Program (draft) of thee 1st QuProCS meeting (*Milan, 8-10 March 2016*)

1st Session (Tue March 8)

14:40 Intro
14:50 **Sabrina Maniscalco** *QuProCS: Where We Are and Where We Are Going*
15:15 **Sougato Bose** *Quenches, Entanglement and Nonequilibrium Thermodynamics in Quantum Impurity Models*
16:00 **Francesco Plastina** *Local quench and local probing in the Ising chain*
16:20 **Fernando Galve** *Microscopic description for the emergence of collective decoherence in extended systems*
16:40 Break
17:10 **Heinz-Peter Breuer** *Generalized trace distance measure connecting quantum and classical non-Markovianity*
17:30 **Andreas Buchleitner** *Single- and many-particle transport on networks*

17:50 WP meeting (WP2 & WP3)
21:00 (Aula Magna, via Festa del perdono 7) **Hong Kong Sinfonietta** *see program www.unimi.it/news/3974.htm*

2nd Session (Wed March 9)

09:00 **Ian Walmsley** *TBA*
09:45 **Vyacheslav Shatokhin** *Spectral detection of resonance fluorescence*
10:05 **Stefano Olivares** *Full quantum state reconstruction of symmetric two-mode squeezed thermal states*
10:25 **Simone Cialdi** *The Milano Quantum Optics Laboratory*
10:45 Break
11:15 **Chuan-Feng Li** *Experimental detection of polarization-frequency quantum correlations in a photonic quantum channel by local operations*
11:35 **Bi-Heng Liu** *Efficient superdense coding in the presence of non-Markovian noise*

12:00 WP5 meeting & lunch

3rd Session (Wed March 9)

14:30 **Markus Oberthaler** *Immersed quantum systems: Lamb shift and bound Bose polarons*
15:15 **Andrew Daley** *Dynamics and probing of atoms in a tilted optical lattice*
15:35 **Elmar Haller** *Towards experiments with ultracold caesium atoms in optical lattice potentials*
15:55 **Francesco Cosco** *Momentum Resolved Spectroscopy Using Atomic Quantum Probes*
16:15 Break
16:45 **Dieter Jaksch** *Atomic impurities in a BEC vortex lattice*
17:05 **Chris Foot** *Atom trapping in dressed-atom adiabatic potentials*

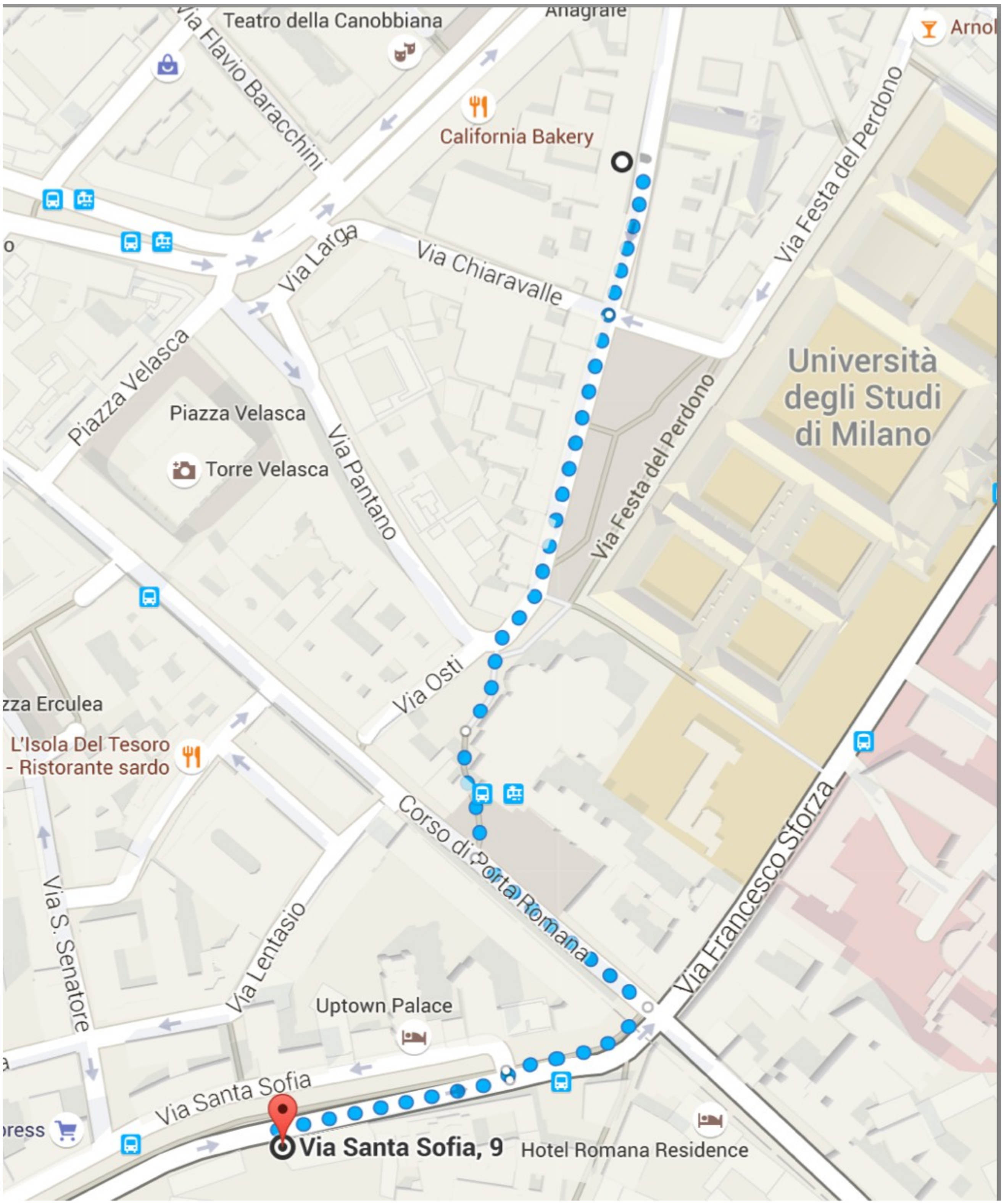
17:30 **Scientific board meeting**
18:30 **Steering committee meeting**

4th Session (Thu March 10)

09:00 **Anna Sanpera** *Quantum metrology in Quantum thermometry*
09:45 **Suzanne McEndoo** *Dissipative dynamics of lattice atoms coupled to reservoirs*
10:05 **Gianluca Giorgi** *Probing a dissipative process through quantum synchronization*
10:25 Break
10:55 **Jyrki Piilo** *Progress on optical simulator for generic dephasing*
11:15 **Claudia Benedetti** *Non-Markovian continuous-time quantum walks on lattices with dynamical noise*

12:00 WP meeting (WP1 & WP4)

From Sala Napoleonica to the guesthouse



1st Session - Tue March 8 starting at 14:40

Sabrina Maniscalco
QuProCS: Where We Are and Where We Are Going

Sougato Bose
Quenches, Entanglement and Nonequilibrium Thermodynamics in Quantum Impurity Models

I will present how the real-space entanglement structure of some quantum impurity models can be unravelled in terms of entanglement measures. Further, how this insight helps in designing devices such as entanglement routers based on quenches will be analysed. That peculiar non-decaying oscillations in non-equilibrium dynamics can be introduced in such impurity systems despite their many-body nature will be exemplified. Finally, how a non-equilibrium thermodynamics quantity, namely the irreversible work can capture a impurity quantum phase transition and show scaling behaviour at criticality will be presented.

Francesco Plastina
Local quench and local probing in the Ising chain

I discuss the reaction of a 1-d many-body system having a non trivial topological phase, when it is subject to a perturbation localized on its boundary. The distortion of the Majorana mode, in presence of the local interaction gives rise to peculiar static and dynamical properties in the system.

Fernando Galve
Microscopic description for the emergence of collective decoherence in extended systems

Practical implementations of quantum technology are limited by unavoidable effects of decoherence and dissipation. With achieved experimental control for individual atoms and photons, more complex platforms composed by several units can be assembled enabling distinctive forms of dissipation and decoherence, in independent heat baths or collectively into a common bath, with dramatic consequences for the preservation of quantum coherence. The cross-over between these two regimes has been widely attributed in the literature to the system units being farther apart than the bath's correlation length. Starting from a microscopic model of a structured environment (a crystal) sensed by two bosonic probes, here we show the failure of such conceptual relation, and identify the exact physical mechanism underlying this cross-over, showing that it is not only a matter of system size. Peculiar scenarios in 1D environments or beyond isotropic dispersion relations are predicted, with collective dissipation possible for very large distances between probes, opening new avenues to deal with decoherence in phononic baths.

Heinz-Peter Breuer
Generalized trace distance measure connecting quantum and classical non-Markovianity

We establish a direct connection of quantum Markovianity of an open system to its classical counterpart by generalizing the criterion based on the flow of information between the open system and its environment. This information flow is characterized by the time evolution of Helstrom matrices under the action of the quantum dynamical map. It turns out that the introduced criterion is equivalent to P-divisibility of a quantum process, namely divisibility in terms of positive maps, which is demonstrated to provide a direct connection to classical Markovian stochastic processes.

Andreas Buchleitner
Single- and many-particle transport on networks

The talk will provide a short review on quantum transport of single and many particles on networks, with variable symmetry properties. In particular, we will focus on the impact of tunable particle distinguishability on many-particle interference phenomena.

2nd Session - Wed March 9 starting at 9:00

Ian Walmsley
TBA

Vyacheslav Shatokhin
Spectral detection of resonance fluorescence

Single-atom resonance fluorescence has been long associated with the famous triplet structure of the emission spectrum under strong laser driving [1] or the effect of photon antibunching [2]. Less known are spectral correlations between photons that are emitted into components of the Mollow triplet [3]. Recent progress in spectroscopy of semiconductor quantum dots has revived interest in theoretical [4] and experimental [5,6] studies of spectral correlations of resonance fluorescence emitted by single (artificial) atoms. In this contribution, we discuss how to measure and calculate spectral correlation functions in resonance fluorescence. Besides presenting our results, we critically examine some new concepts that have appeared in the recent literature [4,6].

[1] B. R. Mollow, Phys. Rev. 188, 1969 (1969).
[2] H. J. Kimble, M. Dagenais, and L. Mandel, Phys. Rev. Lett. 39, 691 (1977).
[3] A. Aspect et al. Phys. Rev. Lett. 45, 617 (1980).
[4] A. Gonzalez-Tudela et al. New J. Phys. 15, 033036 (2013).
[5] A. Ulhaq et al. 6, 238 (2012).
[6] M. Peiris et al. Phys. Rev. B 91, 195125 (2015).

Stefano Olivares
Full quantum state reconstruction of symmetric two-mode squeezed thermal states: recent advances @ UniMi

Homodyne detection is an effective tool to characterize the quantum states of light in a narrow spectral range and it plays a relevant role in continuous-variable quantum information protocols and to investigate properties of quantum systems. We suggest and demonstrate a scheme to reconstruct the symmetric two-mode squeezed thermal states of spectral sideband modes from an optical parametric oscillator. The method is based on both a single homodyne detector and the error signal from the active stabilization of the oscillator cavity. The measurement scheme has been successfully tested on different two-mode squeezed thermal states usually employed to encode signals or to probe complex systems. In particular here we focus on uncorrelated coherent states and entangled states. Our procedure is a versatile diagnostic tool, suitable to be embedded in quantum information experiments as well as to investigate the properties of complex systems involving continuous variable systems in the spectral domain.

Simone Cialdi
The Milano Quantum Optics Laboratory

The aim of this talk is to present the quantum optics laboratory of Milano. I will describe some experimental techniques we recently developed that are of interest for the QuProCS project. In particular, three different optical devices will be briefly described with the hopeful additional purpose of stimulating new collaborations. Two of these experimental devices are based on the parametric down conversion process in perturbative regime and are dedicated to the generation of two photons entangled states. The third one provides squeezed states generation and is based on a single mode laser and an actively stabilized optical parametric oscillator.

Chuan-Feng Li
Experimental detection of polarization-frequency quantum correlations in a photonic quantum channel by local operations

The measurement of correlations between different degrees of freedom is an important, but, in general, extremely difficult task in many applications of quantum mechanics. Here, we report an all-optical experimental detection and quantification of quantum correlations between the polarization and the frequency degrees of freedom of single photons by means of local operations acting only on the polarization degree of freedom. These operations only require experimental control over an easily accessible two-dimensional subsystem, despite handling strongly mixed quantum states comprised of a continuum of orthogonal frequency states. Our experiment thus represents a photonic realization of a scheme for the local detection of quantum correlations in a truly infinite-dimensional continuous-variable system, which excludes an efficient finite-dimensional truncation.

Bi-Heng Liu
Efficient superdense coding in the presence of non-Markovian noise

Many quantum information tasks rely on entanglement, which is used as a resource, for example, to enable efficient and secure communication. Typically, noise, accompanied by loss of entanglement, reduces the efficiency of quantum protocols. We develop and demonstrate experimentally a superdense coding scheme with noise, where the decrease of entanglement in Alice's encoding state does not reduce the efficiency of the information transmission. Having almost fully dephased classical two-photon polarization state at the time of encoding with concurrence 0.163+/-0.007, we reach values of mutual information close to 1.52+/-0.02 (1.89+/-0.05) with 3-state (4-state) encoding. This high efficiency relies both on non-Markovian features, that Bob exploits just before his Bell-state measurement, and on very high visibility (99.6%+/-0.1%) of the Hong-Ou-Mandel interference within the experimental set-up. Our proof-of-principle results pave the way for exploiting non-Markovianity to improve the efficiency and security of quantum information processing tasks.

3rd Session Wed March 9 starting at 14:30

Markus Oberthaler
Immersed quantum systems: Lamb shift and bound Bose polarons

The experimental realization of two component quantum gases offers a unique way for the study of dynamics of immersed quantum systems. The employed atomic system sodium-lithium allows the exploration of the weak coupling limit which is well captured by the Fröhlich Hamiltonian but makes the observable effects such as the increase of the effective mass experimentally challenging since they are very small. The implementation of a novel motional Ramsey spectroscopy strategy opens now the route for accessing these relative mass changes in the order of 10^{-4}. We will report on the results employing this method for the investigation of the motional coherence of fermions in a bosonic bath [1]. Our latest finding reveal that in the limit of strong confinement the effective mass picture is no sufficient to explain the observation of the energy splitting of the motional states. Indeed the selfenergy has to be properly calculated revealing that additional to the energy shift of the motional degrees of freedom due the increase mass also the phenomenon of Lamb shift becomes accessible. With our system employing fermionic and bosonic impurities immersed in a bosonic bath we can identify the Lamb shift of bound Bose polarons and with that detect for the first time directly the theoretically discussed phononic Lamb shift for bound polarons in condensed matter systems [2].

[1] *Motional Coherence of Fermions Immersed in a Bose Gas,* R. Scelle, et al. Phys.Rev.Lett. **111**, 070401 (2013).
[2] *Ground-State Energy of Bound Polarons*, P.M. Platzman, Phys.Rev. **125**, 1961 (1962).

Andrew Daley
Dynamics and probing of atoms in a tilted optical lattice

We study the non-equilibrium dynamics of bosonic atoms in a tilted optical lattice, beginning from unit filling in the Mott insulator regime. Studying a quench to the resonance point for tunnelling of the particles over one or two sites, we show how in the presence of a superlattice, a spin model emerges involving two subchains described by an Ising model that are then coupled by interaction terms. This allows us to study the system in detail for typical experimental size scales, especially comparing the dephasing of local variables after the quench as a result of coherent dynamics to the corresponding behaviour in the presence of external decoherence (e.g., through light scattering). In the broader QuProCS context, this study sets the stage for experiments in tilted optical lattices, and provides a diagnostic tool for investigating decoherence in probing such out-of-equilibrium dynamics.

Elmar Haller
Towards experiments with ultracold caesium atoms in optical lattice potentials

Ultracold atoms in optical lattices offer the possibility to study quantum systems with almost complete control over all system parameters, e.g., such as densities, temperatures and interactions. Especially caesium atoms provide favourable scattering properties and a precise control of the interaction strength by means of broad magnetic Feshbach resonances. I am going to report on the progress of our experimental setup and on our plans to implement quantum probes with caesium atoms in optical lattice potentials.

Francesco Cosco
Momentum Resolved Spectroscopy Using Atomic Quantum Probes

We propose a non-invasive probing scheme to detect and characterise the superfluid excitations of a cold atomic gas loaded into an optical lattice using a single quantum impurity that acts as a probe. The protocol relies on weak collisional interactions and consequent measurements that are optimised in the impurity position. By tuning a few controllable external parameters in the impurity-lattice interaction and using two subsequent sets of measurements the full dispersion relation of the superfluid phonons can be reliably extracted.

Dieter Jaksch
Atomic impurities in a BEC vortex lattice

We investigate cold bosonic impurity atoms trapped in a vortex lattice formed by a rotating cloud of condensed bosons of another species. We describe the dynamics of the impurities by a bosonic Hubbard model containing occupation-dependent parameters to capture the effects of strong impurity-impurity interactions and the softness of the trapping potential provided by the vortices. These lead to a direct repulsive interaction and an attractive effective interaction mediated by the vortices. The occupation dependence of these two competing interactions drastically affects the Hubbard model phase diagram, including causing the disappearance of some Mott lobes. Furthermore the dynamics of the probes allows the study of vortex core properties.

Chris Foot
Atom trapping in dressed-atom adiabatic potentials

We have created a double well potential by applying three radio-frequency fields to cold rubidium atoms confined in a magnetic quadrupole although the spacing between wells is not yet small enough for controllable tunnelling. These species-selective potentials can be used to immerse atoms of one species in a cloud of another species and we are planning to implement this idea with the isotopes Rb-87 and Rb-85; the apparatus works with the Rb-87 atoms and some preliminary experimental work has been carried out with Rb-85 atoms to demonstrate the first stage of magnetic trapping. The simultaneous trapping and sympathetic cooling has been demonstrated in experiments elsewhere and will be feasible in our apparatus using additional lasers. The advantages of our approach include: i) the potential for each species be controlled independently (by the amplitude and frequency of the applied RF radiation) so that the overlap between the two clouds can be controlled ii) we are setting up a detection system for low numbers of atoms which will allow the detection of 'impurity' atoms in a background of another species. With these experimental tools we shall be able to investigate the behaviour of a small number of probe atoms interacting with a quantum gas.

4th Session - Thu March 10 starting at 9:00

Anna Sanpera
Quantum metrology in Quantum thermometry

Quantum metrology refers to the use of quantum resources to improve parameter estimation. The accuracy of quantum metrology, after removing the sources of classical fluctuations, is limited by quantum fluctuations and thus it is possible to achieve a better resolution than classically. Within this frame we ask ourselves first what is the best quantum thermometer one can construct. And then we move to strongly correlated systems at equilibrium to see what are the limits and observables to attain the best estimation on Hamiltonian parameters.

Suzanne McEndoo
Dissipative dynamics of lattice atoms coupled to reservoirs

Gianluca Giorgi
Probing a dissipative process through quantum synchronization

We introduce a technique that allows one to probe a dissipative process exploiting the emergence of quantum synchronization. Given a qubit immersed in a dissipative environment, a coupling to an external probe is able to generate synchronization between the qubit and the probe itself. We show that the synchronization frequency is subject to a sharp discontinuity that can be observed by tuning the frequency of the probe. Knowing the value at which this discontinuity is observed allows one to reconstruct the shape of the spectral density.

Jyrki Piilo
Progress on optical simulator for generic dephasing

We describe the theoretical progress on developing an optical simulator for generic dephasing dynamics (WP3) and also illustrate some reservoir engineering and correlation control aspects within quantum probe framework (WP2). For complex quantum networks (WP5), results on some basic probing schemes are presented.

Claudia Benedetti
Non-Markovian continuous-time quantum walks on lattices with dynamical noise

We address the dynamics of continuous-time quantum walks on one-dimensional disordered lattices. Noise is introduced as time-dependent fluctuations of the tunneling amplitudes between adjacent sites, and attention is focused on non-Gaussian telegraph noise. We show the emergence of two different dynamical behaviors for the walker, corresponding to two opposite noise regimes: slow noise confines the walker into few lattice nodes, while fast noise induce a transition between quantum and classical diffusion over the lattice. We also address the non-Markovianity of the quantum map by assessing its memory effects as well as evaluating the information backflow to the system. Our results suggest that the non-Markovian character of the evolution is linked to the dynamical behavior in the slow noise regime, and that fast noise induces a Markovian dynamics for the walker.