Conference on

PHYSICS OF NEUTRON STARS

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Book of Abstracts

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Preface

The conference on Physics of Neutron Stars at the Ioffe Physico-Technical Institute on June 27–29, 2005 is the 7th gathering on neutron star physics in Saint-Petersburg (after those in 1988, 1992, 1995, 1997, 1999, and 2001). Its aim is to bring together those who are interested in physics and astrophysics of neutron stars and related problems. The scope of the conference covers a large variety of subjects relevant to theory and observations of neutron stars: radiation (from radio to hard gamma-rays), origin, evolution in binary systems, merging, radio pulsars, X-ray pulsars, X-ray bursters, transients, soft gamma repeaters, anomalous X-ray pulsars, internal structure, atmospheres, neutrino emission, etc. The official language of the conference is Russian, but there are a few talks in English.

The Scientific Organizing Committee of the conference includes:

D.A. Varshalovich (Chair, Ioffe Institute),

R.L. Aptekar (Ioffe Institute),

G.S. Bisnovatyi-Kogan (Space Research Institute, Moscow),

A.M. Bykov (Ioffe Institute),

V.S. Imshennik (Alikhanov Institute for Exper. and Theor. Physics, Moscow),

A.V. Ivanchik (Ioffe Institute),

A.D. Kaminker (Ioffe Institute),

A.M. Krassilchtchikov (Ioffe Institute),

K.A. Postnov (Sternberg Astronomical Institute, Moscow),

A.Y. Potekhin (Ioffe Institute),

M.E. Prokhorov (Sternberg Astronomical Institute, Moscow),

Yu.A. Shibanov (Ioffe Institute),

D.G. Yakovlev (Ioffe Institute).

The sessions include several invited talks, a larger number of contributed talks, and an oral-poster session. The oral talks and poster presentations have been selected by the Scientific Organizing Committee after considering abstracts submitted by the authors. This book contains these abstracts.

Acknowledgments. This conference was supported by the Russian Foundation for Basic Research (RFBR grant 05-02-26079), the *Dynastia* Foundation, and the Presidium of the Russian Academy of Sciences.

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N.R.Ikhsanov	Pulkovo Main Astron. Obs.
N.V.Mikheev	Yaroslavl State (Demidov) Univ.
D.K.Nadyozhin	Alikhanov Inst. (ITEP), Moscow

The masses of compact objects in the X-ray binaries Cen X-3, LMC X-4, SMC X-1, 4U 1538–52, Vela X-1 and 2S 0921–63

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Composite radial-velocity curves obtained in observations of the X-ray binaries Cen X-3, LMC X-4, SMC X-1, 4U 1538–52, and Vela X-1 [1], containing OB-supergiants, are interpreted using the statistical approach for the Roche model. The interaction between the binary components, as well as the anisotropy of stellar wind from the optical counterpart are taken into account. As a result, the estimates of masses of the X-ray pulsars in these binary systems have been improved and the adequacy of the model to the observational data has been checked. Using the same model, an observed radial-velocity curve of the X-ray binary 2S 0921–63 [2], with a low-mass optical counterpart, is interpreted taking into account the interaction between the components and the screening of X-ray flux by the accretion disk. Correlations are obtained between the optical star mass m_v and the compact object mass m_x for the three orbit inclinations: $i = 60°$, $75°$ and $90°$.

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Structure of pair winds from compact objects with an application to the emission from hot bare strange stars

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A stationary wind of electron-positron pairs and photons from a spherically symmetric star is studied. We do not assume thermal equilibrium and include two-body processes ($ee \leftrightarrow ee$, $\gamma e \leftrightarrow \gamma e$, $e^+e^- \leftrightarrow \gamma\gamma$), which occur in this wind, together with three-body radiative processes ($ee \leftrightarrow ee\gamma$, $\gamma e \leftrightarrow \gamma e\gamma$, $e^+e^- \leftrightarrow \gamma\gamma\gamma$). In contrast to previous publications [1, 2], we take into account gravitational forces and the effects of General Relativity.

As an example, we study the wind injected by a hot, bare strange star. Such stars are thought to be powerful sources of hard X-ray photons and $e^{\pm}$ pairs created by the Coulomb barrier at the quark surface. We also present a new, finite-difference scheme for solving general relativistic kinetic Boltzmann equations for pairs and photons. Using this method we study the kinetics of wind particles and photon emission for the energy injection rate in pairs which corresponds to the luminosities up to 10^{39} ergs s^{-1} when gravitational forces are important. The effect of nonthermal photons radiated by the star is also discussed.

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Soft Gamma Repeaters

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Four Soft Gamma Repeaters (SGRs) have now been identified with certainty. In the active phase, SGRs produce short (duration ∼0.1–1 s), soft (peak energy $E_p \simeq$15–40 keV) bursts. But rarely, an SGR emits a giant flare — a short giant radiation pulse followed by a weaker tail, which pulsates with the period of neutron star rotation of ∼5–8 s. Such giant flares were detected from three of four known SGRs: on March 5, 1979 from SGR 0526-66 [1], on August 27, 1998 from SGR 1900+14 [2–4] and on December 27, 2004 from SGR 1806-20 ([5, 6] and references therein). The SGR 1627-41 produced a huge burst on June 18, 1998. It was weaker than the others and had no pulsating tail [7]. The last two giant flares were detected by the same joint Russian-U.S. Konus-Wind experiment on board the GGS-Wind spacecraft.

The enormous intensity of the initial pulse of the December 27 event proved to be far above the saturation level of the γ-ray detectors, which resulted in loosing the most valuable data on the time structure and energy spectrum of the pulse. At the time of the December 27 outburst, Coronas-F, a Russian spacecraft with a γ-ray spectrometer aboard, was occulted by the Earth and could not see the outburst. It succeeded, however, in observing a weak reflected signal due to Compton scattering of γ-rays by the Moon [6]. The detection of a weakened back-scattered initial pulse combined with direct observations by the Konus γ-ray spectrometer on the Wind spacecraft enabled us to reliably reconstruct the intensity, time history, and energy spectra of the outburst.

We give a short overview of observational properties of SGRs, and present our data on SGR 1806-20 activity before and after the giant flare, as well as the detailed temporal and spectral analysis of the giant flare itself. We compare the three giant flares to one another and discuss the relation of giant flares to short γ-ray bursts.

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The synthesis of p-nuclei in supernova explosion

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The model of p-nucleus synthesis in supernova explosion of a massive star is considered. The calculations are made using a fully implicit scheme.The self-consistent nuclear reaction network, which includes more than 4500 nuclei and (n,γ), (p,γ), (α,γ), (p,n), (α,n), (α,p) reactions and their inverse, is solved in order to obtain mass fractions of isotopes. This reaction network is calculated within the whole presupernova star (for all mass coordinates), excluding the iron core. The presupernova model may be arbitrary. In our test calculations, we use a presupernova model from Ref. [1]. Also, from Ref. [1] we get the mass fractions of light isotopes (including Fe and Ni) as well as density and temperature distributions within the star.

The main feature of the model is that the abundance of s-nuclei after the ejection always corresponds to the observational abundance in the solar system (relative to ^{16}O; Ref. [2]). The initial mass fractions of s-nuclei (at presupernova stage) are selected according to the above condition. The initial mass fractions of p- and r-nuclei are set zero. Therefore, the s-nuclei are seed nuclei for p-isotopes.

Our calculations show that the most favorable conditions for p-nucleus synthesis take place in oxygen layers of the supernova. This fact was known long ago (see, for example, Refs. [2,3]). We are able to obtain in sufficient amounts such p-isotopes as ^{113}In, ^{138}La, and ^{180}Ta.

Finally, we find that the calculated abundance of p-nuclei agrees, in general, with the abundance in the solar system.

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Gamma radiation of radio pulsar polar caps with asymmetric magnetic field

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The influence of asymmetric magnetic field on intensity, spectrum and pulse profile of gamma radiation of radio pulsar polar caps is considered. The Goldreich-Julian model for the regime of free-electron emission from the neutron star surface is used. The curvature of non-dipolar magnetic field lines and the distortion of accelerating electric field caused by the magnetic field non-dipolarity are taken into account.
The influence of magnetic field non-dipolarity on radio pulsar death lines is also investigated. When calculating pulsar death lines we take into account electron-positron pair production both by curvature gamma radiation of primary electrons and the inverse Compton scattering of thermal photons from neutron star surface on primary electrons. It is shown that in the considered case the pulsar death line may be shifted to longer periods, for example, to $P = 18B_{12}$ s. This allows us to explain the existence of the long-period pulsars, with periods $P \sim (6-8)$ s.
It is shown that in the case of non-dipolar magnetic field the generation of electron-positron pairs outside of the pulsar tube is present. It may lead to the existence of isotropic-like low-frequency radio emission from pulsars.

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A study of PSR 0531+21 light curve with 6.6 us temporal resolution

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The results of the Crab pulsar observations with the APD avalanche diode photon counter using the 6-meter BTA telescope of the Special Astrophysical Observatory are presented. The observations we performed in November 2003 in the framework of the multi-frequency synchronous observational campaign.

The folded light curve has been constructed by two different methods, using the Jodrell Bank Crab pulsar Timing Ephemeris and using the Fast Folding Period Search method employing only data of optical observations.

Both methods gave the 10^{-11} s accuracy of period determination, which corresponds to 2×10^{-4} precision of photon phases. This allows us to obtain the light curve folding with 6.6 us temporal resolution.

The analysis of the folded light curve shows the presence of some structure in the main pulse peak, which may be interpreted either as an absorption with a 30 us width and 1% amplitude on the smooth peak profile (3.9σ significance level) or as a flat emission-like feature with 0.5% amplitude and 70 us duration (5.9σ significance level). The results may indicate the presence of a small-scale structure of the optical emission region in the magnetosphere, which may be used for constraining models of pulsar emission.

Of course, the presence and parameters of such a small-scale structure of the main pulse ought to be confirmed in future observations.

Evolution of magnetic fields of neutron stars

G. S. Bisnovatyi-Kogan

Estimations of magnetic fields of neutron stars, observed as radio and X-ray pulsars, are discussed. Radiopulsars in close binaries and millisecond pulsars, which have passed the stage of disk accretion (recycled radiopulsars), have magnetic fields 2-4 orders of magnitude smaller than ordinary single pulsars. Most probably, the magnetic field of the neutron star was screened by the infalling material. Several screening models are considered. Properties of pulsars in the unique double-pulsar binary give evidence in favor of this model. Theoretical and observational values for different types of radiopulsars are in good correspondence with theoretical estimations. The formation of single recycled pulsars by loosing their binary companions is discussed.

Magnetic fields of some X-ray pulsars are estimated from the cyclotron line energy. In the case of Her X-1 this estimation exceeds considerably the value of the magnetic field obtained from long term observational data related to the beam structure evolution. Another interpretation of the cyclotron feature, based on the relativistic dipole radiation mechanism, could remove this discrepancy. Observational data on soft gamma repeaters and their interpretation as magnetars are critically analyzed.

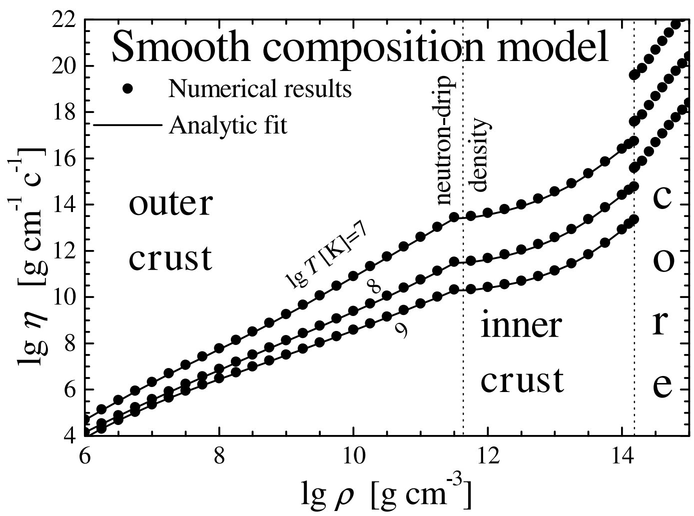
Photon-neutrino interactions in strongly magnetized plasma

M. V. Chistyakov, D. A. Rumyantsev

The influence of the strongly magnetized electron-positron plasma on the processes of two photon neutrino-antineutrino pair emission is investigated with respect to the magnetar model. The neutrino emissivity due to the photon-neutrino reactions is calculated taking into account the photon dispersion and large radiative correction. The role of the processes under consideration in the formation of giant flares in SGRs is discussed.

Shear viscosity of a strongly non-ideal Coulomb plasma and oscillations of neutron star crust

A. I. Chugunov *, D. G. Yakovlev †



We have calculated the shear viscosity of dense matter (determined by Coulomb electron collisions) in a wide range of parameters typical for cores of white dwarfs and envelopes of neutron stars. In the density range from $\sim 10^3$ g cm^{-3} to $10^7 - 10^{10}$ g cm^{-3} we have considered the plasma of widely spread astrophysical elements from H to Fe. For higher densities, $10^{10} - 10^{14}$ g cm^{-3}, we employ the ground-state nuclear composition, taking into account finite sizes of atomic nuclei and the distribution of the proton charge over an atomic nucleus. Results of numerical calculations are approximated by an analytic expression which is convenient for practical applications. The figure presents numerical results (thick dots) and analytic approximation (lines) for three temperatures $T = 10^7$, 10^8, 10^9 K. The figure is extended from the neutron star crust into the core (where the density $\rho \geq 1.5 \times 10^{14}$ g cm^{-3}). The viscosity in the core is about three orders of magnitude higher than in the crust, because atomic nuclei (very efficient electron scatterers) are absent in the core, and the electrons scatter there off strongly degenerate protons.

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Using the approximation of a plane-parallel layer, we have calculated frequencies and eigenmodes (the profiles of hydrodynamical velocity and of variations of density and pressure) as well as viscous damping times of oscillations of high multipolarity $l \sim 500 - 1000$, localized in the outer crust of a neutron star. For instance, at $l \sim 500$ the oscillations have frequencies $f \gtrsim 40$ kHz and are localized not deeper than 300 m under the surface. When the crust temperature decreases from 10^9 K to 10^7 K, the damping time of oscillations (with a few radial nodes) decreases from ~ 1 year to $10 - 15$ days.

The work was partly supported by the Russian Leading Scientific Schools (grant 1115.2003.2), by the Dynasty Foundation and the RFBR (grant 05-02-16245).

On computer modeling of real submillisecond gamma-ray pulsations from rotating neutron stars

E. I. Chuikin

Submillisecond gamma-ray pulsations were discovered by us for the Vela and Geminga pulsars (in 1996 and 2001, respectively) from a database of their observations performed in 1990–1991 with the GAMMA-1 telescope. We have already carried out (in 2002–2003) some modeling of such pulsations of radiation from rotating neutron stars, to prove the possibility to discern short-periodic processes, with periods less than discretization time. The essence of our modeling consists in an alternate imposing of submillisecond pulsations with different periods T on a detection time scale with the discretization T_0 of 1 ms. A sequence of the number of events detected per millisecond was determined for every T. These sequences turned out to be: 1) periodic with repetition characteristic T' for every T; 2) with intrinsic patterns. The phasogram of initial pulsations T was obtained then with the "Superposition of epoch method" just as a resonance frequency is selected by a tuned receiver. However, that first modeling was a somewhat imaginary, numerical experiment, although precise and strict. Now we present results of real computer modeling with variations of input T data and corresponding output results. Together with studies of pulsations by the "Superposition of epoch method", by the "Discrete temporal Fourier series method", and with a number of statistical criteria, our modeling proves the reality of pulsations and the possibility to distinguish even those of them which are significantly shorter than the discretization time. In order to reveal pulsations one should establish synchronous links between investigated pulsations and any parallel periodic process. In our case, such process is the pulsar rotation, specifically, the synchronous emission of low- and high- latitude electrons which generate curvature radiation. Some applications of our results are outlined.

A brief review of the history of SGR and GRB astronomy

T. L. Cline

"Soft gamma repeaters" (SGRs) are the extremely bright bursts of > 50-keV photons detected from sources in the distant disk of the Milky Way and the LMC, and, as has been recently suggested, possibly from other galaxies as well. The phenomenology of SGRs is fascinating, with their episodic time scales ranging from hours to decades and their 'visual magnitudes' brighter than (but time profiles shorter than) most gamma ray bursts (GRBs). The physics of SGRs and of their 'magnetar' neutron-star origins is thus under understandably intense study. The history of SGR astronomy begins with the discovery by Golenetskii and Mazets, from the Ioffe Institute. Its trace through the late 1970s to the present time, and the relation of SGR to GRB astronomy, will be briefly outlined in this talk. A recent development is the dramatic occurrence of the SGR flare of December 2004, that may be classed as even beyond the scale of the previously record-breaking events of March 1979 and August 1998.

High-energy emission from super-critical particles in relativistic jets

E. V. Derishev, F. A. Aharonian, Vl. V. Kocharovsky

We show that in various particle acceleration models (in particular, in the converter acceleration mechanism) the energy of radiating particles can be raised above the critical value, defined as the energy at which the radiation length equals to the gyroradius. The emission of super-critical particles has a number of distinctive features. For example, a population of such particles in a relativistic jet produces decollimated radiation, increasing the effective width of the beam pattern for photons in the GeV-TeV energy range. In general, the off-axis emission appears to be brighter, has a much harder spectrum and a much higher cut-off frequency compared to the values derived for the emission of sub-critical particles. The magnitude of these effects depends on the details of particle acceleration mechanisms, what can be used to discriminate between different models. The broadening of beam pattern strongly influences timing properties of transients, such as Gamma-Ray Bursts, and aid in searches for off-axis jet sources.

Line-driven winds near compact objects

A. V. Dorodnitsyn

We consider a general physical mechanism which could contribute to the formation of fast line-driven outflows in the vicinity of strong gravitational field sources (black holes, neutron stars). Accretion disks around such objects are observed to be sources of fast collimated and uncollimated winds and jets. One of the most important and efficient mechanisms known to work in such a case is the acceleration of plasma due to absorption of the radiation flux from disk in spectral lines of abundant elements. It was believed that such a line-driven wind can be well described by the standard theory of Castor, Abbott and Klein (1975). We argue that the gradient of the gravitational potential plays the same role as the velocity gradient plays in the Sobolev approximation. When both Doppler effect and gravitational redshifting are taken into account in the Sobolev approximation, the radiation force becomes a function of the local velocity gradient and the gradient of the gravitational potential. The derived equation of motion has properties which are different from those in the standard theory. In particular, it has a critical point that is different from that of the CAK theory. A comparison with the CAK theory is presented. It is shown that the developed theory predicts terminal velocities which can be 50% larger than those obtained from the CAK theory. The developed theory can have an important contribution to the formation of radiation-driven jets/winds near compact objects.

Detection of giant pulses in the pulsar J1752+2359

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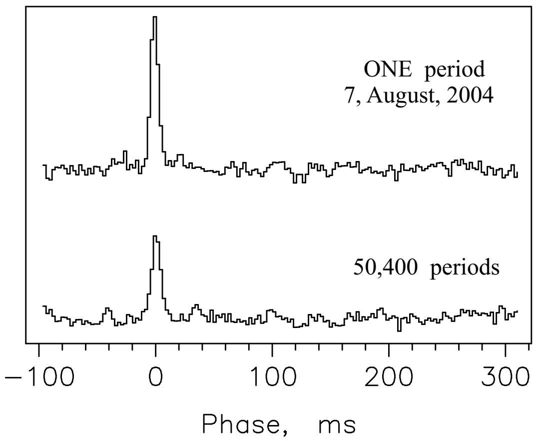

Figure 1: **(Top)** The strongest observed giant pulse. **(Bottom)** The average pulse profile containing 50 400 pulsar periods. The intensity of the profiles is shown in arbitrary units.

Giant pulses (GPs) are short duration burst-like increases of an intensity of individual pulses from pulsars. We report the detection of GPs from the pulsar PSR J1752+2359.

Observations were performed from December 24, 2003 to October 04, 2004 with the Large Phase Array (BSA) Radio Telescope at Pushchino Radio Astronomy Observatory at a frequency of 111 MHz. We used a 128-channel receiver with channel bandwidth 20 kHz. The duration of each observation session was about 3 min (420 pulsar periods). A total of 120 observations containing 50 400 pulsar periods were carried out in the mode of recording single pulses.

The 187 pulses (1 pulse for 270 observed periods) with $S/N \geq 5$ were selected and analyzed. About one pulse in 270 has peak flux density more than 40 times the peak flux density of an average pulse (AP), and the strongest GP was as large as 260 (see Fig. 1). The energy of the strongest GP exceeds the energy of the AP by a factor of 200 in which it differs from other pulsars with GPs. A pulse whose energy exceeded an energy of the AP by more than a factor of 100 is encountered approximately once in 3000 observed periods. Cumulative distribution is fit by a power-law with the index -3.0 ± 0.4.

The detection and first searches of GPs were performed in pulsars with extremely high magnetic field at the light cylinder, $B_{\rm LC} = 10^4 - 10^5$ G. The detection of GPs in the pulsars PSR B1112+50 [1], PSR B0031–07 [2, 3] and presently reported PSR J1752+2359 have revealed that GPs exist also in pulsars with ordinary magnetic field at the light cylinder,

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$B_{\mathrm{LC}} = 1 - 100$ G. These GPs may be associated with the inner gap emission region.

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Pulse intensity histograms for nine pulsars

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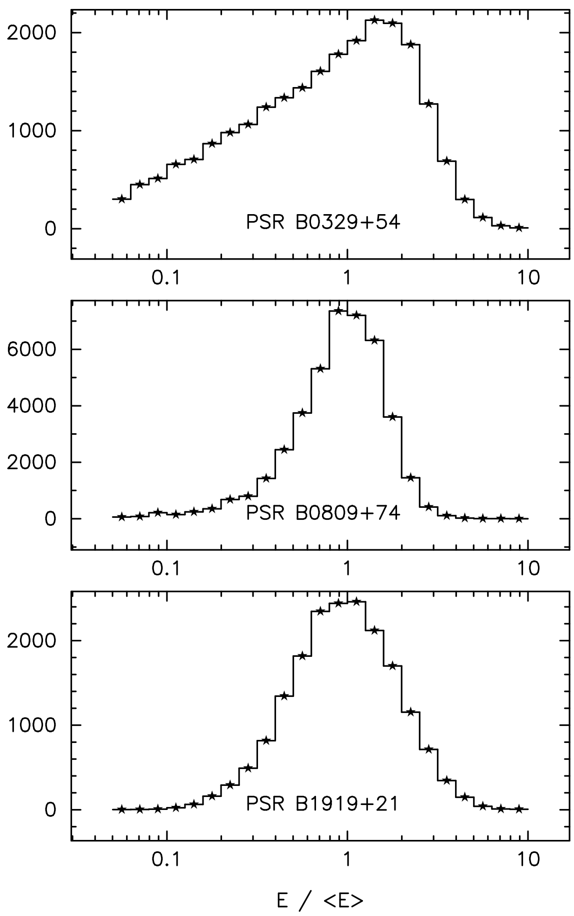

Figure 1: The pulse energy histograms of three pulsars (in units of mean).

The recent literature on the energy distribution of single pulses is rather sparse (except for pulsars showing giant pulses). Johnston et al. [1] showed that the logarithm of the flux density of single pulses from the Vela pulsar had a Gaussian distribution (the so-called log-normal distribution). In retrospect, the distributions of single pulse energies were shown in [2] and [3] for a variety of pulsars. In this report I show the distributions of single pulse energies for nine strong pulsars at the frequency of 111 MHz.

The observations were made during 2004 with the Large Phase Array (BSA) Radio Telescope at Push-chino Radio Astronomy Observatory. BSA is a transit telescope. The duration of each observation session was about $3.2/\cos\delta$ minutes. I used a 128-channel receiver with channel bandwidth 20 kHz, and the time constant was $\tau = 1$ ms.

Figure 1 shows the histograms of energy distributions for the three pulsars: PSR B0329+54 (58 days, 320 min, 26 970 periods), PSR B0809+74 (78 days, 930 min, 43 290 periods), and PSR B1919+21 (155 days, 530 min, 24 025 periods). The abscissae are in units of the mean pulse energy, $\langle \mathrm{E} \rangle$, and the ordinates show the number of pulses contained in every energy resolution bin. The distribution for PSR B1919+21 is clearly log-normal, but one for PSR B0329+54 is not.

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Early-time spectroscopy of the GRB 041218 optical transient with the 6-meter telescope

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We present early-time spectroscopic observations of GRB 041218 optical transient (GRB OT). Observations were performed with the `SCORPIO` instrument attached at the primary focus of the 6-meter telescope of the SAO RAS.

The 60 seconds long GRB 041218 was detected with the `INTEGRAL Burst Alert System (IBAS)` on December 18, 2004 at 15:45:25 UT (Mereghetti et al., 2004, GCN #2858). 20 minutes later an afterglow candidate with brightness of about ~ 16.5 mag was found within the error box (Torii, 2004, GCN #2860). It was confirmed by Gorosabel et al. (2004, GCN #2861) that the object showed clear decay.

Our observations were started on December 18, 2004 at 21:59:04 UT, i.e. about 6^h after the burst. The spectrum taken is one of the earliest spectrum of GRB OTs obtained nowadays. The `VPHG550G` prism was used giving spectral resolution of $FWHM \approx 10$Å and range of $3500 - 7600$ÅÅ. Total exposure time was 2 hours. Due to high Galactic extinction the final spectra were corrected to reproduce a "true" spectral slope. As can be seen from Figure, the spectrum is roughly flat with the presence of absorption features near 5000Å and probably near 6000Å. One of most probable identifications of the feature at ≈ 5000Å is the doublet of Magnesium. If our identification is true then the lower limit of the OT redshift is 0.80.

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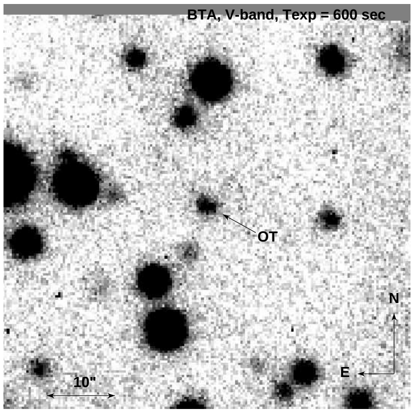
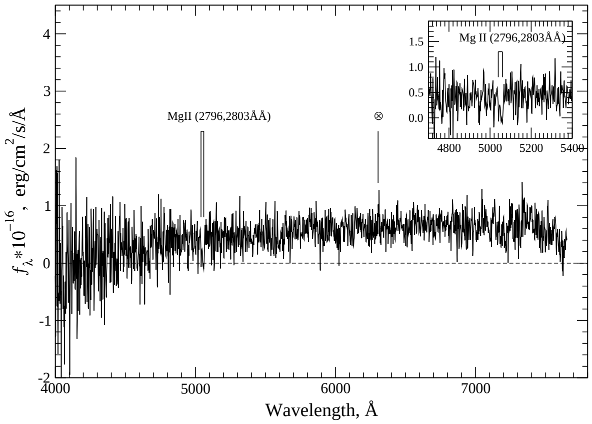


The V-band image of the GRB 041218 OT field on December 18, 2004 at 21:34:35 UT. The OT is marked by arrow. The brightness of the OT is $V = 22.26 \pm 0.06$. The size of the field is 1×1 arcmin.



The spectrum of the OT corrected for the Galactic extinction according to $E(B-V) = 0.634$. The mean epoch of the spectrum is December 18, 2004 at 23:17 UT. Most probable absorption line identification is also shown. If identification is true then lower limit of the OT redshift is 0.80.

INTEGRAL and RXTE observations of the X-ray pulsar OAO 1657–415

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The emission variability of the pulsar OAO 1657–415 in X- and gamma-rays were investigated on timescales of pulse and orbital periods using RXTE and INTEGRAL data. It was found that the source flux is affected by strong orbital modulations, including periodical eclipses of the X-ray source by its optical companion. During these eclipses, which lasted ~ 2 days, the pulsar flux was about 3 mCrab (18 – 60 keV), while at the peak it reached ~ 200 mCrab (18 – 60 keV). The evolution of the system orbital parameters were investigated, using RXTE data.

The source OAO 1657–415 shows episodes of acceleration and deceleration of the pulse period. Combining RXTE and INTEGRAL data we have derived a mean pulse period change rate, which is about 2.5 times lower, than previously reported in Ref. [1], where only RXTE data were used.

The pulsar is clearly detected up to 100 keV. The analysis of the pulsar spectrum for different orbital phases showed a stability of its shape. It can be approximated by a simple power law model ($\Gamma \sim 1.6$) with a high-energy cutoff ($E_{cut} \sim 25$ keV, $E_{fold} \sim 30$ keV), which is typical for objects of this class [2]. The strong photoabsorption with $N_H \sim 16 \times 10^{22}$ cm^{-2} was detected in the source spectrum.

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Perspectives of future X-ray astronomical polarimetry

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X-ray polarimetry is one of perspective methods of the X-ray astronomy. Since the first discovery of X-ray sources the theory has predicted a high degree of polarization that could be expected owing to electron scattering and non-thermal emission mechanisms. The conventional polarimetric techniques are based on Compton scattering and Bragg diffraction. The latest developments are outlined to design sensitive X-ray polarimeters based on the photoelectric effect and most recent micropattern detectors. The latter will be installed in the focus of XEUS-1. In my talk I formulate some new problems that can be solved directly via X-ray polarimetry. X-ray polarimetry is the most effective tool for investigating quantum electrodynamical effects of vacuum polarization and birefringence in extreme magnetic fields. Also, I show how: (a) it is possible via X-ray polarization to distinguish between rotating Kerr and non-rotating Schwarzschild black holes, (b) to derive the dimensionless rotation parameter a/M, (c) to determine the magnitude and structure of the magnetic field in the nearest environment of black holes (the inner radius of an accretion disk, a marginally stable orbit). I show that Faraday rotation of polarization plane in electron scattering affects essentially the wavelength dependence of X-ray polarization.

Short-lived hard X-ray transients discovered with INTEGRAL

S. A. Grebenev

During the first two and a half years of operation in the orbit the INTEGRAL observatory discovered 50 new hard X-ray sources that significantly (by 40-50 percent) enlarges the amount of such sources detected in previous experiments. It is natural that different types of sources are present in this sample but two notable source populations certainly escape: strongly absorbed sources (with a very low flux in the standard X-ray band that made them unobservable in X-ray surveys) and short-lived transients appearing on the sky for only a few hours (that made them again very difficult to detect).

Outbursts of latter sources are too long to be attributed to thermonuclear explosions at the neutron star surface (observed as type I X-ray bursts or superbursts). On the other hand, they are shorter than the typical accretion (viscous) time (exceeds 1.4 days) governing propagation of perturbations in the standard accretion disk. We describe observational properties of these short-lived transients and discuss their possible origin.

Cooling of hybrid neutron stars

H. Grigorian, D. Blaschke, D. Voskresensky

The cooling of compact isolated objects for different values of the gravitational mass M has been simulated under two alternative assumptions: (1) the interior of the star is purely hadronic, (2) the star can have a rather large quark core. It has been shown that within a nonlocal chiral quark model the critical density for a phase transition to color superconducting quark matter under neutron star conditions can be low enough for these phases to occur in compact stars with $M < 1.3\,M_{\odot}$. For a realistic choice of parameters, the equation of state (EoS) allows for 2SC quark matter (with a large quark gap ~ 100 MeV for u and d quarks of two colors) that coexists with normal quark matter within a mixed phase in the hybrid star interior. We argue that, if in the hadronic phase the neutron pairing gap in $^3P_2$ channel is larger than few keV and the phases with unpaired quarks are allowed, the corresponding hybrid stars would cool too fast. Even in the case of strongly suppressed $^3P_2$ neutron gap, if free quarks occur for $M < 1.3M_{\odot}$, as follows from our EoS, one could not satisfy the available observations of cooling neutron stars. It is suggested to discuss a "2SC+X" phase, as a possibility to have all quarks paired in two-flavor quark matter under neutron star conditions, where the X-gap is of the order of 10 keV – 1 MeV. Density independent gaps do not allow us to fit the cooling data. Only the presence of an X-gap that decreases with increasing density could allow us to interpret the data in terms of cooling compact stars with masses similar to masses of purely hadronic stars.

Entrainment matrix and superfluid properties of neutron stars

M. E. Gusakov, P. Haensel

We have derived the entrainment (Andreev-Bashkin) matrix for a neutron-proton mixture at a finite temperature in a neutron star core. The calculation is performed in the frame of the Landau Fermi-liquid theory generalized to account for superfluidity of nucleons. It is shown, that the temperature dependence of the entrainment matrix is described by a universal function independent of a model of nucleon-nucleon interaction employed.

The results are applied for analyzing sound modes in the matter, composed of superfluid neutrons, superconducting protons, and electrons. Pulsations of superfluid neutron stars are also discussed. The emphasis is made on the effects of temperature dependent chirping of pulsation frequencies, which can (in principle) serve as a probe for studying very subtle properties of superdense matter in neutron stars.

This research was supported partly by the Russian Leading Scientific Schools (grant 1115.2003.2), the RFBR (grant 05-02-16247), the Russian Science Support Foundation, and by the INTAS (grant YSF 03-55-2397).

Neutrino cooling of a giant flare from a magnetar

A. A. Gvozdev, I. S. Ognev

Dominant neutrino-lepton processes under the conditions of a giant flare from a magnetar are investigated. In the framework of Duncan and Thompson model, the neutrino cooling rate of a hot, relativistic fireball is calculated. Fireball physical parameters required for explaining the efficiency of neutrino cooling in a giant flare from the magnetar is discussed.

Hydrodynamic processes of asymmetric collapsing supernova explosion with rotation

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Hydrodynamic processes, by which the collapse of stellar core triggers the supernovae explosion, were studied in detail by solving numerically an axially symmetric problem taking into account fast initial rotation of the iron core [1]–[4]. Simulations showed the propagation of a strong diverging shock wave with a large asymmetry of the explosion and with a total post-shock energy comparable to the characteristic energies of observed supernovae. Physical background for the formulation of the problems under consideration is provided by the rotational explosion scenario for collapsing supernovae. According to this scenario, supernovae explosion is preceded by the formation of a compact binary system of neutron stars through the fragmentation of a rapidly rotating preneutron star. Such neutron star binary evolves to the point of explosion due to the losses of energy and angular momentum via the emission of gravitational waves in the presence of uniform or toroidal atmosphere – another remnant of iron core collapse.

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Can a slowly rotating neutron star be a radio pulsar?

Ya. Istomin

It is shown that the curvature radius of magnetic field lines in the polar region of a rotating magnetized neutron star can be significantly smaller than the usual curvature radius of dipole magnetic field. The magnetic field in the polar cap is distorted by the toroidal electric currents flowing in the neutron star crust. These currents close up the magnetospheric currents driven by generation process of electron-positron plasma in the pulsar magnetosphere. Due to the decrease of the curvature radius, the electron-positron plasma generation becomes possible even for slowly rotating neutron stars, $P \cdot B_{12}^{-2/3} < 10$ s, where P is the pulsar spin period, B_{12} is the magnetic field B on the star surface expressed in 10^{12} G, $B_{12} = B/10^{12}$ G.

New scenarios of neutron star cooling

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We discuss new scenarios of neutron star cooling (the so called *minimal cooling scenarios*) in which Cooper-pairing neutrino emission in superfluid nucleon stellar cores initiates an enhanced cooling even if the powerful direct Urca process (or any other enhanced neutrino process in non-superfluid matter) is forbidden. The initial versions of these scenarios were proposed by Page et al. (2004) and Gusakov et al. (2004). We outline the initial and more elaborated versions. We employ phenomenological density-dependent critical temperatures $T_{\rm cp}(\rho)$ and $T_{\rm cnt}(\rho)$ of singlet-state proton and triplet-state neutron pairing in a stellar core, as well as critical temperature $T_{\rm cns}(\rho)$ of singlet-state neutron pairing in a stellar crust. By regulating the density dependence $T_{\rm cn}(\rho)$, we can interpret observations of thermal radiation of isolated neutron stars with forbidden or open direct Urca process. In particular, we can explain observations of isolated neutron stars coldest for their age, PSR J0205+6449 (3C 58), Vela, and RX J0007.0+7302 (CTA 1), by the Cooper-pairing neutrino emission in nucleon cores where the direct Urca process is forbidden. Special attention is paid to the effects of proton superfluidity and surface layers of light (accreted) elements on cooling of low-mass neutron stars. These effects enable one to explain observations of isolated neutron stars hottest for their age, e.g., RX J0822–4300 or PSR B1055–52. We extend the minimal cooling model by using equations of state of supranuclear matter which open the direct Urca process in the interior of most massive neutron stars. For some valid equations of state of dense matter, there exists a representative class of massive neutron stars whose cooling is intermediate between the cooling enhanced by the Cooper-pairing neutrino emission and the very fast cooling due to the direct Urca process.

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X-ray and gamma-ray radiation of cold neutron stars due to neutral interstellar gas accretion

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Effects of neutral gas (hydrogen and helium) accretion on a neutron star are studied. The neutral gas is captured by gravity into the neutron star magnetosphere. Then it is ionized by the surface thermal radiation and accelerated by the electric field at the light cylinder and in a tube of open magnetic field lines. Particles accelerated at the light cylinder generate gamma-rays; some particles move to the star and heat polar caps producing X-ray emission. These emissions are calculated. Their powers appeared to be sufficient to explain observations. It was shown that a neutron star with a magnetic field $B = 10^{12}$ G and a spin period $P = 1$ s radiates most efficiently when it has the surface temperature $T \approx 3 \times 10^4$ K (accretion of hydrogen) and $T \approx 4.5 \times 10^4$ K (accretion of helium). When the number density of the interstellar gas is 1 cm^{-3}, the temperature of polar caps appears to be $\sim 1.5 \times 10^6$ K and their X-ray luminosity $\sim 2 \times 10^{29}$ erg s^{-1}. Such a high radiation level cannot be provided by the reverse positron flux. Gamma radiation of the neutron star with such parameters due to accretion is $\sim 0.2 \times 10^{29}$ erg s^{-1} that is small in comparison with the radiation of the primary electron beam, $\sim 4 \times 10^{29}$ erg s^{-1}.

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High temporal resolution 2-d multiband photometry of the Crab pulsar with the 6-meter telescope

S. Karpov, G. Beskin, A. Biryukov, V. Debur, A. Panferov, I. Panferova, V. Plokhotnichenko, I. Zolotukhin

We report results of the UBVR observations of the Crab pulsar carried out with the panoramic high temporal resolution photometer, mounted on the 6-meter telescope of SAO RAS.

We determine both phase-averaged and phase-resolved color indices of the pulsar emission and show that color characteristics are phase-depended for both pulses.

A special method for the accurate reduction of the nebular background around pulsar was developed. It allowed us to obtain the magnitudes of off-pulse emission in various bands: $B = 21.6 \pm 0.4$, $V = 20.9 \pm 0.2$ and $R = 20.1 \pm 0.2$.

These results are compared with current models of pulsar optical emission.

Neutrino emission from magnetized relativistic outflows

E. V. Derishev, V. V. Kocharovsky, Vl. V. Kocharovsky

We consider two-component (protons plus neutrons) relativistic outflows in the regime of strong decoupling, when the Lorentz factor of the proton component relative to the neutron component is much greater than unity. Under such circumstances, inelastic nucleon-nucleon collisions lead to generation of strong magnetic field and produce powerful neutrino emission. The latter, according to the solution of hydrodynamical equations with losses, drains the major part of the outflow's kinetic energy. One of the most interesting features of the neutrino emission is that the energy of individual neutrinos (in the observer's frame) greatly exceeds the sum of energies of colliding proton and neutron.

This phenomenon is the most prominent in Gamma-Ray Bursts and complicates obtaining highly relativistic outflows. On the other hand, it increases the neutrino signal to the level, which is possible to detect, especially because the energy of neutrinos approaches several TeV.

Optical studies of neutron stars and their surroundings with the 6-meter telescope of SAO RAS

V. N. Komarova, T. A. Fatkhullin, V. G. Kurt, Yu. A. Shibanov

The results of the on-going program to study optical counterparts of pulsars and candidates to isolated neutron stars (NSs) and to search for pulsar wind nebulae (PWNe) in the Hα line at the 6-meter telescope of SAO RAS are presented. Broad band and narrow band observations have been carried out with the prime focus photometer and the focal reducer SCORPIO (`http://www.sao.ru/hq/moisav/scorpio/scorpio.html`) in the image mode. There are close and/or highly energetic (high velocity) NSs and pulsars, such as RX J0007+7302, AXP 4U0142+61, PSR B0823+26, PSR B1951+32, RBS 1774, PSR B2334+61, in a target list. Upper limits on the level of detection and flux estimates of the selected objects have been obtained.

Observational appearances of neutron stars in stellar clusters

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It is known from observations that globular clusters are very efficient in forming close binary systems and their progeny, such as low-mass X-ray binaries, millisecond pulsars and so on. The high densities in the cores of globular clusters greatly increase the formation rate of exotic binary systems through close stellar encounters.

At present, simulations of dense stellar systems share one major difficulty: it is not easy to combine accurate computer codes for modeling stellar dynamics and stellar evolution into one single software environment. In order to solve this computational problem, some year ago the MODEST international consortium was formed for MOdeling DEnse STellar systems. It currently includes nine working groups and has organized a series of meetings every half a year
(http://www.manybody.org/modest.html).

We present one possible approach to modeling the evolution of neutron stars in dense stellar clusters using the population synthesis method. It takes into account the interaction of a binary with single stars in parallel with the dynamical evolution of the globular cluster as a whole. Using generally recognized assumptions on binary star evolution, we calculated for the first time the number of neutron stars, both single and entering binary systems, in different evolutionary states (such as ejectors, accretors, etc.) as a function of time, and found their distributions over main observational characteristic (X-ray luminosity function, orbital periods, etc.). We also computed time variability of total X-ray luminosity of the Galactic center. The results of simulations are compared with modern observations of X-ray sources and millisecond radio pulsars in globular clusters.

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Giant pulses in pulsar radio emission

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Giant pulses (GPs) are short-term burst-like large increases of an intensity of individual pulses observed from pulsars. The peak intensities and energies of GPs greatly exceed the peak intensity and energy of the average pulse. GPs are the brightest radio signals in the sky among the known astronomical objects. This rare phenomenon was observed only in nine pulsars out of more than 1400 known ones. We present a review of this phenomenon, based on our detection of three new pulsars with GPs, PSR B0031–07, PSR B1112+50 and J1752+2359 (belonging to the first group of pulsars found to have GPs without a high magnetic field at the light cylinder), and the comparative analysis of the previously known sources of GPs, including the Crab pulsar B0531+21, the millisecond pulsars J0218+4322, B1821–24, J1823–3021, B1937+21 and PSR B1957+20, and the pulsar B0540–69 in the Large Magellanic Cloud.

Neutrino self-energy operator in a strong magnetic field

A. V. Kuznetsov, N. V. Mikheev, G. G. Raffelt, L. A. Vassilevskaya

The results of the previous calculations of the neutrino self-energy operator $\Sigma(p)$ in a magnetic field are analyzed and shown to be contradictory. The operator $\Sigma(p)$ is calculated for the neutrino ν_ℓ in two limiting cases: in the weak field $eB \ll m_\ell^2$, and in the moderate field $m_\ell^2 \ll eB \ll m_W^2$. In the moderate field it is shown that keeping the contribution of the lepton ground Landau level alone is incorrect because contributions of the next Landau levels are of the same order of magnitude due to a big virtuality of the lepton in the loop, $q^2 \sim m_W^2 \gg eB$. The magnetic field contribution into the neutrino self-energy is calculated. Under the conditions in the early Universe, the field contribution is shown to compete with the partial plasma contribution proportional to $(eB)^2$. Under the conditions of supernova explosion with strong magnetic field generation, we analyze the possibility of the resonance enhancement of neutrino oscillations $\nu_{\mu,\tau} \to \nu_e$ with further ν_e-energy transfer to the stellar matter via the URCA processes, thus solving the long-standing problem of the shock wave revival. To realize such a resonance, one needs the field strength $B \gtrsim 10^{18}$ G far exceeding the maximal magnetic field strength believed to arise inside an exploding supernova.

The Shapiro effect as a possible cause of low-frequency timing noise of pulsars in globular clusters

T. I. Larchenkova, S. M. Kopeikin

The low-frequency (LF) timing noise contaminates residuals of time-of-arrivals (TOAs) of pulsar radio signals on long time intervals and in some cases can be explained by external astronomical factors not intrinsically related to the pulsar itself. A number of millisecond pulsars located in globular clusters show the LF noise that is present in their rotational phase. We discuss a possible origin of this noise as caused by random time variations in the Shapiro time delay produced by stars of the globular cluster passing near the pulsar line of sight. The Shapiro time delay is integrated over space of parameters characterizing a statistical ensemble of stars in a globular cluster and its long-term indeterministic time variation is obtained. We use this result for numerical simulation of the autocovariance function of the LF timing noise and show how it can be used for measuring the density distribution over globular clusters.

Cosmic gamma-ray bursts and a simple model of type II supernova

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Gamma-Ray Bursts (GRBs) were detected at about the same time as pulsars and also accidentally. It turned out that some GRBs of duration more than 2 s are reliably identified with extragalactic supernovae (SNe). To adjust the average rate of GRB detections and SN explosions two variants are possible: either GRBs are related to a very rare type of SNe called hypernovae, or the gamma-ray radiation of GRBs is strongly collimated (10^{-6}–10^{-5} of the celestial sphere area, so that we can register only a small fraction of GRBs and associated SNe).

A SN explosion is the endpoint of the evolution of stars with the initial mass from $8\,M_\odot$ to $150\,M_\odot$. The SN energy balance is formed by the release and loss of energy. The further fate of a star depends on its mass at the moment of collapse and on its axial angular momentum. The following scenarios are possible:

1) The mass is large, the angular momentum small. The released fireball and thermonuclear energies are insufficient for the total destruction of the star or for a partial release of this energy through a kind of valve. In that case neither the SN phenomenon itself, nor GRB phenomena are created. Only the star radius and luminosity increase over those in usual supergiants in the Hertzsprung-Russel diagram.

2) The mass and angular momentum are large. The energy is insufficient to destroy the star but sufficient to break a channel along the spin axis. In that case some fraction ($\sim 10^{-6} - 10^{-5}$) of the stellar mass gets out to the stellar surface (as at volcanic eruptions on planets) from the deepest and hot inner layers, the hottest layers being outside. The free-free and recombination radiation of this hot whirling plasma with an inverse temperature distribution is observed in different spectral ranges as an afterglow in the GRB location. The GRB itself is a remnant of fireball radiation which broke out of the channel punched along the spin axis as from a volcanic orifice. That is why it is so collimated and ob-

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served only in the case if we look directly at this orifice. In that case we will not observe a SN, but only a GRB.

3) The mass and angular momentum are small. The energy is sufficient to destroy the star; the channel along the axis is not formed. A SN without any GRB is observed.

4) The mass is small, the angular momentum large. Both SN and GRB are observed.

$^3P_2$ neutron superfluidity versus quiescent emission of SXTs

K. P. Levenfish, D. G. Yakovlev

We study thermal states of transiently accreting neutron stars (NSs) in soft X-ray transients (SXTs) warmed up by the heat generated due to pycnonuclear burning of accreted matter in the inner stellar crust. These states were shown to be similar to thermal states of cooling isolated NSs. Thermal states of both types depend on properties of superdense matter in NS interiors (on composition, equation of state, superfluid properties, etc). The theory of these states can be compared with observations and impose constraints on the parameters of superdense matter. To obtain such constraints we use an extended basis of observations comprising the data on thermal radiation from isolated NSs and from quiescent SXTs. We show that the observations can be explained assuming the presence of proton superfluidity and the absence of mild neutron superfluidity in low-mass NSs. The data on SXTs indicate also the absence of mild neutron superfluidity in massive NSs. Were mild neutron superfluidity available in NS cores, nearly the same transients would evolve, under some circumstances, to quite different thermal steady states with the barred states in-between.

High-mass X-ray binaries in our Galaxy

A. A. Lutovinov, M. G. Revnivtsev, M. R. Gilfanov, R. A. Sunyaev

We study high mass X-ray binaries (HMXBs) in our Galaxy using data of X-ray and gamma-ray observatories (ASCA, XMM-Newton, RXTE and INTEGRAL). We extended our previous studies, dedicated to HMXBs in the inner part of the Galaxy, to the whole Galaxy. The increased sensitivity of INTEGRAL to absorbed sources and the discovery of several new X-ray pulsars with XMM-Newton and INTEGRAL observatories allows us significantly enlarge the sample of HMXBs in comparison with the previous studies. We present high quality broadband energy spectra for several dozens of new and known sources, including more that 30 X-ray pulsars, discuss their parameters. We investigated the HMXBs distribution along the galactic plane and found that it has peaks towards the galactic spiral arms. We also found a small offsets of these density peaks from spiral arms tangents and suggest that offsets are caused by the time delay between the star formation epoch and the time when the number of HMXBs reached its maximum.

Nature of "magnetars"

I. F. Malov, G. Z. Machabeli

A brief review of known models of Anomalous X-ray Pulsars (AXPs) and Soft Gamma-Repeaters (SGRs) is given. A new model is proposed to explain the main properties of these objects basing on the concept of drift waves in the vicinity of the light cylinder of a neutron star with the surface magnetic field $\sim 10^{12}$ G.

In the framework of this model we calculate rotation periods P, their derivatives dP/dt, and magnetic fields B in the regions of generation of radiation observed from AXPs and SGRs. The ranges of these parameters are $P = 11 - 737$ ms, $dP/dt = 3.7 \times 10^{-16} - 5.5 \times 10^{-12}$, $\log B = 2.63 - 6.25$. Radiation from AXPs and SGRs can be modulated with periods P. A strong relationship between the pulsed X-ray luminosity L_x of AXPs and SGRs and the rate of their rotation energy losses dE/dt is established. It coincides with the dependence of L_x on dE/dt for those radio pulsars whose X-ray emission has been detected. The slopes of the relationships $\log(dP/dt) - \log P$ and $\log\eta - \log P$ for AXPs and SGRs and for radio pulsars with short periods ($P < 0.1$ s) are equal (η being the efficiency of the transformation of the spin energy into radiation). Magnetic fields at neutron star surfaces calculated in the framework of the dipole model for AXPs and SGRs have the same order of magnitude ($\langle\log B_s\rangle = 11.90$) as for normal radio pulsars.

The observed quiescent X-ray emission of AXPs and SGRs can be explained by cyclotron radiation of electrons near the surface of a neutron star with the magnetic field $\sim 10^{12}$ G. The pulsed emission can be generated by the synchrotron mechanism near the light cylinder. Cataclysms on a neutron star can cause short gamma-ray bursts whose power exceeds the X-ray power by a factor of $2\,\gamma^2$ times, γ being the Lorentz-factor of emitting electrons. It is shown that in the 'magnetar' model the electron cyclotron line with the energy ~ 1 MeV must be formed. Its detection would be a good evidence in favor for this model.

It is shown that the drift waves near the light cylinder can also cause the modulation of the emission with periods of the order of several seconds in radio pulsars. These periods explain the intervals between successive pulses observed in radio pulsars with long periods ($P > 5$ s). Our model enables us to calculate real rotation periods of host neutron stars.

They are shorter than 1 s for the investigated objects. The magnetic fields at the surfaces of neutron stars are $\sim 10^{11} - 10^{13}$ G, the same as for normal radio pulsars.

Pulsars of such types must have short periods ($P \lesssim 0.1$ s) and the small angle β between the spin and magnetic axes ($\beta < 10^\circ$). It is expected that these pulsars constitute a rare (~ 0.01) fraction from the entire pulsar population. This estimate is in a good agreement with the known number of AXPs, SGRs and radio pulsars with very long periods.

The formation and properties of toroidal iron atmosphere of a preneutron star

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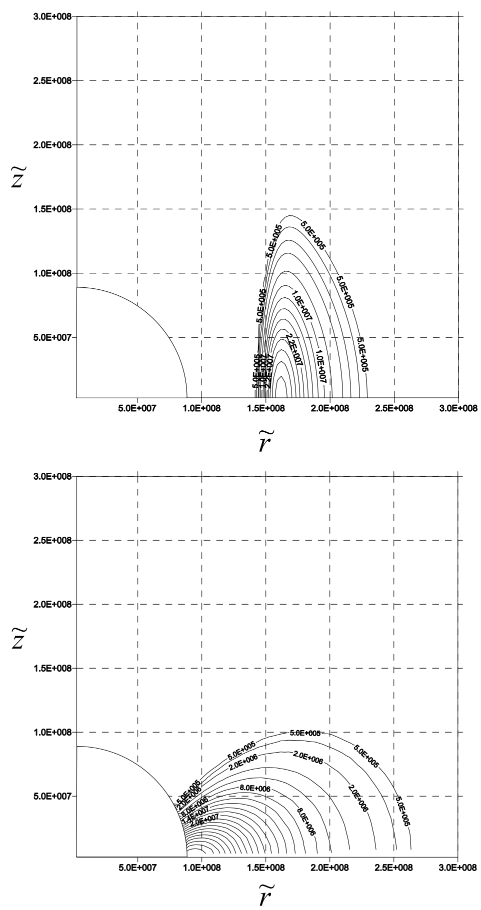

Figure 2: Lines of constant matter density for numerical solution (top) and analytical one (bottom)(from Ref.[2]).

A numerical method (described in [1]) is used to solve the two-dimensional axially symmetric hydrodynamic problem on the formation of a toroidal atmosphere during the collapse of an iron stellar core and outer stellar layers. In the initial data, we roughly specify an angular velocity distribution that is actually justified by the final result – the formation of a hydrostatic equilibrium toroidal atmosphere with reasonable values of total mass and total angular momentum. We analyze in detail the results of simulations and compare the numerical solution with our previous analytical solution in the form of toroidal atmospheres [2]. This comparison indicates that they are identical if we take into account the more general and complex equation of state with a nonzero temperature and self-gravitation effects in the atmosphere. Our numerical calculations, first, prove the stability of toroidal atmospheres on characteristic hydrodynamic time scales and, second, show the possibility of sporadic fragmentation of these atmospheres even after a hydrodynamic equilibrium is established.

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Thermal radiation from magnetic neutron star surfaces

Juan A. Miralles

In this talk, after discussing the observational status of thermal radiation from isolated neutron stars (NSs), we focus on the role that intense magnetic fields can play in the thermal emission of magnetic NS surfaces, presenting results of the thermal spectra obtained by using different surface temperature distributions. We also discuss the effect of the non-isotropic thermal conductivity, due to the presence of intense magnetic fields, on the surface temperature distribution in order to obtain self-consistent models.

Magnetorotational supernovae

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We present the results of 2D simulations of the magnetorotational model of a supernova explosion. After the core collapse the core consists of a rapidly rotating proto-neutron star and a differentially rotating envelope. The toroidal part of the magnetic energy generated by the differential rotation grows linearly with time at the initial stage of the evolution of the magnetic field. The linear growth of the toroidal magnetic field is terminated by the development of magnetorotational instability (MRI), leading to drastic acceleration in the growth of magnetic energy. At the moment when the magnetic pressure becomes comparable with the gas pressure at the periphery of the proto-neutron star $\sim 10 - 15$ km from the star center the MHD compression wave appears and goes through the envelope of the collapsed iron core. It transforms soon to the fast MHD shock and produces a supernova explosion. Our simulations give the energy of the explosion $0.6 \cdot 10^{51}$ ergs. The amount of the mass ejected by the explosion is $\sim 0.14\, M_{\odot}$. The implicit numerical method, based on the Lagrangian triangular grid of variable structure, was used for the simulations.

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INTEGRAL detection of a long powerful burst from SLX 1735–269

S. Molkov, M. Revnivtsev, A. Lutovinov, R. Sunyaev

We present results of an analysis of the bursting behavior of the low mass X-ray binary system SLX 1735–269 during INTEGRAL observations of the Galactic Center region in 2003. Six type-I X-ray bursts were detected in total with one being much longer and more powerful than others. A strong dependence of the burst recurrence time on the mass accretion rate is observed, that is likely caused by a change in the burning regime. The long burst demonstrated a photospheric radius expansion. We discuss possible scenarios of this long burst and show that it was unlikely a carbon burning flash but rather burning of a large pile of hydrogen and helium accelerated by electron capture processes in a dense accumulated layer.

The photon conversion into neutrino pair in a magnetized plasma

N. V. Mikheev, E. N. Narynskaya

The photon conversion into neutrino pair in a magnetized plasma is investigated as a channel of stellar energy loss.

The process of the photon conversion into "sterile" right neutrino pair is analyzed in the framework of an extended standard model when neutrino-electron coupling is caused by the exchange of Z boson. The process is studied in a weakly magnetized plasma. Such physical conditions are typical for a supernova core at the stage when the core interior is opaque for the standard "active" left neutrinos. The comparison of the luminosity due to right neutrino emission in this process (from the supernova core) with the total neutrino luminosity allows us to get a new restriction on the mass of the Z boson.

Effective particle acceleration in the parabolic magnetic field

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The problem of the efficiency of the transformation from the electromagnetic (Poynting) energy flux to particle flux is considered within the Grad-Shafranov approach, i.e., for a stationary axisymmetric MHD flow. Assuming that the magnetic field structure is similar to the exact parabolic force-free solution [1], it is possible to find the disturbance of the magnetic surfaces as well as the position of fast magnetosonic surface and the Lorentz-factor of plasma resulting from the finite particle mass. It is shown that the greatest Lorentz-factor on the fast surface turns out to be $\sigma^{1/3}$ (where σ is the Michel magnetization parameter) as for the radial outflow [2]. On the other hand, it is shown that for the parabolic geometry of the magnetic field the centrifugal force resulting from the curvature of magnetic surfaces plays no role in the force balance. Together with the fact, that the fast surface of the considered problem and the fast surface of a cylindrical flow with the same transverse scale coincide, it allows us to regard the problem as one-dimensional. As a result, we found that at the distance of $r \sim \sigma\gamma_{\rm in} R_{\rm L}$ along the axis ($\gamma_{\rm in}$ corresponds the value in the source) the Lorentz-factor of the outflowing particles is equal to $(\sigma\gamma_{in})^{1/2}$, and at the distance $r \sim \sigma^2 R_{\rm L}$ the Lorentz-factor reaches σ corresponding to the almost total energy conversion of electromagnetic energy flux to particle energy flux.

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Influence of strong magnetic field on neutrino heating of supernova shock wave

I. S. Ognev, A. A. Gvozdev

All significant processes of shock wave heating by neutrinos are investigated in the framework of the magnetorotational model of a core collapse supernova. Since the neutrino heating can increase the efficiency of supernova explosion, these processes can be taken into account in simulations of supernova explosions. It is shown that even in the presence of a strong magnetic field in the region, where the shock wave is formed, the heating rate is mainly determined by the neutrino absorption and emission in direct URCA processes. The main conclusion is that the influence of the magnetic field on these processes can be neglected.

Giant pulse phenomenon in radio pulsars

S. A. Petrova

Giant radio pulses are explained in terms of propagation effects in a plasma of a pulsar magnetosphere. Occasional giant amplifications of pulsar radio emission are attributed to intensity transfer towards higher frequencies as a result of induced scattering by plasma particles. It is demonstrated that the statistics of giant pulse intensities observed can be reproduced if one takes into account pulse-to-pulse fluctuations of the plasma number density and original radio intensity. Polarization properties of the strongly amplified pulses, their location in the average pulse window and the origin of the nanostructure will be discussed as well.

Individual pulse polarization as a result of propagation effects in pulsar plasma

S. A. Petrova

Polarization evolution of natural waves in a plasma of a pulsar magnetosphere is considered. It is shown that, as a result of propagation effects, the outgoing radio waves have elliptical polarization and can be slightly non-orthogonal. Basing on the idea of non-orthogonal superposed modes, a new model of pulsar polarization is suggested. It allows us to reproduce the main features of the observed single-pulse polarization and its statistics. The implications of polarization data of individual pulses for the diagnostics of a pulsar plasma will be discussed.

Soft gamma repeaters and starforming galaxies

S. B. Popov, B. E. Stern

http://xray.sai.msu.ru/~polar/html/sci.html

astro-ph/0503532

We propose that the best sites to search for SGRs outside the Local group are galaxies with an active formation of massive stars. Different possibilities to observe SGR activity from these sites are discussed. In particular, we searched for giant flares from M82, M83, NGC 253, and NGC 4945 in the BATSE data. We present a list of potential candidates. Hyperflares similar to the one of December 27, 2004 can be observed from larger distances. From the BATSE data we select 5 candidates coincident with the galaxies Arp 299 and NGC 3256 which have a very high rate of star formation, and propose that they can be examples of hyperflares; however, this result has low statistical significance.

Magnetar origin and progenitors with enhanced rotation

S. B. Popov, M. E. Prokhorov

http://xray.sai.msu.ru/~polar/html/sci.html

astro-ph/0505406

Among a dozen known magnetar-candidates there are no binary objects. Because an estimate of the fraction of binary neutron stars is about 10%, it is reasonable to address the question of solitarity of magnetars, to estimate theoretically the fraction of binary objects among them, and to mark probable companions. We present population synthesis calculations of binary systems. Our goal is to estimate the number of neutron stars originated from progenitors with enhanced rotation, as such compact objects can be expected to have large magnetic fields (i.e., they can be magnetars). The fraction of such neutron stars in our calculations is about 13–16%. Most of these objects are isolated due to coalescence of components prior to a neutron star formation, or due to a system disruption after a supernova explosion. The fraction of such neutron stars in survived binaries is about 1% or lower. Their most numerous companions are black holes.

Population synthesis as a probe of neutron star thermal evolution

S. B. Popov

http://xray.sai.msu.ru/~polar/html/sci.html

astro-ph/0411618

The study of thermal emission from isolated, cooling neutron stars plays a key role in probing the physical conditions of both the star crust and the core. The comparison of theoretical models for the star thermal evolution with the surface temperature derived from X-ray observations of sources of different age is one of the main tools to investigate the properties of neutron star interiors and to constrain the equation of state. Here we propose to use population synthesis studies as an independent approach to test the physics governing the star cooling. Theoretical Log N-Log S distributions depend on the assumed neutron star thermal evolution. We have computed distributions for several different cooling scenarios and found that comparison with the observed Log N-Log S of isolated neutron stars is effective in discriminating among cooling models. The Log N-Log S test, being a "global" one and despite some limitations, appears capable to ideally complement the standard temperature vs. age test used up to now.

Evidence for a complex non-dipole magnetic field on the surface of the accreting neutron star in Hercules X-1

K. A. Postnov, N. I. Shakura, R. Staubert

An analysis of the evolution of X-ray pulse profiles of Her X-1 with the phase of the 35-day period suggests a complex non-dipole structure of the magnetic field near the neutron star surface in this accreting X-ray binary. I will present the latest results of our analysis of X-ray data (Ginga, RXTE, etc.) obtained over last several years. Our basic model for the long-term (35-day) period of X-ray activity in Her X-1 is free precession of the neutron star. If real, this will be the first observational evidence for free precession of a neutron star in a binary system. The complex structure of the surface magnetic field inferred from this model may signal the process of the accretion-induced decay of the neutron-star magnetic field decay in Her X-1.

Strongly magnetized envelopes of neutron stars and their electromagnetic radiation

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We develop models of neutron-star envelopes that take into account the nonideal plasma effects. The total thermal flux from the surface sensitively depends on chemical composition and in some cases on the magnetic field [1]. In order to calculate the spectral distribution of this flux, we construct models for the envelopes of strongly magnetized neutron stars in thermodynamic and radiative equilibrium [2–4]. We show that bound-bound and bound-free transitions give an important contribution to the opacities in the outer layers of neutron-star atmosphere and may strongly affect the polarization properties of normal waves in specific frequency ranges. Detailed calculations are performed for a model of a partially ionized nonideal hydrogen plasma. In this case, the full account of the coupling of the quantum mechanical structure of the atoms to their center-of-mass motion across the magnetic field is shown to be crucial for the correct evaluation of the polarization properties and opacities of the plasma.

It is however possible that the radiation (at least in some spectral ranges) emerges from a liquid or solid phase boundary, which lies below a thin atmosphere. This case is considered in Ref. [5], where the spectral flux from a condensed, strongly magnetized hydrogen or iron plasma is calculated. Using these results, we calculate the spectra and polarization of thermal radiation for magnetized neutron stars, which can be compared with observations.

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On the connection of soft gamma-repeaters with short duration GRBs

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While the idea of the connection of Soft Gamma-Repeaters (SGRs) with short duration Gamma-Ray Bursts (GRBs) was first discussed more than 20 years ago [1], no direct evidence has been obtained yet. Nevertheless, several cases of indirect evidence may still be considered. Among these are: the apparently different population of short bursts based on the bi-modal GRB duration distribution [2]; the difference in hardness between the two populations [3]; and the absence of any optical counterpart for short events [4]. The Giant Flare (GF) of SGR1806–20 on December 27, 2005 raised the possibility of the connection by adding new details [5–7]. Indeed, this GF could have been detected by BATSE if the source of SGR1806–20 were placed as far away as at 30 – 50 Mpc [7, 8], taking the actual distance to SGR1806–20 to be 15 kpc. However, only the direct observation of a distant SGR (i.e., a GF of a distant SGR accompanied by a pulsating tail) can provide an evidence for the direct connection between SGRs and short GRBs.

In the paper we analyze time histories of the gamma-ray "background" immediately after short duration BATSE Gamma-Ray Bursts ($T_{90} < 2$ s) to search for pulsating tail of these bursts and to find a possible connection between short GRBs and Giant Flares of Soft Gamma-Repeaters. At least in one case of GRB930905 we found a significant pulsating tail with a period of $P = 6.43 \pm 0.16$ s. No bright galaxies were found in a small GRB error box restricted by the IPN annulus and the BATSE error box. The details of data analysis and a possible scenario for the population of short duration GRBs are discussed.

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Evolutionary channels of massive neutron star creation

S. B. Popov, M. E. Prokhorov

http://ru.arXiv.org/abs/astro-ph/0412327

We discuss possible evolutionary channels which result in the creation of massive neutron stars in binary systems. In this paper we consider neutron stars with masses larger than $(1.8 - 2.0)\, M_{\odot}$. Also, we investigate the dependence of the channels on different parameters of the evolutionary scenario of binary systems. (See also astro-ph/0412327.)

Photon splitting in a strongly magnetized plasma

M. V. Chistyakov, D. A. Rumyantsev

The process of photon splitting is investigated in the presence of a strongly magnetized electron-positron plasma. We calculate the amplitude of the process at finite electron chemical potential and temperature. The partial amplitudes and polarization selection rules in a neutral electron-positron plasma are obtained. It is found that the new splitting channels forbidden in magnetized vacuum become allowed. The probabilities of the photon splitting are calculated with account for photon dispersion and wave function renormalization in a strongly magnetized plasma. We show that, although the photon splitting is suppressed at high temperatures, there is space of parameters where photon splitting dominates over pure magnetic field result in the low temperature limit. Possible astrophysical applications of the process under consideration are discussed.

Asymmetry of antineutrino emission from neutron beta decay in magnetized superdense matter

V. L. Kauts, A. M. Savochkin, A. I. Studenikin

We have used exact solutions of Dirac equation for a quantitative estimation of the asymmetry of antineutrino emission from neutron beta-decays in degenerate magnetized Fermi gas of neutrons, protons and electrons. We have used a computer code for modeling this process. Our consideration is of interest for the physics of neutron stars because values of the matter parameters (temperature, magnetic field, density), which we employ, are typical for neutron star matter. We consider the dependence of the asymmetry on the magnetic field strength.

Three slow glitches in the pulsar B1822−09

T.V. Shabanova *

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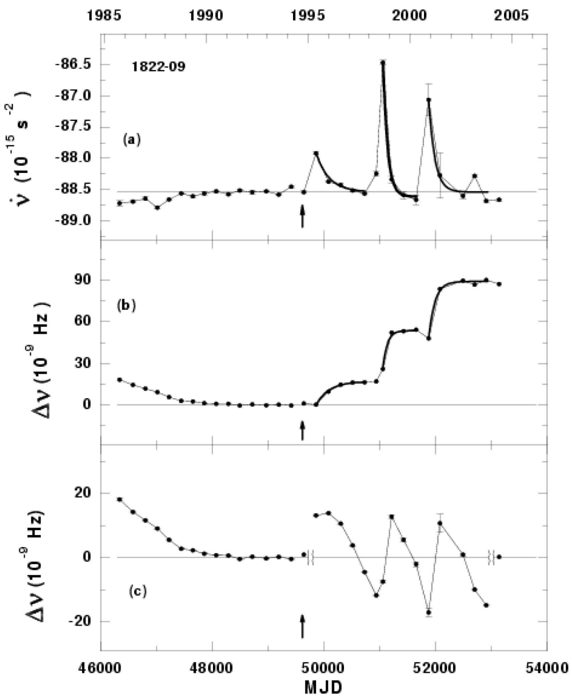

Figure 1: The frequency first derivative $\dot{\nu}$ and frequency residuals $\Delta\nu$ for the pulsar B1822−09 from 1985 to 2005 (from Ref.[3], supplemented with the new last point)

The study of the timing residuals of PSR B1822−09 at the Pushchino Observatory at frequencies 102.5 and 112 MHz allowed us to detect a new kind of variation in the pulsar rotation rate, which may be treated a slow glitch [1–3]. Fig. 1 shows that the pulsar suffered three slow glitches over the 1995–2004 interval. A characteristic feature of the slow glitches is a rapid initial decrease in the magnitude of $\dot{\nu}$ by ∼1–3 per cent of the initial value and subsequent exponential increase back to its initial value with a time-scale of several months (Fig. 1(a)). This causes a slow growth in the frequency residuals $\Delta\nu$ with the same time-scale as shown in Fig. 1(b), where $\Delta\nu$ are obtained relative to the data for the pre-glitch interval 1991–1994. The size of a slow glitch after a span of a few years is rather moderate, with $\Delta\nu/\nu \sim 20\times10^{-9}$. An obvious relaxation in frequency after a slow glitch is not observed. The residuals $\Delta\nu$ relative to a new model fit to the data for the 1995–2004 interval, where the slow glitches occurred, show oscillatory behavior with the time-scale of ∼1000 d (Fig. 1(c)). The reason of significant variations in $\dot{\nu}$ should be attributed to variations in braking torque. A decrease in $\dot{\nu}$ requires a corresponding decrease in torque that brakes rotation of the pulsar crust. Torque variations may be caused by changes in magnetosphere structure, e.g. variations of the polar cap size. The measured oscillatory behavior in ν on a time-scale of 1000 d reflects the oscillatory

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changes in torque, which suggests the existence of a long-term oscillation in the polar cap size.

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The region of anomalous compression in the Bondi-Hoyle accretion

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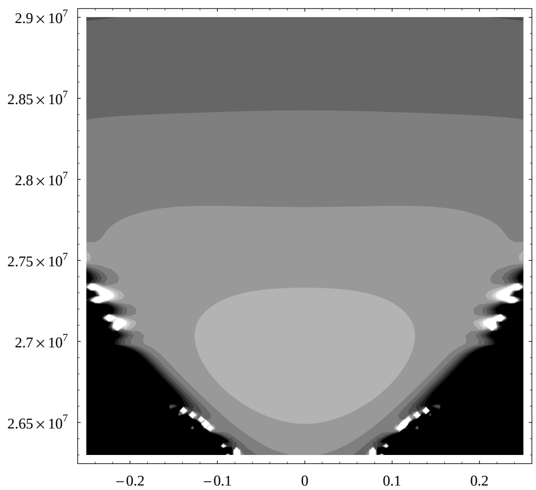

Figure 1: Dependence of the temperature on coordinates in the (θ_0, r) plane. The bright region in the center has the highest temperature, several times larger than the corresponding temperature in the Bondi accretion. r is the distance from the gravitating center, θ_0 is the angle between this radial vector and the symmetry axis for points on the sound surface.

Properties of a gas flow in the Bondi-Hoyle axisymmetric case with zero angular momentum in the supersonic region is explored for accretion onto a small compact object (in particular, onto a Schwarzschild black hole) when the velocity of the object is less than the sound velocity at infinity. It is shown analytically that, for a ballistic flow deep under the sonic surface, flow lines intersect in the front part of the object at some distance r_x from the center at the symmetry axis of the system (caustic forms). An approximate radial size of the region, where flow lines emerged (with angle not exceeding θ_0) from the sound surface intersect themselves, is about $\Delta r = r_x\theta_0^2/3$. The numerical calculation for nonzero pressure gradient is carried out for the detailed elaboration of the flow structure (assuming that the flow is adiabatic). The parameters of the region with anomalously high temperature and matter density are estimated; this compression is accompanied by an enhanced energy release. The effect could highly increase the efficiency of the non-disk accretion.

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On the magnetic field of the soft gamma repeater 1900+14

Yu. P. Shitov

The different existing models, which explain very large observed spin down of SGR 1900+14, result in drastically different estimations of the surface magnetic field. Basing mainly on the measured parameters of the SGR 1900+14 pulsed radio emission and on the best data for estimating the magnetic field, we argue that the field value is $\sim 5 \times 10^{14}$ G.

High mass X-ray binaries in the Magellanic Clouds

P. E. Shtykovskiy, M. R. Gilfanov

We study populations of high mass X-ray binaries in the Magellanic Clouds using the archival data of the XMM-Newton observatory. Basing on the properties of the optical and near-infrared counterparts of the detected sources, we identified likely HMXB candidates and sources, whose nature is uncertain, thus, providing lower and upper limits on the luminosity distribution of HMXBs in observed parts of the Magellanic Clouds. We consider the impact of the "propeller effect" on the HMXB luminosity distribution and compare the theoretical predictions with observed distributions. We also discuss "age" effects, i.e., the dependence of the population of HMXBs on the time elapsed since the star formation event. In particular, we show how they can explain spatial distribution of HMXBs in the Large Magellanic Cloud.

Pulse intensity investigation in the emission zone of the pulsar B0950+08

T.V. Smirnova

We have analyzed the behavior of individual pulses on the base of two series of observations of PSR B0950+08 at the frequency 110 MHz. We have shown that the intensity distribution of pulses depends on the flux density of the average profile that changes up to 10 times from day to day. It is a consequence of scintillation effect. For low flux density of the average profile the intensity of individual pulses can exceed the average profile amplitude by a factor of few tens. It is shown that the intensity distribution of weak pulses as a function of longitude of their appearance in the emission zone differs strongly from the distribution of strong pulses. We have also studied the evolution of the mean profile with a frequency in the range from 110 MHz to 4.85 GHz.

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Mysterious properties of giant radio pulses from neutron stars

V. A. Soglasnov, S. V. Kostyuk, V. I. Kondratiev, Yu. Yu. Kovalev, M. V. Popov

Giant pulses detected from the Crab pulsar, the most rapidly spinning millisecond pulsar B1937+21, and few others, are undoubtedly one of the most striking phenomena demonstrated by celestial sources. Not only huge peak flux density – up to hundreds kJy (!) – but also many other properties (such as an extremely short, nanosecond duration; 100% linear or circular polarization) are unique and have no adequate explanation at the moment. We present the results of our recent observations of Giant Pulses conducted in 2004–2005 in a broad wavelength range from decameter to centimeter. They reveal unusual features, indicating in particular the operation of some resonant processes in neutron star magnetospheres.

Typical GRB spectra and the peak energy – isotropic energy relation (EpEi or the Amati law) can be observational consequences of the compact GRB model

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The purpose of this report is to formulate the basic assumptions of a GRB source scenario with a rather low total/bolometric energy release ($< 10^{49}$ ergs) [1]: we will try to understand soft (in the meaning of photon energies ~ 1 MeV) observational GRB spectra without involving huge kinematical motions of the radiating plasma *a priori* (or *without* an enormous Lorentz factor $\Gamma \gg 10$). This is another attempt to solve the compactness problem with account for the dependence of the threshold for e^-e^+ pair production on the angle between photon momenta and the dependence of this effective collimation on γ-ray photons energy release: the opacity ($\tau_{e^-e^+}$) is also a sensitive function of the *angular* and *spectral* distribution of the radiation field in the GRB source. We argue that only a small number of collimated hard photons (for GRBs with $z > 1$) or a rather strongly collimated high-energy radiation in the GRB spectra reach near-earth detectors. We consider how a jet arises in a region of size $< 10^8$ cm if the relativistic jet is produced by a powerful light pressure of the collimated/non-isotropic *prompt* radiation of the GRB source. This means that for total/bolometric energies up to $\sim 10^{49}$ ergs the "old" estimate of the source size resulting *directly* from the GRB time variability can be true. The *afterglow* arises in a region around a massive star-progenitor of a GRB source, at a distance of $\sim 10^9$ cm (the typical size of a massive star core) to $r \sim 10^{15}$ cm and further (where stellar wind starts to interact with ambient/circumstellar medium), since there is always a dense or windy medium (an envelope) resulting from the evolution of a massive star. In this model (with $\Gamma \sim 10$ or smaller) the peak energy – the isotropic energy (EpEi or $E_p - E_{iso}$) relation extended down to the total energy $E_{iso} \sim 10^{49}$ ergs (the Amati relation for soft X-ray flashes [2]) can be a natural consequence

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of the dependence of the threshold for the e^-e^+ pair production on the angle between photon momenta and the direction of collimation (most probably) by the magnetic field on the surface of the GRB source (which is the compact, $< 10^8$ cm, collapsing object).

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The circumstellar environment of massive stars and all kinds of evidence for all types of core-collapse supernovae in long-duration GRBs

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The goal of this report is to review GRB afterglow spectra (the X-ray lines, blueshifted absorption lines of C IV, Si IV, blueshifted H absorption lines in these spectra) and the ever-increasing list of the photometric evidence of late-time bumps in GRB afterglows. These are all signs of the direct relation between GRBs and explosions of massive stars; they further support the view that, in fact, all long-duration GRBs provide obvious evidence for SN explosions. GRBs *must always* be accompanied by Type Ib/c SNe or other types of massive (Type II) SNe if GRBs/SNe are really produced by the same astrophysical cauldron. A surprising news (e.g., astro-ph/0311326) is the presence of blueshifted H absorption lines in early spectra of GRB afterglows (GRB 021004, GRB 030226). It can directly indicate massive windy envelopes arising due to massive star evolution before core-collapse SN explosions.

1. *The early spectra*: The variety of envelopes surrounding pre-SNe is quite natural in the evolution of massive stars (e.g., astro-ph/0309637). Also, the properties of early spectra of GRB 030329/SN 2003dh (astro-ph/0312359) can be consistent with a shock moving into a stellar wind formed by the pre-SN. Such a behavior (similar to that near the UV shock breakout in SN 1993J; also see, e.g., astro-ph/0312464) can be explained by a dense matter in the very vicinity of a massive stellar GRB/SN progenitor (astro-ph/0012396). Hydrogen appears to be generally present also in SNe Ib/c, although in most events it can be identified reliably only in the earliest spectra of GRB/SNe Ib/c. The bolometric luminosities in the first SN UV peaks can also be of the same order of magnitude as in the GRB OTs ($\sim 10^{45}$ ergs s^{-1}).

2. *The late spectra*: We interpret the BVRI light curves of the GRB 970508 afterglow by the interaction (the "bump" on $\sim$ second day after

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the GRB) between a relativistic jet and a dense extended circumstellar envelope (with characteristic radius $\sim 10^{15}$ cm) and the subsequent interaction (the "shoulder" on the light curve: astro-ph/0107399 and 9710346) of SN ejecta (the shock breakout) with the same extended envelope. The luminosity at the "shoulder period" (> 200 days) was of the same order of magnitude ($M_B \approx -19.5$) as for Type IIn SNe (e.g. SN 1994W, astro-ph/0405369). If Type II SNe can be *still* associated with a part of the GRB afterglow sample, then an observation of blueshifted absorption H lines in *the late spectra* of the long lasting "shoulder" of *some* GRB afterglow light curves would be another observational consequence of the scenario "massive star→ pre-SN = pre-GRB", *but* in the compact GRB model (see our report at this conf.) with sizes of dense ambient/circumstellar windy envelopes up to $\sim 10^{15}$ cm around massive star-progenitors of GRB sources.

Spectra of the LMXB boundary layers in the spreading layer model and the limitation on a neutron star equation of state

V. Suleimanov, J. Poutanen

The spectra of the spreading layers on the neutron star surface were calculated on the basis of the Inogamov-Sunyaev model taking into account the general relativity correction to the surface gravity and the solar chemical abundance of the spreading matter. Local (at a given latitude) spectra of the spreading layer are very similar to bursting neutron star spectra and can be fitted by diluted black body spectra with corresponding hardness factors. Total spreading layer spectra have been integrated including light bending, gravitational redshift, and relativistic Doppler effect. The total spectra can also be fitted by the diluted black body spectra. The total spectra slightly depend on the inclination angle of the neutron star spin axis to line of sight and on the spreading layer luminosity. Therefore, it is shown that color temperatures of the spreading layer spectra depend mainly on a neutron star M/R relation.

As has been demonstrated by Gilfanov et al. (2003) the boundary layer spectra in low mass X-ray binaries (LMXBs) can be fitted by the black body spectrum with $T_{\rm col} = 2.4 \pm 0.1$ keV. The limitations on the neutron star M/R relation were obtained by comparing theoretical spreading layer spectra with the observed boundary layer spectrum. These limitations give the neutron star radius $R = 14.6 \pm 2$ km for the mass $M = 1.4\,M_{\odot}$. Such a radius corresponds to a "mean field" model equation of state of neutron star matter.

Emission mode transition dynamics in the pulsar B0943+10

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The pulsar B0943+10 is well known for its 'B' (burst) mode, characterized by accurately drifting subpulses, in contrast to its chaotic 'Q' (quiet) mode. Six new Arecibo observations at 327 MHz with a duration nearly 2+ hours each have shed considerable light on the modal dynamics in this pulsar. Of these six, three were found to be exclusively in the 'B' mode, while other three were discovered to exhibit transitions from the 'Q' to the 'B' mode. One of these observations has permitted us to determine the circulation time of the sub-beam carrousel in the 'Q' mode for the first time, at some 35.5 stellar rotation periods. The onset of the 'B' mode is then observed to commence similarly in all three observations. The initial circular time is around 35.5 periods and relaxes to perhaps 38 periods in an near exponential fashion with a characteristic time of nearly 1 hour. This is the longest characteristic time ever found in the 'switching' pulsars. Moreover, just after the 'B' mode onset the pulsar exhibits a resolved double profile form with a somewhat larger trailing component, but this trailing component slowly dies away leaving the usual single 'B' mode profile with the longitude of the magnetic axis falling at about its trailing half power point. There are some indications that 'Q' to 'B' and 'B' to 'Q' transitions have different characteristic times.

Additional longer observations are still needed to learn how long each of the modes sequences can persist. Some speculations are given on the nature of the slow modal alternations.

Portions of this work were carried out with support from NSF (grants AST 99-87654 and 00-98685).

Soft GRBs in the BATSE data

Ya. Tikhomirova, B. Stern, A. Kozyreva, Yu. Poutanen

The Burst And Transients Sources Experiment (BATSE) was most sensitive to photons above 20 keV and had very large statistics. To catch GRBs the trigger of the BATSE checked only the 50–300 keV range. However, a prompt emission of some GRBs seems to be softer. Moreover, so-called X-Ray Flashes (2–26 keV) were detected as possible prompt GRB emission events in the range typical for GRB X-ray counterparts. X-ray rich GRBs and/or X-ray Flashes can give a key to understanding the GRB radiation mechanism. Here we present the results of the search for X-ray Rich GRBs in the BATSE records with the trigger in the 20–50 keV and the 50–100 keV range. We found the emission in the BATSE range from X-Ray Flashes detected by some X-ray instruments. We present some conclusions on the shape of spectra of these events and on their relation to the GRB phenomenon.

Radio emission of AXPs

V. M. Malofeev, O. I. Malov, D. A. Teplykh

Observations of a few anomalous X-ray pulsars (AXP) are reported. The observations were made with two high-sensitivity radio telescopes of the Pushchino Radio Astronomy Observatory at the frequencies: 111, 87, 61 and 41 MHz. Mean pulse profiles and the estimation of dispersion measures, distances, flux densities, spectral indices and integral luminosities are presented. A comparison with X-ray data shows large differences in the mean pulse widths and luminosities.

Could we see neutron star oscillations after a pulsar glitch?

A. N. Timokhin

The pulsar "standard model" of a rotating magnetized conducting sphere surrounded by a plasma is generalized in its essential parts for the case of an oscillating star. The Goldreich-Julian charge density, electromagnetic energy losses, as well as the polar cap scenario of particle acceleration are considered. Despite similarities, there are substantial differences between magnetospheres of rotating and oscillating stars. For example, the energy losses of an oscillating star substantially differ from those given by the vacuum formulas. The main attention in this work is drawn to the distortion of the pulsar magnetosphere by neutron star oscillations. The changes in the the Goldreich-Julian charge density due to star pulsations with high harmonic numbers (l, m) could be large, leading to a strong distortion of accelerating electric field near the pulsar polar cap. This results in remarkable changes of individual pulse profiles of radio pulsars. It is shown, that in a moderately optimistic scenario for the excitation of neutron star oscillations by a glitch, such changes in the pulsar radiation could be detected by contemporary radio telescopes.

High resolution numerical modeling of the force-free pulsar magnetosphere

A. N. Timokhin

I consider a force-free magnetosphere of an aligned rotator. Its structure is well described by the Grad-Shafranov equation for the poloidal magnetic field, the so called "pulsar equation". This is a second-order non-linear partial differential equation of elliptic type. No analytical solution for dipolar magnetic field with poloidal current has been found. Previous attempts to solve this equation numerically suffered from poor numerical resolution. Results of these calculations are inconsistent with each other and with analytical solutions near the critical point at the light cylinder. I developed a multigrid code for solving the pulsar equation with the high numerical resolution. On the fine numerical grid, a

current layer along the last closed field line could be accurately incorporated into numerical procedure. All physical properties of the solution such as the Goldreich-Julian charge density, drift velocity, energy losses, etc., could be accurately calculated. Here I report results of these simulations. Among other interesting properties, the solution is not unique, i.e. the position of the last closed field line (and hence the pulsar energy losses) is not determined by a global magnetospheric structure and depends on kinetics of electromagnetic cascades. I discuss the properties of the solutions and their implications for pulsars.

How to distinguish neutron star and black hole X-ray binaries? Spectral index and quasi-periodic oscillation frequency correlation

Lev Titarchuk, Nickolai Shaposhnikov

http:/xxx.lanl.gov/abs/astro-ph/0503081

Recent studies have revealed strong correlations between 1–10 Hz frequencies of quasiperiodic oscillations (QPOs) and the spectral power law index of several Black Hole (BH) candidate sources when seen in the low/hard state, the steep power-law (soft) state, and in transition between these states. In the soft state these index-QPO frequency correlations show a saturation of the photon index ~ 2.7 at high values of the low frequency ν_L. This saturation effect was previously identified as a black hole signature. In this paper we argue that this saturation does not occur, at least for one neutron star (NS) source 4U 1728–34, for which the index monotonically increases with ν_L to the values of 6 and higher. We base this conclusion on our analysis of ~ 1.5 Msec of RXTE archival data for 4U 1728–34. We reveal the spectral evolution of the Comptonized blackbody spectra during the source transitions from the hard to soft states. The hard state spectrum is a typical thermal Comptonization spectrum of the soft photons which originate in the disk and the NS outer photospheric layers. The hard state photon index is ~ 2. The soft state spectrum consists of two blackbody components which are only slightly Comptonized. Thus we can claim (as expected from the theory) that in NS sources thermal equilibrium is established for the soft state. To the contrary in BH sources, the equilibrium is never established due to the presence of the BH horizon. The emergent BH spectrum, even in the high/soft state, has a power law component. We also identify the low QPO frequency ν_L as a fundamental frequency of the quasi-spherical component of the transition layer (presumably related to the corona and the NS and disk magnetic closed field lines). The lower frequency ν_{SL} is identified as the frequency of oscillations of a quasi-cylindrical configuration of the TL (presumably related to the NS and disk magnetic open field lines). We also show that the presence of Fe K_α emission-line strengths, QPOs, and the link between them does not depend on radio flux in 4U 1728–34.

Observations of the X-ray pulsar V 0332+53 by the INTEGRAL and RXTE observatories and RTT-150 telescope

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In this work we present results of observations of the transient X-ray pulsar V0332+53 with the INTEGRAL and RXTE observatories in a broad energy band 1–100 keV performed on December 2004 – January 2005 during a powerful outburst with the peak flux about 1 Crab in the 2–12 keV energy band [1].

The pulse profile dependences on the source luminosity and energy band were revealed; particularly, the source pulse profile becomes one-peaked instead of two-peaked at energies above 25 keV with the object luminosity decreasing.

The source average spectrum can be well fitted by a simple power-law model with a photoelectric absorption at low energies, high energy cutoff and cyclotron line with two higher harmonics.

Pulsar observations with the Russian-Turkish optical telescope RTT-150 were performed on January 2005 simultaneously with X-ray observatories. During these observations the brightness of the object in the R filter was constant (≈14.12 magnitude). Based on a fast photometry we cannot make at the moment a final conclusion about possible pulsations in the optical band. Estimations of the reflected X-rays contribution to the optical radiation are given.

More detailed analysis of the INTEGRAL and RXTE data is now in progress.

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A hydrogenic molecular atmosphere of the neutron star 1E1207.4-5209

A.V.Turbiner

A model of a hydrogenic content in the atmosphere of the isolated neutron star 1E1207.4-5209 is proposed. It is based on the assumption that the main component in the atmosphere is the exotic molecular ion H_3^{2+}, which is the most stable hydrogenic ion at $B > 10^{13}$ G. The magnetic field distribution is assumed to be of a dipole type varying from $(4 \pm 2) \times 10^{14}$ G to $\approx 10^{11}$ G. The density of H_3^{2+} is the highest in the domain of strongest magnetic fields while the density of electrons is the highest in the domain of weakest magnetic fields. Photoionization $H_3^{2+} \to e+3p$ and photodissociation $H_3^{2+} \to H+2p$ at $(4\pm2)\times10^{14}$ G, and the lowest electronic cyclotron transition energies at 10^{11} G correspond to two absorption features at 0.7 keV and 1.4 keV, respectively. These features were discovered by the *Chandra* observatory (Sanwal et al. 2002) and confirmed by the *XMM-Newton* (Bignami et al. 2003). The model predicts another absorption feature at 80-150 eV which corresponds to photodissociation $H_3^{2+} \to H_2^+ + p$.

Gravitational waves from oscillating rotating neutron stars to probe their inner structure

L. Villain, S. Bonazzola, P. Haensel

Any relativistic object whose internal motions are not too simple emits gravitational waves (GWs). Among the potential astrophysical sources, oscillating neutron stars (NSs) are strong candidates, whose GW emission could be detected in the future by GW telescopes such as VIRGO and LIGO. Yet, not all oscillatory modes are relevant from the GW point of view, since the possibility to observe them depends for instance on their damping time and their emissivity. Thus, the so called r-modes (axial inertial modes) of rotating NSs started to be considered as very interesting when it was proven that they are generically driven to instability by their coupling to the gravitational field, whatever the angular velocity of the star. After a short review of GWs and of rotating NS oscillations (with more details on inertial modes), a fully relativistic numerical study of r-modes will be presented (Villain, Bonazzola & Haensel, 2005, to be published in PRD). Through 3D time evolutions of the relativistic Euler equation done with a spectral code, the influence of a trying-to-be realistic description of the microphysics on the main properties of the modes was investigated.

Comprehensive picture of quasi-periodic oscillations in X-ray binaries

K. S. Wood, L.G.Titarchuk

We present a comprehensive, physical framework for interpreting spectral/temporal characteristics (QPOs, PDS breaks) of accreting black hole (BH), neutron star (NS) and white dwarf (WD) systems as gravity wave (g-mode) oscillations. It incorporates features of earlier models by the authors and collaborators in a general scheme that reduces in one limit to a classical treatment by Chandrasekhar (1961). It goes beyond his treatment by inclusion of radial dependence, incorporation of magnetospheric rotation, and application to X-ray timing phenomenology. The physical picture starts with disk accretion onto a BH; accretion in geometries where axisymmetry is broken by magnetic fields is treated as extension of this case. Pairs or groups of QPOs with correlated frequency drifts are treated as splitting of eigenfrequencies in a fluid dynamics analysis, rather than a beat phenomena. One particular QPO is identified with the gravitational (essentially Kepler) frequency and other QPOs are related to that one. Having the basic frequency be the gravitational frequency, which is Newtonian and not a General Relativistic, helps to explain how certain relationships can extend over > five orders of magnitude in frequency, linking WDs, NSs and BHs. The explanatory range of the model is considerable: it addresses the magnetic field strength and configuration near the compact object, extension of the Keplerian disk near the central object (and the location of transition layer between Keplerian and non-Keplerian flow. Many of these topics which have been addressed in earlier papers are background of this model. Successes of earlier treatments, for example fitting the correlated drifts of as many as six persistent PDS features (QPOs and breaks) with minimal parametrization are preserved.

Equation of state under the conditions of NSE and the properties of collapsing stellar cores

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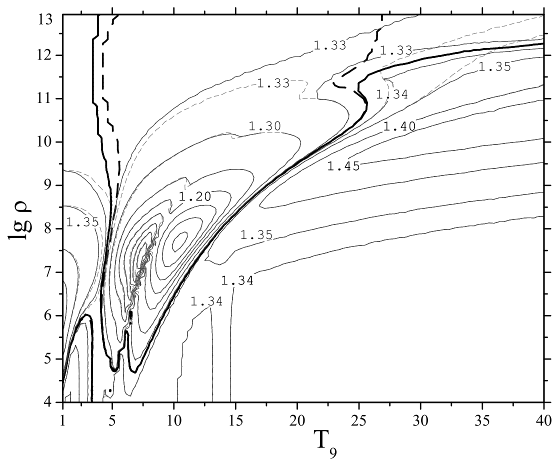

Figure 1: Levels of constant adiabatic index γ on the temperature-density plane for the neutron-to-proton ratio $\theta = 30/26$ (^{56}Fe) with (solid lines) and without (dashed lines) nuclear excitation [1].

We investigate the equation of state for stellar matter under the conditions of nuclear statistical equilibrium (NSE) in a wide range of thermodynamic parameters (temperature T, density ρ and neutron-to-proton ratio θ) specific for the gravitational collapse of massive stellar cores. First of all, we account for a variety of nuclei and try to adequately describe their properties especially such as a rapid increase of the number of nuclear excited states with temperature [1]. We suggest an algorithm that allows us to escape the overestimation of the nuclear partition functions at high temperatures and compare our results with other approaches available in literature. Figure 1 shows how the nuclear excited states modify the ravine of instability ($\gamma < 4/3$). The partition functions delay the nuclear dissociation during the collapse. At the same time, the rapid neutronization of stellar matter increases the neutron-to-proton ratio. Both effects shift the NSE composition to the state dominated by the neutron-rich nuclei whose properties are not well established yet. Moreover, we explore the non-ideal effects produced by the Coulomb interaction [2] and find that during the collapse stellar matter turns out to be in a state somewhere between weak and strong regimes of the Coulomb interaction. There exist domains in the space (T, ρ, θ) where nuclides with noticeably different charges may have comparable (and not negligible!) concentrations. The description of such a complicated multi-component and asymmetric system must be chosen with care to avoid nonphysical behavior of thermodynamic quantities. Our

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final goal is to explore how the aforecited effects influence the dynamics of the collapse and the parameters of resulting neutrino signal such as the temporal behavior of the neutrino spectra and luminosity.

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Measuring the supermassive black hole parameters

A. F. Zakharov, A. A. Nucita, F. DePaolis, G. Ingrosso

Recent X-ray observations of microquasars and Seyfert galaxies reveal broad emission lines in their spectra, which can arise in the innermost parts of accretion disks. Simulations indicate that at low inclination angle the line is measured by a distant observer as a characteristic two-peak profile. However, at high inclination angles ($> 85^0$) two additional peaks arise. This phenomenon was discovered by Matt et al. (1993) using the Schwarzschild black hole metric to analyze such effect. They assumed that the effect is applicable to a Kerr metric far beyond the range of parameters that they exploited. We check and confirm their hypothesis about such a structure of the spectral line shape for the Kerr metric case. We use no astrophysical assumptions about the physical structure of the emission region except for the assumption that the region should be narrow enough. Positions and heights of these extra peaks drastically depend on both the radial coordinate of the emitting region (annuli) and the inclination angle. It was found that these extra peaks arise due to gravitational lens effect in the strong gravitational field. Specifically, they are formed by photons with some number of revolutions around a black hole. This conclusion is based only on relativistic calculations without any assumption about physical parameters of the accretion disc like X-ray surface emissivity, etc. We discuss how an analysis of the iron spectral line shapes could give an information about an upper limit of the magnetic field near the black hole horizon. Based on results of numerical simulations we discuss the origin of double peaked and double horned profiles and clarify the Müller & Camenzind hypothesis (2003).

Recently Holz & Wheeler (2002) have considered a very attracting possibility to detect retro-MACHOs, i.e. retro-images of the Sun by a Schwarzschild black hole. In this paper we discuss glories (mirages) formed near rapidly rotating Kerr black hole horizons and propose a procedure to measure masses and rotation parameters by analyzing these forms of mirages. In some sense that is a manifestation of the gravitational lens effect in the strong gravitational field near a black hole horizon and a generalization of the retro-gravitational lens phenomenon. We analyze the case of a Kerr black hole rotating at arbitrary speed for some selected positions of a distant observer with respect to the equatorial plane of a Kerr black hole. Some time ago Falcke (2000) suggested to search shadows at the Galactic Center. We also propose to use future radio interferometer RADIOASTRON facilities to measure shapes of mirages (glories) and to evaluate the black hole spin as a function of the position angle of a distant observer.

Equation of state of dense matter and rotation of neutron stars

J. L. Zdunik

Short review of the theory of stellar rotation and stability conditions in General Relativity applicable to Neutron Stars (NSs) is presented. The role of the equation of state (EOS) for the rotational properties of NSs is discussed with special emphasis on the softening of the EOS due to the appearance of new particles or phase transitions in the interiors of NSs. This softening could manifest itself as a back-bending phenomenon for a spinning-down solitary pulsar – the epoch of spinning-up by angular momentum loss. An isolated NS can lose a sizeable part of its initial angular momentum without significantly changing its rotation period. In some cases the softening of the EOS results in the existence of an instability region for rotating NSs. The discussion is based on the realistic equations of state with hyperon softening and polytropic models of a mixed phase in NS interiors.

Deep optical observations of the fast moving nearby radio pulsar B1133+16 with the VLT[1]

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Recent optical observations with the 8-meter-class groundbased telescopes and with the HST of the two old radio pulsars, PSR B0950+08 (17 Myr) (Zharikov et al. 2002; Zharikov et al. 2004) and PSR B1929+10 (3 Myr) (Mignani et al. 2002), have shown that old pulsars can produce nonthermal photons in the optical range with almost the same efficiency as young and energetic Crab-like pulsars. Optical data for other old pulsars can provide new insights into the origin of such a high efficiency. Parameters of the high velocity nearby radio pulsar PSR B1133+16 (5 Myr) are almost the same as for the above two pulsars. We report on a deep BR and H_α imaging of the pulsar field obtained in 2003–2004 with the VLT in attempt to detect its optical counterpart and to search for a bowshock nebula (which is possibly produced due to supersonic motion of the pulsar through the interstellar medium). Our images reveal no counterpart at the expected radio position down to a 3σ upper limit of ~ 28.3 mag in the B band. We cannot resolve also any bowshock structure in our H_α and R images. However, archival B band images of the same field obtained earlier within the ESO/VLT program 66.D-0069A by Gallant et al. (2001) have allowed us to go deeper in the B band. After combining the archival and original images the resulting detection limit is B$\sim$ 28.7 mag. In the combined B band image some hints of the counterpart candidates consistent with the pulsar radio position can be resolved within the 28.3–28.7 mag range. We discuss our results in

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connection with a phenomenological picture of the pulsar efficiency evolution in different spectral domains suggested by Zharikov et al. (2004) and by current pulsar bowshock theories.

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