# Ultracold atoms in an optical quasicrystal

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During the last twenty years, ultracold atoms in optical lattices have emerged as a powerful quantum simulator to study the many-body physics of interacting particles in, initially, periodic potentials. This has then been extended to 1D quasiperiodic models such as the Aubry-Andre model to study dominantly localization phenomena.

In this talk, I will discuss our realization of an 8-fold rotationally symmetric optical 2D quasicrystal that is realized using four independent 1D lattices overlapped in a plane. We characterized the optical quasicrystal using matter-wave (Kapitza-Dirac) diffraction and directly observed the self-similarity of this quasicrystalline structure. On short timescales, the diffraction dynamics constitutes a continuous-time quantum walk on a periodic four-dimensional tight-binding lattice.

We furthermore report on the experimental realization of the two-dimensional Bose glass using ultra-cold atoms in the optical quasicrystal. By probing the coherence properties of the system, we observe a Bose glass to superfluid transition and map out the phase diagram in the weakly interacting regime. Moreover, we reveal the non-ergodic nature of the Bose glass by probing the capability to restore coherence.

[1] Konrad Viebahn, Matteo Sbroscia, Edward Carter, Jr-Chiun Yu, Ulrich Schneider, *Matter-wave diffraction from a quasicrystalline optical lattice*, Phys. Rev. Lett. **122** (2019) 110404.

[2] Matteo Sbroscia, Konrad Viebahn, Edward Carter, Jr-Chiun Yu, Alexander Gaunt, Ulrich Schneider, *Observing localisation in a 2D quasicrystalline optical lattice,* Phys. Rev. Lett. **125** (2020) 200604.

[3] Emmanuel Gottlob, Ulrich Schneider, *Hubbard Models for Quasicrystalline Potentials,* Phys. Rev. B **107** (2023) 144202.

[4] Jr-Chiun Yu, Shaurya Bhave, Lee Reeve, Bo Song, Ulrich Schneider, *Observing the two-dimensional Bose glass in an optical quasicrystal*, arXiv: 2303.00737 (2023).

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# A new contribution to transport properties of decagonal quasicrystals

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We present recent highlights of our contributions to the understanding of the physical properties of quasiperiodic systems [1], with a focus on the transport properties (electrical resistivity and thermopower) of *d*-AlCoCu and *d*-AlCoNi monocrystals. The electrical resistivity of both compounds is well described by the slow charge carriers (SCC) model over a broad temperature range. A clear crossover from Boltzmann to non-Boltzmann behavior can be observed in the quasiperiodic direction. The *d*-AlCoCu exhibits a lower-temperature crossover, indicating stronger intrinsic disorder (partial and/or split occupancy of lattice positions) in this compound, likely due to difficulties encountered during single crystal growth [2,3]. These findings demonstrate that a perfectly quasiperiodic potential has Bloch-like solutions of the Hamiltonian as well as a periodic potential, but intrinsic disorder more profoundly affects larger quasiperiodic lattices than smaller periodic ones. This intrinsic disorder reduces the mean free path of electrons and effectively screens metallic behavior along quasiperiodic directions, while also causing larger residual resistivity in both quasiperiodic and periodic directions. The thermopower of *d*-AlCoNi and *d*-AlCoCu shows opposite signs indicating a different slope of the density of states at the Fermi level. *d*-AlCoNi has positive thermopower in both directions, although the Hall effect indicates a different polarity of charge carriers, demonstrating the complexity of the quasi-Fermi surface [4,5]. In both compounds, thermopower along the quasiperiodic direction shows signs of saturation, while along the periodic direction, it is more metallic-like, as is electrical resistivity.

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[1] A. Smontara; I. Smiljanić; J. Ivko; D. Stanić; O.S.Barišić, Z. Jagličić;P. Gille, M.; Komelj, ; P. Jegli; J. Dolinšek, Phys. Rev. B, **78** (2008), 104204
[2] Gille, P Dreier, RU Barz , J. Alloy. Compd. **342** (2002) 7.
[3] G Meisterernst, L Zhang, P Dreier, Phil. Mag. **86** (2006) 323.
[4] P. Popčević, D. Stanić, Ž. Bihar, A. Bilušić, A. Smontara, *European C-MetAC Days 2022 Program* (Split, University of Split, Faculty of Science, Croatia; 2022.) p.58
[5] P. Popčević, *et.al*., in preparation.

# Perpendicular space accounting of compact localized states in quasicrystals

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Quasicrystals can be described as projections of sections of higher dimensional periodic lattices into real space. The image of the lattice points in the projected-out dimensions, called the perpendicular space, carries valuable information about the local structure of the quasicrystal in real space. We use perpendicular space projections to analyze the compact localized states in four quasicrystal tight-binding models. These zero energy states form a massively degenerate manifold akin to flat bands in periodic systems.

For the Penrose tiling [1], we reproduce the six types of localized states and investigate their overlaps and linear independence. We also calculate the fraction of sites which are forbidden by local connectivity to host localized states. For the Ammann-Beenker [2] and Socolar [3] dodecagonal tilings, an infinite number of localized state types are needed to explain the numerically observed degeneracy. We also consider the local isomorphism classes of pentagonal quasicrystals which have the same projection window as the Penrose tiling [4]. These systems lack scaling (inflation-deflation) rules, yet the local configuration frequencies can be found by perpendicular space projections. We find that the behavior of the zero-energy manifold on the two sublattices of such quasicrystals show marked differences, and calculate the localized state fraction a function of local isomorphism class parameter.

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[1] Murod Mirzhalilov and M. Ö. Oktel, Phys. Rev. B **102** (2020) 064213.
[2] M.Ö. Oktel, Phys. Rev. B **104** (2021) 014204.
[3] Akif Keskiner and M.Ö Oktel, Phys. Rev. B **106** (2022) 064207.
[4] M.Ö. Oktel, Phys. Rev. B **106** (2022) 024201.

# Gaps and gap labeling and passage from molecular states to critical states in a 2D quasiperiodic tiling

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The single electron spectrum and wavefunctions in quasicrystals continue to be a fascinating problem, with few known solutions, especially in two and higher dimensions. In this talk we will discuss the energy spectra, the states and gap structures in several tight-binding models on the Ammann-Beenker two-dimensional quasiperiodic tiling. By varying a continuous parameter, we follow the evolution of the band structure and of the states. We describe the passage from the discrete molecular states defined on clusters such as those in Fig. 1, to the multifractal states of the 2D hopping model which are well-known from previous studies and whose density of states is shown in Fig. 2. We deduce from these models an exact result: namely a scheme for labeling gaps in finite approximants. This scheme is equivalent in the limit of infinite systems to the one presented by Kellendonk and Putnam based on the algebraic structure of this quasiperiodic system [1].

[1] J. Kellendonk and I. Putnam, in Directions in Mathematical Quasicrystals, Eds. M. Baake and R. Moody, CRM Monograph series Providence RI (2000).

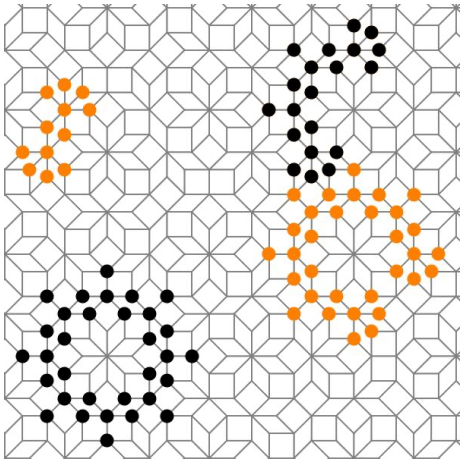

**Fig.1:** Some of the finite clusters defined on the Ammann-Beenker tiling.

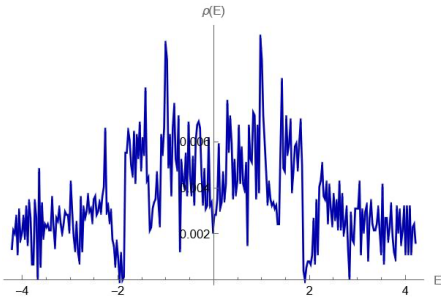


**Fig.2:** The density of states of the uniform hopping model on the AB tiling.