ON REMOVAL OF THE GRADUAL COMPONENT IN ANALYSES OF SOLAR IMPULSIVE BURSTS

J. E. R. COSTA
Centro de Radioastronomia e Aplicações Espaciais, São Paulo, Brazil

J. C. BROWN
Department of Physics and Astronomy, University of Glasgow

AND

E. CORREIA AND P. KAUFMANN
Centro de Radioastronomia e Aplicações Espaciais, São Paulo, Brazil

Received 1988 December 9; accepted 1989 October 27

ABSTRACT

Three methods are considered for the removal of the gradual component in solar flare time profiles. It is emphasized that a time-dependent gradual component can introduce apparent delays between impulsive extrema which may be misinterpreted in terms of physical processes. Running mean subtraction always produces negligible delays in comparison with the period of the fast component; thus, it has major advantages compared with second derivatives and Fourier filtering for recovering the impulsive component.

Subject headings: Sun: flares — Sun: radio radiation — Sun: X-rays

1. INTRODUCTION

Solar impulsive bursts observed at centimeter-millimeter wavelengths, and often simultaneously at hard X-rays (e.g., Cornell et al. 1984; Takakura et al. 1983; Correia et al. 1986; Correia and Kaufmann 1987; Zodi Vaz et al. 1986), usually exhibit rapid fine structures superposed on the gradual component. This pattern may be due either to genuine superposition of two components of physically distinct origins with different time scales (e.g., thermal and nonthermal) or to the smeared appearance of elementary spikes superposed with a repetition time shorter than its duration (e.g., Kaufmann et al. 1984; Loran et al. 1985; Sturrock et al. 1984).

In any case, it is common practice in analyzing data to attempt to remove the slowly varying component in order to reveal more clearly the fine-structure features and permit comparison of peak times at different wavelengths, or to allow analysis of spectral variations in an impulsive component (e.g., nonthermal) as distinct from a gradual component (e.g., thermal) which may dominate the total signal. Assuming these are produced by different processes, a variety of methods can be utilized for removal of gradual components, such as subtraction using running mean technique, subtraction of low-frequency components from the Fourier spectrum or analysis of the second time derivative of the data (Bracewell 1965). Similar procedures to these, for time series, are also used for data analysis in the spectral and spatial domains, such as in the processing of seismological signals (see Bracewell 1965).

It is clear that all of these procedures are to some extent subjective in learning something about the underlying physics. For example, the time evolution of two unknown functions can give rise only to observations of the time evolution of their sum or product. The first case could be related, for example, to impulsive quasi-periodic emission from nonthermal sources superposed on a gradually varying emission from a thermal source. The second case could correspond to fast modulation of the speeds of a gradually varying number of emitting particles. Thus, some hypothesis or procedure must be added to solve the problem of separating the components. Nevertheless, to make any progress, it is presumably better to proceed in this way using some reasonable assumption about the gradual component than to make none. In this note, however, we wish to illustrate by simulations that there are potential dangers in the use of some of the ad hoc methods mentioned above, which can produce misleading results, and also to clarify the effects of the signal composition itself.

For simplicity we concentrate on the case of time series and consider the consequences of procedures for gradual component removal, although our conclusions apply equally to spatially composite signals, for example. In particular, we are interested in the possibility of systematic effects on peak times at different wavelengths, since there has been much effort recently comparing those (as referenced above). Later we will discuss briefly the implications for other types of data analysis.

II. THE EFFECT OF A GRADUAL COMPONENT ON THE PEAK TIMES OF THE IMPULSIVE COMPONENT

a) The Problem

Suppose a total time-dependent signal \( F(t) \) is composed of a slow component \( F_0(t) \) added to a fast component \( F_1(t) \), using

\[
F(t) = F_0(t) + F_1(t). \quad (1)
\]
In the multiplicative case, a fast-Fourier modulation $f(t)$ can only apply to part of the slow-component amplitude $S(t)$, for otherwise the total fast amplitude $F(t) = S(t)f(t)$ would be sometimes negative. That is, we must have $F(t) = F_0(t) + S(t)f(t)$, where $F_0(t)$ and $S(t)$ are slowly varying and $f(t)$ is fast. It follows that in the multiplicative case the signal can also be written in form of equation (1).

Then the essential problem is that if $F_0(t)$ possesses extrema at various times $t_m$ (e.g., $F_0(t) = 0$ with the prime denoting $= d/dt$) in which we are physically interested, then the analysis of the total signal $F(t)$ will not, in general, reveal extrema exactly at the same times $t_m$; that is, from equation (1)

$$F'(t_m) = F'_0(t_m) + F'_1(t_m)$$

will not be zero unless $F'_0(t_m)$ is coincidentally zero. In general, corresponding extrema in $F(t)$ will occur earlier or later than the $t_m$, depending on the magnitude and sign of $F'_0(t_m)$, and may not even occur at all, if $F'_0(t_m)$ is large compared to $F'_1(t)$ in the neighborhood of $t = t_m$. Here we illustrate the magnitude of these effects for two simple cases, and in § III we consider the consequences for peak times of various methods for removal of the gradual component.

### b) Effect of a Linear and Quadratic Gradual Component on Peak Times

Here we suppose, again for simplicity, that the impulsive component takes the form

$$F_1(t) = a \sin(\omega t),$$

and that the gradual component takes the form

$$F_0(t) = A(t/T) + B(t/T)^2,$$

where $T$ is some convenient (long) reference time, of the order of the rise time to the overall peak in $F(t)$. The impulsive component (eq. [3]) has extrema at $\cos(\omega t_1) = 0$, that is,

$$t_1 = (m + 1/2) \frac{\pi}{\omega}, \quad m = 0, 1, 2, \ldots$$

(maxima for even $m$, minima for odd $m$), while extrema in the total $F(t)$ are given by

$$F'(t) = a\omega \cos(\omega t) + \frac{A}{T} + 2B \frac{t}{T^2} = 0,$$

which is clearly not satisfied for $t = t_1$, given by equation (5). If we write equation (6) as

$$\cos(\omega t) = -\left(\frac{A}{a\omega T} - \frac{2Bt}{a\omega T^2}\right),$$

we see that, in fact, for $B = 0$ and $A/(a\omega T) > 1$, or for $B \neq 0$ and $t > T(a\omega T - A)/(2B)$, there are no extrema present in the total signal $F(t)$ but only inflexion points. For $B = 0$ and $A = a\omega T$ or $B \neq 0$ and $t \leq T(a\omega T - A)/(2B)$, the shift of the peaks in $F(t)$ relative to those in $F_0(t)$ clearly depends on the relative amplitudes of the impulsive and gradual components.

Specifically, for the case $B = 0$ (linear gradual component) the shift between corresponding peaks in $F(t)$ and $F_0(t)$ is, from equations (5) and (6),

$$\Delta t = \frac{1}{\omega} \left[ \frac{\pi}{2} - \cos^{-1}\left(\frac{A}{a\omega T}\right) \right],$$

with the shift in the sense that maxima come later and minima earlier in $F(t)$ compared to $F_0(t)$ if $A > 0$; and the opposite occurring if $A < 0$. These shifts thus increase as $A/(a\omega T)$ increases, reaching a maximum shift $\Delta t$ of $\pm \pi/(2\omega)$, e.g., a phase shift of 1/4 in the fast component.

In the case where $B \neq 0$ the effect is clearly equivalent to that of a linear increase in $A$ with time; i.e., maxima and minima in $F(t)$ will become increasingly shifted from those of $F_0(t)$ as $t$ increases until they disappear at $t = T(a\omega T - A)/(2B)$.

Formula (8) provides a useful criterion for whether or not the times of extrema in a total signal $F(t)$ are very different from the intrinsic times of extrema in a high-frequency ("ripple") component (clearly the effects are only small if $A/[a\omega T] \ll 1$). If $\omega T = 2\pi N$, where $N$ is the number of high-frequency maxima in time $T$, while $\alpha = a/A$ is the relative amplitude of the high-frequency component at time $T$, the criterion for negligible shifts can thus be written:

$$\alpha = \frac{a}{A} \gg \frac{1}{2\pi N} = \frac{1}{\omega T} = \frac{\tau}{2\pi T},$$

where $\tau$ is the ripple period. Thus, for example, if we observe 500 ms ripples over a burst with 5 s half-duration ($N = 10$), the apparent high-frequency peak times in Figure 1 will differ substantially from the underlying peak times in

![Figure 1](image-url)
unless the ripple amplitude $\alpha > 2\%$ at the peak of the event. In the case where $B = 0$, it is clear from equation (8) that only the phase and not the frequency of ripples is changed by the linear term $At$ (though the time difference from maximum to minimum differs from the time difference from minimum to maximum). Thus, the effect is only important if we are considering the relative timing of peaks at two different wavelengths, such as X-rays and microwaves. If the relative amplitudes of the fast and slow components are different at different wavelengths, misleading results can be obtained in comparing peak times in the total signals $F(t)$ at the two wavelengths. For example, for 500 ms fine structures, superposed on a slow component with 5 s in duration, exhibiting relative amplitudes of 10% and 2% at burst maximum, at X-ray and microwaves, respectively, will provide delays, even if the fast components are originally in phase. Likewise, a similar situation in time profiles at two different X-ray energies may lead to a false impression of hardening or softening of the X-ray spectrum with impulsive fluctuations. Such information may be considered when analyzing fast structures for physical interpretations in terms of phase differences in acceleration of electrons at different ranges of the energy.

c) Effect of a Sinusoidal Gradual Component on Peak Times

Here we replace equation (4) by the following gradual component:

$$F_0(t) = C \sin \left( \frac{\pi t}{2T} \right),$$

and superpose the fast component from equation (3). Then the fast structure extrema times $t_1$ satisfy:

$$\cos \left( \omega t_1 \right) = -\frac{1}{4N\beta} \cos \left( \frac{\pi t_1}{2T} \right),$$

where $\beta = a/C$ and $N = \omega T/(2\pi)$ is the number of ripple maxima in $T$. In this case, if $4N\beta < 1$, but is very much greater than zero, extrema in $F(t)$ exhibit the same shifts relative to $F(t)$ when $t < T$, similar to those described in § IIIb (i.e., late maxima, early minima). However, as the event maximum is approached (i.e., $t \to T$), the extrema become synchronous [cos $(\pi \omega t_1 / (2T))$] tends to zero in equation (11). This trend reverses in the decay phase ($t > T$). Thus, as should be expected, the trend in the sinusoidal case reflects the trend for the local linear (or quadratic) fit to the sinusoid.

d) Numerical Simulations on Component Composition

In order to analyze better the composition of the gradual and fast component we performed some numerical simulations using equations (3), (4), and (10). In general, the removal of the slow component is used to increase the contrast of small-amplitude signals superposed on a strong background signal. Therefore we will consider the ratios between the amplitudes of the fast and gradual components much smaller than unity. For the ratio between the period of the fast component and the mean time duration, $T$, of the gradual component, we take a value of 1/10, which is a reasonable representation for most cases (see Fig. 1). For the relative amplitudes we set $0.001 \leq a/B \leq 1$ (same for $a/C$). The plots in Figures 2 and 3 show the maximum delays introduced in each such simulation, i.e., the maximum shift of the time of the peaks in the impulsive signal, compared to the final signal resulting from the superposition of the two components (impulsive and gradual), the delays are in time units of the period of the fast component $(2\pi/\omega)$, against

![Fig. 2.—Maximum relative delays in the additive and multiplicative composition of quadratic gradual component and sinusoidal fast component vs. relative amplitude $(a/A)$.](image)

![Fig. 3.—Same as Fig. 2, but for the composition of sinusoidal gradual and fast components vs. relative amplitude $(a/C)$.](image)
the relative amplitude \( a/B \) from equation (4) or \( a/C \) from equation (10), according to each case. Figure 2 is for the composition of a gradual quadratic component with a rapid sinusoidal component (additive and multiplicative cases). Figure 3 is the same as Figure 2, but using a sine function as a gradual component instead of a quadratic one. In the numerical simulations we search for maximum relative delays (or maximum phase shifts of the fast component) in all peaks occurring during the time \( 0 \leq t \leq T \). Since \( a/B \) is not known from observation, we define a parameter called observed relative amplitude as a ratio between the absolute values of the difference in flux, \( \delta \), at given peak and the nearest minimum, and the mean flux between them (see Fig. 1). This "observed relative amplitude" defines the ratio of the ripple to underlying flux in observational terms. We proceed by stopping to increase \( B \) or \( C \) in Figures 2 and 3 as soon as the first maximum in the simulation period analyzed, \( T \), meets the criteria of observed relative amplitude, being of the order of 0.001.

One important feature shown in Figures 2 and 3 refers to the maximum relative delays (maximum phase shift) between the peaks in the impulsive signal and the peaks after the summation of the gradual and impulsive components, in the selected conditions. It is always less than ~20% of the period of the fast component. Of course, it cannot even be a complete period. To figure out a peak-to-peak correspondence we can use the nearest pair of peaks. Specifically, for the additive simulations, we can define an observed positive relative amplitude and plot the maximum relative delays, \( \Delta t \), against the logarithm of the observed relative amplitudes, \( RA^* \) (see Fig. 4). The \( RA^* \) from simulations, using quadratic plus sine function (asterisk in Fig. 4), are comparatively smaller than \( RA^* \) from sine plus sine simulations (open square in Fig. 4). The last case is higher, even up to unreasonable observed relative amplitudes like 10, but this composition does not fit, in general, the profile that we observe for solar flare gradual components. The reason is that the maximum relative delay in the first case happens at the top of the gradual component (when the observed relative amplitude is small) and in the second case at the base of the gradual component (when the observed relative amplitude is large). Apart from this functional dependence of the maximum relative delays in Figure 4, they are defined in the same range of magnitudes for both curves. The least-squares best fit to the linear part of these results, plotted in Figure 4, was \( \Delta t = 0.027 - 0.079 \log (RA^*) \) for gradual + impulsive composition and \( \Delta t = 0.059 - 0.0731 \log (RA^*) \) for sinusoidal + impulsive composition.

III. THE EFFECTS OF REMOVAL OF THE "GRADUAL COMPONENT"

a) General

As noted in § I, it is common to study impulsive components by use of some method of subtraction of the gradual component. In this section we wish to illustrate that such background subtraction methods have the effect of displacing the times of impulsive peaks relative to those in the original \( F(t) \), a point which does not seem to be generally appreciated. As might be anticipated from the discussion in § II, we will see that the subtraction of the "gradual" component tends to produce a time profile with impulsive peaks more closely related to those in \( F(t) \) than in \( F(t) \). If this is the intention of the data analysis, then the gradual component subtraction is a wise procedure. We should, however, emphasize that such procedure does lead to shifts in impulsive peak times. When applied, it is essential to define its effects in relation to the hypothesis, or data property, under consideration.

b) Subtraction of the Running Mean

We define the running mean of a signal \( F(t) \) in time \( \Delta T \) as

\[
\bar{F}(t) = \frac{1}{\Delta T} \int_{t-\Delta T/2}^{t+\Delta T/2} F(t') \, dt'
\]  

and consider the times of extrema in the residual signal \( \Delta F(t) \) after its subtraction, that is,

\[
\Delta F(t) = F(t) - \bar{F}(t) = F(t) - \frac{1}{\Delta T} \int_{t-\Delta T/2}^{t+\Delta T/2} F(t') \, dt'.
\]

These occur when

\[
\frac{d\Delta F}{dt} = \frac{dF}{dt} - \frac{1}{\Delta T} \left[ F\left(t + \frac{\Delta T}{2}\right) - F\left(t - \frac{\Delta T}{2}\right) \right] = 0,
\]

from which it is, at once, clear that peaks in \( \Delta F(t) \) will not correspond to those in \( F(t) \) unless by chance \( F(t + \Delta T/2) = F(t - \Delta T/2) \). In general, if \( F(t) \) is increasing on average, then the term in brackets in equation (14) will be bigger than
zero, and maxima/minima in $\Delta F$ will occur, respectively, earlier/later than those in $F(t)$.

In the particular case of $F(t)$ given by the sum of (3) and (4), using $A = 0$, we find

$$\Delta F' = a \omega \cos (\omega t) \left[ 1 - \frac{2}{\omega \Delta T} \sin \left( \frac{\omega \Delta T}{2} \right) \right],$$

(15)

which has extrema at $\cos (\omega t) = 0$, just as $F(t)$ does. Here, therefore, subtraction of the running mean $\Delta F(t)$ precisely removes the phase shift of the fast structure in $F(t)$ introduced by addition of $F_0(t)$ given by equation (4) and $F(t)$ given by equation (3), although with amplitude slightly modified up or down depending on the quadrant of $\omega AT/2$.

In the case of $F(t)$ given by superposition of equations (3) and (10), however, the same is not true. The result in this case is

$$\Delta F' = b \omega \cos (\omega t) + \frac{\pi c}{2T} \cos \left( \frac{\pi t}{2T} \right) \left[ 1 - \frac{4\Delta T}{\pi \Delta T} \sin \left( \frac{\pi \Delta T}{4T} \right) \right].$$

(16)

where

$$b = a \left[ 1 - \frac{2}{\omega t} \sin \left( \frac{\omega \Delta T}{2} \right) \right],$$

which in general does not have zeros exactly synchronous with $F_0(t)$. Comparison of equation (16) with equation (7) and accompanying discussion shows that the extrema in $F(t)$ may occur earlier or later than in $\Delta F$, depending on the sign of the second (gradual) term in equation (16) (e.g., in the rise or fall phase), and by an amount depending on the size of this second term, e.g., on time and on the choice of $\Delta T$. For $\Delta T \ll T$, the term in brackets in equation (16) approximates $[(\pi \Delta T/4T)^2]/6$. Also, if $\omega \Delta T \gg 1$, as should be the case for any reasonable choice of running mean, and $b = a$, then equation (16) can be approximated:

$$\Delta F' \approx a \omega \cos (\omega t) + \frac{\pi C}{12T} \left( \frac{\pi \Delta T}{4T} \right)^2 \cos \left( \frac{\pi t}{2T} \right),$$

$$\left[ \frac{1}{\omega} \ll \Delta T \ll T \right].$$

(17)

Comparison of equation (17) with equation (6) shows that, in this case, after subtraction of the running mean, displacement of extrema in $\Delta F$ from those in $F(t)$ may still be present but only if the amplitude of the second term in equation (17) is not negligible compared to the first time. Those displacements will be very small, provided

$$B = a \gg \frac{1}{\omega T} \left( \frac{\pi \Delta T}{4T} \right)^2 \frac{\Delta T}{192} \frac{T}{\omega T^2},$$

(18)

which is a factor of $\sim 0.1(\Delta T/T)^2$ less restrictive than criterion (9), when the running mean is not subtracted.

These linear and sinusoidal examples of the gradual component illustrate that running mean subtraction may or may not exactly restore extrema times of the fast component, depending on the functional forms involved.

However, in all the simulations made in § IIId, we subtracted the running mean and found that this procedure recovered the extrema times with a precision better than 0.001 of the period of the fast component. Further, if we consider decomposition of a general form of $F_0(t)$ into Fourier components, the result given by equation (17) can be considered for each component. We thus expect that, unless the gradual component of the Fourier spectrum contained harmonics of amplitude violating equation (18) (near discontinuities in an otherwise gradual form), extrema in $\Delta F$ will reproduce very well those in $F(t)$ in all practical cases. A fast ripple not satisfying equation (18) would be so small as to be unnoticed even in the absence of data noise.

c) Second Derivatives

The second derivative method is also used to enhance the visibility of extrema in a profile $F(t)$ to reduce or eliminate the low-frequency components. In the case of a fast component $F_0(t)$ such as equation (3), this procedure will exactly recover the times of extrema in $F_0(t)$ for gradual components of linear form (4), with $B = 0$; i.e.,

$$F(t) = a \sin (\omega t) + \frac{At}{T},$$

$$F''(t) = -a \omega^2 \sin (\omega t).$$

(19)

This has the same extrema times as $F_0(t)$ (not forgetting the signal). On the other hand, $F_0(t)$ with terms of higher order than linear (such as eq. [4]), will in general not have this property, and the procedure must be treated cautiously. When the gradual component is a sinusoidal function (such as eq. [10]), we can write explicitly

$$F(t) = a \sin (\omega t) + C \sin \left( \frac{\pi t}{2T} \right),$$

(20)

and the second derivative

$$F''(t) = -a \omega^2 \sin (\omega t) + \left( \frac{\pi}{2T} \right)^2 C \sin \left( \frac{\pi t}{2T} \right)$$

(21)

shows the advantage of magnifying the ratio of amplitude of the fast and slow components by a factor $(\omega T)^2 - (2\pi N)^2$ which will generally be large and will reduce any shift between $F_0(t)$ and $F''(t)$ caused by the gradual component.

The $\omega^2$ factor, on the other hand, is dangerous in another way since it acts progressively more on components of higher and higher frequency independent of whether they are real or of noise origin. For example, consider

$$F_1(t) = a_1 \sin (\omega_1 t) + a_2 \cos (\omega_2 t),$$

(22)

where $a_1 \gg a_2$, so that the second term in equation (22) may not be noticeable in the data which will exhibit extrema
times \( t \) such that \( \cos (\omega_1 t) = 0 \). If, however, \( \omega_2 \gg \omega_1 \) such that \( \omega_2^2 a_2 \gg \omega_1^2 a_1 \), then

\[
F''(t) = -a_1 \omega_1^2 \sin (\omega_1 t) - a_2 \omega_2^2 \cos (\omega_2 t)
\]

\[
= -a_2 \omega_2^2 \cos (\omega_2 t),
\]

so that \( F''(t) \) will exhibit extrema of angular frequency \( \omega_2 \), quite unrelated to those of angular frequency \( \omega_1 \) in \( F(t) \). This is essentially the universal problem of differentiation of noisy data (Craig and Brown 1986).

d) Fourier Filtering

Another procedure is to make a Fourier analysis of \( F(t) \) on some interval \(-T < t < T\) and subtract the low frequencies. In the case of \( F_0(t) \) given by equation (10) and \( F(t) \) by equation (3), subtraction of frequencies below \( \omega / 2 \pi \) will precisely restore the high-frequency component. When the gradual component takes the linear form given by equation (4) (with \( B = 0 \)); i.e., when

\[
F(t) = a \sin (\omega t) + \frac{At}{T},
\]

the Fourier sine series is

\[
F(t) = a \sin (\omega t) + \frac{2A}{\pi} \sum_{n=1}^{\infty} \frac{(-1)^n}{n} \sin \left( \frac{n\pi t}{T} \right),
\]

or

\[
F(t) = a \sin (\omega t) + \frac{2A}{\pi} \sum_{n=1}^{\infty} \frac{(-1)^n}{n} \sin \left( \frac{n\omega t}{N} \right),
\]

where \( N = \omega T / \pi \) is the number of fast-component maxima in time \( 2T \).

If we subtract all components of frequency below \( \omega / 2 \pi \) (e.g., \( n < N \)), the residual signal \( f(t) \) can be written

\[
f(t) = \frac{a}{A} \sin (\omega t) + \frac{t}{T} - \frac{2}{\pi} \sum_{n=1}^{N-1} \frac{(-1)^n}{n} \sin \left( \frac{n\omega t}{N} \right).
\]

Fig. 5.—Maximum relative delays found after Fourier filtering (eq. [26]) vs. \( a / A \) (upper curve) and the maximum relative delays from the additive composition of the gradual linear component and sinusoidal fast component (eq. [18]) before Fourier filtering (bottom curve).

In general, \( f(t) \) will not have extrema coincident with \( F(t) \). The result shown in equation (27) depends only on the two parameters \( a / A \) and \( N \) when \( t \) is expressed in units of \( T \). Results are shown in Figure 5 for a range of values of \( a / A \) and \( N \). We might expect a similar result to equation (9); i.e., significant delays in \( f(t) \) compared to \( F(t) \) only if \( a / A \ll 1 / N \). Figure 5 shows the relative delays between the peaks of the impulsive component and the peaks of the total signal (impulsive plus gradual components, represented by crosses) and the total signal after subtracting the slow component using Fourier filtering (represented by circles). We can see that Fourier filtering shifts the peaks, producing higher delays. The finite size of the sample introduces in the Fourier transform some special terms, proportional to the jumps at both cutoffs of the sample interval (Bracewell 1965). To reduce or eliminate these high-frequency terms some special functions, such as hanning (cosine belt), are applied in the original signal in order to avoid these abrupt cutoffs. Applying this in Figure 6 yielded a result similar to the running mean method.

The Fourier subtraction method, therefore, may be unsatisfactory because the removal of all the Fourier terms of the gradual component, of, for example, a linear form, also introduces many of the oscillations of high-frequency signal which we seek to isolate.

IV. CONCLUSIONS

In general, it is possible to say that the time delay which is due to additive or multiplicative compositions between gradual and fast components can be up to some 25% of the period of the fast oscillations. In some studies of "delays" or hardening of the spectrum, this may be very important, and a method to remove the gradual component, recovering the peak times of the impulsive part, needs to be used.

The analysis show that subtraction of the running mean recovers, for almost all practical purposes, the peak times of the fast components. The second derivative is an alternative method, but it amplifies the high-frequency amplitudes of noise origin.

The ordinary way to filter data using the Fourier filtering is not a good technique when the gradual component differs from a sinusoidal form because this procedure could increase the delays instead of recover the peak times of the fast component.
Figure 6 shows one application of the three methods in a solar burst structure observed at 30 GHz on 1984 May 21 (Correia and Kaufmann 1987). The noise of the actual data in the figure is smaller than the thickness of the plot. In this event, the observational relative amplitudes were 19%, 15%, and 22% in the structures A, B, and C, respectively. The labels with primes correspond to peak times of the fast structures A, B, and C expected from Figure 4 in the quadratic gradual plus sine impulsive case. The running mean method confirms this expectation quite well in this example, as shown in Figure 6, the discrepancy only occurs in structure C where the gradual component is no longer quadratic.

The different peak times in the signal filtered using the Fourier method, compared to the running mean method, are only effects of the abrupt cutoffs of the sample (Fig. 6). If the abrupt ends are eliminated using some gradual damping function, such as hanning, the shifts disappear and the peak times coincide in both methods. However, this procedure strongly attenuates the fast-component amplitudes near the sample ends and introduces a new relation between relative delays and relative amplitude which cannot fit the real data.

The noisy signal is a problem in all three cases, especially when the fast-component relative amplitude is comparable to it, but it becomes worse for the second derivative method, which amplifies the noise (Fig. 6).

Finally, for solar burst applications with as supposed correlated fast structure between two spectral regions (e.g., hard X-rays and microwaves) with different gradual components, the composition could result in uncorrelated peaks. The running mean subtraction is a powerful method in this case to study synchronism or shifts between the genuine rapid components. The Fourier method can also be applied since there are no abrupt cutoffs in the sample ends, but it always expends more processing time.

The Centro de Rádioastronomia e Aplicações Espaciais is operated jointly by the Universities of São Paulo (USP), Mackenzie and Estadual de Campinas (UNICAMP), and by the Instituto de Pesquisas Espaciais (INPE).

REFERENCES


J. C. Brown: Department of Physics and Astronomy, University of Glasgow, G128QO, Scotland, UK
E. Correia, J. E. R. Costa, and P. Kaufmann: Centro de Rádioastronomia e Aplicações Espaciais, Escola Politécnica da USP, Cidade Universitária, C. P. 8174, CEP 05508 São Paulo, SP, Brazil

© American Astronomical Society • Provided by the NASA Astrophysics Data System