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Optimisation of the signal to noise ratio in haloscope detectors.

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The signal from an axion haloscope has a certain spectral content, set by the axion rest mass, mc2, and the relative kinetic energy K of the axions at the detector. For virialized halo axions, the ratio of these energies is K/mc2 ~ 10-6. If the detector is operating at 1 GHz, the signal emitted would have a spectral width of 1 kHz. On account of the high Q ~ 105 of the cavity, the detector is sensitive only over 10–20 kHz but its voltage output is likely sampled at 100 kHz, giving a 50 kHz wide spectrum when Fourier analyzed. The user may choose to measure the signal with a spectral resolution of 1 kHz, requiring 2 ms of measurement time, or perhaps at 10 or 100 Hz, requiring 200 or 20 ms respectively. In reality, to improve signal to noise, the voltage is measured for, say, 100 sec and then various averaging techniques are used to produce a medium-resolution spectrum. How should the parameters of these averages be determined? By analysis and by simulations, we will argue that the 100 sec time series should be Fourier analyzed in 1 or 2 ms chunks, producing spectra in which the signal is just barely resolved spectrally, and then the large number (N = 5×104 or 105) of spectra should be averaged. The strength of the signal in the average is the same as in the individual spectra whereas the noise is reduced by the square root of N. Moreover, because every point in the time series contributes in the Fourier transform to each point in the frequency spectrum, a shorter time series contains a smaller noise signal. The SNR versus resolution is not sharply peaked but is definitely maximized by the approach outlined above.

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