

EQUIVARIANT HOMOTOPY THEORY IN CONTEXT REPORT

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1. EQUIVARIANT HOMOTOPY THEORY

Symmetry, group actions, and equivariance are inherent to mathematics. What is less obvious, however, is how to encode and analyze group actions in derived settings. Equivariant homotopy theory is the field where these questions are studied.

Equivariant techniques have played a critical role in the proofs of several major results and developments in algebraic topology over the past decade, starting with the solution to the famous Kervaire invariant one problem by Hill, Hopkins and Ravenel [HHR16]. Inspired by that, the prominence of group actions in chromatic homotopy theory has been highlighted and strengthened by the work of Hahn-Shi [HS20] and Beaudry-Hill-Shi-Zeng [BHSZ21], resulting in computational advances such as [BBHS20], [HSWX18], [LSWX19]. Other novel applications of equivariant methods include the equivariant approach to THH, TC, and algebraic K-theory established by Nikolaus and Scholze [NS18]. Finally, the connections between motivic and equivariant homotopy have seen incredible advances on the computational front, through the work of Isaksen and collaborators [DI17], [BGI21], as well as on the theoretical front, through the work of Hoyois, Bachmann, Heller, and others [Hoy17], [GH21], [BH21], [Hea19].

The renewed interest in applications of equivariant homotopy theory has gone hand in hand with breakthroughs within this area as well. One example is the work of Hausmann [Hau] on understanding equivariant bordism MU_G using the global homotopy theory developed recently by Schwede [Sch18]. In this approach, objects are equipped with coherent actions of *all* compact Lie groups at the same time. Another example is our improved understanding of equivariant commutativity via operads, which began with work of Blumberg and Hill [BH15] and has continued in many directions [Rub17], [BH18], [BBR19], [BGK21], [Wim], [HMQ]. Developing equivariant techniques such as norms and commutativity has also extended to motivic homotopy theory through work of Bachmann and Hoyois [BH21], [Bac].

These advances illustrate the explosion of exciting results in homotopy theory and its interfaces with algebraic geometry (via motivic homotopy theory) and algebra (via operads) over the past decade, made possible by new equivariant techniques.

The aim of this programme was to unite experts and young researchers from various parts of mathematics around the common theme of equivariant methods. We concentrated on modern equivariant methods in homotopy theory present in algebra, algebraic topology and algebraic geometry. We divided the scientific programme into three parts, each with a thematic workshop as a focus point. Though equivariant methods have already led to significant breakthroughs, their potential is clearly far from exhausted. This is visible in the new and important results described in Section 7.

2. STRUCTURE OF THE PROGRAMME

The EHT programme was the biggest research event in algebraic topology in recent years, with over 130 programme participants, who came primarily from Europe and North America, but also from Asia and Australia. The EHT programme adhered to the standard INI model for six month programmes, with four one-week workshops, including a satellite workshop in Belfast, covering the full breadth of algebraic topology. The rest of the programme was relatively unstructured, with two one-hour seminar talks on Tuesdays and an informal gong show on Thursdays, consisting of four 10-minute talks, often given by early-career researchers. Throughout the week, the institute was filled with participants sharing ideas and collaborating. As many participants mentioned, the open design of the Newton Institute building greatly facilitated interactions and discussions.

3. WORKSHOP 1: INTRODUCTORY WORKSHOP

The introductory workshop had two objectives.

Firstly, it introduced participants to the foundations of equivariant homotopy theory. This introduction allowed young researchers to learn about the methods and techniques of the field, enabling them to profit from the rest of the EHT programme. The introductory workshop included several series of two talks by experts in the field. May presented Mackey functors and equivariant algebra, including classification of modules over equivariant Eilenberg–MacLane spectra. Hausmann introduced various flavours of equivariant Thom spectra and their homotopy groups, Merling introduced G -manifolds and equivariant K-theory, and Stojanoska gave an overview of another prominent theme of the EHT programme, namely chromatic homotopy theory. Moreover, Hill discussed the structure of G -commutative monoids, one of the two main topics of Workshop 2, while Barwick explained spectral Mackey functors and infinity-categorical approaches to equivariant homotopy theory, an active area of research that was one of the recurring themes among the seminar talks throughout the EHT programme.

Secondly, the introductory workshop also featured research talks, where the speakers gave an overview of exciting recent developments and applications of equivariant homotopy theory. Meier talked about joint work with Gepner, Gukov, Krushkal and Pei on equivariant topological modular forms. Zou presented joint work with Hahn, Senger, and Zhang on C_3 -equivariant computations of Borelification of $\mathrm{tmf}(2)$. Hahn discussed joint work with Devalapurkar, Raksit, and Yuan, using genuine equivariance to understand the topological cyclic homology of complex bordism. Dotto presented another application of equivariant homotopy theory to an analogue of the Milnor conjecture for the de Rham-Witt complex in characteristic 2, via explicit calculations of the real topological cyclic homology of fields. Gerhardt reported on recent work with Bohmann, Krulewski, Petersen, and Yang, generalising to the equivariant setting the classical relationship between topological Hochschild Homology (THH) and Witt vectors, showing that the equivariant homotopy of twisted THH forms an equivariant Witt complex.

4. WORKSHOP 2: OPERADS AND CALCULUS

The focus of the Operads and Calculus Workshop was on the equivariant homotopy theory that arises in generalisations of operads to G -spaces and G -spectra and on equivariant generalisations and modern descriptions of functor calculus.

The conference brought together researchers from both of these areas of research, based on their common interest in the methods of equivariant homotopy theory. To facilitate interactions between

these two groups, the conference included two introductory lecture series (3 hours each): one on equivariant operads, given by Hill, and the other on functor calculus, given by Bauer.

Hill's series introduced equivariant operads as generalisations of operads to G -spaces, and demonstrated how they create (incomplete) Mackey functors and (incomplete and bi-incomplete) Tambara functors. The series finished with the relation to transfer systems, equivariant spaces and spectra, and different levels of equivariant commutativity. Bauer's series introduced Goodwillie's homotopy functor calculus in general settings, explaining how the notion of linearity of functors develops into the Goodwillie tower, whose fibers are the homogeneous functors. A major result is the classification of homogeneous functors in terms of equivariant spectra, a result that has analogues in several other version of calculus, which were introduced in the final talk of the series.

An important, recurring theme related to the equivariant operads side was the study of transfer systems, both in their own right (Martinez), in connection to questions arising from Tambara functors (Van Niel and DeMark), and as a way of counting the number of different types of equivariant commutativity (Balchin and Osorno). Another theme at the intersection of the two areas concerned more geometric applications, such as those described in Robertson's talk on the Kashiwara-Vergne Problem and Boyde's talk on using calculus to classify stably trivial vector bundles.

Equivariant spectra played a significant role in the context of many talks. Hilman used them to study parametrised calculus, Taggart generalised the algebraic models for rational equivariant spectra to give algebraic models for rational versions of calculus, and Mandell revisited the tom Dieck splitting of equivariant spectra in terms of N -infinity operads.

Finally, the talks of Arone, Blom, and Malin discussed deeper connections between the two areas. Blom and Malin related the Goodwillie tower and the Arone-Ching chain rule in the setting of infinity categories to operads. Arone showed how Goodwillie's n -excisive functors and Weiss' n -polynomial functors may be described in terms of (truncated) modules over the commutative operad. These talks demonstrated how the connections between the two themes of this workshop remain an important area of current research.

5. WORKSHOP 3: NEW HORIZONS FOR EQUIVARIANCE IN HOMOTOPY THEORY

Workshop 3 featured new results in equivariant homotopy theory and related areas, which can be grouped into several themes. The first major theme is equivariant algebra. Kedziorek described joint work with Barnes and Hill, providing idempotent splittings of rational incomplete G -Mackey functors for a finite group G . Going further in this direction, Barnes discussed joint work in progress with Bohmann, Hill and Kedziorek on the global dimension of categories of rational incomplete G -Mackey functors. Interested in global Mackey functors on symmetric groups, Stapleton described partition functors and universal exponential relations between multiplicative and additive power operations. Reaching towards tt-geometry, Balchin reported on joint work with Spitz and Quigley describing prime spectra of bi-incomplete Tambara functors. Opie talked about joint work with Asok, Shin, and Syed on a motivic obstruction theory approach to efficient generation of projective modules.

Secondly, there were several talks on the interplay between equivariant homotopy theory and geometry, motivic homotopy theory, and homological stability. Quigley described recent results from joint work with Botvinnik and works in progress with Bauer and Wang, on detecting smooth rotational symmetries of exotic spheres using stable homotopy theory. Bethea introduced equivariantly enriched enumerative geometry, which seeks to use equivariant homotopy theory to enrich classical enumerative results under the presence of a finite group action. She described joint work with

Wickelgren that has applications to counting rational curves equivariantly. Bachmann provided an overview of equivariant motivic stable homotopy theory, contrasting and comparing with classical equivariant homotopy theory. Belmont discussed joint work with Quigley and Vogeli on equivariant versions of homological stability, focusing on the examples of unordered configuration spaces of G -manifolds and equivariant classifying spaces of symmetric groups.

Thirdly, several speakers described work on improving our understanding THH, TC and algebraic K-theory. Merling described joint work with Angelini-Knoll and Péroux on topological Hochschild homology of rings with twisted group action, generalising real topological Hochschild homology for ring spectra with involution. Nikolaus defined a relative version of TR and proved a generalization of a theorem of Hesselholt–Madsen relating it to the derived de Rham–Witt complex. Rognes reported on joint work in progress with Devalapurkar and Hahn on higher arithmetic duality. They have proved duality theorems for syntomic cohomology and topological cyclic homology of a certain class of ring spectra, similar to Poincaré duality for the singular cohomology of a closed, oriented manifold. Hahn explained joint work with Devalapurkar, Raksit, and Yuan, which proposes that genuine equivariance has an essential role to play in the homotopy theory of cyclotomic spectra. This perspective is closely related to both the arithmetic duality of Rognes’ talk and the equivariant motivic categories of Bachmann’s talk.

Finally, several talks focused on better understanding homotopy theory and equivariant homotopy theory. Equivariant commutativity featured not only in Balchin’s talk, but also in the talks of Hill and Greenlees. Hill presented two structural results for transfer systems, describing how we can build transfer systems out of smaller pieces and how transfer systems themselves fit together. Greenlees gave an overview of work in progress with Kedziorek on the algebraic model of rational genuinely commutative $SO(2)$ -equivariant spectra. In the non-equivariant setting, Pstragowski talked about recent joint work with Lee in which they proved a monochromatic analogue of the Hahn–Wilson conjecture. Shi presented joint work with Duan, Hill, Li, Liu, Wang, and Xu on periodicity theorems for higher real K-theories at the prime 2 and showed how these results can be used to measure the complexity of the $RO(G)$ -graded homotopy groups of Lubin–Tate theories and to compute their equivariant slice spectral sequences.

6. WORKSHOP 4: BEYOND THE TELESCOPE CONJECTURE

Equivariance appears naturally in chromatic homotopy theory, in a way similar to Galois groups in the study of local fields. Specifically, chromatic homotopy theory studies stable homotopy theory through its localizations, which are encoded in the classification of formal group laws. This leads to a stratification of stable homotopy theory by height of the formal group laws in question. At any height n , there are two natural localizations one might study: one that is geometric in nature, namely the telescopic localization $Sp_{T(n)}$, and one that is approachable via algebraic means, namely localization with respect to a Morava K-theory $Sp_{K(n)}$. The approachability of the latter is mainly due to the fact that this category is governed by Galois descent with respect to the Morava stabilizer group, and that is also where the tight relationship between equivariant and chromatic homotopy stems from.

The Telescope Conjecture, formulated by Ravenel in the 1980s and based on the height 1 results of Mahowald and Miller, posited that the telescopic and $K(n)$ localizations agree for all n . Over the years, many experts, including Ravenel, have suspected that the conjecture was false, and the disproof, due to Burklund, Hahn, Levy, and Schlank, finally came in 2023. The disproof involved the discovery of a new and unexpected interface between algebraic K -theory and chromatic homotopy

theory, with equivariance and descent or its failure playing a key role. The aim of this workshop was to address the question “what comes next?” not only in chromatic homotopy theory, but also in the adjacent areas that were instrumental in the disproof.

Levy opened the workshop with an overview of some consequences of the failure of the telescope conjecture, as well as new questions that this work opens. This involved some ongoing work of Levy and a number of collaborators, but also a broad long-term vision for chromatic homotopy theory that instigated many lively discussions among workshop participants for the entire week.

Weinstein, Mann, and Schlank spoke of new work that ties chromatic homotopy theory with arithmetic geometry in unprecedented ways, leading to computations that have been deemed out of reach for decades. These included a full computation of the algebraic part of the $K(n)$ -local Picard group, as well as novel approaches to studying transchromatic phenomena using arithmetic geometry.

Li presented a new perspective on the classical image of J . Namely, Li explained how the J homomorphism can be considered as a profinite transfer, and proposed higher height generalizations of the image of J using transfers with respect to the Morava stabilizer group in the $K(n)$ -local setting. Luecke also took a classical topic, namely complex orientations, and, to a great effect, reframed it in terms of equivariant concepts, namely Tate fixed points with respect to a circle action.

Petersen and Heller introduced C_2 -equivariance in different new settings. Petersen showed a C_2 -equivariant splitting in the co-operations of C_2 -equivariant connective K -theory, analogous to a result of Mahowald and Kane. Heller, on the other hand, described the motivic C_2 -equivariant dual Steenrod algebra, and its implications for the structure of the C_2 -equivariant motivic category.

When it comes to the K-theoretic connection, Klang explored questions in classical spherical geometry through the lens of scissor congruence K-theory. Gerhardt presented work that was completed during this programme, joint with Chan and Klang, on a development of trace methods in equivariant algebraic K-theory. The non-equivariant version of these is a fundamental tool used in numerous applications, including the disproof of the telescope conjecture, and Gerhard showed the audience how introducing equivariance complicated the story in interesting and nuanced ways.

Algebraic K -theory gives a way of studying the homotopical algebra of ring spectra, and recent progress in this area circles around the so-called even or motivic filtration due to Hahn, Raksit, and Wilson, which in turn generalizes an analogous filtration in p -adic geometry. Senger provided a new perspective on this filtration through synthetic methods, while Angelini-Knoll presented some detailed computations with this filtration and related them to chromatic questions and red-shift phenomena in K -theory.

Hahn also spoke on work on algebraic K-theory completed during this programme, jointly with Devalapurkar and Rognes and involving duality phenomena. Hahn was the last speaker and he wonderfully tied his talk with Levy’s and other talks throughout the week, and advertised further open questions that are approachable and very relevant in the post-telescopic landscape. This was a great wrap-up of an inspiring week.

7. RESEARCH

Throughout the programme a wide range of important new results were presented during the weekly seminar talks. We divide them thematically below, to present recent developments in equivariant homotopy theory, as well as the applications of the subject to other areas of mathematics, such as motivic homotopy theory, chromatic homotopy theory, tt-geometry, equivariant manifolds and various flavours of THH, TC and algebraic K-theory. It is inspiring to see how interconnected the

research themes are and how tools and methods of equivariant homotopy theory played an important role in proving substantial new results across such a broad spectrum of algebraic topology.

Tensor-triangulated geometry

The interplay between tensor-triangulated geometry (tt-geometry) and equivariant homotopy theory was visible in the talk of Barnes, who described the Balmer spectrum in the case of profinite groups in the rational setting, and in the talk of Pol, who analysed separable commutative algebras in tt-geometry and provided a classification of those in genuine G -spectra for a finite group G .

The global approach to equivariant homotopy theory was also frequently mentioned in relation to tt-geometry. The Balmer spectrum of global spectra in the rational setting was analysed by Barthel, Barrero, Pol, Strickland and Williamson for various families of finite groups. This case is particularly interesting, as it has primes not only for groups in the family, as one would expect from the classical equivariant homotopy theory for one group G , but also primes that arise strictly from the complexity of compact global spectra.

Arone reported on joint work with Barthel, Heard and Sanders in which they approached the problem of understanding excisive functors from spectra to spectra via tt-geometry. They completely described the Balmer spectrum of this category, leading to a Thick Subcategory Theorem for excisive functors. This project was informed by an analogy between the category of excisive functors and the category of G -spectra.

Global equivariant homotopy theory

Schwede presented a globally-equivariant refinement of Snaith's localization result for complex K-theory: a specific morphism of ultra-commutative global ring spectra from the unreduced suspension spectrum of the global classifying space of $U(1)$ to the global K-theory spectrum is a localization away from certain "pre-Bott classes".

Functor calculus

The interplay between equivariant homotopy theory and functor calculus was one of the main themes of Workshop 2, but it also appeared in the seminar talks. One way this interplay is visible was made more precise in the work of Malin and Taggart on the norm maps that appear through Koszul duality models for functor calculus. Ching presented work in progress with Blom where they generalise the classification result of Taylor towers of Arone and Ching for functors from spectra to spectra to the case of functors from any pointed compactly generated infinity-category C to any stable infinity-category D . Johnson described joint work with Bauer, Brooks, Hess, Rasmussen and Schreiner, where they developed a general, functorial process for creating functor calculus and cocalculus.

Equivariant manifolds

Malkiewich reported on joint work with Igusa, Goodwillie and Merling, in which they showed that the space of stable, equivariant, smooth h -cobordisms for a finite group G can be expressed as a summand of the equivariant algebraic K-theory of spaces, obtaining an equivariant version of the Waldhausen-Jahren-Rognes theorem.

Homological stability

Randal-Williams explained a new point of view on homological stability inspired by chromatic homotopy theory, which can be applied to obtain a good qualitative understanding of what "higher order homological stability" should mean.

Levy reported on joint work with Landesman in which they prove that for a finite group G , certain Hurwitz spaces satisfy homological stability.

Equivariant combinatorics

Bergner talked about joint work with Bonventre, Calle, Chan, and Sarazola, in which they showed that G -equivariant partition complexes and suitable spaces of G -trees are G -homotopy equivalent. Bergner, Calle, Chan, Osorno, and Sarazola are working on the correspondance between G -trees and G -operads, which thematically links to the Workshop 2. Roitzheim presented generalisations of results for transfer systems to lattices, discussing homotopy theory of lattices via model categories.

Algebraic models for rational G-spectra

Greenlees reported on his recent progress towards an algebraic model for rational G -spectra for any compact Lie group G , which has been an open problem for almost thirty years. He discussed in detail the case where G is $SU(3)$.

Williamson presented a different approach to algebraic models, called torsion models, in joint work with Balchin, Greenlees, and Pol.

Motivic homotopy theory

Roendigs discussed certain homotopy groups of the special linear group SL_n , considered as an algebraic variety and so defining an algebraic homotopy type in the Morel-Voevodsky unstable homotopy category over a field F .

Spitzweck reported on joint work with Heine in which they showed that the derived category of representations of orthogonal and (general) symplectic groups over a field of characteristic zero satisfies universal properties, which helps in modelling subcategories of categories of étale motives.

Computations

van Nigtevecht reported on joint work with Carrick and Davies on analysing the homotopy groups of tmf . In particular, they proved the Gap Theorem for Tmf through its descent spectral sequence, based on innovative techniques in synthetic spectra.

Davies presented recent work with Carrick and van Nigtevecht in which they showed that it is better to compute (co)limits in E -synthetic spectra than to compute the E -Adams spectral sequence of the associated (co)limit.

Finally, Xu presented recent joint work with Lin and Wang in which they prove that h_6^2 is a permanent cycle in the Adams spectral sequence. As a result, they established the existence of smooth framed manifolds with Kervaire invariant one in dimension 126, resolving the final case of the Kervaire invariant problem.

Equivariant homotopy theory and infinity categories

A recent infinity-categorical approach to equivariant homotopy theory suggested by Bachmann-Hoyois and Nardin-Shah has proved very powerful. In particular Cnossen presented recent work with Lenz, and Linskens generalising semiadditivity of a category to a parametrized context, allowing for applications in equivariant homotopy theory. Moreover, Haugseng reported on recent joint work with Cnossen, Lenz, and Linskens where they developed the theory of normed equivariant ring spectra and higher Tambara functors, providing an extension of equivariant infinite loop space theory that takes into account multiplicative norms. This new approach, combined with results of Elmanto-Haugsgeng and Barwick-Glasman-Matthew-Nikolaus, produced normed ring structures on equivariant algebraic K-theory spectra. Moreover, Lenz talked about a joint project with Linskens and Pützstück, where they have given an infinity-categorical description of Schwede's ultra-commutative global ring spectra using normed algebras and lax limits.

Hochschild and cyclic homology, algebraic K-theory Dundas presented joint work with Østvær, in which they developed a new approach to the K-theory of complex cobordism MU and its

approximation $TC(MU)$, by working motivically over the complex numbers. Many zeros in topology have appeared as torsion, carrying valuable information. Zakharevich described her generalization of Rognes's filtration for algebraic K-theory.

Twisted THH and Equivariant Witt Complexes

Bohmann expanded on the talk by Gerhardt during the Introductory Workshop, providing more detail about her collaboration with Gerhardt, Krulewski, Petersen and Yang. They have defined the appropriate notion of an equivariant Witt complex and related it to the homotopy groups of twisted THH in all degrees.

Logarithmic THH and TC

Sagave reported on joint work in progress with Rognes and Schlichtkrull on logarithmic topological Hochschild homology and logarithmic topological cyclic homology, as well as on various localization sequences. Lundemo described the residue sequence in logarithmic THH, which, when combined with forthcoming work of Ramzi–Sosnilo–Winges, leads to the question of realizing logarithmic THH as the THH of a stable infinity-category, providing a candidate category of "logarithmic modules" in specific cases.

Chromatic homotopy theory

Patchkoria discussed joint work with Heuts, in which they describe $K(n)$ local duality for infinite groups. Kuhn presented joint work with Balderrama, where they give a new proof of the classical Smith theory for group actions on finite dimensional complexes, with the hope of extending it to the chromatic version of Smith theory, which currently is known for finite complexes by work of Barthel, Hausmann, Naumann, Nikolaus, Noel, and Stapleton.

Derived algebraic geometry

Linskens explained how he and Davies lifted the classical Tate elliptic curve to spectral algebraic geometry.

Equivariant algebraic geometry

Spitz in joint work with Chan, Mehrle, Quigley and van Niel, has begun developing algebraic geometry in the equivariant setting, where commutative rings are replaced by Tambara functors. In particular, they have carried out the first computations of the affine line in this setting.

8. SPECIAL LECTURES

During her Kirk lecture, Nathalie Wahl gave an introduction to homological stability, concentrating on examples of stabilizations for mapping class groups of surfaces and for symplectic groups, one arc at a time.

In his Rothschild Public Lecture, Michael A. Hill gave a basic introduction to homotopy theory in terms of understanding shapes and geometric objects using quantities like the number of pieces or the number of holes. He outlined its history over the last 120 years, as mathematicians worked to make these ideas precise, and described its use nowadays to understand complex data and to address questions of social justice.

9. OTHER EVENTS DURING THE PROGRAMME

As part of the commemorations for the centenary of Professor Christopher Zeeman's birth, we held a joint event on 19th March with the parallel programme on Modern History of Mathematics. Jemma Lorenat (Pitzer College) gave a talk related to the history of knot theory and there was a

showing of Zeeman’s 1978 Royal Institution Christmas Lecture on Linking and Knotting, the first such lecture given by a mathematician. This was followed by a joint social event, providing an opportunity for interaction between participants of the two programmes.

We held an Equality, Diversity and Inclusion event as part of the programme. This took place on 23rd April and involved a moderated discussion with the theme of *Building and maintaining a welcoming community*. A panel made up of programme participants with different backgrounds and at varying career stages offered their insights and there was wider discussion. This event also involved some participants of the parallel programme and several specific suggestions were followed up with INI staff after the event.

An Open for Business event associated with the programme took place on 24th June. This was a one-day workshop on Topological Advances in the Life Sciences, with excellent in-person attendance at West Hub in Cambridge and also in hybrid format. The workshop brought together academics and representatives of industry to facilitate interactions and discuss the latest developments. Leading researchers at this productive interface from both academia and industry presented an overview of useful topological tools and of important biological results established using them.

10. CONCLUSIONS

This was a highly successful programme, with substantial impact on the creation of new interactions and collaborations. It’s remarkable to see how many participants were involved in research connecting equivariant homotopical methods to other areas of mathematics. Both the participant questionnaires and various individual testimonials indicated that participants were very happy with the programme. Participants particularly emphasized new and unexpected connections and the effect of the programme on shaping their future research for years to come. The weekly gong show was particularly well received.

The programme was important for the subject area in the UK. Many researchers from the UK participated, with careful attention paid to inviting early career researchers. For many, the programme provided their first introduction to the international homotopy theory community, and the connections made are likely to be crucial in establishing their careers. Many programme participants connected with universities across the UK by giving seminar talks, including in Glasgow, Loughborough, Lancaster and Sheffield.

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