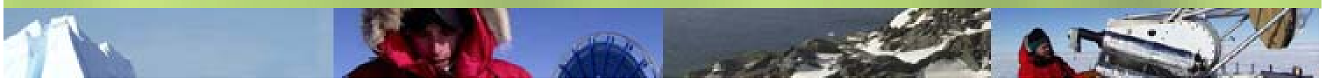

AERONOMY AND ASTROPHYSICS

Aurora australis above the new station complex at Amundsen–Scott South Pole Station in June 2004. (*NSF/USAP photo by J. Dana Hrubes, Raytheon Polar Services, Corp.*)

On this page:

- IceCube.
- Extending the South American Meridional B-field Array (SAMBA) to auroral latitudes in Antarctica.
- 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).
- Dual Auroral Radar Network at South Pole Station.
- Antarctic Submillimeter Telescope and Remote Observatory (AST/RO).
- PAST: The Primeval Structure Telescope.
- 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: A 10-meter telescope for South Pole.

Telescopes and laboratory facilities in the "dark sector" are about 1 kilometer from the main Amundsen-Scott South Station facilities. The "dark sector" is maintained with minimal interference from extraneous light sources and other electromagnetic radiation. (*NSF/USAP photo*.)

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 extend beyond the magnetosphere, including a particular interest in the Sun and cosmic rays. 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 interdisciplinary study of geosphere/biosphere interactions in the middle and upper atmosphere, and improves understanding of the critical processes of solar energy in these regions. Life exists in a balance on Earth because of numerous chemical and atmospheric phenomena that have developed in the specific atmosphere of this 4.6-billion-year-old spinning planet in orbit 149,637,000 kilometers from a middle-sized, middle-aged star. 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 Studies Program), is nowhere better exemplified than in Antarctica.

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Background imaging of cosmic extragalactic polarization (BICEP): An experimental probe of inflation.

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 will be deployed and commissioned during 2004–2005. After BICEP is unpacked and prepared for initial cooldown, the optical loading, bandpass, and noise characteristics of the detector array and modulation systems will be 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)

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The operation of an extremely-low-frequency/very-low-frequency (ELF/VLF) radiometer at Arrival Heights, Antarctica.

Antony C. Fraser-Smith, Stanford University.

We are continuing our multiyear program of monitoring extremely-low-frequency/very-low-frequency (ELF/VLF) radio noise at Arrival Heights, Antarctica. The ELF/VLF radiometer was first installed there during the austral summer of 1984–1985, and it has been in continuous operation ever since, thereby providing a record of antarctic ELF/VLF noise that is unprecedented in its continuity and duration. An identical system that has been operating at Stanford University during almost the same period provides a northern mid-latitude comparison data set. Our principal objective is to improve knowledge of the radio noise statistics at frequencies in the ELF/VLF range, and our project has already added substantially to the knowledge and understanding of these statistics on a short-term basis.

Because of the measurements made by the Arrival Heights radiometer, studies of longer term variations can be done. Simultaneously, the additional data enable the statistical reliability of shorter term variations to be improved. Because of the great difficulty involved in making long-term observations, particularly at remote locations, the Arrival Heights measurements are increasing 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 thunderstorm activity. If such 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.

In addition, the radiometer measurements supplement those made by the automatic geophysical observatories and by other ELF/VLF measurement systems in the Antarctic, including those operated by the British Antarctic Survey. Because of its remote location, Arrival Heights has such a low background noise level that important new measurements are being made even on weak ELF signals, such as the Schumann resonances, for example. There is also the possibility that longer term observations may prove useful in studies of global change. (A–100–M; NSF/OPP 01–38126)

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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)

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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)

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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 will be over the Southern Hemisphere. Thus, it will be 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 and use 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)

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A very-low-frequency (VLF) beacon transmitter at South Pole (2001–2004).

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.

VLF data from the South Pole beacon provide a valuable complement to two other efforts: first, to other antarctic upper-atmospheric research, such as the automatic geophysical observatory program and the Southern Hemisphere coherent high-frequency radar Super4 Dual Auroral Network (SUPERDARN), and second, to ongoing satellite-based measurements of trapped and precipitating high-energy electrons at both high and low altitudes. The latter are collected by the Solar Anomalous and Magnetospheric Particle Explorer (SAMPEX). (A–108–S; NSF/OPP 00–93381)

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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)

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

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

We will continue our studies of the polar ionosphere and magnetosphere from Antarctica and nominally conjugate regions in the Arctic. Magnetometer observations, high-frequency cosmic noise absorption measurements (riometry), and auroral luminosity measurements (photometry) will form the basis of our studies, which will also involve extensive collaboration with investigators using complementary data sets.

We aim to improve understanding of the mechanisms that couple solar processes into the terrestrial environment by investigating phenomena associated with short-term environmental effects (auroras, induced electrical currents, traveling convection vortices, pulsating particle precipitation, and the origin of auroral radio emissions), as well as those associated with longer-term effects (atmospheric composition studies, stratospheric winds, space weather). The object is to understand these physical processes and how they relate to internal or external driving forces. From this may emerge an enhanced capability to predict events with negative technological or societal impacts in time to mitigate their effects.

Moreover, we will combine ground-based data sets with IMAGE (Imager for Magnetopause to Aurora Global Exploration) satellite data when the spacecraft is ideally situated at apogee in the Southern Hemisphere next year.

We will also continue to maintain the magnetometers at South Pole and McMurdo Stations, as well as imaging and broad-beam riometers and two-wavelength zenith photometers at South Pole and McMurdo Stations and imaging riometers at Iqaluit and Sondrestrom in the Arctic. In addition, we will continue to provide the systems at South Pole and McMurdo Stations for the common recording of other geophysical data and their transmission to collaborating investigators. To enhance the usefulness and timeliness of these data, we will maintain a Web site from which antarctic data sets can be accessed in near real time. Further, we will participate in, and contribute to, several major science initiatives and National Space Weather programs.

Our data can enhance many other projects. For example, astronomers have used our particle/optical data to help calibrate the "seeing" conditions at South Pole during auroral activity. Our research will also be integrated with undergraduate education at all three of the investigators' institutions. (A–111–M; NSF/OPP 03–38105)

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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 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 the space environment of Earth. 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 linked 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 will provide 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; NSF/OPP 03–41470)

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All-sky imager at South Pole.

Masaki Ejiri, 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)

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Spaceship Earth: Probing the solar wind with cosmic rays.

John W. Bieber, William H. Matthaeus, and K. Roger Pyle, Bartol Research Institute, University of Delaware, 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 on Earth. 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)

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RICE: Radio Ice Cherenkov Experiment.

David Besson, University of Kansas–Lawrence.

The goals of the RICE experiment are similar to those for the larger Antarctic Muon and Neutrino Detector Array (AMANDA; see A–130–S). Neutrinos are elementary particles with no electrical charge and very little mass. They are the only particles that can elude the cosmic microwave background and penetrate, undeflected by magnetic fields, to Earth. Both RICE and AMANDA seek to measure high-energy neutrinos by detecting Cherenkov radiation, which is visible as a blue glow and results from collisions of high-energy neutrinos with ice or rock. While AMANDA aims to discover the sources, both inside and outside the galaxy, of the shower of very-high-energy neutrinos descending on (and usually passing through) the Earth, RICE is designed to detect the compact electromagnetic cascades that produce Cherenkov radiation. Radio detection is more efficient than optical-based techniques.

This season, the initiation of ice-hole drilling for the IceCube project (see A–333–S) presents a singular scientific opportunity. We will deploy radio receivers in these same holes, thereby increasing RICE's sensitivity to neutrinos by at least two orders of magnitude. Deploying three radio receiver clusters (two dual-polarization, high-bandwidth antennas per cluster per hole) will also allow us to conduct radioglaciology 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 so far. This season, we will perform maintenance on the existing experiment. We will also calibrate the radio antenna and investigate radio-frequency ice response, using existing resources and infrastructure and without drilling additional holes.

Our data and results will contribute greatly to the knowledge of astrophysics and ultra-high-energy astronomy. (A–123–S; NSF/OPP 03–38219)

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A versatile electromagnetic waveform receiver for South Pole Station.

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

The Earth's aurora naturally emits a variety of low-frequency (LF), medium-frequency (MF), and high-frequency (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. This project focuses 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 narrowband emission generated near or at the second and third harmonics of the electron cyclotron frequency.

We will use a versatile electromagnetic waveform receiver deployed at South Pole Station. Only recently has it been possible to conceive of an inexpensive, versatile receiver of this type for the South Pole. An antarctic location is essential for ground-based observations of LF auroral hiss because the broadcast bands usually found in the Northern Hemisphere are typically absent in Antarctica. Also, the absence of broadcast bands improves the effectiveness of automatic wave-detection algorithms.

We can use the receiver to address many issues. For example, it was recently discovered that auroral roar is sometimes modulated at frequencies between 7 and 11 hertz, a phenomenon called flickering auroral roar. This receiver will allow us to find out how common flickering auroral roar is, the conditions under which it occurs, what the frequencies are, and how the amplitude and frequency vary over time.

Between 15 percent and 30 percent of auroral hiss events are not observable 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 similar to that of auroral kilometric radiation and whistler-mode waves in the same frequency range detected in the lower ionosphere. We will also define and test auroral roar and auroral hiss mechanisms. Despite its extensive application for communications, the LF/MF/HF band has been relatively little 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 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 plasma radiation processes at close range. (A–128–S; NSF/OPP 00–90545)

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Effects of enhanced solar disturbances during the 2000–2002 solar-max period on the antarctic mesosphere-lower-thermosphere (MLT) and F regions composition, thermodynamics, and dynamics.

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 just 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. But tracking satellites often have difficulty differentiating between variations in location or time. South Pole ground-based observations will be valuable in sorting out the time-location question. (A–129–S; NSF/OPP 03–37618)

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Antarctic Muon and Neutrino Detector Array (AMANDA) 2004.

Robert J. Morse, Francis Halzen, and Albrecht Karle, University of Wisconsin–Madison.

Neutrinos are elementary particles that have no electrical charge, can take one of three forms, and are believed to have very little or no mass. Coursing through the universe, they interact only rarely with other particles. The primary objective of the Antarctic Muon and Neutrino Detector Array (AMANDA) is to discover the sources, both inside and outside our galaxy, of the shower of very-high-energy neutrinos descending on (and usually passing through) the Earth. As one of the first large neutrino telescopes, AMANDA promises to make seminal contributions to astronomy.

AMANDA uses an array of photo multiplier tubes imbedded between 1 and 2 kilometers into the ice near the South Pole to create a Cherenkov detector out of the natural ice. (Cherenkov radiation, visible as a blue glow, results from collisions of high-energy neutrinos with ice or rock.) This system will detect high-energy neutrinos that have passed through the Earth. They could be made up of contributions from many active galactic nuclei, or they could be point sources coming from supernova remnants, rapidly rotating pulsars, neutron stars, individual blazars, or other extragalactic point sources. Recently, new sources of high-energy gamma rays, such as Mrk 421, have been discovered. AMANDA is designed to study just such objects, which are believed to emit copious numbers of high-energy neutrinos. To date, neutrino astronomy has been limited to the detection of solar neutrinos, plus one brief spectacular burst from the supernova that appeared in the Large Magellanic Cloud in February 1987.

The AMANDA detector has operated for more than 3 years in its final configuration of 677 optical modules on 19 strings. In steady operation, the detector collects roughly 4 neutrinos per day using fast analysis software. This year, we plan a number of upgrades to existing experiments, new staff training, very-low-frequency noise investigations, and computer upgrades in the form of filtering and monitoring software.

Also, we pioneered many of the programs that are now part of the IceCube education and outreach program (see A–333–S), including the Science in the Ice course that involves high school teachers and their students, as well as participants in the Teacher Experience in Antarctica Program. (A–130–S; NSF/OPP 03–37726)

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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 must still 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./Italian agreement)

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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 somewhat 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 one that 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, one that was originally designed for geophysical exploration. Data will be returned to Dartmouth College for analysis. (A–136–S; NSF/OPP 01–32576)

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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 balloon flights to study the origin of cosmic rays. The CREAM instrument is configured with state-of-the-art particle detectors to measure cosmic ray composition 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.

Particle charge measurements will be made with a timing-based detector and a pixelated silicon matrix to minimize the effect of backscatter from the calorimeter. 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 (e.g., B/C), as well as primary spectra, will allow us to determine cosmic ray source spectra at this high energy, where measurements are currently not available.

The instrument has been tested and calibrated with a series of beam tests. It will be integrated with a flight 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. The communication interface between the science instrument and the command data module is through flight computers via an Ethernet connection. Real-time data will be down-linked continuously. All data will also be recorded to two hard drives, so anything that is not down-linked during real time can be retrieved. Other communication platforms serve as backups. (A–137–M; NSF/NASA agreement)

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Balloon-borne experiment with a superconducting spectrometer (BESS).

John W. Mitchell, National Aeronautics and Space Administration, and Akira Yamamoto, High Energy Accelerometer Research Organization (KEK), Japan.

The balloon-borne experiment with a superconducting spectrometer (BESS) investigates elementary particle phenomena in the early Universe. For further studies of low-energy antiprotons and extensive searches for antinuclei in cosmic radiation, BESS was prepared for a long-duration balloon flight in Antarctica. During a 10-day flight, an energy spectrum of cosmic ray antiprotons can be precisely measured with 10 times higher statistics, and cosmic antimatter can be searched for with greater sensitivity.

The BESS balloon payload, solar-cell array structure, and ground support equipment will be transported from the United States to William Field. Eight to ten scientists will work there from the beginning of November until the payload is recovered, after a long-duration flight, by a small plane or helicopter around the end of January. (A–140–M; NSF/NASA agreement)

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Balloon observations of MeV electron precipitation.

George Parks and David Smith, University of California–Berkeley.

We propose to prepare and fly a series of balloon payloads to study energetic electrons precipitated from the outer zone of the Earth's radiation belts into the atmosphere and then analyze the resulting data. These electrons are relativistic (kinetic energy greater than the electron rest mass) and can be responsible for damaging satellites in geosynchronous orbit. They are trapped in the Earth's magnetosphere between 4 and 6 Earth radii at the equator, which means that they hit near the Arctic and Antarctic Circles when they come down. We will address the physics of the various relativistic electron precipitation processes, their patterns in space and time, and the energy and number of electrons precipitated.

When relativistic electrons hit the atmosphere, they can produce enough ionization to create chemically important amounts of "odd nitrogen" (nitrogen dioxide and other compounds). These compounds can either destroy stratospheric ozone or else bind up and deactivate chlorine atoms that destroy ozone, thus perhaps partially protecting the ozone layer. Although their role in either case is understood to be small, it has not been well studied and may represent an important perturbation on the main chemistry.

Instruments on the balloons do not study the electrons themselves, but rather the x rays they emit when they hit the atmosphere. Balloon-borne instruments can therefore observe all the precipitation taking place within 100 kilometers of its location or more and track the variability of the emission over time. A large balloon will fly from McMurdo Station, circumnavigating the continent in 2 to 3 weeks. It will carry several x-ray detectors, as well as instruments to detect electromagnetic fields and waves. Three small payloads will also be launched in a region of the coast below the South Atlantic, where the trapped particles bounce lowest into the atmosphere because of the shape of the Earth's magnetic field.

Improving our understanding of the physics of relativistic electron behavior is not only interesting in its own right, but may also help us better predict ozone depletion and protect satellites from radiation damage. Moreover, balloon projects have proven to be ideal training grounds for graduate students in space sciences. (A–144–E; NSF/OPP 02–30441)

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Long-Duration Balloon Program.

David W. Sullivan, National Scientific Balloon Facility.

The National Scientific Balloon Facility will launch two stratospheric balloons between December 10 and January 10. They 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. All the balloons will be launched from the long-duration-balloon site near Williams Field, reach float altitude, and circumnavigate the continent between 70 degrees and 80 degrees south latitude. They will be terminated and recovered on the Ross Ice Shelf or the Polar Plateau.

When a flight is terminated, an aircraft will fly within line of sight and send a command to the payload from an onboard communication system. At the point of release, the payload will descend by parachute to a predicted impact site. Recovery operations and data analysis will then follow. (A–145–M; NSF/NASA agreement)

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Infrared measurements of atmospheric composition over Antarctica.

Frank J. Murcray, Ronald D. Blatherwick, and Pierre Fogal, University of Denver.

Using passive infrared instruments, we will measure year-round atmospheric chemistry to acquire better data 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, model predictions 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 important contributions, and the data from our instruments will also validate new satellite sensors. We are in the second year of this project. During year 1, we successfully installed and operated emission instruments at Arrival Heights and South Pole. We will install two spectrometers, one at South Pole Station and another at McMurdo Station for year-round operation, and a solar spectrometer at South Pole Station for summer operation. Also, we will collaborate with and receive data from the New Zealand National Institute for Water and Air Research, which operates a similar solar spectrometer at Arrival Heights.

During the polar night, two instruments will provide important 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. The solar spectrometers will be primarily studying the breakup of the polar vortex and photochemical recovery.

The solar instruments will provide some altitude profile information about those molecules and others. The data set we obtain will be used to determine the current state of nitrogen oxide partitioning; to measure denitrification, vapor profiles in the stratosphere, and dehydration; to determine current CFC and stratospheric chlorine levels; and to gain more insight into vortex-related chemical and dynamic effects.

In addition, the 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 data set that comprehensively covers the major constituents of both the catalytic ozone destruction sequence and global warming in order to place the relative influence of the two mechanisms in perspective. (A–255–M/S; NSF/OPP 02–30370)

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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 in this research of graduate students, especially underrepresented minorities. All 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)

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Global thunderstorm activity and its effects on the radiation belts and the lower ionosphere.

Umran S. Inan, Stanford University.

Tracking dynamic storms is a challenge, but lightning associated with thunderstorms can provide scientists with an indirect way of monitoring global weather. This project employs very-low-frequency (VLF) radio receivers located at Palmer Station and operated in collaboration with the British and Brazilian Antarctic Programs, both of which have similar receivers. All are contributors to the Global Change Initiative.

The VLF receivers measure changes in the amplitude and phase of signals received from several distant VLF transmitters. These changes follow lightning strokes 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 then increases ionization in the ionosphere, through which the propagating VLF radio waves must travel. Because the orientations to the VLF transmitters are known, it is possible to triangulate the lightning sources that caused the changes. Once the direction of the lightning source is known, it can be subjected to waveform analysis and used to track—remotely—the path of the thunderstorms.

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

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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 5 years. The detector will consist of 4,800 optical modules deployed on 80 vertical strings. AMANDA (see the Antarctic Muon and Neutrino Detector Array project, A–130–S) serves as a prototype for this international collaborative effort. This season we will to ship the remaining components, begin drilling in the ice sheet, and begin assembling and testing systems.

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)

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

Eftyhia Zesta, University of California–Los Angeles.

The South American Meridional B-field Array (SAMBA) is a longitudinal magnetometer chain extending from the low to mid-latitudes. The installation of a magnetometer at Palmer Station will extend the SAMBA chain from 10 to 12 stations and allow us to study ultra-low-frequency waves and the remote sensing of mass density in the inner magnetosphere during geomagnetically active periods.

Two magnetometer stations will be deployed, one at Palmer Station and the other at Patriot Hills, a Chilean base that operates only in the summer. The Chilean Antarctic Institute will be responsible for that installation. In September 2004, we will install a system at Palmer Station that comprises:

- a magnetometer sensor,
- a magnetometer card and electronics,
- a computer to run the system,
- a 60-yard cable connecting the sensor to the electronics, and

- a global positioning system (GPS) receiver card (installed inside the computer) with an antenna and cable.

The sensor itself is mounted at one end of a 1.1-meter (m) plastic tube with a cross-sectional diameter of roughly 15 centimeters. The sensor includes a 60-m attached cable with conduit that allows the sensor to be buried in the bedrock 1 m below the surface in a magnetically quiet environment that also minimizes temperature variations. A GPS antenna will be installed as well.

Our specific goals are as follows:

- to extend the SAMBA chain to auroral latitudes and to increase the spatial resolution of the effective cusp-to-cusp chain,
- to extend the number of conjugate pairs of stations between the Northern and Southern Hemispheres, thus increasing the size of the inner magnetospheric region that can be remotely monitored,
- to establish an auroral latitude station conjugate to the Canadian Poste de la Baleine and to study the differences in substorms and general auroral activity, and
- to provide the scientific community with near-real-time data that can be used to validate models and indexes that up to now have been tuned primarily with data only from the Northern Hemisphere. (A–357–P; NSF/OPP 03–41861)

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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)

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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 intend to deploy QUEST, a 2.6-meter Cassegrain telescope equipped with a next-generation polarization-sensitive bolometer array, to South Pole Station and operate it over two austral winters. We will mount the telescope on the existing degree angular scale interferometer (DASI) platform and reuse 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 extremely 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 will be disseminated through established structures and mechanisms, which 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 will be integrated into QUaD construction and data analysis. (A–366–S; NSF/OPP 03–38138, NSF/OPP 03–38238, and NSF/OPP 03–38335)

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Dual Auroral Radar Network at South Pole Station.

William Bristow and John Hughes, University of Alaska–Fairbanks.

The Super Dual Auroral Radar Network, or SuperDARN, is an international collaborative experiment for observations of plasma motions in Earth's upper atmosphere. By observing ionospheric plasma motions, many geophysical processes ranging from E-region plasma instabilities, to the relationships between auroral luminosity and electric fields, to the global-scale convective response to changes in the solar wind and the interplanetary magnetic field can be studied. Each of these contributes to the overall goals of space physics: developing an understanding of the coupling of energy from the solar wind into Earth's upper atmosphere and its effects on people or the systems they have created.

SuperDARN covers nearly 15 hours of local time in the Northern Hemisphere and close to 12 hours in the Southern Hemisphere. The continuous monitoring of convective flows requires radar observations that circumscribe the magnetic poles.

We will construct a radar instrument at Amundsen–Scott South Pole Station. The data we derive will be used to study a variety of topics, including the responses of global convection to solar wind and interplanetary magnetic field changes; plasma entry into, and exit from, the polar cap and the accompanying response of the magnetotail;

magnetospheric cusp response to changes in the solar wind; mesospheric winds; and thermospheric gravity waves. In addition, by establishing global-scale coverage in the Southern Hemisphere, we can address questions about conjugacy and the differences caused by the asymmetry of solar illumination.

The SuperDARN network has proven to be among the most powerful tools available for space physics research. The ability to observe global-scale convection with good temporal and spatial resolution allows us to address some of the most interesting and important outstanding questions of space physics.

In addition, as a radar network, SuperDARN fosters international collaboration, especially with the Italian Instituto de Fisica dello Spazio Interplanerario and the French Laboratoire de Physique et Chimie de l'Environnement. The cooperative scientific effort fostered under this program will have broad societal impacts and will also contribute to the education of future scientists.(A–369–S; NSF/OPP 03–37635)

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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 recently 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.

Essential to AST/RO's capabilities is its location at Amundsen–Scott South Pole Station. 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 season we will use recently installed receivers in the terahertz frequency band [SPIFI (the South Pole Imaging Fabry-Perot Interferometer), TREND] to map highly excited lines of carbon monoxide and other molecules toward star-forming regions in the Milky Way and nearby galaxies, as well as emission from ionized nitrogen (the second strongest line emitted from the interstellar medium) toward the Galactic Center. We will begin a survey of atomic and molecular lines from the Lupus and Chameleon clouds, which are being intensively studied at infrared wavelengths with the Spitzer Space Telescope. The data will be made freely available. (A–371–S; NSF/OPP 01–26090)

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PAST: The Primeval Structure Telescope.

Jeffrey B. Peterson, Carnegie-Mellon University.

We propose to build the Primeval Structure Telescope (PAST) and use it to locate and study the era of formation of the earliest luminous objects. The primeval structure we will detect contained the first stars, supernova explosions, and/or black holes. All these objects were strong sources of ultraviolet (UV) radiation, so they ionized the material surrounding them. It is this ionization that we will sense and study.

For decades, the study of the first collapsed objects was largely a theoretical exercise, since almost no data from red shift higher than 5 were available. The high red shift Universe, where the first ionizing objects resided, was inaccessible to observation. That changed suddenly in February 2003, when satellite data provided evidence that the Universe was ionized very early, before age 200 million years. To ionize the Universe at the then-prevailing density of hydrogen would have required a very strong UV flux, which means that the first UV-effusive objects were likely formed much earlier than many cosmologists had thought. Early ionization means that the Universe was more violent, structured, and interesting in its youth than had been believed.

The PAST will be a sparse array of 1,000 antennas that will span several square kilometers of ice surface adjacent to South Pole Station. The regions of sky that we will observe are available 24 hours a day, so for very deep integrations, this means about three times the effective mapping speed of a mid-latitude telescope.

The PAST array will image and spectrally resolve hyperfine emission of neutral hydrogen at red shifts from 6 to 35. As the primeval energy release developed, bubbles of ionization temporarily eliminated this emission. These bubbles were essentially the aggregate Stromgren spheres of protogalaxy groups and clusters. We will image these bubbles in three dimensions, allowing us to study their evolution and merging and pin down when the first bright objects were formed. Currently, it is not clear how many periods of ionization the Universe has passed through. At each transition between ionized and neutral, in either direction, PAST can create snapshots of the structure of the Universe.

During the first year, we will design the telescope, produce prototypes, and test them at the South Pole. During year 2, we will fabricate the telescope and install it. In year 3, the telescope will be operated over the winter. Year 4 is dedicated to continued observations and data analysis (we will release all data within 1 year of collection). (A–375–S; NSF/OPP 03–42448)

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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 scientific 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 that 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. (A–377–S; NSF/OPP 00–94605)

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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 sensitivity that rivals balloon-borne experiments and 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 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 in 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)

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South Pole observations to test cosmological models: A 10-meter telescope for South Pole.

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One of the most important discoveries in cosmology is that apparently much, if not most, of the mass in the Universe is 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). 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 will lead a consortium of six institutions to design and use a 10-meter off-axis telescope at Amundsen-Scott South Pole Station to survey galaxy clusters. One of the members of the team will deploy for 2 weeks in January 2005 to examine work done on foundations for the telescope and shield. A survey of galaxy clusters 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 crucial 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), and 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), is measurable using radio telescopes. The SZE is important to the study of cosmology and the CMB for two main reasons:

- The observed hotspots created by the kinetic effect will distort the power spectrum of CMB anisotropies. These need to be separated from primary anisotropies in order 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)

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