# Continuous linear time-frequency transforms in the analysis of fusion plasma transients

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There is a long history of the use of continuous linear time-frequency transforms in the analysis of transients detected in fusion plasma devices [1]. Despite the fact that numerous alternative methods of time-frequency analysis were proposed during the years, Fourier transform based solutions are still the standard method to approach transient wave-like phenomena. The reason for this continued popularity is that these linear time-frequency transforms do not produce any disturbing interference patterns between the time-frequency atoms, eigenfunctions of linear and quasi-linear theories [2]. This paper concentrates on continuous transforms that are time-shift invariant, thus ideal for the analysis of transient signals (for example: chirps, sawtooth, ELMs, EPMs, etc.).

The two well-known types of continuous linear time-frequency transforms, namely the short-time Fourier transform and the continuous wavelet transform with analytical wavelets, differ mainly in their invariance properties, which determines their optimal field of use. Uncertainty estimation of transform values and derived quantities, like energy density distributions and phases, is also addressed.

Finally, the paper presents some advanced methods based on the time-frequency transforms that have been implemented in the recently developed NTI Wavelet Tools package with practical fusion plasma applications. A mode number determination routine is a main feature, for an application on sawtooth crash analysis see [3]. It is based on fitting mode phases, and now it also provides the uncertainty of the estimated values. Time-frequency coherence and transfer functions are introduced briefly, and time-frequency bicoherence is discussed concentrating on consequences of the invariance properties of the transforms used.

**References**

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