AERONOMY AND ASTROPHYSICS

Transporting the 10-meter dish to be installed on the pedestal at Amundsen-Scott South Pole Station. This new telescope will gather information on cosmic microwave background radiation. (*NSF/USAP photo by Bill Johnson*)

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. They are as follows:

- 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. During November working in the Dark Sector Laboratory (DSL), researchers will refurbish the BICEP receiver and upgrade the focal plane insert. The receiver, which will be cooled and tested in the BICEP lab, will be reinstalled on the BICEP telescope mount in late December and tested for mechanical, cryogenic, and electronic noise performance in simulated observing conditions. From early January through early February, researchers will calibrate the instrument, using sources mounted on the roof of DSL as well as astronomical sources. From early February through the end of the summer, researchers will optimize astronomical calibrations as the telescope is placed in winter operations mode.

BICEP operates simultaneously at 100 and 150 gigahertz 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 gigahertz and 0.7 of a degree at 150 gigahertz.

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 creating 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 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)

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. Specifically, we are interested in the strong coupling between the lower and upper atmospheres 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 an Imaging Riometer for Ionospheric Studies (IRIS) system , 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 (Northwest Territories) 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 Imager for Magnetopause-to-Aurora Global Exploration (IMAGE) 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 following:

- 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 Imager for Magnetopause to Aurora Global Exploration (IMAGE) 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 high school through postdoctoral levels of 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)

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.

Radio-Ice Chrenkov Experiment (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 also 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)

Exploratory measurement of attenuation and reflection properties of the Ross Ice Shelf at radio frequencies between 100 MHz and 1 GHz.

Steven W. Barwick, University of California, Irvine.

We will measure the attenuation and reflection properties of the Ross Ice Shelf near McMurdo Station at radio frequencies between 100 MHz and 1 GHz. In addition, the project will measure both continuous and episodic radio frequencies. This information is vital to the development of the Antarctic Ross Iceshelf Antenna Neutrino Array (ARIANNA), a high-energy neutrino concept that uses the Ross Ice Shelf and requires a medium with low losses of signal strength due to absorption and good reflection from the ice-water interface.

ARIANNA capitalizes on several remarkable properties of the Ross Ice Shelf:

- the shelf ice is relatively transparent to electromagnetic radiation at radio frequencies; and
- the water-ice boundary creates a good mirror to reflect radio signals from neutrinos propagating in any downward direction relative to the ice surface.

As a result, ARIANNA can survey more than half the sky for point and diffusely distributed sources of ultra-high energy neutrinos.

We have identified several potential sites for ARIANNA and will take measurements at one or more locations. (A-127; NSF/OPP 06-09489)

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.

We are investigating solar-terrestrial interactions involving atomic, molecular, and plasma processes in the upper atmosphere above the geographic South Pole. Using electro-optical remote-sensing facilities at Amundsen-Scott South Pole Station, we are measuring the effects of solar disturbances on the composition, dynamics, and thermodynamics of the antarctic thermosphere, mesosphere, and stratosphere. We are particularly interested in understanding five processes

- the source(s) and propagation of antarctic F-region patches;
- variations in the antarctic E-region oxygen/nitrogen ratio;
- antarctic middle atmosphere disturbances generated by Stratospheric Warming Events and energetics of the coupling among the mesosphere and lower thermosphere (MLT) regions with the stratosphere through enhanced gravity waves in SWE;
- the antarctic thermospheric response to Solar Magnetic Cloud/Coronal Mass Ejection events;
- the effects of Joule heating on the thermodynamics of the antarctic F-region.

Data for studies of these five aeronomic processes will come from two sets of remote-sensing instruments—auroral emissions brightness measurements from the sun-synchronous Meridian Scanning Photon Counting Multichannel photometer; and airglow and auroral emission spectra recorded continuously during the austral winter with a high-resolution Infrared Michelson Interferometer and Visible/Near-Infrared CCD spectrographs. From about March through September of each year, such polar studies are only feasible at South Pole Station because arctic stations are continuously sunlit. Changes in airglow temperature, from different MLT heights, permit studies of the dynamical effects of planetary, tidal and gravity waves that propagate in the MLT regions as well as non-linear interactions among these waves. Like-wise, coupling of different atmospheric regions over SPS, through enhanced gravity wave activities during SWE that lead to a precursor as mesospheric cooling, can be investigated through the observed changes in MLT kinetic air temperature and density. (A-129-S; NSF/OPP 03-37618)

Measurements addressing the initial stages of ozone recovery, the nucleation of, index of refraction of, and existence of large PSC particles

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

In the past 20 years stratospheric ozone has rapidly declined above Antarctica in the spring due to halogens released into the atmosphere since the 1930s.

Coupling halogen releases with cold austral polar stratospheric temperatures, which lead to the formation of clouds with surfaces to convert inactive to active chlorine, sets the stage for rapid chlorine-induced, catalytic conversion of ozone to diatomic oxygen as sunlight returns to the polar winter stratosphere. These interactions formed the "ozone hole" that reached unprecedented minimums in the late 1990s as stratospheric chlorine peaked.

We will to continue in situ balloonborne ozonesonde measurements through 2008. These ozone measurements, begun in 1986, documented the decline and minimum in ozone observed as chlorine increased and reached its maximum in the 1990s. The emphasis of our research is now shifting to observing the first signs of ozone recovery. Ozonesondes are uniquely capable of observing in the altitude range suffering the greatest chemical loss, and thus able to separate chemical and transport effects. Thus these instruments may be among the first to establish the ozone benefits resulting from declining chlorine.

During 2007 we will collaborate with European colleagues in a second international Antarctic campaign to test 3D chemical transport modeling of ozone loss. This campaign will occur as part of the International Polar Year and will consist of a second year of winter/spring ozone measurements from McMurdo. Laboratory investigations of the chemistry within electrochemical cell ozonesondes will help establish a transfer function for data sets which include measurements with different ozonesondes and solution strengths. This supports our WMO involvement to establish recommendations for ozonesonde operating procedures.

Another important aspect of the study is observations of polar stratospheric clouds (PSC) in the Antarctic. In this study we will continue to address questions related to the nucleation of nitric acid hydrates, the existence of large particles within Antarctic PSCs, and the index of refraction of PSC particles. Measurements associated with nucleation of nitric acid hydrates within PSCs will include collaboration with the European VORCORE project.

The broader impacts of this work have several aspects. Measurements establishing the first signs of ozone recovery are important reassurances to the world community in support of the commercial sacrifices that have been made to limit the release of chlorine into the atmosphere. Thus, in addition to the scientific interest, there are broad social implications dependent on maintaining ozone measurements through the first decade after maximum chlorine has been reached in the stratosphere. This research also contributes to the training and education of a post-doctoral scholar, engineer, technician, and graduate students. (A-131-M; NSF/OPP 05-38679)

Antarctic Impulsive Transient Antenna.

Peter W. Gorham, University of Hawaii.

The Antarctic Impulsive Transient Antenna (ANITA) is designed to identify high-energy particles created by collisions between cosmic rays and the cosmic microwave photons that pervade the Universe... Carried by a high-altitude balloon to an altitude of approximately 40 kilometers, ANITA will probe both the nature of the sources of these extreme particles, called neutrinos, and the fundamental interactions of high energy physics at extreme scales.

During circumpolar flights, ANITA will monitor radio frequencies of the antarctic ice sheet. Rare radio emissions from electromagnetic cascade interactions of the high-energy neutrinos, also known as Askaryan pulses, transmit through the polar ice.

The ANITA pathfinding mission is a high-energy neutrino astronomy project. Outreach activities of this project include

- enhanced involvement of middle school-aged girls in inquiry-based science via the web-based Antarctic Balloon Observatory Virtual Explorer (ABOVE) program;
- participation by underserved high school and college students in research through the DetectNet Program; and
- mentoring by ANITA scientists in the ANITA Academics program who will assist pre-service teachers at a historically minority campus in research related to the ANITA mission. (A-142; NASA award)

Long-Duration Balloon Program.

William Stepp, Columbia Scientific Balloon Facility.

The Columbia Scientific Balloon Facility (CSBF) provides logistic, engineering, and technical support to scientists working for NASA and for universities from all over the world. CSBF's services include launching large (400 ft. diameter), unmanned, high altitude (120,000+ ft.) research balloons; tracking them during flight; and recovering the payloads. 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. In Antarctica, the long-duration, stratospheric balloons enter the polar vortex to circumnavigate the continent between 70° S and 80° S, carrying scientific payloads to collect data on a variety of astrophysical and geophysical phenomena.

CSBF will launch three stratospheric balloons from the Long-Duration Balloon Facility at Williams Field between December 2006 and January 2007. Once a balloon has completed its mission, project personnel will fly to within line-of-sight of the balloon over the Ross Ice Shelf or Polar Plateau and send a radio command to release the payload and terminate the flight. The payload will descend on a parachute to a predicted impact site, where team members and supported scientists will use air or ground support to recover it. Payload instruments will be returned to the home institutions to be refurbished. (A-145-M; NSF/NASA agreement)

Solar Bolometric Imager.

David M. Rust, Johns Hopkins University.

Solar irradiance variations affect the Earth's climate, but the magnitude of the Sun's intrinsic variation is uncertain. Current observations cannot reject the possibility that intrinsic variations played a major role in the climate changes recorded over the past few millennia. Physical understanding, based on images of the sources of irradiance variation, will clarify the Sun's role in global climate change. From space-borne bolometric radiometers, we know that the total solar irradiance (TSI) during the 11-year sunspot cycle varies in proportion to local magnetic fields.

In this project we will study irradiance at the upcoming sunspot minimum, when the local fields will be weakest. This approach will help detect other possible sources of TSI variation with the least confusion by the large amplitude signals from local magnetic fields. It is also the best observational approach to physical understanding of the possible long-term TSI variations.

The goal is to operate the Solar Bolometric Imager (SBI 2) above Antarctica, where near-space conditions can be attained. The SBI 2 will operate for 10 to 20 days and provide bolometric (wavelength-integrated light) and color temperature images of the Sun, from which both the irradiance signals and their underlying physical causes may be assessed. Images are necessary to characterize irradiance variations associated with subtle magnetic structures, acoustic oscillations, pole-equator temperature differences, and rotational-convective cells. (A-146; NASA award.)

BLAST: A comprehensive plan for galactic and extragalactic surveys at submillimeter wavelengths from an LDB platform in Antarctica.

Mark Devlin, University of Pennsylvania.

The Balloon-borne Large Aperture Submillimeter Telescope (BLAST) will aid in addressing some of the most important cosmological and galactic questions regarding the formation and evolution of stars, galaxies, and clusters.

The telescope will fly from a high-altitude, long duration balloon (LDB). It will incorporate a 2-meter primary mirror with large-format bolometer arrays operating at wavelengths of 250, 350 and 500 m. This will provide the first sensitive large-area (~0.5 to 40 square degrees) submillimeter surveys at these measurements.

BLAST's primary goals are to

- measure photometric redshifts, rest-frame far-infrared (FIR) luminosities, and star formation rates of high-redshift starburst galaxies, thereby constraining the evolutionary history of those galaxies that produce the FIR/submillimeter background;
- measure cold pre-stellar sources associated with the earliest stages of star and planet formation;
- make high-resolution maps of diffuse galactic emission over a wide range of galactic latitudes; and
- observe solar system objects including planets, large asteroids, and trans-Neptunian objects. (A-147; NASA award)

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 (MLT), 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 MLT 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 MLT.

A meteor radar was installed at the South Pole Amundsen-Scott station in January 2001 and has been running continuously since January 2002. Data collected from this meteor radar system in conjunction with medium frequency radar data collected from the Japanese station at Syowa, Australian station at Davis and British station at Rothera will be used for this project. These data will be analyzed simultaneously to determine the structure and evolution of the horizontal circulation pattern in the MLT over the Antarctic continent. Data from a complementary network in the Arctic will also be analyzed for comparative studies in addition to observations from the NASA TIMED spacecraft.

A new sodium nightglow imager will be installed at the South Pole to infer the sodium abundance in the MLT. Observations from this instrument will be combined with the South Pole Fabry-Perot interferometer temperature measurements and the meteor radar wind and meteor flux measurements to improve our understanding of the sodium chemistry and dynamics. These observations will be interpreted using sophisticated numerical models.

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 05- 38672)

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.

Tropospheric lightning results from about 2,000 thunderstorms that are active at any given time and that maintain a global average lightning flash rate of about 100 per second. Our study focuses on the coupling of thunderstorm to the radiation belts, characteristics of lightning flashes that lead to upward electrodynamic coupling, ionospheric variability and parameters, and global lightning and climatology. We will measure the precipitation of radiation belt particles by whistler waves launched by lightning discharges via the associated localized and transient disturbances of the lower ionosphere, which are sensed remotely by means of their effect on the phase and amplitude of very low frequency (VLF) signals propagating in the nearby earth-ionosphere waveguide.

Our project is part of an international collaboration with Stanford observations at Palmer Station being complemented by and coordinated with observations at Rothera Station, Antarctica, by the British Antarctic Survey and at Commandante Ferraz (CF) station on King George Island by Centro de Radio-Astronomia e

Aplicacoes Espaciais of Brazil, and at Vernadsky Station by the National Antarctic Center of Ukraine. The program complements a similar set of measurements that are conducted by Stanford in the northern hemisphere under support from the Atmospheric Sciences Division of NSF and the Office of Naval Research. Coordinated measurements in both hemispheres are needed to study the geomagnetic conjugacy of the phenomena. A new ELF/VLF observations site is proposed to be established in Bermuda, near the geomagnetic conjugate region of Palmer to allow for the simultaneous measurement of the lower ionospheric regions in both hemispheres, especially in association with hurricane systems.

At Palmer Station we will measure broadband ELF/VLF radio atmospherics to determine the characteristic waveforms of the electromagnetic radiation (or sferics) associated with such upward electrodynamic coupling phenomena as sprites and terrestrial gamma-ray flashes. From recent studies, we know that these measurements can be useful as a proxy measure for occurrence of intense upward coupling phenomena on a global scale. The unique location of Palmer Station makes it possible for us to measure sferics originating in lightning discharges over large regions of the globe, including the Americas, Africa and the Atlantic and Pacific oceans. When used with space-borne measurements, the determination of occurrence and arrival bearings of sferics measured at Palmer is a powerful new tool for assessing global lightning activity. This effort to locate geographically lightning discharges will be carried out in collaboration with Vaisala, Inc., which operates the National Lightning Detection Network (NLDN) across the continental United States, as well as several networks in other countries and long-range systems.

As a result of this research we will develop new technologies for lightning detection, at few observation sites and on a global scale. These technologies will benefit agriculture, navigation and other activities where lightning and thunderstorms affect human life.

A new ELF/VLF observation site also will be established on Ascension Island in the southern Atlantic, with support from Vaisala, Inc., Data from Palmer and Ascension Island will provide the capability of long-range (greater than 5,000 km) detection of lightning discharges in South America and Africa.

VLF Observations at Palmer will provide crucial support to the establishment and operation of a VLF Beacon transmitter at South Pole. 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. (A-306-P; NSF/OPP 05-38627)

ELF / VLF observations in the Southern Pacific Ocean.

Umran S. Inan, Stanford University.

This project conducts very low frequency (VLF) radio measurements on board the research ship *Nathaniel B. Palmer*. These measurements are intended to support and complement the High Frequency Active Auroral Research Program (HAARP) heating facility in Gakona, Alaska, which investigates extremely low frequency (ELF)/VLF wave-injection and magnetospheric probing.

The primary tasks of the program are to

- construct and install a VLF receiver on the *Nathaniel B. Palmer*,
- study the magnetospheric amplification of ducted ELF/VLF whistler-mode signals,
- examine associated triggering of ELF/VLF emissions by the injected signals,
- investigate induced precipitation of energetic radiation belt electrons pitch angle scattered in cyclotron resonance interactions with the amplified and triggered waves, and
- transfer and analyze the data.

A key component of this research will be observations near the geomagnetic conjugate point of the HAARP HF heater, which lies in the South Pacific Ocean. The *Nathaniel B. Palmer* regularly cruises between Christchurch, New Zealand, and McMurdo Station, passing directly through the HAARP conjugate point and thus providing an outstanding scientific opportunity for measuring ELF/VLF.

The research vessel also provides a unique diagnostic platform for sampling the ELF/VLF environment in the geomag netic conjugate region of the central United States, an area rich in lightning activities and related phenomena. (A-327; NSF/OPP 05-38242)

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 Antarctic Muon and Neutrino Detector Array (AMANDA) 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, field team members will install 12 to 14 detector strings in the IceCube array and 10 IceTop stations (sensors used to detect air showers, study atmospheric muons and calibrate IceCube). In addition, project personnel will prepare for and implement the move from the temporary lab to the permanent IceCube Laboratory.

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 two 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 two 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.

We intend to

- extend the SAMBA chain to auroral latitudes and increase the spatial resolution of the effective cusp-to-cusp chain comprising Magnetometer Arrays for Cusp and Cleft Studies (MACCS), Magnetometers Along the Eastern Atlantic Seaboard for Undergraduate Research and Education (MEASURE), 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)

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)

Science Coordination Office for Astrophysical Research in Antarctica.

John E. Carlstom, University of Chicago.

Antarctica holds tremendous potential for cosmology and astrophysics that can best be realized if the scientists involved understand and participate in the management, planning, and oversight of the shared resources and logistical support. To ensure the highest quality research is conducted at the Admundsen-Scott South Pole Station, a consortium of investigators conducting cosmology and astrophysics projects, called the Science Coordination Office for Astrophysical Research in Antarctica (SCOARA), will be formed.

SCOARA will have a positive impact on the quality and timeliness of the astrophysical research conducted at the South Pole. In addition, it is anticipated all antarctic projects will benefit from SCOARA's extensive open and maintained communication channels as well as its education and outreach activities. The environment provided by SCOARA will also enhance the career development of young investigators. (A-370; NSF/OPP 04-43177)

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 noninteracting, nonbaryonic particles form 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 mast to measure the CN2 parameter at four different heights within the first 30 meters of the atmosphere (3, 10, 20, and 30 meters). 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 World Wide Web site. (A-442-E; NSF/OPP 04-40874)