

An Atlas of 10-50 Kev Solar Flare X-Rays

Observed by the OGO Satellites

5 September 1964 to 31 December 1966

by

R. L. Arnoldy, S. R. Kane and J. R. Winckler

School of Physics and Astronomy
University of Minnesota
Minneapolis, Minnesota

CR-108

January, 1968

This work has been supported by the National Aeronautics and Space Administration under Contract No. NAS 5-2071.

I. INTRODUCTION:

The large ionization chambers carried by the OGO-I and OGO-III satellites have observed many radiation increases which can be identified as energetic x-rays produced during solar flare events. It is the purpose of this report to make available detailed ionization-rate profiles for about 70 events representing practically all cases detected by these ion chambers during the observing time of the OGO-I and OGO-III satellites up to the end of 1966. Our group has studied the relationship between these energetic x-rays and the accompanying radio emission and the results have been given in several publications (Arnoldy, Kane and Winckler, 1967a; Arnoldy, Kane and Winckler, 1967b; Arnoldy, Kane and Winckler, 1967c). Further details of the instrumentation not contained herein are described in several documents (Kane, 1967; Kane, Pfitzer and Winckler, 1966). Copies of the above quoted papers are available on request.

The preliminary studies relating the x-ray phenomena to radio emission obviously leave many questions unanswered, and it is hoped that this atlas will stimulate further work in identifying the processes in various flare events and in finding some cases particularly on the solar limb which may give further essential information about the location of the sources. Since the Minnesota group is not at present engaged in a detailed study of the optical flares as seen in H_{α} or other emissions or of the magnetic character and development of the active centers, it is hoped that other groups will find interest in such a correlation to reach a better understanding of the flare energetics.

II. DESCRIPTION OF THE MEASURING INSTRUMENT:

The x-ray events tabulated in this report have been detected by a spherical aluminum walled ionization chamber containing argon gas. The general characteristics are given in Table 1.

Table 1

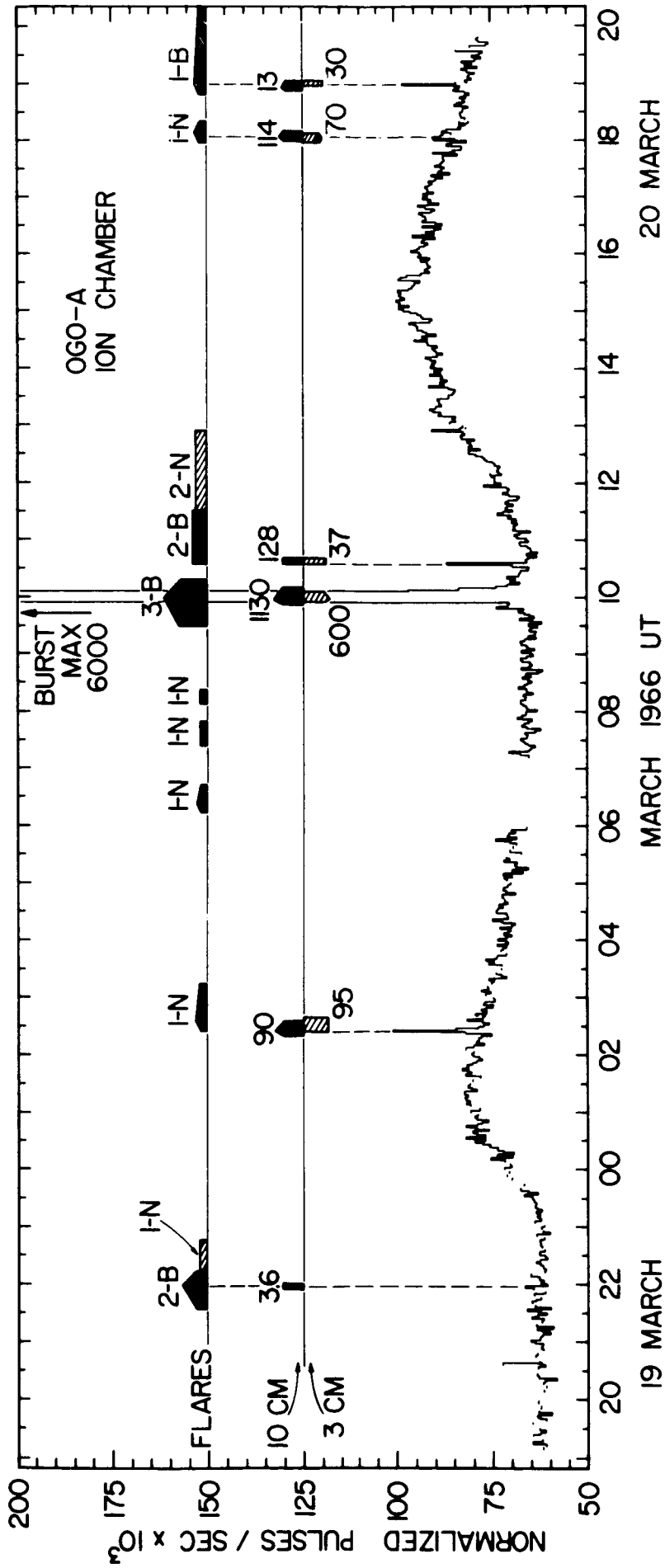
OGO ION CHAMBER CHARACTERISTICS

Diameter	17.8 cms
Wall thickness	0.085 cms Aluminum
Argon pressure	
OGO-I	50 lbs./in. ² absolute
OGO-III	60 lbs./in. ² absolute
Minimum energy for penetration by charged particles	
Protons	12 Mev
Electrons	0.6 Mev

This ionization chamber is mounted at the end of a four foot boom which keeps it away from the main body of the OGO satellite. The ion chamber sphere is adjacent on the end of the boom to a rectangular box containing some electronics and is covered by a very thin blanket of aluminized mylar. It is sensitive over essentially 4π steradians of solid angle but occasionally, due to the rotation of the satellites, will be periodically eclipsed by the body of the satellite. In some of the events shown (for example 28 August 1966) one can clearly see the roll modulation of the solar x-ray beam produced by this effect. In some cases both the OGO satellites have simultaneously

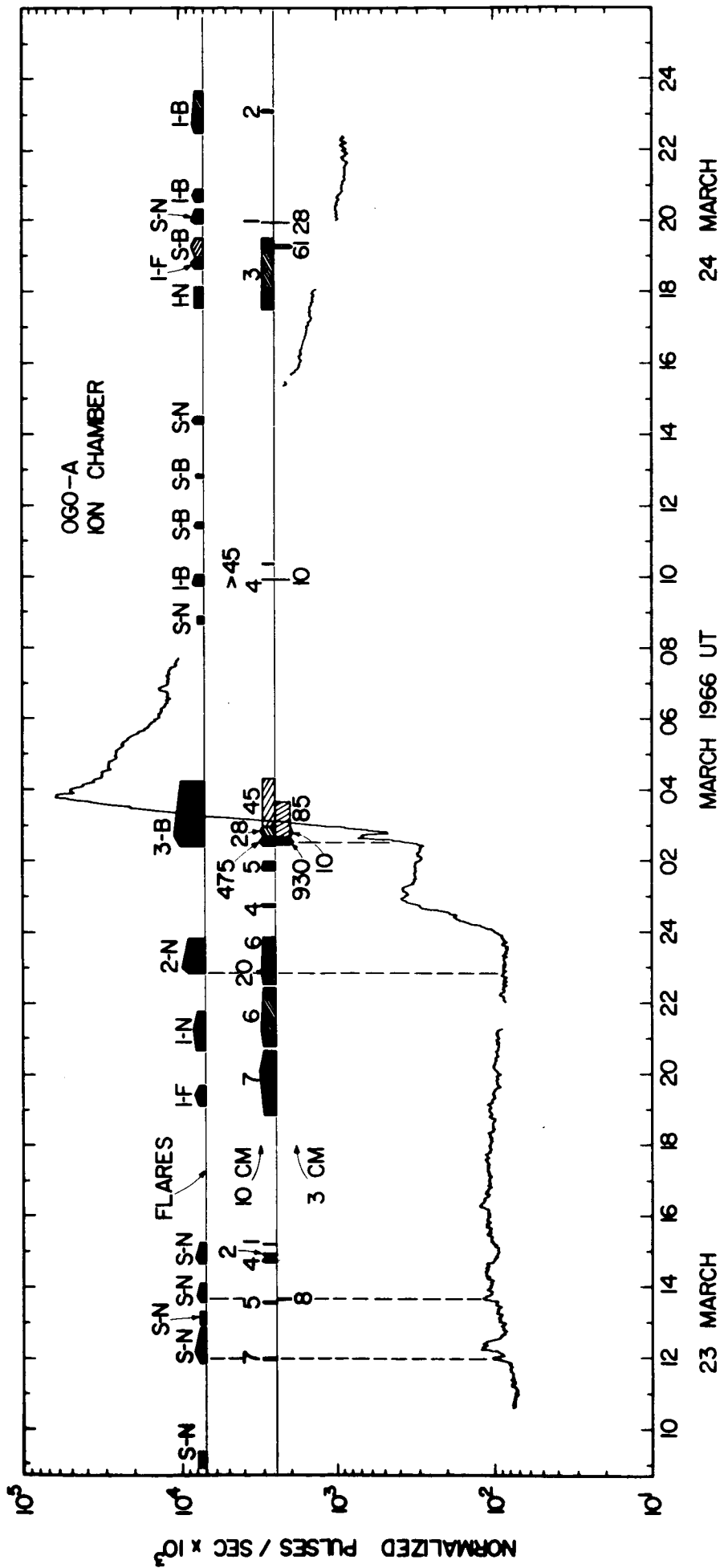
observed the same solar x-ray burst. (See, for example, 20 September 1966.) These features plus correlation with other electromagnetic radiations from the flare serve to identify the ionization increases as being due to x-rays. Usually these x-ray increases consist of isolated events detected when the satellites are outside the magnetosphere and the ionization chambers are responding only to the galactic cosmic ray background. In such cases the x-ray bursts are easily identified. Sometimes, however, the identification is more difficult especially in the transition region of the magnetosphere where electron "spikes" are often seen or during solar particle events in space to which the chambers are also sensitive. As an illustration of the response of these ionization chambers to various space radiations one may refer to Figures 1 and 2 which are "event plots" obtained during March 1966 with OGO-I when there was a complex series of x-ray and particle increases. These event plots are direct tracings of the automatic computer plot routine from the OGO data tapes but have, in addition, flare and radio burst data added above.

The graphs shown in the figures are expressed in an arbitrary rate of resetting of the ion chamber drifting electrometer in units called normalized pulses per second $\times 10^3$ (NPPS $\times 10^3$). These ionization production rates in the chamber can be converted from arbitrary units to energy fluxes in $\text{ergs cm}^{-2} \text{sec}^{-1}$ by referring to the response characteristics of the chamber. Such response curves assuming exponential spectra for the x-rays are shown in Figure 3. The conversion factors for the different spectral constants shown in Figure 3 are summarized in Table 2.



Event plot obtained by an automatic data reduction which plots the ionization rate in two-minute averages. The galactic cosmic ray background outside the magnetosphere is about $62 \text{ NPPS} \times 10^3$ as shown up to 2300 on 19 March. At this point a small solar particle event appears reaching a maximum at 0130 and then decaying away for a number of hours. This particle event was probably associated with the flare at 2200. Another particle event is associated with the large flare at 1000 on 20 March. X-ray bursts can be seen at 0220, 0950, 1035, 1800 and 1900.

FIGURE 1



Event plot (continued) for March 1966. Note logarithmic scale due to large rates associated with the succession of proton events beginning at 2400 on 23 March. An x-ray event at 0230 occurs shortly before the beginning of the large proton event. A similar event was already in progress at this time. The gradual increase and decrease of the base line between 1100 and 2400 on 23 March is caused by a small particle event with possible superposed x-ray "noise".

FIGURE 2

The differential response of the ion chamber to photon spectra of exponential type. The curve labeled $E_0 = \infty$ corresponds to the ion chamber response to a ~~flat~~ spectrum. One expects that a E_0 characteristic energy of 50 Kev or less will characterize ~~flat~~ most spectra and thus the chamber response is concentrated between 10 and 50 Kev

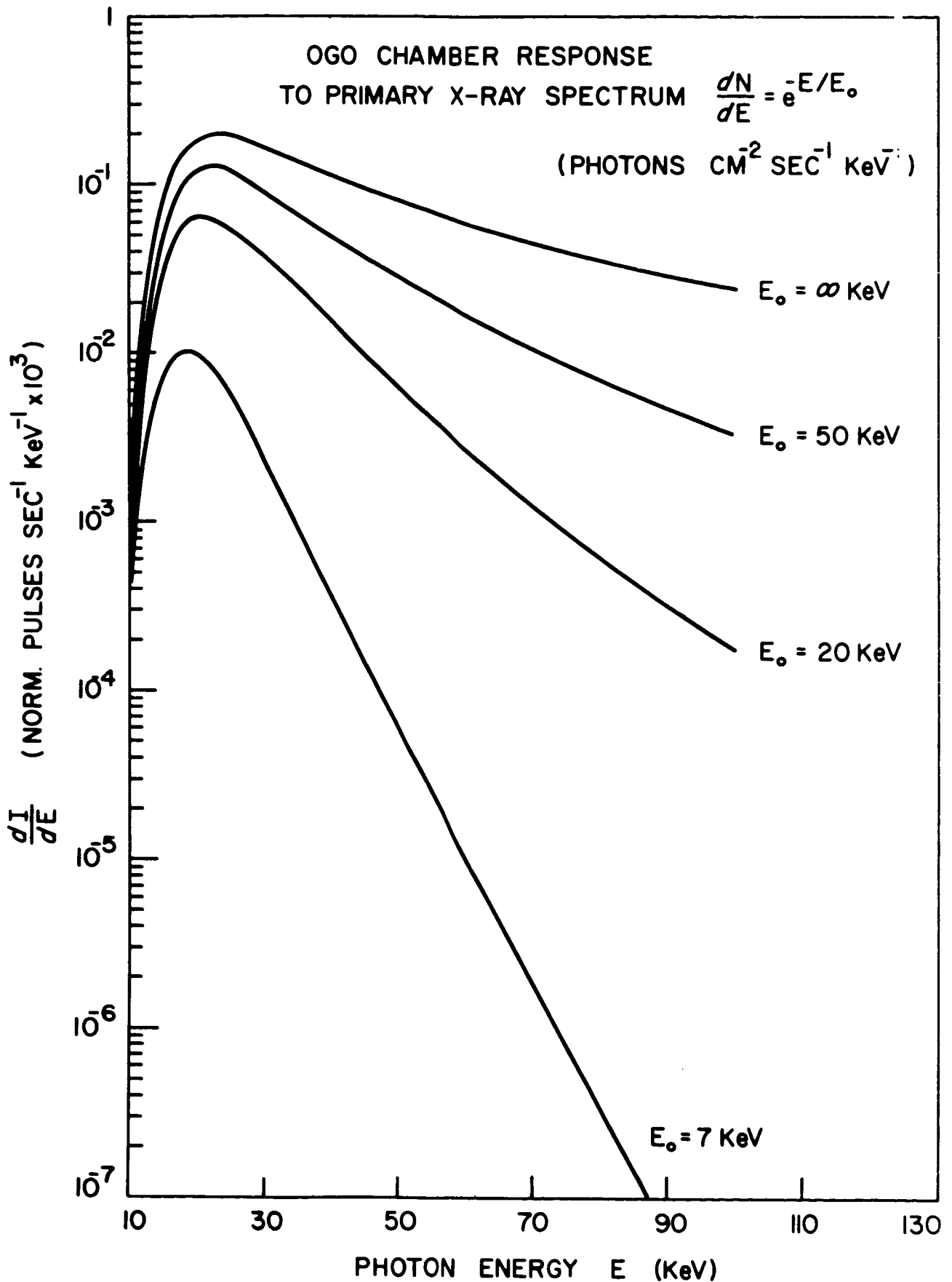


Table 2

ION CHAMBER RESPONSE

Primary X-ray Spectrum $dN/dE = e^{-E/E_0}$ photons $\text{cm}^{-2} \text{sec}^{-1} \text{Kev}^{-1}$

E_0 (Kev)	CHAMBER RATE (N. pulses $\text{sec}^{-1} \times 10^3$)			TOTAL	INCIDENT ENERGY FLUX > ²⁰ 10 Kev ⁻² ergs cm^{-2} sec^{-1}	CONVERSION FACTOR
	10-16 Kev	16-106 Kev	106-150 Kev			ergs $\text{cm}^{-2} \text{sec}^{-1}$ N. pulses $\text{sec}^{-1} \times 10^3$
7	0.026	0.116	5.1×10^{-8}	0.142	1.7×10^{-8}	1.2×10^{-7}
20	0.106	1.16	1.8×10^{-3}	1.27	4.7×10^{-7}	3.7×10^{-7}
50	0.165	2.61	0.07	2.85	3.8×10^{-6}	1.3×10^{-6}

With the aid of this table and an assumption or other knowledge about the spectral shape one may convert the arbitrary ion chamber units to absolute fluxes expressed as $\text{ergs cm}^{-2} \text{sec}^{-1}$ above ²⁰10 Kev incident energy, but actually for a practical sense between ²⁰10 Kev and 50 Kev. In the figures shown in this report the cosmic ray or particle background has been subtracted or in some cases the zero of the scale has been set on the cosmic ray baseline as shown in the figure.

The orbital characteristics of the two OGO satellites are tabulated in Table 3.

Table 3

	OGO-I	OGO-III
Launch date	5 Sept. 1964	7 June 1966
Height of perigee	280.5 km	295.3 km
Height of apogee	149,408.5 km	122,219.7 km
Inclination to equator	31.11 degrees	30.97 degrees
Local time at apogee	\approx 2100 hrs.	\approx 2300 hrs.
Orbital period	63.98 hrs.	48.63 hrs.
Spin period	11.85 sec	\approx 96 sec (variable)

III. PRESENTATION OF DATA IN GRAPHICAL FORM:

The data from which the figures are plotted was taken in one of three ways:

- (a) ten second averages of the ionization rate calculated from the telemetered ramp as the ion chamber electrometer drifted between resets. The ten second average data is plotted as a smooth curve which frequently shows baseline noise.
- (b) by computing the equivalent rate for one reset of the drifting electrometer by an accurate measurement of the time Δt of one reset. Since a rate point is obtained for each reset this means that higher rates give more points per unit time in the plot. The graphs using electrometer resets are plotted as histograms.
- (c) the third method is to plot a point each minute but with the average taken over approximately 1.5 minutes of time. Data in this manner is plotted as a histogram.

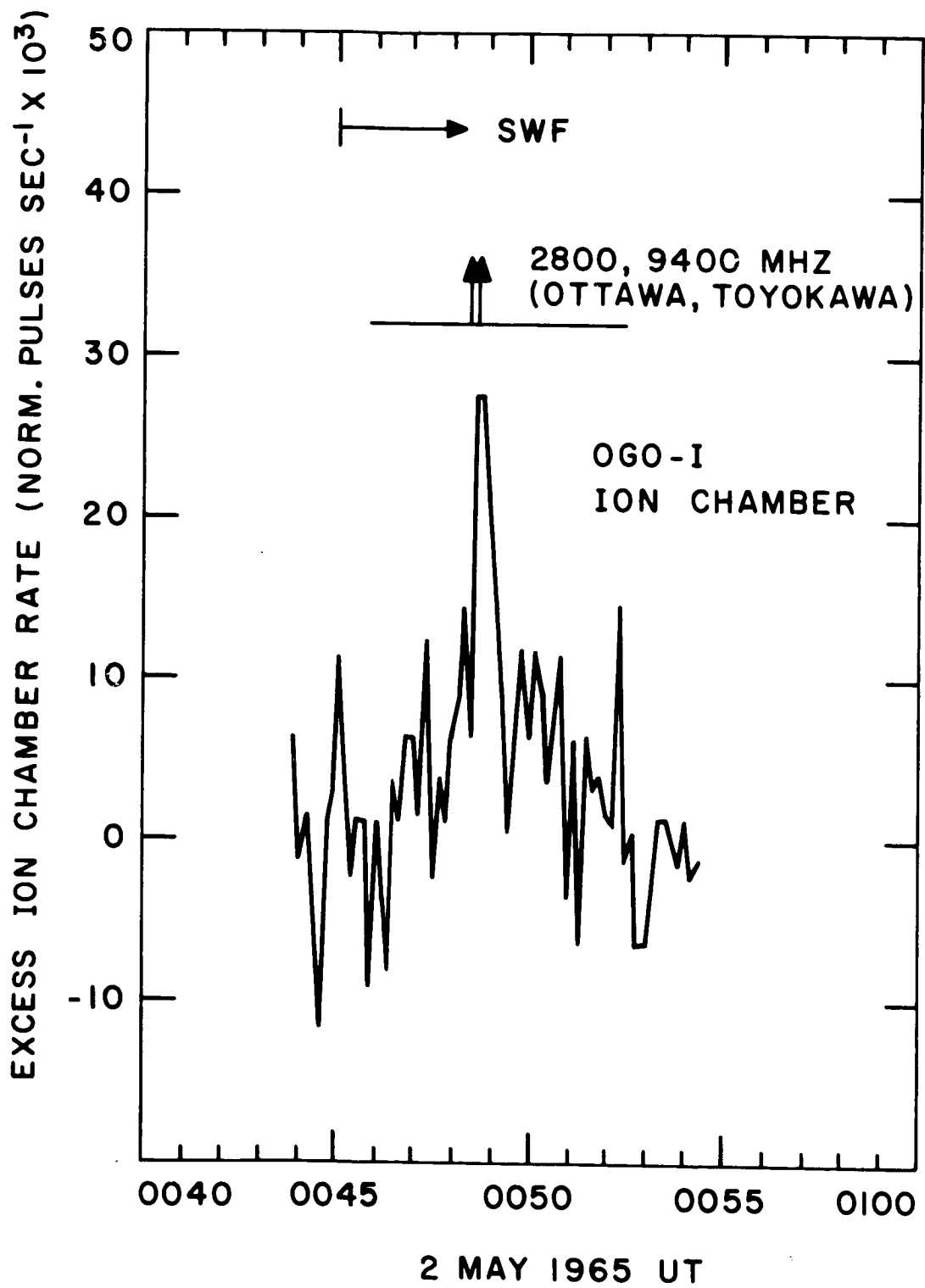
The choice of the time interval in the plot depends on the data mode of the satellite, of the size of the event and several other factors. The ultimate time resolution available is <1 second.

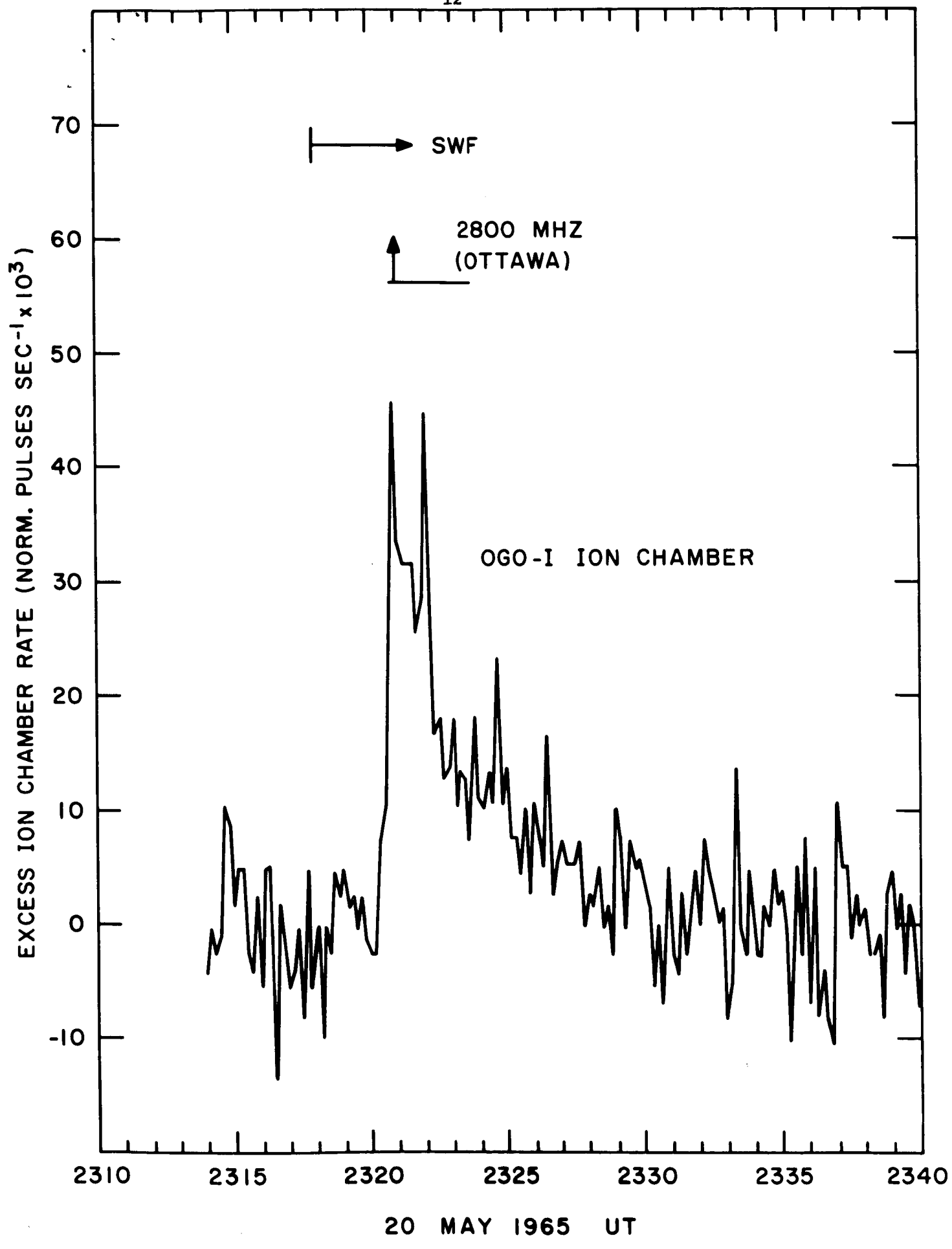
We have also given on the plots the designation of which satellite has received the data and other relevant information such as accompanying shortwave fadeouts (SWF) shown as horizontal arrows starting from a vertical marker. This information was obtained from the Boulder reports of geophysical and solar data. We have also given some information about associated solar radio emission also obtained from the Boulder reports of geophysical and solar data. Beside the listing of the frequency and the observing station the presence

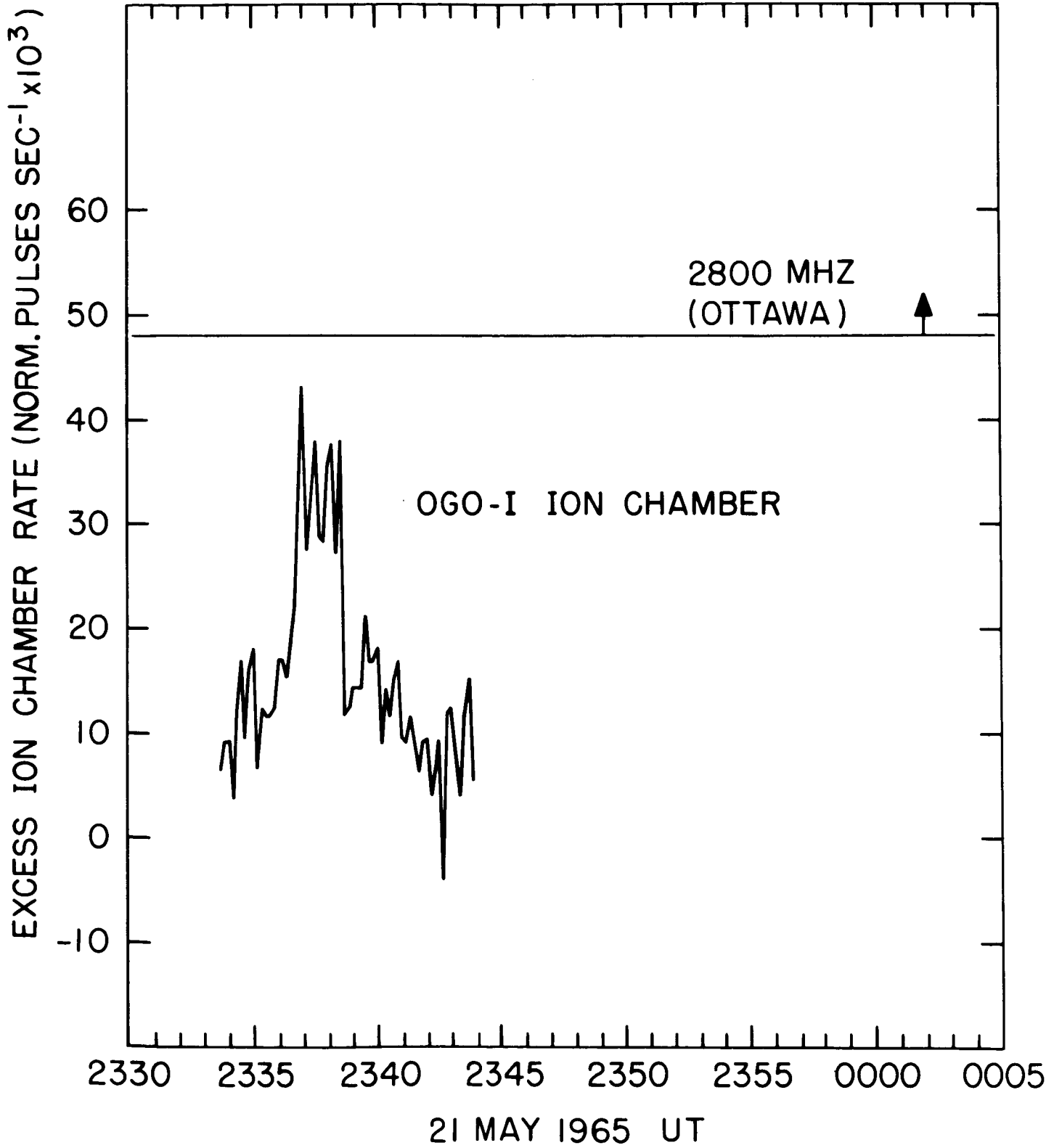
of the radio emission is indicated by a horizontal line with a vertical arrow marking the reported time of maximum. Although radio information is quite complete, the absence of an indicated radio burst may in some cases be due to the unavailability of information and does not necessarily mean that a radio burst did not occur.

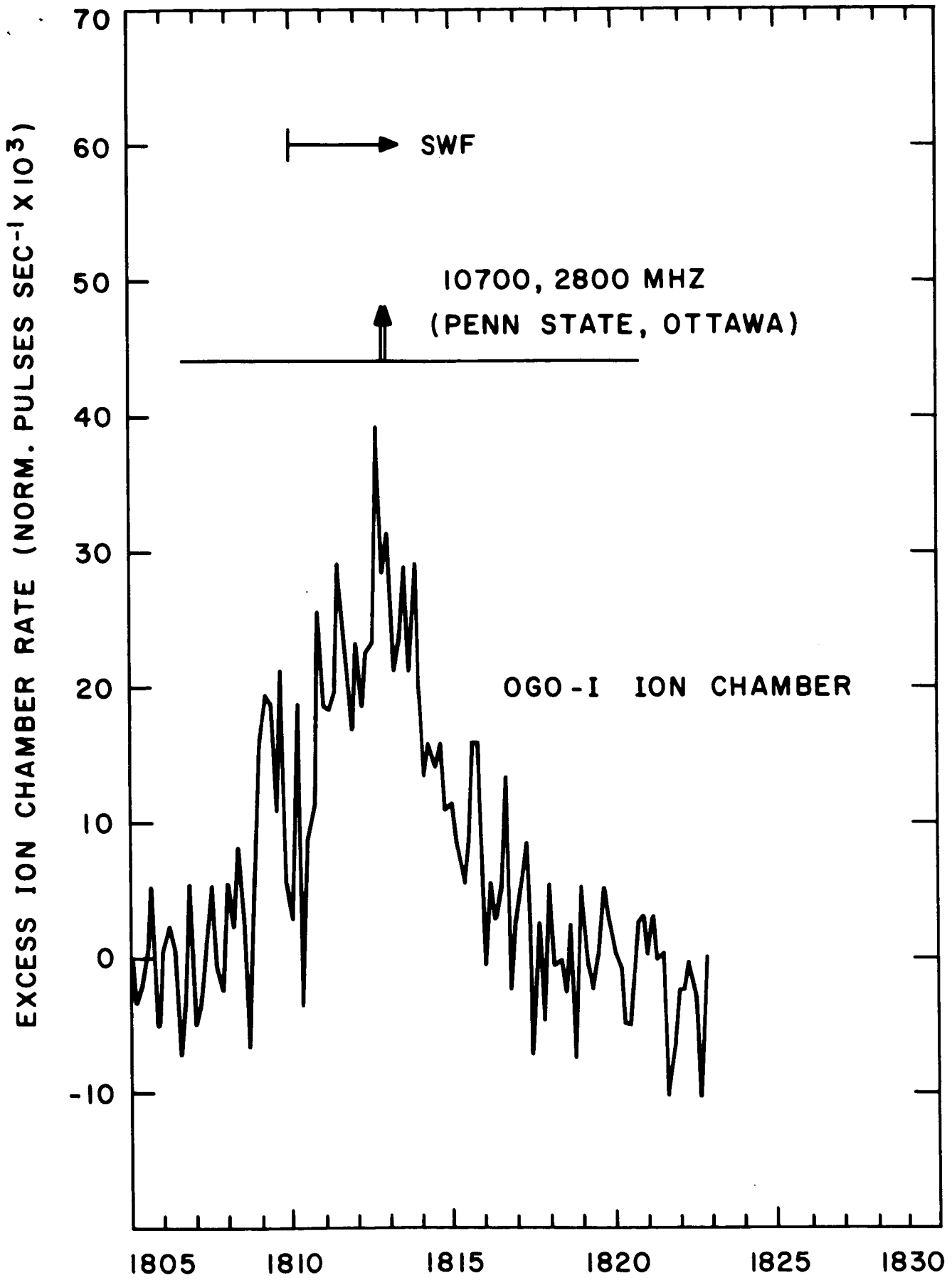
Bibliography

- Arnoldy, R. L., S. R. Kane and J. R. Winckler, A Study of Energetic Solar Flare X-Rays, *Solar Physics*, 2, 171-178, 1967(a).
- Arnoldy, R. L., S. R. Kane and J. R. Winckler, Energetic Solar Flare X-Rays Observed by Satellite and Their Correlation with Solar Radio and Energetic Particle Emission, *Astrophysical Journal*, 151, to be published February, 1968; also available as University of Minnesota Technical Report CR-97, 1967(b).
- Arnoldy, R. L., S. R. Kane and J. R. Winckler, The Observation of 10-50 Kev Solar Flare X-Rays by the OGO Satellites and Their Correlation with Solar Radio and Energetic Particle Emission, paper presented at International Astronomical Union Symposium No. 35 on the Structure and Development of Solar Active Regions, September 4-8, 1967, Budapest, Hungary; available as University of Minnesota Technical Report CR-107, 1967(c).
- Kane, S. R., Application of an Integrating Type Ionization Chamber to Measurements of Radiation in Space, Ph.D. thesis, School of Physics and Astronomy, University of Minnesota, September 1967; available as University of Minnesota Technical Report CR-106.
- Kane, S. R., K. A. Pfitzer and J. R. Winckler, The Construction, Calibration and Operation of the University of Minnesota Experiments for OGO-I and OGO-III, University of Minnesota Technical Report CR-87, September, 1966.

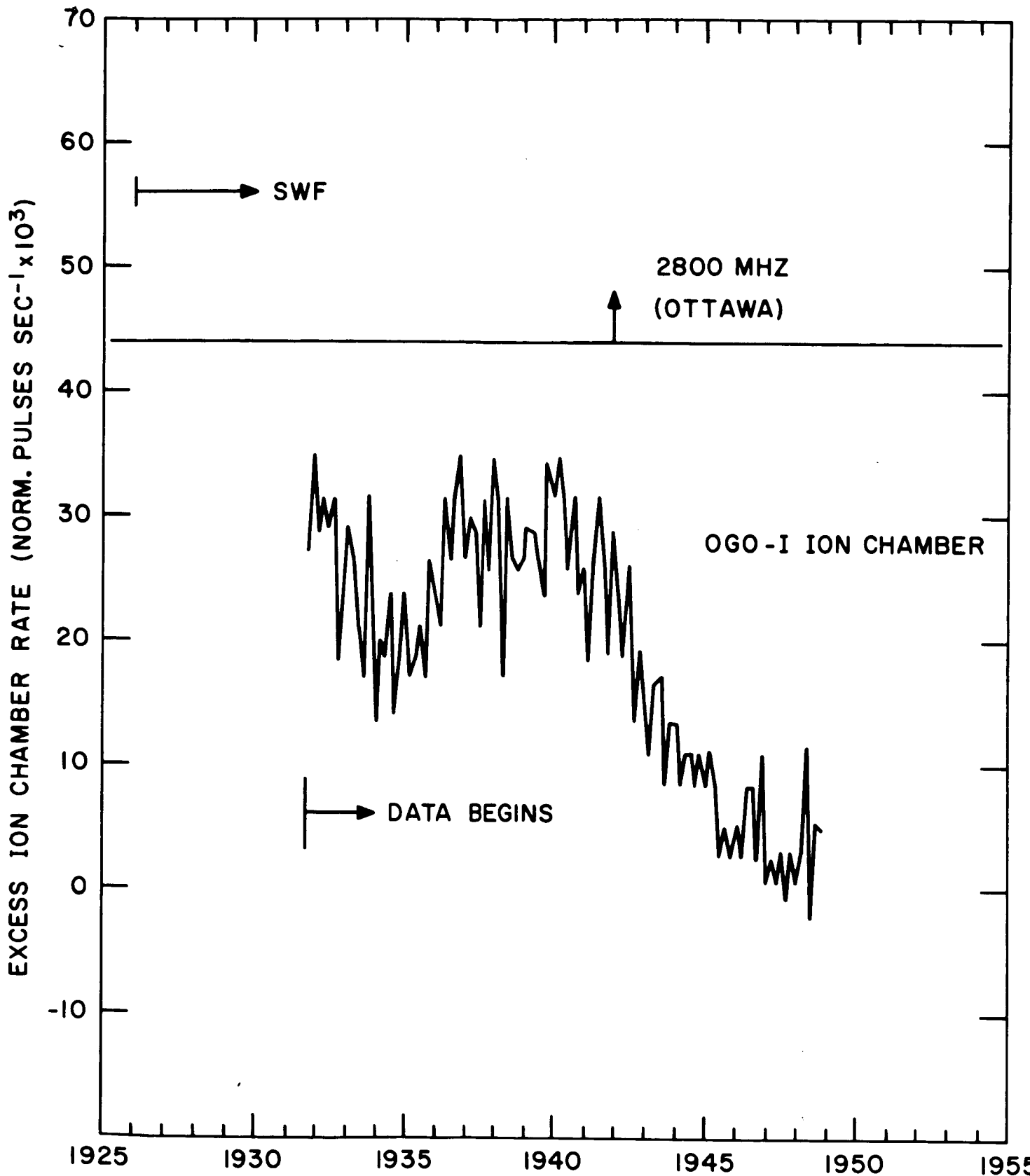




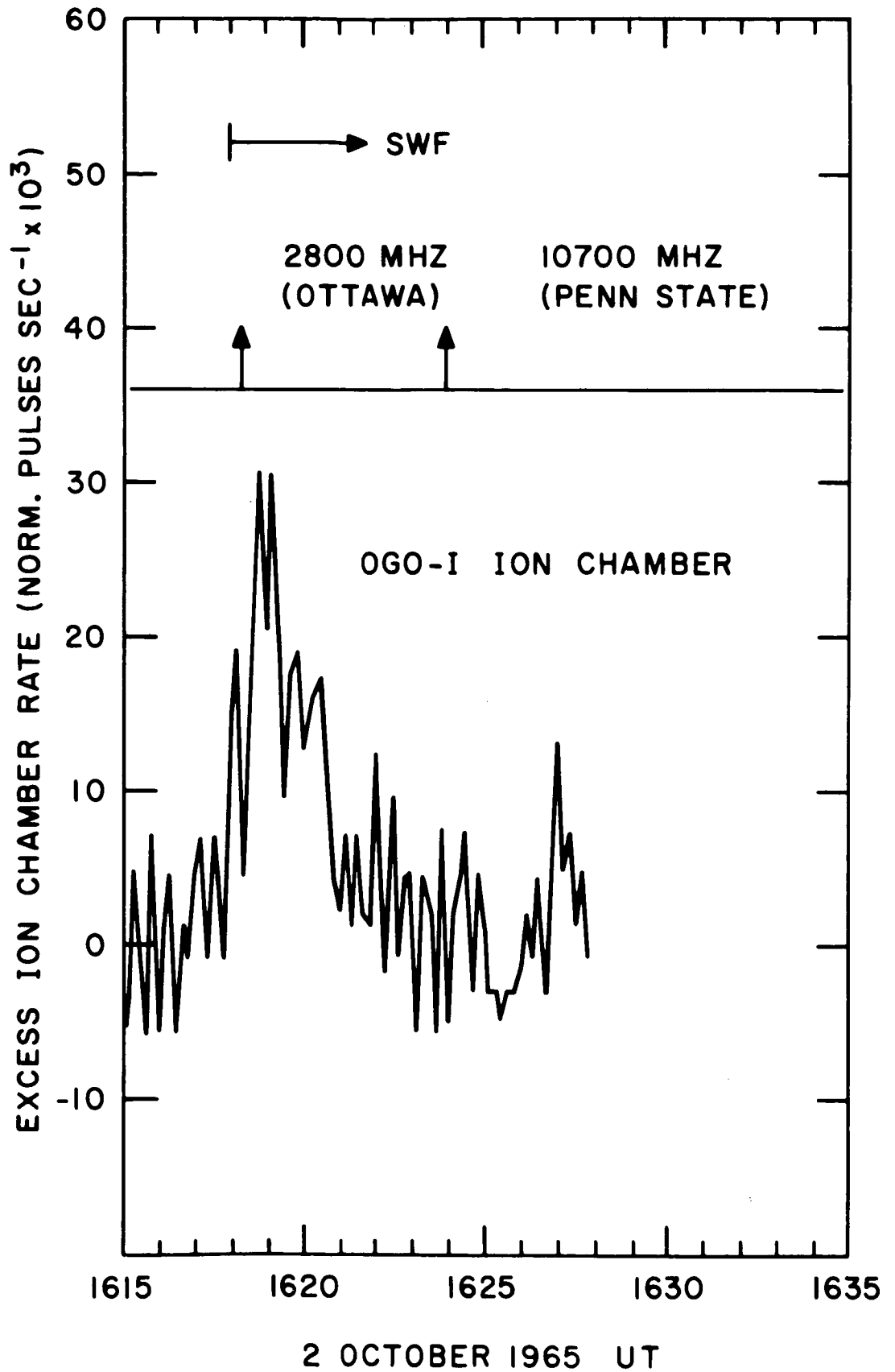


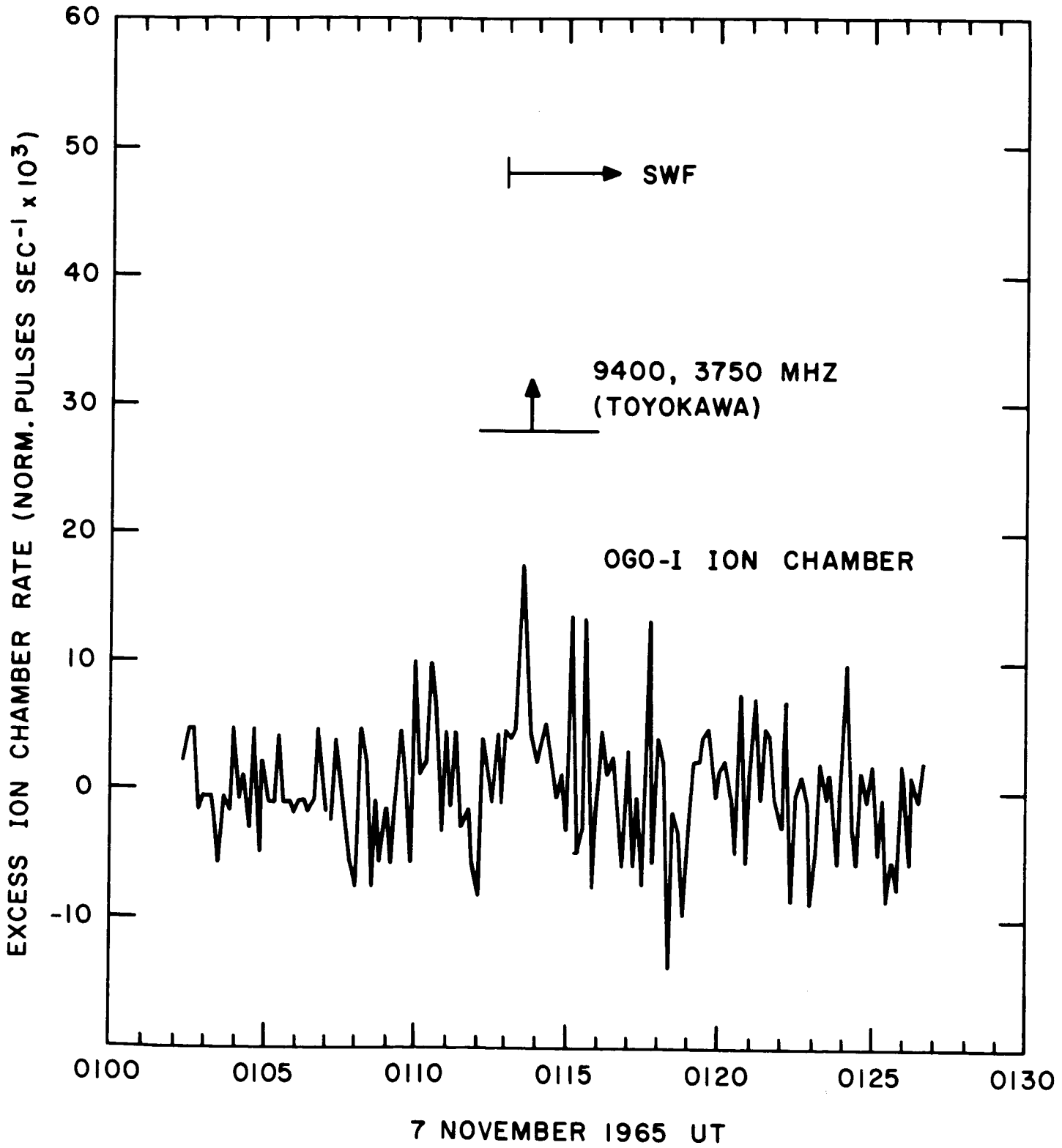


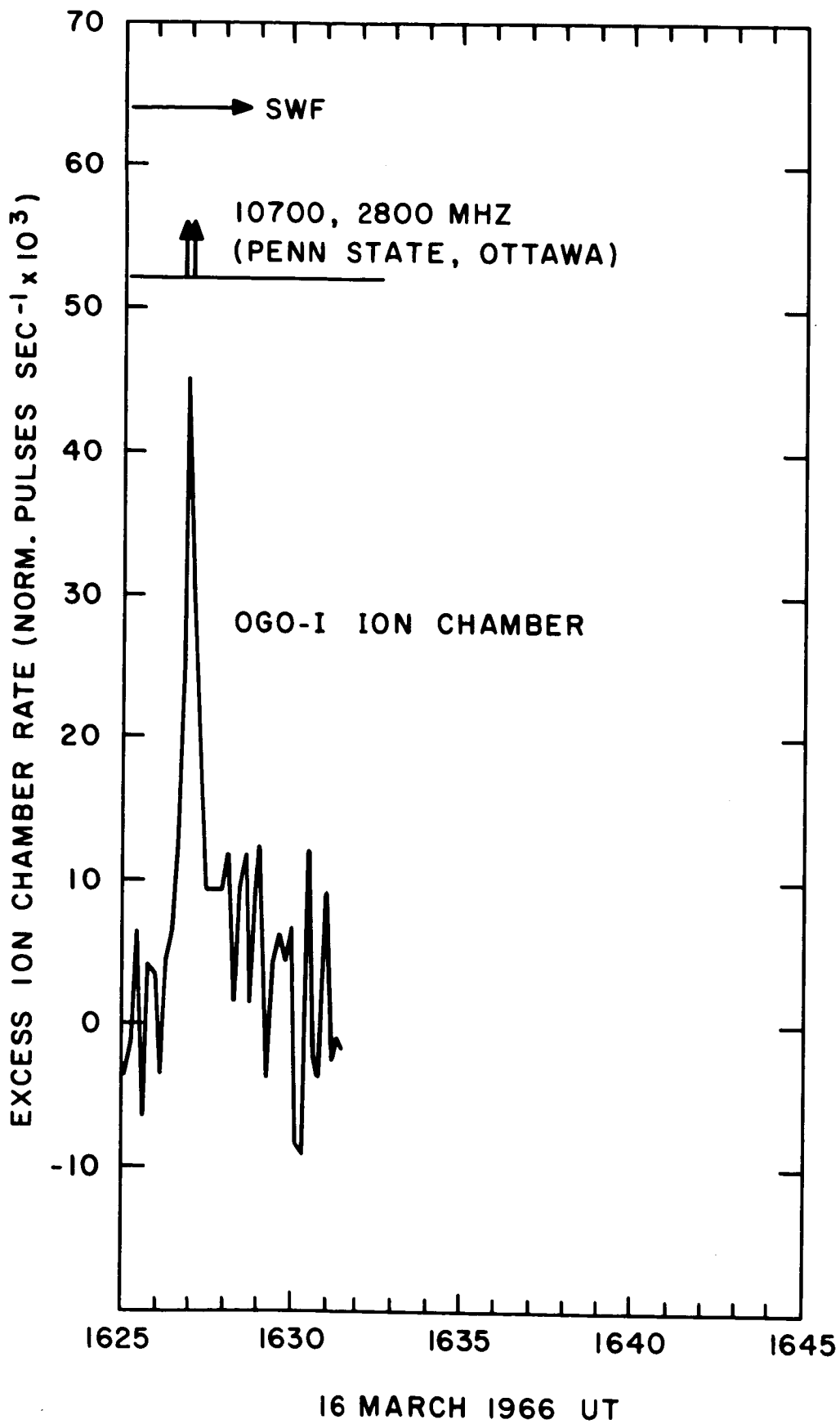
5 JUNE 1965 UT

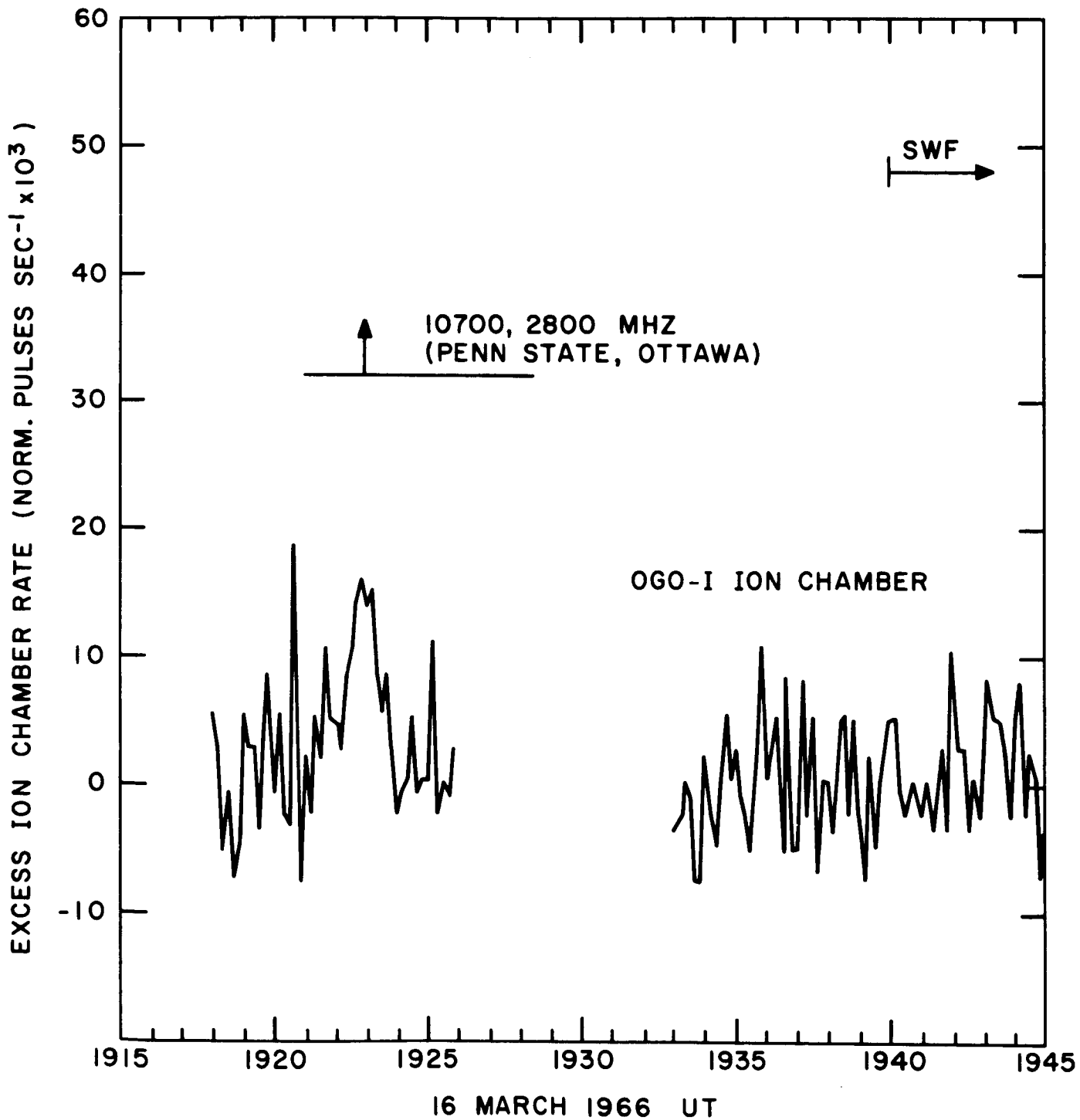


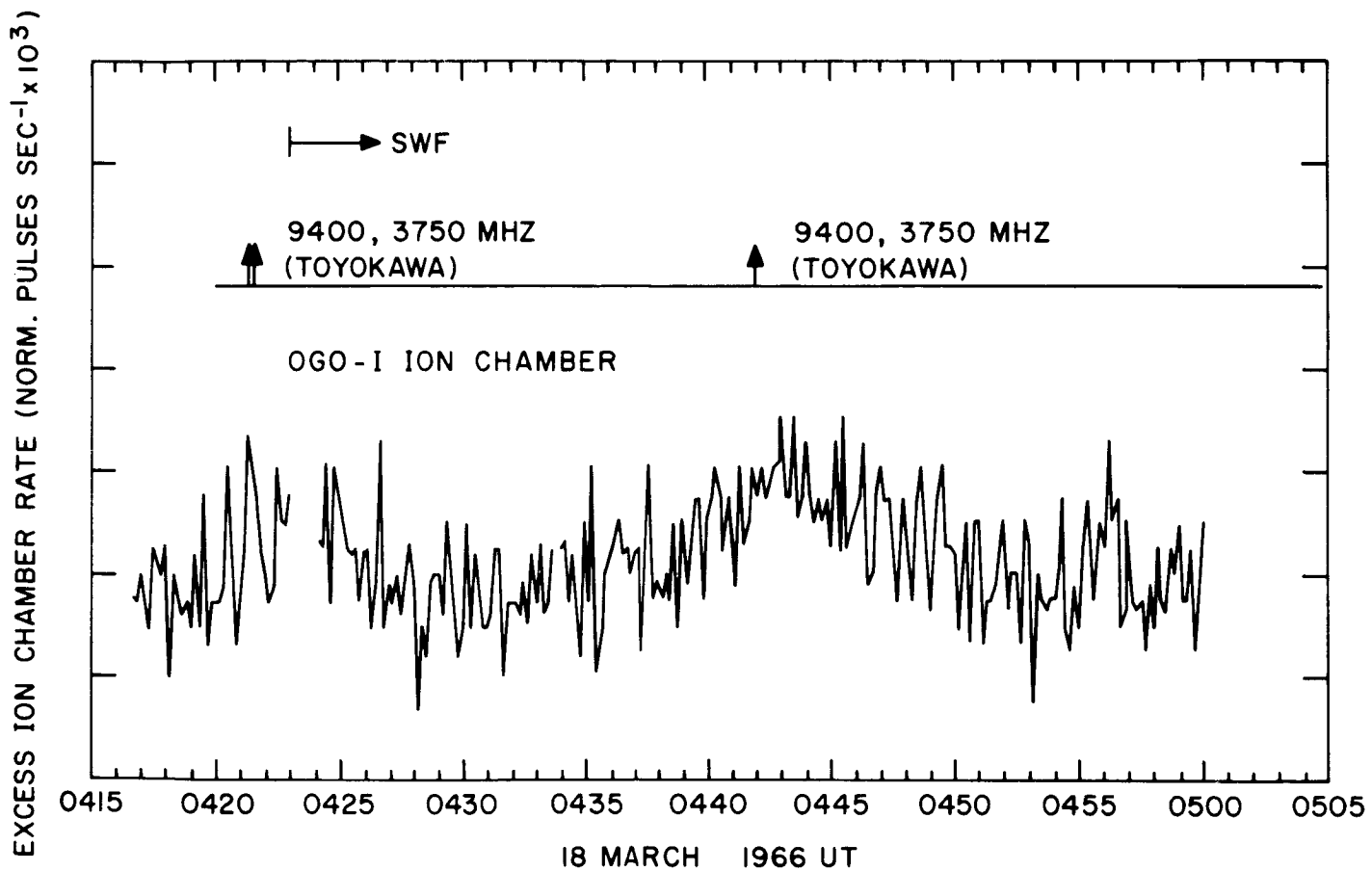
30 SEPTEMBER 1965 UT

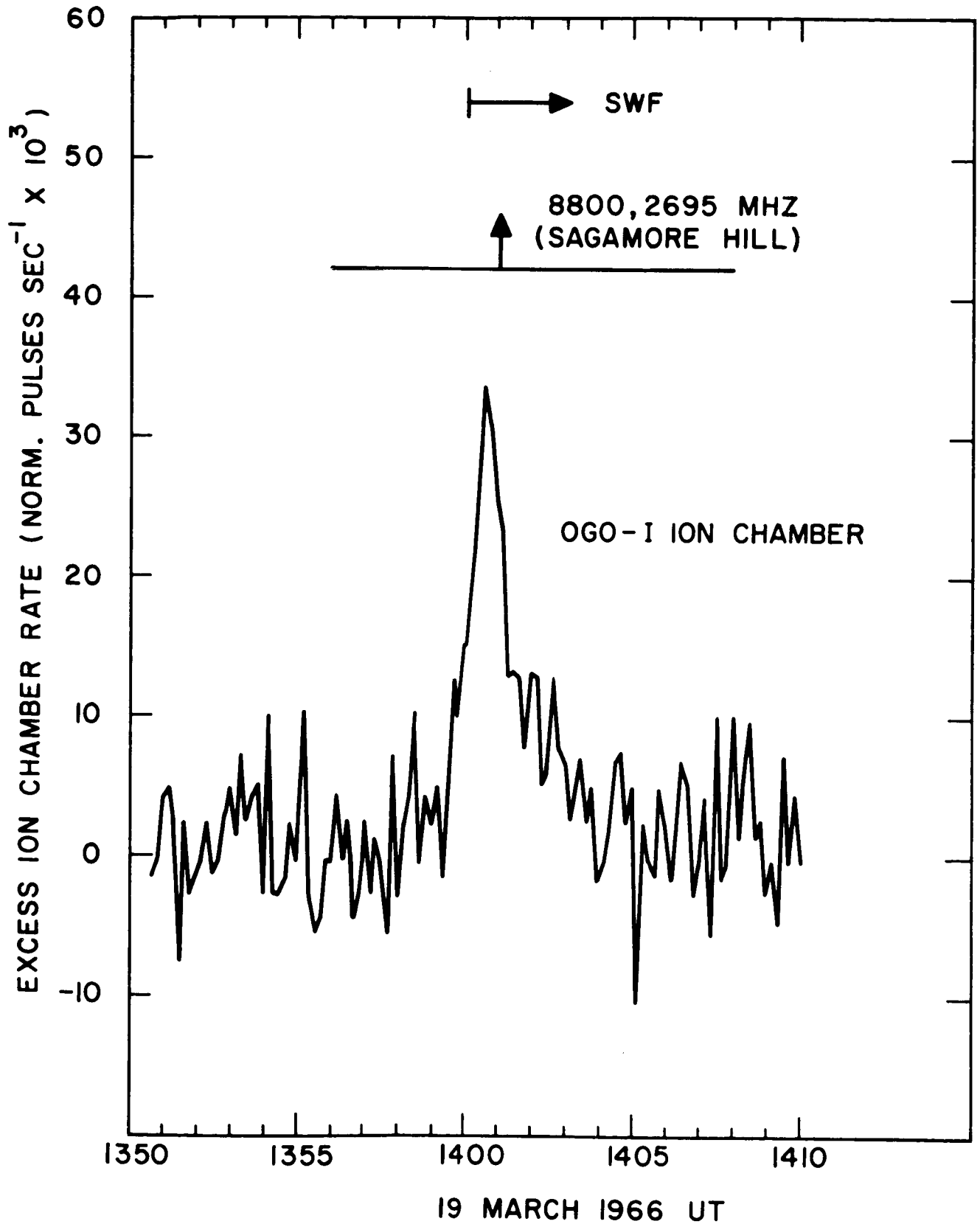


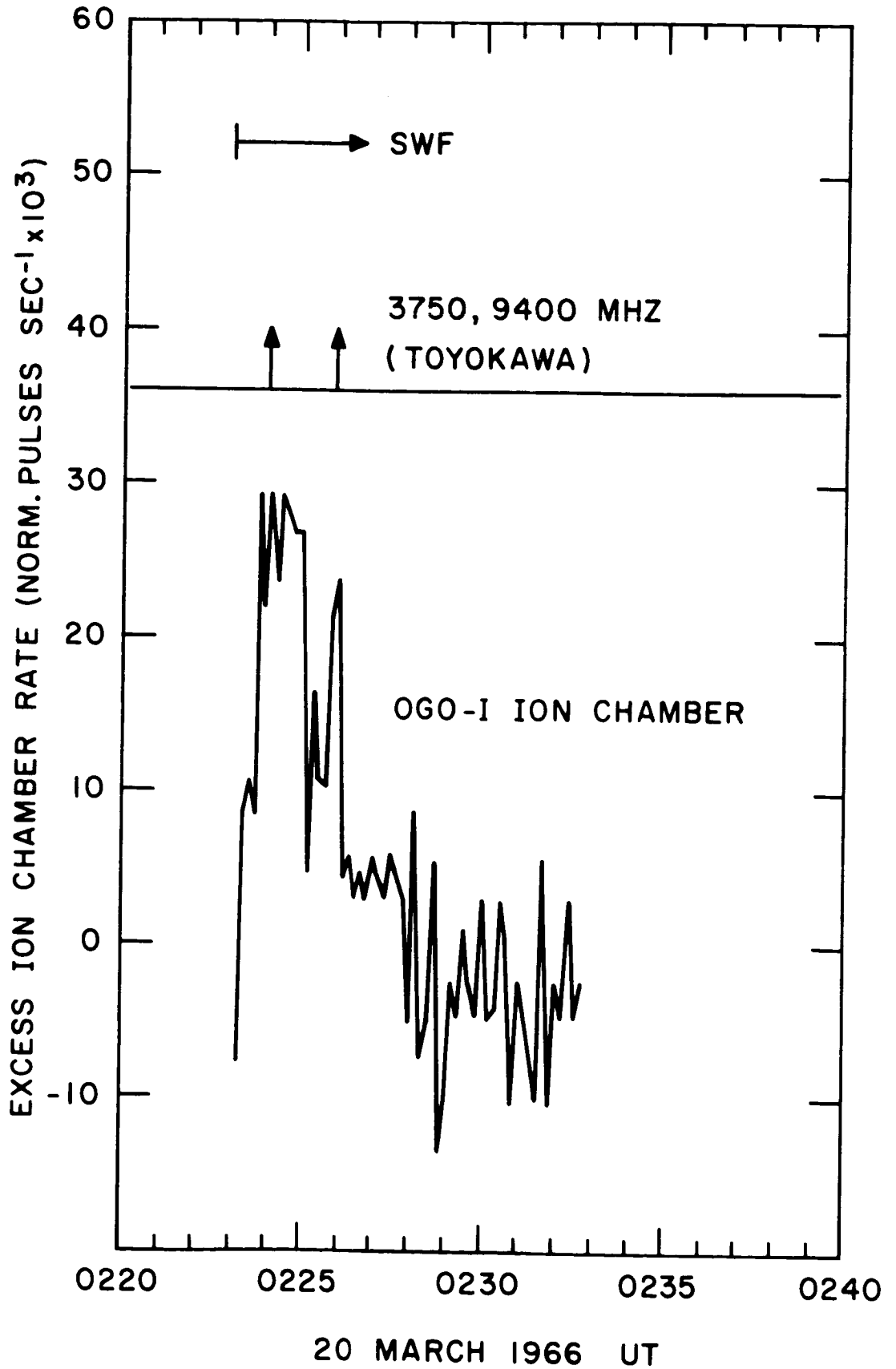


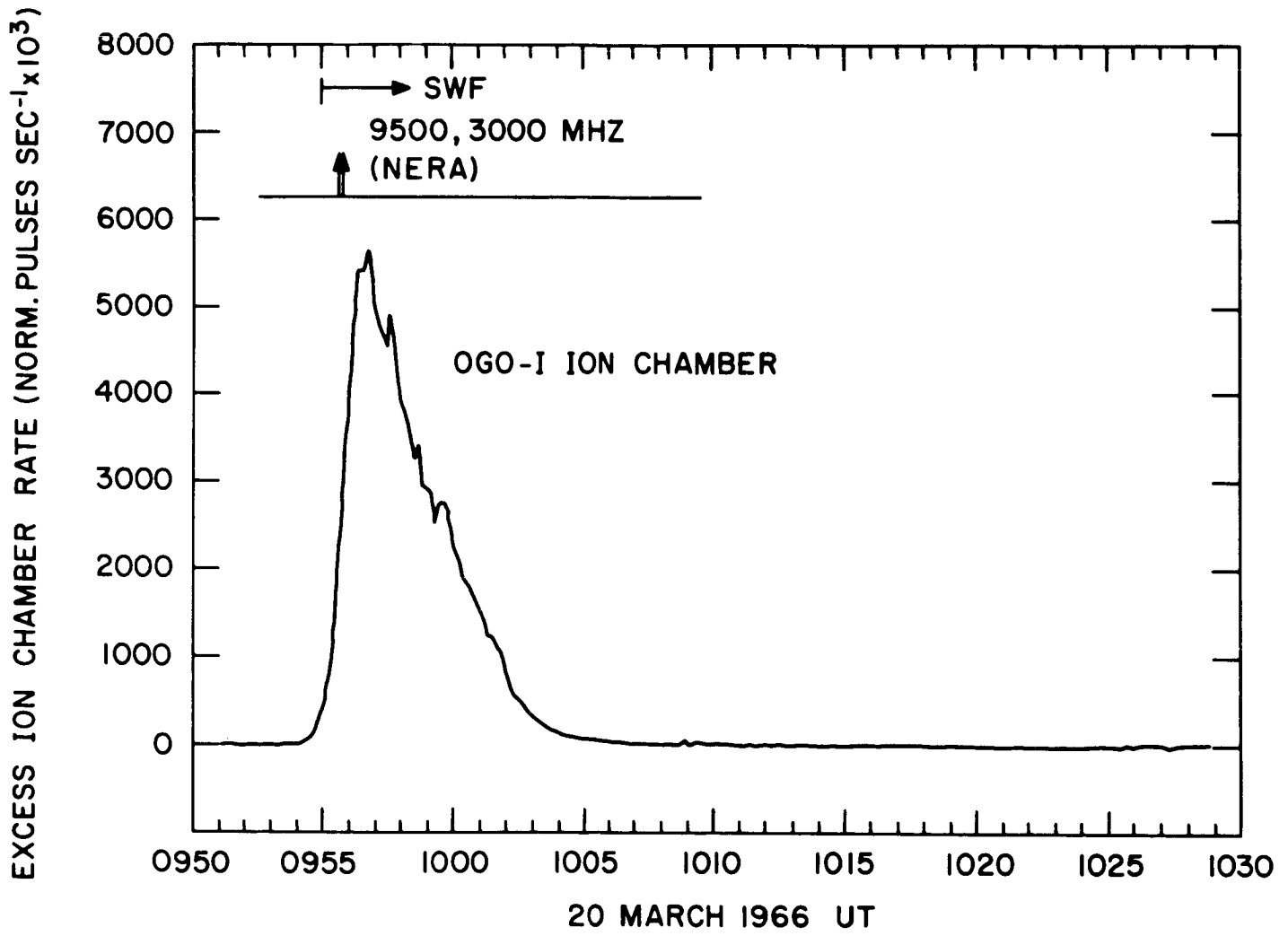


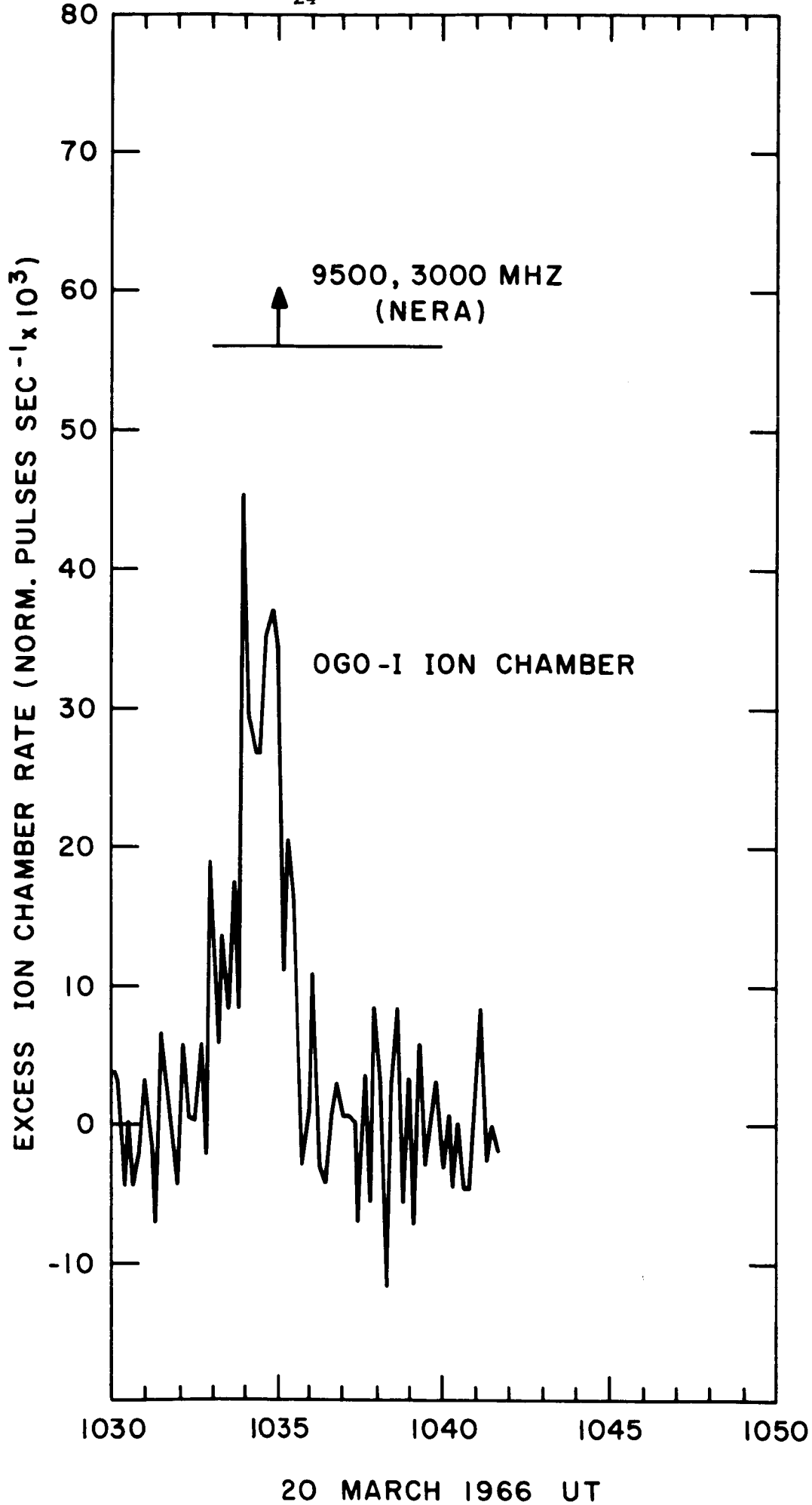


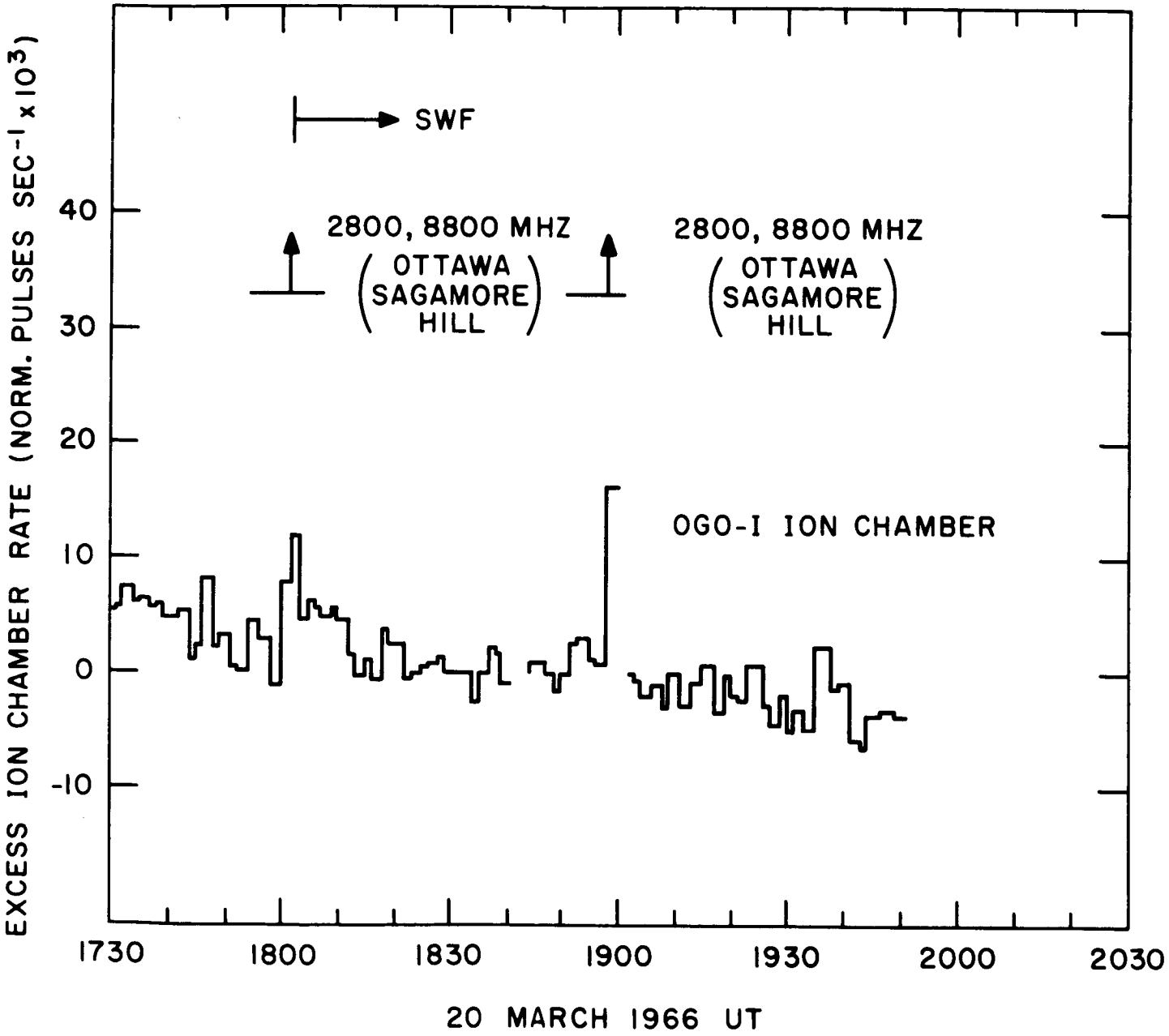


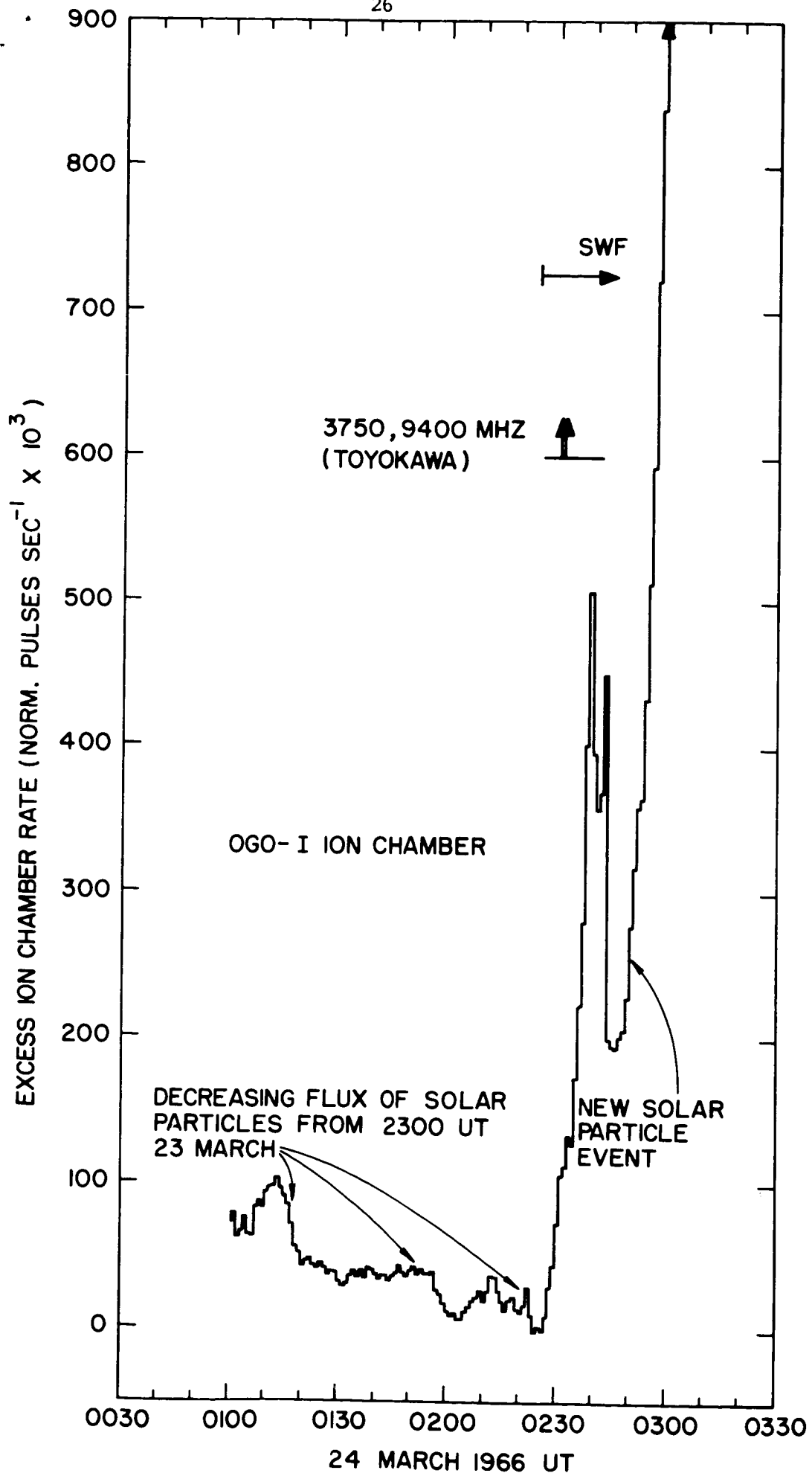


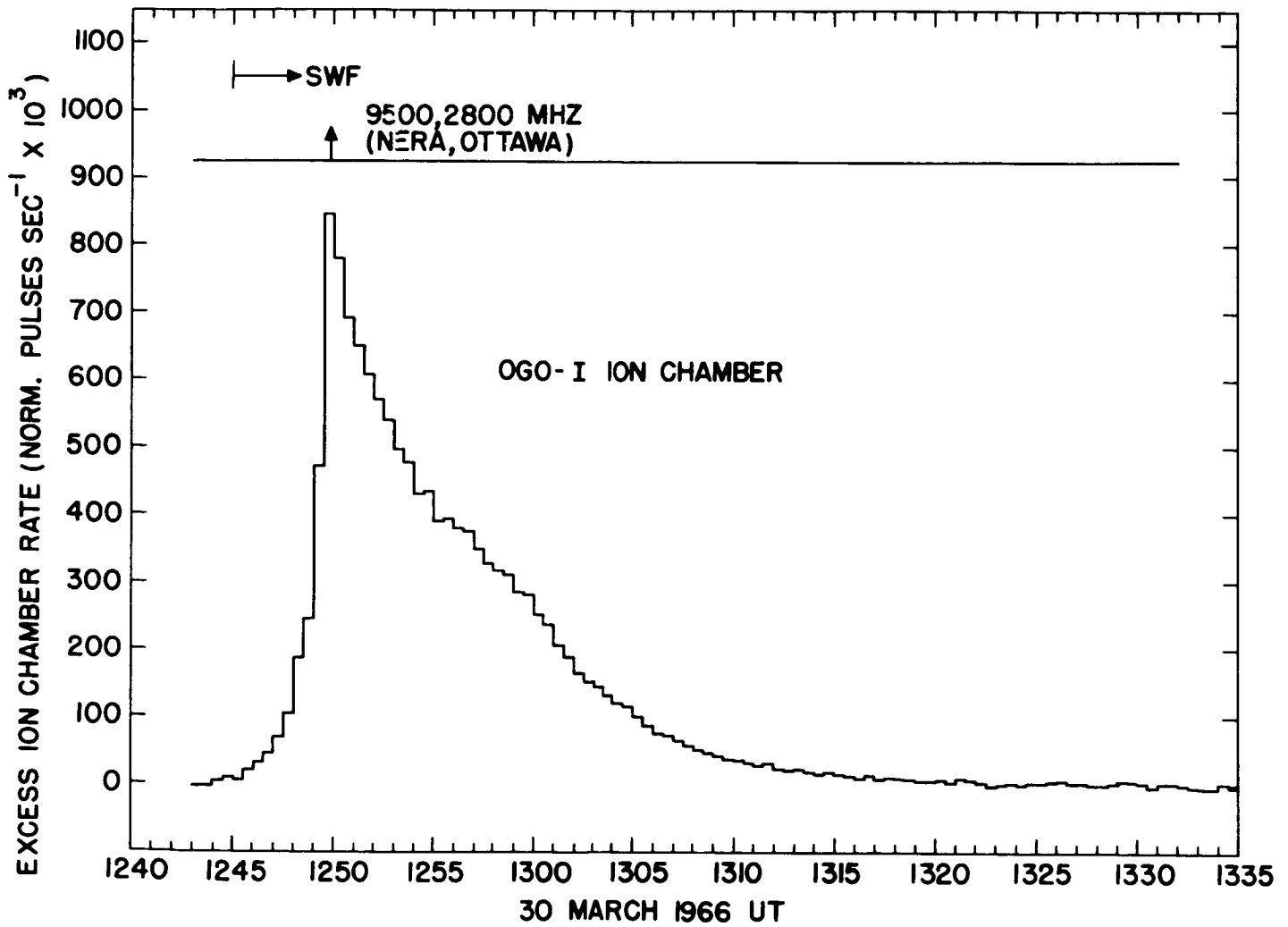


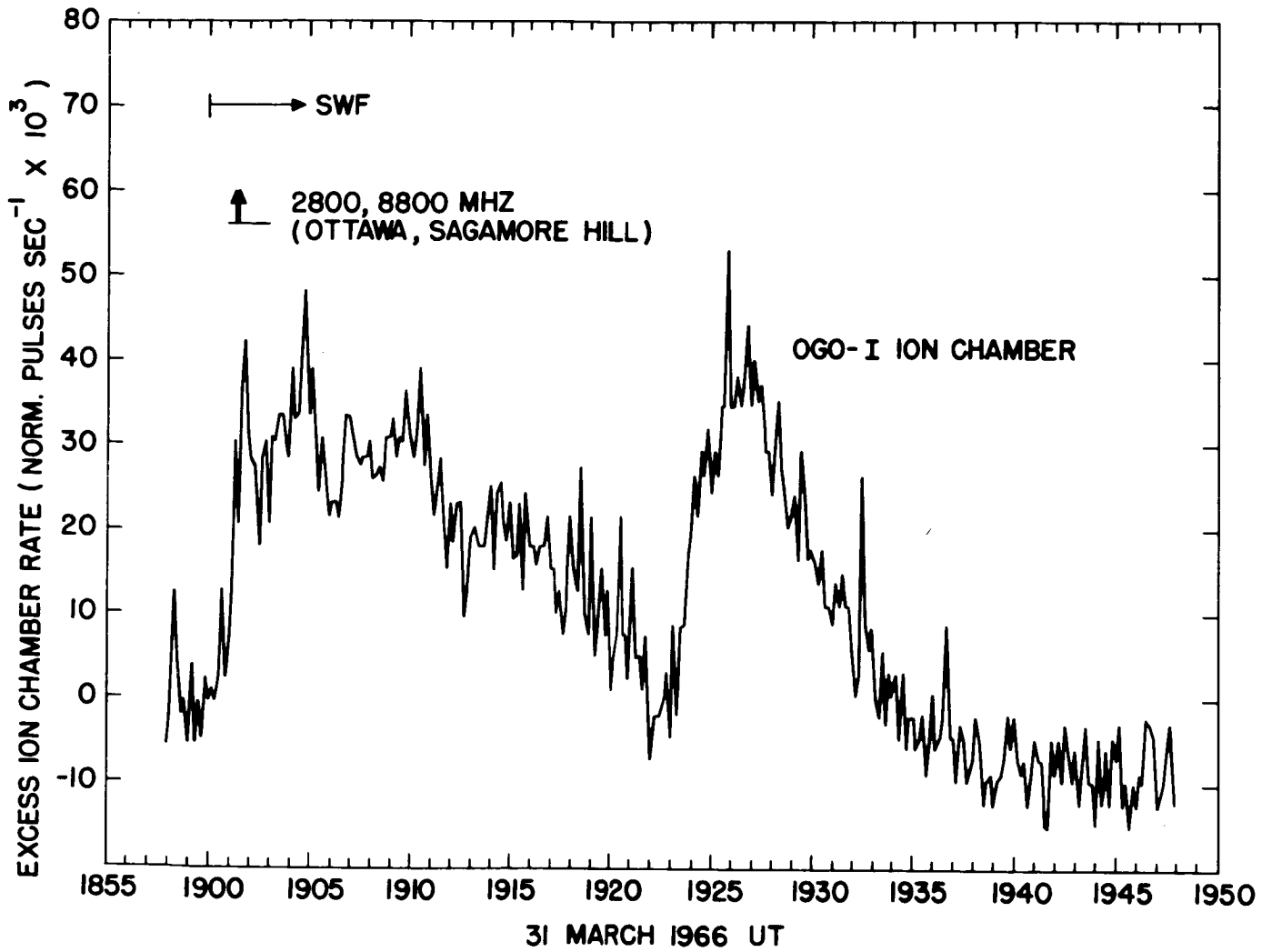


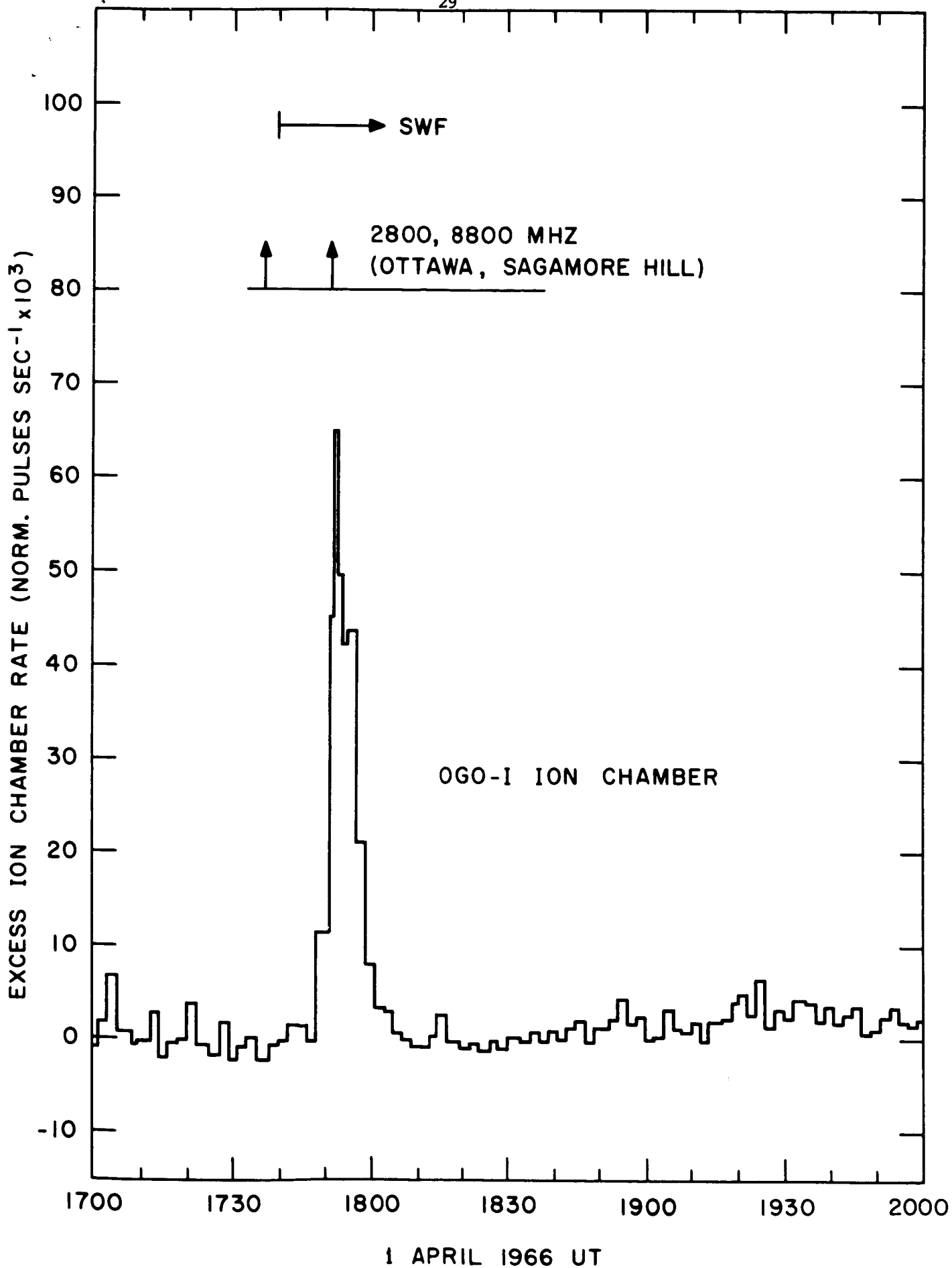


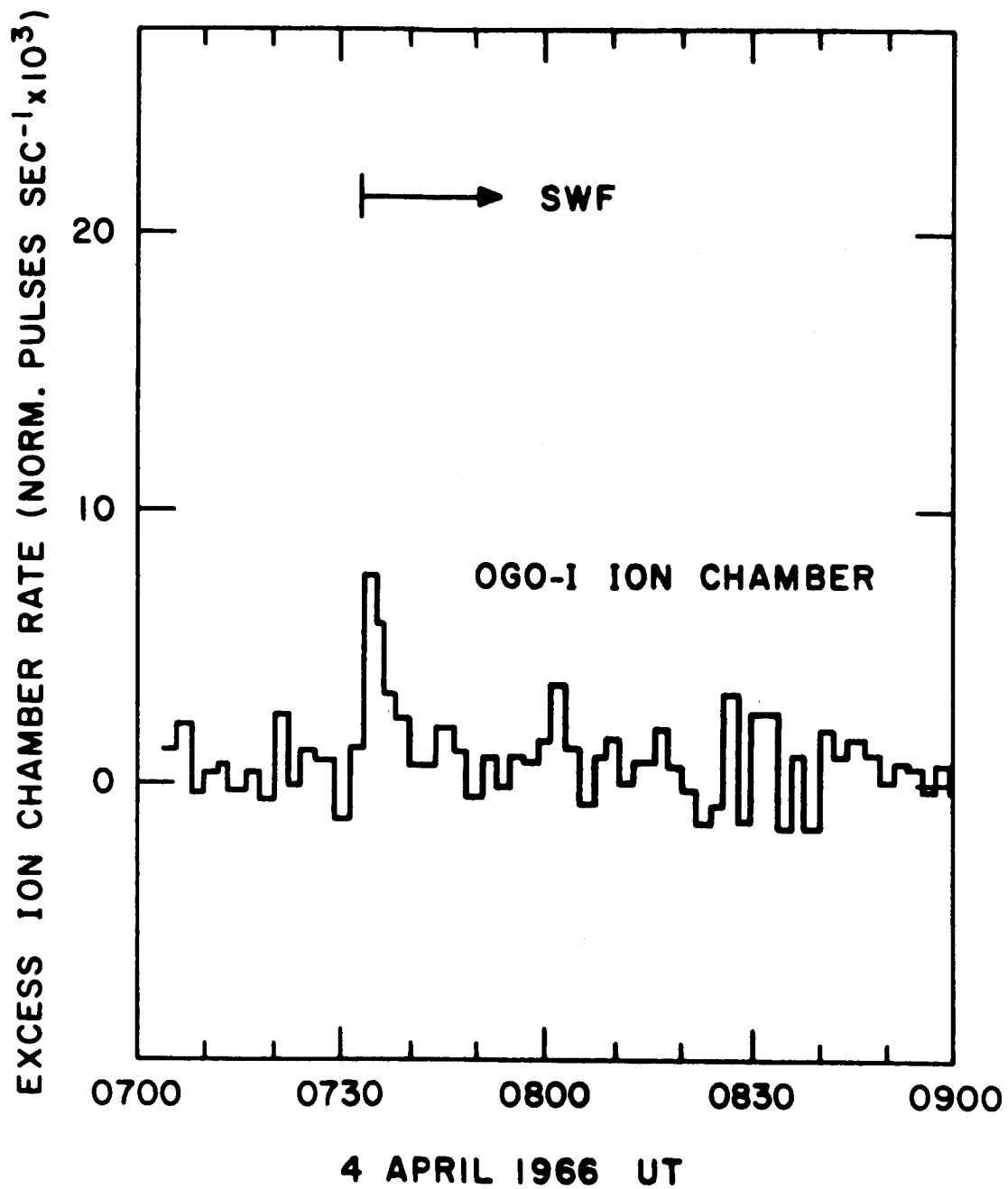


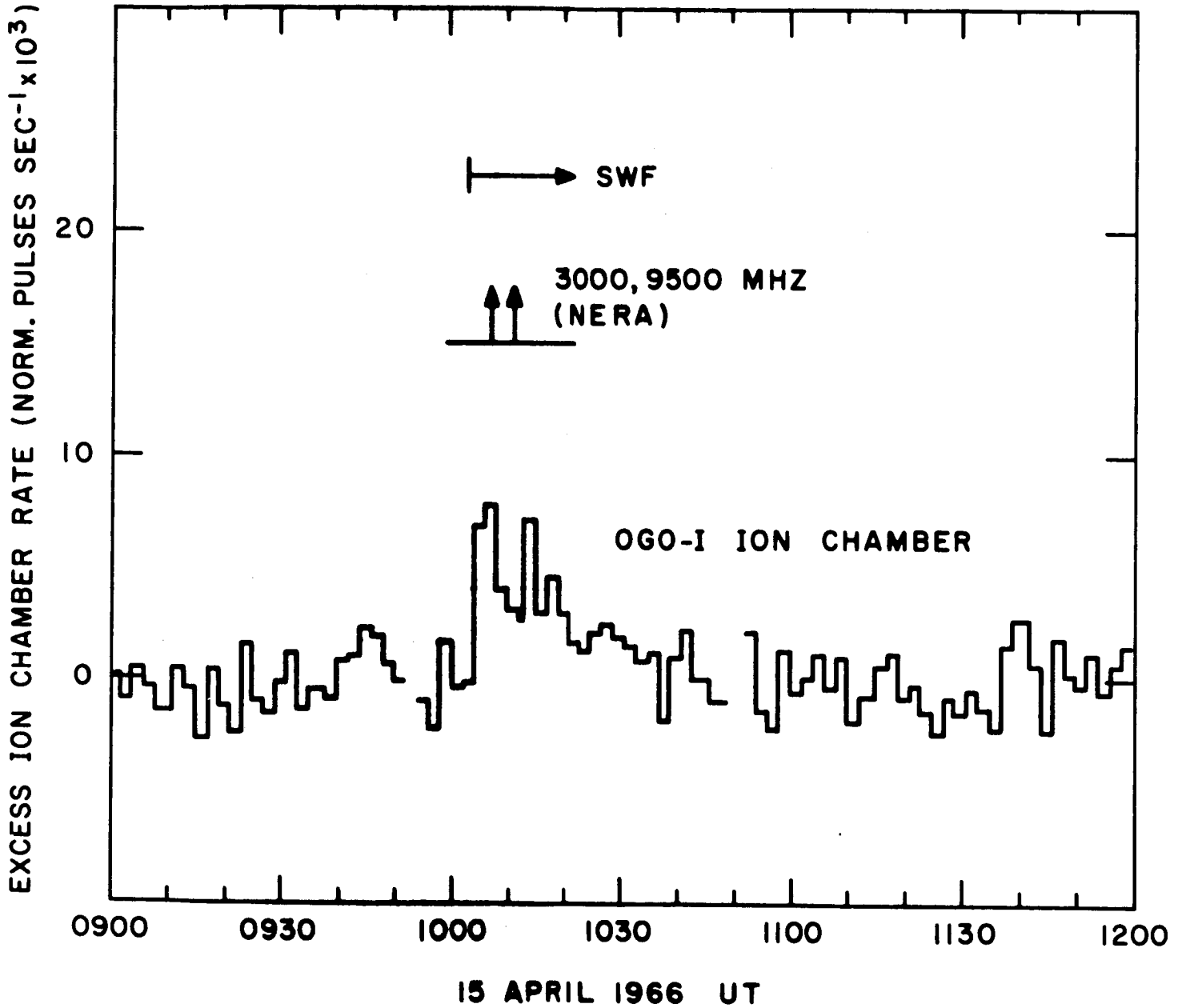


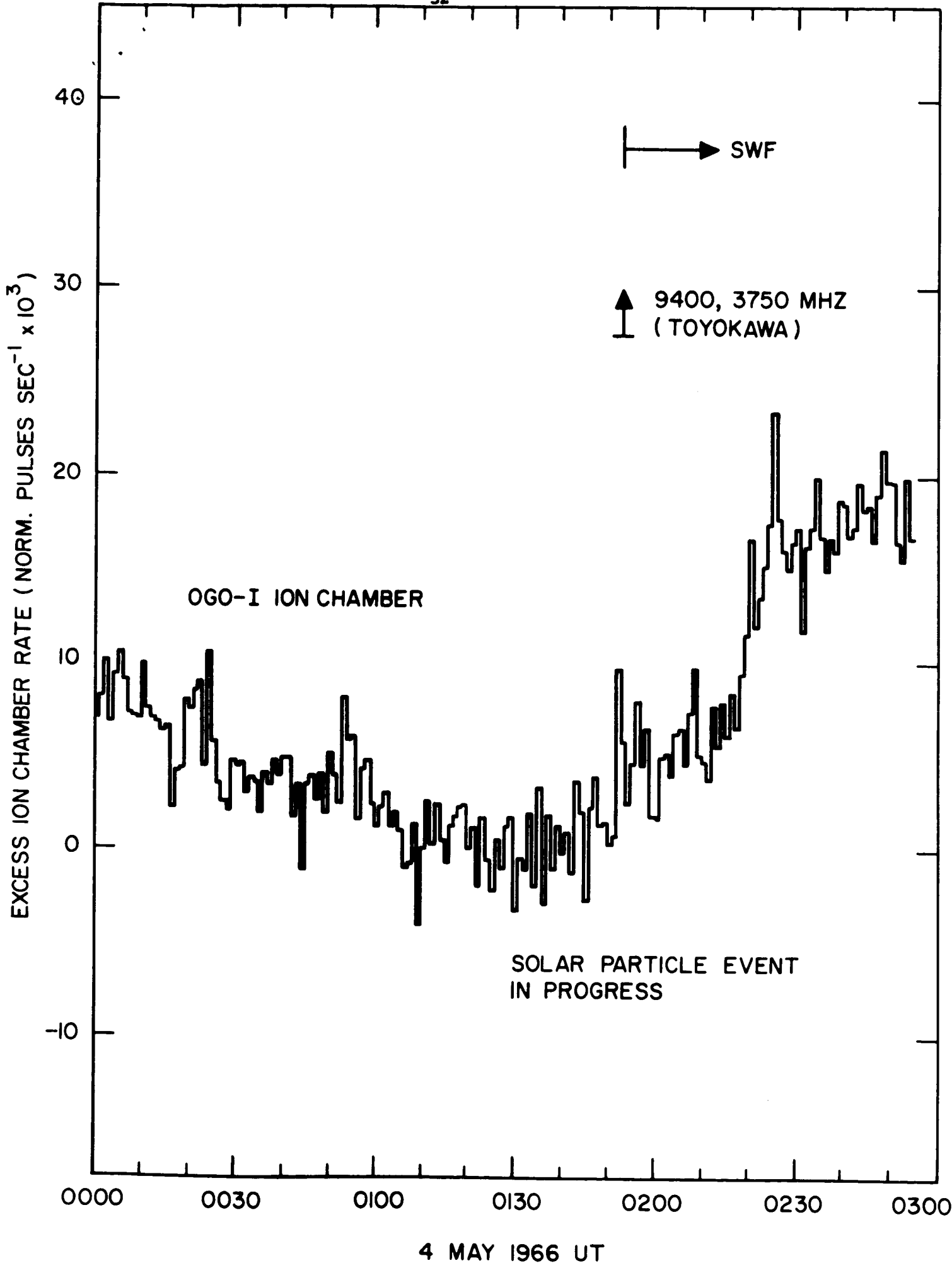


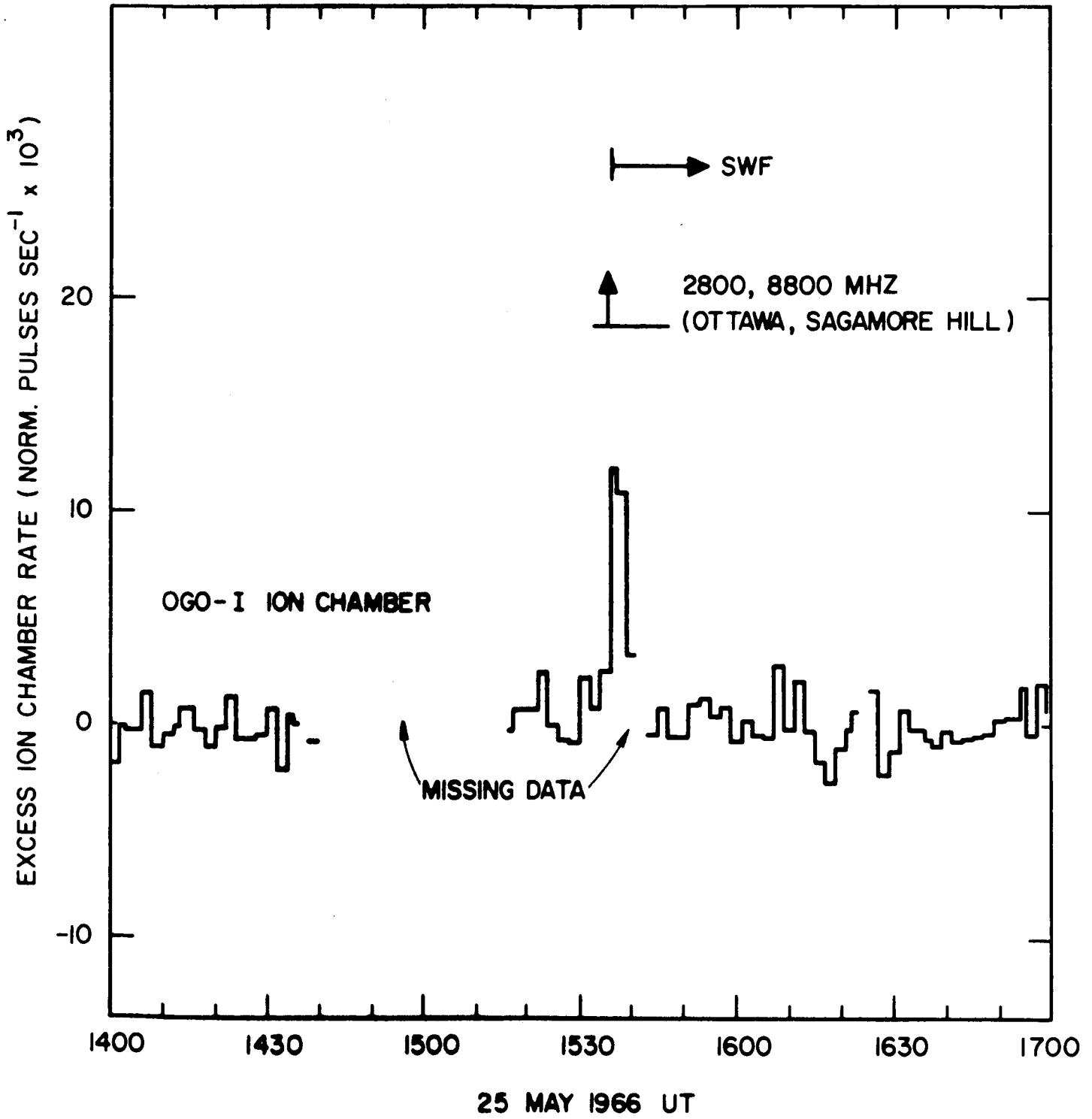


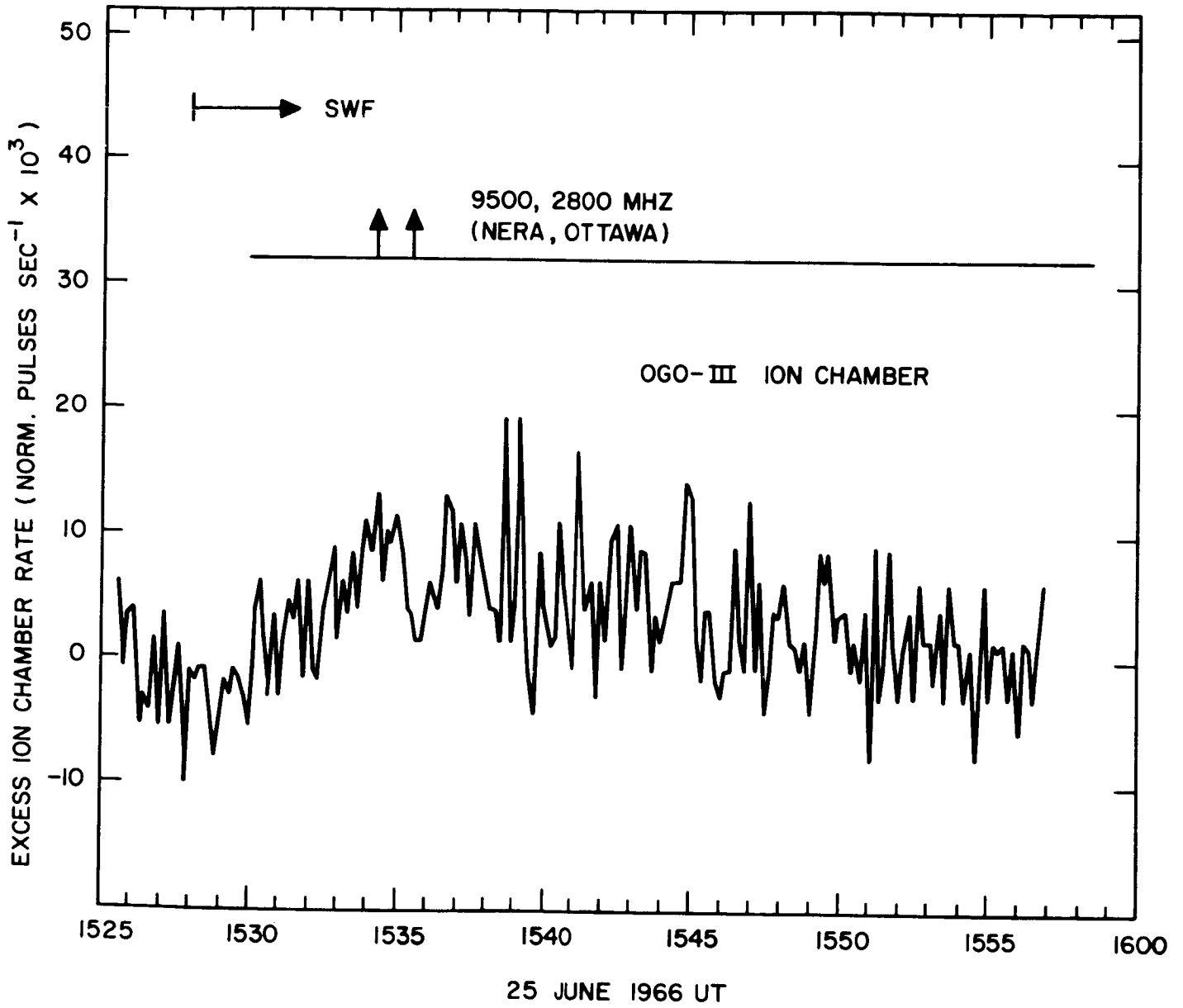


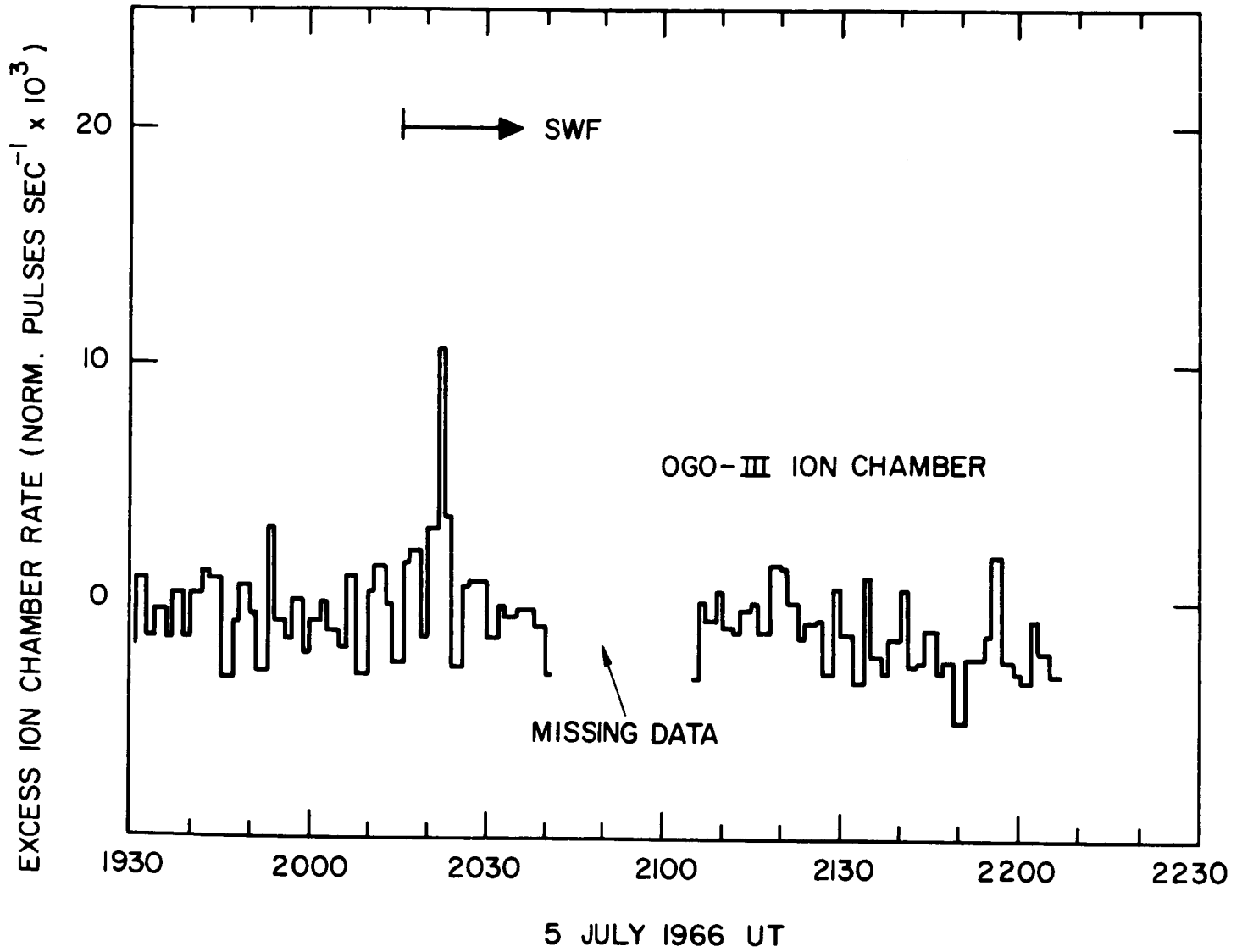


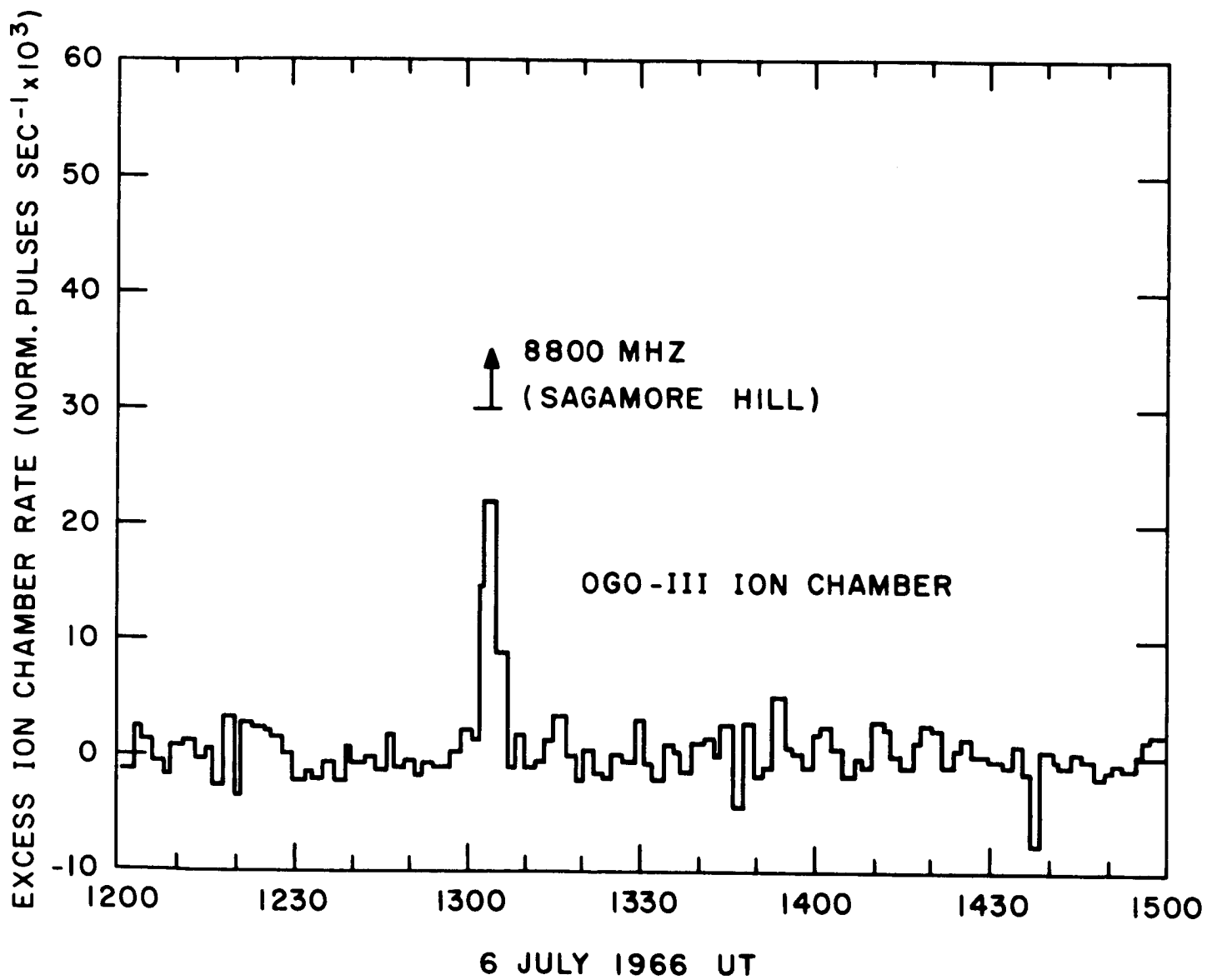


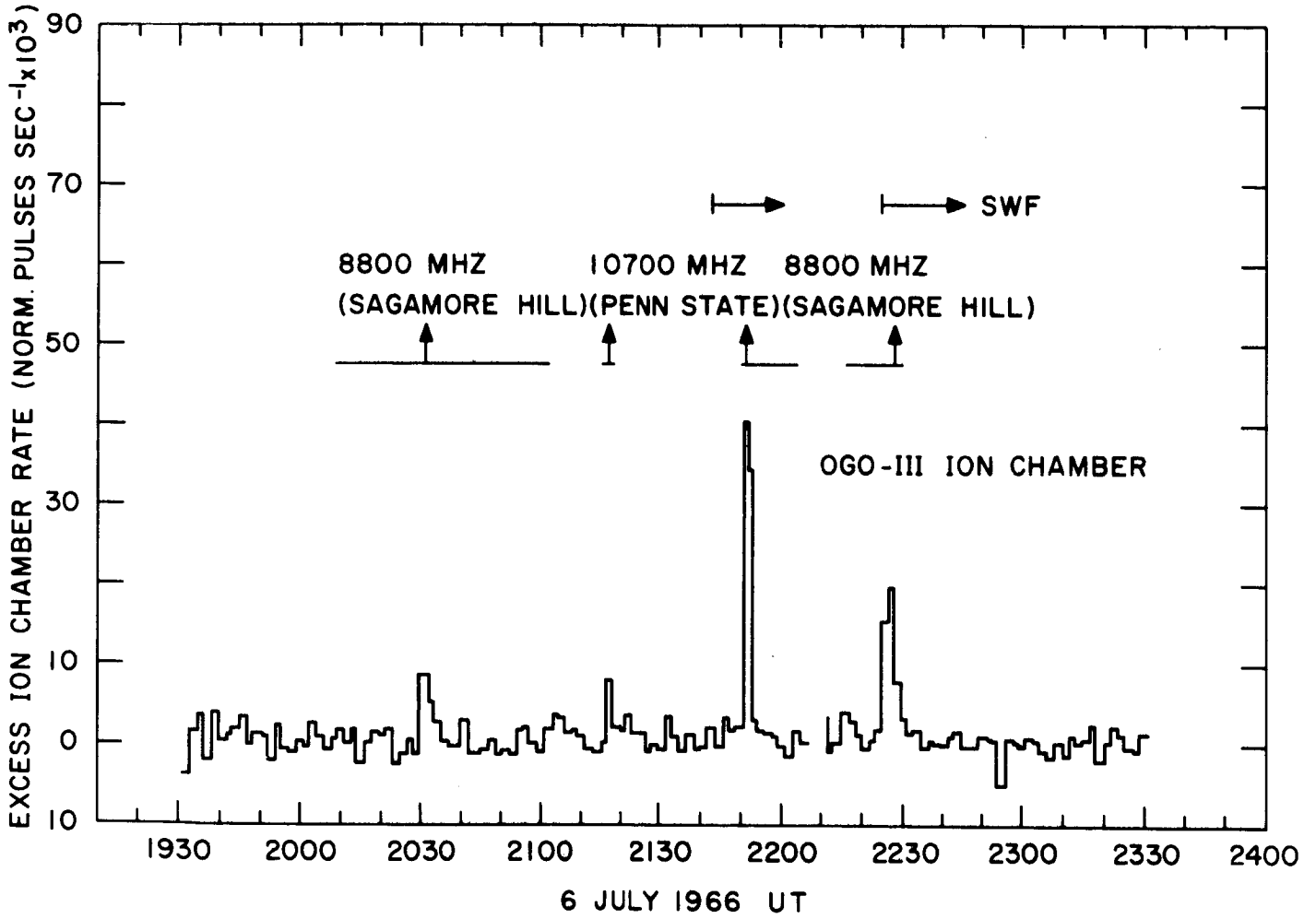


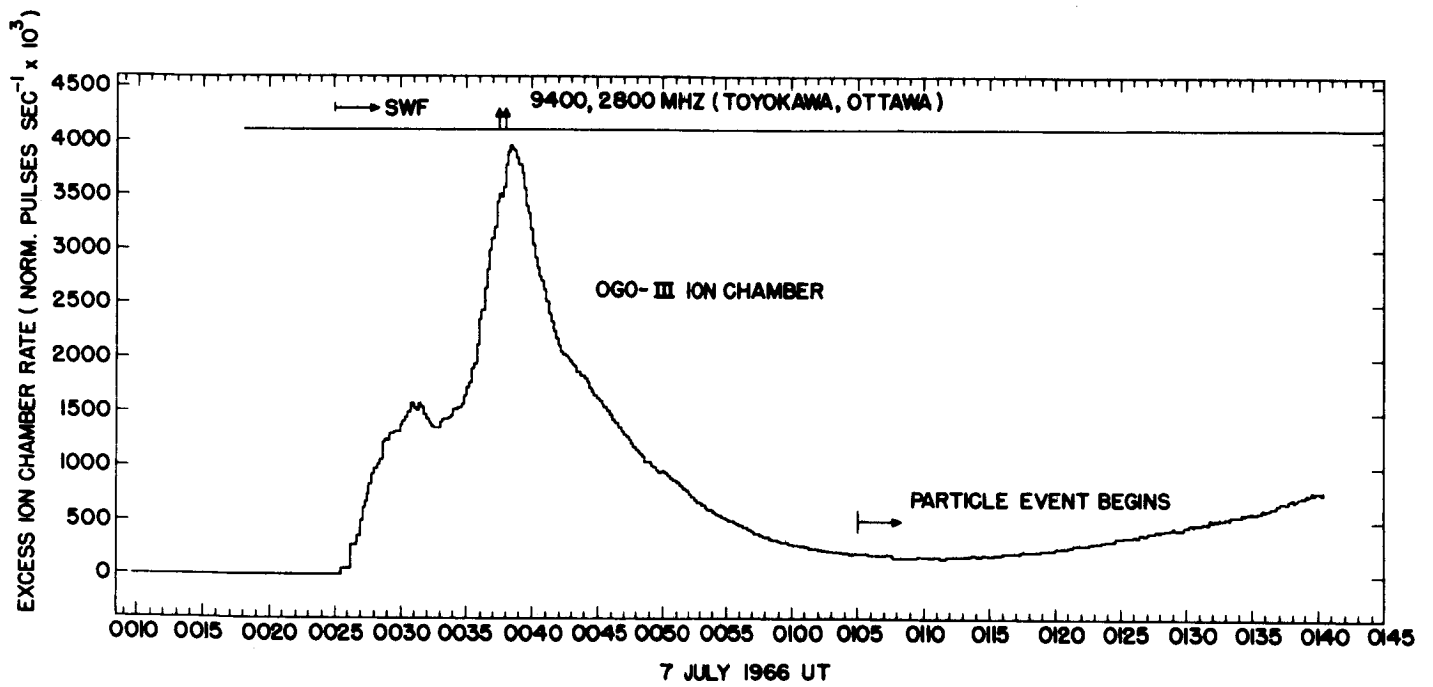


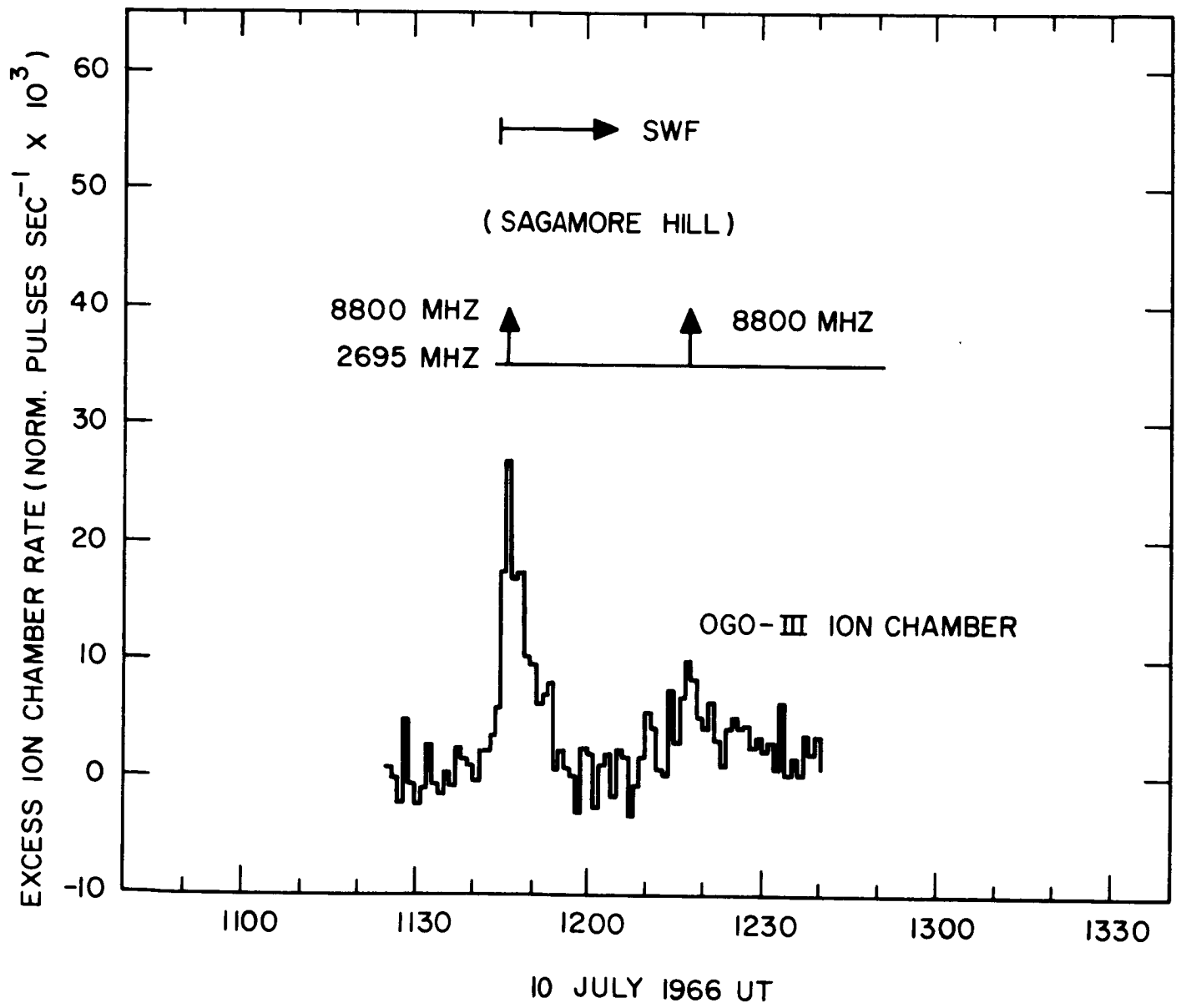


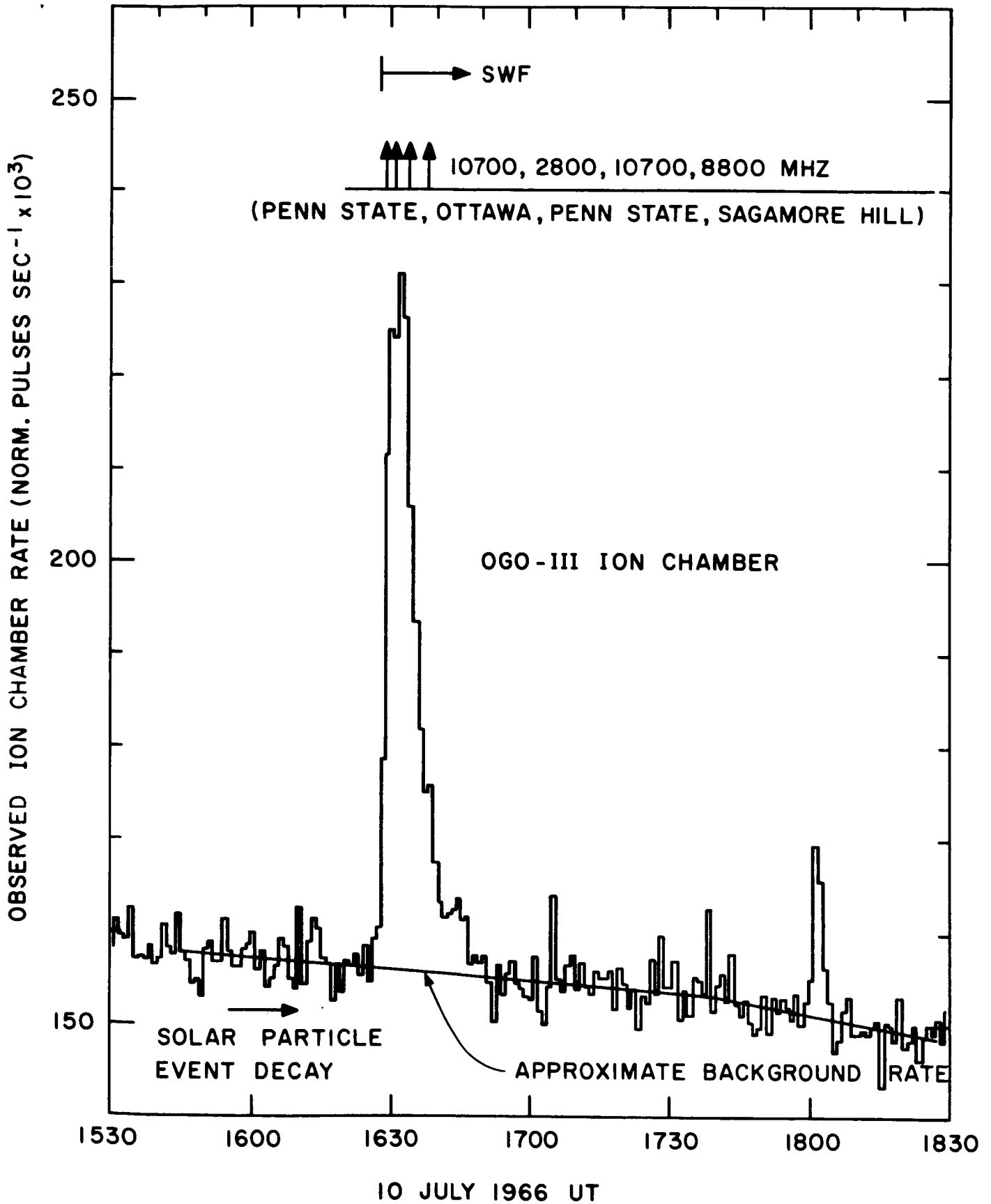


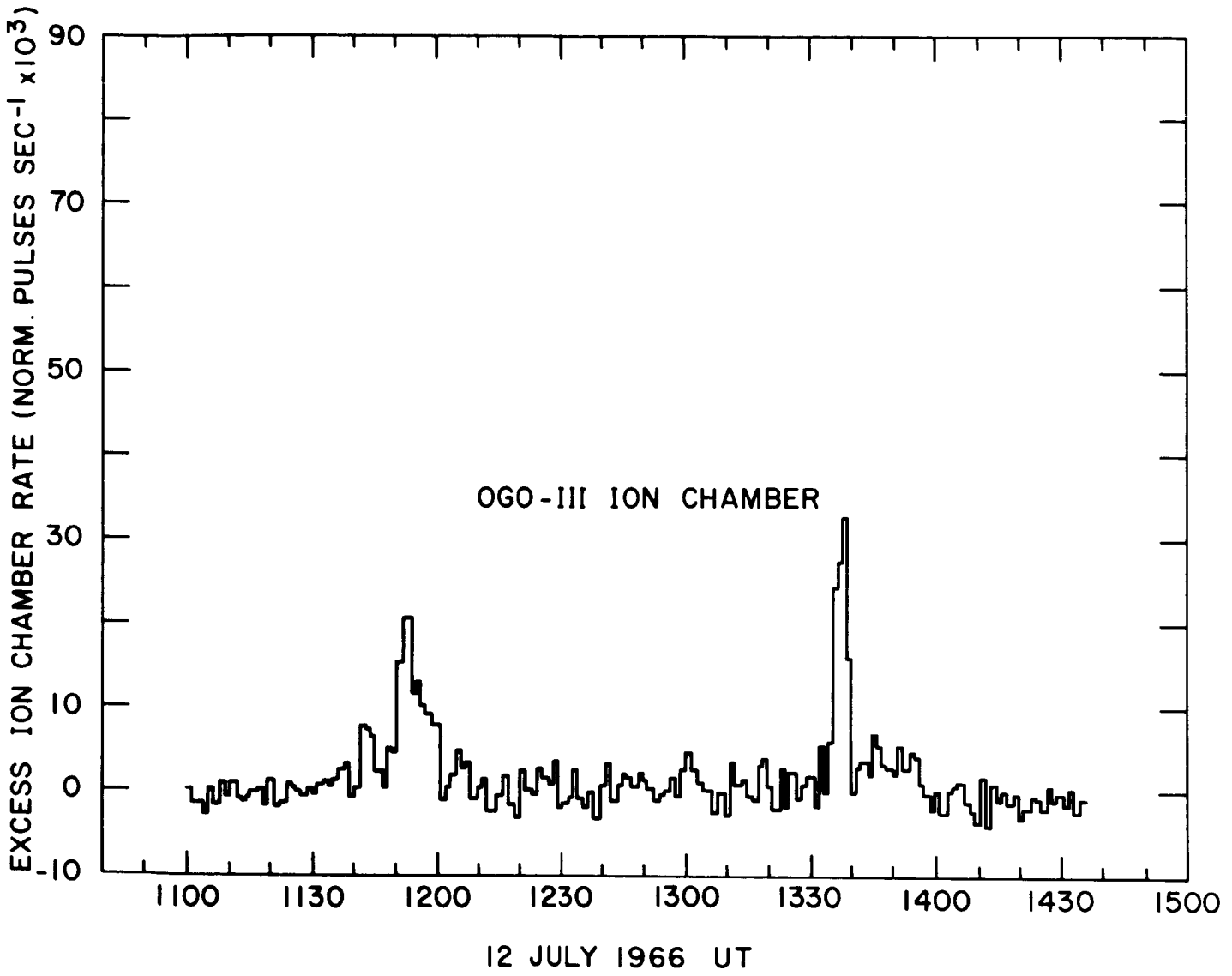


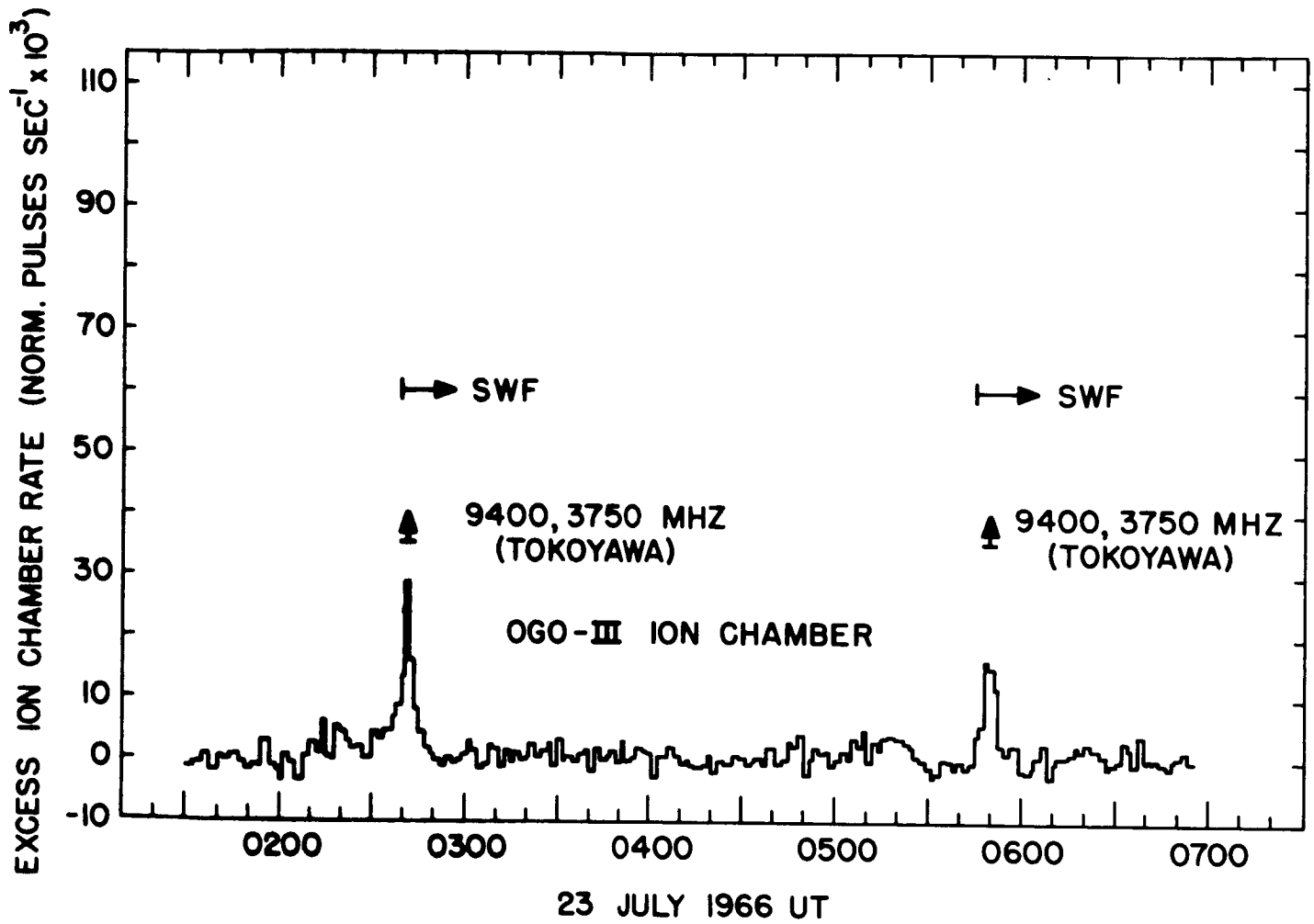


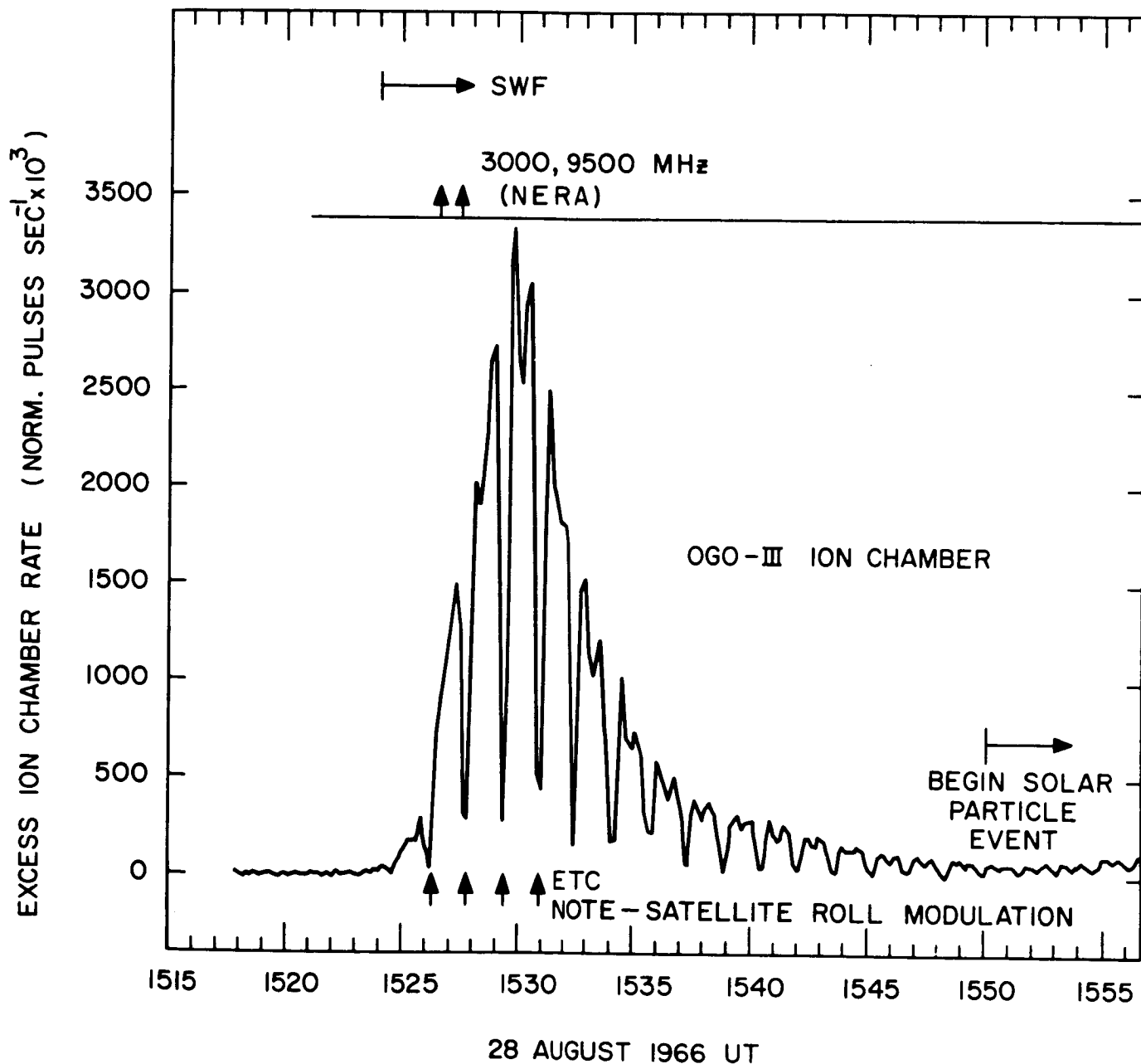


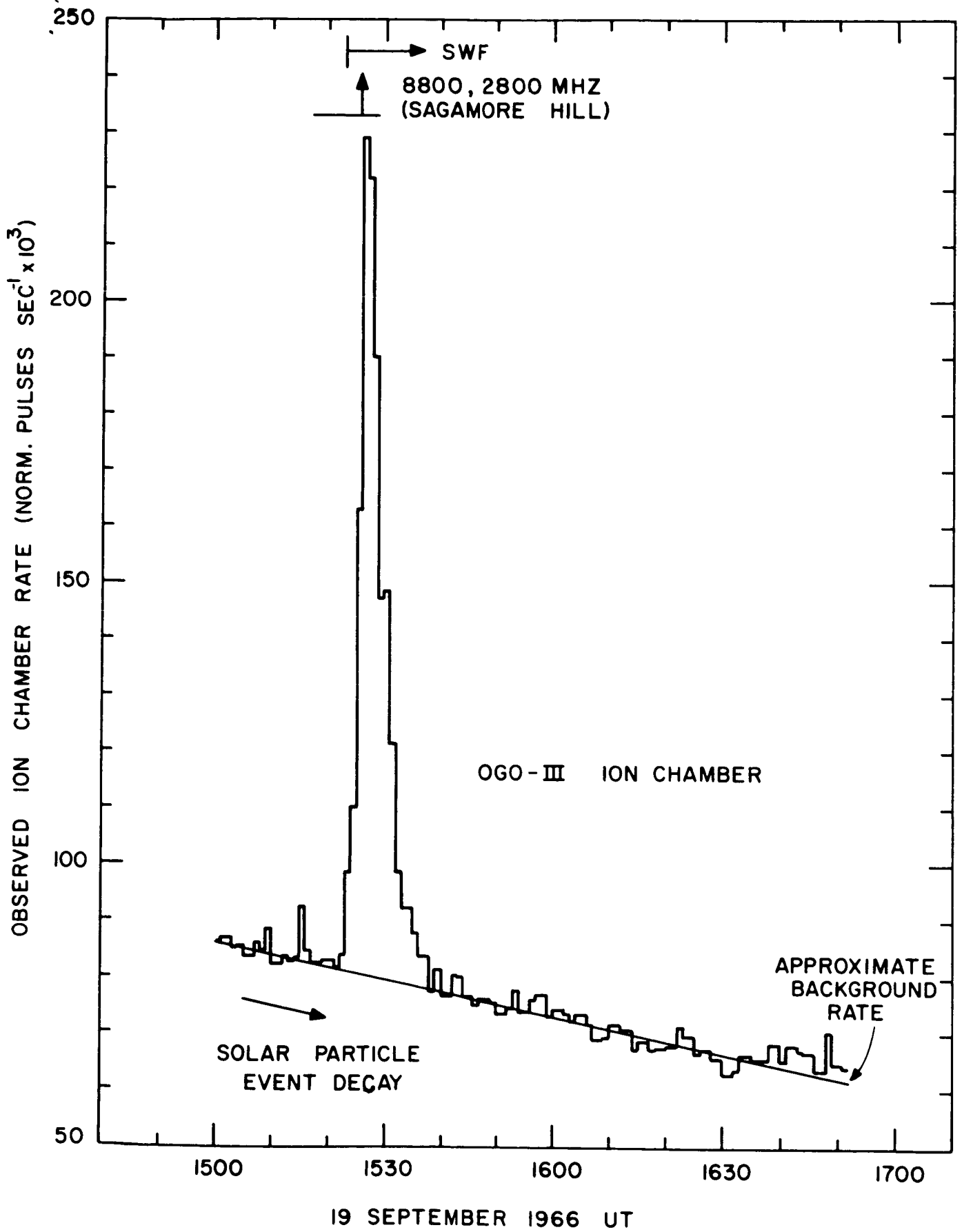


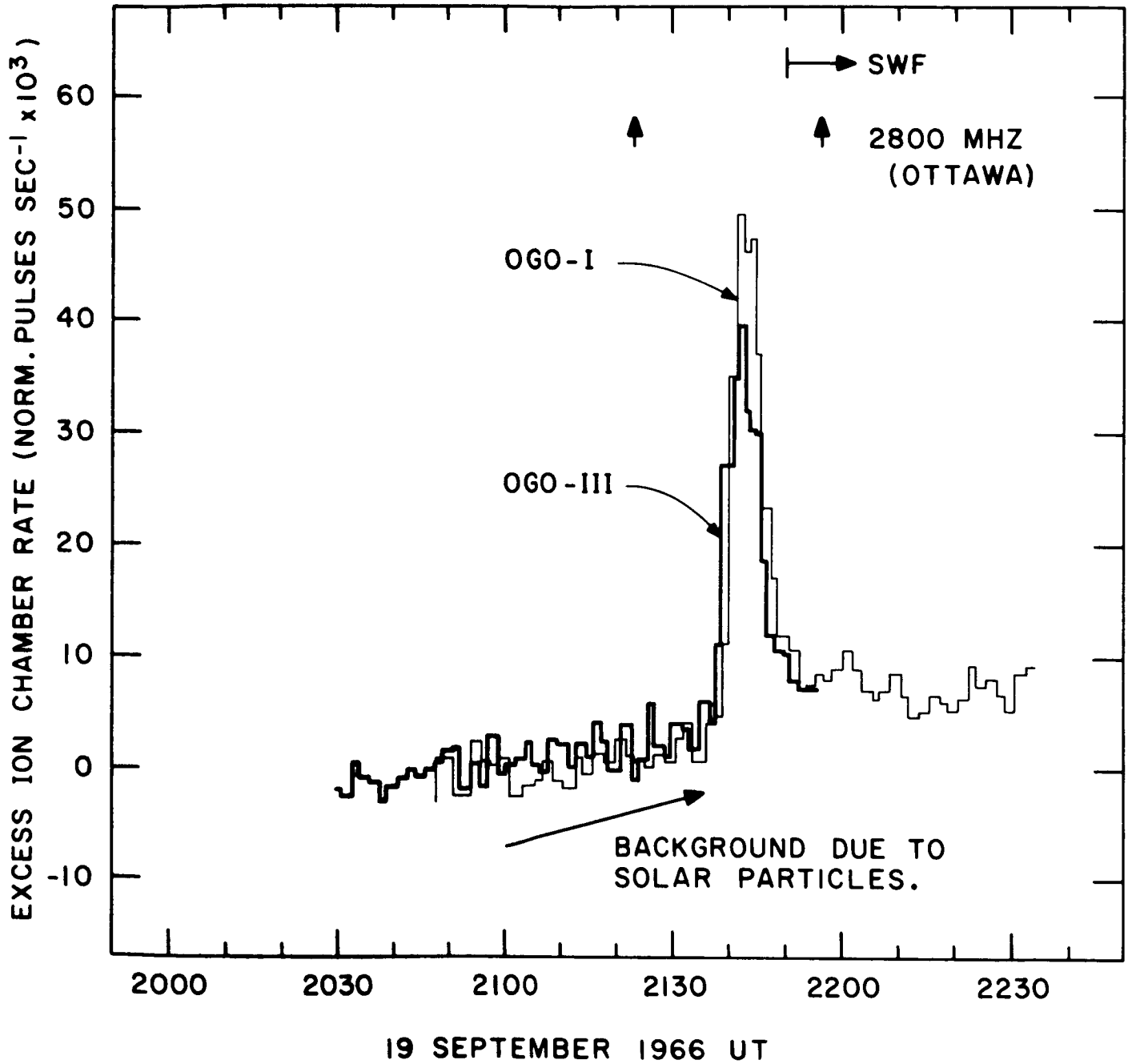


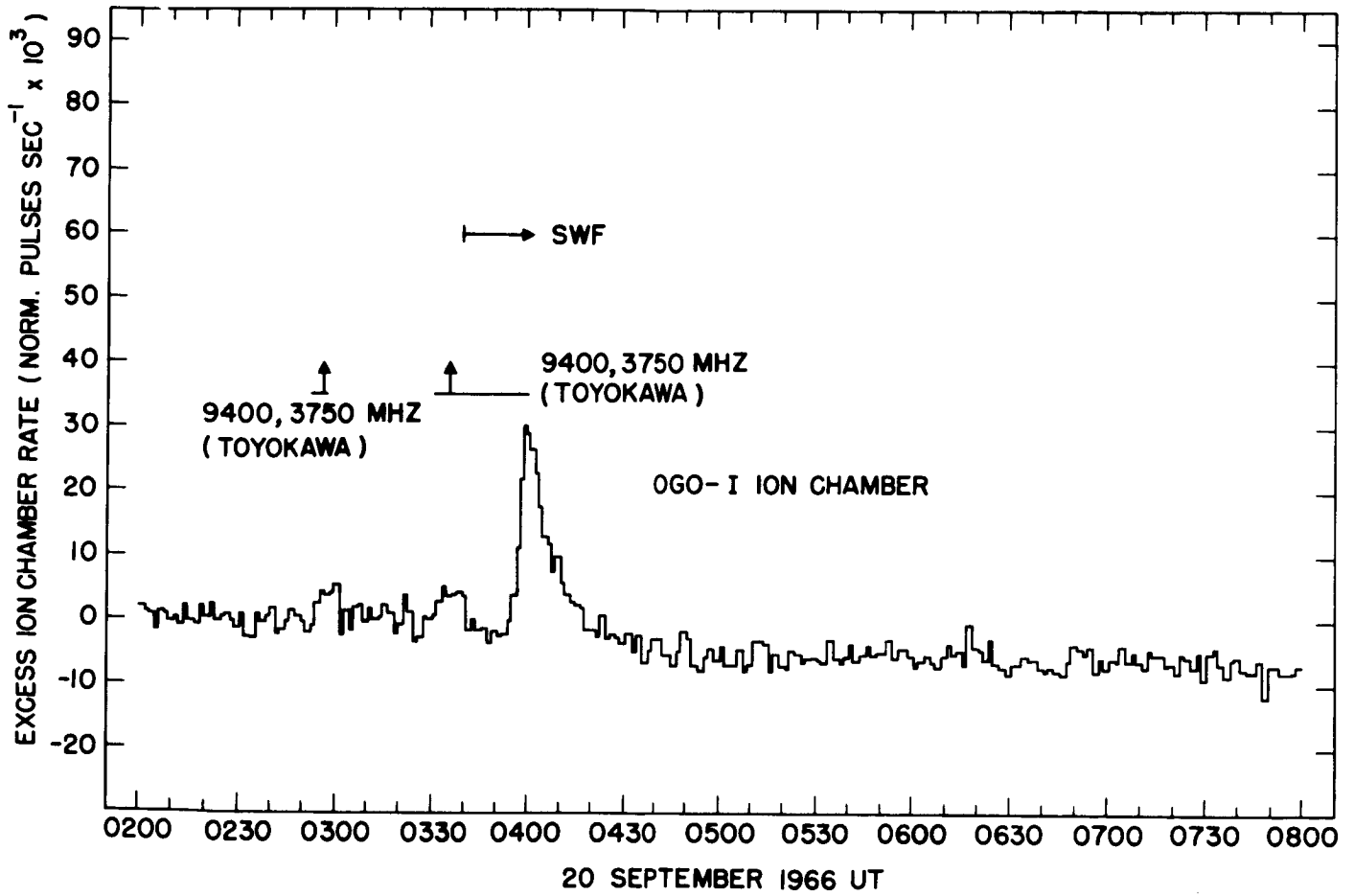


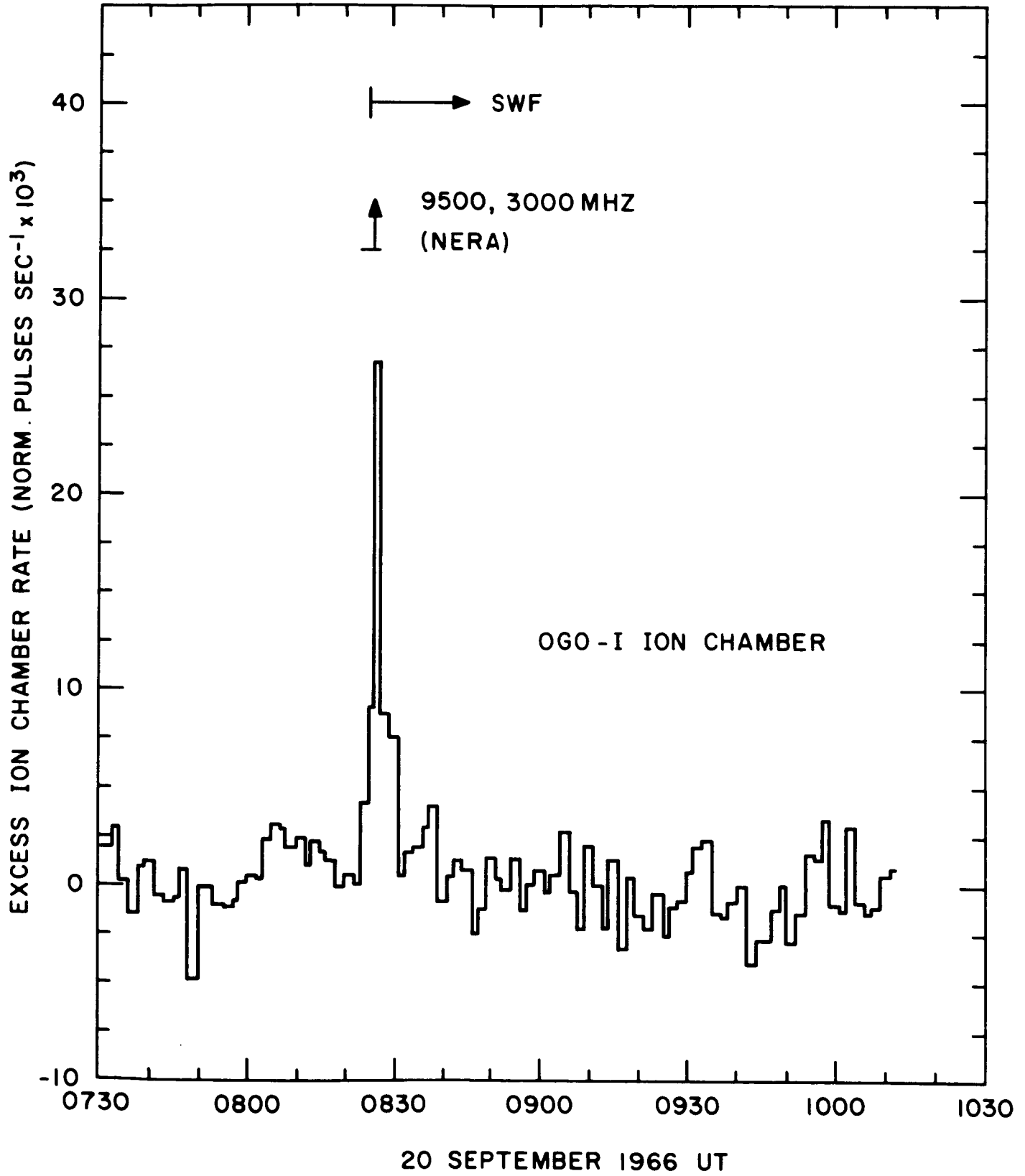


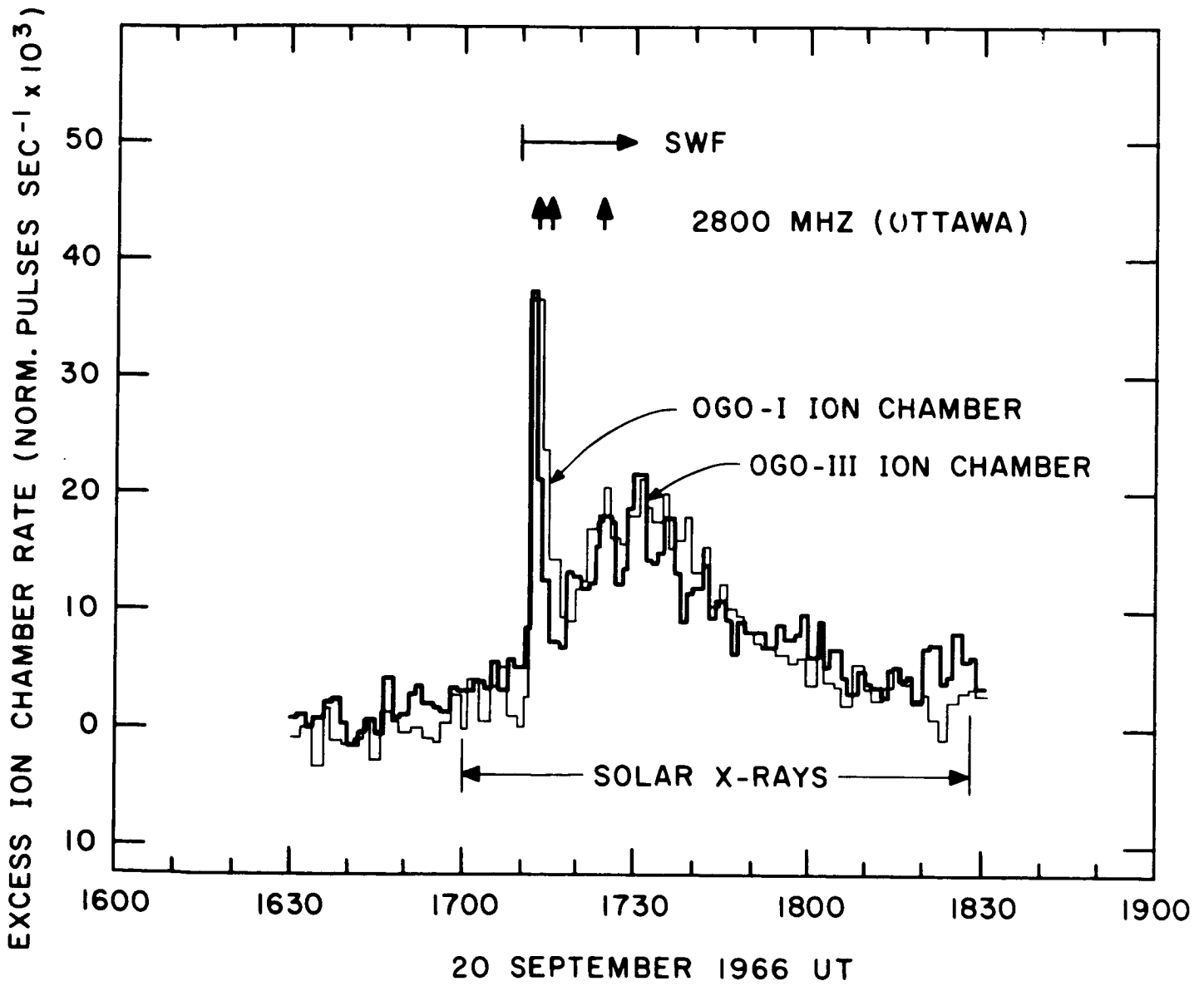


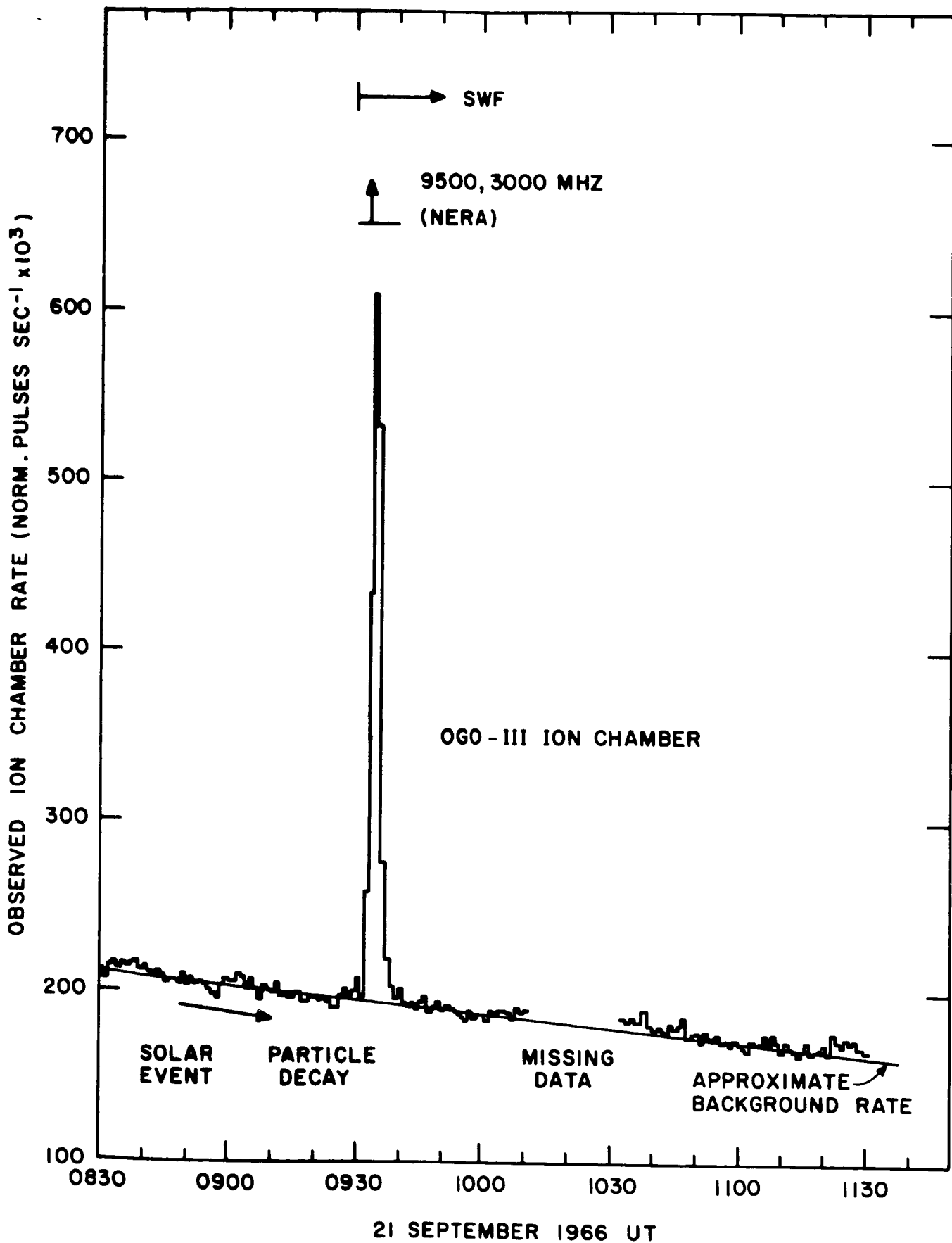


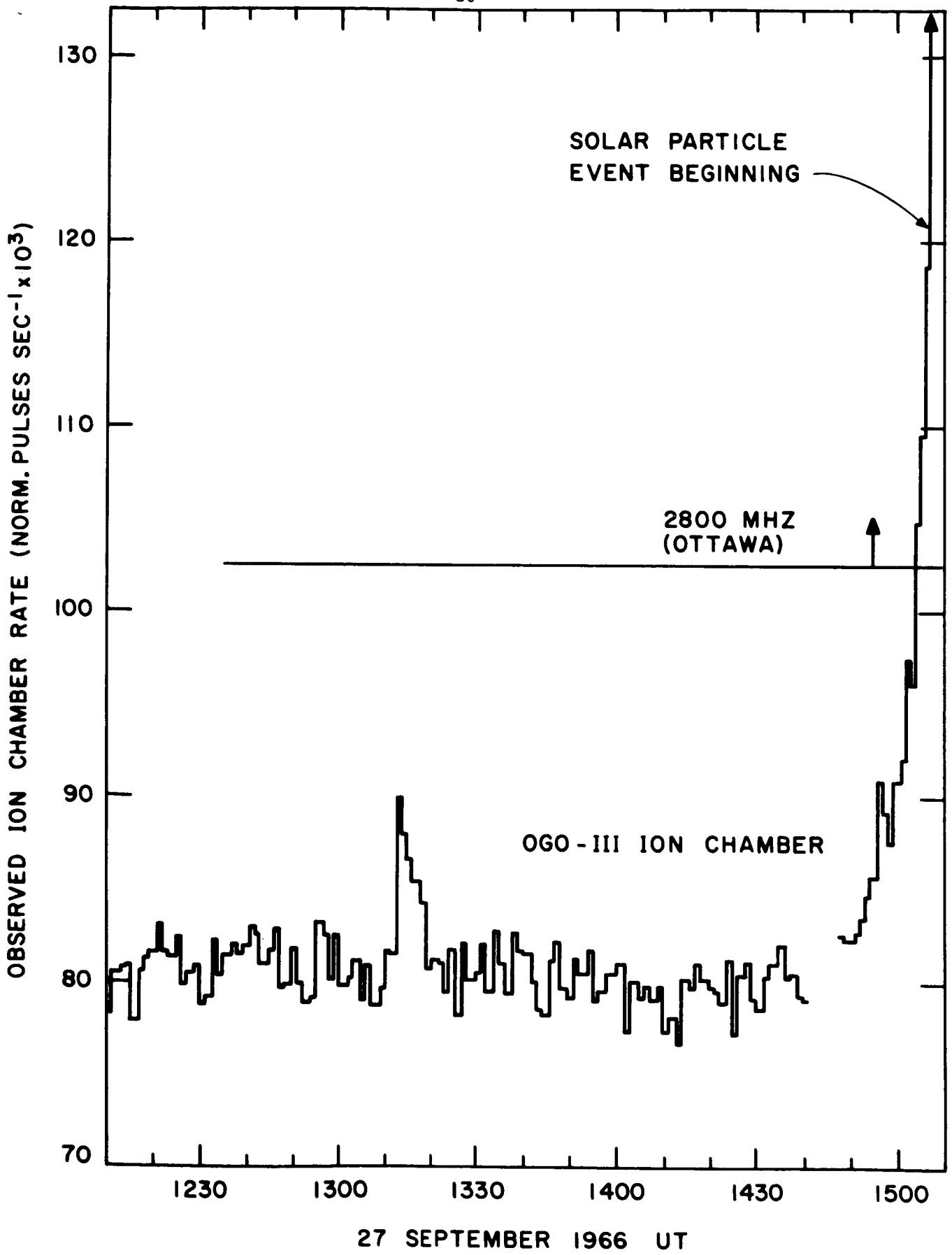


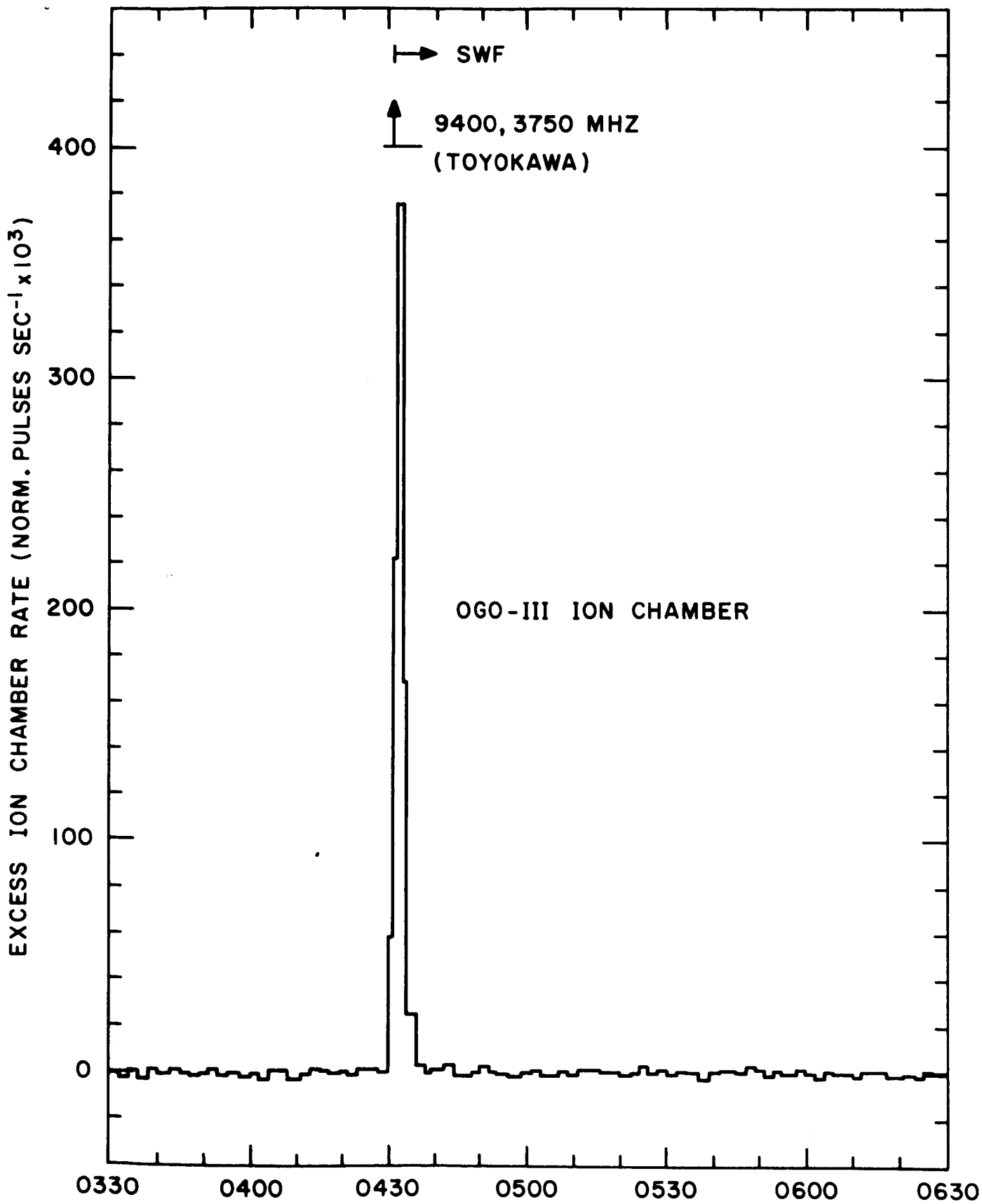




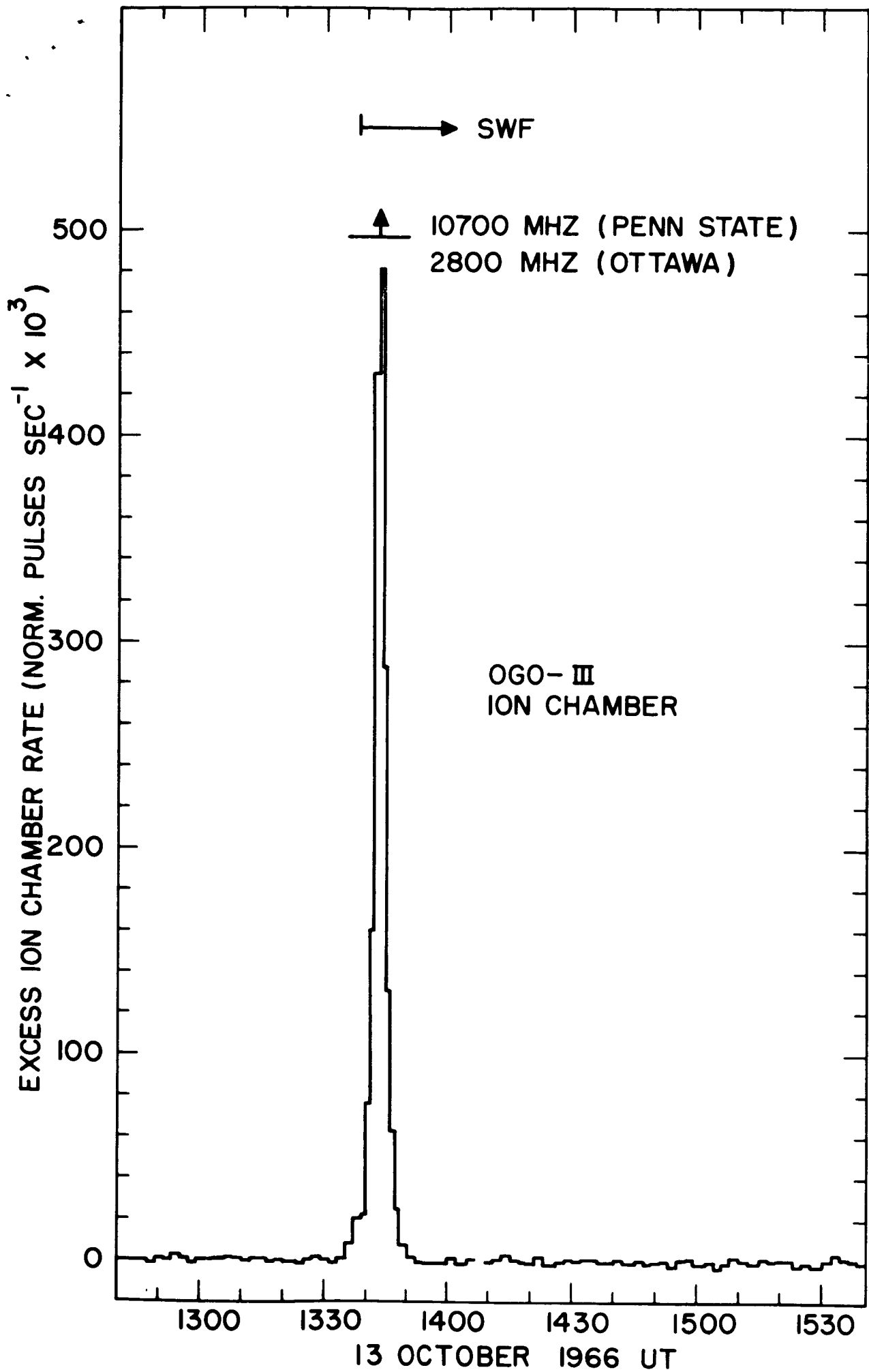


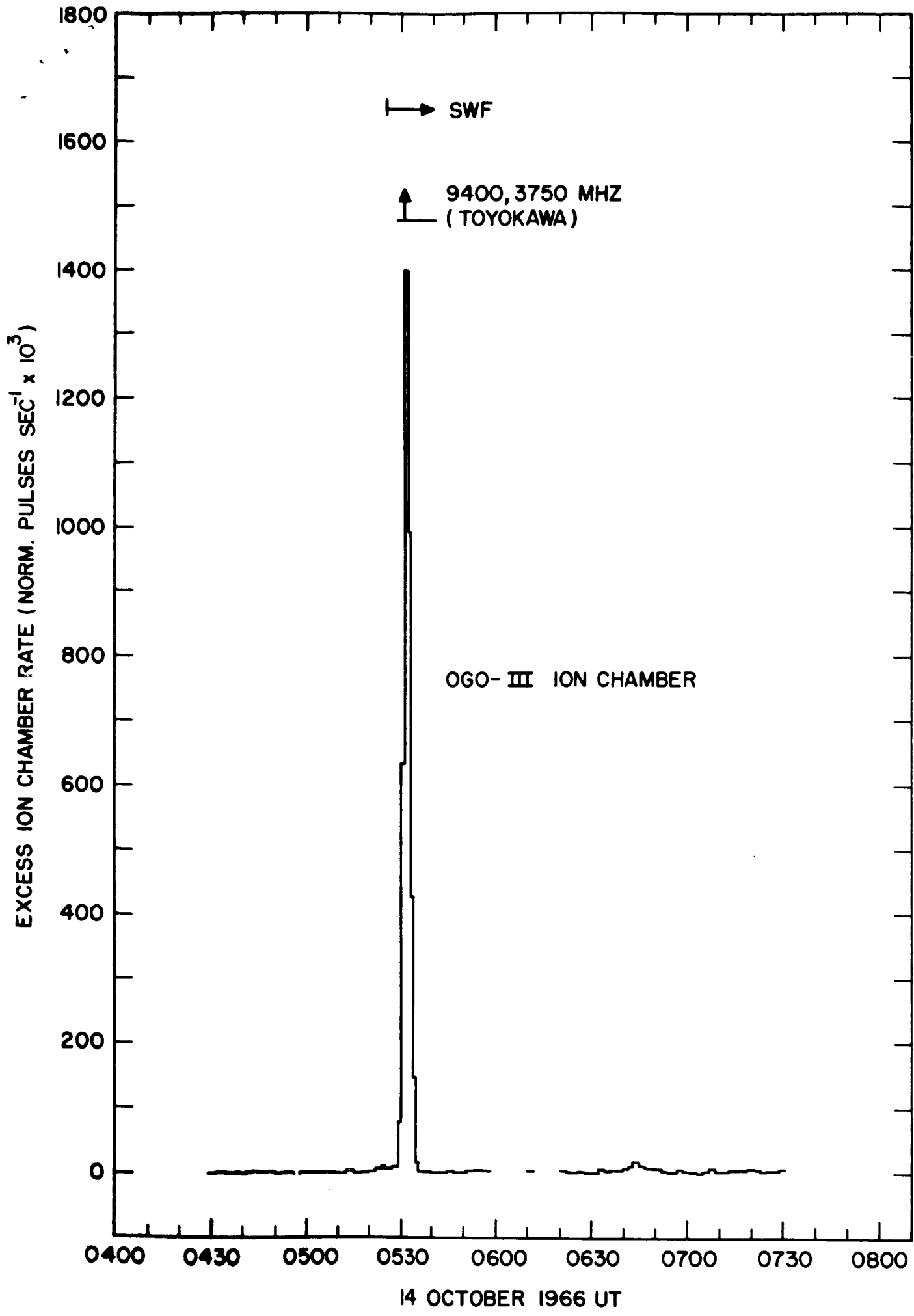


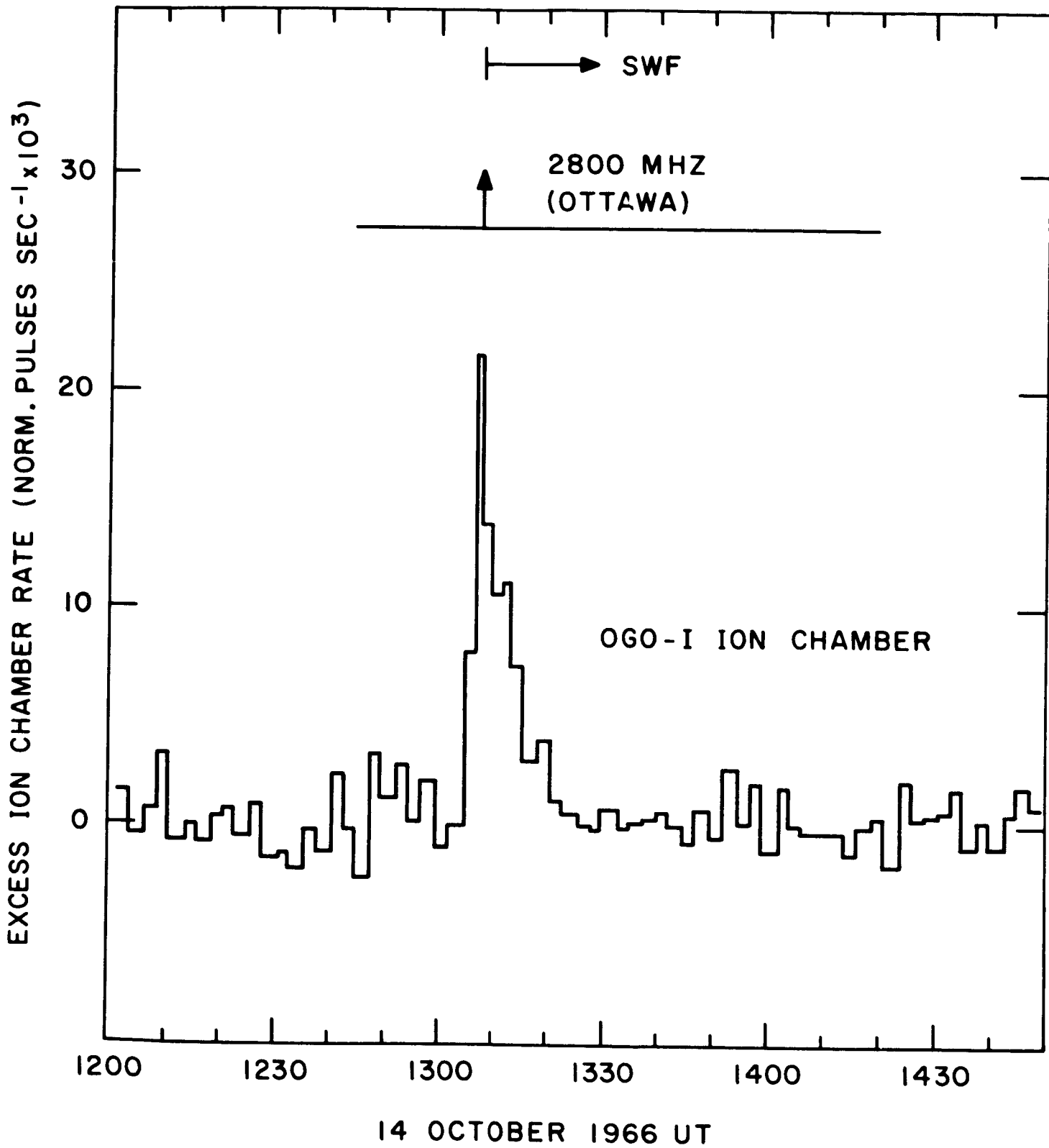


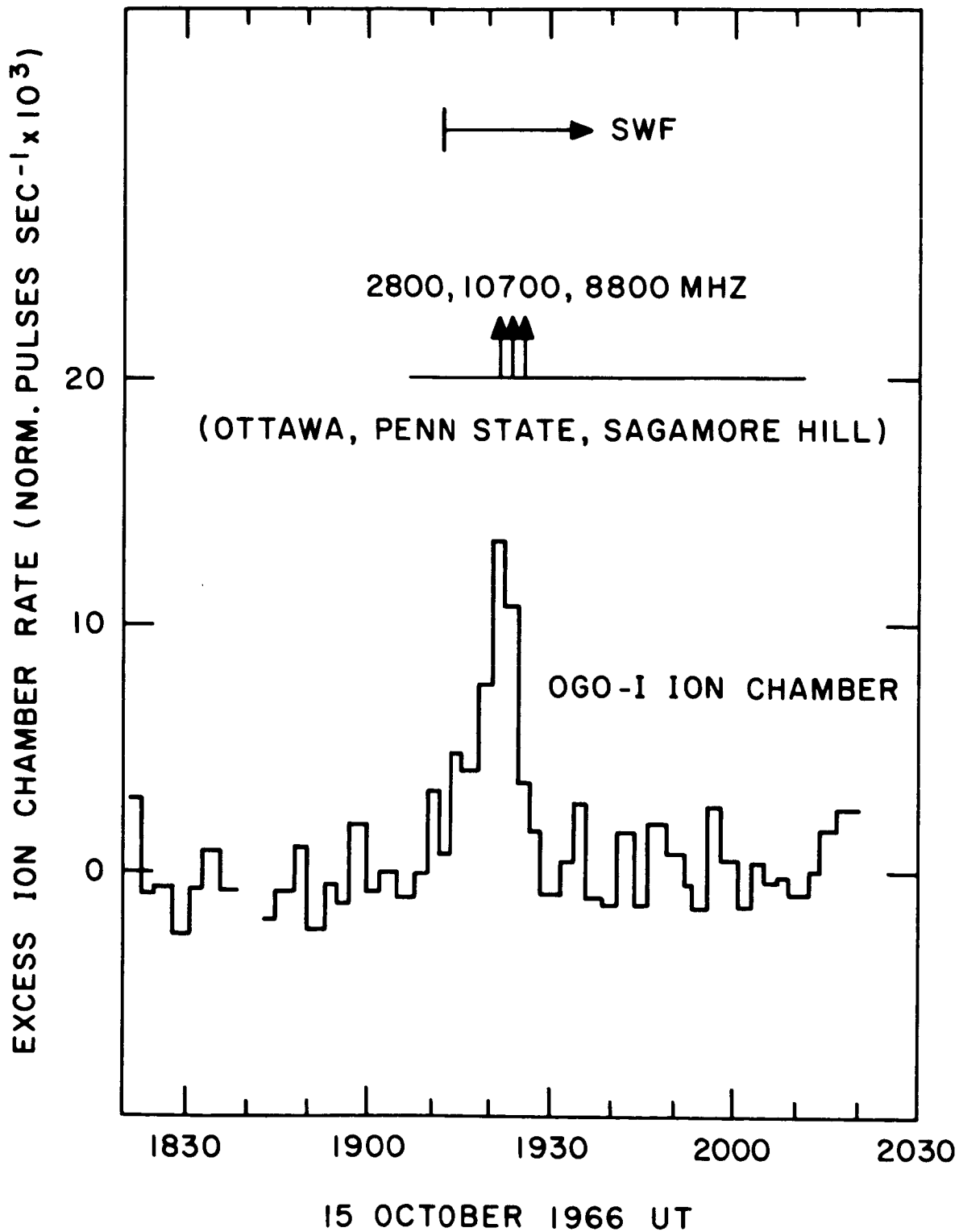


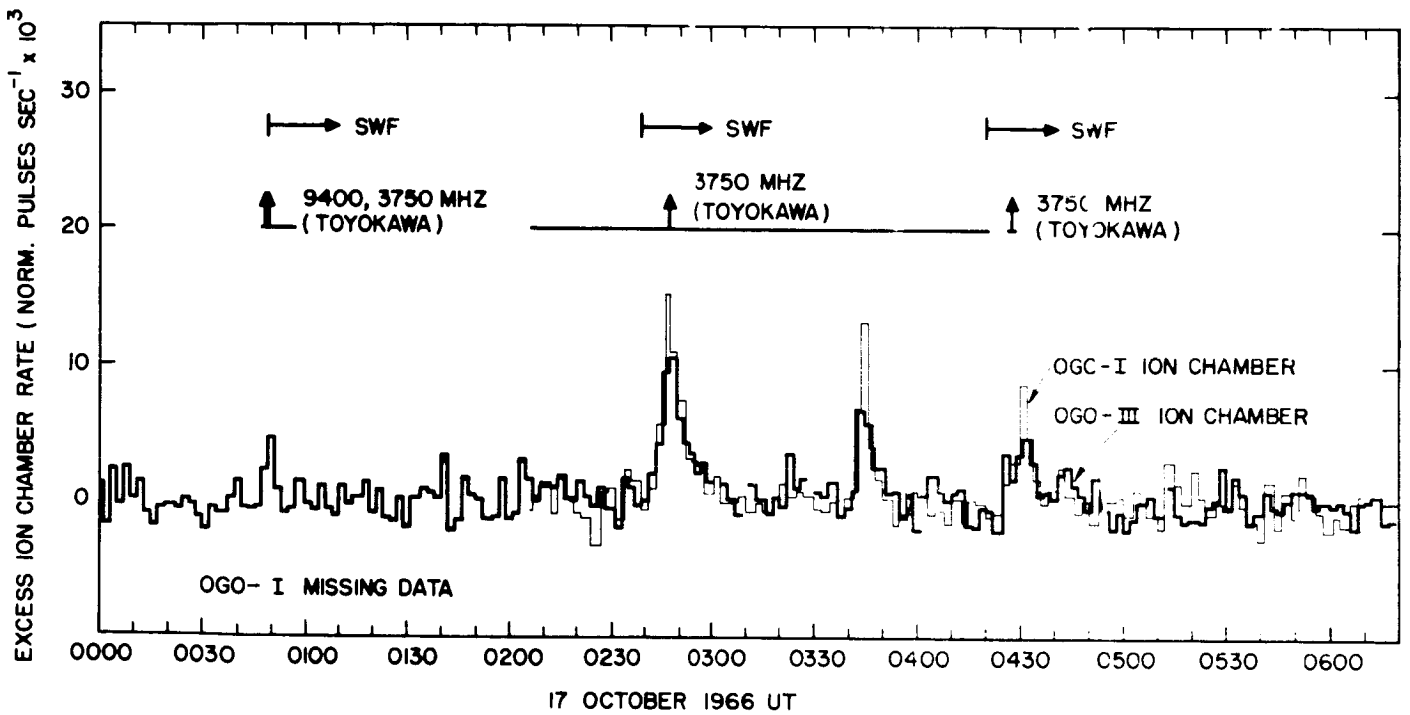
13 OCTOBER 1966 UT

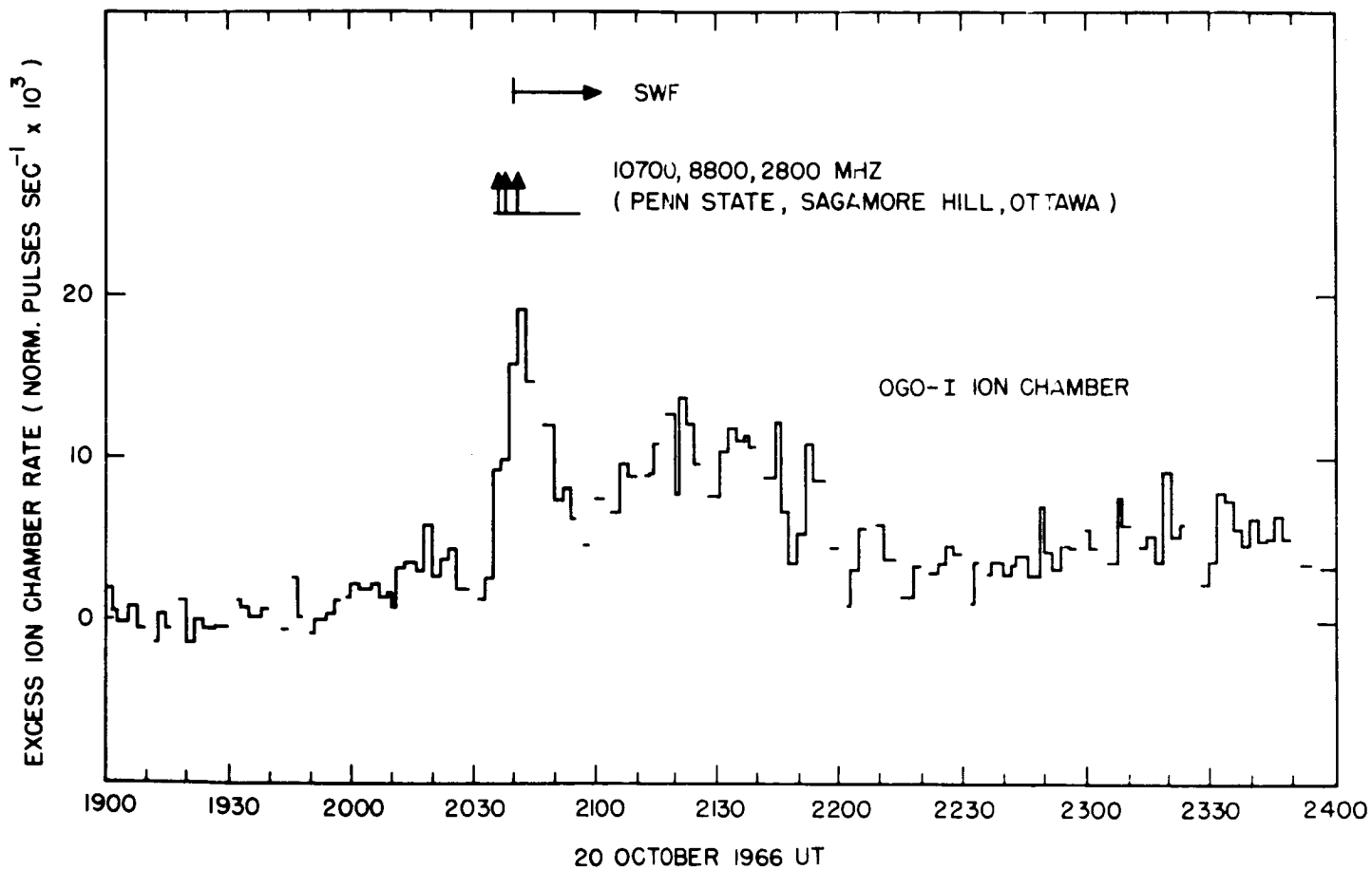


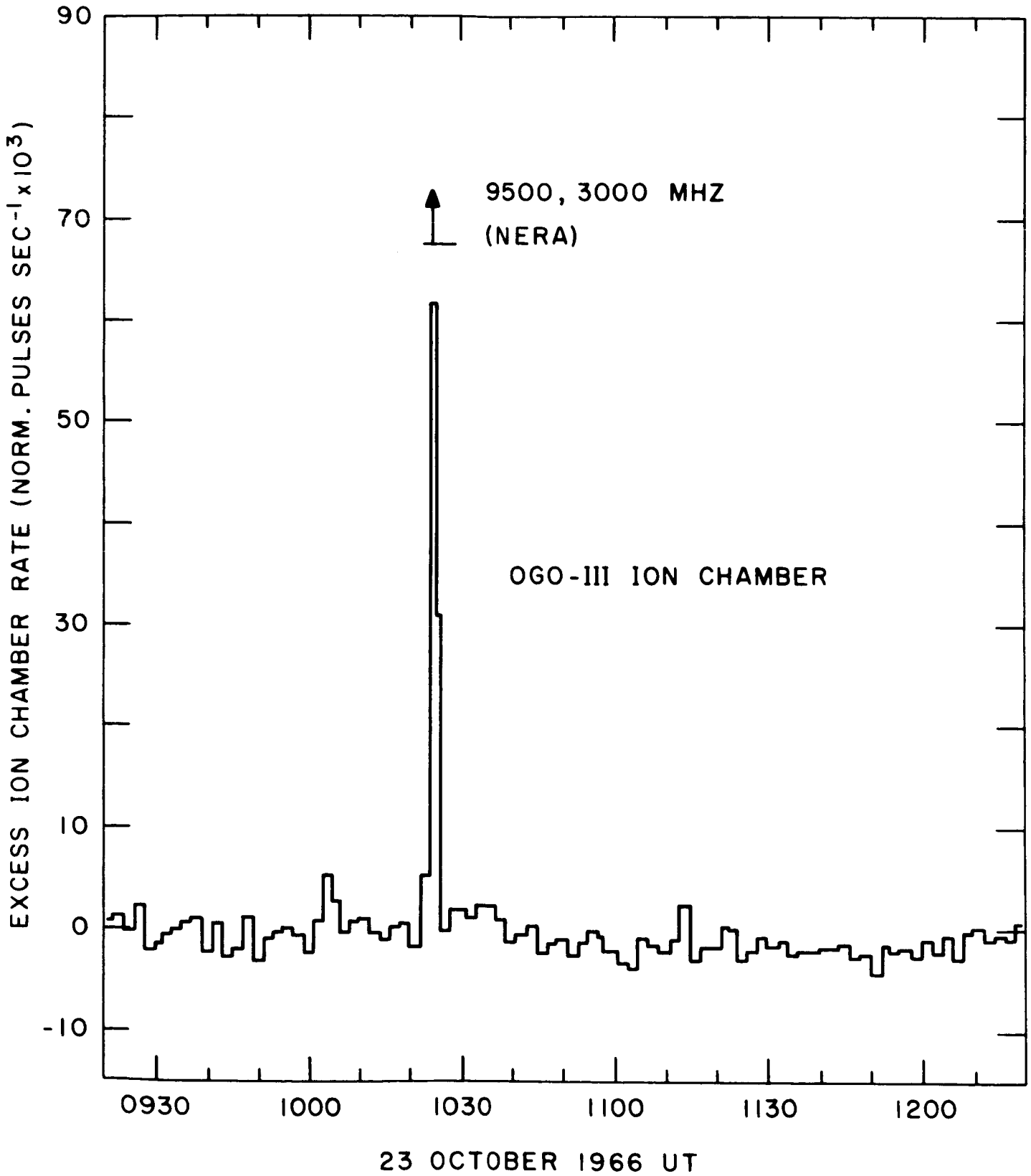


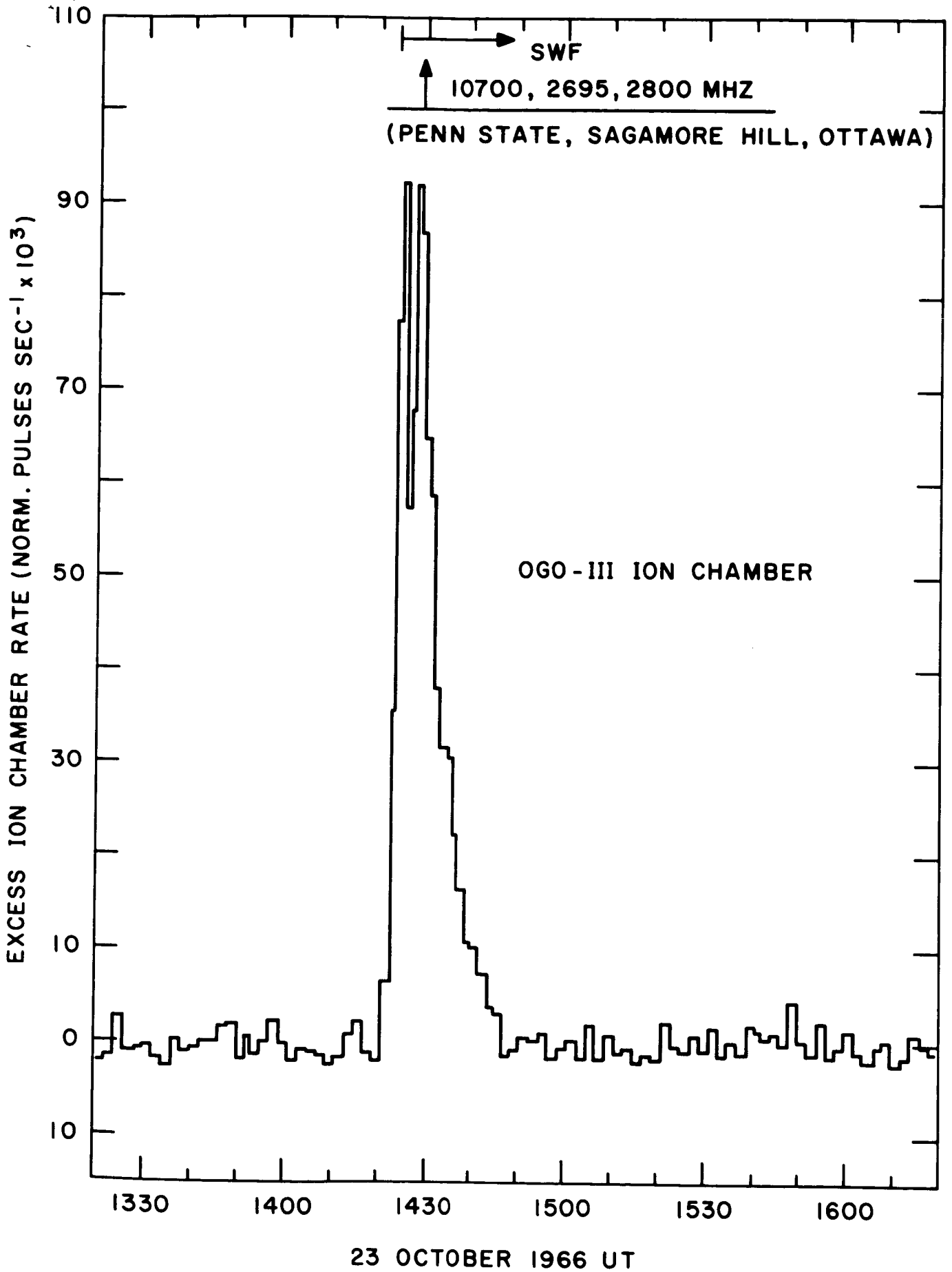


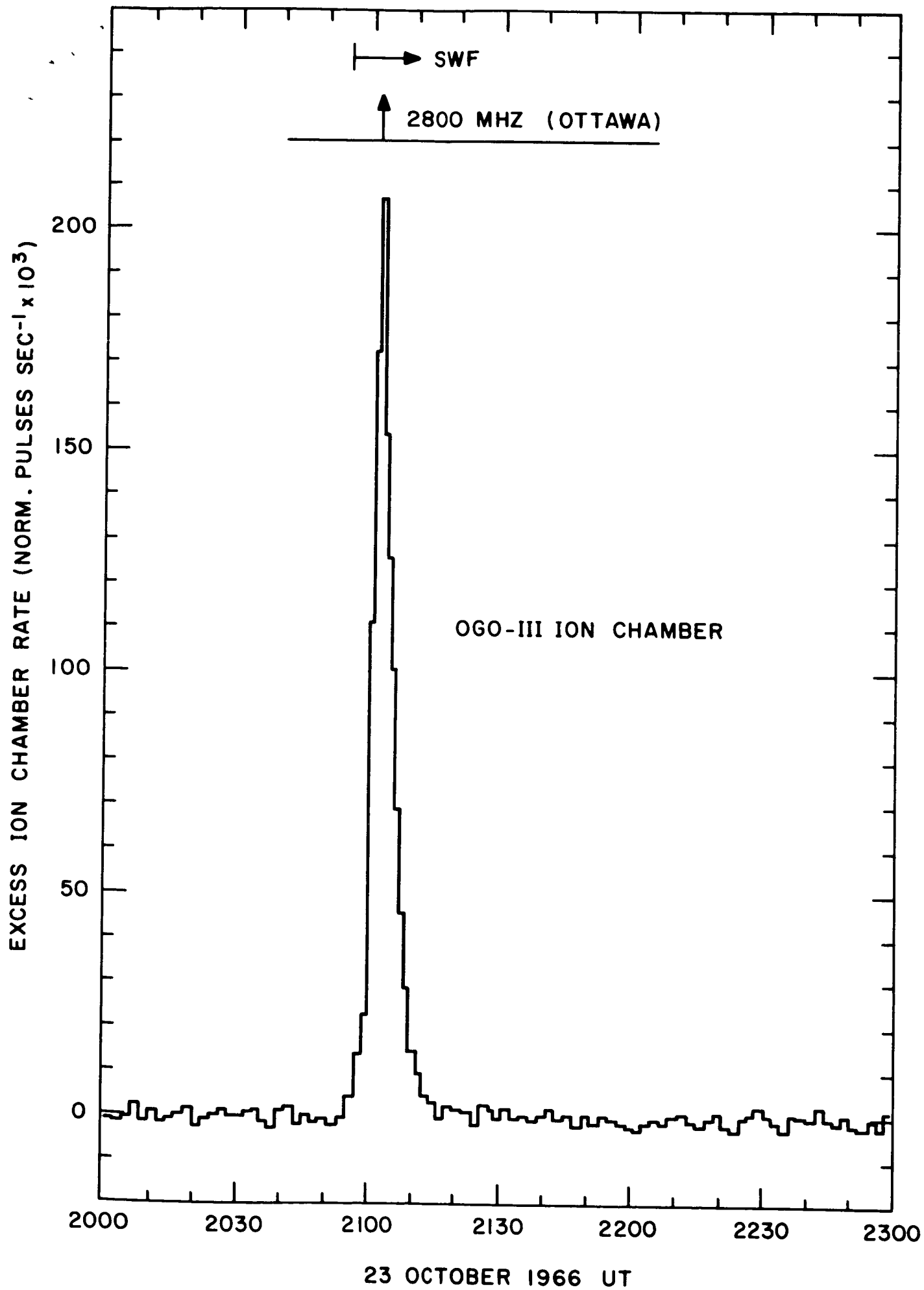


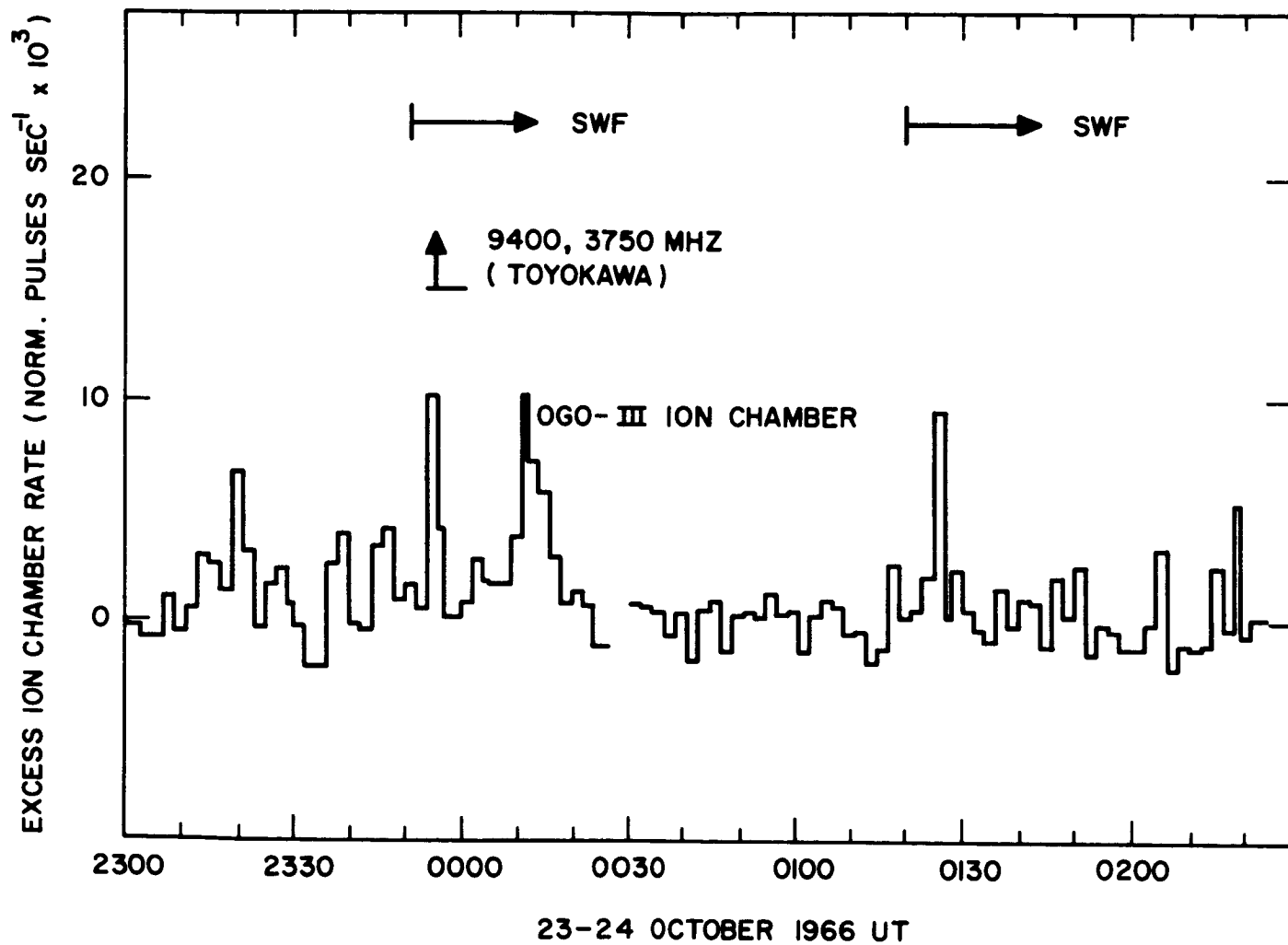


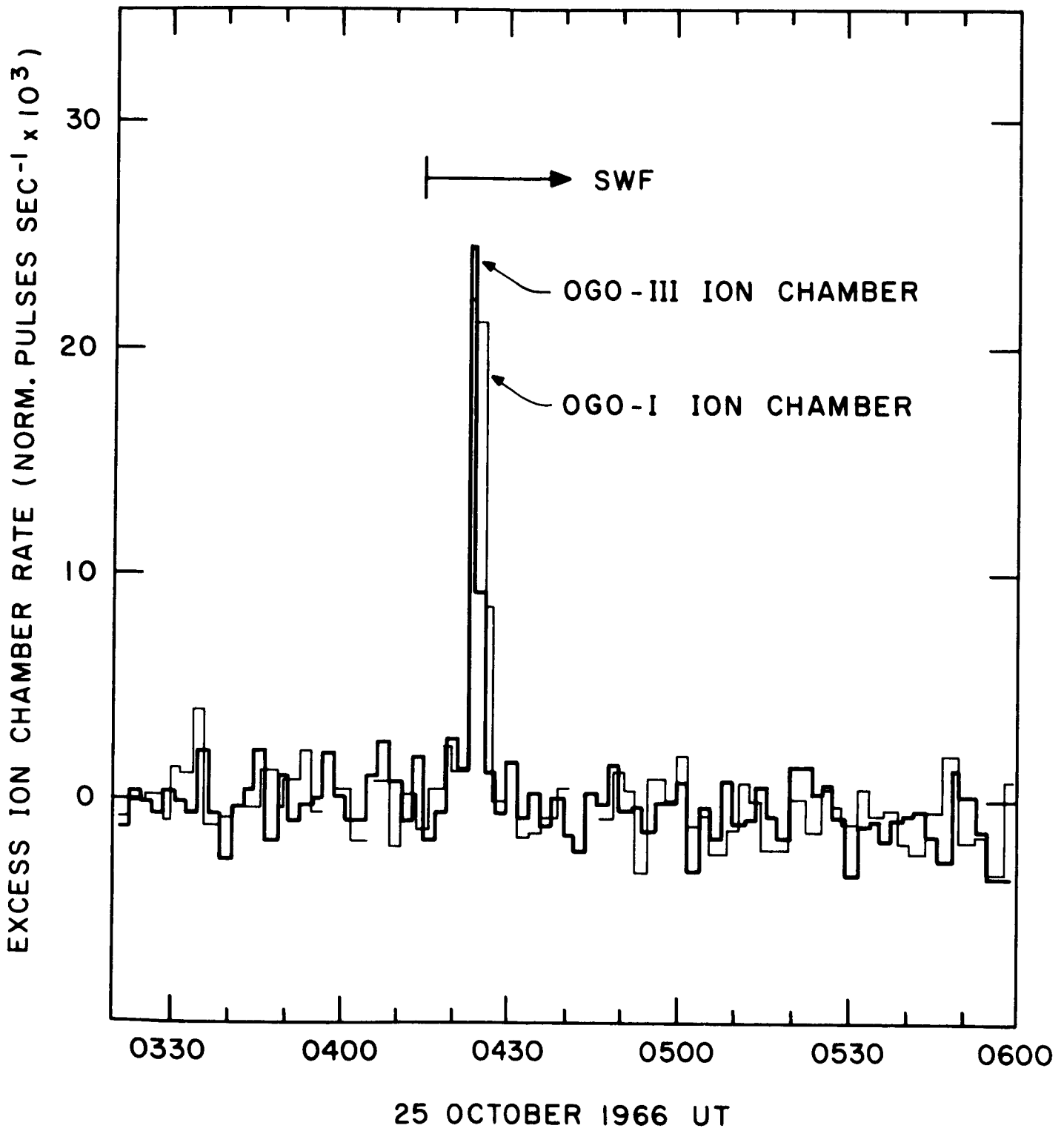


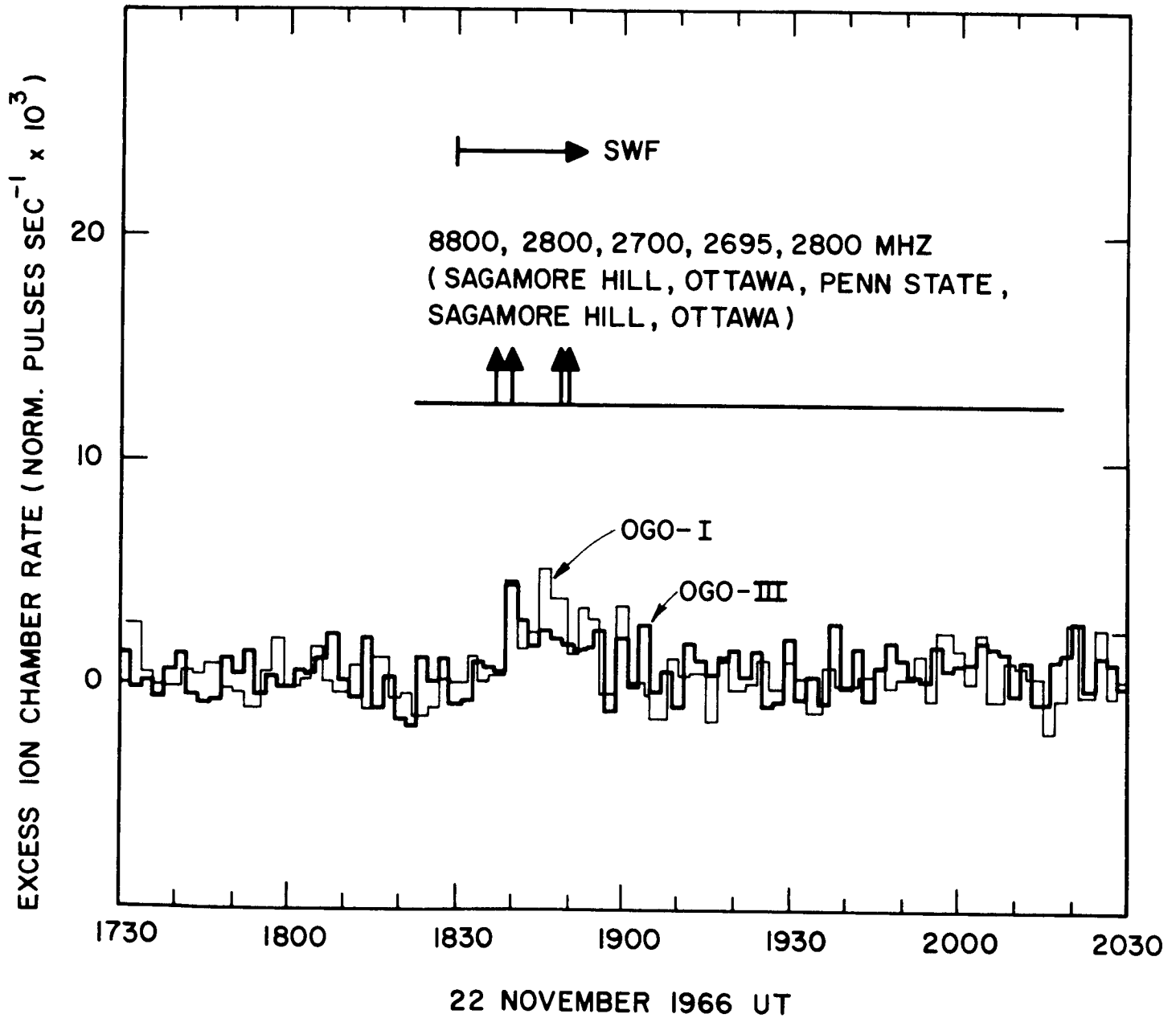


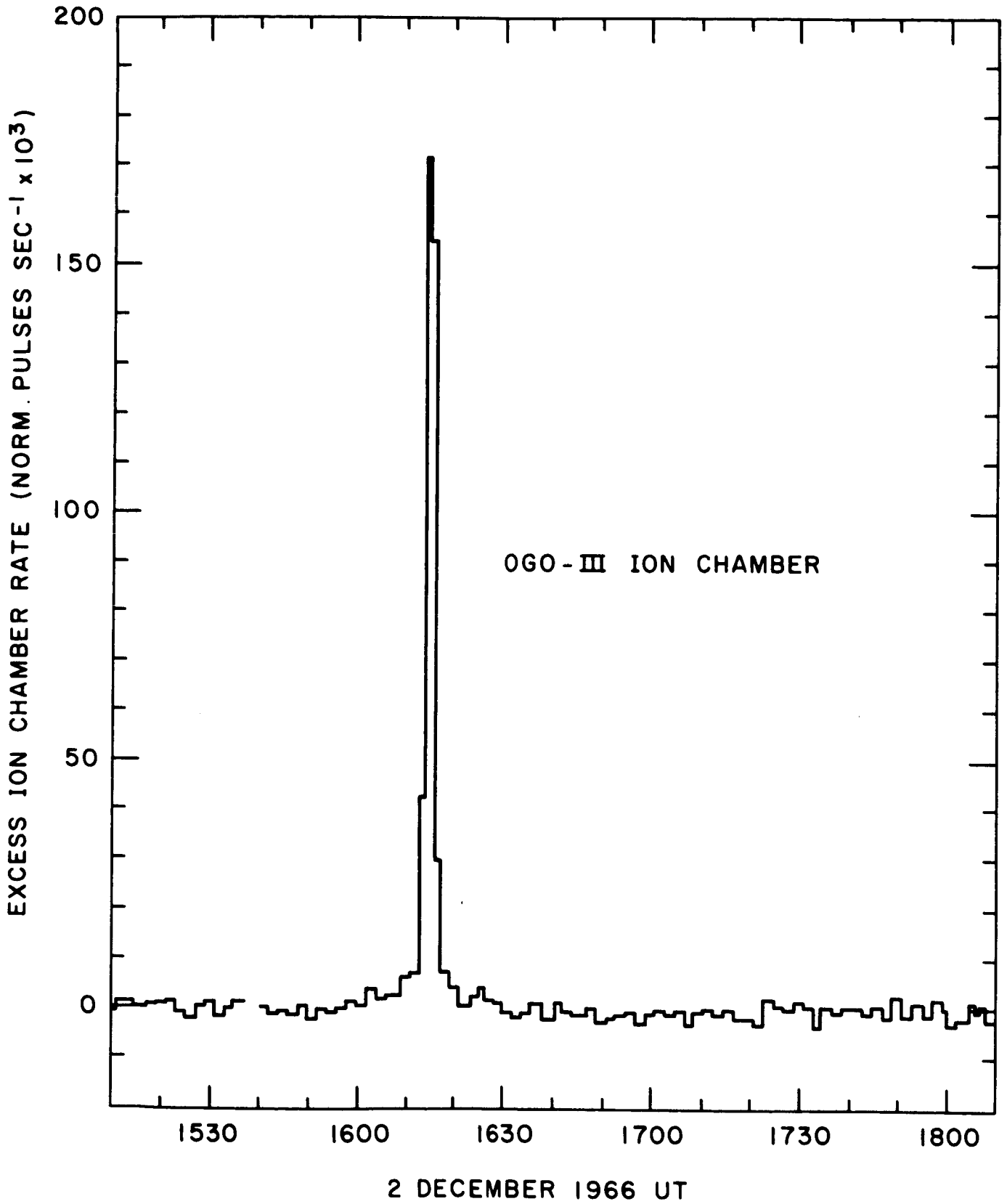


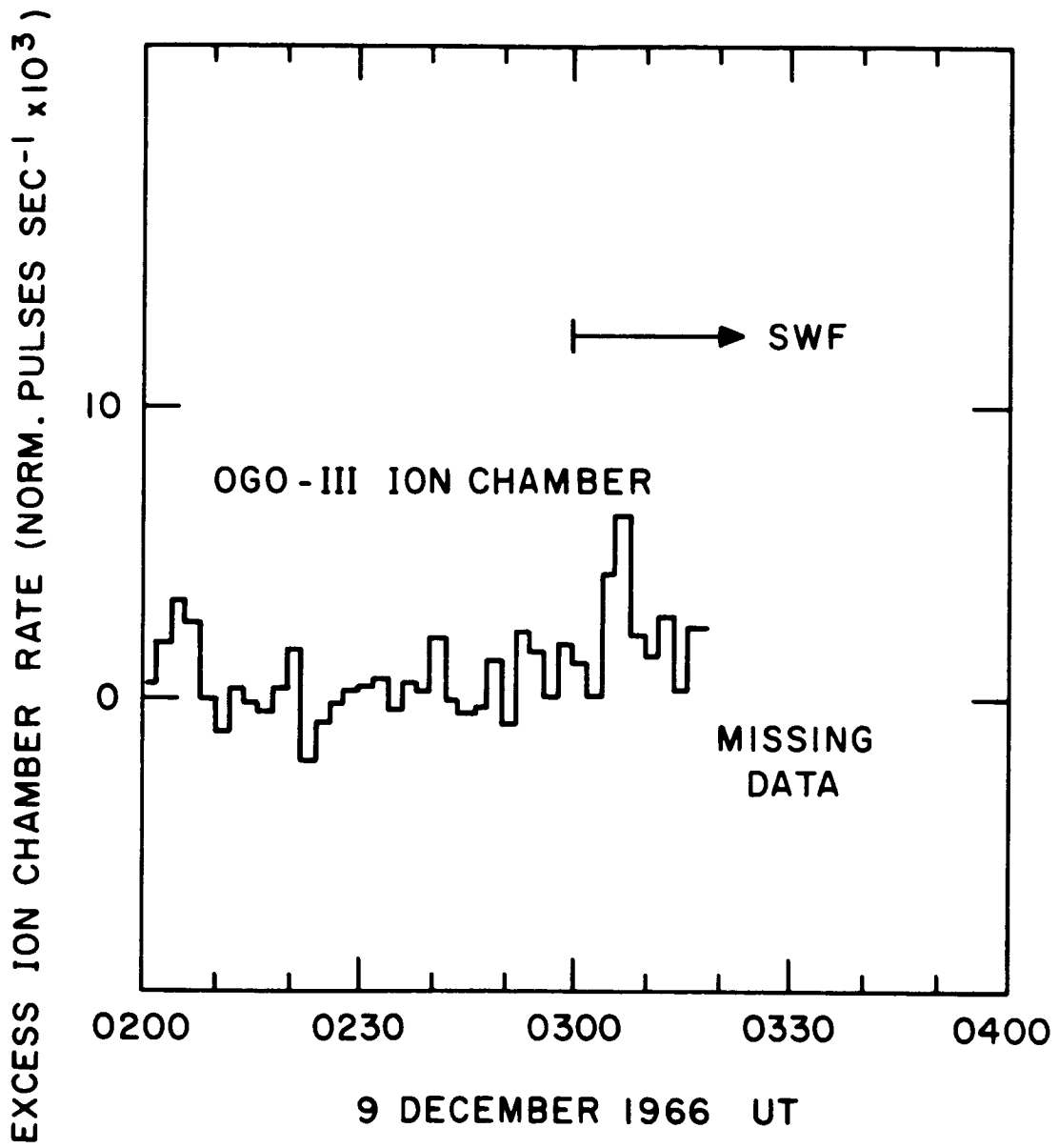


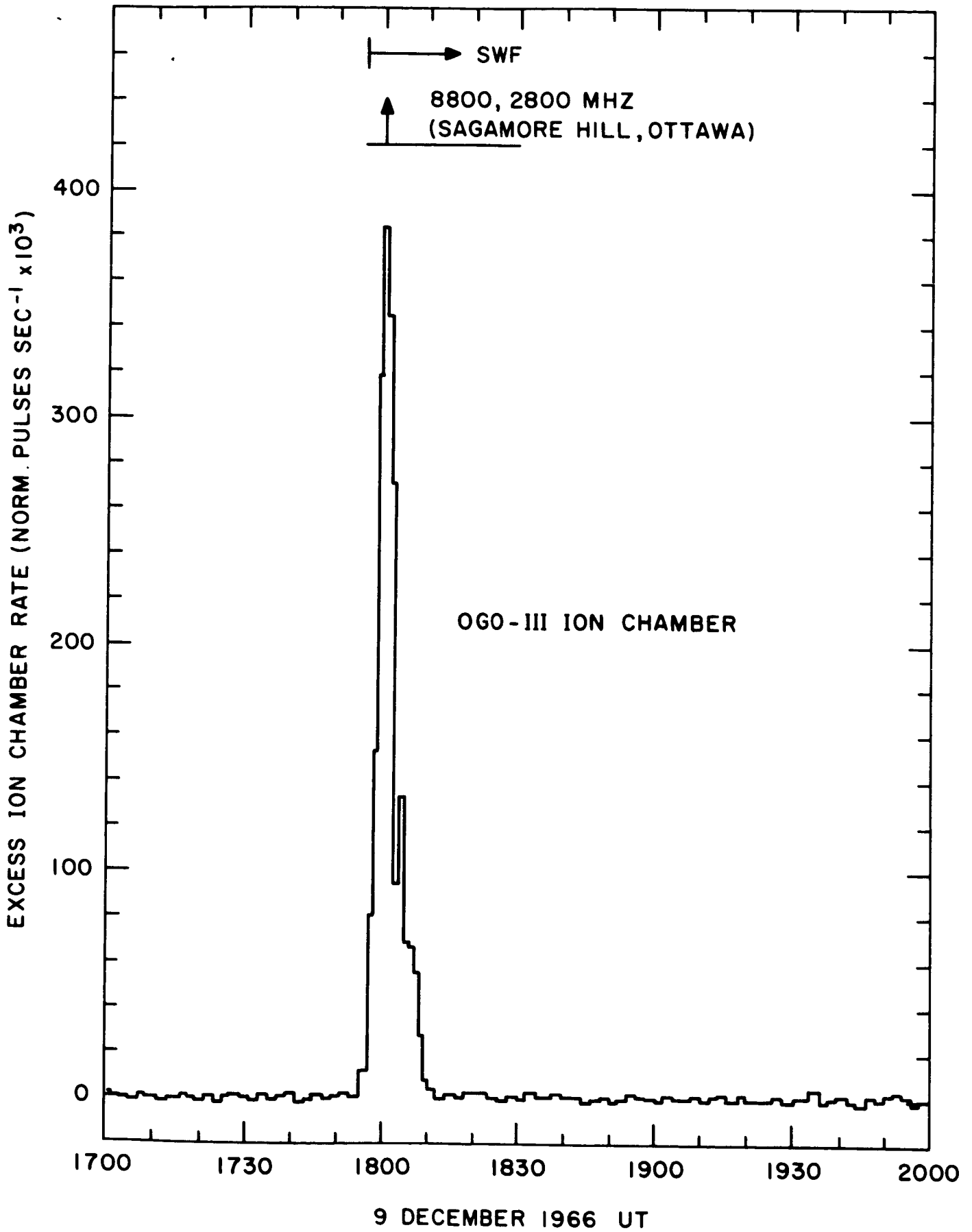


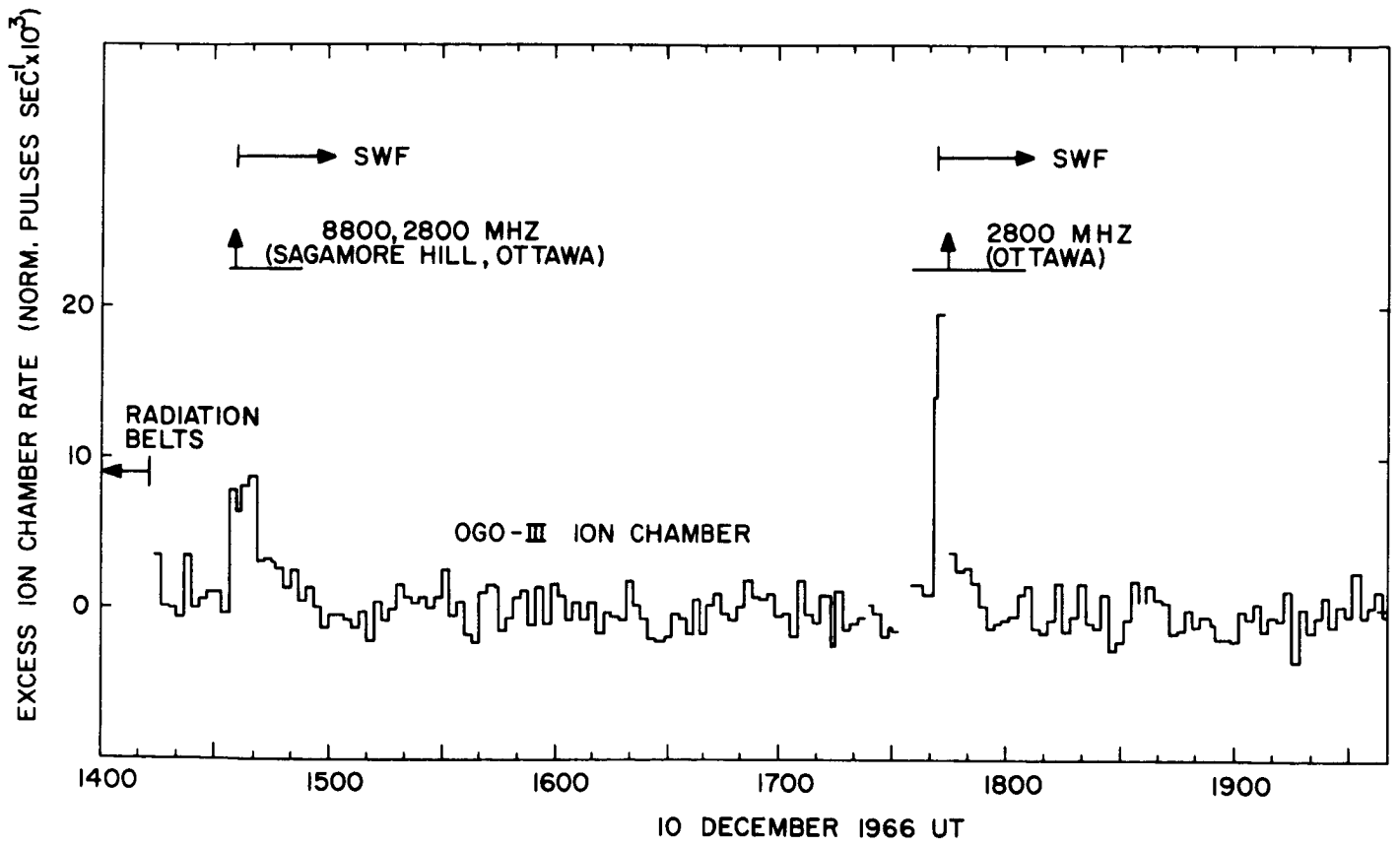


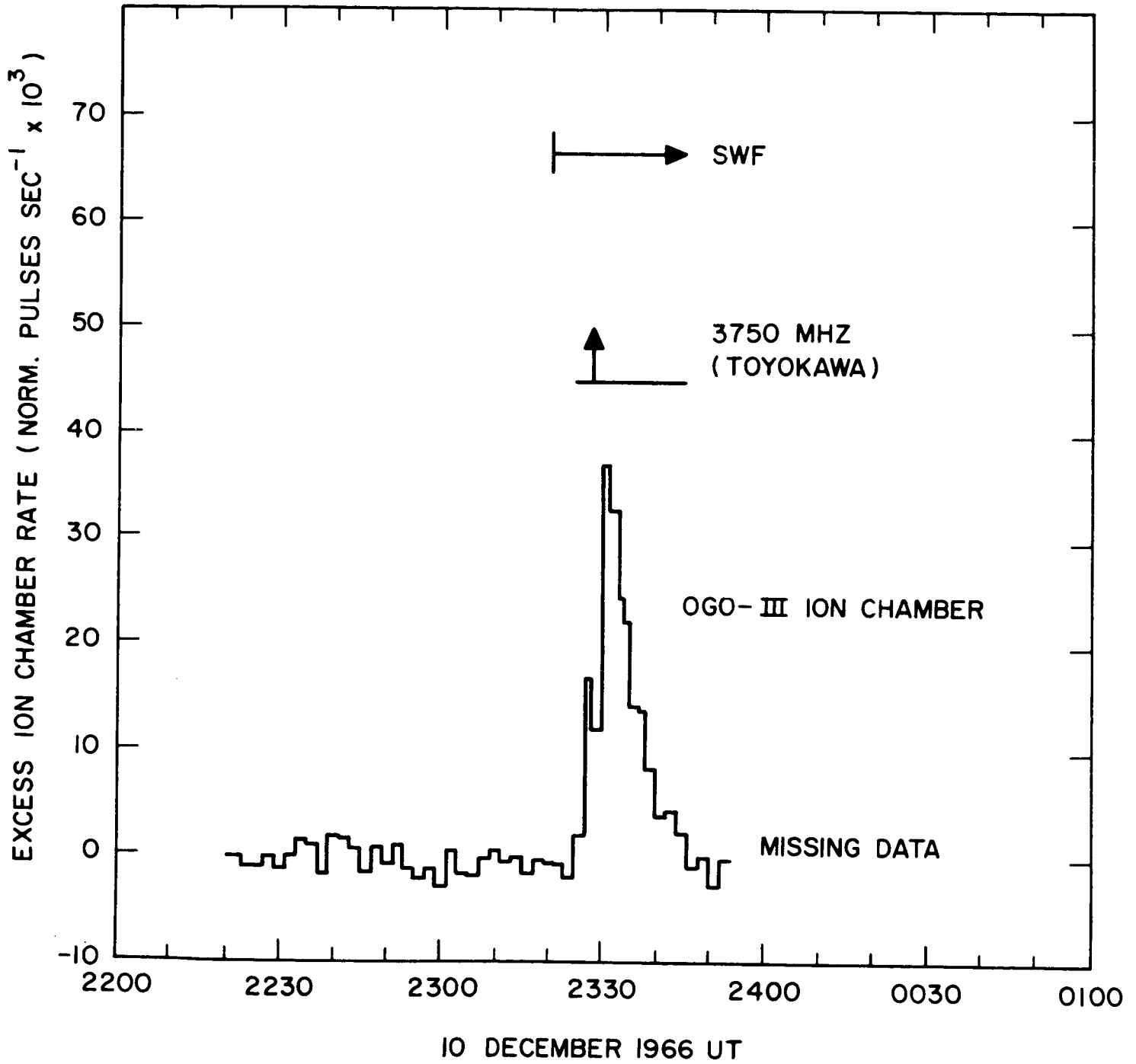


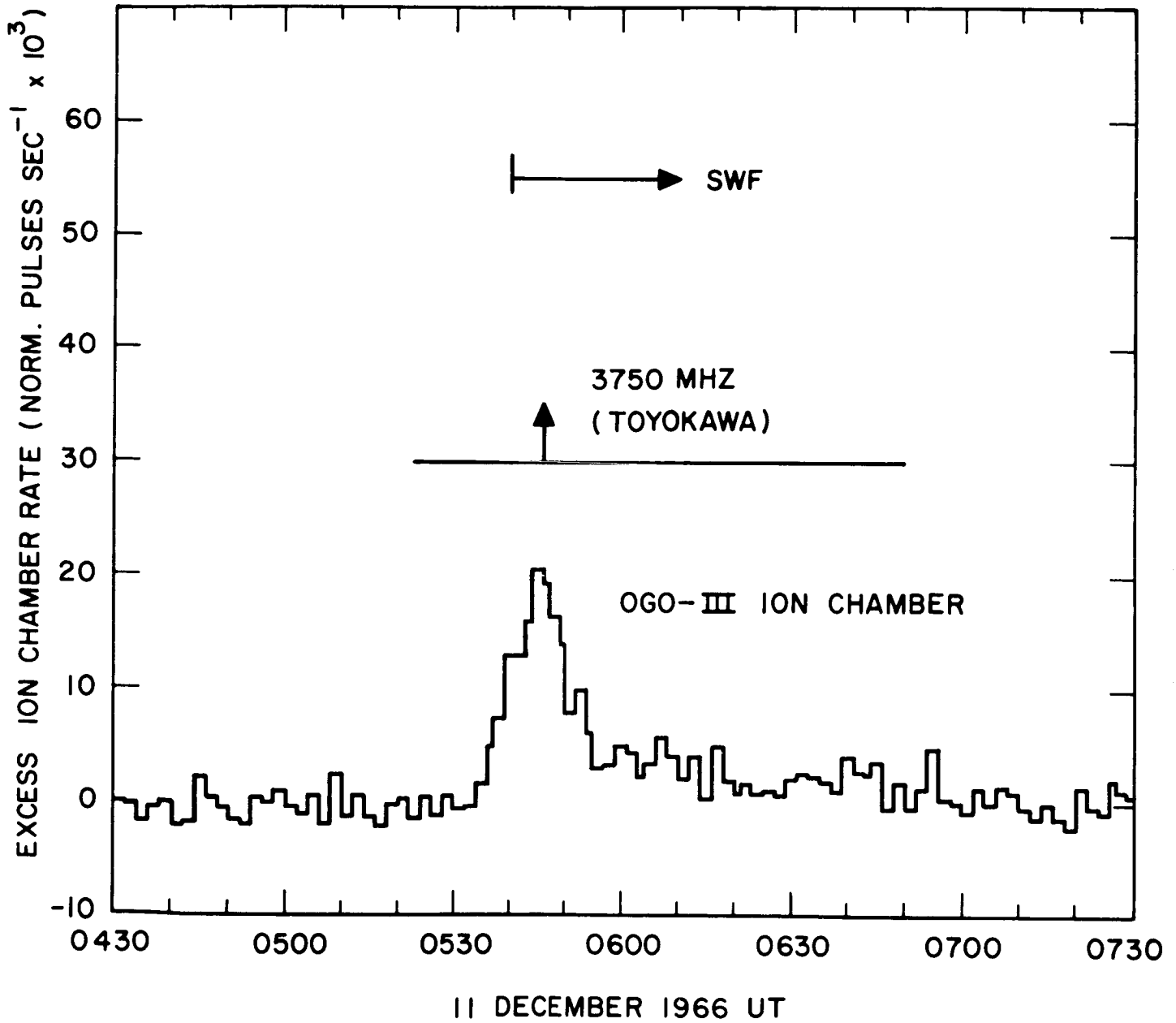


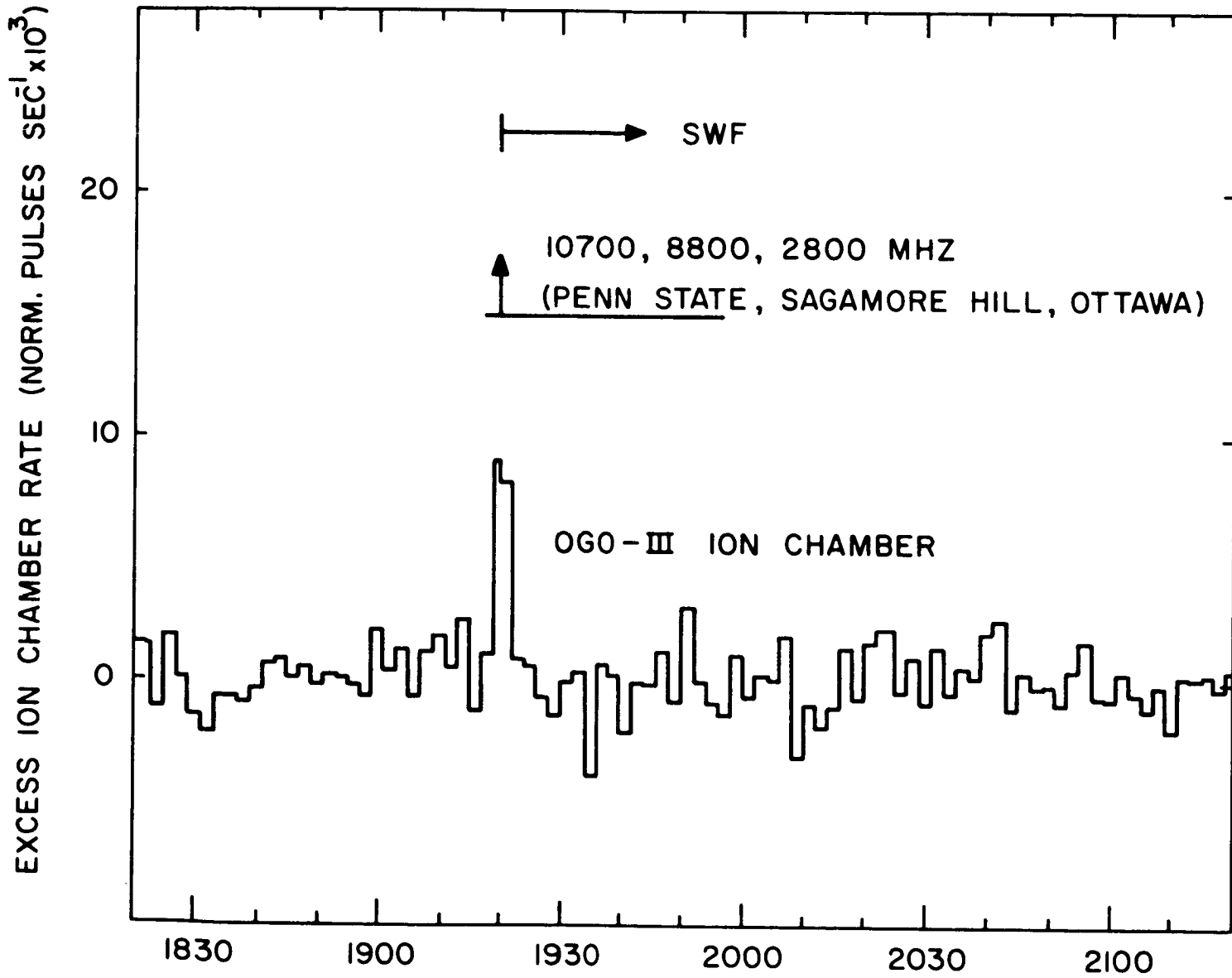




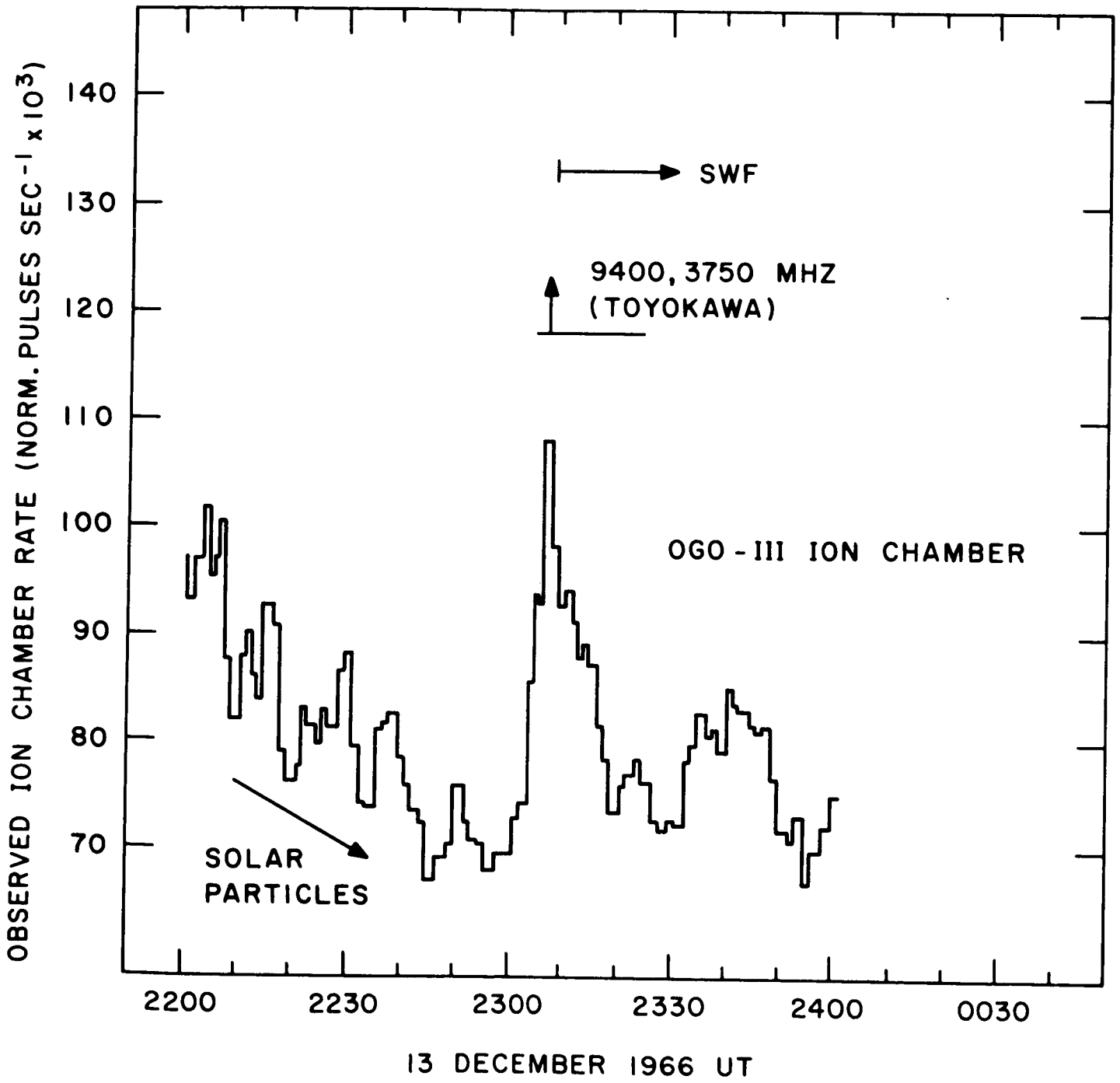


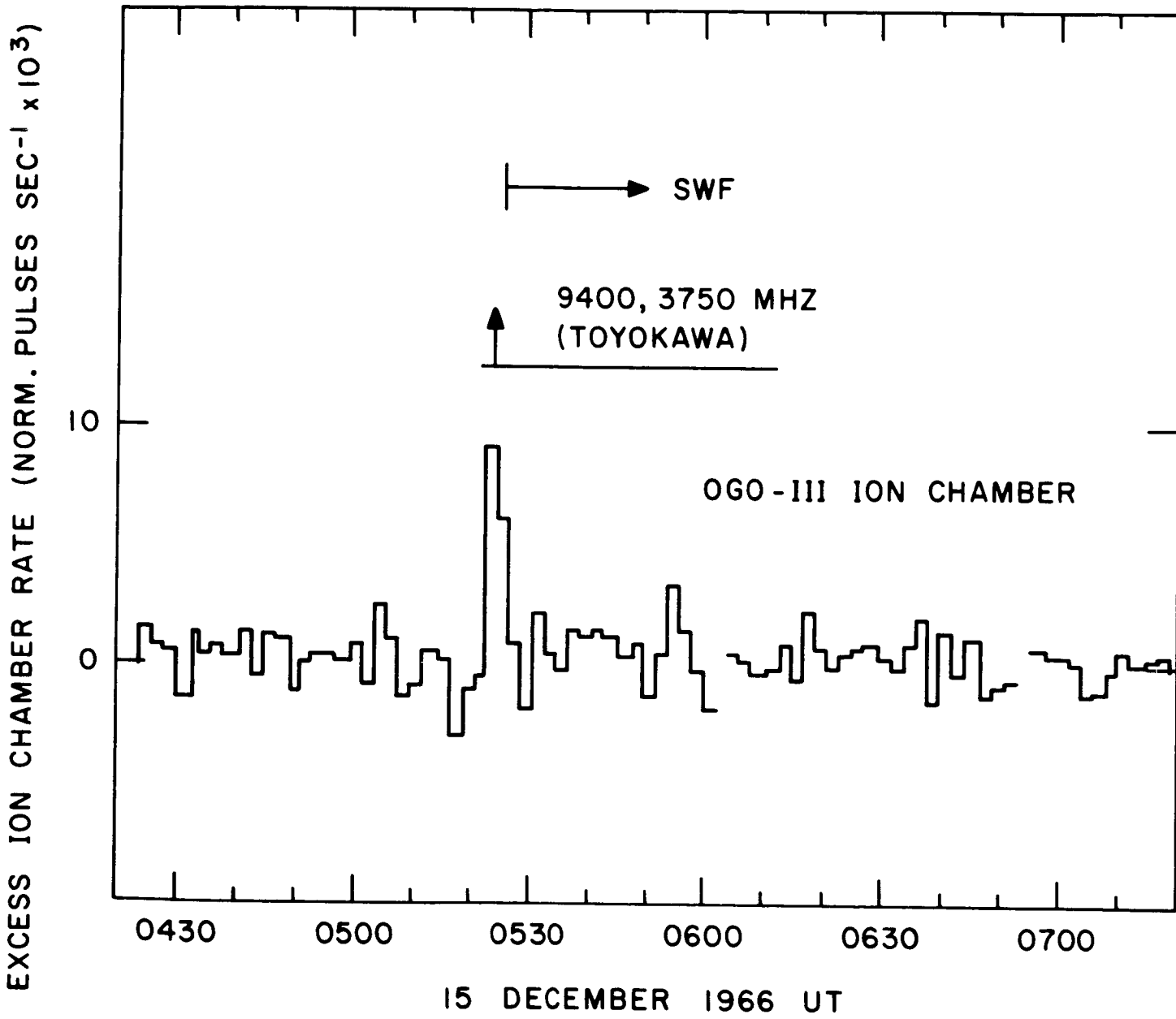


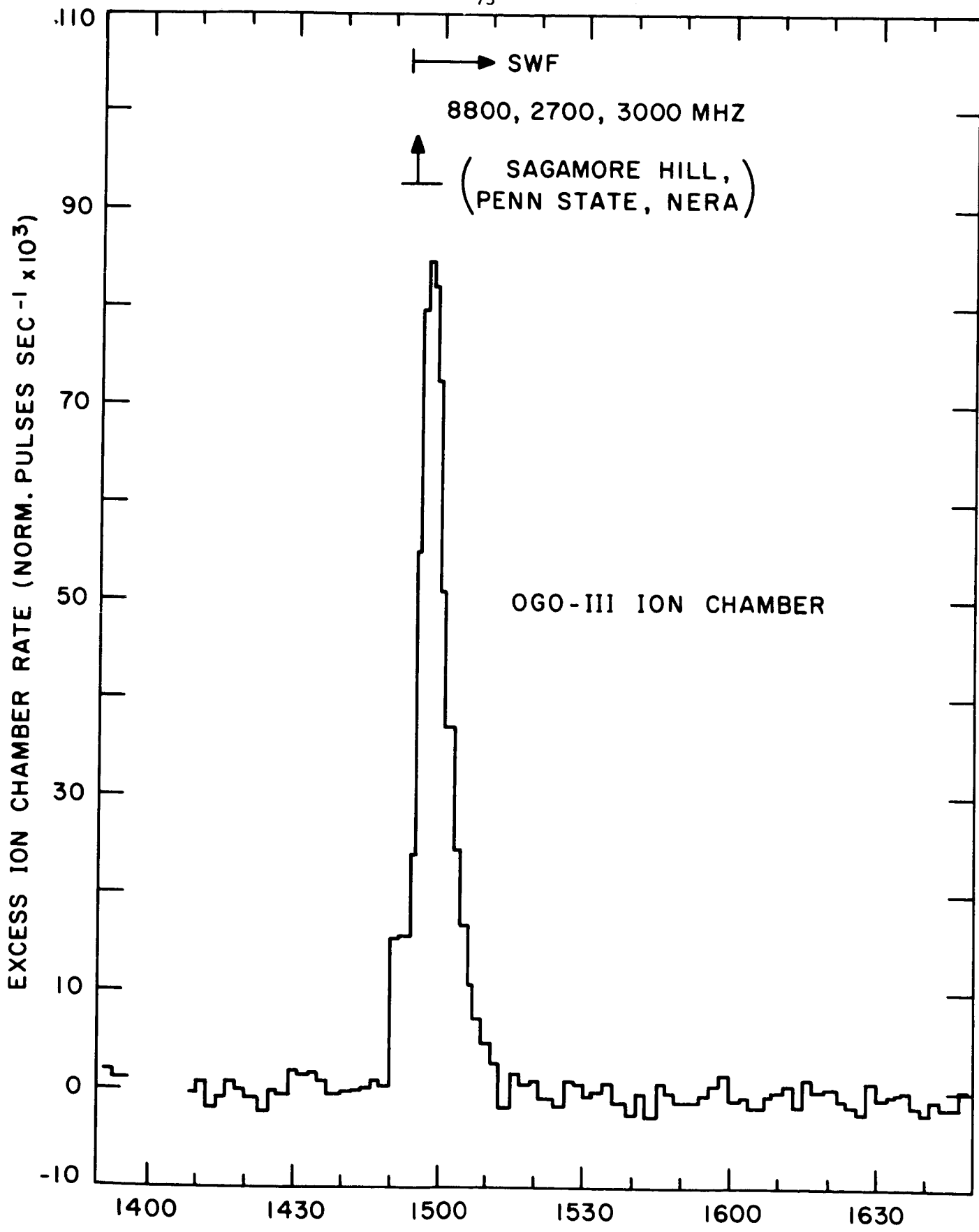


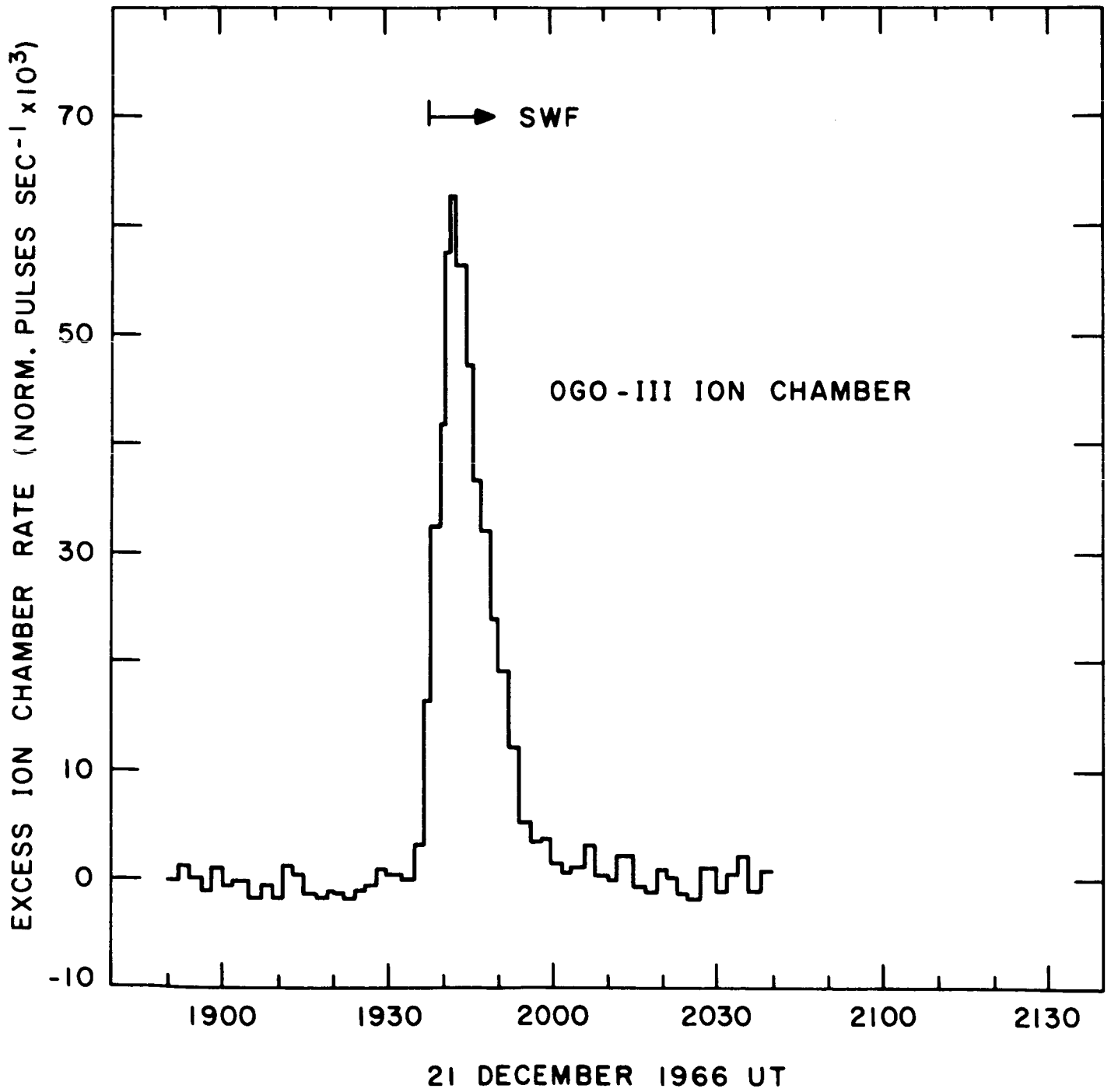


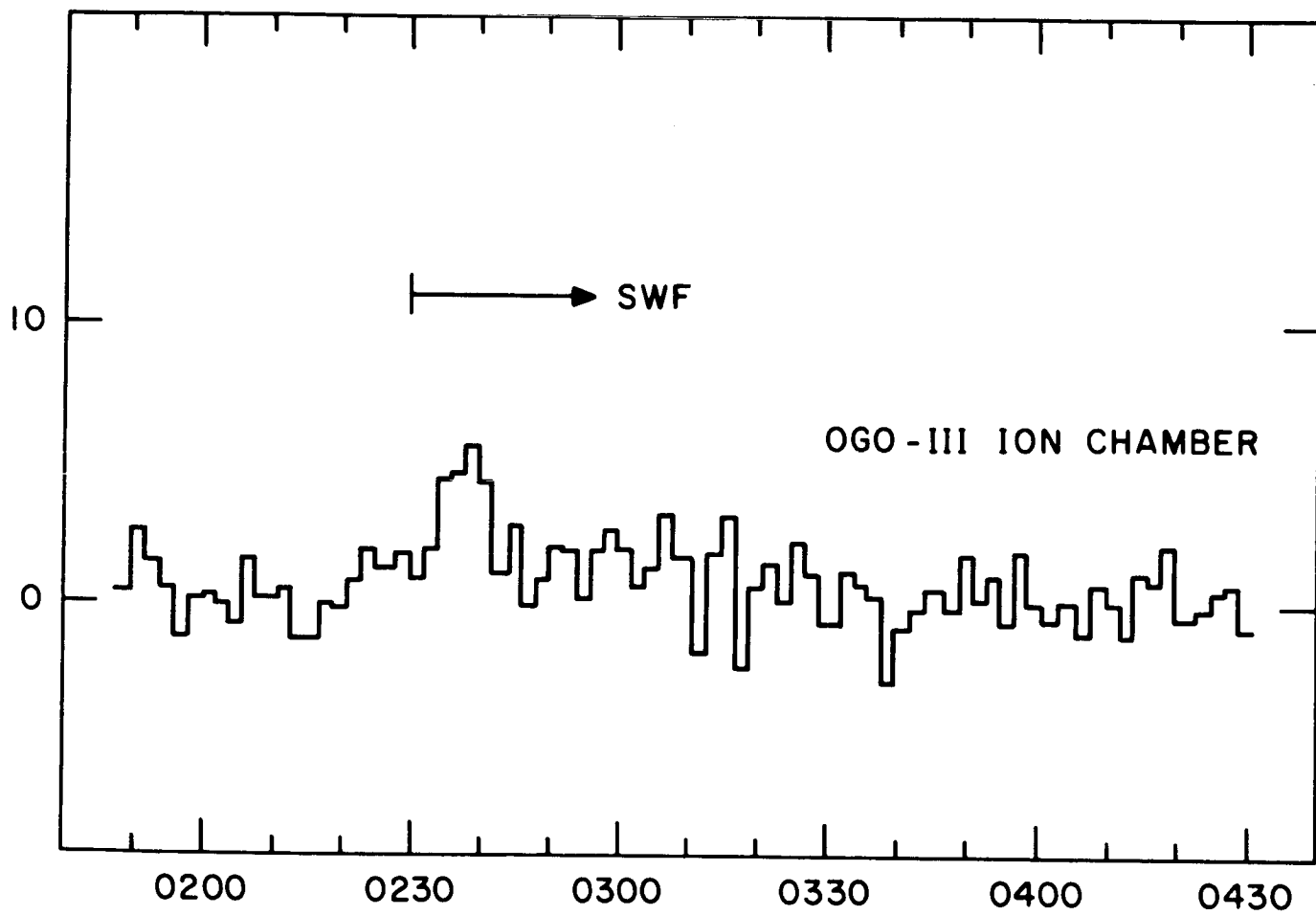
11 DECEMBER 1966 UT









EXCESS ION CHAMBER RATE (NORM. PULSES SEC⁻¹ x 10³)

23 DECEMBER 1966 UT

