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Specialty and related panel:

100%	Mathematics	Mathematics and Computing Science

Interdisciplinary evaluation requested: No

Are research data being produced during the course of the project?:	No
Are you going to use international research infrastructure in the project?:	No
Are you going to purchase (expand/upgrade) research infrastructure (instrument) within the project?:	No
Are you planning in-house development of instrument (equipment) within the project?:	No

Summary

Summary of the research and its aims for experts
Describe the major aims of the research for experts.

Our aim is to use tools and techniques from matrix analysis, functional analysis, operator algebras, convex analysis, and other mathematical disciplines to make significant progress in a number of directions in quantum information theory. Our main focus is on the study of quantum Rényi divergences and their applications, especially in state and channel discrimination, state convertibility problems, resource theories, and the study of correlations in statistical physical models and in communication problems. We plan to study state and channel discrimination in a wide range of settings, including multiple, composite, and non-i.i.d. hypotheses; in infinite-dimensional, operator algebraic, and generalized probabilistic settings; and in concrete physical models including fermionic and bosonic quasi-free states, finitely correlated states, and various spin models. Moreover, we plan to identify among these concrete physical models those where state discrimination is possible with error probabilities vanishing with a non-trivial super-exponential speed in the sample size, and find general criteria for this phenomenon in terms of correlations. From the purely mathematical point, we aim at finding a large class of multi-variate Rényi divergences with good mathematical properties like monotonicity under quantum operations, additivity, and lower semi-continuity. In particular, we plan to define multi-variate versions of the most relevant quantum Rényi divergences, the Petz-type and the sandwiched families, and to explore their applications in state convertibility problems.

What is the major research question?
Describe here briefly the problem to be solved by the research, the starting hypothesis, and the questions addressed by the experiments.

We plan to study a wide range of mathematical problems in quantum information theory, mainly related to state discrimination and quantum Rényi divergences. Our main focus is on three different, but mathematically closely related groups of problems, where we aim to make significant progress.

1. a) Give sharp lower bounds on the optimal error exponents in binary composite state discrimination in terms of the worst-case pairwise error exponents, and improve these to finite-copy bounds when possible. Determine the strong converse exponent and the strong converse property of Stein's lemma in this setting.

b) Settle the problem of Stein's lemma in a state discrimination problem related to general resource theories, and also establish other types of trade-off relations in this setting.

c) Determine the possible type I error asymptotics when the type II exponent is above the (channel) relative entropy in the discrimination of infinite-dimensional i.i.d. states or channels (with product strategies and possible energy constraint).

2. Investigate the phenomenon of correlated state discrimination with super-exponentially vanishing error probabilities, discovered by the the group members; determine the fastest possible speed of decrease, establish trade-off relations on a super-exponential scale, find quantitative relations to correlation/entanglement asymptotics, link the effect to criticality, etc.

3. Define multi-variate weighted matrix geometric means and quantum Rényi divergences using different approaches. Give necessary, and if possible, sufficient conditions on multi-state convertibility in terms of these quantities.

What is the significance of the research?
Describe the new perspectives opened by the results achieved, including the scientific basics of potential societal applications. Please describe the unique strengths of your proposal in comparison to your domestic and international competitors in the given field.

Quantum information science is one of the most dynamically developing research fields of our days. Due to its great technological promises, it has been a priority research area internationally as well as on various national levels; in Hungary within the large-scale projects HunQuTech (2017-2021) and the Quantum Information National Laboratory (2020-2025), in which the participants of the proposed project also took part.

Our goal is to make profound contribution in a number of directions related to the mathematical/statistical foundations of quantum information science, including problems related to state and channel discrimination, state convertibility, resource theories, the study of quantum correlations in statistical physics and communication, and the mathematical study of various information measures and their applications. The proposed research plan builds largely on the results of the participants in the past years, and addresses problems at the forefront of research in mathematically rigorous quantum information theory, with a high expected impact on the field. This is evidenced, among others, by the facts that the related prior results of the applicants appeared in top-ranking journals like Communications in Mathematical Physics, IEEE Transactions on Information Theory, Annales Henri Poincaré, Quantum, etc., and were presented at the most prestigious conferences in the field, including two talks at the annual Quantum Information Processing conference series. Our two preceding NRDI grants (K 124152 and KH 129601) both received outsanding evalutaions with the highest possible score (10).

Currently our group is the only one working in Hungary on mathematically rigorous quantum information theory. The PI is an international leader in the core problems of the proposal, the study and applications of quantum Rényi divergences and state discrimination, and all the senior participants bring relevant and complementary expertise in pure mathematics, quantum information theory, and mathematical and theoretical physics. The three PhD students all have relevant publications to the proposal, and will keep working on the project after graduation, while we also plan to involve further students.

Summary and aims of the research for the public

Describe here the major aims of the research for an audience with average background information. This summary is especially important for NRDI Office in order to inform decision-makers, media, and others.

Quantum information science is one of the fastest developing fields of research of our days. This is driven partly by its great technological promises, like unconditionally secure cryptography, ultra-precise sensing, and the expectation that quantum computers may significantly outperform today's computers in a range of computational tasks. This progress has grown out of the theoretical study of quantum information theory that started some five decades ago, and which has been growing intensively ever since, still providing the theoretical foundations of the technological applications and exploring the directions in which quantum information science may develop in the future.

In this project we address fundamental problems at the mathematical/statistical foundations of quantum information theory, related to the tasks of encoding classical information into quantum systems, and the convertibility of quantum resource states into each other, and we aim to characterize the ultimate achievable performance in these tasks using various measures of quantum information. Our investigations lead to highly non-trivial problems in various branches of mathematics, solving which also contributes to the development of the respective mathematical disciplines.

I. Introduction

Quantum information science is one of the fastest developing fields of research of our days. This is driven partly by its great technological promises, like unconditionally secure cryptography, ultra-precise sensing, and the expectation that quantum computers may significantly outperform today's computers in a range of computational tasks. This progress has grown out of the theoretical study of quantum information theory that started in the early 1970's, and which has been growing intensively ever since, still providing the theoretical foundations of the technological applications and exploring the directions in which quantum information science may develop in the future. Interestingly, the notions and techniques of quantum information theory found applications and deepened our understanding in a wide range of problems and scientific disciplines, making it a truly interdisciplinary field. Most importantly for the present proposal, quantum information theory is a rich source of intriguing problems, and field of applications, for many branches of mathematics, including matrix analysis, functional analysis, operator algebras, and convex analysis, to name a few that are closest related to the proposal. The interplay between quantum information theory and mathematics is genuinely two-way; problems arising in quantum information theory have motivated research in such abstract areas of mathematics as Banach space theory [3] and operator spaces [52], and most recently insights from the study of quantum correlations in the form of non-local games have led to the solution of one of the most famous open problems in the theory of von Neumann algebras, the Connes embedding conjecture, which resisted the attacks of some of the best mathematicians for decades [31].

Currently the only research group in Hungary working on mathematically rigorous quantum information theory is the one established by the PI of the present proposal in 2017, with the help of a previous research grant of the NRDI (K 124152). The aim of this proposal is to secure the continued successful activity of the group. Based on the diverse expertise and range of interest of the proposed participants, we expect to work on a wide range of mathematical problems in quantum information theory; however, to respect page restrictions while making the research plan as self-contained as possible, we focus only on three main research lines that we plan to pursue in the project.

II. Detailed research plan

A Error exponents for state discrimination

Many of the problems in quantum information theory are intimately connected to some form of state discrimination problem, where a sender encodes one of finitely many possible messages into the state of a quantum system, and a receiver has to read it out using some prior knowledge about the possible code states. Already this basic problem can be studied in a great variety of settings: considering only two possible messages (binary case) or more; encoding the messages into a single copy of the system (single-shot), or multiple copies (asymptotic); assuming the copies to be identical and independent (i.i.d.) for every message, or allowing correlations; assuming the identity of the code states to be perfectly known by the receiver (simple case), or only certain sets into which they fall (composite case); using only finite-dimensional systems, or allowing systems described by infinite-dimensional Hilbert spaces, operator algebraic models, or even generalized probabilistic theories (GPTs), etc. In every setting, the aim of the receiver is to find measurements that minimize the erroneous identification of the messages according to some constraints. In the binary asymptotic i.i.d. setting, the optimal asymptotics achievable for the two possible error probabilities $\gamma_{\mathrm{I}}^{(n)}$ and $\gamma_{\mathrm{II}}^{(n)}$ (mistakenly dismissing the first or the second message, respectively), is an exponential decay of the form $\gamma_{\mathrm{I}}^{(n)} \sim e^{-nr_1}$, $\gamma_{\mathrm{II}}^{(n)} \sim e^{-nr_2}$, with a trade-off between the two exponents, given by the *direct exponent* $\mathrm{d}_r(\rho\|\sigma) := \sup\{r_1 : r_2 \geq r\} = \sup_{\alpha\in(0,1)} \frac{\alpha-1}{\alpha}[r - D_\alpha(\rho\|\sigma)] =: H_r(\rho\|\sigma)$ [5, 23, 27, 50]), where $D_\alpha(\rho\|\sigma)$ is the *Petz-type Rényi α-divergence* [53, 54] of the states ρ and σ encoding the first and the second message, respectively ($D_\alpha(\rho\|\sigma) = (\alpha-1)^{-1} \log \operatorname{Tr} \rho^\alpha \sigma^{1-\alpha}$ in the finite-dimensional case). This gives that the optimal type II error exponent under the constraint of asymptotically vanishing type I error (the *direct Stein exponent* $\mathrm{s}(\rho\|\sigma)$) is lower bounded by the *Umegaki relative entropy* [62] $D(\rho\|\sigma) := \operatorname{Tr} \rho(\log \rho - \log \sigma) = \lim_{\alpha\to 1} D_\alpha(\rho\|\sigma)$. On the other hand, if the measurements are chosen such that the type II errors decay with an exponent $r > D(\rho\|\sigma)$ then the type I errors go to 1 as $1 - e^{-n\cdot \mathrm{sc}_r(\rho\|\sigma)}$ (strong converse of Stein's lemma [49, 51]), where the exact strong converse exponent has been determined by the PI and coauthors [25, 41, 44] as $\mathrm{sc}_r(\rho\|\sigma) = \sup_{\alpha>1}\frac{\alpha-1}{\alpha}[r - D^*_\alpha(\rho\|\sigma)]$, where $D^*_\alpha(\rho\|\sigma)$ is the *sandwiched Rényi α-divergence* of the states ρ and σ [9, 28, 29, 48, 63] ($D^*_\alpha(\rho\|\sigma) = (\alpha-1)^{-1}\log\mathrm{Tr}(\rho^{1/2}\sigma^{\frac{1-\alpha}{\alpha}}\rho^{1/2})^\alpha$ in the finite-dimensional case).

A.1 Error bounds for composite state discrimination

In the case of composite binary i.i.d. state discrimination, where for n copies the receiver's knowledge of the code states is described by sets of the form $\{\rho_i^{\otimes n}\}_{i\in\mathcal{I}}$ and $\{\sigma_j^{\otimes n}\}_{j\in\mathcal{J}}$, it is easy to see that $\mathrm{d}_r(\{\rho_i\}_{i\in\mathcal{I}}\|\{\sigma_j\}_{j\in\mathcal{J}}) \le \inf_{i\in\mathcal{I},j\in\mathcal{J}}\mathrm{d}_r(\rho_i\|\sigma_j) = \inf_{i\in\mathcal{I},j\in\mathcal{J}} H_r(\rho_i\|\sigma_j)$, i.e., the direct exponent of distinguishing two sets of states cannot be better than the worst-case pairwise direct exponents of discriminating individual members of the two sets. We[1] have shown in [46] (based on [15]) that equality holds in the finite-dimensional classical case if both sets are finite, or both sets are convex and compact (in fact, even in the more general correlated settings of arbitrarily varying or adversarial hypothesis testing); in particular, in these cases, the optimal direct exponent can be given by a single-letter formula for every r. On the other hand, we have also shown in [46] that, in sharp contrast with the classical case, strict inequality holds for quantum states in general, already in the simplest case when $\mathcal{I}$ has only one element, and $\mathcal{J}$ has only two. The Stein exponent has been expressed in [8] in terms of a regularized relative entropy, and we have obtained analogous lower bounds on other exponents in [46]. These expressions, however, contain complicated optimizations and limits, and therefore evaluating them explicitly is not feasible in general. It is therefore highly desirable to find efficiently computable single-letter bounds for the various error exponents, preferably ones that are also sharp, i.e., are attainable by certain special configurations of states. An upper bound of this kind on the minimum of the sum of the two error probabilities was given by the PI and Audenaert in [4] as $|\mathcal{I}|\cdot|\mathcal{J}|\cdot e^{-\frac{n}{2}C(\{\rho_i\}_{i\in\mathcal{I}}\|\{\sigma_j\}_{j\in\mathcal{J}})}$, where $C(\{\rho_i\}_{i\in\mathcal{I}}\|\{\sigma_j\}_{j\in\mathcal{J}}) := \min_{i,j}\max_\alpha(1-\alpha)D_\alpha(\rho_i\|\sigma_j)$ is the *Chernoff divergence*. This gives the asymptotic bounds $\frac{1}{2}C(\{\rho_i\}_{i\in\mathcal{I}}\|\{\sigma_j\}_{j\in\mathcal{J}}) \le \mathrm{c}(\{\rho_i\}_{i\in\mathcal{I}}\|\{\sigma_j\}_{j\in\mathcal{J}}) \le C(\{\rho_i\}_{i\in\mathcal{I}}\|\{\sigma_j\}_{j\in\mathcal{J}})$ on the optimal exponent $\mathrm{c}(\{\rho_i\}_{i\in\mathcal{I}}\|\{\sigma_j\}_{j\in\mathcal{J}})$ of the sum of the two error probabilities (*Chernoff exponent*) whenever $\mathcal{I}$ and $\mathcal{J}$ are finite sets. It is not known whether the factor 1/2 in the lower bound above is optimal; however, an example due to the PI and coauthors suggests that this is probably the case [26]. Our first goal in this project point will be answering this question. Second, we will look for analogous bounds for the other exponents. The right approach here seems to be to scale the plane of achievable error exponent pairs by straight lines of constant slope, analogously to [58], and obtain bounds on the resulting variants of the direct exponents; our preliminary results suggest that this should be possible, leading to similar bounds as above with the prefactor in the lower bound depending on the slope of the line. These should then be ideally refined to finite-copy bounds, at least for finite $\mathcal{I}$ and $\mathcal{J}$. We will also look for regularized entropic expressions of other error exponents, analogous to the one given for the Stein exponent in [8]. Apart from their conceptual significance, these may serve as intermediate steps towards proving single-letter bounds, e.g., by using convexity estimates of the relevant divergences, and the exact equalities might also be helpful in proving optimality of such bounds. Preliminary results in this direction have already been obtained in [46]. We will also aim at extending our results to other settings, e.g., for the composite state discrimination problem for certain types of correlated states, or for $r > 2$ hypotheses, where the goal is to describe the set of r-tuples of achievable exponents in $\mathbb{R}^r_+$, extending the result given in [37] for the Chernoff exponent of the simple i.i.d. case .

A particular type of composite non-i.i.d. state discrimination problem is strongly connected to general resource theories [18] (e.g., that of entanglement). Here, for every $n\in\mathbb{N}$, the receiver has to decide whether the true state of the n-copy system is $\omega^{\otimes n}$ for some fixed state ω on a finite-dimensional Hilbert space $\mathcal{H}$, or it falls into the closed convex set $\mathcal{F}_{\mathcal{H}^{\otimes n}}$ of free states of the given theory, which are permutation-invariant and satisfy a number of compatibility conditions for different n values [16]. If the direct Stein exponent of every problem of this form in the resource theory is equal to the regularized relative entropy distance $D^\infty(\omega) := \lim_n \frac{1}{n}D(\omega^{\otimes n}\|\mathcal{F}_{\mathcal{H}^{\otimes n}})$, as claimed in [16], that implies that the optimal asymptotic conversion rate of one state ρ into another σ by so-called asymptotic resource non-generating maps is equal to the ratio $D^\infty(\rho)/D^\infty(\sigma)$, i.e., it can be given by a single function on the state space [13]. However, an error in the proof in [16] has been pointed out very recently [7], and currently it is not known whether the

[1]Here and henceforth "we" refers to participants of the present proposal.

statement is true in full generality or not. Our aim in this project point will be to settle this version of Stein's lemma for certain concrete resource theories as a minimal plan, and to prove it or show that it is not true in full generality as a more ambitious goal. Moreover, we intend to extend the connection between resource conversion and state discrimination by establishing more refined trade-off relations among the conversion rate, the goodness of conversion, and the speed with which the resource-generating capability of the conversion maps vanishes.

A.2 Strong converse of Stein's lemma

The direct Stein exponent of binary composite i.i.d. state discrimination was given in [8] as a regularized relative entropy, but it was left open whether this is also the smallest strong converse rate, i.e., for all type II error rates above this expression, the type I errors go to 1. We conjecture that this is indeed the case, and that the exact strong converse exponent can be expressed analogously to the simple binary i.i.d. case, in terms of regularized sandwiched Rényi divergences. This would follow from a suitable continuity bound for sandwiched Rényi divergences of the form $(1/n)D_\alpha^*(\rho^{\otimes n}\|\int \sigma^{\otimes n}\,d\nu(\sigma))$ (with an arbitrary probability measure ν) in α around $\alpha=1$, strengthening prior analogous bounds given in [59, 60], which will be our aim to obtain. We expect such a bound to find a wide range of applications in non-i.i.d. problems, analogously to the bounds in [59, 60] in i.i.d. problems.

The strong converse of Stein's lemma is a non-trivial problem already in the simple binary i.i.d. case if the states can be infinite-dimensional. As it was pointed out in [41], in this case it may happen that $D(\rho\|\sigma)<+\infty=D_\alpha^*(\rho\|\sigma)$, $\alpha>1$, whence the type I errors do not go to 0 for type II error rates above $D(\rho\|\sigma)$, but they also do not converge to 1 exponentially fast. The possible behaviours of the type I errors in this case seems to be unknown, and it will be our aim to explore this landscape, and in particular, to settle the question whether the strong converse property always holds in the weaker sense of the type I error probabilities converging to 1 with some speed. We will also study this problem in the more general setting of infinite-dimensional channel discrimination with product strategies and with possible energy constraint (in the finite-dimensional case, the strong converse property with no energy constraint was proved independently in [19] and by the PI and Hiai in [43], in the latter case using a newly established continuity property of the Rényi divergences, the possible extensions of which to the infinite-dimensional setting we will also study). When more general adaptive discrimination strategies are allowed, the strong converse exponent in the finite-dimensional case can be given by an exactly analogous formula to the case of state discrimination, in terms of the regularized channel sandwiched Rényi α-divergences, and the strong converse to Stein's lemma would follow if these could be proved to converge to the regularized channel relative entropy as $\alpha\searrow 1$ [21, 64]. We will attempt to tackle this problem using the techniques developed for the problems described above.

B Super-exponential state discrimination

As explained above, the optimal asymptotics of the error probabilities in simple binary i.i.d. state discrimination is an exponential decay of the two error probabilities, and it is also easy to see that a faster (super-exponential) decrease of both error probabilities is only possible in the trivial case when the states ρ and σ are supported on orthogonal subspaces, and hence they can be perfectly distinguished using only a single copy of the system. For this reason, it is natural to study the trade-off between the type I and the type II error probabilities on the level of exponents, and in fact, studying trade-off relations on the exponential scale is a general paradigm all over (quantum) information theory; e.g., between the compression rate and the decompression error in source coding, the coding rate and the decoding error in noisy channel coding, as well as between the relevant operational quantities in channel discrimination, entanglement conversion, and many other information-theoretic tasks.

However, in a recent paper [17], we have shown that there exist correlated state discrimination problems where the exponential paradigm does not apply anymore. Namely, we have shown a general construction of correlated translation-invariant state pairs on an infinite spin chain such that the error probabilities of discriminating their n-site restrictions decay super-exponentially in n, at least with the speed $\gamma_{\mathrm{I}}^{(n)}\le e^{-cn\log n}$, $\gamma_{\mathrm{II}}^{(n)}\le e^{-cn\log n}$, with some positive constant c, while all their local density operators are invertible. This striking phenomenon leads to a host of exciting open questions that we plan to investigate. For instance, it is not known what the exact asymptotics is in our examples, whether different/faster decrease of the error probabilities is possible with other constructions, and if this depends on the dimension of the single-site Hilbert spaces (in our example it is the smallest possible, 2), and maybe most importantly, what types of correlations are needed for a super-exponential asymptotics. In particular, we intend to find quantitative relations between the speed of the error decay and measures of entanglement (our constructions lead to highly entangled states). We will also aim at establishing tight trade-off relations between the error probabilities on the super-exponential scale; we expect that these may be obtained in terms of Rényi divergences regularized on a suitably chosen superlinear scale. Solving this problem for the class of states in [17] will require a new type of Szegő theorem for Toeplitz operators, which might be of independent interest.

These problems are also very strongly connected to quantum statistical physics: our construction in [17] uses gauge-invariant and translation-invariant quasifree states of fermionic lattice systems, and includes as a special case the family of thermodynamical limit ground states of the XX-model on a 1-dimensional spin chain corresponding to different transversal magnetic fields. We expect to prove similar results for other relevant physical models, including bosonic lattice states and ground states of critical spin models. To the best of our knowledge, this research direction is completely new within quantum information theory, and we expect our results to have significant impact.

C Multi-variate Rényi divergences

A central problem in quantum information theory is the convertibility of a set of states $(\rho_i)_{i\in\mathcal{I}}$ into another set of states $(\sigma_i)_{i\in\mathcal{I}}$ with a joint quantum operation. This problem can be studied in a large variety of settings; single-shot or asymptotic, exact or approximate, with or without catalysts, allowing arbitrary quantum operations or only those respecting some symmetry or being free operations of some resource theory, any combination of these, and more. Necessary conditions for convertibility can be obtained using multi-variate functions on quantum states with suitable mathematical properties; for instance, for exact single-shot convertibility, $F((\rho_i)_{i\in\mathcal{I}'}) \geq F((\sigma_i)_{i\in\mathcal{I}'})$ has to hold for any function F whose variables are indexed by a subset $\mathcal{I}'\subseteq\mathcal{I}$ and which is monotone non-increasing under the joint application of an allowed quantum operation on its arguments; the same has to hold also for multi-copy or catalytic single-shot convertibility, if F is additionally additive on tensor products, and for asymptotic catalytic convertibility, if, moreover, F is lower semi-continuous in its variables. Many of the quantum Rényi divergences provide such functions on pairs of states (i.e., $|\mathcal{I}'|=2$), including the maximal Rényi α-divergences [39] with $\alpha\in[0,2]$, and the Rényi (α,z)-divergences [6] for certain values of α and z [65]. In the converse direction, sufficient conditions in terms of Rényi divergences have been given for the convertibility of pairs of commuting states in [14, 30, 33, 47, 61], and these have been extended very recently in [20] to a complete characterization of asymptotic as well as approximate catalytic convertibility between finite sets of commuting states in terms of the monotonicity of the multi-variate Rényi quantities $Q_{\underline{\alpha}}(\rho_1,\dots,\rho_r) := \operatorname{Tr}(\rho_1^{\alpha_1}\cdot\ldots\cdot\rho_r^{\alpha_r})$, where $\alpha_1+\ldots+\alpha_r=1$ and either all of them are non-negative or exactly one of them is positive. This motivates the study of the possible quantum extensions of the multi-variate Rényi quantities, for which we propose three different approaches that we plan to explore in this project.

First, for a given probability space $(\mathcal{X},\mathcal{A},\alpha)$, quantum relative entropies $(D^{q_x})_{x\in\mathcal{X}}$, and states $(\rho_x)_{x\in\mathcal{X}}$, one may define $Q_\alpha^{\mathrm{b,q}}((\rho_x)_{x\in\mathcal{X}}) := \sup_\omega\left\{\operatorname{Tr}\omega - \int D^{q_x}(\omega\|\rho_x)\,d\alpha(x)\right\}$, with optimization over all positive semi-definite (PSD) operators on the given Hilbert space, the logarithm of which gives (up to normalization) the *barycentric Rényi divergence*: $-\log Q_\alpha^{\mathrm{b,q}}((\rho_x)_{x\in\mathcal{X}}) = \inf_\omega\int D^{q_x}(\omega\|\rho_x)\,d\alpha(x)$, where the infimum is over all states[2]. These quantities for finite $\mathcal{X}$ have been introduced and investigated in detail by us in [42], where we showed that they inherit many of the important properties of the parent relative entropies, including monotonicity under quantum operations and lower semi-continuity. Moreover, any optimal $\omega_\alpha^{\mathrm{b,q}}$ gives a non-commutative generalization of the α-weighted geometric mean (equal to $e^{\int\log\rho_x\,d\alpha(x)}$ for commuting operators). Second, for any collection $Q_\beta^{q_x} = e^{(\beta-1)D_\beta^{q_x}}$, where $D_\beta^{q_x}$ is a quantum Rényi β-divergence, $x\in\mathcal{X}$, any optimizer $\tau_\alpha^{\mathrm{q},\beta}$ of $\inf_\tau\int(1-\beta)^{-1}[\beta\operatorname{Tr}\rho_x + (1-\beta)\operatorname{Tr}\tau - Q_\beta^{q_x}(\rho_x\|\tau)]\,d\alpha(x)$ (called a *Tsallis divergence center*) gives a non-commutative generalization of the α-weighted β-power mean $(\int\rho_x^\beta\,d\alpha(x))^{1/\beta}$. The

[2] For brevity, we disregard the technically important but conceptually irrelevant issues regarding measurablity, integrability, the supports of states, etc.

limit $Q_\alpha^{\mathrm{T},\mathrm{q}}((\rho_x)_{x\in\mathcal{X}}) := \lim_{\beta\searrow 0}\operatorname{Tr}\tau_\alpha^{\mathrm{q},\beta}$, if exists, gives the desired quantitiy. If, moreover, the limit exists without taking the trace, then the resulting operator gives a notion of α-weighted geometric mean for non-commuting operators. Third, for any family of non-commutative extensions of the 2-variable β-weighted geometric mean G_β, any solution $\gamma_\alpha^{\mathrm{q},\beta}$ of the fixed point equation $\gamma = \int G_\beta(\rho_x\|\gamma)\,d\alpha(x)$ gives again a non-commutative generalization of the α-weighted β-power mean, and we can repeat the same procedure as above. As it was pointed out by the PI and Ogawa in [45], for $G_\beta^{q_x}(\rho_x\|\gamma) := G_{\beta,z(\beta)}(\rho_x\|\gamma) := (\gamma^{\frac{1-\beta}{2z(\beta)}}\rho_x^{\beta/z(\beta)}\gamma^{\frac{1-\beta}{2z(\beta)}})^{z(\beta)}$ and $Q_\beta^{q_x} := Q_{\beta,z(\beta)} := \operatorname{Tr} G_{\beta,z(\beta)}$, $x\in\mathcal{X}$, we get that $\tau_\alpha^{\mathrm{q},\beta} = \gamma_\alpha^{\mathrm{q},\beta}$ for all $\beta\in(0,1)$ and $z(\beta) > 1-\beta$, whence the second and the third approaches coincide, while if G_β is the β-weighted Kubo-Ando geometric mean [34] then $\tau_\alpha^{\mathrm{q},\beta} \neq \gamma_\alpha^{\mathrm{q},\beta}$ may happen, according to [56]. In this latter case, the convergence of the $\gamma_\alpha^{\mathrm{q},\beta}$ operators to a multi-variate weighted matrix geometric mean was shown in [38] for finite $\mathcal{X}$.

The first and the second approaches can be studied also in the von Neumann algebra setting, as well as in GPTs; one important point is the available choices of relative entropies and Rényi divergences in these settings. The family of quantum relative entropies defined by us in [42] is available also in von Neumann algebras, and we also plan to extend the PI's definition [41] of Rényi (α,z)-divergences [6] of infinite-dimensional density operators to the von Neumann algebra setting. One can also use the measured and the maximal relative entropies and Rényi divergences, and we can also rely on a recent integral representation of the Umegaki relative entropy by Frenkel [22], and its extension to the definition of a new family of Rényi divergences, which can be readily extended to the GPT setting. Additivity of these quantities, as well as of the multi-variate Rényi divergences proposed above, is a non-trivial question, and we will study their regularized versions as well, w.r.t. the ordinary tensor product in the quantum, and the minimal and the maximal tensor products in the GPT setting.

While our ultimate goal is to give necessary, and if possible, also sufficient conditions for various state convertibility problems in terms of the above described quantities, and to explore their potential other information theoretic applications, we remark that these problems are also very interesting from the purely mathematical point of view of matrix analysis, where the problem of barycenters and multi-variate matrix means have been the subject of intensive research in recent years; see, e.g., [1, 2, 10, 11, 12, 24, 32, 35, 36, 38, 40, 55, 56, 57].

III. Resources and impact

The proposed research plan builds strongly on the results achieved by the group in the past five years, and it aims at developing further some of the interesting research lines discovered during that period while also setting the ambitious goal of making progress in some of the most challenging open problems in quantum information theory. Our expected results will likely have high impact; indeed, our prior results appeared in the top ranking journals of Communications in Mathematical Physics [41], Annales Henri Poincaré [25], IEEE Transactions on Information Theory [45, 46] ([43] under review there), and the results of [46] and [17] were selected for talks at the 2022 and 2023 editions of the most prestigious annual conference series in (mainly) theoretical quantum information science, QIP. The senior participants bring a diverse range of expertise from different fields, which will contribute to the success of the project: Péter Frenkel from pure mathematics, Mihály Weiner from operator algebras and mathematical physics, the PI from quantum information theory and matrix analysis, and Zoltán Zimborás from theoretical and mathematical physics. The three student participants are currently PhD students supervised by the PI and Mihály Weiner, and we expect them to join the project as junior researchers (indicated as “researchers to be employed” among the participants) after graduating, while we will also aim at involving new PhD students in the project. The project will be hosted at the Department of Analysis, Budapest University of Technology, where all the necessary conditions are guaranteed for its successful running. The research being of theoretical nature, no extra infrastructure is required.

Finally, we note that while our proposed project is in basic research, some of our results are expected to contribute to the theoretical underpinning of the emerging quantum technology of the near future.

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According to the grant call, if multiple proposals are submitted from the same research group then the respective PIs have to state whether there are overlaps between the proposals. Among the senior participants of the present proposal, the PI, Mihály Weiner, and Zoltán Zimborás are or were at some point members of the MTA-BME Lendület (Momentum) Quantum Information Theory Research Group, together with Péter Vrana, the PI and sole senior member of the proposal FK 146643 submitted also in the current call of the NRDI. Regarding this, we state the following:

1. The funding of the Lendület group ends in 2023.08.31., well before the expected starting date 2024.01.01. of the proposed projects K 146380 and FK 146643.

2. While both proposals address mathematical questions in quantum information theory, their objectives and mathematical toolsets are different. Proposal K 146380 focuses mainly on quantum state discrimination and related problems, the interplay of different types of correlations in communication problems, the mathematical study of quantum Rényi divergences, and information theory in generalized probabilistic models, using techniques from matrix analysis, functional analysis, operator algebras, and convex analysis. In contrast, proposal FK 146643 focuses on the interplay between algebraic complexity theory and the manipulation and quantification of multi-partite entanglement. This approach was pioneered by Péter Vrana and coworkers and developed further by Péter Vrana during his work as a member of the Lendület research group. The aim of the proposal FK 146643 is to set the foundations of Péter Vrana's own research group to push this research line further, in line with the concept of the FK (Young Researcher) grant scheme.

Workplan

In accordance with the characteristics of research in Mathematics, we don't give a year-by-year work plan. This is additionally justified by the fact that various project goals can be pursued in parallel, and the completion of one is not a prerequisite of another. Instead, we give a rough estimate of the expected outcome of the various project points, and the time needed to achieve them. As required by the application guidelines, we also detail our plans for dissemination of results, and other relevant activities.

I. Expected outcome and time frame of the different project points.

A.1 Error bounds for composite state discrimination
Finding bounds on the error exponents of composite state discrimination is a direct continuation of prior work and the subject of ongoing research by the PI, Mihály Weiner, and Zsombor Szilágyi, and therefore we expect significant progress already in the first year of the project. On the other hand, we anticipate the problem of the quantum Stein's lemma related to resource theories a very challenging one, where any progress during the project will be considered a good outcome.

A.2 The problems of the strong converse of Stein's lemma in composite i.i.d. state discrimination and in infinite-dimensional simple i.i.d. state discrimination, as well as of infinite-dimensional channel discrimination with product strategies, are all very closely related to, or are direct continuations of, the recent research of the PI, and therefore we expect significant progress in the first two years of the project, and a complete solution of these problems before the end of the project. On the other hand, we expect the problem of the strong converse of Stein's lemma for channel discrimination with general adaptive strategies a very challenging one, where any progress will be considered a good outcome.

B. The study of super-exponential state discrimination was initiated in a very recent paper by Gergely Bunth, Gábor Maróti, the PI, and Zoltán Zimborás, all participants of the proposed project. As this is a completely new research direction, we expect many interesting results on it spread over the whole duration of the project.

C. The study of multi-variate matrix geometric means has been the subject of intensive research activity in matrix analysis and functional analysis in the past 20 years or so, while the study of multi-variate Rényi divergences of non-commuting variables seems to be new. Given the PI's expertise in (2-variable) quantum Rényi divergences, and related prior work by Frenkel, we expect significant progress on the proposed problems, spread over the whole duration of the project.

Finally, we remark that quantum information theory is a very fast progressing field, where new and important research directions might emerge every few years, and we might extend the work of the project in such new directions, in line with the general aims of the project of studying interesting mathematical problems in quantum information theory.

II. Dissemination of results

As is common in the field, we are going to disseminate our results in scientific publications in refereed journals and at international conferences. We anticipate an average of 2-4 publications/FTE-year in top-ranking journals in mathematics, information theory, and mathematical physics. We will be aiming at publishing the majority of our results in Communications of Mathematical Physics, IEEE Transactions on Information Theory, Quantum, and other journals of equivalent or higher ranking. This seems very feasible based on the publication activity of the group members in recent years.

We will also disseminate our results at prestigious international conferences, both in the form of invited and contributed talks. We expect to present our results in the form of contributed talks at 2-4 international conferences/FTE-year, and 1-2 invited talks/FTE-year. We will also regularly present our results at seminars, both in Hungary and abroad. On top of these, we plan to organize an annual workshop in Budapest on Quantum Information Theory and Mathematical Physics, continuing the successful series started by the PI in 2016.

Research capacity devoted to this project

Name	Participation time	Senior	2024-01-01 - 2024-12-31	2025-01-01 - 2025-12-31	2026-01-01 - 2026-12-31	2027-01-01 - 2027-12-31	FTE
			FTE				
Mosonyi Milán	2024-01-01 - 2027-12-31		0.70	0.50	0.50	0.50	2.20
Frenkel Peter	2024-01-01 - 2027-12-31		0.50	0.50	0.50	0.50	2.00
Weiner Mihály	2024-01-01 - 2027-12-31		0.60	0.60	0.60	0.60	2.40
Zimborás Zoltán	2024-01-01 - 2027-12-31		0.10	0.10	0.20	0.20	0.60
Felveendő kutató	2025-09-01 - 2027-12-31		-	0.17	0.50	0.50	1.17
Felveendő kutató	2024-09-01 - 2027-12-31		0.12	0.35	0.35	0.35	1.17
Total							9.54
Budget/FTE (HUF)							3 445 493

Participants', list of publications and citations, scientometrics

Dr. Mosonyi, Milán Curriculum vitae

Degree

Year of PhD	2005
University/Institution	Leuveni Katolikus Egyetem; honositás: BME, 2009
PhD registration number	523.239/2009
Title of the PhD dissertation	Entropy, Information and Structure of Composite Quantum States

Languages

English	**Intermediate Level Write and read (C)**

Qualifications

2000	**Mathematician**
2004	**Physicist**

Decorations

2006 JSPS postdoctoral fellowship and research budget
by: Japan Society for the Promotion of Science
Achievement:

2006 Junior Research Fellowship of the Erwin Schrödinger Institute for Mathematical Physics
by: Erwin Schrödinger Institute for Mathematical Physics, Vienna
Achievement:

2006 Junior Research Fellowship of the Hungarian Academy of Sciences (declined)
by: Hungarian Academy of Sciences
Achievement:

2009 Junior Research Fellowship of the Erwin Schrödinger Institute for Mathematical Physics
by: Erwin Schrödinger Institute for Mathematical Physics, Vienna
Achievement:

2011 Marie Curie International Incoming Fellowship
by: European Commission
Achievement:

2016 Bolyai János Research Fellowship
by: Hungarian Academy of Sciences
Achievement:

2017 NKFI K124152 research grant
by: National Research, Development and Innovation Office
Achievement:

2018 NKFI KH129601 research grant
by: National Research, Development and Innovation Office
Achievement:

2018 HAS Momentum research grant
by: Hungarian Academy of Sciences
Achievement:

Study trips - stipends

2002 (3 Month)	**Catholic University of Leuven** *Sponsor*: Prof. Mark Fannes *Research topic*: Visiting Scholar; research on correlated quantum spin chain states
2006 (3 Month)	**Erwin Schrödinger Institute for Mathematical Physics, Vienna** *Research topic*: Junior Research Fellow; research on large deviations in spin chain states
2009 (3 Month)	**Erwin Schrödinger Institue for Mathematical Physics, Vienna** *Research topic*: Junior Research Fellow; research on state discrimination of correlated quantum states and Rényi relative entropies

Role in scientific community

2016 -	**Journal of Mathematical Physics, Member of the Editorial Advisory Board**
2016 - 2021	**Quantum, Editor**
2018 - 2021	**IEEE Transactions on Information Theory, Associate Editor for Quantum Information Theory**
2018 - 2021	**Member of the board of referees for the Hungarian National Agency for Research, Development and Innovation (NRDI), section of Mathematics**
2021 -	**Quantum, Member of the Steering Board**

Workplaces

2005 - 2012	**Department of Analysis, Budapest University of Technology and Economics** *Position*: assistant professor
2006 - 2008	**Tohoku University, Sendai, Japan** *Position*: postdoctoral research fellow
2009 - 2011	**Centre for Quantum Technologies, National University of Singapore** *Position*: research fellow
2011 - 2013	**University of Bristol** *Position*: Marie Curie research fellow
2012 -	**Department of Analysis, Budapest University of Technology and Economics** *Position*: associate professor
2013 - 2015	**Universitat Autónoma de Barcelona** *Position*: postdoctoral research fellow
2015 - 2016	**Technical University of Munich** *Position*: postdoctoral research fellow

Specialty

Quantum Information Theory

Miscellaneous

Up-to-date cv: https://math.bme.hu/~mosonyi/

Selected five citations:

1. Cited work: M. Mosonyi, T. Ogawa: Quantum hypothesis testing and the operational interpretation of the quantum Rényi relative entropies; Communications in Mathematical Physics, Volume 334, Issue 3, pp. 1617--1648, (2015)

Citing work: Mario Berta, Volkher B. Scholz, Marco Tomamichel: Rényi divergences as weighted non-commutative vector valued Lp-spaces; arXiv:1608.05317

p.14: "Our work elicits the question whether the Araki-Masuda divergences characterize the strong converse exponent in binary hypothesis testing on von Neumann algebras. Mosonyi and Ogawa [MO15] showed that this is the case in the finite-dimensional setting.

Let us recapitulate the notation and setup in [JOPP12] and the result in [MO15] for the case of binary hypothesis testing between identical product states."

p.14: "Mosonyi and Ogawa [MO15], again in the finite-dimensional case, show that ... yielding an operational interpretation of the sandwiched Renyi divergence for $\alpha \geq 1$.

p.14: "To support our conjecture we derive a bound in one direction. Following the footsteps of [MO15], it is easy to show using the multiplicativity of Lp-norms under tensor products and the data-processing inequality (Theorem 14) that ..."

2. Cited work: M. Mosonyi, T. Ogawa: Quantum hypothesis testing and the operational interpretation of the quantum Rényi relative entropies; Communications in Mathematical Physics, Volume 334, Issue 3, pp. 1617--1648, (2015)

Citing work: Marco Tomamichel: Quantum Information Processing with Finite Resources: Mathematical Foundations; Springer International Publishing, (2016)

"4.3.3 Data-Processing Inequality
Here we show that Deα satisfies the data-processing inequality for α ≥1/2. First, we show that our pinching inequalities in fact already imply the data-processing inequality for α > 1, following an instructive argument due to Mosonyi and Ogawa in [119]."

3. Cited work: Milán Mosonyi, Fumio Hiai: On the quantum Rényi relative entropies and related capacity formulas; IEEE Trans. Inf. Theory, 57, pp. 2474-2487, (2011)

Citing work: Andreas Winter: Tight uniform continuity bounds for quantum entropies: conditional entropy, relative entropy distance and energy constraints; Commun. Math. Phys 347(1):291-313 (2016)

p.6: "Remark 9. Lemma 7 improves upon similar-looking general bounds by Synak-Radtke and Horodecki [45], which were subsequently optimized by Mosonyi and Hiai [28, Prop. VI.1]. The latter paper also explains lucidly (in Sec. VI) that the coefficient 1/1+ϱ in the convex decomposition of ω in two ways, into ρ and Δ′ and into σ and Δ, is optimal, and gives a nice geometric interpretation of ω as a max-relative entropy center of ρ and σ (cf. [24]). Thus, at least following the same strategy one cannot improve the bound any more."

4. Cited work: Fumio Hiai, Milán Mosonyi, Dénes Petz, Cédric Bény: Quantum f-divergences and error correction; Rev. Math. Phys., volume 23, issue 7, pp. 691 - 747, (2011)

(and also M. Mosonyi and D. Petz, Structure of sufficient quantum coarse grainings, Lett. Math.
Phys. 68 (2004) 19–30.)

Citing work: A. Jencova: Reversibility conditions for quantum operations; Rev. Math. Phys. Volume 24, Issue 07, (2012)

p.2: "The very recent paper [13] extends the monotonicity results to the case that T is the adjoint of a subunital Schwarz map and proves that reversibility is equivalent to preservation of a large class of quantum f-divergences, as well as distinguishability measures related to quantum hypothesis testing: the quantum Chernoff and Hoeffding distances. In the present paper, we find conditions for reversibility in terms of the L1- distance and complete the results for the Chernoff and Hoeffding distances and L1- distance for n copies of the states, giving an answer to some of the questions left open in [13]."

p.9: "In the original approach of [29], the map T and the recovery map S were both required to be 2-positive. The possibility of weakening this assumption was discussed in [13, Remark 5.8]"

p.10: "It was proved in [13] that any operator convex function has an integral representation of the form ..."

p.10: "The f-divergence of σ with respect to ρ is defined by ... see [13] also for the case of arbitrary pairs of density operators."

p.10: "Let T* :B → A be a unital Schwarz map. Then any f-divergence is monotone under T [13], in the sense that ..."

p.10: "Theorem 3 ([13]). Under the Conditions 1 and 2, the following are equivalent."

p.13: "The first such factorization result was proved in [22], see also [13, Theorem 6.1]."

p.21: "Proposition 3 ([13]). Let σ and ρ be two density operators in A such that supp σ = supp ρ. Let T :A→B be the adjoint of a unital Schwarz map and suppose that one of the following conditions holds ... "

p.23: "Suppose (i), then (17) holds and by [13, Lemma 5.2], this implies that"

"[13] F. Hiai, M. Mosonyi, D. Petz and C. Beny, Quantum f-divergences and error correction,
Rev. Math. Phys. 23 (2011) 691–747."

"[22] M. Mosonyi and D. Petz, Structure of sufficient quantum coarse grainings, Lett. Math.
Phys. 68 (2004) 19–30."

5. Cited work: F. Hiai, M. Mosonyi, T. Ogawa: Large deviations and Chernoff bound for certain correlated states on a spin chain; J. Math. Phys. 48, (2007);

(and also Hiai, F., Mosonyi, M., Ohno, H., Petz, D.: Free energy density for mean field perturbation of states of a one-dimensional spin chain. Rev. Math. Phys. 20, 335–365 (2008))

Citing work: Y. Ogata: Large Deviations in Quantum Spin Chains; Commun. Math. Phys. 296, pp. 35–68, (2010)

p.35: "Furthermore, it was shown that a state in one dimension, which satisfies a certain factorization property satisfies a large deviation upper bound [HMO]. This factorization property is satisfied by KMS-states as well as C*-finitely correlated states. It was also shown in [HMO] that the distributions of the ergodic averages of a one-site observable with respect to an ergodic C*-finitely correlated state satisfy the full large deviation principle."

p.35: "Other types of large deviation results can be found in [HMOP,LLS,PRV,P], and [RW].)"

"[HMO] Hiai, F., Mosonyi, M., Ogawa, T.: Large deviations and chernoff bound for certain correlated states on a spin chain. J. Math. Phys. 48, 123301 (2007)"

"[HMOP] Hiai, F., Mosonyi, M., Ohno, H., Petz, D.: Free energy density for mean field perturbation of states of a one-dimensional spin chain. Rev. Math. Phys. 20, 335–365 (2008)"

Relevant publications published in the last five years

Publication or achievement	Impact	Number of citations
Mosonyi Milán: ***The strong converse exponent of discriminating infinite-dimensional quantum states***, COMMUNICATIONS IN MATHEMATICAL PHYSICS, 2023; doi:10.1007/s00220-022-04598-1; Research field: Mathematical Physics ; position: 6/69 (D1) (Scopus ranking: journal position/length of list) *	-	0
Mosonyi Milan, Hiai Fumio: ***Test-measured Rényi divergences***, IEEE TRANSACTIONS ON INFORMATION THEORY 69: (2) pp. 1074-1092., 2023; doi:10.1109/TIT.2022.3209892; Research field: Computer Science Applications ; position: 59/695 (D1) (Scopus ranking: journal position/length of list) *	-	0
Hiai F., Mosonyi M.: ***Quantum Rényi Divergences and the Strong Converse Exponent of State Discrimination in Operator Algebras***, ANNALES HENRI POINCARE, 2022; doi:10.1007/s00023-022-01250-5; Research field: Mathematical Physics ; position: 16/69 (Q1) (Scopus ranking: journal position/length of list) *	-	0
Mosonyi Milán, Szilágyi Zsombor, Weiner Mihály: ***On the error exponents of binary state discrimination with composite hypotheses***, IEEE TRANSACTIONS ON INFORMATION THEORY 68: (2) pp. 1032-1067., 2022; doi:10.1109/TIT.2021.3125683; Research field: Computer Science Applications ; position: 59/695 (D1) (Scopus ranking: journal position/length of list) *	-	5
Milán Mosonyi, Tomohiro Ogawa: ***Divergence radii and the strong converse exponent of classical-quantum channel coding with constant compositions***, IEEE TRANSACTIONS ON INFORMATION THEORY 67: (3) pp. 1668-1698., 2021; doi:10.1109/TIT.2020.3041205; Research field: Computer Science Applications ; position: 59/695 (D1) (Scopus ranking: journal position/length of list) *	-	7

* : It is transferred from a publication database

Additional publications (no restriction on the date of publication except for KKP proposals where the additional publications should be from the last 10 years)

Publication or achievement	Impact	Number of citations
Mosonyi M, Ogawa T: ***Strong Converse Exponent for Classical-Quantum Channel Coding***, COMMUNICATIONS IN MATHEMATICAL PHYSICS 355: (1) pp. 373-426., 2017; doi:10.1007/s00220-017-2928-4; Research field: Mathematical Physics ; position: 2/52 (D1) (Scopus ranking: journal position/length of list) *	-	49
Tom Cooney, Milán Mosonyi, Mark M Wilde: ***Strong Converse Exponents for a Quantum Channel Discrimination Problem and Quantum-Feedback-Assisted Communication***, COMMUNICATIONS IN MATHEMATICAL PHYSICS 344: (3) pp. 797-829., 2016; doi:10.1007/s00220-016-2645-4; Research field: Mathematical Physics ; position: 2/52 (D1) (Scopus ranking: journal position/length of list) *	-	80
Milán Mosonyi, Tomohiro Ogawa: ***Quantum Hypothesis Testing and the Operational Interpretation of the Quantum Rényi Relative Entropies***, COMMUNICATIONS IN MATHEMATICAL PHYSICS 334: (3) pp. 1617-1648., 2015; doi:10.1007/s00220-014-2248-x; Research field: Mathematical Physics ; position: 2/52 (D1) (Scopus ranking: journal position/length of list) *	-	110
Mosonyi Milan: ***Coding theorems for compound problems via quantum Rényi divergences***, IEEE TRANSACTIONS ON INFORMATION THEORY 61: (6) pp. 2997-3012., 2015; doi:10.1109/TIT.2015.2417877; Research field: Computer Science Applications ; position: 46/529 (D1) (Scopus ranking: journal position/length of list) *	-	25
Mosonyi M, Hiai F: ***On the quantum Rényi relative entropies and related capacity formulas***, IEEE TRANSACTIONS ON INFORMATION THEORY 57: (4) pp. 2474-2487., 2011; doi:10.1109/TIT.2011.2110050; Research field: Computer Science Applications ; position: 9/471 (D1) (Scopus ranking: journal position/length of list) *	-	74

* : It is transferred from a publication database

Summary of scientific productivity

Number of publications	In Hungarian	Not in Hungarian (published in Hungary)	Not in Hungarian (published abroad)	Total
Article in periodical			29	29
Article in periodical in SCI/WoS			29	29
Article in periodical in SCI/WoS first author			13	13
Article in periodical in SCI/WoS last author			6	6
Book				
Monograph, critical edition, edition of primary source				
Chapter				
Conference proceedings			1	1
Patent				
Other			1	1
Total			31	31

Imported from MTMT database (MTMT) : 2023-04-19 (Mosonyi Milán)

Scientometric data	In the last 10 years	Total
Number of independent citations	702	828
Independent citations in SCI/WoS & Scopus	585	687
Number of journal articles in the first quarter (Q1) of the journal ranking list of the discipline	12	14
Number of journal articles in the top 10% (D1) of the journal ranking list of the discipline	10	11

Imported from MTMT database (MTMT) :
2023-04-19 (Mosonyi Milán)

Impact factor in the last 5 years (by own admission)	16.752

PhD students supervised	
Number of PhD students supervised	2
Students who received absolutorium	1
PhD students supervised	2

Frenkel, Peter Curriculum vitae

Degree

Year of PhD	2008
University/Institution	BMGE
PhD registration number	1892-PhD
Title of the PhD dissertation	New constructions in classical invariant theory

Languages

English	**Intermediate Level Write and read (C)**
French	**Intermediate Level Write and read (C)**

Qualifications

2002	**MSc in pure mathematics**

Decorations

1998	**III. Miklos Schweitzer prize** *by*: Janos Bolyai Mathematical Society *Achievement*: achievement in the Miklos Schweitzer Memorial Competition in Mathematics
1999	**II. Miklos Schweitzer prize** *by*: Janos Bolyai Mathematical Society *Achievement*: achievement in the Miklos Schweitzer Memorial Competition in Mathematics
2000	**I. Miklos Schweitzer prize** *by*: Janos Bolyai Mathematical Society *Achievement*: achievement in the Miklos Schweitzer Memorial Competition in Mathematics
2001	**I. Miklos Schweitzer prize** *by*: Janos Bolyai Mathematical Society *Achievement*: achievement in the Miklos Schweitzer Memorial Competition in Mathematics
2002	**I. Miklos Schweitzer prize** *by*: Janos Bolyai Mathematical Society *Achievement*: achievement in the Miklos Schweitzer Memorial Competition in Mathematics
2008	**Grünwald Medal** *by*: János Bolyai Mathematical Society *Achievement*: research
2022	**András Gács Prize** *by*: Board of Trustees of the András Gács Prize *Achievement*: teaching and research

Study trips - stipends

2001 (3 Month)	**University College London** *Sponsor*: University College London, Lorand Eotvos University (Budapest) *Research topic*: real analysis
2003 (4 Month)	**Warwick University (UK)** *Sponsor*: EU Marie Curie grant *Research topic*: algebraic geometry
2008 (36 Month)	**University of Geneva** *Research topic*: postdoctoral position

Role in scientific community

2015 -	**Bolyai János Matematikai Társulat, választmányi tag**

Workplaces

2006 - 2008	**Alfréd Rényi Institute of Mathematics, Hungarian Academy of Sciences** *Position*: junior researcher
2008 - 2011	**University of Geneva, Switzerland** *Position*: postdoctoral assistant
2011 -	**Chair of Algebra and Number Theory, Mathematics Institute, Eötvös Unversity, Budapest** *Position*: assistant professor; associate professor since 2020
2015 - 2023	**(Alfréd Rényi Institute of Mathematics)** *Position*: research associate

Relevant publications published in the last five years

Publication or achievement	Impact	Number of citations
Frenkel PE: ***Convergence of graphs with intermediate density***, TRANSACTIONS OF THE AMERICAN MATHEMATICAL SOCIETY 370: (5) pp. 3363-3404., 2018; doi:10.1090/tran/7036; Research field: Applied Mathematics ; position: 28/461 (D1) (Scopus ranking: journal position/length of list) *	-	13
Péter Ernő Frenkel, Gergely Zábrádi: ***Estimating the greatest common divisor of the value of two polynomials***, INTERNATIONAL JOURNAL OF NUMBER THEORY 14: (9) pp. 2543-2554., 2018; doi:10.1142/S1793042118501518; Research field: Algebra and Number Theory ; position: 24/92 (Q2) (Scopus ranking: journal position/length of list) *	-	4
Frenkel E. Péter, Weiner Mihály: ***On entanglement assistance to a noiseless classical channel***, QUANTUM 6: p. 662., 2022; doi:10.22331/Q-2022-03-01-662; Research field: Atomic and Molecular Physics, and Optics ; position: 9/194 (D1) (Scopus ranking: journal position/length of list) *	-	5
Frenkel Péter E.: ***Classical simulations of communication channels***, QUANTUM 6: 751, 2022; doi:10.22331/q-2022-06-29-751; Research field: Atomic and Molecular Physics, and Optics ; position: 9/194 (D1) (Scopus ranking: journal position/length of list) *	-	3
Péter E. Frenkel: ***Integral formula for quantum relative entropy implies data processing inequality***, , 2022 *	-	0

* : It is transferred from a publication database

Additional publications (no restriction on the date of publication except for KKP proposals where the additional publications should be from the last 10 years)

Publication or achievement	Impact	Number of citations
Domokos M, Frenkel PE: ***Mod 2 indecomposable orthogonal invariants***, ADVANCES IN MATHEMATICS 192: (1) pp. 209-217., 2005; doi:10.1016/j.aim.2004.04.005; Research field: Mathematics (miscellaneous) ; position: 12/238 (D1) (Scopus ranking: journal position/length of list) *	-	7
Frenkel PE: ***Pfaffians, hafnians and products of real linear functionals***, MATHEMATICAL RESEARCH LETTERS 15: (2-3) pp. 351-358., 2008; Research field: Mathematics (miscellaneous) ; position: 34/283 (Q1) (Scopus ranking: journal position/length of list) *	-	23
Csikvári P, Frenkel PE: ***Benjamini-Schramm continuity of root moments of graph polynomials***, EUROPEAN JOURNAL OF COMBINATORICS 52: pp. 302-320., 2016; doi:10.1016/j.ejc.2015.07.009; Research field: Computational Theory and Mathematics ; position: 25/109 (Q1) (Scopus ranking: journal position/length of list) *	-	27
Frenkel PE, Weiner M: ***Classical Information Storage in an n-Level Quantum System***, COMMUNICATIONS IN MATHEMATICAL PHYSICS 340: (2) pp. 563-574., 2015; doi:10.1007/s00220-015-2463-0; Research field: Mathematical Physics ; position: 2/52 (D1) (Scopus ranking: journal position/length of list) *	-	26
Abert Miklos, Csikvári Péter, Frenkel Péter E, Kun Gábor: ***Matchings in Benjamini–Schramm convergent graph sequences***, TRANSACTIONS OF THE AMERICAN MATHEMATICAL SOCIETY 368: (6) pp. 4197-4218., 2016; doi:10.1090/tran/6464; Research field: Applied Mathematics ; position: 18/428 (D1) (Scopus ranking: journal position/length of list) *	-	13

* : It is transferred from a publication database

Summary of scientific productivity

Number of publications	In Hungarian	Not in Hungarian (published in Hungary)	Not in Hungarian (published abroad)	Total
Article in periodical			20	20
Article in periodical in SCI/WoS			19	19
Article in periodical in SCI/WoS first author			14	14
Article in periodical in SCI/WoS last author			3	3
Book			1	1
Monograph, critical edition, edition of primary source				
Chapter				
Conference proceedings				
Patent				
Other		1		1
Total		1	21	22

Imported from MTMT database (MTMT) : 2023-04-18 (Frenkel Péter Ernő)

Scientometric data	In the last 10 years	Total
Number of independent citations	144	162
Independent citations in SCI/WoS & Scopus	96	108
Number of journal articles in the first quarter (Q1) of the journal ranking list of the discipline	8	12
Number of journal articles in the top 10% (D1) of the journal ranking list of the discipline	5	8

Imported from MTMT database (MTMT) :
2023-04-18 (Frenkel Péter Ernő)

Impact factor in the last 5 years (by own admission)	

Weiner, Mihály Curriculum vitae

Degree

Year of PhD	2005
University/Institution	Università di Roma "Tor Vergata"
PhD registration number	001394
Title of the PhD dissertation	Conformal covariance and related properties of chiral QFT

Languages

English	**Advanced Level Write and read (C)**
Italian	**Advanced Level Write and read (C)**

Qualifications

2001	**physicist**

Decorations

2012	**Bolyai János Research Fellow** *by*: Hungarian Academy of Sciences *Achievement*:

Role in scientific community

2014 -	**editor (Periodica Mathematica Hungarica)**

Workplaces

2006 - 2007	**University of Rome "Tor Vergata"** *Position*: post-doc position
2007 - 2007	**Erwin Schrödinger Institute** *Position*: Junior Fellow
2007 - 2009	**(Alfréd Rényi Institute of Mathematics)** *Position*: Junior Fellow
2009 - 2010	**University of Rome "Tor Vergata"** *Position*: post-doc position
2010 - 2011	**(Alfréd Rényi Institute of Mathematics)** *Position*: Junior Fellow
2011 - 2015	**Department of Mathematical Analysis (Budapest University of Technology and Economics)** *Position*: assistant professor
2015 -	**Department of Mathematical Analysis (Budapest University of Technology and Economics)** *Position*: associate professor

Specialty

Neumann alg., conf. quant. field theory, q. inf. theory

Miscellaneous

"However, if d
Cites:
P.E. Frenkel and M. Weiner:
Classical Information Storage in an n-Level Quantum System. Commun. Math. Phys. 340 (2015)

By:
M. Dall'Arno, S. Brandsen and Francesco Buscemi:

Device-independent tests of time-like correlations. arxiv: 1606.02799 (2016)

"It was shown by M. Weiner [83] that the existence of d MUBs in M_d(C^d) implies the existence of d+1 MUBs."

Cites:
M. Weiner:
A gap for the maximum number of mutually unbiased bases.
Proc. Amer. Math. Soc. 141 (2013)

By:
F. Hiai and D. Petz:
Introduction to Matrix Analysis and Applications. Springer Universitext, 2014.

"In two recent papers, [6] and [7], Matolcsi et al. explain how to use techniques from
Fourier analysis to attack the mutually unbiased bases problem. We briefly summarise
their ideas for completeness and to define the notation used later. (...) We now present
the main result of this paper proving Conjecture 2.3 of Matolcsi et al [7] for the case of
Karlsson Hadamard matrices."

Cites:
M. Matolcsi, I. Z. Ruzsa and M. Weiner:
Systems of mutually unbiased Hadamard matrices containing real and complex matrices.
Australas. J. Combin. 55 (2013)

By:
A. S. Maxwella and S. Brierley:
On properties of Karlsson Hadamards and sets of mutually unbiased bases in dimension six.
Lin. Alg. Appl. 466 (2015)

"Frenkel and Weiner [24] showed that (a multiple of) the matrix W is doubly nonnegative but not completely psd, which proves the strict inclusion (...) at the end of this section, we will present the proof given in [24] and we will show how we can use their ideas to prove that, in fact, W does not belong to the closure.. "

Cites:
P. E. Frenkel and M. Weiner:
On vector configurations that can be realized in the cone of positive matrices.
Linear Alg. Appl. 459 (2014)

By:
M. Laurent and T. Piovesan:
Conic Approach to Quantum Graph Parameters Using Linear Optimization Over the Completely Positive Semidefinite Cone
SIAM J. Optim. 25 (2015)

"Connections between the different approaches to CFTs only lately became clearer, thanks to the work of Carpi et al. [55].."

Cites:
S. Carpi, Y. Kawahigashi, R. Longo and M. Weiner:
From vertex operator algebras to conformal nets and back.
To appear in Mem. Amer. Math. Soc.

By:
R. Koenig and V. B. Scholz:
Matrix product approximations to conformal field theories.
arXiv:1509.07414 (2015)

Relevant publications published in the last five years

Publication or achievement	Impact	Number of citations
Carpi Sebastiano, Tanimoto Yoh, Weiner Mihaly: ***Local Energy Bounds and Strong Locality in Chiral CFT***, COMMUNICATIONS IN MATHEMATICAL PHYSICS 390: (1) pp. 169-192., 2022; doi:10.1007/s00220-021-04291-9; Research field: Mathematical Physics ; position: 6/69 (D1) (Scopus ranking: journal position/length of list) *	-	0
Frenkel E. Péter, Weiner Mihály: ***On entanglement assistance to a noiseless classical channel***, QUANTUM 6: p. 662., 2022; doi:10.22331/Q-2022-03-01-662; Research field: Atomic and Molecular Physics, and Optics ; position: 9/194 (D1) (Scopus ranking: journal position/length of list) *	-	5
Mosonyi Milán, Szilágyi Zsombor, Weiner Mihály: ***On the error exponents of binary state discrimination with composite hypotheses***, IEEE TRANSACTIONS ON INFORMATION THEORY 68: (2) pp. 1032-1067., 2022; doi:10.1109/TIT.2021.3125683; Research field: Computer Science Applications ; position: 59/695 (D1) (Scopus ranking: journal position/length of list) *	-	5
Morinelli V, Tanimoto Y, Weiner M: ***Conformal Covariance and the Split Property***, COMMUNICATIONS IN MATHEMATICAL PHYSICS 357: (1) pp. 379-406., 2018; doi:10.1007/s00220-017-2961-3; Research field: Mathematical Physics ; position: 3/59 (D1) (Scopus ranking: journal position/length of list) *	-	15
S Carpi, Y Kawahigashi, R Longo, M Weiner: ***From vertex operator algebras to conformal nets and back***, MEMOIRS OF THE AMERICAN MATHEMATICAL SOCIETY 254: (1213) pp. 1-97., 2018; doi:10.1090/memo/1213; Research field: Applied Mathematics ; position: 8/461 (D1) (Scopus ranking: journal position/length of list) *	-	51

* : It is transferred from a publication database

Additional publications (no restriction on the date of publication except for KKP proposals where the additional publications should be from the last 10 years)

Publication or achievement	Impact	Number of citations
Frenkel PE, Weiner M: ***Classical Information Storage in an n-Level Quantum System***, COMMUNICATIONS IN MATHEMATICAL PHYSICS 340: (2) pp. 563-574., 2015; doi:10.1007/s00220-015-2463-0; Research field: Mathematical Physics ; position: 2/52 (D1) (Scopus ranking: journal position/length of list) *	-	26
M Weiner: ***A gap for the maximum number of mutually unbiased bases***, PROCEEDINGS OF THE AMERICAN MATHEMATICAL SOCIETY 141: (6) pp. 1963-1969., 2013; doi:10.1090/S0002-9939-2013-11487-5; Research field: Applied Mathematics ; position: 81/415 (Q1) (Scopus ranking: journal position/length of list) *	-	24
Weiner Mihály: ***An Algebraic Version of Haag's Theorem***, COMMUNICATIONS IN MATHEMATICAL PHYSICS 305: (2) pp. 469-485., 2011; doi:10.1007/s00220-011-1236-7; Research field: Mathematical Physics ; position: 2/45 (D1) (Scopus ranking: journal position/length of list) *	-	9
Jaming P, Matolcsi M, Móra P, Szöllősi F, Weiner M: ***A generalized Pauli problem and an infinite family of MUB-triplets in dimension 6***, JOURNAL OF PHYSICS A-MATHEMATICAL AND THEORETICAL 42: (24) 245305, 2009; doi:10.1088/1751-8113/42/24/245305; Research field: Modeling and Simulation ; position: 31/184 (Q1) (Scopus ranking: journal position/length of list) *	-	50
M. Weiner: ***Conformal covariance and positivity of energy in charged sectors.***, COMMUNICATIONS IN MATHEMATICAL PHYSICS 265: pp. 493-506., 2006; doi:10.1007/s00220-006-1536-5; Research field: Mathematical Physics ; position: 3/34 (D1) (Scopus ranking: journal position/length of list) *	-	20

* : It is transferred from a publication database

Summary of scientific productivity

Number of publications	In Hungarian	Not in Hungarian (published in Hungary)	Not in Hungarian (published abroad)	Total
Article in periodical			24	24
Article in periodical in SCI/WoS			24	24
Article in periodical in SCI/WoS first author			6	6
Article in periodical in SCI/WoS last author			17	17
Book				
Monograph, critical edition, edition of primary source				
Chapter				
Conference proceedings			1	1
Patent				
Other		1		1
Total		1	25	26

Imported from MTMT database (MTMT) : 2020-02-17 (Weiner Mihály)

Scientometric data	In the last 10 years	Total
Number of independent citations	156	171
Independent citations in SCI/WoS & Scopus	133	142
Number of journal articles in the first quarter (Q1) of the journal ranking list of the discipline	13	18
Number of journal articles in the top 10% (D1) of the journal ranking list of the discipline	8	12

Imported from MTMT database (MTMT) :
2020-02-17 (Weiner Mihály)

Impact factor in the last 5 years (by own admission)	15.802

Zimborás, Zoltán Curriculum vitae

Degree

Year of PhD	2009
University/Institution	Eötvös Loránd Tudományegyetem
PhD registration number	P-2718/2009
Title of the PhD dissertation	The von Neumann entropy asymptotics of pure quasifree states

Languages

English	**Advanced Level Write and read (C)**
Norwegian Bokmål	**Advanced Level Write and read (C)**
Swedish	**Intermediate Level Write and read (C)**

Qualifications

2000	**ELTE Physics MSc**
2009	**ELTE Physics PhD**

Decorations

2017	**Emerging Talent (J. Phys. A)** *by*: Journal of Physics A *Achievement*: "To recognize the best early-career researchers in our research communities"
2017	**Bolyai János Research Fellowship** *by*: Hungarian Academy of Sciences *Achievement*:

Workplaces

2009 - 2012	**Institute for Scientific Interchange (Torino)** *Position*: Postdoctoral fellow
2012 - 2014	**University of the Basque Country Bilbao** *Position*: Postdoctoral fellow
2014 - 2016	**University College London (UCL)** *Position*: Research associate
2016 - 2017	**Freie Universität Berlin** *Position*: Research fellow
2017 - 2019	**Theoretical Physics Department (Wigner Research Centre for Physics)** *Position*: Wigner fellow
2018 - 2021	**Institute of Mathematics, Budapest University of Technology and Economics** *Position*: Assistant Professor (part time)
2019 - 2021	**Theoretical Physics Department (Wigner Research Centre for Physics)** *Position*: Permanent senior research fellow *Description*: From 2020
2021 -	**RMI - Komputációs Tudományok Osztálya (Wigner Research Centre for Physics)** *Position*: Research Group Leader, Permanent Senior Research Fellow

Specialty

quantum information theory, quantum statistical physics

Miscellaneous

Selected five citations:

1) Cited work: V. Eisler and Z Zimborás, New J. Phys. 17, 053048 (2015)
Citing work: A. Coser, E. Tonni, and P. Calabrese, J. Stat. Mech. P08005 (2015)

"It is highly desirable to have an exact representation of the negativity also for free fermionic systems.
A major step in this direction has been very recently achieved by Eisler and Zimboras [37] who showed
that the partial transpose is a linear combination of two Gaussian operators."
"Eisler and Zimboras in [37] showed how to obtain the partial transpose of a fermionic Gaussian density matrix, a procedure which can be applied to the spin reduced density matrix in equation (19) using the linearity of the partial transpose (...)"

2) Cited work: S. Farkas and Z. Zimborás, J. Math. Phys. 48, 102110 (2007)
Citing work: R. Helling, H. Leschke, and W. Spitzer, Int. Math. Res. Notices 7,1451-1482 (2011)

"Wolf [50] and later Farkas and Zimboras [19] then proved for d ≥ 2 and cubic \Omega \subset Z^d a lower bound on the partial particle number variance that scales as R^{d-1} ln R."

3) Cited work: V. Eisler and Z Zimborás, New J. Phys. 16, 123020 (2014)
Citing work: P Calabrese, J Cardy, E Tonni, J. Physics 48, 015006 (2014)

"For this reason, to quote a concrete example, the finite temperature calculation of the negativity between two adjacent intervals in [25], which is based on the calculation of a three-point function on the plane, is indeed free from these troubles and therefore correct."

4) Cited work: S. Farkas and Z. Zimborás, J. Math. Phys. 46, 123301 (2005)
Citing work: J. Eisert, M. Cramer, and M. B. Plenio, Rev. Mod. Phys. 82, 277 (2010)

"If one allows for long-range interactions and a fractal structure of the Fermi surface, one can show that one can even approach arbitrary well a valume law for the entanglement entropy (Fannes et al., 2003; Farkas and Zimboras, 2005)."

5) Cited work: V. Eisler and Z Zimborás, Phys. Rev. A 71, 042318 (2005)
Citing work: F. Kheirandish et al, European Physical Journal D 57, 129-140 (2010)

"For non-equilibrium thermal entanglement in spin systems, Eisler and Zimboras [13] calculated the von Neumann entropy of a block of spins in XX spin chain in the presence of the energy current and showed that the enhancement of the amount of entanglement due to an energy current is possible. After them, the non-equilibrium thermal entanglement for steady state of some systems has been studied in a number of works."

Relevant publications published in the last five years

Publication or achievement	Impact	Number of citations
Bunth G, Maróti G, Mosonyi M, Zimborás Z: ***Super-exponential distinguishability of correlated quantum states***, LETTERS IN MATHEMATICAL PHYSICS 113: (1) 7, 2023; doi:10.1007/s11005-022-01620-4; Research field: Mathematical Physics ; position: 23/69 (Q2) (Scopus ranking: journal position/length of list) *	1.520 (Declaration)	0
Glos A., Krawiec A., Zimborás Z.: ***Space-efficient binary optimization for variational quantum computing***, NPJ QUANTUM INFORMATION 8: (1) 39, 2022; doi:10.1038/s41534-022-00546-y; Research field: Computational Theory and Mathematics ; position: 6/146 (D1) (Scopus ranking: journal position/length of list) *	10.760 (Declaration)	1
Oszmaniec M., Dangniam N., Morales M.E.S., Zimborás Z.: ***Fermion Sampling: A Robust Quantum Computational Advantage Scheme Using Fermionic Linear Optics and Magic Input States***, PRX QUANTUM 3: (2) 020328, 2022; doi:10.1103/PRXQuantum.3.020328 *	7.514 (Declaration)	3
Ding L., Mardazad S., Das S., Szalay S., Schollwöck U., Zimborás Z., Schilling C.: ***Concept of Orbital Entanglement and Correlation in Quantum Chemistry***, JOURNAL OF CHEMICAL THEORY AND COMPUTATION 17: (1) pp. 79-95., 2021; doi:10.1021/acs.jctc.0c00559; Research field: Computer Science Applications ; position: 69/695 (D1) (Scopus ranking: journal position/length of list) *	6.006 (Declaration)	24
Maciejewski FB, Zimboras Z, Oszmaniec M: ***Mitigation of readout noise in near-term quantum devices by classical post-processing based on detector tomography***, QUANTUM 4: 257, 2020; doi:10.22331/q-2020-04-24-257 *	6.777 (Declaration)	83
Eisert J, Eisler V, Zimborás Z: ***Entanglement negativity bounds for fermionic Gaussian states***, PHYSICAL REVIEW B 97: (16) 165123, 2018; doi:10.1103/PhysRevB.97.165123; Research field: Condensed Matter Physics ; position: 29/403 (D1) (Scopus ranking: journal position/length of list) *	3.693 (Declaration)	29

* : It is transferred from a publication database

Additional publications (no restriction on the date of publication except for KKP proposals where the additional publications

should be from the last 10 years)

Publication or achievement	Impact	Number of citations
Oszmaniec M, Zimboras Z: ***Universal Extensions of Restricted Classes of Quantum Operations***, PHYSICAL REVIEW LETTERS 119: (22) 220502, 2017; doi:10.1103/PhysRevLett.119.220502; Research field: Physics and Astronomy (miscellaneous) ; position: 11/251 (D1) (Scopus ranking: journal position/length of list) *	8.839 (Declaration)	11
Eisler V, Zimboras Z: ***On the partial transpose of fermionic Gaussian states***, NEW JOURNAL OF PHYSICS 17: (5) 053048, 2015; doi:10.1088/1367-2630/17/5/053048; Research field: Physics and Astronomy (miscellaneous) ; position: 17/248 (D1) (Scopus ranking: journal position/length of list) *	3.570 (Declaration)	74
Eisler V, Zimborás Z: ***Entanglement negativity in the harmonic chain out of equilibrium***, NEW JOURNAL OF PHYSICS 16: 123020, 2014; doi:10.1088/1367-2630/16/12/123020; Research field: Physics and Astronomy (miscellaneous) ; position: 10/246 (D1) (Scopus ranking: journal position/length of list) *	3.895 (Declaration)	94
Zimboras Z, Faccin M, Kadar Z, Whitfield JD, Lanyon BP, Biamonte J: ***Quantum Transport Enhancement by Time-Reversal Symmetry Breaking***, SCIENTIFIC REPORTS 3: 2361, 2013; doi:10.1038/srep02361; Research field: Multidisciplinary ; position: 4/114 (D1) (Scopus ranking: journal position/length of list) *	5.158 (Declaration)	45

* : It is transferred from a publication database

Summary of scientific productivity

Number of publications	In Hungarian	Not in Hungarian (published in Hungary)	Not in Hungarian (published abroad)	Total
Article in periodical	1	1	51	53
Article in periodical in SCI/WoS		1	51	52
Article in periodical in SCI/WoS first author			4	4
Article in periodical in SCI/WoS last author		1	31	32
Book				
Monograph, critical edition, edition of primary source				
Chapter			1	1
Conference proceedings		1	5	6
Patent				
Other				
Total	1	2	57	60

Scientometric data	In the last 10 years	Total
Number of independent citations	758	823
Independent citations in SCI/WoS & Scopus	726	791
Number of journal articles in the first quarter (Q1) of the journal ranking list of the discipline	30	33
Number of journal articles in the top 10% (D1) of the journal ranking list of the discipline	17	19

Impact factor in the last 5 years (by own admission)	41.979

Doctoral dissertations supervised	
Name	Year of defense
Jakab Dávid	2022 *

Rows marked by asterisk are transferred from www.doktori.hu
date of import: 2023-04-30

PhD students supervised	
Number of PhD students supervised	9
Students who received absolutorium	1
PhD students supervised	8

Tasks of the participants

Mosonyi Milán			**Department of Mathematical Analysis (Budapest University of Technology and Economics)**
		Mode of participation:	Researcher, not on the project's budget
FTE:	2.20	Scientific tasks:	Group management and coordination of research; participation in the study of all project points; supervision of students in topics related to the project.
Frenkel Peter			**Department of Algebra and Number Theory (Eötvös Loránd University)**
		Mode of participation:	Full-time or part-time research employment or extra salary for researcher.
FTE:	2.00	Scientific tasks:	General mathematical study of quantum divergences; study of classical, quantum, and more general correlations in communication problems; information theory in general probabilistic models.
Weiner Mihály			**Department of Mathematical Analysis (Budapest University of Technology and Economics)**
		Mode of participation:	Full-time or part-time research employment or extra salary for researcher.
FTE:	2.40	Scientific tasks:	Research in quantum hypothesis testing and channel coding; study of classical, quantum, and more general correlations in communication problems; information theory in generalized probabilistic models. Supervision of students in topics related to the project.
Zimborás Zoltán			**Theoretical Physics Department (Wigner Research Centre for Physics)**
		Mode of participation:	Researcher, not on the project's budget
FTE:	0.60	Scientific tasks:	Quantum information theory in concrete physical models, connections to quantum statistical physics.
Bunth Gergely			**Budapest University of Technology and Economics**
		Mode of participation:	Student participant
		Scientific tasks	Research on quantum divergences and their applications in quantum information theory.
Maróti Gábor			**Budapest University of Technology and Economics**
		Mode of participation:	Student participant
		Scientific tasks	State discrimination problems on spin, fermion, and boson lattices.
Szilágyi Zsombor			**Budapest University of Technology and Economics**
		Mode of participation:	Student participant
		Scientific tasks	Composite state discrimination and information theory in generalized probabilistic models.
Felveendő kutató			
		Mode of participation:	Full-time or part-time research employment or extra salary for researcher.
		Participation time:	2025-09-01 - 2027-12-31
FTE:	1.17	Scientific tasks:	Research on state discrimination, channel coding, and information theory in generalized probabilistic models. (This will be one of our current PhD students continuing as a junior researcher after graduation.)
Felveendő kutató			
		Mode of participation:	Full-time or part-time research employment or extra salary for researcher.
		Participation time:	2024-09-01 - 2027-12-31
FTE:	1.17	Scientific tasks:	Research on quantum divergences and their applications in quantum information theory. (This will be one of our current PhD students continuing as a junior researcher after graduation.)

NKFI/OTKA				
Principal investigator	Participant in this proposal		FTE	
Abért Miklós	Frenkel, Peter		2.50	
Title: Groups and graph limits				
Project identifier	Number of participants	Amount of support (HUF)	Starting year	Closing year
139502 (Contract)	11	299583000	2021-09-01	2026-08-31

Summary:

Summary of the research and its aims for experts

Describe the major aims of the research for experts.

We analyze Benjamini-Schramm convergence in the realm of finite graphs, Riemannian manifolds of finite volume and locally symmetric spaces. We propose to understand the asymptotic behavior of the finite volume invariants by connecting it to an analytic object on the limit of the sequence. When groups are involved, the emerging notion of invariant random subgroups serves as a unifying language for convergence.

The list of natural finite volume invariants to be studied includes the minimal number of generators, Betti numbers, various spectral and representation theoretic invariants, characters, eigenfunctions and geometric tesselations. The limit objects are invariant processes on groups, profinite actions, graphings, invariant random subgroups, measured complexes and invariant eigenwaves. The corresponding analytic invariants include L^2 Betti numbers, spectral and Plancherel measures, cost and local entropy.

What is the major research question?

Describe here briefly the problem to be solved by the research, the starting hypothesis, and the questions addressed by the experiments.

We pose an array of problems in various directions. They are connected by the underlying methods and there are also some surprising connections between them.

The problems include the sofic problem for unimodular random rooted graphs, proving the vanishing of rank gradient of lattices in Lie groups, computing the cost of Poisson process, establishing the Poisson boundary of a group using biased graph limits, producing a totally isotropic discretization of Euclidean spaces, constructing an invariant random subgroup with nontrivial sup norm, proving that the sin wave can not emerge as a limit of eigenfunctions in negative curvature and showing that the ratio of the Heegaard genus and the rank can get arbitrarily large.

What is the significance of the research?

Describe the new perspectives opened by the results achieved, including the scientific basics of potential societal applications. Please describe the unique strengths of your proposal in comparison to your domestic and international competitors in the given field.

Graph limits in general deals with the large scale behavior of finite networks. A better understanding of robust invariants is also expected to find its applications outside mathematics. The Renyi Institute is a leading place for graph limit theory. The proposed research is mainstream and well recognized in the community. Positive results in this area have a good chance to be published in top journals.

Summary and aims of the research for the public

Describe here the major aims of the research for an audience with average background information. This summary is especially important for NRDI Office in order to inform decision-makers, media, and others.

The proposal deals with very large networks and manifolds. It aims to fundamentally understand how they behave and how one can measure their properties in a robust way, by identifying their major measurable invariants.

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There is no thematic overlap between the project KKP 139502 and our proposal.

NKFI/OTKA				
Principal investigator	Participant in this proposal		FTE	
Matolcsi Máté	Weiner, Mihály		1.00	
Title: Fourier analysis: theory and applications				
Project identifier	Number of participants	Amount of support (HUF)	Starting year	Closing year
132097 (Contract)	4	7478000	2019-12-01	2023-11-30

Summary:

Summary of the research and its aims for experts

Describe the major aims of the research for experts.
During the project we plan to apply the methods of Fourier analysis to solve some specific well-known problems or, at least, achieve some major new results in them. Another natural goal is to settle theoretical problems that arise along the way.

The first main topic is the Fuglede conjecture, where we examine the relation of "spectral" sets and "tiles". It has been known for a while that the two classes of sets do not contain each other (there have been counterexamples to both directions). However, as a result of a joint work of Nir Lev and the PI it has now been proved that the properties coincide in the case of convex domains. The notion of the "diffraction measure" used in the proof is likely to have further applications in this area.

The second main topic concerns "Delsarte-type" problems, i.e. problems in which some variant of the Delsarte LP-bound can be applied. A typical problem of this type is sphere-packing: what is the maximal density packing of a body which cannot tile the space by translation? Some of the questions arising in connection with the Fuglede conjecture can be tackled naturally with the Delsarte LP-bound, and many theoretical problems arise.

The third topic is the MUB-problem, where the Delsarte LP-bound can also be used (in principle). In this case we can make use of the non-commutative version of the method, or the extra constraints which arise from complete positivity of certain arising matrices.

What is the major research question?
Describe here briefly the problem to be solved by the research, the starting hypothesis, and the questions addressed by the experiments.
We would like to study the following specific problems:

1. Investigation of spectral sets with the properties of the diffraction measure. What classes of sets can be seen to be non-spectral upon using the necessary conditions obtained by the existence of the diffraction measure? This question is particularly interesting in finite cyclic groups and on the real line (dimension 1), where many basic questions remain open, such as the case of the union of a few intervals or closed nowhere dense sets of positive measure.

2. The existence of the diffraction measure raises the possibility of using the Delsarte LP-bound (Nir Lev and the PI have used geometric considerations instead). Many theoretical questions arise here as to whether the witness functions used in the LP-bound always exist, and if so, how we can construct them.

3. In the applications of the Delsarte LP-bound, linear duality is of utmost importance. The theoretical background of this is neatly worked out in finite and compact groups but some questions remain to be clarified in the Euclidean setting. Answering these questions concerning duality will probably lead us closer to solving some of the problems mentioned in the points 1-2 above.

4. The PI has introduced the application of the Fourier analytic version of the Delsarte LP-bound to the problem of the MUBs, and an improvement of the bound as well as a non-commutative version was given later in a joint work with M. Weiner. The aim in this project is to make use of these methods together with the complete positivity of certain matrices arising from complete systems of MUBs. Adding such constraints may lead to a non-existence proof in dimension 6.

What is the significance of the research?
Describe the new perspectives opened by the results achieved, including the scientific basics of potential societal applications. Please describe the unique strengths of your proposal in comparison to your domestic and international competitors in the given field.
This project is mainly basic research. Nevertheless, the "diffraction measure" used in the investigation of the Fuglede conjecture has been already known in crystallography, and it possible that some new mathematical results of our project can later be useful for applications in that field. Similarly, it is possible that results concerning the MUB-problem may be used in the future when quantum-information will be a reality.
As to the originality of the project I mention the diffraction measure machinery which is a new tool in the study of Fuglede's conjecture, developed by Nir Lev and the PI. Also, the use of completely positive matrices in the MUB-problem is again a new approach.

Summary and aims of the research for the public
Describe here the major aims of the research for an audience with average background information. This summary is especially important for NRDI Office in order to inform decision-makers, media, and others.
During the project the participants will study topics that belong to the broad field of harmonic analysis, i.e. topics in which periodicity manifests itself in one way or another. The first main topic ("the Fuglede conjecture") is concerned with properties of sets that can tile the plane (or higher dimensional spaces) by translation. The second main topic (Delsarte-type problems) is connected to the maximal possible density of packing with sets that cannot tile the space (e.g. density of sphere-packing). The third main topic examines the existence of a system of vectors of unit length with some prescribed properties.
In all of these topics the tools of Fourier analysis is indispensable.

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There is no thematic overlap between the project K132097 and our proposal. Moreover, the project K132097 will end before our project would start.

NKFI/OTKA				
Principal investigator	Participant in this proposal		FTE	
Asbóth János Károly	Zimborás, Zoltán		0.40	
Title: Quantum Error Correcting Codes				
Project identifier	Number of participants	Amount of support (HUF)	Starting year	Closing year
146806 (Finalized)	15	47946000	2024-01-01	2027-12-31

Summary:

Summary of the research and its aims for experts

Describe the major aims of the research for experts.

We plan to do theoretical and numerical research on quantum error correcting codes (quantum codes), a timely topic as quantum computer prototypes are now nearing the size and precision where these codes could become useful. We will explore the resilience of quantum codes against coherent errors, which is not fully covered by the current theory, using recently proposed numerical tools (mapping to free fermions and tensor network methods). We will suggest ways in which quantum codes can be better tailored to experimental setups, which bring both limitations and extra possiblities. Limitations here come from shared control in cross-bar architectures, necessary when scaling up solid-state quantum computers. Extra possibilities arise from the so-called “soft information”, i.e., more complete processing of the full experimental time series used in the measurement of qubits, rather than compressing the time series to a single bit of information as is standard practice, as well as from advanced post-processing of measurement outcomes as in quantum error mitigation schemes. We will explore connections of quantum codes to areas of theoretical physics, including AdS/CFT and quantum chaos, and investigate artificial dynamics defined on hyperbolic quantum codes. We will investigate how quantum codes bring an advantage to simulation of iterative quantum dynamics with measurement-induced nonlinearity, and implement this on publicly available quantum computer prototypes.

What is the major research question?

Describe here briefly the problem to be solved by the research, the starting hypothesis, and the questions addressed by the experiments.

Our research addresses timely questions about quantum error correcting codes (quantum codes).

Do coherent errors pose a serious challenge to the applicability of quantum codes? It is commonly believed that quantum codes provide protection against coherent errors, although neither current theory nor numerics apply in a rigorous sense. We plan to provide clues by intermediate-scale simulations using recently proposed numerical tools (mapping to free fermions and tensor network methods).

What are the best approaches to implement quantum codes on near-term quantum computers? How do scalable experimental solutions to the so-called wiring problem, e.g., crossbar architecture, impact the trade-off offered by quantum codes (extra quantity of qubits and number of timesteps required to compensate for low quality of quantum logic gates)? How to profit from the extra “soft” information experiments extract from each ancilla qubit during a measurement process?

How can we use hyperbolic quantum codes to learn more about the AdS/CFT correspondence, what happens to these codes when endowed with a discrete-time dynamics? Could nonlinear iterative quantum dynamical systems gain an advantage if combined with the repetition code or other quantum codes?

What is the significance of the research?

Describe the new perspectives opened by the results achieved, including the scientific basics of potential societal applications. Please describe the unique strengths of your proposal in comparison to your domestic and international competitors in the given field.

Building large-scale quantum computers is one of today’s main current technological goals, as quantum computers promise exponentantial acceleration in tasks such as simulation of chemistry for drug development and other goals. Computations here consist of millions of subsequent operations, and thus require a low error rate of the quantum logic gates at least million-fold better than the state of the art. Quantum error correcting codes (quantum codes) offer the only realistic route to achieve this, by distributing each logical qubit over several physical qubits, offering a trade-off of qubit quantity vs quality. Several types of quantum codes have been proposed, many of which build on concepts of quantum condensed matter and quantum field theory. The leading quantum code, the so-called surface code, builds on the theoretical tools developed for topological order, a topological phase of strongly interacting quantum matter. With the rapid development of quantum computing prototypes, some quantum codes have already been demonstrated experimentally, and we are near the point where they can be meaningfully applied to make quantum computations more precise.

Our theoretical research proposal aims at bringing the implementation of quantum codes closer to reality, and investigating their links to other areas of theoretical physics. We will pay special attention to the oft neglected coherent errors, whose numerical modeling requires cutting-edge theoretical tools (mapping to free fermions and tensor network methods) with which we have considerable expertise. We will go beyond the usual treatment of quantum codes in taking the limits and advantages of scalable experimental proposals (cross-bar architecture, soft information from qubit readout), building on our past and present collaboration with experimental physics groups where we model quantum hardware components, as well as on our experience with readout error mitigation. We will explore the connections of hyperbolic quantum codes with AdS/CFT and with discrete-time quantum dynamical systems, building on theoretical expertise, and explore the use of quantum codes in iterative quantum logic circuits, a unique flavor of quantum dynamical system that we have proposed.

Summary and aims of the research for the public

Describe here the major aims of the research for an audience with average background information. This summary is especially important for NRDI Office in order to inform decision-makers, media, and others.

Building large-scale quantum computers is one of today's main technological goals, as quantum computers promise exponential acceleration in tasks such as simulation of chemistry for drug development. Quantum error correcting codes (quantum codes) offer the only viable route to achieve the extremely high precision of quantum logic gates required: they distribute each logical qubit over several physical qubits, offering a trade-off of qubit quantity vs quality. The first proof-of-principle experiments have recently been performed on leading quantum computer prototypes, and we are nearing the turning point where quantum codes could be meaningfully deployed.

Our research proposal plans to 1) explore the limits of robustness offered by quantum codes, 2) find ways to adapt them to existing quantum hardware, and 3) look for their use in theoretical physics and for problems where even their small-scale implementation can be useful. We will use cutting-edge numerical approaches to assess the robustness of quantum codes against coherent errors, a class of error processes neglected in most analyses. We will explore the limitations that scalable experimental implementations bring to quantum codes, stemming from shared control as in cross-bar architectures, and the advantages that could be gained from real-world experimental qubit readout as opposed to the idealized textbook projective measurement models. We will also explore the ways in which quantum codes are related to other areas of theoretical physics (e.g., AdS/CFT correspondence or quantum chaos), and employ them for a numerical task that we proposed, already used for benchmarking quantum computers.

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The physics project OTKA K 146806 plans to investigate various aspects of quantum codes. There is no thematic overlap with our proposed project.

NKFI/OTKA				
Principal investigator	Participant in this proposal		FTE	
Zimborás Zoltán	Zimborás, Zoltán		2.20	
Title: Quantum information processing methods tailored to near-term quantum computers				
Project identifier	Number of participants	Amount of support (HUF)	Starting year	Closing year
135220 (Contract)	10	35486000	2020-12-01	2024-11-30

Summary:

Summary of the research and its aims for experts

Describe the major aims of the research for experts.

In 2019, an important intermediate milestone for quantum computing was reached by Google's researchers: the demonstration of quantum computational advantage (also termed "quantum supremacy") for a particular sampling problem. However, to achieve a useful application of near-term quantum devices is a more difficult goal, and is pursued currently around the world. Despite the tremendous technological progress in recent years, scientists will be forced to work with noisy and intermediate-scale quantum (NISQ) devices in the near future. This creates an urgent need for quantum information processing methods tailored for such devices and an underlying theory showing how to utilize these devices efficiently. Our project aims to identify possible error characterization and mitigation techniques and finding optimal implementation of useful quantum protocols in such near-term devices. In particular, our goal is to introduce new methods of benchmarking and manipulating noisy multiqubit systems. At the same time, we will be exploring heuristic quantum gate decomposition methods tailored to the native gates of NISQ devices and study the error tolerance of variational routines with the hope of a possible implementation in the near future.

What is the major research question?

Describe here briefly the problem to be solved by the research, the starting hypothesis, and the questions addressed by the experiments.

The major research question that our project eventually strives to answer is this: What could be a realistic proposal for a useful quantum algorithm that would be experimentally implementable within the next few years? The identification of such feasible quantum algorithms would, of course, be a big breakthrough in quantum computing. However, even if we don't achieve this overly ambitious goal, we hope to at least pinpoint a few quantum information processing primitives that are both experimentally achievable, and usable as a building block for the solutions of other problems. Our main research hypothesis is that we can make progress in this direction if we tailor all the elements of a quantum information protocol to the particular features of NISQ-devices. Accordingly, we approach the targeted breakthrough question in a modular way: first we aim to develop efficient noise benchmarking and mitigation schemes adapted for existing quantum processor architectures; next we intend to establish gate compilation schemes knowing the native gates of the device; and finally, we apply both the error mitigation and novel compilation methods for the most popular variational circuits (QAOAs and VQEs), which we have singled out as possible candidates for feasible and useful quantum algorithms. This way, we hope to establish a road towards practical quantum computation that could also lead to some partial results in the short-term.

What is the significance of the research?

Describe the new perspectives opened by the results achieved, including the scientific basics of potential societal applications. Please describe the unique strengths of your proposal in comparison to your domestic and international competitors in the given field.

In view of how different quantum computing technology is from the information technology we use today, we have only a very limited ability to glimpse into its future. However, as with any comparable technology (e.g., classical computers or the internet), its future impact cannot be underestimated. In the case of our research proposal, the choice of studying variational circuits such as QAOA or VQE is a natural one,

as it can be projected that they will have practical applications in fields such as quantum chemistry and machine learning. Both of these are deeply connected to society. New methods in quantum chemistry would be readily employed by the pharmaceutical industry. Similarly, machine learning techniques are used everywhere, from social media and search engines to applications in industry, such as automated driving. Therefore, the study of these variational circuits could lay the groundwork of many future projects. Of course, we should mention that our project will be just a small, although hopefully meaningful, step towards practical quantum computing.
The unique strength of our proposal lies in the fact that unlike many of our competitors working in quantum computation, we underline a need to adopt our research to near-term quantum computers instead of the full-fledged, fault-tolerant quantum computers of the future, without, however, limiting ourselves to producing interim methods. On the contrary, we believe that tailoring the error characterization and mitigation techniques, as well as the gate compilation methods to the native gates of the devices will yield an ideal balance of short- and long-term applicability. Our team has the added advantage that it comprises researchers with different backgrounds, thus combining a firm grasp of the fundamental aspects of quantum computing with a know-how of real-life implementability.

Summary and aims of the research for the public
Describe here the major aims of the research for an audience with average background information. This summary is especially important for NRDI Office in order to inform decision-makers, media, and others.
From the discovery of quantum physics, the first quantum revolution emerged, which brought technologies such as lasers, transistors (the main components of computers), MRI and many more. We are on the brink of a second quantum revolution focused on the quantum computer. This machine uses quantum bits, qubits (as opposed to bits in a classical computer) to do computation. There are programs that can only run on these types of machines and can achieve results inconceivable to classical computers. It is unclear how far we are from full-fledged, fault-tolerant quantum computing, where it will be possible to control large numbers of qubits at the individual level. Nevertheless, we are now in a pivotal new period of quantum technology, the era of the Noisy Intermediate-Scale Quantum (NISQ) devices. There are devices available now with a number of qubits ranging from 20 to 60, and in the near future this could rise to a few hundred. Due to the nature of quantum physics, we have imperfect control over these qubits, and noise (interference) places serious limitations on what they can achieve. Therefore, new ideas are needed to fully realize the potential of this technology. To investigate practical applications of such devices, we have to introduce new methods of control, manipulation and benchmarking of noisy multiqubit systems. This is the aim of our proposal. The topics of our research range from designing better quantum compilers (methods to translate programs into physical processes in the computer) tailored for NISQ devices to understanding the limits of noisy quantum computers, and thus implement new certification schemes for quantum processors.

:
The aim of OTKA FK 135220 is to study error mitigation and the implementation of quantum algorithms on noisy intermediate scale quantum devices. Both its aims and its methods are very different from our proposal's. (Joint participants: Zoltán Zimborás and Mihály Weiner).

NKFI/OTKA				
Principal investigator	Participant in this proposal		FTE	
Kiss Tamás	Zimborás, Zoltán		1.13	
Title: Dynamics and measurement in coherent and open quantum information networks				
Project identifier	Number of participants	Amount of support (HUF)	Starting year	Closing year
124351 (Contract)	17	38826000	2017-09-01	2022-12-31

Summary:
Summary of the research and its aims for experts
Describe the major aims of the research for experts.
In the last decade, we have witnessed a vast development in the experimental and theoretical study of coherent quantum systems with a few degrees of freedom. It is anticipated that these systems will find practical applications in quantum sensing and measurement, quantum communication and quantum simulation: in the newly emerged field of quantum technology. From the point of view of these applications, it is of vital importance to be able to control and understand the dynamics of increasingly large complex quantum systems that are built up of smaller ones. The ultimate aim is to connect the building blocks in a manner where both coherence and control are sustained as much as possible, thereby scaling up the desired quantum effects. Therefore, it is crucial to understand the processes leading to decoherence in such quantum systems and, especially, to understand the evolution of open quantum systems influenced by noise and/or measurements. The goal of the present project is to better understand the behaviour of various networks of quantum systems under the influence of environmental noise, measurements and conditional feedback from measurements.

What is the major research question?
Describe here briefly the problem to be solved by the research, the starting hypothesis, and the questions addressed by the experiments.
How do complex quantum networks behave under the influence of random environmental changes? How do measurements performed on a quantum network affect its behaviour? The aim of the project is to approach these problems from various viewpoints.

How do the recurrence and spreading properties of a quantum walk with coherent or open evolution (dynamical percolation) change if the graphs have nontrivial topology? Does disorder-induced delocalization appear in quantum walks with no symmetries, or in higher dimensional quantum walks? How do distributed multipartite quantum systems evolve under pairwise Hamiltonian coupling and various types of environmental noise or weak measurements? What happens to entanglement here? How can one optimally reveal the quantum state prepared in quantum networks from measurements? What sort of correlation structures can emerge in the most general case from distributed quantum states? What are the correct definition and properties of quantum dynamical entropy? How does the measurement conditioned evolution affect the quantum state? When can we use the emerging nonlinear dynamics for quantum state discrimination? Can we reveal the bulk topological invariant with periodic measurements in higher dimensional chiral symmetric quantum walks? What is the optimal way to create a single-photon source by spatial and time multiplexing? How can one devise a scheme for simulating interactions between photons using conditional dynamics in time multiplexed implementations of quantum walks?

What is the significance of the research?
Describe the new perspectives opened by the results achieved, including the scientific basics of potential societal applications. Please describe the unique strengths of your proposal in comparison to your domestic and international competitors in the given field.
Scaling up the system size while maintaining coherence is one of the key problems when we speak about possible applications in quantum technology. Truly coherent large quantum systems would be able to carry out computational or communicational tasks with fundamentally enhanced efficiency. Environmental noise and decoherence are not only a technical obstacle, but are intimately related to the foundational problems of quantum mechanics, the so-called measurement problem. Measurements cause an unavoidable disturbance in a quantum system but also provide information which, in turn, can be used for feedback and selection. Better understanding of the resulting dynamics in a network of quantum systems can serve as a basis for designing tools for quantum technological applications.

Project participants have great expertise in open systems research, some of them are pioneers in some subfield. We possess a variety of analytical and numerical methods (solution of quantum stochastic equations, finding the asymptotic attractors of finite-dimensional iterated open quantum systems, construction of entanglement witnesses, tomographic methods for quantum state reconstruction, etc.) and in this project we plan to combine these methods in a systematic way for the treatment of the above problems.

Summary and aims of the research for the public
Describe here the major aims of the research for an audience with average background information. This summary is especially important for NRDI Office in order to inform decision-makers, media, and others.
Quantum technology, the new field which emerged from quantum information theory and related fields (quantum sensing and measurement, quantum communication and quantum simulation), has received great attention lately. Systems, applying quantum cryptography are already commercially available, and industrial companies like Microsoft and Intel have increased their investments in the development of potential quantum computer hardwares. The question arises at the short term already: Building up bigger systems from the currently available simple quantum elements while maintaining their coherent quantum behaviour, what tasks will one be able to complete? Besides the expected practical significance of these systems, we may be able to answer questions of fundamental interest: What novel dynamical phenomena appear in such networks? How does the quantum mechanical measurement affect the behaviour of the networks? How do the essentially quantum features (e.g. entanglement) behave when the system evolves coherently or when it becomes an open system (for instance due to the random behaviour of its environment or to the mesurement performed on it)? Answering these questions holds the promise of discovering new dynamical behaviours which may be applicable for communication, information processing or sensing with fundamentally enhanced efficiency.

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There is no thematic overlap between the physics project OTKA K 124351 and our proposal. Moreover, OTKA K 124351 will end before the expected start of our project.

NKFI/OTKA				
Principal investigator	Participant in this proposal		FTE	
Penc Karlo	Zimborás, Zoltán		1.73	
Title: Magnetism, topology, and entanglement in quantum insulators				
Project identifier	Number of participants	Amount of support (HUF)	Starting year	Closing year
124176 (Contract)	10	20362000	2017-11-01	2022-11-30

Summary:
Summary of the research and its aims for experts
Describe the major aims of the research for experts.
The ongoing experimental pursuit in material science and artificial systems such as ultracold quantum gases provide inexhaustible sources of unexplained new phenomena. Strong correlations lead to formation of Mott insulators where the relevant degrees of freedom are localized on the transition metal ions or ultracold atoms sitting at lattice sites generated by crossing laser beams. These degrees of freedom are usually electron spins in lighter and entangled spin-orbital states in heavier transition metal compounds, or nuclear spins in case of ultracold atoms. Competing interaction between such localized degrees of freedom may lead to highly entangled quantum mechanical states, referred to as spin liquid.

An entangled quantum spin liquid is characterized by properties it does not have. It does not conduct electricity, does not order magnetic, and does not break local symmetry of any kind, making experimental observations difficult, to say the least. A quantum spin liquid has, however, topology and therefore, fractionalization, emergent gauge fields and long-range entanglement enabling new alternative routes to detect fingerprints of these elusive phases.

Apparently, many novel phenomena arising in correlated electron systems can be (only) formulated and answered in the language of topology. Therefore, our proposal is centered around the role that topology plays in insulating quantum systems. We aim to describe both general and system specific properties of strongly correlated insulators with nontrivial magnetic and topological phases, focusing on the emergence of topology in the dynamical and ground state properties in both quantum and classical spin systems.

What is the major research question?
Describe here briefly the problem to be solved by the research, the starting hypothesis, and the questions addressed by the experiments.
Our purpose is to deeper our understanding of the role of topology in the formation of quantum spin liquid states and in the emergence of non-trivial excitations.

The key questions are related the underlying topology of quantum systems and its consequences: How is topology involved in the physics of frustrated, multi-orbital, or SU(N) symmetrical systems. How can we import the desired topological properties of non-interacting models when electron-electron correlations become important? Do we need to play by certain rules to obtain topologically non-trivial properties in quantum magnets, and if yes, what are the conditions? How is topology related to entangled quantum ground states of magnets, such as the spin liquid state?

We address the following specific problems:

1) How can we describe the excitations in a SU(N) chiral phase. Are they related to anyons, and do they have non-abelian braiding statistics?

2) We have seen a few examples of materials and models showing thermal Hall effect, when the magnetic excitations are deflected by external magnetic field. What are the general symmetry requirements behind the phenomenon?

3) Recently, skyrmions have been realised in a multiferroic materials. How can we manipulate skyrmions is such a material using electric field?

4) How can we use quantum entanglement to distinguish topological properties of a state?

5) How can we construct SU(N) phases using tensor networks with minimal tensor dimensions? How can we characterise them using the projective symmetry group?

What is the significance of the research?
Describe the new perspectives opened by the results achieved, including the scientific basics of potential societal applications. Please describe the unique strengths of your proposal in comparison to your domestic and international competitors in the given field.
Topological properties of magnetic excitations has mostly been discussed in cases of spin-half materials such as $Lu_2V_2O_7$. We propose the generalization of topological excitations to larger spin multiplets. If they appear in a material with a space group symmetry which supports magnetoelectric coupling, the topologically protected magnetic edge states may be manipulated by external electric fields. Therefore, asides from being fundamentally appealing, they may be important for potential technological uses.

Although the theoretical study of magnetic and electronic behaviour of fascinating new materials such as heavy-fermion compounds is material specific, the proposed models in most cases contain novel phenomena. The numerical study of certain Sm-based compounds deepens our knowledge on charge Kondo effect which is much less studied compared to the conventional spin Kondo effect. Such impurity models are also of relevance to describe physics in quantum dots. The energy levels in the quantum dot correspond to the impurity levels, which are connected to external leads via different geometries. Our simulations may provide guiding principles to engineering such quantum dots in nanotechnological devices.

In heavy transition metal compounds the Coulomb interaction and spin-orbit coupling cooperate to realize the insulating phase. The strength of electron-electron correlations decides whether we end up with a novel quantum spin liquid phases or a topological insulator. Compounds accommodating such phases are commonly discussed in terms of effective spin Hamiltonians, neglecting the higher energy modes. The multiboson theory, developed by our group, is a suitable method to discuss both the low and high energy spin and orbital degrees of freedom in a unified framework, allowing for the interpretation of wide range of energy resolved spectroscopy experiments.

Studies of spin-relaxation mechanisms proposed in this project will determine which material is applicable for spintronics implementations, in particular for information carrying, processing and storing.

Summary and aims of the research for the public
Describe here the major aims of the research for an audience with average background information. This summary is especially important for NRDI Office in order to inform decision-makers, media, and others.
In classical views, the laws of physics were said to exhibit certain symmetries. Today the concept is reversed: the laws of nature follow

from the principles of invariance, symmetry is dictating the rules. In modern physics, augmenting the concepts of symmetry, a new paradigm has appeared in the form of topology. The notion of topology in physics has revolutionized the theory of phase transitions enabling us to distinguish between phases of the same symmetry. A renowned example is the integer quantum Hall effect, in which the integers appearing in the Hall conductance are examples of topological quantum numbers, known as the first Chern numbers. The importance of topology in physics has been recognized by awarding the Nobel prize "for discoveries of topological phase transitions and topological phases of matter".

This novel angle of contemporary physics is what we address in our proposed research. To understand topological properties emerging in materials and artificial quantum systems is fundamentally important in its own right. Furthermore, its robustness against small perturbations, such as defects and impurities inevitable in real materials, makes topologically protected phases uniquely desirable for applications. It is believed that the excitations in some topological phases can bear quantum numbers which can be used for quantum computing. Manipulation of such excitations with external fields is essential for construction of a quantum computing device. We will explore the properties of such excitations and their interaction with electric and magnetic fields.

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There is no thematic overlap between the physics project OTKA K 124176 and our proposal. Moreover, OTKA K 124176 will end before the expected start of our project.

MTA Lendület				
Principal investigator	Participant in this proposal		FTE	
Dr. Milán Mosonyi	Mosonyi, Milán		2.50	
Title: Quantum Shannon theory				
Project identifier	Number of participants	Amount of support (HUF)	Starting year	Closing year
Lendület_2023-17	9	250000000	2023-09-01	2028-08-31

Summary:

This is an application under evaluation. While it overlaps with the present application OTKA K 146380 both in topics and in participants, the structure of the two funding schemes are completely different and serve different purposes. The proposed annual budget of the OTKA K 146380 application is about 8.000.000 HUF (20.000 EUR), of which roughly 3.500.000 HUF (9.500 EUR) goes towards research expenses, and about 2.000.000 HUF (5.400 EUR) to a small salary top-up for students and young researchers. In contrast, the proposed annual budget of Lendület_2023-17 is 50.000.000 HUF (135.000.000 EUR), of which 4.700.000 HUF (12.600 EUR) goes towards research expenses, and 30.000.000 HUF (80.000 EUR) goes towards the full-time or part-time employment of researchers, which is the main purpose of the Lendület application. The success of the Lendület application would guarantee the continuation of the group with roughly the same conditions as in the past five years (or a bit below that, taking into account the drastic change in prices in the past years), while if both applications succeed, that might enable a slight extension of the group (e.g., the continued employment of the current PhD students after graduation as young researchers, and the employment of new PhD students).

MTA Lendület				
Principal investigator	Participant in this proposal		FTE	
Mosonyi Milán	Mosonyi, Milán		2.50	
Title: Quantum divergences and their role in quantum information theory				
Project identifier	Number of participants	Amount of support (HUF)	Starting year	Closing year
96141	11	175000000	2018-09-01	2023-08-31

Summary:

This grant has provided the main funding of our research group in the past five years; however, it ends on 31 August 2023, well before the planned starting date 01 January 2024 of the proposed project OTKA K 146380.

Closed OTKA/NKFIH projects' details

Project identifier	Principal investigator	Starting year	Closing year	
46599	Petz, Dénes	2004-01-01	2007-12-31	10 (excellent)
Title: Linear analysis and its applications				
68258	Petz, Dénes	2007-07-01	2011-06-30	10 (excellent)
Title: Inequalities in information theory				
49835	Fritz, József	2005-01-01	2008-12-31	9 (excellent)
Title: Randomness in Space and Time				
104206	Matolcsi, Máté	2012-09-01	2017-08-31	10 (excellent)
Title: Research and application of matrices				
124152	Mosonyi, Milán	2017-09-01	2022-08-31	10 (excellent)
Title: Trade-off relations and divergences in quantum information theory				
129601	Mosonyi, Milán	2018-12-01	2021-11-30	10 (excellent)
Title: Mathematical Analysis of Quantum Communication Problems				
42769	Böröczky, Károly	2003-01-01	2006-12-31	10 (excellent)
Title: Algebraic Geometry				
46365	Szenes, András	2004-01-01	2009-06-30	10 (excellent)
Title: Symmetry and Group Actions in Algebraic Topology				
61116	Szamuely, Tamás	2006-02-01	2010-06-30	10 (excellent)
Title: Algebraic Geometry and Its Neighbouring Fields				
72523	Pálfy, Péter Pál	2008-04-01	2011-06-30	10 (excellent)
Title: Groups and other algebraic structures				
109684	Abért, Miklós	2013-09-01	2018-08-31	10 (excellent)
Title: Stochastic processes on graphs and groups				
43159	Vecsernyés, Péter	2003-01-01	2006-12-31	8 (well satisfied)
Title: Investigations in low dimensional quantum field theory				

Budget table			
		NKFI registration number:	
		Identifier:	146380
Principal investigator:	Dr. Mosonyi, Milán		
Title:	Mathematical problems in quantum information theory		
Institution:	Department of Mathematical Analysis (Budapest University of Technology and Economics)		
Duration:	48	Duration:	2024-01-01 - 2027-12-31

	Cost (in Forint)	2024.01.01 -2024.12.31	2025.01.01 -2025.12.31	2026.01.01 -2026.12.31	2027.01.01 -2027.12.31	Total
1	Personnel	3 907 000	3 907 000	2 890 000	2 890 000	13 594 000
2	Travel and consumables	3 250 000	3 250 000	3 250 000	3 250 000	13 000 000
3A	Overhead	715 000	795 000	614 000	614 000	2 738 000
3B	Open Access costs	715 000	795 000	614 000	614 000	2 738 000
4	Operational costs (1+2+3A+3B)	8 587 000	8 747 000	7 368 000	7 368 000	32 070 000
5	Equipment	0	800 000	0	0	800 000
6	Total costs (1+2+3A+3B+5)	8 587 000	9 547 000	7 368 000	7 368 000	32 870 000

Total costs/FTE (HUF)	3 445 493
Personnel costs/FTE: (1)/FTE	1 424 948
Travel and consumable costs/FTE: (2)/FTE	1 362 683
Equipment costs/FTE: (5)/FTE	83 857

Justification of personnel costs
In the first two years we plan a gross monthly salary of 75.000 HUF (cca. 200 EUR) to two student participants each (Gábor Maróti and Zsombor Szilágyi) and to one of the senior researchers (Mihály Weiner). In the second two years, we plan the same amount to Gábor Maróti and Zsombor Szilágyi, who are by then expected to finish their PhDs and join the project as junior researchers. These amounts are top-ups to the scholarships/salary of the respective participants. The exact amounts and their distribution might change depending on additional financial sources. A monthly gross salary of 35.000 HUF (cca. 93 EUR) is planned for a secretary for the administrative management of the project. An annual gross amount of 350.000 HUF (cca. 930 EUR) is planned for per diem of conference visits; approx. 15.000 HUF (40 EUR) per day, covering 4 conference trips of 6 days.

Justification of travel and consumable costs
We plan 3.000.000 HUF (cca. 8.000 EUR) per year to cover the expenses of work trips (travel, accommodation, registration fee). Of this, about 1 - 1.2 million HUF will be used for the expenses of a workshop that we plan to organize annually in Budapest, while the rest goes towards the work trips of the project participants. With the price of a single trip varying between 0 HUF (invited, with full expenses covered by host) and 800.000 HUF (overseas conference with high registration fee), we expect to be able to cover about 1-2 conference trips per participant per year. 250.000 HUF (cca. 670 EUR) per year is planned for the expenses of the conference dinner and the coffee breaks of the workshop that we plan to organize in Budapest.

Justification of equipment costs
In the second year, we plan to buy two laptops, for about 400.000 HUF (cca. 1070 EUR) each.