magnetic field and the polar zone of prominences [M. Waldmeier, ZS. f. Astrophys. **49** (1960) 176]. This zone is a separation between magnetic fields of opposite polarities. As this zone is migrating towards the pole, the polar field vanishes and becomes replaced by the opposite field on the low-latitude side of the zone. As the long coronal streamers originate from regions occupied by prominences, these streamers indicate the boundary of the general magnetic field rather than the field itself.

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INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part II

II-3A-P2. Solar Radio Outbursts and Acceleration of Electrons

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Wide-band spectra of intense long-duration outbursts are studied. In a course of such an outburst there occur three distinctive components of outburst. One is long-duration outburst on cm-waves and the other is believed to be original type IV burst on m-waves. These groups occur with a clear gap in the frequency range or are mixed in some frequency ranges by accompanying another group on dm-waves.

In order to account for the above characteristics, acceleration of electrons due to hydromagnetic waves is discussed. In order that the accelerations proceed to relativistic energies, redistribution of the velocity of accelerated electrons must be made. This redistribution may be made by Coulomb collisions with thermal electrons before their energies are lost by the collisions.

The accelerated electrons tend to accumulate to the places where the magnetic field is greater to radiate synchrotron radiations. At intense eruption, a few magnetic bulges would be made to be separate radio sources for m-IV, dm-IV and cm-IV outbursts.

It is also shown that hard X-ray bursts and microwave bursts with short durations are consistently explained by the same electrons accelerated at moderate eruptions.

§1. Wide-Band Spectra of Intense Outbursts with Long Durations.

Dynamic spectra of intense outbursts have been studied in Japan in a wide frequency range, from 9400 Mc to 67 Mc, at about ten point frequencies and partly using swept frequency records[1),2)]. Number of the outbursts studied from 1958 through the end of 1960 is about twenty.

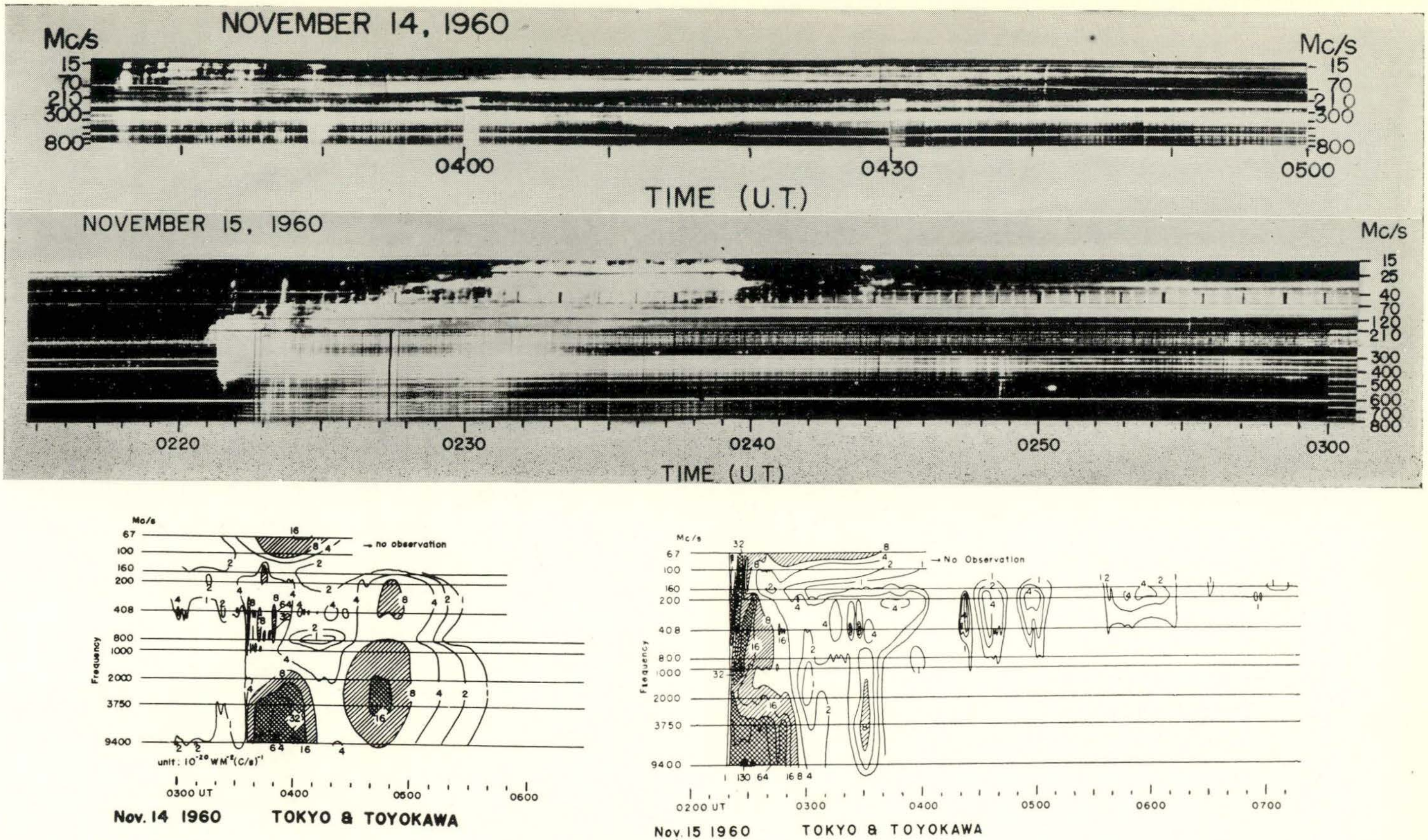
Generally, the spectra show complex patterns. However, in the course of such an outburst, there appears at least three distinctive components of long-duration outbursts. One is outburst in centimeter-wave range (tentatively named cm-IV), the other is in decimeter-wave range (dm-IV) and another is in meter-wave range (m-IV) which seems to be original type IV named by A. Boischot. At large eruptions, all of three components occur and they are mixed in some frequency ranges, but sometimes have clear frequency gap. In some moderate events only two of them occur.

Examples of intense outbursts are shown in Fig. 1. These spectra show clear frequency-gap between dm-IV (above about 200 Mc) and m-IV (below 200 Mc).

Sometimes, dm-IV and m-IV show slow frequency drift with time towards lower frequencies (see, Fig. 1). It should be noted that outbursts at 200 Mc are generally an *extension of dm-IV* except during 10−20

(a)

(b)



(c)

(d)

Fig. 1. Dynamic spectra of November 14 and 15, 1960.

a, b) Swept frequency records: 800-210Mc, Tokyo; 210-15Mc, Sydney.

c, d) Contour maps: 9400-1000Mc, Toyokawa; 800-67Mc; Tokyo.

a) Slow frequency drift of m-IV (below about 200Mc) is remarkable. Frequency gap between the drifting m-IV and dm-IV (above 200Mc) is remarkable after about 0400 UT.

b) After 0240 UT, a frequency gap between about 200Mc and 120Mc is remarkable.

minutes from the onset of the outburst (see, Fig. 1). The "second part" and "continuum storm" named by Boischot and Pick[5] would be an extension of dm-IV. Also "meter-wave post-type IV (group C)" named proviously by the author[1] would be an extension of dm-IV. A schematic picture of an intense outburst complex is shown in Fig. 2. As shown in this picture, in early phase of the outburst M-type burst[3] (short-duration outburst at microwaves), type II, type III group, type V, dm-short-continuum[4] and dm-fast-drift bursts[4] (indicated by dm-IIIg in Fig. 2) generally occur.

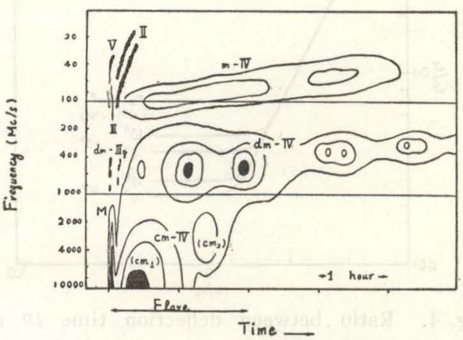


Fig. 2. A schematic dynamic spectrum of an intense outburst complex.

The most remarkable differences among three components of so called type IV are position and motion of their radio sources. Radio source of cm-IV is fixed about 0.05 $R_\odot$ above the associating flare (H. Tanaka and T. Kakinuma[2]), while m-IV source shows rapid motion into the upper corona (J.P. Wild[6] and A. Boischot[7]). The source of dm-IV moves slowly or is almost fixed in the corona at about 0.3 $R_\odot$ above the photosphere (M. Morimoto and K. Kai[8]). It has been pointed out by H. Tanaka and T. Kakinuma[2] that the sense of circular polarization for cm-IV and dm-IV is opposite to each other. The sense of cm-IV is extraordinary referring to the magnetic sense of preceding sun-spot.

Although the characteristics are different from each other, the author believes that all of these three components (cm-IV, dm-IV and m-IV) are attributed to synchrotron emissions[1,9].

It may be pointed out that the bandwidths of *individual* components are rather narrow as shown in Table I, even if a total bandwidth of so called type IV which include three components is ranging from 10^4 Mc to 10 Mc. Energies of electrons radiating synchrotron emissions are estimated from the observed bandwidths assuming nearly circular orbits of electrons. They are given in Table I. The energy is of the order of 10^5 eV, which is more than one order lower than previous estimation by A. Boischot[7].

As have been shown the spectra of type IV are very complicated and composed of a few components whose relative intensities change case by case, so that it is desirable to pay more attention to distinguish the components when we take correlations between solar radio emissions and terrestrial phenomena.

Recent statistical studies, as far as the author knows, have revealed the following correlations.

M-type (short duration microwave burst): hard X-ray bursts.

Post-increases and gradual rise and falls at microwaves: S.I.D. due to soft X-rays.

cm-IV { most intense: C.R. unusual increases.
intense and moderate: P. C. B. (fast type).

dm-IV* } : C.R. small increases, P.C.B. (slow type), Forbush decreases of C. R. and magnetic storms.
m-IV

* In statistical studies so far dm-IV and m-IV are not distinguished.

Table I.

	cm-IV	dm-IV	m-IV
Frequency range (Mc)	>10,000-800	1,500-150	<200
Center frequency (f_{max})	10,000-3,000	1,000-200	100-70
Bandwidth ($f_{1/2}/f_{max}$)	2.6-4.4	1.3-2.2	1.4-2.3
Energy of electron* (10^5 eV)	2.7-4.8	0.3-2	0.5-2.2
H (gausses)	2,300-700	200-60	25-15

The other characteristics are shown in Table I given by Tanaka and Kakinuma (paper II-3A-5).

* Estimated from the bandwidth assuming nearly circular orbits.

These problems are treated in more detail in the other sessions (II-3B, II-5).

§ 2. Acceleration of Electrons in the Solar Atmosphere.

The reason why the synchrotron radiations come from different radio sources with different characteristics will be discussed in the following. First, the repeated acceleration process of electrons at the eruption must be considered[10].

Owing to strong magnetic fields of sunspots, velocity V_m of Alfvén waves along the magnetic lines of force is very high. V_m is shown in Fig. 3 as a function of height. Therefore it seems easy for thermal electrons to get

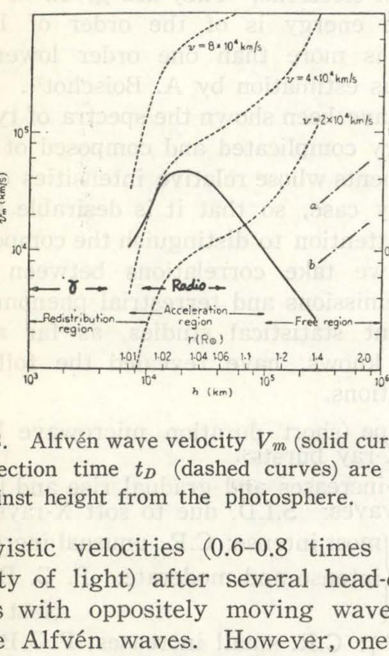


Fig. 3. Alfvén wave velocity V_m (solid curve) and deflection time t_D (dashed curves) are plotted against height from the photosphere.

relativistic velocities (0.6–0.8 times of the velocity of light) after several head-on collisions with oppositely moving wave-fronts of the Alfvén waves. However, one reflection of the electrons from the wave front results in an increase in V_{11} alone (velocity component parallel to the magnetic lines of force) so that helical pitch angle θ ($\tan\theta = V_{\perp}/V_{11}$) becomes so small that no more reflection arise. In order that the accelerations proceed to relativistic velocities, redistribution of the electron velocities must be made. This redistribution may be made due to Coulomb collisions with ambient thermal electrons sufficiently before a large portion of the initial energy is lost[10].

Ratio between the deflection time t_D (Spitzer[11]) and energy exchange time t_E is of the order of 0.1 when the velocity of accelerated electron is greater than about three times of that of thermal electrons (Fig. 4). Thus the velocity redistribution of accelerated electrons may be made to proceed the accelerations, as long as the Alfvén waves exist. As shown in Fig. 3 the redistribution is effective in upper chromosphere in which t_D is short but some redistribution may be

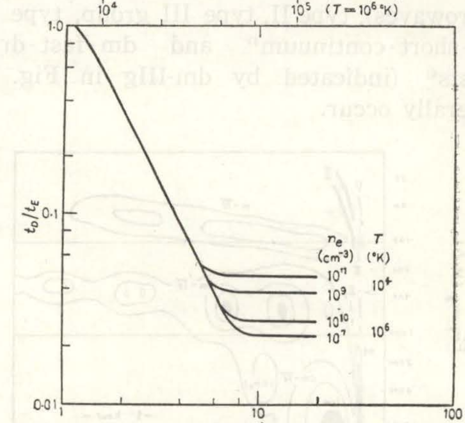


Fig. 4. Ratio between deflection time t_D and energy exchange time t_E. v is velocity of an electron and v_e is that of thermal electrons.

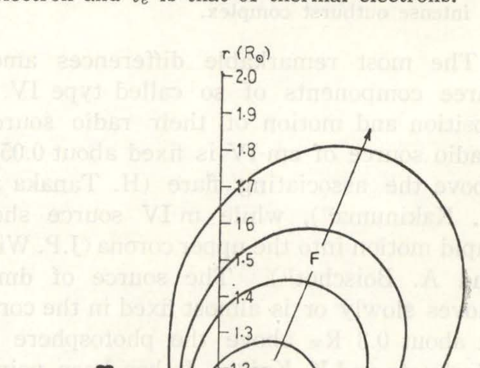


Fig. 5. Schematic picture of a bipolar sunspot magnetic field in which accelerations of electrons are taking place. A, A': acceleration regions and A is also radio source for outburst at microwaves. D, D': Redistribution regions. γ: γ-ray (hard X-ray) sources. F: Accelerated electrons go foward and backward along the magnetic field between their mirror points. Some redistribution occur also in this region.

made also in the corona, while the acceleration is effective in lower corona (10^4–10^5 km) in which V_m is high. Fig. 5 shows a bipolar sunspot field in which accelerations of electrons are taking place.

The accelerated electrons tend to accumulate to the places where the magnetic field is greater so that helical pitch angle is greater. One place is just above the preceding sunspots (Fig. 5). Here may be the radio source at microwaves (the magnetic field of following sunspot is weaker so that the emission may be weak). The relativistic electrons with smaller pitch angles flow into the middle chromosphere, say 5×10^3 km in height. These electrons radiate hard-X rays (20–500 KeV) due to atomic collisions with neutral hydrogens. These Bremsstrahlungs were observed by J. Winckler and others[12),13)]. This problem will be mentioned later.

At intense eruptions, eruptive material motion pushes out the sunspot magnetic field *selecting the weaker parts* of the field. One place might be above the *following spot* since the field is weaker than that of the preceding spot. The other weaker places may be pushed out into the outer corona. Thus a few magnetic bulges would be created as shown schematically in Fig. 6. The magnetic field in the bulges increases owing to

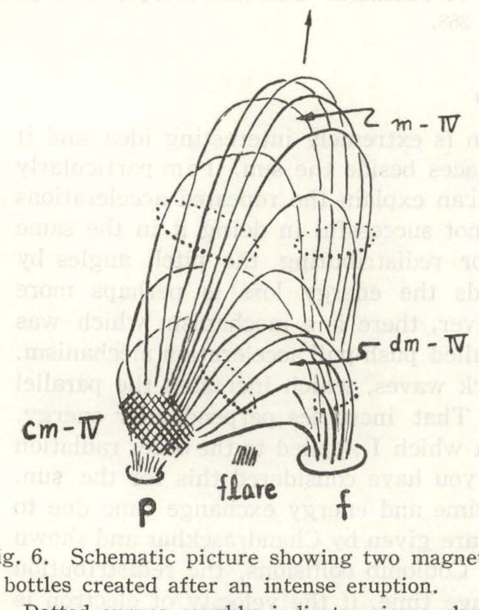


Fig. 6. Schematic picture showing two magnetic bottles created after an intense eruption.
Dotted curves roughly indicate mirror planes for the relativistic electrons which have greater pitch angles, say$>30°$, in the magnetic bulges.

a compression of the field by the material motion, which results in an increase in the density of relativistic electrons in the bulges since pitch angles of electrons increases. Relativistic electrons which get greater pitch angles (say$>30°$) due to the redistribution in or near the magnetic bulges are also trapped in the bulges. Thus a few magnetic bottles would be created to be separate radio sources.

The frequency ranges of synchrotron emissions from the radio sources is mainly determined by the magnetic field in the sources. Therefore, a few components of type IV (m-IV, dm-IV and cm-IV) may appear on dynamic spectrum.

A magnetic bottle above the following spot as shown in Fig. 6 might be the radio source for dm-IV. The high degree of circular polarization, high directivity and rather narrow bandwidth of dm-IV would be explained, if we suppose that the radiations are *fundamental* waves of synchrotron radiations, that is *extraordinary waves referring to the following spot*, escaping due to Doppler frequency-shift nearly parallel to the magnetic lines of force in the magnetic bottle.

§ 3. X-ray Bursts and M-type Radio Bursts.

J. Winckler *et al.* observed hard X-ray bursts at solar flares[12),13)]. While in an ordinary session, M. Kundu[14)] showed good coincidences of the X-ray bursts with M-type[3)] bursts (short duration microwave bursts).

For the first event, Winckler *et al.* pointed out that the X-rays (0.3–0.5 MeV at this event) are Bremsstrahlungs due to atomic collisions between relativistic electrons (0.5–1 MeV) and neutral hydrogens, while radio waves are due to synchrotron mechanism[12)]. They found a discrepancy of 10^4 between the number of electrons to radiate X-rays (N_e) and the number of electrons radiating radio waves (N_R), that is $N_e \simeq 10^4 N_R$. However, this discrepancy seems to be due to their inadequate estimation. We can find much better fit, if we adopt a picture shown before (cf. Fig. 5). Following this picture, we have

$$\text{radio flux} \propto n_R Sl \quad = N_R,$$
$$\text{X-rays} \quad \propto n_e S v_{11} \Delta t = N_e,$$

where n_R is *number density* of relativistic electrons in the radio source, S is area of the source, l is the thickness of the source, n_e is *number density* of relativistic electrons flowing into the middle chromosphere through the radio source, v_{11} is electron velocity parallel to the magnetic field and Δt is the duration of the X-ray burst.

They compared N_R to N_e and found that $N_e \simeq 10^4 N_R$, but a comparison between n_R and n_e seems to be more reasonable. If we take $l=10^4$ km, $v_{11}=2\times10^5$ km/s and $\Delta t=20$ sec., we have $n_e=25\ n_R : n_e=25\ \mathrm{cm}^{-3}$, $n_R=1.0\ \mathrm{cm}^{-3}$; if we further put $S=10^{11}\ \mathrm{km}^2$, we have $N_e=1.0^{34}\ \mathrm{cm}^{-3}$ and $N_e=10^4 N_R$. This discrepancy of 25 is not serious because electrons with very small pitch angles do not contribute to the synchrotron radiations but contribute to the Bremsstahlungs.

As a conclusion, X-ray bursts seems to be Bremsstrahlungs from relativistic electrons which flow into the middle chromosphere through the radio source above the chromosphere. While, M-type bursts are synchrotron radiations from about the same electrons in the radio source. The spectrum and polarization of M-type bursts have been explained consistently by the synchrotron radiations[15] from 0.1-0.5 MeV electrons with number density of $1.0\text{-}10^2\ \mathrm{cm}^{-3}$ which depend on the burst intensity and the size of radio source.

The acceleration mechanism of electrons for M-type may slightly different from that of cm-IV. The electrons radiating M-type might be accelerated for a short time at the onset of the flare, say due to pinch effect.

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Discussion

Singer, S.F.: This suggestion for acceleration is extremely interesting idea and it correct may have wide applicability in other places beside the sun. I am particularly interested in seeing whether such a mechanism can explain the repeated accelerations of electrons in the outer radiation belt. I am not successful in doing it in the same way, because I found that the time scale for redistributing the pitch angles by coulomb collision is too long, in another words the energy loss is perhaps more affected for nearly relativistic electrons. However, there is a mechanism which was proposed several years ago by Fan, which is called push-pull acceleration mechanism. It has Alfvén waves and collisions with shock waves, which increases the parallel energy but it also uses betatron acceleration. That increases perpendicular energy. It seems to me that this is the type of mechanism which I applied to the outer radiation belt, but with not great success. I wonder if you have considered this for the sun.

Takakura, T.: I simply applied deflection time and energy exchange time due to Coulomb collisions in a fully ionized gas, which are given by Chandrasekhar and shown in Spitzer's text book. Main point is that, for Coulomb collisions, the redistribution time is about *one tenth* of the energy exchange time, if the velocity of electron is greater than three times of that of thermal electrons.

Lüst, R.: Since it has just been referred to the energy losses of the electrons, I would like to point out that the main energy loss of the electrons in the corona is due to the ionization and excitation of heavier elements. Therefore the estimated time may be considerably shorter.

Takakura, : I don't agree, because the abundance of heavier elements is small and also energy of electrons is high; after only one acceleration due to Alfven wave, the energy of the electron is more than a few KeV.

As far as I have roughly estimated from Allen's "Astrophysical Quantities," the ionization and excitation losses are much smaller than the energy loss due to Coulomb collisions with thermal electrons (added in proof).

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II-3A-P3. The Radio Emission from Solar Flares

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The radio emission from solar flares is of special interest in the study of geomagnetic storms and solar cosmic rays because it gives a direct indication of the passage of ionized streams of gas through the Sun's atmosphere. The purpose of this paper is to review the nature of these emissions in a general way with particular reference to the papers and discussions contributed at the Kyoto Symposium.

§1. Origin of the Emissions

The observed emissions originate from all levels of the Sun's atmosphere between the chromosphere (centimetre waves) and the corona out to a height of 2-3 solar radii (metre and decametre wave). Three physical processes have been proposed to account for different components of the emission, namely:—

a) *Bremsstrahlung*, recognized at centimetre wavelengths only, due to encounters between thermal or superthermal electrons and protons or neutral atoms.

b) *Radiation at the plasma frequency and harmonics* due to electromagnetic emission from plasma waves. The excitation of the plasma waves results from the passage of electron streams through the plasma, and part of the energy in the plasma waves is converted into electromagnetic raiation either by scattering at inhomogeneities in the plasma[1] or, in the case of inward-moving streams, by direct coupling with the electromagnetic wave[2].

In favourable circumstances plasma radiation is recognized directly by the appearance of 2 : 1 harmonic features in the spectral records. These features are evident in bursts of spectral types II and III discussed below.

c) *Radiation at harmonics of the gyro frequency* due to electrons spiralling in the magnetic field. The gyro frequency itself cannot escape, but emission at low harmonics ("gyro radiation") and high harmonics ("synchrotron radiation") are both believed to occur. With synchrotron radiation the electron velocities are relativistic; in practical circumstances the closely-spaced harmonics merge with one another to form a continuum, the presence of which provides one criterion of recognition. Thus type IV and V bursts, which appear as continua, are attributed, in part at least, to synchrotron radiation.

§2. Metre Waves: the two phases

A conclusion of general importance which has emerged from studies at metre wave-