Coherence structure by Cross correlation spectrometry (XCS)

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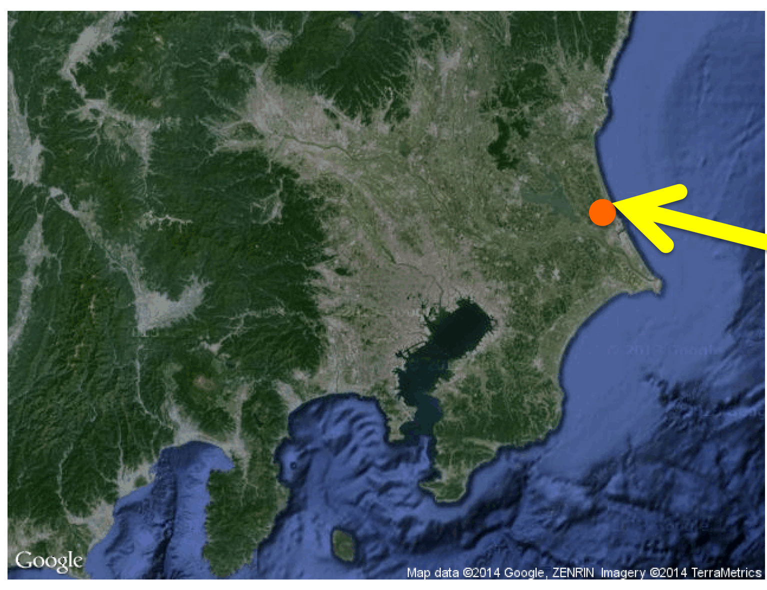
Abstract

We have developed a new method of data processing for radio telescope observation data to measure time-dependent temporal coherence, and we have named it “cross- correlation spectrometry” (XCS) [Takefuji+,2016,PASJ]. XCS is an autocorrelation procedure that expands time lags over the integration time and is applied to data obtained from a single-dish observation.
The temporal coherence property of received signals is enhanced by XCS.
We tested the XCS technique using the data of strong H2O masers in W3 (H2O), W49N, and W 75 N. We obtained the temporal coherent lengths of the maser emission to be 17.95 ± 0.33μs, 26.89 ± 0.49μs, and 15.95 ± 0.46μs for W3 (H2O), W49N, and W75N, respectively. These results may indicate the existence of a coherent astrophysical maser.



34 meter RT in Kashima

Development of XCS

General spectrometry:

We assume that the spectrum of data obtained with a receiver output of a radio telescope $X(f)$ is composed of a signal $S(f)$ arriving from a radio source in the sky and the system noise $N(f)$. The signal of $X(f)$ is dominated by the receiver and off-source sky noise in most cases. The power spectrum is obtained by calculating the inner product of $X(f)$ and its complex conjugate $X*(f)$ as follows:

$$|X(f)|^2 = X(f)X*(f) = S(f)S*(f) + S(f)N*(f) + S*(f)N(f) + N(f)N*(f).$$

Since the signal and noise are independent, these cross terms vanish upon averaging.
Consequently, the signal and noise terms remain to give

$$\langle |X(f)|^2 \rangle \sim= \langle S(f)S*(f) \rangle + \langle N(f)N*(f) \rangle$$

where ⟨⟩ indicates averaging over the data accumulation period.

Cross-correlation spectrometry:

A series of data digitized by a sampler is divided into datasets with time interval T considering Fourier transform. Here, $X(t_i, f_k)$ indicates the complex component at frequency $f_k = k / T$ and epoch $t_i = i \times T$ (i=0,1,2,... and k=0,1,2,...), and is expressed as

$$X(t_i,f_k) = S(t_i,f_k) + N(t_i,f_k).$$

Computing **the time-delayed correlation** of the data along time series t_i at frequency f_k, the averaged cross terms of the signal and noise vanish because of their independence. Note that the fourth term of the right-hand side in following equation also vanishes because both noises are taken in different epochs and are therefore independent. When the signal has temporal coherence, only the first term will remain:

$$\langle X(t_i,f_k)X*(t_{i+j},f_k)\rangle = \langle S(t_i,f_k)S*(t_{i+j},f_k)\rangle + \langle S(t_i,f_k)N*(t_{i+j},f_k)\rangle + \langle N(t_i,f_k)S*(t_{i+j},f_k)\rangle + \langle N*(t_i,f_k)N*(t_{i+j},f_k)\rangle$$
$$\sim= \langle S(t_i,f_k)S*(t_{i+j},f_k)\rangle$$

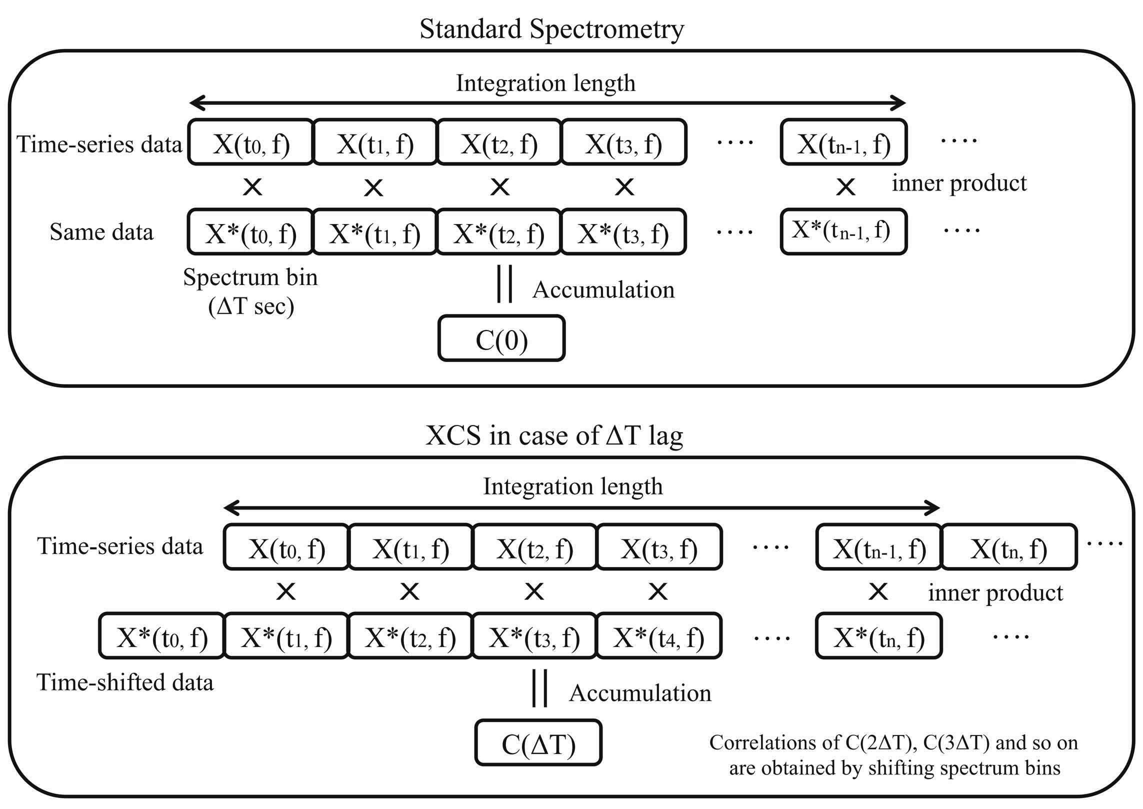


Fig. Schematic explanation of XCS

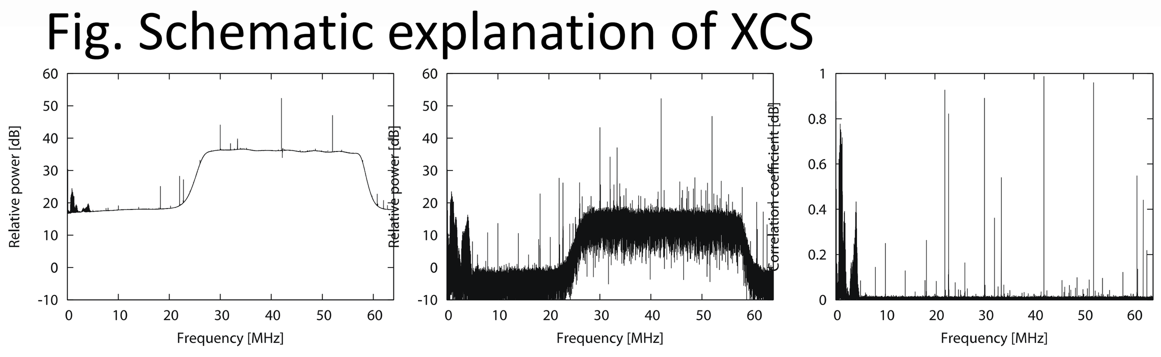
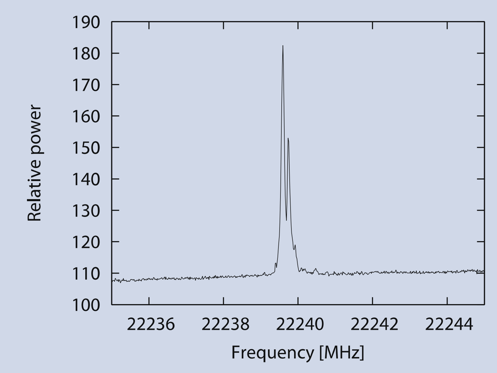
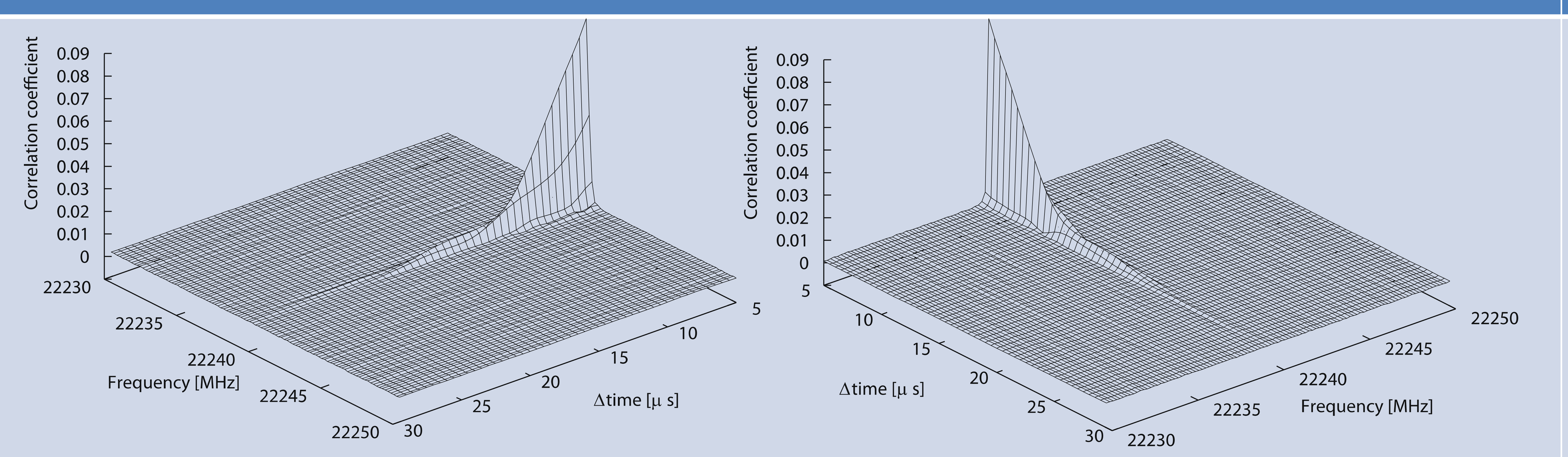
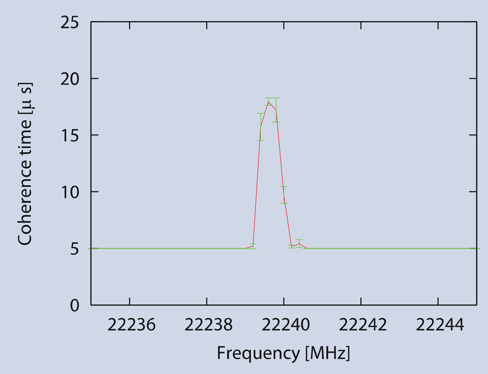
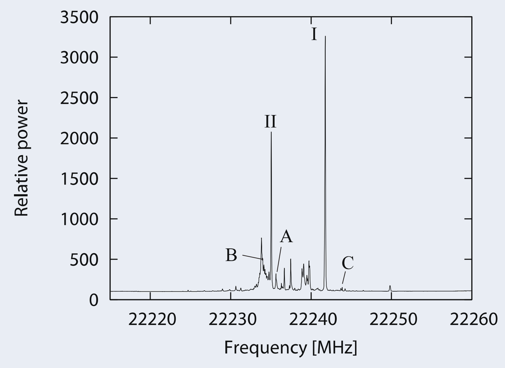
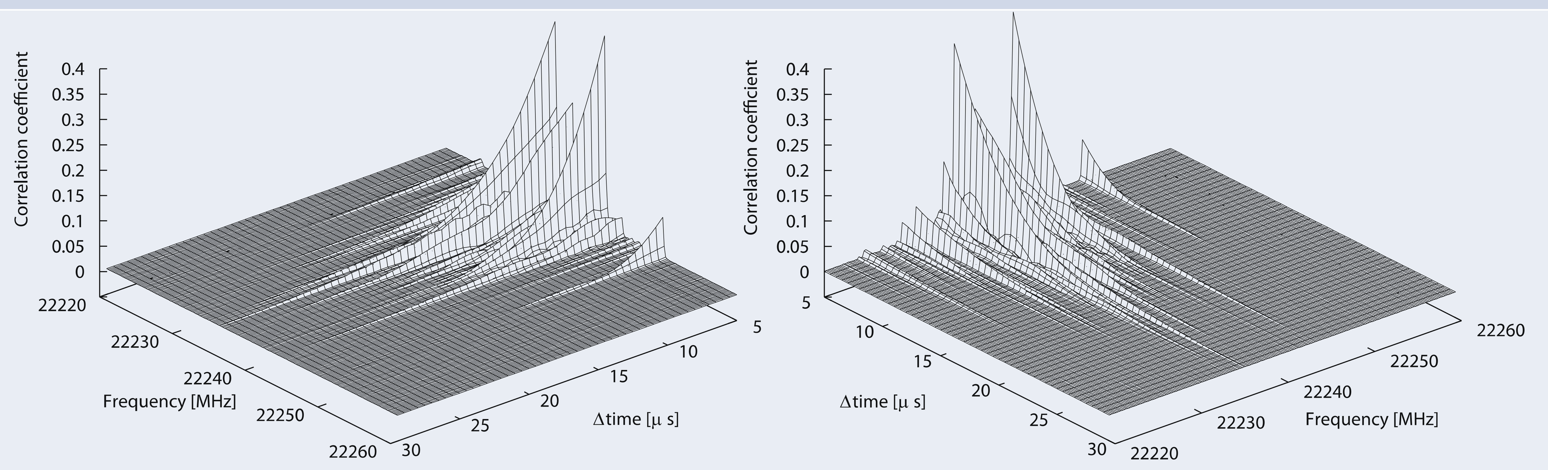
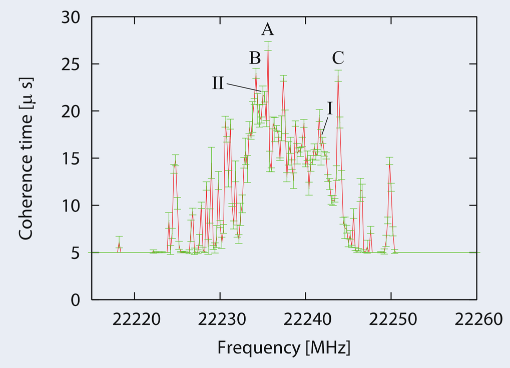
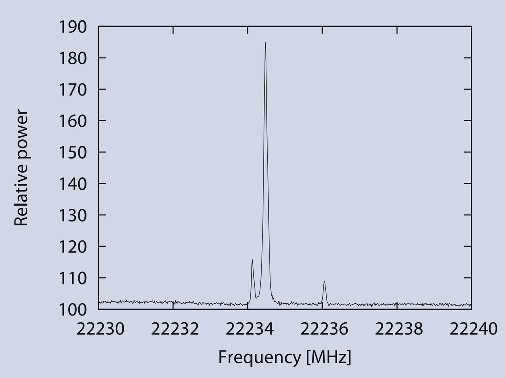
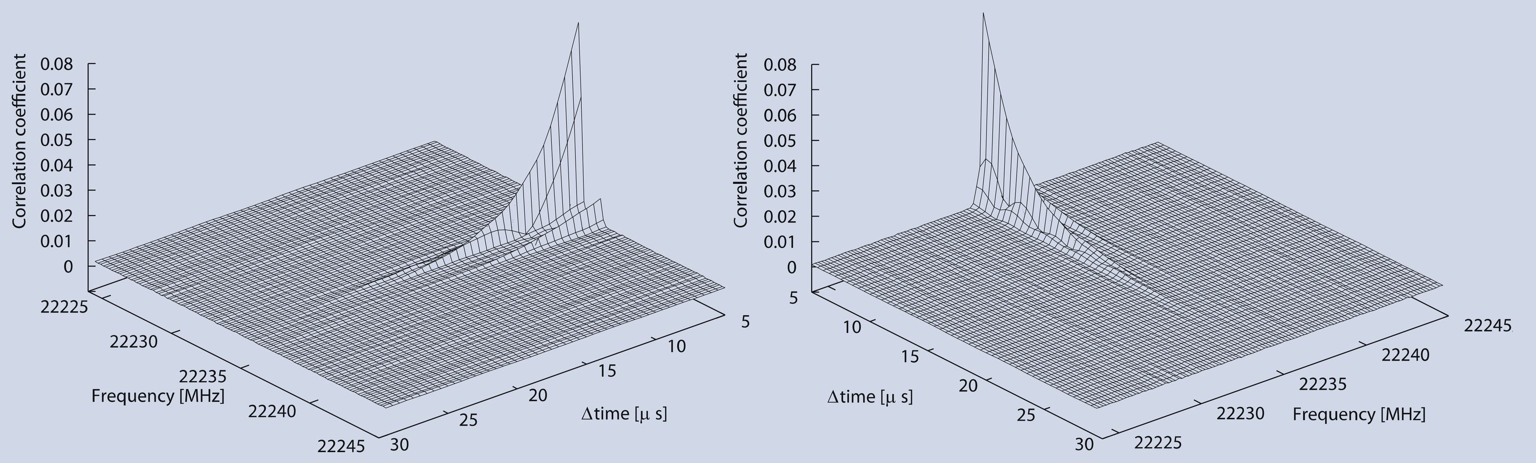
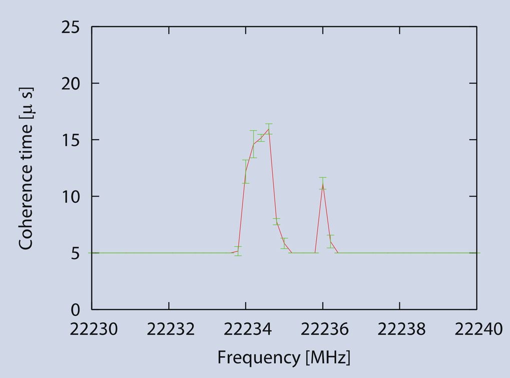


Fig. Example of XCS, Left figure shows the band-profile of Kashima L-band.
Middle figure shows the XCS processing result and right shows the XCS with normalized result.

Maser observation and results

2013 October 28	General spectrometry 10 s integ, 15.625 kHz RBW	Cross-correlation spectrometry 30 s integ, 200kHz RBW, 5-30us, 500ns step	Coherence time	Estimated Tb [K}
$W3(H_2O)$				(8.47±0.41) × 10^{18} for the peak flux
W49N				(8.91±1.28) × 10^{20} for the longest coherence (6.21±1.15) × 10^{22} for the peak flux
W75N				(4.77±0.54) × 10^{18} for the peak flux

According to Elitzur 1992, if the brightness temperature T_b of a maser meets the value from **3.7×10^{17} K** to **3.7×10^{19} K** for Hydrogen 22G, the likelihood of a coherent maser is anticipated.
The Estimated brightness temperature of W49N clearly exceeds the value !!!