NASA/CR-96- 207357

Final Report for NAGW-4901

The Johns Hopkins University

Applied Physics Laboratory

Please refer to:
AC-23469

December 12, 1996

IN-12-CR
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National Aeronautics and Space Administration
300 E Street, SW
Washington, DC 20546

Attention: Dr. James B. Willett, Code SR (HQ5J82)

Subject: Grant Proposal for the Continuation of the Voyager Interstellar Mission: LECP Investigation

References: (1) Funding Authorization letter, dated 18 October 1996, from the Voyager Project Manager (G. P. Textor, JPL) to NASA Headquarters (Dr. J. B. Willett)

(2) JHU/APL Letter, TS-4611, January 1995, Proposal for Voyager Interstellar Mission Reconfirmation Review for the Continuation of the "Voyager Interstellar Mission: LECP Investigation"

Enclosure: Proposal: Voyager Interstellar Mission: LECP Investigation; Part A—Scientific and Technical Section; Part B—Cost Plan

Dear Dr. Willett,

The Johns Hopkins University Applied Physics Laboratory (JHU/APL) is pleased to submit the subject proposal for scope of effort to be undertaken during the period January 1, 1997–December 31, 2000. This proposal has been prepared as a grant proposal in response to verbal discussions with NASA Headquarters (Dr. J. B. Willett) and to continue the grant activities initiated in January 1996. The Cost Plan is consistent with instructions from the Voyager Program Manager at the Jet Propulsion Laboratory (Dr. G. P. Textor) in the form of a one-year funding authorization (Reference 1) and in the form of instructions for the preparations for the Voyager Interstellar Mission Reconfirmation Review (Reference 2). With updates concerning accomplishments, the enclosed proposal is essentially identical to the Reference 2 proposal that was scientifically reviewed during the Voyager Interstellar Mission Reconfirmation Review. It is understood that the actual funding for the second through fourth years of this activity is contingent on the availability of funds. This effort is consistent with the essential research, engineering, and development capability of the Laboratory based upon APL's prior experience on the Voyager Interstellar Mission: LECP Investigation.

SUMMARY

This proposal documents the plans of the Low Energy Charged Particle (LECP) investigation team for participation in NASA's Voyager Interstellar Mission (VIM) as the Voyager 1 and 2 spacecraft explore the outer reaches of the heliosphere and search for the termination shock and the heliopause. The proposal covers the four year period from 1 January 1997 to 31 December 2000. The LECP instruments on Voyager 1 and 2 measure *in situ* intensities of charged particles with energies from about 30 keV to 100 MeV for ions, and about 20 keV to >10 MeV for electrons. The instruments provide detailed spectral, angular, and compositional information about the particles. Composition is available for > 200 keV/nuc using multi-parameter measurements. Angular information is obtained by a mechanically scanned platform that rotates at various commanded rates.

Measurements of low energy ion and electron intensities versus time and spatial location within the heliosphere contain an abundance of information regarding various transport and acceleration processes on both local (~1 hr, ~0.01 AU) and global (~11 yrs, ~100 AU) scales. *The LECP instruments provide unique observations of such dynamical processes, and we anticipate that it will return critical information regarding the boundaries of the heliosphere.* Several recent and exciting discoveries based on LECP measurements emphasize the important role that low energy charged particle distributions play in physical processes in the interplanetary medium. Yet, at the same time, these discoveries also underscore the fact that our understanding of processes in the outer heliosphere is, in most cases, incomplete, and in others, only rudimentary at best.

Among the discoveries referred to above are the following. ***(1). Shocks***: Examination of ≥30 keV ion intensities have revealed: (a) a total absence of acceleration beyond only ~100-200 keV at a strong transient shock in May 1991 at 35 AU, despite an enhanced level of seed particles; (b) a large transient shock in September 1991 of global scale, with intensities of shock-accelerated ions ≥30 keV to ~30 MeV showing complex, highly energy-dependent spatial evolution, and small-scale (~few gyroradii), often anisotropic, micro-structures; (c) recurrent intensity increases in ≥30 keV to ~few MeV ions, with structures that, in some cases, show *no correlation* with the associated corotating shock. ***(2). Superthermal ion pressure***: A global merged interaction region with a leading shock, downstream of which the superthermal ion (≥30 keV to ~4 MeV) pressure is *comparable* to that of the thermal plasma, and the total particle pressure yields a *plasma beta of order unity*. ***(3). Pickup ions***: Measurements of the C/O ratio within transient structures at 35-45 AU showing the first clear evidence that transient shocks can pre-accelerate interstellar pickup ions from ~1 keV/nuc to *at least* 1 MeV/nuc. ***(4). Seed particles***: Injection of ions for acceleration to high energies at the termination shock is unlikely to be a problem, since interplanetary transient and recurrent shocks are continually accelerating ions, of solar wind or interstellar origin, to highly superthermal energies. ***(5). Precursor electrons***: Ambient solar electrons (≥ few tens of keV) that exist in the outer heliosphere can form a broad precursor, several days wide, that is upstream of the termination shock and *potentially observable a few months prior to the shock crossing*. ***(6). Solar wind velocity at Voyager 1***: We can use LECP ion data to *obtain the solar wind velocity at Voyager 1*, enabling us to provide critical measurements of the plasma flow as we approach and encounter the termination shock and other regions (necessary due to the partial failure of the Voyager 1 PLS experiment).

The work of the LECP investigator team during the VIM will include: (1). Continuing operations with regard to the receipt, processing, verification, cataloging, display, and distribution of the data from the LECP instruments on Voyager 1 and 2. (2). Monitoring the health and performance of the LECP instruments, and evaluating and characterizing the response of the LECP instruments to various energetic particle and plasma environments. (3). Participating in, and supporting Voyager Project planning exercises and other coordinated activities relevant to exploration of the outer heliosphere. (4). Developing analysis techniques and operational procedures suitable for searching for and characterizing the boundaries and unique regions of the

outer heliosphere. (5). Continuing the preparation of data sets appropriate for submission to the National Space Sciences Data Center (NSSDC) and, where appropriate, the Planetary Data System (PDS). (6). Maintaining direct Web access to online LECP data through the JHU/APL Voyager LECP home page. (7). Performing scientific evaluations of the Voyager 1 and 2 LECP data sets in conjunction with other data sets and other investigators, with particular focus on the outer regions of the heliosphere. (8). Publishing the results of these evaluations in the scientific literature and presenting the results in scientific conferences.

Dr. J. B. Willett
NASA Headquarters

The subject proposal (enclosure) includes two parts. Part A is the Scientific and Technical Section which gives a brief presentation of the science justifications and goals of the investigation, and of the operations, archiving and science support tasks proposed for JHU/APL and the Co-Investigator institutions (University of Kansas, University of Maryland, Bell Laboratories (Lucent Technologies), and the Max-Planck Institute für Aeronomie in Lindau, Germany). Part B is the Cost Plan, which includes budget estimates, based on instructions from NASA. The program at JHU/APL will be directed by Dr. S. M. Krimigis, LECP Principal Investigator; at the Universities of Maryland and Kansas by Professors D. C. Hamilton and T. P. Armstrong, respectively; at Lucent Technologies by Dr. L. J. Lanzerotti; and at the Max-Planck Institute in Lindau by Dr. W.-H. Ip. It is noted that the efforts at both Lucent Technologies and the Max-Planck Institute are at no cost to the US Government.

This proposal includes data that shall not be disclosed outside the Government and shall not be duplicated, used, or disclosed in whole or in part, for any purpose other than to evaluate this proposal. If, however, a grant is awarded to JHU/APL as a result of, or in connection with, the submission of this data, the Government shall have the right to duplicate, use or disclose the data to the extent provided in the resulting grant. This restriction does not limit the Government's right to use information contained in this proposal if it is obtained from another source without restriction.

Should additional information be required, Dr. Barry H. Mauk, the LECP Project Manager, can be reached at telephone number (301) 953-6023 or the Principal Investigator, Dr. S. M. Krimigis, can be reached at telephone number (301) 953-5287. Questions concerning the budget may be addressed to Mr. Barry R. Handloff, (301) 953-6156.

Yours truly,

S. M. Krimigis

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Head, Space Department

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Director

GLS/SMK/CIM/BHM
Enclosure

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PROPOSAL FOR THE CONTINUATION OF:
VOYAGER INTERSTELLAR MISSION: LECP INVESTIGATION
JANUARY 1997 - DECEMBER 2000

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CONTENTS

PART A: SCIENTIFIC AND TECHNICAL SECTION

1.0 Introduction

This proposal documents plans of the Low Energy Charged Particle (LECP) Investigator team for its participation in NASA's Voyager Interstellar Mission (VIM) during the period 1 January 1997 to 31 December 2000 as the Voyager spacecraft explore the outer heliosphere and search for the termination shock and heliopause. The LECP team (S. M. Krimigis, Principal Investigator) designed, constructed, and delivered the LECP instruments that continue to operate on the Voyager 1 and 2 spacecraft. These instruments have operated successfully since launch and have returned valuable and unique data sets concerning the magnetospheres of Jupiter, Saturn, Uranus and Neptune, and the interplanetary environment. The scientific value of these data is documented in over 200 refereed journal articles. A bibliography of publications for the last five years is in Appendix B.

The LECP instruments measure *in situ* intensities of charged particles with energies between ~30 keV to ~100 MeV for ions, and between ~20 keV and ≥10 MeV for electrons. The instruments provide detailed spectral, angular, and compositional information for the particles. Compositional information is available for energies >200 keV/nuc. Angular information is obtained by means of a mechanically scanned platform that rotates at various commanded rates. Two forms of data are generated by the LECP instrument: channel rate data and pulse-height data (whereby individual particles are analyzed with respect to energy and composition). The LECP instruments are documented in detail by *Krimigis et al.* [1977].

The LECP instruments work together with the PLS experiments (measuring lower energies), the CRS experiments (measuring higher energies), the MAG experiments (magnetic fields), and the PWS experiments (plasma waves) in characterizing the *in situ* fields-and-particles environment of the interplanetary medium as the Voyager spacecraft explore the outer regions of the heliosphere. Since launch of the Voyagers, the LECP team has continued to participate with the Voyager Project by (i) receiving, processing, verifying, analyzing, archiving, and publishing data from the LECP instruments, and (ii) supporting Voyager spacecraft and ground operations.

In Science Investigations (Section 2) we describe the measurement capabilities of the LECP instruments and discuss the science objectives and the proposed science investigations for the LECP Project. In the Implementation plan (Section 3), we provide a complete Statement of Work, a summary of Investigator Roles, and describe the LECP team efforts regarding Data Dissemination and Archiving, Outreach, and Diversity.

2.0 Science Investigations

Low-energy ion populations observed by spacecraft in the inner and outer heliosphere generally exhibit complex structures that vary considerably with energy and time at a given spacecraft. Observed fluxes are evidently admixtures of particles from several sources that have undergone various localized and distributed acceleration and transport processes. Sources include solar energetic particles (SEPs) injected during solar flares, ions pulled from the solar wind thermal populations, ions originating at comets and planetary magnetospheres, and interstellar neutrals that are ionized in the interplanetary medium. Transport processes range from nearly scatter-free, to diffusive, to mainly convective in the outer heliosphere. Energization processes include acceleration at lower-coronal shocks, at cometary and planetary bow shocks, at corotating (recurrent) and traveling (transient) interplanetary shocks and, most likely, at the solar wind termination shock, acceleration by resonant and nonresonant wave-particle interactions, and adiabatic deceleration in the expanding solar wind.

Measurements of low energy ion fluxes as a function of time and spatial location within the heliosphere contain a wealth of information regarding these transport and acceleration processes. Detailed analyses of individual "events" at single spacecraft have proven invaluable for elucidating the dominant physical process or processes on a local level. Such analyses are an integral part of the heliospheric physics research program. However, another major goal of this program is to develop a global picture of the production and evolution of low energy particle populations and of the characteristics of large-scale structures in the solar wind over the long time scales (~11 years) and vast distances (≥ 50-100 AU) that characterize the solar envelope. The Voyager spacecraft are unique and indispensable for achieving this latter goal. We propose to continue our efforts to use the LECP data from Voyager 1 and 2 to investigate both local and global processes within, and eventually outside, the heliosphere during the next five years of VIM.

2.1 Overview

The mission overview Figs. 1 and 2 summarize over 19 years of data for selected LECP ion channels from Voyager 1 (V1) and Voyager 2 (V2) from launch in the Fall of 1977 through mid-November 1996. The color spectrograms in Figs. 1a (V1) and 1b (V2) display 10-day averaged fluxes of Z≥1 ions from 40 to 4000 keV. Ion fluxes at a given energy are color-coded according to the horizontal color bar. Fig. 2 shows 10-day averaged fluxes of ~1 MeV protons at V1 and V2 (upper panel) and, for a 1-AU baseline comparison, at the Earth-orbiting satellite IMP-8 (lower panel). Spacecraft helioradius and heliographic latitude at two-year intervals are given at the top of Figs. 1 and 2.

LECP ion intensities during the past six years are summarized at V1 in Fig. 3a at V2 in Fig. 3b. The upper panels of Figs. 3a and 3b show >70 MeV cosmic ray proton rates that have been inter-normalized between V1 and V2 using data acquired soon after launch. These data consist of three-point moving averages of five-day averaged rates. The lower panels show five-day averaged fluxes of two Z≥1 ion and two proton channels with the indicated energy passbands. Figure 4 shows one-day averages of ~1 MeV proton fluxes at V1 (top trace) and V2 (bottom trace), with the period 1991 through 1993 in the upper panel, and 1994 through 1996 in the lower panel. Note that the vertical scale and the offset of the V1 trace are different in the two panels. Dotted vertical lines in Fig. 4 indicate one solar rotation (here, 26 days).

High ion intensities seen from launch to mid-1983 in Figs. 1 and 2 were mainly SEPs from solar transients during the rising phase of Solar Cycle 21. The ~one-year period from early 1984 to early 1985, characterized by the 'flattop' response in the ~1 MeV fluxes in Fig. 2, was dominated by recurrent, 13-day (at V2) and 26-day (at V1) intensity increases due to local acceleration at forward and reverse shocks that bound corotating interaction regions (CIRs). One can identify intensity increases as transient or recurrent by examining the ~3-17 MeV proton intensities (e.g., bottom flux traces in lower panels of Fig. 3) that increase at the arrival of SEPs, which possess hard spectra that extend to relatively high energies, but not at the passage of recurrent ion structures, whose energy spectra fold over rapidly with increasing energy above ~few MeV [*Gold et. al.*, 1988]. The ~1 MeV proton fluxes seen in Figs. 2-4 increase at both transient and recurrent structures. Beyond mid-1985 the "background" levels upon which flux increases of ions >40 keV are superposed, fell to lower levels, where they have remained for the past 11 years.

Extremely low particle activity during mid-1986 to late 1987 ended when ions from recurrent structures reappeared in 1988. From 1989 through 1991, during the rising phase of Solar Cycle 22, the outer heliosphere saw broad transient energetic particle increases and associated structures, e.g., transient shocks and plasma drivers, merged interaction regions (MIRs), and global merged interaction regions (GMIRs) [e.g., *Burlaga*, 1994]. Note the large increases of low energy ion fluxes in the spectrograms and line plots at both Voyagers, particularly in late 1991, when ion fluxes ≥40 keV reached levels comparable to those in late 1982, nine years earlier when the spacecraft radii were ~1/3 those in 1991.

The period 1992-recent shows a marked reduction in low energy ion fluxes in the outer heliosphere (Figs. 3a, 3b, and 4, lower panels) and a concomitant steady recovery of cosmic ray proton rates (Fig. 3a and 3b, upper panels). From 1992 through 1994, low energy ion activity at both Voyagers was dominated by local acceleration at CIRs, with the activity at V2 occurring in two broad periods consisting of trains of ~26-day recurrent flux increases, and that at V1 occurring more sporadically. From 1995-recent, low energy ion fluxes have been very near background levels, with the exception of a brief reappearance of recurrent, albeit relatively low-intensity, structures at V2 in late 1995. It is believed that Solar Cycle 22 ended in mid-1996, and that the new Solar Cycle 23 is upon us. Within the next year or so, we expect that increasing solar activity will manifest itself at 1 AU and, a few months later, at both V1 and V2 as rising fluxes of SEP ions >40 keV.

2.2 Proposed Investigations

2.2.1 Processes and Structures in the Outer Heliosphere

Interplanetary shocks. With the exception of periods at or near solar minima, transient and recurrent interplanetary shocks continue to be observed on a regular basis at both Voyagers. The effects of such shocks on ≥30 keV ions and ≥20 keV electrons are of fundamental interest for understanding the physics of particle acceleration and associated effects on both the structure and evolution of collisionless shocks in astrophysical plasmas. Indeed, as displayed in Figs. 3 and 4, the past six years illustrate the various local and global processes in the interplanetary medium, and we will refer these data often in the following discussion.

The shocks labeled "May '91" and "September '91" in Figs. 3 and 4 are associated with solar activity in March and the May-June 1991 periods, respectively. The May 1991 MIR was extremely unusual. Although the associated shock was relatively strong, as discerned from the PLS data, there was no evidence of ion acceleration above ~100-200 keV, and even those increases were small and confined between the shock and the driver gas [*Selesnick et al.*, 1991; *Decker and Krimigis*, 1993]. By contrast, the September 1991 shock at the leading edge of a GMIR, also responsible for a large Forbush decrease [*Van Allen and Fillius*, 1992; *Webber and Lockwood*, 1993; *Decker and Krimigis*, 1993; *Krimigis et al.*, 1995] evident in the cosmic ray curves, was associated with ion acceleration extending from at least 30 keV to 30 MeV; however, the complex, energy-dependent spatial evolution of these shock-associated intensity increases is poorly understood [*Decker et al.*, 1995a]. The two trains of recurrent events at V2 (lower panel of Fig. 3b, Fig. 4) are striking in their longevity and apparent association of the ion peaks with discontinuous solar wind flow changes that indicate CIR shocks. However, there are cases where the passage of the CIR shock and the intensity peak of ~1 MeV protons show no correlation [*Lazarus et al.*, 1995].

It is clear that our physical understanding of particle acceleration at shocks in the outer heliosphere is inadequate. The pleasing agreement between data and shock acceleration models that one enjoys for shocks observed in the inner heliosphere [e.g., *Kennel et al.*, 1984; *Sarris and Krimigis*, 1985] simply *does not apply* in the outer heliosphere. We will continue careful and detailed analysis of the shock-accelerated particles in LECP data, in conjunction with the available plasma and magnetic field data, to clarify the basic physical processes that must be incorporated to improve the explanatory and predictive capabilities of theoretical models. These investigations will involve both in-depth analysis of individual shock events, including energy spectra, composition, and anisotropies [e.g., *Kane et al.*, 1993, 1995; *Decker et al.*, 1992, 1995a, 1995b; *Krupp et al.*, 1995], as well as statistical analysis of many shock events [e.g., *Gold et al.*, 1988, 1992; *Lanzerotti et al*, 1991; *Decker et al.*, 1995c].

Some specific questions amenable to analysis using LECP data are as follows. Shocks in the outer heliosphere are expected to be nearly perpendicular on average. Are the low energy ion fluxes and angular distributions consistent with this expectation? Why are shock-accelerated electron distributions so rare? Are shock-accelerated low energy ion distributions different when such electrons are present? Are there features in the low energy ion and electron fluxes at particularly strong transient shocks that are common to such events? For example, is there a typical spatial scale of upstream precursor fluxes? Can we then draw an analogy from transient shocks to the termination shock and remotely sense the termination shock using low energy ion and electron measurements?

Superthermal ion pressure. Another aspect of the shock acceleration process that has been largely ignored, but may have important implications, particularly at the termination shock, is the pressure carried by superthermal, but not high energy (i.e., not cosmic ray) ions. Fig. 5a shows data from the LECP, PLS, and MAG instruments on Voyager 2 during the September 1991 event. Embedded within this GMIR and behind the leading shock is a broad (~3 AU thick) shell of low energy ions. The bottom panel of Fig. 5a shows the thermal plasma pressure determined from the PLS data, and the pressure in the $Z\geq1$ ions from 28 to 3500 keV. The middle panel of Fig. 5b shows the combined LECP and PLS pressure and the magnetic pressure, and the top panel shows the observationally determined plasma beta. *The post-shock pressure in the superthermal ions is comparable to that of the thermal plasma, and the total particle pressure yields a plasma beta of order unity.*

In addition, we estimate that the total energy contained in the post-shock shell of superthermal ions is ~10^{31} ergs at V2 and ~10^{32} ergs at V1. This is illustrated in Fig. 5b, which shows the time development of the energy in the superthermal ion tail at V1 and V2 as averaged over radial shells of width $V_{SW}\Delta t$, $\Delta t = 1$ day, V_{SW} = solar wind speed. The solid-line plus solid-circle traces are for the nominal energy ranges, 40-4000 keV at V1 and 28-3500 keV at V2. We show also cases for extrapolation down to 10 keV and 1 keV. The box gives the estimated total energy summed over ~3-AU wide superthermal ion shells observed during days 251-263 at V2 and 258-275 at V1. We emphasize that although the total particle pressure of ~3 x 10^{-13} dyne/cm^2 is small compared to the solar wind dynamic pressure of ~10^{-10} dyne/cm^2, the enhancement of the particle pressure and plasma beta at a structure such as the termination shock may have important implications for the structure and strength of the shock.

We will continue to calculate the contribution to particle pressures from the LECP ion data for events of interest and extrapolate to lower energies if warranted. We anticipate that this procedure, as part of our data analysis package, will be very useful when we encounter the termination shock.

Pickup ions. Figure 6 summarizes LECP pulse height analysis (PHA) data for medium and heavy nuclei accumulated during (I) the May 1991 MIR at V2 and (II) the September 1991 GMIR at both V1 and V2. The histogram in (I) shows that during days 145-200 at V2, the ratio of 0.6-1.2 MeV/nuc carbon (C) to oxygen (O) nuclei was C/O=0.29 ± 0.01. For the September GMIR (II), a similar analysis yields C/O=0.16±0.07 at V1 (days 200-310) and C/O=0.28±0.11 at V2 (days 200-300).

PHA analyses by *Lanzerotti et al.* [1992] of SEPs 0.5-2.0 MeV/nuc observed by the HI-SCALE instrument on Ulysses (2.5 AU) during a large flare in late March 1991, most likely the major source of SEPs and solar wind disturbances later identified as the May 1991 event at V2, yielded C/O=0.52 ± 0.08. (A similar analysis has not been reported for the May-June solar events related to the September 1991 events at V1 and V2.) Evidently, between the sun and ≈35 AU there occurred a ≈40% decrease in C/O at ≈1 MeV/nuc. In a survey of abundance ratios of SEP nuclei from large solar flares, as observed at 1 AU, *Mason et al.* [1980] found that at ≈1 MeV/nuc, the average C/O=0.5, with 2/3 of the cases falling in the range 0.40-0.59. *Hamilton et al.* [1978] report an average C/O≈0.68 for three CIR-associated events measured near 4 AU by the V2 LECP.

A plausible interpretation of these PHA data is that at the Voyagers the O is an admixture of SEPs and interstellar pick-up O ions that have been accelerated to ≈1 MeV/nuc by transient interplanetary shocks. *This is the first compelling evidence that large transient shocks can pre-accelerate interstellar pickup ions from ~1 keV/nuc to at least 1 MeV/nuc.* We will revisit the early data and perform PHA analysis on individual transient events to determine the C/O ratio and search for a radial dependence (i.e., a decrease in C/O with increasing radius), and continue to perform such analysis on transient events observed at the Voyagers in the future. We will also perform long-term averages of recurrent structures, such as those at V2 from 1992 through 1994, to determine if pre-acceleration of pickup ions also occurs at the weaker, but longer-lived, recurrent shocks.

Transport processes. Comparisons of the upper and lower panels of Figs. 3a and 3b show that the transport of cosmic rays is radically different from that of low energy ions. On the one hand, the cosmic rays, which originate from outside the heliosphere, have propagated inward to the spacecraft, their observed intensities being a convolution of distributed, nonlocal processes including diffusion, convection, adiabatic deceleration, guiding center drifts, and interactions with interplanetary structures, such as shocks, MIRs and GMIRs, and current sheets. An example showing the effect of a GMIR on the cosmic rays is the Forbush decrease at both V1 and V2 in September 1991 (Fig. 3a and 3b). On the other hand, the low energy ions respond mainly to small-scale, local conditions, and are therefore good "tracers" of local conditions in the interplanetary medium. An important diagnostic of the processes that determine how low energy ions are transported within the interplanetary medium are angular distributions, i.e., anisotropies and, if magnetic field data is available, pitch angle distributions.

The LECP instrument steps through eight 45° sectors in a scan plane that is tangent to a cone with vertex at the Sun and an opening angle with respect to the solar spin axis equal to the spacecraft colatitude. During the VIM period the LECP is scanning at the rate of 1 step/192 sec, yielding a full scan through 360° in 25.6 min. We have examined the angular distributions of the low energy ions before, during, and after the passages of several interplanetary shocks [*Decker et al.*, 1981; *Kane et al.*, 1993, 1995; *Decker et al.*, 1995]. Generally, upstream of shocks, there are large anisotropies, most likely signatures of the shock acceleration process. Downstream of the shock, usually where the intensities are relatively flat for a few days or so, the angular distributions are those of a convected isotropic ion population that evidently has come into diffusive equilibrium with the magnetic irregularities that pitch angle scatter the particles. This population propagates through the heliosphere, most likely right out to the termination shock, by convecting with the solar wind.

Our ability to analyze angular distributions measured by the LECP is *essential* to understanding transport processes, and we will continue to exploit this diagnostic tool to the fullest. *The LECP is the only instrument with this capability on the 3-axis oriented Voyager spacecraft.* The proper determination of pitch angle distributions will be essential for ascertaining how ions are accelerated at the termination shock, and, as will be discussed below, for determining plasma flow speeds at V1 downstream of the termination shock.

Global structures. Global structures are those that span a large spatial region of the heliosphere. An example is the September 1991 GMIR, which extends from V1 to V2, despite the fact that the two spacecraft were separated by 37 AU. In contrast, the May 1991 event was observed only at V2; evidently, the latitudinal separation of the two spacecraft has become an increasingly important factor. By definition, one can unambiguously determine only if a structure is of global extent by use of two or more spacecraft. When possible, we will use the spacecraft IMP-8, Wind, ACE, Voyager 1, Voyager 2, and Ulysses to examine structures of a global nature.

Figs. 7a and 7b illustrate of the power of multi-spacecraft comparisons, and exemplify the type of investigations we plan to undertake during the next four years. Fig. 7a shows ~1 MeV proton fluxes at four different spacecraft over the four-year period 1992-1996 (minor tics show 26 day intervals). From top to bottom, the spacecraft, instrument, and proton energy ranges are V1 LECP (0.57-1.78 MeV), V2 LECP (0.52-1.45 MeV), Ulysses (ULS) HI-SCALE (0.48-0.97 MeV), and IMP-8 CPME (0.50-0.96 MeV). The variation in spatial coordinates over from 1992 through 1995 are given in each panel. *The closely matched energy ranges enable us accurately calculate and compare absolute fluxes among the four spacecraft.* From mid-1992 to mid-1993, V2, ULS, and IMP-8 saw ~26-day recurrent proton flux increases associated with acceleration at CIR shocks (S and N in the ULS panel indicate the southern and northern solar polar passes). By contrast, V1, at high northern latitude, saw sporadic CIR-associated flux increases, implying that a large asymmetry must have existed in the stream structure patterns between the northern and southern solar hemispheres during this period.

In Fig. 7b we focus on the V2 and ULS data during the period mid-1992 to mid-1993, during which ULS's helioradius decreased from 5.3 to 4.6 AU and its heliographic latitude increased from 13°S to 34°S, and V2's helioradius increased from 37.6 to 40.4 AU and its latitude increased from 6.7°S to 9.5°S. Also displayed in the top panel is the solar wind speed at V2. Background counts due to penetrating cosmic rays have been removed from both the V2 and ULS proton data prior to calculation of fluxes. We compare the maximum and minimum recurrent proton fluxes seen at ULS during the second half of 1992 with those seen at V2 during the first half of 1993. During these periods the two spacecraft were at comparable southern latitudes, V2 had entered faster solar wind, presumably associated with the same southern coronal hole sampled by ULS, and the half-year offset accounts roughly for convective delay of CIRs from ULS to V2.

The dashed horizontal lines indicate the maximum (max) and minimum (min) recurrent fluxes during the appropriate periods at V2 and ULS. The ratio of peak fluxes at ULS to those at V2 is ~4000, while that of the between-peak fluxes is only ~5. The large radial gradient in peak fluxes from ULS to V2 is consistent, within a factor of two or so, to the r^{-2} decrease implied by comparing peak fluxes in the V2 LECP data as V2 moved radially outward from 1978 to 1994 (see Fig. 8). The striking result in Fig. 7b is the extremely small gradient in the between-peak fluxes. *The implication is that as CIRs propagate outward, the enhanced background, or between-peak flux, of accelerated low energy ions upon which the peak fluxes are superposed decays so weakly with radial distance that such particles constitute a major source of pre-accelerated seed ions for further acceleration at the termination shock.* This is discussed further in the next section.

2.2.2 Anticipating the Outer Boundaries of the Heliosphere

Seed particle populations. In anticipation of crossing the termination shock, a number of investigators have performed simulations of ion acceleration at a hypothetical termination shock. One issue that has arisen is the seed particle problem: how does one inject solar wind ions with thermal energies, or, more importantly, interstellar pickup ions with energies ~1 keV/nuc? The LECP data shows that injection is not likely to be a problem, since interplanetary transient and recurrent shocks are continually accelerating ions, of solar wind or interstellar origin, to highly superthermal energies. This was discussed above in reference Fig. 7b showing the comparison of recurrent, low energy proton fluxes at V2 and Ulysses. As also mentioned, V2 LECP data has allowed us to determine the radial decrease of peak fluxes for CIR-associated ion increases.

Fig. 8 shows the flux of recurrent ion events accelerated at CIR shocks observed at V2 as a function of radial distance, covering the period from 1978 through 1994. All three flux curves, representing ions with energies 43-80 keV, 137-215 keV, and 540-990 keV, are well fit by an r^{-2} dependence. Even if the termination shock is at 100 AU, the flux of 43-80 keV recurrent ions will only be reduced by a factor of 5 from its value in late 1994 at 45 AU. [Because the eight Z≥1 ion channels (43-4000 keV at V1, 28-3500 keV at V2) are single-parameter channels, the background due to penetrating cosmic ray ions is relatively high, and a determination of the radial gradient for between-peak, recurrent fluxes in these channels (e.g., Fig. 7b) cannot readily be performed.]

We have begun to look carefully at higher Z ion channels (from the Low Energy Particle Telescope subsystem of the LECP) to determine the relative abundances in the interplanetary medium of other ion species having energies above ~1 MeV/nuc. This is being done using long-term sums of the PHA data (e.g., Fig. 6) and also by appropriately averaging the rate channel data. Fig. 9 shows, from top to bottom, alpha particles (0.42-1.7 MeV/nuc), protons (0.52-1.45 MeV), and the ratio p/α of the proton to alpha rate, as measured by the V2 LECP during 1994. The plotted values are five-point moving averages of a one-day average data base, and the light vertical bars are two statistical standard deviations long.

The CIR-associated increases in helium nuclei rates are clearly evident and well-correlated with those in the proton rates. The geometric factors for the alpha and proton channels are identical, so the p/α ratio is basically at equal energy per nucleon, or equal velocity. The consistent increase in p/α at peaks is different from CIR-associated ion events observed near 5 AU [*Barnes and Simpson*, 1976; *Decker et al.*, 1981], in which p/α decreases at reverse shock events. Either there are no reverse shocks in the 1994 period, which is unlikely (although the shocks have not yet been classified), or else we are measuring mainly accelerated singly-ionized pickup helium nuclei rather than fully-ionized helium nuclei accelerated out of fast solar wind plasma upstream of reverse shocks. This is also consistent with the unusually small ratio of p/α both at the peaks and between the peaks. This has important implications for the interplanetary pre-acceleration of pickup helium. We will continue to investigate compositional variations of low energy ion accelerated at transient and recurrent interplanetary shocks.

In addition to the long-duration, but relatively low intensity recurrent ion events, there are the episodic, high intensity transient events, such as during 1989 through 1991. The peak flux of the September 1991 event at V2 is shown in Fig. 8 for comparison. These events will deliver to the termination shock intense fluxes extending to ion energies ~several tens of MeV. In addition, it is unclear what effect a GMIR itself will have on the stability and location of the termination shock.

We emphasize again that the interplanetary medium creates its own population of superthermal ions. We have been providing theorists with realistic ion spectra from both transient and recurrent events for use in their transport codes. *Giacalone et al.* [1996] used a 2-D transport model to investigate the acceleration of anomalous hydrogen at the termination shock. This requires that the incident seed particles be pre-accelerated to a minimum injection energy. The authors assumed that the seed particle energy spectrum was produced by pre-acceleration at interplanetary shocks, and used the V2 LECP >30 keV low energy recurrent ion fluxes observed during 1992 to 1995 to normalize this pre-acceleration spectrum. The resultant computed spectra of anomalous cosmic ray protons are consistent with observed fluxes. This strongly suggests that interplanetary shocks play an important role in the initial acceleration of pickup ions that are subsequently accelerated to cosmic ray energies at the termination shock. We will continue to provide Voyager LECP data and guidance on its proper interpretation and use to interested theoretical investigators.

Plasma flow determination at Voyager 1. The plasma instrument on Voyager 1 has not worked properly since Saturn (1980) encounter. Under present conditions in the solar wind, the Voyager 1 PLS instrument cannot measure plasma flow velocities, densities, or temperatures (however, total flux *can* be measured if it sufficiently high). We have developed a least squares non-linear inversion procedure that uses the sectored LECP ion data to determine the plasma flow speed and direction at both Voyager 1 and 2. We have tested the procedure using the Voyager 2 LECP data, since plasma flow velocities are available from the PLS instrument on Voyager 2.

The top panel in Fig. 10 shows PLS-determined, daily-averaged flow speeds (solid histogram) downstream of the May 1991 shock at Voyager 2. The symbol × represents the flow speed determined using the fitting procedure on the LECP ion data. It is clear that the procedure generally does an adequate job in predicting the actual flow speeds. We are in the process of automating this procedure to produce flow speeds at Voyager 1. It is necessary to have a qualitycontrol parameter as a measure of how good the flow determination is. Again, we have used the Voyager 2 data as the test case. The bottom panel in Fig. 10 plots the χ^2 of the fit as a function of time for the LECP-determined flow speeds in the top panel. This parameter provides a good quantitative measure of the reliability of the LECP-determined flow speed. We are confident that we can estimate flow speeds ~50-100 km/sec or less downstream of the termination shock if the fluxes are sufficiently high, e. g., comparable to those downstream of the September 1991 shock, and the angular distributions are quasi-isotropic. Both conditions will be satisfied if the termination shock is strong and the downstream region is highly turbulent, which is expected to be the case.

Search for precursors. Our concern here is with the remote detection of the termination shock using LECP measurements from V1 and V2. Can we predict an impending traversal of the termination shock from the upstream region (supersonic flow) to downstream region (subsonic flow) based upon the LECP observations? Based on observations of a ~three-day wide precursor of ions upstream of a global transient shock in mid-1989, we have argued that if the termination shock position does not fluctuate too rapidly in time, we could begin to see an ion precursor upstream of the termination shock 2-3 months prior to the shock crossing.

The basic argument, motivated by the observed shock event, is that an incident, mildly superthermal ion population is accelerated at the shock that is, on average, perpendicular or nearly so. The upstream fluxes result from ions that venture upstream of the shock along temporary magnetic loops formed when large-scale directional variations in the upstream magnetic field cause the field line to intersect the shock at multiple points. This process has in fact been simulated and the upstream precursor of shock-accelerated ions formed as anticipated [*Decker*, 1993].

Fig. 11 shows one proton and three electron channels during the mid-1989 shock. The upstream precursor in the ~1 MeV protons is clearly evident. However, even more striking are the upstream precursors of the three electron channels that cover the energy range from 22 to 112 keV. In contrast to the proton intensity, which is nearly symmetric about the shock passage, there are very few electrons downstream of the shock. The electron precursor width is bounded and is independent of electron energy, as predicted by *Decker* [1993]. Since there were electrons in the interplanetary medium from previous solar activity, the most likely interpretation is that the electron precursors are ambient electrons simply confined upstream of the shock by the magnetic field increase across the shock. *If there are ambient solar electrons in the interplanetary medium, we expect them to form a broad precursor, several days wide, upstream of the termination shock.* Such an electron precursor is a more reliable predictor than low energy ions, which are routinely accelerated at interplanetary shocks, and therefore much more abundant in the interplanetary medium.

3.0 Implementation

3.1 Introduction and Statement of Work

The Principal Investigator, Dr. S. M. Krimigis, will provide the overall direction and focus for the LECP Investigation. He, with the help of his Project Manager, Dr. B. H. Mauk, will coordinate the activities of the various groups of the investigation and will insure that all of the groups and individuals are working efficiently together to deliver the work proposed here and outlined in the Statement of Work given below. The roles of the individual investigators on the team are described in the section that follows the Statement of Work. During the proposed Voyager Interstellar Mission period the LECP Investigator Team will:

1) Continue its operations with regard to the receipt, processing, verification, cataloging, display, and distribution of the data from the LECP Instruments on Voyager 1 and 2.

2) Monitor the health and the performance of the LECP Instruments on Voyager 1 and 2. From an instrument performance standpoint, continue to evaluate and characterize the response of the LECP instruments to various energetic particle/plasma environments.

3) Participate in, and support, Voyager Project planning exercises and other coordinated activities with regard to the exploration of the outer heliosphere (e.g., development and implementation of quicklook data stream, etc.).

4) Develop analysis techniques and operational procedures suitable for searching for and characterizing the boundaries and unique regions of the outer heliosphere (e.g., procedures for characterizing plasma flow on Voyager 1, where the PLS instrument is not fully operational).

5) Continue the preparation of data sets suitable for submission to the National Space Sciences Data Center (NSSDC) and, where appropriate, the Planetary Data System (PDS).

6) Maintain direct Internet access to online LECP data through the JHU/APL Voyager LECP home page.

7) Perform scientific evaluations of the Voyager 1 and 2 LECP data sets in conjunction with other data sets and other investigators with particular focus on the outer regions of the heliosphere.

8) Publish the results of these studies in the scientific literature and present the results at scientific conferences.

3.2 Principal Investigator and Co-Investigator Roles

S. M. Krimigis (JHU/APL), Principal Investigator: Establishes the overall direction and focus for the LECP Investigation. Participates in the science analysis and publishing activities.

T. P. Armstrong (University of Kansas) Co-Investigator: Responsible for maintaining the high level processing of the LECP rate data (as opposed to the event data: dE x E). Responsible for the analysis of aspects of the LECP instrument response functions. Participates strongly in archiving activities. Participates, along with his students, in the science evaluation activities.

R. B. Decker (JHU/APL) Co-Investigator: Performs scientific analysis of the LECP data and performs modeling studies to understand the data theoretically. Prepares selected data sets for archiving at the NSSDC.

G. Gloeckler and D. C. Hamilton (University of Maryland) Co-Investigators: Responsible for maintaining the high level processing of the LECP pulse-height event data for composition studies (as opposed to the rate data). Participate, along with post-doctoral help, in the scientific evaluation of the data with focus on the compositional aspects of the data.

W.-H. Ip (Max Planck Institute at Lindau) Co-Investigator: Will participate in the scientific evaluation and theoretical analysis of the outer heliospheric regions, with emphasis on particle acceleration at the termination shock and its effects on the characteristics of anomalous cosmic rays.

E. P. Keath (JHU/APL) Co-Investigator: Has participated in the hands-on development of the LECP and is the individual most knowledgeable about the internal workings of the instrument. Responsible for the evaluation of instrument health and performance, and for maintaining the lowest level processing of the data where an intricate knowledge of the instrument is required.

L. J. Lanzerotti (AT&T Bell Laboratories) Co-Investigator: Principal Investigator with the Ulysses project. Responsible for coordinating collaborative studies of heliospheric energetic particles among the Voyagers, Ulysses, and other spacecraft. Will participate in the general scientific analysis.

B. H. Mauk (JHU/APL) Co-Investigator: As Project Manager he is responsible for the day-to-day operations of the LECP Project including the financial aspects and the coordination between the co-investigator groups. Will participate in all aspects of the investigation.

R. L. McNutt, Jr. (JHU/APL) Co-Investigator: Co-Investigator with both the Voyager PLS and LECP investigation teams. Will coordinate collaborative studies of structures in the solar wind plasma and in the energetic particles. Will participate in general science evaluation activities.

We will benefit greatly from the additional expertise of individuals identified as Associates to the LECP Investigation. Dr. A. F. Cheng will provide theoretical support. Dr. E. C. Roelof, a very active participant in the Ulysses Program, will serve, along with Dr. L. J. Lanzerotti and C. G. Maclennan, as liaisons between the Voyager and Ulysses Programs. Dr. E. T. Sarris and his students will participate in the science evaluation of the LECP data.

3.3 Data Dissemination and Archiving

It has been the practice of the LECP team to make data available to all investigators as soon as the data is available in a validated form. Data in the form of text files and graphical displays for both LECP instruments are available online over the World Wide Web on the JHU/APL home page, "Voyager Low Energy Charged Particle (LECP) Experiment," (Fig. 12) at URL

http://sd-www-sd/VOYAGER/index.html

Currently, the downloadable text file data bases consist of onr-hour and one-day averages of counting rates and flux conversion factors for eight $Z \geq 1$ low energy ion channels, two low energy proton channels, and one cosmic-ray proton channel. At the time of this writing (25-Nov-96), these data extend from launch to 20-Nov-96. Soon to be added in both one-hour and one-day averages are text files of seven additional low energy ion rate channels, including helium, medium (CNO), and heavy (Fe) nuclei. We are making these data easily accessible to encourage investigations of ion composition variations in the outer heliosphere. We are also adding a link containing solar wind bulk flow velocities determined using the LECP data (Section 2.2.2) along with a tutorial explaining the procedures used. Interested users can obtain LECP data not available online (such as angular distributions) by contacting via phone, fax, or e-mail, any of the personnel listed on the JHU/APL LECP Home Page (Fig. 12).

In addition, data from both of the LECP instruments are available at NSSDC as part of the COHO data base. The current one-day average LECP data sets extend from launch to the end of 1994. We have made arrangements to update these data sets to include 1995 data and, when complete, 1996 data. One can access V1 and V2 LECP data by anonymous ftp at the respective URLs:

ftp://nssdca.gsfc.nasa.gov/coho/vy1lcp/
ftp://nssdca.gsfc.nasa.gov/coho/vy2lcp/

Further information regarding LECP data availability at JHU/APL, Co-Investigator institution Web sites, and at NSSDC can be obtained by reviewing the at Space Physics Data Availability Voyager Mission Matrix at URL:

http://nssdc.gsfc.nasa.gov/cgi-bin/spcat/SPD/SPDMissionMatrix.pl?mission=Voyager

To date, much of the LECP team's attention has been focused on the archiving of the planetary encounter data. Data sets for the encounters of Jupiter, Saturn, Uranus, and Neptune reside at the fields and particles node of the Planetary Data System (PDS). We are now in the process of submitting the highest time resolution data from Saturn (a low resolution set now resides at PDS), and in GFY 96 we hope to complete the submission of the highest time resolution data from the encounters with Jupiter (again, low resolution data now resides at the PDS). The schedule for these submissions is dictated by the fields and particles node of PDS who are assimilating data from the different planets in a planet-by-planet fashion. (The full LECP data, for example, is now available on the Uranus and Neptune CD's that have been issued over the last couple of years.) Following the final submissions of the planetary data, which should be completed by the end of the present contract period, much more attention will be expended on archiving the interplanetary data during the proposed contract period.

3.4 Outreach and Diversity

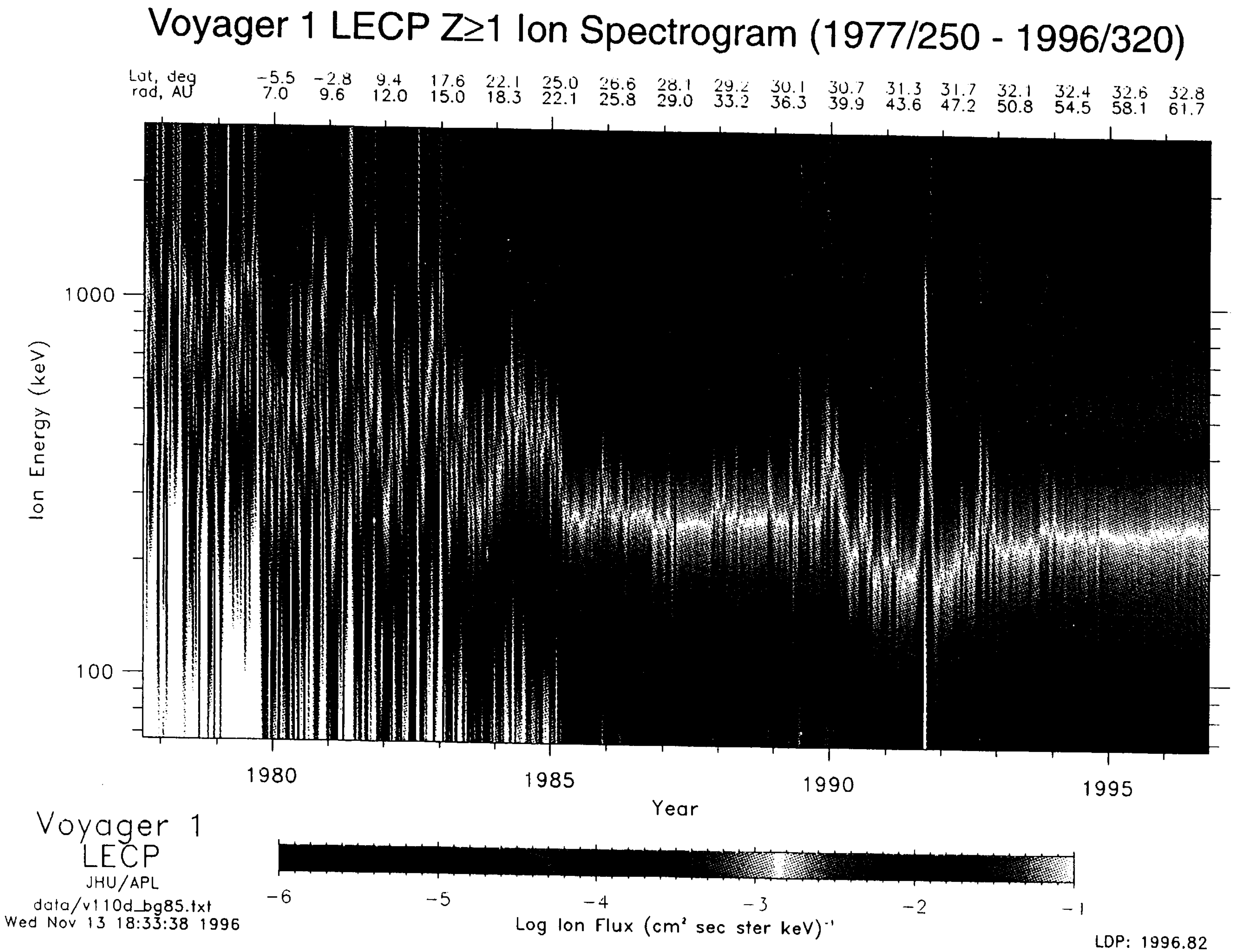
The Voyager LECP Team recognizes the desirability of involving NASA Programs in educational and public outreach activities. In the past, a number of Ph.D. degrees have been awarded on the basis of work with the Voyager LECP data at the University of Kansas (UK), the University of Maryland (UM), and at The Johns Hopkins University. Undergraduate students have always been heavily involved with the operational aspect of the LECP Project at UK and UM, and occasionally at JHU/APL. During summers, high school students participate in research at JHU/APL.

High school students who were enrolled in JHU/APL's mentoring program during the 1994-95 and 1995-96 school years worked on Voyager related research activities with Voyager LECP personnel. The research project performed by two students enrolled during the 1994-95 school year won them First Prize at the Baltimore Science Fair, Top Prize and three separate monetary awards totaling $20,000 at the 46th International Science and Engineering Fair (ISEF) in Ontario, Canada, and an invitation to attend the European Union Contest for Young Scientists in Newcastle-Upon-Tyne, England, with all expenses paid. For a project performed during the 1995-96 school year, one student was chosen as one of 40 finalists (out of 1839 entries) in the Westinghouse Science Talent Search. A high school student hired during the summer of 1996 worked extensively with the LECP data and developed an IDL-based graphical display package for constructing color spectrograms and line plots for use in scientific publications, presentations, and the LECP Web Page.

During summers the LECP project will recruit several Center for Talented Youth High School Students, and other high school students for participation in the Voyager LECP project at JHU/APL. In addition, Voyager LECP project personnel are regular participants in such elementary school programs as the Career Day activities and other activities in Maryland. Finally, JHU/APL together with The Johns Hopkins University and Morgan State University manage the Space Grant Consortium, which hosts space-related workshops and other activities for the benefit of teachers and students. This has the participation of our personnel. The LECP team will be continuing, and will expand, these kinds of outreach activities. Appendix E presents the students that have been involved with the LECP project over the last five years.

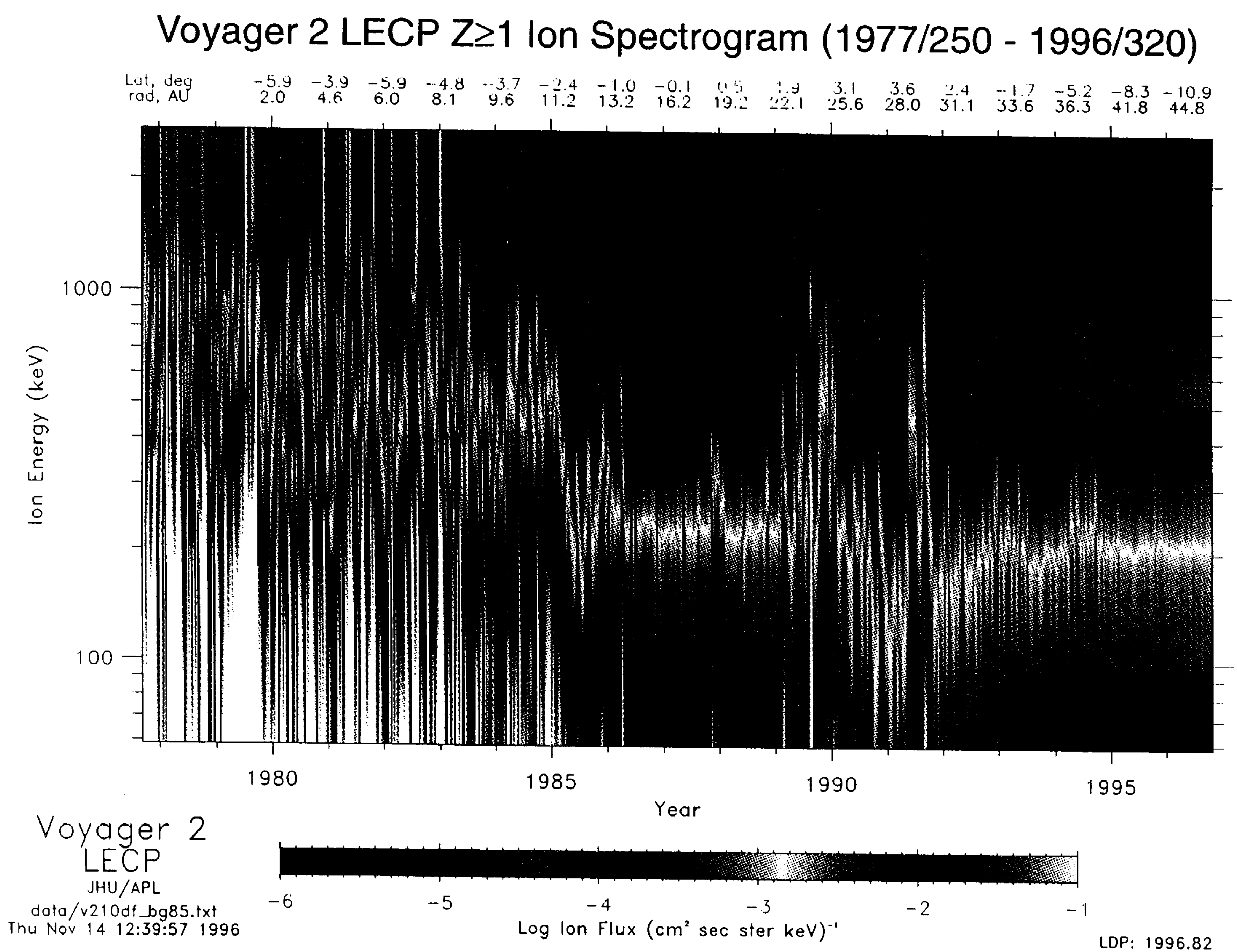
The LECP team is concerned with the issue of Diversity. Appendix G lists all individuals that have been involved with the LECP program over the last 5 years. As this list shows, the LECP effort has been diverse in both institutional participation and in the professional expertise of the participants. Also, women and minorities are represented here. However, it is to be acknowledged that the distribution of women and minority participation has been substantially skewed. The institutional participants to this effort have equal opportunity/employment and affirmative action/outreach programs in place; however, it is understood that concept of diversity goes beyond these concepts.

JHU/APL recognizes that its future success depends, in part, on how well it uses the diverse background, capabilities, and talents of its staff, and that its workforce must reflect the composition of the population at large. JHU/APL and its Space Department implemented several diversity initiatives in early 1994. The Laboratory Director established a Diversity Action Team to help the Laboratory maximize the potential of all its employees. The Diversity Action Team set several goals, including conducting an assessment of the Lab's work environment to determine staff members' perceptions of career growth and development, the work environment, and relationships among peers and supervisors.



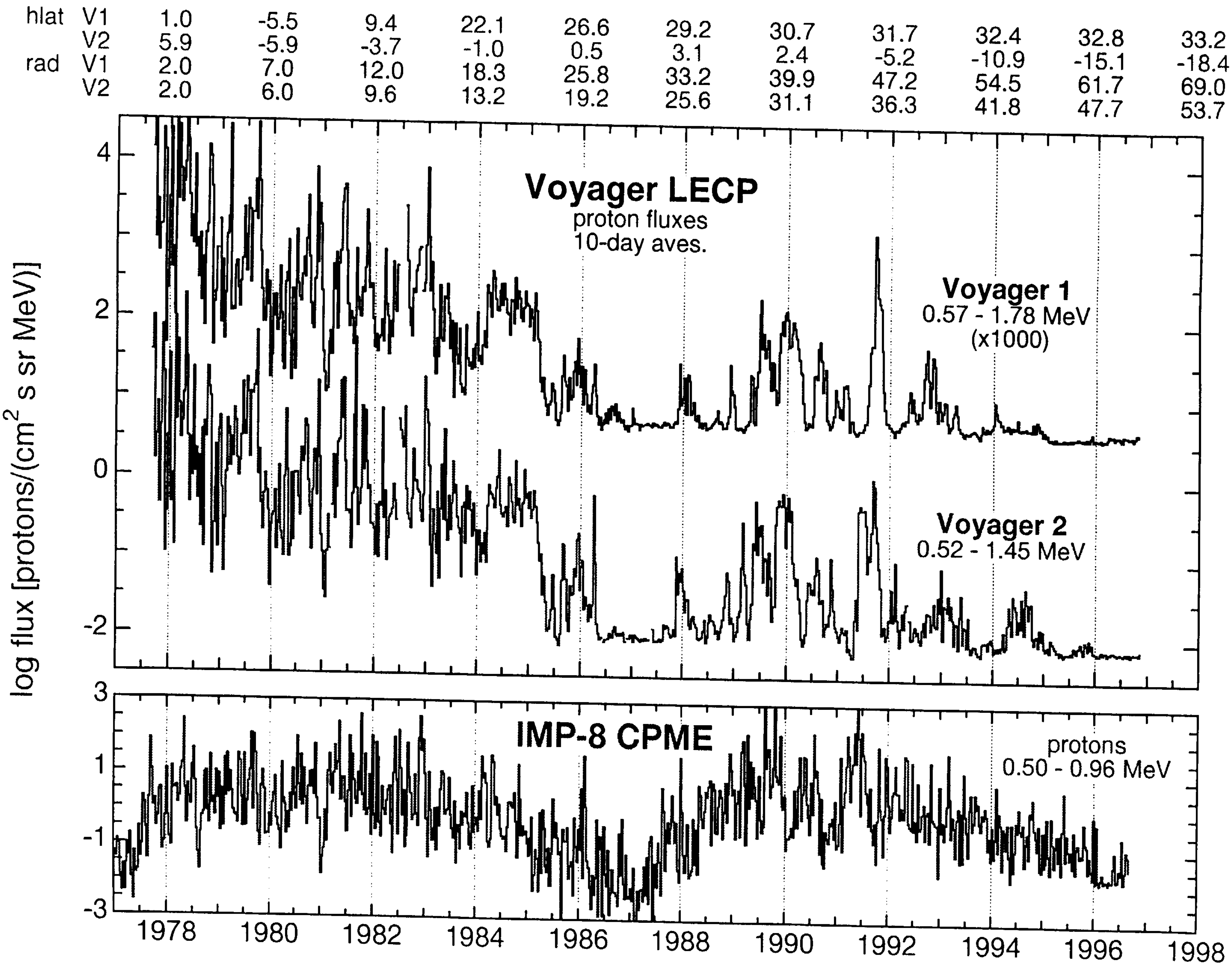
Voyager 1 LECP Z≥1 Ion Spectrogram (1977/250 - 1996/320)
Lat, deg
rad, AU
-5.5 7.0
-2.8 9.6
9.4 12.0
17.6 15.0
22.1 18.3
25.0 22.1
26.6 25.8
28.1 29.0
29.2 33.2
30.1 36.3
30.7 39.9
31.3 43.6
31.7 47.2
32.1 50.8
32.4 54.5
32.6 58.1
32.8 61.7
1000
100
Ion Energy (keV)
1980
1985
1990
1995
Year
Voyager 1
LECP
JHU/APL
data/v110d_bg85.txt
Wed Nov 13 18:33:38 1996
-6
-5
-4
-3
-2
-1
Log Ion Flux (cm² sec ster keV)⁻¹
LDP: 1996.82

Figure 1a



Voyager 2 LECP Z≥1 Ion Spectrogram (1977/250 - 1996/320)
Lat, deg
rad, AU
-5.9 2.0
-3.9 4.6
-5.9 6.0
-4.8 8.1
-3.7 9.6
-2.4 11.2
-1.0 13.2
-0.1 16.2
0.5 19.2
1.9 22.1
3.1 25.6
3.6 28.0
2.4 31.1
-1.7 33.6
-5.2 36.3
-8.3 41.8
-10.9 44.8
1000
100
Ion Energy (keV)
1980
1985
1990
1995
Year
Voyager 2
LECP
JHU/APL
data/v210df_bg85.txt
Thu Nov 14 12:39:57 1996
-6
-5
-4
-3
-2
-1
Log Ion Flux (cm² sec ster keV)⁻¹
LDP: 1996.82

Figure 1b



hlat V1 1.0 -5.5 9.4 22.1 26.6 29.2 30.7 31.7 32.4 32.8 33.2
V2 5.9 -5.9 -3.7 -1.0 0.5 3.1 2.4 -5.2 -10.9 -15.1 -18.4
rad V1 2.0 7.0 12.0 18.3 25.8 33.2 39.9 47.2 54.5 61.7 69.0
V2 2.0 6.0 9.6 13.2 19.2 25.6 31.1 36.3 41.8 47.7 53.7
Voyager LECP
proton fluxes
10-day aves.
Voyager 1
0.57 - 1.78 MeV
(x1000)
Voyager 2
0.52 - 1.45 MeV
IMP-8 CPME
protons
0.50 - 0.96 MeV
log flux [protons/(cm2 s sr MeV)]
4
2
0
-2
3
1
-1
-3
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998

Figure 2

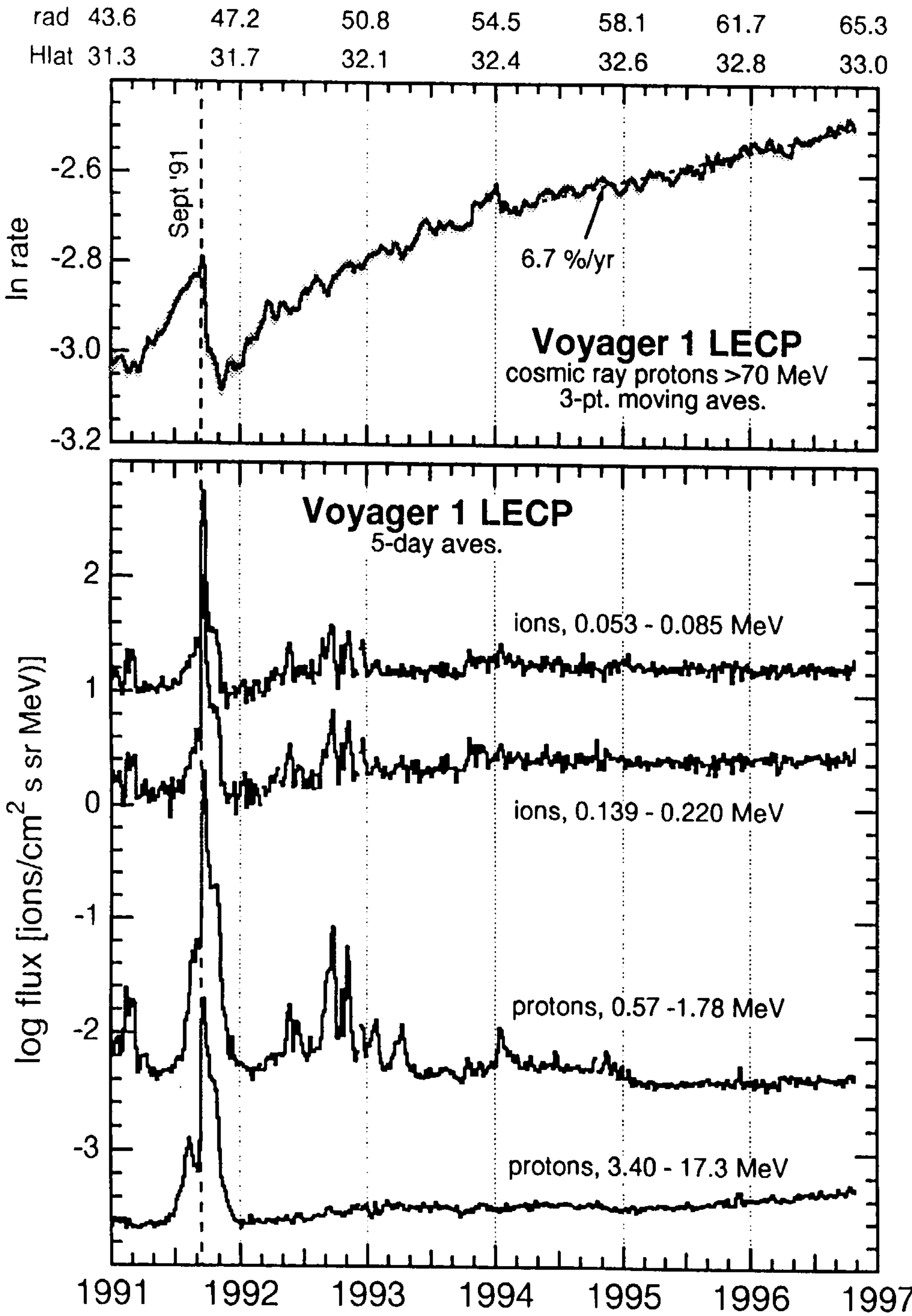


Figure 3a

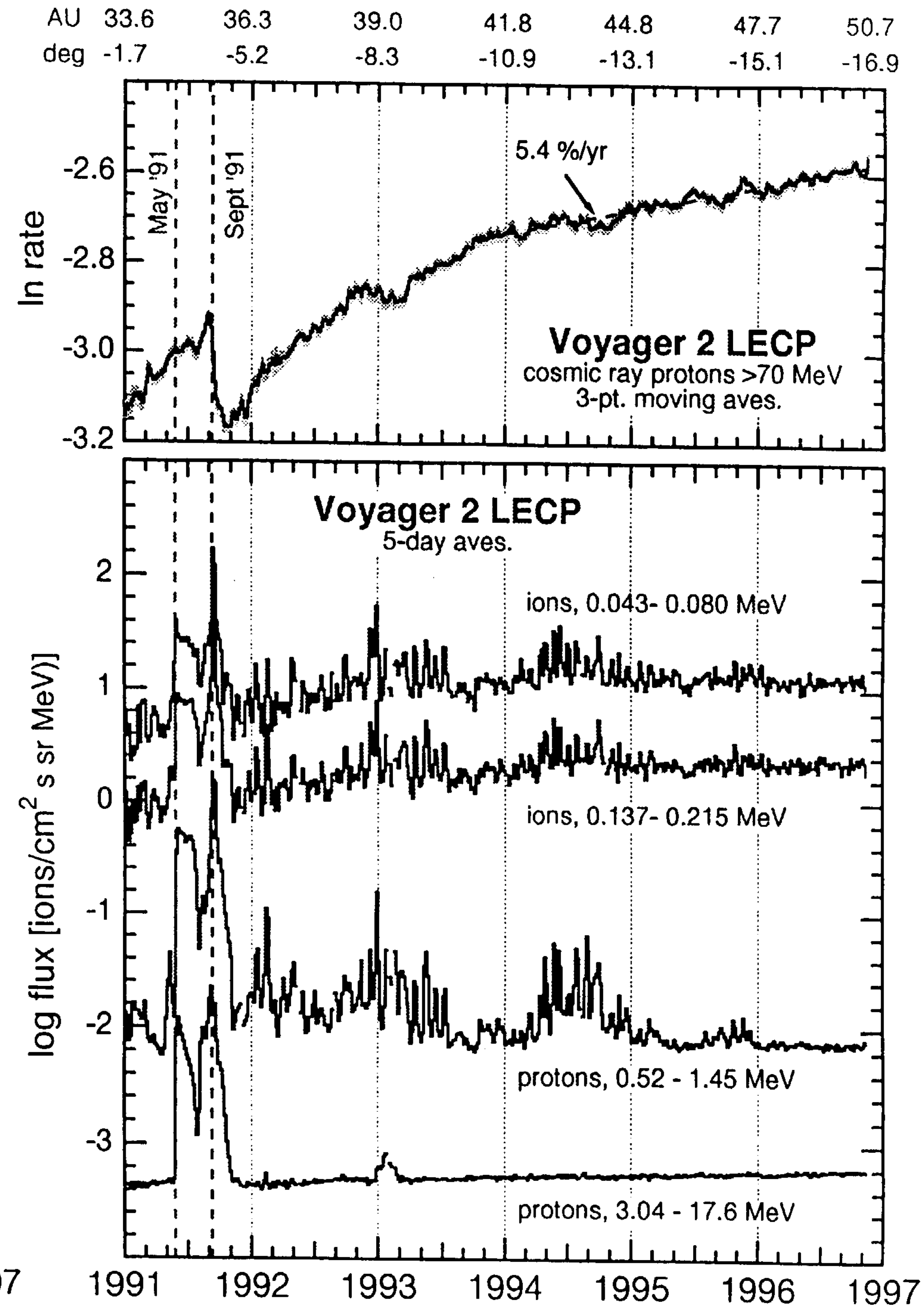
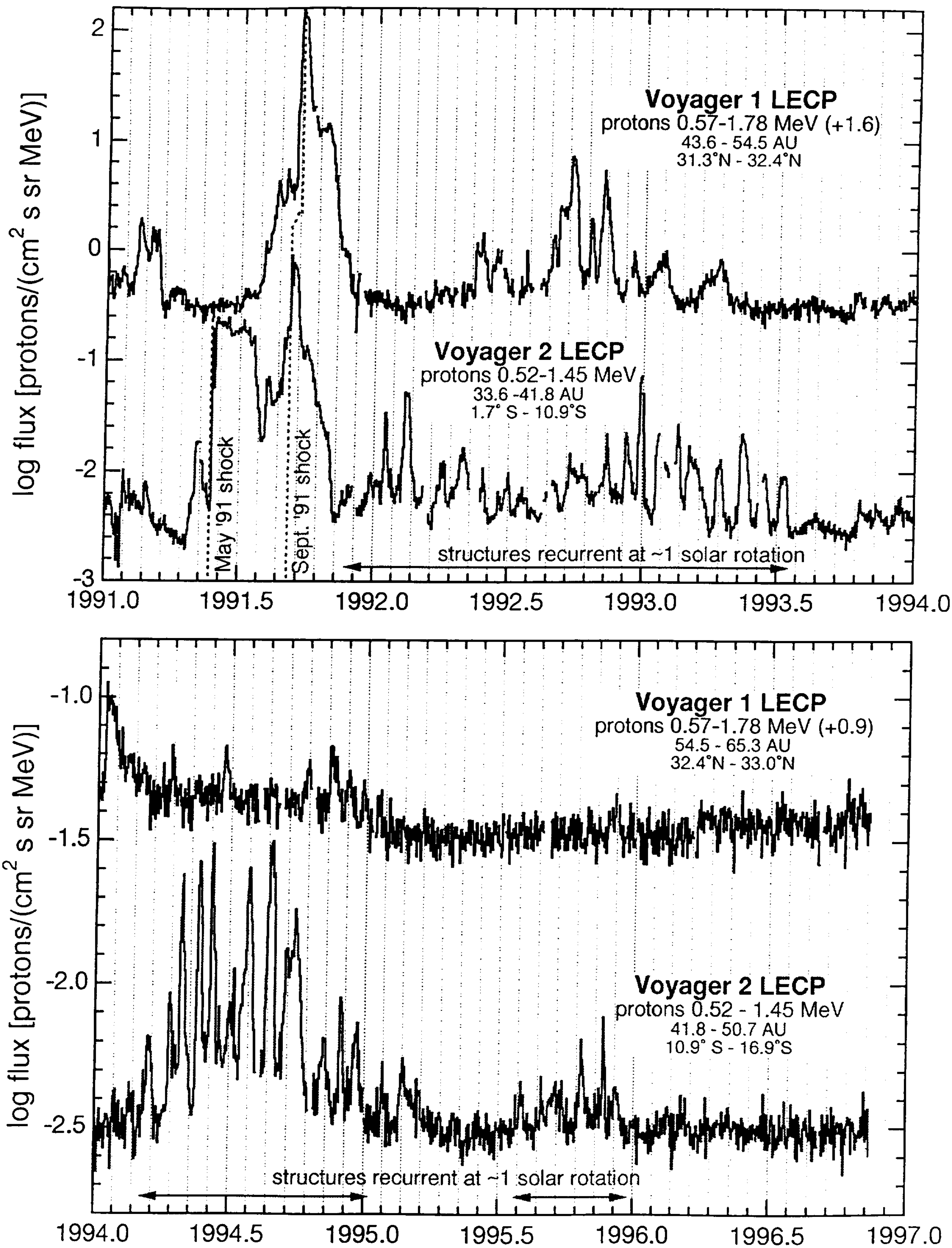


Figure 3b



Voyager 1 LECP
protons 0.57-1.78 MeV (+1.6)
43.6 - 54.5 AU
31.3°N - 32.4°N
Voyager 2 LECP
protons 0.52-1.45 MeV
33.6 -41.8 AU
1.7° S - 10.9°S
May '91 shock
Sept. '91 shock
structures recurrent at ~1 solar rotation
log flux [protons/(cm^2 s sr MeV)]
1991.0 1991.5 1992.0 1992.5 1993.0 1993.5 1994.0
Voyager 1 LECP
protons 0.57-1.78 MeV (+0.9)
54.5 - 65.3 AU
32.4°N - 33.0°N
Voyager 2 LECP
protons 0.52 - 1.45 MeV
41.8 - 50.7 AU
10.9° S - 16.9°S
structures recurrent at ~1 solar rotation
log flux [protons/(cm^2 s sr MeV)]
1994.0 1994.5 1995.0 1995.5 1996.0 1996.5 1997.0

Figure 4

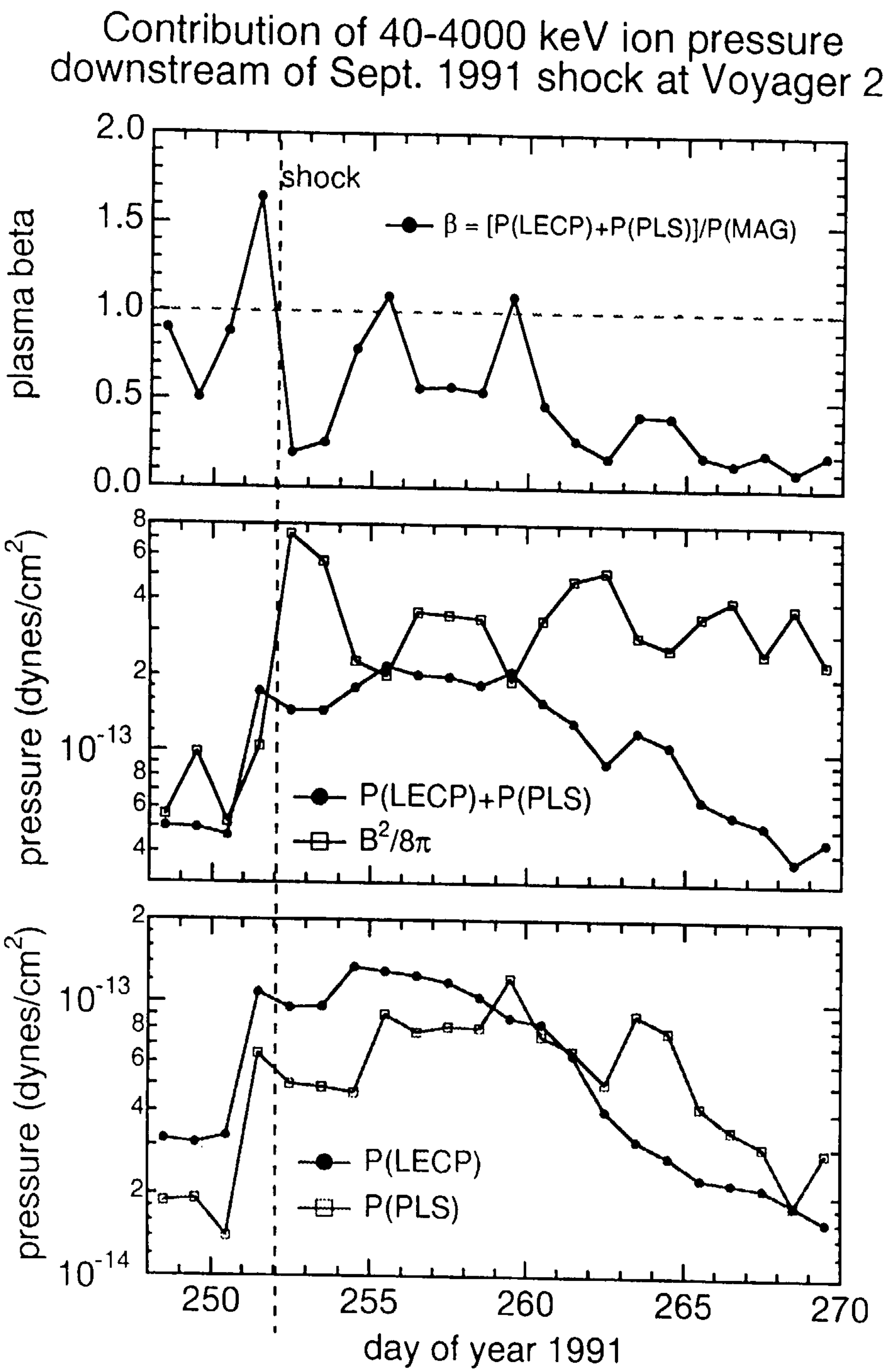
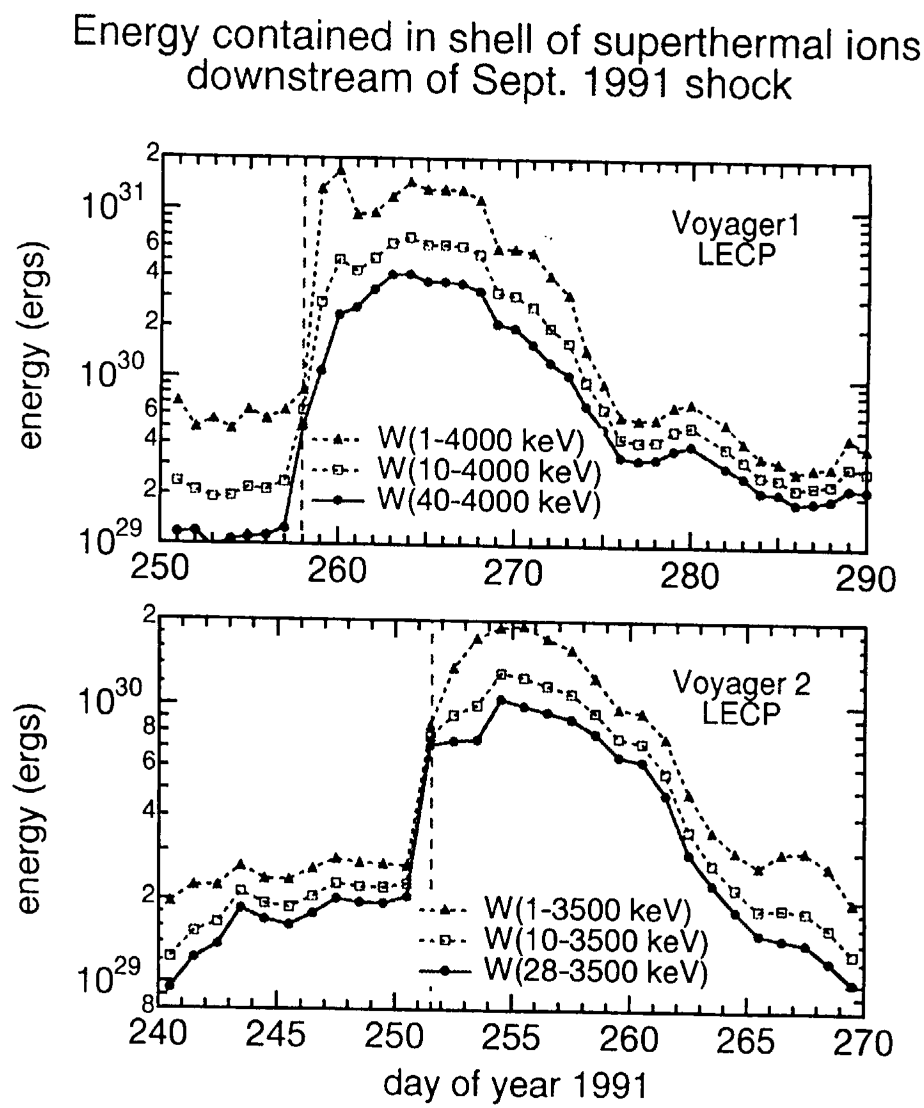


Fig. 5a



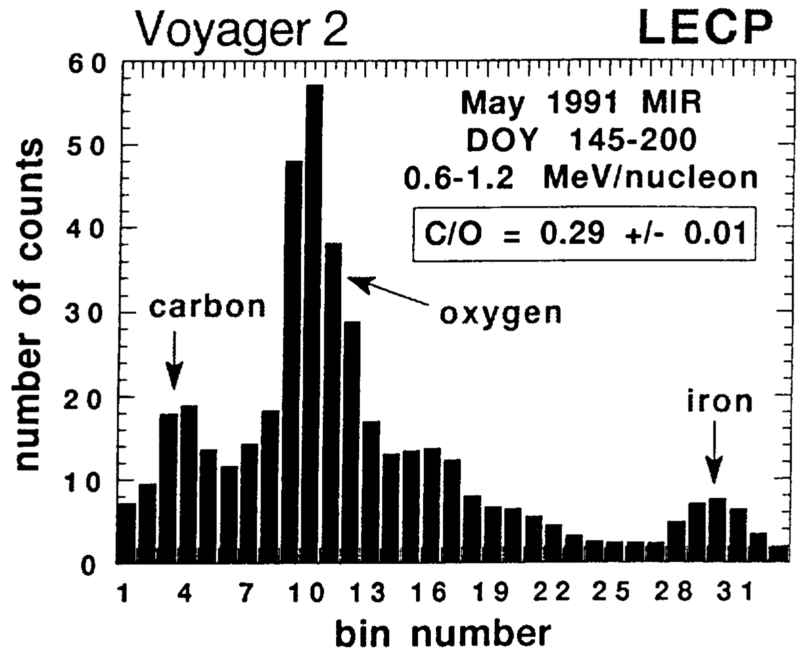
Total Energy in Superthermal Ions

Voyager 2 (doy 251-263): 1-2 x 10^{31} ergs

Voyager 1 (doy 258-275): 4-20 x 10^{31} ergs

Fig. 5b

I. May 1991 MIR at Voyager 2



•Note: Lanzerotti et al. (1992) [Ulysses HI-SCALE PHA]:
C/O = **0.52** ± **0.08** during March 1991 SEP event

II. Sept. 1991 GMIR at Voyager 1 and 2

Voyager 1 (DOY 200-310): **C/O = 0.16** ± **0.07**
Voyager 2 (DOY 200-300): **C/O = 0.29** ± **0.10**

Relevant reports of C/O at ~1 MeV/nucleon:

1) survey of **SEP** nuclei at 1AU (Mason et al., 1980),
C/O ≈ 0.50 (2/3 of cases in range 0.40-0.59)

2) 3 **CIR** events near 4 AU (Hamilton et al, 1980),
C/O ≈ 0.68

Figure 6

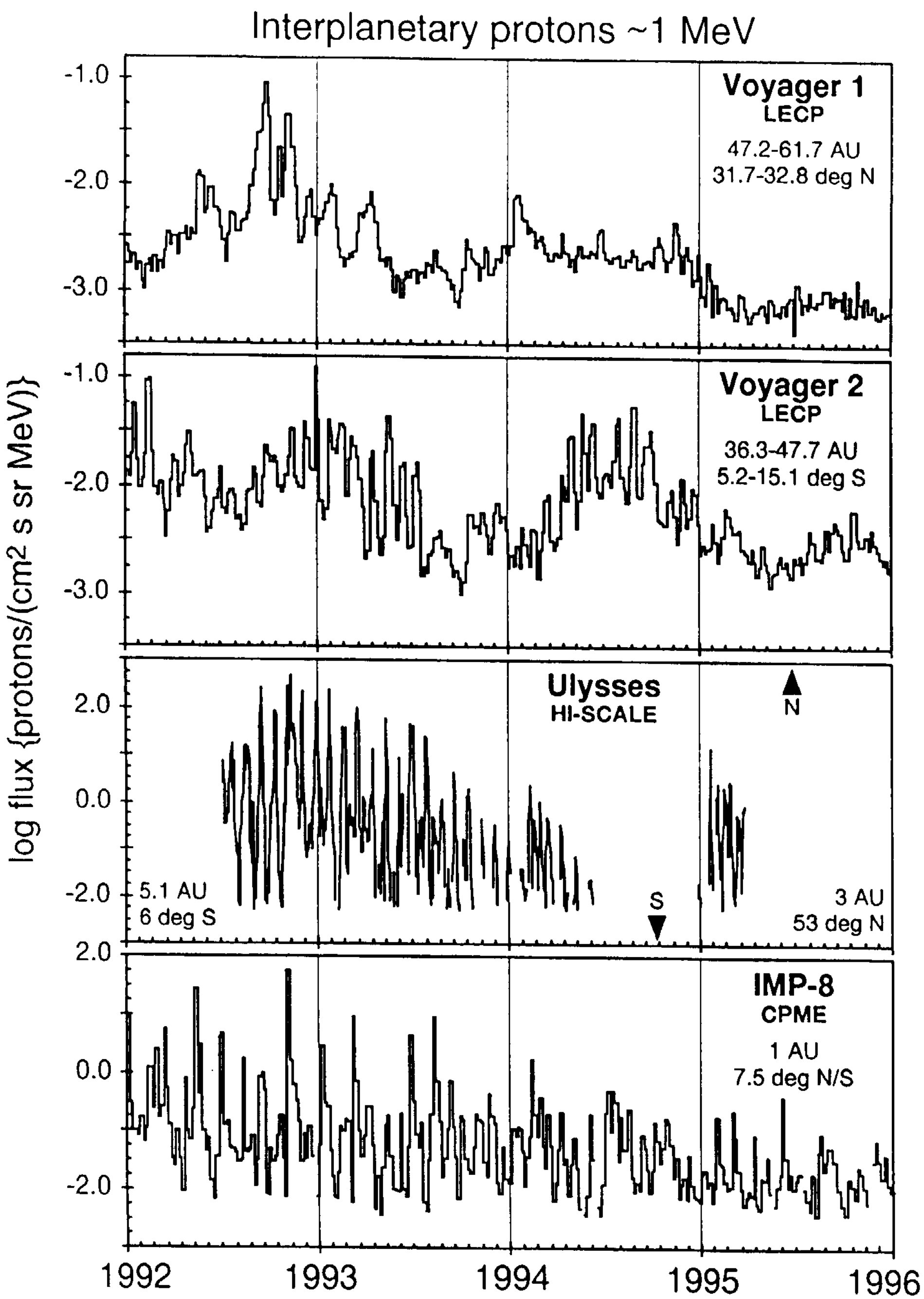
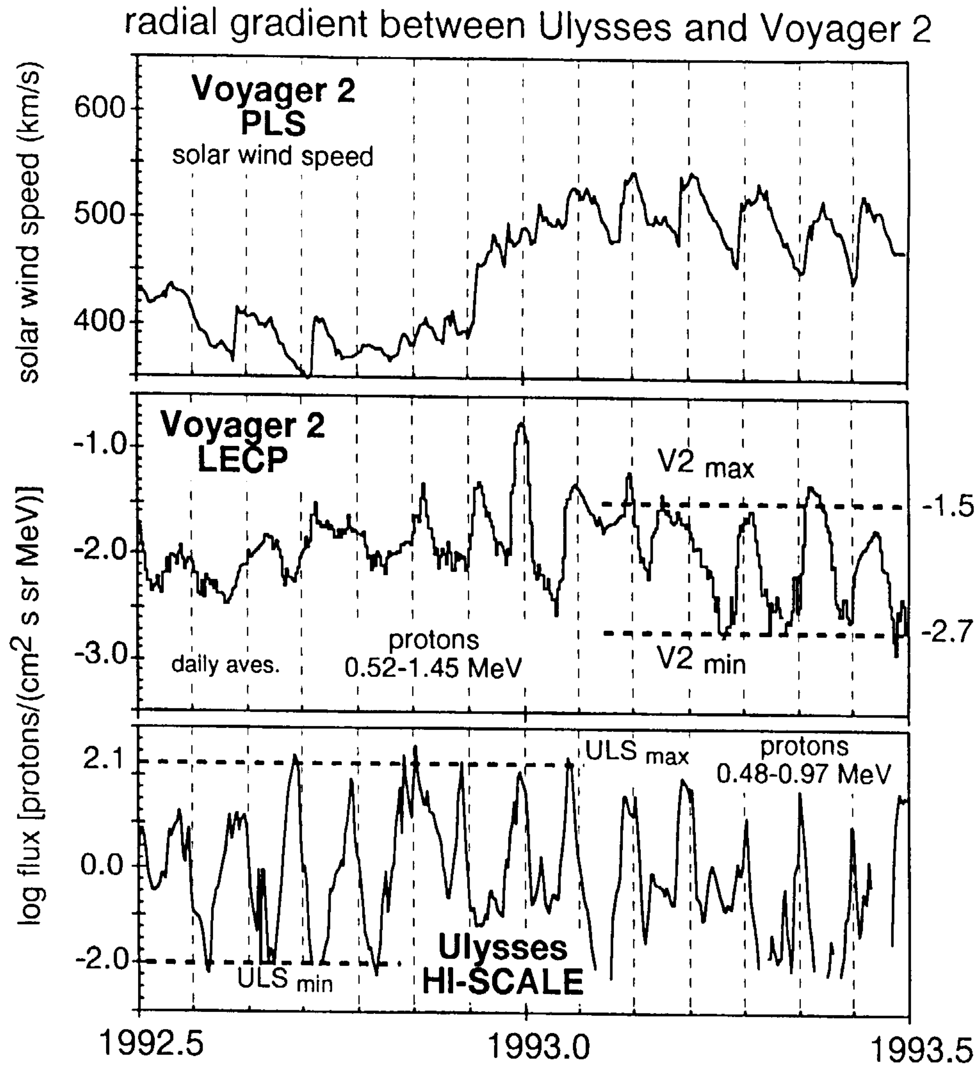


Figure 7a



Peaks:
$flux(ULS)_{max}$ / $flux(V2)_{max}$ ~ $10^{2.1}/10^{-1.5}$ = **4000**
Between peaks:
$flux(ULS)_{min}$ / $flux(V2)_{min}$ ~ $10^{-2.0}/10^{-2.7}$ = **5**

Figure 7b

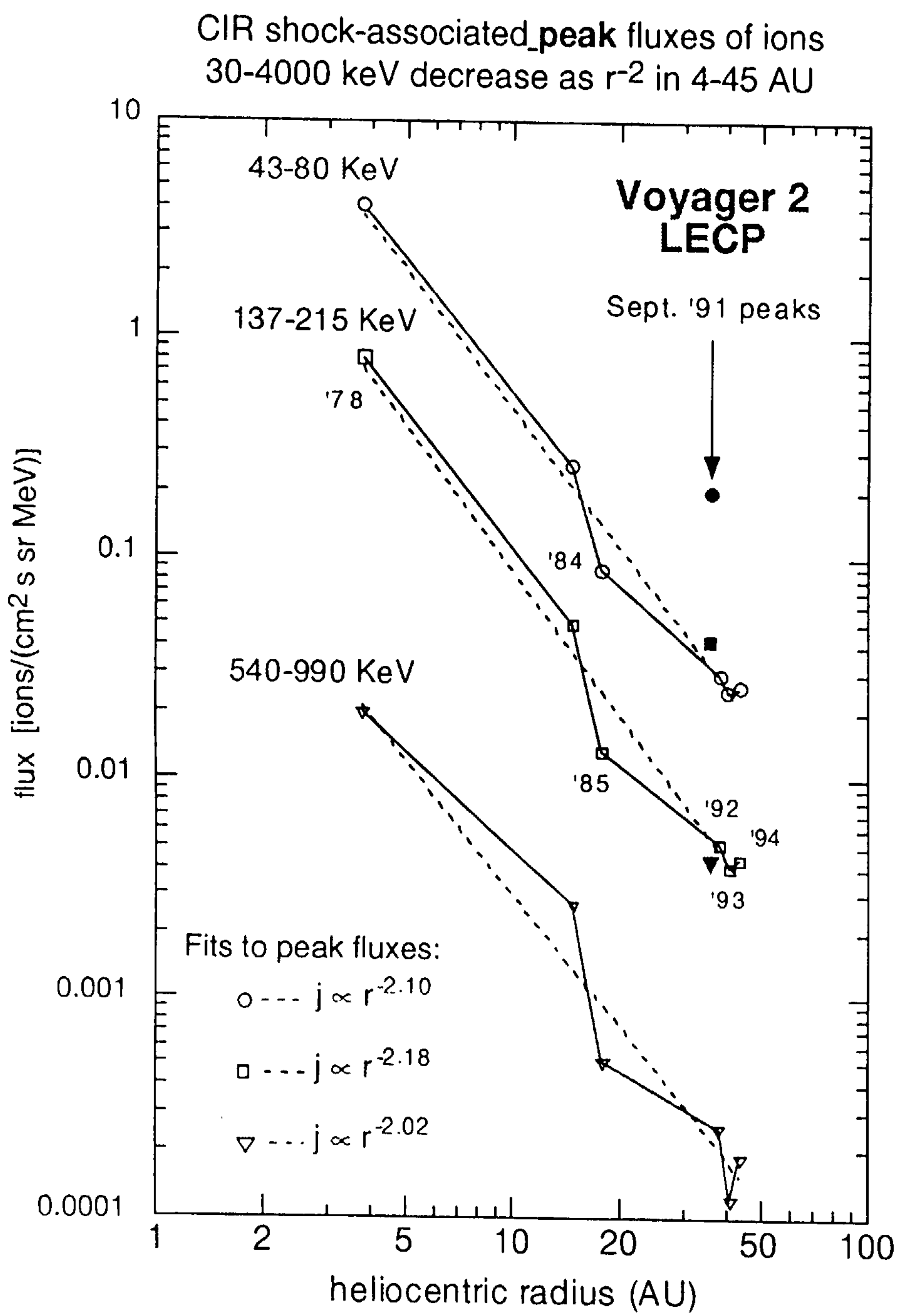


Figure 8

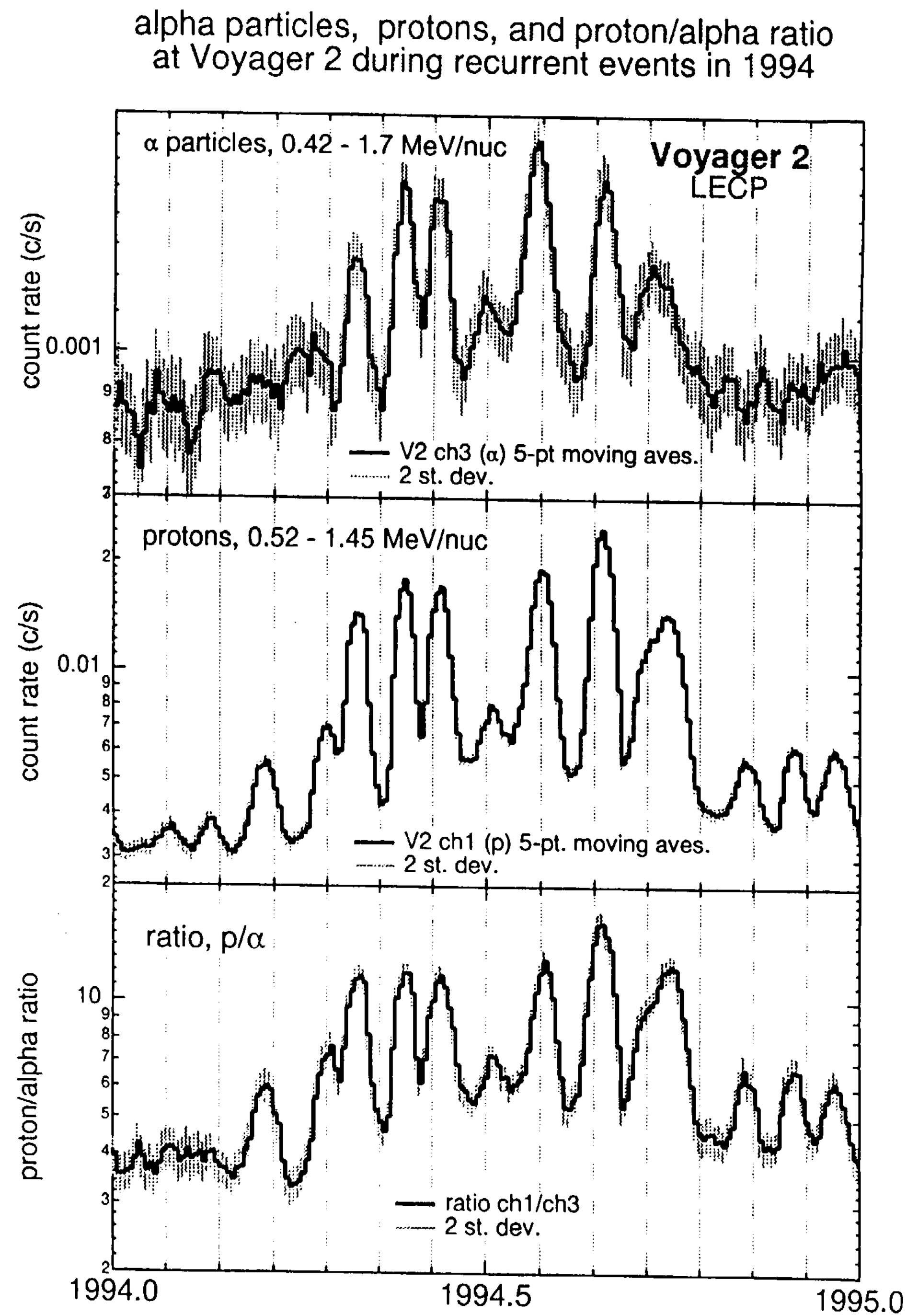


Figure 9

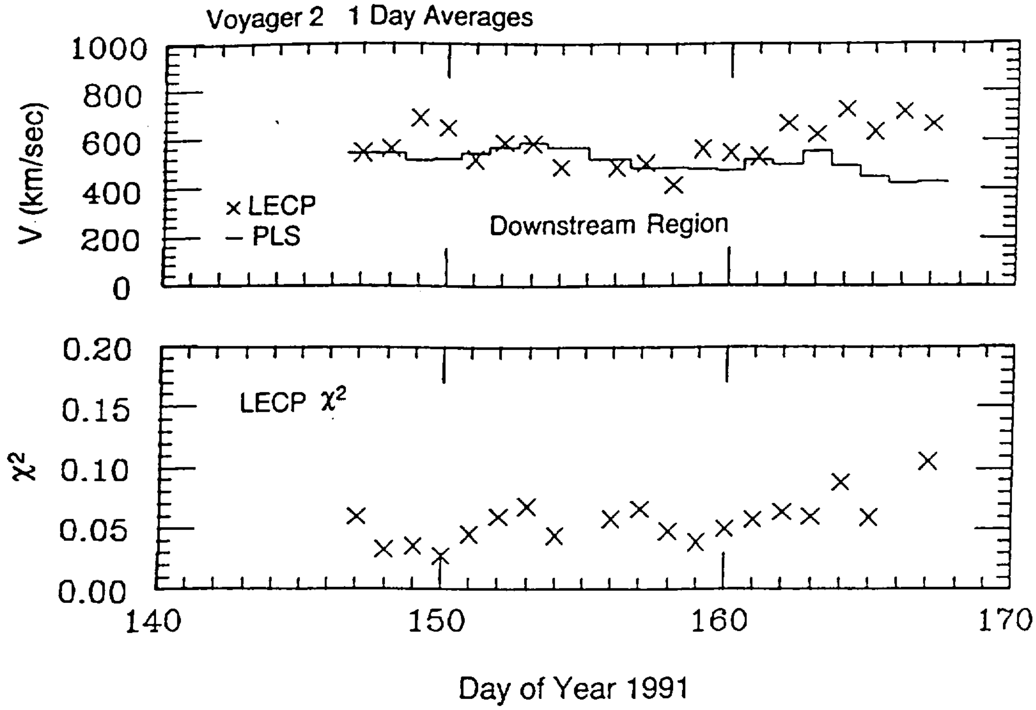


Figure 10

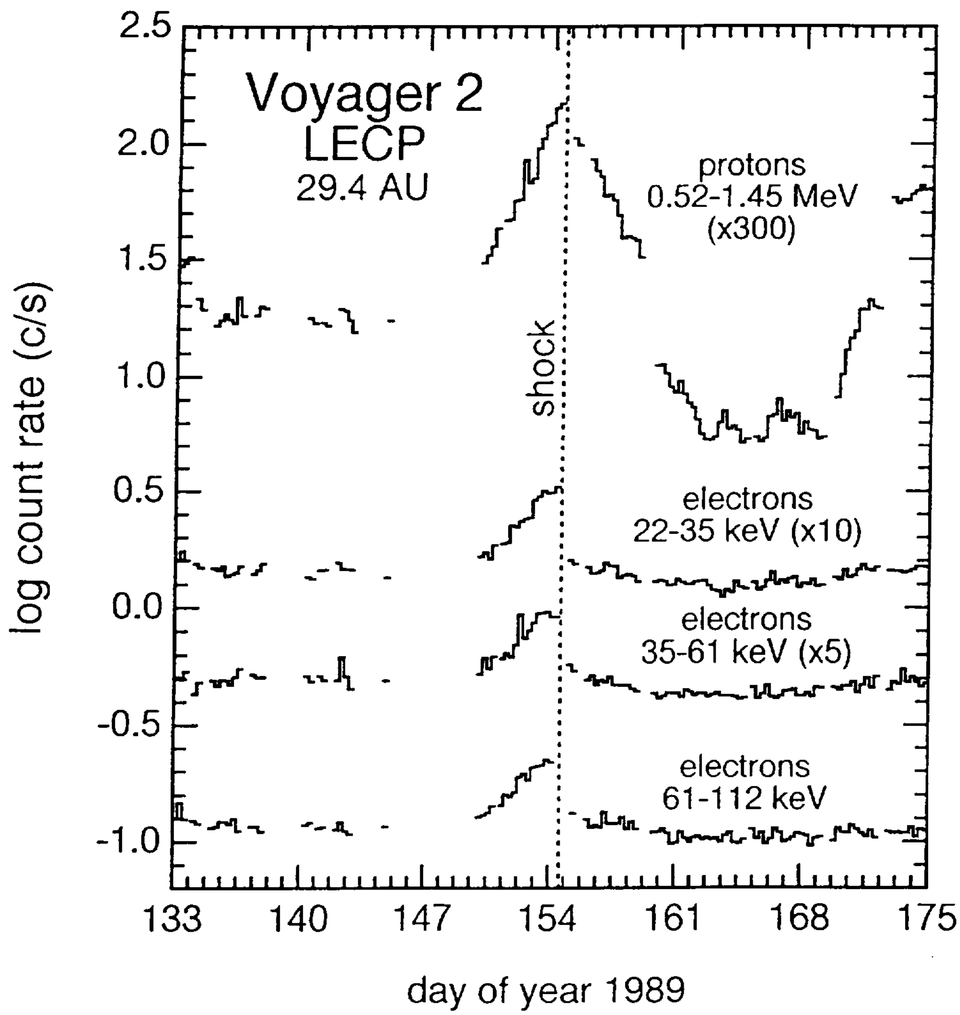
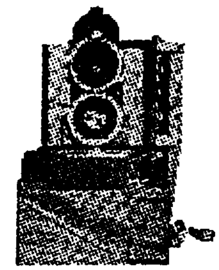


Figure 11

JHU/APL Voyager Low Energy Charged Particle (LECP) Experiment



General Information

- LECP Instrument (103K jpg)
  - CPT Subsystem Schematic (241K jpg)
  - LEMPA Subsystem Schematic (271K jpg)

- Spacecraft Schematic (103K gif)
- Spacecraft Photo (44K gif)
- LECP Contact Personnel at JHU/APL

- Check out the Voyager Data Availability Matrix at NSSDC

Interplanetary Medium

- Online Data Files
  - Voyager LECP: count rates and fluxes
  - IMP-8 CPME: 1 AU baseline, count rates and fluxes

- Data Displays
  - Spectrograms: color displays of ion fluxes in the interplanetary medium
  - Line plots: intensity vs time displays of various ion and electron channels

- LECP Solar Wind Velocities

- Voyager Interplanetary Trajectories

Voyager Planetary Encounters

- Planetary Encounters Trajectories
- Jupiter
- Saturn
- Uranus
- Neptune

- LECP Planetary Encounter Data
  - CD-ROMs (NSSDC)
  - Voyager 1 Master Catalog (NSSDC)
  - Voyager 2 Master Catalog (NSSDC)

- Spectrograms: color displays of ion and electron data in various planetary magnetospheres

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Figure 12

Related Voyager Links

- Voyager Project Home Page (JPL)
- Voyager 1 (JPL)
- Voyager 2 (JPL)
- Space Physics Data Availability Voyager Mission Matrix (NSSDC)
- The MIT Voyager Plasma Experiment (MIT)
- Voyager Magnetometer Experiment (GSFC)
- Voyager Plasma Wave Investigation (Univ. of Iowa)
- Voyager Cosmic Ray Experiment (GSFC)
- Online Voyager LECP Data (Univ. of Kansas)
- Voyager Project Information (NSSDC)
- Voyager Mission to the Outer Planets - Online Resources (JPL)

Other Spacecraft and Data of Interest at JHU/APL

- CPME and EPE Instruments on IMP-8 Satellite
- HI-SCALE Instrument on ULYSSES Spacecraft
- EPIC Instrument on GEOTAIL Satellite
- EPD Instrument on GALILEO Spacecraft
- Near Earth Asteroid Rendevous (NEAR)
- Advanced Composition Explorer (ACE)

For further information on the LECP instruments contact:
Dr. B. H. Mauk (e-mail: Barry_Mauk@jhuapl.edu)
Dr. R. B. Decker (e-mail: Robert_Decker@jhuapl.edu)
Dr. R. L. McNutt (e-mail: Ralph_McNutt@jhuapl.edu)
All at: The Johns Hopkins University Applied Physics Laboratory, Johns Hopkins Road, Laurel, Maryland, 20723-6099, U.S.A.

Return to JHU/APL Space Department Projects and Missions Page
or
Return to JHU/APL Space Department Home Page

Figure 12 (cont.)

PART B: COST PLAN

1.0 Introduction and Assumptions

Presented here is the cost plan for the Voyager Interstellar Mission: LECP Investigation for the four year period of 1 January 1997 to 31 December 2000. The efforts being proposed here are largely a continuation of activities that have been going on for many years, including six years of the Voyager Interstellar Mission. The costing is based largely on that experience. The total costs are consistent with the Voyager Project instructions given by G. P. Textor, Voyager Program Manager.

These costs include those of two of the Co-Investigator Institutions: The University of Maryland and the University of Kansas. These institutions will be funded via subcontract to The Johns Hopkins University Applied Physics Laboratory (JHU/APL). The efforts of the other two Co-Investigator Institutions, AT&T Bell Laboratories (Lucent Technologies) and Max-Planck Institut für Aeronomie in Lindau, will be provided at no cost to NASA.

2.0 Work Breakdown

During a previous proposal period it was requested that we divide our costs into three task areas: Operations, Archiving, and Science Analysis. The breakdown in terms of total costs, based on previous experience, was: Operations: 25%; Archiving: 25%; and Science Analysis: 50%. We have received no instructions for the present proposal period concerning a breakdown of the costs, and thus only top level costing information is provided here. If requested we are prepared to divide our costs according to new instructions. We anticipate that the breakdown into Operations, Archiving, and Science Analysis given above will be maintained for the proposal period.

3.0 Subcontracts

The major subcontracts specifically identified for the proposal period are:

	CY1997	CY1998	CY1999	CY2000
University of Kansas	$60K	60	60	60
University of Maryland	$45K	45	45	45
JHU Physics Postdoctoral Research Associate	$29K	—	—	—
ComputerMaintenance	$10K	10	10	10
Miscellaneous Supplies (e.g., Optical Discs)	$6K	6	6	6
Publications	$3K	3	3	3

All of these subcontracting costs are added into a single number within the cost sheets presented in Section 4. The data processing and analysis for the project at JHU/APL will be performed on existing computer equipment that are maintained by JHU/APL. The Computer Systems item listed above is for contractual manpower needed to oversee the operations of the computing systems used.

4.0 The JHU/APL Cost Sheets

The sheets following this section give the top level JHU/APL cost sheets for each of the four years in 1 January 1997 to 31 December 2000. "Total Estimated Costs" are consistent with instructions from the Voyager Project office.

Within all of these cost sheets, the individual workers, and their corresponding salaries, are not shown. JHU/APL often estimates costs according to experience with previous programs and determines salary costs based on standard labor rates and the labor mix of these labor categories found with the previous program. The last two years of the ongoing Voyager Interstellar Mission: LECP Investigation, was used as a guideline for this experience.

ATTACHMENT ( ) TO MAUK97
COST ESTIMATE FOR FG412
JAN 01,1997 - DEC 31,1997

APPLIED PHYSICS LABORATORY - THE JOHNS HOPKINS UNIVERSITY
COST ESTIMATE

TASK FG412 TITLE VOYAGER - LECP INVESTIGATION CONTINUATION

SPONSOR ORGANIZATION NASA/HQ, CODE SS
SPONSOR TECHNICAL REP DR. JAMES B. WILLETT PHONE 202-358-0888

	APL MAN MONTHS	RSE MAN MONTHS		$ AMOUNT
1. DIRECT LABOR COSTS				
DIRECT APL LABOR	28.0		(A)	129,761
EMPLOYEE BENEFITS			(B)	65,207
DIRECT RSE LABOR		0.0		0
DEPT OVHD ON DIR LABOR				62,171
SUB-TOTAL	28.0	0.0		257,139
2. DIRECT PROCUREMENT COSTS				
MATERIAL				0
SUBCONTRACT				134,000
MISCELLANEOUS CONTRACT MATERIAL				1,427
SUB-TOTAL				135,427
3. PROCUREMENT BURDEN (TASK Y4)				3,928
4. OTHER DIRECT COSTS				
TRAVEL				18,329
RSE NON-LABOR				0
CONSULTING				0
SPECIAL TEST EQUIPMENT				0
MISCELLANEOUS OTHER DIRECT COSTS				20,253
SUB-TOTAL				38,582
5. TOTAL DIRECT LABOR, PROCUREMENT BURDEN AND OTHER DIRECT COSTS (1 + 3 + 4)				299,649
6. ADMINISTRATION AND RESEARCH BURDEN (TASK X)				39,924
7. TOTAL ESTIMATED COSTS (2 + 5 + 6)				475,000

SEE EXPLANATION OF NOTES ON THE FOLLOWING PAGE

ATTACHMENT (   ) TO MAUK98
COST ESTIMATE FOR FG412
JAN 01,1998 - DEC 31,1998

APPLIED PHYSICS LABORATORY - THE JOHNS HOPKINS UNIVERSITY
COST ESTIMATE

TASK FG412   TITLE VOYAGER - LECP INVESTIGATION CONTINUATION

SPONSOR ORGANIZATION NASA/HQ, CODE SS
SPONSOR TECHNICAL REP DR. JAMES B. WILLETT   PHONE 202-358-0888

	APL MAN MONTHS	RSE MAN MONTHS		$ AMOUNT
1. DIRECT LABOR COSTS				
DIRECT APL LABOR	29.3		(A)	141,134
EMPLOYEE BENEFITS			(B)	71,359
DIRECT RSE LABOR		0.0		0
DEPT OVHD ON DIR LABOR				67,974
SUB-TOTAL	29.3	0.0		280,467
2. DIRECT PROCUREMENT COSTS				
MATERIAL				0
SUBCONTRACT				105,000
MISCELLANEOUS CONTRACT MATERIAL				1,552
SUB-TOTAL				106,552
3. PROCUREMENT BURDEN (TASK Y4)				3,198
4. OTHER DIRECT COSTS				
TRAVEL				20,008
RSE NON-LABOR				0
CONSULTING				0
SPECIAL TEST EQUIPMENT				0
MISCELLANEOUS OTHER DIRECT COSTS				21,175
SUB-TOTAL				41,183
5. TOTAL DIRECT LABOR, PROCUREMENT BURDEN AND OTHER DIRECT COSTS (1 + 3 + 4)				324,848
6. ADMINISTRATION AND RESEARCH BURDEN (TASK X)				43,600
7. TOTAL ESTIMATED COSTS (2 + 5 + 6)				475,000

SEE EXPLANATION OF NOTES ON THE FOLLOWING PAGE

ATTACHMENT ( ) TO MAUK99
COST ESTIMATE FOR FG412
JAN 01,1999 - DEC 31,1999

APPLIED PHYSICS LABORATORY - THE JOHNS HOPKINS UNIVERSITY
COST ESTIMATE

TASK FG412 TITLE VOYAGER - LECP INVESTIGATION CONTINUATION

SPONSOR ORGANIZATION NASA/HQ, CODE SS
SPONSOR TECHNICAL REP DR. JAMES B. WILLETT PHONE 202-358-0888

	APL MAN MONTHS	RSE MAN MONTHS		$ AMOUNT
1. DIRECT LABOR COSTS				
DIRECT APL LABOR	28.2		(A)	141,686
EMPLOYEE BENEFITS			(B)	70,985
DIRECT RSE LABOR		0.0		0
DEPT OVHD ON DIR LABOR				68,029
SUB-TOTAL	28.2	0.0		280,700
2. DIRECT PROCUREMENT COSTS				
MATERIAL				0
SUBCONTRACT				105,000
MISCELLANEOUS CONTRACT MATERIAL				1,559
SUB-TOTAL				106,559
3. PROCUREMENT BURDEN (TASK Y4)				3,517
4. OTHER DIRECT COSTS				
TRAVEL				19,977
RSE NON-LABOR				0
CONSULTING				0
SPECIAL TEST EQUIPMENT				0
MISCELLANEOUS OTHER DIRECT COSTS				20,424
SUB-TOTAL				40,401
5. TOTAL DIRECT LABOR, PROCUREMENT BURDEN AND OTHER DIRECT COSTS (1 + 3 + 4)				324,618
6. ADMINISTRATION AND RESEARCH BURDEN (TASK X)				43,823
7. TOTAL ESTIMATED COSTS (2 + 5 + 6)				475,000

SEE EXPLANATION OF NOTES ON THE FOLLOWING PAGE

ATTACHMENT ( ) TO MAUK00
COST ESTIMATE FOR FG412
JAN 01,2000 - DEC 31,2000

APPLIED PHYSICS LABORATORY - THE JOHNS HOPKINS UNIVERSITY
COST ESTIMATE

TASK FG412   TITLE VOYAGER - LECP INVESTIGATION CONTINUATION

SPONSOR ORGANIZATION NASA/HQ, CODE SS
SPONSOR TECHNICAL REP DR. JAMES B. WILLETT   PHONE 202-358-0888

	APL MAN MONTHS	RSE MAN MONTHS		$ AMOUNT
1. DIRECT LABOR COSTS				
DIRECT APL LABOR	27.1		(A)	141,522
EMPLOYEE BENEFITS			(B)	70,902
DIRECT RSE LABOR		0.0		0
DEPT OVHD ON DIR LABOR				67,957
SUB-TOTAL	27.1	0.0		280,381
2. DIRECT PROCUREMENT COSTS				
MATERIAL				0
SUBCONTRACT				105,000
MISCELLANEOUS CONTRACT MATERIAL				1,557
SUB-TOTAL				106,557
3. PROCUREMENT BURDEN (TASK Y4)				3,516
4. OTHER DIRECT COSTS				
TRAVEL				19,955
RSE NON-LABOR				0
CONSULTING				0
SPECIAL TEST EQUIPMENT				0
MISCELLANEOUS OTHER DIRECT COSTS				20,768
SUB-TOTAL				40,723
5. TOTAL DIRECT LABOR, PROCUREMENT BURDEN AND OTHER DIRECT COSTS (1 + 3 + 4)				324,620
6. ADMINISTRATION AND RESEARCH BURDEN (TASK X)				43,823
7. TOTAL ESTIMATED COSTS (2 + 5 + 6)				475,000

SEE EXPLANATION OF NOTES ON THE FOLLOWING PAGE

APPENDIX A:

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FIVE YEAR LECP BIBLIOGRAPHY, JANUARY 1992 TO DECEMBER 1996

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APPENDIX C:
INVESTIGATOR ADDRESSES, PHONE NUMBERS, FAX, AND E-MAIL ADDRESSES

INVESTIGATOR ADDRESSES, PHONE NUMBERS, FAX, AND E-MAIL ADDRESSES

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APPENDIX D:
LECP INVESTIGATOR TEAM
BRIEF CURRICULUM VITAE

S. M. Krimigis
Principal Investigator

Current Position: Head of the Space Department of The Johns Hopkins University Applied Physics Laboratory (JHU/APL). **Date of Birth:** September 10, 1938. **Education:** Ph.D., Physics, University of Iowa, 1965; M.S., Physics, University of Iowa, 1963; B.S., Physics, University of Minnesota, 1961. **Professional Background:** Research Associate, University of Iowa, 1965-66; Assistant Professor of Physics, University of Iowa, 1966-68; Joined Staff of JHU/APL, 1968. **Research Experience:** Has published over 300 papers in journals and books on solar, interplanetary and magnetospheric plasma physics, cosmic rays, magnetospheres of Earth, Jupiter, Saturn, Uranus and Neptune. Has been Principal Investigator or Co-Investigator on numerous spacecraft, including Earth (IMP, AMPTE), Mars (Mariner 4), Venus (Mariner 5), Outer Planets (Voyager, Galileo), and Jupiter-Sun (Ulysses). Is Principal Investigator, Magnetospheric Imaging Instrument on Cassini. **Awards:** Space Sciences Award, International Astronautical Academy (IAA); NASA Medal for Exceptional Scientific Achievement in 1981 and 1986; NASA Group Achievement Awards for Voyager, AMPTE, Galileo, and Ulysses. **Professional Societies:** Fellow of the American Geophysical Union (AGU) and the American Physical Society (APS); Associate Fellow, AIAA.

Thomas P. Armstrong
Co-Investigator

Current Position: Professor of Physics and Astronomy, University of Kansas. **Date of Birth:** November 24, 1941. **Education:** Ph.D., Physics, University of Iowa, 1966; M.S., Physics, University of Iowa, 1964; B.S., Physics, University of Kansas, 1962. **Research Experience:** Is the author or co-author of approximately 140 research papers. Has been a Co-Investigator on the Voyager LECP investigation since its beginning. Has been responsible for most of the second-level analysis programming and instrument characterizations. Has contributed data expertise, instrumental characterizations, and scientific analysis to the Explorer 33 and 35, Injun 3, 4, and 5, Mariner 4 and 5, Voyager, IMP 7 and 8, Galileo, Geotail, Ulysses, and Cassini flight programs. **Academic Contributions:** As a Professor of Physics and Astronomy since 1977, has directed or co-directed with other faculty the Ph.D. studies of 20 students and the Master's degrees of nine. Two more Ph.D.'s and one Master's students are expected to complete this year. Has also supervised numerous undergraduate research students, several of whom have attained distinguished graduate careers elsewhere. Customarily teaches plasma physics, space physics, computational physics, and other courses as needed by the department.

Robert B. Decker
Co-Investigator

Current Position: Principal Professional Staff, The Johns Hopkins University Applied Physics Laboratory (JHU/APL). **Date of Birth:** February 2, 1951. **Education:** Ph.D., Physics, University of Kansas, 1979; B.A., Physics (Magna Cum Laude) Lock Haven University, 1974; **Professional Experience:** Assistant Professor, Department of Physics and Astronomy, University of Kansas, 1979; Research Associate, JHU/APL (1979-1984); Senior Staff Physicist, JHU/APL (1984-present). **Research Experience:** Collaborating Scientist with LECP experiment. Principal Investigator and Co-Investigator on various NASA grants. Specific experience includes: (i) Numerical modeling and theoretical analysis of charged particle acceleration and transport at collisionless shocks, in electromagnetic plasma waves, in planetary magnetospheres, in planetary and interplanetary current sheets; (ii) Monte Carlo simulations of neutral torus formation and new-born ion injection, including ionization and collision processes, applicable to neutral atmospheres of planets and planetary satellites; (iii) Analysis of energetic ion and electron data from CPME instruments on Earth-orbiting satellites IMP 7/8 and from the LECP instruments on Voyagers 1/2 to study the acceleration and transport of low energy charged particles and the modulation of galactic cosmic rays. **Awards:** Group Achievement Award for Voyager Science Investigation; Group Achievement Award for AMPTE Mission Operations. **Academic Contributions:** Has directed research at JHU/APL related to Voyager LECP data for one Masters and one Ph.D. student. Is involved in the JHU/APL Mentor Program and supervises high school students in research projects related to LECP data and space physics in general.

George Gloeckler
Co-Investigator

Current Position: Professor of Physics, Department of Physics and Institute for Physical Science and Technology, University of Maryland. **Education:** Ph.D., Physics, 1965; M.S., Physics, 1961; B.S., Physics, 1960; all at the University of Chicago. **Principal Investigator:** (1) Solar Wind and Suprathermal Composition Studies (SMS experiment) on Wind; (2) Solar Wind Ion Composition Spectrometer (SWICS) on Ulysses; (3) SWIMS SWICS Spectrometer Experiment on Advanced Composition Explorer (ACE) Spacecraft. **Research Experience:** (1) Sources and acceleration of energetic particles in (a) the heliosphere, (b) the Sun, and (c) planetary and terrestrial magnetospheres; (2) Origin and composition of the solar wind; (3) Production, dynamics, and acceleration of interstellar pickup ions; (4) Anomalous cosmic rays; (5) Composition of the interstellar gas; (6) Development of time-of-flight ion composition spectrometers: (a) CHEM on AMPTE/CCE and Cassini; (b) SWICS on Ulysses and Wind; (c) STICS on Geotail and Wind; (d) MASS on Wind; (e) SWIMS on ACE. **Research Objectives:** (1) Dynamics and acceleration of pickup ions in the distant heliosphere; (2) Multi-spacecraft studies of pickup ions and their acceleration to the anomalous cosmic rays using data from LECP on the Voyagers, SWICS on Ulysses, STICS on WIND and Geotail, and CHEMS on Cassini.

Douglas C. Hamilton
Co-Investigator

Current Position: Associate Professor of Physics, University of Maryland. **Education**: Ph.D., Physics, University of Chicago. **Research Experience**: Has directed the University of Maryland LECP data analysis effort since 1991, concentrating on studies involving the use of the detailed PHA data returned by the LECP composition telescope. Has studied the composition of the energetic ion populations in the magnetospheres of Jupiter, Saturn, Uranus, and Neptune. Has studied ion composition and transport in energetic solar particle events and ion composition in particle events associated with corotating interaction regions and traveling interplanetary shocks. **Research Objectives:** Interested in using LECP composition data to establish the source populations of major energetic particle events observed by the Voyager spacecraft in the outer heliosphere and to search for compositional changes that might indicate an approach to the termination shock. Co-Investigator on the SMS and EPACT investigations on the WIND spacecraft that are now providing ion composition information from solar wind to MeV energies. The WIND observations will serve as a 1 AU baseline for Voyager LECP outer heliosphere measurements.

Wing-H. Ip
Co-Investigator

Current Position: Staff Scientist, Max-Planck-Institut für Aeronomie. **Date of birth:** [redacted] **Education:** Ph.D., Applied Physics, University of California at San Diego, 1974; M.A., Physics, The University of Pittsburgh, 1970; B.A., Physics, The Chinese University of Hong Kong, 1969. **Professional Background:** Postdoctoral Assistant Physicist, UCSD (1974-1976); Assistant Research Physicist, UCSD (1976-1978); Staff Scientist, Max-Planck-Institut für Aeronomie (1978-present); Chief Scientist/Director, Research and Development Division, National Program Office, Taiwan, ROC (1992-1993); Chairman/National COSPAR Committee of ROC (1992-present). **Research Experience:** Co-Investigator of the IMS experiment on Giotto; Interdisciplinary Scientist on Galileo; Team member of the NMIS facility instrument on Cassini; Co-Investigator on the MIMI experiment on Cassini; Co-Investigator on the High Resolution Stereo Camera experiment on Mars 96; Co-Investigator on the UVPS experiment on Mars 96; Co-Investigator on the RAPID experiment of Cluster; Co-Investigator on the HEP-LD experiment of Geotail. **Editorial Service:** European Editor, *Journal of Geophysical Research* (1990-1992); Associate Editor, *Planetary and Space Science* (1992-present).

Edwin P Keath
Co-Investigator

Current Position: Principal Professional Staff, The Johns Hopkins University Applied Physics Laboratory (JHU/APL). **Date of Birth:** [redacted], [redacted], [redacted]. **Education:** Ph.D., Physics, North Texas State University, 1972. **Professional Background:** Research Fellow, University of Texas at Dallas, studying high-energy gamma rays using a balloon-borne detector system; Co-Investigator on the Pioneer 8 and 9 Cosmic Ray Detector Instruments; joined JHU/APL in 1974. **Research Experience:** Primary research interests have been the development of spacecraft instrumentation and the study of planetary magnetospheres. Has been Co-Investigator on a number of spacecraft programs, including the Low Energy Charged Particle (LECP) analyzer on the Voyager Spacecraft, the Medium Energy Particle Analyzer on the NASA-Active Magnetospheric Particle Tracer Explorer spacecraft, and the Magnetospheric Imaging Instrument on the Cassini mission to Saturn. **Awards:** NASA Group Achievement Awards for the Voyager investigations of Jupiter, Saturn, Uranus, and Saturn, and for the AMPTE Program.

Louis J. Lanzerotti
Co-Investigator

Current Position: Distinguished Member of Technical Staff, AT&T Bell Laboratories, and Adjunct Professor of Electrical Engineering at the University of Florida, and has served as Regents' Lecturer at UCLA. **Date of Birth:** April 16, 1938. **Education:** Ph.D., Physics, Harvard University, 1965; M.A., Physics, Harvard University, 1963; B.S., Engineering Physics, University of Illinois, 1960. **Research Experience:** Has published over 400 papers, and is a co-author or co-editor of three books. Principal research interests include space plasmas, geophysics, and engineering problems related to the impact of space processes on space and terrestrial technologies. Is a Principal Investigator and Co-Investigator on NASA missions, and conducts extensive ground-based and laboratory research on space-related topics. **Awards:** Has twice received NASA's Distinguished Public Service Medal. **Committee Service:** Was Chairman (1984-1988) of NASA's Space and Earth Science Advisory Committee and a member of the 1990 Advisory Committee on the Future of the US Space Program. Has served as Chairman (1988-1994) of the Space Studies Board of the National Research Council and a member (1991-1993) of the Vice President's Space Advisory Board. Has served on numerous NASA, National Science Foundation, and university advisory bodies concerned with space and geophysics research. **Professional Societies:** Elected to National Academy of Engineering and the International Academy of Astronautics. Is a Fellow of the American Geophysical Union, the American Physical Society, and the American Association for the Advancement of Science.

Barry H. Mauk
Co-Investigator

Current Position: Principal Professional Staff Physicist at The Johns Hopkins University Applied Physics Laboratory (JHU/APL) specializing in space plasma physics. **Education:** Ph.D., Physics, 1978; B.A., Physics, 1972; both from the University of California at San Diego. **Professional Background:** Has held the position of Research Assistant Professor at the University of Washington in Seattle (1978-1981), and has then been at JHU/APL since 1982. **Research Experience:** Over 70 papers published in refereed journals. Co-Investigator on the Voyager LECP and the Cassini MIMI Investigations; formerly Principal Investigator on the ENACEOS Investigation selected for flight on NASA's EOS mission; formerly Project Scientist on BMDO's Nuclear Electric Propulsion Space Test Program and on NASA's TIMED mission for the development of the Conceptual Design. **Awards:** NASA Group Achievement Awards for Voyager Science Investigations at Uranus (1986), for Voyager Science Investigations at Neptune (1989), and for the AMPTE Mission Operations (1990); Editor's Citation for Excellence in Refereeing from the *Journal of Geophysical Research* (1988); awarded two AGU Certificates of Appreciation for contributions to the U.S. National report to the IUGG (1983-1866 and 1987-1990). **Committee Service:** Member of the NRC/NAS Committee on Planetary and Lunar Exploration and on the NASA Science Definition Team for the Inner Magnetospheric Imager. **Editorial Service:** Associate Editor of the *Journal of Geophysical Research* from 1990-1993.

Ralph L. McNutt, Jr.
Co-Investigator

Current Position: Principal Professional Staff, The Johns Hopkins University Applied Physics Laboratory. **Date of Birth:** October 29, 1953. **Education:** Ph.D., Physics, Massachusetts Institute of Technology, 1980; B.S., Physics, Summa Cum Laude, Texas A&M University, 1975. **Professional Background:** Technical Staff, Sandia National Laboratories, 1980-1981; Sponsored Research Staff, MIT, 1981-1982; Assistant Professor of Physics, 1982-1986; Associate Professor of Physics, 1986-1990; Sponsored Research Staff, MIT, 1990; Senior Project Scientist, Visidyne, Inc., 1990-1992; Consultant, Sandia National Laboratories, 1981-1987; Consultant, Visidyne, Inc., 1986-1988; Relevant Research Associate Professor of ECS Engineering, Boston University, 1991-1992. **Research Experience:** Author of over 45 scientific papers. Data interpretation and analysis and instrument concepts and designs. Work on diverse topics including physics of the magnetospheres of the outer planets, physics of the outer heliosphere, Pluto's atmosphere, pulsars, physics of very high current electron beams, and interaction of electron beams with the mesosphere/thermosphere (X-ray spectrum analysis). Co-Investigator on Voyager Plasma Science Investigation; Team Member on the Cassini Orbiter Ion Neutral Mass Spectrometer investigation; Instrument Scientist on NEAR X-ray/Gamma-ray Spectrometer instrument; Principal Investigator and Co-Investigator on various NASA Grants. **Awards:** NASA Group Achievement Award for Voyager Science, 1990; NASA Group Achievement Award for the Voyager Uranus Interstellar Mission, 1986; NASA Group Achievement Award for the Voyager Project, 1981. **Professional Societies:** Member of The American Astronomical Society and the Division of Planetary Sciences, The American Geophysical Union, Sigma Xi, The Planetary Society, and The British Interplanetary Society. **Editorial Service:** Associate Editor of *Geophysical Research Letters*.

APPENDIX E:
VOYAGER LECP PERSONNEL (1990-1996)

VOYAGER LECP PERSONNEL (1992-1996)

Provided are lists of individuals that have participated in the Voyager LECP efforts over the last five years (1992-1996). "Research Participants" are *not* just co-authors on papers but are individuals who have spent substantial time at one of the LECP institutions and have concentrated substantial efforts utilizing the LECP data or results.

Principal and Co-Investigators:

Stamatios M. Krimigis, Principal Investigator, JHU/APL
Thomas P. Armstrong, Co-Investigator, University of Kansas
Ian Axford, Co-Investigator, The Max Planck Institute at Lindau
George Gloeckler, Co-Investigator, The University of Maryland
Douglas C. Hamilton, Co-Investigator, The University of Maryland
Edwin P. Keath, Co-Investigator, JHU/APL
Louis J. Lanzerotti, Co-Investigator, AT&T Bell Laboratories
Barry H. Mauk, Co-Investigator, JHU/APL

Research Participants:

Andrew F. Cheng, Principal Professional Staff, JHU/APL
Michael R. Collier, Post-Doctoral Fellow, University of Maryland
Robert B. Decker, Principal Professional Staff, JHU/APL
Mark Kane, Post-Doctoral Fellow, The Johns Hopkins University
Carol G. Maclennan, Research Staff, AT&T Bell Laboratories
Ralph L. McNutt, Jr.,Principal Professional Staff, JHU/APL
Chris P. Paranicas, Senior Staff, JHU/APL
Valerio Pirronello, Visiting Scientist (at AT&T Bell Laboratories), University of Calanis, Italy
Edmond. C. Roelof, Principal Professional Staff, JHU/APL
Emmanuel T. Sarris, Visiting Scientist (at JHU/APL), National Observatory of Athens
Doraswamy Venkatesan, Professor of Physics, University of Calgary, Calgary, Canada
Gang Ye, Post-Doctoral Fellow, University of Kansas

Students and Other Staff:

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Moncef Boufaida, Graduate Student (Ph.D.), University of Kansas
Dale Brown, Graduate Student (Ph.D.), University of Maryland
Tom Brown, Data Technician, JHU/APL
Michael Brox, Graduate Student (Masters), University of Kansas

Jonathan Edwards, High School Science Research Student, Atholton High School, Atholton, MD
Wesley Hendricks, Data Technician, The University of Maryland
Joy Hook, Systems Programmer, JHU/APL
Mark Kane, Post Doctoral Research Associate, The Johns Hopkins University
Oliver Lamm, Programmer and Data Technician, JHU/APL
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Nathan Newell, Undergraduate Student, University of Maryland
Sheela Shodhan, Graduate Student (Masters), University of Kansas
Edith Stahl, Undergraduate Student, University of Maryland
Lora Suther, Section Supervisor, Software and Data Systems, JHU/APL
David Thomson, Engineer and Mathematician, AT&T Bell Laboratories
Travis Walters, Undergraduate Student, University of Kansas
Jeanette Williams, Data Technician, University of Maryland

APPENDIX F:
JHU/APL CERTIFICATIONS

CERTIFICATION

The following certifications apply to Proposal Entitled Voyager Interstellar Mission: LECP Investigation (AC-23469)

(a) Pursuant to the requirements of OMB Circular A-129, this organization certifies that it is not delinquent on any Federal debt.

(b) Pursuant to Executive Order 12549 and implementing rule, this organization certifies that it presently is not debarred, suspended, proposed for debarment, declared ineligible or voluntarily excluded from covered transactions by any Federal department or agency.

(c) Pursuant to PL 100-690 and implementing rule, this organization certifies that it will provide a drug-free workplace. The place of performance is:

Johns Hopkins Road
Street Address

Laurel, Howard, MD 20723
City, County, State, Zip Code

Organization: Johns Hopkins University Applied Physics Laboratory

Authorized Representative: E. M. Portner E M Portner

Date: 12/11/96

CERTIFICATION REGARDING LOBBYING CONTRACTS, GRANTS, AND COOPERATIVE AGREEMENT

The undersigned certifies, to the best of his/her knowledge and belief, that:

(1) No Federal appropriated funds have been paid or will be paid, by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any Federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement;

(2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or any employee of a member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the undersigned shall complete and submit Standard Form-LLL, "Disclosure Form to Report Lobbying," in accordance with its instructions;

(3) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers (including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements) and that all subrecipients shall certify and disclose accordingly;

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by section 1352, title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure.

Certified by:

Proposal Number: AC-23469

E M Portner (signature) — 12/11/96

Signature — Date

E. M. Portner
Name

Asst. Director for Business Operations
Title

Johns Hopkins Univ. Applied Physics Lab.
Institution