Advanced Composition Explorer Science Requirements Document

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Advanced Composition Explorer

(ACE)

Science Requirements Document

April 18, 1994

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ACE Science Requirements Document

This is a Project Office Controlled Document. Changes require prior approval of the Project Manager. Proposed changes shall be submitted to the ACE Project Configuration Management Office (Code 410).

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Advanced Composition Explorer

(ACE)

Science Requirements Document

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Advanced Composition Explorer

Science Requirements Document

1.0 Introduction

1.1 Scope

The Advanced Composition Explorer (ACE) was selected in 1989 to perform a comprehensive study of the composition of energetic nuclei from solar, interplanetary, and galactic sources over ~6 decades in energy/nucleon. This document establishes the scientific requirements for the ACE Mission. It is divided into six sections, starting with this Introduction. Section 2 summarizes the scientific objectives which ACE was selected to address, the measurements required to accomplish these objectives, and the mission success criteria. Following a brief summary of the instruments selected to make these measurements and their general capabilities, the performance requirements for these instruments are stated. The reader is referred to documents listed in Section 1.2 for more detailed information on instrument design and expected performance.

Section 3 and 4 summarize the scientific requirements on the ACE mission and spacecraft design. Because this material overlaps to a great extent with that in the ACE Mission Requirements Document (MRD), the intent is to state only the top level requirements here, and to refer to the MRD and other related documents for further information. Similarly, the scientific requirements on mission operations and data reduction are stated in Sections 5 and 6. Additional information of these topics can be found in the ACE Science Requirements Document and the ACE Science Operations and Data Analysis Plan.

1.2 Related Documents

Additional information can be found in the following related documents:

"Phase A Study of an Advanced Composition Explorer", Vol. 1: Technical Section, E. C. Stone, Principal Investigator, July, 1989.

"ACE Science Requirements Document"

"ACE Mission Requirements Document"

"ACE Science Operations and Data Analysis Plan"

"ACE Mission Operations Concept Document"

"ACE Payload Interface Requirements Document"

"ACE Level 1 Requirements Definition"

"ACE Project Data Management Plan"

2.0 Science Requirements

2.1 Scientific Objectives

The prime objective of ACE is to determine and compare the elemental and isotopic composition of several distinct samples of matter, including the solar corona, the interplanetary medium, the local interstellar medium, and galactic matter. This objective is approached by performing comprehensive and coordinated determinations of the elemental and isotopic composition of energetic nuclei accelerated on the Sun, in interplanetary space, and from galactic sources. These observations will span five decades in energy, from solar wind to galactic cosmic ray energies, and will cover the element range from $_{1}H$ to $_{40}Zr$. The comparison of these samples of matter will be used to study the origin and subsequent evolution of both solar system and galactic material by isolating the effects of fundamental processes that include nucleosynthesis, charged and neutral-particle separation, bulk plasma acceleration, and the acceleration of suprathermal and high energy particles. Specifically, these observations will allow the investigation of a wide range of fundamental problems in major areas summarized in Table 2.1.

Table 2.1 - ACE Scientific Objectives

1) The Elemental and Isotopic Composition of Matter

A major objective is the accurate and comprehensive determination of the elemental and isotopic composition of the various samples of "source material" from which nuclei are accelerated. Thus, using ACE measurements we will:

- Generate a set of solar *isotopic* abundances based on *direct* sampling of solar material.
- Determine the coronal *elemental and isotopic* composition with greatly improved accuracy.
- Establish the pattern of isotopic differences between galactic cosmic ray and solar system matter.
- Measure the elemental and isotopic abundances of interstellar and interplanetary "pick-up ions".
- Determine the isotopic composition of the "anomalous cosmic ray component", thought to represent a sample of the local interstellar medium.

2) Origin of the Elements and Subsequent Evolutionary Processing

Isotopic "anomalies" in meteorites indicate that the solar system was not homogeneous when formed, while other data suggest that the solar composition continues to evolve. Similarly, the galaxy is neither uniform in space nor constant in time due to continuous stellar nucleosynthesis. Using measurements from ACE we will:

- Search for additional differences between the isotopic composition of solar and meteoritic material.
- Determine the contributions of solar-wind and solar flare nuclei to lunar and meteoritic material, and to planetary atmospheres and magnetospheres.
- Determine the dominant nucleosynthetic processes that contribute to cosmic ray source material.
- Determine whether cosmic rays are a sample of freshly synthesized material (e.g., from supernovae), or of the contemporary interstellar medium.
- Search for isotopic patterns in solar and galactic material as a test of galactic evolution models.

3) Formation of the Solar Corona and Acceleration of the Solar Wind

Solar energetic particle, solar wind, and spectroscopic observations show that the *elemental* composition of the corona is differentiated from that of the photosphere, although the processes by which this occurs, and by which the solar wind is subsequently accelerated, are poorly understood. The detailed composition and charge-state data provided by ACE will allow us to:

- Isolate the dominant coronal formation processes by comparing a broad range of coronal and photospheric abundances.
- Study plasma conditions at the source of the solar wind and the solar energetic particles by measuring and comparing the charge states of these two populations.
- Study solar wind acceleration processes and any charge or mass-dependent fractionation in various types of solar wind flows.

4) Particle Acceleration and Transport in Nature

Particle acceleration is ubiquitous in nature and is one of the fundamental problems of space plasma astrophysics. The unique data set obtained by ACE measurements will enable us to:

- Make direct measurements of charge and/or mass-dependent fractionation during solar flare and interplanetary acceleration.
- Constrain solar flare and interplanetary acceleration models with charge, mass, and spectral data spanning up to five decades in energy.
- Test theoretical models for ^{3}He-rich flares and solar γ-ray events.
- Measure cosmic ray acceleration and propagation time scales using radioactive clocks.
- Test whether the "anomalous cosmic rays" are a singly-ionized sample of the neutral interstellar gas by directly measuring their charge state.

2.2 Required Measurements

The energetic nuclei that ACE will study ultimately derive from one of three main reservoirs, the solar photosphere, the local interstellar medium, or the galactic matter that provides the source material for galactic cosmic rays. Figure 2.2-1 illustrates schematically how energetic particles provide a flow of material to 1 AU from these sources. These energetic nuclei manifest themselves in the following particle and plasma components (see also Figure 2.2-2):

- Solar wind, including high speed streams
- Coronal mass ejection events
- Suprathermal solar particles
- Small and large solar flare events
- Interplanetary CIR events
- Interplanetary ESP Events
- Anomalous cosmic rays
- Galactic cosmic rays

Also illustrated in Figures 2.2-1 and 2.2-2 are various selection, acceleration, and transport processes that act to fractionate these samples of matter. The basic objective of ACE will be to undertake a coordinated, comparative study of these compositions, providing crucial information for understanding the origin and subsequent evolution of both solar system and galactic matter, including fundamental processes ranging from nucleosynthesis to the acceleration of suprathermal and high energy particles.

The composition measurements to be provided by ACE must simultaneously span a number of dimensions, including (where the exact values depend on the species and component):

- Elemental composition from $Z = 1$ to 30
- Isotopic composition from $A = 1$ to 70
- Ionic charge state composition from $Q/M = 0.05$ to 1
- Energy distributions from 10^{-4} to 10^{+3} MeV/nuc
- Absolute fluxes from ~ 10^{-12} to 10^{+14} per cm^2sr sec MeV/nuc
- Temporal variations on time scales from ~ 10^{-1} to ~10^{+7} sec.

Figure 2.2-3 illustrates the broad dynamic range in flux and energy/nucleon that must be covered for a single representative element (oxygen), in order to measure and intercompare the various components of energetic nuclei ranging from solar wind to galactic cosmic rays. Also indicated are the energy/nucleon ranges over which the various ACE sensors will be able to measure isotopes, elements, and ionic charge states for oxygen.

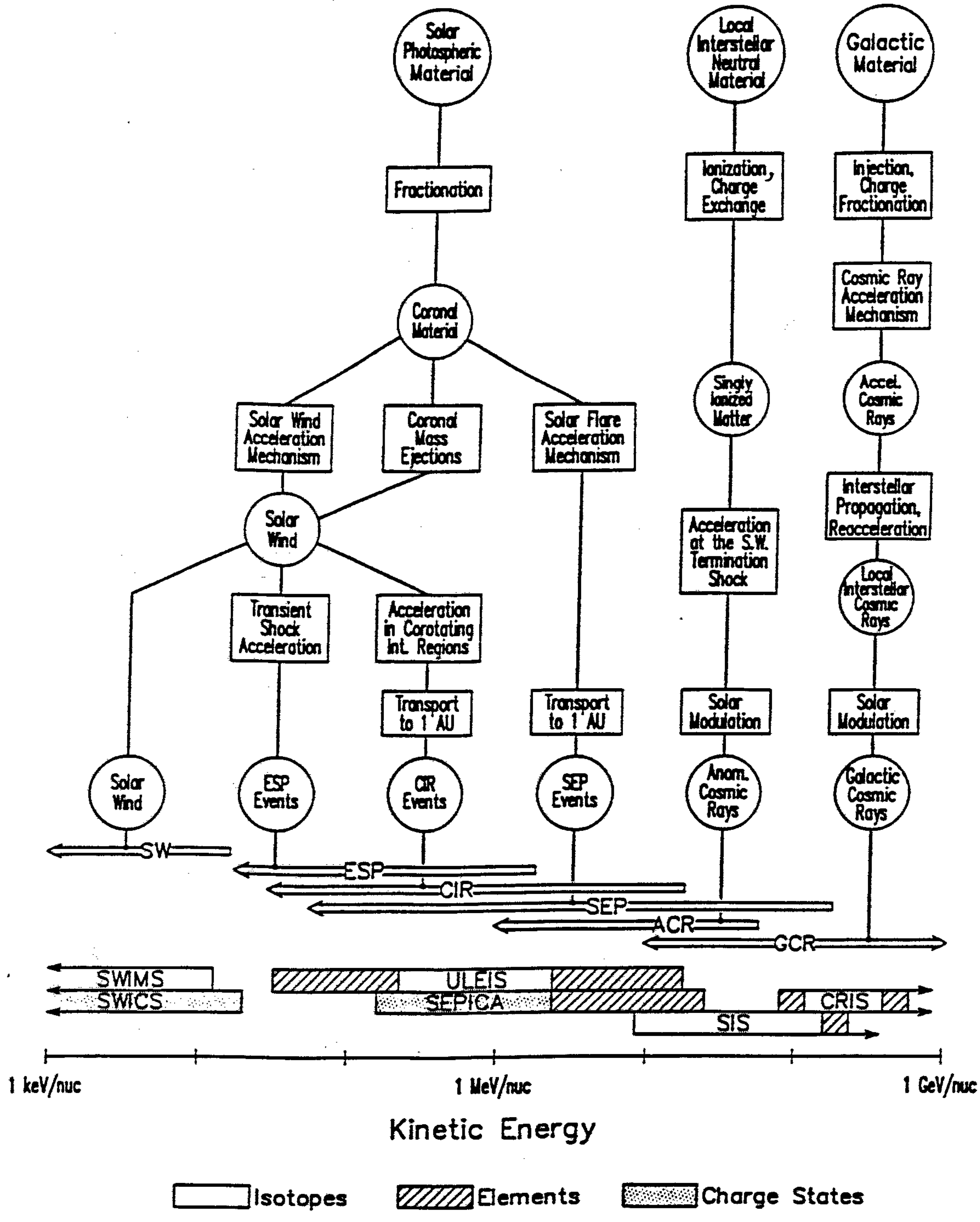

Figure 2.2-1: Diagram showing how energetic particles provide a flow of material to 1 AU from the solar photosphere, the neutral interstellar medium, and galactic cosmic ray sources. (Circles represent particle populations; rectangles represent fractionation/acceleration/transport processes). Also indicated are the energy ranges over which the ACE instruments can measure the elemental, isotopic, and ionic charge state composition of these particle populations.

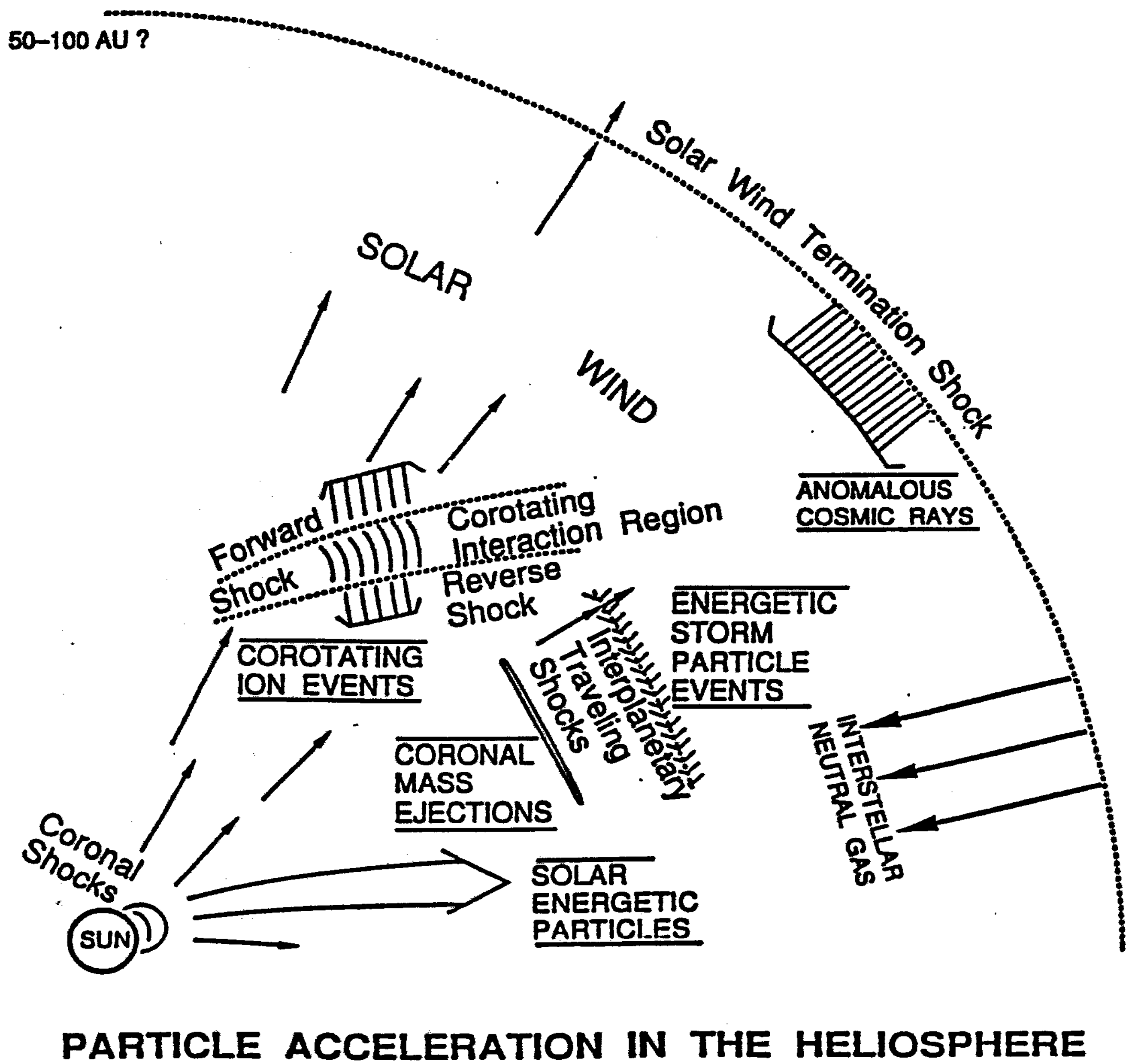

Figure 2.2-2: Schematic representation of acceleration processes on the Sun and in the heliosphere, and the various populations of energetic particles that result.

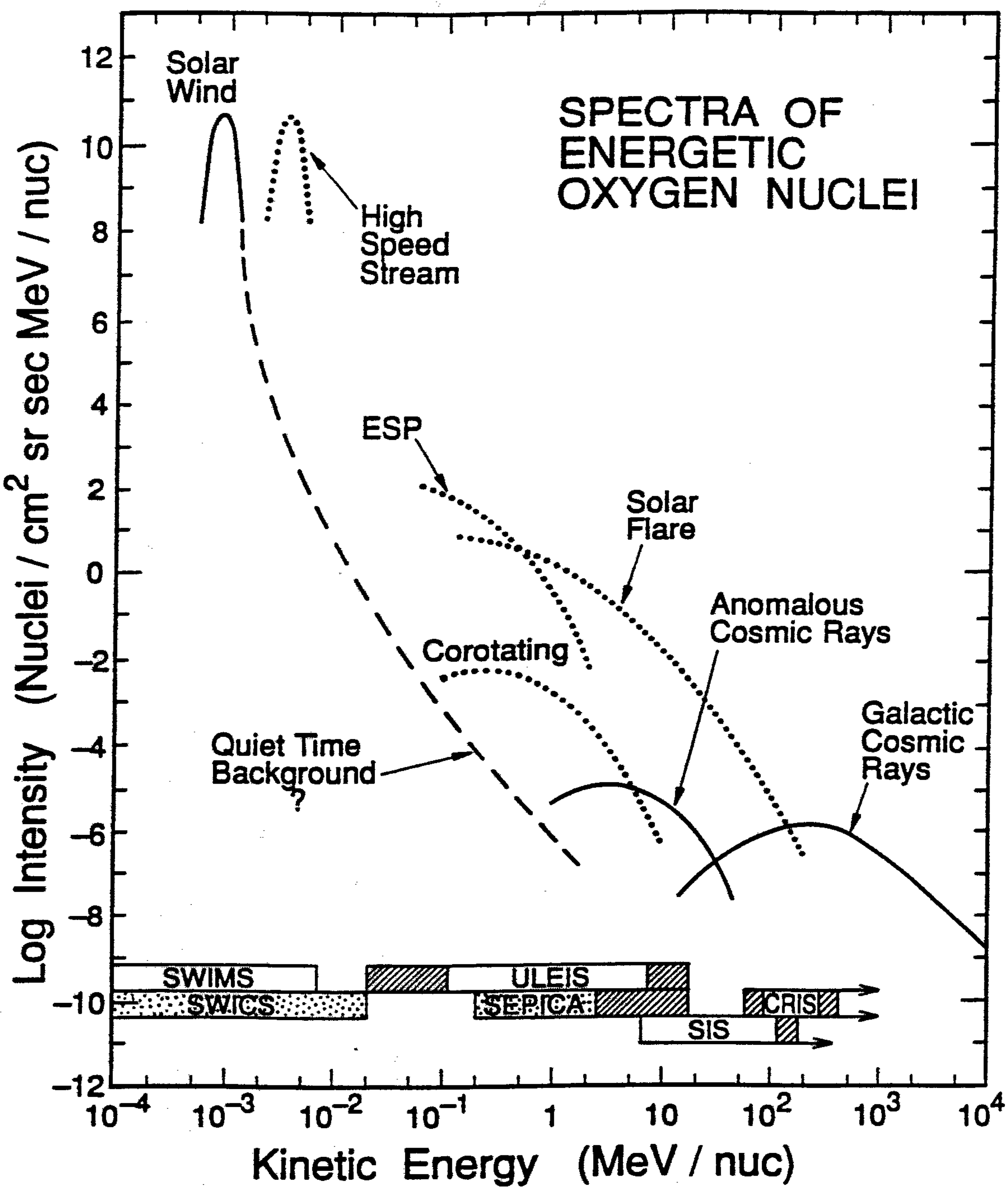

Figure 2.2-3: Typical energy spectra of energetic ^{16}O nuclei resulting from the various particle populations illustrated in Figures 2.2-1 and 2.2-2. The solid curves represent "steady-state" components, while the dotted curves are for "transient" phenomena. Also shown is a postulated quiet-time flux of supra-thermal solar particles (dashed curve). The energy ranges of the various ACE instruments are indicated for resolution of isotopes (blank), elements only (cross-hatched), and ionic charge-states (stippled). Other nuclear species generally tend to have spectra that are similarly shaped to that of oxygen (but of varying intensity) when plotted as a function of energy/nucleon.

2.3 Instruments

The following instruments have been selected for the ACE payload:

SWIMS - .... Solar Wind Ion Mass Spectrometer
SWICS - .... Solar Wind Ionic Charge Spectrometer
ULEIS - .... Ultra Low Energy Isotope Spectrometer
SEPICA - .... Solar Energetic Particle Ionic Charge Analyzer
SIS - .... Solar Isotope Spectrometer
CRIS - .... Cosmic Ray Isotope Spectrometer
SWEPAM - .... Solar Wind Electron, Proton, and Alpha-particle Monitor
EPAM - .... An energetic Electron, Proton, and Alpha-particle Monitor
MAG - .... Magnetometer

General characteristics of these instruments are summarized in Table 2.3-1. Figure 2.3-1 illustrates the energy range over which the ACE spectrometers will measure the elemental and isotopic composition of nuclei from He to Zr (Z = 2 to 40). Measurements of the properties of the various particle components that are required to address the ACE scientific objectives are summarized in a graphical fashion in Figure 2.3-2, along with the contributions that the selected instruments make to achieving these objectives. It should be noted that a prime objective of ACE is to intercompare the observed composition across many decades in energy per nucleon in, for example, solar flare, CIR, and ESP events, in order to understand particle acceleration and transport processes. Such coordinated studies will require simultaneous data from several instruments.

For further details on instrument design, performance, and resource requirements see the ACE Payload Interface Requirements Document.

Table 2.3-1: Instrument System Summary

Instrument	Technique	Typical Energy (MeV/nuc)
CRIS	dE/dX × E	~300
SIS	dE/dX × E	~30
ULEIS	TOF × E	~1
SEPICA	dE/dX × E × E/Q	~1
SWICS	TOF × E × E/Q	~0.001
SWIMS	TOF thru special E-field	~0.001
SWEPAM	Electrostatic Analyzer	~0.001
EPAM	dE/dX × E	~0.3
MAG	Triaxial fluxgate	-

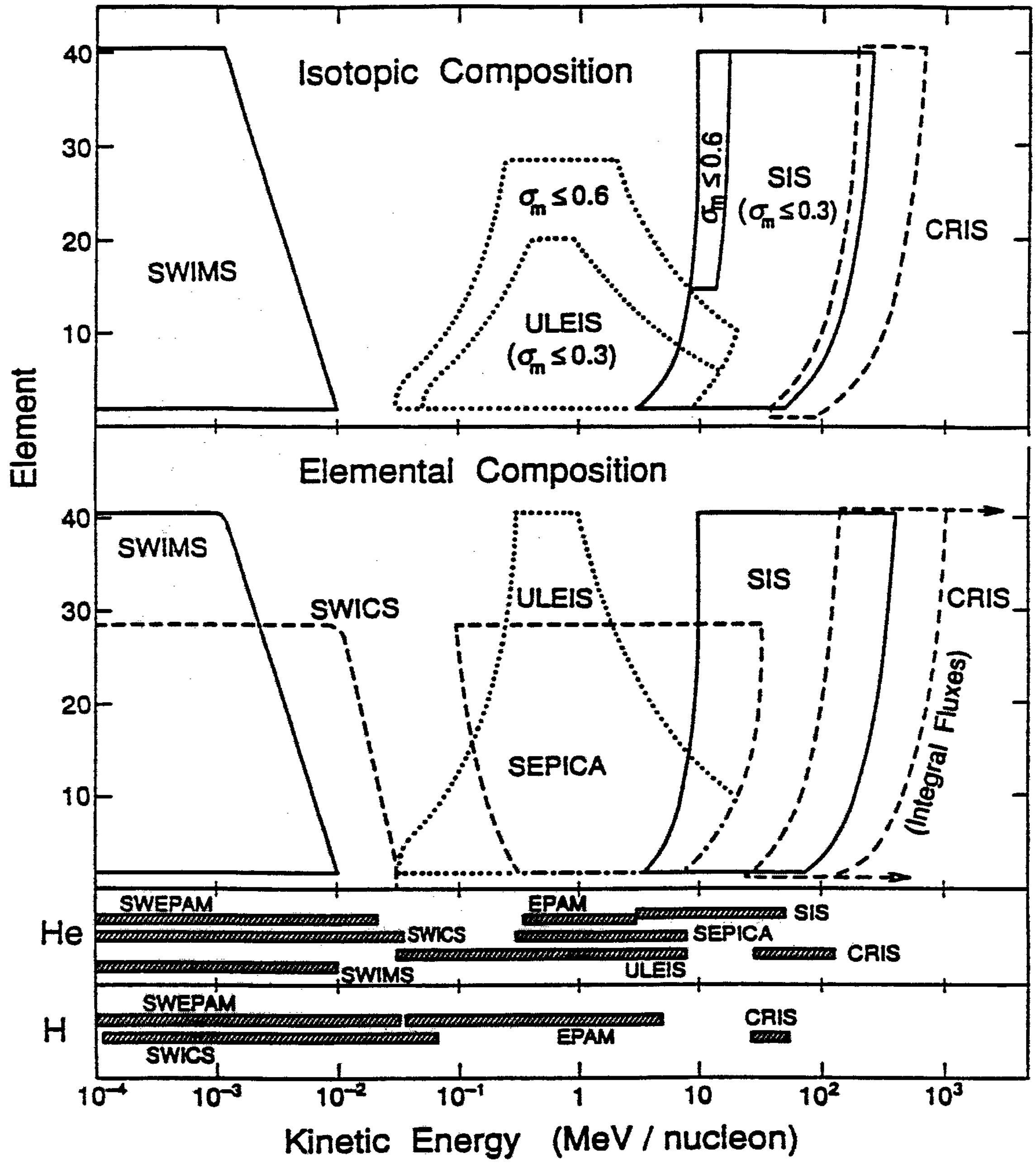

Figure 2.3-1: A plot of the energy/nucleon range over which the various ACE sensors will measure the elemental and isotopic composition of nuclei from He to Zr (Z = 2 to 40). In the top panel, boundaries for a mass resolution of $\sigma_m \leq$ 0.3 amu and $\sigma_m \leq$ 0.6 amu are indicated (note that many studies, e.g., $^{22}Ne/^{20}Ne$, do not require resolution of adjacent isotopes). The H and He panels at the bottom indicate the coverage for these elements. Note that a typical solar wind velocity of 400 km/sec corresponds to ~0.8 x 10^{-3} MeV/nucleon.

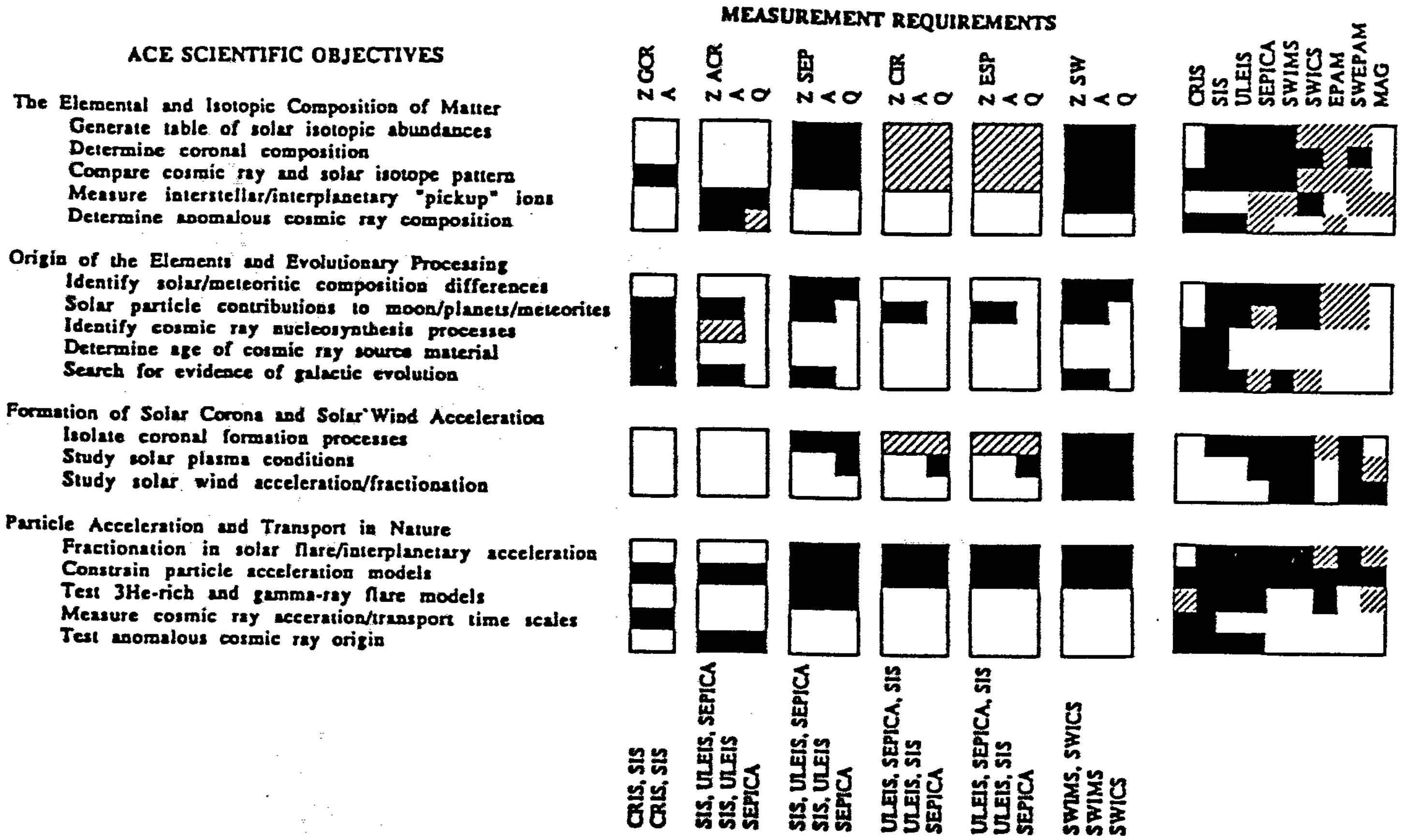

Figure 2.3-2: Graphical representation of the measurements required to satisfy the ACE scientific objectives, and the capabilities of the six high resolution spectrometers on ACE. In the first group of 4 X 6 blocks the required charge (Z), mass (A), and charge-state (Q) measurements of the various particle components are indicated. Here blackened squares represent primary measurements and cross-hatched squares indicated contributing measurements. The high resolution spectrometers that can measure the properties of each of these particle components on ACE are indicated at the bottom. The right-hand four blocks indicated schematically which sensors will address each of the objectives.

2.4 Instrument Performance Requirements

The sensor systems for the Ace investigation must have the following general capabilities:

A. *Coordinated Measurements over a Broad Range in Charge, Ionization State, Mass and Energy* - These are essential to isolate the contributions from the variety of particle populations observed in the heliosphere, and to relate the observed isotopic and elemental patterns back to the appropriate sample of source material and acceleration process. Figure 2.3-1 summarizes the nominal energy and charge range over which these sensors can resolve elements and isotopes.

B. *Excellent Mass Resolution* - To resolve some of the most interesting rare isotopes will require a mass resolution of $\sigma_m = 0.2$ to 0.25 amu, while adjacent species with a relative abundance of 10 to 1 or less may be resolved with $\sigma_m = 0.3$ amu. For some interesting species such as $^{22}Ne/^{20}Ne$ and $^{60}Ni/^{58}Ni$, where the separation is 2 amu, a mass resolution of $\sigma_m = 0.6$ amu may be sufficient.

C. *Optimized Collecting Power* - Large geometry factors and wide energy ranges are essential to ensure statistically significant measurements of rare isotopes. In general, the energetic particle spectrometers CRIS, SIS, ULEIS, and SEPICA should each have a geometry factor resulting in a collecting power at least an order of magnitude greater than previous instruments in their energy range.

D. *Broad Dynamic Range* - This is essential for accommodating both quiet-time and solar-flare composition studies where the expected flux levels may vary by a factor of ~10^6.

E. *Established Calibrations* - To perform reliable composition studies over a period of years and under a variety of interplanetary conditions it is essential that the six high resolution spectrometers on ACE be calibrated at appropriate accelerators prior to launch, and that means be provided to periodically verify this calibration following launch.

2.4.1 Cosmic Ray Isotope Spectrometer (CRIS)

The Cosmic Ray Isotope Spectrometer (CRIS) is required to measure the isotopic composition of elements from Li to Ni (Z = 3 to 28) over the general energy range from about one hundred to several hundred MeV/nucleon. To achieve statistically accurate measurements of rare nuclei CRIS must have a collecting power sufficient to register ~10^5 Si nuclei in two years of solar minimum operations. CRIS must be capable of essentially 100% duty cycle for quiet time measurements of galactic cosmic ray nuclei, and it must continue to measure galactic cosmic rays in the presence of small solar flare or interplanetary events, but it is not required to make measurements during large solar flares.

2.4.2 Solar Isotope Spectrometer (SIS)

The basic design requirement for SIS is to provide isotopically-resolved measurements of the elements from Li to Ni (Z = 3 to 28) over the energy range from ~10 to 100 MeV/nuc. SIS must be capable of operating under a variety of interplanetary conditions, ranging from quiet time to very large solar particle events, so as to provide measurements of solar flare isotopes, as well as low-energy anomalous and galactic cosmic rays. To achieve statistically meaningful measurements of rare isotopes, SIS must have a geometry factor of ~25 cm^2sr or more, and it must be allocated sufficient data rate to allow measurement and transmission of at least five events per second in large solar flares.

2.4.3 Ultra Low Energy Ion Spectrometer (ULEIS)

ULEIS is required to provide element and isotope measurements of suprathermal particles in a variety of interplanetary conditions over the charge range from He to Ni ($Z = 2$ to 28) and the energy range from ~30 keV/nuc to ~10 MeV/nuc. Individual elements should be resolved over this entire charge range, with individual light isotopes resolved through at least Ne ($Z = 10$).

ULEIS must be capable of providing accurate measurements over a wide dynamic range in particle intensities, ranging from intense solar particle events and strong shocks to small ^{3}He-rich flares. A geometry factor approaching 1 cm^2sr is required to achieve sufficient collecting power for measurements of heavy nuclei in small solar and interplanetary events.

2.4.4 Solar Energetic Particle Ionic Charge State Analyzer (SEPICA)

The basic requirement for SEPICA is to measure the ionic charge state, Q, of energetic ions from He to Ni, in the energy range from ~0.2 to ~2 MeV/nucleon. These measurements must be performed in a variety of interplanetary conditions, including both small and large solar flare events, ESP and CIR events, as well as interplanetary quiet times. At the lowest energies, SEPICA should be capable of resolving individual charge states; at higher energies, and for the heaviest elements, the mean and rms width of charge state distributions should be measurable. The elemental composition of nuclei from He to Ni should be measurable.

To achieve sufficient statistical accuracy in small events SEPICA should have a collecting power about an order of magnitude greater than that of previous instruments of this kind, such as that flown on ISEE-3.

2.4.5 Solar Wind Ion Composition Spectrometer (SWICS)

A Solar Wind Ion Composition Spectrometer is required to determine the elemental and ionic-charge state composition and the temperature of the major solar wind ions from H to Fe. SWICS must be capable of measurements in both the bulk solar wind and in high speed streams.

2.4.6 Solar Wind Ion Mass Spectrometer (SWIMS)

A Solar Wind Ion Mass Spectrometer is required to measure the elemental and isotopic composition of the solar wind over the mass range from 4 to ~ 60 amu. The instrument should be capable of operating under all solar wind conditions.

2.4.7 Electron, Proton and Alpha-particle Monitor (EPAM)

An energetic Electron, Proton, and Alpha-Particle Monitor is required to provide measurements of the fluxes and energy spectra of low energy electrons, protons, and alpha-particles in solar flare, CIR, and ESP events. The proton coverage should extend from <100 keV to >1 MeV, combined with the capability to measure the flux and energy spectra of ~ 100 keV electrons. This instrument should also be capable of identifying ^{3}He-rich solar flares at energies of ~ 1 MeV/nuc.

A knowledge of the fluxes and energy spectra of energetic protons, electrons, and alpha particles is essential for characterizing the dynamic behavior of solar flare, CIR, and ESP events. Because the high-resolution spectrometers SWIMS, ULEIS, SEPICA, and SIS will in most cases be incapable of measuring protons and electrons because of dynamic range considerations, a conventional instrument which uses modest resources is required to monitor these species.

2.4.8 Solar Wind Electron, Proton, and Alpha-particle Monitor (SWEPAM)

A solar wind electron, proton, and alpha-particle monitor is required to provide velocity, temperature, and density measurements of these species in all solar wind conditions. SWEPAM should be capable of detecting bi-directional halo-electron signatures to uniquely identify coronal mass ejections in interplanetary space.

These measurements will provide detailed knowledge of the solar wind conditions required to interpret ACE composition measurements, as well as providing information for studying solar wind phenomena. They also provide realtime solar wind speed information required to operate SWIMS.

2.4.9 Magnetic Field Monitor (MAG)

MAG is required to monitor the intensity, direction, and dynamics of the interplanetary magnetic field, thereby providing essential supporting data for interpreting the composition measurements to be carried out by ACE. The MAG instrument must have a dynamic range that accommodates the known variations in the interplanetary field at 1 AU, and it must have the sensitivity and time resolution to permit identification of propagating interplanetary shock waves (in combination with plasma data), interaction regions associated with different solar sources, directional discontinuities, and interplanetary sector structure.

2.5 Mission Success Criteria

The ACE mission is designed to measure and compare the elemental, isotopic, and ionic charge state composition of a number of separate particle populations, all of which are variable in intensity. In particular, galactic and anomalous cosmic ray fluxes reach their maximum intensity during solar minimum, while large solar flares are more numerous at solar maximum. As a result, the degree to which ACE will address some of its broad range of scientific objectives will depend to some extent on the launch date and mission duration.

The ACE mission will be considered successful if it accomplishes at least seven of the following measurements:

- Measurement of the composition of heavy nuclei in both the bulk solar wind and in several high speed streams.
- Measurement of the composition of coronal mass ejection events over a one year period.
- Measurement of solar wind "pick-up" ions over a one year period.
- Measurement of the composition of heavy nuclei in CIR events over a two year period.
- Measurement of the composition of heavy nuclei in ESP events over a two year period.
- Measurement of the composition of heavy nuclei in ten solar particle events, including three large events.

- Measurement of the composition of heavy nuclei in small impulsive solar flares over a one year period.
- Measurement of the isotopic composition of anomalous cosmic rays.
- Measurement of the abundances of at least four radioactive "clock" isotopes in galactic cosmic rays.
- Measurement of the isotopic composition of a majority of the "primary" galactic cosmic ray elements from carbon to zinc.

3.0 Science Requirements on Mission Design

3.1 Orbit

ACE must be launched into an orbit which is free of Earth's magnetosphere the vast majority of the time, in order that it can provide essentially continuous measurements of solar wind, low energy solar and interplanetary particles, and cosmic rays.

The optimal orbit is a modified halo about the Earth-Sun interior libration point, L_1, similar to that originally obtained by ISEE-3.

3.2 Duty Cycle

ACE must be capable of providing essentially continuous measurements of all particle species. With on-board data storage, a reasonable requirement is that at least 90% of the data be recovered during the first 2 years of the mission. After 2 years, there is no longer a strict data recovery requirement, but there remains a goal of continuing to recover at least 90% of the data. The ACE mission and observatory shall be designed to ensure that the data recovery requirement can be met during solar active as well as solar quiet times. The requirement to recover at least 90% of the data should be interpreted to mean that over the course of the primary 2 year mission, at least 90% of the ACE data during both solar active and solar quiet times should be recovered with a bit error rate of $<10^{-6}$ *(See Section 3.6).*

A primary tool for identifying the source of the particle components observable at 1 AU is the time history of the intensity variations that occur in the various particle energy intervals, and in the solar wind and its embedded magnetic field. Only with essentially continuous measurements will it be possible to sort out the various solar and interplanetary events and processes that affect the composition of the low-energy particle fluxes at 1 AU.

Among the most interesting scientific data to be obtained by ACE will be measurements made during the largest solar flares. At these times it can be anticipated that solar radio noise and other tracking interference may be at a maximum, with a potential impact on ACE tracking. Because of the significance of large solar flare measurements it is essential that data recovery not be compromised during solar active periods.

It is understood that during the spacecraft transition to L_1, the Sun-Earth-spacecraft alignment will at times be less than ideal, leading to possible restrictions on the available spacecraft power, or on telemetry coverage. During such periods recovery of at least 90% of the data should be considered a goal rather than a strict requirement. A strategy to optimize the scientific return during the transition to L_1 will be developed once the available options are defined.

3.3 Mission Lifetime

The mission lifetime should be not less than 2 years.

It is assumed that the operational phase of the mission will begin once the basic operational capability of the spacecraft and instruments have been demonstrated, typically within a period of 30 days following launch.

Although a mission lifetime of 2 years is sufficient to satisfy the minimum success criteria for ACE, all of the ACE studies would benefit significantly from a substantially longer mission that samples both solar minimum and solar maximum conditions. A reasonable goal is for ACE to provide data for 5 years. In particular, the spacecraft and instruments should carry sufficient expendables so as to not preclude a nominal mission lifetime of 5 years.

3.4 Launch Window

There is no scientific requirement on the launch time for ACE.

The ACE measurement objectives include particle species such as the solar wind and low energy suprathermal particles which are continuously present, solar particles which predominate at solar maximum but occur throughout the solar cycle, galactic cosmic rays which have their maximum flux levels at solar minimum, and anomalous cosmic rays which are observable only at solar minimum. As a result, it is possible to accomplish a majority of ACE's scientific objectives independent of when it is launched. There is, however, a strong preference to be launched prior to January 1998 so as to ensure exposure to the anomalous cosmic ray component.

3.5 Telemetry Data Rate

The ACE instrument payload requires a data rate of 6552 bps twenty-four hours a day.

The ACE spacecraft will have a single science data rate. Telemetry requirements of the various ACE instruments are summarized in the Payload Interface Requirements Document. Any decrease in these rates would have its most significant impact on the data returned from high intensity events such as solar flares and CIR and ESP events.

Assuming that these data are returned by means of an on-board storage device which is periodically dumped to the DSN, then: The required science data rate and a maximum dump interval of 26 hours implies that the capacity of the storage device must exceed about 75 MBytes. A more conservative dump interval of 50 hours (to achieve the data recovery fraction specified in 3.2) implies a capacity of greater than about 150 MBytes. This 50 hour capacity should also provide redundancy against parts failure.

3.6 End-to-End Data Accuracy

A maximum bit error rate of 10^{-6} is required. This requirement applies to both solar active and solar quiet times

3.7 Real Time Data for Solar Wind Monitoring

There is no scientific requirement for real-time data from ACE beyond periodic (typically daily) quick-look data required to monitor instrument health and status, and to verify instrument response to commands, as described in Section 5.

Every reasonable effort should be made to provide real time solar wind data from ACE in an effort to address objectives that go beyond those in Section 2.1. Such measurements are of scientific value, and while they are not required to satisfy the scientific goals of ACE, they are important as a monitor of the interplanetary plasma wind ("space weather"). This capability would be paid for by NOAA and made available to anyone who could make use of the information.

4.0 Science Requirements on Spacecraft Design

4.1 Spacecraft Orientation

ACE must be a spinning spacecraft with a spin rate of 5.0±0.1 rpm. The only scientific requirement on the orientation of the spacecraft spin axis during normal operations is that the solar wind be within the field of view (FOV) of the solar wind instruments: SWICS, SWIMS, and SWEPAM.

A spinning spacecraft is required for the solar wind and energetic particle experiments on ACE to sample as much solid angle as possible. The spacecraft spin axis will generally be pointed within 20° of the Sun because of other considerations. This angular range is compatible with the viewing requirements of the solar wind instruments.

Although there are a range of spacecraft spin rates that can in principle satisfy the scientific objectives of ACE, it is important for instrument design activities that the spin rate be specified as early as possible. The spin rate of 5.0±0.1 rpm specified in the ACE Phase A Study is compatible with the requirements of all instruments, including (in particular) those inherited from earlier missions.

4.2 Instrument Location, Alignment, and Field of View

The primary fields of view of the CRIS, SIS, SEPICA, ULEIS, SWIMS, SWICS, EPAM, and SWEPAM sensors must be kept clear.

The SWIMS, SWICS, and SWEPAM sensors must be mounted on the spacecraft so that the solar wind is within their FOV during normal spacecraft operations.

The MAG experiment is to be mounted and deployed so that one of its three orthogonal axes is parallel to the spacecraft spin axis. The uncertainty in the in-orbit orientation of each of the three axes of the MAG experiment should be less than ±0.5 deg (this is a goal, but not a strict requirement). Similarly, there is a goal of achieving a stability of ±0.25 deg. in the orientation of these axes, except during spacecraft maneuvers.

The orientation of SWIMS, SWICS, ULEIS, EPAM, and the SWEPAM Electron instrument must be known to an accuracy of ±1.0 deg with respect to the spacecraft spin axis. For the SEPICA, SIS, and CRIS instruments, the required accuracy is ±2 deg.

The SWEPAM Ion sensor must be mounted at an angle of 18.75±1.0 deg with respect to the spacecraft spin axis.

Although the required pointing direction for the SWEPAM Ion sensor is 18.75±1.0 deg with respect to the spin axis, there is a goal of achieving a precision of ±0.5 deg for this specification, and a goal of achieving ±0.5 deg in the (after the fact) knowledge of the overall pointing direction. To achieve this precision, it may be necessary to "trim" the pointing direction of this sensor after mounting on the spacecraft, following an analysis of the actual location of the spin axis.

Although the requirement for knowledge of the SWIMS and SWICS orientation is ±1.0 deg, there is a goal of achieving ±0.5 degrees accuracy.

Table 4.2-1 summarizes preliminary information on instrument FOV specifications, desired pointing directions, and requirements for (after the fact) knowledge of the pointing direction. The requirements on knowledge of the instrument pointing directions are to be interpreted as tolerance limits or "3σ" uncertainties, not "1σ" uncertainties. The pointing directions assume that the spacecraft spin axis normally points within 20° of the Sun.

For additional information on instrument requirements see the Payload Interface Requirements Document.

Table 4.2-1 Instrument Pointing and Field of View

Instrument	Primary FOV (degrees)	Desired Pointing Direction, (degrees)	Knowledge of Pointing Direction (degrees)
CRIS	45 half cone	No Requirement	±2
SIS	55 half cone	25+10,-5	±2
SEPICA	80 x 35	60±2	±1
ULEIS	24 x 20	60±1	±1
SWIMS	62 x 60	0±1.25	±1 (goal ±0.5)
SWICS	70 x 4.2	34.5 ±1.25	±1 (goal ±0.5)
EPAM	51, 45, 53 53, 51, resp	30, 60, 150 60, 120 (all±1)	±1
SWEPAM (Ions)	90x24	18.75±1	±1 (goal ±0.5)
SWEPAM (Electrons)	160 x 30	90±1	±1
MAGNETOMETER		One of three orthogonal axes parallel to S/C spin axis	±0.5 (goal)

NOTES:
1) Pointing angles measured from the spin axis lying in the sunward hemisphere.
2) Pointing direction knowledge requirements should be interpreted as tolerance limits, not 1σ uncertainties.

4.3 Contamination/Interference Control

Environmental effects, including contamination during development, transportation, launch and operations, shall not jeopardize the scientific performance of the ACE mission.

The electron multipliers, solid state detectors, and high voltage supplies of several of the ACE sensors will require careful control of outgassing materials on the spacecraft and in the instruments.

There is a goal of achieving a spacecraft magnetic field at the position of the MAG sensor(s) of less than 0.1 nT. The goal for AC interference at the location of the MAG sensors is less than 0.001 nT over the frequency range from 0 to 10 Hz, as well as at the primary and harmonics of the magnetometer drive frequencies of 15 kHz (±200 Hz), 30 kHz (±200Hz), 60 kHz (±200Hz).

4.4 Spacecraft Location, Orientation and Timing Accuracy

ACE Science data must be time correlated with measurements made on other spacecraft and on Earth. The time associated with any particular datum needs to be known with an accuracy of 0.1 seconds absolute and an accuracy of 0.025 seconds relative to data from other ACE instruments.

To correlate ACE science data with measurements made of terrestrial or solar phenomena, the spacecraft position should be known to within 10,000 km.

The observatory orientation must be known (after the fact) to an accuracy sufficient to satisfy the requirements for knowledge of the instrument pointing directions (see Section 4.2). The spin axis orientation of the observatory should be stable to ±0.5 deg. during normal operations.

The term "spin axis stability" is meant to include the effects of nutation, coning, and any long-term drift in the alignment of the principal axis over the course of the mission. It does not include any initial misalignment of the spacecraft spin axis with the principal axis of the spacecraft. This pointing/orientation accuracy is required to properly interpret the magnetometer data and the plasma and particle flow data. Requirements on spacecraft and spin-axis orientation are to be interpreted as tolerance limits or "3σ" uncertainties, not "1σ" uncertainties. The stability requirements do not apply during spacecraft maneuvers.

The timing accuracy requirements specified above are not intended to drive the spacecraft or mission design; it is assumed that this accuracy is readily achievable with the current design.

Similarly, the requirement of less than 10,000 km uncertainty in spacecraft location is not meant to drive the mission design; this value is understood to be readily achievable. Note that 10,000 km in the radial distance of the spacecraft from the Earth corresponds to 0.03 light seconds, and to ~25 sec uncertainty in the solar wind arrival time at Earth. An uncertainty of 10,000 km transverse to the Earth-Sun line (at L_1) corresponds to an angle of 0.3 deg when viewed from Earth.

5.0 Science Requirements on Mission Operations

5.1 Commanding during Turn-on and Special Operations

Following launch, the spacecraft and instruments must be commanded to normal operating status. There is a requirement for the capability to send a command or commands, observe the response in near real time (within 10 minutes), and send a pre-planned follow-up command or commands; all within a single uplink period.

During the first few weeks of the mission, many instruments will be turned on and configured. Command load should be up to several dozen commands per day, with commands being sent almost every day. For a few instruments (~2) the high-voltage ramp-up period may last for 1 to 2 months, with commanding ~2 times per week. After operating configuration is reached, optimization and maintenance of the entire payload will require very few commands, as discussed below.

If a command has unexpected or undesirable effects, it must be possible to detect and correct this condition (with another command) in near real time. It is clearly possible to prepare safeing commands and commands that restore previous states of operation ahead of time and have them waiting for the possibility that they will be needed. With near real time (<10 minute) access to the data to monitor the effect of commands, and given typical instrument subcommutation cycles of 5 to 15 minutes, decisions to proceed with the next command or commands can typically be made in less than 20 minutes, making it possible to configure the instruments in an efficient manner. Significantly longer delays would limit the number of commands that can be sent during a single uplink period, thereby extending the overall time interval over which instrument configuration takes place.

Memory loads will be required, with a total over all instruments of as much as ~8 MBytes or ~64 Mbits. At an uplink rate of 1000 bits per second, transmission time for these loads is as much as 9-18 hours. If uplinks are limited to less than one hour by various non-science constraints, then the instruments may need the capability to accept memory loads in separate segments.

5.2 Commanding during Normal Operations

Some instruments will require commanding on an occasional basis throughout the mission to achieve and maintain optimal operating condition.

Several instruments have on-orbit calibration capabilities that will occasionally (~weekly) require initiation by command. There will likely also be occasional commands required to optimize instrument operating modes. These commands can typically be scheduled a week or more in advance, and will not normally require real time monitoring or response except at the ACE Project Mission Operations Center (MOC). After operating configuration is reached, optimization and maintenance of the entire payload should require only a few commands per week at most, with the obvious reservation that unforeseen anomalies may require dozens of commands. Note that the spacecraft will require daily commanding for tasks such as data dumps.

5.3 Monitoring and Quick-look Evaluation

Both health/house-keeping and science data must be monitored to avoid possible data loss due to instrument anomalies or improper operations. This monitoring will include alarm processing and quick look processing at the ACE Project MOC in real time; and (on special occasions) alarm processing, interactive displays, quick-look processing in real time at a facility under the direct supervision of the ACE Science Team.

The data latency time for alarm processing must be less than 1 minute after receipt of data and no more than 2 minutes after spacecraft transmission of data; for interactive displays, it must be less than 5 minutes after receipt of data. The latency time for quick look processing must be less than 24 hours after spacecraft transmission of data during normal work days, less than 36 hours after resumption of normal work days for data received on weekends and holidays, and less than 3 hours upon pre-arranged special request.

The MOC will monitor in near real time (~1 minute) health-related data and status data, whenever the real time data stream is available during the entire length of the mission. The ACE Science Team requires the ability to monitor these same variables while performing more complicated health, status, and science checks, using algorithms and coding supplied by the instrument teams. This more elaborate capability will only be needed occasionally, typically for special commanding occasions as described above (section 5.1), but should be available in a facility operated under direct supervision of the ACE Science Team.

Latency times are intended to be long enough to make satisfaction of these requirements easy, while still being short compared to an expected typical acquisition period of ~2 hours. Round-trip light time for ACE will be ~10 seconds.

Generally, alarm-processing refers to those checks which are performed by a computer and result in binary decision that the specified criteria are or are not satisfied. Other techniques for monitoring instrument health, such as interactive displays, quick-look checks, and trend analysis will be employed.

GSFC must ensure that the processed real time data stream can be made available on special occasions to the ACE Science Team in "real time" as specified by the latency times above. The processed real time data stream consists of data from the spacecraft real time virtual channel converted into the standard data format used by the ACE science team. These special occasions would be primarily instrument turn-on and high voltage operations, as well as unforeseen anomalies.

For more information, see the ACE Science Operations and Data Analysis Plan.

5.4 Data Delivery

The Data Capture Facility (DCF) must deliver level 0 and ancillary data to the ACE Science Team within 10 calendar days after transmission from the spacecraft.

This requirement allows early detection of possible instrument or data processing problems, efficient processing of scientific data, and checking that data can be processed by the ACE Science Team before the archival period at the DCF has expired (typically 30 days).

6.0 Science Data Reduction Requirements

6.1 Data Processing

Data processing will be a cooperative process, with data shared promptly among all the instrument teams. After a 3-week debug phase, at least 80% of the level 1 data from the ACE Science Center (ASC) must be delivered to the ACE Science Analysis Remote Sites (ASARS) in less than 15 working days after receipt of level 0 data; at least 90% must be delivered in less than 25 working days. After a 3-month debug phase, at least 70% of the level 2 data from each instrument team must be delivered back to the ASC in less than 2 months after receipt of level 1 data; at least 90% in less than 4 months.

All level 0 and ancillary data will be delivered from the DCF to the ASC, where level 1 processing will be done. While performing level 1 processing, the ASC will also prepare a common browse data file which will allow early identification of interesting time periods for cooperative analysis. Level 2 and 3 data will be prepared at instrument team sites and delivered to the ASC for sharing.

Because the DCF typically archives data for only 30 days after receipt, it is essential that the ASC process data on a schedule that allows for possible replacement of bad or unreadable data on a timely basis.

6.2 Data Products, Archiving, and Distribution

Data products must be archived in a central location for the ACE team. Data must be delivered to a public domain site such as the NSSDC in accordance with an agreed upon schedule.

Level 0 data consists of a reconstructed spacecraft data stream with data in time order, overlaps removed, including those from pass to pass, and data quality flags attached. Ancillary data will include spacecraft position (both predict and measured) and command history. Predict position data must be delivered early to allow calculation of spacecraft event time when level 0 is delivered. We expect GSFC to provide all level 0 processing and to deliver ancillary data from the Flight Dynamics Facility in 2 working days.

Level 1 is a proper superset of level 0, with addition of calibrations, co-ordinate transformations, and (perhaps) some averaging. It will include decompression of compressed rates, etc.; conversion of counts and times to rates; etc.

Level 0 and level 1 will be archived at the ASC; archival data will also be delivered to the NSSDC and/or the SPDS (Space Physics Data System) on an appropriate schedule, which will be specified in the ACE Project Data Management Plan (PDMP). This delivery schedule must reflect adequate time to ensure complete validation of the data set. Level 1 processing will immediately be followed by preparation of a common browse data file which will allow early identification of interesting time periods for cooperative analysis. Some of this browse data will be delivered immediately to the public domain. Level 2 and 3 data include substantial averaging and are not reversible to levels 1 or 0. They also include detailed scientific input and corrections. Level 2 and 3 data will be delivered to the ASC for archiving, and made available to the public domain as required by NASA.

6.3 Instrument Calibration and Response Algorithms

The ACE instrument teams are required to provide calibration data and/or response algorithms to the ASC to permit Level 1 data processing for each of the sensors.

All data will be delivered from GSFC to the ASC, where level 1 data will be processed. Level 1 processing will include preparation of a common data browse file which will allow early identification of interesting time periods for cooperative analysis. These processes will run at the ASC, but must be specified by the instrument teams, preferably by delivery of functioning software modules. The instrument teams will take part in the testing and validation of the processing.

The ASC must provide a programming environment which makes these specifications straightforward.