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Some astrophysical processes around magnetized black hole

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Abstract. We study the dynamics of charged test particles in the vicinity of a black hole immersed into an asymptotically uniform external magnetic field. A real magnetic field around a black hole will be far away from to be completely regular and uniform, a uniform magnetic field is used as linear approximation. Ionized particle acceleration, charged particle oscillations and synchrotron radiation of moving charged particle have been studied.

Key words: magnetic fields – black holes – charged particle

The motion of a charged particle with the charge q and mass m in Kerr black hole spacetime with mass M and spin a in the presence of a uniform magnetic field b is governed by the Lorentz equation

$$\frac{\mathrm{d}u^\mu}{\mathrm{d}\tau} + \Gamma^\mu_{\alpha\beta} u^\alpha u^\beta = \frac{q}{m} g^{\mu\rho} F_{\rho\sigma} u^\sigma, \qquad g_{\mu\nu} u^\mu u^\nu = -1, \tag{1}$$

where $u^\mu = dx^\mu/d\tau$ is the four-velocity of the particle, $\Gamma^\mu_{\alpha\beta}$ are Christoffel symbols for a Kerr black hole metric and $F_{\mu\nu}$ is the tensor of the electromagnetic field. The magnetic field B is weak (it does not contribute to the metric), but the magnetic field influence on the charged particles motion can be fairly large depending on the specific particle charge. The "charged particle" can represent matter ranging from electron to some charged inhomogeneity orbiting in the innermost region of the accretion disk. The specific particle charge q/m for any such structures will then range from the electron maximum to zero. The dimensionless quantity b (magnetic parameter) can be introduced as relative Lorenz force $b = qBGM/2mc^4$. For a stellar mass black hole $M \approx 10$ M$_\odot$, we can have an electron e$^-$ in the magnetic field $B = 10^{-5}$ Gs, or charged dust grain (one electron lost, $m = 2 \times 10^{-16}$ kg) in the field $B = 10^9$ Gs – the absolute value of the magnetic field parameter is the same in both cases, $b = 0.004$.

Ionized particle acceleration - model of jet

Relativistic jets, i.e. collimated streams of escaping charged particles (velocities $v \sim c$) are observed in a wide variety of astrophysical systems. Many models have been proposed for a relativistic jet engine (jets driven by the accretion disk / driven by the central black hole); the exact mechanism is still unknown,

but it is generally accepted that large scale magnetic fields play a fundamental role in the jet formation. In Stuchlík & Kološ (2016) we study the dynamics of neutral particles forming an accretion disk that are ionized and start to feel the magnetic field. Chaotic scattering in combined black hole gravitational and uniform magnetic field then occurs and interchange between velocity around the black hole u^{ϕ} and velocity along the rotational axis u^{z}, providing mechanism for charged particle acceleration and escape along the magnetic field lines. Relativistic escape velocity of light particles can be obtained even for relatively small magnitudes of magnetic fields.

Magnetic field and microquasar quasi-periodic oscillations

Microquasars are binary systems composed of a black hole and a companion (donor) star, demonstrating quasi-periodic oscillations (QPOs) of the X-ray power density. Different types of QPOs were distinguished: these are the high frequency (HF) and low frequency (LF) QPOs in the timing spectra. The HF QPOs are sometimes detected with the twin peaks (upper f_{U} and lower f_{L}) which have frequency ratio close to $3:2$. In addition to HF QPOs, some sources display simultaneous existence of the low frequency LF QPOs f_{low} in the timing spectra. In Kološ et al. (2017) we examine the magnetic field influence on the QPOs phenomena, determining mass and spin of the black hole inside the GRS 1915+105, XTE 1550-564 and GRO 1655-40 sources.

Radiation reaction of a charged particle - synchrotron radiation

Synchrotron radiation emitted by a charged particle leads to appearance of the back-reaction force which can significantly affect its motion. In Tursunov et al. (2017) we study the dynamics of a charged particle undergoing radiation reaction force in combined Schwarzschild black hole gravitational field and an external asymptotically uniform magnetic field. The final state of the particle depends on the orientation of the Lorentz force with respect to the black hole. In case where the Lorentz force is directed towards the black hole, the radiation reaction leads to the fall of the charged particle from initially stable orbit into the black hole. Inversely, when the Lorentz force is repulsive, the orbit of the charged particle remains bounded while oscillations decay.

References

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