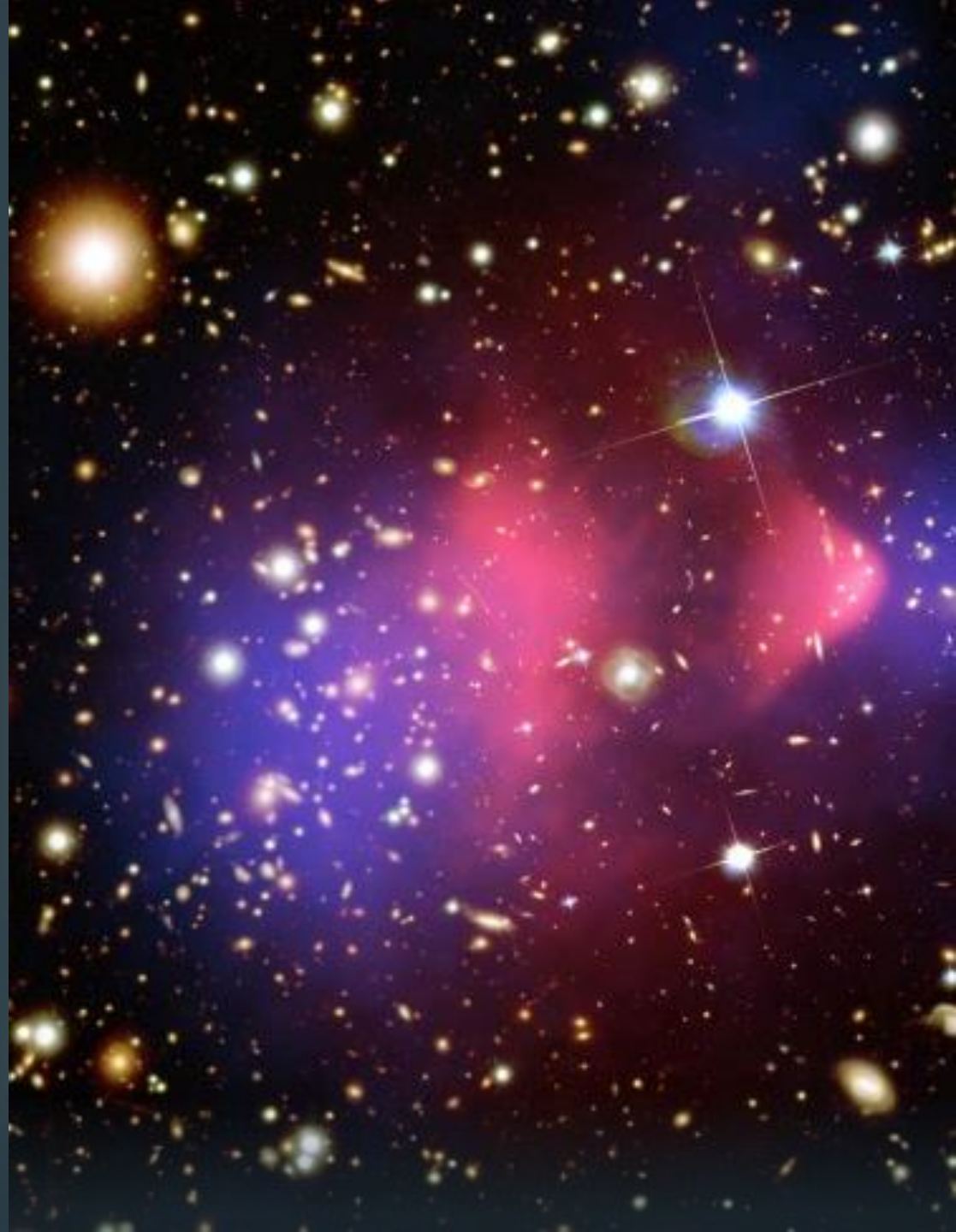
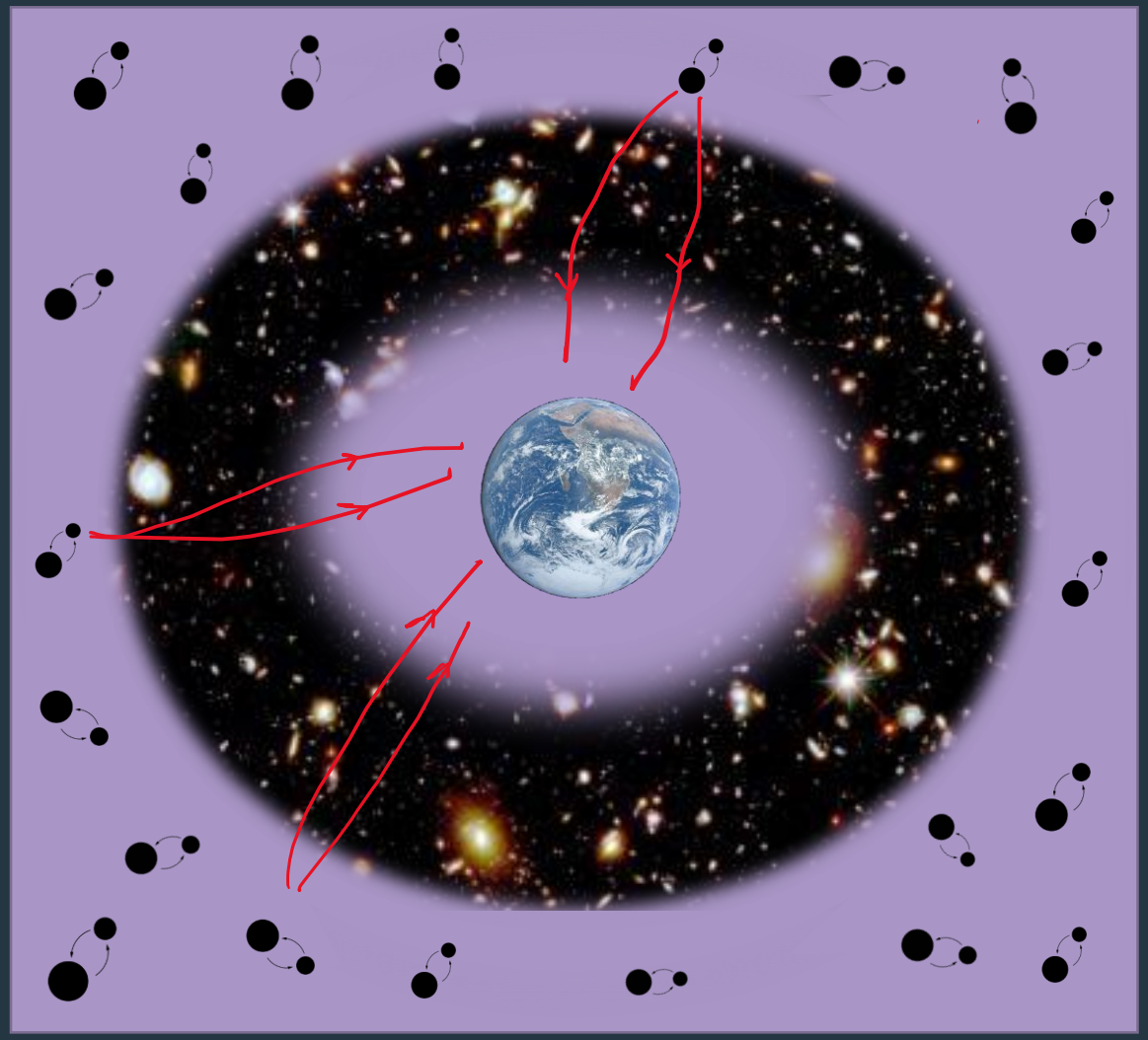
Study of Angular Correlation Signatures Induced on GW Stochastic Background by Lensing Effects

G. Cella, A. Ain



The basic idea

- An “original” Gravitational Wave Stochastic Background, of Astrophysical or Cosmological origin, is modified during propagation by lensing effects.
- This can have effects on the statistical structure of the background
- Is it possible to detect these effects?
- What can we learn?
- What are the perspectives for current and next generation detectors?



Gravitational Wave Stochastic Background

$$g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu}$$ Sum of (many) statistically independent events

A possible parameterization of observable quantities can be given in term of correlations:

$$\Gamma^{a_1 b_1 \cdots a_k b_k}(\boldsymbol{x}_1, t_1; \cdots; \boldsymbol{x}_k, t_k) = \left\langle h^{a_1 b_1}(\boldsymbol{x}_1, t_1) \cdots h^{a_k b_k}(\boldsymbol{x}_1, t_1) \right\rangle$$

which scales with the rate of events as

$$\Gamma^{a_1 b_1 \cdots a_k b_k} \to \mathcal{R}^{\frac{k-2}{2}} \Gamma^{a_1 b_1 \cdots a_k b_k}$$

Modeled as a sum over modes:

$$h_{ab}(x,t) = \sum_P \int_{S^2} d\hat{\Omega}_n \epsilon_{ij}(n) \int df \tilde{h}_P(f,n) e^{2\pi i f(t - n\cdot x)}$$

In the Gaussian, unpolarized and stationary approximation this is completely characterized by

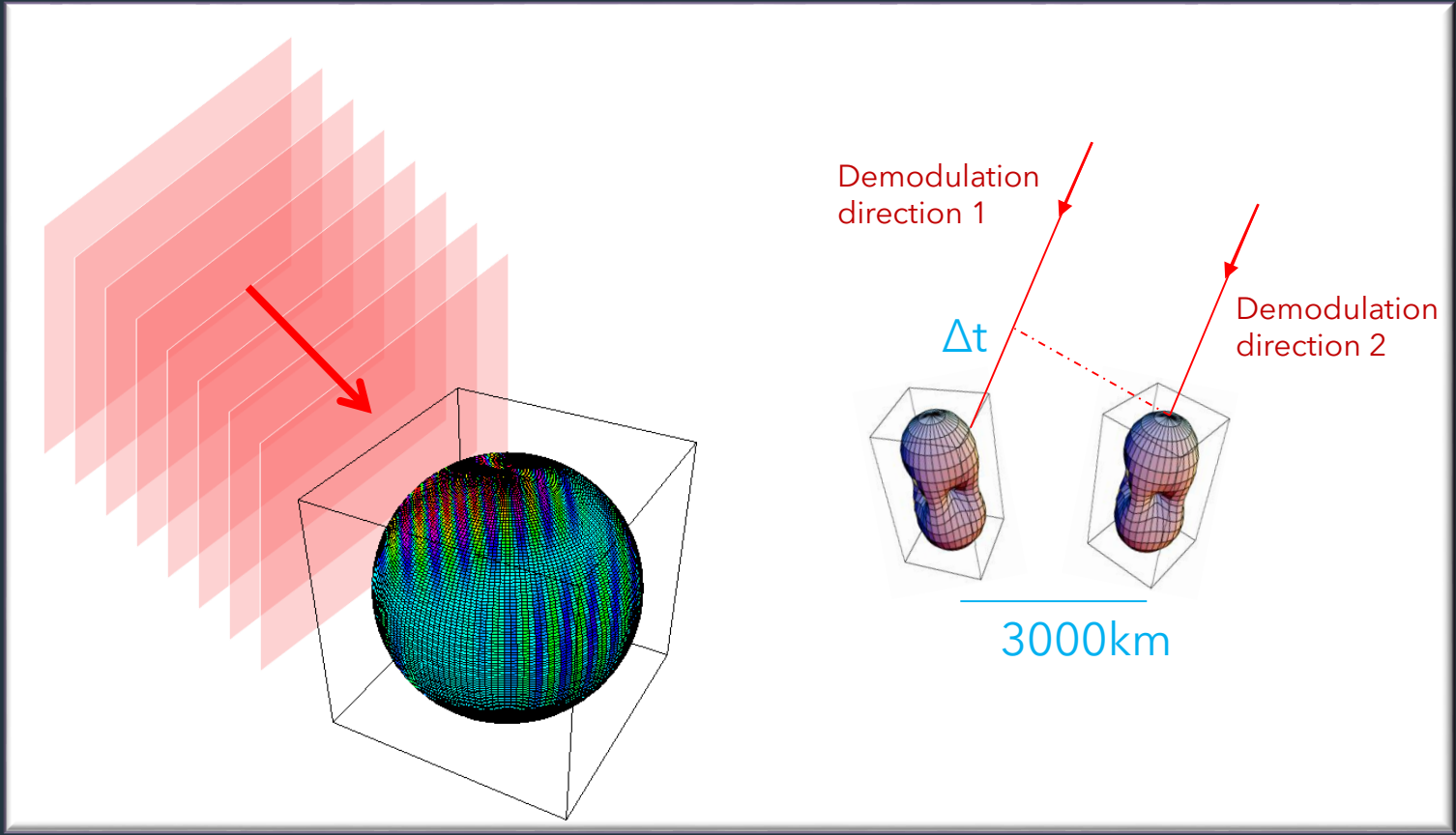
$$\left\langle \tilde{h}_A(f,n) \tilde{h}_B(f',n') \right\rangle = \delta_{AB} \delta^2(n,n') \, \delta(f - f') P(f,n)$$

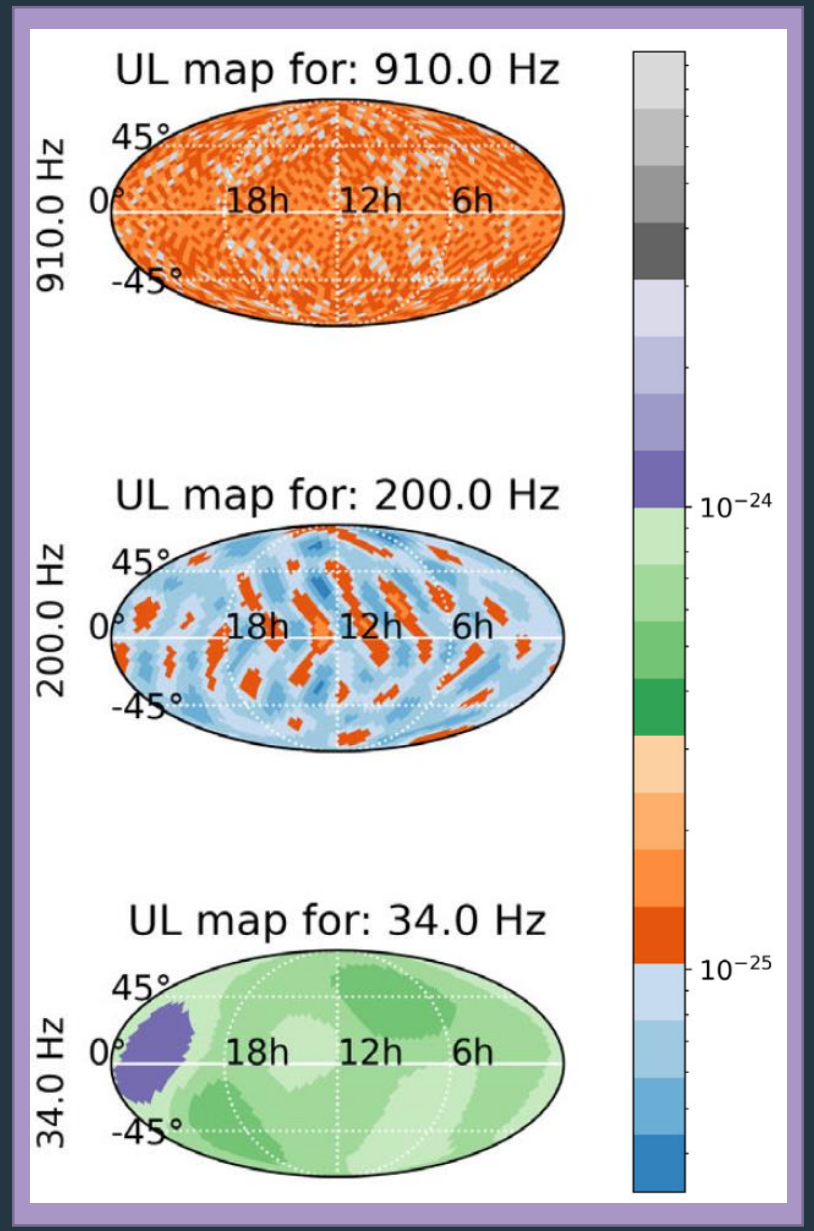
No angular correlations

Map reconstruction

- It is possible to infer information about the $P(f,n)$ factor (maps). See for example **PHYSICAL REVIEW D 105, 122001 (2022)**

- Basic idea: take advantage of modulation effects induced by detectors' motion. **Correct the direction-dependent modulation and cross-correlate**

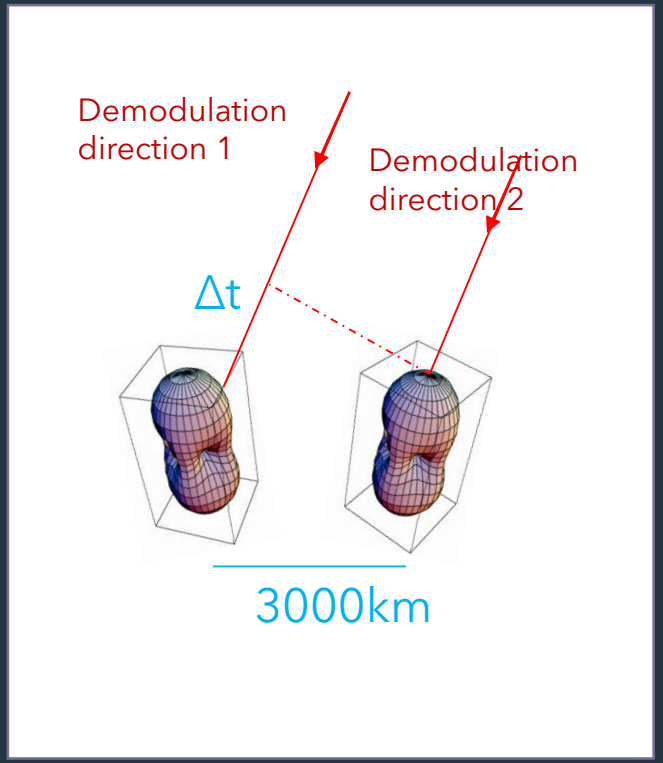




Introducing angular correlations

$$\left\langle \tilde{h}_A(f,n)\tilde{h}_B(f',n') \right\rangle = \delta_{AB}\delta^2(n,n')\,\delta(f-f')P(f,n)$$

$$\left\langle \tilde{h}_A(f,n)\tilde{h}_B(f',n') \right\rangle = \delta_{AB}\mathcal{C}(n,n',f)\,\delta(f-f')P(f,n)$$



- Redesign the demodulation procedure to estimate the correlation factor
- Should work better on a “large” network

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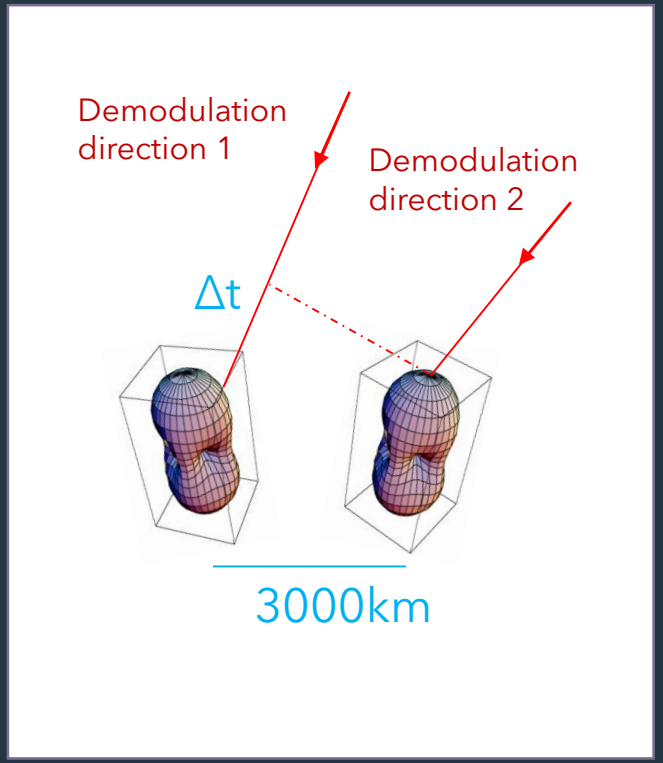

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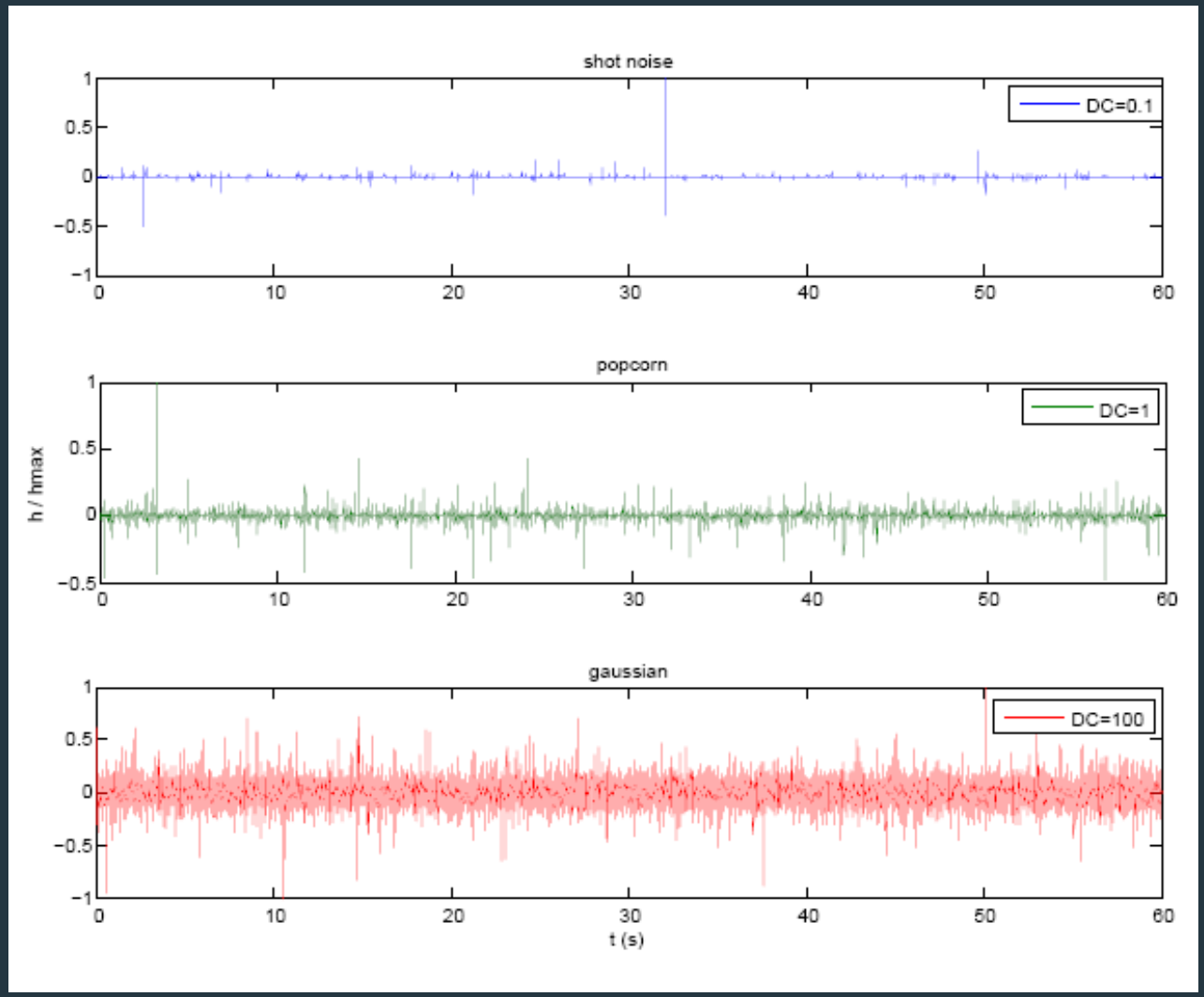
Generalizations: non-Gaussian backgrounds

- Non-Gaussian backgrounds: potentially more information to extract
- Rich statistical structure both in the frequency and time domain
- Non-Gaussianity enhanced by the demodulation procedure needed to construct the map

$$D(z) = \int_0^z \underbrace{[(1+z')\tau]}_{\text{Observed event duration}} \underbrace{\left[\frac{dR^O}{dz'}(z')\right]}_{\text{Inverse observed time interval between events}} dz'$$



Plan

- **Simulation of gravitational wave astrophysical like stochastic background signals (toy model) *[months 1-3]***
  - **Introduction in the toy model simulation of correlation signatures**
- Reconstruction of GW skymaps with existing algorithm [months 4-10]
  - Data reduction: folded data (see https://arxiv.org/abs/1504.01714)
  - Identification and sensitivity study for correlation signatures
- Application of an optimal Bayesian search and parameter estimation to the data *[months 11-18]*
  - Identification and characterization of correlation signatures
  - Estimation of computational requests, and approach to their reduction (both in signal simulation and MCMC parameter estimation)

Integration with data lake/VRE

1. Release of simulation/estimation code
2. Release of typical sets of data
3. Notebook interface for data generation on cloud

FTE

- 1 postdoc
- 2 undergraduate students (doing their master thesis work on this)
- 1 senior (10%)