H2-L1 Correlated Noise

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Outline

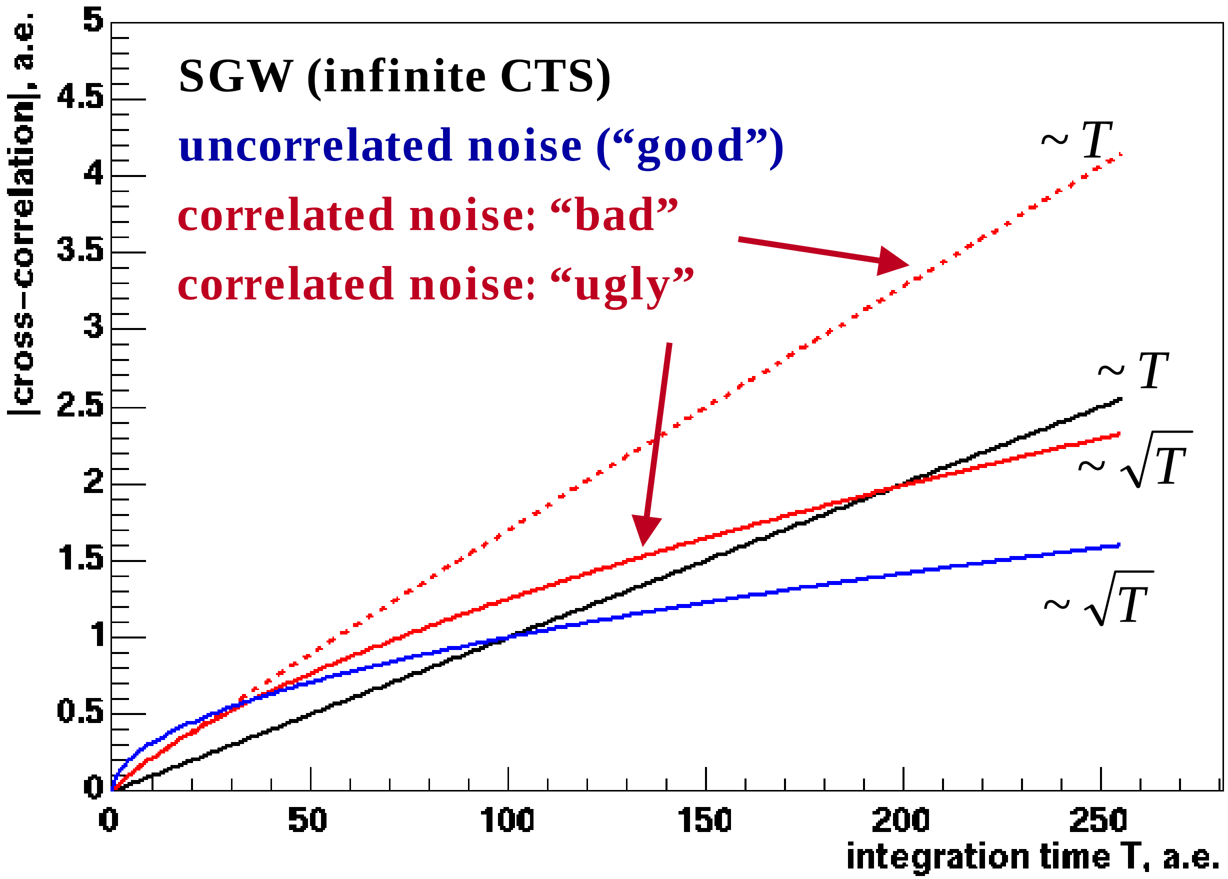
- **Introduction**
- **Goals of this analysis**
- **Coherence of power monitors**
- **Sign X-Correlation**
- **H2-L1 x-correlation**
- **Conclusion**

Introduction

- **Stochastic GW can be detected by measuring x-correlation of two detectors.**

$$C = \overline{(h_L + n_L)\cdot(h_H + n_H)} = \overline{h_L h_H} + \overline{n_L n_H}$$

: ***h*** – SGW signal, ***n*** – noise



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Goals

- study correlated noise from power lines
  - **Q: Does it have “bad” components with very large time scale (~T)?**
    - **How: Look at the coherence of power monitors**
  - **Q: How strong is it compare to uncorrelated noise?**
    - **How: Look at correlation of H & L ifo output using Sign Correlation Test.**
- study other possible sources of correlated noise
  - **Q: Is there another significant correlated noise in addition to power mains?**
    - **How: Look at correlation of H & L signals with power lines removed.**

Coherence of Power Monitors

more details in J.Castiglione's talk on DC meeting

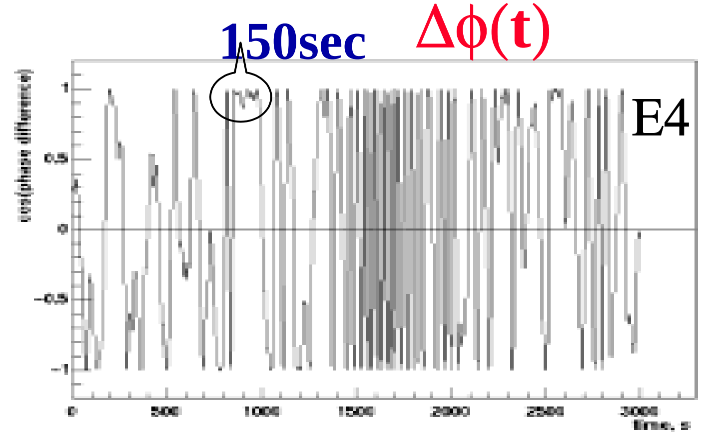
- **Coherence of $s_L(t)$** (L0:PEM-LVEA_V1) and **$s_H(t)$** (H0:PEM-LVEA_V1).

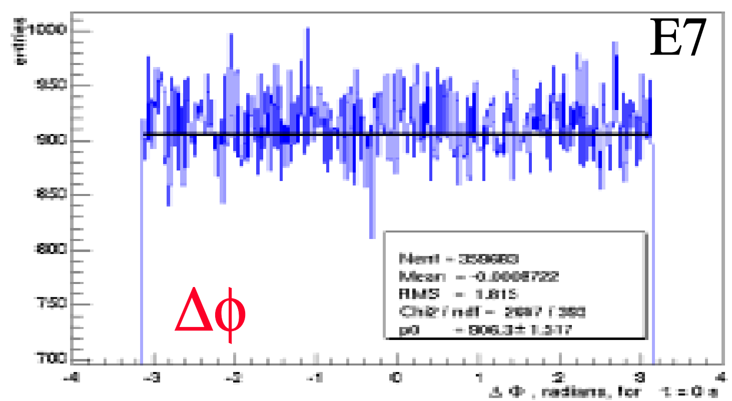
$$s(t) = s_L(t) + s_H(t) = A \cdot \sin(\omega t + \theta)$$

- **Average square amplitude**

$$\overline{A}^2 = a_L^2 + a_H^2 + 2a_L a_H \overline{\cos(\phi_L - \phi_H)}.$$

  - ϕ_L, ϕ_H – measured with LineMonitor





- **Coherence**

$$\gamma = \frac{1}{N}\left|\sum_{k=1}^{N} \exp(i\Delta\phi_k)\right|$$

- **Coherence at long time scale?**

$$\gamma(T) \sim \frac{1}{\sqrt{T}}$$

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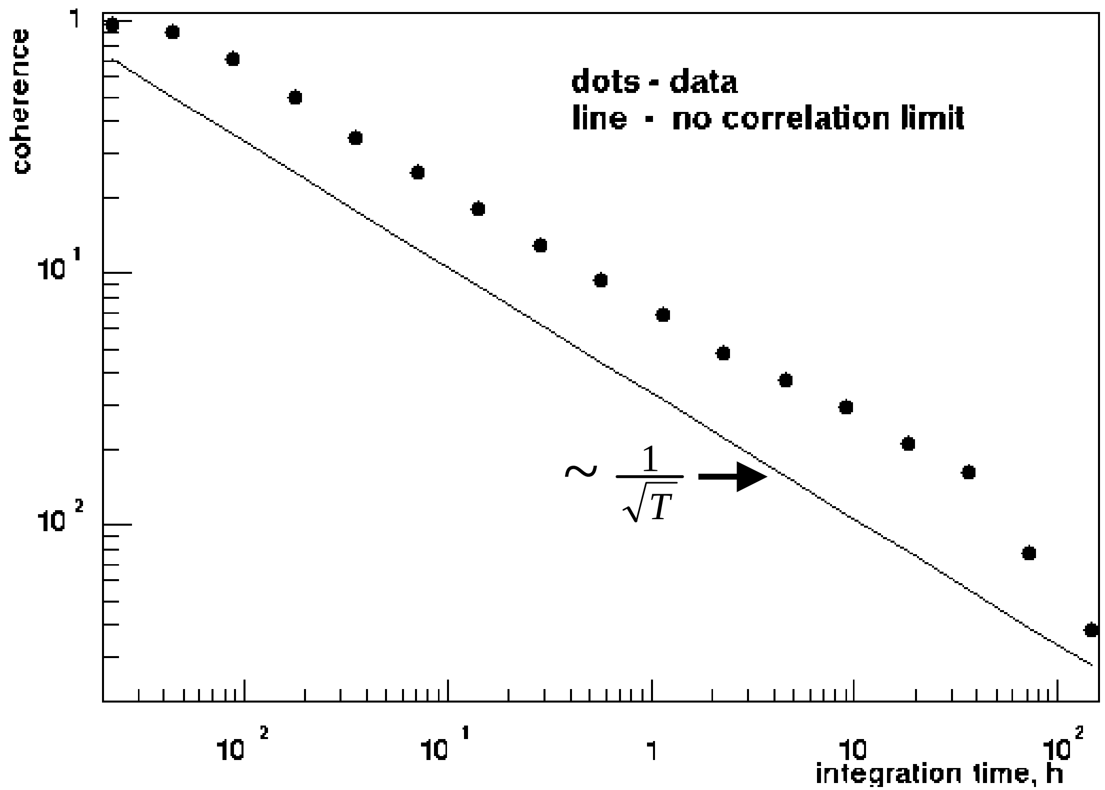
Coherence (T)

- $\gamma(T)=const$, (small $T<1min$)
- $\gamma(T) \sim \frac{1}{\sqrt{T}}$, (large T)



- Conclusion: **no terms ~*T* are observed on 17 days data.**

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Correlation of L1 and H2 GW Channels

- Wavelet transform of L1 & H2 data
  - **bi-orthogonal interpolating wavelet of 10th order.**
  - **time-frequency representation of data in wavelet domain W_{mn}**
    - **n – scale (frequency) index, m – time index**
  - **due to of locality of wavelet basis, wavelet layers can be considered as decimated time series (similar to windowed FT).**
- x-correlation in wavelet domain
  - **calculated correlation coefficient separately for each wavelet layer**
  - **sign correlation test was used to estimate x-correlation**

Sign Correlation Test

- Sign transform: $u_i = sign(x_i - \hat{x})$
  - $\hat{x}$ - **median of *x***
- Sign statistics: $s_i = sign(x_i - \hat{x}) \cdot sign(y_i - \hat{y})$
- Correlation coefficient γ: $\gamma = mean(s_i)$
- γ distribution (n – number of samples):
  - **Gaussian (large n):** $P(n,\gamma) \approx \sqrt{\frac{n}{2\pi}} \cdot \exp\left(-\frac{n\gamma^2}{2}\right)$
- very robust:
  - error from $\hat{x}$ and $\hat{y}$ $\sim 2/n^2$, much less then $\boldsymbol{var(\gamma)=1/n}$ for large n

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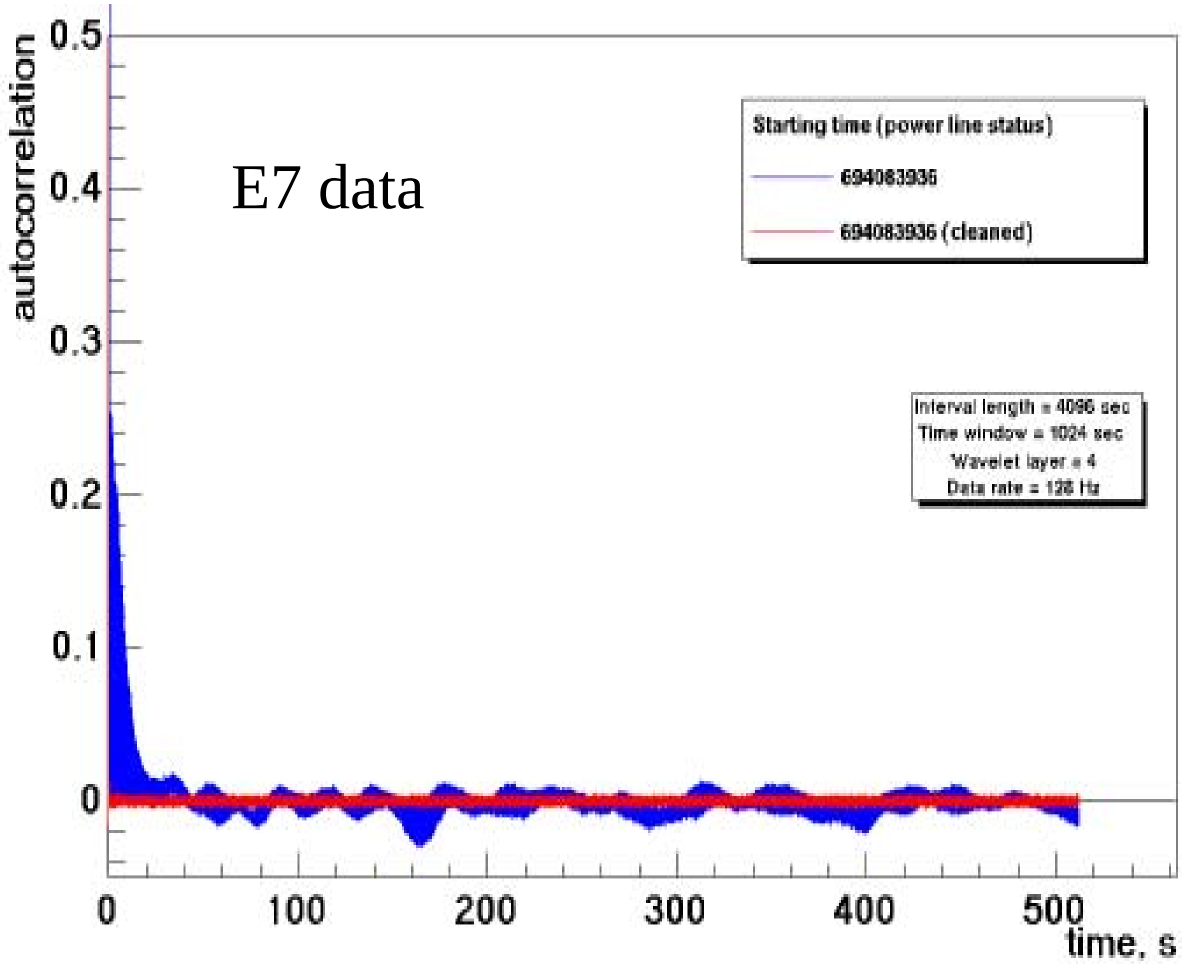
Autocorrelation Function

- sign statistics $s(t)=\{u_x u_y\}$
- $a(t)$ - autocorrelation function of $s(t)$
  - **a measure of correlated noise.**

X-correlation of L1:AS_Q & H2:AS_Q in wavelet domain: 32-64 Hz band



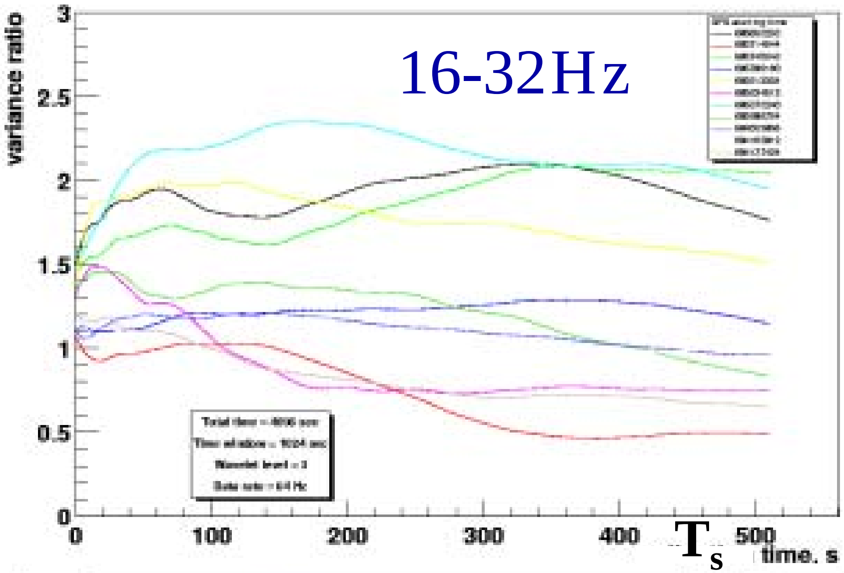
Variance of Correlation Coefficient

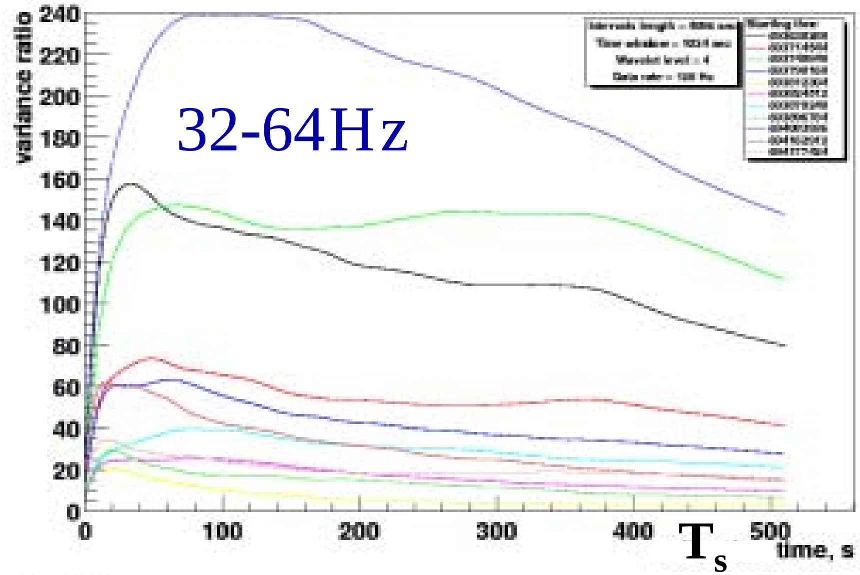
- **uncorrelated noise**
  - **autocorrelation function:** $a(0) = 1, \quad a(\tau \geq \Delta t) = 0$
  - **variance:** $\mathrm{var}_u(\gamma) = \sigma^2 = 1/n$
- **correlated noise with time scale <*T_s***
  - **autocorrelation function:** $a(\tau < T_s) = a_n(\tau), \quad a(\tau > T_s) = 0$
  - **variance:** $\mathrm{var}_c(\gamma) = \frac{1}{n} R$
- **variance ratio – measure of © noise (depends on $a_n(t)$ only)**

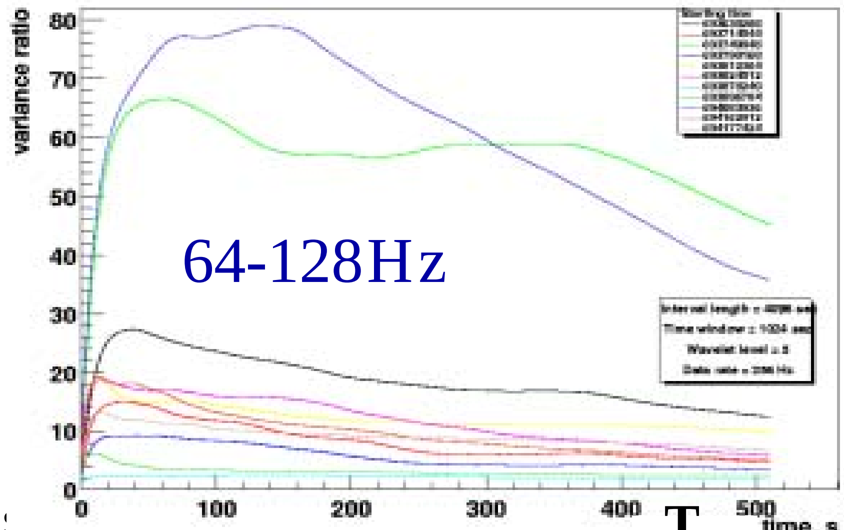
$$R = 1 + \sum_{m=1}^{T_s/\Delta t} (n-m) a_n(m\Delta t)$$

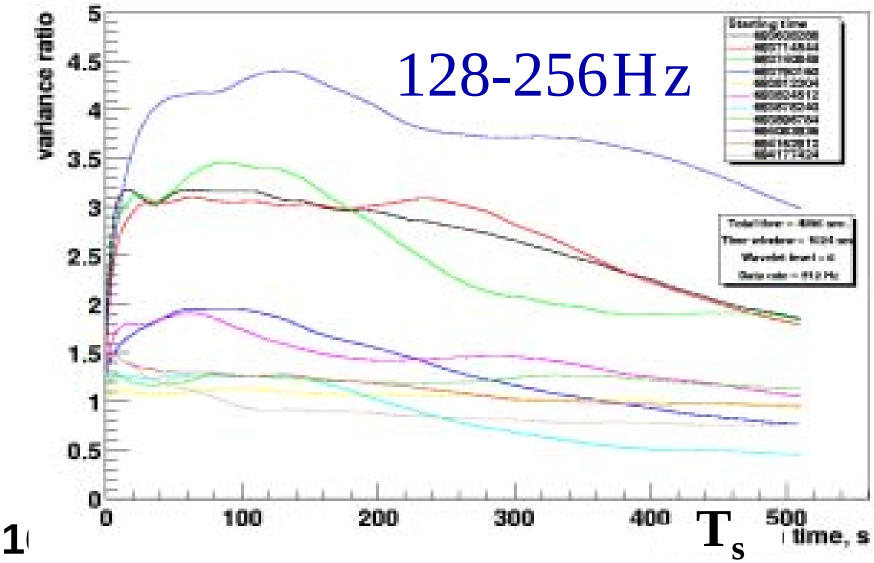
Variance Ratio (T_s)

- **11 data segments 4096 sec each (total 12.5 h of E7 data)**

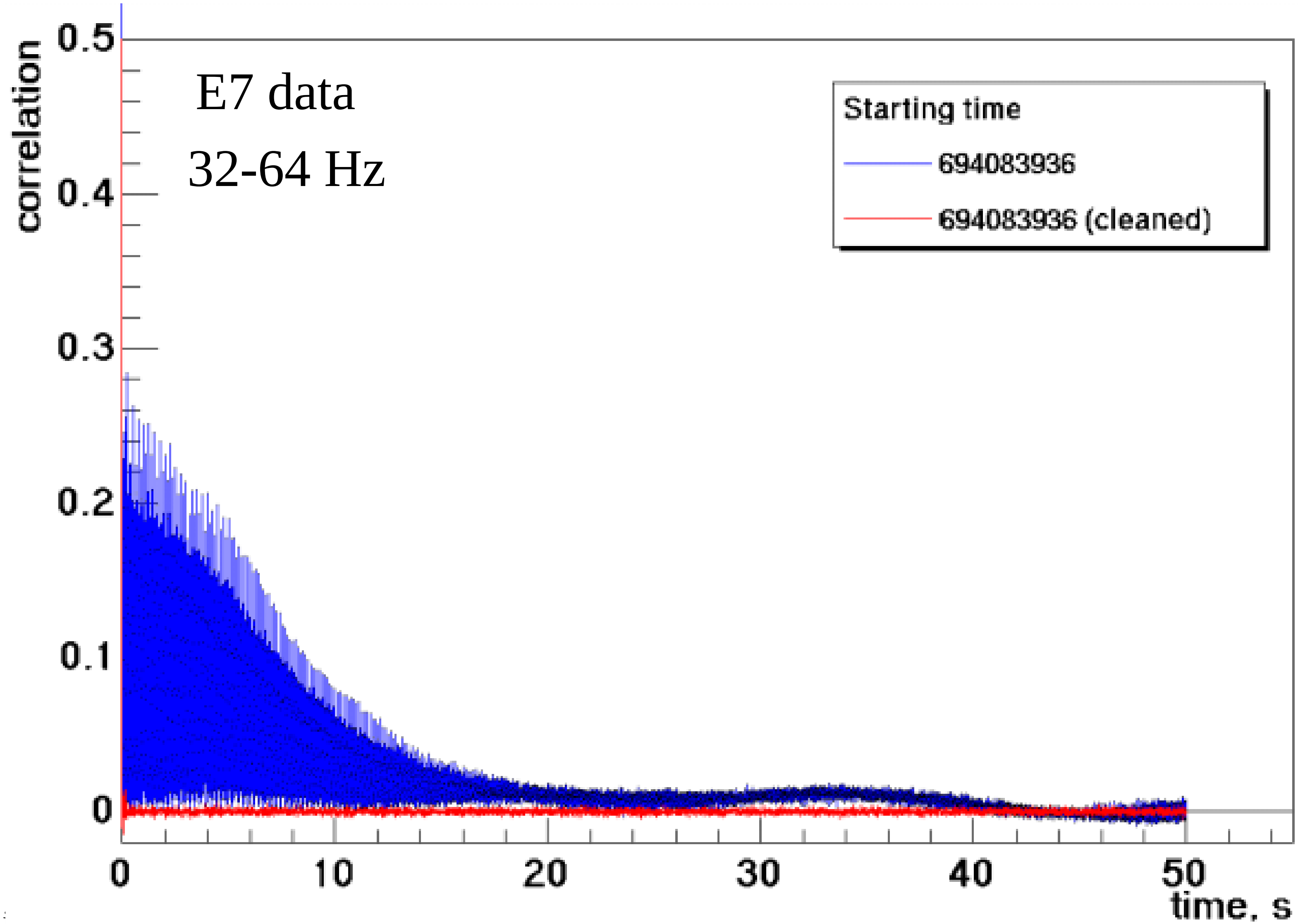








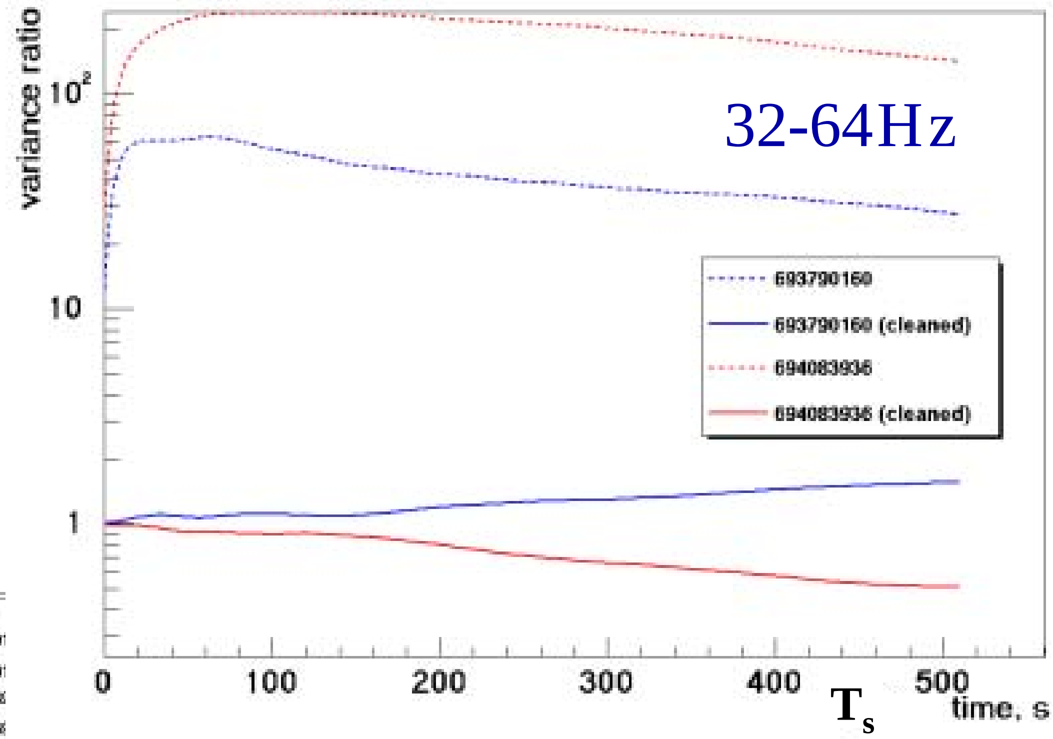
a(t) after Line Removal

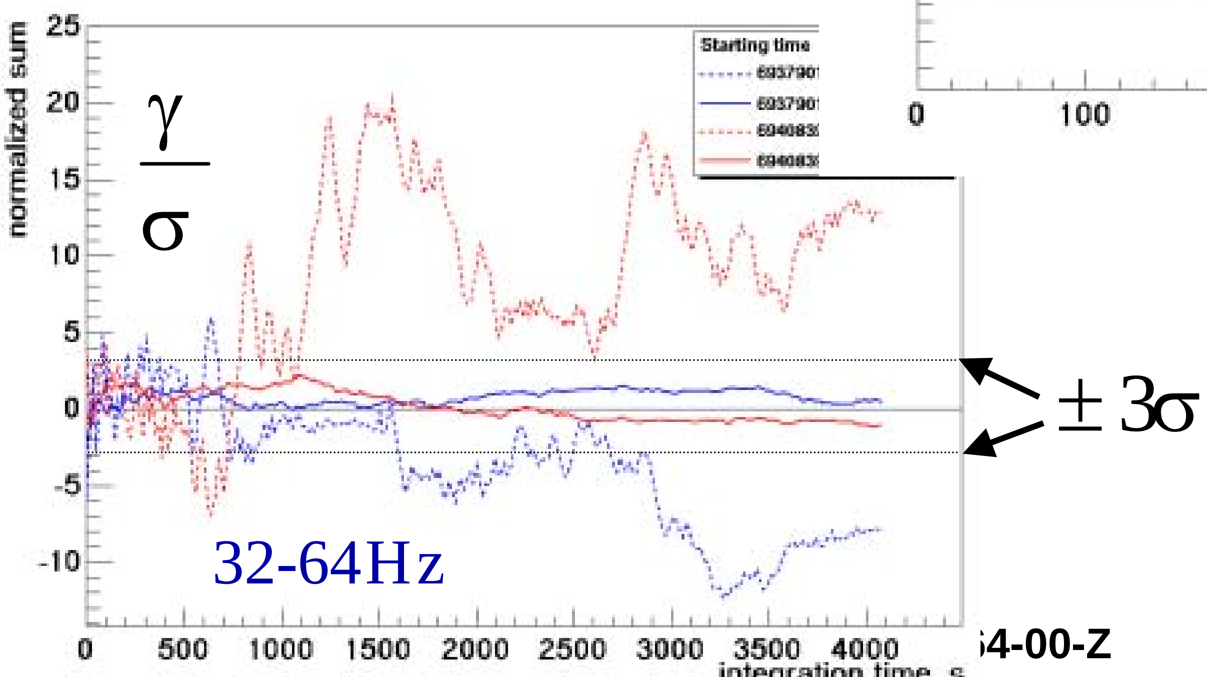


Data with Lines Removed

- **QMLR method was used**

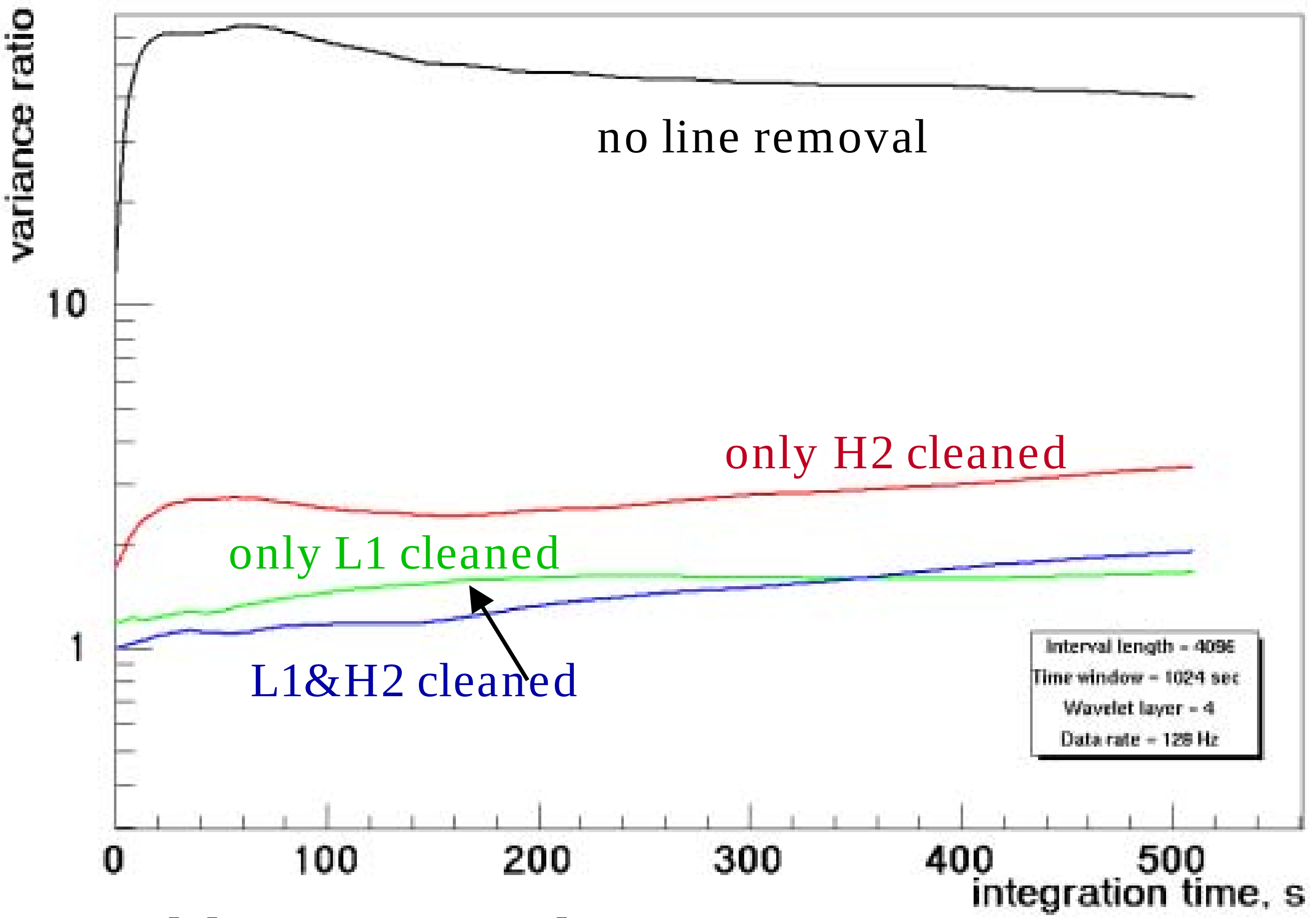
σ – rms for uncorrelated noise





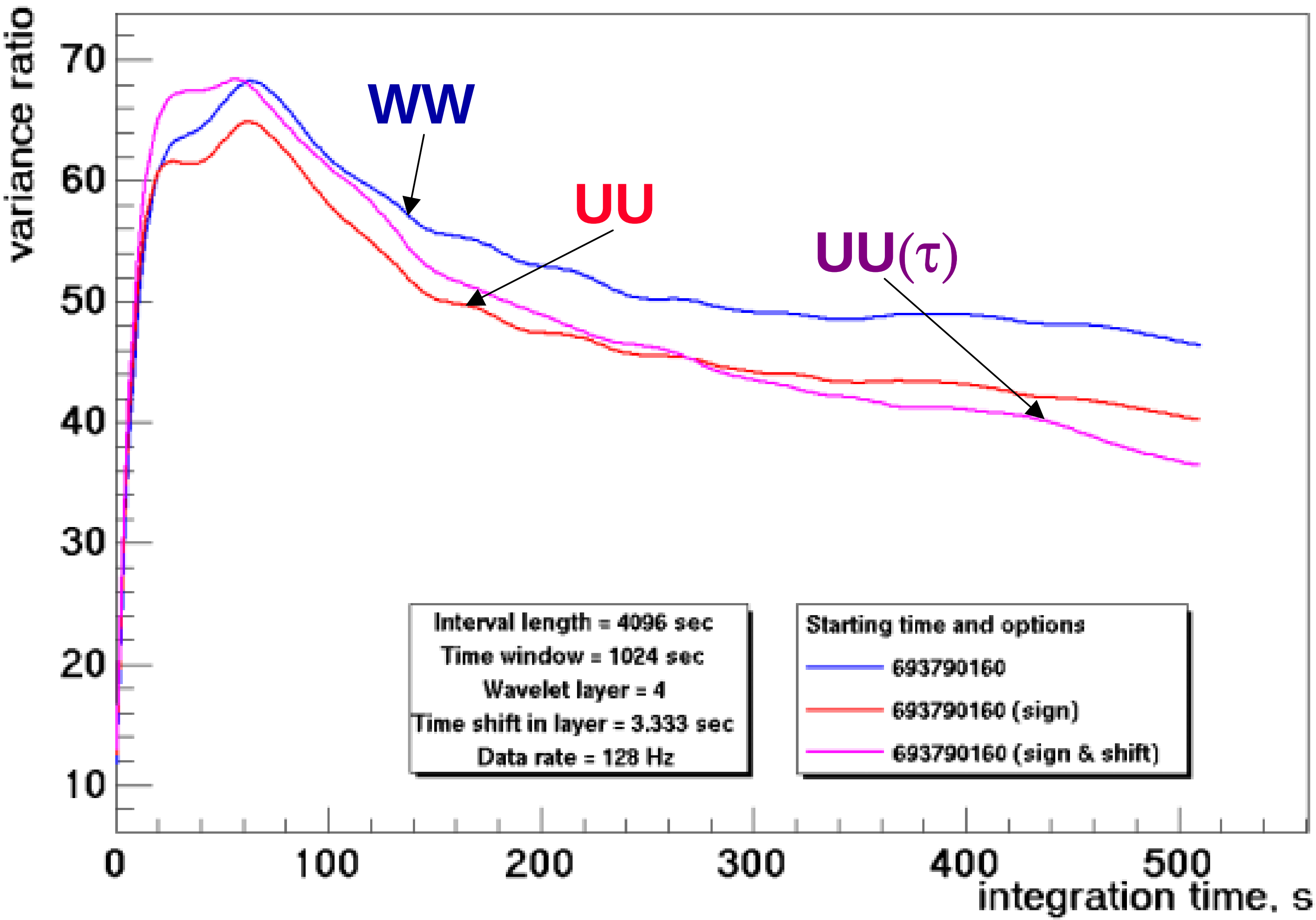
dots - before
solid - after

Clean L1 or H2



- **Line removal for one IFO only**
  - **Good test for line removal algorithms**
  - **ensure that no artificial correlation is introduced**

R



WW
UU
UU(τ)
variance ratio
70
60
50
40
30
20
10
0
100
200
300
400
500
integration time, s
Interval length = 4096 sec
Time window = 1024 sec
Wavelet layer = 4
Time shift in layer = 3.333 sec
Data rate = 128 Hz
Starting time and options
693790160
693790160 (sign)
693790160 (sign & shift)

Summary

- **results from power monitors**
  - **no evidence of "bad" noise (~*T*) observed on 17 day data**
- **results from sign x-correlation of IFO output**
  - **correlated power noise is too strong to be ignored.**
  - **the noise is very non-stationary (variation by order of magnitude)**
  - **the noise is manly due to power lines (proven by removing lines)**
  - **there are at least two components of correlated noise (Ts<1min & >500)**
  - **removing of power lines will considerably improve the SGW UL**
- **removal of power lines may introduce artificial x-correlation ~*T***
  - **safe option: remove power lines from one IFO output only.**