



# Cross-Correlation Searches for Periodic Gravitational Waves



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- Cross-corr method adapted to periodic GWs
- Uses signal model to correlate data @ diff times
- Tuning max time-lag btwn cross-correlated data allows tradeoff of sensitivity for computing time
- Can search for young NSs (e.g., SN1987A) (search over  $f_0$  & braking model params)
- Can search for LMXBs (e.g., Sco X-1) (search over  $f_0$  & binary orbit params)

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**Abstract**  
 Cross-correlation in gravitational wave (GW) data streams have been used to search for stochastic backgrounds, and the same technique was applied to look for periodic GWs from the low-mass X-ray binary (LMXB) Sco X-1. A technique has been developed which refines the cross-correlation scheme to take full advantage of the signal model for periodic gravitational waves from rotating neutron stars. By varying the time window over which data streams are combined, the search can "trade off" between parameter sensitivity and computational cost. Possible search targets include SN1987A remnant and Sco X-1.

**Cross-Correlation for Stochastic Signals**  
 Cross-correlation is a standard technique to search for faint signal in noise:  
 $s(t) = n(t) + h(t) = n(t) + h_0 \cos(\omega t + \phi)$   
 $n(t) = n_0(t) + h_0(t) = n_0(t) + h_0 \cos(\omega t + \phi)$   
 Application to stochastic background (S) expects true value due to correlations in random signals  
 $\langle S(t)S(t') \rangle = \langle n_0(t)n_0(t') \rangle + \langle h_0(t)h_0(t') \rangle$   
 $\langle n_0(t)n_0(t') \rangle = 0$  (white noise)  
 $\langle h_0(t)h_0(t') \rangle = h_0^2 \cos(\omega(t-t'))$   
 Optimal filter statistic:  
 $Y = \int dt \int dt' Q(t)S(t)S(t')$   
 with optimal filter  
 $Q(t) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} \frac{df}{f} e^{-i2\pi ft} S(t)$   
 Used to search for periodic stochastic sources (e.g. including Scorpius X-1).

**Cross-Correlation for Periodic Signals**  
 Sco X-1 not random emitter: low-mass X-ray binary neutron star in binary orbit w/companion. GW signal from rotating neutron star:  
 $R(t) = h_0 \left[ \frac{1 + \cos^2 \iota}{2} \cos(2\pi f(t - t_0)) + \cos \iota \sin(2\pi f(t - t_0)) \right]$   
 • inclination of NS spin  
 •  $\iota$ : phase evolution in rest frame  
 •  $\dot{\iota}$ : Doppler mod from detector motion (binary orbit)  
 Include features of signal in cross-corr method:  
 • Long term coherence  
 • Can cross-correlate data from different times  
 • Doppler shift @ detector  
 • Correlations peaked @ different freqs  
 Note signal cross-correlation deterministic:  
 $\langle R(t)R(t') \rangle = h_0^2 [f_0(t-t')]^2$   
 $= h_0^2 [f_0(t-t')]^2 + \dots$   
 • only pairs separated by  $T_{\text{obs}}$  or less.  
 $R^2 \approx T_{\text{obs}}^{-1} T_{\text{obs}}^2$

**Theoretical Sensitivity**  
 Amplitude sensitivity of combined statistic:  
 $S_{\text{min}} \propto \sqrt{\frac{1}{2} \frac{1}{\sqrt{2\pi}}}$   
 • If all pairs included,  $N_{\text{pairs}} \propto N_{\text{freq}}^2$   
 $S_{\text{min}} \propto \sqrt{N_{\text{freq}}^2} \propto N_{\text{freq}}$   
 Coherent search  
 • Only simultaneous pairs,  $N_{\text{pairs}} \propto N_{\text{freq}}$   
 $S_{\text{min}} \propto \sqrt{N_{\text{freq}}} \propto \sqrt{N_{\text{freq}}}$   
 • If only pairs separated by  $T_{\text{obs}}$  or less.  
 $R^2 \approx T_{\text{obs}}^{-1} T_{\text{obs}}^2$

**Figure 2: Geometrical factor  $(\frac{1}{2}(1+\cos^2\iota))^{-1}$  appearing in the cross-correlation sensitivity, averaged over  $\iota$ , and sidereal time, as a function of declination. The sky positions of the supernova 1987A remnant and Scorpius X-1 are shown for reference.**

**Figure 3: Theoretical sensitivity to SN 1987A remnant for 1 year simultaneous initial LIGO design data set, 5% false alarm & 5% detection.**