Editors / Jack Houlton & Nathan Youngblood

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PhysicsFocus

Bethel University Physics & Engineering Newsletter

This summer newsletter for 2009 will be a "year in review", highlighting upper level research projects conducted by the Bethel University's Physics Department, senior research by recent years graduates, as well as summer research by students and faculty. Newsletter submissions and photos to Dr. Peterson at petric@bethel.edu are welcome and appreciated.

Structural Modeling of Mars Decelerator Systems

In NASA's continuing Mars program, larger and more massive payloads are required. NASA is exploring new decelerator concepts to replace the current decelerator technology, which is nearly at the end of its effectiveness. The concepts NASA is now considering are parachutes and inflatable aeroshells to replace the current prefabricated structures. Building many aeroshells would be a costly and time consuming endeavor so the option of choice is computational modeling. Dr. Keith Stein has been working with the University of Minnesota for a few years now to establish structural modeling capability that is being used to study fluid-structure dynamics of these new decelerator systems.

The code allows for structural-dynamic analysis of cable- membrane structures. Computer models of the structures to be tested are generated and the computational analysis is then carried out to determine the dynamics and geometry of the structure under prescribed loads. An earlier example of the utilization of this structural modeling code focused on the inflated geometry and stresses for a disk-gap-band parachute. Laura Steen, a Bethel physics alumnus, carried out her senior research using the computational model for this variety of parachute. This type of parachute is being considered by NASA as a possible decelerator for upcoming Mars missions. The inflated structure of the parachute and the stresses on the structure are shown in Figure 1.

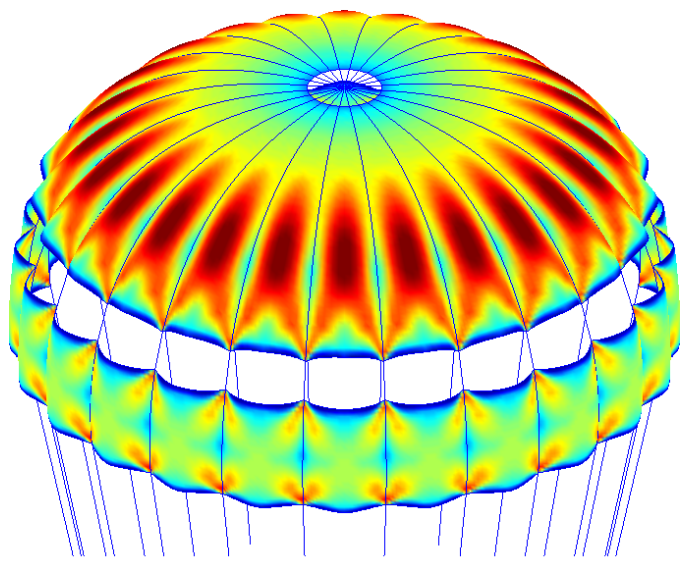


Figure 1: Inflated geometry (colored with membrane stresses) for a Disk-Gap-Band parachute.

Another application of the structural modeling code is inflatable toroid structures. NASA is considering inflatable toroid aeroshells as an alternative to the current prefabricated rigid aeroshells. These toroids are composed of membranes and would be inflated upon entry, descent and landing. Using lighter weight, inflatable structures would increase the fuel available for the payload of the craft, and the space inside the craft. The structural response of the toroids to highly dynamic loads and aerothermal heating requires investigation. Bethel senior Kyle Anderson did his senior research on the thermal effects on membrane structures. Using the structural modeling code, he was able to account for changes in elasticity based on different heating situations.

Another challenge area for these inflated structures is buckling. Under certain aerodynamic loads, an inflated structure will buckle. Using computational modeling, Kyle is looking into various buckling inducing situations for individual inflated toroids. The models are created with a series of cables which are arranged to impose buckling inducing loads to observe the inflated toroids under various adverse conditions (see figures 2-3).

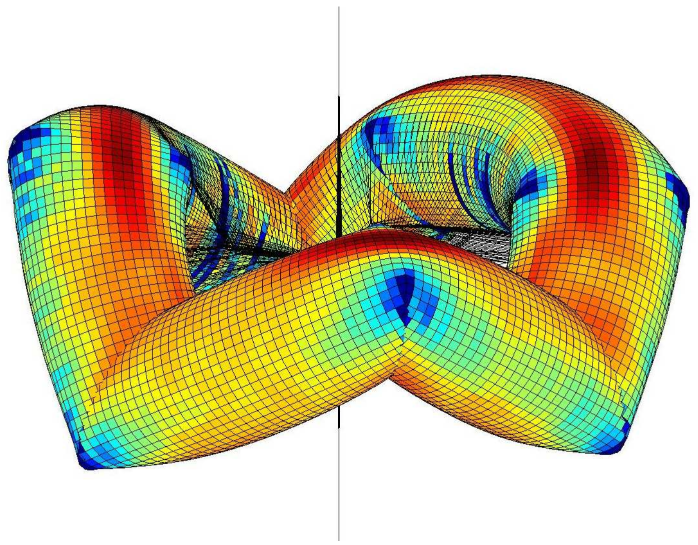


Figure 2: Inflated toroid exhibiting out of plane buckling.

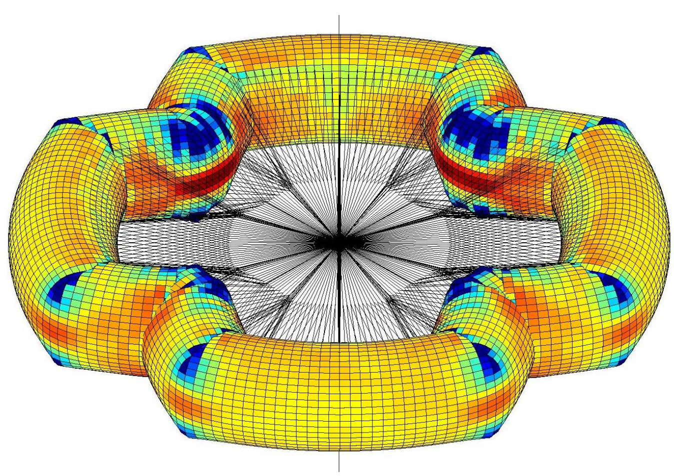


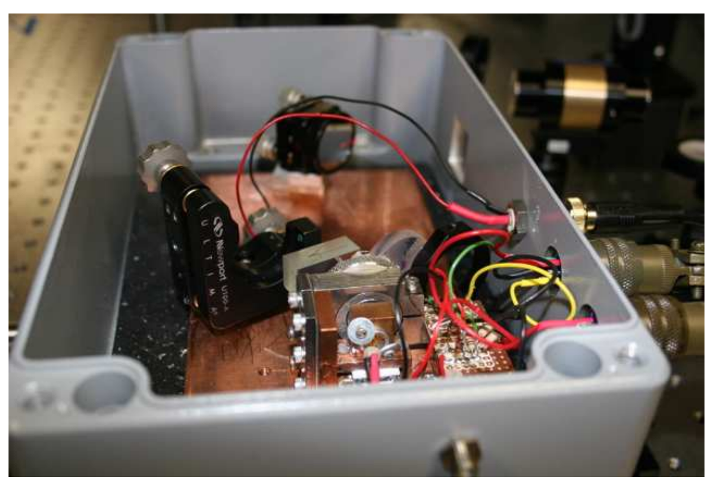
Figure 3: Inflated slender toroid in a different buckling mode.

Computational modeling is a powerful tool that can be used to simulate various conditions and structures that would be difficult or costly to physically produce. Computational results such as these support NASA interests as they consider various candidates for future decelerator systems for Mars missions. As the code continues to grow and change, it will be able to handle a greater variety of tasks. Computational modeling will likely be an important part of Bethel physics for several years to come.

–Kyle Anderson

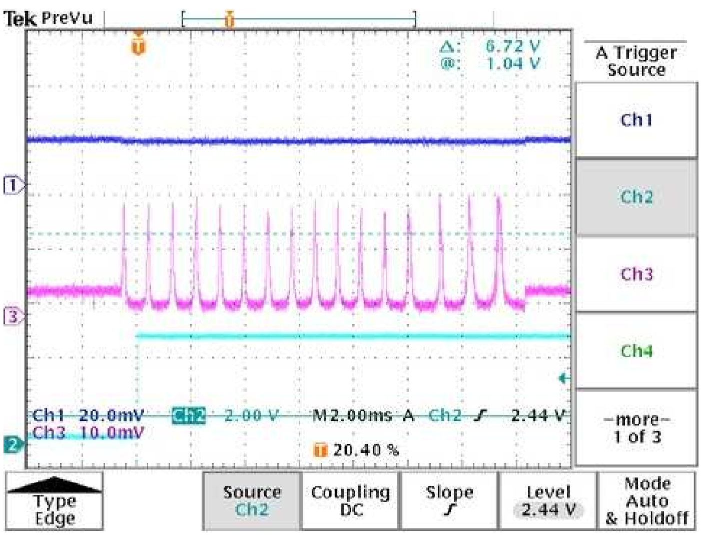
Update from Professor Chad Hoyt

The new advanced optics lab was a busy place during the summer of 2008. Building on the previous summer's efforts by Gus Olson (who graduated in 2007 and went on to grad school at the U of Illinois) and Paul Weavers (an Edgren Scholar who graduated in 2008 and went on to grad school at the Mayo Medical School), Bethel physics students made initial steps toward an apparatus for laser cooling and trapping of lithium atoms. Five talented students contributed: second-year students Adam Banfield, Sarah Kaiser and Jami Johnson, third-year student Andy Rheingans, and recent graduate Sarah Anderson. Trapping atoms with speeds of only several centimeters per second allows long interaction times and high precision tests such as frequency measurements and photoassociation spectroscopy (the formation of molecules using light). Sample densities of approximately 1011 atoms per square centimeter are routinely achieved in cold atom traps. These samples are the pathway to Bose-Einstein condensation and Fermi gases, relatively recent experimental phenomena in the field of atomic, molecular and optical physics.

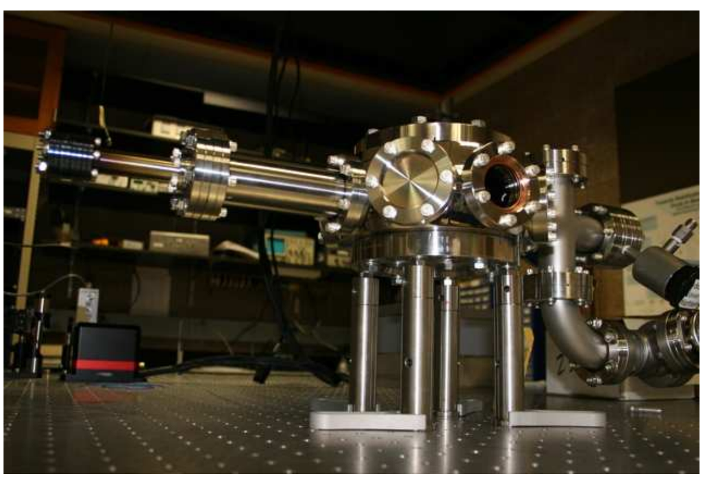


The insides of an ECDL assembled by Jami Johnson and Sarah Kaiser.

Our initial steps during the summer of 2008 included demonstrating wide ($\succ$5 nm on a coarse scale) and continuous (up to 12 GHz on a fine scale) tuning of an external cavity diode laser (ECDL) at 671 nm and many of the required mechanical and vacuum systems. The lab's Michelson-type wavemeter, useful for tuning the ECDL to the required wavelength, yielded high precision by resolving the adjacent longitudinal modes of a helium neon laser with a 640 MHz mode spacing.

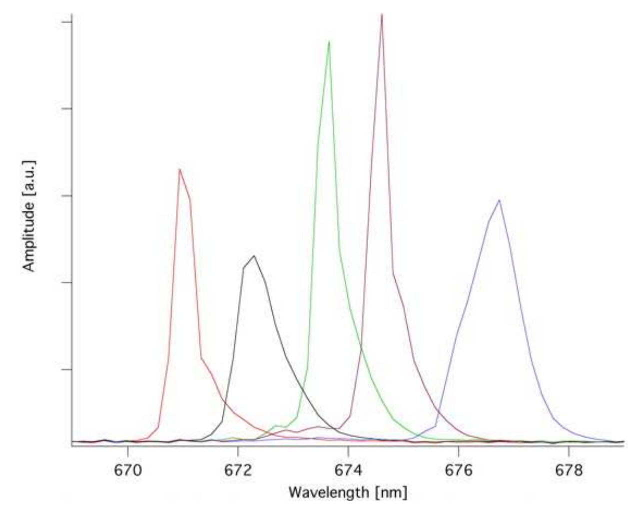


External cavity diode laser fire tuning. Peaks are light transmission through an external optical cavity showing ≻8 GHz continuous mode-hop-free tuning.



Turbomolecular vacuum pump constructed by Andrew Rheingans during the summer of 2008.

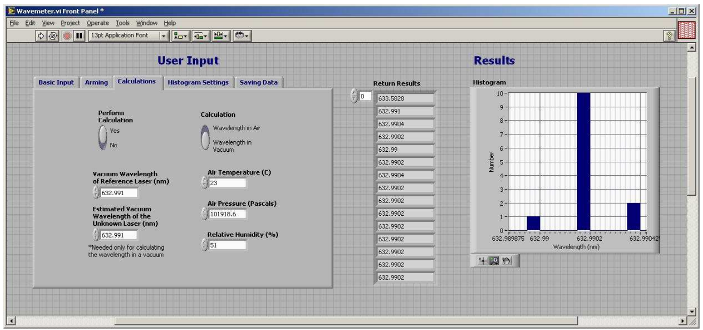
Edgren Scholar Andy Rheingans designed the vacuum chamber system (see figure) and several accompanying mechanical systems. He built a portable turbomolecular pumping station with which we have achieved chamber pressures as low as $2*10^{-7}$ torr. When combined with our 20 l/s ion pump we should be able to reach pressures of 10^{-9} - 10^{-10} torr. The chamber should allow for ample optical access through seven 2" diameter windows and two 4" diameter windows. Andy stepped into a graduate student-like role when he searched many vendors for the optimum (quality and economy) window solution. He also designed and built an oven for a lithium atomic beam. This includes a mechanism for heating lithium to above 400 °C and a nozzle for beam collimation. Andy assisted the laser diode part of the effort by building a driver for length-changing piezoelectric transducers. Based on a power operational amplifier (PA89) design used at the National Institute of Standards and Technology (NIST), the +/-200 V driver integrates into a feedback loop for laser stabilization.



Fine tuning the ECDL containing the 671 nm laser diode.

Two students who had just finished their first year at Bethel, Jami Johnson and Sarah Kaiser, built two ECDLs. Sarah helped complete the mechanical housings for the NIST-designed opto-mechanical system as shown in the picture. As a test she stabilized and characterized an infrared laser diode using a grating, the same laser diode two Bethel physics alumni had studied in 1994. It was gratifying to reproduce the original data and to demonstrate smooth grating tuning. Jami did the same for a 10 mW laser diode at 671 nm. She achieved grating stabilization in the Littrow configuration with tunability over 5 nm (see figure). After adding a piezoelectric transducer behind the grating she demonstrated up to 12 GHz of mode-hop-free fine-tuning by changing the cavity length (using Andy's high voltage driver). She measured this range by tuning across the resonances of a low finesse Fabry-Perot optical cavity. As shown in the figure, a continuous resonance signal means continuous laser tuning and the separation between adjacent peaks is calibrated by the optical cavity length (30 cm). This tuning is necessary for initial lithium spectroscopy and stabilization.

An accurate and precise wavelength measurement is necessary to tune the laser to the appropriate lithium



User interface designed by Adam Banfield to enable easy measurement with the wavemeter.

atomic resonance for cooling and trapping. Sarah Anderson (2008, University of Michigan) built a wavemeter for her senior research project earlier in the 2008 school year, for which she won a prize for the best student paper at the spring meeting of the Minnesota Area American Association of Physics Teachers. Using a common air track, existing frequency counter and stabilized helium-neon (HeNe) laser, she built a low-cost wavelength meter with picometer-level accuracy. She used light from an iodine-stabilized commercial ECDL at 636 nm to test accuracy at this level. Sarah returned for two weeks this summer to demonstrate the instrument's precision by measuring adjacent longitudinal frequency modes of another stabilized HeNe laser. She measured the wavelength difference to be 0.8 pm, which corresponds to the intermodal frequency spacing of 642 MHz. Adam Banfield continued Sarah's work by interfacing the counter to a computer via parallel communication (GPIB). This increased the speed and ease of measurements and included a simplified interface for the calculation that accounts for ambient conditions such as temperature and humidity. A snapshot of Adam's program including a histogram of several wavelength measurements is shown in the figure. Along with Sarah Kaiser and Jami, Adam helped to make the first wavelength measurements of the ECDL at 671 nm for lithium spectroscopy.

–Dr. Chad Hoyt

Professor Beecken's 2008 Summer Research

I was honored to be offered a ten-week Faculty Fellowship by the American Society for Engineering Education and the United States Air Force. The fellowship enabled me to work at the Air Force Research Lab, located in Lexington, Massachusetts, during the summer months of 2008. I worked with the Space Weather group. Personally, I never thought of space as having weather, but the scientists there work hard at predicting the occurrence, composition, and severity of solar flares, sun spots, and other events that drastically alter the performance of spacecraft. Primarily, these plasma physicists are interested in the survivability of satellites.

The current life expectancy for a satellite is around five years. Given the hundreds of millions of dollars it costs to build and launch a satellite, the goal is to extend that life expectancy to ten years. One of the biggest dangers to a spacecraft is being charged by bombardment of high-energy electrons in space. The charge builds up in the insulating material of a spacecraft. Some of it bleeds away, but some of it causes an electrostatic discharge (much like when one shuffles across a carpeted room in the winter). These high voltage pulses cause significant malfunctions on a satellite, and sometimes the damage can be so bad that the satellite becomes useless.

Several years ago, I was introduced to this field of research while working at NASA's Jet Propulsion Laboratory at Caltech. We were building and testing computational models that predicted the buildup and movement of charge within the spacecraft's insulators. I was able to bring some of this work back to Bethel, and students like Aaron Rendahl, Sarah Boswell, Tom McElmurry, and Erik Dahlman worked with me on improving the models. At the time, the applicability of such models was greeted with some skepticism by the spacecraft charging community. However, in recent years, it has become apparent that such models can be applied to specific conditions in space and used to predict how and when danger of electrostatic discharge exists.

One of the Beeckens enjoying the view.

Most of my family spent most of last summer with me in the Boston area. We certainly enjoyed the opportunity to see many historical sites such as the Lexington Battle Green, the Old North Church, "Old Ironsides," Plymouth, etc. We also enjoyed the beach a couple of times, although most days were rainy. Because we had spent the last few summers in Albuquerque, my family was used to hiking in the mountains. So we couldn't resist finding out what the Boston area had to offer. On the Fourth of July, Kim and our six-year-old son Jacob made the 2,000 foot climb to the top of Mt. Monadnock. The picture shows Jacob relaxing at the top.

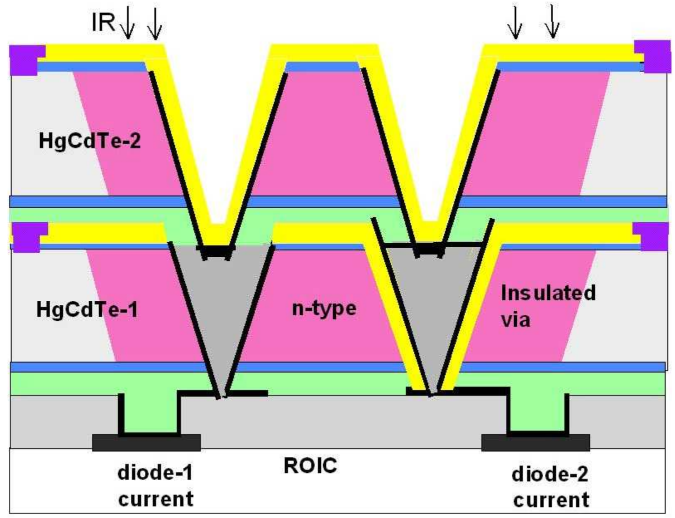
I spent much of the summer of '08 researching what had been done since I worked in the spacecraft charging field and then updating the lab group as to what was going on and suggesting the steps that should be taken next. This work laid a good foundation for continuing research with current students at Bethel. During the 08-09 academic year, seniors David Carlson and Tommy Hofer made significant strides in the development of a computational model that includes time-delayed effects. Now I have been invited back for summer 2009 to the Air Force Research Lab in Massachusetts to continue the collaboration.

–Dr. Brian Beecken

Footnote: Apparatus, Data Analysis, and Publications

In 2007's final edition of the *PhysicsFocus*, Dr. Beecken wrote about his Air Force Office of Scientific Research Summer Fellowship. That was Dr. Beecken's third consecutive summer research fellowship—enabling him to do research at the Air Force Research Laboratory in Albuquerque, New Mexico. The collaboration with that lab has already resulted in five published papers (with four student co-authors), and another paper is currently in the works.

Recently a paper entitled "Progress on characterization of a dual-band IR imaging spectrometer," was presented by Professor Brian P. Beecken at an international optics conference in Orlando (SPIE). It represented the work of then undergraduates Cory Lindh and Randall Johnson (class of 2008) in collaboration with Dr. Paul LeVan of the Air Force Research Laboratory. Cory and Randy had worked at analyzing the spectrometer's measurement capabilities as well as locating and mathematically "repairing" dead pixels. They also demonstrated the device's ability to remotely determine temperatures to within one percent accuracy. Earlier, the spectrometer had been used to simultaneously image the sun in hundreds of different infrared wavelengths—images processed and compiled by Bethel graduate Ben Todt (2007).



Dual band focal plane array stacked detection sites.

The spectrometer is capable of obtaining simultaneous images at two octaves of wavelengths in the infrared. The heart of the device is a dual-band infrared focal plane array, which allows two octaves of wavelengths to be recorded simultaneously and separately at one pixel site. The illustration shows how the two layers of a detector element correlate to one pixel. Combined with the appropriate reflection grating, the resulting imaging spectrometer is compact and low mass, with perfect spectral registration—ideal characteristics for space-based applications.

Beyond Bethel Physics: Going Mach 6

Purdue doctoral student and Bethel University graduate Matt Borg holds up a model of the X-51A, a hypersonic scramjet being researched at Purdue.

Last summer, Bethel was privileged to have one of its alumni give expert assistance on initial instrumentation and pressure measurements on the newly assembled shock tunnel (details to come in the next newsletter) thanks to a Bethel Alumni Association grant. Matt Borg (Bethel Physics class of 2003) is in his final stages of his PhD in aerospace engineering at Purdue, where he is conducting his research in a state-of-the-art Mach 6 wind tunnel. While at Bethel, Borg gave a short lecture on his research. Borg was pictured in a Science Daily News article in January of '08 titled "Purdue Wind Tunnel Key for 'Hypersonic Vehicles,' Future Space Planes" which discussed the research done by the team of Purdue researchers of which Borg is a part. The X-51A test vehicle is estimated at going Mach 6, useful for "time-critical" targets such as incoming projectiles.

Borg spent two weeks at Bethel in early June of 2008 advising and assisting construction of Bethel's own supersonic tunnel - under leadership of Prof. Stein.

The technology is not seen as limited only to anti-missle applications. Possible uses include space planes. The research conducted on the engine involved, studying the front portion of the craft, and seeing how well they could reduce friction, thereby reducing the heat generated by such high speeds.

One interesting problem arose in the tests surrounding the need for the engine to "breathe". Since it is still combustion which is taking place, the fuel requires oxygen to burn. At such high speeds, where disruptions in laminar flow would seem crucial, scientists had to "trip" the air to allow the air to enter at hypersonic speeds.

–Dr. Keith Stein

Congratulations Graduating Classes of 2008 and 2009

The Bethel University Physics Department is exceptionally proud of all of its students. We wish our graduates all the best as they pursue careers or further education.

(Class of 2008) The photo includes the following faculty and graduates from back left to front right: Professor Brian Beecken, Professor Richard Peterson, Gary Kearns, Michael Slotman, Nathan Freize, Chris Stelter, Jonathan Sass, Matthew Freeland, Randy Johnson, Cory Lindh, Erik Bostrom, Sarah Anderson, Tim Johnson, Laura Steen, Professor Thomas Greenlee, Professor Chad Hoyt, and Professor Keith Stein. Not pictured: Brett Anderson, Mitch Baker, Andrew Cureton, and Chris Scheevel.

(Class of 2009) The photo includes the following graduates from left to right: Joshua Tschetter, David Carlson, Caleb Ahlquist, Andrew Hendel, Andrew Rice, Nathan Holm, Jonathan Dallmann, Kevin Kelley, Thomas Hofer, and Andrew Rheingans. Not pictured: Paul Weavers, Andrew Dirks, Mark Stegman, Donald Mathers, Eric Haase, and Yelena Bailey.