Quanta and Cosmos

Content Page

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Frank Krennrich

A message from the chair

Another academic year marked by many significant faculty successes in our department has come to a close. Two of our assistant professors have received a CAREER award by the National Science Foundation. One was given to Amanda Weinstein for work in gamma-ray astrophysics and one to Rebecca Flint for theoretical condensed matter physics research (*Features*). Furthermore, Rebecca also received a CAREER award from the Department of Energy. Three CAREER awards in a single department in a given year is highly unusual and bodes well for our future research programs.

An award by the Gordon and Betty Moore Foundation to Paul Canfield, and the Rolf Landauer Medal to Costas Soukoulis highlight some of our world-renowned research programs. Finally, we just received word that Jigang Wang received an award from the W.M. Keck Foundation's Science and Engineering Research Grant Program. These are very prestigious and competitive grants that are given to just a few universities per year.

The recent report by the Academic Ranking of World Universities (ARWU) ranks our department within the top 51 - 75 physics departments worldwide. We are listed right after Brown University, Duke University and Universite libre des Bruxelles, making the Department of Physics and Astronomy a top ranked department internationally and the highest ranked department in the physical sciences at Iowa State. Physics and Astronomy moved up in the rankings compared to the previous years, when it was in the 76 - 100 category. This reflects very positively on the recognition for research achievements of our faculty, postdocs and students, and the support by our alumni. In general, research funding in our department is very strong and has been stable over recent years, which is a significant achievement by many of our faculty, given that financial support for research for the physical sciences within the U.S. at the national level has been mostly flat or declining across many fields. Our faculty have gone above and beyond in seeking funding to support our research programs.

Iowa State's physics and astronomy program covers a wide range of research incuding astronomy, biophysics, condensed matter physics, high energy physics, nuclear physics and particle astrophysics. This substantial research footprint translates into a wide range of faculty expertise and skills. As a case in point, this issue of the newsletter features high-energy physicist Jim Cochran who currently serves as the deputy manager of the US-ATLAS Operations program. He plays an important role as he looks after the U.S. contributions to the ATLAS detector, located at the Large Hadron Collider in Switzerland (*Features*). A very exciting new setting for experimental research is provided by biophysicist Sanjeevi Sivasankar, who just returned from a sabbatical at Georgia Tech University (*Features*). Astrophysicist Massimo Marengo discusses his recent work on his search for extraterrestrial phenomena, including aliens (*Features*).

Our research programs also set an environment for a state-of-the-art physics and astronomy education. Leading scientists in their fields are able to capture our students' interest in recent science results and contribute to setting high standards for them to follow. A solid education in physics and astronomy at the graduate/undergraduate level, provides a broad intellectual grounding for analytical and creative thinking as demonstrated by the array of successful careers our alumni have in academia, industry and government sectors. Several recent successful alumni who have chosen careers in a range of professions are featured under *Alumni News*.

Finally, the year 2016 marks the start of the Zaffarano Lecture series (see *Lectureship*). Thanks to the generosity of our alumni, we are now able to support the Zaffarano Lectureship in Physics and Astronomy. The purpose of the lectureship is to bring an outstanding scholar to central Iowa and Iowa State University each year, to speak on a topic in the physical sciences, to discuss relevant technical applications, philosophical implications and relation to broader human affairs.

The inaugural Zaffarano Lecture will be given by Sir John Pendry from Imperial College London. Professor Pendry has received high profile awards including the Dirac Medal and Prize, the Royal Medal, the Isaac Newton Medal and the Kavli Prize in Nanoscience. The lecture will be held on October 20, 2016 at Benton Auditorium (Scheman Building) and alumni, faculty and staff will be able to meet the speaker at a reception the evening before.

Finally, we hope to see you in Ames during the week of the Zaffarano Lecture. A number of alumni will be in town for the annual Physics and Astromomy Council meeting planned for the day after the lecture. I would love to have the opportunity to visit with you during that time. I also would like to thank you for your support. Further information on how to support the deparment can be found under *How to contribute*.

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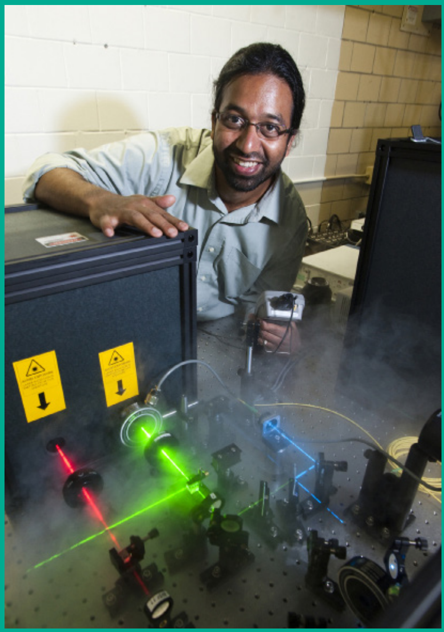
Probing biology: one molecule at a time

Sanjeevi Sivasankar

The biological cell is a complex assembly-line of protein based nanoscale machines that perform well defined tasks with amazing efficiencies. These include transducing electrical, chemical and mechanical signals, resisting mechanical forces and catalyzing chemical reactions. Consequently, life depends on the seamless and integrated functioning of these nanoscale devices. The key goal of my research program is to elucidate the physical principles that underlie the structure, function and organization of protein based biological machines.



Sanjeevi Sivasankar

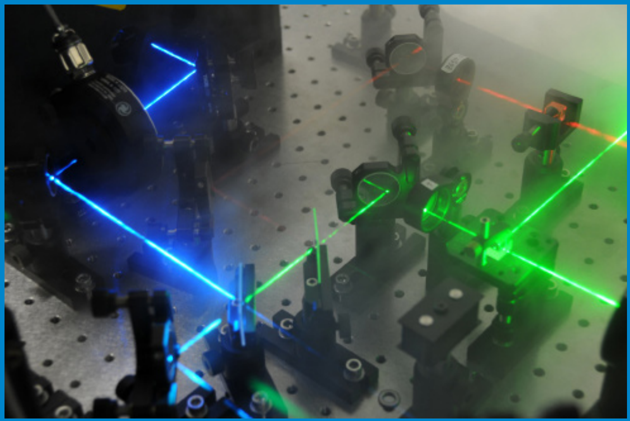
A key area of research in my group is to understand the physical mechanisms by which tissues and organs sense mechanical signals and maintain their integrity despite constant mechanical perturbations. For instance the human body is comprised of more than a trillion cells that stick to each other in elaborate ways to form multicellular structures. During tissue formation and wound healing, these cells tug on each other as they rearrange and migrate. Similarly, tissue like the skin, blood vessels, cartilage, and muscle are exposed to continuous mechanical assault from their external environment. In healthy tissue, cells stick tightly to their neighbors using adhesive proteins that are present on the cell surface. An essential adhesion protein that mediates the integrity of all soft tissue are the cadherin family of proteins. However, the molecular mechanisms by which cadherins withstand mechanical stress are unclear. By measuring the forces between single cadherins using an Atomic Force Microscope (AFM) and coupling these measurements with atomistic computer simulations, my group has shown that cadherins alter their structure in order to withstand mechanical stress. For instance, we have discovered that cadherins adopt a structure that functions as a nanoscale seatbelt and becomes stronger when pulled. Similarly, we have shown that cadherins can also change their structure to serve as nanoscale shock-absorbers that dampens mechanical stress. Thus, by altering their structure in response to force, cadherins sense forces, withstand mechanical stress and maintain tissue integrity. A breakdown of this force sensing mechanism results in severe diseases like cancer and cardio-vascular disease.

Until now, the physical principles that mediate cell adhesion have been studied in a piecemeal fashion where individual component of the adhesive machinery are isolated and studied in an artificial, 'in-vitro' environment using biophysical techniques. The next generation of transformative breakthroughs in wound healing and tissue repair will however rely on resolving the physics of adhesion in a holistic fashion, within the context of interacting cells. However, the tools to perform these types of measurements are currently lacking. In order to develop these tools, I spent fall 2015 on a Professional Development Assignment (PDA) aka Sabbatical at the Georgia Institute of Technology, obtaining specialized training in cellular mechanobiology. I now plan to leverage this experience to develop technologies that can be used to study the cell's adhesive machinery in living cells, in a tissue specific context. I anticipate that these approaches will transform our understanding of the biophysics of cell adhesion and provide key insights into new therapeutic approaches.

A second area of research in my group is in resolving how protein machines undergo catastrophic failure in neurodegenerative diseases like prion disease aka Mad Cow disease. Prion proteins are a biological equivalent to the fictional 'ice-nine', a plot-device in Kurt Vonnegut's novel, Cat's Cradle. In this novel, the physicist Felix Hoenikker creates ice-nine which is a highly stable form of crystalline water that seeds its own replication and instantly freezes any liquid water it touches. Like ice-nine, a prion protein can misfold and impose its structure upon natively folded proteins and templates their aggregation. The consequence of this self-amplifying cycle is prion disease in which prion proteins form toxic aggregates that destroy neurons and invariably kill the organism. Previous studies show that copper exposure is linked to prion disease pathogenesis, however, the mechanism of its action is unknown. My group has been using quantitative biophysical measurements and system level assays to establish a direct link, at the molecular level, between copper exposure and neurotoxicity. We have demonstrated that copper induces single prion proteins to misfold into a high-affinity conformation and have identified key regions of the protein that are obligatory in this process. We have also shown that the misfolded prion proteins serve as seeds that impose their structures upon native prion proteins and template their aggregation. Finally, in collaboration with Prof. Anumantha Kanthasamy, in the ISU College of Veterinary Medicine, we have demonstrated that the copper induced misfolding of prion proteins mediate inflammation and degeneration of neuronal tissue. Our results thus establish, for the first time, the mechanistic basis by which copper ions induce a structural change in prion proteins and template amyloid formation and neurotoxicity. Since a similar cascade of protein misfolding and aggregation underlies other devastating neurodegenerative disorders including Parkinson's disease and Alzheimer's disease, my group is to currently developing physics based models for the structural conversion and aggregation of proteins in these disorders.

Finally, as physicists, we are very aware that one of the driving forces for the current revolution in biology is the development of novel instruments that make it possible to manipulate single molecules and visualize biological structures at spatial resolutions that transcend the diffraction barrier. My group is therefore developing technologies capable of nanometer precision 3D-imaging and bottom-up assembly of biological structures in fluid environments and at room temperature, one molecule at a time. For instance, while fluorescence microscopes are widely used in biology to image biomolecular assemblies, the wave nature of light limits the resolution of conventional fluorescence microscopes to several hundred nanometers in the x-, y- and z-dimensions. Recently, new types of microscopes called super-resolution fluorescence microscopes have been developed that can image single molecules with nm resolution in the x- and y-direction. Super-resolution fluorescence microscopes have revolutionized modern biology, as evidenced by the award of the 2014 Nobel prize in chemistry to the three physicists who invented this technology. Super-resolution fluorescence microscopes however have one limitation: a very poor resolution along the third-dimension, the z-axis, which limits their ability to image biological structures in three dimensions. To overcome this limitation, my group recently invented a fluorescence technique, called Standing Wave Axial Nanometry (SWAN), that can localize single molecules along the z-axis with nm resolution.

Furthermore, in collaboration with Prof. John Lajoie in the Department of Physics and Astronomy, we are combining this imaging technology with an ultra-stable manipulation technique to develop the world's first microscope capable of building biological structures by precisely positioning individual fluorescent biomolecules, one molecule at a time. We are building this microscope by integrating an ultra-stable Atomic Force Microscope (AFM) that eliminates thermal drift and can precisely position single biomolecules under physiological conditions with a super-resolution fluorescence imaging technology to visualize assembled structures in 3D, with a resolution of a few nm in each dimension. We are working towards achieving ultra-stable operation by directly measuring the AFM tip and sample position with reflected laser light and correcting for thermal drift using fast feedback technologies adopted from high energy physics experiments. We anticipate that these technologies will have broad applications in building miniaturized biomedical devices by placing biomolecules with exquisite control and for assembling biomolecular networks which develop new functionalities depending on the arrangement of their constituents.


The tip of the atomic force microscope is positioned over the focused laser beam creating a standing wave pattern.

Currently, biology still remains a largely unexplored frontier. My group is driven by the realization that we can harness the power of physics based approaches to resolve important, outstanding questions related to both normal and abnormal biological function, including human disease. It is indeed an exciting time to be a biophysicist.

A Fresh Perspective on Cosmic Accelerators

Amanda Weinstein

For most people, the words "particle accelerator" conjures up images of the large particle colliders at the US national laboratories, or most recently the Large Hadron Collider in Europe. However, our planet is bathed in charged particles that we know come from space: electrons, protons, and nuclei. We call these particles cosmic rays, and their existence tells us that the universe creates accelerators, too. In fact, it creates accelerators far more powerful than the LHC or anything that we know how to build on Earth! Some of these accelerators---neutron stars, supernova remnants---are born from the violent death of stars. Others are powered by the supermassive black holes found at the centers of active galaxies. All of them are fascinating in their own right. Like their man-made cousins on Earth, they are also valuable tools for answering questions about the fundamental structure of the universe.

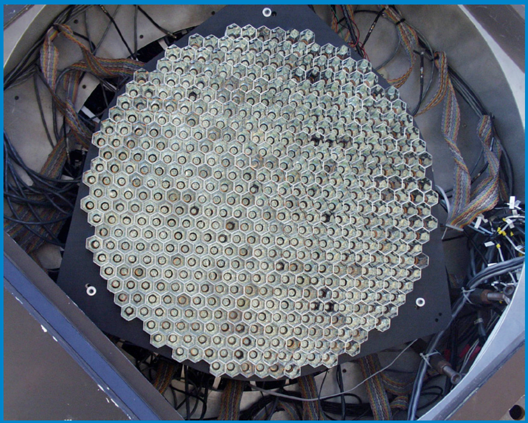
Amanda Weinstein

My research in particle astrophysics can be summed up in three questions. What kinds of cosmic particle accelerators exist? How do they work? And how do we use them to answer questions about the fundamental particles that make up the universe and the ways in which these particles behave and interact? I'm interested in a broad range of these possibilities. The neutrinos produced in nearby supernovae can provide valuable information about neutrino physics as well as the evolution of the supernovae themselves. If detected, a characteristic high-energy photon (gamma-ray) "glow" from galaxy clusters would tell us something about the nature of dark matter. I am also particularly interested in the question of where cosmic rays themselves come from.

Answering these questions requires me to make use of information from many different areas of physics and astronomy. The science that I do relies on astronomical observations made across the electromagnetic spectrum, from radio waves to the very highest energy photons that we call gamma rays. It also uses data from detectors sensitive to particles such as electrons, protons, nuclei, and even neutrinos. Putting together a complete picture from these disparate observations can be tricky. Each of these experiments has its own advantages and limitations and its own kind of data that needs to be analyzed in a particular way.

Data from the VERITAS observatory provide the perfect example. VERITAS, which I helped to design and build, is a very-high-energy (VHE) gamma-ray observatory sensitive to photons with energies greater than 85 gigaelectron volts (GeV). VERITAS uses the atmosphere---the bane of most astronomers---to make it possible to detect these incredibly energetic photons. While the gamma rays themselves are absorbed farther up in the atmosphere, that absorption process produces a shower of charged particles that move faster than the speed of light in air. Because of this they produce what is known as Cherenkov radiation. In this case, the Cherenkov radiation reaches the ground in a large pool of visible light (peaked toward the blue part of the spectrum). By putting an array of telescopes on the ground that image these pools of light from multiple directions, we can actually work out where each original gamma ray came from and how much energy it has.

VERITAS plays a critical role in the type of work I do, because it has the best angular resolution of any gamma-ray observatory in the northern hemisphere and the best sensitivity for energies between 100 GeV and a few TeV. When we look at the gamma-ray sky, we are seeing all the gamma-ray emission from sources at different distances projected onto the same surface. This means that astrophysical phenomena at very different locationslocations in the Galaxy (or even elsewhere in the universe) may cluster close together or sit partly on top of each other in our gamma-ray "snapshots." VERITAS' good angular resolution gives us the



A VERITAS camera with 499 pixels (photomultipliers) and lightguides

best chance of teasing these overlapping sources out from one another, in addition to showing us important substructure within individual objects. VERITAS, however, can only observe a small chunk of the sky at one time, a circle 3.5° across. We refer to this as the "field of view" of the instrument. With our usual data analysis methods this makes it difficult, even impossible, to detect regions of gamma-ray emission that fill up a large part of the field of view. Unfortunately, some of the most interesting sources of gamma-ray emission for studying cosmic ray acceleration and diffusion are very extended! In some scenarios, the gamma-rays seen from dark matter annihilation in galaxy clusters are also spread out over a large region.

I recently received a five-year NSF CAREER grant to work on solving both the problem of combining data from multiple observatories and the challenge of detecting extended regions of gamma-ray emission with VERITAS. My graduate student Josh Cardenzana and I have developed a pilot version of a technique that can detect these very extended regions of gamma-ray emission in VERITAS data when other methods fail. With the support of the CAREER grant we will be able to expand and refine the technique and do intensive studies of its performance in a wide range of different scenarios. We can also unlock the secrets of several gamma-ray sources with particularly interesting stories to tell about how cosmic rays are accelerated and make their way out of their accelerators into the wider Galaxy. Eventually we hope to apply the technique to dark matter searches using galaxy clusters. This is a game-changing approach in more than one way. The maximum likelihood fitting technique that underlies the method is naturally suited to separating out gamma-ray emission from different sources piled on top of one another. It's also perfect for combining data from multiple instruments. A later phase of the project will connect our technique with maximum likelihood frameworks developed for other observatories and simultaneously fit data from multiple instruments. This type of simultaneous fitting lets us do a much more effective job of constraining the astrophysical models that predict the behavior of cosmic ray accelerators (and other interesting phenomena) across the electromagnetic spectrum. This is a huge effort, and involves another graduate student---Alisha Chromey--- as well as a postdoc, Tom Brantseg. The CAREER award also provides outreach funds for undergraduates and even high school students to contribute to aspects of the project.

I don't only use data from existing experiments and observatories. I am also involved in designing and building several future experiments (not all of them gamma-ray observatories). This aspect of my research often involves new technology development. My particle expertise involves the mix of fast custom electronics and software used to decide (in real time) what data an experiment wants to keep, as well as methods of tagging and associating data from a large array of distributed sensors. The topics I work on can be diverse but all of them touch on the same fundamental physics questions or enable experiments related to these questions. If there is another common theme to my work, it's that I enjoy coming up with novel solutions to difficult problems.

The VERITAS telescopes at the Fred Lawrence Whipple Observatory in southern Arizona.

Hunting Quarks at the LHC

James Cochran

The top quark is by far the heaviest fundamental particle yet discovered. It is because of this that it was not discovered until 1995 (more powerful accelerators are needed to produce heavier particles: E = mc2). The particle-physics community had anticipated the top quark since the discovery of its sister particle the bottom quark in 1977. I was fortunate enough to participate in the search for and later discovery of the top quark as a graduate student and postdoc on the DZero experiment at the Fermilab Tevatron accelerator just west of Chicago. By virtue of its large mass, the top quark is still a very active area of research. In particular, because of this large mass, the lifetime of the top quark is very short, only 0.5 yocto-seconds (10-24 s). This allows for studies of the top quark that are not possible with the other quarks. In addition, this large mass hints at a deeper connection with the Higgs mechanism that is responsible for the generation of mass.

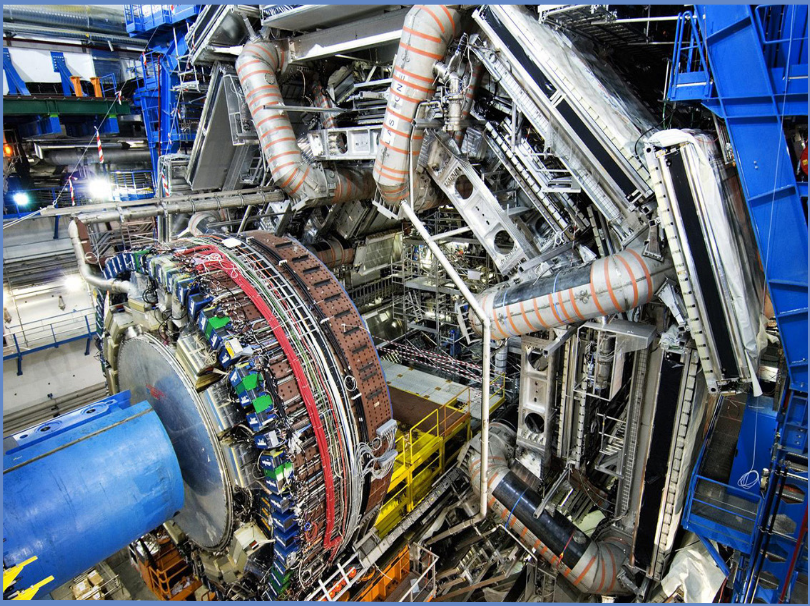
My various top-quark studies led to numerous service tasks in support of my work and that of others. These included many aspects of the large, experiment-wide, simulation production effort, data management, and physics sub-group convenorship. Upon joining ISU in 1998, I changed my focus to the BaBar experiment at the Stanford Linear Accelerator Center. After completing several physics analyses on BaBar, I moved in 2005 to the ATLAS experiment at the Large Hadron Collider at CERN in Geneva, Switzerland. Over time I became involved in various aspects of the US specific efforts on the experiment. Then, in 2008, I was persuaded to become the manager for the US Analysis Support effort. In effect, my job was to make sure that the US scientists had the tools they needed to perform their physics analyses with a minimum of hindrance and aggravation (such tools include computing cycles, network bandwidth, and access to experts on the software). As this was the time period leading up to the initial run of the LHC, much of our infrastructure and software was untested. I organized a series of analysis stress tests (testing the computing, software, networking, and the analyzers themselves) that indeed found problems that we were able to fix and thus ease our transition to the analysis of real data from the LHC a few months later.

James Cochran

The position of Analysis Support manager above was part of the US ATLAS Operations Program. Before continuing I should give a brief description of the program and place it in context with other aspects of the US LHC program. The US contributes to the LHC in three primary ways: (1) via the research grants that are awarded by the DOE and NSF to the participating universities and national laboratories, (2) via construction projects approved by the DOE and/or NSF that build or upgrade the detectors or accelerator, and (3) via the Operations program. As the name implies, the Operations program is the US contribution to the running or operation of the detector. As such, it has efforts in maintenance and operation (M&O), Software and Computing (S&C), Physics Support (PS), and upgrade research and development (R&D). To set the scale of this effort, the 2016 annual budget for the US ATLAS Operations Program is $25.6M from the DOE and $9M from the NSF.

Towards the end of my second two-year term as Analysis Support manager, I was asked if I would agree to be considered for the deputy manager of the entire operations program. I did not feel that had the right experience or skill set for this position so I politely declined. However, after discussions with several of my colleagues, I agreed to stand. The selection process ings with the selection committee and chair alone.

I was beyond surprised when I was offered the appointment in the spring of 2012. The other faculty members in our HEP group at ISU, Soeren Prell, Chunhui Chen, and Eli Rosenberg encouraged me to accept – so I did. The initial plan was for me to serve one year (September 2012 – August 2013) shadowing the former Operations Manager, Mike Tuts of Columbia, and then assume the role of Deputy Manager for the following three years (September 2013 – August 2016). The job is interesting and has many aspects. In addition to overseeing the variouscomponents of the Operations Program, I, along with the Operations Manager, Srini Rajagopalan [BNL], also serve as liaisons between the US (universities, national laboratories, DOE, and NSF) and the CERN-based management of the experiment. The management of the Operations Program takes the bulk of the time as it employs 109 FTEs who are managed through numerous subcontracts with 32 of the universities and national laboratories in US ATLAS. With the current state of government oversight, we seem to be constantly either reviewing ourselves or under review by the US funding agencies. Not surprisingly, all of this requires significant travel – especially to CERN.



The ATLAS detector at CERN

One aspect of our activities that has taken a considerable amount of time over the past two years has been the preparation for the next after next upgrade of the detector that will be completed in 2026. To increase the amount of interesting data that we collect, the LHC is planning very significant increases to its collision rate over the next 10 years. To fully exploit such increases in collision rate requires upgrades to the detector. The first such upgrade is well underway and will be completed in 2020 (US budget is DOE: $33M, NSF: $11M). Once the US components are delivered to CERN and tested, the responsibility will fall on us (the Operations Program) to install and commission these components. Our planning for this is already well underway. The second major upgrade (next after next) is significantly larger (US budget is DOE: $155M, NSF: $75M). It is in the early phase of the approval process and until it becomes a real project (next year), it is managed out of the Operations Program. This has required a tremendous amount of planning and negotiation between the various stakeholders: US universities & labs, non-US universities & labs, ATLAS management, DOE, NSF. Although I've been in the field for 30 years, I've never been involved in the early planning of a detector or major upgrade. It has been fascinating and quite satisfying to see it all come together. There is, however, a truly daunting amount of work yet to do.

Overall this has been a most interesting job and I have learned a great deal, especially about human nature. I am beyond pleased with the performance of the ATLAS detector and the US contribution to it. To date ATLAS has over 500 publications (either published or submitted) in peer-reviewed journals – this is an accomplishment that everyone in the collaboration can be very proud of. And with the start of the next run in April of 2016, we excitedly look forward to potential new discoveries.

Have we found the aliens?

Massimo Marengo

Well, most likely not. But before addressing the alien situation, let me first take a step back.

It all started with the Kepler Space Telescope, NASA's facility tasked with finding worlds orbiting other stars. The spacecraft worked beautifully: since its 2009 launch it has already found 1041 extrasolar planets, with thousands more waiting for confirmation. Even after surviving a near-death experience due to the failure of its reaction wheels (the crucial devices that maintain its precise pointing), Kepler is still churning out top science, discovering new planets and characterizing their stars.

Massimo Marengo

It is not one of the planets discovered by Kepler, however, that has astronomers around the world furiously scratching their head. It is a star, one of the 160,000 stars that Kepler monitored continuously for over 4 years during its main mission, that gave us the biggest surprise. It turns out that this star, with the uninspiring name KIC[1] 84628521 has been undergoing a "dimming" behavior so unique to start a veritable firestorm of speculations among the scientific community, and the public as well.

The reason why this otherwise ordinary star is so special is that KIC 8462852 during some of its dimming episodes decreased its brightness by as much as 20%. This kind of behavior is normally associated to events where an opaque body (e.g. a planet) transits in front of its star, partially blocking its light. When that happens, however, the dimming is usually less than one percent, it repeats periodically, and has a very well defined ingress and egress profile. Whatever obscured the light from KIC 8462852, however, did it in a very disorderly fashion, managing to occult as much as 1/5 of the disk of the star. This is unprecedented, rising the intriguing possibility that the culprit could be some gigantic artificial structure being built around of the star with the purpose of intercepting its light and use it as the ultimate energy source. Such structures, known as "Dyson Spheres", have been described as the next step of an alien civilization that, having outgrown its home planet, expands to occupy its entire planetary system. In this view the dimming episodes observed around KIC 8462852 would be caused by the elements of an incomplete Dyson sphere transiting in front of the star, as the structure is still being assembled.

But, is this what is really happening around KIC 8462852?

As advanced as an alien civilization could be, it must still satisfy the fundamental laws of physics. And among such laws, are the principles of thermodynamics: if a Dyson sphere is intercepting a large fraction of the light from the star it surrounds, it must be heated in the process, and it must dissipate vast amounts of residual heat in the form of thermal radiation. To test this hypothesis, and to search for natural explanations for the unusual behavior of KIC 8462852, together with my students I have analyzed archival data from another NASA facility, the Spitzer Space telescope, designed to observe the cosmos in infrared light. Spitzer happened to observe this star several months after the last dimming episode detected by Kepler, offering the perfect opportunity to check for evidences of waste thermal emission from any structure closely orbiting the star. As shown in the analysis we published in the November issue of The Astrophysical Journal Letters, we didn't find any sign of infrared radiation in excess of the light from the star. Whatever caused

[1] KIC stands for "Kepler Input Catalog" and the index code, despite appearances, is not a telephone number, although it does answers a landline in Pleasantville, IA (don't try this at home).

dimming of KIC 8462852 is not anymore orbiting the star up close, but must have receded to the frigid outskirts of the system, where any leakage radiation would be tuned to a wavelength much longer than the infrared radiation to which Spitzer is sensitive. This is hardly the behavior expected from a Dyson sphere closely encircling a star. Furthermore, an extensive search for extraterrestrial intelligence (SETI) transmission has so far failed to detect any signal coming from this system (the gamma-ray astronomy group in our department has also been involved in this search).

If not aliens, what is then happening on the doorstep of KIC 8462852? We still don't know for sure. The leading hypothesis is that the dimming was caused by the fragments of some small planetary body (a large asteroid or a dwarf planet) that had the misfortune to break-up along a highly eccentric orbit circling the star (such breakup events are rare, but not unprecedented). As the fragments approached their orbit's periastron the furious radiation from the star could have caused ablation and sublimation of volatile elements from the surface of the fragments, leading to the formation of enormous and opaque streams of left-behind debris, capable to partially obscure the star. This process is not different from the mechanism in which Solar System comets form their dusty tails as they sweep around the Sun; it is just on a vastly more massive scale. By the time Spitzer trained its optics toward KIC 8462852 the fragments and debris tails would have had enough time to travel along their orbit to the outskirt of the system, where not even the sensitive infrared detectors of Spitzer could have detected their residual heat.

We still don't know if this hypothesis will hold true: more data is needed to confirm or rule out this scenario. For this reason, we have launched an international effort to monitor the star from space and from the ground, hoping to catch a future dimming episode and perhaps detect the elusive thermal radiation that must be associated with it. In the meantime, KIC 8462852 remains one of the most mysterious stars in our Galaxy, a puzzle that has stimulated the curiosity of scientist and public alike, and that we hope will soon reveal its wondrous secrets.

Artistic impression of a swarm of comet-like fragments transiting in front of KIC 8462852. The debris tails left behind by each fragment could be responsible for the observed dimming of the star (source: NASA/JPL-Caltech). The inset shows the the image of the star as observed at infrared wavelength with NASA's Spitzer Space telescope.

Exploring spin liquid universes

Rebecca Flint

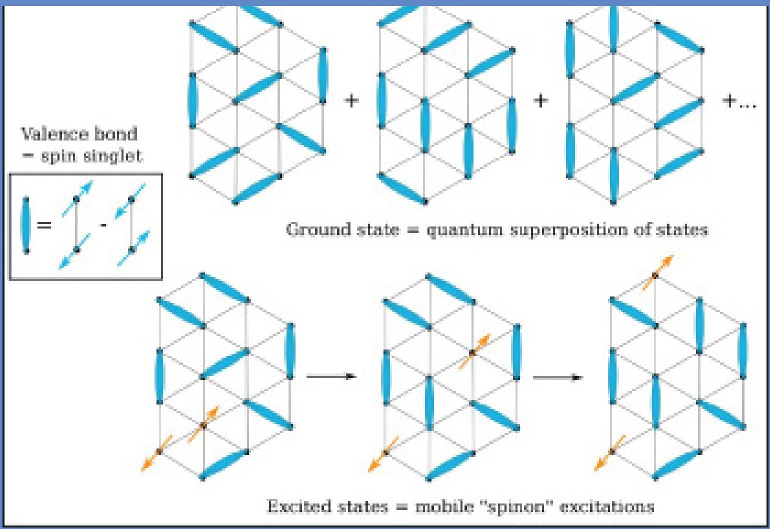
When I first got into physics, I wanted to learn the secrets of the universe – what it was made of and what the rules were. Now I study condensed matter physics, where instead of just looking at the fundamental particles and laws of our universe, I can study a multitude of new universes realized in tiny crystals in the lab. While all the materials I study are made up of electrons and ions, at low temperatures, each reveals a different version of nature, where the laws of physics and even the fundamental particles can be completely different from their high temperature constituents. Some materials, like metals, are relatively straightforward variants of our high temperature universe, where the low energy excitations behave essentially like electrons, perhaps with modified masses, but still electrons. Even most insulating materials can be described in terms of electron-like excitations, but instead of having a continuum of possible states for electrons to occupy, they have a modified energy spectrum that doesn't allow very low energy excitations. Since there can be no low energy excitations at low temperatures, these insulators cannot carry a current. We say that the electrons in these metals and insulators are weakly correlated, with only small modifications. Weakly correlated materials tend to be fairly straightforward, although there have certainly been some interesting surprises recently, like topological insula-tors where the electron states are tangled up in interesting ways. Treating these materials theoretically is relatively easy, as we can consider interactions to be a small perturbation. However, in other materials, the Coulomb interaction between electrons becomes more important, and they become strongly correlated, which completely transforms the low energy excitations of the material into something that doesn't resemble our universe at all. These new worlds are a challenge to theorists like me, and require entirely new ways of thinking. Since the interactions are no longer small compared to the kinetic energy of the particles, there are no more small parameters, and perturbation theory fails. Instead, one has to be inventive in proposing possible explanations and ways to test them. Indeed, developing and testing these new methods relies on a continuous back and forth between theoretical and experimental research. It's fascinating that one can really quickly and fairly inexpensively probe these new universes in the lab to test out different ideas and refine our understanding of these new universes.

Rebecca Flint

Spin liquids are probably the simplest new strongly correlated materials. They behave nothing like their constituent electrons and ions. Instead, in these materials, the electrons are so strongly interacting that they get stuck to the ions, and can't move about freely – this works because these materials have one electron per lattice site and therefore are insulators. Although the electrons are frozen to the lattice of ions, each electron carries a little spin, a tiny magnetic moment that can flip up or down, and so there is still the possibility of interesting physics. In fact, unlike conventional insulators, spin liquids do have low energy particle-like excitations that can move around freely! However, these particles are not electron-like. They carry no electric charge, and therefore no electric current. They do, however carry both heat and spin, allowing heat and spin currents.

The electron has been split in half, with the charge half frozen to the ion lattice, and the spin half free to move. These spinon excitations can be described in terms of the collective motion of all of the electrons, but from a theoretical point of view, we can simply treat this spin liquid state as a new universe where the elementary particles are spinons. These fractional particles can also wind about one another in new ways – in other words, they may be neither bosons, which wind trivially around one another, nor fermions, which pick up a negative sign as they move around each other. Instead they have fractional statistics, where their winding picks up a complex number or even mixes types of particles, which could be useful for topological quantum computation. Understanding spin liquids is a fascinating problem on its own, however the hope is that we can use these to develop a new paradigm for other strongly correlated materials. Spin liquids are closely related to high tem-perature superconductivity, which in some theories can be understood by adding extra electrons to a spin liquid, which can move around, carry current, and even become superconducting.

Unfortunately, in order to really understand spin liquids, we need to study a number of examples, both in theory and experiment, and spin liquids turn out to be really rare in both realms. Often, candidate materials instead form magnets, which are essentially spin solids, where the spins freeze in some ordered arrangement rather than forming a quantum superposition. That is where my research comes in. Currently, I am developing new models that can stabilize spin liquids; this research will be funded by an NSF CAREER grant starting in fall 2016. Spin liquids fluctuate much more strongly than competing phases like magnets, and these fluctuations can be favored by increasing the degree of magnetic frustration – basically, we can think of these spins as just wanting to anti-align with their nearest neighbors. On a square lattice, all the spins can be perfectly happy. However, a triangular lattice is frustrated, as there is no way to make all the spins perfectly happy. Even the triangular lattice by itself is not frustrated enough to stabilize a spin liquid, although an expansion of it called the kagome lattice is. Currently, I am engineering new lattices that couple together different frustrated lattices to further stabilize spin liquids. Once they have been stabilized, then we can study and understand them both on the blackboard and in the lab.



In spin liquids, the electron charge is frozen to the lattice, but the electron spins are free to flip. The basic building block of spin liquids is the valence bond - a spin singlet formed between spins at two different lattice sites. Spin liquids can be described as a quantum superposition of different valence bond arrangements (top). The low energy excitations involve breaking a valence bond and allowing the two constituent spi-nons to move independently by rearranging valence bonds (bottom). These fractional excitations can have exotic statistics and carrying topological properties.

Meet Our New Faculty

Dr. Peter P. Orth focuses in his research on non-equilibrium dynamics of quantum many-body systems, competing interactions in magnetic and superconducting materials and interacting topological phases. He theoretically explores the use of non-equilibrium probing techniques such as pump-probe spectroscopy or rapid parameter quenches to gain new insights into strongly correlated matter. Other specific interests are emergent order in frustrated magnets, percolation in disordered complex oxide films, interactions effects in graphene and topological insulators, and superconducting LEDs.

Dr. Peter P. Orth received his Ph.D. from Yale University in 2011, where he worked with Prof. K. Le Hur on dissipative quantum spin dynamics. As a postdoc with Prof. J. Schmalian at the Karlsruhe Institute of Technology (KIT) he worked on frustrated magnetism, superconductivity and non-equilibrium dynamics close to quantum critical points. In 2012, he received a KIT Young Investigator Award, which allowed him to establish an independent junior group. In 2015, he moved to the University of Minnesota to join Prof. R. Fernandes' group as a NSF MRSEC scholar, doing research on unconventional superconductivity and percolation in complex oxide thin films. He will join the department in August.

Peter Orth

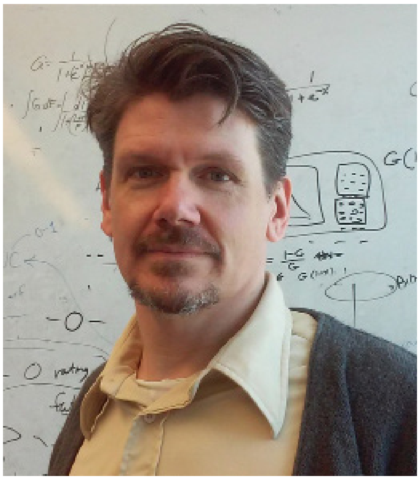
Alumni News

Stephanie Law

I graduated from Iowa State in the spring of 2006 with a major in Physics with minors in Philosophy and Math. During my time at ISU, I worked with Prof. Paul Canfield growing single crystals of novel magnetic materials. I then moved to the University of Illinois Urbana-Champaign for a Ph.D. in Physics. At UIUC, I worked with Prof. Jim Eckstein using molecular beam epitaxy (MBE) to grow thin films of semiconducting structures coupled to superconductors. I graduated in 2012, moving to the electrical engineering department at UIUC to do postdoctoral research with Prof. Dan Wasserman. As a postdoc, I continued to use MBE to grow semiconductor materials, this time for applications in infrared optical devices. I am currently the Clare Boothe Luce assistant professor in Materials Science and Engineering at the University of Delaware, where I have been employed since 2014. My research group continues to study semiconductors for infrared optical applications and has expanded to grow new topological insulator materials by MBE for THz optical applications. In my spare time, I play French horn in the First State Symphonic Band and run ultra-distance trail races.

Frank Samuelson

After graduating from Iowa State University with a Ph.D. in Astrophysics under David Lewis' mentorship in 1999, I took a post-doctoral position at Los Alamos National Laboratory (LANL) working on MILAGRO, another high energy astrophysics experiment. In 2004 I started a position as a physicist with the US Food and Drug Administration (FDA) in the Division of Imaging and Applied Mathematics where I have been for the last 12 years. Half of my work at the FDA is research and half is reviewing others' work. My research work is very similar to what I did as a graduate student, though in another field. I investigate methods for evaluating the detection of targets in images. At ISU and LANL the targets were gamma rays, or simulations thereof, and the images were of particle cascades created in atmospheric Cherenkov telescopes and water Cherenkov detectors. At the FDA, I evaluate the detection of pathological targets in patients using images created by CT, MRI, or PET scanners or simulations thereof. The other part of my job is to review the experimental designs and data analysis for studies performed by other researchers and companies who want to demonstrate the safety and effectiveness of their imaging systems or software for the automated detection or diagnosis of pathology in medical images.



Todd Kempel

After graduating from Iowa State in 2010 with a PhD in nuclear physics, I began work as an embedded software engineer at Rockwell Collins in Cedar Rapids, IA. My experience doing low level hardware development for the PHENIX experiment was instrumental in getting me that first job out of graduate school, and it has continued to be invaluable to my work in embedded software development. My physics experience at Iowa State taught me to simplify complicated, seemingly intractable problems in to manageable components. This skill has proven to be incredibly useful in my day-to-day work, whether the task is designing software implementations for complicated systems by splitting the code in to manageable components, or solving complicated integration issues involving software, electronics, and mechanical hardware. I am now working as a senior software engineer for Stratasys, Ltd., a manufacturer of 3D printers in Eden Prairie, MN. My current role consists of designing and implementing software for controlling hardware to produce 3D plastic models in systems that must be safe and easy for the operator to use. I am also beginning to manage development efforts on engineering projects, coordinating with engineers in other disciplines while developing schedules and guiding software developers toward project milestones.

Eundeok Mun

After having completed doctorate at Iowa State University in 2010, I (Eundeok Mun) spent 4 years at the pulsed-field facility (National High Magnetic Field Lab) in Los Alamos, then moved to Simon Fraser University to be on the faculty. As one of Canada Research Chairs, I am working to identify novel materials that have unusual physical properties. Whenever I think of the Ames, it brings back so many memories. While at Iowa State, I had played soccer for fun. Our team "Red Storm" took home Gold medals at the Iowa games in 2005. Red Storm comprised of the most geographically diverse groups on campus, including Iowan, Korean, European, Mexican, and so on. One day, I learned how to cook a delicious Ribeye steak from Iowan at The Open Flame. I do remember, there was a competition on Friday night in the restaurant that filled with farmers with one goal in mind – cook the best steak ever! Whenever I went to Hickory Park, always a crowd, I am never disappointed with baby back ribs. I and Hyuna (my wife) are continuously looking for restaurants like The Open Flame and Hickory Park for a nice evening out in the metro Vancouver area. Not successful so far! My greatest memory from my time at Ames will be of working together with colleagues at the department of Physics. Since I joined the Canfield group, I have gained lots of valuable experience and knowledge, especially for how to cook intermetallic compounds. Now I am transferring the recipes of growing single crystals from flat cornfields to one of majestic coastal mountains in the Pacific Province.

Liz Kruesi

My time as a Cyclone may have been brief — just one year, in 2006-2007 — but the people I met, the classes I took, and the research I did have remained integral to where I am now. These days, I spend my time writing about astrophysics, planetary science, and physics for magazines and websites for the general public and even books for kids. I wrote about the incredible gravitational-wave detection for Smithsonian.com, built a robot with a paper-origami body for Popular Science, and wrote about the Milky Way's center for Astronomy magazine. I even won the David N. Schramm Award for High-Energy Astrophysics Science Journalism, presented by the American Astronomical Society, a few years ago for an article about black holes. While for the past two years I have written for many publications, I spent the previous six years as an Associate Editor for Astronomy magazine. I still write several articles for them each year, but I've been lucky to explore topics in addition to astronomical science — using origami ideas in engineering designs, the rise of women in the drone industry, and the clash of culture and telescopes atop Hawaii's Mauna Kea. I write these stories from my home office or an independent coffee shop in Austin, Texas, which I moved to in fall 2014 after my husband (Jacob Hoberg, MS '08, Condensed Matter Physics) began a medical physicist position with Austin Cancer Centers. We're having a lovely time in Austin, a city where something is always happening, the lakes are always kayak-able (if that's a word), and the BBQ is always delicious.

Xingdon Wang

I have been working in financial industry for the past 14 years, mostly in the fixed income analytics and modeling area. During the financial crisis, I was literally in the "eye of the storm", working in Fannie Mae as we built the risk management platform for the Chief Risk Office of Fannie Mae. And before that, I was working for Lehman Brothers (left in mid 2007), building Mortgage Analytics. Having these experience certainly helps my current job in model risk management in Wells Fargo. One anecdote stands out when I look back before the storm hit and I would like to share with my fellow alumni below. In 2005, I joined Royal Bank of Scotland, Greenwich Capital Market, in Greenwich Connecticut. We had this routine year end holiday party in midtown Manhattan. On the way there, I shared a limo with a senior executive who was telling me about all the outlandish leverage that Fannie and Freddie was allowed to enjoy because of their agency status while the wall street firms can only envy. But then at the party, the CEO told us that for the year (2005), RBS GCM made more money than the sum of money made in all previous years! (15?) It was interesting I left for Wall Street after my first child Arthur was born, in pursue of higher pay. I left Wall Street when my wife was pregnant with my second child Diana. I consider myself so blessed that my children are healthy and growing every day, both physically and spiritually

Daniel Zaffarano Lectureship

The inaugural Daniel Zaffarano Lectureship will be held at Iowa State University on October 20, 2016. This lecture series was established in 2015 and was made possible by the generosity of our alumni. The purpose of the lectureship is to bring an outstanding scholar to central Iowa and Iowa State University each year, to speak on a topic in the physical sciences, discuss relevant technical applications, philosophical implications and relation to broader human affairs.

The lectureship will be shortly before this years Physics and Astronomy Council meeting.
An evening reception at the ISU Alumni Center on October 19 will present an opportunity for our alumni and faculty to meet with the speaker. **The lecture will take place on October 20 at Benton Auditorium.**

The tradition of bringing prominent scientists to Iowa State University dates back to the John Franklin Carlson Lectures (1955 – 1969), which were inaugurated (see picture) by J. Robert Oppenheimer (1955), followed by Niels Bohr (1957) and others. The Zaffarano Lectureship is our effort to revive this fine tradition.

Professor Sir John Pendry

Sir John Pendry from Imperial College London will give the first Zaffarano Lecture. Professor Pendry is a theoretical physicist and works in the area of metamaterials and applications. Among the applications are a practical "invisibility cloak'' and the "perfect lens''. He received high profile awards including the Dirac Prize, the Royal Medal, the Isaac Newton Medal and the Kavli Prize in Nanoscience. Sir John Pendry will give the inaugural Zaffarano Lecture on the topic of metamaterials and their possible applications.

Time & Location: October 20, 8 pm at Benton Auditorium

Title:
Metamaterials, invisibility, & transformation optics: a new world for electromagnetism

Abstract:
Recently a new paradigm has entered into electromagnetism. Transformation optics is a tool exact at the level of Maxwell[1]s equations that is intuitive and easily solves previously difficult problems. Metamaterials partner this tool. They produce radically new material properties through engineering of internal physical structure and help to realise design parameters specified by transformation optics. I shall show how these two concepts working together have enabled cloaks of invisibility, and negative refraction, and given us the ability to concentrate light into a nanometre or less.

Postdoctoral prize Fellowship in Astronomy & Astrophysics

The purpose of the prize fellowship is to offer an outstanding young scientist, typically within a few years after receipt of the PhD, the opportunity to pursue new and innovative research. It is expected that this research will have some overlap with research within the Department of Physics and Astronomy. However, collaborations with research groups at other institutions would be strongly encouraged.

A prize fellowship in astronomy and astrophysics would attract some of the best postdocs in astronomy to Iowa State University, and would substantially help to strengthen astronomical research at Iowa State, through interactions with graduate students and faculty. The Prize Fellowship will be for a two-year duration. It carries a competitive annual stipend and also offers an annual research expense fund.

Candidates considered for the prize fellowship should show exceptional promise for pursuing a career in scientific research.

The awardee would be required to hold a series of several public lectures on campus geared towards the general public, and thus contribute to outreach in central Iowa, a region with a lot of interest by the general public in astronomy.

The fundraising goal is $250k to start the fellowship on an expendable base, and $1,000k for an endowed fellowship.

How to Contribute

We hope that you would designate your contribution directly to the Department of Physics and Astronomy. Please feel free to call Frank Krennrich (515 294 5442), department chair, to discuss possibilities to donate or if you have questions about the different endowment funds.

1) Contrbutions to the Physics and Astronomy Unrestricted Fund provides the department with the greatest flexibility to finance awards and projects.

2) Contributions to the Zaffarano Lectureship fund will allow us to sustain the event over years to come.

3) Inaugural contributions to the Postdoctoral Prize Fellowship in Astronomy & Astrophysics would allow us to establish the Fellowhip fund.

Other existing endowed funds include:
Robert M. and Evelyn W. Bowie Physics Fellowship,
Charles E. Ruby Scholarship in Physics,
Bernice Black Durand Undergraduate Research Scholarship,
Mather Observatory fund,
ISU Planetarium Fund,
Gordon C. Danielson Memorial Endowment Fund,

If you are considering making a very significant gift, you could establish a new endowed fund for a purpose that you designate, e.g., the Postdoctoral Prize Fellowship.

For details and guidance, please refer to Michael Gens, Executive Director of Development (call 515 294 0921 or e-mail to mgens@iastate.edu) or Neel Bal, Director of Development (call 515 294 8868 or e-mail to nsbal@iastate.edu).