CompStar 2010 :
School « Computational Tools for Compact Star Astrophysics »,
and Workshop « Neutron Star Physics and Nuclear Physics »

Scientific Report

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Abstract

Compstar2010, a winter school followed by a three-day workshop, was the third of a series of five meetings of the RNP Compstar and have gathered together 103 scientists. It took place in GANIL from the 8th to the 16th of February. The focus of the school, 8-13 February, was on the Computational Tools for Compact Star Astrophysics. It consisted of 5 lectures of 7h in total divided in 3h conventional lecture plus 4h of computational session. The workshop was dedicated to the Neutron Star Physics and Nuclear Physics with five review talks of 40 min, 21 regular talks of 25 min, 21 short talks of 10 min given by the PhD students, a round table and a poster session with 14 contributions. A total of 103 participants from 20 countries attended the event. From these, 45 were master or Ph.D. students, and 24 young post-doctoral researchers. Additionally to the 87 participants coming from ESF member countries, 16 participants came from non-ESF member countries (1 Argentinean, 1 Armenian, 1 Australian, 2 from Belgium, 1 Brazilian, 1 Hungarian, 1 Mexican, 1 Romanian, 5 Russians, 1 from Sweden, 1 from USA).
The school and the workshop have been supported by ESF-CompStar (26 keuros), ESF-Astrosim (10 keuros), CNRS (2 keuros), GANIL (1 keuros plus giving time of a secretary team, S. Rastello and E. Faure, plus a large access to all local facilities like restaurant, guest-house, lecture room for free) and University of Caen UCBN (giving access to the university restaurant for a cheap price and opening during the weak-end).
Full information about the program, participants, lectures, codes given during the computational session, posters and oral contributions is online at ipnweb.in2p3.fr/compstar2010/.

Description of the scientific content and discussion at the event

The winter school took place during the first six days of the event and was focused on Computational Tools for Compact Star Astrophysics, giving to the students some of the important numerical tools for their research. The lecturers presented both some practical exercises on computer as well as the basic concepts in the following topics :

- « Structure of Rotating Neutron Stars » by E. Gourgoulhon,
- « Relativistic equation of state for hadronic and quark matter » by S. Typel and T. Klähn,
- « Cooling of neutron stars » by D. Page,
- « Magnetic fields in compact stars » by J. Pons,
- « Solutions of hyperbolic partial differential equations » by L. Rezzolla.

For the practical sessions, a bootable USB stick with Ubuntu 9.10 operating system and including all the material provided by the lectures (codes, documentation and libraries) was given to all the participants.

A questionnaire has been filled by the students at the end of the school to get back their comments and criticisms in order to improve the future schools. The main impression was that they appreciate the initiative and the program of the school. During the practical session, the balance between the simple and illustrative codes and the more advanced one's were appreciated, but some improvement should however be taken into account for the next events. We indeed realized that the more advanced codes were fruitful for a sub-group of students, but not for the majority. Problems with mac computers (minority of students) were also encountered. Other suggestions from the students were: lectures dedicated to the phenomenology of compact stars, a longer break between the school and the workshop. A majority of the students suggested "Gravitational Wave Emission" as a topic for the next school.

The school was followed by a three day workshop on « Neutron Star Physics and Nuclear Physics » which covered most of the fields of interest to the RNP, namely:

- Nuclear Physics Aspects of Compact Stars; their impact on the Astrophysical Evolution of Compact Stars and vice versa,
- Properties of QCD in compact Stars and phase transitions that could take place in their interior,
- Gravitational wave emission from single and binary Compact Stars.

In particular there were five review talks on "*Equation of state for neutron star matter*" by P. Haensel, "*A characteristic approach to QNMs*" by L. Samuelson, "*Implication of magnetar non-precession*" by K. Glampedakis, "*Cooling of CFL core hybrids and their bigger mass twins*" by D. Blaschke, "*Modeling the inspiral and merger of binary neutron stars*" by L. Rezzolla. The review talks were followed by several regular talks on the same topic (all online in the site of the meeting). Some other topics also covered were: X-ray bursts, collective modes, low density matter and clustering, crust and pasta structures with magnetic field, supernovae and 3D modeling, experimental probes of nuclear matter properties (symmetry energy, pairing, incompressibility, …).

Moreover, contacts with the nuclear experimental community have been pushed forward with the inclusion of a special session devoted to experimental nuclear physics and a visit of GANIL facility. This session covered the following review talks:

- "Pairing properties of nuclei", D. Beaumel (IPNO Orsay), replaced at the last minute by J. Margueron,
- "EoS at low densities", A. Chbihi (GANIL, Caen),
- "Are giant resonances measurements useful for neutron star physics ", E. Khan (IPNO, Orsay),

- "Determining the EoS via Kaon production", C. Hartnack (SUBATECH Nantes).

The program included two sessions where the PhD students could present briefly their research topics and their results. The topics of these short talks have covered all CompStar interest fields. In these sessions the absence of ordering the topics of the talks made easier the discussion and exchange between the participants, especially among the students.
To conclude, summarize and emphasize the future and open issues of CompStar RNP, a round table was organized at the end of the workshop. The discussion was driven by the phenomenology of neutron stars. A summary of the main topics and questions that were pointed out and addressed in the round table follows:

- The implication of non-precessing magnetars for the structure of the star was proposed by I. Jones and K. Glampedakis and have open the discussion. It was pointed out that one of main ingredient is related to pairing, and especially proton pairing in the core of neutron stars.
- Jose Pons then briefly summarized the present understanding of cooling, with or without magnetic fields, and he pointed out that any reasonable model (fast or standard cooling scenario) can at present explain simultaneously observation data. It is then necessary to verify at the same time that the models reproduce also other observational data such as population synthesis. We might expect in the near future a limited number of additional observational datas.
- Glitches phenomenon provides complementary information on the microphysics acting in the crust of neutron stars since, as pointed out by P. Pizzochero, it is strongly related to superfluidity. For instance, to make the link with the discussion of magnetars, it was remarked that up to now no glitches have been observed in these type of objects. It generated a discussion about the role of magnetic fields in flux tubes, their interaction with the vortices, and the pinning force.
- Motivated by the talk of D. Blaschke, P. Haensel initiated a discussion of the instability triggered by a first order phase transition in the neutron star core. He presented a stability criterion (Newtonian and GR) under which such instability appears and that could describe either the collapse or the breathing of the star.
- A special emphasis of the burst emitted by accreting neutron stars was point out by L. Keek. It has motivated discussion with students as well as the necessity to cover this topic during one of the next schools. The next workshop which will be held in Leiden in July will offer the opportunity to join the CompStar community and the one studying bursts.
- Finally L. Rezzolla proposed to join the effort of CompStar community to built and provided one or several equations of state which cover a large range of densities, asymmetries and temperatures. Such a product of the RNP CompStar would serve as a reference for the simulations from supernovae to neutron stars mergers. It was decided to send a round email to evaluate the interest of the community in going further into this idea. In case of a positive reaction of the community, an exploratory workshop will be organized by the end of 2010.
- As a conclusion of the discussion, N. Chamel said few words about the NuPECC-ESF long range plan for which he contributes in the nuclear astrophysics section. A letter from CompStar can help to improve the representation of the CompStar community in NuPECC-ESF.

The round table was also the place to present or to remind that CompStar-ESF has a website which for registered users gives access to wider information such as job openings, grants, mailing list, wiki, ... The participants have also been reminded that they should submit their papers to the website and not omit acknowledging CompStar in them.

All of the participants, the lecturers and the speakers were impressed by the excellent local organization of the event that made it scientifically productive and enjoyable.

Lectures

1- *STRUCTURE OF ROTATING NEUTRON STARS* by Eric Gourgoulhon, LUTH, France.
The framework for computing rotating stellar models within general relativity has been introduced. The equations governing the structure of compact stars was derived from Einstein equations, under the assumptions of stationarity, axisymmetry and perfect fluid interior. The global properties of the stars (maximum mass, maximum angular velocity, last stable orbit, etc.) was discussed, as well as the extension to the Einstein-Maxwell system for computing magnetized neutron stars.
Computational session: We have computed various models of rotating neutron stars by means of the RotStar code from the Lorene C++ library (http://www.lorene.obspm.fr/). The studies were performed by changing the input parameters, as well as the equation of state, or the magnetic field configuration, and by producing various graphical outputs. For the students mostly interested by nuclear physics, the objective was to implement a new equation of state (prepared e.g. during the EOS session of that School). For the students mostly interested by general relativity, the objective was to compare two formulations for the equilibrium structure of compact stars, differing by the choice of space-time coordinates (e.g. quasi-isotropic coordinates and Dirac gauge).

2- *RELATIVISTIC EQUATION OF STATE FOR HADRONIC AND QUARK MATTER* by Stefan Typel, GSI, Germany, and Thomas Klähn, Univ. of Wroclaw.
The lecture covered the following topics: a model for hadron EoS (relativistic mean field theory with hyperons), a model for quark matter (NJL), and the description of the phase transition.
Computational session: a computer code solving the RMF equations in dense matter was provided as well as one for quark matter phase (both in C).

3- *COOLING OF NEUTRON STARS* by Dany Page, UNAM, Mexico.
The physical processes controlling the thermal evolution of a neutron star was presented: neutrino emission, thermal conductivity and specific heat, as well as the occurrence of pairing and its effect on these physical processes. The possible internal heat sources from non-equilibrium processes have been presented, such as magnetic field decay, superfluid differential rotation and nuclear reactions induced by accretion.
Computational session: a 1D (spherical symmetry) NS cooling code was presented (in F77). The code can model isolated cooling NSs as well as accreting ones, with continuous or transient accretion. The code solves for the whole temperature profile inside the star, crust and core, and allows observing in detail its evolution. This can include heating in the crust from pycnonuclear reactions induced by accretion and the relaxation of the crust/core when accretion stops.

4- *MAGNETIC FIELDS IN COMPACT STARS* by Jose Pons, University of Alicante, Spain.
In the first lecture it has been described how B fields affect different astrophysical scenarios, as a general overview. Some emphasis is put on the different numerical tools needed and problems that appear in each case. The second lecture had a more technical content, focusing on magnetic diffusion and aspects of non-linear evolution in the EMHD case, which is the valid approximation for the crust of a neutron star.
Computational session: We have studied a toy model (purely diffusion, without non-linear terms). The purpose of the session was to get familiar and work with a basic code (in F77) to solve magnetic diffusion in this simplified toy model. We have studied different regimes and explored the limitations of the code.

5- *SOLUTIONS OF HYPERBOLIC PARTIAL DIFFERENTIAL EQUATIONS (PDEs)* by Luciano Rezzolla, AEI Golm, Germany.
The lecture consisted in a brief introduction to the solution of hyperbolic PDEs such as those that are encountered when simulating the dynamics of neutron stars or fluids around compact objects.
Computational session: The computational session was devoted to the practical implementation of the theory presented during the lecture and allowed the student to solve in 1D (and possibly in 2D) either linear and nonlinear equations such as the wave equation or the Burgers equation with a code provided in F95.

Assessment of the results and impact of the event on the future direction of the field

During the present meeting it was possible to see the importance of the RNP: students are supervised by researchers of different institutions/countries, and collaborations have started or have been strengthened since there was plenty of time for discussions and exchange of ideas. It is important that the RNP finances short visits that allow completing the interchange between the different institutions inside and outside the RNP.
The discussion meetings are important to define which priorities should be taken and which observations/measures would help the field. In particular, it was pointed out the important role of nuclear physics community in bringing additional constraints and reducing the degrees of freedom in the parameters used to analyze the signals emitted by neutron stars. Also, the problems/suggestions raised during the round table are open problems whose solution would bring important progress in the field. A clear impact of the Compstar-ESF RNP is already seeing in the increasing number of participants. The previous meeting in 2009 gathered together 83 participants, in 2010, we have had 112 participants which represent an increase of almost 20%. This increase shows explicitly the good impact of CompStar-ESF training activities in bringing together experts and students of different fields. In the near future, we expect that this increase will continue.

Final program of the meeting
School

Material of the school such as notes, codes, manuals is available on line.

Monday, 8th		
08:00	*Registration*	
09:00	Solutions of hyperbolic pde	L. Rezzolla
10:30	*Break*	
11:00	Structure of Rotating Neutron Stars	E. Gourgoulhon
13:00	*Lunch at GANIL*	
14:00	Computational : Solutions of hyperbolic pde	L. Rezzolla, G. M. Manca & O. Zanotti
16:00	Computational : Structure of Rotating Neutron Stars	E. Gourgoulhon, J. Novak & M. Oertel
18:00	*End of the lectures*	
19:00	*Diner at University restaurant B*	

Tuesday, 9th		
09:00	Solutions of hyperbolic pde	L. Rezzolla
10:30	*Break*	
11:00	Structure of Rotating Neutron Stars	E. Gourgoulhon
13:00	*Lunch at GANIL*	
14:00	Computational : Solutions of hyperbolic pde	L. Rezzolla, G. M. Manca & O. Zanotti
16:00	Computational : Structure of Rotating Neutron Stars	E. Gourgoulhon, J. Novak & M. Oertel
18:00	*End of the lectures*	
19:00	*Diner at University restaurant B*	

Wednesday, 10th

09:00	Cooling of neutron stars	D. Page
10:30	*Break*	
11:00	Magnetic fields in compact stars	J. Pons
13:00	*Lunch at GANIL*	
14:00	Computational : Cooling of neutron stars	D. Page, J. Pons
18:00	*End of the lectures*	
19:00	*Diner at University restaurant B*	

Thursday, 11th

09:00	Cooling of neutron stars	D. Page
10:30	*Break*	
11:00	Rel. EoS for hadronic and quark matter	S. Typel
13:00	*End of the lectures*	
13:00	*Lunch at GANIL*	
14:00	***Visit of GANIL***	
19:00	*Diner at University restaurant B*	

Friday, 12th

09:00	Magnetic fields in compact stars	J. Pons
10:30	*Break*	
11:00	Rel. EoS for hadronic and quark matter	T. Klaehn
13:00	*Lunch at GANIL*	
14:00	Computational : Magnetic fields in compact stars	J. Pons, D. Page
18:00	*End of the lectures*	
19:00	*Diner at University restaurant B*	

Saturday, 13th

09:00	Computational : Rel. EoS for hadronic and quark matter	S. Typel, T. Klaehn
13:00	*End of the lectures*	
13:00	*Lunch at University restaurant B*	
14:00	***Visit of the Bayeux Tapestry***	
19:00	*Diner at University restaurant B*	

19:00

Workshop

All the talks are available on line.

Sunday, 14th				
08:30	*Registration*			
09:00	EOS (S. Typel)	Haensel	Pawel	Equations of state for neutron stars - a review (*review*)
09:40		Providencia	Constanca	Effect of small clusters on the pasta phase
10:05		Ducoin	Camille	Collective modes with pairing in the outer core of neutron stars
11:30	*Break*			
11:00	EOS (A. Polls)	Rios Huguet	Arnau	Hot neutron matter within a Green's functions approach
11:25		Typel	Stefan	Clusters in Nuclear Matter
12:20		Benhar	Omar	Unified description of equilibrium and non equilibrium properties of neutron star matter
13:00	*Lunch*			
14:00	PhD session (I. Vidana)	Alvarez Castillo	David Edwin	Extension to the fourth order approximation in the symmetry energy
14:10		Birkl	Reiner	Stationary, Axisymmetric Neutron Stars with Meridional Circulation in General Relativity
14:20		Carbone	Arianna	Shear viscosity of beta-stable nuclear matter
14:30		Cornou	Jean-Louis	Some numerical studies of the stability of magnetized neutron stars using spectral methods
14:40		Fantina	Anthea	Study of electro-weak processes in core-collapse phase of type II Supernova
14:50		Gabler	Michael	Torsional shear oscillations of magnetized neutron stars
15:00		Grill	Fabrizio	Vortex-Lattice Interaction in Pulsar Glitches
15:10		Grygorov	Pavlo	Description of inhomogeneous nuclear matter derived from the realistic low momentum NN interaction
15:20		Herzog	Matthias	Burning of a Neutron Star into a Strange Star
15:30		Kaeppeli	Roger	Core-collapse supernova with strong magnetic fields & jet formation
15:40	*Break*			
16:10	Structure of NS (O. Benhar)	Samuelsson	Lars	A characteristic approach to QNMs (*review*)
16:50		Haskell	Brynmor	Superfluid Neutron Star dynamics
17:15		Corvino	Giovanni	Shearing Instabilities in differentially rotating neutron stars with realistic equation of state
17:40		Villain	Loic	On differentially rotating neutron stars
18:05	*End of the*			

	sessions			
20:00 23:00	***Social dinner***			

Monday, 15th				
09:00	Magnetars (M. Bejger)	Glampedakis Pena	Kostas	Implications of magnetar non-precession (*review*)
09:40		Arteaga	Daniel	Magnetic field effects on the masses of neutron star crust nuclei
10:05		Chamel	Nicolas	HFB mass models and applications to neutron stars
10:30	*Break*			
11:00	Welcoming	Gales	Sydney	Welcoming at GANIL
11:10	Experimental nuclear physics (F. Gulminelli)	Beaumel	Didier	Superfluidity in nuclei
11:35		Chbihi	Abdou	Nuclear EoS at low density
12:00		Hartnack	Christoph	Determining the EoS via Kaon production
13:00	*Lunch at GANIL*			
14:00	Nuclear physics (C. Providencia)	Vidana	Isaac	Symmetry energy, neutron star crust and neutron skin
14:25		Baldo	Marcello	Energy density functional with a microscopic basis
14:55		Wolter	Hermann	The nuclear symmetry energy at high density
15:20		Khan	Elias	Are giant resonances measurements useful for neutron stars physics ?
15:50	*Poster session and Break*			
17:00	QCD (J. Zdunik)	Blaschke	David	Cooling of CFL core hybrids and their bigger mass twins (*review*)
17:40		Klahn	Thomas	Dense Matter in QCD
18:05		Pagliara	Giuseppe	Quark hadron mixed phases in protoneutron stars
18:30	*End of the session*			
19:00	*Diner at U. restaurant*			

Tuesday 16th				
09:00	Merging and burning (J. Novak)	Rezzolla	Luciano	Modelling the inspiral and merger of binary neutron stars (*review*)
09:40		Keek	Laurens	Thermonuclear burning in the neutron star envelope
10:05	*Break*			
10:40	PhD session (K. Glampedakis)	Lander	Samuel	Oscillations of rotating magnetised neutron stars
10:50		Lastowiecki	Rafal	Can hybrid stars with CFL quark cores form a third family of compact stars?
11:00		Liang	Haozhao	Nuclear Physics with Relativistic Hartree-

				Fock Theory
11:10		Millmore	Stephen	Current non-linear numerical simulations of neutron stars use single component models
11:20		Petrik	Kristian	Comparison of density dependence behaviour of coupling constants within different relativistic mean-field models
11:30		Sagert	Irina	A strange quark matter EOS for explosive astrophysical systems
11:40		Scheidegger	Simon	3d mhd core-collapse supernovae & possible gravitational wave signature
11:50		Shternin	Petr	Transverse plasma screening in kinetics of degenerate matter and cooling of young neutron stars
12:00		Turlione	Anabela	Crustal cooling of neutron stars in X-ray transients
12:10		Wlazlowski	Gabriel	Quantum Monte Carlo study of dilute neutron matter at finite temperatures
12:20		Zablocki	Daniel	Two particle correlations in dense quark matter
13:00	*Lunch at GANIL*			
14:00	Round table (J. Margueron)			**Future Goals in Compact Star Astrophysics** T. Klaehn, J. Pons, L. Rezzolla, S. Typel
15:30	*End of the workshop*			
16:00	***Meeting of the CompStar advisory board***			
18:00				

Poster session

Hutauruk	Parada	Effects of EM neutrinos and antineutrinos in Dense matter
Blottiau	Patrick	Role of microphysics in the success of Type-II supernova explosions
Chashkina	Anna	Magnetic field estimates for accreting neutron stars in massive binary systems and models of the magnetic field decay
Chugunov	Andrey	Equation of state of classical Coulomb plasma mixtures and nuclear reaction rates
Gusakov	Mikhail	Response functions of superfluid Fermi mixtures in neutron stars
Illarionov	Alexey	Microscopic calculation of the low-temperature equation of state of dense matter and neutron star structure
Lovato	Alessandro	Density dependent effective NN interaction from three-body forces
Perez-Garcia	Angeles	Low temperature relativistic Fermi liquids
Polls	Artur	Latent heat in the liquid-gas phase transition of nuclear matter
Santos	Alexandre	Dynamical Instabilities in Relativistic Mean-field Models and the Inner Edge of the Compact Star Crust
Sebille	François	self-organisation in isospin-asymmetric nuclear matter
Skorzewski	Marcin	Cluster decomposition for dense quark matter