MINISTRY OF SCIENCE AND HIGHER EDUCATION OF THE RUSSIAN FEDERATION
Federal State Autonomous Educational Institution of
Higher Education
"Ural Federal University named after the First President of Russia B.N. Yeltsin"

Institute of Natural Sciences and Mathematics

APPROVED BY
Vice-Rector for Research
A.V. Germanenko
«___» _____ 2023 г.

PROGRAM OF THE DISCIPLINE
SPACE PHYSICS, ASTRONOMY

List of information about the program of the discipline	Credentials
Postgraduate program Space physics, astronomy	**Code PP** 1.3.1.
Group of scientific specialties Physical sciences	**Code** 1.3.
Federal State requirements (FSR)	Order of the Ministry of Science and Higher Education of the Russian Federation No. 951 dated 20.10.2021
Self-approved requirements (SAR)	The order "On the introduction of "Requirements for the development and implementation of training programs for scientific and scientific-pedagogical personnel in UrFU postgraduate school" № 315/03 dated 03.31.2022.

Yekaterinburg
2023 г.

Program of the discipline is compiled by:

№	Full name	Academic degree, Academic Title	Position	Affiliation
1	Anton I. Vasyunin	PhD	Associate Professor	Department of Astronomy, Geodesy, Ecology and Environmental Monitoring of the Institute of Natural Sciences and Mathematics
2	Eduard D. Kuznetsov	Dr. Sci., Associate Professor	Head of Department	Department of Astronomy, Geodesy, Ecology and Environmental Monitoring of the Institute of Natural Sciences and Mathematics
3	Anton F. Seleznev	Dr. Sci.	Associate Professor	Department of Astronomy, Geodesy, Ecology and Environmental Monitoring of the Institute of Natural Sciences and Mathematics
4	Andrei M. Sobolev	PhD, Senior Researcher	Leading Researcher	Kourovka Astronomical Observatory, Institute of Natural Sciences and Mathematics

Recommended by:

Educational and methodological board of Institute of Natural Sciences and Mathematics

Head of the Educational and Methodological board of the Institute of Natural Sciences and Mathematics — E. S. Buyanova

Record № _1_ от 19.01.2023 г.

Agreed by:

Head of academic staff training department — E.A. Butrina

1. GENERAL CHARACTERISTICS OF THE DISCIPLINE SPACE PHYSICS, ASTRONOMY

1.1. Abstract of the discipline content

The objective of the course is to provide the students with a broad overview of some most important problems of dynamical evolution of planetary systems as well as physical processes associated with the generation of radiation, propagation and absorption of radiation in space medium; methods for analyzing electromagnetic radiation in various spectral ranges as applied to astronomical observations; physical properties of space objects (planets, stars, galaxies and their systems) of the interplanetary, circumstellar, interstellar and intergalactic medium based on astronomical observations; questions of the origin, movement and evolution of space objects on the basis of fundamental physical theories and astronomical observations; formation of a large-scale structure and cosmological evolution of the Universe as a whole, including the early stages of its expansion, explanation of the origin of galaxies, stars, planets and their systems; cosmic factors that determine the conditions for the formation and existence of life on Earth and other planets.

1.2. The language of the program is English.

1.3. Planned results of scientific research

The discipline "Physics of space, astronomy" refers to the basic part of the postgraduate program, aimed at preparing for the delivery of the candidate's minimum in the scientific specialty 1.3.1. Space physics, astronomy.

As a result of mastering the discipline, the graduate student must demonstrate the following results:

Knowledge:

- modern scientific achievements, including in interdisciplinary fields;
- theoretical foundations of astronomy and space physics, taking into account modern achievements of domestic and foreign science and technology.

Skills:

- analyze and evaluate modern scientific achievements, generate new ideas in solving research and practical problems, including in interdisciplinary areas;
- design and implement comprehensive research, including interdisciplinary, based on a holistic systemic scientific worldview using knowledge in the field of history and philosophy of science.

Mastering (to demonstrate skills and experience):

- participate in the work of Russian and/or international research teams to solve scientific problems;
- independently carry out research activities in the field of space physics and astronomy using modern research methods and information and communication technologies;
- solve astronomical, physical and mathematical problems arising in the course of scientific research, both theoretical and experimental (observational) in nature;
- develop the theoretical foundations of space physics and astronomy, taking into account modern achievements of domestic and foreign science and technology;
- analyze the results of research work, prepare scientific publications, review and edit scientific articles.

1.4. Content of the discipline

№	Types of educational work	Volume of discipline		Distribution of the volume of discipline by semester (hours)
		Total hours	Incl. contact work (hours)	6^{th}
1.	**Auditory lessons**	**4**	**4**	**4**
2.	Lectures	4	4	4
3.	Practical classes	0	0	0
4.	**Individual work of graduate students, including all types of current attestation**	**104**	**1**	**104**
5.	**Interim attestation**	**Exam**	**1**	**Exam, 18**
6.	**Total volume according to the curriculum, hours.**	**108**	**5**	**108**
7.	**Total volume according to the curriculum, credit**	**3**		**3**

2. CONTENT OF THE DISCIPLINE

Section number	Section, topic of discipline *	Content
1	**Celestial mechanics.** *Lecture — 1 hour;* *Self-study — 21 hours.*	Two-body problem, *N*-body problem, Three-body problem, analytical and qualitative methods, planetary system dynamics, artificial satellite motion theory
2	**Astrometry.** *Self-study — 20 hours.*	General, practical, and fundamental astrometry
3	**Astrophysics.** *Lecture — 1 hour;* *Self-study — 21 hours.*	Practical, general, and theoretical astrophysics
4	**Stellar astronomy.** *Lecture — 1 hour;* *Self-study — 21 hours.*	Galactic astronomy
5	**Astrochemistry.** *Lecture — 1 hour;* *Self-study — 21 hours.*	Radio astronomy, physics of the interstellar medium, astrochemistry

3. ORGANIZATION OF PRACTICAL EXERCISES, INDIVIDUAL WORK

3.1. Practical exercises

not provided

3.2. Approximate topics of individual work

3.2.1. An approximate list of topics for essays (essays, creative works)

not provided

3.2.2. Approximate topics of individual or group projects

not provided

4. FUND OF EVALUATION FACILITIES FOR CURRENT AND INTERIM ATTESTATION

4.1. CRITERIA FOR EVALUATING THE RESULTS OF CONTROL AND EVALUATION ACTIVITIES OF THE CURRENT AND INTERIM CERTIFICATION IN THE DISCIPLINE

The criteria approved by the department are used to evaluate the achievements of graduate students for each control and evaluation event. The system of assessment criteria is based on three levels of mastering the components of competencies: threshold, advanced, high.

Competency components	**Signs of the level of mastering the components of competencies**		
	threshold	**advanced**	**high**
Knowledge	A graduate student demonstrates knowledge-acquaintance, knowledge-copy: recognizes objects, phenomena and concepts, finds differences in them, shows knowledge of sources of information, can independently reproduce actions on knowledge by independently reproducing and applying information.	A graduate student demonstrates analytical knowledge: he confidently reproduces and understands the acquired knowledge, assigns it to one or another classification group, independently systematizes it, establishes relationships between them, and applies it productively in familiar situations.	A graduate student can independently extract new knowledge from the outside world, creatively use it to make decisions in new and non-standard situations.
Skills	A graduate student is able to correctly perform prescribed actions according to an instruction, an algorithm in a known situation, independently performs actions to solve typical problems that require a choice from among known methods, in a predictably changing situation	A graduate student is able to independently perform actions (techniques, operations) to solve non-standard tasks that require a choice based on a combination of known methods in an unpredictably changing situation	A graduate student is able to independently perform actions related to solving research problems, demonstrates the creative use of skills (technologies)
Personal qualities	A graduate student has a low motivation for learning activities, shows an indifferent, irresponsible attitude to learning, assigned work	The graduate student has a pronounced motivation for learning activities, demonstrates a positive attitude towards learning and future work, and is active.	The graduate student has a developed motivation for educational and labor activity, shows perseverance and enthusiasm, diligence, independence, creative approach.

4.2. EVALUATION TOOLS FOR CURRENT AND INTERIM ATTESTATION

4.2.1. List of sample questions for the Test

not provided

4.2.2. List of sample questions for the Exam

1. The phenomena of precession, nutation, aberration and refraction. Reduction to a apparent place.
2. Methods for determining the main astrometric constants. Theoretical connections between constants. Systems of astronomical constants.
3. Geometric, kinematic and dynamic methods for constructing a reference system.
4. Time measurement: IAT atomic time scale. Classical time scales UT0, UT1, UT2, ET. Relativistic time scales TDT and TDB, TT, TCG.
5. Storage and reproduction of time scales and reference frequencies. Methods for their distribution and synchronization.
6. Meridian astrometry. Theory and arrangement of the main meridian instruments. Methods of absolute and relative determinations of coordinates.
7. Star catalogs and their systematic errors. Derivation of the fundamental system of stellar positions and proper motions. Coordinate system orientation. Relative and summary catalogs. The most important fundamental catalogs.
8. Photographic astrometry. Astrographs. Measured and standard coordinates. Turner and Schlesinger methods. Photographic determinations of the coordinates of the Moon, planets and satellites.
9. Determination of proper motions and parallaxes of stars. Using galaxies to deduce errors in the system of proper motions of stars.
10. Use of CCDs in astrometry.
11. Technique of laser location of satellites and the Moon.
12. Methods for positional measurements of celestial objects using spacecraft. Projects Hipparcos, Gaia.
13. Interferometric methods in astrometry. Ground and space interferometers.
14. Satellite navigation systems. Orbital and ground technical means.
15. Very long baseline radio interferometers (VLBI), device, measurement principle. Correlation signal processing in VLBI.
16. Radio astronomical methods for determining the coordinates of objects, the irregularity of the Earth's rotation, the movement of the poles and distances on the Earth's surface.
17. Celestial Reference System (ICRS) and Terrestrial Reference System (ITRF).
18. Radar and radio interferometric methods for observing the bodies of the Solar System.
19. Methods for matching optical and radio coordinate systems.
20. Equations of Euler, Poisson, Liouville.
21. Variations of the Earth's axial rotation. The movement of the poles.
22. Instruments for studying the Earth's rotation: a transit instrument, a zenith telescope, a prism astrolabe, a photographic zenith tube, VLBI, a laser ranging, global navigation satellite systems.
23. Interpretation of the movement of the poles and variations of the Earth's rotation. Short-period, seasonal, secular variations of the Earth's rotation. Chandler's movement of the pole.
24. International Earth Rotation Service (IERS), its organizations and tasks. IERS standards.
25. Study of precession and nutation of the Earth's axis of rotation by VLBI methods.
26. Unperturbed motion. Equations of motion in the problem of two bodies and their solution. Perutbed motion. Equations of motion of N bodies and their first integrals. Equations of motion in Jacobi coordinates.
27. Equations of motion of Euler and Lagrange in osculating elements. Theory of perturbed motion. Small parameters in the theory of motion of planets and satellites. intermediate orbits. Expansion of the perturbation function.
28. Integration with the help of series in powers of time (the method of indefinite coefficients and the method of Lie series).

29. Formal integration of the equations of motion in the elements of an intermediate orbit by the method of the small Lyapunov–Poincaré parameter. Small denominators. Resonance.
30. Poincare's theorems on the rank and class of perturbations. Convergence in the small parameter method.
31. Formal integration by the averaging method. Asymptotic character of the averaging method.
32. Canonical transformations. Hamilton-Jacobi method.
33. The method of Lie transformations in perturbation theory. Theory of secular perturbations.
34. Action-angle variables. Integrated systems. Liouville's theorem Bruns' and Poincare's theorems on the integrability of the several-body problem.
35. Conservation of the phase volume. Periodic Orbits. Methods of Lyapunov and Poincaré. follow function.
36. Conditionally periodic functions. Average value. Invariant tori. Basic ideas of the Kolmogorov-Arnold-Moser method.
37. Fundamentals of the first and second Lyapunov methods for determining the stability of motion. orbital stability. Stability according to Lagrange. Poisson stability.
38. Restricted three-body problem. Jacobi integral. Topology of Hill surfaces. Stability of libration points. Families of periodic solutions near libration points.
39. Fundamentals of the theory of gravitational potential. Representation of the potential as an expansion in terms of spherical functions. Gravitational potential of the Earth, Moon, planets. Mascons.
40. Fundamentals of the theory of the figure of the Earth. Methods for determining the parameters of the gravitational field and figure of the Earth.
41. Perturbed motion of satellites. intermediate orbit. Disturbing factors in the motion of natural satellites of planets. Disturbing factors in the motion of artificial earth satellites.
42. Expansion of the perturbing function due to the non-centrality of the planet's gravitational field. Perturbations from zonal harmonics. Perturbations from tesseral and sectorial harmonics. Perturbing function of the attraction of an external body. Lunar-solar perturbations of satellites.
43. Integration of the equations of the generalized problem of two fixed centers. The properties of the movement. Intermediate orbit formulas. Perturbations based on the intermediate orbit of the generalized problem of two fixed centers.
44. Hill's problem and its use in the theory of motion.
45. Disturbances caused by the resistance of the planet's atmosphere. Perturbations from light pressure and tides in the body of an elastic planet.
46. Statement of the problem of determining the orbits. Determination of the orbit by two positions. Fundamentals of the Laplace and Gauss methods for determining the orbit from three angular observations.
47. Method of differential improvement of motion parameters of celestial bodies from observations. The method of least squares with a known covariance matrix of observations. collocation method. Method of least modules.
48. Construction of conditional equations in the refinement of the elements of satellite orbits from laser and radio observations.
49. Structure of the Galaxy. Subsystems of the Galaxy.
50. Kinematics of the Galaxy. Characteristics of rotation and distributions of residual velocities.
51. Models of the Galaxy and the orbits of stars in them.
52. Dynamics of collisionless stellar systems. Boltzmann equation. Integrals of motion.
53. Theory of motion in the field of a rotationally symmetric potential. Direction field.
54. Equilibrium figures of celestial bodies.
55. Optical telescopes. Telescope efficiency, relation to image quality. Methods for achieving high angular resolution. Active and adaptive optics.
56. Principles of spectral analysis. Spectrographs. Spectral resolution and factors determining it.
57. Solar telescopes: celestial, coronograph. Principles of measurement of magnetic fields on the Sun.

58. Receivers of optical radiation. Photoelectric multiplier. Charge coupled devices. The concept of quantum output. Features of registration of infrared radiation.
59. Scale of stellar magnitudes and color indices. photometric systems. Modern methods of photoelectric photometry. polarization observations.
60. Radio telescopes, the principle of operation. Various types of antennas (parabolic, dipole, antenna arrays). The effective area of the antenna. The size and shape of the radiation pattern.
61. Radiometers. Antenna temperature, noise temperature, bandwidth, sensitivity.
62. Principles of interferometry. Radio interferometers. Aperture synthesis method. Radio telescopes with an unfilled aperture. Interferometry with very long bases. Angular resolution of interferometers.
63. Extra-atmospheric observations, tasks to be solved. Infrared, ultraviolet, X-ray and gamma-ray observatories.
64. Optical telescopes. Optical schemes of reflectors and mirror-lens telescopes. Mechanical structures of telescopes. Equatorial and azimuth mounts.
65. Aberrations of optical systems, ways to reduce them. Influence of the atmosphere on the image of a point object. Methods for improving image quality. Active and adaptive optics.
66. Principles of spectral analysis. Spectral resolution and its dependence on the parameters of the spectrograph and the dispersive element.
67. Classical diffraction spectrograph. Echelle spectrograph. Obtaining a spectrum using a Fabry-Perot interferometer.
68. The main characteristics of the Sun as a star. Internal structure. Photosphere. Chromosphere. Crown. solar wind.
69. Active formations on the Sun, connection with magnetic fields. Solar flares and their accompanying phenomena. X-ray radiation from the sun. Quiet and sporadic radio emission. Introduction to helioseismology.
70. The main characteristics of the planets (mass, density, rotation, properties of the atmosphere, magnetic fields, conditions on the surface). Terrestrial and space methods for studying the bodies of the Solar System.
71. Small bodies of the solar system. Satellites and rings of planets. Asteroids and asteroid belts. Comets.
72. The physical state of the interplanetary medium. meteor substance.
73. Radio emission of planets. Radar methods for studying planets and small bodies of the Solar System.
74. Spectral classification of stars, its physical interpretation.
75. Luminosities, effective temperatures and color indices of stars. Direct and indirect methods for determining the sizes and masses of stars from observations.
76. Sources of energy at various stages of the evolution of stars. Evolutionary tracks of stars of different masses on the Hertzsprung-Russell diagram (color-luminosity diagram). Final stages of stellar evolution. Degenerate stars (white dwarfs), neutron stars, black holes, their physical properties and observable manifestations. Radio pulsars.
77. Binary and multiple stars. Eclipse-variables. The Mass Function and Estimation of the Masses of Components in Binary Systems.
78. Close binary systems and features of their evolution. Accretion onto compact stars. X-ray sources in binary systems. New stars. Bursters.
79. Variable and non-stationary stars. Pulsating variables (Cepheids, long-period variables, RR Lyra type variables). Stars with shells. T Tauri stars. Ae/Be Herbig objects. cataclysmic variables.
80. Supernovae, types of supernovae, observed features. Processes leading to an explosion. The role of supernovae in the enrichment of the interstellar medium with heavy elements.
81. Elementary processes of radiation and absorption of electromagnetic quanta. Radiation and propagation of radio waves in thermal plasma. Cosmic sources of thermal and non-thermal radiation in various regions of the spectrum.
82. Mechanisms of energy transfer. Transfer equation. Local thermodynamic equilibrium. Eddington luminosity limit.

83. Sources of absorption in the continuum in the atmospheres of stars and the form of continuous spectra for stars of various classes.
84. Models of stellar atmospheres. Mechanisms for the formation of absorption lines. The concept of equivalent line width. Line profiles, line broadening mechanisms. growth curve. Chemical composition of stellar atmospheres.
85. Equations describing the internal structure of stars. The structure of stars of different spectral types. Equation of state of a degenerate gas. Limiting mass of white dwarfs and neutron stars.
86. Theory of cosmic radio emission. Synchrotron radiation of relativistic electrons. Illumination time. Inverse Compton effect.
87. Structure of the Galaxy. Stellar populations and subsystems. Spiral structure of the Galaxy, observed manifestations. Nucleus of the Galaxy.
88. Star clusters and associations. Interpretation of color-magnitude diagrams.
89. Stellar kinematics. The motion of the Sun relative to the stars. Rotation of the Galaxy. Connection of kinematic properties with the spatial distribution of objects.
90. Stellar dynamics. Phase density and the Boltzmann equation for stellar systems. Integrals of motion. The virial theorem and its application. Regular and irregular forces. Relaxation time. collision integral.
91. Gravitational stability of a thin rotating disk. Dispersion equation. Spiral branches, concept of density waves.
92. Physical state of interstellar gas. Molecular clouds, HI and HII regions, coronal gas, maser condensations. Mechanisms of gas emission in various states.
93. Optical radiation of interstellar gas. Forbidden lines. Gas nebulae of various types. Radio links. maser sources.
94. Shock waves in the interstellar medium. Supernova remnants and their evolution.
95. Gravitational instability of a gas medium and gas condensation. Protostars and young stars. circumstellar disks. Regions of star formation.
96. Interstellar dust, observed manifestations. Own emission of dust. Interstellar absorption and its accounting.
97. Interstellar magnetic fields, observed manifestations. The concept of frozen-in field. Cosmic rays, their manifestations, main sources. Propagation of cosmic rays in the magnetic field of the Galaxy.
98. Classification of galaxies. Features of the structure of galaxies of different morphological types. Gas content and star formation in galaxies.
99. Dimensions, luminosity, soonrotation and mass of galaxies, principles of their estimation. The problem of the existence of a dark halo. Dwarf galaxies, observed features.
100. Groups and clusters of galaxies. interacting galaxies. Intergalactic gas in galaxy systems.
101. Galaxies with active nuclei. Quasars. Representation of the mechanisms of activity.
102. Radio emission of galaxies and their nuclei. Radio galaxies: power of radio emission, radio structure. Radio jets.
103. Distance scale, Hubble's law. Large-scale distribution of galaxies.
104. Friedmann's models of the expanding Universe, the concept of critical density and cosmological constant. The Hubble constant and the "age" of the Universe.
105. Cosmic microwave background, its origin. fluctuations in brightness. Early stages of the expansion of the universe. primary nucleosynthesis.
106. The problem of the formation of galaxies. Expected properties of young galaxies. Galaxies at high redshifts.

5. EDUCATIONAL-METHODOLOGICAL AND INFORMATION SUPPORT OF THE DISCIPLINE

5.1. Recommended literature

5.1.1. The basic literature

1. Moon-Earth-Sun: The oldest three-body problem. http://sites.apam.columbia.edu/courses/ap1601y/Moon-Earth-Sin%20RMP.70.589.pdf
2. Introduction to Space Physics. https://mcgoodwin.net/pages/spacephysics_ess471.pdf
3. Astrometry. http://ircamera.as.arizona.edu/Astr_518/astrometry_2016.pdf
4. Introduction to Astrometry. https://pholus.mtk.nao.ac.jp/~toshio/education/Astrometry(Note-BW).pdf
5. Introduction to Optical Telescopes. https://rwoconne.github.io/rwoclass/astr1230/telescopes.html
6. Large Optical Telescopes. https://vdoc.pub/documents/the-design-and-construction-of-large-optical-telescopes-6171ci7f13i0
7. Basics of Radio Astronomy. https://www2.jpl.nasa.gov/radioastronomy/radioastronomy_all.pdf

5.1.2. The additional literature

1. Astronomy2e. https://openstax.org/details/books/astronomy-2e
2. Review of Neutrino Astronomy. https://arxiv.org/pdf/astro-ph/0204527.pdf

5.2. Methodological developments

not provided

5.3. Software

1. Microsoft office (Word, Excel, Power point);
2. Adobe Reader
3. Software package GILDAS: http://www.iram.fr/IRAMFR/GILDAS/
4. Software package IRAF: http://iraf.noao.edu/
5. Software package SAOImage DS9: http://ds9.si.edu/site/Home.html
6. Software package OrbFit: http://adams.dm.unipi.it/~orbmaint/orbfit/
7. Publishing system MiKTeX: https://miktex.org

5.4. Databases, information and reference and search systems

1. ScienceDirect: http://www.sciencedirect.com;
2. Web of Science: http://apps.webofknowledge.com;
3. Scopus: http://www.scopus.com;
4. Reaxys: http://reaxys.com;
5. SciFinder https://scifinder.cas.org
6. Espacenet https://ru.espacenet.com
7. RSCI https://www.elibrary.ru
8. Search system EBSCO Discovery Service http://lib.urfu.ru/course/view.php?id=141;
9. Federal Institute of Industrial Property http://www1.fips.ru;
10. Digital Library of Physics and Astronomy ADS, http://adsabs.harvard.edu/abstract_service.html
11. Russian Astronomical Network Astronet, http://www.astronet.ru
12. Service for access to published astronomical databases and catalogs, http://vizier.u-strasbg.fr/viz-bin/VizieR
13. Base of chemical reactions for astrochemistry KIDA, http://kida.obs.u-bordeaux1.fr/

5.5. Electronic educational resources

1. Zonal Scientific Library http://lib.urfu.ru;
2. Library Catalogs http://lib.urfu.ru/course/view.php?id=76;

3. Electronic catalog http://opac.urfu.ru;
4. Electronic library systems http://lib.urfu.ru/mod/resource/view.php?id=2330;
5. Electronic resources of free access http://lib.urfu.ru/course/view.php?id=75;
6. Electronic resources by subscription http://lib.urfu.ru/mod/data/view.php?id=1379.

6. LOGISTICS AND TECHNICAL SUPPORT OF THE DISCIPLINE

Information about the facilities of the discipline with specialized and laboratory equipment

Ural Federal University has special facilities for conducting lecture-type classes, seminar-type classes, group and individual consultations, current control and intermediate certification, as well as rooms for independent work and rooms for storage and preventive maintenance of equipment. Special rooms are equipped with specialized furniture and technical teaching aids that serve to present information to a large audience.

Ural Federal University has the material and technical support necessary for the implementation of the postgraduate program, the provision of disciplines (modules), research work and practices, in accordance with the requirements for the material, technical and educational and methodological support of the program orientation.