SIRP Modeling of LIGO Noise Floor
Methods and Results.
A Progress Report

Roberto Conte,
Maurizio Longo,
Stefano Marano,
Vincenzo Matta,
Innocenzo M. Pinto

Research Goal

Goal : validating a gaussian-exogenous (SIRP) model for LIGO noise floor;

Motivation: possibly *simplest* (though fairly *general*) model capturing noise floor *non-gaussianity / non-stationarity* features, while being still manageable, as concerns :

i) detector optimization;
ii) noise simulation;
iii) identification of physical sources of specific noise-floor features.

Work on Noise-Floor in LIGO-LSC

ARMA modeling of IFO noise-floor

[Mukherjee, CQG 21 (2004) S1783
Mukherjee LIGO G040361-00-Z (2004)]

Median based noise-floor tracker

[Mukherjee, CQG 20 (2003) S925]

Change-Point

[Mohanty, PRD 61 (2000) 122002
Mohanty & Mukherjee, CQG 19 (2002) 1471
McNabb et al., CQG 21 (2004) S1705
Mohanty & Jimenez, CQG 22 (2005) S1233]

Exogenous Gaussian Noise in a Nutshell

Compound gaussian (exogenous) RP

$$x(t) = s(t)\,g(t)$$

long-coherency RP — $s(t)$

N(0,1) gaussian RP — $g(t)$

-*"Long"* $x(t)$ time series markedly *non - gaussian;*

-*"Short"* time series *locally gaussian*, but *nonstationarity* shows up (*different variance* in different time stretches)

To some extent, you may trade gaussianity for stationarity..

More on Exogenous Gaussian & SIRP

LIGOG060473

LIGO Data Used to Draw Next Slides

H-H1_RDS_C02_LX-833000031-128.gwf
H-H1_RDS_C02_LX-833000159-128.gwf
H-H1_RDS_C02_LX-833000287-128.gwf
H-H1_RDS_C02_LX-833000415-128.gwf
H-H1_RDS_C02_LX-833000543-128.gwf
H-H1_RDS_C02_LX-833000671-128.gwf
H-H1_RDS_C02_LX-833000799-128.gwf
H-H1_RDS_C02_LX-833000927-128.gwf

Data Conditioning (Pre-Processing)

Passband filter - (FIR, L=3518) chop outside frequency band of interest. (40-400Hz).

PSD estimate – piecewise linear in lin/log scales fit in frequency band of interest.

Spectral equalization -divide spectral data by sqrt of smoothed PSD.

Narrowband features detection - Use Kay's $\chi 2$ test for tones ($\chi 2$ distribution assumed in each spectral bin) [S.Kay, *Modern Spectral Estimation*, Prentice-Hall, 1984].

Narrowband feature removal - Estimate amplitude frequency and phase of detected narrowband features using a sliding 2^{15} time-bin window. Subtract estimated tones in time domain from next 2^{10} time-bins.

Subsampling – Whiten (decorrelate) process by subsampling according to first zero of correlation function.

Data-Conditioning related work in LIGO-LSC:

[Sintes & Schutz, PRD 58 (1998) 122003
PRD 60 (1999) 062001;
Finn & Mukherjee, PRD 63 (2001) 062004
PRD 67 (2004) 109902]

SIRP Property of Exogenous-Gaussian

- Form triplets out of time series $\vec{\tau}_j = \{x_j, x_{j+1}, x_{j+2}\}$,
- View those triplets as cartesian coords. in R^3, and transform to spherical (polar) coords. $\vec{\tau}_j = \{R_j, \theta_j, \varphi_j\}$.
- Check that the $\{\vartheta_j \mid j = 1,2,\ldots\}$, $\{\varphi_j \mid j = 1,2,\ldots\}$ are distributed as follows

$$\left.\begin{array}{l} f_\vartheta(\vartheta) = \sin\vartheta \\ f_\varphi(\varphi) = (2\pi)^{-1} \end{array}\right\} \Longleftrightarrow$$

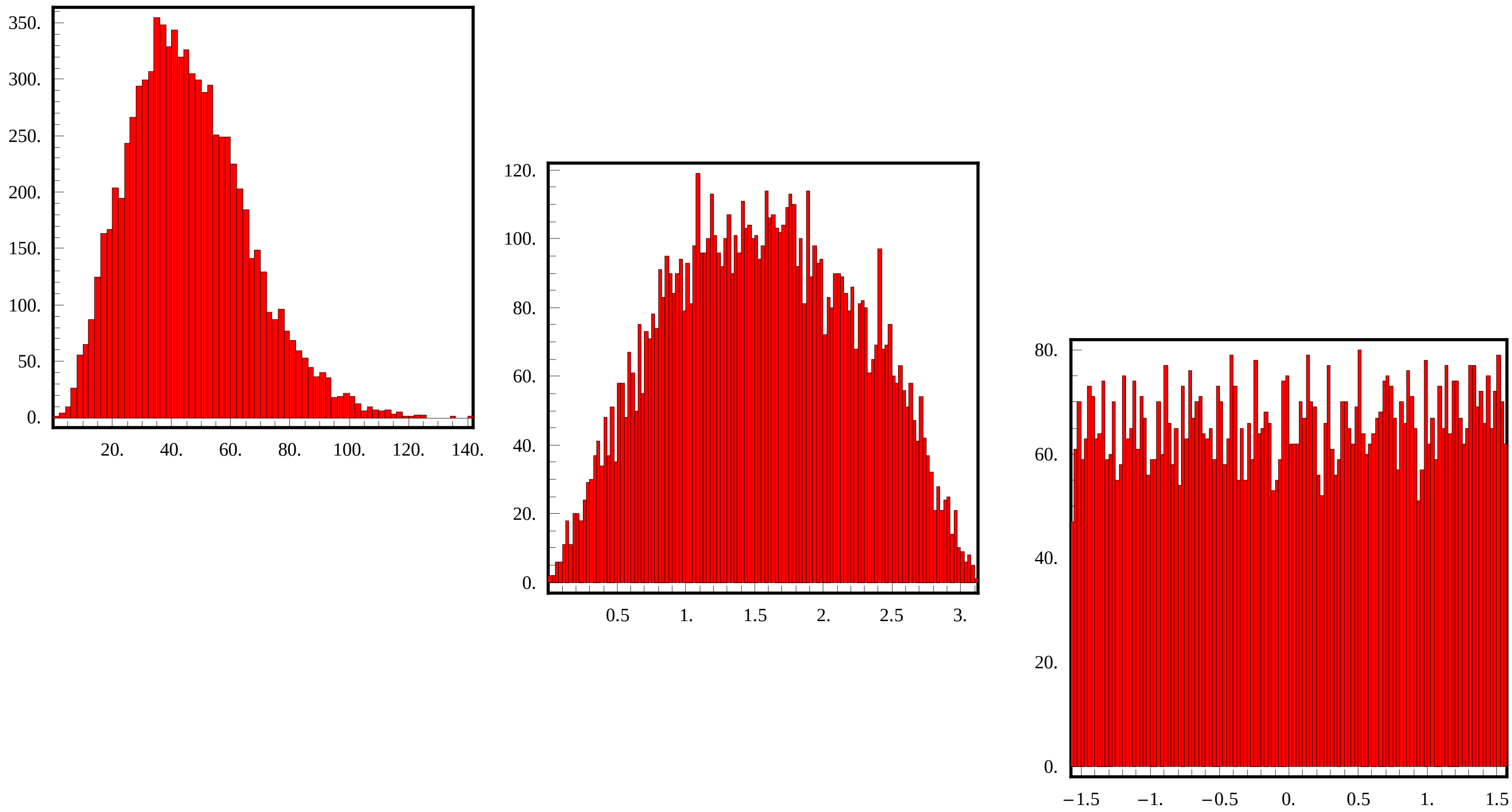
The tips of the random (unit) vectors $\vec{\tau}_j / |\vec{\tau}_j|$ fill the unit sphere *uniformly.*

These guys <u>do not</u> depend on breathing factor *s* ...

⟹ The uniform-sphere-filling property holds also for plain gaussian noise ...

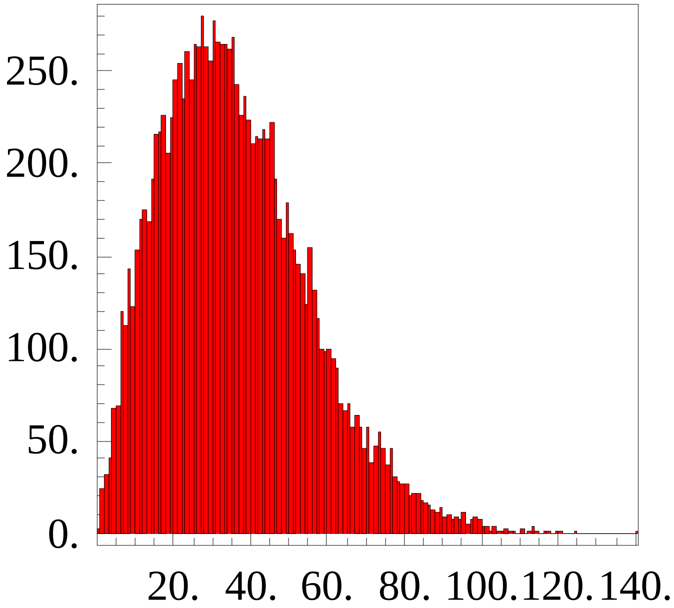
…but the radial distribution is peculiar (χ)

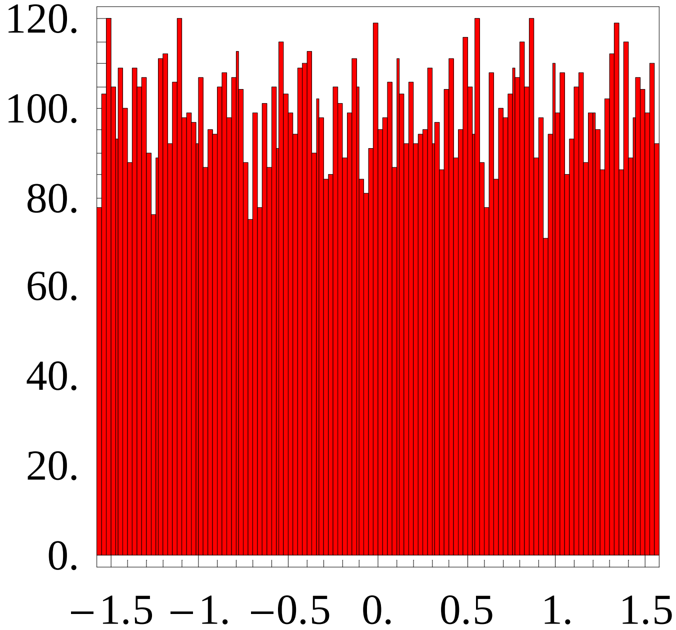
3D SIRP Behaviour of H1 Noise Floor



Triplets of LIGO (H1) noise-floor samples as points in R^3
distributions (histograms) of ρ, θ, φ.

2D SIRP Behaviour of LIGO Noise Floor





Doublets of LIGO (H1) noise-floor samples as points in R^2
distributions (histograms) of ρ, θ.

Investigating *Local* Gaussianity

-Gaussianity test tools
-Testing the testers
-Power spectrum of exogenous RP

Gaussianity Tests, I

EDF based (generic)

Kolmogorov-Smirnov

Anderson-Darling

(*composite* hypothesis test, distribution parameters estimated *from data*)

[Dagostino & Stephens, *Goodness of Fit Techniques*, Dekker, 1986, ch.4]

Skewness/Kurtosis based ("omnibus")

Jarque-Bera [Intl. Stat. Rev., 55 (1987) 163.]

Urzua [Economics Lett., 53 (1996) 247]

Rank based

Shapiro & Co-workers [Biometrika, 52 (1965) 591;
J. Am. Stat. Soc., 67 (1972) 215];

Royston [The Statistician, 42 (1993) 37]

Gaussianity Tests, II

Characteristic Function based

Koutrouvelis & Kellermeier [J. Roy. Stat. Soc. B43 (1981) 173]

Epps [Ann. Stat., 15 (1987) 1683]

HOS based

Giannakis & Tsatsanis [IEEE T-SP 32 (1994) 3460]

Hinich [J. Time Series Anal., 3 (1982) 169]

Nonlinear (memoryless) filtering based

Bussgang [Res. Lab. Elec. MIT, n. 216 (1952)]

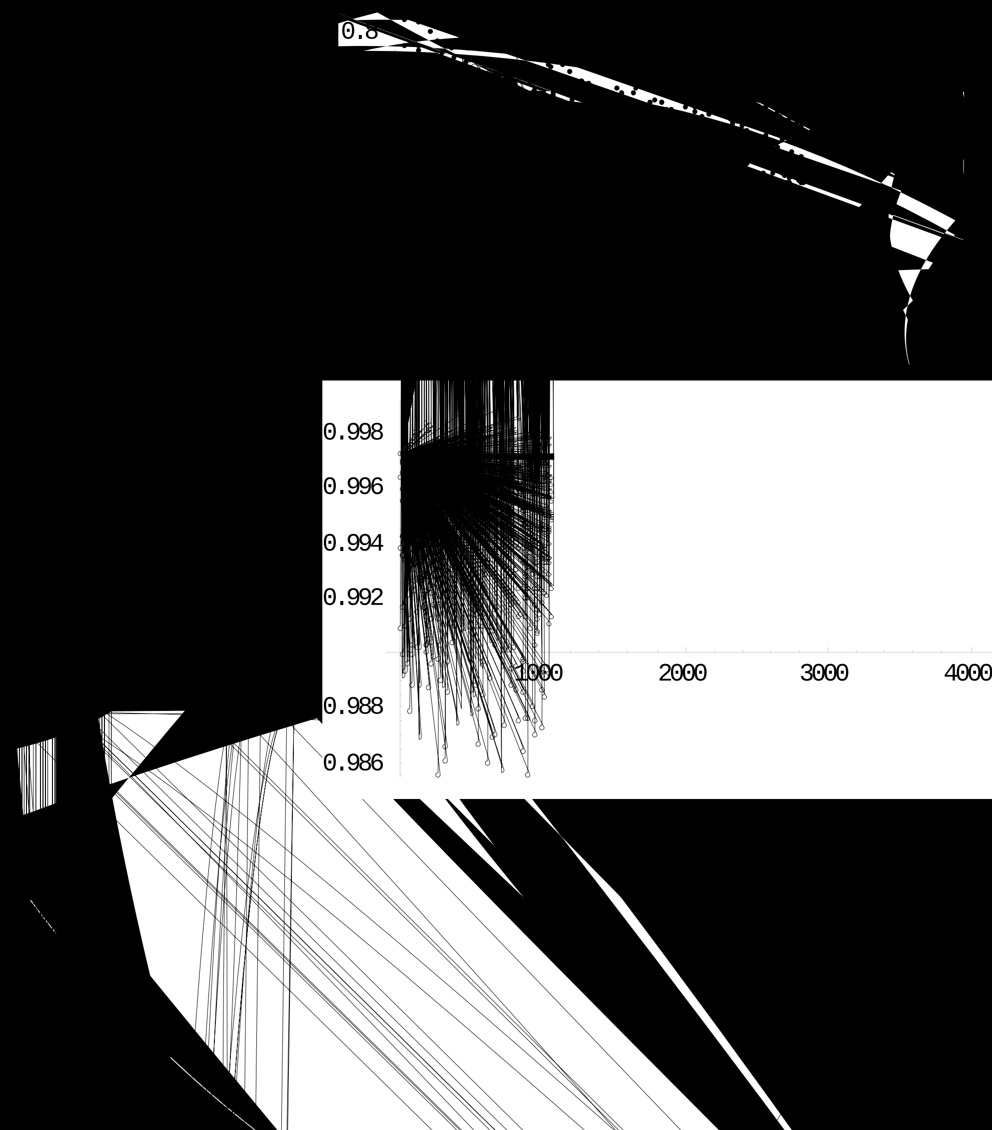
Scarano et al., [IEEE-SP HOS-WS (1887) p.434 , ISBN: 0-8186-8005-9]

LIGO-LSC

TF-Rayleigh Monitor [Finn, Gonzales & Sutton, LIGO G020133-00-Z]

GaussMon (Hinich)

[Penn, gallatin.physics.lsa.umich.edu/~keithr/lscdc/GaussMon.pdf]


0.8
0.998
0.996
0.994
0.992
1000
2000
3000
4000
0.988
0.986

Local Gaussianity Tests vs Chunk Size

Chunk fraction for which Gaussianity is rejected at 5% error level				
Chunk size	Kolmogorov.Smirnov (composite hyp.)	Anderson-Darling (composite hyp.)	Urzua (mod. Barque-Jera)	Shapiro-Francia
256	0.0510	0.488	0.0427	0.0434
1024	0.0566	0.0517	0.0889	0.0839
4096	0.0781	0.0898	0.1367	0.1328
[redacted]				
131072	0.625	0.875	1.000	1.000

At $N_C = 2^{17}$, Urzua & Shapiro-Francia (*gaussianity- specific tests*) reject gaussianity for *all* chunks; Kolmogorov-Smirnov and Anderson-Darling (*generic tests*) reject 62.5% and 87.5% of chunks

“Short” (Truly) Non Gaussian Chunks

-A fraction of “short” chunks identified as non-gaussian found to contain *true non gaussian* features, (e.g., abrupt (*non adiabatic*) jumps in the exogenous factor;

-Jumps can be finely located using *change-point* detection algos (e.g., blocknormal, or akin);

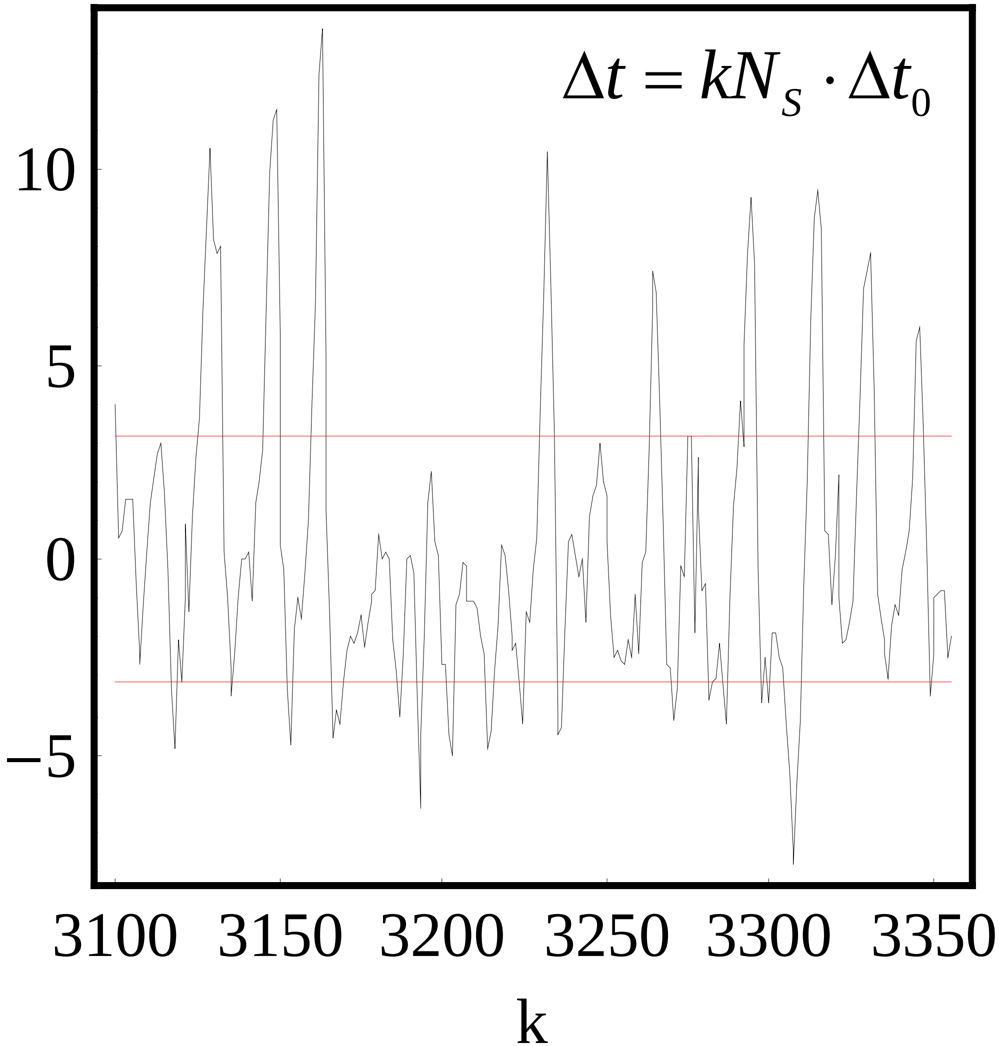
-It makes sense to look for *correlations* between these abrupt-changes, and data from IFO aux-channels;

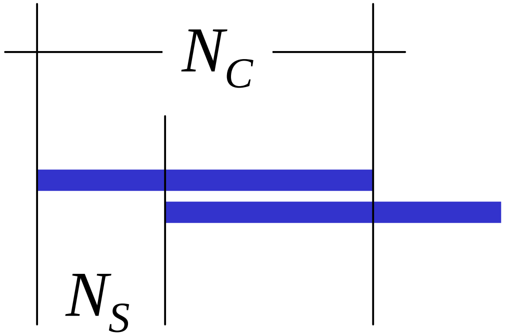
-Exogenous models apply on the left/right of the above non-adiabatic changes *only*.

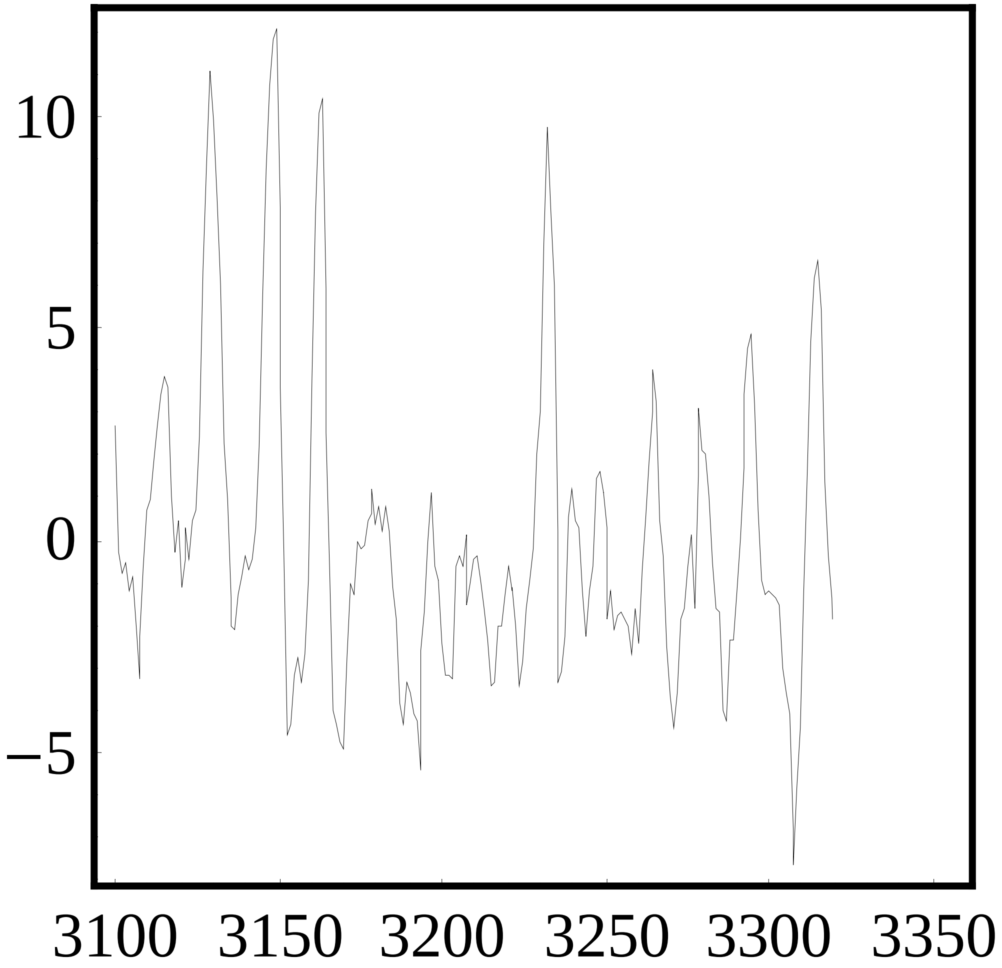
The Exogenous Factor (Local StDev)

-Moving window estimation of exogenous RP
-Distribution of local std. deviation. Moments
-Time correlation of exogenous RP
-Power spectrum of exogenous RP

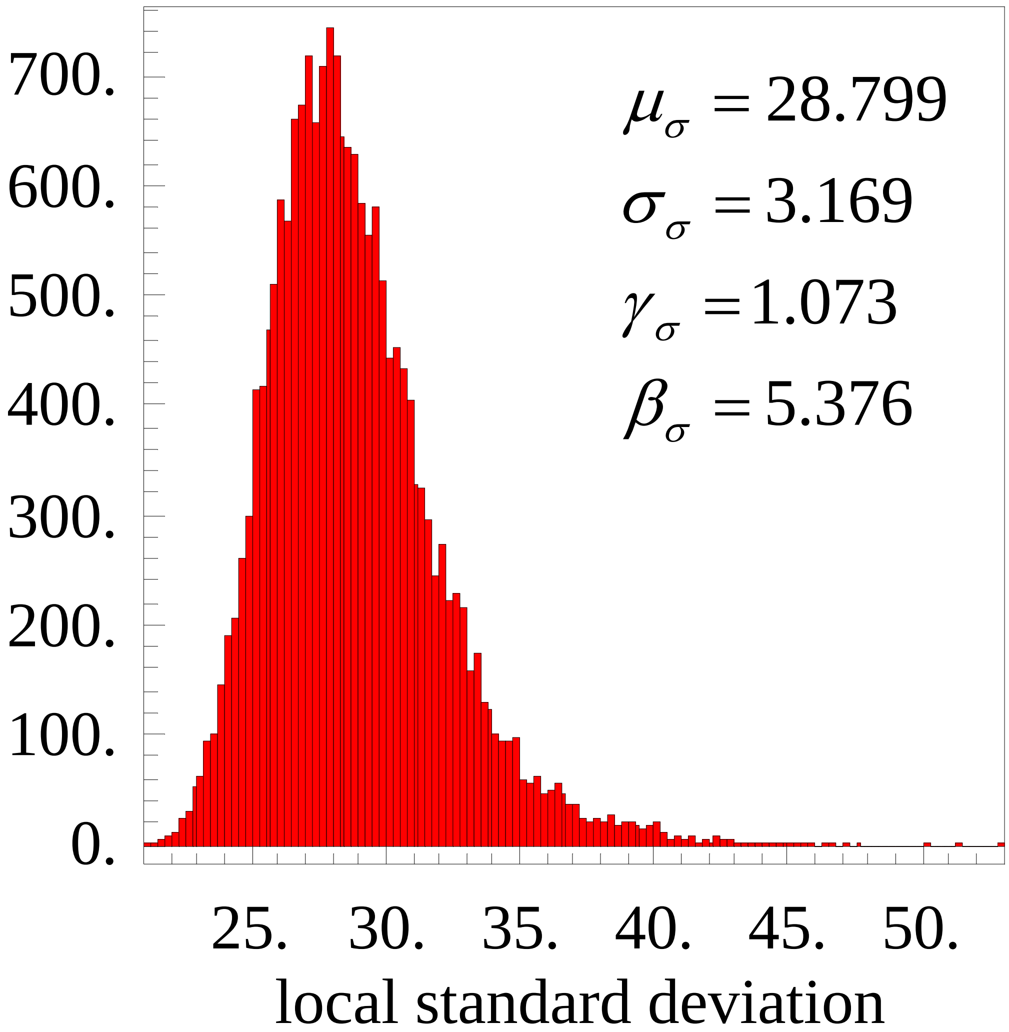
Local StDev – Robust Estimator

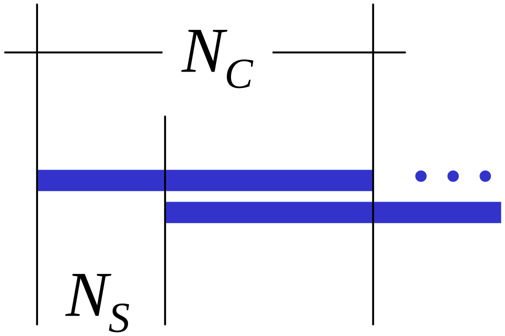





10
5
0
−5
3100
3150
3200
3250
3300
3350

Local StDev Distribution – ML Estimator

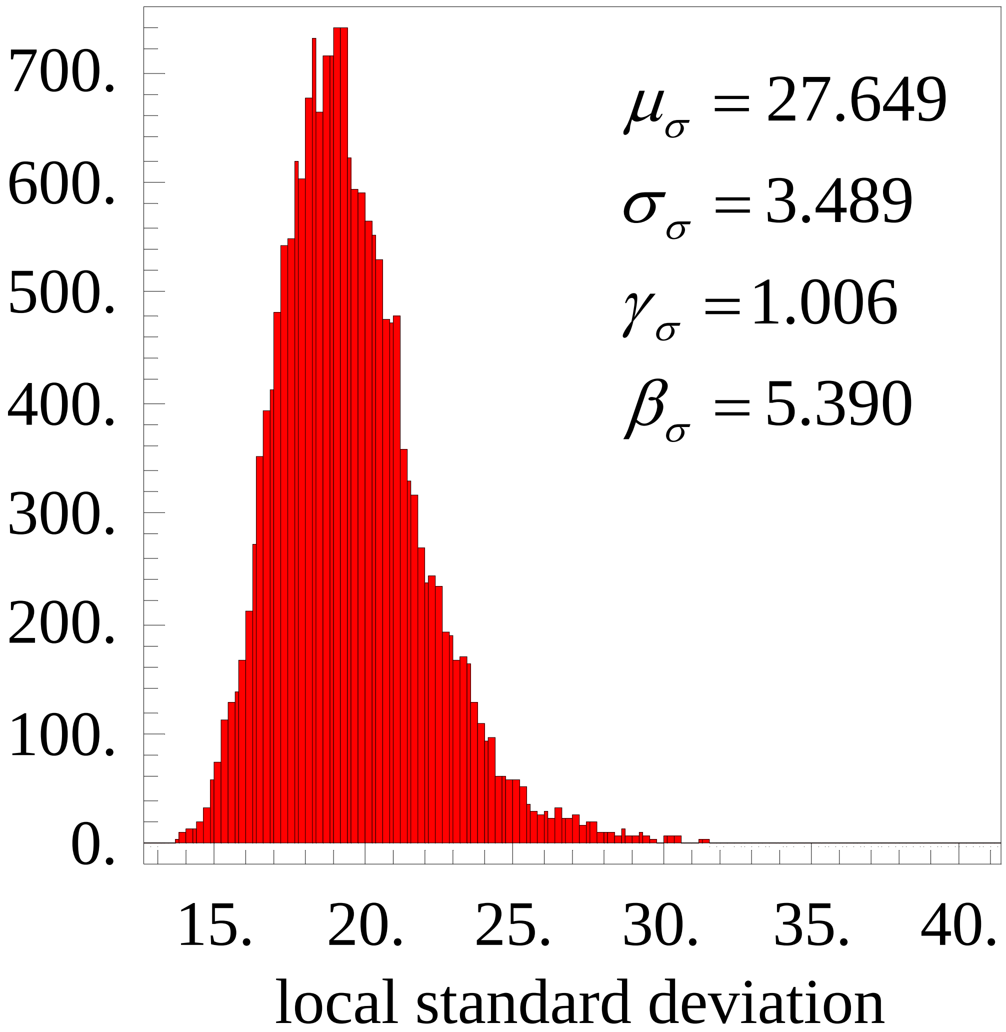


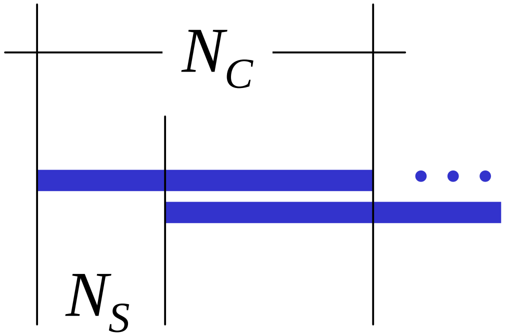


$N_C = 256$

$N_S = 64$

Local StDev Distribution – Robust Estimator

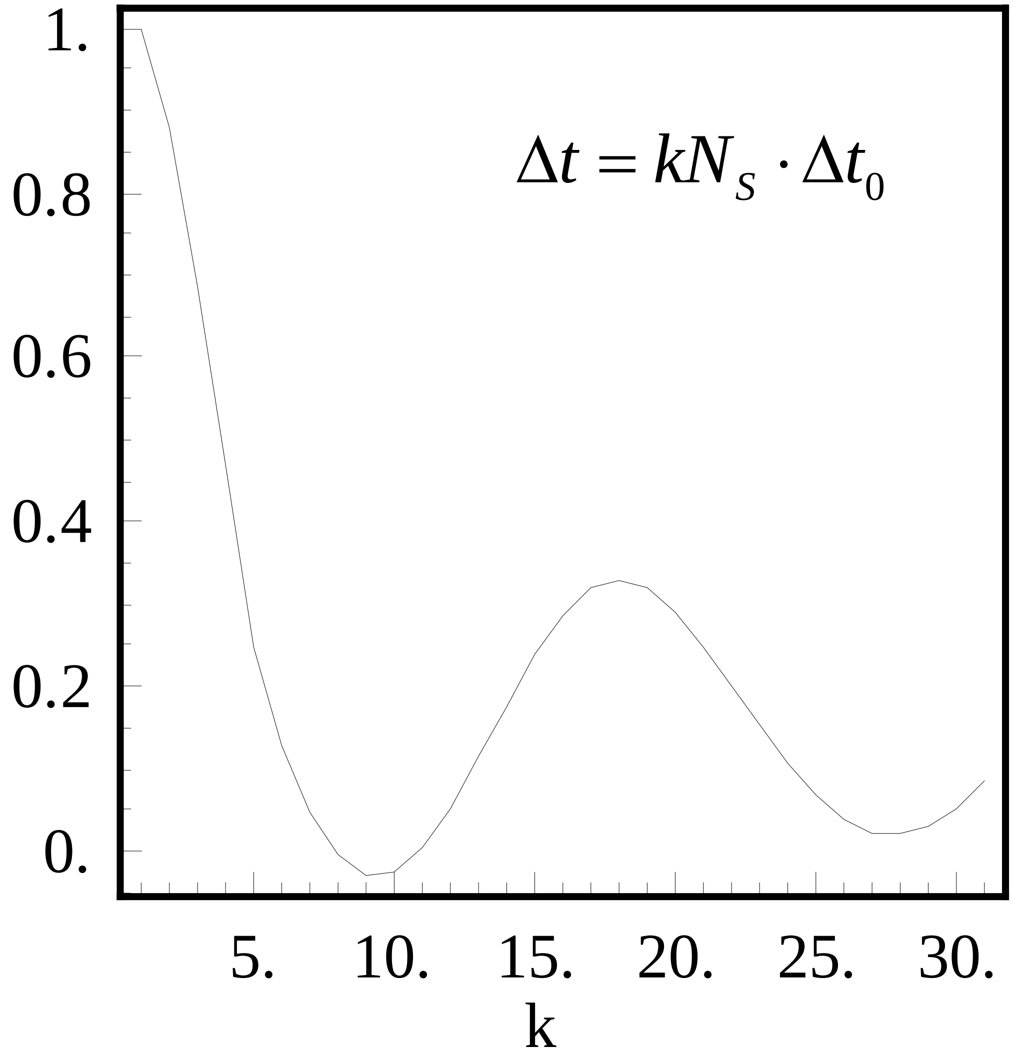


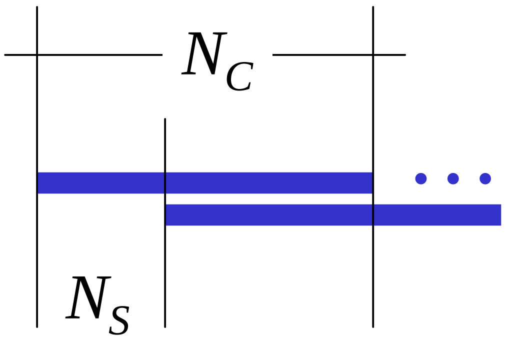


$N_C = 256$

$N_S = 64$

Local StDev Correlation – ML Estimator

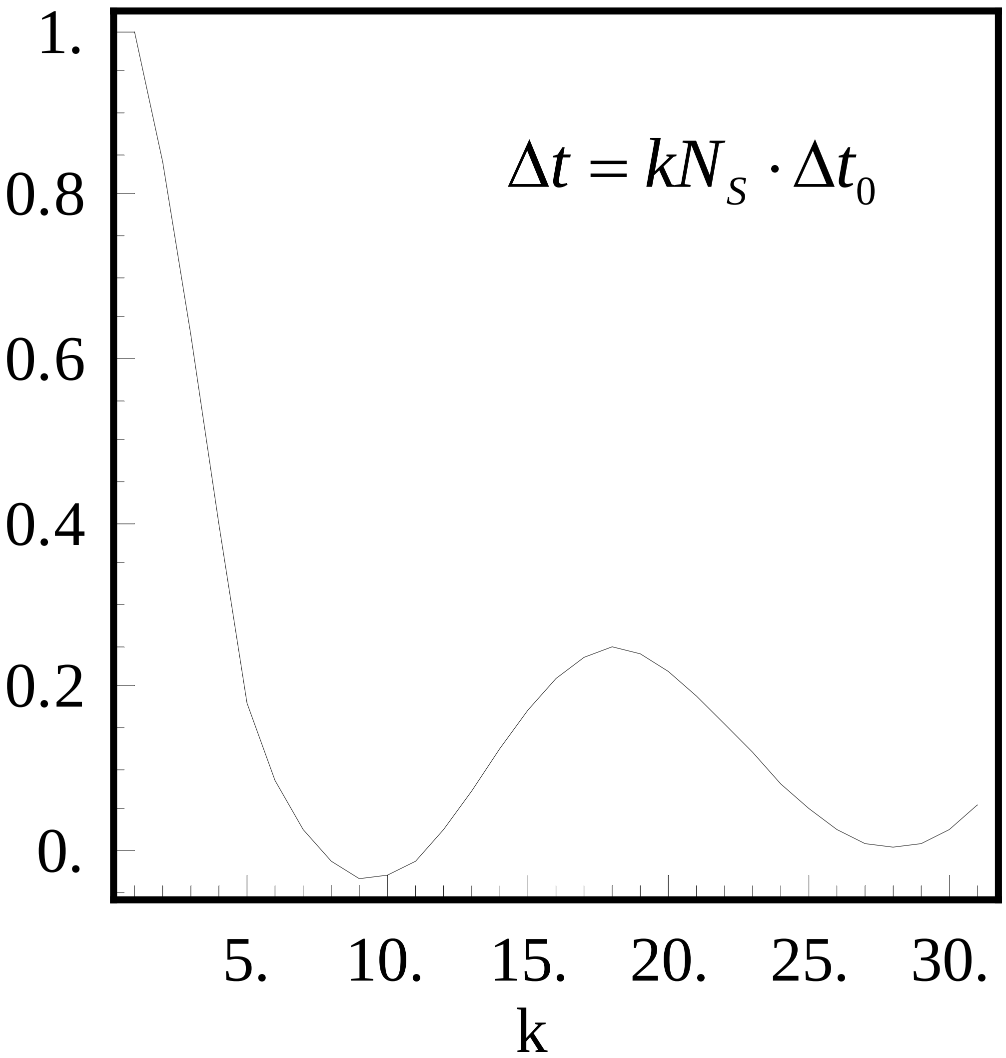


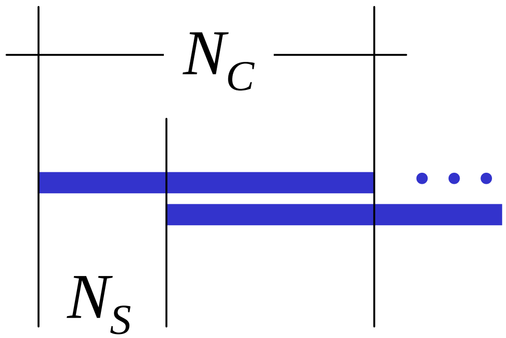


$N_C = 256$

$N_S = 64$

Local StDev Correlation – Robust Estimator



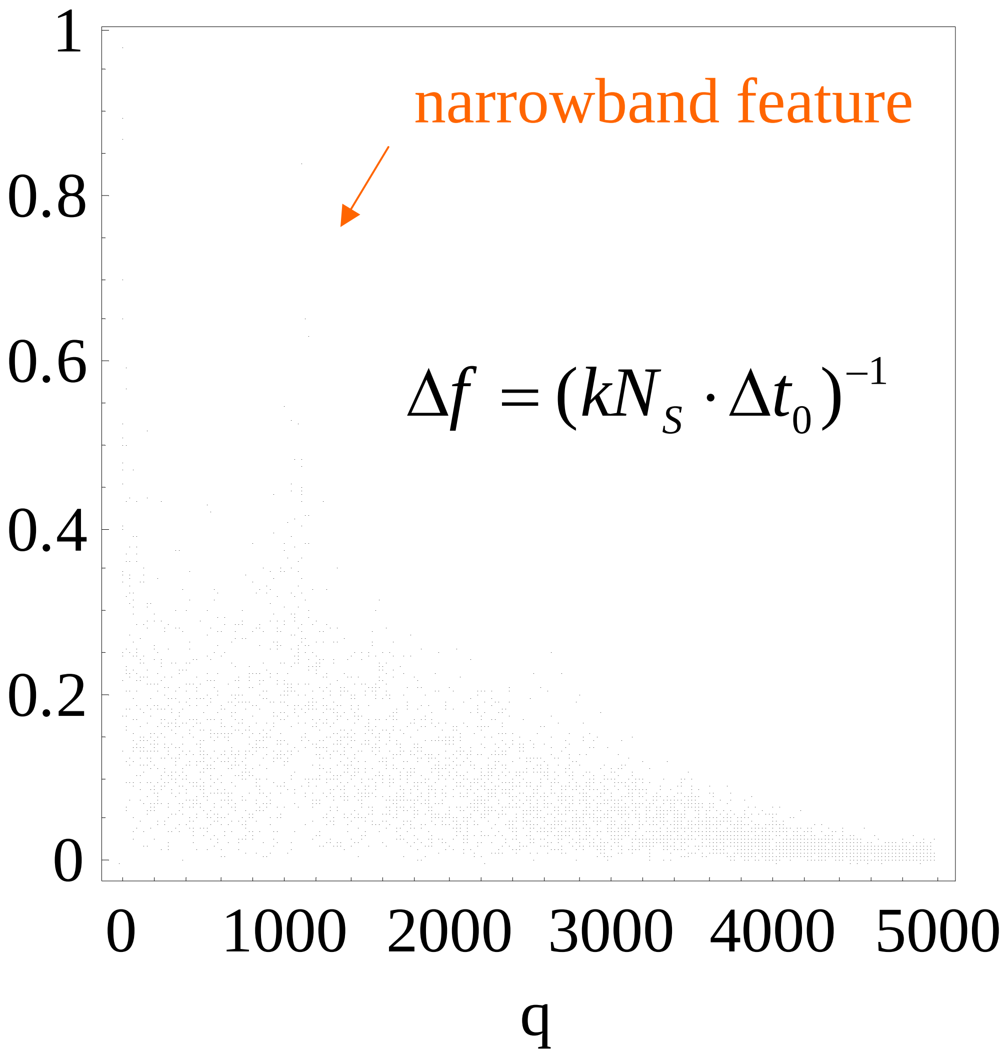


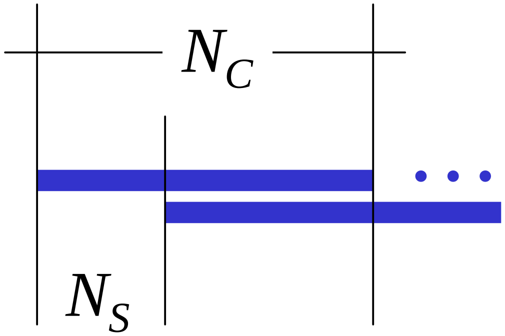
$N_C = 256$

$N_S = 64$

[redacted]

Local StDev Spectrum – Robust Estimator





$$N_C = 256$$

$$N_S = 64$$

Future Work Directions

-Synthesis and performance (in terms of statistical departure from “experimental” IFO noise of exogenous gaussian noise-floor simulator

-Tools for investigating correlation between noise-floor features (change points, narrowband spectral features) and auxiliary channels

-Synthesis and performance of “generalized matched filter” in exogenous/SIRP noise

… Time for Dinner