**Research Networking Programmes**

## Short Visit Grant ☐ or Exchange Visit Grant ☑

*(please tick the relevant box)*

## Scientific Report

**The scientific report (WORD or PDF file – maximum of eight A4 pages) should be submitted online within one month of the event. It will be published on the ESF website.**

***Proposal Title:*** **Entropy from Holography of Flat Space**

***Application Reference N°:*** **5106**

1) **Purpose of the visit:**

To carry out the research project in collaboration with the host Prof. Stephane Detournay and intense interactive discussions with other scientists in the “Service de Physique Mathématique des Interactions Fondamentales" at the Université Libre de Bruxelles (ULB), Belgium. The period of the visit, as supported by the HoloGrav network of European Science Foundation was for 5 weeks, starting from 25th May, 2015.

2) **Description of the work carried out during the visit:**

The work carried out was one of the rare attempts towards realizing the concept of holography in asymptotically flat space-time in 4 dimensions. As a primary step, we investigated the boundary dynamics, which is expected to be concretely manifested by a quantum field theory (QFT). Now ‘boundary’ of an asymptotically flat space-time is composed of three components: two null and a space-like sub-manifold. The asymptotic symmetry group of the future (and past) null component (a null 3-manifold) is governed by the famous BMS group. This group is a semi-direct product of Lorentz group and infinite number of supertranslation generators. In the small number of earlier attempts made in order to study the QFTs on future null infinity, this group, which is globally defined on the null infinity, has played a very important role. However, a much more enhanced asymptotic symmetry is there as discovered by Glenn Barnich and collaborators. This replaces the finite Lorentz group by the conformal group in two dimensions, at least at the level of its Lie algebra.

Representation theory of the BMS group in three dimensions are successfully captured by induced representations, as this has a semi-direct product structure with one 'semi-factor' being Abelian. However the extended BMS group in four dimensions is actually a semi-group and becomes or a semi-groupoid depending upon central extensions. The analysis of induced representation for this structure is much more challenging. We have been greatly benefited by discussion with Blagoje Oblak.

But we found an alternative route of tackling the problem of flat space holography head-on by constructing a highest weight representation of the extended symmetry, through its Lie algebra. The assumption we make here is that the field content of a QFT on the future null infinity should arrange itself in this representation. The peculiar structure of the algebra does not allow definite weight for any of the supertranslation modes. However holomorphic and anti-holomorphic weights are assigned to the Virasoro modes as done in 2 dimensional conformal field theory. Although similar highest weight states label the modes, the representation is completely different than the Verma module one constructs in Virasoro representations. We calculated the degeneracy at each level. The analytic values of these degeneracies at each 'level' are much more than that of Virasoro and is analytically given by a complicated function of integer partitions. We also carried out the null state analysis to some extent, up to level 2. A more rigorous analysis is going on in this direction.

## 3) Description of the main results obtained

We have constructed the degeneracy of the states in the theory and found a combinatoric formula for it. However we are yet to construct the closed analytic form of a generating function for that, which can be interpreted as a character formula corresponding to the representation.

Moreover we have derived correlation functions of fields having definite weights. A construction similar to the conformal Ward identity is also being pursued. This is a significant improvement in comparison to existing results, where only scalar operators were constructed, using the global part of the BMS group.

Apart from this, I have completed another work completely during the period of the visit. This work is on quantum gravity on 3d de Sitter background in presence of higher spin fluctuations. The main result obtained in this analysis is that, when all possible classical saddles are taken into consideration, the 1-loop partition converges for spins greater than three. This is a significant improvement over the previously known result that pure Einstein gravity has diverging partition function on de Sitter background.

## 4) Future collaboration with host institution (if applicable)

The amount of work that's already been done for the proposed project is a self consistent set of results and we hope would surely lead to an advancement towards the understanding of flat-holography in general. However as outlined above, there are many open problems that have been generated by our studies. This of course indicates that I will have future collaboration with the host and other people in the institution. The next immediate sub-project we aim to is using the spectrum of the asymptotic symmetry, that we have derived, in describing black-hole micro-states in the bulk. This would lead to an understanding of entropy of black-holes which have flat asymptotics.

5) **Projected publications / articles resulting or to result from the grant *(ESF must be acknowledged in publications resulting from the grantee's work in relation with the grant)***

As is evident from the discussion above, the works done on asymptotic symmetries of flat spaces during the visit are definitely going to be presented as a publication. The next immediate project that is concerned with our impending work, on finding black hole microstates, is heavily based on the present work done. That work when completed will result in to at least another publication.

Moreover the work on 3d de Sitter quantum gravity, that was mentioned above is soon to be communicated for publication.

6) **Other comments (if any)**

This is related to the grant. Initially the sanctioned grant of Eur 2500 was divided in to two parts: Euro 2000 for period of 4 weeks' stay and Euro 500 for travel. I was paid a sum of Euro 1600 in advance. However I later requested to augment my stay period by another week, making it 5 weeks' stay in lieu of the travel expense, which was also approved through email. I would request the appropriate personnel or the committee to consider the extension by one week in exchange of travel expense, as mentioned above, while releasing the rest of the grant of Euro 900. Thank you. I gratefully acknowledge the support by ESF through the HoloGrav grant, which helped in making the present collaborative work fruitful.