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H-alpha flare associated microwave emissions

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Abstract. We have carried out a statistical association of 321 two-ribbon and 1564 non two-ribbon (normal) H-alpha flares which occurred during 1976 to 1980 with microwave bursts in the frequency range 3–35 GHz. Important results obtained are as follows. (i) The two-ribbon (TR) flares show 1.5 to 3 times higher correlation as compared to normal (N) flares, indicating that TR flares are strong emitter of microwave emissions. (ii) The TR flares show 2 to 4 times better association as compared to N flares with impulsive microwave bursts ($\geqslant 10^2$ sfu) thereby further indicating that they are energetic flares. (iii) The higher correlation of TR flares with impulsive microwave bursts is perhaps due to their occurrence in complex magnetic configurations. This implies that it is the strong magnetic field gradient which is responsible for the production of two-ribbon flares and hence for nonthermal electrons which give rise to impulsive microwave bursts. (iv) The strong and weak correlation of TR flares and N flares respectively, with impulsive microwave bursts at higher frequencies (10–35 GHz) indicates that the source of the TR flares is near photosphere or the low chromosphere (strong magnetic fields) and that of the normal flare is the upper chromosphere (weak magnetic fields).

Key words : solar flares—microwave bursts

1. Introduction

Generally all types of solar radio bursts are more or less directly associated with solar flares seen in visible light. Thus the optical flare is one aspect of the flare-bursts phenomenon. The largest contribution to the optical radiation comes from the photosphere and lower and upper chromosphere whereas the radio emission originates in the chromosphere and the corona. Thus flare-bursts phenomenon occurs at different heights in the solar atmosphere in different ways. Further, it is not necessary that all flares occurring on the sun will produce all types of solar radio bursts. The bursts of lower intensity (< 100 sfu) sometimes appear without reported H-alpha flares, and for weak bursts ($\leqslant 20$ sfu) the correlation with flares is only 65% (Kundu 1965). The correlation with reported flares appears to be much better when bursts at millimeter wavelengths are considered, where essentially all bursts are associated with H-alpha flares (Shimabukuro 1968, Croom & Powell 1971). The reverse association is weaker: only about 60% of H-alpha flares of importance 1 are accompanied by bursts at 10 GHz and for sub-flares the correlation percentage is very small (Kundu 1965). This association however is different for different active regions. In some of them microwave bursts do not occur at all. In others, particularly where a magnetically complex configuration forms, microwave bursts accompany almost all flares and even many subflares (Svestka & Simon 1969; Svestka 1971; Matsuura & Nave 1971; Kruger 1972).

In this paper we attempt to find out which of the two types of H-alpha flares—two-ribbon (TR) or non two-ribbon, i.e. normal (N), is more frequently associated with various types of microwave bursts in the frequency range 3–35 GHz. The correlation is made separately for H-alpha importance classes 1, 2, 3, and above for the period 1976–80, (ascending phase of cycle 21) to determine which type of flare (TR or N) is a stronger emitter of microwave bursts in the same importance class.

2. Data selection

An H-alpha flare is called two-ribbon (TR) if it has two bright parallel or converging branchcs seen on the solar disc, or has a system of loop prominences at solar limb. Such a criterion was given by Bruzek (1964). In our analysis a flare is designated as TR flare if in the 'remarks' column of H-alpha solar flare data in solar & geophysical publications, at least one station has reported it as U or Y. All other flares are considered as non two-ribbon or normal (N) flares. The analysis is made only for flares of importance 1, 2, 3, or above. A flare is selected as class 1 flare if at least one station has reported it to be of importance 1, and so on. However, flares of importance above 3 are also included in class 3. A detailed methodology for selection of H-alpha flares for statistical analysis is described in Krivsky (1969, 1973, 1974) and Jain (1983). A total of 321 TR and 1564 N flares during 1976–1980 were analysed for correlation with microwave bursts. We have made groups of frequency interval in which microwave flux enhancement is observed. The groups A, B, C, D and E are made in such a way that when a flare is associated with microwave (MW) bursts during this period, some stations opearate in each group interval. The frequency group intervals are as follows:

A	2950–3100 MHz	$\sim$ (3 GHz)
B	5730–7100 MHz	$\sim$ (6 GHz)
C	9100–9500 MHz	$\sim$ (9.3 GHz)
D	10400–10715 MHz	$\sim$ (10.5 GHz)
E	35000 MHz	= (35 GHz)

3. Analysis and results

Table 1 summarizes the association of H-alpha flares (TR and N) with MW bursts. The number of flares analysed and associated with MW flux enhancement in different

Table 1. Associatlon of H-alpha flares with MW-bursts in different frequency groups during 1976–80

Frequency (MHz)	Flare type	H-alpha flares	Flares associated	%	Association in different importance class								
					1			2			3		
					H-alpha flares	Assoc. flares	%	H-alpha flares	Assoc. flares	%	H-alpha flares	Assoc. flares	%
2950–3100	TR	321	144	45	204	72	35	96	55	57	21	17	81
	N	1564	490	31	1336	371	28	212	110	52	16	9	56
5730–6100	TR	321	38	12	204	14	7	96	13	14	21	11	52
	N	1564	225	14	1336	151	11	212	70	33	16	4	25
9100–9500	TR	321	127	40	204	69	34	96	46	48	21	12	57
	N	1564	428	27	1336	324	24	212	98	46	16	6	38
10400–10715	TR	321	55	17	204	22	11	96	23	24	21	10	48
	N	1564	182	12	1336	136	10	212	42	20	16	4	25
35000	TR	321	27	8	204	7	3	96	11	11	21	9	43
	N	1564	52	3	1336	30	2	212	21	10	16	1	6

frequency groups are given for each importance class. Shown in figure 1 are histograms of percentage association of TR (open) and N (hatched) flares in different importance class with MW flux enhancement in different frequency groups. It is obvious that the TR flares are 1.5 to 3 times better associated with MW bursts in all frequency groups except in 5730–6100 MHz frequency interval. The percentage association increases from class 1 to class 3 in TR flares in each frequency interval but this is not true for N flares in some frequency intervals. The association of

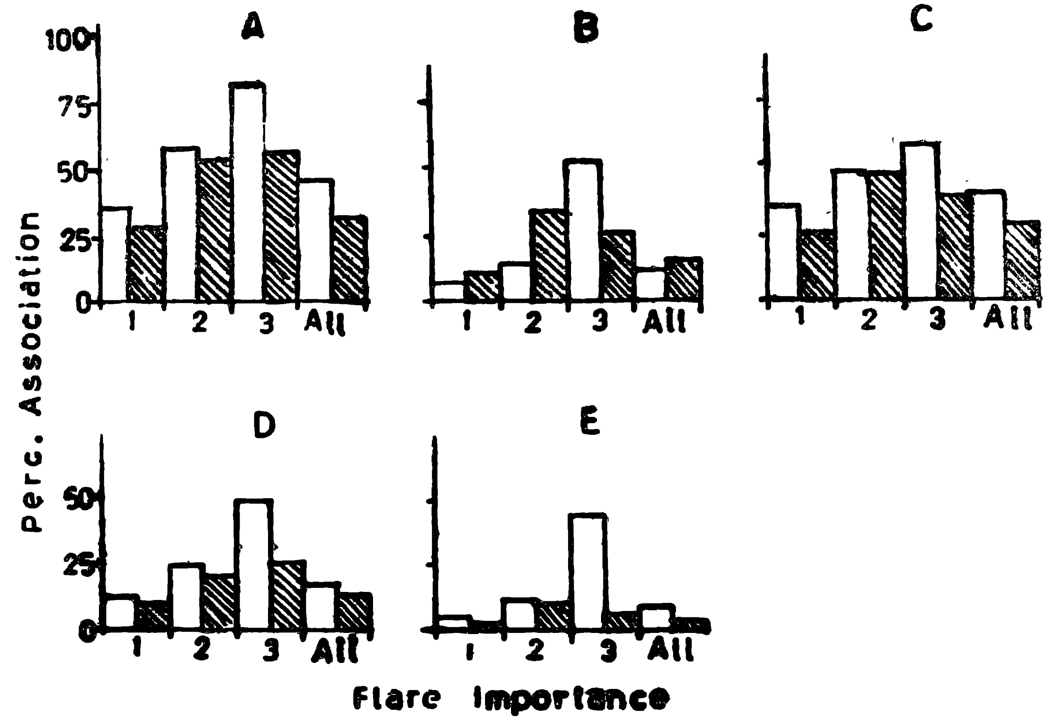

Figure 1. Histograms showing percentage association of TR (open) and N (hatched) H-alpha flares of different importance class with microwave bursts at different frequencies during 1976–80.

H-alpha flares with MW bursts decreases towards higher frequency in all importance class, no matter whether the flares are two-ribbon or normal. In figure 2, we have attempted to show the variation in percentage association from 3 GHz to 35 GHz. The correlation decreases abruptly from 3 GHz to 6 GHz in both TR and N flares. However, at 6 GHz the association of N flares of class 1 and 2 is 1.5 times higher than TR flares for the same importance class. This is no longer true for class 3 flares as TR flares are 2 times better correlated with MW bursts at this frequency (6 GHz). For all other frequencies (except 6 GHz) the percentage association of TR flares in each importance class remains higher than N flares of the same importance. For centimetric bursts (3–10.5 GHz) the percentage association

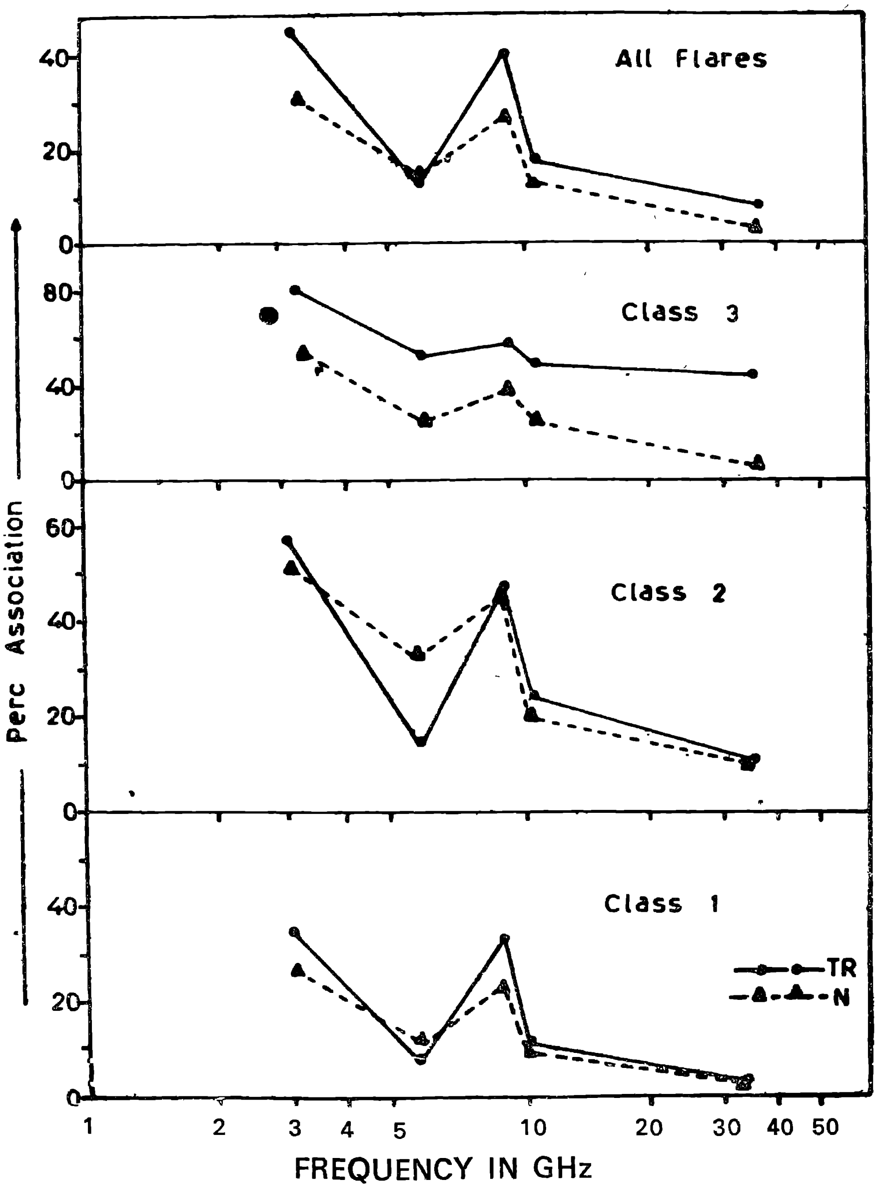

Figure 2. Plots showing variation in percentage association in different H-alpha importance class of TR and N flares with microwave bursts in the range 3 to 35 GHz.

of TR flares, irrespective of importance class, is 1.5 times higher than N flares (except at 6 GHz), and for millimeter bursts (35 GHz) TR flares have almost 3 times higher correlation with MW bursts as compared to N flares. A better correlation of TR flares as compared to N flares with MW bursts at various frequencies gives us an idea that TR flares of any importance are stronger than N flares of the same importance class. However, this may be confirmed in an alternative way which is discussed below.

The gradual MW bursts associated with flares, called 'gradual rise and fall' and 'post-burst increases' are considered to be of the same origin as the soft x-ray burst, i.e., due to thermal bremsstrahlung (Kawabata 1966; Kundu 1963; Elwert 1964). These thermal radio bursts are generally weak, mostly below 40 sfu (or 10^2 sfu), in the range 3 mm (100 GHz) and 20 cm (1.5 GHz). On the other hand, implusive microwave bursts, i.e., fast radio enhancement of frequencies above 1 GHz occur simultaneously with hard x-ray bursts and have similar characteristics. The maximum flux of impulsive bursts is often much higher ($\geqslant 10^2$ sfu) and it can exceed 10^4 sfu in case of outstanding events. The gyrosynchrotron is a possible mechanism for impulsive microwave bursts.

The percentage association of TR flares and N flares with MW bursts having peak flux $\phi_{\max} < 10^2$ sfu and $\geqslant 10^2$ sfu has been determined to see which category of flares (TR or N) give higher number of impulsive bursts. Given in table 2 is the percentage correlation of H-alpha flares with microwave bursts of maximum flux below 10^3 and above 10^2 sfu in each importance class and at frequencies ranging from 3 GHz to 35 GHz during 1976–80. Shown in figure 3 are the variation in percentage association of flares at different frequencies under reference $< 10^2$ sfu and $> 10^2$ sfu.

The data in table 2 show that the percentage association of TR flares with MW bursts having peak flux $< 10^2$ sfu is not much higher as compared with N flares. The N flares of each importance class show at all frequencies very high correlation with MW bursts below 10^2 sfu as compared to above 10^2 sfu. In the case of TR flares, class 1 and 2 importance flares indicate slightly higher correlation with MW bursts below 10^2 sfu whereas TR flares of importance 3 showed completely reverse association, i.e., they were associated with higher percentage at all frequencies to the MW bursts having peak flux above 10^2 sfu (*cf.* figure 3). However, the

Table 2. Percentage association of H-alpha flares with MW-bursts (3 GHz to 35 GHz) of flux below and above 10^2 sfu

Frequency interval in MHz	Two-ribbon flares								Normal flares							
	$< 10^2$ sfu				$> 10^2$ sfu				$< 10^2$ sfu				$> 10^2$ sfu			
	1*	2	3	All flares	1	2	3	All flares	1	2	3	All flares	1	2	3	All flares
2950 – 3100	32	40	14	33	4	18	67	12	25	39	38	27	3	13	19	4
5730 – 6100	6	9	24	8	0.5	2	38	3	10	22	25	11	2	11	0	3
9100 – 9500	30	29	14	28	4	19	43	11	20	31	19	22	4	15	19	6
10400–10715	8	13	14	10	3	11	38	8	8	11	13	9	2	8	6	3
35000	3	5	19	5	0.5	6	24	4	2	7	6	2	0.5	3	0	1

*1, 2, 3 are the importance classes in H-alpha flares. Class 3 also includes higher class.

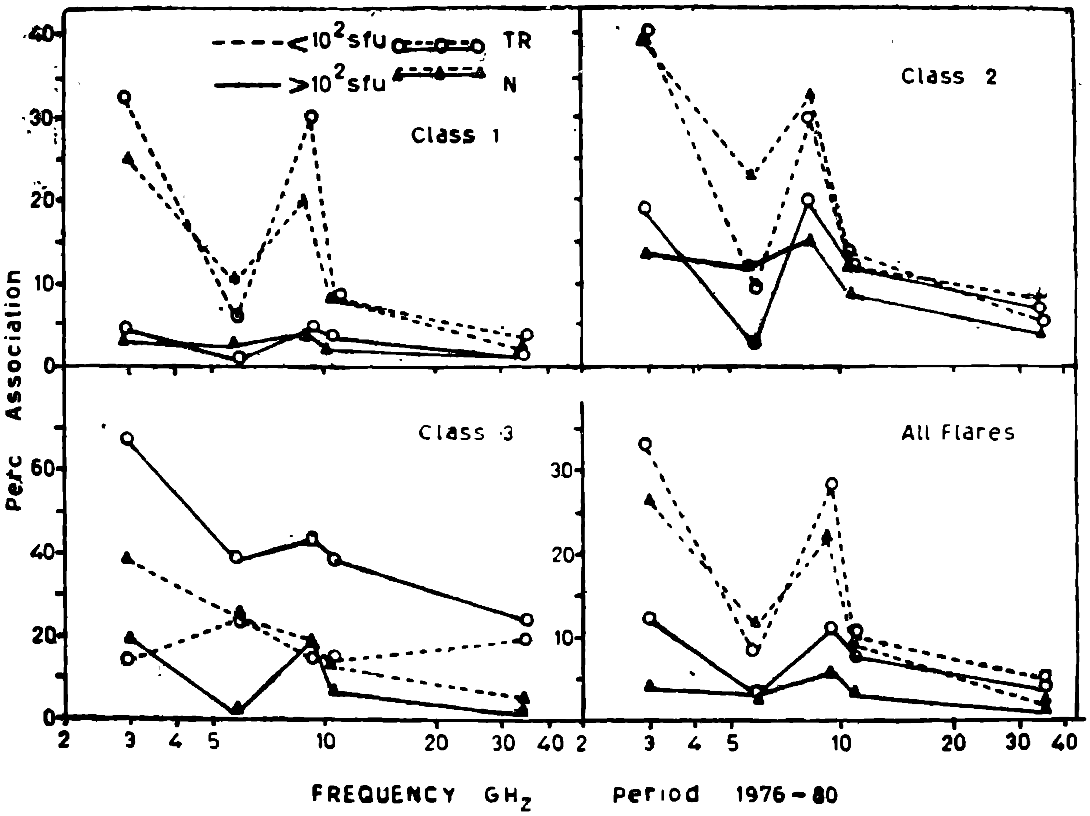

Figure 3. Plots showing percentage association of H-alpha TR and N flares with thermal ($< 10^2$ sfu) and nonthermal ($> 10^2$ sfu) microwave bursts in the frequency range 3 to 35 GHz.

percentage association of N flares with MW bursts of peak flux above 10^2 sfu is very low and ranges between 1 to 6 at different frequencies. On comparing the percentage association of TR and N flares in each importance class with MW bursts of peak flux above 10^2 sfu, we find that almost all TR flares have 2 to 4 times higher correlation as compared to N flares of the same importance class. This implies that TR flares are strong flares as they are capable of producing impulsive microwave bursts more often as compared to N flares.

4. Discussion

The magnitudes of the H-alpha and microwave emission parameters are observed to vary from one flare to another according to the flare's location within the active region thereby suggesting that the strength of the magnetic field plays a role in the active region (Neidig 1978). Similar efforts, relating the flare position to the quality of its emission have been reported earlier by Malville & Smith (1963) and Dodson & Hedeman (1970). According to Donnelly (1973) strong magnetic fields are required for the production of impulsive emission.

Our results show that N flares rarely produce impulsive microwave bursts. Further, association of N flares with thermal bursts is comparable with that of association of TR flares with thermal bursts. This implies that N flares are low-energy phenomena. But on the other hand, TR flares produce 2–4 times more impulsive microwave bursts as compared to N flares, indicating that the TR are strong flares. Furst (1971) analysed more than 1000 bursts by plotting average fluxes in various frequency bands and suggested that the resulting relationship of approximately $\phi_{\max} \sim f^2_{\max}$ could be interpreted as $\phi_{\max} \sim B^2$ on the assumption that $f_{\max} \sim B$. (Takakura 1967), where $f_{\max}$ is the peak flux frequency. This implies that impulsive microwave bursts with flux $> 10^2$ sfu are formed in strong magnetic fields of 500–1000 G regions. From the correlation study of TR and N flares with MW bursts, we infer that such impulsive MW bursts are better associated with TR flares than N flares. This suggests that the strong magnetic field regions produce TR flares. Using high resolution H-alpha observations of TR flares and magnetograms of the active regions, Jain (1983) showed that complex spot groups, in which polarities are mixed, or polarities intermingle, or reversed polarity appears, give strong and higher importance TR flares. Further, it has been well established that microwave bursts accompany almost all flares and even many subflares appearing in magnetically complex configuration (Svestka & Simon 1969; Svestka 1971; Kruger 1972). Also impulsive type of microwave bursts are more associated with spots having 'changing type' of magnetic configuration (Das Gupta *et al.* 1977). Thus it is the complex magnetic configuration of the active region or, in other words, magnetic field gradient is important for the production of TR flares and hence the non-thermal electrons to give rise to impulsive MW bursts.

The strong correlation of TR flares with impulsive microwave bursts inferred from figure 3 at higher frequencies (10 GHz–35 GHz) indicates that emission from a height 0.002–0.001 $R_{\odot}$ above the photosphere is capable of moving out from the source at this height. Thus source of the TR flare is near photosphere or in the lower chromosphere (strong magnetic fields) and perhaps that of the N flare is in the upper chromosphere (weak magnetic fields). It is obvious that gyrosynchrotron is more effective in strong magnetic fields and hence the higher correlation of two-ribbon flares with impulsive microwave bursts is unambigous.

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References

Bruzek, A. (1964) *Ap. J.* **140**, 746.
Croom, D. C. & Powell, R. J. (1971) *Solar Phys.* **20**, 136.
Das Gupta, M. K., Chattapodhayay, T. & Sarkar, S. K. (1977) *Solar Phys.* **51**, 409.
Dodson, H. W. & Hedeman, F. R. (1970) *Solar Phys.* **13**, 401.
Donnelly, R. F. (1973) in *Symp. on High Energy Phenomena on the Sun*, NASA, GSFC, p. 242.
Elwert, G. (1964) in *AAS-NASA Symp. on Physics of Solar Flares*, p. 365.
Furst, E. (1971) *Solar Phys.* **18**, 84.
Jain, R. (1983) *Ph.D. Thesis*, Gujarat Univ.
Kawabata, K. (1966) *Rep. Ionos. Space. Res. Japan* **20**, 118.
Krivsky, L. (1969) *Solar Phys.* **9**, 194.

Krivsky, L. (1973, 1974) *Bull. Astr. Inst. Czech.* **24**, 96; **25**, 62.
Kruger, A. (1972) *Solar Phys.* **27**, 217.
Kundu, M. R. (1963) *Space. Sci. Rev.* **2**, 438.
Kundu, M. R. (1965) *Solar Radio Astronomy*, Interscience.
Malville, J. M. & Smith, S. F. (1963) *J. Geophys. Res.* **68**, 3181.
Matsuura, O. T. & Nave, M. F. F. (1971) *Solar Phys.* **16**, 417.
Neidig, D. F. (1978) *Solar Phys.* **57**, 385.
Shimabukuro, F. I. (1968) *Solar Phys.* **5**, 498.
Solar and Geophysical Data (1976–1980) NOAA, Boulder.
Svestka, Z. & Simon, P. (1969) *Solar Phys.* **10**, 3.
Svestka, Z. (1971) *Solar Phys.* **19**, 202.
Takakura, T. (1967) *Solar Phys.* **1**, 314.