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50 years after the Pulsar Discovery

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I. "Physics of neutron stars – 2017. 50 years after", international conference (Saint-Petersburg)

This book of abstracts contains summary of presentations at the International Conference "Physics of Neutron Stars – 2017. 50 Years After" held in Saint Petersburg from July 10 to July 14, 2017. This was the 11th conference on Neutron Star Physics organized by the Theoretical Astrophysics Department of the Ioffe Institute. In 2017 it was dedicated to the 50th anniversary of the discovery of pulsars.

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Preface

The International Conference "Physics of Neutron Stars – 2017" in Saint-Petersburg is the 11th event in the series after those in 1988, 1992, 1995, 1997, 1999, 2001, 2005, 2008, 2011 and 2014. Its aim is to bring together physicists and astrophysicists working on neutron stars and related problems all over the world. In 2017 the conference commemorates the semicentenary of the Pulsar Discovery.

The Conference covers all major topics of observations and theory of neutron stars, particularly rotation powered pulsars, pulsar emission mechanisms, pulsar wind nebulae, magnetars and high-B pulsars, fast radio bursts, isolated cooling neutron stars, central compact objects, accreting X-ray pulsars (including millisecond pulsars), neutron stars in low-mass X-ray binaries, X-ray bursters, equation of state, structure and evolution of neutron stars, mechanisms of supernova explosions and evolution of supernova remnants, gravitational waves from neutron stars and black holes. It is organized by the Ioffe Institute (St. Petersburg, Russia) and the Sternberg Astronomical Institute (Moscow, Russia). The official language of the Conference is English.

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Contents

Probing of interstellar plasma distribution in the direction to pulsars PSR 0525+21 and 1919+21 with RadioAstron mission

A. S. Andrianov[1*], T. V. Smirnova[2†], V. I. Shishov[2‡], M. V. Popov[1§], C. Gwinn[3¶]

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We carried out observations of the pulsars 0525+21 and 1919+21 at 1668 MHz and 324 MHz to study the distribution of the interstellar plasma in the direction to these pulsars. We used the RadioAstron space telescope together with large ground telescopes: Arecibo, Green Bank and Westerbork. The maximum baseline projections for the space-ground interferometer were 60000 km for the PSR 1919+21 and 233600 km for the PSR 0525+21. We measured the scattering angles in the direction to PSR 0525+21 as $\theta_{sc} = 0.028$ mas at 1668 MHz and $\theta_{sc} = 0.7$ mas at 324 MHz in the direction to the PSR 1919+21. We found for the first time that two scattering regimes are realized in the direction to the PSR 1919+21: diffractive scintillations from inhomogeneities in a layer of turbulent plasma at a distance $z_1 = 440$ pc from observer and weak scintillations from a screen located at $z_2 = 0.14$ pc. We also found that a prism with a distance $z \leq 2$ pc exist in this direction. We have shown that the scattering of the emission from the PSR 0525+21 takes place on the screen located close to pulsar: $0.1D$, where D is a distance to pulsar. For $D = 1.6$ kpc we have $z = 1.44$ kpc from the observer.

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The Critical Strain Angle in the Neutron Star Crust

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The critical strain angle in the Coulomb crystal in the neutron star crust is estimated on the assumption that this dimensionless number is of the order of the ratio of the Coulomb potential energy to the kinetic energy of the relativistic electrons, $\theta_{cr} \sim E_C/E_K$. This estimate scales with the fine structure constant, the charge Z, and microscopic length scales. The scaling also depends on the dimensionality according to the shapes of the nuclear clusters in various "pasta" geometries (i.e. spherical, rod-like, slab-like) in the inner crust. It is found that $\theta_{cr} \sim 10^{-1}$ in the outer crust, in agreement with the numerical results of [1], while it reduces to $10^{-2} - 10^{-3}$ in the inner crust where the lower dimensional rod and slab configurations prevail. Calculating the maximum quadrupole moment with varying critical strain throughout the crust, we predict the strain amplitude of gravitational waves for a maximally deformed crust and compare these with the recently updated [2] observational upper limits from LIGO.

References

[1] Horowitz, C. J., & Kadau, K. 2009, PRL, 102, 191102

[2] Abbott, B. P. et. al., 2017, arXiv:1701.07709

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Neutron Star Dynamics under Time Dependent External Torques

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The two component (or multicomponent) neutron star models for neutron star dynamics are conventionally solved for external torques that are constant on dynamical timescales of the neutron star interior. These models are applicable for pulsar glitch dynamics. We present the solution for two component neutron star models, for linear coupling (eg mutual friction between the superfluid interior and the crust), as well as for nonlinear coupling (nonlinear regime of vortex creep) under arbitrary time dependent external torques. These solutions are applied to extract the spin-up or spin-down behaviour of neutron stars under external torque noise, power law external torques or post-burst exponential decay of the external torque, as relevant for accreting neutron stars and magnetars as well as for pulsars.

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Hard X-ray Quiescent Emission in Magnetars via Resonant Compton Upscattering

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Non-thermal quiescent X-ray emission extending between 10 keV and around 150 keV has been seen in about 10 magnetars by RXTE, INTEGRAL, Suzaku and Fermi-GBM. For inner magnetospheric models of such hard X-ray signals, resonant Compton upscattering is anticipated to be the most efficient process for generating the continuum radiation. This is because the scattering becomes resonant at the cyclotron frequency, and the effective cross section exceeds the classical Thomson value by over two orders of magnitude. We present hard X-ray upscattering spectra for uncooled monoenergetic relativistic electrons injected in inner regions of pulsar magnetospheres. These model spectra are integrated over closed field lines and obtained for different observing perspectives. The spectral cut-off energies are critically dependent on the observer viewing angles and electron Lorentz factor. We find that electrons with energies less than around 15 MeV will emit most of their radiation below 250 keV, consistent with the turnovers inferred in magnetar hard X-ray tails. Electrons of higher energy still emit most of the radiation below around 1 MeV, except for quasi-equatorial emission locales for select pulse phases. In such cases, attenuation mechanisms such as pair creation will be prolific, thereby making it difficult to observe signals extending into the Fermi-LAT band. Our spectral computations use new state-of-the-art, spin-dependent formalism for the QED Compton scattering cross section in strong magnetic fields.

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The influence of positronium photoionization rate on the polar cap X-ray luminosity of radio pulsars

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The influence of positronium photoinization rate on the polar cap X-ray luminosity of old radio pulsars is considered. It is assumed that the polar cap is heated only by reverse positrons, accelerated in a pulsar diode. It is supposed that the pulsar diode is in a stationary state with the lower plate on the star surface (the polar cap model), occupies all the pulsar tube cross section and operates in the regime of steady space charge limited by the electron flow. The influence of a small-scale magnetic field on the electric field inside the pulsar diode is taken into account. The reverse positron current is calculated in the framework of two models, (i) rapid [1] and (ii) gradually screening [2, 3]. To calculate the production rate of electron-positron pairs we take into account only the curvature radiation of primary electrons and its absorption in a magnetic field. It is assumed that some fraction of electron-positron pairs may be created in a bound state (positronium). Later such positroniums are photoionized by thermal photons from the polar cap.

References

[1] Arons, J., & Scharlemann, E. T. 1979, ApJ, 231, 854
[2] Harding, A. K., & Muslimov, A. G. 2001, ApJ, 556, 987
[3] Lyubarskij, Y. E. 1992, A&A, 261, 544

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Deep optical observations of the γ-ray pulsar PSR J2055+2539 with the GTC

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We present the results of deep, down to a 28 magnitude limit, optical observations of the γ-ray pulsars J2055+2539 (total exposure time $\approx$ 7.9 ks), that were obtained with the *Gran Telescopio Canarias* (*GTC*) in the g'-band. To determine the most precise pulsar position we utilized recent *Chandra* observations, where the pulsar X-ray counterpart was detected with a high significance. Using one reference star detected both with the *GTC* and *Chandra* we improved the absolute astrometry accuracy for the *Chandra* image of the PSR J2055+2539 field. The resulting *Chandra* pulsar position error circle of $0\farcs3$ is compatible with the 1σ *Fermi* position of the pulsar ($0\farcs5$), obtained from timing analysis.

No optical counterpart was detected within the refined pulsar error circle. However, we managed to correct a shallow upper limit on the optical flux of the pulsar, which was derived early from *BTA* observations [1]. The new value $M_{lim}(3\sigma) = 26.6$ for the g'-band is obtained. It is brighter than the limit stated above due to the presence of a nearby star ($0\farcs8$ from the pulsar position) with $M = 20.3$. The inspection of the pulsar multiwavelength spectrum suggests a break between the X-ray nonthermal power law component and the optical range.

References

[1] Beronya, D. M., Shibanov, Y. A., Zyuzin, D. A., & Komarova, V. N. 2015, JPCS, 661, 012001

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So, How Do Radio Pulsars Slow-Down?

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In 1983 our team has shown that for zero longitudinal electric current circulating in the pulsar magnetosphere, the energy losses $W_{\rm tot}$ vanish for any inclination angle χ [1]. This effect (confirmed later by L.Mestel group [2]) results from full screening of the magneto-dipole radiation by the magnetospheric plasma. This implies that the pulsar braking results solely from the impact of the torque $\mathbf{K}$ due to the longitudinal currents.

On the other hand, rotating magnetized star can be slowed down only due to action of the Ampére force associated with surface currents $\mathbf{J}_{\rm s}$: $W_{\rm tot} = -\mathbf{\Omega K}$, where

$$\mathbf{K} = \frac{R^3}{c}\int \mathbf{J}_{\rm s}\,(\mathbf{Bn})\,{\rm d}o = \frac{R^3}{4\pi}\int \{[\mathbf{n}\times\mathbf{B}^{(3)}](\mathbf{B}^{(0)}\mathbf{n}) + [\mathbf{n}\times\mathbf{B}^{(0)}](\mathbf{B}^{(3)}\mathbf{n})\}\,{\rm d}o. \qquad (1)$$

Here indices $(0,3)$ correspond to expansion powers in terms of the small parameter $\varepsilon = \Omega R/c$. Careful analysis for the vacuum magneto-dipole radiation shows surprisingly that in the Landau-Lifshitz solution both terms play a role, while in the Deutsch solution only the first one does (giving, certainly, the same well-known result).

Returning to the magnetosphere filled with plasma, one can find that the torque acting on the star via the surface currents $\mathbf{J}_{\rm s}$ closing the longitudinal electric currents [1]

$$K_{\parallel}^{\rm sur} \approx -\frac{\mathbf{m}^2\Omega^3}{c^3}i_{\rm s}, \quad K_{\perp}^{\rm sur} \approx -\frac{\mathbf{m}^2\Omega^3}{c^3}\left(\frac{\Omega R}{c}\right)i_{\rm a}, \quad I_{\rm r}\,\dot{\Omega} = K_{\parallel}^{\rm A} + (K_{\perp}^{\rm A} - K_{\parallel}^{\rm A})\sin^2\chi, \quad (2)$$

corresponds to the first term in (1). Here we have introduced two components of the torque $\mathbf{K}$, parallel and perpendicular to the magnetic dipole $\mathbf{m}$. Besides, the dimensionless current $i = j_{\parallel}/j_{\rm GJ}$ (normalized to the 'local' Goldreich-Julian current density $j_{\rm GJ} = |\mathbf{\Omega}\cdot\mathbf{B}|/2\pi$ with the scalar product) is also separated into symmetric and antisymmetric contributions, $i_{\rm s}$ and $i_{\rm a}$, depending on whether the direction of the current in the north and south parts of the polar cap is the same or opposite.

Hence, to satisfy the Spitkovsky's relation $\dot{\Omega} \propto (1+\sin^2\chi)$ we have to assume too large antisymmetric current $i_{\rm a} \sim \varepsilon^{-1}$ while in reality $i_{\rm a} \sim \varepsilon^{-1/2}$. Thus, it is necessary to introduce an additional contribution resulting from the mismatch between the magneto-dipole and magnetospheric radiation and corresponding to the second term in (1)

$$K_{\perp}^{\rm mag} = -A\,\frac{B_0^2\Omega^3R^6}{c^3}\,i_{\rm a}. \qquad (3)$$

For $i_{\rm a} \sim \varepsilon^{-1/2}$ we obtain $A \sim \varepsilon^{1/2}$. This implies that for local GJ current $i_{\rm a} \approx 1$, for most inclination angles, one can neglect the additional term $K_{\perp}^{\rm mag}$, as was done in [1].

References

[1] V. S. Beskin, A. V. Gurevich & Ya. N. Istomin, 1983, Sov. Phys. JETP 58, 235

[2] Mestel, L., Panagi, P., & Shibata, S. 1999, MNRAS, 309, 388

Heat blanketing envelopes and neutron stars cooling

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Interpretation of observations of isolated neutron stars is a difficult task. One of the problems is our poor knowledge of chemical composition of the outer neutron star envelopes. The uncertainties in the chemical composition lead to the uncertainties in our theoretical inference of the internal temperature and, thus, the internal structure of a neutron star.

We have studied the impact of different chemical compositions of the heat blanketing envelopes on thermal states and thermal evolution of isolated neutron stars. Although such studies were conducted in the past, they often relied on simplified "onion"-like models of the envelopes which consist of different shells of pure chemical species with abrupt boundaries between the shells. A well known and widely used example of such a model is a model by Potekhin et al. [1]. In contrast, we have investigated the heat blanketing envelopes with proper treatment of diffusion. To do this, we have extended our previous work on diffusion in isothermal dense stellar plasmas [2] to handle non-isothermal systems and have constructed models of diffusively-equilibrated and non-equilibrated heat blanketing envelopes composed of binary ionic mixtures (H–He, He–C, C–Fe) with different amounts of lighter ion species [3].

Using these envelopes and taking the Vela pulsar as an example, we have demonstrated that the uncertainties in the chemical composition of the heat blanketing envelopes can cause up to ~ 2.5 times variation in the internal temperature of the Vela pulsar for a fixed surface temperature inferred from observations. In turn, the uncertainty in the internal temperature causes up to ~ 200 times variation of the neutrino cooling function. We have also studied the effect of variations of the chemical composition on cooling curves of isolated neutron stars [4].

References

[1] Potekhin, A. Y., Chabrier, G., & Yakovlev, D. G. 1997, A&A, 323, 415

[2] Beznogov, M. V., & Yakovlev, D. G. 2013, PRL, 111, 161101

[3] Beznogov, M. V., Potekhin, A. Y., & Yakovlev, D. G. 2016, MNRAS, 459, 1569

[4] Beznogov, M. V., Fortin, M., Haensel, P., Yakovlev, D. G., & Zdunik, J. L. 2016, MNRAS, 463, 1307

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Structural properties of Keplerian rotating neutron stars

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Observations indicate the existence of rapidly rotating neutron stars, which are millisecond pulsars (MSPs). A rapid rotation affects the global properties of the neutron stars. The study of structural properties of these objects such as maximum mass, radius and spin has intrigued theoretical astrophysicists over the last decades [1, 2]. The global structure of a neutron star is sensitive to its angular velocity, and the maximum mass increases by increasing the rotation velocity. Here, we have computed the structural properties of a Keplerian rotating neutron star for the maximum mass configuration, M_K, R_K, f_K and j_{max}, using the numerical RNS code [3]. We have also proposed a universal formula for the maximum mass of neutron stars in units of maximum Keplerian mass [4]. In this work, we have employed the equation of state (EOS) for neutron star matter which describes the neutron star outer crust, inner crust and the liquid core. For the inner crust, the EOS is calculated by Douchin and Haensel [5], and we use the Baym-Pethick-Sutherland EOS for the outer crust [6]. For the liquid core, we have applied the lowest order constrained variational (LOCV) method to generate the equation of state [7, 8].

References

[1] Lo, K.-W., & Lin, L.-M. 2011, ApJ, 728, 12

[2] Qi, B., Zhang, N.-B., Sun, B.-Y., Wang, S.-Y., & Gao, J.-H. 2016, RAA, 16, 60

[3] http://www.gravity.phys.uwm.edu/rns/.

[4] Farajian, A. M., Bigdeli, M. & Belbasi, S., submitted to ApJ

[5] Douchin, F., & Haensel, P. 2001, A&A, 380, 151

[6] Baym, G., Pethick, C., & Sutherland, P. 1971, ApJ, 170, 299

[7] Bigdeli, M. 2010, PRC, 82, 054312

[8] Modarres, M., & Bordbar, G. H. 1998, PRC, 58, 2781

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The apparent decay of pulsar magnetic fields

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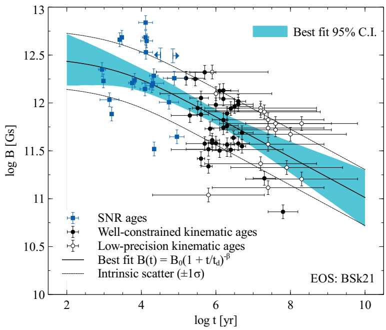

Figure 1: Apparent evolution of magnetic fields of 76 isolated radiopulsars.

The semi-numerical spindown law of a normal radiopulsar with realistic plasma-filled magnetosphere has been derived recently (starting from [1]). According to it, the spin-down luminosity depends on the magnetic obliquity relatively weakly, and thus it allows one to observationally constrain the surface field strength B of a neutron star within a quite narrow interval using its timing properties only.

We have accurately reviewed all the sources of uncertainty related to directly unmeasurable parameters arising in this spindown law, such as neutron star mass (radius, moment of inertia), obliquity etc, and derived the modified timing-based estimator of the pulsar magnetic field strength, which is quite accurate and allows one to explicitly estimate its uncertainty.

Using a representative subset of modern theoretical equations of state for dense matter, we demonstrate that the magnetic field strength may be estimated with the accuracy up to 10-20%, and discuss how the possible timing irregularities may influence it (see [2] for details).

We applied this estimator to probe in a statistically and physically correct way the evolution of magnetic field during pulsar's lifetime. To do it, we used the ages of supernova remnants (SNRs) associated with young pulsars, along with kinematic ages of older pulsars, for 76 objects in total (see Figure 1). We found a significant trend $B(t) \propto t^{-\beta}$ with $\beta = 0.21 \pm 0.04$. We discuss the astrophysical implications of this result taking into account the effects of observational selection.

References

[1] Spitkovsky, A. 2006, ApJL, 648, L51

[2] Biryukov, A., Astashenok, A., & Beskin, G. 2017, MNRAS, 466, 4320

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Magnetars or Central Explosions in Superluminous Supernovae?

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The number of Superluminous Supernovae (SLSNe) discovered is growing. We show that the models explaining those events with the minimum energy budget involve multiple ejections of mass in presupernova stars. Mass loss and buildup of envelopes around massive stars are generic features of stellar evolution. Normally, those envelopes are rather diluted, and they do not change significantly the light produced in the majority of supernovae.

In some cases, large amounts of mass are expelled just a few years before the final explosion. Then, the "clouds" around the supernovae may be quite dense. The shock waves produced in collisions of supernova ejecta and those dense shells may provide the required power of light to make the supernova much more luminous than a "naked" supernova without pre-ejected surrounding material.

This class of the models is referred to as "interacting" supernovae. We show in [1] that the interacting scenario is able to explain both fast and slowly fading SLSNe, so that the large range of these intriguingly luminous objects can in reality be almost ordinary supernovae placed into extraordinary surroundings.

Many SLSNe-I have photospheric velocity of the order of 10^4 km/s which is hard to explain in interacting models with a modest energy of explosion. That is why, to explain those events a "magnetar" central engine is invoked. However, the magnetars postulated in this scenario are not yet observed, and the physics of transformation of their rotational energy into photon luminosity requires a detailed investigation.

Our new study shows that a strong explosion (on the observed hypernova scale) within a dense envelope produced by previous weaker explosions explains naturally both high luminosity and high photospheric velocity of SLSNe.

References

[1] Sorokina, E., Blinnikov, S., Nomoto, K., Quimby, R., & Tolstov, A. 2016, ApJ, 829, 17

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Phase-dependent absorption features in X-ray spectra of XDINSs

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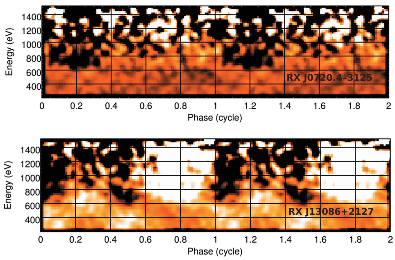

Figure 1: Normalized energy versus phase images of RX J0720.4–3125 (top panel) and RX J1308.6+2127 (bottom panel) obtained by binning the EPIC-pn source counts into 100 phase bins and 25-eV-wide energy channels.

A detailed pulse phase spectroscopy using all the available XMM-Newton observations of X-ray dim isolated neutron stars (XDINSs) have revealed the presence of narrow and strongly phase-dependent absorption X-ray features. The first discovered was in the X-ray spectrum of the nearby XDINS RX J0720.4–3125 [1]. The line seems to be stable in time over a timespan of 12 years and is present in 20% of the pulsar rotation. Because of its narrow width and its strong dependency on the rotational phase, the spectral line is probably due to proton cyclotron absorption in a $\sim 10^{14}$ G confined magnetic structure (with a field strength about 7 times the dipolar field of this pulsar). Performing the same analysis to all archival XDINS data, a new possible candidate was found in the X-ray spectrum of RX J1308.6+2127 [2]. This absorption feature shows the same phase dependency and energy as the first one, revealing the presence of a high-B structure close to the stellar surface.

In both cases we performed Monte Carlo simulations to verify the significance of these discoveries and the outcome has confirmed the detection of the phase-variable absorption feature in both sources. This result provides evidence for deviations from a pure dipole magnetic field on small scales for highly magnetized neutron stars and supports the proposed scenario of XDINSs being aged magnetars, having still a strong non-dipolar crustal B-field component.

References

[1] Borghese, A., Rea, N., Coti Zelati, F., Tiengo, A., & Turolla, R. 2015, ApJL, 807, L20

[2] Borghese, A., Rea, N., Coti Zelati, F., et al. 2017, MNRAS, 468, 2975

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Thermonuclear Magnetic Deflagrations and Type I Bursts

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When the surface layers of accreting neutron stars explosively burn the fresh fluid, the ensuing Type I Burst outshines all the other accretion powered emission for tens of seconds: that makes the bursts one of the best observable phenomena of accreting neutron stars.

Due to general relativistic effects of the star gravitational potential, the escaping photons of the bursts encode information about star parameters such as spin, mass and radius that are key to constraining the equation of state of the core matter. However, to be able to unambiguously extract that information from the observations, we need to know the details of the emission on the surface and that begins with understanding how the burning flame propagates.

We will present the results of ab initio calculations of the flame spreading, describing the physical mechanisms behind the propagation [1, 2] and showing how the balance between magnetic tension and Coriolis force can lead to *fast* deflagrations in very good agreement with the observations [3].

References

[1] Cavecchi, Y., Watts, A. L., Braithwaite, J., & Levin, Y. 2013, MNRAS, 434, 3526

[2] Cavecchi, Y., Watts, A. L., Levin, Y., & Braithwaite, J. 2015, MNRAS, 448, 445

[3] Cavecchi, Y., Levin, Y., Watts, A. L., & Braithwaite, J. 2016, MNRAS, 459, 1259

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Resistive, viscous MHD simulations of accretion disk around millisecond pulsar

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In our resistive and viscous MHD simulations of a thin accretion disk around a neutron star with the dipolar magnetic field of 10^8 Gauss, we capture 500 millisecond pulsar rotations. Matter is accreted from the disk onto the star through a stable accretion column. We also show formation of magnetospheric ejection through stellar corona with the stellar wind. We analyze the mass accretion flux and torques on the star from various components of the flow in the system.

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Radiation from neutron stars with internal variable heaters

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We extend our studies [1] of thermal radiation from neutron stars with internal heaters in the crust by considering variable heaters. We have simulated [2] variations of the thermal surface luminosity of the star $L_s(t)$ produced by the heater whose power $L_h(t)$ is varied over a certain period of time Δt. We model either internal outbursts or heat drops (increasing or decreasing $L_h(t)$) and study the conditions at which the variability of the heater produces a noticeable variability of $L_s(t)$ that can be used to explore physical conditions in the heater's region. We consider neutron stars with standard neutrino cooling from the core (via modified Urca process) and with the neutrino cooling enhanced by the direct Urca process. We examine different positions and powers of the heater in the crust, different heat variation times Δt including the effects of superfluidity of free neutrons in the crust.

It was found that only a small fraction of heat is emitted by photons through the surface, whereas the rest of the heat energy is emitted by neutrinos. To increase the surface emission it is profitable to shift the heater closer to the surface. Time variations of $L_s(t)$ are distorted with respect to the variations of $L_h(t)$. For instance, in the case of an internal outburst, the variation of $L_s(t)$ is delayed and broadened relative to $L_h(t)$. If the shape of $L_h(t)$ is symmetrical with respect to the internal outburst peak maximum t_0, the shape of the surface luminosity can be strongly asymmetrical and contain an extended tail. The presence of crustal superfluidity can strongly reduce the time dilatation and broadening of $L_s(t)$ and considerably enhance an amplitude of $L_s(t)$ for relatively deep heater's location. In the case of very strong heaters and/or warm stars, variations of $L_s(t)$ are greatly reduced because the generated heat is efficiently carried away by neutrinos just from the heater. All in all, neutron stars tend to hide their internal activity.

Applications of the results to study the internal activity of neutron stars in soft X-ray transients, magnetars and other neutron stars are discussed.

References

[1] Kaminker, A. D., Kaurov, A. A., Potekhin, A. Y., & Yakovlev, D. G. 2014, MNRAS, 442, 3484

[2] Chaikin, E. A., Kaurov, A. A., Kaminker, A. D., & Yakovlev, D. G. 2017, EPL, 117, 29001

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Multinary ionic compounds in neutron-star crusts

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The outer crust of a neutron star has been generally assumed to be stratified into different layers, each of which consists of a pure body-centred cubic ionic crystal in a charge compensating electron background [1]. The validity of this assumption is examined by analysing the stability of multinary ionic compounds in dense stellar environments [2]. It is shown that their stability against phase separation is uniquely determined by their structure and their composition irrespective of the stellar conditions. However, equilibrium with respect to weak and strong nuclear processes imposes very stringent constraints on the composition of multinary compounds, and thereby on their formation. By examining different cubic and noncubic lattices, it is found that substitutional compounds having the same structure as cesium chloride are the most likely to exist in the outer crust of a nonaccreting neutron star. The formation of binary and ternary compounds in accreted crusts will be also discussed.

References

[1] Haensel, P., Potekhin, A. Y., & Yakovlev, D. G. 2007, ASSL, 326

[2] Chamel, N., & Fantina, A. F. 2016, PRC, 94, 065802

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Amplification of the magnetic field by r-mode instability: role of the back-reaction

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We discuss unstable r-modes (driven by the gravitational radiation-reaction force) in rotating magnetized Newtonian stellar models. In the absence of a magnetic field, the gravitational radiation leads to the exponential growth of not only an r-mode amplitude α, but also of differential rotation [1]. For a magnetized star, the differential rotation enhances the magnetic field energy. As has been argued by Rezzolla et al. [2], if the magnetic field energy grows faster, than the rate at which the gravitational radiation-reaction force pumps the energy to the r-modes, the r-mode instability should be suppressed. Chugunov [3] has demonstrated that in the absence of the gravitational radiation the r-modes and differential rotation are decoupled. In particular, the magnetic field does not lead to the r-mode damping. We discuss the effect of back reaction of the magnetic field on the differential rotation for unstable r-modes and demonstrate that it limits the magnetic field amplification, preventing thus the suppression of the r-mode instability by an enhancement of the magnetic field.

References

[1] Friedman, J. L., Lindblom, L., & Lockitch, K. H. 2016, PRD, 93, 024023

[2] Rezzolla, L., Lamb, F. K., & Shapiro, S. L. 2000, ApJL, 531, L139

[3] Chugunov, A. I. 2015, MNRAS, 451, 2772

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Systematic study of magnetar outbursts

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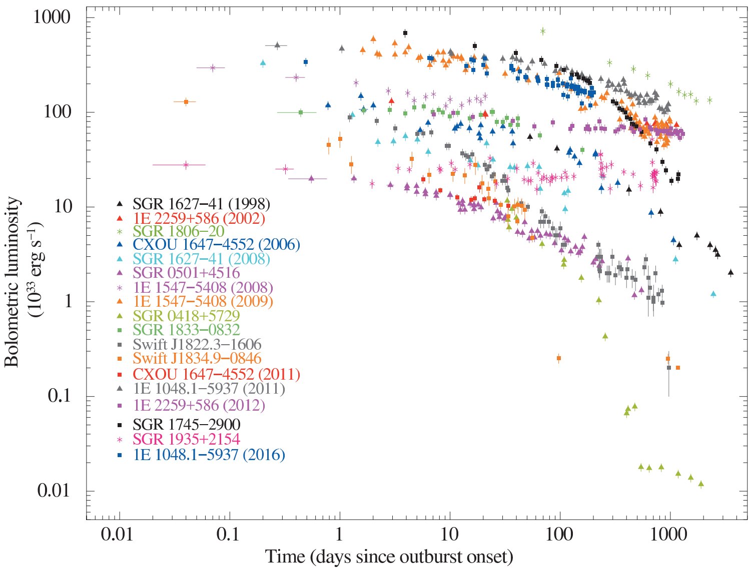

Figure 1: Temporal evolution of the bolometric luminosities for all magnetars showing major outbursts between 1998 and 2016 (Coti Zelati et al., in preparation).

In the past decade, extensive study of magnetars in outburst has led to a number of unexpected breakthroughs which have changed our understanding of these objects. So far, several outbursts have been the object of many observational campaigns in the soft X-ray band. Although detailed studies have been conducted for each of these events, an overall systematic analysis of their spectral properties, from the very first

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active phases throughout the decay, is still missing. **I will present the results of our X-ray spectral modeling for 19 magnetar outbursts occurred over the past 2 decades.** We have reduced and reanalysed all the available data acquired by the *Swift*, *Chandra*, and *XMM–Newton* X-ray observatories, as well as data collected in a few observations by the instruments aboard *Beppo*SAX, *ROSAT*, and *RXTE* (about 900 observations in total). We tracked the temporal evolution of the absorbed fluxes and the luminosities for all these events (that of the single spectral components and the total one in the X-rays, and also the bolometric luminosity; see Fig. 1 for the light curves of all these episodes). We then modeled empirically the decays of the bolometric luminosities, and we have estimated the characteristic decay time scales as well as the total energetics involved for each of these events. We investigated the anti-correlation between the maximum flux (luminosity) increase reached during these episodes and the source quiescent X-ray flux (luminosity), and characterized the link between the energetics released and other parameters of the outburst, such as the X-ray luminosity in the quiescent phase and that at the peak of the outburst. We will soon publish the results of our analysis on a website, making publicly available all files used for the analysis as well as all the material required to reproduce all cooling curves and investigate the interdependence between the characteristic parameters of our sample of magnetars and their outbursts. We will maintain the website with regular updates as new transient magnetars will be discovered.

Discontinuous Galerkin finite element methods for radiative transfer in strongly magnetized plasma

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Application of the discontinuous Galerkin finite element method (DG-FEM) to the solution of radiative transfer in strongly magnetized plasma is presented. The goal is to construct a formal solver which exploits the capability of Graphical Processing Units (GPUs). More specifically, we use the DG-FEM to solve two coupled diffusion equations, which describe transfer of the two normal modes in the magnetized plasma [1], for a given temperature profile. This is a key part of the lambda iteration method, which is usually used to construct a model of the neutron star magnetized atmosphere. We emphasize those parts of the DG-FEM which can be accelerated using GPUs.

References

[1] Shibanov, I. A., Zavlin, V. E., Pavlov, G. G., & Ventura, J. 1992, A&A, 266, 313

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CCOs and the slow magnetar in RCW 103

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Central Compact Objects (CCOs) are a handful of sources located close to the geometrical center of young supernova remnants. They show thermal-like, soft X-ray emission and have no counterparts at any other wavelength. Based on the measured values of P and $\dot{P}$ for three members of the family, CCOs are supposed to be young, isolated neutron stars (INSs) endowed with a low dipolar magnetic field ($10^{10} - 10^{11}$ G), hence also dubbed "anti-magnetars". However, the properties of CCOs (also including, in some cases, very high surface thermal anisotropies) and their relationship with other classes of INSs, possibly ruled by supernova fall-back accretion, are far from being well understood.

Here we focus on the case of 1E 161348–5055 (1E) in RCW103. It was the first proposed radio-quiet INS candidate in a supernova remnant, and thus a prototype for the CCO class. However, peculiar temporal properties, including a 6.67 hour periodicity, as well as a dramatic long-term variability, set the case for a unique source, whose nature has been debated for a decade. Very recently, on 2016, June, 1E underwent a new outburst, emitting for the first time a millisecond burst of hard X-rays, coupled to a factor of 100 brightening in the persistent soft X-ray emission. A non-thermal emission component extending up to 30 keV was also detected. This strongly suggests that 1E is an isolated magnetar, with the slowest spin period ever observed, by orders of magnitude.

The most viable slow-down scenario for 1E points to a picture involving fall-back accretion after the supernova explosion, similarly to what is invoked (although in a different regime) to explain the properties of the other CCOs. It is apparent that a very complex scenario (with many unconstrained parameters!) is required to understand the wide, puzzling diversity in the manifestations of INSs.

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Temperature-dependent oscillation modes in rotating superfluid neutron stars

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According to the standard r-mode theory, hot and rapidly rotating neutron stars (NSs) in low-mass X-ray binaries (LMXBs) should be CFS-unstable with respect to the emission of gravitational waves [1, 2]. As a consequence, the probability to observe them should be very small, but this conclusion contradicts observations [3]. To resolve the paradox, in a series of papers [4–8], we introduced a new scenario, in which the finite-temperature effects in the superfluid core of an NS lead to resonance coupling and enhanced damping (and hence stability) of oscillation modes at certain "resonance" stellar temperatures. We demonstrated that NSs in LMXBs with high spin frequency may spend a substantial amount of time at these resonance temperatures, so that their interpretation does not constitute a problem.

The scenario of Refs. [4–8] was based on a simplified phenomenological model (in particular, resonance temperatures have never been calculated explicitly). In this work, we put it on a more solid ground by considering realistic NS models. Moreover, to find the resonance temperatures (and hence to verify the scenario) we perform extensive calculations of oscillation spectra for *rotating* NSs, accounting for the effects of nucleon superfluidity, finite-temperatures, and multilayer structure of NS cores with different particle compositions. Our work provides a new method to quantitatively constrain the properties of superdense matter by comparing the observed temperatures of NSs in LMXBs with the theoretically calculated resonance temperatures in their oscillation spectra.

References

[1] Andersson, N. 1998, ApJ, 502, 708
[2] Friedman, J. L., & Morsink, S. M. 1998, ApJ, 502, 714
[3] Ho, W. C. G., Andersson, N., & Haskell, B. 2011, PRL, 107, 101101
[4] Gusakov, M. E., Chugunov, A. I., & Kantor, E. M. 2014, PRL, 112, 151101
[5] Gusakov, M. E., Chugunov, A. I., & Kantor, E. M. 2014, PRD, 90, 063001
[6] Chugunov, A. I., Gusakov, M. E., & Kantor, E. M. 2014, MNRAS, 445, 385
[7] Kantor, E. M., Gusakov, M. E., & Chugunov, A. I. 2016, MNRAS, 455, 739
[8] Chugunov, A. I., Gusakov, M. E., & Kantor, E. M. 2017, MNRAS, 468, 291

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The distributions of isolated pulsar periods and magnetic fields

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Using our population synthesis code [1] for isolated neutron stars we modeled the distributions of pulsar periods P, period derivatives $\dot{P}$, and pulsar magnetic fields B in the modern epoch. We started modeling with our code from the birth of massive OB stars and followed their motion within the spiral arms to the point of supernova explosion. Next we considered the evolution of neutron stars up to the death line together with considering the magnetic field decay. Obtained distribution appears to be in a good agreement with those taken from ATNF catalog [2]. The shape and the width of their magnetic field distribution seems to be close to that for masive OB stars. The mass distribution of the compact remnants of the supernova explosions was also investigated.

References

[1] Igoshev, A. P., & Kholtygin, A. F. 2011, Astronomische Nachrichten, 332, 1012

[2] Manchester, R. N., Hobbs, G. B., Teoh, A., & Hobbs, M. 2005, AJ, 129, 1993 (http://www.atnf.csiro.au/research/pulsar/psrcat/)

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An accurate dispersion measure toward the pulsar PSR B1530+27 based on single-pulse observations at the frequency of 111 MHz

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The observations of the pulsar B1530+27 in the mode of single pulses have been made. The 11,084 single pulses have been detected. The dispersion measure toward this pulsar, $DM = 14.6904 \pm 0.0009$ pc cm^{-3}, is derived. The upper limit (at a 3 sigma level) on the time derivative of the dispersion measure is equal to $|\mathrm{d}DM/\mathrm{d}t| < 0.001$ pc cm^{-3}/year. Dispersion measure variations associated with the passage of the emission inside the Earth's orbit do not exceed 0.01 pc cm^{-3}.

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The glitch activity of radio pulsars and magnetars

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We present a statistical study of pulsar glitches and the behaviour of the glitch activity across the known pulsar population. An unbiased glitch database was put together based on published systematic searches of radio timing data of 903 pulsars, obtained with the Jodrell Bank and Parkes observatories. Similar searches for magnetar glitches were also included. The database contains 384 glitches found in the rotation of 141 of the pulsars. We confirm that the pulsar glitch size distribution is at least bimodal, with the large glitches sharply peaked around $20\,\mu$Hz, and a broader distribution of small glitches. We also explored how the glitch activity $\dot{\nu}_{\rm g}$, defined as the mean frequency increment per unit of time due to glitches, correlates with the spin frequency ν, spin-down rate $|\dot{\nu}|$, and various combinations of these, such as energy loss rate, magnetic field, and spin-down age. We found that a constant ratio $\dot{\nu}_{\rm g}/|\dot{\nu}| \approx 10^{-2}$ is consistent with the behaviour of nearly all radio pulsars (except a couple with the highest $|\dot{\nu}|$, including the Crab) as well as the magnetars. This relation is dominated by large glitches, but small ones taken separately follow a similar one. For low $|\dot{\nu}|$, the activity appears to be lower than predicted from this relation, but this can be attributed to insufficient observing time, which did not allow for the detection of any large glitches. On the other hand, pulsars with high $|\dot{\nu}|$, such as the Crab, exhibit a smaller glitch activity, intrinsically different from each other and from the rest of the population.

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The braking indices of glitching pulsars

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Braking index measurements are used to characterise the long-term spin evolution of pulsars. For young pulsars the trends are generally obscured by short-term phenomena such as timing noise and the recoveries form large glitches. We developed a new method to overcome the latter and report on new braking index measurements for the Vela-like pulsars B1800−21 and B1823−13, an updated measurement for the Vela and new estimates for four more glitching pulsars observed at Jodrell Bank Observatory [1].

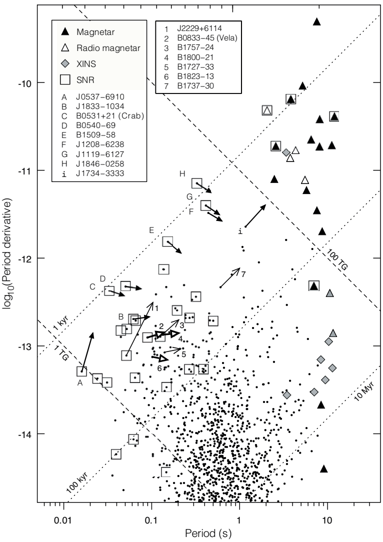

Figure 1: The P-$\dot{P}$ diagram. Pulsars will move with a slope of $2-n$, as indicated by the arrows (more details in [1]).

These measurements describe the evolution of pulsars across the P-$\dot{P}$ diagram (Fig. 1). Our results suggest a common trend involving low braking indices ($n \leq 2$) among young glitching pulsars. Such values introduce a new variant in the evolution of young pulsars and their relationship with other populations in the P-$\dot{P}$ diagram. Furthermore, using these values, the characteristic ages of these pulsars can become considerably larger. This effect can help accommodate age inconsistencies between some pulsars and their surrounding supernova remnants.

Between glitches, the short-term evolution of Vela-like pulsars is characterised by large inter-glitch braking indices $n_{\mathrm{ig}} > 10$. We interpret both short and long term trends as signatures of the large glitch activity, and speculate that they are driven by short-term post-glitch recoupling and a cumulative long-term decoupling of superfluid to the rotation of the star.

References

[1] Espinoza, C. M., Lyne, A. G., & Stappers, B. W. 2017, MNRAS, 466, 147

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Sky-localization of the LIGO-Virgo events as a test of possible polarization state of the gravitational waves

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Detection of the first gravitational wave (GW) events GW150914, GW151226 and LVT151012 by the Advanced LIGO antennas [1] has opened new possibility for study the fundamental physics of the gravitational interaction. Recent analysis [2] showed that the sky-circles of allowed positions of the GW sources for the three detected LIGO events lie parallel to the supergalactic plane of the disc-like large-scale structure known as the Local Super-Cluster of galaxies having the radius ~ 80 Mpc and the thickness ~ 30 Mpc. This points to a possibility for the reconsideration of the distances to these GW sources, which will be tested soon during the second Advanced LIGO Observing Run.

In the absence of electromagnetic identification of the GW events, an interpretation of the physics of the GW source is still uncertain. Even though the tens solar masses binary black holes coalescence at the distance 400 – 1000 Mpc is generally accepted [1], one should also test alternative possibilities allowed by modern theories of the gravitational interaction [3], [4].

In this work, we demonstrate that very general physical arguments allow us to distinguish between different polarization states predicted by the scalar-tensor gravitation theories. An actual localization of the source of GW on the sky by means of measurements of the arrival time delays between each pair of antennas together with relative amplitudes of the detected signals at each antenna can be used for the determination of the polarization state of the GW independent on the nature of the GW source. Hence the GW observations give new information about the physics of the gravitational interaction.

References

[1] Abbott, B. P., Abbott, R., Abbott, T. D., et al. 2016, PRX, 6, 041015

[2] Fesik, L. E., Baryshev, Y. V., Sokolov, V. V., & Paturel, G. 2017, arXiv:1702.03440

[3] Will, C. M. 2014, Living Reviews in Relativity, 17, 4

[4] Baryshev, Y. 2017, arXiv:1702.02020

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Neutron star equation of state and uncertainty on the radius determination

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Contrary to the core of neutron stars (NS), the crust is non-uniform and composed of nuclear clusters. Consequently, calculating the crust equation of state (EOS) is much less straightforward than for the core, which explains the smaller number of the crustal EOS available compared to those for the core. Thus non-unified EOS, i.e. based on different nuclear models for the crust and core, are often used. However, as shown in [1], for masses $M \geq 1\,M_{\odot}$ the use of non-unified EOS can introduce an uncertainty on the radius determination on the order of 5%, which is as large as the accuracy expected from the next generation of X-ray telescopes: NICER, Athena, and potential LOFT-like missions.

I will present two solutions to this problem. On the one hand, 50 unified EOS (for a purely nucleonic core or a hyperonic one) have been calculated and made available to the NS community in [1]. On the other hand, in [2] we developed an approximate approach to the NS crust, whether it is catalyzed or accreted. Then, for a given core EOS, the NS radius can be determined independently of the crust model with an error smaller than 0.1%. I will conclude by discussing correlations obtained for large sets of nuclear models in [1, 3] between the NS radius and some nuclear parameters, which are properties of nuclear matter that can be indirectly measured in laboratory. This opens the possibility of potentially constraining the NS radius with experiments on the Earth.

References

[1] Fortin, M., Providência, C., Raduta, A. R., et al. 2016, PRC, 94, 035804

[2] Zdunik, J. L., Fortin, M., & Haensel, P. 2017, A&A, in press

[3] Alam, N., Agrawal, B. K., Fortin, M., et al. 2016, PRC, 94, 052801

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Reconstruction of Light-curve Anomalies of Radio Pulsars

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Five years ago the theoretical aspects of the polarization formation based on the Kravtsov & Orlov approach were studied, and the numerical simulation method was proposed [1]. It allowed us to describe the general properties of mean profiles such as the position angle of the linear polarization *p.a.* and the circular polarization for the realistic structure of the magnetic field in a pulsar magnetosphere. We found the correlation of signs of the circular polarization, V, and the derivative of the position angle with respect to pulsar phase, $\mathrm{d}p.a./\mathrm{d}\phi$, for both emission modes. In most cases it gave us the possibility to recognize the orthogonal mode, ordinary or extraordinary, playing the main role in the formation of the mean profile.

On the other hand, there are some pulsars which observations disagreed with our predictions. For example, PSR J0452–1759 and J0738–4042 show transitions between the polarization modes which occur not at the transitions between subpulse components. Furthermore, PSR B0329+54 whose linear polarization demonstrates the presence of two orthogonal modes has the same sign of the circular polarization V within the entire pulse. And v.v., for some pulsars such as PSR J2048–1616 the position angle data correspond to one orthogonal mode while the Stokes parameter V changes sign through the mean profile.

To clarify these properties, we focus on a more detailed analysis of the wave propagation in the pulsar magnetosphere. It is shown that within our theory the circular polarization of a given mode can switch its sign, without the need to introduce a new radiation mode or other effects. The point is that the role of the electric drift motion of particles in the pulsar magnetosphere (affecting the dielectric tensor and, hence, the propagation properties) is different at small and large distances from the neutron star. As a result, the sign of the circular polarization can be different in different parts of the mean profile although they correspond to the same orthogonal mode. Moreover, generation of different emission modes on different altitudes can explain the deviation of some pulsars from the prediction of the O-X-O mode sequence for pulsars with triple mean profiles. This work was partially supported by the Russian Foundation for Basic Researches (grant N. 17-02-00788).

References

[1] Beskin, V. S., & Philippov, A. A. 2012, MNRAS, 425, 814

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Partial frequency redistribution in cyclotron lines of neutron stars

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We present a summary of our analysis [1, 2] of the frequency redistribution effects during the resonance (cyclotron) scattering of photons by electrons in a magnetized plasma. We point out the principal role of this effects on the transfer of radiation in the atmospheres of compact stars with strong magnetic fields. They are especially important if multiple scattering dominates over absorption of photons which is common for neutron stars. We estimate analytically and numerically (using Monte-Carlo simulations) the rate of frequency redistribution and show that is a very pronounced effect despite the fact that it is strongly inhibited with respect to usual Doppler redistribution which takes place in the case of atomic or ion spectral lines. Statistically, the escape of photons out of the cyclotron line results in a boosted probability of their escape from a large optical depth. As our simulations show, the emerging radiation is gathered over a large interval of optical depths, spanning one or two orders of magnitude. Potentially, this causes all sorts of inhomogeneities to show up in the resulting spectrum in a more pronounced way, and the radiation transfer equation in these situations should be solved over a range of optical depths sufficiently large to capture the origin of the major part of outgoing photons. The escape of photons from the cyclotron line greatly affects both the lines profile and the characteristic optical depth, from where the outgoing radiation originates. Through this, the spectral redistribution of gyroresonant photons changes the radiation pressure on the atmospheric plasma, that makes it one of the key phenomena which needs to be included in the studies of radiation transfer in the atmospheres of neutron stars.

References

[1] Garasev, M. A., Derishev, E. V., Kocharovsky, V. V., & Kocharovsky, V. V. 2016, MNRAS, 459, 1847

[2] Garasyov, M., Derishev, E., Kocharovsky, V., & Kocharovsky, V. 2011, A&A, 531, L14

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On the origin of pulsing X-ray emission of AE Aquarii

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The cataclysmic variable AE Aquarii is a low-mass close binary system containing a red dwarf and a rapidly rotating ($P_\mathrm{s} \simeq 33\,\mathrm{s}$) magnetized white dwarf (pulsar-like white dwarf). The optical, UV and X-ray emission of the system contains pulsing component at the spin period of the white dwarf. In contrast to optical and UV pulsations, X-ray pulsations with the period $P = 16.5\,\mathrm{s}$ have not been detected. The UV and optical oscillations are identified with two hot spots located in the regions of the magnetic poles on the white dwarf surface. The nature of the X-ray pulsing emission of AE Aqr is not yet understood. The X-ray emission of cataclysmic variables is generated due to accretion but this process cannot be applied to AE Aqr. We suggest the mechanism of magnetic poles heating by charged particles accelerated into the white dwarf magnetosphere. We assume that the primary acceleration occurs in the current sheet at the magnetospheric boundary. The next phase is the particle acceleration in the electric field generated due to the rotation of the magnetized white dwarf. The validity of our assumption is confirmed by estimations of required particle density.

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Calculation of thermal conductivity coefficients of electrons in magnetized dense matter

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The solution of the Boltzmann equation for a plasma in a magnetic field, with arbitrarily degenerate electrons and non-degenerate nuclei, is obtained by the Chapman-Enskog method [1]. The generalizing Sonin polynomials are used for obtaining an approximate solution. A gully ionized plasma is considered. The tensor of the heat conductivity coefficients in a non-quantized magnetic field is calculated. For non-degenerate and strongly degenerate plasmas the asymptotic analytic formulas are obtained, which are compared with the results of previous authors. The Lorentz approximation, with the neglect of electron-electron collisions, is asymptotically exact for a strongly degenerate plasma.

We obtain, for the first time, the analytic expressions for the heat conductivity tensor in the three polynomial approximation, taking into account of electron-electron collisions, for non-degenerate electrons in a magnetic field. The inclusion of the third polynomial improved substantially the precision of the results. In the two polynomial approximation, our solution coincides with the published results.

For strongly degenerate electrons we obtain, for the first time, an asymptotically exact analytical solution for the heat conductivity tensor in the presence of the magnetic field. This solution has a considerably more complicated dependence on the magnetic field than those in the previous publications. It gives several times smaller relative value of a thermal conductivity across the magnetic field at $\omega\tau \sim 0.8$.

References

[1] S. Chapmen and T.G. Cowling, 1952, Mathematical Theory of Nonuniform Gases, Cambridge University Press, Cambrige, UK

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Magnetized neutron star atmospheres under particle bombardment

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Thermal emission from transient and persistent magnetars may show substantial deviation from that of a passively cooling neutron star (NS). In particular, large currents associated to a twisted magnetic field are expected to be present in these objects, leading to particle bombardment onto the NS atmosphere. In this talk, we will present our radiative transfer calculations of magnetized NS atmospheres under the particle bombardment. In the model we assume that the charged particles accelerated along the twisted field lines are stopped within the inner atmospheric layers mainly by the magneto-coulomb interaction. We will show the solutions for the grey (frequency integrated) magnetized atmosphere and discuss the implications of the temperature profile for the thermal emission from the star surface

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Vacuum birefringence and X-ray polarimetry in transient magnetars

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Recent optical polarimetry observations of an X-ray dim isolated neutron star, RX J1856.5−3754, showed a first evidence for QED vacuum birefringence induced by a strong magnetic field. This important result can be confirmed by performing systematical polarimetry observations in the X-ray band for other strongly magnetized neutron stars, such as transient or persistent magnetars. We computed the phase averaged polarization fraction (PF) and polarization angle (PA) expected in the thermal emission from transient magnetars in the soft X-ray energy band. We found that the detection of a PF higher than 40% is a strong evidence for vacuum birefringence. We also found that a steady change in the PA measured from transient magnetars during their outburst decay (up to 16 degrees for a magnetospheric untwisting of 0.5 rad) is a strong evidence for vacuum birefringence. This latter detection would also provide an independent strengthening of the magnetospheric untwisting model for these sources. Simulations show that these measurements are achievable by future polarimetry missions such as XIPE and eXTP, with observations of 10 – 700 ksec.

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Spectra of accretion columns in X-ray pulsars

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We discuss recent spectral correlations with changing mass accretion rate found in transient X-ray pulsars, including the spectral hardness increase and saturation in high-luminosity sources and cyclotron resonant scattering feature (CRSF) energy increase with X-ray luminosity in low-luminosity sources. In high-luminosity pulsars, 2D calculations of radiation-dominated accretion columns with Compton-saturated sidewall spectra taking into account of reflection from the neutron star (NS) surface are able to explain the observed spectral hardness ratio correlations [1]. In low-luminosity pulsars, the X-ray spectrum is produced in semi-transparent plasma behind a collisionless shock above the NS surface, and CRSF is formed in a resonant layer in an inhomogeneous magnetic field of NS. This physical model can explain the observed CRSF correlations, including the energy dependence, line width and depth changes with X-ray luminosity. We apply this model to the recent analysis of RXTE observations of GX 304-1 [2] and NuSTAR observations of Cep X-4 [3].

References

[1] Postnov, K. A., Gornostaev, M. I., Klochkov, D., et al. 2015, MNRAS, 452, 1601

[2] Rothschild, R. E., Kühnel, M., Pottschmidt, K., et al. 2017, MNRAS, 466, 2752

[3] Vybornov, V., Klochkov, D., Gornostaev, M., et al. 2017, arXiv:1702.06361

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Glitches as Probes of Neutron Star Internal Structure and Dynamics

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Glitches, sudden spin-ups of pulsars with comparatively longer recovery, provide us with a unique opportunity to investigate various physical processes, including the crust-core coupling, distribution of reservoir angular momentum within different internal layers, spin-up in neutral and charged superfluids and constraining the equation of state of the neutron star matter. In this work, depending on the dynamic interaction between the vortex lines and the nuclei in the inner crust and between the vortex lines and the magnetic flux tubes in the outer core, various types of the relaxation behaviors are obtained and confronted with the observations. It is shown that the glitches have strong potential to deduce information about the cooling behavior and interior magnetic field configuration of neutron stars. Some implications of the relative importance of the external spin-down torques and the superfluid internal torques for recently observed unusual glitches are also discussed.

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Rotation-induced deep crustal heating of millisecond pulsars

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The spin-down of a neutron star, e.g., due to magnetic dipole losses, results in the compression of the stellar matter and induces nuclear reactions at phase transitions between different nuclear species in the crust. We show that this mechanism is effective in heating recycled pulsars, in which the previous accretion process has already been compressing the crust, so that it is out of nuclear equilibrium. We calculate the corresponding thermal surface emission and confront it with the available observations, showing that it might account for the likely thermal ultraviolet emission of PSR J0437–4715.

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Quasistationary evolution of the magnetic field in the cores of neutron stars

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We propose [1] a general method to self-consistently study the quasistationary evolution of the magnetic field in the cores of neutron stars. The traditional approach to this problem is critically revised. Our results are illustrated by calculation of the typical timescales for the magnetic field dissipation as functions of temperature and the magnetic field strength. Possible applications of these results are briefly discussed.

References

[1] Gusakov, M. E., Kantor, E. M., & Ofengeim, D. D. 2017, arXiv:1705.00508

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Conquering systematics in the timing of the Pulsar Triple System: Towards a unique and robust test of the strong equivalence principle

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PSR J0337+1715 is a millisecond radio pulsar in a hierarchical stellar triple system containing two white dwarfs. The pulsar orbits the inner white dwarf every 1.6 days. In turn, this inner binary system orbits the outer white dwarf every 327 days. The gravitational influence of the outer white dwarf strongly accelerates the inner binary, making this system an excellent laboratory for testing the strong equivalence principle (SEP) of general relativity – especially because the neutron star has significant gravitational self-binding energy. This system has been intensely monitored using three radio telescopes: Arecibo, Green Bank and Westerbork. Using the more than 30000 pulse times of arrival (TOAs), we have modeled the system with direct 3-body numerical integration and performed an initial SEP violation test. We will present our efforts to quantify the effects of systematics in the TOAs and timing residuals, which can limit the precision to which we can test the SEP in this system. For example, we are applying Fourier-based techniques to the residuals in order to isolate the effects of systematics that could masquerade as an SEP violation. We are also evaluating how different aspects of the TOA production process affect the inferred systematics. Our ultimate goal is to provide an SEP test that is robust to the complications in modeling the astrophysics of the system, and which maximizes the precision we can achieve.

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RCW 86 as a remnant of a calcium-rich core-collapse supernova explosion

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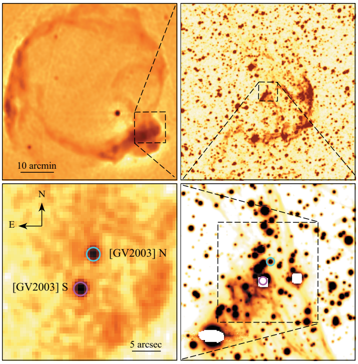

Figure 1: From the upper left clockwise: MOST 843 MHz image of RCW 86, DSS-II red band image of an arc-like optical nebula in the south-western corner of RCW 86, and VLT/FORS2 and *Chandra* images of two point sources, [GV2003] N and [GV2003] S, in the centre of the optical arc (marked, respectively, by blue and magenta circles). The orientation of the images is the same. At the RCW 86 distance of 2.3 kpc, 10 arcmin and 5 arcsec correspond to ≈6.6 and 0.05 pc, respectively.

The pyriform appearance of the supernova remnant (SNR) RCW 86 (Fig. 1) can be explained as a result of a supernova (SN) explosion near the edge of a bubble blown by the wind of a moving massive star. This interpretation implies that the SN exploded near the centre of the arc-like optical nebula in the south-western part of RCW 86. Using *Chandra* data we have discovered two sources in the expected position of the SN progenitor (Fig.1), one of which, [GV2003] S, turns out to be a foreground late-type active star, while the second one, [GV2003] N, was interpreted as a candidate neutron star [1]. Using the 7-channel imager GROND we have detected a G-type star at the position of [GV2003] N. Follow-up VLT/FORS2 spectroscopy of this star has revealed clear radial velocity variations, indicative of a close, eccentric binary, and has shown that the star is strongly polluted with calcium and other elements [2]. Our findings mean that [GV2003] N is a post-SN binary system, which has lost most of its initial mass due to common-envelope evolution shortly before core collapse, and that the SN explosion which formed RCW 86 might belong to the class of Ca-rich SNe – faint and fast transients, whose origin is strongly debated. The short orbital period of [GV2003] N indicates that this binary system will evolve into a low-mass X-ray binary (LMXB) within its nuclear time scale ($\sim 10^{10}$ yr), providing the first definite example of a pre-LMXB located within an SNR.

References

[1] Gvaramadze, V. V., & Vikhlinin, A. A. 2003, A&A, 401, 625

[2] Gvaramadze, V. V., Langer, N., Fossati, L., et al. 2017, Nature Astronomy, 1, 0116

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Equation of State for Neutron Stars: a Status Report

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The equation of state (EOS) of neutron star (NS) matter is necessary for constructing NS models. The $T = 0$ approximation is assumed. The baryon number density n_b is conveniently measured in the standard nuclear density $n_0 = 0.16\ \mathrm{fm}^{-3}$, corresponding to the matter density $\rho_0 = 2.7 \times 10^{14}\ \mathrm{g\ cm}^{-3}$. The density of matter is expected to reach up to $10\rho_0$ at the centers of the most massive NSs (those with the maximum allowable mass, M_max). The corresponding maximum baryon density can be as large as $8n_0$, because the kinetic and interaction energies contribute to ρ. Basically, the EOS, $P = P(\rho)$, consists of a crust segment with $\rho \lesssim 0.5\rho_0$ and a liquid core segment with $0.5\rho_0 \lesssim \rho \lesssim 10\rho_0$. Within the core, containing more than 95% of the NS mass, the pressure is dominated by the strong (nuclear) interactions between nucleons (baryons). Pulsar observations show that the strong repulsion due to nuclear forces can support against gravity $2M_\odot$ NS, a mass which is nearly triple of $M_\mathrm{max} = 0.7M_\odot$ that can be supported by the pressure of a non-interacting Fermi gas of nucleons.

More than forty unified EOSs are now available, derived using the same nuclear interaction model for the crust and the core. Experimental constraints, as well as recent precise ab initio many-body calculations for neutron matter and nuclear matter, put strong constraints on the EOS at $n_\mathrm{b} \lesssim n_0$ ($\rho \lesssim \rho_0$). However, then, from n_0 up to $8n_0$ at the centers of NSs with the maximum allowable mass M_max, the uncertainty in the EOS grows rapidly with the density, being nevertheless constrained in the $P - \rho$ plane by the conditions of causality (on the high-P side) and $M_\mathrm{max} > 2M_\odot$ (on the low P-side). We briefly review unified EOSs for NSs starting from realistic two-nucleon ($N = 2$) and three-nucleon $N = 3$ nuclear forces. Uncertainties resulting from the poor control over the $N > 2$ contribution to the EOS, are relevant not only for M_max, but are present alas already at n_0, are stressed. Recent versions of the relativistic mean-field theory of dense hadronic matter, where the basic lagrangian involves baryon fields coupled to meson fields and the EOS is obtained in the mean-field approximation are reviewed. These extensions involve a density-dependence for the meson masses and the nucleon-meson coupling constants, and some effects of the finite size of nucleons. Problems resulting from the finite size of nucleons and its treatment via the excluded-volume approximation are briefly discussed. In this context, the non-linearity of the high density $\rho - n_\mathrm{b}$ relation is stressed and its physical importance is illustrated. The uncertainty in the theoretical prediction of the EOS for densities $\rho_0 \lesssim \rho \lesssim 10\rho_0$ grows so rapidly with increasing ρ, that an extrapolation procedure to the high-density regime should actually be considered. The uncertainty strip narrows only after reaching $\rho \gtrsim 100\rho_0$, where quarks are certainly deconfined and perturbative QCD can be used. Perspectives for getting the true EOS for NSs from the simultaneous precise measurements of mass and radius of NSs are outlined.

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The stationary electromagnetic fields of a slowly rotating relativistic magnetized star in the braneworld

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In the present work we study the contribution of the brane tension parameter to the electromagnetic fields of a spherically symmetric slowly rotating magnetized neutron star and obtain exact analytic solution of the Maxwell equations for the magnetic and electrical fields both inside and outside the star. The influence of the brane tension on the electromagnetic energy losses of the rotating magnetized star is considered. Also, the results are compared with those previously obtained in the case of the Schwarzschild space.

Table 1: Observational data on AXPs with $\epsilon = 2GM/c^2R \sim 0.4$ and $B_0 \sim 10^{13}$G

Source	P	$\dot{P}$	$P/2\dot{P}$	$B_{\rm R}$	L	Q^*/M^2	Q^*
	s	10^{-11} s/s	kyr	10^{14} G	10^{35} erg/s		10^{11} cm^2
4U 0142+61	8.7	0.20	70	1.3	0.72	–15.49	–6.807
1E 1048.1–5937	6.4	1.3–10	4.3	3.9	0.053–0.25	–16.04	–7.049
1RXS J170849– –400910	11.0	1.9	9.0	4.7	1.9	–16.04	–7.049
XTE J1810–197	5.5	81.5	5.7	2.9	0.01-2.6	–16.04	–7.047
1E 1841–045	11.8	4.2	4.5	7.1	1.1	–16.04	–7.049
AX J1844–0258	7.0	0.048	220	0.60	0.05–1.2	–9.170	–4.029

References

[1] Ginzburg, V. L., Ozernoy, L. M., 1965, Sov. Phys. JETP 20, 689

[2] Petterson, J. A. 1974, PRD, 10, 3166

[3] Geppert, U., Page, D., & Zannias, T. 2000, PRD, 61, 123004

[4] Rezzolla, L., Ahmedov, B. J., & Miller, J. C. 2001, MNRAS, 322, 723

[5] Randall, L., & Sundrum, R. 1999, PRL, 83, 3370

[6] Dadhich, N., Maartens, R., Papadopoulos, P., & Rezania, V. 2000, Physics Letters B, 487, 1

[7] Ahmedov, B. J., & Fattoyev, F. J. 2008, PRD, 78, 047501

[8] Landau, L. D., Lifshitz, E. M., The Classical Theory of Fields, 1987, Pergamon Press, Oxford

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Fast Radio Bursts and their Possible Neutron Star Origin

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I will review our current observational understanding of the Fast Radio Bursts (FRBs), which are millisecond-duration radio pulses originating at extragalactic distances [2, 4, 7, 10]. Many theories for the physical nature of the FRBs have been proposed — including both cataclysmic events involving neutron star collision (or collapse), along with non-cataclysmic scenarios involving a young and/or highly magnetized neutron star. While some FRBs appear to be one-off events — arguably supporting a cataclysmic origin — a sporadically repeating FRB has also recently been discovered [8]. It is thus currently unclear whether there is a single type of FRB, or whether we are seeing multiple source populations [6]. In any case, it seems very likely that exotic manifestations of neutron stars are at least part of the puzzle. Most recently, our group has achieved a precise localization for the repeating FRB 121102, which shows that it is hosted by a dwarf galaxy at a distance of $\sim 1\,\mathrm{Gpc}$ [1, 9]. FRB 121102 is also physically associated with a persistent source of radio waves, which is offset from the center of light of the host galaxy [3]. Together, these findings suggest that FRB 121102 may be an extremely young and highly magnetized neutron star, and since superluminous supernovae and long gamma-ray bursts are also preferentially found in dwarf galaxies similar to the FRB 121102's host, there is the possibility that it was created during such an event [3, 5, 9].

References

[1] Chatterjee, S., Law, C. J., Wharton, R. S., et al., 2017, Nature, 541, 58
[2] Lorimer, D. R., Bailes, M., McLaughlin, M. A., et al., 2007, Science, 318, 777
[3] Marcote, B., Paragi, Z., Hessels, J. W. T., et al., 2017, ApJ, 834, L8
[4] Masui, K., Lin, H.-H., Sievers, J., et al., 2015, Nature, 528, 523
[5] Metzger, B. D., Berger, E., & Margalit, B., 2017, arXiv:1701.02370
[6] Scholz, P., Spitler, L. G., Hessels, J. W. T., et al., 2016, ApJ, 833, 177
[7] Spitler, L. G., Cordes, J. M., Hessels, J. W. T., et al., 2014, ApJ, 790, 101
[8] Spitler, L. G., Scholz, P., Hessels, J. W. T., et al., 2016, Nature, 531, 202
[9] Tendulkar, S. P., Bassa, C. G., Cordes, J. M., et al., 2017, ApJ, 834, L7
[10] Thornton, D., Stappers, B., Bailes, M., et al., 2013, Science, 341, 53

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Enigmatic results from an X-ray/radio campaign on the radio-mode-switching pulsar PSR B1822–09

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We report on an X-ray and radio campaign of the radio-mode-switching pulsar PSR B1822–09 [1]. This pulsar switches between a radio-bright (B) and radio-quiet (Q) mode. Its radio Q mode exhibits an interpulse (IP) located at about half a rotation period from the main pulse (MP), which switches simultaneously but in anti-correlation with the MP. We now discovered, in addition, a relationship between the durations of its modes and known underlying radio-modulation time-scales within the modes. The fact that both, mode change and the modulations, occur simultaneously at both poles suggests that both reflect magnetospheric effects, rather than local polar cap physics.

Furthermore, we discovered X-ray pulsations with a single broad sinusoidal pulse, slightly lagging the radio main pulse in phase, with an energy-dependent pulsed fraction reaching a value of ~ 0.6 at 1 keV. The total X-ray spectrum appears to consist of a pulsed hot component and cool unpulsed emission. The high pulsed fraction seems to require rather enigmatic explanations like magnetic anisotropic beaming effects in its strong magnetic field.

The original aim of the simultaneous X-ray and radio observations was to reveal simultaneous X-ray and radio moding like we discovered earlier for the nearly aligned pulsar PSR B0943+10 [2]. However, we found no evidence for X-ray mode switching of PSR B1822–09. It appears that the thermal X-ray emission, of local origin, has no relation with the magnetospheric effects that explain the radio properties.

The characteristics of PSR B1822–09 will be discussed in the light of the synchronous mode switching in the radio and X-ray emission properties of PSR B0943+10 [2, 3].

References

[1] Hermsen, W., Kuiper, L., Hessels, J. W. T., et al. 2017, MNRAS, 466, 1688

[2] Hermsen, W., Hessels, J. W. T., Kuiper, L., et al. 2013, Science, 339, 436

[3] Mereghetti, S., Kuiper, L., Tiengo, A., et al. 2016, ApJ, 831, 21

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Multipoles re-emergence and central compact objects

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Multiple recent studies highlight the essential role of the small scale magnetic field for accreting and isolated pulsars as well as for the central compact objects. To understand the evolution of such magnetic field the detailed numerical simulations are required. For the first time we perform the simulations of the crust confined magnetic field of a radio pulsar containing the higher order multipoles [1]. Our aim is to analyse the field re-emergence which follows the fall-back of material after the supernova explosion. We find that the higher order multipoles which are potentially responsible for the activation of the radio pulsar emission, survive the fall-back episode. For a first few kyrs the strength of higher order multipoles is suppressed strongly, so the external poloidal magnetic field of a neutron star looks exactly dipolar which is in a good agreement with observations of the central compact objects that show no sign of radio pulsations. The re-emergence timescales for multipoles with number $\ell > 6$ is significantly shorter than the dipole re-emergence timescale. Thus the relative strength of multipoles ($\ell > 6$) is larger during few 10 kyrs till 1 Myr. It means that we expect to observe old-looking pulsars (large spin-down age) in which a partly re-emerged magnetic field activated the radio emission but the dipolar component is still weak which sets the huge spin-down age. We discuss the observational prospects to discover such objects.

References

[1] Igoshev, A. P., Elfritz, J. G., & Popov, S. B. 2016, MNRAS, 462, 3689

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The white dwarf radio pulsar AR Sco challenges pulsar physics

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Marsh et al. [1] have recently reported the discovery of a radio-pulsing white dwarf in the cataclysmic variable AR Sco. The period of pulsations, which are also seen in the optical and UV, is about 117 seconds. High intensity of the pulsing radiation and the non-thermal character of its spectrum leave little room for doubt that the white dwarf in AR Sco operates as a spin-powered pulsar and, therefore, is in the ejector state. Using the approach developed earlier for the interpretation of the pulsar-like white dwarf in AE Aqr [2–4] we evaluate the surface magnetic field of the white dwarf in AR Sco as 100–300 MG. We argue that this source has originated due to accretion-driven spin-up in a previous epoch in which the magnetic field of the white dwarf had substantially evolved being initially buried by the accreted matter. It recovered to its initial value after the spin-up phase had ended. We show that the mechanism of pulsing radio emission in this source is rather puzzling. The large radius of the white dwarf makes general relativity effects at its surface negligible and the magnetic field is too weak to produce pair creation. Possible alternative mechanisms for particle acceleration and generation of radio emission in the magnetosphere of the white dwarf are briefly discussed.

References

[1] Marsh, T.R., Gänsicke,B.T., Hümmerich, S., et al., 2016, Nature, 537, 374.

[2] Ikhsanov, N.R., 1998, A&A, 338, 521.

[3] Ikhsanov, N.R., Biermann, P.L., 2006, A&A, 445, 305.

[4] Ikhsanov, N.R., Beskrovnaya, N.G., 2012, Astron. Rep., 56, 595.

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What can we learn about stellar magnetization by studying unique spin evolution of the X-ray pulsar OAO 1657-415

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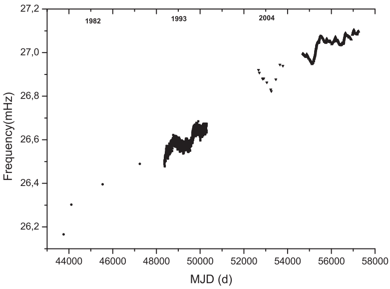

Figure 1: Spin evolution of OAO 1657–415

The persistent X-ray pulsar OAO 1657–415 is associated with a wind-fed High Mass X-ray Binary and shows a peculiar spin evolution. Its basic parameters are well studied including the magnetic field of the neutron star which is measured through observations of the cyclotron line. The pulsar is observed to experience a regular long-term spin-up superposed with chaotic spin-up/spin-down events during which its period changes at a very high rate. According to our analysis, such a behavior can be expected if the stellar wind of the massive component is relatively slow and magnetized. Considering the neutron star as a probe, we find that the velocity of the wind in the orbital plane at the distance of the binary separation does not exceed 300 km/s and the magnetic field in the wind from which the neutron star captures material lies in the interval 20–70 mG. Finally, the observed spin evolution of the pulsar suggests that the stellar wind velocity may decrease as the massive star is approaching the final stage of its evolution.

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Plasma polarization in compact stars

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Macroscopic plasma polarization, which is created by gravitation and other mass-acting forces in massive astrophysical objects (MAO), is under discussion. New "non-ideality force" due to the effects of strong Coulomb interaction of charged particles was claimed (Iosilevskiy, NS-2008 [1]) as an additional significant source of such a polarization. A standard description in the local (LTE) approximation is well-known (e.g. L. Bildsten, 2010, etc.) Simplified situation of totally equilibrium isothermal star without any magnetic field and relativistic effects is considered. The study based on a multi-component version of variational formulation of equilibrium statistical mechanics. A compact and general (non-local!) formula is presented as a general solution of the problem [2]. It includes naturally all non-ideality effects within the main Jakoby matrix for densities on chemical potentials [3]. One of the significant consequences of this formula is the prediction of macroscopic charge localization at any phase interface and/or any other discontinuities in homogeneous thermodynamic profiles in the interiors of compact stars.

References

[1] Iosilevskiy I., Plasma Polarization in Massive Astrophysical Objects, 2008, Int. Conf. "Physics of Neutron Stars", St. Petersburg, Russia; http://www.ioffe.ru/astro/NS2008.

[2] Iosilevskiy, I. 2009, Contributions to Plasma Physics, 49, 755; astro-ph:0902.2386.

[3] Iosilevskiy, I.L., 2010, High Temperature, 48: 766

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Enthalpic and entropic phase transitions in compact stars

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Features of Gas-Liquid (GL) and Quark-Hadron (QH) phase transitions (PT) in dense nuclear matter are under discussion in comparison with their terrestrial counterparts, e.g. the so-called "plasma" PT in shock-compressed hydrogen, nitrogen, etc. Both, GLPT and QHPT, when being represented in a widely accepted temperature – baryonic chemical potential plane, are often considered as similar, i.e. amenable to one-to-one mapping by simple scaling. It is argued that this impression is illusive and that GLPT and QHPT belong to different subclasses: GLPT is a typical enthalpic PT (e.g. Van-der-Waals-like) while "deconfinement-driven" QHPT is a typical entropic PT. A subdivision of all 1st-order fluid-fluid phase transitions into two subclasses: enthalpic and entropic PTs (i.e. H-PT and S-PT), was proposed earlier [arXiv:1504.05850]. Thermodynamics of S-PT is more complicated than that of H-PT. In particular, an isostructural entropic PT is always an internal part of a more general thermodynamic anomaly – extended domain with abnormal (negative) sign for the set of (usually positive) second cross derivatives of the thermodynamic potential, e.g. Gruneizen coefficient, thermal expansion coefficient, thermal pressure coefficient etc. Negative sign of all the derivatives leads to the violation of standard behavior and relative order for many iso-lines in the $P-V$ plane, e.g. isotherms, isentropes, shock adiabats etc. Besides, the entropic PTs (e.g. QHPT) have more complicated topology of stable and metastable domains within the two-phase region in comparison with the conventional enthalpic PTs (e.g. VdW-like GLPT). In particular, a new additional metastable region, bounded by new additional spinodals, appears in the case of the entropic PTs. All the features of the entropic PTs and accompanying anomalous thermodynamics have transparent geometrical interpretation – multi-layered structure of thermodynamic surfaces for temperature, entropy and internal energy as a pressure-volume functions, e.g., for $T(P,V), S(P,V)$ and $U(P,V)$.

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r-mode instability windows for superfluid neutron stars

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The finite-temperature r-mode spectrum of a slowly rotating superfluid Newtonian neutron star (NS) is calculated neglecting the entrainment between neutron and proton liquid components (i.e., neglecting the off-diagonal element of the entrainment matrix). It is shown that for the 'minimal' NS core composition (neutrons, protons, and electrons) only two $m = 2$ r-modes exist — a normal mode, which is similar to the ordinary r-mode in a nonsuperfluid star, and a superfluid temperature-dependent mode. The presence of muons in the core dramatically modifies the oscillation spectrum, resulting in an infinite set of superfluid r-modes, whose frequencies vary with temperature. It is demonstrated that the normal r-mode can exhibit avoided crossings with superfluid modes at certain "resonance" temperatures, where it dissipates strongly, leading to a substantial suppression of the r-mode instability near these temperatures. The corresponding instability windows are calculated and discussed.

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Pulsar wind nebulae in X-rays and other wavelengths

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We will review recent progress in multiwavelength observations of pulsar wind nebulae (PWNe). In particular, we will talk about (1) constraining the pulsar magnetosphere geometry with high-resolution Chandra images, (2) properties of tails and misaligned outflows of supersonic pulsars, (3) far-UV emission from bowshocks, and (4) PWNe detected in TeV and GeV bands. We will also discuss the some open problems and future observing strategies.

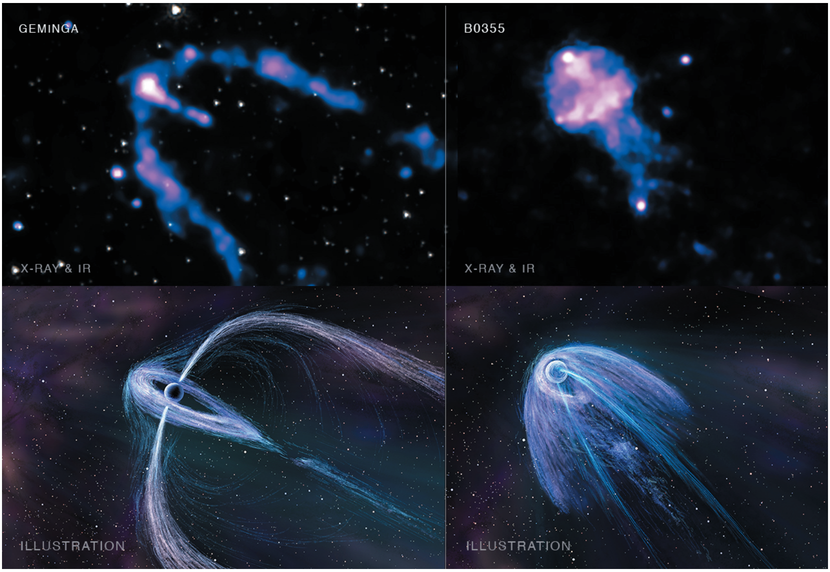

Figure 1: Chandra images of compact structures in two PWNe (illustrations made by Nahks TrEhnl).

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XMM-Newton **observations of the γ-ray pulsar J0633+0632**

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PSR J0633+0632 is a radio-quiet pulsar discovered with *Fermi*. Analysing the *Chandra* data, we found evidence of an absorption feature in the pulsar spectrum at ≈0.8 keV though its nature remained unclear due to the low statistics [1]. For a better study of the J0633+0632 and its pulsar wind nebula, we performed *XMM-Newton* observations. An analysis of these data did not confirm the existence of the absorption feature. It revealed new details of unusual morphology of the pulsar wind nebula. We also found diffuse emission in the pulsar field that is likely to be filaments of the Monoceros Loop supernova remnant. We report on the results of timing and spectral analysis of J0633+0632 and on the spectral analysis of its nebula and the presumed filaments. The work was supported by RF Presidential Programme MK-2566.2017.2.

References

[1] Danilenko, A., Shternin, P., Karpova, A., Zyuzin, D., & Shibanov, Y. 2015, PASA, 32, e038

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Evolution of magnetic field of massive stars

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Based on the recent measurements of magnetic fields of massive OB stars we calculate the magnetic field distribution function $f(B)$. We found that the magnetic fields are distributed according to a log-normal law with a mean $\log B = 2.5$ and a standard deviation sigma=0.5. The shape and width of the magnetic field distribution appeared to be similar to that for neutron stars. It probably means that the magnetic fields of neutron stars are determined the magnetic fields of massive OB stars. We argue that the observed fraction of magnetic stars is determined by the physical conditions at the pre-main sequence stages of stellar evolution. We also compare the spatial distribution of the OB stars and neutron stars.

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Interaction of the jet from the neutron star with the interstellar medium

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The interaction between a supersonic plasma jet from an accreting neutron star and the ambient interstellar medium is studied. It is assumed that the jet is launched from the accretion disk via the open magnetic field lines anchored in the disk. The analytical investigation for the structure of the working surface of the jet is carried out. Estimations of plasma parameters of the interaction region between the jet and the interstellar medium are obtained.

Magnetocavitation mechanism for the generation of quasi-periodic oscillations of X-ray radiation in the accretion disk coronae of neutron stars and black holes

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The process of generation of quasi-periodic oscillations of X-ray radiation in the coronae of the accretion disks of neutron stars and black holes is investigated. The magnetocavitation mechanism of this process is suggested. According to this mechanism, the quasi-periodic oscillations of X-ray radiation are produced by oscillations and destruction of plasmoids in the coronal plasma of the accretion disk. Estimations of the parameters of quasi-periodic oscillation are performed.

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Magnetocavitation mechanism for the generation of the flares and the plasma ejections from the corona of the accretion disk of the neutron star

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The processes of generation of flares and plasma ejections from a corona of an accretion disk of neutron stars are investigated. The magnetocavitation mechanism as a possible mechanism for these processes is proposed. According to this mechanism, the plasma ejections and flares are produced because of the destruction of plasmoids in the coronal plasma of the accretion disk. These plasmoids are created by the magnetic reconnection in the current sheets of the coronal plasma of the accretion disk [1]. Some plasmoids are ejected from the corona, but others are collapsed because of the resonant wave processes and shock waves in the coronal plasma. The estimations of the flare and ejection parametres are performed. The possibility of the application of the suggested mechanism to the plasma turbulization in the corona of an accretion disk and the acceleration of jets from the neutron stars is discussed.

References

[1] Priest, E., & Forbes, T. 2000, Magnetic reconnection : MHD theory and applications. New York : Cambridge University Press, 2000.

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Luminosity of synchrotron radiation in pulsar magnetospheres

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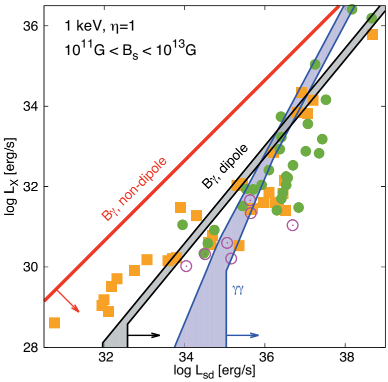

Figure 1: Synchrotron X-ray luminosity L_X from particles created through $\gamma\gamma$ (blue) and Bγ processes with dipole (black) and non-dipole magnetic field (red) at the emission region as a function of the spin-down luminosity L_{sd}. The circles are the observed values [1].

Synchrotron radiation is widely considered to be the origin of the pulsed non-thermal emissions from rotation-powered pulsars in optical and X-ray bands. The observed X-ray and optical emissions provide the energy flux of secondary particles created from curvature photons emitted by primary particles in the magnetosphere. Since γ-ray, X-ray, and optical emitting particles are related through a pair cascade process, their flux ratios are useful to understand the pair cascade process in the magnetosphere.

We study the synchrotron radiation emitted by the created electron and positron pairs in the pulsar magnetosphere to constrain the energy conversion efficiency η from the Poynting flux to the particle energy flux. We model two pair creation processes, two-photon collision ($\gamma\gamma$) and magnetic pair creation (Bγ). Using the analytical model, we derive the maximum synchrotron luminosity (Fig. 1). The synchrotron luminosity is proportional to the energy conversion efficiency η for all models. From the comparison with observations, we find that the energy conversion efficiency to the accelerated particles should be an order of unity to explain the observed luminosities, even though we make a number of optimistic assumptions to enlarge the synchrotron luminosity. The obtained maximum luminosity would be useful to select observational targets in X-ray and optical bands.

References

[1] Kisaka, S., & Tanaka, S. J. 2017, ApJ, 837, 76

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Deep Chandra Observations of Nebulae Produced by Three Supersonic Pulsars

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When pulsars move with supersonic speeds, the ram pressure exerted by the oncoming ambient interstellar medium exceeds the pulsar wind pressure, thus confining the pulsar wind to the direction opposite the pulsar motion, resulting in a bow shock nebula with an extended tail behind the pulsar. Deep Chandra observations of PSRs J1509–5850, J1747–2958 (the Mouse), and B0355+54 have revealed both the small and large-scale structures of the pulsar wind nebulae (PWNe) produced by these pulsars. We have observed contrasting morphologies of the compact PWN heads, resolved jets and extended tails, and measured the spatially-resolved spectra of these PWNe. We also attempt to make a connection between the pulsar geometries and the appearances of their PWNe. For PSRs J1509 and B0355 we have discovered asymmetric misaligned structures similar to those seen in the Guitar and Lighthouse PWNe. These observations probe the physics of magnetized relativistic outflows including particle diffusion, collisionless shock structure, magnetized flow collimation, magnetized plasma turbulence, and reconnection.

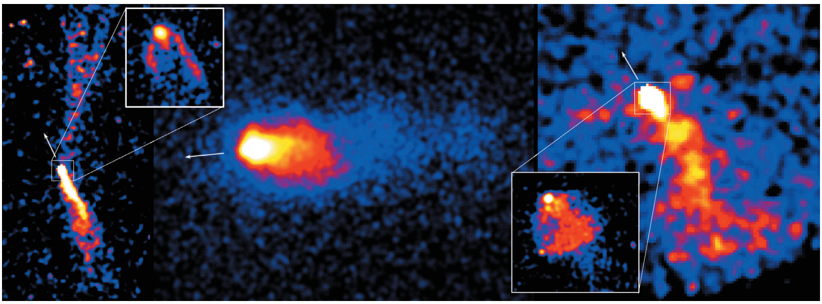

Figure 1: Chandra images of PWNe and tails produced by supersonic pulsars (from left to right: J1509–5850, the Mouse, and B0355+54). The arrows show the direction of proper motion.

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Nucleus–nucleus interactions in the inner crust of neutron stars

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The interaction between nuclei in the inner crust of neutron stars consists of two contributions, the so-called “direct” interaction and an “induced” one due to density changes in the neutron fluid. For large nuclear separations r the contributions from nuclear forces to each of these terms are shown to be nonzero. In the static limit they are equal in magnitude but have opposite signs and they cancel exactly. We analyze earlier results on effective interactions in the light of this finding. We consider the properties of long-wavelength collective modes and, in particular, calculate the degree of mixing between the lattice phonons and the phonons in the neutron superfluid. Using microscopic theory, we calculate the net non-Coulombic contribution to the nucleus–nucleus interaction and show that, for large r, the leading term is due to exchange of two phonons and varies as $1/r^7$: it is an analog of the Casimir–Polder interaction between neutral atoms.

References

[1] Kobyakov, D., & Pethick, C. J. 2016, PRC, 94, 055806

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Magnetic energy stored in relativistic force-free magnetosphere

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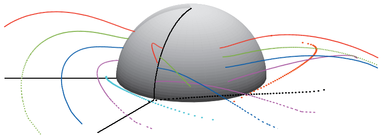

Figure 1: Three-dimensional magnetic field-line structure in the upper half-plane. The lines are twisted by current flow in the force-free magnetosphere. As an example, four lines starting from the stellar surface at azimuthal angles $\phi = 0, \pi/3, 2\pi/3$ are displayed. Field lines on the torus are also displayed. They start from $\phi = 0, \pi/3$, and $2\pi/3$ on the equator and return to it.

Magnetars are a class of neutron stars, and have strong magnetic fields. Their activities are supplied by the strong fields. Study of the magnetosphere and long term evolution is one of very important issues. Magnetar magnetospheres are gradually twisted due to shearing motion at the surface. At the same time, the energy is stored there. When it exceeds a threshold, the energy is abruptly released on a much shorter dynamical timescale as observed in energetic flares. The process is analogous to solar flare, and is so far discussed as a giant flare model on magnetars. The objects are however relativistic ones. Here, their magnetospheres are calculated by taking into account general relativistic effect. Static and axially symmetric force-free magnetospheres are calculated in the exterior of non-rotating stars. The magnetic energy increases by the twist degree. In a highly twisted case, a magnetic flux rope, in which a large toroidal field is confined, is detached in the vicinity of the star. Numerical result for twisted structure is demonstrated in Fig. 1. It is found that larger amount of energy is capable to be stored in the relativistic magnetosphere. In an extreme case, the magnetic energy increment in the presence of current flow exceeds that of current-free dipole. There is an upper limit in any model, and a catastrophic event like a giant flare would occur, when the field is further twisted.

References

[1] Y. Kojima, Axisymmetric force-free magnetosphere in the exterior of a neutron star, 2017 in preparation

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Drift of HF components in PSR 0531+21 radiation as confirmation of the idea of nonlinear reflection from the surface of neutron star

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20 years after the detection of the high frequency (HF) components in the radiation of the Crab pulsar by D. Moffet and T. Hankins [1], T. Hankins, G. Jones & J. Eilek returned to the observation of these objects at even higher frequencies [2]. The detailed analysis of physical results and problems is discussed in the authors' review [3]. The questions of inter pulse shift and HF component appearance have been marked as unresolved but one of the results, a frequency drift of HF components has been discovered. The emergence of the HF components in the same frequency range, as that in which the inter pulse shift [1] takes place, permits us also to associate these components with reflection [4] from the neutron star surface. (See more detailed examination of the problem with the discussion of coherence and spectrum in the report by the author and S.V. Trofymenko at this conference [5]). In the non-linear reflection model [6] (which is the model of induced Raman scattering by surface waves), the frequency shift of the HF components appears in the natural way, regardless of the type of surface waves that induce the Raman scattering. It is only important in our consideration that the reflection is associated with "Wood's anomaly" involving the diffraction waves creeping along the star surface. In the previous work [6] we have assumed that different HF components are produced by opposite magnetic poles. The unidirectional drift, that is intrinsic to both components [2], stipulates one to associate them with the single magnetic pole of the star and maybe with the birefringence in the magnetosphere.

References

[1] Moffett, D. A., & Hankins, T. H. 1996, ApJ, 468, 779
[2] Hankins, T. H., Jones, G., & Eilek, J. A. 2015, ApJ, 802, 130
[3] Eilek, J. A., & Hankins, T. H. 2016, Journal of Plasma Physics, 82, 635820302
[4] Kontorovich, V. M., & Trofymenko, S. V. 2016, arXiv:1606.02966
[5] Kontorovich, V. M., & Trofymenko, S. V. 2017, "On the mystery of the interpulse shift in the Crab pulsar", this Book
[6] Kontorovich, V. M. 2016, Low Temperature Physics, 42, 672; arXiv:1701.02302.

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On the mystery of the interpulse shift in the Crab pulsar

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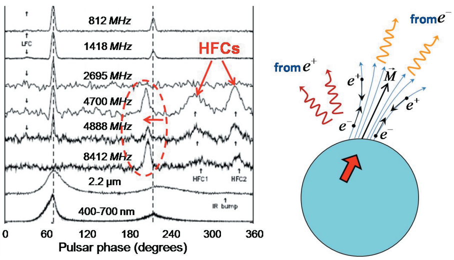

Figure 1: *Left:* Light curves obtained at multi-frequency observations in [1]. The shifted (to about $7^{\rm deg}$) interpulse and high-frequency components (HFCs) are marked. With gratitude to the authors. *Right:* Schematic picture of motion and radiation by electrons and positrons in the polar gap of the pulsar in the case of a tilted magnetic axis [3]. The directions of radiation by electrons and reflected radiation by positrons are shifted at the angle of mirror reflection

A new mechanism of radiation emission in the polar gap of a pulsar is proposed. It is based on the curvature radiation which is emitted by positrons moving toward the surface of the neutron star along magnetic field lines and it reflects from the surface (Fig. 1, right). It is shown that the proposed mechanism may be applicable for explanation of the mystery of the interpulse shift in the Crab pulsar at high frequencies discovered by Moffett and Hankins [1] twenty years ago (for a recent confirmation, see [2]).

We also took into account the coherence of positron curvature radiation and calculated the spectrum which coincides with the observed one. The high-frequency components, appearing at the same frequencies as the interpulse shift, can be naturally explained by a nonlinear reflection (stimulated scattering) of radiation produced by returning positrons [4].

References

[1] Moffett, D. A., & Hankins, T. H. 1996, ApJ, 468, 779

[2] Hankins, T. H., Jones, G., & Eilek, J. A. 2015, ApJ, 802, 130

[3] Kontorovich, V. M., & Trofymenko, S. V. 2016, arXiv:1606.02966

[4] Kontorovich, V. M. 2016, Low Temperature Physics, 42, 672; arXiv:1701.02302.

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How young the accretion-powered pulsars could be?

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A question about the age of accretion-powered X-ray pulsars has recently been reopened by the discovery of the X-ray pulsar SXP 1062 in the SMC. This High Mass X-ray Binary (HMXB) contains a neutron star rotating with the period of 1062 s and is associated with a supernova remnant of the age $\sim 10^4$ yr [1–3]. An attempt to explain the origin of this young long-period X-ray pulsar within the traditional scenario of three basic states (ejector, propeller and accretor) encounters difficulties. Even if this pulsar were born as a magnetar, the spin-down time during the propeller stage would exceed 10^4 yr. Here we explore a more circuitous way of the pulsar spin evolution in HMXBs, in which the propeller stage in the evolutionary track is avoided. We find this way to be possible if the stellar wind of the massive companion to the neutron star is magnetized. The geometry of the plasma flow captured by the neutron star in this case differs from spherically symmetrical, and the screening of the dipole magnetic field of the neutron star does not occur. We show that the age of an accretion-powered pulsar in this case can be as small as $\sim 10^4$ years without the need of invoking initial magnetic field in excess of 10^{13} G.

References

[1] Haberl, F., Sturm, R., Filipović, M. D., Pietsch, W., & Crawford, E. J. 2012, A&A, 537, L1

[2] Hénault-Brunet, V., Oskinova, L. M., Guerrero, M. A., et al. 2012, MNRAS, 420, L13

[3] Sturm, R., Haberl, F., Oskinova, L. M., et al. 2013, A&A, 556, A139

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Physical features of multicomponent Coulomb crystals

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Coulomb crystals consist of fully ionized ions arranged in a crystal lattice and immersed into the uniform neutralizing electron background. It is thought that matter in white dwarf cores and neutron star crusts is arranged in the body-centered cubic (bcc) Coulomb lattice because this lattice has the lowest electrostatic energy among all lattices which were ever been studied. Most of these studies were devoted to one-component crystals with one type of the ion in the elementary cell. However, in the interior of degenerate stars the existence of crystallized mixtures is not excluded.

In this work, we consider electrostatic and phonon properties of different multicomponent Coulomb crystal lattices. For instance, an analysis of the phonon spectra shows that the binary bcc Coulomb crystal is stable if the ratio $\alpha \equiv Z_2/Z_1$ lies between 1/3.6 and 3.6 (Z_i is an i-th ion charge number) so the sufficiently different ions can not form the bcc lattice. On the other hand the binary "MgB_2 lattice" is stable if $\alpha \in [0.1; 0.375]$. And while the binary bcc lattice stay cubic at any possible α, the binary hexagonal close-packed lattice changes its size. The distance between its hexagonal layers decreases with the growth of $|\alpha - 1|$.

Also, for some lattices the energy of zero-point vibrations was calculated and the linear mixing rule was checked.

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Properties of Konus-*Wind* SGR bursts

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Magnetars are enigmatic objects, which are defined as highly magnetized isolated neutron stars. They manifest themselves as soft gamma repeaters (SGRs) and anomalous x-ray pulsars (AXPs), which are, fundamentally, the same type of objects. From its launch in 1994, Konus-*Wind* (KW) has detected several hundred bursts from 6 SGRs.

We present results of systematic temporal and spectral analysis of KW observational data on short and intermediate SGR bursts. We conclude that the bursts with the 20–200 keV energy spectra are equally well described by both power law with an exponential cutoff (CPL), and by double black-body (2BB) functions. We also discuss energetics and durations of the bursts, distributions of spectral parameters and correlations between them.

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Pulsed emission from a rotating off-centred dipole in vacuum

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Studying electromagnetic field around neutron stars is one of the vital methods to understand the physics of the pulsars. From the very beginning of the efforts made to understand these objects, most of the works have been based on the assumption of a standard centred dipolar electromagnetic field. However, later there have been some studies which focus on including higher multipolar field components while considering the electromagnetic fields and explain how these components modify our current ideas about these objects [1].

Also, another prevalent standard assumption is that the magnetic moment lies at the geometrical centre of the star. Possibilities of deviation from this standard centred case have been seen to exist for stars and, even, planets. Apart from the simplicity, there is no special reason to consider such centred case. In [2] a more generalized picture has been put forward for pulsars in which the magnetic dipole moment is shifted off the centre of the star showing how a rotating off-centred dipole can be expanded into multipolar components.

We will discuss the effects of such off-centred rotating dipole on various characteristic features of pulsars in vacuum. Showing how the magnetic field line structure is different for the two geometries, the reliability of the off-centred geometry will be analyzed. We will outline the consequences of this approach on the shape of the polar caps, radio and high energy emission phase plots and light curves presenting a comparison with the standard centred case [3]. We will conclude with a summary of possible future investigations for improvement along with a small highlight on the next steps involving force free environment.

References

[1] Pétri, J. 2015, MNRAS, 450, 714

[2] Pétri, J. 2016, MNRAS, 463, 1240

[3] Kundu, A., Pétri, J. 2017, Pulsed emission from a rotating off-centred dipole in vacuum (in prep.)

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Rotating progenitors of single and binary neutron stars and black holes

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We discuss the formation of dynamically unstable rotating stellar cores due to a merger process of two stellar cores in a common envelope. We applied population synthesis calculations to assess the expected fraction of such rapidly rotating stellar cores which may lead to fission and formation of a pair of proto-neutron stars. We have used the BSE (Binary Star Evolution) population synthesis code supplemented with a new treatment of stellar core rotation during the evolution via effective core-envelope coupling, characterized by the coupling time, τ_c. The validity of this approach is checked by direct MESA calculations of the evolution of a rotating 15 $M_\odot$ star. From comparison of the calculated spin distribution of young neutron stars with the observed one we infer the value $\tau_c \simeq 5 \times 10^5$ yr. We show that merging of stellar cores in common envelopes can lead to collapses with dynamically unstable proto-neutron stars, with their formation rate being $\sim 0.1 - 1$ per cent of the total core collapses, depending on the common envelope efficiency [1]. We also discuss low effective black hole spins inferred for LIGO GW150914 and LTV151012 events. Population synthesis calculations of the expected spin and chirp mass distributions of black holes from the standard field massive binary formation channel are presented for different metallicities (from zero-metal Population III stars up to solar metal abundance) [2].

References

[1] Postnov, K. A., Kuranov, A. G., Kolesnikov, D. A., Popov, S. B., & Porayko, N. K. 2016, MNRAS, 463, 1642

[2] Postnov, K., & Kuranov, A. 2017, arXiv:1702.08056

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High Resolution Radio Polarimetric Study of the Pulsar Wind Nebula MSH 15−52

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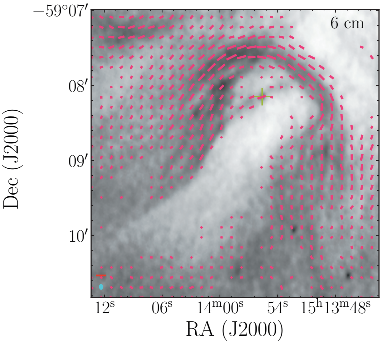

Figure 1: Intrinsic *B*-field vectors for MSH 15−52 overlaying on the 6 cm radio intensity map in grey-scale. The vector length is porportional to the polarized intensity. The beam size and polarization scale is indicated at the lower-left corner. The pulsar B1509−58 is indicated by a green cross.

Pulsar winds are charged particles accelerated by the extremely strong magentic field of rotation-powered pulsars. These particles are shocked upon interacting with the ambient environment and they emit broadband synchroton radiation. Such a structure is known as a pulsar wind nebula (PWN).

We present a high-resolution radio imaging study of the PWN MSH 15−52 with new Australia Telescope Compact Array observations at 6 cm and 3 cm. The system is powered by a young and energetic radio pulsar B1509−58 with a high spin down luminosity of $\dot{E} \approx 2 \times 10^{37}$ erg s^{-1} [2].

Previous X-ray studies found a complex morphology for the PWN: the overall shape resembles a hand, extending over 10 pc with small-scale features like jets, arc, filaments and enhanced emission knots in the associated HII region RCW 89 [1]. The new radio images show different morphology than the X-ray counterpart. No radio emission is detected at the X-ray jet position; instead we found enhanced emission in a sheath surrounding the jet. Additional small-scale features including a polarized linear filament next to the pulsar have also been discovered. Our polarization measurements show that the intrinsic orientation of magnetic field aligns with the sheath wrapping around the edge of the jet. Spectral analysis results indicate a flat spectrum across the nebula, with some spatial variations. Implications of these findings will be discussed.

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References

[1] Gaensler, B. M., Arons, J., Kaspi, V. M., et al. 2002, ApJ, 569, 878

[2] Gaensler, B. M., Brazier, K. T. S., Manchester, R. N., Johnston, S., & Green, A. J. 1999, MNRAS, 305, 724

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On the second derivatives of the spin periods and braking indices in radio pulsars

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The analysis of some braking mechanisms for neutron stars was carried out to determine the sign of the second derivative of the pulsar spin period. This quantity is the important parameter for calculations of the braking index n. It is shown that this derivative can be positive and lead to decreasing of n. It is necessary to correct the current methods of calculations of n because they are based, as a rule, on the suggestion on the constancy of pulsar parameters (magnetic fields, angles between some axes and so on). The estimations of the corrections to braking indices are obtained. It is shown that these corrections can be noticeable for pulsars with long periods and small period derivatives.

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Pulsar timing and its applications

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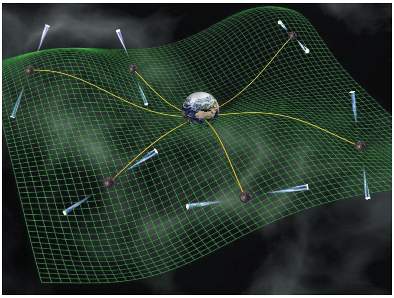

Figure 1: Gravitational-wave detection with Pulsar Timing Arrays. Image credit: D. J. Champion.

Pulsar timing observations reveal a wide range of perturbations to the normal, extremely stable pulse periodicity, allowing investigation of many areas of astrophysics. These investigations range beginning from studies of neutron-star interiors using glitches and ending by tests of gravitational theories using double-neutron-star and other binary systems and searches for gravitational waves from the distant Universe using millisecond pulsars (Fig. 1). In between are the studies of stellar winds in interacting binary systems and of AU-scale structure in the interstellar medium using dispersion and scintillation variations. These and other applications will be reviewed with the aim of illustrating the great power and versatility of pulsar timing.

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Δ resonances and charged ρ mesons in neutron stars

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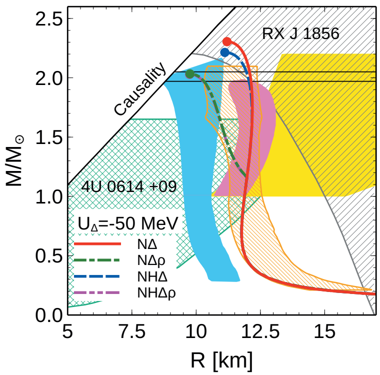

Figure 1: Neutron star mass-radius relation for MKVOR-based models confronted with various observational constraints. Key labels specify the included degrees of freedom: N – nucleons, H – the hyperon octet, Δ – Δ-isobars and ρ – the condensate of ρ^- mesons. Lines N$\Delta\rho$ and NH$\Delta\rho$ visually coincide. The constraints are described in [4].

We study the equation of state of cold and dense baryon matter within the relativistic mean-field framework with hadron masses and coupling constants dependent on the σ mean scalar field. We included $\Delta(1232)$ isobars into previously developed models with hyperons [1] which have resolved the "hyperon puzzle" and consider a possibility of charged rho-meson condensation discussed earlier in [2, 3]. Δ-isobars, being included with realistic values of attractive Δ in-medium potential, do not lead to a strong decrease of the maximum predicted neutron star mass [4]. Thus our models resolve also the "Δ-resonance puzzle" risen in [5]. Concerning the charged ρ-meson condensation, the results are shown to be strongly model dependent. In models of one type (KVORcut-based models described in [1]) the charged rho condensation does not significantly affect the value of the neutron star maximum mass. In other (MKVOR-based) models [1], the condensation leads to a substantial neutron star maximum mass decrease, shown in Fig. 1. However, the observational constraint on the minimal value of the maximum neutron star mass ($2.01 \pm 0.04\, M_\odot$, shown by the band in Fig. 1) remains fulfilled in both cases.

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References

[1] Maslov, K. A., Kolomeitsev, E. E., & Voskresensky, D. N. 2016, Nuclear Physics A, 950, 64

[2] Voskresensky, D. N. 1997, Physics Letters B, 392, 262

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[3] Kolomeitsev, E. E., & Voskresensky, D. N. 2005, Nuclear Physics A, 759, 373

[4] Kolomeitsev, E. E., Maslov, K. A., & Voskresensky, D. N. 2017, Nuclear Physics A, 961, 106

[5] Drago, A., Lavagno, A., Pagliara, G., & Pigato, D. 2014, PRC, 90, 065809

New techniques for unveiling fundamental parameters in neutron star harboring low-mass X-ray binaries

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Low mass X-ray binaries (LMXBs) harbour a low-mass donor star which transfers matter to a compact object (typically a neutron star) via an accretion disc. Among them, transient systems spend most part of their lives in a faint, quiescent state, but show occasional outbursts where their X-ray luminosity increases several orders of magnitude. On the other hand, the so-called persistent systems are always X-ray active.

The combination of X-ray observations with optical photometry provides the first hint about the nature of the compact object early after the discovery, but in order to determine the full set of fundamental parameters of a LMXB the spectroscopic study of the companion star is fundamental, as it reveals the dynamical solution of the system. However, this task has been hampered so far in many systems due to several reasons: (i) the high contribution in the optical range of the accretion disc during the outburst completely veils the donor star features, sometimes even in quiescence; (ii) as the vast majority of these systems are located in the Galactic disc, they are sometimes found in crowded fields where interloper stars prevent a proper study.

In the recent years, our team has led the development of novel techniques to overcome these situations. In particular, we will review: (i) the Bowen technique, which has been successfully applied to a dozen of both persistent and transient systems during the outburst, revealing dynamical information of the donor while it is still veiled and (ii) the exploitation of the better spatial resolution inherent to the NIR observations as well as adaptive optics techniques to obtain phase-resolved spectra of systems placed in crowded fields. These novel methods have been successfully applied to classical systems such as Sco X-1 and Aql X-1, unveiling their (until now) hidden fundamental parameters.

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Why after 50 years is there no consensus on the pulsar radio emission mechanism?

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After nearly five decades there is still no consensus on what the pulsar radio emission mechanism is. There is a proverbial "catch-22": we need to know specific pulsar parameters, including the obliquity angle α, the angle ζ between the line of sight and the rotation axis, and the height of the emission source, in order to constrain the emission mechanism; however, we need to know the emission mechanism in order to use the enormous body of radio data to determine these parameters and to constrain models for pulsar electrodynamics that depend on them. There has been some recent progress: improved constraints on α and ζ by combining radio and high-energy data to [1], and several different arguments pointing to a radio source region at a height above about 10% of the light cylinder radius. Perhaps the strongest indication of the emission mechanism has come from attempts to interpret nanosecond features in the emission from the Crab pulsar [2].

It is convenient to separate possible emission mechanisms into two classes, based on analogy with the two well-established coherent emission mechanisms, electron cyclotron maser emission (ECME) and plasma emission. One class involves accelerated motion (curvature, linear acceleration and free-electron maser emissions) that can lead to the emission in vacuo, and in this sense they are analogous to ECME from planets (notably Jupiter's DAM and the Earth's AKR) and from flare stars. I will argue that these mechanisms encounter seemingly insurmountable difficulties in explaining the brightest pulsar radio emission, due to the growth rates being relatively small and the path length for growth being too restricted. The other class is "relativistic plasma emission" (RPE), analogous to plasma emission in solar radio bursts. The defining characteristic is at least two stages in the emission process: the growth of plasma waves that cannot escape from the plasma and partial conversion of the energy of these waves into escaping radiation. RPE allows one to assume that extremely bright emission provided the plasma waves can build up to sufficiently large amplitudes [2]. In most existing versions of RPE the properties of the growing waves do not take account of the dispersive properties of the pulsar plasma, specifically, a one-dimensional pair plasma with a relativistic spread in velocities in a superstrong magnetic field. I will summarize the dispersive properties of such pulsar plasma, and comment on possible ways in which energy can be fed into relevant large-amplitude waves and on the processes through which these might result in RPE.

References

[1] Pierbattista, M., Harding, A. K., Grenier, I. A., et al. 2015, A&A, 575, A3

[2] Eilek, J. A., & Hankins, T. H. 2016, Journal of Plasma Physics, 82, 635820302

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X-ray properties of the mode-switching pulsar PSR B0943+10

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The prototypical mode-switching pulsar PSR B0943+10 has been extensively studied in the radio band since many years and more recently it has been found to vary also in X-rays. It alternates between two states: in B (radio-bright) mode, its radio emission displays a regular pattern of drifting subpulses, while during the Q (radio-quiescent) mode the radio pulses have a chaotic pattern and the X-ray flux is higher by a factor $\sim$2.4. Previous X-ray observations only partially constrained the spectrum of PSR B0943+10, especially during the X-ray-fainter B-mode, where pulsations could not be detected.

A new, longer campaign of observations was obtained with *XMM-Newton* and the LOFAR, LWA and Arecibo radio telescopes in November 2014. This allowed us to detect X-ray pulsations also during the B-mode and to better constrain the spectral and variability properties. We found that in Q-mode the pulsed emission has a thermal blackbody spectrum with temperature $\sim 3.4 \times 10^6$ K and the unpulsed emission is a power-law with photon index $\sim$2.5, while during B-mode both the pulsed and unpulsed emission can be fit by either a blackbody or a power law with similar values of temperature and photon index. These results support a scenario in which both unpulsed non-thermal emission, likely of magnetospheric origin, and pulsed thermal emission from a small polar cap ($\sim$1500 m^2) with a strong non-dipolar magnetic field ($\sim 10^{14}$ G), are present during both radio modes and vary in intensity in a correlated way. This is broadly consistent with the predictions of the partially screened gap model and does not necessarily imply global magnetospheric rearrangements to explain the mode switching.

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Radio Frequency Studies of the Pulsar Binary PSR J1614−2318

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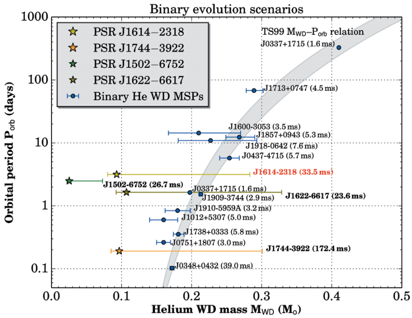

Figure 1: PSR J1614−2318 (labelled in red) is among other three pulsar binaries (non-blue colors) whose orbits must be close to face-on to agree with theoretical expectations (grey region) on the binary orbital period $P_{\rm orb}$ versus companion mass $M_{\rm wd}$ plane. Other binaries with measured Shapiro delays (blue color) all agree with the theoretical curve.

PSR J1614−2318, a radio pulsar binary unexpectedly discovered during the Parkes survey of unidentified EGRET γ-ray sources in 2002 [1, 2], has a number of unique features. Along with a significant (nearly 100%) pulse duty cycle at low frequencies, the binary possesses a very low-mass companion ($M_{\rm c,min} \sim 0.08 M_\odot$) but spins way slower ($P_{\rm spin} = 33.5\,{\rm ms}$) than what standard evolutionary models predict [3]. Moreover, binary orbital period and companion mass ratio agrees with the theory only at low orbital inclinations (see Fig. 1). We outline 13 years of multi-frequency and radio timing observations of PSR J1614−2318. An optical non-detection of the companion down to the 25th magnitude suggests it is likely a white dwarf, whereas an unmeasured Shapiro delay again signifies the orbit is not close to edge-on. We provide an updated timing solution with multi-wavelength radio profiles, discuss potential multi-component profile distribution as well as possible formation scenarios for such a binary system. Our results suggest an interplay between an aligned rotation, inefficient accretion, and a possibly high-mass neutron star.

References

[1] Crawford, F., Roberts, M. S. E., Hessels, J. W. T., et al. 2006, ApJ, 652, 1499

[2] Hessels, J., Ransom, S., Roberts, M., et al. 2005, Binary Radio Pulsars, ASP Conf. Ser., 328, 395

[3] Tauris, T. M., & Savonije, G. J. 1999, A&A, 350, 928

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Binary pulsars as a test of general relativity

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We report on the discovery of the first binary pulsar, hence leading a test of general relativity.

Given the measured masses, rotational rate and orbital diameter, general relativity predicts that their "year" is shortening by 78.8 seconds per million earth years. Hulse and Taylor[1] measured the shortening of the orbital period to be 76.5 ± 0.8 seconds per million earth years, where 0.8 is the uncertainty due to limitation of instrumental precision. The experimental data says the rate is most probably between 75.7 and 77.3, which confirms the prediction of general relativity to a precision of 1%.

References

[1] Manchester, R. N. & Taylor, J. H. Pulsars (A Series of books in astronomy and astrophysics) 1978, W.H.Freeman & Co Ltd.

[2] Robert. L. Piccioni Einstein for everyone 2010, Jaico Publishing House.

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Monitoring and modeling of type IIP supernovae

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Observations of SNe IIP 2013ej and 2012aw were performed with the AZT-8 (Crimea, settl. Nauchny) and LX200 (Petershof, SPBU) telescopes. Then the data were processed and analyzed. Models for this type of SNe were constructed using the package STELLA developed by Blinnikov S.I. et al. Models which correspond to the best fits of the observations were selected.

References

[1] Blinnikov, S., Tolstov, A., Sorokina, E., & Dolgov, A. 2013, High Energy Density Physics, 9, 17

[2] Blinnikov, S. I., & Bartunov, O. S. 2011, Astrophysics Source Code Library, ascl:1108.013

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Single Particle Potential and Nucleon Effective Masses in the LOCV formalism

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The momentum dependence of single-particle potential (SPP) and the nucleonic effective mass of asymmetric nuclear matter are studied in the framework of the lowest order constrained variational (LOCV) method at zero temperature [1]. The Av18 interactions including two-body interactions and Urbana type three-body force (TBF) are considered as the input nucleon-nucleon potential. We investigate the TBF effect on the momentum-dependence of neutron and proton SPP. The isospin splitting and especially the density dependence of the neutron and proton effective masses in neutron-rich nuclear matter are calculated. It is shown that the neutron effective mass is larger than the proton effective mass in our framework. Finally, the effect of density dependent effective masses on neutrino emissivity from neutron and proton branches [2] of modified Urca processes are investigated.

References

[1] Goudarzi, S., & Moshfegh, H. R. 2015, PRC, 91, 054320

[2] Dehghan Niri, A., Moshfegh, H. R., & Haensel, P. 2016, PRC, 93, 045806

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X-ray pulsars at extremely high mass accretion rates

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X-ray pulsars (XRPs) form a special class in the family of accreting neutron stars (NSs) [1]. They differ from the other sources by their strong magnetic field, which typically exceeds 10^{12} G and affects even fundamental properties of matter [2]. Magnetic field funnels the accretion flow and its gravitational energy is released in the form of X-rays coming from the compact area on the NS surface. Resent discoveries of pulsations from ultra-luminous X-ray sources (point-like X-ray sources with the observed luminosity well above 10^{39} erg/s) – ULXs – have opened a new chapter in the studies of XRPs [3]. The classical theoretical limitation for the luminosity is given by the Eddington value, which is about 2×10^{38} erg/s for NSs. The discovery of ULXs powered by accreting NSs is a challenge for modern astrophysics. At the same time, we know a few bright transient XRPs, which might be considered as a link between normal XRPs and ULXs. I will discuss the basic features of XRPs, which arise and become essential at high mass accretion rates: accretion columns, which appear at super-critical mass accretion rates [4, 5] and provide a principal possibility to exceed the Eddington value [6], and optically thick envelopes [7], which are formed by hot accretion flow at the magnetospheric surface and can affect the spectral and timing properties of bright XRPs and ULXs.

References

[1] Walter, R., Lutovinov, A. A., Bozzo, E., & Tsygankov, S. S. 2015, A&ARv, 23, 2

[2] Harding, A. K., & Lai, D. 2006, Reports on Progress in Physics, 69, 2631

[3] Bachetti, M., Harrison, F. A., Walton, D. J., et al. 2014, Nature, 514, 202

[4] Mushtukov, A. A., Suleimanov, V. F., Tsygankov, S. S., & Poutanen, J. 2015, MNRAS, 447, 1847

[5] Basko, M. M., & Sunyaev, R. A. 1976, MNRAS, 175, 395

[6] Mushtukov, A. A., Suleimanov, V. F., Tsygankov, S. S., & Poutanen, J. 2015, MNRAS, 454, 2539

[7] Mushtukov, A. A., Suleimanov, V. F., Tsygankov, S. S., & Ingram, A. 2017, MNRAS, 467, 1202

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Gyrosynchrotron radiation: polarisation, kinetic equation, and damping

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The expressions are obtained for the Stokes parameters of polarised radiation emitted by electrons in a magnetic field with arbitrary distribution over energies as well as for arbitrary matrix of absorption coefficients of such electrons as functions of frequency and direction. The computer codes are written for calculating all these quantities. The relativistic kinetic equation is formulated to describe a multiple action of the mechanism taking into account polarisation, induced radiation and blocking principle. The energy losses of radiating electron and the law of damping of its radiation are found. The results can be applied for the interpretation of spectra of the jets in AGNs and accretion discs in binary systems containing black holes or neutron stars.

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Analytical Theory of Neutral Current Sheets with a Sheared Magnetic Field in Collisionless Relativistic Plasma

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Quasistationary neutral current sheets are important elements of various structures in collisionless plasma, including the relativistic plasma of neutron stars' magnetosphere and wind. Most analytical studies of these structures are limited by a plain configuration of the field lines and ignore the effect of shear. At the same time the latter appears naturally in the system "rotating magnetosphere – outgoing wind".

We derive and describe analytically a new wide class of magnetostatic structures with sheared field lines using a superposition of current sheets with orthogonal magnetic fields and arbitrary energy distribution of particles [1]. We consider particle distributions as functions of generalized particle momenta and restrict ourselves to the sum of two cylindrically symmetric particle distribution functions with orthogonal axes. In this simple but yet poorly explored situation, the equations of magnetostatics break down into two independent nonlinear Grad–Shafranov equations. We develop a way to find analytically their solutions and present a complete classification of possible current and magnetic field profiles.

In the talk, we analyze various superpositions of two current sheets taken so, that the magnetic field of one solution is directed along the cylindrical symmetry axis of the distribution function of the other. These superpositions satisfy the general equation of pressure balance and allow us to construct configurations with an arbitrarily sheared magnetic field. It turns out that periodic helical structures and localized current sheets exist with either constant direction of magnetic field rotation, or with a single switch in the shear direction. The presence of an external magnetic field is allowed in each "combinable" solution. We provide analytical examples for all these structures and describe possible relations between their spatial scales, magnitudes of currents and magnetic field, the degree of anisotropy of particle distributions, and the magnetic-to-particle energy ratio.

We show that the major part of previously known current sheets with sheared field lines are particular cases of this novel wide class of current sheets. Finally, we discuss possible applications of the outlined class of sheared magnetic field configurations to the physics of wind and magnetosphere of neutron stars.

References

[1] Kocharovsky, V. V., Kocharovsky, V. V., Martyanov, V. Y., & Tarasov, S. V. 2016, Physics Uspekhi, 59, 1165

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The X-ray Pulsar 2A 1822-371 as a Super Eddington source

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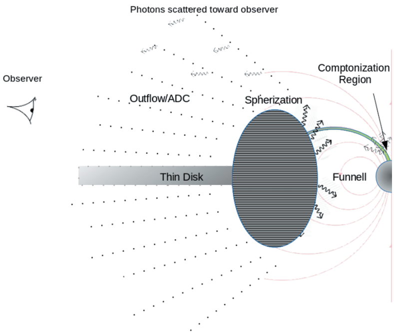

Figure 1: The geometry of 2A 1822-371, according to the super-Eddington solution we propose. The observer is located at an inclination angle of about i=82°. The thick part of the accretion disk begins at the spherization radius and ends at the magnetospheric radius where the plasma is channeled towards the neutron star poles.

The LMXB pulsar 2A 1822-371 is a slow X-ray pulsar in an accretion disc corona system, which shows properties that are inconsistent with standard theories on how these systems should behave. The pulsar has been observed to spin up continuously over a baseline of 13 years with a spin frequency derivative which gives a spin up timescale of about 7000 years, much shorter than expected for this type of systems [1]. An open question is whether this system will show torque reversal in the future, such as seen for example in 4U 1626-67, or if it is really spinning up exceptionally fast. The orbital period is also expanding on a timescale much smaller than expected. Furthermore, to explain some of the peculiarities of this system, it has historically been suggested that the accretion disc must be surrounded by a thick accretion disk corona [2]. However, this poses a problem, because we observe X-ray pulsations, which, presumably, should be smeared out by the thick corona. To address the above problems, we propose that the system is a super Eddington source. We suggest that 2A 1822-371 has a thin accretion outflow (due to the super Eddington mass transfer from the donor, evolving on a thermal timescale) being launched from the inner accretion disk region. The inner part of the accretion disk is, by contrast, geometrically thick (as seen in the Fig. 1). The solution we propose reconciles the need for an accretion disk corona, the fast spin-up, and the change in the orbital separation [3].

References

[1] Iaria, R., Di Salvo, T., Matranga, M., et al. 2015, A&A, 577, A63

[2] White, N. E., & Holt, S. S. 1982, ApJ, 257, 318

[3] Bak Nielsen, A.-S., Patruno, A., & D'Angelo, C. 2017, MNRAS, 468, 824

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On some estimates of magnetic fields in the frame of different models of pulsar braking

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There are several mechanisms of pulsar braking (via magnetic dipole radiation, current losses at the surface and in the magnetospere, accretion from a debris disk, some processes in the neutron star etc.). Usually the magnetic dipole model is used to calculate magnetic fields at the surfaces of pulsars. These fields are listed in the known catalogues of radio pulsars.

We have proposed to carry out calculations of magnetic inductions using our estimates of the angle β between magnetic moments and rotation axes of neutron stars and different braking models. It is shown that new values of inductions obtained in this way differ from those in the known catalogues, by several times as a rule.

References

[1] Nikitina, E. B., & Malov, I. F. 2016, arXiv:1608.08525

[2] E. B. Nikitina, I. F. Malov, On magnetic fields of radio pulsars (Astronomy Reports, submitted)

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Magnetic field amplification during core collapse

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Magnetic fields, if sufficiently strong, may affect the dynamics of core collapse. Though most likely present in all progenitor stars as well as in the neutron stars produced in core collapse, they are only expected to play an important in a subclass of events in which a rather weak pre-collapse field strength can be amplified by a large factor and on time scales comparable to those of the dynamics of collapse and explosion. Such an amplification can be provided by several different mechanisms. The mechanisms can be broadly classified in those that require rapid rotation and those that can operate even in non-rotating stars. The latter group contains amplification by compression and hydrodynamic instabilities excited in the proto-neutron star and the surrounding layers, while the former group contains the winding of poloidal field into toroidal and the magneto-rotational instability. We will discuss these processes, the conditions under which they occur, and likely consequences for the dynamics.

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Towards model-independent analysis of cooling neutron stars

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We have elaborated a method for analysing cooling neutron stars with nucleon cores. The method is almost independent of a model equation of state in neutron star cores. It is based on nearly universal approximations of the neutrino luminosity L_ν and the heat capacity C of the star (e.g., [1]) by analytic functions of stellar mass M, radius R and redshifted internal temperature, for some selected basic cooling scenarios.

This allows us to analyse neutron stars at the neutrino cooling stage (ages $t \lesssim 10^5$ yr) which is governed by the L_ν/C ratio. In particular, we have considered the neutron star XMMU J173203.3–34418 in the HESS J1731–347 supernova remnant [2] and the Vela pulsar (whose spectral analysis was kindly provided by D. Zyuzin). For both stars, we calculate/constrain the neutrino cooling factor $f_\ell = (L_\nu/C)/(L_{\nu\,\mathrm{SC}}/C_{\mathrm{SC}})$, as a function of M, R and the composition of the heat blanketing envelope. Here, the subscript 'SC' refers to the standard neutrino candle [3] — a non-superfluid model of the same star which cools via the modified Urca process.

For neutron stars of ages $\sim 10^5 - 10^6$ yr which transit from the neutrino to the photon cooling stage, we find a simple temperature — age relation valid for both, the neutrino and photon cooling stages. Using these results, we analyze the cooling neutron star RX J1856.5–3754 [4]. We show that the influence of baryon superfluidity on its cooling should be described by two factors, f_ℓ and $f_C = C/C_{\mathrm{SC}}$, which we constrain.

This model-independent analysis allows one to investigate the properties of neutron and proton superfluidities in neutron stars cores. Its perspectives are described.

References

[1] Ofengeim, D. D., Fortin, M., Haensel, P., Yakovlev, D. G., & Zdunik, J. L. 2016, arXiv:1612.04672

[2] Ofengeim, D. D., Kaminker, A. D., Klochkov, D., Suleimanov, V., & Yakovlev, D. G. 2015, MNRAS, 454, 2668

[3] Yakovlev, D. G., Ho, W. C. G., Shternin, P. S., Heinke, C. O., & Potekhin, A. Y. 2011, MNRAS, 411, 1977

[4] Ofengeim, D. D., & Yakovlev, D. G. 2017, MNRAS, 467, 3598

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Effect of Rotation in Magnetic Strange Dwarfs

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White dwarfs are the final stage in the stellar evolution of a star with an initial mass less than eight solar masses. They have, in average, one half to a limit of 1.4 solar masses and radius of order 1000 km. A recent theoretical work [1] had predicted a new class of dense white dwarfs, the so called strange dwarfs. Following this idea, the properties of strange magnetic white dwarfs are computed for a crust with an equation of state which describes the matter in terms of a heterogenous composition in a regular crystal bcc type lattice of atomic nuclei at zero temperature and a core described by the MIT Bag Model, immersed in a totally magnetized electron gas. Strange dwarfs are studied for different magnetic fields and stellar rotation rates. Moreover, we calculate the mass-radius relationships of strange magnetic white dwarfs for magnetic fields ranging from zero up to 10^{12} Gauss and rotational stellar frequencies between zero and the Kepler frequency, which sets an absolute limit on rapid rotation.

References

[1] Weber, F. 2005, Progress in Particle and Nuclear Physics, 54, 193

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Core-Collapse Supernova Mechanisms

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The core-collapse supernova problem is central to our understanding of neutron star and black hole formation and the chemical enrichment of the universe. Stellar explosions from massive stars are intrinsically 3D and require complex multi-scale, multi-physics simulations. The availability of petascale supercomputers recently enabled the first high-resolution self-consistent 3D simulations. I review the progress in the simulation and modeling of stellar collapse and the subsequent post-core-bounce core-collapse supernova evolution. Specificially, I present new results from general-relativistic 3D simulations of neutrino-driven and magnetorotational core-collapse supernovae. I discuss both explosion mechanisms and their implications and limitations in detail.

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Accretion Flows and Millisecond Pulsars, from Light Cylinder to Magnetic Funnel

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We will present the results from the first relativistic MHD simulations of accretion onto magnetized neutron stars, performed in general relativity in the Kerr spacetime geometry. Four regimes are recovered, in order of increasing stellar magnetic field strength (equivalently, decreasing mass accretion rate): (a) crushing of the stellar magnetosphere and direct accretion; (b) magnetically channeled accretion onto the stellar poles; (c) the propeller state, where material enters through the light cylinder but is prevented from accreting by the centrifugal barrier; (d) almost perfect exclusion of the accretion flow from the light cylinder by the pulsar's electromagnetic wind. A Poynting-flux-dominated relativistic jet, powered by stellar rotation, is produced when the intruding plasma succeeds in opening the pulsar's previously closed magnetic field lines. We will demonstrate the effect of changing the relative orientation of the stellar dipole and the large-scale magnetic field in the accreted plasma, and discuss our results in the context of the transitional millisecond pulsars and the neutron-star-powered ultra-luminous X-ray sources.

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MHD simulations of oscillating cusp-filling tori around neutron stars

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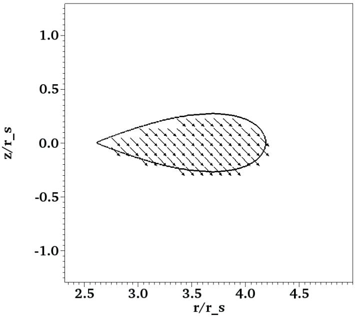

Figure 1: Initial configuration of the cusp-filling torus around a non-rotating neutron star. Solid line represents the density contour in a meridional cross-section of the cusp-filling torus at $r_c = 3.47\ r_s$. The inner edge of the torus is terminated by a cusp at $2.62\ r_s$. Solid arrows represent the initial uniform sub-sonic diagonal velocity perturbation.

We performed axisymmetric, grid-based, ideal magnetohydrodynamic (MHD) simulations of oscillating cusp-filling tori orbiting a non-rotating neutron star [1]. A pseudo-Newtonian potential was used to construct the constant angular momentum tori in equilibrium. The inner edge of the torus is terminated by a "cusp" in the effective potential. The initial motion of the model tori were perturbed with uniform sub-sonic diagonal and vertical velocity fields. As the configuration evolved in time, we measured the mass accretion rate ($\dot{M}$) on the surface of the neutron star and obtained the power spectrum of $\dot{M}$. The prominent mode of oscillation in the cusp torus is the radial epicyclic mode. From our analysis it follows that the mass accretion rate carries a modulation imprint of the oscillating torus [2]. Our results can be verified by the astronomy satellite ASTROSAT. It is equipped with the Large X-ray Proportional Counters which can investigate quasi-periodic oscillations in low mass X-ray binaries.

References

[1] Parthasarathy, V., Kluźniak, W., Čemeljić, M. Manuscript in preparation

[2] Abramowicz, M. A., Horak, J., & Kluzniak, W. 2007, Acta Astronomica, 57, 1

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Ultraviolet Emission from Isolated Neutron Stars

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The launch of the *Hubble Space Telescope* (*HST*) 27 years ago made it possible to study UV emission from neutron stars (NSs). Only a handful of NSs have been observed in UV, but each of these observations provided important new information on NS properties. Particularly interesting were the measurements of surface temperatures of old NSs, including two millisecond pulsars, and the unexpected discovery of far-UV bow shocks. I will overview the results of UV observations of isolated NSs of different types throughout the *HST* era and discuss the perspectives of future UV observations.

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Basic radiation from an off-centred rotating dipole

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When a neutron star forms, after the collapse of its progenitor, a strong magnetic field survives in its interior. This magnetic topology is usually assumed to be well approximated by a dipole located right at the centre of the star. However, a slight shift from the stellar centre has strong implications for the surrounding electromagnetic field configuration leading to distinct observational signatures. We study the effect of the most general off-centred dipole anchored in the neutron star interior. Exact analytical solutions are given in vacuum outside the star to any order of accuracy in the small parameter $\epsilon = d/R$, where d is the displacement of the dipole from the stellar centre and R the neutron star radius. As a simple diagnostic of the decentred dipole, the spin-down luminosity and the torque exerted on its crust are computed to the lowest leading order in ϵ. Results are compared to earlier works and a discussion on repercussions on pulsar braking index and multi-wavelength light curves is proposed [1].

Moreover, radio polarization measurements of pulsed emission from pulsars offer a valuable insight into the basic geometry of the neutron star: inclination angle between the magnetic and rotation axis, inclination of the line of sight and magnetic topology. So far, all studies about radio polarization focused on the standard rotating vector model with the underlying assumption of a centred dipole. This model is generalized to an off-centred dipole with an exact analytic expression for the phase-resolved polarization angle. Contrary to the rotating vector model, for an off-centred dipole, the polarization angle also depends on the emission altitude. Although the fitting parameter space increases from two to six (position of the dipole, altitude and shift of the zero phase), statistical analysis remains tractable and is applied to several radio pulsar observations. An evolution of the polarization angle with frequency would undeniably furnish a strong hint for the presence of a decentred magnetic dipole in neutron stars [2].

References

[1] Pétri J., 2016, MNRAS, 463, 1240.
[2] Pétri J., 2017, MNRAS, 466, L73.

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Model of synchrotron spectra of pulsar wind nebula associated with PSR J0437-4715

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An adequate interpretation of the multiwavelength observations of the pulsar wind nebulae (PWNe) requires studying of the relativistic pulsar wind (PW) interaction with the ambient matter. If the pulsar proper velocity relative to the ambient matter is supersonic, the bow shock (BS) and the region containing the converging flows carrying magnetic inhomogeneities occur. In this case, the energy-dependent transport can result in a significant deformation of the particle energy distribution in the vicinity of the PWN and the BS, in comparison with the spectrum of particles accelerated at the PW termination shock. In particular, it can manifest in different observed PWN morphologies in various energy ranges.

In this work, the results of stationary test-particle Monte Carlo modeling for the PW pairs propagation through the system of a PWN with a BS are presented. The results for the particle energy distributions across the system and the evaluated spatial distributions of the synchrotron emission intensity form the modeled source are obtained.

In the presentation, a possible interpretation of the multiwavelength observational data for the PWN related to the pulsar J0437–4715 in the framework of the developed model will be discussed.

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Pulsar Magnetospheres

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The modeling of pulsar radio and gamma-ray emission suggests that in order to interpret the observations one needs to understand the field geometry and the plasma state in the emission region. In recent years, significant progress has been achieved in understanding the magnetospheric structure in the limit of abundant plasma supply. However, the very presence of dense plasma everywhere in the magnetosphere is not obvious. Even the region where the observed emission is produced is subject to debate. To address this from first principles, we constructed global kinetic simulations of pulsar magnetospheres using relativistic Particle-in-Cell codes, which capture the physics of plasma production and particle acceleration. In this talk I will describe how plasma is produced in magnetospheres of pulsars and show that effects of general relativity are crucial for the activity of pulsars with low inclination angles. I will present modeling of high-energy lightcurves, calculated self-consistently from particle motion in the pulsar magnetosphere. I will also show evidence that observed radio emission is powered by non-stationary discharge at the polar cap. Finally, I will argue that giant radio pulses in the Crab are produced by coherent plasma currents, which appear at the interfaces of merging plasmoids in the current sheet beyond the light cylinder.

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Missing links of neutron star evolution in the eROSITA sky

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Since the discovery of the first radio pulsar fifty years ago, the population of neutron stars in our Galaxy has grown to over 2500, of which a handful is exclusively seen in X-rays. Despite their scarcity, these objects are key to understanding evolutionary aspects that are neither predicted by theory, nor probed by the normal pulsar population. In particular, scenarios involving magnetic field decay [1, 2] and field burial by fallback accretion after the supernova explosion [e.g. 3–5] are worth noting, as they are expected to significantly alter the star's rotational and thermal evolution and, hence, visibility across the electromagnetic spectrum. The forthcoming all-sky X-ray survey of eROSITA is therefore timely for a better sampling of neutron stars that are especially silent in the radio and gamma-ray regimes.

To estimate the number of isolated neutron stars to be detected in the eROSITA all-sky survey through their thermal X-ray emission, we performed Monte Carlo simulations of a population synthesis model [7]. Our study indicates an expected number of up to 100 well-detected thermally emitting neutron stars to be found after four years. The selection of newly proposed neutron star candidates among the myriad of eROSITA-detected sources will be challenging and will require synergy with multiwavelength surveys. Although optical follow-up will require very deep observations – in particular, the identification of most of the faintest candidates will have to wait for the next generation of extremely large telescopes – sources at intermediate fluxes can be selected for follow-up investigations using current facilities. Beyond the discovery of new sources and long-sought evolutionary missing links, the eROSITA survey has therefore the unique potential to unveil the faint X-ray end of the neutron star population.

References

[1] J. A. Pons, J. A. Miralles, & U. Geppert 2009. A&A, 496, 207
[2] D. Viganò, N. Rea, J. A. Pons, et al. 2013. MNRAS, 434, 123
[3] Chevalier, R. A. 1989, ApJ, 346, 847
[4] Geppert, U., Page, D., & Zannias, T. 1999, A&A, 345, 847
[5] Ho, W. C. G. 2011, MNRAS, 414, 2567
[6] Predehl, P. 2014, Astronomische Nachrichten, 335, 517
[7] Pires, A. M., Schwope, A. D, & Motch, C. 2017. Astronomische Nachrichten; in press. DOI: 10.1002/asna.201713333

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Scenario of flaring activity of the SFXT IGR J16418–4532

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Supergiant fast X-ray transients (SFXTs) are a sub-class of wind-fed High Mass X-ray Binaries (HMXB) in which the normal companion is a supergiant. These systems were collected in a sub-class because of short flares (a few hours duration) in which the X-ray luminosity increases by 3–5 orders of magnitude. The X-ray transient IGR J16418–4532 was discovered by INTEGRAL in 2003 and proposed as a SFXT by Sguera in 2006 after the identification of short duration flares from the system. We explore a possibility to explain the X-ray flaring of this source in terms of a transition of the accretion flow geometry. We consider a situation in which the neutron star in the quiescent state is surrounded by a hot envelope. The flares in this scenario are associated with a collapse of the envelope and its re-formation.

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Surface magnetic field structure and Hall evolution in the crust

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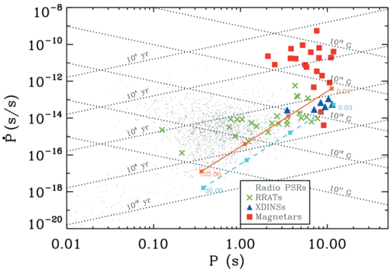

Figure 1: The P-$\dot{P}$ diagram showing the different INS classes. The full orange (dashed light blue) line corresponds to an age equal to two (three) Hall timescales; here an initial period $P_0 = 0.01\,\mathrm{s}$ has been assumed and the initial magnetic field is in the range $10^{12}\,\mathrm{G} \leq B_0 \leq 10^{15}\,\mathrm{G}$. The asterisks along the two lines mark the true age of the star in Myrs, the spacing between two symbols corresponds to a factor of 10 decrease, moving from left to right.

The evolution of magnetic field in isolated neutron stars is one of the most important ingredients in the attempt to build a unified description of these objects. A prediction of field evolution models is the existence of an equilibrium configuration, in which the Hall cascade vanishes. Recent calculations have explored the field structure in this stage, called the Hall attractor [1]. At first, we present results of calculations [2] (and comparison with observational data) of neutron star emission parameters related to the magnetic field structure in the crust.

We use X-ray data of near-by, cooling neutron stars to probe this prediction, as these sources are surmised to be close to or at the Hall attractor phase. We show that the source RX J1856.5–3754 might be closer to the attractor than other sources of its class. Our modelling indicates that the properties of surface emission, assuming that the star is in the Hall attractor, are in contradiction to the spectral data of RX J1856.5–3754.

Then we discuss the prospects for probing magnetic field configuration in the crust and in the outer space in different types of neutron stars, including central compact objects with emerging fields [3]. Specifically, we focus on the possibility to test the Hall attractor hypothesis.

References

[1] Gourgouliatos, K. N., & Cumming, A. 2014, MNRAS, 438, 1618

[2] Popov, S. B., Taverna, R., & Turolla, R. 2017, MNRAS, 464, 4390

[3] Igoshev, A. P., Elfritz, J. G., & Popov, S. B. 2016, MNRAS, 462, 3689

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Magnificent in infrared – an unusual isolated neutron star

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RX J0806.4−4123 is a nearby (≈ 250 pc) radio-quiet isolated neutron star (NS) with purely thermal X-ray emission. Its spin-down properties place this NS together with the other 6 members of the so-called the Magnificent Seven between the magnetar and the radio pulsar populations in the $P-\dot{P}$ diagram. Remarkably, there is a near-infrared (NIR) source at the position of RX J0806.4−4123, while no other member of the Magnificent Seven has an NIR detection. This NIR source was first detected with the ESO's Very Large Telescope [1] and then confirmed with the Gemini Telescope [2]. Our recent *Hubble* Space Telescope observation shows a rather intriguing NIR source which is much brighter than the expected flux from the NS surface and even might be slightly extended. The existence of an additional far-infrared source very close to RX J0806.4−4123 (detected with the *Herschel* PACS instrument [3]) accentuates the peculiarity of this NS. We will present our recent observations and discuss possible physical interpretations of the unusual NIR source, such as a possible disk or torus structure around the pulsar.

References

[1] Posselt, B., Neuhäuser, R., & Haberl, F. 2009, A&A, 496, 533

[2] Posselt, B., & Luhman, K. L. 2016, Astronomische Nachrichten, 337, 576

[3] Posselt, B., Pavlov, G. G., Popov, S., & Wachter, S. 2014, ApJSS, 215, 3

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A propelling neutron star in the enigmatic Be-star γ Cassiopeia

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γ Cassiopeia (γ Cas) is known to be a binary system consisting of a Be-type star and a low-mass ($M \sim 1M_{\odot}$) companion of unknown nature orbiting in the Be-disc plane. Here, we apply the quasi-spherical accretion theory to a compact magnetized star and show that if the low-mass companion of γ Cas is a fast spinning neutron star, the key observational signatures of γ Cas are remarkably well reproduced [1]. Direct accretion on to this fast rotating neutron star is impeded by the propeller mechanism. In this case, a hot shell is formed around the neutron star magnetosphere which emits thermal X-rays in qualitative and quantitative agreement with observed properties of the X-ray emission from γ Cas. We suggest that γ Cas and its analogues constitute a new subclass of Be-type X-ray binaries hosting rapidly rotating neutron stars formed in supernova explosions with small kicks. The subsequent evolutionary stage of γ Cas and its analogues should be the X Per-type binaries comprising low-luminosity slowly rotating X-ray pulsars. The model explains the enigmatic X-ray emission from γ Cas [2], and also establishes evolutionary connections between various types of rotating magnetized neutron stars in Be-binaries.

References

[1] Postnov K., Oskinova L., Torrejón J. M., 2017, MNRAS, 465, L119

[2] Postnov K., Oskinova L., Torrejón J. M., 2017, arXiv:1701.00336

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Time-dependent ionization in the envelope of supernovae of type II during the photosphere phase

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The importance of allowance for the time-dependent effect in the kinetics at the photospheric phase during a supernova explosion has been confirmed by several independent research groups [1, 2]. The time-dependent effect provides a higher degree of hydrogen ionization in comparison with the steady-state solutions and strengthens the Hα line in the resulting simulated spectrum, with the intensity of the effect increasing with time. However, some researchers [3] argue that the time-dependent ionization effect is unimportant. Its allowance leads to an insignificant strengthening of Hα in their modeling only in the first days after the explosion. We have demonstrated the importance of the time-dependent effect with the models of SN 1999em as an example using the new original `LEVELS` software package [4]. The role of a number of factors that can weaken the time-dependent effect has been checked. We have confirmed that the intensity of the effect is affected by the abundance of metal admixtures in the envelope, while the addition of extra levels to the model hydrogen atom weakens the time-dependent effect to a lesser degree and never removes it completely. Accounting for the fine structure of hydrogen also does not cancel the time-dependent effect.

References

[1] Utrobin, V. P., & Chugai, N. N. 2005, A&A, 441, 271

[2] Dessart, L., & Hillier, D. J. 2008, MNRAS, 383, 57

[3] De, S., Baron, E., & Hauschildt, P. H. 2010, MNRAS, 401, 2081

[4] Potashov, M. Sh., Blinnikov, S. I. & Utrobin, V. P., 2017, Astron. Lett. 43, 36

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Ultra-luminous X-ray pulsars

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For many years the main competing models for ultra-luminous X-ray sources (ULXs) were intermediate-mass black holes and stellar-mass black holes accreting at super-Eddington. Three years ago the discovery of coherent pulsations in M82 X-1 [1] proved that some (or maybe even most) ULXs are in fact neutron stars. Two more ULX-pulsars were discovered during last year [2–4]. These sources exceed the standard Eddington limit by a factor up to 500. In this talk, I will review the observational advances as well as theoretical models that were put forwards to explain huge observed luminosities.

References

[1] Bachetti, M., Harrison, F. A., Walton, D. J., et al. 2014, Nature, 514, 202

[2] Israel, G. L., Papitto, A., Esposito, P., et al. 2017, MNRAS, 466, L48

[3] Israel, G. L., Belfiore, A., Stella, L., et al. 2017, Science, 355, 817

[4] Fürst, F., Walton, D. J., Harrison, F. A., et al. 2016, ApJL, 831, L14

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Relativistic Mean Field study of Neutron stars and Hyperon stars

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Neutron stars are the valuable laboratories for the study of dense matter. Recent measurements of their masses have set a constraint on the neutron star radii. At present, precise simultaneous measurements of mass and the radii of neutron stars are not available. The most accurate measurements of neutron star masses come from pulsar timing. We now know the precise masses for$\sim$ 35 neutron stars spanning the range from 1.17 to $2.0M_{\odot}$ and the radii from 9.9 to 11.2 km [1].

The effect of hyperons resulting in the strong softening of Equation of State (EoS), and the consequent reduction of the maximum mass of neutron stars is more intriguing and difficult to solve because of the recent measurements of unusually high masses of millisecond pulsars PSR J1903+0327 ($1.667\pm0.021M_{\odot}$), PSR J1614–2230 ($1.97\pm0.04M_{\odot}$) and PSR J0348+0432 ($2.01\pm0.04M_{\odot}$)[2]. Current goals to combine the available observations and infer the underlying EoS of dense matter are studied.

We intend to study the impact of hyperon cores on the radius-mass relation for neutron stars and to determine the EoS of dense matter inside the stars by using the promising theoretical model of relativistic mean field (RMF) with different parameterizations. The neutron stars are the excellent emitters of gravitational waves which occur due to magnetic deformations in newly-born and older isolated radio pulsars [3, 4].

References

[1] Lattimer, J. M. 2012, Annu. Rev. Nuc. Part. Sci., 62, 485

[2] Vidaña, I. 2016, JPCS, 668, 012031

[3] Lasky, P. D. 2015, PASA, 32, e034

[4] S. Bonazzola and E. Gourgoulhon, Gravitational waves from neutron stars. Lecture notes.

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Plasma magnetosphere of deformed magnetized neutron star

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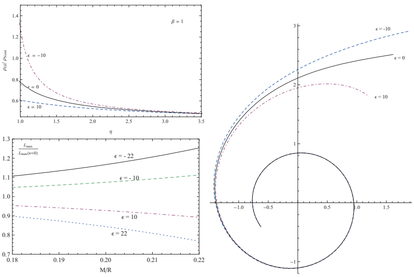

Figure 1: Analytical solutions of Goldreich-Julian charge density along open field lines of slowly rotating magnetized non-Kerr neutron star. They indicate the modification of an accelerating electric field, charge density along the open field lines and radiation losses of energy of the neutron star by the deformation parameter.

The plasma magnetosphere surrounding a rotating magnetized neutron star described by non-Kerr spacetime metric in slow rotation approximation has been studied. First we have analyzed the vacuum approximate solutions of the Maxwell equations in spacetime of slowly rotating magnetized non-Kerr star with dipolar magnetic configuration [1, 2]. Then for the magnetospheric model we have derived second-order differential equation for electrostatic potential [3] from the system of Maxwell equations in spacetime of slowly rotating magnetized non-Kerr star. Analytical solutions of Goldreich-Julian charge density [4] along open field lines of slowly rotating magnetized non-Kerr neutron star have been obtained (in Fig. 1) which indicate the modification of an accelerating electric field, charge density along the open field lines and radiation losses of energy of the neutron star [5] by the deformation parameter.

References

[1] Rezzolla, L., Ahmedov, B. J., & Miller, J. C. 2001, MNRAS, 322, 723. Erratum: 2003, MNRAS, 338, 816

[2] Rezzolla, L., Ahmedov, B. J., & Miller, J. C. 2001, arXiv:gr-qc/0108057

[3] Muslimov, A. G., & Tsygan, A. I. 1992, MNRAS, 255, 61

[4] Goldreich, P., & Julian, W. H. 1969, ApJ, 157, 869

[5] Muslimov, A., & Harding, A. K. 1997, ApJ, 485, 735

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HST UV observations of the tMSP XSS J12270–4859

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Transitional millisecond pulsars (tMSP) are the evolutionary link between low mass X-ray binaries and radio millisecond pulsars (MSPs). Up to date only 3 confirmed tMSP are known. Thus, in order to understand these systems we should get as much information as possible using observations at different wavelengths.

In this work, we present results on the tMSP XSS J12270–4859 in its pulsar state using the first near and far ultraviolet (UV) images taken with the Hubble Space Telescope (HST). Thanks to the great sensitivity of the HST, these images allow us to study the object in more detail compared to UV images from other telescopes (for instance, swift/UVOT or XMM/OM). We have compared the large amplitude variations observed in our UV light curves to those obtained by other authors at different wavelengths in the same state. Previous studies suggest that the optical and infrared emission from this system likely comes from an irradiated companion star without the need of an accretion disk being present. We will discuss whether our UV observations are consistent with this or whether a quiescent accretion disk could still exist.

We have also analyzed some archival and unpublished UV images of the tMSP PSR J1023+0038, also taken in the pulsar state. We carried out a comparison in UV of both tMSPs. We will discuss their similarities and differences, which ultimately help us to understand the evolution of MSPs.

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Radio Emission Mechanism in Pulsar Magnetosphere

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Pulsars emit beamed electromagnetic radiation in the form of periodic pulses, as it sweeps across the observer. As we know from observations, the radio emission of the pulsars is coherent and highly polarized. The typical brightness temperature of the pulsars range from 10^{25} to 10^{32} K. The mechanism of radio emission of pulsars is still an outstanding problem in pulsar astronomy. However, it is generally believed that the coherent curvature radiation mechanism can explain the high brightness temperature and polarization of pulsars in radio band. Physicists have suggested several mechanisms like Plasma antenna mechanism, Maser amplification and Relativistic plasma instabilities. We believe that the coherent curvature radiation mechanism can incorporate both relativistic plasma instabilities and antenna mechanism, and worth enough to explain the high brightness temperature of pulsars. Coherent curvature radiation model is developed by taking into account detailed viewing geometry and dipolar magnetic field. The relativistic pair plasma (e^-, e^+) tied to the dipolar magnetic field lines, changes direction every moment which results in the acceleration and hence emission. Several non-linear processes take place in the pulsar magnetosphere like wave-wave coupling and instability process like the two-stream instability. Ion and electron motion in a plasma generates standing longitudinal waves. Now wave coupling among the plasma waves will lead to the generation of non-linear wave mode, and finally this non-linear wave partially converts to a transverse wave to stabilize the amplitude of plane waves. We are trying to develop a theoretical model based on the above plasma processes, which is believed to explain the enhanced emission intensity as well as high brightness temperature.

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Resonances in two-point tree-level amplitudes in a magnetized medium

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The tree-level two-point amplitudes for the transitions $jf \to j'f'$, where f is a fermion and j is a generalized current, in a constant uniform magnetic field of an arbitrary strength and in charged fermion plasma, for the jff interaction vertices of the scalar, pseudoscalar, vector and axial-vector types have been calculated. The generalized current j could mean the field operator of a boson, or a current of fermions, i.e. the neutrino current.

It is remarkable, that all the amplitudes obtained appear to be Lorentz invariant, due to the choice of the Dirac equation solutions as the eigenfunctions of the covariant operator $\hat{\mu}_z$. In this case, partial contributions to an amplitude from the channels with different fermion polarization states are calculated separately, by direct multiplication of the bispinors and the Dirac matrices. This approach is an alternative to the method where the squared amplitudes are calculated, with the summation over fermion polarization states, and with using the fermion density matrices, see, e.g. Refs. [1, 2]. However, the use of the density matrix in a magnetic field, as is usually done in the absence of a magnetic field, in the case of the two-vertex processes leads to extremely difficult analytical calculations.

Possible resonances in tree-level two-point amplitudes for the transitions $jf \to j'f'$ have been analysed. It has been shown, that in the case of δ – shaped resonance peak, the squared amplitude of the process $jf \to j'f'$ is factorized into squared amplitudes of the processes $jf \to f''$ and $f'' \to j'f'$, where f'' is an intermediate fermion state.

As an illustration of the obtained results, we have calculated the cross section of the Compton scattering process, $\gamma e \to \gamma e$, for the conditions of pulsar magnetosphere taking into account of a possible resonance of a virtual electron. It is shown, that the obtained results agree with the previous calculations [3] for the case of a wide resonance peak.

References

[1] Andreev, M. S., Mikheev, N. V., & Narynskaya, E. N. 2010, Sov. J. Exp. Theor. Phys., 110, 227

[2] Gvozdev, A. A., & Osokina, E. V. 2012, Theor. Math. Phys., 170, 354

[3] Mushtukov, A. A., Nagirner, D. I., & Poutanen, J. 2016, PRD, 93, 105003

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The correlation between the magnetic field strengths and X-ray spectra of O-type stars

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Massive hot stars are progenitors of neutron stars. If we know the nature of O-stars in detail we can understand the neutron star evolution. Many of High mass X-ray binaries (HMXB) consist of an OB-star and a neutron star. Nowadays it is thought that the X-ray emission of O-type stars is formed in collisions of stellar winds in binary systems or as a result of heating of the matter of stellar winds by shock waves of single O-type stars [1]. The X-ray emission formation in the spectra of magnetic O-type stars can be described in the framework of Magnetically confined wind-shock model (MCWS) [2, 3]. In this model, the stellar wind flows move along the magnetic field lines to the magnetic equator, where they collide and form a shock wave. The X-ray emission is formed in the hot gas heated by this shock. In addition, a circumstellar disk can be formed in the area of the magnetic equator. From this paradigm one can derive that the spectrum hardness must increase with such stellar parameters, as magnetic field, termination velocity and mass loss rate. The aim of our work is to study if there is a dependence of X-ray spectrum hardness of O-stars on these parameters. We have analyzed the archival X-ray observations of twenty O-stars and HMXBs obtained with XMM-Newton in the period from 2000 to 2015. We have extracted spectra using the SAS 14.0 software. As a result of our analysis, we can made a preliminary conclusion about connection between X-ray spectrum hardness and other parameters of O-stars and HMXBs.

References

[1] V. Petit et al. 2014, Geology & Astronomy, 302, 330
[2] Babel, J., & Montmerle, T. 1997, A&A, 323, 121
[3] ud-Doula, A., & Owocki, S. P. 2002, ApJ, 576, 413

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Observational diversity and evolution of neutron stars

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Ever since the discovery of the Crab and Vela pulsars in their respective Supernova Remnants (SNRs), our understanding of how neutron stars manifest themselves observationally has been dramatically shaped by the surge of discoveries and dedicated studies across the electromagnetic spectrum, particularly in the high-energy band. The growing diversity of neutron stars includes the highly magnetized neutron stars (magnetars) and the Central Compact Objects (CCOs) shining in X-rays and mostly lacking pulsar wind nebulae. These two subclasses of high-energy objects however seem to be characterized by anomalously high or anomalously low surface magnetic fields (thus dubbed as 'magnetars' and 'anti-magnetars', respectively), and have pulsar characteristic ages that are often much offset from their associated SNRs' ages. In addition, some neutron stars act 'schizophrenic' in that they occasionally display properties that seem common to more than one of the defined subclasses.

I will review the growing diversity of neutron stars from an observational perspective, then highlight recent/on-going theoretical and observational work attempting to address this diversity, particularly in light of their magnetic field evolution, energy loss mechanisms, and supernova progenitors' studies.

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Mass and radius constraints for neutron stars from pulse shape modeling

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We present a method that can be used to constrain masses and radii of neutron stars. The method is suitable for accreting millisecond pulsars, where a rapidly rotating neutron star accretes matter from a relatively low mass companion star onto the magnetic poles of the neutron star. Because of the accretion, we observe radiation from two hot spots on the neutron star surface. This radiation is pulsating coherently at the spinning frequency of the neutron star. We model the exact shape of the pulses using Schwarzschild-Doppler approximation, which takes the general and special relativistic effects into account. An empirical model is used to describe the oblate shape of the star caused by the fast rotation. The spectrum of the radiation is obtained from an empirical model of Comptonization in which a fraction of photons in a seed blackbody spectrum is scattered into a power-law component.

The pulse profiles carry information about the mass and radius of a neutron star since e.g., the light bending and thus pulse shape depends strongly on the compactness of the star. Also, many other physical parameters and observing angles affect the light curves. Therefore, we use Bayesian analysis and a novel Monte Carlo sampling method, called "ensemble sampler", to obtain probability distributions for the different parameters, especially for the mass and the radius. To test the robustness of our method, we have generated synthetic data and fitted the pulse profiles to these. The synthethic data is as closely as possible resembling the real observations of SAX J1808.4 − 3658 observed by *RXTE*. The results of our samplings show that obtaining new constraints for radius and mass is possible. However, prior information obtained from polarization measurements may be used the get significantly tighter constraints.

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The time evolution of roll-off frequency of the synchrotron spectrum from youngest Galactic supernova remnant G1.9+0.3 using *Suzaku*

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G1.9+0.3 is the youngest known Galactic supernova remnant (SNR) dominated by X-ray synchrotron emission. Synchrotron X-rays can be a useful tool to study the electron acceleration in young SNRs. The X-ray spectra of young SNRs give us information about the particle acceleration at the early stages of evolution of SNRs. In this work, we investigate the time evolution of roll-off frequency of the synchrotron spectrum from SNR G1.9+0.3 using *Suzaku*. For this analysis we use $\sim$101 ks (2011) and $\sim$92 ks (2015) observations with the X-ray Imaging Spectrometer. We present the results of our analysis and interpretations about the time evolution of roll-off frequency of the synchrotron spectrum from SNRs.

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High time resolution multi-band photo-polarimetric observations of the binary millisecond "redback" pulsar J1023+0038 with the BTA

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An eclipsing binary 1.64 ms pulsar J1023+0038 with the 4.754 h orbital period and the $\sim$0.2M$_\odot$ non-degenerate secondary star belongs to the so-called 'redback' millisecond binary pulsar systems where the pulsar heats the companion's face. It is one of a few redback systems known, where the transition of a neutron star from a low-mass X-ray binary to a rotation powered pulsar, predicted a long time ago, is observed directly. The object was initially found in the low-mass X-ray binary stage. Since 2002, it has been consistently observed as the radio pulsar. In 2013, the pulsar suddenly switched back to the low-mass X-ray binary raising new questions on mechanisms causing the stage transitions. Currently, it continues to be monitored in various spectral domains. We have observed J1023+0038 in 2017 in the optical with the Multichannel Analysis of Nanosecond Intensity Alterations (MANIA) instrument at the BTA 6 m telescope. The time resolution has been varied from 10 to 150 ms depending on observational mode. Our data show that the pulsar still remains in the low-mass X-ray binary stage, that is characterised by rapid flaring at time scales of 10–100 s with amplitudes of 0.2–0.5 mag. We resolved a fine structure of the flares at time scales of a few seconds. We also set conservative upper limits on the linear polarisation degree of about 2–4% in quiet and flaring stages. We present preliminary results of the observations and discuss their possible implications.

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Transport coefficients of superdense matter in nucleon cores of neutron stars in BHF approach. Comparison of different nucleon potentials

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We study transport coefficients of npeμ matter in non-superfluid neutron star cores. These coefficients (in particular, the thermal conductivity and shear viscosity) are mediated by nucleon collisions. In [1] the nucleon-nucleon interaction was considered in the framework of Brueckner-Hartree-Fock formalism and the Argonne v18 nuclear potential was used supplied with the Urbana IX effective three-body forces. In the present study, we compare different nuclear potentials and different three-body forces. We employ the same models as were used in Ref. [2] where the nucleon effective masses were considered. We find that different three-body forces can lead to the order-of-magnitude different values of nucleon transport coefficients; still they remain smaller than the lepton ones. The work is supported by RFBR grant # 16-32-00507-mol-a.

References

[1] Shternin, P. S., Baldo, M., & Haensel, P. 2013, PRC, 88, 065803

[2] Baldo, M., Burgio, G. F., Schulze, H.-J., & Taranto, G. 2014, PRC, 89, 048801

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Proper motion of the radio pulsar B1727−47 and its association with the supernova remnant RCW 114

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PSR B1727−47 was discovered in 1968. It is one of the brightest radio pulsars known. It is relatively young, with characteristic age of 80 kyr, DM distance of 2.7 kpc, and spindown-estimated magnetic field of 1.2×10^{13} G. Despite a long observational history, the proper motion of PSR B1727−47 has never been reported due to a large timing noise and regular glitching behavior. We have performed timing analysis of more than 20 yr of Parkes archival observations as well as ATCA archival radio-iterferometric observations made in 2004 and 2011. In addition, we conducted original observations with ATCA in September 2016. As a result, we for the first time measured a substantial proper motion of PSR B1727−47 at the level of 150 ± 20 mas yr^{-1}. For a DM distance of 2.7 kpc this transforms to a very high transverse velocity of 1700 km s^{-1}. However, the pulsar projects on the edge of a large Galactic supernova remnant RCW 114 and the backward extrapolation of the obtained proper motion vector points right towards the center of the remnant. This strongly suggests a genuine association between the two objects. Detailed analysis of multiwavelength appearance of RCW 114 implies that the distance to the pulsar+remnant system is in fact much smaller than the DM distance, in the range of $0.7-1$ kpc. A lower distance to the pulsar points to a possibility of its X-ray observations.

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The Neutron Star – Supernova Remnant Connection

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Despite impressive advances in modeling the gravitational collapse of a massive star that leads to a supernova explosion and formation of a relic neutron star (NS), there remain large gaps in our understanding of the process. Many of the most important constraints on this process come from studies of young NSs and the supernova remnants (SNRs) in which they reside. These include connections between SNR asymmetries and pulsar kick velocities, estimates of progenitor characteristics from SNR ejecta studies, and searches for any imprint on SNR properties that might be associated with the extreme variations between the associated NS properties. In addition, studies of composite SNRs provide our best information on the structure of pulsar winds, their interaction with SNR ejecta, and the ultimate escape of the relativistic particles into the ISM. Here I present a summary of recent work on both observational results and modeling efforts of NS/SNR systems.

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Accretion heated atmospheres of X-ray bursting neutron stars

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X-ray bursts taking place at hard persistent states of low-mass X-ray binaries show a spectral evolution consistent with the passively cooling neutron star model. This kind of bursts are used for neutron star radii and masses determination by the cooling tail method and its modifications. However, many of the bursts exhibit significant deviations of the model at the later cooling phases of the burst, at burst fluxes less than half the Eddington flux. The deviation significance depends on the persistent flux before the burst, and we propose that the restarted accretion on the neutron star surface is the main reason of the deviation. Here we present a method for the modeling of neutron star atmospheres heated from above by the accreted fast particles to check this hypothesis. We further compare the computed models to the data for the spectral evolution of the several X-ray bursts at late stages of the cooling tail.

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Confinement of Pulsar Wind Nebulae by Their Supernova Remnant and Magnetic Dissipation

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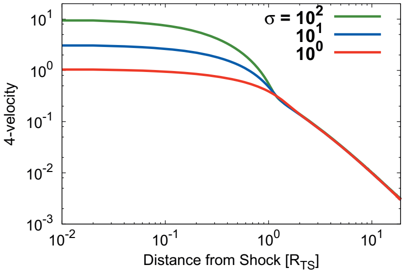

Figure 1: The velocity profile inside a PWN. Three lines refer to different magnetization just before the termination shock. Dissipation length-scales are also different for three lines.

Pulsar wind nebulae (PWNe) are composed of relativistic magnetized plasma wind supplied from their central pulsars. The basis of the pulsar wind is a magnetosphere of the pulsar, where the magnetization σ (the ratio of the magnetic to particle energy) is much larger than unity (e.g., [1]). On the other hand, the magnetization of the PWN plasma is thought to be much smaller than unity from both the observed non-relativistic expansion velocity of PWN and the observed broadband spectrum of PWNe (e.g., [2]). This is the σ-problem of the pulsar wind [3, 4]. It is known that reducing from $\sigma \gg 1$ to $\sigma \ll 1$ is difficult for ideal magnetohydrodynamics outflows.

We study a steady and spherically symmetric model of PWNe. Although the dissipation of the magnetic energy in the pre-shock pulsar wind region have been discussed [5], here, we discuss the magnetic energy dissipation at the post shock PWN region. We adopt the phenomenological expression of the magnetic dissipation from [6], which was applied the magnetic dissipation to accelerate the supersonic outflow. We find that the significant dissipation of the magnetic field allows one to decelerate the post shock flow to non-relativistic velocity (Figure 1). Recently, the similar results for the deceleration of outflow were also obtained in [7]. We also discuss the broadband spectrum of PWNe.

References

[1] Daugherty, J. K., & Harding, A. K. 1982, ApJ, 252, 337

[2] Rees, M. J., & Gunn, J. E. 1974, MNRAS, 167, 1

[3] Kennel, C. F., & Coroniti, F. V. 1984, ApJ, 283, 694

[4] Kennel, C. F., & Coroniti, F. V. 1984, ApJ, 283, 710

[5] Coroniti, F. V. 1990, ApJ, 349, 538

[6] Drenkhahn, G. 2002, A&A, 387, 714

[7] Zrake, J., & Arons, J. 2016, arXiv:1612.02430

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Period distribution of pulsars in the Magellanic Clouds: Propeller line versus Equilibrium period

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We consider High Mass X-ray Binaries (HMXB) in which neutron stars accrete matter from the stellar wind of their massive early-type companions. Most of the systems are transients characterized by short luminous outbursts, while spending the majority of time in quiescence. A survey of such quiescent states of transients located in the Magellanic Clouds was recently reported by Christodoulou et al. [1]. They have examined the data in an attempt to trace the lowest propeller line, defined by the equality of the corotation radius and the radius of the neutron star magnetosphere. Below this line the accretion onto the star stops due to centrifugal barrier at the magnetospheric boundary, and pulsations cease. The data, indeed, allow one to trace the line with the slope close to the theoretical one. At the same time, the same line is expected if the neutron stars are rotating with the equilibrium period. Moreover, the expected slope of this line is close to the slope of the propeller line, but only for relatively fast rotating neutron stars, $P_{\rm eq} \lesssim 100\,{\rm s}$, which undergo accretion of a weakly magnetized flow. A scenario of spin evolution of neutron stars within this hypothesis is presented.

References

[1] Christodoulou, D. M., Laycock, S. G. T., Yang, J., & Fingerman, S. 2016, ApJ, 829, 30

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On the spectrum and polarization of magnetar flare emission

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Bursts and flares are among the distinctive observational manifestations of magnetars, isolated neutron stars endowed with an ultra-strong magnetic field ($B \approx 10^{14}$–10^{15} G). It is believed that these events arise in a hot electron-positron plasma, injected in the magnetosphere, due to a magnetic field instability, which remains trapped within the closed magnetic field lines [the "trapped-fireball" model, see 1, 2]. We have developed a simple radiative transfer model to simulate magnetar flare emission in the case of a steady trapped fireball. After dividing the fireball surface in a number of plane-parallel slabs, the local spectral and polarization properties are obtained integrating the radiative transfer equations for the two normal modes. We assume that magnetic Thomson scattering is the dominant source of opacity, and neglect contributions from second-order radiative processes, although the presence of double-Compton scattering is accounted for in establishing local thermal equilibrium in the fireball atmospheric layers [3]. The observed spectral and polarization properties, as measured by a distant observer, are obtained summing the contributions from the patches which are visible for a given viewing geometry by means of a ray-tracing code. The spectra we obtained in the 1–100 keV energy range are thermal and can be described in terms of the superposition of two blackbodies. The blackbody temperature and the ratio of the emitting areas are in broad agreement with the observations available so far [4–6]. The predicted linear polarization degree is in general greater than 80% over the entire energy range. Such a large degree of polarization should be easily detectable by new-generation X-ray polarimeters, like IXPE, XIPE and eXTP, allowing one to confirm the model predictions.

References

[1] Thompson, C., & Duncan, R. C. 1995, MNRAS, 275, 255

[2] Thompson, C., & Duncan, R. C. 2001, ApJ, 561, 980

[3] Lyubarsky, Y. E. 2002, MNRAS, 332, 199

[4] Israel, G. L., Romano, P., Mangano, V., et al. 2008, ApJ, 685, 1114-1128

[5] Olive, J.-F., Hurley, K., Sakamoto, T., et al. 2004, ApJ, 616, 1148

[6] Feroci, M., Caliandro, G. A., Massaro, E., Mereghetti, S., & Woods, P. M. 2004, ApJ, 612, 408

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On the search for gamma emission from the known radio pulsars and radio emission from the gamma-pulsars

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Pulsars play a crucial astrophysical role as the highly energetic compact radio, X-ray, and gamma-ray sources. Our previous works show that the radio pulsars found as the pulsating gamma sources by the Large Area Telescope (LAT) on board of the Fermi Gamma-Ray Space Telescope [1] have high values of magnetic field near the light cylinder, two-three orders of magnitude stronger compared with the magnetic fields for quiet radio pulsars [2, 3]. Moreover, their losses of the rotation energy, on average, are also three orders higher than the corresponding values for the main group of radio pulsars. The correlation between gamma-ray luminosities and radio luminosities is found. It allows us to select those objects from all set of the known radio pulsars that can be detected as gamma pulsars with the high probability. We give the list of such radio pulsars and propose to search for gamma emisson from these objects. On the other hand, the mentioned catalog of gamma pulsars contains some sources which are not known as radio pulsars at this moment [4]. Some of them have the large value of gamma luminosities and, according to the obtained correlation, we can expect a noticeable radio emission from these objects.

References

[1] Abdo, A. A., Ajello, M., Allafort, A., et al. 2013, ApJSS, 208, 17
[2] Malov, I. F., & Timirkeeva, M. A. 2014, Astronomy Reports, 58, 611
[3] Malov, I. F., & Timirkeeva, M. A. 2015, Astronomy Reports, 59, 865
[4] Manchester, R. N., Hobbs, G. B., Teoh, A., & Hobbs, M. 2005, AJ, 129, 1993

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Low-level accretion onto highly magnetized neutron stars

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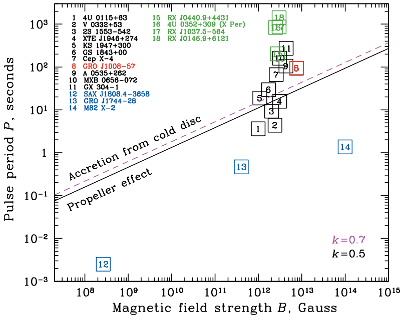

Figure 1: Collection of some known BeXRPs (shown with black color), as well as millisecond accreting pulsar SAX J1808.4−3658, intermediate pulsar GRO J1744−28 and accreting magnetar M82 X-2 (all three shown with blue color) on the $B-P$ plane. Solid and dashed lines divide all sources into two groups: (i) with propeller regime onset at low mass accretion rate (below the line), and (ii) with stable accretion from the cold disc (above the line). Solid and dashed lines correspond to magnetospheric radius of 0.5 and 0.7 of the Alfvén radius, respectively. Persistent low-luminous BeXRPs are shown with green color.

In my talk I will consider the case of transient highly magnetized neutron stars accreting in a broad range of rates, focusing on their behaviour in the very end of the outbursts. At low mass accretion rates the centrifugal inhibition of the accretion (aka "propeller effect" [1], one of the most direct evidence of the ultra-strong magnetic field presented in the vicinity of the neutron stars) was discovered in a few systems. I will review observational manifestations of the propeller effect in X-ray pulsars with broad range of the magnetic fields, from 10^8 to 10^{14} G, with the main focus on our recent discoveries [2-4].

In the second part of my talk I will introduce a model explaining the existence in some X-ray pulsars of an unexpected quasi-stable state characterized by the accretion rate of $\sim 10^{14}-10^{15}$ g s^{-1}. We associate this state with the accretion from cold (non-ionised) disc with temperature below ~ 6500 K (Tsygankov et al., submitted). We argue that a transition to such accretion regime should be observed in all X-ray pulsars with certain combination of the rotation frequency and magnetic field strength (see Fig. 1). Moreover, the propeller effect should never be observed in such sources even for very low mass accretion rates.

References

[1] Illarionov A. & Sunyaev R. 1975, A&A39, 185

[2] Tsygankov, S. S., Mushtukov, A. A., Suleimanov, V. F., & Poutanen, J. 2016, MNRAS, 457, 1101

[3] Tsygankov, S. S., Lutovinov, A. A., Doroshenko, V., et al. 2016, A&A, 593, A16

[4] Lutovinov, A. A., Tsygankov, S. S., Krivonos, R. A., Molkov, S. V., & Poutanen, J. 2017, ApJ, 834, 209

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Polarization of neutron star emission in future missions

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Radiation emitted in the vicinity of an isolated neutron star is expected to be intrinsically polarized because the high magnetic field ($B \sim 10^{12}$–10^{15} G) strongly affects the plasma opacity. The polarization fraction and polarization angle measured by an instrument, however, do not necessary coincide with the intrinsic ones, due to the effects of both quantum electrodynamics in the highly magnetized vacuum around the star (the vacuum polarization) and rotation of the Stokes parameters in the plane perpendicular to the line of sight induced by the non-uniform magnetic field.

I will review theoretical estimates for the polarization observables in the case of thermal surface emission from neutron stars and of the (soft) X-ray emission from magnetars, where magnetospheric reprocessing of radiation by resonant Compton scattering is important. The potentials of X-ray polarimetry to probe the physical conditions in neutron star sources and to test, for the first time, vacuum polarization are discussed in connection with the recently proposed polarimetric missions: IXPE, recently selected by NASA, and XIPE, under evaluation by ESA for the M4 competition.

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Superfluid hydrodynamics in the inner crust of neutron stars

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The inner crust of neutron stars is supposed to be inhomogeneous and composed of dense structures (clusters) that are immersed in a dilute gas of unbound neutrons. Here we consider spherical clusters forming a BCC crystal and cylindrical rods arranged in a hexagonal lattice. We study the relative motion of these dense structures and the neutron gas using superfluid hydrodynamics. Within this approach, which relies on the assumption that Cooper pairs are small compared to the crystalline structures, we find that the entrainment of neutrons by the clusters is very weak since neutrons of the gas can flow through the clusters. Consequently, we obtain a low effective mass of the clusters and a superfluid density that is even higher than the density of unbound neutrons. Consequences for the constraints from glitch observations are discussed.

References

[1] Martin, N., & Urban, M. 2016, PRC, 94, 065801

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Polarized synchrotron X-ray emission from supernova shells. XIPE perspective

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Young supernova remnants are the sources of a broadband nonthermal synchrotron continuum emission from radio to X-rays produced by accelerated electrons. The process of electron acceleration by diffusion mechanism is accompanied by an efficient amplification of the turbulent magnetic field which is a significant agent of the diffusion shock acceleration itself. Synchrotron X-rays are produced by the high energy (multi-TeV) electrons that are concentrated in the narrow region near the shock front due to strong synchrotron radiation energy looses. This near shock confinement of energetic electrons together with the turbulent nature of a magnetic field leads to a complex small scale structure of SNR synchrotron X-ray maps including filament and clump structures. These X-ray structures are observed from almost all shell-type SNRs including Tycho, SN 1006, RX J1713.7–3946 etc. Some SNRs have even more rich structures like RX J1713.7–3946 where X-ray image revealed time variable clumps, while the strip-like structures were found in Tycho's SNR. In X-rays there is no Faraday depolarization. Accordingly, these synchrotron structures should be polarized and the degree of polarization could give a valuable information about magnetic field turbulence spectrum and anisotropy. This prediction is confirmed by radio observations that revealed polarized radiation from a number of SNRs including Tycho, SN 1006, Kes 69, W44, IC 443 and others while the Faraday depolarization is significant in the radio band.

Therefore, the observations with future generation of X-ray polarimeters are highly appreciated. XIPE is a suggested international ESA mission of an X-ray polarimeter with high angular and spectral resolution. In order to estimate the ability of XIPE to detect polarization emission from a typical young SNR like Tycho we model the polarized emission maps of the Tycho-like SNR with different assumptions on magnetic field fluctuation power spectrum and anisotropy. We conclude that for some models of anisotropic turbulent magnetic field the polarized X-ray emission could be detected from the Tycho SNR with the expected sensitivity and resolution of XIPE.

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Non-thermal particles in spectra and light-curves of Sco X-1

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Fast and strongly variable optical emission of accreting neutron star binaries was thought to be originating from the reprocessing of the X-ray emission coming from the central regions in the outer parts of the accretion disc. This picture is supported by the temporal properties, where the optical light-curve is delayed with respect to the X-ray light-curve [2, 4]. However, recent observations [1] show that this scenario is not always realised, and the optical/X-ray cross-correlation function shows a complex structure with the so-called precognition dip (anti-correlation), commonly seen in black hole binary systems [1, 3]. We show that the anti-correlation can be explained in the scenario where optical emission is partially produced by the synchrotron self-Compton mechanism in hybrid plasma [6]. This scenario is supported by the detected non-thermal MeV emission in Sco X-1 [5].

References

[1] Durant, M., Shahbaz, T., Gandhi, P., et al. 2011, MNRAS, 410, 2329

[2] Ilovaisky, S. A., Chevalier, C., White, N. E., et al. 1980, MNRAS, 191, 81

[3] Kanbach, G., Straubmeier, C., Spruit, H. C., & Belloni, T. 2001, Nature, 414, 180

[4] Muñoz-Darias, T., Martínez-Pais, I. G., Casares, J., et al. 2007, MNRAS, 379, 1637

[5] Revnivtsev, M. G., Tsygankov, S. S., Churazov, E. M., & Krivonos, R. A. 2014, MNRAS, 445, 1205

[6] Veledina, A., Poutanen, J. & Vurm, I. 2011, MNRAS, 410, 2329

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The small-scale magnetic field and the evolution of pulsar rotation in the framework of three-component model of neutron star

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We consider the evolution of pulsar rotation assuming that the star consists of the crust component (whose rotation is observed) and two core components. All components are supposed to rotate as rigid bodies. One of the core components contains pinned superfluid which can, for some reasons, suddenly inject a small fraction of angular momentum stored in it. In the framework of this toy model, the star can demonstrate glitch-like events together with a long period precession (with a period of $10-10^4$ years). The precession can survive on pulsar braking time-scale if the external electromagnetic torque acting on the neutron star has an equilibrium inclination angle. It can take place, for instance, if pulsar tubes are bent by a small-scale magnetic field. The details of the model describing the influence of the small-scale field on the external torque are given elswhere [1].

References

[1] Barsukov, D. P., Polyakova, P. I., & Tsygan, A. I. 2009, Astronomy Reports, 53, 1146

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Twist-induced Magnetosphere Reconfiguration for Intermittent Pulsars

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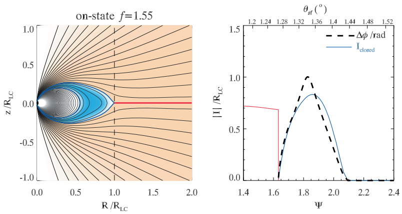

Figure 1: *Left*: The field lines configuration of twisted magnetosphere for the on-state of PSR B1931+24. Currents induced by twisting in closed lines are flowing in the blue shaded area. The spin-down rate ratio $f \approx 1.55$. *Right*: The distribution of $|I|$ in open lines region (solid red) and closed line region (solid blue). The dashed black line represents the distribution of corresponding twist angle $\phi(\Psi)$ in closed line region. The local crustal active region is within the boundary $\theta_{\rm m} = 1.44°$. The maximal twist angle $\Delta\phi_{\rm max}$ reaches the saturated value $\Delta\phi_{\rm thres} \sim 1$.

We propose that the magnetosphere reconfiguration induced by magnetic twists can account for the mode-switching of intermittent pulsars[1]. We investigate the properties of axisymmetric force-free pulsar magnetospheres with magnetic twists in closed field line region. The magnetic twist leads to enhanced spin-down rates. The enhancement in spin-down rate depends on the size of region with twisted closed lines. Typically, it is increased by a factor of ~ 2, consistent with the intermittent pulsars' spin down behavior during the 'off' and 'on' states. There is a threshold of maximal twist angle $\Delta\phi_{\rm thres} \sim 1$. The magnetosphere is stable only if twist angle is less than $\Delta\phi_{\rm thres}$. Beyond this value, the magnetosphere becomes unstable and gets untwisted. The spin-down rate would reduce to its off-state value. The quasi-periodicity in spin-down rate change can be explained by long-term activities in star's crust and the untwisting induced by MHD instability. The estimated duration time of on-state is about one week, consistent with observations. Due to the MHD instability, there exists an upper limit for the spin down ratio ($f \sim 3$) between the on-state and the off-state, if the Y-point remains at the light cylinder‡.

References

[1] Huang, L., Yu, C., & Tong, H. 2016, ApJ, 827, 80

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Abrupt Changes in Pulsar Pulse Profile Through Multiple Magnetospheric State Switching

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A purely magnetospheric model is introduced for observed abrupt changes in pulsar radio profile. The motion of the magnetospheric plasma is described in terms of a drift frequency, $\omega_{\rm dr}$, that depends on a parameter $0 \leq y \leq 1$, and a change in the magnetospheric state is described by a change in y. Emission is assumed to arise from m spots distributed uniformly around the magnetic axis, so that the spots drift by at the rate $m\omega_{\rm dr}$. Observable features, such as subpulses, appear to rotate as $\omega_{\rm R} = m\omega_{\rm dr} - \omega_{\rm V}$. The motion of the visible point, described by the angular frequency $\omega_{\rm V}$, is ignored in a "standard" version of the viewing geometry that assumes a fixed line of sight (rather than a fixed line-of-sight direction), implying $\omega_{\rm V} = 0$. Neglect of $\omega_{\rm V}$ is strictly valid only for $\alpha = 0$; for $\alpha \neq 0$ it is a valid approximation only in a narrow range of pulsar phase ψ about $\psi = 0$, and this range decreases as α increases. With $\omega_{\rm V} \neq 0$, the apparent distribution of emission spots around the trajectory of the visible point is uneven, and the apparent motion of an individual spot is not constant. The apparent density of spots is highest around $\psi = 0$ (the center of the pulse window), where their apparent motion is slowest, allowing more spots to be present simultaneously in the pulse window than in the "standard" version. An abrupt (or more gradual) change in y implies a change in $\omega_{\rm R}$, which affects the pulse structure and profile. For example, a change from smaller y to larger y causes a peak in the profile (at a fixed ψ) to appear to shift to an earlier ψ. We apply the model for profile shifts observed with PSR B0919+06.

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Confirming the nature of the knot near pulsar B1951+32

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The middle-aged, energetic and fast moving radio and gamma-ray pulsar PSR B1951+32 is associated with the supernova remnant CTB 80. It powers a complex pulsar wind nebula detected in the radio, H-alpha and X-rays [1]. A puzzling optical knot was detected about $0\rlap{.}''5$ from the pulsar in the optical and near-IR [1, 2]. It is reminiscent of the unique "inner optical knot" located $0\rlap{.}''6$ from the Crab pulsar. Until now there was no evidence that the B1951+32 knot is indeed associated with the pulsar.

We observed the pulsar field with Gemini-North in 2016 to confirm the association. We performed first near-IR high-spatial resolution imaging in the K_s band using the NIRI+Altair instrument and deep optical imaging in the *gr* bands using the GMOS instrument. Our observations showed that the current knot position is shifted by $\approx 0\rlap{.}''5$ from the position measured with the HST (1997 epoch). This is consistent with the known pulsar proper motion and is a direct evidence of the pulsar–knot connection. We established the spectral energy distribution (SED) of the knot and compared with the SED of the Crab knot. We discuss possible implications of the results.

References

[1] Moon, D.-S., Lee, J.-J., Eikenberry, S. S., et al. 2004, ApJL, 610, L33

[2] Hester, J. 2000, Bulletin of the American Astronomical Society, 32, 82.16

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Author index

FOR NOTES

FOR NOTES

Международная конференция

ФИЗИКА НЕЙТРОННЫХ ЗВЁЗД
2017
50 лет с момента
открытия первого пульсара
(Санкт-Петербург, 10–14 июля 2017 г.)

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