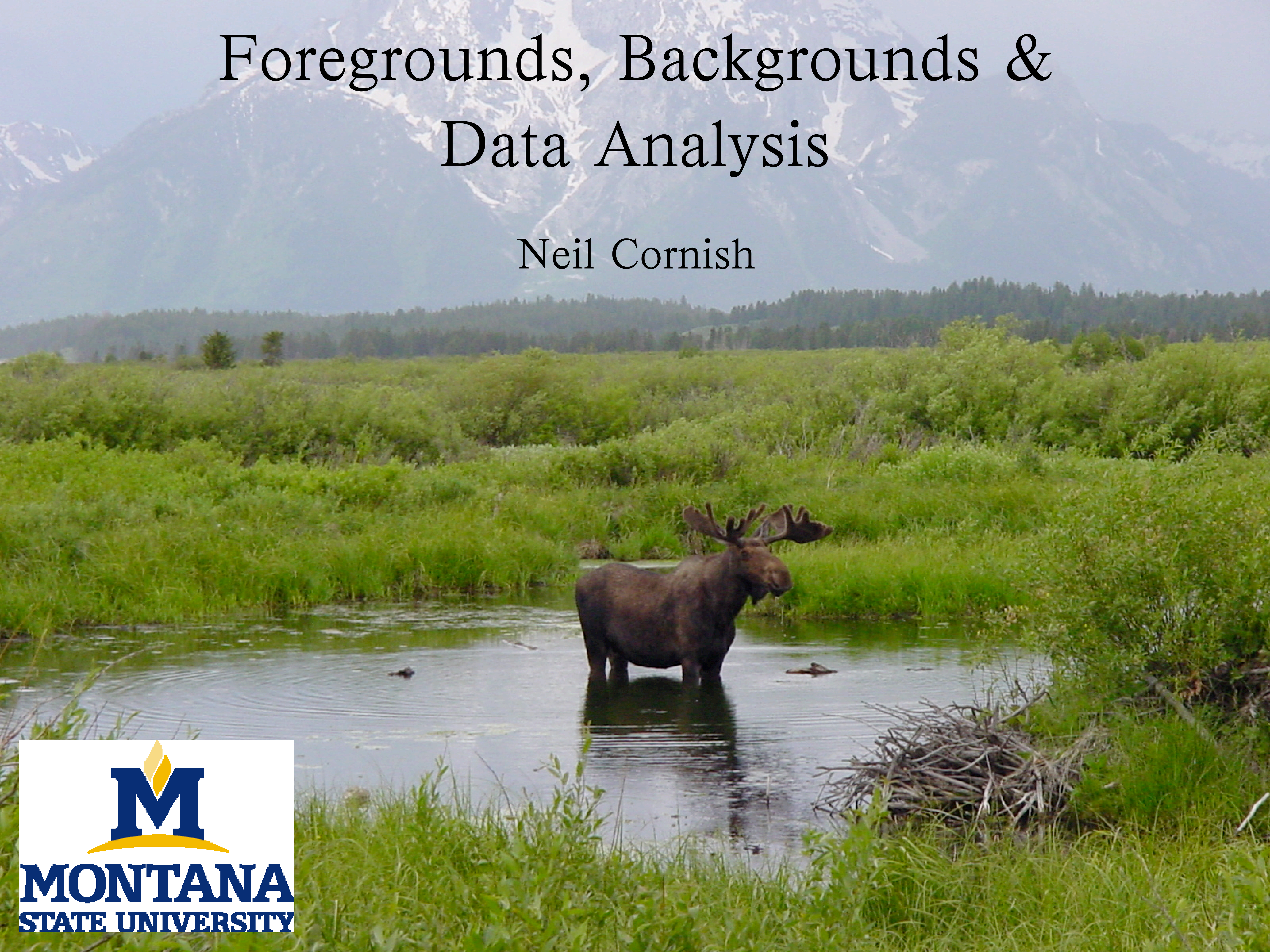
Foregrounds, Backgrounds & Data Analysis

Neil Cornish



MONTANA STATE UNIVERSITY

Embarrassment of Riches

- Galactic & Extra-Galactic Stellar Binaries
- Massive Black Hole Binaries
- Extreme Mass Ratio Inspirals
- Cosmic String Cusps
- Bursts
- KUs, UUs

"All Sky, All the Time"

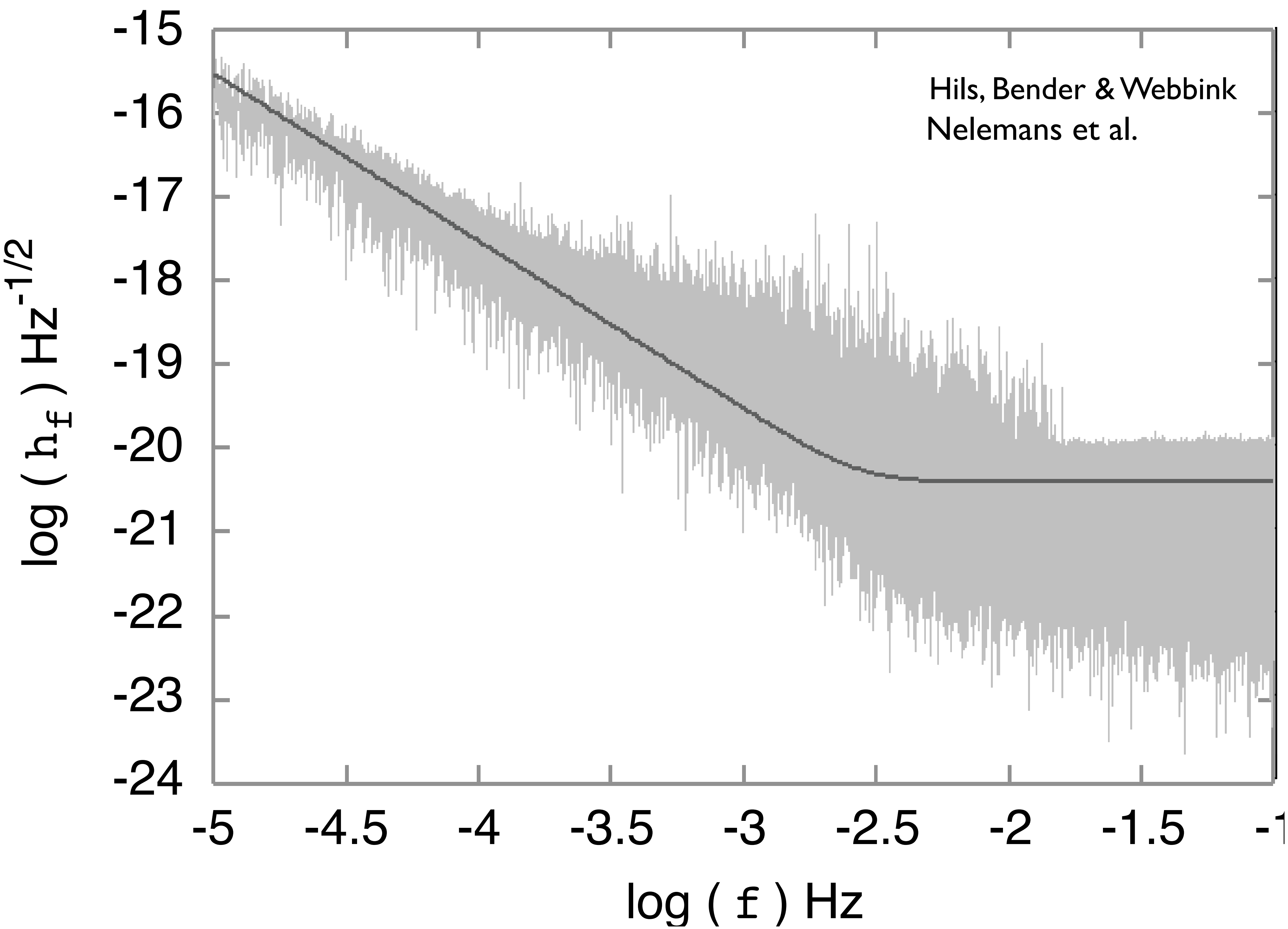
Non-Orthogonal Signals ➡ Overlap and Confusion

Backgrounds & Foregrounds

- Galactic Binary Foreground
- Backgrounds
  - Inflation
  - Extra Galactic Stellar Binaries
  - Massive Black Hole Binaries
  - EMRIS
  - Cosmic Superstrings
  - Other Exotica

"Be careful what you wish for"

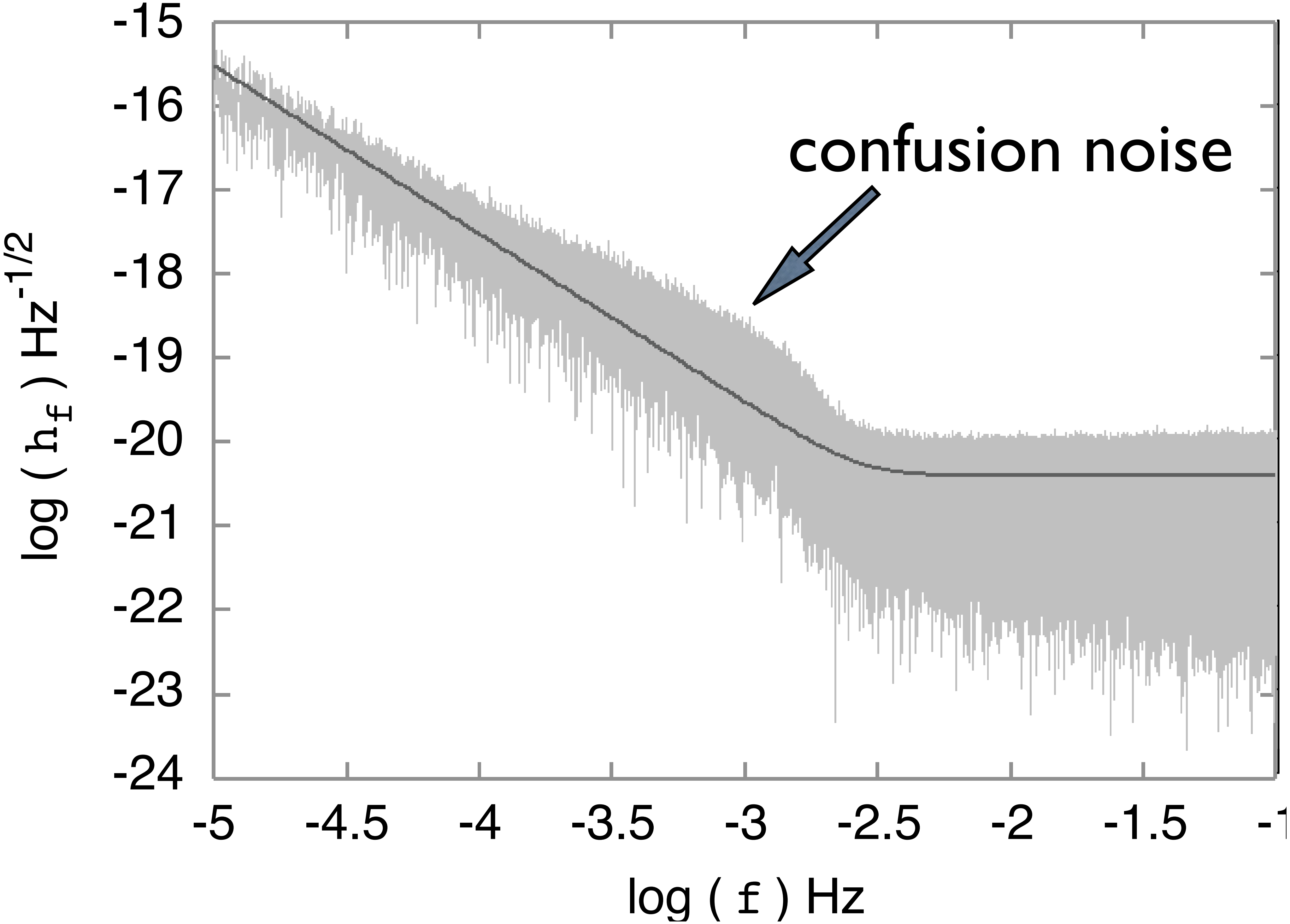
Galactic Foreground



Timpano, Rubbo & Cornish, PRD 73, 122001, 2006

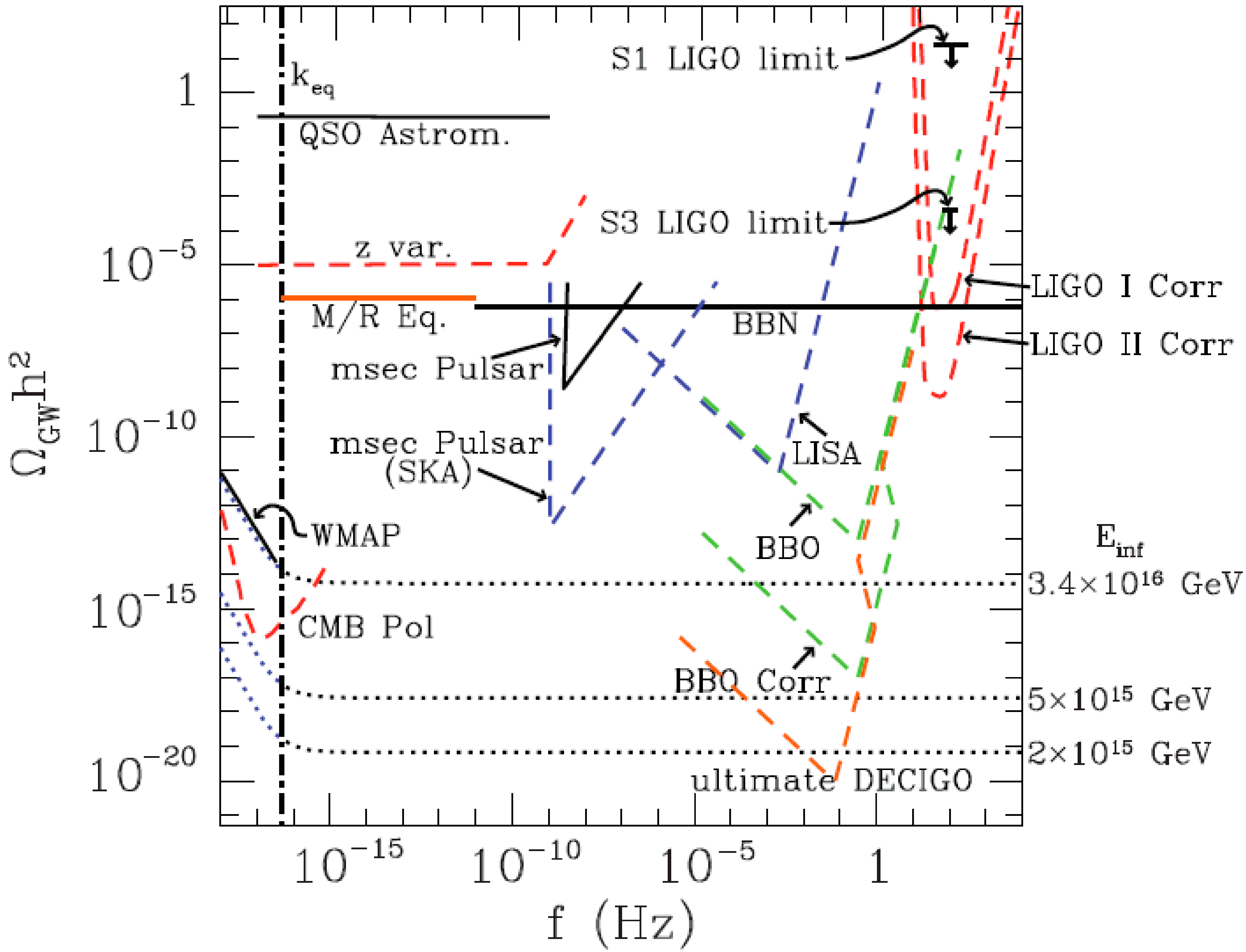
(also see Edlund et al. and Benacquista et al.)

Bright Sources Resolved & Removed



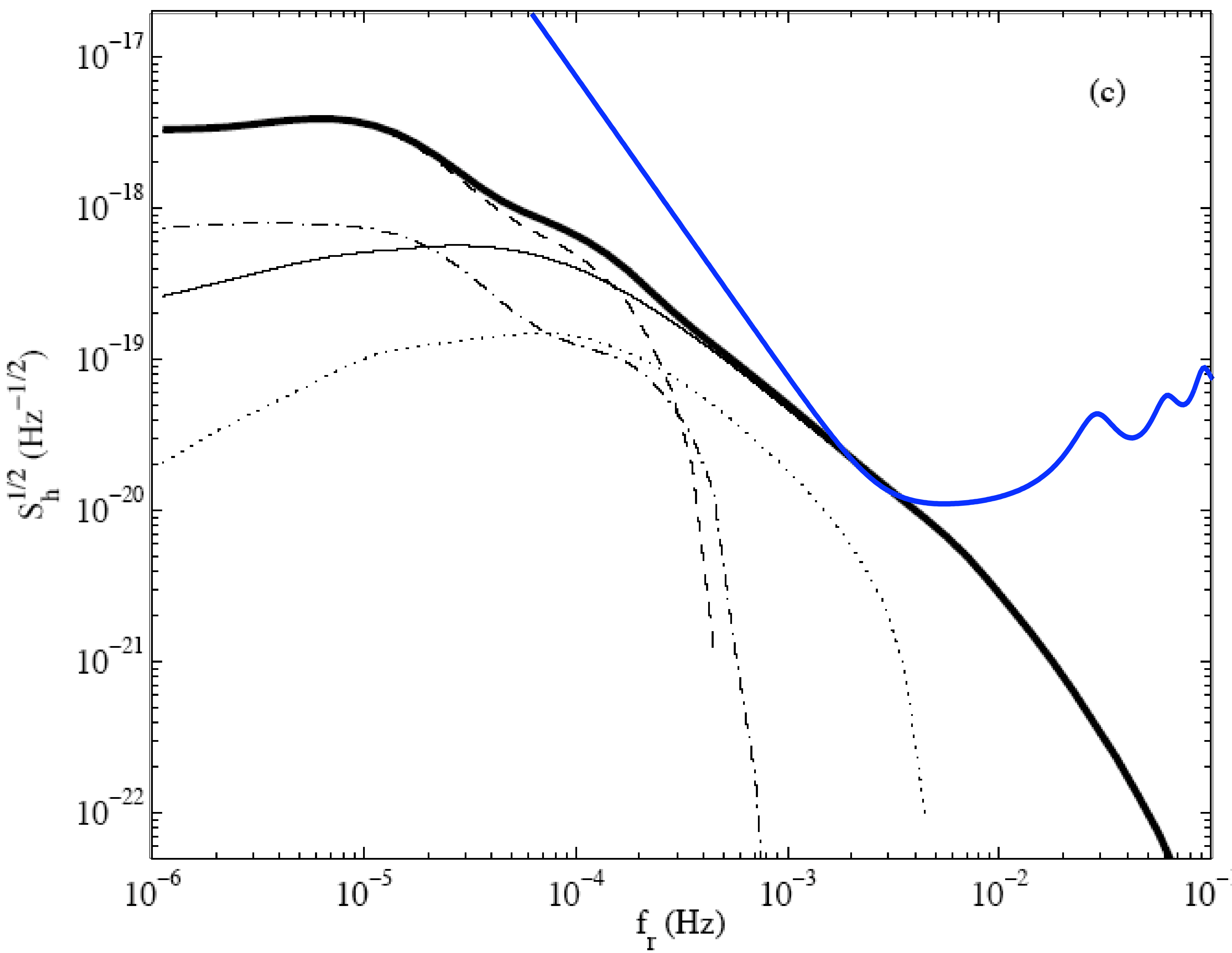
Resolve 16,000 Compact Binaries in Milky Way in 1 Year

Inflationary Background



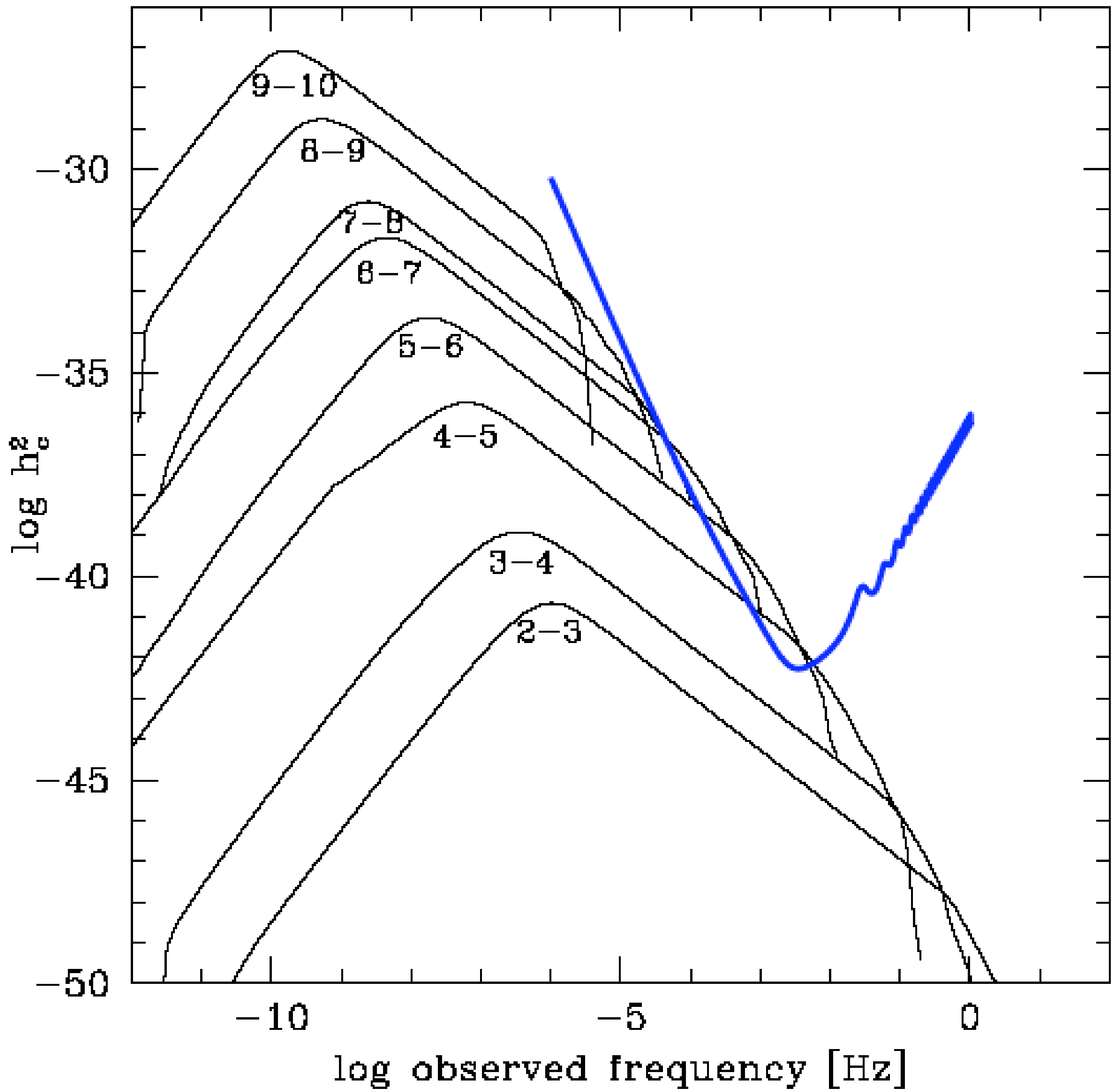
Smith, Kamionkowski & Cooray

Cosmological Stellar Binary Background



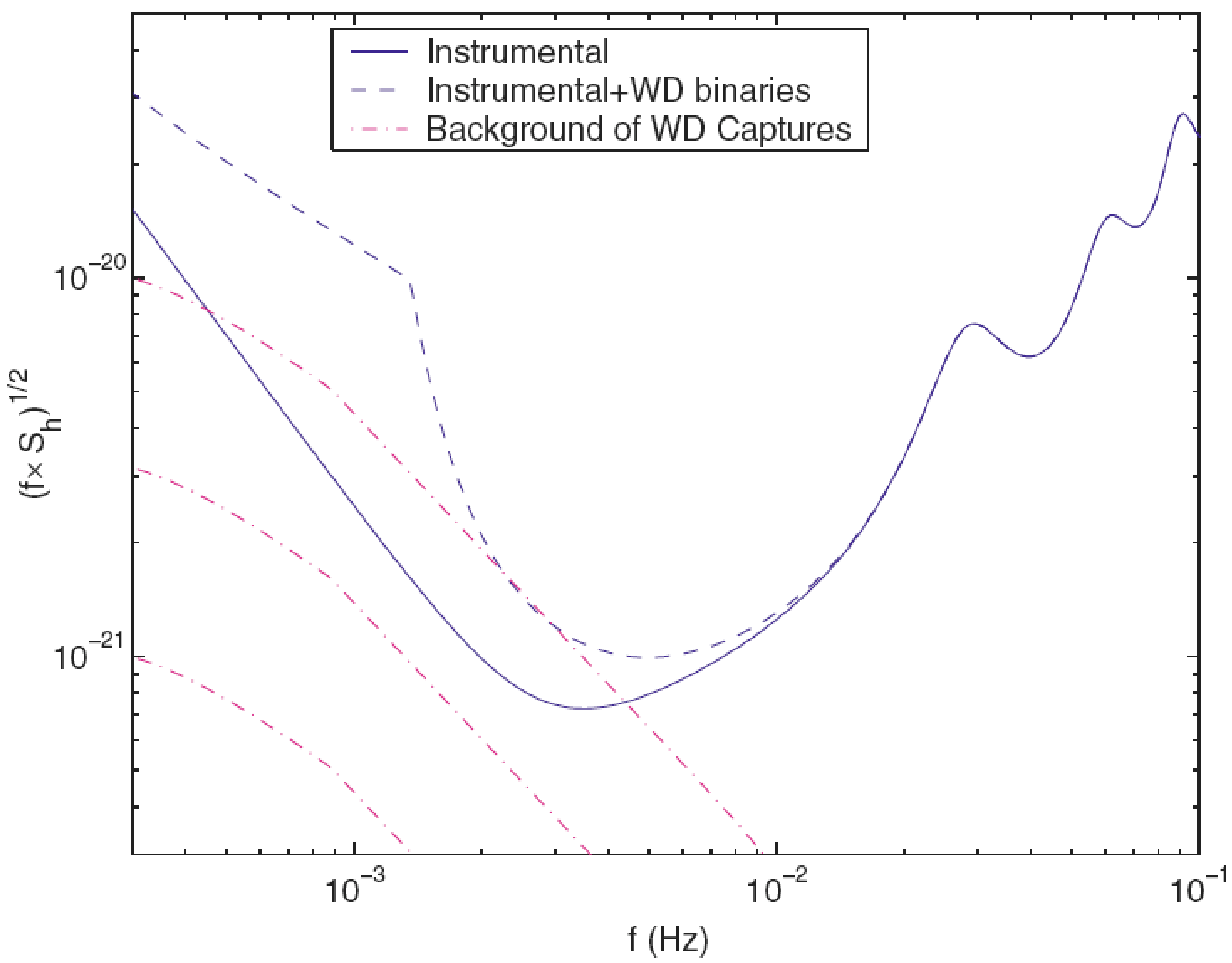
Farmer & Phinney

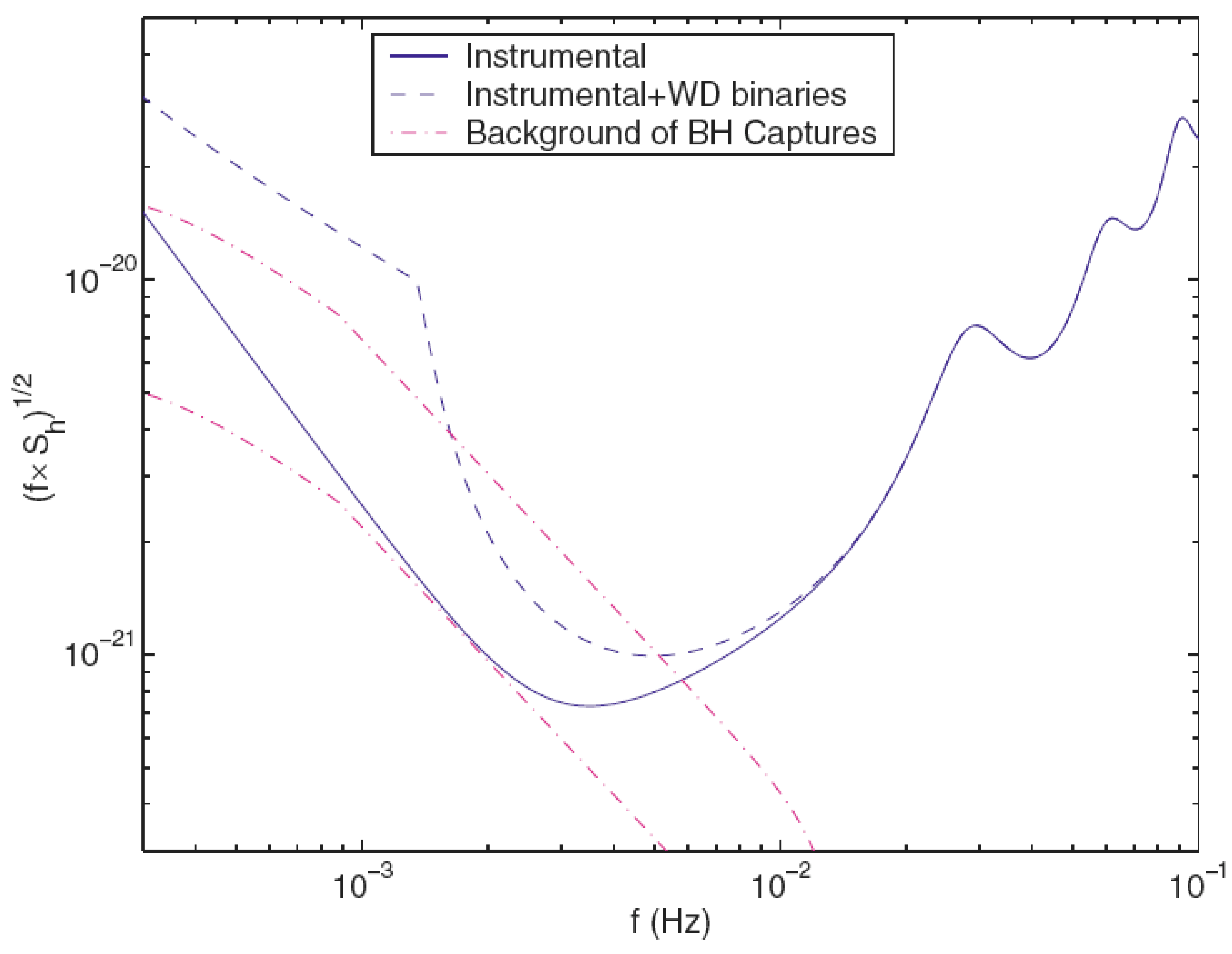
BH Background



Sesana, Haardt, Madau & Volonteri

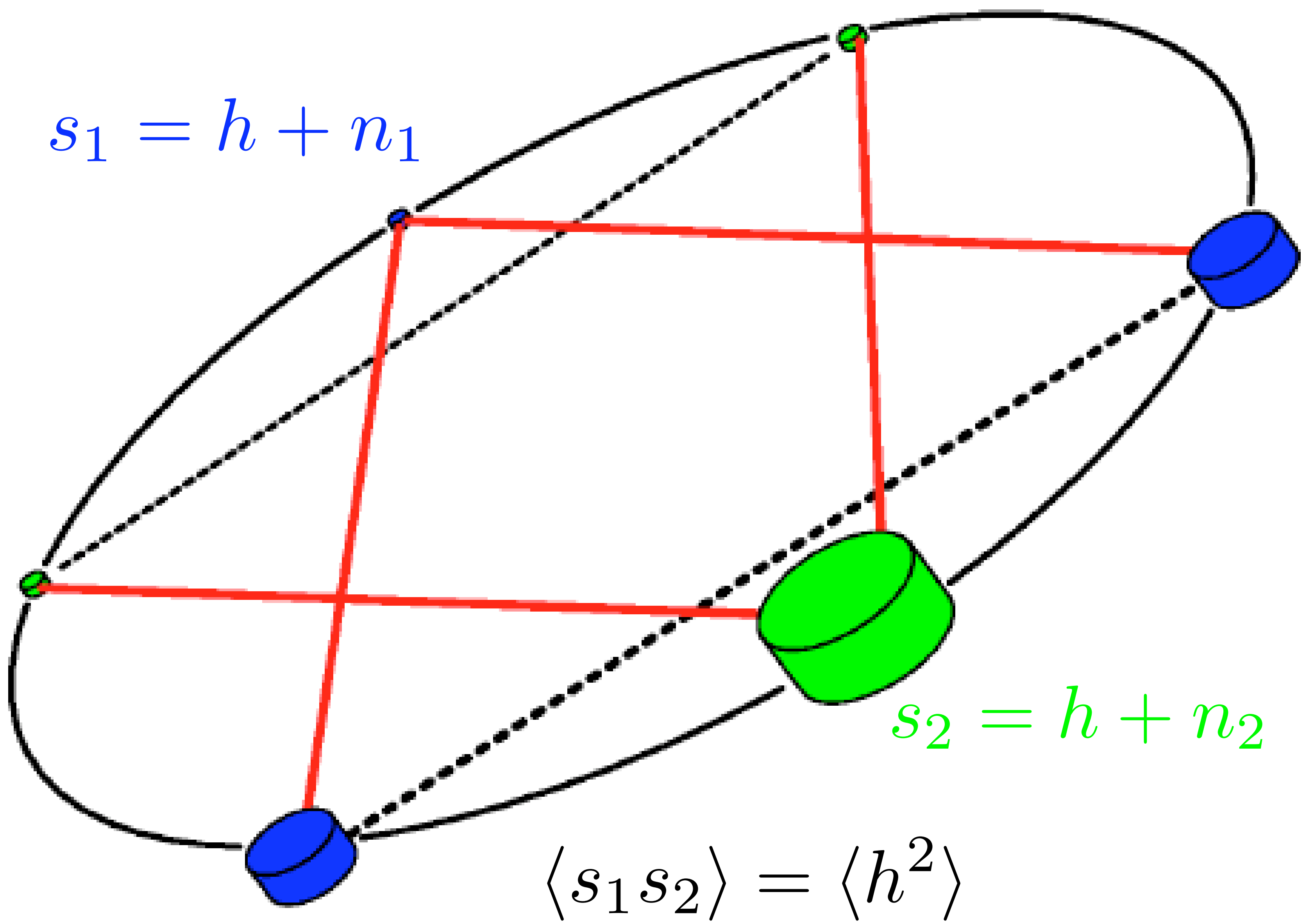
EMRI Background





Barack & Cutler

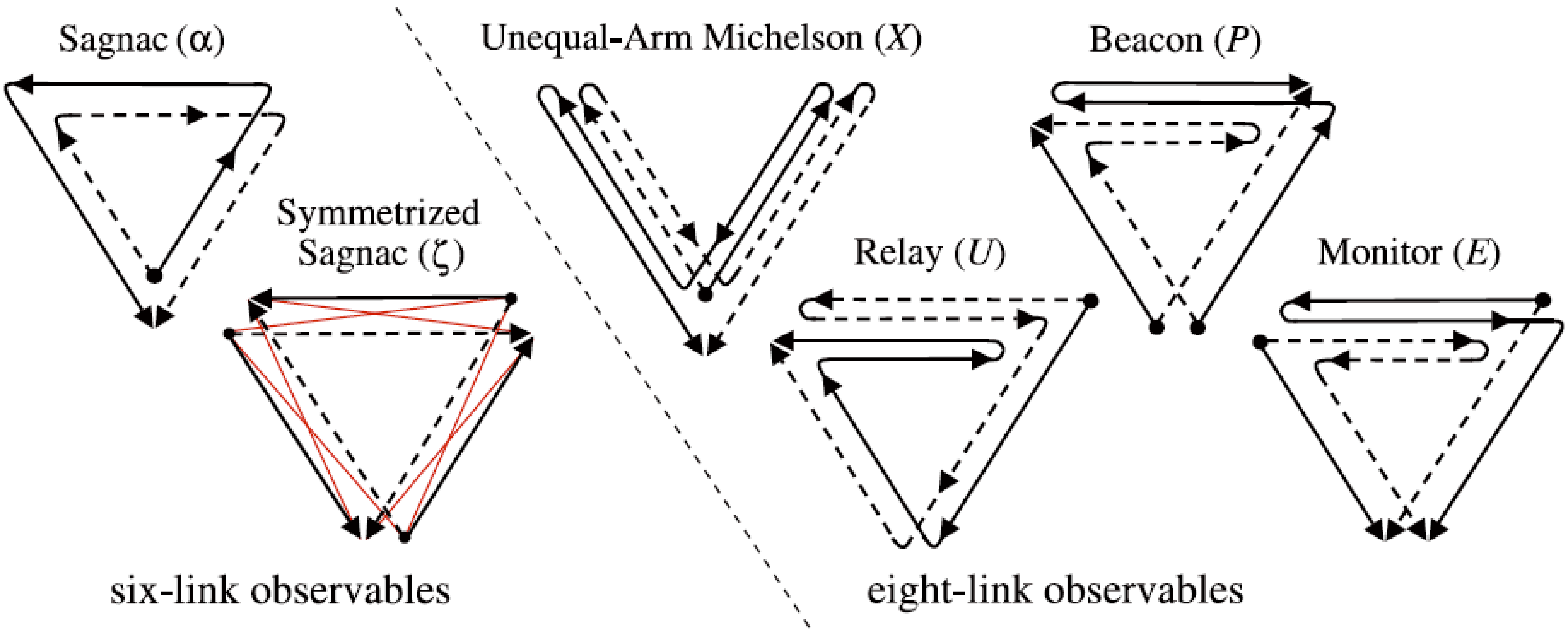
Data Analysis for Backgrounds



Cornish & Larson
Ungarelli & Vecchio

What we would like....

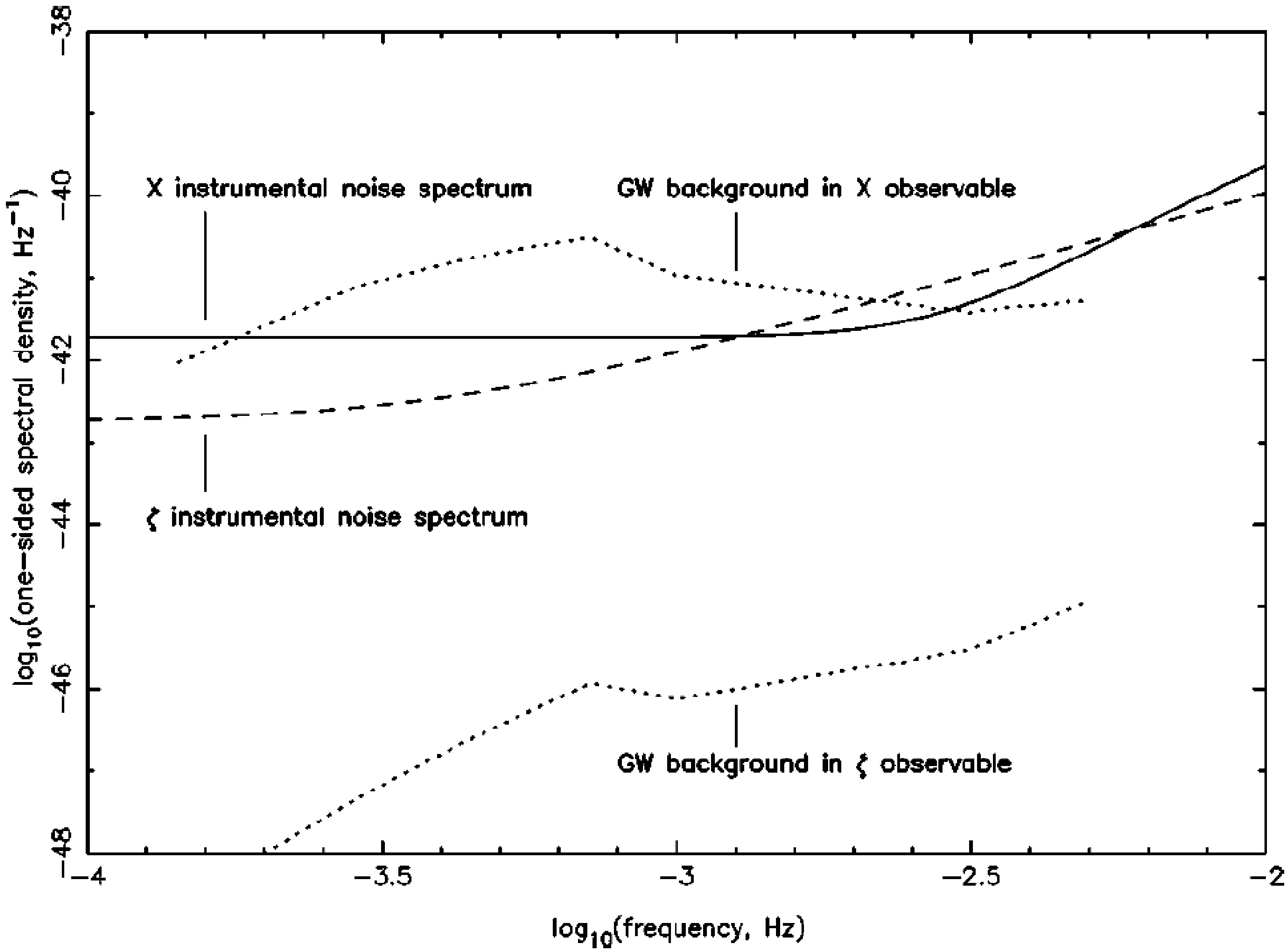
Data Analysis for Backgrounds



(Armstrong, Estabrook & Tinto)

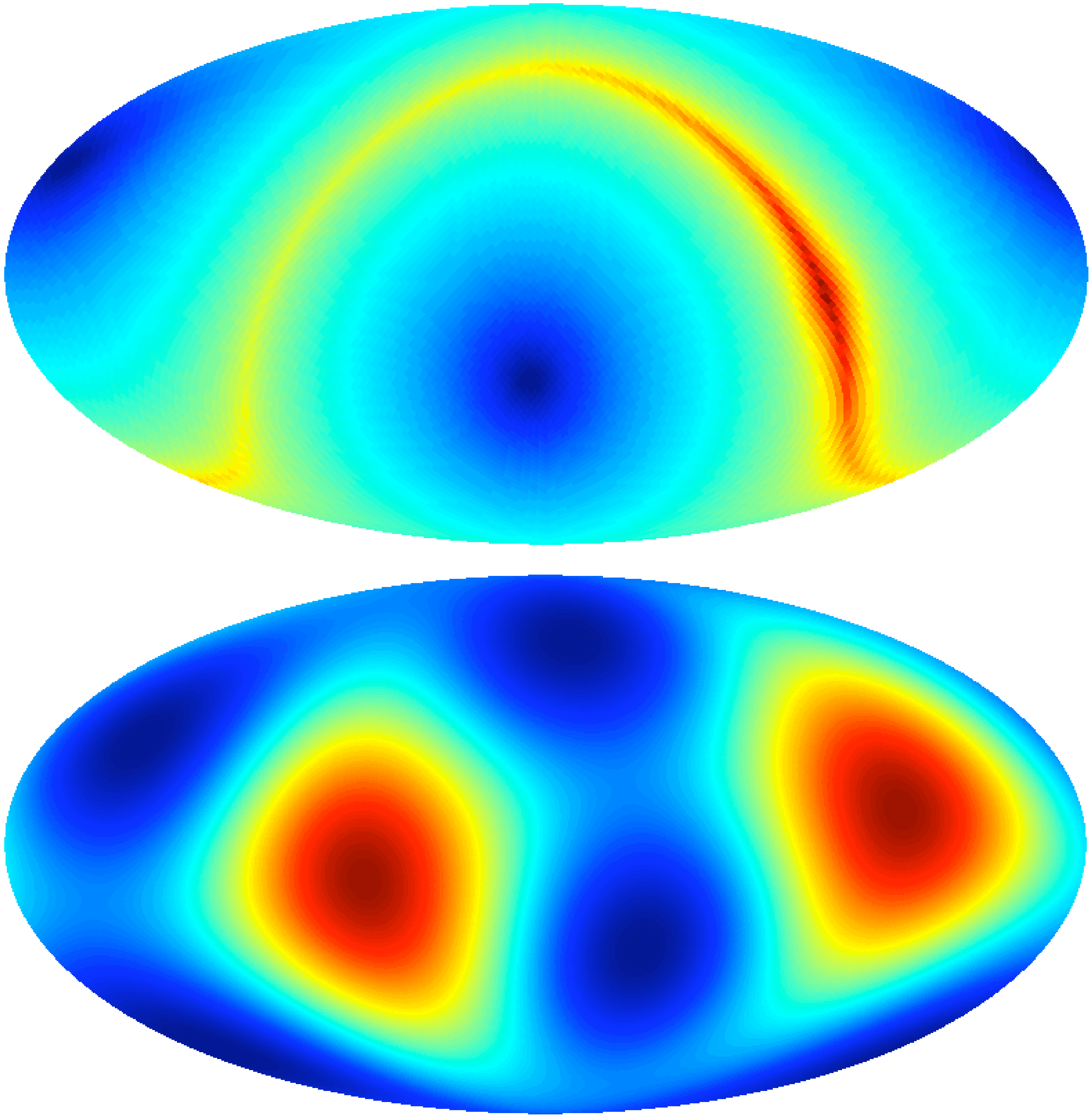
What LISA would give us

Symmetric Sagnac & T Channel

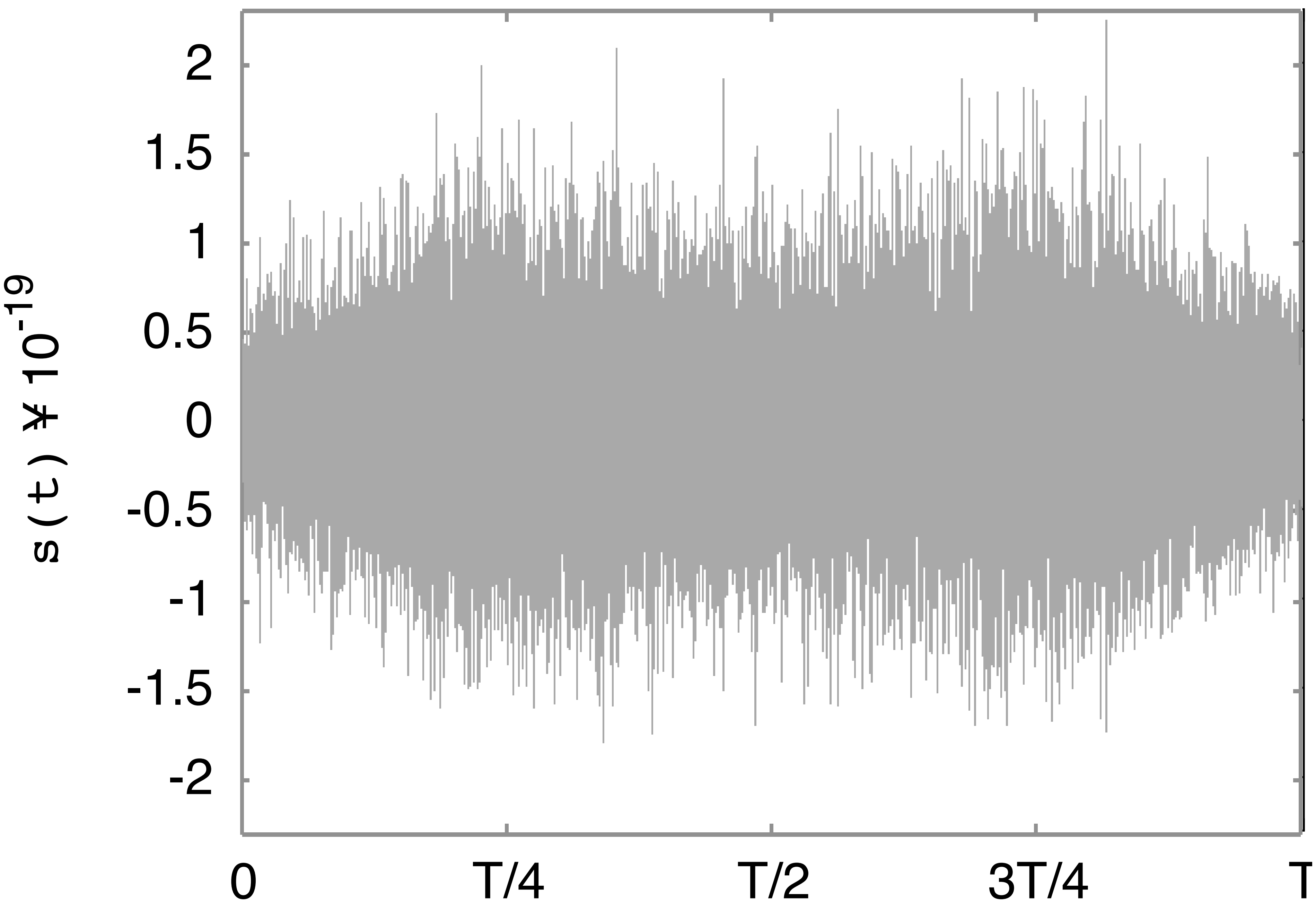


"Discriminating a gravitational wave background from instrumental noise in the LISA detector."
M. Tinto, J. W. Armstrong, F. B. Estabrook Phys.Rev.D63:021101,2001

Anisotropic Backgrounds



X-Channel Time Series Response



Deconvolve to map background

Cornish, Ungarelli & Vecchio, Seto, ...

LISA Data Analysis

- Template Based
  - Iterative (Grid Based)
    - gCLEAN (Cornish & Larson)
    - Slice & Dice (Cornish & Rubbo)
    - Stack Slide (Gair, Barack, Creighton, Cutler, Larson, Phinney, Vallisneri)
  - Simultaneous (Off the Grid)
    - Markov Chain Monte Carlo (Montana, Glasgow, Birmingham)
    - Genetic Algorithms (Crowder, Cornish & Reddinger)
- Other Methods
  - Null Channel (Armstrong, Estabrook, Tinto; Tinto & Larson)
  - Maximum Entropy (Finn & Larson)
  - Demodulation/Tomography (Hellings, Cornish & Larson, Mohanty & Nayak)
  - Direct Reconstruction (Cornish)
  - Time-Frequency (Wen & Gair)

The Super Template

Optimal Data Analysis = Matched Filtering

$$s(t) = h(t) + n(t) = \sum_{i=1}^{N} h_i(t) + n(t)$$

Optimal Filter includes all *N* resolvable sources

Source parameters $\vec{\lambda} = \vec{\lambda}^{(1)} + \vec{\lambda}^{(2)} + \dots$

Parameters per source $d_i = 7 \to 17$

Parameter Space Dimension $D = \sum_{i=1}^{N} d_i \sim 40,000$

Direct Search Cost $\sim \text{const.}^N$

How to Proceed

- Iterative removal starting with high SNR, broad-spectrum, small dimension sources. Re-solve for global solution
- and/or
- Simultaneously solve for all sources using MCMC, Genetic Algorithms etc.

Model Selection - Stopping Conditions

Penalized Log Likelihoods

$$\mathrm{BIC} = \log(L) - \frac{D}{2}\log\mathcal{L}$$

(also AIC)

$$\mathrm{MDL} = \log(L) - K(M)$$

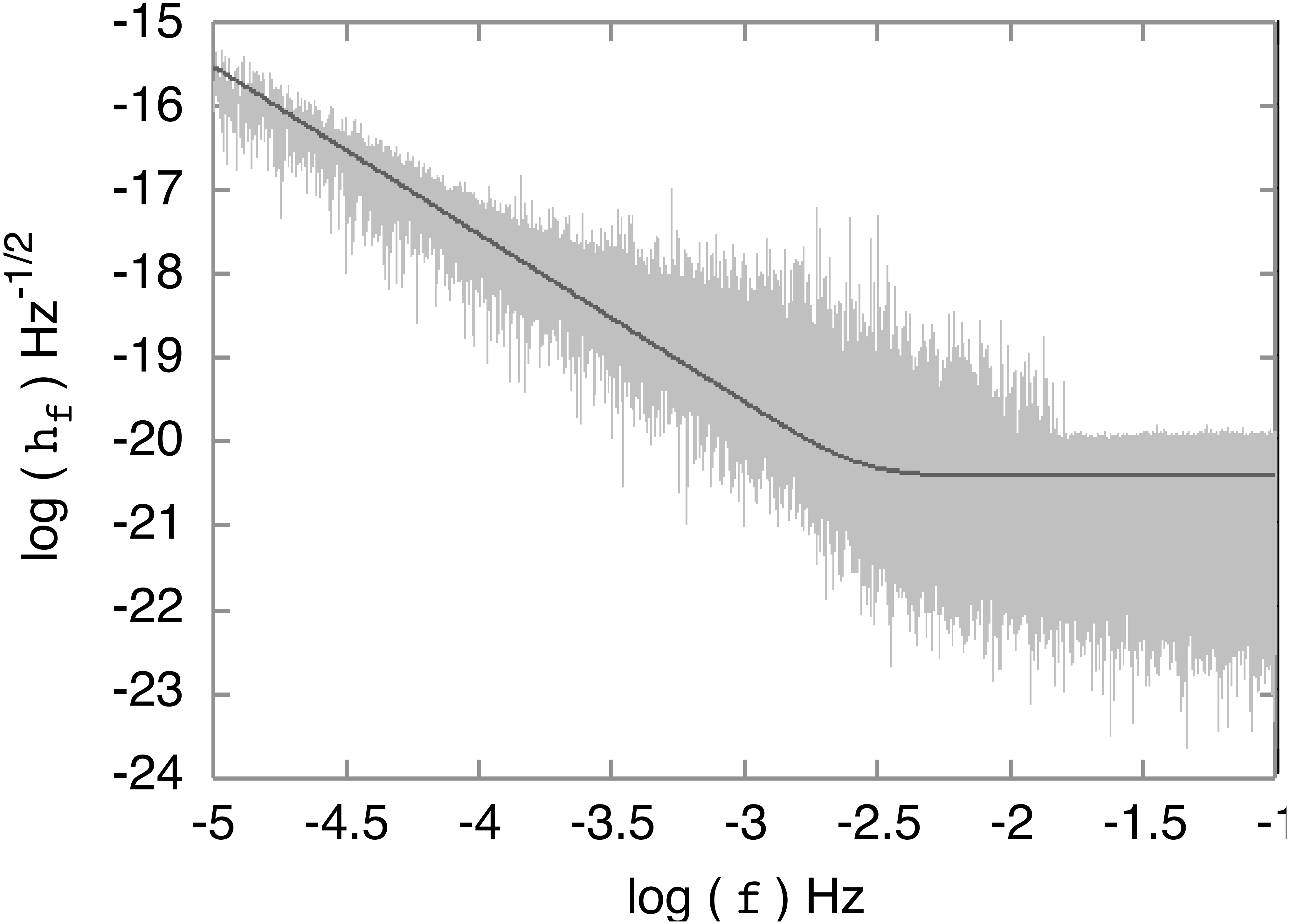
(also MML)

Automatic in a Bayesian approach such as MCMC

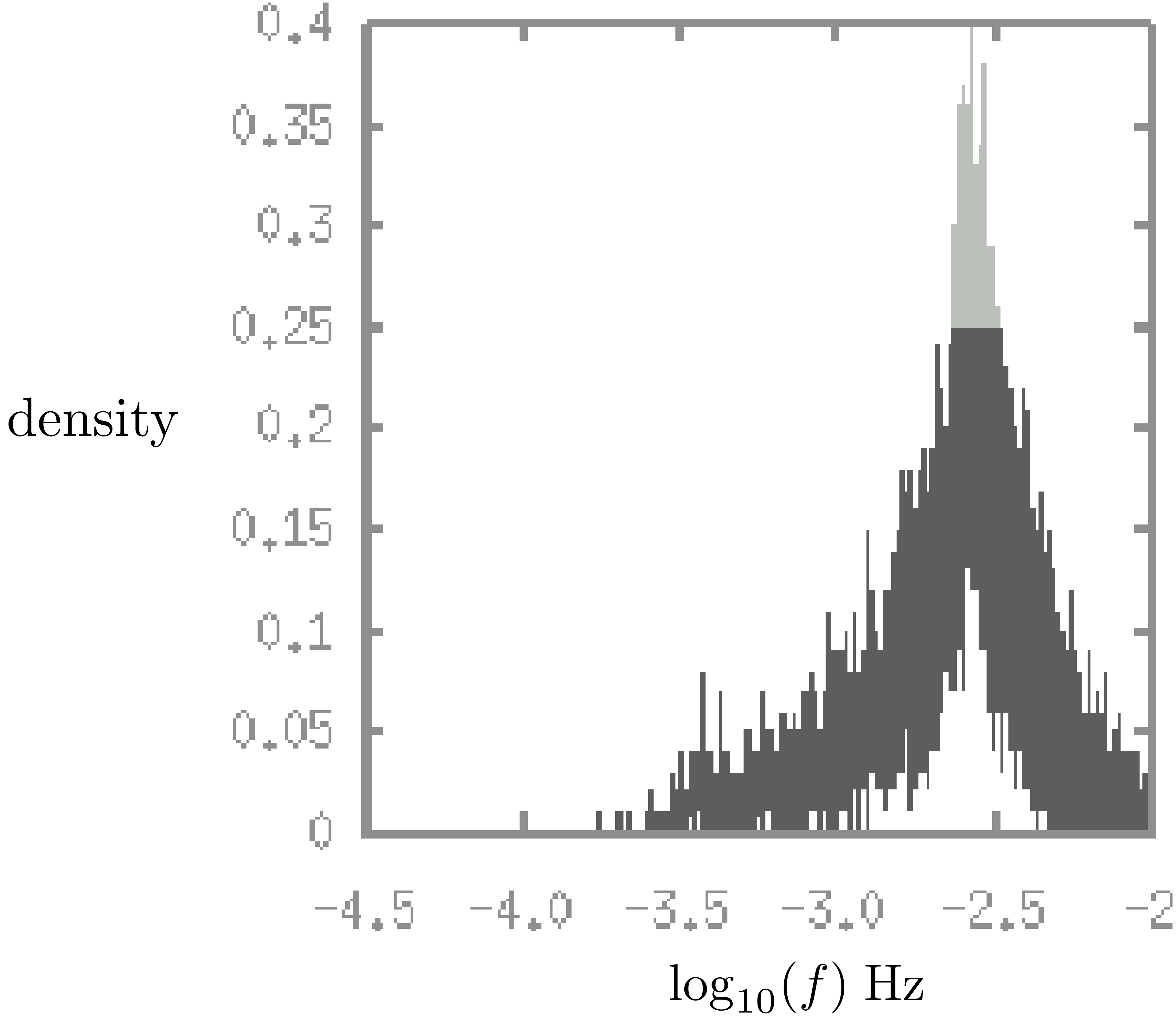
$$\log(\mathrm{Evidence}) = \log L + \log(\Delta V/V)$$

$\Delta V/V$ small for complex models

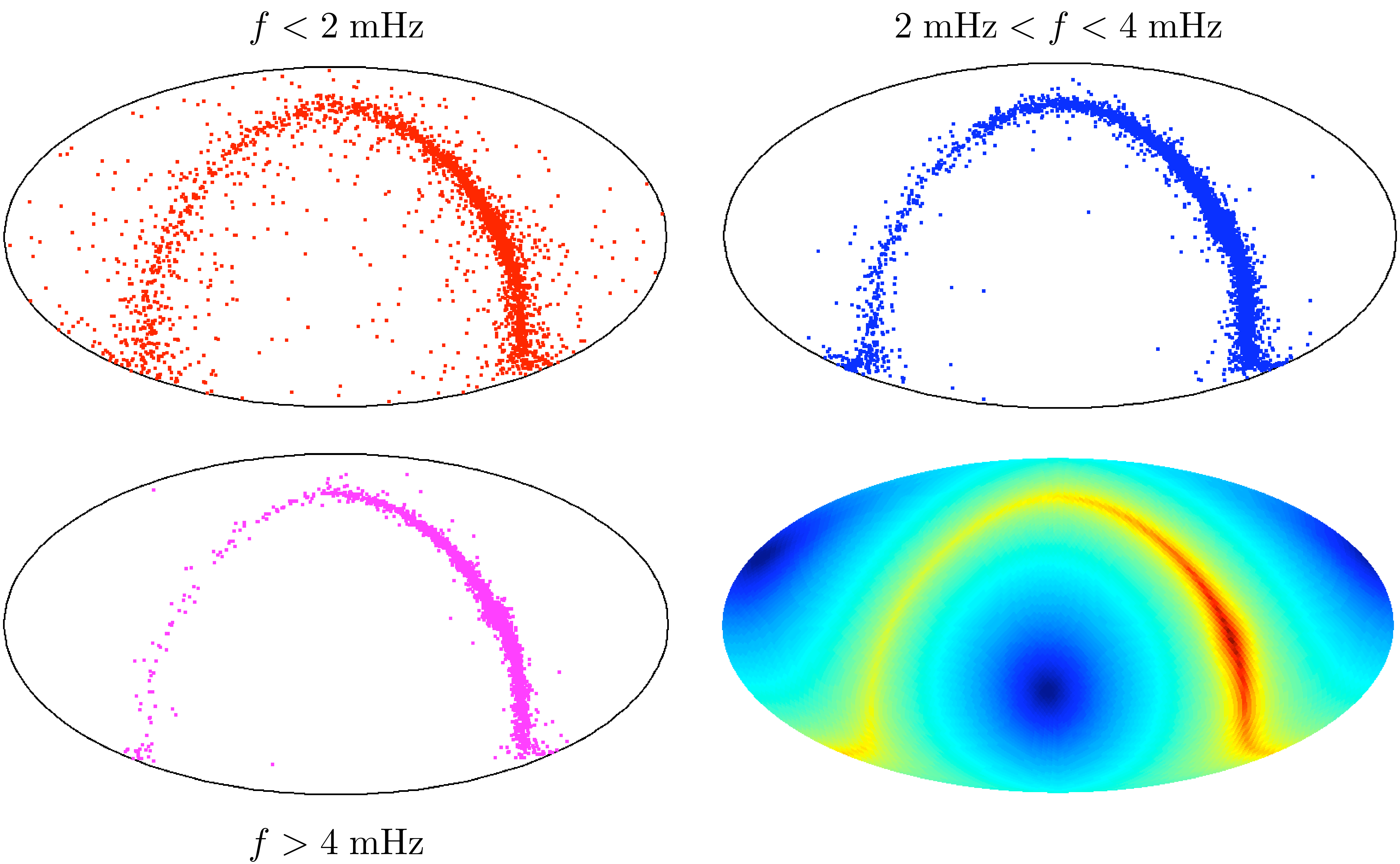
The Cocktail Party Problem



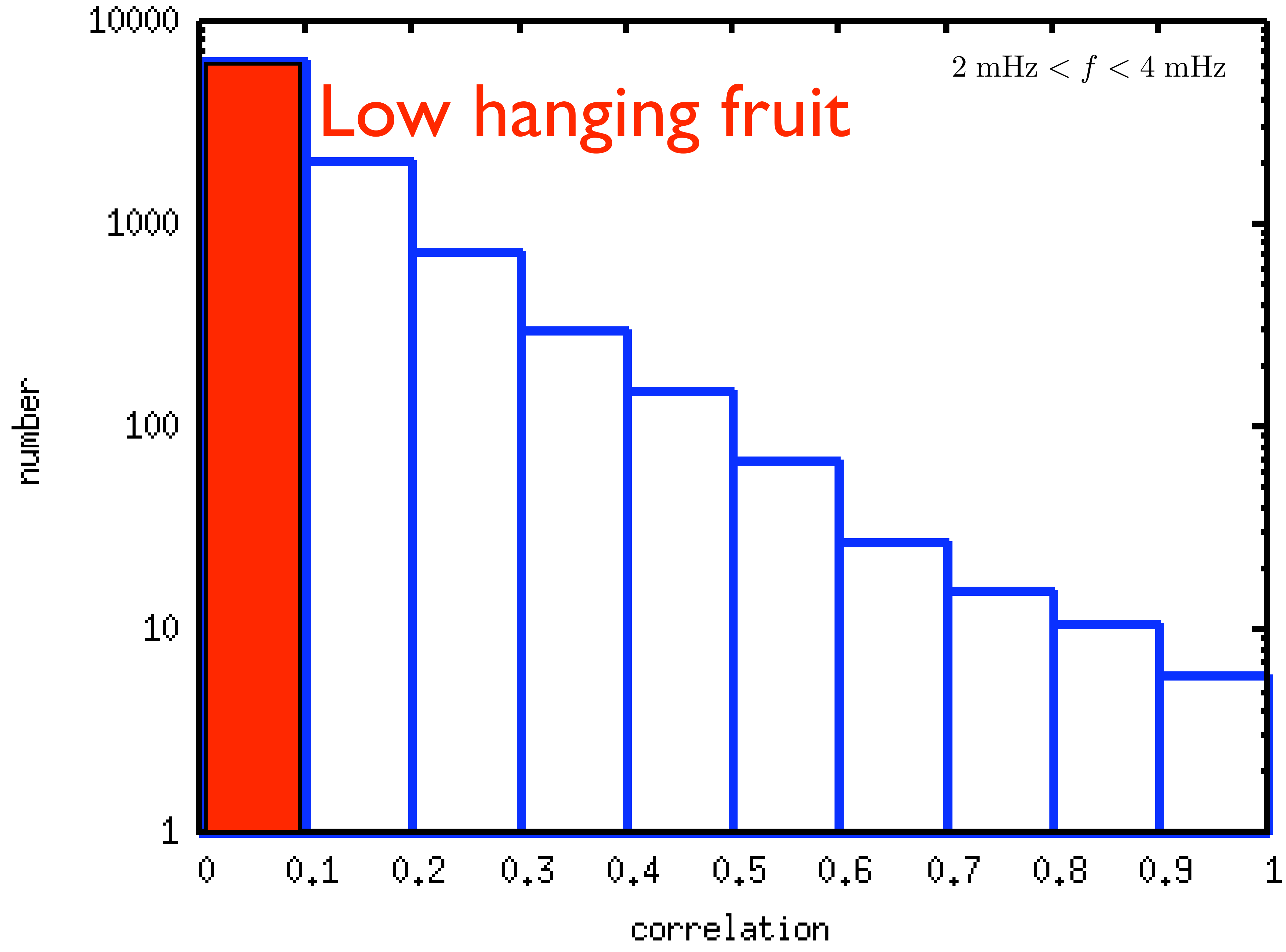
Bright Source (SNR > 10) Frequency Distribution



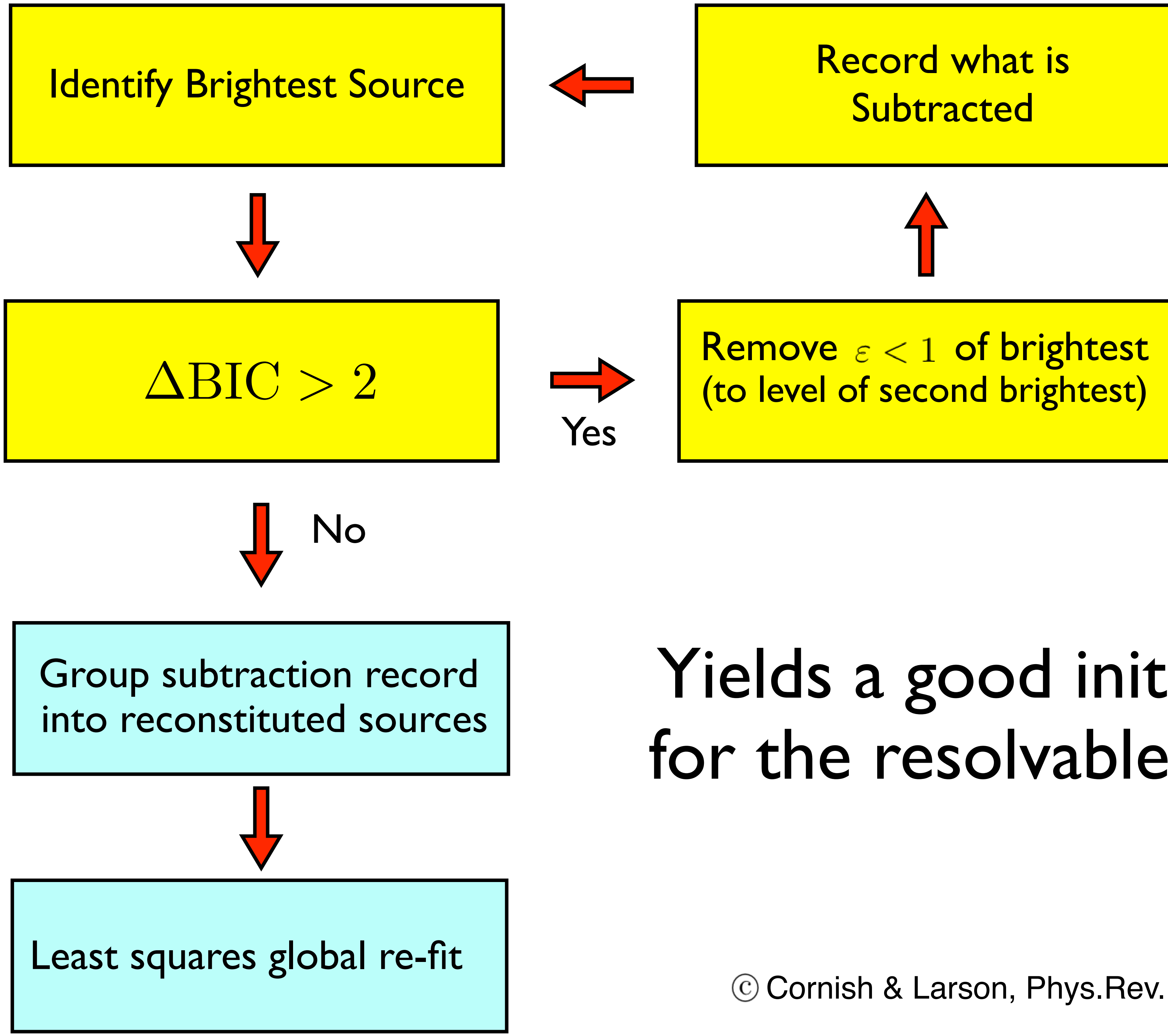
Bright Source Sky Distribution



Source Correlations



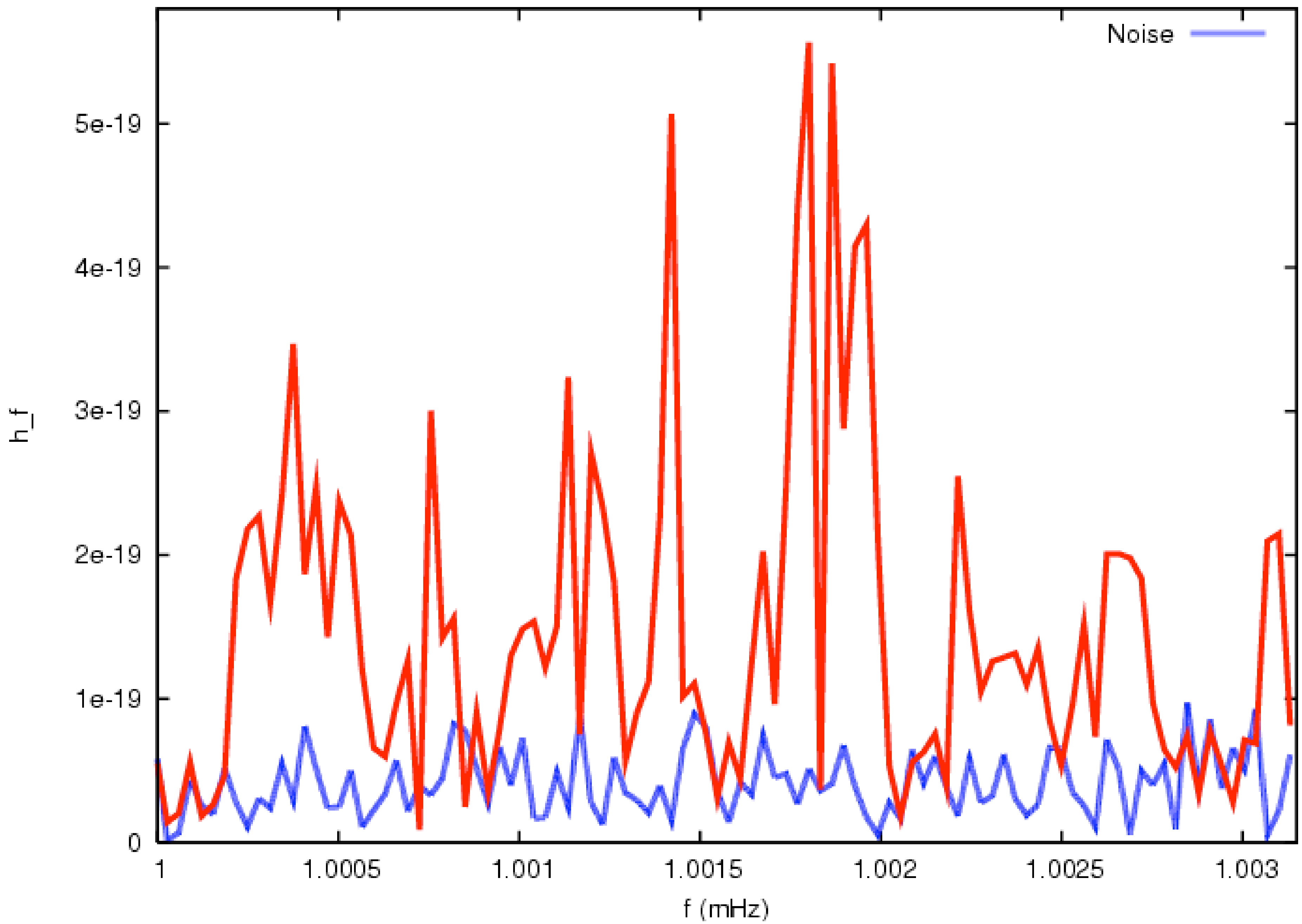
gCLEAN©



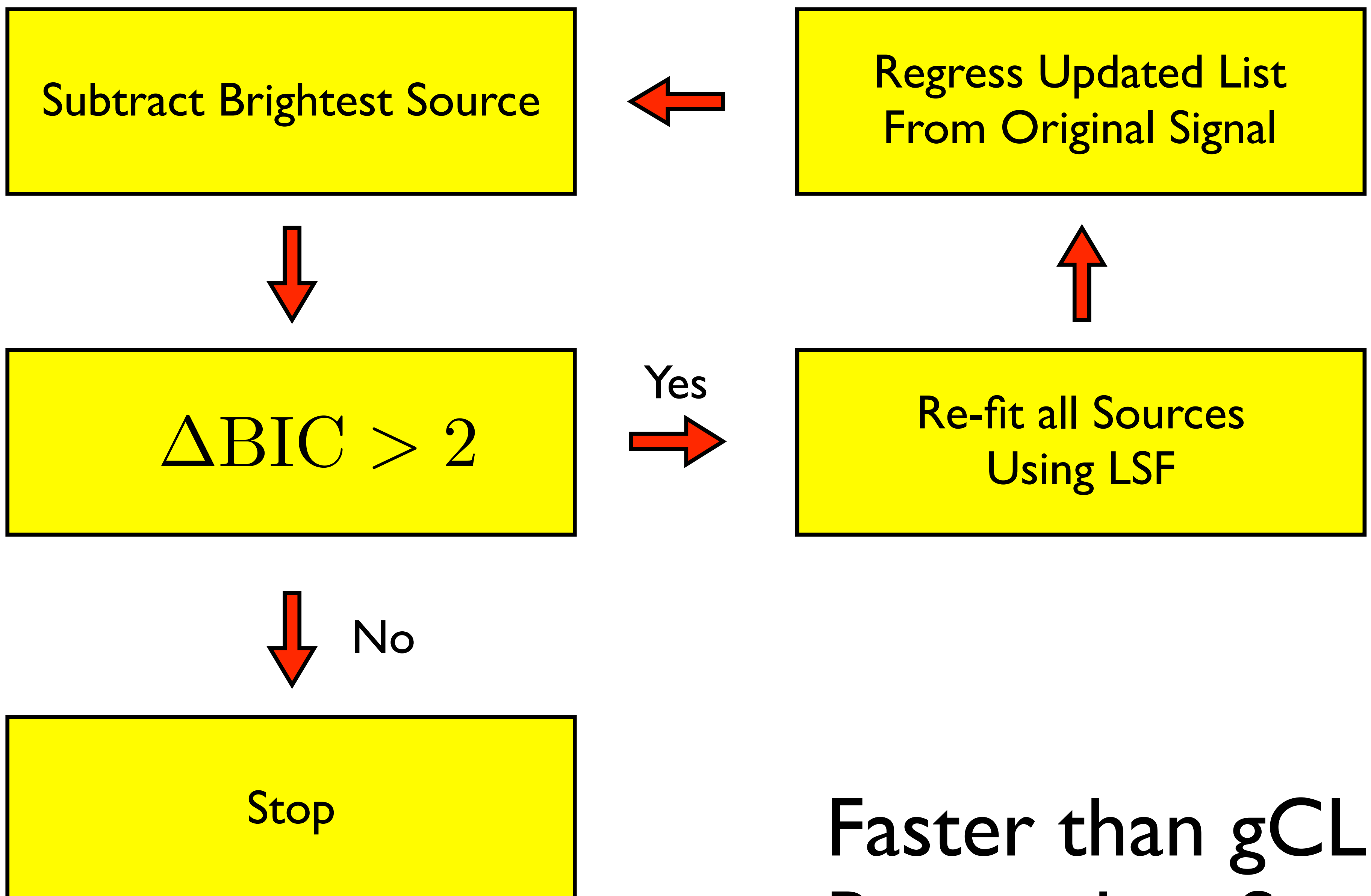
Yields a good initial guess for the resolvable sources

© Cornish & Larson, Phys.Rev.D67:103001,2003

gCLEAN in Action

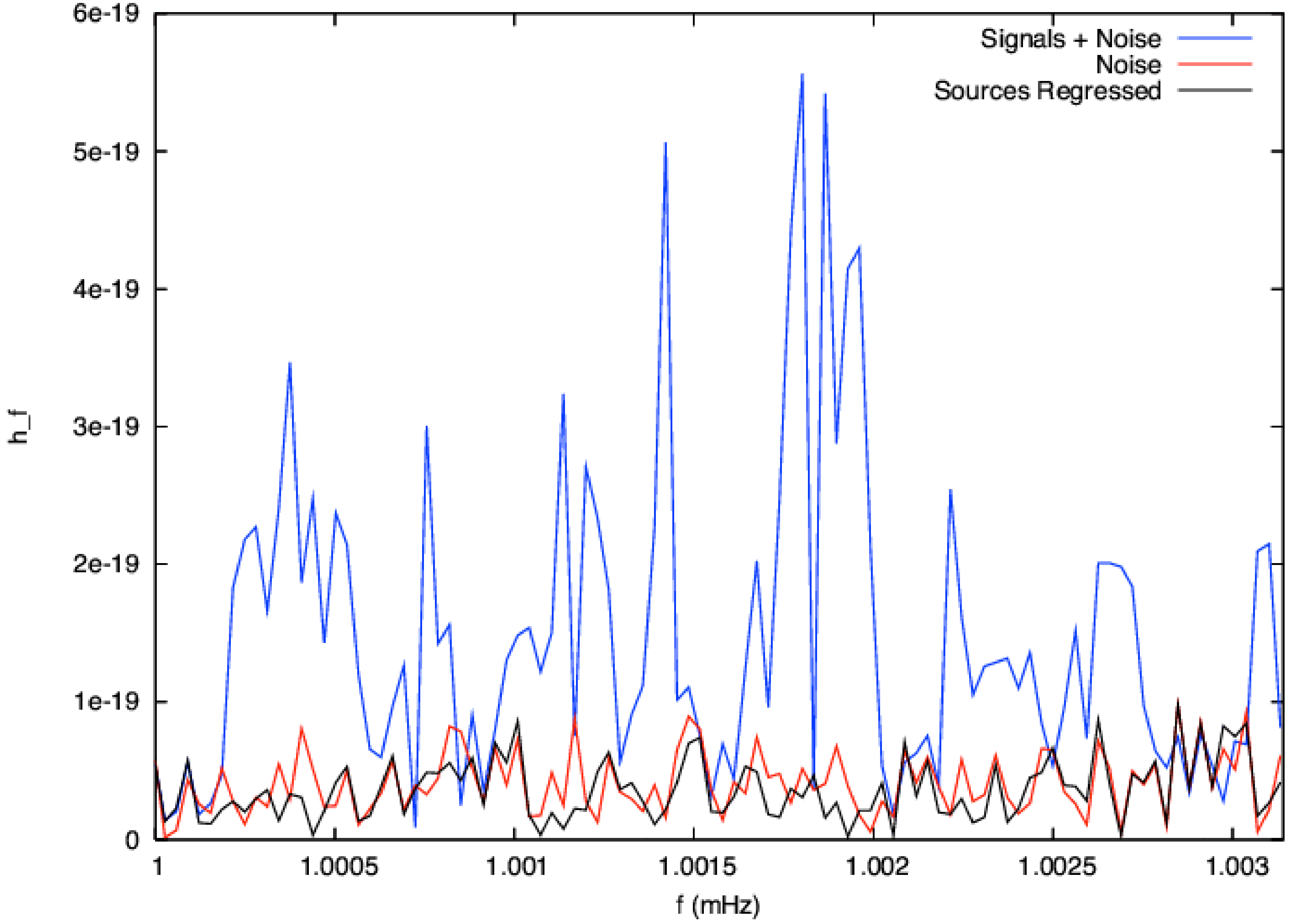


“Slice & Dice”



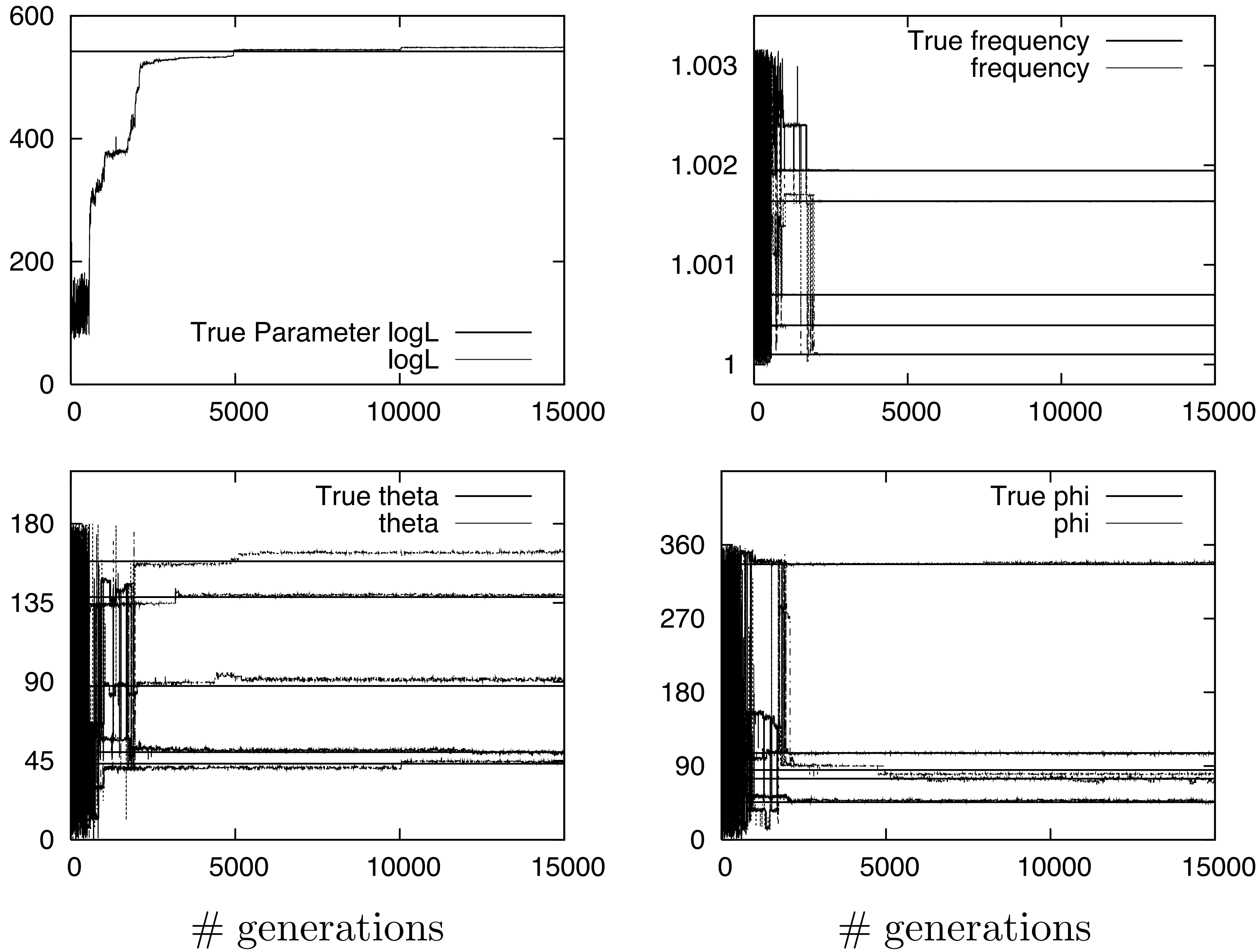
Faster than gCLEAN
Better than Sequential

Slice & Dice



Signals + Noise
Noise
Sources Regressed
6e-19
5e-19
4e-19
3e-19
2e-19
1e-19
0
h_f
1
1.0005
1.001
1.0015
1.002
1.0025
1.003
f (mHz)

Genetic Algorithms



Crowder & Cornish, PRD **73**, 063011 (2006)

Markov Chain Monte Carlo

Cost grows linearly with search dimension

Simultaneous Parameter Determination and Error Estimation

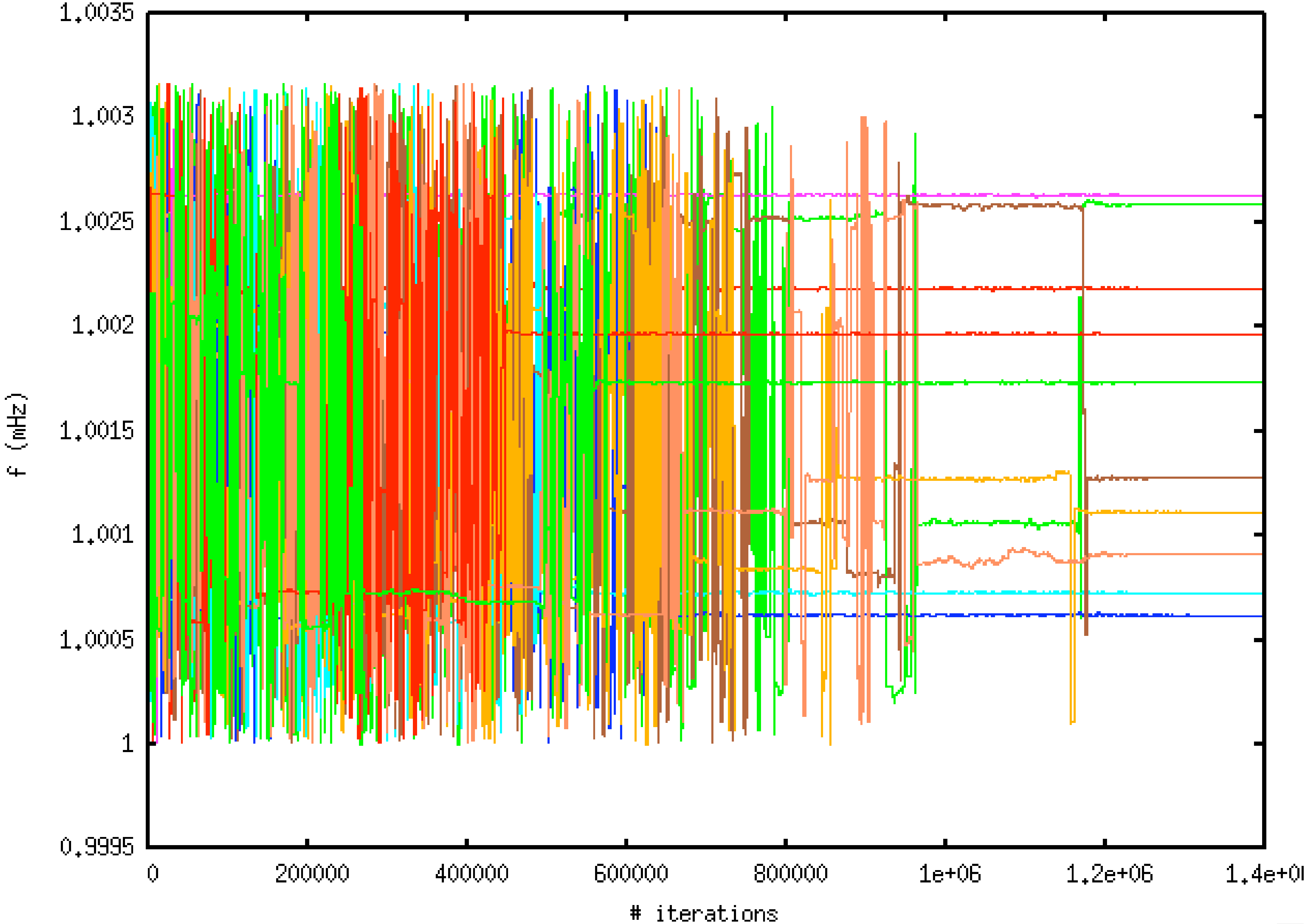
Incorporates Prior Knowledge

$$\vec{x} \xrightarrow{\text{prob}(H)} \vec{y}$$

Prior — Likelihood — Proposal

$$H = \frac{\pi(\vec{y})p(s|\vec{y})q(\vec{x}|\vec{y})}{\pi(\vec{x})p(s|\vec{x})q(\vec{y}|\vec{x})}$$

First outing with MCMC



Cornish & Crowder, PRD **72**, 043005 (2005)

Annealed Blocked Gibbs MCMC

$$p(s|\vec{x}) = \text{const.}\ e^{-\langle s-h(\vec{x})|s-h(\vec{x})\rangle/2}$$

Likelihood

$$\langle a|b\rangle = 2\beta \int \frac{ab^* + a^*b}{S_n(f)} df$$

Heated Inner Product

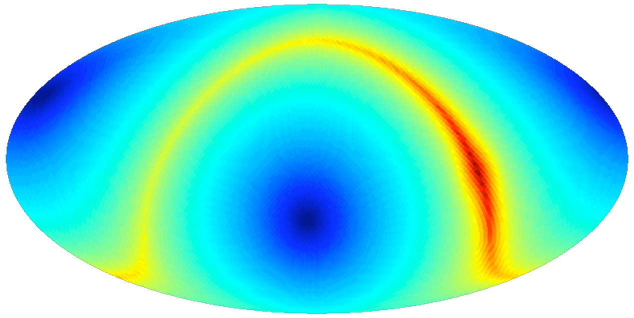
$$q(\vec{x}+\Delta\vec{x}|\vec{x}) = \text{const.}\ e^{-\frac{\Gamma_{ij}(\vec{x})\Delta x^i \Delta x^j}{2}}$$

Proposal Distribution

$$\Gamma_{ij}(\vec{x}) = \partial_i \partial_j \ln p(s|\vec{x}) = \langle \partial_i h(\vec{x}) | \partial_j h(\vec{x}) \rangle$$

Jumps use sub-matrices of the full Fisher matrix

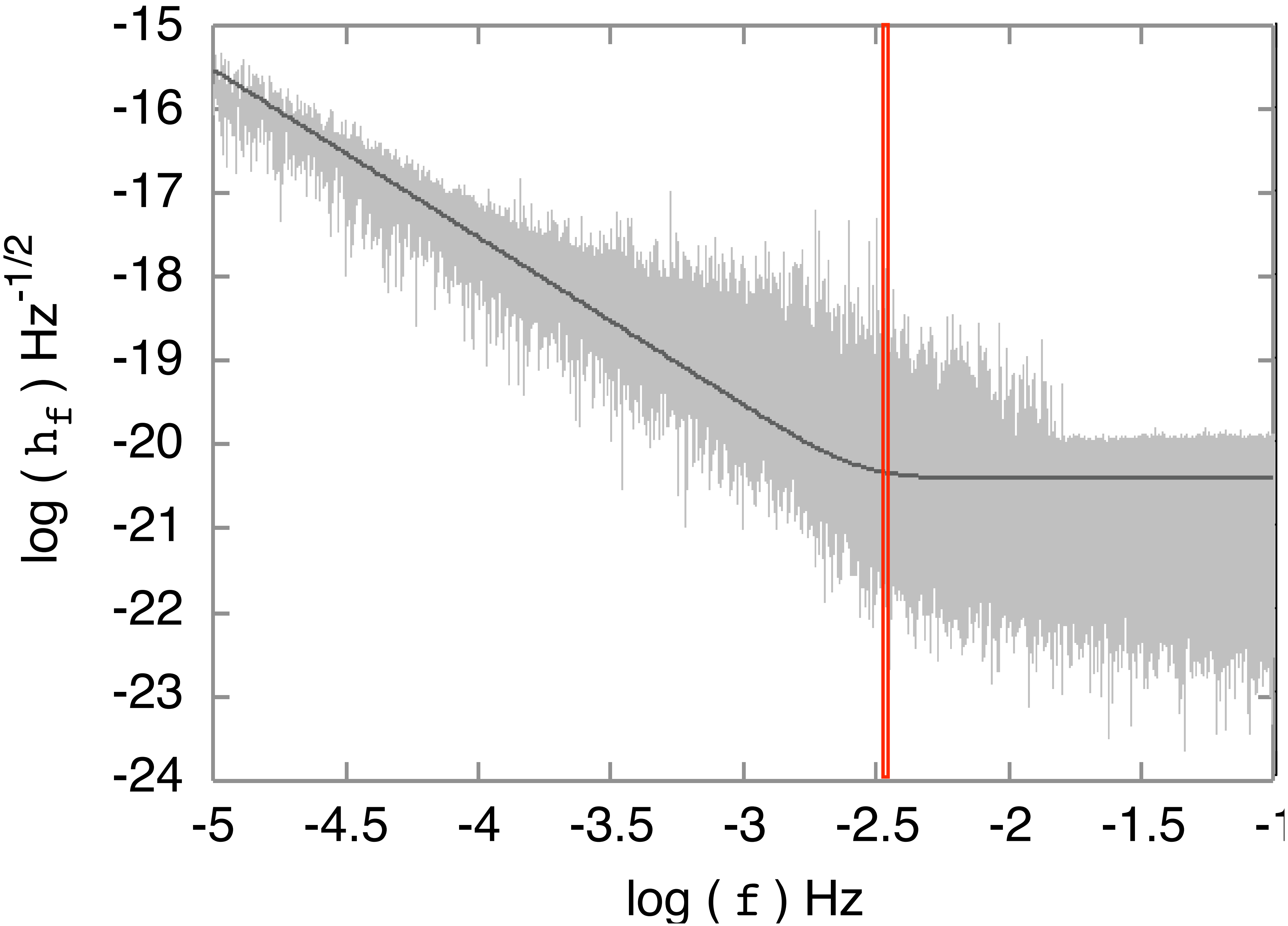
$$\pi(\theta, \phi) =$$



Galaxy Prior

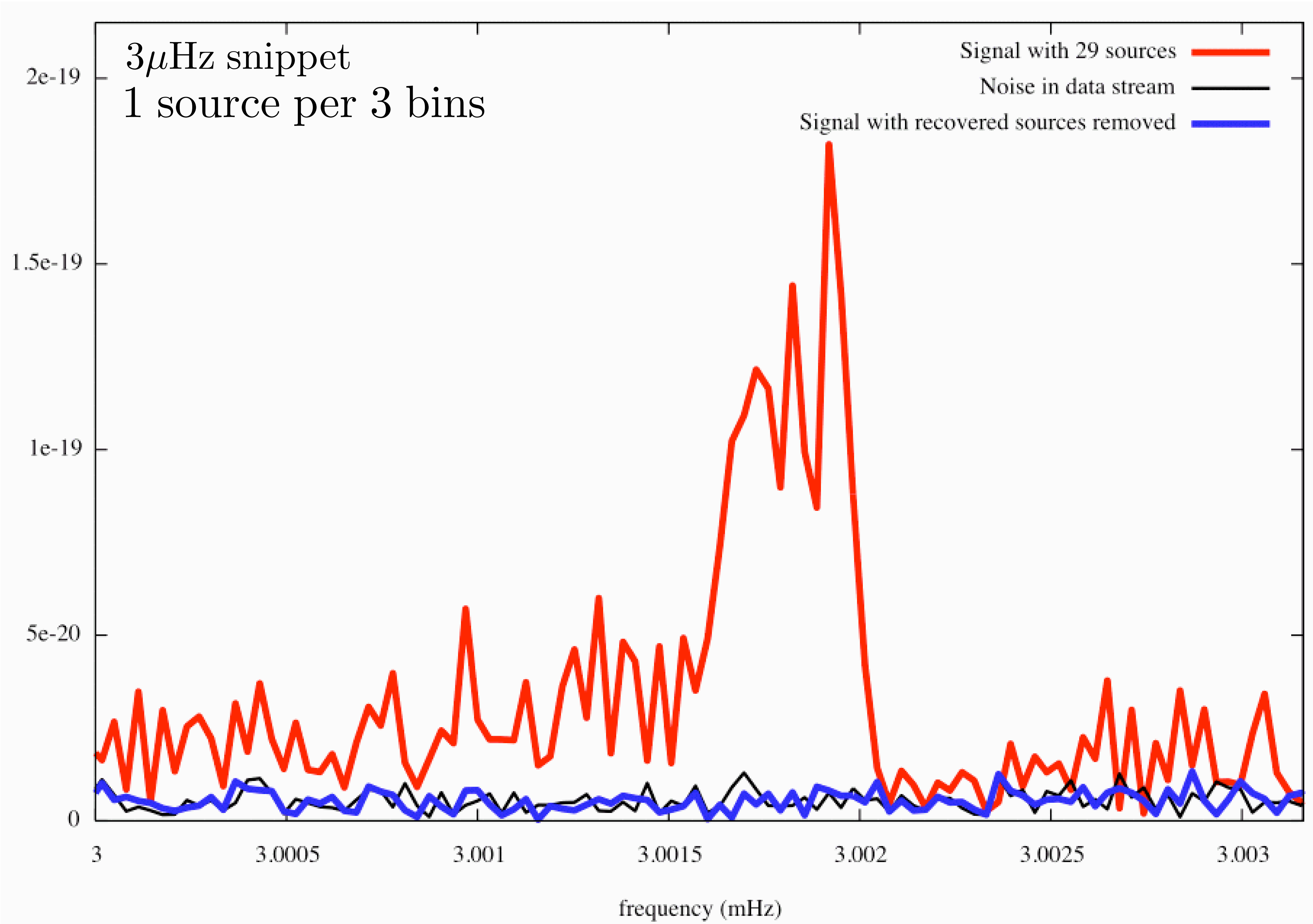
Computational cost scales linearly with # parameters

Blocked Gibbs MCMC

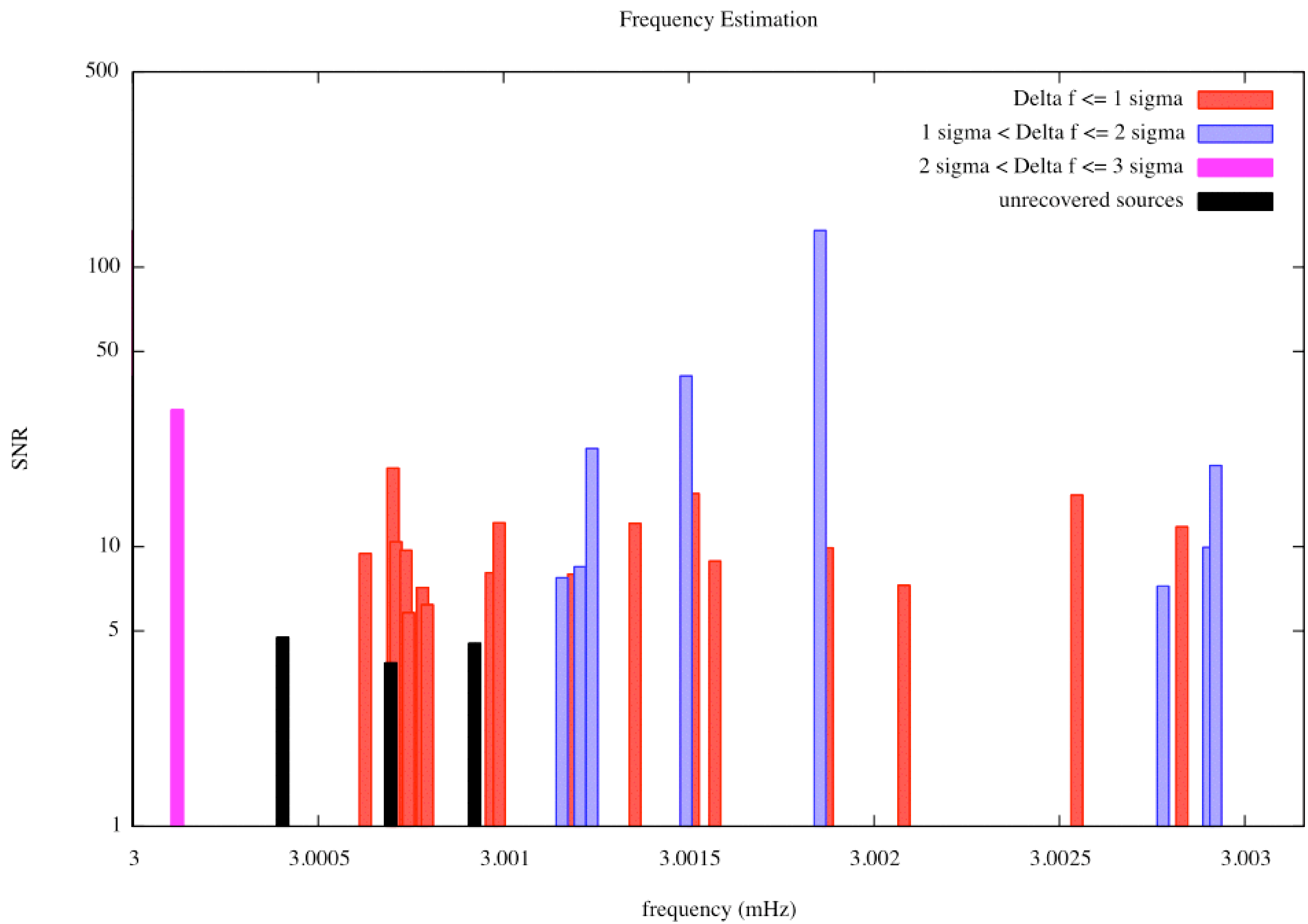


Cornish & Crowder in preparation

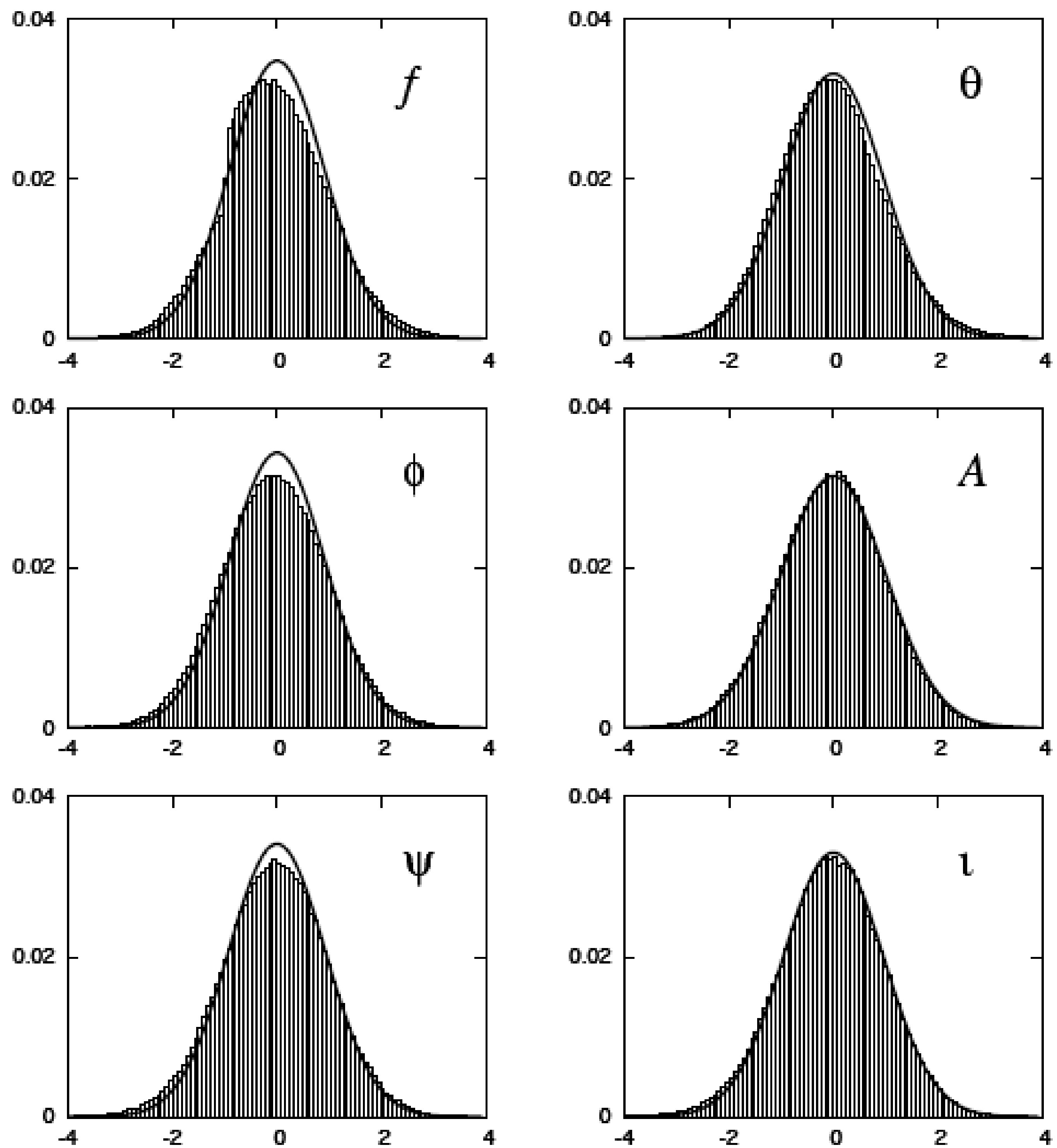
Searching the Nelemans Galaxy



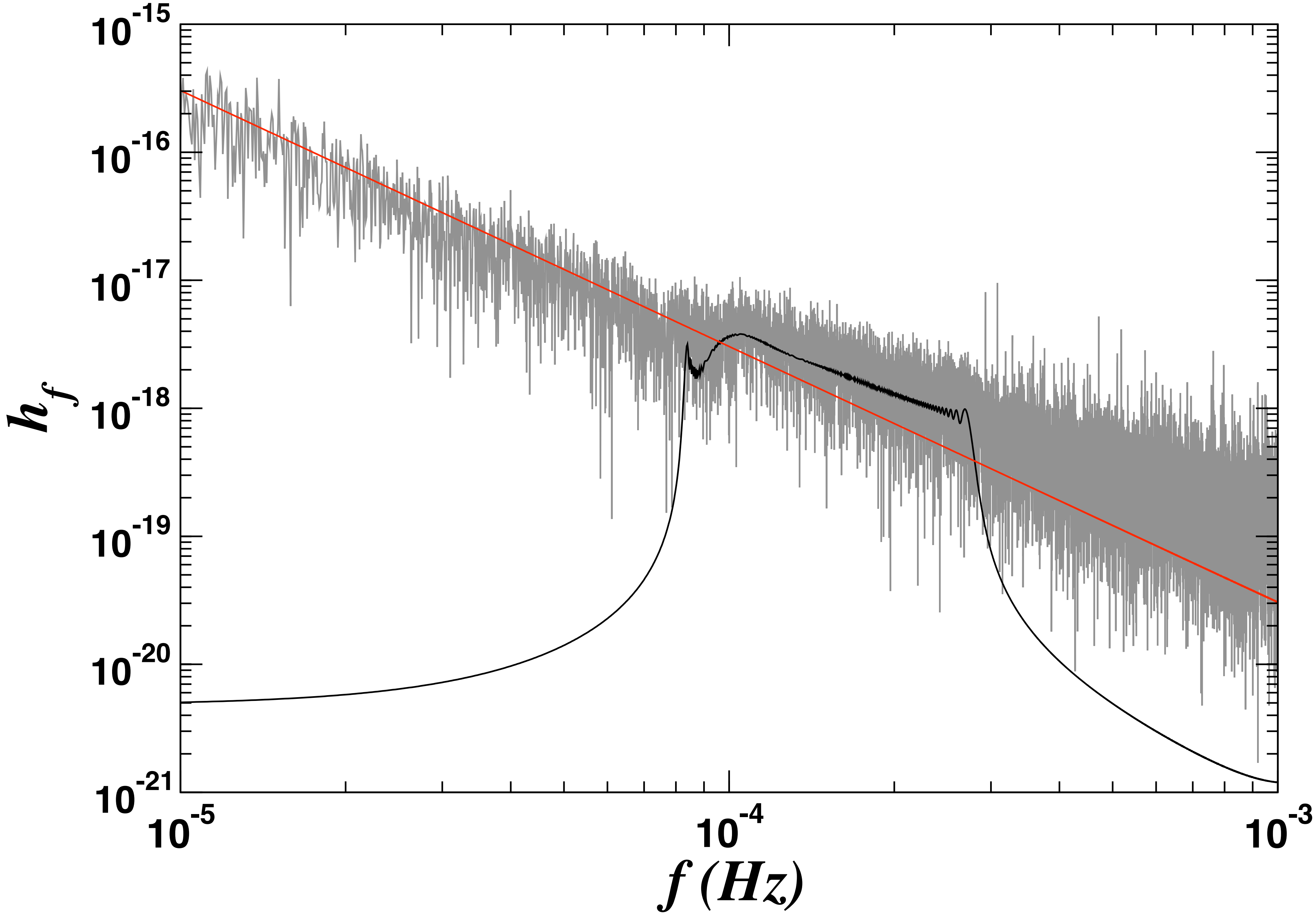
Parameter Recovery



Error Estimation

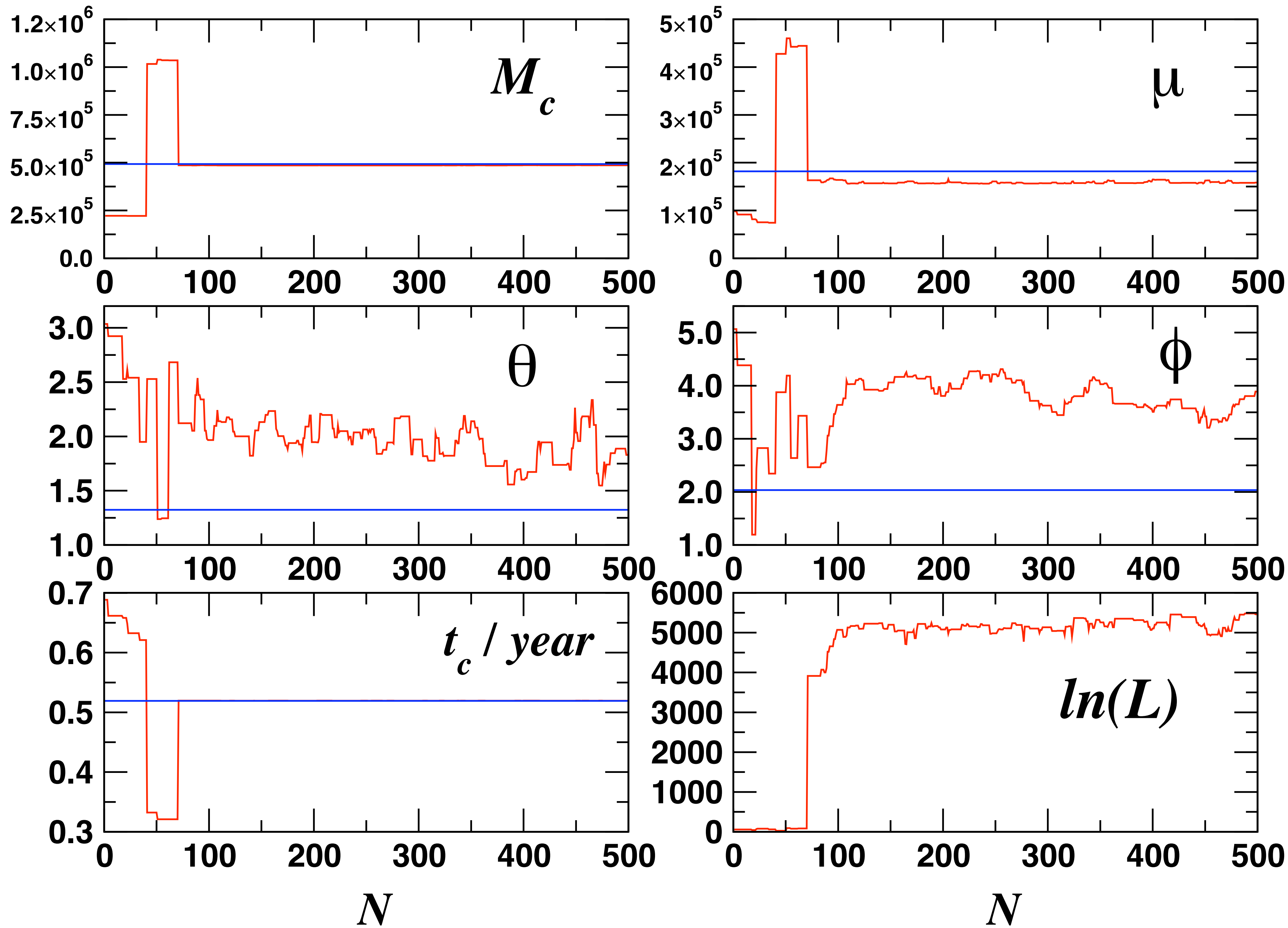


SMBH & Galactic Foreground



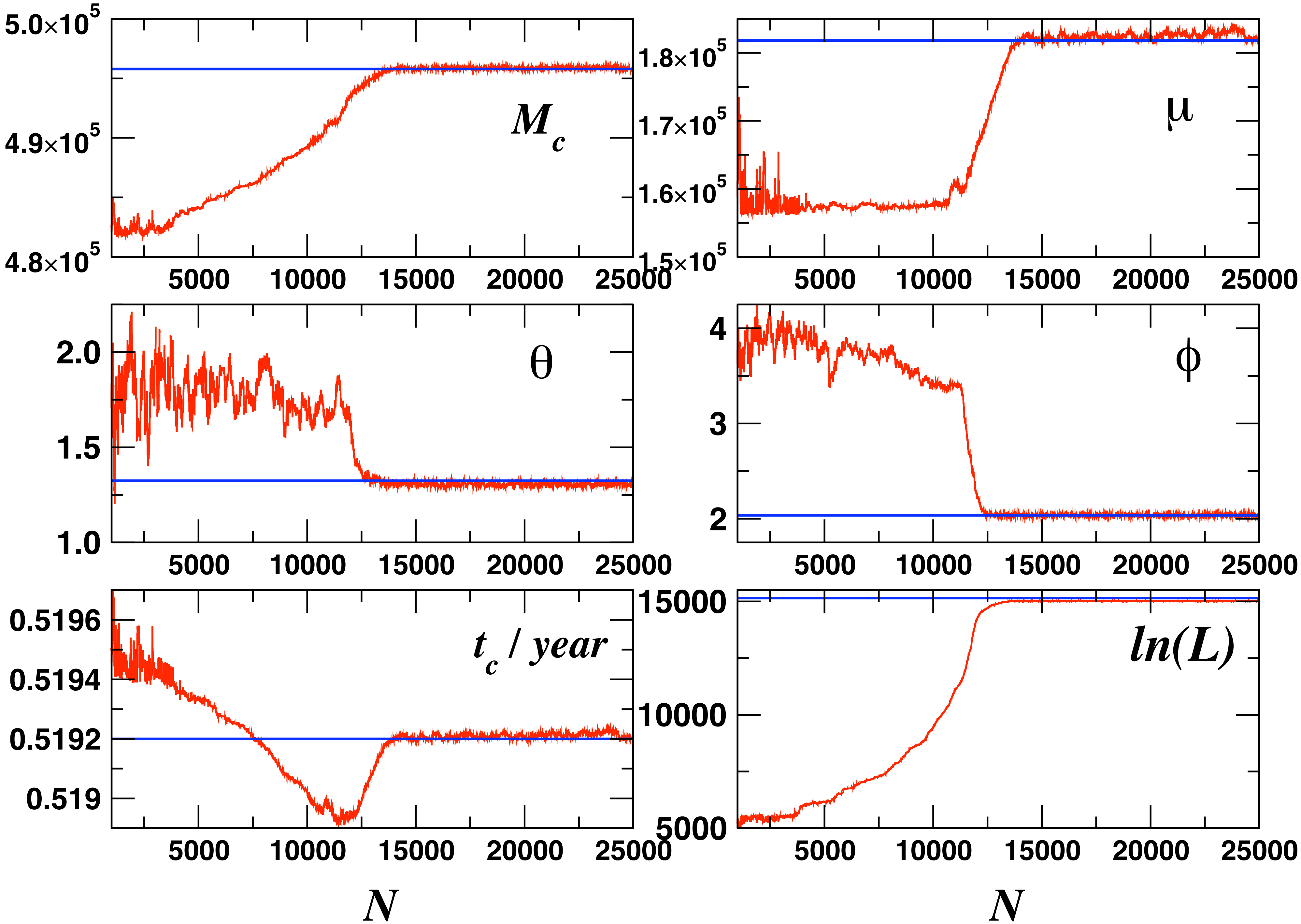
20 Million DWD signals overlap with SMBHB signal

SMBH Signal Extraction



Cornish & Porter, gr-qc/0605135

SMBH Signal Extraction



Cornish & Porter, gr-qc/0605135

http://astrogravs.gsfc.nasa.gov/docs/mldc/

AstroGravS

Mock LISA Data Challenge

Mock LISA Data Challenge

In support of the Laser Interferometer Space Antenna (LISA) gravitational wave observatory, we are conducting several rounds of mock data challenges. The LISA Mock Data Challenges were proposed and discussed at meetings organized by the US and European LISA Project that were attended by a broad cross section of the international gravitational-wave community. These challenges are meant to be blind tests, but not really a contest.These serve the dual purposes of fostering the development of LISA data analysis tools and capabilities, and of demonstrating the technical readiness already achieved by the gravitational-wave community in distilling a rich science payoff from the LISA data output.

The Mock LISA Data Challenge (MLDC) Taskforce has been working since the beginning of this year to formulate challenge problems of maximum efficacy, to establish criteria for the evaluation of the analyses, to develop standard models of the LISA mission (orbit, noises) and of the LISA sources (waveforms, parameterization), to provide computing tools such as LISA response simulators, source waveform generators, and a Mock Data Challenge file format, and more generally to provide any technical support necessary to the challengers, including moderated discussion forums and a software repository.

WHAT'S NEW:

- **First Round Coming soon!** To be released June 23, 2006.

Summary

- Significant Progress in LISA Data Analysis since LISA 5
- EMRIs are the main remaining challenge
- Mock LISA Data Challenges should have us at TRL 5 by LISA 7 in Baracelona