



Science Meeting – Scientific Report

Scientific report (one single document in WORD or PDF file) should be submitted online within two months of the event. It should not exceed seven A4 pages⁴.

Proposal Title: Noncommutative geometry and particle physics

Application Reference N°: 4631

1) Summary (up to one page)

One of the key applications of noncommutative geometry (NCG) is to particle physics. In 2007 Chamseddine, Connes and Marcolli introduced a noncommutative manifold that describes the Standard Model of elementary particles, very much in the spirit of Einstein's geometric description of gravity – in fact, even providing a unification of both. The above description is at the classical level, but physically relevant (in fact, falsifiable) results can be derived by a clever combination with (conventional) methods from renormalization theory (excluding gravity). This is a bottom-up approach to particle physics of the Standard Model, in fact waiting to go beyond.

Thus, in one direction the mathematical theory of noncommutative geometry has something to say about physics at particle colliders such as the LHC, but, probably more importantly, experimental results dictate the possible noncommutative models. **It is this type of cross-fertilization which was at action during the present workshop**, with the participants ranging from scientists working in noncommutative geometry and in particle physics phenomenology (PP), working eg. on quantum field theories Beyond the Standard Model. The issues that were discussed were noncommutative geometric particle physics models, their predictions for collider physics, and, of even greater importance, the recent findings in particle colliders (Higgs searches, supersymmetric particles, et cetera) and their implications for the noncommutative models.

The timing of the workshop was crucial, with the Large Hadron Collider at CERN unraveling much of physics beyond the Standard Model. This is applicable to both the mathematical field of noncommutative geometry and to particle physics phenomenology: new findings at, say, the LHC demand for new models in noncommutative geometry

and, vice versa, new predictions from models in NCG indicate new terrains to be explored in particle colliders.

2) Description of the scientific content of and discussions at the event (up to four pages)

The workshop brought together scientists working in noncommutative geometry and in particle physics. One of the questions addressed during the week was how experimental findings (e.g. in particle accelerators, but not exclusively) provide inspiration for noncommutative geometry, and vice versa, how noncommutative geometry can provide tools for phenomenological model-building.

The workshop consisted of morning lectures (crash courses) on topics in noncommutative geometry for particle physicists and vice versa on particle physics for noncommutative geometers. Also on Monday, an experimental update was given on dark matter, particle searches at the LHC, and the status of the Higgs-search, which already on the first day led to lively discussions. Here it became clear that noncommutative geometry and experiments in particle physics both take a *spectral point of view* in analyzing the fine-structure of spacetime and matter: in the first through the spectrum of a linear operator, in the second through the energy spectrum.

Besides more advanced seminars there was much discussion time during the workshop, in particular through the 'study groups'. In the latter, two topics were selected out of four by the participants: *Higgs vacuum stability* and *Lorentzian NCG: Is space-time non-commutative?*. After the discussions in two groups, a plenary discussion brought thoughts and new insights together. Also, the discussions were sustained by a website noncommutativegeometry.nl, serving also as a repository with background material. The organizational support of the Lorentz Center was excellent, leaving essentially only research problems for the organizers. Also the open nature of the Snellius-facility was greatly appreciated by all participants.

Let us now give a day-by-day, more detailed description of the lectures, seminars and discussions, from a participants point of view.

*On **Monday** we took off on the venture to facilitate mutual communication and appreciation between the fields of particle physics on the one hand and noncommutative geometry on the other. The talks of the day immediately spanned that entire spectrum.*

After a welcome, Alain Connes provided the participants a conceptual birds eye view of noncommutative geometry. This all started with the simple but intriguing question 'where are we?'. From there he took us along some of the key concepts of the field, showing that the Standard Model of particle physics is essentially a gravitational theory, but on a more complex space.

After lunch, Patrick Decowski set some experimental bounds by shedding light on the current status of the hunt for Dark matter particles. The need for their existence is truly compelling but to date, there is no conclusive evidence from

experiment. Where are we currently, and what can we expect in the next years?

His talk was followed by overviews of the status at the LHC from Paul de Jong and Stan Bentvelsen. Now the Higgs has been found, what aspects remain to be unveiled? To what extent do we possibly see effects of Beyond the Standard Model physics and what might we expect in the next years? Undoubtedly important boundary conditions for those that want to do noncommutative model building. After the introduction of the study group subjects and the lively discussion that followed, the stage was set, and the actors were introduced.

Tuesday was a field day: Walter van Suijlekom got us rapidly into business with a full-fledged discussion of the “Inner perturbations (it used to be fluctuations) of non-commutative geometry”. He faced squarely the subtleties in constructing gauge theories with the non-commutative tools. We learned (or re-learned) a couple of things, in particular about the semigroup structure of the gauge potentials, and the order-1 condition, which is most honored in the breaching. The discussion was lively, and the comments by Alain Connes on the above, very illuminating. The comment on the dressed propagator, a bit mystifying as usual. After that Igor Cherednikov gave a profound talk on the structure of nucleons from the viewpoint of Wilson loop theory. It was quite hard-going, but one could see at work a strong machinery there, toiling against formidable obstacles. It is fair to say that NCG has had nothing to say about QCD in the non-perturbative realm, so far. And then the moment for the study groups to take off had come. Two of the four proposals were deserted or nearly-deserted, so most everybody coalesced around the group headed by Fedele Lizzi (higgs vacuum stability) or the group headed by John Barrett (Lorentzian NCG). From the first, well attended by phenomenologists, it is apparent that the question of the meta-stability of the higgs potential (which is almost a relief to particle physicists, since after all the mass region for meta-stability is narrow) has preoccupied a lot the model-builders of NCG. As Fedele said, discussion of that entailed going into all the nitty-gritty of the spectral action of Connes and Chamseddine. From the second, I retain that the subject still keeps jealous watch on its approaches. The plenary discussion was enlivened by consideration of relativistic equations with characteristic initial data, surely more in the spirit of spectral geometry.

On **Wednesday** morning Ali Chamseddine lectured on what NCG can say about the SM and Beyond. In particular, he explained that the dropping of the mathematical condition of being at first-order in the noncommutative derivation of the Standard Model naturally leads to Pati-Salam $SU(2) \times SU(2) \times SU(4)$ Grand Unified Theory. Besides all Standard Model fermions being in the right representation, there are additional scalar fields in the right representation to allow for a truncation to the Standard Model, including the σ -field that allowed for a realistic Higgs mass. Next, Enrique Alvarez gave an interesting seminar about unimodular gravity, containing an interesting discussion on the conformal anomaly.

Because of mutual interest, during the afternoon the studygroups ‘Higgs vacuum stability’ and ‘Lorentzian NCG’ were promoted to two elucidating

plenary discussions. Among other topics, in the first the origin and significance of the aforementioned σ -field was discussed. In the second discussion session a proposal was put forward to induce the spectral Standard Model via the determinant of the (noncommutative) Dirac operator, i.e. the fermionic partition function. This might be suitable for a generalization of the spectral action to Lorentzian NCG, even though the actual computation of the path integral then still demands for a Wick rotation of the Dirac operator to Euclidean signature.

On **Thursday** morning we had a lecture by Elisabette Pallante on particle physics phenomenology. It was great to see what the current open problems are, and the challenges to understand: naturalness, hierarchy, Higgs vacuum stability and meta-stability bounds. A lively discussion followed, getting us back late for the seminars of Fedele Lizzi and Christoph Stephan.

Lizzi showed us the possibility to generate the σ -field from a so-called Grand algebra, which contained an intriguing mixing of spinorial degrees of freedom with the finite noncommutative space. As opposed to dropping the first-order condition, their approach demands however dropping the bounded-commutator condition. Next, Stephan showed us an alternative road to noncommutative model-building, proposing a model that contains in addition to the Standard Model a scalar field (of much lower mass) and additional fermions.

Again, the discussion in the afternoon study groups were very inspiring, ranging from a Lorentzian distance formula in the one group to the cosmological relevance of the σ -field in the other, and much more.

Friday – the last day of the workshop – was a morning full of seminar talks and afternoon with final discussion and closing remarks.

The seminar of Mairie Sakellariadou contained an overview of cosmological consequences of the noncommutative spectral model, and vice versa, how cosmological observations put restrictions on some of the parameters in that model. An interesting point raised was on topological defects that might appear in the course of spontaneous symmetry breaking. As the Pati-Salam model seems to be suggested by noncommutative geometry, it is interesting to see whether breaking this to the Standard Model fits with cosmology.

Next, John Barrett presented an interesting list of matrix geometries, building Dirac operators using Clifford and matrix algebras. In particular, fuzzy circles and fuzzy spheres fit in this scheme.

The long-awaited almost-associative geometries were presented in the last two seminars of the workshop by Latham Boyle and Shane Farnsworth. Though the general theory of non-associative noncommutative geometry is still to be developed, there are interesting models available with potential applications to unified theories. Intriguing similarities were displayed with the inner perturbations in the absence of the first-order condition.

After lunch, we had concluding remarks from the study groups. The Lorentzian NCG group made some progress in analyzing a distance formula for Lorentzian manifolds, working towards a translation of causal conditions in terms of spectral data. The Higgs vacuum stability group concluded that in

order to say something about the cosmological consequences, a better understanding is needed about the physical meaning of the spectral action.

3) Assessment of the results and impact of the event on the future directions of the field (up to two pages)

One of the great successes of the workshop was that the mixing between noncommutative geometers and particle physicists actually took place, which is not automatic. In this respect, the active attitude of the latter in critically evaluating the noncommutative approach was very valuable.

The aforementioned open and new research questions that resulted from the final discussions on Friday naturally suggests directions for future research in noncommutative model building and in making predictions for physics beyond the Standard Model. And even though this means it left the participants with an unanswered question, the clarity with which we arrived at this open problem can be considered as one of the great successes of the week.

4) Annexes 4a) and 4b): Programme of the meeting and full list of speakers and participants

Annex 4a: Programme of the meeting

Monday 14 October 2013

09:00 - 10:00 Arrival and coffee

10:00 - 10:15 Welcome by **Henriette Jensenius** of Lorentz Center

10:15 - 10:30 Introduction by organizers

10:30 - 12:00 **Alain Connes**: NCG - What it is

12:00 - 14:00 Lunch break @ Snellius Restaurant and informal discussions

14:00 - 14:30 **Patrick Decowski** - Dark matter

14:30 - 15:00 **Paul de Jong** - New particle searches at the LHC

15:00 - 15:30 Coffee/tea break

15:30 - 16:00 **Stan Bentvelsen** – Higgs status and prospects at LHC

16:00 - 16:30 16:30 - 17:00

17:00 - 19:00 Wine and cheese party @ common room

Tuesday 15 October 2013

09:30 - 10:30 **Walter van Suijlekom** lecture: NCG- what it has done

10:30 - 11:00 Plenary discussion, Coffee/tea break

11:00 - 12:00 Seminar talk **Igor Cherednikov**: Structure of the nucleon, high-energy hadronic processes and geometry of the Wilson loop space

12:00 - 14:00 Lunch break @ Snellius Restaurant and informal discussions

14:00 - 15:00 Studygroups
15:00 - 15:30 Coffee/tea break
15:30 - 16:30 Studygroups
16:30 - 17:00 Plenary discussion

Wednesday 16 October 2013

09:30 - 10:30 **Ali Chamseddine**: lecture: NCG- what it can do
10:30 - 11:00 Plenary discussion, Coffee/tea break
11:00 - 12:00 Seminar talk **Enrique Alvarez**: Unimodular Gravity

12:00 - 14:00 Lunch break @ Snellius Restaurant and informal discussions

14:00 - 15:00 Studygroups
15:00 - 16:30 Coffee/tea break – informal discussions

16:30 - 17:00 Departure by bus to harbour
17:00 - 21:00 Workshop dinner and boat trip

Thursday 17 October 2013

09:30 - 10:30 **Elisabetta Pallante** lecture: Particle Physics Phen
10:30 - 11:00 Plenary discussion, Coffee/tea break
11:00 - 11:30 Seminar talk: **Fedele Lizzi**: Grand Symmetry in the spectral action
11:30 - 12:00 Seminar talk: **Christoph Stephan**: Model Building in Almost-Commutative Geometry

12:00 - 14:00 Lunch break @ Snellius Restaurant and informal discussions

14:00 - 15:00 Studygroups
15:00 - 15:30 Coffee/tea break
15:30 - 16:30 Studygroups
16:30 - 17:00 Plenary discussion

Friday 18 October 2013

09:30 - 10:00 Seminar talk: **Mairi Sakellariadou**: Doubling of the algebra: neutrino mixing, dissipation and the seeds of quantization
10:00 - 10:30 Seminar talk: **John Barrett**: Matrix geometries

10:30 - 11:00 Plenary discussion, Coffee/tea break
11:00 - 11:30 Seminar talk: **Shane Farnsworth**: From almost-commutative to almost-associative geometries: key concepts and illustrations
11:30 - 12:00 Seminar talk: **Latham Boyle**: From almost-commutative to almost-associative geometries: phenomenological possibilities

12:00 - 14:00 Lunch break @ Snellius Restaurant and informal discussions

14:00 - 15:00 Final discussion/presentation results studygroups

15:00 - 15:30 Closing/outlook

Annex 4b: Full list of speakers and participants

Name	First name	Institute	City	Country
Alvarez	Enrique	ift-UAM/CSIC and DFT	Madrid	Spain
Barrett	John	University of Nottingham	Nottingham	United Kingdom
Beenakker	Wim	Radboud University, IMAPP	Nijmegen	Netherlands
Bentvelsen	Stan	University of Amsterdam	Amsterdam	Netherlands
Boeijink	Jord	Radboud University Nijmegen	Nijmegen	Netherlands
Borinsky	Michael	Humboldt-University	Berlin	Germany
Boyle	Latham	Perimeter Institute	Waterloo, Ontario	Canada
Chamseddine	Ali	American University of Beirut	Beirut	Lebanon
Cherednikov	Igor	Universiteit Antwerpen	Antwerpen	Belgium
Connes	Alain	IHES	Bures-sur-Yvette	France
De Jong	Sijbrand	IMAPP, Radboud University Nijmegen	Nijmegen	Netherlands
De Jong	Paul	Nikhef/Universiteit van Amsterdam	Amsterdam	Netherlands
Devastato	Agostino	Università di Napoli Federico II	Marigliano	Italy
Farnsworth	Shane	Perimeter Institute	Waterloo	Canada
Gracia-Bondia	Jose	Depto. Fisica Teorica, Univ. Zaragoza	Zaragoza	Spain
Kleiss	Ronald	Radboud University	Nijmegen	Netherlands
Laenen	Eric	Nikhef	Amsterdam	Netherlands
Lai	Alan	Caltech	Pasadena	United States
Landi	Giovanni	University of Trieste	Trieste	Italy
Lizzi	Fedele	Università di Napoli Federico II	Napoli	Italy
Martin	Carmelo Perez	Universidad Complutense de Madrid	Madrid	Spain
Martinetti	Pierre	Università di Napoli Federico II	Napoli	Italy
Mulders	Piet	Theoretical Physics, Nikhef/VU	Amsterdam	Netherlands
Ortiz	Pablo	Instituut-Lorentz / NIKHEF	Leiden	Netherlands
Pallante	Elisabetta	Centre for Theoretical Physics	Groningen	Netherlands
Sakellariadou	Mairi	King,s College London, Univ. of London	London	United Kingdom
Spisso	Bernardino	Università degli studi Federico II	Napoli	Italy
Stephan	Christoph	Universität Potsdam	Potsdam	Germany
Van den Broek	Thijs	Radboud Universiteit Nijmegen	Nijmegen	Netherlands
Van den Dungen	Koen	Australian National University	Canberra	Australia
Van Suijlekom	Walter	Radboud University Nijmegen - IMAPP	Nijmegen	Netherlands