The core objective of this project is to investigate in depth structured light beams propagation in nonlinear media. Considered optical nonlinearity causes that the light beam propagation depends on the beam intensity (power density of light), leading to self-focusing or self-defocusing of light beam (depending on a type of optical nonlinearity). In particular, the light beam of high enough power can induce optical waveguide, that, in turn, guides itself throughout propagation as if it were confined in an optical fiber. The resulting nondiffracting beam (where the diffraction broadening is counterbalanced by nonlinear selffocusing) is called spatial optical soliton. Interestingly, in such self-induced waveguide, optical solitons can guide another beam, in general with different wavelength and low power, too small to induce nonlinear effects.

There is a particular type of nonlinear media called liquid crystals. These materials possess the attributes of both liquids and solids: on the one hand the flow like liquids, on the other hand the preserve the long-distance arrangement of molecules like in solids, what causes that rotation of one molecule entails the rotation of the next one. In addition, the liquid crystal molecules rotate under the influence of light beam and these rotation modifies the refractive index “perceptible” by the propagating beam. In general, this is the basis of the giant optical nonlinearity which has the nonlocal response (the range of the interaction is wider than the beam width) and competes among others with thermal effects, Spatial solitons in liquid crystals have attracted a great deal of attention due to the possibility to create reconfigurable circuits as well as management of the direction of light beam propagation, what is extremely interesting in all optical switching and routing devices.

The traditional way of employing light in nonlinear optics has involved a Gaussian beams (beams with regular bell-like intensity structure produce by lasers and modified in standard optical systems), with the cross-section similar to the cross-section of the simplest solitons. However, in recent years it has become apparent that it can be greatly extended by using beams with much more complex distribution of intensity, phase and polarization. These beams, the so-called structured beams, gives the opportunity for much more complete and varied employing the electromagnetic waves in optics and photonics. A very distinctive type of structured light beams are the so called optical vortices, characterized by their cross section which does not have an uniform distribution of phase, but each point of the section may be assigned to a different state of phase. They attracted quite a bit of attention due to the application for example in optical tweezers which are manipulators of the position of individual molecules and small objects. Another type of structured beams are for example the Airy beams, which propagates not along straight line but parabolic line.

An interesting issue is the combination of properties of structured beams with optical nonlinearity. In particular, we can create for example vector solitons while Airy beams can induce curved structures able to guide light. Although more and more work appears across this subject, the way the structured beams propagate and interact with the nonlinear media needs further fundamental study. This applies in particular to the media with non-trivial nonlinearity, especially with nonlocal response, competing or in anisotropic media. Therefore, in this project we will thoroughly analyze the impact of this type of nonlinearity on the propagation properties of structured light beams. Moreover, it is also planned to design the shape and intensity distribution, as well as polarization and phase of the beam so as to be best suited for such nonlinear medium.

This will enable for efficient creation of spatial solitons having complex shapes in experiment and study the interactions between them. This requires advance methods for beam synthesis, in particular for nonlinear optics. That’s why in experimental part of this project we will employ novel all-fiber technology. As an experimental platform we will employ a nematic liquid crystal medium, exploiting their giant nonlinearity, extended spectral transparency, high nonlocality, birefringence, anisotropy and adjustable structure. In theoretical analysis and in modelling part both analytical and numerical methods will be used.