A directed continuous-wave search from neutron stars in binary systems with the five-vector resampling technique

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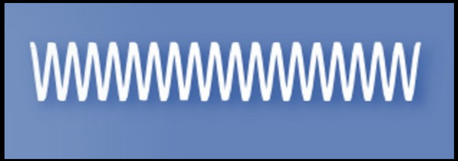
Gravitational waves

Persistent

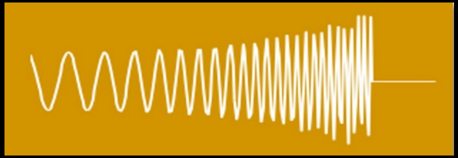


CONTINUOUS

STOCHASTIC

Transient

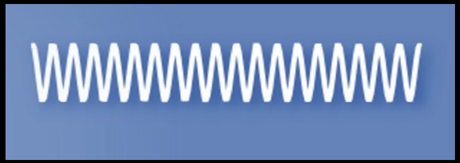
BURST



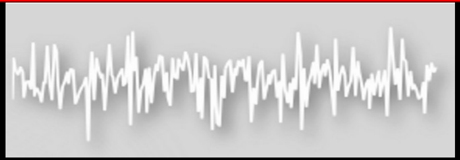
INSPIRAL

Gravitational waves

Persistent



CONTINUOUS



STOCHASTIC

Transient

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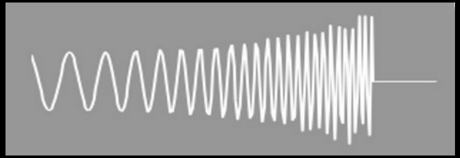
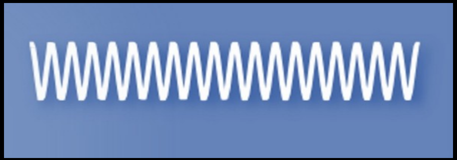


INSPIRAL

Quasi-monochromatic

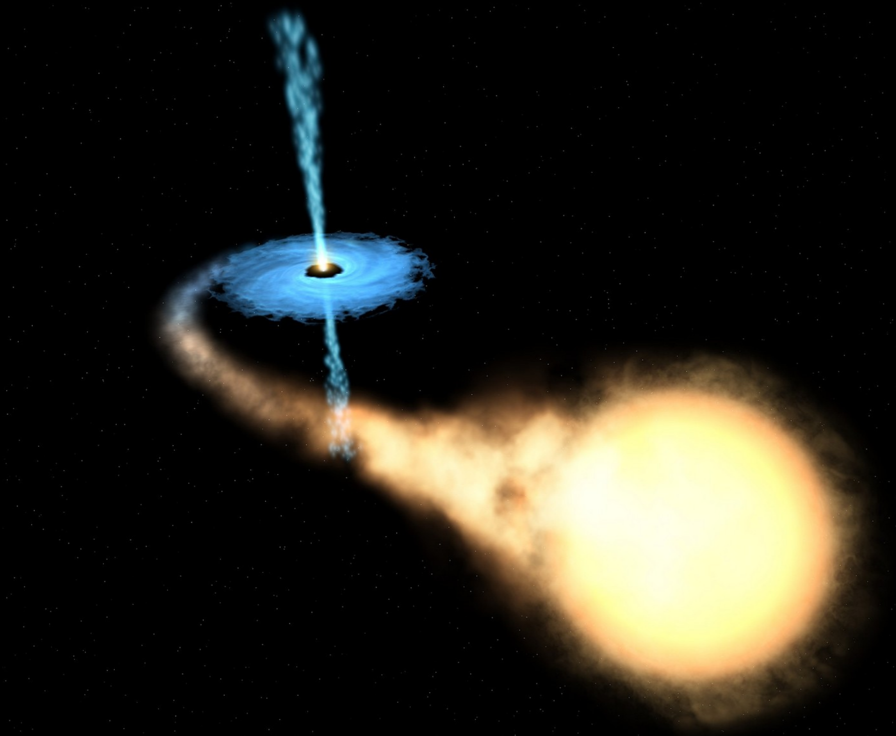
Weak but **persistent**

Scorpius X-1

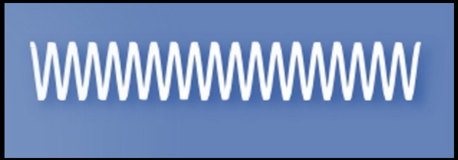


$$h = 5 \times 10^{-27} \sqrt{\frac{300\ \mathrm{Hz}}{f_{\mathrm{rot}}}} \sqrt{\frac{\mathcal{F}_{\mathrm{Xray}}}{10^{-8}\ \mathrm{erg\ cm^{-2} s^{-1}}}}$$

Image: ESA, NASA, and Felix Mirabel



Scorpius X-1



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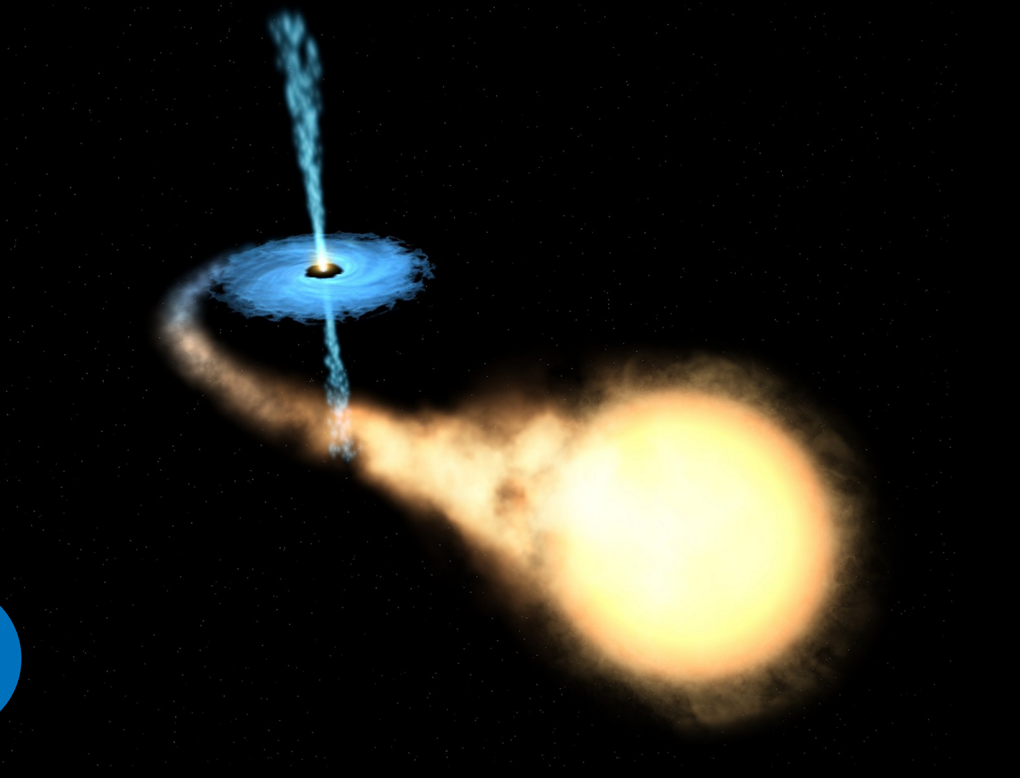

Resampling technique

$$\Phi(t) = \Phi_0 + 2\pi f_{\rm GW}(t + \Delta\tau(t) - \tau_0)$$

Not a sinusoid

$$\Phi(\mathbf{t}') = \Phi_0 + 2\pi f_{\rm GW}(\mathbf{t}' - \tau_0)$$

A sinusoid!

Conclusions

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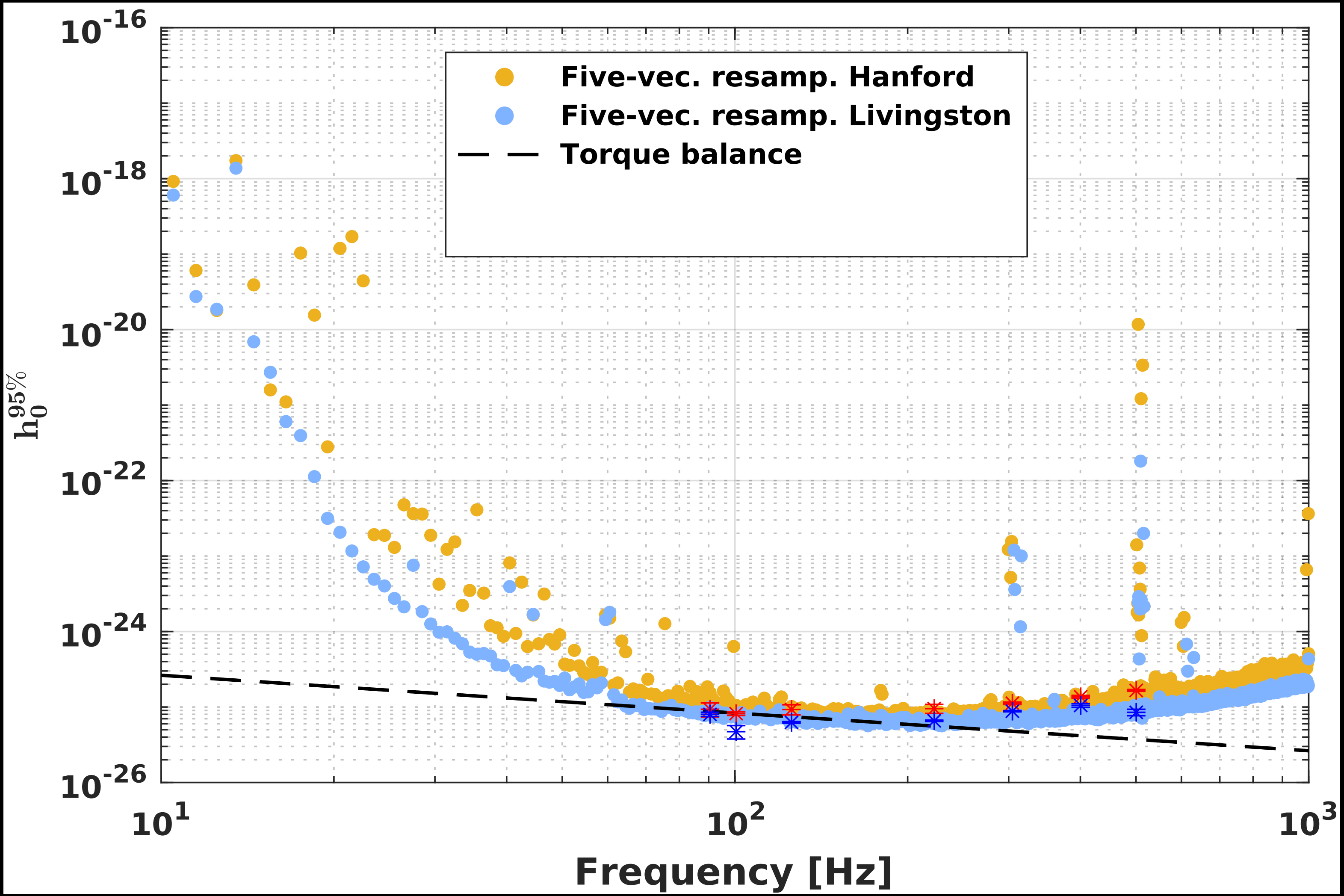
Amicucci et al2025
Class. Quantum
Grav.42145008



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Resampling: Coincidence veto

For every **candidate above threshold** in a given detector, **coincidence candidates** are searched for in 9 intervals in the other detector, having widths outlined below

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Resampling: Coincidence veto

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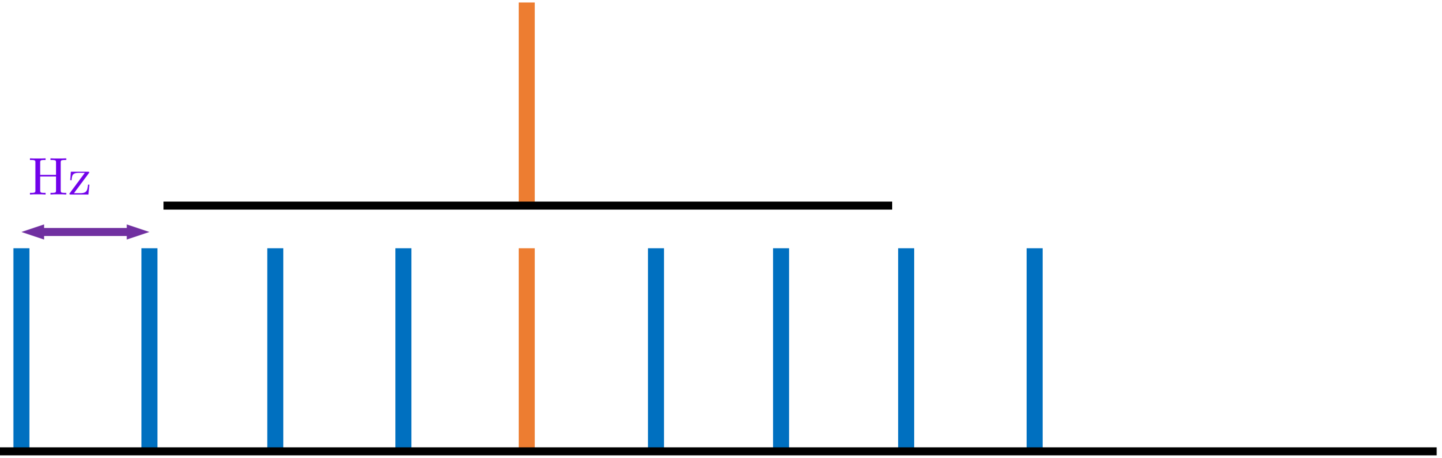
$\mathbf{f_{sidereal} = 1.15 \times^{-5}}$ Hz



INTERNAL VETO

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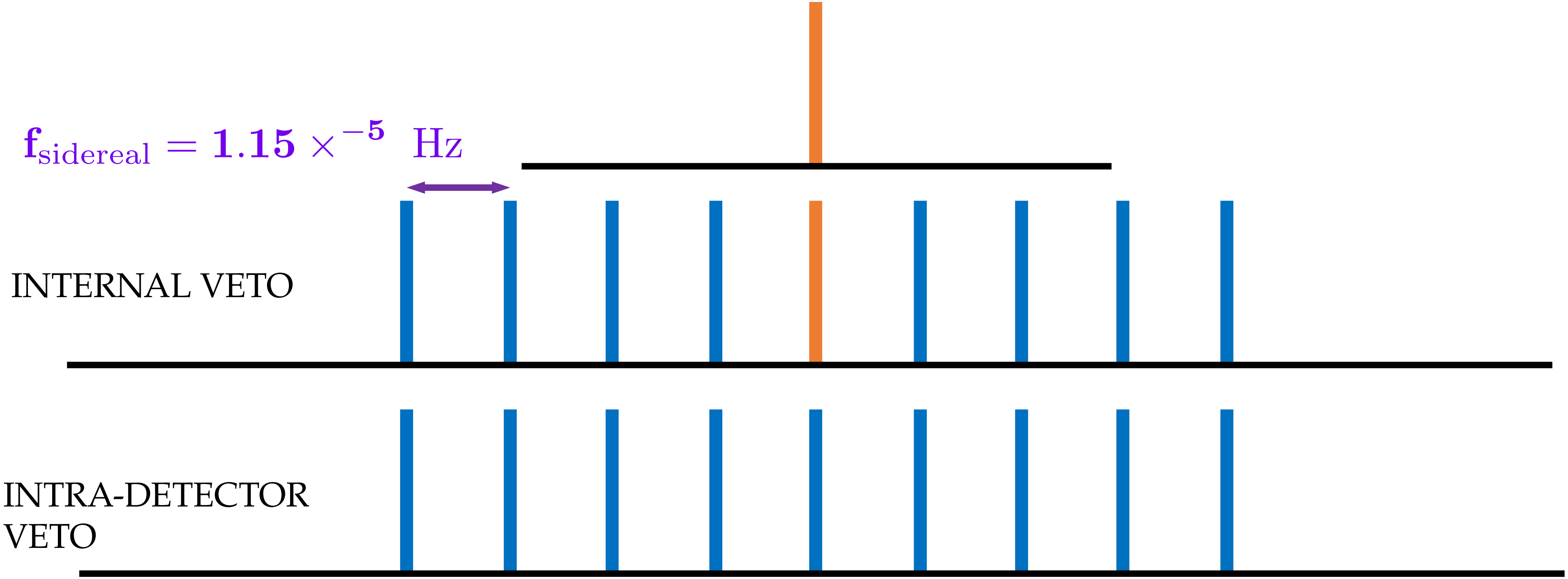

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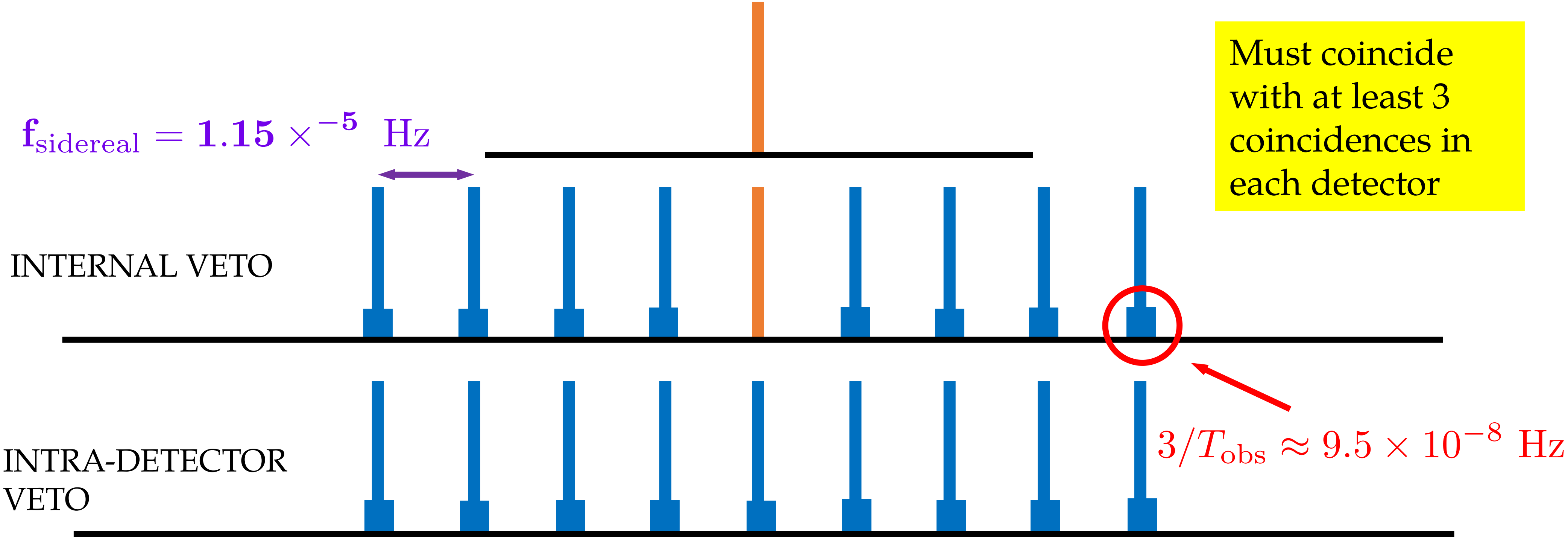

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Bibliography

Some of the papers used as reference in the presentation are here collected:

- B. P. Abbott et al Phys. Rev Lett 116, 061102 (2016)
- A Singhal et al 2019 Class. Quantum Grav. 36 205015
- P Astone et al 2010 Class. QuantumGrav. 27 194016
- Robert V. Wagoner, The Astrophysical Journal, 278:345-348, (1984)
- Mark Zimmermann and EugeneSzedenits, Jr.,Phys. Rev. D 20, 351 (1979)
- Pia Astone et al. (2014)Phys Rev. D 89, 062008
- PaolaLeaciand Reinhard Prix (2015).Phys. Rev. D, 91:102003.

Introduction: CW signal

- Signal model $h(t) \propto h_0 e^{i\Phi(t)}$

We set spindown terms to zero, i.e., $f_{\mathrm{GW}}=const$

- At the source

$$\Phi^{\mathrm{NS}}(\tau) = \phi_0 + 2\pi f_{\mathrm{GW}} \cdot (\tau - \tau_0)$$

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Time delays

Earth rotation

Earth revolution

Neutron star binary revolution

Relativistic effects

- At the detector

$$\Phi(t) = \Phi_0 + 2\pi f_{\mathrm{GW}} \cdot (t + \Delta\tau(t) - \tau_0)$$

Introduction: CW signal

- Signal model $h(t) \propto h_0 e^{i\Phi(t)}$

- At the source

$$\Phi^{NS}(\tau) = \phi_0 + 2\pi f_{GW} \cdot (\tau - \tau_0)$$

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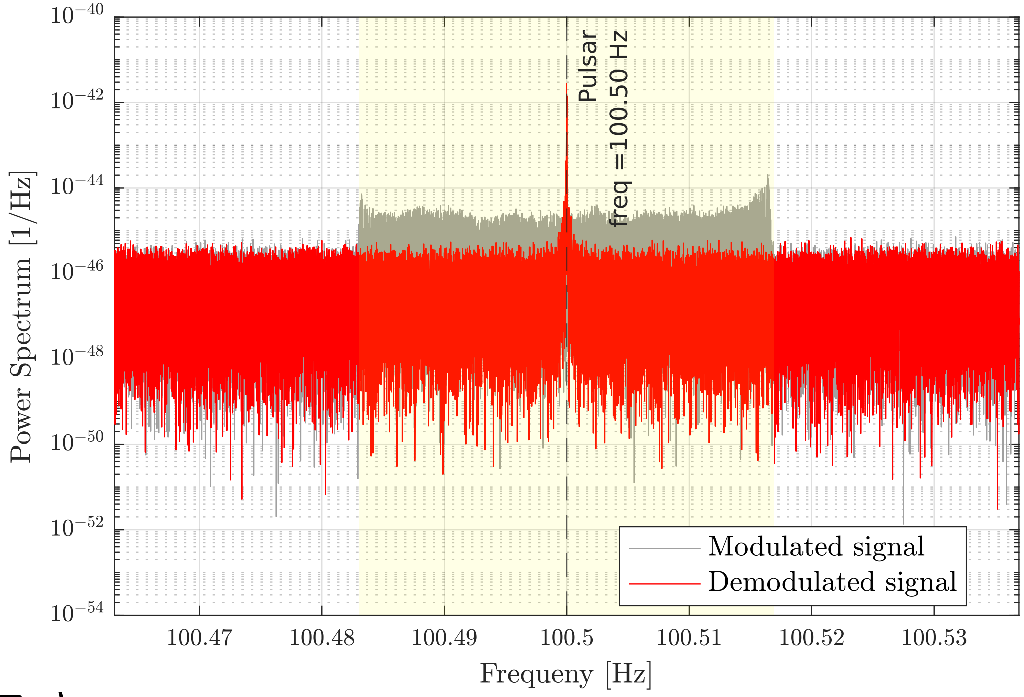
Time delays

- At the detector

$$\Phi(t) = \Phi_0 + 2\pi f_{GW} \cdot (t + \Delta\tau(t) - \tau_0)$$

Artificial CW signal in 10 days Hanford O3 data

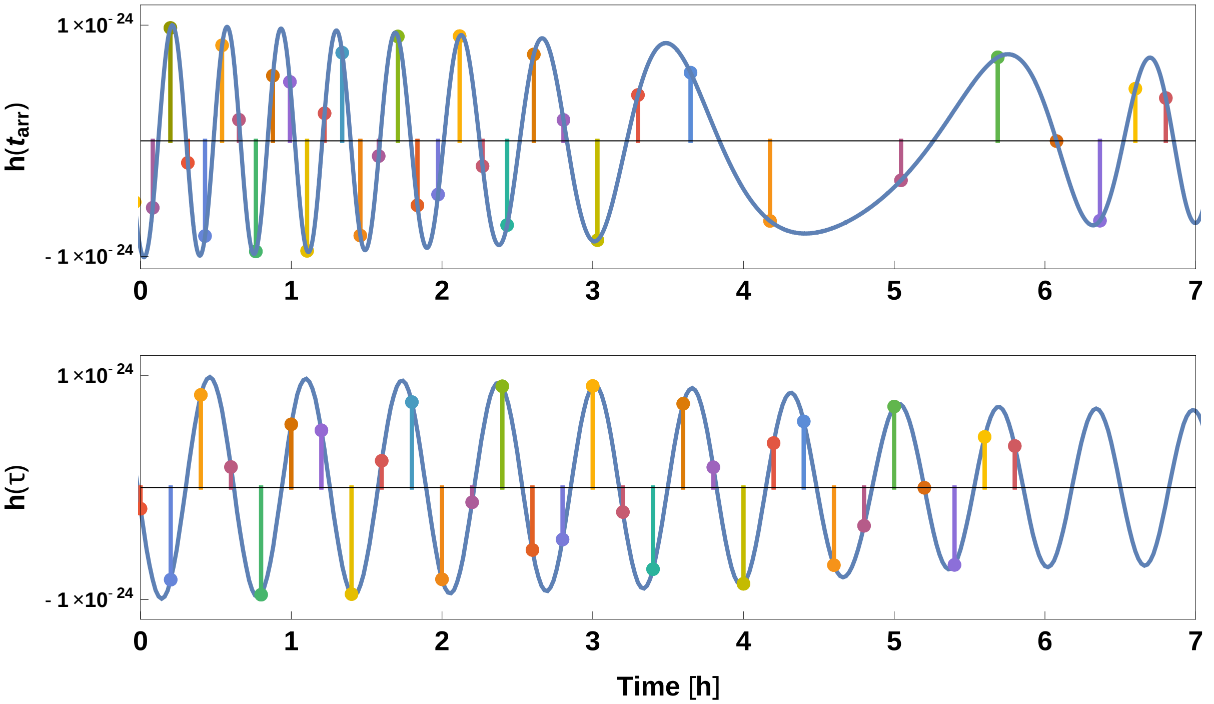


Resampling technique

$$\{\alpha, \delta\} + \{P, a_p, e, \omega, t_p\}$$

$$\Phi(t) = \Phi_0 + 2\pi f_{\mathrm{GW}}(t + \Delta\tau(t) - \tau_0)$$

$$\Phi(\mathbf{t}') = \Phi_0 + 2\pi f_{\mathrm{GW}}(\mathbf{t}' - \tau_0)$$



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Resampling: Signal at detector

$$h(t) = h_0 \underbrace{\left(H_+ A_+(t) + H_\times A_\times(t)\right)}_{\text{Amplitude modulation term}} e^{i\Phi(t)}$$

Fast term

- $H_{+,\times}$ are the complex polarization amplitudes
- $A_{+,\times}(t)$ are the time-dependent **sidereal** detector response functions

Resampling: Signal at detector

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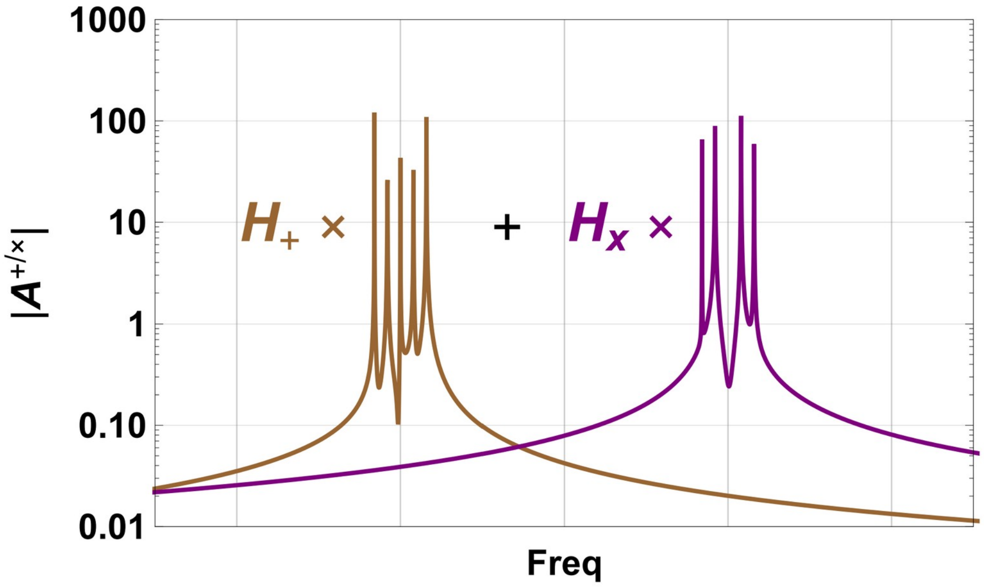
Fast term

- $H_{+,\times}$ are the complex polarization amplitudes
- $A_{+,\times}(t)$ are the time-dependent **sidereal** detector response functions

They depend on the source location

5 Fourier components



A Singhal (2019) *PhD thesis*

P Astone *et al* 2010 *Class. Quantum Grav.* **27** 194016

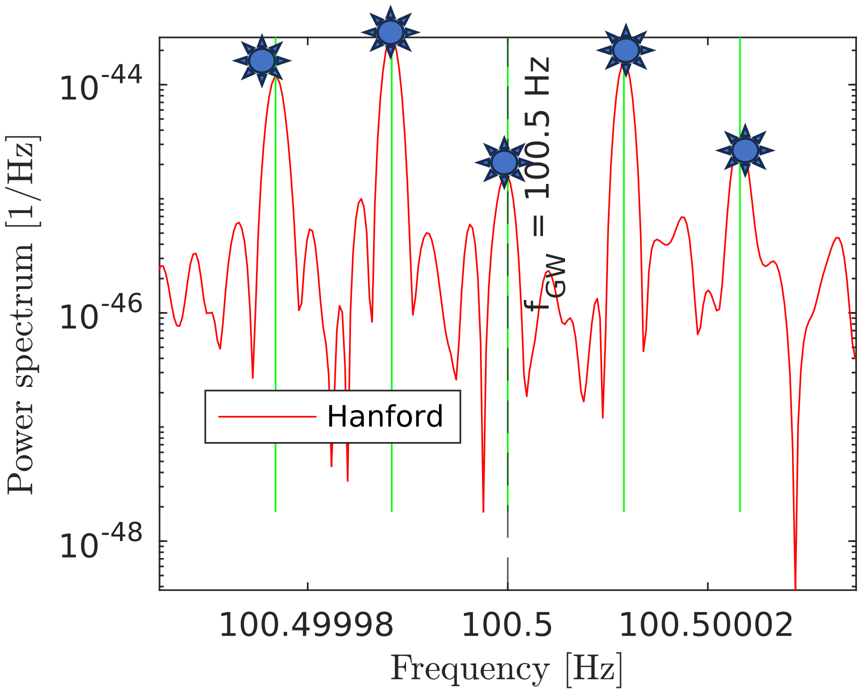
Resampling: Signal at detector

$$h(t) = h_0 \underbrace{\left(H_+ A_+(t) + H_\times A_\times(t)\right)}_{\text{Amplitude modulation term}} e^{i\Phi(t)}$$

Fast term

- 5 frequencies centred at f_{GW} spaced with the **sidereal frequency** 1.16×10^{-5} Hz .
- Accuracy on the $\{P, a_p, e, \omega, t_p\}$ parameters determines the ability to recover the 5 peaks

ΔP [ms]	Δa_p [ms]	Δe	$\Delta\omega$ [$\circ$]	Δt_p (s)
24	14	10^{-4}	0.01	0.1



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Resampling: 5 vectors

$$A_{+,\times}(t)$$

Detector functions

$$\downarrow$$

$$\mathbf{A}_{+,\times}(\mathbf{f})$$

Source templates
5-vectors

$$x(t) = h(t) + n(t)$$

Data series

$$\downarrow$$

$$\mathbf{X}(\mathbf{f})$$

Data 5-vectors

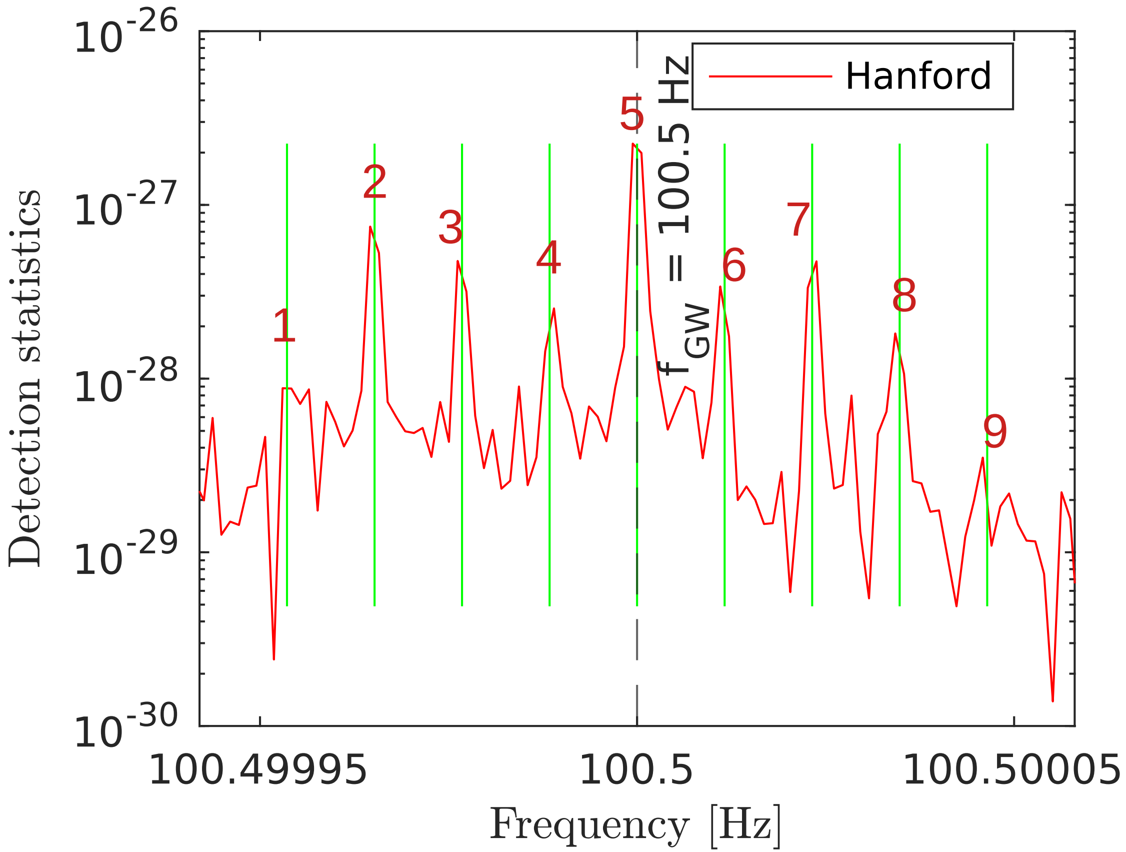
Fourier components at the 5 frequencies where the signal power is split

$$F_k(f) = \int f(t) e^{-2\pi (f - \mathbf{k} f_{\mathrm{sd}})} \mathrm{d}t$$

$$\mathbf{k} = \{-2, -1, 0, 1, 2\}$$

Resampling: Detection Statistics (DS)

- We use the five vector to **cross correlate** the five peaks template with the five peaks signal-vectors



Signal parameter estimation $$\hat{h}^{+,\times}(f) = \frac{\mathbf{X}(f)\cdot\mathbf{A}^{+,\times}}{|\mathbf{A}^{+,\times}|^2}$$

- We build a DS according to

$$\boxed{\mathcal{S} = |\mathbf{A}^{+}|^4|\hat{h}^{+}|^2 + |\mathbf{A}^{\times}|^4|\hat{h}^{\times}|^2}$$

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P Astone et al 2010 Class. Quantum Grav. 27 194016

Resampling: DS threshold

$$\boxed{\mathcal{S}' = \frac{\mathcal{S} - \mu}{\sigma}}$$

is more robust to noise

- # of candidates out of 10^{10} templates
  - $\simeq 1.8 \times 10^5$ Hanford
  - $\simeq 5.3 \times 10^4$ Livingston

- $\mathcal{S}'=18$ (conservative) for HL detectors ($\sim$ minimum among both detectors)

A peak above the threshold **18** is considered a CW candidate that must undergo further vetoes