Part VI

TRANSIENT PHENOMENA

https://doi.org/10.1017/S0074180900021902 Published online by Cambridge University Press

ANALYSIS OF SOME SOLAR FLARES FROM OPTICAL, X-RAY, AND RADIO OBSERVATIONS*

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ABSTRACT

Using an improved isodensitometric technique it has been possible to study in great detail the photometric structure and the evolution of eight flares. A comparison has been made between the evolutive curves and the ones obtained from measurements of solar X-rays and radio fluxes at $\lambda\lambda$ 3·2 and 21 cm.

A reduction of the flare areas (and of the emitted energies) before the flash phase and a continuous pulsation of the flare have been observed. Further it seems that the flares associated with radio bursts or X-ray events are those which show regions of a sufficiently high intensity, the emitting areas not being a very important parameter.

The correlation in time between the various examined aspects of the AR seems to indicate that the sequence for the beginning of the different phenomena is, in general: optical flare, X-ray events, radio events.

It has been pointed out several times in the past that flare patrol is handled mostly as if it were to be used only by geophysicists (Severny, 1965*a*). Nevertheless in the last years much progress has been made, particularly from an observational point of view. The same cannot be said for the analysis of the photographic data. All of us know that flare classification is still left to a more or less personal judgment of the observer, that the area of a flare is very often obtained by empirical and questionable methods, and that there only exist very few and scanty photometric studies of the intensity distribution within the flare region and of the photometric evolution of the flare (Ballario, 1958, 1959; Billings and Roberts, 1953; Dodson *et al.*, 1956; Ellison *et al.*, 1960; Van Gruithuyzen and Houtgast, 1959; Russo and Righini, 1961). Of course this is due to the fact that a detailed photometric analysis of a number of frames for a single flare is a huge and very time-consuming task.

However, at the Prague General Assembly we briefly described a photographic technique to obtain rapidly a network of very reliable isodensity thresholds from photographs of extended sources. We used this technique to get isophotes from corona photographs and the success obtained in this kind of work suggested us to try to use the technique also for the analysis of Hα-flare photographs.

So we analyzed eight solar flares recorded at Arcetri to test the possibilities of our method.

At the same time we used some X (NRL Solrad satellite) and radio ($\lambda\lambda$ 3·2 and 21 cm)

* Presented by M. Rigutti.

Kiepenheuer (ed.), Structure and Development of Solar Active Regions, 451–464. © *I.A.U.*

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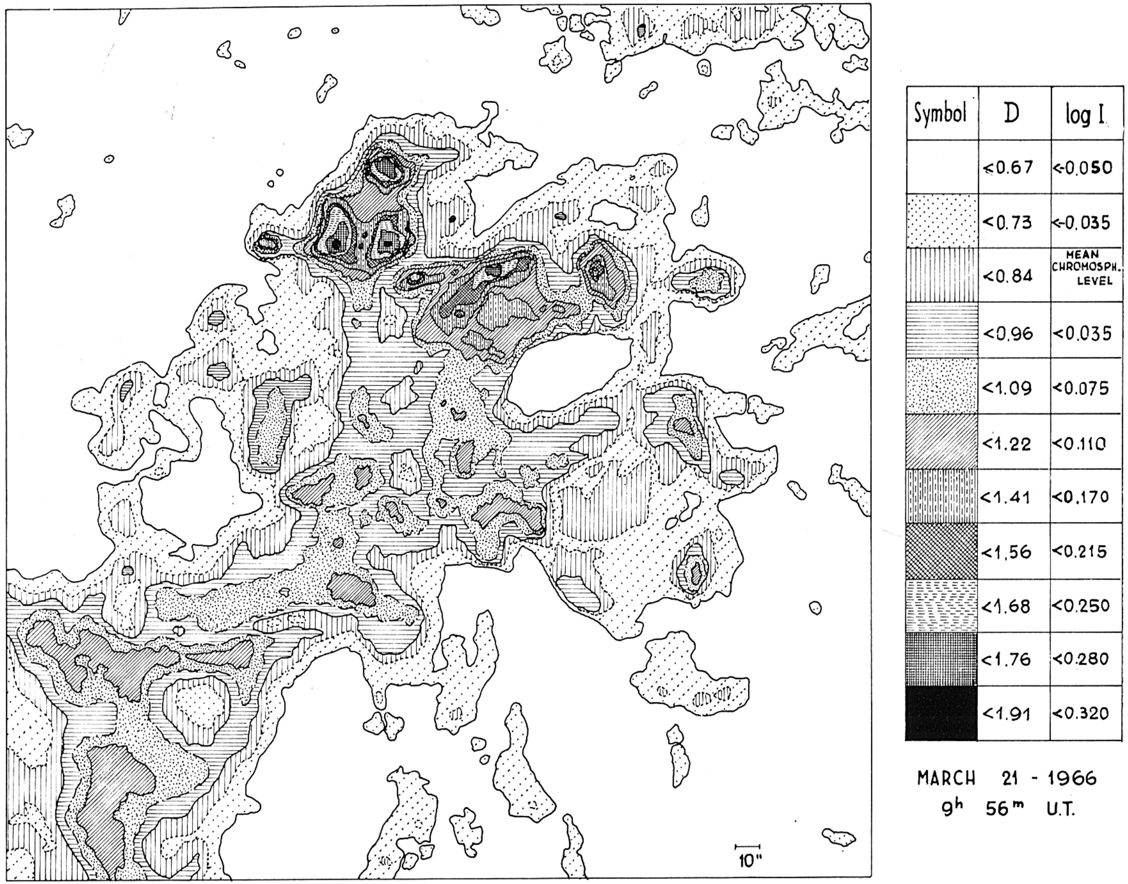

FIG. 1. *Isophotes of the March 21, 1966 flare. D is the photographic density of the isophote on the original filtergram and I is the corresponding intensity in terms of the nearby mean undisturbed chromospheric intensity level.*

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results of observations performed at the Arcetri Observatory to try to get some correlations between the various phenomena from single flares.

With our technique (De Gregorio *et al.*, 1966, 1967*a*, *b*, *c*) we can obtain from a filtergram a high contrast print of the flare region in such a way that the copy shows only two regions: one completely transparent and another completely black. A very reliable isophote can then be obtained. By changing the exposure time in the process it is possible to get a number of isophotes from a single filtergram. The density corresponding to the line separating the transparent and black regions (the isophote) is obtained by photographing a photometric wedge together with the original. Each isophote encloses regions of the flare showing photographic densities larger, or smaller, than the one corresponding to the isophote itself. So, the isophote is a density threshold. By difference of the areas enclosed by two successive isophotes one gets the area of a density step in the flare. This area is transformed into energy through the calibration curve and the photographic density of the nearby undisturbed chromosphere. The energy emitted from a given flare intensity level upward, is obtained by adding the energies of the single steps starting from the considered level.

A picture of the intensity structure of the flare will be obtained by superimposing the different isophotes (Figure 1). Finally, taking into account the foreshortening effect, it is possible to compare the energies of different flares. The measurements of the areas can be performed photoelectrically using the black-and-transparent prints as diaphragms in a suitable instrument. All the numerical reductions can be made by a computer. So, the whole analysis process may easily be done automatically or semi-automatically.

The choice of the flares we took into consideration for this first try has been made on the basis of the coincidence of optical and X-ray or radio observations. Unfortunately, for various reasons these coincidences were not very numerous.

Figures 2–5 are examples of evolutive curves of four of the considered flares (the ordinate scales in Figs. 2–5 are the same if the limb-darkening laws for flares and undisturbed chromosphere coincide).

We would like to say at this point that the technique is very appropriate for analyzing flares as far as sensitivity, reliability, rapidity and cost are concerned, also with a sun image of about 20 mm in diameter. We made the first print using an enlargement of a factor 2, and arranged the successive operations in a semi-automatic way but are now preparing a new instrumentation, basically very simple and inexpensive, to operate almost fully automatically.

It is very difficult to give a complete picture of the results of our analysis. We will here point out the most important features we obtained from our research.

(1) The flash phase of the optical flare is preceded by a more or less large pulsation of the active region; just before the flash a rapid and more or less conspicuous diminution of the emitted energy takes place at all levels of intensity in the flare (i.e., also in the emitting areas).

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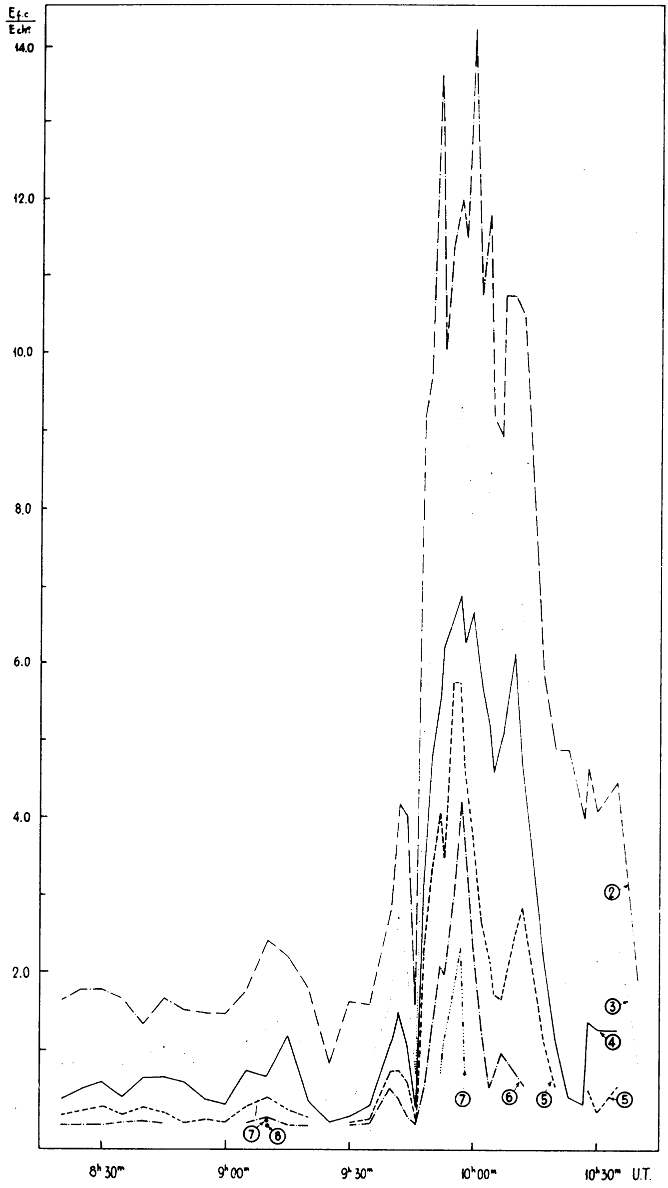

FIG. 2. *Evolutive curves of the October 4, 1965 flare. In the ordinates are the energies $E_{f.c}$ emitted by the flare from the intensity level I_f (over the nearby mean chromospheric level $I_{ch.}$) up, in terms of the energy $E_{ch.}$ emitted by an area, covering 1 mm² on the original frame, of the nearby undisturbed chromosphere. 1 refers to $I_f = 1{\cdot}23\ I_{ch}$. 2 refers to $I_f = 1{\cdot}32\ I_{ch}$. 3 refers to $I_f = 1{\cdot}42\ I_{ch}$. 4 refers to $I_f = 1{\cdot}52\ I_{ch}$. 5 refers to $I_f = 1{\cdot}62\ I_{ch}$. 6 refers to $I_f = 1{\cdot}74\ I_{ch}$. 7 refers to $I_f = 1{\cdot}86\ I_{ch}$. 8 refers to $I_f = 2{\cdot}00\ I_{ch}$. 9 refers to $I_f = 2{\cdot}14\ I_{ch}$. 10 refers to $I_f = 2{\cdot}29\ I_{ch}$.*

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(2) The pulsation of the flare lasts during the whole life of the flare with several maxima and minima, sometimes rather important.

(3) As it is seen in Figure 1 the region around the flare shows densities smaller than that of the near-undisturbed chromosphere. The presence of this nimbus already observed by other researchers (Ellison *et al.*, 1960, 1961; Severny, 1965*b*), seems to be a constant feature of the flare. On this point we will come back in the very near future.

(4) Sometimes it happens that the optical flare associated with radio bursts does

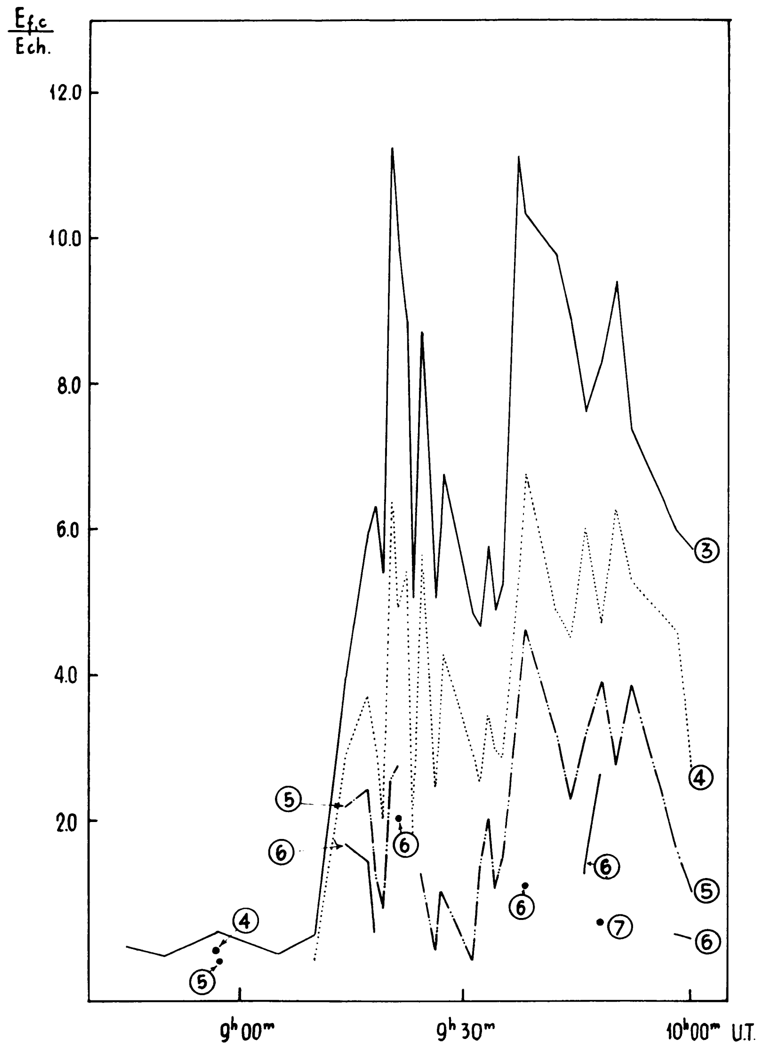

FIG. 3. *Evolutive curves of the March 16, 1966 flare. For explanations see Figure 2.*

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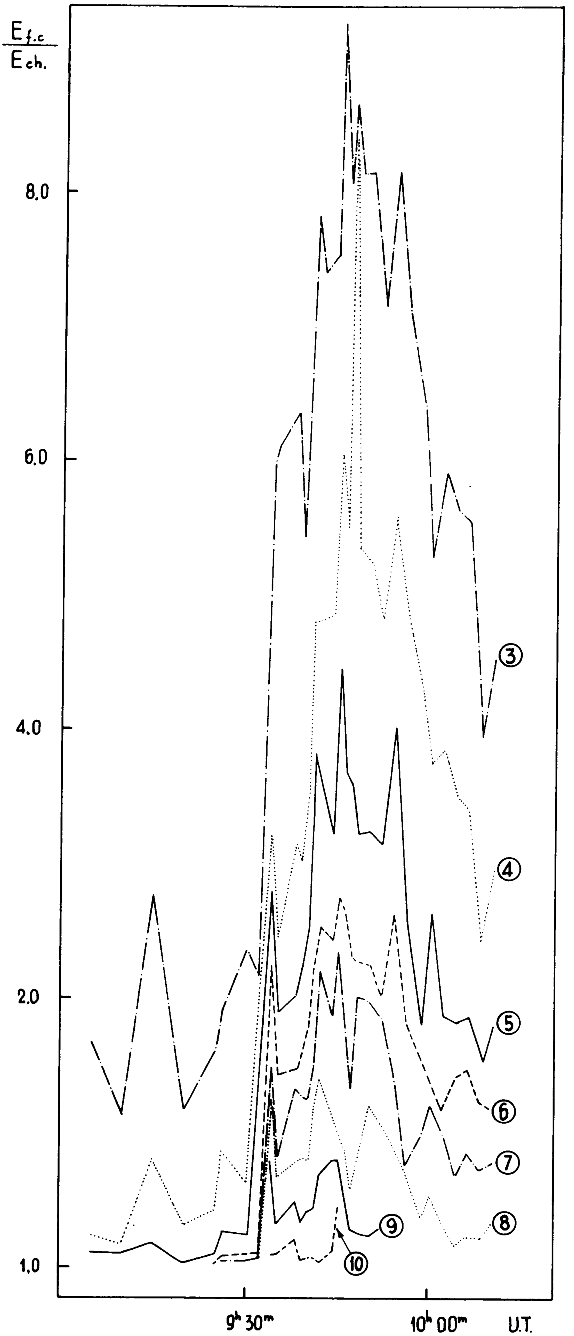

FIG. 4. *Evolutive curves of the March 21, 1966 flare. For explanations see Figure 2.*

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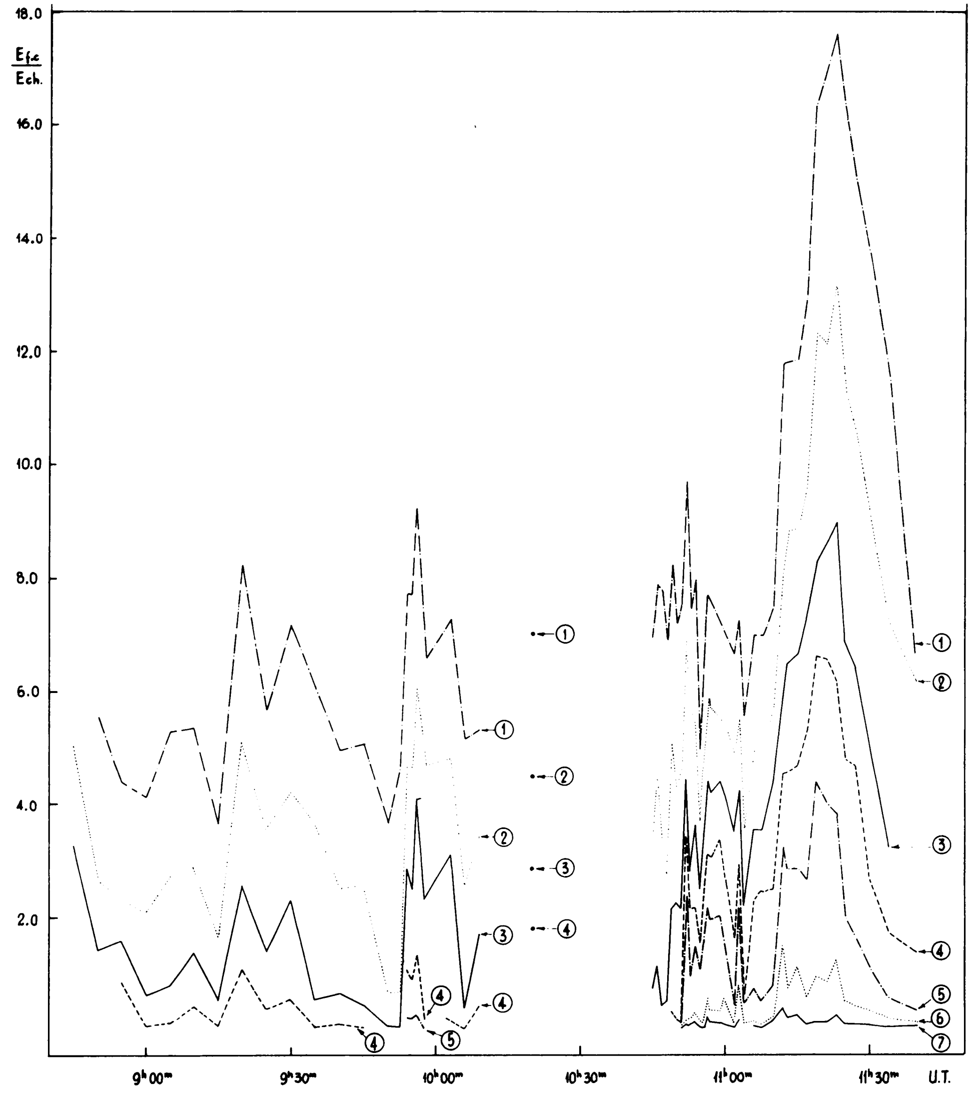

FIG. 5. *Evolutive curves of the March 29, 1966 flare. For explanations see Figure 2.*

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not end its life with the associated radio phenomenon. The optical flare may last much longer and show other conspicuous maxima of energy emission. In this connection it can be noted that (see e.g. the event of March 29, 1966; Figures 5 and 8) after a strong radio burst associated with an optical peak, the flare can show variations with peaks much more conspicuous than the previous one and that these peaks are associated with weaker radio bursts.

(5) Within the errors (particularly in the areas of the radio sources) no clear and definite correlation has been found between the energy emitted by the optical flare from any given threshold of intensity and the energy emitted by the radio bursts at λ 3·3 or λ 21 cm.

(6) The same result came out for the gradients of the optical and radio phenomena.

(7) Instead, it seems that an impulsive radio burst is always associated with the presence within the optical flare of regions of a sufficiently high intensity. On the basis of our few examined examples one would say that when an impulsive radio burst is observed, the optical flare shows either regions also very small, for instance with an area of about 30 millionths of the disk, but with an intensity $\geqslant 1{\cdot}86$ that of the surrounding undisturbed chromosphere, or regions with an intensity $\simeq 1{\cdot}74$ that of the undisturbed chromosphere, but with an area of at least 400 millionths of the disk.

This criterion would explain, for example, why a flare rather unimportant from the optical point of view, like the one of March 3, 1967 (importance $1n+Sn$), may be associated with strong radio bursts at λ 3·2 cm and λ 21 cm and to a long-enduring radio event as flares much more complex and important like the ones of March 29, 1966 (importance $2b$) and March 16, 1966 (importance $2b+4n$).

If from the analysis of a larger number of flares this criterion should appear to be the right one, it might solve the problem of why small optical flares may be associated with radio bursts and sometimes large ones may not. It could be that the amount of energy released by the flare as a whole is not the most important parameter but, perhaps, the quality of this energy, or, in other words, the level of excitation of the flare.

(8) The correlation with the X-ray events has been more difficult to establish because we had at our disposal only three cases. Two of these gave a constant signal during the life of optical flares that showed some emission at a level of intensity $= 1{\cdot}74$ that of the undisturbed chromosphere over a very small area (6–60 millionths of the disk) and no emission at higher intensity levels. The third X-ray observation showed a very sharp and important burst associated with an optical flare that showed emissions from intensity levels up to 2·3 that of the undisturbed chromosphere. At this level – the 'top' of the flare – the emitting area was about 100 millionths of the disk. We may say, very tentatively, having also in mind the hard X-ray event associated with flare-like points studied recently by De Jager (1967), that the X-ray events might be associated with optical flares which show regions of high intensity ($\geqslant 2$ that of the undisturbed chromosphere) with an area also very small (i.e. few millionths of the

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disk). In this connection, we can mention a not yet published result by Landini, Noci and Tagliaferri regarding the position and size of one X-ray source observed during the solar eclipse of May 20, 1966. According to these authors the source coincided with the very brightest region of the optical flare. The size of the X-ray source was about 300 millionths of the disk.

(9) We also tried to get some information about the association in time of the various observations. Figures 6–9 show schematically the times of beginning, ending and maxima of the various phenomena. For the optical observations we considered only three intensity steps, the ones from intensity levels 1·42, 1·74, and 1·86 times the value of the undisturbed chromosphere intensity upward.

Although the time resolution of the optical observations is not very high, it seems rather clear that the disturbance begins in general at the lower intensity levels of the optical flare. With a delay ranging from 1 to 5 min, the high-excitation regions in the flare flash up and then, with a delay of about 2 min, the X-ray event, if it occurs, takes place. With respect to the high-excitation regions the radio events begin with a delay of about 2–3 min. However, in one case (flare of March 3, 1967) the radio events preceded the optical flare's beginning.

The conclusion can be that in general the time sequence for the beginning of the various examined phenomena in an active region should be: optical flare, X-ray events, and radio events.

As far as the maxima of energy releases are concerned it seems that, when there is an association, they are more or less simultaneous. Our time resolution of the optical observations is too poor at the moment to have the possibility of saying something more on this point.

These are, at present, our experimental results. Unfortunately we had not enough time to try to get a model of the flares consistent with the observed features. On the other hand, to get a model from an insufficiently large number of phenomena might be a wrong way to go on with the problem or simply a waste of time. So, although certain facts, as e.g. the contraction of the optical flare before the flash phase, seem to be well enough established, we think that the first thing to be done in the near future is to examine much more experimental data than we have done so far. Furthermore, it is evident that the needed time resolution for the optical observation is much better than our present one and that we need as much information as possible about solar X-radiation bursts. It would be very nice to know quantitatively also the evolution of the magnetic fields before and during the flare. Our purpose is to go on working on this line possibly with the cooperation of some other researchers.

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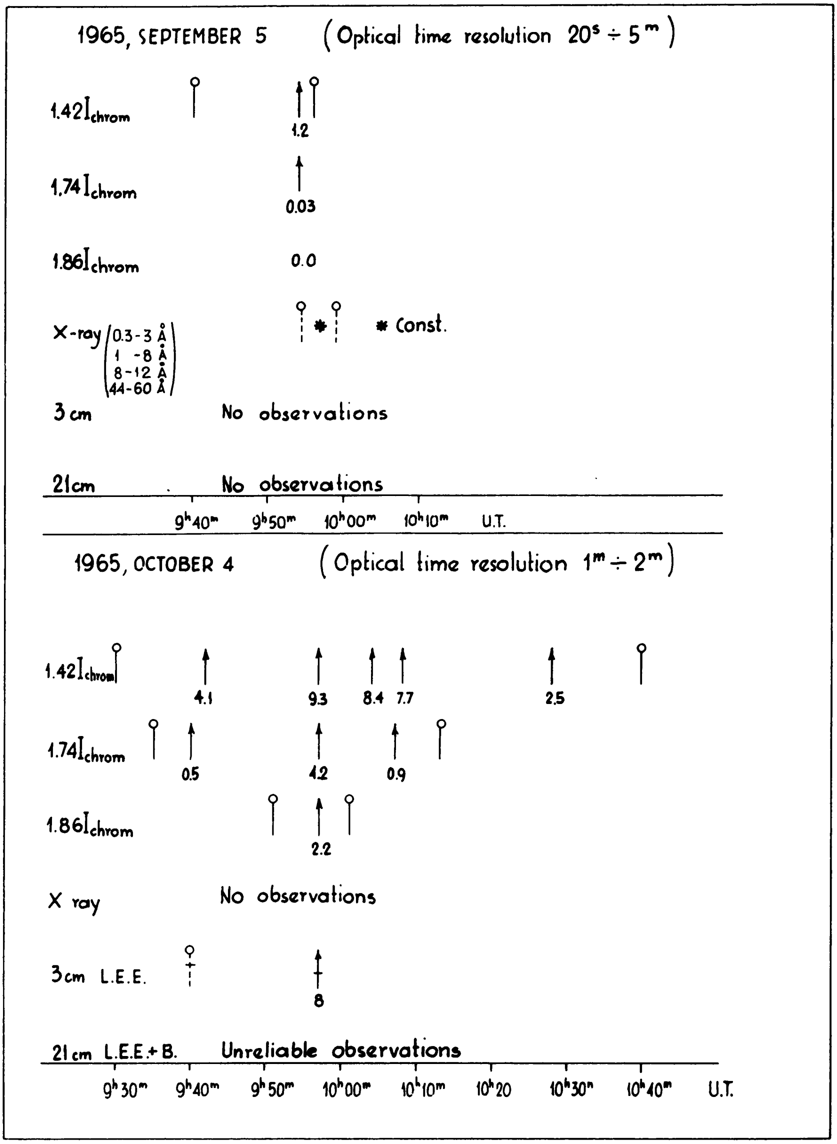

FIG. 6. *Schematical representation of the association in time of various observations for two AR.* ↑ *indicates the maxima of the considered phenomena and the numbers under the arrows are the energies of these maxima;* ⫯ *indicates the beginning and the ending of the considered phenomenon;* ⋮ *indicates the beginning and the ending of the observations;* × *indicates the presence of isolated points, not a peak in the evolutive curve; L.E.E. indicates a long-enduring event (♀ in the graphs) and B. indicates a superimposed impulsive burst. As for the symbol 1·42* I_{chrom} *and similar ones, see the text. The figures under the arrows describing the optical phenomenon indicate the values* $(E_{f.c})/(E_{ch.})$*, while those under the arrows describing the radio phenomenon indicate the ratio of the energy emitted by the radio source to the one emitted by an equivalent area of the mean undisturbed disk.*

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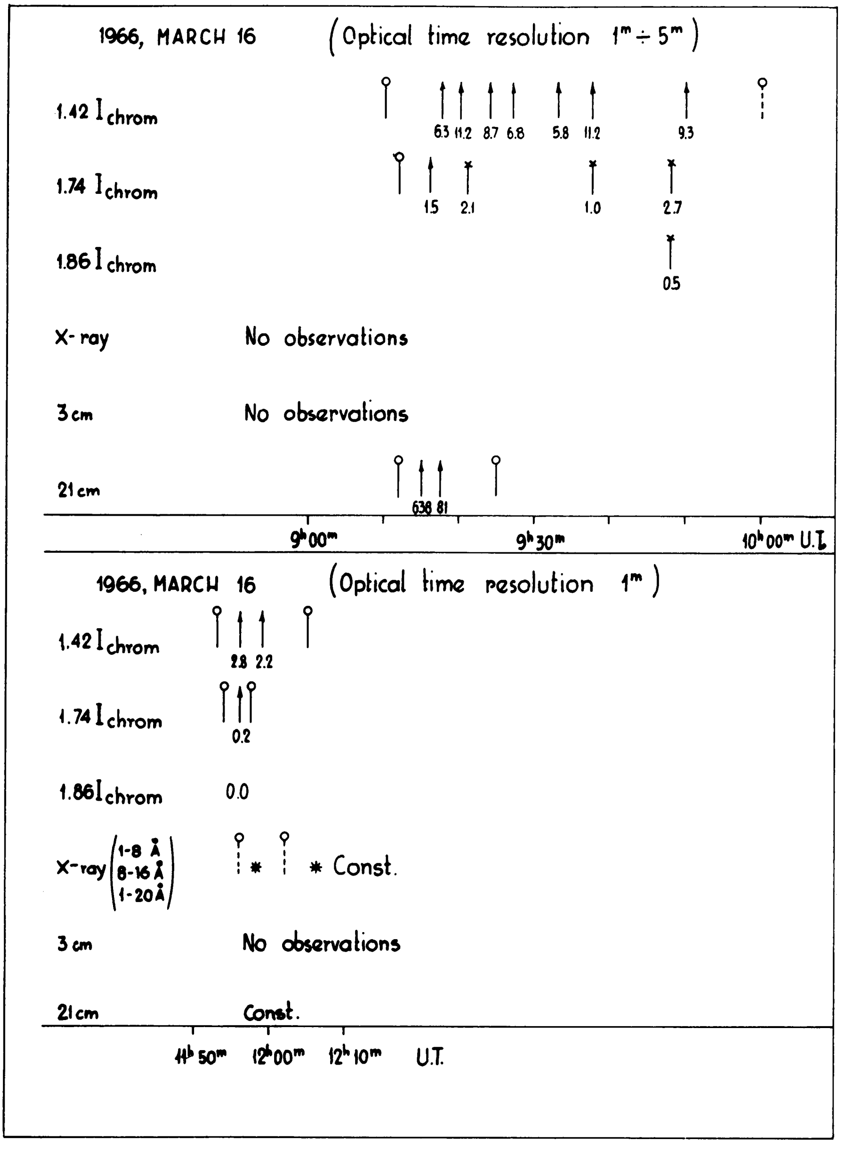

FIG. 7. *Schematical representation of the association in time of various observations for two AR. The notations are the same as in Figure 6.*

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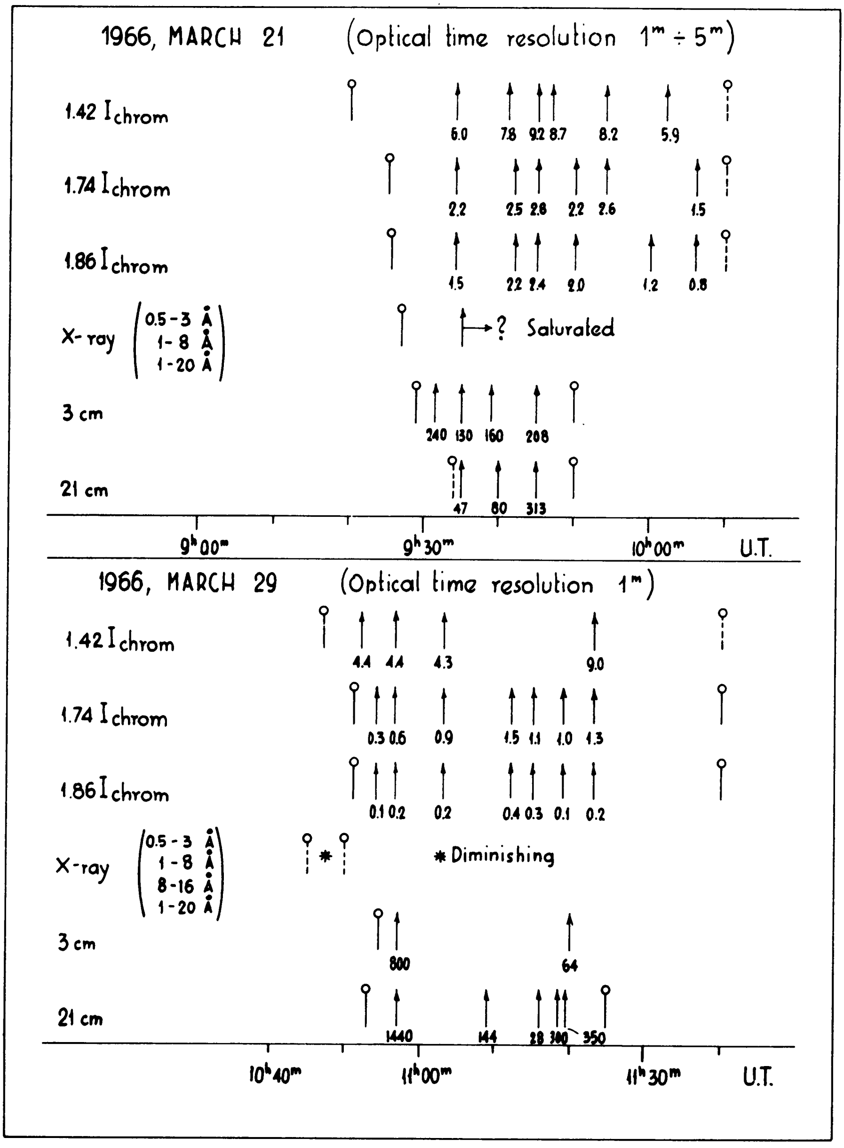

FIG. 8. *Schematical representation of the association in time of various observations for two AR. The notations are the same as in Figure 6.*

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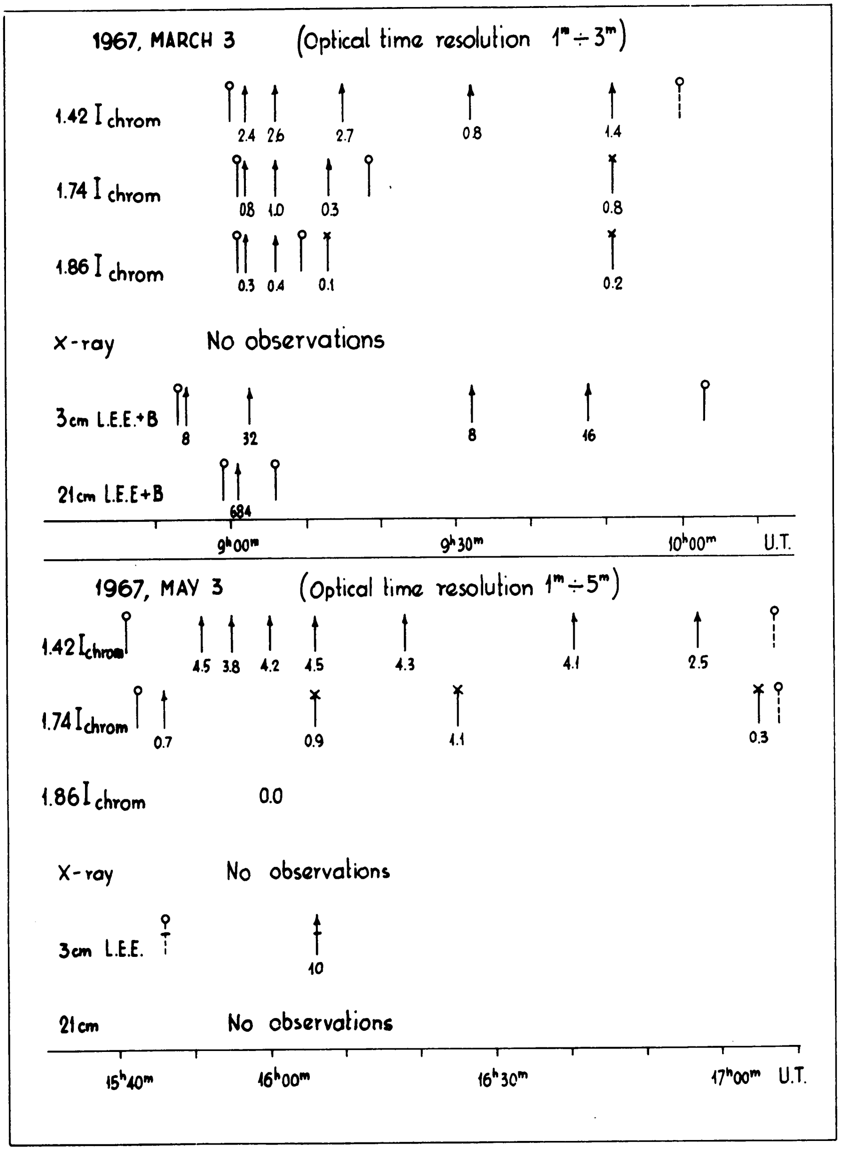

FIG. 9. *Schematical representation of the association in time of various observations for two AR. The notations are the same as in Figure 6.*

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DISCUSSION

Houtgast: At one of your slides you mentioned the large area around the Hα-flare, of which the intensity was below that of the normal chromosphere. Did you follow the development of this nimbus-like feature with time?

Rigutti: No. We did not search in particular for the 'nimbus', but some of our cases showed it clearly. At this stage we can say that our measurements gave us the feeling that a more or less important nimbus could always be present around a flare. We shall investigate this problem in the near future.

Fokker: On some of the slides was mentioned: 3 cm, no observations. Now, actually, the solar radio-patrol coverage at 3 cm is practically complete. Therefore, I understand that in these cases no 3-cm observations were made at the Arcetri Observatory itself. I would suggest to ask the Heinrich-Hertz Institute (Berlin) or the Sagamore Hill Observatory (AFCRL, Bedford) for the records of the respective 3-cm events.

Rigutti: We actually took into consideration only observations made at the Arcetri Observatory. We began this work on February and a dead-line for presentation of papers was put on April 15. So we considered there was not enough time to ask for data from other institutions. We will certainly do it in the future.

De Jager: Are flares always preceded by a contraction in area and/or integrated Hα luminosity?

Rigutti: As far as the flares we considered are concerned, yes. The contraction takes place – more or less conspicuously – both in area and in integrated Hα luminosity.

Koeckelenbergh: (1) Quel est votre temps de résolution sur vos enregistrements radioélectriques?

(2) Les pulsations d'éclat de la plage avant l'éruption sont-elles associées avec l'apparition de sous-éruptions, ainsi qu'il m'est arrivé de l'observer?

(3) J'ai eu l'occasion d'étudier la corrélation entre les aires éruptives et l'énergie émise pendant la phase croissante des sursauts associés sur 600 MHz. Il y a une corrélation qui apparaît dans ce cas.

(4) De même, une corrélation se présente avec l'intensité de la raie Hα. Mais ici il y a une grande dispersion, les données sortant du *Quarterly Bulletin*.

Rigutti: (1) About 10 sec.

(2) I do not know. We did not look at this particular point.

(3) and (4) Our results are obtained from a few cases only, but I would like to call attention to the fact that the flare areas given in the *Quarterly Bulletin* come from eye estimates, which are very rough and questionable.

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