Understanding Advanced Virgo noise

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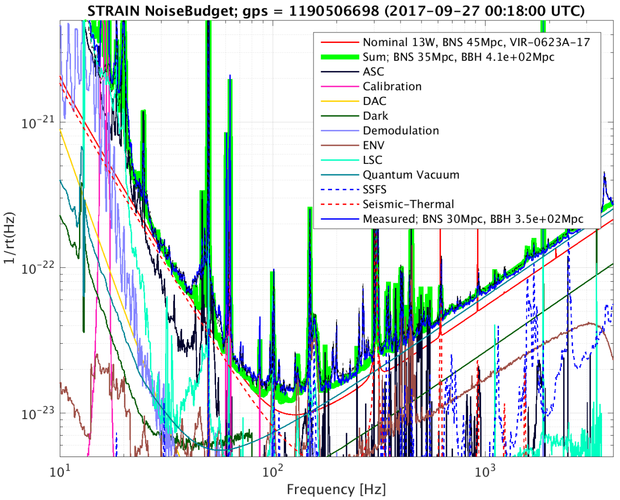
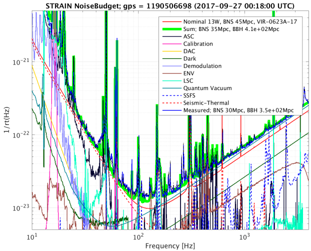
Advanced Virgo full noise budget



Noise budget basics

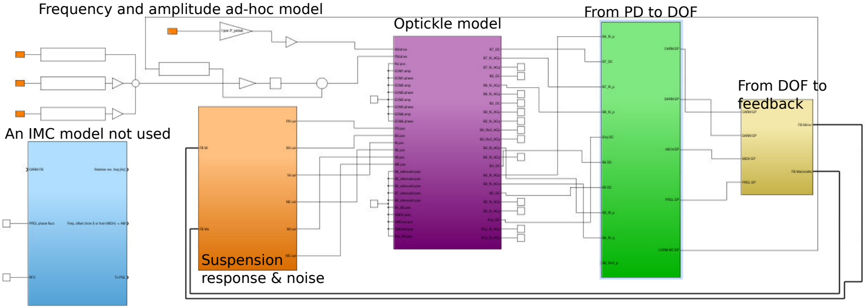


- Usually consider linear coupling

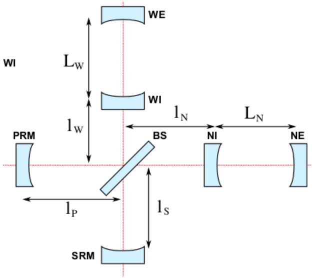
$$\text{noise contribution to strain} = TF_{\text{coupling function}} \times S_{\text{noise level}}$$

- Coupling function $TF_{\text{coupling function}}$
  - modeled
  - modeled with factors measured online - frequency noise (losses & assymetry)
  - measured through noise injections - angular noise
- Noise level $S_{\text{noise level}}$
  - modeled - shot noise
  - measured offline - DAC noise
  - measured online with auxiliary channels - angular noise
- Add in quadrature all the noise contributions

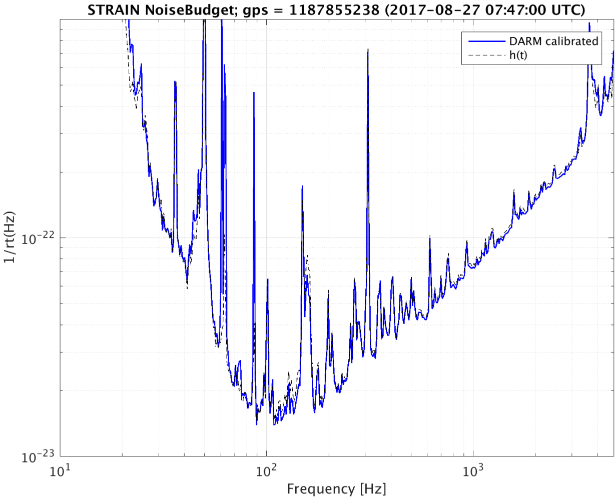
Building a complete interferometer model



- Construct a simulink diagram of the interferometer
- Double pendulum to model suspensions
- Use simulation to compute optical response
- Include many degrees of freedom:
  - DARM: differential arm length
  - CARM: common arm length / laser frequency
  - MICH: Michelson
  - PRCL: power recycling cavity length

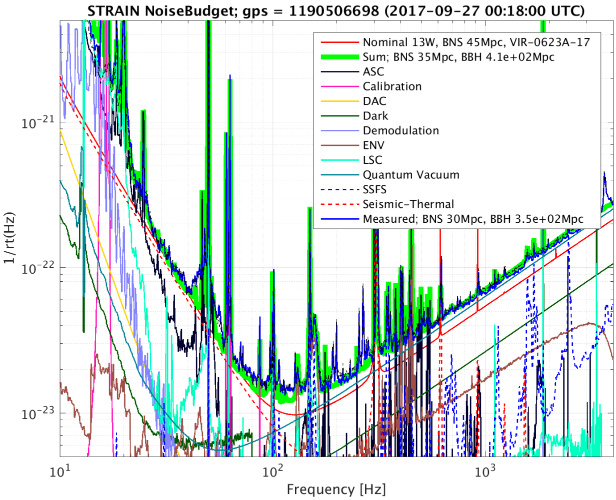


ITF model → a rough calibration of DARM into h(t)

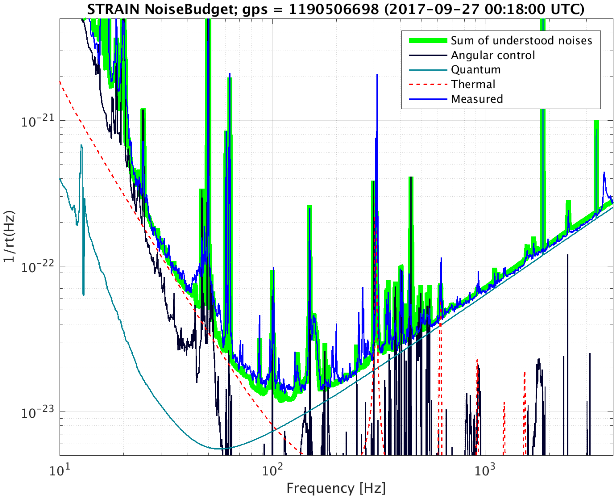


- Matches well proper data calibration

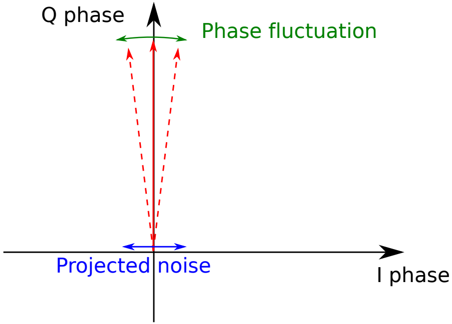
Advanced Virgo full noise budget



Advanced Virgo main limitations



Demodulation phase noise - a bilinear coupling

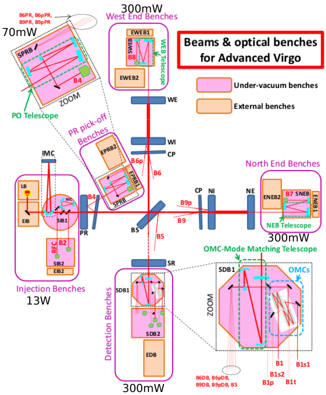


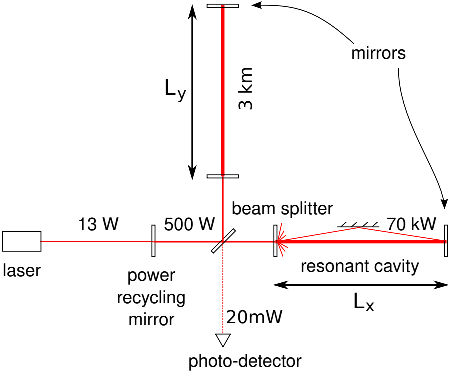
$$\delta I(t) = Q(t) \times \delta\phi(t)$$

- Large offset an issue

⇒ Uncontrolled degrees of freedom are an issue

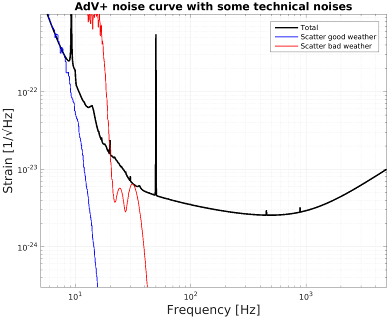
Scattered light

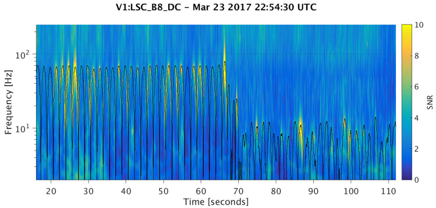




- >90% of injected light lost inside the interferometer
  - absorption in mirrors (causes thermal lensing)
  - mirror imperfection $\Rightarrow$ scattered light
  - $\Rightarrow$ put absorbing materials everywhere
- Difficult, measure light phase with 10^{-12} precision
  - $\Rightarrow$ $\sim$ 1 photon per second in 100 kW

Scattered light - a non linear coupling





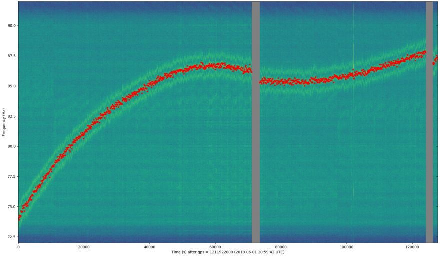
- $\sim$ 10% of light detected at various ports
- Non linear coupling of scattering surface motion $x(t)$

$$n(t) = K \sin\left(\frac{4\pi}{\lambda} x(t)\right)$$

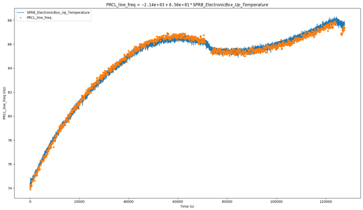
  - Move in a controlled way different benches to locate coupling
  - In bad weather ground motion at 0.3Hz leads to noise up to 50Hz

Brute force coherence to understand noise drifts

Observed wandering line

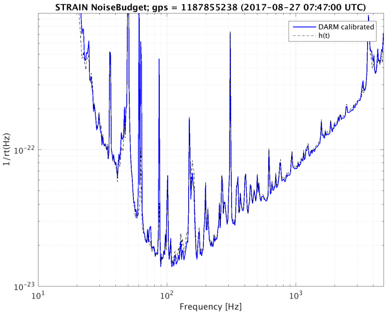


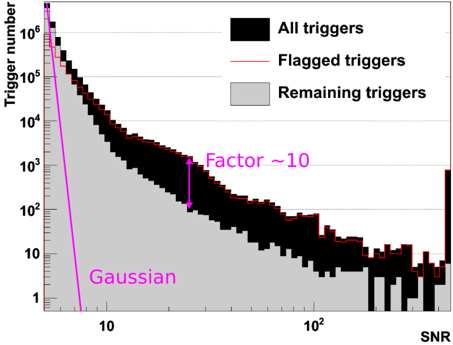
Found correlation



- Track frequency of a moving line
- Correlate with slow monitoring, e.g. temperature
- Automated blind search on thousands of channels

GW sensitivity



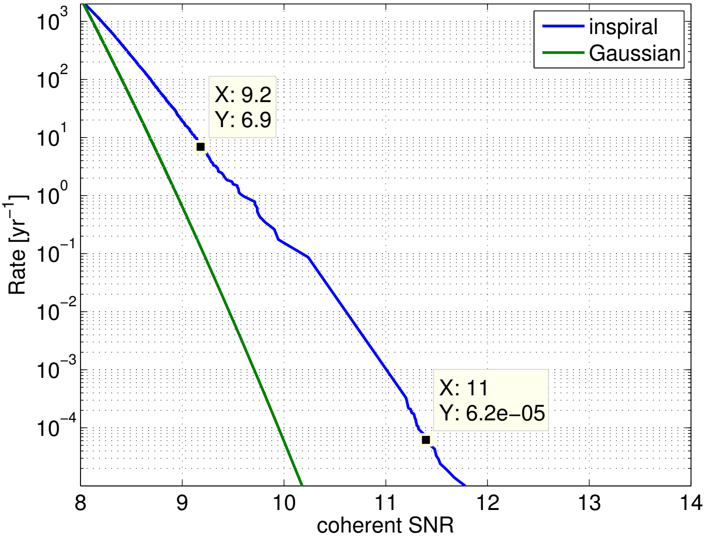


smallest observable GW amplitude $\propto S(f) \times \mathrm{S/N}_{\mathrm{threshold}}$

- Astrophysical triggers, GW models, etc ... changes search parameter space

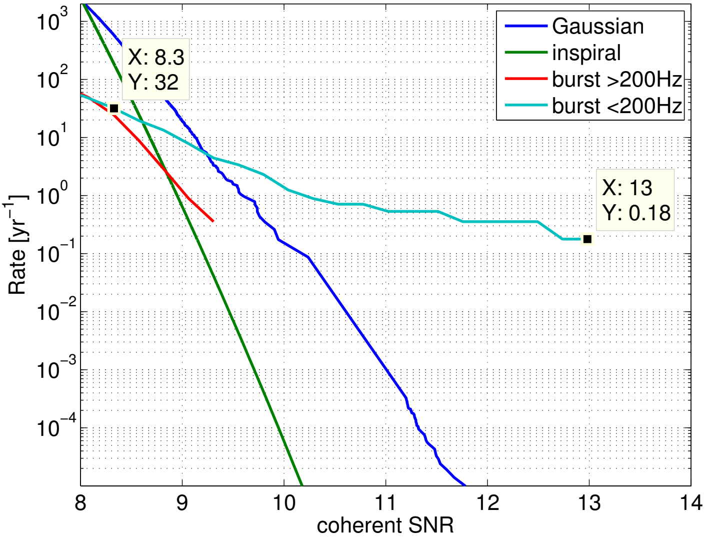
$\Rightarrow$ $\mathrm{S/N}_{\mathrm{threshold}}$ depends on the search hypothesis

Modeled inspiral search



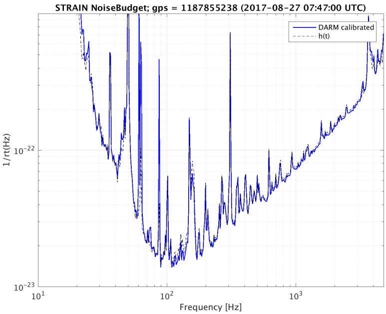
- For modeled search noise is close to Gaussian

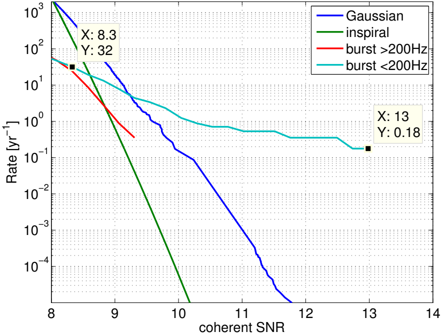
Non stationary noise impact depends on GW search type



- Unmodeled transient searches are more affected by transient noise

Summary





- Both stationary spectrum and short transients limit detector sensitivity
- Global instrument simulations help understanding cross-coupling
- Shaking instrument in different ways allows to measure coupling
- Looking for time correlations helps finding origin of issues