New CompStar

Exploring Fundamental Physics with Compact Stars

2014 — 2017

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Compact stars, such as neutron stars, strange stars or hybrid stars, are unique laboratories that allow us to probe the building blocks of matter and their interactions at regimes that terrestrial laboratories cannot explore. These exceptional objects have already led to breakthrough discoveries in nuclear and subnuclear physics, QCD, general relativity and high-energy astrophysics.

The upcoming generation of observatories and gravitational-wave detectors will continue to nurture innovative and fundamental discoveries complementary to those achieved through the nuclear and subnuclear experimental facilities.

The MPNS COST Action MP1304 Exploring fundamental physics with compact stars (NewCompStar) has brought together the leading experts in astrophysics, nuclear physics and gravitational physics to address this fascinating but challenging research area through an interdisciplinary approach. In addition to an innovative and well-defined research agenda, the network has provided a dedicated training program for a new generation of scientists with wide-ranging expertise and multiple skills oriented also towards knowledge transfer and innovation.

Fig. 1 – The European Space Agency (ESA) XMM-Newton spacecraft, a X-ray space observatory.
Image Credit: Spacecraft Icons at NASA Science

1. OBSERVATIONS AND MODELLING OF COMPACT STARS

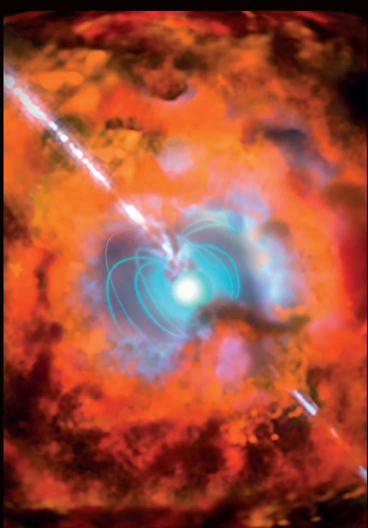


Fig. 2 – Gamma-ray bursts and magnetars. Gamma Ray Bursts (GRBs) are the most violent events in the Universe. We know today that the "long" GRBs are associated to the death of massive stars, while the "short" ones are more likely due to merger events of old compact objects (Neutron Stars and/or Black Holes). Artist's impression of a supernova and associated gamma-ray burst driven by rapidly spinning magnetar, a neutron star with a very strong magnetic field.
Image credit: ESO (http://www.eso.org/public/images/eso1527a/)

The recent past has seen substantial advances in our understanding of the astrophysics of compact stars, thanks to the availability of new telescopes and space observatories. The input of these instruments has been crucial for our understanding of compact stars. In addition, planned instruments, (e.g., FAST being the world's largest single dish radiotelescope, LOFT with its novel pulse profile modelling and SKA with its very high sensitivity) will provide us with an unprecedented wealth of information on compact stars.

By close interaction with the theoretical and observational teams, this Action has developed an all-encompassing approach to the diverse manifestations of neutron stars, taking input both from the microphysics and from the theoretical modelling of the spacetime.

The ultimate goal of the Action has been to link the various, partly contradictory results, in an approach that uses radio, X-ray and gamma-ray observations, and to contrast them with the theoretical predictions (e.g., neutron star hydrodynamical and magnetohydrodynamic simulations, pulsar glitch models, emission processes, atmospheric and magnetospheric models, supernova simulations) and their implications (through neutron star population synthesis).

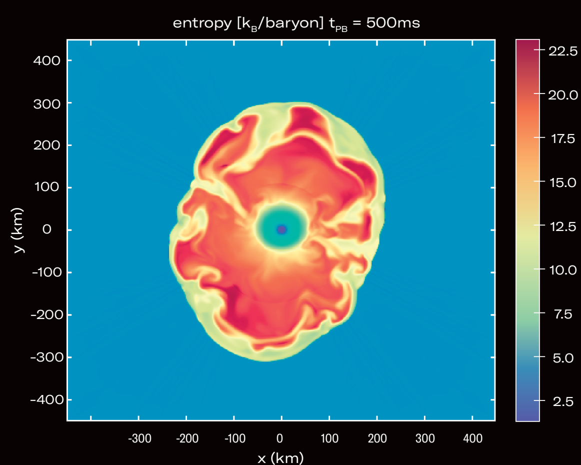
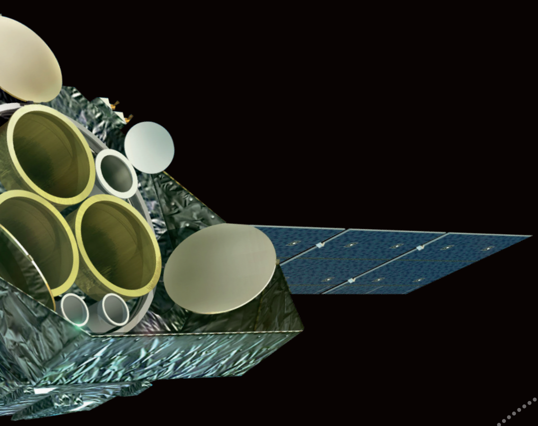


Fig. 3 – Core-collapse supernovae: fascinating cosmic fireworks. Snapshot from a three-dimensional core-collapse supernova simulation. Shown is the entropy per baryon at the onset of the explosion for the innermost 1000 km of the supernova.
Image Credit: K. Ebinger, O. Heinimann, M. Liebendörfer

2. PHYSICS OF THE STRONG INTERACTION THEORY AND EXPERIMENT



Compact stars, and the observed astrophysical processes related to them, give stringent constraints on the properties of dense and hot hadronic matter, such as equation of state, superfluidity, transport coefficients and elasticity parameters. Probing strongly interacting matter under extreme conditions requires bringing together experts in low-energy QCD and in many-body theories. Indeed, one of the main theoretical issues is that the theory describing the interaction and dynamics of quarks and gluons, i.e., QCD, is non-perturbative in the regimes of interest for compact stars. Additionally, many-body effects such as pairing or collective behavior make the phase diagram of hadronic matter very rich and at the same time, subtle to describe.

The relation between nuclear experiments and the physics of compact stars is not straightforward but the novel synergy between nuclear experiments and astronomical observations of compact stars, that has been at the very heart of the Action, will impact on all of the theoretical modelling of compact stars.

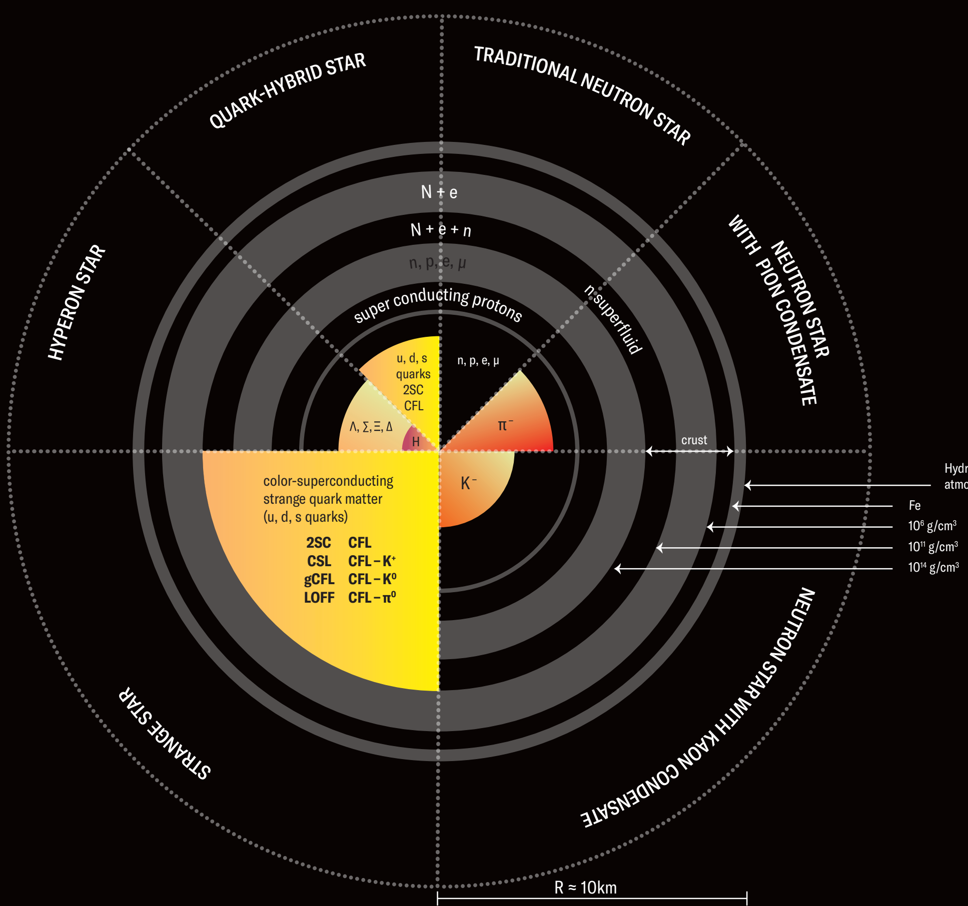


Fig. 4 – What are neutron stars made out of? Some of the theoretical predictions for the of matter existing inside of neutron stars.
Image credit: F. Weber

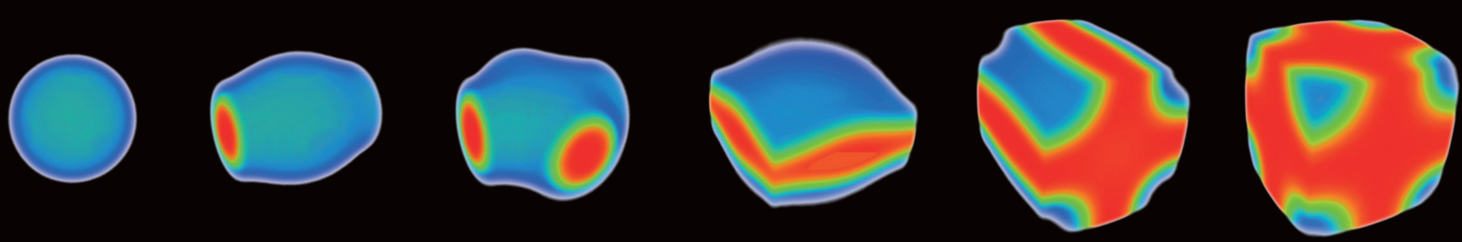


Fig. 5 – How complex is the crust of a neutron star? The inner crust is formed by a lattice of deformed clusters with exotic shapes, called “pasta” phases, immersed in a fluid of neutrons and a relativistic electron gas. These nuclear pasta phases have shapes that go from spherical clusters to rods, sheets, tubes and bubbles of nuclear matter. Searching for observational signatures of these phases was one of the challenges of the Action.
Image credit: H. Pais and J. Stone

3. GRAVITATIONAL PHYSICS THEORY AND OBSERVATIONS

The strong gravitational fields of neutron stars make them potentially detectable sources of gravitational waves, both as members of binary systems, and as individual emitters when they are produced in a core-collapse supernova, when they collapse to a black hole, or undergo any sort of non-spherical oscillation. Indeed, the inspiral and coalescence of neutron star binary systems (either as double neutron star systems or when considering the presence of a black hole) are candidates for the detection of gravitational waves by the LIGO/Virgo detector network. Their observation will provide important information on strong-field gravity, the equation of state, and the origin of short gamma-ray bursts.

Merging binary systems of neutron stars emit gravitational waves which depend on the mass, the mass ratio and the equation of state. The numerical modelling of the emitted waveforms is essential for a successful detection.

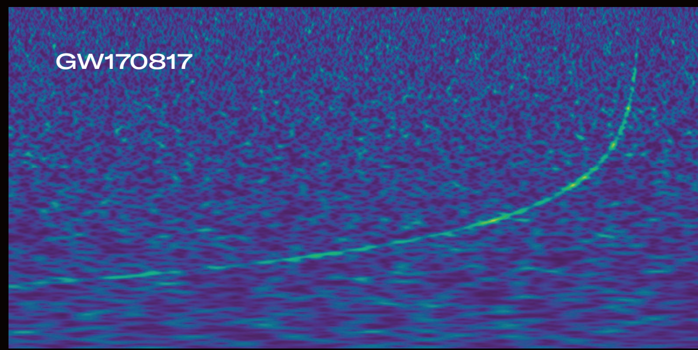


Fig. 6 – LIGO's data shows the "chirp" sound produced as the two neutron stars inspiral. *Image Credit: LIGO*

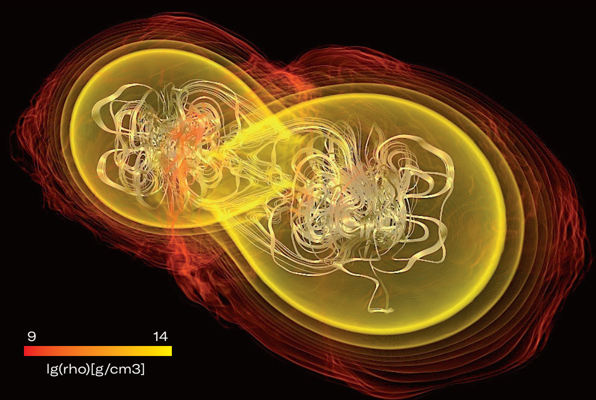


Fig. 7 – Merger of a binary system of magnetised neutron stars. Shown is the rest-mass density and the magnetic field lines at the time of the merger. *Image Credit: FIAS/GU/AEI*

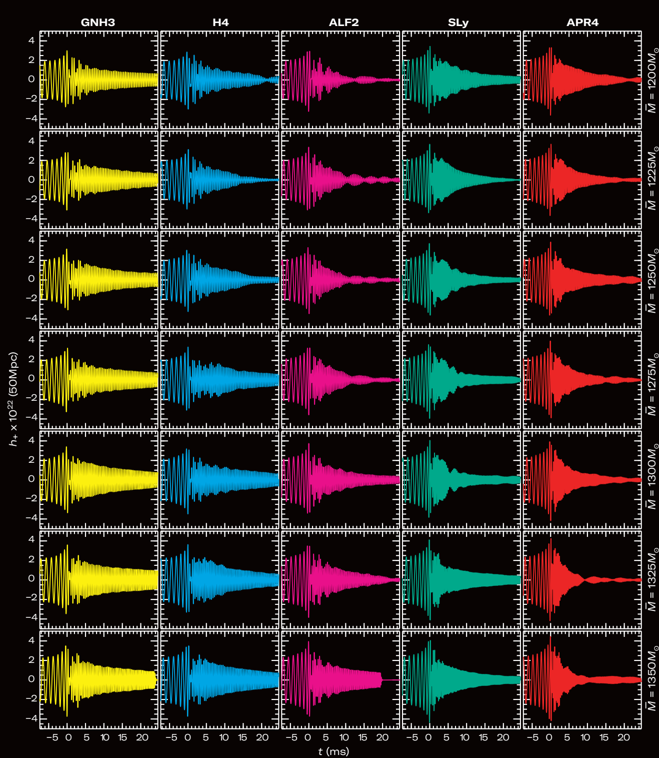


Fig. 8 – Gravitational waveforms predicted for merging binary systems of neutron stars. Different colours refer to different equations of state, while different lines refer to different masses of the binaries.

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THE NETWORK

29 countries have participated in NewCompStar, and, in addition, four institutions of two countries as Near Neighbouring Countries Institutions, and three institutions as International Partner Countries Institutions

COST PARTICIPANTS
Austria, Belgium, Bulgaria, Croatia, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Malta, The Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom.

COST NEAR NEIGHBOUR Countries Institutions
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COST International Partner Countries Institutions
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