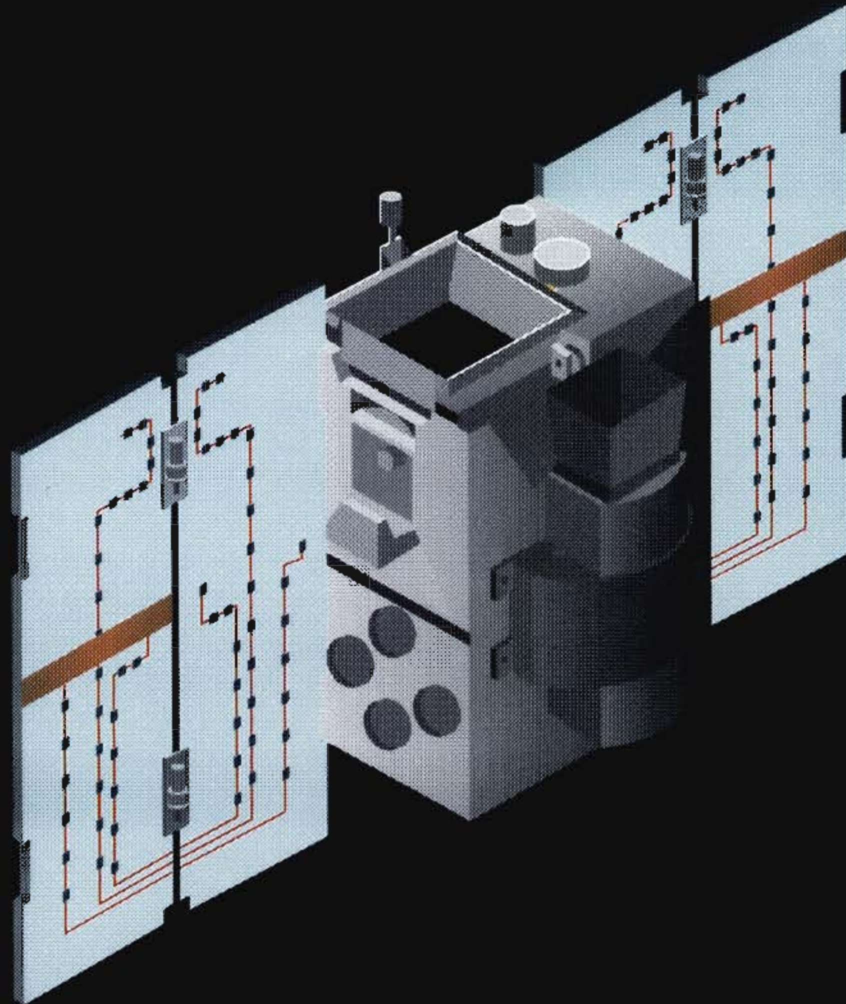
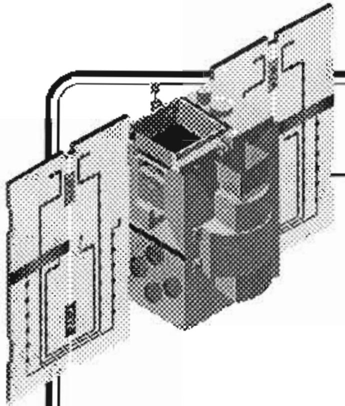


Solar, Anomalous, and Magnetospheric Particle Explorer

NASA SMALL EXPLORERS



SAMPEX

First of the Small Explorers

The Solar, Anomalous, and Magnetospheric Particle Explorer (SAMPEX) is the first in a series of NASA Small Explorer missions designed to provide frequent, low-cost access to space.

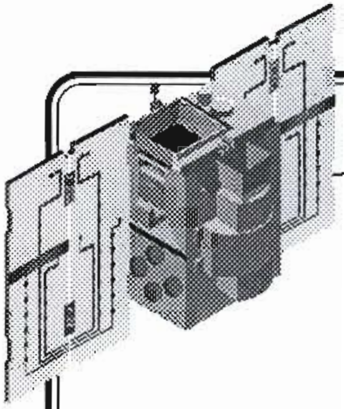
Scheduled for a June 1992 launch aboard a Scout expendable vehicle, SAMPEX will investigate the properties of four classes of charged particles that originate beyond the Earth:

- Galactic cosmic rays: atomic nuclei accelerated by shock waves from supernova explosions in our Galaxy;
- Anomalous cosmic rays: ionized atoms from the interstellar gas surrounding our Solar System;
- Solar energetic particles: atomic nuclei and ionized atoms from explosions in the solar atmosphere; and
- Magnetospheric electrons: trapped by the Earth's magnetic field from the solar wind.

The SAMPEX observations will provide important new information on the cosmic abundances of elements and their isotopes, the composition of local interstellar gas, solar composition and the mechanisms responsible for solar atmospheric heating, and electron energy injection into the Earth's upper atmosphere.

SAMPEX is the first in a series of Small Explorer missions

- Scientifically important
- Low cost
- Rapid development
- Launch with Small Expendable Launch Vehicle



SAMPEX

NASA's Small Explorer Program

- **February 1987: Small Payloads Workshop held at GSFC**
  - Concluded that there were scientifically important missions that could be orbited by a small, expendable launch vehicle

- **April to June 1987: Program formulated and budgeted (FY 89)**

- **May 1988: AO for Small Explorers issued**
  - First launch on Scout, others on TBD Small Expendable Launch Vehicle
  - 51 proposals received September 30, 1988

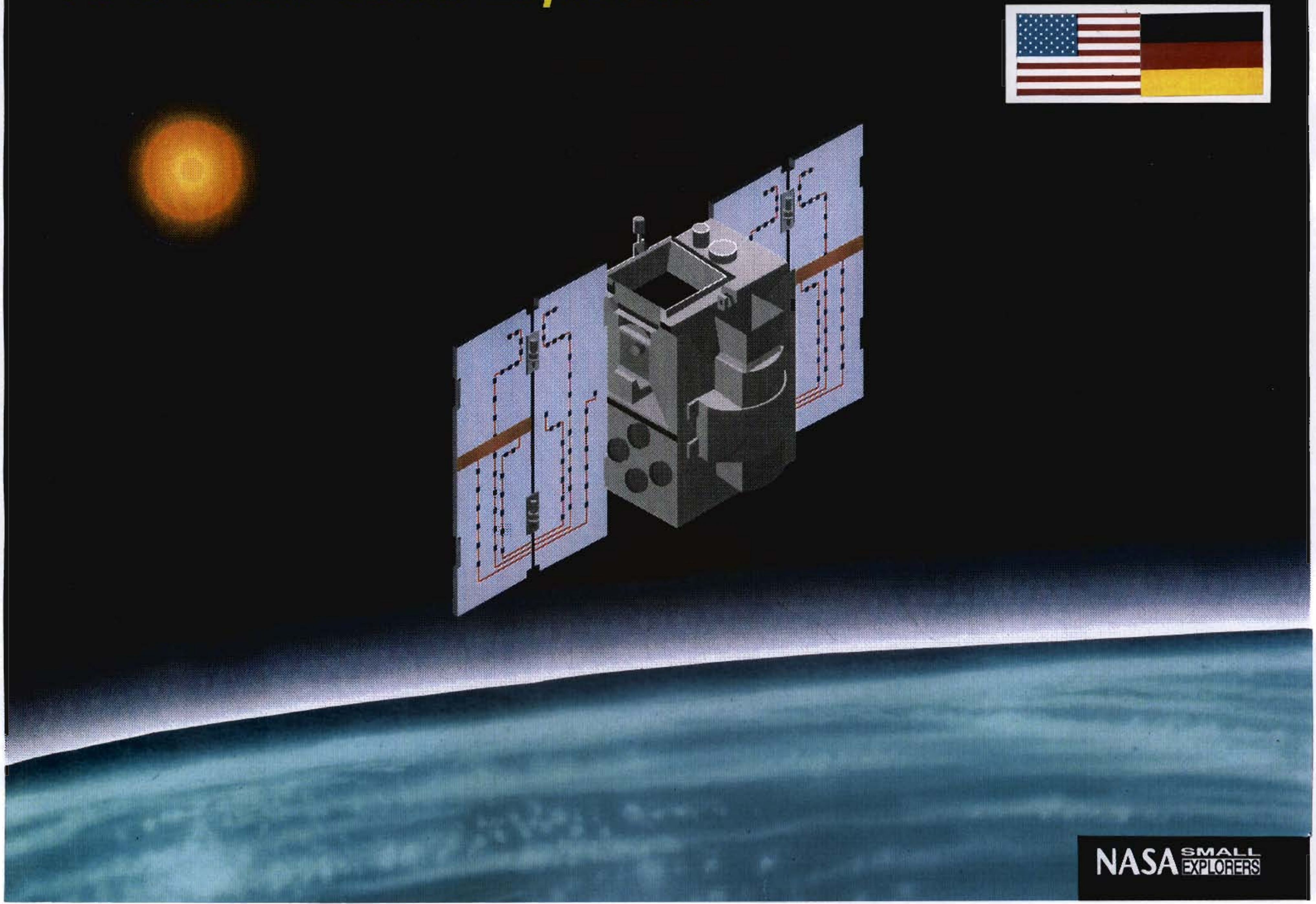
- **October 1988: Funding approved, and Small Explorer Program begun**

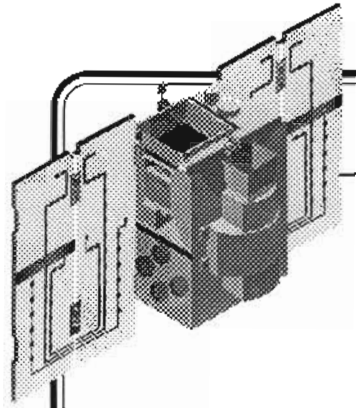
- **April 1989: Four missions selected**
  - Solar, Anomalous, and Magnetospheric Particle Explorer
  - Submillimeter Wave Astronomy Satellite
  - Fast Auroral Snapshot Explorer
  - Total Ozone Mapping Satellite

- **October 1989: TOMS transferred to Earth Probes Program**
- **August 1989 to February 1990: Start up and management problems plague the Program and Project**
- **February to November 1990: Program and Project problems fixed; team in place**
- **November 1990: Mission development order resequenced**
- **March 1991: Pegasus chosen for Small Expendable Launch Vehicle**
- **June 1992: Ready to launch SAMPEX**

First of the Small Explorers

SAMPEX





SAMPEX

SAMPEX Science Overview

SAMPEX will collect data on energetic particles, mostly ionized atoms, that reach the Earth

Galactic Cosmic Rays (low energy)

- All elements, fully ionized
- In energy range of SAMPEX, are supressed during periods of solar activity
- Objective: Improve knowledge of composition by factor of 5

Solar Energetic Particles

- All elements, range of ionization states
- Arrive in events lasting a few hours to a few days
- Events occur during periods of solar activity
- Objective: Obtain composition of 5 times more events than ever before

Anomalous Cosmic Rays

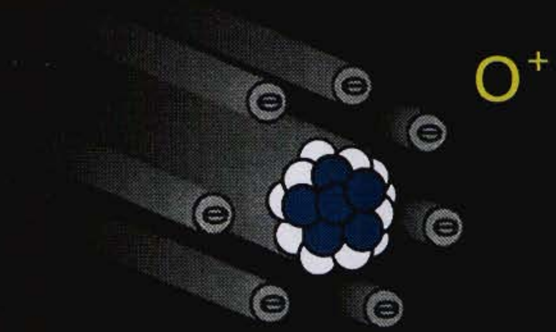
- Only certain elements, thought to be singly ionized
- Present during periods of low solar activity
- Objective: Obtain isotopic composition and definite charge state for the first time

Magnetospheric Electrons

- Precipitate into the atmosphere in bursty events
- Produce ionized molecules which destroy ozone
- Objective: Determine if events occur often enough and strongly enough to be important in the global destruction of ozone

Science Overview

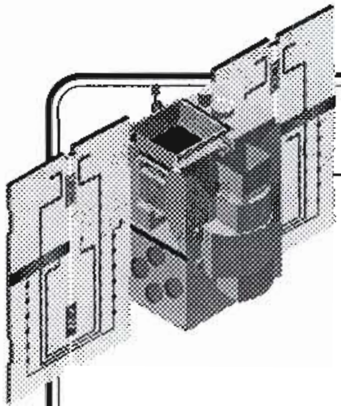
Galactic Cosmic Rays (GCR)



Anomalous Cosmic Rays (ACR)

Solar Energetic Particles (SEP)

Magnetospheric Electrons



SAMPEX

Where Do Cosmic Rays Come From?

Where do cosmic rays come from?

- Active regions in the solar atmosphere
- The interstellar medium near the Sun, then energized by contact with the solar wind
- The galaxy - probably from supernova remnants
- Beyond the galaxy

What kind of places are these?

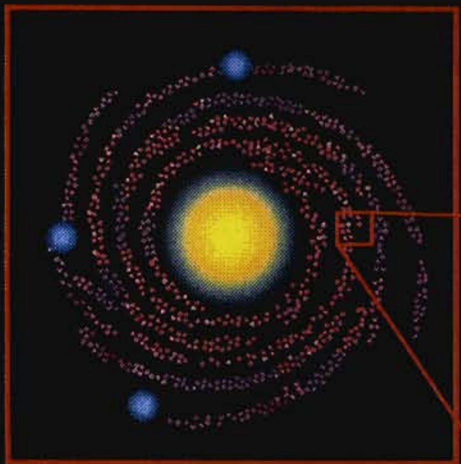
- Thin, ionized gas (plasma) in a magnetic field
- Large, violent changes in gas speed
- Larger sources make more energetic cosmic rays

How did we learn this?

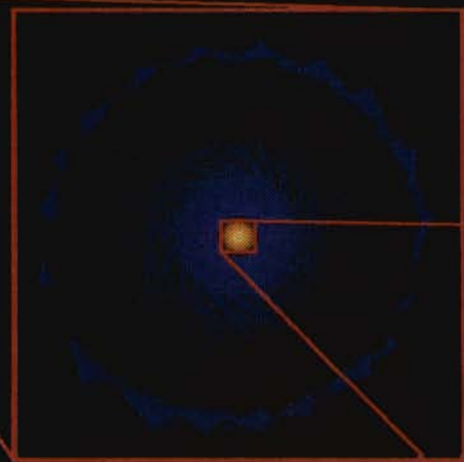
- From spacecraft observations of smaller events in the solar wind
- Elemental and isotopic composition of cosmic rays, measured on spacecraft and balloons

Where Do Cosmic Rays Come From?

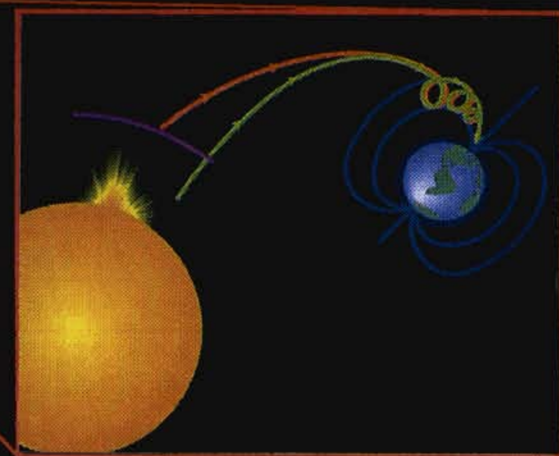
SAMPEX



Supernova
Shock Explosions

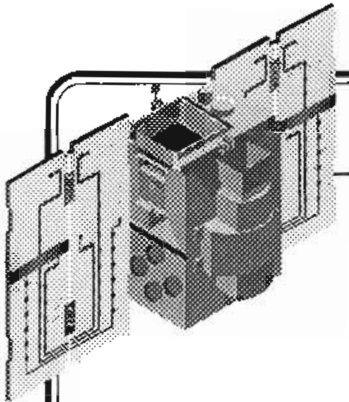


Heliosphere:
Ionization of Local
Interstellar Medium



Sun:
Coronal
Shock Waves

NASA SMALL EXPLORERS



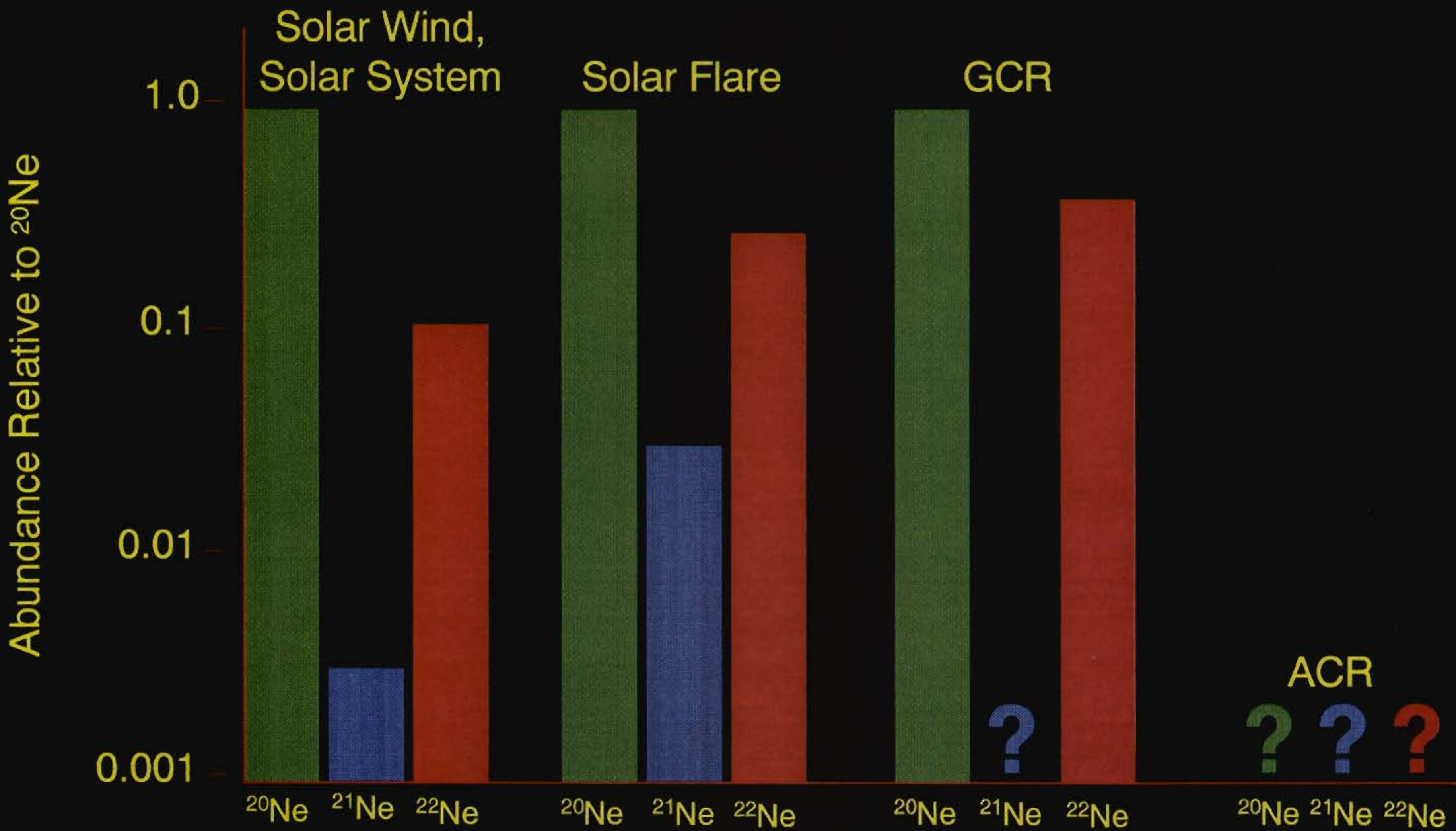
Neon Isotopes: Relative Abundances

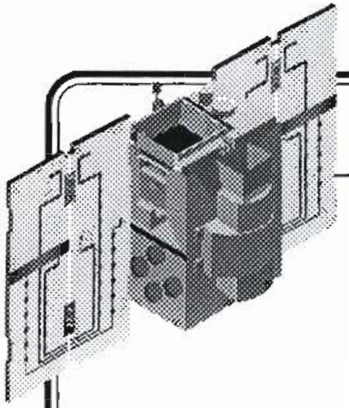
Solar system composition fixed 4.5 billion years ago
- Solar flare composition indicates a mechanism for separating isotopes

Galactic cosmic ray source in interstellar medium is a mixture of recent stars
- Galactic cosmic rays also make nuclear fragments in collisions with interstellar gas

Anomalous cosmic rays are from the local bubble of interstellar gas

Neon Isotopes: Relative Abundances





SAMPEX

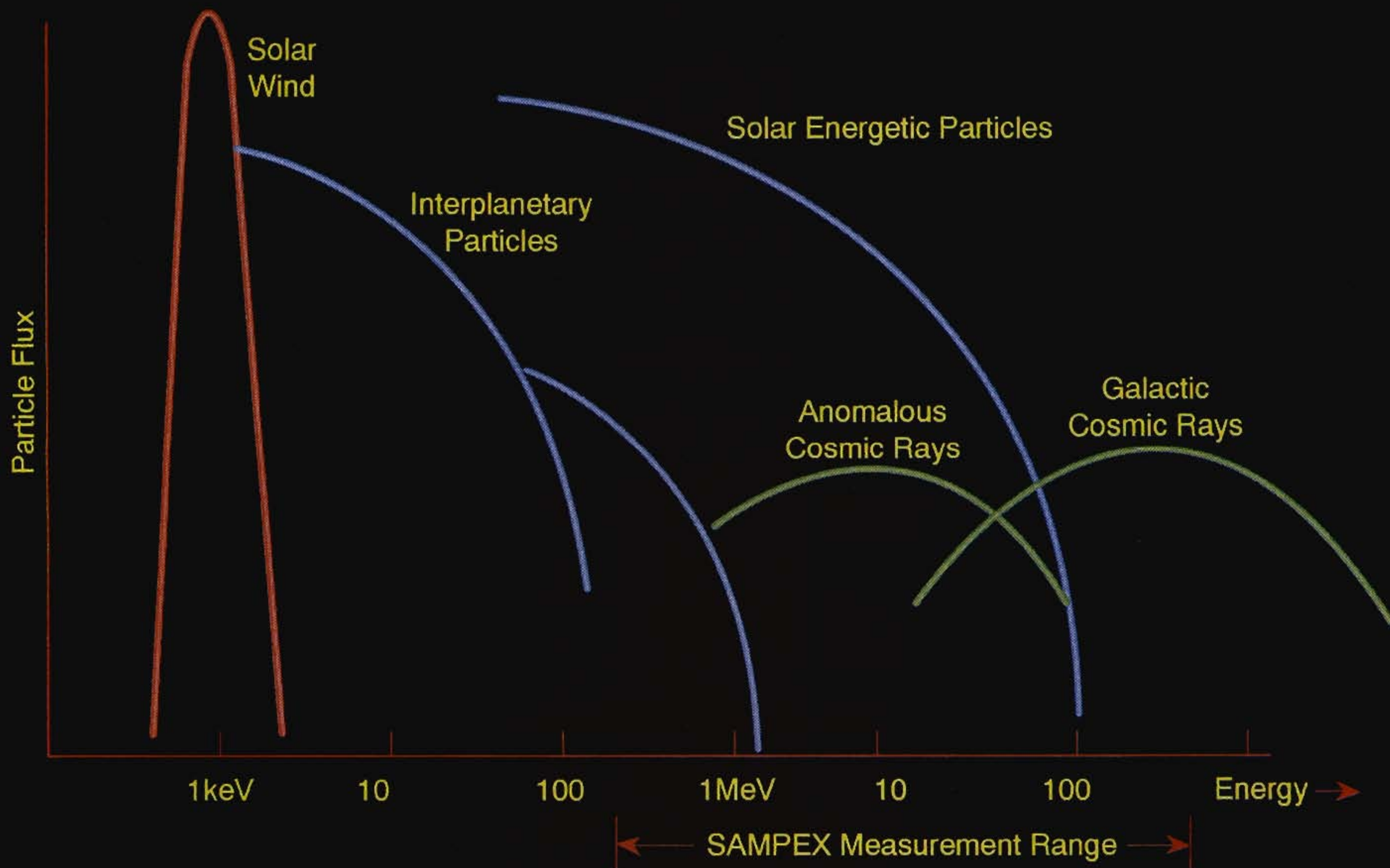
Solar System Particle Populations

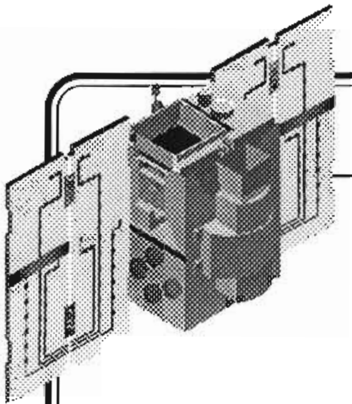
The particle population studied by SAMPEX is distinguished by unique energy distributions:

- Galactic cosmic rays have the highest energy - their spectrum extends to at least 10^{12} MeV
  - The low-energy part studied by SAMPEX is strongly suppressed during solar maximum by magnetic fields in the solar wind
- Anomalous cosmic rays have intermediate energies
  - They are also suppressed during solar maximum
- Solar energetic particles appear sporadically, for a few hours or days, most often near solar maximum

A million electron volts (1 MeV) is the energy of an electron or proton accelerated by a million volts.
10 MeV = 1.6 x 10^{-12} joule

Solar System Particle Populations





SAMPEX

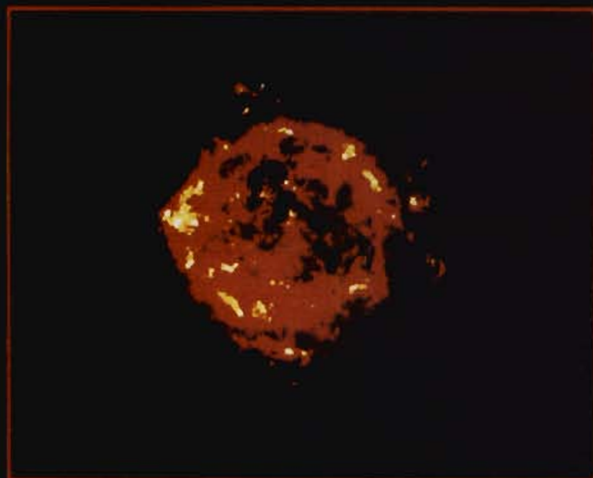
Galactic Cosmic Rays

Supernovae are the only power sources with enough energy

- Galactic cosmic rays light up the galaxy in gamma rays by colliding with interstellar gas
  - The gamma ray/gas ratio indicates that galactic cosmic ray density is mostly uniform over the whole visible galaxy
- Galactic cosmic rays take long complicated paths from supernovae shocks to us
- Composition of galactic cosmic rays is slightly different from the solar system

SAMPEX

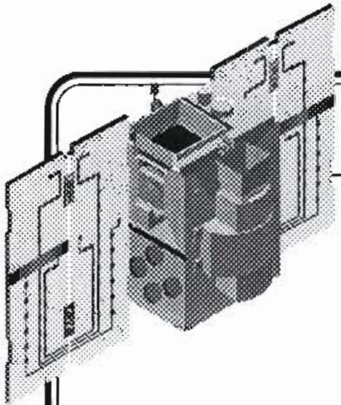
Galactic Cosmic Rays



Shock Waves from Supernova:
Cas A in X-rays

Cosmic Rays Colliding with Interstellar Gas:
Our Galaxy in Gamma Rays

NASA SMALL EXPLORERS



SAMPEX

Anomalous Cosmic Rays

Elements in Anomalous Cosmic Rays

- Helium, Carbon, Nitrogen, Oxygen, Neon, Argon
- Abundant and neutral in the interstellar medium
- Resist ionization until well inside the solar wind cavity

Theory in 1974 proposed

- Singly ionized
- Accelerated in the solar wind

All known facts are consistent with singly ionized atoms accelerated at the termination shock

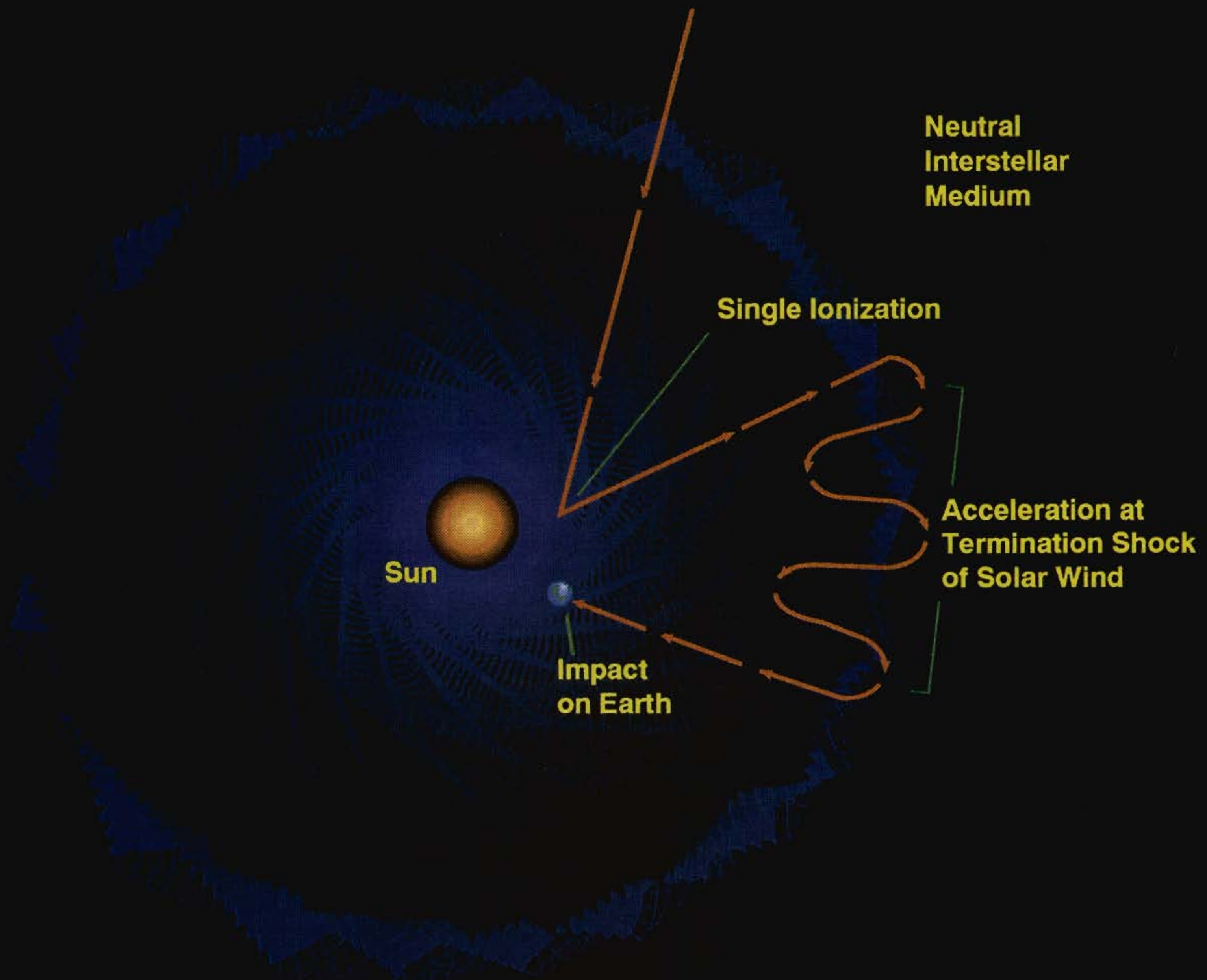
- No instrument has directly measured their charge to confirm this theory

SAMPEX will measure the charge of these cosmic rays using the Earth's magnetic field in low-Earth, polar orbit

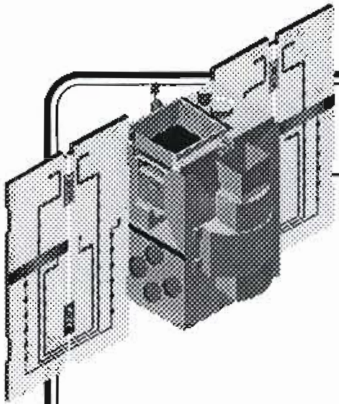
SAMPEX also measures isotopic composition for nuclear history of local and interstellar medium

Anomalous Cosmic Rays

SAMPEX



NASA SMALL EXPLORERS



SAMPEX

Deflection of Charged Particles in Magnetic Field

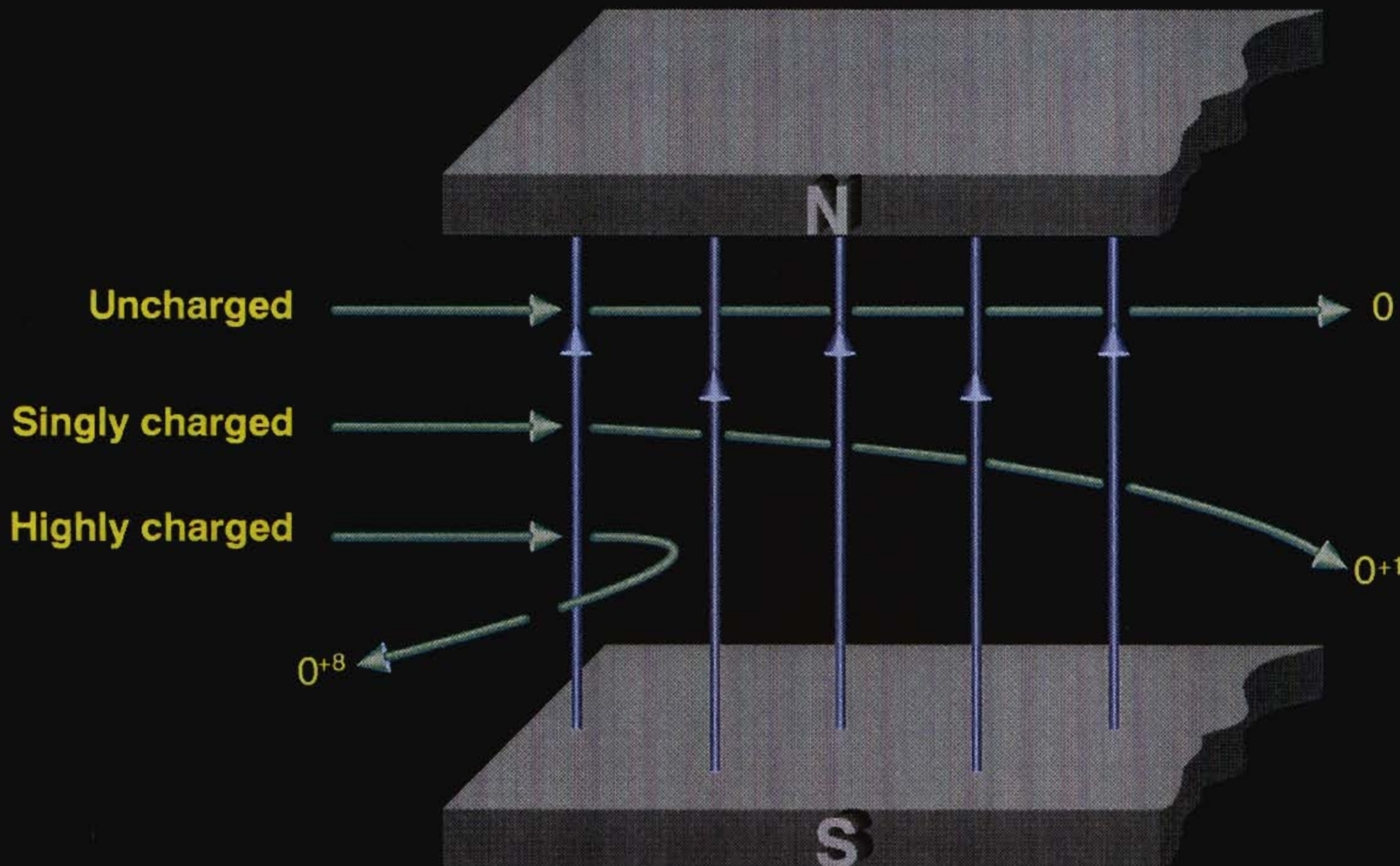
The higher the charge on the particle, the greater the deflection

- Singly ionized anomalous cosmic rays will penetrate the Earth's magnetic field more effectively than fully ionized galactic cosmic rays

Example: Oxygen at energy of anomalous cosmic rays

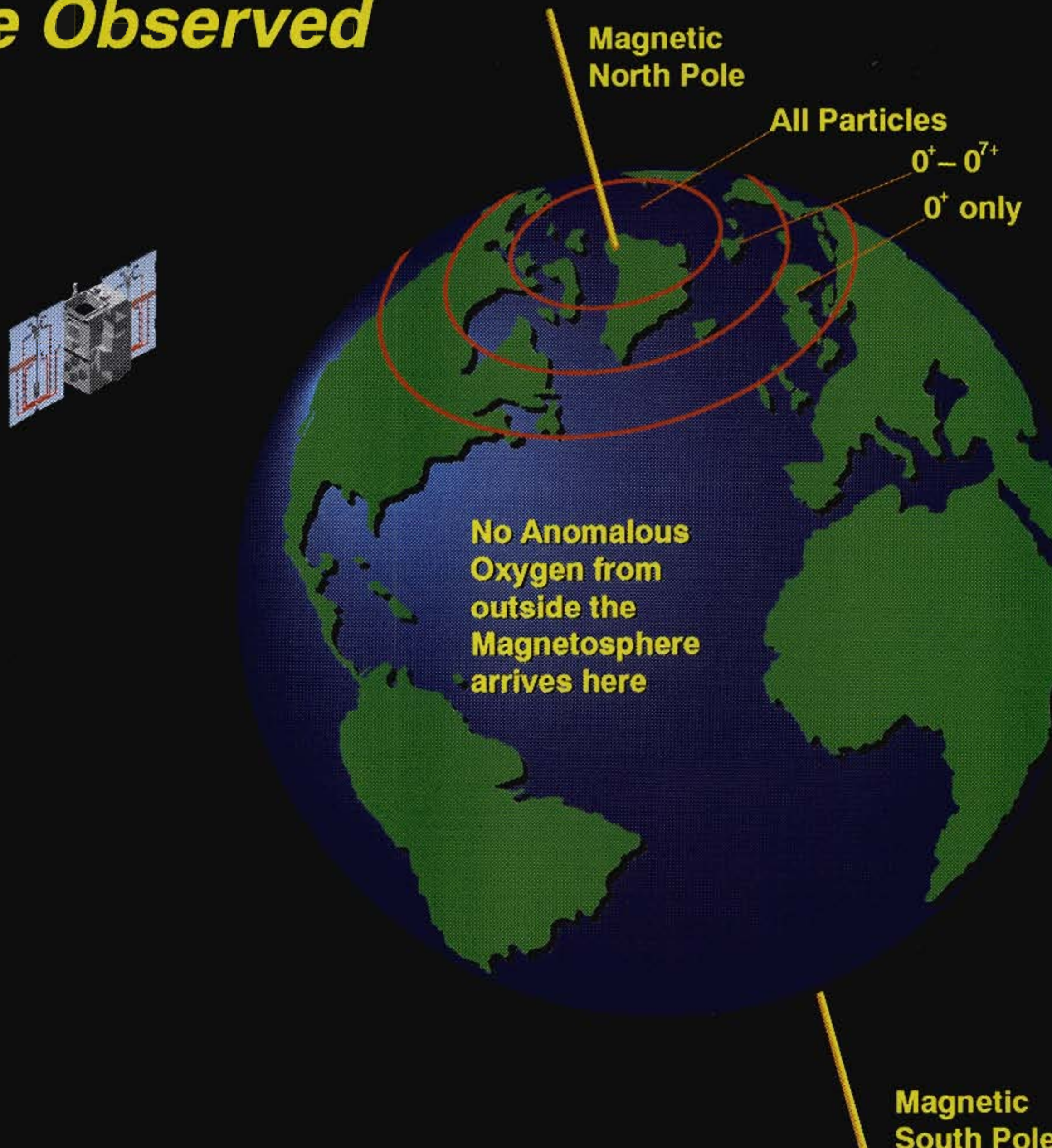
- O^{+8} can only be observed very near the Earth's magnetic poles
- O^{+} can be observed as low as 45° magnetic latitude

Deflection of Charged Particles in a Magnetic Field



SAMPEX

Latitudes where Anomalous Oxygen will be Observed



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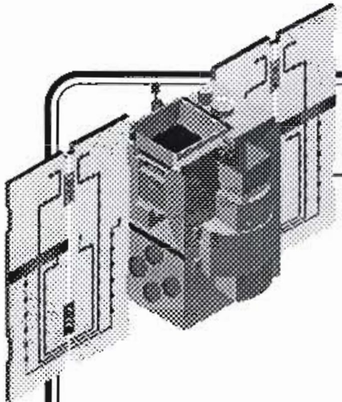


SAMPEX

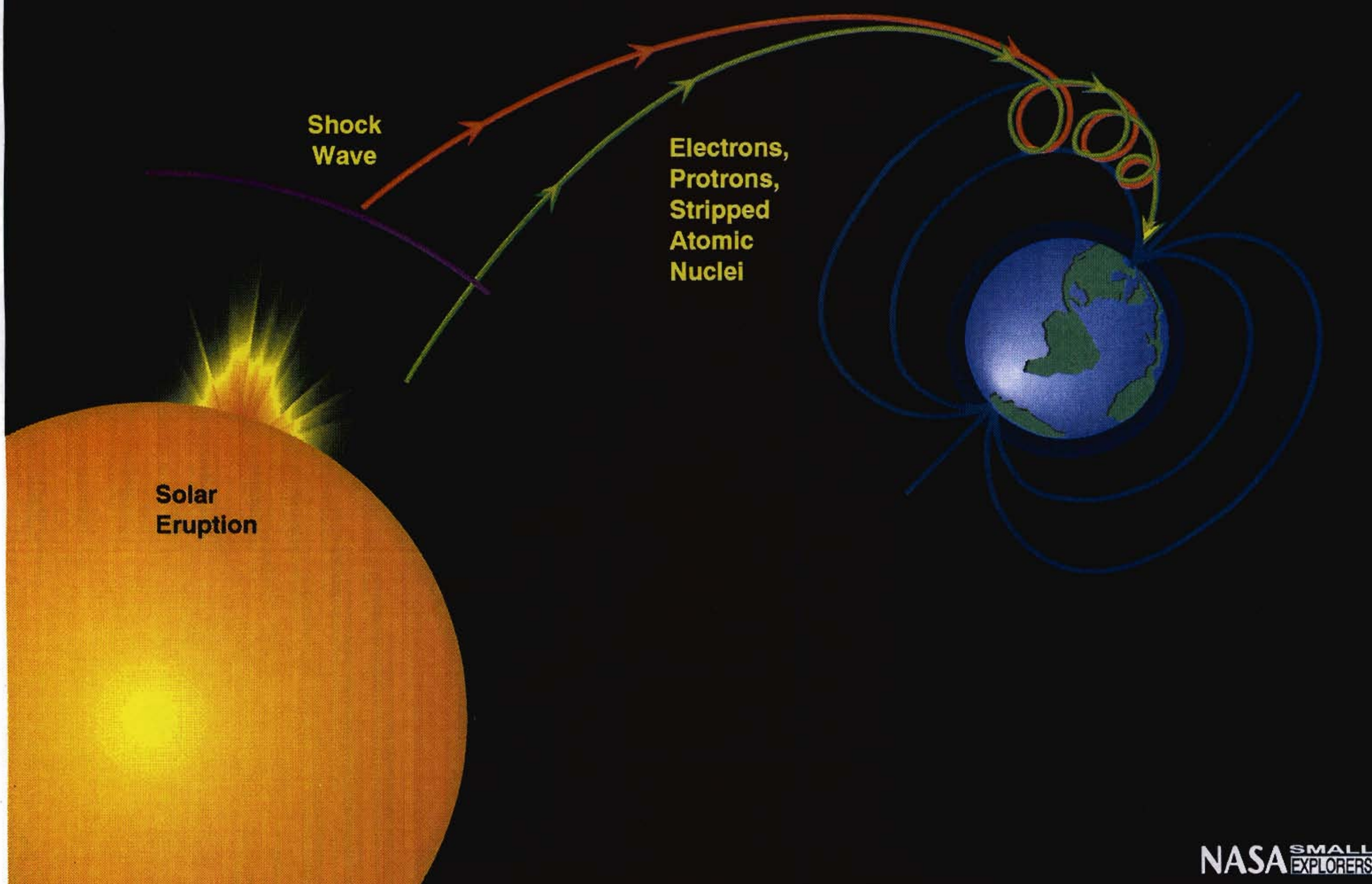
Solar Energetic Particles

Two main types of events:

- "Normal" are long-duration (days) events, in which composition is similar to solar corona. Believed to be caused by shocks in the corona, in front of mass ejection
- "He^3- rich" are short (hours) events, which have a high proportion of the rare isotope of helium, He^3 and other peculiarities
- Believed to come from deep in the corona in very sudden, violent, and turbulent electromagnetic explosions
- Several theories proposed for explaining helium abundance
  - Predictions for heavier elements are vastly different
  - SAMPEX will measure charge states and isotopes to precision

Solar Energetic Particles

SAMPEX



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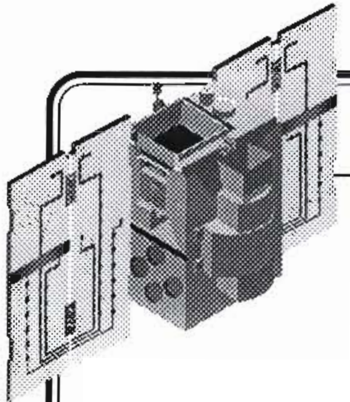


SAMPEX

Magnetospheric Electrons

Sporadic accumulations are observed at geosynchronous altitudes
- Most frequently during solar minimum

Electrons precipitate into the atmosphere at high latitudes

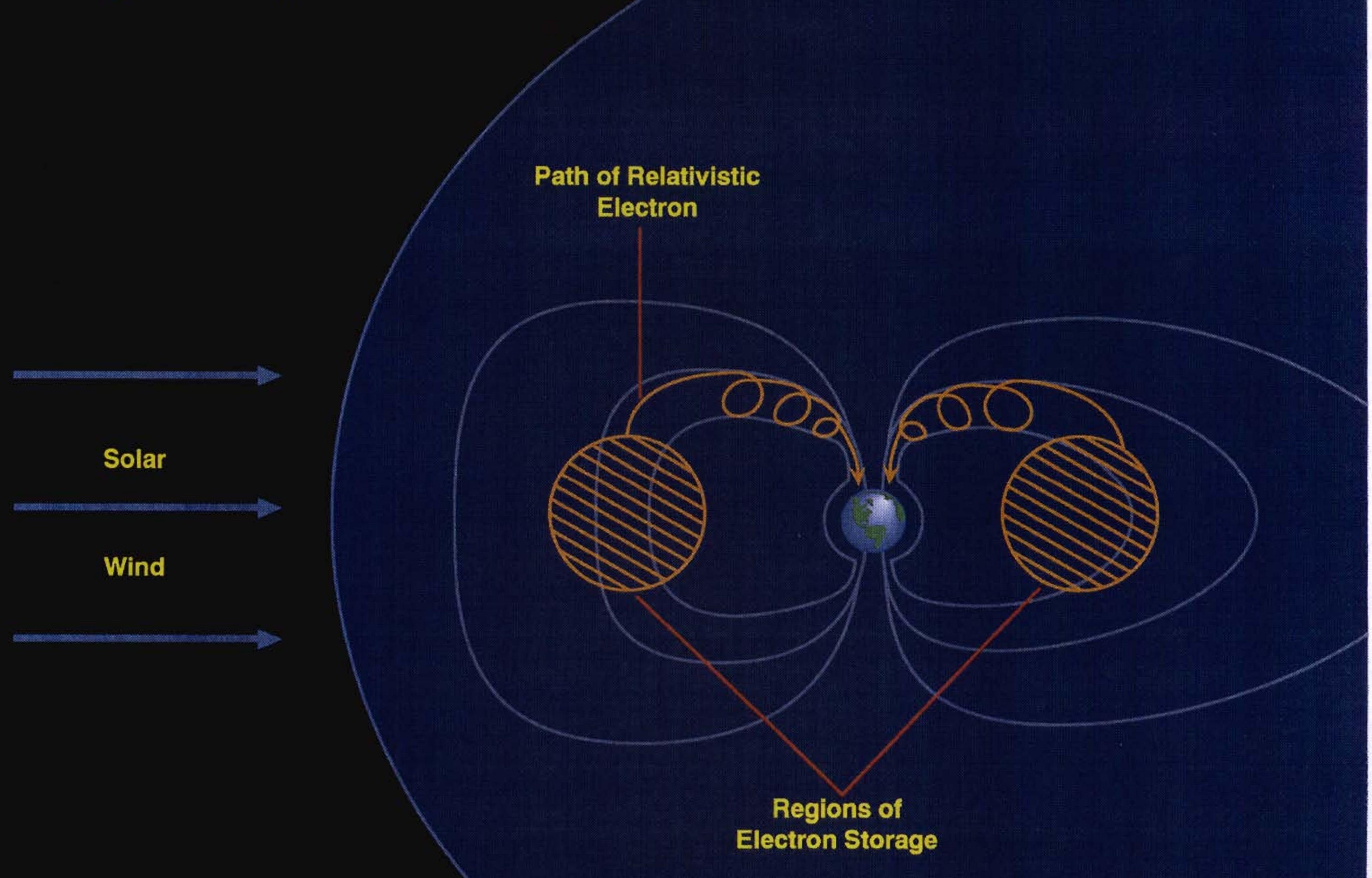
Energetic electrons are known to produce ionized molecules that can destroy ozone

We <u>do not know</u> if enough electrons enter the atmosphere to be a major cause of ozone destruction

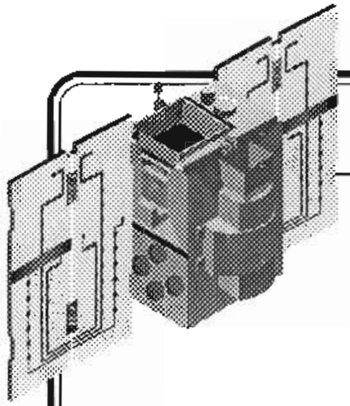
SAMPEX will:
- Record many precipitation events
- Determine the dependence on solar activity

Magnetospheric Electrons

SAMPEX



NASA SMALL EXPLORERS



SAMPEX

Instruments: Element and Energy Coverage

Low Energy Ion Composition Analyzer (LEICA)
- Based on time-of-flight spectroscopy
- Yields isotopic composition as well as energy and direction

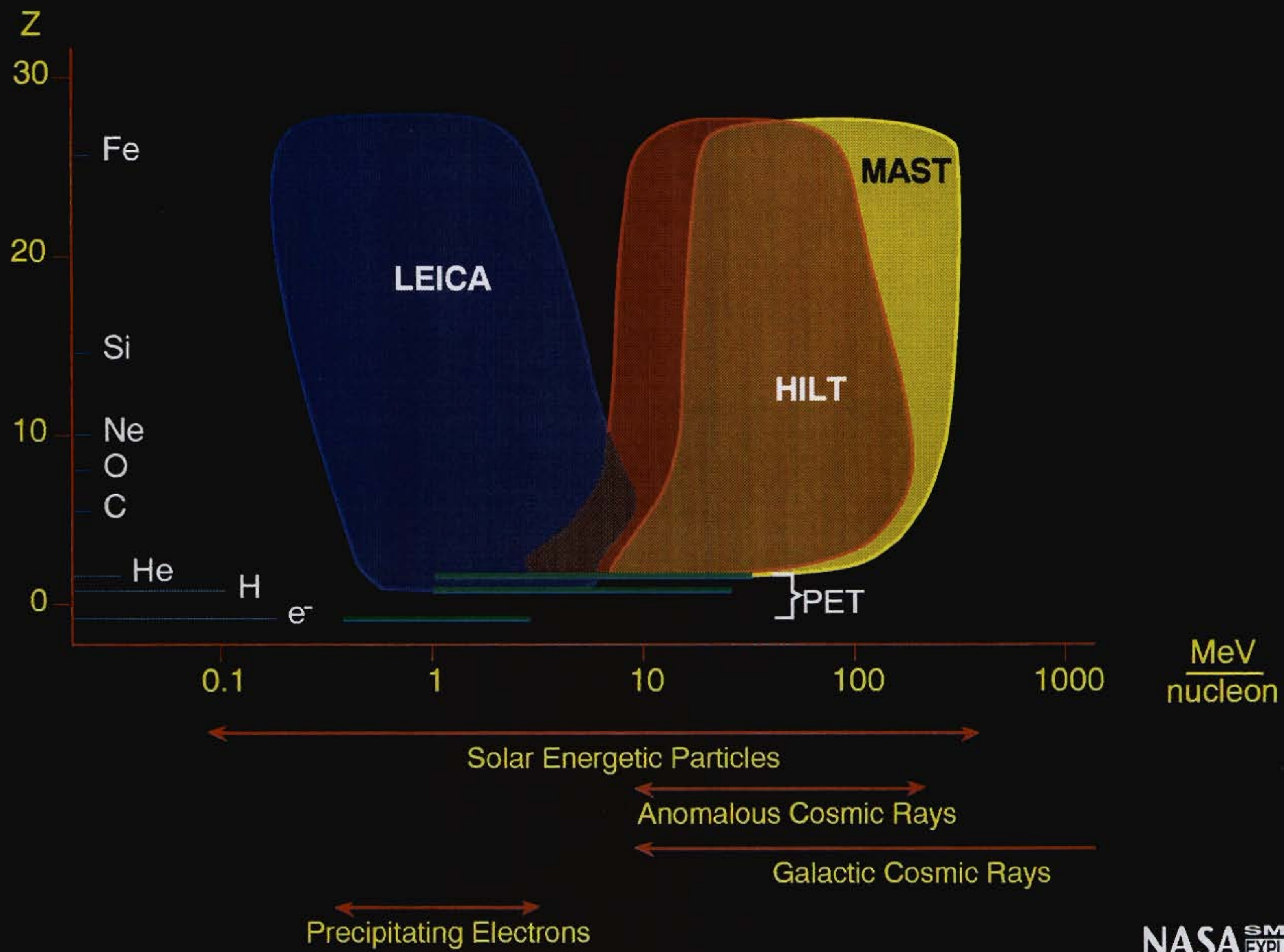
Heavy Ion Large Telescope (HILT)
- Based on energy and energy-loss spectroscopy
- Isobutane gas for energy-loss measurement
- Yields atomic composition, energy, and direction
- Very large opening

Mass Spectrometer Telescope (MAST)
- Based on energy and multiple energy-loss spectroscopy
- All solid-state detectors
- Yields isotopic composition, energy and density

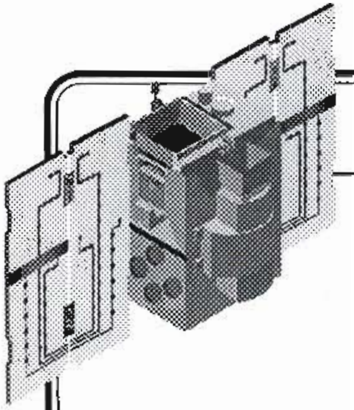
Proton-Electron Telescope (PET)
- Based on energy and multiple energy-loss spectroscopy
- Protons, helium, and electrons

Instruments: Element and Energy Coverage

SAMPEX



NASA SMALL EXPLORERS



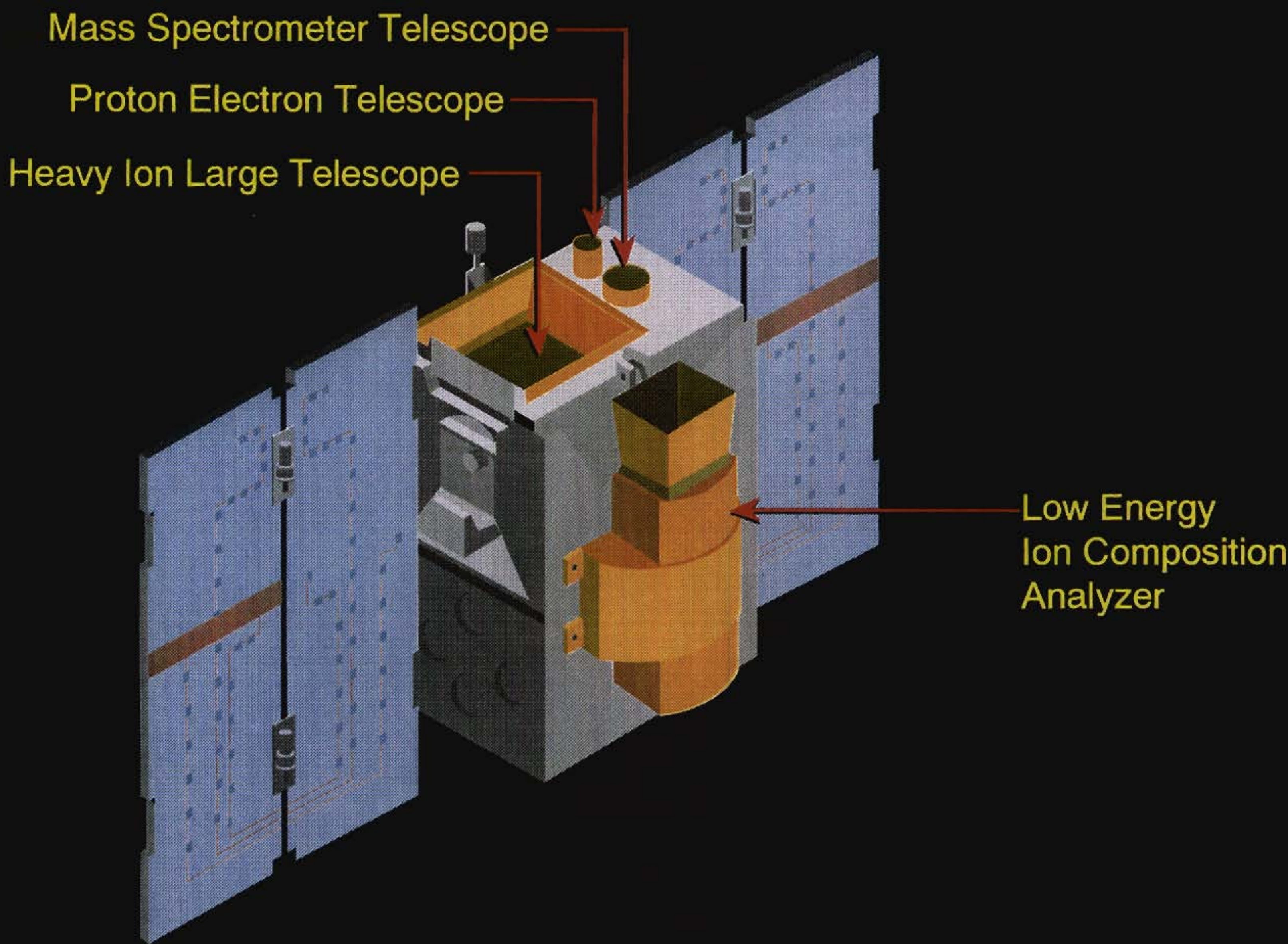
Instruments

The instruments are aligned so they can view the zenith together, especially when SAMPEX passes over the Earth's magnetic poles

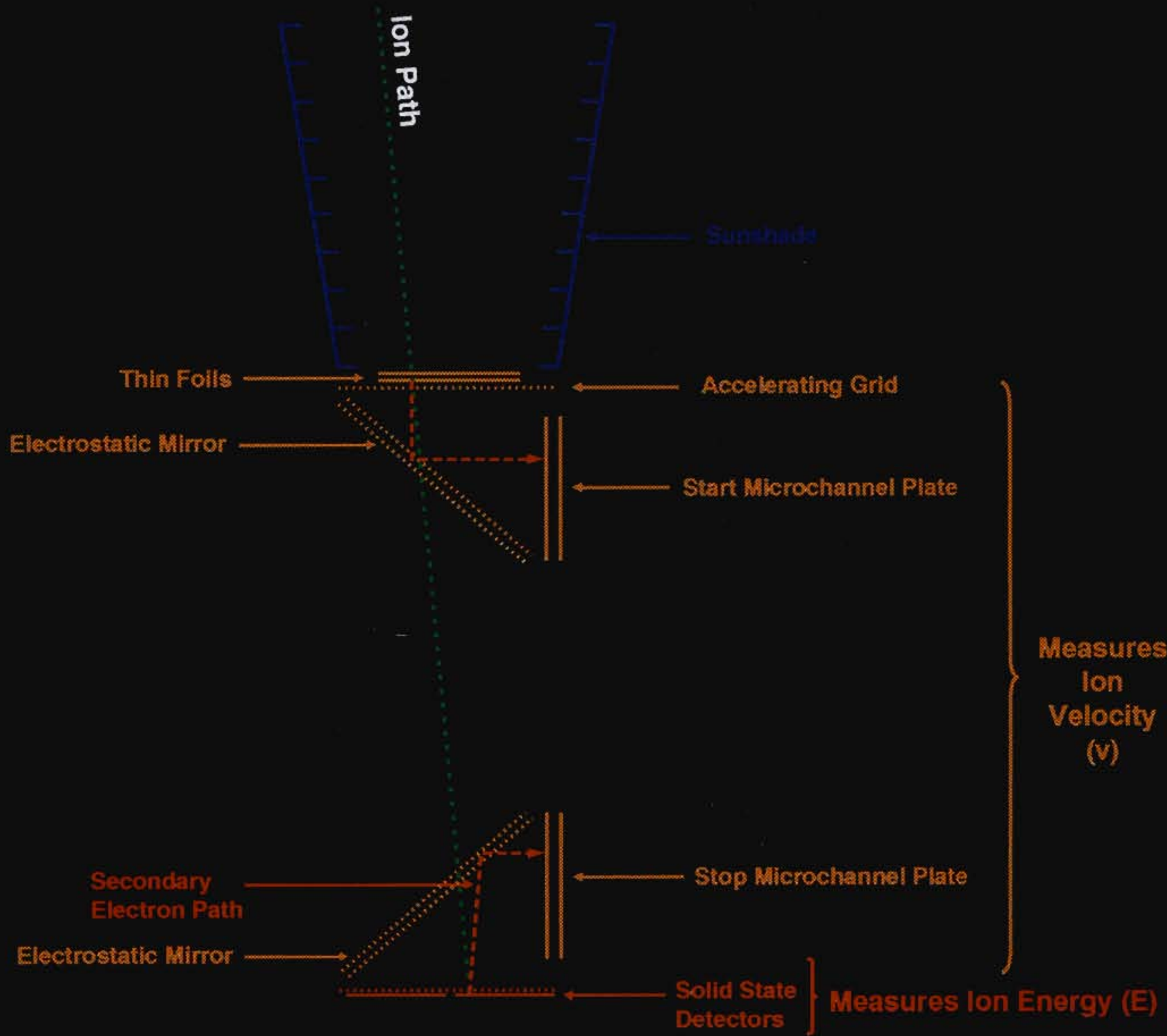
The instruments occupy over half the volume of the spacecraft

- HILT also has a supply tank of isobutane which is located in the center of the spacecraft

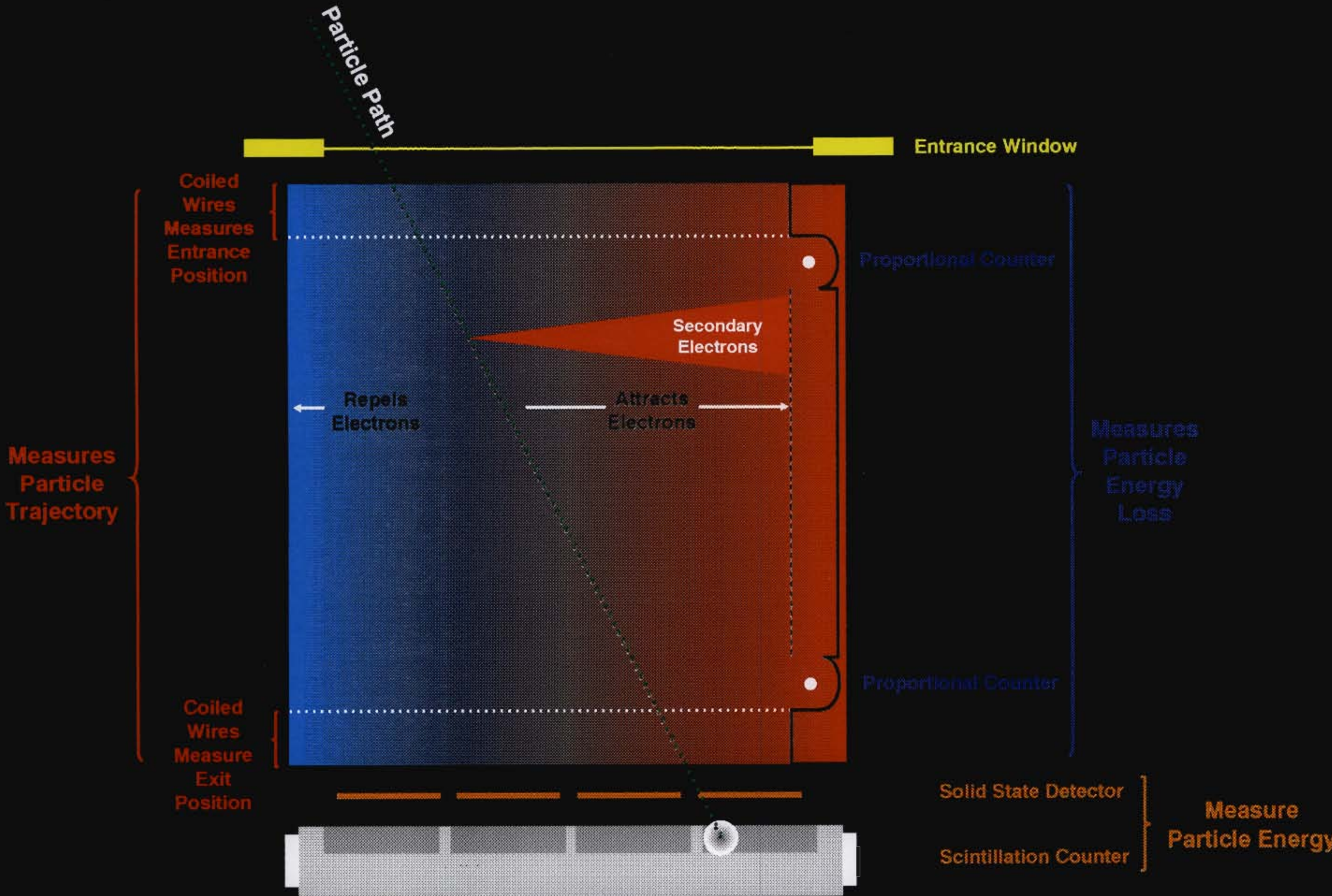
Instruments



LEICA: Operation



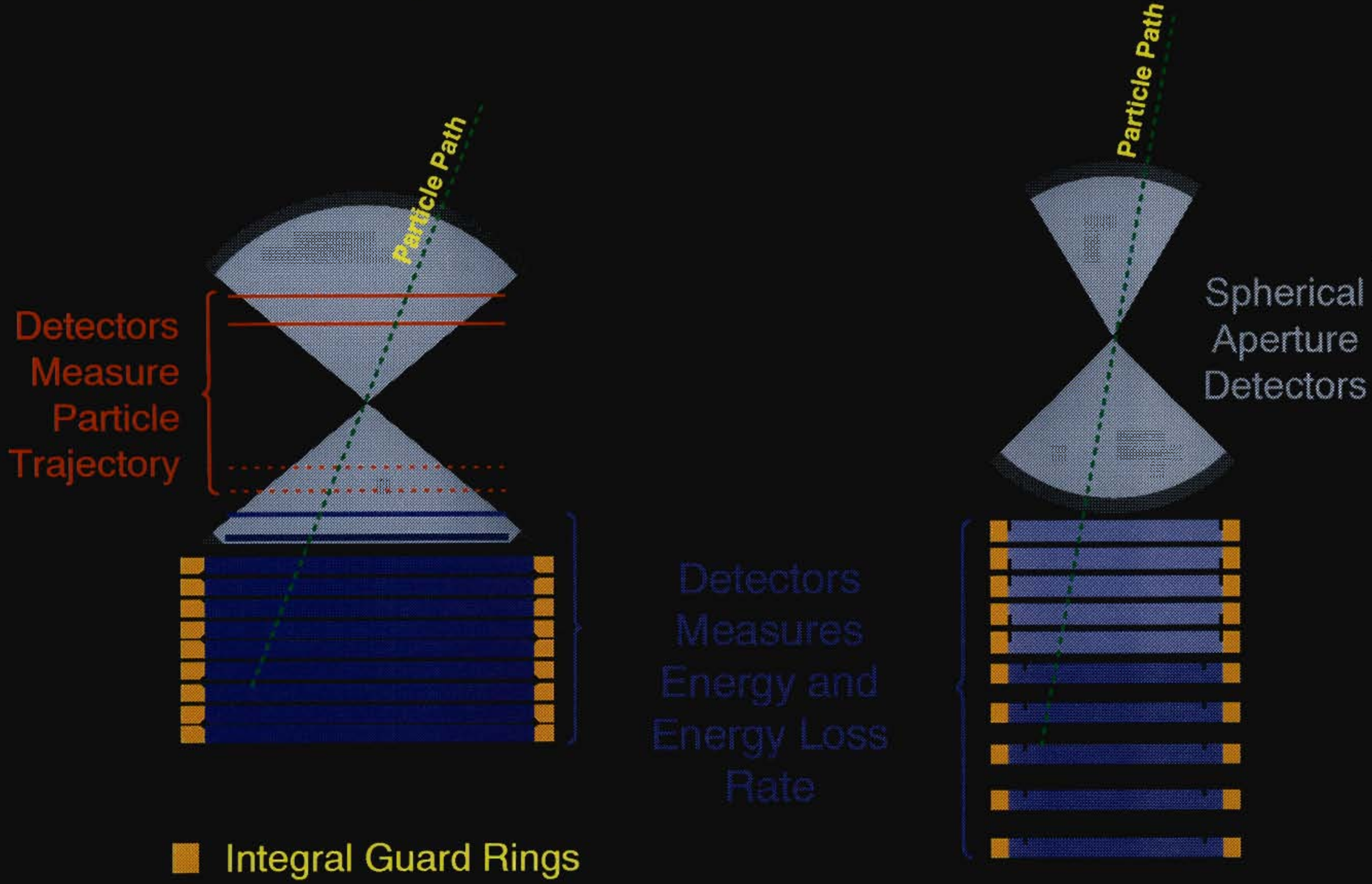
HILT: Operation

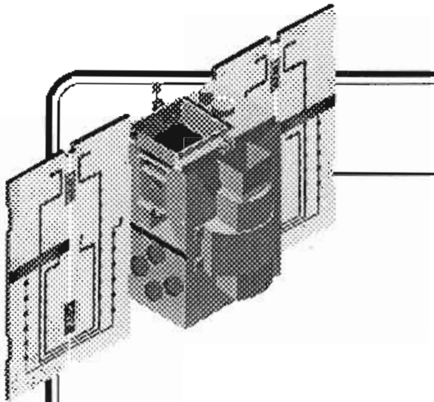


MAST/PET: Operation

MAST
Mass Spectrometer
Telescope

PET
Proton Electron
Telescope





SAMPEX

Mission Heritage

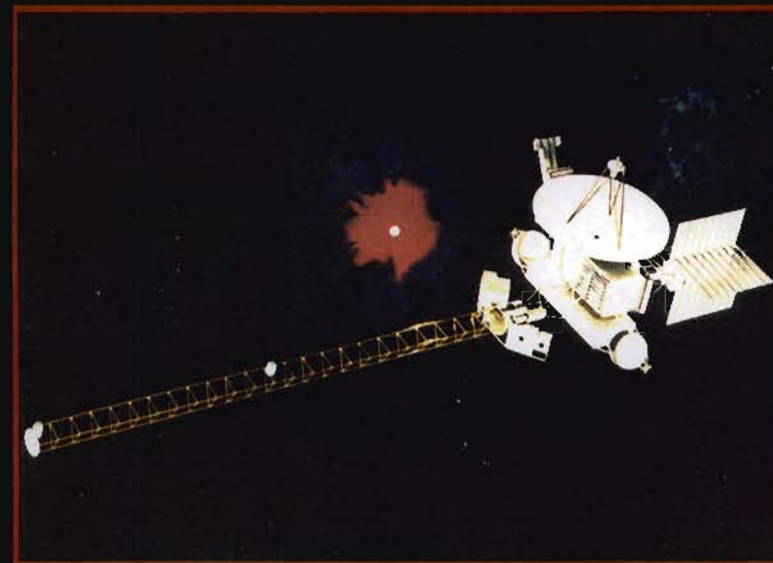
Two instruments are modifications of instruments that flew before as Get-Away-Special payloads on the Shuttle

- Heavy Ion Large Telescope (HILT)
- Low Energy Ion Composition Analyzer (LEICA)

Two instruments were refurbished after being stored away following the cancellation of the U.S. spacecraft of the International Solar Polar Mission

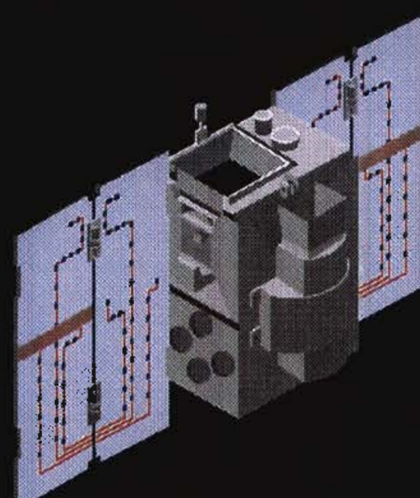
- Mass Spectrometer Telescope (MAST)
- Proton Electron Telescope (PET)

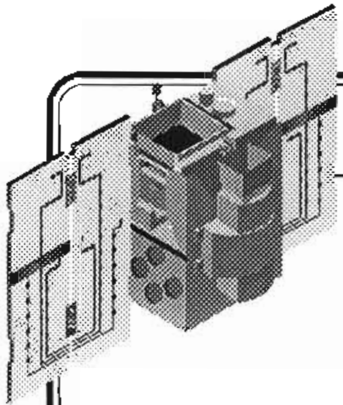
Mission Heritage



HILT
and
LEICA

MAST/PET





SAMPEX

Orbit

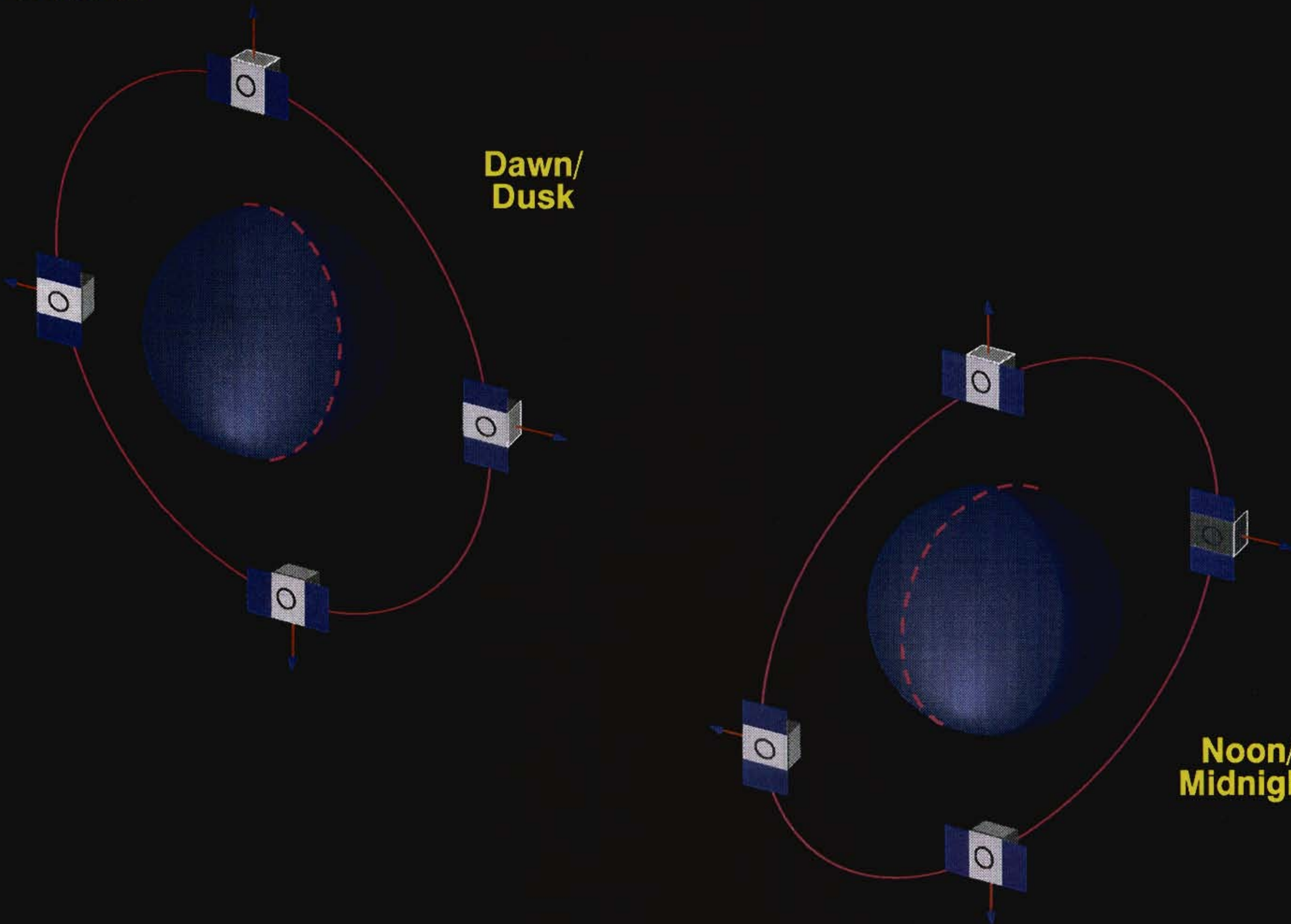
The scientific instruments must point toward the zenith, especially over the Earth's magnetic poles

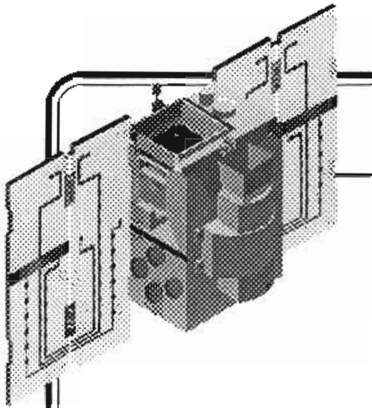
In order to use the smallest possible, fixed, solar arrays, the solar arrays must always face the Sun.

A compromise was reached in which a single momentum wheel spins with its axis toward the Sun, and the spacecraft rotates once around the axis each orbit

- In dawn-dusk orbits, the instruments always point at the zenith
- In noon-midnight orbits, the instruments point at the zenith over the magnetic poles but not over the equator

Orbit





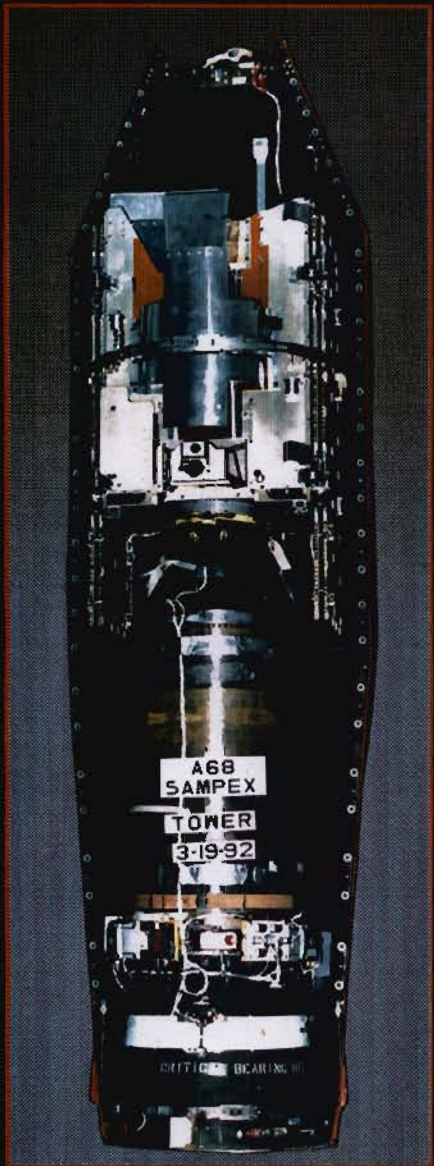
SAMPEX

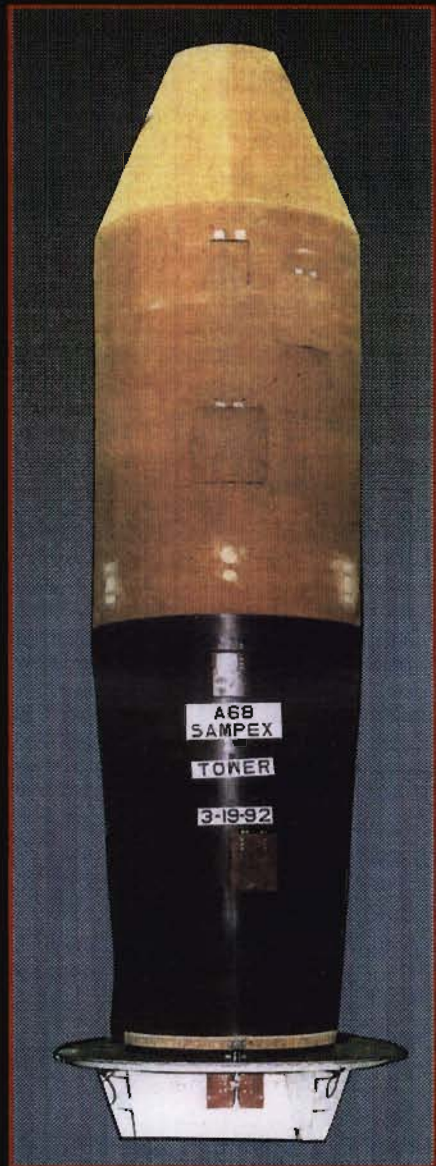
SAMPEX in Scout Heat Shield

A major technical challenge was to fit some of the largest cosmic ray instruments ever flown into the small Scout heat shield

- These instruments are by far the largest ever flown for the energy range of anomalous cosmic rays

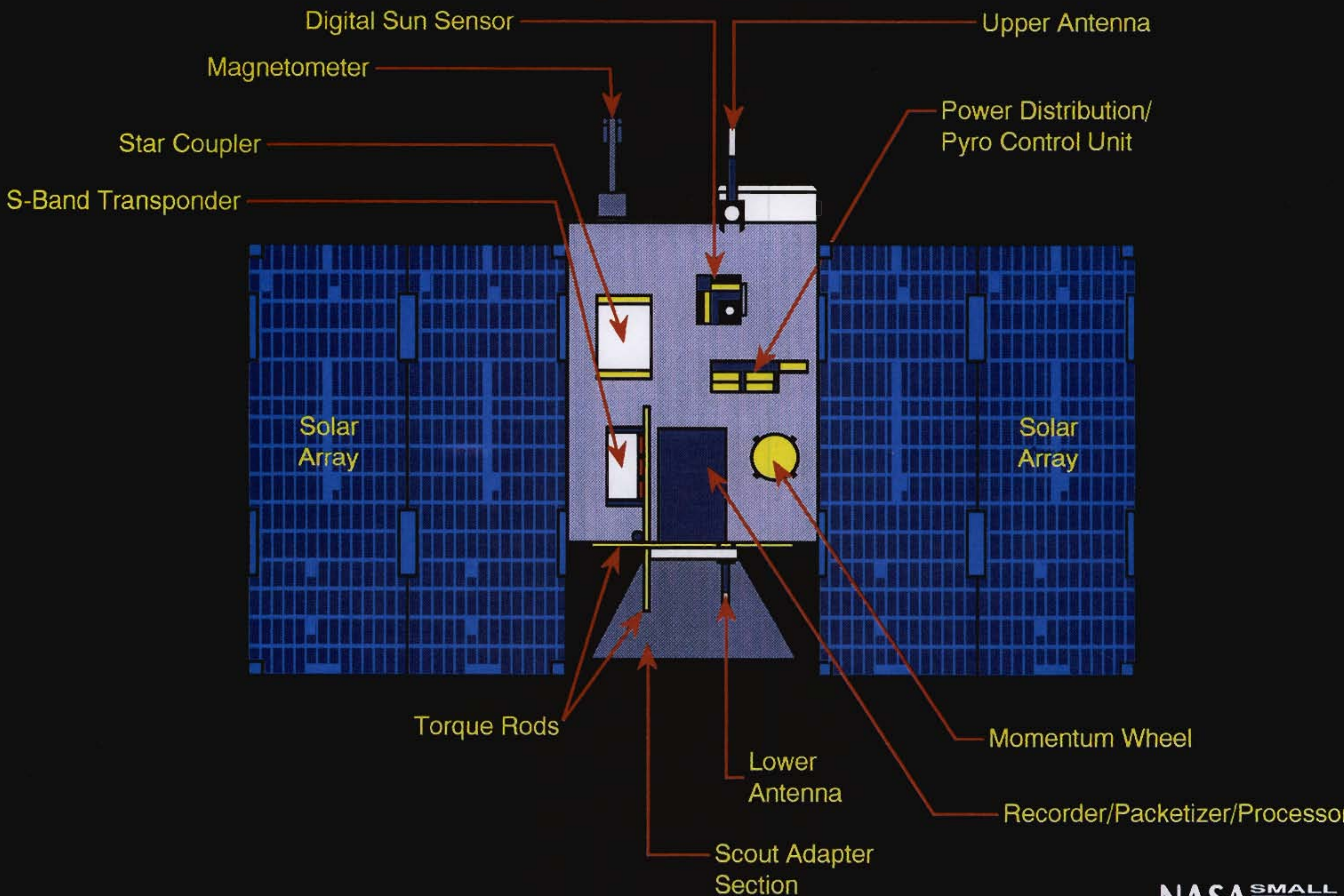
SAMPEX in Scout Heat Shield





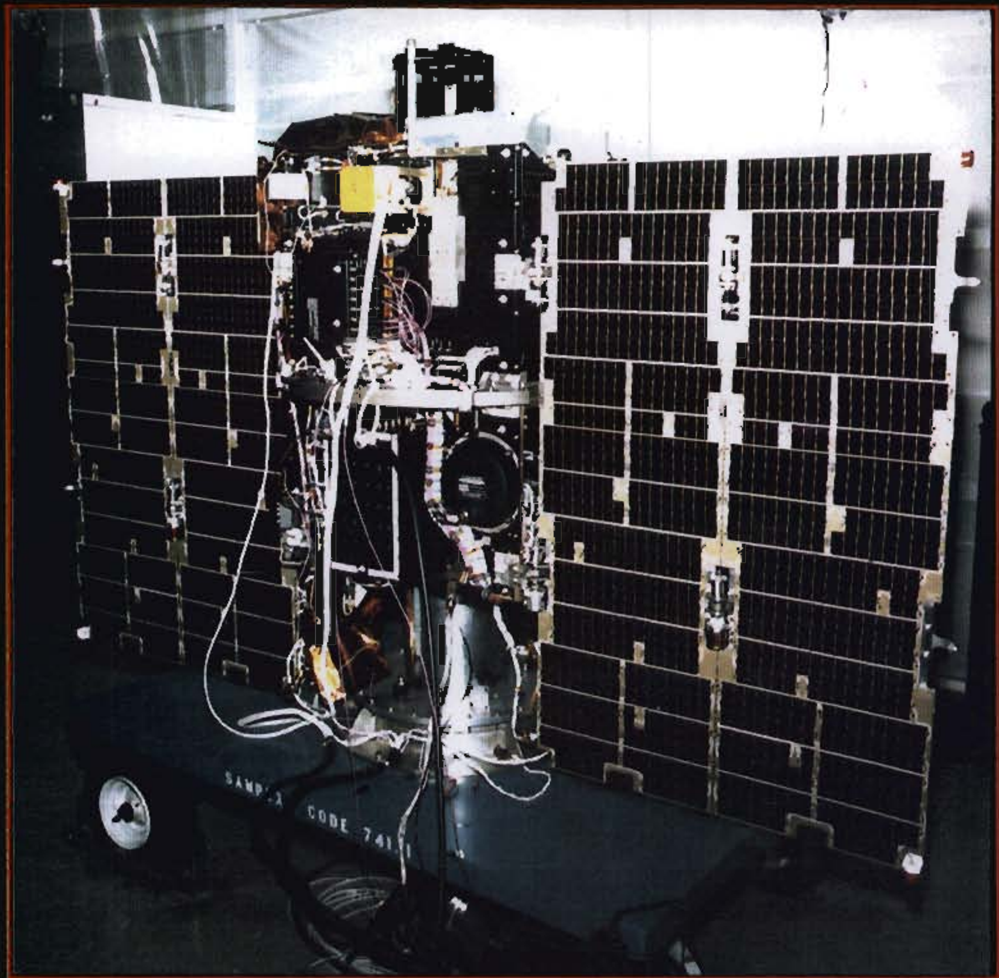
Spacecraft Subsystems

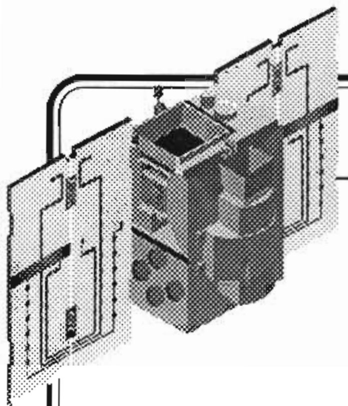
SAMPEX



NASA SMALL EXPLORERS

Spacecraft





SAMPEX

Spacecraft Operations

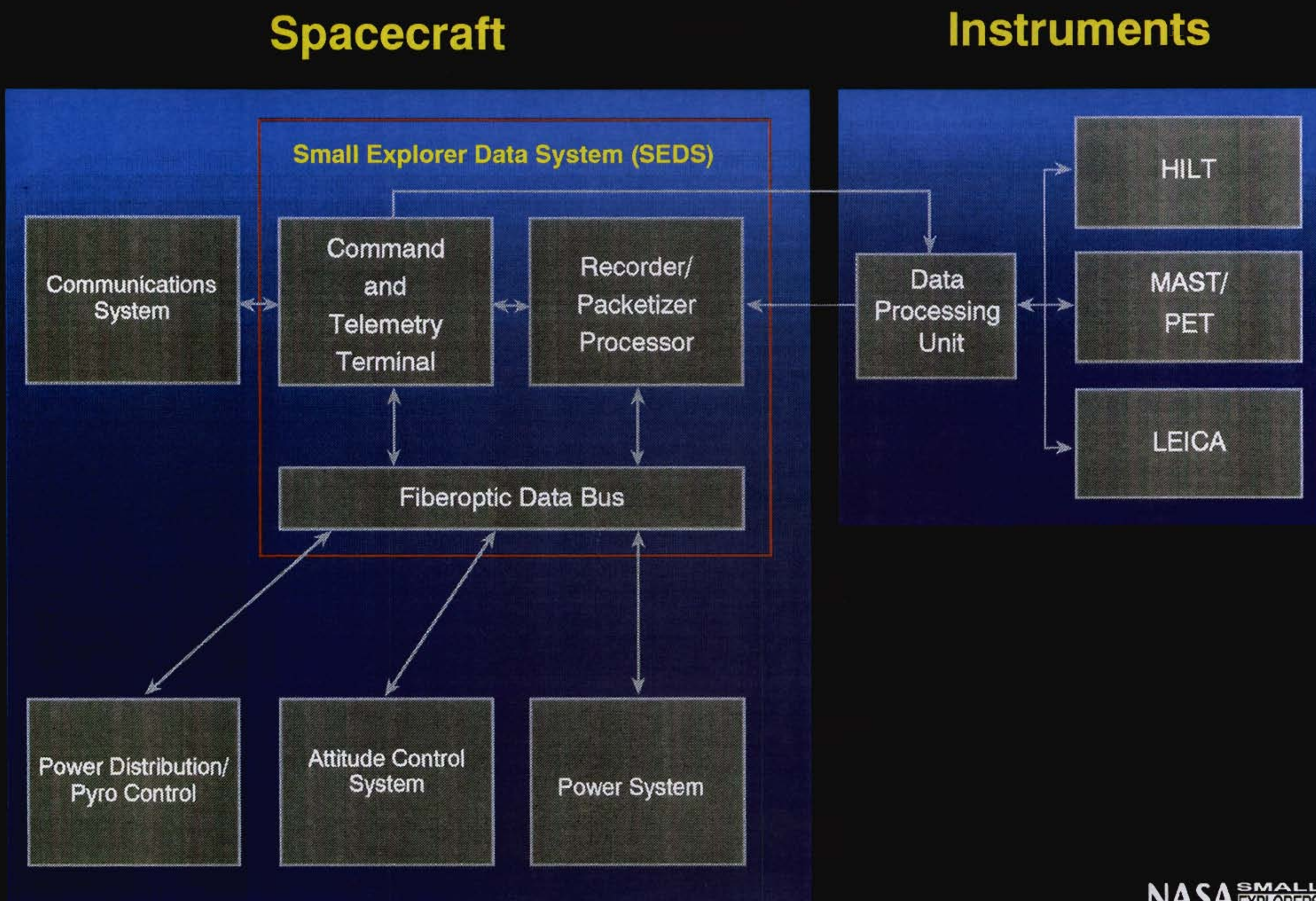
For the Small Explorer Program, a new, highly capable data system was developed —The Small Explorer Data System

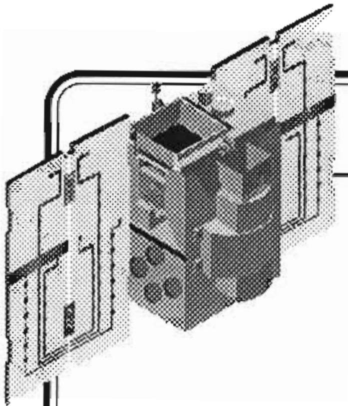
- Recorder/Packetizer/Processor
  - Controls the spacecraft
  - Computes position and attitude
  - Uses 26 Megabytes of solid-state, computer memory instead of a tape recorder to store the scientific data
- Command and Telemetry Terminal
  - Handles communications with the ground
- Fiberoptic data bus
  - Mil-Standard 1773
  - Handles all communication among the spacecraft subsystems

This data system provides many features that make SAMPEX easy to use

- Easy integration and test
- Position and attitude are stored directly in the science data
- Bits do not have to be reversed on the ground as they must for data stored on a tape recorder

Spacecraft Operation





SAMPEX

Ground System

SAMPEX is the first mission to fully implement standards of the Consultative Committee for Space Data Systems (CCSDS)

- Packetized data allows automated routing and handling of data by NASA networks

Data will be downlinked twice per day to Wallops Flight Facility

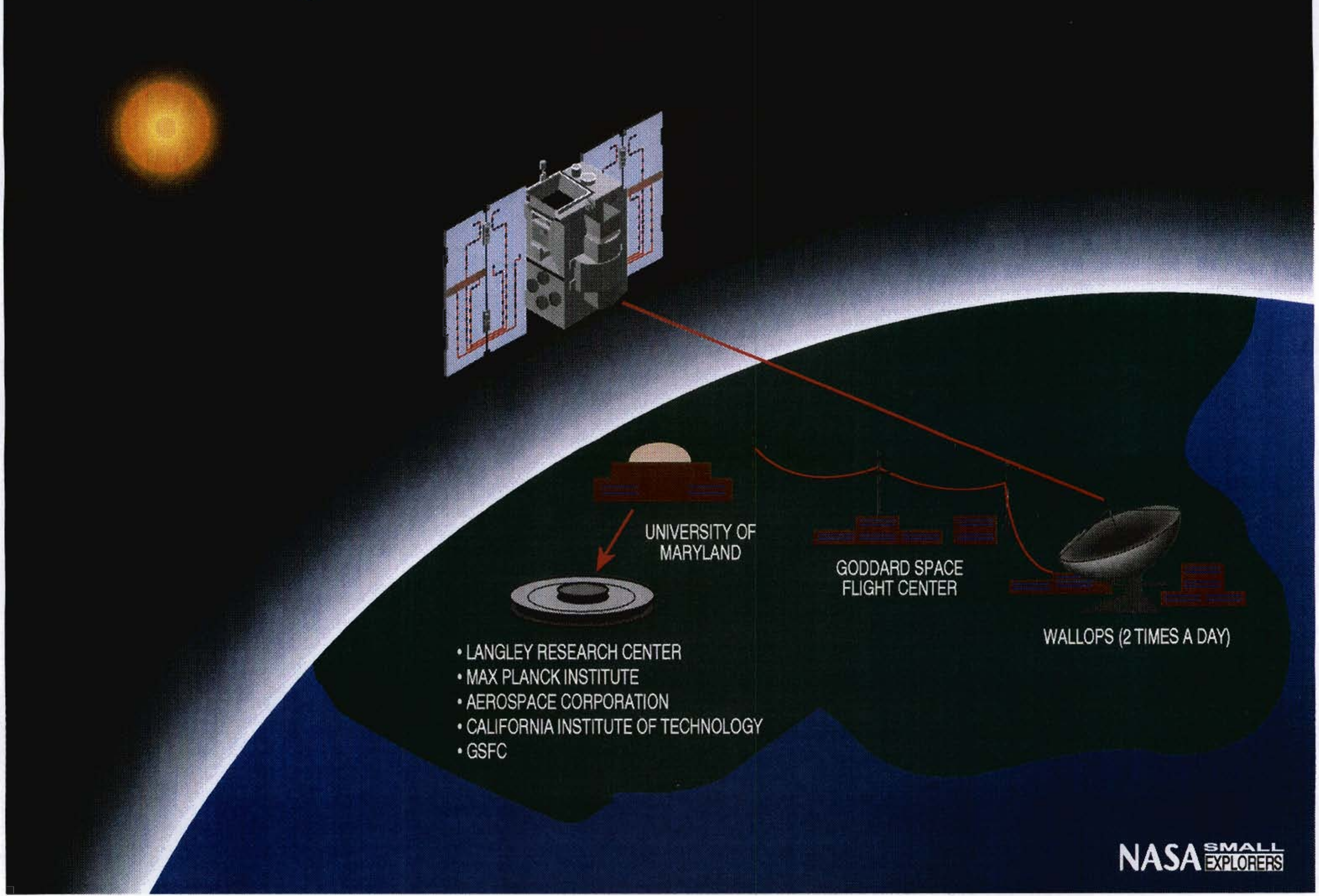
Goddard Space Flight Center

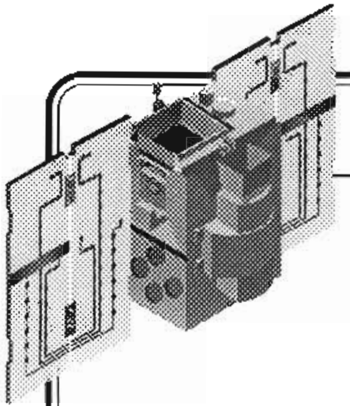
- Strip out engineering data for the Flight Operations Team
- Perform low-level quality checks of the science data
- Prepare command loads and orbit prediction data for uplink

University of Maryland

- Reduce the data
- Monitor instrument performance
- Distribute reduced data to the science team

Ground System





SAMPEX

Development Schedule

The SAMPEX mission was developed in 3 years

- From the initiation of detailed design to launch

SAMPEX was developed on time

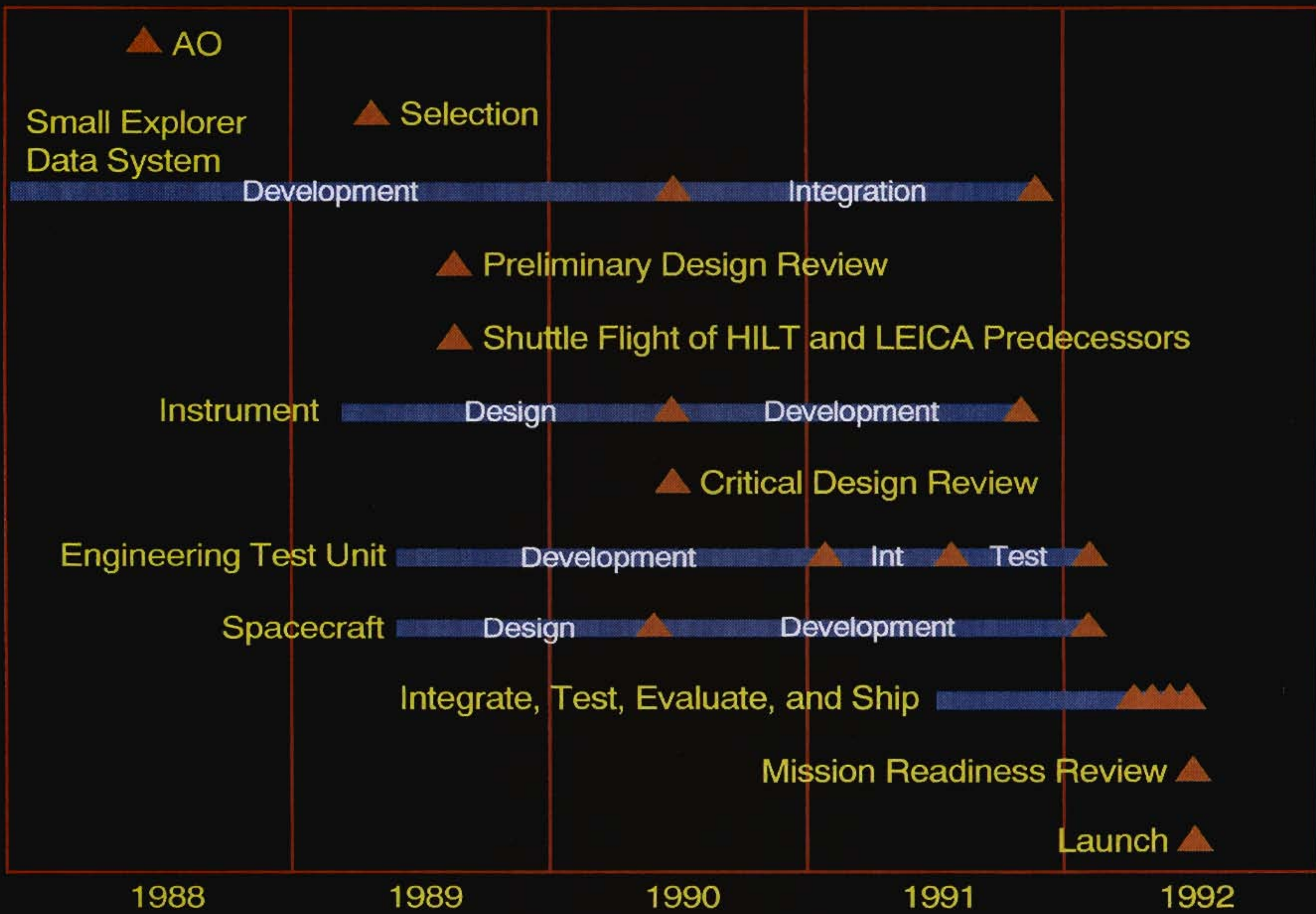
- June 1992 established as launch date at the time of selection

Time-consuming efforts during the development included

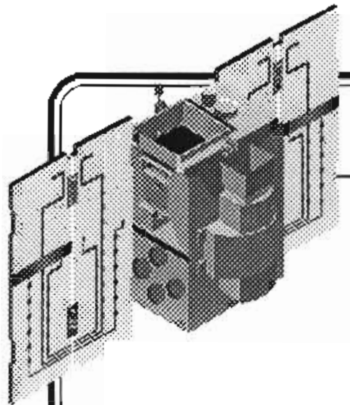
- Small Explorer Data System
- Solar arrays
- Scientific instruments
- Integration and test program

SAMPEX

Development Schedule



NASA SMALL EXPLORERS



SAMPEX

Meeting the Challenge

Rapid development was made possible by a group of mostly young engineers and managers at the Goddard Space Flight Center

- Systems engineering
- Design
- Acquire the hardware
- Develop the software
- Develop the ground support equipment
- Integrate
- Test

In order to move quickly through flight integration and test, the team began by integrating and testing a system built up from the engineering test units

Meeting the Challenge

▲ Announcement of Opportunity

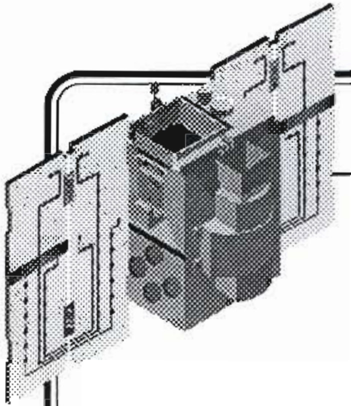
Selection ▲

▲ Preliminary Design Review

▲ Critical Design Review

Launch ▲

1988 1989 1990 1991 1992



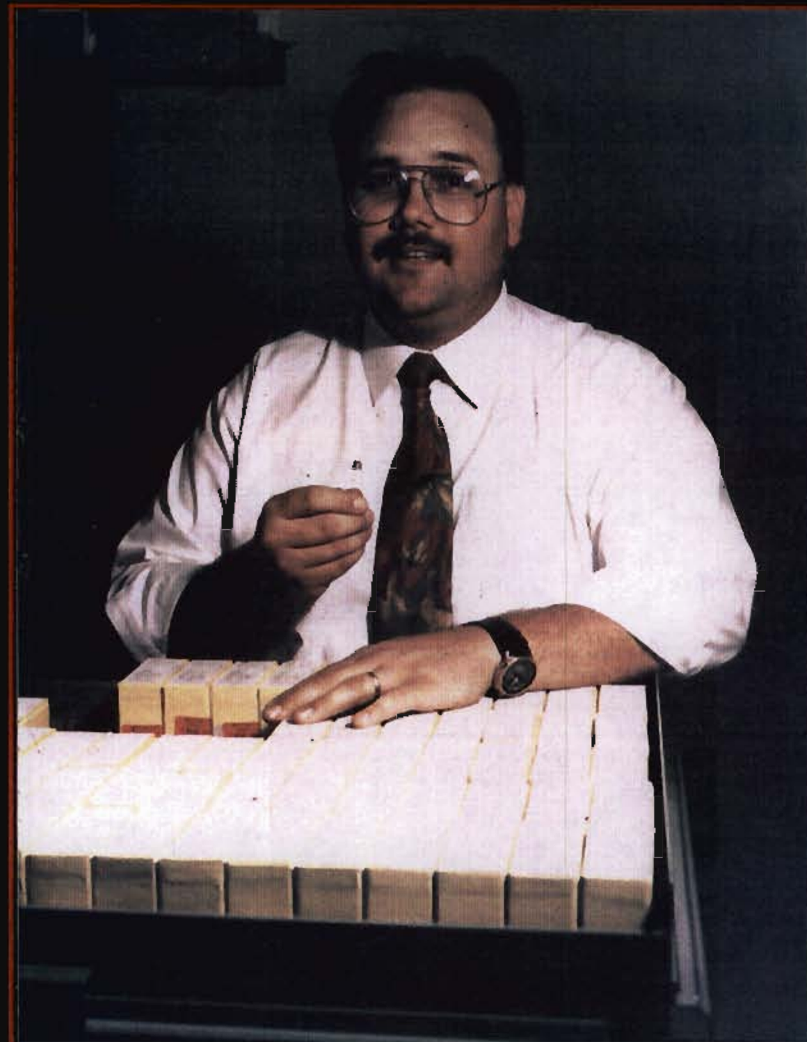
Getting Key Parts on Time

The Parts Engineer kept watch over the delivery of piece parts

- Sat for 3 days in the waiting room of one vendor until the SAMPEX relays were delivered

Getting Key Parts on Time

SAMPEX



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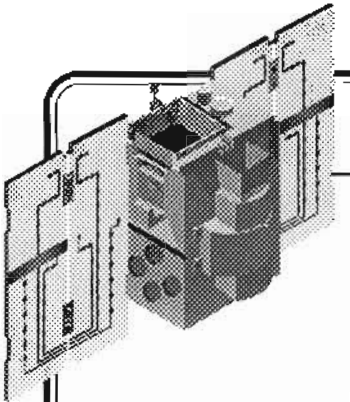


SAMPEX

Project Team

Mission Management

- Instrument Manager, managed the coordination of the investigator teams providing instruments
- Mission Manager, managed the development of the SAMPEX mission

Making the Mission Happen

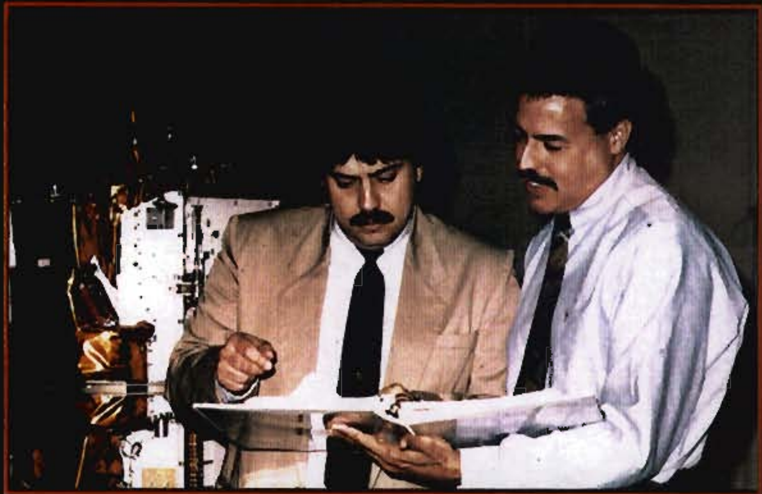
- Lead Engineer, RF Systems
- SAMPEX Instrument Manager
- Contracting Officer for the Small Explorer Project
- SAMPEX Mission Manager
- Ground Systems Engineer

Program Teamwork

- Small Explorer Program Manager
- Chief of Special Payloads
- Small Explorer Project Manager

Project Team

SAMPEX

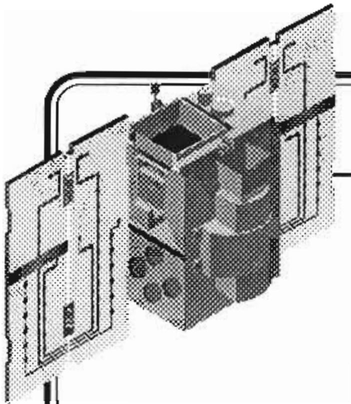


Mission Management

Making the Mission Happen

Program Teamwork

NASA SMALL EXPLORERS



SAMPEX

Benefits of the Small Explorer Program

Having small, relatively low cost missions with a flight rate of about 1 per year allows

- A vital program of low-cost, exploratory missions
- A chance for more scientific disciplines to acquire space data
- An on-going opportunity to try out technical and management innovations

Having a short, 3-year, development time allows

- Opportunities to be responsible for a part of a mission from concept to launch at the beginning of one's career
- Participation of graduate, undergraduate, and even high school students
- Relatively quick return of scientific results from the time the proposal is submitted

Benefits of the Small Explorer Program

SAMPEX

- Scientific Exploration
- Scientific Diversity within the Disciplines of Astrophysics and Space Physics
- Technical and Management Innovaton
- Concept-to-Launch Training
- Education
- Increased Productivity of Science Team

NASA SMALL EXPLORERS

SAMPEX

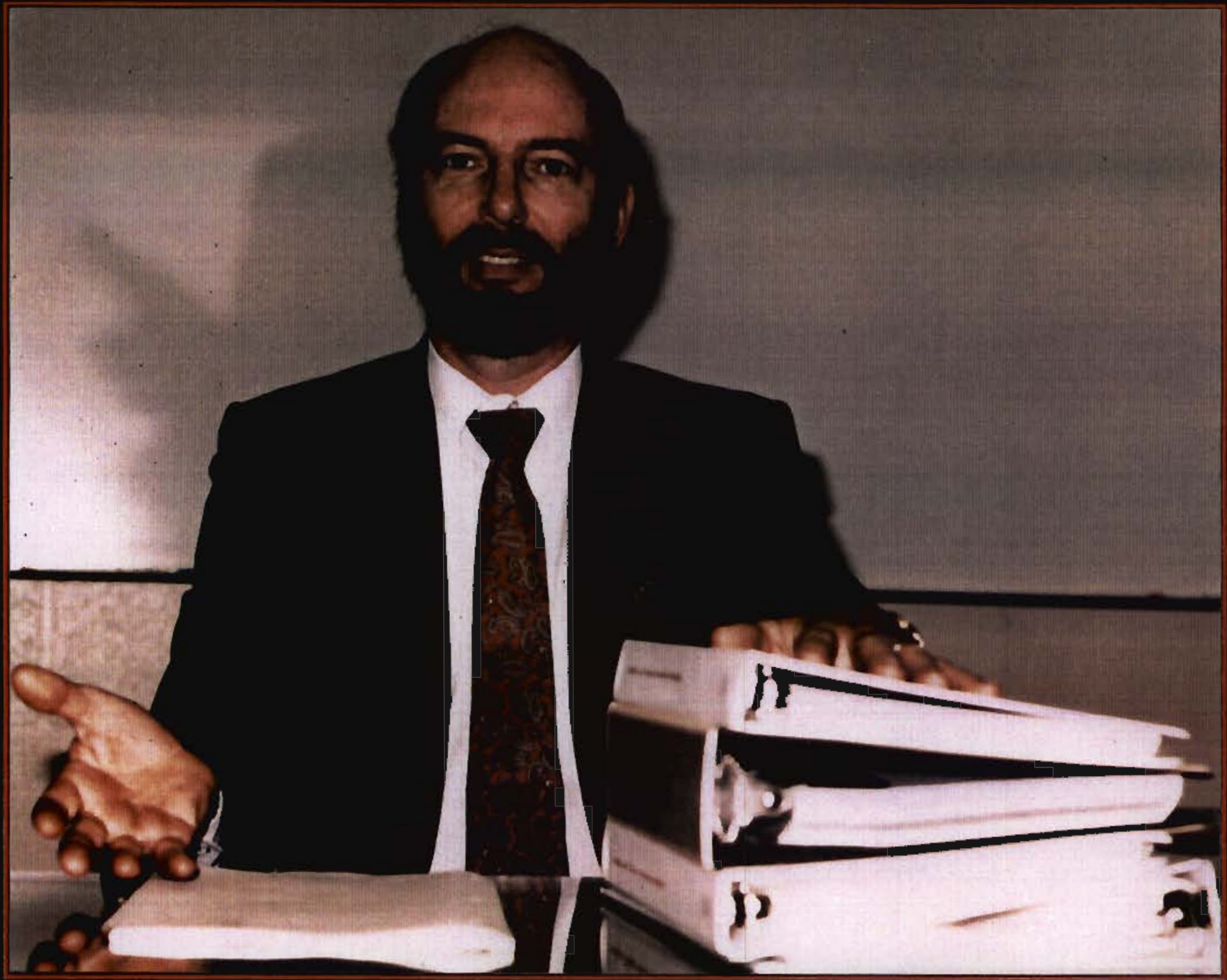
Performance Assurance

The pile on the left is the actual Performance Assurance Requirements Document for the SAMPEX instruments

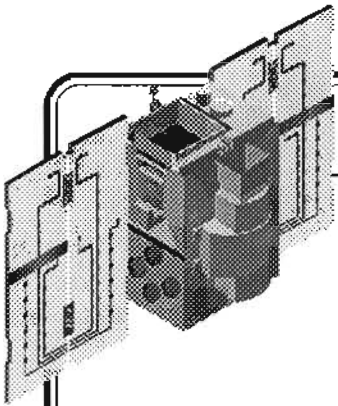
On the right are documents representative of the Performance Assurance Requirements Documents required in larger, more complex missions

Performance Assurance

SAMPEX



NASA SMALL EXPLORERS



SAMPEX

Student Involvement

In addition to having physics graduate students involved in the mission, a large number of undergraduate students have been involved as well

- Adding students in Germany brings the total number to 50

Mike Fatig, leader of the Bendix Flight Operations Team for SAMPEX, initiated a highly successful program involving a high school in Laurel, Maryland

- Bendix and Falcon Microsystems have contributed equipment and manpower to help students develop a Mission Monitoring System at the high school
  - The success has been recognized at state and national levels
- NASA has provided briefings, tours, and access to spacecraft flight engineering data which the students will record and analyze
  - Results of the pilot program and a demonstration are planned for the next meeting of the National Science Teachers Association

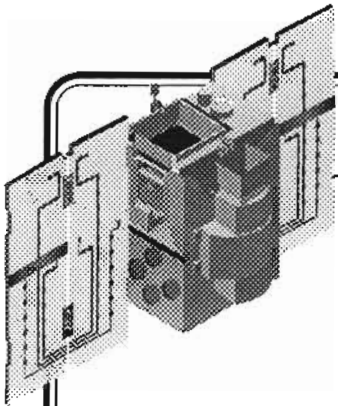
Student Involvement

University Students:

	Caltech	U. Maryland
- Engineering	-	14
- Physics	3	-
- Other undergraduate	-	7
- Physics graduate	1	2
	4	23

Laurel High School: Cooperative Satellite Learning Project

- Led by Mike Fatig, Bendix Flight Operations Team
- Support by NASA as pilot program



Fast Auroral Snapshot Explorer (FAST)
Scientific Program

FAST will be the second Small Explorer mission

- Launch September/October 1994
  - Annual launch window constrained in order to place apogee high over the northern polar region during a northern winter campaign

FAST will investigate the physical causes that produce aurora by measuring particles and fields in the acceleration region above the aurora

- Extremely rapid sampling of particles and fields will allow the separation of cause and effect among the phenomena encountered there