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Final Report

NASA Grant NAG 5-579

Analysis of ISEE-3/ICE Solar Wind Data

Introduction

Under the grant that ended November 11, 1988 work was accomplished in a number of areas. They are listed below:

1. Analysis of solar wind data
2. Analysis of Giacobini/Zinner encounter data
3. Investigation of solar wind and magnetospheric electron velocity distributions
4. Experimental investigation of the electronic structure of clusters

Reprints and preprints of publications resulting from this work are included in the Appendices. A general description of the different categories follows below:

General Description of Work Accomplished

The University of Maryland analysis of the solar wind ICI data up to the beginning of the grant was generally restricted to the determination of $^{3}He^{++}$, $^{4}He^{++}$ and the +6 and +7 charge states of oxygen. Under this grant the analysis was expanded to include the charge states of C, N, Mg, Ne, Fe and Si. The basic program WINDCOMP can be used to calculate minor ion abundances and coronal temperatures subject to a wide variety of chemical and physical constraints. Results from the program have been checked against the analogous program of Kunz, Bochsler and Schmid.

At the same time that WINDCOMP was being written, the helium routines were updated and used to reduce almost all the available ICI data. Modifications to the routines were generally minor, but in one case where the explicit

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calculation of an integral replaced an analytic approximation there were significant improvements in the results. A summary of this procedure is included in the Appendices. A draft of a manuscript on solar wind abundances and variation with the solar cycle is included in the Appendices.

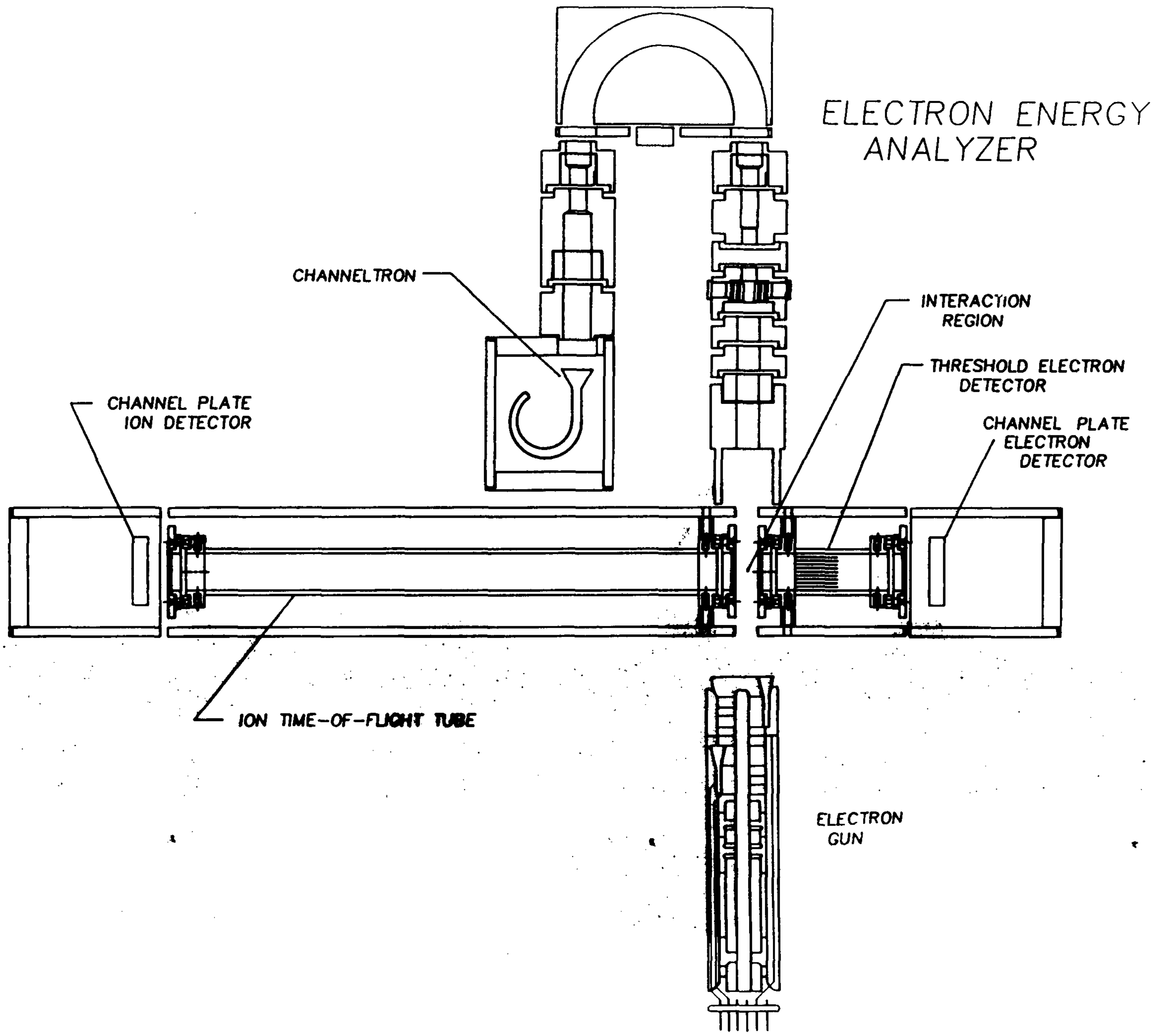
In September 1985, ISEE-3 passed through the tail of comet Giacobini-Zinner. The ICI had been reprogrammed to operate in the mass per charge range from 1 to 32, effectively covering solar wind as well as cometary species. The results from the encounter resulted in three publications and a contributed paper at the Heidelberg Conference on Halley's Comet. These are included in the Appendices.

The measurement of the velocity distribution of the electrons in space plasmas is a fundamental measurement since the velocity distribution functions contain information about the elementary processes associated with plasma formation and evolution. During the grant period we have worked on both experimental and theoretical aspects of this subject. The experimental work has concentrated on developing instruments based on tomographic principles for measuring electron velocity distribution functions. We have identified a number of interesting electric and magnetic field configurations suitable for a tomographic mapping of velocity distributions. Though all tomography is based on the inversion of integrals to obtain source functions, the problem of velocity distribution functions is qualitatively different from well known medical tomography because of the wide dynamic range of the source function. As a result, an entirely new mathematics must be developed for this problem. Our results are summarized in the Appendices. It is important to note that the velocity distribution problem is a special case of a much broader range of problems where the source function spans several orders of magnitude; a problem largely ignored up to the present.

Our theoretical work on electron velocity distributions has concentrated on the origins of the "long tails". We have shown that the outer portions of the distribution can be associated with multiplicative rather than additive processes in the course of the formation of the plasma. This analysis is from a point of view that focuses on the overall form of the plasma interactions rather than the details. A reprint of this work is included in the Appendices.

In the last year a significant part of the research performed under the contract has been associated with cluster research. The technique we have developed for investigating the electronic structure of clusters is derived directly from the dipole (e,2e) techniques and threshold photoelectron spectroscopy. The combination of the two techniques provides an efficient tunable excitation source, near 100% collection of the photoelectrons and photoions and high energy resolution. The present apparatus shown in the figure consists of an electron gun, an electron energy loss spectrometer for detecting incident electrons that have lost a predetermined amount of energy to the target cluster, a threshold secondary electron detector and a residual ion time-of-flight (TOF) mass analyzer. The combination of the fixed energy electron source and energy loss spectrometer is equivalent to a variable energy photon source. For example, if the incident electrons have an energy of 1 keV and the energy loss spectrometer is set to pass electrons of 980 eV, electrons transmitted through the spectrometer will have lost 20 eV to the target. This is equivalent to the absorption of a 20 eV photon by the target. If the deposition of 20 eV into the target results in ionization, the simultaneous measurement of the ejected electron energy is sufficient to give the ionization potential of the target. This is the electron excitation equivalent of conventional photoelectron spectroscopy. In the present apparatus, however, the secondary electron detector is sensitive to only threshold electrons and the pass energy of the energy loss spectrometer is scanned while recording those events giving correlated signals in both the threshold and energy loss detectors. The advantage of this system is efficient collection of secondary electrons and high energy resolution limited only by the energy spread of the incident electron beam and passband of the energy loss spectrometer. A TOF residual ion mass analyzer is used to identify the ion resulting from the ionization event. In the case of fragmentation, the residual ion signal gives a broadened TOF spectrum.

At present each of the elements of the apparatus have been tested separately using N_2 and rare gas targets. An unanticipated difficulty has been the accumulation of residual ions and electrons in the collision region giving rise to high background levels, especially in the TOF spectrum. The unwanted electrons have been effectively eliminated by maintaining a small draw-out field across the interaction region. For the case of the residual ions this solution is not practical because unreasonably large fields are required; instead, fast timing circuits are used to continuously record all ion flight times after the simultaneous detection of an energy loss and threshold electron. The resulting TOF spectrum shows a peak at the time corresponding to the residual ion's flight time down the tube. This departure from the normal TOF method, where at most one electron is allowed to be in the flight tube at any time.


ELECTRON ENERGY ANALYZER
CHANNELTRON
INTERACTION REGION
THRESHOLD ELECTRON DETECTOR
CHANNEL PLATE ION DETECTOR
CHANNEL PLATE ELECTRON DETECTOR
ION TIME-OF-FLIGHT TUBE
ELECTRON GUN

APPENDICES

I. WINDCOMP

II. Reformation of the $^4He^{++}$ Data Analysis Program for ICI

III. Solar Wind Observations with the Ion Composition Instrument aboard the ISEE-3/ICE Spacecraft

IV. Reprints from the Giacobini/Zinner Encounter

  a. "Ion Composition Results During the International Cometary Explorer Encounter with Giacobini-Zinner", Science, 232, 374 (1986).

  b. "Origin of metal ions in the coma of P/Giacobini-Zinner", Astron. Astrophys., 166 L1, 1986.

  c. "Carbon Clusters as a Source of C_1, C_2, and C_3 and their Ions in the Atmospheres of Comets Giacobini-Zinner and Halley", Proc. 20th ESLAB Symposium on the Exploration of Halley's Comet, Heidelberg, October 1986, ESA SP-250 (Dec. 1986), pp. 437.

  d. "Ion Composition and Upstream Solar Wind Observations at Comet Giacobini-Zinner", J. Geophys. Res., 92, 39 (1987).

V. Tomography

  a. Two electromagnetic field geometries for measuring velocity distribution functions.

  b. The Radon transform

VI. On the Long-Tail Solar Wind Electron Velocity Distribution, J. Stat. Phys., 52, 1423 (1988).