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Strategies for Tuning Downtime and Duty Cycle to Optimize Gravitational Wave Detections

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ABSTRACT

I give some order-of-magnitude arguments about how to optimize the duty cycle of multiple, heterogeneous GW detectors, to maximize the number of detections. I consider networks that are representative of likely configurations in the near future and mid-2020s.

1. PRELIMINARIES

It is almost always the right choice to optimize the number of detections, N_{det} which scales as

$$N_{\mathrm{det}} \propto VT, \tag{1}$$

where V is the sensitive volume for a particular source type, and T is the overall uptime. In a Euclidean universe (appropriate for binary neutron star (BNS) events, and even a good approximation for binary black hole (BBH) events up until the 3G era),

$$V \propto \rho^3 \tag{2}$$

where ρ is the signal to noise ratio (SNR) of a representative source at a fixed distance. Due to the cubic scaling with SNR, for a single detector, it is almost always the right decision to trade a small amount of downtime for a sensitivity improvement that boosts the SNR.

For multiple detectors, however, the issue of scheduling of downtimes has an effect. In a multi-detector network, SNRs add in quadrature

$$\rho = \sqrt{\sum_{i=1}^{N_{\mathrm{IFO}}} \rho_i^2}, \tag{3}$$

and the overall observation time depends on the scheduling strategy.

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Here we will assume that the sensitive volume is dominated by the gravitational wave (GW) detection horizon, not by a simultaneous electromagnetic (EM) horizon; in this latter case, optimizing the uptime is the only consideration.

2. ADDITIONAL LESS-SENSITIVE DETECTOR

Consider the scheduling problem for the addition of one more detector to an existing network of N interferometers (IFOs), where the additional detector is a factor $f \ll 1$ less sensitive than the typical detector in the network and operates with a duty cycle $T_{\rm obs} = (1-\tau)T_{\rm wall}$ (e.g. the current VIGO detector has $f \simeq 1/3$). If we schedule the detector downtime synchronously with the remainder of the network (here assumed to have comparable duty cycle), then the total VT is

$$VT \propto (1-\tau)\left(1+f^2\right)^{3/2} \simeq (1-\tau)\left(1+\frac{3}{2}f^2\right). \tag{4}$$

On the other hand, if the downtime of this additional detector is scheduled randomly, then we have

$$VT \propto (1-\tau)^N\tau + N(1-\tau)^N\tau\left(1-\frac{1}{N}+f^2\right)^{3/2} + (1-\tau)^{N+1}\left(1+f^2\right)^{3/2} + \mathcal{O}\left(\tau^2\right). \tag{5}$$

(The three cases correspond to the N original IFOs operating, new IFO down; one of the N original IFOs down, new IFO operating; and all IFOs operating.) This is approximately

$$VT \propto \left(1-\left[\frac{3}{2}+\frac{3}{8N}\right]\tau\right)\left(1+\frac{3}{2}f^2\right) + \mathcal{O}\left(\tau f^2\right) \tag{6}$$

Comparing Eq. (4) and Eq. (6), we see that the synchronous strategy dominates the random-downtime strategy in all cases.

3. ADDITIONAL COMPARABLE-SENSITIVITY DETECTOR

Suppose we are considering whether to add an additional detector to the network that is comparable sensitivity to the existing network of N. Then in the synchronous case we have

$$VT \propto (1-\tau)\left(1+\frac{1}{N}\right)^{3/2} \simeq (1-\tau)\left(1+\frac{3}{2N}\right). \tag{7}$$

In the random scheduling case we have

$$\begin{aligned} VT &\propto (1-\tau)^N\tau + N(1-\tau)^N\tau + (1-\tau)^{N+1}\left(1+\frac{1}{N}\right)^{3/2} \\ &\simeq \left(1-\frac{3}{2}\tau\right)\left(1+\frac{3}{2N}\right) + \mathcal{O}\left(\frac{\tau}{N}\right) \end{aligned} \tag{8}$$

Once again, we see that the random-scheduling case is dominated by synchronous scheduling case.

4. CONCLUSION

If possible, detector downtimes should be scheduled synchronously.

REFERENCES