TECHNICAL DIGEST

THE IX INTERNATIONAL SYMPOSIUM
MODERN PROBLEMS OF LASER PHYSICS

MPLP 2021

Novosibirsk, Russia:
27-28 August, 2021

International School on Laser Physics and Photonics for Young Scientists

P R O G R A M

MPLP-2021

International School on Laser Physics and Photonics

Novosibirsk, Russia, 27-28 August, 2021

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Organized by:

Institute of Laser Physics, SB RAS, Novosibirsk, Russia

Novosibirsk State University, Novosibirsk, Russia

SYMPOSIUM CHAIR

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SCHOOL SECRETARY

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General Information

In the framework of MPLP-2021 **International school on laser physics and photonics for young scientists** will be organized for young scientists (students, PhD students, PhD and others under 35 years old). The school will be held from **27 August to 28 August online in Zoom format**.

A few top-ranking scientists will give lectures on “hot” topics of modern laser physics and applications.
Young scientists will also have an opportunity to make oral presentations within young scientist’s school.
The School abstracts will be published in School technical digest.

All participants (speakers and listeners) are welcome to attend the School for free, but registration is required.

Lecturers

	**Prof. Masahiko Tani** *Research Center for Development of Far-Infrared Region University of Fukui, Japan* **Lecture: “Nonlinear Optics for THz wave generation and detection”**
	**Dmitry Budker** *Helmholtz Institute, Johannes Gutenberg University, Mainz* **Lecture: “In search of ultralight bosonic dark matter”**
	**Prof. Gerd Leuchs** *Max Planck Institute for the Science of Light, Erlangen-Nuremberg, Germany* **Lecture: “Oscillations in space and time through interference”**

Novosibirsk time (GMT+7)

Friday, August 27

International School on Laser Physics and Photonics

Opening Speeches

$14^{30} – 15^{00}$ **Academician, Prof. *S.N. Bagayev***

Chairman of the Symposium and School

$15^{00} – 16^{00}$ **Prof. Masahiko Tani**

Research Center for Development of Far-Infrared Region University of Fukui, Japan

Lecture: «Nonlinear Optics for THz wave generation and detection»

$16^{00} – 17^{00}$ **Dmitry Budker**

Helmholtz Institute, Johannes Gutenberg University, Mainz

Lecture: «In search of ultralight bosonic dark matter»

$17^{00} – 17^{10}$ **Short Break**

$17^{10} – 17^{30}$ **Alexander Tyutrin**

Irkutsk Branch of Institute of Laser Physics SB RAS

“Synthesis of luminescent carbon quantum dots by plasma method”

$17^{30} – 17^{50}$ **Marina Rumenskikh**

Institute of Laser Physics SB RAS

“Investigation of spherical laser plasma expansion in a magnetic field and vacuum”

$17^{50} – 18^{10}$ **Gavriil Voloshin**

Peter the Great St.Petersburg Polytechnic University

“Research of the shape and shifts of the resonances of coherent population trapping, detected by the Ramsey method, in an optically dense medium with a nonzero temperature”

Novosibirsk time (GMT+7)

Saturday, August 28

$14^{00} – 15^{00}$ **Prof. Gerd Leuchs**
Max Planck Institute for the Science of Light, Erlangen-Nuremberg, Germany
Lecture: «Oscillations in space and time through interference»

$15^{00} – 15^{10}$ **Short Break**

$15^{10} – 15^{30}$ **Emil Chiglintsev**
Russian Quantum Center
“Infrared ultrastable laser based on crystalline reference cavity”

$15^{30} – 15^{50}$ **Gulnara Vishnyakova**
P.N. Lebedev Physical Institute of the Russian Academy of Sciences
“Open-air link for the ultra-stable optical frequency signal transfer”

$15^{50} – 16^{10}$ **Evgenii Erushin**
Institute of Laser Physics SB RAS
“Tunable optical parametric oscillator with diode injection-seeding”

$16^{10} – 16^{30}$ **Ekaterina Vetrova**
Institute of Laser Physics
“Numerical simulation of the absorption of the line of hot Jupiter WASP-52b”

Synthesis of luminescent carbon quantum dots by plasma method

A. A. Tyutrin[1], **R. Wang**[2] **and E. F. Martynovich**[1]
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Carbon quantum dots (CQDs) were synthesized by plasma treatment of glucose at atmospheric pressure and room temperature.

The objective of this work was the formation of carbon quantum dots by the plasma method, the study of the spectral-kinetic characteristics of their luminescence and identification of the specific features of their synthesis.

Scanning confocal fluorescence microscope MicroTime 200 with picosecond time resolution with a spatially-selective time-correlated single photon counting was used to determine spectral-kinetic characteristics of photoluminescence of the synthesized CQDs. Spectra of photoluminescence (Fig. 1) measured under excitation by picosecond laser at different wavelengths were recorded by the spectrometer Ocean Optics 65000.

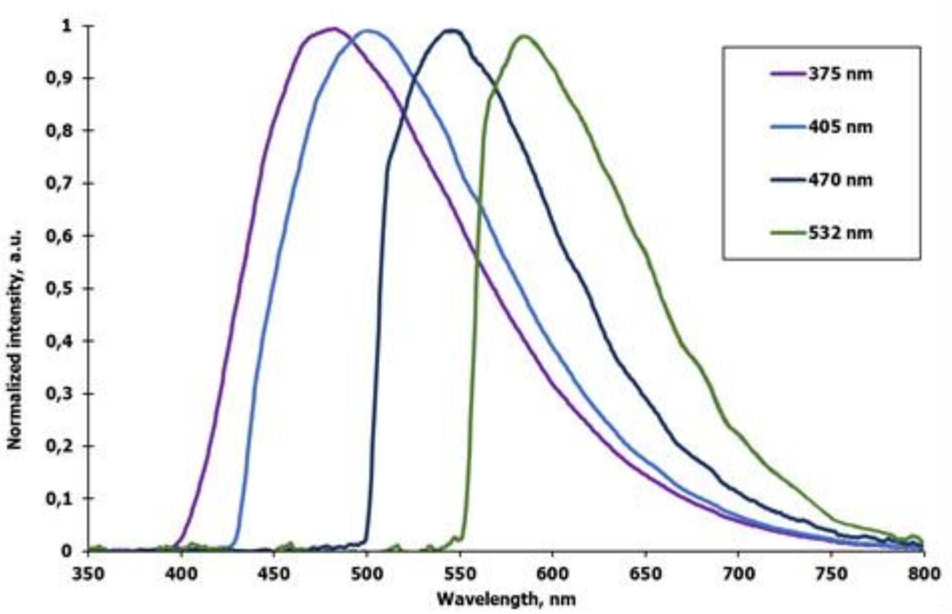

Fig. 1. Normalized photoluminescence spectra of synthesized CQDs at excitation wavelength 375, 405, 470 and 532 nm.

CQDs have a wide emission spectrum in 400 - 800 nm range at excitation in the 375 - 532 nm range. CQD have a bright radiation in the blue range. The concentration of quantum dots was controlled by varying the microplasma treatment duration of the glucose solution. The time-resolved fluorescence decay curve was measured by the time-correlated single photon counting (TCSPC) method. The luminescence kinetics has three exponential components with decay time constants of 0.65, 2.2, and 6.2 ns. The formation of these components is presumably associated with the quantum confinement effect and with the presence of different functional groups between which quantum transitions take place.

This work was supported by the Basic Research Plan of the Russian Academy of Sciences for the Period up to 2025 (Project No. 0243-2021-0004).

Investigation of spherical laser plasma expansion in a magnetic field and vacuum

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Spherical expansion of a plasma in a magnetic field is of practical interest in connection with the problem of the origin and evolution of various types of instabilities that affect the process of plasma confinement in a CCF. In addition, experiments on plasma expansion in a magnetic field have not lost their relevance in view of the development of the theory of magnetosphere of the Solar system objects and other stellar systems.

Spectral diagnostics opens up a number of possibilities for studying the processes occur in plasma. This method gives possibility to detect the effects that occur during the outflow of plasma into a vacuum and a magnetic field, such as interactions between different plasma components (recombination, photoionization, collisional interactions, ion acceleration due to interaction with faster particles); diffusion of the magnetic field into the plasma; development of instabilities due to the interaction of plasma with a magnetic field for different ionic components. In addition, spectral diagnostics is a non-contact method, which makes it possible to study collective phenomena in plasma without introducing perturbations.

The study of the expansion of a spherical cloud of laser plasma into a magnetic field and vacuum was carried out on a KI-1 laser facility. Spectral diagnostics includes a monochromator with registration of the luminescence dynamics using a photomultiplier and spectral line shapes using a CCD matrix.
When the ions scattered, a nontrivial dependence of the luminosity of various spectral lines on external conditions was found. When the magnetic field was switched on, some lines became brighter, while others, on the contrary, decreased, which may indicate the presence of complex interactions of plasma components, as well as the diffusion of the magnetic field into the plasma. In addition, a shift of the maxima and inhomogeneous line broadening were observed, which indicates a nontrivial plasma flow, in particular, the development of instabilities in the interaction of a plasma with a magnetic field. The spatial distributions of the luminosities of the spectral lines in the laser plasma cloud indicate the inhomogeneity of the motion of various plasma ions. The components of a low degree of ionization show a high symmetry degree expanding both into vacuum and into a magnetic field, while ions of higher charges fly away asymmetrically.

The work was supported by the RFBR projects 19-02-00993 and 18-29-21018, as well as within the project of the Ministry of science and higher education of the Russian Federation (№121033100062-5).

Research of the shape and shifts of the resonances of coherent population trapping, detected by the Ramsey method, in an optically dense medium with a nonzero temperature

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The interaction of bichromatic laser radiation with atomic ensembles under certain conditions leads to the appearance of the phenomenon of coherent population trapping (CPT) [1-4]. This phenomenon occurs in a resonant manner with respect to the frequency difference of the incident fields. It is noteworthy that the width of such resonances turns out to be many times smaller than the width of the natural emission line. This opens up wide opportunities for using this effect for various practical applications, such as optical magnetometers [5, 6], high-resolution spectroscopic devices [7, 8], devices for recording and storing quantum information [9-11], lasers without inversion [12-15]. Of particular importance is the use of the CPT effect in the development of a small-size quantum frequency standard [16-21].

Recently, a widespread method for detecting CPT by means of a pulsed supply of an external field (Ramsey scheme) [22]. The first long-term (pumping) pulse transfers the system to a stationary CPT state, then a dark pause follows, during which the system freely evolves, followed by a second short (reading) pulse, which detects the system in the CPT state. In this case, CPT resonances become the envelope for new narrower resonances. The width of such resonances turns out to depend only on the duration of the dark pause and can reach hundreds or even tens of hertz [23].

In the process of creating a frequency standard, it is necessary to increase the signal, which can be realized by increasing the number of active atoms. At a certain concentration of active atoms, one begins to speak of an optically dense medium. The influence of the effects of the optical density of the medium on the line shape of CPT resonances detected by the Ramsey method was theoretically considered in papers [35–37]. In turn, the concentration can be increased by increasing the temperature of the medium. However, the motion of atoms leads to additional effects such as Doppler and collisional broadening. In this regard, the aim of this work is to answer the question of how exactly CPT resonances change at a nonzero temperature in an optically dense medium. In this case, the dependences of the shifts of the reference resonances on the frequency scale on temperature are of particular interest. Since random temperature fluctuations will lead to fluctuations in the position of CPT resonances and reduce the stability of the standard built on the basis of such resonances.

In this work, a mathematical model was constructed for the interaction of bichromatic laser radiation with an optically dense atomic medium having a nonzero temperature. Within the framework of this model, the quantum state of the medium of mobile atoms is described by the one-particle density matrix method in the Wigner representation, which allows one to simultaneously take into account both the Doppler effect and collisions of active atoms with buffer gas atoms. When describing the energy structure of an atom, a four-level model is used, which takes into account the hyperfine splitting of its ground and excited states, which makes it possible to study the behavior of the resulting light shifts of resonances. To take into account the optical density of the medium, the system of equations for the density matrix was supplemented with truncated transport equations for the electrical components of the incident fields.

A numerical scheme for solving the system of integro-differential equations obtained within the framework of the considered model was proposed. Using this scheme, we simulated the interaction of two laser pulses spaced in time with an atomic medium.

The results of this simulation were analyzed for changes in the shape and frequency shifts of CPT resonances with temperature changes depending on various parameters of the medium and laser pumping. The range of pump parameters was determined in which the temperature dependence of the light shift turns out to be the weakest.

This work was supported by the Ministry of Education and Science of Russia: State task (basic part), "Precision spectroscopy of quantum systems and nanoobjects in a wide range of energies", FSEG-2020-0024, 2020 - 2022; as well as the Grant of the President of the Russian Federation for state support of young Russian scientists - candidates of sciences, MK-1452.2020.2, 2020 - 2021.

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Infrared ultrastable laser based on crystalline reference cavity

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Ultrastable laser systems can be used in a wide range of research areas: gravitational wave detection [1], searching for dark matter [2], and the drift of fundamental constants [3]. Such stable laser systems are a crucial part of optical clocks - modern frequency standards. The fractional frequency instability of optical clocks can reach $6\text{x}10^{-19}$ in an averaging time of one hour [4]. These opportunities of optical standards open perspectives to use them as quantum sensors, for example, to make the geopotential map of the Earth [5].

To create an atomic clock with fractional frequency instability of 10^{-19}, we need to get a laser source with fractional frequency instability of 10^{-16}. Such kind of laser source can be created by laser frequency locking to the Fabry-Perot cavity by Pound-Drever-Hall technique [6]. Frequency instability is defined by fluctuations of length between mirrors of the cavity. Stabilization of the cavity length requires thermal stabilization and vibrational isolation. The fundamental limit on frequency stability is set by the thermal noise of cavity parts: spacer, substrate, and mirror coatings.

The prospective material to make a cavity with low thermal noise is monocrystalline silicon. The main contribution to the thermal noise of the silicon cavity is introduced by dielectric coating. For example, the configuration of the silicon spacer and mirrors substrates with SiO_2/Ta_2O_5 coatings yield fractional frequency instability of $2.2\text{x}10^{-16}$. If we switch the coating to a crystalline one made of GaAs/AlGaAs, the thermal noise can be lowered down to $5.4\text{x}10^{-17}$ due to the better mechanical quality factor of the crystalline material.

(a) (b)

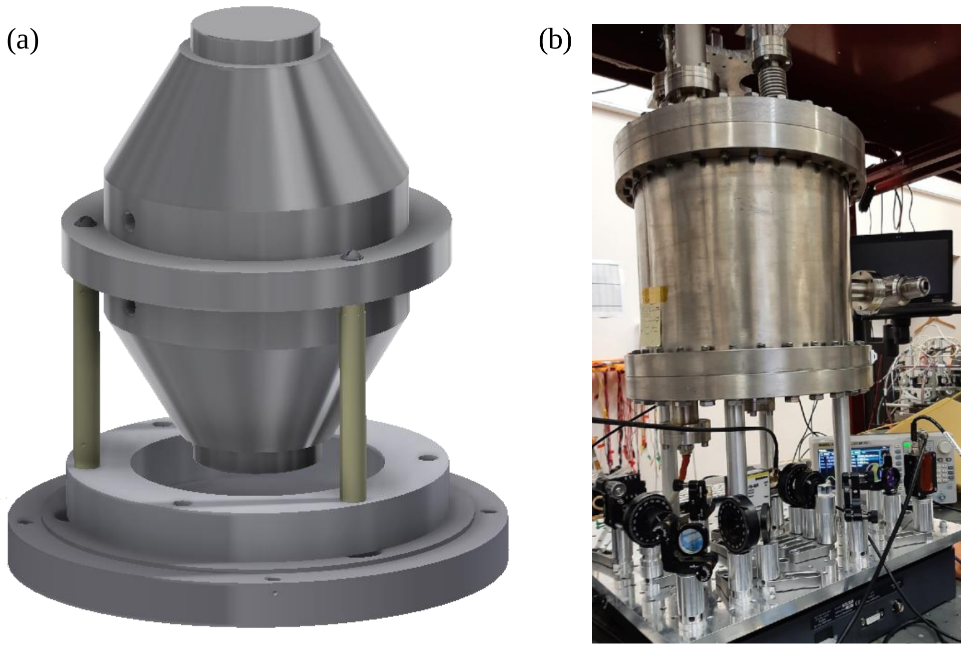

Fig. 1. a). Silicon cavity in a suspension system. b). Photo of the vacuum chamber with the part of the laser stabilization system.

Our lab works on developing a pair of laser systems based on silicon cavities with crystalline coatings. The length of the cavity is 77.5 mm. These cavities are operated inside the cryostat at the temperature of 124 K which corresponds to the zero thermal expansion coefficient of the silicon. The pressure in the cryostats is less than 10^{-8} mbar. We measured the finesse of both cavities in a wide temperature range on a wavelength of 1550 nm and it turned out to be 200000 and 143000. Each eigenmode of both cavities is split into two components corresponding to different light polarization with a frequency separation of 150kHz, which means that the crystalline mirrors coatings are birefringent. The frequencies of two lasers are locked to these cavities with Pound-Drever-Hall technique. Our next step will be the comparison of two laser systems by measuring the beat frequency.

This work is supported by The Russian Science Foundation (Grant 19-72-10166).

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Open-air link for the ultra-stable optical frequency signal transfer

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Nowadays the best modern optical clocks have reached the level of relative uncertainty and instability of 10^{-18} [1,2]. Optical clocks connected with links [3] create great opportunities in such fields of science and technology as the formation of national and international time scales, relativistic geodesy, satellite navigation, very-long-baseline interferometry, tests of fundamental theories, search for dark matter, etc. Transferring signals of such kind of frequency standards with preserving of their characteristics using radio frequency methods is not possible, since the latter cannot provide fractional instability better than 10^{-16} [4]. However, it is possible to reduce the level of the phase noise introduced by the communication link by transferring signals using optical carrier and active noise compensation technique. The rapid development of stationary and transportable [5] optical clocks shows the necessity of designing both fiber [6] and open-air [7] links for the highly stable signals transfer.

We have developed an atmospheric 17 m link operating at 1550 nm. We have obtained more than 11 000 s of uninterrupted data and have showed that our active noise compensation system allows to reduce the fractional frequency instability caused by air turbulence from $2.6\cdot10^{-16}$ to $1.7\cdot10^{-19}$ at averaging time of $\tau = 1000$ s in terms of Allan deviation (Fig.1) calculated from data measured by K+K phase recorder. The link contribution to inaccuracy of transferred signal is reduced from $1.9\cdot10^{-17}$ to $5\cdot10^{-20}$.

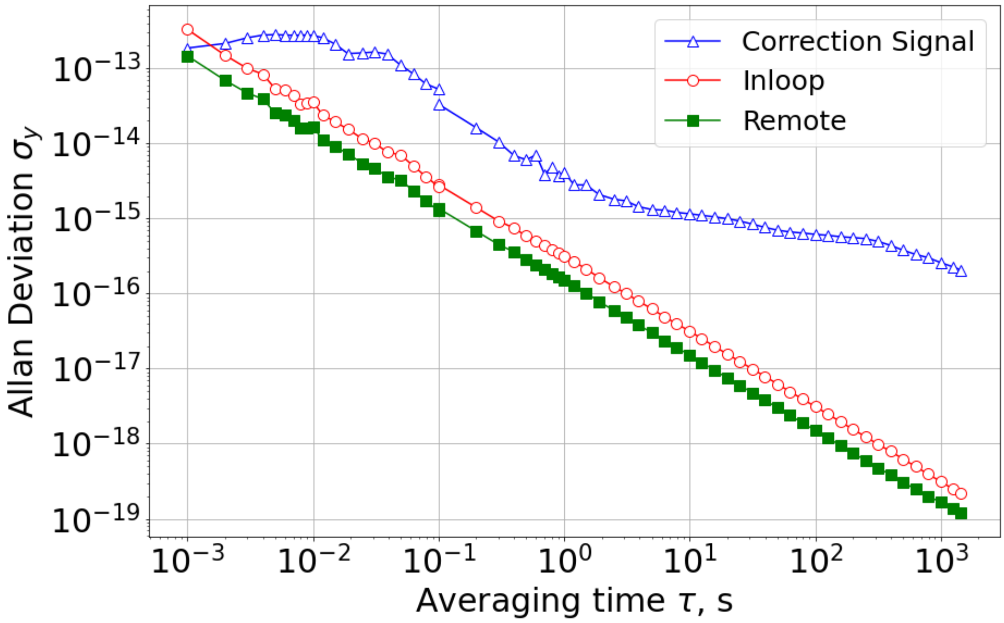

Fig. 1 Allan deviation vs averaging time. Blue empty triangles correspond to the correction signal (that is to the detected and compensated link noise), green filled squares – to the remote signal (that is to the stabilized delivered signal), red empty circles – to the inloop signal (that is to the signal used in the feedback loop). Symbols are connected by lines for eye guidance.

As a next step we plan to increase the link length up to 500 m and use an unmanned aerial vehicle with a mirror fixed on it as a moving receiver model.

This work is supported by the Russian Science Foundation (Grant 19-72-10166).

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Tunable optical parametric oscillator with diode injection-seeding

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Precision spectroscopy of fundamental bands of molecules in the mid-infrared (MIR) region is of great interest in applications of trace detection and testing fundamental physics, where high-power and narrow-linewidth MIR lasers are needed. Optical Parametric Oscillators (OPO) are universal solid-state coherent sources with possibility of wavelength tuning in the aforenamed spectral range. However, the output spectra of OPO consist of on multiple resonance modes spectra which lead to a significant broadening of the lasing spectrum and does not always allow use this source for precision spectroscopy. Therefore, various techniques of spectral narrowing were developed for OPOs.

Using intracavity spectral selectors such as an intracavity etalon [1, 2] or a diffraction grating [3, 4] is a typical technique of spectral narrowing that enable also wavelength tuning which makes OPO suitable for photoacoustic spectroscopy and trace gas. However, the aforenamed methods reduce the output power the much needed for precision spectroscopy. The opposite is the injection-seeding technique which, in addition to narrowing the spectrum, improves the quality of the output beam and increases the output power of the slave source [5].

In this work, we present an original fan-out-PPLN-based configuration of a narrowband, continuously tunable, high-energy pulsed OPO with diode injection-seeding which is intended for high-sensitivity trace-gas analysis at 3.1-3.4 μm spectral region. The applied injection seeding has provided by a factor of 9 spectral narrowing, wavelength stabilization (the standard deviation of the central wavelength was 0.001 nm), beam-quality improvement, and possibility of fine wavelength tuning for the OPO idler radiation. The resulting increase in the power spectral density available at an analyzed gas absorption line has improved sensitivity of the gas detection. Thus, we have revealed almost double (~80%) increase in the photoacoustic response of a methane detector to the reference gas mixture with low concentration methane when the injection seeding was applied.

This work was partially supported by Ministry of Science and Higher Education of the Russian Federation FSUS-2020-0036 (Methane PAD equipment). Fan-out MgO:PPLN chip was prepared by financial support of Russian Foundation of basic research (RFBR-mk-18-29-20077).

All injected seed Fan-out OPO experiments were realized by financial support of Russian Scientific Foundation (17-72-30006) and CH4 spectroscopic experiments was funded by RFBR, project number 19-32-60055.

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Numerical simulation of the absorption of the $H\alpha$ line of hot Jupiter WASP-52b

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Transit spectroscopy (i.e. analysis of the radiation spectrum of a parent star when a planet crosses (transit) in front of its parent star's disk, the observed visual brightness of the star drops by a small amount) is one of the main methods in the study of exoplanets. To interpret the observations of $H\,\alpha$ line absorption in the atmospheres of hot Jupiters [1], a numerical Monte Carlo model was written, with the help of which calculations were performed earlier for HD 189733b and HD 209458b [2], which showed the need to take into account intra-atmospheric processes, since the radiation from the parent star contributes to the excitation of hydrogen atoms to the second energy level, but it is not decisive.

The initial parameters for the Monte Carlo model were calculated using a three-dimensional multi-fluid gas dynamic model [3], in which we varied parameters such as XUV and atmospheric composition, resulting in different distributions of the volume density of hydrogen atoms and temperature in the atmosphere.

Modeling was carried out by the Monte Carlo method, the problem was solved in three-dimensional geometry, and also considered in dynamics. In the problem being solved, the radiation of the parent star falls on the planet by a spherical front consisting of model photons. The process of resonant scattering of $Ly\alpha$ photons in the atmospheres of exoplanets, which are characterized by spherically symmetric distributions of the volume density of hydrogen atoms and temperature, is considered. Also, when modeling and obtaining the distributions of the volume density of hydrogen atoms excited to the $2\,p$ level, intra-atmospheric processes were taken into account, for example, the collision of hydrogen atoms with electrons, which is also capable of exciting an electron in an atom.

Based on the developed model, it is expected to obtain the distributions of the volume density of hydrogen atoms excited to the $2\,p$ level and $H\,\alpha$ transmission spectrum of the planet WASP-52b, which will coincide with [1].

References

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