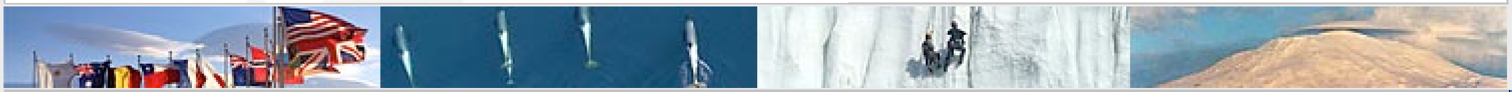
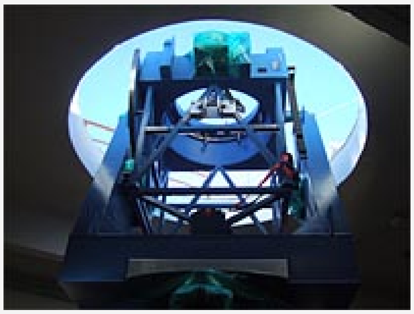
National Science Foundation

WHERE DISCOVERIES BEGIN



AERONOMY AND ASTROPHYSICS



The mount for the new Background Imaging Cosmic Extragalactic Polarizaiton (BICEP) telescope being installed at Amundsen-Scott South Pole Station. The BICEP telescope will measure the polarization of the cosmic microwave background (CMB) to unprecedented precision in search of answers to questions about the beginnings of the universe. (*NSF/USAP photo by Yuki Takahashi*)

In this section:

- Overview
- Background imaging of cosmic extragalactic polarization (BICEP).
- The operation of an extremely-low-frequency/very-low-frequency (ELF/VLF) radiometer at Arrival Heights, Antarctica.
- Conjugate studies of ultra-long-frequency (ULF) waves and magnetospheric dynamics using ground-based induction magnetometers at four high-latitude manned sites.
- A search for extrasolar planets from the South Pole.
- Dayside auroral imaging at South Pole.
- A very-low-frequency (VLF) beacon transmitter at South Pole.
- Austral high-latitude atmospheric dynamics.
- Studies of the polar ionosphere and magnetosphere from measurements in Antarctica and conjugate regions.
- Polar Experiment Network for Geospace Upper-Atmosphere Investigations: PENGUIn—A new vision for global studies.
- All-sky imager at South Pole.
- Solar and heliospheric studies with antarctic cosmic rays.
- RICE: Radio-Ice Cherenkov Experiment.
- Direction-finding measurements of low-frequency/medium-frequency/high-frequency (LF/MF/HF) auroral radio emissions at South Pole Station.
- The antarctic investigations of upper atmospheric disturbances over the South Pole Station.
- Measurements addressing quantitative ozone loss, polar stratospheric cloud nucleation, and large polar stratospheric particles during austral winter and spring.
- Measurement and analysis of extremely-low-frequency (ELF) waves at South Pole Station.
- Cosmic Ray Energetics and Mass (CREAM).
- Wallops Flight Facility Component of the Cosmic Ray Energetics and Mass (CREAM) Balloon Payload.
- Advanced Thin Ionization Calorimeter (ATIC) Long-Duration Balloon Flight.
- Long-Duration Balloon Program.
- Infrared measurements of atmospheric composition over Antarctica.
- Dynamics of the antarctic mesosphere–lower-thermosphere (MLT) region using ground-based radar and TIMED instrumentation.
- Extremely-low-frequency/very-low-frequency (ELF/VLF) observations of lightning discharges, whistler-mode waves, and electron precipitation at Palmer Station, Antarctica.
- IceCube.
- Extending the South American Meridional B-field Array (SAMBA) to auroral latitudes in Antarctica.
- Strateole-Vorcore.
- Development of an autonomous real-time remote observatory (ARRO).
- Next-generation cosmic microwave background polarization measurements with the QUEST experiment on the degree angular scale interferometer (DASI).
- Continued operation of the Antarctic Submillimeter Telescope and Remote Observatory (AST/RO).
- Wide-field imaging spectroscopy in the submillimeter: Deploying SPIFI on the Antarctic Submillimeter Telescope and Remote Observatory (AST/RO).
- High-resolution observations of the cosmic microwave background (CMB) with the Arcminute Cosmology Bolometer Array Receiver (ACBAR).
- South Pole observations to test cosmological models.
- Measurements of the surface layer turbulence at Dome C.

Overview

The polar regions have been called Earth's window to outer space. Originally, this term applied to dynamic events like the aurora, staged as incoming solar plasmas encountered the Earth's geomagnetic fields. Unique properties create a virtual screen of the polar upper atmosphere on which the results of such interactions can be viewed (and through which evidence of other processes can pass). During the mid-1980s, Earth's window was extended to refer to the "ozone hole" in the polar atmosphere. As scientists have verified an annual loss of ozone in the polar stratosphere, a window previously thought closed (stratified ozone blocking the Sun's ultraviolet rays) is now known to "open," consequent to chemical cycles in the atmosphere.

For astronomers and astrophysicists, the South Pole presents unique opportunities. Thanks to a minimum of environmental pollution and anthropogenic noise, the unique pattern of light and darkness, and the properties of the geomagnetic force field, scientists staging their instruments here can probe the structure of the Sun and the Universe with unprecedented precision. Studies supported by the Antarctic Aeronomy and Astrophysics Program explore three areas of research:

- **The stratosphere and the mesosphere:** In these lower regions, current research focuses on stratospheric chemistry and aerosols, particularly those implicated in the ozone cycle.
- **The thermosphere, the ionosphere, and the magnetosphere:** These higher regions derive many characteristics from the interplay between energetically charged particles (ionized plasmas in particular) and geomagnetic/geoelectric fields. The upper atmosphere, particularly the ionosphere, is the ultimate sink of solar wind energy transported into the magnetosphere just above it. This region is energetically dynamic, with resonant wave-particle interactions and joule heating from currents driven by electric fields.
- **The galaxy and the Universe beyond, for astronomical and astrophysical studies:** Many scientific questions, including a particular interest in the Sun and cosmic rays, extend beyond the magnetosphere. Astrophysical studies are conducted primarily at Amundsen–Scott South Pole Station or on long-duration balloon flights launched from McMurdo Station. The capability of such balloons is expanding dramatically.

All research projects sponsored by this program benefit from (indeed, most require) the unique physical conditions found only in the high latitudes, yet their ramifications extend far beyond Antarctica. High-latitude astrophysical research contributes to the understanding of Antarctica's role in global environmental change, promotes the interdisciplinary study of geosphere/biosphere interactions in the middle and upper atmosphere, and improves the understanding of the critical processes of solar energy in these regions.

An example of the unique conditions that can be exploited for science is the IceCube Neutrino Observatory (under construction). This observatory relies on photo detectors buried up to 2.5 kilometers deep in the ice sheet at South Pole Station to detect high-energy neutrinos that can be used to image portions of the Universe normally obscured to light and ordinary electromagnetic radiation. Another example is the Center for Astrophysical Research in Antarctica (CARA), which was active at South Pole in the 1990s and phased out in 2001. However, the center's outstanding research activity led to the development of the 10-meter South Pole Radio Telescope, which will study cosmic microwave background radiation—the residual energy from the Big Bang—with unprecedented accuracy.

The 20th-century expansion of traditional astronomy to the science of astrophysics, coupled with the emerging discipline of atmospheric science (see also the Antarctic Ocean and Climate Systems Program), is nowhere better exemplified than in Antarctica.

Background imaging of cosmic extragalactic polarization (BICEP).

Andrew E. Lange and James J. Bock, California Institute of Technology; William L. Holzapfel, University of California–Berkeley; and Brian G. Keating, University of California–San Diego.

The cosmic microwave background (CMB) provides three strong but circumstantial pieces of evidence that the visible Universe was created by the superluminal inflation of a tiny volume of space: namely,

- the near isotropy (homogeneity) of the horizon,
- the flatness of space, and
- the phase-synchronicity of acoustic oscillations in the early Universe.

To better understand the origins of the Universe, we must probe this epoch of inflation directly. The most promising probe is the unique signature that the gravity wave background (GWB) imprints on the polarization of the CMB. The amplitude of this signature depends on the energy-scale of inflation.

Detection will require only modest angular resolution (about 1 degree), but long integration (about a year) on a restricted and contiguous patch of sky. The 6-month night, the extremely dry and stable weather, and the precise rotation of the sky about the zenith make South Pole Station the ideal terrestrial site for this ambitious project. A CMB polarimeter (BICEP) uniquely capable of detecting the signature of the GWB was deployed and commissioned during 2004–2005. After BICEP was unpacked and prepared for initial cooldown, the optical loading, bandpass, and noise characteristics of the detector array and modulation systems were tested under realistic conditions. The next steps will be erecting the groundshield, refining the pointing model of the mount, and mapping the beams of the 96 detectors before testing on galactic sources and dark fields begins.

BICEP operates simultaneously at 100 and 150 gigahertz (GHz) to both minimize and recognize confusion from polarized astrophysical foregrounds. At these frequencies, a modest (and thus relatively easy to deploy and maintain) 20-centimeter primary aperture will provide a resolution of 1 degree at 100 GHz and 0.7 of a degree at 150 GHz.

By combining a new polarization-sensitive bolometric detector technology developed for the European Space Agency's Planck satellite (to be launched in 2007) with four independent levels of signal differencing and a carefully optimized observing strategy, BICEP will reach the current limit on CMB polarization in the first hour of integration, reach the sensitivity of Planck over 1 percent of the sky in the first week, and precisely measure CMB polarization on the critical angular scales of 1 degree to 10 degrees.

Observational cosmology is enjoying a renaissance that has captured the public imagination and serves as one of the most effective vehicles for stimulating interest in science in general. Detecting the signature of the GWB in the CMB would represent a triumph of fundamental physics and cosmology that would revolutionize our understanding of the origins of the Universe. (A–033–S; NSF/OPP 02–30438)

The operation of an extremely-low-frequency/very-low-frequency

(ELF/VLF) radiometer at Arrival Heights, Antarctica.

Antony C. Fraser-Smith, Stanford University.

Since it was discovered in the 1930s that natural phenomena emit the lowest form of electromagnetic energy (radio waves), the field of radio astronomy has joined the effort to analyze both atmospheric and extraterrestrial signals. The extremely-low-frequency and very-low-frequency (ELF/VLF) record of data collected at Arrival Heights, Ross Island, Antarctica—chosen because it is unusually free from human electromagnetic interference—now extends unbroken since the austral summer of 1984–1985. An identical system has been operating at Stanford University for almost the same period, thus providing a mid-latitude comparison data set.

Because the Arrival Heights radiometer has been operating for so many years, studies of longer-term variations can now be done. The data also help improve the statistical reliability of shorter-term variations. The difficulty of making long-term observations, particularly at remote locations, means that the Arrival Heights measurements increase in scientific value as the radiometer continues to operate.

Since the predominant source of ELF/VLF radio noise is thunderstorms occurring in the tropics, the Arrival Heights and Stanford systems provide alternate views of this activity. If thunderstorm activity depends on the temperature of the tropical atmosphere, as has been argued, the long-term statistical measurements of ELF/VLF radio noise made by the Arrival Heights and Stanford systems can provide independent information about global warming. Moreover, our radiometer measurements supplement those made by automatic geophysical observatories.

Because of its remote location, Arrival Heights has such a low background noise level that important new measurements are being made on weak ELF signals. The Schumann resonances, for example, which are so weak that observation is severely affected by the noise usually encountered in developed areas, are easily measured at Arrival Heights.

Since the 2001–2002 austral summer, our program has provided new information on the long-term variations in the noise at various frequencies throughout the ELF/VLF range, while at the same time providing an opportunity for more detailed studies of phenomena such as the Schumann resonances and the propagation of ELF radio waves from the few human sources around the world. There is also a possibility that the longer-term observations will prove useful in studies of global change. (A–100–M; NSF/OPP 01–38126)

Conjugate studies of ultra-long-frequency (ULF) waves and magnetospheric dynamics using ground-based induction magnetometers at four high-latitude manned sites.

Mark J. Engebretson, Augsburg College, and Marc R. Lessard, University of New Hampshire.

The Earth's magnetic field arises from its mass and motion around the polar axis, but it creates a powerful phenomenon at the edge of space known as the magnetosphere, which has been described as a comet-shaped cavity or bubble around the Earth, carved in the solar wind. When that supersonic flow of plasma emanating from the Sun encounters the magnetosphere, the result is a long cylindrical cavity, flowing on the lee side of the Earth, fronted by the blunt nose of the planet itself. With the solar wind coming at supersonic speed, this collision produces a "bow shock" several Earth radii in front of the magnetosphere proper.

One result of this process is fluctuations in the Earth's magnetic field, called micropulsations, which can be measured on time scales between 0.1 second and 1,000 seconds. It is known that magnetic variations can significantly affect power grids and pipelines. We plan to use magnetometers (distributed at high latitudes in both the antarctic and arctic regions) to learn more about how variations in the solar wind can affect the Earth and anthropogenic systems.

We will study these solar-wind-driven variations and patterns at a variety of locations and over periods up to a complete solar cycle. Since satellite systems are now continuously observing solar activity and also monitoring the solar wind, it is becoming feasible to develop models to predict the disruptions caused by such magnetic anomalies. And while our work is geared specifically toward a better understanding of the world and the behavior of its anthropogenic systems, it will also involve space weather prediction. (A–102–M/S; NSF/OPP 02–33169)

A search for extrasolar planets from the South Pole.

Douglas A. Caldwell, Laurance R. Doyle, and William Borucki, SETI Institute, and Zoran Ninkov, Pixel Physics, Inc.

We will operate a small optical telescope at the South Pole to search for and characterize extrasolar planets by continuously following a southern galactic star field with a charge-coupled device photometer and searching for the periodic dimming that occurs as a planet transits its parent star.

The recent discovery of many close-in giant exoplanets has expanded our knowledge of other planetary systems and has demonstrated how different such systems can be from the solar system. However, their discovery poses important questions about the effects of such planets on the presence of habitable planets. To date, only one extrasolar planet—HD 209458b—has been observed to transit a parent star. This project has the potential for a 10-fold increase in the number of extrasolar planets for which transits are observed. The South Pole is an excellent location for detecting such planets because randomly phased transits can most efficiently be detected during the long winter night. Also, the constant altitude of a stellar field at the pole avoids large daily atmospheric extinction variations and allows for higher photometric precision and a search for smaller planets.

Specifically, we will establish an automated planet-finding photometer at the South Pole for two austral winters. The statistics of planetary systems of nearby solar-type stars would indicate that about 10 to 15 extrasolar planets should be detected. There is also the possibility of finding planets that have a lower mass and have not previously been detectable. Combining the transit results (which give the size of the planet) with Doppler velocity measurements (which give the mass) will allow the planetary density to be determined, thus indicating whether the planet is a gas giant like Jupiter, an ice giant like Uranus, or a rocky planet like the Earth. These data will provide basic observational information that is vital to theoretical models of planetary structure and formation. (A–103–S; NSF/OPP 01–26313)

Dayside auroral imaging at South Pole.

Stephen B. Mende and Harald Frey, University of California–Berkeley.

We plan to operate two ground-based imagers at South Pole Station and combine their observations with simultaneous global auroral observations by the IMAGE (Imager for Magnetopause to Aurora Global Exploration) spacecraft investigating temporal and spatial effects in the ionosphere from the reconnection processes at the magnetopause. The South Pole has advantages for auroral imaging because the continuous darkness during the winter allows 24 hours of optical observations and because the ideal magnetic latitude permits observation of the dayside aurora. The reconnection (merging) region of the magnetosphere provides the most significant entry point for solar wind plasma. It is now widely accepted that the dayside region contains the footprint of field lines that participate in reconnection processes with the interplanetary field.

Although a body of literature about the auroral footprints of the dayside reconnection region has been derived from ground-based observations, it has not been possible to relate those results to simultaneous global auroral images. Global observations of proton auroras from the IMAGE spacecraft have provided direct images of the footprint of the reconnection region, showing that reconnection occurs continuously and that the spatial distribution of the precipitation follows theoretically predicted behavior as a function of the interplanetary field. The apogee of the IMAGE spacecraft orbit is slowly drifting south, and during the austral winter of 2004, the apogee was over the Southern Hemisphere. Thus, it was possible to obtain simultaneous global images of the aurora by IMAGE and of the high-latitude dayside region by two ground-based imagers (electron and proton auroras) at South Pole Station.

Our main goal is to capitalize on this unique opportunity by using the IMAGE satellite as the telescope and the ground-based imagers as the microscope for these observations in an attempt to better understand substorms and related phenomena. Understanding the Earth's electromagnetic environment is key to predicting space weather and to determining how geoactive magnetic storms are. We will continue to involve students in every phase of the program, thereby encouraging some of them to start a career in upper-atmospheric research. (A–104–S; NSF/OPP 02–30428)

A very-low-frequency (VLF) beacon transmitter at South Pole.

Umran S. Inan, Stanford University.

This 3-year project to establish and operate a very-low-frequency (VLF) beacon transmitter at the South Pole will measure solar effects on the Earth's mesosphere and lower ionosphere. Relativistic electrons, measured at geosynchronous orbit to have energies of more than 300 kiloelectronvolts, appear to fluctuate in response to substorm and solar activity. During such events, these highly energetic electrons can penetrate as low as 30 to 40 kilometers above the Earth's surface. At that altitude, they can wreak havoc in the atmosphere; they ionize chemical species, create x rays, and may even influence the chemistry that produces ozone.

By comparing how the South Pole VLF signal varies in both amplitude and phase when it arrives at various antarctic stations, we can calculate the extent of relativistic electron precipitation. The transmitter will also produce other data on solar proton events, relativistic electron precipitation from the Earth's outer radiation belts, and the joule heating components of high-latitude/polar cap magnetosphere/ionosphere coupling processes. (A–108–S; NSF/OPP 00–93381)

Austral high-latitude atmospheric dynamics.

Gonzalo Hernandez, University of Washington.

Observations of atmospheric dynamics in Antarctica help us better understand the global behavior of the atmosphere in high-latitude regions. Compared with lower latitude sites, the South Pole is a unique spot from which to observe the dynamic motion of the atmosphere. Its position on the Earth's axis of rotation strongly restricts the types of wave motions that can occur.

We will use high-resolution Fabry-Perot spectrometers at South Pole Station and Arrival Heights to make simultaneous azimuthal observations of the individual line spectra of several upper-atmospheric trace species, specifically the hydroxyl radical and atomic oxygen. The observed Doppler shift of the emission lines provides a direct measure of line-of-sight wind speed; wind field structure can also be derived from these measurements. Simultaneously observed line widths provide a direct measurement of kinetic temperature.

Our goal is to observe, characterize, and understand high-latitude mesospheric and thermospheric motions, as well as the thermal structure of these regions. In particular, we are interested in the strong coupling between the lower and upper atmosphere and the existence of persistent upper-thermospheric vertical winds.

At both South Pole Station and Arrival Heights, we make observations during the austral winter, when the instruments operate in 24-hour data-acquisition mode. At this time, station technicians perform routine maintenance and monitor operations. During the austral summer, project team members deploy to both stations to perform calibrations, maintenance, and upgrades. (A–110–M/S; NSF/OPP 02–29251)

Studies of the polar ionosphere and magnetosphere from measurements in Antarctica and conjugate regions.

Allan T. Weatherwax, Siena College; Louis J. Lanzerotti, New Jersey Institute of Technology; and Theodore J. Rosenberg, University of Maryland.

We will continue our studies of the polar ionosphere and magnetosphere from Antarctica and nominally conjugate regions in the Arctic. High-frequency cosmic noise absorption measurements (riometry) and auroral luminosity measurements (photometry) form the basis of our investigations. However, our research also involves extensive collaboration with other investigators using complementary data sets. Our previous work has provided insights into high-latitude substorm dynamics, magnetic variations, day- and night-side absorption spike events, traveling convection vortices, pulsating auroral particle precipitation, ionospheric transient and cusp-latitude absorption events, the origin of auroral radio emissions, and the possible application of riometry to the study of the Martian ionosphere.

Riometers measure the relative opacity of the ionosphere. Working at both McMurdo and South Pole Stations, we maintain and use a system called IRIS (Imaging Riometer for Ionospheric Studies), broad-beam riometers, and auroral photometers. These instruments, which work synergistically with other instruments operated at various sites by other investigators, also provide the data acquisition systems for the common recording of geophysical data at South Pole and McMurdo Stations and the provision of these data to collaborating investigators. To enhance their usefulness and timeliness to the general scientific community, data are made available in near real time on the Internet.

We will also continue imaging riometer measurements at Iqaluit in the Arctic, the nominal magnetic conjugate point of South Pole Station. Further, we will participate in, and contribute to, several major science initiatives and National Space Weather programs. A primary focus of our analysis over the next year will be coordinated ground- and satellite-based studies of Sun-Earth connection events. Specifically, we will be able to combine ground-based data sets with IMAGE (Imager for Magnetopause-to-Aurora Global Exploration) satellite data when the spacecraft is ideally situated at apogee over the Southern Hemisphere. These disparate activities have the common goal of enhancing scientific understanding of the relevant physical processes and forces that drive the observed phenomena, both internal (magnetospheric/ionospheric instabilities) and external (solar wind/interplanetary magnetic field variations). From such knowledge may emerge an enhanced forecasting capability. Many atmospheric events can have negative technological or societal impacts that accurate forecasting could ameliorate. (A–111–M/S; NSF/OPP 03–38105)

Polar Experiment Network for Geospace Upper-Atmosphere Investigations: PENGUIn—A new vision for global studies.

Allan T. Weatherwax, Siena College.

Since the advent of space flight, we have witnessed the importance of understanding the Earth and its space environment. Such an understanding requires a deep knowledge of the atmosphere-ionosphere-magnetosphere system—knowledge based on upper-atmosphere physical processes in the polar regions in both hemispheres. Only from the surface of Earth can many of the critical coupling processes and feedback systems that define this global system be studied with high temporal and spatial resolution.

We will investigate, from Antarctica and nominally conjugate regions in the Arctic, the multiscale electrodynamic system that comprises Earth's space environment. Our plan entails

- the phased development of a new and comprehensive upper-atmosphere geophysical measurement program based on distributed autonomous instruments operating in an extreme antarctic environment,
- real-time data collection via satellites,
- a methodology to build synergistic data sets from a global distribution of Southern and Northern Hemisphere instrument arrays, and
- an analysis and data distribution/outreach program tied to modeling and computer simulation to link measurement and theory.

Over the next 5 years, we will investigate dayside phenomena such as magnetic impulse events and traveling convection vortices, substorms at the highest latitudes, auroral zone poleward boundary intensifications, and magnetic reconnection and ion flows.

We will also study the causes of space weather processes that affect technologies on Earth and in near-Earth space, including charged particle energization and loss and the effects of solar particles on the polar cap ionosphere. Having the IMAGE (Imager for Magnetopause to Aurora Global Exploration) satellite at apogee in the Southern Hemisphere provided unprecedented opportunities for unraveling processes involved in internal and external driving forces in the global system. From such research will ultimately emerge an enhanced capability to predict the likely occurrence of events that might have deleterious effects on technology or people.

We will make our data and data acquisition tools widely available, and our research will be integrated with all levels of education from high school through postdoctoral study. Also, the development of new low-power sensors and innovative approaches to extreme environment engineering will benefit other disciplines. (A–112–M/S; NSF/OPP 03–41470)

All-sky imager at South Pole.

Yusuke Ebihara, National Institute of Polar Research, Japan.

The South Pole is an unparalleled platform for observing aurora during the austral winter. As a point on the Earth's rotational axis, the pole provides a unique vantage point from which to observe the airglow and discern the characteristics of acoustic gravity waves in the polar region as they vary in altitude and wavelength. Observing aurora continuously over 24 hours allows us to collect data on

- the dayside polar cusp/cleft aurora (due to the direct entry of the solar wind);
- afternoon aurora that are closely associated with the nightside magnetospheric storm/substorm activities; and
- the polar cap aurora, which depends on the polarity of the interplanetary magnetic field.

Research has shown that these auroras develop from precipitating low-energy particles entering the magnetosphere from the solar wind.

Though data have been gathered at the South Pole with a film-based, all-sky camera system since 1965, newer technology now produces digital images and permits us to process large amounts of information automatically. Currently, we are using the all-sky imager, a digital charge-coupled device imager monitored and controlled by the National Institute of Polar Research in Japan.

These international collaborations should enhance knowledge of the magnetosphere, the ionosphere, and upper/middle atmosphere physics. The high-frequency radar installations at Halley Bay, Sanae, and Syowa Stations provide the vector velocity of ionospheric plasma over the South Pole. These studies should provide further insight into the physics of the magnetosphere, the convection of plasma in the polar cap, and solar wind effects, specifically dayside auroral structure, nightside substorm effects, and polar cap arcs. (A–117–S; U.S./Japan agreement)

Solar and heliospheric studies with antarctic cosmic rays.

John W. Bieber, William H. Matthaeus, and K. Roger Pyle, University of Delaware, Bartol Research Institute, and Evelyn Patterson, U.S. Air Force Academy.

Cosmic rays—penetrating atomic nuclei and electrons from outer space that move at nearly the speed of light—continuously bombard the Earth. Colliding with the nuclei of molecules found in the upper atmosphere, they create a cascade of secondary particles that shower down. Neutron monitors, which are deployed in Antarctica and are part of a global network of nine stationary monitors and two transportable ship-borne monitors, provide a vital three-dimensional perspective on this shower and how it varies along all three axes. Accumulated neutron-monitor records (begun in 1960 at McMurdo Station and in 1964 at Amundsen–Scott South Pole Station) provide a long-term historical record that supports efforts to understand the nature and causes of solar/terrestrial and cosmic ray variations as they are discerned over the 11-year sunspot cycle, the 22-year Hale cycle, and even longer time scales. Data from the neutron monitors in this network will be combined with data from other ground-based and spacecraft instruments in various investigations of cosmic rays in relation to the Sun and solar wind. Specific objectives include the study of acceleration and transport of solar energetic particles, the scattering of cosmic rays in the solar wind, and the use of cosmic-ray observations for space weather forecasting.

This project at McMurdo and Amundsen–Scott South Pole Stations continues a series of year-round observations recording cosmic rays with energies in excess of 1 billion electron volts. These data will advance our understanding of a number of fundamental plasma processes occurring on the Sun and in interplanetary space. At the other extreme, we will study high time-resolution (10-second) cosmic ray data to determine the three-dimensional structure of turbulence in space and to elucidate the mechanism by which energetic charged particles scatter in this turbulence. (A–120–M/S; NSF/ATM 00–00315)

RICE: Radio-Ice Cherenkov Experiment.

David Z. Besson, University of Kansas–Lawrence.

We live at the dawn of the era of ultra-high-energy astronomy. Celestial accelerators, achieving energies 109 times higher than previously possible, can produce protons, photons, and neutrinos. Neutrinos are elementary particles with no electrical charge and very little mass. At the highest energies, neutrinos are the only particles that can elude the cosmic microwave background and penetrate, undeflected by magnetic fields, to Earth.

RICE is aimed at measuring high-energy neutrinos by detecting Cherenkov radiation, which is visible as a blue glow and results from collisions of very-high-energy neutrinos with ice or rock. RICE is designed to detect the compact electromagnetic cascades that produce Cherenkov radiation. At such high energies, radio detection of cascades is more efficient than optical-based detection.

We will work with the researchers on the IceCube drilling project, which began in 2004 (see A–333–S); specifically, we will deploy radio receivers in IceCube holes, thereby increasing RICE's sensitivity to neutrinos by at least two orders of magnitude. Deploying three radio receiver clusters (with two dual-polarization, high-bandwidth antennas per cluster) per hole will allow us to conduct radioglaciology measurements, in addition to astrophysics experiments. We will design the radio array for coincident (RICE plus IceCube) electromagnetic cascade detection, and special hardware will allow microsecond time-scale elimination of the surface anthropogenic backgrounds that have proved a problem in the past.

RICE data from the past 4 years have allowed the most detailed study of *in situ* radio detection systematics thus far; we have presented these data in two recent publications on the electrodynamics of the expected radio frequency pulse and two publications on RICE simulation and calibration and limits on the neutrino flux. Those limits were based on just 3 percent of the RICE data set. Expanded results based on 50 percent of the data set and improving on those limits by an order of magnitude, as well as results on the first *in situ* measurements of the polar dielectric constant, are being prepared for journal submission. Other studies are well underway. Our data and results will contribute greatly to the knowledge of astrophysics and ultra-high-energy astronomy. (A–123–S; NSF/OPP 03–38219)

Direction-finding measurements of low-frequency/medium-frequency/high-frequency (LF/MF/HF) auroral radio emissions at South Pole Station.

James W. LaBelle, Dartmouth College, and Allan T. Weatherwax, Siena College.

The Earth's aurora naturally emits low-, medium-, and high-frequency (LF/MF/HF) radio waves that are signatures of the interaction between the auroral electron beam and the ionospheric plasma. Yet some of the mechanisms that generate plasma waves are not well understood. Using an electromagnetic waveform receiver that we designed and constructed at South Pole Station, we will focus on several types of signals detectable at ground level, including auroral hiss, which occurs primarily at very low frequencies but often extends into the LF/MF range, and auroral roar, a relatively narrow-band emission generated near or at the second and third harmonics of the electron cyclotron frequency.

Because the broadcast bands found in the Northern Hemisphere are lacking in Antarctica, automatic wave-detection algorithms are more effective. Auroral roar has been found to be occasionally modulated (a phenomenon called flickering auroral roar). Our receiver will enable us to discover how common flickering auroral roar is, the conditions under which it occurs, what the frequencies are, and how the amplitude and frequency vary. Between 15 and 30 percent of auroral hiss events cannot be observed at very low frequencies. The receiver will determine whether LF auroral hiss consists exclusively of relatively unstructured broadband impulses or whether it sometimes displays a fine structure like that of auroral kilometric radiation and whistler-mode waves in the same frequency range detected in the lower ionosphere.

Despite its extensive application for communications, the LF/MF/HF band has not been extensively investigated as a source of natural radio emissions detectable at ground level. A complete knowledge of our geophysical environment requires understanding the physics of these emissions. Further, electron beam/plasma interactions analogous to the terrestrial aurora occur in many space physics and astrophysics applications. Often, the electromagnetic radiation emitted by these systems is our only source of knowledge about them. The local auroral plasma provides an opportunity to view some radiation processes at close range. (A–128–S; NSF/OPP 04–42369)

The antarctic investigations of upper atmospheric disturbances over the South Pole Station.

Gulamabas G. Sivjee and Syed Azeem, Embry Riddle Aeronautical University.

While variations in the Sun's energy affect people in obvious ways by driving the weather and the seasons, there are actually many cycles and variations of deeper interest to science, on scales from seconds to centuries to eons. One of the most basic is the 11-year cycle when the Sun's magnetic poles reverse direction (since reliable observations began, 23 of these have occurred and the last recently peaked) and sunspots and other solar activity wax to peak levels. The National Aeronautics and Space Administration is using this opportunity to conduct its TIMED (thermosphere-ionosphere-mesosphere-energetics and dynamics) satellite study, which will focus on the region between 60 and 180 kilometers above the Earth's surface.

Taking advantage of the timing of both of these events, we will use observations in the visible and near-infrared ranges of upper-atmospheric emissions above South Pole Station to study the heating effects of auroral electrical currents in the ionosphere, as well as planetary waves and atmospheric tides.

As it passes overhead, TIMED will provide data on the temperature, winds, and tides of the Earth's upper atmosphere, especially above the poles. Since tracking satellites often have difficulty differentiating between variations in location or time, ground-based observations from the South Pole will be valuable in sorting out the time-location question. (A–129–S; NSF/OPP 03–37618)

Measurements addressing quantitative ozone loss, polar stratospheric cloud nucleation, and large polar stratospheric particles during austral winter and spring.

Terry Deshler, University of Wyoming, and Marcel Snels, Instituto di Fisica dell'Atmosfera, Rome, Italy.

The stratospheric ozone layer provides life on Earth with an essential shield from solar ultraviolet radiation. The discovery in 1985 of large ozone losses above Antarctica each spring took the world and the scientific community by surprise. Since that time, the cause of this unprecedented ozone loss has been determined to be chlorine compounds interacting on the surfaces of clouds that formed when temperatures dropped below –78°C the previous winter [polar stratospheric clouds (PSCs)]. This interaction helps explain why ozone depletion is so severe in the polar regions. However, many details still must be clarified before we can comprehensively model the stratospheric ozone balance.

Observations of vertical ozone profiles from McMurdo Station will add to our database of annual measurements and will be completed as stratospheric chlorine levels are peaking to provide a baseline to detect the first signs of ozone recovery. In addition, we will extend our observations of PSCs. We use balloon-borne *in situ* instruments and an optical light detection and ranging radar (lidar) to study PSCs, stratospheric aerosol, and the thermal behavior and dynamics of the atmosphere above McMurdo Station. Continuous lidar observations and comparison of lidar and *in situ* measurements provide insight into the nature of these PSCs. Specifically, measurements of the size, concentration, and optical properties of the particles that form in these clouds provide estimates of the surfaces available for heterogeneous chemistry (the activation of chlorine so it can destroy ozone), the rates of denitrification and dehydration, and particle composition.

Measurements of vertical ozone profiles and lidar aerosol profiles are archived in the database of the Network for the Detection of Stratospheric Change, a global set of high-quality remote-sounding research stations for observing and understanding the physical and chemical state of the atmosphere (see www.ndsc.ws). This project represents a collaboration between Italian researchers and the University of Wyoming. (A–131–M; NSF/OPP 02–30424 and U.S./Italy agreement)

Measurement and analysis of extremely-low-frequency (ELF) waves at South Pole Station.

Marc R. Lessard, University of New Hampshire, and James W. LaBelle, Dartmouth College.

We aim to detect and record magnetic field fluctuations in the extremely-low-frequency (ELF) range, specifically auroral ion cyclotron waves, which have been well correlated with flickering aurora, at South Pole Station. Theory predicts that these waves modulate precipitating electron fluxes, thereby causing the flickering in luminosity emissions. Substantial evidence now supports this theory, although the excitation mechanism responsible for the ion cyclotron waves is uncertain. The most well developed theory suggests that the waves result from an electron-beam instability. In any case, the frequency of the flickering or, equivalently, the frequency of the ground-based observations of ion cyclotron waves can be used to infer the altitude of the excitation mechanism, since the wave frequency depends on the strength of the background magnetic field, which is a known quantity. As such, the information that will be acquired can be used to test models of auroral acceleration mechanisms, as well as study dispersive ELF waves, a type of wave that has been reported in the literature only a few times but may provide important information on substorm onset or, perhaps, the boundaries of open and closed magnetic fields.

A first step is to identify the wave mode and to determine the location and geomagnetic conditions under which these waves can be observed. The equipment used to make these observations consists of an induction coil magnetometer and data acquisition system. The induction coil is a commercially available device that was originally designed for geophysical exploration. Data will be returned to Dartmouth College for analysis. (A–136–S; NSF/OPP 01–32576)

Cosmic Ray Energetics and Mass (CREAM).

Eun-Suk Seo, University of Maryland; Simon Swordy, University of Chicago; James Beatty and Stephane Coutu, Pennsylvania State University; Michael Duvernois, University of Minnesota; Il Park, Ewha Woman's University; and Pier Simone Marrocchesi, University of Siena.

The Cosmic Ray Energetics and Mass (CREAM) project is a joint National Science Foundation/National Aeronautics and Space Administration (NASA) endeavor that will use a series of long-duration balloon flights to study the origin of cosmic rays. The CREAM instrument is configured with state-of-the-art particle detectors to measure the composition of cosmic rays from protons to iron nuclei over the energy range of 1 to 10^3 tera electron volts. The goal is to observe cosmic ray spectral features and abundance changes that might signify a limit to supernova acceleration.

To minimize the effect of backscatter from the calorimeter, particle charge measurements will be made with a timing-based detector and a pixelated silicon matrix. Particle energy measurements will be made with a transition radiation detector and a sampling tungsten/scintillator calorimeter. In-flight cross-calibration of the two detectors allows better determination of particle energy. Measurements of the relative abundance of secondary comic rays, as well as primary spectra, will allow us to determine ultra-high-energy cosmic rays for which measurements are not available.

The instrument has been tested and calibrated with a series of beam tests. It will be integrated with a command data module support system that was developed for the NASA Wallops Flight Facility and is attached to the bottom of the instrument to provide CREAM with power and communications. The power system consists of 10 solar panels and 4 batteries that will provide 28 volts of power to the instrument and 5, 12, and 28 volts of (regulated and unregulated) power to the support system instrumentation. Flight computers provide the communication interface between the science instrument and the command data module via an Ethernet connection using the universal datagram protocol. Real-time data will be downlinked continuously. All data will also be recorded on two hard drives, so anything that is not downlinked during real time can be retrieved. Other communication platforms serve as backups. (A–137–M; NSF/NASA agreement)

Wallops Flight Facility Component of the Cosmic Ray Energetics and Mass (CREAM) Balloon Payload.

Linda D. Thompson, National Aeronautics and Space Administration.

The National Aeronautics and Space Administration (NASA) Wallops Flight Facility developed the command data module and its external systems to support the science instrument for the Cosmic Ray Energetics and Mass (CREAM) project, which will use a series of long-duration balloon flights to investigate high-energy cosmic rays over the elemental range from protons to iron. These support systems provide the CREAM instrument with power, telecommunications, command and data handling, mechanical structures, thermal management, and attitude control. The power system consists of 10 solar panels and 4 batteries that will provide 28 volts of power to the instrument and 5, 12, and 28 volts of (regulated and unregulated) power to the support system instrumentation.

An Ethernet connection using the universal datagram protocol provides the communication interface between the science instrument and the command data module. The ballooncraft is instrumented to provide relay switch status, current, voltage, and temperature for telemetry health and status. The Tracking and Data Relay Satellite System serves as the prime over-the-horizon communications system and has a downlink capability of 100 kilobits per second. All data and system monitoring is both downlinked and stored on two hard drives on board so anything that is not downlinked during real time can be retrieved. Attitude control points solar panels toward the sun within ±2 degrees. (A–138–M; NSF/NASA agreement)

Advanced Thin Ionization Calorimeter (ATIC) Long-Duration Balloon Flight.

John P. Wefel, Louisiana State University–Baton Rouge.

Cosmic rays are the only sample of matter from distant regions of the galaxy, and possibly elsewhere in the Universe, that can be directly observed by space experiments in the solar system. This high-energy matter consists of atomic nuclei that travel at speeds very close to the speed of light. In fact, the highest energy cosmic rays observed are more than 10,000,000 times more energetic than those that can be produced in the largest particle accelerators on Earth. Cosmic rays, which include electrons, the natural elements from hydrogen and helium to iron and beyond, and antimatter in the form of positrons and antiprotons, play an important role in galactic dynamics and can be used to probe astrophysical conditions throughout our galaxy. They appear to gain their very high energy as the result of supernova explosion shock waves traveling through interstellar gas. The supernova shock wave acceleration model makes specific predictions about the cosmic ray energy spectrum as a function of elemental charge. The Advanced Thin Ionization Calorimeter (ATIC) project is designed to measure the energy spectrum of individual cosmic ray elements to study the validity of this model.

The ATIC balloon flight program will concentrate on measuring the cosmic ray proton and helium spectra from below 5×10^{10} electron volts to more than 10^{14} electron volts, with statistical accuracy of better than 30 percent at the highest energy. This unique coverage will enable us to investigate the spectral difference between hydrogen and helium and identify any spectral breaks over a broad energy range. In addition, ATIC will fill an existing gap in measurements of the proton/alpha ratio and concurrently will measure the spectra of nuclei up to iron, with individual element and superior energy resolution.

To achieve these objectives, ATIC will depend on a series of long-duration balloon flights that will be launched near McMurdo Station. During these flights, a large-volume helium-filled balloon will carry the experiment to the very edge of space (about 120,000 feet) for between 10 and 15 days. (A–143–M; NASA grant)

Long-Duration Balloon Program.

David W. Sullivan, National Scientific Balloon Facility.

The National Scientific Balloon Facility will launch two stratospheric balloons between 10 December 2005 and 10 January 2006. The balloons have a volume of 40 million cubic feet and will ascend at a rate of approximately 900 feet per minute to a float altitude of 125,000 feet. Both balloons will be launched at the Long-Duration Balloon site near Williams Field, reach float altitude, and circumnavigate the continent between 70°S and 80°S.

Balloons are terminated and recovered on the Ross Ice Shelf or on the Polar Plateau. For termination, an aircraft flies within line-of-sight of the balloon, and a radio command is sent to the payload. At the point of release, the payload descends with a parachute to a predicted impact site. Air or ground support (depending on the location) is used to recover the payload instruments, which are then returned to the home institutions to be refurbished and float another day. (A–145–M; NSF/NASA agreement)

Infrared measurements of atmospheric composition over Antarctica.

Frank J. Murcray, University of Denver.

We will use passive infrared instruments to measure year-round atmospheric chemistry for the photochemical transport models used to predict ozone depletion and climate change. The ozone hole has shown how sensitive the southern polar stratosphere is to chlorine, and although gradual healing of the hole is expected in response to the Montreal Protocol, models indicate a possible delay in recovery because of the impact of global warming on the catalytic ozone destruction process. Since most satellite instruments do not sample the polar regions in the winter, ground-based instruments can make an important contribution, and our data will also validate data from new satellite sensors.

We have installed two Fourier Transform Spectrometers, one at South Pole Station and the other at McMurdo Station, for year-round operation and a solar spectrometer at South Pole Station for summer operation. Also, we are collaborating with and receiving data from the New Zealand National Institute for Water and Air Research, which operates a similar spectrometer at Arrival Heights. During the polar night, two instruments provide information on nitric acid and denitrification, as well as dehydration, and high-resolution spectra from which we will derive vertical profiles, vertical column amounts of many molecules important in the ozone destruction process, and atmospheric tracers. Specifically, we will derive year-round column abundance measurements of nitric acid, methane, ozone, water, nitrous oxide, the chlorofluorocarbons (CFCs), and nitrogen dioxide.

We will use the data to determine the state of nitrogen oxide partitioning; to measure denitrification, vapor profiles in the stratosphere, and dehydration; to determine CFC and stratospheric chlorine levels; and to gain more insight into vortex-related chemical and dynamic effects. In addition, our data will allow photochemical transport modelers to compare outputs with actual measurements, especially at intermediate stages. As the recovery from ozone destruction begins, it is important to have a comprehensive data set that covers the major constituents of both the catalytic ozone destruction sequence and global warming, in order to place the relative influence of these two mechanisms in perspective. Also, the data will be available on a Web site for high school instruction. (A–255–M/S; NSF/OPP 02–30370)

Dynamics of the antarctic mesosphere–lower-thermosphere (MLT) region using ground-based radar and TIMED instrumentation.

Scott E. Palo, James P. Avery, and Susan K. Avery, University of Colorado–Boulder.

The mesosphere–lower thermosphere, which is found between 80 and 120 kilometers above the surface of the Earth, is a highly dynamic region that couples the lower atmosphere (troposphere/stratosphere) with the upper atmosphere (thermosphere/ionosphere). Of particular importance in this region are both the upward propagating, thermally forced atmospheric tides and global planetary waves. Both of these phenomena transport heat and momentum from the lower atmosphere into the upper atmosphere.

Studies in recent years have indicated that the high-latitude mesosphere–lower thermosphere has a rich spectrum of previously undiscovered planetary waves that can interact with the sun-synchronous migrating semidiurnal tide, thereby modifying its spatial and temporal structure while giving rise to the nonmigrating semidiurnal tide. Understanding the structure and variability of the semidiurnal tide is an important step toward understanding the global heat and energy balance of the mesosphere–lower thermosphere.

We will observe and model the spatial-temporal structure and variability of the semidiurnal tide, with a focus on the horizontal wind and temperature fields in the arctic and antarctic mesosphere–lower thermosphere. Previous observations have indicated that planetary waves play a significant role in the variability of the semidiurnal tide. We will therefore estimate the structure of the semidiurnal tide and the planetary waves simultaneously. These estimates will be analyzed in conjunction with both linear mechanistic and global circulation models to help interpret the observations. The data for this project will also include horizontal wind measurements from a global network of 30 ground-based meteor and medium-frequency radars. (The radar data are collected by colleagues in Australia, Canada, Japan, Russia, the United Kingdom, and the United States.) Moreover, wind and temperature measurements from the National Aeronautics and Space Administration's TIMED (thermosphere-ionosphere-mesosphere-energetics and dynamics) satellite will be combined with the radar data and incorporated into existing databases.

Teaching, training, and learning will be advanced by the inclusion of graduate students, especially underrepresented minorities, in this research. All of the students involved in this project will be encouraged to present their results and participate in professional meetings. (A–284–S; NSF/OPP 03–36946)

Extremely-low-frequency/very-low-frequency (ELF/VLF) observations of lightning discharges, whistler-mode waves, and electron precipitation at Palmer Station, Antarctica.

Umran S. Inan, Stanford University.

Although tracking dynamic storms is a challenge, the lightning associated with thunderstorms can provide an indirect way of monitoring global weather. We will use very-low-frequency (VLF) radio receivers at Palmer Station to study thunderstorm coupling to the Van Allen radiation belts, the characteristics of lightning flashes that lead to upward electrodynamic coupling, ionospheric variability and parameters, and global lightning and climatology. In collaboration with the British and Brazilian Antarctic Programs, both of which use similar receivers, we will contribute data to the Global Change Initiative.

Our VLF receivers measure changes in the amplitude and phase of signals received from several distant VLF transmitters. These changes follow lightning discharges because radio (whistler) waves from the lightning can cause very energetic electrons from the Van Allen radiation belts to precipitate into the upper atmosphere. This particle precipitation increases ionization in the ionosphere, through which the propagating VLF radio waves must travel. Because the orientations to the VLF transmitters are known, we can triangulate the lightning sources that caused the changes. Once the direction of the source is known, it can be subjected to waveform analysis and used to track the path of thunderstorms remotely.

In addition, our VLF observations at Palmer Station will provide crucial support to a program involving the establishment and operation of a VLF beacon transmitter at South Pole Station. The reception of the beacon signal at Palmer Station will allow the continuous measurement of relativistic electron precipitation from the outer radiation belts, an important component of worldwide efforts to assess space weather.

The data we derive will be correlated with data from the antarctic automatic geophysical observatory network and used by scientists studying the magnetosphere and the ionosphere. (A–306–P; NSF/OPP 02–33955)

IceCube.

Francis Halzen, University of Wisconsin–Madison.

We are building the IceCube Observatory, which will be installed at the South Pole. IceCube, a neutrino telescope that will be buried 1.4 to 2.4 kilometers below the surface of the ice, will be constructed during the austral summers over the next 4 years. The detector will consist of 4,800 optical modules deployed on 80 vertical strings. The now-completed AMANDA (Antarctic Muon and Neutrino Detector Array project) served as a prototype for this international collaborative effort. Last season, we shipped the remaining components, began drilling in the ice sheet, and started to assemble and test systems. During this austral summer, drilling will continue and additional optical modules will be deployed.

Using neutrinos as cosmic messengers, IceCube will open an unexplored window on the Universe and will answer such fundamental questions as what the physical conditions in gamma ray bursts are and whether the photons originating in the Crab supernova remnant and near the supermassive black holes of active galaxies are of hadronic (derived from subatomic particles composed of quarks) or electromagnetic origin. The telescope will also examine the nature of dark matter, aid in the quest to observe supersymmetric particles, and search for compactified dimensions.

Since many parts of the Universe cannot be explored using other types of radiation (protons do not carry directional information because they are deflected by magnetic fields, neutrons decay before they reach the Earth, and high-energy photons may be absorbed), IceCube will fill a gap in our knowledge and occupy a unique place in astronomical research. (A–333–S; NSF/OPP 03–31873)

Extending the South American Meridional B-field Array (SAMBA) to auroral latitudes in Antarctica.

Eftyhia Zesta, University of California–Los Angeles.

We intend to install 2 additional magnetometer stations in Antarctica and thus extend the South American Meridional B-field Array (SAMBA), which now comprises 10 stations, to higher latitudes. The 2 additional magnetometers will be at Palmer Station, a year-round U.S. research station in the Antarctic Peninsula region, and at Patriot Hills, a more remote, nonpermanent Chilean base. The Patriot Hills installation will be done with the logistical support of the Chilean Antarctic Institute.

More specifically, we intend to

- extend the SAMBA chain to auroral latitudes and increase the spatial resolution of the effective cusp-to-cusp chain comprising MACCS (Magnetometer Arrays for Cusp and Cleft Studies), MEASURE (Magnetometers Along the Eastern Atlantic Seaboard for Undergraduate Research and Education), SAMBA, the automatic geophysical observatories, and a few other individual stations;
- extend the number of conjugate pairs of stations between MEASURE in the Northern Hemisphere and SAMBA in the Southern Hemisphere, thus increasing the size of the inner magnetospheric region that can be remotely monitored from the two hemispheres;
- establish an auroral latitude station conjugate to the Canadian Poste de la Baleine and study the conjugate differences in substorms and general auroral activity;
- determine, with the addition of other antarctic auroral stations, a Southern Hemisphere auroral electrojet (AE)-type index and compare it with the standard AE index; and
- provide the scientific community with near-real-time data from Southern Hemisphere low- and auroral-latitude stations that can be used to validate models that up to now have been tuned primarily with data from the Northern Hemisphere. (A–357–M/P; NSF/OPP 03–41861)

Strateole-Vorcore.

François Vial, École Polytechnique, Laboratoire de Météorologie Dynamique.

The Strateole-Vorcore experiment was designed to examine the dynamics of the stratospheric antarctic polar vortex, the transport of minor constituents, and the interaction with ozone chemistry during late winter and spring.

We will launch a series of superpressure, long-duration balloons from McMurdo Station. These balloons are equipped with lightweight instrumented gondolas containing two temperature sensors, a pressure sensor, a global positioning system receiver, and an ARGOS transmitter to document wind and temperature horizontal fields inside the vortex core. This will permit us to study

- the dynamic structure of the polar vortex and its evolution up to its final breakdown,
- the influence of tropospheric forcing on the stratospheric circulation at high latitudes,
- the role of small-scale movements (gravity waves and turbulence) on the horizontal diffusion processes,
- the different regimes of horizontal transport around the isentropic layer (below which the exchange with mid-latitudes should be relatively free), and
- the temperature history of air masses—key to understanding the formation of polar stratospheric clouds. (A–360–M; U.S.–France agreement)

Development of an autonomous real-time remote observatory (ARRO).

Marc R. Lessard, University of New Hampshire, and James W. LaBelle, Dartmouth College.

We will develop an autonomous real-time remote observatory (ARRO), which will be designed to accommodate at least a dozen instruments, with the goal of enabling reliable observations from several sites on the antarctic plateau. We will build two prototypes of this observatory and test them for extended periods in cold chambers on Mount Washington and at the South Pole.

Significant outstanding issues in diverse fields drive the need for a network of reliable autonomous observatories capable of operating in the polar regions. ARRO will contribute to the pursuit of a broad scientific agenda by a large group of institutions and investigators in fields ranging from solar-terrestrial physics to seismology. In solar-terrestrial physics, the geomagnetic polar cap—the region of geomagnetic field lines connected to interplanetary space—forms a key window on the interaction between the solar wind and the Earth's magnetosphere. Continued progress in understanding the Sun's influence on the structure and dynamics of the Earth's upper atmosphere depends on increasing knowledge of the role that the polar cap plays in coupling the solar wind with the magnetosphere, ionosphere, and thermosphere. Furthermore, a network of observatories at high latitudes will contribute significantly to studies of energy input into the magnetosphere, reconnection, nightside energization of particles and auroral substorms, subauroral and inner magnetospheric physics, and development of a new polar cap index of solar-terrestrial activity.

Also, because the seismic character of Antarctica is not well known, a central goal is to determine crustal and mantle structure from seismic signals. This requires a network of receiving stations. In atmospheric science, one vital object of study is nitric acid trihydrate polar stratospheric clouds, which are implicated in the annual springtime destruction of stratospheric ozone over Antarctica.

In addition, ARRO development includes several different layers of research and training. Students will be directly involved, from the initial design stages to deployment. Finally, ARRO includes significant connections to industry and Government units outside the academic community, and participation will sharpen the capabilities of these units to serve the Nation in applying technology to challenging environments of cold weather and high altitudes. (A–362–S; NSF/OPP 02–16279)

Next-generation cosmic microwave background polarization measurements with the QUEST experiment on the degree angular scale interferometer (DASI).

Sarah E. Church, Stanford University; Clement L. Pryke, University of Chicago; and Andrew E. Lange and James J. Bock, California Institute of Technology.

We deployed QUEST, a 2.6-meter Cassegrain telescope equipped with a next-generation polarization-sensitive bolometer array, to South Pole Station and will operate it for another austral winter. We mounted the telescope on the existing degree angular scale interferometer (DASI) platform and reused large parts of the DASI infrastructure and control system. We will use the combined QUEST/DASI (or QUaD) system to make maps of the polarization of the cosmic microwave background (CMB) with unprecedented sensitivity and angular resolution.

The CMB—the faint, relic heat from the Big Bang—offers a snapshot of the Universe at the point where it transitioned from hot plasma to neutral gas. The statistics of the expected sky pattern for a given cosmological theory can be accurately calculated, and a host of experiments have now measured the variation of the total intensity, or temperature, of the CMB. Taken together, these measurements have begun to reveal the origin, composition, evolution, and ultimate fate of the Universe.

The polarization of the CMB results from bulk motions of material at the time of the plasma–neutral gas transition. Several experiments are either running or under construction to improve measurements of CMB polarization. QUaD has raw sensitivity similar to that of the European Space Agency's planned Planck satellite (to be launched in 2007) and in fact shares much of the same technology. However, while Planck plans to survey the whole sky, QUaD will go very deep on small patches selected for extremely low foreground contamination. QUaD's maps will have dramatically higher signal-to-noise per pixel and will prove crucial to disentangling the cosmic signal from instrumental and foreground effects.

The enterprise of modern cosmology is one with which almost everybody can identify. QUaD project members communicate with the public in both formal and informal settings. Outreach and education related to the project are disseminated through established structures and mechanisms that reach out to local and distant K–12 schoolteachers and students to inform and to help attract women and minorities to science. Also, graduate and undergraduate education and research are being integrated into QUaD construction and data analysis. (A–366–S; NSF/OPP 03–38138, NSF/OPP 03–38238, and NSF/OPP 03–38335)

Continued operation of the Antarctic Submillimeter Telescope and Remote Observatory (AST/RO).

Antony A. Stark and Adair P. Lane, Smithsonian Institution Astrophysical Observatory; Christopher K. Walker, University of Arizona; and Jacob Kooi and Richard Chamberlin, California Institute of Technology.

Astronomy is undergoing a revolutionary transformation, where for the first time we can observe the full range of electromagnetic radiation emitted by astronomical sources. One of the newly developed and least explored bands is the submillimeter, at frequencies from about 300 gigahertz up into the terahertz range. Submillimeter-wave radiation is emitted by dense gas and dust between the stars, and submillimeter-wave observations allow us to study the galactic forces acting on that gas and the star formation processes within it in unprecedented detail.

The Antarctic Submillimeter Telescope and Remote Observatory (AST/RO) is a 1.7-meter, single-dish instrument that has been operating since 1995 in several submillimeter bands. It has made position-position-velocity maps of submillimeter-wave spectral lines with arcminute resolution over regions of sky that are several square degrees in size. AST/RO provides a valuable complement to the planned arrays, which are inefficient when observing large areas because of their small field of view. AST/RO can observe molecular clouds throughout the fourth quadrant of the Milky Way and the Magellanic Clouds to locate star-forming cores and study in detail the dynamics of dense gas in our own galaxy. AST/RO studies are showing how molecular clouds are structured, how newly formed stars react back on the cloud, and how galactic forces affect cloud structure. Also, these studies

- have shown that the structure of molecular clouds is affected by their heavy element content and their proximity to spiral arms,
- have examined the gradient of heavy elements in the galaxy, and
- have produced extensive, high-sensitivity maps of several atomic and molecular transitions toward the Galactic Center and an unbiased survey of molecular and atomic gas in the fourth quadrant of the Galaxy.

Location at Amundsen–Scott South Pole Station is essential to AST/RO's capabilities. Most submillimeter radiation is absorbed by irregular concentrations of atmospheric water vapor before it reaches the Earth's surface. The desiccated air over South Pole Station allows an accurate intercomparison of submillimeter-wave power levels from locations on the sky separated by several degrees. This is essential to the study of submillimeter-wave radiation on the scale of the Milky Way and its companion galaxies.

This will be the last austral summer that we will operate the telescope. (A–371–S; NSF/OPP 01–26090)

Wide-field imaging spectroscopy in the submillimeter: Deploying SPIFI on the Antarctic Submillimeter Telescope and Remote Observatory

(AST/RO).

Gordon J. Stacey, Cornell University.

SPIFI (South Pole Imaging Fabry-Perot Interferometer), the first direct detection imaging spectrometer for use in the submillimeter band, was designed for use on the 1.7-meter Antarctic Submillimeter Telescope and Remote Observatory (AST/RO) at the South Pole in the far-infrared and submillimeter windows. After having developed and extensively field-tested SPIFI, our primary goals are to

- image the inner regions of the galaxy, in particular submillimeter lines that characterize excitation conditions in the Central Molecular Zone (CMZ), and trace the dynamics of the gas. Questions to be answered are, among others, Can we trace neutral gas flowing through the CMZ? Are there shocks from cloud-cloud collisions in this flow? What is the connection between the CMZ molecular clouds and the circumnuclear ring?
- map the Large Magellanic Cloud and Small Magellanic Cloud in these lines. The low metalicity environment in these dwarf galaxies may mimic that of protogalaxies, so investigating the interaction between star formation and the interstellar matter in these galaxies is key to understanding the star formation process in the early Universe.
- characterize and map the physical conditions of the interstellar matter in nearby galaxies. These data are unique and will be essential to understanding the relationships between density waves, bar potentials, and galaxy-wide star formation.

These projects can be undertaken only with the high sensitivity and mapping capabilities of the SPIFI AST/RO combination. SPIFI is much more sensitive than the best heterodyne receivers, which do not have the sensitivity or (often) the bandwidth, to detect the broad, weak lines from galaxies or the spatial multiplexing capability necessary for wide-field mapping projects. We plan to gradually upgrade SPIFI by a factor of 10. We will also make modest optical and cryogenic modifications to improve it in ways important to successful polar operations. The result will be better spatial resolution, with a wider field of view, and a large improvement in system sensitivity. Moreover, the new cryogenic system will require servicing only every 5 days instead of the current 40 hours. This is helpful for outdoor polar operations. This new system also reduces helium consumption (by a factor of 2) and therefore reduces cost.

Our observations this austral summer will complete the SPIFI-AST/RO program, begun during the 2005 austral winter. When our observations are completed, we will remove SPIFI from AST/RO and prepare it for shipment back to Cornell University. (A–377–S; NSF/OPP 03–38149)

High-resolution observations of the cosmic microwave background (CMB) with the Arcminute Cosmology Bolometer Array Receiver (ACBAR).

William L. Holzapfel, University of California–Berkeley.

We will continue our observations with the Arcminute Cosmology Bolometer Array Receiver (ACBAR), a 16-element 230-micro-Kelvin bolometer receiver designed to produce high-resolution images of the cosmic microwave background (CMB) in 3-millimeter wavelength bands. Mounted on the 2.1-meter Viper telescope at the South Pole, ACBAR has a sensitivity that rivals balloon-borne experiments and an angular resolution that they cannot hope to achieve. Making full use of the excellent atmospheric conditions during the austral winter at the South Pole, ACBAR is producing images of CMB radiation with a sensitivity and resolution that exceed the capabilities of even the European Space Agency's proposed Planck satellite (to be launched in 2007).

Observations of the CMB provide a unique window on the early Universe; moreover, these data play a key role in transforming cosmology into a precise science. In particular, small angular-scale observations of the CMB are a new frontier about which comparatively little is known. On these angular scales, contributions from secondary anisotropies introduced by intervening structures are expected to become dominant. For example, the scattering of photons by hot gas bound to clusters of galaxies results in a spectral distortion of the CMB known as the Sunyaev-Zel'dovich Effect (SZE). Observations of the SZE can provide important new constraints on theories of how the Universe grew.

The unique capabilities of ACBAR, which was deployed to the South Pole in December 2000, allow it to address a broad range of science focused on measuring primary and secondary CMB anisotropies. Our observations and analysis will help realize the full potential of this powerful instrument for the study of cosmology. Four institutions will continue to collaborate on the maintenance and operation of ACBAR and Viper and participate in the data analysis.

The results will serve as a vital complement to the large-scale Microwave Anistropy Probe (MAP) spacecraft data set and provide an essential check of the fine-scale excess power reported by other single-frequency experiments. The novel instrumentation, observation techniques, and analysis developed for ACBAR are generally applicable to future ground-based millimeter astronomy experiments. In addition, this project has provided hands-on research experience to several undergraduate and graduate students. (A–378–S; NSF/OPP 02–32009)

South Pole observations to test cosmological models.

John E. Carlstrom, University of Chicago; Antony A. Stark, Smithsonian Institution Astrophysical Observatory; John Ruhl, Case Western Reserve University; Joseph J. Mohr, University of Illinois–Urbana-Champaign; and William L. Holzapfel, University of California–Berkeley.

One of the most important discoveries in cosmology is that much, if not most, of the mass in the Universe is apparently made up not of stars and glowing gas, but of dark matter, which emits little or no light or other electromagnetic radiation and makes its presence known only through the gravitational force it exerts on luminous matter. There is some indication that dark matter may in fact not even be baryonic (baryons are subatomic particles that are built from quarks and interact via strong nuclear force). Determining just what fraction of the mass is in the form of noninteracting nonbaryonic particles is of great interest to cosmologists and physicists.

The University of Chicago leads a consortium of six institutions in designing and using a 10-meter off-axis telescope at Amundsen–Scott South Pole Station to survey galaxy clusters. Such a survey will allow us to study integrated cluster abundance and its red shift evolution and will give us precise cosmological constraints that are completely independent of those from supernova distance and cosmic microwave background (CMB) anisotropy measurements.

Measuring the mass in baryons along with the total mass in a region of the Universe that could be considered a fair sample would provide a direct determination of the dark matter content. In recent years, just such a test-bed has been found in massive clusters of galaxies, which contain large amounts of gas (baryons) in the form of a highly ionized gas atmosphere that emits x rays. Nearly all of the baryons in the clusters are believed to be in the hot phase (millions of degrees), so it is likely that we are truly measuring the baryonic mass in the cluster.

In addition to emitting x rays, the hot cluster gas also scatters CMB radiation. This scattering, called the Sunyaev-Zel'dovich Effect (SZE), can be measured by using radio telescopes. The SZE is important to the study of cosmology and the CMB for two reasons:

- The observed hotspots created by the kinetic effect distort the power spectrum of CMB anisotropies. These need to be separated from primary anisotropies to probe inflation properties.
- The thermal SZE can be measured and combined with x-ray observations to determine the values of cosmological parameters, in particular the Hubble constant. (A–379–S; NSF/OPP 01–30612)

Measurements of the surface layer turbulence at Dome C.

Tony Travouillon, California Institute of Technology.

Over two austral winters, we will study surface layer turbulence to fill the gaps in knowledge about the total turbulence profile at Dome C. We will use sonic anenometers placed along an existing 30-meter (m) mast to measure the C_N^2 parameter at four different heights within the first 30 m of the atmosphere (3, 10, 20, and 30 m). This parameter describes the strength of the optical turbulence at any given point in the atmosphere. By interpolating and integrating these measurements, we will be able to calculate the surface layer component.

A complete understanding of the spatial and temporal evolution of the turbulence above Dome C is important in comparing this site with other existing or potential observatory sites. This section of the atmosphere is particularly crucial for small and intermediate-size projects that are currently proposed for this site and will be affected by the turbulence.

Other fields, notably geophysics, will be greatly interested in these measurements. Other parameters, such as temperature, wind speed and direction, and surface heat flux, will be derived from them and will help us understand the structure of the airflow on the antarctic continent.

The data we derive will be made available to the international community in semi–real time on a dedicated Web site. (A–442–E; NSF/OPP 04–40874)