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

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**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

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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

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Compound gaussian (exogenous) RP

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

long-coherency RP

$N(0,1)$  gaussian RP

- “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

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LIGOG060473

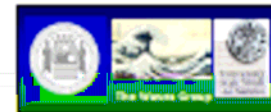


DetChar Session

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## SIRP Modeling of LIGO Noise Floor Preliminary Results

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*TWG / University of Sannio at Benevento*



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12-17 August 2005 @ LSU Baton Rouge, LA

# LIGO Data Used to Draw Next Slides

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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)

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**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  $\mathbb{R}^3$ , and transform to spherical (polar) coords.  $\vec{\tau}_j = \{R_j, \theta_j, \varphi_j\}$ .
- Check that the  $\{\vartheta_j \mid j = 1, 2, \dots\}$ ,  $\{\varphi_j \mid j = 1, 2, \dots\}$  are distributed as follows

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



The tips of the random (unit) vectors

$$\frac{\vec{\tau}_j}{|\vec{\tau}_j|}$$

fill the unit sphere *uniformly*.

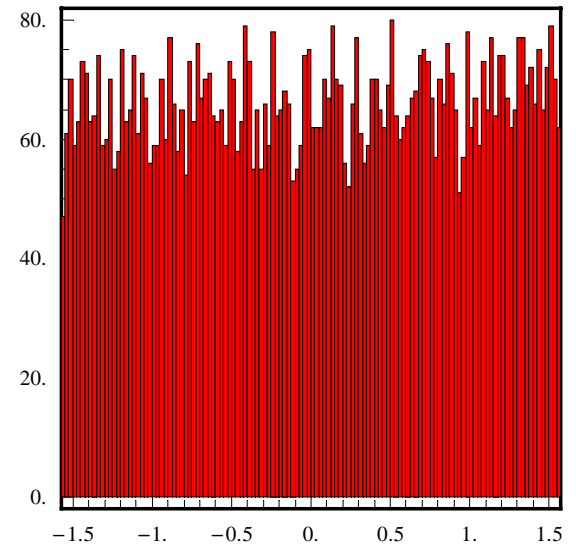
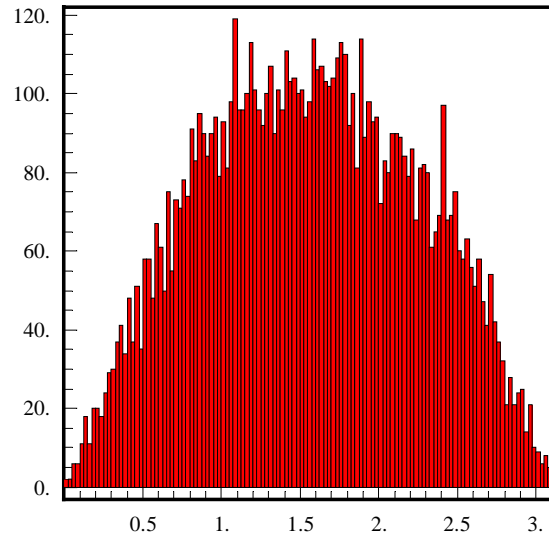
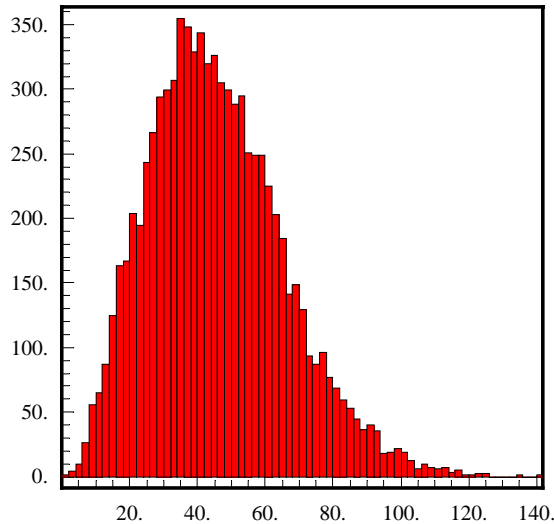
These guys do not depend on breathing factor  $s$  ...

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

...but the radial distribution is peculiar ( $\chi$ )



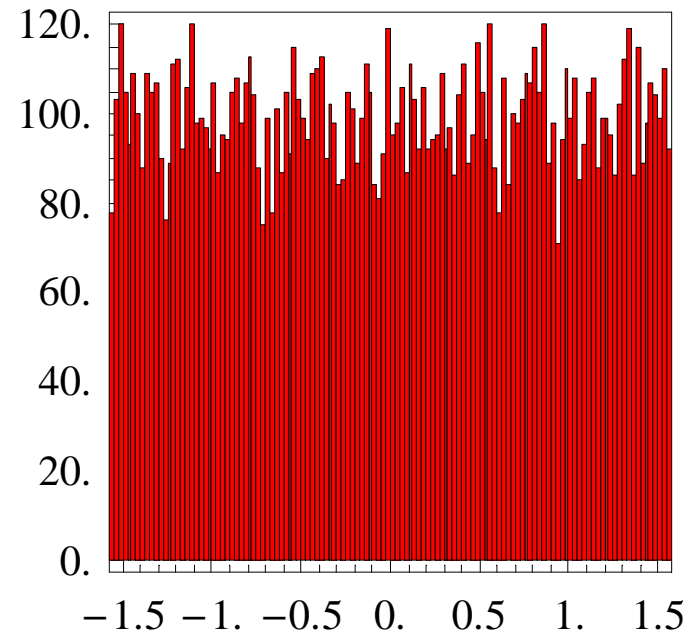
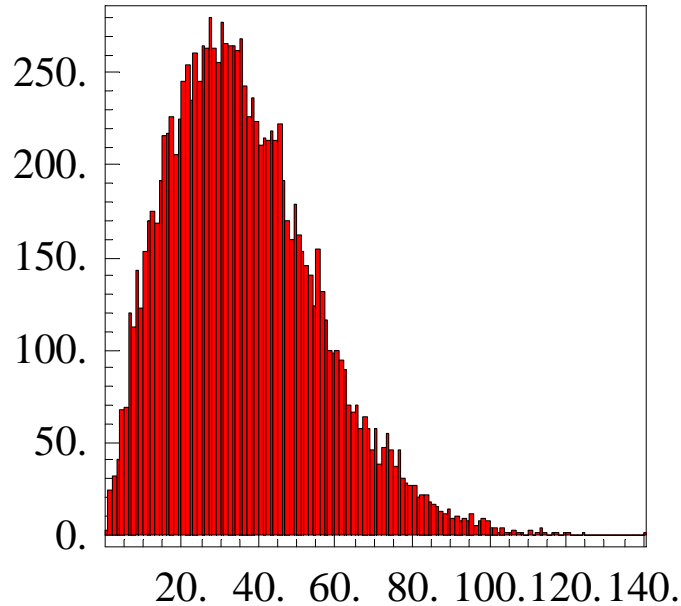
# 3D SIRP Behaviour of H1 Noise Floor



Triplets of LIGO (H1) noise-floor samples as points in  $\mathbb{R}^3$  distributions (histograms) of  $\rho$ ,  $\theta$ ,  $\phi$ .

# 2D SIRP Behaviour of LIGO Noise Floor

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Doublets of LIGO (H1) noise-floor samples as points in  $R^2$  distributions (histograms) of  $\rho$ ,  $\theta$ .

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# Investigating *Local* Gaussianity

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

# Gaussianity Tests, I

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## 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

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## 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

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

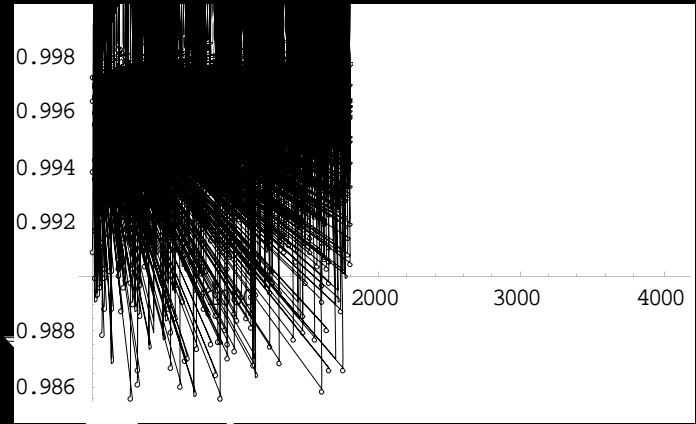
**Scarano et al.**, [IEEE-SP HOS-WS (1887) p.434 , ISBN: 0-8186-8005-9]

## LIGO-LSC

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

GaussMon (Hinich)

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



# 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
16384	0.1000	0.1000	0.1000	0.1000
65536	0.1250	0.1250	0.1250	0.1250
262144	0.1500	0.1500	0.1500	0.1500
1048576	0.1750	0.1750	0.1750	0.1750
4194304	0.2000	0.2000	0.2000	0.2000
16777728	0.2250	0.2250	0.2250	0.2250
67100160	0.2500	0.2500	0.2500	0.2500
268400640	0.2750	0.2750	0.2750	0.2750
1073602560	0.3000	0.3000	0.3000	0.3000
4294410240	0.3250	0.3250	0.3250	0.3250
17177640960	0.3500	0.3500	0.3500	0.3500
68710563840	0.3750	0.3750	0.3750	0.3750
274842252800	0.4000	0.4000	0.4000	0.4000
1095369024000	0.4250	0.4250	0.4250	0.4250
4381476102400	0.4500	0.4500	0.4500	0.4500
17526304409600	0.4750	0.4750	0.4750	0.4750
70105217638400	0.5000	0.5000	0.5000	0.5000
280420870553600	0.5250	0.5250	0.5250	0.5250
1121683482214400	0.5500	0.5500	0.5500	0.5500
4486733928857600	0.5750	0.5750	0.5750	0.5750
17946935715430400	0.6000	0.6000	0.6000	0.6000
71787742861721600	0.6250	0.6250	0.6250	0.6250
287151071446880000	0.6500	0.6500	0.6500	0.6500
1148604285787520000	0.6750	0.6750	0.6750	0.6750
4594417143150080000	0.7000	0.7000	0.7000	0.7000
18377668572600320000	0.7250	0.7250	0.7250	0.7250
73510674290401280000	0.7500	0.7500	0.7500	0.7500
294042697161605120000	0.7750	0.7750	0.7750	0.7750
1176170788646420480000	0.8000	0.8000	0.8000	0.8000
4704683154585683840000	0.8250	0.8250	0.8250	0.8250
18818732618342732800000	0.8500	0.8500	0.8500	0.8500
75275010473370944000000	0.8750	0.8750	0.8750	0.8750
301100041893483776000000	0.9000	0.9000	0.9000	0.9000
12044001675739351040000000	0.9250	0.9250	0.9250	0.9250
48176006703057404160000000	0.9500	0.9500	0.9500	0.9500
192704026812229616640000000	0.9750	0.9750	0.9750	0.9750
770816107248918466560000000	1.0000	1.0000	1.0000	1.0000

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

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- 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*.

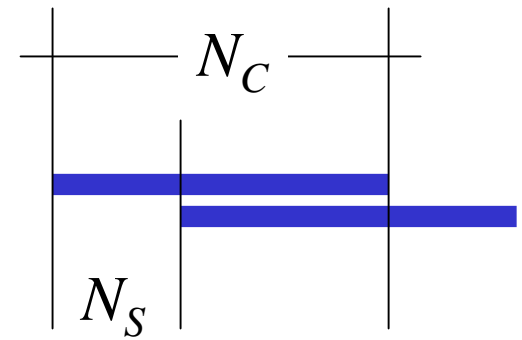
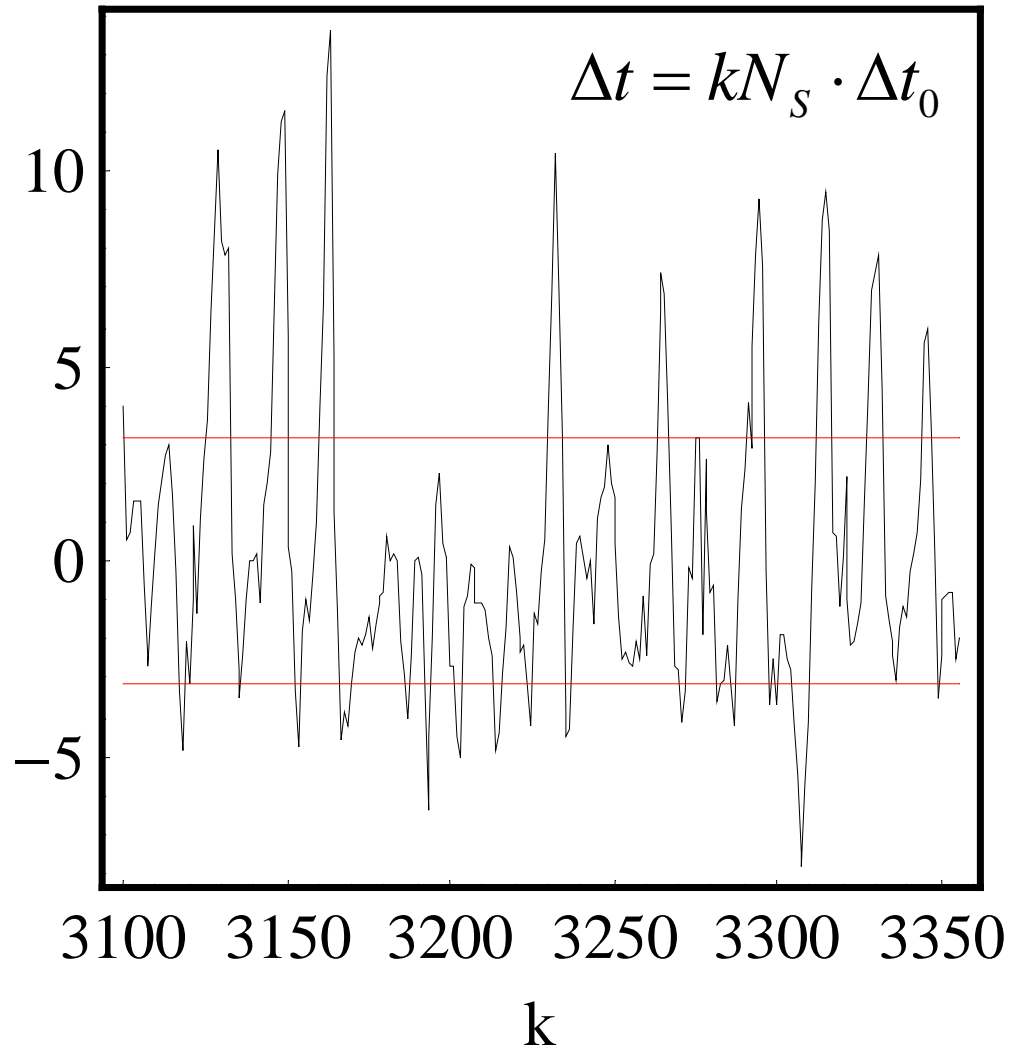


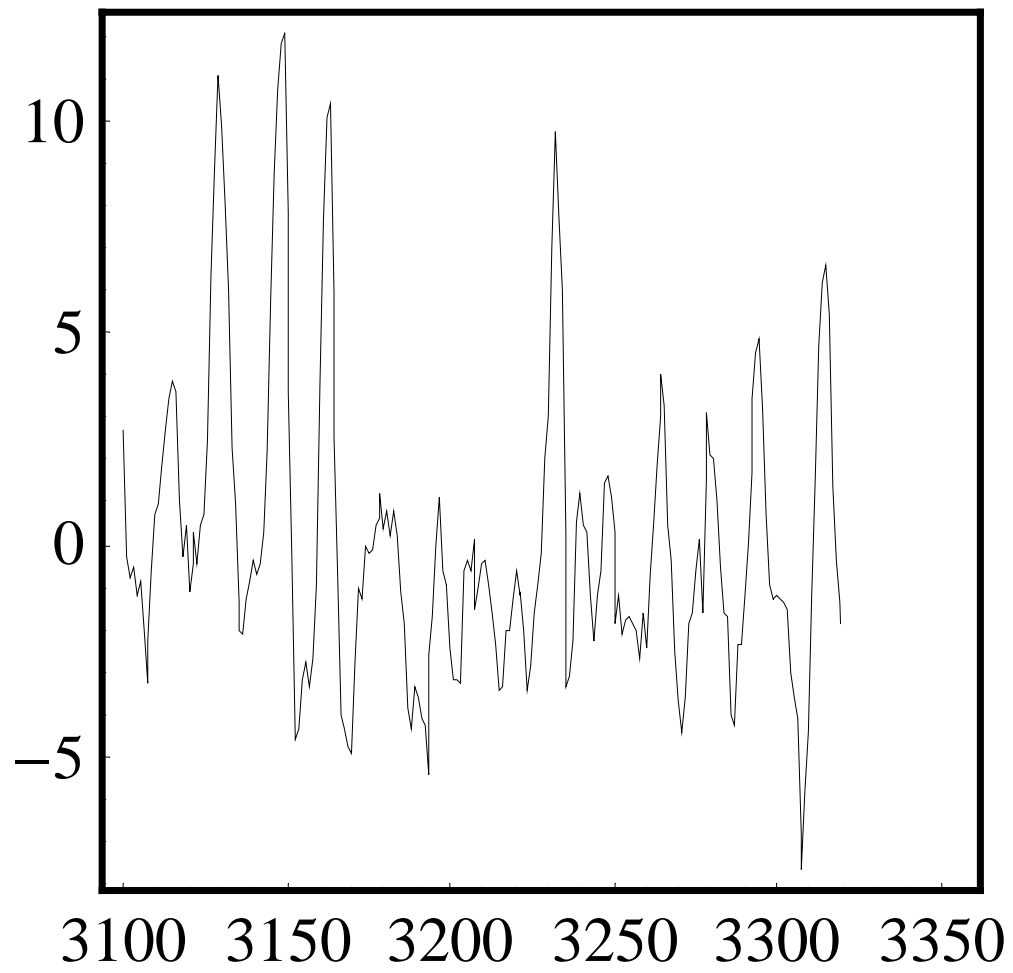
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# The Exogenous Factor (Local StDev)

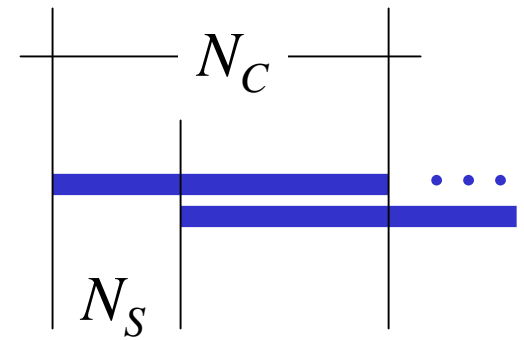
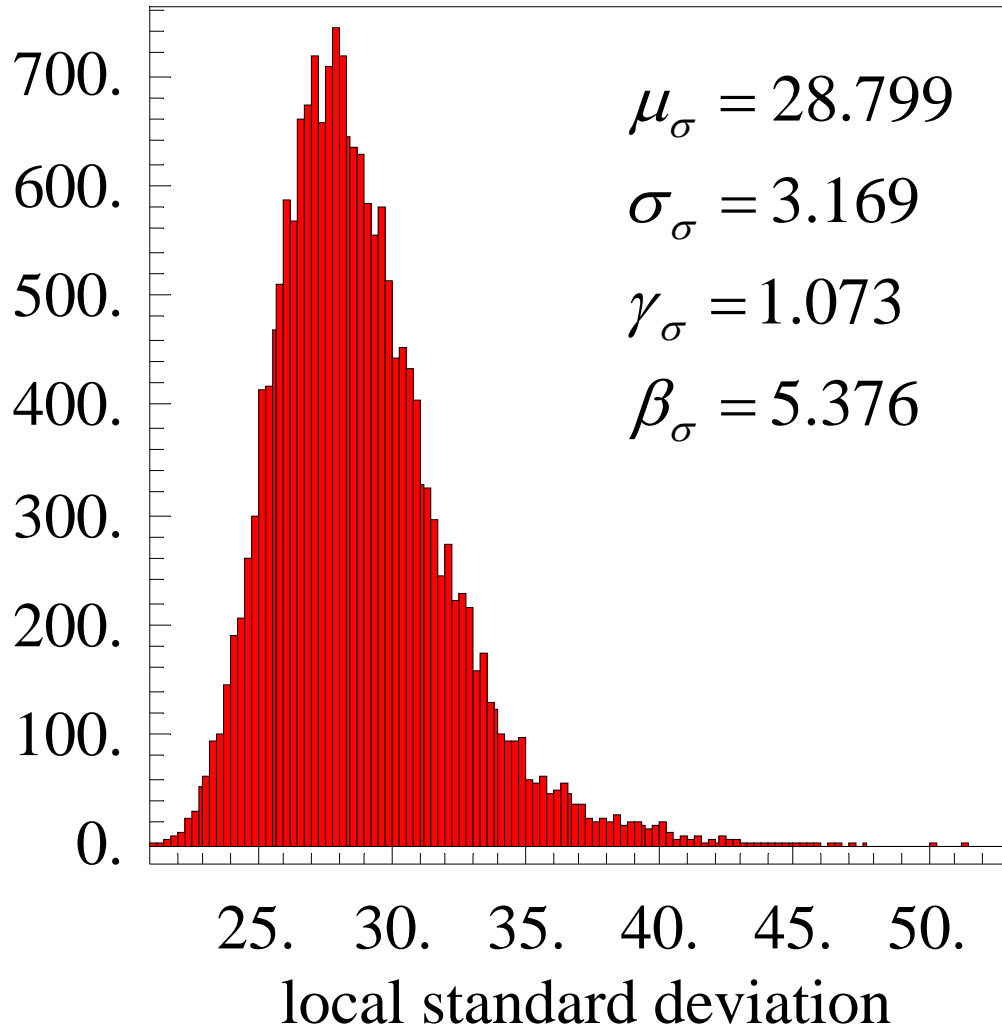
- Moving window estimation of exogenous RP
- Distribution of local std. deviation. Moments
- Time correlation of exogenous RP
- Power spectrum of exogenous RP

# Local StDev – Robust Estimator





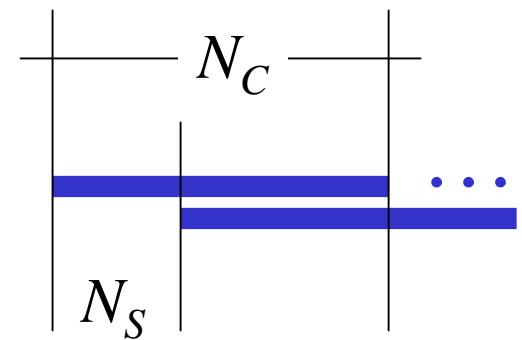
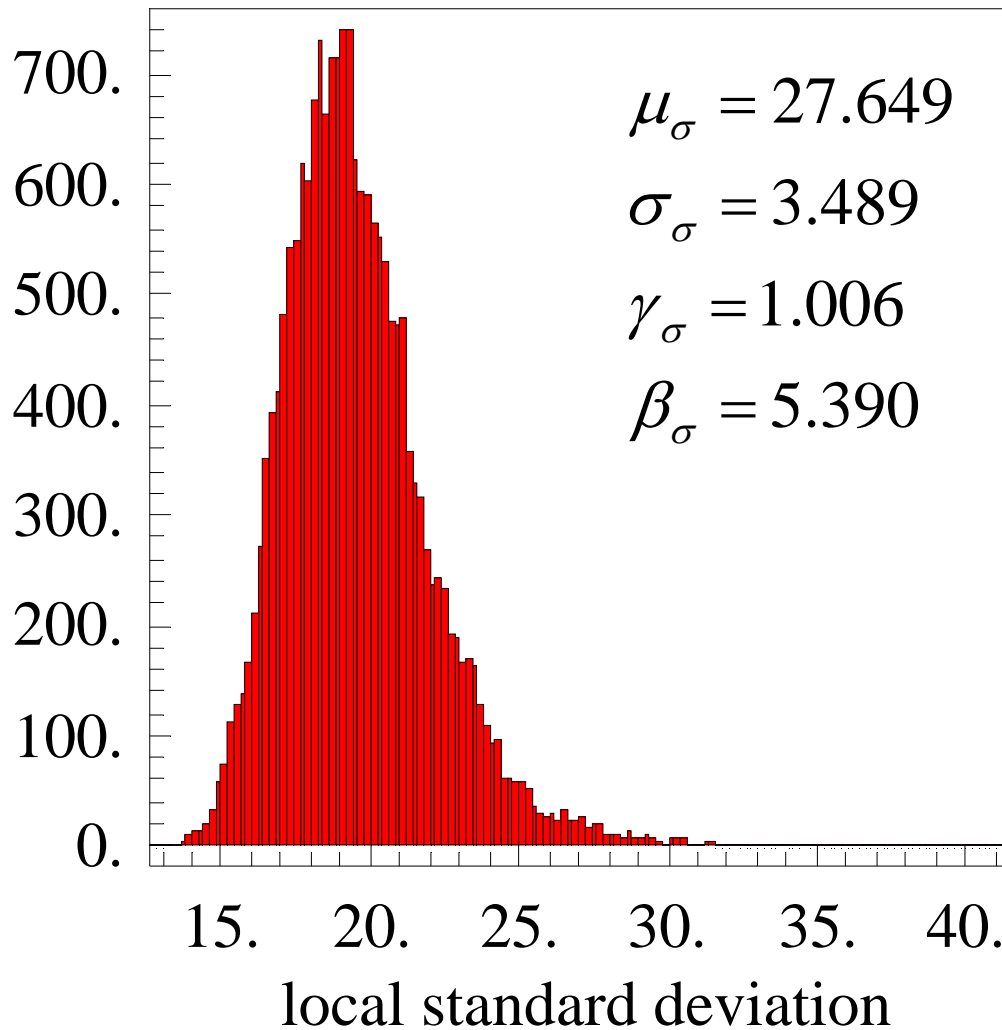
# Local StDev Distribution – ML Estimator



$$N_C = 256$$

$$N_S = 64$$

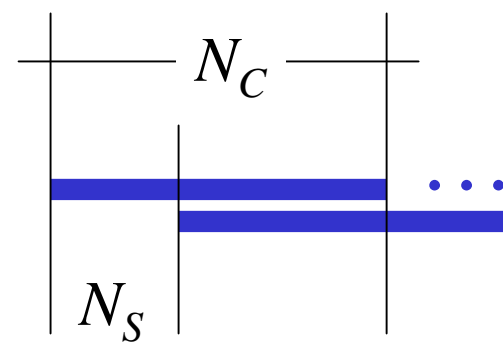
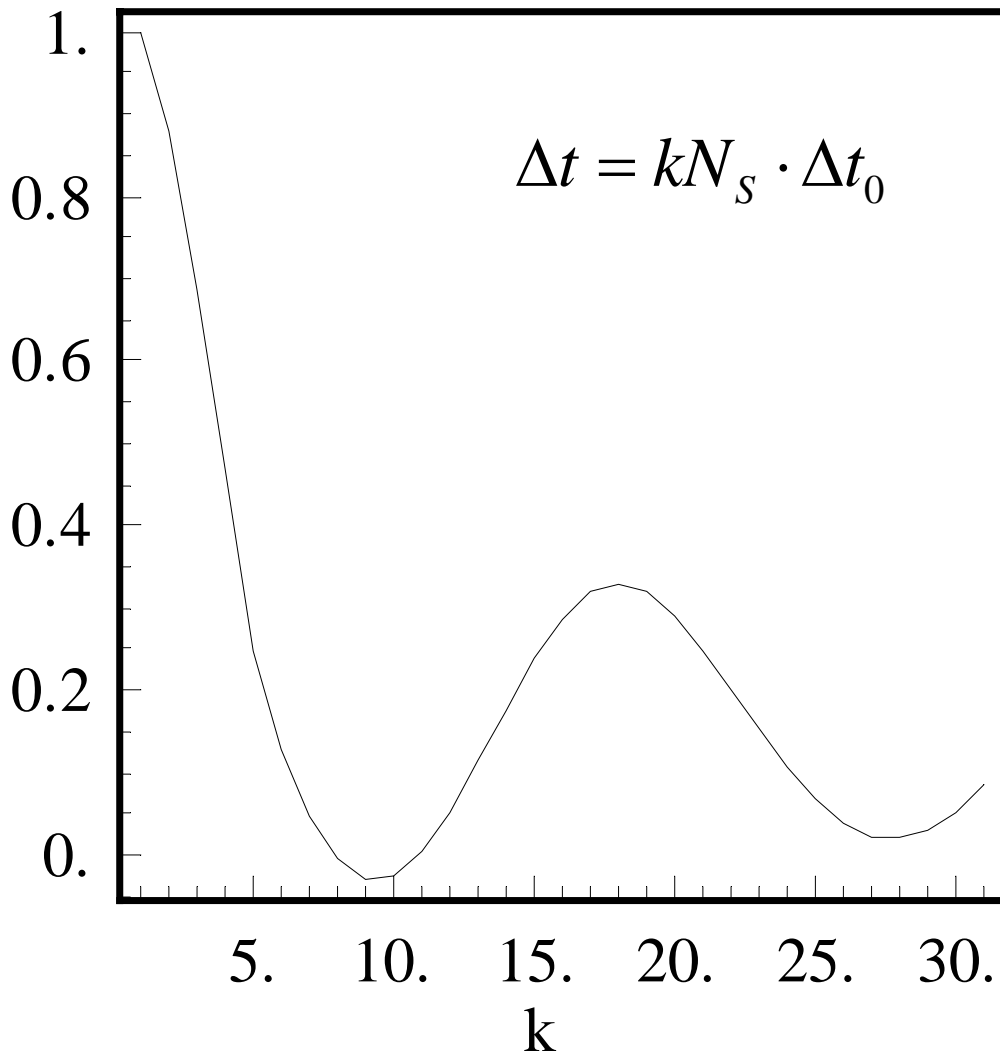
# Local StDev Distribution – Robust Estimator



$$N_C = 256$$

$$N_S = 64$$

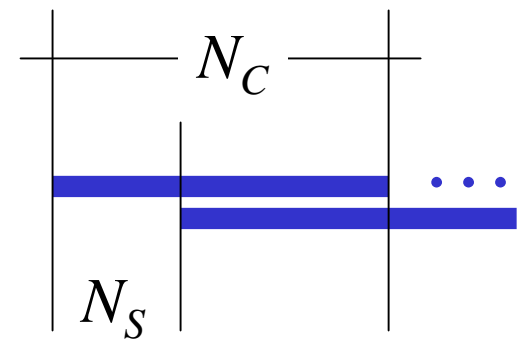
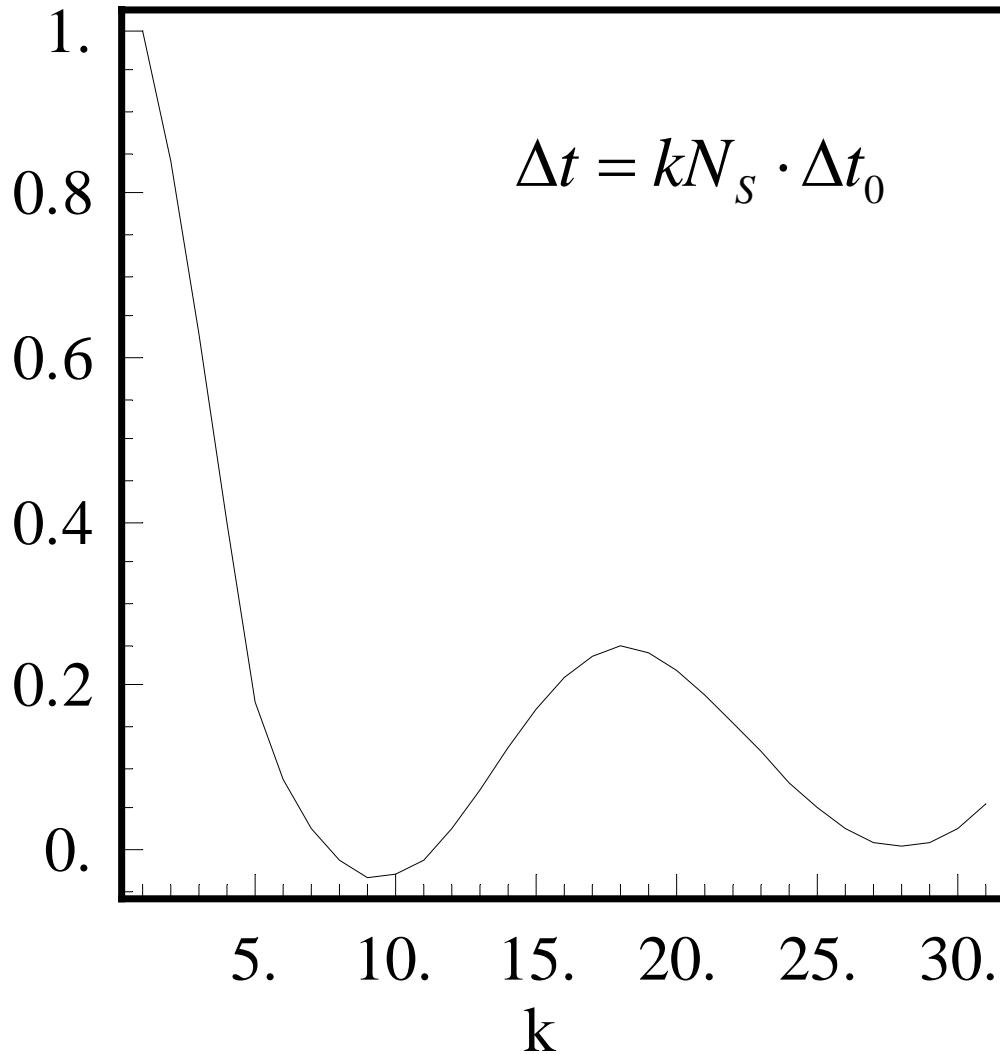
# Local StDev Correlation – ML Estimator



$$N_C = 256$$

$$N_S = 64$$

# Local StDev Correlation – Robust Estimator



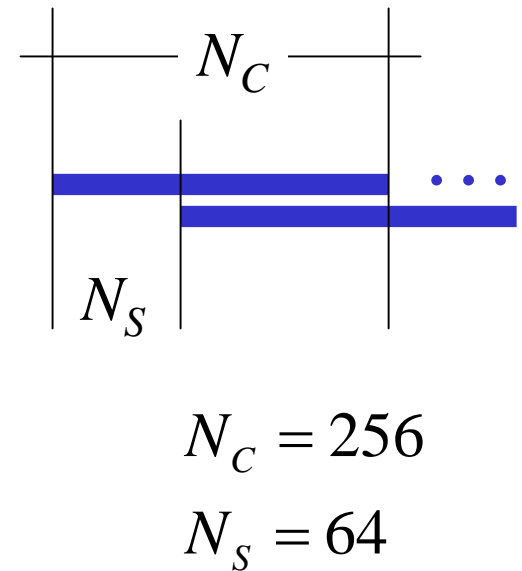
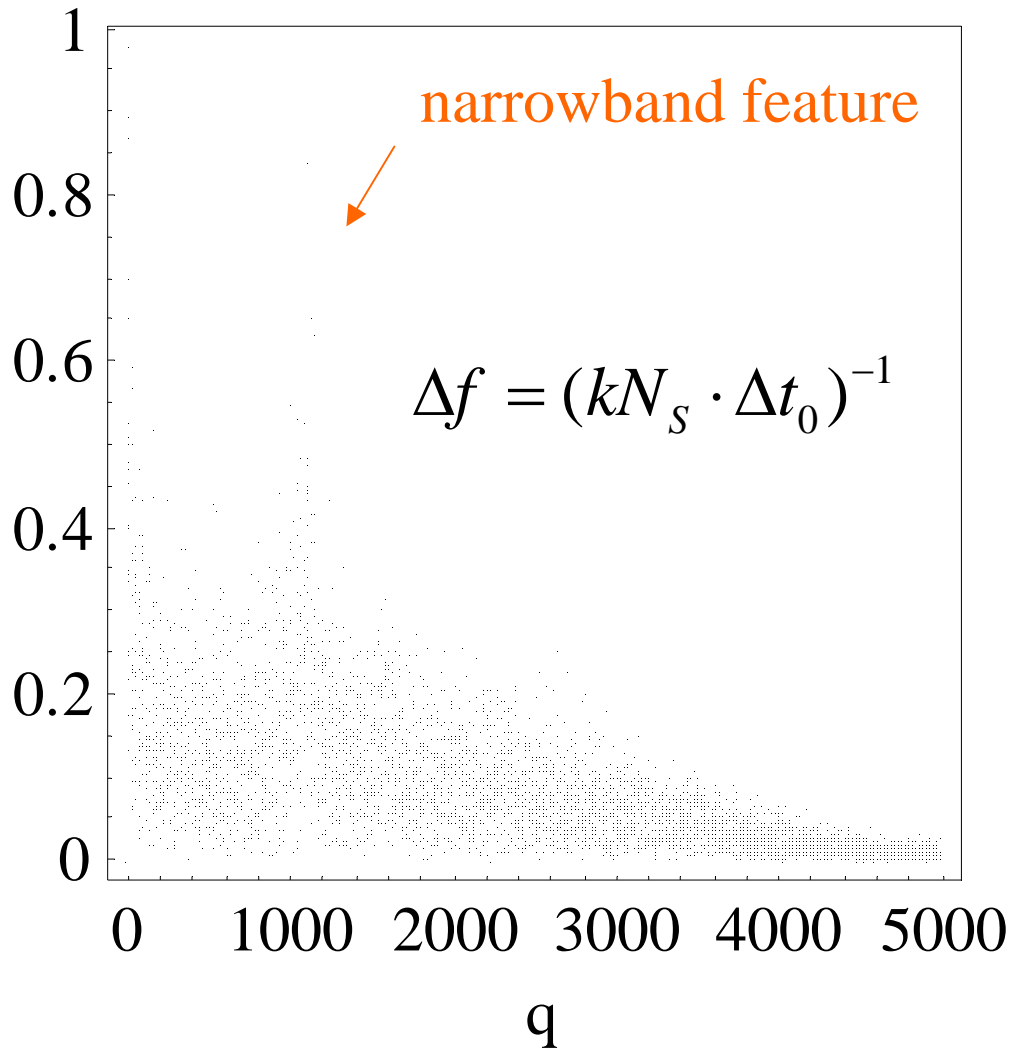
$$N_C = 256$$

$$N_S = 64$$





# Local StDev Spectrum – Robust Estimator



# Future Work Directions

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- 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

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