Synopsis

AdS/CFT duality is the conjectured duality between a theory of quantum gravity on an Anti-de Sitter(AdS) space-time and a Conformal Field Theory(CFT) living on the asymptotic boundary region of the AdS. By this it is meant that quantities in the gravity side can be calculated by computing some quantities in the CFT and vice versa. This duality has been subject to many tests in the context where it is stated as a duality between a particular superstring theory on AdS space-time and a supersymmetric quantum field theory with a large amount of supersymmetry (which turns out to be a CFT) on the asymptotic boundary of the AdS space. There also most of the focus has been on a particular sub-sector of this string theory called the supergravity limit which is dual to a strongly coupled sector of the field theory. Using this duality quantities in the strongly coupled sector of the field theory can be calculated with much more ease in the supergravity limit of string theory.

So, there are two important aspects of this duality that has to be probed further. One of them being able to move to a sector of string theory different from supergravity. The second being able to test this duality for non-supersymmetric systems. Higher spin theories provide us with the tool to address both these issues simultaneously. In the tensionless limit a particular sub-sector of the full string theory is believed to give rise to the massless higher spin theories. Also, these theories have a spectrum which can in principle be only bosonic and hence we have a good non-supersymmetric theory to test the AdS/CFT duality. A consistent theory of massless higher spin gauge theories in AdS space has been proposed by Vasiliev. In arbitrary dimensions these theories are consistent only in an asymptotic AdS(or de-Sitter) background and their spectrum must include fields with all spin from 2 to $\infty$ and some scalars.

In my thesis work I have focused on the higher spin theories in $AdS_3$. In 3 dimensions there are many simplifications that make the theory much more tractable than
in higher dimensions like the spectrum of fields can be consistently truncated at any finite upper value of integral spin. Also, in 3 dimensions for a theory consisting of purely higher spin fields there are no bulk propagating degrees of freedom. The theory is completely defined by the boundary values of its fields. These issues make them computationally much more tractable than other theories. Even after all these simplifications the theory is not void and retains enough complexity to provide us with some intuition into AdS/CFT duality in this context and also in general.

In the first project in this thesis I calculated the first quantum correction to a system consisting of all fields with spin from 2 to \( \infty \) by calculating the leading order correction to the partition function around a classical saddle point which we take to be the thermal AdS. We showed that it is the same as vacuum character of a CFT with an extended symmetry group with a lie algebra called \( W_\infty \). The motivation for this was an earlier established fact that the classical Poisson bracket algebra followed by the generators of the higher spin symmetries which can change the boundary configurations is a W algebra. In this context our work took this matching to the next level where we checked that the spectrum of fluctuations of fields on the AdS side matches with the spectrum of operators corresponding to this sector in the CFT side.

In the second work in this thesis we wrote down the most general action of a parity violating, gauge invariant and 3 derivative action for higher spin theories at the quadratic level. We called this the Topologically Massive Higher Spin Gravity or TMHSG. We found out that a good basis for solutions to the equations of motion at arbitrary point in parameter space consists of three branches called 1) The left moving mode 2) The right moving mode and 3) The massive mode. We showed that the energies of all three of these modes are never non-negative together except at a particular point in parameter space called the chiral point. But we showed that the basis of solution also becomes degenerate at this point as the left moving branch merges with the massive branch. We found out that at this special point there is a new branch of solution called the “log branch” and hence we find a new complete basis of solution...
at this point. Energy calculation though showed that even at this “chiral point” there are negative energy modes with this new complete basis of solution. So, it looks like that the theory has a genuine linear instability at all points in phase space.

In the third work we studied the phase structure of a higher spin system in $\text{AdS}_3$ with a maximal spin 3 in the canonical approach. There are two types of classical solution in the euclidean system at a finite temperature which has the topology of a torus. This depends on the identification of the contractible cycle of the torus. If the contractible cycle is time like we have a “black hole” like solution and if the contractible cycle is spatial we have a “thermal AdS” type solution. We found out all possible solution of either type and studied their phase structure. We found out 2 types of solutions for contractible spatial cycle and we called them “Thermal AdS” like solution and “Extremal thermal AdS” like solution. Similarly we found out 4 types of solutions for the solution with contractible time cycle. Out of these we discard 2 solutions because they have negative entropy and hence are unphysical. Of the remaining 2 solutions we get a BTZ black hole like solution and an extremal black hole like solution. We found a Hawking-Page like transition between the black hole like and thermal AdS like solutions at a temperature dependent upon chemical potential for spin 3. We find that all the black hole like and thermal AdS like solution do not exist beyond a certain value of temperature for a particular chemical potential and the region of existence of thermal AdS like solution is greater than that of black hole solution. So, we see the presence of a new type of phase transition here where after a particular temperature only the thermal AdS like solution is present. We also studied how by a similarity transformation the field content of this theory can be converted to that of a theory with spectrum containing fields of spin 1, 2 and $\frac{3}{2}$ with a chemical potential for spin $\frac{3}{2}$. Here the black hole solutions exist for all temperatures. Here also, we have 4 branches of solution out of which 2 have negative entropy and hence are discarded. We were able to show that the solutions which were discarded in the earlier case map to the good solutions here and vice versa. Also, we showed that solutions here have a good scaling behaviour at
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very high temperatures and hence this may well be the way the phase structure of the system should be studied at very high temperature.