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Microwave fluctuations associated with the October 19, 1989 solar flare

A. Méndez, G. Gil and R. E. Rodríguez
Astronomy Department, Institute of Geophysics and Astronomy, La Lisa, Havana, Cuba

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RESUMEN

Se estudiaron las observaciones de fluctuaciones en las microondas solares en 15.0 GHz, 9.5 GHz y 6.7 GHz en la estación de CUBA desde 3 días antes hasta un día después de la ráfaga solar 4B/X13 del 19 de octubre de 1989. Los periodogramas muestran un desplazamiento del periodo principal de 60 a 80 minutos y un aumento en la amplitud del periodo de 20 minutos comparado con el periodograma del 4 de octubre de 1989. La evolución temporal de cada frecuencia muestra una estabilidad mayor en la señal de 6.7 GHz y en los días cercanos a la ráfaga. Las fluctuaciones se atribuyen a un flujo descendente de plasma calentado el cual excita oscilaciones en modos propios de tubos magnéticos verticales anclados en la fotosfera en la región activa donde ocurrió la ráfaga.

PALABRAS CLAVE: Microondas solares, ráfagas, oscilaciones de plasma.

ABSTRACT

Solar microwave fluctuations on 15.0 GHz, 9.5 GHz and 6.7 GHz observed at CUBA station were studied from three days before to one day after the 4B/X13 solar flare of October 19, 1989. Periodograms show a displacement of the main period from 60 to 80 min and an increase in amplitude of the 20 min period as compared to the periodogram for October 4, 1989. Time evolution for each frecuency shows greater stability in the 6.7 GHz signal and on the days closer to the flare. Fluctuations are attributed to a downward flux of heated plasma which excites eigenmode oscillations of vertical magnetic tubes anchored to the photosphere in the active region where the flare occurred.

KEY WORDS: Solar microwaves, flares, plasma oscillations.

1. INTRODUCTION

The observation of solar microwave fluctuations two decades ago (Kobrin *et al.*, 1973) was interpreted as evidence of coronal preflare instabilities (Kobrin *et al.*, 1978). These solar microwave fluctuations have been proposed as precursors of great solar flares, ever since.

Microwave fluctuations originate in developed active regions (source diameter of approximately 1 minute of arc) and have amplitudes of only a few percent of the total solar flux. Instruments with medium resolving power are indicated if such fluctuations are to be used in practical forecasting. Small radiotelescopes are mainly used for the solar radio patrol. It is therefore important to know how microwave fluctuations behave on these records in order to assess their forecasting potential.

We describe microwave fluctuations in the 20 - 80 minutes range for the October 19, 1989 solar activity, in the framework of a model proposed by Vrsnak *et al.* (1990) for the study of active loop-prominence oscillations.

2. DATA

Fluctuations were obtained from regular observations at 15.0, 9.5 and 6.7 GHz recorded at ERH at CUBA station (Astrakhan *et al.*, 1974) three days before and one day after the 4B/X13 flare registered at 12:32 on October 19, 1989. This flare was emitted by an active region at 209 degrees Carrington longitude and 27 degrees South, which crossed the central meridian on October 20. This group was classified as E when it first appeared on the east limb on October 14, and it disappeared with a G classification on October 26. During transit the area of the active region never fell below a 1000 millionth of the visible hemisphere.

The intervals were digitalized every 30 seconds (Table 1). Bursts recorded on the days of record were disregarded.

Fluctuations were found after eliminating the trend by a 45 minute smoothing from the curve obtained for 3 minute

Table 1

Intervals used (Times in U.T.)

Date	Start	End	Frequencies [GHz]		
10.04.89	15:20	21:00	6.7	9.5	15.0
10.16.89	13:00	17:40	6.7	9.5	15.0
10.17.89	13:10	17:10		9.5	15.0
10.18.89	13:00	18:05	6.7	9.5	
10.19.89	18:30	21:30	6.7	9.5	15.0

smoothing in order to remove short-period variations (Figure 1). The resulting curves were processed with the STATGRAPHICS Time Series module. Fast Fourier power spectra, cross-correlations and auto-correlations were also computed.

We selected October 4, 1989, a day with no outstanding events close to those under study, to compare atmospheric fluctuations as well as average solar variations.

3. RESULTS

Periodograms of the intensity signal at 6.7, 9.5 and 15.0 GHz for October 16th, 17th, 18th and 19th are shown in Figures 2 and 3. Fluctuation power spectra on the days prior to the event show that the main periods shifted from a 60 min period on the reference day to a 80 min period at all three frequencies. On the 9500 MHz curves we find a secondary maximum at 20 min which was not significant on October 16th, but emerged on the 17th and 18th. After the G.B. occurrence on October 19th, the 20 min component disappears and the main maximum drops to the 60 min range (Figure 2).

The incomplete time sequences for 15.0 GHz and 6.7 GHz in Figure 3 reflect the same behaviour. For the 20 min component, the 6.7 GHz power spectra show a weak but noticeable enhancement on October 18th, but at 15.0 GHz we do not notice a well defined trend. The 20 min component is not found at any frequency on October 16th nor on the 19th after the occurrence of the G.B.

Cross-correlation shows that 6.7 GHz and 9.5 GHz signals are the best correlated over the period studied. On October 16th and 18th no significant lag is noticed, nor on the reference day. On October 19th the 6.7 GHz signal is 5 min ahead of the 9.5 GHz signal and 10 min ahead of the 15 GHz signal (Figure 4).

Stability in the time domain was studied by autocorrelation for each frequency. The 9.5 GHz autocorrelation curves showed higher stability on October 18th than on the 17th and the stability on October 17th was higher than on the 16th and 19th (Figure 5). The 6.7 and 15.0 GHz signals showed a similar behaviour. Thus stability increases toward the day of the flare and diminishes after its occurrence.

When studying autocorrelation curves for each separate day an increase in stability was found for decreasing frequencies (Figure 6a, 5a, and 6b).

4. DISCUSSION AND CONCLUSIONS

The identical power spectra for all three frequencies, registered with two different radiotelescopes on the day chosen as reference, suggest that variations due to equipment instabilities are not significant in the period range studied. While atmospheric fluctuations cannot be ruled out, differences in the time evolution of power spectra as the event approached may be attributed to the evolution of the active region.

The observed fluctuations may be due to a downward flux of heated plasma exciting eigenmode oscillations of a bipolar magnetic structure, similar to those sustaining loop prominences, associated to the active region during pre-flare conditions.

According to Vrsnak *et al.* (1990),

$$\omega^2 + \delta^2 = K^2 V_a^2 \tag{1}$$

$$\omega_0 \approx V_a / R \tag{2}$$

where ω is the observation frequency, δ is the damping factor, V_a is the Alfvén velocity and R is the radius of the structure.

Thus, assuming N = 1, $\delta = 0.4 \times 10^{-4} s^{-1}$ and an Alfvén velocity of 300 kms^{-1}, we find that the 80 and 20 min periods correspond to structures of 0.6×10^5 and 0.4×10^5 km.

These lengths are consistent with typical values of the magnetic field and electron densities for active regions. We assume an electron density of 0.2×10^{10} cm^{-3} for the 80 min structure, with a field at the footprints of 2500 gauss and a pitch angle of 78 degrees. For the 20 min structure, electron densities of 0.5×10^{10} cm^{-3}, a magnetic field of 1200 gauss and an 85 degree pitch angle must be assumed.

A higher pitch angle in the lower structure is consistent with pitch angles measured by Vrsnak (1990) while studying eruptive prominence dynamics. He obtained initial values of 80 degrees which diminished gradually as the structure increased in length.

The main periods of the power spectra were shifted from the 60 to the 80 min range on the days prior to the flare. This may be due to the growth of the characteristic length of the magnetic structure as the fields penetrate further into the corona. The increase of the relative importance of 20 min periods may be the result of the appearance of a new magnetic structure. This is consistent with the fact that 20 min periods are present in the 6.7 GHz and 9.5 GHz power spectra and not in the 15.0 GHz power spectrum.

No significant enhancement of the 20 min periods at 15.0 GHz was observed. This can be explained if we suppose that the perturbation has not reached the gyroresonant levels or that these levels have not developed yet in the new magnetic structure.

The idea of a newborn magnetic structure is more plausible than supposing that the 20 min periods are harmon–

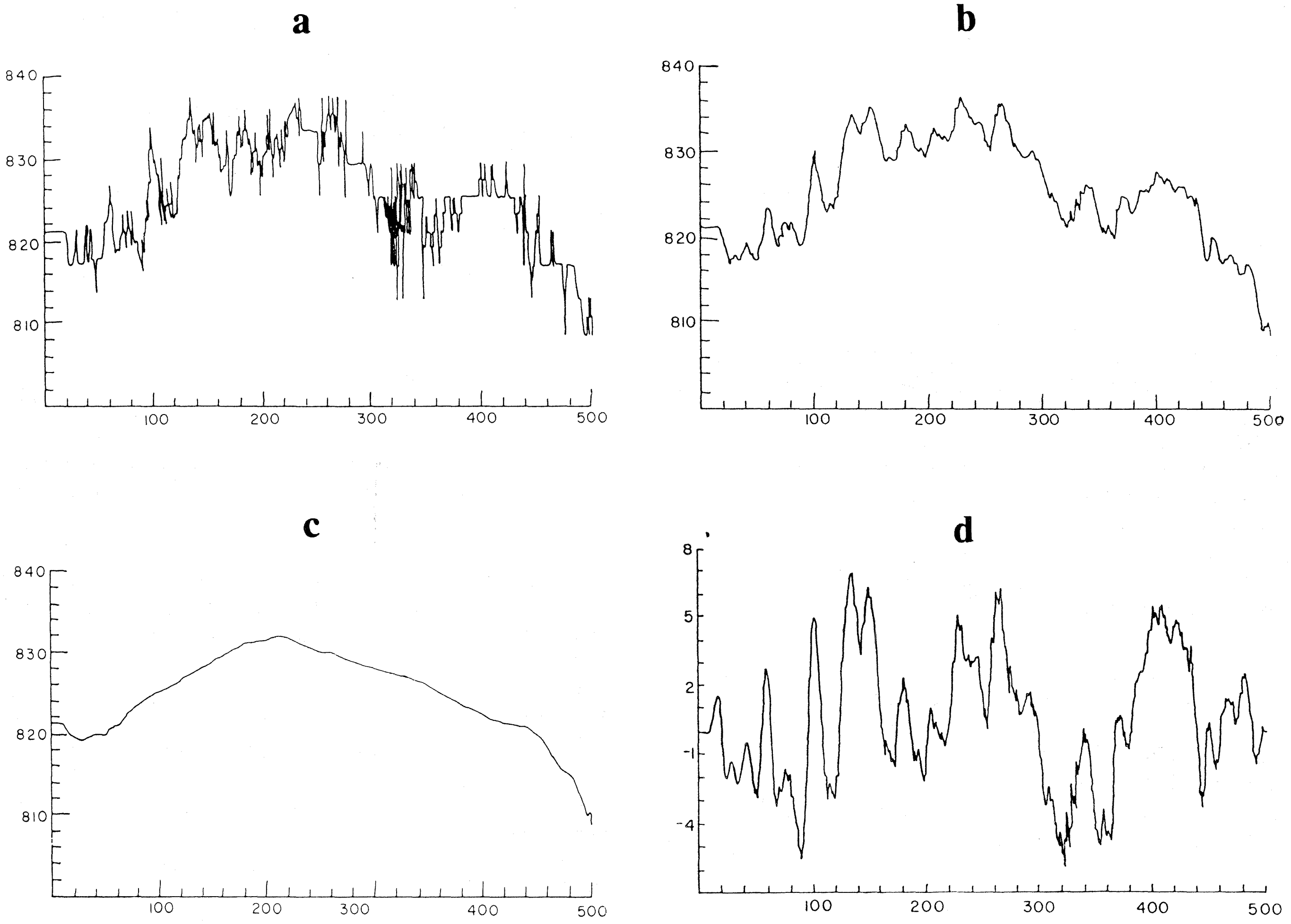

Fig. 1. Data reduction example for 15 GHz on Oct. 17,1989. a) Solar flux in arbitrary units. Sampling interval 30 s. b) Signal smoothed (N=3, 1.5 min) to eliminate short period variations. c) Signal smoothed (N=45, 22.5 min) to estimate the trend. d) Fluctuations resulting from eliminating the trend from the 3 min smoothed signal.

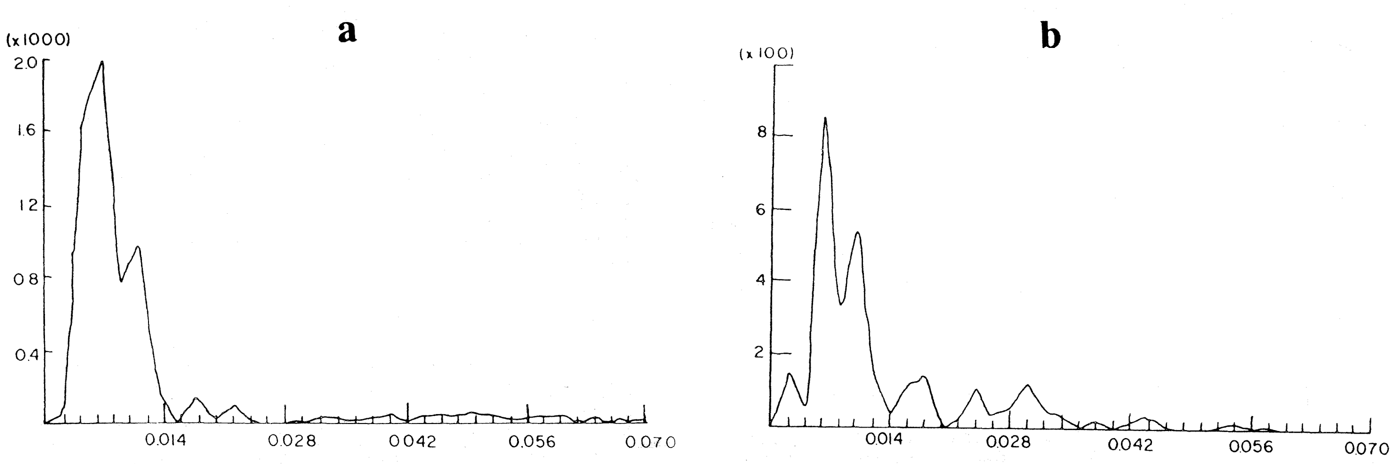

Fig. 2. Periodograms for 9.5 GHz on Oct. 16th (a), 17th (b) and 18th (c), in which the 60 to 80 min range displacement, and the increase of the relative importance of the 20 min. period component can be seen. On Oct. 19th (d), after the great burst, the main period returns to 60 min range, and the 20 min component dissapears. The X axis refers to cycles/sampling interval.

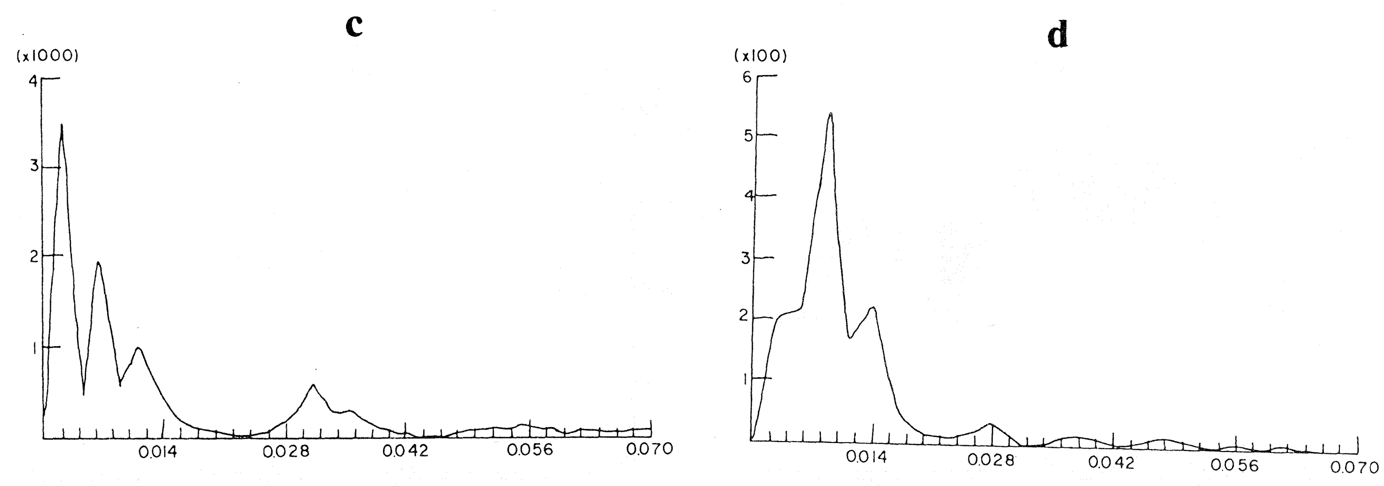

Fig. 2. (Cont.)

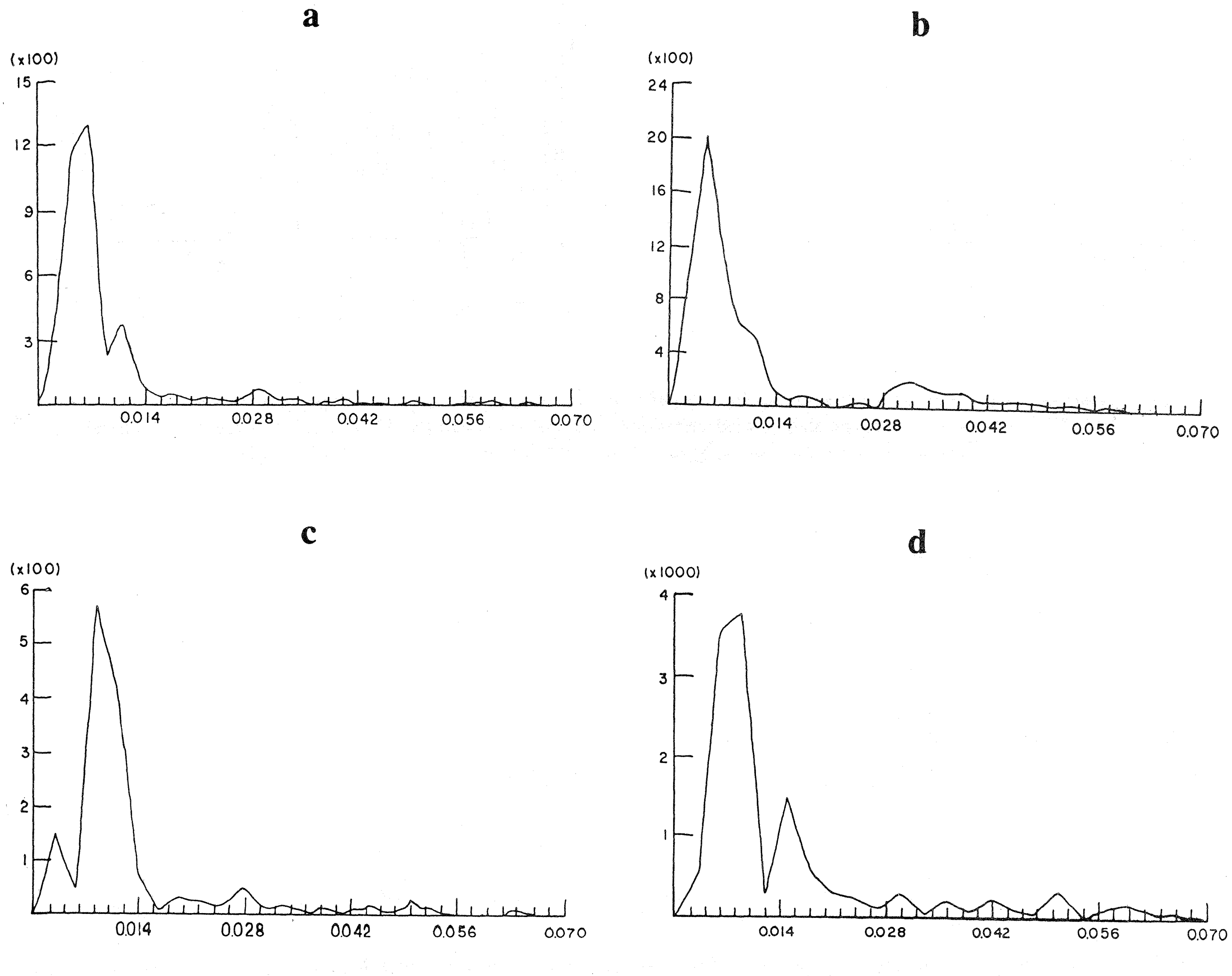

Fig. 3. Periodograms for the incomplete time sequences on 6.7 and 15 GHz on Oct 16th (a), 18th (b), and 19th (c). The X axis refers to cycles/sampling interval.

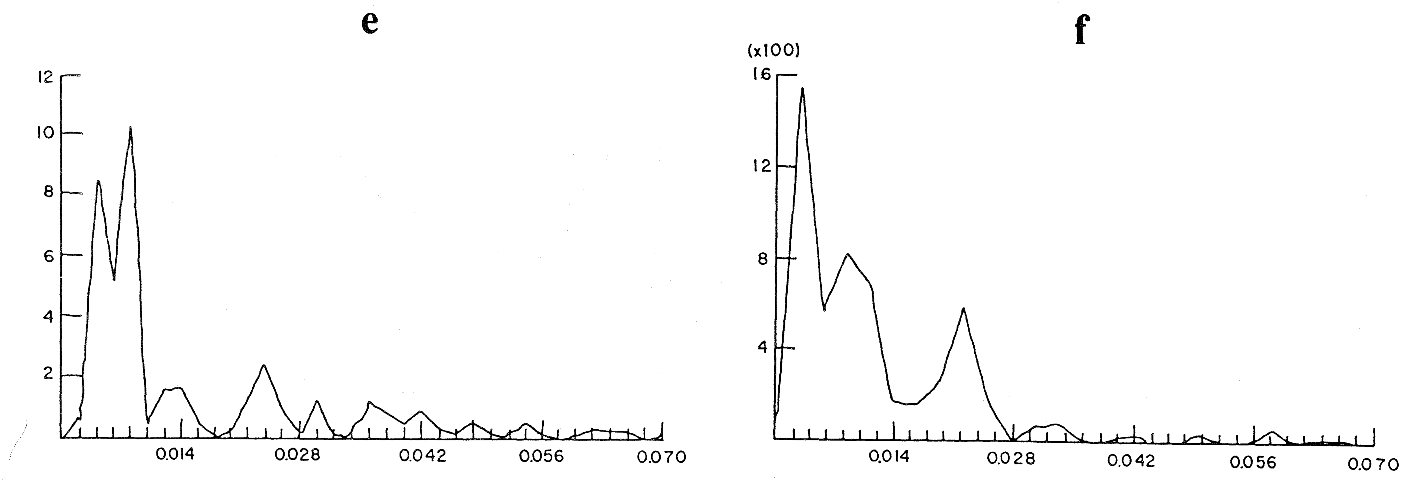

Fig. 3. (Cont.)

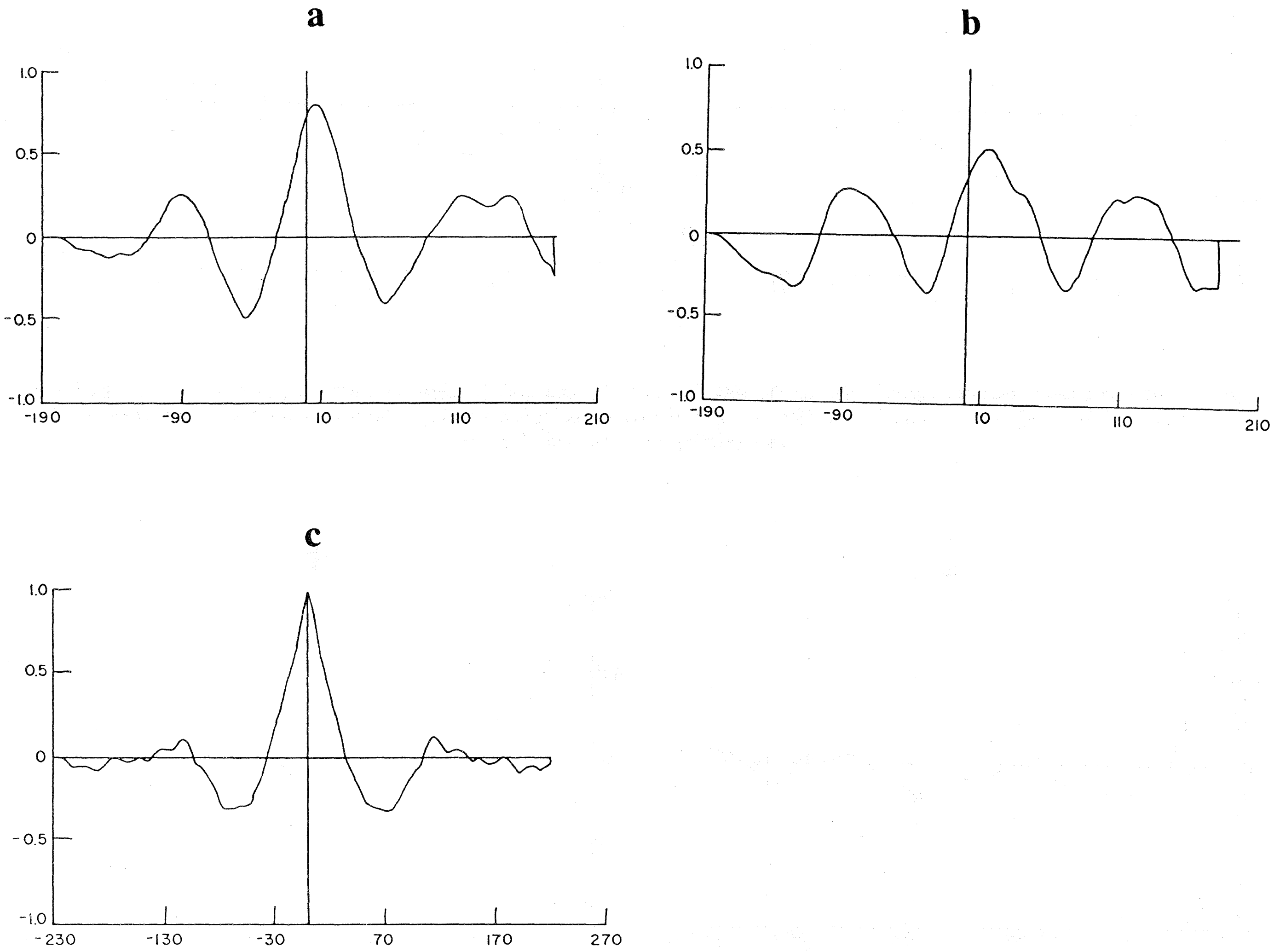

Fig. 4. Cross-correlations of the 6.7 GHz signal on the 19th with the 9.5 GHz signal (a) and the 15 GHz signal (b) show a lag which is absent on the reference day (c). The X axis refers to 30 seconds lag.

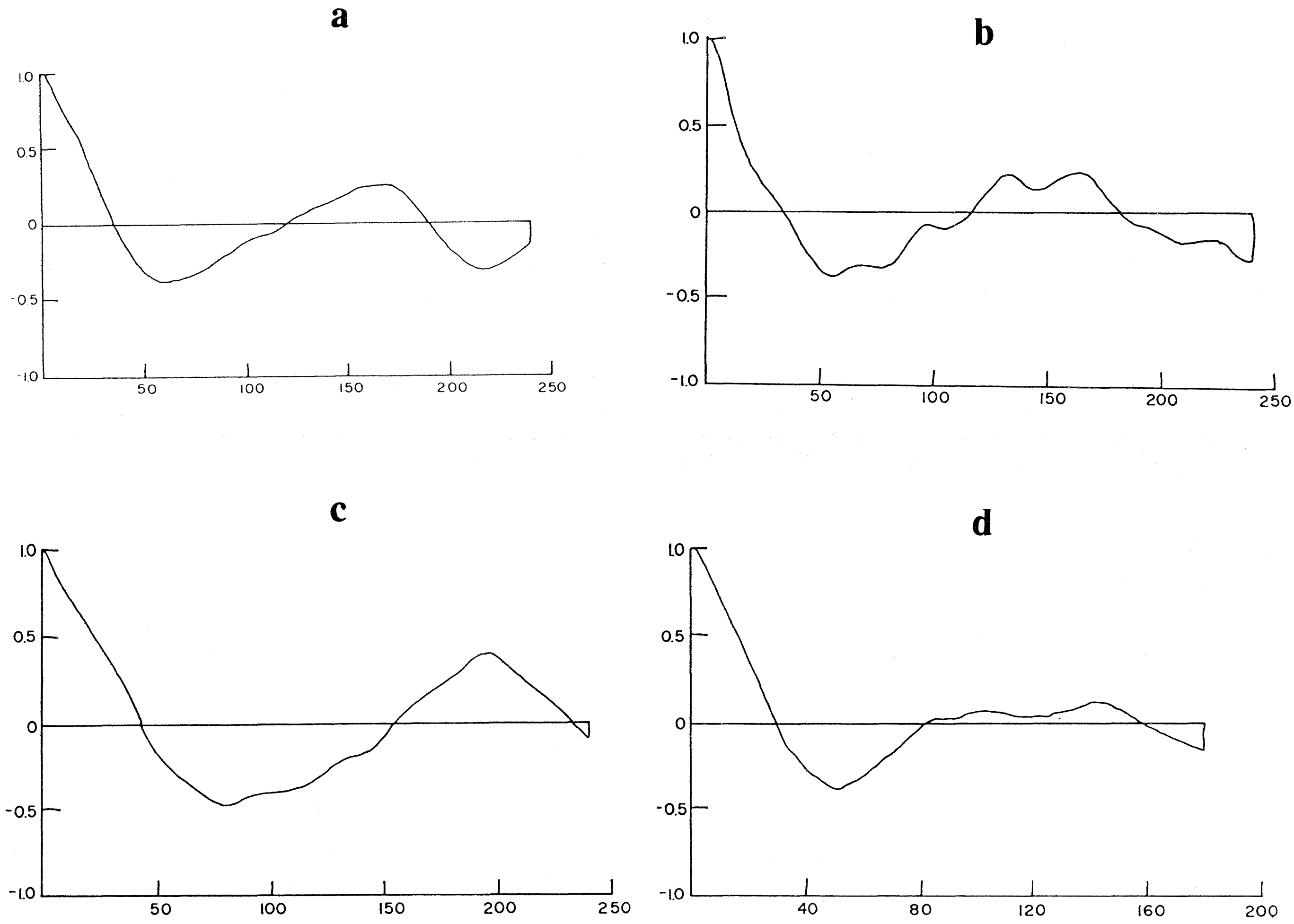

Fig. 5. Auto-correlation functions for 9.5 GHz on the 16th (a), 17th (b), and 18th (c) show an increasing stability of the signal as it approaches the day of the great burst. On the 19th (d), after the burst, the signal stability returns to control day conditions. The X axis refering to 30 seconds lag.

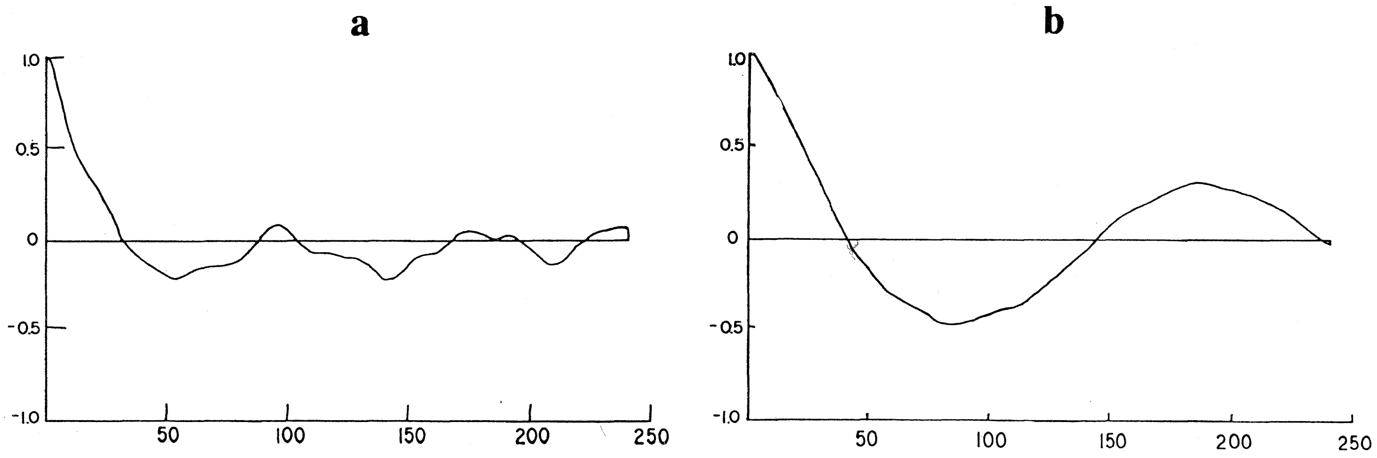

Fig. 6. Auto-correlation functions on the 16th for 15 (a) and 6.7 GHz (b) show the increase of signal stability for lower frequencies. The X axis refers to 30 seconds lag.

ics, since the geometry hardly changes. Also, a new disturbing factor of the structure would have to be introduced to account for the appearance of 20 min oscillations.

The ten minute phase difference between the 6.7 GHz and 15.0 GHz signals on October 19th can be explained by assuming a descending flow of hot material with a speed of 30 km/s which produces an increase in temperature of the gyroresonant level at different heights inside the structure, and perhaps also some broadening of the magnetic tube. The increase in stability for lower frequencies can be explained in the same manner by the influence of the descending hot flux on the upper levels of the transition region.

This model proposes that solar microwave fluctuations may be a result of the evolution of magnetic structures associated to active regions. The oscillation periods provide information on the characteristic lengths of these magnetic structures.

Further studies of spectral dynamics using medium and low resolution equipment together, may lead to the development and implementation of real time calculations of microwave fluctuations for solar flare prediction.

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A. Méndez, G. Gil and R. E. Rodríguez
Astronomy Department, Institute of Geophysics and Astronomy, Calle 212 No.2906, La Lisa, Havana, Cuba.

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