While Hawaii is proud to be the 50th state of the U.S., a non-AAPPS member, our geographic proximity and cultural affinity to Asia, plus our strong ties to colleagues there, seems to qualify our University’s Department of Physics & Astronomy for some type of affiliate connection to the AAPPS. As such, we are pleased to have this opportunity to describe physics research activities in our department to AAPPS Bulletin readers.

The “Astronomy” part of our Physics & Astronomy department is primarily based in the University’s well known Institute for Astronomy. Their activities would more than fill a single Bulletin issue. In this article we focus on the physics activities in our department, which are concentrated in three main areas: Free Electron Lasers, Nanophysics, and Elementary Particle Physics.

1. FREE ELECTRON LASERS
The UH physics department Free Electron Laser group is led by John Madey, the inventor of the FEL, and includes faculty members Luis Elias, Pui Lam and Eric Szarmes. The group’s research is centered around the MOPA III infrared laser and the THz terahertz laser.

1.1. The MOPA III Free-Electron Laser
The department is currently installing an infrared, rf-linac-based FEL. The MOPA III FEL, originally developed by Madey at Stanford University, is a continuously tunable, mid-IR laser source that delivers a diffraction-limited beam of phase-
locked, picosecond optical pulses of extremely high peak power and spectral brightness for fundamental and applied research, including:

- ultra-sensitive lidar and remote sensing.
- high-resolution excited state spectroscopy.
- generation of tunable, high brightness single-mode radiation by optical phase-locking techniques.
- Doppler-free nonlinear spectroscopy and Doppler limited absorption spectroscopy.
- compact x-ray sources.
- studies of the non-classical nature of FEL light.
- optical pulse compression and pulse shaping.
- photo-chemistry and surface science.
- novel FEL configurations including multiple inverse-tapered undulators.
- medical research; hard- and soft- tissue-laser interactions.

Current research activities of the group include remote sensing and excited state spectroscopy, cavity electrodynamics, the fundamental theory of free-electron lasers, novel configurations of FELs for coherent multicolor spectroscopy, the design of optical resonators for the production of coherent optical pulse trains and tunable x-rays, and novel techniques for linear and nonlinear optical spectroscopy.

1.2. Terahertz Free Electron Laser Group

The Terahertz free electron laser is based on an electrostatic Van-de-Graf accelerator using a novel recirculating beam system that was developed by Elias. This device has been transported from the University of Central Florida to the UH where it is currently being installed. The FEL will be operate as a user facility generating high power, highly coherent output in the range 0.6-1.3 THz. The research plans for this activity include:

- Study the interaction of THz radiation with molecular, biological and solid-state systems.
- Develop solid state sensors and devices in the THz region.
- Develop plasma gating techniques which can be used to generate short THz pulses.
- Use the Lienard-Wiechert potentials to conduct theoretical studies.

![Fig. 2: The undulator section of the MOPA III FEL.](image1)
![Fig. 3: The recirculating CW THz FEL.](image2)
![Fig. 4: A stretched bundle of carbon nanotubes in an image that was produced by the UH scanning-tunneling electron microscope.](image3)
studies of the generation of coherent FEL radiation in the time domain.
• Development of CW FELs.

2. NANOPHYSICS
The Hawaii Nanophysics Cluster Research Group, led by Prof. Klaus Sattler, is involved in research that centers around the data provided by the excellent array of ultra-high resolution microscopes and spectrometers that are available in the lab. These include a state-of-the-art Atomic Force Microscope, and a scanning-tunneling electron microscope, both of which produce stunning images of atomic surface structures, and encourage a variety of exciting solid state research topics. These are used to study carbon nanostructures such as nanotubes and metallic clusters on a graphite substrate.

3. PARTICLE PHYSICS
Particle physics has been a prominent research activity of the physics department since the 1960’s and involves the largest group of faculty. The major research activities are phenomenology, particle astrophysics, and studies of heavy quarks produced in e+e- annihilations. All of these activities involve close collaborations with institutions in Asia. The proximity to the superb facilities at KEK and the Kamioka underground laboratory in Japan and IHEP in Beijing have greatly benefited the experimental group’s productivity.

3.1. Particle Theory
The Theoretical Physics Group consists of faculty members Kirill Melnikov, Sandip Pakvasa and Xerxes Tata together with two post-doctoral researchers and graduate students. The interests of the members of the Group span a wide range of topics in particle physics phenomenology including, neutrino physics, CP violation, heavy quark systems, precision calculations in quantum field theory, supersymmetry, grand unification, implications of extra spatial dimensions, and other ideas for physics beyond the Standard Model, and the implications of particle physics for cosmology and astrophysics. They interact vigorously with one another, and over the years have formed wide-ranging and long-term collaborations with colleagues at other institutions, both in the USA as well as abroad. The visibility of the theory research program may be judged by the fact that the group members are regularly invited to describe their research at international conferences as well as to lecture at particle physics summer schools world-wide.

The central theme of the group’s work is the exploration of different ways in which the Standard Model (SM) of particle physics may be extended, and how these various extensions would manifest themselves in various experiments, either at high energy colliders or at non-accelerator facilities. Pakvasa is a recognized expert on neutrino physics and astrophysics as well as the phenomenology of CP violation. Together with Hirotaka Sugawara, he co-authored what is probably the first paper on the examination of the phenomenology of the now text-book Kobayashi-Maskawa model. His many seminal suggestions for models of neutrino masses and mixing, which include the celebrated bimaximal neutrino-mixing matrix, have received much attention from both the theoretical and experimental communities. Melnikov is one of the leading experts on the application of quantum field theory to particle physics phenomenology. He is a versatile researcher whose contributions encompass a wide range including: radiative corrections in quantum electrodynamics (with recent applications to positronium), three loop QCD corrections to quark masses, studies of the tt system near threshold at linear e+e- colliders, QCD corrections to Higgs boson production at hadron colliders, heavy quark physics, lattice perturbation theory, the anomalous magnetic moment of the muon. He is currently working on developing new techniques that will enable calculations that, despite ever-increasing computer power, are intractable by current methods. Tata has been a leader in the development of strategies for the detection and elucidation of different new physics scenarios at high energy colliders, with a strong emphasis on supersymmetry, a novel symmetry that, unlike any other symmetry, relates the properties of bosons and fermions, providing a new level of synthesis.

The broadly common phenomenological goals but their diverse expertise leads to healthy and fruitful interactions between the various members of the theory group. They interact vigorously with their experimental colleagues in Hawaii and elsewhere, and are on the cutting edge of new developments on the frontiers of particle physics phenomenology.

3.2. Neutrinos and Particle Astrophysics
The UH High Energy Physics group has a long association with neutrino physics and nucleon decay studies and some associated particle astrophysics. The group is led by faculty members Peter Gorham, John Learned and Shige Matsuno, and their present programs are in neutrino studies with the Super-Kamiokande and KamLAND experiments located in Japan, the ANITA experiment which will fly on a balloon in 2006 in Antarctica, and other initiatives.

ANITA (Antarctic Impulsive Transient Antenna) is a NASA-funded balloon experiment, led by Gorham, to fly a payload consisting of a cluster of 40 broadband radio antennas high above the Antarctic ice sheet in late 2006 for up to 40 days or more. The goal of the project is to observe cosmic ultra-high energy neutrinos for the first time. The experiment is based on the fact that electromagnetic showers produced ultra-high energy neutrinos in ice will yield strong radio Cherenkov emission, detectable even far above the ice as an extremely sharp radio impulse. The process by which such radio impulses is produced was first experimentally measured by Gorham and collaborators using the
Stanford Linear Accelerator Center’s electron linac. This observation has led to a number of new initiatives to detect high energy particles. ANITA is unique in this field because of the enormous volume of ice it can monitor simultaneously during the flight. Since Antarctic ice is extremely transparent to radio waves, ANITA can peer far down into the ice to detect cosmic-ray-neutrino-induced interactions, giving it an instantaneous effective detector volume of several million cubic kilometers of ice. This makes ANITA larger, by many orders of magnitude, than any other neutrino experiment. The relatively short duration of the balloon flight limits the total exposure, but, even so, ANITA is expected to have a sensitivity in its energy regime that is 2 to 3 orders of magnitude higher than any previous experiment. ANITA was validated by a prototype flight completed in early 2004. This successful 18 day flight, with only two antennas, has provided the best limits on neutrino fluxes in the 10 EeV energy regime. This bodes extremely well for the full ANITA mission.

3.3. Underground Neutrino Physics

The UH group led by Learned were original members of the IMB proton-decay experiment where they concentrated on using the detector for neutrino physics. This paid off when UH researchers were able to observe neutrinos produced by Supernova 1987a. When IMB closed down, the group joined with Kamiokande colleagues on Super-Kamikoande, and subsequent projects.

Super-K discovered neutrino oscillations in 1998. The UH team was active in the neutrino oscillation analysis; a UH student wrote the first thesis on the subject and the 1998 paper has become the most cited ever in its field. Solar neutrinos were also observed and along with the SNO results these demonstrated the solution to the solar neutrino puzzle of many years standing was in fact oscillation of the electron neutrinos. Nobel Prizes were awarded to Masatoshi Koshiba and Fred Reines partly for this work.

KamLAND uses a 1,000 ton tank of liquid scintillator to detect neutrinos from reactors typically 200 km distant around Japan. This experiment discovered that some electron anti-neutrinos disappear during the flight time from their production point to the KamLAND detector. This result, along with those from solar neutrino experiments, confirms that electron neutrinos oscillate with some combination of muon and tau neutrinos, and that the mass squared difference is now known to about 10%.

The UH group has participated in the construction and operation of this experiment. One student has written her dissertation in a search for anti-neutrinos coming from a hypothetical reactor at the core of the earth, and has found slight positive evidence for this, but not statistically significant. A paper reporting the first measurement of the total radioactivity of the earth was recently published in Nature. This marks the beginning of geo-neutrino physics.

3.4. Other Astrophysics Initiatives

Hanohano is a proposal by Learned to implement a seagoing, mid-Pacific version of the KamLAND experiment. The focus is measurement of the geo-neutrinos from U and Th decay throughout the earth. The KamLAND measurements are dominated by the local earth crust near Kamioka, while a new experiment in mid-ocean can detect the more interesting neutrinos coming from throughout the earth’s mantle and core.
Moreover such an experiment can make a definitive search for a hypothetical reactor at the core of the earth. Such a reactor could solve the problem of excess heat from the earth and might be responsible for the generation of the earth’s magnetic field. A funded design study got underway in June 2005, and it is hoped that construction can start in several years.

**Ashra** is a new generation experiment to study the fluorescent trail of light produced by extremely high-energy particle showers crossing the sky (“Fly’s Eye” technique). The new twist, developed by colleagues from the University of Tokyo, employs modern CCDs to permit an increase in sky resolution by a factor of 10,000 over present photomultiplier based experiments. The UH group acts mostly as host to this collaboration from Japan and Taiwan. We will focus upon the neutrino studies of which this detector is capable. A site has been acquired on Mauna Loa and construction is starting summer 2005. A test station, shown in the Fig. 7 has been in operation on the island of Maui’s Mt. Haleakala since late 2004.

### 4. $e^+e^-$ PHYSICS

The largest research activity in the department involves studies of $e^+e^-$ annihilations near the charmed quark threshold with the BES detector at the BEPC collider in Beijing and in the $b$ quark threshold region with the Belle detector at the KEKB collider in Tsukuba, Japan.

**BES** is an experiment at the BEPC electron positron collider at the Institute for High Energy Physics in Beijing that studies $e^+e^-$ annihilations in the charmed-quark and $t$ lepton threshold region. Fred Harris leads the UH contingent at BES and is
Fig. 9: The unprecedented luminosity provided by the KEKB collider has resulted in a large number of non-CP related discoveries. These include the observation of the $\eta_c$ charmonium state, and the $X(3872)$ and $Y(3940)$ mesons, which emerged from research led by Hawaii and Gyeongsang (Korea) researchers. The $X(3872)$, which showed up as a narrow spike in the $\pi^+\pi^-\psi'\Upsilon'$ invariant mass spectrum just to the right of the well-known $\psi(3686)$ charmonium state, is still not well understood theoretically. It may be the first known example of a four-quark meson.

The UH group has made major contributions to the BES detector, including the mechanical structure and electronic preamplifiers for the recently constructed Main Drift Chamber (V3). Four UH graduate students have completed Ph. D. research with BES data. The most recent UH thesis from BES was on the precise measurement of the total cross section for $e^+e^-$ annihilation into hadrons for center-of-mass energies between 2 and 5 GeV. These results provide very important input to tests of the Standard Model of particle physics and the theoretical predictions of the Higgs Boson mass value. In addition, the UH group participated strongly in the work that led to the discovery of an unusual subatomic particle that we call the $X(1835)$, which appears to be the first clear example of a baryonium meson, i.e. a meson formed from a proton and antiproton that are bound together by the strong nuclear force. The existence of such particles were predicted over fifty years ago by C. N. Yang & Enrico Fermi, but, in spite of extensive searches, not seen until now. Hawaii researchers plan to continue on in this successful collaboration as it evolves into the BES III collaboration, and eagerly look forward to data at much higher luminosities from the upgraded BEPCII collider with a new, state-of—the-art detector in early 2007.

**Belle** is an experiment to study particle-antiparticle (CP) asymmetries in the decays of B mesons (mesons comprised of a b quark and either an anti-up or anti-down quark) and their antiparticles. (The Belle program is described in detail in the feature article of the June 2001 issue of the AAPPS Bulletin.)

The Belle team, including UH faculty members Thomas...
Browder, Michael Jones, Stephen Olsen, Michael Peters and Gary Varner, is a large collaboration consisting of about 400 researchers from many institutions around the world, including many from different Asian countries. UH particle physicists have participated in the Belle collaboration from its very beginning, contributing to the time-of-flight system, the beam-pipe and silicon vertex detector and the analysis software. In 2001, Belle discovered that large differences between B and anti-B mesons occur when they decay to matter-antimatter symmetric final states (such as $J/\psi K^0$). This was the first observation of so-called CP violation outside of the neutral K meson system and confirmed the Kobayashi-Maskawa model for CP violation. The UH-Belle team is enthusiastic about the discovery possibilities of the proposed Super-KEKB upgrade, which would increase the luminosity of KEKB by an order of magnitude.

5. INSTRUMENT DEVELOPMENT LABORATORY

Exploiting the exciting discovery physics potential of the ANITA ultra high-energy neutrino experiment and the Super-B high-luminosity B-factory experiment requires advances in high-performance instrumentation. The Instrumentation Development Laboratory, lead by Gary Varner, provides support from project conception, through design, prototyping, fabrication and field support of the world-class detectors and electronics needed for such demanding applications.

In the case of ANITA, the power requirements of 80-channels of available radio-frequency impulsive transient digitization would have made such a balloon-borne experiment unfeasible. A special low-power 3 Gigasample/s digitizer ASIC was developed that meets the experiments requirements. In the case of the Belle experiment, which already operates at the world’s highest luminosity collider, KEKB, the next phase will require the development of a new technology for operation very close to the collision region of the accelerator. The “ID-Lab” has already successfully fabricated a couple of generations of a Continuous Acquisition Pixel (CAP) detector, capable of operating under very harsh radiation and charged particle density conditions, while actually improving the tracking performance compared with the current silicon strip detector system. The lab serves as an excellent resource to the physics department and in the instruction of undergraduates, graduate students, and post-doctoral fellows in state-of-the-art experimental measurement techniques.

6. OUTREACH

Since we are the only major university physics faculty in the State of Hawaii, we have an important responsibility for reaching out to the community. Under the direction of faculty member Arnold Feldman, our department works closely with high school teachers in the state on the development of science teaching techniques and the promotion of science-related activities. Every year, our undergraduate student physics society helps organize and run a “Physics Olympic” for high school students. In addition our department hosts an annual Physics Open House, which is well attended by high school students and the general public.

7. SUMMARY

Physics research at the University of Hawaii is thriving, thanks in a large part to our very successful collaborations with researchers and institutions in Asia. With the imminent operation of BEPCII and BESIII in China, JPARC in Japan and ASHRA here in Hawaii, and the possibility of an upgraded Super-B factory at KEK, we look forward to an interesting and rewarding future.