University of Turku
Department of Physics and Astronomy

HIGH ENERGY ASTROPHYSICS

Questions for the exam

Exam

There will be two questions from the list below as well as one problem from the set of home exercises. When answering onto theoretical questions, a description in words as well as formulae are necessary for full points. No help from the books, lecture notes, or any other material is allowed during the exam (one A4 page of formulae only can be brought to the exam). A standard non-programmable calculator could be used.
It is required to know the necessary physical and astronomical constants. Physical constants: $c, k, m_e, m_p, G, h, e, \sigma_{\rm SB}$, Thomson cross-section σ_T.
Astronomical constants: AU, pc, $L_\odot, M_\odot, R_\odot$. Transformation of energy-frequency units keV–Hz–erg–K.

Questions

1. Neutron stars. Formation. Typical masses, radii, densities. Simple estimates of the radius based on the neutron degenerate pressure arguments.

2. Different populations of pulsars. Their typical periods and properties. Discovery of radio pulsars. Minimum period of rotation (and minimum density) of a stable star. Period distribution and galactic distribution of radio pulsars.

3. Estimation of the period and magnetic field of a newly born pulsar. $P - \dot{P}$ diagram. Pulsar energetics: relation between rotational energy loss and $P, \dot{P}$. Powering of pulsar wind nebula.

4. Magnetic dipole radiation formula. Breaking index. Determination of the magnetic field B from $P, \dot{P}$. Lines of constant B on $P - \dot{P}$ diagram. Estimating pulsar age. Age of millisecond pulsars.

5. Gravitation as a source of energy. Energy released by accretion of a proton onto a star. The accretion luminosity. The efficiency of accretion, comparison with nuclear burning efficiency. Classification of X-ray binaries.

6. Low-mass X-ray binaries. Roche equipotentials. Roche lobes. Why the matter from the L_1 point does not fall directly to a compact object, but forms the accretion disk?

7. High-mass X-ray binaries. Derivation of the formula for estimation of the accretion rate from the wind.

8. The Eddington limit and the limiting accretion rate. Can the luminosity of a source be above the Eddington limit? How?

9. Determining the masses of compact objects in binaries. The 3rd Kepler's law, mass function.

10. X-ray pulsars. The origin of X-ray pulsations from neutron stars. Measuring the magnetic field from cyclotron lines. Typical periods. Derivation of the magnetospheric (Alfven) radius.

11. Corotation radius and spin equilibrium. The "spin-up" line and its position on $P - \dot{P}$ diagram for pulsars. How it is related to the origin of millisecond pulsars? Centrifugal barrier. Spin-up time–luminosity relation.

12. X-ray polarimetry of X-ray pulsars. Modern detection principle for X-ray linear polarization. Difference between ordinary and extraordinary photons.

13. Accretion-powered millisecond pulsars. Typical rotational frequencies. Determination of the companion masses from the pulsar mass function. Rotating vector model.

14. Gravitational redshift and bending of light. Observed vs emitted (at neutron star surface) luminosity. Apparent stellar radius.

15. Origin of X-ray bursts. Relationships between the recurrence time and the persistent flux; burst energy and waiting time. The ratio of the (time-averaged) energy released by accretion and during the bursts.

16. X-ray burst spectra, colour correction. Neutron star mass-radius relation from the apparent black body radius.

17. Spherical accretion onto a black hole. The accretion radius. The continuity equation. Estimation of the accretion rate without (almost) any equations. The Euler equation for steady-state spherical accretion. The Bernoulli equation.

18. Adiabatic ($\gamma = 5/3$) spherical accretion. Accretion velocity, temperature, and density as functions of radius. The radius, r_*, where electrons become relativistic.

19. Standard accretion disk theory. Mass conservation equation. Conservation of angular momentum. The relation between the specific angular momentum and the viscous torque.

20. Power dissipated per unit radius. The radiation flux and the surface temperature of the disk, and their radial dependences. Typical surface disk temperatures in stellar and supermassive accreting black holes.

21. Spectra of accreting black holes and neutron stars. Basics of Comptonization: typical energy change of photons by thermal Comptonization.

22. Fourier transform, discrete Fourier transform. Power-density spectrum (PDS). Cross-spectrum and time lags.

23. Reflection of X-rays from the accretion disk around compact objects, main features. Origin of Kα iron line, main effects affecting its shape.

24. Masses of supermassive black holes. Characteristic sizes, angular size (as viewed from the Earth) and variability timescales of the black holes in M87 and Sgr A*. Measuring black hole masses from velocity dispersion of broad lines (or stars in Sgr A*).

25. AGN Zoo. Seyfert galaxies, their types, unification scheme.

26. Reverberation mapping. The shape of the isodelay surface. Black hole mass determination.

27. Relativistic jets in the Galaxy and in active galactic nuclei. The effect of superluminal motion. Derivation of the relation between the apparent velocity $\beta_{\rm app}$ and the true velocity, $\beta = v/c$.

28. Relativistic beaming, Doppler effect and Doppler factor, and luminosity amplification due to relativistic motion (for a blob, i.e. from received power).