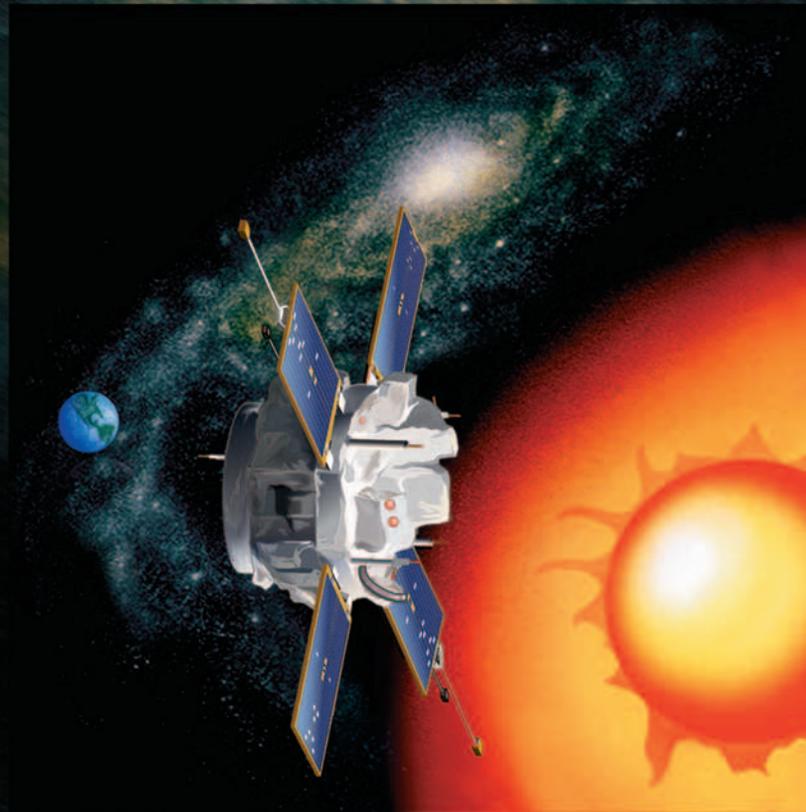


ADVANCED COMPOSITION EXPLORER



ACE

2nd Edition

Advanced Composition Explorer

ACE Facts

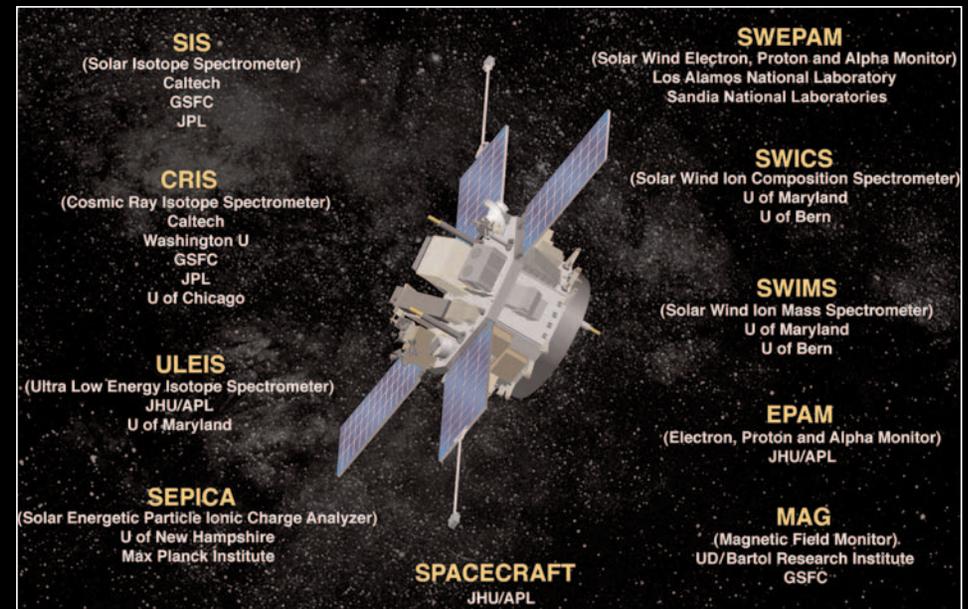
Mission:

- Launch: August 25, 1997
- Launch Vehicle: Delta II
- Primary Mission: Measure the composition of energetic particles from the Sun, the heliosphere, and the Galaxy
- Orbit: Halo orbit around the Earth-Sun libration point, L1
- Mission Lifetime: There is sufficient hydrazine for ACE to remain in an L1 orbit until 2019, depending on the details of the orbit.

Spacecraft:

- Mass: 785 kg (includes 195 kg fuel at launch)
- Structure: Two octagonal decks, 1.6 m across, 1.0 m high
- Propulsion: Hydrazine fuel for insertion and maintenance in orbit
- Power: 443 W, four fixed solar arrays
- Attitude Subsystem: Spinning spacecraft (5 rpm), spin axis is Earth/Sun pointing
- Communication Subsystem: S-band, 7 kbps (real time), 2 Gbit (total) solid state recorders
- Instrumentation: Eight instruments that measure plasma and energetic particle composition, and one to measure the interplanetary magnetic field

ACE Science Investigations



Who among us has not asked, "Where did I come from?" This question is usually one about life, but behind it are scientific questions about the material of which we are made, the elements in the atoms and molecules of our bodies. The answer to the question "Where did the matter we are made of come from?" is not so easy to find. Some could be satisfied with an answer such as "We are made of the same elements that are found on the Earth we live on." But where did that material come from? The Earth is but one planet in the solar system, and most of the solar system material is inside the Sun. How can we find out what the Sun is made of? Where did the Sun come from? One can even go further and ask, "What is the Galaxy made of?" There is a whole series of related questions that are involved in understanding the cycles the matter goes through as the universe and the structures within it evolve.

The material that Earth and the solar system are made of has been changed and rearranged during the billions of years since its creation, so measuring its complete composition, or makeup, is difficult. We have good evidence that the first elements to appear in the early universe were the lightest ones, hydrogen and helium. Most of the gas found between the stars in our Milky Way galaxy, and, we think, in other galaxies throughout the universe as well, are hydrogen and helium. We also know that the Sun is made chiefly of hydrogen and helium. We understand that stars, including our Sun, shine by the process of combining, or "burning", lighter elements into heavier ones, hydrogen into helium, and helium into carbon, and so on. In fact, in the outer layers of the Sun, we can see the light emitted by heavy elements, like carbon, silicon, and iron. These elements were formed by an earlier generation of stars.

Scientists have attempted to answer questions about where this matter came from and how it evolved in a variety of ways. Meteorites that have hit the Earth can be studied since, in some respects, they seem to be like the solar system when it formed. Another way to study the material is by going into space, above Earth's atmosphere, to study particles that come from the Sun. Early in the 20th century, scientists learned that energetic particles from space are bombarding the Earth. With the advent of space missions, we learned that they come not only from the Sun, but also from the distant reaches of the Galaxy. It has been recently discovered that some of these particles come from the gas clouds outside our solar system. The primary purpose of the Advanced Composition Explorer, ACE for short, is to study these particles. We are learning more about what matter is there: about its composition, where it comes from, and what it tells us about the evolution of the larger universe.

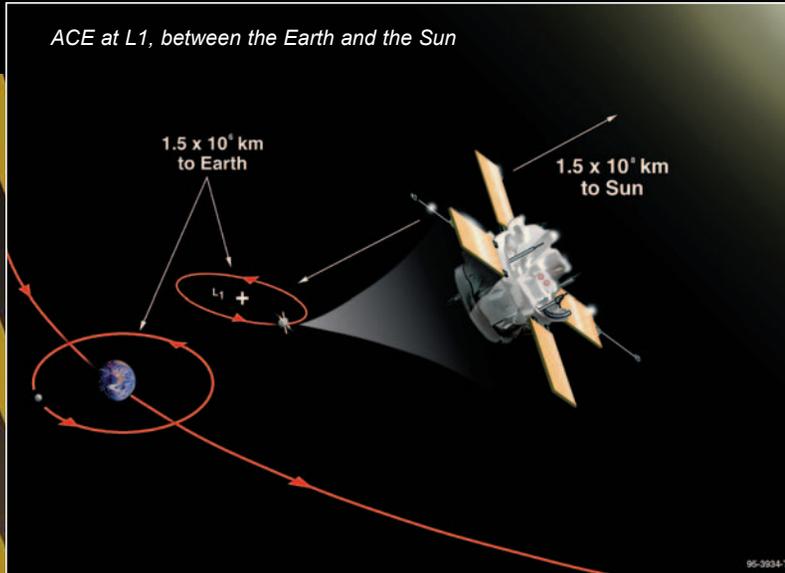


"What canst thou see elsewhere which thou canst not see here? Behold the heaven and the earth and all of the elements, for of these are all things created."

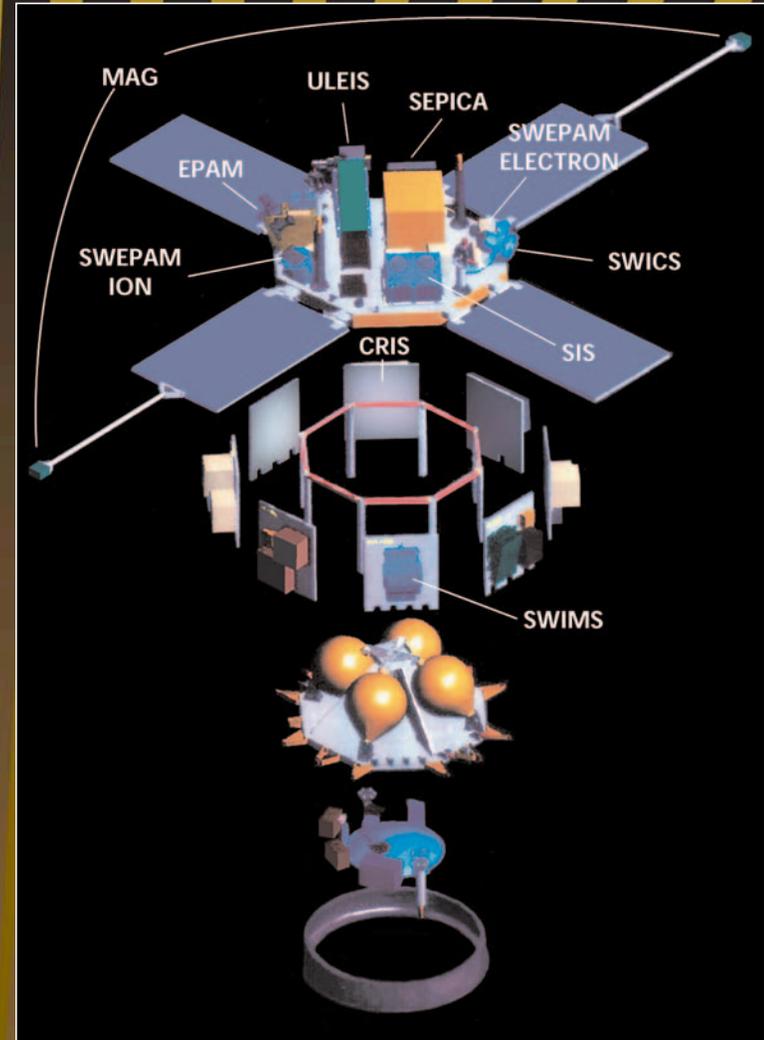
Thomas à Kempis, c. 1420

High-speed gas from a supernova explosion slams into dark cooler clouds of interstellar material. Shocked and heated by this tidal wave of energy, the clouds glow in bright, neon-like colors.

THE MISSION



The ACE spacecraft was built at the Applied Physics Laboratory of The Johns Hopkins University (JHU/APL).



Expanded view of the ACE spacecraft

MISSION OVERVIEW

The instruments on the ACE spacecraft are designed to sample the matter that comes near the Earth from the Sun, from the apparently (but not actually) empty space between the planets, and from the Milky Way galaxy beyond the solar system. They do so with a collecting power 10 to 1000 times greater than previous experiments. Particles are identified by their type (which atom they are), by their mass (which isotope they are), by their electric charge or ionic state, and by their energy. Even very rare isotopes can be studied. The information gathered by ACE is compared with that from other missions, past and present, for a better understanding of the interaction between the Sun, the Earth, and the Galaxy.

In order to measure solar particles and plasma twenty four hours a day without being affected by the Earth's magnetic field, ACE has traveled about 1.5 million km (about a million miles) from the Earth to the Earth-Sun **libration point, L1**. This is the point where the centripetal force and the gravitational pulls of the Earth and Sun balance. This balance keeps ACE at an ideal location for these studies. From its vantage point, 1/100 of the distance from the Earth to the Sun, ACE performs measurements over a wide range of energy. By orbiting the L1 point in a halo, ACE can follow the Earth as it revolves about the Sun, always staying between them.

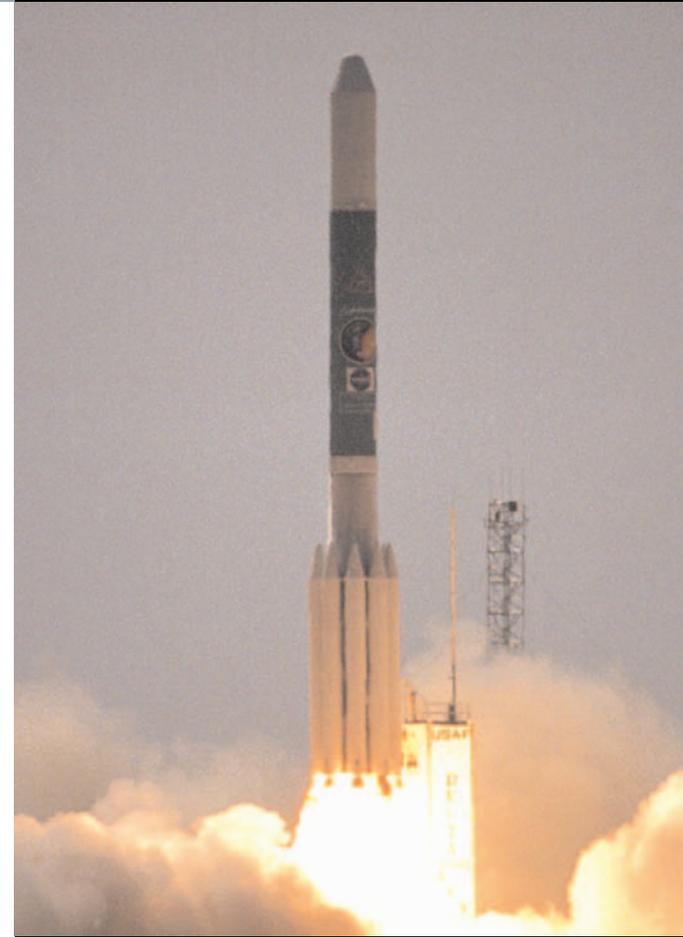
The ACE mission has a goal of lasting at least five years. Overall NASA responsibility for the mission is in the hands of the Space Science Mission Operations Project Office of NASA Goddard Space Flight Center (GSFC) in Greenbelt, MD. The lead scientific institution is the California Institute of Technology (Caltech) in Pasadena, CA. The Applied Physics Laboratory of The Johns Hopkins University (JHU/APL) in Laurel, MD was responsible for building the spacecraft.

ACE SPACECRAFT AND INSTRUMENTS

The ACE spacecraft consists of a two-deck irregular octagon, about 1.6 m (65 inches) across and about 1.0 m (40 inches) high. It spins about its axis so that one end always points toward the Sun and the other toward the Earth. It contains redundant equipment for collecting and storing data, and transmitting the data back to Earth. Data is transmitted via a highly directional parabolic dish antenna mounted on the aft (bottom) deck of the spacecraft. Four other broad-beam antennas, capable of transmitting data at lower rates, are also available if needed. Twenty four hours worth of science and housekeeping data (about 1 Gigabit), recorded on one of two solid-state recorders, is transmitted to Earth in one three- to four-hour telemetry pass each day. Spacecraft attitude (the orientation of the spacecraft) is provided by a star tracker and digital Sun sensors.

Mounted to the spacecraft are eight scientific instruments which measure a variety of different particle types. Four arrays of solar cells power the spacecraft and the instruments. These arrays provide sufficient power to allow ACE operations to continue for at least five years. Attached to two of the solar panels are booms, or long arms, for the ninth instrument, a pair of magnetometers.

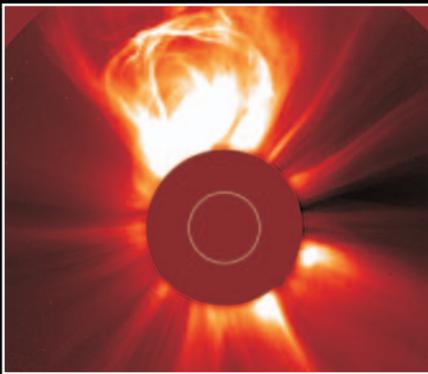
Measuring a particle's type, charge, mass, energy, direction of travel, and time of arrival provides the clues needed to help determine its source and the processes by which it has gained energy. The ACE instruments cover an unprecedented range of particle type and energy; simultaneous measurements from these instruments are coordinated to create a comprehensive picture of the energetic particles that pervade the inner solar system.



ACE was launched on a Delta II rocket in August 1997 from the Kennedy Space Center in Florida. Delta II is an expendable two-stage, liquid-fueled rocket that stands at a height of 38 m (126 ft) and weighs 232,000 kg (511,000 lb). It is currently the world's most reliable launch vehicle.

What's New on ACE

- Coordinated measurements of three distinct samples of matter
 - Solar
 - Local interstellar
 - Galactic
- 10 - 1000 times larger collecting power
- Measures all solar elements from carbon to zinc
- Determines the masses of individual atomic nuclei over a wide range of velocities
- Real-time transmission of solar wind parameters and interplanetary magnetic field a half hour or more prior to arrival of solar wind at Earth's magnetosphere



During coronal mass ejections (CMEs), magnetic fields become unstable, releasing previously constrained hot material from the upper atmosphere of the Sun. As a result, hot gas streams out into the solar system, impacting planets, moons, and spacecraft, and causing space weather that can cause storms in Earth's magnetosphere and endanger spacecraft and astronauts.

WHAT'S IMPORTANT ABOUT THIS MISSION?

TO THE SCIENTIFIC COMMUNITY:

A primary goal of ACE is to study the composition of material from the Sun, the local interstellar medium, and the Galaxy to better understand the formation and evolution of the solar system. Each of these samples tells a different story: pickup ions and anomalous cosmic rays are samples of the present-day interstellar medium; galactic cosmic rays provide a sample of matter from the Galaxy that was accelerated millions of years ago; and solar matter represents an older sample of interstellar matter that has been stored in the Sun for the last 4.6 billion years. With coordinated observations that extend from solar wind to cosmic ray energies for elements ranging in mass from hydrogen to zinc, ACE is a major extension of composition studies by earlier spacecraft and balloon-borne instruments. Precise studies of even rare isotopes are possible due to vastly increased capabilities to collect particles and more accurately identify them.

ACE is providing new determinations of the composition of the Sun, which comprises more than 99% of the matter in the solar system. By measuring how many electrons remain attached to solar wind and higher energy ions ACE is measuring the (several million degree) temperatures of regions from which these particles originate. Elemental and isotopic composition measurements reveal the composition of the solar atmosphere, as well as composition patterns that arise when some particles are accelerated more easily than others. The broad range of composition measurements that ACE provides now makes it possible to identify the origin of energetic particle populations observed in interplanetary space and understand the processes by which they are accelerated. Comparisons of the composition of solar wind and higher energy solar particles with that of meteorites, comets, the moon, planetary atmospheres, and galactic material are providing key information on the history of our solar system.

Measurements of radioactive isotopes in the galactic cosmic rays by ACE have shown that cosmic rays must have

been accelerated at least 100,000 years after they were synthesized in supernova explosions. Other isotope measurements show that cosmic rays typically spend about 15 million years in our Galaxy before leaking out, implying that they must be replenished continually. The relative abundances of the stable isotopes of Mg, Si, Ca, Fe, and Ni in cosmic rays are found to be very similar to those in solar system material, indicating that the effects of galactic evolution since the creation of the solar system are not large.

ACE was launched during solar minimum conditions and then observed the transition to solar maximum. During this period the number of solar flares and coronal mass ejections increased dramatically, including some of the largest solar particle events observed since the dawn of the space age. The new capabilities provided by the fleet of spacecraft now in space have combined to make this one of the most productive solar maximum periods in history in terms of providing new understanding of the Sun. Studies of solar wind, solar particles, and cosmic rays by ACE, in combination with other spacecraft such as Ulysses and Voyager, are providing new insight into the bubble of solar wind that envelops our solar system, and the nature of its interactions with the Galaxy.

ACE has become a key component of NASA's new "Living with a Star" Program, which seeks to understand how solar variations affect life and society, and to provide a scientific basis for improved forecasting of "space weather." From its position at L1 ACE is able to measure directly Earth's ever-changing solar wind and solar particle environment, including interplanetary disturbances that disrupt Earth's magnetic field and cause the aurora. The combination of ACE data from L1 and magnetospheric data from the Polar, Geotail, SAMPEX, and IMAGE spacecraft has made it possible to determine how the magnetosphere and upper atmosphere respond to solar variations.

TO THE WORLD AT LARGE:

In addition to the information base provided to the science community, ACE has many benefits for the rest of us.

In a partnership with the National Oceanic and Atmospheric Administration, the Real-Time Solar Wind (RTSW) system on ACE functions as a “space weather station”, allowing a half-hour or more advance warning of magnetic storms. With proper notification, the harmful effects of these storms can be minimized, since ACE provides information about solar wind plasma, the interplanetary magnetic field, and intermediate and high-energy particle information to NOAA for its predictions. ACE, SOHO, and GOES work together to provide space weather data on the internet that is used by space agencies around the world.

ACE is also involved in a public education partnership with the Cooperative Satellite Learning Project (CSLP). CSLP is a successful and award-winning partnership joining NASA, Honeywell Technology Solutions, Inc., and schools nationwide. It is designed to motivate students of all ages into science, engineering, math, and careers in the space industry through hands-on involvement in a NASA scientific satellite mission. Through CSLP, ACE has been adopted by the Old Bridge High School in Old Bridge, New Jersey. Students there are involved with, and learn from, the various stages of the ACE mission.

ACE was chosen as the first mission to follow NASA’s Renaissance approach. “Renaissance” stands for Reusable Network Architecture for Interoperable Space Science, Analysis, Navigation, and Control Environment. This approach involves re-engineering the process by which flight projects build space communications, data, and information systems. The goal is development and operations that are cost-effective with maximum flexibility. ACE made the best use of existing hardware designs and flight

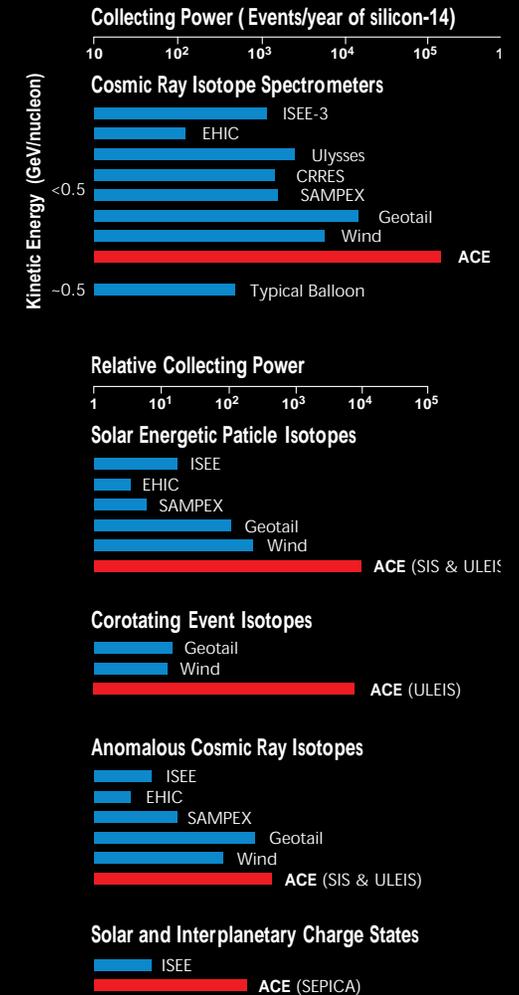
spares from other NASA missions. These instruments use flight-proven technologies, requiring less development and verification time and effort.

Scientists from Germany and Switzerland, in addition to California, Delaware, Illinois, Maryland, Missouri, New Hampshire, and New Mexico were involved in building ACE. The ACE team is currently working with scientists from around the world and the United States on a broad range of investigations. Such cooperation makes it possible to address questions with diverse approaches, data sets, and models, and leads to a freer flow of ideas and to more efficient and robust solutions to problems.



Full-scale model of ACE spacecraft built by Old Bridge High School in Old Bridge, NJ

ACE’s Collecting Power Compared

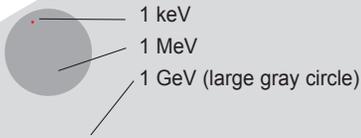


A comparison with ACE of the collecting power of previous spectrometers designed to measure the isotopic composition and charge states of solar and interplanetary particles. Note that the collecting power scale is logarithmic.

In addition to the charge state instruments shown above, the STOF sensor on SOHO measures charge states from ~0.02 to ~0.2 MeV/nucleon with a collecting power similar to that shown for ISEE.

THE SCIENCE

Energy comparison:



1																	0
1																	2
3	4											9	10				
11	12											17	18				
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
55	56	57	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
87	88	89	104	105	106	107	108	109	110								

¹ Lanthinide Series	58	59	60	61	62	63	64	65	66	67	68	69	70	Lu
[*] Actinide Series	90	91	92	93	94	95	96	97	98	99	100	101	102	Lr

Periodic Table of the Elements

BASIC COMPOSITION

The particles studied by ACE are **atoms** or pieces of atoms. Atoms are composed of three major building blocks: **protons** (with a positive charge), **neutrons** (with no charge), and **electrons** (with a negative charge). The **nucleus** of an atom contains the protons and neutrons, while the electrons orbit the nucleus. The number of protons determines to which **element** the atom belongs: hydrogen has one proton, carbon has six, etc.

The number of neutrons tells us which **isotope** of the element is present. The **isotope number** is the total of the number of protons plus the neutrons. Take carbon, for example, which is a very common element necessary for life, and is found in nature as diamonds and graphite. We find several different isotopes of carbon in nature. Carbon-12 has an equal number of protons and neutrons, six of each. Carbon-14 (see isotopes diagram on the left) contains two more neutrons (eight) than carbon-12, but still has only six protons. This makes carbon-14 an isotope of carbon, but it is different from carbon-12. While carbon-12 is a stable isotope, carbon-14 is unstable, or **radioactive**. It is much less common in nature, but is found where carbon-12 is found. Because of its radioactive nature, carbon-14 is used to date archaeological artifacts.

In an atom, the number of electrons that orbit the nucleus equals the number of protons in the nucleus, thus making an atom electrically neutral. When bombarded by ultraviolet (UV) radiation or after being struck by energetic particles, atoms can lose one or more of their electrons. The positively-charged remains of these atoms are called **ions**. The number of electrons lost determines the charge state of the particle. For example, **alpha particles** are helium nuclei with a double positive charge; they have two protons and two neutrons, but no electrons.

Together with their freed electrons, the ions form a **plasma**. Plasma is a fourth state of matter, not a liquid solid, or gas. Matter in the Sun is in a plasma state. Plasma is the most common state of matter in the universe. More than 99% of all matter is plasma, so what we

see on Earth is the exception. Since plasmas consist of electrically-charged particles, electric and magnetic forces affect a plasma.

When we measure the elemental, isotopic, and charge composition of ions, it helps us to understand how nature selected the particles and accelerated them to the energies at which we find them. The “composition” of the electrons is not interesting, since all electrons look the same. But the number, energy, and direction of travel are important.

ENERGETIC PARTICLES

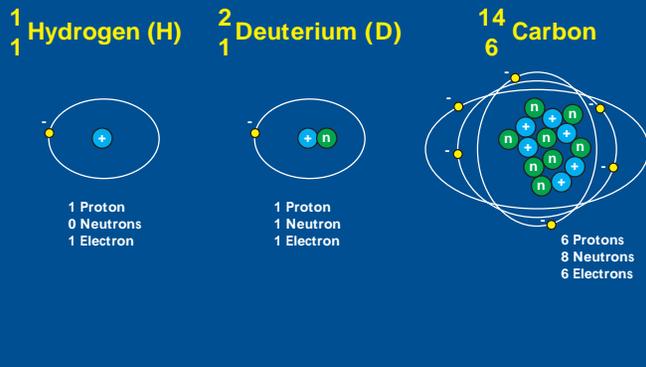
The particles that ACE investigates have a lot of kinetic energy (they are moving very fast). An electron volt (eV), is a unit of energy used to describe the total energy carried by a particle. (See the energy comparison in the upper left corner of this page.)

1 keV = 1 kilo-electron volt = 1,000 eV
— typical of dental X-rays

1 MeV = 1 mega-electron volt = 1 million eV
— typical of radioactive decay particles

1 GeV = 1 giga-electron volt = 1 billion eV
— the equivalent energy of a proton (hydrogen nucleus) at rest

The molecules in our atmosphere have kinetic energies around 0.03 eV. The Sun’s plasma and Earth’s **magnetosphere** (the area around Earth where its own magnetic field dominates) contain particles that are much more energetic. Protons in the magnetosphere range in energy from a few keV (magnetospheric plasma) to 1 GeV (inner Van Allen belt). And particles having still higher energies are quite common throughout the universe.



Hydrogen and carbon isotopes—deuterium is an isotope of hydrogen

THE SUN

One of ACE's primary goals is to learn more about particles from the Sun. It contains the vast majority of all matter in our solar system. The Sun is mostly hydrogen, with some helium and smaller amounts of other elements.

The visible surface of the Sun is called the **photosphere**. The Sun's atmosphere has two transparent layers. The **chromosphere** is just above the photosphere. The **corona** is the outer part of the Sun's atmosphere. In the outer region of the corona, particles travel away from the Sun and stretch far out into space. The chromosphere and corona can only be seen during solar eclipses, or with instruments that simulate a solar eclipse.

The SOHO (Solar and Heliospheric Observatory) spacecraft is also in position at the L1 point. One of its instruments, LASCO, is a visible-light coronagraph, a device that blocks the bright light from the Sun's surface, allowing the details in the corona to be clearly seen. In the LASCO image on the right, blobs of plasma are seen emitting from the Sun. The material in these blobs of thin ionized gas is an example of what ACE studies.

NUCLEOSYNTHESIS

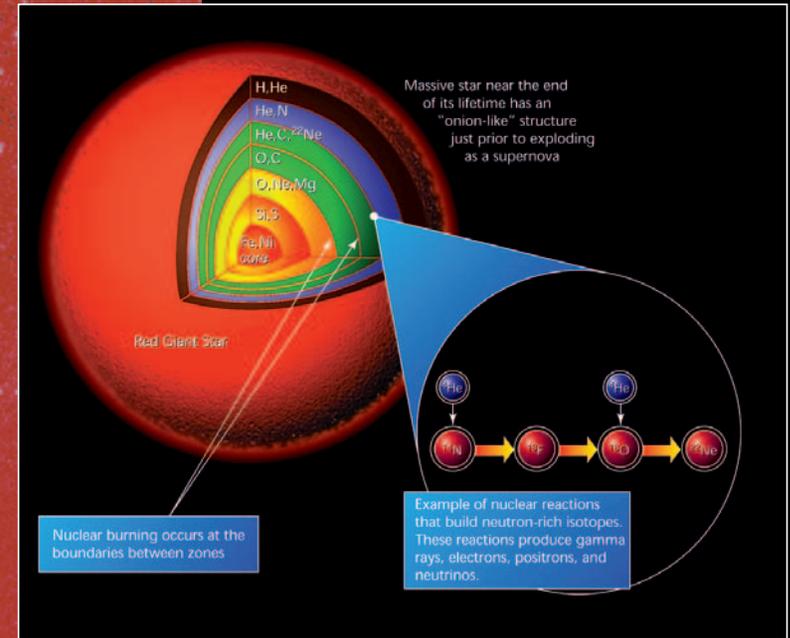
A star's energy comes from the combining of light elements into heavier elements in a process known as **fusion** or "nuclear burning". It is generally believed that most of the elements in the universe heavier than helium are created, or synthesized, in stars when lighter nuclei fuse to make heavier nuclei. This process is called **nucleosynthesis**.

Nucleosynthesis requires a high-speed collision, which can only be achieved with very high temperature. The minimum temperature required for the fusion of hydrogen is 5 million degrees. Elements with more protons in their nuclei require still higher temperatures. For instance, fusing carbon requires a temperature of about one billion degrees! Most of the heavy elements, from oxygen up through iron, are thought to be produced in stars that contain at least ten times as much matter as our Sun.

Our Sun is currently burning, or fusing, hydrogen to helium. This is the process that occurs during most of a star's lifetime. After the hydrogen in the star's core is exhausted, the star can burn helium, carbon and oxygen and so on, until iron and nickel are formed. Up to this point the process releases energy. The formation of elements heavier than iron and nickel requires the input of energy. **Supernova** explosions result when the cores of massive stars have exhausted their fuel supplies and burned everything into iron and nickel. The nuclei with mass heavier than nickel are thought to be formed during these explosions.

ACCELERATION

The acceleration of charged particles to extremely high energies takes place almost everywhere in the universe, very far away from us and at our front door. Particles are accelerated on the Sun, in interplanetary space, at the edge of the solar system, at the blast waves of supernova remnants, in neutron stars, and probably in black hole systems. The last two are remains from the collapse of large stars, either to the density of atomic nuclei (**neutron star**), or even further to a point such that even light cannot escape (**black hole**). Sampling a wide range of accelerated particles from local and distant sources with the ACE instruments and comparing their features provides crucial information for understanding the sources, acceleration, and transport of these high-energy particles.



Cosmic rays include nucleosynthetic products from other regions of our Galaxy.

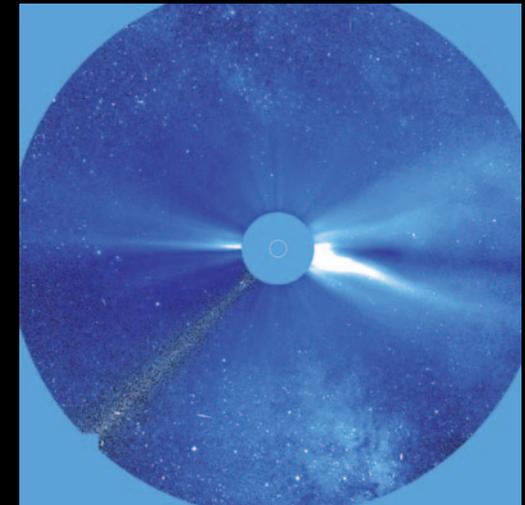


Image of a solar wind stream as recorded by the outer LASCO coronagraph (C3) on 24 December 1996 at 02:50 UT

SEPICA

The Solar Energetic Particle Ionic Charge Analyzer (SEPICA) determines the ionic charge state, elemental composition, and energy spectra of energetic solar ions. This is vital information in studying the material accelerated in solar events. It also allows us to learn more about element and isotope selection processes and particle acceleration on the Sun. During solar quiet times, SEPICA directly measures the charge of ACR ions (described later), including nitrogen, oxygen, and neon. It covers a range from 0.5 MeV/charge to about 5 MeV/charge for charge state composition, and up to 10 MeV/nucleon for element analysis (a **nucleon** is a particle from the nucleus, either a proton or a neutron).

SEPICA contains three multi-slit collimators that select the arrival direction of ions so that they are focused to a line in the detector. The detector system holds an electrostatic analyzer and gas-proportional counters that measure the point of impact and energy loss of the particle through a gas. The remaining energy is measured in solid-state detectors behind the proportional counter. The combination of energy loss and remaining energy allows the identification of different elements in the incoming particles. SEPICA achieves improvements of a factor of 3 in charge resolution and of a factor of 20 in collecting power over previous instruments. SEPICA is a new instrument developed by the University of New Hampshire and the Max Planck Institute for Extraterrestrial Physics, Germany.



SOLAR ACTIVITY

The output of the Sun in all forms - light, solar wind, and energetic particles - is not constant. It varies with both time and position on the Sun. These changes are called **solar activity** and are reflections of changes below the Sun's surface. Scientists can study the output and how it varies to probe the workings of the Sun.

The electric currents in the Sun, as well as in planets and galaxies, generate magnetic fields. **Magnetic field lines** describe the structure of magnetic fields in three dimensions. A compass needle will always try to point along a field line. Lines close together represent strong magnetic forces and weak forces are represented as lines further apart.

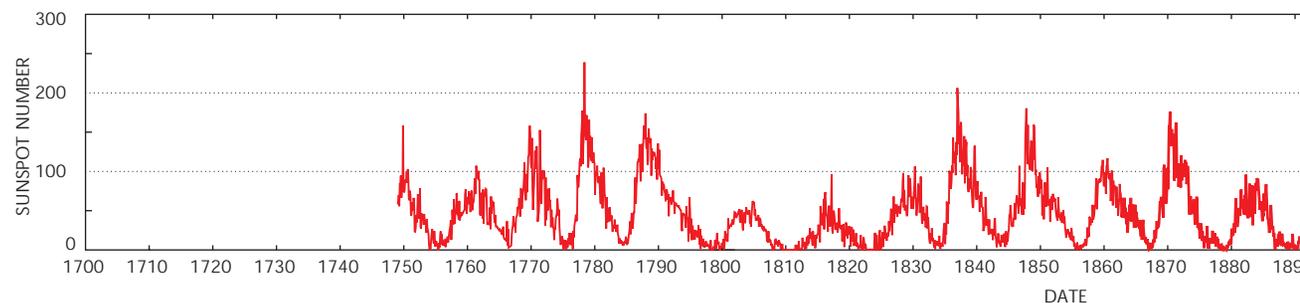
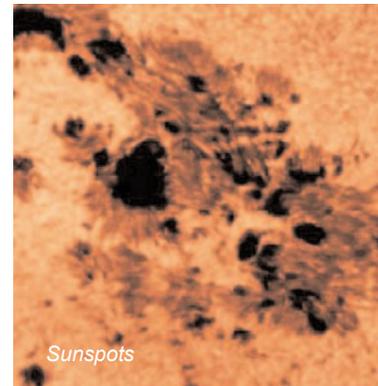
Sunspots, temporary disturbances in the photosphere, are the most visible advertisement of the solar magnetic field. They appear dark because temperatures are considerably lower than in surrounding areas. Sunspots occur where the magnetic field lines emerge from the inside of the Sun to form expanding loops above its surface.

A **solar flare** is an enormous explosion in the solar atmosphere. It results in sudden bursts of particle acceleration, heating of plasma to tens of millions of degrees, and the eruption of large amounts of solar mass. Flares are believed to result from the

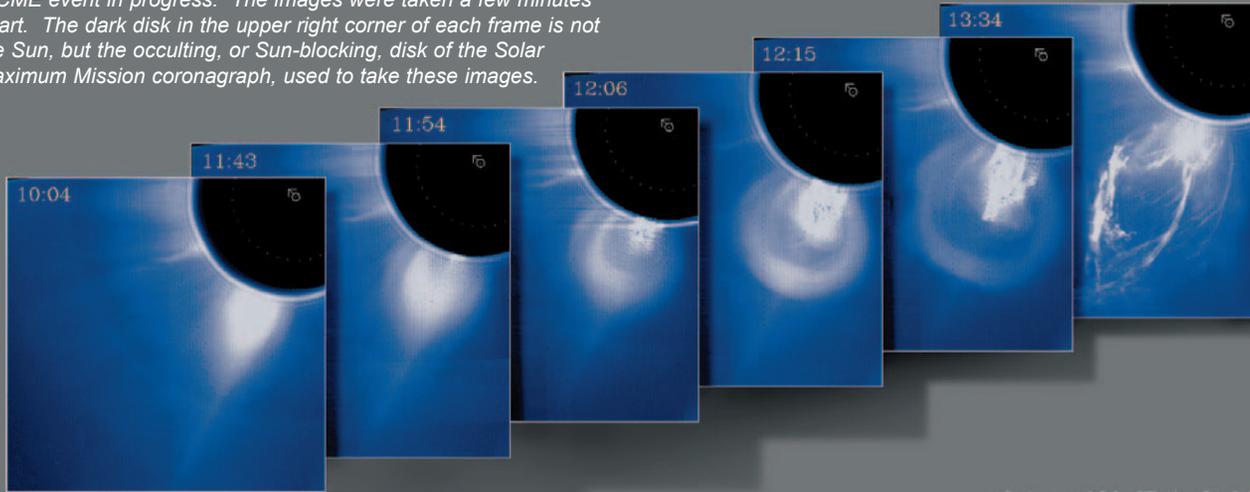
abrupt release of the energy stored in magnetic fields in the zone around sunspots.

This acceleration of solar flare particles to extremely high energies involves all the different elements in the solar atmosphere. Ions of elements such as carbon, nitrogen, oxygen, neon, magnesium, silicon, and iron, excited in this way are called **solar energetic particles (SEPs)**. In order to understand the acceleration processes involved and to measure the composition of the Sun, ACE instruments study the quantity and type of these particles.

Another form of solar activity is the eruption of huge amounts of mass from the Sun, which may or may not be associated with solar flares. These **coronal mass ejections (CMEs)** are balloon-shaped bursts of solar wind rising above the solar corona, expanding as they climb. Solar plasma is heated to tens of millions of degrees, and electrons, protons, and heavy nuclei are accelerated to near the speed of light. The superheated electrons from CMEs move along the magnetic field lines faster than the solar wind can flow. A shock wave may form ahead of the CME loop, and SEPs are accelerated at these shock waves, too. Each CME releases up to 100 billion kg (about 100 million tons) of this material, and the speed of the ejection can reach 1000 km/second (2 million mph) in some cases. Solar



A CME event in progress. The images were taken a few minutes apart. The dark disk in the upper right corner of each frame is not the Sun, but the occulting, or Sun-blocking, disk of the Solar Maximum Mission coronagraph, used to take these images.



Source: High Altitude Observatory/Solar Maximum Mission Archives

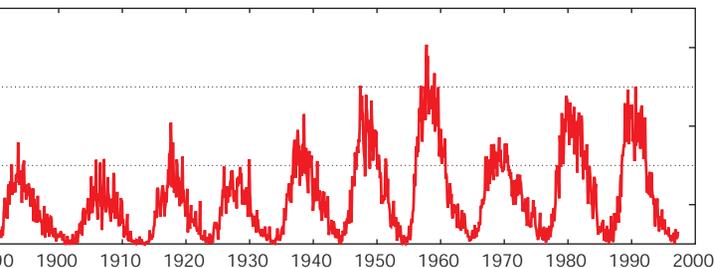
18 Aug 1980: White Light
HAO A-013

flares and CMEs are currently the biggest “explosions” in our solar system, occasionally approaching the power in ONE BILLION hydrogen bombs!

Solar plumes are long, feathery jets that extend from near the poles of the Sun to more than 13 million miles into space. They may be the origin of high-speed solar wind. Solar plumes expel a high-speed stream of plasma from the corona that can reach several million degrees! The base of the plume contains churning magnetic fields and solar gases. At its base, a plume is about 2500 km (1600 miles) wide.

These various solar events can interact and interfere with each other, creating a very complex system. Their frequency varies with time. The smaller flares tend to follow the eleven-year solar activity cycle and peak at several tens of flares per day. The largest solar events usually

occur only a few times during solar maximum, the period of maximum solar activity during the eleven-year cycle. Sunspots increase with **solar maximum**, and are relatively rare during solar quiet times. During its first few years, ACE observed the transition from solar minimum to solar maximum, including some of the largest solar events ever observed.



Monthly averages of the sunspot numbers show that the number of sunspots visible on the Sun waxes (during solar maximum) and wanes (solar minimum) with an approximate 11-year cycle.

ULEIS

The Ultra Low Energy Isotope Spectrometer (ULEIS) measures element and isotope **fluxes** (rates of particle flow) over the range of hydrogen through nickel, from about 45 keV/nucleon to several MeV/nucleon. Studies of ultra-heavy particles, those heavier than iron, are also performed in a more limited energy range near 0.5 MeV/nucleon. ULEIS also allows the study of SEP composition and the way SEPs are energized in the solar corona.

The ULEIS instrument is a **time-of-flight** mass spectrometer. A time-of-flight system uses the difference in travel time through a chamber to separate ions of different masses. Along with the time-of-flight, the spectrometer simultaneously measures the energy of particles entering the telescope and stopping in one of the arrays of seven silicon solid-state detectors in the telescope. This instrument has a collecting power for SEP isotopes more than 10 times greater than any previous instrument. ULEIS provides more than a one thousand-fold improvement in detection for the study of CIR events, and it is a significant advance in the research of ACR isotopes (CIRs and ACRs are described later).

ULEIS is a new instrument built by the University of Maryland and JHU/APL.



ULEIS

SWIMS

The Solar Wind Ion Mass Spectrometer (SWIMS) is a versatile instrument that provides solar wind composition data for all solar wind conditions. It clearly determines, every few minutes, the quantities of most of the elements and a wide range of isotopes in the solar wind. The abundances of rare isotopes are determined every few hours, providing information crucial to the understanding of pickup ions and ACRs (described later). SWIMS is extending knowledge of solar wind composition to additional elements and isotopes.

The instrument consists of an electrostatic deflection system that selects a narrow range of energy or charge, followed by a time-of-flight High-Mass Resolution Spectrometer (HMRS). The HMRS determines the mass of a solar wind ion with high accuracy. The sensor measures speeds depending on particle mass, ranging from about 200 - 1500 km/s for helium, and from 200 - 500 km/s for iron.

SWIMS was built by the University of Maryland and the University of Bern, Switzerland. It is a copy of portions of the CELIAS experiment from the SOHO mission, adapted only slightly to optimize it for ACE.



SWIMS

Comet Hale-Bopp as seen from Shenandoah National Park, VA April 9, 1997

SOLAR WIND

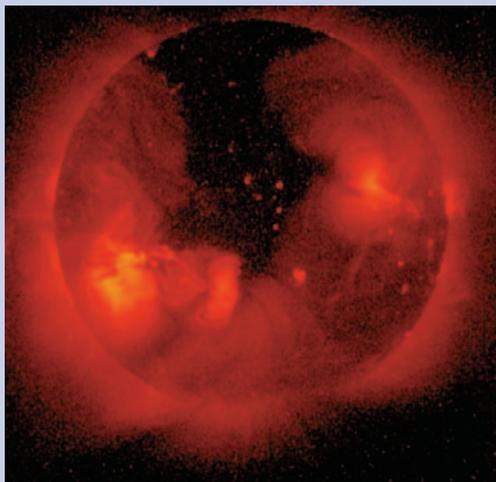
This image, taken March 7, 1996, by the Extreme-ultraviolet Imaging Telescope (EIT) on the Solar and Heliospheric Observatory (SOHO), shows an ultraviolet image of the "quiet" solar atmosphere close to the surface.

Solar wind is the plasma of charged particles (protons, electrons, and heavier ionized atoms) coming out of the Sun in all directions at very high speeds — an average of about 400 km/sec, almost a million mph! It is responsible for the anti-sunward tails of comets and the shape of the magnetic fields around the planets. Solar wind can also have a measurable effect on the flight paths of spacecraft.

The composition of the solar wind reflects the composition of the solar corona, modified by solar wind processes. The exact mechanism of solar wind formation is not known. Accurately measuring its composition, as ACE does, aids in separating the effects of these processes from the original makeup of the corona.

Coronal holes are large regions in the corona that are less dense and cooler than surrounding areas. The open structure of their magnetic field allows a constant flow of high-density plasma to stream out of the holes. Solar plumes can appear in coronal holes. There is an increase in the intensity of the solar wind effects on Earth when a coronal hole faces us. Coronal holes do not last as long during solar maximum. ACE was launched at solar minimum and continues its work through the solar maximum, following the evolution of these events.

The **heliosphere** is the immense magnetic bubble containing our solar system, solar wind, and the entire solar magnetic field. It extends well beyond the orbit of Pluto. While the density of particles in the heliosphere is very low (it's a much better vacuum than is created in a laboratory), it is full of particles of interest to ACE scientists. The **heliopause** is the name for the boundary between the heliosphere and the interstellar medium outside the solar system. As the solar wind approaches the heliopause, it slows suddenly, forming a shock wave. This **solar wind termination shock** is exceptionally good at accelerating particles.



This X-ray image shows the Sun as viewed by the Yohkoh satellite. A large coronal hole, extending from the northern into the southern hemisphere is near the Sun's center. The brightest region shows hot loops that remain after a solar flare.

In spite of its low density, the solar wind is strong enough to interact with the planets and their magnetic fields to shape magnetospheres. Because the ions in the solar plasma are charged, they interact with these magnetic fields, and solar wind particles are swept around planetary magnetospheres.

The shape of Earth's magnetosphere is the direct result of being blasted by solar wind. Solar wind compresses its sunward side to a distance of only 6 to 10 times the radius of the Earth. A supersonic shock wave is created sunward of Earth, somewhat like a sonic boom. This shock wave is called the **bow shock** and is normally located at about 15 Earth radii out. Most of the solar wind particles are heated and slowed at the bow shock and detour around Earth. Solar wind drags out the night-side magnetosphere to possibly 1000 times Earth's radius; its exact length is not known. This extension of the magnetosphere is known as the **magnetotail**. Many other planets in our solar system have magnetospheres of similar, solar wind-influenced shapes.

SWEPAM

The Solar Wind Electron, Proton, and Alpha Monitor (SWEPAM) measures the solar wind plasma electron and ion fluxes as functions of direction and energy. These data provide detailed knowledge of the solar wind conditions every minute. SWEPAM also provides real-time solar wind observations that are continuously sent to the ground for space weather purposes.

Electron and ion measurements are made with separate sensors. The ion sensor measures particle energies between about 0.26 and 36 KeV, and the electron sensor's energy range is between 1 and 1350 eV. Both sensors use electrostatic analyzers with fan-shaped fields-of-view. The electrostatic analyzers measure the energy per charge of each particle by bending its flight path through the system. The fields-of-view are swept across all solar wind directions by the rotation of the spacecraft.

SWEPAM was built by the Los Alamos National Laboratory in New Mexico. It was built from the spare solar wind electron and ion analyzers from the Ulysses mission, with selective modifications and improvements.



SWEPAM
(Electron sensor)

EPAM

Knowledge of the fluxes and energy of high-energy protons, alpha particles, and electrons is essential in understanding the dynamic behavior of solar flare, CIR, and interplanetary shock particle (CIR and ISP are described later) events. These measurements are made by EPAM: the Electron, Proton, and Alpha Monitor. This instrument provides information that can reflect changes in both coronal and interplanetary magnetic fields, and information on solar flares. EPAM covers the range of energies from 30 keV/nucleon up to 4 MeV/nucleon. It measures the composition of elements up through iron.

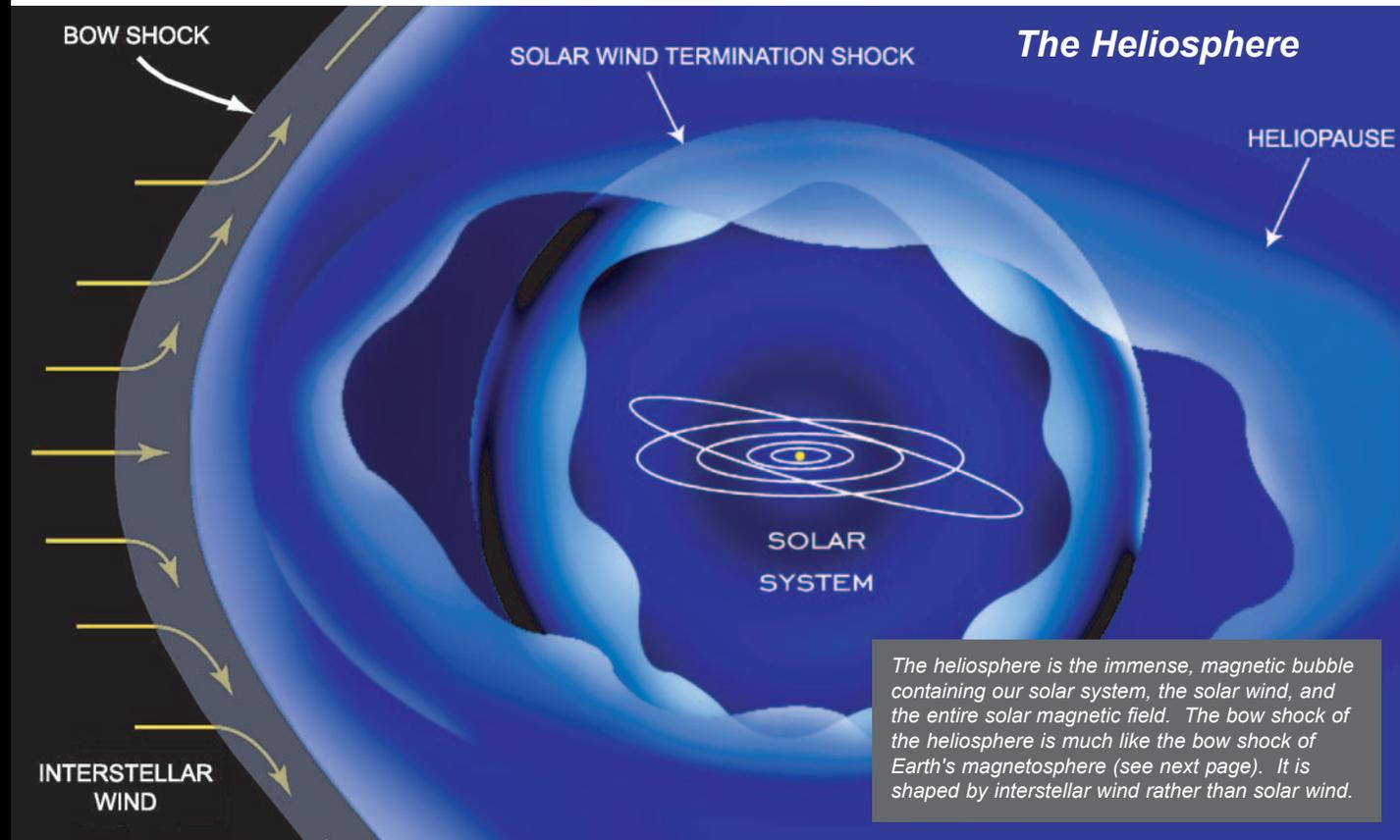
EPAM includes five telescopes of three different types. Two Low Energy Foil Spectrometers (LEFS) measure the flux and direction of electrons above 30 keV. Two Low Energy Magnetic Spectrometers (LEMS) measure the flux and direction of ions greater than 30 keV. And the Composition Aperture (CA) measures the composition of the ions. Solid-state detectors on each telescope analyze the energy of the incoming particles. These telescopes use the spin of the spacecraft to sweep the full sky.

The EPAM instrument was built by JHU/APL with Dr. L.J. Lanzerotti of Lucent Technologies as Principal Investigator. It is the flight spare of the HI-SCALE instrument from the Ulysses spacecraft.



EPAM

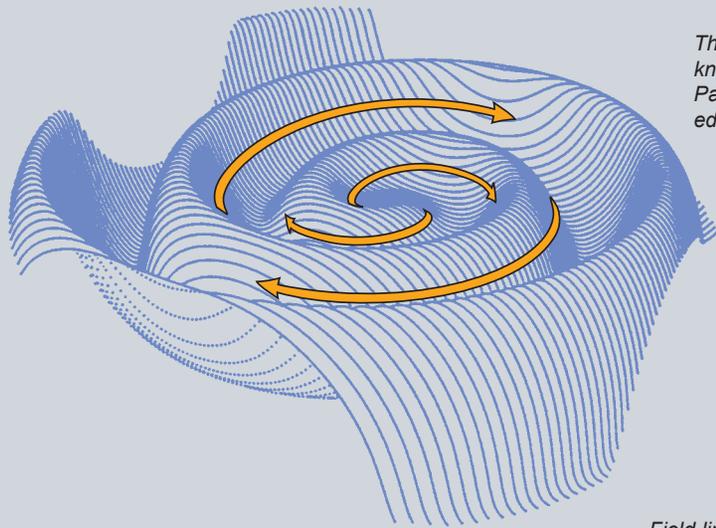
THE HELIOSPHERE



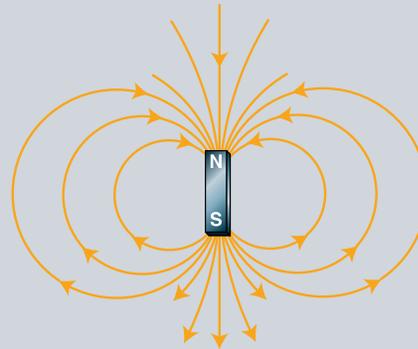
The electric currents in the Sun generate a complex magnetic field which extends out into interplanetary space to form the interplanetary magnetic field. In space, charged particles tend to become attached to magnetic field lines, spiraling around them while sliding along them, like beads on a wire. Because of this attachment, the behavior of energetic particles in space is dictated by the structure of field lines. Magnetic field lines are frozen into plasmas and move as the plasmas move.

As the Sun's magnetic field is carried out through the solar system by the solar wind, the Sun is rotating. Its rotation winds up the magnetic field into a large rotating spiral, known as the **Parker spiral**, named after the scientist who first described it.

The magnetic field is primarily directed outward from the Sun in one of its hemispheres, and inward in the other. This causes opposite magnetic field directions in the Parker spiral. The thin layer between the different field directions is described as the **neutral current sheet**.



The neutral current sheet, sometimes known as the "ballerina skirt". The Parker spiral magnetic field is indicated by the arrows.



Field lines show the magnetic field around a bar magnet.

Since this dividing line between the outward and inward field directions is not exactly on the solar equator, the rotation of the Sun causes the current sheet to become "wavy", and this waviness is carried out into interplanetary space by the solar wind.

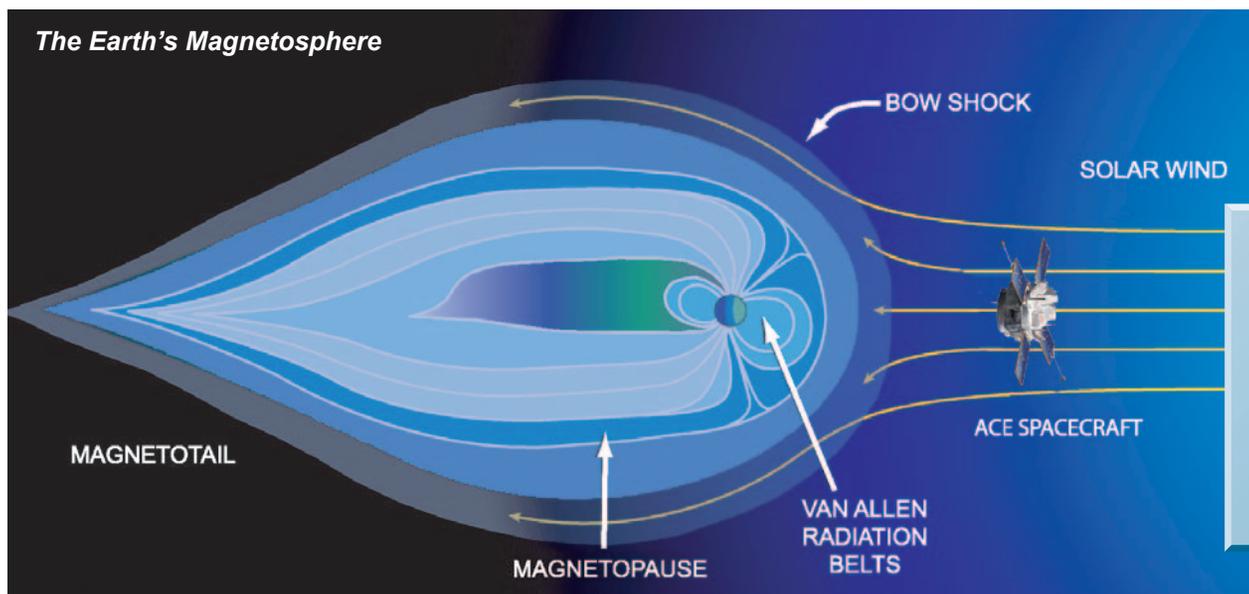
In addition, every eleven years the entire magnetic field of the Sun "flips"- the north magnetic pole of the Sun becomes the south, and vice versa. The flip takes place at solar maximum. The last maximum was in 2001.

MAG

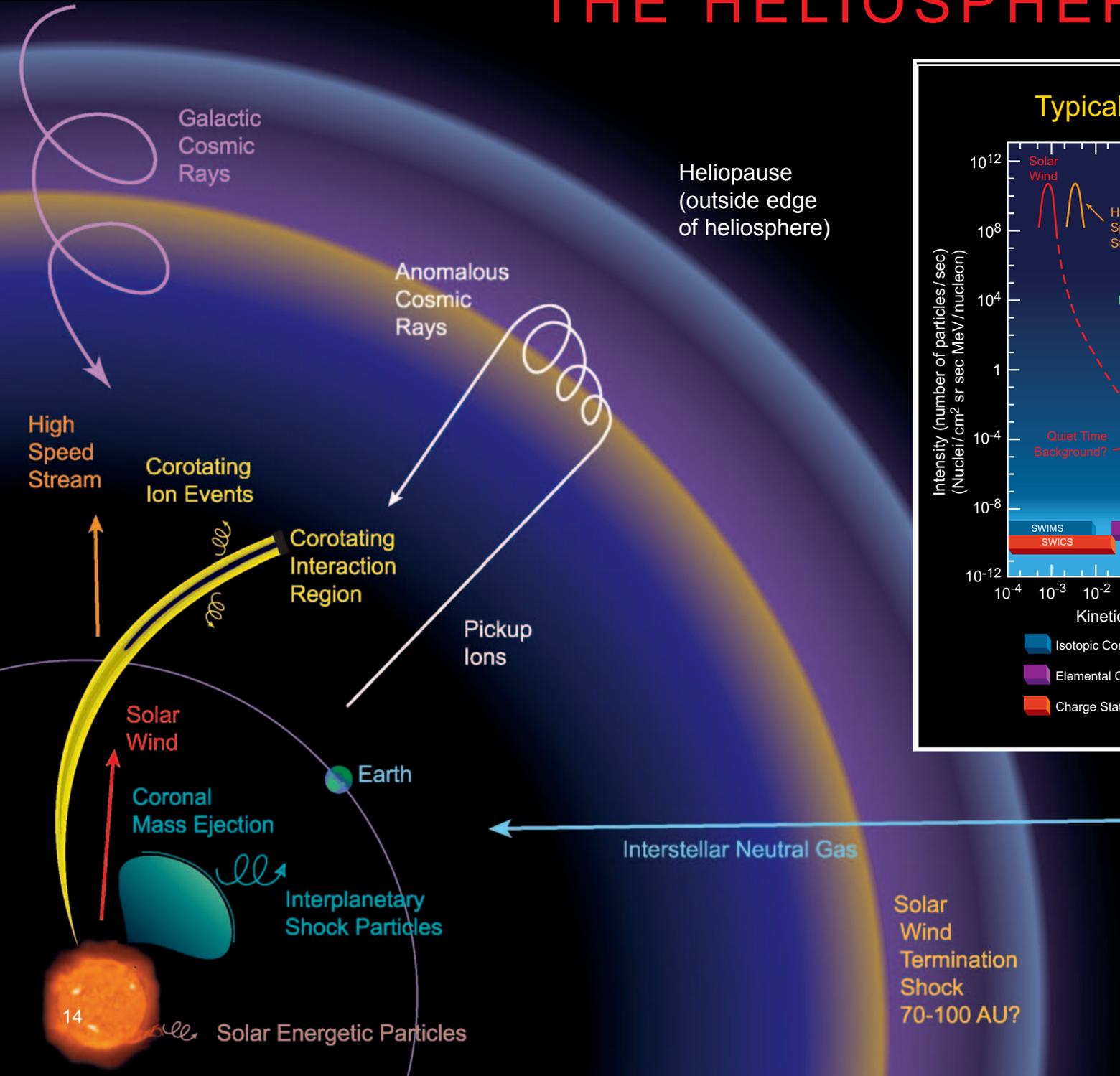
Precise examination of the interplanetary and solar magnetic fields and their dynamics provides essential supporting information for the other ACE instruments. The two magnetometers (MAG) on ACE detect and measure the magnetic fields in the vicinity of the spacecraft. As the magnetometers sweep through a field when the spacecraft rotates, electrical signals are produced which are proportional to the strength and direction of the field.

MAG consists of two wide-range triaxial magnetometers. Triaxial means that all three axes (x, y, and z) of the magnetic field are measured. This allows for the determination of its exact direction. The magnetometers are mounted out from the spacecraft on separate long booms to reduce the effects of any magnetic fields from the spacecraft and instruments. MAG measures the strength and direction of the interplanetary magnetic field 30 times per second and can calculate any pattern of variations in it.

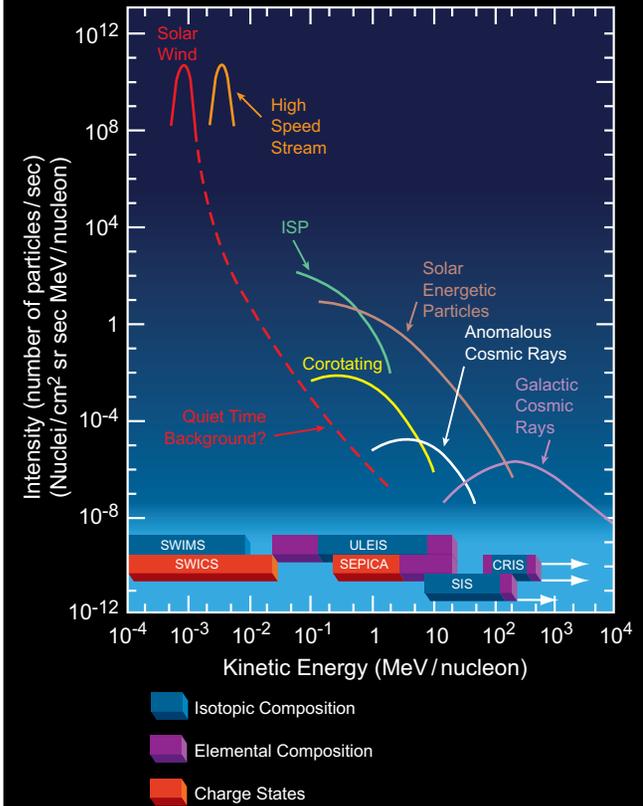
The scientific institutions involved in building MAG were the Bartol Research Institute in Newark, Delaware and GSFC. It is a flight spare from the Wind mission.



THE HELIOSPHERE-PART 2



Typical Energy Spectra



SWICS

The Solar Wind Ion Composition Spectrometer (SWICS) determines not only the charge of ions, but also the temperature and speeds of all the major solar wind ions. SWICS covers solar wind speeds ranging from 145 km/s (protons) to 1532 km/s (iron). The information recovered tells scientists about the nature of not only the solar wind, but also of solar flares, ISPs, CIRs, and pickup ions (described later).

SWICS combines an electrostatic analyzer with post-acceleration, followed by a time-of-flight and energy measurement. Post-acceleration means that after the electrostatic analyzer, the particle is re-accelerated to determine its mass.

SWICS was built by the University of Maryland and the University of Bern, Switzerland. The instrument is the same as one fully developed, designed, and tested during the Ulysses mission. A flight spare from that mission was used for ACE.

The solar wind near our Sun's surface contains alternating streams of high and low speed. The sources of these streams **corotate** with the Sun; that is, they rotate along with it. The high-speed streams originate in coronal holes and extend toward the solar poles; the low-speed streams typically come from near the equator. ACE sees mostly the low-speed solar wind due to its location, but can observe the compositional differences between the high- and low-speed wind when coronal holes extend down near the equator. One objective of ACE is to understand how the high- and low-speed winds are accelerated.

With increasing distance from the Sun, the high-speed streams overtake the slower plasma, producing **corotating interaction regions (CIRs)** on their leading edges. CIRs are bounded by two shocks at the front and rear edges, called the **forward** and **reverse shocks**. At these

shocks, the density, pressure, and magnetic field strength are all higher. These regions are quite effective as energetic particle accelerators. When ions that have been accelerated at a CIR are observed, they are called **corotating ion events**.

Interplanetary shock particles (ISPs), accelerated by shocks associated with solar flares and CMEs, are another example of interplanetary acceleration. ACE is able to directly compare the composition of ISPs with that of the solar wind to test shock acceleration theories.

ACE is studying the many different types of speeding (energetic) particles in the solar system. These include:

- the solar wind, high-speed streams (high-speed solar wind), coronal mass ejections (CMEs), and solar energetic particles (SEPs) coming from the Sun,
- interplanetary shock particles (ISPs) and corotating ion events (CIRs) from interplanetary space,
- anomalous cosmic rays (ACRs) from the edge of the solar system (the solar wind termination shock),
- interstellar neutral gas, and the pickup ions which originate in the gas right outside the solar system (the very local interstellar medium),
- and galactic cosmic rays (GCRs) from the far reaches of the Galaxy.

These energetic particles are described in this brochure.

The smaller figure (opposite page) is an illustration of the number of particles observed (for a standard area and energy interval) versus energy, for the many different energetic particles observed by ACE. Most of these particle types actually vary with time by large factors. As a result, these "spectra" are not really accurate for any particular element; the figure is just an example.

In the larger figure (opposite page), the color used for each type of particle or event matches the color of its corresponding energy population, shown in the graph in the smaller figure.



The Solar Isotope Spectrometer (SIS) measures the elemental and isotopic composition of nuclei from helium to zinc in the energy range from about 10 to 100 MeV/nucleon. During solar active periods the flux of solar energetic particles can suddenly increase by a factor of 10,000 or more, providing an opportunity for SIS to measure the composition of solar material. The SIS detector system consists of two identical particle telescopes. Each telescope has a pair of silicon-strip detectors to sense the **trajectory** (path) of incident nuclei, followed by a stack of large-area silicon solid-state detectors that measure the energy lost by nuclei as they slow and stop. By combining these measurements it is possible to compute the nuclear charge, mass, and kinetic energy of each incident particle.

An innovative feature in SIS is the use of custom low-power VLSI (very large-scale integration) circuitry to measure signals from the 512 strips of the trajectory system. This circuitry, which uses only about 1/10 the power of previous instrumentation, enables measurements of both position and energy loss for multiple particles that may arrive within a few microseconds of each other during large solar particle events. The collecting power of SIS is about 100 times greater than that of previous solar particle isotope spectrometers.

SIS is a new instrument developed by Caltech, GSFC, and NASA's Jet Propulsion Laboratory at Caltech (JPL).



SIS

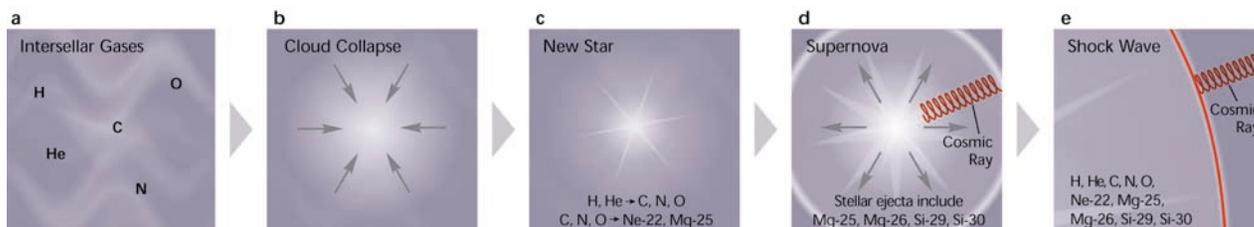
LOCAL INTERSTELLAR MEDIUM

The relative numbers of different isotopes found in the Galaxy are established by the life cycle of massive stars. Star formation, evolution, and explosion results in the creation of many of the heavier isotopes ACE finds in space. The process is illustrated by the figures below.

In a part of the Galaxy where the composition of the interstellar gas is much like that of our own solar system (a), a cloud of gas collapses under the influence of its own

gravity, and creates a new star (b). Inside the star (c), fusion converts some of the original hydrogen and helium into particles like carbon-12 and oxygen-16. At the same time, the carbon, nitrogen, and oxygen nuclei that were originally present in the stellar fuel are converted into heavier, neutron-rich nuclei, like neon-22 and magnesium-25.

When this quiescent burning has exhausted all of the nuclear fuel in the core of the star, the star explodes as a supernova (d). The shock wave generated by the explosion synthesizes additional heavy nuclei and ejects most of the products of nucleosynthesis back into the interstellar gas. Repetition of these events in each generation of stars steadily enriches the interstellar gas in carbon, nitrogen, and oxygen, and in heavy nuclei with an excess of neutrons. Some of the nuclei in the gas are accelerated to cosmic ray speeds, possibly by the shock waves from supernovae (e). Cosmic ray acceleration



Nucleosynthesis in massive stars

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Photo-ionization occurs when an electron is knocked off by a solar UV photon, and charge exchange involves giving up an electron to an ionized solar wind atom. Once these particles are charged, the Sun's magnetic field picks them up and carries them outward to the solar wind termination shock. They are called **pickup ions** during this part of their trip. By measuring the distribution of these pickup ions, ACE determines the composition, flow and temperature of the neighboring interstellar gas.

The ions repeatedly collide with the termination shock, gaining energy in the process. This continues until they escape from the shock and diffuse toward the inner heliosphere. Those that are accelerated are then known as **anomalous cosmic rays (ACRs)**. **Cosmic rays** are the particles that bombard the Earth from anywhere beyond its atmosphere.

There may also be additional sources of particles, which ACE can shed light on, that are accelerated at the solar wind termination shock.

GALACTIC COSMIC RAYS

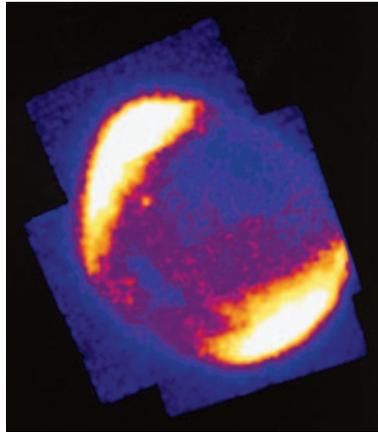
Galactic cosmic rays (GCRs) come from outside the solar system but generally from within our Galaxy. GCRs are atomic nuclei from which all of the surrounding electrons have been stripped away during their high-speed passage through the Galaxy. They have probably been accelerated within the last few million years, and have traveled many times across the Galaxy, trapped by the galactic magnetic field. As they travel through the very thin gas of interstellar space, some of the GCRs interact and emit gamma rays, which is how we know that they pass through the Milky Way and other galaxies.

GCRs have been accelerated to nearly the speed of light, probably by supernova remnants. But exactly which particles the supernova remnants accelerate is one of the questions that ACE is trying to answer.

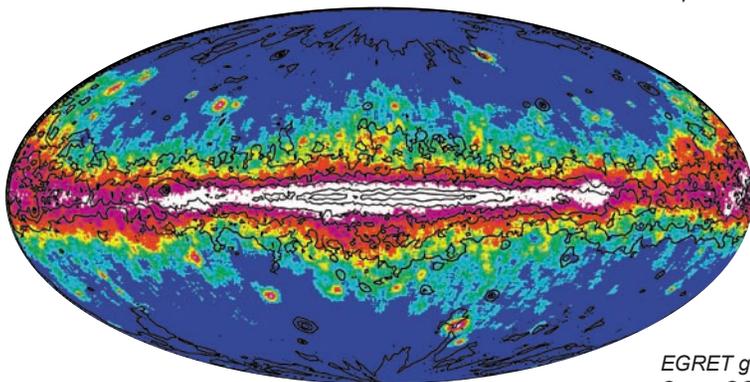
The *elemental* makeup of GCRs has been studied in detail by earlier experiments, and is very similar to the composition of the Earth and solar system. But previous studies of the composition of the *isotopes* in GCRs may

indicate that the seed population for GCRs is neither the interstellar gas nor the shards of giant stars that became supernovae. ACE is performing a detailed survey of the isotopic makeup of GCRs, which should shed light on this intriguing puzzle.

Included in the cosmic rays are a number of radioactive nuclei whose numbers decrease over time. As in the carbon-14 dating technique, measurements of these nuclei by ACE are being used to determine how long it has been since cosmic ray material was synthesized in the Galaxy before leaking out into the vast void between the galaxies. These nuclei are called "cosmic ray clocks".



This false color composite picture of the bright supernova remnant SN1006 (above) was taken by the ASCA satellite. The expanding gas from the star collides into the surrounding material. The collision generates a violent shock, which produces X-ray light. The bright regions in the picture show the locations of this shock along the rim of the remnant. The energy spectrum produced in SN1006 provides the first clear link between particle acceleration at supernova shock fronts and high-energy cosmic rays.



EGRET gamma-ray all-sky survey - above 100 MeV. Some GCRs interact with the interstellar medium and produce gamma rays.

CRIS

The Cosmic Ray Isotope Spectrometer (CRIS) is measuring the abundances of galactic cosmic ray isotopes, with energies from ~100 to ~600 MeV/nucleon over the element range from helium to zinc, with a collecting power more than 50 times greater than previous instruments of its kind.

CRIS determines the nuclear charge, mass, and kinetic energy of incident cosmic rays that stop in one of four identical stacks of large-area silicon solid-state detectors. Particle trajectories are measured with scintillating optical fibers arranged in six layers above the four detector stacks. When a charged particle passes through one of the 7000 plastic fibers, it sparkles, and a portion of this light is piped to the ends of the fiber. This is where it is amplified and read by two CCD (charge-coupled device) cameras that record the pattern of "hits" in each fiber layer. An onboard microprocessor then uses these data to determine the position coordinates of the incident particles. A primary objective for CRIS is to measure the abundances of various radioactive isotopes, such as cobalt-57 and nickel-59, that can be used to measure the time elapsed between nucleosynthesis and acceleration in supernovae; and isotopes such as beryllium-10, aluminum-26, and chlorine-36 that measure how long cosmic rays are confined by galactic magnetic fields.

CRIS is a new instrument developed by Caltech, GSFC, JPL, and Washington University in St. Louis.



CRIS

SPACE WEATHER



Astronaut William McArthur appears suspended over the blue and white Earth during space walk activities near the Space Shuttle Discovery.

Solar activity produces many noticeable effects on and near the Earth, including the northern and southern lights. This photograph of the aurora australis (southern lights) is from Spacelab 3.





The Sun's activity causes large changes in the Sun's plasma and energetic particle populations, and these changes are responsible for the "space weather" that affects Earth. Space weather can impact the upper atmosphere and may influence long-term climate trends. The effects are related to CMEs, SEPs, and coronal holes, the source of high-speed streams. The largest storms occur when a fast CME hits Earth shortly after its shock arrives.

Geomagnetic storms (magnetic storms on Earth due to solar activity) produce the awe-inspiring *aurora borealis* and *aurora australis* — the northern and southern lights. However, they can also cause a variety of highly undesirable consequences. "Killer" electrons accelerated in the magnetosphere during geomagnetic storms can cause communications satellites to fail. Electrical current surges in power lines, interference in the broadcast of radio, television, and telephone signals, and problems with defense communications are all associated with magnetic storms. Odd behavior in air and marine navigation instruments has been observed, and a compass anywhere on Earth is certainly affected. These storms are known to alter the atmospheric ozone layer. Even increased pipeline corrosion has been attributed to them.

Major solar activity is a very serious concern in space flight. Communications may be disrupted. Large solar disturbances heat the upper atmosphere, causing it to expand and create increased drag on spacecraft in low orbits, shortening their orbital lifetime. Spacecraft could potentially tumble and burn up in the atmosphere. Intense SEP events contain very high levels of radiation, more than a million times the normal daily dose of a human on Earth. Radiation sickness can result when humans are outside the protective magnetosphere of the Earth, as in missions to the moon and to Mars.

High-energy solar protons can produce increased radiation in the atmosphere at altitudes where supersonic aircraft fly. This is especially true for flights over the north and south magnetic poles, areas unprotected by the Earth's

magnetic field, where the radiation has direct access to the atmosphere. To reduce the risk to aircraft crews and passengers, and reduce risk to the aircraft, routine forecasts and alerts are sent through the Federal Aviation Administration so that a flight in potential danger can consider what course of action to take to minimize radiation exposure. The National Oceanic and Atmospheric Administration (NOAA) forecasts high-speed solar wind and solar particle events from the Space Environment Center.

The continuous broadcast of solar wind, magnetic field, and SEP data from ACE allows very accurate forecasts of major activity up to one hour beforehand. In particular, ACE detects large CMEs and their associated shocks before they reach Earth, just like weather stations on Earth measure major storms as they move across the continent. This removes much of the guesswork from space weather forecasts and represents a major advance in NOAA's forecast ability, and furthers our understanding of the scientific processes involved.

NASA has recently embarked on a new "Living with a Star" program that has the goal of improving the scientific basis for space weather predictions. The role of ACE in this program is to measure the solar wind input into the magnetosphere, thereby covering one of the key links in the chain by which solar variations cause geomagnetic storms. It appears that ACE has enough fuel onboard to remain at L1 through the next solar maximum.

DATA ANALYSIS AND DELIVERY

The ACE Science Center at Caltech obtains the spacecraft telemetry from the ACE Flight Operations Team and GSFC. It then produces a data set that is more appropriate for science data processing. The Center makes interesting plots available to scientists around the world and takes advantage of emerging World Wide Web technology, making it possible for users to request specific information as needed.

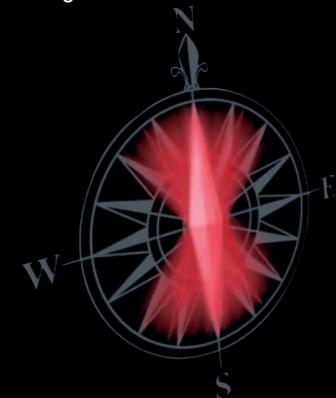
Real-Time Solar Wind (RTSW)

Geomagnetic storms are a natural hazard that NOAA forecasts for the benefit of the public, as it does hurricanes and ground tornadoes. The location of ACE enables it to provide about one-hour advance warning of impending major geomagnetic activity.

The ground system developed by NOAA receives the data broadcast by ACE in real-time (as it is happening). This system includes NOAA stations at Wallops Island, Virginia and Boulder, Colorado; dedicated stations at the Communications Research Laboratory in Japan and Rutherford Appleton Laboratory in England; with additional tracking by the US Air Force Satellite Control Network, India Space Research Organization in India, and NASA's Deep Space Network. A subset of data is sent from SWEPAM, EPAM, MAG, and SIS during the time that ACE is not transmitting its full telemetry.

For about 21 of 24 hours per day, ACE broadcasts the real-time solar wind data. The data is received by the ground stations around the world and sent directly to NOAA. During the three hours per day that NASA ground stations are receiving full ACE telemetry, NOAA receives a copy of the data. This gives them 24 hour per day forecasting. NOAA processes the data at its Space Environment Center in Boulder, CO, which issues alerts of any potential geomagnetic problems. Data is put on the Web within seconds, and many other groups around the world also use these data to make their own predictions.

The ACE RTSW data can be found at <http://sec.noaa.gov/ace/>



CONCLUSIONS

World Wide Web Access

ACE home page:
<http://www.srl.caltech.edu/ACE/>

ACE project page:
<http://helios.gsfc.nasa.gov/ace/ace.html>

ACE News:
http://www.srl.caltech.edu/ACE/ACENews_curr.html

ACE Real Time Solar Wind (RTSW):
<http://sec.noaa.gov/ace/>

NOAA Space Environment Center's
"Space Weather Now":
<http://www.sec.noaa.gov/SWN/>

NASA home page:
<http://www.nasa.gov/>

"Cosmic and Heliospheric Learning Center"
at NASA GSFC:
<http://helios.gsfc.nasa.gov/>

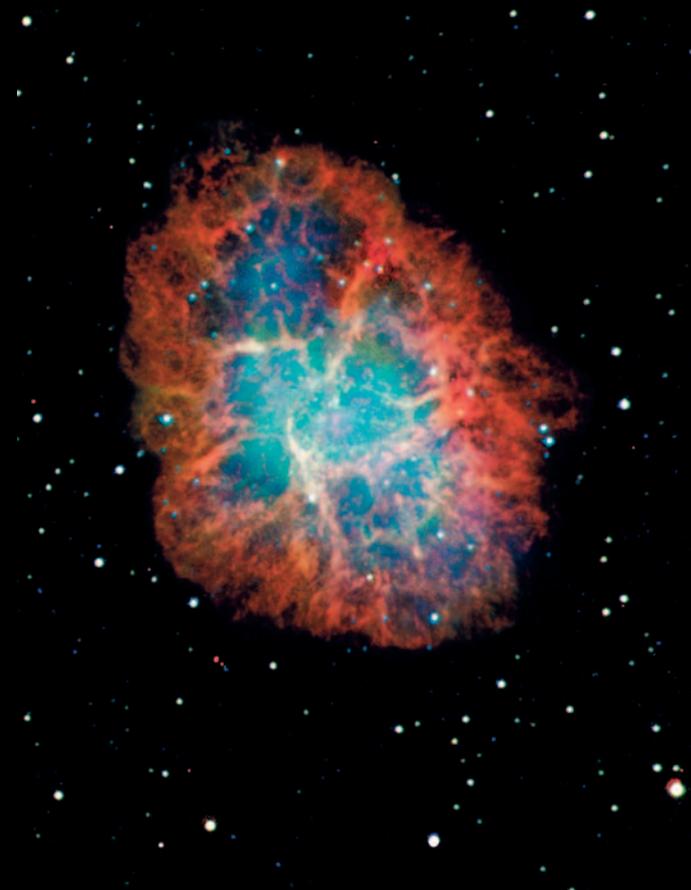
CSLP home page:
<http://cslp.gsfc.nasa.gov/>

Science has barely scratched the surface in examining the actual sources of the particles traveling through space around us. The mix of particles that ACE measures is the result of a complex history. The ability of ACE's nine instruments to measure a wide range of particle types and energies at the same time and location is what enables scientists to separate the many processes the matter has undergone on its way to ACE.

The prime purpose of ACE is to study the composition of several distinct sources of matter, the Sun and solar system, the local interstellar space, and the Galaxy as a whole. This, in turn, will lead us to a better understanding of the origin of the elements, and the subsequent evolutionary processing of matter (how it has changed since it was created). Along the way, ACE is learning more about particle acceleration and transport in the universe, information needed to separate the changes in composition during the particles' travel. Learning the differences in composition between the solar wind and the Sun helps answer questions about how the solar corona is formed and how solar wind is accelerated. All of these interesting problems are part of the larger question "Where did we come from?" ACE is providing several pieces of the enormous puzzle.

As new information becomes available, from both spacecraft and Earth-based instruments, the picture becomes clearer. Theories are upheld or upset, and new theories take their place. ACE provides an abundance of information to further our understanding of the way our solar system, Galaxy, and universe were created and how they continue to evolve.

This is a ground-based image of the entire Crab nebula, the remnants of a supernova explosion over 900 years ago. The green, yellow and red filaments toward the edges are the remains of the star that were ejected into space by the explosion. The blue glow in the inner part is light emitted by energetic electrons as they spiral through the Crab's magnetic field.



ACE Management Team

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— Senior Program Executive
Dr. W. Vernon Jones
— ACE Program Scientist

NASA Goddard Space Flight Center

Space Science Mission Operations Project

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— Project Manager
Mr. Robert Sodano
— Mission Director
Mr. Edward Nace
— Flight Control Services Manager
Mr. Craig Roberts
— Trajectory Analyst
Ms. Jacqueline Snell
— Lead Engineer, Flight Operations Team
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— ACE Project Scientist
Dr. Eric Christian
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Explorer Project Office

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— ACE Mission Manager

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Space Radiation Laboratory

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Dr. Richard Mewaldt
— ACE Mission Scientist
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— Pre-launch Payload Manager
ACE Science Center
Dr. Andrew Davis
— ACE Science Center Manager

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Dr. Robert Gold — JHU/APL
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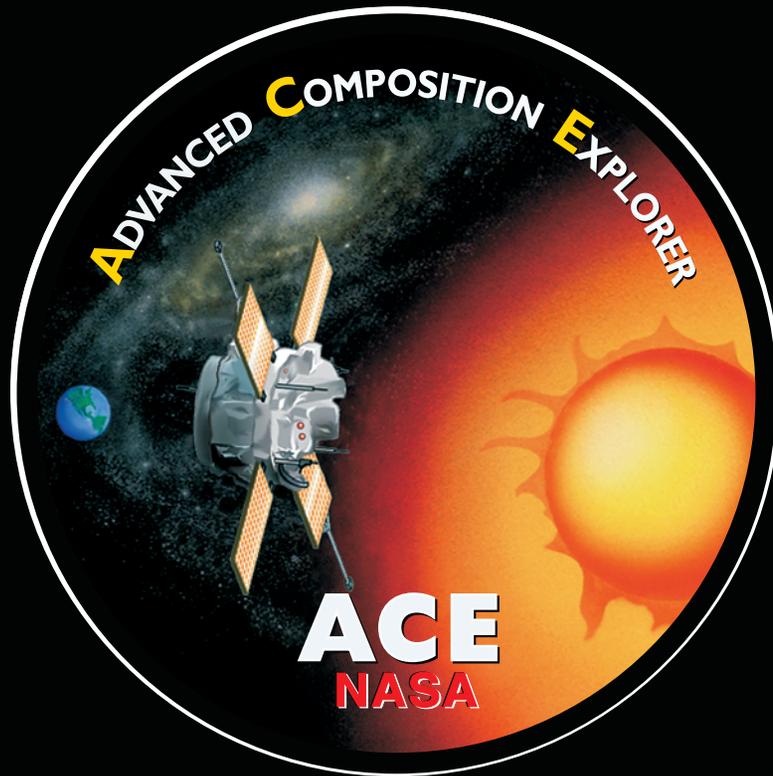
Acknowledgments

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Delta II rocket photograph
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- Yohkoh mission of ISAS, Japan -
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