AE AND DE MASS SPECTROMETER OBSERVATIONS RELEVANT TO THE SHUTTLE GLOW

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Abstract. Recent work by Swenson et al. [1985] has suggested that NO_2 may be responsible for the observed continuum glow near surfaces of the space shuttle. This report will review the observations of atomic nitrogen (N) at shuttle altitudes using mass spectrometers, giving special attention to the surface reactions of N relevant to the production of NO_2 on spacecraft surfaces. We will present data from two semi-open source mass spectrometers, the OSS instruments on the Atmosphere Explorer-C and -D satellites, and the closed source Neutral Atmospheric Composition Spectrometer (NACS) on the Dynamics Explorer-2 satellite, to show the similar behavior of NO in each case and the contrasting behavior of NO_2. Although signals of NO and NO_2 are highly dependent on surface temperature and surface composition, it appears that direct exposure of ion source surfaces to rammed gas is a necessary condition for the production of large amounts of NO_2. We will also present evidence that elevated surface temperatures can significantly reduce the production of NO_2, likely by causing more rapid desorption of NO from these surfaces.

Introduction

The first comprehensive study of N densities in the thermosphere was presented by Mauersberger et al. [1975], using data from the Open Source Neutral Mass Spectrometer (OSS) on the Atmosphere Explorer-C satellite [Nier et al., 1973]. It is standard practice to use the mass spectrometer signal of mass 32 (O_2) as a measure of ambient atomic oxygen because of ion source surface adsorption of O and subsequent recombination into O_2 (see, for example, Hedin et al., 1973). A similar process was discovered to occur in the case of atomic nitrogen: observations from the Open Source Neutral Mass Spectrometer (OSS) on the Atmosphere Explorer-C satellite indicated that the mass 30 (NO) signal and the direct signal of atomic nitrogen (mass 14) exhibited identical variations with local time, latitude, and season, once the relatively large source background of NO was subtracted out. Approximately 95% of the N atoms detected appeared as NO or NO_2, the dominant spectral peak of which is also at mass 30. These observations suggested that highly reactive N atoms entering the ion source of a mass spectrometer were likely to adsorb on metal surfaces and/or to react chemically with the dominant adsorbed species, atomic oxygen.

A recent study of data from the Neutral Atmospheric Composition Spectrometer (NACS) on the Dynamics Explorer-2 satellite [Carignan et al., 1981] has confirmed that with this instrument also the mass spectrometer signal of NO provides a quantitative measure of thermospheric N densities [Engebretson and Nelson, 1985].

Temperature Dependence

As part of the analysis of NO signals it was found that the level of background NO in the mass spectrometer ion source could be correlated with the temperature of the ion source walls. When data were taken on successive orbits, the background level of mass 30 decreased significantly after the first orbit, reaching stable levels on the third and subsequent orbits, but reverting to earlier levels after one or more orbits of experiment inactivity.

Shown in Figures 1 and 2 are logarithmic plots of source densities of mass 30 (NO), 40 (Ar), 14 (a product of electron bombardment of N_2), and 4 (He) as a function of time for two spinning orbits, 1630 and 1632, run November 21, 1981. The NACS instrument was off during orbit 1629, but on during successive perigee passes during orbits 1630-1633. Note that at the beginning of orbit 1630 the mass 30 background was nearly 8×10^8 cm^{-3}, while on orbit 1632 it was a factor of 10 lower at comparable altitudes. All other signals shown appear to be nearly identical on both orbits.

This contrast between "cold" and "warm" orbits, with ion source surface temperatures of approximately 300 K and 450 K, respectively, is characteristic of data from each of the satellite mass spectrometers studied here. Table 1 shows representative data for masses 30 and 46 from elliptical orbit passes of AE-C and DE-2 for such "cold" and "warm" orbits. In each case there are significantly lower signals of masses 30 and 46 on the downleg of these orbits when ion source surfaces are warmed up. Near the end of each pass, however, there is considerably less variation between "cold" and "warm" passes, consistent with the closer agreement in surface temperature near the end of each pass.

It is also clear in Table 1 that the abundance of NO_2 on the downleg of an orbit is dependent on temperature effects. Data from both AE-C and DE-2 instruments indicate that NO_2 signals are even more sensitive than NO signals to variations in surface temperature. Figures 3 and 4 show data from the OSS mass spectrometer on AE-C for two orbits specially programmed for a study of the variation of NO and NO_2 with surface temperature history. During this period in late 1975 the AE-C satellite was operated only one day a week, for two full circular orbit passes at 310 km altitude. Orbit 8530 was run after the usual 30-min OSS warmup. Orbit 8536 was preceded by a 4-hour warmup, thus simulating operations during two previous perigee passes in elliptical orbit operations.

The sharp early morning rise characteristic of thermospheric N densities is evident in Figure 3, a plot of net mass 30 signals from orbit 8536, but is obscured in the data from the beginning of orbit 8530 (Figure 4). Comparison of the two figures indicates that NO_2 accounts for most of the excess mass 30 signal observed on orbit 8530 (NO_2 produces 2.7 times as much signal at mass 30 as at mass 46). It is also important to note that although the ratio of NO_2 to NO appears to drop throughout orbit 8530, indicating the gradual desorption of an adsorbed species, the spin modulation evident on both orbits suggests that much of the NO_2 observed must be attributed to a relatively fast production process.

Ram Effects

The method of using mass 30 signals to measure thermospheric N worked successfully with other satellite mass spectrometers as well. Signals of masses 30 and 14 on the AE-D OSS instrument also were proportional, and the use of a gold-plated ion source on the AE-D instrument appeared to reduce considerably the dependence of the net NO signal on surface temperature effects. The NACS instrument on DE-2 also used a gold-plated ion source, but the closed source design of this instrument prohibited direct access of any molecules or atoms to the ionization chamber, hence excluding any direct measurements of N atoms.

A comparison of NO and NO_2 observations from the AE-C, AE-D, and DE-2 mass spectrometers is presented in Table 2. The ion source surfaces of the AE-C instrument are made of nichrome, while those of the AE-D and DE-2 instruments are gold plated. The AE-C and -D ion sources are of an open source design, with ram acceptance angles of 30 and 12 degrees, respectively, while the DE-2 ion source is closed, necessitating typically 100 wall collisions and complete thermal accommodation of all gas molecules before they will be analyzed by the mass spectrometer. Table 2 shows that the open source instruments produce large amounts of NO_2, with the fraction increasing as the satellite proceeds toward higher altitudes. The AE-D data at 700 km indicate nearly 100% of the mass 30 signal is due to NO_2. Although the DE-2 NACS instrument also uses a gold-plated source, the DE-2 data indicate the reverse effect: the fraction of NO_2 decreases to less than 3% as the satellite passes toward higher altitude. We attribute this striking difference to the closed source geometry of the DE-2 instrument, and infer that the thermal accommodation of the ramming gas (much of which is thermospheric O) significantly reduces the probability of converting adsorbed NO into NO_2.

Further analysis of the surface chemical processes reported here is contained in papers by Engebretson and Mauersberger [1979] for the Open Source Neutral Mass Spectrometer (OSS) instruments on the Atmosphere Explorer satellites, and Engebretson and Nelson [1985] for the Neutral Atmospheric Composition Spectrometer (NACS) instrument on the Dynamics Explorer-2 satellite.

Summary of Observations

Data from three satellite mass spectrometers have shown that odd nitrogen molecules are formed in abundance on the surfaces of mass spectrometer ion sources as a result of the impact of thermospheric O and N atoms. The adsorption and desorption of NO and NO_2 from these surfaces appears to vary considerably with surface temperature. Heating of ion source surfaces appears to significantly reduce the concentration of these species, especially NO_2. Comparison of data from open and closed source instruments with gold-plated surfaces indicates that adsorbed NO is much more likely to be converted to NO_2 by ramming O atoms than by less energetic (thermalized) O atoms.

Implications for Shuttle Glow

The large mass spectrometer background and small spin modulation we have observed suggest that NO and NO_2 will likely form long-lasting monolayers on various satellite and/or shuttle surface materials. Production of NO_2 is likely to be greatly enhanced on cold surfaces exposed to ramming thermospheric gas. Although our experience is clearly limited to two metallic surfaces, we consider it likely that the simple gas-surface reactions reported here will take place on other spacecraft surfaces as well. The optical observations and modeling of Swenson et al. [1985] and the mass spectrometric observations reported here make NO_2 a likely candidate for the source of the glow observed near the ram-oriented surfaces of various spacecraft.

It is intriguing to consider the use of a mass spectrometer to verify the presence of NO and NO_2 on surfaces other than those within the mass spectrometer's ion source. Although the large signal of odd nitrogen from mass spectrometer ion source surfaces makes this a difficult task, a beam inlet system, which is essentially an extension of the open source geometry used in the Atmosphere Explorer satellite mass spectrometers, may provide a feasible way to complement existing optical detection systems.

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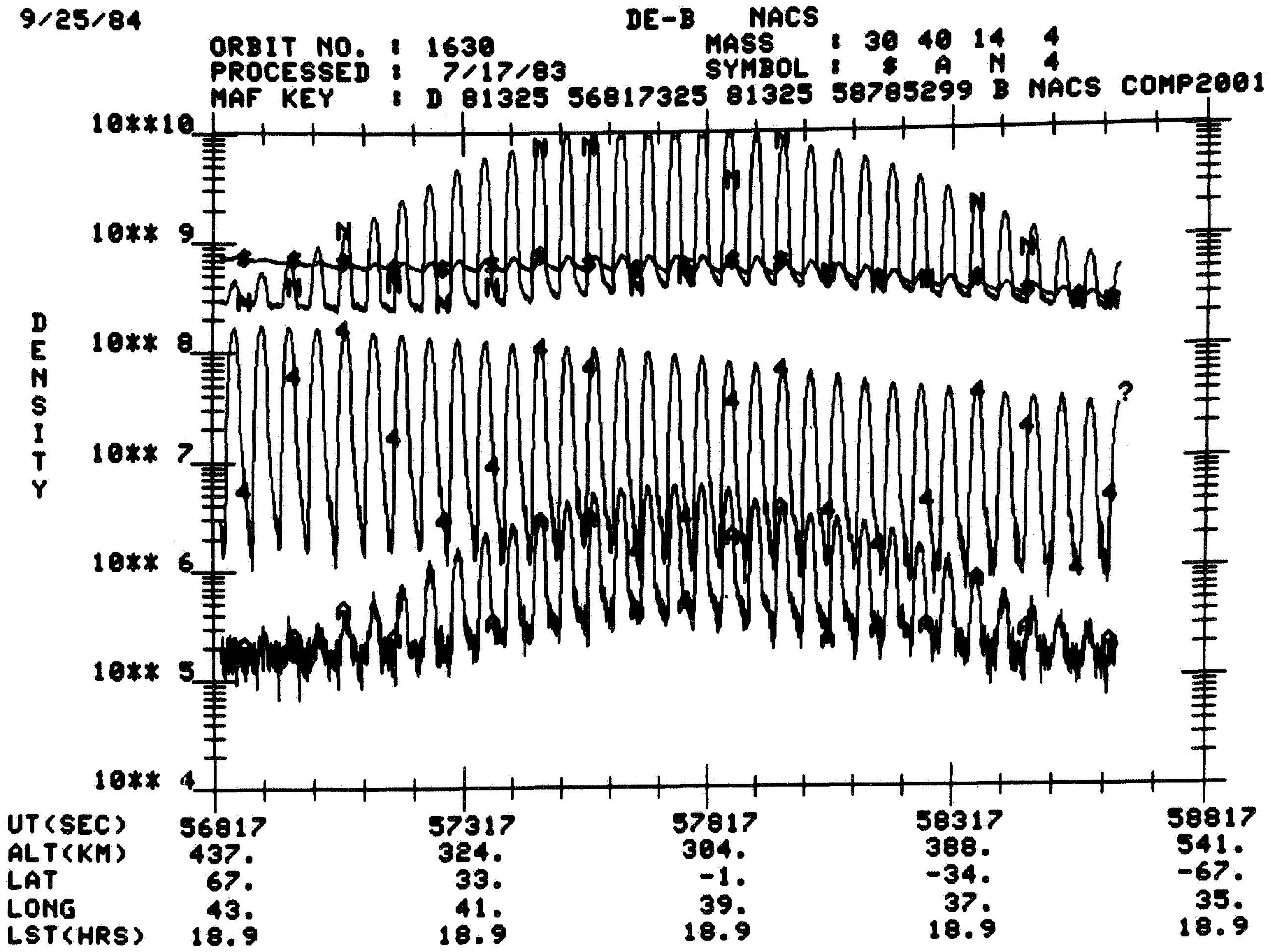

Fig. 1. Ion source number densities of NO, Ar, N_2, and He measured by the Neutral Atmospheric Composition Spectrometer (NACS) on orbit 1630 of the Dynamics Explorer-2 satellite, plotted as a function of universal time (UT). The NACS instrument was off during the previous orbit.

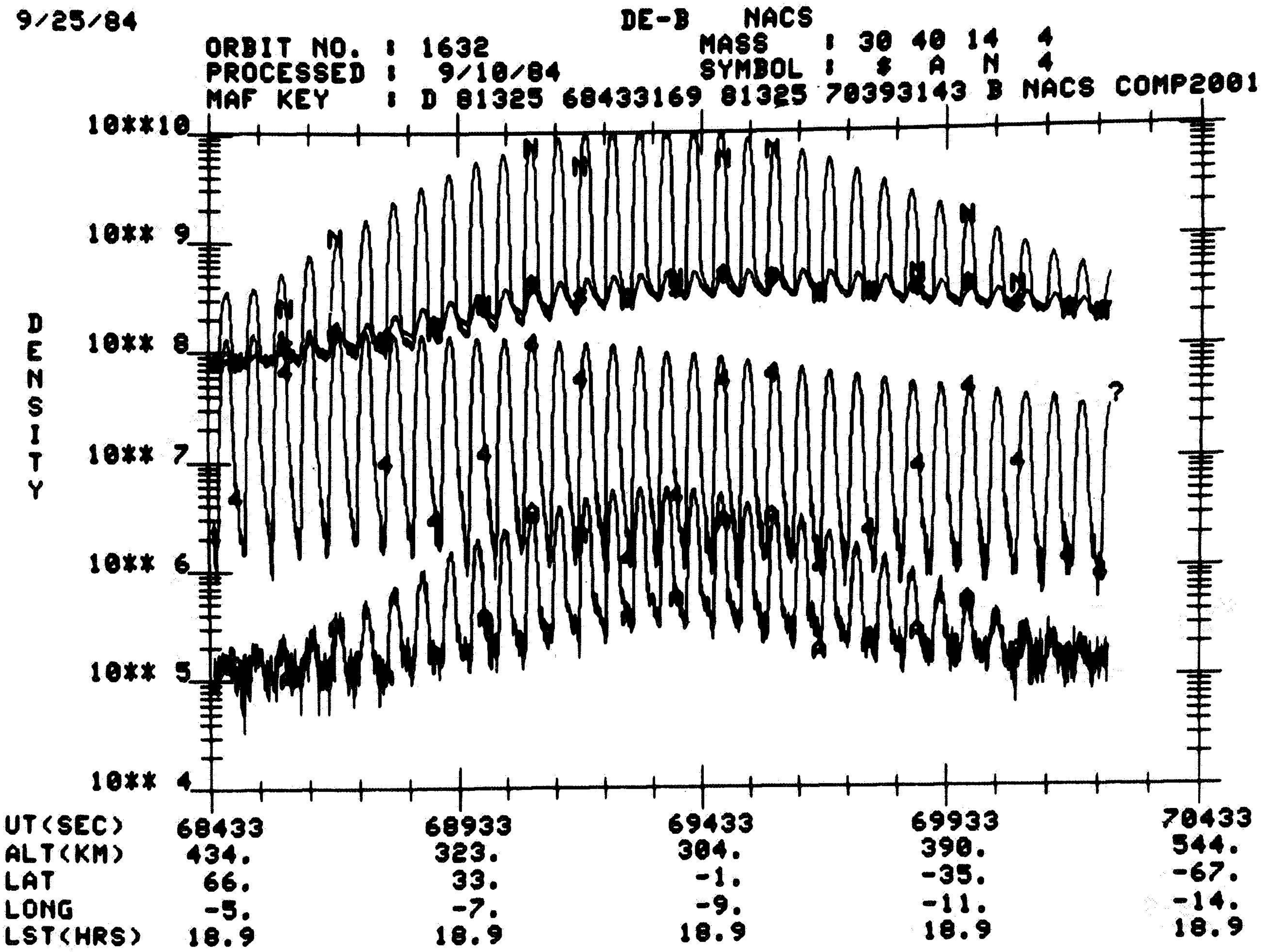

Fig. 2. Ion source number densities of NO, Ar, N_2, and He for orbit 1632 of DE-2, as in Figure 1. The NACS instrument was on for two successive perigee passes prior to this orbit.

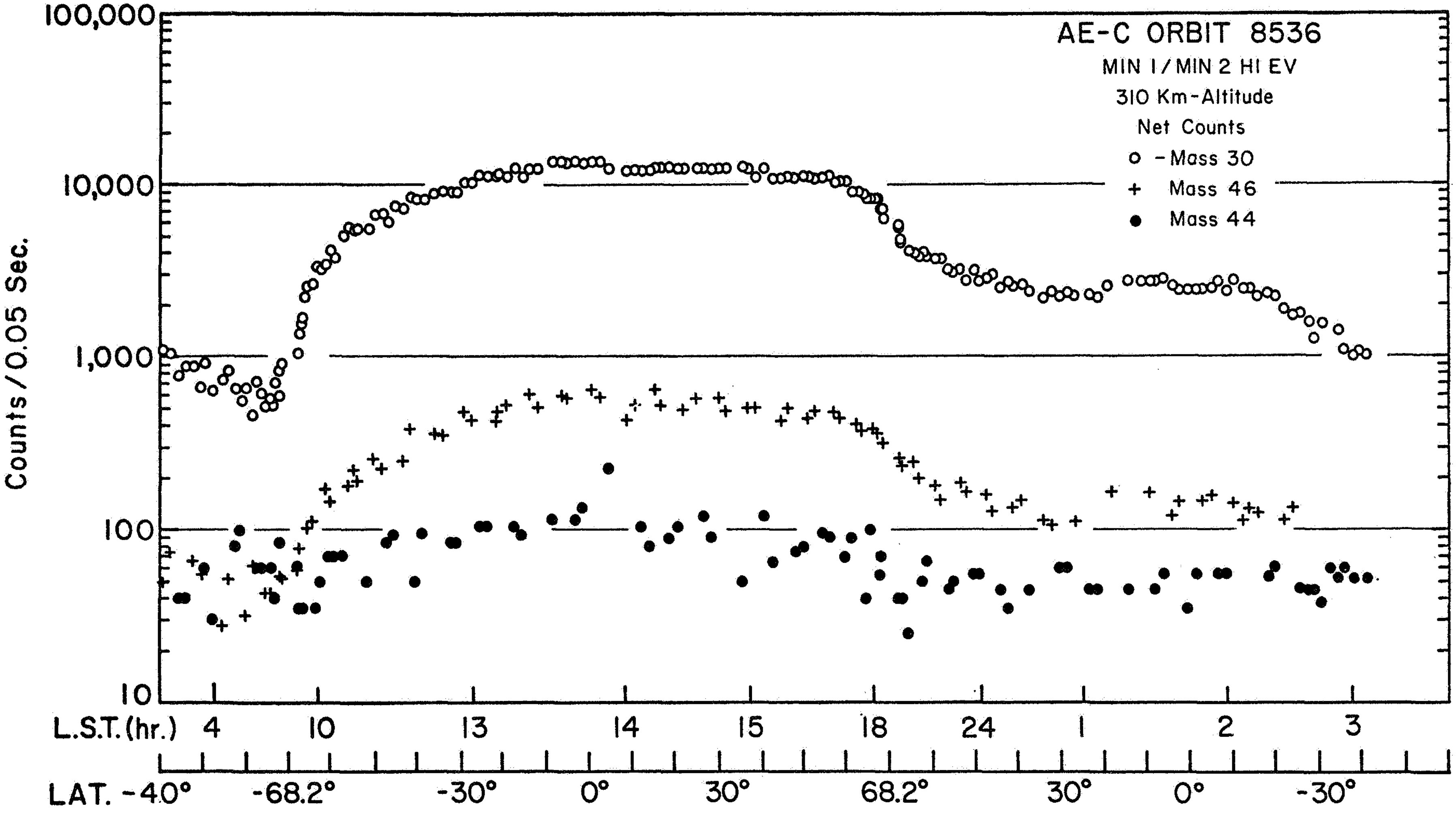

Fig. 3. Net (forward facing minus backward facing) counts of masses 30, 44, and 46 measured by the Open Source Neutral Mass Spectrometer (OSS) on orbit 8536 of the Atmosphere Explorer-C satellite, plotted as a function of time during a full orbit pass. This orbit was preceded by a 4-hour warmup.

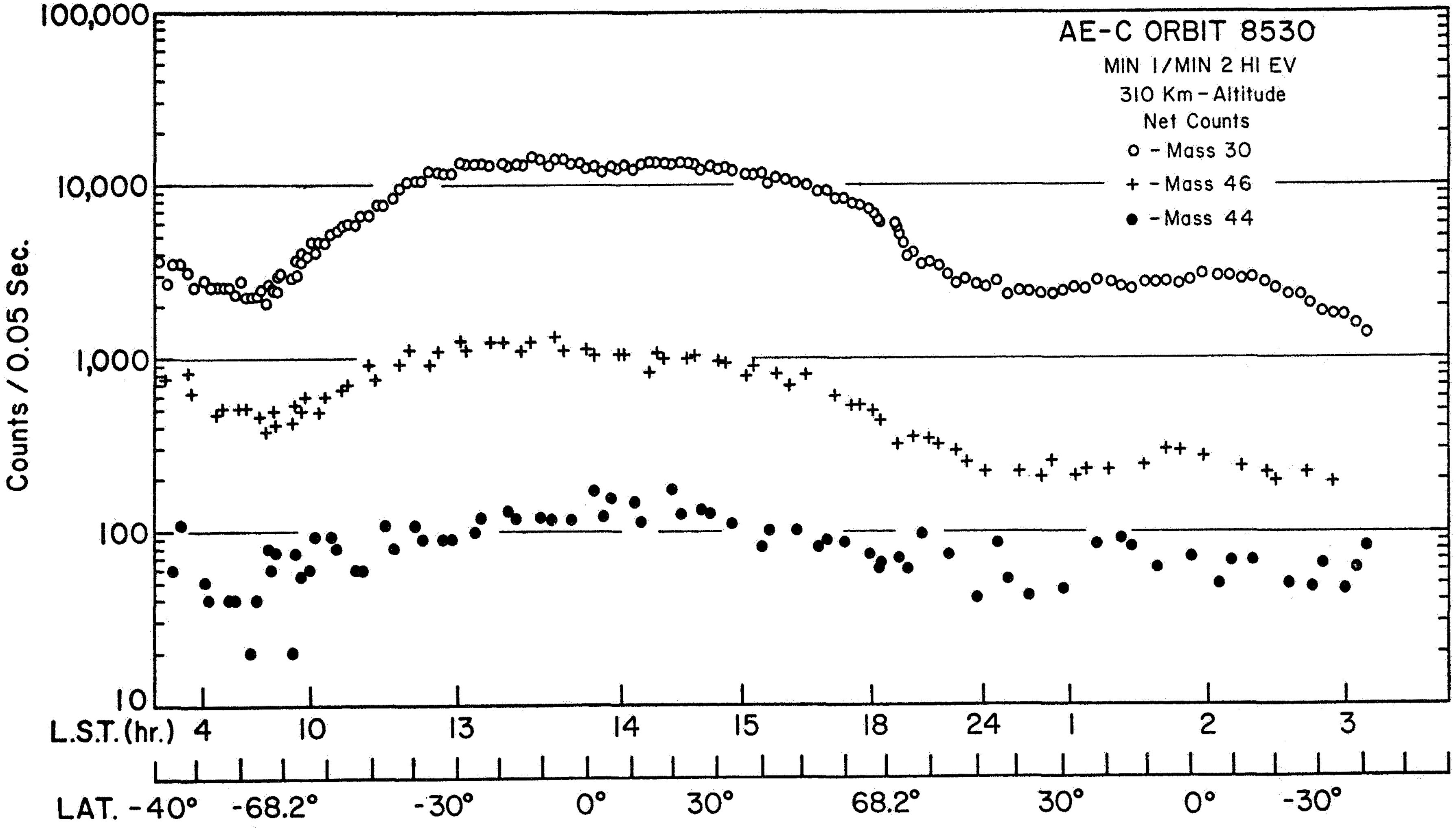

Fig. 4. Net counts of masses 30, 44, and 46 for orbit 8530 of AE-C, as in Figure 3. This orbit was preceded by a standard 30-min warmup.

TABLE 1. TYPICAL ORBIT COUNT RATES OF MASSES 30 AND 46 FROM ELLIPTICAL DESPUN ORBITS OF THE AE-C AND DE-2 SATELLITES

	AE-C			DE-2		
Altitude	Mass 30	Mass 46	30/46	Mass 30	Mass 46	30/46
			"COLD" orbits			
500	1,800	500	3.6			
300	17,500	2,000	8.8	29,200	3,130	9.3
Perigee						
300	17,000	1,000	17.0	12,900	1,200	10.8
500	2,850	310	9.2			
700	1,450	260	5.6			
			"WARM" orbits			
500	320	36	8.9			
300	7,800	430	18.1	9,900	161	61.7
Perigee						
300	12,400	670	18.5	13,800	330	41.3
500	2,000	230	8.7	3,500	30	115
700	1,060	200	5.3	2,050	15	137

TABLE 2. RATIOS OF SIGNALS OF MASSES 30 AND 46 FOR THREE SATELLITE MASS SPECTROMETERS. INTENSITY RATIOS ARE DETERMINED AT THE GIVEN ALTITUDES ON THE UPLEG OF ELLIPTICAL ORBITS UNDER SUNLIT CONDITIONS.

	AE-C	AE-D	DE-2
Source material	nichrome	gold	gold
Geometry	open (30°)	open (12°)	closed
Altitude		N(30) / N(46)	
300 km	18	4.6	41
400	13	3.6	56
500	8.7	3.6	92
600	6.6	3.5	120
700	5.3	2.7	137