A Search for Transient Events at 843 MHz

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Abstract: The Molonglo Observatory Synthesis Telescope is equipped with a transient event monitoring system which operates during normal synthesis observations. The device is designed to respond to impulsive signals which occur within the passband (843.0 ± 1.5 MHz) with time scales between 0.001 ms and 800 ms. The multiple beam facility of the telescope provides some discrimination against local interference. An upper limit of $1.7 \times 10^{-2}$ events $s^{-1} \cdot sr^{-1}$ has been placed on celestial events with durations between 1 ms and 25 ms and energy density $\geq 10^{-28} \, J \cdot m^{-2} \cdot Hz^{-1}$. The monitoring system has been recently reconfigured to improve the recognition and rejection of impulsive signals of non-celestial origin.

Introduction

The east-west arm of the Molonglo Cross Radio Telescope proved well suited to the discovery of pulsars by single pulse techniques (Large and Vaughan 1971; Manchester 1985). When the instrument was converted from the 408 MHz Cross to the 843 MHz Molonglo Observatory Synthesis Telescope, or MOST (Mills 1981) it was decided to install a facility for recording short time scale events. To do this it was necessary to provide some means of distinguishing noise peaks and local interference from genuine sky signals. Other workers have done this by splitting the passband and correlating the detected signals to seek dispersed pulses (Huguenin and Moore 1974; Edwards et al. 1974). For MOST, it was more appropriate to take advantage of the multiple real-time beams than to attempt de-dispersion in the relatively narrow passband (of 3 MHz). The equipment eventually built for the purpose is known as the Molonglo Observatory Transient Event Recorder (MOTER), first described by Large et al. (1984) hereafter referred to as LVDL. MOTER records, with a timing resolution of two seconds, any occurrence of an impulsive signal which exceeds a preset threshold in any one of 32 total power fan-beams spaced at full beamwidth intervals of 44" arc. Pulses are binned according to their width, in the range of 1 ms to 800 ms.

At the time of the LVDL paper, MOTER had made a small number of dedicated observations and had detected some known pulsars. Its operation in conjunction with normal synthesis observations was not possible, as MOTER introduced spurious correlations which seriously affected the synthesis maps. During 1985, isolating amplifiers were installed between MOST and MOTER, allowing simultaneous observations to take place as had been initially planned, but further technical problems hampered reliable observations until June 1986.

Signal Processing and Recording

The multiple real-time beams of MOST provide, in principle, a means for recognizing and rejecting signals of local origin. Celestial signals appear in the main lobe of at most two beams, whereas, signals from sources closer than about 3000 km are significantly out of focus, and generally appear on many beams. Based upon early experiments with the transient event recorder and Fresnel diffraction theory, an 'expectation filter' was implemented in the analysis programs to conservatively reject signals of local origin. Signals are rejected if they occur in more than three contiguous beams unless the signal is extremely strong, when the rejection criterion is relaxed to allow for the possibility of real sidetrails. Events which occur in only one beam and one time constant bin, are also rejected on the assumption that they are probably random noise. The filter eliminates relatively strong signals from local sources, but of necessity cannot eliminate weak signals from local sources which can have a 'signature' that mimics celestial signals. Experience has shown that the expectation filter provides useful discrimination between events of local and of celestial origin. Of the events detected by MOTER, about 80% are rejected and 20% accepted. Data on all events are archived for possible subsequent analysis.

Figure 1 shows one of the ways in which the MOTER output is presented. The square represents the field being syntheses-mapped on 1988 February 19 as part of the galactic survey (Whiteoak et al. 1989). Each event accepted by MOTER is plotted as a line corresponding to the position and orientation of the beam in which it occurred. The intersection of the lines locates the source, in this instance PSR 0835-41. We believe that the striated appearance is related to the variation in the strengths of the received pulses. The near verticle lines to the right of the square are the response of MOTER to occasional large pulses from the Vela pulsar (PSR 0833-45) which lies at the intersection of the lines – 3.1 degrees below the field centre. No events are plotted in Figure 1 at position angles between 180° and 270° since the software event limit was reached about halfway through the synthesis observation.

Figure 1 — The intersection of lines corresponding to MOTER events locates PSR 0835-41 and PSR 0833-45 (Vela, off-field). The observation was made during the synthesis mapping of a field for the MOST galactic survey. See text.
Pulsar Observations
Since June 1986, a total of 63 known pulsars have been observed in dedicated programmes, and of these 12 have also been detected in the course of normal synthesis observations. These observations illustrate the response of MOTER to pulsed signals known to come from the sky.

In Figure 2, the mean pulse energy density of 63 observed pulsars is plotted against the pulse width as dispersion broadened in the MOST passband. The mean pulse energy densities at 843 MHz have been estimated from the 400 MHz values using tabulated spectral indices (Manchester and Taylor 1988). Where no tabulated spectral index, an average value of $\alpha = -1.6$ was used. Detected pulsars are plotted as closed circles; pulsars observed but not detected are plotted as open circles. The continuous line indicates the measured sensitivity of MOTER, that is the energy density for which the probability of detection of an individual pulse is 50%. The figure is a revised version of that given by LVDL, and applies to observations made since 1986 June. Many pulsars have been detected for which the mean pulse energy density lies well below the sensitivity curve: MOTER is responding to the small number of intense pulses lying at the upper end of the pulse-amplitude distribution.

Many weak pulsars, including the millisecond pulsars, are well below the sensitivity of MOTER, but the possibility remains that there could be highly erratic pulsars, detectable with MOTER, that may have been missed in computer searches for pulsed signals. To date, no such pulsar has been recognized.

Event Characteristics
The simple answer to the question of what has MOTER seen during synthesis observations is 'only known pulsars'. It is true that only known pulsars have generated recognizably celestial events, but MOTER has also accepted many unexplained events. It is easy to dismiss most of these events as 'one of those things' since a threshold detector such as MOTER is exquisitely sensitive to any minor malfunctions, gain variations or interference.

In Table 1 we have attempted to classify, according to the broad characteristics of the events seen, the 360 12-hour records obtained during synthesis between 1987 January 1 and 1988 May 9. The percentages sum to greater than 100%, as the categories are not mutually exclusive (e.g. a pulsar may be recognized in a field which also has an excessive number of apparently non-pulsar events).

The table is divided into two sections, according to whether or not we have a satisfactory explanation of the pattern of events seen. Eleven percent of the fields have fewer than 4 events, apparently consistent with the discrimination thresholds and peaks in the noise. In three percent of fields events were clearly due to a known pulsar: between 5 and 1001 events were recorded on beams intersecting at the pulsar position. Eight percent of fields were affected to a significant extent by known sources of interference (e.g. storms) or by equipment problems noted at the time of the observation.

The majority of fields include a number of unexplained events, which have non-the-lets passed the expectation filter and are thus not ruled out as being of celestial origin. However, we have not been able to associate them with any known sky phenomenon, and Ockham's razor suggests that we first seek to explain them as instrumental malfunctions or of local origin. Fifty-four percent of records have many short time scale (T< 1 ms) events, and twenty percent have many long duration events (T> 1 ms).

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1 This limit is set in software.
As shown in Table 1, the large number of unexplained events is noteworthy. The majority of these have triggered a number of time constant channels in the range $1 \text{ ms} < r \leq 25 \text{ ms}$, and occur in only one beam. We infer from this that they are either unusually strong pulses or that they have complex structure. The MOTER response is similar to that to a single strong pulsar pulse. These 40 events are not associated with known pulsars, and show no obvious correlation with galactic latitude. We have no idea at present whether these events are astronomical with the result shown as a histogram in Figure 3. For 4000 hours of observations, we have had little success so far in correlating these events with environmental or other effects. The majority are presumed to be artifacts. Sample analyses with the expectation filter bypassed suggest that the majority of rejected events fall in the short or long time scale ranges.

### Event Rates

As shown in Table 1, the large number of unexplained events on the majority of records can be grouped into 'short' and 'long' time scales. To pursue this further, we have taken a random sample of such records (excluding explained phenomena) and counted the number of accepted events in the three time scale ranges:

- $1 \mu s \leq r \leq 1 \text{ ms}$
- $1 \text{ ms} < r \leq 25 \text{ ms}$
- $25 \text{ ms} < r \leq 800 \text{ ms}$

with the result shown as a histogram in Figure 3.

The rather numerous events with $r \leq 1 \text{ ms}$ are apparently not simply thermal noise peaks, as on many nights observation very few such events are observed. One possible source of these events is coherent, very short duration horizontally polarized radio pulses which are produced at the ground by cosmic ray air showers (Clay 1972; Clay 1988). Although the response of MOST to such pulses is not well understood, a rough analysis implies that it is unlikely that many short time scale MOTER events could be attributed to such showers. On one or two occasions, numerous short time scale events have been positively identified with an (unknown) source of local interference fixed relative to the ground. The short time scale channels ($r \leq 1 \text{ ms}$) of MOTER are realized using analogue circuits with the thresholds maintained by an automatic gain control system (see LVDL). It is possible that environmental factors are affecting the circuits and producing large changes in the random event rate. However, no such factors have been identified.

Unexplained events in the time scale range $1 \text{ ms} < r \leq 25 \text{ ms}$ are relatively rare, occurring at a rate of less than one per 12-hour observation. Sample counts show that the rate is $1.7 \times 10^2 \text{ events s}^{-1} \text{ sr}^{-1}$, or 163 events yr$^{-1}$ (sq.deg)$^{-1}$, and this can be taken as an upper limit on the rate of celestial radio pulses at 843 MHz, having an energy density $\geq 10^{-29} \text{ J m}^{-2} \text{ Hz}^{-1}$, and $r \sim 5 \text{ ms}$ (excluding known pulsars). Previous searches for radio pulses have generally used dedicated observing time on a radio telescope to study particular objects (Hughes and Retallack 1973; Edwards et al. 1974; O’Sullivan et al. 1978). These searches have not yielded an overall event rate to compare with our limit. An exception is the work of Huguenin and Moore (1974) who quote a rate of $\leq 5.6 \times 10^8 \text{ events s}^{-1} \text{ sr}^{-1}$ at 270 MHz. This rate is considerably less than ours, but refers to pulses $\geq 10^{-22} \text{ J m}^{-2} \text{ Hz}^{-1}$, large enough to be detected with a single dipole antenna.

Longer time scale events ($r > 25 \text{ ms}$) detected by MOTER are relatively numerous, and as with the very short time scale events ($r < 1 \text{ ms}$), we have had little success so far in correlating these with environmental or other effects. The majority are presumed to be artifacts. Sample analyses with the expectation filter bypassed suggest that the majority of rejected events fall in the short or long time scale ranges. This suggests the hypothesis that the accepted short and long time scale events are of local origin.

### MOTER Reconditioning

In the two years of successful MOTER observations in conjunction with the MOST observing program, it has become clear that the major problem has been the recognition of events of genuine celestial origin. The spurious event rate has been far too high, even with the requirement that sources appear in focus in the fan beams of MOST.
Ideally, to recognize isolated radio bursts from the sky one would like to seek coincidences between events from spatially separated antennas directed to the same area of sky. Such a system can be realized at Molonglo by using the East and West arms as the two antennas. Although the arms are not widely separated, the east and west electronics are well isolated from each other to minimize spurious correlation in synthesis mapping. Also, by good fortune, the MOTER circuits were built as two separate banks of 16 channels. As from early June 1988, MOTER has been reconfigured as two separate systems. Instead of the original thirty two 44 arcsec fan-beams of the whole telescope there are now sixteen 88 arcsec fan-beams formed by the East arm and a corresponding set formed independently by the West arm. Events will now be accepted as of celestial origin only if they are in focus in both arms, and occur in coincidence in corresponding beams of the East and West antennas.

As before, MOTER is running simultaneously with synthesis mapping. In the two months since the reconfiguration MOTER has recorded several pulsars, but no other event which satisfies the criterion of being in focus and coincident in the two arms. We are hopeful that, in future, any genuine cosmic radio burst will be clearly identified.

Conclusion

In two years of operation, the Molonglo Observatory Transient Event Recorder has observed various regions of the sky for a total of about 4000 hours. In addition to pulsars, it has recorded many events, most of which are thought to be interference or other artifacts.

From our limited experience so far with MOTER in its new configuration, it is apparent that local signals are now very effectively rejected. The chances of recognizing and rejecting radio bursts from the sky are thus greatly improved, and we look forward to the next few years operation with interest.

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