Stochastic Background of Gravitational Waves from Cosmological Sources

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Motivation

- First generation GW detectors are up and running.
- Next generation of detectors has been funded.
- What other types of sources can we find?
- GW's are a great probe of the early universe.

What Type of Cosmological Sources?

Inhomogeneities (perturbations) **after** inflation.

Not quantum fluctuations **before** inflation!

E.g. Phase transitions, bubble collisions, other processes involving scalar fields where effects of expansion are important...

Example: Preheating

Preheating is the first stage of reheating in many models.

$$\mathcal{L} = \frac{1}{2}\partial_\mu\phi\partial^\mu\phi + \frac{1}{2}\partial_\mu\chi\partial^\mu\chi - \frac{\lambda}{4}\phi^4 - \frac{1}{2}g^2\phi^2\chi^2$$

Inflaton has a time-dependent mass: Parametric Resonance

Previous Work

- Khlebnikov & Tkachev: Flatspace approximation.
  PRD **56**, 653 (1997)
- Dufaux, Bergman, Felder, Kofman & Uzan: Approximate Green's function.
  PRD **76**, 123517 (2007)
- Easther, Giblin & Lim: Evolve TT gauge metric perturbation.
  arXiv:0712.2991
- Garcia-Bellido, Figueroa & Sastre: Evolve metric then take TT part.
  arXiv:0707.0839
- LP & Siemens: Exact Green's function.

Theoretical Framework

Background Spacetime: $ds^2 = a^2(\eta)(-d\eta^2 + dx^2 + dy^2 + dz^2)$

Perturbations: $$\ddot{h}_{ab}^{\mathrm{TT}} + 2\frac{\dot{a}(\eta)}{a(\eta)}\dot{h}_{ab}^{\mathrm{TT}} - \partial_x^2 h_{ab}^{\mathrm{TT}} = 16\pi T_{ab}^{\mathrm{TT}}$$

Assumption: $a(\eta) = \alpha\eta$ ($a(\eta) = \alpha\eta^n$)

Theoretical Framework

Spatial Fourier Transform: $$\ddot{h}_{ab}^{\mathrm{TT}} + \frac{2}{\eta}\dot{h}_{ab}^{\mathrm{TT}} + k^2 h_{ab}^{\mathrm{TT}} = 16\pi T_{ab}^{\mathrm{TT}}$$

Easy Solution:

$$h_{ab}^{\mathrm{TT}} = \frac{16\pi}{k}\int_{\eta_i}^{\eta_f} d\eta'\,\frac{\eta'}{\eta}\sin[k(\eta-\eta')]T_{ab}^{\mathrm{TT}}$$

Theoretical Framework

Analytic:

$$\frac{dE_{\rm gw}}{d\Omega} = \frac{16\pi^2}{\alpha^2\eta^6}\sum_{i,j}\int_{-\infty}^{\infty} d\omega\,\left[\sin(\omega\eta) - \omega\eta\cos(\omega\eta)\right]^2 \left|\frac{\partial}{\partial\omega}T_{ij}^{\rm TT}(\omega,\mathbf{k})\right|^2$$

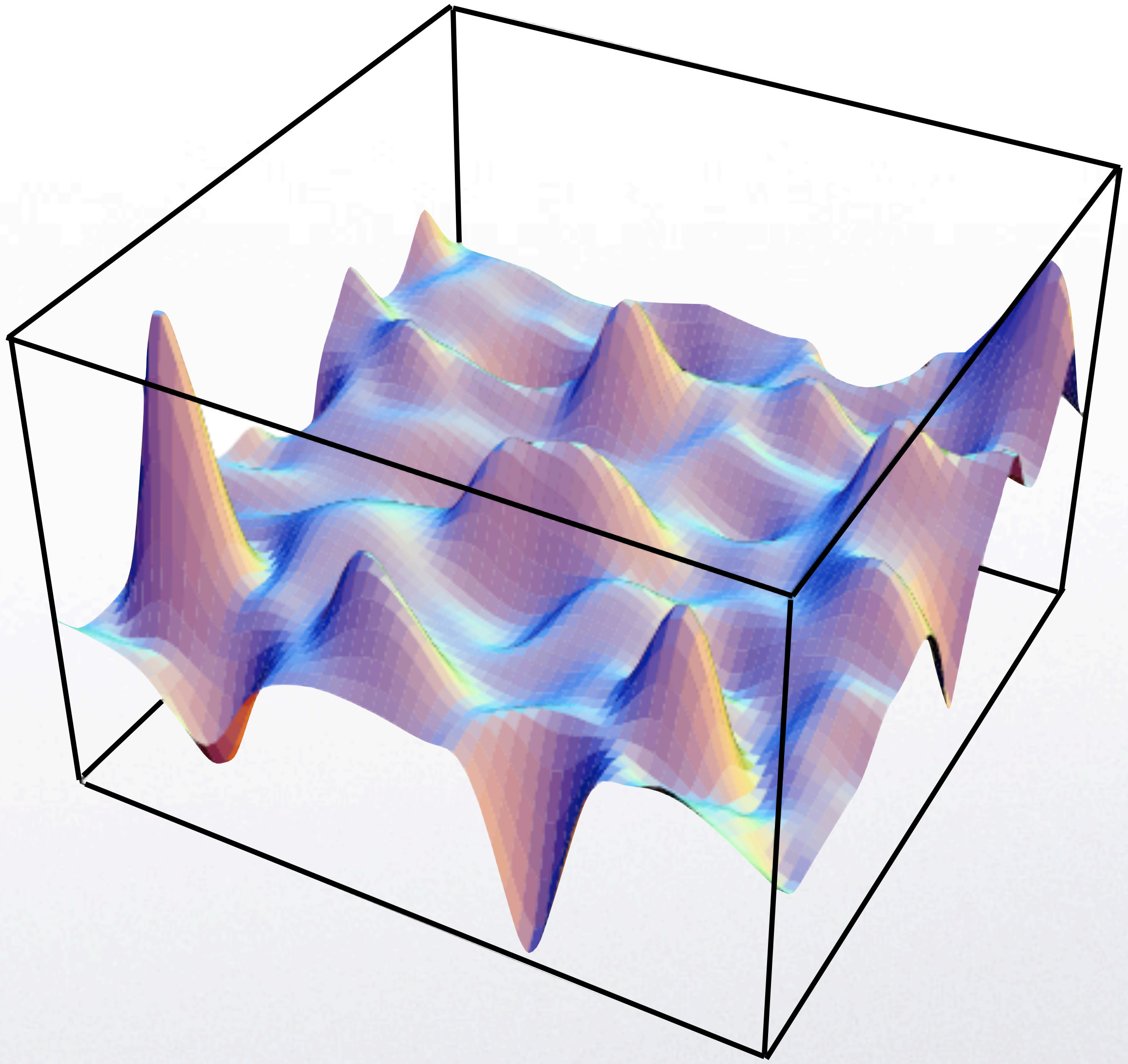
Compare with Weinberg:

$$\frac{dE_{\rm gw}}{d\Omega} = \pi^2\sum_{i,j}\int_{-\infty}^{\infty} d\omega\,\omega^2\left|T_{ij}^{\rm TT}(\omega,\mathbf{k})\right|^2$$

Computational Framework

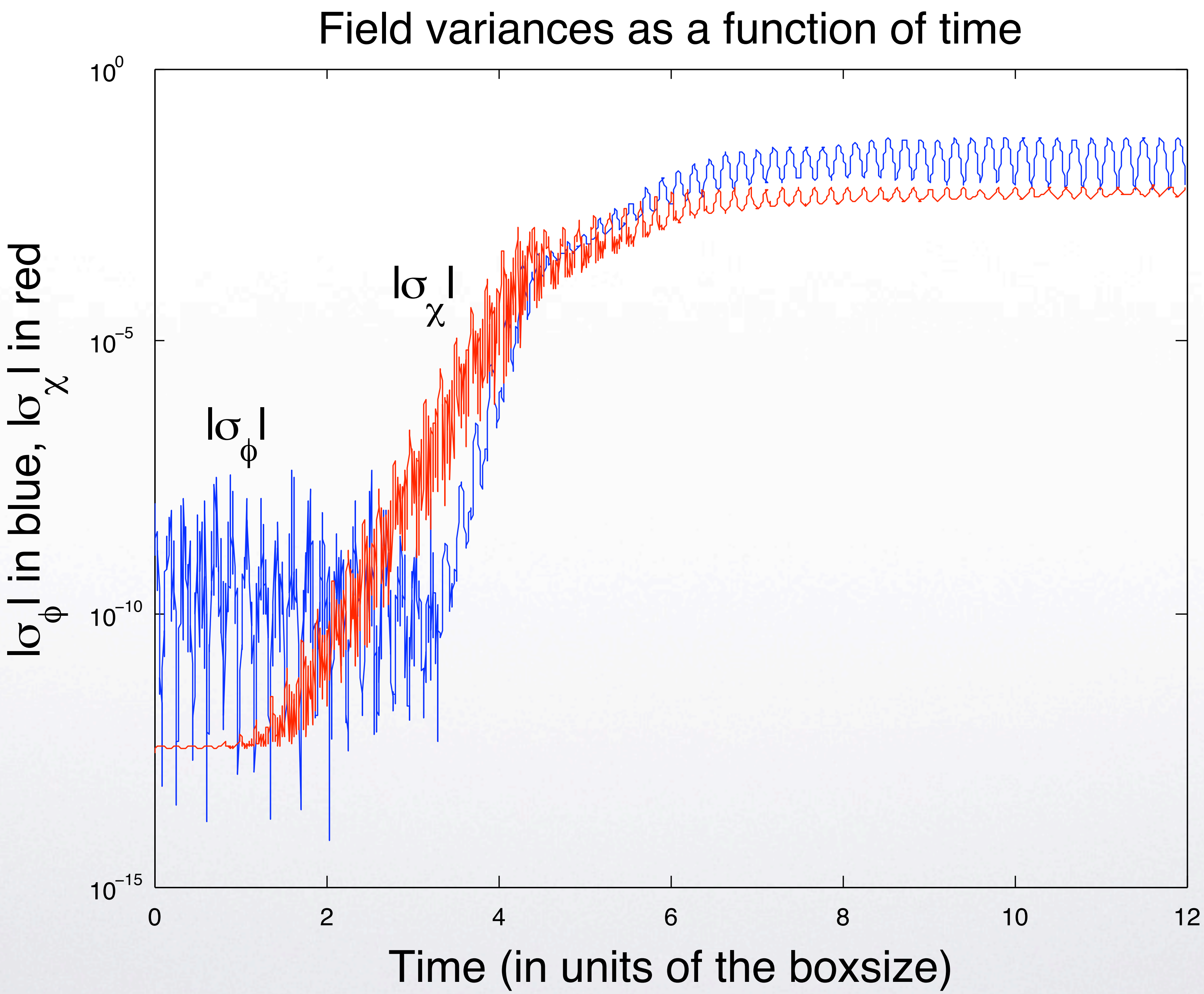
- Evolve the source with LATTICEASY (Felder & Tkachev).
- Use FFTW.
- Threading with OpenMP.

On a 4 core 3GHz machine
256^3 box takes 18 hours!



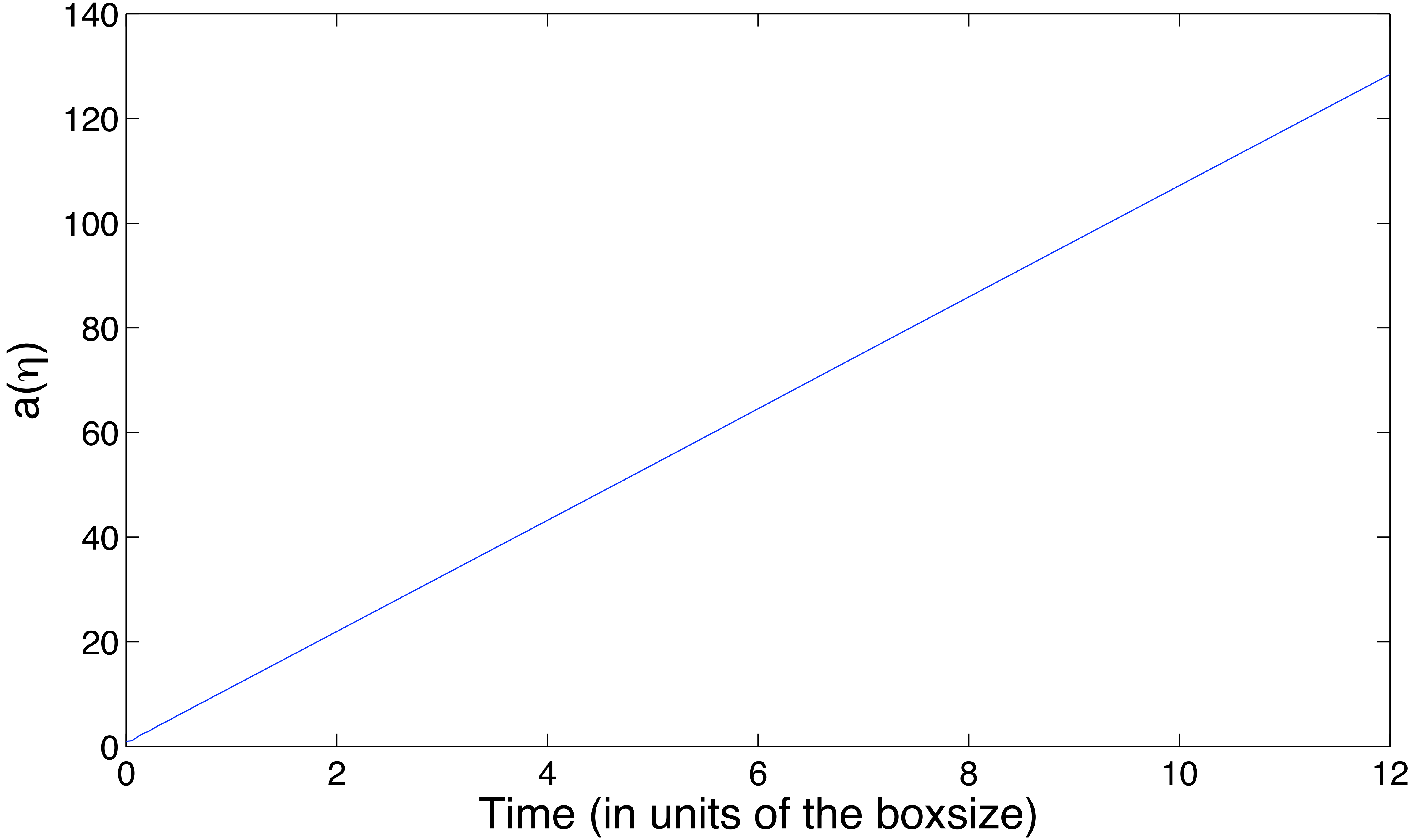
Dufuax, Bergman, Felder, Kofman & Uzan (2007)

Results



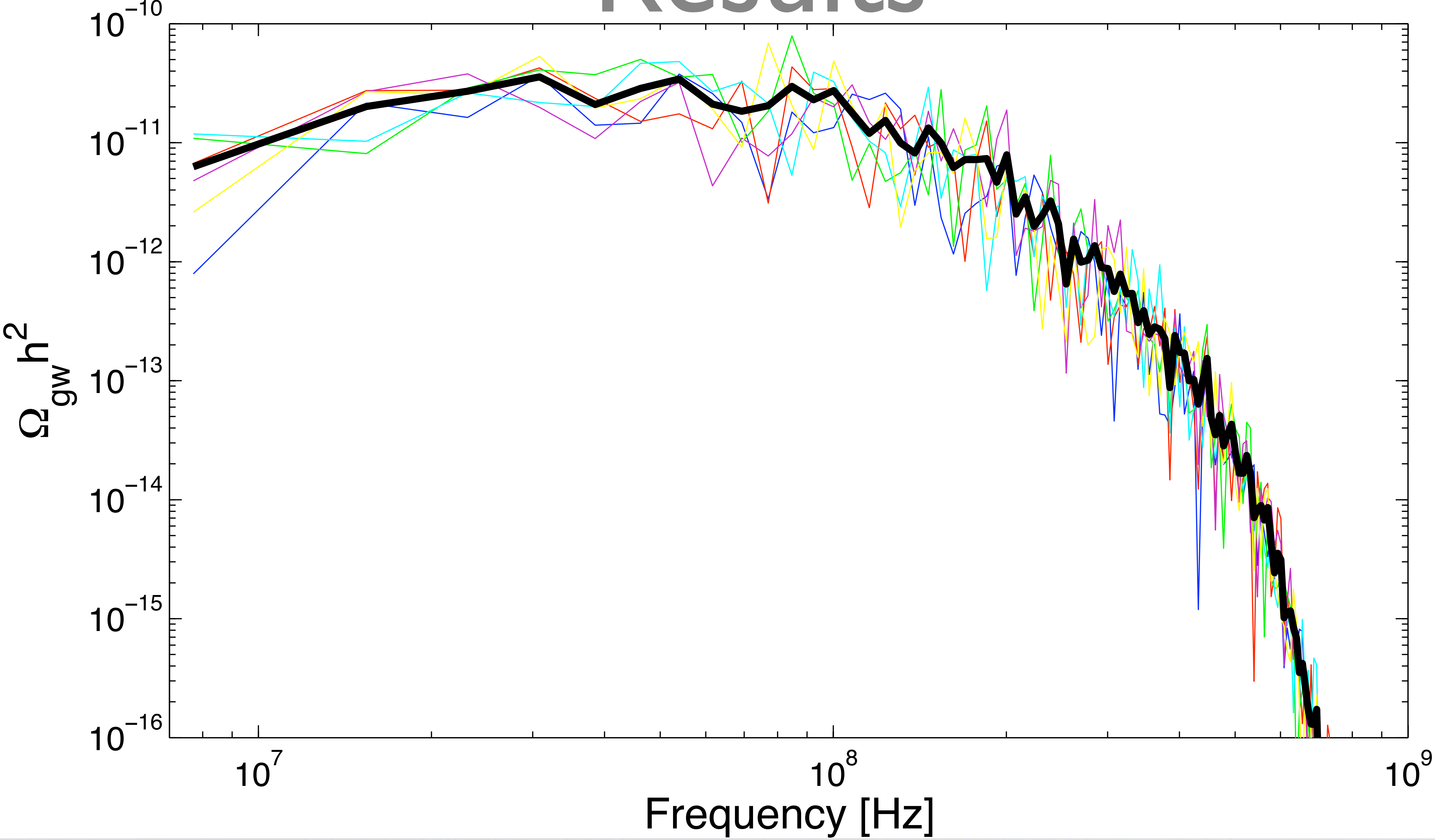
Field variances as a function of time
10^{0}
10^{-5}
10^{-10}
10^{-15}
0
2
4
6
8
10
12
Time (in units of the boxsize)
$|\sigma_\phi|$ in blue, $|\sigma_\chi|$ in red
$|\sigma_\chi|$
$|\sigma_\phi|$

Results



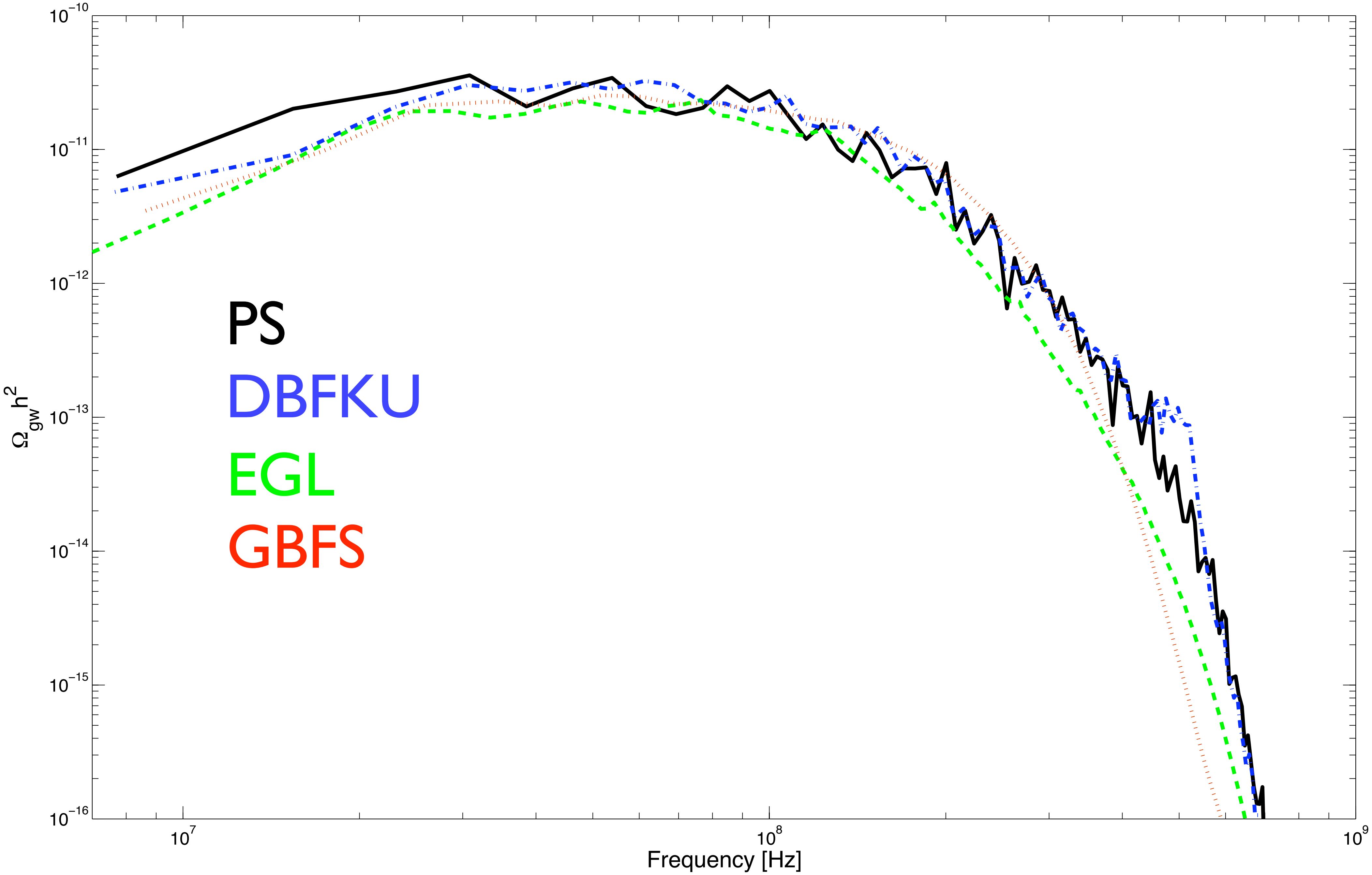
140
120
100
80
60
40
20
0
a(η)
0
2
4
6
8
10
12
Time (in units of the boxsize)

Results



10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-16}
$\Omega_{gw} h^2$
10^{7}
10^{8}
10^{9}
Frequency [Hz]

Results



PS
DBFKU
EGL
GBFS
$\Omega_{gw} h^2$
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-16}
10^{7}
10^{8}
10^{9}
Frequency [Hz]

On The Horizon

- Electroweak scale physics (LISA)
- More matter fields
- Got a model?