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CHARACTERISTICS OF THE X-RAY EMISSIONS ASSOCIATED WITH SOLAR PROTON FLARES

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Sudden ionospheric disturbances (SID) such as SWF, SEA, SPA and others are usually associated with solar proton flares (for example, Smith and Smith, 1963). These disturbances are generated by enhanced ionization of the lowest part of the ionospheric D region due to the incidence of energetic X-rays of wavelength $\lesssim 5\mathring{A}$.

Solar flares of importance 3 or 3+ sometimes generate energetic protons and heavier nuclei of Bev-energy range which are detected as an unusual increase of cosmic-ray intensity by ground based observation, while in association with many solar flares of the same importance just mentioned, protons and heavier nuclei of Mev-energy range are produced about ten times more frequently than the cases of Bev-energy particle production throughout the solar cycle (Carmichael, 1962; Bailey, 1964; Obayashi, 1964). Here, we shall call the proton flares which produced Bev- and Mev-energy particles Bev-proton and Mev-proton flares, respectively. In considering the latter flares, we only consider those which produced the solar proton events of F and F* types since the other solar proton events of S type seem to be connected with the development of Sc magnetic storms rather than with parent flares themselves (Sakurai, 1963). The definition of these types is described in the literature (Sakurai, 1965).

As is well known, the pattern of SWF's associated with the proton flares defined above is always of the sudden drop-out type (Hakura, 1966). However, the characteristics of SEA's associated with Bev-proton flares are clearly different from those associated with Mev-proton flares with respect to the rise time of atmospheric field intensity increase and the behavior of SEA's at 10 Kc/s. The examples of SEA's observed by using three discrete frequencies 10, 21 and 27 Kc/s at Toyokawa, Japan are shown in Fig. 1(a) and (b), where the Bev-proton flare on 15 November 1960 and the Mev-proton flare on 20 September, 1963 are described with flare data on importance, position and developmental pattern. The arrows in the figure indicate the onset time of the explosive phase of the parent flares. These two developmental patterns of SEA's as shown in Fig. 1 (a) and (b) are respectively defined as the sudden- and slow-onset type of SEA's by referring to the rise time of the field intensity at 21 and 27 Kc/s. We have analyzed the observational data on SEA's associated with both Bev- and Mev-proton flares which are tabulated in the literature (Sakurai, 1968). All Bev-proton flares analysed are associated with the sudden-onset type of SEA's, while 93 per cent of Mev-proton flares analysed are associated with the slow-onset type of SEA's. The rest of Mev-proton flares produce very similar patterns as slow-onset type of SEA's, but did not show any decrease of the field intensity at 10 Kc/s. It therefore seems that the developmental pattern of SEA's can give some clue to

infer characteristics of X-ray emissions associated with solar proton flares.

Solar flares are in general detected by observing sudden brightening of Hα emission intensity. We now define the rise time of Hα-brightness increase associated with solar proton flares with the time intervals from the start to the maximum brightness of Hα emission, in order to compare the time scale of the development of Bev-proton flares with that of Mev-proton flares. This time interval is shown in Fig. 2 as for both Bev- and Mev-proton flares. On the average, the rise time of Hα-brightness increase for Bev-proton flares are clearly shorter than those for Mev-proton flares. The mean time intervals for Bev- and Mev-proton flares are about 6 and 15 minutes, respectively. This result suggests that the rise time of proton flares observed by means of Hα emission is clearly related to the acceleration efficiency of solar cosmic-ray protons and heavier nuclei. Furthermore, this rise time is correlated with the rise time of SEA development which is generated due to strong enhancement of energetic X-ray emissions.

We can thus conclude that the acceleration efficiency of energetic protons and heavier nuclei is closely connected with the rise time of the increase of both Hα and X-ray emissions associated with the development of solar proton flares. The importance of both Bev- and Mev-proton flares in all cases is identified with 3 or 3+ except for a few cases. It thus seems that the magnitude of both Bev- and Mev-proton flares is nearly equal

to each other with respect to their areas and duration. Consequently, the time scale of development of solar proton flares strongly controls the acceleration efficiency of energetic protons and heavier nuclei such as being observed as solar cosmic rays, and the mechanism of X-ray emissions is closely related to the acceleration process of energetic electrons which are now believed to be responsible for energetic X-ray emissions due to the bremstrahlung mechanism (Kundu, 1963).

As has been shown above, the magnitude of time scale of proton flare development is closely correlated to that of accelerated energy of particles. This suggests that some sudden acceleration process works very efficiently in generating such energetic particles, during the explosive phase of parent proton flares, since the rise time of Hα brightness increase (Fig. 2) certainly gives the order of magnitude for the duration of that phase. It is clear that the rise times of both Hα-brightness increase and SEA's is, in nature, related to the development of some hydromagnetic instability which produces the onset of solar flares. The acceleration mechanism of energetic particles and its efficiency are, therefore, strongly connected with the development of the instability mentioned above, since the efficiency of particle acceleration becomes greater as the rise time of Hα-brightness increase becomes shorter.

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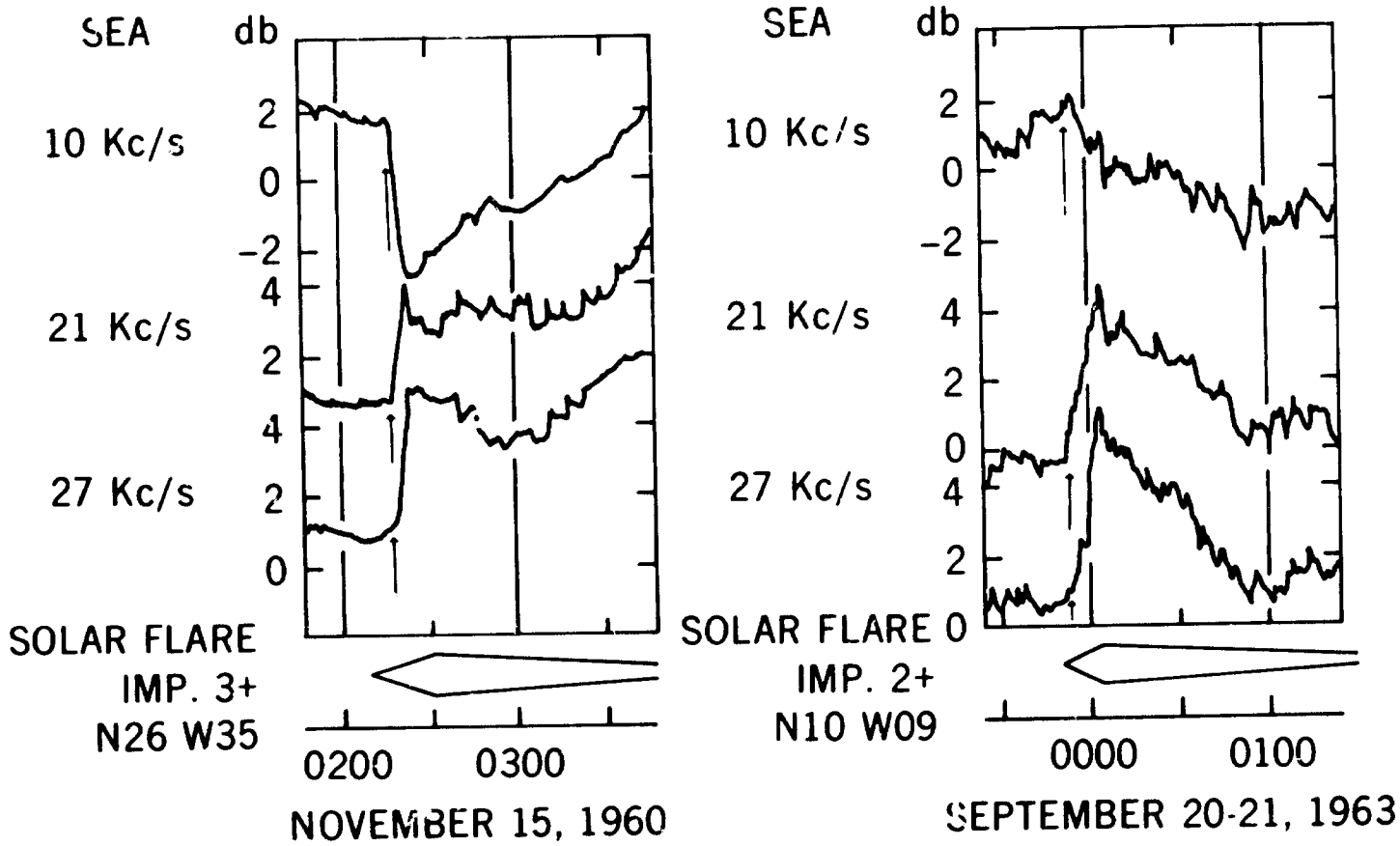
CAPTION OF FIGURES

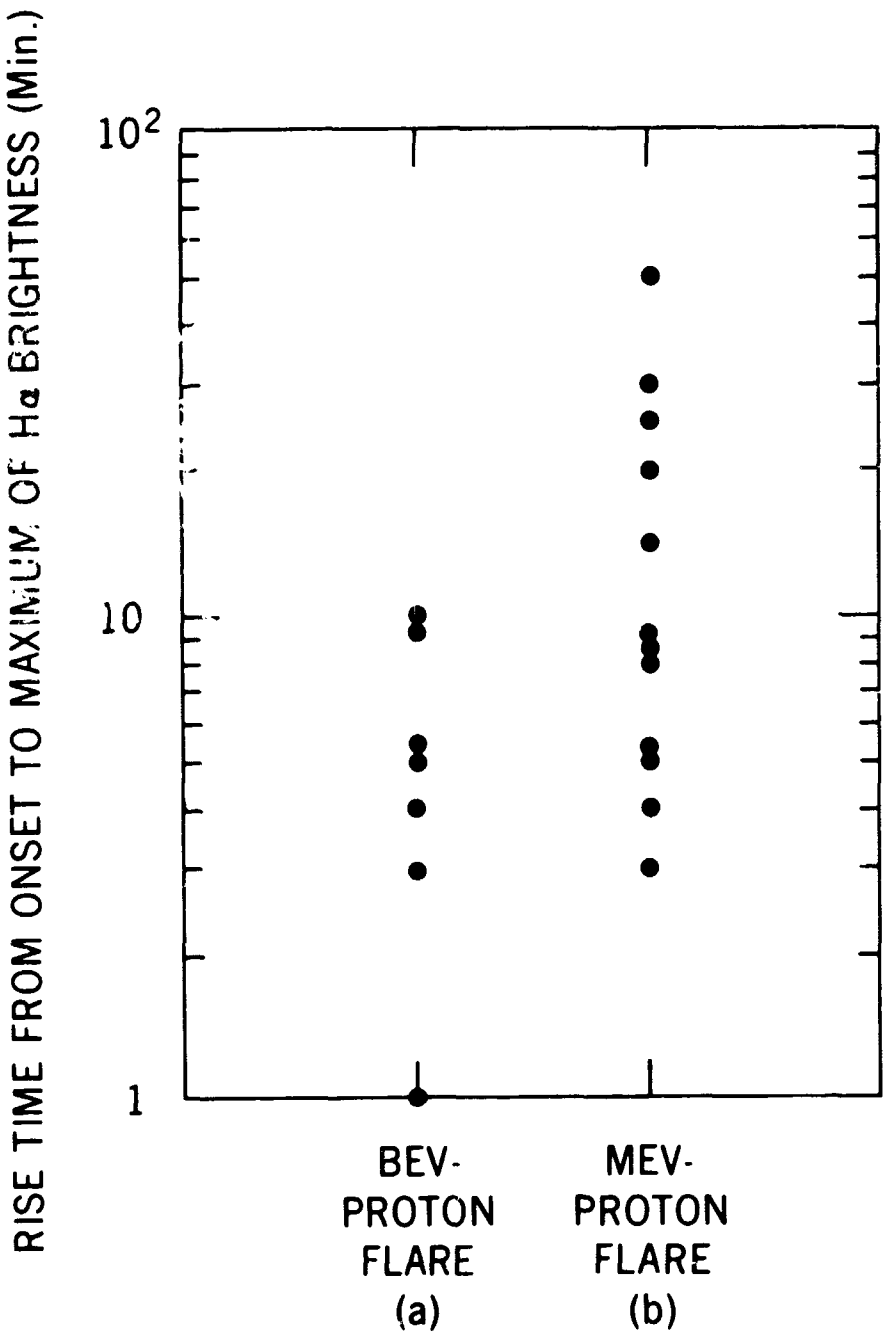
Fig. 1 - The examples of SEA's associated with solar proton flares.

(a) SEA associated with Bev-proton flares,

(b) SEA associated with Mev-proton flares.

Fig. 2 - The rise time from the start to the maximum of Hα-brightness increase for (a) Bev- and (b) Mev-proton flares.


SEA
db
10 Kc/s
21 Kc/s
27 Kc/s
2
0
-2
4
2
4
2
0
SOLAR FLARE
IMP. 3+
N26 W35
0200
0300
NOVEMBER 15, 1960
(a)
SEA
db
10 Kc/s
21 Kc/s
27 Kc/s
2
0
-2
4
2
0
4
2
0
SOLAR FLARE
IMP. 2+
N10 W09
0000
0100
SEPTEMBER 20-21, 1963
(b)


RISE TIME FROM ONSET TO MAXIMUM OF Hα BRIGHTNESS (Min.)
10^2
10
1
BEV-
PROTON
FLARE
(a)
MEV-
PROTON
FLARE
(b)