A SEARCH FOR OPTICAL PULSES FROM THE
GALACTIC CENTRE

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(Received 1975 June 17; in original form 1975 March 14)

SUMMARY

A search has been carried out for optical flashes in the direction of the centre
of the Galaxy. Most of the flashes recorded are adequately accounted for
by faint meteors crossing the area of the sky under examination. There
remain a few multiple optical pulses, closely grouped in time, which are not
readily explained. Possible origins are discussed.

1. INTRODUCTION

For several years, gravitational wave detectors at two sites, separated by
approximately 1000 km, have been operated by Weber (1972). Coincident
mechanical distortions of these widely-separated detectors have been interpreted
as being caused by pulses of gravitational radiation. The mean rate inferred from
these observations (Weber 1969, 1972) is 50 d^{-1}. Crude directional information
has pointed to the nucleus of the Galaxy as being a possible, or even probable,
source.

The measured gravitational wave energy flux, extrapolated to an isotropically
radiating source at the galactic centre, would indicate an equivalent rate of mass
loss of $\sim 10^4 M_\odot y^{-1}$. Such a rate of mass loss would have a serious influence on
our understanding of galactic dynamics (Sciama 1969). Interpretations other
than by gravitational waves have been proposed to explain Weber's results but
none of these has been entirely satisfactory. Independent means for elucidating
the true nature of Weber's coincidences is still needed.

Other gravitational wave detectors have been constructed in an effort to
duplicate Weber's result (Braginskii et al. 1972; Drever et al. 1973; Tyson 1973)
but similar pulses have not been indicated. An alternative approach to the problem
has been the attempt to detect a flux of electromagnetic waves which might accom-
pany such highly energetic events as are necessary for producing pulses of gravita-
tional waves. These experiments have also produced negative results (Charman et
al. 1970; Baird, Delaney & Lawless 1972; Ó Mongáin & Weekes 1974) and in-
creasingly stringent limits have been placed on the electromagnetic energy flux
that may accompany Weber's pulses. We describe here an experiment carried
out in an attempt to detect isolated optical pulses from the direction of the galactic
centre.

2. EQUIPMENT

A specially-designed two-channel photometer was mounted on the 81-cm
ADH Baker–Schmidt telescope at the Boyden Observatory, Bloemfontein, South
Fig. 1. (a) Fields in the galactic centre region; (b) fields in the Small Magellanic Cloud and 47 Tucanae.
Africa, and observations were carried out during the winter period May–July 1971. Each photocathode of two photomultiplier tubes, placed in the focal plane of the telescope, received light from a circular area of sky 1.5° in diameter. The main amplifiers were mounted immediately behind the tubes (EMI type 9531A with ‘Super S-11’ cathodes) and the entire assembly was electrically and magnetically shielded from its surroundings so as to reduce the electrical noise. High-stability voltage supplies were used for the PM tubes and the amplifiers. Their stability was better than 0.001 per cent for 10 per cent mains input variation, <0.001 per cent/°C, and <0.001 per cent mains ripple.

The DC component of the sky signal was removed from the amplifiers by series capacitors. These, in conjunction with the input impedance of the amplifiers, gave a time-constant of ~30 s. Thus changes in light level in times >30 s were not recorded. Two methods of recording were used. The first was a paper chart recorder with fsd response time ~0.1 s. A paper speed of 0.8 m per hr made possible a timing accuracy of ~1 s. For the second record the DC sky signal was converted to a frequency-modulated signal recorded on magnetic tape. The overall frequency response of the magnetic tape system was 1–800 Hz; a description has appeared elsewhere (Jordan 1974). Timing marks were manually superimposed on all records every 5 min (see Fig. 2).

3. OBSERVATIONS

The dates and times of continuous observation are given in Table I. The galactic centre region was recorded for 176 hr and areas of the sky containing parts of the Small Magellanic Cloud and the globular cluster 47 Tuc for ~20 hr. Fig. 1 shows the areas of sky, from SAO Sky Atlas charts, covered by the photo-

![Sample of the paper chart record.](image)

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cathodes. The photocathode exposed to the galactic centre and its associated equipment is always referred to as 'Channel 1' but two orientations of the detectors were used in observing the galactic centre. 'Position 1' (Fig. 1) was used on or before the morning of 1971 June 15 and 'Position 2' for the remainder.

**Table I**

**Dates of observations**

<table>
<thead>
<tr>
<th>Date</th>
<th>Periods of observation (UT)</th>
<th>No. of hours observation</th>
<th>No. of events (&gt;3 mV amplitude)</th>
</tr>
</thead>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Ch. 1</td>
</tr>
<tr>
<td>30/31.5</td>
<td>21.55-02.00</td>
<td>4.90</td>
<td>12</td>
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<tr>
<td>02.26-03.15</td>
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<td></td>
<td></td>
</tr>
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<td>31.5/1.6</td>
<td>22.37-02.06</td>
<td>4.67</td>
<td>9</td>
</tr>
<tr>
<td>02.34-03.45</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1/2.6</td>
<td>21.50-02.12</td>
<td>5.29</td>
<td>9</td>
</tr>
<tr>
<td>02.49-03.57</td>
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<td></td>
</tr>
<tr>
<td>14/15.6</td>
<td>20.52-01.25</td>
<td>4.55</td>
<td>11</td>
</tr>
<tr>
<td>15/16.6</td>
<td>20.42-01.50</td>
<td>6.25</td>
<td>14</td>
</tr>
<tr>
<td>02.12-03.19</td>
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<td></td>
</tr>
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<td>20.47-02.31</td>
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<td>20.06-02.05</td>
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To test for instrumentally-produced pulses, 13 hr of recording were made under conditions that duplicated actual observing conditions but with no light falling on the photometers. No pulses were recorded during these hours above a threshold 0.01 times that used in the analysis of following sections. A further 13 hr of testing was carried out under laboratory conditions. During this time the photometers viewed a diffuse light source that was brightened briefly every 5 min. No noise pulses were produced of appreciable size.

A sample paper chart recording is shown in Fig. 2. It will be noted that the amplitudes of the general noise background in the two channels are different. This is adequately accounted for by a measured difference in overall sensitivity (a factor of 1.22) between the two channels, rather than any large difference in the surface brightness of the two areas of sky. The amplitude of the background noise is consistent with its origin in stellar scintillation.

4. THE RECORDED FLASHES

The paper chart records were examined for sudden deflections in either channel that exceeded 3 mV on the scale of the recorder deflections. This particular threshold amplitude was chosen to be greater than three times the peak-to-peak background noise of the records on all but the brightest nights; such nights were not used in the analysis and are not listed in Table I. The number of deflections above the threshold found on each night are listed in Table I. These total 293 in Channel 1 and 237 in Channel 2, corresponding to rates of 1.67 hr⁻¹ and 1.36 hr⁻¹ respectively.

A 3 mV chart deflection corresponds to a light flux incident on the telescope aperture, according to an approximate estimate, of $F = 1.25 \times 10^{-11}$ Wm⁻² μm⁻¹ within the recorder response time. This flux is equivalent to the flux from a star at the zenith of $B = 9.31$ according to figures given by Allen (1973, p. 202). From the same reference source (pp 156–7) it is calculated that the expected mean rate at the zenith for meteors brighter than $B = 9.3$ in a field $1.43^\circ$ in diameter is ~ 7 hr⁻¹. This is larger than the rate of deflections above the threshold adopted. It is therefore reasonable to assume that most of the deflections are caused by faint meteors crossing the field of view. The discrepancy between the observed and calculated rates is adequately accounted for by the circumstances:

(a) That the observations were mostly not made at the zenith and would be diminished by the greater extinction;
(b) That the times of observation were more frequently in the first half of the night when the meteor rate is less; and
(c) That the estimate of overall sensitivity is uncertain.

The mean deflection rate in the two channels is different. This probably arises by taking 3 mV as the threshold in two channels with differing overall sensitivity. For the ratio of 1.22 quoted above, we estimate that, according to Allen’s tables, the observed meteor rate will differ by a factor of 1.27, near to the observed ratio of 1.24.

A complete list of the dates and times of the deflections with chart amplitude greater than 3 mV is available on request from the authors.
5. SEARCH FOR PERIODICITY

A search was carried out for possible periods in the range 10 min to 4 hr among the times of 177 individual events recorded from the galactic centre channel (Ch. 1). Shorter periods than 10 min would not be efficiently revealed when the mean rate is less than 2 per hour and the aliasing produced by nightly observation would prevent good results for periodicities greater than 4 hr being obtained. The method employed was an adaptation of that of Lafler & Kinman (1965). A starting period was chosen and each event time-sorted into one of ten phase intervals with respect to that period. Phase zero is accorded to the first observation. Each new period is chosen such that the phase of the last event of all does not change by more than 0·2. The number of events in each phase bin is determined for each period tested, the total number of periods being 7745.

In a random distribution of events, the mean number of events per phase interval is 17·7 with a standard deviation of 4·2. The number $n$ of events in any phase interval is expected to be distributed according to the Poisson Law:

$$N(n) = N_0 \frac{(17.7)^n}{n!} \exp(-17.7)$$

where $N_0$ is the total number of 0.1 phase intervals examined, i.e. 77450. The numbers $N(n)$ of phase intervals containing $n$ events according to equation (1) are compared with $N_{\text{obs}}$, the numbers observed, for $n \geq 31$ in Table II. In no case does $N_{\text{obs}}$ exceed $N(n)$. We conclude that the galactic centre event times exhibit no discoverable period within the range examined.

| Phase-distribution in testing for periodicity |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| $n$             | 31              | 32              | 33              | 34              | 35              | 36              | 37              | 38              |
| $N(n)$          | 94              | 52              | 28              | 15              | 7               | 3               | 2               | 1               |
| $N_{\text{obs}}$| 76              | 41              | 18              | 15              | 4               | 2               | 1               | 0               |

6. DISTRIBUTION OF INTER-ARRIVAL TIMES

In each period of continuous observation, the time-difference between pairs of successive events was calculated and the frequency distribution of these differences compared with a Poissonian distribution. The distribution of inter-arrival times for Poisson events may be represented by the following equation:

$$N_t = (N/t) \Delta t \exp (-t/T)$$

$N$ is the total number of time-differences considered, $T$ is the mean time-difference between successive events, and $N_t$ gives the number of pairs of events separated by a time-interval between $t$ and $t + \Delta t$.

The results of the comparison are illustrated in Fig. 3. The continuous curve is given by equation (2) and a chi-squared test has been performed on the closeness with which the observed data fit this curve. The test indicates that random sampling will result in a worse fit in 84 per cent of cases for the Channel 2 data, but in only 0·01 per cent of cases for the Channel 1 data. The contribution to
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Fig. 3. Histogram of event inter-arrival times (a) galactic centre, (b) control region.

χ² for the Channel 1 events is largely due to the number of inter-arrival times which are less than 1 min.

The mean number of events expected in any interval of 1 min in the Channel 1 data is 2.78 x 10⁻². The expected number of minute intervals containing n events may be represented by an equation similar in form to equation (1), i.e.

\[ N(n) = T \left( \frac{2.78 \times 10^{-2}}{n!} \right)^n \exp \left( -2.78 \times 10^{-2} \right) \] (3)

where \( T \) is the total time of observation expressed in minutes. Table III compares the predictions of equation (3) with the observed numbers.

<table>
<thead>
<tr>
<th>Table III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minute intervals containing n flashes</td>
</tr>
<tr>
<td>n</td>
</tr>
<tr>
<td>N(n)</td>
</tr>
<tr>
<td>Nobs</td>
</tr>
</tbody>
</table>

The short inter-arrival times arise from two occasions when three deflections take place within one minute and from one six-fold event. The six-fold event took place on July 29 at 18.58 UT; it has a vanishingly small probability of occurrence in a random sample. The triple events, too, are improbable on a random basis. We return to a consideration of these multiple pulses in Section 8 below.

7. THE MAGNETIC TAPE RECORDS

Some 200 of the events from Channel 1, and 150 of those from Channel 2, were examined using the magnetic tape records. The profiles of individual events were displayed on a fast-response chart recorder (response-time \( \sim 10^{-8} \) s).
variable low-pass filter was used to reduce the background noise. Examples of the traces obtained are given in Fig. 4. The detailed shapes of individual events were found to be varied and complex. To carry out a simple comparison of the

**Fig. 4. Sample of demodulated magnetic tape record.**
events in the galactic centre channel and the comparison channel, the durations were measured. The 'expanded' records provided by the magnetic recordings (see Fig. 4) gave eye-estimate limits and hence durations.

The distribution of the durations, so measured, is shown separately for each channel in Fig. 5. They are seen to be similar, with maximum frequency around 60–65 ms, and this appears to confirm the impression that most of the events were caused by meteors crossing the area of the photocathodes. In order that a body at a height $h \sim 100$ km may cross the diameter $\Omega$ of one field of view in $\tau = 60$ ms, it must have a transverse component of velocity of $V = h\Omega/\tau \approx 42$ km s$^{-1}$. This agrees well with the mean geocentric velocity of meteors, which (Allen 1973, p. 155) is 40 km s$^{-1}$.

Measurement of the variation in sensitivity across the photocathodes of the PM tubes showed that large variations in signal may occur from a source of constant brightness moving across the field of view. It is therefore impossible to distinguish any features of the pulse profile that might be intrinsic to the source from those due to the detector non-uniformity. Occasionally large variations are seen (Fig. 4(a)) which can be said with confidence to have occurred in the source and these are attributable to the phenomenon of 'flaring' in meteor trails (Smith 1954).

8. THE MULTIPLE PULSES

The magnetic tape record covering the triple event of 1971 June 1 at 02.42 UT is shown in Fig. 6. The durations have been measured as 126, 50 and 133 ms. Careful measurement of the two inter-arrival times has shown them to be equal to within 0.1 s at 10$^{-7}$ s. The probability of three events occurring within 21.4 s

---

**Fig. 5. Histogram of event durations.**
out of the whole recording period is, from equation (3),

$$N(3) = \left( \frac{T}{21.4} \right) \frac{(9.92 \times 10^{-3})^3}{3!} \exp \left( -9.92 \times 10^{-3} \right)$$

$$= 4.8 \times 10^{-3}$$

where $9.92 \times 10^{-3}$ is the expected mean number of events in 21.4 s and $T$ is the total time of observation expressed in seconds. The 21.4-s interval is defined by the first and last deflections of the triple event. If this interval is divided into 214 bins each of width 0.1 s the third deflection may be assigned, on a random basis, to any one of these with equal \textit{a priori} probability. Thus the probability for the occurrence in the records of an equi-spaced triple event within 21.4 s is

$$P = 4.8 \times 10^{-3}/214 = 2.2 \times 10^{-5}.$$

\begin{figure}[h]
\centering
\includegraphics[width=0.8\textwidth]{fig6.png}
\caption{(a)--(c) Profiles of the Triple event of June 1.}
\end{figure}
Fig. 6. (d) Magnetic tape record of the Triple event of June 1.
The light profiles for the July 29 triple event are shown in Fig. 7. They show no peculiarities other than that they occur within 24 s. No magnetic tape records were available for the six-fold event of July 29 and there is no possibility of measuring the inter-arrival times with better accuracy than ~1 s. To this accuracy, the separations appear to be equal at 3 s.

![Profiles of the Triple event of 1971 July 29.](image)

9. OBSERVATIONS OF SMC/47 TUC

The 19.83 h of observations of regions of the sky containing the Small Magellanic Cloud and 47 Tucanae were analysed in the same manner as those covering the galactic centre regions (see Fig. 1(b)). Channel 1 (47 Tuc) yielded deflections of amplitude > 3 mV 36 times and Channel 2 (SMC) 42 times, corresponding to mean rates of 1.83 hr\(^{-1}\) and 2.12 hr\(^{-1}\) respectively. These rates are higher than those recorded previously and this may be attributable to the Perseid meteor shower which occurred during these observations. The total numbers above the 3 mV threshold are, however, too small to provide material for a meaningful comparison with the rate for the galactic centre channels. A second search was therefore carried out for pulses above a 1.5 mV threshold of amplitude. This yielded 69 Channel 1 events and 83 Channel 2 events at mean rates 3.48 and 4.18 per hour, respectively. The distribution of inter-arrival times, with a function
of the same form as equation (2) superimposed, is shown in Fig. 8. The fit of the observed data to equation (2) is good; no multiple pulses were observed, and there is no excessive tendency for events to group themselves with inter-arrival times less than 1 min.

Fig. 8. Distribution of inter-arrival times of (a) Channel 2 and (b) Channel 1 events.

### 10. Discussion

Times of individual simultaneous deflections were not available from Professor Weber at the time of writing; these would have made possible a detailed comparison with optical data. Nevertheless, it is possible to place an upper limit on the optical flux at the time of a gravitational wave event.

Weber’s observations imply a mean rate of events \( \sim 2.1 \text{ hr}^{-1} \). We have observed in the direction of the galactic centre a rate of optical flashes of \( 1.67 \text{ hr}^{-1} \), which agrees reasonably well with the predicted meteor rate. Therefore if each gravitational wave event is accompanied by a light pulse, it must have a flux-density less than (see Section 3):

\[
F < 1.25 \times 10^{-11} \text{ Wm}^{-2} \mu\text{m}^{-1}
= 6.6 \times 10^{-3} \text{ Jy}^*
\]

In the absence of absorption, this corresponds to the flux density from an isotropically radiating source at the galactic centre (distance = 9.6 kpc) of strength \( 8.1 \times 10^{13} \) WHz\(^{-1}\). Visual absorption between the Sun and the galactic centre has been estimated as \( \sim 28 \) magnitudes (Becklin & Neugebauer 1968; Spinrad et al. 1971) corresponding to diminution by a factor \( 1.6 \times 10^{11} \). It might be surmized

* 1 Jy (Jansky) = \( 10^{-26} \) Wm\(^{-2}\) Hz\(^{-1}\).
here that, with so great absorption and with an unspecified ratio between forward scattering, isotropic scattering and absorption, any 'direct' sharp pulse might well be lost in a body of phase-retarded, forward-scattered light. In the absence of a detailed calculation to settle this question, we have, possibly with insufficient reason, discounted any effect on the fixing of upper limits. Thus, with this reservation, the optical luminosity placed by this experiment for pulses from the galactic nucleus is:

\[ F < 1.3 \times 10^{35} \text{ WHz}^{-1} \]

Weber's observations imply a gravitational wave energy of \(~ 10^{44} \text{ WHz}^{-1}\) at the galactic nucleus, that is, \(10^{19}\) times the optical limit established here.

This result may be compared with those of two other experiments. Ó Mongáin & Weekes (1974) have placed an upper limit of \(4 \times 10^{-3} \text{ Jy}\) to the optical energy flux density accompanying radio pulses at 380 MHz and 610 MHz. Their optical photometer was a single channel device which used a radio wave detector to discriminate against local flashes. This technique is insensitive to optical pulses generated without accompanying radio emission. Baird et al. (1972) have placed an upper limit of \(7 \times 10^{-2} \text{ Jy}\) in a two-channel optical experiment.

We have not been able to account satisfactorily for observation on three occasions of three or more pulses within one minute. These multiple events were only observed in the channel viewing the galactic centre region of the sky. We consider three possible origins: (i) instrumental; (ii) man-made but external to the instrument; and (iii) natural origin, possibly from an astronomical object.

Instrumental pulses cannot be entirely eliminated. Every precaution was taken to avoid large instrumental pulses and no noise pulses were observed during the 13 hr of laboratory tests during which a pulsed light source was registered, nor during a further 13 hr of testing under dark conditions at the telescope, nor during 20 hr of observation of the SMC/47 Tuc region. The profiles of the individual pulses are similar to those observed throughout the experiment and the duration of the pulses is much longer than would typically be associated with electronic noise (discharges, etc.). The regular spacing of one of the triple events,

![Fig. 9. (a) Distribution of times (SAST) of multiple events. (b) Distribution of durations of multiple events.](http://www.astrobyrne.com/fig9.png)

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and perhaps of the six-fold event, is likewise not to be expected for intermittent
noise pulses.

The regular spacing of two of the multiple events makes a man-made origin
appear likely at first sight. As a source of optical signals they must, however,
be considered as very faint (approximately 40 times fainter than limiting naked-eye
visibility) and the varying pulse-interval between examples would also seem
unlikely. Fig. 9(b) shows the distribution of inter-arrival times for the three
multiple events and for the 14 double events. It appears that there is no preference
for any particular intervals, as might be expected from a signalling source (earth
satellite or aeroplane navigation light). Furthermore, the events so selected are
distributed uniformly with respect to local time, as shown in Fig. 9(a). Thus a
terrestrial source of light seems unlikely, quite apart from the expectation that
if a local source were the cause it should affect both channels equally. Finally,
it is important to note that the ratio of duration to average inter-arrival time is
rather small (0.18/10s = 0.01) and if this ratio were, say, the characteristic of a
revolving capstan lamp, a fairly elaborate optical arrangement would be necessary
to produce a sufficiently narrow rotating beam.

It appears then that an astronomical or other natural origin for these multiple
pulses remains at any rate open as a possibility. The individual pulse profiles
are, as far as can be told, similar to those obtained from faint meteors. The grouping
of faint meteors has been studied but no supporting evidence has been found for
this phenomenon (Porubcan 1968). If the multiple events had their origin in
meteors we would have expected them to have also occurred in other regions
of the sky.

We ask whether there is any reason why electromagnetic pulses in a group
might be associated with gravitational radiation. The spiralling of matter into
a 'black hole' has been considered by Misner (1972) as a possible source of gravita-
tional wave pulses. The last few orbits of material about the black hole will be
relativistic, with consequent beaming of radiation. It could be that e-m radiation
as received at one point is modulated with the orbital period and that periods of
the order of seconds are appropriate. The observed multiple pulses are not coinci-
dent with any of Weber's pulsed events (Weber, private communication) but
it must be noted that the statistics are such that the real events to which they
are attributed must be considerably more numerous than the coincidences which
are recorded by Weber.

II. CONCLUSIONS

We have observed many optical flashes from an area of sky which contains
the direction of the galactic centre. The bulk of these flashes are attributable to
faint meteors crossing the field of view. It is possible to place an upper limit
to the optical flux density accompanying the pulses of gravitational radiation
reported by Weber of 6.6 x 10^-3 Jy, on the basis that these pulses originate in
the direction of the galactic nucleus. An anomaly has been found in the distribution
of inter-arrival times of the flashes in the galactic centre area of the sky, which
takes the form of a tendency to group within times less than one minute. Inter-
pretation of this result is not clear. An instrumental origin is unlikely, although it
cannot be entirely eliminated, and consideration must be given to the possibility
that the grouped flashes are associated with an astronomical source lying in the
direction of the galactic centre.
ACKNOWLEDGMENTS

We thank Dr J. V. Jelley of AERE, Harwell, for the original suggestion of the experiment, and Professor A. H. Jarrett, Director of Boyden Observatory, and his staff for friendly co-operation during the observing period.

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