SFB

FoQuS

# Foundations and Applications of Quantum Science

34th SFB meeting
6-7 October 2016, Innsbruck

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# Program

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| 14:25 (20’+5’) | Georgy Kazakov, TU Wien – Atominstitut<br>*About the possibility of creation of active optical frequency standard on forbidden transition in trapped cold ions* |
| 14:50 | Poster flash talks (2’ and 1 slide each) |
| 15:10 | Coffee Break and Poster Session |
| 16:10 (20’+5’) | Christine Maier, University of Innsbruck/IQOQI<br>*Scalable tomography of a quantum simulator* |
| 16:35 (20’+5’) | Daniele De Bernardis, TU Wien – Atominstitut<br>*Instability and non-linear dynamics in polariton condensates* |
| 17:00 (45’+10’) | Dmitry S. Petrov, Univ. Paris Sud, Univ. Paris-Saclay<br>*Beyond mean-field effects in a cold gas: multibody interactions and quantum droplets* |
| 18:30 | SFB-bus to the dinner location at the bus stop *Technik* |
| 19:00 | Dinner at the *Bierstindl* (see directions on page 12) |

| Friday, October 7th | |
|---|---|
| 08:00 | Business meeting *(Project PIs and Co-PIs only)* |
| 09:00 (45’+10’) | Thierry Lahaye, Université Paris Sud/CNRS<br>*Realizing spin Hamiltonians in tunable 2D arrays of single Rydberg atoms* |
| 10:00 (20’+5’) | Florian Meinert, University of Stuttgart<br>*Bloch oscillations in the absence of a lattice* |
| 10:25 (20’+5’) | Philippe Allard Guérin, University of Vienna/IQOQI<br>*Exponential Communication Complexity Advantage from Quantum Superposition of the Direction of Communication* |
| 10:50 | Coffee Break and Poster Session |

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| 11:15 (45’+10’) | Simon Fölling, Ludwig-Maximilians-Universität München<br>*Quantum gases of ytterbium with SU(N)-symmetry and orbital degree of freedom* |
| 12:10 (20’+5’) | Hendrik Poulsen Nautrup, University of Innsbruck<br>*Topological Code Switching in Two Dimensions* |
| 12:35 (20’+5’) | Michael Schuler, University of Innsbruck<br>*Universal Signatures of Quantum Critical Points from Finite-Size Torus Spectra* |
| 13:00 (20’+5’) | Katja Ried, University of Innsbruck<br>*Causal modeling and what it can tell us about quantum mechanics* |
| 13:25 | End of SFB meeting |

# Talks

*Thursday, October 6th*

14:00

**Fictitious magnetic field gradients in optical microtraps as an experimental tool for interrogating and manipulating cold atoms**

Christoph Clausen, TU Wien – Atominstitut

Optical microtraps provide a strong spatial confinement for laser-cooled atoms. They can, e.g., be realized with strongly focused trapping light beams or the optical near fields of nano-scale waveguides and photonic nanostructures. Atoms in such traps often experience strongly spatially varying AC Stark shifts which are proportional to the magnetic quantum number of the respective energy level. These inhomogeneous fictitious magnetic fields can cause a displacement of the trapping potential that depends on the Zeeman state. Hitherto, this effect was mainly perceived as detrimental. However, it also provides a means to probe and to manipulate the motional state of the atoms in the trap by driving transitions between Zeeman states. Furthermore, by applying additional real or fictitious magnetic fields, the state-dependence of the trapping potential can be controlled. Here, using laser-cooled atoms that are confined in a nanofiber-based optical dipole trap, we employ this control in order to tune the microwave coupling of motional quantum states. We record corresponding microwave spectra which allow us to infer the trap parameters as well as the temperature of the atoms. Finally, we reduce the mean number of motional quanta in one spatial dimension to $n = 0.3 \pm 0.1$ by microwave sideband cooling. Our work shows that the inherent fictitious magnetic fields in optical microtraps expand the experimental toolbox for interrogating and manipulating cold atoms.

14:25

**About the possibility of creation of active optical frequency standard on forbidden transition in trapped cold ions**

Georgy Kazakov, Atominstitut – TU Wien

Bad cavity laser is a laser where the linewidth of the cavity mode is broader than the gain profile. Frequency of radiation emitted by such laser is robust with respect to fluctuations of the cavity length. It opens the possibility to create a highly stable active optical frequency standard. Theoretical estimations shows that such bad-cavity lasers on the forbidden transition in alkali-earth-like atoms trapped io optical lattice potential may have milliherz-narrow linewidth. On the other hand, the lifetime of the atoms in the optical lattice potential is quite, and sophisticated methods are necessary to refill the atomic ensemble. In contrast with atoms, ions trapped in the linear Paul trap have much longer trap lifetime. I plan to discuss the possibility of creation of a bad cavity laser (and probably the active optical frequency standard) on the basis of a weak transition in cold ions trapped in linear Paul trap and forming large Coulomb crystal. Different ion species, pumping schemes, inhomogeneous broadening mechanisms and trap configurations will be considered, and some preliminarily estimations will be given.

16:10

**Scalable tomography of a quantum simulator**

Christine Maier, University of Innsbruck/IQOQI

Quantum state tomography (QST) is the gold standard technique for estimating wave functions of small quantum systems in the laboratory. Applying QST to the larger systems currently being developed in laboratories around the world is impractical due to the large number of measurements and processing time required. In 2010 Cramter et al. proposed a tomography scheme [1] to efficiently reconstruct large quantum states that are well approximated by matrix product states (MPS). In my talk I present the experimental application of this MPS tomography to characterise a trapped ion quantum simulator of spin-1/2 particles. A product state of up to 20 ions is prepared and evolved under an Ising-type interaction, giving rise to many-body entangled states. The MPS reconstruction scheme is then performed at various times during the evolution, and the resulting quantum state investigated. We show that the reconstructed state has a significant overlap with the actual state created in the laboratory and reproduces non-classical correlations to a high degree.

[1] M. Cramer et al., Nature Communications 1, 149 (2010).

16:35

**Instability and non-linear dynamics in polariton condensates**

Daniele De Bernardis, TU Wien – Atominstitut

Non-resonatly pumped polaritons in an optical cavity can exhibit out of equilibrium Bose-Einstein condensation, in which the phase is totally decoupled from the external pumping. This interesting effect is the consequence of a very complex relaxation dynamics, in which *hot carriers* uses the energy from the pump to populate the whole spectrum of excitations of the cavity via scattering processes. As a consequence of this mechanism, close to the bottom of the spectrum (the dispersion) of the cavity, a large population of incoherent excitons takes place, and, again they can relax to the bottom of the spectrum, giving rise to the polariton condensate. One of the more accepted model to describe the dynamics of the condensate is a dissipative version of the Gross-Pitaevskii equation, coupled to a rate equation for the density of the reservoir of incoherent excitons. We will show that, due to back reaction from the condensate to the reservoir, the model admits two different phases: one in which an homogeneous steady state is achievable, and one in which the steady state is a turbulent/chaotic state. In the turbulent/chaotic phase (which is called *unstable regime*) the system is formally similar to a equilibrium BEC with negative scattering length, but its non-equilibrium nature makes the physics much richer. Looking at some recent experiments, we will also discuss the case on a lattice geometry, and we will show that the effect which leads to the unstable regime, could work as a *band selector* for condensation.

17:00, Invited talk

**Beyond mean-field effects in a cold gas: multibody interactions and quantum droplets**

Dmitry S. Petrov, Université Paris Sud, Université Paris-Saclay/CNRS

In the first part of the talk I will discuss the problem of generating three-body and higher-order interactions in an ultracold gas. I propose a mechanism which can be implemented for dipolar bosons in the bilayer configuration with tunneling or in an atomic system by using radio-frequency fields to couple two hyperfine states. In the second part I will talk about a condensed Bose-Bose mixture with attractive inter- and repulsive intraspecies interactions which, according to the mean-field analysis, is close to collapse. I will show that beyond mean-field effects stabilize the gas. Instead of collapsing, it gets into a droplet state, physical properties of which I will discuss.

*Friday, October 7$^{th}$*

09:00, Invited talk

**Realizing spin Hamiltonians in tunable 2D arrays of single Rydberg atoms**

Thierry Lahaye, Université Paris Sud/CNRS

In this talk, I will show how a 2D array of single atoms held in optical tweezers and excited to Rydberg states can be used to realize tunable, synthetic spin systems. After describing our experimental setup, and in particular how we generate fully loaded arrays of single atoms using a fast *atom-sorting machine* [1], I will present two examples of artificial magnets that we implemented in the lab: a small spin chain of three atoms governed by the XY Hamiltonian [2], and larger systems of up to 30 spins, arranged in various geometries, and interacting via Ising-like couplings [3].

[1] D. Barredo *et al.*, ArXiv:1607.03042.
[2] D. Barredo *et al.*, Phys. Rev. Lett. **114**, 113002 (2015).
[3] H. Labuhn *et al.*, Nature **534**, 667 (2016).

10:00

**Bloch oscillations in the absence of a lattice**

Florian Meinert, University of Stuttgart

We experimentally investigate the quantum motion of an impurity atom that is immersed in a strongly interacting one-dimensional Bose liquid and is subject to an external force. We find that the momentum distribution of the impurity exhibits characteristic Bragg reflections at the edge of an emergent Brillouin zone. While Bragg reflections are typically associated with lattice structures, in our strongly correlated quantum liquid they result from the interplay of short-range crystalline order and kinematic constraints on the many-body scattering processes in the one-dimensional system. As a consequence, the impurity exhibits periodic dynamics that we interpret as Bloch oscillations, which arise even though the quantum liquid is translationally invariant. Our observations are supported by large-scale numerical simulations.

10:25

**Exponential Communication Complexity Advantage from Quantum Superposition of the Direction of Communication**

Philippe Allard Guérin, University of Vienna/IQOQI

In communication complexity, a number of distant parties have the task of calculating a distributed function of their inputs, while minimizing the amount of communication between them. It is known that with quantum resources, such as entanglement and quantum channels, one can obtain significant reductions in the communication complexity of some tasks. In this work, we study the role of the quantum superposition of the direction of communication as a resource for communication complexity. We present a tripartite communication task for which such a superposition allows for an exponential saving in communication, compared to one-way quantum (or classical) communication; the advantage also holds when we allow for protocols with bounded error probability.

[1] P. A. Guérin, A. Feix, M. Araújo, and Č. Brukner, Phys. Rev. Lett. **117**, 100502 (2016).

11:15, Invited talk

**Quantum gases of ytterbium with SU(*N*)-symmetry and orbital degree of freedom**

Simon Fölling, Ludwig-Maximilians-Universität München.

Quantum simulation experiments implement effective Hamiltonians by using control over both the internal and the external degrees of the particles, traditionally alkali atoms. Degenerate ensembles of atoms with Alkaline-earth-like electronic structure, such as ytterbium, allow for novel many-body systems to be modeled and probed, due to their more complex internal structure. We use the specific properties of fermionic $^{173}$Yb properties to implement SU($N$)-symmetric gases as well as to couple internal degrees of freedom of the atoms to the external degrees with state-dependent potentials and interactions. As a consequence of the enhanced SU($N$)-symmetry of the interactions in the fermionic gas, we can realize a generalized Fermi-Hubbard model with up to SU(6)-symmetry. Another motivation for using Yb is a Kondo-like lattice structure with two effective orbitals resulting from the internal states. For this, we implement a state-dependent lattice setup and characterize the unusual inter-orbital interactions in such a system.

12:10

**Topological Code Switching in Two Dimensions**

Hendrik Poulsen Nautrup, University of Innsbruck

To exploit the particular advantages of different topological codes for fault-tolerant quantum computation, it is desirable to switch between them. We propose a lattice surgery based procedure for the fault-tolerant transfer of quantum information between arbitrary topological codes in two dimensions that can be employed to teleport quantum information between surface and color codes. While the former encoding is more robust, the latter supports the transversal implementation of the whole Clifford group. Our method hence provides a practical interface between noise resilient surface code memories and fault-tolerant color code processors.

12:35

**Universal Signatures of Quantum Critical Points from Finite-Size Torus Spectra**

Michael Schuler, University of Innsbruck

The low-energy spectra of quantum many-body systems on a finite torus are well understood in magnetically ordered, paramagnetic and gapped topological phases. At quantum critical points separating such phases the torus spectra are, however, widely unexplored for 2+1D systems. In this talk, I will present and analyze the low-energy torus spectrum at an Ising critical point, obtained with numerical as well as analytical techniques. This spectrum provides a universal fingerprint of the corresponding quantum field theory. In the second part of this talk, I will present the implications of a neighboring topological phase on the spectrum by studying the Ising* transition. Such an unconventional transition is characterized by the lack of any local order parameter and is driven by the condensation of a fractional particle.

13:00

**Causal modeling and what it can tell us about quantum mechanics**

Katja Ried, University of Innsbruck

The task of discerning causal influences from spurious correlations is relevant to a wide range of applications, from econometrics to neuroimaging. I will show how the peculiarities of quantum mechanics allow us to solve a particularly challenging class of causal discovery problems. This result is one application of a broader framework of quantum causal models, which can also provide insights into the foundations of quantum mechanics.

# Posters

### Performance of compressed quantum computation

Martin Hebenstreit, University of Innsbruck

It has been shown that the Ising interaction of a 1D - chain consisting out of n qubits can be simulated using a $log(n)$ qubit universal quantum computer making use of compression of match gate circuits [1]. Such a simulation has been performed on a five qubit nuclear magnetic resonance quantum simulator, simulating a 32 qubits chain, recently [2]. In order to test the performance of the recently available few qubit quantum computer (IBM) we perform the simulation of the compressed circuit on it and compare the results to the ones obtained using the NMR quantum computer.

[1] B. Kraus, Phys. Rev. Lett. **107**, 250503 (2011).
[2] Z. Li *et al.*, Phys. Rev. Lett. **112**, 220501 (2014).

### Non reciprocal devices based on chiral light matter interactions

Adèle Hilico, TU Wien – Atominstitut

In order to control the flow of light in an integrated optical environment, one needs to use nanophotonic components which confine the light at the wavelength scale. This strong confinement leads to an inherent link between the local polarization of the light and its propagation direction - the light obtains a chiral character - and thereby fundamentally alters the physics of light-matter interaction [1]. We employ this effect in order to investigate the realization of novel nonreciprocal optical devices that operate at the single-photon level. For this purpose, we use a single spin-polarized 85Rb atom that is strongly coupled to a novel type of whispering-gallery-mode microresonator - a so-called bottle microresonator [1] - which can be interfaced by two optical nanofibers. These resonators offer the advantage of being fully tuneable and provide very long photon lifetimes in conjunction with near lossless coupling to the nanofibers. Coupling one nanofiber to the bottle microresonator, we studied the on-resonance performance of the system and observed a strong imbalance between the transmissions in forward and reverse direction [2]. This realizes an optical diode whose directional behaviour is controlled by the internal state of a single atom. By interfacing the bottle microresonator with two nanofibers we extended this system to a 4-port device, where photons are nonreciprocally directed from one fibre port to the next. In contrast to the diode such an optical circulator is based on a non-dissipative process [3], which would enable one to employ these devices for quantum information protocols.

[1] C. Junge *et al.*, Phys. Rev. Lett. **110**, 213604 (2013).
[2] C. Sayrin *et al.*, Phys. Rev. X **5**, 041036 (2015).
[3] M. Scheucher *et al.*, ArXiv:1609.02492.

**Inhibition of ground-state superradiance and light-matter decoupling in circuit QED**

Tuomas Jaako, TU Wien – Atominstitut

We study effective light-matter interactions in a circuit QED system consisting of a single *LC* resonator, which is coupled symmetrically to multiple superconducting qubits. Starting from a minimal circuit model, we demonstrate that in addition to the usual collective qubit-photon coupling the resulting Hamiltonian contains direct qubit-qubit interactions, which have a drastic effect on the ground and excited state properties of such circuits in the ultrastrong coupling regime. In contrast to a superradiant phase transition expected from the standard Dicke model, we find an opposite mechanism, which at very strong interactions completely decouples the photon mode and projects the qubits into a highly entangled ground state. These findings resolve previous controversies over the existence of superradiant phases in circuit QED, but they more generally show that the physics of two- or multi-atom cavity QED settings can differ significantly from what is commonly assumed.

**A fiber cavity setup for a quantum network based on trapped ions and cavity QED**

Pierre Jobez, University of Innsbruck

A single atom coupled to an optical cavity can be used as a coherent quantum interface between stationary and flying qubits in a quantum network. Using fiber-based cavities, it may be possible to reach the strong coupling regime of cavity QED with a single trapped ion. This regime would enhance the fidelity and efficiency of protocols useful for quantum communication. The challenge of integrating fiber cavities with ion traps is that the dielectric fibers should be far enough from the ions so that they do not significantly alter the trap potential. Using the $CO_2$-laser ablation technique, we have built fiber cavities with finesses up to 70,000 at 854nm and at a length of 550$\mu$m. We will report on the integration and interplay of such a fiber cavity with a calcium ion stored in a Paul trap.

**About the possibility of creation of active optical frequency standard on forbidden transition in trapped cold ions**

Georgy Kazakov, Atominstitut – TU Wien

Bad cavity laser is a laser where the linewidth of the cavity mode is broader than the gain profile. Frequency of radiation emitted by such laser is robust with respect to fluctuations of the cavity length. It opens the possibility to create a highly stable active optical frequency standard. Theoretical estimations shows that such bad-cavity lasers on the forbidden transition in alkali-earth-like atoms trapped in optical lattice potential may have milliherz-narrow linewidth. On the other hand, the lifetime of the atoms in the optical lattice potential is quite, and sophisticated methods are necessary to refill the atomic ensemble. In contrast with atoms, ions trapped in the linear Paul trap have much longer trap lifetime. I plan to discuss the possibility of creation of a bad cavity laser (and probably the active optical frequency standard) on the basis of a weak transition in cold ions trapped in linear Paul trap and forming large Coulomb crystal. Different ion species, pumping schemes, inhomogeneous broadening mechanisms and trap configurations will be considered, and some preliminarily estimations will be given.

**Non-Equilibrium $8\pi$ Josephson Effect in Atomic Kitaev Wires**

Catherine Laflamme, University of Innsbruck/IQOQI

In this poster we will present a new signature of Majorana quasi-particles, qualitatively different from the behaviour of a conventional superconductor, which can be detected in cold atom systems using alkaline-earth-like atoms. The system studied is a Kitaev wire interrupted by an extra site, which gives rise to super exchange coupling between two Majorana bound states. We show that this system hosts a tunable, non-equlibrium Josephson effect with a characteristic 8pi periodicity of the Josephson current. We further show the robustness of this effect in the presence of imperfections, in the form of dephasing and particle loss.

**Cooling phonons with phonons: acoustic reservoir-engineering with silicon-vacancy centers in diamond**

Marc-Antoine Lemonde, Atominstitut – TU Wien

I present a setup where a single negatively-charged silicon-vacancy center in diamond is magnetically coupled to a low-frequency mechanical bending mode and via strain to the high-frequency phonon continuum of a semi-clamped diamond beam. We show that under appropriate microwave driving conditions, this setup can be used to induce a laser cooling like effect for the low-frequency mechanical vibrations, where the high-frequency longitudinal compression modes of the beam serve as an intrinsic low-temperature reservoir. We evaluate the experimental conditions under which cooling close to the quantum ground state can be achieved and describe an extended scheme for the preparation of a stationary entangled state between two mechanical modes. By relying on intrinsic properties of the mechanical beam only, this approach offers an interesting alternative for quantum manipulation schemes of mechanical systems, where otherwise efficient optomechanical interactions are not available.

**Estimation of coherent errors from stabilizer measurements**

Davide Orsucci, University of Innsbruck

In the context of Measurement-Based Quantum Computation (MBQC) a way to maintain the coherence of the *graph state* is given by measuring stabilizer operators. Aside from performing Quantum Error Correction (QEC), it is possible to exploit the information gained from these measurements to characterize a coherent source of errors; that is, an error channel that applies a fixed – but unknown – unitary operation. Specifically, we study the case in which the error channel acts differently on each qubit of the graph state, and is given by a rotation of the Bloch sphere around either the $\hat{x}$, $\hat{y}$ or $\hat{z}$ axis. The possibility to reconstruct the channel for each qubit depends non-trivially on the topology of the graph state.

**Pure state transformations via finitely many round LOCC protocols**

David Sauerwein, University of Innsbruck

We consider generic pure n-qubit states and a general class of pure states of arbitrary dimensions and arbitrary many subsystems. We characterize those states which can be reached from some other state via Local Operations assisted by finitely many rounds of Classical Communication ($LOCC_N$). For qubits we show that this set of states is of measure zero, which implies that the maximally entangled set is generically of full measure if restricted to the practical scenario of finite-round LOCC. Moreover, we identify a class of states for which any $LOCC_N$ protocol can be realized via a concatenation of deterministic steps. We show, however, that in general there exist state transformations which require a probabilistic step within the protocol, which highlights the difference between bipartite and multipartite LOCC.

**Quantum engineering of a low-entropy gas of RbCs molecules in an optical lattice**

Andreas Schindewolf, University of Innsbruck

Quantum many-body systems with long-range dipolar interaction are currently of immense interest in the theory and experiment community. Until recently, experimental realization with dipolar molecules was unfeasible due to high sample entropy. We present a novel method to prepare low-entropy samples of molecules as an ideal starting point for such experiments [1]. Starting from two spatially separated BECs, we form Rb-Cs precursor pairs by overlapping a Cs Mott insulator with superfluid Rb in an optical lattice. For this purpose, the Rb-Cs interaction is nulled at a Feshbach resonance's zero crossing. After the Rb atoms are localized by further enhancing the lattice depth, the paired atoms are associated to Feshbach molecules by means of the aforementioned Feshbach resonance. With this method we produce a low-entropy molecular sample with a filling fraction exceeding 30%. Combining the method with a STIRAP technique to produce dipolar ground-state molecules, which we already realized with 90% efficiency [2], we will be able to address experiments in the context of dipolar many-body physics.

[1] L. Reichsöllner, A. Schindewolf, T. Takekoshi, R. Grimm, H.-C. Nägerl, ArXiv:1607.06536.
[2] K. Aikawa *et al.*, Phys. Rev. Lett. **113**, 263201 (2014).

**2D Quantum Repeaters**

Julius Wallnöfer, University of Innsbruck

The endeavour to develop quantum networks gave rise to a rapidly developing field with far reaching applications such as secure communication and the realization of distributed computing tasks. This ultimately calls for the creation of flexible multi-user structures that allow for quantum communication between arbitrary pairs of parties in the network and facilitate also multi-user applications. To address this challenge, we propose a 2D quantum repeater architecture to establish long-distance entanglement shared between multiple communication partners in the presence of channel noise and imperfect local control operations. The scheme is based on the creation of self-similar multi-qubit entanglement structures at growing scale, where variants of entanglement swapping and multi-party entanglement purification are combined to create high fidelity entangled states. We show how such networks can be implemented using trapped ions in cavities.

# Directions

## To/From the venue

### Train connections

→ *Innsbruck, Thursday, 06.09.2016*

Wien Hbf 08:30 – Salzburg Hbf 10:52 (RJ 262) +
Salzburg Hbf 11:00 – Innsbruck Hbf 12:54 (IC 662)

→ *Vienna, Friday, 07.09.2016*

Innsbruck Hbf 14:17 – Wien Hbf 18:30 (RJ 165/565)
Innsbruck Hbf 14:58 – Wien Hbf 19:30 (RJ 869)
Innsbruck Hbf 16:17 – Wien Hbf 20:30 (RJ 167/567)

From *Innsbruck Hauptbahnhof*, platform *E* take the *bus #4123* (departure 13:12) in direction *Telfs* and get off the bus at *Innsbruck Technik*.

Alternatively, you can take *#3 tram* from platform *C* towards *Höttinger Au/West* (departure 13:06) and change at *Innsbruck Fürstenweg* onto the bus *O-bus* in direction *Allerheiligen*. Get off the bus at *Innsbruck Technik*.

Please find more connections and timetables at http://fahrplan.vvt.at.

## To the meeting's dinner

The meeting's dinner will take place at the *Bierstindl*, Klostergasse 6, 6020 Wilten (Innsbruck), on Thursday at 19:00.

### Via SFB bus

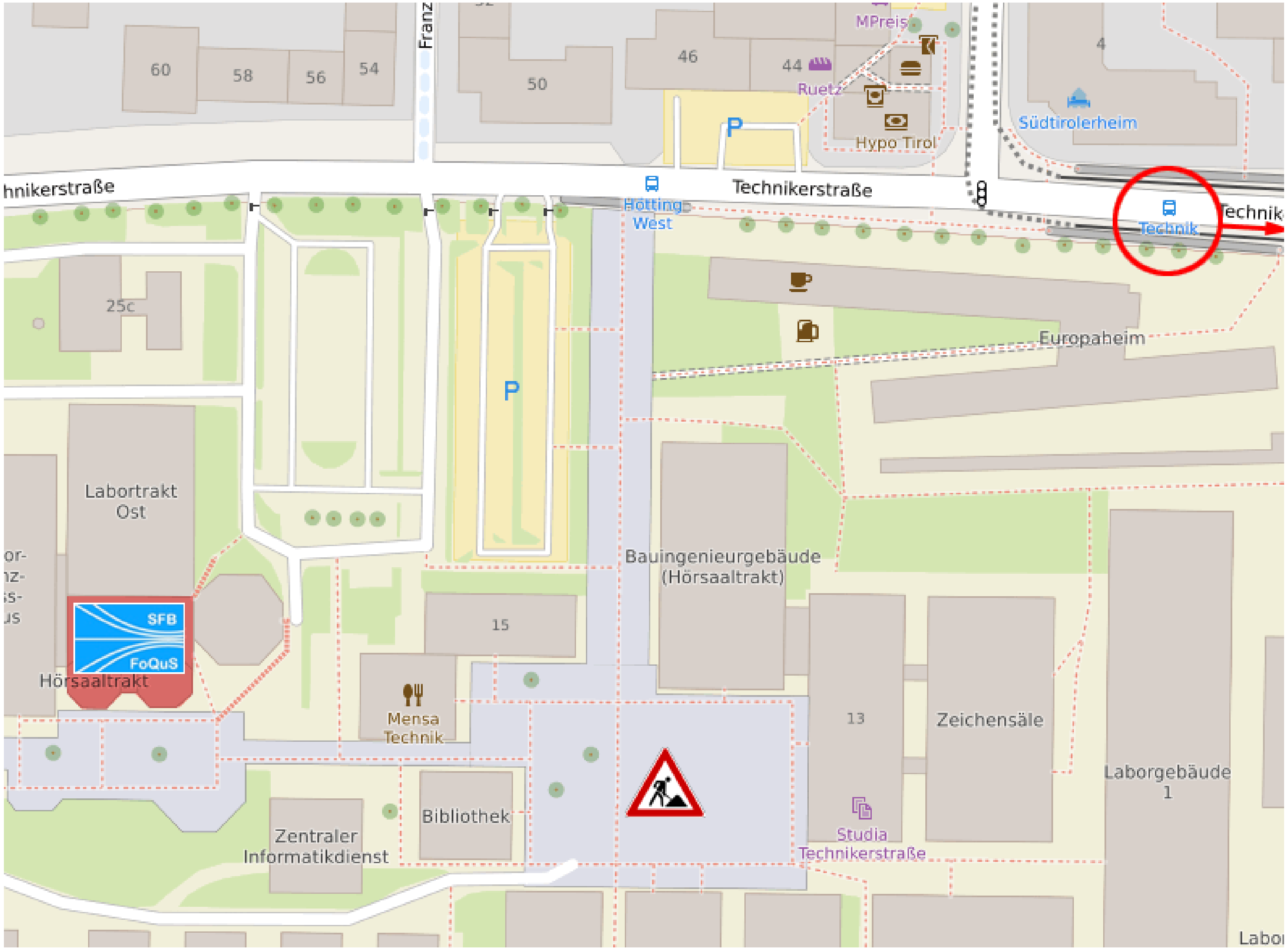
There will be an organized bus going from the campus to the dinner location. Please be at the bus stop *Technik* as indicated on the campus map at 18:30 at the latest. Note that there will be limited seating! If there are no more seats left please use the public transportation option.

### Via public transportation

From the Technik campus at the stop *Technik* catch the *T-bus* (in direction *Neu-Rum Kaplanstraße*). Get off the bus at the stop *Innsbruck Westbahnhof*, transfer to the *#1 tram* (in direction *Bergisel*), get off the tram at the stop *Innsbruck Bergisel* and walk the remaining 370m.

Note, some *T*-busses also stop at *Hötting West* close by, which you may also take. Please find more connections and timetables at http://fahrplan.vvt.at.

## Campus area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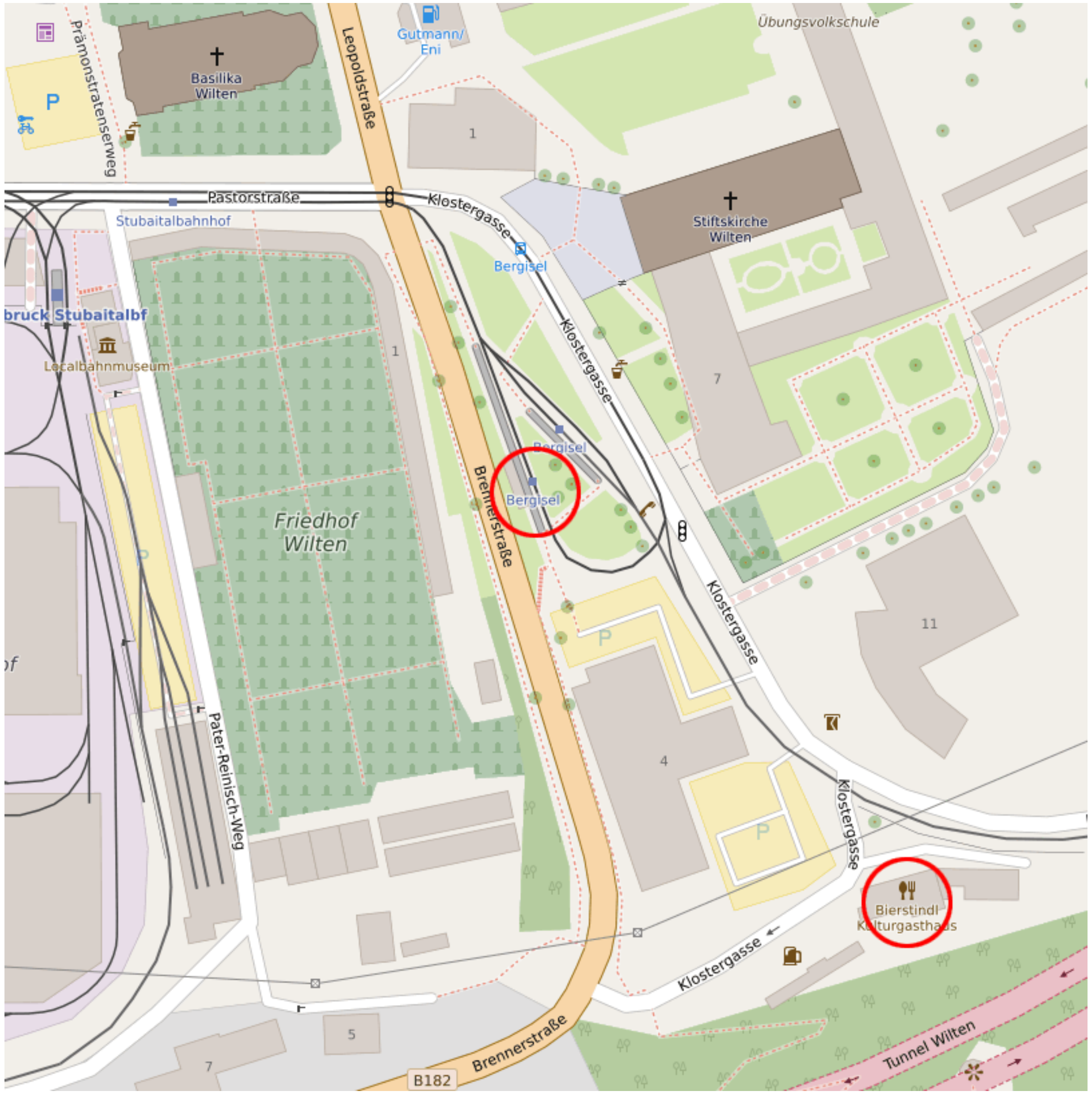
## Bergisel/Bierstindl area



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