SMC-TR-96-9

AEROSPACE REPORT NO.
TR-94(4940)-6

Specification of the Plasma Environment at Geosynchronous Orbit in the Energy Range 87 eV to 288 keV

15 August 1994

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Leslie Belsma, Maj. USAF
SMC/CIB

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)

2. REPORT DATE
15 August 1994

3. REPORT TYPE AND DATES COVERED

4. TITLE AND SUBTITLE
Specification of the Plasma Environment at Geosynchronous Orbit in the Energy Range 87 eV to 288 keV

5. FUNDING NUMBERS
F04701-93-C-0094

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
The Aerospace Corporation
Technology Operations
El Segundo, CA 90245-4691

8. PERFORMING ORGANIZATION REPORT NUMBER
TR-94(4940)-6

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Space and Missile Systems Center
Air Force Materiel Command
2430 E. El Segundo Boulevard
Los Angeles Air Force Base, CA 90245

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
SMC-TR-96-9

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT (*Maximum 200 words*)

The particle measurements by the P78-2 SCATHA satellite at near-geosynchronous altitudes have been analyzed to obtain average electron and proton fluxes in the energy range 87 eV to 288 keV. The variation of the fluxes about the average values is also reported and the average fluxes are compared to those measured during an intense spacecraft charging event on September 22, 1982. These calculations provide a representation of the plasma environment, which can be used to quantify the surface charging of spacecraft materials in geosynchronous orbit.

14. SUBJECT TERMS
Spacecraft charging, Magnetosphere, Plasma

15. NUMBER OF PAGES
13

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	

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Spacecraft in geosynchronous orbit may sometimes experience problems of differential electrical charging due to the ambient plasma environment.[1] The charging phenomena are of two distinct types: surface charging and bulk charging. Surface charging of spacecraft materials is caused primarily by electrons in the energy range from a few keV to several tens of keV. Bulk charging is caused by electrons with energies of a few hundred keV to 1.5 MeV. This report will focus on the lower energy plasma responsible for surface charging using measurements from the P78-2 SCATHA satellite.[2]

In order to mitigate problems due to spacecraft charging it is useful to characterize the plasma environment as accurately and completely as possible. In a previous report the average plasma environment was analyzed using data in the energy range 87 eV - 19.2 keV.[3] In the present work this energy range has been extended upward to 288 keV for electrons and 526 keV for protons by combining the data from several instruments on the SCATHA satellite. The average particle fluxes were also compared to measurements taken during an extremely intense spacecraft charging event on September 22, 1982.

Using a large amount of the SCATHA data set for this study would entail prohibitive computational costs. Instead, two one-week periods in 1979 were selected as having a "representative" level of geomagnetic activity. Averages of the flux at each of the thirteen energy levels were computed of the data for each of these days. Only data from intervals in which the satellite was inside the plasma sheet near geosynchronous altitudes were used for the averages. The average value of flux at each energy was then calculated for the fifteen days and the variation of the data about the average was estimated.

Figure 1 shows the differential electron flux as a function of energy. The thirteen channels in the energy range 87 eV - 19.4 keV were computed using the data from the SC2 instrument and the twelve points in the energy range 57-288 keV were derived from the SC3 data. The squares mark the average of the values observed during the selected fifteen days. Fifteen data points do not comprise a set which is sufficiently large to estimate accurately the true standard deviation. As an alternative to the standard deviation, the heights of the error bars represent the maximum and minimum values of the flux during the fifteen days. The variations of the electron flux are observed to exceed an order of magnitude for almost all energies in the measured range. The dotted line represents the flux observed by the same instruments during the "worst case" charging event of September 22, 1982. The flux during that event exceeds the 15-day maximum at energies in the range 50-150 keV and is less than or equal to the maximum outside this range. The decrease in flux at the energies below 2 keV is probably an effect of a large negative charge on the surface of the spacecraft during the 1982 event. Such a negative charge would repel electrons from the detector, causing an underestimate of the flux.

The total electron flux integrated over all energies during the charging event of September 22, 1982 were less than the maximum flux observed during the fifteen days studied in this work. Yet the spacecraft experienced a large amount of differential surface charging and discharges.[4] The reason for the charging in this particular instance is the anomalously high fluxes of electrons at energies above 20 keV.

Figure 2 shows the averages and variations of the proton differential flux for the same fifteen days that were used for the electron measurements. The variations of the proton flux are approximately a factor of 3-5 at low energies, which is somewhat smaller than the variations of the electron flux. The proton flux observed during the September 22, 1982 event are larger than the 15-day maximum at all energies outside the range 10-20 keV. Note the increase in the proton flux at energies below 500 eV for the 1982 case, which is due to the negative charge of the spacecraft accelerating protons into the detector.

The distribution functions for electron and protons are shown in Figures 3 and 4, respectively. These were computed by dividing the flux by the energy. As in Figures 1-2, the squares and error bars represent the averages and variations measured during the fifteen days that were selected for study. The dotted lines in Figures 3-4 show the distribution functions of the particles during the worst case charging event.

The electron and proton spectrum observed during the September 22, 1982 event have been subjected to further analysis because this event represents a "worst case" to test the susceptibility of space systems to charging phenomena. Such testing uses one of two methods: actual irradiation of a prototype with a similar particle spectrum using an accelerator, or computer modelling of the charging of the system with the NASCAP program. The NASCAP program requires that the electron distribution function be specified by either a single or double Maxwellian model fit to the data, or as a table of the particle distribution as a function of energy.[5, 6] The proton distribution is much less important for spacecraft surface charging so it is usually not specified.

Trial fits of the electron data during this event using a single Maxwellian have shown the such a model is grossly incapable for representing the spectrum during a charging event. The difference between a non-charging environment and and charging environment is most prominent in the energy range from 10 keV to 200 keV. A single Maxwellian model has extreme difficulty in accurately fitting the data in just this range of energy. Such an environment is usually represented by a two component Maxwellian model, which is sometimes called a double Maxwellian[5]. The double Maxwellian model of electrons may be written as a function of the electron kinetic energy:

$$f(E) = 10^{24}\left(\frac{m}{2\pi D}\right)^{3/2}\left[\left(\frac{N_1}{T_1^{3/2}}\right)\exp\left(-\frac{E}{T_1}\right) + \left(\frac{N_2}{T_2^{3/2}}\right)\exp\left(-\frac{E}{T_2}\right)\right],$$

where f = particle distribution function in units of $s^3\ km^{-6}$,

E = kinetic energy of the particle in keV,

m = mass of the electron, 9.11×10^{-31} kg,

D = energy conversion factor, 1.6×10^{-16} Joules/keV,

N_i = number density for the i^{th} component in units of cm^{-3}, where $i = 1$ and 2,

T_i = temperature of i^{th} component in units of keV, where $i = 1$ and 2.

Note that the extra factor of 10^{24} results from the conversion of the length units into kilometers. The electron data from the September 22 event is well represented by a double Maxwellian model using the parameters listed in Table 1. Figure 5 shows that the fit of this model to the measured electron distribution function is excellent. The range of validity of the model extends over the entire energy range of the data: 87 eV - 288 keV. The model parameters of Table 1 may be used as input to the NASCAP code, or alternatively, the values of the distribution function listed in Tables 2 may be used for that purpose. The proton data is shown in Table 3 for completeness. Tables 2 and 3 also show the actual measured values of the particle number flux as a function of energy. The fluxes listed in Tables 2 and 3 may be used as a specification of the particle spectrum for testing using an accelerator. A simple conversion can be used to convert the fluxes to values of the distribution function for both electrons and protons:

$$f_e = 1.616 \times 10^{-7} \; (J_e / E),$$

$$f_p = 5.449 \times 10^{-1} \; (J_p / E),$$

where f_e and f_p are the distribution functions of electrons and protons in units of s^3 km^{-6}, J_e and J_p are the number fluxes of electrons and protons in units of s^{-1} cm^{-2} sr^{-1} kev^{-1}, respectively, and E is the energy of the measurement in keV.

Figure 6 compares this model with two other models of the electron distribution used for spacecraft charging studies. The dashed line in Figure 6 represents the model of the average electron distribution reported by Purvis[5]. Over most of the energy range it falls below the data of September 22 shown as the solid line. The dotted line shows a distribution measured on April 24, 1979 by SCATHA, which was proposed by Gussenhoven and Mullen[7, 5] to be a "worst case". Figure 6 clearly shows that the two distributions are comparable at energies above 10 keV, but that the September 22, 1982 case has a significant excess of electrons in the 1-10 keV range.

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Table 1. Electron Distribution Model
September 22, 1982

	Component 1	Component 2
ne (cm^{-3})	2.67	0.625
Te (keV)	3.1	25.1

Table 2. SCATHA Electron Data
September 22, 1982

Energy keV	f_e $s^3\ km^{-6}$	Flux $s^{-1}\ cm^{-2}\ sr^{-1}\ kev^{-1}$
0.087	1.32×10^2	7.10×10^7
0.187	2.66×10^1	3.08×10^7
0.316	1.86×10^1	3.63×10^7
0.446	1.59×10^1	4.39×10^7
0.815	1.04×10^1	5.23×10^7
1.09	7.48×10^0	5.04×10^7
1.94	5.34×10^0	6.41×10^7
2.58	4.03×10^0	6.43×10^7
4.52	1.88×10^0	5.25×10^7
5.9	1.07×10^0	3.90×10^7
10.95	2.95×10^{-1}	2.00×10^7
14.4	2.69×10^{-1}	2.40×10^7
19.4	1.42×10^{-1}	1.70×10^7
57.	9.73×10^{-3}	3.43×10^6
77.	6.50×10^{-3}	3.10×10^6
98.	4.06×10^{-3}	2.46×10^6
119	1.51×10^{-3}	1.11×10^6
140.	1.63×10^{-4}	1.41×10^5
161.	9.56×10^{-5}	9.52×10^4
182.	6.15×10^{-5}	6.92×10^4
203.	3.66×10^{-5}	4.59×10^4
224.	3.37×10^{-5}	4.67×10^4
245.	1.76×10^{-5}	2.67×10^4
267.	1.26×10^{-5}	2.08×10^4
288.	1.01×10^{-5}	1.80×10^4

Table 3. SCATHA Proton Data

September 22, 1982

Energy keV	f_p $s^3\,km^{-6}$	Flux $s^{-1}\,cm^{-2}\,sr^{-1}\,kev^{-1}$
0.074	3.24×10^7	4.40×10^6
0.154	8.00×10^6	2.26×10^6
0.255	3.48×10^6	1.63×10^6
0.36	1.30×10^6	8.59×10^5
0.655	6.83×10^5	8.21×10^5
0.88	4.70×10^5	7.59×10^5
1.55	2.50×10^5	7.12×10^5
2.06	1.66×10^5	6.29×10^5
3.6	8.36×10^4	5.52×10^5
4.8	5.66×10^4	4.99×10^5
8.8	2.55×10^4	4.12×10^5
11.6	1.33×10^4	2.84×10^5
15.6	1.03×10^4	2.94×10^5
19.	6.76×10^3	2.36×10^5
36.	1.86×10^3	1.23×10^5
71.	6.35×10^2	8.27×10^4
133	7.05×10^1	1.72×10^4
262.	2.85×10^0	1.37×10^3
566.	5.47×10^{-2}	5.68×10^1

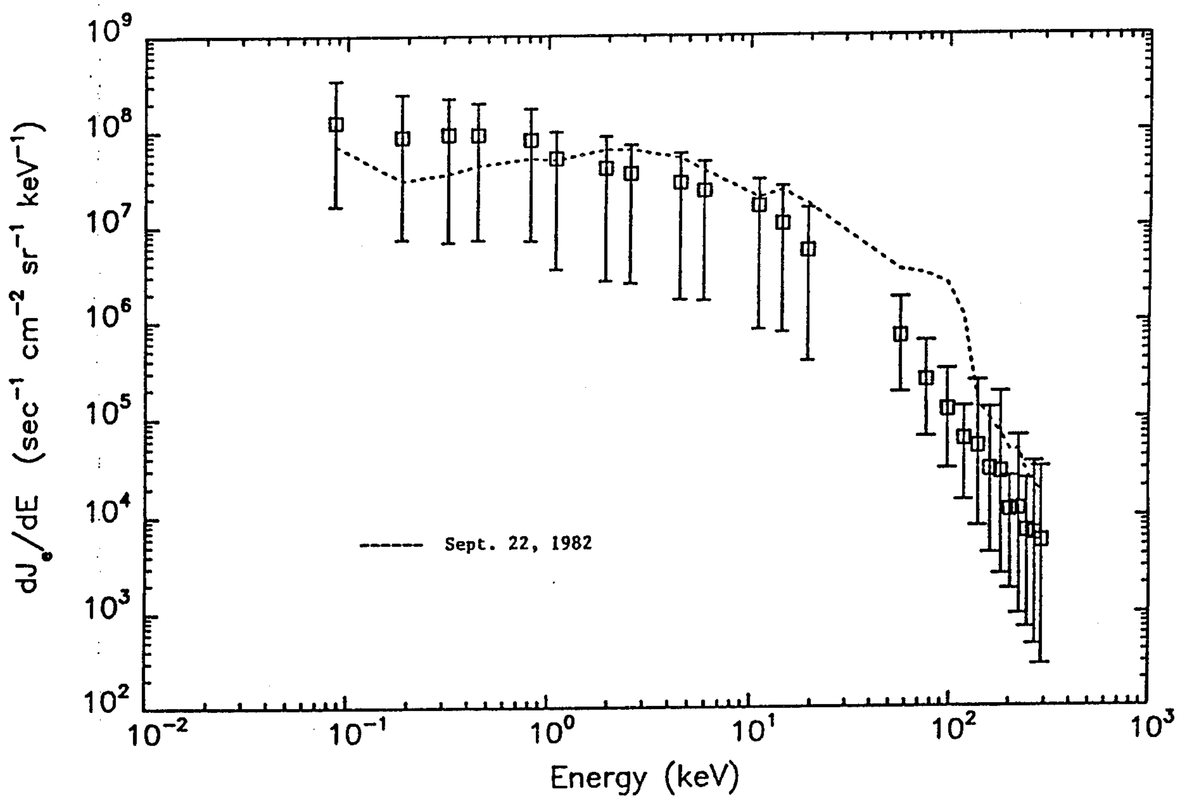

Figure 1. Electron differential flux.

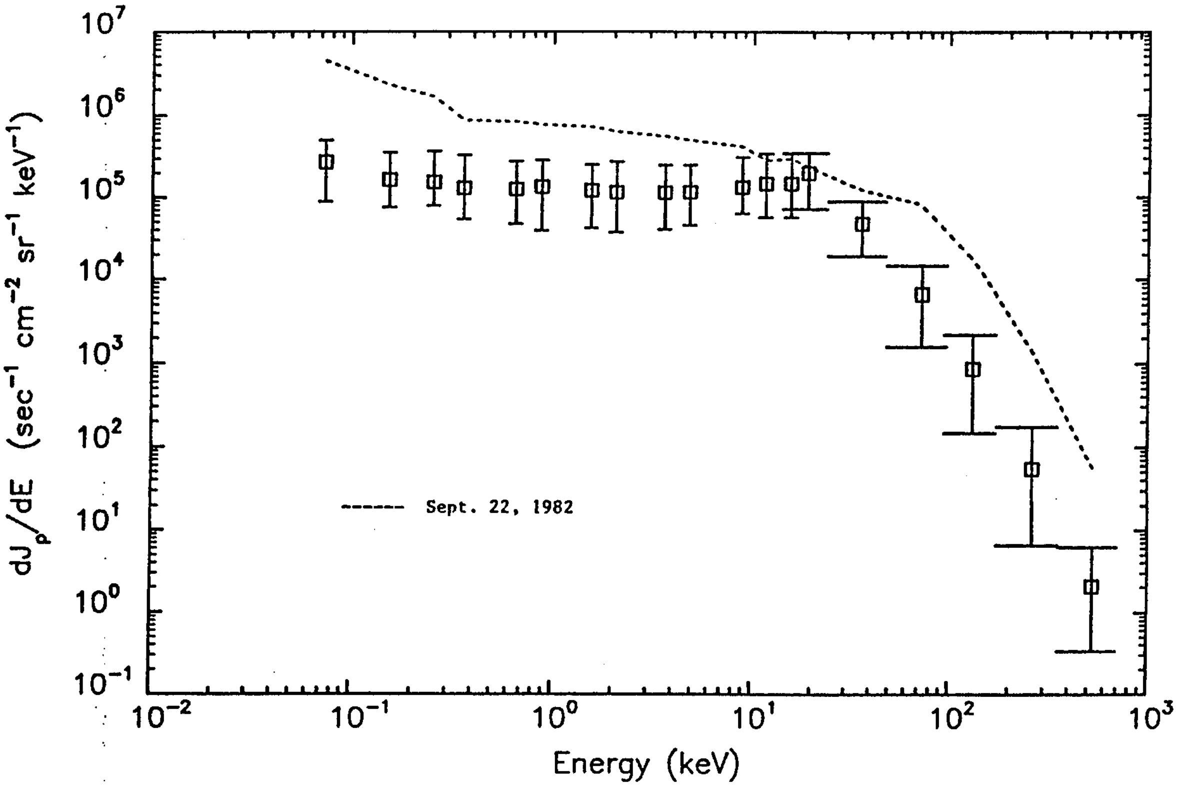

Figure 2. Proton differential flux.

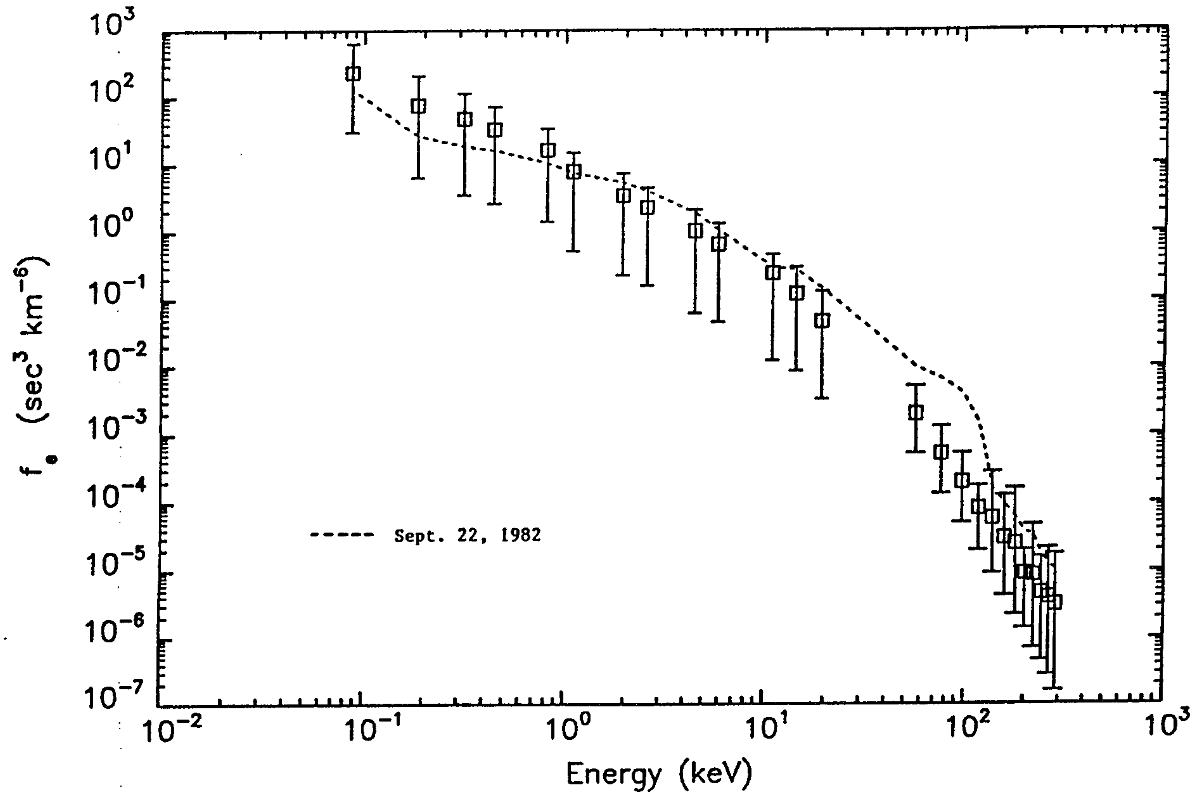

Figure 3. Electron distribution function.

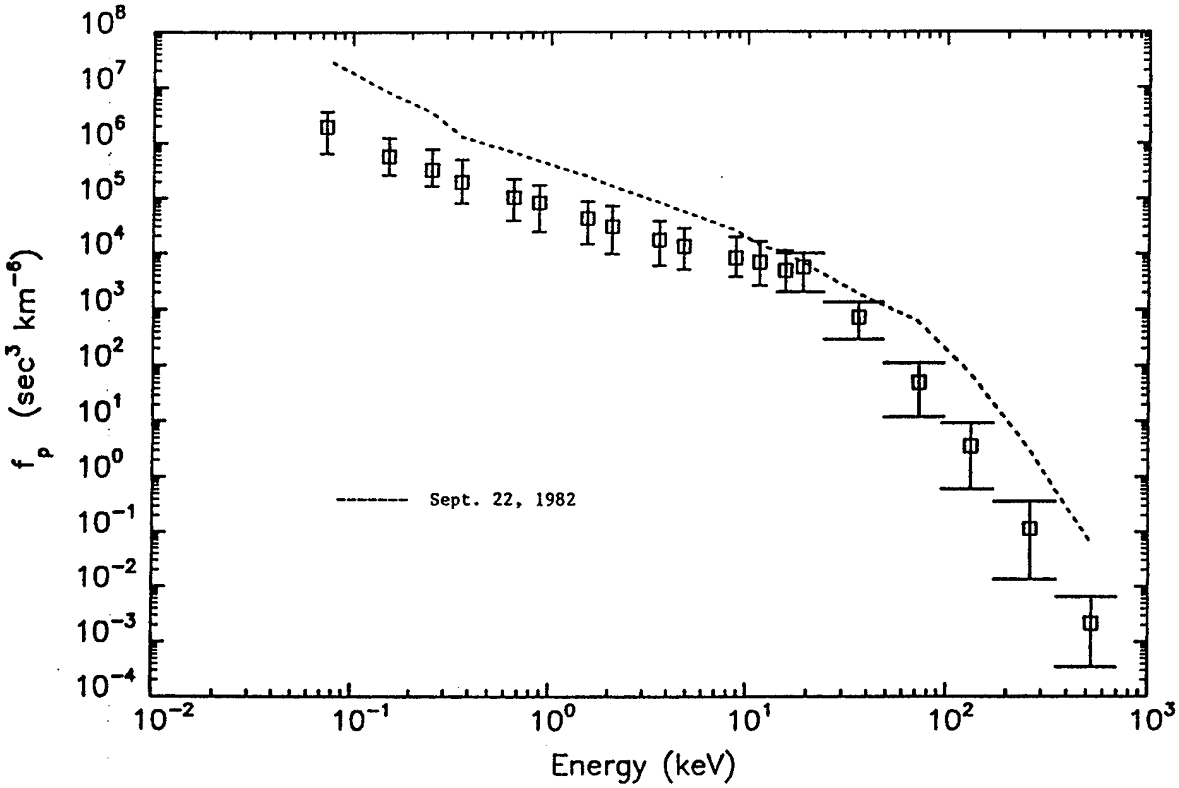

Figure 4. Proton distribution function.

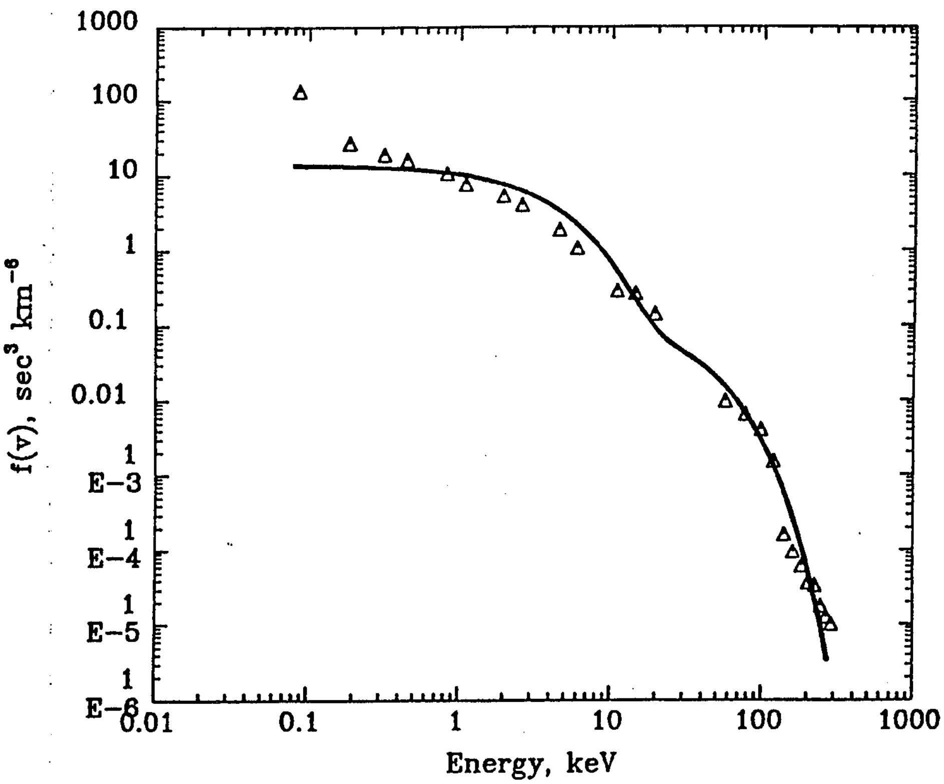

Figure 5. SCATHA day 4265 at 6.71 hrs UT.

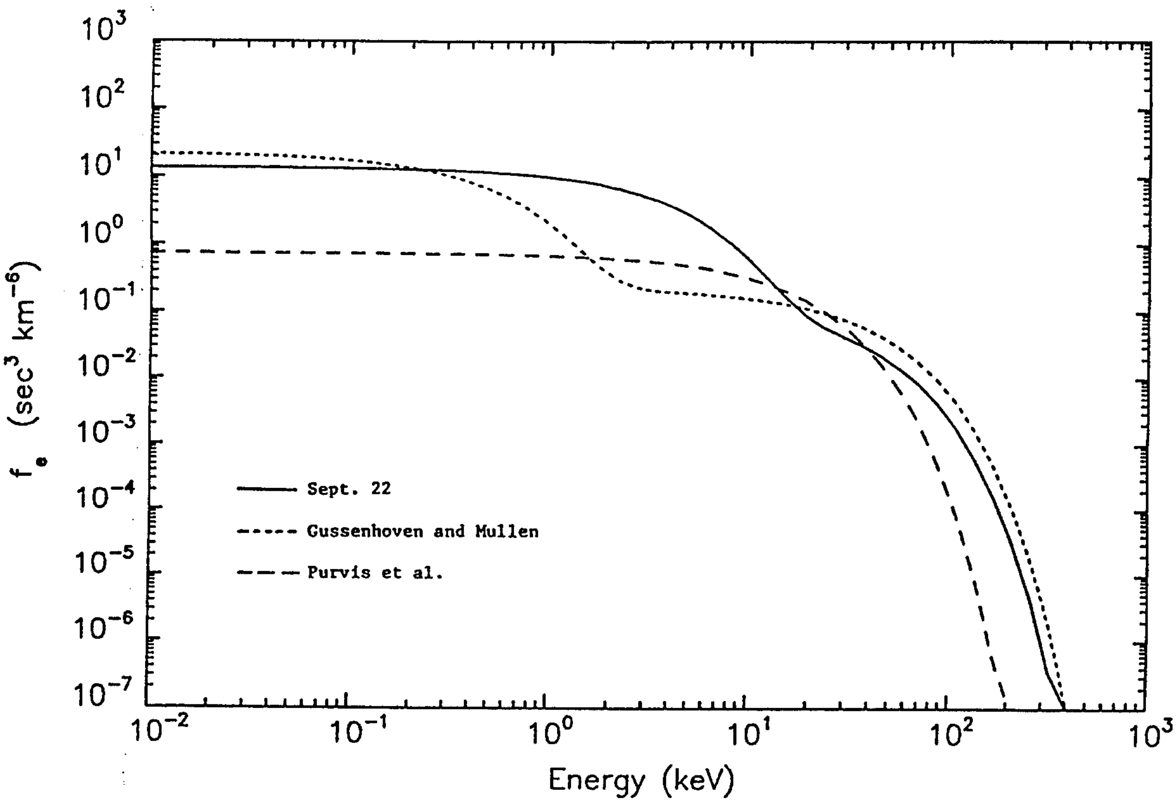

Figure 6. Electron distribution function models.

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