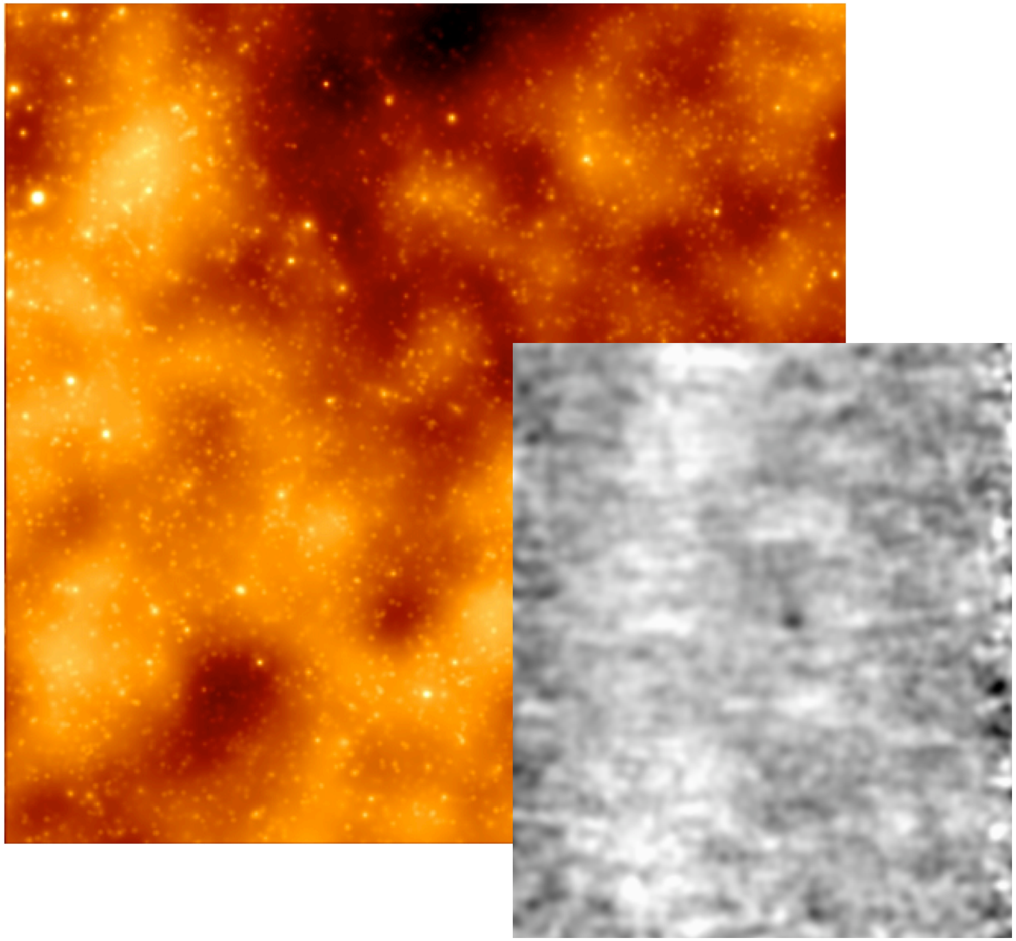
I am a theorist

This is not an SPT policy

This is *highly* idealized

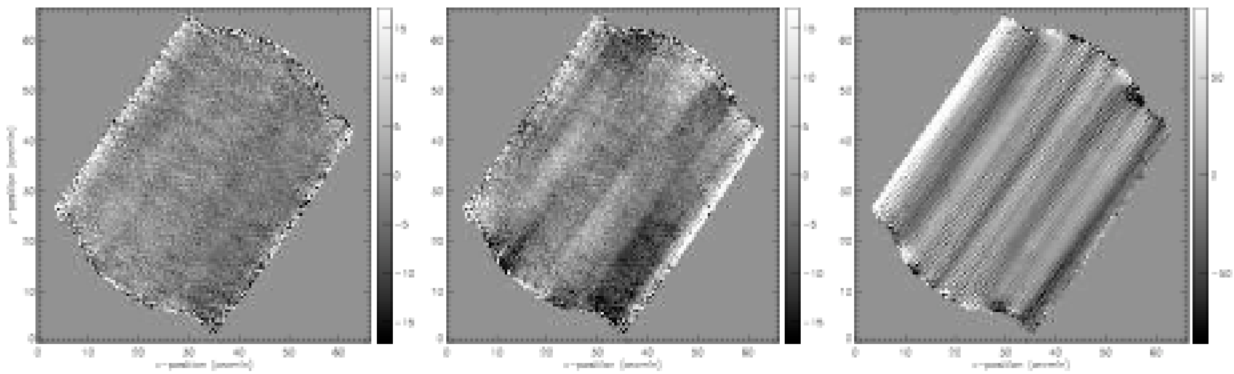
Cosmic Mapmaking

- How do we make an image which maximizes science opportunities?

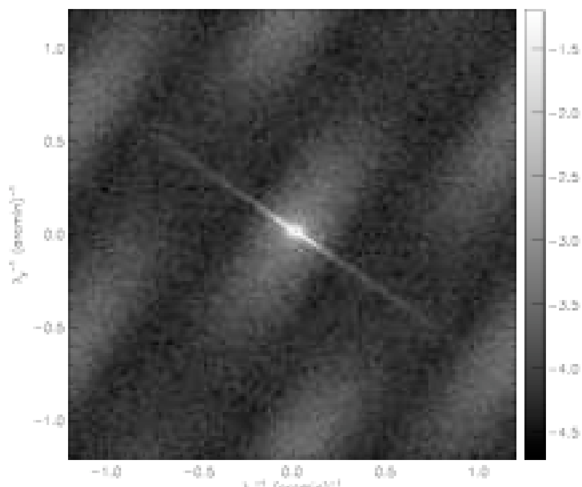


Striping

- Common to get stripes in maps perpendicular to the scan direction
- De-striping maps non-trivial



map space



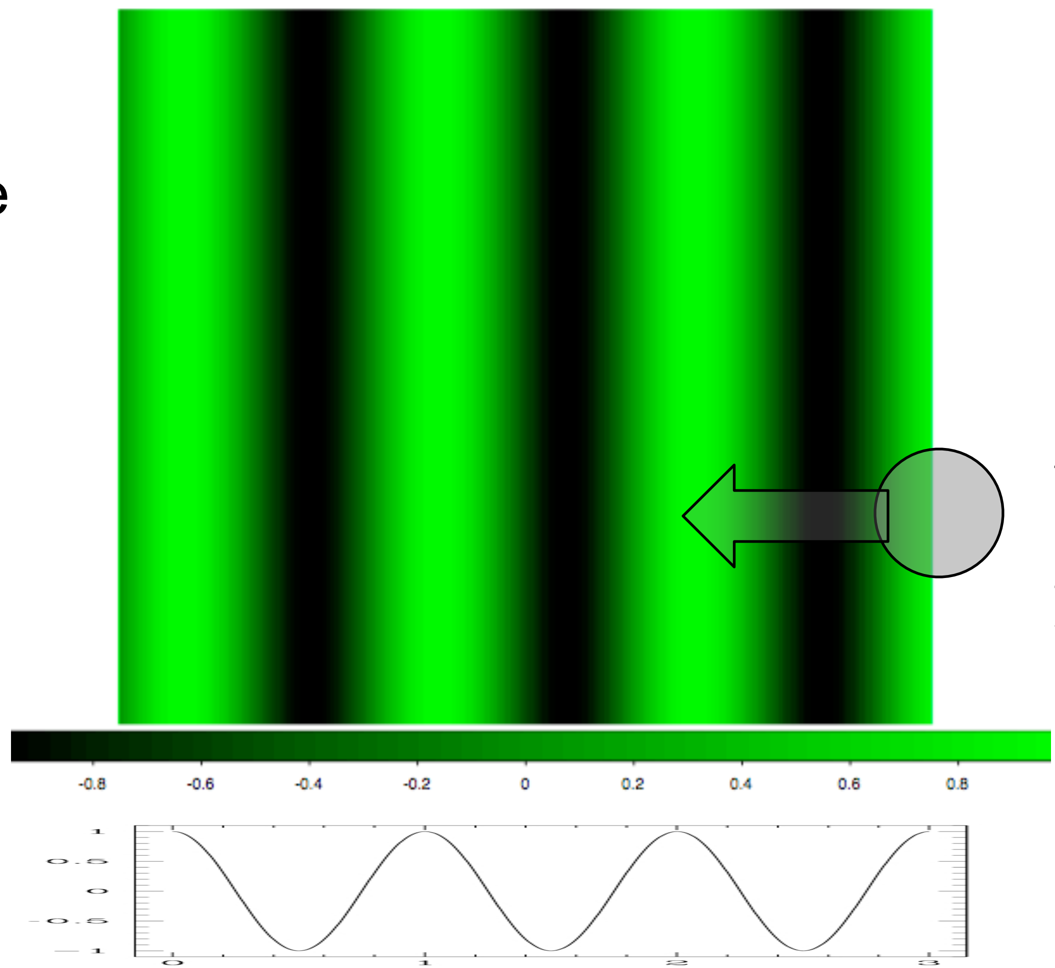
Fourier space

Patanchon et al ; BLAST data

astro-ph/0711.3462

Single detector

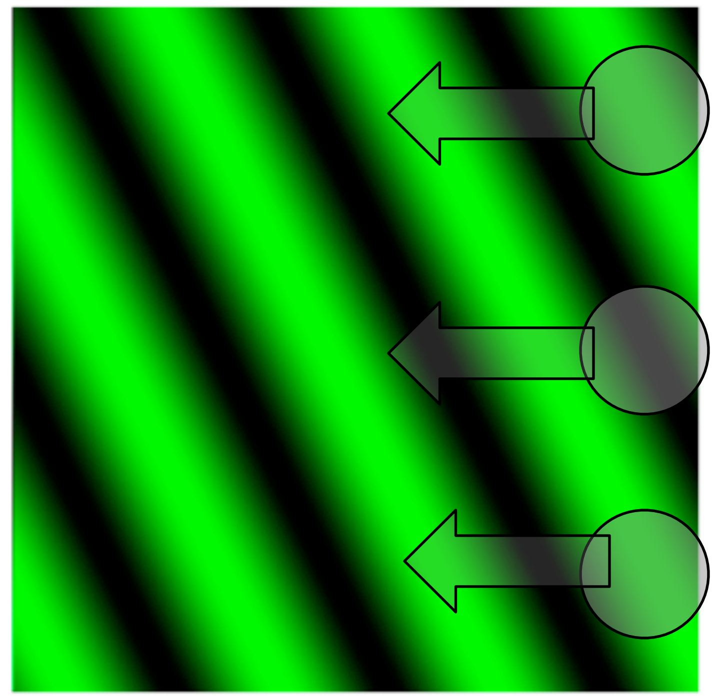
- A single detector measures the sky at some location at some time, with the location moving across the sky at constant speed

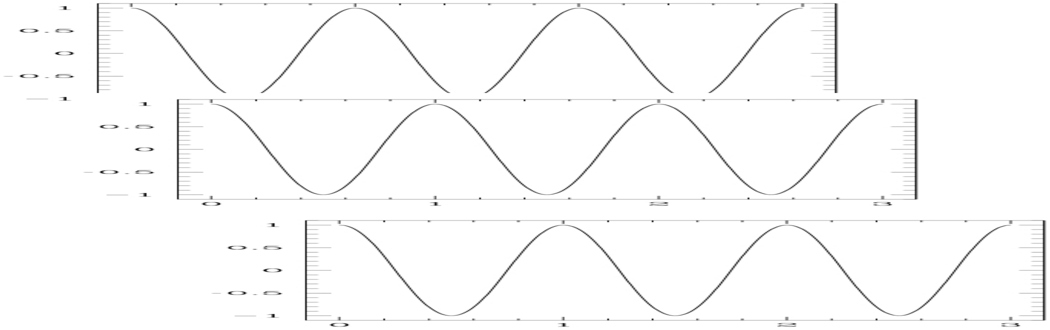


Spatial frequencies along scan map into temporal variations in detector

Multiple Detectors - y

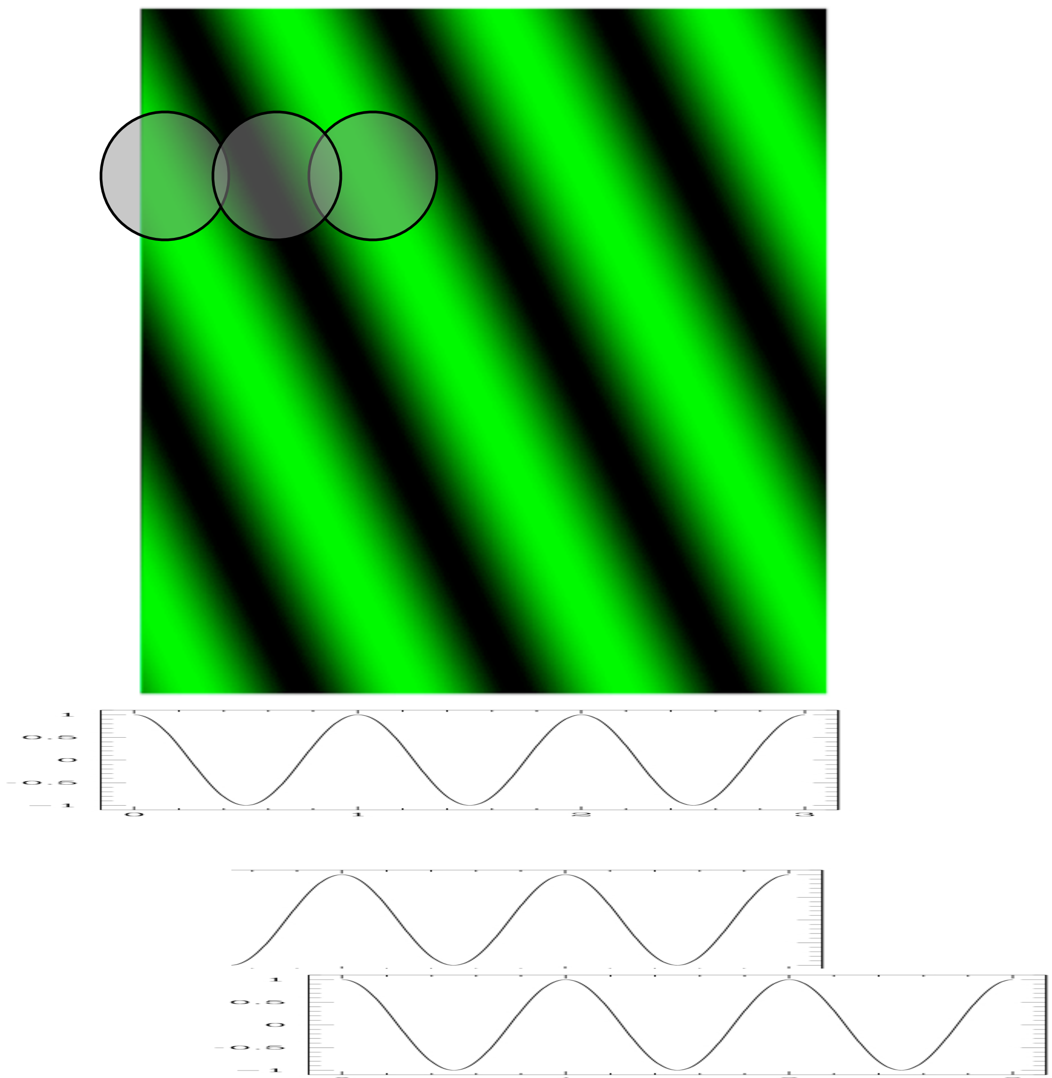
- Temporal frequency set by x-spacing
- y spatial frequency unaffected





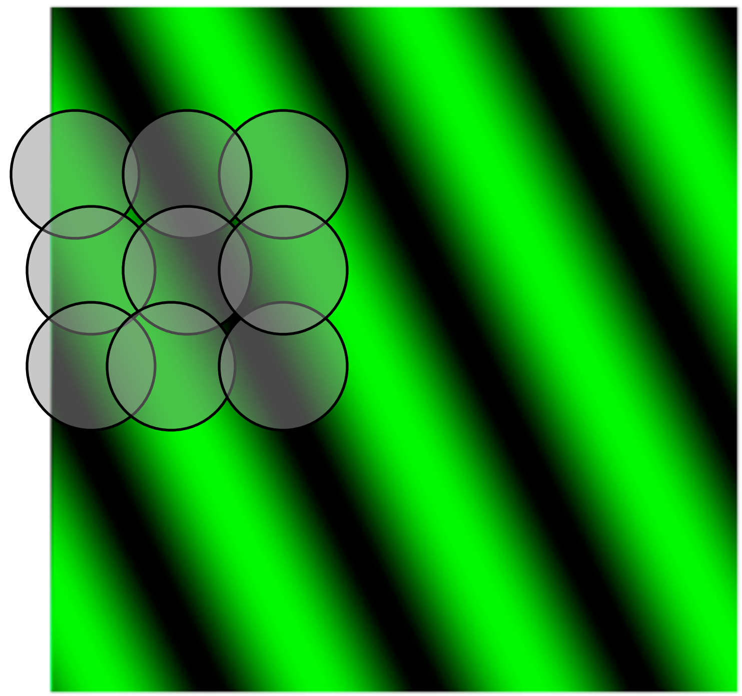
Multiple Detectors - x

- Temporal frequency set by x-spacing
- x spatial frequency must match temporal frequency



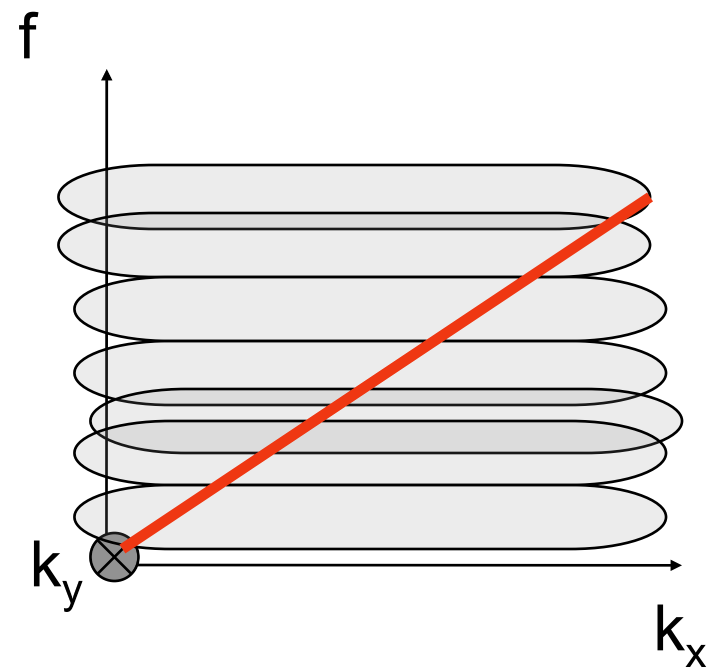
Multiple Detectors: Array

- Detector y direction maps into y on sky
- Detector time domain maps into x on sky
- Detector x direction provides redundant modulation



Fourier transform the data cube

- Fourier transform data stream w.r.t. time, detector pixel x, detector pixel y
- Signal strongly localized to a plane (set by scan speed)
- Noise easy to understand
- Atmosphere also confined to a different plane (set by wind speed and scan speed)



- "sky x" maps into f
- array in x-direction picks out line in Fourier space

“Real” Arrays

- Finite timestream, finite field of view slightly more difficult
- Sky structure along the scan direction shows up in f, not kx!
- Mixing is completely calculable from geometry, and can be measured from data

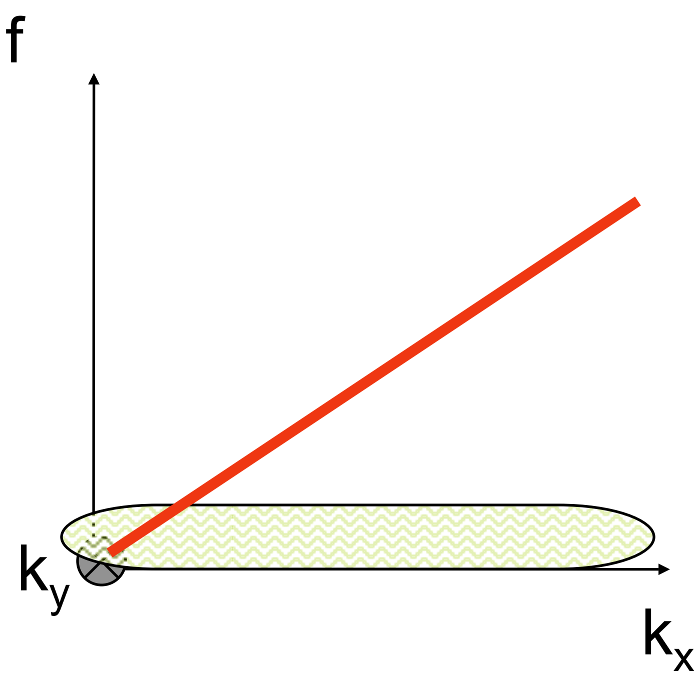
$$\underbrace{\tilde{T}_c(k_x, k_y, f)}_{\text{FT with respect to array position and time}} = \underbrace{\left[\int\int di' dj e^{2\pi i(i' f/v + j k_y)} T_c(i', j) W_j(j)\right]}_{\text{Fourier transform of sky (with window in perpendicular direction)}} \underbrace{\tilde{W}_i(k_x + f/v)}_{\text{Window due to finite array along scan}}$$

Implications

- Noise from atmosphere is strongly anisotropic (two planes meet in a line!)
- Most of the nastiness in maps from 1/f is strongly localized in Fourier space (just throw them out!)
- Conventional wisdom based on single detectors is not necessarily getting the whole picture

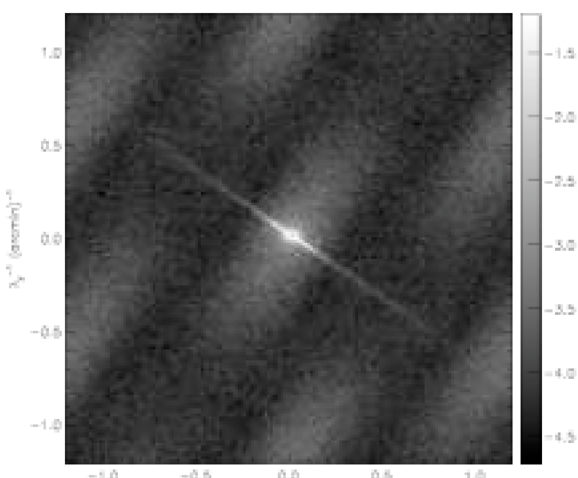
“1/f” Noise

- Pure 1/f noise (Gaussian, uncorrelated or trivially correlated, etc., etc.) should not be a problem beyond corrupting some small number of modes irrevocably - DOES THIS MATTER?
- The real question is what happens if “1/f” noise is really just “long timescale systematic drifts and miscellaneous other poorly understood effects”
- pure 1/f noise is a straw man: no array should be troubled much by it; evaluation of cross-linking strategies requires something more sophisticated than pure 1/f

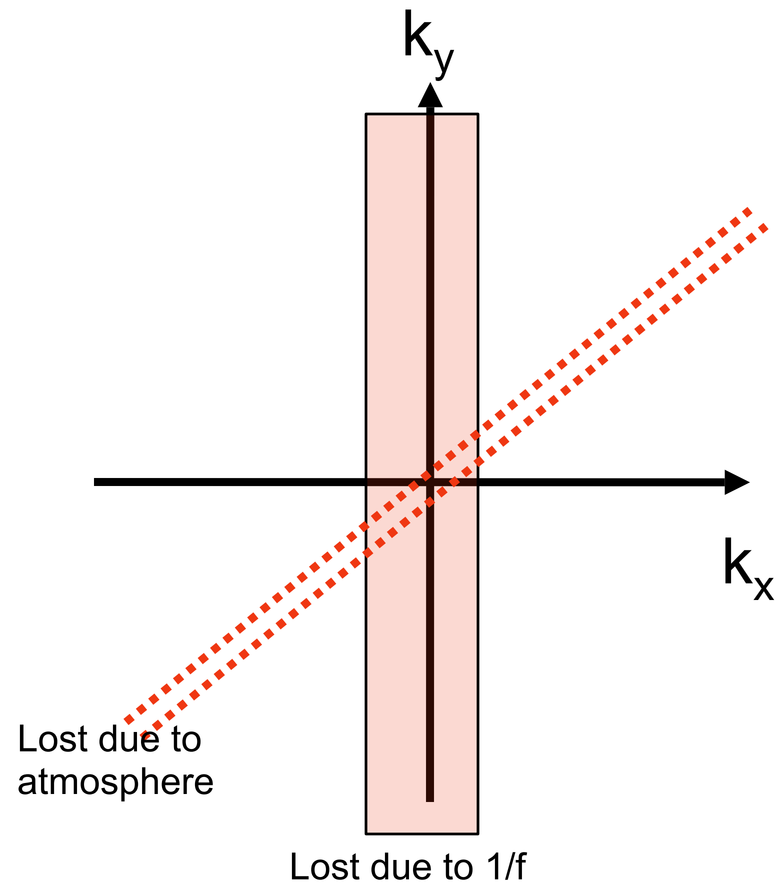


Cosmic cartography

- In a single scan, some fraction of the Fourier plane is missed
- To recover lost



Patanchon et al ; BLAST data noise



Crawford 2007 astro-ph/0702608

Conclusions

- Large arrays have relatively simple data streams in Fourier space
- Signal, detector noise, atmosphere noise well-separated in Fourier space except for a small number of well-localized modes (thus striping in the map)
- 1/f shouldn’t scare anyone; close relatives could be scary, though

Useless trivia: the "Flat Sky"

Spherical harmonics

$$Y_{\ell,m}(\theta,\phi) = \sqrt{\frac{(2\ell+1)(\ell-m)!}{4\pi(\ell+m)!}}\, P_\ell^{(m)}(\cos\theta)\, \underline{\underline{e^{im\phi}}} \qquad -\ell \le m \le \ell.$$

General Legendre equation

$$(1-x^2)\,y'' - 2xy' + \left(\ell[\ell+1] - \frac{m^2}{1-x^2}\right) y = 0,$$

Expand near the equator: x~0 !

$$y \sim \exp[i\sqrt{l(l+1)-m^2}\,\vartheta']$$

- near the equator, spherical harmonics are equivalent to Fourier expansion with

  - $k_x \sim m$
  - $k_y \sim [l(l+1)-m^2]^{1/2}$
  - $|k| \sim l$