From a Physicist and New Nobel Winner, Some Food for Thought

By DENNIS OVERBYE

OLETA, Calif. - Fresh from a new Nobel Prize, with a smile as wide as the Pacific Ocean only a Frisbee throw away, Dr. David Gross stood with a microphone on a stage at the Kavli Institute for Theoretical Physics here.

"The most important product of knowledge is ignorance," he declared. And without much more ado than that, Dr. Gross proceeded to enumerate what he considered to be the most enticing items that physics had learned enough to be ignorant about in 25 different areas.

If there are any limits of the ambitions of physicists to probe and quantify every last aspect of the world, they are not to be found here. The questions, culled from hundreds of e-mail messages from physicists around the world in the wee hours of the morning, show how physicists' ambitions have expanded. No longer content to examine the origin of the universe, they are injecting themselves into the search for the origin of consciousness and other life science issues; not content to muse about building quantum computers, they are thinking of training computers themselves to be physicists.

The occasion was a three-day conference this month modestly titled "The Future of Physics" that had been planned as a double celebration, but turned into a triple one. It was both the 25th anniversary of the institute, which was founded by the National Science Foundation on the University of California at Santa Barbara campus here in 1979, and the dedication of a new wing, designed by the architect Michael Graves, complete with a portholed lounge on the second floor looking out to sea.

The center, named three years ago for Fred Kavli, an inventor and businessman who has become a financial angel of physics.

On Oct. 5, the day before some 150 physicists were to arrive, Dr. Gross, the director of the institute, was named one of three winners of this year's Nobel

Prize in Physics, along with Dr. Frank Wilczek of the Massachusetts Institute of Technology and Dr. H. David Politzer of the California Institute of Technology, for helping explain the force that holds atomic nuclei together and pens quarks together inside protons and neutrons, where they cannot be seen.

As a result, the strawberries and whipped cream heaped in bowls on the seaside lawn seemed especially sweet.

"Let's take this house of science on a ride through the stars to solve some of humanity's most fundamental questions," Mr. Kavli said at the dedication.

Dr. Gross had enlisted an all-star cast of physicists, including Dr. Wilczek and six other Nobelists, to discourse on what the last 25 years in physics had wrought and the next 25 might bring.

As reflected in the talks here, the history of physics as well as the history of the institute in the last quarter century, is, like the universe, a story of expansion outward from fundamental forces and particles, like gravity and electrons, to the behavior of larger and larger agglomerations of matter, complex systems, the weird quantum properties of materials chilled to near absolute zero, subject to huge pressures or magnetic fields, to planets, stars and even life itself. Physicists who went into biology once were content to apply their methods and training to answering the questions raised by biologists, noted Dr. William Bialek of Princeton, but now physicists were asking their own questions about living systems, searching for universal principles underlying the activities at different levels of life.

In assembling his list, Dr. Gross was joining distinguished company. In 1900 the mathematician David Hilbert published a list of 23 important problems that has formed a research agenda ever since. At the millennium four years ago, Dr. Gross, and two other physicists, Dr. Michael Duff of the University of Michigan and Dr. Edward Witten of the Institute for Advanced Study inPrinceton, N.J., assembled a list of 10 questions in particle physics and cosmology.

Some of Dr. Gross's questions are ripped from the headlines. What is the dark matter that enfolds the visible galaxies? What is the dark energy that seems to be accelerating the expansion of the universe? Was there a time before the Big Bang that started the universe, or is time itself an "emergent concept" deriving from something more fundamental that we don't know yet? Can physicists make room-temperature superconductors?

Others reach into less publicized fields in an effort to tap into uncharted controversies of the future. Here is a sampler. Dr. Gross's talk is online at online.itp.ucsb.edu/online /kitp25/gross/.

Can we measure the onset of consciousness in an infant?

"I love this one," said Dr. Gross, who speculated that such an event was what physicists call a "phase transition," like the sudden melting of ice into water, when some microscopic change causes a large-scale change in behavior. "At some point it turns on," he said. Putting the emphasis on measuring this, Dr. Gross explained, meant that physicists would first have to define precisely what consciousness was.

Can the theory of evolution be made quantitative and predictable?

Given what we know about the genetic code and about organisms, is it possible to do experiments on real organisms and make quantitative predictions? In particular, Dr. Gross asked, "Can one tell the shape of an organism by its genome?" This, he mused, to much laughter, could be homework in biology classes: give out a chart of the genome and have the student "draw the picture."

Is quantum mechanics the ultimate description of nature?

It is amazing Dr. Gross noted, that 80 years after the theory was formulated physicists and philosophers are still debating the meaning of the paradoxical rules that govern atomic behavior and underlie all modern technology. They include such infuriating features as the uncertainty principle, which ascribes a certain randomness to atomic events.

"I see no evidence that anything is wrong with quantum mechanics," Dr. Gross said to a ripple of laughter, but, he added, physics should explore the possibility that it would break down at short distances where gravity becomes important, or in large complex systems, or as a description of the universe itself.

Can we use astronomical observations to determine the geometry of space-time around a black hole?

Einstein's general theory of relativity, which explains gravity as the warped geometry of space-time, is the mathematical language of cosmology, but is it really correct? The theory has never been experimentally tested in the really strong gravitational fields that prevail in a black hole, the gravitational abysses that according to Einstein can stop time and swallow everything, even light.

"Right now we have no data," Dr. Gross said. But many physicists hope that they will eventually be able to diagnose the space-time structures of black holes by studying the roiling and rippling of space-time, so-called gravitational waves, from the collisions of black holes, or by following the motions of individual stars caught in that fatal black grip, and thus find out if Einstein's theory is right.

Modern particle physics, despite its success as exemplified by his own Nobel, is awash in mystery, Dr. Gross said. For example, physicists have yet to come up with satisfactory equations to describe quantum chromodynamics, the theory of the strong force.

Nor can physicists explain in any quantitative detail why the universe consists of matter and not antimatter, its bad-twin opposite. Neither question can be answered by the present reigning theory, a suite of equations, known as the Standard Model, he said. Rather it has whetted physicists' desires for a grander more encompassing theory.

Is there low-energy supersymmetry?

Nearly every scheme that seeks to unify the forces of nature into a single equation relies in part on this concept. It posits a relationship between the particles known as fermions that comprise matter and the particles known as bosons that comprise forces like electromagnetism or the strong force. If it is true, all of the known elementary particles have partners, as yet undiscovered, but which might constitute the dark matter in the universe.

But there is as yet no scintilla of evidence in favor of supersymmetry. Does it exist at the low energies available to human experimentation? "The whole field hangs on the answer," said Dr. Gross, who added that it was the "undying hope" of physicists that supersymmetric particles would be discovered when the Large Hadron Collider, to be the world's largest, most energetic particle accelerator, starts operating in 2007 at CERN, the European research consortium in Geneva.

Is physics an environmental science?

This is one of the more philosophical and contentious questions facing modern physics. Is it possible, Dr. Gross explained, to calculate all the parameters characterizing nature, like the ratios of masses of elementary particles or the strengths of the fundamental forces, from whatever the final theory turns out to be? Or are some things simply accidents of history or random quantum mechanical events?

Einstein proclaimed a theory that left God "no choice" in such matters as the goal of physics, but, as Dr. Gross acknowledged, recent results from string theory, the putative theory of everything, and cosmological speculations about the Big Bang, produce a "landscape" of gazillions of possible universes, each with different properties determined basically by chance. Our own universe has the features it has, some theorists go on to suggest, because those are the conditions under which life could evolve. We live where we can live goes the argument, but Dr. Gross admits that he hates it.

"I hate to give up this ambitious goal," he said, referring to the Einsteinian dream of being able to predict everything. He added that it was "kind of fun" being a conservative.

Can we understand big things by understanding little things?

After all, big things, no matter how complicated, are made of little things. Physics has been guided since the time of the Greeks by the assumption, known as reductionism, that the world can be understood by breaking it down into tinier parts, a few elementary particles interacting through four basic forces.

But, Dr. Gross, a card-carrying reductionist, asked of the reductionist principle, "Is this anymore obviously true than was the idea that nature can't tell the difference between the left hand and the right hand?" He was alluding to surprising experiments at Brookhaven National Laboratory in the 1950's showing in fact that nature did know the difference between left and right when it came to the "weak" force that causes some kinds of radioactivity.

Could physicists be so wrong again? "Who knows?" Dr. Gross said.

When will computers become creative theoretical physicists? And how will we train them?

Dr. Gross attributed this question to his fellow Nobelist and former student, Dr. Wilczek. While others have suggested that computers will eventually take over, the issue of how to teach them was novel. In keeping with his job nurturing theorists Dr. Gross added, "And that's really fun to think about."

Will physics still continue to be important?

This, Dr. Gross admitted, was the 26th question, but he allowed himself to go over his own limit, he said, because this one had an answer.

"Yes," he said.