Publications of the Department of Astronomy — Beograd. № 3, 1971.

# THE CRITERIA FOR HOMOLOGOUS RADIO EVENTS ASSOCIATED WITH FLARES

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## INTRODUCTION

Though Waldmeier in 1938 as well as Dodson and Hedeman in 1949 already perceived that some solar flares were repeating for more days at the same spot exactly, the idea of homology for optical flares had been introduced by Ellison, Mc Kenna and Reid in 1960 (**1**). They defined them as: „. . . . flares which occur successively in the same active region, correspond in position to the local sunspots and show a common pattern and development". Fokker and Roosen (**2**) extended the concept of homology to the flare associated radio events as well. In his later work (1967) Fokker (**3**) gave some additional informations and a criterion of homology for radio events. In 1969 Pinter (**4**) indicated the existence of homology for solar x-ray burst. In 1970 White and Janssens (**5**) confirmed Fokker's assumption that the optical homologous flares are associated with homologous radio events. Gopala Rao reached the same conclusion in 1970 (**6**). Studying the relationship between optical flares and radio events the cited authors (**5, 6**) observed that there had been some inadequacies in the definition of homology in the radio domain though they did not exhibit precisely where the problem is neither gave some suggestion for solving it.

The purpose of this contribution is to derive a conclusion by analysing the homologous radio events as to what are the strong and weak points of Fokker's criteria. In addition, an attempt has been made to improve these criteria by introducing certain contributions.

## ANALYSIS OF FOKKER'S CRITERIA FOR HOMOLOGOUS RADIO EVENTS

The degree of homology is denoted with $H$ and is obtained by comparing the duration and intensity of two radio events at exactly defined frequencies as follows: 9,000; 3,000 (or 3,750); 550 (or 600); 200; 110 and 20 MHz.

I) A contribution of 0.25 is given to $H$ for each of these frequencies at which both radio events produce a response.

II) For each of the frequencies 3000, 550 and 200 MHz a contribution of 0.25 is added to $H$ whenever the durations of the responses differ by less than a factor 3.

III) A contribution of 0.5 is added if the peak intensities of the response at 3000, 550 and 200 MHz differ by less than a factor 3.

IV) The additional convention is adopted and a contribution of 1.0 is given to $H$ if both radio events produce responses at centimetric and metric frequencies, but fail to do so at 550 MHz.

According to the above criteria the maximum possible value of $H$ is 3.75, and those pairs of radio events are homologous if $H$ equals 3 or more.

These have been the only published criteria for homology of radio events so far (**3**). Investigating the time period between two homologous radio events Fokker found that the greatest number was repeated in a time period less than 48 hours.

Analysing a larger number of homologous radio events according to a.m. criteria by using the Solar — Geophysical Data (Boulder) we have come to the following conclusions. The adequacy of these criteria is in the following:

1) the selection of homologous radio events and an estimation of degree (extent) of their homology have been made possible;

2) it is possible to analyse the radio events on the basis of tabular data published in journals as: Quarterly Bulletin on Solar Activity or Solar Geophysical Data, but original time curves of radio events may not be available;

3) these criteria provide an objectiveness in the statistical processing of data what is not the case with the criteria for optical homology which are subjective in general;

4) they are applied easily.

But, there appear certain problems, too, as for example:

1) Depending on the selection of related available frequencies there are obtained various values for the homology degree $H$. This multivocality becomes a problem when the range of values for $H$ is great; e. g. with the Solar flare on August 11, 1969 (example 6a in Table 1). The pair of homologous radio events following this flare was as follows:

   August 11, 1969 0944 U. T. and August 11, 1969 1220 U. T.

   For these radio events there exist data on radio burst at the frequencies of: 200, 225, 234, 235, 240, 260 MHz, that is, 536, 600, 606 and 610 MHz, i. e. 2695, 2800, 2900 and 3000 MHz. Here the value of $H$ will vary considerably depending on which combination of three frequencies according to Fokker is selected for criteria II) and III). The difference is so great that the final value of $H$ of this pair of events varies as $H = 1.75 - 3.50$. This means that it is up to the selection of related frequencies whether two events will be highly homologous ($H = 3.50$) or they will not be at all ($H = 1.75$). There are many such examples. In Table 1 eight examples are cited.

2) Equal importance is attributed to all frequency ranges: cm, dm, m and dkm. Thus for example, if for a radio burst we have not the data available at $f \leqslant 200$ MHz, then two such events cannot be homologous according

to Fokker though they otherwise show an agreement as to their duration and intensity at all the remaining frequencies within the cm and dm wave band. Since the emission on metric and decametric wavelengths takes place at great distance from the spot the flare develops, we are of the opinion that the lack or disagreement of emission on these waves should not be decisive for the appraisal of homology of the events observed. In this case, the analysis of time curves would be decisive but they are not always reachable and the appraisal is subjective at last.

3) Confining ourselves to three fixed frequencies only: 3000, 550 and 200 MHz with the criteria II) and III) we miss the opportunity to use a great number of related frequencies. Due to this, these criteria become irrational in the application of plenty of tabular data being published in modern bulletins already mentioned extending detailed information on radio events.

## SUPPLEMENT TO FOKKER'S CRITERIA

For the purpose of removing the a.m. drawbacks of Fokker's criteria herewith we suggest the following:

1) In the analysis of two radio events not to limit oneself to three or six fixed frequencies but compare any identic frequencies in the cm — dm — m waveband. For each of three cited bands in which the emissions of two events appear at any frequencies, a contribution of 0.25 is given to $H$. The maximum obtainable in this way is $H = 0.75$. We think that thus the multivocality of parameter $H$ will be avoided.

2) For each pair of frequencies for which the data are available and at which the duration of events does not differ by more than factor 3, a contribution of 1 divided by total number of frequencies is added. Thus we get

$$H = \frac{n}{n_{tot}}$$

where: $n$ — number of frequencies satisfying the criterion of duration,
$n_{tot}$ — total number of frequencies available.

Maximum contribution is $H = 1$, if all frequencies satisfy the criterion of duration and the minimum $H = 0$ if none frequency satisfies that criterion.

3) For each pair of frequencies for which we have data available, if the peak intensity does not differ by more than factor 3 a contribution of $\frac{1}{n_{tot}}$ is added. Maximum contribution is $H = 1$.

By their essence the criteria 2) and 3) are Fokker's criteria II) and III) but here duration and peak intensity are of the same importance. Besides, it has been made possible to use all the available frequencies and carry out a refined analysis of homology degree from 0 to 1.

4) For each pair of frequencies of two radio events being of the same type, a contribution of $\frac{1}{n_{tot}}$ is added. The maximum number obtainable, if

the types of both events agree at all available frequencies is $H = 1$, and the minimum, if none type agrees is $H = 0$.

This is a new criterion Fokker did not considered and concerns the type of radio events. Our opinion was that type is an important parameter in estimating the homology degree of radio events because it gives us some information on the spot and procedure of origin of radio emission we are observing.

According to these criteria (1 — 4) the maximum value of homology degree is $H = 3.75$, while those two radio events should be considered homologous for which $H \geqslant 2.90$.

## AN ADDITIONAL CONDITION

If the number of frequencies observed is greater or equal to 10, the quantity 0.25 will be added to the degree of homology.

The additional condition has been stated to reflect a great number of data onto the degree of homology, the former being of greater statistical importance, exclude occasional agreement of the events observed at several frequencies, and reduces eventual differences between particular observations. Maximum value for $H$ in this case is $H = 4.00$ whereby those events are homologous for which $H \geqslant 2.90$.

It is evident from the cited criteria and suggested quantities for $H$ that our intention was to keep all the strong points of Fokker's criteria and the modifications were done only for the purpose of removing the problems listed under items 1 — 3.

To demonstrate on examples how much we have succeeded in this, we have analysed the following events:

Example 1

| optical flares | beg. | max. | dur. | coor. | McMath | imp. |
|---|---|---|---|---|---|---|
| Dec. 11, 1967 | 1442 | 1448 | 24 | N15; W44 | 9101 | —N |
| Dec. 13, 1967 | 1609 | 1612 | 9 | N11; W73 | 9101 | —B |

radio events:

| | | |
|---|---|---|
| Dec. 11, 1967 | 1441—1445 | U.T. |
| Dec. 13, 1967 | 1610 | U.T. |

Example 2

| optical flares | beg. | max. | dur. | coor. | McMath | imp. |
|---|---|---|---|---|---|---|
| Oct. 30, 1968 | 2339 | 0013 | 114 | S14; W37 | 9740 | 3B |
| Oct. 31, 1968 | 2232 | 2245 | 90 | S15; W49 | 9740 | 2N |

radio events:

| | | |
|---|---|---|
| Oct. 30, 1968 | 0011 | U.T. |
| Oct. 31, 1968 | 2257—2301 | U.T. |

Example 3

| optical flares | beg. | max. | dur. | coor. | McMath | imp. |
|---|---|---|---|---|---|---|
| Nov. 1, 1968 | 0830 | 0844 | 73 | S15; W47 | 9740 | 1N |
| Nov. 2, 1968 | 0949 | 1012 | 59 | S14; W66 | 9740 | 2B |

| radio events: | | |
|---|---|---|
| Nov. 1, 1968 | 0912 | U.T. |
| Nov. 2, 1968 | 0956 | U.T. |

Example 4

| optical flares | beg. | max. | dur. | coor. | McMath | imp. |
|---|---|---|---|---|---|---|
| May 3, 1969 | 1945 | 1955 | 45 | N06; W59 | 10057 | 1N |
| May 5, 1969 | 1240 | 1245 | 17 | N09; W77 | 10057 | 1N |

| radio events: | | |
|---|---|---|
| May 3, 1969 | 1948 | U.T. |
| May 5, 1969 | 1238 | U.T. |

Example 5

| optical flares | beg. | max. | dur. | coor. | McMath | imp. |
|---|---|---|---|---|---|---|
| May 18, 1969 | 1710 | 1720 | 36 | N08; E83 | 10109 | 1B |
| May 19, 1969 | 1431 | 1435 | 27 | N07; E67 | 10109 | 1B |

| radio events: | | |
|---|---|---|
| May 18, 1969 | 1719 | U.T. |
| May 19, 1969 | 1433 | U.T. |

Example 6

| optical flares | beg. | max. | dur. | coor. | McMath | imp. |
|---|---|---|---|---|---|---|
| Aug. 10, 1969 | 1420 | 1432 | 12 | S21; W49 | 10250 | —B |
| Aug. 11, 1969 | 1938 | 0945 | 21 | S22; W57 | 10250 | 1B |
| Aug. 11, 1969 | 1212 | 1223 | 31 | S22; W60 | 10250 | 1B |

| radio events: | | |
|---|---|---|
| Aug. 10, 1969 | 1423 | U.T. |
| Aug. 11, 1969 | 0944 | U.T. |
| Aug. 11, 1969 | 1220 | U.T. |

Detailed analysis of radio events in the above mentioned examples at all frequencies in the cm, dm and m waveband both by duration, peak intensity and type of the burst as well, gave results that are listed in Table 1.

Table 1.

| Example | $H$ after Fokker | cm, dm, m | $\frac{n}{n_{tot}}$ for duration | $\frac{n}{n_{tot}}$ for peak intens. | $\frac{n}{n_{tot}}$ type | $n_{tot}$ | $H^*$ | $H^{**}$ |
|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 1 | | 0.50 | 0.60 | 1.00 | 0.60 | 5 | 2.70 | |
| 2 | 2.75 | 0.75 | 1.00 | 1.91 | 1.00 | 12 | 3.66 | 3.91 |
| 3 | 2.75—3.50 | 0.75 | 0.94 | 0.62 | 0.84 | 18 | 3.15 | 3.40 |
| 4 | 3.00—3.25 | 0.75 | 0.64 | 0,72 | 0.36 | 11 | 2.47 | 2.72 |
| 5 | 2.50—3.50 | 0.75 | 0.41 | 0.58 | 0.41 | 17 | 2.15 | 2.57 |
| 6 a | 2.75—3.25 | 0.75 | 1.00 | 0.78 | 0.73 | 15 | 3.26 | 3.51 |
| b | 2.25—2.50 | 0.75 | 0.90 | 0.66 | 0.73 | 19 | 3.04 | 3.29 |
| c | 1.75—3.50 | 0.75 | 0.90 | 0.85 | 0.65 | 29 | 3.15 | 3.40 |

$H^*$ value for the degree of homology according to new criteria $H_{max} = 3{,}75$

$H^{**}$ value for the degree of homology with the additional condition $H_{max} = 4.00$.

By analysing Table 1 we can come to a conclusion that by means of new criteria we have omitted the multivocality for the value $H$ what has been quite ordinary earlier (column 2). If we look at example 5 it would be highly homologous, $H = 3.50$, if strictly applying Fokker's criteria ($f = 200$, 600, 3000 MHz). But, out of 17 pairs of frequencies (column 7) only 41% agree by duration, 58% by peak intensity, and only 41% by the type. Consequently, low degree of homology, $H = 2.15$ or 2.57 should not surprise us. It indicates that these two events agree only at several frequencies what is not sufficient to declare them homologous. Similar situation is with example 4, too.

A contrary picture shows example 2 that will be illustrated in more detail in Table 2 for the purpose of making it evident.

The degree of homology calculated according to Fokker's criteria is $H = 2.75$ what would mean that these two radio events are not homologous. This result is a consequence of the fact that both radio events do not have emission at 110 and 20 MHz and that their peak intensity differs by more than factor 3 at 500 MHz. The result would be even worse if we would hold on strictly the prescribed fixed frequencies. However, from 12 pairs of frequencies all are of the same type and all fulfill the criterion of duration. Only one out of 12 frequencies does not satisfy the criterion of peak intensity at 500 MHz. Natural conclusion is that these two radio events are homologous so that even if the additional condition is not taken into account, the degree of homology amounts to $H = 3.66$ (Table 1 — column 8), and if this condition considered, $H = 3.91$ what indicates a high degree of homology.

Similar situation is with example 3 and example 6, as well, under a), b) and c) as evident from Table 1.

30. X 1968. 0011 U.T. Table 2.

| Frequency MHz | type | durat (min) | peak intensity $10^{-22}$ Watt $m^{-2}$ $(c/s)^{-1}$ |
|---|---|---|---|
| 1 | 2 | 3 | 4 |
| 200 | complex | 60 | 790.0 |
| 208 | complex | 56 | 311.0 |
| 500 | complex | 118 | 5050.0 |
| 1000 | complex | 60 | 475.0 |
| 1415 | complex | 39.5 | 610.0 |
| 2000 | complex | 60 | 1200.0 |
| 2695 | complex | 39.5 | 1680.0 |
| 3750 | complex | 60 | 2150.0 |
| 4995 | complex | 40.7 | 2855.0 |
| 8800 | complex | 40.7 | 1950.0 |
| 9400 | complex | 60 | 2000.0 |
| 1700 | complex | 40 | 940.0 |

30. X 1968. 2257—2304 U.T.

| | | | |
|---|---|---|---|
| 200 | complex | 40 | 470.0 |
| 208 | complex | 39 | 333.0 |
| 500 | complex | 48 | 190.0 |
| 1000 | complex | 100 | 195.0 |
| 1415 | complex | 91.2 | 254.5 |
| 2000 | complex | 100 | 720.0 |
| 2695 | complex | 91.2 | 1112.0 |
| 3750 | complex | 100 | 800.0 |
| 4995 | complex | 91.2 | 2060.0 |
| 8800 | complex | 91.2 | 1905.0 |
| 9700 | complex | 100 | 2270.0 |
| 17000 | complex | 50 D | 400.0 D |

## CONCLUSION

By some modifications in the existing criteria for homology of the radio events and introducing the type as an important parameter indicating the origin and functioning of the radio emission, we believe that the classification and possibility for comparing the radio events will be improved. In formulating the criteria, the main point has been shifted from the decametric to the centrimetric band.. Among others this has been done because of the results, too, which Takakura exposed in his paper (7).

The study of optical and radio homologous events indicates a considerable time period of unchanged conditions in the intensity and configuration of local magnetic fields what is of particular importance for understanding the development of the Active Regions on the Sun.

## ACKNOWLEDGEMENT

The authors thank the Institute „Mihailo Pupin" for making available their data and the „Solar Geophysical Data" , (Boulder) what has enabled to prepare this work. The work has been financially supported by the Union for Scientific Work of the Socialist Republic of Serbia.

## REFERENCES

1. Ellison, M. A., Mc Kenna, S. M. P., Reid, J. H. 1960, *Dunsink Obs. Publ.*, **1**, No. 1.
2. Fokker, A. D., Roosen, J. 1961, *Bull. astr. Inst. Netherl.*, **16**, 83.
3. Fokker, A. D. 1967, *Solar Physics*, **2**, No. 3, 316.
4. Pintér, Š. 1969, *Solar Physics*, **8**, No. 1, 179.
5. White, K. P., Janssens, T. J. 1970, *Solar Physics*, **11**, No. 2, 291.
6. Gopala Rao, U. V. 1970, *Solar Physics*, **14**, No. 2, 389.
7. Takakura, T. 1967, *Solar Physics*, **1**, No. 3/4, 304.