Applying magnetic reconnection to relativistic jets
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Abstract for the general public

The goal of this project is to investigate the structure of relativistic jets, which are powerful collimated outflows produced by the central regions of certain active galaxies. All large galaxies have in their centers an extremely massive black hole, equivalent to about a billion masses of our Sun. Some of these supermassive black holes accrete large quantities of gas, typically in the form of accretion disks, making their galaxies active. In addition, certain active galaxies produce relativistic jets, the key component of which are strong magnetic fields that cannot be swallowed by black holes. The jets are accelerated to relativistic velocities (very close to the speed of light) by means of converting a part of their magnetic energy to the kinetic energy of their matter components. They are also collimated to the opening angles of only a few degrees by interaction with their external environment. Relativistic jets produce strong beams of radiation which can be observed across the electromagnetic spectrum – from the radio waves to highly energetic gamma rays. Especially luminous are those jets that happen to be directed towards us, their luminosity can be magnified by factor of several thousands and easily outshine the entire host galaxy – such active galaxies are known as blazars. Observations of blazars revealed extreme variability in time, with certain gamma-ray flares being variable on time scales as short as a few minutes. Such rapid gamma-ray flares of blazars are particularly difficult to explain.

We will investigate a physical process called magnetic reconnection, in which oppositely directed magnetic field lines can meet and change their geometry (reconnect), which allows a part of the local magnetic energy to be released and converted into heat or motion. Magnetic reconnection is well known to operate in the solar corona, and in the Earth's magnetosphere. However, reconnection may also be expected in other strongly magnetized astrophysical plasmas including the relativistic jets of active galaxies. In particular, magnetic reconnection has been proposed as one of the leading models for the production of gamma-ray flares observed in blazars.

Magnetic reconnection in relativistic plasmas has been investigated extensively by means of large-scale numerical simulations, including our previous NCN-funded project. In this project, we will investigate the structure of relativistic jets in order to determine how magnetic reconnection may operate there in detail. The proposed project consists of two main research tasks.

1. **Energy density enhancement of reconnection plasmoids and relativistic jets.** One of the main problems posed by observations of very rapid gamma-ray flares of blazars is that they require a large part of the total jet power to be squeezed into a very small emitting region. That means that the energy density of such emitting regions should be very high, much higher than what are though to be typical values for the relativistic jets. We will address this problem by measuring the radial profiles of so-called reconnection plasmoids. Plasmoids are compact structures arising spontaneously in large-scale reconnection layers, they have a form of dense particle clouds carrying an electric current and wrapped about by magnetic fields that can be stronger than the background fields. This means that plasmoids have enhanced energy density, and we will calculate the enhancement factor by analyzing the results of numerical simulations. Furthermore, we noticed a close analogy between the structure of reconnection plasmoids and the structure of relativistic jets, and hence we will apply the same argument to estimate the enhancement factor of the energy density of the jets.

2. **Magnetization structure of relativistic jets.** Magnetic reconnection is most efficient in relativistically magnetized plasma, which means that magnetic energy density would exceed even the rest mass density of all particles. Relativistic jets are thought to originate as relativistically magnetized plasma in the direct vicinity of black holes, subsequently they evolve over large distances, accelerating to become relativistically fast. In the acceleration process, relativistic magnetization is thought to be converted rather efficiently to relativistic velocity. Is it possible that relativistically fast jets remain also relativistically magnetized? That seems to be a necessary condition in order to explain rapid gamma-ray flares of blazars in terms of magnetic reconnection. In order to answer that question, we will investigate the detailed lateral structure of relativistic jets. Our hypothesis is that relativistically magnetized regions should be present at intermediate jet radii, between the central core region and the outer sheath region.