Temporal and Spectral Features of an Intense Auroral Zone X-ray Event in the 4-5 Second Period Range

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Abstract

In the magnetic activity following the September 2, 1966 PCA event, an intense auroral zone x-ray pulsation event was observed in the 4-5 second period range. Comparison of this event with the temporal features of micropulsations in the same period range does not support the suggestion that pulsating electron precipitation arises from processes directly involving micropulsation fields.

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Introduction

Auroral x-ray fluxes frequently display pulsation activity in the hours between midnight and dawn, the most common form being irregular bursts with half-widths of 2-10 seconds and spacings of 4-30 seconds between consecutive peaks (Anger et al, 1963; Brown et al, 1965; Barcus et al, 1966). More organized pulsations have been observed (Barcus and Christensen, 1965) but this has been primarily in longer period events with time scales of the order of 100 seconds. Similar features have been noted in studies of ionospheric absorption in the auroral zone (Brown, 1964; Parthasarathy and Hessler, 1964).

The long period pulsations have proved to be larger in spatial extent than the short period events, Barcus and Rosenberg (1965) noting cases where pulsating electron precipitation extended more than 1,000 km in longitude when the period was the order of 300 seconds while other observations (Brown et al, 1965; Barcus et al, 1966) showed that the spatial correlation of short period pulsations deteriorates when detectors were separated by more than 100 km. This has led to the suggestion (Brown et al, 1965) that short period pulsations arise from small scale magnetospheric plasma instabilities while the longer period events result from modulation processes acting on electron precipitation already in progress over a large scale.

The present note summarizes observations of a short period pulsation event, unique for its intensity and temporal organization, pointing toward modulation processes at shorter periods than considered previously. Its brief duration compared to magnetic micropulsations in the same period range argues against the particle precipitation originating from wave-particle interactions.

Observations

The present event was encountered during a balloon flight from Fairbanks, Alaska in the magnetic activity associated with the solar cosmic ray flare event of 0538 UT on September 2, 1966. These observations were obtained at 9 gm/cm^2 atmospheric depth, using an uncollimated NaI(Tl) scintillation counter (5.08 cm dia., 1.27 cm ht.) with a multi-channel pulse-height analyzer. Starting at 1646 UT on September 3, 1966, the x-ray intensity showed an intense series of pulses (up to 350 $photons/cm^2$-sec-ster in excess of 25 keV averaged over the upper hemisphere) with a high degree of temporal order. The x-ray variations noted in the 25-50 keV channel are given in Figure 1; each data point represents the average counting rate over a period of 0.2 second. Examination of this figure shows 47 consecutive pulsation peaks distributed over an interval of 210 seconds. These pulsations occurred during complex, extended bay activity (K = 7 at College) which reached $\Delta H = -1450\gamma$ around 1645 UT; during all this activity, micropulsation induction loops recorded (R. R. Heacock, private communication) a strong component at 4-5 second period, reaching peak amplitudes of 3γ during the pulsation event. Before the event, there was essentially no structured x-ray activity and afterwards the activity declined into weak, irregular variations and then disappeared by 1654 UT.

Spectral features of the x-ray peaks and valleys were determined, first removing effects of the appropriate background rates. For each well-defined peak, the excess rate above the slowly varying background was examined for its energy distribution; the results of this analysis gave exponential spectra with an average e-folding energy $E_o = 14$ keV, extreme values of E_o ranging from 11 keV to 17 keV. Similar steps were taken with each valley, removing now the background of galactic and solar cosmic ray origin; this gave e-folding energies between 11 keV and 17 keV, with an average of 13 keV. Examples of the peak and valley energy distributions are shown in Figures 2 and 3, respectively.

The gross temporal features of the x-ray intensity were quite evident from visual inspection of the flight record: 47 pulsations over about 210 seconds, with an average spacing of about 4.5 seconds. Beyond that, however, there is a definite division between the early and late portions of the event, the early half showing a mean spacing of 3.9 seconds between peaks while the latter half showed a longer spacing of 5.0 seconds. This feature of the data is presented more elegantly in the normalized auto-covariance functions in Figures 4 and 5 where five oscillations extend over 100 lags in the first portion of the data as compared to four oscillations in a similar sampling of the second half. A power spectrum analysis (Blackman and Tukey, 1958) shows peaks at 4.0 seconds and 5.5 seconds, respectively, as indicated in Figures 6 and 7. A similar analysis of the whole 210 second record, given in Figure 8, shows the two peaks resolved, separately and distinctly.

Discussion

From well over 50 hours of pulsating x-ray data to date, the present event is the most striking example of this form of electron precipitation. Rather than the more typical pulsating event which is irregular and weak in intensity, the x-ray flux in the most intense peaks exceeded anything else noted previously by at least a factor of two and the number of distinct, related peaks was greater by more than a factor of three. The energy spectra for both the peaks and valleys were less distinctive however, falling within the range of observation noted earlier (Barcus and Rosenberg, 1966); with both peaks and valleys showing soft spectra, the present event is consistent with modulation processes affecting precipitation rather than spectrally distinct pulsating precipitation embedded within a large scale background of a different origin.

As for the temporal features, even though showing considerable organization, there was a clear change in the precipitation midway in the event (as shown by the power spectrum analysis). This did not involve any gradual decline and subsequent regrowth of the precipitation but, rather, within a few cycles of pulsation, the establishment of a longer dominant period. Throughout this transition, the energy spectra did not change appreciably.

Such non-stationary behavior has been noted before (Barcus et al, 1966) but not within quite as short a time interval. Usually, it has involved the emergence and disappearance of significant peaks in power spectra at about 8 seconds period rather than the shift in frequency within a sample of comparable duration (expressed in terms of cycles).

In the period range noted in the present case, there is also a significant micropulsation band, discussed recently by Heacock (1966), which shows a positive correlation with K_p. Magnetic observations within this band during the morning hours appear relatively stable and of long duration, at least for modest K_p values. The frequency of occurrence of pulsations increases in the afternoon hours and it is at these times, when K_p increases, that sporadic bursts of a few minutes or longer appear in the 4-second band. For large K_p, the bursts appear in a near continuum with a few minutes separation. Even considering the possibility that high K_p in the morning hours might be similar to that found in the afternoon, there appears little resemblance between micropulsations and the present precipitation event, the x-ray activity around the 4-second band emerging only briefly rather than being sporadic and extensive.

This goes again to the principal difficulty of relating pulsating electron precipitation to pulsating magnetic disturbances. In the past, considerable scrutiny has been given to the possibility that x-ray pulsations might show detailed correlations with magnetic pulsations, all the way from the short period to long period events; the results of this search have been essentially negative. This, plus the non-stationary character of electron precipitation as compared to the greater duration and temporal stability of geomagnetic pulsations, makes it difficult to attribute electron precipitation directly to a wave-particle interaction. By the same token, this serves to place the source region for pulsating electron precipitation beyond the regions responsible for exospheric resonances (Field and Greifinger, 1965). The interpretation, then, is that the source region controls and/or modulates the electron flux at a particular band of frequencies and magnetic pulsations reaching ground-based instruments reflect both the source mechanism characteristics as well as resonances along the path of propagation.

Finally, it has been suggested earlier (Anderson and Milton, 1964) that brief intervals of electron precipitation termed "microbursts", typically 0.2 second half-width, are the fundamental unit of pulsation activity and that observations of x-ray pulsations really amount to periods of microburst activity which appear smooth because of insufficient experimental resolution. There is considerable difficulty with this idea since microbursts, even under the best experimental conditions, have never been found close to local midnight, where pulsations are frequently observed (Barcus et al, 1966). Instead, the two types of fast time variations seem to divide around dawn, pulsations occurring on the early morning side while microbursts extend into the afternoon hours. In the region of over-lap, both types of activity are present. For the present event, the intensity of precipitation was far in excess of that needed to reveal the presence of microbursts with digital counting techniques; <u>none</u> was found in the most detailed examination of the data. Thus, the pulsations belonged to the early morning category; for them to be unresolved microbursts would require a microburst occurrence rate greatly beyond that now known to exist (Anderson et al, 1966).

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Figure Captions

Figure 1 - X-ray intensity variations in the 25-50 keV range during the pulsating event

Figure 2 - Example of the energy distribution for an x-ray peak; $E_o = 15$ keV

Figure 3 - Example of the energy distribution for an x-ray valley; $E_o = 12$ keV

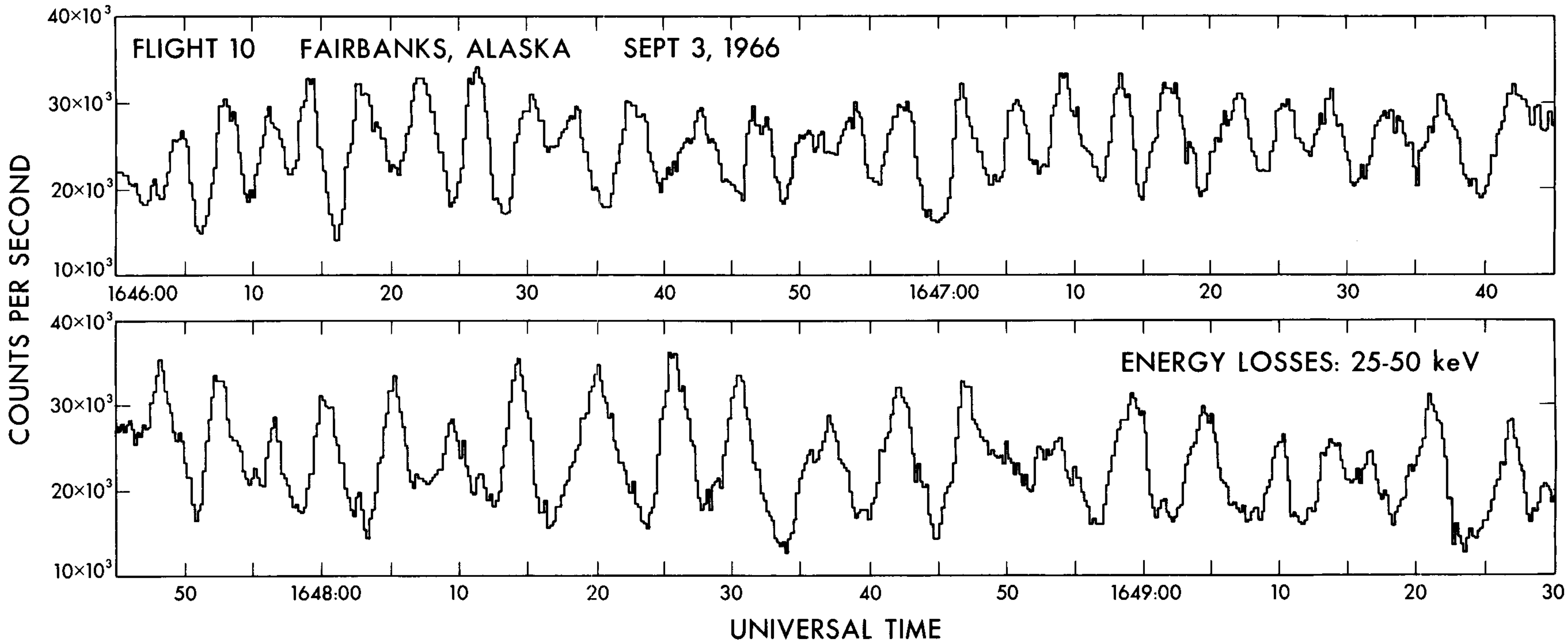
Figure 4 - Normalized auto-covariance for x-ray variations in the first half of the pulsation event

Figure 5 - Normalized auto-covariance for x-ray variations in the second half of the pulsation event

Figure 6 - Power spectrum for x-ray variations in the first half of the pulsation event

Figure 7 - Power spectrum for x-ray variations in the second half of the pulsation event

Figure 8 - Power spectrum for x-ray variations in the entire pulsation event



FLIGHT 10 FAIRBANKS, ALASKA SEPT 3, 1966
ENERGY LOSSES: 25-50 keV
COUNTS PER SECOND
40×10³
30×10³
20×10³
10×10³
1646:00
10
20
30
40
50
1647:00
1648:00
1649:00
UNIVERSAL TIME

Figure 1

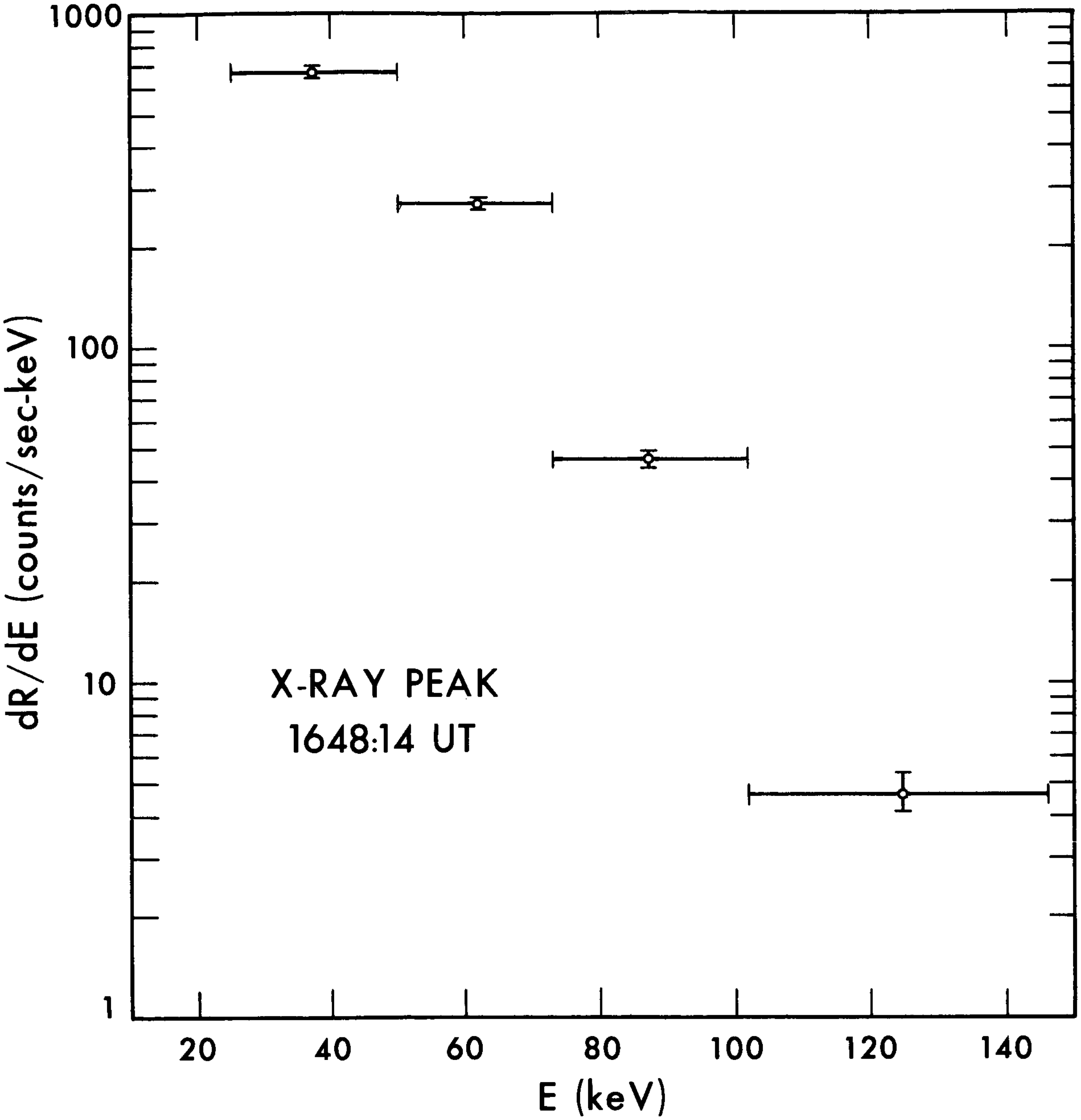
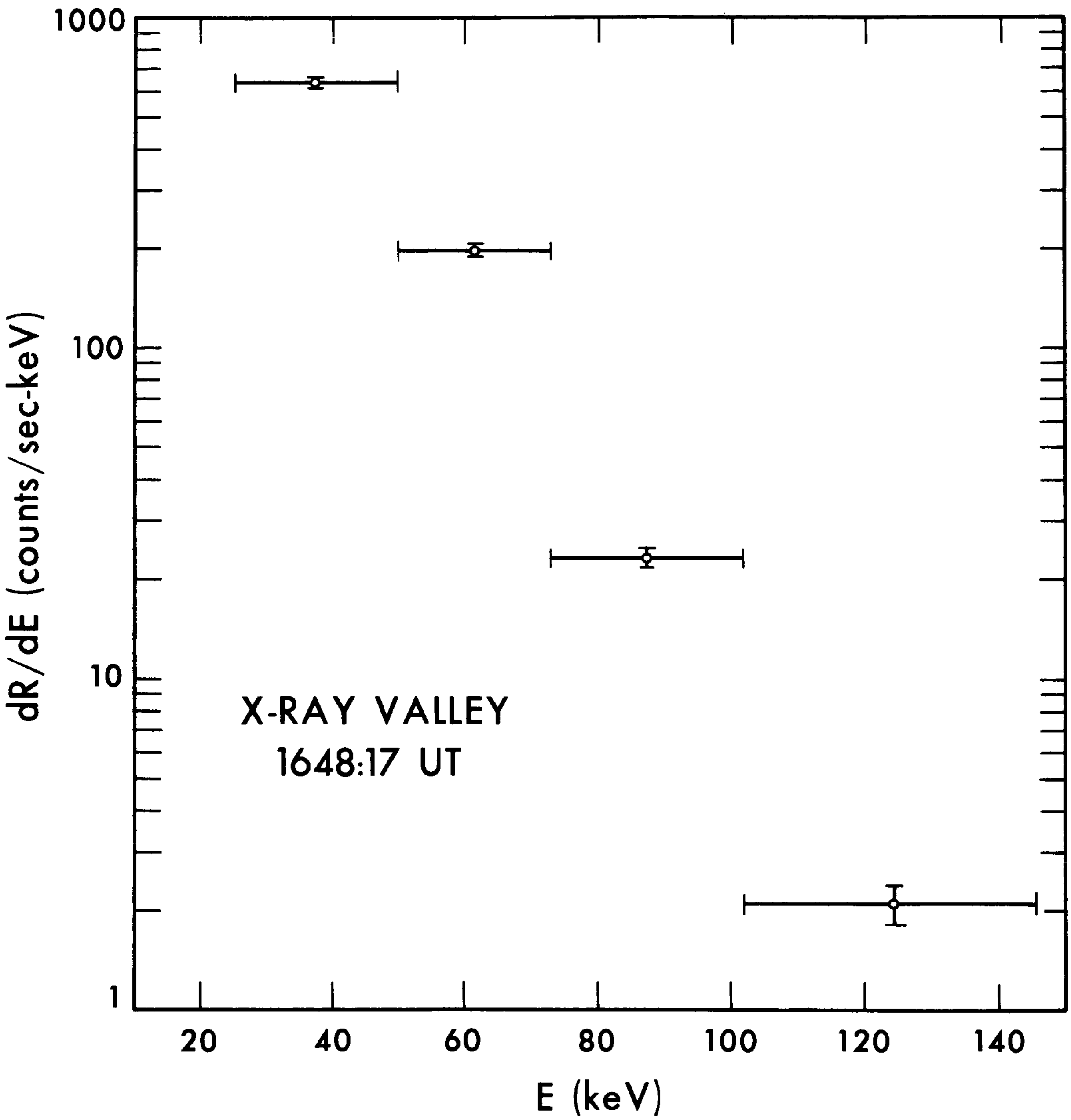

1000
100
10
1
dR/dE (counts/sec-keV)
X-RAY PEAK
1648:14 UT
20
40
60
80
100
120
140
E (keV)

Figure 2



1000
100
10
1
dR/dE (counts/sec-keV)
X-RAY VALLEY
1648:17 UT
20
40
60
80
100
120
140
E (keV)

Figure 3

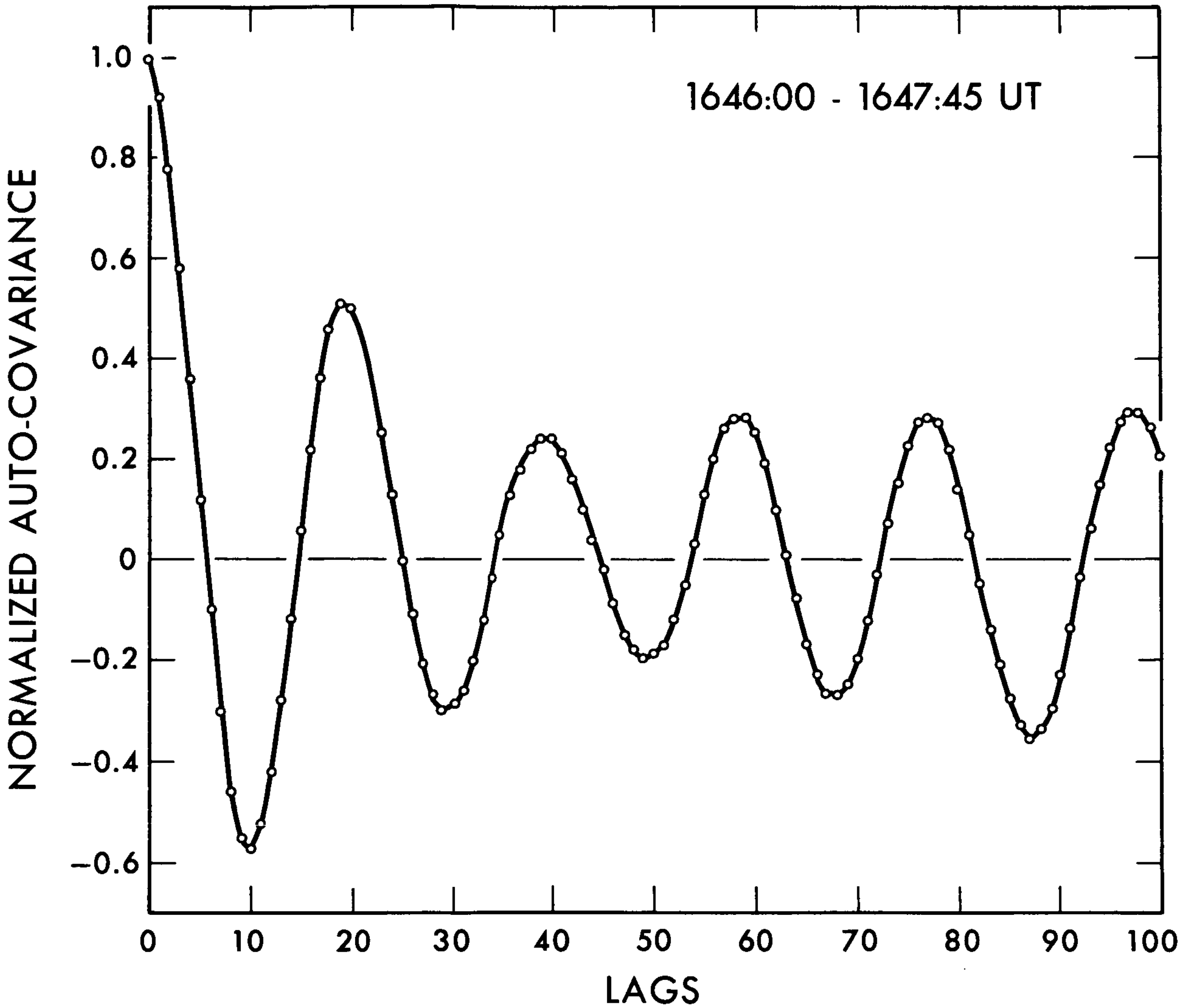
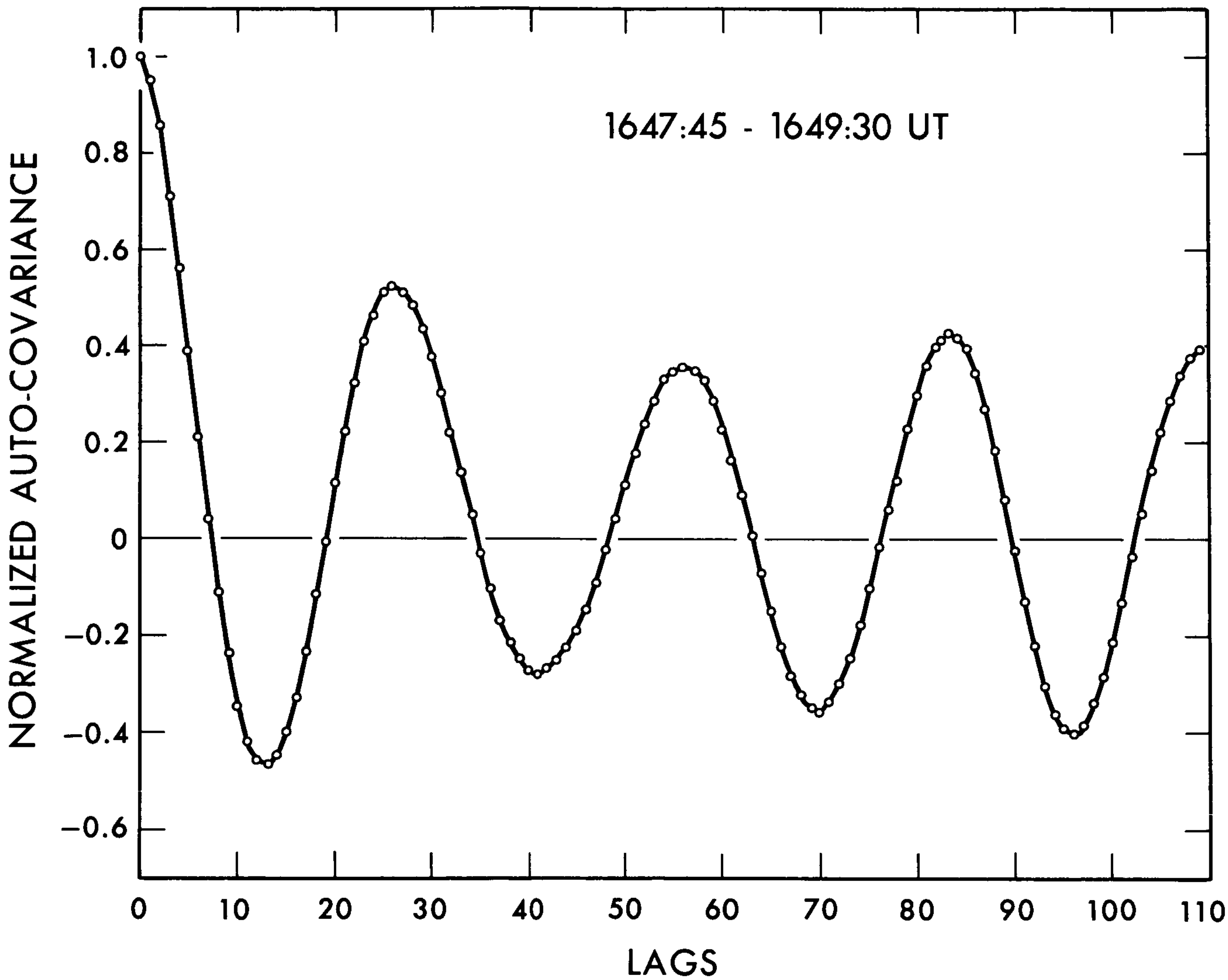

1646:00 - 1647:45 UT
NORMALIZED AUTO-COVARIANCE
1.0
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
0
10
20
30
40
50
60
70
80
90
100
LAGS

Figure 4


1647:45 - 1649:30 UT
NORMALIZED AUTO-COVARIANCE
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0.6
0.4
0.2
0
−0.2
−0.4
−0.6
0
10
20
30
40
50
60
70
80
90
100
110
LAGS

Figure 5

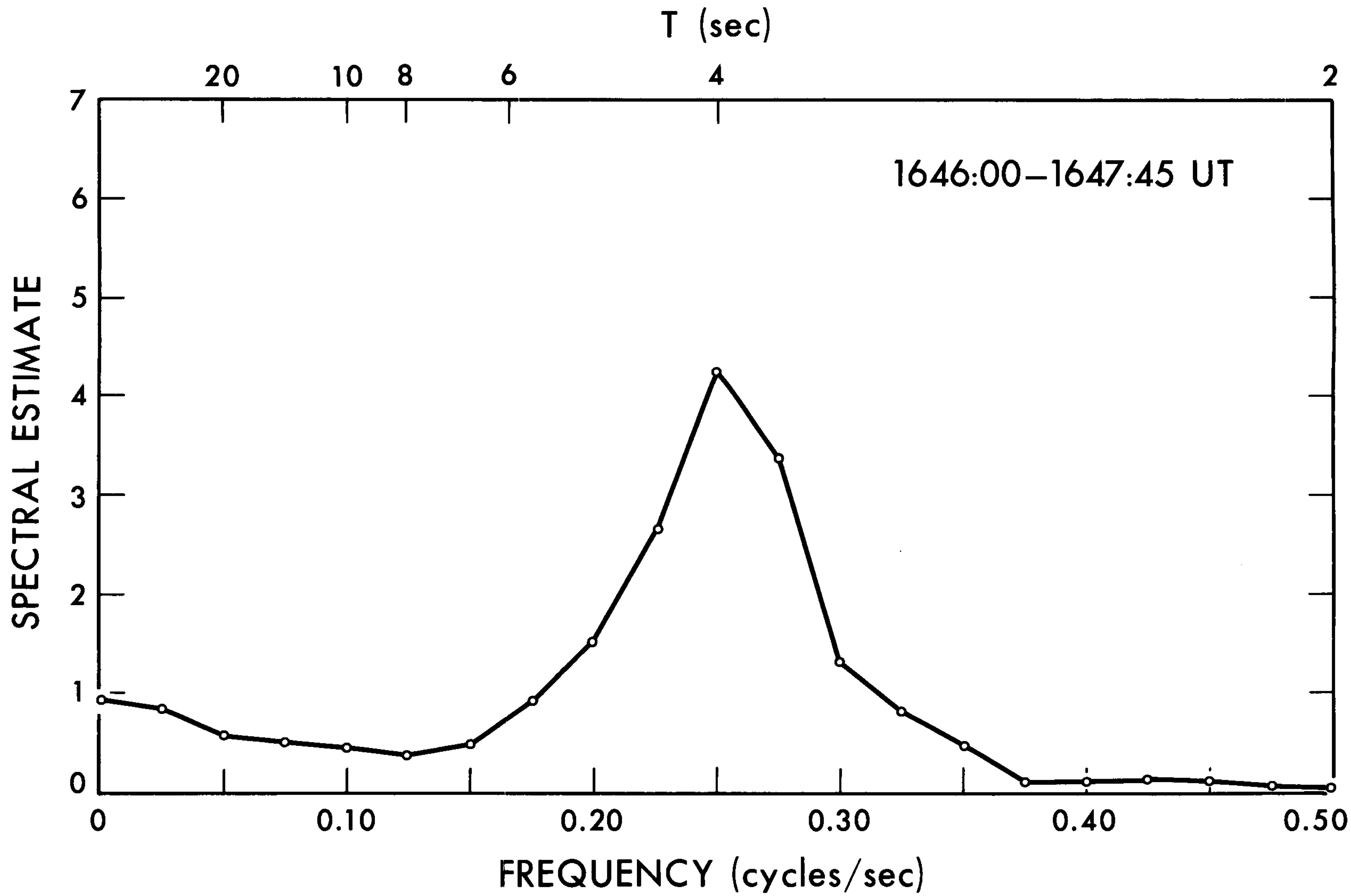
T (sec)
20
10
8
6
4
2
7
6
5
4
3
2
1
0
SPECTRAL ESTIMATE
1646:00–1647:45 UT
0
0.10
0.20
0.30
0.40
0.50
FREQUENCY (cycles/sec)

Figure 6

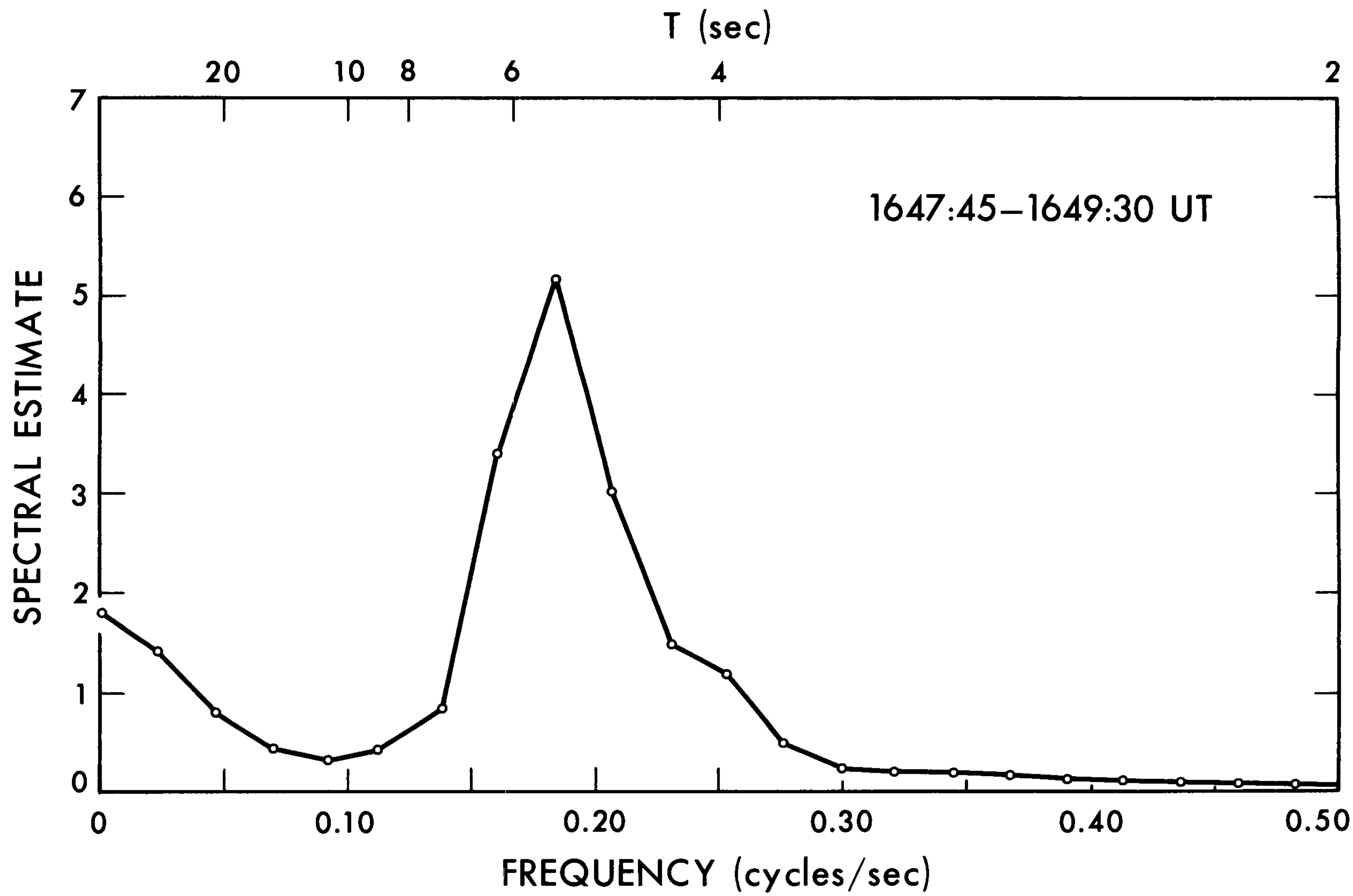
T (sec)
20
10
8
6
4
2
7
6
5
4
3
2
1
0
SPECTRAL ESTIMATE
1647:45–1649:30 UT
0
0.10
0.20
0.30
0.40
0.50
FREQUENCY (cycles/sec)

Figure 7

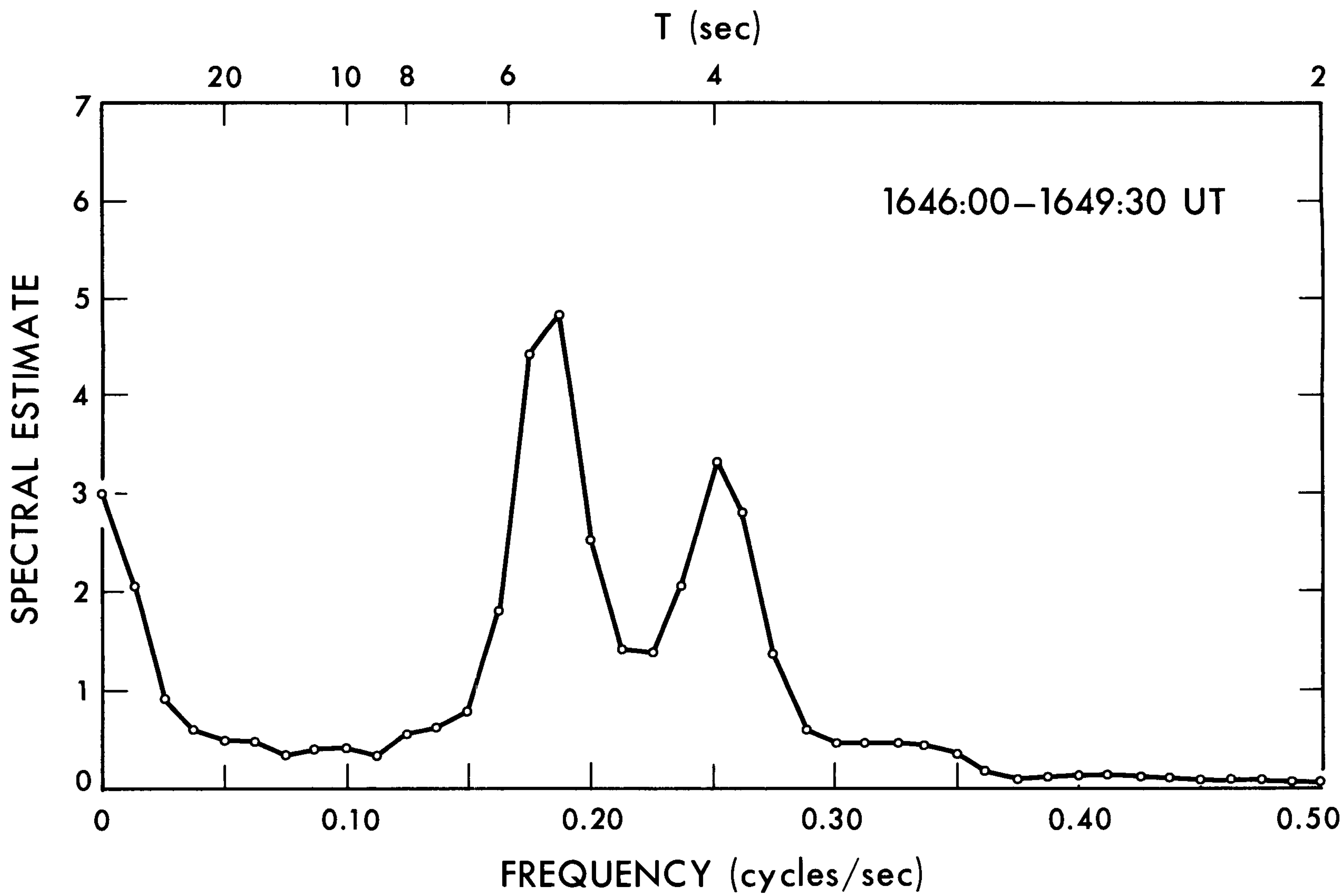
T (sec)
20
10
8
6
4
2
7
6
5
4
3
2
1
0
SPECTRAL ESTIMATE
1646:00–1649:30 UT
0
0.10
0.20
0.30
0.40
0.50
FREQUENCY (cycles/sec)

Figure 8