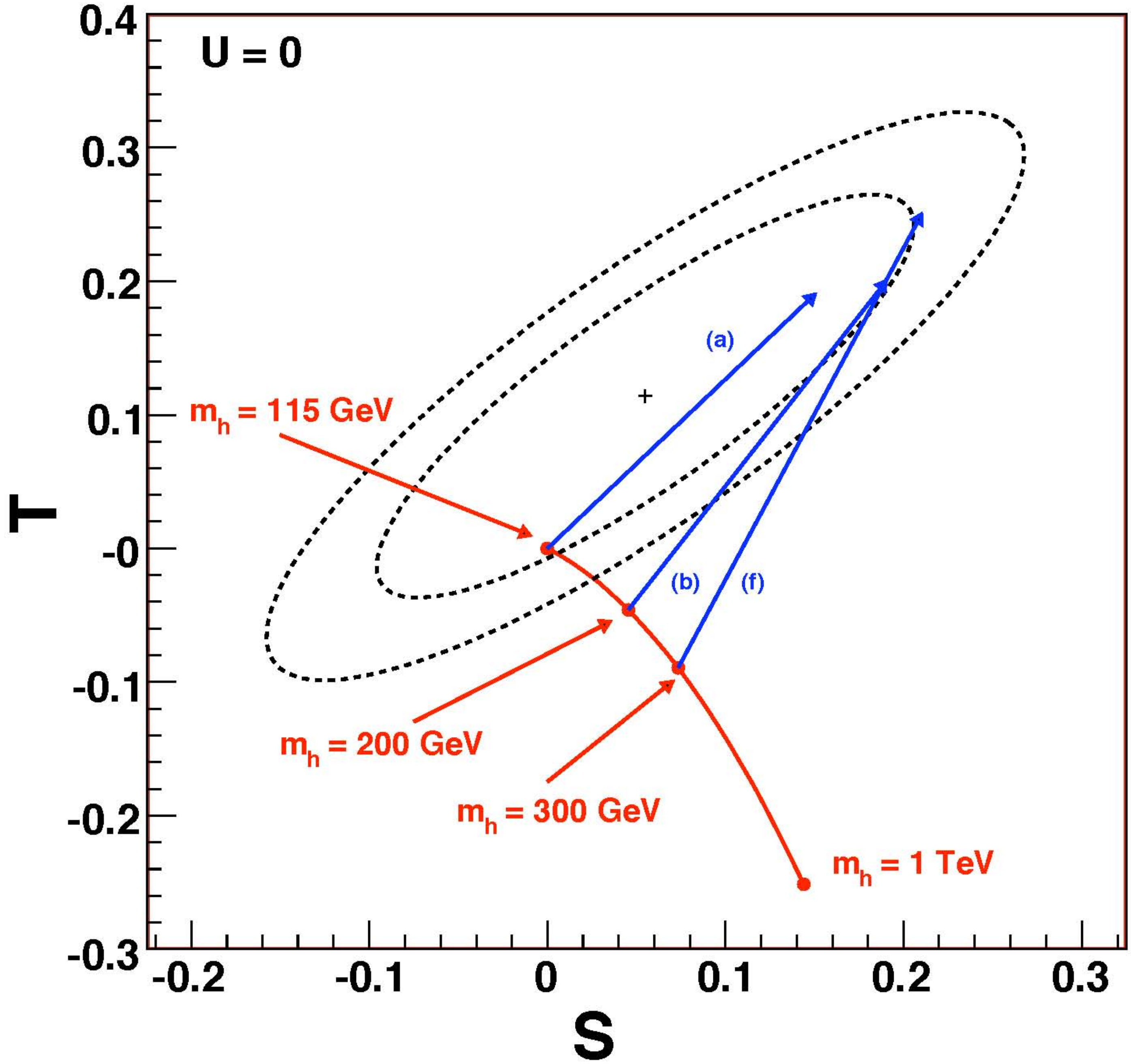
Dimensions

Fall 2008

Northwestern University's Department of Physics and Astronomy

Four Generations of Matter?



Research

Four Generations of Matter?

Tim Tait

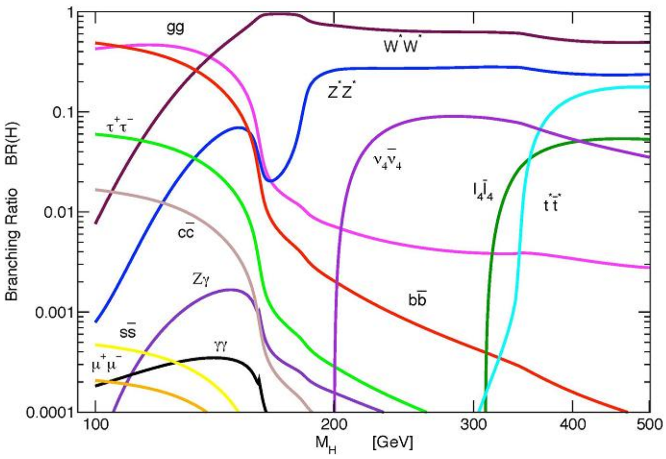
One of the great mysteries of the Standard Model of particle physics is why there are three generations of matter. Everything we see around us in the Universe today can be explained by one 'family' - the up quark, the down quark, the electron, and its neutrino. (The up and down quarks are bound into the more familiar protons and neutrons). Experiments at high energies have discovered two copies of those fundamental matter particles, identical to their first generation counter-parts in every way except for their masses. The most recently discovered particle is the top quark, discovered at Fermilab by teams including Northwestern Professors Buchholz, Gobbi, and Schellman. Having found three generations with no explanation as to why there are three and not some other number, the immediate question that comes to mind is 'Could there be more? What about a fourth generation?'.

For more than a decade, particle physics believed the answer to that question was 'No!'. Precision measurements at the LEP and SLC accelerators were interpreted by the particle data book (the ultimate authority on properties of particles) to imply that virtual creation of fourth generation particles -- temporary creation of the particles by 'borrowing' energy from the vacuum for a short time through the Heisenberg uncertainty principle -- would lead to deviations in the measurements that were not observed by the experiments. For a fourth generation, such effects were reported to disagree with the observations at a confidence level of more than 99.9999%.

Professor Tim Tait, working with colleagues at the University of Oregon, Edinburgh University in Scotland, and the Max Planck Institute in Germany, has recently shown that despite the statements in the particle data book, a fourth generation is not only allowed by the data, but is as consistent with it as the standard three generation model. Their findings have been published in Physical Review D76, 075016 (2007), and have revived research into fourth generation physics. By considering a wider set of masses for fourth generation particles than those considered by the particle data book, they found regions of parameter space where the effects of the virtual particles were small enough to be consistent with the data.

Precision measurements are usually presented in the plane of two observables, the "S" and "T" parameters. The Higgs boson, the only missing piece of the Standard Model, contributes positively to S and negatively to T. Fourth generation particles contribute positively to both S and T. The observation which allows them to remain consistent with the data is that net positive contributions to both S and T can remain consistent with the data, despite the fact that a large increase of one but not the other is excluded. The fourth generation contribution to T can be compensated by a larger Higgs mass. This is illustrated by the plot on the cover, showing the elliptical region measured by experiments, the red line predicted by different Higgs masses, and different blue arrows providing examples of the effects of a fourth generation. A fourth generation thus changes our expectations for the Higgs boson mass, and where we should look for it at colliders like the CERN Large Hadron Collider (LHC). The LHC experiment is just beginning (and Northwestern professors Gobbi, Schmitt, and Velasco are currently hard at work getting it started), and one of its major tasks is to discover the Higgs boson. Since a fourth generation would prefer a heavier Higgs, it changes the way we expect the Higgs to decay and how we search for it.

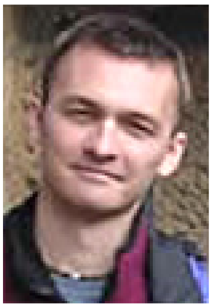
A fourth generation of matter would do more than just predict a heavier Higgs mass. Fundamental



Branching ratios for the decay of a Higgs boson as a function of its mass in a model with four generations of matter. Included are Higgs decays into force mediators (pink, brown, dark blue, purple, and black lines), ordinary matter (orange, light green, tan, yellow, mustard, and light blue lines) and potential new decay modes into fourth generation particles (violet and light green lines).

News and Notes

Brian Odom joins the department faculty



Brian Odom

The Department is happy to welcome Dr. Brian Odom as the newest member of the faculty. Odom received his Bachelor's from Stanford, his Ph.D. from Harvard, and most recently was a postdoctoral fellow at University of Chicago.

Odom's research background is diverse. As a graduate student at Harvard, he worked under the supervision of Jerry Gabrielse on spectroscopy of a single electron confined in a cryogenic trap. This research led to a 6-fold improvement in our knowledge of the fine structure constant, a fundamental quantity which characterizes the strength of the electromagnetic interaction. The measurement was the AIP "Physics Story of the Year" for 2006, and Odom's thesis was awarded the 2006 Thesis Award for the AIP Division of Atomic, Molecular, and Optical Physics. Moving on to the Kavli Institute for Cosmological Physics at University of Chicago, Odom did postdoctoral work in the quite different field of Particle Astrophysics, working with the COUPP collaboration to use bubble chambers as direct detectors for dark matter.

Odom's research at Northwestern follows the theme of his previous research, using low-energy experiments to address questions in particle physics. His lab is currently setting up experiments to perform precision spectroscopy on milliKelvin molecular ions held in radiofrequency traps. Applications include a search for time-variation of fundamental constants and observation of mirror-symmetry breaking at the molecular level.

Overbeck grant allows Tom Senior to join the department

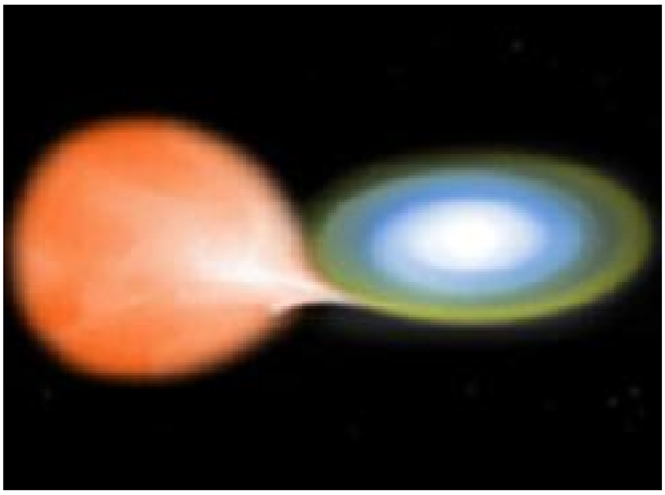
Tom Senior is a retired New Trier High School physics teacher who will work closely with Professor Art Schmidt this coming year on various projects related to undergraduate education. Primarily, he will help update the Intro Physics Lab Manual, develop new lab experiments and revise the lecture demo home page. Senior is an award winning teacher and active member of PIRA, the Physics Instructional Resource Association a group of Physics Instructors that are dedicated to the advancement of physics instruction. To that end, they have organized and maintain a web site of 200 Physics Demonstrations. Among his awards, most recently Senior received the AAPT Distinguished Service Citation at the AAPT winter meeting in Baltimore in January.

Senior's position is being financed through a generous donation from Ann Overbeck. Overbeck's father Professor C J Overbeck was on the physics faculty here at Northwestern from 1927 through 1969. He received a doctorate from Northwestern in 1931. During that time, part of his responsibility was to run the undergraduate labs, and he authored and published a lab manual which Ann Overbeck helped assemble. He also invented many lecture demonstrations for the department, so it is quite fitting that 50 years later Senior's work would be funded by Overbeck's daughter Ann.

Honors:

Program Assistant Carrie Middleton won the WCAS "Sunshine Award" for providing excellent customer service.

Professor Vicky Kalogera has been recognized as one of the top ten young astronomers by Astronomy magazine for her cutting edge research modeling of the processes that form black holes, neutron stars in multiple stellar systems. To read more about Kalogera's research, go to www.astro.northwestern.edu/Vicky/index.html.



Black hole accreting matter from its low-mass stellar companion

Compiled by Anne Colilla

Research

particles all start out massless, and the Higgs field gives them a mass by filling space and slowing the particles as they pass through it. It is kind of like wading through a swimming pool of water. The drag of the water provides more inertia and makes it harder to accelerate. A particle that couples strongly to the Higgs feels more drag as it moves though the field and feels more massive than a particle with a weaker coupling to the Higgs. In order to end up so heavy, fourth generation particles would have to interact very strongly with the Higgs. Such a strong interaction with the Higgs allows the fourth generation particles to influence some of its important properties. For example, the LHC is expected to produce ten times as many Higgs particles if there is a fourth family, because of the strong coupling. A fourth generation would also influence the processes by which the Higgs boson is expected to decay into lighter particles, which can change the way we search for the Higgs at the LHC.

A fourth generation can also help with other mysteries of particle physics. In the early Universe, a fourth generation can catalyze the electroweak phase transition, allowing the electroweak interaction to generate the observed asymmetry between matter and anti-matter. A fourth generation neutrino could even be the mysterious dark matter whose gravitational effects are seen in the Universe, but whose identity is still a mystery. If there are fourth generation fermions, we can discover them directly at the LHC. The fourth generation quarks experience the strong nuclear reaction and can be produced in pairs at the LHC by transforming the high energies contained in the proton beams into the mass of the new heavy particles. Their decays produce ordinary matter, including electrons and muons that are relatively easy to detect at the LHC.

About the Author:

Professor Tim Tait is an assistant professor at Northwestern University with a joint appintment with the high energy physics division of Argonne National Lab. His research is focused on physics beyond the Standard Model of particle physics and early cosmology. With the Large Hadron Collider experiment turning on next year at CERN in Geneva, Switzerland, it is a very exciting time for these areas of fundamental research.

Tim Tait

Tait's primary area of research is the theory which describes the collisions at high energy particle colliders such as the LHC. This collider will smash protons together in order to produce reaction energies about ten times higher than those previously produced in a laboratory (the current record is at Fermilab in Batavia). At these energies we hope that the elusive Higgs boson, the origin of all particle masses, will reveal itself and provided an important missing piece of the puzzle. However, discovering the Higgs is just the first step -- the second is likely to prove even more enlightening, revealing super-particles, new forces, or even tiny curled up extra dimensions. Currently with Northwestern graduate students Kunal Kumar, William Sheppherd, and Roberto Vega-Morales and undergraduate Yonatan Kahn, he is exploring new ways to look at LHC data, in the hopes of finding new and better ways to make these discoveries and understand how they connect to a more fundamental description of nature.

Understanding very high energies is equivalent to understanding high temperatures, such as were present in the early Universe. There are a number of mysteries in our Universe that seem to be begging for an explanation, and probably require physics beyond the Standard Model in order to be explained. One of the most pressing is the identity of the dark matter which is about ten times more common than the ordinary matter we are made of. Tait has shown that this missing mass of the Universe could actually be ordinary photons traversing a tiny curled up dimension. Such extra-dimensional echos could be detected either through their rare interactions with nuclei, or annihilating with each other into gamma rays at the center of the galaxy.

A second mystery is why the Universe is made entirely out of matter and not anti-matter, whereas fundamental interactions make very little distinction between the two. Tait has explored the idea that a new gauge force could be responsible for generating the matter-anti-matter asymmetry through non-perturbative manifestations of instantons. If this theory is a correct explanation for the matter asymmetry, we should be able to discover its mediators at the Large Hadron Collider.

Activities

Selected Publications:

"Theory of Nonequilibrium Spin Transport in Superconducting-Ferromagnetic Nanostructures", Zhao and Sauls, Physical Review B **78** (2008)
By controlling the spin degree of freedom in solid-state heterostructures, spintronics provides a new paradigm and possibilities for making devices and circuits with functionality improved or unrealized by conventional electronics. We demonstrate that superconducting/ferromagnetic nanostructures provide a new route to constructing spintronic devices with unique I-V characteristics, as well as quantum-state manipulation of nano-scale magnets in voltage-controlled circuits.

"Temperature dependence of surface layering in a dielectric liquid", Mo, Kewalramani, Evmenenko, Kim, Ehrlich, and Dutta, Physical Review B **76,** 024206 (2007)
Liquids are isotropic and disordered by definition, but it has been observed that metallic liquids such as mercury form non-isotropic layers very close to their free surfaces. We studied X-ray reflectivity to confirm the surprising prediction that even nonmetallic liquids could exhibit surface-layering at low temperatures.

"Massive Star Formation in the Molecular Ring Orbiting the Black Hole at the Galactic Center", Yusef-Zadeh, Braatz, Wardle, and Roberts, The Astrophysical Journal **683**, L147 (2008)
A ring of dense molecular gas orbits the supermassive black hole at the center of our Galaxy. Using radio telescopes, we detected water and methanol maser emission from the molecular ring. These masers are collisionally excited and are signatures of early phases of massive star formation, suggesting that star formation in the molecular ring is in its infancy.

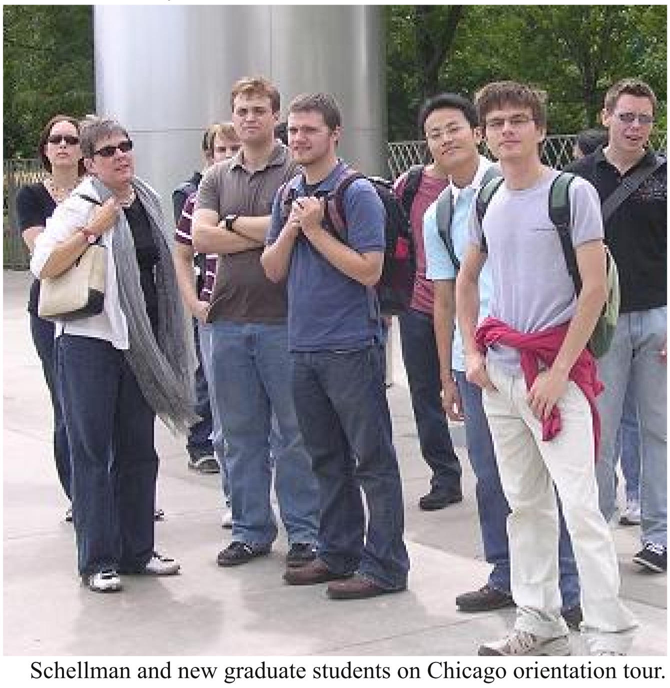
"Gas Disks to Gas Giants: Simulating the Birth of Planetary Systems", Thommes, Matsumura, and Rasio, Science **321**, 814 (2008)
The more than 300 exoplanets discovered to date display a wide range of masses and orbits, representing the end point of a complex sequence of events wherein an entire protostellar disk converts itself into a small number of planetary bodies. Our new numerical modeling of this process gives results in agreement with observations and suggests that analogs to our own Solar System are uncommon.

New Graduate Student Event:

The Department is thrilled to welcome the incoming graduate student class, so thrilled in fact, that Director of Graduate Studies Heidi Schellman, Professor Brian Odom and Graduate Secretary Grant Darktower organized a field trip to downtown Chicago. The trip started with a ride on the "L" from Evanston, followed by lunch and a walk along the lakefront, a ride on the water taxi, a hike down Rush street, a visit to the 96th floor of the John Hancock building, and a ride home on the NU shuttle.

Besides welcoming this year's class, Schellman wanted to make an effort to foster a sense of community among the new graduate students. "At the end of the five and half mile death march, all the first year students knew each other much better," Schellman said with a smile. Schellman added that she hopes a stronger community will help a class made up of students from both within the United States and from India, Russia, China, Korea and France adjust quickly to rigors of Northwestern and translate to higher achievement overall.

Exhaustion from urban trekking aside, some students reported that it was fun to explore the city for the first time, and that the trip made them appreciate the location of the Evanston campus—not in the busy city center, but only one "L" ride away.



Schellman and new graduate students on Chicago orientation tour.

News from Alumni:

Former student Andrew Richter (PhD 2000 with Pulak Dutta) has been promoted to Associate Professor at Valparaiso University in Valparaiso, IN. VU is a primarily undergraduate institution that focuses on teaching and mentoring students and uses rearch as one important teaching tool. Richter's work uses synchrotron x-ray reflectivity techniques to examine the adsorption of proteins onto chemically functionalized surfaces. Knowledge about protein adsorption is important in a large array of biomedical applications, from contact lenses to artificial joints, and Richter's techniques provide information that is unavailable or less precise using other methods. Richter has also been collaborating with researchers at the University of Memphis on the creation of artificial liposomes with controllable pore sizes for use in drug delivery and sensor applications. This research has involved neutron scattering experiments at Oak Ridge, TN, and Grenoble, France. Richter's research program has been awarded grants from The Research Corporation, the National Science Foundation, and FedEx.

Transitions

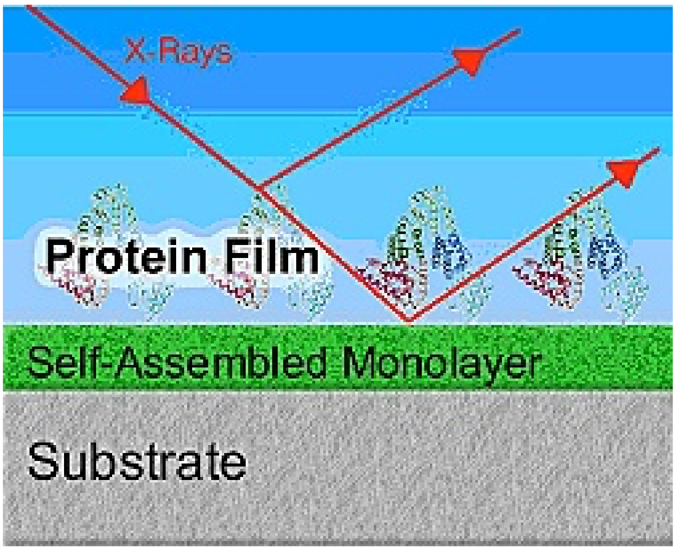


Diagram showing how synchrotron x-rays are used to examine the adsorption of proteins onto chemically functionalized surfaces.

Former student Tom LeCompte (PhD 1992 with Jerry Rosen) has been appointed Physics Coordinator for the ATLAS experiment at CERN. Since his graduation, he has worked as a physicist at Argonne National Laboratory. He also has a long standing affiliation with the ATLAS experiment and has made extensive contributions to the tile calorimeter and software and computer projects.

Former student Anton Vorontsov (PhD 2005 with James Sauls) was recently appointed Assistant Professor in the Department of Physics at Montana State University in Bozeman. He completed his PhD in theoretical physics on investigations of superfluid ^{3}He in confined geometries. Vorontsov's expertise is in the area of novel states of matter associated with spontaneous symmetry breaking. Since leaving Northwestern, Vorontsov expanded his research into the physics of electronic and magnetic properties of high temperature and actinide superconductors in high magnetic fields, and most recently into spin dynamics in quantum dots. Among Vorontsov's accomplishments (as an ICAM Junior Exchange Fellow) is work (Vorontsov et al., Physical Review Letters 2008) with co-workers at LSU and University of Karlsruhe in Germany, predicting novel electronic spin states in noncentrosymmetric conductors with spin transport properties analogous to birefringence of light in materials with broken chiral symmetry. Vorontsov is currently a post-doc in the Condensed Matter Theory Group at University of Wisconsin in Madison and will assume his new position January 2009.

Former student Priya Sharma (PhD 2004 with James Sauls) received the Leverhulme Early Career Fellowship and a research appointment at Royal Holloway University of London (RHUL) starting October 2008. Sharma completed her PhD in theoretical physics on investigations of the effects of disorder on broken symmetry states in quantum fluids. Sharma's expertise is in quantum statistical mechanics and transport theory in disordered condensed matter. After moving to London, Sharma joined one of the leading international groups in quantum fluids and solid at RHUL. Among her accomplishments is her work identifying the symmetry of the superfluid phases of ^{3}He impregnated into low density glass (silica aerogel) and the remarkable magnetic properties of these phases.

Department Alumni Request:

The department welcomes submissions from alumni of newsworthy items for publication in the newsletter. Please send your submissions to physics-astronomy@northwestern.edu or detach the last page of the newsletter and mail it to the department.

Name: ____________________________________

Degree: ______

Graduation Year: ______

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News:

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