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GSFC — GODDARD SPACE FLIGHT CENTER
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ABSTRACT

An ensemble of six independent aeronomy experiments was launched from Wallops Island, Virginia on March 2, 1966, at 1300 EST. Two Bayard-Alpert ionization gauges, similar to those on the Explorer 17 satellite, were flown to measure neutral atmospheric density and temperature. However, the Bayard-Alpert gauges appear to have pumped or adsorbed virtually all of the atmospheric atomic oxygen (O) to which they were exposed, and thus measured only the molecular nitrogen (N_2), molecular oxygen (O_2), and helium (He), in the region from 150 km to 450 km altitude. Deduced N_2 number densities (1.9×10^{10}, 3.5×10^{7}, and 1.9×10^{5} particles cm^{-3} at 150 km, 300 km, and 450 km respectively) agree with nearly simultaneous measurements obtained from a neutral mass spectrometer and a solar EUV extinction experiment. Previous N_2 measurements from Thermosphere Probes, obtained under similar solar and geomagnetic conditions, agree well with these data. An exospheric temperature near 875°K was determined for the 1300 hour local solar time atmosphere. The O pumping, presumably by initially oxygen free surfaces in the Bayard-Alpert gauges, is discussed and contrasted to the oxygen processed surfaces in the magnetron gauges flown on the Explorer 17 and 32 satellites, which apparently did not pump the ambient O.

INTRODUCTION

An aeronomy experiment, called Geoprobe, consisting of six independent measurement systems, made nearly simultaneous determinations of the vertical distribution of the neutral and ion composition, density and temperature, and the electron temperature and concentration. Measurements of the extinction of the solar ionizing radiation were obtained from an accompanying experiment launched five minutes prior to the Geoprobe (Hall et al., 1967).

This paper reports the results of the neutral density and temperature experiment and includes:

(1) a molecular nitrogen number density determination from 150 km to 450 km altitude,

(2) a determination of the neutral gas temperature as a function of altitude from 150 km to approximately 350 km,

(3) a comparison with results from two other experiments which obtained nearly simultaneous data and with previous measurements obtained during comparable solar and geomagnetic conditions,

(4) a comparison of the total density measurement capability of the Bayard-Alpert gauges with that of the Explorer 17 and Explorer 32 satellite magnetron gauges.

INSTRUMENTATION

The Geoprobe scientific experiment complement was mounted in a vacuum tight housing shown in Figure 1. The neutral density and temperature experiment, the subject of this paper, consisted of two identical, independent systems each composed of a Bayard-Alpert ionization gauge, a logarithmic current detector, a power supply and a logic system. These systems were basically quite similar to the Explorer 17 satellite pressure gauge (PG) systems described by Newton et al. (1963). Both PGs were mounted such that the gauge orifice normals were perpendicular both to the payload spin axis and to each other (See Figure 1). The sensors were sealed under vacuum (pressures near 10^{-9} and 10^{-6} Torr) and exposed to the ambient atmosphere on the upleg of the flight, after the protective nosecone had been ejected.

GENERAL FLIGHT INFORMATION

The Geoprobe was launched by an Argo D-4 Javelin at 17 hr. 59 min. 42 sec. Greenwich Mean Time on 2 March, 1966, from Wallops Island, Virginia. The rocket nosecone was ejected at 170 km altitude and the pressure gauges were opened at 210 km altitude. The payload orientation was determined throughout the flight using magnetometer and solar aspect data (Ott et al., 1967), and the payload spin period was 0.80 sec, the precession period was 10.55 sec, and the precession cone half angle was 11.5°. The trajectory parameters (apogee = 630 km, horizontal range = 874 km, latitude = 38°N to 37°N, longitude = 75°W to 66°W) were determined from radar data and are believed accurate to better than ±1 km vertical and ±2 km horizontal distance.

DATA ANALYSIS

The PGs were calibrated in our laboratory using the same comparison standards (i.e., same absolute gas calibration) as the gauges used for the

Explorer 17, Explorer 32, and OGO-4 satellites. The laboratory nitrogen gas calibration was also compared with that of the Geoprobe neutral composition experiment and agreed to better than 25%, which is the estimated accuracy of our absolute calibration.

The angles of attack of the pressure gauges (angle between the orifice normal and the payload velocity vector) were determined for the desired times by using the payload orientation and velocity data. The angle of attack and maximum and minimum gauge pressures each roll cycle were used with the velocity data to determine the atmospheric density based on the techniques developed previously by Schultz et al. (1948), Havens et al. (1952), and Horowitz and Kleitman (1953).

The neutral gas temperature was calculated using the ideal gas law, assuming hydrostatic equilibrium, and integrating the measured density profile downward.

Since Bayard-Alpert gauges have a different sensitivity for different gases, the interpretation of the total output current of these devices in terms of atmospheric density is dependent upon the composition of the gas being ionized. The Geoprobe data were interpreted for three different cases of relative composition as follows:

(1) Case one (1); relative composition as predicted from a model atmosphere (1964 Harris and Priester, model 2 at 1300 hrs).

(2) Case two (2); relative composition as measured by the Geoprobe neutral composition experiment (Reber and Cooley, 1967).

(3) Case three (3); relative composition as in case two except atomic oxygen (O) was excluded. That is, the molecular nitrogen (N_2), molecular

oxygen (O_2) and Helium (He) densities measured by the Geoprobe mass spectrometer were used, and all O was assumed lost to the pressure gauge internal surfaces. The relative concentrations of the N_2, O_2, and He were not affected by this assumption because of the long mean free paths and attendant absence of particle collisions.

DATA AND RESULTS

Because of rocket nosecone outgassing, only the data obtained below 450 km on the downleg of the trajectory have been analyzed, and reported here.

Figure 2, a photograph of the telemetry record, shows the outputs of the logarithmic electrometers employed with the pressure gauges, as a function of time, and indicates the general good quality of the telemetered data. A detailed display of the pressure variation in a PG during one spin cycle is shown in Figure 3.

Two independent density measurements were obtained from the two systems every 0.8 sec between 450 and 150 km altitude. Since they always agree to better than 10% when interpolated to a common altitude, a single density profile was generated by averaging the two density measurements.

The data were analyzed assuming three cases of relative composition as defined previously. Figure 4 shows the calculated density assuming atmospheric composition as in case 1, with the predicted total density from the appropriate Harris and Priester model. It can be seen that for this case the model values are higher than the data by a factor of 2 at 150 km and a factor of 50 at 450 km altitude. This is in contrast to earlier comparisons between the model densities and densities measured by satellite borne ionization gauges (Newton et al., 1964, 1965, Cook, 1967) where the model densities were higher than measured densities by approximately a factor of 2 at nearly all altitudes reported.

When the case 2 composition was assumed in the density calculation, and the results compared to the Geoprobe mass spectrometer measurements, the density profiles agreed between 150 and 200 km altitude, and then diverged with increasing altitude with the pressure gauge densities becoming a factor of 10 below the mass spectrometer values at approximately 400 km altitude. It was determined that the pressure gauge densities were less than the mass spectrometer densities by an amount approximately equal to the density of the O measured by the mass spectrometer.

Figure 5 shows the results obtained using case 3 composition (an all N_2, O_2, and He atmosphere) in terms of number density of molecular nitrogen. This N_2 profile was obtained by assuming: (a) all atmospheric O in the gauge was adsorbed or pumped before reaching the gauge ionization regions and made no contribution to the sensor output currents, (b) O_2/N_2 and He/N_2 ratios as measured by the Geoprobe mass spectrometer, and (c) argon, hydrogen and atomic nitrogen are negligible in this altitude range. The minor density contributions due to the He and O_2 were subtracted from the total, and the N_2 profile was obtained from 450 to 150 km altitude. Also shown in Figure 5 for comparison are the N_2 measurements from the Geoprobe mass spectrometer (Reber and Cooley,

1967) and the solar EUV extinction experiment (Hall et al., 1967), both obtained nearly simultaneously with our data. It should be noticed that our N_2 measurements agree to better than 20% with the mass spectrometer values and to better than 50% with the EUV extinction values, within the stated experimental accuracies of all experiments. It is particularly evident in Figure 5 that the shapes of the curves and thus the density scale heights measured by the three experiments are very similar.

Figure 6 compares our case 3 N_2 profile with the Thermosphere probe (TP) measurements (Spencer et al., 1965) obtained under similar local time, solar and geomagnetic conditions. The local times, a_p and $F_{10.7}$ index values pertaining to the flights are listed in Table 1. Also shown for comparison in Figure 6 is the appropriate Harris and Priester model. The familiar difference between in-situ measurements and model predictions is apparent in this figure.

Table 1

Geoprobe and Thermosphere Probe Geophysical Parameters

	Geoprobe	TP 18.01	TP 6.06
Date (day, month, year)	2 March 1966	19 March 1965	20 Nov. 1962
Local solar time of launch (hrs)	1300	1309	1641
a_p six hrs prior to launch	0	6	4
$F_{10.7}$ daily average, day prior to launch (w/m^2 c/s)	81	74	86

The neutral gas temperature calculated from the case 3 N_2 density profile, is shown in Figure 7. It can be seen that the shape of the density profile, and not the initial temperature (T_i) assumed at 450 km altitude, determines the calculated temperature below about 350 km altitude. We believe this represents the neutral thermosphere temperature between 150 and 350 km altitude and indicates an exospheric temperature near 875°K during the flight. Also shown in Figure 7 are the temperature at 225 km altitude reported by Hall et al. (1967), and the temperature profile obtained by Spencer et al. (1965) from the TP 18.01.

DISCUSSION

As shown above, the agreement between the deduced nitrogen number density and altitude distributions obtained from the pressure gauges, mass spectrometer, and EUV extinction experiment, is within the stated experimental errors. This leads to the conclusion that atomic oxygen, although the dominant specie in the altitude region concerned, was not measured but was probably adsorbed by the gauges. This conclusion can be further supported by considering how the gauges were prepared. The gauges had been baked-out, outgassed by electron bombardment, and sealed at low pressures prior to launch. Thus, the metal surfaces were believed to be free of adsorbed oxygen until the sensors were exposed to the atmosphere on the upleg of the flight. If every O atom which then passed through the gauge orifices was adsorbed permanently (for the duration of the flight) on a metal surface, the metal surfaces inside each sensor would have had approximately a single monolayer coverage of O by the time the payload had descended to 200 km altitude.

In contrast to these results are those from cold cathode magnetron gauges used on satellites (Newton et al., 1963, 1964, 1965, 1968, Pelz and Newton, 1967). These magnetron gauges were "oxygen-processed" prior to calibration and flight, and we do not believe they pumped a significant amount of O in orbit. The preflight oxygen processing consisted of operating each gauge for hours at 10^{-6} Torr in molecular oxygen (O_2), turning off the gauge, pumping away the O_2, and baking the gauge at 400°C. Thereafter the gauges were calibrated in various gases including O_2, baked, and packaged for flight. We believe the exposure of the cold cathode gauge surfaces to the O produced in the magnetron discharge during operation in O_2 $[O_2 + e \rightarrow O^+ + O + 2e]$, enhances stabilization of these surfaces prior to flight, and therefore permits atmospheric O atoms to have wall collisions within the gauges during flight without significant pumping or adsorption effects. It should be noted that magnetron gauges are never outgassed at high currents or intentionally cleaned by electron bombardment to produce clean metal surfaces and thus negate previous exposure history, as are the Bayard-Alpert gauges. The effects of oxygen recombination alone in these gauges has been discussed previously (Newton et al., 1964).

CONCLUSIONS

We have determined the N_2 number density and neutral temperature distributions for the atmosphere above Wallops Island during the Geoprobe flight. These density data, obtained under conditions of a quiet sun, agree well with the measurements from Thermosphere Probes NASA 6.06 and 18.01. Good agreement also exists between our density values and those obtained in the same atmosphere, nearly simultaneously, by the Geoprobe mass spectrometer and solar EUV extinction experiment.

Our temperature data agree well with the Thermosphere Probe results obtained under similar solar and geomagnetic conditions. The exospheric temperature calculated by Brinton et al. (1968), from the Geoprobe ion composition and concentration experiment results, is also within estimated experimental accuracies. The Jacchia (1964) model temperatures ($F_{10.7} = 90$, 1200 hrs) are higher than our values at the low altitudes, but agree with our exospheric temperature, while the Harris and Priester (1964) temperatures are higher at all altitudes and predict an exospheric temperature near 1050°K.

ACKNOWLEDGEMENTS

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REFERENCES

Brinton, H. C., M. W. Pharo III, H. G. Mayr, and H. A. Taylor, Jr., Ion concentrations in the daytime F_2 Region Measured at a Time of Rising Solar Activity, Paper presented at 49th Annual Meeting of A.G.U., Washington, D. C., 1968.

Cook, G. E., Comparison of air densities from orbital decay and instruments, Phil. Trans. Roy. Soc. London, A, 262, 172-184, 1967.

Hall, L. H., C. W. Chagnon, and H. E. Hinteregger, Daytime variations in the composition of the upper atmosphere, J. Geophys. Res., 72, 3425-3427, 1967.

Harris, I., and W. Priester, The upper atmosphere in the range from 120 to 800 km, Goddard Space Flight Center, 1964.

Havens, R. J., R. T. Koll, and H. E. Lagow, The pressure, density, and temperature of the earth's atmosphere to 160 kilometers, J. Geophys. Res., 57 pp 59-72, 1952.

Horowitz, R., and D. Kleitman, Upper atmosphere research report 18, NRL report 4246, U. S. Naval Research Laboratory, Wash., D. C., Oct., 1953.

Jacchia, L. G., Static diffusion models of the upper atmosphere with empirical temperature profiles, Smithsonian Institution Astrophysical Observatory Special Report 170, Smithsonian Institution Astrophysical Observatory, Cambridge, Mass., 30 December, 1964.

Newton, G. P., D. T. Pelz, G. E. Miller, and R. Horowitz, Response of modified Redhead magnetron and Bayard-Alpert vacuum gauges aboard Explorer 17, Transactions of the Tenth National Vacuum Symposium, edited by George H. Bancroft, pp 208-212, The MacMillan Company, New York, 1963.

Newton, G. P., R. Horowitz, and W. Priester, Atmospheric densities from Explorer 17 density gages and a comparison with satellite drag data, J. Geophys. Res., 69, 4690-4692, 1964.

Newton, G. P., R. Horowitz, and W. Priester, Atmospheric density and temperature variations from the Explorer 17 satellite and a further comparison with satellite drag, Plant. Space Sci., 13, pp 599-616, 1965.

Newton, G. P., D. T. Pelz, and H. Volland, Direct in-situ measurements of wave propagation in the neutral thermosphere, submitted to J. Geophys. Res., 1968.

Ott, R. H., H. M. Horstman, and R. M. Lahn, The determination of the orientation of a uniformly or rapidly rotating vehicle utilizing the outputs of solar sensors and a lateral magnetometer, AIAA Sounding Rocket Vehicle Technology Specialist Conference Volume, pp 450-470, 1967.

Pelz, D. T. and G. P. Newton, Pressure conversion constants for magnetron ionization gauges, J. Vac. Sci. Tech., 4, 239-245, 1967.

Reber, C. A., and J. E. Cooley, Neutral atmosphere composition measurement between 180 and 420 km from the Geoprobe rocket mass spectrometer, Paper presented at 48th Annual Meeting of A.G.U., Washington, D. C., 1967.

Schultz, F. W., N. W. Spencer, and A. Reifman, Upper air research program, progress report 2, contract W-33-038, AC-14050, Engineering Res. Inst., Univ. Mich., p 129, July, 1948.

Spencer, N. W., L. H. Brace, G. R. Carignan, D. R. Taeusch, and H. Niemann, Electron and molecular nitrogen temperature and density in the thermosphere, J. Geophys. Res., 70, 2665-2698, 1965.

Figure Captions

Figure 1. A sketch of the Geoprobe (NASA-8.25) scientific payload which included the following aeronomy experiments:

(1) Neutral gas density and temperature (Bayard-Alpert ionization gauge [2])

(2) Neutral gas composition and concentration (magnetic mass spectrometer)

(3) Ion gas composition and concentration (RF mass spectrometer)

(4) Electron temperature and concentration (cylindrical electrostatic probe)

(5) Electron concentration (cw propagation)

(6) Ion temperature and concentration (retarding potential analyzer [2])

Figure 2. A photograph of a Geoprobe telemetry record with 0 to 5 volt scale superposed. The gauge pressures are related to the voltage logarithmically.

Figure 3. The detailed pressure variation in Bayard-Alpert pressure gauge-2 during one payload spin cycle. The sensor altitude, velocity and minimum angle of attack were 160 km, 3.1 km per sec, and 54° respectively during this cycle.

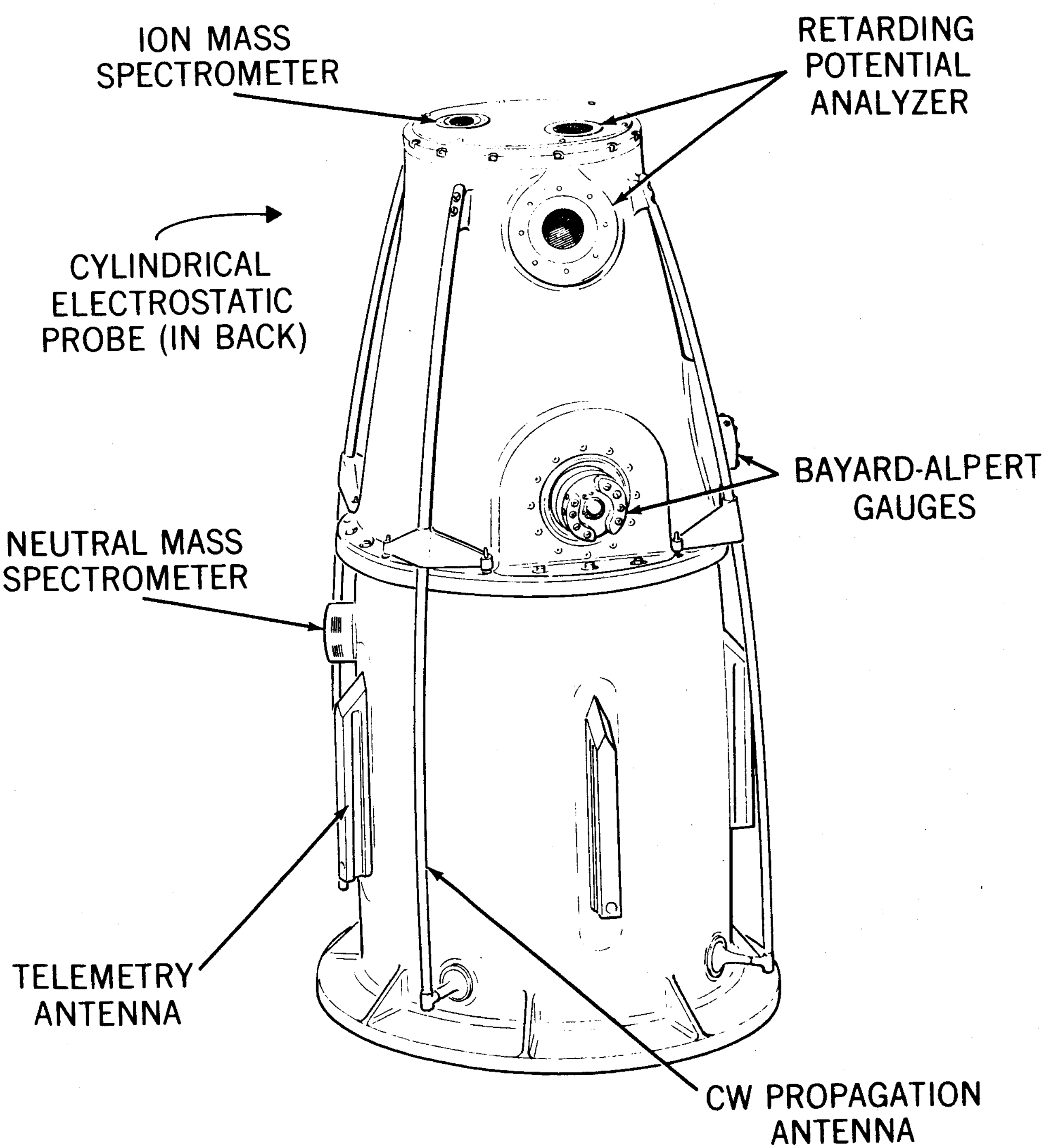
Figure 4. Density vs altitude measured by the Geoprobe pressure gauges (PGs), assuming a relative composition as predicted by the 1964 Harris and

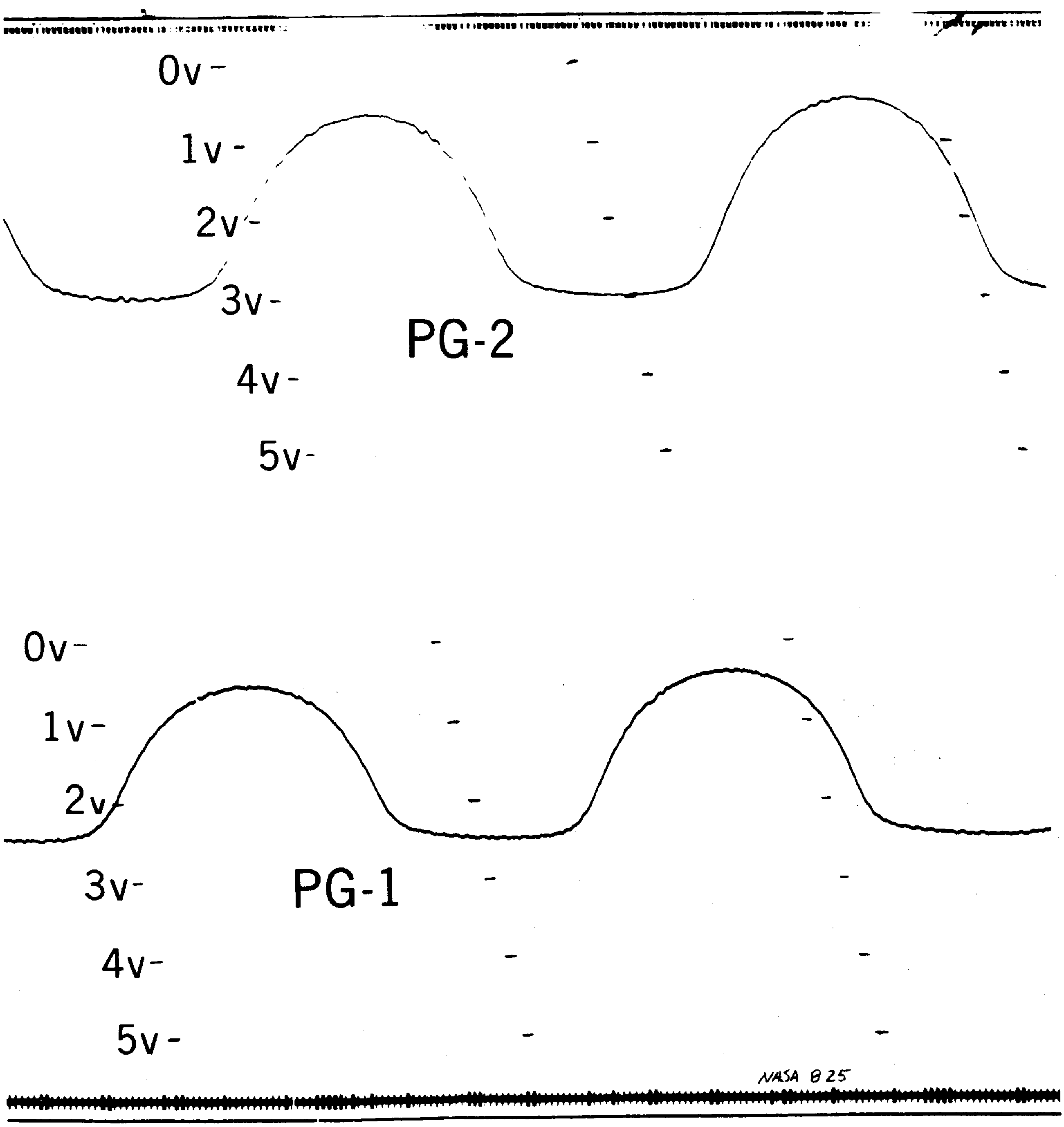
Priester model 2 at 1300 hrs (case 1 composition). Also shown for comparison is the model density.

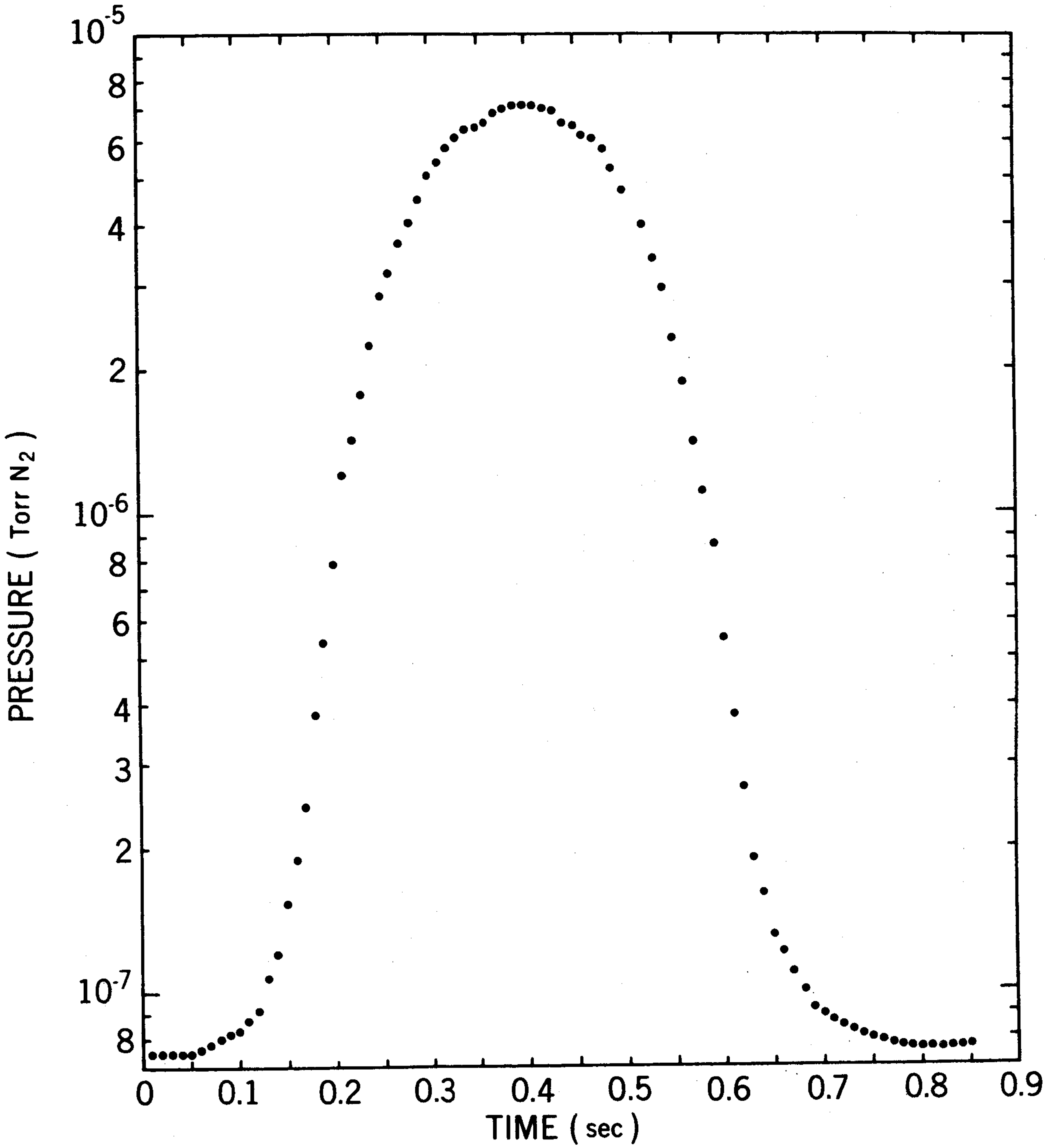
Figure 5. Molecular nitrogen number density vs altitude measured by the Geoprobe pressure gauges (PGs), assuming an all N_2, O_2 and He atmosphere (case 3 composition). Also shown are two independent, nearly simultaneous measurements by the Geoprobe mass spectrometer and the EUV extinction experiment.

Figure 6. Molecular nitrogen number density measured by the Geoprobe (NASA 8.25) pressure gauges (case 3 composition), compared to previous measurements obtained under similar solar and geomagnetic conditions (Thermosphere Probes NASA 6.06 and 18.01, see Table 1). A Harris and Priester model density is also shown.

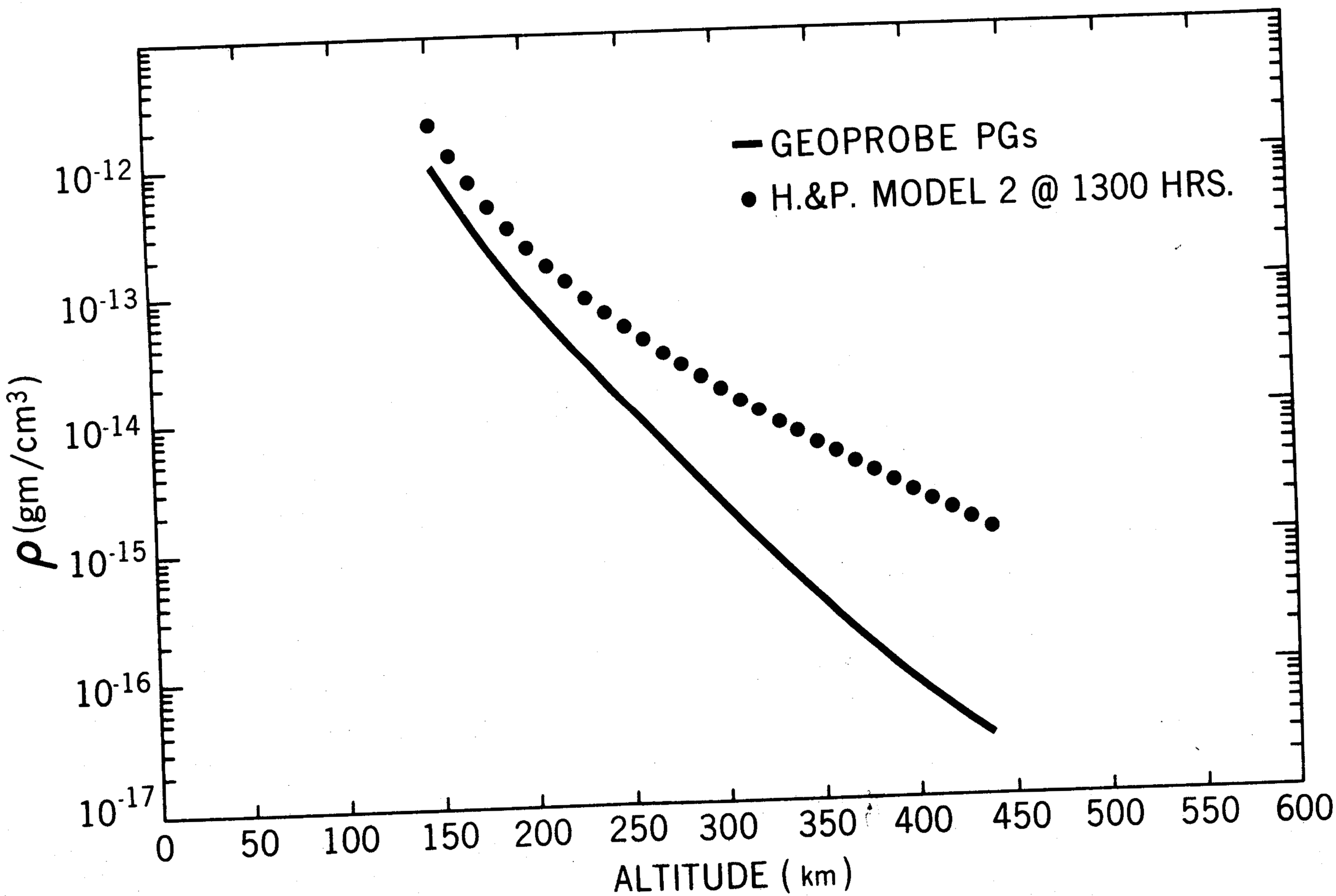
Figure 7. Neutral thermosphere temperature obtained from the Geoprobe (NASA 8.25) pressure gauges using the N_2 profile shown in Figure 6. The temperature determination below approximately 350 km altitude is independent of the exospheric temperature (T_i) assumed in the calculation. Also shown is the temperature reported by Hall et al. (1967), and the temperature profile measured by the Thermosphere Probe NASA 18.01.


ION MASS SPECTROMETER
RETARDING POTENTIAL ANALYZER
CYLINDRICAL ELECTROSTATIC PROBE (IN BACK)
BAYARD-ALPERT GAUGES
NEUTRAL MASS SPECTROMETER
TELEMETRY ANTENNA
CW PROPAGATION ANTENNA

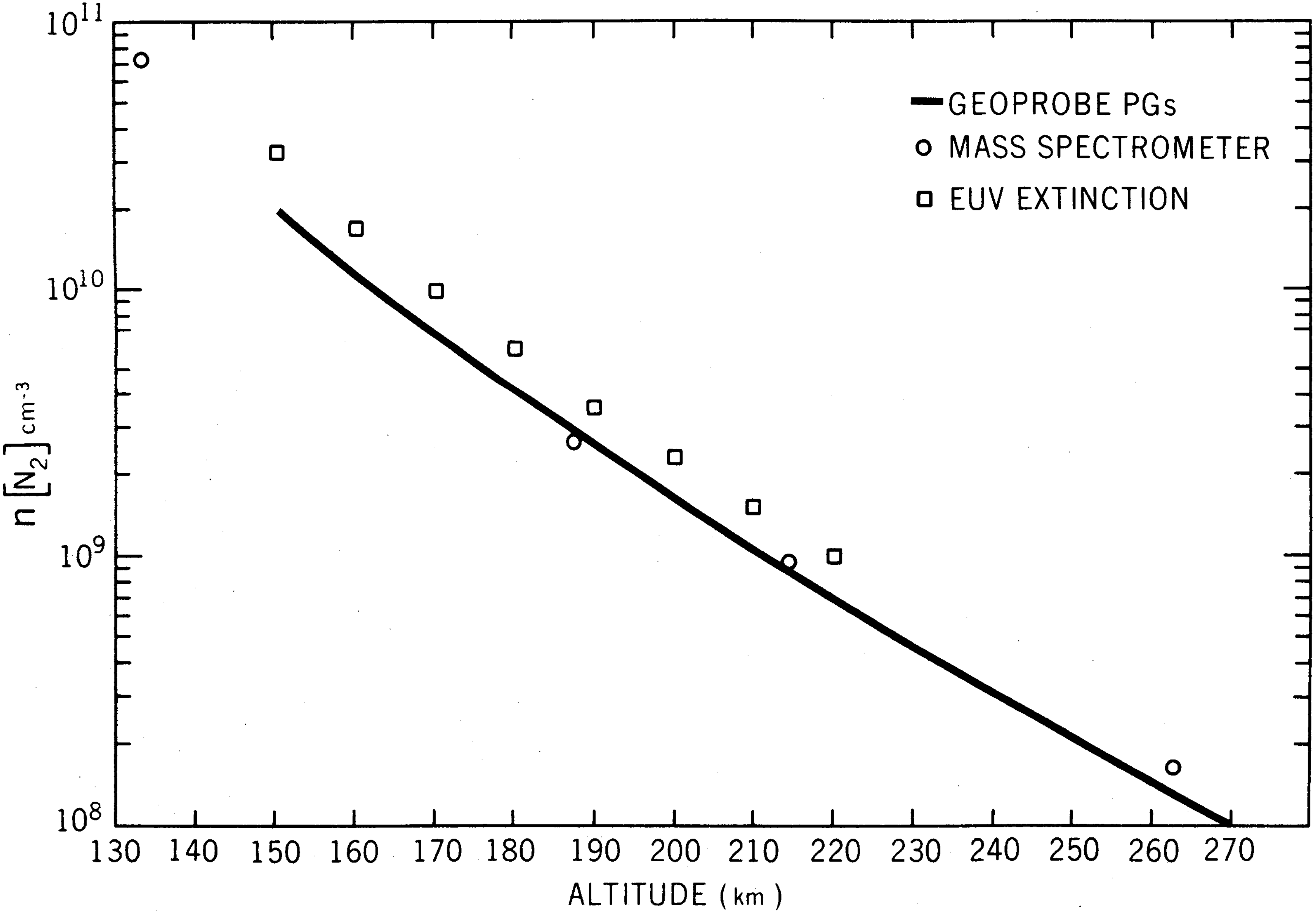

0v
1v
2v
3v
4v
5v
PG-2
0v
1v
2v
3v
4v
5v
PG-1
NASA 8 25

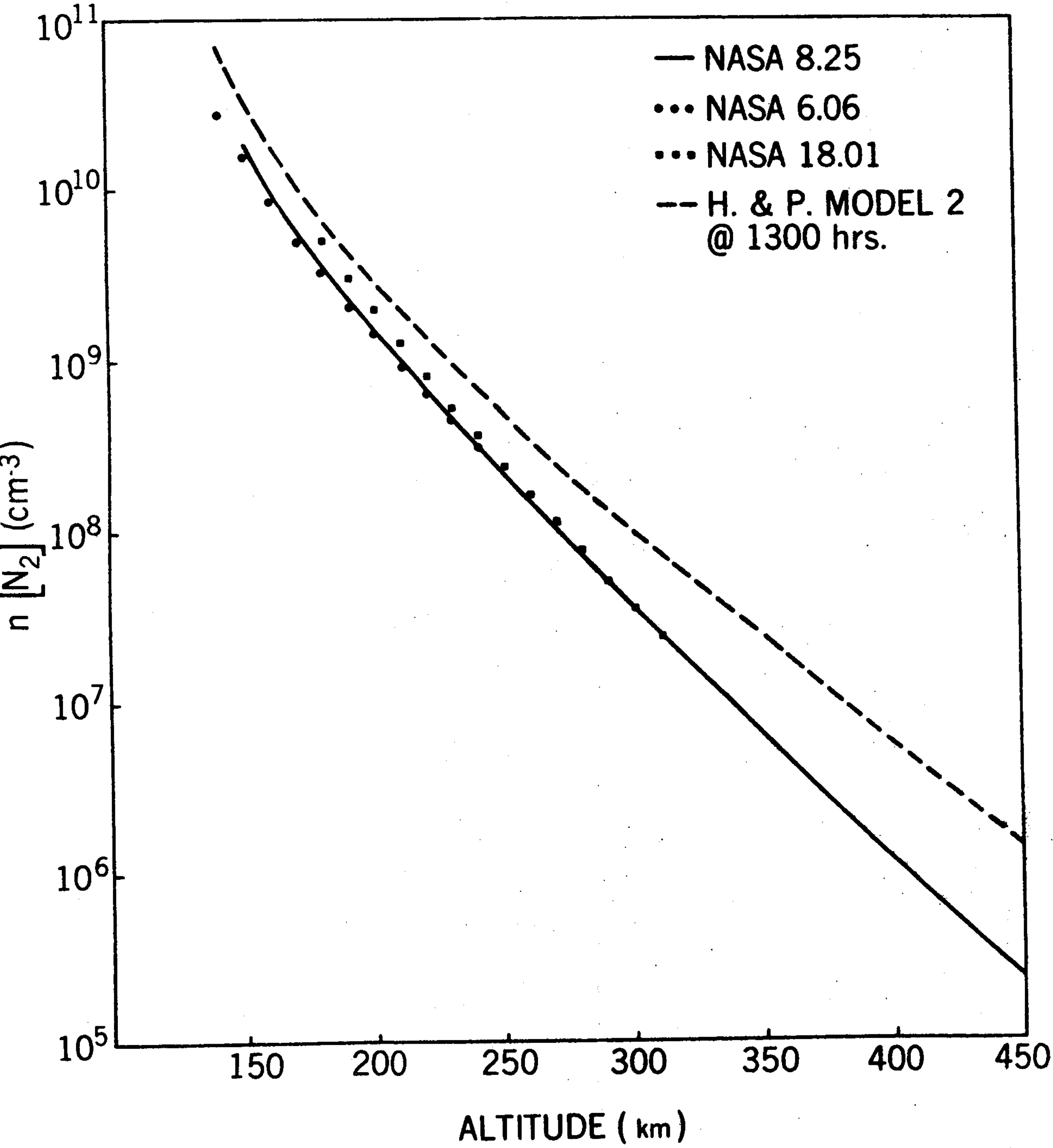


PRESSURE (Torr N_2)
10^{-5}
8
6
4
2
10^{-6}
8
6
4
3
2
10^{-7}
8
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
TIME (sec)

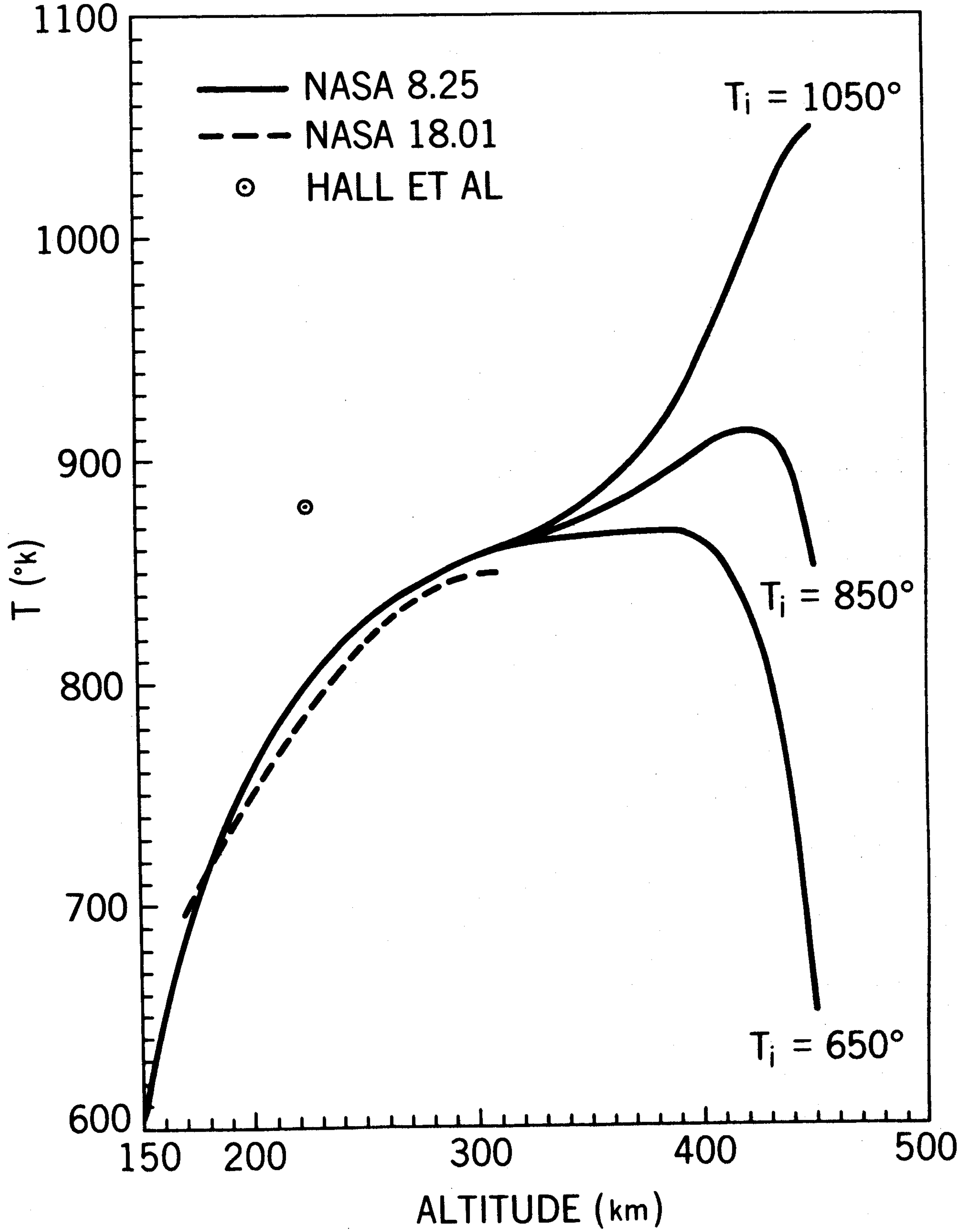


GEOPROBE PGs
H.&P. MODEL 2 @ 1300 HRS.
ρ (gm/cm³)
10-12
10-13
10-14
10-15
10-16
10-17
0
50
100
150
200
250
300
350
400
450
500
550
600
ALTITUDE (km)


GEOPROBE PGs
MASS SPECTROMETER
EUV EXTINCTION
n [N2] cm-3
10^11
10^10
10^9
10^8
130 140 150 160 170 180 190 200 210 220 230 240 250 260 270
ALTITUDE (km)



10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
n [N_2] (cm-3)
150
200
250
300
350
400
450
ALTITUDE (km)
NASA 8.25
NASA 6.06
NASA 18.01
H. & P. MODEL 2
@ 1300 hrs.


1100
1000
900
800
700
600
T (°K)
NASA 8.25
NASA 18.01
HALL ET AL
T$_i$ = 1050°
T$_i$ = 850°
T$_i$ = 650°
150
200
300
400
500
ALTITUDE (km)