Kurt Miller - A Biography of a Scientist
By Anna-Laura Sloan

In a past issue of our newsletter, Professor Jeff Peterson wrote about the Carnegie Mellon astrophysics group's research at the South Pole investigating cosmic microwave radiation. The following article gives a view of this exciting work from an unusual angle. The author, Anna-Laura Sloan, is a 12-year-old sixth grader at Parker School, a public charter school in Boston, Mass. Assigned a science report on a "living scientist," she chose as her subject Kurt Miller, a 1995 Carnegie Mellon physics graduate and member of Jeff Peterson's group, who had just spent the austral summer of December 1995 through February 1996 at the South Pole. As part of the research for her report, Anna-Laura interviewed Kurt on the Internet. We decided to reprint the article in its original form so as to preserve its flavor and charm.

My scientist is a 21 year old named Kurt Miller. He studies astrophysics at Carnegie Mellon. The part that he is focusing on is Cosmic Microwave Background Radiation. C.M.B.R. is believed to be left over from the Big Bang, the beginning of the universe. The Big-Bang theory is that approximately 15 billion years ago, the universe began as a small expanding ball. In that tiny little ball, was all the matter in the universe at this present moment. Inside that ball was hot, glowing energy, but the light couldn't escape because of the matter all around it. After the universe expanded a lot, that light escaped and came shooting out. That light or C.M.B.R. is still bombarding the whole world at this very instant. He is trying to see if the inequality in spacing in the universe is the same as the inequality in C.M.B.R. This would mean that you could tell the pattern of the development of the universe from C.M.B.R.

He started working for the Viper microwave telescope project as an undergraduate to help pay the rent, but became interested in it very quickly. Now he is in charge of mechanics & some of the optics for the telescope being built at Carnegie Mellon. The most important part in the mechanical aspect is for the telescope to be able to move in its azimuth which means around in a circle, and in elevation in other words up and down. The most important part of the optics is the primary mirror, which is 2m across. The primary mirror acts like a large pupil collecting the light. The other mirrors take the light & direct it into the detector. All of these mirrors are made of shiny aluminum. He also needs to test the telescope at really low temperatures because it will have to last in the freezing Antarctica temperatures of more than negative 100 F when it is completed. It is tested by spraying the telescope with liquid nitrogen which is negative 196 degrees Celius. Testing matter at low temperatures such as these is the science of cryogenics. Using cryogenics to test the energy of the microwaves or to see the differences in their low heat, the detector has to be cooled down with liquid Helium to 10.9 Kelvin or -440 F.

Kurt believes that the best way to learn something is to do it. He went to Antarctica to work with COBRA (cosmic background radiation anisotropy) and an older system to practice for Viper. While he was there he learned about COBRA and how to study C.M.B.R. They choose Antarctica as the sight for the telescopes for three reasons. First it is easier to go down to the low temperatures you need to detect the differences between the microwaves because it is already so cold. Second, since water soaks up CMBR it is best to detect these differences in Antarctica because the coldness takes all of the moisture out of the atmosphere. Thirdly the south pole is two miles above sea level and avoids having the CMBR going through two miles of the densest atmosphere.

Kurt brought with him: A big, warm hat, normal, everyday clothes, a Walk-man and tapes, warm sweat-shirts, rope (which came in handy with repair jobs), good sunglasses (the sun never set & shined off of the snow), some candy, 'Calvin and Hobbes' and 'Outland' Comic books and other odds and ends. When he

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Our Astrophysics group continues to grow, with the appointments of Richard Griffiths and Robert Nichols. They, along with Jeff Peterson, populate the 8300 corridor of Wean Hall with an enthusiastic and productive ensemble of faculty, postdocs and students. The common theme uniting this group is interest in the early universe and cosmology. Last year also saw the establishment of the Buhl Lectureship with John Bahcall delivering public lectures about the Hubble Space telescope and the Solar Neutrino problem.

The department is busy preparing for the visit of its Advisory Board, October 28-29. Comprising alumni and leaders in business, science and academics, this board advises the department and the university administration on all aspects of our department’s goals and operation. Our first priority in the area of new faculty hiring is a junior faculty appointment in theoretical particle physics to replace Martin Savage, who left us to take a position at the University of Washington in Seattle.

This coming winter brings the retirement of Bob Schumacher after 40 years of service to Carnegie Mellon. He will remain associated with our department as professor emeritus. We wish him well in his retirement and thank him for his many contributions to our department.

Facts and figures: Our entering sophomore physics class size is 35. Last year we graduated 23 students with bachelor of science degrees, 10 master’s and 12 Ph.D. degrees. Many of our students earned honors upon graduation. We are proud to mention in particular, Kurt Miller who received the University and College Research honors, a Senior Leadership award and the Pugh Memorial Scholarship; Andrea Santoro who received the University and College Research honors, the Judith A.

Reesnik Award and a National Science Foundation graduate fellowship. Both Miller and Santoro won the department’s Cutkosky Award.

Our faculty has enjoyed honors of their own. Brad Keister became a Fellow of the American Physical Society. Bob Sekerka was recently granted an honorary Ph.D. by West University of Timisoara in Romania. The degree was awarded for Sekerka’s contributions to the science of crystal growth. This event holds special personal significance for Sekerka because Timisoara is the area from which his grandmother emigrated to the USA near the turn of the century.

We invite alumnae/alumni to visit the department any time you are in Pittsburgh. The departmental phone number is 412-268-6681. You can visit our World Wide Web site at http://info.phys.cmu.edu.

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was in New Zealand where he was given: a lot of gloves (including ‘Bear Paws’), lots of insulated hats, different types of insulated clothing, a huge warm parka, wind pants, & large heavy boots. He has things for pleasure to keep him sane and clothing to keep him safe.

Kurt left for Antarctica on December 24, 1995. He flew from Pittsburgh to Chicago, to LA, to Auckland. The flight from LA to Auckland, New Zealand takes from 12-14 hours and crosses the International Date Line and he lost Christmas. From Auckland, he took an LC-130 cargo plane to McMurdo station, from McMurdo Kurt took another noisy cargo-plane to the Amundsen-Scott South Pole Station (which is actually on the south pole). That flight took 3 hours. Even though it is the best place on earth to detect these microwaves it is very hard to reach.

After the usual sleep of 6-8 hours a day Kurt would wake up and eat. His meal would consist of either rice, beans, or pasta because these are easy to store. One strange thing about Antarctica is that it is the only place where the refrigerators are heated. Then he might stay up for 24-36 hours depending on how much he had left to do in his current project. This is possible because the sun never sets, it just goes around the sky in a circle. After work he might catch a second meal, or he might watch a movie, talk with friends, read, write a letter, listen to music, play cards, or something like that. The buildings he was in were either built on stilts or had tubes going underneath them. The cold air was supposed to blow through these because if the building was just on
Computing in undergraduate courses
by Tom Ferguson, Mike Procario and Hugh Young

Professors Ferguson, Procario and Young are using computation to help students learn the physics in our standard courses. In addition to being excellent physics teachers, these authors have made other contributions to the subject of physics. Professors Ferguson and Procario are both particle experimentalists. Professor Young is author of a widely used freshman physics textbook.

Computing plays an increasingly significant role in our undergraduate physics curriculum. Several required physics courses now have substantial computing components.

Our objectives are two-fold: First, we aim to raise the level of computer literacy of our graduates, both in the use of programming languages and in the use of symbolic computing systems such as Maple. Second, use of computer-based examples, demonstrations, and problems helps our students develop deeper understanding and intuition about physical and mathematical principles.

The Maple system, an easily learned but versatile symbolic, numerical and graphical computing system, is introduced in the course Physical Analysis, taken by all sophomores majoring in physics. In this course, taught by Prof. Michael Procario, students develop analytical and modeling skills through detailed analysis of systems such as the damped driven harmonic oscillator.

For example, the student can use Maple to differentiate the position-vs.-time function r(t) quickly and easily to obtain the velocity v(t) and acceleration a(t) functions and to graph them. Similarly, the time-varying total energy of a damped driven oscillator, a somewhat complicated function, can easily be plotted. Normal-mode frequencies and eigenvectors of a system of coupled oscillators can also be obtained using Maple.

In the junior-level courses Physical Mechanics I and II, taught by Prof. Thomas Ferguson, students use Maple's versatile analytic and graphical capabilities as a calculational tool and to enhance their intuition about the behavior of physical systems.

An example is a particle in a Lennard-Jones potential, often used to describe interatomic interactions. Students plot the function by hand and find the equilibrium point. They check their result by using Maple to plot the function and to find the minimum by differentiation.

For a given total energy, Maple is used to find the turning points of the motion, both graphically and numerically. Then students set up the appropriate integral for the time of travel between the turning points and evaluate it numerically using Maple. Finally, they expand the potential in a Taylor series, both by hand and using Maple; this expansion is then used to approximate the turning points and the travel time.

Physical Mechanics also introduces the programming language cT, developed by our Prof. Bruce Sherwood and his colleagues in the Center for Innovation in Learning. The cT language is similar to C and FORTRAN; but it also features versatile graphics capabilities and easy portability of programs across various types of computers. Students write cT programs to compute particle trajectories numerically and display the results through ordinary or animated graphs.

The junior-level course Mathematical Methods of Physics makes extensive use of Maple for in-class demonstrations and homework problems. Prof. Hugh Young cites Fourier series as an example of the usefulness of Maple. Its versatile graphing capability helps students develop intuition about convergence of series, and its ability to carry out symbolic evaluation of complicated integrals enables students to look at a wide variety of examples and applications.

Maple's animated-graphics capabilities also provide an ideal medium for visualizing such physical phenomena as normal modes of vibrating mem-

Sequence of three plots of vibrating membrane

branes (shown in the figures) and non-equilibrium heat and diffusion problems.

All three professors stress the need to balance computing versus physics, to avoid having the computing content of the courses overshadow the physics and to provide valuable enrichment to our undergraduate programs.
CP Violation
By Fred Gilman

Fred Gilman earned his Ph.D. in theoretical physics at Princeton. After 23 years at Stanford Linear Accelerator Lab he spent five years as associate director of the Superconducting Supercollider in Texas. He joined the faculty of Carnegie Mellon in 1995, accepting the endowed Buhl Chair in Theoretical Physics.

In the study of the fundamental forces and constituents of matter, symmetries of the force laws, or interactions, play a very important role. One of the great discoveries of the 1950s was that space reflections — what you see when you look at things in a mirror — were not a symmetry of the weak interactions. Indeed, this symmetry (symbolized by the letter P for parity) was found to be so strongly violated that a weak interaction process, such as a radioactive decay involving electrons and neutrinos, and its mirror image generally do not both occur in nature. At the same time it was found that the expected symmetry under changing all particles to antiparticles and vice versa (symbolized by the letter C for charge conjugation) proved also not to be a symmetry of the weak interactions. However, in the theory that emerged at the end of that decade to successfully describe the weak interactions, the combined transformation of doing both a mirror reflection and changing particles to antiparticles, symbolized CP, was still a "good" symmetry.

This situation lasted until 1964 when an experiment found a very small, but definite violation of CP symmetry in particles known as K mesons. From then until the present day, particle physicists have been trying to understand this effect, which won the leaders of the experiment that discovered it, Jim Cronin and Val Fitch (Fitch is on the Carnegie Mellon Physics Department's Advisory Board), the Nobel Prize in Physics. A long series of experiments confirmed and measured with increasing accuracy the basic effect in various ways. All these measurements may be summarized theoretically in terms of one parameter that gives a small (about 2 in a thousand) admixture of the "wrong" CP property to the neutral K mesons. A basic model, set forth by Lincoln Wolfenstein of our department shortly after the initial discovery, proposes violation of the CP symmetry arises from some, as yet unknown, "superweak" interaction.

More than a decade later, after the basic features of what is now called the Standard Model of the constituents of matter and their interactions had been developed, the theoretical situation changed dramatically. With six quarks (the last of which, the long-sought top quark, was finally found this past year) and six leptons as the building blocks of all matter, it is possible to naturally explain CP violation as a result of a phase difference between the weak interaction amplitudes of the quarks.

"It was possible, at least in principle, to get the right magnitude for the effect seen by Fitch and Cronin that corresponds to the superweak theory, but now this would have a calculable relationship to a fundamental parameter of the Standard Model. In 1978, my student, Mark Wise, and I pointed out that there should be an additional (non-superweak), but much smaller, effect in the decays of K mesons. This has been pursued over more than a decade in a series of experiments at Fermilab and at CERN, with still conflicting results — the Fermilab result is statistically consistent with no effect, while the CERN experiment gives a positive result. Both experimental teams are in the course of gearing-up for the next round experiments that will be carried out in the next couple of years. With 10 times more precision, they should settle the experimental conflict unambiguously, and be able to see if there is a non-superweak effect.

In the 1980s was understood that much bigger effects of CP symmetry violation could be seen in the decays of B mesons — particles containing the b-quark and 10 times heavier than K mesons. Many theorists noted that the phase differences between quark decay amplitudes could be very large for B's, while small for K's, and moreover could be very cleanly measured in certain B decays. Further, the Standard Model provides a characteristic pattern that can be tested for consistency between different decays. Both the Stanford Linear Accelerator Center and the KEK National High Energy Physics Laboratory in Japan are now building "B-Factories" — high intensity colliding beam accelerators that should produce large enough samples of B decays to test the theoretical predictions coming from the Standard Model when they start operation at the turn of the century. Theorists meanwhile continue to dream up alternatives to the Standard Model and propose ways of finding out which of the alternatives, if any, might lead toward understanding the origin of CP violation."
The Future of Semiconductor Physics is Bright
By Randall M. Feenstra

Randall M. Feenstra did undergraduate work at the University of British Columbia, and received a Ph.D. degree from California Institute of Technology in 1982. He worked at the IBM T.J. Watson Research Center in New York for 13 years applying the technique of scanning tunneling microscopy to the study of semiconductor surfaces and heterostructures. He joined the Carnegie Mellon faculty in 1995.

Advances in semiconductor physics in the past several decades have transformed daily life. Silicon, the basic material from which integrated circuits are fabricated, dominates the semiconductor market in terms of volume and revenue. Other semiconducting materials, such as gallium arsenide, fill important niche applications in high-speed electronics and optical devices.

What will be the next hot material? Materials such as zinc selenide and gallium nitride have large band gaps, which should prove useful in electronics that function at high temperatures (for example sensors in automobile engines). Large band gap materials also may find application as light emitting diodes and lasers in the blue to ultraviolet spectral range. The recent announcement of blue lasers (see http://nsr.mij.mrs.org/news/flash.html and http://www.sony.co.jp/CorporateCruise/News/96D-014E.html) on the World Wide Web) demonstrate that the future is bright for this field of research.

Most optical semiconductor devices are heterostructures, containing thin layers of differing materials grown one on top of the other. The different band gaps of the respective materials localize the electron or hole carriers in specific layers. Adding another dimension to such band gap engineering is strain between the layers. Although strain allows the tailoring of otherwise inaccessible band alignments, it creates some undesirable side-effects such as rough layer growth and dislocation formation. These often lead to reduced operating efficiency of devices and may produce catastrophic device failure.

In addition there are a number of physically interesting consequences of strain on the geometric structure of surfaces, such as novel surface reconstructions (different arrangements of atoms on a surface compared to the bulk) and unique morphology of steps and islands on the surface. These effects are especially common in alloys containing three or four different chemical constituents.

My research studies the geometric and electronic structure of semiconductor heterostructures on an atomic scale. I use a scanning tunneling microscope (STM), an instrument that allows one to image the atoms arranged on a surface and also to probe the spectroscopy of electronic states at specific spatial locations. With its unprecedented capability for imaging a surface on a nanometer (10^-9 m) scale, the STM has revolutionized the field of surface physics.

Whereas conventional surface probes such as low-energy electron diffraction reveal mainly the periodic aspects of surface structure, the STM provides an detailed view of non-periodic features such as defects, dislocations, and interfaces between different structures or materials.

In the STM, a sharp metal probe tip is brought within about 1.0 nm of the surface of a sample to be studied. A voltage is applied between tip and sample, and a current flows through the vacuum barrier by means of quantum-mechanical tunneling. The magnitude of the current depends exponentially on the separation between the tip and sample, so that by raster scanning the probe tip over the surface a map of the surface morphology can be constructed.

Since the current flows through only the outermost few atoms of the probe tip, atomic resolution can be obtained in the images, as illustrated in the accompanying figure. Varying the voltage between tip and sample allows spectroscopic measurements of the density of electronic levels lying a few volts on either side of the Fermi level.

When I moved to Carnegie Mellon from IBM research labs, IBM donated much of the apparatus for performing our STM studies. With this equipment, my research group can continue our research program using cross-sectional STM to study semiconductor heterostructures. In this work, the heterostructure is cleaved apart to expose a cross-sectional face, thereby permitting observation of the interfaces between layers and the unique properties of the thin layers themselves. At IBM we demonstrated the capability to atomically resolve interface structure and to spectrally resolve both two-dimensional subbands of electron confined in thin quantum wells and states introduced into the semiconductor band gap by atomic impurities. At Carnegie Mellon, together with a graduate student and postdoctoral researcher, we continue this type of study on layers of gallium nitride buried between adjacent layers of gallium arsenide in an effort to determine the composition and homogeneity of the material. Future work is planned on zinc selenide films, where the use of gallium arsenide substrates creates dislocations and eventual device failure. A detailed understanding of the interface structure may lead to improved device

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John Bahcall, this year's Buhl Lecturer, got his PhD from Harvard and did much of his early research at Caltech. He moved to the Institute for Advanced Study in the late 60's, where he became not only one of the outstanding astrophysicists in the world, but established a research center in which many other astrophysicists have been trained as students and postdoctoral fellows. During the past two decades he has been involved in the scientific leadership of astronomy and astrophysics. He was awarded NASA’s Distinguished Public Service Medal for his leadership role in the proposal of the Hubble Space Telescope and in his research with it. At the beginning of this decade he chaired a committee of the National Academy of Sciences to look at both space- and ground-based astrophysics projects for the next decade, with the resulting "Bahcall Report" serving as a model for setting goals and priorities under restrictive budgetary conditions.

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reliability. Both of these projects are conducted with external collaborators (at Oklahoma State University, and at Philips Laboratories) who grow the layers of semiconductor crystal.

In a major new initiative, we are constructing a molecular beam epitaxy (MBE) system to grow semiconductors for *in situ* characterization by STM and other techniques. This work is done in collaboration with Prof. David Greve of the Electrical and Computer Engineering Department, and is funded by the Office of Naval Research. The system will be used for studies of gallium nitride and aluminum nitride growth on various substrates. A significant problem affecting the growth of this material is lack of a suitable substrate with a similar size lattice constant, so a very high dislocation density occurs in the grown films. Remarkably, devices still function with reasonable efficiency and lifetime. We hope to understand film growth and strain relaxation mechanisms to explain why the gallium nitride devices are so much more resistant to degradation by dislocations compared to those made from zinc selenide. The MBE system being constructed will be suitable for growth of a wide range of other materials as well. We intend in the future to probe general mechanisms of epitaxial growth in strained semiconductor alloys.
Retirements

Robert T. Schumacher
came to the
Carnegie
Institute of
Technology
Department of Physics
in February of
1957, after 18
months as an
instructor at the University
of Washington. His undergraduate
degree was from the University of
Nevada in Reno in 1951, and his
Ph.D. from the University of Illinois at
Urbana-Champaign (1955), where he
worked on magnetic resonance under
Charles P. Slichter. Except for an NSF
senior postdoctoral fellowship in 1965
in Erwin Hahn’s lab at UC Berkeley,
and sabbatical semesters at Cam-
bridge, England (1977) and Stanford
(1989), he spent his entire career at
Carnegie Mellon in the Physics
Department. His professional career
has been divided into two distinct
halves. In the first half he was con-
cerned with applications of magnetic
resonance in solids. In that period,
with the aid of several accomplished
postdoctoral “students” he shep-
pered 10 students to Ph.D. degrees
on a variety of thesis topics involving
both nuclear magnetic resonance and
electron spin resonance. He is very
proud of the subsequent careers of
his students and postdocs, which
include among the students the late
Bill Vehse, Provost of West Virginia
University, and John Hall, the only
Carnegie Mellon Ph.D. to be elected
to the National Academy of Sciences.
Among the postdocs he is particularly
pleased to have worked with Walter
Goldburg (now at Pitt) and Ned
VanderVeen (now at Carnegie Mellon).

In 1975, stimulated by the lack of
appropriate explanations of musical
instrument oscillations suitable for
explanations in the undergraduate
musical acoustics course that he
initiated in 1970, he changed re-
search fields to musical acoustics.
Frustrated collaborations with Cambridge
University colleagues lead to tech-
niques for computer simulations of
musical instrument oscillations that
have even seen commercial applica-
tions. He has recently allowed his life-
long interest in the violin to steer him
into a research interest in friction of
the kind that causes the bowed string
to sometimes produce beautiful
music. He expects to have an inter-
esting “after-life” pursuing that path
and others of similar ilk.

New Astrophysics
Faculty Hiring

Our astrophysics effort continues to
grow. Richard E. Griffiths and Robert
C. Nichol will join our department this
year. They, along with Jeff Peterson,
give the department a strong pres-
ence in observational cosmology.

Richard
Griffiths
joins us from
Johns Hopkins
University. He
received his
Ph.D. from
University of
Leicester in
X-ray astron-
omy and
held positions at Penn State and the
Space Telescope Science Institute.
His research programs are in space
astronomy using earth-orbiting optical
and X-ray telescopes. In the Medium
Deep Survey, he uses the Hubble
Space Telescope to unravel the
origins and evolution of galaxies. With
data from orbiting X-ray telescopes
such as ROSAT and ASCA, Richard
probes the origins of the X-ray back-
ground from space.

Robert
Nichol spent
the last three
years at the
University of
Chicago,
working on the
Sloan Digital
Sky Survey.
Robert re-
ceived his Ph.D. from University of
Edinburgh, Scotland. His research
program presently centers on the Sky
Survey, which will comprehensively
catalogue objects in the local uni-
verse. With these data and observa-
tions made in the microwave and
X-ray wavelength regions, Robert
and his group will examine how the
complex structure of our local uni-
verse formed from the earlier smooth,
hot Big Bang.