LIGO-G070760-00-Z

Numerical optimization of AdvLIGO for simultaneous multiple source types detection

I.S. Kondrashov[2], S.L. Danilishin[1], F.Ya. Khalili[2], D.A. Simakov[2]

[1]MPI für Gravitationsphysik (AEI),
[2]Moscow State University

LSC-VIRGO Meeting, QND workshop
Hannover, October 26, 2006

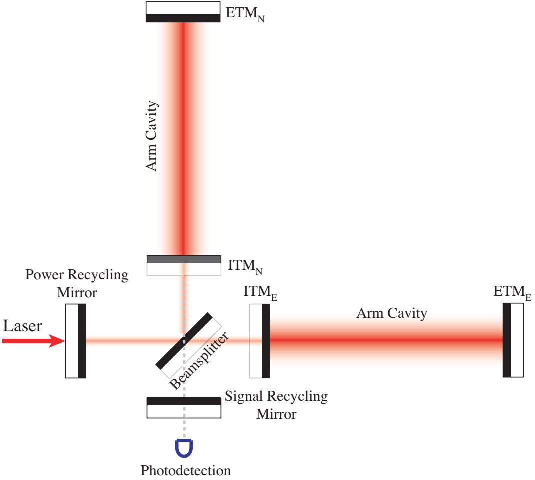
Outline

1. Advanced LIGO interferometers conventional optimization

2. Simultaneous optimization for different sources
   - Optimization for HF pulsars
   - Optimization for GW bursts

3. Conclusion

Advanced LIGO signal recycled interferometers (SRI)

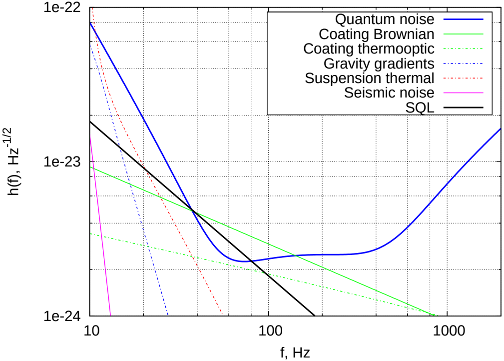


Characteristic parameters of SRI:

Quantum noise of SRI $\Longrightarrow$ 3 parameters

- Bandwidth
  $\gamma \iff (\rho_{\mathrm{SRM}}, \phi_{\mathrm{SRM}})$;
- Detuning
  $\delta \iff (\rho_{\mathrm{SRM}}, \phi_{\mathrm{SRM}})$
- Homodyne quadrature angle φ

A. Buonnanno,Y. Chen, Phys. Rev. D ***67****, 062002 (2003)*



Optical configuration:

Certain set of 3 numbers $(\gamma,\ \delta,\ \varphi)$

Characteristic parameters of SRI:

Quantum noise of SRI $\Longrightarrow$ 3 parameters

- Bandwidth
  $\gamma \iff (\rho_{\rm SRM},\ \phi_{\rm SRM})$;
- Detuning
  $\delta \iff (\rho_{\rm SRM},\ \phi_{\rm SRM})$
- Homodyne quadrature angle φ

A. Buonnanno, Y. Chen, Phys. Rev. D ***67****, 062002 (2003)*

How to evaluate which configuration of SRI is better?

Detection range for NS-NS binaries

Evident candidate $\Longrightarrow$ NS-NS binaries detection range:

$$r_{\mathrm{NS-NS}} = \left(\frac{2}{15} \frac{G^{5/3}}{\pi^{4/3} c^3} \frac{\mathcal{M}^{5/3}}{\bar{\rho}_0^2} \int\limits_{f_{\min}}^{f_{\max}} \frac{df}{f^{7/3} S_h(f)} \right)^{1/2} .$$

Conventional way $\Longrightarrow$ optimal configuration for NS-NS binaries

Quantum part of $S_h(f)$ depends on $(\gamma,\ \delta,\ \varphi)$

$$S_h(f) = S_h^q(f, \gamma,\ \delta,\ \varphi) + S_h^{cl}(f)$$

How to evaluate which configuration of SRI is better?

Detection range for NS-NS binaries

Evident candidate $\Longrightarrow$ NS-NS binaries detection range:

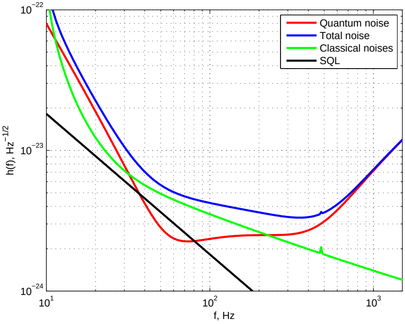
$$r_{\mathrm{NS-NS}} = \left(\frac{2}{15} \frac{G^{5/3}}{\pi^{4/3} c^3} \frac{\mathcal{M}^{5/3}}{\bar{\rho}_0^2} \int_{f_{\min}}^{f_{\max}} \frac{df}{f^{7/3} S_h(f)} \right)^{1/2} .$$

Conventional way $\Longrightarrow$ optimal configuration for NS-NS binaries

Optimizing $r_{\mathrm{NS-NS}}$ in $(\gamma,\, \delta,\, \varphi) \Longrightarrow$ optimal configuration

$$\min[r_{\mathrm{NS-NS}}(\gamma,\, \delta,\, \varphi)] \longrightarrow (\gamma_{\mathrm{opt}},\, \delta_{\mathrm{opt}},\, \varphi_{\mathrm{opt}})_{\mathrm{NS-NS}}$$

Why one might need another optimization?

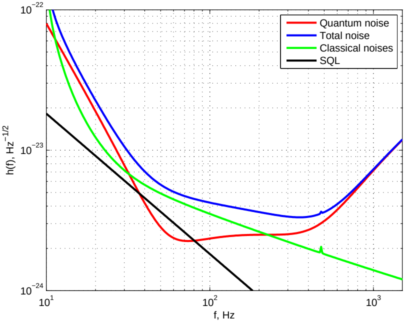


$$\gamma_{\text{opt}}^{NS} \simeq 960 \text{ sec}^{-1},\ \delta_{\text{opt}}^{NS} \simeq 2090 \text{ sec}^{-1},$$
$$\varphi_{\text{opt}}^{NS} \simeq -1.02 \text{ rad}$$

Disadvantages of conventional way

1. Lock-in to specific GW sources type;
2. High classical noises at medium frequencies $\Longrightarrow$ weak dependence on optical parameters;
3. $|h_{\text{NS}}(f)|^2 \sim \frac{1}{f^{7/3}} \Longrightarrow$ no optimization at high frequencies.

Why one might need another optimization?

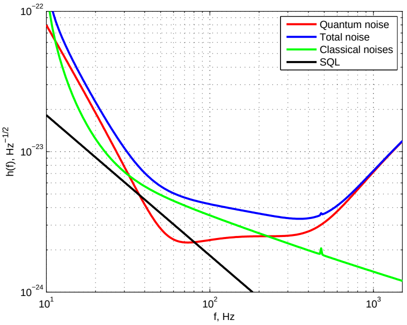


$$\gamma_{\rm opt}^{NS} \simeq 960 \text{ sec}^{-1},\ \delta_{\rm opt}^{NS} \simeq 2090 \text{ sec}^{-1},$$
$$\varphi_{\rm opt}^{NS} \simeq -1.02 \text{ rad}$$

Disadvantages of conventional way

1. Lock-in to specific GW sources type;
2. High classical noises at medium frequencies $\Longrightarrow$ weak dependence on optical parameters;
3. $|h_{\rm NS}(f)|^2 \sim \dfrac{1}{f^{7/3}} \Longrightarrow$ no optimization at high frequencies.

Why one might need another optimization?

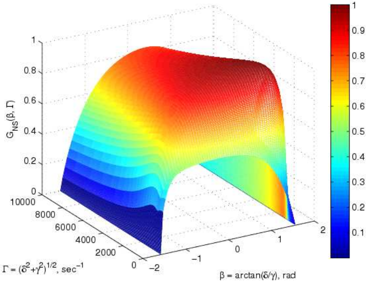


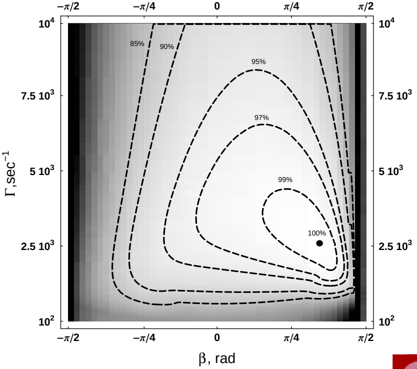
$$\gamma^{NS}_{\text{opt}} \simeq 960 \text{ sec}^{-1},\ \delta^{NS}_{\text{opt}} \simeq 2090 \text{ sec}^{-1},$$
$$\varphi^{NS}_{\text{opt}} \simeq -1.02 \text{ rad}$$

Disadvantages of conventional way

1. Lock-in to specific GW sources type;
2. High classical noises at medium frequencies $\Longrightarrow$ weak dependence on optical parameters;
3. $|h_{\text{NS}}(f)|^2 \sim \dfrac{1}{f^{7/3}} \Longrightarrow$ no optimization at high frequencies.

Dependance of DR for NS-NS binaries on optical configuration is rather weak!





Redefinition of optical parameters

$$\gamma, \delta \Longrightarrow \Gamma = \sqrt{\gamma^2 + \delta^2}, \beta = \arctan \frac{\delta}{\gamma}$$

Why don't we sacrifice a little bit
in sensitivity to NS-NS
and improve sensitivity to other sources?

What sources can be included into consideration?

1. High frequency pulsars with $f_{\rm rot} \gtrsim 300$ Hz
2. Bursts of GWs from, say, supernovae explosions

Criteria for optimization

Relative gain for specific source:

$$G_{\rm source} = \frac{\rm SNR_{source}(\Gamma,\ \beta,\ \varphi)}{\rm SNR_{source}(\Gamma^{NS}_{opt},\ \beta^{NS}_{opt},\ \varphi^{NS}_{opt})}$$

What sources can be included into consideration?

1. High frequency pulsars with $f_{\mathrm{rot}} \gtrsim 300$ Hz
2. Bursts of GWs from, say, supernovae explosions

Criteria for optimization

Relative gain for specific source:

$$G_{\mathrm{source}} = \frac{\mathrm{SNR}_{\mathrm{source}}(\Gamma,\ \beta,\ \varphi)}{\mathrm{SNR}_{\mathrm{source}}(\Gamma^{\mathrm{NS}}_{\mathrm{opt}},\ \beta^{\mathrm{NS}}_{\mathrm{opt}},\ \varphi^{\mathrm{NS}}_{\mathrm{opt}})}$$

SNR for HF pulsars

$$\mathrm{SNR}_{\mathrm{puls}} \propto \left[\frac{1}{S_h(f_{puls},\ \Gamma,\ \beta,\ \varphi)}\right]^{1/2}$$

What sources can be included into consideration?

1. High frequency pulsars with $f_{\rm rot} \gtrsim 300$ Hz
2. Bursts of GWs from, say, supernovae explosions

Criteria for optimization

Relative gain for specific source:

$$G_{\rm source} = \frac{{\rm SNR}_{\rm source}(\Gamma,\ \beta,\ \varphi)}{{\rm SNR}_{\rm source}(\Gamma^{\rm NS}_{\rm opt},\ \beta^{\rm NS}_{\rm opt},\ \varphi^{\rm NS}_{\rm opt})}$$

SNR for GW bursts

$${\rm SNR}_{\rm burst} \propto \left[\int_{f_{min}}^{f_{max}} \frac{df}{S_h(f,\ \Gamma,\ \beta,\ \varphi)}\right]^{1/2}$$

How do we optimize?

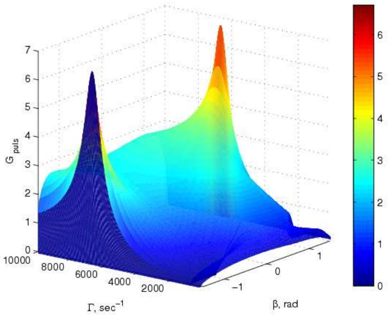
Our optimization procedure:

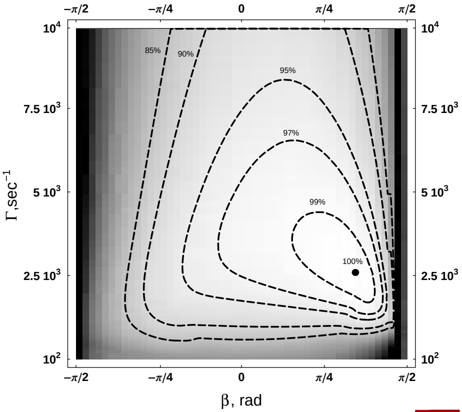
1. Calculate and optimize over all possible configurations $\Longrightarrow G_{\rm NS}(\gamma,\ \beta,\phi)$
2. Optimize $G_{\rm NS}(\gamma,\ \beta,\varphi)$ over all $\varphi \Longrightarrow G_{\rm NS}(\gamma,\ \beta)$
3. Fix price to pay ($\%$ of loss in NS sensitivity) and maximize $G_{\rm puls}$ and $G_{\rm burst}$ taking this price into account

BENCH Software, http://ilog.ligo-wa.caltech.edu:7285/advligo/Bench/

Optimization for HF pulsars

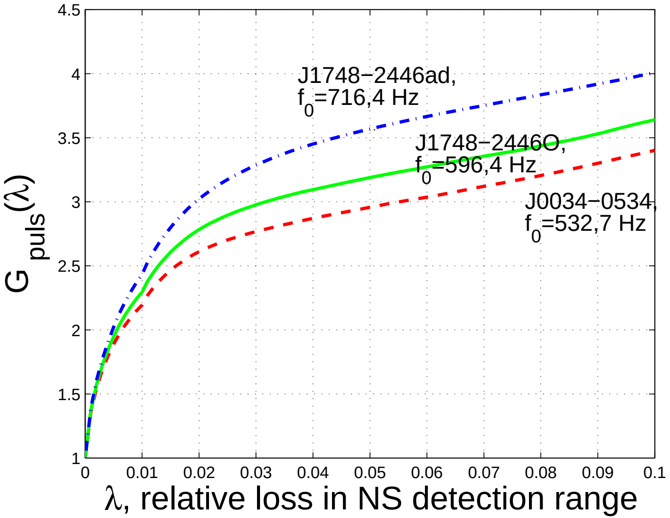
$G_{puls}(\Gamma,\ \beta)$ for pulsar J0034-0534 with rotation frequency $f_{\rm rot} = 532.7$ Hz



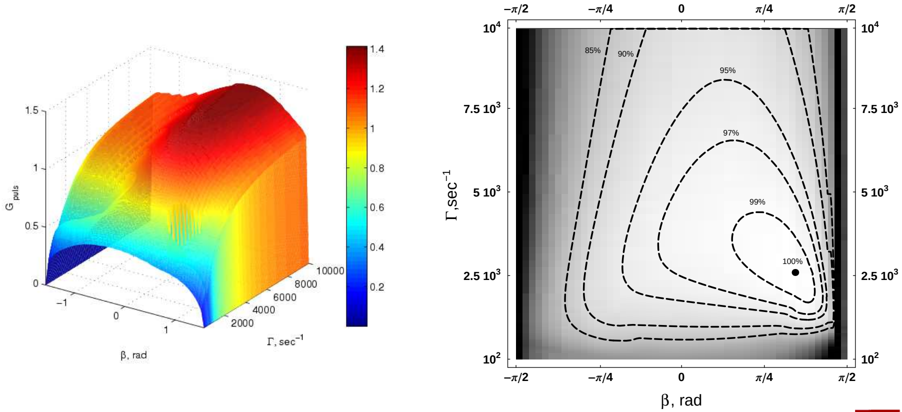


Optimization for HF pulsars

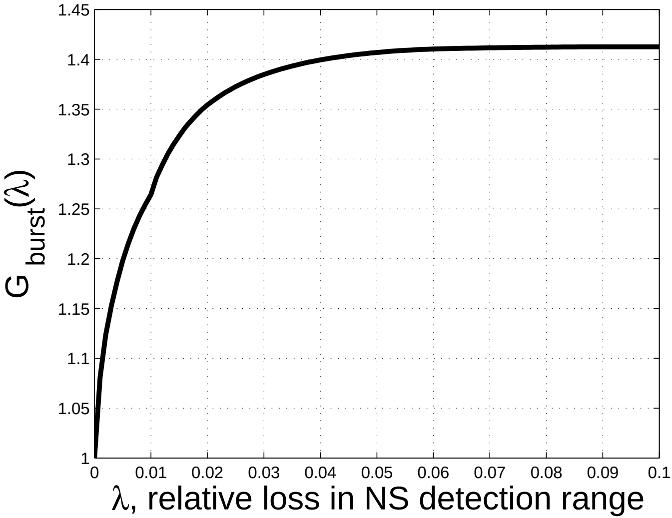
Measure of sacrifice in NS sensitivity: $\lambda = 1 - G_{\rm NS}(\Gamma_{\rm puls}, \beta_{\rm puls}, \varphi_{\rm puls})$



Relative loss in sensitivity for GW bursts $G_{burst}(\Gamma,\ \beta)$



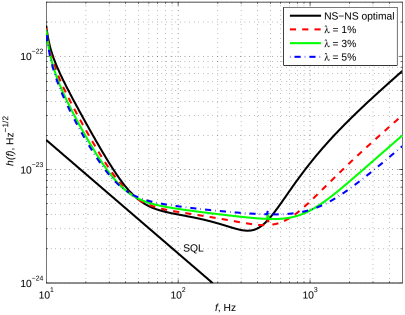
Measure of sacrifice in NS sensitivity: $\lambda = 1 - G_{\mathrm{NS}}(\Gamma_{\mathrm{burst}}, \beta_{\mathrm{burst}}, \varphi_{\mathrm{burst}})$



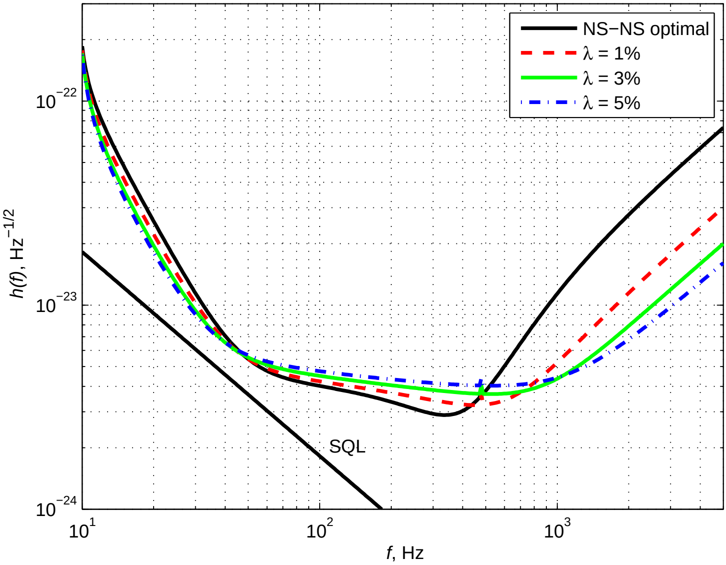
Optimized total noise curves and corresponding configurations

For given λ one can choose optimal configuration of SRI

Rel. NS loss λ,	0.01	0.02	0.03
γ, sec^{-1}	2294	3160	4076
δ, sec^{-1}	2775	3063	3229
φ, rad	-0.59	-0.44	-0.34
$G_{\rm burst}$	1.3	1.36	1.39
$G_{\rm puls}(f_1)$	2.35	2.64	2.77
$G_{\rm puls}(f_2)$	2.46	2.81	2.99
$G_{\rm puls}(f_3)$	2.6	3.06	3.31



Optimized total noise curves and corresponding configurations



Conclusion

1. Optimization for NS-NS binaries seems to be non-optimal for HF sources of GWs
2. Optimization of AdvLIGO SRI sensitivity aiming at several different sources is demonstrated
3. Significant improvement in sensitivity for HF pulsars and GW bursts along with small loss in sensitivity to NS is shown

Conclusion

1. Optimization for NS-NS binaries seems to be non-optimal for HF sources of GWs
2. Optimization of AdvLIGO SRI sensitivity aiming at several different sources is demonstrated
3. Significant improvement in sensitivity for HF pulsars and GW bursts along with small loss in sensitivity to NS is shown

Conclusion

1. Optimization for NS-NS binaries seems to be non-optimal for HF sources of GWs
2. Optimization of AdvLIGO SRI sensitivity aiming at several different sources is demonstrated
3. Significant improvement in sensitivity for HF pulsars and GW bursts along with small loss in sensitivity to NS is shown

THAN YOU

FOR YOUR ATTENTION!!!