Abstracts of the contributions to "Ergodicity Breaking and Integrability in Long-Range Systems and on Random Graphs"

Name	Surname	Type	Format	Title	Abstract
Yevgeny	Bar Lev	invited	in person	*Transport in long-range interacting systems*	
Eugene	Bogomolny	invited	in person	*Statistical properties of quantum barrier billiards*	Barrier billiards are the simplest but non-trivial examples of pseudo-integrable models. The talk is devoted to the discussion of recent analytical calculations of spectral properties of eigenvalues and eigenfunctions for barrier billiards. The main result is that their spectral statistics is independent on the barrier position and is well described by the semi-Poisson distribution.
Alexander	Burin	invited	in person	*Many body localization in the presence of the long-range power law interaction*	Many-body localization is considered in the system with power law interactions. The dependence of critical disorder on the system size and the nature of localization transition are discussed.
John	Chalker	invited	in person	*The statistical properties of eigenstates in chaotic many-body quantum systems*	The established understanding of the statistical properties of eigenstates in chaotic many-body systems is represented by the eigenstate thermalisation hypothesis. The ETH describes how these properties vary with energy, in terms of the statistics of matrix elements of local observables between eigenstates of the Hamiltonian. However, it takes account of spatial structure only in limited ways. I will describe work intended to complement the ETH by focussing on correlations between eigenstates that are specific to spatially extended systems and that lie outside this established ETH framework. We propose a maximum-entropy Ansatz for the joint distribution of n eigenvectors. In the case n=2 this Ansatz reproduces ETH. For n=4 it captures both the growth in time of entanglement between subsystems, as characterised by the purity of the time-evolution operator, and also operator spreading, as characterised by the behaviour of the out-of-time-order correlator. We test these ideas by comparing results from Monte Carlo sampling of our Ansatz with exact diagonalisation studies of Floquet quantum circuits. Joint work with Dominik Hahn (MPIPKS Dresden) and David Luitz (Bonn)
Robin	Kaiser	invited	online	*Resonant dipole-dipole interactions: Dicke subradiance and Anderson localisation*	The quest for Anderson localization of light is at the center of many experimental and theoretical activities. Cold atoms have emerged as interesting quantum system to study coherent transport properties of light. Initial experiments have established that dilute samples with large optical thickness allow studying weak localization of light, which has been well described by a mesoscopic model. Recent experiments on light scattering with cold atoms have shown that Dicke super- or subradiance occurs in the same samples, a feature not captured by the traditional mesoscopic models. The use of a long range microscopic coupled dipole model allows to capture both the mesoscopic features of light scattering and Dicke super- and subradiance in the single photon limit. I will review experimental and theoretical state of the art on the possibility of Anderson localization of light by cold atoms.
Manuel	Pino Garcia	invited	in person	*Scaling up the Anderson transition in random-regular graphs*	We study the wavefunctions of a particle hopping on a random-regular graph at the metallic side of the Anderson transition. We use a polynomial filter to numerically obtain eignestates at the middle of the spectrum for sizes up to a few million. We compute the first two and infinite moments of the probability associated to each wavefunctions and their corresponding fractal derivatives. Our results show that fractal dimensions are continuous across the Anderson transition, but a discontinuity occurs on their derivatives, implying the existence of a nonergodic metallic phase with multifractal eigenstates. Our data at small disorder also supports the existence of a weak multifractal given by a smaller than one infinite moment fractal dimension, up to lengths $N = 4 \cdot 10^6$.

Valentina	Ros	invited	in person	*Fluctuation-driven transitions in insulators: Intermittent metallicity and path chaos*	I this talk I will discuss a simple toy model aimed at capturing the interplay between the quenched disorder and some slow, thermally induced fluctuations affecting the effective local disorder of the system. I will summarise the rich phenomenology brought about by these additional fluctuations, stressing in particular the connections to the unfreezing transition and configurational chaos in the simplest models of glassy systems. The talk is based on joint work with M. Mueller.
Luis	Santos	invited	in person	*Dynamics and localization in polar lattice gases*	In this talk, I will summarize some of our recent works on the dynamics of polar lattice gases, formed by ultra-cold dipolar atoms or molecules in optical lattices, in which strong inter-site interactions result in an intriguing new physics. On one hand, dipole-mediated interactions between polar particles pinned at the lattice sites may be employed to simulate spin models with a power-law exchange. I will first briefly comment on localization and multi-fractality of single spin excitations, and then move to the case of many-excitations in the presence of disorder, for which an unexpected universal algebraic growth of entanglement entropy is observed in many-body localized systems. On the other hand, itinerant polar particles realize different forms of the extended Hubbard model. Inter-site interactions significantly handicap particle dynamics in polar lattice gases even for relatively modest dipolar strengths. I will first illustrate this with a brief discussion on dynamically-bound dimers. I will then discuss how the decay tail of the dipolar interaction results in Hilbert-space shattering and disorder-free non-ergodic dynamics under conditions which may be soon available in experiments. Finally, I will briefly comment on how, under rather general experimental conditions, the actual inter-site interaction departs from the usual dipolar power-law dependence. This may be very relevant in actual experiments, in which the dynamics will rather mimic that of a system with an externally controllable power law.
Antonello	Scardicchio	invited	in person	*Universality in the Anderson transition on random graphs*	
Marco	Tarzia	invited	in person	*Loop expansion around the Bethe approximation for the Anderson model*	
Ward	Vleeshouwers	invited	in person	*Unitary matrix integrals and applications to long range random walk models*	The connections between matrix models and random walks are manifold and have been extensively explored over the past decades. In this talk, I will treat the application of unitary matrix integrals over Schur polynomials to long range random walk models. We derive various novel identities on such integrals which, together with well-known identities on symmetric polynomials, can be directly applied to long range random walks. These results can be checked in experimental setups, and can also be applied to the benchmarking thereof.
Matthias	Weidemueller	invited	in person	*Does an isolated quantum spin system thermalize?*	Understanding how closed quantum systems dynamically approach thermal equilibrium presents a major unresolved problem in statistical physics. Generically, it is expected that non-integrable quantum systems thermalize as they comply with the Eigenstate Thermalization Hypothesis (ETH). A notable exception to this is the phenomenon of many-body localization, where the emergence of local conserved quantities prevents thermalization, which has been observed in finite low-dimensional systems. We study an ensemble of Heisenberg spins with a tunable distribution of random coupling strengths realized by a Rydberg quantum simulator. The total magnetization as a function of external field after a quench serves as a probe for thermalization, showing striking non-analytic behavior at zero field. We find that such an isolated quantum system exhibits a non-thermalizing regime despite being non-integrable. It is shown that thermalization can be restored by reducing the disorder in the coupling strengths. As our system consists of up to 4000 spins, we show that closed quantum systems can fail to reach thermal equilibrium even at system sizes approaching the thermodynamic limit [1]. [1] T. Franz et al., arXiv:2207.14216 (2022)
Martin	Zirnbauer	invited	in person	*Field theory of Anderson transitions at strong coupling: scenario of spontaneous symmetry breaking*	

Soumi	Ghosh	contributed	online	*Spectral properties of disordered interacting non-Hermitian systems*	Localization and non-ergodicity in many-body disordered systems have been studied quite extensively in recent years. Very recently, localization has been discussed in the context of interacting disordered non-Hermitian many-body systems. In this talk, I will discuss such many-body systems and analyze their chaotic behavior or lack of it through the lens of recently introduced non-Hermitian analog of the spectral form factor and the complex spacing ratio. I will discuss three widely relevant non-Hermitian models, two of which are short-range with different symmetries. The third model is long-ranged whose Hermitian counterpart has been investigated. We show that at relatively weak disorder, all these models exhibit a deep connection with the non-Hermitian random matrix theory of corresponding symmetry classes. On the other hand, at relatively strong disorder, the models show the absence of complex eigenvalue correlation, thereby, corresponding to Poisson statistics.
Alexander	Gorsky	contributed	in person	*New findings for localization on RRG*	
Gabriel	Lemarie	contributed	online	*The Anderson transition in random graphs: Kosterlitz-Thouless type flow and MBL transition*	The Anderson transition in random graphs has raised great interest, partly because of its analogy with the many-body localization (MBL) transition. Unlike the latter, many results for random graphs are now well established, in particular the existence and precise value of a critical disorder separating a localized from an ergodic delocalized phase. However, the renormalization group flow and the nature of the transition are not well understood. In turn, recent works on the MBL transition have made the remarkable prediction that the flow is of Kosterlitz-Thouless type. In this talk, we will show that the Anderson transition on graphs displays the same type of flow. Our work attests to the importance of rare branches along which wave functions have a much larger localization length ξ∥ than the one in the transverse direction, ξ⊥. Importantly, these two lengths have different critical behaviors: ξ∥ diverges with a critical exponent ν∥=1, while ξ⊥ reaches a finite universal value ξ⊥c at the transition point Wc. Indeed, ξ⊥^{-1}≈ξ⊥c^{−1}+ξ^{−1}, with ξ~(W−Wc)^{−ν⊥} associated with a new critical exponent ν⊥=1/2, where exp(ξ) controls finite-size effects. The delocalized phase inherits the strongly non-ergodic properties of the critical regime at short scales, but is ergodic at large scales, with a unique critical exponent ν=1/2. This shows a very strong analogy with the MBL transition: the behavior of ξ⊥ is identical to that recently predicted for the typical localization length of MBL in a phenomenological renormalization group flow. We demonstrate these important properties for a smallworld complex network model and show the universality of our results by considering different network parameters and different key observables of Anderson localization.
Sthitadhi	Roy	contributed	online	*Hilbert-space correlations and bipartite entanglement*	The structure of quantum state amplitudes on the Hilbert-space graph is fundamental to the states' ergodicity or lack thereof. The fractal dimension of the states is often used as a marker of ergodicity. In this talk, I will describe how appropriate Hilbert-space correlations can be used to understand the entanglement properties of quantum states. These correlations go beyond the notion of multifractality. As such they can be used to distinguish between ergodic states with volume-law entanglement, multifractal states with volume-law entanglement, and multifractal states with area-law entanglement. I will demonstrate these in two settings, one of many-body localised systems and the other of hybrid quantum circuits.
Jing	Yang	contributed	in person	*One-Dimensional Integrable Systems from the Jastrow Wave Functions*	Integrable many-body models are very rare yet valuable in physics. In one dimension, they are typically solved by Bethe ansatz. In this work, we construct an infinite family of many-body Hamiltonians describing quantum many-body models with ground state of Jastrow form, which includes the famous Lieb-Liniger model and the family of Calogero-Sutherland-Moser models as

					special cases. The approach also allows embedding the model in an external trap. Furthermore, by constructing the integrals of motion explicitly, we prove that any Hamiltonian belonging to this class is integrable. Remarkably, we find upon supplementing with proper long-range interactions, integrability can be still preserved when embedding in an external potential, which would otherwise break integrability. We also provide a user guide of how to generate such an integrable family of models. Reference: [1] arXiv:2204.12792 (2022).
David	Aceituno Chavez	Poster	in person	Slow growth of number entropy in the the Many-Body Localized phase from the l-bit picture.	It has been put forward in recent years that the slow (log-log) growth of the number entropy that is observed in quenches of disordered quantum systems is a sign of delocalization for any finite disorder strength. This existence of a MBL phase in the thermodynamic limit. We study the number entropy in a system which is MBL by construction. We are able to reach long time scales by time-evolving directly in the basis of local integrals of motion (l-bits), before evaluating the particle-number fluctuations in real space. We find that the slow growth, consistent with log-log, is also present in this framework. This growth originates from the exponential decay of the l-bits, and is therefore a feature of the MBL phase.
Wouter	Buijsman	Poster	online	Circular Rosenzweig-Porter random matrix ensemble	Random matrix theory provides a powerful tool for studying transitions from ergodic to non-ergodic phases in complex quantum systems. A well-established phenomenological model for many-body localization in static (time-independent) systems is provided by the Rosenzweig-Porter (RP) random matrix ensemble. This single-parameter ensemble is analytically tractable, and covers both an ergodic, delocalized yet non-ergodic, and localized phase. As such, it serves as one of the simplest models for the level statistics and fractality of eigenstates across the many-body localization transition. Motivated by the observation of many-body localization in periodically driven (Floquet) systems, we propose a unitary ("circular") analogue of the RP random matrix ensemble. Like Floquet operators, this ensemble consists of unitary matrices with the eigenvalues located on the unit circle in the complex plane. Similar to the role of the RP random matrix ensemble for static systems, this ensemble provides a model for the many-body localization transition in Floquet systems. We define our ensemble as the outcome of a Dyson Brownian motion process. We provide analytical arguments and show numerical evidence that this ensemble shares key statistical properties with the RP ensemble for both the statistics of the eigenvalues and the eigenstates in each of the phases.
Adway	Das	Poster	online	Non-ergodicity in the beta ensemble	Matrix models showing a chaotic-integrable transition in the spectral statistics are important for understanding many-body localization (MBL) in physical systems. One such example is the β ensemble, known for its structural simplicity. However, eigenvector properties of the β ensemble remain largely unexplored, despite energy level correlations being thoroughly studied. In this work we numerically study the eigenvector properties of the β ensemble and find that the Anderson transition occurs at $\gamma = 1$ and ergodicity breaks down at $\gamma = 0$ if we express the repulsion parameter as $\beta = N^{-\gamma}$. Thus, other than the Rosenzweig-Porter ensemble (RPE), the β ensemble is another example where nonergodic extended (NEE) states are observed over a finite interval of parameter values ($0 < \gamma < 1$). We find that the chaotic-integrable transition coincides with the breaking of ergodicity in the β ensemble but with the localization transition in the RPE or the 1D disordered spin-1/2 Heisenberg model. As a result, the dynamical timescales in the NEE regime of the β ensemble behave differently than the latter models.
Roopayan	Ghosh	Poster	online	Resonance induced growth of number entropy in strongly disordered systems	We study the growth of the number entropy in one-dimensional number-conserving interacting systems with strong disorder, which are believed to display many-body localization. Recently a slow and small growth of number entropy has been numerically reported, which, if holding at

					asymptotically long times in the thermodynamic limit, would imply ergodicity and therefore the absence of true localization. By numerically studying the number entropy in the disordered isotropic Heisenberg model we first reconfirm that, indeed, there is a small growth. However, we show that such growth is fully compatible with localization. To be specific, using a simple model that accounts for expected rare resonances we can analytically predict several main features of numerically obtained number entropy: trivial initial growth at short times, a slow power-law growth at intermediate times, and the scaling of the saturation value with the disorder strength.
Asmi	Haldar	Poster	online	Suppression of Heating in Clean Interacting Floquet Quantum Matter	We consider a clean quantum system subject to strong periodic driving. The existence of a dominant energy scale, can generate considerable structure in an effective description of a system that, in the absence of the drive, is nonintegrable and interacting, and does not host localization. In particular, we uncover points of freezing in the space of drive parameters (frequency and amplitude). At those points, the dynamics is severely constrained due to the emergence of an almost exact, local conserved quantity, which scars the entire Floquet spectrum by preventing the system from heating up ergodically, starting from any generic state, even though it delocalizes over an appropriate subspace. At large drive frequencies, where a naïve Magnus expansion would predict a vanishing effective (average) drive, we devise instead a strong drive Magnus expansion in a moving frame. There, the emergent conservation law is reflected in the appearance of the “integrability” of an effective Hamiltonian. These results hold for a wide variety of Hamiltonians, including the Ising model in a transverse field in any dimension and for any form of Ising interaction. The phenomenon is also shown to be robust in the presence of two-body Heisenberg interactions with any arbitrary choice of couplings. Furthermore, we construct a real-time perturbation theory that captures resonance phenomena where the conservation breaks down, giving way to unbounded heating. This approach opens a window on the low-frequency regime where the Magnus expansion fails.
Anton	Kutlin	Poster	in person	Anatomy of eigenstates distribution: a quest for a genuine multifractality	Due to a series of recent works, an interest in multifractal states has risen as they are believed to be present in the MBL phase. Inspired by the success of the Rosenzweig-Porter (RP) model with normally distributed transition amplitudes, a similar ensemble but with the fat-tailed distributed amplitudes was proposed, with claims that it must host the desired multifractal phase. In the present work, we develop a general (graphical) approach allowing a self-consistent analytical calculation of the spectrum of eigenstate's fractal dimensions for various RP models and investigate what features of the RP Hamiltonians can be responsible for the multifractal phase emergence. We conclude that the only feature contributing to a genuine multifractality is the on-site energies distribution, meaning that no random matrix model with uniformish diagonal and uncorrelated off-diagonal disorder can host a multifractal phase and hence model a true MBL.
Youcef	Mohdeb	Poster	in person	Logarithmic Growth of Entanglement Entropy in Disordered Spin Chains with Tunable Range Interactions	The non-equilibrium dynamics of disordered many-body quantum systems after a global quench unveils important insights about the competition between interactions and disorder, yielding in particular an insightful perspective on many body localization (MBL). Still, the experimentally relevant effect of sole bond randomness in long-range interacting spin chains on the quench dynamics have so far not been investigated. Here, we examine the entanglement entropy growth after a global quench in a quantum spin chain with randomly placed spins and long-range tunable interactions decaying with distance with power α. Using a dynamical version of the strong disorder renormalization group (SDRG) we find for $\alpha \geq \alpha_c$ that the entanglement entropy grows logarithmically with time and that its prefactor decays with α as $S(t) = S_p/(2\alpha) \ln(t)$, where $S_p = 2 \ln 2 - 1$. For $0 < \alpha \leq \alpha_c$, we find that the entanglement grows in a power-law fashion $S(t) \sim t^{\beta}$ with $0 < \beta < 1$ being a decaying function of α, then reaches a saturation value which is

					consistent with our previous findings using RSRG-X. We use numerical exact diagonalization simulations to verify our results for system sizes up to $N \sim 16$ spins, yielding good agreement for sufficiently large α.
DILLIP KUMAR	NANDY	Poster	online	Probing Many-body localization using Adiabatic gauge potential	One of the most debating questions in the area of condensed matter physics is about the presence of a many-body localized (MBL) phase in a finite lattice system. So far most of the diagnostics in this direction is carried out by numerical simulation using some conventional approach based on the energy level of the many-body Hamiltonian. In this talk, I will discuss an alternative technique based on adiabatic gauge potential (AGP) to investigate the many-body localization phenomena in an all-to-all Sachdev-Ye-Kitaev (SYK) model and in the interacting Aubre-Andre chain. I will present our latest results for these models obtained from our exact diagonalization analysis.
Lukas	Pausch	Poster	online	Chaos in the Bose-Hubbard model versus Gaussian orthogonal and embedded random matrix ensembles	We benchmark spectral and eigenvector statistics of the Bose-Hubbard Hamiltonian against those of the Gaussian orthogonal and the bosonic two-body embedded random-matrix ensembles. The latter, in contrast to the Gaussian ensemble, mirrors the few-body nature of interactions and is therefore expected to better describe chaotic quantum many-particle systems. Within the energy and parameter range where chaos fully unfolds, the expectation value and the eigenstate-to-eigenstate fluctuations of the fractal dimensions of Bose-Hubbard eigenstates show clear signatures of ergodicity and are well described by the two random-matrix ensembles [1,2]. On top, the bosonic embedded ensemble reproduces the energy dependence of the chaotic domain. As the limit of infinite Hilbert space dimension is approached along different directions, keeping either particle number *N*, system size *L*, or particle density *n = N/L* constant, the limit $N \to \infty$ at constant *n* leads to a faster convergence of the chaotic phase towards the random-matrix benchmarks than the same limit at constant *L*. The fastest route to chaos is found at fixed density $n \leq 1$ [3]. Despite the agreement of the three models on the level of the fractal dimensions' lowest-order statistical moments, the models are ever more distinguishable from each other in terms of their full fractal dimension distributions as Hilbert space grows, even along the fastest route to chaos. These results provide evidence of a way to discriminate among different many-body Hamiltonians in the chaotic regime. [1] L. Pausch et al., Phys. Rev. Lett. 126, 150601 (2021) [2] L. Pausch et al., New J. Phys. 23, 123036 (2021) [3] L. Pausch et al., J. Phys. A 55, 324002 (2022)
Shilpi	Roy	Poster	online	Localization and ergodicity breaking in long-range self-dual models with correlated disorder	Self-dual Aubry-Andre model provides an example of a system with the fully correlated quasiperiodic disorder potential, which demonstrates the Anderson transition already in a one-dimensional system. Its self-dual cousin with uncorrelated disorder and all-to-all translation-invariant (TI) coupling, known as a TI Rosenzweig-Porter ensemble, carries along with the ergodic and localized phases also a fractal one. In this paper, we consider an interpolation between the above two models, characterized by both the power-law correlated diagonal elements and the TI off-diagonal elements, power-law decaying with a distance from the diagonal. We show that the interplay of the partially correlated disorder and the power-law decay hopping terms may lead to the emergence of the two types of the fractal phases in an entire range of parameters, even without having any quasiperiodicity of the Aubry-Andre potential.
Madhumita	Sarkar	Poster	online	Multifractality in periodically driven Aubry-Andre model	We study the localization-delocalization transition of Floquet eigenstates in a driven fermionic chain with an incommensurate Aubry-Andre potential and a hopping amplitude which is varied periodically in time. Our analysis shows the presence of a mobility edge separating single-particle delocalized states from localized and multifractal states in the Floquet spectrum. The presence of

					the mobility edge is shown to leave a distinct imprint on fermion transport in the driven chain; it also influences the Shannon entropy and the survival probability of the fermions at long times. Then we add a small interaction term to the above Hamiltonian and show how that the nature of the Floquet eigenstates change from ergodic to Floquet-MBL with increasing frequency; moreover, for a significant range of intermediate frequency, the Floquet eigenstates exhibit non-trivial fractal dimensions. We find a transition from the ergodic to this multifractal phase followed by a gradual crossover to the MBL phase as the drive frequency is increased. We study the short time and long time dynamics of various quantities and show that the auto-correlation, fermion transport and NPR displays qualitatively different characteristics (compared to their behavior in the ergodic and MBL regions) for the range of frequencies which supports multifractal eigenstates. In contrast, the entanglement growth in this frequency range tends to have similar features as in the MBL regime. [1] M. Sarkar, Roopayan Ghosh, K. Sengupta and Arnab Sen, Phys. Rev. B 103, 184309 (2021). [2] M. Sarkar, Roopayan Ghosh, K. Sengupta and Arnab Sen, Phys. Rev. B 105, 024301 (2022).