ABSTRACT

The success of the AdS/CFT correspondence has motivated efforts to extend the holographic principle to more realistic spacetimes, particularly those that are asymptotically flat. Celestial holography has emerged as a leading framework in this pursuit. It aims to recast the S-matrix elements of gravity and gauge theories in $(3+1)$-dimensional asymptotically flat spacetimes as correlation functions of a two-dimensional celestial conformal field theory (CCFT) living on the celestial sphere at null infinity.

Most progress in celestial holography has focused on the scattering of massless particles, where celestial amplitudes are obtained by Mellin transforming momentum-space S-matrix elements. These amplitudes transform covariantly under global conformal transformations, yet they differ in key ways from conventional 2D CFT correlators. Notably, CCFTs feature infinite-dimensional current algebra symmetries, which are directly connected to the soft factorization properties of the S-matrix in gauge theory and gravity. These symmetries have no counterpart in standard 2D CFTs and impose strong constraints on celestial amplitudes.

A striking manifestation of these constraints is the emergence of null decoupling equations for celestial MHV (Maximally Helicity Violating) amplitudes in trivial backgrounds. While these equations have been solved in some specific cases, this thesis demonstrates that they do not have unique solutions. In particular, we show that pure Yang-Mills theory chirally coupled to a massive scalar background also satisfies the same set of null decoupling equations.

Recent advances have revealed that gluon scattering amplitudes are governed by the S algebra, while graviton amplitudes are controlled by the wedge subalgebra of $w_{1+\infty}$, both generated by positive helicity soft particles. This thesis extends the study of the S algebra by deriving the general structure of S-invariant operator product expansions (OPEs) up to $\mathcal{O}(1)$ and identifying Knizhnik-Zamolodchikov (KZ)-type null states associated with these symmetries. Our results point to the existence of infinitely many unexplored sectors of pure Yang-Mills theory in flat space, with MHV and self-dual Yang-Mills (SDYM) being the only currently known examples.

Furthermore, this thesis addresses a gap in the literature by identifying KZ-type null states for negative helicity gluons and gravitons in celestial MHV amplitudes.

In a recent development, it was proposed that celestial amplitudes in Klein space can be decomposed into more fundamental building blocks known as celestial leaf amplitudes, which are smooth functions on the celestial sphere. The full distributional nature of celestial amplitudes is then recovered by summing over timelike and spacelike leaf amplitudes. We extend this line of inquiry by investigating the singularity structure of four-point celestial leaf amplitudes for both MHV gluons and massless scalars.