Revista Brasileira de Flsica, Vol. 12, Nº 4, 1982

Periodicity of About 13 Days in the Cosmic-Ray Intensity in the Solar Cycles nº 18, 19 and 20

O. FILISETTI and V. MUSSINO

Istituto di Fisica Sperimentale del Politecnico di Torino (Italia)

Recebido em 8/8/82

The quasi-periodical variations of the cosmic-ray intensity, with a period of about 13 days, have been studied in the data recorded through shielded ionization chambers at Huancayo and at Cheltenham-Fredericksburg during the solar cycles n? 18, 19 and 20 (1944-1974). The temporal variation of the annual average amplitudes of the oscillation of about 13 days for both stations is compared with the behaviour of the Wolf number R of sunspot. For the cycles n? 18 and 19, these amplitudes present, like of 27-day oscillation, two maxima, while for the cycle n? 20 there is only one clear maximum. In thls work is also presented the negative correlation between the annual mean cosmic-ray intensity and the amplitude of the 13-day oscillation.

A variação quase periódica da intensidade da radiação cósmica, com periodo de cerca 13 dias, foi estudada nos dados registrados por meio de câmaras de ionização protegidas em Huancayo e em Cheltenham-Fredericksburg durante os ciclos solares n? 18, 19 e 20 (1944-1974). O gráfico em função do tempo das amplitudes anuais médias da oscilação de 13 dias em ambas as estações é comparado com o comportamento do n? R de Wolf de manchas solares. Nos ciclos n? 18 e 19, as amplitudes acima nomeadas apresentam, como já aquelas das oscilações de 27 dias, dois máximos, enquanto no ciclo n? 20 é evidenciado um Único claro máximo. Neste trabalho é também apresentada a correlação negativa que existe entre a média anual da intensidade da radiação cósmica e a amplitude da oscilação de 13 dias.

1. INTRODUCTION

The variation of the annual mean cosmic-ray intensity, at a given site, with the sunspot activity cycle has been known for many years[1]. It is referred to as the eleven-year variation of the cosmic ray in the literature. Somehow the lower energy cosmic rays are prevented from reaching the earth, as the solar activity increases. The "obstruction" gradually disappears with the decline in solar activity.

Also the 27-day quasi-periodic variations in the intensity of the cosmic-ray are well known and are attributable to fluctuations in the properties of the interplanetary medium in connection with the sun's rotation and are investigated by many authors[2]. However, the direct cause of the variations may be found in several diverse effects, such as the non-uniform heliolongitude distribution of active regions on the solar disk, recurrent Forbush decreases and the sectored structure of the interplanetary magnetic field. Since the result of the modulation process is not mere sinusoidal it is likely to expect, beside the fundamental oscillation, also the presence of higher harmonics.

Then, in addition to the well known variation of 27 days, we took into consideration those of shorter periods (13 and 6 days respectively) of which some experimental information is already available[3].

The quasi-periodical variations of the cosmic-ray intensity, with a period of about 13 days, have been studied in the data recorded through shielded ionization chambers at Huancayo and at Cheltenham-Fredericksburg during the years from 1944 to 1974.

2. METHOD OF DISCRIMINATION OF THE 13-DAY VARIATION AND TEST OF EFFICIENCY OF THE FILTER

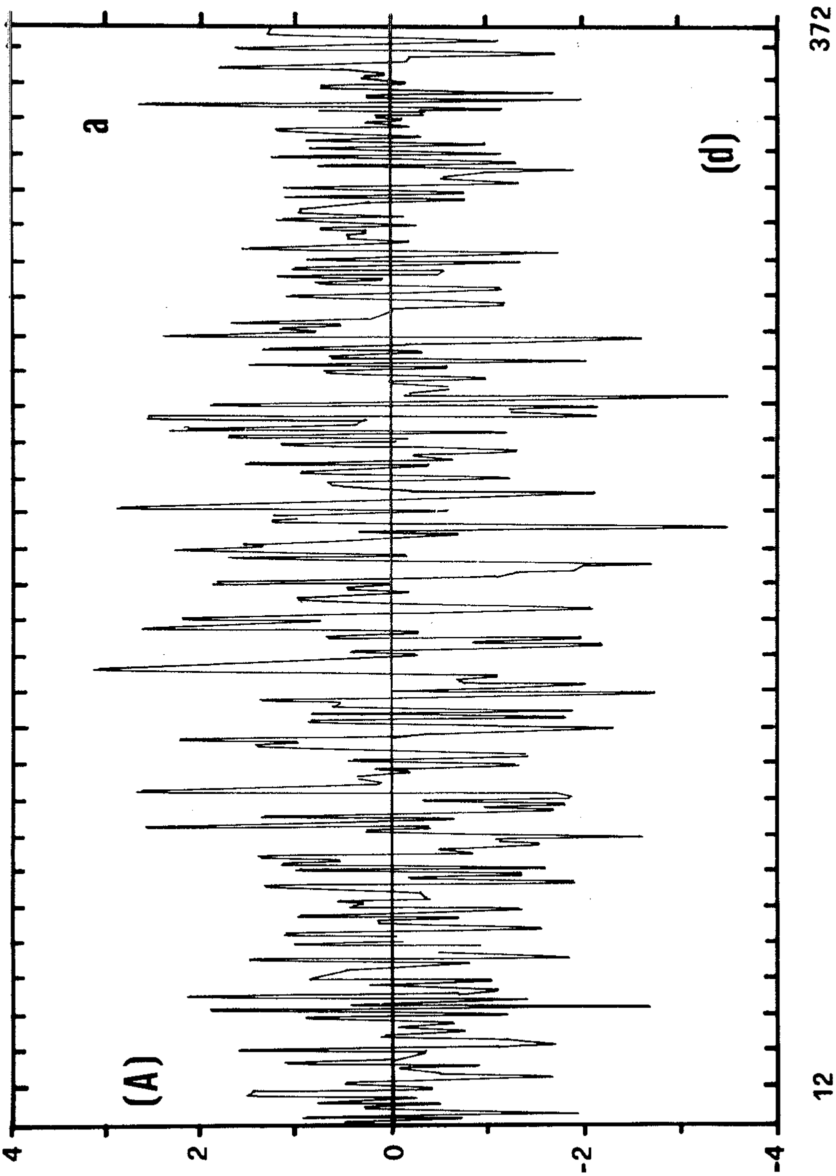
The action of the selective filter in the presence of dicrete data, for example the diurnal-mean valuesof the cosmic-ray intensity is described by transformation of the type

$$X(t) = \sum_{k=-N}^{N} h(k) \quad x(t-k)$$

where $h(k)$ is the weighting function of the linear transformation, $x(t)$ is the investigated process, and $X(t)$ is the transformed process[4]. The frequency response of the particular filter used here is such that the response maximum, which is equal to unity, occurs at a period of about 13 days, and the half-suppression points at 9 and 18 days. In our case N=32. To test the efficiency of the filter in discriminating a period component against randon noise it is used to process a superposition of a sinusoidal process with a randon array of numbers having a normal distribution function for various signal-to-noise ratios (from 0.1 to 1.0). The processing results are given in Table 1, which lists the amplitudes (A) of the sine waves used for superposition and the average amplitudes (A_{13}) of the sine waves extracted by filter frorn the superimposed processes. These data indicate that for a signal-to-noise ratio equal to

Table I - Amplitudes (A) of the sine waves and average amplitudes (A_{13}) of the sine waves extracted.

Signal/noise	A	A_{13}	A_{13}/A
1	1.49	1.43 ± 0.05	0.96
0.9	1.34	1.28 ± 0.05	0.96
0.8	1.19	1.13 ± 0.05	0.95
0.7	1.04	0.98 ± 0.05	0.94
0.6	0.89	0.83 ± 0.05	0.93
0.5	0.74	0.69 ± 0.05	0.93
0.4	0.59	0.55 ± 0.05	0.93
0.3	0.45	0.42 ± 0.05	0.93
0.2	0.30	0.41 ± 0.04	1.37
0.1	--	--	


(A)
a
(d)
12
372
4
2
0
-2
-4

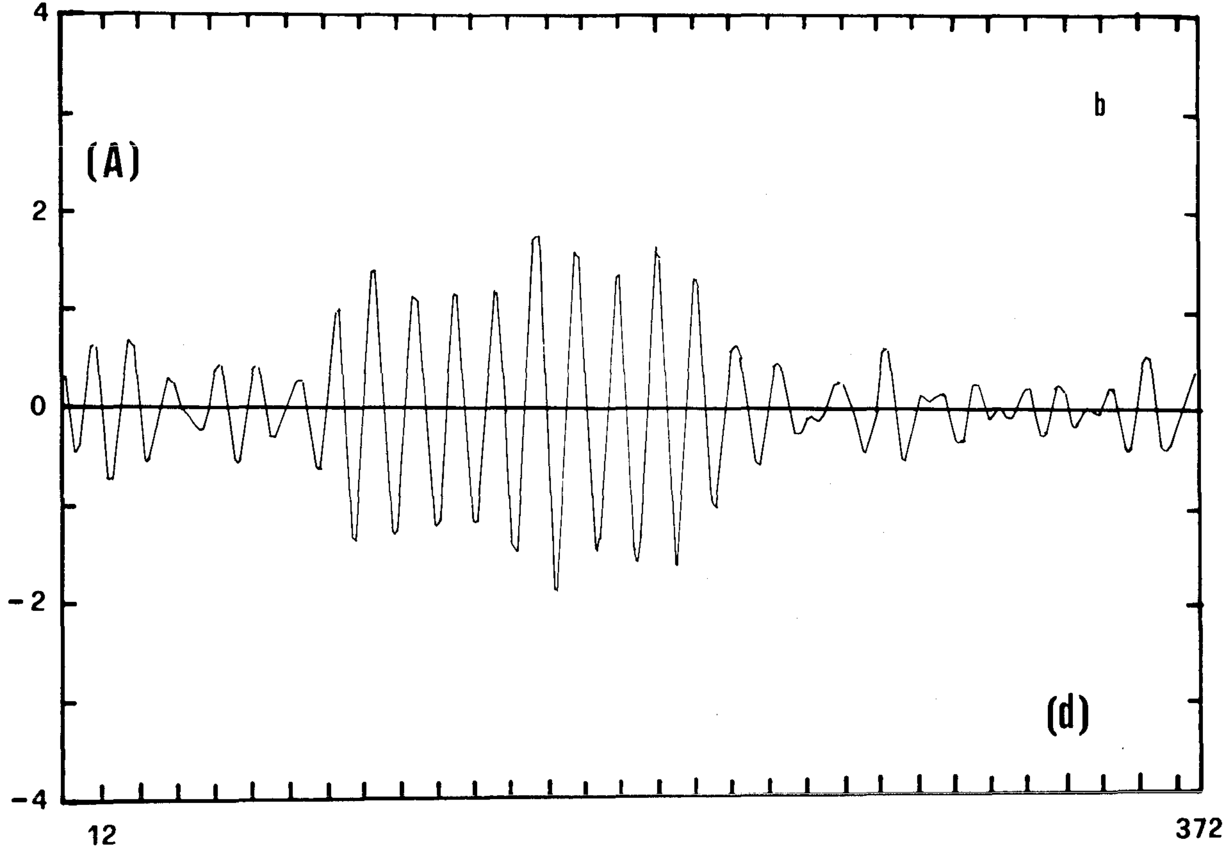


Fig.1 - Extraction of harmonic component by a 13-day filter for unit signal-to-noise ratio: a) sum of random process (with normal distribution) and sinusoidal process; b) result of processing of curve a) by the selective filter.

unity the amplitudes A_n and A almost coincide, but the differencegrows larger as the ratio is decreased.

Fig. 1 gives as an example the results of processing by the selective filter of a typical process with signal/noise = 1. It is seen that the 13-day selective filter reliably discriminates the periodic component against the random process.

In fig. 2 are reported, as an example, for the period going from January 1, 1973, to April 15, 1973: a) the experimental daily mean value of cosmic-ray intensity for Huancayo neutron monitor; b) the result of a smoothing process on the experimental data, with a scheme that cuts-off small period fluctuations; c) the result of periodical analysis for the about 13-day oscillation. The correspondence between the 13-day oscillation (c) and the ondulation of curve (b), superposed to the fundamental oscillation of 27 days, is quite evident.

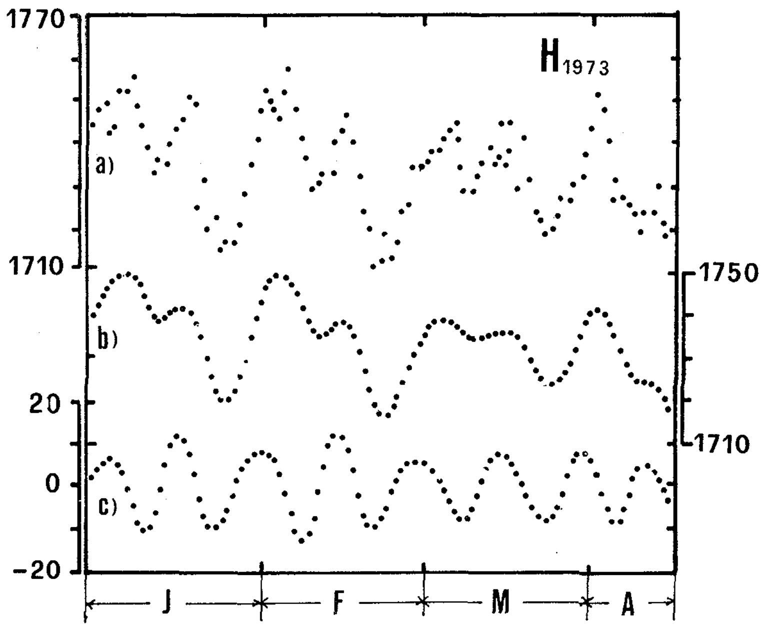


Fig.2 - Neutron monitor data at Huancayo (January 1 to April 15, 1973): a) experimental data; b) smoothed data; c) 13-day oscillation. In c) 10 units correspond to about 6% of cosmic-ray intensity.

3. EXPERIMENTAL DATA

Table 2 (a, b, c) reports the annual average amplitudes of the oscillation of about 13 days during the solar cycles n? 18, 19 and 20, at

Table 2.a - Average amplitudes of the 13-day oscillation in the cycle n? 18 (H: Huancayo; C: Cheltenham).

Year	H	C
1944	1.3	3.2
1945	1.4	2.8
1946	4.6	4.9
1947	3.7	4.2
1948	2.6	3.1
1949	3.0	4.5
1950	2.4	3.3
1951	3.1	3.7
1952	2.9	3.3
1953	1.6	2.8

Table 2.b - Average amplitudes of the 13-day oscillation in the cycle n? 19 (H: Huancayo; C-F: Cheltenham -Fredericksburg).

Year	H	C-H
1954	1.1	3.2
1955	1.8	3.3
1956	3.2	4.4
1957	5.0	5.6
1958	3.5	4:1
1959	4.2	4.5
1960	3.7	5.0
1961	1.9	4.1
1962	1.6	3.8
1963	2.0	3.2
1964	1.3	2.8

Table 2.c - Average amplitudes of the 13-day oscillation in the solar cycle n? 20 (H: Huancayo; F: Fredericksburg.

Year	H	F
1965	1.2	3.1
1966	2.9	3.3
1967	2.9	3.5
1968	3.4	3.4
1969	2.6	3.5
1970	3.8	4.4
1971	2.8	3.7
1972	3.2	3.7
1973	2.9	3.3
1974	3.1	3.0

Huancayo and Cheltenham-Fredericksburg. The cosmic-ray intensity amplitudes are given in millesimal of the average intensities of the examined interval.

The errors have been evaluated as the average amplitudes which would be obtained for the oscillation, in the case that the initial data fluctuations were purely random[5], taking into account the filter used. The amplitudes exceed at least 3 times the relative errors and therefore it is plausible to assume the reality of these oscillations.

In fig. 3 the temporal variation of these amplitudes, both at Huancayo and Cheltenham-Fredericksburg is compared with the behaviour of the Wolf number R of sunspot during the cycles n? 18, 19 and 20. In

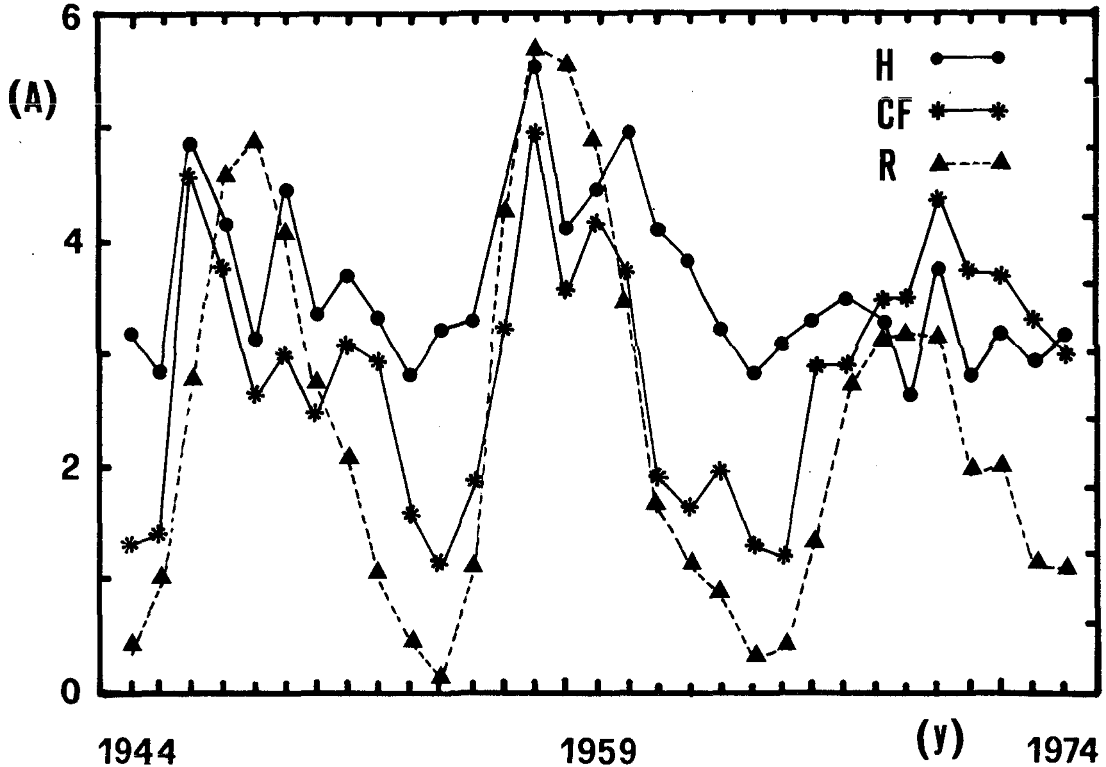


Fig.3 - Variations in solar cycles nº 18, 19 and 20 of sunspot number (R) and 13-day oscillation amplitudes of cosmic-ray intensity at Huancayo (H) and Cheltenham-Fredericksburg (C-F).

the solar cycle n? 18 (1944-1953), the Wolf number R, shows a maximum in 1947 anda hint to a secondary maximum in 1949, while the average amplitude for both stations has a maximum in 1946. It is not clear the second maximum at 1952 found by Venkatesan[6] and confirmed by Lovera *et al.*[7] for the 27-day oscillation. In the solar cycle n? 19 (1954-1964) the average amplitude for the 13 day oscillation shows two prominent maxima: one in 1957 and another in 1959 (Huancayo) or 1960 (Fredericksburg). Furthermore a less prominent maximum is found in 1963 at Huancayo. This third maximum was pointed out yet by Lovera *et al.*[8], and so the third one for the 27-day oscillation. On the countrary the sunspot number *R* has only a maximum in 1957 (a value a bit smaller appears in 1958).

In the n? 20 cycle the solar activity has been largely less than those of n? 19 and n? 18 cycles, as we can see, from the Wolf sunspot number R behaviour, that presents a broad maximum during the years 1968, 1969 and 1970. The 13-day oscillation of cosmic-ray intensity shows, both for Huancayo and Fredericksburg a maximum in 1970. The values of the average amplitude of the 13-day oscillation at Huancayo, during the years 1973 and 1974 remain anomalously high. During these years, where the solar activity exhibits a very deep decrease, is seems that the oscillation of about 13 days appears strictly controlled by the boundary crossing of the interplanetary magnetic field sector structure[9].

The nagative correlation between the annual cosmic-ray intensity and the amplitude of the 13-day oscillation in see in fig. 4 **(a)** and (b) both for the station of Huancayo and Cheltenham-Fredericksburg.

In the years of high solar activity in which appear many proheminents Forbush decreases (and so the annual mean cosmic-ray intensity is low) the values of the amplitude of the 13-day oscillationare higher than in the other ones. These amplitudes are indicated with arrows in fig. 4 (a) e (b). In conclusion, it is interesting to point out the strict connection observed during the years 1973 and 1974[9] between the 13-day oscillation of the cosmic-radiation and the modulation dueto the boundary crossing of the two-sector interplanetary magnetic field corotating with the sun. Therefore, for the 13-day oscillation there is a reality criterion based on the existence of a physical phenomenon that originates it, beside the mathernatical formalism for the analytical representation of the temporal variation of the cosrnic-ray intensity.

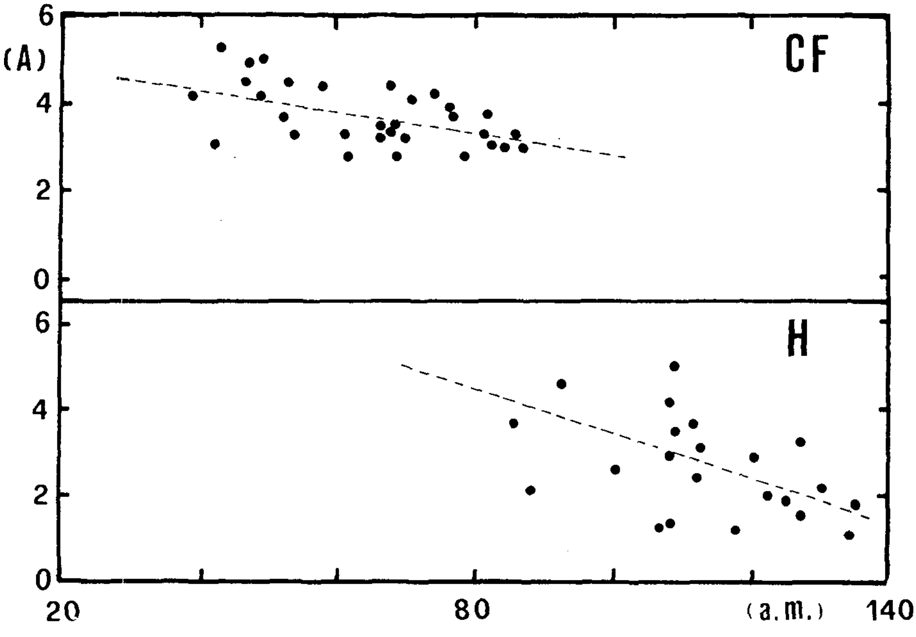


Fig.4 - Negative correlation between the annual mean cosmic-ray intensity (a.m.) and the amplitude of the 13-day oscillation at Huancayo (a) and Cheltenham-Fredericksburg (b).

REFERENCES

1. S.E.Forbush, 1966, in S.Flugge (ed), *Handbuch der Physik*, Springer--Verlag, New York, 49/1, 159.

2. L.I.Dorman: Geophysical and Astronomical Aspects of Cosmic- Radiation, Progress in Element. Part. and Cosmic-Ray Phys., 7, 100 (1963).

3. S.E.Forbush: Bull. Int. Union Geod. Geophys, 11, 438 (1940); G. Lovera: Atti Acc. Sc. Lett. Arti Modena, *17*, 3 (1959); Geofisica e Meteorologie, 27, 33 (1968); M.Wilcos, N.F. Ness: J. Geophys. Res., 70, 5793 (1965).

4. F.Vercelli: "Guida per l'analisi della periodicità nei diagrammi oscillanti". Comitato Talassografico Italiano del C.N.R., Mernoria 285 (1940); G.Lovera and C.Oldano, N.Cim. 2B, 28 (1971); G.A.Bazilevskaya, V.P.Okhlopkov, T.N. Charakhch'yan: "The 27-day cosrnic-ray variations and

their relationship to the nonuniform distribution of active regions on the sun". Proceedings of the P.N.Lebedev Physics Institute, ***88,*** 89-107 (English translation, 1978).

5. K.Stumpff: "Ermittlung und Realität Von Periodizitäten Korrelations-rechnung", Hdb. der Geophysik, Bd. X, Lief I (Berlin 1940) 58-60.

6. D.Venkatesan: Tellus, *10,* 117 (1958), Il Nuovo Cimento Suppl. 8,285, (1958); V.R.Balasubrahmanyan, D.Venkatesan: Solar Physics, *11*, 151 (1970).

7. G.Lovera, O.Filisetti, V.Mussino and P.G.Tedde, Rev. Bras. de Fisica, *11,* nº 2, 359-373 (1981).

8. O.Filisetti, G.Lovera, C.Oldano and P.G.Tedde - Il Nuovo Cimento Lettere, *11,* 29 (1974).

9. O.Filisetti, G.Lovera and V.Mussino, Rev.Bras.de Fisica, *11,* n? 3, 653 (1981).