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Ion Mass Spectrometer Experiment

for

ISIS-II Spacecraft

FINAL REPORT

CONTRACT NUMBER NSG 5087

To

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From

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INTRODUCTION

The International Satellite for Ionospheric Studies (ISIS) program of NASA was the longest duration program in NASA history. A number of satellites were flown under this program, the last being called ISIS-II, which was launched on April 1, 1971 and operated successfully for over 13 years.

The University of Texas at Dallas developed an experiment called the Ion Mass Spectrometer (IMS), that flew on the ISIS-II spacecraft. It operated for 10 years providing a large data base of positive ion composition and ion flow velocities along the orbit of the satellite, the latter being circular at 1400 km with a 90° inclination. The data have been processed and reside in the National Space Sciences Data Center.

ION MASS SPECTROMETER

For most of the lifetime of the ISIS-II satellite, the Ion Mass Spectrometer (IMS), obtained data on the composition, number density and flow velocity of thermal positive ions in the ionosphere. From the composition, number density, and flow velocity of the positive ion species, the ion flux normal to the spacecraft trajectory was obtained. Because the spacecraft is in a circular orbit, this flux is in the vertical direction and in the polar regions also lies along the magnetic field lines. Hence, the instrument can determine the velocities and fluxes of the polar wind particles, and indeed, much of the data has been analzyed for such flows. These data exist on magnetic tapes and on microfiche. Full orbit plots as well as those of individual passes are available.

The ISIS program was controlled by a working group comprised of the experiment Principal Investigators, satellite controller and representatives from many other countries which participated in the program through operation of ground stations or ground based experiments. A sub-set of the Working Group, the Experimenters' Team met periodically to compare results from on-going investigations and to plan additional activities.

A set of 4 ISIS-II data books was published by the National Space Science Data Center as pertinent examples of ISIS data to show the types and breadth of ISIS data that are available from the Data Center. Ion composition results appear mainly in Volumes 3 and 4. A special format for the ion mass data was prepared in order to show its correlation with other direct measurements. In particular, the IMS data are presented with the electron temperature data from the Cylindrical Electrostatic Probe. The format shows the data over 20 minute time segments as concentrations of the more dominant ion species, H^+, He^+, O^{++}, N^+, and O^+. Universal time is given in two minute intervals with ephemeris data at the bottom of the page. A sample page is attached as Fig. 1. The data shown is for the summer day time (MLT) period with solar zenith angles ranging from 83 to 35^{o}. The region covered extends from midlatitude to over the summer polar cap. O^+ is the dominant ion species with H^+ at only a few percent level. The top portion of Fig. 2 shows the crossover from O^+ to H^+ as the season changes to winter daytime. The lower plot gives the typical nighttime composition, wherein H^+ is dominant and O^+ is much less than 1% of H^+ in the winter hemisphere (left side) but increases to 10% near the equator.

Fig. 3, top, shows the nighttime polar region which is markedly in contrast to the day polar region. Suddenly O^+ becomes the dominant ion by an increase in concentration of over 3 decades coupled with a decrease of a factor of 20 of the light ions. Polar wind flows exist in the region of O^+ dominance. The bottom part of the figure shows daytime winter data with O^+ dominant but quite structured as compared with summer. At the right side of the plot the spacecraft has gone over the pole into the night side (MLT) where a large spike of O^+ and N^+ is observed. This region is similar to the left side of the upper graph. These plots are typical of the many thousands that have resulted from the ISIS-II IMS spectrometer operation.

The polar wind plasma flows have been found in broad regions of the ionosphere from somewhat equatorward of the H^+ trough to well into the polar cap region.

Polar plots of the location of H^+ fluxes for quiet and disturbed times have been made. The lower boundary of the fluxes, 50 to 60^{o} invariant latitude, exhibits large magnitudes with low velocities, whereas above 70^{o} invariant latitude the fluxes are generally smaller with higher velocities. This boundary moves towards the equator during a magnetic storm. New field lines then open to the tail causing large fluxes of hydrogen ions to flow to the tail region emptying these field tubes. When these field lines reconnect, plasma begins to flow up along the field line refilling them. Since the mean time between substorms is longer than the filling cycle of flux tubes, there is a continuous filling of these tubes and a rather continuous flow of polar wind particles which can often be along closed field lines. In the winter polar wind velocities tend to be larger than in the summer time but confined to a narrow region, while in the summer the area is quite broad with fairly low velocities. Also in the winter there is a very marked polar cavity essentially devoid of ionization, whereas, the summer polar cap region contains a broad region of O^+ dominance of the order of 10^4 ions cm^{-3}.

The ISIS-II ion mass spectrometer has observed large (up to an order of magnitude) increases in ion concentrations in the polar regions between 80 and 84 degrees invariant latitude. These enhancements were observed at 1400 km, the ISIS circular orbit altitude, in the nighttime in October - November, 1971 (northern hemisphere) and again in the summer of 1972. O^+ is the dominant species although increases in H^+, He^+, and N^+ are seen as well. The peaks appear to be a quiet time phenomenon and either disappear during magnetically disturbed days or shift equatorward to as low as 50°. The low latitude peaks may not be necessarily related to those in the polar caps. Enhancements in T_e and low energy electron precipitation are observed to occur a degree or two equatorward of the ion peaks. A polar wind is seen to occur in the regions of the peaks.

There is much evidence that the knee in electron concentration at $L = 4$ and the trough in total ion concentration are related phenomena. Near the F peak, O^+ is the dominant ion at all latitudes and its distribution with latitude is dependent mainly on the chemical loss processes and convective motion of the plasma. The plasma lifetime in the vicinity of $L = 4$ is on the order of 30 minutes and thus the plasma displays latitudinal distributions that are dependent on processes that have relatively short time scales. These time scales and processes will dominate the plasma distribution in altitude until O^+ becomes a minor ion or until the motion of ions along the field lines becomes an important factor. Above about 1000 km altitude hydrogen and helium ions play a dominant role in the distribution of the plasma. H^+ is produced by charge exchange between O^+ and neutral hydrogen and once produced it will flow along magnetic field lines to attempt a diffusive equilibrium profile. The rate of H^+ flow is determined primarily by the rate of production of H^+ and the electron temperature, which determines the H^+ scale height. In the simple case of a corotating dipole flux tube, H^+ will flow up the field lines during the day when O^+ is being produced and the electron temperature is high, and H^+ will tend to flow down the field lines at night when charge exchange provides a net loss for H^+ and the electron temperature is lower. This simple breathing of the protonosphere is complicated, as one moves to higher latitudes, by the fact that the field tubes no longer corotate or maintain their dipole shape. In principle, it is possible to locate a line in the equatorial plane, and a surface made up of the magnetic field tubes that pass through that line, such that at a given instant in time all plasma earthward of this surface rotates around the earth and stays on magnetic field tubes that are approximately dipolar in shape. Outside this surface the plasma motion is dominated by the electric field derived from the solar wind-magnetosphere interaction, and in the equatorial plane the plasma moves along a surface coincident with or parallel to the magnetopause. The line separating these two flow regimes has frequently been called the plasmapause.

Studies of the high latitude convection pattern in the ionosphere are essential to our understanding of the plasma distribution in this region and indeed the F-region midlatitude trough formation is critically dependent on the nature of the convection pattern. Models for the formation of the trough would actually predict that the stagnation region or bulge is located on the evening side of dusk in most cases. This has some interesting consequences in relation to the magnetic activity dependence of the plasmapause observed in the ISIS-II data. ISIS-II IMS, Atmosphere Explorer MIMS and Dynamics Explorer RIMS data all show these effects.

Two dimensional distributions of the H^+ and O^+ densities constructed statistically from the ISIS data set reveal the coexistence of two types of density depressions (troughs) in the dusk side: one is the well-known LIT (Light Ion Trough) which can be seen in the H^+ distribution at 60°; the other is a latitudinally narrow trough seen commonly in the H^+ and O^+ distributions at latitudes higher than LIT. The position of the later type of trough (NT) has a local time dependence similar to that of the F-layer main trough (MT). Examination of NT events observed in particular orbits show that NT has identical characteristics with HLT (High Latitude Trough) observed by OGO-6 and is located at the equatorward edge of the soft-particle precipitation region. It was concluded that the two types of troughs observed at 1400 km have different origins. LIT is caused by the low plasma pressure near the equatorial plane beyond the plasmapause. NT is a topside signature of MT which is produced by competition of various processes operating in the polar F layer, such as plasma drift, enhanced chemical reaction rate due to the magnetospheric convection electric field, and particle precipitation.

The IMS data from ISIS-II showed cold flowing hydrogen and helium ions in the auroral and polar regions. Some of the data show a marked flux asymmetry with respect to the relative wind direction. The observed data can be modelled as drifting Maxwellian distributions perturbed by a first order Spitzer-Harm heat flux distribution function. The ISIS data is fitted to the model to determine the ion flow velocities and the heat flux magnitude and direction at the ISIS altitude. Comparisons are made with Dynamics Explorer RIMS data to which this model has already been applied. RIMS data are generally at a much higher altitude and frequently show supersonic flow velocities. Having data at two different altitudes will enable analysis of the whole problem of transition from subsonic to supersonic flows.

The attached bibliography lists papers on or using data from the IMS.

Selected papers are appended.

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"Light Ion Concentrations and Fluxes in the Polar Regions During Magnetically Quiet Times," J. H. Hoffman, and W. H. Dodson, J. Geophys. Res., 85, 626, 1980.

"An Unusual SAR Arc Observed During Ring Current Development, August 4, 1972," with G. Shepherd, L. Brace, J. Burrows, H. Hames, D. Klumpar, A. Nagy, E. Stathopoulos, and J. Whitteker, Planetary and Space Science, 28, pp. 69-84, Jan. 1980.

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ABSTRACTS

"Light Ion Velocities and Fluxes in the Polar Region Observed from the ISIS-II Satellite," W. H. Dodson.

"The Behavior of H^+ Ions in the Polar Region," W. H. Dodson.

FIGURE 1

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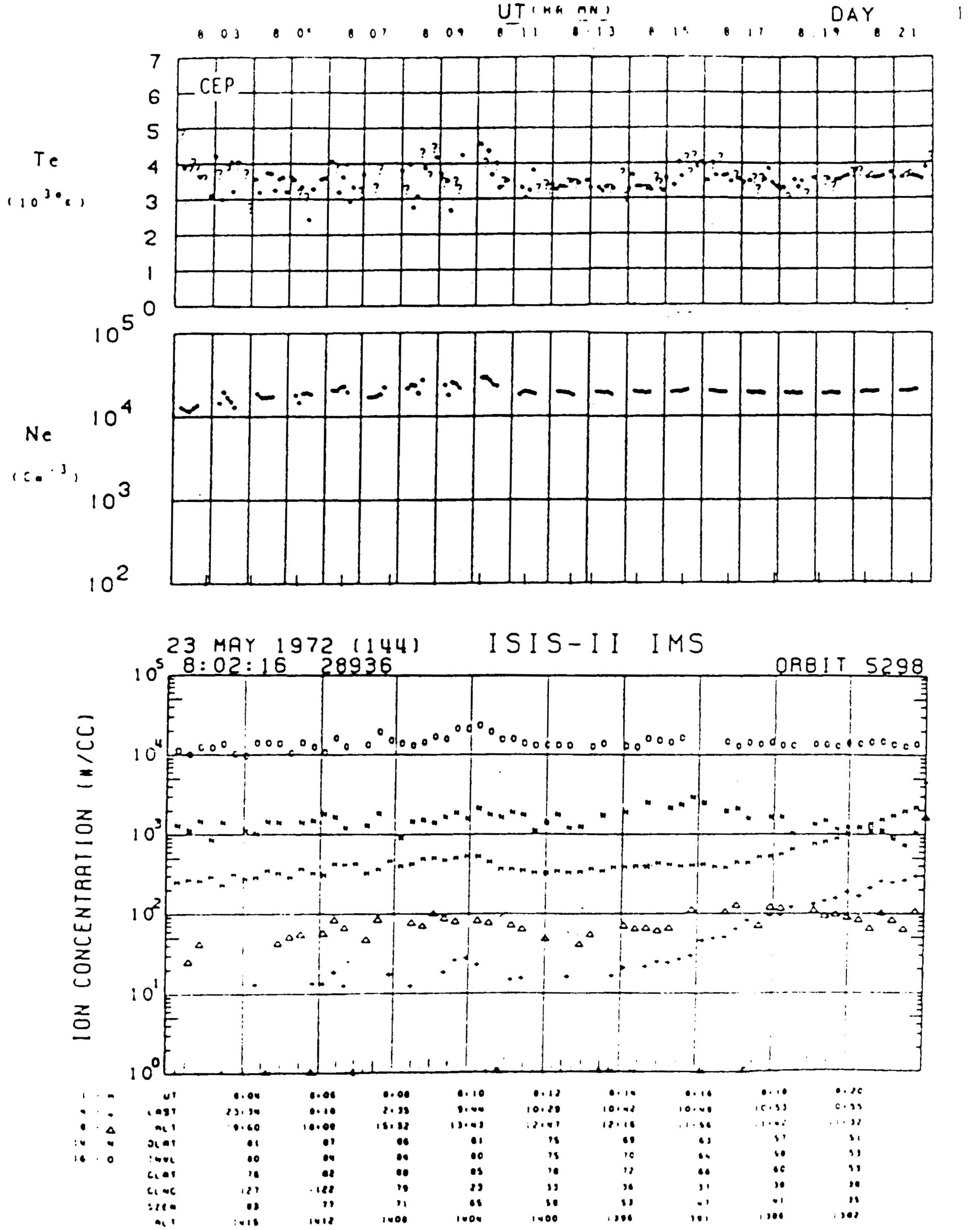

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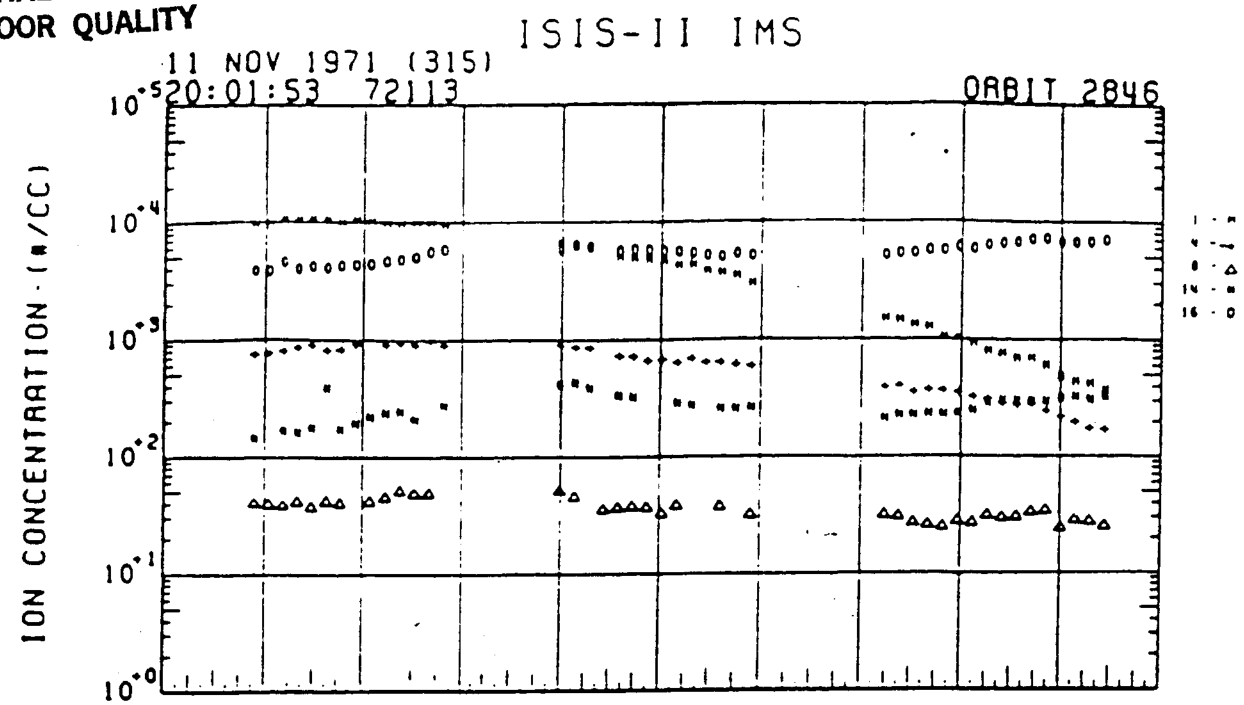
FIGURE 2



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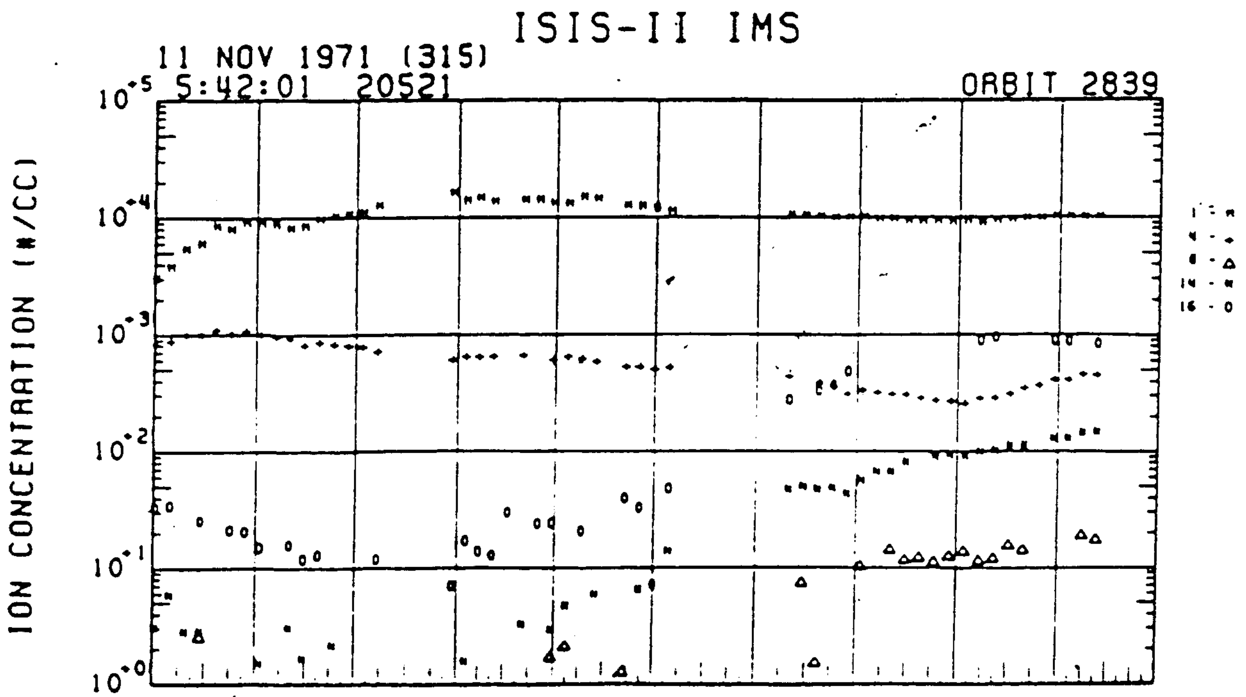

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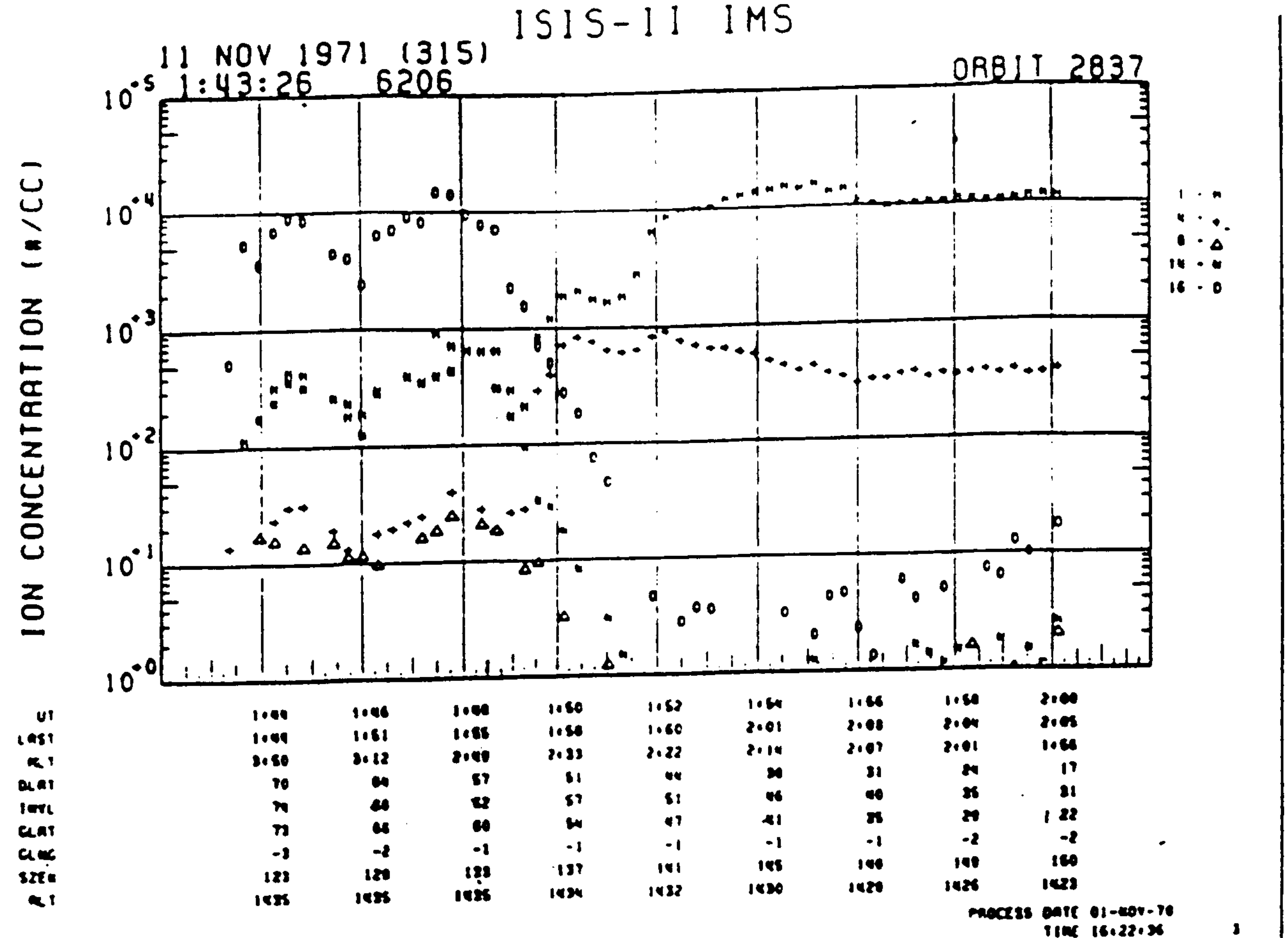
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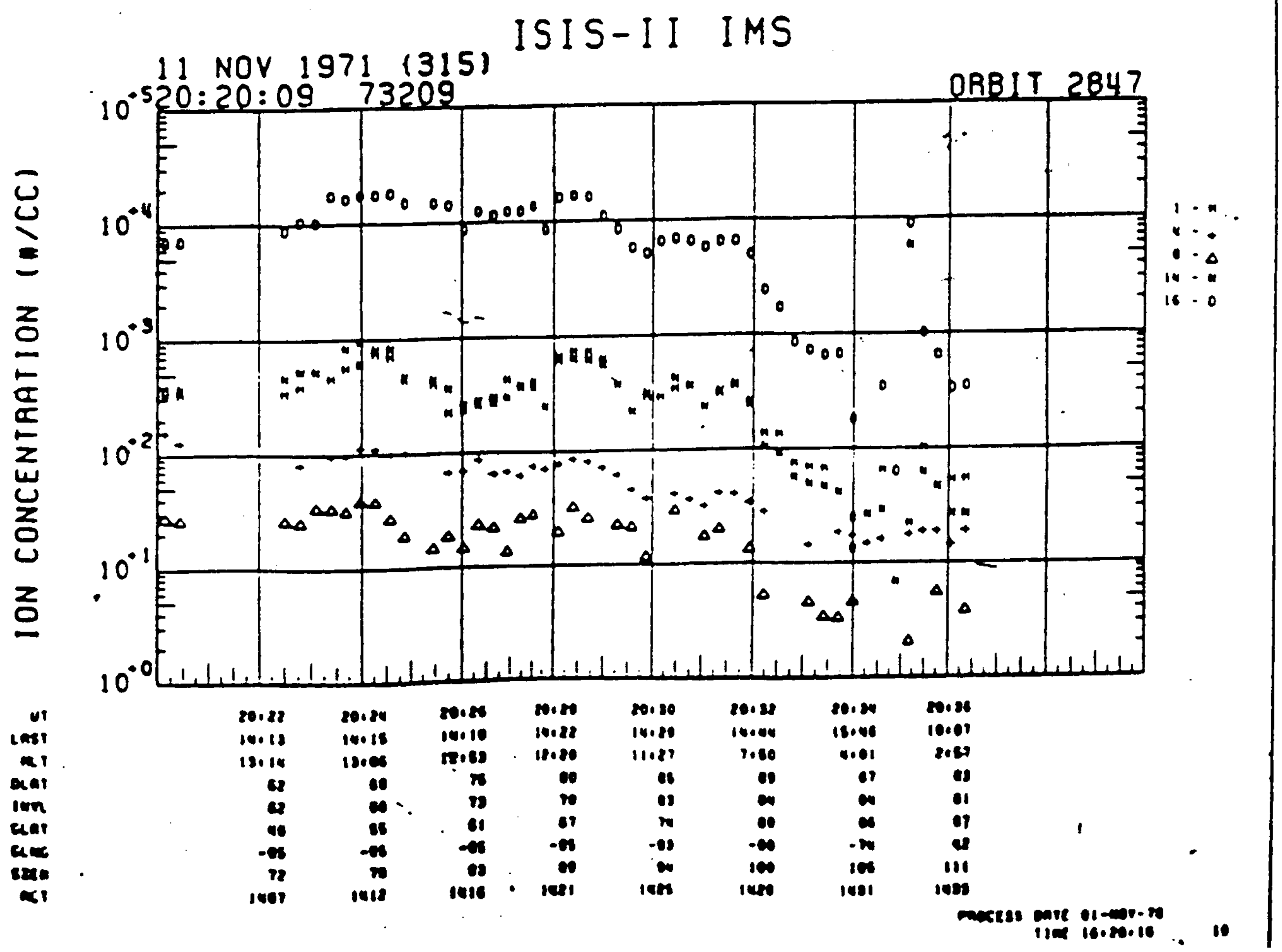
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