PHAROS Conference 2019: the multi-messenger physics and astrophysics of neutron stars

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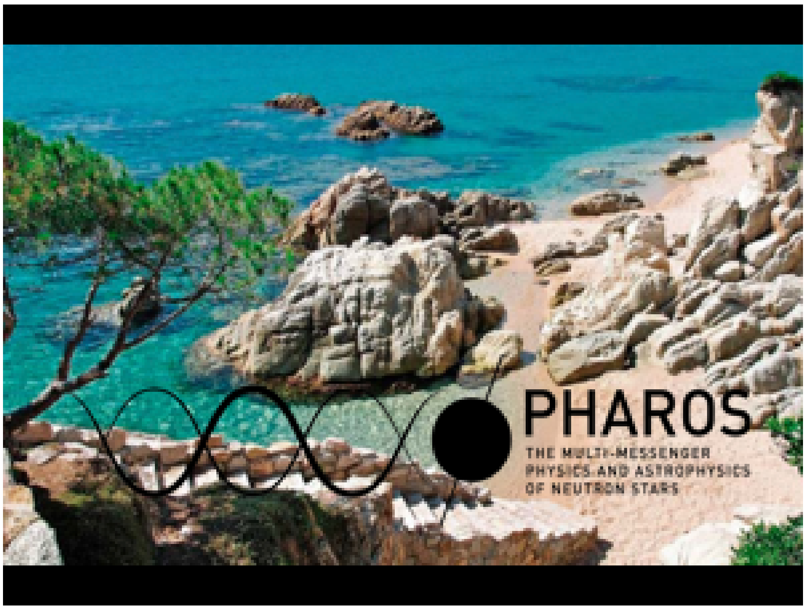
HOTEL CAP ROIG



Book of Abstracts

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Complex polarisation variability in radio pulsars and the implication for pulsar magnetospheres

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Pulsar polarisation is key to understanding the emission mechanism. Some radio pulsars exhibit puzzling polarisation properties and variability at the single-pulse level. PSR B0031-07 is one such radio pulsar, which shows rapid changes in position angle that are apparently modulated as the star rotates, and periodical changes are seen from pulse to pulse. It is demonstrated that this variability is linked to periodic pulse shape changes seen in total intensity. We show that the complex position angle variability can be explained by the presence of two coupled orthogonal polarisation modes (OPMs) that are attenuated as they propagate through the magnetosphere. This model is applied to as-yet unpublished data for B0031-07, which will be discussed in detail in the talk. This provides a way to reconcile the issue of asymmetrical pulse profiles and pulse shape variability with the predictions of the well-established carousel model, the often-invoked model to explain the origins of the radio emission of pulsars. By interpreting the variability as arising from these carousels of "sparks" circulating around the magnetic axis, the polar emission region can then be mapped. Understanding the structure and location of the emission region is fundamental in understanding the radio pulsar radiation processes.

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Gravitational-wave data analysis for constraining the NS EoS

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The first detection of a gravitational-wave signal from a binary neutron star coalescence, known as GW170817, by the LIGO and Virgo observatories, signifies the beginning of a new era in astrophysics. By analysing gravitational wave signals from neutron star binaries, using adequate modelling of matter effects, we can constrain the barotropic equation of state (EoS) of cold matter at supranuclear densities found in the neutron-star interior. In this talk I will summarise the analyses performed on GW170817, that allowed us to measure the *tidal parameters* of the two neutron stars and put tight constraints on their *radii*. These measurements also translate to constraints on the pressure-density function that defines the EoS, excluding a range of stiff EoS models. I will then discuss the prospects of extracting additional useful information by modelling and analysing the *post-merger* part of such events. In the last part of the talk we will explore methods for *combining information* from the multiple detections expected in the coming years and for exploiting the potential of *multi-messenger* observations, in order to improve our measurements on the properties of neutron-star matter.

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The formation of (heavy) magnetars and collapsars

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Using numerical simulations in two and three dimensions, we investigate the collapse of the highly compact cores of high-mass stars with varying degrees of rotation and magnetic fields that are commonly considered progenitors of gamma-ray bursts (GRBs) within the collapsar or the proto-magnetar model. Our simulations aim to find the specific values of the magnetic field and its topology that separate the formation of proto-magnetars from collapsars. We will show the outcome or our models for various stellar progenitors including different metallicities and masses.

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Neutron Star Equation of State after the GW170817 event

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In this talk I will review the method of estimation of tidal deformabilities of compact stars and present results for pure hadronic
as well as hybrid stars that include the mass twins case. Then I will discuss the impact of the nuclear symmetry energy in
the determination of the compact star radius.In particular, the recent detection of gravitational radiation from the GW170817 event
shed light on the properties of the neutron star equation of state (EoS), thus comprising both the study of the symmetry energy
and stellar radius. Furthermore, I shall address the question of the possibility of a universal symmetry energy contribution to
the neutron star equation of state under restricted Direct Urca cooling. When these two aspects are combined, powerful predictions for the
stiffness of the neutron star EoS are obtained.

Furthermore, I will focus on the case of mass twin compact stars, hybrid compact stars with approximately the same masses but different radii.
To qualify the above, I will show a recent developed EoS that features of a color superconducting chiral quark model with nonlocal, covariant
interactions bearing density dependent vector meson coupling and a density-dependent bag pressure. This model allows for a scenario where the
compact stars of the GW170817 event are either both hadronic, both hybrid, or simultaneously hadronic and hybrid configurations.

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Superfluidity and glitches

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The observation of a large glitch in the Vela pulsar in 1969 initiated a discussion that is still – more than half a century later – ongoing. The general view is that the glitch phenomenon is linked to the presence of a superfluid component penetrating the neutron star crust. However, this remains (in many ways) a cartoon-level explanation. Quantitative modelling is a challenge. In this talk I will contrast the growing observational evidence (including recent anti-glitch event) with available theory. The aim is to establish what we actually know and what we need to do in order to make decisive progress on this vexing problem.

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Pulsar glitches: a window on neutron star interior

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Nuclear superfluidity is thought to play a key role in the dynamics of isolated neutron stars. In particular, pulsar glitches offer a glimpse into the superfluid interior of a neutron star: within the currently accepted scenario these timing irregularities are explained in terms of the motion of quantized vortex lines that permeate the superfluid region.

To store the angular momentum which can be eventually released during a glitch, some sort of "pinning mechanism" that blocks the vortex lines is invoked. Hence, understanding the collective dynamics of superfluid vortex lines in complex environments (like the stellar crust) is an essential ingredient that is required if we want to take our understanding of glitches to the next level.

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The role of magnetic field in pulsar glitches

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Spin-up or 'glitch' events in neutron stars are believed to be driven by an internal neutron superfluid component that is only weakly coupled to the rest of the star. Recent calculations have shown that the inner crust superfluid is not enough to explain the largest glitches, suggesting that interactions between superfluid components in the core are also involved. Rotational vortices and magnetic fluxtubes impede each other's motion until some critical threshold is reached, at which the vortices are released and angular momentum is transferred to the crust in a glitch. We present preliminary work to study this process quantitatively, which requires modelling of both the macroscopic fluxtube and vortex geometries (which are typically not symmetric about the same axis) and also the microscopic interaction between them.

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Spindown-powered transients from long-lived BNS merger remnants

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The observation of Gravitational Wave (GW) event (GW170817) and its electromagnetic counterpart in gamma rays (GRB 170817) and in optical and near-infrared (AT2017gfo) marked the beginning of the multimessenger astronomy with GWs. This event was also the first detection of a binary neutron star (BNS) coalescence as well as the first clear observation of a kilonova, an astrophysical transient powered by radioactive decay of neutron-rich matter expelled during the BNS merger. Kilonovae are particularly interesting for multimessenger astronomy because they are nearly isotropic and observable for a long time (several hours) after the peak GW signal, but they are not the only transients with these features: if a long-lived and fast rotating neutron star (NS) with a high magnetic field results from the BNS coalescence, it can radiate its rotational energy and power a different kind of "spindown-powered" transient. In this talk, I will present our ongoing investigation on spindown-powered transients, approaching the problem for the first time via hydrodynamic simulations in special relativity. The final goal of our work is to provide reliable predictions for observable quantities (i.e. peak luminosity, peak time, spectral range), which are extremely important for the planning of a follow-up observational strategy as well as for the interpretation of future detections.

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GW170817: lessons from the observations of a binary neutron star merger

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The historically first detection of gravitational waves from a binary neutron star merger turned out to be a treasure trove for the dense matter physics, relativistic astrophysics, testing the theories of gravity and to emerging multi-messenger astronomy. I will summarize the LIGO/Virgo results related to GW170817 event, discuss implications of this observation and the future outlook.

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Gamma-ray bursts and magnetars: observational signatures and predictions in the multimessenger era

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Newly-born millisecond magnetars are competing with black holes as source of the gamma-ray burst (GRB) power, mainly with their rotational energy reservoir. In ten years of activity, Swift has provided compelling observational evidences supporting the magnetar central engine, as the presence of a plateau phase in the X-ray light curve, the extended emission in SGRBs and the precursor and flaring activity. We review the major observational evidences for the possible presence of a newly-born magnetar as the central engine for both long and short GRBs. We then discuss about the possibility that all GRBs are powered by magnetars, and we propose a unification scheme that accommodates both magnetars and black holes, connected to the different properties and energetics of GRBs. Since the central engine remains hidden from direct electromagnetic observations, we discuss the observational perspectives for GRB powered by magnetars in the multi messenger era.

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Modeling the strong-field dynamics of binary neutron star merger

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The observation of gravitational and electromagnetic waves from a binary neutron star merger in August 2017 conveyed key information on the nature of matter at supranuclear densities, on the origin of short-gamma ray burst, on the production site of of heavy elements via r-process nucleosynthesis, and on cosmography.
Thus, multimessenger observations of compact binary mergers hold the promise to unprecedent insights on some of the most fundamental physics questions.
A crucial and necessary ingredient to intepret such observations is the precise knowledge of the dynamics of the sources.
I will talk about recent developments on the modeling of neutron star mergers using numerical simulations in general relativity.
I will focus on the numerical exploration of the the merger remnant and mass ejecta and their dependence on the binary parameters. I will discuss detailed models of the gravitational waves and kilonova light curves, highlighting the prospect of using them in joint analysis of multimessenger data.

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Thermal evolution of neo-neutron stars. I. Envelopes and Eddington luminosity phase.

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A neo-neutron star is the next step in a neutron star evolution after the proto-neutron star phase. It begins $30 - 60$ seconds after the birth of the neutron star when neutrinos are free to escape and the

crust of the neutron star is forming. This phase lasts about
10^4 seconds until the star "forgets" its initial conditions. Super-Eddington luminosities may still be present for some time. However, in the current work we do not consider mass loss and stellar winds and, thus, limit ourselves to luminosities not exceeding Eddington limit.

A neo-neutron star produced in a core collapse supernova is not observable but the one produced by a binary merger, likely associated with a short gamma-ray burst, may be observable for some time while the super-massive neutron star is supported by fast rotation. A neutron star envelope can also reach Eddington luminosity during an X-ray burst. In any case, investigation of this phase requires handling of the expansion and/or contraction of the star's outer layers.

We present the first part of our results of study of this neo-neutron star phase obtained with a modified version of a "standard" neutron stars' thermal evolution code, which was adapted to handle this regime. We investigated how long the star can have Eddington or near-Eddington luminosity and demonstrate that this depends greatly on the initial conditions unlike the "standard" cooling scenarios in which the initial conditions are quickly forgotten. One of the interesting findings was that the surface temperature actually maps the initial luminosity profile of the envelope, not the temperature profile as in the case of x-ray transients.

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An eye on two magnetars

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Magnetars are the strongest magnets we know of. Their X-ray emission is powered by the instabilities and decay of their huge magnetic field (~10^14-10^15 G). They are characterized by unpredictable and variable bursting activity in the X-/gamma ray regime, often accompanied by enhancements of the persistent X-ray flux. These events are called outbursts. In this talk, I will present new results in the field.
I will focus on the multi-outburst activity of the magnetar CXOU J164710.2-455216, hosted in the massive star cluster Westerlund I. After two outbursts in 2006 and 2011, CXOU J1647 underwent three bursting episodes during its latest activation on May 2017. Moreover, I will bring to your attention the longest outburst ever detected from a magnetar: 1E 1547.0-5408 is slowly recovering from an outburst with onset in 2009.

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Fast Moving Pulsars in the ISM: 3D RMHD modelling of Bow-Shock Pulsar Wind Nebulae

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Pulsars out of their parent SNR directly interact with the ISM producing so called Bow-Shock Pulsar Wind Nebulae. These have been directly observed from Radio to X-ray, and are found also associated to TeV halos, with a large variety of morphologies. They offer a unique environment where the pulsar wind can be studied by modelling its interaction with the surrounding ambient medium, in a

fashion that is different/complementary from the canonical Plerions. These system have also been suggested as the possible origin of the positron excess detected by AMS and PAMELA, in contrast to dark matter. I will present results from the first 3D Relativistic MHD simulations of such nebulae, with a particular focus on the expected emission signatures, the properties of high energy particle escape, the level of turbulence and magnetic amplification, the contamination by ISM neutrals and how they depend on the wind structure and magnetization.

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Disk formation from the collapse of a rotating neutron star

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An unstable rotating neutron star can collapse to a black hole.
A particle in the Innermost Stable Circular Orbit (ISCO) of this black hole has
the lowest possible angular momentum that prevents it to fall into the black hole.
Only the particles of the unstable neutron star that have a specific angular
momentum greater than that of the black hole ISCO will escape the collapse.
Using this criterion, we estimate the mass of the disk that might form in a
neutron star collapse for a variety of Equation Of States (EOSs).
This is achieved by analysing the neutron star equilibrium configurations obtained
with the XNS code and by checking our predictions with general relativistic
hydrodynamical simulations performed with the BAM code.
We find that for all considered EOSs the disk mass is too low to generate gamma
ray bursts with significant energy.

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Equation of state for neutron stars employing chiral interactions within the Green's function approach

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The reach for a reliable microscopic description of infinite nuclear matter is a fundamental task for theoretical nuclear physics. Successfully completing this task can have great impact on the comprehension we have of exotic states of matter, from heavy neutron-rich nuclei to the equation of state of neutron star matter. In this talk I will present the Self-consistent Green's function method as a convenient way to investigate the properties of infinite nuclear matter from first principles employing full chiral interactions. We will see how chiral potentials, built to reproduce radii or binding energies of light nuclei, predict both microscopic and thermodynamical properties of nuclear matter. Based on these microscopic calculations I will try to put nuclear physics constraints on both the zero and finite-temperature equation of state for neutron star matter.

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General predictions for the neutron star crustal moment of inertia

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The neutron star crustal EoS and transition point properties are computed within a unified meta-modeling approach.

The variational equations in the crust are solved within a Compressible Liquid Drop (CLD) approach, with surface parameters consistently optimized for each EoS set on experimental nuclear mass data. When EoS parameters are taken from known Skyrme or RMF functionals, the transition point of those models is nicely reproduced.
A model-independent probability distribution of EoS parameters and of the transition density and pressure is determined with a Bayesian analysis, where the prior is given by an uncorrelated distribution of parameters within the present empirical uncertainties, and constraints are applied both from neutron star physics and ab-initio modelling. We show that the characteristics of the transition point are largely independent of the high density properties of the EoS, while ab-initio EoS calculations of neutron and symmetric matter are far more constraining.

Considering these constraints, a quantitative prediction of crustal properties with controlled confidence intervals and increased precision with respect to previous calculations ($\approx 9\%$ dispersion on the crustal width and $\approx 25\%$ dispersion on the fractional moment of inertia) can be reached.
The crustal moment of inertia is also evaluated as a function of the neutron star mass.
The possible crustal origin of Vela pulsar glitches is discussed within the present estimations of crustal entrainment, disfavoring a large entrainment phenomenon if the Vela mass is above $1.4M_{\odot}$.
Further refinement of the present predictions requires a better estimation of the high order isovector empirical parameters, e.g K_{sym} and Q_{sym}, and a better control of the surface properties of extremely neutron rich nuclei.

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Magnetic field evolution in neutron star cores

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The study of the evolution of neutron star magnetic fields is likely to help us understand the connection between the different classes of NSs, which have magnetic fields of very different strengths, depending on their age. This observational evidence suggests that the NS magnetic field evolves in time. Numerous studies, both purely theoretical and numerical, have contributed to understand the processes that drive this evolution. However, most of the numerical efforts have focused in the crust, since the physics of the evolution of the magnetic field is conceptually much simpler there than in their core.

The NS core is a fluid mixture of neutrons, protons, and electrons (joined by other species at increasing densities) that scatter off each other through strong and electromagnetic interactions, causing effective friction forces, and can also convert to each other by weak interactions (''Urca reactions''). Likely, the dominant process evolving the magnetic field there is ambipolar diffusion, i.e., the joint

motion of the charged particles and the magnetic field relative to the neutrons, driven by the Lorentz force and controlled by frictional forces and pressure gradients.

Using numerical simulations restricted to axially symmetric geometry, we study the long-term evolution of the magnetic field in the interior of an isolated neutron star under the effects previously described.

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3D instabilities during the Type I bursts

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When a neutron star accretes from a low mass companion, the fluid that accumulates on the surface of the compact object can burn unstably. The result of the thermonuclear runaway is the Type I bursts: X-ray flashes that last for tens to hundreds of seconds. The lightcurves of the bursts encode information about the mass and radius of the neutron star. These can be used to put constraints on the equation of state of the core, also in combination with other observations like gravitational waves.

In order to understand the emission pattern that leads to the burst lightcurves, it is fundamental to understand how the thermonuclear flame propagates across the star after ignition.

In this work, I will present the first 3D numerical simulations of the hydrodynamical instabilities that develop along the flame front and discuss their implications for the burst lightcurves.

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Relativistic r-modes during type-I X-ray bursts

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Accreting neutron stars (NS) can exhibit high frequency modulations in their lightcurves during thermonuclear X-ray bursts, known as burst oscillations. These frequencies can be offset from the NS spin frequency by several Hz (known independently) and can drift by 1-3 Hz. One plausible explanation is that a wave is present in the bursting ocean that decreases in frequency (in the rotating frame) as the burst cools, hence explaining the drifts - the strongest candidate is the buoyant r-mode. Future X-ray missions aim to use the burst oscillation phenomenon to measure NS parameters; this effort would be helped by a more accurate understanding of the underlying mechanism. To date, models that calculate frequency and drift during these bursts include realistic composition and temperature evolution but have not yet taken into account relativistic effects known to be important from simpler modelling. In this talk, I present a relativistic calculation of a buoyant r-mode in a NS

ocean for several ocean equations of state. I also compare to a Newtonian calculation to demonstrate the change in including these effects.

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Unified equations of neutron-star interiors: role of the symmetry energy

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Formed in the aftermath of gravitational core-collapse supernova explosions, neutron stars are the most compact observed stars. Their average density exceeds than that found inside the heaviest atomic nuclei. Neutron stars are also endowed with the strongest magnetic fields known, which can reach millions of billions times that of the Earth. According to our current understanding, a neutron star is stratified into distinct layers. The surface is probably covered by a metallic ocean. The solid layers beneath consist of a crystal lattice of pressure-ionized atoms embedded in a highly degenerate electron gas. With increasing density, nuclei become progressively more neutron rich until neutrons start to drip out of nuclei thus delimiting the boundary between the outer and inner regions of the crust, where neutron-proton clusters are immersed in a neutron liquid. At about half the density of heavy nuclei, the crust dissolves into an homogeneous liquid mixture of nucleons and leptons. During this talk, our latest series of unified and thermodynamically consistent equations of state of dense matter in neutron stars will be presented. These equations of state were specifically developed to assess the role of the symmetry energy on neutron-star properties.

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Multi-wavelength observations of High Mass X-ray Binaries

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Most High Mass X-ray Binaries (HMXB) host a neutron star accreting from the intense stellar wind of a massive star. They have been revealed by a wealth of multi-wavelength observations, from X-ray to infrared domain. I will review here what these observations have brought to light about our knowledge of HMXB, and which part of HMXB still remains mysterious.

Intensive programs, including imaging, photometry, low and high resolution spectroscopy, stellar spectra modeling, spectral energy distribution (SED) fitting, timing and interferometry, have shown that properties of HMXB are mainly dictated by the nature of their massive host stars. Imaging and photometry allow us to identify various types of HMXB; Low and high resolution spectroscopy, combined to stellar spectra modeling, lead us to derive accurate parameters of the companion star

(interstellar absorption, metallicity, rotation, gravity, etc); SED fitting gives us information on intrinsic absorption and characteristics of circumstellar enveloppe; Mid-infrared imaging allows us to explore the impact of these active stars on their environment; Timing brings us orbital and spin periods; and finally interferometry opens the way to directly imaging the dust cocoon surrounding HMXB…

The INTEGRAL satellite has launched the revival of HMXB studies, extending the population of supergiant HMXB (from only 5 in 1986 to nearly 35 today), revealing previously unknown highly obscured and transient HMXB (so-called supergiant Fast X-ray Transients, SFXT). The first detections of gravitational waves has boosted the interest of studying compact binaries hosting massive stars, obscured HMXB being candidate precursors of binary systems entering the common enveloppe phase.
Many questions are still pending, related to the accretion processes, the wind properties in these massive and active stars, and the overall evolution due to transfer of mass and angular momentum between the companion star and the compact object. We will see how future observations should be able to answer to these questions, which put together, constitute the mysterious part of HMXB.

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Neutron transfer reactions in accreting neutron stars

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I discuss a novel type of nuclear reactions in accreting neutron stars - neutron transfer, which is quantum tunneling of weakly bounded neutron from one nucleus to another. The rate of this process is estimated for fixed nuclei separation and then averaged over realistic distribution of nuclei to get the rate value for astrophysical conditions. It is shown that the neutron transfer can modify reaction chains in accreting neutron stars and affects their heating and cooling. In particular, it can suppress cooling by URCA pairs of nuclei, which is supposed to be crucial for the hottest neutron stars.

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Observations of highly magnetic neutron stars

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I will review the state of the art of strongly magnetic neutron stars, magnetars, from an observational perspective. In particular, I will focus on the prolonged outburst of the magnetar at the Galactic Centre, as well as the magnetar-like activity of the peculiar central compact object at the centre of the supernova remnant RCW 103. I will also report on the magnetar-like signatures recently discovered in a couple of thermally emitting isolated neutron stars. I will then present the results of the first systematic study of all magnetar outbursts observed over the past two decades.

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GW 170817 / GRB 170817A: results of follow-up observations and future perspectives

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The spectacular detection of the first electromagnetic counterpart of a gravitational wave event detected by the LIGO/Virgo interferometers and originated by the coalescence of a double neutron star system (GW 170817) marked the dawn of a new era for astronomy. The (weak) short GRB 170817A associated to the GW event provided the long-sought evidence that at least a fraction of short GRBs are originated by NS-NS merging and suggested the intriguing possibility that relativistic jets can be launched in the process of a NS-NS merger. A world-wide extensive observing campaign was launched across the electromagnetic spectrum leading to the rapid discovery of a bright UV/optical/NIR transient in the galaxy NGC 4993 (at ~40 Mpc). The wealth of data collected provided the first compelling observational evidence for the existence of "kilonovae", i.e. the emission due to radioactive decay of heavy nuclei produced through rapid neutron capture. A faint X-ray and radio counterpart was detected only at relatively late-times, suggesting for the possibility of off-axis GRB afterglow emission. The extensive follow-up campaign carried out at all wavelengths over almost a year probed the GRB emission geometry, providing clear evidence for a successful jet endowed with an angular energy profile, featuring a narrow and energetic core surrounded by a slower, less energetic layer/sheath/cocoon.
In this talk I will present a review of the steps that led to this epochal achievement and discuss the results, implications and future perspectives of electro-magnetic follow-up of GW events.

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MULTIWAVELENGTH VARIABILITY IN MSEC PULSAR BINARIES

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We will discuss the multi-band orbital variability and long-term behaviour of millisecond pulsar binaries particularly of redback systems and transitional millisecond pulsars in the rotation-powered state to understand the role of pulsar spin down power in the intrabinary shock emission and irradiation of the companion.

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Creation and dissipation of magnetic fields in the relativistic plasmas of compact objects

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Compact objects, and neutron stars in particular, are characterised by strong magnetic fields that are crucial to explain the high-energy emission from the sources. These magnetic fields may be subject to complex evolution inside the hosting relativistic plasma, like dynamo or chiral processes amplifying initial seed fields in early stages, or dissipative reconnection events in thin current sheets as believed to occur in the magnetospheres of magnetars. Here we present a unified treatment of these non-ideal effects within the framework of general relativistic magnetohydrodynamics (GRMHD) and numerical simulations obtained with the ECHO code will be shown for selected test cases.

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What can we learn about neutron star cores from gravitational waves?

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Neutron-star mergers can help us understanding what kind of matter exists in the core of compact stars, in addition to new states of matter generated during the events themselves. More specifically, gravitational waves from neutron-star mergers can tell us if quarks can exist in a deconfined way in our universe. Our results include possible signals for a strong deconfinement phase transition in merger simulations and, before that takes place, signals that can provide evidence for the strength and the role played by repulsive interactions in neutron stars.

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Differentially rotating neutron stars in alternative theories of gravity

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We will present the first numerical models of differentially rotating stars in alternative theories of gravity. More specifically, we will concentrate on a particular class of scalar-tensor theories that is indistinguishable from GR in the weak field regime but can lead to significant deviations when strong fields are considered. We show that the presence of scalar field significantly alters the structure and properties of neutron star models. Our findings can have important implication for the neutron star merger observations and the possibilities to further constrain the scalar-tensor theories of gravity

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Coherent polarisation effects in radio pulsars

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Observed radio pulsar polarization exhibits a range of complicated phenomena which cannot be explained by the rotating vector model. These include strong distortions of a polarization angle curve and high levels of circular polarization V. Properties of the circular polarization are quite peculiar: V tends to peak in coincidence with orthogonal mode transitions, and can have both signs within the same (single) orthogonal polarization mode. All these properties can be interpreted in terms of empirical model in which the observed polarization results from coherent addition of orthogonal polarization modes. The main model parameter is the relative phase lag and the amplitude ratio of the interacting modal waves. I will show what are the model's generic predictions for the pulsar polarization, and how these results compare with the well-known observations of complex pulsar polarization, e.g. the core-component polarization of B1237+25.

1

Time series of glitches in Neutron Stars

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Glitches are spin-up events that punctuate the smooth rotation of pulsars.
We analyze the glitch sizes $\Delta\nu$ and the times between consecutive events of the seven pulsars with more than 10 detected glitches.

The distributions of glitch sizes of the individual pulsars are different between them (and none of them resembles the global distribution of all known glitches). In particular, we find that both PSR B1737−30 and PSR J0631+1036 exhibit very similar distributions, which are best described by a power law with index $1.4(1)$. On the other hand, the glitch sizes of the Vela pulsar and PSR J0537−6910 are best described by Gaussian distributions centered at 21 and 15 μHz, and with dispersions of the order of 10 μHz. This range of glitch sizes does almost not overlap with the ranges covered by the other pulsars in the sample. PSR B1758−23 is the only pulsar with a size distribution described by and exponential function, and the size distribution of the Crab pulsar, and possibly PSR B1338−62, are best described by log-normal functions.

The distributions of times between consecutive glitches exhibit less variety and can be classified between Gaussian (the Vela pulsar and PSR J0537−6910) and exponential (all other pulsars). PSR J0537−6910 is the only pulsar that exhibits a significant correlation between glitch sizes and times to the next glitch. We used simulations to explore the possibility that other pulsars also have correlated glitches. Our conclusion is that the data are consistent with an scenario in which pulsars produce correlated glitches only above certain size and the smaller glitches are uncorrelated.

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Pulsar glitches

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In this talk I will summarize our current understanding of pulsar glitches based on analyses of recent data. Aspects such as glitch size distributions, the time series of glitches, glitch rates, and glitch activity will be reviewed; and some selected particular cases will be discussed.

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Crustal heating in accreting neutron stars

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X-ray observations of soft X-ray transients in quiescence suggest the existence of heat sources in the crust of accreted neutron stars. The heat is thought to be released by electroweak and nuclear processes triggered by the burying of ashes of X-ray bursts.

In this talk, the heating in the crust of accreting neutron stars will be discussed. In particular, the importance of nuclear physics inputs and the impact of the details of the nuclear structure (e.g. shell effects) on the crustal heating will be assessed. Indeed, we will show that the evolution of an accreted matter element and therefore the location of heat sources are governed to a large extent by the existence of nuclear shell closures. The question of the shallow heat sources will also be discussed.

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The asymmetric double neutron star system PSR J1913+1102

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PSR J1913+1102 is a double neutron star system (DNS) discovered with the Arecibo radio telescope in the PALFA survey. With previous observing campaigns, we have determined that with its short orbital period of less than 5 hours, it is one of the most relativistic DNSs known. We have precisely determined the individual masses, which are the most asymmetric among compact DNS binaries. In this talk, we address the potential impact of its evolutionary history on the interpretation of

observed DNS mergers such as GW170817, and the unique constraints it can provide on alternative gravitational theories.

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Neutron stars, neutron skin and mirror nuclei

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I will discuss whether correlations exist between the radius of neutron stars and various nuclear properties: nuclear parameters (symmetry energy, its slope, …), neutron skin of neutron-rich nuclei and the difference in the charge radius of mirror nuclei. I will in particular point out that a careful treatment of the crust of neutron stars is critical when looking for correlations between the properties of neutron stars and the ones of nuclei and nuclear matter.

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Exploring the GAIA view of Neutron Star High Mass X-ray Binaries

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High mass X-ray binaries (HMXBs) are binary systems formed by a compact object (either a neutron star (NS) or a black hole) accreting from a massive stellar companion. These objects have gained new attraction after the discovery of gravitational waves emitted in compact object mergers of binary black holes and neutron stars. HMXBs are thought to be progenitors of these systems, depending on several uncertainties in binary stellar evolution: particularly the strength of natal kicks in supernovae.
On 2018, April 22nd, Gaia Data Release 2 (DR2) was published, containing 1.7 billion stars. For 76% of the sources in the catalog, a five-parameter (5D) astrometric solution was obtained, including the position, parallax and proper motion. We cross-matched an updated list of HMXBs, finding 92 counterparts with good astrometry, previously unknown for these sources.
We used the 5D information from GAIA DR2 to study their peculiar velocities in the Milky Way, aiming to put constraints on the natal kicks experienced during the formation of the NS in these systems. We find that roughly 10% of the HMXB population shows a high peculiar velocity, incompatible with Galactic rotation, which we interpret as an indication of an strong kick. This part of the population includes HMXBs already classified as high-proper motion systems but, based on the proper motions derived from GAIA DR2 data, we were able to also reveal new sources and significantly increase the statistics.
We compare our velocity distribution with simulations of systemic velocities of HMXBs for different natal kicks of NSs and we discuss our results with other results coming from the pulsar population and NSs in low-mass X-ray binaries.

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Effects of Chiral Effective Field Theory Equation of State on Binary Neutron Star Mergers

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I will present fully general relativistic simulations of binary neutron star mergers employing a new zero-temperature chiral effective field theory equation of state (EOS), the Bombaci-Logoteta (BL) EOS, and compare with simulations using the older GM3 EOS, which is based on standard relativistic mean-field theory. I will provide a detailed analysis of the dynamics, with focus on the post-merger phase and on the properties of the post-merger remnant. For all models, I will show the gravitational wave strain and the post-merger frequency spectrum. I will also discuss the properties of ejected matter and of the resulting kilonova signals.

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Starquakes on millisecond pulsars and gravitational waves emission

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In accreting neutron stars (NSs), centrifugal forces can cause the failure of the crust. This event, called starquake, may produce a rotating mass quadrupole moment that allows the emission of gravitational waves (GWs). The angular momentum lost via GWs can balance the one gained from accretion, stopping the stellar spin-up. We use a Newtonian model, describing a compressible, stratified NS, to study the above physical picture. In particular, we calculate the breaking and equilibrium frequency for different EoS and masses. Furthermore, we estimate an upper limit for the ellipticity due to a sequence of starquakes. The study of the corresponding gravitational waves emission allows us to discuss their detectability.

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Core-crust transition and properties in neutron stars

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A precise determination of the core-crust transition is necessary when modelling neutron stars for astrophysical purposes.
The core-crust transition in this work is studied with finite-range nuclear interactions using the dynamical approach for detecting the instability of the matter in the core against density perturbations. Also, we analyze the correlation of the transition properties, such as the density and pressure, with the slope of the symmetry energy associated to the nuclear equation of state. Finally, knowing the core-crust transition point for these finite-range forces, we obtain their relation between the neutron star masses and radii, predictions of the mass and thickness of the neutron star crust, as well results for the tidal deformability in binary neutron stars.

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Low-frequency radio observations of gravitational wave merger events and GRBs with LOFAR

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On 17 August 2017, gravitational waves (GWs) from a binary neutron star inspiral (GW170817) were detected for the first time, by the Advanced LIGO and Advanced VIRGO GW detectors. This triggered an observing campaign of unprecedented scale that covered the full electromagnetic spectrum and launched the era of multimesseneger astronomy. Ongoing monitoring of the radio emission in particular, which traces the high-velocity ejecta from the merger, has proven to be instrumental in discriminating between models of the merger event. Here, I outline the LOFAR rapid response and follow-up strategy of compact merger events such as GW170817, in particular making use of the telescope's very large instantaneous field of view. I will describe the various relevant emission mechanisms and what is required in order to detect them using LOFAR. I will present initial LOFAR results from gravitational wave events. I also show how our LOFAR strategy can be applied to rapidly respond to GRBs and place constraints on the possible existence of a neutron star central engine in some cases. Finally, I present our results for long GRB 180706A.

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Magnetic Field Evolution in Neutron Stars

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I will review the ideas behind neutron star magnetic field evolution. The magnetic field of neutron stars can evolve in short (~seconds) and long (~kyr) timescales. The former is manifest in magnetar explosive activity, while the latter is most likely related to persistent thermal emission from strongly magnetised neutron stars. We can distinguish three main regions where magnetic field evolution occurs: the core, the crust and the magnetosphere. In this talk, I will focus primarily in the crust. Crustal magnetic field can evolve via the conservative Hall effect and Ohmic dissipation. These phenomena typically take kyr-long timescales to lead to a drastic change of the magnetic field structure and power thermal emission via magnetic field decay. They can also push the crust and the magnetosphere into unstable states and trigger explosive events. Moving from axisymmetric to three-dimensional studies a rich phenomenology is revealed, with the creation of complex structures in the form of spots and magnetic field arcades. Finally, I will discuss the range of applicability and the limitations of this approach.

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Probing the neutron star equation of state with gravitational waves: higher-order tidal terms in compact binary waveforms

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Gravitational waves from compact binaries are probably the most promising probe of the behaviour of matter in the inner core of neutron stars. Recently the tidal deformability of neutron stars has been measured by LIGO/Virgo, leading to a reliable estimate of the radius and to constraints on the equation of state. I will discuss how these measurements can be made more accurate, providing valuable information on the neutron star equation of state, including higher-order tidal terms in the gravitational wave template.

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r-process nucleosynthesis from matter ejected in binary neutron star mergers

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We perform full GR simulations of binary neutron-star mergers employing three different nuclear-physics EOS, considering both equal- and unequal-mass configurations, and adopting a leakage scheme to account for neutrino radiative losses. Using a combination of techniques, we carry out an extensive and systematic study of the hydrodynamical, thermodynamical, and geometrical properties of the matter ejected dynamically, employing a nuclear-reaction network to recover the relative

abundances of heavy elements produced by each configurations. Three results are particularly important. First we find that within the sample considered here, both the properties of the dynamical ejecta and the nucleosynthesis yields are robust against variations of the EOS and masses. Second, using a conservative but robust criterion for unbound matter, we find that the amount of ejected mass is less than 1e-3 solar masses, hence at least one order of magnitude smaller than the standard assumptions in modelling kilonova signals. Finally, using a simplified and gray-opacity model we assess the observability of the kilonova emission, finding that for all binaries the luminosity peaks around ~1/2 day in the H-band, reaching a maximum magnitude of -13, and decreasing rapidly after. Supported by European Research Council Grant No. 677912 EUROPIUM

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Magnetic field amplification in proto-neutron stars

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Extremely strong magnetic fields of the order of 10^15 Gauss are required to explain the properties of magnetars, the most magnetic neutron stars. Such a strong magnetic field is expected to play an important role for the dynamics of core-collapse supernovae, and in the presence of rapid rotation may power superluminous supernovae and hypernovae associated to long gamma-ray bursts. The origin of these strong magnetic fields remains, however, obscure and most likely requires an amplification over several orders of magnitude in the protoneutron star. I will review our current understanding of the physical processes that may lead to this magnetic field amplification, including the magnetorotational instability and the convective dynamo.

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X-ray pulsation searches from neutron stars with NICER

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The Neutron Star Interior Composition Explorer (NICER) has been in operation from the International Space Station since June 2017. One of its key science goals is the search for X-ray modulations from a variety of neutron star classes. To achieve this, NICER offers new capabilities in the soft X-ray band, namely, high effective area, precise timing (~100 nsec), and flexible scheduling. The working group on Pulsation Searches and Multiwavelength Coordination had prepared a list of a few tens of sources to observe, for a total of 2.5 Ms. Among them were known neutron stars (e.g., radio pulsars) or potential neutron stars (e.g., Fermi sources). On behalf of this working group, I will present the results of these pulsation searches among millisecond pulsars with suspected surface thermal emission, isolated neutron stars, low-mass X-ray binaries, ultra-luminous X-ray sources, accretion-powered pulsars, and other types of X-ray sources.

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On the effect of microphysics inputs on the dynamics of supernova core-collapse

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The importance of microphysical inputs from laboratory nuclear experiments and theoretical nuclear structure calculations in the understanding of the core collapse dynamics, and the associated neutrino luminosity, is largely recognized in the recent literature.

Different recent sensitivity studies [1,2] have shown that mass models, electron capture rates, and the equation of state can all play a role in the determination of the electron fraction evolution and the dynamics of the shock formation.

In this work, we analyze independently the effect of
(i) the mass model and the possible quenching of magicity of neutron rich nuclei,
(ii) the use of realistic nuclear rates based on large scale shell-model calculations
(iii) the account of the full nuclear distribution beyond the single-nucleus approximation.
The independent variation of the different quantities is made possible by the use of a recently developed method [3] to calculate the nuclear distribution associated at finite temperature to any given equation of state of stellar matter based on the Wigner-Seitz approximation.

Simulations are performed within a general relativity collapse code in spherical symmetry with a multi-group treatment of neutrinos, using a simplified leakage scheme [4].
Our results indicate that the use of a realistic nuclear distribution and of up-to-date capture rates on exotic nuclei is essential to produce reliable results, while the simulations are relatively robust with respect to the other poorly constrained part of the nuclear interaction.

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Magnetic field evolution in superconducting neutron stars

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In our recent work [Gusakov et al. PRD, 96, 103012, (2017); Ofengeim & Gusakov, PRD, 98, 043007 (2018)] we have proposed and developed a new method to self-consistently

study the quasistationary evolution of the magnetic field in the cores of normal (nonsuperfluid) neutron stars. Most interestingly, we found that a general configuration of the stellar magnetic field induces macroscopic fluid motions in the core, which can exceed the diffusion particle velocities, and hence dramatically accelerate the evolution of the magnetic field. In my talk, I will discuss how (and whether) these results can be extended
to superfluid and superconducting neutron stars. New timescales for the magnetic field evolution will be identified and confronted to observations.

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Pulsar Magnetospheres and High-Energy Emission

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Recent progress in global simulation of pulsar magnetospheres is changing our models of pulsar particle acceleration, cascade pair production and high-energy emission. Simulation of a force-free pulsar magnetosphere 15-20 years ago marked a major advance in understanding the current closure and the structure of the wind. The first simulations of dissipative MHD pulsar magnetospheres with finite conductivity opened the door to modeling particle acceleration and radiation on a global scale. For simulations having very high conductivity, as would be expected for young and energetic pulsars, most of the high-energy emission comes from outside the light cylinder near the current sheet. Most recently, particle-in-cell simulations that couple particle dynamics to field structure are the next step in self-consistent pulsar magnetosphere modeling. The radiation characteristics in models based on these simulations match those of gamma-ray pulsars detected by Fermi. The next steps toward a full pulsar magnetosphere model will require global simulations coupled to pair cascade microphysics.

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Fast radio bursts

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Fast radio bursts (FRBs) are millisecond-duration radio flashes, apparently originating at cosmological distances. As such, FRBs promise to provide a new view of extreme astrophysics in action - with, e.g., potential insights into the deaths of massive stars, particle acceleration, and the properties of the intergalactic medium. While some FRBs may be associated with cataclysmic astrophysical explosions, there are also repeating FRBs, like FRB 121102, whose origin requires a more long-lived progenitor. FRB 121102 has been localized to an intense star-forming region in a dwarf galaxy at redshift z = 0.19. It is also associated with a persistent radio source and inhabits an environment of extreme magnetic field. The short durations of the bursts themselves argue that a neutron star is the likely source, but understanding how such a source can be visible at about 3 billion light years distance remains a puzzle. Perhaps FRB 121102 has a very different origin, and even its relation to the apparently non-repeating FRB population is still unclear. Here I will

present an overview of the FRB phenomenon, focusing on the observational facts to date, and my own work on FRB 121102.

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New constraints on physics of NSs from parallaxes and proper motions

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Using the most precise interferometric measurements of parallax and proper motion together with the rigorous statistical methods, we refined the natal kick velocity distribution for the neutron stars. The proper modelling of the natal kicks is essential to understand the formation of X-ray binaries, millisecond radio pulsars and double neutron stars (gravitational wave sources). We have found that the velocity distribution is bimodal: 42% of NSs receives the natal kicks with the standard deviation of 75 km/s and 58% with the standard deviation of 316 km/s. Using this natal kick distribution, we derived the Bayesian posteriors for kinematic ages for a large sample of young neutrons stars and found that the long-term magnetic field decay cannot occur on timescales shorter than 8 Myr, and it seems to happen on timescales of 12 Myr or longer.

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Evidence for magnetospheric effects on the polarized radiation of pulsars

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It is known that the radio signals of pulsars are highly linearly polarized, with the position angle (PA) of many pulsars changing across rotational phase in a way which is well described by the Rotating Vector Model (RVM). When the pulsar radiation propagates through the magnetized interstellar medium, it is affected by Faraday rotation. This results in a rotation of the plane of linear polarization as a function of observing wavelength, with a constant of proportionality known as the Rotation Measure (RM). If Faraday rotation is the only source of frequency dependence of the PA, we expect the derived RM to be independent of the rotational phase of the pulsar. However, for a small number of pulsars it has been observed that the phase-resolved RM varied, due to additional frequency dependencies affecting observed polarization. Until now, these additional frequency dependencies have been attributed to interstellar scattering. We have conducted the largest investigation to date into the origin of the frequency dependencies of polarized signals in radio pulsars, and showed that internal effects caused by the pulsar magnetosphere can play an important role as well, and sometimes even dominate.
Furthermore, we observe a clear correlation between the complexity of pulse shapes and the degree of RM variability, something inconsistent with an interstellar origin of the polarization variability. It is likely that, given sufficient signal-to-noise, such effects will be present in all radio pulsars. Our results imply that the frequency dependence of polarization gives a new way to probe the complex processes operating in pulsar magnetospheres.

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Probing neutron star interiors via pulsar inclination angles

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A newly born magnetised neutron star can undergo free precession if its spin and magnetic axes are misaligned. The magnetic axis can then either tend to align or become orthogonal to the spin axis, depending upon a delicate interplay of magnetic spin-down torques and internal viscous dissipation. In this talk I will describe our modelling of this process, and how the distribution of pulsar magnetic inclination angles can potentially constrain neutron star interiors.

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General Relativistic Magnetohydrodynamic Simulations of Binary Neutron Star Mergers

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Recent detection of gravitational waves (GWs) from the merger of two neutron stars (NSs) by the Advanced LIGO-Virgo interferometers also accompanied by the observation of electromagnetic (EM) counterparts across the entire spectrum has opened the new field for multimessenger astrophysics with GW sources. Binary neutron star (BNS) merger events can be used as a laboratory to investigate the NS equation of state (EOS), short gamma-ray bursts (SGRBs), and kilonova/macronova transients associated with the r-process nucleosynthesis of very heavy elements. General relativistic (GR) numerical simulations play a pivotal role to investigate the merger process. Moreover, to incorporate the crucial effects of magnetic fields, very challenging GR magnetohydrodynamics (GRMHD) simulations are necessary. In this work, we perform GRMHD simulations of BNS mergers using the numerical relativity codes Einstein Toolkit (ET) and WhiskyMHD. In particular, we consider magnetized and unmagnetized irrotational BNS models with different mass ratios, a fixed chirp mass, and the APR4 equation of state for NS matter. For all our models, we study in detail the overall dynamics, the magnetic field evolution, the GW emission, and the matter ejection.

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r-modes in rapidly rotating neutron stars

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In this talk I will discuss recent progress in r-mode physics. r-modes attract attention of neutron-star community since 1998 when it was realized that they should be unstable in rotating neutron stars due to radiation of gravitational waves. Various dissipative mechanisms stabilize r-modes in a wide range of parameters, so that r-mode instability can potentially take place only in sufficiently hot and rapidly rotating neutron stars,
in the so-called "instability window". Even being unstable r-mode may saturate at very low, negligible, amplitude, as some authors predict. I will review possible dissipative and saturation mechanisms, which could be relevant to r-modes. I will also discuss how the r-modes can show up in observations and what we can learn confronting observations of rapidly rotating neutron stars with the r-mode theory.

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Neutron Star Science with the Square Kilometre Array

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In this talk I will give an overview of the Square Kilometre Array (SKA) and describe what it will do for neutron star science. The SKA is a project to build the largest radio telescope in the world and is currently in the final stages of its design. When constructed and operational it will focus on several scientific priorities, and chief amongst these is the study of neutron stars. The pulsar search system has been designed to be particularly capable at finding pulsars in binary systems. The SKA will be able to detect all radio pulsars in the Milky Way that are beamed towards Earth, perhaps numbering as many as 40 thousand. In the SKA's smaller initial deployment the expected yield is approximately 10 thousand, ~4 times the currently known population. The resultant population will then be studied using pulsar timing techniques to determine (i) many more precise mass measurements; (ii) moment of inertia measurements in short orbital period binaries; (iii) ever more neutron stars spinning at rates >500 Hz; (iv) the properties of glitches. Together these provide vital information on the neutron star equation of state, the physics of ultra-high density environments impossible to create in an Earth-bound laboratory, high density superfluidity, the physics of supernovae, and much more besides.

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Studying Neutron Stars with long-duration gravitational wave transients

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Neutron Stars can emit gravitational waves on many different timescales, ranging from milliseconds to the quasi-permanent continuous wave regime. Among the signals accessible to ground-based detectors, long-duration transients are among the least studied, and searching for them poses many practical challenges. Interesting sources of such transients are both newborn compact objects (including remnants of mergers like GW170817) as well as mature NSs disturbed by energetic transient events such as pulsar glitches, type I X-ray bursts and magnetar bursts. I will talk about these source types, current search methods, their application to data from LIGO's second observing run, how such

searches can be improved with constraints from modeling advances and electromagnetic observations, and what they can contribute to determining the inner structure and dynamics of neutron stars.

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On the possibility of registering X-ray flares related to fast radio bursts with the eROSITA telescope

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We discuss the possibility of detecting associated X-ray emission from sources of fast radio bursts with the eROSITA telescope onboard the Spektr-RG observatory. It is shown that during the four years of the survey program, about 300 bursts are expected to appear in the field of view of eROSITA. About 1% of them will be detected by ground based radio telescopes. For a total energy release $\sim 10^{46}$ ergs, depending on the spectral characteristics and absorption by the interstellar and intergalactic media, an X-ray flare can be detected from distances from ~ 1 Mpc (thermal spectrum with $kT = 200$ keV and strong absorption) up to ~ 1 Gpc (power-law spectrum with photon index $\Gamma = 2$ and realistic absorption). Thus, eROSITA observations will help to provide important constraints on the parameters of sources of fast radio bursts, or may even allow identification of X-ray transient counterparts, which will help to constrain models for the generation of fast radio bursts.

22

Testing theories of gravity with pulsars

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We are living in a golden era for testing gravitational physics with precision experiments. This talk will give a status of the field using a variety of tests with radio pulsars. It will highlight the use of multi-messenger information, which allows us to place the results in context of other experiments (including LIGO, EHT, etc). I will demonstrate how pulsars continue to provide unique constraints on gravity and fundamental physics in general, and how they complement other methods.

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Magnetic-field evolution and plastic flow in a neutron star's crust

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Stresses build up in a neutron star's crust as its magnetic field evolves, until the crust eventually yields. This occurs as a plastic deformation, and is believed to be responsible for coronal activity from magnetars. Existing simulations of crustal magnetic-field evolution assume, however, that the crustal lattice is fixed and never yields, meaning that the field evolves only under the processes of Hall drift and Ohmic decay. Here we present the first simulations which solve for the plastic flow that occurs when magnetic stresses become too large to be sustained, and the effect of this flow on the crust's magnetic-field evolution.

18

The intriguing journey towards the Continuous Gravitational-Wave detection

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Following the discoveries of transient gravitational-wave signals, more efforts and resources have been employed to detect continuous gravitational waves (CWs). These faint signals are emitted by asymmetric and quickly rotating neutron stars, both isolated and in binary systems, and are among the most interesting targets of the Advanced LIGO-Virgo detectors.
The search for this kind of signals is challenging due to their expected weakness, and can be very computationally expensive when the source parameters are not known or not well constrained.
The CW detection will allow us to characterize the emitting source for long times, better constraining its time-varying properties, and possibly test theories of gravity alternative to General Relativity. In addition, such a new kind of detection will give us insights to deeply study the physics of matter at supranuclear density and in presence of ultra-strong magnetic fields.
Although to date no direct CW detection can be claimed yet, we have been able to reach marvelous results and stringent upper limits on the CW amplitude strength.
I will present the methodologies used in CW searches and some remarkable results from the advanced LIGO-Virgo most recent observational runs.

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Fat and sexy: Massive pulsars in compact binaries

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The maximum mass of a neutron star constrains the properties of ultradense matter and the possible outcomes of double neutron star mergers. Compact binary millisecond pulsars (with orbital periods shorter than about a day) are a rapidly-growing pulsar population, and provide a good opportunity to search for the most massive neutron stars. Because their main sequence companion stars are faint and irradiated, accurate mass measurements in these systems require large optical telescopes. We present observations and detailed modeling of an extremely irradiated companion to a millisecond pulsar. We apply a

new method to measure the velocity of both sides of the companion star, and find that the binary hosts one of the most massive neutron stars known to date, with a mass of 2.27 [+0.17-0.15] Msun. A 2.3 Solar-mass neutron star would rule out most currently proposed equations of state, casting doubt on the existence of exotic forms of matter in the core.

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A new zero and finite temperature EOS for nucleonic and hyperonic matter from microscopic calculations

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I will report on the calculation of a new equation of state (EOS) derived from Chiral Effective Field Theory (ChEFT) for nucleonic and hyperonic matter. A new feature of this EOS is the inclusion in a consistent way of the effect of hyperonic three-body forces.
I will focus in particular on the three-body force originating from the interaction between two nucleons and a Λ-hyperon (NNΛ). Such interaction has been recently derived in the framework of ChEFT at next-to-leading order (NLO). Using the many-body non relativistic Brueckner-Hartree-Fock (BHF) approach, I will discuss the calculation of the β-stable equation of state (EOS) of neutron star matter including realistic nucleon-nucleon (NN), nucleon-nucleon-nucleon (NNN), nucleon-hyperon (NY) and nucleon-nucleon-hyperon (NNY) interactions. I will show the resulting neutron stars structure. I will finally discuss the inclusion of thermal effects necessary for consistent binary neutron star merging simulations as well as for the study of core collapse supernovae.

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Electromagnetic signatures of neutron star mergers

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Observations and theoretical modelling of the first confirmed neutron star merger event, GW170817, have allowed us to probe for the first time the electromagnetic signatures of this catastrophic event. I will present an overview of the extensive multi-wavelength follow-up that was obtained for the 'kilnova' event that occurred with GW170817 (and any others that may have occurred by the time of this meeting!). I will highlight the major results of these studies and the many outstanding questions that remain. I will also discuss the leading European electromagnetic follow-up campaign for gravitational-wave sources, ENGRAVE, that is currently operating at European Southern Observatory facilities in Chile. The aim of ENGRAVE is to study the diversity of neutron star mergers and give insights into the yields of heavy elements, as well as measure the structure of their jets, how they produce gamma-ray signals, and how these events can be used to measure distances in the Universe.

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How well does neutron star mergers constrain the equation of state of dense matter?

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The detection of gravitational waves from the neutron-star merger GW170817 provided the first firm observational constraint on the radius of neutron stars—nature's densest visible objects. We find that modern nuclear-physics-based calculations of the equation of state of dense neutron-rich matter predict radii that are compatible but more restrictive. We critically examine associated uncertainties and determine how improved constraints from future observations can provide new insights into dense matter and possible phase transitions in the neutron-star core.

4

Evidences of non-conservative mass-transfer in AMXPs

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Since 1998, when the discovery of the first Accreting Millisecond X-ray Pulsar (AMXPs) SAX J1808.4-3658 occurred, the family of these sources kept growing on. Up to now, it counts 22 members, object of several studies due to the interesting, and sometimes puzzling, behavior shown by some of them. All AMXPs are transients with usually very long quiescence periods, implying that mass accretion rate in these systems is quite low and not constant. Moreover, for some of these sources, a non-conservative mass-transfer scenario, i.e. the case where only a fraction of the transferred mass is effectively accreted onto the neutron star, was proposed.

We tried to demonstrate that a non-conservative scenario is necessary to explain the low averaged mass-accretion rate in three AMXPs: XTE J0929-314, IGR J17498-2921 and XTE J1814-338. The method used consists in calculating the expected mass-transfer rate under the hypothesis of a conservative evolution, based on their orbital periods and the mass of the secondary (as derived by the mass function). Depending on the mass of the secondary, we considered this mass-transfer as driven by gravitational radiation only or also by magnetic braking. Using this theoretical mass-transfer, we determined the accretion luminosity of the systems. Then, we compared this luminosity to the X-ray flux observed from the systems, averaged over the time elapsed since their discovery. This comparison gives a lower limit to the distance of the sources, which might be compared to the value of the distance reported in literature in order to evaluate how reasonable is the hypothesis of a conservative mass-transfer. If else the distance of the source is not known, as in the case of XTE J0929-314, the level of "unlikeliness" of the distance estimate determined by this method was used as a test for the unlikeliness of the whole conservative mass-transfer scenario.

The distance for XTE J0929-314 is shown to be >7.4 kpc in the direction of the Galactic anticentre, implying a large height, >1.8 kpc, of the source with respect to the Galactic plane, placing the source

in an empty region of the Galaxy (*Marino et al., 2017*). For the other two sources in the sample, the lower limits on the distances estimated, i.e. of 10 kpc for IGR J17498-2921 and 22 kpc for XTE J1814-338 (*Marino et al., 2018*, submitted to A&A), are higher than and not compatible within the error with the known distances of both sources. These problems can be solved under the hypothesis of a non-conservative mass-transfer in which a fraction of the mass accreted onto the compact object is swept away from the system, likely due to the (rotating magnetic dipole) radiation pressure of the pulsar.
With this argument, the count of AMXPs showing non-conservative mass-transfer becomes 6 over the 22 sources discovered so far, confirming that this phenomenon might be quite common in this class of systems.

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Bayesian two-sample test for the mass distribution of neutron stars in binary systems and glitchers

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In the interior of a mature neutron star, the differential rotation of the neutron superfluid star with respect to the normal component allows to store angular momentum, which is released during a pulsar glitch. Recent studies show how it is in principle possible to estimate pulsar masses from observations related to their timing properties. In this talk we will compare the mass estimates made with this method with the masses of neutron stars in binary systems, measured with standard observational techniques. In particular, we conduct a Bayesian analysis to test if the two samples come from the same underlying statistical distribution. We consider different samples of measured masses, according to whether they have undergone accretion or not, in order to test if glitchers are close to their birth mass. Finally, we also test different models for the theoretical mass estimate of the pulsars, by employing equations of state with different stiffness or limiting the superfluid reservoir to a small spherical layer.

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Discovery of a 12-second radio pulsar and optimally searching for the slowest pulsars in the Galaxy

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We will present the latest data on PSR J2251−3711, a radio pulsar with a 12.1-second spin period discovered in the SUPERB survey at Parkes. Combined with the recent unexpected discovery of PSR J0250+5854, which has an even longer 23.5-second spin period, the possibility of finding even slower radio emitting pulsars is now wide open. Not only do these objects challenge our understanding of when radio emission should cease, but their evolutionary history is also a matter of debate. Discovering more slow pulsars will be useful in understanding the links between all the classes of isolated neutron stars. But we need the proper searching arsenal to find them.

The Fast Folding Algorithm (FFA) is a fully phase-coherent search technique for periodic pulsar signals. It has historically seen limited use on large scale surveys, having been supplanted by more computationally efficient Fast Fourier Transform (FFT). We have however demonstrated analytically that a properly implemented FFA is several times more sensitive to the shorter pulse duty cycles (<1%) expected from the slow pulsar population, which has therefore been significantly under-explored until now. We have developed a fast end-to-end FFA search code that we are currently running on the SUPERB and the LOFAR Tied-Array All-Sky (LOTAAS) surveys: we will report on these ongoing searches and advocate running the FFA on all available data.

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The abundance and disorder of nuclear pasta from quantum simulations

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We present the most extensive set of 3D, microscopic quantum calculations of nuclear pasta to date, under conditions relevant to the crusts of neutron stars, and spanning the current uncertainty in nuclear models. We show that quantum shell effects and the small differences in surface energies of different pasta configurations lead to a large number of local minima in their energy surfaces at a given density. The minima are separated by barriers of order 10keV. As the crust freezes, we estimate that pasta freezes into microscopic domains of order tens of lattice spacings or less, likely leading to an enhanced electrical and thermal resistivity from electron scattering on domain boundaries. We find pasta phases are predicted to occur at lower densities than typically estimated, around one-quarter nuclear saturation density, and that they initially they coexist with spherical nuclei. We show that it is a robust prediction that pasta accounts for around 70% of the crust mass and moment of inertia, and 25% of its thickness.

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Neutrino-nucleon interactions in dense and hot matter

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Neutrinos play an important role in compact star astrophysics: neutrino-heating is one of the main ingredients in core-collapse supernovae, neutrino-matter interactions determine the composition of matter in binary neutron star mergers and have among others a strong impact on conditions for heavy element nucleosynthesis and neutron star cooling is dominated by neutrino emission except for very old stars. Many works in the last decades have shown that in dense matter medium effects considerably change the neutrino-matter interaction rates, whereas many astrophysical simulations use analytic approximations which are often far from reproducing more complete calculations. In this talk I will present a scheme which allows to incorporate improved rates into simulations and show as an example some results for core-collapse supernovae.

83

R-mode instability windows for realistic models of hyperon stars

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One of the promising solutions to the r-mode stability problem is to account for hyperons in the deepest layers of neutron stars (NSs). The presence of hyperons allows for a set of powerful non-equilibrium (lepton-free) reactions, which can dramatically increase the NS bulk viscosity, and thus suppress the r-mode instability. Modern equations of state, calibrated to the up-to-date hypernuclear data, predict that hyperons are mainly presented in the form of Λ's and Ξ^-'s (Σ^-'s are optional), while all the existing calculations of non-equilibrium reaction rates have been performed for $\Sigma^-\Lambda$ hyperonic composition.

In the present work we fill this gap by calculating the bulk viscosity for $npe\mu\Lambda\Xi^-$ matter. A number of viscosity-generating non-equilibrium reactions is considered, some of them have never been studied in the neutron-star literature before. The calculated reaction rates and bulk viscosity are approximated by simple analytic formulae, in order to facilitate their use in applications. We also calculate the instability windows for several NS models with modern equations of state and for a set of NS masses. We argue that, even within conservative assumptions about the superfluid properties of baryonic matter, the calculated bulk viscosity allows one to explain observations of many rapidly rotating NSs in low-mass X-ray binaries.

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Gravitational waves from neutron star mountains

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Many LMXBs are spinning within a narrow frequency range, considerably lower than the neutron star break-up frequency. Gravitational wave emission might account for this observed maximum spin cap. For an isolated neutron star to emit gravitational waves, it must deform from its axial symmetry to produce a time-varying gravitational field. One way this can occur is through the development of a misaligned quadrupole moment. A quadrupole moment or 'mountain' can develop if temperature asymmetries exist in a neutron star crust. We are investigating how temperature asymmetries can develop through deep crustal heating via accretion and the role the magnetic field plays in the thermal conductivity of the crust.

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Studying the Neutron Star Interior in Transient Low-Mass X-Ray Binaries

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Neutron star low-mass X-ray binaries with transient accretion are unique systems to study the interior of neutron stars. During the accretion phase the crust of the neutron star is strongly heated and most of this heat flows into the core. During the quiescence phase the star relaxes back to thermal equilibrium and observation of this phase allows to map the physical properties of the stellar crust. Long term evolution also gives information about the core properties as its neutrino emission efficiency and its specific heat. In contradistinction to gravitational wave signals from mergers and mass or mass-radius determinations that are mostly sensitive to bulk properties of dense matter, such studies allow us to probe the low energy excitation levels of this matter. I will review what has been learned from these studies in the last few years by the study of almost a dozen such systems.

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The magnetic field role in low mass X-ray binaries

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The magnetic field of most of the neutron stars in low mass X-ray binaries are much weaker than in younger systems such as neutron stars with a high mass companion, magnetars and most of the radio pulsars. Nonetheless, even a low magnetic field may have a significant impact on the flow of matter transferred by the companion star: plasma is either accreted or ejected depending on the balance between the infalling matter and the pressure of the electromagnetic field and radiation emitted by the neutron star. A class of recently discovered transitional millisecond pulsars showed that a single source can
switch between different states over a few days or even less, following variations of the mass inflow rate. I will review the rich and complex phenomenology of low-magnetic field pulsars in X-ray binaries, highlighting lessons learned and problems yet to be solved.

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Pulsar gamma-ray emission in the radiation reaction regime

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Since the era of the Fermi/LAT and atmospheric Cerenkov telescopes, pulsars are known to emit high and very high-energy photons, in the MeV-GeV range and sometimes up to TeV. To date, it is still unclear where and how these photons are produced. Nevertheless gamma-ray photons require particle acceleration to ultra-relativistic speeds. In this talk, we compute single particle trajectories for leptons in an arbitrary strong electromagnetic field in the so-called radiation reaction limit. In this picture, particle velocity only depends on the local electromagnetic field which we assume to follow the vacuum dipole rotator. From this velocity field, we compute the curvature radiation spectrum and light-curves. Sky maps and phase-resolved spectra are then deduced accounting for realistic pulsar periods and magnetic field strengths. Emission sites within the pulsar magnetosphere where most of radiation emanates are then localized. For standard parameters of millisecond and normal pulsars, we show that a break in the spectrum occurs at several GeV in agreement with the

Fermi/LAT second pulsar catalogue. A sample of representative phase-resolved spectra and sky-maps are shown. A pair multiplicity of several tenths to several thousands is required to account for the total gamma-ray luminosity. Moreover depending on the geometry, single or double-peaked light-curves are found. Our model shows that minimalist assumptions are already able to reproduce salient features of pulsars emission characteristics.

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A method for directed searches of continuous gravitational waves in advanced detector data

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Continuous waves (CW) are still undetected gravitational wave signals emitted by rotating neutron stars, isolated or in binary systems. The estimated number of isolated neutron stars in our Galaxy is 10^8-10^9. Information provided by electromagnetic observations is crucial to constrain the signal parameter space, lower the computational cost of a CW search and increase the number of potential targets. Accordingly to the information available about the source, different searches can be set up. In this work we present prospects for the directed search of CW signals in advanced LIGO-Virgo data using the BSD-directed search method. A list of potentially interesting sources, which are present in the main astronomical catalogues, along with some young supernova remnants, is investigated and theoretical indirect upper limits are computed when possible. Estimate of the computational power needed to perform a directed search for the selected sources is also provided.

11

How to make a mature accreting magnetar

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Several candidates for accreting magnetars have been proposed recently by different authors. Existence of such systems contradicts the standard magnetic field decay scenario where a large magnetic field of a neutron star reaches a few $\times 10^{13}$ G at agees $>$ Myr. Among other sources, the high mass X-ray binary 4U0114+65 seems to have a strong magnetic field around 10^{14} G. We develop a new Bayesian estimate for the kinematic age and demonstrate that 4U0114+65 has kinematic age 2.4-5 Myr since the formation of the neutron star. We discuss which conditions are necessary to explain the potential existence of magnetars in accreting high-mass binaries with ages about few Myrs and larger. Three necessary ingredients are: the Hall attractor to prevent rapid decay of dipolar field, relatively rapid cooling of the crust in order to avoid Ohmic decay due to phonons, and finally, low values of the parameter Q to obtain long Ohmic time scale due to impurities. If age and magnetic field estimates for proposed accreting magnetars are correct, then these systems set the strongest limit on the crust impurity for a selected sample of neutron stars and provide evidence in favour of the Hall attractor.

We also propose that recently discovered radio pulsar J0250+5854 with 23.5 sec spin period is presently at the Hall attractor stage. This can explain low temperature and absence of magnetar-like activity

of this source together with its spin period and period derivative. We present results of calculations of the evolution of this source in a simple model of magnetic field decay. The neutron star could start its evolution as a magnetar with initial field $\sim 10^{14}$–10^{15} G for realistic range of parameter Q describing crust imperfections. Future measurements of surface temperature and age of this neutron star might help to probe this hypothesis.

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Is SAX J1808-3658 an hyperonic star?

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We analyse the effect of the density dependence of the symmetry energy on the hyperonic content of neutron stars within a relativistic mean field description of stellar
matter. For the Λ-hyperon, we consider parametrizations calibrated to Λ-hypernuclei. For the Σ and Ξ-hyperons uncertainties that reflect the present lack of experimental information on Σ and Ξ-hypernuclei are taken into account. We perform our study considering nuclear equations of state that predict two solar mass stars, and satisfy other well settled nuclearmatter properties. The effect of the presence of hyperons on the direct Urca processes and the cooling of accreting neutron stars are discussed. The density dependence of the symmetry energy affects the order of appearance of the different hyperons, which may have direct implications on the neutron star cooling as different hyperonic neutrino processes may operate at the center of massive stars. For models which allow for the direct Urca process to operate, hyperonic and purely nucleonic ones are shown to have a similar luminosity when hyperons are included in agreement with modern experimental data. It is shown that for a density dependent hadronic model constrained by experimental, theoretical and observational data, the low-luminosity of SAX J$1808.4-3658$ can only be modelled for a hyperonic NS, suggesting that hyperons could be present in its core.

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How the bulk properties of nuclear matter influence neutron star observables?

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Description of dense nuclear matter rely on the experimental constraints
coming from the properties of "normal" nuclear matter found in nuclei and
observational data from neutron stars which consist of ultra dense nuclear matter.
In this presentation I show how the parameters of nuclear matter (effective nucleon mass, compressibility, and proton neutron asymmetry) influence the properties of neutron stars by using multiple Walecka type models with different scalar self interaction terms.
In relativistic mean field theories of nuclear matter the values of the Landau mass and nucleon effective mass are not independent hence they can not be fitted in a given model simultaneously, which gives at least two different parametrization of the same model.

The effect of this ambiguity on neutron star observable is studied by solving The Tollmann-Oppenheimer-Volkov equations using these different parametrizations. The sensitivity of the M-R diagram to different parametrizations of a given model is also
studied especially in the case of maximum mass neutron stars.

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Uncovering the Pulsating Ultra Luminous X-rays sources (PULXs) Population with Data Mining and the UNSEeN Project

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The discovery of Ultraluminous X-ray Sources (ULXs) showing fast and rapidly evolving pulsations (PULXs) unambiguously associated
these sources to neutron stars (NSs) exceeding up to more than 500 times their Eddington Luminosity . These discoveries challenge our
understanding of accretion physics and pose a key question about the nature of the ULXs as a class, thought to represent the population
of extragalactic intermediate-mass or stellar-mass black holes (BH) until few years ago. Shaping the number and properties of of this new
class of NSs, and understanding the way they evolve and work is therefore also important for the understanding of the ULXs population
in general.
However, so far only a handful of PULXs have been discovered and the search for new ones is in progress. Their detection is hampered
by their extreme timing properties, among which are the highest first period derivatives ever recorder for a NS coupled with orbital motion.
In this talk I'll describe how the properties of the known PULXs, and the extensive use of High Performance Computing are put together,
with the aim of looking for new member of the class both in archival and new requested datasets from high energy missions.

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Equation of state of neutron stars consistent with astrophysical, low- and high- energy nuclear physics data and its applications

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We apply the novel equation of state, which includes the surface tension contribution induced by the interparticle interaction and the asymmetry between neutrons and protons, to the study of neutron star properties. This equation of state is obtained from the virial expansion for the multicomponent particle mixtures that takes into account the hard-core repulsion between them. The considered model is in full concordance with all the known properties of normal nuclear matter, provides a high

quality description of the proton flow constraints, hadron multiplicities created during the nuclear-nuclear collision experiments and equally is consistent with astrophysical data coming from neutron star observations and GW170817 merger. The found mass-radius relation for neutron stars computed with this equation of state is consistent with astrophysical observations. This talk will show how the induced surface tension (IST) equation of state opens an elegant way to describe the properties of matter across a very wide range of densities and temperatures.

Within the IST EoS we have studied radial oscillations of six stars with different masses and radii. We will present the detailed analysis how the changes of thermodynamic properties of the matter leave an imprint on star oscillations.

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Transport in neutron stars

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I will give a review of transport properties of matter inside neutron stars and point out their significance for astrophysical observables. This includes various phases of the star, from the outer layers to the densest possible phases, such as deconfined quark matter. I will mostly focus on general methods and principles, but also discuss specific open questions for future research.

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Equation of state effects in core-collapse supernovae

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We investigate the impact of different properties of the nuclear equation of state in core-collapse supernovae, with a focus on the proto-neutron star contraction and its impact on the shock evolution. To this end, we introduce a range of equations of state that vary the nucleon effective mass, incompressibility, symmetry energy, and nuclear saturation point. This allows us to point to the different effects in changing these properties from the Lattimer and Swesty to the Shen *et al.* equation of state, the two most commonly used equations of state in simulations. In particular, we trace the contraction behavior to the effective mass, which determines the thermal contributions to the equation of state at nuclear densities. Larger effective masses lead to lower pressures and a lower thermal index. This produces a more rapid contraction of the proto-neutron star and consequently higher neutrino energies, which aids the shock evolution to a faster explosion.

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Phase of dense matter including heavy baryons and quarks

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I will discuss the recent progress in understanding some of the properties of compact stars which feature hyperons, delta-resonances and quark matter. The discussion will include static properties of such stars and their cooling behaviour.

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Transport coefficients in nucleon NS cores for different nucleon potentials

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Transport coefficients of nucleon matter in neutron star cores are considered in the Brueckner-Hartree-Fock formalism following our previous work (Shternin et al. 2013, PRC, 88, 065803). In that work, one particular nucleon-nucleon interaction model was employed. In the present study, we extend the consideration by analyzing the dependence of the results on the choice of the nuclear potential. We consider npeμ composition of the core and employ the same nuclear interaction models as in Baldo et al. (2014, PRC 89, 048801). We show that the nucleon contribution to the transport coefficients varies by an order of magnitude when different nucleon potentials are used. The nucleon contribution is compared to the lepton one in non-superfluid neutron star cores and in the presence of a strong proton superfluidity (Shternin 2018, PRD 98, 063015).

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Global parameters of compact stars with phase transitions

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Using parametric equations of state (relativistic polytropes and simple quark bag model) to model dense-matter phase transitions, we study global, measurable astrophysical parameters of compact stars, such as their allowed radii and tidal deformabilities.
We also investigate the influence of stiffness of matter before the onset of the phase transitions on the parameters of the possible exotic dense phase.
The aim of our study is to compare the parameter space of the dense matter equation of state permitting phase transitions to a sub-space compatible with by current observational constraints, such as the maximum observable mass, tidal deformabilities of neutron star mergers, radii of configurations before the onset of the phase transition, and to give predictions for future observations.
We study solutions of the Tolman-Oppenheimer-Volkoff equations for a flexible set of parametric equations of state, constructed using a realistic description of neutron-star crust (up to the nuclear saturation density), and relativistic polytropes connected by a density-jump phase transition to a simple bag model description of deconfined quark matter.
In order to be consistent with recent observations of massive neutron stars, a compact star with a strong phase transition cannot have a radius smaller than 12 km in the range of masses $1.2 - 1.6\,M_{\odot}$. We also compare

tidal deformabilities of stars with weak and strong phase transitions with
the results of the GW170817 neutron star merger. Specifically, we study
characteristic phase transition features in the $\Lambda_1 - \Lambda_2$ relation,
and estimate the deviations of our results from the approximate formulae for
$\tilde{\Lambda} - R(M_1)$ and Λ-compactness, proposed in the literature.
We find constraints on a hybrid equations of state to produce stable neutron stars on the twin branch. For the exemplary equation of state most of the high-mass twins can be formed for the minimal values of the density jump $\lambda = 1.33 - 1.54$ and corresponding values of the square of the speed of sound $\alpha = 0.7 - 0.37$. We compare results with gravitational waves observations, as well as with the theoretical causal limit and find out that the more favorable equations of state have phase transition point at the baryon density around $0.34 - 0.51$ [fm^{-3}]. We also show, that minimal radius that can be produced on a twin branch is between 9.5 and 10.5 km.

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How do pulsars spin-down?

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The movement of pulsars through the P-Pdot diagram is crucially important to understanding how the different classes of pulsars are related and to our understanding of the coupling between the neutron star interior and the magnetic field.

We have carried out a long-term monitoring program for 250 pulsars over the last decade and developed new techniques for measuring their long-term spin evolution. We will present these results and discuss the consequences of timing noise, braking index and glitches. Differences between young and older pulsars will be discussed along with the overall implications for the evolution of the population as a whole.

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Stratification of the Crust of Magnetars and Nuclear Abundances

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The r-process triggered by the decompression of ejected crustal materials from binary neutron star mergers has been recently confirmed by observations of the kilonova following the detection of gravitational waves from GW170817. Isolated neutron stars endowed with very high magnetic fields, so called magnetars, might be also at the origin of r-process nucleosynthesis since some material is ejected during giant flares. The final abundance distribution depends on the crustal composition. Making use of the latest experimental nuclear mass data supplemented with microscopic models, we show that the presence of a high magnetic field can have a significant influence on the stratification of neutron-star crusts and on the nuclear abundances of the different layers.

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Statistical measurement of the Hubble constant from compact binary coalescences without electromagnetic counterparts

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The binary neutron star event GW170817 with its optical counterpart led to the first standard siren measurement of the Hubble constant H_0. This was possible due to a direct estimate of the luminosity distance from the gravitational-wave strain and a measurement of the redshift from the transient electromagnetic counterpart. Even in the absence of such a counterpart, we can statistically correlate the luminosity distance with redshifts present in a galaxy catalog to measure H_0. However, we need to correct for certain systematic effects coming from finite sensitivity of the detectors and incompleteness of the galaxy catalogs. I discuss such a method for the estimation of H_0 which is independent of any cosmic distance ladder.

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The modified carousel model of drifting subpulses: one year after

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In Szary & van Leeuwen (2017) we proposed a modification to the carousel model which follows from the insight that the discharging regions, i.e., sparks, do not rotate around the magnetic axis per se, but rather around the point of maximum potential at the polar cap. The model allows us to link the observed subpulse shift with the underlying spark motion, and hence explore conditions at the polar-cap which are essential for plasma generation processes in the inner acceleration region. We developed a simulation which allows to generate single pulses for a given pulsar geometry and structure of surface magnetic field. The simulation was used to explain the highly unusual bi-drifting feature of PSR B1839-04. We found that A) the variation of global electric potential at the polar cap that leads to a solid-body-like rotation of spark forming regions is favourable, and B) the main parameter that affects the occurrence of bi-drifting is the impact factor divided by the opening angle (β/ρ), the lower the value, the more likely the bi-drifting is.

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A unifying perspective of the high-energy spectra of pulsars: theory, predictions and tests

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In this talk I introduce a model based on only 3 parameters and a global normalization scale that is able to describe the varied spectra of gamma-ray/X-ray pulsars known across 7 orders of magnitude in energy. This model provides at once an answer of what process is behind the emission spectra and how the spectral variety arises. It explains why we have detected sub-exponential cutoffs in gamma-rays, or why the spectra of some pulsars flattens at low energies. Using this model, I analyze how observations in gamma-rays can predict the detectability of pulsars in X-rays, providing a searching tool for new X-ray pulsars, and insights into what makes a pulsar shine in one or the other frequency. Based on these predictions, I present several tests, including the results of an analysis of archival Chandra and XMM X-ray observations of PSR J1747-2958 (the pulsar in the Mouse nebula), PSR J2021+3651 (the pulsar in the Dragonfly nebula), and PSR J1826-1256, that leads to detecting all three, with the agreement between the measured and predicted spectra found to be remarkable. Finally, I consider an analysis of the population of detected pulsars to see how the derived parameters correlate and the possible reasons behind this.

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The VHE gamma-ray morphology of the MSH 15-52 asymmetric pulsar wind nebula

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Pulsar wind nebulae (PWNe) are higly magnetised clouds of relativistic particles, injected and accelerated by the relativistic wind of a rapidly rotating neutron star. Observations in various wavelengths during the last decades have highlighted different nebula morphologies. In this study, we focus on the composite supernova remnant MSH 15-52 containing within its radio emitting shell a PWN. The nebula has been observed in the radio, X-ray and gamma-ray domains, where its intriguing shape underlines a strong asymmetry among the axis of the beams emerging from the central pulsar PSR B1508-59. We explore the shape of its emission in the very high energy (VHE) gamma-ray realm using observations with the High Energy Stereoscopic System (H.E.S.S.).
We compare the Inverse Compton emission in the VHE regime with the synchrotron radiation from the same lepton population as observed in X-rays. We analyse the latest H.E.S.S. data ranging from 0.3 to 30 TeV, whose morphology we model using an X-ray template and making assumptions on the magnetic field within. We find a distinct VHE component extending beyond the X-ray nebula, and examine the energy dependence of this morphology. We discuss the physical implications for the magnetic field and the density of the surrounding medium, and an interpretation of the extended component in terms of lepton transport beyond the synchrotron nebula, in order to account for the asymmetry of the PWN.

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Apertif transient detections of single and merging double neutron stars

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Apertif is a highly innovative receiver system that is currently starting operations on the Westerbork Synthesis Radio Telescope. Its factor 40 increase in field-of-view allows astronomers to survey the sky at 1.4 GHz with an unprecedented combination of sensitivity and speed. At high time resolution this enables deep searches for millisecond transients over the entire Northern hemisphere. In the image domain, even the large error boxes accompanying triggered, multi-messenger events can be quickly searched.

I will report on ALERT, the Apertif Lofar Exploration of the Radio Transient Sky, our pulsar and FRB survey that started Jan 2019. ALERT is a highly sensitive, real-time search, that is unique in providing excellent interferometric localisation, essential for discovering the hosts and nature of the enigmatic one-off FRBs.

I next describe ARGO, the Apertif Radio - Gravitational wave Observatory, our program to discover and interpret the electromagnetic bursts that accompany gravitational-wave events. We focus on mergers involving neutron stars, as these produce relativistic mass ejections and strong radio emission – possible even delayed, prompt FRB-like bursts when an intermediate-stage supermassive neutron star collapses.

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Asymmetry of the neutrino mean free path in hot neutron matter under strong magnetic fields

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The neutrino mean free path in neutron matter under a strong magnetic field is evaluated for the inelastic scattering reaction and studied as a function of the neutron matter density in the range $0.05 \leq \rho \leq 0.4$ fm^{-3} for several temperatures up to 30 MeV and magnetic field strengths B=0 G, 10^{18} G and 2.5×10^{18} G.
Polarized neutron matter is described within the non–relativistic Brueckner–Hartree–Fock (BHF) approach using the Argonne V18 nucleon-nucleon potential supplemented with the Urbana IX three-nucleon force. Explicit expressions of the cross section per unit volume for the scattering of a neutrino with a spin up or spin down neutron are derived from the Fermi Golden rule. Our results show that the mean free path depends strongly on the angle of the incoming neutrino, leading to an asymmetry in this quantity. This asymmetry depends on the magnetic field intensity and on the density, but it is rather independent of the temperature. For a density of 0.16 fm^{-3} at a temperature T= 30MeV, the asymmetry in the mean free path is found to be of $\sim 15\%$ for B=10^{18}G and $\sim 38\%$ for B=2.5×10^{18}G.

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Title : Timing of spider pulsars: what can we learn ?

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Spider pulsars are composed of a millisecond pulsar (MSP) and a low-mass companion, forming the so-called black widows (companion mass Mc < 0.1Msol) and redbacks (Mc>0.1Msol). As MSPs these pulsars are privileged targets for precision timing and possibly timing arrays, but the complex interaction with their companion is still poorly understood and renders their behaviour virtually unpredictable by current models. Indeed multiple spider pulsars are known to display significant orbital variability on months/years timescale which has long been suspected to be connected to the Applegate mechanism.
In this talk we will quickly review the physical ingredients at play in these binaries, discuss the physical meaning of the timing models used to follow these pulsars, and propose an extension in order to extract new observables such as the (bulk) quadrupole moment of the companion star, thus, walking a step further towards predictable spider timing.

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Equation of state constraints from NICER

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One of the primary goals of NICER, the Neutron Star Interior Composition Explorer, is to measure the masses and radii of several relatively bright, thermally-emitting, rotation powered millisecond pulsars. To achieve this the NICER team is using the waveform (or pulse profile) modelling technique: exploiting the effects of General and Special Relativity on the rotationally-modulated radiation emitted from the pulsars' hot polar caps. On behalf of the team, I will review the target selection and data processing methodology, the models and statistical inference tools being used, and the process by which we have tested and verified our analysis procedures and codes. I will then present the mass-radius results obtained by the mission to date, and discuss the implications for our understanding of the ultradense matter in neutron star cores.

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Neutron star cooling with microscopic equations of state

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We model neutron star cooling with several microscopic nuclear equations of state based on different nucleon-nucleon interactions and three-body forces, and compatible with the recent GW170817 neutron star merger event. They all feature strong direct Urca processes. We find that all models are able to describe well the current set of cooling data for isolated neutron stars, provided that large and extended proton 1S0 gaps and no neutron 3PF2 gaps are active in the stellar matter. We then analyze the neutron star mass distributions predicted by the different models and single out the preferred ones.

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Diffusive nuclear burning in the envelopes of accreting and isolated neutron stars

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One of the challenges affecting the study of neutron star cooling is obtaining the interior temperature from observations of surface emission. The relation between surface temperature and interior temperature is set by the heat conducting properties of the thin outer envelope, which are highly sensitive to chemical composition. Most state-of-the-art cooling models consider the envelope to consist of chemically pure layers separated by narrow transition bands driven by diffusive mixing. However, diffusion can drive elements to depths where the density and temperature are sufficient to ignite nuclear burning, thus changing the composition and conductivity. We show how (diffusive) nuclear burning can alter the heat conduction and chemical composition over time and how this affects the interpretation of observed neutron star cooling behaviour. We find that, for some compositions,(diffusive) nuclear burning in the envelope can produce a non-negligible heat flux for neutron stars in quiescence after accretion outbursts, and therefore these stars may not be passively cooling. Finally, we discuss the potential contribution of (diffusive) nuclear burning to the unknown shallow heating mechanism that is often invoked to explain large observed temperatures after accretion outbursts.

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Towards efficient, resistive, multi-fluid merger simulations

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Current models used for neutron star mergers involve a number of approximations, the most widely used of which is ideal MHD. There is reason to believe that at the point of merger, conditions will be such that electrical resistivity may be important and the ideal approximation of perfect conduction breaks down. Furthermore, in order to capture multi-fluid effects such as entrainment, one would need to model the individual particle species separately, namely the neutrons, protons and electrons. At present, simulations of this kind are too computationally demanding for merger simulations, even if the correct multi-fluid formulation were at hand.

Here, we will present the numerical problems incurred by more physically realistic models and discuss methods of reducing the computational overhead set by them. We will describe the benefits of executing simulations on massively parallel hardware, and the steps towards a sub-grid extension of ideal to resistive, multi-fluid MHD.

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Simultaneous Radio and X-ray Mode-changing: Three Pulsars – Three Puzzles!

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Recent simultaneous radio (LOFAR, Lovell & GMRT) and X-ray observations (ESA's XMM-Newton) of three old and relatively nearby pulsars (B0943+10, B1822-09, B0823+26) have led to puzzling results. All three are known at radio frequencies to switch intermittently and suddenly between B ('Bright') and Q ('Quiet') modes with differing strengths and modulation patterns. In each case the X-ray response has been found to be different. In two of the pulsars the X-ray and radio emissions clearly change mode synchronously, while in another no change was detected. The combination of thermal surface emission and non-thermal X-rays (and their switch) was also different in each case. These groundbreaking results clearly indicate that mode-changing is a powerful pan-magnetosphere phenomenon and provide major clues towards understanding its true nature.

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The enhanced X-ray Timing and Polarimetry (eXTP) and compact objects studies

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The enhanced X-ray Timing and Polarimetry (eXTP) mission is a mission concept developed by an international Consortium led by the Institute of High Energy Physics (IHEP) of the Chinese Academy of Sciences, and with a substantial EU contribution. The mission is expected to be launched around 2025.
The scientific payload of eXTP consists of four instruments: The Spectroscopic Focusing Array (SFA), the Polarimetry Focusing array (PFA), the Large Area Detector (LAD) and the Wide Field Monitor (WFM). eXTP is conceived as the most powerful and general observatory for compact Galactic and bright extragalactic objects ever.
It will offer for the first time the most complete diagnostics of compact sources: excellent spectral, timing and polarimetry sensitivity on a single payload.

In this talk I will present the mission concept and the characteristics of the 4 instruments. I will then present the science potential of the eXTP mission, with particular emphasis on studies of strongly magnetized objects (magnetar candidates, accreting and rotation powered pulsars) and on the expected eXTP impact on QED and EOS studies.

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Gravitational wave luminosity peak of binary neutron star mergers.

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We give numerical relativity estimate of the luminosity peak of gravitational waves emitted during the coalescence of binary neutron stars. Our model is constructed from the CoRe-collaboration database and depends only on the main binary's parameters, allowing to make predictions of the luminosity of such events. Highest luminosity peaks are produced when the merger ends in a black hole that promptly forms after the collision of the two stars, while the largest amount of gravitational wave energy is emitted when a massive, rapidly rotating neutron star forms. This allows to make estimates on the outcome of binary neutron star mergers based on the fundamental parameters of the binary only. In addition we provide an upper limit for the maximum energy of gravitational waves emitted in the process as predicted by numerical relativity. Eventually we discuss a simple empirical relation between the total GW's energy emitted and the remnant's angular momentum and its implications.