EUROPEAN SCIENCE FOUNDATION
SETTING SCIENCE AGENDAS FOR EUROPE

Exploratory Workshop Scheme

Standing Committee for Physical and Engineering Sciences (PESC)

ESF Exploratory Workshop on

GRAVITY AS THERMODYNAMICS
Towards the microscopic origin of geometry

Trieste (Italy), 5-8 September 2011

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SCIENTIFIC REPORT

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1. Executive summary

- Venue: The workshop took place at the International School of Advanced Studies (SISSA/ISAS) in Trieste (Italy). It started the 5th of September and ended the 8th. The talks and the discussion sessions took place in the big meeting room of the institute (see the attached program for more details on the timetable). The workshop covered all the four days, from 9:30 to the late afternoon, due to the vast amount of time devoted to the discussion sessions.

- Participants: besides the three convenors and the other four members of the organizing committee there were 25 participants, for a total of 32 registered participants. Due to the choice of the venue, several members of the institute joined the audience in various moments, senior staff and postdoc researchers of SISSA, especially (but not only) from the high energy physics sector.

- As explained in details in section 5, of the 32 total participants, 25 are affiliated to institutions in Europe, while 7 are coming from outside the Union. If we do not count the local organizing committee, there is no nation that is obviously overrepresented, both in terms of nationality and of affiliation. This testifies the international level of the meeting.

- Schedule: The spirit of the workshop was to provide a common ground on which researchers (coming from rather different areas of theoretical physics) could confront among themselves on the selected theme of the workshop, that is the thermodynamical nature of the gravitational interaction, in all its various aspects, from the classical foundations to the speculations about its quantum gravity origins.

- The workshop has been organized to include a relatively small number of speakers, in order to provide enough time for the talks to cover all the relevant ideas coming from the various approaches and hence to successfully establish a common background on which to develop the discussions. The schedule allowed for plenty of time for questions on the talks and further discussions. This contributed to make the atmosphere relaxed but nonetheless very productive in terms of debates and exchanges of ideas. The time devoted to questions and further discussions grew beyond the originally planned schedule, leading to four full days of activity.

- Scientific content. The program of the workshop was organized in such a way to group together presentations about affine topics as much as possible, to have a common thread for each session and make the evolution of the discussion more coherent. We had roughly six full sessions, plus two afternoons mostly devoted to organized discussions. The six threads were (apart from last minute changes): foundations, string theory and the gravity/ fluid correspondence, perspectives from quantum information and spin systems, the renormalization group approach, discrete and analogue models and the causal set approach.

- The talks provided the basic notions and key ideas, often interdisciplinary, which were needed on one hand to cover the existing body of knowledge, even in terms of critical perspectives, while on the other hand setting the stage for the true debate and the attack of the main subject of the workshop. We refer to the scientific report for a more detailed account of the scientific content.

- Discussion sessions: During the entire duration of the workshop there have been several discussion sessions. They were devoted to the clarification (and often to further elaboration) of some of the points raised during the talks, as well as the discussion of the main topics of the workshops, in order to lead to concrete advances and not to just the overview of the various perspectives. This has been the subject of the last discussion session, in which it has directly addressed the issue of what should be the next step to be done within the community.

- Due to the intrinsic interdisciplinary nature of the subject and to the variety of points of view of the participants, the discussions have always been interesting and animated, giving the opportunity to confront different perspectives on the nature of the thermodynamical behavior of general relativity, its relation to various microscopic models and theories for quantum gravity, the critical issues that have to be addressed as well as specific signatures and key clues that might lead to a more deep understanding of the nature of spacetime and its dynamics. Given the informal environment, a large part of the audience was actively involved in the discussions that have continued even beyond the time allocated in the schedule.

- Results: We believe that the workshop has accomplished the tasks for which it was originally conceived, in some cases beyond the expectations. We summarize them here. At the scientific level, a number of basic problems to be addressed by the community have been identified. In particular, the necessity for the development of a suitable phenomenological platform has emerged as a priority for short term plans. The formulation of phenomenological models encoding in an effective way some of the features expected to characterize the microscopic theory of spacetime on large scale is required to put constraints on these ideas, thus helping the theoretical investigation in providing a concrete guide for the development of models. This would represent a considerable expansion of the body of work presently known as quantum gravity phenomenology, in an attempt to go beyond the mere investigation of Lorentz violation effects. The ideal candidate phenomena to be considered are nonlocality and the deformation of fundamental symmetries. The exchange of opinions following the discussions have lead to the strengthening of existing collaborations as well as the establishment of new ones, between researchers working in different disciplines. Collaborative projects have been initiated, while future activities have been planned (see the proposal for a follow-up activity already submitted to the ESF). For additional details we refer to the section of assessment of the results.

2. Scientific content of the event

In this section we provide a detailed summary of each talk and of the main points raised during question time and discussion sessions.

DAY 1 - 5th of September 2011

Talk 1 (Monday 10 am)
Speaker: T. Jacobson (Title: *Horizon entropy and higher curvature equation of state*)
Summary: Introduction to the general concept of general relativity derived from thermodynamics. Followed by an up-to-date discussion of some of the open questions arising from such an approach.

Discussion: Amongst several questions, the issue has been raised if such an approach, starting from a flat spacetime, without involving any dynamics at that level, can be compatible with any full quantum gravity gravity theory possibly underlying this approach. This question could not be answered, but the hope is that the two notions of entropy, the one from the actual dynamics, and the one derived from the Rindler horizon will be able to co-exist or even turn out to be equal.

Talk 2 (Monday 11.20 am)

Speaker: T. Padmanabhan (Title: *Gravity as an emergent phenomenon: status and prospects*)

Summary: Emergent aspects of higher derivative gravity theories were discussed. In particular, it was shown that the models discussed naturally reduce to thermodynamic and fluid dynamic entities at the black hole horizon.

Discussion: One question was to ask if it necessary to know the full microscopic substructure, i.e. the full underlying quantum gravity theory, in order to establish the connection between gravity and thermodynamics. Again, the question could not be answered, and to some extend it should be possible to neglect possible dissipative effects originated by the micro-physics.

Talk 3 (Monday 3 pm)

Speaker: Jan de Boer (Title: *Black Holes: Lessons from AdS/CFT*)

Summary: Based on the AdS/CFT duality, which states that string theory on asymptotically AdS spacetimes is exactly identical to some unitary, conformal, quantum field theory (in one dimension less), it was argued that a unitary theory of black holes can be achieved only within a theory of quantum gravity that includes matter degrees of freedom.

Discussion: Postponed to general discussion at the end of the day.

Talk 4 (Monday 3.30 pm)

Speaker: Matt Visser (Title: *Conservative entropic forces*)

Summary: A new derivation for gravity as an entropic force has been presented. Within this approach it is possible to constrain Verlinde's model (titled *Gravity as an entropic force*). Implementing Verlinde's idea into this new approach a particle dependent notion of temperature follows. However, the standard notion of entropic force really only has room for a single temperature to be assigned to the whole thermodynamic system. Similar arguments will lead to the notion of multiple notions of entropy.

Discussion: The notion of negative entropy where discussed, which for example appear close to phase-transitions.

Talk 5 (Monday 4.40 pm)

Speaker: Sera Cremonini (Title: *Lessons from holography: probing universality*)

Summary: AdS/CFT is a powerful tool to study fluid dynamical properties of strongly coupled field theories. Given the exotic nature of AdS/CFT systems, it is important to find universities. The possible lessons from looking at universities are discussed.

Discussion: Where does the fact that the ratio eta/s doesn't flow come from? (Flow, in the sense of Wilson.) Some technical and physical details of the derivations were discussed.

Discussion session 1 (Monday 6 pm)

The following questions were discussed:

- Questions for Jan de Boer:

  The duality does not capture non-black hole configurations, such as high entropic initial data, that do not form a black hole. This implies that the duality cannot capture a very large class of systems, which seems worrisome. The answer was more or less that the speaker does not agree with the statement that the duality would not be able to capture those situations. Comment: It is not clear if the field theory at the boundary captures the physics of the black hole beyond the horizon, which is an important aspect to answer this question.

- Question on entropic force and notion on temperature:

  The temperature is dependent on the particular configuration of the N-particles. The question is if that corresponds to a non-equilibrium situation. The opinions are divided, some are they are, and some argue they are not. This led to a general discussion on the Verline approach. The general confusion was as to the basic assumptions made by Verlinde.

- Question for Ted Jacobson:

  Can Lorentz violations be incorporated in the Einstein equation of state approach? The answer is more or less that one first has to derive the thermodynamic laws for just a Lorentz violating gravity theory, for example Horava-Lifshitz gravity. However, nobody seems to have successfully looked into this problem. This started a long discussion about the role of a background structure, and diffemorphism invariance.

- Question for Ted Jacobson:

  Does one still have a Rindler-wedge in Einstein-Aether? The answer is that the extra Aether field destroys the boost-invariance, necessary for the Rindler-wedge. This was followed by a more general and critical discussion about emergent gravity.

DAY 2 - 6th of September 2011

Talk 1 (Tuesday 9 am)

Speaker: Yaron Oz (Title: *Gravity and hydrodynamics*)

Summary: The relations between gravity, i.e. general relativity, and fluid dynamics were discussed in details. Furthermore, it was stressed that relativistic hydrodynamics, as a relativistic description of fluid dynamics, is naturally related to general relativity. Beyond that it was stated that also non-relativistic fluid dynamics is related to general relativity. The framework used to demonstrate these relations is the gravity dual description, which was discussed in detail. The two main problems in the dual gravity description are presented. Most flows in nature are turbulent, the Reynolds number is very large. However, the duality cannot be used to look into turbulence. Furthermore, the singularities in hydrodynamics and cosmic censorship were briefly mentioned, but the speaker run out of time to discuss its role in the duality description.

Discussion: The questions were postponed to the discussion session before lunch.

Talk 2 (Tuesday 10 am)

Speaker: Markopoulou (Title: *Effective geometries in spin systems*)

Summary: Recent results of Quantum Graphity were discussed. First the general motivation for quantum graphity was discussed briefly. The question quantum graphity is investigating is: What is the toy model for quantum gravity which is equivalent to the Ising model for statistical mechanics? In particular, the interplay between matter and geometry was discussed. First, it was shown how it could be possible to obtain some notion of light-cone in

a truly embedded graph. Highly connected regions in the graph can act like a trapping region as it is defined in terms of Lorentzian geometry. It was shown that in a particular class of foliated (onion-like) graphs matter can be trapped in the highly connected region, which in this sense could correspond to a black hole configuration. Taking the hydrodynamic limit seems to connect quantum graphity to the analogue gravity program, that is an emergent relativistic wave equation.
Discussion: Mainly the problem of the interchanging notion of dimensions and locality was pointed out. Furthermore, it was pointed out that one would expect Lorentz symmetry breaking effects for different particles, as different matter fields are described by different Hamiltonian.

Discussion session 1 (Tuesday 10.45 am)
The following items were discussed:
- Question for Yaron Oz:
  The interplay between the "physics" in the bulk and the boundary was discussed.
- Some questions concerning the technical points of the emergent analogue gravity/model.

Talk 3 (Tuesday 11:40 am)
Speaker: Annalisa Marzuoli (Title: *Spin networks: from quantum topology to quantum computing and back*)
Summary: First, topological quantum computation was briefly discussed. Within topological quantum computation it is possible to set up decoherence-free and fault-tolerant quantum computational frameworks. A particular theoretical framework is discussed in detail. Furthermore, Anyonic computation was introduced. Finally, the relations to quantum gravity models in terms of techniques and concepts were elucidated.
Discussion: The applicability of topological quantum computation (t.q.c.) was discussed. The speaker was stressing that t.q.c. can in principle solve any computational problem. However, there are problems of effectiveness of the t.q.c. is not so clear. Also, in order to solve a problem using t.q.c. one needs to convert the problem in the language of t.q.c., and the speaker was briefly outlining how this works.

Discussion session 2
The following items were discussed:
- Question for Markopoulou:
  What about the cosmological constant problem - are there any lessons to be learnt from quantum graphity.

Talk 4 (Tuesday 2:30 pm)
Speaker: Ruth Williams (Title: *Introduction to Quantum Regge Calculus*)
Summary: General introduction to the underlying idea of how to discretize geometry was presented. In detailed it was lined out how to solve the Wheeler-DeWitt equation within the Regge Calculus. Besides that various other approaches that fall under wider framework of Regge Calculus were discusses, such as Ponzano-Regge Calculus. Briefly mentioned were are also more recent models such as canonical simplicial gravity, and recent results in Quantum Regge Calculus.
Discussion: The question was raised as to what extend the Regge Calculus is a quantum gravity approach, as all that has been done is to evaluate a partition function/path integral. The general reply focussed on the fact that the path integral formalism with the 1/hbar is a truly quantum approach. Furthermore, that one can calculate transition amplitudes. Besides that, the question was raised concerning about the difference between Lorentzian versus

Euclidean dynamical triangulation, which will be discussed in the next presentation.

Talk 5 (Tuesday 3:20 pm)
Speaker: Dario Benedetti (Title: *Quantum gravity and critical phenomena*)
Summary: Brief introduction to Wilson's RG and continuum limit and how this could be applied to quantum gravity. Furthermore, a specific discreet quantum quantum approach was discussed, i.e. causal dynamical triangulation. In detail almost all aspects of CDT were covered.
Discussion: A general question concerning the analogy between Lifshitz points and Horava-Lifshitz gravity were asked. Euclidean versus Lorentzian: The fact that in CDT one cuts out a big part of the configuration space should be worrisome. However, it turns out that some recent simulations with Lorentzian signatures seem to produce similar results.

Talk 6 (Tuesday 4:30 pm)
Speaker: Daniel Litim (Title: *Black hole thermodynamics and the renormalisation group*)
Summary: It was suggested to take the metric field serious as the fundamental force at all scales, then moving on to thermodynamic aspects. In particular, the program of asymptotic safety was promoted, the idea of having an IR and UV fixed-point. The issue of relevant and irrelevant operators has been discussed. In particular, in various RG flow results, e.g. f(R) and higher derivative gravity. This was followed by a discussion of black hole thermodynamics. After a brief introduction, a scale dependent effective action for gravity was presented, which represents a family of Kerr-Newman BH solutions. Then apply some particular coarse-graining "not too coarse- and not to fine-grained". Then the speaker run out of time, but there seem to be some predictions, extensions and challenges in terms of black hole thermodynamics arising from such an approach.
Discussion: What happens to the dimension full gravitational coupling constant G(mu)? The answer was that G(mu)/G would run from 1 for mu/mu_Plank=0 to zero for mu>>mu_Planck.
What about the predictions briefly mentioned at the end of the talk, e.g. a mim. black hole size? The theory presented predicts a smallest black hole, once that mass is reached the horizon would disappear. Naked singularities might not be present due to the running of the gravitational coupling constant.

Discussion session 3
Since the session was severely overtime, the discussion session 3 was merged with the questions from the preceding talk (see above).

DAY 3 - 7th of September 2011

Talk 1 (Wednesday 9.30 am)
Speaker: Bianca Dittrich (Title: *Towards the many particle regime of quantum gravity models: baby spin foams and nets*)
Summary: First, the spin foam construction principle in 3d was introduced, and the role of BF theory (first order action in 3d) within the spin foam approach. It was shown that gravity can be formulated as gauge theory, a lattice gauge theory. It was explained that Baby spin foams are working with a finite group considering a general class of projectors, while baby spin networks are a simplification/dimension reduction of spin foam models. A simple example for a baby spin network is the Ising model. It was discussed that those models have a complex action. It was pointed out that in the models presented by choice translational symmetry is broken ad-hoc. Finally, it was shown how to apply coarse graining for cut-off models to this model (real space renormalization). There are two phases / fix-points: A zero temperature

(flat space), or infinite temperature phase. The results for 3d lattice gauge theory, presenting 3d gravity, were presented. Depending on the cut-off and other parameters, there is a flow to the LTF, or HTF. In 4d lattice gauge / 2d edge models besides a LTF and HTF, there are also nontrivial non stable (quasi) fixed points. These areas might be of interest, as they might correspond to second order phase transitions. Furthermore, the models can be written in terms of a tensor network representation. This should connect to Wen's tensor-network models. Outlook: Spin foam or spin network models are takable, there is a way to coarse grain, but there are various way to do that. This needs further investigation. Furthermore, it would be desirable to apply the methods presented to non-Ablian spinfoam.
Discussion: The question was raised concerning unitary evolution. The reply was that unitarity aspects were not at all taken into account.

Talk 2 (Wednesday 10.30 am)
Speaker: Francois David (Title: *A few remarks about causality and reversibility in quantum theory (and quantum gravity?)*)
Summary: A slightly non-standard point of view on the principles of quantum mechanics is presented, focussing on causality, reversibility and locality & separability. Discussion: Postponed.

Talk 3 (Wednesday 11.45 am)
Speaker: Serena Fagnocchi (Title: *Gravity, cold atoms and analogue models: from theory to experiment (from kinematics to thermodynamics?)*)
Summary: Starting with an introduction of Analogue Models of gravity. Deriving the relativistic wave-equation twice, for fluids and BEC superfluids. The talking about various aspects of detection mechanism, moving on to the simulation results. Followed by a collection of other experimental approaches, which were commented on. Concluding that there are many ongoing experiments in the field. Finishing off, with some thoughts on black hole thermodynamics.
Discussion: The dimensionality of the BEC analogue geometry was discussed, and various other aspects of the dynamical Casimir effect was discussed. The question was raised if experimental groups are really interested in the subject in setting up experimental black hole evaporation in BECs. The answer is that there is a growing interest in the subject, however there is still a bit of resemblance on working on this issues.

Discussion session 1
The following items were discussed:
- Question for Bianca Dittrich:
  The various phases arising from the different scaling approaches were discussed.
- Question for Bianca Dittrich on a comment by Rafael Sorkin:
  This is concerning the thermodynamic limit, and how this could lead to diffemorphism invariance. It was argued in both ways, however this remains an open question.

Talk 4 (Wednesday 2.30 pm)
Speaker: Steve Carlip (Title: *Pitfalls for emergent gravity: an outsider view*)
Summary: Emergent gravity as a general framework was discussed by reviewing several different approaches, from quantum gravity to causet. It was suggested that quantum spacetime does not need to be considered at the basis of the classical space-time, instead could be viewed as a tool to identify the fundamental degrees of freedom, which one expect to be different from the ones involved in the classical description.
Discussion: Merged with general discussion session.

Discussion session 1

It was suggested that the fundamental queries emergent theory must address are the following:

(i) Lorentz symmetry

- Question for Steve Carlip:

  In which sense is the Donoghue paper relevant (by Liberati)? What about using the large N limit to make the RG running fast into the fixed point (by Jacobson)?

(ii) The presence of a metric

- Fay Dowker noted that there exist examples where a notion of Lorentz invariance can be defined directly in terms of discrete structures, without using a metric.

(iii) What about the equivalence principle

- David commented on the sense of universality of the gravitational coupling with matter in general: Universality: is the emergent space-time, rather than matter, which sets the universality?

(i) Emergent gravity should explain why we get general relativity at larger scale?

- Diffeomorphism invariance: coordinate independence, no fixed (non-dynamical) background structure dynamics in the pre-emergent structure? Sorkin commented that it is not necessarily true that a dynamic pre-emergent structure should have a preferred time. Oriti commented that in fact matrix models and other examples of emergence work without pre-emergent spacetime structure. David replied that that is not so clear to him.
- There are some misleading emergent gravity approaches when it comes to diffeomorphism invariance, such as Horava-Lifshitz gravity, which can indeed be written down in a diffeomorphism invariant manner, but still breaks Lorentz invariance.
- In diffeomorphism invariant theories there is a set of constraints, but how does one get these constraints? Markopoulou mentioned that gauge invariance can be assumed and emergence can be limited to some constraints of the theory.

(i) Where does the emergent theory live?

- The problem is that every structure with a possible dynamics is not justified. Jacobson commented that this might be too radical a statement. mentioned that maybe we don't want to obtain general relativity, instead a generalized gravity theory is emergent. Padmanabhan commented, that maybe the metric and spacetime are not emergent, but dynamics is.

DAY 4 - 8th of September 2011

Talk 1 (Thursday 9.40 am)

Speaker: Rafael Sorkin (Title: *A quantum field theory with a covariant cut off in which black hole radiance could be studied*)

Summary: The connection between entropy and gravity was motivated. The objective of the presentation was to present the quantum field theory of a real scalar field on a causal set. The way to obtain a continuum field theory is to study retarded Green functions. It was demonstrated how to obtain a quantum field theory of a free scalar field from a causal set. General aspects of the Green's functions were discussed. Followed by a list of open

questions.
Discussion: It was asked what kind of state is picked out/is special? The answer is that in general one would need to look at the continuum field theory. Followed by a discussion on various configuration, the so-called diamond construction, which would be flat inside, but shows big deviation from flat spacetime on the boundary.
What if one puts a Klein-Gordon equation onto a spacetime lattice, and the outcome is that one obtains superluminal dispersion relations - does something similar happen in the case of defining a quantum field theory on a set? The answer is that the Poisson sprinkling is a necessary ingredient, and that causal set is predicting Lorentz symmetry.

Talk 2 (Thursday 10.35 am)
Speaker: Helen Fay Dowker (Title: *Entropy of causal horizons from Causal Sets*)
Summary: A proposal for a microscopic account of horizon entropy was put forward. The approach is based on two other studies. (1) Black hole thermodynamics is due to the causal nature of the horizon; all causal horizons obey the laws of thermodynamics. (2) Without a physical cutoff the entropy of a black hole would be infinite; the finite physical value of the black hole entropy tells us the cutoff scale. Furthermore, any (causal) Lorentzian spacetime can modeled by nothing more than a causal set. A general introduction to the concept of how to set up a causal set. It was explained how a causal set is changing when going from flat spacetime to a spacetime with a horizon, which is that there are ensemble of elements in the set which are not connected with each other. The 2D and 4D causal set action was presented. It was discussed as how from such an action the Einstein action could emerge. Furthermore, it was pointed out that the causal set action is non-local. Finally, it was explained how one can calculate the horizon, such that only elements of the sets that are close to the horizon are contributing, indicating the role of the area by calculating the black hole entropy. Although the outcome is promising, by looking for all causal horizons in the limit of large horizon area, it is not conclusive.
Discussion: It was asked if causal sets also works for closed time-like loops. The answer was no, one has to prohibit those. It has been noticed that this implies that it will not be possible to reproduce the full Kerr solution.
It was asked as how to derive (or understand) the action for the causal sets. The speaker presented some more slides on the subject.

Talk 3 (Thursday 11.45 am)
Speaker: Renaud Parentani (Title: *Structure of the WDW (Wheeler-De Witt) equation: Diffeomorphism invariance and emergence of probabilities in Quantum Cosmology*)
Summary: It was pointed out that there is a probabilistic interpretation of the solutions of the Schroedinger equation but there is no consensus on the interpretation of the solution of the WDW equation. First, it was compared (mathem.) the structure of the Schroedinger equation to that of the WDW equation. How can one solve perturbatively the WDW equation - calculate transition amplitudes. It was stressed that transition amplitudes are governed by frequency rations and not by coupling constants (called Non-Adiabatic Transition Amplitudes NATA). The key idea is to not only taking one direction of expansion into account. One has to consider expanding and contracting solutions, which allows us to talk about probability interpretation. However, although experimentally suppressed there is a probability for the universe to suddenly change its direction of expansion. Concluding that statistical interpretation of the NATA is not a fundamental property, but should be conceived as an emergent property of QC.
Discussion: Some issues of the final interpretation are discussed.

Talk 4 (Thursday 2.45 pm)
Speaker: Bei-Lok Hu
Title: *Gravity and Theremodynamics: What exactly do we want?*
Summary: First, the difference between Emergent Gravity (macroscopic structure of spacetime emerges/evolve from micro structures) and Quantum Gravity (induce micro structures from Macro) was discussed. In particular, 1-5 levels of emergence are discussed. The various levels are discussed in detail. The second part of the talk discussed the possibility of a "Black Hole Atom".

Discussion session 1
The following items were discussed:

- Question for Fay Dowker: Is there a continuum description of the non-local Causal Sets d'Alembertian? The answer is yes, there is.
- Question for Fay Dowker: Given that Causal Sets does not break LI, any action will give you the same the results? The answer is no, because Causal Set Theory is highly non-local, and only the one action kind of gets rid of the non-locality.
- Question for the audience: What is the necessary ingredient to get emergent gravity? Answer, in order to circumvent the Weinberg-Witten theorem, one should work with a non-local or Lorentz violating theory. Another question is can we have gravity without the graviton?
- General question: What about the interplay between unitarity and non-locality?
- General question: What about other aspects of the background structure of geometry? - In some quantum gravity candidates spacetime dimension is a dynamical structure as well. The general agreement is that it is very unlikely to obtain the signature of spacetime dynamically.
- Question for Renaud Parentani: The question was what about the regime when the probability has not yet emerged? The answer was that the whole question of probability is meaningless and only emerges approximately at some limit. It was stressed that unitarity evolution for the Wheeler deWitt equation does not apply.
- General discussion about holography.
- Question for Steve Carlip: Why do we need an action at the fundamental level and what is the implication for AdS/CFT?

3. Assessment of the results, contribution to the future direction of the field, outcome

The first outcome of the workshop was the establishment of an active, if small, community of researchers with a shared interest in a new perspective on quantum spacetime. This new perspective is based on the three main ideas:

1. that the fundamental description of spacetime will not result from the naive quantization of classical General Relativity, and that on the contrary General Relativity could be understood as an effective hydrodynamic or thermodynamic description of fundamental, non-geometric and non-gravitational building blocks of quantum spacetime;

2. that the step from fundamental constituents to macroscopic description will require techniques and ideas from statistical physics and condensed matter theory;

3. that it is crucial, before a complete characterization of the fundamental degrees of freedom and of their collective, macroscopic behaviour is obtained, to identify some key signatures of them that could be amenable to an approximate description and would result in new phenomenology.

This community, which includes (but is not limited to) the participants to the workshop, comprises researchers working in different areas and it is therefore by nature multi-disciplinary.

This is to be expected given the variety of issues involved in the construction of a complete description of structure and dynamics of quantum spacetime. The community that met at the workshop comprises researchers working on various approaches to quantum gravity (string theory, loop quantum gravity, group field theory, discrete gravity, asymptotic safety etc) , scientists studying the thermodynamic aspects of gravitational theories, experts in condensed matter and statistical physics, researchers dealing with analogue gravity models and with quantum gravity phenomenology. This community now plans to meet on a more regular basis, possibly with similar workshops to be organized on an annual or bi-annual basis, to start joint research projects, and the idea was also put forward to apply for networking programmes funded by ESF, by FQXi and by other agencies.

At the scientific level, the main results achieved are the following:

1. similarities have been identified between seemingly different quantum gravity approaches, both in terms of mathematical structures used, and of tools that have to be applied to study the emergence of continuum spacetime from the discrete building blocks proposed by such approaches;

2. the role of renormalization group, coarse graining and statistical methods in various quantum gravity approaches has been clarified, and some more specific applications have been singled out;

3. two key aspects of this emergence process have been singled out as potentially interesting for effective quantum gravity phenomenology based on them: non-locality effects and deformation/breaking of spacetime symmetries at high energies;

4. a new line of attack to issues like the cosmological constant problem (dark energy), the role of unitarity in quantum field theory and the role and limitations of probabilistic interpretation in quantum gravity, is suggested by the emergent spacetime scenario;

5. the limitation of a purely macroscopic, effective description of gravitational phenomena has been clarified, as well as the inputs that a microscopic theory of spacetime structures has to provide.

6. the critical issues that the emergent spacetime idea has to address to be considered viable (specifically, the emergence of effective quantum field theories) have been singled out in clear terms.

All the above topics are now the subject of research projects being carried out by participants to the workshop and of collaborations that have been initiated among them. These results have a considerable impact on several current research directions in the field of quantum gravity, as they inform and guide, and at the same time inspire them.

To further support research in these directions, several participants expressed the intention to apply for research grants at both the national and international (e.g. ERC) level, and to try to establish additional links to the existent network of researchers working on them.

4. Final programme

FINAL PROGRAMME

Sunday 4th September 2011

Afternoon	*Arrival*

Monday 5th September 2011

08.30-10.00	**Registration**
10.00-10.10	**Welcome by Convenor** **Stefano Liberati** (SISSA, Trieste, Italy)
09.30-12:30	**Morning Session**
10.10-10.50	**Horizon entropy and higher curvature equations of state** **Ted Jacobson** (University of Maryland, , USA)
10.50-11.20	*Coffee / Tea Break*
11.20-12.00	**Gravity as an emergent phenomenon: status and prospects** **Thanu Padmanabhan** (IUCAA, Pune, India)
12.00-12.30	**Discussion**
12.30-13.45	*Lunch*
13.45-14.00	**Presentation of the European Science Foundation (ESF)** **Sauro Succi** Standing Committee for Physical and Engineering Sciences (PESC)
14.00-18:30	**Afternoon Session**
14.00-14.40	**Black holes - some lessons from AdS/CFT** **Jan de Boer** (University of Amsterdam, Amsterdam, Netherlands)
14.40-15.20	**Conservative entropic forces** **Matt Visser** (Victoria University, Wellington, New Zealand)
15.20-15.50	*Coffee / tea break*
15.50-16.30	**Lessons from holography: probing universality** **Sera Cremonini** (DAMPT, Cambridge University, Cambridge, United Kingdom)
16.30-18.30	**Discussion**

Tuesday 6th September 2011

09.30-12:30	**Morning Session**
09.30-10.10	**Gravity and hydrodynamics** **Yaron Oz** (University of Tel Aviv, Tel Aviv, Israel)
10.10-10.50	**Effective geometries in spin systems** **Fotini Markopoulou** (AEI, Golm, Germany)
10.50-11.20	*Coffee / Tea Break*
11.20-12.00	**Spin networks: from quantum topology to quantum computing and back** **Annalisa Marzuoli** (University of Pavia, Pavia, Italy)

12.00-12.30	**Discussion**
12.30-14.00	*Lunch*
14.00-18:30	**Afternoon Session**
14.00-14.40	**Introduction to quantum Regge calculus** **Ruth Williams** (DAMPT, Cambridge University, Cambridge, United Kingdom)
14.40-15.20	**Quantum gravity and critical phenomena** **Dario Benedetti** (AEI, Golm, Germany)
15.20-15.50	*Coffee / tea break*
15.50-16.30	**Black hole thermodynamics and the renormalisation group** **Daniel Litim** (Sussex University, Brighton, United Kingdom)
16.30-18.30	**Discussion**

Wednesday 7th September 2011

09.30-12:30	**Morning Session**
09.30-10.10	**Towards the many particle regime of quantum gravity models: baby spin foams and nets** **Bianca Dittrich** (AEI, Golm, Germany)
10.10-10.50	**Remarks about causality and reversibility in quantum theory (and quantum gravity?)** **Francois David** (SPHT, Saclay, France)
10.50-11.20	*Coffee / Tea Break*
11.20-12.00	**Gravity, cold atoms and analogue models** **Serena Fagnocchi** (University of Nottingham, Nottingham, United Kingdom)
12.00-12.30	**Discussion**
12.30-14.00	*Lunch*
14.00-18:30	**Afternoon Session**
14.00-14.40	**Pitfalls for emergent gravity: an outsider view** **Steve Carlip** (UC Davis, Davis, California,USA)
14.40-15.20	**Discussion**

Thursday 8th September 2011

09.30-12:30	**Morning Session**
09.30-10.10	**A quantum field theory with a covariant cutoff in which black hole radiance could be studied** **Rafael Sorkin** (Perimeter Institute, Waterloo, Ontario, Canada)
10.10-10.50	**Entropy of causal horizons from Causal Sets** **Fay Dowker** (Imperial College, London, United Kingdom)
10.50-11.20	*Coffee / Tea Break*
11.20-12.00	**Diffeomorphism invariance and emergence of probabilities in Quantum Cosmology** **Renaud Parentani** (LPT, University of Paris XI, Paris, France)
12.00-12.30	**Discussion**
12.30-14.00	*Lunch*
14.00-18:30	**Afternoon Session**
14.00-14.40	**Gravity and thermodynamics: What exactly do we want?** **Bei-Lok Hu** (University of Maryland, College Park, USA)

14.40-15.20	**Discussion**
15.20-15.50	*Coffee / tea break*
15.30-16.30	**Discussion on follow-up activities/networking/collaborations**
16.30	*End of Workshop*

5. Statistical information on participants

The registered participants consisted of 25 participants, four members of the organizing committee and the three convenors. Here we report the salient statistical data.

Age brackets		
25-35	12	(37.5%)
35-45	5	(15.7%)
45-55	6	(18.7%)
>55	9	(28.0%)
Gender balance		
Women	8	(25%)
Men	24	(75%)
Ratio W/M:	1:3	
Geographical distribution by nationality		
European Union	24	(75%)
Non EU	8	(25%)
EU participants		
Italy	12	
France	4	
Germany	3	
United Kingdom	2	
Greece	1	
Belgium	1	
The Netherlands	1	
Geographical distribution by affliliation		
EU	25	(78.1%)
Others	7	(21.9%)
Italy	8	(25%)
France	6	(18.7%)
Germany	5	(15.6%)
United Kingdom	5	(15.6%)
USA	3	(9.37%)
Canada	1	(3.1%)
India	1	(3.1%)
Israel	1	(3.1%)
The Netherlands	1	(3.1%)
New Zealand	1	(3.1%)

6. Final list of participants

Dario Benedetti (AEI, Golm, Germany)
Steve Carlip (UC Davis, USA)
Antonin Coutant (LPT, Universitè de Paris Sud, Orsay, France)
Sera Cremonini (DAMTP, Cambridge, United Kingdom)
Francois David (SPHT Saclay, France)
Jan de Boer (University of Amsterdam, The Netherlands)
Bianca Dittrich (AEI, Golm, Germany)
Christopher Eling (SISSA, Italy)
Serena Fagnocchi (University of Nottingham, United Kingdom)
Helen Fay Dowker (Imperial College, London, United Kingdom)
Bei-Lok Hu (University of Maryland, USA)
Ted Jacobson (University of Maryland, USA)
Marc Lachièze-Rey (APC, Université Paris 7, France)
Daniel Litim (University of Sussex, United Kingdom)
Fotini Markopoulou (AEI, Golm, Germany)
Annalisa Marzuoli (Università di Pavia, Italy)
Daniele Oriti (AEI, Golm, Germany) (co-convenor)
Yaron Oz (Tel Aviv University, Israel)
Thanu Padmanabhan (IUCAA, India)
Renaud Parentani (LPT, Universitè de Paris Sud, Orsay, France)
Matteo Smerlak (CPT, Marseille, France)
Lorenzo Sindoni (AEI, Golm, Germany) (co-convenor)
Rafael Sorkin (Perimeter Institute for Theoretical Physics, Waterloo, Ontario, Canada)
Simone Speziale (CPT, Marseille, France)
Sauro Succi (CNR, Roma, Italy)
Matt Visser (Victoria University of Wellington, New Zealand)
Ruth M Williams (DAMTP, Cambridge, United Kingdom)

Local Organizing Committee:
Goffredo Chirco (SISSA)
Eolo Di Casola (SISSA)
Stefano Finazzi (SISSA)
Stefano Liberati (SISSA)
Silke Weinfurtner (SISSA)