Final Report

The constituents of atoms in nature are quarks and gluons. The quarks source a color flux between them that results in the strong nuclear force, confining them together. The same gluonic color flux controls almost any strong interaction dynamics in the theory of gluons, namely quantum chromodynamics. Hence, to understand fundamental phenomena that originate from strong coupling dynamics we need to understand the dynamics of the color flux. Recently a new tool has emerged, in which the color flux is described by a two-dimensional string. The string naturally lives in a holographic higher dimensional space-time. Excitingly, in some cases, the dynamic of the string turns out to be integrable, namely solvable.

In this project, the PI has applied techniques of exactly solvable two-dimensional models to a four-dimensional holographic theory of gluons. Significant focus is given to what are probably the most fundamental observables in any theory of gluons – Scattering Amplitudes, Wilson Loops, and Correlation functions. Scattering amplitudes represent the probability to find some set of asymptotic particles in the far future provided that some other set of particles were prepared in the far past. They are the building blocks for the analysis of high energy collisions such as the ones taking place at the LHC experiments. Wilson Loops are extended objects that represent the coupling of the gluonic degrees of freedom to a charged particle that is carried along a closed curve. One way of thinking about them is as the QCD generalization of the Aharonov Born phase in QED. In the special theory studied in this project, certain Wilson Loops turned out to be equal to scattering amplitudes. Correlation functions are the most fundamental local observable in any quantum field theory. In a scale-invariant theories, the correlation functions between any number of local operators are determined from the ones between two and three operators. The two-point functions are fixed by the spectrum of the theory and were solved in the special theory in question. Hence, the PI has focused on the computation of the three-point functions.

During the project, significant progress has been made in several directions for the objectives above. Several studies have been conducted which lay the ground to a deeper and extended exploration. Below we summarize the main results and achievements.

- The PI have studied scattering amplitudes and Wilson loops using integrability methods. He has reviled how to extend the use of this method for computing amplitudes with any possible helicity configuration of the external particles, [1]. He has also bootstrapped the necessary building block for computing these amplitudes with arbitrary helicity at finite value of the coupling, [2].

- The PI has provided a finite coupling prediction for all the terms in the expansion of the six gluon amplitudes around the collinear limit, [3]. These furnish for the first time a non-perturbative representation of the full amplitudes.

- To date, integrability was successfully used for studying the planar limit in which the number of colors tends to infinity. We expect that integrability methods will also allow one also to go beyond the planar limit and study corrections order by order in inverse powers of the number of colors. The PI has initiated a pioneer study of scattering amplitudes and their duality to Wilson loops beyond the leading planar contribution. He has succeeded in extending the known planar tools for computing scattering amplitudes to the non-planar level, [4]. These include the integrability based method, the loop integrand and a generalization of some hidden powerful symmetries.

- One of the most useful consequences of integrability is the existence of a coordinate system where the degrees of freedom become independent. The PI has used this method for computing correlation functions of local operators in a conformal four-dimensional theory, [5]. He has found that they lead to a huge simplification. This breakthrough gives us a realistic hope that a certain interacting four-dimensional gauge theory can be solved.

[1] B. Basso, J. Caetano, L. Cordova, A. Sever and P. Vieira, "OPE for all Helicity Amplitudes", JHEP 08 (2015) 018.

[2] B. Basso, J. Caetano, L. Cordova, A. Sever and P. Vieira, "OPE for all Helicity Amplitudes II. Form Factors and Data Analysis", JHEP 12 (2015) 088.

[3] B. Basso, A. Sever and P. Vieira,"Hexagonal Wilson loops in planar $\mathcal{N} = 4$ SYM theory at finite coupling," J. Phys. A **49**, no. 41, 41LT01 (2016).

[4] R. Ben-Israel, A. G. Tumanov and A. Sever, "Scattering amplitudes – Wilson loops duality for the first non-planar correction," JHEP **1808**, 122 (2018).

[5] A. Cavaglià, N. Gromov and A. Sever, "Fishing and Twisting", To appear.