Oak Ridge National Laboratory
Physics Division

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The following report covers astrophysical research activities within the Physics Division between October 2003 and September 2004.

1. INTRODUCTION

As a natural extension of its long tradition of research excellence in nuclear and atomic physics, the Physics Division at Oak Ridge National Laboratory conducts a broad program of laboratory and theoretical research in astrophysics. Within the Division are two research groups dedicated to astrophysics, the Theoretical Astrophysics and Experimental Astrophysics groups. Members of the Atomic Physics, Nuclear Physics Theory and High Energy Reactions & Neutrals Science groups also conduct astrophysically motivated research. This year saw the formation of the Astrophysics Program within the division to serve as a nexus for these research efforts.

Members of the Physics Division collaborate broadly with researchers at universities and other national laboratories, particularly with the Department of Physics and Astronomy at the University of Tennessee at Knoxville (UTK). Several members of the division hold joint or adjunct positions at UTK, which also serves as the host for many of the postdoctoral researchers and graduate students within the division.

2. THEORETICAL ASTROPHYSICS

This year saw critical expansion of the Theoretical Astrophysics Group with the hiring of scientific staff members C. Y. Cardall (joint with UTK) and W. R. Hix to join group leader A. Mezzacappa, F. E. Barnes and UTK professor M. W. Guidry. This expansion solidifies within the group the expertise essential for its prime focus: the modeling of stellar explosions and their nucleosynthesis. Visiting Distinguished Scientist K. Laganke (Århus) is a frequent collaborator as are members of the Experimental Astrophysics and Nuclear Theory groups. The group added visiting faculty member J. R. Stone (Oxford) and E. J. Lentz and E. Endeve joined A. O. Razoumov as postdoctoral associates within the group. Four new graduate students, M. Baird (UTK), C. Downum (Oxford), W. Goddard (UTK), and W. Newton (Oxford) joined R. D. Budiardja (UTK), C.-T. Lee (UTK), and S. T. Parete-Koon (UTK) in pursuing research projects with the group. The group also serves as the central hub for the TeraScale Supernova Initiative (TSI), a collaboration consisting of two dozen investigators at a dozen institutions (www.phy.ornl.gov/tsi/) focused on the core collapse supernova mechanism. TSI is supported by DOE Office of Science through the Scientific Discovery through Advanced Computing (SciDAC) program.

A collaboration, led by Hix and Langanke with Mezzacappa, D. J. Dean (ORNL), O. E. B. Messer (U. Chicago), M. Liebendörfer (CITA), G. Martínez-Pindeo (IEEC/ICRA, Barcelona) & J. Sampaio (U. Basel), performed the first simulations of stellar core collapse to integrate state-of-the-art neutrino transport and astrophysics with state-of-the-art nuclear structure theory, requiring the collaboration of the nuclear physics and astrophysics research communities (see §3). The inclusion of far more sophisticated models of electron capture on nuclei in ORNL models altered the dynamics of stellar core collapse in a significant way, with ramifications for the explosion mechanism and supernova nucleosynthesis. In particular, increased electron capture in the inner core resulted in a 15-20% reduction in the size of the homologous core (and hence the initial size of the protoneutron star). In contrast, the outer regions of the core saw less electron capture, which slowed their collapse.

J. M. Blondin (NC State U.), C. DeMarino (NC State U.) & Mezzacappa have continued their studies, now in three spatial dimensions, of the stationary accretion shock instability (SASI) in core collapse supernovae. Recent studies by other groups are confirming that the SASI, discovered by the NCSU/ORNL group, may in fact, as they suggested, be the underlying mechanism for the large-scale asymmetries thought necessary to account for observations of the polarization of supernova light and neutron star kicks. Mezzacappa also teamed with S. W. Bruenn (Florida Atl. U.) and E. A. Raley (U. Georgia) to investigate fluid instabilities below the neutrinospheres of supernovae. They find that the previously suggested doubly diffusive ‘‘neutron finger’’ instability is dominated by ‘‘Lepto-Entropy’’ fingers.

Hix participated in a collaboration led by S. Starrfield (Arizona State) with F. X. Timmes (Los Alamos), W. M. Sparks (Los Alamos) and E. M. Sion (Villanova) which investigated the growth of white dwarf stars toward the Chandrasekhar mass limit. These simulations are the first to show that accretion onto a massive white dwarf over a wide range of rates can lead to the growth of the white dwarf and ultimately to its demise as a thermonuclear (or Type Ia) supernova. Furthermore, their simulations have observational signatures quite similar to Supersoft X-ray sources, confirming the prior suggestion that these objects are the progenitors of Type Ia supernovae. It is hoped that identifying and studying the progenitors of these supernovae will allow improvements in their use as cosmological distance indicators and therefore further refine our understanding of our accelerating universe.

Parete-Koon, Hix, M. S. Smith (ORNL), Starrfield, D. W. Bardayan, Guidry & Mezzacappa published the results of their nucleosynthesis calculations which revealed the changes in the elemental production that occur in nova outburst models due to recent HRIBF determinations of the rates of ^{17}F(p,γ)^{18}Ne and ^{18}F(p,α)^{15}O (see §4). They found abundance changes as large as a factor of three for isotopes like ^{17}O, whose solar system abundance may come from novae, as well as ^{18}F, a suggested γ-ray source from novae.

This year also saw further progress on Monte Carlo reaction sensitivity studies on novae, performed by Smith, Hix, Starrfield, Mezzacappa & D. L. Smith (ANL). This approach allows the determination of the total impact of all nuclear uncertainties and also helps to prioritize reaction measurements by determining the most sensitive reaction rates. Both of these projects were the subject of conference presentations and proceedings articles by members of both the Theoretical Astrophysics and Experimental Astrophysics groups.

Significant progress has been made by Cardall and Razoumov on the development of GenASiS, a new 2D/3D Boltzmann neutrino transport code. GenASiS has successfully performed some hydrodynamics and radiation transport test problems and efforts are underway to use GenASiS to study the neutrino energy deposition in the collapsar model for γ-ray burst. It has been proposed that neutrino-antineutrino annihilation of neutrino pairs emerging from the inner hot disk around the central black hole provides the energy to power the supernova and relativistic outflows associated with γ-ray bursts and current collapsar models have simply assumed the necessary energy deposition rate. This mechanism is extremely sensitive to the neutrino transport in and around the disk, and it is possible this energy source is insufficient to drive the explosion. The studies undertaken by Razoumov and Cardall will compute the energy deposition rate from a first principles solution of the 2D neutrino Boltzmann equations for the 2D neutrino radiation field in a collapsar-like environment. This will go a long way towards determining whether the neutrino deposition mechanism is a viable mechanism for collapsars/gamma ray bursts. The next application for GenASiS will be fully dynamic 2D core collapse supernova simulations.

The collaboration of Hix, Mezzacappa, J. C. Hayes (UCSD), Bruenn and Blondin have made significant progress on the development of 2D/3D radiation hydrodynamic and magnetohydrodynamic simulations of core collapse supernovae. These will employ ''ray-by-ray'' neutrino transport coupled to the VH-1 and ZEUS-MP codes. While only a stepping stone to simulations with true 2D/3D transport, the inclusion of multi-frequency ray-by-ray neutrino transport will mark a significant advance in realism in 2D/3D models. Most importantly, no contemporary, realistic models of core collapse supernovae that include magnetic fields exist. Therefore, the precise role of magnetic fields in the core collapse supernova mechanism remains unknown. Perhaps the most fundamental question in current core collapse supernova theory is whether such supernovae are driven by neutrinos, MHD or both and these ray-by-ray models will represent a significant step to resolving this question.

Stone, Newton & Downum in collaboration with Mezzacappa & Barnes have initiated a new study focused on the high-density equation of state (EOS) relevant for the hot proto-neutron star at the center of a core collapse supernova. The central goal of this study is to replace phenomenological models based on the Skyrme parameterizations of the nucleon-nucleon interaction potential with more microphysically motivated models based on quark interactions. When a new EOS based on the quark models of the nucleon interactions is available, studies that can for the first time investigate the sensitivity of our supernova models to this high-density stellar core physics will be performed.

In addition to their work in support of the nuclear astrophysics experimental program at HRIBF, Hix and Mezzacappa also organized the astrophysics motivation for the nuSNS proposal, which seeks to build a neutrino experimental station to take advantage of the large neutrino flux from the Spallation Neutron Source (SNS), and continue to be involved in nu_SNS activities. (see §7).

3. NUCLEAR PHYSICS THEORY

The primary focus of the Nuclear Physics Theory group is research on the structure of atomic nuclei. An important byproduct of this research are nuclear properties of astrophysical utility. Group members contributing to astrophysically relevant research include group leader D. J. Dean, postdoctoral associates G. S. Stoitcheva and A. Juodagalvis (joint with Århus) and Visiting Distinguished Scientist K. Langanke (Århus). Langanke and Dean, with G. Martínez-Pindeo (IEEC/ICRA, Barcelona) and J. Sampaio (U. Basel), developed a method combining shell model Monte Carlo and random phase approximation techniques to calculate electron capture reaction rates at finite temperature for nuclei with more than 65 nucleons, the current limit of full shell model diagonalization methods. Juodagalvis, with Langanke, Dean, Martínez-Pindeo, Sampaio and Hix, applied similar methods to calculate reaction rates for neutrinos scattering off of nuclei with 50-65 nucleons, an often overlooked means for the escaping supernova neutrinos to interact with the supernova ejecta.

4. ASTROPHYSICS AT THE HOLIFIELD RADIOACTIVE BEAM FACILITY

The research activities in the Experimental Astrophysics Group involves tightly coupled work in three areas, all directed towards improving our understanding of stellar explosions. First, measurements of nuclear reactions on unstable nuclei are made with unique beams of radioactive nuclei at ORNL's Holifield Radioactive Ion Beam Facility (HRIBF). HRIBF, the only national user facility in the U.S. dedicated to basic research experiments with beams of reaccelerated radioactive nuclei, has more radioactive species than any other lab in the world and is the only facility with heavy, neutron-rich radioactive nuclei of importance to the r-process in supernova explosions. The results of HRIBF measurements are then folded in with known nuclear physics information, converted into thermonuclear reaction rates, and processed into formats needed for astrophysical models; this work is carried out under the auspices of the Nuclear Data Project. Finally, element synthesis calculations with predetermined temperature and density histories and the latest collection of thermonuclear rates are carried out in collaboration with members of the Theoretical Astrophysics Group (see §1). Group members include group leader M. S. Smith, staff members J. C. Blackmon and D. W. Bardayan, postdoctoral associates M. Johnson (Oak Ridge Assoc. U.), K. L. Jones (Rutgers), C. D. Nesaraja (UTK/ORNL), S. D. Pain (Oak Ridge Assoc. U.), D. W. Visser (U. NC), Tenn. Tech. U. professor R. L. Kozub, and programmers J. P. Scott

(UTK/ORNL) and E. J. Lingerfelt (UTK/ORNL). Graduate students working with the group include K. Chae (UTK), R. Fitzgerald (U. NC), R. J. Livesay (Colo. Sch. Mines), Z. Ma (UTK) and J. S. Thomas (Rutgers). Frequent collaborators include C. R. Brune (Ohio U.), A. E. Champagne (U. NC), J. A. Cizewski (Rutgers), T. Davinson (Edinburgh U.), U. Greife (Colo. Sch. Mines), C. Iliadis (U. NC), P. Parker (Yale), F. Sarazin (Colo. Sch. Mines), L. Sahin (Dumlupinar U.) and P. Woods (Edinburgh U.) This year Blackmon earned a Presidential Early Career Award for Scientists and Engineers (PECASE) award and Bardayan was named ORNL Young Scientist of the Year.

In this past year, the analysis of two measurements at HRIBF with unique radioactive ^{18}F beams have been completed and are leading to a better understanding of the production of ^{18}F in novae. This is important because ^{18}F freshly synthesized in novae has a radioactive half-life sufficiently long (two hours) so that it decays after the expanding nova envelope is transparent to radiation, making it an observable of the nova outburst. One of the latest measurements, led by Bardayan, involved scattering ^{18}F off hydrogen in a thick target. Kozub headed another experiment that involved transferring a neutron from a deuterium target onto an ^{18}F beam particle. The Silicon Detector Array (SIDAR) was used in both measurements to detect reaction particles, and the latter reaction also utilized the Daresbury Recoil Separator (DRS), a 13 m long series of electromagnets and electrostatics that can separate reaction products from other nuclei at more than 1 part in 10 billion. The results of the measurements are a factor of two to three decrease in the rates of the $^{18}\mathrm{F} + \mathrm{p}$ fusion reactions that destroy ^{18}F in the expanding nova envelope. When this laboratory information was processed and inserted into an ORNL computer model of the outburst, it was found that three times more radioactive ^{18}F should survive the explosion and be ejected into space. The decay of this ^{18}F should be visible to multi-million dollar orbital satellites and provides an important window into the workings of novae.

A ^{7}Be beam of intensity greater than 10 million particles per second was also developed for a measurement of the ^{7}Be + proton fusion reaction that is crucial to understanding the flux of neutrinos emitted by our Sun. The beam was successfully used for a proton scattering measurement, led by Livesay, to help normalize the fusion reaction, and will soon be used for the fusion reaction measurement, spearheaded by Fitzgerald. The DRS was commissioned with a windowless hydrogen gas target system in preparation for this experiment, as well as for others involving capture reactions on radioactive heavy ion beams. Blackmon led 16 short commissioning experiments utilizing 100 eight-hour shifts of beam to characterize the transmission of the recoils through the separator to 8% and the total gas target thickness to 3%.

Jones and Kozub headed a very successful proof of principle neutron transfer experiment with a beam of stable Sn nuclei in preparation for upcoming similar measurements with beams of radioactive ^{130}Sn and ^{132}Sn nuclei. These nuclei are in the path of the rapid neutron capture process (r-process) in supernovae, and their location near a closed neutron shell makes their rate of capturing neutrons particularly influential in supernovae element synthesis models. Thomas led measurements and analysis of neutron transfer reactions on radioactive ^{82}Ge and ^{84}Se closed-shell nuclei the first such measurements of nuclei in the r-process path. The success of these transfer studies demonstrate the viability of a technique touted for years as a cornerstone of astrophysics studies to be done at the Rare Isotope Accelerator (RIA) facility, a future, billion-dollar, next-generation radioactive beam facility. Planning is also underway for a test of another technique led by Johnson, this one looking for gamma decays in coincidence with the signature of the neutron transfer, which promises to give significantly higher energy resolution (a more precise experiment) than previous measurements.

Group members took a leadership role in planning for a nuclear astrophysics program at RIA by establishing the Astrophysics at RIA (ARIA) Working Group. One experimental hall at RIA will be devoted to experiments in nuclear astrophysics primarily capture and scattering reactions of heavy ion radioactive nuclei on light mass target nuclei such as Hydrogen and Helium. With almost 30 members from over 15 institutions, ARIA has drafted up floor plans of equipment needed for forefront nuclear astrophysics measurements at RIA.

Smith, Lingerfelt, Scott, Nesaraja, Chae, and Hix made a major advancement this past year in the Nuclear Data Project with the release of a unique online suite of computer programs (available at nucastrodata.org) that enable the rapid incorporation of new nuclear physics results into astrophysical models. Users can import their own nuclear data, modify this data, convert it into thermonuclear reaction rates, modify and plot these rates, combine the rates into rate libraries, merge libraries, document the contents of the libraries, share libraries with others in the community, and run and visualize element synthesis calculations with these libraries. This suite is revolutionizing the way that nuclear astrophysics obtain and utilize nuclear data in their calculations. The work done with a few mouse clicks in our suite was previously done using numerous incompatible codes and often numerous individuals at different institutions. This suite makes it possible to very quickly determine the astrophysical impact of new nuclear physics measurements. The suite is hosted at nucastrodata.org, and this site was redesigned this year to better provide hyperlinks to all available nuclear data sets relevant for astrophysics studies.

5. ASTROPHYSICS WITH NEUTRONS

Research in neutron nuclear astrophysics at ORNL is centered at the Oak Ridge Electron Linear Accelerator (ORELA) facility. This high flux and extremely high resolution white neutron source is ideally suited for nuclear astrophysics in the energy range (100 eV to 1 MeV) of importance for nucleosynthesis of the heavy elements during the slow neutron capture (s) process. Physics division members P. E. Koehler and the late S. Raman participated in astrophysics related activities as well as Nuclear Science and Technology Division members K. H. Guber and C. W. Alexander.

Koehler, in collaboration with Yu. Gledenov (Joint Institute for Nuclear Research, Dubna, Russia), T. Rauscher, and

C. Frolich (U. Basel) performed a detailed R-matrix resonance analysis of ^{147}Sm(n,α)) data from ORELA and compared the results to models typically used to predict astrophysical reaction rates. The high signal-to-background ORELA data together with the detailed resonance analysis allowed a much more direct comparison between the results of the experiment and the theoretical expectations than previously was possible. This comparison revealed that the theory is less accurate than thought, and, in fact, that some underlying premises of the theory may be incorrect. So far as we know, these are the only data that allow such a detailed and direct comparison to this theory. We are planning new experiments at ORELA and at the Los Alamos Neutron Science Center (LANSCE) to collect similar and better data with which to see if these startling new results can be confirmed.

In collaboration with H. Harada, K. Furataka, S. Nakamura (Japan Nuclear Cycle (JNC) Development Institute), M. Igashira, K. Ohgama, T. Osaki (Tokyo Institute of Technology), and Alexander, Koehler has developed a new apparatus for neutron capture measurements on long-lived radioactive samples at ORELA. The apparatus was installed on flight path 6 in the 40-m station at ORELA. It consists of a pair of gamma-ray detectors based on deuterated benzene scintillator together with a 6Li-glass scintillator serving as a neutron flux monitor. First test measurements were made with a ^{197}Au sample, and a 2-g ^{99}Tc sample is being prepared. This new apparatus doubles our capacity for neutron capture measurements at ORELA. It will be used mainly for measurements on long-lived radionuclides of importance to s-process nucleosynthesis studies.

Koehler and Raman participated in the n_TOF collaboration to measure neutron capture cross sections in the energy range between 100 eV and 500 keV for ^{135}Cs, ^{151}Sm, and isotopes of Mg, Os, and Zr at the n_TOF facility at CERN and at the Forschungszentrum Karlsruhe. The first two nuclides are radioactive branching points in the nucleosynthesis flow during the s process and hence can be used to constrain the neutron flux and temperature of the s-process environment in AGB stars. One surprise was that all theoretical predictions for the previously unmeasured ^{151}Sm(n,γ) rate at kT=30 keV were substantially smaller than our newly measured rate of 3100160 mb. The stable Mg isotopes can be important neutron poisons during the s process in AGB stars. In addition, a resonance analysis of the ^{25}Mg(n,γ) cross section can be used to constrain the s-process neutron source reaction ^{22}Ne(α,n)^{25}Mg. Previous neutron capture measurements for these nuclides are thought to be unreliable due to possible background problems in the old data. Neutron capture cross sections on Os isotopes are important for estimating the age of the galaxy using the cosmochronometer ^{187}Os. Neutron capture measurements on the Zr isotopes will be useful for setting constraints on the neutron density during the s process. Preliminary results show large differences with the currently recommended astrophysical reaction rates.

Koehler participated in a collaboration led by Guber to measure neutron capture and total cross sections for Al, Cl, and K. These light elements can be important neutron poisons during the s process and also may affect the abundances of very rare stable nuclides that may be used as diagnostics of nucleosynthesis environments. Our new data exhibit much improved signal-to-noise ratio over previous measurements. The new data from ORELA show large discrepancies with previous measurements. In some cases, these differences were expected because, as was the case for Mg and Zr isotopes, previous neutron capture measurements for these nuclides are thought to be unreliable due to possible background problems in the old data. In addition to verifying these problems in the old measurements, our new data show that several important resonances had been assigned to the wrong isotope, that some previously assigned resonances do not exist, and that some fairly strong resonances had not previously been reported. As a result, our new astrophysical reaction rates sometimes are substantially different from previously recommended ones

6. ATOMIC ASTROPHYSICS

The atomic physics group at ORNL is principally supported by the US DOE to perform research in fundamental atomic-scale interactions that are relevant to the agency's plasma science mission (i.e. relating to fusion energy, semiconductor processing, etc.), utilizing both experimental and theoretical means. The close synergy of these activities with the needs for modeling astrophysical plasmas has lead to increasing interest, especially since several early projects beginning in 1996, in exploiting the capabilities of the Multicharged Ion Research Facility (MIRF) at ORNL and the computational expertise of the associated group in laboratory astrophysics. Members of the atomic physics group include group leader D. R. Schultz, staff members M. E. Bannister, C. C. Havener and P. S. Krstic, and post-doctoral associates E. Bahati, M. Fogle, T.-G. Lee (joint with U. Kentucky) and R. Rejoub. Frequent collaborators include D. W. Savin (Columbia Astrophysics Laboratory), P. C. Stancil (U. Georgia), G. J. Ferland (U. Kentucky), and M. S. Pindzola (Auburn U.). A number of activities are ongoing within the group.

The line emission, charge state (ionization balance), and momentum balance of an astrophysical plasma, such as those in regions where UV starlight photoionizes gas, are influenced by the process known as charge transfer whereby an ion captures electrons from neutral species such as H or H_2. Havener, Rejoub, Savin, Krstic, Bannister and Stancil have recently carried out laboratory measurements of charge transfer for astrophysically relevant ions with atomic hydrogen utilizing the unique ion-atom experiment at the MIRF which is the only facility in the world capable of measuring charge transfer with H at astrophysically relevant low temperatures. The work is pertinent to the study of active galactic halos, H II regions, the IGM, planetary nebulae, and shocks in supernova remnants and Herbig-Haro objects.

Bannister, Savin, Fogle, Bahati & Pindzola are also undertaking measurements at MIRF of electron-ion collisions. In one project, ionization of solar atmosphere ions by electron impact is being measured to remediate significant gaps in the known ionization rates needed in models used to analyze spectra of the chromosphere, transition region, and corona. In another set of experiments, electron impact ionization of ions relevant to supernova remnants and stellar atmospheres are being studied in order to improve ionization balance calculations and thereby synthetic spectra of these objects. Recent work has called into question previous modeling based on existing measurements, theories, or estimates of key ionization rates.

Previous work to develop models of atomic collisions relevant to modeling nebular spectra of Type Ia SNe (e.g., Liu, W, Jeffery, D.J. & Schultz, D.R. 1998 ApJ 494, 812) and x-ray emission from Jupiter (e.g., Liu, W. & Schultz, D.R. 1999 ApJ 526, 538) and comets (e.g., Hasan, A. A., Eissa, F., Ali, R., Schultz, D. R. & Stancil, P.C. 2001 ApJL 560, L201) have been extended by Schultz, Stancil, Lee, Krstic & Ferland to address open issues pertaining to young stellar objects (YSOs) and photodissociated regions (PDRs). In the former, competing theories of MHD jets in YSOs depend on rates of ambipolar diffusion (Shang, H., Glassgold, A.E., Shu, F. H. & Lizano, S 2002 ApJ 564, 853). To remediate the uncertainties in the amibipolar diffusion coefficients, we have undertaken extensive and very accurate calculations of the proton-hydrogen momentum transfer cross sections (described in a forthcoming publication). Also, since there remains a significant need to provide accurate collision rate coefficients for rovibrational inelastic collisions of He with H_2 in PDRs, we have initiated a collaboration to use the best available theoretical approaches to compute the large database of required information. A first test of the available quantum molecular potential energy surfaces for HeH_2 has been published. This data will be critical for improving models of cooling processes, molecular emission, and nonequilibrium effects in molecular gaseous nebulae and other molecular environments. It will ultimately encompass accurate data production for H, He, and H_2 impacting H_2, HD, and CO.

7. NEUTRINO ASTROPHYSICS

The world's most powerful pulsed neutron source, the Spallation Neutron Source (SNS), is under construction at ORNL. At full power (1.4 MW) the SNS will bombard its mercury target with a 60 Hz, 1.1 mA, 1.3 GeV proton beam, producing 10^{15} neutrinos per second from pion and muon decays in bursts 700 ns long—so the SNS is also the world's most powerful neutrino source. The time structure allows elimination of $>99.9\%$ of cosmic-ray backgrounds; the energy spectra of the decay-at-rest neutrinos produced at the SNS are kinematically determined and overlap significantly with supernova neutrino spectra; and the prodigious flux allows an accurate measurement of neutrino nucleus cross sections in one year with a ten ton (fiducial) target.

A finite, but strategically chosen set of neutrino nucleus cross section measurements would validate the fundamental nuclear structure models at the foundation of the thousands of rate computations that are input to supernova models. In addition, the ability to detect, understand, and ultimately use the detailed neutrino light curve from a future core collapse supernova in our galaxy requires an accurate normalization of the neutrino flux in a supernova neutrino detector and knowledge of the cross sections and byproducts of neutrino interactions in the detector material.

Preliminary approval and floor space allocation has been secured from the SNS management to construct a facility consisting of a shielded enclosure (surrounded by an active veto) at a mean distance of 21 m from the spallation target, and at an angle of 160° relative to the incoming proton beam direction. The available volume ($4.5\,\mathrm{m} \times 4.5\,\mathrm{m}$ floor space with a clear height of 6.5 m) is sufficient to contain two ten ton (fiducial) targets/detectors. We envision two detectors, one optimized for solid targets, one optimized for targets which can exist in aqueous or liquid scintillator solution. Since the cross section for a target can be measured in one year, the detectors are being designed such that they can be reused for different targets. A multi-institution collaboration (www.phy.ornl.gov/workshops/nusns/), spearheaded by Y. V. Efremenko (UTK), is developing a proposal to build such a facility for submission to the Department of Energy.

The publication list includes all papers published or submitted between October 2003 and September 2004.

PUBLICATIONS

Abbondanno, U., Aerts, G., Alvarez, F., Alvarez-Pol, H., Andriamonje, S., Andrzejewski, J., Badurek, G., Baumann, P., Becvár, F., Benlliure, J., Berthoumieux, E., Cavino, F., Cano-Ott, D., Capte, R., Cennini, P., Chepel, V., Chiaveri, E., Colonna, N., Cortes, G., Coritina, D., Couture, A., Cox, J., Bababneh, S., David, S., Dolfini, R., Domingo-Pardo, C., Duran, I., Embid-Segura, M., Ferrant, L., Ferrari, A., Ferreira-Marques, R., Frais-Koelbl, H., Furman, W., Goncalves, I., Gallino, R., Gonzalez-Romero, E., Goverdovski, A., Gramegna, F., Griesmayer, E., Gunsing, F., Haas, B., Haight, R., Heil, M., Herrera-Martinez, A., Isavev, S., Jericha, E., Käppeler, F., Kadi, Y., Kerveno, M., Ketlerov, V., **Koehler, P.**, Konovalov, V., Krticka, M., Leeb, S., Lindote, A., Lopes, I., Lozano, M., Lukic, S., Marganiec, J., Marrone, S., Martinez-Val, J., Mastinu, P., Mongini, A., Milazzo, P.M., Molina-Coballes, A., Moreau, C., Mosconi, M., Neves, F., Oberhummer, H., O'Brien, S., Pancin, J., Paradela, C., Pavlik, A., Pavlopoulos, P., Perlado, J.M., Perrot, L., Pignatari, M., Plag, R., Plompen, A., Plukis, A., Poch, A., Policarpo, A., Pretel, C., Quesada, J., **Raman, S.**, Rapp, W., Rauscher, T., Reifarth, R., Rosetti, M., Rubbia, C., Rudolf, G., Rullhusen, P., Salgado, J., Soares, J.C., Stephan, C., Tagliente, G., Tain, J., Tassan-Got, L., Tavora, L., Terlizzi, R., Vannini, G., Vaz, P., Ventura, A., Villamarin-Fernandez, D., Vincente-Vincente, M., Vlachoudis, V., Voss, F., Wendler, H. Wiecsher, M. & Wisshak, K., 2004, ''Neutron Capture Cross Section Measurement of ^{151}Sm at n_TOF,'' Phys. Rev. Lett., 93 161103.

Abbondanno, U., Aerts, G., Alvarez, H., Andriamonje, S., Angelopoulos, A., Assimakopoulos, P., Bacri, C. O., Badurek, G., Baumann, P., Becvár, F., Beer, H., Benlliure, J., Berthier, B., Berthomieux, E., Boffi, S., Borcea, C., Boscolo-Marchi, E., Bustreo, N., Calviño, P., Cano-Ott, D., Capote, R., Carlson, P., Cennini, P., Chepel, V., Chiaveri, E., Coceva, C., Colonna, N., Cortes, G., Cortina, D., Couture, A., Cox, J., Dababneh, S., Dahlfors, M., David, S., Dolfini, R., Domingo-Pardo, C., Duran, I., Eleftheriadis, C., Embid-Segura, M., Ferrant, L., Ferrari, A.,

Ferreira-Lourenco, L., Ferreira-Marques, R., Frais-Koelbl, H., Furman, W. I., Giomataris, Y., Goncalves, I. F., Gonzalez-Romero, E., Goverdovski, A., Gramegna, F., Griesmayer, E., Gunsing, F., Haight, R., Heil, M., Herrera-Martinez, A., Ioannides, K. G., Janeva, N., Jericha, E., Käppeler, F., Kadi, Y., Karamanis, D., Kelic, A., Ketlerov, V., Kitis, G., **Koehler, P. E.**, Konovalov, V., Kossionides, E., Lacoste, V., Leeb, H., Lindote, A., Lopes, M. I., Lozano, M., Lukic, S., Markov, S., Marrone, S., Martinez-Val, J., Mastinu, P., Mengoni, A., Milazzo, P. M., Minguez, E., Molina-Coballes, A., Moreau, C., Neves, F., Oberhummer, H., O'Brien, S., Pancin, J., Papaevangelou, T., Paradela, C., Pavlik, A., Pavlopoulos, P., Perez-Parra, A., Perlado, J. M., Perrot, L., Peskov, V., Plag, R., Plompen, A., Plukis, A., Poch, A., Policarpo, A., Pretel, C., Quesada, J. M., Radici, M., **Raman, S.**, Rapp, W., Rauscher, T., Reifarth, R., Rejmund, F., Rosetti, M., Rubbia, C., Rudolf, G., Rullhusen, P., Salgado, J., Savvidis, E., Soares, J. C., Stephan, C., Tagliente, G., Tain, J. L., Tapia, C., Tassan-Got, L., Tavora, L. M. N., Terlizzi, R., Terrani, M., Tsangas, N., Vannini, G., Vaz, P., Ventura, A., Villamarin-Fernandez, D., Vincente-Vincente, M., Vlachoudis, V., Vlastou, R., Voss, F., Wendler, H., Wiescher, M., Wisshak, K., & Zanini, L. 2004, ''New experimental validation of the pulse height weighting technique for capture cross-section measurements,'' Nuclear Instruments and Methods in Physics Research A, 521, 454.

Bardayan, D. W., **Blackmon, J. C.**, Gómez del Campo, J., **Kozub, R. L.**, Liang, J. F., **Ma, Z.**, Sahin, L., Shapira, D., & **Smith, M. S.**, 2004, ''Search for astrophysically important ^{19}Ne levels with a thick-target ^{18}F (p,p) ^{18}F measurement,'' Phys. Rev. C, 70, 015804.

Bruenn, S. W., Raley, E. A., & **Mezzacappa, A.**, 2004, ''Fluid Stability Below the Neutrinospheres of Supernova Progenitors and the Dominant Role of Lepto-Entropy Fingers,'' ApJ in press; astro-ph/0404099.

Cardall, C. Y., 2004, ''General Relativity and Neutrino-driven Supernova Winds,'' in *Proceedings of the First Argonne/MSU/JINA/INT RIA Workshop on The r-Process: The Astrophysical Origin of the Heavy Elements and Related Rare Isotope Accelerator Physics,* ed. Y.-Z. Qian, E. Rehm, H. Schatz & F.-K. Thielemann, (Singapore: World Scientific) 186; astro-ph/0409716.

Cardall, C. Y., 2004, ''Core-collapse supernovae and gravitational waves,'' in *Proceedings of the 8th International Workshop on Topics in Astroparticle and Underground Physics (TAUP03),* in press; astro-ph/0401060.

Cardall, C. Y., 2004, ''Conservative Formulations of General Relativistic Radiative Transfer,'' in it Proceedings of the Tenth Marcel Grossmann Meeting on General Relativity, ed. M. Novello, S. Perez-Bergliaffa & R.Ruffini (Singapore:World Scientific) in press; astro-ph/0404254.

Cardall, C. Y., 2004, ''An Approach to Neutrino Radiative Transfer in Supernova Simulations,'' in *Proceedings of the Workshop on Numerical Methods for Multidimensional Radiative Transfer Problems,* ed. R. Rannacher & R. Wehrse, in press; astro-ph/0404401.

Cizewski, J. A., **Jones, K. L.**, **Thomas, J. S.**, **Bardayan, D. W.**, **Blackmon, J. C.**, Gross, C. J., Liang, J. F., Shapira, D., **Smith, M. S.**, Stracener, D. W., **Kozub, R. L.**, **Nesaraja, C. D.**, Greife, U., **Livesay, R. J.**, & **Ma, Z.**, 2004, ''Single-Particle Structure of Neutron-Rich Nuclei,'' in *The Labyrinth in Nuclear Structure: International Conf. on The Labyrinth in Nuclear Structure,* AIP Conference Proceedings 701, 73.

Fröhlich, C., Hauser, P., Liebendoerfer, M., Martínez-Pinedo, G., Bravo, E., **Hix, W. R.**, Zinner, N. T., & Thielemann, F.-K., 2004, ''The Innermost Ejecta of Core Collapse Supernovae,'' in *Proceedings of the 8th International Symposium on Nuclei in the Cosmos,* ed. L. Buchmann, Nuclear Physics A, in press; astro-ph/0408067.

Fröhlich, C., Hauser, P., Liebendoerfer, M., Martínez-Pinedo, G., Thielemann, F.-K., Bravo, E., Zinner, N. T., **Hix, W. R.**, Langanke, K., **Mezzacappa, A.**, & Nomoto, K., 2004, ''Composition of the Innermost Supernova Ejecta,'' ApJ submitted; astro-ph/0410208.

Glassgold, A.E., **Krstic, P.S.** & **Schultz, D.R.**, 2004, ''H^+ + H scattering and ambipolar diffusion heating,'' ApJ, submitted.

Hix, W. R., Messer, O. E. B. & **Mezzacappa, A.** 2004, ''The Interplay of Electron Capture and Fluid Dynamics in Core Collapse Supernovae, in *Cosmic Explosions in Three Dimensions: Asymmetries in Supernovae and Gamma-Ray Bursts,* ed. P. H'óflich, P. Kumar, & J.C. Wheeler (Cambridge: Cambridge University Press), in press.

Hix, W. R., Messer, O. E., **Mezzacappa, A.**, Liebendörfer, M., Sampaio, J., Langanke, K., **Dean, D. J.**, & Martínez-Pinedo, G. 2003, ''Consequences of Nuclear Electron Capture in Core Collapse Supernovae,'' Phys. Rev. Lett., 91, 201102.

Hix, W. R., Messer, O. E. B., **Mezzacappa, A.**, Sampaio, J., Langanke, K., Martínez-Pinedo, G., Liebendörfer, M. & **Dean, D. J** 2004, ''Nuclear Electron Capture in Core Collapse Supernovae,'' in *Proceedings of the 8th International Symposium on Nuclei in the Cosmos,* ed. L. Buchmann, Nucl. Phys. A in press.

Hix, W. R. & Meyer, B.S., 2004, ''Thermonuclear Kinetics in Astrophysics,'' Nucl. Phys. A, in press.

Hix, W. R., **Mezzacappa, A.** & Messer, O. E. B., 2004, ''Neutrinos and the Deaths of Massive Stars,'' in *Proceedings of the 5th Workshop on Neutrino Oscillations and their Origin (NOON2004),* (Singapore:World Scientific), in press.

Hix, W. R., **Mezzacappa, A.**, Bronson Messer, O. E. B. & Bruenn, S. W., 2003, ''Supernova Science at Spallation Neutron Sources,'' Journal of Physics G Nuclear Physics, 29, 2523.

Juodagalvis, A., Langanke, K., Martinez-Pinedo, G., **Hix, W. R.**, **Dean, D. J.**, & Sampaio, J. M. 2004, ''Neutral-Current Neutrino-Nucleus Cross-sections for A$\sim$50-65 Nuclei,'' Nucl. Phys. A, in press; nucl-th/0404078.

Koehler, P. E., Gledenov, Y. M., Rauscher, T., & Fröhlich, C., 2004, ''Resonance analysis of ^{147}Sm(n,α) cross sections: Comparison to optical model calculations and indications of nonstatistical effects,'' Phys. Rev. C, 69, 015803.

Kozub, R. L., **Bardayan, D. W.**, Batchelder, J. C., **Blackmon, J. C.**, Brune, C. R., Champagne, A. E., Cizewski, J. A., Davinson, T., Greife, U., Gross, C. J., Jewett, C. C., **Livesay, R. J.**, **Ma, Z.**, Moazen, B. H., **Nesaraja, C. D.**, Sahin, L., **Scott, J. P.**, Shapira, D., **Smith, M. S.**, **Thomas, J. S.** & Woods, P. J., 2004, ‘‘New Constraints on the ^{18}F(p,α) ^{15}O Rate in Novae from (d,p) Reaction Sum Rules,’’ Phys. Rev. Lett. submitted; nucl-ex/0405033.

Lee, T-G., Rochow, C., Martin, R., Clark, T.K., Forrey, R.C., Balakrishnan, N., Stancil, P.C., **Schultz, D.R.**, Dalgarno, A. & Ferland, G.J 2004, ‘‘Close-coupling calculations of low-energy inelastic and elastic processes in He collisions with H_2: a comparative study of two potential energy surfaces,’’ J. Chem. Phys. submitted.

Lewis, R., Caggiano, J., Parikh, A., Deibel, C., **Visser, D. W.**, Fear, K., Parker, P. & **Hix, W. R.** 2005, ‘‘^{26}Al^{gs} + p and ^{26}Al^{m} + p Resonances Studied via Proton Decays of ^{27}Si,’’ in *Proceedings of the 8th International Symposium on Nuclei in the Cosmos,* ed. L. Buchmann, Nucl. Phys. A, in press.

Liebendörfer, M., Messer, O. E. B., **Mezzacappa, A.**, Bruenn, S. W., **Cardall, C. Y.**, & Thielemann, F.-K., 2004, ‘‘A Finite Difference Representation of Neutrino Radiation Hydrodynamics in Spherically Symmetric General Relativistic Spacetime,’’ ApJS, 150, 263.

Liebendöerfer, M., Rampp, M., Janka, H. T., & **Mezzacappa, A.**, 2004, ‘‘Supernova Simulations with Boltzmann Neutrino Transport: A Comparison of Methods,’’ ApJ in press; astro-ph/0310662.

Mezzacappa, A., 2004, ‘‘The Core Collapse Supernova Mechanism: Current Models, Gaps, and the Road Ahead,’’ in *Supernovae as Cosmological Lighthouses,* ed. M. Turatto, W. R. J.Shea, S. Benetti & L. Zampieri (Provo: Astronomical Society of the Pacific) in press; astro-ph/0410085.

Mezzacappa, A., Liebendörfer, M., **Cardall, C. Y.**, Messer, O.E.B. & Bruenn, S. W., 2004, ‘‘Neutrino Transport in Core-Collapse Supernovae’’ in *Stellar Collapse (Astrophysics and Space Science Library, Vol. 302),* ed. C. L. Fryer, (Dordrecht: Kluwer), 99.

Mezzacappa, A., 2003, ‘‘The Road to Prediction: Toward Gravitational Wave Signatures from Core Collapse Supernovae,’’ in *The Astrophysics of Gravitational Wave Sources (AIP Conf. Proc. 686),* (New York: AIP), 686, 29.

Mroczkowski, A., Savin, D.W., **Rejoub, R.**, **Krstic, P.S.** & **Havener, C.C.**, 2003, ‘‘Electron capture by Ne^{2+} ions from atomic hydrogen,’’ Phys. Rev. A, 68, 032721.

Pancin, J., Abbondanno, U., Aerts, G., Alvarez, H., Andriamonje, S., Angelopoulos, A., Assimakopoulos, P., Bacri, C., Badurek, G., Baumann, P., Bečvář, F., Beer, H., Benlliure, J., Berthier, B., Berthoumieux, E., Boffi, S., Borcea, C., Boscolo-Marchi, E., Bustreo, N., Calvino, F., Cano-Ott, D., Capote, R., Carlson, P., Cennini, P., Chepel, V., Chiaveri, E., Colonna, N., Cortes, G., Cortina, D., Couture, A., Cox, J., Dababneh, S., Dahlfors, M., David, S., Delbart, A., Derre, J., Dolfini, R., Domingo, C., Duran-Escribano, I., Eleftheriadis, C., Embid-Segura, M., Ferrant, L., Ferrari, A., Ferreira-Lourenco, L., Ferreiramarques, R., Frais-Koelbl, H., Furman, W., Giomataris, Y., Goncalves, I., Gonzalez-Romero, E., Goverdovski, A., Gramegna, F., Griesmayer, E., Gunsing, F., Haight, R., Heil, M., Herrera-Martinez, A., Ioannides, K., Janeva, N., Jeanneau, F., Jericha, E., Käppeler, F., Kadi, Y., Karamanis, D., Kelic, A., Ketlerov, V., Kitis, G., **Koehler, P.**, Konovalov, V., Kossionides, E., Lacoste, V., Leeb, H., Lindote, A., Lopes, I., Lozano, M., Lukic, S., Markov, S., Marrone, S., Martinez-Val, J., Mastinu, P., Mengoni, A., Milazzo, P., Minguez, E., Molina-Coballes, A., Moreau, C., Neves, F., Oberhummer, H., O’Brien, S., Papadopoulos, I., Papavengelou, T., Paradela, C., Pavlik, A., Pavlopoulos, P., Perez-Parra, A., Perlado, J., Peskov, V., Perrot, L., Peskov, V., Plag, R., Plompen, A., Plukis, A., Poch, A., Policarpo, A., Pretel, C., Quesada, J., Radici, M., **Raman, S.**, Rapp, W., Reifarth, R., Rejmund, F., Rosetti, M., Rubbia, C., Rudolf, G., Rullhusen, P., Salgado, J., Savvidis, E., Stephan, C., Tagliente, G., Tain, J., Tapia, C., Tassan-Got, L., Tavora, L., Terlizzi, R., Terrani, M., Tsangas, N., Vannini, G., Vaz, P., Ventura, A., Villamarin-Fernandez, D., Vincente-Vincente, M., Vlachoudis, V., Vlastou, R., Voss, F., Wendler, H., Wiescher, M., Wisshak, K., & Zanini, L. 2004, ‘‘Measurement of the n_TOF beam profile with a micromegas detector,’’ Nuclear Instruments and Methods in Physics Research A, 524, 102.

Parete-Koon, S., **Hix, W. R.**, **Smith, M. S.**, Starrfield, S., **Bardayan, D. W.**, Guidry, M. W., & **Mezzacappa, A.**, 2003, ‘‘A New ^{17}F(p, γ)^{18}Ne Reaction Rate and Its Implications for Nova Nucleosynthesis,’’ ApJ, 598, 1239.

Patronis, N., Dababneh, S., Assimakopoulos, P. A., Gallino, R., Heil, M., Käppeler, F., Karamanis, D., **Koehler, P. E.**, Mengoni, A., & Plag, R., 2004, ‘‘Neutron capture studies on unstable ^{135}Cs for nucleosynthesis and transmutation,’’ Phys. Rev. C, 69, 025803.

Rejoub, R., **Bannister, M.E.**, **Havener, C.C.**, Savin, D.W., Verzni, C., Wang, J.G. & Stancil, P.C., 2004, ‘‘Electron capture by Ne^{3+} ions from atomic hydrogen,’’ Phys. Rev. A, 69, 052704.

Smith, M. S., **Mezzacappa, A.**, **Hix, W. R.**, Starrfield, S. & Smith D.L., 2004, ‘‘Monte Carlo Approach to Determine the Impact of Nuclear Reaction Rate Uncertainties on Nova Models,’’ in *Proceedings of the 8th International Symposium on Nuclei in the Cosmos,* ed. L. Buchmann, Nucl. Phys. A in press.

Smith, M. S., **Hix, W. R.**, Parete-Koon, S., Dessieux, L., Ma, Z., Starrfield, S., **Bardayan, D. W.**, Guidry, M. W., Smith, D. L., **Blackmon, J. C.** & **Mezzacappa, A.**, 2004, ‘‘Element Synthesis Calculations for Stellar Explosions: Robust Uncertainties, Sensitivities, and Radioactive Ion Beam Measurements,’’ in *Proceedings of the 6th International Conference on Radioactive Nuclear Beams,* Nucl. Phys. A in press.

Smith, M. S., Meyer, R. A., **Bardayan, D. W.**, **Blackmon, J. C.**, Chae, K., Guidry, M. W., **Hix, W. R.**, Kozub, R. L., Lingerfelt, E. J., Ma, Z. & Scott, J. P., 2004, ‘‘Nuclear Data on Unstable Nuclei for Astrophysics,’’ in *Proceedings of the 6th International Conference on Radioactive Nuclear Beams,* Nucl. Phys. A in press.

Smith, M. S., Parete-Koon, S., **Hix, W. R.**, Guidry, M. W., **Mezzacappa, A.**, **Bardayan, D. W.**, **Blackmon, J. C.** & Starrfield, S., 2004, ‘‘Nova Nucleosynthesis with New ^{17}F(p,γ)^{18}Ne and ^{18}F(p,α)^{15}O Reaction Rates,’’ in *Proceedings of the 8th International Symposium on Nuclei in the Cosmos,* ed. L. Buchmann, Nucl. Phys. A in press.

Starrfield, S., Timmes, F. X., **Hix, W. R.**, Sion, E. M., Sparks, W. M., & Dwyer, S. J., 2004, ‘‘Surface Hydrogen-burning Modeling of Supersoft X-Ray Binaries: Are They Type Ia Supernova Progenitors?,’’ ApJL, 612, L53.

Starrfield, S., **Hix, W. R.**, Timmes, F. X., Sion, E. M., Sparks, W. M., & Dwyer, S. J., 2005, ‘‘Studies of Accretion onto Hot, Massive White Dwarfs: The Growth to the Chandrasekhar Limit?,’’ in *Proceedings of the 8th International Symposium on Nuclei in the Cosmos,* ed. L. Buchmann, Nucl. Phys. A in press.

Starrfield, S., Timmes, F. X., **Hix, W. R.**, Sion, E. M., Sparks, W. M. & Dwyer, S. J., 2004, ‘‘Semi-Steady Burning Evolutionary Sequences for CAL 83 and CAL 87: Super Soft X-ray Binaries are Supernova Ia Progenitors,’’ in it Cosmic Explosions in Three Dimensions: Asymmetries in Supernovae and Gamma-Ray Bursts, ed. P. Höflich, P. Kumar, & J.C. Wheeler (Cambridge: Cambridge University Press), in press.

The ν_SNS Collaboration, 2004, ‘‘Neutrino Program at the Spallation Neutrino Source;’’ www.phy.ornl.gov/workshops/nusns/vSNSstudy.pdf.

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