DISSERTATION EXAM
field of study: ASTROPHYSICS

4.1.8 Joint expert committee will determine one of the subjects listed below as the subject of the exam, according to the focus of a PhD student

Topics from the field: **ASTROPHYSICS**

Specializations: solar physics, variable stars

A: radiation, radiation processes

1. Characteristics of radiation

Specific intensity, mean intensity and energy density, radiation flux, radiative power, radiation (energy) flux density, radiation pressure. Relationship between radiation flux and specific intensity.

2. Black-body radiation

Thermodynamic equilibrium, temperature, Kirchhoff's law
Wien's law, Stefan-Boltzmann's law, Planck's law, electromagnetic spectrum.

3. Radiations of cosmic objects

Physical processes producing continuous and line spectrum. Spectra of atoms and molecules. Stellar spectrum – continuous and line spectrum, absorption and emission spectral lines. Thermal and non-thermal radiation, synchrotron radiation. Bremsstrahlung (braking radiation).

4. Spectral lines

Profiles of spectral lines. Broadening of spectral lines: natural line width (radiation damping), thermal broadening (Doppler line width), broadening by micro-turbulence, pressure, rotation, collisions, instrumental line width, Zeeman's effect, Paschen-Back's effect Stark's effect, Doppler line shift, FWHM, line depth, equivalent line-width, curve of growth.

5. Theory of stellar atmospheres

Description of radiation in stellar atmospheres, atom excitation and ionization. Absorption and emission coefficient, optical thickness. Radiative transfer equation and its solution, source function. Local thermodynamic equilibrium. Saha equation, Boltzmann's equation, equation of statistical equilibrium. Model atmospheres, negative ion of hydrogen, continuous radiation of stellar atmosphere, limb darkening.

B: Observational astrophysics

6. Observational methods in astrophysics

Spectroscopy, spectrophotometry, photometry (visual, photographic, photoelectric, CCD). Photometric systems (Johnson's, Cousines', Stromgren's, Walraven's), color index and excess, polarimetry.

7. Astrophysics in different domains of electromagnetic spectrum

Absorption of electromagnetic radiation by Earth's atmosphere. Methods of study in different domains: optical astronomy, radio astronomy, infrared, ultraviolet, X-ray and gamma astronomy. Research from satellites. Typical radiation sources in individual domains of spectrum. Particle astrophysics, cosmic radiation, nuclei of atoms, electrons, positrons, antiprotons. Detecting of various kinds of particles. Types of detectors, neutrinos.

8. Data analysis in astrophysics

Statistical methods of data processing. Fourier analysis. Determination of power spectra. Digital data reduction, filtrations. “Fast Fourier Transform”method. Weighted “least-mean-square” analysis. Noise analysis in periodic phenomena. Image processing (of spectra) and image reconstruction technique (of spectra), “Flat-field” techniques, noise, defects in data, incomplete data series, instrumental errors and false gradients in data.

C: Chacteristics and structrure of stars, energy sources, energy transfer in stars

9. Basic characteristics of stars

Brightness, luminosity, apparent and absolute magnitude, temperature, spectral type, mass and radius and their units. Ranges of stellar characteristics depending on their evolutional stage. Mutual relationships of fundamental characteristics. HR diagram, mass-luminosity diagram, theoretical HR diagram, evolutionary tracks of stars.

10. Stellar structure

Physical properties of star’s material. Fundamental equations of stellar structure, hydrostatic equilibrium, virial theorem, equation of state, central temperature, pressure, pressure of degenerate gas, Eddington limit. Solutions of fundamental equations of stellar structure: analytical approximation, numerical techniques, boundary conditions. Star structure depending on its evolutional stage.

11. Sources of energy and its transfer in stars

Characteristic stellar time-scales (thermal, gravitational, chemical, nuclear, thermonuclear). Energy production by gravitational contraction, thermonuclear reactions. Nuclear binding energy, Coulomb barrier, hydrogen burning (p-p chain, CNO cycle, 3-alpha process). Production of neutrinos and their oscillations. Helium burning. Energy transfer by radiation (equation of energy transfer by radiation). Energy transfer by convection (Schwarzschild criterion)

D: Evolution of stars and binary stars

12. Stages of stellar evolution

Star formation, Jeans criterion, interstellar gas and dust, gravitational collapse/protostar. Problem of angular momentum loss. Evolution of star before entering the main sequence. Trajectory of star in HR diagram. Young stellar objects, low massive stars, brown dwarfs.

13. Evolution of low massive and massive stars

Evolution of low massive stars, evolution on main sequence, red giant phase, helium flash, asymptotic transition to giant branch, ejection of mass, planetary nebula, white dwarf, Chandrasekar mass limit criterion. Evolution of massive stars, supernova types, collapse of nucleus, thermonuclear explosion, classification of supernovae, light curves, mass criterion, nucleosynthesis in supernovae. R and S processes, neutron stars, pulsars, black holes.

14. Evolution of binary stars

Classification, formation and evolution of binary stars, mass function, Roche potential, mass transfer in binary stars, Algol paradox, binary stars with compact components, accretion and ejection of matter, novae.

RECOMMENDED LITERATURE

● Gray, D.F.: The observation and analysis of stellar photospheres. A Whilley - InterscicencePublication, New York, 1976.
● Kourganoff, V.: Introduction to Advanced Astrophysics. Reidel Publ., Dordrecht, 1980.
● Tatum, J.B.: Stellar Atmospheres, http://orca.phys.uvic.ca/~tatum/universe@uvvm.uvic.ca, 2003.

Topics from the field**: SOLAR PHYSICS**

Specialization: solar physics

1. Astrophysical basis

Plasma properties. Plasma in magnetic and gravitational field. Hydrostatic equilibrium. Definition of radiation intensity. Spectral lines. Natural line width, broadening of spectral lines by Zeeman effect, Stark effect, temperature, turbulence, pressure and dumping. (Other questions about stellar atmospheres are listed in section Astrophysics).

2. Sun as a star

Position and motion of the Sun in Galaxy. Mass, radius and chemical composition. Luminosity, effective temperature and spectrum. Evolution of the Sun. Sun in H-R diagram.

3. Thermonuclear reactions in solar body.

Processes of energy generation, p-p chain and CNO cycle. Chemical composition of the Sun interior.

4. Standard model of the Sun’s interior

Definition. Physical conditions. Luminosity, density and temperature in solar body. Observational possibilities of testing standard model.

5. Solar convection

Conditions of origin – mixing length theory. Dynamics, granulation, mezogranulation, supergranulation, observations.

6. Sun rotation

Convection in rotating spherical layers. Theory of global circulation. Meridional circulation. Differential rotation. Observations of rotation.

7. Global magnetic field of the Sun

Solar dynamo theory. Magnetic structures. Solar activity cycle. Butterfly diagram. Change of magnetic polarities of solar hemispheres.

8. Solar atmosphere

Layers of solar atmosphere. Physical processes in individual layers. Energetic balance of solar atmosphere. Oscillations.

9. Spectral diagnostics of solar atmosphere

Determination of abundances, temperature, density, velocity and magnetic field from spectral analysis and modelling – synthetic spectra.

10. Solar photosphere

Chemical composition. Limb darkening. Structure, dynamics and heating of photosphere. Energetic equilibrium. Photosphere models.

11. Magnetic and velocity field in photosphere

Magnetic structures of quiet and active photosphere. Granulation. Flux tubes. Faculae, sunspots. Velocity field of photosphere.

12. Solar chromosphere and solar transition region

Physical characteristics. Energy equilibrium. Heating. Dynamics. Structures. Observation at limb and on solar disc.

13. Solar flares

Observation. Physical conditions. Dynamics and processes of energy release. Magnetic reconnection. Acceleration and spread of energetic particles in solar flare. Radio emission of solar flares.

14. Solar corona – description of properties

Spectrum – division into components K, F, E. Physical properties. Phenomena in corona – coronal rays, prominences, condensations, coronal holes, bright points, transients. Radio and X-ray-corona.

15. K-corona and E-corona

Thomson scattering. Determination of electron density. Distribution models. Best-known lines of E-corona and their identification. Elementary processes. Excitation and ionization equilibrium principle.

16. Determination of corona temperature

From density distribution, Doppler’s broadening of emission lines.

17. Solar activity cycle in corona

K-corona – shape, flattening, overall brightness. E-corona (coronal index). Relations to other activity manifestations.

18. Prominences

Description, types, spectra. Physics of prominences. Classification. Occurrence during activity cycle.

19. Solar wind and heliosphere

Sources of solar wind. Structure and dynamics of solar wind. High-speed current-flows. Coronal transients and expansion of corona. Geometry of interplanetary magnetic field. Shock waves.

RECOMMENDED LITERATURE

● Physics of The Sun I, II, III. Geophysics and Astrophysics Monographs, eds: P.A. Sturrock, T.E.Holzer, D.M. Mihalas a R.K. Ulrich, Reidel Publ., Dordrecht, 1986.
● Zirin, H.: Astrophysics of the Sun. Cambridge Univ. Press, Cambridge, 1988.
● Stix, M.: The Sun - An Introduction. Springer Verlag; 2nd edition, 2002.

Topics from the field**: STELLAR PHYSICS**

Specialization: variable stars

1. Basic characteristics of stars

Position of stars in H-R diagram and its dependence on evolutionary stage

2. Stellar wind

P Cygni profile of spectral lines, acceleration mechanism of stellar wind, radiative force in Sobolev approximation, mass-loss rate, CAK (Castor, Abbot, Klein, 1975), stellar wind theory, stellar wind of hot O, B, W-R stars and cool giants.

3. Characteristics of various types of stars

Herbig Ae/Be stars, Wolf Rayet stars, Be stars
(properties of emission line profiles, reasons of Be stars phenomenon: rotation, binary star origin, effect of rotation to stellar wind, non-radial pulsations).

4. Chemically peculiar and magnetic stars

Classificaton: CP1 – classic metallic Am stars, CP2 – magnetic CP stars (from type SrCrEu to Si), CP3 - HgMn stars, CP4,5 - with helium deficiency, CP6,7 - with helium overabundance. Causes of spectral anomaly, distribution of elements on the star surface, oblique rotator model, origin of magnetic field.

5. Observation methods of variable stars

Photometry and photometric systems, broad-band UVBRIJHKL photometry, narrow-band photometry. Correction for Earth's atmosphere influence, transformation of photometric colors. Visual, photographic and CCD photometry, spectroscopy analysis of spectral line profiles and determination of spectral type. Determination of radial velocities, heliocentric correction of radial velocities.

6. Light curve of variable star

Observation time, heliocentric correction of time, heliocentric Julian date, determination of minimum or maximum of variable star, period of light variations, composing of observations, phase light-curve.

7. Period analysis

Fourier and PDM method, apparent and false periods, O-C diagram, real and apparent changes of period and their causes: mass transfer between components and mass outflow from system. Presence of third body in system, apsidal motion.

8. Types of variable stars

Geometric (rotating stars: magnetic and spotted binaries: eclipsing and interacting). Physical: changes around star, in surface layers (manifestations of stellar activity), in subsurface layers (pulsations), in nucleus (fast stellar evolution stages, supernovae). Light-curve shapes, catalogues of variable stars.

9. Pulsating variable stars

Pulsation mechanism, radial and non-radial pulsations, modes of pulsations. Position of variable stars in H-R diagram, Instability belt and its explanation. Cepheids: period-luminosity dependence, oscillations and asteroseismology, long-period variable stars.

10. Supernovae

Evolution of massive stars and supernovae of type II, evolution of binary stars and supernovae of type I (Ia, Ib, Ic).

11. Observation methods of binaries

Astrometric observations, satellite astrometry – Hipparcos, micrometric measurements, interferometry and aperture synthesis, occultations of binary stars by Moon, visual and photographic photometry, photoelectric photometry, CCD photometry, polarimetry, magnetometry, multifrequency observations (gamma, X-ray, ultraviolet, infrared and radio), spectroscopy. Methods for detecting compact objects.

12. Definition, classification and occurrence of binaries

Visual, spectroscopic and eclipsing binaries, occurrence of binary stars among main sequence stars, occurrence of binary stars among peculiar and physically variable stars, binaries in clusters, catalogues of binaries.

13. Roche's model. Origin and evolution of binaries

Detached, semi-detached and contact binaries, mass transfer stages, Algol paradox, final stages of binary stars evolution, X-ray binaries, novae and symbiotic stars.

14. Visual binaries

Optical pairs and temporary binaries, relative motions of components in visual binary, orbital elements of visual binary and their determination, Kowalski and Glasenapp method, dynamical parallaxes.

15. Spectroscopic binaries

Radial velocity curve, one-line and two-line spectrum, spectroscopic elements and their determination, Lehmann-Filhes method, Schwarzschild and Zurhellen methods, proximity effects and rotational effect.

16. Eclipsing binaries

Light-curve types of eclipsing binaries (Algol, Beta Lyrae, W UMa), geometric and photometric elements, fine effects affecting light-curve, limb darkening, reflection effect, gravitational darkening, Methods of determination of photometric elements: Russell-Merrill method, Kopal method, Wilson-Devinney method.

17. Absolute parameters of binaries

Using photometric and spectroscopic elements to determine masses, radii and luminosities of components and their separation. Distance determination of binary from Earth.

18. Interacting binaries and their evolution

Jet phenomena, X-ray binaries and their classification in term of masses of optical components and type of the accretion object. X-ray pulsars and flare sources (bursters), binary pulsars (PSR 1913 + 16).

RECCOMMENDED LITERATURE

● Sidney, C., Wolf. F.: *The A-stars: Problems and perspectives*. NASA, Washington, 1983.
● de Loore, C.W.H., Doom, C.: *Structure and Evolution of Single and Binary Stars*. Kluwer Acad.
Publ., Dordrecht, 1992.
● Hiltitch, R.W.: *An introduction to close binary stars*. Cambridge University Press, 2001.
● Sterken, C., Jaschek, C.: *Light curves of variable stars - a pictorial atlas*. Cambridge University
Press, 1996.

A specialist in a particular field of science (solar physics, interplanetary matter, variable stars) is moreover required to have knowledge of the selected field within the scope of the review papers at international conferences over the previous 5 years.