## Solar and galactic cosmic rays and the interplanetary magnetic field 28 January - 25 February 1967.

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Abstract

Solar and galactic particle fluxes after the 28 January 1967 particle flare are discussed in relation to interplanetary field observations. A soft pre-event began at 0214 on 28 January. It shows modulation features carried by the solar wind from Explorer 33, 67 $R_E$ upstream, to IMP-3, 15 $R_E$ downstream from the earth. The interplanetary magnetic fiel shows a sudden, major change of direction in coincidence with the onset of the main event, which begins at 0835. New injections of energetic protons take place late on 2 and 13 February.

The enhanced diurnal variation seen by neutron monitors 31 January - 7 February coincides well with a two-fold increase in the magnitude of the interplanetary magnetic field. Several hours before a magnetic storm at the end of this period, the interplanetary magnetic field appears to be strongly squeezed; it enters the ecliptic plane from below at a theta-angle of 60° and with a magnitude of 10 gammas.



## Introduction

The 28 January 1967 particle flare has been discussed in several papers (Baird et al., 1967; Lockwood, 1968; Masley and Goedeke, 1968; Mathews and Wilson, 1968; Paulikas and

Blake, 1969). The most outstanding features of this event are: (1) the high particle fluxes at MeV energies; (2) essentially as a consequence of that, the long duration at MeV energies; (3) the lack of anisotropy at the onset; (4) the absence of a reasonable parent flare on the solar disk. Lockwood (1968) has suggested a flare site 60$^{\circ}$ beyond the west limb.

The purpose of the present paper is to present additional data on the 28 January event, mainly to add information on the small particle event which preceded the main event by 6 hours, and to look for interactions between the interplanetary magnetic field and the flux of low energy solar protons ($E > 0.5$ MeV).

<u>General characteristics of solar and galactic particle fluxes</u>

An overall picture of observed particle fluxes and the geomagnetic activity is given in Fig. 1. The low energy particle data come from K.A. Anderson's experiments on AIMP-1 (Explorer 33) and IMP-3. The pre-event can be seen most clearly in the IMP-3 "open" counter, which is a conventional Geiger counter. Unfortunately, the scale shows a rate which is 10 times too high. The count rate increases from 0.4 to 10 counts/sec and remains at the higher level for five hours until the main event brings the rate up to a maximum level well three orders of magnitude above the initial background rate. The characteristic decay time of the ion chamber pulse rate is close to 2 days during the first four days after the peak rate. Later in the event, 11 - 13 February, the decay time is much longer, close to six days. The top diagram shows that two particle increases are superimposed on the main event. The first additional event begins late on 2 February, the second event late on 13 February. The dashed lines are meant to show what the main event would have looked like without the two superimposed events. It is our definite impression that fluxes from the 28 January flare are still present at the end of the 13 February event, implying a total duration of three weeks.

The most outstanding feature in the galactic cosmic ray intensity, apart from the increase on 28 - 29 January, is the enhanced diurnal variation from 1 to 7 February (Venkatesan and Mathews, 1968; Hashim and Thambyahpillai, 1969), a period which is geomagnetically quiet and completely free from Forbush type modulations.

The interplanetary magnetic field.

Hourly averages of the interplanetary magnetic field are presented in Figs. 2-4. The field was measured by the AMES magnetometer experiment on Explorer 33 (Milhalov et al., 1968). The diagrams show three sets of data, with intermediate gaps due to perigee passes on 1-2 February and 14-15 February. Figure 2 shows magnitude and phi-angle in the solar equatorial system, Figure 3 magnitude and theta-angle.

From 0100 to 0900 on 28 January the field flows into the region observed by Explorer 33 from above the equatorial plane (theta $\sim -45^{\circ}$) and from a direction (phi $\sim 215^{\circ}$) perpendicular to the garden-hose angle (0700 in Fig. 2 should be 0100, as in Fig. 3). The field switches to a normal direction at the time when the pre-event is succeeded by the main event.

Figure 2 shows that there are several periods, lasting about a day, when the field is more or less perpendicular to the garden-hose direction (31 Jan. - 1 Feb., 7 Feb., 11-12 Feb., 15 Feb., 17 Feb.). There are also extended periods when the magnetic flux enters the equatorial plane from below at large theta-angles (7 Feb., 9-13 Feb.). During the first 15 hours of 7 February the field appears to be strongly squeezed: it comes up into the equatorial plane at a theta-angle of $\sim 60^{\circ}$ and is very strong ($\sim$ 10 gammas). An SSC is observed at the earth at 1636 UT (Fig. 4). After the SSC the field is roughly in the equatorial plane, although pointing in a strange direction (phi-angle $\sim 255^{\circ}$).

During the period 31 January - 8 February the field is roughly twice as strong as before and after this period (Fig. 4). The very strong field on 7-8 February should be related to the SSC at 1636 on 7 February. It is clear that this period of high field magnitudes coincides very well with a period of strongly enhanced diurnal variation. We feel that the strong magnetic field explains the enhanced diurnal amplitude in this case, since no modulation of the Forbush type is present to furnish an explanation in terms of a disturbed density distribution.

Some remarks on the solar particle fluxes.

The pre-event which begins at 0214 on 28 January is illustrated in Fig. 5. The "open" counter on IMP-3 is a conventional Geiger counter, which accepts protons >0.5 MeV and electrons >40 keV. The scatter counter is sensitive only to electrons >45 keV, scattered into the counter from a gold foil. Besides, both counters accept penetrating particles, protons >55 MeV and electrons >5 MeV. The IMP-3 ion chamber is sensitive to protons >15 MeV and electrons >1 MeV, the Explorer 33 chamber to protons >12 MeV and electrons >0.7 MeV.

It is possible to get a rough, qualitative picture of the spectrum of the observed solar particles by taking the ratio between the open and scatter counters. With only penetrating particles present, the ratio should be 1. A flux of sub-relativistic electrons only, E < 5 MeV, should give the ratio 19. Soft protons, E < 55 MeV, should increase the ratio to a very large value, since the scatter counter has a very low efficiency for such protons. As Figure 5 Shows, the pre-event is characterized by a ratio just below 15, a value which is reached very late during the main event, on 6 February (Fig. 6). At the time when sea level neutron monitors see the maximum relativistic proton flux, ~1100 UT on 28 January, the ratio is at its lowest value, < 3. What is seen during the pre-event appears to be sub-relativistic electrons, followed by protons.

As Figure 5 indicates, Explorer 33 seems to observe certain features 20 - 25 min before IMP-3. Explorer 33 is 82 $R_E$ or 522,500 km closer to the sun at this time, which leads to a solar wind velocity of 350 - 435 km/sec, a reasonable value.

The onset time of the main event is estimated to 0835 from the data shown in Fig. 5. The solar observatory at Culgoora observed a type II herringbone burst on the meter and decameter bands 0755 - 0855, of intensity 2 on the decameter band. If we assume that the scatter counter sees only protons at the time of maximum count rate, ~1800 on 28 January, we arrive at a maximum flux of 900 protons/cm$^2$ sec at E > 55 MeV.

Figure 6 shows a decrease in the ratio between the open and scatter counters late on 2 February, in coincidence with a rate increase in the open counter. This implies an additional injection of more energetic protons. The onset is gradual, ~1915 UT, and maximum intensity is reached five hours later by the Geiger counters.

The increase in the open counter 1500-1630 UT on 4 February is present also in the scatter counter but not in the ion chambers. The nature of this increase is not known.

On 5 February all detectors suffer a temporary reduction of the count rate. The decrease is sudden in the Geiger counters, where it occurs at 0348 UT, but very slow in the ion chambers, extending over > 3 hours. Complete recovery has taken place in all detectors at 2100 UT. The interplanetary field shows a complicated structure on 5 February (Fig. 2). At BeV energies the strong anisotropy disappears temporarily near midnight 4-5 February (Fig. 1; also Hashim and Thambyahpillai, 1969). The possibility of an interaction between the interplanetary medium and the cosmic rays cannot be excluded. High fluxes of soft protons are present before and after the SSC at 1636 on 7 February (Fig. 6). The same situation is repeated on 15-16 February (Fig. 1).

The only increase during this period which can be associated with a definite optical flare is the event at 1840 on 13 February, beyond any doubt due to an importance 3 flare at N21, W10.

<u>Acknowledgements</u>

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## References

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Figure Captions

Fig. 1. Flux of solar and galactic cosmic rays 28 Jan. - - 25 Feb. 1967. Scale of IMP-3 open counter shows rates 10 times too high. Sudden commencements in geomagnetic activity marked by wedges.

Fig. 2. Magnitude and phi-angle of interplanetary magnetic field observed on Explorer 33 by C.P. Sonett, AMES. Solar equatorial coordinates. Flags mark 2400 UT. (0700 on 28 Jan. should be 0100.)

Fig. 3. Magnitude and theta-angle of interplanetary magnetic field observed on Explorer 33. Solar equatorial coordinates. Flags mark 2400 UT.

Fig. 4. This figure shows that a period of enhanced diurnal variation closely coincides with a twofold increase in the strength of the interplanetary magnetic field.

Fig. 5. Detailed time profiles of pre-event, beginning at 0214 on 28 January. Certain features appear 20 - 25 min earlier at Explorer 33, 82 $R_E$ closer to the sun than IMP-3. Ratio at bottom reflects hardening of spectrum when main event begins.

Fig. 6. Illustrates how particle injections on 28 Jan. and 2 Feb. reduce ratio between open and scatter counters. High ratios 7 - 8 Feb. indicate fluxes of soft protons before and after SSC.

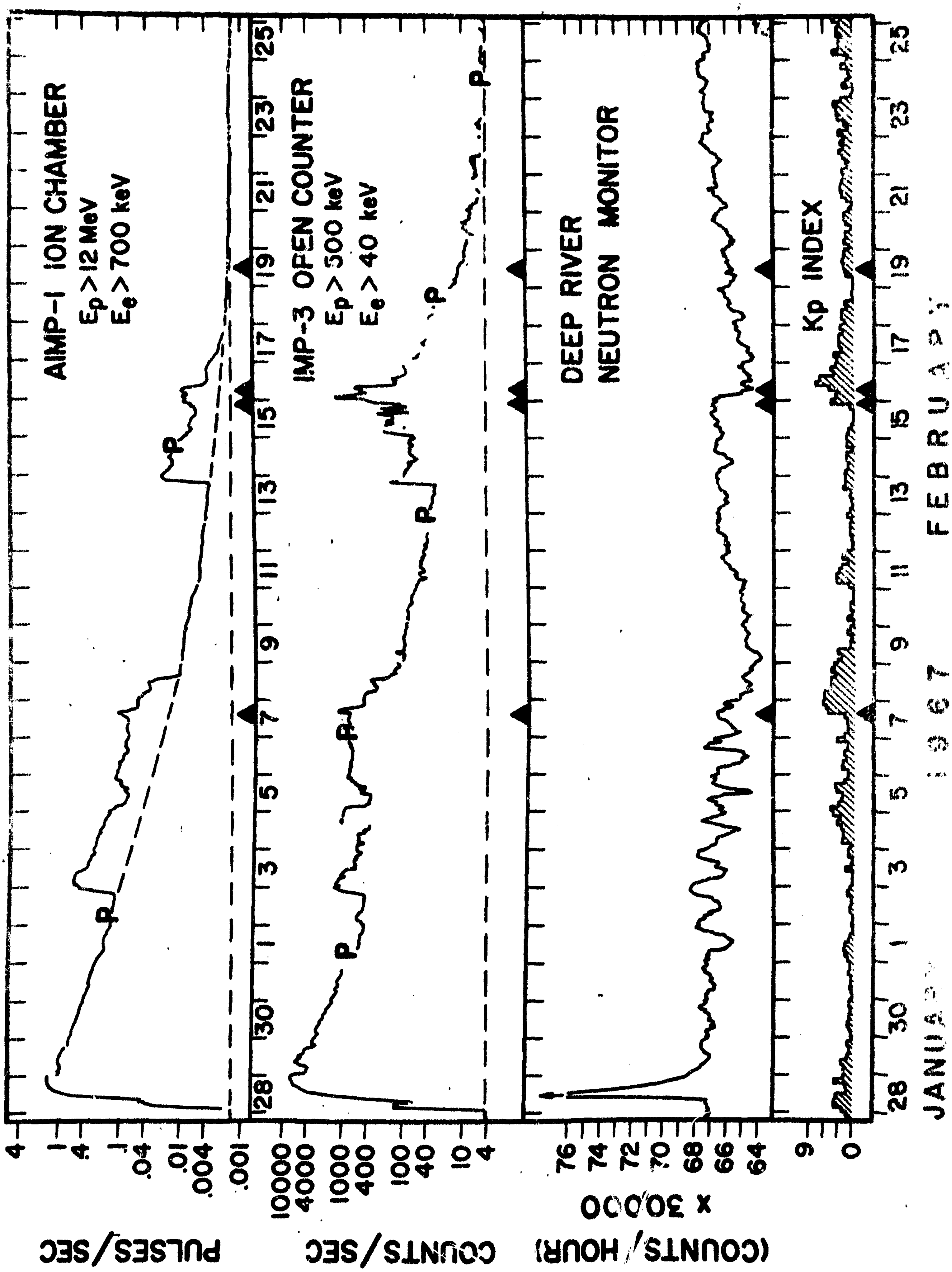

AIMP-I ION CHAMBER
$E_p > 12$ MeV
$E_e > 700$ keV
IMP-3 OPEN COUNTER
$E_p > 500$ keV
$E_e > 40$ keV
DEEP RIVER
NEUTRON MONITOR
Kp INDEX
PULSES/SEC
COUNTS/SEC
(COUNTS/HOUR)
x 30,000
FEBRUARY
JANUARY
1967
P

Fig. 1

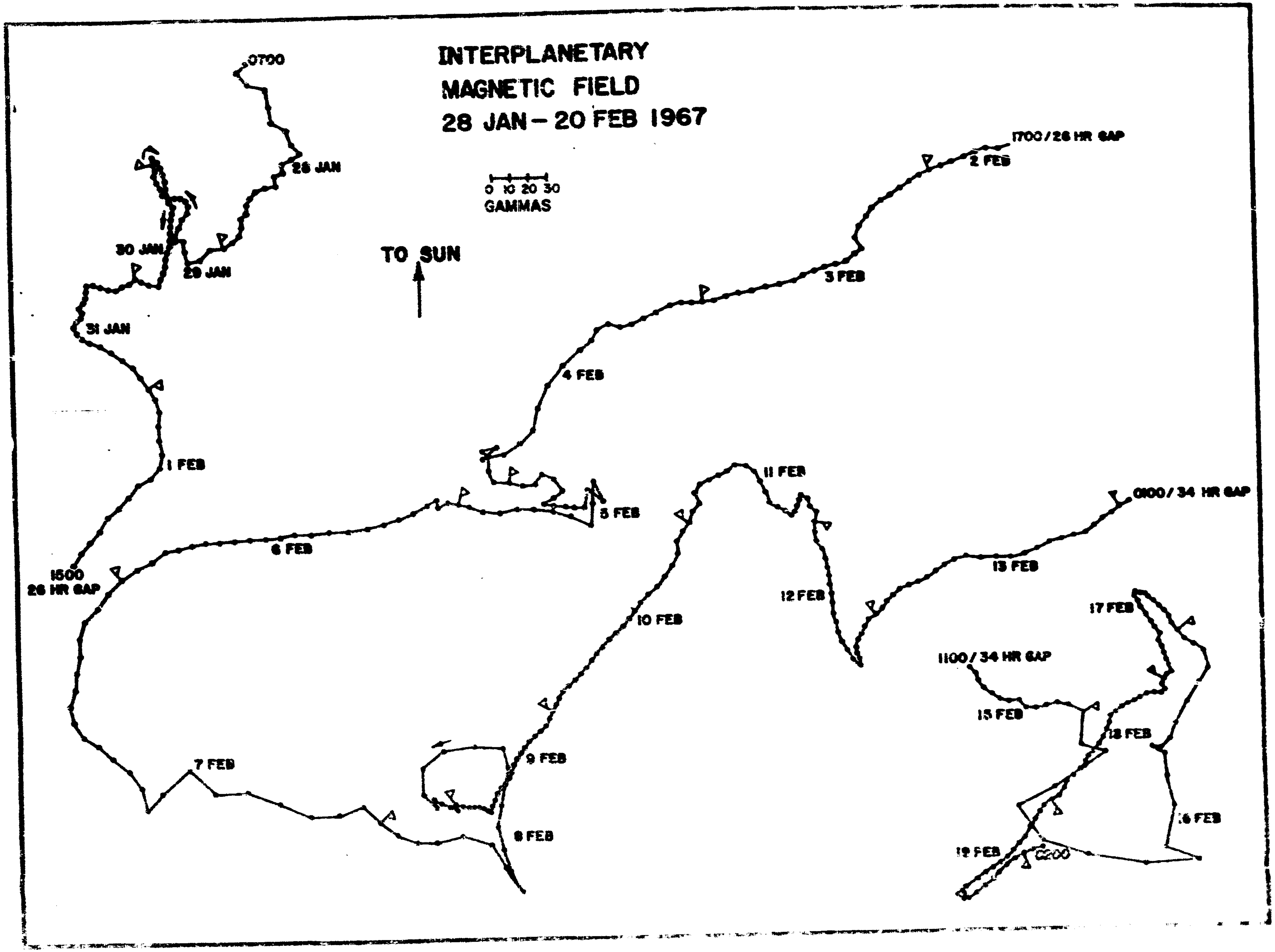

INTERPLANETARY
MAGNETIC FIELD
28 JAN – 20 FEB 1967
0 10 20 30
GAMMAS
TO SUN
0700
28 JAN
29 JAN
30 JAN
31 JAN
1 FEB
1500
26 HR GAP
1700/26 HR GAP
2 FEB
3 FEB
4 FEB
5 FEB
6 FEB
7 FEB
8 FEB
9 FEB
10 FEB
11 FEB
12 FEB
13 FEB
0100/34 HR GAP
1100/34 HR GAP
15 FEB
16 FEB
17 FEB
18 FEB
19 FEB
0200

Fig.

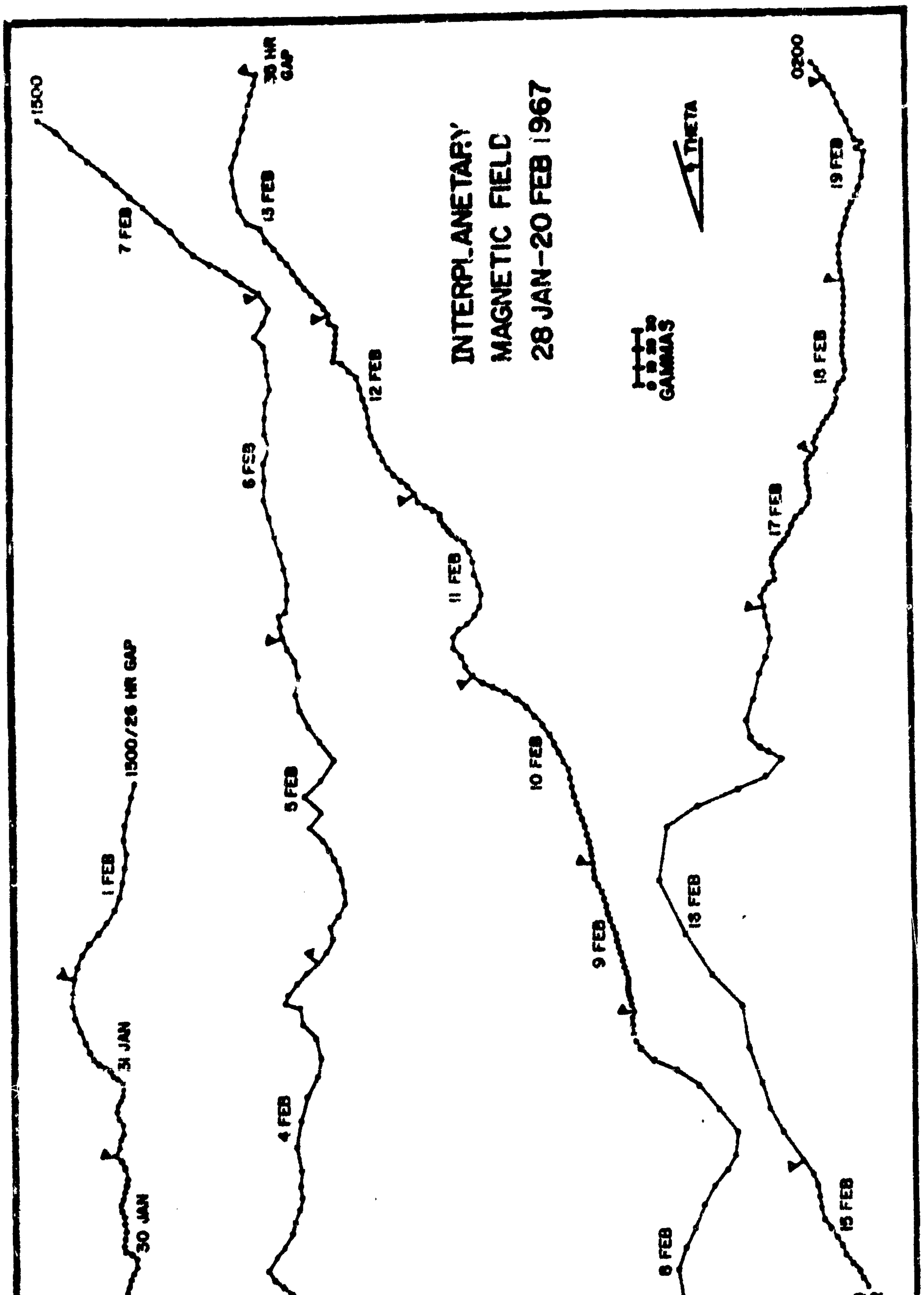
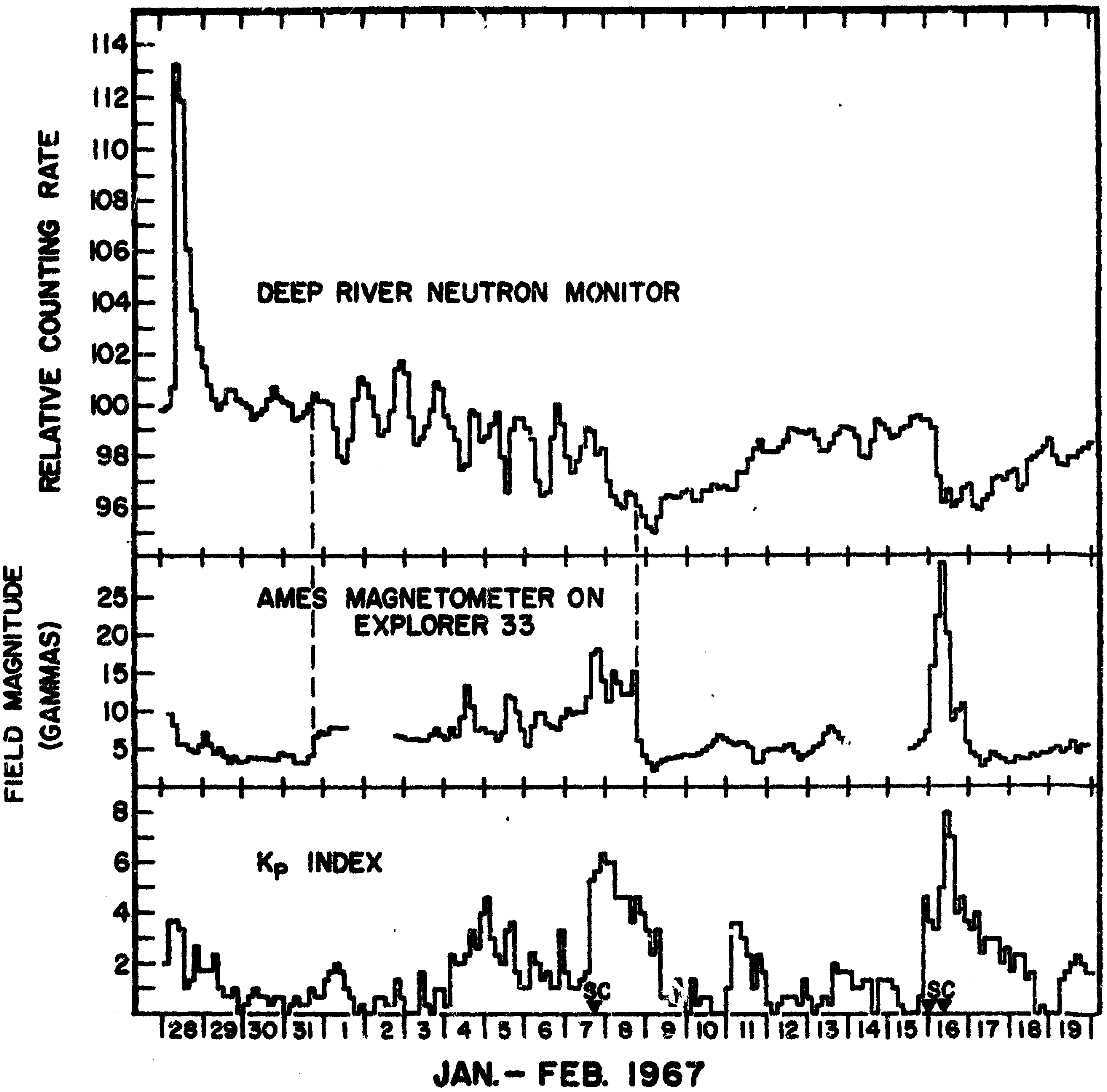
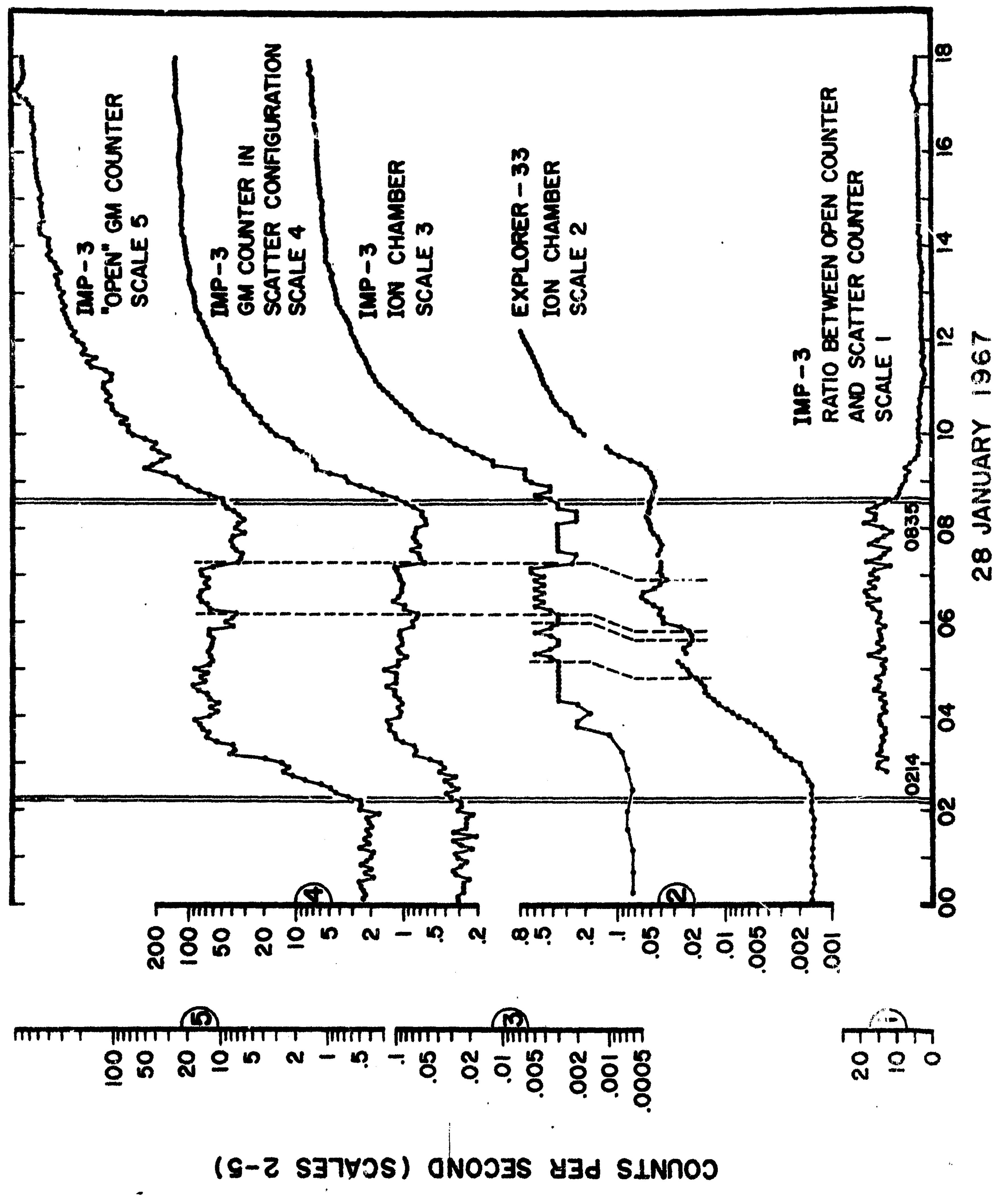

INTERPLANETARY
MAGNETIC FIELD
28 JAN-20 FEB 1967
THETA
GAMMAS
0100
28 JAN
29 JAN
30 JAN
31 JAN
1 FEB
1500/26 HR GAP
1700
26 HR
GAP
3 FEB
4 FEB
5 FEB
6 FEB
7 FEB
1500
8 FEB
9 FEB
10 FEB
11 FEB
12 FEB
13 FEB
35 HR
GAP
1100
35 HR
GAP
15 FEB
16 FEB
17 FEB
18 FEB
19 FEB
0200

Fig. 3



RELATIVE COUNTING RATE
DEEP RIVER NEUTRON MONITOR
114
112
110
108
106
104
102
100
98
96
FIELD MAGNITUDE (GAMMAS)
AMES MAGNETOMETER ON EXPLORER 33
25
20
15
10
5
$K_p$ INDEX
8
6
4
2
SC
SC
28 29 30 31 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
JAN.– FEB. 1967


Fig. 4



IMP-3
"OPEN" GM COUNTER
SCALE 5
IMP-3
GM COUNTER IN
SCATTER CONFIGURATION
SCALE 4
IMP-3
ION CHAMBER
SCALE 3
EXPLORER-33
ION CHAMBER
SCALE 2
IMP-3
RATIO BETWEEN OPEN COUNTER
AND SCATTER COUNTER
SCALE 1
0214
0835
00 02 04 06 08 10 12 14 16 18
28 JANUARY 1967
200 100 50 20 10 5 2 1 .5 .2
.8 .5 .2 .1 .05 .02 .01 .005 .002 .001
100 50 20 10 5 2 1 .5 .1 .05 .02 .01 .005 .002 .001 .0005
20 10 0
COUNTS PER SECOND (SCALES 2-5)


Fig. 5

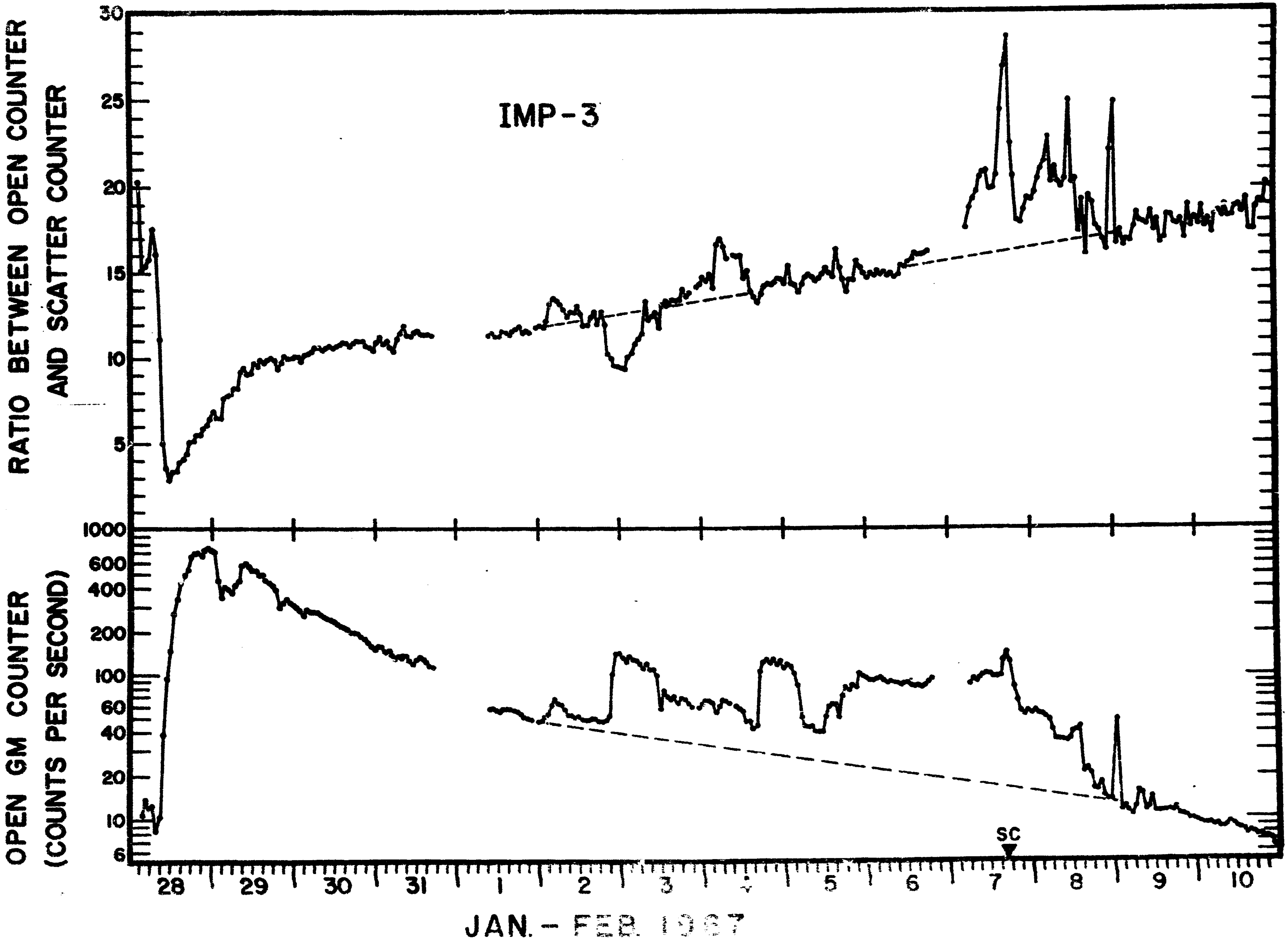

IMP-3
RATIO BETWEEN OPEN COUNTER AND SCATTER COUNTER
OPEN GM COUNTER (COUNTS PER SECOND)
30
25
20
15
10
5
1000
600
400
200
100
60
40
20
10
6
SC
28
29
30
31
1
2
3
4
5
6
7
8
9
10
JAN. - FEB. 1967

Fig.