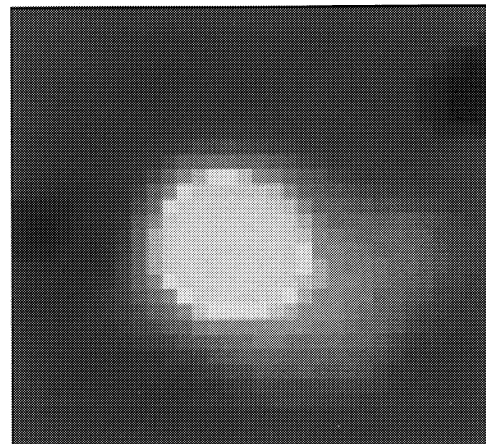
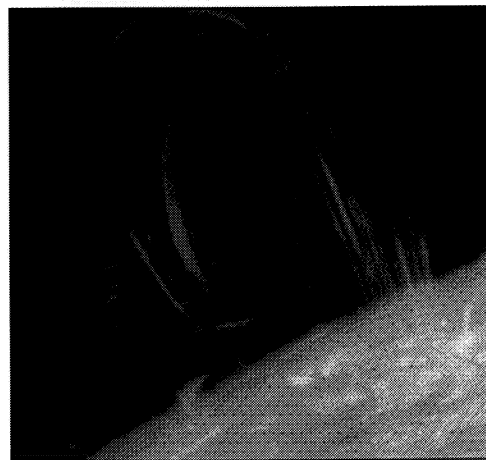
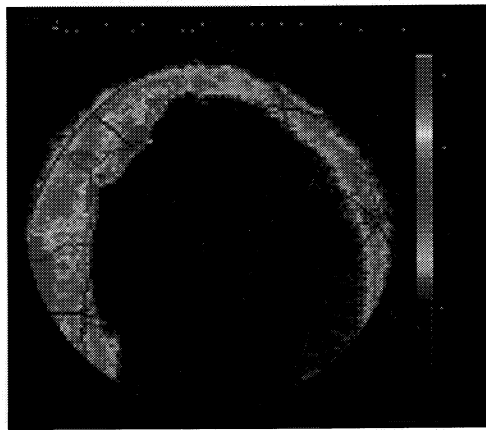
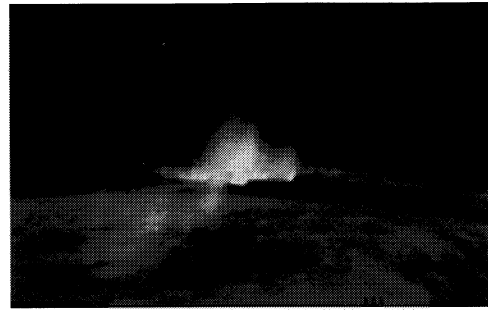
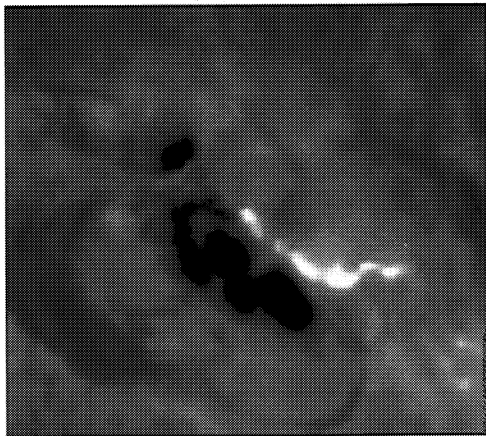


Institute for Space Physics, Astrophysics & Education

The University of Alabama in Huntsville • NASA/Marshall Space Flight Center • Universities Space Research Association

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ISPAE

Research Highlights

1995-1997

ISPAE

Institute for Space Physics, Astrophysics & Education

A Cooperative Agreement Between

The University of Alabama in Huntsville • NASA/Marshall Space Flight Center • Universities Space Research Association

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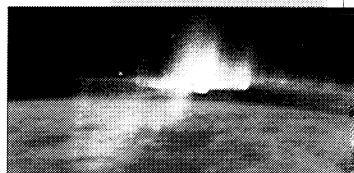
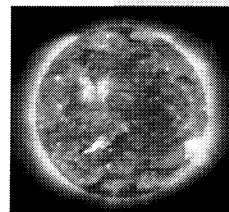
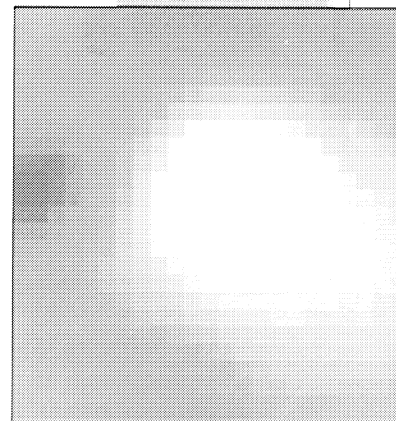
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Dr. Ken Harwell

Dr. Greg Wilson

When The University of Alabama in Huntsville joined with NASA's Marshall Space Flight Center and the Universities Space Research Association to create the Institute for Space Physics, Astrophysics and Education, this type of cooperative program was both new and familiar.

Familiar because UAH, NASA and USRA had a longstanding history of close association in both research and teaching efforts. Now, because ISPAE took that cooperation to a new level.

As ISPAE partners, UAH, USRA and NASA are pleased to participate in this report on highlights of research and educational activities supported through ISPAE programs. We are proud of the contributions that have been made toward improving our understanding of the sun, geospace and the universe. And we are excited about the future development of this collaboration.

Kenneth E. Harwell, Ph.D., P.E.
Sr. Vice President for Research
UAH

Greg Wilson, Ph.D.
Director, Space Science Lab
NASA/MSFC

The Institute for Space Physics, Astrophysics and Education (ISPAE) was established February 15, 1995 as a cooperative agreement among The University of Alabama in Huntsville, the Universities Space Research Association and NASA's Marshall Space Flight Center.

ISPAE's goal is to perform fundamental research and advance technology in the areas of space physics and astrophysics. An additional goal is to use space science research to improve science education.

As the first term of the institute agreement nears completion, numerous scientific achievements have been made and reported in more than 200 scientific publications. This document presents a few highlights of this exciting research.

Scientific instruments aboard NASA's Polar Mission have advanced our understanding of the complex magnetosphere region. The Thermal Ion Dynamics Experiment has surveyed the "polar wind" flowing out of the Earth's upper atmosphere into space, while the Ultraviolet Imager (UVI), has examined auroral emissions from space and demonstrated that UVI can monitor energy flow into the Earth's atmosphere.

Nearer Earth, ISPAE scientists measured extremely low-energy electrons over dayside auroras using instruments aboard a sub-orbital rocket.

Solar scientists are striving to understand the sun-Earth connection. Studies include solar magnetic fields and their effects in the photosphere, corona and interplanetary medium. Using MSFC's solar vector magnetograph and observed X-ray images of the sun, analyses and modeling, ISPAE researchers made significant progress toward understanding the solar atmosphere's fundamental physics and processes.

The Tethered Satellite System mission showed that a tether flown in space can collect large currents from the ionosphere. One application under investigation by an ISPAE scientist is using a tether for electrodynamic satellite propulsion.

The Burst and Transient Source Experiment aboard the Compton Gamma Ray Observatory has been involved in many discoveries, including a bursting pulsar, evidence of bursting sources from

outside our galaxy, the spin rate of a black hole, and an optical source that may be the origin of a gamma-ray burst.

Using data from Antarctic balloon flights, ISPAE scientists developed new theories about the origins of high energy cosmic rays.

Support for future space science missions was an important contribution during the first term of this cooperative venture. Researchers engaged in analysis, experimentation and modeling for future magnetospheric, solar and high energy astronomy missions, including:

- The IMAGE mission, scheduled for launch in early 2000, will produce "images" of particles trapped in geospace;
- Solar-B, a collaboration building on the successful Japan/U. S. Yohkoh mission, will reveal the mechanisms for solar variability, the origins of space weather, and global climate change;
- During Fall 1998, the Advanced X-Ray Astrophysics Facility, one of NASA's "Great Observatories," will carry the highest resolution X-ray mirror ever flown in space; and
- Gravity Probe-B, a mission to test Einstein's General Theory of Relativity, the fundamental theory of gravitation, is on track for launch in 2000.

In each of these upcoming missions, ISPAE scientists perform research to assure success and advance scientific knowledge.

Improving science education is a national and NASA priority. ISPAE is engaged in an outreach program to support this goal. In addition to training undergraduate and graduate students in space physics and astrophysics, a program is being prepared to help space scientists throughout the Southeast become involved in space science education and outreach kindergarten through the early years of college.

S.T. Wu, Ph.D.
ISPAE Director
UAH

Chryssa Kouveliotou, Ph.D.
ISPAE Deputy Director
USRA

Finding the smoking gun in gamma-ray bursts

A flash of light from a distant galaxy provides new evidence that cosmic bursts of gamma radiation which sweep past the Earth come from the distant reaches of the universe.

And that would mean the gamma-ray bursts come from cosmic events which release in seconds as much energy as our sun will emit in its ten-billion-year-life.

An ISPAE-supported team led by Dr. Jan van Paradijs, the Pei-Ling Chan eminent scholar in physics at The University of Alabama in Huntsville and a professor of astronomy at the University of Amsterdam, has identified a dim, distant galaxy as the possible source of a gamma-ray burst that swept through the sky on Feb. 28, 1997.

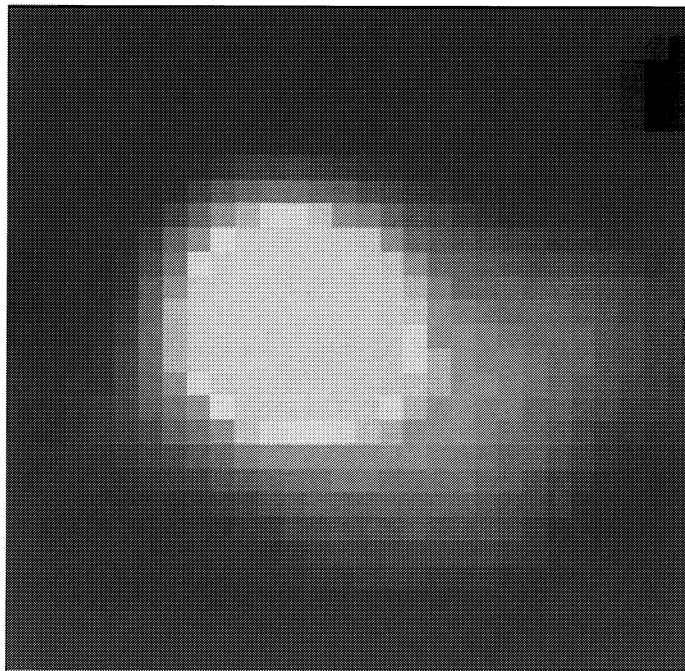
The team used data from three satellites, two optical observatories and a radio observatory in its attempt to pinpoint the burst's origin.

Detailed results of the research were published in the scientific journal "Nature." These findings are forcing many astrophysicists to rethink their theories about the origins of these violent explosions of energy.

The Feb. 28 burst was spotted by a camera aboard the Italian/Dutch BeppoSAX satellite, which provides fairly accurate locations for gamma-ray bursts. That data was used to obtain optical images using a 4.2 meter telescope at the La Palma Observatory about 21 hours and then a week after the burst. In the first image, van Paradijs and his team found a light source that does not appear on the second. Later observations found the faint image of a distant galaxy at the same point in the sky.

X-ray imaging instruments aboard the BeppoSAX satellite which were quickly pointed toward the burst location saw a glowing X-ray source, 5,000-times fainter than the Crab Nebula. Three days later, it was virtually gone, dropping in brightness by nearly a factor of 20.

"To me, this is fairly convincing evidence that the transient X-ray and optical sources are the same, and that both are associated with the gamma-ray burst," said van Paradijs. "If these transients are from the distant galaxy, we have, for the first time, found the site of a gamma ray burst."



The Hubble Space Telescope took this 'picture' of a distant galaxy which may be the source of a gamma-ray burst.

What is a gamma-ray burst?

One of the least understood phenomena in astrophysics, gamma-ray bursts are powerful flashes of gamma rays which come from random locations in the sky.

Gamma rays are electromagnetic radiation at the highest end of the energy spectrum, carrying energies almost a million times higher than visible light.

When they happen (about once a day), gamma-ray bursts outshine all other sources of gamma rays combined.

The discovery of gamma-ray bursts in the late 1960s was accidental. Since

that time, astronomers who tried to find the source of gamma-ray bursts found nothing unusual when they looked in the directions from which bursts originated.

Early theories, developed using data from NASA's orbiting Burst and Transient Source Experiment (BATSE), placed the bursts' origins either just outside the Milky Way galaxy in a large spherical halo, or from remote parts of the universe at what astronomers call "cosmological distances."

Scientists who say the bursts come from cosmological distances must

develop theories for much more powerful explosions than those needed to explain bursts if they come from a halo of neutron stars surrounding our galaxy.

Scientists can measure how powerful gamma-ray bursts are when they reach Earth, but that tells them nothing about the distance the energy has travelled.

With no information about the light source, for instance, you cannot see any difference between a 100-watt bulb one mile away and a 400-watt bulb two miles away.

*

Playing peekaboo with gamma-ray bursts

See something once — such as an optical or X-ray counterpart to a mysterious gamma-ray burst — and what you have is a scientific curiosity (albeit an important curiosity).

See something two or three times and you have a recurring phenomenon that can be measured, analyzed and modeled.

UAH's Dr. Marc Kippen, a member of the ISPAE team, has helped develop a method that accurately and quickly pinpoints the spot in the sky from which a burst came, improving the odds that a network of satellite and ground-based observatories will see the scientific curiosity of X-ray and optical counterparts to gamma-ray bursts many more times.

Getting the accurate location of a gamma-ray burst can be challenging. A telescope aboard the Italian/Dutch Beppo/SAX satellite can provide accurate locations, but sees only 20 percent of the sky at a time.

The Burst and Transient Source Experiment (BATSE) aboard NASA's Compton Gamma Ray Observatory sees the entire sky, but the computer programs which give instantaneous reports on each burst provide an accuracy of only about five to ten degrees. To scan an area that big, optical telescopes powerful enough to see the optical counterparts would need to take about 900 ten-minute exposures — twice, if you are looking for changes in the optical signal.

And it apparently takes a powerful telescope to see the optical counterparts to gamma-ray bursts: The optical counterpart to a February burst spotted by BeppoSax — the first optical counterpart ever seen — was a 24th magnitude object. That's really dim.

Kippen's team, however, found the key to getting more accurate location readings from BATSE: Insert a human into the equation.

"By using humans to analyze the data, we can use our judgement and experience to exclude background emissions so that we see only the burst data," Kippen explained. This new system gives an location within two degrees in about 15 minutes.

"The big thing we've been doing is using the BATSE data to guide the Rossi X-ray Timing Explorer (RXTE), which can pinpoint the location of an X-ray counterpart down to ten arc minutes," Kippen said. An area that size can be scanned by a large optical telescope in only four exposures.

The data are automatically distributed via the Internet, Kippen said. "We have a network of about 20 observatories which are willing to interrupt their schedules to look for counterparts. If RXTE finds an X-ray source, we make a little more effort to wake people up."

That happened three times from May through July 1997. When RXTE scanned the area from which a burst originated on June 16, 1997, it found a weak X-ray source. When other telescopes scanned that part of the sky, however, scientists found themselves facing a classic flophouse dilemma: Too many transients. In addition to a single fading optical transient, they found not one but *four* nearby X-ray sources — one of them transient.

It isn't clear which of those, if any, was the source from which the gamma-ray burst originated.

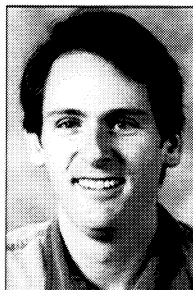
Red-shift data show bursts travel FAR

No other astronomical sources match gamma-ray bursts for their extraordinary behavior.

Since the first BATSE observations, which showed that the bursts cannot be associated with any known population of galactic objects, astronomers have debated whether the bursts come from some hitherto unknown sources within our galaxy or whether they come from far outside, at so-called "cosmological" distances.

Evidence in favor of the latter was provided by the Ph.D. dissertation of UAH student (now ISPAE staff scientist) Robert Mallozzi.

Working with BATSE data, Mallozzi showed that the energy spectral characteristics of bursts are consistent with the red-shift expected in the cosmological scenario, i.e., the characteristic energy of the burst emission is lower for weaker bursts. Mallozzi's Ph.D. adviser was Dr. William Paciesas, a research professor in UAH's Physics Department.



Robert Mallozzi

Spectral pulses muddle burst source study

The enigma of gamma-ray bursts continues to pile contradiction on top of mystery: While red shift data and the first optical counterparts might tend to show these powerful bursts coming from the farthest reaches of the universe, a new analysis of burst brightness says some of the dimmer bursts may have a "local" address.

Instead of looking at only the overall intensity of the bursts, Dr. Geoffrey Pendleton and others in UAH's Center for Space Plasma and Aeronomy Research also looked at the energy carried by the photons and electrons that make up each burst.

"There are two ways of looking at brightness," Pendleton explained. "One is that the bright events are near to us and the dim ones are far away. That's the conventional way of looking at astronomical events (using brightness to estimate distance).

"But you can also look on it as the difference between a bright lightbulb and a candle flame. That's what we looked for, by studying the presence or absence of high energy photons in each burst."

They divided the bursts into two groups, those with gamma-ray photons with energies above 300,000 electron volts (300 KeV), and those whose photons stayed in the 50 to 300 KeV range. (The weaker photons are about one-tenth as bright as the more energetic high-energy photons.)

Using those two sets of bursts, they looked for cosmological effects (*please see "Counting cosmology"*) by studying the distribution and number of bright and dim bursts in each set (a "dim" burst can have high energy photons, like a bright spotlight seen from a distance of several miles, while a "bright" burst might have no high energy photons, like a candle held close to your face).

"The brighter high-energy bursts show the expected cosmological effects," Pendleton said. "When we look at the high-energy bursts we don't see nearly as many dim ones as we would expect to see if they were distributed uniformly through space.

"When we look at the lower-energy ones, however, as they get dimmer their number density is increasing way too quickly to be cosmological," Pendleton said. "So they appear to be 'nearby' for that reason. They don't seem to originate at cosmological distances."

With one set of bursts apparently coming from the farthest reaches of the universe and the other originating nearby, could that indicate that there is more than one type of event causing gamma-ray bursts? When Pendleton's team looked again at the high-energy bursts, they found that these bursts also show "peaks" of lower energy photons.

"When I studied bursts and broke them into pulses, we found both high energy and low energy pulses in the same bursts," Pendleton said. "That says, 'OK, we're not looking at something that emits a fixed luminosity.' One gamma-ray burst source can make both kinds of emissions.

"It doesn't force you to choose either a galactic or cosmological model, but the presence of these two types of emissions with different luminosities must be taken into account in all future studies of gamma-ray bursts."

Counting cosmology

How can you tell if something in space is close to Earth or far away? By looking at how bright it is, and what it is.

Because the perceived brightness of a light or radiation source decreases with distance, astronomers use the brightness of stars and galaxies to estimate their distances from Earth. If light sources are evenly distributed throughout the universe, the number of light sources should increase as they become dimmer — there are more dim stars and galaxies in the sky than bright stars and galaxies.

If you double the distance out to which you can see, since double the distance means eight times the volume, you should see eight times as many lights, but only one-quarter as bright. Or, looked at the other way, if you look at the number of light sources down to one quarter as bright as the brightest, you would expect to see eight times more dim ones — unless the light is coming from "cosmological distances," i.e., from the most distance reaches of the universe.

If the energy is coming from that far away, by the time it gets to Earth it may be too weak for our instruments to see it. Or it may be thinned out by the expansion of the universe.

For whatever reason, astronomers say that if a phenomenon is at cosmological distances from Earth, at some point the number of dim sources decreases, instead of increasing.

An Education Facilitator/Outreach Program is being planned through NASA's Office of Space Science, in cooperation with the Universities Space Research Association, NASA's Marshall Space Flight Center, and a distributed network of educators in Space Grant and other institutions of higher education in the Southeast. This program, encompassing grades K-12 and the first year of college, will help space scientists by formulating projects and programs that integrate NASA resources and results from NASA missions into such activities as workshops, curricula, on-line activities, museum exhibits, and planetarium programs.

Einstein was right: Black holes do spin

An ISPAE scientist has made the first observation of spinning black holes, confirming Einstein's theory that black holes spin.

The observations from several orbiting spacecraft shed light on how these mysterious objects are formed and behave.

Black holes, which are predicted by Einstein's General Theory of Relativity, are believed to result from the collapse of a star or a group of stars. A black hole is an extremely compact and massive object with such a powerful gravitational field that nothing — not even light — can escape.

In a paper published by "The Astrophysical Journal, Letters," Dr. Shuang Nan Zhang of the Universities Space Research Association at NASA's Marshall Space Flight Center, and his research associates report that two of the black holes they've studied are rapidly spinning — rotating 100,000 times per second — while others spin very slowly or not at all.

By comparison, before this discovery the Crab Pulsar was considered to be among the most rapidly spinning objects in the universe, rotating 33 times per second.

"Black holes have always been difficult objects to define," said Zhang. "We can only characterize them with three properties — mass, charge and spin.

"In the past, we've only been able to measure a black hole's mass. But now that we've learned how to measure a second property — spin rate — one might say that we are two-thirds of the way to understanding black holes. This is a major leap in unraveling the black hole mystery."

"Determining the spin of black holes is of enormous importance, not only that the spin gives us an idea of how much angular momentum the black hole has 'swallowed' during its lifetime, but also we can examine whether the spin is related to the formation of powerful jets," said Dr. Mario Livio, senior scientific staff member at the Space Telescope Science Institute.

"The two rapidly spinning black holes (named GRO J1655-40 and GRS-1915+105-) also occasionally eject streams of high-speed material called relativistic jets from the black hole region — at roughly the same speed at which the hole is spinning," said Zhang.

A black hole emits no light, so the best way to observe and learn about its properties is to study its interaction with the environment around it.

"The Theory of Relativity explains that there should be a last stable orbit around the black hole," said Zhang. "Material inside this orbit cannot survive and is consumed by the black hole."

The researchers determined the spin rate by accurately measuring the closest stable orbit of material around the black hole.

"The size of this orbit is related to the spin of the black hole," Zhang said. "By looking at the material occupying this orbit and measuring the orbit's size, we can learn how fast the black hole is spinning."

To measure the orbit, Zhang and his colleagues, Dr. Wei Cui of the Massachusetts Institute of Technology in Cambridge, Mass., and Dr. Wan Chen, who is associated with both the University of Maryland at College Park and NASA's Goddard Space Flight Center in Greenbelt, Md., used data from several satellites which collect x-rays emitted from the material orbiting near a black hole.

Using this technique, they measured the spins of several stellar mass black holes — small black holes with masses comparable to stars. Those measured reside in binary systems, comprised of a black hole and an ordinary star.

The black hole, with its massive gravitational force, consumes material from the atmosphere of the companion.



NASA Photo

This is a cosmic ray detector?

Technology that will let astrophysicists use the largest high energy cosmic ray detector available (shown above) to map flaws in the universe is being developed at The University of Alabama in Huntsville.

The Orbiting Wide-Angle Light-collectors (OWL) will use Fresnel lens technology developed at UAH's Center for Allied Optics and Physics Department to watch Earth's night sky for flashes of light from highest energy (10^{20+} electron volts) cosmic rays hitting the atmosphere.

Because they can find no cosmic source that would boost particles to that energy, scientists believe they are remnants of the Big Bang that created the universe, said Dr. Yoshiyuki Takahashi, a research professor of physics. X-particles, large particles that represent the transition between the pure energy of the Big Bang and atoms, were trapped at high temperatures in "topological defects" — such as cosmic strings and primordial black holes.

Particles passing through these defects, or any disturbances, would cause X-particles in the defect to decay. Mass would be converted to energy for a few particles, sending them flying through space at almost the speed of light. By looking at the directions from which these particles hit Earth's atmosphere, Takahashi hopes to be able to "map" their origins, pinpointing in the sky the flaws and defects in the universe.

Astronomers find 'one-man X-ray band'

A new type of star, which exhibits a combination of behaviors never before seen, has been discovered near the center of the Milky Way galaxy.

The "bursting pulsar" was spotted in December 1995 by scientists using the Burst and Transient Source Experiment (BATSE) aboard NASA's Compton Gamma Ray Observatory. BATSE found energetic outbursts of high energy X-rays and low energy gamma rays being emitted every few minutes.

The source brightened until it became the brightest X-ray source in the sky in February.

When the Rossi X-ray Timing Explorer satellite, launched on Dec. 30, 1995, looked in the same spot it found another surprise: An additional source of steady radiation, which emitted pulses of X-ray radiation about twice per second. In addition, bright outbursts of X-rays and gamma-rays occur approximately once every hour. From January to mid-May, these bursts lasted from 2 to 10 seconds, with the X-ray intensity decreasing for a short time after the burst. With the reappearance of the bursts in early June, their duration lengthened to from 20 to 30 seconds.

But what was the relationship between these two objects?

The answer soon came back: The pulsar and the burster were one and the same.

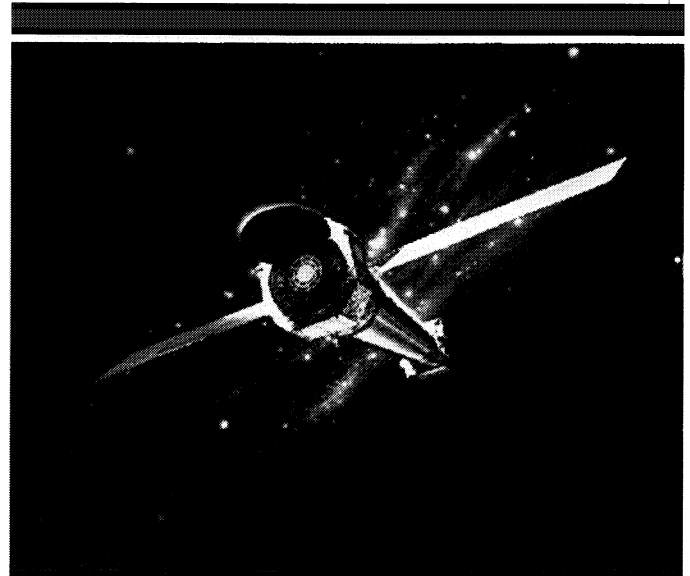
"The properties of this X-ray source are unlike those of any we know," said an ISPAE scientist, Dr. Chryssa Kouveliotou of the Universities Space Research Association at the Marshall Center. "The burst repetition rate makes this phenomenon very different from gamma ray bursts that we have observed several thousand times from throughout the universe. Also, the longer duration and persistent bursting makes the object very different from so-called soft gamma ray repeaters, which have been observed to burst in short, isolated episodes separated by several years."

"What's unique about this object is that it does so many different things all at once," said Fred Lamb, an astrophysicist at the University of Illinois at Urbana-Champaign. "We've seen sources that play the drums, some that crash cymbals, and a few that play the trumpet, but this source is a one-man band."

The bursting pulsar was later found by Dr. Mark Finger of the Universities Space Research Association at NASA Marshall to be a neutron star in a binary system, performing one full revolution around its low-mass companion every 12 days. A neutron star has mass greater than the sun and a diameter of only about 10 miles.

"The most likely explanation at this time is that the bursts of X-ray energy may result when the lighter of the pair of stars loses its material by gravitational or magnetic forces to the neutron star," said Kouveliotou.

"First, matter is accelerated to half the speed of light because of the neutron star's enormous gravitational force. Then, it crashes into the surface of the neutron star and is heated to nearly one billion degrees," Lamb explained. "Because it is so hot, it radiates almost entirely in X-rays rather than visible light, in this case with a power comparable to 1 million times the power of the sun originating from an area about the size of the National Mall in Washington, DC."

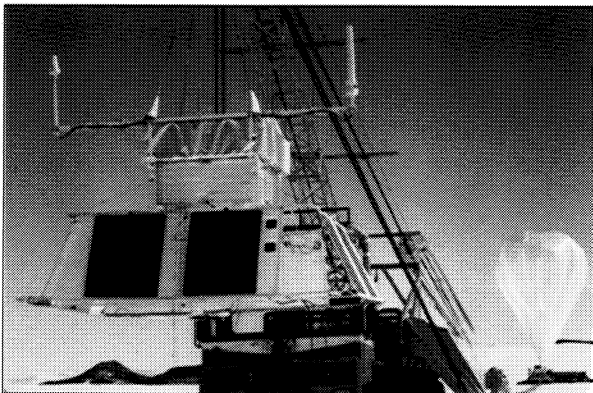


When it is launched in late 1998, the Advanced X-ray Astrophysics Facility (AXAF) will carry into orbit the highest resolution X-ray mirror ever flown in space. AXAF will study, in great detail, every class of X-ray source using sub-arcsecond and spectrometric imaging. ISPAE scientists played important roles in the AXAF program's ambitious calibration effort. This included developing the X-ray calibration source and supporting the calibration in the X-Ray Calibration Facility within the System Analysis and Integration Lab at NASA's Marshall Space Flight Center. The facility includes a 518-meter guide tube, which provides a controlled thermal-vacuum environment large enough to hold any experiment or satellite that will fit into the space shuttle's payload bay.

Cosmic rays from the supernova next door?



A 30-million-cubic-foot helium balloon (above) which will carry a cosmic ray detector (below) into the stratosphere is prepared for launch in the Antarctic.



Expanding outward for millenia, shock waves from exploding supernova stars ram into atoms in interstellar space, ripping off electrons and sending the nuclei zipping through space at almost the speed of light.

While this theory satisfactorily explains the creation of most of the cosmic rays which hit Earth's atmosphere, it can't explain the creation of cosmic rays which carry the highest levels of energy.

"Standard cosmic ray theory says a single cosmic ray can't be accelerated much beyond 10^{14} or 10^{15} electron volts, because there's just so much power in a supernova," said Dr. John Gregory, a professor of chemistry at UAH. Where then is the origin of cosmic rays with higher energies?

Using detectors which "orbit" the Antarctic beneath giant balloons, Gregory and Dr. Yoshiyuki Takahashi, a research professor of physics, may have collected enough rare high energy cosmic rays to answer that question.

While the number of cosmic rays decreases as energy increases, when the UAH team looked at the highest energy cosmic rays they found more of them than they expected. And the "mix" changed. While lower energy cosmic rays have roughly the same mix of elements as the solar system, higher energy cosmic rays have more "heavy" elements, such as iron and carbon, and less hydrogen and helium.

"It's as if the source of lower energy particles has run out of steam and we're looking at a new source," Gregory said. "Our data no longer fits the standard model."

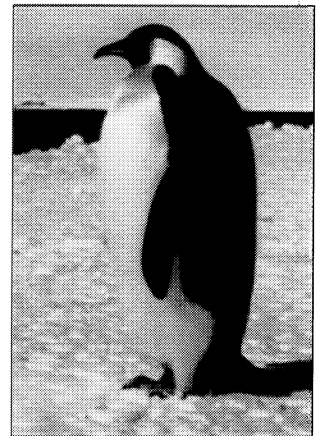
A new theory suggests that high energy cosmic rays come from binary star systems containing a recent supernova and a giant star which has blown off most of its outer layers of material.

Heavier elements from the star's core are then expelled and further accelerated by strong shock waves from its supernova neighbor. This may be the first hard evidence for identifying stellar objects as cosmic ray sources.

The cosmic ray data was collected by detectors developed as part of a program supported by the National Science Foundation and NASA. The detectors are carried aloft by giant helium balloons, which fly at altitudes in excess of 100,000 feet above sea level. The balloons are flown during the Antarctic summer, when scientists can bask in temperatures as high as 20° Fahrenheit, because circumpolar winds return a scientific payload to the area near the McMurdo Sound launch site after a 10 to 14-day journey.

Each payload included hundreds of alternating layers of lead and photographic film. High-energy cosmic rays shatter and react with silver bromide particles in the photographic emulsion as the cosmic ray's component pieces spread through the film.

Using special technology developed at UAH, scientists analyze the chain of reactions in the film to determine how much energy the cosmic ray carried, and its chemical identity.



Bright burst confirms solar storm model

A bright burst of plasma from the sun may give Earth a 40-hour warning of an incoming geomagnetic storm, says Dr. S.T. Wu, director of UAH's Center for Space Plasma and Aeronomy Research (CSPAR).

The Large Angle Spectrometric Coronagraph, launched aboard the Solar and Heliosphere Observatory in December 1995, has provided the first opportunities to test a solar storm warning system, instead of just testing theories about the causes of these storms.

Data from coronal mass ejections (CMEs) in July 1996 and January 1997 were fed into a computer model developed at CSPAR. As the preliminary data were fed into the model, the computer successfully mimicked the event, "predicting" the CME.

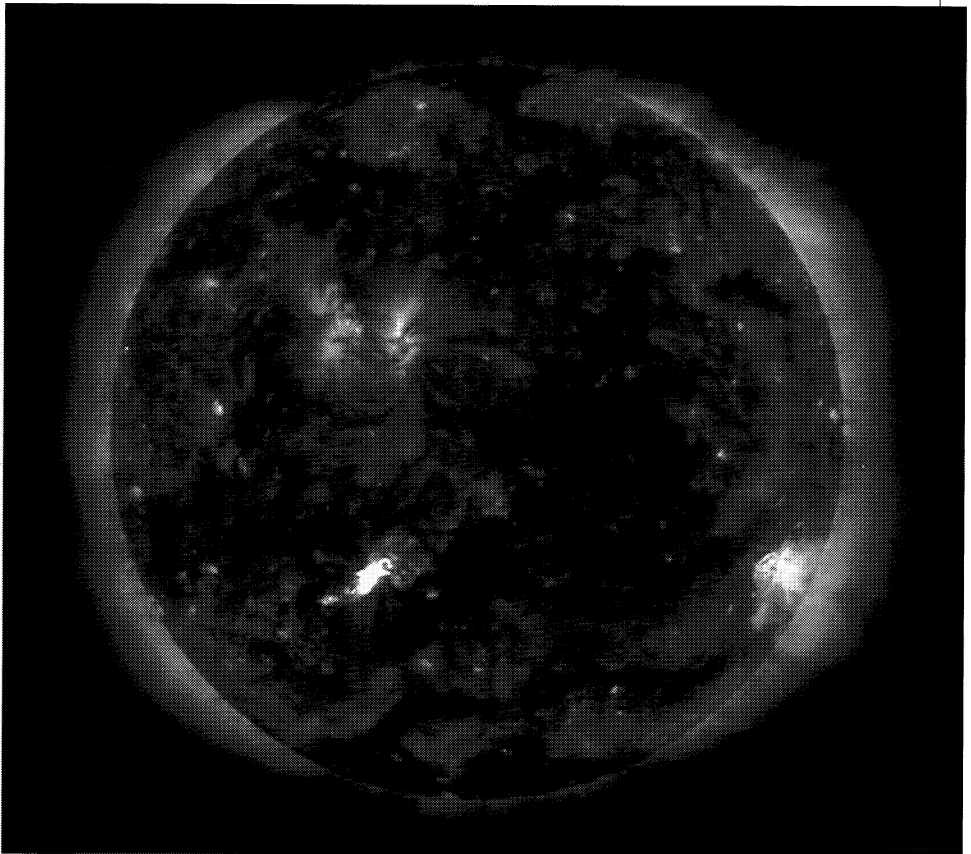
The prospect of being able to forecast bursts of solar plasma — which can cripple power systems and interfere with telecommunications — grew out of new information about what were, until recently, known as solar flares.

"In the past, we called all of these events solar flares," explained Wu. "We thought flares were responsible for everything. Now we know there are two different types of events: solar flares, which happen on the surface, and CMEs, which are corona events happening in the solar atmosphere.

"From reasoned understanding of the observations, (it seems) a majority of geomagnetic storms are caused by CMEs," Wu said.

Working in an ISPAE project supported by the National Science Foundation and NASA, Wu and other CSPAR scientists think they have uncovered the sequence of events that lead to a CME eruption. A key discovery was that coronal mass ejections always occur inside "streamers," relatively stable open flame-like structures that extend from the sun's surface. The second element is a powerful magnetic flux rope.

"The sun is a fusion machine, which very active magnetic fields that are generated by pools of hot gases that rub against each other (like magnets in a dynamo)," Wu said. "Some of these magnetic structures build so much energy



they burst out of the surface of the sun, pushing plasma into the corona."

Over most of the sun's surface, these magnetic structures are confined by a variety of forces. When a sufficiently powerful magnetic burst occurs within a streamer, however, those forces are overcome and a bright "burst" of solar material is ejected through the streamer — like a bubble rising through a hole in the ice.

"These magnetic bursts push the coronal material in front of them, causing a two-part burst, first the coronal material and then the solar material," Wu said. "There is a distance equal to a couple of Earth radii between the two materials. And it takes about two days from when we see the bright outburst until these materials reach the Earth, so we would have time to warn everyone.

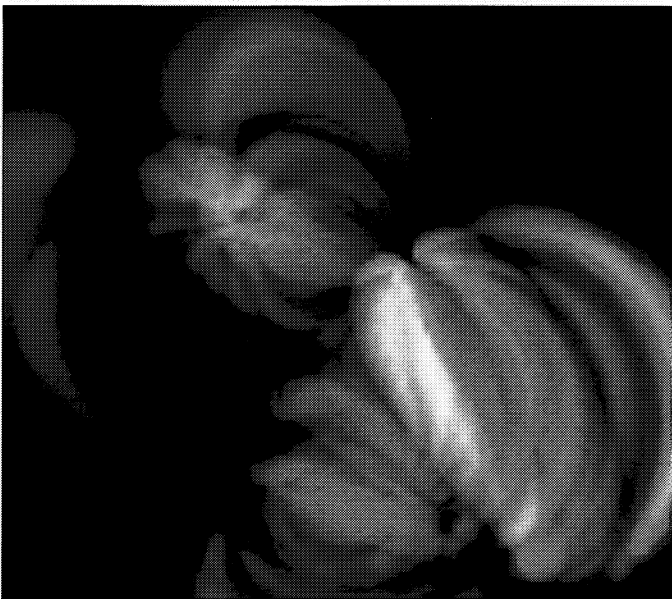
"Now our model has been backed up by these observations. That means we have developed a fundamental model that we can use to understand and predict these events, and can get a better understanding of the physics that are involved."

This image of the bright burst from an April 1997 coronal mass ejection (just below and left of the center) was captured by the Large Angle Spectrometric Coronagraph aboard the Solar and Heliosphere Observatory.

S.T. Wu, W.P. Guo, M.D. Andrews, G.E. Brueckner, R.A. Howard, M.J. Koomen, C.M. Korendyke, D.J. Michels, J.D. Moses, D.G. Socker and K.P. Dere, P.L. Lamy, A. Liebaria, and M.V. Bout, R. Schwenn, G.M. Simnett, D.K. Bedford and C.J. Eyles, "MHD Interpretation of LASCO Observations of a Coronal Mass Ejection as a Disconnected Magnetic Structure," "Solar Physics," 1997 (in press).

S.T. Wu, W.P. Guo and M. Dryer, "Dynamical Evolution of a Coronal Streamer-Flux Rope System: II. A Self-Consistent, Non-Planar Magnetohydrodynamics Simulation," "Solar Physics," Vol. 170, p. 265, 1997.

S.T. Wu, W.P. Guo and J.F. Wang, "Dynamical Evolution of a Coronal Streamer-Bubble System: I. A Self-Consistent, Non-Planar Magnetohydrodynamics Simulation," "Solar Physics," Vol. 157, p. 325, 1995.



A synthesized image of a system of X-ray coronal loops which outline the magnetic field above sunspots.

3-D rendering of solar X-ray loops

The Japanese Yohkoh satellite has revealed many new aspects of solar coronal physics: coronal structures and dynamics, gigantic arcade formations, cusp-shaped flares, soft x-ray jets, microflares, single-loop flares, and loop-loop interactions.

A research effort underway at NASA's Marshall Space Flight Center is developing unique X-ray telescopes and analysis tools for image display.

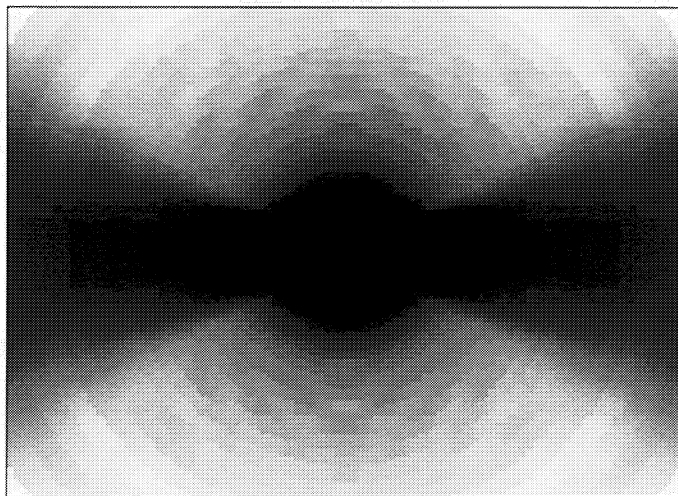
One objective is to develop innovative 3-D dynamic displays, tools and programs to simulate gaseous configurations, interactions and dynamics by rendering 3-D gaseous volumes into 2-D images, according to Dr. G. Allen Gary, a solar physicist at MSFC's Space Science Laboratory. Having line-of-sight images allows the interpretation of observations to obtain the 3-D structure of the phenomena.

The research goal is to develop pseudo-imaging techniques of soft X-ray emissions to compare with observations, in order to investigate the structure of the coronal magnetic field by analyzing the field line and emission characteristics.

A.H. Wang, S.T. Wu, S.T. Suess and G. Poletto, "Global model of the corona with heat and momentum addition," "Journal of Geophysical Research," in press, 1997.

S.T. Suess, A.H. Wang and S.T. Wu, "Volumetric heating in corona streamers," "Journal of Geophysical Research," Vol. 101, p 19,957, 1996.

A.H. Wang, S.T. Wu, S.T. Suess and G. Poletto, "Numerical modeling of coronal mass ejections based on various pre-event model atmospheres," "Solar Physics," Vo. 161, p. 365, 1995.



A computer-generated model shows the velocity of the solar wind, ranging from slowest (dark) to fastest (light). Because the solar wind twists along the sun's magnetic field lines, the solar wind that flows around the Earth comes from about midway between the sun's equator and its poles.

Model predicts speed of solar wind in space

Like dandelion seeds carried in the breeze, energized particles thrown out of the sun by a coronal mass ejection (CME) are driven by the solar wind. Sometimes those particles are thrown into a solar wind that's blowing toward Earth.

If you could put a wind gauge in the middle of that flow, you could measure its speed and predict how long it will take those particles to reach the Earth.

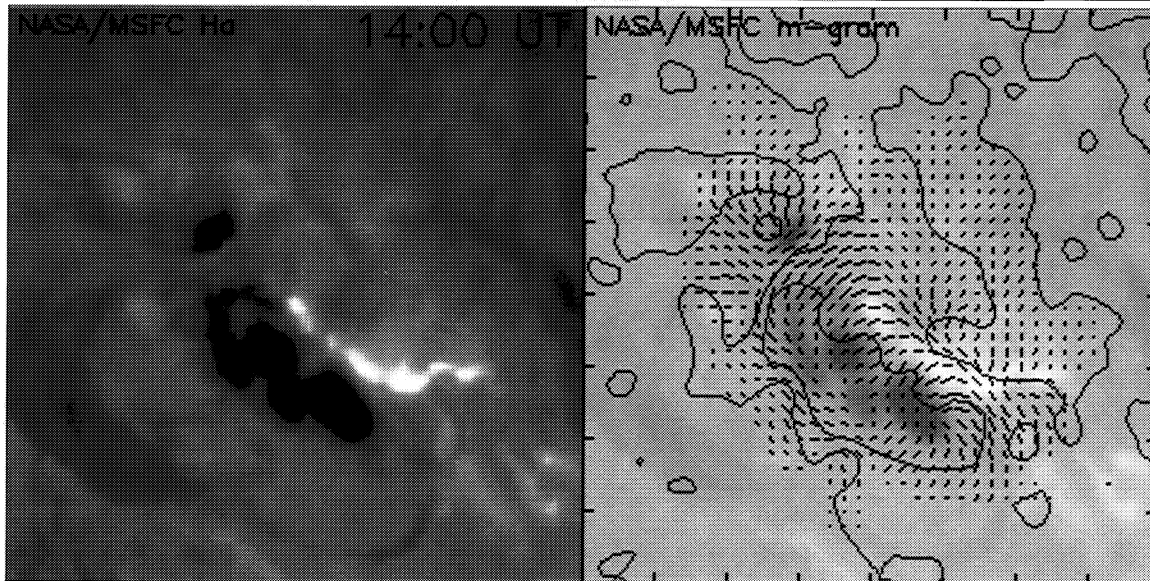
Now scientists can do the same thing using a computer model developed by Dr. Ai-Hwa Wang and others at UAH's Center for Space Plasma and Aeronomy Research (CSPAR) and the Space Science Lab at NASA's Marshall Space Flight Center.

"This is for looking at the steady state solar wind environment, from the sun to Earth and beyond," said Dr. S.T. Wu, a distinguished professor of mechanical and aerospace engineering at UAH, and CSPAR director. "This is a fundamental tool for studying these phenomenon and their effects on the Earth, because one of the major effects in the propagation of solar disturbances is the background solar wind."

To determine the speed of the solar wind in two dimensions, the model uses data on solar magnetic field measurements, and on the density and temperature of plasma in the sun's lower corona.

Plasma blowing in the solar wind is accelerated by energy flowing outward from the sun. While the fastest solar winds blow from the poles, where the sun's magnetic fields are strongest, the wind coming from the mid-latitudes toward Earth is moving pretty quickly, Wu said. "At four solar radii, it's already reached a speed of 700 kilometers per second. This will influence when the plasma from a CME impacts the Earth."

Accelerated by the power of the coronal eruption, the "enhanced" solar wind can hit Earth about 40 hours after the CME event.



Courtesy NASA/MSFC

A photo of a flare-producing sunspot, left, and the magnetic fields around it, showing the shear between positive and negative fields.

Angry sunspots snap under the strain

Powerful magnetic fields are stretched and distorted near complex sunspot groups by churning motions on the surface of the sun, strained until they snap like rubber bands. So much energy is released, the sun's surface erupts in a solar flare that launches millions of tons of superheated plasma into space.

At least, that's what some people think.

Scientists in the Solar Physics Branch of the Space Science Lab at NASA's Marshall Space Flight Center are studying the magnetic fields around sunspots, looking for the events that trigger solar flares.

"Solar flares, 99 percent of the time, occur in the region of these sunspots, which have powerful magnetic fields," said Dr. Mona Hagyard, an MSFC solar physicist. "It is thought that the magnetic fields are the source of the energy that is released in flares.

"We find that in areas where flares seem to occur, instead of the field lines going directly between the positive and negative areas, the field lines run perpendicular to that line, introducing shear.

"The field has somehow gotten twisted," she said. "It's sort of like a rubber band. If you twist it or stretch it, then let go, it snaps back. Or, if you keep stretching and if it has a weak point, it

breaks. The same is true with the magnetic tensions created along those field lines.

"One of the unsolved mysteries of solar physics is, 'What sets that off?'"

Visual images captured by MSFC's Vector Magnetograph tell the scientists the location, orientation and strength of the sun's magnetic fields.

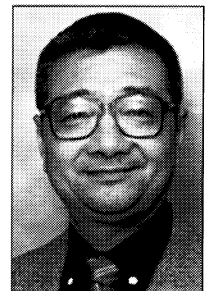
"Magnetic fields cause the light leaving the sun to be polarized, what's called the Zeeman effect," Hagyard explained. "Depending on the orientation of the magnetic field to the observer, it will be either circularly polarized or linearly polarized. The ratio of linear to circular polarization gives us the direction of the field.

"The percentage of the light that is polarized gives you the strength of the field. And the direction of linear polarization tells you which way the fields are moving across the face of the sun."

Ultimately, scientists would like to be able to predict flares. They aren't there yet, Hagyard said. "We can say, by looking at the data we get, that if the fields are strong there is a likelihood of a flare developing there. Really big flares generally occur where you see this magnetic shear.

"If we see this signature, and the fields are strong, and it's in a mean looking region, we would feel confident."

A computer model that may be able to predict solar storms was scheduled to be published on a compact disk inside the October 1997 edition of "Solar Physics." The model was developed at UAH's Center for Space Plasma and Aeronomy Research (CSPAR). Principal investigators were Dr. S.T. Wu, CSPAR director and distinguished professor of mechanical and aerospace engineering, and Dr. Weiping Guo, a postdoctoral research associate in CSPAR.



Dr. S.T. Wu

Studying things that go ‘bump’ in the flight

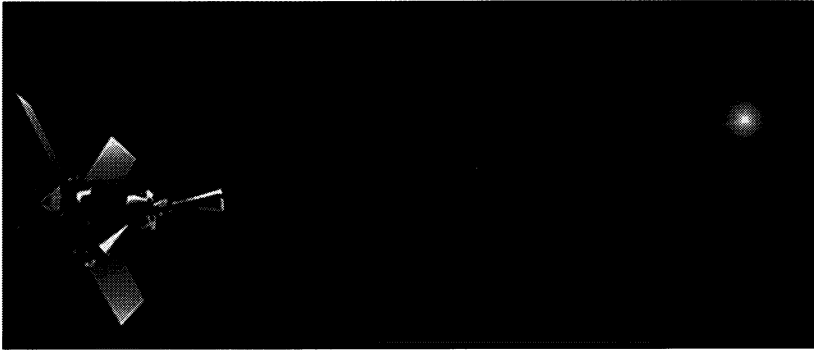


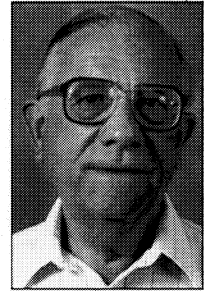
Illustration courtesy Stanford University

With Gravity Probe B's orientation in space "locked" in position using a distant star as its guide, four free-spinning gyroscopes aboard the satellite should be almost perfectly stable — unless they are disturbed by distortions in the space-time continuum.

For Stanford University scientists designing an experiment to test Einstein's general theory of relativity, even after all the engineering problems have been solved and the experiment is safely in orbit, a lot of things can still go wrong.

But are those problems enough to prevent Gravity Probe B from measuring a minute distortion in space-time caused by Earth's rotation?

Nope, apparently not, says a group led by Dr. Rudolf Decher, a principal research scientist at UAH's Center for Space Plasma and Aeronomy Research. Working in conjunction with scientists at Stanford and NASA, Decher and his team studied more than 120 "error sources" to see how much each might effect the probe's accuracy.



Dr. Rudolf Decher

When it is launched into a polar orbit in 2000, Gravity Probe B will use four gyroscopes made of almost perfectly spherical quartz balls to look for gravitational effects caused by Earth's rotation. With the satellite's orientation in space "locked" in position using a distant star as its guide, the free-spinning gyroscopes should be almost perfectly stable — unless they are disturbed by distortions in the space-time continuum.

"A rotating mass will distort, or drag, the space around it," Decher said. "The effects of the rotating mass would cause the gyroscope's axis to precess, or shift. But Earth is a very small mass, on a cosmic scale, so we get a very weak effect."

Measuring that weak effect will require remarkable precision. A complete circle is 360 degrees. There are 3,600 arc-seconds in a degree. Each arc-second is divided into 1,000 milliarc-seconds, each equal to the width of a human hair — as seen from ten miles away. The prediction is that in one year each gyroscope's axis will move about 42 milliarc-seconds due to space-time distortions caused by Earth's rotation.

Obviously, it is important to quantify everything that might torque, nudge or otherwise influence the gyroscopes.

"We're looking at various disturbances, using a computer model to see what kind of accuracy can be achieved," Decher said. "We studied more than 120 error sources or disturbances, but found that the experiment can still be done, and with good reliability.

"For example, we know the gyroscope has a lot of forces acting on it, such as irregularities in the shape of the quartz balls. There are cosmic rays impacting on the ball. Most of these have very little effect.

"The goal is to be able to measure to an accuracy of half of a milliarc-second per year in drift of each gyro's axis. After long analysis based on actual hardware tests, it looks like the experiment can be done with an accuracy of about 0.3 milliarc-seconds per year."

Tether is 'current' propulsion technology

Like a giant dynamo in a planet-sized generator, the Tethered Satellite System soared through Earth's magnetic field in February 1996 at almost five miles per second, generating an electric current in a tether which linked satellite to space shuttle.

In fact, it produced two to four times as much electrical power as had been expected, as much as 1.8 kilowatts.

One way to harness that power might be to use a tether as an electrodynamic propulsion system, to move a satellite to a higher or lower orbit, or to change its orbital inclination to Earth's equator.

"The act of drawing current will provide an electrodynamic force, converting the satellite's kinetic energy into electric energy," explained James Sorenson, a research associate at UAH's Center for Space Plasma and Aeronomy Research. As the tether system flies through space, it induces an electric current.

"Electrons are flowing down the wire," Sorenson said. "As these electrons move down the teather, there is a force on them."

NASA plans to test this theory with the Propulsive Small Expendable Deployer System (ProSEDS), which is scheduled to be launched atop an expendable booster in Fall 1999. The mission will extend a 25 kilometer tether between the payload and a 25 kilogram "end weight." The first five kilometers of tether will be a bare conductor designed to collect and carry electrical current.

One of the main problems, said Sorenson, is designing a suitable tether.

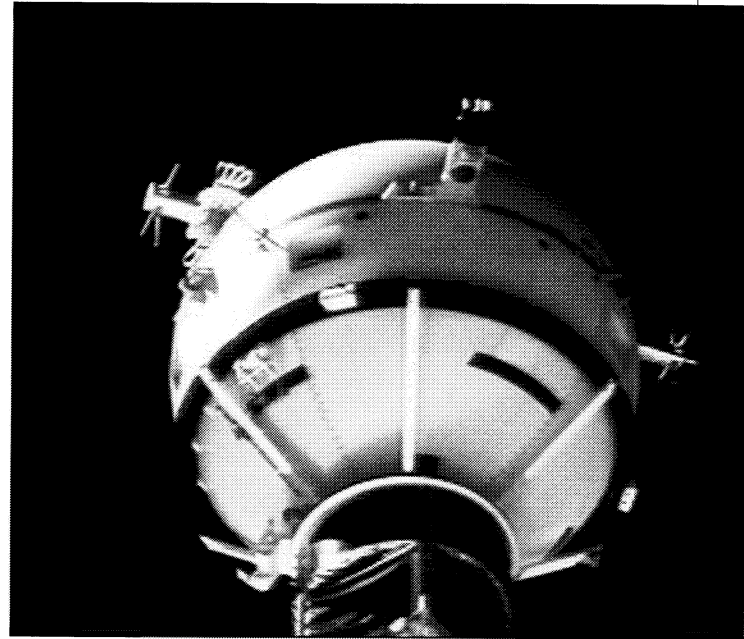
"With a single wire, the chances of it breaking within a couple of weeks due to things like micrometeor hits are less than 50 percent," he said. "A multi-wire system could probably take thousands of hits without breaking. It increases the odds of survival to nearly 100 percent for a couple of weeks, or even a couple of years."

While the main concern with using a multiline tether is whether it can be deployed using existing hardware, another concern is, will two or three smaller wires gather as many electrons as one large wire?

Using a plasma generator and a vacuum chamber in the Space Science Laboratory at NASA's Marshall Space Flight Center, Sorenson has been testing the current gathered characteristics of a variety of tether configurations, varying the sizes of the wires and the distances between them.

"So far, it appears that the multi-wire array collects about the same (electric current) as the single wire," Sorenson said. "It is possible that at some spacing, the three wires could collect more than the single wire."

This seems to be especially true when the plasma is low density, a characteristic that could be important during a mission, Sorenson said. "Such an effect would be beneficial to an electrodynamic tether because it could decrease the effects day-to-night variations in ambient plasma density have on current collection. And more constant current collection would allow more current to be collected, increasing thrust, and would be less likely to make the system unstable."

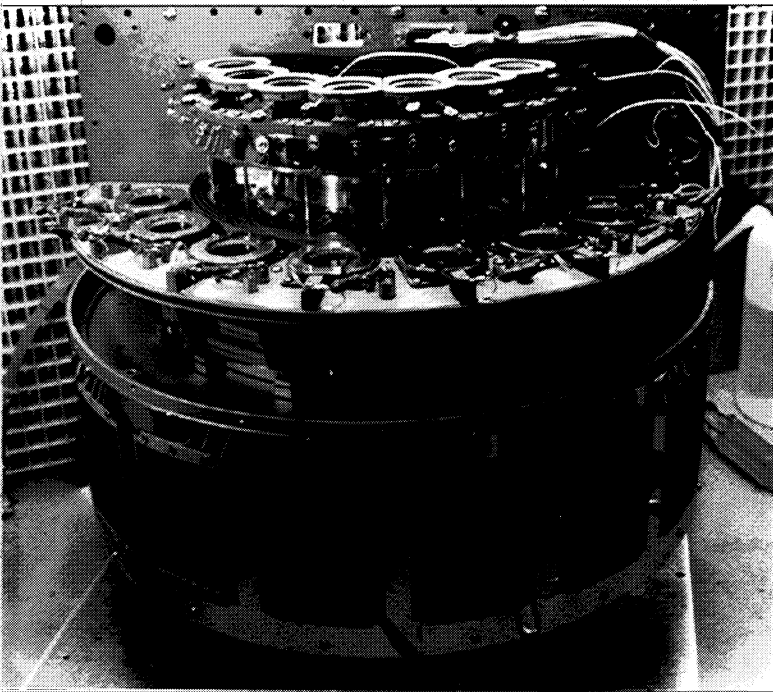


NASA Photo

The second flight of the Tethered Satellite System (above) proved the concept of 'collecting' electricity in space — perhaps enough to power an electrodynamic propulsion system like the one planned for the ProSEDS mission (below).



Plasma winds blow from the polar regions



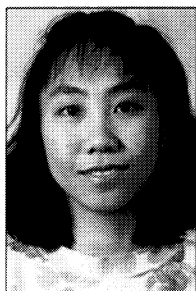
NASA Photo

The Thermal Ion Dynamics Experiment (TIDE) on NASA's POLAR satellite measures low-energy ions, from zero to 450 electron volts, as these ions are being ejected from Earth's polar regions.

The workshop "Encounter between global observations and models in the ISTP Era" was convened by Dr. James Horwitz, associate director of the Center for Space Plasma and Aeronomy Research at UAH, and NASA/MSFC's Dennis Gallagher in September 1996 in Guntersville, Ala. About 100 scientists from around the U.S. and the world attended.



Dr. James Horwitz



Ms. Yi-Jiun Su received an "Outstanding Student Paper" award for her presentation, "A couple fluid-semi-kinetic treatment of ionospheric plasma outflow: Initial results," which was presented at the Fall 1995 meeting of the American Geophysical Union in San Francisco.

A supersonic, mostly-hydrogen "wind" blows from Earth's poles into space, especially when the sun is shining, according to new data gathered by the Thermal Ion Dynamics Experiment (TIDE) on NASA's POLAR satellite.

This polar wind is slow and cold when POLAR flies through at its lowest point, only 5,000 kilometers high. It is seen to be hotter and strongly accelerated, possibly by an upward-oriented electrical field, when the satellite flies through at its uppermost point, about 50,000 kilometers high.

"We measure these ions being ejected from the polar regions," said Dr. James Horwitz, associate director of UAH's Center for Space Plasma and Aeronomy Research, and a member of the ISPAE team. "TIDE measures low-energy ions, from zero to 450 electron volts. It counts them and measures their energy and composition."

Scientists have found that this polar wind is stronger over sunlit portions of the atmosphere than over dark regions. While predominantly made up of hydrogen ions, it also includes some helium and oxygen ions as well.

The composition changes with altitude, Horwitz said. "We found that at low altitude, oxygen is about 3-to-1 more populous than hydrogen. At high altitudes, there's a dramatic turnaround. Hydrogen is 50-to-1 over oxygen. Gravity apparently inhibits oxygen from going out to high altitudes."

Horwitz and UAH graduate student Yi-Jiun Su are analyzing the data from several perspectives. They found, for instance, that at the lower altitude hydrogen ions move at "supersonic" speeds, while O₂ molecules move at subsonic speeds. *(The speed of sound in this case isn't the 600+ miles per hour speed of sound in the atmosphere. Instead, it is determined for each element based on mass and density. For hydrogen ions at that altitude, the speed of sound would be between 10,000 and 20,000 kilometers per second. The speed of sound for O₂ would be slower.)*

To count and analyze these low-energy ions and molecules, the POLAR satellite had to be grounded — electrically.

"At apogee, where it is in dilute plasma, the spacecraft is bathed in sunlight," Horwitz said. "Photons hit the spacecraft and free electrons, which collect around the spacecraft and build an electric field. Normally, there is a positive charge built up on the spacecraft, as much as 40 volts. And we're trying to measure ions at the lowest energy, so this charge is like an electric shield pushing the ions away from the satellite."

At low altitudes, collisions with the auroral plasma can build a negative charge of as much as several kilovolts, potentially leading to harmful discharges — similar to lightning strikes in space.

This is overcome by an instrument which releases and "ignites" a xenon plasma, creating an artificial electric cloud around the spacecraft that "grounds" POLAR to the surrounding environment.

"The system can get down to nearly zero volts, decreasing the electrostatic shield," Horwitz said. "That's why we have been able, for the first time, to measure the outward flows of ions in the polar wind."

De-SCIFERing thermal electrons

Above Earth's north and south poles, magnetic field lines send electrons spiraling into the upper atmosphere, where they bump into and heat ions of oxygen, nitrogen and other elements.

Thus heated, these ions are ejected outward, filling the magnetosphere and "convecting" beyond the orbit of the moon. And the electrons, which lose in these collisions the energy that helped bind them to Earth's magnetic field lines, retire to a vast cloud of low-energy "thermal" electrons.

In trying to understand the physical and chemical reactions taking place in Earth's magnetic "cusp," scientists have been hindered by not knowing how many thermal electrons there are, where they are and how much energy they carry after their journey.

Data from the Sounding of the Cleft Ion Fountain Energization Region (SCIFER) sounding rocket flight is helping scientists get a better understanding of what is happening in the boundary layer between space and Earth's atmosphere.

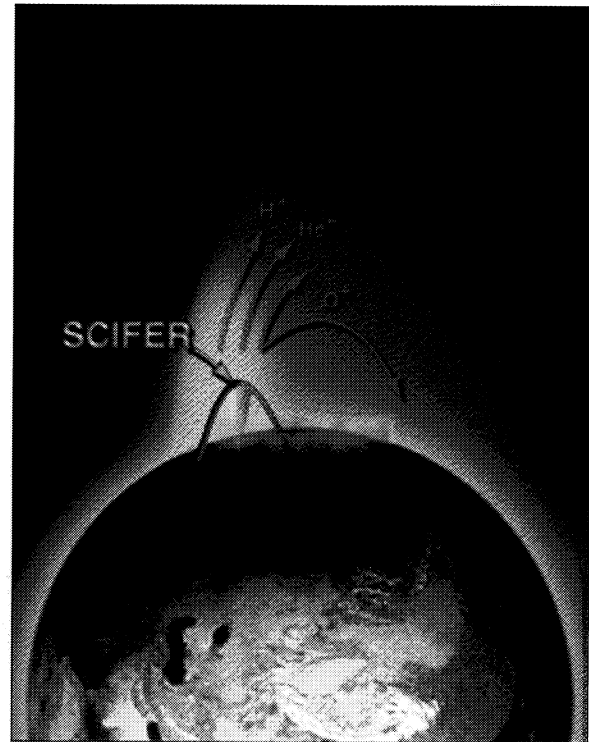
"The thrust of the mission was to categorize ion heating that takes place in this part of the atmosphere," said Mark Adrian, a Ph.D. student at UAH and a member of the ISPAE team. "I'm looking at the lowest energy electrons, which are also the biggest population. There have been only two or three measurements of these thermal electrons and none at this altitude, about 1,400 kilometers above the Arctic."

The electron counting and imaging instrument used an electrical potential across a tiny opening to deflect thermal electrons into the detector. Like iron filings caught by a magnet, electrons with too much or too little energy were deflected away from the detector. Only thermal electrons were channeled into the detector.

But how do you count electrons, especially electrons charges so small it takes 5 trillion to make a single arc across a spark plug? By inducing a cascade of electrons. The detector was made using three "microchannel plates," essentially tiny lengths of hollow glass fiber bonded side-by-side to make a thin sheet, Adrian explained. "The plates we use are made of glass fibers which release a cascade of electrons when they are struck by an electron, ion or energetic packet of light. If I drop one electron of the right energy on the top, I'll get roughly ten thousand out the back. That's enough of an electrical impulse to be able to measure.

"I can look at those impulses and know how many electrons per instant are being pulled into the system. And, since I know how the instrument was oriented in relation to the magnetic field, I can take the data and make a 'snapshot' of what the environment was like in terms of pitch angle. (*Pitch angle tells how much energy an electron was carrying, since electrons with a lot of energy travel a more vertical spiral along the field line.*) Using these snapshots, you can get information about where the electrons have been and the mechanisms that heat them.

"My measurements show that thermal electrons are not evenly distributed in space. There appears to be a lot of activity where the electrons are heated. I have some features in my data ... that suggest dual populations of electrons occupying the same space but with very different energy levels."



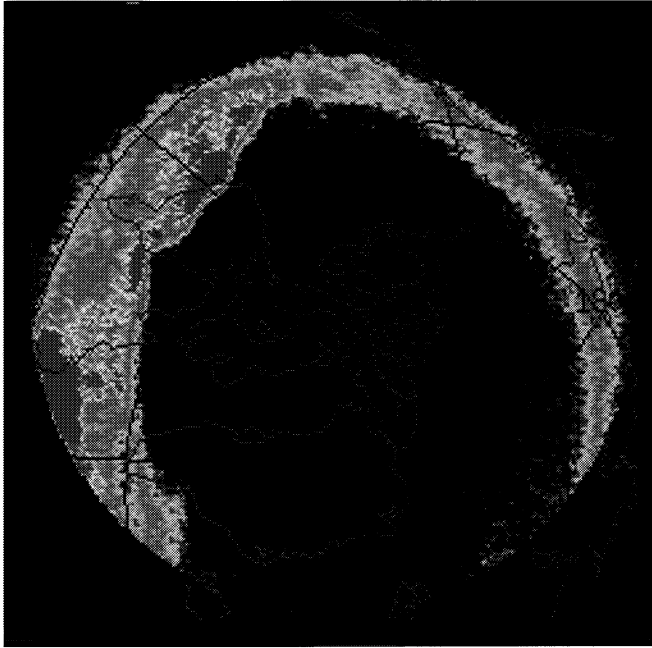
NASA Illustration

Mark Adrian received an "Outstanding Student Paper" award for his presentation, "The thermal electron plasma environment associated with transversely accelerated ions in the dayside ionospheric cleft," which was presented at the Fall 1996 meeting of the American Geophysical Union in San Francisco.

UVI lets scientists see the daytime aurora



NASA Photos



At night, the aurora is easy to see (top). By looking at only ultraviolet light, an imager aboard NASA's POLAR satellite can also "see" the aurora (below) during the daytime — which at the poles can last for several weeks during the summer months.

G.A. Germany, M. R. Torr, D. G. Torr, P. G. Richards, "Use of FUV Auroral Emissions as Diagnostic Indicators," *Journal of Geophysical Research*, vol. 99, p. 383, 1994.

M. Brittacher, R. Elsen, G. Parks, L. Chen, G. Germany and J. Spann, "A dayside auroral energy deposition case study using the Polar Ultraviolet Imager," *Geophysical Research Letters*, vol. 24, no. 8, pp. 991-994, April 15, 1997.

M. Brittacher, J. Spann, G. Parks, and G. Germany, "Auroral observations by the Polar Ultraviolet Imager," *Advances in Space Research*, in press, 1997.

Trying to study the daytime aurora boreallis is like trying to find the North Star at noon: You know it's there, but sunlight makes it doggone difficult to see.

The Ultraviolet Imager (UVI) aboard NASA's POLAR satellite, however, gives scientists the tool they need to study the entire aurora both night and day.

Auroras are caused by plasma flowing out from the sun. As it passes Earth's magnetosphere, it induces electrical currents. Electrons "are accelerated down Earth's magnetic field lines by processes we don't fully understand," said Dr. Glynn Germany, a UAH CSPAR research associate and a member of the ISPAE team. "When they get far enough down — between 100 and 300 kilometers above the Earth — these electrons start colliding with atoms and molecules in the atmosphere. They're like electrons being accelerated in a TV tube: As they hit the screen, it starts to glow."

With each collision, each electron transfers part of its energy, setting up a series of chemical and physical reactions. As these reactions release energy, the visible part comes out as the spectacular Northern Lights. Another part comes out as ultraviolet radiation.

"We're looking at those ultraviolet emissions coming up from the atmosphere," said Germany. Since UV radiation from the sun isn't reflected by Earth back into space, the UVI sees only the ultraviolet radiation that comes from the aurora.

The UVI is helping scientists understand the energy flow from space into the polar ionosphere, Germany said. "We are able to isolate individual emissions. That means we can actually model what the energy level should be."

They do this by looking at both the number of electrons and the average energy each electron carries when it hits the atmosphere. Cumulatively, a typical aurora dumps a lot of energy into the upper atmosphere, "as much as 100 gigawatts deposited, with a current in the millions of amps flowing through the atmosphere," Germany said. "It heats the atmosphere quite a bit. If you heat the atmosphere, it expands. And that causes problems for people who are trying to understand and model the energy flow into this region.

"Knowing how much energy is flowing into the atmosphere is essential if you want to understand the dynamics of what is happening there."

Scientists have studied the aurora from the ground, but could see only a small piece from any one spot, he said. "You need a satellite to see the whole circle and confirm what was seen from the ground. POLAR is the highest we have gone (*Apogee is about 57,000 kilometers above the North Pole*) with imagers, which improves our ability to see all the oval with better resolution than we had from earlier satellites."

While techniques used to analyze the data are still being refined, Germany's team found one interesting phenomenon when it looked at the aurora accompanying a major magnetic storm in January 1997: "We were looking at the energies of that storm, and we were seeing changes in the mean energy in that region as much as 30 to 45 minutes before the storm hit," he said. "It was apparently a precursor of the magnetic storm."