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AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
L. G. HANSCOM FIELD, BEDFORD, MASSACHUSETTS

The Great Burst of May 23, 1967

JOHN P. CASTELLI
JULES AARONS
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This research was supported by the Air Force
In-House Laboratory Independent Research Fund

OFFICE OF AEROSPACE RESEARCH
United States Air Force

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SPACE PHYSICS LABORATORY PROJECT 000D

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Abstract

One of the largest radio bursts on record took place on May 23, 1967. Peak flux densities ranged between 23,000 flux units ($10^{-22}Wm^{-2}Hz^{-1}$) at 8800 MHz to about 370,000 units at 606 MHz. In addition to the high accuracy measurements of the peak flux densities at 606, 1415, 2695, 4995, and 8800 MHz, sweep frequency observations from 19 to 41 MHz show Type IV emission with Type II bursts occurring during the Type IV continuum. The associated flare was clearly visible in white light. In reviewing and compiling microwave radio data recorded during earlier white-light flares, it was found that all but one of eight events listed by Svestka (1966) had high microwave flux densities associated with them. In comparing radio burst intensity with optical flare importance for the series of three flares between 1809 and 2150 UT on May 23, 1967, there is only moderate agreement. The first radio burst was small; the second flare had the highest optical classification, while the third radio burst was by far the largest. The flux densities of the third radio burst may have been the highest ever recorded in the decimeter portion of the radio spectrum and among the largest four in the 8800 MHz region. It is suggested that the details of the development of the flare be followed on radio flux density plots to determine detailed correlation with particle events in space and with terrestrial effects.

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The Great Burst of May 23, 1967

1. INTRODUCTION

The first half of the year 1967 was one in which a series of anomalies was observed in the optical-flare radio-burst proton area. As early as January 28 and 29, neutron monitors at ground level clearly indicated that a proton event had occurred although there was at best only questionable optical and radio correlation.

On February 13, a 4B flare with accompanying Type IV meter wavelength radiation was observed. Though quickly predicted by some optical observers to be a probable proton-producing flare, the very weak microwave burst radiation indicated that it was highly unlikely (and subsequently confirmed) that a PCA would follow.

On February 27, an Importance 2B-3B flare was observed with such intense microwave emission as to lead one to suspect that the event would surely produce a PCA (see Table 1). It was quite surprising that no increase in protons was recorded.

On March 11, with no large optical or microwave burst observed, an increase in proton flux was detected via satellite; absorption at Shepherd's Bay began at 1800 UT and was still in progress at 1949 UT on March 12. It is strongly

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suspected that the very "hot region (McMath Plage No. 8704), which had rounded the west limb in early March, was the source of a flare on the far side of the sun. A Type IV dekameter event that was observed might be explained if the source of radiation was high enough in the solar atmosphere to be seen at angles just grazing the west limb.

Table 1. Distinctive Solar Radio Emissions Recorded at Air Force Cambridge Research Laboratories, Sagamore Hill Radio Observatory, Hamilton, Massachusetts (42.632°N, 70.821°W)

<table>
<tr><th colspan="6">February 27, 1967</th></tr>
<tr><th>Frequency MHz</th><th>Start Time UT</th><th>Max. Time UT</th><th>Duration (Min)</th><th>Peak Flux Units $10^{-22}Wm^{-2}Hz^{-1}$</th><th>Mean</th></tr>
<tr><td>8800</td><td>1638</td><td>1649.2</td><td>78</td><td>6200</td><td>974</td></tr>
<tr><td>4995</td><td>1637</td><td>1649.2</td><td>85</td><td>2300</td><td>450</td></tr>
<tr><td>2695</td><td>1637</td><td>1649.2</td><td>64</td><td>990</td><td>200</td></tr>
<tr><td>1415</td><td>1637</td><td>1647.3</td><td>53</td><td>595</td><td>100</td></tr>
<tr><td>606</td><td>1637</td><td>1645.5</td><td>53</td><td>750</td><td>125</td></tr>
<tr><th colspan="6">Optical Data (Flare)</th></tr>
<tr><th>Region</th><th>Location</th><th>Importance</th><th>Start Time</th><th>Max. Time</th><th>Configuration</th></tr>
<tr><td>157</td><td>N26, WO3</td><td>2B* 3B†</td><td>1640 UT</td><td>1650 UT</td><td>DELTA</td></tr>
</table>

* SAC. PEAK

† CLIMAX

2. MAY 21, 1967

The first decisive correlation between PCA (proton events) and radio optical data in 1967 occurred during the last ten days of May. Prior to this, the microwave solar emission had been lower at all frequencies than at any time in 1967 until then. A minimum was recorded on May 11 to 13. Just prior to May 18, nine consecutive days had passed without a single burst being recorded at Sagamore Hill Radio Observatory. On May 17 and 18, as an extremely hot region began to round the east limb, the total daily flux climbed rapidly (ESSA Monthly Bulletin of Solar Geophysical Data, No. IER-FB-274, 1967). On May 18, 19, and 20, flare associated burst activity also began to increase, reaching a temporary "high" on May 21 when at about 1922 UT a large complex burst was observed in McMath Plage No. 8818. (See Figure 1.) A Type IV dekameter event, which lasted over one hour from 1922 to 2034 UT, was also observed at 19 to 41 MHz. By the

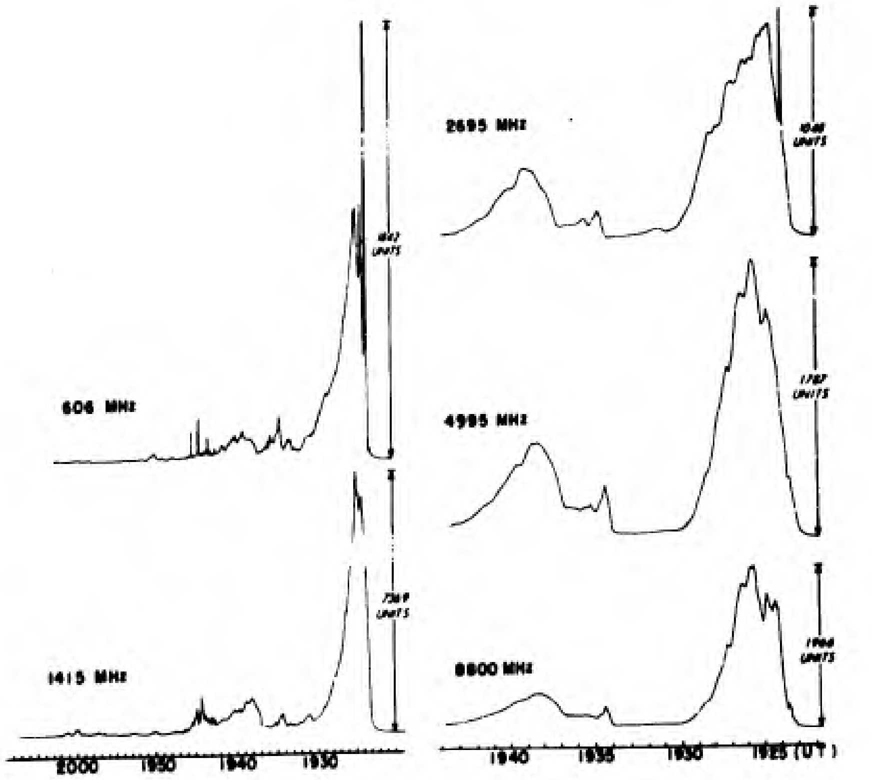

Figure 1. Complex Radio Burst Observed on May 21, 1967, at Sagamore Hill Observatory (AFCRL), Hamilton, Massachusetts

usual standards (Dodson et al., 1954), the intensity was large. It was a "great burst" by either "URANE" classification (>1000 flux units) or the usual microwave classification (>750 flux units). The associated flare was located at approximately N25, E39. The highest final optical classification was 2B.

3. MAY 23, 1967

The following day, May 22, 1967, was ominously quiet at Sagamore Hill except for one small event at about 1530 UT. On May 23, however, all quiet ceased with events which followed. The first of at least three burst components in McMath Plage No. 8818 reached a maximum at about 1809 UT, coinciding approximately with the start of a 2N-2B optical flare that reached a maximum in H_α 1810 to 1812 UT. The second component reached a maximum near 1839 UT somewhat earlier than the 3B flare maximum of 1845 UT. The third component "peaked" between 1947 and 1954 UT, depending on the frequency. Optical maximum for the associated 2B flare occurred at about 1947 UT. The first two radio events apparently "peaked" before the H_α maximum, while the third and largest microwave radio component reached maximum at about the same time or a little later than the optical maximum. The three flares emanated from a region roughly N27-30, E25-28. So intense was the flare that it was observed in white light by observers at Sacramento Peak, New Mexico, and at ESSA Space Disturbance Forecast Center at Boulder Colorado (Sky and Telescope, 1967).

In the history of solar astronomy dating back to 1859, there have only been about two dozen flares observed in white light. Svestka (1966) pointed out that from 1956 to 1960, when PCA observations were made and nine white-light flares were reported, only three of the latter could not be identified with a PCA. The radio data from these white-light flares will be reviewed in Section 8.

There was no question about PCA association on May 23, for at 1925 UT satellites began "reading" an increase in proton level associated with the second component. Ultimately, a PCA of >20 dB was recorded. The corrected flare area of the second flare was greater than the third. In the radio portion of the spectrum, the third component was by far the largest. So large in fact was the radio burst that we were inclined to doubt our own calibration—needlessly so, however, since no data were lost from recorder "off scale" or receiver saturation.

4. CALIBRATION VERIFICATION

At Sagamore Hill Radio Observatory, argon noise generators are used in calibration. Beyond the range of these accurately calibrated generators (~10,000°K), cw sources are conventionally used. With the possible exception where logarithmic i.f. receivers are used, the cw method is valid. The correspondence between broad band noise signals, between 100 and 10,000°K, with cw signals over a 20 dB range has been verified many times; the correspondence is valid regardless of receiver bandwidth. The incredibly high burst fluxes led us to construct extremely high temperature broad band noise sources with argon tubes, TWT's, broad band amplifiers, and suitably calibrated precision attenuators to verify the cw calibration of solar fluxes. In both instances, the results were the same. Final peak flux values are presented in Figure 2. Curves were reconstructed from raw data sampled at intervals equal to or less than one minute. The indications are that the radio event was one of the largest ever recorded. Unfortunately, many observers in North and South America were either not observing or completely lost the peak from "off scale" conditions. The spectrum of the peak fluxes, as recorded at Sagamore Hill Radio Observatory, is shown in Figure 3 and Table 2. Two additional confirming points by Ottawa at 2800 MHz are shown for components 2 and 3.

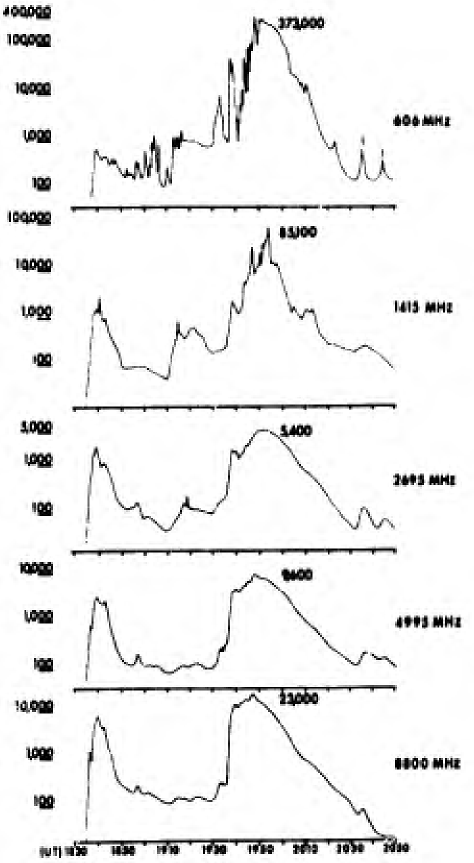

Figure 2. Great Radio Burst of the Solar Proton Flare May 23, 1967, Sagamore Hill Radio Observatory, Hamilton, Massachusetts. Chart reconstructed-flux values plotted at intervals of one minute or less. Flux density in units of $10^{-22}Wm^{-2}Hz^{-1}$

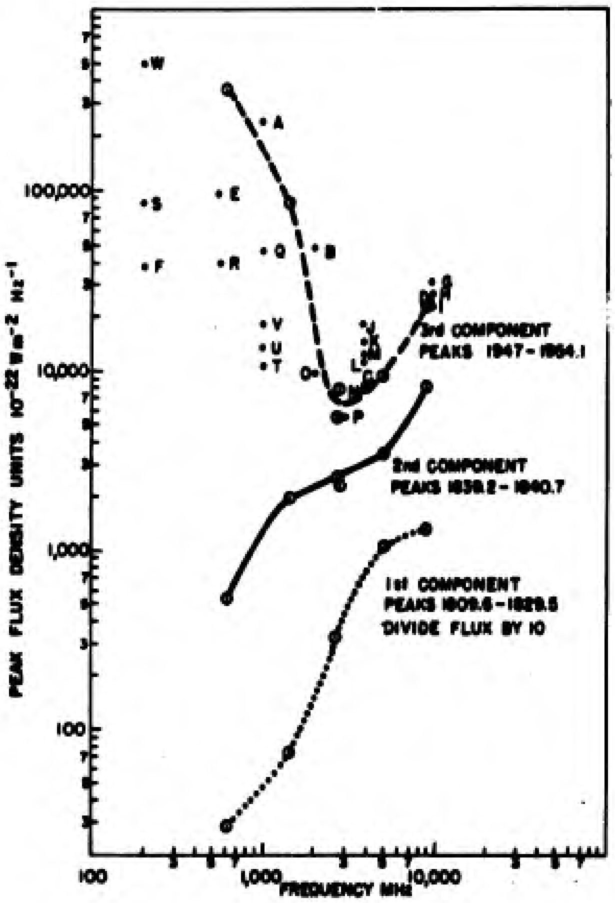

Figure 3. Radio Spectrum Proton Event May 23, 1967. Points represent maximum flux increases. Observations at Sagamore Hill and Ottawa (2800MHz) with highest earlier single frequency fluxes (see Table 3)

Table 2. Distinctive Solar Radio Emissions Recorded at Air Force Cambridge Research Laboratories, Sagamore Hill Radio Observatory, Hamilton, Massachusetts (42.632°N, 70.821°W)

Date	Freq (MHz)	Time UT		Dur Min	Type* Event	Flux Density $X10^{-22}Wm^{-2}Hz^{-1}$	
		Start	Max			Peak	Mean
May 21, 1967	8800	1922.8	1925.7	26.2	45	1966.0	500.0
	4995	1922.2	1925.7	25.8	45	1787.0	447.0
	2695	1922.5	1923.7	25.5	45	1048.0	260.0
	1415	1921.0	1924.8	63.6	45	736.9	180.0
	606	1922.0	1923.2	55.0	45	1842.0	465.0
May 23, 1967	8800	1802.5	1809.6	32.5	28	130.8	21.8
	4995	1757.0	1809.6	38.0	28	108.8	28.0
	2695	1800.0	1809.7	35.5	28	33.4	2.5
	1415	1802.5	1829.5	33.0	28	7.6	2.5
	606	1755.3	1813.8	32.9	20	2.9	1.0
	8800	1835.0	1839.7	112.0	47	8100.0	2800.0
	4995	1835.0	1839.2	110.0	47	3400.0	2000.0
	2695	1835.5	1839.1	108.5	47	2500.0	1400.0
	1415	1835.5	1840.7	129.5	47	2000.0	1100.0U
	606	1835.6	1839.5	159.4	47	534.0	2000.0U
	8800	1835.0	1947.0	112.0	47	23000.0	2800.0
	4995	1835.0	1948.0	110.0	47	9600.0	2000.0
	2695	1835.5	1951.8	108.5	47	5400.0	1400.0
	1415	1835.5	1954.1	129.5	47	87000.0	>1100.0
	606	1835.6	1948.5	159.4	47	370000.0	>2000.0

*Codes: 45 - Complex
47 - Great Burst
28 - Precursor
20 - Simple 3
U - Uncertain

5. SWEEP FREQUENCY AND DISCRETE FREQUENCY OBSERVATIONS IN THE 19 TO 401 MHz RANGE

Dynamic spectra from a sweep frequency interferometer operating in the 19 to 41 MHz range were also recorded at Sagamore Hill Radio Observatory on May 23 (Straka, 1967). Prior to the region flaring, weak Type IV radiation started near 1545 UT and became stronger with time. A reproduction of the spectrogram for the period from 1800 to 2400 UT and, in more detail, the period from 1800 to 1900 UT is shown in Figures 4a and 4b. Fringe reversals and saturations occur during the periods from 1837 to 1900 UT and from 1937 to 1950 UT.

The flare associated portion of this dekameter Type II-Type IV event evolved as follows: Soon after 1837 UT, a group of intense Type III bursts occured, lasting for three minutes, followed by a Type II burst from 1843 to 1906 UT; additionally, the Type IV in progress intensified. This series of events correlated with the H_α flare, whose maximum was near 1845 UT, and, several times, in

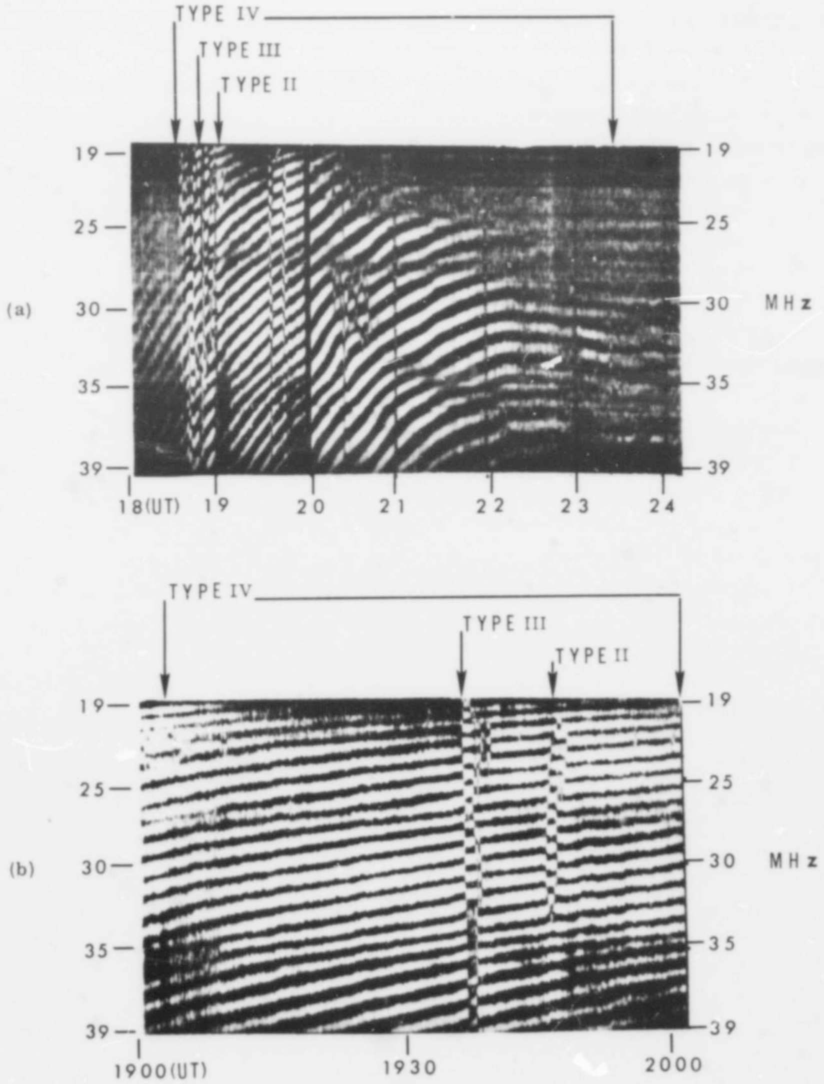

Figure 4. Type II to IV Spectra of the Solar Proton Flare of May 23, 1967, Sagamore Hill Radio Observatory (AFCRL), Hamilton, Massachusetts

fact, saturated the receiving equipment. Superimposed upon this strong Type IV and occurring near the maximum of the third optical flare was a group of Type III bursts near 1937 UT and a Type II burst at 1945 UT. From recordings of the total emission in this frequency range, the most intense portion of the entire event was probably observed during the period from 2015 to 2045 UT.

During this event two riomenters also were in operation, one at 30 MHz and the other at 50 MHz. The recordings are reproduced in Figure 5. The 50 MHz system recorded much of the event entering through back and side lobes of a 19 dB gain array (Whitney, 1967) Both signals started their rise at about 1837 UT. Details differ in the middle of the burst but the lower frequency burst terminated earlier, at about 2050 UT, while the 50 MHz signal maintained a high level until 2225 UT. It is unlikely that this difference is due to absorption since the signal level difference is so large between the two signals.

In addition to the riometers, other systems at Sagamore Hill Radio Observatory, which were making observations of satellite beacons at 136 and 401 MHz, recorded the solar burst profile through back and side lobes of stationary antennas. It has been possible from calibrations of Cassiopeia A, satellite signals, and an estimation of antenna gains to assign lower limits to fluxes at these frequencies. These values are >6,000 flux units at 401 MHz and >19,000 units at 136 MHz. Peak times were

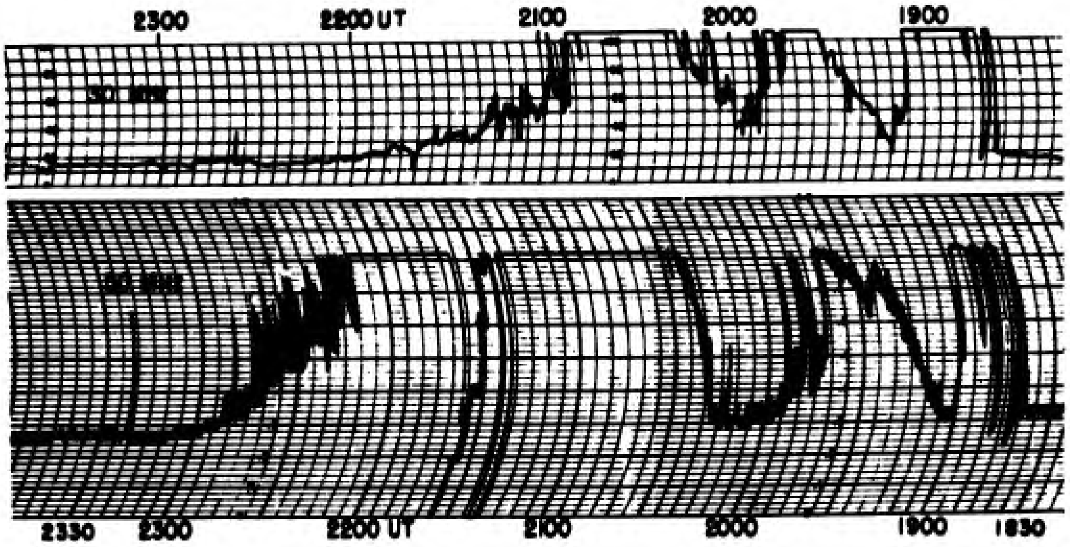

Figure 5. Great Burst of May 23, 1967, Sagamore Hill Radio Observatory, (AFCRL), Hamilton, Massachusetts. Upper curve is 30 MHz riometer record; lower curve at 50 MHz is recording through minor lobes of antenna array. Temperature difference is approximately 6000°K

1952 and 1944 UT respectively (Elkins, 1967). Figure 6 shows data at this critical period. The 401 MHz equipment used an 84 ft antenna, while the 136 MHz system used a simple Yagi antenna. The principal bursts recorded at these two frequencies occurred from 1938 to 1940 UT and from 1944 to 1951 UT at 136 MHz, and between 1950 and 2000 UT at 401 MHz as shown in Figure 6. It might be noted that a burst can be seen at all frequencies ranging from 19 to 8800 MHz at 1944 UT.

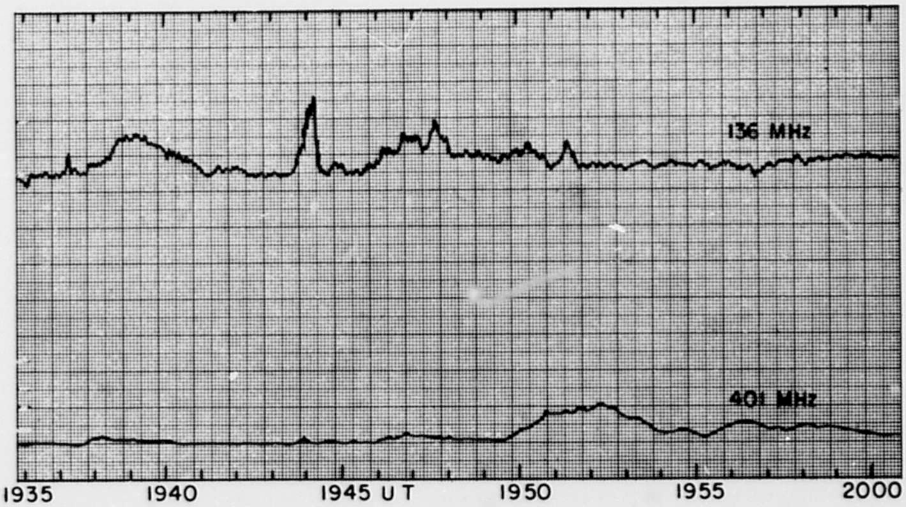

Figure 6. Great Burst of May 23, 1967, Observed Through Antenna Minor Lobes, Sagamore Hill Radio Observatory, (AFCRL), Hamilton, Massachusetts

6. 35 GHz OBSERVATIONS

During this same period on May 23, 1967, equipment at 35 GHz recorded the entire burst sequence associated with the 3B flare (Oliver, 1967). The burst started at about 1836 UT and reached a maximum flux increase of 3200 flux units at 1839:16 UT. The radio burst, starting at 1936:40 and related to the third flare was very large by comparison. Although the trace went "off scale" at 10,000 units increase, it would not be surprising if the maximum reached 25,000 or 3,000 units.

Flux values presented are corrected for antenna beamwidth and are probably accurate to within 10 percent. There is nothing in the sparse millimeter literature that indicates burst levels even approaching these intensities during earlier observations.

7. THE PCA AND THE SID

If we compare the PCA from the present event at 30 MHz (>20 dB) with earlier large PCA's or with the 30 dB September 2, 1966, event (Castelli et. al., 1967), we find that between 1956 and 1963 from 189 PCA's only nine had an absorption greater than 17 dB (Fritzova and Svestka, 1966). Among these nine events, it appears to be extremely difficult to accurately compare one with the other or to assign valid calibrations at levels greater than 20 dB from the very nature of riometers operating at 30 MHz.

On both May 21 and 23, propagation equipment operating at 7.35 MHz recorded the events in absorption. On May 23, all three components were detected. The duration of the absorption, which reached close to 40 dB for the two larger components, was long compared to the event of May 21. This latter event though short in duration may have had a slightly larger absorption (Toman, 1967). There is also a possiblitiy that some emission may have been detected.

8. WHITE-LIGHT FLARES

Returning to the subject of flares visible in white light, we have reviewed available microwave radio data in the International Astronomical Union Quarterly Bulletins of Solar Activity (1956-1960) for correlation with the nine events from 1956 to 1960 listed in Table 3 of Svestka (1966). These data (peak flux increases) are presented in Figure 7 and Table 4. The curves are marked in alphabetical order, corresponding to the chronological sequence of events. Among these, Svestka (1966) found PCA correlation for all events except C, F, and G. The microwave fluxes for F seem very small. It appears that there is also very little correlation with event C on August 30, 1957, although the event reportedly persisted for twenty minutes, the longest of all white light flares reported. Of the remaining seven events, three (namely, A, B, and I) had an associated ground level event; there is a similar possibility for event H. Of certainty, this latter event (H) had PCA association. Two other events, D and E, had PCA association. Event G on April 8, 1959, with no known PCA relation, must have been one of the largest recorded radio events at 200 MHz. We should note that in some instances peak fluxes were estimated from mean values based on knowledge of peak to mean ratios at other frequencies. From the data for four events, the microwave radiation was obviously among the highest ever recorded; for the others, it was very high, and for two other, small enough to be "suspect".

Table 3. Single Frequency Radio Burst Maxima (1956 to present)

Symbol	Observatory	Frequency MHz	Date	Peak Flux Units $10^{-22} W m^{-2} Hz^{-1}$
A	Nagoya	1000	March 29, 1960	247,000
B	Nagoya	2000	March 29, 1960	49,000
C	Nagoya	3750	March 29, 1960	8,250
D	Tokyo	9500	March 29, 1960	~25,000*
E	Hollandia	545	March 29, 1960	~100,000
F	Hollandia	200	March 29, 1960	38,000
G	Nagoya	9400	February 23, 1956	31,400†
H	Nagoya	9400	July 10, 1959	26,500
I	Nagoya	9400	November 15, 1960	24,000
J	Nagoya	3750	February 23, 1956	18,000†
K	Nagoya	3750	April 5, 1960	14,200
L	Nagoya	3750	November 15, 1960	11,600
M	Nagoya	3750	September 3, 1960	12,000
N	Nagoya	3750	September 15, 1960	8,080
O	Nagoya	2000	November 11, 1960	9,600
P	Tokyo	3000	September 3, 1960	5,600
Q	Nagoya	1000	November 11, 1960	47,000
R	Hollandia	545	July 14, 1959	40,000
S	Hollandia	200	August 26, 1958	85,000
T	Nagoya	1000	July 14, 1959	10,600
U	Nagoya	1000	September 15, 1963	13,800
V	Nagoya	1000	April 5, 1960	18,000
W	Netherlands	200	April 8, 1959	~500,000

* Estimated from Mean Data

† See KUNDU P201

Table 4. White-Light Flares (1956 to 1960) From Table 3 Svestka (1966)

Symbol	Date	Position	Importance	Duration (Min)
A	1956 Feb 23	79W	3+	5
B	1956 Aug 31	15E	3+	1
C	1957 Aug 30	20E	?	20
D	1957 Sept 3	30W	3	6
E	1958 Mar 23	74E	3+	8
F	1958 Mar 30	63E	2	2
G	1959 Apr 8	85E	2+	?
H	1960 Sept 3	88E	2+	15
I	1960 Nov 15	33°	3	3

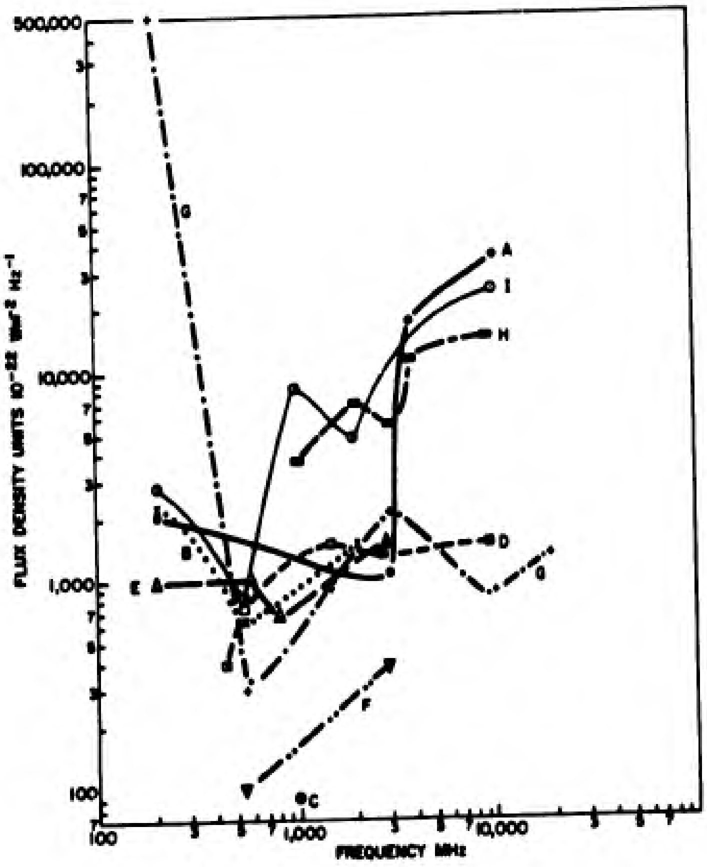

Figure 7. Spectra Peak Radio Flux White-Light Flares (see Table 4.)

9. EARLIER LARGE RADIO BURSTS

An investigation of earlier large radio bursts, based mainly on "distinctive events" from the International Astronomical Union Quarterly Bulletin of Solar Activity and personal communications from Covington (1967) and Tanaka (1967), disclosed the following information. There were possibly three or four larger events in the 3 cm region. These points are plotted in Figure 3 and described in Table 3. There were no data at 3750 MHz for the present event; but from the spectral curve of May 23, assuming a smooth spectrum, we would conclude that there were perhaps six larger events at this frequency in the past. At 2800 MHz, Ottawa's peak flux of 8000 units is about the largest ever recorded at that frequency. In the last sunspot cycle, events with peak fluxes of 5600, 6000, and 6500 units were recorded (Covington, 1967).

10. CONCLUSION

After the great burst of May 23, 1967, everything else must be anticlimactic. There have been unconfirmed reports that a flare at 1037 UT on May 25 produced and increase in proton flux. Sagamore Hill Radio Observatory recorded a radio event starting at 1041.2 with maxima at 1109 to 1229 UT and with small flux increases (~40 units) in the 3 to 10 cm range but with an increase of 8100 units at 606 MHz.

A major magnetic storm associated with the great event of May 23 took place on May 26, beginning at 1225 on May 25. The storm was one of the largest on record; auroras were observed on May 25 as far south as latitude 32°N.

As the active region moved to the west limb, activity remained high. A final proton flare, Importance 3B, took place on May 28 at 525 UT. The region was then N28, W32. A PCA with 5.5 dB absorption began at 625 UT. Microwave burst levels were considerably lower than those of May 23.

There can be little doubt that the microwave radio burst at 1947 to 1954 UT on May 23, 1967, was among the largest events ever recorded. It is not clear how the optical events would rank among large optical flares. Most observers agree that the first and third components did not exceed Importance 2B. Not all are agreed that the second component was larger than 2B, though some classified it 3B. No one has suggested that any phase of the event reached Importance 4. In the catalogue of white-light flares, eight earlier events were classified 3+ by the older scheme. There are numerous examples of 3+ flares during the previous cycle. We cannot conclude, therefore, that the event of May 23, 1967, was as unique optically as it was in the radio portion of the spectrum. It might, therefore, be suggested that detailed studies of this event take into account the time structure of the burst at various frequencies.

Acknowledgments

The authors wish to express their appreciation to CWO Walter Clark, USAF, for his most valuable contribution in successfully operating the equipment, logging signal level settings, and calibrating the five microwave systems during a bewildering period. They also wish to express thanks to SMSgt Arthur Francis, USAF, for his data reduction and art work and to Mr. Paul Lyons of Wentworth Institute for assistance with drawings.

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13. ABSTRACT

(10 [illegible] peak [illegible] W[illegible]/Hz)

One of the largest radio bursts on record took place on May 23, 1967. Peak flux densities ranged between 23,000 flux units (10^{-22} $Wm^{-2}Hz^{-1}$) at 8800 MHz to about 370,000 units at 606 MHz. In addition to the high accuracy measurements of the peak flux densities at 606, 1415, 2695, 4995, and 8800 MHz, sweep frequency observations from 19 to 41 MHz show Type IV emission with Type II bursts occurring during the Type IV continuum. The associated flare was clearly visible in white light. In reviewing and compiling microwave radio data recorded during earlier white-light flares, it was found that all but one of eight events listed by Svestka (1966) had high microwave flux densities associated with them. In comparing radio burst intensity with optical flare importance for the series of three flares between 1809 and 2150 UT on May 23, 1967, there is only moderate agreement. The first radio burst was small; the second flare had the highest optical classification, while the third radio burst was by far the largest. The flux densities of the third radio burst may have been the highest ever recorded in the decimeter portion of the radio spectrum and among the largest four in the 8800 MHz region. It is suggested that the details of the development of the flare be followed on radio flux density plots to determine detailed correlation with particle events in space and with terrestrial effects.

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Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Proton Event Flare Associated Solar Radio Emission Centimeter Radio Burst Solar Burst Spectra Outstanding Event						

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