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Book of Abstracts

07 - Nuclear Astrophysics

25^{th} International Nuclear Physics Conference (INPC 2013), Firenze (Italy), 2-7 June 2013

Foreword

In the present booklet we have collected the one-page abstracts of all contributions (invited, oral and poster) accepted at the INPC2013 Conference in the topic

Nuclear Astrophysics

The submitted abstracts have been divided into the various topics of the Conference following mostly the indication given by the authors. In few cases, where the subject was on the borderline of two scientific areas or it appeared misplaced, the abstracts have been moved to the booklet of the more appropriate topic.

The abstracts are numbered and arranged alphabetically according to the name of the first author. In the parallel and poster sessions of the Conference, each contribution will be identified by the number of the corresponding abstract.

We wish you a pleasant and stimulating Conference.

The Organizing Committee

Nuclear Astrophysics (NA)

NA 001.	β-decay measurements of ^{12}B using Gammasphere *M. Alcorta, H. O. U. Fynbo, M. Albers, S. Almaraz-Calderon, P. F. Bertone, P. F. F Carnelli, M. P. Carpenter, C. J. Chiara, B. DiGiovine, J. P. Greene, C. R. Hoffman, R. V. F. Janssens, K. L. Jensen, T. Lauritsen, S. T. Marley, C. Nair, O. Nusair, K. E. Rehm, D. Seweryniak, C. Ugalde, S. Zhu* Contact email: *malcorta@anl.gov*
NA 002.	Direct measurement of the ^{23}Na(α,p)^{26}Mg reaction cross section at energies relevant for the production of galactic ^{26}Al *S. Almaraz-Calderon, P. F. Bertone, M. Alcorta, K.E. Rehm, M. Albers, C. M. Deibel, J.P.Greene, D.H. Henderson, C.R. Hoffman, S. T. Marley, J. Rohrer* Contact email: *salmaraz@phy.anl.gov*
NA 003.	Phase Diagram of Antikaon Condensed Matter in Compact Stars *Sarmistha Banik, Rana Nandi, Debades Bandyopadhyay* Contact email: *debades.bandyopadhyay@saha.ac.in*
NA 004.	Evolution of shell structure and its implication on r-path abundance *Rupayan Bhattacharya* Contact email: *rup_bhat@hotmail.com*
NA 005.	First results with the Array for Nuclear Astrophysics and Structure with Exotic Nuclei (ANASEN) *J. C. Blackmon, G. V. Rogachev, I.Wiedenhöver, L. Baby, J. Belarge, C. M. Deibel, E. D. Johnson, E. Koshchiy, A. N. Kuchera, L. E. Linhardt, J. Lai, K. T. Macon, M. Mato, B. C. Rasco, and D. Santiago-Gonzalez* Contact email: *blackmon@lsu.edu*
NA 006.	Astrophysical S factor for the ^{17}O(p, γ)^{18}F reaction at Novae energy *A.Caciolli* Contact email: *caciolli@pd.infn.it*
NA 007.	Measurement of the ^{25}Mg(α,n)^{28}Si reaction cross section at LNL *A. Caciolli, T. Marchi, S. Appannababu, N. Blasi, C. Broggini, F. Camera, M. Cinausero, G.Collazuol, R. Depalo, D. Fabris, F. Gramegna, V. L. Kravchuk, M. Leone, A. Lombardi, P.Mastinu, R. Menegazzo, G. Montagnoli, G. Prete, V. Rigato, C. Rossi Alvarez, O. Wieland* Contact email: *rdepalo@pd.infn.it*

NA 008.	Study of the $^4He(^3He,\gamma)^7Be$ astrophysical reaction using activation and direct recoils detection methods *M. Carmona-Gallardo, B. Davids, M.Hass, B.S. Nara Singh, A. Rojas and O.Tengblad* Contact email: *m.carmona.gallardo@csic.es*
NA 009.	Towards a study of the $^{22}Ne(p, \gamma)^{23}Na$ reaction at LUNA *F. Cavanna* Contact email: *francesca.cavanna@ge.infn.it*
NA 010.	Some characteristics of plasma in a white dwarf *Vania COVLEA, Alexandru JIPA, Marius CĂLIN, Oana RISTEA, Cătălin RISTEA, Tiberiu EŞANU, Călin BEŞLIU, Ionel LAZANU* Contact email: *vanea.covlea@yahoo.com*
NA 011.	Quantifying the $^{12}C+^{12}C$ sub-Coulomb fusion with the time-dependent wave-packet method *A. Diaz-Torres, M. Wiescher* Contact email*: torres@ectstar.eu*
NA 012.	Re-measurement of the ^{60}Fe half-life at PSI *R. Dressler, I. Günther-Leopold, N. Kivel, D. Schumann, M. Wohlmuther* Contact email: *rugard.dressler@psi.ch*
NA 013.	Applications of Recent Shell-Model Calculations for fp-Shell Nuclei to Type Ia Supernovae and X-Ray Bursts *M.A. Famiano, T. Kajino, T. Otsuka, T. Suzuki* Contact email: *michael.famiano@wmich.edu*
NA 014.	Constraints on the equations of state of cold dense matter from nuclear physics and astrophysics *A. F. Fantina, N. Chamel, J. M. Pearson, S. Goriely* Contact email: *afantina@ulb.ac.be*
NA 015.	News from the Latest Close Supernova *L. Fimiani, P. Ludwig, M. Auer, S. Bishop, V. Chernenko, R. Egli, T. Faestermann, J.M. Gómez Guzmán, K. Hain, G.F. Herzog, G. Korschinek, G. Rugel, A. Wallner* Contact email: *thomas.faestermann@ph.tum.de*
NA 016.	Broad resonances in light nuclei studied with β- and γ-spectroscopy *H.O.U.Fynbo* Contact email: *fynbo@phys.au.dk*

NA 017.	Momentum dependent mean-field dynamics of compressed nuclear matter and neutron stars *T. Gaitanos, M. Kaskulov* Contact email: *Theodoros.Gaitanos@theo.physik.uni-giessen.de*
NA 018.	Cluster model parameters of the heaviest elements nucleosynthesis. *G. Goncharov* Contact email: *ggontcharov@mail.ru*
NA 019.	Studying stars by going underground: The LUNA experiment at Gran Sasso Laboratory *Alessandra Guglielmetti* Contact email: *guglielmetti@mi.infn.it*
NA 020.	Virtual Neutron Method applied to the study of ^{17}O(n, α)^{14}C reaction *M. Gulino, C. Spitaleri, X.D. Tang, G.L. Guardo, L. Lamia, S. Cherubini, B. Bucher, V. Burjan, M. Couder, P. Davies, R. deBoer, X. Fang, V.Z. Goldberg, Z. Hons, V. Kroha, L. Lamm, M. La Cognata, C. Li, C. Ma, J. Mrazek, A.M. Mukhamedzhanov, M. Notani, S. OBrien, R.G. Pizzone, G.G. Rapisarda, D. Roberson, M.L. Sergi, W. Tan, I.J. Thompson, M.Wiescher* Contact email: *gulino@lns.infn.it*
NA 021.	New Determination of the ^{13}C(α, n)^{16}O reaction rate and its influence on the s-process nucleosynthesis in AGB stars *B.Guo, Z. H. Li, M. Lugaro, J. Buntain, D. Y. Pang, Y. J. Li, J. Su, S. Q. Yan, X. X. Bai, Y. S. Chen, Q. W. Fan, S. J. Jin, A. I. Karakas, E. T. Li, Z. C. Li, G. Lian, J. C. Liu, X. Liu, J. R. Shi, N. C. Shu, B. X. Wang, Y. B. Wang, S. Zeng, W. P. Liu* Contact email: *guobing@ciae.ac.cn*
NA 022.	The ^{2}H(α,γ)^{6}Li experiment at LUNA *C. Gustavino* Contact email: *carlo.gustavino@roma1.infn.it*
NA 023.	Charged particle capture and elastic scattering experiments relevant to the astrophysical p-process *Gy. Gyürky* Contact email: *gyurky@atomki.mta.hu*
NA 024.	Non-resonant Triple-α Reaction Rate at Low Temperature *T. Itoh, A. Tamii, N. Aoi, J. Carter, L. Donaldson, H. Fujita, Y. Fujita, T. Furuno, K. Hatanaka, T. Hashimoto, M. Itoh, T. Kawabata, K. Miki, R. Neveling, M. Kamimura, K. Ogata, H.J. Ong, H. Sakaguchi, T. Shima, E. Sideras-Haddad, F.D. Smit, T. Suzuki, and T. Yamamoto* Contact email: *itot@rcnp.osaka-u.ac.jp*

NA 025.	Nuclear Weak Interaction, Supernova Nucleosynthesis and Neutrino Oscillation *Toshitaka Kajino, Ko Nakamura, Jun Hidaka, Shota Shibagaki, Dai G. Yamazaki, Toshio Suzuki, Takehito Hayakawa, Myung Ki Cheoun, Grant J. Mathews, and Michael A. Famiano* Contact email*: kajino@nao.ac.jp*
NA 026.	Astrophysical *S*-factors and thermonuclear reaction rates for the $^{12}\mathrm{C}(\alpha, \gamma)^{16}\mathrm{O}$ reaction *M. Katsuma* Contact email: *mkatsuma@sci.osaka-cu.ac.jp*
NA 027.	Experimental investigation of the astrophysical γ-process *G. G. Kiss* Contact email*: ggkiss@atomki.hu*
NA 028.	Measurement of the -3keV resonance in the $^{13}\mathrm{C}(\alpha, \mathrm{n})^{16}\mathrm{O}$ reaction and its influence on the synthesis of A>90 nuclei *M. La Cognata* Contact email: *lacognata@lns.infn.it*
NA 029.	Electron Capture and Beta-Decay Rates for the Collapse of O+Ne+Mg Cores *Y. H. Lam, G. Martínez-Pinedo, K. Langanke, S. Jones, R. Hirschi, R. G. T. Zegers, B. A. Brown* Contact email: *lamyihua@theorie.ikp.physik.tu-darmstadt.de*
NA 030.	Lithium & Boron burning S(E)-factor measurements at astrophysical energies via the Trojan Horse Method *L. Lamia, C. Spitaleri, S. Cherubini, S. Degl'Innocenti, J. Grineviciute, M.Gulino, M. La Cognata, A. Mukhamedzhanov, S. Palmerini, L. Pappalardo, R.G. Pizzone, P.G. Prada Moroni, S.M.R. Puglia, G.G. Rapisarda, S. Romano, M.L. Sergi, E. Tognelli, A. Tumino* Contact email*: llamia@lns.infn.it*
NA 031.	Measurement of astrophysically important excitation energies of $^{58}\mathrm{Zn}$ with GRETINA *C. Langer, F. Montes, A. Aprahamian, D. W. Bardayan, D. Bazin, J. Browne, H. Crawford, C. Domingo-Pardo, A. Gade, S. George, P. Hosmer, A. Kontos, I-Y. Lee, A. Lemasson, E. Lunderberg, Y. Maeda, M. Matos, Z. Meisel, S. Noji, A. Nystrom, G. Perdikakis, J. Pereira, S. Quinn, F. Recchia, H. Schatz, M. Scott, K. Siegl, A. Simon, M. Smith, A. Spyrou, J. Stevens, R. Stroberg, D. Weisshaar, J. Wheeler, K. Wimmer, R.G.T. Zegers* Contact email: *langer@nscl.msu.edu*

NA 032.	Low-energy enhancement of nuclear strength and its impact on astrophysical reaction rates *A.C. Larsen, A. Bürger, T. K. Eriksen, S. Goriely, M. Guttormsen, A. Görgen, T. W. Hagen, S. Harissopulos, H.T. Nyhus, T. Renstrøm, S. Rose, I. E. Ruud, A. Schiller, S. Siem, G.M. Tveten, and A. Voinov* Contact email: *a.c.larsen@fys.uio.no*
NA 033.	Nucleosynthesis from neutrino-dominated accretion disks in gamma-ray bursts and its application *Tong Liu, Li Xue, Wei-Min Gu, and Ju-Fu Lu* Contact email: *tongliu@xmu.edu.cn*
NA 034.	Study of the key reactions that determine the evolution and fate of the first stars *W. P. Liu, B. Guo, Z. H. Li, X. X. Bai, Y. B. Wang, S. Q. Yan, J. Su, Y. J. Li, Y. S. Chen, Q. W. Fan, S. J. Jin, E. T. Li, Z. C. Li, G. Lian, J. C. Liu, N. C. Shu, S. Zeng* Contact email: *wpliu@ciae.ac.cn*
NA 035.	β-decay properties of fission fragments in the r-process path *M. Madurga, R. Surman, I.N. Borzov, R. Grzywacz, K. P. Rykaczewski, W.A. Peters, C.J. Gross, D. Miller, D.W. Stracener, D. Bardayan, J.C. Batchelder, N.T. Brewer, J.A. Cizewski, L. Cartegni, J.H. Hamilton, J.K. Hwang, A. Fijałkowska, S.H. Liu, S.V. Ilyushkin, C. Jost, M. Karny, A. Korgul, W. Królas, B. Manning, M. Matoš, C. Mazzocchi, A.J. Mendez II, K. Miernik, S.W. Padgett, S.V. Paulauskas, A.V. Ramayya, A. Ratkiewicz, J.A.Winger, M. Wolińska-Cichocka, E.F. Zganjar* Contact email: *mmadurga@utk.edu*
NA 036.	Proton-proton weak capture in chiral effective field theory *L.E. Marcucci* Contact email: *laura.marcucci@df.unipi.it*
NA 037.	The $^{14}\mathrm{N}(\mathrm{p},\gamma)^{15}\mathrm{O}$ reaction studied at Ep = 0.6 to 2.1 MeV *M. Marta, D. Bemmerer, R. Beyer, C. Broggini, A. Caciolli, M. Erhard, Zs. Fülöp, E. Grosse, Gy. Gyürky, R. Hannaske, A.R. Junghans, R. Menegazzo, C. Nair, R. Schwengner, T. Szücs, E. Trompler, S. Vezzù, A. Wagner and D. Yakorev* Contact email: *m.marta@gsi.de*
NA 038.	Asymmetric Neutrino Emission Process in Rapid Spin-Deceleration of Magnetized Proto-Neutron Stars *T. Maruyama, J. Hidaka, T. Kajino, N. Yasutake, T. Kuroda, M.K. Cheoun and C.Y. Ryu and G.J. Mathews* Contact email: *maruyama.tomoyuki@nihon-u.ac.jp*

NA 039.	Structure and Properties of Nuclear Matter in Compact Stars *Toshiki Maruyama, Nobutoshi Yasutake, Toshitaka Tatsumi* Contact email: *maruyama.toshiki@jaea.go.jp*
NA 040.	The nucleosynthesis of heavy elements in Stars: the key isotope ^{25}Mg *C. Massimi, F. Mingrone* Contact email: *massimi@bo.infn.it*
NA 041.	The lifetime of the 6.79 MeV state in ^{15}O as a challenge for nuclear astrophysics and γ–ray spectroscopy: a new DSAM measurement with the AGATA Demonstrator array *C. Michelagnoli, R. Depalo, R. Menegazzo, C.A. Ur, D. Bazzacco, C. Broggini, A. Caciolli, E. Farnea, S. Lunardi, C. Rossi-Alvarez, D. Bemmerer, N. Keeley, M. Erhard, Zs. Fülöp, A.Gottardo, M. Marta, D. Mengoni, T. Mijatoviç, F. Recchia, T. Szücs, J.J. Valiente-Dobón* Contact email: *cmichela@pd.infn.it*
NA 042.	Ultra-High Energy Cosmic Rays and Doubly Special Relativity *J. M. Mira, A. Tapia* Contact email: *alex.tapia@iteda.cnea.gov.ar*
NA 043.	Quantum Monte Carlo for momentum dependent interactions *A. Mukherjee, A. Roggero, F. Pederiva* Contact email: *mukherjee@ectstar.eu*
NA 044.	Pasta structures in neutron star crust by three-dimensional calculation *Minoru Okamoto, Toshiki Maruyama, Kazuhiro Yabana, Toshitaka Tatsumi* Contact email: *okamoto@nucl.ph.tsukuba.ac.jp*
NA 045.	The ^{6}Li(^{22}Ne, ^{26}Mg)d α-transfer experiment for the study of low energy resonances in ^{22}Ne (α,γ) ^{26}Mg *S. Ota, H. Makii, T. Ishii, K. Nishio, S. Mitsuoka, I. Nishinaka, S. Chiba* Contact email: *ota.shuya@jaea.go.jp*
NA 046.	Formation of quark matter in protoneutron stars: the burning process and the neutrino emission *G. Pagliara* Contact email: *pagliara@fe.infn.it*
NA 047.	Improving predictions from nova models through nuclear physics measurements *Anuj Parikh* Contact email: *xrayburst@gmail.com*

NA 048.	Superfluid properties of the inner crust of neutron stars at finite temperature *A. Pastore* Contact email: *pastore@ipno.in2p3.fr*
NA 049.	Exotic Nuclei Reactions and Astrophysics *Yu. Penionzhkevich* Contact email: *pyuer@nrmail.jinr.ru*
NA 050.	Protoquark stars: stability windows and magnetic field effects *D.Peres Menezes* Contact email: *debora.p.m@ufsc.br*
NA 051.	Magnetization and susceptibility of asymmetric nuclear matter under strong magnetic fields with Fermi Liquids in non-linear effective field theories *M. A. Pérez-García, C. Providencia, A. Rabhi* Contact email: *mperezga@usal.es*
NA 052.	Trojan Horse particle invariance for ^{2}H(d,p)^{3}H reaction: a detailed study *R.G. Pizzone, C. Spitaleri, C.A. Bertulani, A.M. Mukhamedzhanov, L. Blokhintsev, M. LaCognata, L. Lamia, A. Rinollo, R. Spartá, A. Tumino* Contact email: *rgpizzone@lns.infn.it*
NA 053.	Current quests in nucleosynthesis: present and future neutron induced reactions measurements *Javier Praena* Contact email: *jpraena@us.es*
NA 054.	The LUNA-MV project: a step forward in underground nuclear astrophysics *P.Prati* Contact email: *prati@ge.infn.it*
NA 055.	The *pasta* phase in neutron stars *C. Providência, F. Grill, R. Camargo, S. S. Avancini* Contact email: *cp@fis.uc.pt*
NA 056.	Strangeness-driven phase transition in star matter *Ad. R. Raduta, M. Oerte, J. Margueron, F. Gulminelli* Contact email: *araduta@nipne.ro*
NA 057.	Shell-model nuclear structure studies in the 0s1d shell for the astrophysical rp process *W. A. Richter and B. Alex Brown* Contact email: *richter@sun.ac.za*

NA 058.	Weak-decay rates in stellar scenarios *P. Sarriguren* Contact email: *p.sarriguren@csic.es*
NA 059.	Measurement of Gamow-Teller transitions from ^{56}Ni *M. Sasano, G. Perdikakis, R.G.T. Zegers, Sam M. Austin, D. Bazin, B. A. Brown, C.Caesar, A. L. Cole, J.M. Deaven, N. Ferrante, C.J. Guess, G. W. Hitt, M. Honma, R.Meharchand, F. Montes, J. Palardy, A. Prinke, L. A. Riley, H. Sakai, M. Scott, A.Stolz, T. Suzuki, L. Valdez, K. Yako* Contact email: *sasano@ribf.riken.jp*
NA 060.	Precise study of the supernova reaction ^{40}Ca(α,γ)^{44}Ti by activation and in-beam γ-spectroscopy *K. Schmidt, C. Akhmadaliev, M. Anders, D. Bemmerer, K. Boretzky, A. Caciolli, M.Dietz, Z. Elekes, Z. Fülöp, G. Gürky, R. Hannaske, A. R. Junghans, M. Marta, M.-L.Menzel, R. Schwengner, T. Szücs, A. Wagner, L. Wagner, D. Yakorev, K. Zuber* Contact email: *konrad.schmidt@hzdr.de*
NA 061.	Preparation of a ^{44}Ti source for the investigation of the ^{44}Ti(α,p)^{47}V reaction in inverse kinematics at CERN ISOLDE *D. Schumann, R. Dressler, T. Stowasser, M. Ayranov* Contact email: *dorothea.schumann@psi.ch*
NA 062.	Three-nucleon forces and neutron-rich matter *A. Schwenk* Contact email: *schwenk@physik.tu-darmstadt.de*
NA 063.	Relativistic EOS for Supernova Simulations *H. Shen* Contact email: *shennankai@gmail.com*
NA 064.	Nuclear Data and rapid neutron capture nucleosynthesis *R. Surman, M. Mumpower, J. Cass, A. Aprahamian, G.C. McLaughlin* Contact email: *surmanr@union.edu*
NA 065.	New Neutrino-Nucleus Reaction Cross Sections at Solar, Reactor and Supernova Neutrino Energies *Toshio Suzuki, Michio Honma, Akif B. Balantekin, Toshitaka Kajino, Satoshi Chiba* Contact email: *suzuki@phys.chs.nihon-u.ac.jp*
NA 066.	Neutron Skin Thickness of ^{208}Pb and Constraints on Symmetry Energy *A. Tamii, I. Poltoratska, P. von Neumann-Cosel* Contact email: *tamii@rcnp.osaka-u.ac.jp*

NA 067.	New cooling mechanism of hybrid stars in the inhomogeneous chiral phase *T. Tatsumi, T. Muto* Contact email: *tatsumi@ruby.scphys.kyoto-u.ac.jp*
NA 068.	New Nuclear Equation of State for Core-Collapse Supernovae with the Variational Method *H. Togashi, S. Yamamuro, K. Nakazato, M. Takano, H. Suzuki, K. Sumiyoshi* Contact email: *hajime_togashi@ruri.waseda.jp*
NA 069.	Nuclear symmetry energy and the role of the tensor force *Vidaña, A. Polls and C. Providência* Contact email: *ividana@fis.uc.pt*
NA 070.	Studies on alpha-induced astrophysical reactions using the low-energy RI beam separator CRIB *H. Yamaguchi, D. Kahl, T. Nakao,Y. Wakabayashi, S. Kubono, T. Hashimoto, S. Hayakawa, T. Kawabata, N. Iwasa, T. Teranishi, Y.K. Kwon, D.N. Binh, L.H. Khiem, and N.G. Duy* Contact email: *yamag@cns.s.u-tokyo.ac.jp*
NA 071.	Non-uniform structures of hadron-quark phase transition with Dyson-Schwinger method *Nobutoshi Yasutake, Huan Chen, Toshiki Maruyama, Toshitaka Tatsumi* Contact email: *nobutoshi.yasutake@it-chiba.ac.jp*

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β-decay measurements of ^{12}B using Gammasphere

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The precise branching ratio to the Hoyle state is important for understanding the R-Matrix fits of excitation energies in ^{12}C between 9-13 MeV from studies of β-delayed triple-alpha decay. Accurate fits to the data are crucial to fully disentangle the different states of natural spin and parity in the region. Recent measurements of the β-branch of ^{12}B to the Hoyle state give 0.58(2)% [1], in contradiction with the value found in the literature of 1.2(3)% [2]. In order to obtain an independent measurement of the β-branch, we measured the γ-branch of the Hoyle state (a cascade going through the 4.44-MeV 2^+ state) using the Gammasphere array at ATLAS. The branching ratio to the Hoyle state was obtained from the following relation:

$$\mathrm{BR}(7.65) = \mathrm{BR}(4.44) \cdot \frac{N_{\gamma\gamma}}{N_{4.44} \cdot \epsilon_{3.21}} \frac{1}{C_\theta \cdot \Gamma_\gamma/\Gamma} \qquad (1)$$

where BR(4.44) is the well-known branching ratio of 1.28(4)% [2] to the 4.44-MeV state in ^{12}C which will be used for normalization. The efficiency of the 3.21-MeV transition was determined to be 2.95(9)%, and C_θ, a correction factor allowing for the angular correlation in the 0-2-0 cascade, is 1 given the 4π coverage of Gammasphere. For this experiment, we used the literature value of $\Gamma_\gamma/\Gamma = 4.12(11)\times10^{-4}$ [3] and obtained a result of BR(7.65)= 0.68(9)%.

This result served a dual purpose: it confirmed the recent measurements of the β-branch of ^{12}B of half the literature value, and indicates that the method works well. Given the success of this method, we have turned this idea around and are currently carrying out an experiment with higher statistics using the same technique and the now confirmed BR(7.65) of ^{12}B of 0.58(2)% [1] to determine Γ_γ/Γ with an uncertainty on the same level as that in the literature. The current value for the radiative partial width is determined from a weighted average of various measurements, mostly comprised of inelastic scattering data. With this measurement, we will determine a value of Γ_γ/Γ with different systematics.

In this contribution, results on the measured value of the β-branch and implications of these results will be presented. In addition, we will present the results from the new higher statistics experiment to measure the partial gamma width that is currently underway. This work is supported by the U.S. Department of Energy Office of Nuclear Physics under Contracts No. DE-AC02-06CH11357 and No. DE-FG02-04ER41320.

[1] S. Hyldegaard et al., Phys. Lett. B **678**, 459 (2009).
[2] F. Ajzenberg-Selove, Nucl. Phys. **A506**, 1 (1990).
[3] R. G. Markham, S. M. Austin, and M. A. M. Shahabuddin, Nucl. Phys. **A270**, 489 (1976)

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Direct measurement of the ^{23}Na(α,p)^{26}Mg reaction cross section at energies relevant for the production of galactic ^{26}Al

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The 1809 keV γ-ray from the decay of ^{26}Al^{g} is an important target for γ-ray astronomy. This γ-ray is a key tracer of interstellar medium enriched with fresh radioactive isotopes produced in hydrostatic and explosive stellar nucleosynthesis processes. Comparison of the observed intensity of γ-rays from galactic ^{26}Al^{g} to the calculated production constitutes a powerful test for models of stellar and supernova nucleosynthesis. It is therefore crucial to understand the production and destruction mechanisms that contribute to abundances of this radioisotope [1].

In the convective C/Ne burning shell of massive pre-supernova stars, the ^{23}Na(α,p)^{26}Mg reaction is one of the main sources of protons for the ^{25}Mg(p,γ)^{26}Al reaction, which is the primary direct process for ^{26}Al production in this environment [2]. A recent study found that a factor of 10 increase in the ^{23}Na(α,p)^{26}Mg reaction rate corresponds to a factor of 3 change in the final abundance of ^{26}Al for this particular scenario [2]. There is only one measurement of this reaction with astrophysics motivation [3]. However, no reliable experimental information on this reaction exists at appropriate astrophysical energies, $E_{cm} \sim 1.2$ MeV to 2.2 MeV. The recommended rate is based on a statistical model where large uncertainties are possible, particularly in cases such as this, when the level density is low [4].

We have performed a direct measurement of the ^{23}Na(α,p)^{26}Mg reaction cross section using inverse kinematics with a ^{23}Na beam from ATLAS, a cryogenic ^{4}He gas target, and an array of Double Sided Silicon Detectors. Integrated cross sections for the reactions ^{23}Na(α,p$_0$)^{26}Mg and ^{23}Na(α,p$_1$)^{26}Mg* in the energy region of E_{cm} = 1.84 MeV to 2.63 MeV, have been extracted. These measurements include for the first time, experimental cross sections at astrophysically relevant energies. The corresponding stellar reaction rate has been recalculated and compared with the statistical model recommended rate.

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Phase Diagram of Antikaon Condensed Matter in Compact Stars

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We investigate the Bose-Einstein condensation of K^- mesons in neutrino-trapped as well as neutrino-free (proto)neutron star matter within the framework of relativistic field theoretical models at finite temperature where nucleon-nucleon and (anti)kaon-nucleon interactions are mediated by the exchange of mesons. The melting of the antikaon condensate is studied for different values of antikaon optical potential depths. It is noted that the critical temperature of antikaon condensation increases with baryon number density. On the other hand, the critical temperature is lowered as antikaon optical potential becomes less attractive. At a fixed baryon density, the critical temperature of antikaon condensation in a protoneutron star is smaller than that of a neutron star. Next we discuss the phase diagram of neutron star matter with K^- condensate in (proto)neutron stars. Heavy ion collisions in Compressed Baryon Matter (CBM) experiment in FAIR might produce matter with density a few times normal nuclear matter density and temperature a few tens of MeV. Similarly, a phase diagram with antikaon condensate could be constructed for heavy ion collisions which might be probed in future experiments at FAIR, GSI.

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Evolution of shell structure and its implication on r-path abundance

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The formation of heavy elements in nature happens through the r-process, i.e. a combination of rapid neutron captures, the inverse photodisintegrations, and slower β^{-}-decays, β-delayed processes as well as fission and possibly interactions with intense neutrino fluxes. Proper understanding and modelling of this phenomenon requires the knowledge of nuclear properties far from stability and a detailed prescription of the astrophysical environment. Experiments with radioactive ion beams have played a pioneering role in exploring the characteristics of nuclear structure in terms of masses and β-decay properties. The investigations led to highly unstable nuclei with magic neutron numbers and their β-decay properties, related to the location and height of r-process peaks, while recent works focus on the evolution of shell effects at large distances from the valley of stability [1].

It is well known that nuclear abundances are inversely proportional to the beta-decay rate rather than the neutron-capture rate. Presumably, the slowest beta-decays will be in conjunction with magic numbers, so the highest abundances will thus be associated with magic numbers. The evolution of shells along the nuclear chart plays an important role in the abundance of nuclei. Quenching of the N = 82 shell due to a softening of the neutron potential [2] has been invoked to explain this abundance deficiency [3] and experimental evidence for a reduced shell gap for N = 82, Z - 50 has been presented [4,5]

With the inclusion of tensor interaction in Skyrme Hartree Fock theory the splitting of spin-orbit partners of single particle states of shell closed nuclei gets modified [6-7]. As a result, the shell gap which is the energy difference between the last filled hole state and first unfilled particle state changes with increase of neutron/proton number. This raises the question whether this development could provide a possible scenario to understand the r-path abundance deficiency trough below the A ~ 130 peak in astrophysical network calculations [8]

Using an optimized tensor interaction in SKHF which has shown the best reproduction of observed splitting of shell model states of ^{40}Ca, ^{56}Ni, ^{48}Ca and ^{208}Pb, we have calculated the ground state properties and spin-orbit splitting of occupied states below the Fermi surfaces of several shell closed nuclei. Evaluated shell gaps show better agreement with experiment after inclusion of tensor interaction.

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First results with the Array for Nuclear Astrophysics and Structure with Exotic Nuclei (ANASEN)

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The Array for Nuclear Astrophysics and Structure with Exotic Nuclei (ANASEN) is an array of charged-particle detectors designed for highly-efficient studies of nuclear reactions using radioactive ion beams. ANASEN includes 1000 cm^2 of silicon strip detectors backed with CsI scintillators. ANASEN also includes an array of gas proportional and gas ionization counters that allows ANASEN to be used as an extended active gas target/detector. The positions of ions are measured in the gas and with the silicon strip detectors with good (< 1 cm) position resolution. The vertex of each reaction is reconstructed on an event-by-event basis, allowing improved energy resolution to be achieved with thick gas targets.

We are using ANASEN to directly measure (α,p) reaction cross sections with radioactive nuclei that are important for understanding the αp process occurring in X-ray bursts. We are also studying the the structure of exotic nuclei through scattering and transfer reactions with radioactive ion beams. The first measurements with ANASEN were performed at the John D. Fox Superconducting Linear Accelerator Laboratory at Florida State University using beams of ^{6}He, ^{8}B, ^{17}F, ^{18}Ne and ^{19}O produced by the in-flight technique using RESOLUT. The capabilities of ANASEN and results from this first series of measurements will be presented. ANASEN will move to the new reaccelerated radioactive ion beam facility ReA3 at the National Superconducting Cyclotron Laboratory this year, and the scientific program with ANASEN at ReA3 will also be discussed.

Support for the construction of ANASEN was provided by the U.S. National Science Foundation's Major Research Instrumentation Program by awards PHY-0821308 and PHY-0820941. The scientific research program not utilizing ANASEN is supported by grants from the U.S. Department of Energy (Award DE-FG02-96ER40978) and the U.S. National Science Foundation (Award 1064819).

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Astrophysical S factor for the ^{17}O(p,γ)^{18}F reaction at Novae energy

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The ^{17}O(p,γ)^{18}F and ^{17}O(p,α)^{14}N reactions are part of the hot CNO cycle, their reaction rate is required for evaluating the elemental abundances in a number of hydrogen burning stellar sites including Red giants, AGB stars, Massive stars and Classical Novae In particular, in Novae the ^{17}O and ^{18}F isotopes are regulated by the rate of the ^{17}O(p,γ)^{18}F reaction. At the LUNA facility its cross section has been determined in a range of energy from 200 keV up to 360 keV in the CM system and also the $\omega\gamma$ of the 183 keV resonance has been measured, solving the discrepancy between the two previous results of Chafa et al. and Fox et al. With this new set of data we are able to cover the all Gamow peak for Classical Nova and to calculate the reaction rate in this scenario reducing the previous uncertainties reported in literature.

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Measurement of the ^{25}Mg(α,n)^{28}Si reaction cross section at LNL

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The detection of the 1809 keV emission line associated with the decay of ^{26}Al ($T_{1/2} \sim 7.2{\cdot}10^5$ years) in the interstellar medium provides a direct evidence that nucleosynthesis is ongoing in our galaxy.
^{26}Al is thought to be mainly produced in massive stars, but in order to have a quantitative understanding of the ^{26}Al distribution, the cross section of all the nuclear reactions involved in its production should be accurately known.
A recent sensitivity study [1] demonstrated that the ^{25}Mg(α,n)^{28}Si is the reaction with the strongest impact on the synthesis of ^{26}Al during explosive Neon and Carbon burning.
In the energy range E_α = 1 - 6 MeV, the ^{25}Mg(α,n)^{28}Si cross section has been reported by many authors ([2] - [6]). Below 3 MeV the literature data are characterized by large uncertainties due to beam - induced background. Moreover the reaction rate reported by NACRE [7] is based on unpublished data. At higher energies the NACRE rate is based on Hauser-Feshbach calculations, disregarding the experimental cross sections.
In order to improve the experimental knowledge of the ^{25}Mg(α,n)^{28}Si cross section, a new direct measurement has been performed at Legnaro National Laboratories.
A pulsed α beam with energies E_α = 3-5 MeV was provided by the CN electrostatic accelerator. The neutrons were detected with 10 liquid scintillators from the RIPEN array, covering the angular range from 0 to 110 degrees in the laboratory frame of reference. γ - n discrimination is achieved applying the Pulse Shape Analysis technique. Furthermore, measuring the neutron energy with the Time Of Flight method it is possible to disentangle the contribution to the cross section of different ^{28}Si excited states, and to identify the background neutrons produced by (α,n) reactions with light contaminants in the setup. The experimental setup, the data processing and preliminary results of the data analysis are discussed.

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Study of the ^{4}He(^{3}He,γ)^{7}Be astrophysical reaction using activation and direct recoils detection methods

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Since the first measurement by Holmgren et al. [1] vast efforts have been made to study the ^{4}He(^{3}He, γ)^{7}Be reaction rate both from experimental and theoretical point of views. The new measurements performed by our group solve the discrepancies between previous experiments [2-3] in the medium energy range from 1 to 3 MeV centre of mass energy and help to constrain the extrapolation power of the theoretical models, confirming for example the new ab initio calculations performed by T. Neff [4].

We report here upon the results from two recent experiments performed at medium energies using two complementary experimental techniques:

Firstly [5], in the direct reaction using the activation method at the *Centro de Microanálisis de Materiales (CMAM)* in Madrid, where the ^{7}Be recoils were collected onto Cu-catchers, and the subsequent beta delayed gamma radiation was measured off-line using a low-background HPGe station.

Secondly, a complementary experiment using the direct recoil detection method with the DRAGON spectrometer [6] at TRIUMF. In this case, we study the cross section of the reaction in inverse kinematic detecting the recoiling ^{7}Be directly in a Double Sided Si-strip detector placed at the focal plane of the spectrometer. Furthermore, a real density profile measurement of the windowless target was performed on-line using the resonance reaction ^{3}He (^{12}C,γ), reducing the systematic error of this method.

In this presentation we will detail the two experimental techniques. We will show the analysis of the two experiments and we will discuss and compare the results between themselves and to previous experimental and theoretical works.

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Towards a study of the ^{22}Ne(p,γ)^{23}Na reaction at LUNA

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The ^{22}Ne(p,γ)^{23}Na reaction is involved in the hydrogen burning NeNa cycle. In second-generation stars, whose stellar temperature T is higher than 0.05 10^9 K, hydrogen burning can proceed also via the NeNa cycle. [1] This cycle determines the nucleosynthesis of the Ne and Na isotopes. The ^{22}Ne(p,γ)^{23}Na cross section, dominated by a large number of resonances never measured directly, is still affected by large uncertainties. [2] [3]

At the Laboratory for Underground Nuclear Astrophysics (LUNA), in the Gran Sasso National Laboratory, several cross sections have been measured in the past down to the energies of astrophysical interest. The site is shielded against cosmic rays by a 1400 m thick rock cover, suppressing the muon and neutron fluxes by six and three orders of magnitude, respectively. [4]

The 400 kV accelerator at LUNA delivers a proton beam of 80-300 μA in the energy range of E_p = 50-400 keV to a windowless gas target.

In an initial phase with natural neon gas and a large germanium detector (high E_γ resolution, low efficiency $\eta \approx 1\%$), the energy range 120-400 keV was explored with a gas target pressure ranging from 0.6 to 2.5 mbar. Some improved upper limits for low-energy resonance have been obtained.

For the near future a measurement of the ^{22}Ne(p,γ)^{23}Na cross section, with isotopically enriched neon-22 gas and a HPGe detector is planned. High resolution detector and well defined solid angle allow a measurement of the different branching ratios of the resonance decay.

Subsequently the ^{22}Ne(p,γ)^{23}Na non-resonant cross section should be studied with enriched neon-22 gas and a high efficiency ($\eta \approx 70\%$ @ E_γ = 7 MeV) 4π BGO detector at the lowest energies.

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Some characteristics of plasma in a white dwarf

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A white dwarf, also called a degenerate dwarf, is a stellar remnant composed mostly of electron-degenerate matter, cold, degenerate gases of electrons. As it is well known, the white dwarfs are considered to be a component of so-named space plasma. However, the classical theory of plasma does not consider this as self-evident.

Our goal is to calculate the specific parameters of such plasma with an essential role not only of electromagnetic field but also of an intense gravitational field of a white dwarf, like "quasi-neutrality condition", the Debye length, the Langmuir frequency, the number of particles into Debye sphere. The involved forces, the intensities of the electromagnetic and gravitational fields and the potentials inside a white dwarf are also calculated.

Finally, there is the possibility to make a connection with the plasma formed in the early stages of the relativistic nuclear collision (so-named fireball). The results can help to the understanding of the evolution of the Universe and can offer some new ways in the understanding of the fireball behavior in the early stages of the relativistic nuclear collisions

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Quantifying the $^{12}C+^{12}C$ sub-Coulomb fusion with the time-dependent wave-packet method

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Understanding the $^{12}C+^{12}C$ sub-Coulomb fusion is a long-standing issue in heavy-ion physics. This reaction is critical for a number of stellar environments and conditions, and plays a key role in the chemical evolution of the Universe. Of importance is to know the fusion cross section at energies near the Gamow peak (~ 1.5 MeV). It is usually obtained by extrapolating high-energy fusion data, as direct measurements are extremely difficult to carry out at stellar energies (< 3 MeV). The presence of pronounced resonant structures in the observed fusion excitation curve makes the extrapolation very uncertain.

We will report on a study of this reaction using the time-dependent wave-packet method within a nuclear molecular picture. The results seem to correspond well with observations. The present method might be a more suitable tool for expanding the cross-section predictions towards stellar energies than the commonly used potential-model approximation.

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Re-measurement of the ^{60}Fe half-life at PSI

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It is well known that short-lived cosmogenic radio-nuclides, i.e. isotopes with half-lives of less than hundred million years (e.g. ^{10}Be, ^{26}Al, ^{36}Cl, ^{53}Mn, ^{59}Ni and ^{60}Fe), were present in the early development stages of the solar system. These isotopes are produced by neutron capture reactions (e.g. supernovae explosions or thermally pulsing low mass asymptotic giant branch stars), or by induced reactions with high energetic cosmic radiations. Moreover, short-lived cosmogenic radio-nuclides are sensitive chronometers to determine the age of meteoritic objects or the exposure time of terrestrial sediments to high energy cosmic radiation. Especially, ^{60}Fe plays an important role as a waiting point nuclide in the stellar synthesis of heavy elements and represents an important chronometer for the early solar system.

The first and most important prerequisite to perform experiments with short-lived cosmogenic radio-nuclides is to obtain a considerable amount of these rare isotopes and to prepare samples in the required quantity and quality. Nowadays, sources for weighable amounts of short-lived cosmogenic radio-nuclides are components of medium and high energy proton accelerators which have been exposed to high-intensity irradiation over many years. One of these production facilities is the 590 MeV Ring cyclotron at the Paul Scherrer Institute (PSI). With a proton current exceeding 2 mA, this cyclotron is one of the worldwide leading accelerators applying very high beam power to experimental facilities. An initiative to exploit this resource for science and technology (ERAWAST project [1, 2]) was initiated at PSI several years ago, comprising now about 30 partners from different scientific fields.

The first reliable determination of the ^{60}Fe half-life was performed about 30 years ago by W. Kutschera et al. [3]. In the course of the ERAWAST project a ^{60}Fe sample containing 6×10^{15} atoms was prepared for a first re-determination of the half-life [4]. The presence of a well known amount of stable iron was mandatory in the samples because the exact determination of the number of ^{60}Fe atoms was conducted via isotope dilution measurements using Multi Collector Inductively Coupled Plasma Mass Spectrometry (MC-ICP-MS) [5]. The long term activity measurement for the experiment was performed at the Technical University of Munich, whereas the ICP-MS measurements were conducted at PSI.

The finally obtained value of the half-life of $t_{1/2} = (2.62\pm0.04)$ Ma [6] is significantly higher than the previously reported one of $t_{1/2} = (1.49\pm0.27)$ Ma [3]. This huge discrepancy of 1.13 Ma demands repeated measurements of the ^{60}Fe half-life to establish a reliable value. Therefore, two samples containing 3.5×10^{15} atoms ^{60}Fe each were prepared at PSI in 2009. One sample is used at the University Vienna (W. Kutschera et al.) and the other at PSI for two independent re-determinations of the half-life.

The presentation will in detail discuss the results of the γ-measurements monitoring the in grow of ^{60}Co using an HPGe-well detector to determine the absolute ^{60}Fe activity and the MC-ICP-MS measurements to determine the absolute number of ^{60}Fe atoms performed at PSI.

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Applications of Recent Shell-Model Calculations for fp-Shell Nuclei to Type Ia Supernovae and X-Ray Bursts

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Recent shell-model calculations for the fp-shell nuclei have indicated a reduction in some of the GT strengths by a factor of several times. In particular, the GT^- strengths for ^{56}Ni have been shown to be reduced by a significant amount for $E_x < 4$ MeV for the GXP1F parameter set [1] when compared to the widely-used KBF parameter set. The match between the GXP1F results and experiment [2] lends credence to the possibility that the GT^- strength functions are much lower for the fp-shell nuclei than previously thought. This can have significant implications in two astrophysical scenarios. One is the production of ^{56}Ni in Type Ia supernovae, and the other is the effect on the light curves of x-ray bursts, both of which are studied using two different shell-model results. Differences in the observable results of both astrophysical scenarios are shown.

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Constraints on the equations of state of cold dense matter from nuclear physics and astrophysics

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The equation of state of cold dense matter is studied using a family of generalized Skyrme functionals that have been recently developed [1,2]. Various constraints on the equation of state are discussed, coming from both nuclear physics and astrophysics. In particular, the nuclear physics constraints include atomic masses, the analysis of experimental data from heavy-ion collisions, neutron skins in nuclei, giant dipole resonances, dipole polarizability measurements, as well as microscopic calculations of homogeneous neutron matter and symmetric nuclear matter (see e.g. [3,4,5] and refs. therein). On the other hand, astrophysical observations provide valuable constraints on the high density part of the equation of state, especially neutron-star mass measurements [6].

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News from the Latest Close Supernova

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Some time ago, we reported on an increased concentration of the radioisotope ^{60}Fe ($T_{1/2}$ = 2.62 Myr) in approximately 2.8 Myr old layers of a ferromanganese crust from the Pacific [1]. The detection of isotopic ratios far below 10^{-15} was only possible with the extremely sensitive Accelerator Mass Spectrometry (AMS) method. The only reasonable explanation for this enhancement is the debris of a rather close Supernova (SN) that was distributed among the Solar system. Here we report on a number of new results concerning this SN.

- The dating of the crust was improved with ^{10}Be.
- The ^{60}Fe enhancement was found also in a different crust from the Pacific.
- In a sediment from the North-Atlantic we found no enhancement, possibly because the signal is too much diluted [2].
- With the help of ^{53}Mn ($T_{1/2}$ = 3.7 Myr) we could improve our understanding, how much of the ^{60}Fe entering the atmosphere ended up in the crust.
- Another reservoir, where the SN debris can enter undisturbed, is the surface of the moon. We found in several lunar samples an increased ^{60}Fe concentration. This gives (nearly) no temporal but a quantitative information on the total influx.
- In the same samples we also measured the ^{53}Mn concentration. ^{53}Mn is much more abundant due to cosmic ray production in cosmic dust. However, we seem to find a positive correlation with the ^{60}Fe concentration, indicating ^{53}Mn to be the 2nd live relic nuclide of this SN.
- The techniques to extract the authigenic iron (having been dissolved in the water column) from a sediment has been improved by exploiting the magnetic properties of the minerals [3]. This feature we owe to magnetotactic bacteria which imprinted the magnetic structure. Thus we hope to get a well dated and independently a quantitative measurement of the ^{60}Fe influx.

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Broad resonances in light nuclei studied with β- and γ-spectroscopy

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In the spectra of light nuclei exist very wide resonances with widths of an MeV or more. Classical examples are the 2^+ and 4^+ resonances in ^{8}Be, and the lowest natural parity resonances in ^{12}C. For several reasons these resonances are difficult to study experimentally. First, overlapping levels in the same nuclei, which may be populated much stronger, can hide the broad resonances. Second, their appearance in spectra will be modified by phase space effects depending on the method of population, which must be corrected for in order to get to the genuine resonance properties. Third, it may be difficult to distinguish between resonant and non-resonant population of the continuum, and the non-resonant contribution will depend on the experimental method used to populate the continuum.

We have recently used the beta-decays of ^{8}B, and ^{12}N and ^{12}B, as a method to selectively populate resonances of interest in ^{8}Be and ^{12}C respectively [1-3]. Naturally, this method will only allow to study the resonances chosen by the selection rules of β-decay in each case. Therefore, in order to be able to gain further selectivity, we have developed a method to populate broad resonances by γ-decay of higher lying resonances. By appropriately choosing the initial state, a much larger range of resonances can be made available for study.

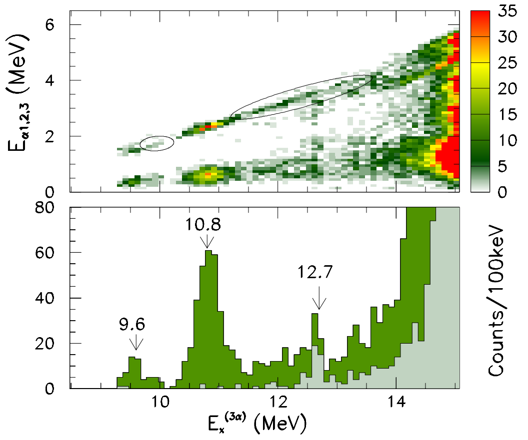

Figure 1 Spectrum of resonances in ^{12}C populated in the γ-decay of the 16.11MeV 2^+ resonance. The ovals in the scatterplot indicate previsouly unknown strength.

I will discuss results from using the reaction ^{11}B(p,γ)3α to populate 2^+, 2^-, 1^- and 3^- resonances in ^{12}C and their subsequent γ-decay to lower lying broad resonances of interest (figure 1). This provides a new take on the long-standing problem of finding the first 2^+ resonance in ^{12}C [4] as well as other broad resonances in ^{12}C. I will also discuss future plans to address similar problems in ^{8}Be and ^{16}O using the same method.

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Momentum dependent mean-field dynamics of compressed nuclear matter and neutron stars

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Nuclear matter and compact neutron stars are studied in the framework of the non-linear derivative (NLD) model [1] which accounts for the momentum dependence of relativistic mean-fields. The generalized form of the energy-momentum tensor is derived which allows to consider different forms of the regulator functions in the NLD Lagrangian. The thermodynamic consistency of the NLD model is demonstrated for arbitrary choice of the regulator functions. The NLD approach describes the bulk properties of the nuclear matter and compares well with microscopic calculations and Dirac phenomenology. We further study the high density domain of the nuclear equation of state (EoS) relevant for the matter in β-equilibrium inside neutron stars. It is shown that the low density constraints imposed on the nuclear EoS and by the momentum dependence of the Schrödinger-equivalent optical potential lead to a maximum mass of the neutron stars around $M \simeq 2M_{\odot}$ which accommodates the observed mass of the J1614-2230 millisecond radio pulsar.

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Cluster model parameters of the heaviest elements nucleosynthesis.

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Previous research [1,2] showed the signatures of asymmetric fission of actinide (Th, U) and superheavy (Z ~ 114 and 126) elements in atomic mass distributions of the solar system material and other Galaxy objects. The fission fragments of these nuclides were found in carbonaceous chondrites, in the solar photosphere, on the surface of massive stars and in cosmic rays. There are no fission products of the 126 element in the Earth and Moon crust matter and on the surface of barium stars, but there is a large contribution to Th and U fission fragments and presents 114 element's fission fragments. Fission of Th and U nuclides in the excited states (~30 MeV) exists in all cases. In this and prior research, I demonstrate that the two sources of heaviest elements nucleosynthesis and their fission fragments find in the solar system matter. These include the products of supernovae explosions in the solar nebula and the products of the Sun flare at the T-Tauri stage. This report considers the synthesis of heaviest nuclides using an approach of cluster model [3] in pycnonuclear reaction processes. I describe the partial neutronization of Fe and Ni nuclides resulting from electron capture and the subsequent fusion of these nuclei in their clusters into dense electron-nuclear plasma of the collapsing star cores. I take into account the Fermi energy of the electrons and evaluate the density of matter and the internuclear distances in clusters before nuclear fusion in stellar cataclysms. I point to the possible role of the r - process neutrons in cluster nucleosynthesis and modification of the atomic mass distributions of fission fragments. The report provides a more detailed scenario of Th and U nucleosynthesis in iron-nickel core of the early Sun, owing to catastrophic H - He burning in its outer shells during accretion at the T-Tauri stage. I estimate the matter density ($5{,}8*10^{10}$ g/cm^3) in the Sun core at the time of Th and U nucleosynthesis, the number of compound ($1{,}4*10^{48}$) and "cold" ($1{,}8*10^{46}$) Th and U nuclei, the flare energy ($1{,}7*10^{43}$ erg) at the fission of Th and U compound nuclei, the mass of ejected material ($\leq 8{,}9*10^{27}$ g) from the Sun interior in space around the Sun at the T-Tauri stage and other parameters.

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Studying stars by going underground: The LUNA experiment at Gran Sasso Laboratory

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Energy generation and element production in stars are accomplished by means of thermonuclear fusion reactions which start from the most abundant and lightest element, hydrogen, and gradually synthesize heavier elements.

All these fusion reactions occur in a very well defined energy range, the so-called Gamow peak, which arises from the convolution of the energy distribution of nuclei in the stellar plasma and the tunneling probability through the Coulomb barrier between the interacting nuclei. The Gamow peak for most reactions in either the p-p chain or the CNO cycle of Hydrogen burning, which is responsible for the formation of Helium with a net energy release, is below 30 keV and as a result reaction cross sections can be extremely low, down to the femto-barn level. It follows that a direct investigation of thermonuclear reactions at or near their Gamow energy is often beyond technical capabilities as the signal-to-noise ratio is severely dominated by any source of unwanted background.

The LUNA (Laboratory for Underground Nuclear Astrophysics) collaboration has exploited the low-background environment of the underground laboratory under the Gran Sasso Mountain in Italy (LNGS) to perform direct measurements at the relevant astrophysical energies. The rock overburden of about 1400 m reduces the muon component of the cosmic background by a factor of 10^6; the neutron component by a factor of 10^3; and the gamma component by a factor of 10 with respect to a laboratory on the Earth's surface. As a result, the gamma background above 3 MeV in an HPGe detector placed underground at LNGS is reduced by a factor of ~2500 with respect to the same detector placed over-ground. In addition, going underground enhances the effect of passive shielding particularly for lower energy gammas where the background is dominated by environmental radioactivity. The LUNA collaboration has installed two accelerators underground: a compact 50 kV "home-made" machine [1] and a commercial 400 kV one [2]. Common features of the two are the intense beam currents achievable, the long-term stability, and the precise energy determination. Several reactions belonging to the Hydrogen burning or Big Bang nucleosynthesis have been measured in the relevant energy regions [3,4]. After a general introduction, more recent results will be described.

The LUNA collaboration is now starting a new challenging program which foresees the installation of a 3.5 MV machine underground, to study key reaction of the Helium burning and the so-called neutron source reactions which produce the neutron flux necessary for the s-process. The perspectives given by this project, recently financed by the Italian Research Ministry with a "Progetto Premiale", will be outlined.

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Virtual Neutron Method applied to the study of $^{17}O(n,\alpha)^{14}C$ reaction

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The reaction ^{17}O$(n,\alpha)^{14}$C was studied using virtual neutrons coming from the quasi-free deuteron break-up in the three body reaction ^{17}O+$d \to \alpha$+^{14}C+p. This technique, called virtual neutron method (VNM), extends the Trojan Horse indirect method to neutron-induced reactions [1,2].

The reaction is interesting for both nuclear energy and nuclear astrophysics. In fact, in nuclear reactors the neutron induced reactions on ^{14}N and ^{17}O are the dominant sources of the radioactive isotope ^{14}C ($T_{1/2}$=5730 yr) [3]. In nuclear astrophysics, this reaction takes place in the nucleosynthesis of heavier elements in various astrophysical scenarios [4,5], and it could also help to explain anomalies in ^{18}O$/^{16}$O and ^{17}O/^{16}O ratios found in asymptotic giant branch stars and in circumstellar Al_2O_3 meteorite grains [6].

For incident neutron energies from thermal up to a few hundred keV, the cross section of this reaction is characterized by the presence of several narrow resonant states in the ^{18}O compound nucleus. Direct measurements [7-9] have shown the population of two out of three expected excited states at energies 8213 keV and 8282 keV and the influence of the sub-threshold level at 8038 keV. The 8125 keV state of ^{18}O would be populated by f-wave neutrons, but due to the high orbital momentum barrier, the cross section is too low for direct measurement. The reaction rate calculated at the astrophysical relevant temperatures (T$\in [0.01-1.3]\cdot 10^9$ K) by using the available data sets [7-9] differ by a factor 2-2.5, with a consequent change in the abundance ratios for some elements (e.g. ^{22}Ne, ^{26}Mg) [4].

In the present experiment the ^{18}O excited state at $E^* = 8.125$ MeV is observed in VNM experiments and the angular distributions of the populated resonances have been measured for the first time. The results unambiguously indicate the ability of the method to overcome the centrifugal barrier suppression effect and to pick out the contribution of the bare nuclear interaction. The astrophysical consequences of the present results will be discussed in the presentation.

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New Determination of the $^{13}C(\alpha, n)^{16}O$ reaction rate and its influence on the s-process nucleosynthesis in AGB stars

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The $^{13}C(\alpha, n)^{16}O$ reaction is believed to be the main neutron source for the s-process in AGB stars. The direct measurements have been performed at energies down to 270 keV [1 and references therein], whereas the Gamow window is at 190 ± 40 keV (T=100MK). At present the experimental cross sections have to been extrapolated below 270 keV. This extrapolation is critically affected by the $1/2^+$ subthreshold resonance (E_x = 6.356 MeV) in ^{17}O. Its contribution depends strongly on the α-width of the $1/2^+$ state in ^{17}O, which can be derived from the spectroscopic factor (S_α) or the ANC of the α-cluster in this state. Although three indirect measurements via the (^6Li, d) or the (^7Li, t) system have been performed to study the S_α or the ANC of the $1/2^+$ state [2-4], a significant discrepancy of up to a factor of ~30 still exists in the derived S_α and ANC. Therefore, it is interesting to perform a new measurement of the S_α and the ANC via an independent transfer reaction. In addition, it is necessary to understand the impact of the different resulting $^{13}C(\alpha, n)^{16}O$ rates on the *s*-process nucleosynthesis in AGB stars.

We present a new measurement of the S_α and the asymptotic normalization coefficient for the $1/2^+$ subthreshold state of ^{17}O through the $^{13}C(^{11}B, ^7Li)^{17}O$ transfer reaction and we determine the α-width of this state [5]. This provided an independent examination to shed some light on the existing discrepancies in the S_α and ANC values derived from different authors. The most recent measurement via Trojan horse method [6] confirmed our new result. Based on the new width we derive the astrophysical S-factor and the stellar rate of the $^{13}C(\alpha, n)^{16}O$ reaction. At a temperature of 100 MK, our rate is roughly two times larger than that by Caughlan & Fowler and two times smaller than that recommended by the NACRE compilation (see Figure 1). We use the new rate and different rates available in the literature as input in simulations of AGB stars to study their influence on the abundances of selected *s*-process elements and isotopic ratios. When the ^{13}C burns completely in radiative conditions, there are no changes in the final results using the different rates. When the ^{13}C burns in convective conditions, as in stars of initial mass lower than ~$2M_{sun}$ and in post-AGB stars, some changes are to be expected, e.g., of up to 25% for Pb in our models.

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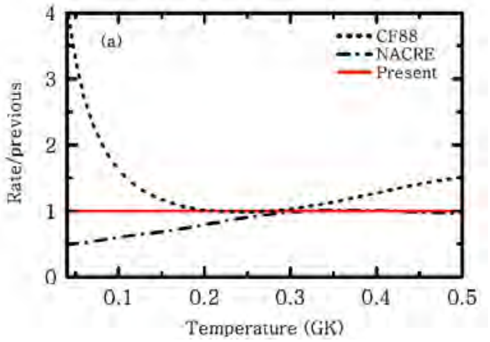

Figure 1: *Comparison of the present rate with the previous compilations*

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The ^{2}H(α,γ)^{6}Li experiment at LUNA

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The ^{2}H(a,γ)^{6}Li reaction is the leading process for the production of ^{6}Li during the Big Bang Nucleosynthesis. The knowledge of its cross section is necessary to calculate the primordial abundance of the ^{6}Li isotope, whose detection in the halo of metal poor stars has been recently debated. As the ^{2}H(a,γ)^{6}Li cross section drops steeply at low energy, it has never before been studied at BBN energies. In fact, in literature are reported only measurements at energies greater than 1 MeV and around the 711 keV resonance [1,2]. On the other hand, the existing Coulomb dissociation measurements, where the time reversed reaction ^{6}Li(γ,α)^{2}H is studied, gave only upper limits for the ^{2}H(α,γ)^{6}Li astrophysical factor, because the dominance of nuclear effects [3,4]. Exploiting the ultra-low background at the 400 keV LUNA accelerator, located deep underground in Italy's Gran Sasso laboratory, for the first time the reaction has been studied at Big Bang energies. The preliminary results will be shown, and their implications for Big Bang nucleosynthesis will be discussed.

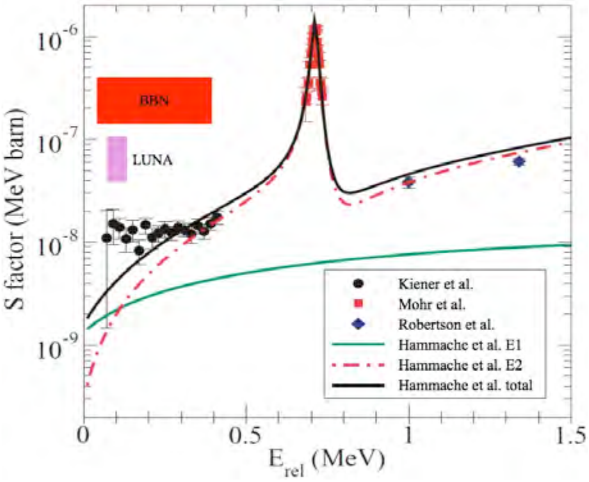

Figure 1: The astrophysical factor of the ^{2}H(α,γ)^{6}Li reaction as a function of the center-of-mass energy. Direct [1,2] and indirect measurements [3,4] are reported. The BBN energy region (red band) and the energy range studied by LUNA (violet band) are also shown.

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Charged particle capture and elastic scattering experiments relevant to the astrophysical p-process

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The explanation of the origin of the heavy, proton rich isotopes (the so-called p-nuclei) is a long-standing problem of nuclear astrophysics. These isotopes are not produced by neutron capture reactions in the s- and r-processes and their synthesis requires special conditions. Although different processes are considered which might contribute to the p-isotope nucleosynthesis, models are not able to reproduce well the p-isotope abundances as observed in the solar system. These processes are in general referred to as the astrophysical p-process.

Perhaps the most important sub-process of the p-process is the so-called gamma-process which operates through gamma-induced reactions on pre-existing heavy seed nuclei in an explosive astrophysical event. Huge reaction networks are involved in gamma-process models and the necessary reaction rates are taken from theory in lack of experimental information. If the theoretical reaction rates are not accurate, this may contribute to the poor predictive power of the gamma-process models. The experimental check of the relevant reaction rates is therefore very important. This can be achieved by the cross section measurement of the gamma-induced reactions or, preferably, of the inverse particle induced reactions.

For reactions involving alpha particles the uncertainty of the reaction rate calculations is especially high. Therefore, huge experimental effort was devoted recently to the measurement of alpha-induced reaction cross sections. Moreover, the alpha-nucleus optical potential, which is one of the most important source of uncertainty in the calculations, can be studied directly with alpha elastic scattering experiments. Experimental details of such measurements will be shown in this talk as well as some of the results and their consequences.

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Non-resonant Triple-α Reaction Rate at Low Temperature

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Carbon is one of the most fundamental elements for planetary lives. Triple-α reaction rate in stars is quite important in astrophysical scenarios of stellar evolution, accreting supernova, X-ray burst, explosive supernova, and synthesis of carbon and heavier elements [1]. Recently the triple-α reaction rate has been reevaluated by employing the continuum-discretized coupled-channels (CDCC) method by directly solving the three-body Schrödinger equation [2]. The description of the α-α non-resonant states in the calculation significantly quenches the Coulomb barrier between the first two α-particles and the third α particle. Consequently the non-resonant reaction gives a dramatically larger contribution at low temperatures ($\leq 2 \times 10^8$ K) than reported in NACRE compilation [3]. There are several other theoretical predictions recently [4-6].

We have planned an experimental study on the non-resonant reaction rate at low temperature in order to draw conclusion on the reaction rate from experimental data. Since the direct measurement of the triple-α reaction is far from the experimental realization, we focus on observing the α-unbound continuum state, which is located between the α-threshold and the Hoyle resonance. Amount of the transition strength from the ^{12}C ground state to the α-unbound continuum is closely related to the non-resonant triple-α reaction rate because an accurate description of three-α scattering state at low relative energy is the main origin of the difference between the CDCC calculation and the NACRE compilation. The predicted transition strengths are different to each other by orders of magnitude.

It is challenging to observe the α-unbound continuum state because the transition strength of the α-unbound continuum state is very small. Thus, we need to achieve experimental conditions of low background and relatively high yield. We did a test experiment at Research Center for Nuclear Physics for searching the best experimental reactions. Based on the test, we will make an experiment to observe the cross sections of the α-unbound continuum state via the ^{13}C (p, d) and ^{12}C (p, p') reactions at iThemba LABS in March, 2013. In this conference, I will report on the experimental results .

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Nuclear Weak Interaction, Supernova Nucleosynthesis and Neutrino Oscillation

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Still unknown mass and oscillation properties of neutrinos take the important keys to resolve many fundamental questions such as why core-collapse supernovae explode, which particle the neutrino is, Dirac or Majorana particle, why Baryon- and Lepton-symmetries were broken in the early universe, why we need unified theory of elementary particles beyond the standard model, etc. Supernovae are the unique sources in nature that provide three flavors of energetic neutrinos. We here discuss how to determine the neutrino mass and oscillation parameters from the studies of nuclear weak-response, supernova nucleosynthesis, galactic chemical evolution (GCE), and cosmic microwave background (CMB) anisotropies.

Neutrinos play a significant role in explosive nucleosynthesis of the light-to-heavy mass nuclei like ^{7}Li, ^{11}B, ^{138}La, ^{180}Ta, etc (ν-process) and heavy-mass nuclei up to actinides (p-process and r-process) in core-collapse supernovae. We first discuss how to calculate reliable neutrino-nucleus cross sections by using the nuclear shell model [1] and quasi-particle random phase approximation [2] for the nuclear structure in order predict accurate elemental abundances from nucleosynthesis calculations. We find average neutrino temperatures of three flavor neutrinos so that the supernova nucleosynthesis models of the ν-, p-, and r-processes can explain the observed solar-system abundances and their GCE [3,4]. We then propose a method to determine the unknown neutrino oscillation parameters, i.e. the 13-mixing angle θ_{13} and mass hierarchy, simultaneously by the use of the MSW matter oscillation effects on the supernova nucleosynthesis [5-7].

Recent long-baseline and reactor neutrino experiments have constrained the θ_{13}-value $\sin^2 2\theta_{13} = 0.1$ in good concordance among them at 5σ C.L. There arises also a recent suggestion that SiC X grains from the Murchison meteorite indicate the possible existence of ^{11}B from the ν-process along with an upper limit on ^{7}Li. Applying these constraints on supernova ^{11}B and ^{7}Li abundances to our theoretical prediction, we conclude a marginal preference for an inverted-neutrino mass hierarchy, $\Delta m^2_{13} < 0$, among three active neutrino families [7]. We also discuss cosmological constraints on the total neutrino mass from the CMB temperature and polarization anisotropies [8].

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Astrophysical S-factors and thermonuclear reaction rates for the ^{12}C(α,γ)^{16}O reaction

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The $^{12}\mathrm{C}(\alpha,\gamma)^{16}$O reaction is considered as the key reaction for the carbon-oxygen ratio in the universe, and it influences not only the production of all elements heavier than $A = 16$, but also the stellar evolution from the He-burning phase to the explosive phase. The knowledge of $^{12}\mathrm{C}(\alpha,\gamma)^{16}$O, however, has not been established yet, because the Gamow energy corresponding to He-burning temperatures ($E_{\mathrm{c.m.}} = 0.3$ MeV) is too low to measure the cross section at the present laboratories [1].

The representative studies of the $^{12}\mathrm{C}(\alpha,\gamma)^{16}$O reaction rates have been provided by KU02 [2] and BU96 [3], based on the R-matrix analyses. For the extrapolated astrophysical S-factors at $E_{\mathrm{c.m.}} = 0.3$ MeV, which are used instead of cross sections, KU02 estimates $S_{E1} = 76 \pm 20$ keV b, $S_{E2} = 85 \pm 30$ keV b, $S_{\mathrm{casc}} = 4 \pm 4$ keV b for the $E1$, $E2$, and cascade transitions. BU96 predicts $S_{E1} = 79 \pm 21$ keV b, $S_{E2} = 70 \pm 70$ keV b, $S_{\mathrm{casc}} = 16 \pm 16$ keV b. The derived reaction rates are reported to give the different temperature dependence from that in the pioneering Fowler's compilation of the reaction rates (CF88 [4]). The so-called NACRE [5] following CF88 is the milestone of the compilation work, providing the evaluated rates to the astrophysical community. In this presentation, I would like to show the theoretical analysis of the S-factors, γ-ray angular distribution, and compare the derived reaction rates KA12 with the preceding studies (KU02, BU96, NACRE and CF88) [6].

The investigation of elastic scattering provides the information of the initial channel in the direct capture model, so we first show the result of elastic scattering [7]. The internuclear potential should be chosen in the appropriate strength, because the potentials describing elastic scattering equally well are found in low energies. To obtain the correct strength, we refer to nuclear rainbow at high energies [8,9]. For the bound states the potential is adjusted so as to reproduce the separation energy. This is the same as a textbook method in direct reaction models e.g. distorted wave Born approximation (DWBA) [10]. It gives appropriate wavefunctions in the peripheral region that are sensitive to nuclear reactions. The spectroscopic factors and asymptotic normalization factors can be obtained phenomenologically. The large difference of the potential between the bound state and scattering state may indicate that the wavefunction is not appropriate in the assumed configuration. However, it is good for description of direct reactions as a doorway making fused nuclei from scattering states.

The uncertainties of the S-factors and the reaction rates are estimated from the sensitivity of the parameters. The $E1$ and $E2$ S-factors at $E_{c.m.} = 0.3$ MeV are 3 keV b and 150^{41}_{-17} keV b, respectively. The $E2$ is enhanced by the 2_1^+ state belonging to the α+^{12}C rotational band. The sum of the cascade transitions is $S^{\mathrm{casc}}_{E1+E2} = 18 \pm 4.5$ keV b. Although the assumed reaction mechanism is different, the reaction rate seems to be concordant with the preceding studies.

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Experimental investigation of the astrophysical γ-process

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The stable proton-rich nuclei with charge number Z$\geq$34 are the so called *p*-nuclei [1]. It is generally accepted that the main stellar mechanism synthesizing these nuclei, the so called γ-process, is initiated by (γ,n) photodisintegration reactions on preexisting neutron-rich seed nuclei [2]. As the neutron separation energy increases along this path towards more neutron deficient isotopes, (γ,p) and (γ,α) reactions become stronger and process the material towards lower masses.

In order to reproduce the path of the γ-process experimental data are clearly needed. Here, an overview on the charged particle-capture cross section measurements [3-6] and α elastic scattering experiments (e.g. [7]) related to γ-process studies — carried out at ATOMKI — will be given .

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Measurement of the -3 keV resonance in the ^{13}C(α, n)^{16}O reaction and its influence on the synthesis of A > 90 nuclei

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The ^{13}C(α, n)^{16}O reaction is the neutron source for the main component of the main component of the s-process, responsible of the production of most nuclei in the mass range $90 < A < 204$. It is active inside the helium-burning shell in asymptotic giant branch stars, at temperatures ~10^8 K, corresponding to an energy interval where the ^{13}C(α,n)^{16}O is effective of 140 − 230 keV.

In this region, the astrophysical S(E)-factor is dominated by the -3 keV sub-threshold resonance due to the 6.356 MeV level in ^{17}O, giving rise to a steep increase of the S-factor. Notwithstanding that it plays a crucial role in astrophysics, no direct measurements exist inside the 140 − 230 keV range. The contribution of the -3 keV resonance is still controversial as extrapolations, e.g., through R-matrix calculations, and indirect techniques, such as the asymptotic normalization coefficient (ANC), yield inconsistent results. The discrepancy amounts to a factor of 3 or more right at astrophysical energies.

Therefore, we have applied the Trojan Horse Method (THM) to the ^{13}C(^{6}Li,n ^{16}O)d quasi-free reaction to achieve an experimental estimate of such contribution. For the first time, the ANC for the 6.356 MeV level has been deduced through the THM as well as the n-partial width, allowing to attain an unprecedented accuracy in the ^{13}C(α, n)^{16}O study. The THM cross section is shown in Fig.1. Though a larger ANC for the 6.356 MeV level is measured, our experimental S(E) factor agrees with the most recent extrapolation in the literature in the 140 − 230 keV energy interval, the accuracy being greatly enhanced thanks to this innovative approach, merging together two well establish indirect techniques, namely, the THM and the ANC.

The results have been recently published in Physical Review Letters [1].

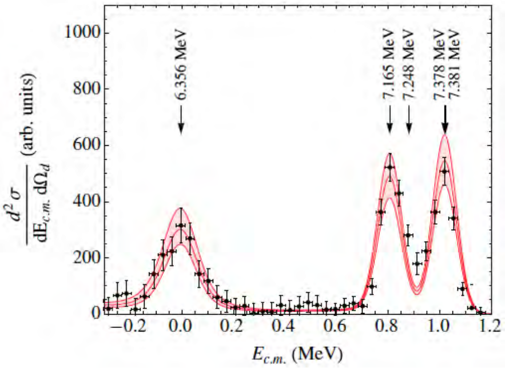

Figure 1: *Black points: cross section of the ^{13}C(^{6}Li,n ^{16}O)d THM reaction. The red bands show the modified R-matrix calculation used to deduce the ANC of the 6.356 resonance [1].*

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Electron Capture and Beta-Decay Rates for the Collapse of O+Ne+Mg Cores

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The electron (e^-) capture on ^{20}Ne and ^{24}Mg nuclei is important for the evolution of 8 – 12 $M_\odot$ stars [1]. We present a new set of e^- capture and β-decay rates that improves previous calculations by Takahara *et al.* [2] and Oda *et al.* [3] in three main aspects: (a) incorporation of recent charge-exchange and β-decay data [4], (b) contributions of forbidden transitions, and (c) inclusion of electron screening corrections [5]. The experimental nuclear input is supplemented by theoretical data based on large-scale shell model calculations in the full sd-shell space using the USDB interaction [6]. However, for the relevant temperature-density range, the rates are fully detemined by the experimental input. Comparing to previous calculations of Refs.[2,3], we find that the e^- capture on ^{20}Ne is enhanced by several orders of magnitude, in the density range $\rho = (4\text{–}10) \times 10^9$ g/cm^3 and temperatures below 0.7 GK, due to the contribution of the second forbidden transition from ^{20}Ne ground state to ^{20}F ground state. The e^- capture on ^{24}Mg is enhanced by about a factor of two due to the recent β-decay data from Nishimura *et al.* [4]. The impact of these new rates on the late stellar evolution will also be discussed.

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Lithium & Boron burning S(E)-factor measurements at astrophysical energies via the Trojan Horse Method

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Light elements lithium, beryllium and boron represent one of the most interesting probe to understand stellar mixing phenomena acting in stars. These are gradually destroyed mainly via (p,α) reactions at different depths in stellar interior thus implying that their residual atmospheric abundances should reflect the effect of plasma mixing acting in stellar interior. For such a reason, charged-particle induced reactions have been matter of study of several works, for which low-energy extrapolations provide both zero-energy astrophysical S(E)-factor and electron screening potential, U_e. To avoid extrapolation procedures, the Trojan Horse Method (THM) has been developed, allowing one to measure the bare nucleus S(E)-factor for astrophysically relevant reactions without experiencing Coulomb penetrability effects. Here, in view of the recent measurements, the ^{6,7}Li and ^{11}B burning S(E)-factor and the corresponding U_e values will be discussed by applying the THM to the corresponding quasi-free reactions. Astrophysical implications will be also discussed [1-3].

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Measurement of astrophysically important excitation energies of ^{58}Zn with GRETINA

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Type I X-ray bursts are thermonuclear explosions taking place on an accreting neutron star in a low-mass X-ray binary system. The accreted material, consisting of H/He, heats up under high pressure and at a certain temperature a thermonuclear runaway is ignited. The main energy generation is driven by the rapid proton capture process (rp-process), which synthesizes elements up to $A \approx 100$ via fast (p,γ),(α,γ) and (α,p) reactions, and slower β^+ and electron-capture decays. Along the reaction path of the rp-process, several waiting points affecting element and energy production have been identified. Of special interest is doubly-magic ^{56}Ni. It has been shown that the reaction ^{57}Cu(p,γ)^{58}Zn determines the effective lifetime of ^{56}Ni since the electron-capture lifetime of ^{56}Ni is larger than 1000 s and ^{56}Ni is in (p,γ) - (γ,p) equilibrium with ^{57}Cu at rp-process temperatures. Proton capture on ^{57}Cu is the only open break-out reaction channel within typical burst timescales. So far, the rate was only calculated theoretically with large uncertainties due to the unknown level structure of ^{58}Zn.

At the National Superconducting Cyclotron Laboratory we studied the astrophysically important excitation energies of ^{58}Zn, which determine the ^{57}Cu(p,γ)^{58}Zn rate. The secondary ^{57}Cu beam was produced by many-nucleon transfer reactions of a primary ^{58}Ni beam impinging on a Be target, and further purification and separation of the beam was performed using the A1900 fragment separator. The secondary beam was transported to the S800 large-acceptance spectrometer, where a CD$_2$ target with a thickness of 200 mg/cm^2 was installed and surrounded by the next-generation gamma-ray detector GRETINA. Excited levels in ^{58}Zn were populated using a (d,n) reaction in the secondary target, and the de-excitation γ-rays were measured.

The presentation will focus on the details of the study and present the measured excitation energies of astrophysically important 2^+ states in ^{58}Zn and their astrophysical implications.

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Low-energy enhancement of nuclear γ strength and its impact on astrophysical reaction rates

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An unexpected enhancement in the low-energy part of the gamma strength function for medium-mass and light nuclei has been discovered at OCL [1, 2, 3]. This enhancement could lead to an increase in the neutron-capture rates up to two orders of magnitude for very exotic, neutron-rich nuclei (see Fig. 1 and Ref. [4]).

The existence of this enhancement has very recently been confirmed in ^{95}Mo in an experiment at Lawrence Berkeley National Laboratory [5]. However, the nature of the enhancement is not known, and there is still an open question whether this structure persists when approaching the neutron drip line.

In this talk, the present status of the low-energy increase will be discussed. Fresh data on Cd and
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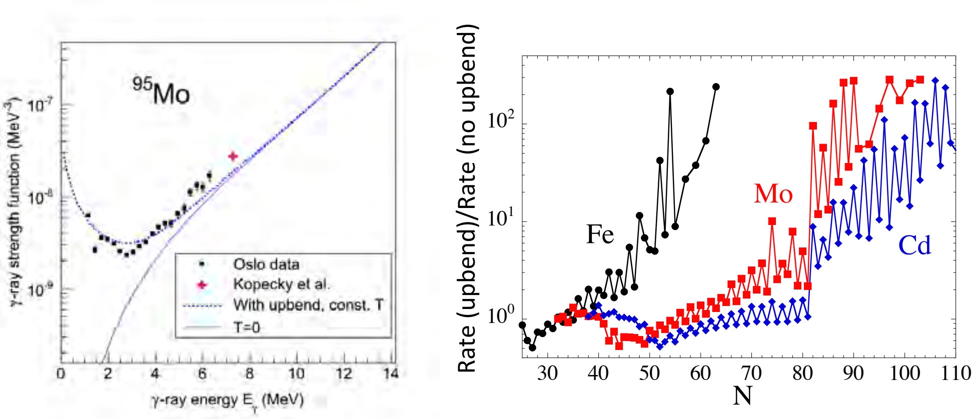

Figure 1: *Left: Oslo data of the γ-strength function of ^{95}Mo (black squares, from Ref. [2]), and models of the strength assuming zero temperature (solid, blue line) and with a constant temperature, including also a parameterization of the upbend (dashed line). Right: Ratios of (n, γ) reaction rates at $T = 1 \cdot 10^9$ K, with and without the upbend in the γ strength, for Fe, Mo, and Cd isotopes approaching the neutron drip line. See Ref. [4] for details.*

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Nucleosynthesis from neutrino-dominated accretion disks in gamma-ray bursts and its application

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We investigate the vertical structure and elements distribution of neutrino-dominated accretion flows around black holes in spherical coordinates with the proton-rich nuclear statistical equilibrium. According our calculations, heavy nuclei tend to be produced in a thin region near the disk surface, whose mass fractions are primarily determined by the accretion rate and the vertical distribution of temperature and density. In this thin region, we find that ^{56}Ni is dominated for the flow with low accretion rate but ^{56}Fe is dominated for the high counterpart. The solutions indicate that ^{56}Ni comes from the central engine, whose decay drives the bumps in the light curve of core-collapse supernova.

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Study of the key reactions that determine the evolution and fate of the first stars

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The first generation of stars formed at the end of the cosmic dark ages, which marked the key transition from a homogeneous and simple universe to a highly structured and complex one [1]. The first stars of zero metallicity are so-called Population III. A classic question on the evolution of these supermassive stars is whether they contributed any significant material to later generations of stars by supernova explosions. Fuller et al. studied the evolution of non-rotating supermassive stars and concluded that these stars will collapse into black holes without experiencing a supernova explosion [2]. This is because the triple alpha process does not produce sufficient amounts of CNO seed nuclei so that the hot CNO cycle and *rp*-process are unable to generate the nuclear energy enough to explode the stars. Wiescher et al. suggested the rap-processes as alternative paths which would permit these stars to bypass the triple alpha process and to yield the CNO material [3].

Our group has measured most of the reactions in the rap-processes, such as ^{7}Be(p, γ)^{8}B, ^{8}B(p, γ)^{9}C, ^{11}C(p, γ)^{12}N, ^{12}N(p, γ)^{13}O and ^{13}N(p, γ)^{14}O via the asymptotic normalization coefficient (ANC) method [4-9]. In addition, we have recently performed an indirect measurement of the ^{7}Be(α, γ)^{11}C reaction. ^{7}Be(α, γ)^{11}C is one of the most crucial reactions in the rap-processes. It is suggested that the subthreshold resonance at E_x = 7.5 MeV plays an important role in the ^{7}Be(α, γ)^{11}C reaction. To date, no experimental information on the subthreshold resonance has been available.

We applied the ANC approach based on charge symmetry to study the ^{7}Be(α, γ)^{11}C reaction. The ^{7}Li(^{6}Li,d)^{11}B (E_x = 7.978 MeV) angular distribution was measured by using the Q3D spectrograph at HI-13 tandem accelerator. The ANC of the ^{11}B-7.978 MeV state was derived via the DWBA analysis. According to charge symmetry, the α-width of its isospin analog of ^{11}C-7.5 MeV state was then extracted, and used to determine the ^{7}Be(α, γ)^{11}C reaction rate.

We are seeking collaboration to input above reaction rates to study their impact on the evolution and the fate of Pop III process.

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β-decay properties of fission fragments in the r-process path

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The study of nuclei far from stability offers unique opportunities to test and validate our understanding of nuclear structure.For example, the region of nuclei around and above N=50 has been subject of recent experimental and theoretical studies, see i.e. [1,2]. The new isotope separation platform IRIS-2 at the Holifield Radioactive Ion Beam Facility (HRIBF) at ORNL was used to produce high-intensity high-purity beams of neutron rich nuclei in the N=50 region. We will report the measurement of the beta decay half-lives of several exotic fission products including ^{82,83}Zn and ^{85}Ga isotopes [3]. These three new half-lives are found to be substantially shorter than the predictions from Finite Range Droplet Model, but close to our new microscopic model based on density functional DF3a [4]. Further, the newly measured nuclei fall, under certain conditions, in the path of the rapid neutron capture, or *r*, process. The r-process abundances obtained using our new calculated half-lives show a significant redistribution across the whole pattern, with increases of more than 200% at A=200.

Ultimately, integrated values like the mass or half-life contain limited information. Qualitatively, the beta-decay strength distribution may provide a deeper insight on the nuclear structure. Since large beta-delayed neutron branching ratios are known or predicted in the N=50 region, comprehensive beta-decay studies will require measuring delayed neutron energies. For this purpose, the time-of-flight Versatile Array for Neutron Detection at Low Energy (VANDLE) was built at HRIBF. The setup consisted of 48 individual plastics scintillator bars for a combined 14% efficiency at 1 MeV. Selected results will be presented about the campaign to measure the beta-delayed neutron emission of twenty-eight precursors at HRIBF. In several of the studied decays, the measured neutron energy spectrum points to large β strength from Gamow-Teller transitions, as predicted by our DF3a microscopic model. This work was supported by the U.S. Department of Energy Office of Nuclear Physics (DE-FG02-96ER40983), and the National Nuclear Security Administration's Stewardship Science Academic Alliances (DE-FG52-08NA28552).

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Proton-proton weak capture in chiral effective field theory

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Chiral effective field theory (chiEFT) provides a unique opportunity to study nuclear reactions within a framework, where the nuclear Hamiltonian and the nuclear electro-weak transition operators are consistently derived. We have applied such a framework to study muon capture on light nuclei [1], and we have verified that the calculated total capture rate is in agreement with the available experimental data, as well as with the results obtained in the ”old-fashion” potential-model approach [2]. Encouraged by these results, we have applied the same chiEFT framework to study the proton-proton weak capture reaction, in a wide energy range (0-100 keV). After reviewing the main aspects of this calculation, I will present the results for the astrophysical S-factor, and discuss their implications.

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The ^{14}N(p,γ)^{15}O reaction studied at E_{p} = 0.6 to 2.1 MeV

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The ^{14}N(p,γ)^{15}O is the slowest reaction of the hydrogen burning carbon-nitrogen-oxygen cycle and determines its rate. The cycle contributes less than 1% to our Sun's luminosity, but it is responsible for neutrinos from the beta-decays β^+ of ^{13}N and ^{15}O, which are expected to be observed in the Borexino and SNO+ underground neutrino detectors. Those neutrino fluxes are proportional to the nitrogen and carbon abundances in the solar core and the nuclear reaction rate. If measured, they may deliver a direct insight of our Sun's interior and constrain the so-called solar composition problem, provided that the nuclear information is known with sufficient precision.

The ^{14}N(p,γ)^{15}O has been re-studied recently by several groups including LUNA, focusing on the energy region $70<E<500$ keV. However, the most recent experiment providing higher-energy data dates back to 1987 [1]. High energy data are important for the S-factor extrapolation towards lower energies, hence the need for a new set of data in that region.

An experiment has been performed at the Dresden-Rossendorf 3 MV tandem accelerator: the proton beam impinged on a solid titanium nitride target, which was surrounded by three high-purity germanium detectors at different angles in order to detect the prompt γ-rays. The reaction cross section has been measured in the energy region from E = 0.6 to 2 MeV, including the resonance at E = 0.987 MeV. New S-factors for the strongest transitions at several energies will be presented.

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Asymmetric Neutrino Emission Process in Rapid Spin-Deceleration of Magnetized Proto-Neutron Stars

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We calculate the neutrino scattering and absorption cross sections in the magnetized proto-neutron-star (PNS) matter in fully relativistic mean field (RMF) theory [1]. The calculation results showed that the magnetic contribution increases the neutrino momentum emitted along the south magnetic pole and decrease it along the north magnetic pole. Furthermore, we applied this asymmetry to the calculation of the pulsar-kick in the context of a one-dimensional Boltzmann equation, and estimated PNS kick velocities of ~ 610 km s^{-1} for a neutron star of mass $M_{NS} = 1.68 M_{\odot}$, a uniform dipole magnetic fields of $B = 2 \times 10^{17}$ G, and isothermal temperature of $T = 20$ MeV, and a total emitted neutrino energy of $E_T \approx 3 \times 10^{53}$erg.

Recent supenovae simulations [2] suggest the toroidal magnetic field configurations of the magnetic field in PNSs. In this work we apply for the first time the aymmetry to the neutrino propagation and calculate the the spin deceleration of PNSs stars.

For this purpose we use themagnetic field distribution as $B = B_0 G_L(z) G_T(r_T) \hat{e}_\phi$ with

$$G_L(z) = 4e^{z/a_0} \Big/ \Big[1 + e^{z/a_0}\Big]^2, \qquad G_T(r_T) = 4e^{(r_T - r_0)/a_0} \Big/ \Big[1 + e^{(r_T - r_0)/a_0}\Big]^2, \tag{1}$$

where $a_0 = 0.5$ km and $r_0 = 8.0$ km. Solving the neutrino transport in a Boltzmann equation gives the ratio of total rate of angular momentum loss to the total power $(c dL_z/dt)/(E_T/dt)$. Then, we can estimate $\dot{P}/P$ as

$$\frac{\dot{P}}{P} = \frac{P}{2\pi c I_{NS}} \left(\frac{c dL_z/dt}{dE_T/dt} \right) \mathcal{L}_\nu. \tag{2}$$

When the neutrino luminosity is $\mathcal{L}_\nu \approx 3 \times 10^{52}$ erg·s^{-1}, and a magnetar spin period is $P = 10$s. we can get a result of $\dot{P}/P \approx 0.1$s^{-1} in the asymmetric neutrinon emission. On the other hand, the magnetic dipole radiation gives $\dot{P}/P \sim 10^{-11}$s^{-1} in the poloidal magnetic field with 10^{15}G.

Thus, the asymmetric neutrino emission in a toroidal magnetic field makes much larger effetcs than a magnetic dipole configuration which is usally used.

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Structure and Properties of Nuclear Matter in Compact Stars

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To understand the structure and the dynamics of compact stars, such as neutron stars and supernova cores, equation of state (EOS) of matter is crucial. We explore properties of nuclear matter fully taking into account its inhomogeneous structures called "pasta" [1,2]. In our study of inhomogeneous matter, we employ the Thomas-Fermi approximation i.e., a local-density approximation for nucleons and electrons, which interact with each other by the relativistic mean field (RMF) and the Coulomb potential [3].

In our previous studies of nuclear matter without neutrino, we have observed pasta structures in nuclear matter with a fixed electron fraction, while there appeared only spherical nuclei in catalyzed nuclear matter [3]. In our present study of catalyzed nuclear matter with a fixed lepton fraction, pasta structures are found to be persistent due to the increase of proton fraction which causes the formation of cluster of protons and neutrons by their strong attraction.

In Fig. 1 we present the density profiles of nuclear matter, showing that the structures with a fixed lepton fraction are similar to those with a fixed electron fraction. From the top, the structure corresponds to three-dimensional (3D) droplet, 2D rod, 1D slab, 2D tube, and 3D bubble. In the case of catalyzed matter without neutrino, on the other hand, only a droplet structure appears besides uniform matter.

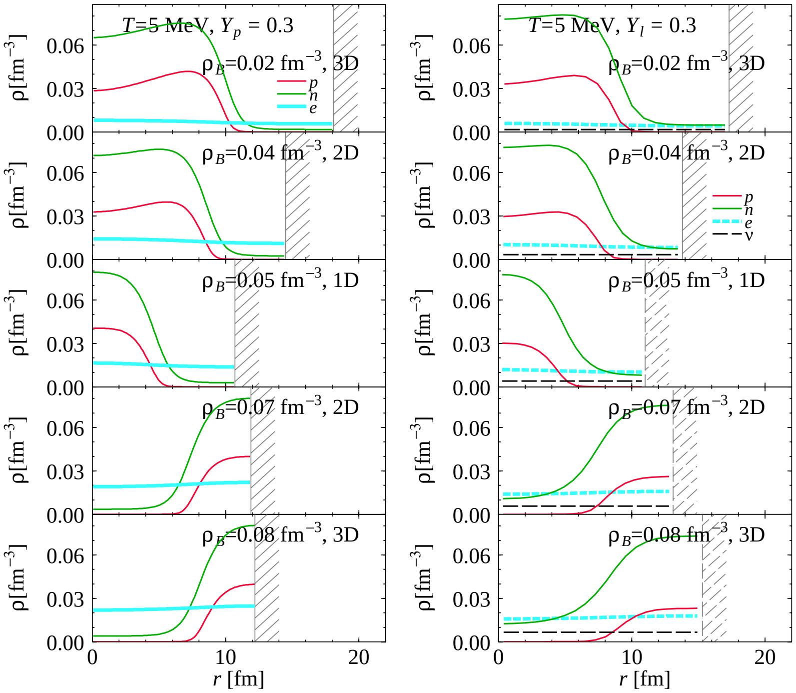

Figure 1: Examples of density distribution in Wigner-Seitz cells. Left panel shows the case without neutrino and the electron fraction $Y_e = 0.3$. While the right panel shows the case with the lepton fraction $Y_l = 0.3$ which includes neutrino.

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The nucleosynthesis of heavy elements in Stars: the key isotope ^{25}Mg

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The slow neutron capture process (s process) in stars is responsible for the production of about half of the elemental abundances beyond iron that we observe today [1, 2]. Most of the s-process isotopes between iron and strontium ($60 < A < 90$) are produced in massive stars [3] ($M > 10$-$12\ M_{\text{sun}}$) where the ^{22}Ne(α ,n)^{25}Mg reaction is the main neutron source. Beyond strontium, the s-process abundances are mostly produced in low mass Asymptotic Giant Branch stars [4] ($1.2\ M_{\text{sun}} < M < 3\ M_{\text{sun}}$), where the neutrons are provided by the ^{13}C(α, n)^{16}O reaction and by the partial activation of the ^{22}Ne(α ,n)^{25}Mg reaction. In stars with an initial metal content similar to solar, ^{25}Mg is the most important neutron poison via neutron capture on ^{25}Mg in competition with neutron capture on ^{56}Fe that is the basic s-process seed for the production of the heavier isotopes. For this reason, a precise knowledge of the ^{25}Mg(n,γ)^{26}Mg is required to properly simulate s-process nucleosynthesis in stars.

In addition the ^{25}Mg(n,γ)^{26}Mg reaction cross-section gives important constraints for the yet uncertain reaction rate of the important neutron source ^{22}Ne(α ,n)^{25}Mg. The relevant information in this respect are the spin and parity of the neutron resonances formed in the (n,γ) reaction, which can be deduced from a combined resonance analysis of neutron capture and total cross section data.

Taking advantage of the innovative features of the neutron time-of-flight facility n_TOF [5] at CERN, i.e. the high instantaneous flux, the high energy resolution and low background, measurements of the (n,γ) cross section have been performed in 2003 [6] and - with an improved experimental setup - in 2012. The combined results of the ^{25}Mg(n,γ)^{26}Mg measurements at n_TOF, are providing the required accuracy for a substantially improved discussion of the astrophysical implications mentioned above.

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The lifetime of the 6.79 MeV state in ^{15}O as a challenge for nuclear astrophysics and γ–ray spectroscopy: a new DSAM measurement with the AGATA Demonstrator array

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An accurate determination of the lifetime of the first excited $3/2^+$ state in ^{15}O is of paramount importance in the determination of the astrophysical S–factor and the derived cross section for the ^{14}N(p,γ)^{15}O reaction. This is the slowest process in the CNO cycle and the accurate determination of its S–factor at solar energies is fundamental in order to answer many astrophysical questions, as the ones regarding the *solar composition problem* and the age of the globular clusters [1,2,3].

The results of a new direct measurement of this nuclear level lifetime are discussed. The first excited states in ^{15}O (and ^{15}N) were populated via fusion–evaporation and nucleon–transfer reactions of ^{14}N on ^{2}H (implanted at the surface of a $\approx$4 mg/cm^2 Au layer) at 32 MeV beam energy, provided by the XTU Tandem at LNL. Gamma rays were detected with 4 triple clusters of the AGATA Demonstrator array, placed close to the beam line, providing a continuous angular distribution of the emitted gamma rays. The energy resolution and position sensitivity of this state–of–the–art gamma spectrometer have been exploited to investigate lifetimes of nuclear levels in the $\approx$fs range via the Doppler Shift Attenuation Method. The deconvolution of the lifetime effects on the line–shapes of the gamma peaks from the ones due to the kinematics of the emitting nuclei has been performed by means of detailed Monte Carlo simulations of the gamma emission and detection. Coupled–channel calculations for the nucleon transfer process have been used for this purpose. The comparison of experimental and simulated spectra of high–energy gamma rays, de–exciting $\approx$fs lifetime levels, will be shown for the 6.79 MeV transition in ^{15}O and for known cases in ^{15}N, together with details of the chi–square analysis. Preliminary lifetime estimates will be discussed and compared with previous data available in the literature [3].

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Ultra-High Energy Cosmic Rays and Doubly Special Relativity

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There has been much interest in theories that search a modification of special relativity. In particular, we are interested in Doubly Special Relativity (DSR). In this theory a physical energy, which may be the Planck energy, joins the speed of light as an invariant, in spite of a complete relativity of inertial frames and agreement with Einsteins theory at low energies [1]. In this work we present the results of a detailed calculation of physical properties of the ultra high energy cosmic rays (UHECR) interacting with photons of the cosmic microwave background radiation, in DSR theory. We also present the calculation of the modification of the UHECR spectrum caused by DSR and we then compare these results with the experimental UHECR data from Pierre Auger Observatory [2]. Based on these data, we find a best fit of DSR with $\chi^2/dof = 0.26$.

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Quantum Monte Carlo for momentum dependent interactions

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Quantum Monte Carlo methods in conjunction with real space based two and three nucleon interactions (like the Argonne and Urbana/Illinois family of models) have been applied successively to calculate properties of light nuclei and nuclear matter. Locality in real space is crucial for the current application of these methods. I will report on our recent investigations in trying to develop similar (projection based) quantum Monte Carlo methods, but for momentum dependent interactions (for example, the recent effective field theory based models of nuclear interactions). The focus will be on building accurate, yet computable guiding wave functions and short time propagators in momentum space.

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Pasta structures in neutron star crust by three-dimensional calculation

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The nuclear structure in the bottom of neutron star crust can be non-uniform. With increasing density, the shape of nuclear matter region changes from spherical droplet to cylindrical rod, planar slab, cylindrical tube, spherical bubble and uniform [1]. These strange structures of nuclear matter are often called “nuclear pasta”. Such pasta structures may play important roles for, e.g., neutrino opacity during supernovae, cooling process of neutron stars [2] and mechanical strength of the crust [3], etc besides the equation of state (EOS). For mechanical strength, pasta structures might be the key of understanding the quasi periodic oscillations (QPOs) in the soft gamma repeaters [4]. QPOs are interpreted as torsional shear modes of the solid crust. Since the torsional shear frequencies depend on the structures in neutron star crust, the observations of QPOs could tell us the existence of pasta structures.

In the previous studies, the crystalline structures of “nuclear pasta” and uniform electron background are often assumed. For droplets, it has been concluded that body-centered cubic (bcc) lattice is more favored than face-centered cubic (fcc) and simple cubic lattice, by comparing only the Coulomb energy. However, the energy difference between bcc and fcc latices is almost indistinguishably small. To obtain a correct structure, we should take into account all the effects, i.e., non-uniformity of electron distribution and sizes of the droplets.

We perform a three-dimensional calculation of non-uniform nuclear matter based on the relativistic mean field model (RMF) and the Thomas-Fermi approximation for fermions without any simplification of geometry, i.e., the Wigner-Seitz (WS) approximation [6]. We demonstrate that there is a slight difference in the species of pasta structures with and without the WS approximation. In fact, we have observed only droplets in neutron-star matter with the WS approximation [5]. In the meanwhile, not only droplet (bcc and fcc) but also rod structure appears in the present three-dimensional calculation. The most stable structure and the EOS of matter with and without WS approximation and the energy difference between fcc and bcc of droplets are compared.

We also discuss the finite-size effect on droplets and the effect of crystalline structures on the shear modulus.

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The ^{6}Li(^{22}Ne, ^{26}Mg)d α-transfer experiment for the study of low energy resonances in ^{22}Ne (α, γ) ^{26}Mg

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While the reaction ^{22}Ne(α,n)^{25}Mg in stellar He burning is considered the dominant neutron source for the s-process in massive stars, the competing ^{22}Ne(α,γ)^{26}Mg reaction may be of considerable strength and significantly suppress the neutron production [1]. The resonance parameters such as levels and strengths in ^{26}Mg produced by α + ^{22}Ne at some low energy resonances within the Gamow window (E_{α} = 400 ~ 1000 keV) should be experimentally determined with better accuracy to improve our understanding of those reaction rates [2]. In this work, we studied the feasibility of the ^{6}Li(^{22}Ne, ^{26}Mg)d α-transfer reaction to better investigate those resonance parameters. The ^{6}Li(^{22}Ne, ^{26}Mg)d α-transfer experiment was performed at the JAEA (Japan Atomic Energy Agency) -Tokai tandem accelerator. Two sets of four Si ΔE-E detectors were used for detection of Mg and deuteron, respectively. Details of detection systems for Mg and deuterons are described in [3]. The energies of deuterons were measured to determine the excitation energy of ^{26}Mg and coincidence detection of ^{26}Mg and deuteron were attempted to remove the deuteron background from unwanted reactions. We succeeded in detecting the expected Mg-d coincidence events and concluded that the ^{6}Li(^{22}Ne, ^{26}Mg)d α-transfer experiment can be a good tool to search for resonance levels of ^{22}Ne + α reactions in the Gamow window at stellar He burning in massive stars.

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Formation of quark matter in protoneutron stars: the burning process and the neutrino emission

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The temporal evolution of a protoneutron star could be schematically divided into two processes, the deleptonization and the cooling, which modify respectively the isospin asymmetry and the temperature of the stellar matter. In turn, the change of these two thermodynamic variables could trigger several possible phase transitions to quark matter before the protoneutron star reaches its cold and catalysed state. We investigate two scenarios: two-flavor color superconducting quark matter [1] and three-flavor absolutely stable quark matter [2]. In particular, an equation of state is provided in both cases which is then implemented in a neutrino diffusion code for the numerical simulation of the first tens of seconds of the evolution of the protoneutron star. Hydrodynamical simulations of the burning of nuclear matter into quark matter will be also presented [2]. In both scenarios, the formation of the quark phase is accompanied by a huge amount of released energy which is then transported out of the star by neutrinos. We finally discuss possible astrophysical consequences of our scenarios in connection with the observed "double" gamma-ray-bursts [3,4].

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Improving predictions from nova models through nuclear physics measurements

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Classical nova explosions are unique in nuclear astrophysics because most of the thermonuclear reaction rates thought to be involved in these phenomena are constrained by experimental measurements. This situation allows for rather precise statements to be made about which measurements are still necessary to improve the nuclear physics input to astrophysical models. We review desired measurements in these environments with an emphasis on recent experimental progress made to better determine key rates.

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Superfluid properties of the inner crust of neutron stars at finite temperature

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The thermalization process of the neutron star's crust can give important informations on the properties of the crust matter [1]. Several studies have shown that such process depends significantly on the superfluid properties of the inner-crust baryonic matter. This region of the star is composed by a crystal lattice of nuclear clusters immersed in a sea of superfluid neutrons and ultra-relativistic electrons.

In a recent article [2,3], we have studied, within the Nuclear Energy Density Functional theory based on non-relativistic Skyrme interaction, the impact of different pairing functionals on the superfluid properties of the inner crust at both zero and finite temperature.

In Fig.1 we show the behavior of the specific heat, C_V, for a cluster located at very low density ($\approx 7.93 \times 10^{-5}$ fm^{-3}) as a function of the temperature. Compared to the homogeneous case ($i.e.$ without the cluster) at the same density, we observe that the specific heat C_V presents two possible critical temperatures, T_c, corresponding to two phase transitions [3]. Standard calculations of cooling time of neutron stars based on BCS approximations do not take into account such effect, since the BCS theory allows only one critical temperature according to standard formula $T_c \approx 0.56\Delta_0$. In the presentation we will discuss the possible implication of such effects on astrophysical models.

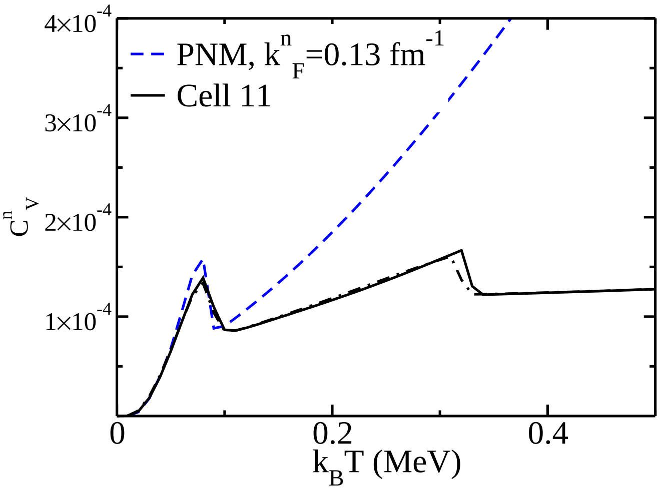

Figure 1: *The neutron specific heat for* ^{180}*Zr calculated using the* V_{low-k} *pairing interaction (solid line), a simple density dependent contact interaction (dashed-dotted line). In the same figure we show the corresponding results for a pure neutron matter system (dashed line) at* k_F^n *=0.13 fm*$^{-1}$.

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Exotic Nuclei Reactions and Astrophysics

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In recent years, nuclear-physics investigations into the laws of the microscopic world have contributed to extend significantly our knowledge of phenomena occurring in the macroscopic world (Universe) and made a formidable contribution to the development of astrophysical and cosmological theories. First of all, this concerns the expanding-universe model, the evolution of stars, and the abundances of elements, as well as the properties of various stars and cosmic objects, including "cold" and neutron stars, black holes, and pulsars. Without claiming to give a full account of all cosmological problems, we will dwell upon those of them that, in my opinion, have much in common with nuclear-matter properties manifesting themselves in nuclear interactions at different energies including the energies near the Coulomb barrier.

Reactions with light loosely- bound nuclei, which proceed at energies close to the Coulomb barrier, are of particular interest for astrophysics. These reactions have many peculiarities that have been revealed lately by means of radioactive nuclear beams. One of these features is the enhancement in interaction cross sections in the subbarrier region of energies. This effect manifests it self most evidently for cluster nuclei (^{6,9,11}Li) [1] and also for neutron halo nuclei (^{6,8}He) [2,3]. The results are discussed from the viewpoint how the nuclear cluster structure influence the probability of interaction at near- barrier energies and solving astrophysical problems, particularly for understanding of the mechanism of formation of light elements in the Universe. During the nucleosynthesis, a large cross section of interaction of cluster loosely- bound nuclei can change the chains of β- decays leading to formation of different elements [4]. For example, the following channels of reactions: ^{1}H(^{6}He, $n\gamma$)^{6}Li, ^{12}C(^{6}He, $2n\gamma$)^{16}O, ^{1}H(^{9}Li, $n\gamma$)^{9}Be, ^{3}He(^{9}Li, $2n\gamma$)^{10}B, etc. may appear to be most probable for synthesis of light stable nuclei.

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Protoquark stars: stability windows and magnetic field effects

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The influence of strong magnetic fields on the QCD phase diagram covering the whole $T - \mu$ plane was investigated with the Nambu–Jona-Lasinio model [1]. It was shown that the first order segment of the transition line becomes longer as the field strength increases so that a larger coexistence region for hadronic and quark matter should be expected for strong magnetic fields. The location of the critical end point is also affected by the presence of magnetic fields which invariably increase the temperature value at which the first order line terminates. At low temperatures, the critical chemical potential displays an oscillation around the $B = 0$ value for magnetic fields within the $10^{17} - 10^{20}$ G range. These findings have non trivial consequences for the physics of magnetars.

Hence, we have calculated stability windows [2] at finite temperature for different models that are generally applied to describe quark stars: the MIT bag model and the Nambu-Jona-Lasinio model[3]. The quantity that has to be investigated in the search for stable strange matter at finite temperature is the free energy per baryon and we analyze stability windows up to temperatures of the order of 40 MeV. The effects of strong magnetic fields on the stability windows are then computed.

Next, we have chosen the MIT bag model and analyzed different stages of magnetized quark star evolution incorporating baryon number conservation and an anisotropic energy momentum tensor [4]. The first stages of the evolution are simulated through the inclusion of trapped neutrinos and fixed entropy per particle, while in the last stage the star is taken to be deleptonized and cold. We find that, although strong magnetic fields allow for more massive quark stars, the evolution of isolated stars needs to be constrained by fixed baryon number, which lowers the star masses. Moreover, magnetic field effects, measured by the difference between the parallel and perpendicular pressures, are more pronounced in the beginning of the star evolution when there is a larger number of charged leptons and up quarks. Within the model employed, large magnetic fields appear only at high densities, where the longitudinal matter pressure is large enough to partially compensate for the negative magnetic field longitudinal pressure.

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Magnetization and susceptibility of asymmetric nuclear matter under strong magnetic fields with Fermi Liquids in non-linear effective field theories

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In this contribution we consider a generalized Landau Fermi liquid treatment for a non-superfluid isospin asymmetric nuclear system under a strong magnetic field. We use a relativistic field theory treatment including non-linear terms to compute the magnetization and the differential magnetic susceptibility for i) a general composition with fixed proton fraction and ii) stellar matter including beta equilibrium. This result focuses on the magnetic properties of the system and relies on previous calculations for neutron matter [1] [2] including relativistic effects and isospin asymmetry [3] where the general formalism was presented. The obtained results are of interest to describe the dense magnetized interior of neutron stars. The effect of the magnetization on the nuclear matter first order phase transition at subsaturation densities, and, in particular, the crust-core transition is discussed.

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Trojan Horse particle invariance for ^{2}H(d,p)^{3}H reaction: a detailed study

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In the last decades the Trojan Horse method has played a crucial role for the measurement of several charged particle induced reactions cross sections of astrophysical interest. To better understand its cornerstones and its applications to physical cases many tests were performed to verify all its properties and the possible future perspectives. The Trojan Horse nucleus invariance [1] for the binary d(d,p)t reaction was therefore tested using the quasi free ^{2}H(^{6}Li, pt)^{4}He and ^{2}H(^{3}He,pt)H reactions after ^{6}Li and ^{3}He break-up, respectively. The astrophysical S(E)-factor for the d(d,p)t binary process was then extracted in the framework of the Plane Wave Approximation applied to the two different break-up schemes. The obtained results are compared with direct data as well as with previous indirect investigations [2]. The very good agreement confirms the applicability of the plane wave approximation and suggests the independence of binary indirect cross section on the chosen Trojan Horse nucleus also for the present case. Moreover the astrophysical implications of the results will also be discussed in details.

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Current quests in nucleosynthesis: present and future neutron induced reactions measurements

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The nucleosynthesis of the elements in the stars was well established in the Fifties in the works of B2FH and Cameron. However, astrophysical models cannot provide a complete description of the physical properties of the stellar sites as well as the solar abundances of the different elements. For instance, the main part of the elements with mass above iron can be ascribed to neutron captures and successive beta decays, either during the He burning in Red Giant stars s-process (neutron captures occur at slow rate that beta decay) or Supernovae r-process (rapid rate). On the other side, there are 32 proton-rich stable isotopes in the mass region $74<A<196$ that cannot be formed in neutron capture scenarios. These isotopes are attributed to the p-process (photo-dissociation and proton capture) and their abundances are 10 to 100 times less than the neighboring s- and r-nuclei. The astrophysical site of p-process is still under discussion and the astrophysical models cannot explain the solar abundances in a single scenario. The current favored site is the explosive burning in type II Supernovae. Moreover, at temperatures around 3e9 degrees all nuclear processes occur in great profusion, including those involving heavier nuclei. The abundances of the elements in the iron peak could be synthesized under conditions of temperature and density such that statistical equilibrium (e-process) between nuclei and the free protons and neutrons was achieved. This equilibrium can be reached through the beta processes among the nuclei in a time-scale long enough.

One of the most important quantities for the astrophysical models are the cross-sections of the reactions involved in the different processes mentioned and in particular the Maxwellian-averaged cross sections (MACS). The MACS of the elements can be measured by the time-of-flight (TOF) or the activation techniques. Here we present an overview of recent measurements with impact in astrophysics in different facilities with different methods and techniques. We consider n_TOF at CERN as an example of large facility and the TOF technique. Moreover, we will try to motivate the research in new ideas and methods to provide new data in large and small facilities. According to this we discuss the measurements of the MACS of different elements at CNA (Seville, Spain) as example of a small facility, the activation technique and new method. Finally, and in deep relation with the previous, we show the very challenge measurements at Legnaro (Italy) that should be possible in the near future with a big impact in astrophysics.

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The LUNA-MV project: a step forward in underground nuclear astrophysics

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In the last twenty years, LUNA (Laboratory for Underground Nuclear Astrophysics) has obtained important achievements in experimental Nuclear Astrophysics, in particular in the assessment of the cross section and stellar reaction rate of key reactions as, for instance, ^{3}He(^{3}He,2p)^{4}He, ^{14}N(p,γ)^{15}O,^{3}He(α,γ)^{7}Be (see [1] and references therein) and several others. Past experiments have been carried out at the facility located deep underground in the INFN-Gran Sasso National Laboratory (LNGS), equipped with an ion accelerator with maximum voltage of 50 kV (pilot phase) and 400 kV (present phase). Based on this fruitful experience, the LUNA Collaboration has proposed a new step forward, based on a higher energy machine able to open the experimental study of nuclear processes beyond the hydrogen burning phase. In this view, a research program aimed to study reactions such as the ^{12}C(α,γ)^{16}O, the ^{13}C(α,n)^{16}O, the ^{22}Ne(α,n)^{25}Mg, and several (α,γ) reactions having deep consequences in several topics of nuclear astrophysics as nucleo-synthesis, stellar evolution, supernova mechanism has been submitted to the LNGS Scientific Committee. The LUNA-MV project has been approved and it has started at the end of the year 2012, thanks to a special grant of the Italian Ministry of Research. The works to prepare the new laboratory and to purchase a new 3.5 MV ion accelerator have already started. In February 2013, a kick-off workshop has been held in Gran Sasso to fix the schedule of the experimental program, the technological developments (targets, detectors, models) and the composition of the new international collaboration needed to address this new challenging adventure.

All the details on the scientific program, the characteristics of the new facility and the status of advancement will be given in the talk.

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The *pasta* phase in neutron stars

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The cell structure of clusters in the inner crust of a cold β-equilibrium neutron star is studied within a Thomas Fermi approach and compared with other approaches which include shell effects. Relativistic nuclear models within different frameworks are considered and the effect of the symmetry energy slope is disucssed. In particular, both models with density dependent couplings and models with constant couplings and non-linear meson term are considered. The temperature dependence of the pasta phase extension and structure of beta-equilibrium stellar is calculated. A study of the effect of the pasta phase on the extension of the crust, and the mass and radius of the star is performed. The effect of strong magnetic fields on the pasta structure will also be discussed. We conclude that the symmetry energy slope L may have quite dramatic effects on the cell structure if it is very large or small. Rod-like and slab-like pasta clusters have been obtained in beta-equilibrium stellar matter in all models except one with a large slope L. Strong magnetic fields affect the crust-core transition, and properties of the clusters such as the radius, neutron skin, surface tension.

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Strangeness-driven phase transition in star matter

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The phase diagram of a system constituted of neutrons, protons, Λ-hyperons and electrons is evaluated in the mean-field approximation in the complete three-dimensional space given by the baryon, lepton and strange charges. It is shown that first and second-order phase transitions take place. In addition to the well-known phase transition which occur at sub-saturation densities and which is dramatically affected by the electromagnetic interaction, we evidence a new strangeness-driven phase transition which is almost independent of the electric charge. What makes this supra-saturation phenomenon interesting for stellar matter is the fact that, according to our calculations, it might be explored under the condition of strangeness equilibrium. Consequences on the neutrino mean-free path and neutron star masses are discussed.

Shell-model nuclear structure studies in the 0s1d shell for the astrophysical rp process

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In explosive stellar environments, such as classical novae and x-ray bursters, thermonuclear radiative capture reactions on unstable nuclei determine the path of nucleosynthesis towards the proton drip line. These processes are often dominated by resonant capture to excited states above the particle-emission threshold and therefore depend critically on the nuclear properties of the levels involved. We have embarked on a systematic study of important astrophysical rp-process rates for sd shell nuclei. Results for the ^{25}Al(p,γ)^{26}Si [1], ^{35}Ar(p,γ)^{36}K [2] and ^{29}P(p,γ)^{30}S reactions have been completed, and calculations for several other reactions are in progress.

In many of the proton-rich final nuclei the properties of only the few lowest levels are well established. There are three different sources for these energies that are input into reaction rate calculations: (1) well-established experimental energies (2) predicted levels based on the IMME (Isobaric Mass Multiplet Equation) (3) theoretical level energies obtained from reliable sd-shell interactions, such as USDA and USDB [4].

In the method based on the IMME for T=1 states the predicted states are based on known experimental binding energies of the isobaric multiplet partners, and the only theoretical input consists of calculated c coefficients of the IMME [1], which can be calculated with good accuracy. For the calculation of the *c*-coefficients we use the USDA or USDB Hamiltonians for the charge-independent part and add the Coulomb, charge-dependent and charge-asymmetric nuclear Hamiltonian obtained by Ormand and Brown for the sd shell [3]. These composite interactions are called usda-cdpn and usdb-cdpn in NuShellX [5]. The cd refers to charge-dependent and pn indicates that the calculations are done in the pn formalism.

We present results for resonance-capture rates for several 0s1d-shell nuclei undergoing (p,γ) reactions. We also present new results for levels in ^{30}S (the mirror nucleus of ^{30}Si) that are used in rp reaction rate calculations for ^{29}P(p,γ)^{30}S. The resonance energies used in the reaction rate calculations are based on recent measurements which extend the excitation energy spectrum. The levels are checked against results from the Isobaric Mass Multiplet Equation and the binding energies of the T=1 analog states. Where the analog states are not known the levels are calculated with the sd-shell two-body interactions usda-cdpn and usdb-cdpn. The gamma-decay lifetimes and ^{29}P to ^{30}S spectroscopic factors are also calculated with the same interactions, and together with experimental information on the levels of excited states, are used to determine the ^{29}P(p,γ)^{30}S reaction rates.

A detailed analysis of error sources in rate calculations has been given in Ref. [1]. Some indication of the theoretical error due to using different interactions is also given by comparing rates calculated with usda-cdpn, usdb-cdpn and usd-cdpn. Comparisons are also made with the 2010 Evaluation are also made.

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Weak-decay rates in stellar scenarios

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Weak decay rates under various stellar density and temperature conditions are studied in several mass regions including neutron-deficient medium-mass waiting point nuclei involved in the rapid proton capture process [1], as well as pf-shell nuclei of special relevance as constituents in presupernova formations [2]. The rates are relevant to understand the nucleosynthesis path on the proton-rich side of stability and the global time scale and luminosity profiles observed in X-ray bursts in the first case and the late stages of stellar evolution leading to supernova explosions and the nucleosynthesis of heavier nuclei in the second case.

The nuclear structure involved in the weak decay processes is described within a microscopic deformed quasiparticle random-phase approximation (QRPA) based on a selfconsistent mean field obtained from Skyrme Hartree-Fock + BCS calculations. This approach reproduces reasonably well both the experimental beta-decay half-lives and the more demanding Gamow-Teller strength distributions, measured under terrestrial conditions in the case of the unstable nuclei [3]. In the case of stable nuclei the QRPA accounts well for the Gamow-Teller strength distributions measured in charge-exchange reactions [4].

In this work we discuss the various sensitivities of the weak decay rates to both density and temperature, as well as their dependence on the nuclear model. In the case of unstable nuclei we pay special attention to the competition between the contributions from continuum electron captures and from beta-decays to the total rates that depend on the density and temperature conditions as well as on the Q-energy window of the decay [5]. We also consider the relevance of contributions to the rates coming from excited states in the parent nucleus that become thermally populated as the temperature raises.

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Measurement of Gamow-Teller transitions from ^{56}Ni

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Electron-capture (EC) and β-decay play important roles in type-Ia and type-II supernovae. These decay modes are mediated by Gamow-Teller (GT) and Fermi transitions, which have been studied extensively as a means to estimate weak interaction rates. Intermediate-energy charge exchange reactions (such as (p,n) and (^{3}He, t) reactions) provide powerful probes for studying GT transitions experimentally, as they can selectively excite GT transitions over a wide range of excitation energies. Until recently, however, intermediate-energy charge exchange studies have been restricted to stable nuclei.

In this talk, we present the first (p,n) experiment performed with the missing mass spectroscopy in inverse kinematics using rare isotope beams: ^{56}Ni(p,n)^{56}Cu at 110MeV/u [1,2]. The experiment was performed at the National Superconducting Cyclotron Laboratory with the newly developed Low-Energy Neutron Detector Array (LENDA) [3] and the S800 Spectrometer [4]. ^{56}Ni is produced in large abundance during the pre-explosion phase of core-collapse supernovae, and considered to be one of the most important contributors to the change in electron-to-baryon ratio of these systems. The GT transitions in ^{56}Ni serve as a stringent test of the inertness of the N=Z=28 core, and are therefore relevant for a large number of nuclei in the Fe region.

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Precise study of the supernova reaction ^{40}Ca(α,γ)^{44}Ti by activation and in-beam γ-spectroscopy

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The radioactive nuclide ^{44}Ti is believed to be produced in the α-rich freezeout preceding supernova explosions. The γ-rays from its decay have been observed in space-based γ-observatories for the Cassiopeia A and very recently also SN 1987A supernova remnants [1]. The rates of the nuclear reactions governing the production and destruction of ^{44}Ti should therefore be known with high precision [2].

Over the last years there have been various studies of the ^{40}Ca(α,γ)^{44}Ti reaction, which is dominating the ^{44}Ti production in supernovae. Those studies have been performed using in-beam γ-spectroscopy, activation, accelerator mass spectrometry (AMS), and recoil mass spectrometry via inverse kinematics. However, there are still discrepancies in the resulting reaction rates.

Using an α-beam of 1-2 μA intensity the strengths of the strongest ^{40}Ca(α,γ)^{44}Ti resonances from 3.5 to 4.5 MeV laboratory α-energy have been studied by in-beam γ-counting and activation. The samples have been analyzed in the ultra-low-background underground γ-counting facility "Felsenkeller Dresden" (Figure 1). The target stoichiometry has been determined by nuclear reactions and by elastic recoil detection analysis (ERDA). An AMS measurement of the activated samples is in preparation.

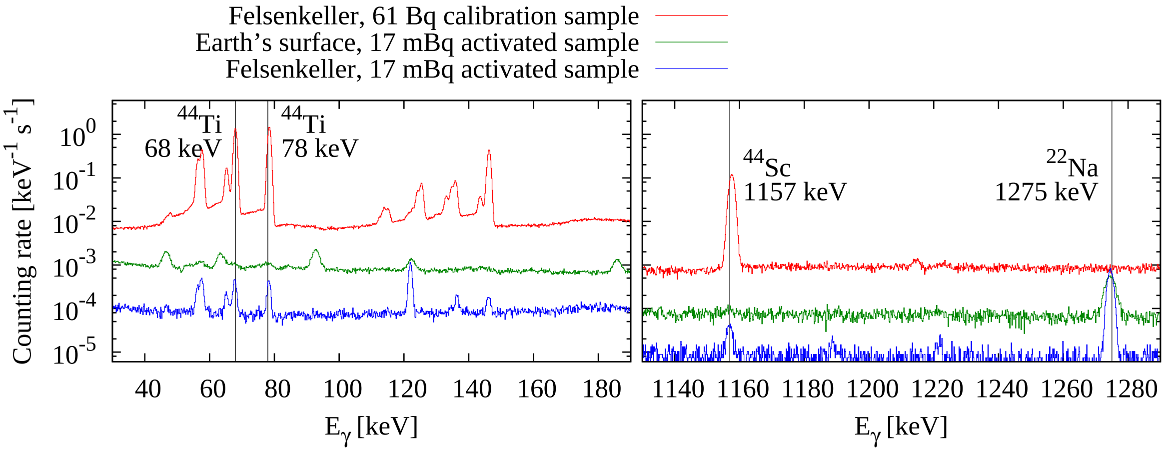

Figure 1: *Spectra of ^{44}Ti samples, measured in a low-background counting facility at the earth's surface and in the ultra-low-background facility Felsenkeller Dresden.*

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Preparation of a ^{44}Ti source for the investigation of the ^{44}Ti(α,p)^{47}V reaction in inverse kinematics at CERN ISOLDE

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Core collapse supernovae explosions are remarkable astronomical events, exhibiting a unique combination of extreme temperature, density and energy. One of the few reasonably direct methods to study the mechanism is comparing the amount of ^{44}Ti observed by satellite (via its delayed gamma-ray emission), to the amount predicted to have been generated during the explosion. The et al. [1] and Magkotsios et al. [2] found the ^{44}Ti-producing ^{40}Ca(α,γ)^{44}Ti and the ^{44}Ti-destroying ^{44}Ti(α, p)^{47}V reaction to be the most significant concerning the uncertainty in the ^{44}Ti abundances. The cross section of ^{44}Ti(α,p)^{47}V has been measured at several energies by Sonzogni et al [3] using a beam of ^{44}Ti produced in an offline ion source. However, due to the limited beam intensity and low ^{44}Ti(α,p)^{47}V cross section, these measurements were unable to reach astrophysical relevant energies. In the frame of the ERAWAST initiative at the Paul Scherrer Institute, new sources for astrophysical interesting radionuclides are going to be explored [4]. We identified proton-irradiated stainless steel samples, stemming from the so-called STIP program on material research [5] at PSI to be the most promising for the production of ^{44}Ti samples sufficient for the study of the above mentioned nuclear reactions. A radiochemical separation procedure has been developed to isolate ^{44}Ti, ^{26}Al and ^{53}Mn from these materials. Details of the experimental work as well as the astrophysical impact are reported in [6]. In total, 100 MBq ^{44}Ti could be produced till now. 50 MBq were successfully used for a first experiment at CERN ISOLDE in December 2012.

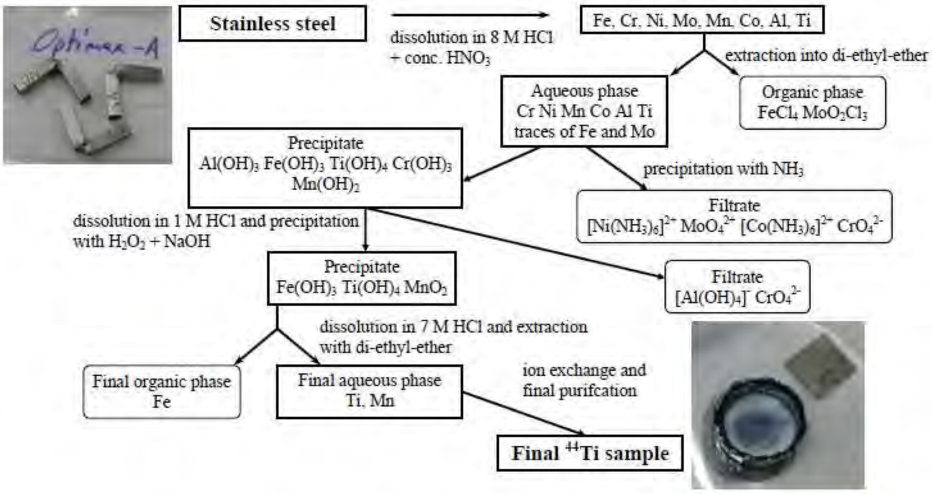

Figure 1: *Scheme for chemical isolation of ^{44}Ti.*

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Three-nucleon forces and neutron-rich matter

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Three-body forces are at the forefront of theoretical developments based on chiral effective field theories of quantum chromodynamics. I will discuss our understanding of three-nucleon forces and their impact on neutron-rich nuclei and neutron-rich matter in astrophysics. This will range from three-nucleon forces and the properties of exotic nuclei, and how new measurements test and constrain these subtle components of nuclear forces, to their impact on the symmetry energy and the nuclear equation of state, and on neutron star structure and neutron star mergers and their gravitational wave signal. Three-nucleon forces therefore provide an exciting link between theoretical, experimental and observational nuclear astrophysics frontiers.

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Relativistic EOS for Supernova Simulations

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We construct the relativistic equation of state (EOS) of dense matter covering a wide range of temperature, proton fraction, and baryon density for the use of supernova simulations. The study is based on the relativistic mean-field theory (RMF) [1] and the Thomas-Fermi approximation [2]. The Thomas-Fermi approximation in combination with assumed nucleon distribution functions and a free energy minimization is adopted to describe the non-uniform matter, which is composed of a lattice of heavy nuclei. We treat the uniform matter and non-uniform matter consistently using the same RMF theory. We present two sets of EOS tables [3]. The first one takes into account only the nucleon degree of freedom, while the second one considers additional contributions from Lambda hyperons. We tabulate the resulting EOS with an improved design of ranges and grids comparing with our earlier work used as Shen-EOS [4,5].

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Nuclear data and rapid neutron capture nucleosynthesis

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In rapid neutron capture, or *r*-process, nucleosynthesis, heavy elements are built up via a sequence of neutron captures and beta decays that involves thousands of nuclei far from stability. Though we understand the basics of how the *r*-process proceeds, its astrophysical site is still not conclusively known. The nuclear network simulations we use to test potential astrophysical scenarios require nuclear physics data (masses, beta decay lifetimes, neutron capture rates, fission probabilities) for all of the nuclei on the neutron-rich side of the nuclear chart, from the valley of stability to the neutron drip line. Here we discuss recent sensitivity studies [1-4] that aim to determine which individual pieces of nuclear data are the most crucial for *r*-process calculations. We will also discuss how, once nuclear physics uncertainties are reduced, we can use an understanding of late-time *r*-process dynamics to constrain the *r*-process astrophysical site [5].

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New Neutrino-Nucleus Reaction Cross Sections at Solar, Reactor and Supernova Neutrino Energies

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Remarkable improvements in the evaluations of neutrino-nucleus reaction cross sections are obtained based on new shell-model Hamiltonians at solar, reactor and supernova neutrino energies. New shell-model Hamiltonians can successfully describe spin responses in nuclei and explain shell evolutions toward drip-lines. A common feature of the new intearctions is that they have proper tensor components.

A new shell-model Hamiltonian for p-shell nuclei, SFO[1], which proved to be quite successful in the evaluation of the ν-^{12}C cross sections [2,3], is used to evaluate charged- and neutral-current neutrino cross sections on ^{13}C leading to low-lying states in ^{13}N and ^{13}C [3]. ^{13}C is an attractive target for detecting very low energy neutrinos as it is free from the contamination of ^{12}C at $E_\nu \leq 13$ MeV. A knowledge of these cross sections would help scintillator-based searches for low-energy electron neutrinos in environments dominated by the electron antineutrinos, such as nuclear reactors.

A new shell-model Hamiltonian for pf-shell nuclei, GXPF1J, is shown to reproduce well ν-^{56}Fe cross section for DAR neutrinos [4]. It describes also well the Gamow-Teller (GT) strengths in Ni isotopes, in particular ^{56}Ni [5, 6]. Neutral-current reactions on ^{56}Ni are evaluated, and proton-emission cross sections are found to be enhanced due to a large spreading of the GT strength and lead to enhanced production of ^{55}Mn element in supernova explosions in population III stars [5].

Gamow-Teller (GT) strength in ^{40}Ar is studied by shell-model calculations with monopole-based universal interaction [7], which has tensor components of π+ρ-meson exchanges. Calculated GT strength is found to be consistent with the experimental (p, n) reaction data. Cross sections for the charged-current reaction, ^{40}Ar (ν_e, e^-) ^{40}K, are evaluated by a hybrid model, where contributions from the GT and IA transitions are obtained by shell-model calculations while other multipoles are treated by RPA. A better evaluation of the cross section for the GT contributions has been achieved [8]. An enhancement of the cross section for solar neutrinos from ^{8}B is found compared to previous calculations. An accurate knowledge of the cross section is important for the studies of supernova neutrinos and neutrino oscillations. Implications on the effects of neutrino oscillations will be discussed.

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Neutron Skin Thickness of ^{208}Pb and Constraints on Symmetry Energy

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The symmetry energy term of the nuclear equation of state (EOS) is relevant to the size, structure and dynamic properties of neutron stars and various astrophysical simulations, *e.g.* neutron star cooling, X-ray burst, supernova, and nucleosynthesis. Even at and below the saturation density the symmetry energy parameter is poorly known. The first order density dependence of the symmetry energy, called *slope parameter*, is of particular interest since it is directly related to the baryonic pressure in a neutron rich matter [1].

The nuclear EOS can be studied by precisely measuring the proton and neutron density distributions or the difference between the proton and neutron radii in neutron rich nuclei, *e.g.* $^{208}\mathrm{Pb}$. The proton density distribution of $^{208}\mathrm{Pb}$ was well determined by electron scattering experiments. The neutron radius has been studied by proton elastic scattering [2], anti-protonic atom X-ray [3], and parity-violating asymmetry in electron scattering [4]. The experimental data have, however, large uncertainty due to model-dependence of the strong interaction (the former two), and statistical uncertainty (the last).

As an alternative method, we have precisely determined the electric dipole ($E1$) response of$^{208}\mathrm{Pb}$ by using electromagnetic excitation via proton inelastic scattering at very forward angles. The experiment has been carried out at the Research Center for Nuclear Physics, Osaka University employing a 295 MeV polarized proton beam, accelerated by cascade cyclotrons, and high-resolution spectrometer *Grand Raiden*. The details can be found in publications [5]. The nuclear dipole polarizability of$^{208}\mathrm{Pb}$ has been determined as α_D=20.1(6) fm$^3/e^2$ by inversely-energy weighted sum-rule of the measured $E1$ reduced transition probability combining with existing data. The dipole polarizability is closely correlated with the neutron skin thickness: difference between the proton and neutron radii [6]. With help of mean-field calculations, the neutron skin thickness of $^{208}\mathrm{Pb}$ has been determined as 0.168(22) fm including the model-uncertainty [7]. This result constrains the slope parameter as $L = 46 \pm 15$ MeV. The allowed region of L is small. Reasonably consistent values are reported from other experimental methods [1], theoretical predictions [8], and astrophysical observation [9].

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New cooling mechanism of hybrid stars in the inhomogeneous chiral phase

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As a current topic in the QCD phase diagram, the possible appearance of the inhomogeneous phases has been discussed near the chiral transition [1]. Extending the chiral condensate to be complex, $\Sigma \equiv \langle\bar\psi\psi\rangle + i\langle\bar\psi i\gamma_5\tau_3\psi\rangle = \Delta\mathrm{exp}(i\theta)$, inhomogeneous phases are specified by the spatial modulation of Δ and/or θ. θ means the chiral angle associated with the chiral transformation, $U(\theta) = \mathrm{exp}(iQ_5^3\theta)$. If $\theta = 0$ is further imposed, where is left no phase degree of freedom, the configuration called *real kink crystal* (RKC) is realized [2]. Another type of configuration, called *dual chiral density wave* (DCDW), is given by $\Delta = \mathrm{const.}, \theta = \mathbf{q}\cdot\mathbf{r}$ [3]. For these typical configurations, the quark wave function enjoys a property in one period L, $\psi(\mathbf{r}+\mathbf{L}) = \mathrm{exp}(i\mathbf{k}\cdot\mathbf{L})\mathrm{exp}(i\gamma_5\tau_3/2\mathbf{q}\cdot\mathbf{L})\psi(\mathbf{r})$, with the Bloch momentum $\mathbf{k}$. This results from the generalized Bloch theorem. Hence the elasticity or periodic property of the system should be important for phenomenological implications. However, there have been little works about them. We discuss here the cooling of hybrid stars by considering the neutrino emission in the inhomogeneous chiral phases.

Cooling of compact stars have provided information about form of matter at high-densities [4]. Recent observations of the surface temperature of young pulsars have suggested interesting possibilities: 3C58 or Vela looks to have rather low temperature which should be hard to be explained by the standard scenario. Cas A also presents important information about the thermal evolution of pulsars. As a cooling mechanism in quark matter, the direct Urca process (quark cooling) is well-known and standard. It has been shown that it works for interacting quarks, while this process is strongly prohibited for free quarks due to the kinematical condition (triangular condition). Using the one-gluon-exchange (OGE) interaction, the neutrino emissivity is given as $\epsilon_\nu \propto \alpha_s T^6$ with the QCD coupling constant α_s [5]. So it has a *perturbative* nature as it is.

Generally the extra momentum supply may be expected at the weak-interaction vertex by the inhomogeneous condensates, which modifies the triangle condition. In the following we consider the quark β decay in the DCDW phase. We shall see how the neutrino emission becomes efficient in the DCDW phase from the symmetry consideration. Since the DCDW state can be represented as a chirally rotated state from the normal quark matter, $|\mathrm{DCDW}\rangle = U_{\mathrm{DCDW}}(\theta)|\mathrm{normal}\rangle$ with $U_{\mathrm{DCDW}} = \mathrm{exp}(i\mathbf{q}\cdot\int\mathbf{r}A_0^3d^3r)$, the quark weak-current h_μ is accordingly transformed to get an additional phase factor, $h^\mu \to U_{\mathrm{DCDW}}h^\mu U_{\mathrm{DCDW}}^\dagger = \mathrm{exp}(i\mathbf{q}\cdot\mathbf{r})h^\mu$. This factor then modifies the energy-momentum conservation at the vertex to modify the triangular condition. The direct evaluation of the neutrino emissivity gives $\epsilon_\nu = O(10^{26}T_9^6)$ $(\mathrm{erg}\cdot\mathrm{cm}^{-3}\cdot\mathrm{s}^{-1})$, which is comparable with the quark or pion cooling. Note that since chiral transition or appearance of the DCDW phase should occur at moderate densities and can be considered as a *nonperturbative* effect of QCD, we can say that new cooling mechanism is also originated from nonperturbative QCD.

Since the DCDW phase develops only in the limited density region, this novel mechanism may suggest an alternative scenario for cooling of hybrid stars. We briefly discuss the possibility that higher-mass hybrid stars cool more slowly. The neutrino emission in the RKC state is also discussed.

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New Nuclear Equation of State for Core-Collapse Supernovae with the Variational Method

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We are constructing a new nuclear equation of state (EOS) for numerical simulations of high-energy astrophysical phenomena such as core-collapse supernovae (SNe), cooling of neutron stars (NSs), black hall formations and NS mergers, using the cluster variational method for uniform nuclear matter and using the Thomas-Fermi (TF) method for non-uniform nuclear matter.

For uniform asymmetric nuclear matter, we begin with the nuclear Hamiltonian composed of the AV18 two-body potential and the UIX three-body potential. At zero temperature, we express the two-body energy E_2 as the expectation value of the two-body Hamiltonian with the Jastrow wave function in the two-body cluster approximation, and minimize E_2 with respect to the state-dependent correlation functions included in the Jastrow wave function. In this minimization, we impose appropriate constraints on the correlation functions so that the obtained E_2 reproduces the result obtained using the Fermi Hypernetted Chain (FHNC) method [1]. The three-body energy is calculated somewhat phenomenologically so that the total energy reproduces the empirical saturation point. The obtained nuclear EOS at zero temperature is reasonable: the structure of NSs calculated using the present EOS is consistent with that obtained from recent observational data [2, 3].

At finite temperatures, we calculate the free energy F of uniform asymmetric nuclear matter using an extension of the variational method proposed by Schmidt and Pandharipande [4]. In this method, F is expressed by the averaged occupation probabilities of single-nucleon states, which are parameterized by the effective masses for protons and neutrons. Then, F is minimized with respect to these effective masses. The obtained F and related thermodynamic quantities are reasonable, as compared with the values obtained through FHNC calculation [5], and the self-consistency of the present variational method is validated.

For non-uniform matter, we calculate the averaged free energy density of a Wigner-Seitz (WS) cell, f_{cell}, in the TF approximation, following the method by Shen et al. [6]. In this method, we assume that a spherical nucleus is located at the center of a WS cell in the BCC lattice and express f_{cell} using the parameterized density distribution functions for nucleons. Then, we minimize f_{cell} with respect to the parameters for various averaged nucleon densities, averaged proton fractions and temperatures. The obtained phase diagrams at selected temperatures are reasonable, as compared with those of the SN-EOS by Shen et al. [6]. The mixing of α particles is also taken into account.

We will report the current status of our project to construct the SN-EOS and its application to the SN numerical simulation.

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Nuclear symmetry energy and the role of the tensor force

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Using the Hellmann–Feynman theorem we analyze the contribution of the different terms of the nucleon-nucleon interaction to the nuclear symmetry energy E_{sym} and its slope parameter L. The analysis is performed within the microscopic Brueckner–Hartree–Fock approach using the Argonne V18 potential plus the Urbana IX three-body force. We find that the main contribution to both E_{sym} and L is due to the tensor component of the nuclear force.

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Studies on alpha-induced astrophysical reactions using the low-energy RI beam separator CRIB

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CRIB (CNS Radioisotope Beam Separator) is a low-energy RI beam separator operated by CNS, the University of Tokyo, located at RIBF of RIKEN. Results of recent astrophysical reaction studies performed at CRIB are presented.

We have been studying nuclear resonances, which may enhance astrophysical reaction rates, via proton or α resonant scattering with the thick target method in inverse kinematics. Measurements of ^{7}Li/^{7}Be+α resonant elastic scattering have been performed recently [1,2], and we will mainly discuss on their results. The excitation functions of ^{7}Li/^{7}Be+α around 180^{o} in the center-of-mass system were successfully measured with the inverse kinematics method. They provided important information on the α cluster structure in ^{11}B/^{11}C and the reaction rate of ^{7}Li(α,γ) and ^{7}Be(α,γ) at high temperature (T > 1 GK). The ^{7}Li(α,γ) reaction is relevant to the ^{11}B production in the ν-process in core-collapse supernovae. The number ratio of ^{11}B/^{7}Li, mainly determined by the ^{7}Li(α,γ) reaction rate, is considered to have a sensitivity on the neutrino mixing parameter, θ_{13} and the neutrino mass hierarchy [3]. The ^{7}Be(α,γ) reaction is one of the important reactions in the hot pp chain, and a calculation of the νp-process in core-collapse supernovae [4] has shown that the reaction may be responsible for the production of carbon as much as the triple-alpha process at high temperature. The excitation functions of the ^{7}Li/^{7}Be(α,α') inelastic scattering and the ^{7}Li/^{7}Be(α,p) reactions were also obtained in the same measurement.

Another major interest at CRIB is the direct measurement of (α, p) reactions. Direct measurements have been performed for several (α, p) reactions such as ^{11}C(α, p), ^{14}O(α, p), ^{18}Ne(α, p), ^{30}S(α, p), and ^{22}Mg(α, p), which may play important roles in the hot pp chain, the hot CNO cycle, and the αp-process. An active target system using GEM detector (GEM-MSTPC) [5] was built at CNS and used for some of these measurements, to perform a clear identification of the reaction. The status and results of these studies will also be presented.

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Non-uniform structures of hadron-quark phase transition with Dyson-Schwinger method

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We study the hadron-quark phase transition with the finite size effects for neutron star matter. For the hadron phase, we adopt a realistic equation of state (EOS) in the framework of the Brueckner- Hartree-Fock theory. For the quark phase, we do the Dyson-Schwinger method. The properties of the mixed phase are clarified by considering the finite size effects. We find that, if the surface tension is strong, the EOS becomes to be close the one with the Maxwell condition, though we adopt the Gibbs conditions. The behavior is universal, hence, this result is qualitatively same with the one with a simple bag model. We also find that the mass-radius relations by the EOS are consistent with the observations by Ref.[1] and Ref.[2]. Note that our methods are not based on the mean field at all.

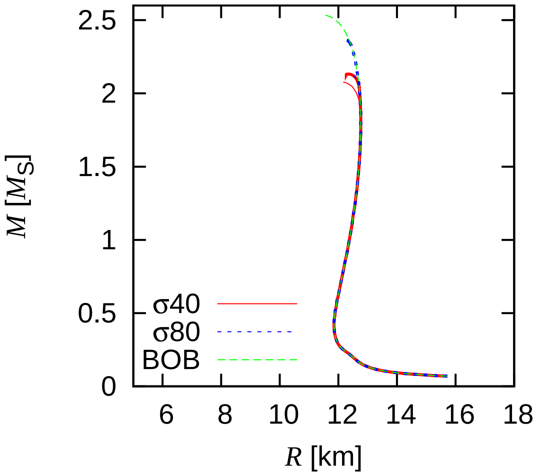

Figure 1: *Mass-radius (MR) relations by our EOS. The line of caption "BOB" is the result for nucleon EOS by Bonn B potential with three-body force. Other lines are the ones with the hadron-quark phase transition. Our methods are not based on the mean field at all, hence we need only a few parameters. Even though these parameters are not so important for the MR relation. It means that our results are consistent with Ref.[1] and Ref.[2] without fine tunings.*

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