Some Features of Solar Radio Bursts at around 3000 Mc/s

Kenji AKABANE

Tokyo Astronomical Observatory

(Received December 28, 1956)

Abstract

The nature of solar radio bursts at frequencies around 3000 Mc/s is studied statistically. It is found that the number of bursts does not increase monotonously with decreasing intensity but shows a maximum for bursts with the intensity of 5 to 10 units. (1 unit is 10^{-22} w.m.$^{-2}$ (c/s)$^{-1}$). The number of bursts decreases as $I^{-1.8}$ for bursts with intensity greater than 5 units, where I is the intensity of a burst. The frequency distribution of the number of bursts over the solar disk is derived. If this frequency distribution is interpreted by assuming an absorbing layer above the source of a burst, the optical thickness of the layer is about 0.3 or 0.4.

1. *Introduction.*

The purpose of this paper is to discuss some statistical nature of solar radio bursts observed at the frequencies of around 3000 Mc/s. Bursts at this frequency range are usually classified into the following four classes: (a) single burst, (b) single burst with post increase, (c) burst with gradual rise and fall and (d) group burst (complex burst). In this paper, however, all bursts observed are discussed together, and the intensity of a burst is defined as

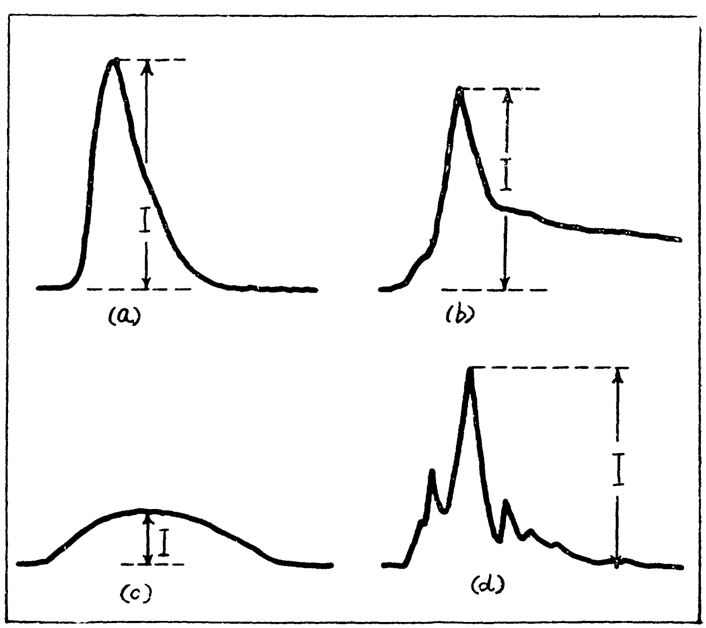

Fig. 1. Definition of the intensity of a burst.

the smoothed peak value as shown in Fig. 1 and is expressed in units of 10^{-22} w.m.$^{-2}$ (c/s)$^{-1}$. The following materials are used in the present discussion:

Station	Frequency	Period used in the present discussion	Number of bursts
Ottawa	2800 Mc/s	Jan. 1951 —Jun. 1956	587
Toyokawa	3750 Mc/s	Jan. 1952 —Dec. 1955	148
Tokyo	3000 Mc/s	Sept. 1955—Sept. 1956	386

2. *Frequency Distribution of the Intensity of Bursts.*

The frequency distribution of number of bursts with different intensities are summed up for each station and for each year. The results are shown in Fig. 2. It might be supposed

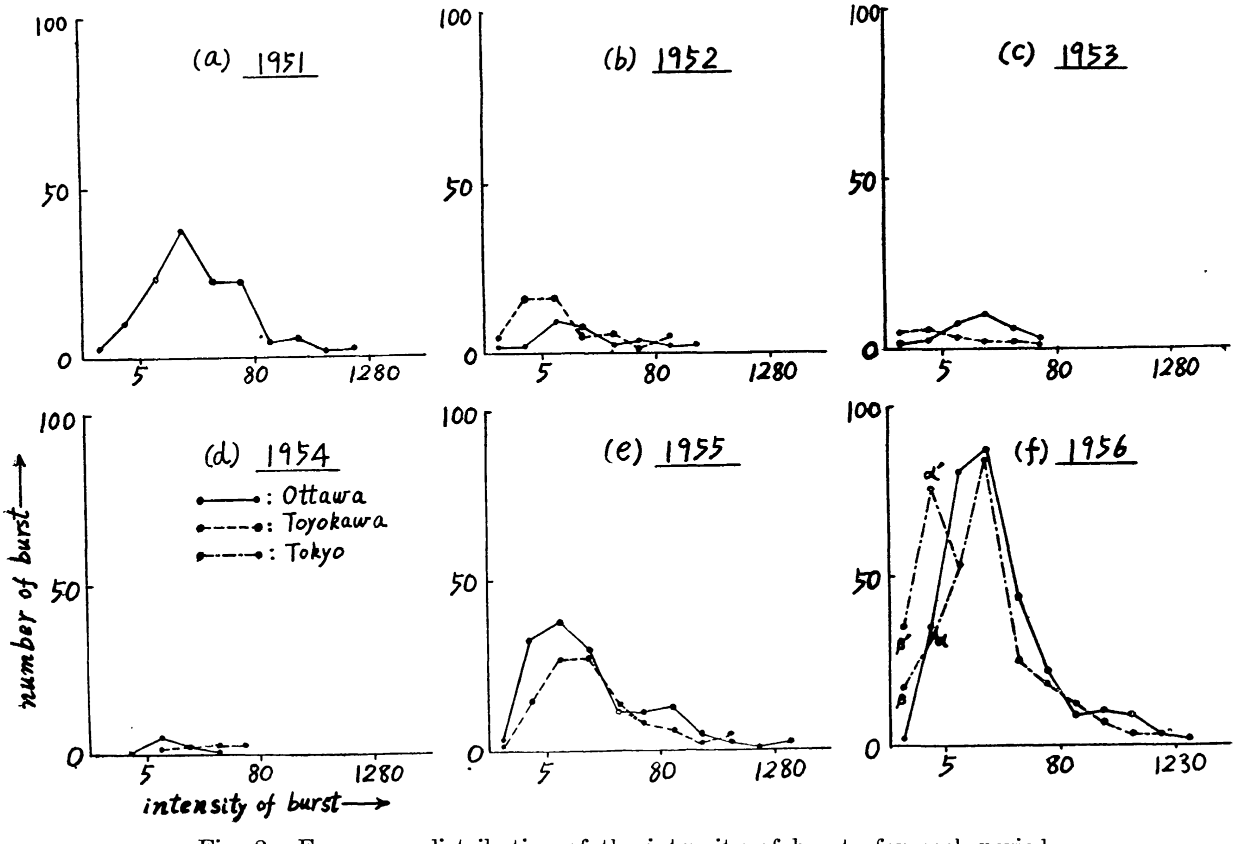

Fig. 2. Frequency distribution of the intensity of bursts for each period.

that the number of bursts would increase as the intensity of bursts decreases. But the curves in Fig. 2 show a common tendency to have a maximum at the intensity of around 5 to 10 units. To see this point more closely, the observed tapes at the Tokyo Astronomical Observatory during January through September, 1956, have been re-examined. The curve $\alpha'\beta'$ in Fig. 2(f) is based on the counting of all the burst-like phenomena appeared on the tapes. Since such phenomena of intensities less than 5 units are usually confused with man-made interferences, the numbers between α' and β' are halved and are shown as the curve $\alpha\beta$.

The new curve for Tokyo in Fig. 2(f) agrees fairly well with that for Ottawa and shows a maximum at around the intensity of 10 units. Since the amplitude of the fluctuation on the tape is of the order of magnitude less than 2 units, the existence of the maximum seems to be real.

The frequency distribution of the intensity of bursts are summed up for the whole period for each station and shown in Fig. 3. The presence of the maximum is again clearly seen. No explanation for this maximum is yet given.

Next, the numbers of bursts for three stations have been summed up for each intensity

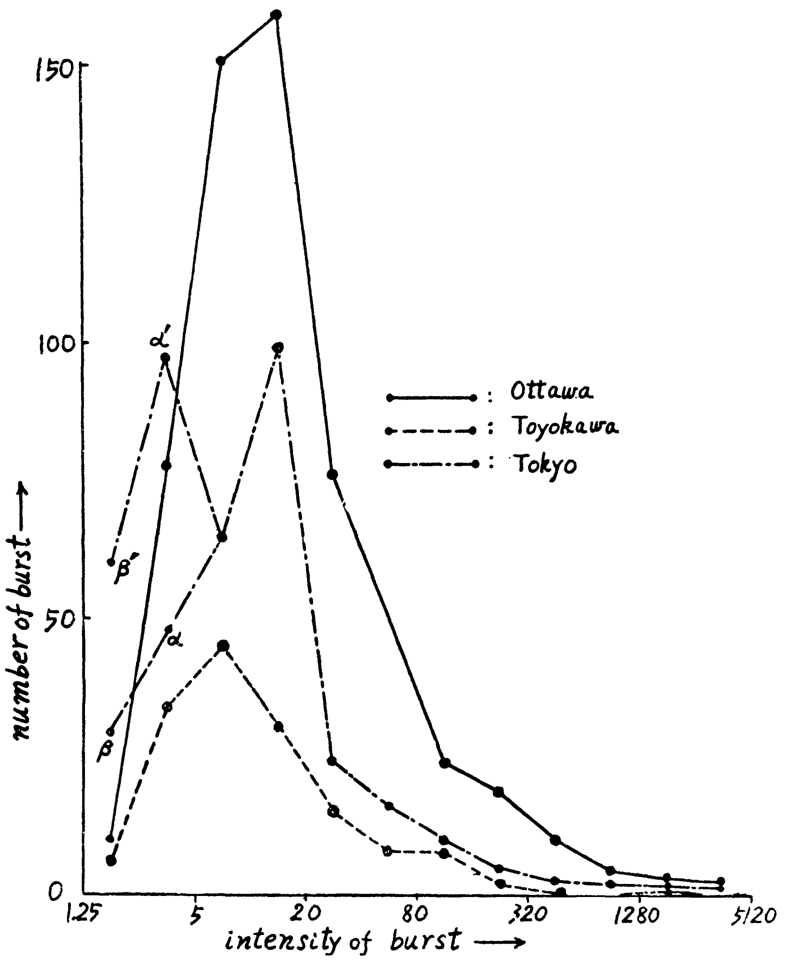

Fig. 3. Frequency distribution of the intensity of burst for the whole period.

Table 1. Frequency distribution of burst for each intensity interval.

Intensity intervals	5–9	10–19	20–39	40–79	80–159	160–319	320–639	640–1279	1280–2560
I_{Δ}	5	10	20	40	80	160	320	640	1280
Number of bursts, N_{Δ}	260	288	115	74	41	26	13	6	4
$\Delta N/\Delta I$	52.0	28.8	5.75	1.85	5.12×10^{-1}	1.62×10^{-1}	4.05×10^{-2}	9.40×10^{-3}	3.12×10^{-3}

interval. Here we are concerned only with the bursts whose intensity is stronger than 5 units. The result is given in Table 1, and $\log(\Delta N/\Delta I)$ is plotted against $\log I$ in Fig. 4. It is remarkable that the points in Fig. 4 are expressed by a straight line with the gradient of -1.8. Therefore we can conclude that the frequency distribution $f(I)$ of bursts is expressed by

$$f(I) \propto I^{-1.8}, \quad (I \geq 5), \qquad (1)$$

for bursts stronger than 5 units.

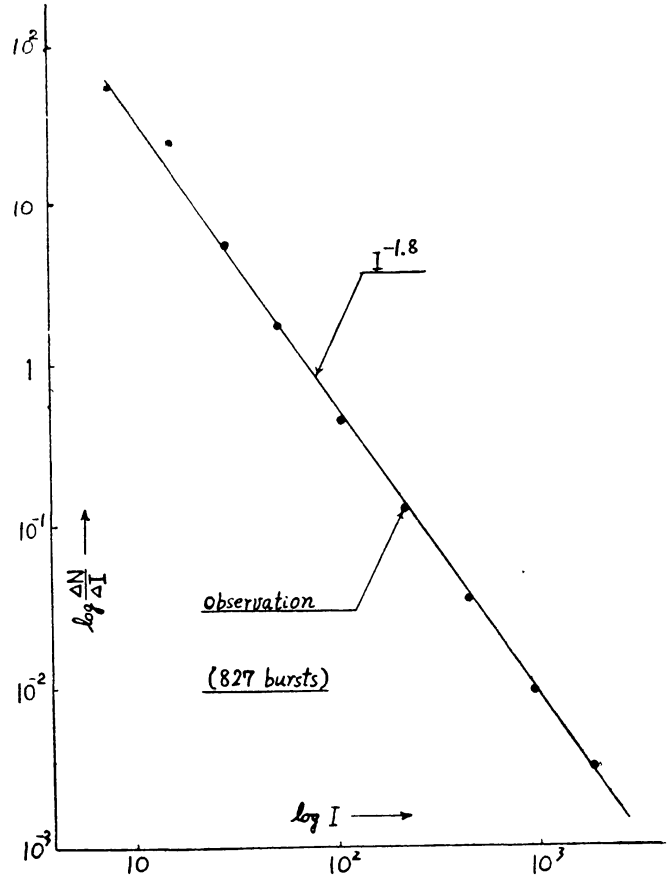

Fig. 4. Determination of the frequency distribution law for bursts stronger than 5 units.

3. *Directivity of the Burst.*

We now want to discuss the distribution of bursts on the solar disk. Since no interferometric measurements of bursts for these periods are available, the following procedure is adopted. It is known[1] that the slowly varying component at this frequency range attains its maximum intensity at the time of the central meridian passage (C.M.P.) on the solar disk of the enhanced region. Therefore the position of a burst is calculated from the time of maximum intensity of the

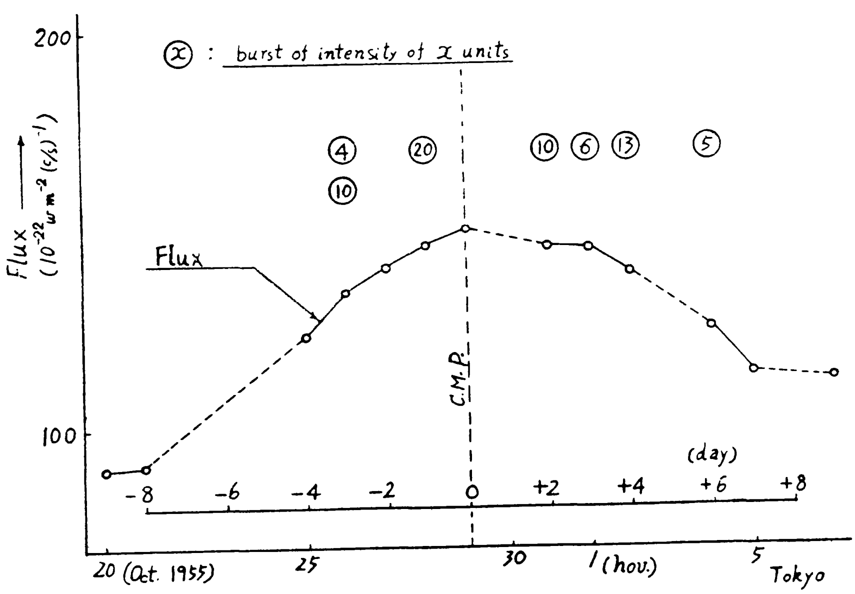

Fig. 5. The C.M.P. of an enhanced region and associated bursts.

slowly varying componet. Bursts are excluded when the enhanced region showed rapid variation or when there were two or more enhanced regions. We shall also limit the following discussion to those bursts whose intensities are stronger than 5 units. An example of this procedure is illustrated in Fig. 5.

496 bursts are thus picked up from the observation made at three stations. In Fig. 6 the number of bursts is plotted against the time interval counted from the day of C.M.P. of the corresponding enhanced region. The open circles and the dotted line in Fig. 6 show the mean of the corresponding position of the eastern and western hemisphere. It is clearly seen that the bursts are observed more frequently when the source is near the centre of the solar disk.

We then divide these bursts into four groups according to the ordinate of Fig. 6; i.e. 0 and ±1 days, ±2 and ±3 days, ±4, ±5 and ±6 days, and ±7, ±8 and ±9 days. A diagram similar to Fig. 4 is constructed for each group as shown in Fig. 7. It is remarkable

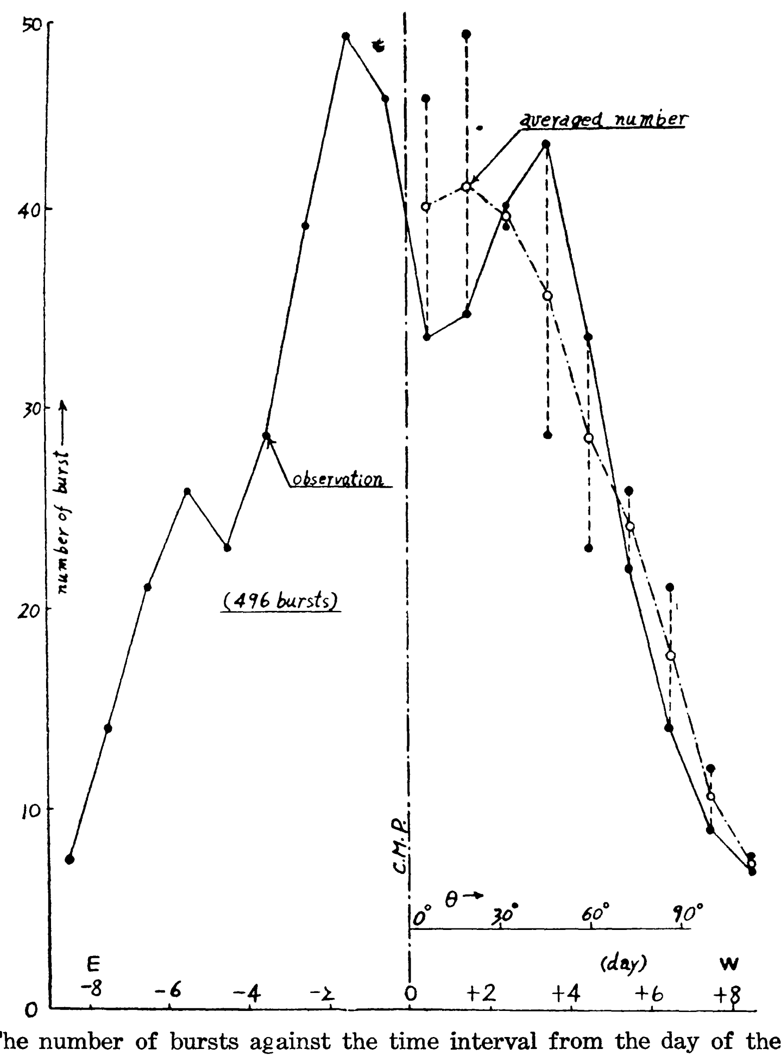

Fig. 6. The number of bursts against the time interval from the day of the C.M.P. of the enhanced region.

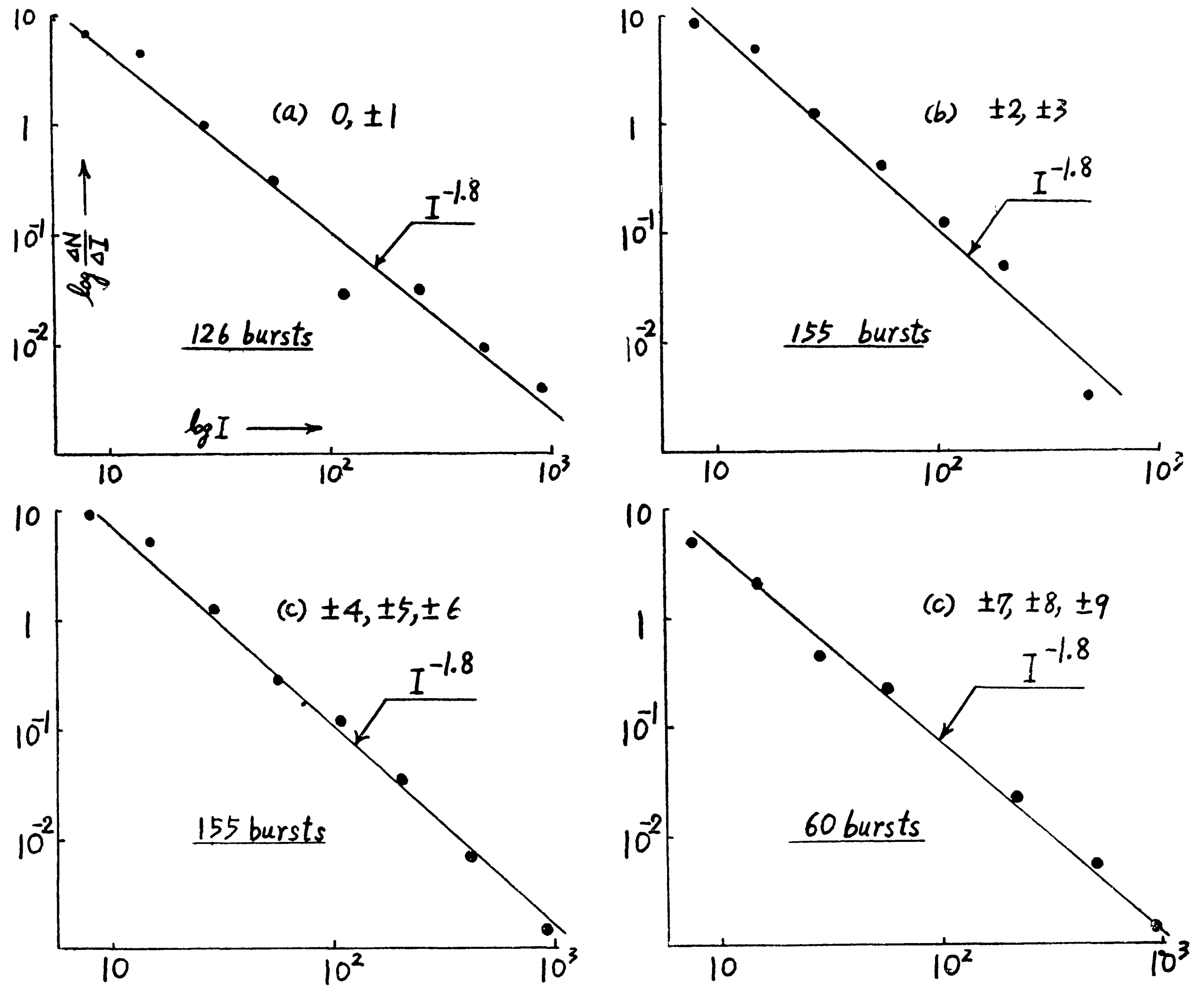

Fig. 7. The same diagram as Fig. 4, grouped according to the position of the burst. The attached figures indicate the time interval from the day of the C.M.P. of the associated enhanced region expressed in days.

that the distribution of the points in each diagram in Fig. 7 is again expressed by a straight line with a slope of -1.8. In other words although bursts are observed less frequently as the source moves to the limb, the frequency distribution of the intensities of bursts follows the same law as eq. (1).

This relation can be formulated as follows. Suppose that the intensity of a burst is reduced by a factor $a^{-1}(\theta)$ when observed in the direction θ from the normal to the solar surface, with $a(0)=1$. Since we have counted only the bursts whose intensities exceeded a certain limit I_0 (5 units in this case), this corresponds to have counted the bursts whose intensities exceeded the limit $a(\theta)I_0$ for the bursts which occurred at a point on the solar surface with an angle θ from the center of the solar disk. Therefore the number of bursts occurred at θ, $N(\theta)$, is given by

$$N(\theta)=\int_{a(\theta)I_0}^{\infty} aI^{-1.8}dI=\beta a(\theta)^{-0.8}I_0^{-0.8}\,, \tag{2}$$

where α and β are constants. If it is admitted to identify the angle θ with the time interval from the day of the C.M.P. of the corresponding enhanced region, we can solve for $a^{-1}(\theta)$ with the aid of the frequency distribution of number of bursts given in Fig. 6. By noting that

$$N(0)=\beta I^{-0.8}\,,$$

$a^{-1}(\theta)$ is obtained from the following equation :

$$\frac{N(\theta)}{N(0)}=a^{-0.8}(\theta)\,. \tag{3}$$

The result is shown in Table 2.

Table 2. Directivity of the burst

θ	6°.7	20°.0	33°.2	46°.6	59°.9	73°.2	86°.4	99°.8
$N(\theta)/N(0)$	0.96	1.00	0.94	0.86	0.68	0.58	0.42	0.28
$a(\theta)^{-1}$	0.98	1.00	0.92	0.83	0.62	0.51	0.34	0.21

$a^{-1}(\theta)$ represents a kind of "directivity" of bursts. But, this directivity may be interpreted as a result of attenuation caused by the absorbing layer above the source of a burst. Fig. 8 gives a schematic diagram for this model. If τ is the optical thickness of the absorbing layer we have the following equation for $a^{-1}(\theta)$, when the curvature of the layer is negligible :

$$a^{-1}(\theta)=\frac{Ie^{-\tau\sec\theta}}{Ie^{-\tau}}=e^{-\tau(\sec\theta-1)}\,. \tag{4}$$

The value of τ is equal to 0.3—0.4, as is seen from Fig. 9, where $\log a^{-1}(\theta)$ is plotted against $(\sec\theta-1)$.

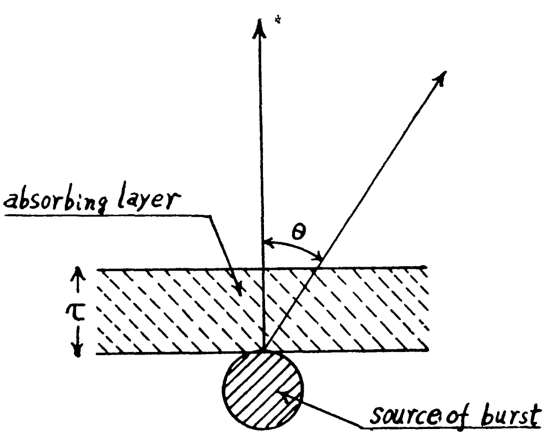

Fig. 8. Absorbing layer model.

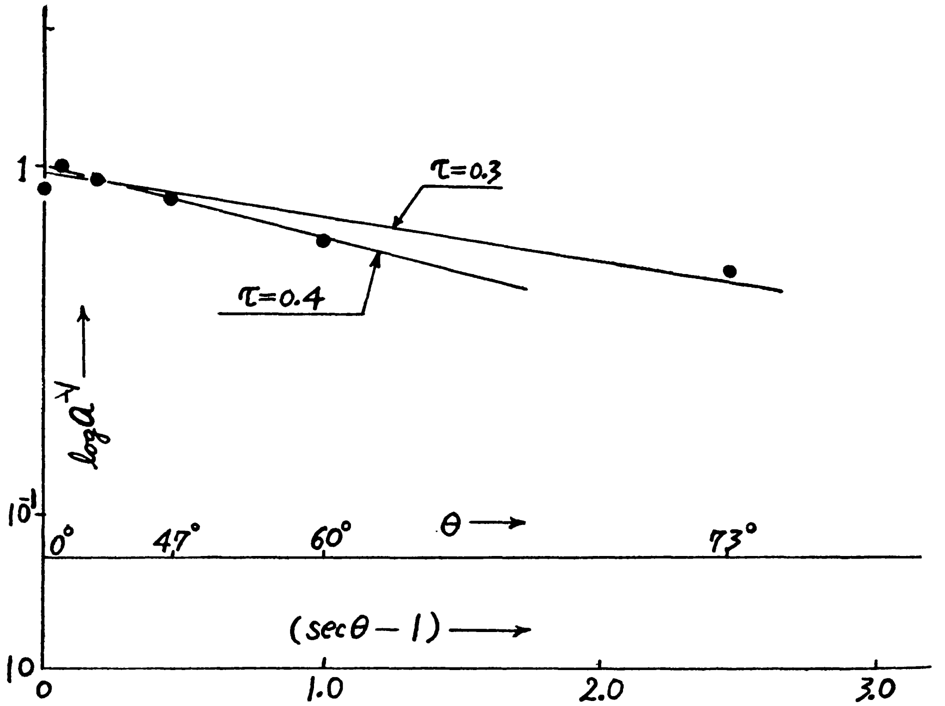

Fig. 9. Determination of the optical thickness of the absorbing layer above the source of bursts.

It is to be remarked that the perspective effect on the area of the source and the emission mechanism of a burst still remain to be discussed besides the absorption hypothesis introduced here in order to explain the observed directivity of bursts.

4. *Mean Intensity of the Burst.*

As the frequency distribution of intensities of bursts is found to be proportional to $I^{-1.8}$,

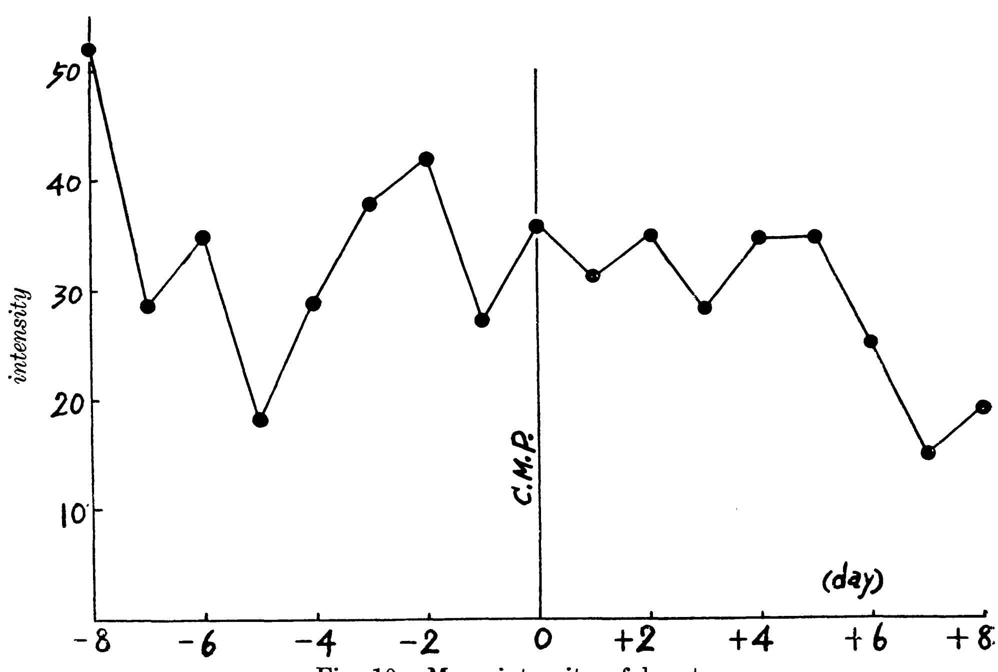

Fig. 10. Mean intensity of bursts.

at any part of the solar disk, the mean intensity of bursts whose intensity lies between I_0 and I_m is given by

$$\bar{I}=\left(\int_{a(\theta)I_0}^{a(\theta)I_m} a^{-1}(\theta)aI^{-0.8}dI\right)\Big/\int_{a(\theta)I_0}^{a(\theta)I_m} aI^{-1.8}dI=4\,\frac{I_m^{0.2}-I_0^{0.2}}{I_0^{-0.8}-I_m^{-0.8}}, \tag{5}$$

and is independent of $a(\theta)$. If we take $I_0=5$ units and $I_m=300$ units respectively, $\bar{I}$ is 25 units from eq. (5). On the other hand, as is seen from Fig. 10, the observed value of the mean intensity for such bursts is equal to about 30 units independent of θ, and is consistent with the theoretical expection. Furthermore, if we take all bursts from Table 1 whose intensity lies between 5 and 300 units, the mean value turns out to be 31 units. This again shows the consistency of our procedure.

5. *Conclusion.*

The resuls of the present investigation are summarized as follows:

(1) The number of bursts does not increase monotonously as the intensity decreases, but has its maximum at around 5 to 10 units in intensity.

(2) The number of bursts with intensity greater than 5 units decreases as $I^{-1.8}$ independent of the position of the source of bursts on the solar disk.

(3) The number of bursts decreases as the source moves to the limb of the solar disk. If we interpret this decrease by assuming an absorbing layer above the source, the optical thickness of the layer is between 0.3 and 0.4.

(4) The mean intensity of bursts whose intensities lie between 5 and 300 units is about 30 units. This is consistent with the frequency distribution law of bursts of different intensities discussed in this paper.

The author wishes to express his hearty thanks to Prof. T. Hatanaka for his encouragement and interest. His thanks are also due to the staffs of the Tokyo Astronomical Observatory for their discussions and kind collaboration.

Reference

1) M. Waldmeier. *Zs. f. Ap.*, **32**, 116, 1953.