Institute for Computational Astrophysics ICA

ANNUAL REPORT 2007

Compiled by:
Robert G. Deupree, Director
Florence Woolaver, ICA Assistant

SAINT MARY'S UNIVERSITY SINCE 1802
One University. One World. Yours.

Institute for Computational Astrophysics

Saint Mary's University

Annual Report 2007

The Institute for Computational Astrophysics (ICA) was formed in late 2001 by Saint Mary's University in response to a proposal by Drs. David Clarke and David Guenther to promote research into astrophysical problems using high performance computing.

This year saw significant developments including some arrivals and departures of personnel. Dr. Rob Thacker was awarded a Tier 2 Canada Research Chair in the ICA and the Department of Astronomy and Physics and took up his position here in August. Ms. Florence Woolaver, who had been serving as the ICA Assistant in a temporary role, took over the job full time in mid January and has become a mainstay of the institution. Master's students Mr. Chris Geroux, Mr. Aaron Gillich, and Mr. Joel Tanner finished their theses this year. Mr. Geroux is continuing in the ICA as a Ph. D. student working with Dr. Deupree. Mr. Gillich has joined his partner in Australia, and Mr. Tanner is pursuing a Ph. D. at Yale University. The ICA maintained its size with the addition of Ph. D. graduate students Mr. Mike Casey and Mr. Dave Williamson, who will be working with Drs. David Guenther and Rob Thacker, respectively. Dr. Eduard Vorobyov joined the ICA as a post doctoral fellow in November, joining current fellows Drs. Alex Razoumov, Nathalie Toqué, and Joris Van Bever.

Events in 2007

The ICA hosted several workshops during the course of this year, mostly for ACEnet related activities. On February 6-9 the ICA hosted a data storage workshop provided by ACEnet's primary vendor, SUN Microsystems, for the ACEnet staff (approximately ten people). inSORS provided training on using Access Grid technology on March 20-22. The ICA organized a three day workshop run by Jim Himmer and sponsored by SUN Microsystems for users from the various ACEnet institutions at the end of April. This included finding a venue outside the normal computing labs (unavailable because of computer upgrading) which had twenty workstations. A final three day workshop was held with Mechdyne and Iowa Sate University personnel in July for acquainting users with the data cave.

The ICA completed the changeover of its web site to the Contribute system, as mandated by Saint Mary's. This system is quite easy to use and has aided Ms. Woolaver in keeping the ICA web site more current than had been done in the past.

The presence of ACEnet, the resource for academic high performance computing in Atlantic Canada, was significantly amplified at Saint Mary's (as elsewhere in Atlantic Canada) this year. Mr. Phil Romkey moved into the newly constructed ACEnet space in January and continues to perform as the system administrator for the ACEnet systems located at Saint Mary's. He was interviewed by CTV on its Breakfast AM show about ACEnet on February 19. He was joined in late November by Dr. Sergiy Khan, the ACEnet high performance computing consultant stationed at Saint Mary's. Dr. Ross Dixon was hired as a high performance computing consultant at Dalhousie University late this spring and has been helping some ICA members find and solve problems with bringing up their codes on the ACEnet Mahone cluster at Saint Mary's. Some of these problems were related to the marriage of system software with the Myranet interconnects on this machine. The hiring of these high performance computing consultants has been made possible by a $2 million grant from NSERC to the seven consortia that make up Compute Canada. Dr. Deupree participated in a grant proposal to NSERC submitted this fall to double that amount. The Mahone cluster had more nodes added this summer, bringing the total of cores to 244 (the total number of ACEnet cores is currently 1064). The ICA has access to all four ACEnet machines, and in addition has its own small 48 processor cluster for code development, code testing, and for running small jobs. Dr. Thacker is preparing for the procurement of a system of approximately 300 processor cores funded by his CFI award related to his Canada Research Chair award.

The ACEnet space for the Remote Collaboration Room, the Data Cave, and the Graphics Workroom was also completed early in 2007. The open house for the Remote Collaboration Room, a multi-site video teleconferencing system using Access Grid technology provided by inSORS, was held on March 23, with guests from various ACEnet institutions (many attending remotely over the Access Grid) and the Nova Scotia Office of Economic Development. The Remote Collaboration Room is routinely used for ACEnet Research Directorate and Technical Team meetings, but also for the Coast to Coast seminars in mathematics and for meetings of researchers. The room has three projectors which display a window about the size of the long wall in the room. So far, up to 17 different cameras have been displayed simultaneously. The room in action is shown in Figure 1. The three projectors normally used to project the camera windows on the wall have been found useful by the ACEnet high performance computing consultants for work with researchers in attempting to find problems, and thus the room has been used for this purpose. The rate of usage between the beginning of February and the end of November is approximately 30 hours per month. The ICA expects the Remote Collaboration Room to be used even more frequently once most of the other universities in Canada install Access Grid as a part of the Canada Foundation for Innovation National Platform Fund.

Figure 1

The ACEnet Data Cave was installed in late spring and officially released to users in the middle of July. Drs. Clarke and Deupree, along with graduate students Nick MacDonald and Jonathan Ramsey, are able to visualize their 3D hydrodynamic calculations in the cave, although much work needs to be done to truly master the “art” of visualizing data in an immersive environment. The Data Cave was the subject of a piece which appeared on the CBC National in mid November. This has elicited inquiries that might lead to commercial researchers utilizing the Data Cave. An open house for the Data Cave is planned for sometime in 2008 once all the Science Building construction is completed.

The Data Cave is located in a 38x27x15 foot room, which looks huge when empty (see Figure 2). However, the Data Cave does fill the room (see Figure 3). The Data Cave in operation is pictured on the front cover of this report.

Figure 2

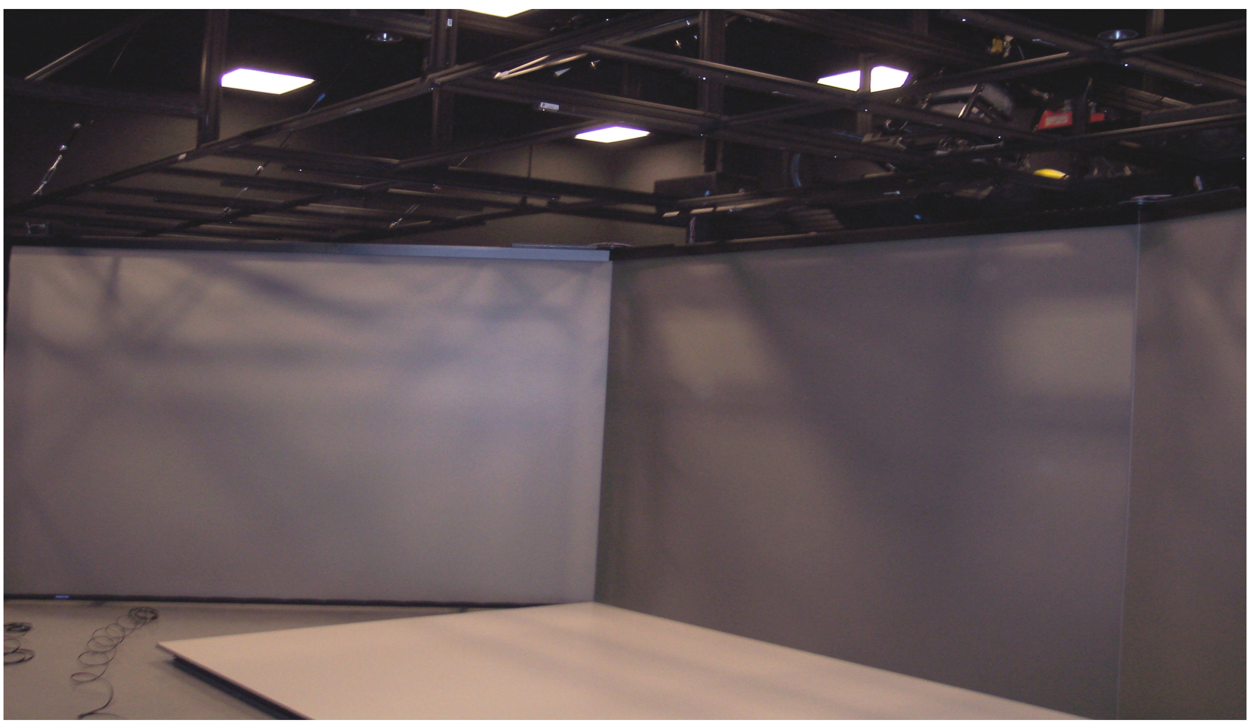

Figure 3

The requirements for the Graphics Workroom have been determined and the workstations have been ordered with an early 2008 expected arrival. Several prospective users contributed to defining the specifications. Four high quality graphics work stations, each with two 30 inch monitors will be installed.

The ICA was a significant beneficiary of the ACEnet Fellowships Program, receiving almost $100,000 per year for two years in matching funds to support post doctoral fellows in the ICA. These awards resulted from a competitive process conducted by a panel of researchers from outside Atlantic Canada for ACEnet.

Dr. Deupree continues to serve on the Advisory Board of the Hertzberg Institute of Astrophysics and on the Board of C3.ca. He remains the Principal Investigator of ACEnet. This year Dr. Thacker was elected to a Directorship of CASCA and received, as the project leader and along with the other members of the Black Holes and Cosmic Evolution Project, the ORION (Ontario Research and Innovation Optical Network) Discovery Award of Merit for 2007. The award was for the very large simulation of the effects of black holes on the evolution of the largest galaxies and on the intracluster gas in clusters of galaxies. Dr. Thacker also worked with members of the C3.ca Board on the development of a proposal for a Tier 1 computational research facility.

The ICA welcomed a number of visitors this year. These included Dr. Suzanne Talon (Montreal), Dr. Pavel Dennisenkov (Ohio State University), Dr. Steven Lameroux (Yale), Dr. Eduard Vorobyov (University of Western Ontario), Ms. Houria Belkus (Vrije Universiteit Brussel), Dr. Amanda Karakas (Australian National University), Dr. Sergiy Khan (University of Western Ontario), and Dr. Michael Normal (University of California at San Diego).

Undergraduate Researchers

ICA faculty members employed three undergraduate research students this summer: Mr. Mark Richardson worked with Dr. Clarke on numerical hydrodynamics, Ms. Heather Pickup worked with Dr. Short on synthetic photometry using the PHOENIX stellar atmospheres code, and Mr. Joey Richard worked with Dr. Guenther to develop computer software to improve the efficiency of oscillation spectra searches in asteroseismology. Mr. Richardson was supported by an NSERC USRA, while Ms. Pickup and Mr. Richard were supported from the relevant faculty NSERC grants.

Research

Here we present summaries of the research of individual ICA members conducted during 2007.

Code development and testing continues to occupy a considerable amount of the efforts of Dr. David Clarke and his students. Dr. Clarke has recently developed a new MHD boundary value scheme which is particularly suitable for the staggered mesh environment in ZEUS-3D. It has solved most of the chronic problems with boundary conditions particularly at inflow boundaries, leaving only the need for better transparent (outflow) conditions.

These new boundary conditions allow the launch of a jet cleanly from the surface of an accretion disc. Illustrated in Figure 4 is the innermost region of a large 2-D axisymmetric simulation of a magneto-centrifugally launched jet. The left edge is the inflow boundary and the bottom edge is the rotation axis. Grey scale is density (black high), black lines are magnetic field lines, white arrows (not to the same scale in the two panels) are velocity, and black arrows accelerations. The gravitational core is located at the origin, and the disc is established along the left edge as a boundary condition. Jet outflow dominated by outgoing “clumps" or “rings” is confined to the region within $r < \sim 6$ of the core. The upper panel shows the simulation with the old inflow boundary conditions with numerous numerically driven features growing in the boundary layer. On the lower panel is a similar simulation with the much cleaner inflow boundary conditions of the new paradigm.

Mr. Jon Ramsey is in the final stages of testing the Adaptive Mesh Refinement (AMR) magnetohydrodynamical fluid code AZEuS after implementing the major changes in the boundary condition algorithm developed in ZEUS-3D by Dr. Clarke. Mr. Ramsey is also testing the AMR part of AZEuS and has passed several major milestones. AZEuS can now do 1-D shock tubes across grid boundaries with refinement ratios of 2 and 4. This has required us to reinvent the so-called “refluxing" aspect of AMR for ZEUS' staggered mesh environment, as well as develop “self-computing boundary conditions" for ZEUS' operator-split scheme. In the past year, he has also parallelized and tuned the performance of AZEuS for use with ACEnet computing resources.

Once testing is complete, Mr. Ramsey will be ready to commence simulations directly relevant to his Ph.D. dissertation. These simulations, never before attempted, will simulate a protostellar jet launched from an accretion disc and will be followed to observational length scales. The magnitude of this project is such that it would not be possible in a reasonable time frame without access to the ACEnet computing resources.

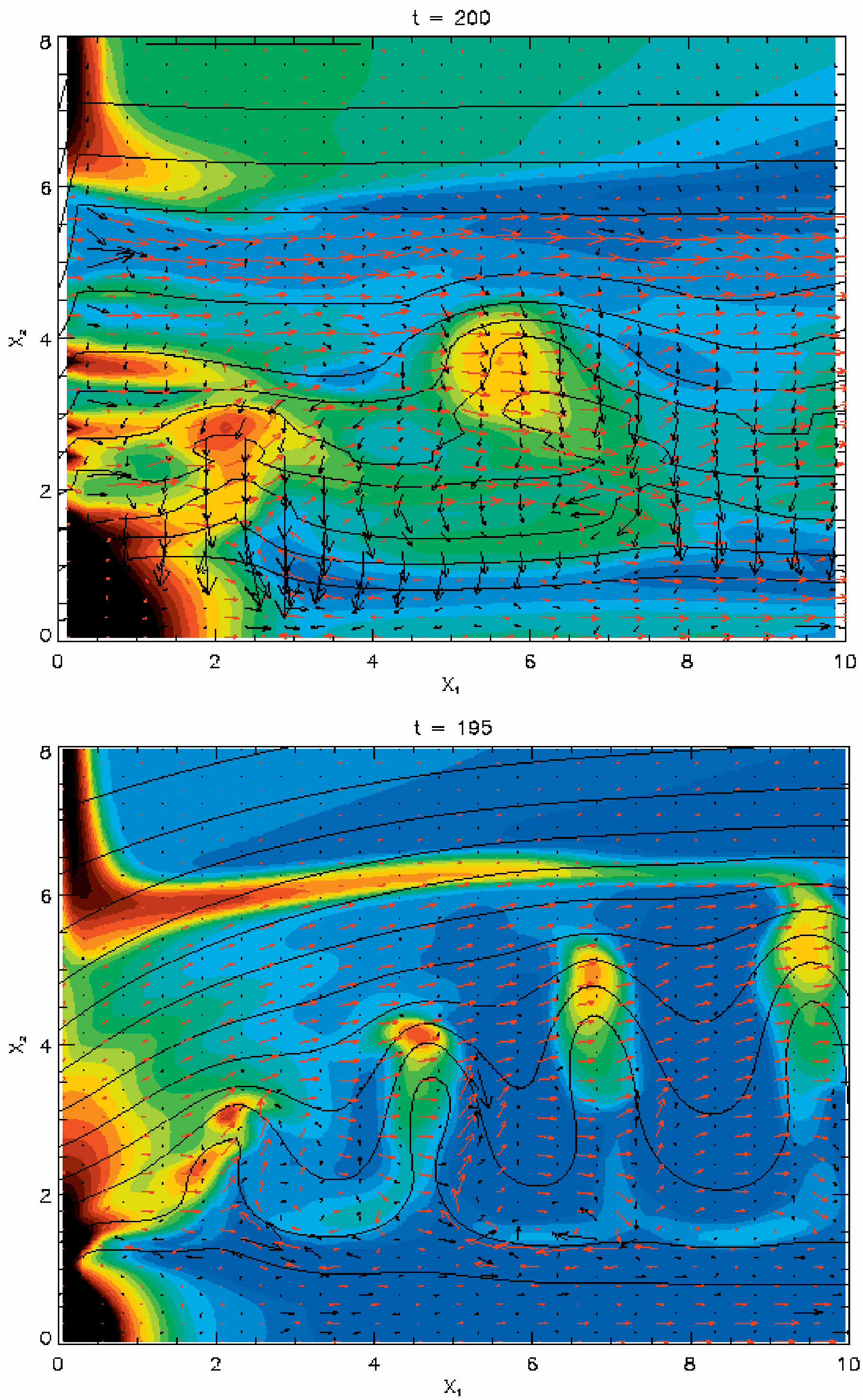

Figure 4

Mr. Nick MacDonald's thesis will consist of utilizing the ZEUS-3Dcode to simulate the multiple jet outflow of 3C 75, a pair of active galaxies in the Abell 400 cluster. To date no full three-dimensional MHD simulations have been undertaken in an attempt to model this beautifully complex system of extra-galactic jets.

Mr. MacDonald spent the summer and early fall developing a semi-empirical algorithm within the code to model the effects of synchrotron aging in these types of extra-galactic jets without actually keeping track of the electron population distribution itself. This was accomplished through the introduction of an independent 'age' variable within the code which is updated each numerical time step. Modeling the particle spectrum as a two-index power law, this method keeps track of where the break in the emission spectrum is, which is affected by both the local conditions (e.g., energy density and magnetic field strength) and the history of the fluid (e.g., recent passage through a shock or rarefaction fan). This age is utilized in computing zone emissivities which are then convolved using a post-processing code to create synthetic radio observations of the jet being simulated. These radio images can then be compared to actual observations of extragalactic jets providing a crucial test of any numerical model's validity. To date he has carried out a large number of two and three-dimensional simulations to test and perfect this new algorithm.

With summer student Mr. Mark Richardson, Mr. MacDonald has also run a 3-D propagating jet with a confining toroidal magnetic field. This simulation has benefited from the new boundary conditions and he finds that this jet is kink-unstable. The instability saturates (i.e. it doesn't disrupt the jet) and excites a high-frequency, low wavelength (of order a jet diameter) undulation along the jet which could be an observable signature of such a magnetic field configuration and strength if it were to exist in nature.

In addition to the above treatment of synchrotron aging, Mr. MacDonald was involved in a joint project with Mr. Richardson this summer in which 'Lagragian' particles or tracers were introduced into the simulated outflows. The code, being Eulerian by design, is unable to provide detailed information on the physical conditions that an individual element of fluid experiences during its passage through the jet. In contrast, these tracer particles act as probes moving along with the flow recording the physical conditions they encounter during their passage through the jet.

Mr. MacDonald also modified the code to launch two parallel jets and angle them toward one another, thus taking the first step in creating a model of interacting extra-galactic jets similar to 3C 75. Work will continue over the coming months to expand upon this basic simulation in an attempt to come to some physical understanding of the mechanisms (either hydrodynamic or magnetohydrodynamic) responsible for the complex structure of 3C 75.

Dr. Deupree's work has been focused on devising models of rapidly rotating stars and trying to develop methods to determine their internal angular momentum distribution. This has led to modeling the spectral energy distributions and line profiles of computed rapidly rotating stars using the PHOENIX stellar atmospheres code and computing pulsation frequencies and mode properties using the NRO pulsation code. The stellar models are generated by Dr. Deupree's 2D stellar evolution code ROTORC. With Mr. Chris Geroux Dr. Deupree developed and applied a code to determine how the HR diagrams of young clusters with massive stars would appear when the effects of rotation were taken into account assuming various distributions of angular momentum amongst the cluster members whose rotation axes are randomly inclined with respect to the observer. As expected, rotation broadens the observed main sequence below the turnoff, but the variation does not allow any firm conclusions to be made about how angular momentum is distributed among the cluster members.

Mr. Aaron Gillich computed both spectral energy distributions and line profiles for stellar models with rotation for his Master's thesis with Drs. Deupree and Short as supervisors. He computed a suite of stellar atmospheres models, from which he could take the intensity in the direction of the observer to perform the integral to determine what the observer would see as a function of inclination. He performed these calculations both for uniformly rotating 2D stellar models and for 2D models in which the rotation rate decreases with distance from the rotation axis. The stellar structure models were computed with the 2D stellar evolution code ROTORC. The resulting spectral energy distributions and line profiles are an improvement on previous work because the 2D stellar structure models do not depend on von Zeipel's law (which fails at large rotation rates) and because most lines were computed in non LTE in the stellar atmospheres simulations. The spectral energy distribution work has been submitted for publication and the manuscript for the line simulation results is nearing completion. Mr. Geroux devised analytical expressions for the curves in the HR diagram that define the deduced luminosity and effective temperature as a function of inclination for his cluster synthesis work.

Ms. Catherine Lovekin has been pursuing her Ph. D. thesis work on computing accurate pulsation frequencies and eigenfunctions for rapidly rotating stellar models. She has examined how the coupling of spherical harmonics affects the frequencies and at what rotation rate the usual approach of identifying a mode with a single spherical harmonic (valid at zero rotation, approximately true for small rotation, false for moderately fast rotation) breaks down. She also has studied how her results differ from those of second order perturbation theory, the most common method for determining eigenfrequencies for stars in which the rotation is sufficiently large to affect the structure. Again the differences become significant at moderate to fast rotation. She has also noted that the departures from both one spherical harmonic and from second order perturbation theory become significant at lower rotational velocities for higher overtones and for modes dominated by higher order spherical harmonics. She is extending her calculations to differentially rotating stars in which the material closer to the rotation axis rotates more quickly than material farther away from the axis. The results show that the oscillation frequencies do depend on differential rotation, but only when the differential rotation is so pronounced that it begins to affect the structure of the core and hence the gravitational potential of the model.

Dr. Deupree, Mr. Geroux, and Mr. Joel Tanner performed stellar evolution, model atmosphere, and adiabatic oscillation calculations to examine the four fundamental radial mode pulsators in NGC 3293, at least one star of which rotates at a fairly rapid rate. This work involved starting with uniformly rotating Zero Age Main Sequence (ZAMS) models and performing stellar evolution calculations through core hydrogen burning assuming local conservation of angular momentum. These calculations were performed for several different masses and rotation rates. From these models the radial fundamental periods were determined, and their observed effective temperatures and luminosities as functions of inclination were calculated. Success would be a model which matched the observed frequency, effective temperature, luminosity, and the projected rotational velocity, v sin(i). The models are successful for all but the most rapidly rotating member, for which the observed effective temperature was too high. It may be possible to fit this star with significant differential rotation.

Nathalie Toqué continued her work on stellar evolution of rotating stars, including the simulation of the redistribution of composition and angular momentum by hydrodynamic and secular instabilities. The purpose of the study is to better understand how the meridional circulation affects the evolution on the main sequence of intermediate and high mass stars with a convective core. Dr. Toqué first simulates ZAMS model with differential rotation with the ROTORC code. Then she evolves the models along the main sequence, solving the problem of conservation of the total energy during the evolution by taking into account the meridional circulation.

The initial model on the ZAMS is rotating according to some prescription (the rotation law). No hydrodynamic motions are assumed to generate this model. The rotation law depends only on the distance from the rotation axis with the rotation rate decreasing with distance from the rotation axis. The rotation law is modelled on that given by Jackson, MacGregor, and Skumanich [ApJS, 156, 245] and given by

$$\Omega(\varpi) = \frac{\Omega_0}{1+(\alpha\varpi)^{\beta}},$$

where Ω is the rotation rate, $\tilde{\omega}$ is the distance from the rotation axis, and Ω_0, α, and β are constants. Only values of β between 0 (solid body) and 2 (largest value for stability) are considered. ZAMS models with differential rotation can now be routinely computed.

To evolve the model along the main sequence, Dr. Toqué developed a theoretical formulation of the internal flow produced by the differential rotation which ensures the conservation of the total energy of the star. With this secular motion, models can be evolved through the entire sequence of core hydrogen burning for an initial rotation which is weakly differential ($\alpha = 2$ and $\beta \sim 0.4$). The initial conservative rotation law evolves toward a shellular one on a time scale which is shorter for higher masses. For lower masses the core rotates much faster than the envelope. Work is continuing to extend these calculations to higher values of β.

Dr. Guenther continued to analyze the data coming from Canada's first space telescope, MOST. He shares responsibility with the other seven science team members for the stellar modeling, oscillation modeling, and interpretation of the data obtained from the satellite. Dr. Guenther continued to collaborate with Dr. Werner Weiss' asteroseismology group at the University of Vienna. He worked on oscillations in giants with Ph.D. candidate Mr. Thomas Kallinger. He worked on oscillations in Procyon, alpha Cen A and other solar type stars with undergraduate Mr. Daniel Huber, and he worked on oscillations in pre-main-sequence stars with post doctoral fellow Dr. Konstanze Zwintz.

Last year's discovery of nonradial oscillations on giant stars by Mr. Kallinger and Dr. Guenther has now been confirmed by a number of other researchers.

Last year's work on oscillations in pre-main-sequence stars with Dr. Zwintz has been extended, for the first time ever, to a young cluster of stars. Drs. Guenther, Zwinz, Weiss, and Mr. Kallinger used both the common origin of the stars and their oscillation spectra to test and constrain models of the stars. They were able to overcome the usual limitations of young cluster analysis in which the surface temperatures are poorly determined.

Dr. Guenther continued to advise Ph.D. candidate Mr. Chris Cameron, University of British Columbia, on stellar models of roAp stars. Mr. Cameron is modeling the effect of magnetic fields on the oscillation frequencies and is expected to complete his Ph.D. thesis in early 2008. He has been invited to work with Dr. Guenther as a postdoctoral fellow in 2008.

Dr. Guenther continued his work with the Yale Convection Group (Dr. P. Demarque, P.I.) on calculating three-dimensional stellar convection zones. The controversial results from MOST on Procyon (Nature 2004), are now confirmed by other researchers. Drs. Guenther, Demarque and the Yale Convection Group have proposed an explanation for the surprising results on Procyon and are currently in the process of checking their numerical computations.

Dr. Guenther supervised Mr. Joel Tanner's Master's thesis on asteroseismology of pre main sequence stars. This work found that the large spacing for both pre and post main sequence stars near the ZAMS is similar, but that the small spacings exhibit significant differences between the two. Another conclusion is that more precise observed stellar parameters are more effective in reducing the number of models which can match the observed frequencies than just observing more frequencies. Mr. Mike Casey will be working with Dr. Guenther on pre-main-sequence stars, particularly using their pulsation properties to better determine their evolutionary status and other properties.

With Ph.D. student Ms. Birgit Fuhrmeister and Dr. Peter Hauschildt (Hamburger Sternwarte) Dr. Short has revived a program to adapt the *PHOENIX* atmospheric modeling and spectrum synthesis code to model the spectrum formation if the atmospheres of stars, such as the Sun, that have a temperature inversion such that the star is surrounded by a chromosphere and corona of much higher temperature than the visible photosphere. The nature of the physical mechanism by which the outer atmosphere is so dramatically heated is one of the main outstanding problems in the astrophysics of late type stellar atmospheres. Unlike previous investigations in which only a few spectral features that diagnose the state of the outer atmosphere could be modeled in NLTE while most spectral lines were held in unrealistic LTE, *PHOENIX* can model simultaneously tens of thousands of spectral lines in NLTE taking into account NLTE effects among chemical species due to overlapping transitions. Preliminary results indicate that the computed strength of diagnostic spectral lines, and hence the inferred state of the outer atmosphere, depends much more sensitively than previously known on irradiation of the chromosphere from emission lines of the third and fourth ionization stages of elements in the transition region between the chromosphere and corona.

With Drs. Pierre Demarque and Christian Straka (Yale University) Dr. Short has begun a collaboration to model the outer boundary condition of M dwarf interior structure models more realistically by accounting for hydrodynamic atmospheric turbulence. He will be calculating mean radiative opacities suitable for radiation hydrodynamic simulations. The goal is to resolve the discrepancy between the observed and computed mass-radius relation among M dwarf stars.

The relatively cool barely evolved standard star Procyon (α Canis Minoris) has been the subject of much interest recently. It has been the target of a recent interferometric study in the near IR band that has provided unprecedented information of the variation of the visibility with wavelength tantalizingly close to the visible band. This is a major step toward imaging the surface of a dwarf star other than the Sun at optical wavelengths. Moreover, Procyon was a target of the Canadian MOST satellite and was found to have significantly lower amplitude oscillations than expected for a star of its parameters. However, previous analyses of the star's spectrum and spectroscopic determinations of its atmospheric properties were based on LTE modeling. Dr. Short has begun a program to model the high resolution Griffin atlas of Procyon with the same type of massively Non-LTE modeling that he has recently applied to the Sun and metal poor red giants to investigate how the inferred atmospheric properties are affected when more realistic modeling is applied.

Dr. Thacker is continuing his research on active galactic nuclei and has been in discussions with researchers involved in the Sloan Digital Sky Survey to compare his simulation results to their data. Mr. David Williamson is beginning his PhD research in galactic dynamics under Dr. Thacker. The long-term goal is to investigate the evolution of gas in model (dwarf) disc galaxies (including a self-consistent halo) at a mass resolution of one solar mass using over 10^8 gas particles.

Dr. Alexei Razoumov continued his work on physical conditions in high-redshift star-forming galaxies and their contribution to the cosmic UV background. In collaboration with Dr. Jesper Sommer-Larsen from the University of Copenhagen he wrote a follow-up to their last year's paper on this subject, in which they combined a point-source radiative transfer code with high-resolution galaxy formation models to compute Lyman continuum (LyC) emission for a sample of galaxies spanning a mass range of a factor of twenty, as well as a range of star formation rates. Star formation and feedback (both radiative and mechanical) in these models were computed using either a Salpeter or a Kroupa initial mass function. Besides contributing to the cosmic UV background, LyC photons heat and ionize gas in host galaxies, which was accounted for in the models. Their results imply that the cosmic galactic ionizing UV luminosity was monotonically decreasing from redshift $z = 3.6$ to 2.4, due to the steady gas infall and higher gas clumping at lower redshifts, curiously anti-correlated with the star formation rate in the smaller galaxies, which on average rises during this redshift interval. These models also explained the variance in the far-UV spectra seen in real life high redshift galaxies as the result of the combined scatter in the intrinsic variations in the LyC emission of individual galaxies and orientation effects. Dr. Razoumov and Dr. Sommer-Larsen are now working to extend this study to much higher numerical resolution (10 pc) and higher redshifts.

Dr. Razoumov also continued a related project on performing coupled radiation-hydrodynamical (RHD) simulations of galaxy formation, using a specially-developed version of the adaptive mesh refinement (AMR) cosmological structure formation code ENZO. At high redshifts, when early galaxies started to assemble from relatively small protogalactic clumps, including radiative feedback is particularly important, as small galaxies are most susceptible to feedback. In July 2007 Dr. Razoumov ran exploratory RHD simulations of feedback in $z = 15$ galaxies. Similar larger-scale simulations should provide clues to the early metal enrichment of the Universe, which resulted in the transition from zero-metallicity Pop III stars to the second generation of metal-poor stars.

Dr. Razoumov also worked on gas kinematics in damped Lyman-alpha absorbers (DLAs) at $z = 3$. DLAs are linked to forming protogalaxies in the early Universe, and because they are seen in absorption, they present an incredible tool for probing physical processes on small (in the cosmological context) galactic scales. In October 2007, in collaboration with several researchers outside of the ICA, Dr. Razoumov submitted a paper on neutral gas kinematics and star formation in DLAs, where they presented results from very large simulations of thousands of galaxies in computational volumes of up to 32 Mpc in size, while resolving physical scales down to 45 pc. They used high-angular resolution radiative transfer to calculate the effect of UV radiation on the ionization structure of gas in these galaxies, concluding that in order to explain the observed neutral gas velocity dispersion in DLAs one has to resolve the dynamics of individual components of the multiphase interstellar medium, as opposed to just treating them as a single multi-component fluid at a subgrid resolution. To get insight into the physics of feedback in star forming regions, Dr. Razoumov is now working to improve his simulations to resolve the scales (1-10 pc) and processes in large molecular clouds. This work is done in collaboration with a number of other researchers, including Dr. Michael Norman from UCSD and Dr. Daniel Whalen from LLNL.

Dr. Joris Van Bever has continued his research on the influence of stellar dynamics in dense stellar systems on the population and spectral synthesis properties of young massive starburst clusters. Dr. Van Bever has implemented the fast numerical scheme for the evolution of extremely massive stars he has developed in collaboration with members of the Brussels (Belgium) research group (Dr. Dany Vanbeveren and PhD student, Ms. Houria Belkus) into his direct N-body code ('Youngbody'). This scheme accounts for the latest theoretically predicted stellar wind mass loss rates for very massive stars. Preliminary direct N-body simulations of young massive clusters made using Youngbody (Belkus et al., in preparation) indicate that the runaway merger product that is formed in sufficiently dense clusters does not necessarily reach masses on the order of 1000 solar masses as has been suggested in the past. Especially at high metallicities, the stellar wind mass loss is able to compete with the mass gained through stellar collisions. The black hole remnants of these objects have masses of about 100 solar masses, instead of 1000. It is therefore unlikely that at high metallicity, runaway collisions can lead to intermediate mass black holes in young clusters. Also in 2007, Dr. Van Bever (again in collaboration with Dr. Dany Vanbeveren and PhD student, Ms. Houria Belkus) examined the differences between massive single star and massive close binary population synthesis predictions of WR stars, accounting for the latest developments in massive star stellar wind predictions. It is shown that the WC/WN number ratio as a function of metallicity depends significantly on whether or not binaries are included. Furthermore, the observed WC(+OB)/WN(+OB) number ratio in the solar neighborhood seems to indicate that the WR mass loss rates are lower by another factor of two compared to recently proposed clumping-corrected formalisms.

Refereed Publications

Barban, C., Matthews, J., De Ridder, J., Baudin, F., Kuschnig, R., Mazumdar, A., Samadi, R., **Guenther**, **D.B.**, Moffat, A.F.J., Rucinski, S.M., Sasselov, D., Walker, G.A.H. and W.W. Weiss 2007, "Detection of Solar-Like Oscillations In the Red Giant Star Epsilon Ophiuchi by MOST spacebased photometry", A&A, 468, 1033.

Belkus, H., **Van Bever, J**., Vanbeveren, D. 2007, "The Evolution of Very Massive Stars", ApJ, 659, 1576.

Croll, B., Matthews, J. M., Rowe, J. F., Gladman, B., Miller-Ricci, E., Asselove, D., Walker, G. A. H., Kuschnig, R., Lin, D. N. C., **Guenther, D. B**., Moffat, A. F. J., Rucinski, S. M., Weiss, W. W. 2007, "Looking for Super-earths in the HD 189733 System: A search for transits in MOST space-based photometry", ApJ, accepted.

Croll, B., Matthews, J. M., Rowe, J. F., Kuschnig, R., Walker, A., Gladman, B., Sasselov, D., Cameron, C., Walker, G. A. H., Lin, D. N. C., **Guenther, D. B.**, Moffat, A. F. J., Rucinskin, S. M., Weiss, W. W 2007, "Looking for Giant Earths in the HD 209458 System: A Search for Transits in MOST Space-Based Photometry", ApJ, 658, 1328.

Croll, B., Matthews, J. M., Walker, G. A. W., Rowe, J. F., Miller-Ricci, E., Kuschnig, R., Sasselov, D., Rucinski, S. M., Walker, A., **Guenther, D. B.**, Moffat, A. F. J., Weiss, W. W. 2007, "Spot Modulation of the Exoplanetary system HD 189733: continuous space-based photometry returned by MOST", ApJ, submitted.

Demarque, P., **Guenther, D. B.**, Li, L. H., Maxumdar, A., Straka, W. S. 2007, "YREC: The Yale Rotating Stellar Evolution Code", Astrophysics and Space Science, submitted.

Foyle, K., Courteau, S., and **Thacker**, **Robert J.** 2007, "An n-body/SPH Study of Galaxy Mass Density Profiles", MNRAS, submitted.

Gillich, A., Deupree, R., Lovekin, C.C., Short, C.I., and **Toque, N.** 2007, "Determination of Effective Temperatures and Luminosities for Rotating Stars", ApJ, submitted.

Gruberbauer, M., Kolenberg, K., Rowe, J., Huber, D., Matthews, J. M., Reegen, P., Cameron, C., Kallinger, T., Werner, W., **Guenther, D. B.**, Moffat, A. F., Rucinkski, S., Sasselov, D., Walker, G. 2007, "MOST photometry of the RRd Lyrae AQ Leo: Two radial modes, 32 combination frequencies, and beyond", MNRAS, 379, 1498.

Gruberbauer, M., Saio, H., Huber, D. Kallinger, T., Werner, W. W., **Guenther, D. B.**, Kuschnig, R., Matthews, J. M., Moffat, A. F. J., Rucinski, S., Sasselov, D., Walker, G. A. J. 2007, "MOST photometry and modeling of the rapidly oscillation (roAp) star Gamma Equ", A&A, submitted.

Guenther, D. B., Kallinger, T., Zwintz, K., Weiss, W. W., Tanner, J. 2007, "Seismology of Pre-Main-Sequence Stars in NGC 6530", ApJ, accepted.

Guenther, D. B., Kallinger, T., Reegen, P., Weiss, W. W., Matthews, J. M., Kuschnig, R., Moffat, A.F.J., Rucinski, S. M., Sasselov, D., Walker, G. A. H. 2007, “The search for p-modes in solar-type stars by MOST: tau Boo and Procyon revisited”, CoAst, 151, 5.

Kallinger, T., **Guenther, D. B.**, Weiss, W. W., Huber, D., Matthews, J. M., Kuschnig, R., Moffat, A. F., J., Rucinski, S. M., Sasselov, D., Walker, G. A. H. 2007, "Modeling solar-type oscillations in the red giant eps Oph using MOST space photometry", ApJ, accepted.

Kallinger, T., **Guenther, D. B.**, Weiss, W. W., Hareter, M., Ruckinski, S. M., Kuschnig, R., Matthews, J. M., Moffat, A. F. J., Reegen, P., Sasselov, D., Walker, G. A. H. 2007, "MOST detects solar-type oscillations in the K2 giant star HD 20884", ApJ, submitted.

Kaminski, K.Z.; Rucinski, S.M.; Matthews, J.M.; Kuschnig, R.; Rowe, J.F.; **Guenther, D.B.**; Moffat, A.F.J.; Sasselov, D.; Walker, G.A.H.; Weiss, W.W. 2007, “MOST photometry and DDO spectroscopy of the eclipsing (white dwarf + red dwarf) binary V471 Tau”, AJ, 134, 1206.

Lovekin, C.C. and **Deupree, R.G.** 2007, “Radial and Nonradial Oscillation Mode in Rapidly Rotating Stars”, ApJ, submitted.

Miller-Ricci, E., Rowe, J. F., Sasselov, D., Matthews, J. M., **Guenther, D. B.**, Kuschnig, R., Moffat, A. F. J., Rucinski, S. M., Walker, G. A. H. 2007, "MOST Spacebased Photometry of the Transiting Exoplanet System HD 209458: Transit Timing to Search for Additional Planets", ASPC, 366, 164.

Miller-Ricci, E., Rowe, J. F., Sasselov, D., Croll, B., Matthews, J. M., **Guenther, D. B.**, Kuschnig, R., Moffat, A. F. J., Rucinski, S. M., Weiss, W. W. 2007, "MOST Spacebased Photometry of the Transiting Exoplanet System HD 189733: Precise Timing Measurements for Transits Across an Active Star", ApJ, submitted.

Razoumov, Alexei O., Sommer-Larsen, Jesper 2007, "Modeling Lyman continuum emission from young galaxies”, ApJ, 668, 674.

Rucinski, S., Kuschnig, R., Matthews, J. M., Dimitrov, W., Pribulla, T., **Guenther, D. B.**, Moffat, A. F. J., Sasselov, D., Walker, G. A. H., Weiss, W. W. 2007, "Discovery of the strongly eccentric, short-period binary nature of the B-type system HD 313926 by the MOST satellite", MNRAS, 380, 63.

Saio, H., Cameron, C., Kuschnig, R., Walker, G. A. H., Matthews, J. M., Rowe, J. F., Lee, U., Huber, D., Weiss, W. W., **Guenther, D. B**., Moffat, A. F. J., Rucinski, S. M., Sasselov, D. 2007, "g-modes in the late-type Be star Beta CMi detected by the MOST satellite", CoAst, 150, 215.

Scannapieco, E., **Thacker, Robert J.,** and Couchman, H. M. P. 2007, “Measuring AGN Feedback with the Sunyaev-Zel'dovich Effect", ApJ submitted.

Walker, G. A.H, Croll, B., Kuschnig, R., Walker, A., Slavek, M. R., Matthews, J. M., **Guenther, D. B.**, Moffat, A. F. J., Dimitar, S., Weiss, W. W. 2007, "The Differential Rotation of Kappa[1] Ceti as Observed by MOST", ApJ, 659, 1611.

Vanbeveren, D., **Van Bever, J**., Belkus, H. 2007, "The WR population predicted by massive single star and by massive binary evolution", ApJ, 662, 107.

Zamiñski, K. Z., Ruciñski, S. M., Matthews, J. M., Kuschnig, R., Rowe, J. F., **Guenther, D. B.**, Moffat, A. F. J., Sasselov, D., Walker, G. A. H., Weiss, W. W. 2007, "MOST photometry and DDO spectroscopy of the eclipsing (white dwarf + red dwarf) binary V471 Tau", MNRAS, submitted.

Other Full Publications

Barban, C., Matthews, J., De Ridder, J., Baudin, F., Kuschnig, R., Mazumdar, A., Samadi, R., **D.B. Guenther**, Moffat, A.F.J., Rucinski, S.M., Sasselov, D., Walker, G.A.H and Weiss, W.W. 2006, "Studying Solar-Like Oscillations In Red Giants: Most Spacebased Photometry Of Epsilon Ophiuchi", SOHO-GONG, proceedings.

Deupree, R. G., Gillich, A., Lovekin, C. C., and **Toque, N.** 2007, "Rotating Stars Toolkit", Proceedings of the Unsolved Problems in the Stellar Physics Conference, accepted.

Toque, N., Deupree, R. G., Gillich, A., and **Lovekin, C. C.** 2007, “Rapid Differential Rotation in Intermediate Mass Stars”, A.N. , accepted.

Colloquia and Presentations Given by ICA Members

Guenther, D. B., Saint Mary’s University, "Revealed! Secrets of Teenaged Stars", 9 February 2007.

Catherine Lovekin, Saint Mary's University, "Good Vibrations: Reliable Oscillation Frequencies for Rotating Stars", 16 March 2007.

Alexei Razoumov, University of California, San Diego, USA, " High-redshift galaxies in absorption: can our models reproduce observations?", April 2007.

Alexei Razoumov, Saint Mary's University, " High-redshift galaxies in absorption: can our models reproduce observations?", 13 April 2007.

Nathalie Toqué, Stellar Club of the Institute of Astrophysics of Paris (IAP), “Internal rotation of a convective core star", 22 May 2007.

Alex Razoumov, Abbazia di Spineto, Sarteano, Italy, “Effect of star formation and feedback on neutral gas kinematics in z=3 galaxies", 14 June 2007.

Nathalie Toqué, Thinkshop5, Potsdam, Germany, “Rapid differential rotation in massive stars", 24-29 June 2007.

Robert Deupree, Unsolved Problems in Stellar Physics Conference, Institute of Astronomy, University of Cambridge, UK, “Rotating Stars Toolkit”, 2 July 2007.

David Guenther, Stellar Pulsation: Cycles of Discovery, University of British Columbia, Vancouver, “Asteroseismology of PMS Stars in a Cluster”, 25 July 2007.

Catherine Lovekin, Stellar Pulsation: Cycles of Discovery, University of British Columbia, BC, “Good Vibrations: Accurate Oscillation Frequencies for Rapidly Rotating Stars", 25 July 2007.

Ian Short, 8th Annual Bluenose Numerical Analysis Day, Saint Mary's University, “Numerical radiative transfer in astrophysics", 27 July 2007.

Nathalie Toqué, European Science Foundation, "Turbulent diffusion", 16 August 2007.

Joris Van Bever, Dynamical Evolution of Dense Stellar Systems International Astronomical Union Symposium 246, Capri, Italy, "The formation and evolution of massive and very massive stars in dense stellar systems”, 5-9 September 2007.

Robert Thacker, St. Francis Xavier University, “A New Technique to Understand the Impact of Black Holes on Galaxy Formation”, November, 2007.

Poster Presentations

Jon P. Ramsey & David A. Clarke, 2007 JETSET School and Workshop, Turin, Italy, “AZEuS: An adaptive-grid staggered-mesh MHD fluid code”, January, 2007.

Catherine Lovekin & Robert Deupree, CASCA 2007, Poster Presentation: "Good Vibrations: Reliable Oscillation Frequencies for Rotating Stars", 5-8 June 2007.

Jon P. Ramsey & David A. Clarke, CASCA 2007, Poster Presentation: "Simulating protostellar jets on observational length scale", 5-8 June 2007.