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A LATITUDE COMPARISON OF N_2 DENSITY MEASUREMENTS BY MASS SPECTROMETER

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ABSTRACT

Ambient N_2 densities at altitudes between 100 and 200 km derived from the data of three nighttime mass spectrometer rocket flights at different latitudes are compared. The three flights occurred under nearly identical solar and geomagnetic conditions. The temperate and northern N_2 densities are compared with results obtained by other experimenters and found to be in good agreement. A density gradient, increasing with increasing north latitude is a principal result. The southern tropic N_2 density is found to be about 10% of that above Wallops Island at an altitude of 200 km. Satellite data are shown to support the results qualitatively. The possibility that the low tropic density is due in part to instrumental error is considered. It is concluded that the weight of experimental evidence supports the validity of the results. The extremely low temperatures around 110 km which are deduced from the tropic density results are shown to be compatable with mesopause temperatures derived from a grenade experiment at nearly the same latitude.

INTRODUCTION

During a program of upper atmosphere composition measurements, nine successful rocket-borne mass spectrometer flights were launched at different times and from several locations. The ion source density of each detectable species as a function of altitude was obtained on eight of these flights. Conversion to ambient densities was not originally attempted because of the involved geometry of the open ion source, the uncertainties in the nature of the interactions between an impinging particle and a surface during a single encounter, and the possible errors in angle of attack which can only be estimated from the available data. Since ratios of constituents are much less sensitive to instrument motion than are absolute densities (Schaefer and Nichols, 1964 a, b), composition data were obtained and published, the most recent by Schaefer (1969). In addition, temperatures were obtained from the altitude rate of change of ratios of selected pairs of constituents (Schaefer, 1968).

When nitrogen ion source densities of three nighttime flights at different latitudes were compared, however, the tropic data were significantly lower than temperate and northern. The unexpected magnitude of the differences was obviously not attributable to angle of attack alone. Efforts to extend the composition results already reported to absolute density values were renewed. This paper describes the method which was developed. The results are presented and, where possible, comparisons are made with the results of other experiments performed at comparable times and locations. The possibility of instrumental error is discussed and the evidence of error, pro and con, is presented.

INSTRUMENTATION

The instrumentations used on the three flights considered in this paper were basically the same as that described in earlier publications (Schaefer, 1969; Schaefer and Nichols, 1961, 1964 a, b). The instrumentation flown at Ft. Churchill, Canada, alternately performed ambient neutral and ion analyses while the other two analyzed neutral composition only. Except for minor detail, however, the Ft. Churchill payload differed from the other two only in the ionizing electron energy used in the neutral analysis configuration (see Table 1).

Pre-flight laboratory calibrations were run on each instrumentation using an adjustable air leak into a high-speed vacuum system. The ion current for each species as a function of total system pressure (or density) was obtained. Calibrations were run up to a pressure of $5x10^{-4}$torr or higher in which region a McCleod gauge was used as the standard. The sensitivity of a nude ion gauge used as the standard at lower pressures was determined by comparison with the McCleod gauge in the region of overlapping operation. It is important to note that calibrations were performed on the tropic payload on three occasions because of its role as a spare in a prior series of experiments. Thus tropic payload calibrations were performed on May 12, 1964, October 22, 1964 and January 27, 1965, the final one after a series of environmental tests which included shake tests and hot and cold temperature soaks. Despite the eight months which separated the calibrations and the environmental tests between them, the nitrogen sensitivities obtained at high emission (used at high altitudes) were within ±10% of the mean value which was used in data reduction.

FLIGHT DATA

The experiments were flown on Nike-Apache rockets NASA 14.08, 14.95, and 14.98 UA. Launch dates, times, coordinates and certain trajectory and performance parameters are listed in Table 1. These flights occurred during essentially the same season of the year. All were in the early morning hours near the minimum in the diurnal cycle. Although separated by almost two years, the flights occurred during essentially identical solar and geomagnetic conditions. The chief environmental variable apparent in Table 1 is the launch latitude. Differences in the results of the flights considered herein are therefore assumed to indicate a latitude effect. While the instrumentation motions varied widely, it is important to note that they all had a relatively small horizontal component of velocity.

To illustrate the quality of the data, Figure 1 shows the observed nitrogen ion current as a function of altitude during the flight of 14.98 UA in the south tropic zone. The small scatter of the data points is typical of all three flights. Modulation of the ion current due to the changing angle of attack is obvious. Percentage modulation decreases toward peak as velocity decreases. Downleg modulation due to attitude is typically greater than upleg because enrichment of an ambient species in the ion source is limited at positive angles of attack (Schaefer and Nichols, 1964 b) but the depletion factor on the downleg at negative angles of attack can approach infinity at speed ratios where the vehicle outruns virtually all of the ambient molecules.

The discontinuity observed in the ion current at 127.2 km on the upleg is due to an increase in sensitivity by an increase in emission current. This was triggered automatically by increasing the filament temperature when the electrometer output dropped to a preset value. No corresponding decrease in sensitivity occurred on the downleg because the ion current never reached the preset value to trigger sensitivity reduction. The significance of this event is discussed in a later section.

The data point at 128 km on the upleg in Figure 1 occurred immediately after the increase in filament temperature. Its singular departure from the smooth curve generated by all the other points of Figure 1 is probably related to a sudden large increase in the level of heavy contaminants (greater than mass 40) which occurred with the increase in filament temperature and which probably caused a momentary loss in sensitivity by scattering collisions in the ion source. The contaminants pumped off rapidly so that the next data point at 131 km, taken about 2.7 seconds later, is consistent with the data taken at higher altitudes. It is worthy of note that the observations above were made possible by the unique property of the quadrupole mass spectrometer, operated in the staircase mode, which indicates the residual gas beyond the mass range of the instrument (*Schaefer and Nichols,* 1961, 1964 *a, b*). Other than the postulated transient effect on sensitivity due to the observed temporary flux of contaminants, no further significance appears attributable to this singular data point.

DATA ANALYSIS

Ion source nitrogen number densities for each flight were computed at selected altitudes from smoothed ion current data and laboratory calibrations. The results are shown in Figure 2. As expected, the switching discontinuity in the tropic flight data is not evident in the density plots of Figure 2. In the case of the temperate latitude flight, NASA 14.08 UA, however, the increase in sensitivity with emission during flight was less than that observed in calibrations and a discontinuity appeared in the computed densities. This and other indirect evidence led to the conclusion that one of the two filaments probably failed during this flight. Greater confidence was placed in data taken at low emission because sensitivity would be reduced by the greater space charge effects when high emission were obtained from half the filament. Thus all 14.08 UA densities computed from data obtained at high emission (after 128.4 km on the upleg, Figure 2) were multiplied by a factor of 2.5 to normalize them to the low emission results at lower altitudes on the upleg.

The wide divergence of the tropic densities from the temperate and northern densities near peak is immediately apparent in Figure 2. The low velocities (Table 1), and the estimated variations in angle of attack of each payload on either side of 90^o in the vicinity of peak preclude an explanation based on attitude alone.

In order to obtain a nitrogen density comparison between the flights, calculations of ambient density profiles were made based on the relation

$$n_1 = n_o \frac{T_o}{T_1} \exp\left(- \frac{M}{R} \int_{z_o}^{z_1} \frac{g}{T} \, dz \right) \qquad (1)$$

where n = number density

T = temperature, ^oK

M = molecular weight

R = universal gas constant = $8.3146 \cdot 10^7$ erg · deg^{-1}K· g−mole^{-1}

g = acceleration due to gravity, cm· sec^{-2}

z = altitude, cm.

and the subscripts o, 1 refer to the altitude. An ambient temperature profile for each flight was obtained using the relation (Pokhunkov, 1967; Schaefer, 1968)

$$T = (g/R)\,(M_b - M_a) \Big/ (d/dz)\,\ln\,(n_a/n_b) \qquad (2)$$

where the subscripts a, b refer to the species of gas. Equations 1 and 2 are derived from the hydrostatic equation and the equation of state of a perfect gas. Temperatures for the tropic flight calculated from (2) using several pairs of constituents are illustrated in Figure 3. The curve fitted to the data of Figure 3 takes account of the fact that the temperatures computed from the argon-nitrogen ratios are subject to errors in the positive direction by the influence of contaminants on the relatively small argon peaks.

Advantage was taken of the low velocity near peak to obtain an initial density point upon which to construct a density profile. At these low velocities and at an angle of attack of about 90^o, ambient and open ion source densities are essentially equal. An ambient nitrogen density was picked from each of the curves of Figure 2 at a point near peak where the angle of attack was estimated at 90^o. These densities and the altitudes at which they were measured are given in Table 2. Barring unforeseen changes in sensitivity between calibration and flight, the estimated error in this process is ±25% or less. For example, in the case of an open ion source in front of an infinite plane, the ion source nitrogen density was computed at 1.33 and 0.67 of ambient density for angles of attack of 0^o and 180^o respectively. The velocity was taken at 0.23 km/sec, perfect reflection of the particles at the surface and an ambient temperature of 1000^oK were assumed. When a surface temperature of 300^oK and complete thermal accommodation at the surface were assumed, the values obtained were 2.15 and 0.84. In the latter case, a simple average would be within 50% of the correct value and, in the first case, an average would be correct. Recognizing the severity of the assumptions of the second case compared with actual conditions, the estimated error of ±25% appears quite reasonable.

Starting with the values listed in Table 2, nitrogen number density profiles for each flight were obtained by an iterative computation performed by insertion of the calculated temperatures into Equation (1). The results are shown as dashed lines in Figure 2 and, for purposes of clarity and comparison, are again reproduced in Figure 4.

DISCUSSION

The accuracy of the calculated number densities is best at peak where the measured value was chosen for the initial point. Systematic errors in the temperature will result in a number density error which increases as the computation progresses downward. Nevertheless, the computed values indicated by the dashed lines of Figure 2 appear to offer a reasonable qualitative fit to the upleg and downleg data of both 14.08 and 14.95 UA. In the case of the tropic firing, 14.98 UA, however, the computed densities below 135 km are obviously too low. For example, the maximum density obtainable in an idealized open ion source in front of an infinite plane occurs if the particles are completely accommodated to the surface temperature and the velocity is normal to the surface. In this case, if we assume surface and ambient temperatures of $290^{\circ}K$ at 120 km, the ion source nitrogen density is computed to be six times the ambient. From the data of 14.98 UA in Figure 2, the ion source nitrogen number density measured at 120 km on the upleg was 7.2×10^{11} molecules/cm^3. By the results of aerodynamic considerations cited above, it follows that the minimum possible ambient value is 1.2×10^{11} molecules/cm^3, a factor of three greater than the value of 3.7×10^{10} obtained by the iterative computation downward from peak. Resolution of this discrepancy requires a temperature profile which departs from that of Figure 3 at about 150 km and reaches a value of $175^{\circ}K$ at 120 km, approximately $100^{\circ}K$ cooler than the curve of Figure 3 indicates. This just falls within the estimated error band of $\pm 55^{\circ}K$ at 115 km in the temperatures calculated from the rate of change of O/N_2 with altitude. The real existence of such extremely low temperatures above the southern tropics is supported by the results of a series of grenade experiments reported by de Mendonça et al (1969). Their analysis of the data gathered from a flight launched on October 2, 1966 from Natal, Brazil ($5.6^{\circ}S$ lat, $35^{\circ}W$ long) yields a temperature of only $130^{\circ}K$ at 90 km, the highest altitude of reported results. Their data show no evidence of having reached a minimum temperature so that an even lower value at higher altitudes in the mesopause is indicated.

For comparison with the computed data of 14.08 UA, the Wallops Island nitrogen number densities published by Pelz and Newton (1969) and by Cooley and Reber (1969) are plotted in Figure 4. Likewise, the Fort Churchill values obtained by Müller and Hartmann (1969) are plotted for comparison with the 14.95 UA calculated nitrogen number densities. Since data obtained by von Zahn and Gross (1969) from another instrument on the same rocket are about 80-90% of the values published by Müller and Hartmann (1969), they are not included in Figure 4. Unfortunately, no comparative rocket data has been taken near the latitude of 14.98 UA, Nitrogen number densities obtained from the U. S. Standard Atmosphere Supplements (1966) are also shown in Figure 4. Winter profiles for exospheric temperatures of 700°K and 1100°K were selected, the former to agree with the model temperature of 670°K at the time of the 14.98 UA flight (Schaefer, 1969) and the latter to agree with the experimental results presented in Figure 3.

While separated by three years, all the data illustrated in Figure 4 were taken between late fall and early spring. The Wallops Island data of Pelz and Newton (1969) and of Cooley and Reber (1969) were taken under solar and geomagnetic conditions strikingly similar to those listed in Table 1. The data of Müller and Hartmann (1969) at Fort Churchill were obtained roughly midway during a burst of solar activity which began around December 3 and subsided around December 18. The measured solar flux, F, normalized to 1 AU, on the day of their flight was 158. The geomagnetic index, A_p, was only 2 and began to climb only the day after their flight, reaching 48 on December 14 and returning to 8 on December 16. The calm geomagnetic conditions at launch and the timing of their flight to almost coincide with the winter solstice may be indicative that the effects of variations in the solar flux were attenuated at Fort Churchill relative to those occurring at lower latitudes. The Ft. Churchill densities published by Müller and Hartmann (1969) are somewhat lower than those of 14.95 UA, (Figure 4). Newton (1969) reports that measurements by Explorer 32 density gauges show diurnal density variations wherein nighttime densities at high latitudes are larger than daytime. Since the flight results reported by Müller and Hartmann (1969) were daytime and 14.95 UA was launched at night, the small differences between the nitrogen number densities obtained from these flights may indicate a diurnal effect in agreement with the satellite observations above. Newton (1969) further observes that diurnal density variations decrease as mid-latitude is approached and then reverse in phase so that equatorial densities at night are lower than during the day. Thus very little diurnal variation would be expected at Wallops Island, and the data of Figure 4 agree with this observation. However, the excellent agreement between the mid-latitude sets of data is tempered by the fact that two sets include rather large adjustments made on the basis of assumptions which, though logical, lack absolute proof. The 14.08 UA data at higher altitudes has been normalized by a factor of 2.5 as discussed in the previous section. The data of Pelz and Newton (1969) were adjusted on the assumption all atomic oxygen entering the gauge was lost by surface effects and made no contribution to output current. Since n(O) and n(N_2) become equal around 200 km, this correction increases the calculated value of N_2 about a factor of 2 at 200 km. Notwithstanding these reservations, however, the agreement between the experimental results at each latitude is taken to indicate the validity of the computed nitrogen density profiles.

Comparison of the high altitude nitrogen densities of Figure 4 indicates that they increase with northern latitude. Since all result from data obtained under strikingly similar diurnal, seasonal, solar and geomagnetic conditions, the effect is assigned to the difference in latitude. The rejection of effects due toyear of launch is supported by Lindblad (1968) who finds that densities obtained in the 100-110 km altitude range from falling sphere data show a variation of only about ten per cent from 1963 to 1965. On the other hand, the bulk of the evidence found in the literature indicates a positive density gradient with latitude at high altitudes. Spencer et al (1967, 1968) report a 200 km nighttime N_2 density obtained at Ft. Churchill in November 1965 to be about forty per cent greater than at Wallops Island in March 1965 and twice that at Wallops Island in January 1964. On the basis of data obtained from a series of falling sphere experiments at White Sands Proving Grounds, New Mexico, and from shipboard en route to Greenland in November 1956, Jones et al (1959) report a negative density gradient with increasing north latitude at an altitude of 60 km amounting to 1.9 per cent per degree of latitude. However, considering the second isopycnic level around 80 to 90 km first suggested by Cole (1961) and later placed at 91 km by Champion (1967), the observations of Jones et al (1959) indicate a positive density gradient with increasing northern latitude in the lower thermosphere.

On the basis of density gauge measurements in the altitude range 300 to 700 km aboard Explorer 32 during 1966, Newton and Pelz (1969) report northern high latitude ($> 55^{\circ}$) densities greater than equatorial by a factor of 1. 3 during the day but increasing to values greater than 2 at night. In their analysis of the orbits of Explorers XIX and XXIV from December 1963 through February 1966, Keating and Prior (1967) find the winter polar densities between 550 and 750 km are approximately twice as high as the densities predicted from the static diffusion models of Jacchia (1964). Due to synchronization of the Explorer XIX orbit, all polar densities based on observations of this satellite were those near midnight while the densities obtained at the equator, in good agreement with Jacchia (1964), were measured close to noon. The single winter polar density reported from observations of Explorer XXIV in the daytime is nearly a factor of three greater than the model. The evening and nighttime equatorial density derived from this satellite averaged near to the model values. Taking account of the model predictions of a nighttime polar density at 200 km about 20 - 30% greater than the minimum equatorial nighttime densities, the observations of Keating and Prior (1967) indicate winter nighttime polar densities an order of two or three greater than equatorial with some evidence the same conclusion may be true for the daytime hours. A much smaller density variation with latitude is reported by Champion, Marcos and Schweinfurth (1969) on the basis of accelerometer data obtained from a dense satellite, OV 1-16 (Cannon Ball), launched July 11, 1968 with a perigee of only 148 km. Densities obtained about 80°N latitude at an altitude of about 160 km are in substantial agreement with the U. S Standard Atmosphere Supplements (1966) summer model for an exospheric temperature of 950°K. However, densities obtained around 17°N latitude at an altitude of about 190 km are about 20% below the model values. The same general conclusion might be inferred from orbital drag data obtained from the same satellite despite the concealing effect of larger variations of density in correlation with solar flux and the geomagnetic index. It should be noted that no nighttime equatorial data and no northern winter data were gathered by this satellite due to its orbital parameters and short lifetime of only 39 days. A companion satellite, OV 1-15 (Spades) yielded accelerometer data from which densities significantly lower than the model values were obtained at 200 to 220 km (Champion, Marcos, and McIsaac, 1969). These densities were all obtained in the temperate and tropic zones (34.3° S to 14.8° N latitude) during the day. No nighttime equatorial density measurements are reported. On the other hand, in an orbital drag analysis of OV 1-16, King-Hele and Walker (1969) conclude that any latitudinal or day-to-night variations in density were too small to be detected. In their analysis of the orbital drag on a dense Russian satellite launched on November 2, 1966, King-Hele and Hingston (1967) find no evidence of any correlation of density with latitude at an altitude of 155 km but conclude the daytime maximum density at this altitude is 1.7 times the nighttime for an average value of solar radiation of S = 150. They also note a correlation of nighttime densities with S but none in the daytime. Due to the orbit of this satellite, their observations are limited to latitudes between 49°N and 49°S.

In puzzling contrast to the above results, May (1964) concludes that at fixed heights of 200 to 260 km, the air density near the poles is about 30 per cent lower than over the equator at a local time of 14 hours. This conclusion was based on the analysis of orbital drag effects on several Discoverer satellites. Density values span the period from August 1959 to December 1960. All results were normalized to a value of solar radiation, S, of 200 and to 14 hours local time. It may be significant that his results at the lowest altitudes, 190 and 200 km, (which coincide with the highest altitudes attained by the flights of the present paper) showed a positive density gradient with increasing latitude. Because these gradients disagreed with the higher altitude data, they were attributed to errors in the perigee height of the satellite from which the values were derived and dismissed from further consideration.

Despite the obvious contradiction of the conclusions in the last reference cited above, the foregoing literature survey may be summarized as indicating that a positive density gradient exists from the equator to the poles at high altitudes; that the gradient is largest at night and probably greatest toward the winter pole; and that diurnal variations appear to peak at or near the equator. These conclusions are in qualitative agreement with the results reported in this paper. However, the very low nighttime densities in the altitude range 140 to 200 km obtained in the southern tropic zone from 14.98 UA (Figures 2 and 4) are not supported in magnitude by the foregoing references.

The possibility of instrument malfunction was considered, particularly since the results departed from the accepted models by so great a factor. The data were examined for evidence bearing on the behavior of the instrument. On the upleg of 14.98 UA, below the first data point of Figure 1, the total output current was observed to briefly exceed that obtained in laboratory calibrations at any pressure. This is a result of the reduction in the relative importance of scattering losses in the analyzing section when, at small positive angles of attack, its pressure is aerodynamically maintained below that in the ion source. (Under these conditions, laboratory calibrations run at uniform pressure are not applicable. Hence data are accepted only above that altitude where scattering losses in the analyzing section become negligible--a condition indicated by the clear and sharp delineation of the steps in the staircase spectrums). Although the greater total current observed during flight is not a precise quantitative indicator, nevertheless it confirms that instrument sensitivities during laboratory calibrations and this portion of the flight were nearly the same. Additional evidence is noted in the upleg ion source densities of 14.98 UA which equal or exceed those of 14.08 and 14.95 UA below 115 km (Figure 2). The important point here is that the instrument was operating normally during this portion of the flight after all the rigors of transportation, preparation, launch and ejection had been experienced.

The changes in sensitivity for N_2, O_2 and A which occurred at the change in emission at 127.2 km on the upleg were checked and compared with those observed during laboratory calibrations. Ignoring the singular data point at 128 km discussed in the section "Flight Data", flight changes were found to vary between 0.9 and 1.1 of the laboratory values. Again, this operation appears to have been quite normal during flight.

On the downleg, the total output current never reached a value large enough to trigger a decrease in sensitivity. One possible explanation is that the sensitivity at this point of the flight was too low. While this might explain the low computed densities near peak, it raises a new problem since it has already been noted that sensitivity around 100 km on the upleg was about normal. We are then faced with the task of explaining how, in two minutes of flight, a major change occurred in the sensitivity of a unit which had checked within ±10% during calibrations over a period of eight months (see "Instrumentation"). A more plausible explanation is that, at negative angles of attack on the downleg, the ion source was aerodynamically maintained at a lower density than the analyzing section. Hence attenuation in the analyzer played a greater role in determining the peak value reached by the total output current, reducing it below the preset value for switching.

The foregoing summarizes the detailed study of the behavior of the spectrometer which led to the conclusion that the instrument behaved normally during the flight and that the results are real. The large departure of the tropic data from the models is recognized but no density data taken under similar conditions exist with which to compare the results. As stated earlier, the available satellite data are in qualitative agreement with the results of this paper. It may be significant to note that smaller density variations would occur at most satellite altitudes because of the larger scale heights of the lighter ambient species. The results of de Mendonça et al (1969) provide support for the extremely low mesopause temperatures required to produce the tropic density profile of this paper. Finally, evidence that large density variations can occur at one location is found in the results of 23 thermosphere probe flights reported by Spencer et al, (1969). Six of these launched from Wallops Island during solar activity comparable to those in Table 1 yield N_2 densities at 200 km which differ by a factor of four. The lowest value, $6.79 \times 10^8/\text{cm}^3$, obtained January 28, 1964 at 2154 hours local solar time, is 1/3 the value obtained from 14.08 UA and only a factor of three greater than that from the tropic flight, 14.98 UA. In private conversation, it was ascertained that the authors know of no reason to believe the instrument operated abnormally during this flight. Thus, there is evidence that the low tropic density of Figure 4 may be due in part to a time-dependent phenomenon as well as to the latitude.

CONCLUSIONS

Nighttime N_2 densities obtained from mass spectrometer flights at temperate and northern latitudes agree well with results published by other experimenters. Although surprisingly low densities in the altitude range 140 to 200 km were obtained above the southern tropics, the weight of experimental evidence indicates the instrument performed normally. Further support is obtained from the extremely low mesopause temperatures deduced from a grenade experiment performed in the same latitude region.

In the above altitude range, the data show a nighttime positive density gradient with increasing north latitude in the late winter to early spring. In general, satellite data support this conclusion qualitatively but do not support the magnitude of the difference seen in the rocket data of the southern tropics. However, most satellite data were taken in an altitude region in which corresponding density gradients would be expected to be considerably less.

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TABLE 1. Trajectory and Performance Parameters

Nike-Apache Flight Number (NASA Designation)	14.08 UA	14.95 UA	14.98 UA
Date	Mar. 28, 1963	Feb. 19, 1965	Mar. 11, 1965
Latitude	37° 50' N	58° 44' N	9° 27' S
Longitude	75° 29' W	93° 49' W	82° 26' W
Local time	02h 54m 59s	03h 17m 31s	04h 35m 14s
Peak time, sec	220.3	216.7	223.2
Peak altitude, km	189.6	187.0	196.7
Horizontal velocity, km/sec	0.440	0.229	0.232
Precession period, sec	75	4.37	80
Spin period, sec	3.81	0.171	Long
Calculated precession cone half-angle, deg	38	0	90 (approx.)
Data sweep time, sec	0.92	0.94	0.91
Electron accelerating grid voltage	43	62	42
10.7 cm flux, F 10^{-22} watt/m^2 Hz	73	72	72
Daily geomagnetic index, A_p	4	4	4

TABLE 2. Selected Particle Densities and Altitudes.

Initial points selected from Figure 2 for computation of nitrogen number density altitude profiles.

Nike-Apache Flight Number (NASA Designation)	14.08 UA	14.95 UA	14.98 UA
Ambient nitrogen number density, particles cm^{-3}	2.82×10^9	4.5×10^9	2.41×10^8
Altitude, km	189	186	194

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Fig. 1	Raw N_2 ion currents obtained from the staircase spectrums of the tropic flight, 14.98 UA, illustrating the small scatter in the data points. The discontinuity at 127 km is due to an automatic increase in sensitivity. Note the relatively small attitude modulations near peak.
Fig. 2	Nitrogen densities obtained from three late winter-early spring nighttime flights. Solid lines are ion source densities: dashed lines are computed ambient densities. Values increase with increasing north latitude. The low tropic density near peak is an unexpected result. Note similarity of ion source densities around 110-120 km. The densities of 14.08 UA above 128.4 km have been normalized to extrapolate to values at lower altitudes (see text).
Fig. 3	Temperatures calculated from the data of the tropic flight, 14.98 UA. The curve gives little weight to the A/N_2 results because of the positive errors which result from the contribution of contaminants to the argon peak at mass 40.
Fig. 4	Computed ambient densities of three nighttime flights compared with results of other experimenters and with U. S. Standard Atmospheres.

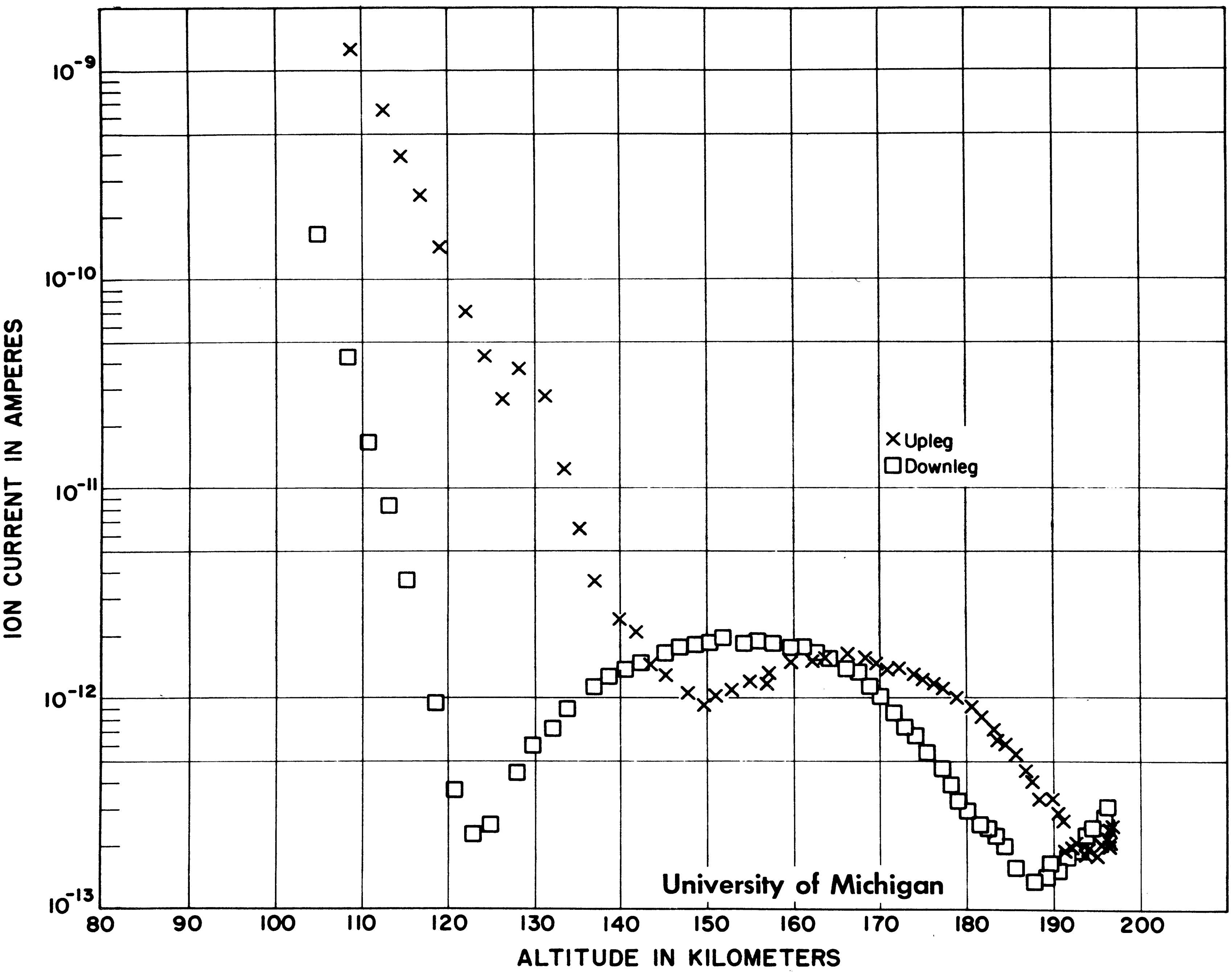

ION CURRENT IN AMPERES
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
80
90
100
110
120
130
140
150
160
170
180
190
200
ALTITUDE IN KILOMETERS
× Upleg
□ Downleg
University of Michigan

Figure 1

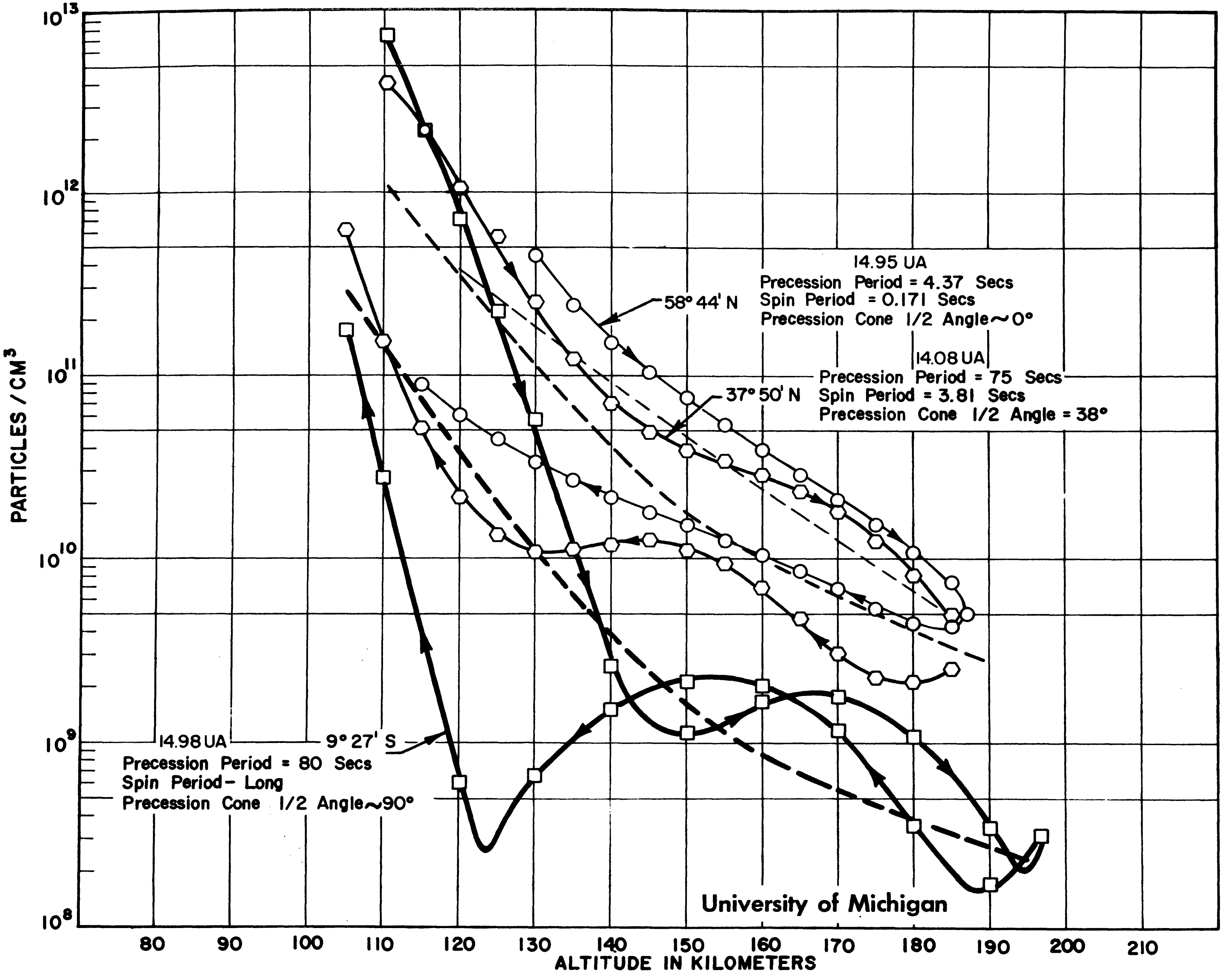

PARTICLES / CM^3
10^{13}
10^{12}
10^{11}
10^{10}
10^{9}
10^{8}
80
90
100
110
120
130
140
150
160
170
180
190
200
210
ALTITUDE IN KILOMETERS
58° 44' N
14.95 UA
Precession Period = 4.37 Secs
Spin Period = 0.171 Secs
Precession Cone 1/2 Angle~0°
37° 50' N
14.08 UA
Precession Period = 75 Secs
Spin Period = 3.81 Secs
Precession Cone 1/2 Angle = 38°
14.98 UA
9° 27' S
Precession Period = 80 Secs
Spin Period - Long
Precession Cone 1/2 Angle~90°
University of Michigan

Figure 2

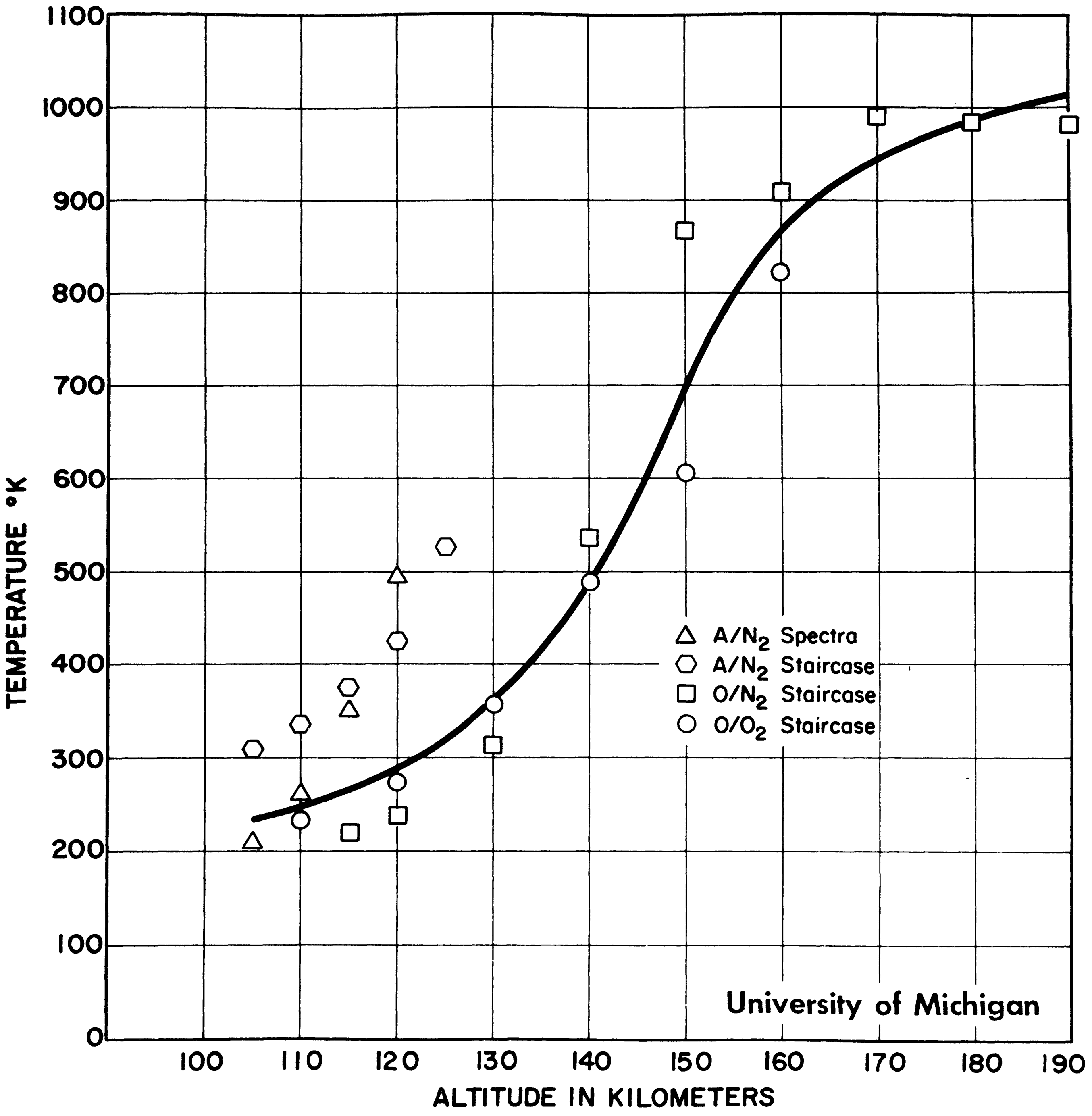
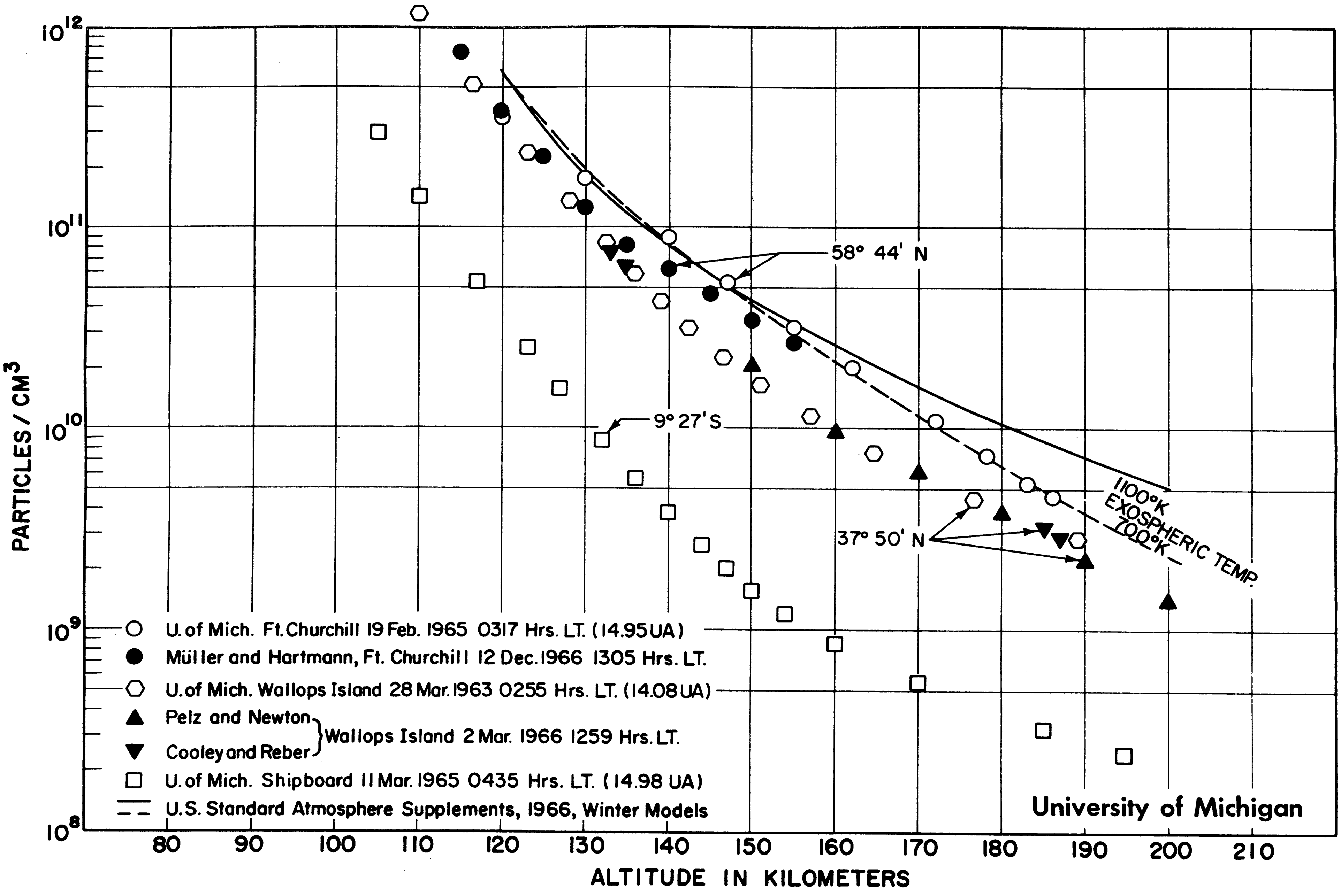

1100
1000
900
800
700
600
500
400
300
200
100
0
TEMPERATURE °K
100
110
120
130
140
150
160
170
180
190
ALTITUDE IN KILOMETERS
△ A/N_2 Spectra
⬡ A/N_2 Staircase
□ O/N_2 Staircase
○ O/O_2 Staircase
University of Michigan

Figure 3



10^{12}
10^{11}
10^{10}
10^{9}
10^{8}
PARTICLES / CM^3
80
90
100
110
120
130
140
150
160
170
180
190
200
210
ALTITUDE IN KILOMETERS
58° 44' N
9° 27' S
37° 50' N
1100°K
EXOSPHERIC TEMP.
700°K
○ U. of Mich. Ft. Churchill 19 Feb. 1965 0317 Hrs. LT. (14.95 UA)
● Müller and Hartmann, Ft. Churchill 12 Dec. 1966 1305 Hrs. LT.
⬡ U. of Mich. Wallops Island 28 Mar. 1963 0255 Hrs. LT. (14.08 UA)
▲ Pelz and Newton
▼ Cooley and Reber
Wallops Island 2 Mar. 1966 1259 Hrs. LT.
□ U. of Mich. Shipboard 11 Mar. 1965 0435 Hrs. LT. (14.98 UA)
— – – U.S. Standard Atmosphere Supplements, 1966, Winter Models
University of Michigan

Figure 4