Ioffe Physical Technical Institute of the Russian Academy of Sciences
Theoretical Astrophysics Department

Report on Scientific Activity in 1997 Physics of Quasars, Neutron Stars, Interstellar and Intergalactic Matter

Recent preprints and publications related to the projects (gzipped ps-files) can be found at **http://stella.ioffe.rssi.ru/DTA/DTA-Pub1.html** and **http://stella.ioffe.rssi.ru/NSG/NSG-Pub1.html**

1 Spectroscopy of quasars and cosmology

Investigators: D.A. Varshalovich (PI), A.V. Ivanchik, A.D. Kaminker, S.A. Levshakov, A.Y. Potekhin, A.I. Ryabinkov,

The problem of possible variation of fundamental physical constants is one of the key problem of General Physics and Cosmology. Current theories (SUSY GUT, superstrings, scalar-tensor theories of gravitation, Kaluza-Klein models, etc.) predict small but finite variations of the constants.

An **analysis** has been performed of high-resolution **quasar spectra** obtained with the 6-meter Telescope of the Special Astrophysical Observatory of the Russian Academy of Science (HS 1945+68, S50014+81, S40636+68) and also with the 4-meter Telescope of the Inter-American Observatory in Serro Tololo (PKS 0528-250).

New, refined and more reliable **upper limits** have been obtained **for relative variation rates** (time-averaged): (i) **of the fine structure constant** $\alpha = e^2/\hbar c$; **and** (ii) of the **electron-to-proton mass ratio** $\mu = m_e/m_p$. These upper limits appear to be more accurate than those given by high-precision laboratory measurements (Prestage et al., 1995, PRL 74, 3519) and by astrophysical measurements obtained with Keck-Telescope (Cowie and Songaila, 1995, ApJ 453, 596).

The results obtained within **this project** (Astron. Letters, 20, 771, 1994; Astron. Letters 22, 1, 1996; Astron. Letters 22, 6, 1996) **in 1996-1997 are widely cited** by cosmologists and also by specialists in the field theory and in the physics of elementary particles (e.g., Barrow, 1997; Drinkwater, Webb et al., 1997; Combe and Wiklind, 1996;

Damour and Dyson, 1996). **In 1997** this work **received the Grant Prize of International Academic Publisher Co. "Nauka" for the "best publication of the year in field of natural sciences"**
(D.A. Varshalovich, A.Y. Potekhin, V.E. Panchuk, A.V. Ivanchik)

2 Physics of neutron stars: internal structure and evolution, atmosphere physics, electrodynamic and magnetohydrodynamical processes

Studies of atmospheres of neutron stars with strong magnetic fields.

Investigators: Yu.A. Shibanov (PI), V.G. Bezchastnov, A.D. Kaminker, K.P. Levenfish, G.G. Pavlov, A.Y. Potekhin, D.G. Yakovlev (PI), V.E. Zavlin

Multiconfiguration calculations have been carried out of energy levels and wave functions of H atoms and He^+ ions moving in strong magnetic fields $10^{11} - 10^{13}$ G typical for atmospheres of neutron stars. Calculations of photoionization cross sections and spectral opacity of hydrogen plasma in magnetized atmospheres have been continued with account for atomic motion. Thermal conductivity of degenerate electrons due to the Coulomb scattering of electrons by electrons and ions in the neutron star envelopes has been reconsidered. Generation of neutrino pairs in a dense plasma with superstrong magnetic fields $10^{11} - 10^{15}$ G has been studied for the cases of (i) the synchrotron emission by electrons in the neutron-star envelopes and (ii) electron scattering by fluxoids in superconducting neutron-star cores.

Modeling the thermal structure and cooling of neutron stars

Investigators: D.G. Yakovlev (PI), , V.G. Bezchastnov, A.D. Kaminker, K.P. Levenfish, G.G. Pavlov, A.Y. Potekhin, Yu.A. Shibanov (PI), V.E. Zavlin

Temperature profiles in the envelopes of neutron stars have been calculated and a new relationship has been found between the internal and surface temperatures of neutron stars with and without accreted envelopes made of light elements. Selfconsistent temperature profiles in the envelopes and atmospheres of these stars have been constructed together with the spectra of thermal radiation from these stars in a wide energy band (from X-rays to optics). A detailed study of standard and fast cooling of neutron stars has been done assuming the presence or absence of accreted shells, and the presence or absence of proton and/or neutron superfluidity in the stellar cores.

The results obtained above have been used for **interpretation of radiation** observed **from the pulsars** PSR 0002+6246, PSR 0656+14, PSR 1055-52 , Vela, Geminga and

Crab in different spectral bands with the ROSAT, EUVE, HST, ASCA orbital observatories (the main attention has been paid to the ROSAT data). In case the spectra observed are fitted by the black-body law, the observations have been found to be consistent with standard cooling of neutron stars with accreted shells, without invoking exotic assumption on rapid cooling and without assuming the presence of nucleon superfluid in the stellar cores. In the absence of the accreted shells, this interpretation would be highly unlikely. In case the spectra observed are fitted by the hydrogen atmosphere models, the observations can be explained in different manner — by the standard cooling of neutron stars with superfluid cores. The critical temperatures of the neutron and proton superfluids in the stellar cores required for this interpretation fall in the range 10^8 – 10^{10} K which agrees qualitatively with the results obtained using the microscopic theories of superfluidity of dense matter.

Electronic archive of neutron star atmosphere models

Investigators: G.G.Pavlov, A.V. Vulegzhanin, Yu.A. Shibanov (PI), A.N. Sokolov, V.E. Zavlin

The archive **"Neutron Star Atmosphere Models"** is created (**http://stella.ioffe.rssi.ru/Stars**) and it is widely used by astrophysical centers of the world.

Magnetohydrodynamical processes in neutron stars

Investigators: V.A. Urpin (PI), D.Y. Konenkov, D.A. Shalybkov

It is shown that the Hall currents can produce magnetic fields with high multipolarity even for rather simple initial magnetic configurations. Evolution of these multipoles is accompanied by their energy exchange, and, consequently, by oscillations of their amplitudes. Evolutionary tracks of pulsars are calculated for different equations of state in the pulsar interiors and for different pulsar cooling models. Joule heating can strongly affect thermal evolution of neutron stars at late evolutionary stages. As a results, even very old stars whose age is 10 – 100 Myr can be much warmer than predicted by the standard cooling theories.

A computer program is created for **numerical simulation of neutron stars** taking into account various evolutionary phases which can be passed. The program allows one to study the objects of various types (low-massive and massive binaries, transients, etc.). The program has been used to follow evolution in low-massive systems. It is shown that millisecond pulsars are naturally formed from the normal neutron stars in such systems. Various magnetohydrodynamic instabilities has been analyzed which can be generated in accretion disks in the presence of a magnetic field and vertical gradient of angular velocity. The criteria for onset of such instabilities are derived.

Pulsar electrodynamics

Investigators: A.I Tsygan (PI), V.D. Palshin

It is shown that the **external magnetic fields** can strongly **affect the rate of ejection of charged particles, gamma-quanta and radioemission of pulsars** due to increase of the polar open-lines corner. For the pulsars with period of $P = 1$ s and the magnetic field $B_0 = 10^{12}$ at the pulsar pole, this effect starts to operate for an external magnetic field of about 0.5–3 G. The effect depends also on angle β between the magnetic moment of the neutron star and direction of the external magnetic field. In the wide range of angles β the external magnetic field enhances the particle emission. The magnetic field suppresses the particle ejection only for β close to 180^o. In this case the pulsar can be even switched off.

The parameters of the electron-positron plasma and intensity of X-ray emission from hot spots in the polar regions of radio pulsars are calculated using a Goldreich-Julian model in the regime of free electron emission from the neutron star surface. In this case the electric field is generated by the general relativistic effect of internal frame dragging. The results obtained are in agreement with the observational data for the radio pulsars PSR 1055-52 and PSR 1929+10, and Geminga pulsar (E0630+18).

3 Physical processes in interstellar and intergalactic medium

Spectral line formation in turbulent medium

Investigators: S.A. Levshakov (PI), I.E. Mazets

Inverse problem of analysis of pairs of $H+D$ absorption lines has been studied taking into account the effects of finite correlation length of **stochastic velocity fields**. It is shown that low and high values of primordial deuterium abundance obtained recently by analyzing quasar absorption systems can be artifacts produced by incorrect interpretation ignoring the correlation effects. A generalized procedure is proposed, basing on reverse Monte Carlo method, for a correct interpretation of measurements of the D/H ratio. It is found that absorption by **deuterium observed at** $z = 2.504$ in the direction toward Q1009+2956 (with the Keck Telescope) **and at** $z = 0.701$ in the direction toward Q1718+4807 (with the Hubble Space Telescope) are quite **compatible with** the D/H=$4.1 - 4.6 \cdot 10^{-5}$. This results confirms **the standard model of Big-Bang nucleosynthesis**, and the nonuniformity of the cosmological expansion (widely discussed in the literature) is not required for interpretation of observations.

4 Gamma-ray spectroscopy of interstellar medium

Investigators: A.M. Bykov (PI), S.V. Bozhokin, Y.A. Uvarov

Detailed quantitative models were constructed to study nonthermal phenomena in the vicinity of active objects with a great energy release. The code was created to model the **hard nonthermal emission from active star-formation regions with young massive stars and multiple supernova explosions**. It is shown that an efficient acceleration of nonthermal nuclei (He, C, O, Ne, Si etc.) by MHD shock waves ensemble occurs in the extended caverns created by collective action of strong stellar winds and supernovae. The fluxes of the nonthermal nuclei population can be very high and their spectra extended up to a few tens MeV/nucl can contain a substantial part of the kinetic energy released by the winds and supernovae.

The **spectra of broad-line gamma-ray emission produced by deexitation of energetic nuclei** were calculated. We show that distinct line splitting can occur, resulting from the anisotropy of the photon emission in the rest frame of the nuclei (as is seen in accelerator experiments) and following Doppler boosting (Astron. Astroph. v.307, L37, 1996). The spectra may be applied to gamma ray sources like Orion as detected by COMPTEL GRO (Ap.J. v.475, L25, 1997) This can have a drastic impact on the interpretation of observed gamma-ray spectra. We have modeled in detail extended sources powered by stellar winds and supernovae. Since gamma-ray line emission from Orion-like objects indicates the presence of high fluxes of low-energy nuclei, these objects are potentially important sites of nonthermal nucleosynthesis of light isotopes (see Space Sci. Rew. v.74 (3/4), p.397, 1995).

Broad-line scenarios are most efficient from the energetics point of view. and we apply them also for modeling of other sources — **candidates for the broad-line gamma-ray emission**, such as **accretion powered binary systems**.