Template

PROJECT FINAL REPORT

Grant Agreement number:

Project acronym:

Project title:

Funding Scheme:

Period covered: from to

Name of the scientific representative of the project's co-ordinator[1], Title and Organisation:

Tel:

Fax:

E-mail:

Project website Error! Bookmark not defined. **address:**

[1] Usually the contact person of the coordinator as specified in Art. 8.1. of the Grant Agreement.

4.1 Final publishable summary report

This section must be of suitable quality to enable direct publication by the Commission and should preferably not exceed 40 pages. This report should address a wide audience, including the general public.

The publishable summary has to include **5 distinct parts** described below:

- An executive summary (not exceeding 1 page).
- A summary description of project context and objectives (not exceeding 4 pages).
- A description of the main S&T results/foregrounds (not exceeding 25 pages),
- The potential impact (including the socio-economic impact and the wider societal implications of the project so far) and the main dissemination activities and exploitation of results (not exceeding 10 pages).
- The address of the project public website, if applicable as well as relevant contact details.

Furthermore, project logo, diagrams or photographs illustrating and promoting the work of the project (including videos, etc…), as well as the list of all beneficiaries with the corresponding contact names can be submitted without any restriction.

Executive summary

The quantum technologies that are coming to fruition are narrow, isolated niches separated by vast domains of technologies still ruled by classical physics. The formidable challenge of creating a broad quantum-technological base calls for bridging and integrating these niches. In this spirit, we endeavour to capitalize on the remarkable analogies that have recently emerged between two previously unrelated classes of quantum systems with potentially fascinating applications: ultracold-atoms (UCA) degenerated gases and solid-state superconductors (SC). These analogies stem from the notion of macroscopic quantum-coherent transport known as Josephson supercurrent, common to both fields. Building on this, we have studied fundamental and applied aspects of macroscopic quantum coherence/supercurrents in UCA- and SC-based devices through active cooperation between leading teams in the two fields.

This project aims at creating a unified base for genuinely quantum regimes of operation in both fields. This unified base serves a twofold purpose:

i. It allows substantial improvement in the state-of-the-art of both fields: our ability to exploit the properties of macroscopic quantum coherence/supercurrents in novel UCA- and SC-based devices greatly benefits from active cooperation between leading teams in the two fields.
ii. It is used to explore the feasibility of *integrating* the two types of devices. Progress towards this ambitious goal has already been made, with a view towards creating a new quantum technology suitable for various applications .

From both fundamental and applied perspectives, the project has led to highly innovative, significant advances: 1) quantum noise understanding and control, which are prerequisites for quantum operations; 2) quantum entanglement of UCA-based Josephson devices (Josephson junctions – JJ) as well as of their SC counterparts; 3) proof of the feasibility of quantum interfaces based on “strong” coupling of SC quantum devices with storage/readout systems based on spin ensembles (NV-centers or impurities in SC, JJ); 4) proof of the feasibility of a hybrid quantum circuit: transfer from the SC device (via a SLR link) to the spin ensemble.

The pledged milestones reached in the third period (42-months) can be detailed as follows:

i. Atomic homodyne technique for detecting continuous-variable entanglement. This breakthrough in UCA ensembles has been developed by Heidelberg jointly with Weizmann.
ii. We implemented SC quantum circuits incorporating coupled / entangled JJ devices usable for quantum information transmission and processing, quantum interferometry and metrology. To this end we have studied the ability to control and manipulate robust (noise resilient) collective variables of entangled elements in UCA JJs (jointly by Heidelberg, Vienna and Weizmann) and in SC JJs (by Grenoble and by Karlsruhe)

We have implemented quantum interconnects / interfaces between NV-center-based quantum memory and readout JJ devices (by Saclay and Vienna, jointly with Weizmann). This daring undertaking stems from a basic question: can we entangle these two very different types of elements, either by direct coupling, or via electromagnetic field modes? This achieved objective was the most challenging one, aimed at establishing a new quantum technology based on hybrid atomic-solid, macroscopically coherent, modules for quantum information processing (memory + readout).

Summary of project context and objectives

a) Detailed understanding / modeling of environmental (extrinsic) vs. intrinsic fluctuations and noise in SC and UCA JJ devices
b) Study and demonstration of dynamical control of noise decoherence on relaxation in SC and UCA JJ devices

c) Detailed understanding / modeling of fluctuations and noise in superconducting (SC) and ultracold atom (UCA) or spin-ensemble devices.
d) Study and demonstration of dynamical control of noise (decoherence or relaxation) in SC and UCA devices.
e) Quantum coherence / entanglement control: strive for coherence time improvement by at least one order of magnitude.
f) Control of macroscopic quantum coherence via Andreev states in high-Tc superconducting (HTS) circuits.
g) Bloch oscillations in SC JJ circuits.
h) Study and strive to demonstrate entanglement for SC and UCA devices: collective variable squeezing.
i) Study and strive to demonstrate coupling or hybridization of SC and UCA devices.

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l) Quantum coherence / entanglement control: strive for coherence time improvement by at least one order of magnitude.
m) Control of macroscopic quantum coherence via Andreev states in high-Tc superconducting (HTS) circuits.
n) Bloch oscillations in SC JJ circuits.
o) Study and strive to demonstrate entanglement for SC and UCA devices: collective variable squeezing.
p) Study and strive to demonstrate coupling or hybridization of SC and UCA devices.

Main S&T results / foregrounds

D1.1+D1.2

T1.1

T1.1a Publication: **Unitary and Non-Unitary Manipulations of Qubit-Bath Entanglement: non-Markov Qubit Cooling**
(Partner 1 – Weizmann)
*Quantum Information Processing, **8**, 607 (2009)*

Initialization of quantum logic operations makes it imperative to cool down the information carrying qubits as much and as fast as possible, so as to purify their state, or at least their ensemble average. Yet, the limit on the speed of existing cooling schemes is either the duration of the qubit equilibration with its bath or the decay time of an auxiliary state to one of the qubit states. Here we show that highly-frequent phase-shifts or measurements of the state of thermalized qubits can be designed to affect the qubit-bath entanglement so that the qubits undergo cooling, well before they re-equilibrate with the bath and without resorting to auxiliary states. These processes can be used in principally novel, advantageous, cooling schemes to assist quantum logic operations.

T1.1b Report: **Non-Markovian decoherence of two-level systems weakly coupled to bosonic baths**
(Partner 7 – Chalmers)

We theoretically investigated non-Markovian effects in long-time decoherence of superconducting JJ qubits coupled to a radiative bath. We developed consistent diagrammatic theory and formulated self-consistent Born approximation for the weak coupling limit to correctly evaluate non-Markovian tails in qubit decoherence. A novel result is conclusion about exponential temporal behavior of non-Markovian part of decoherence.

T1.1c Publication: **Breakdown of integrability in a quasi-1D ultracold bosonic gas**
(Partner 2 – Vienna)
Phys. Rev. Lett. 100, 210403 (2008)

We demonstrate that virtual excitations of higher radial modes in an atomic Bose gas in a tightly confining waveguide result in effective three-body collisions that violate integrability in this quasi-one-dimensional quantum system and give rise to thermalization. The estimated thermalization rates are consistent with recent experimental results in quasi-1D dynamics of ultracold atoms.

T1.1d Publication: **Dephasing in two decoupled one-dimensional Bose-Einstein condensates and the subexponential decay of the interwell coherence**
(Partner 2 – Vienna)
Eur. Phys. J. B 68, 335 (2009)

We provide a simple physical picture of the loss of coherence between two coherently split one-dimensional Bose-Einstein condensates. The source of the dephasing is identified with nonlinear corrections to the elementary excitation energies in either of the two independent condensates. We retrieve the result by Burkov, Lukin and Demler [Phys. Rev. Lett. 98, 200404 (2007)] on the subexponential decay of the coherence $\alpha \exp[-(t/t\_0)^{2/3}]$ for the large time t, however, the scaling of t0 differs.

T1.1e Publication: **Restoring integrability in one-dimensional quantum gases by two-particle correlations**
(Partner 2 – Vienna)
Phys. Rev. A 79, 061603(R) (2009)

We show that thermalization and the breakdown of integrability in the one-dimensional Lieb-Liniger model caused by local three-body elastic interactions is suppressed by pairwise quantum correlations when approaching the strongly correlated regime. If the relative momentum k is small compared to the two-body coupling constant c the three-particle scattering state is suppressed by a factor of $(k/c)^{12}$. This demonstrates that in one-dimensional quantum systems it is not the freeze out of two body collisions but the strong quantum correlations which ensures integrability.

T1.1f Publication: **Geometry-dependent interplay of long-range and short-range interactions in ultracold fermionic gases**
(Partners 2+1 – Vienna+Weizmann)
New J. Phys. 10, 045013 (2008)

We study the two mechanisms of the interplay of long- and short-range interactions in different geometries of ultracold fermionic atomic or molecular gases. We show that in the range of validity of the one-dimensional (1D) approximation, both mechanisms yield similar superconductivity. We show that electromagnetically induced isotropic dipole–dipole interactions in a spin-polarized non-degenerate fermionic gas can cause an extremely exothermic phase transition, analogous to the isothermal collapse in gravitationally interacting star clusters. This collapse may result in fragmentation of the gas into a hot 'halo' and a highly degenerate 'core'. Possible realization is envisaged in microwave-illuminated fermionic molecular gases at microkelvin temperatures.

T1.2

T1.2a Publication: **Quantum Dynamics in a Camelback Potential of a dc SQUID**
(Partner 8 – CNRS)
PRL 102(9):097004, 2009 Mar 6

We investigate a quadratic-quartic anharmonic oscillator formed by a potential well between two potential barriers. We realize this novel potential with a dc SQUID at near-zero current bias and flux bias near half a flux quantum. Escape out of the central well can occur via tunneling through either of the two barriers. We find good agreement with a generalized double-path macroscopic quantum tunneling theory. We also demonstrate an ‘‘optimal line’’ in current and flux bias along which the oscillator, which can be operated as a phase qubit, is insensitive to decoherence due to low-frequency current fluctuations.

T1.2b **Demonstration of a high fidelity single-shot QND readout**
(Partner 4 – Saclay)
Nature Physics (in press)

Coherence of superconducting qubits has been recently significantly improved (x5 compared to Quantronium) by placing Cooper pair boxes of the transmon type, insensitive to charge noise, in microwave resonators providing little relaxation to the qubit. We have developed an efficient qubit readout for this appealing architecture. For this purpose, we have exploited the bifurcation transition that occurs when the cavity is made non-linear by introducing a Josephson junction inside (so-called cavity bifurcation amplifier) . For Midas research, we have investigated in depth the compromise between readout fidelity and coherence, and the back-action of readout on the qubit. We have demonstrated in particular that this new method does not add relaxation to the qubit. In a nut, projection fidelity goes with readout readout fidelity in the readout that we have demonstrated. All results are summarized in the preprint:

T1.2c Report / preprint: **Rabi Spectroscopy of a Strongly Driven Qubit-Fluctuator System**
(Partner 5 – Karlsruhe)

Superconducting qubits often show signatures of coherent coupling to microscopic two-level fluctuators (TLFs), which manifest themselves as avoided level crossings in spectroscopic data. In this work we study a phase qubit, in which we induce Rabi oscillations by resonant microwave driving. When the driven qubit is tuned close to a resonance with an individual TLF, 4-level dynamics are observed. The experimental data of the frequency components in the response of the driven 4-level system show a clear asymmetry between biasing the qubit above and below the fluctuators level-splitting. This data indicates a direct coupling of the TKF to the external microwave field, as verified by a theoretical analysis reproducing the experimental data.

T1.2d Report: **Entangling a Josephson macro-"atom" with a microscopic atomic dipole**
(Partner 5 – Karlsruhe)

Nearly all known types of superconducting qubits show signatures of coherent coupling to microscopic two-level fluctuators (TLFs), which manifest themselves as avoided level crossings in spectroscopic data. The microscopic TLFs are currently understood as nanoscale dipole states emerging from metastable lattice configurations in amorphous dielectrics forming the tunnel barrier of the qubit's Josephson junction or its shunting capacitor. A switching between different metastable charge configurations at low temperatures occurs by quantum tunneling, and such an atomic-scale charge displacement can be associated with the creation of a electrical dipole. Such a dipolar TLF couples to the electrical field of the qubit, which oscillates at the qubit frequency. The qubit ac field has a maximal strength in the tunnel barrier of the Josephson junction. Since TLFs are considered as a source of decoherence, experiments are usually conducted by biasing the qubit in a microwave frequency range where none of these strongly coupled natural two-level systems are present. Alternatively, one can also take an advantage of longer coherence times of TLFs for using them as a kind of quantum memory that can store the quantum information about an arbitrary quantum state of the macroscopic qubit. *We are using a Josephson phase qubit for manipulating the quantum state of a single TLF*. Driving Rabi oscillations of a qubit tuned close to a resonance with TLF leads to the observation of true 4-level dynamics. The experimental data of the frequency components in the response of the driven 4-level system show a clear asymmetry between biasing the qubit above and below the fluctuators level-splitting. A theoretical analysis of our data points towards the existence of a direct coupling between the external microwave field and the two-level fluctuator.

T1.2e Report: **Decoherence of anharmonic artificial atoms**:
(Partner 8 – CNRS)

We have studied the very low frequency noise in an anharmonic artificial atom based on a dc-SQUID. This circuit may be trapped in the superconducting state (where it is described as an artificial atom) but may escape in the voltage state. We have measured the escape probability Pesc(t) versus time by keeping the external parameters constant. Pesc(t) is fluctuating with time showing peaks or dips. This noise depends on the bias parameters such as flux, current and temperature. It can not be interpreted as flux or current bias noise but could be explained by a critical current noise whose measured standard deviation varies but also its frequency strongly depend on the bias flux and show one quantum of flux periodicity. Moreover the noise suddenly disappears when the temperature is above 600mK.

D1.1a Publication: **Non-Markovian decoherence of two-level system weakly coupled to bosonic bath**
(Partner 7 – Chalmers (T))
EuroPhys. Lett. 96, (2011) (in press)

Theoretical modeling/analysis of non-Markovian relaxation and decoherence: We performed analytical study of non-Markovian decoherence in spin-boson model. We extended our previous analysis to non-separable initial conditions by considering experimentally relevant preparatory manipulation.

D1.2a report:
(partner 4 – Saclay)

CEA has operated a two-qubit quantum processor fitted with non-destructive single-shot readout, as needed for demonstrating the quantum speed-up claimed by quantum algorithms. This processor is based on two capacitively coupled transmon qubits, each one embedded in a non-linear resonator for readout. The coupling implements the gate Sqrt(iSWAP). The process tomography of this universal gate was performed, and the effect of decoherence characterized. Ref.: A. Dewes, F.R. Ong, V. Scmitt, R. Lauro, N. Boulant, P. Bertet, D. Vion, and D. Esteve, Characterization of a two-transmon qubit gate with individual readouts, to be submitted to Phys. Rev. Lett.) **[Highlight]**

D1.2b report:
(Partner 7 – Chalmers (E))

We have realized Nb Josephson junctions with various LC circuits shunting the junctions. Spectroscopic measurements in the quantum limit clearly show that the phase dynamics of the system are two-dimensional, resulting in two resonant modes of the system. These findings have important implications for the design and operation of Josephson junction based quantum bits.

D1.2c Publication: **Quantum phase dynamics in an LC shunted Josephson junction**
(Partner 7 – Chalmers (E))
J. Appl. Phys. 109, 093915 (2011)

We have studied both theoretically and experimentally how an LC series circuit connected in parallel to a Josephson junction influences the Josephson dynamics. The presence of the shell circuit introduces two energy scales, which in specific cases, can strongly differ from the plasma frequency of the isolated junction. Josephson junctions were manufactured using the Nb/Al-AlO_x/Nb fabrication technology with various on-chip LC shunt circuits. Spectroscopic measurements in the quantum limit show excellent agreement with theory taking into account the shunt inductance and capacitance in the resistively and capacitively shunted junction model. The results clearly show that the dynamics of the system are two-dimensional, resulting in two resonant modes of the system. These findings have important implications for the design and operation of Josephson junction based quantum bits.

D1.2d Report: **UCA detection at the quantum limit**
(Partner 8 – ENS)

Using a custom-made optical microscope (numerical aperture NA~0.3), we are able to count the relative populations of the Zeeman components (sacrificing spatial resolution) around 200 using fluorescence imaging and around 60 using absorption imaging, with further improvements possible using spatial filtering techniques. This is sufficient to achieve single-atom sensitivity for small samples with a few tens to hundred atoms.

D1.2e Report:
(Partner 6 – Naples)

Phase dynamics has been investigated in different types of high critical temperature superconductors (HTS) grain boundary (GB) Josephson junctions (JJs). Switching current probabilities measurements have been realized down to 20 mK for different junction configurations with a variable orientation of the interface with respect to the electrodes. The GB forming the barrier

changes as a function of the interface orientation and determines different barrier transparency and levels of dissipation. Apart from canonical quantum and thermal regimes (T1.8), we have found evidence of a tunable moderately damped regime. Thermal fluctuations assist in premature switching into the resistive state and, on the other hand, help in retrapping back to the superconducting state. These processes are unavoidable in junctions characterized by low values of the critical currents, and therefore in quantum superconducting electronics employing nanotechnologies. We have compared systems based on low critical temperature superconductors (LTS) JJs designed to be in a moderately damped regime. These junctions employ NbN as a superconductor and may present some advantages with respect to Nb junctions for the realization of superconducting qubits, because of possible reluctance to form intrinsic two-level systems. HTS JJs seem to offer complementary functionalities when compared to LTS systems and some more flexibility in tuning the crossover temperature of the phase diffusion regime (D1.2). In addition phase diffusion both in LTS (results available in literature) and HTS (our measurements) seem to enter into a freeze-out regime independent of temperature below a temperature threshold in the range of hundred of mK. An understanding of dissipation as a function of the junction morphology (through interface orientation) is instrumental also for advances in the performance of a rf-SQUID (Superconducting QUantum Interference Device), i.e. the "qubit's" Josephson junction is embedded in a superconducting loop, therefore forming a rf-SQUID. Magneto-conductance measurements on intrinsic self-protected embedded nanoscale GB junctions have given evidence of the occurrence of a specific proximity regime and of a length scale hierarchy favourable to the presence of a minigap in the GB region, and therefore to coherent Andreev reflection processes. The phenomena are however 'technologically' critical due to the difficulty at the moment in obtaining nanoscale reproducible HTS JJs.

T1.3

T1.3a Report: **Exploration of low energy excitations in HTS Josephson junctions: experiment and theory.**
(Partners 6+7 – Naples+Chalmers)

Macroscopic quantum coherence in Josephson circuits of high-Tc superconductors (HTS) is a debated issue because of the possible presence of low energy excitations. These excitations may exist in the nodal directions of the d-wave order parameter of HTS, and as midgap bound states (MGS) in HTS contacts. Observation of low energy excitations and understanding their role in the junction macroscopic dynamics is of a great importance for potential implementation of HTS Josephson junctions in quantum information processing.

Observation of the Coulomb blockade effect and the parity effect may shed light on the existence of a minigap in the energy spectrum due to an imaginary subdominant component of the order parameter. We have achieved a significant progress in this direction by experimentally realizing all-HTS SET made of an YBCO island confined between two submicron biepitaxial Josephson junctions. We observed several distinct Coulomb diamonds at 20-400 mK with features typical for a single grain SET. The diamonds are strongly affected by an external magnetic field, which might indicate the presence of the minigap.

A crucial advance in this experiment is the development of a novel "self assembling procedure" for fabricating YBCO nanostructures. This is the first successful attempt to master deep sub-micron biepitaxial Josephson devices with atomically flat grain boundary interface.

The Josephson effect in biepitaxial HTS junctions is usually affected by MGS. Except of specific (symmetric) junction orientations, the macroscopic phase dynamics is strongly coupled to the MGS. Because of this a common adiabatic picture of the phase dynamics breaks down: the time evolution of the superconducting phase excites resonant transitions among the MGS pairs. The excited MGS ensemble imposes non-linear and damping effects on the phase dynamics. The resulting picture

resembles a wave interaction with a medium of two-level atoms. We derived a classical equation of motion for the superconducting phase coupled to the MGS ensemble, and analyze various non-linear dynamic regimes.

T1.3b Report: **Sub-micron biepitaxial Josephson junctions for Macroscopic Quantum Tunneling (MQT) experiments**
(Partners 6+7 – Naples+Chalmers)

The HTS activity in MIDAS is fundamentally exploratory. Although the central goal of MIDAS is to promote hybridization between superconductors and atoms, it also covers all aspects which elucidate coherence and dissipation in each of them. HTS has good potential, since it is a structurally different system from LTS, and its strongly correlated nature may affect issues of coherence. However, at present, HTS is not an alternative to LTS technology. Although HTS devices have recently shown macroscopic quantum properties, such as macroscopic quantum tunneling and energy level quantization in thin film structures that can be integrated into real circuits, they still lack reproducibility and yield. The technology gap with LTS junctions is still significant, but HTS can still offer unique functionalities to be exploited in hybrid circuits. The idea is to follow the progress in the qubit design of LTS and the path to hybridization paved by LTS and atomic systems, so as to be able, on a longer time scale, to benefit from novel functionality offered by the HTS peculiar nature. This may become possible only if HTS junctions match the parameters indicated by LTS counterparts.

The planned task is to push HTS junction technology to its extreme limits of performance.

We have demonstrated in the first part of the project that a possible strategy towards higher-performance, more uniform and reproducible HTS junctions passes through the realization of sub-micron and nano-structures. Size reduction could further decrease the influence of artifacts in the barrier microstructure on the junctions characteristics, allowing the realization of more predictable devices.

In the sub-micron regime, we obtain significant improvement in terms of properties reproducibility and quality factors. We have measured switching current distribution of the junction from the superconducting to the resistive state for different orientations of the grain boundary barriers in the thermal regime. Additional insights are given by resonances in current-voltage characteristics, which are possibly linked to resonant dynamics of flux oscillating along the GB line. The possibility to observe such dynamics is owed to the clean barrier structure, characterized by few facets, and low dissipation.

We believe that this is a significant step in view of the ultimate limit of grain boundary nanostructures, to be possibly integrated into quantum circuits, and able to give a more complete understanding of dominant transport processes in HTS junctions.

The complete body of work represents a prerequisite for the fabrication of quantum devices made of HTS . The qubit's Josephson junction will be embedded in a superconducting loop, forming a rf-SQUID. In this way the bias can be executed by inductively coupling an on-chip superconductive coil to the qubit. The two flux states of the qubit can be discriminated using a dc-SQUID switching magnetometer also integrated on-chip and inductively coupled to the qubit. We will take advantage of the flexibility of low Tc superconductors to implement the flux bias lines and the dc-SQUID read-out magnetometer.

T1.3c Report: **High critical temperature superconductor (HTS) junctions and microbridges:**
(Partners 6+7 – Naples+Chalmers)

In this first stage, efforts have been directed to the realization and characterization of submicron and nano- devices:

1. We have set a reliable fabrication process based on Ti or C masks and e-beam lithography, which, at the moment, allows to produce working devices of dimensions down to 100nm for

simple microbridges, down to 500 nm for biepitaxial junctions and down to 200 nm for the average radius of nanorings with arms of the same size.

2. Novel junction configurations with micrometric dimensions have been explored. The interest in these junctions is because they show clear tunnel behaviors and large hysteresis already at 4.2 K, important for studying their properties in both thermal and quantum limits.
3. Measurements on the switching currents distribution have been carried out systematically down to 250 mK in the thermal regime both on submicron biepitaxial grain boundary (GB) junctions, for different orientations of the barrier with respect to the d-wave electrodes, and on bicrystal GB junctions with one off-axis electrode. All junctions have high quality performances with tunnel-like properties, which manifest themselves through high levels of hysteresis in the current-voltage characteristics, high values of the normal state resistance (RN) and low values of the critical current density. These parameters are even more significant if framed in the HTS scenario (where in general it is very hard to achieve tunnel-like barriers) with the additional potential advantage of exploiting the functionality of a d-wave order parameter in frustrating a π-ring. Junctions, about 500 nm wide, show directionality of the tunnelling process and follow the ideal profile of the d-wave order parameter symmetry, with ICRN values up to 4 meV and switching voltages of a few meV as well. Some correlation between the switching histogram and the angle orientation can be established, with information on the quality factor $Q=\omega_P R_N C$ which is in a moderately damped regime (where ω_P is the plasma frequency and C is the junction capacitance). In some configurations thermal fluctuations assist in premature switching into the resistive state and, on the other hand, help in retrapping back to the superconducting state.
4. Measurements on YBCO biepitaxial Josephson junctions on samples 100 nm wide have given additional evidence of coherence, manifested through universal conductance fluctuations (UFC) in magnetic field. Measurements have been analyzed using autocorrelation function protocols, typical of traditional mesoscopic systems. An energy scale of the order of 1 meV arises naturally from the comparison on the autocorrelation function, that we identify with the Thouless energy. This is proportional to the inverse time an electron spends in moving coherently across the mesoscopic sample. Quasiparticles seem to travel coherently across the junction even if $V >> e_C$. Hence, microscopic features of the weak link appear as less relevant, in favour of mesoscopic non local properties. In this case, the qp phase coherence time t_j does not seem to be limited by energy relaxation due to voltage-induced non-equilibrium. The remarkably long lifetime of the carriers, found in these experiments, appears to be a general property in high-Tc YBCO junctions, as proved by optical measurements and macroscopic quantum tunnelling.

T1.3d Publication: **Mesoscopic conductance fluctuations in YBCO grain boundary Junction at low temperature**
(Partners 6+7 – Naples+Chalmers)
PRB 79 024501 (2009)

The magnetoconductance in $YBa_2Cu_3O_{7-\delta}$ grain boundary Josephson junctions displays fluctuations at low temperatures of mesoscopic origin. The morphology of the junction suggests that transport occurs in narrow channels across the grain boundary line with a large Thouless energy. Nevertheless the measured fluctuation amplitude decreases quite slowly when increasing the voltage up to values about 20 times the Thouless energy, of the order of the nominal superconducting gap. Our findings show the coexistence of supercurrent and quasiparticle current in the junction conduction even at high nonequilibrium conditions. Model calculations confirm the reduced role of quasiparticle relaxation at temperatures up to 3K. This represents another direct proof of coherence in HTS junctions to add to macroscopic quantum experiments.

T1.3e Publication: **Eck-Like Resonances in High-Tc Long Faceted Josephson Junctions**
(Partners 6+7 – Naples+Chalmers)
IEEE Trans. On Appl. Supercond. 19, 911 (2009)

By means of numerical simulations we study the dynamics of the phase difference in faceted long Josephson junctions. We compare our simulations with experiments on a sample of high quality high-T_c biepitaxial junctions. Adjusting junction length and dissipation to reproduce the observed data we found a significant agreement, which permits to identify the observed resonances mostly as Eck steps. Some considerations are also made on the requirements to observe flux-flow or Fiske resonances in these junctions.

T1.3f Publication: **Sub-micron $YBa_2Cu_3O_{7-x}$ Biepitaxial Junctions**
(Partners 6+7 – Naples+Chalmers)
IEEE Trans. On Appl. Supercond. 19, 174 (2009)

We report on the fabrication and properties of sub-micron $YBa_2Cu_3O_{7-x}$ off-axis biepitaxial junctions. The vision behind this work is to set up a reliable nanotechnology processing to improve junctions' performances and reproducibility through the reduction of their size. We illustrate the fabrication procedure employed and show the results obtained on samples where the transport parameters were tuned in a predictable way. Also, proofs of a clean barrier structure with few facets and low disorder were obtained. This is the first report on the technology steps used to obtain submicron structures, along with preliminary transport results. More transport results will appear in forthcoming publications.

T1.3g Publication: **Kondo conductance in an atomic nanocontact from first principles**
(Partner 6 – Naples)
Nature Materials, 8, 563 (2009)

The electrical conductance of atomic metal contacts represents a powerful tool for detecting nanomagnetism. Conductance reflects magnetism through anomalies at zero bias-generally with Fano line shapes-owing to the Kondo screening of the magnetic impurity bridging the contact. A full atomic-level understanding of this nutshell many-body system is of the greatest importance, especially in view of our increasing need to control nanocurrents by means of magnetism. Disappointingly, at present, zero-bias conductance anomalies are not calculable from atomistic scratch. Here, we demonstrate a working route connecting approximately but quantitatively density functional theory (DFT) and numerical renormalization group (NRG) approaches and leading to a first-principles conductance calculation for a nanocontact, exemplified by a Ni impurity in a Au nanowire. A Fano-like conductance line shape is obtained microscopically, and shown to be controlled by the impurity s-level position. We also find a relationship between conductance anomaly and geometry, and uncover the possibility of opposite antiferromagnetic and ferromagnetic Kondo screening-the latter exhibiting a totally different and unexplored zero-bias anomaly. The present matching method between DFT and NRG should permit the quantitative understanding and exploration of this larger variety of Kondo phenomena at more general magnetic nanocontacts. This theoretical exploratory activity is meant to address possible two levels functionalities of a solid state system composed by superconductors integrated with molecules.

T1.3h Publication: **YBCO nanobridges: simplified fabrication process by using a Ti hard mask**
(Partner 6 – Naples)
IEEE Trans. On Appl. Supercond. 19, 183 (2009)

An innovative fabrication procedure has been developed to obtain $YBa_2Cu_3O_{7-x}$ (YBCO) nanobridges from c-axis oriented films. The novelty regards the use of a thin titanium mask used in the patterning process. The use of the Ti makes simpler the fabrication procedure guaranteeing high quality devices, as demonstrated by transport measurements. Critical temperatures and critical

current densities scale with the width of the microbridge down to 200 nm in agreement with most results available in literature. The actual properties of the devices, performances, yield and reproducibility, along with an accurate control on doping, may allow the use of these micro-bridges for nanoscale experiments. This work demonstrates that it is possible to have 60 nm wide c-axis microbridges and very small rings shows the way to further reduce with a top-down approach the linewidth of the junctions.

T1.3i Publication: **Properties of inductance and magnetic penetration depth in (103)-oriented $YBa_2Cu_3O_{7-\delta}$ thin films**
(Partner 7 – Chalmers)
PRB 79, 214513 (2009)

We present a study of the anisotropy of the inductance in (103) $YBa_2Cu_3O_{7-\delta}$ (YBCO) films. YBCO superconducting quantum interference devices (SQUIDs) were fabricated by the biepitaxial technique. SQUIDs with (001)- and (103)-oriented YBCO electrodes characterized by different grain-boundary angles were realized on the same chip. Two extrainjection lines were attached to the (103) YBCO electrode. These devices, when operated in current injection mode, allow us to measure the inductance of the (103) YBCO electrode. We have found that the inductance L of the (103) YBCO can differ by a factor of 20 in the two extreme cases: L determined by current transport parallel to the ab planes and L dominated by the transport in the c-axis direction. The full in-plane angular dependence of the inductance has been obtained by considering geometrically identical SQUIDs oriented with different angles with respect to the (100) direction of the (103) film. From these measurements, we have determined the London penetration depths in the *ab* direction λ_{ab} and the c direction λ_c and their temperature dependence.

T1.3j Publication: **Measurement of the current-phase relation in Josephson junction rhombi chains**
(Partner 8 – CNRS)
Phys. Rev. B 78, 104504 (2008)

We present low-temperature transport measurements in one-dimensional Josephson junctions rhombi chains. We have measured the current-phase relation of a chain of eight rhombi. The junctions are either in the classical phase regime with the Josephson energy much larger than the charging energy, EJ EC, or in the quantum phase regime where EJ / EC 2. In the strong Josephson coupling regime EJ EC kBT we observe a sawtoothlike supercurrent as a function of the phase difference over the chain. The period of the supercurrent oscillations changes abruptly from one flux quantum 0 to half the flux quantum 0 / 2 as the rhombi are tuned in the vicinity of full frustration. The main observed features can be understood from the complex energy ground state of the chain. For EJ / EC 2, we do observe a dramatic suppression and rounding of the switching current dependence which we found to be consistent with the model developed by Matveev et al. Phys. Rev. Lett. 89, 096802 (2002) for long Josephson junctions chains.

T1.3k Report: **Superconducting Networks for the Construction of a Topologically Protected Qubit**
(Partner 8 – CNRS)

During the last decade, superconducting qubits have proved to be a promising approach for the construction of a quantum processor. The main obstacle for the moment is the relatively short coherence time of these systems. The usual strategy for constructing protected qubits has consisted in finding operating points in the phase space, where the first derivative of the energy would be zero. By doing this, in a first-order approximation, the qubit is decoupled from the environmental noise. However, superior order contributions to the coupling still dramatically reduce the coherence times. Recently, a new theoretical proposal for the design of a superconducting topoloically protected qubit,

has emerged. The idea is to build a significantly more robust qubit, using an ingenious arrangement of N faulty qubits, which would assure protection against local noise to the Nth order. Practically, this implies the construction and manipulation of complex Josephson junctions networks. We have concentrated our attention on the experimental study of two types of superconducting networks.

The first network we have studied is a chain of 8 flux qubits. Each qubit in the chain consists in a superconducting ring interrupted by 4 Josephson junctions. We have measured the current-phase relation of this chain. When we apply a half flux quantum inside each ring, we observe a doubling of the periodicity in the current-phase relation. For the classical regime (corresponding to small quantum fluctuations of the phase over the qubits in the chain), this is the expected signature of the protected ground state of the chain. Recently, another research group has confirmed this observation for the quantum regime. The second system we have studied is a chain of 6 SQUIDs. This is practically a chain of 6 equivalent Josephson junctions where the Josephson energy can be continuously tuned toward zero by applying a perpendicular magnetic field.

We have measured the current phase relation of the chain from the classical (Josephson Energy >> Charging Energy) to the quantum regime (Josephson Energy <<Charging Energy). We have confirmed that the ground state energy in the presence of quantum fluctuations can be well described using a simple tight binding model. These results are the first experimental confirmation for the underlying theoretical models of the new proposal for a topologically protected qubit. The confirmation of these models describing the ground state energy, strongly encourages us to pursue our research with the study of the excited states and ultimately, the construction of a prototype for this new type of qubit.

T1.3*l* Report: **Cross correlations between charge noise and critical current fluctuations in a Josephson coupled circuit**
(Partner 8 – CNRS)

We study a protocol to test cross-correlations between charge and critical current noise in the small superconducting contacts of an Asymmetric Cooper Pair Transistor coupled to a phase qubit. The superconducting circuit behaves as a tunable 4-level quantum system that can be prepared in two different configurations where cross-correlation terms are respectively absent or present and therefore in principle detectable. We propose measurements of the cross-correlations to be performed either through the escape probability of the dc-SQUID or a quantum state tomography of a few elements of the reduced density matrix of the 4-level quantum system.

T1.4+T1.5

T1.4/5a Publication: **Spin squeezing in Bosonic Josephson junction**
(Partner 3 – Heidelberg)
Nature 455, 1216-1219 (2008)

Generation of spin squeezed states for matter waves is the first step pushing atom interferometry beyond the classical limit due to projection noise. We report on our recent experimental results obtained with a new very stable double well setup combined with high spatial resolution imaging which allows the generation and characterization of number squeezed atomic states. The direct observation of the conjugate variable to the number difference – the relative phase – allows the experimental confirmation of a successfully generated spin squeezed atomic state. The results show that a many particle quantum state has been produced which can improve the precision of Ramsey type interferometer. Furthermore, with the observed squeezing a sufficient criterion for pairwise entanglement can be constructed confirming that for our experimental parameters pairwise entanglement between the atoms exist even at finite temperature. In the conclusion we will report on the status of the squeezing of internal atomic states.

T1.4/5b Publication: **Creation of macroscopic quantum superposition states by a measurement**
(Partners 2+1+3 – Vienna+Weizmann+Heidelberg)
Europhys. Lett. ***83*** *60004 (2008)*

We propose a novel protocol for the creation of acroscopic quantum superposition (MQS) states based on a measurement of a non-monotonous function of a quantum collective variable. The main advantage of this protocol is that it does not require switching on and off nonlinear interactions in the system. We predict this protocol to allow the creation of multiatom MQS by measuring the number of atoms coherently outcoupled from a two-component (spinor) Bose-Einstein condensate.

T1.4/5c Publication: **Short-time Enhancement of the Decay of Coherent Excitations in Bose-Einstein Condensates**
(Partner 1 – Weizmann)
PRL 102, 110401 (2009)

We study, both experimentally and theoretically, short-time modifications of the decay of excitations in a Bose-Einstein Condensate (BEC) embedded in an optical lattice. Strong enhancement of the decay is observed compared to the Golden Rule results. This enhancement of decay increases with the lattice depth. It indicates that the description of decay modifications of few-body quantum systems also holds for decay of many-body excitations of a BEC.

T1.4/5d Publication: **Reversible state transfer between superconducting qubits and atomic ensembles**
(Partners 1+2 – Weizmann+Vienna)
Physical Review A, Vol. 79, No. 4. (2009), 040304.

We examine the decoherence mechanisms and their implications on the possibility of coherent reversible information transfer between solid-state superconducting qubits and ensembles of ultracold atoms. Strong coupling between these systems is mediated by a microwave transmission line resonator that interacts near resonantly with the atoms via their optically excited Rydberg states. The solid-state qubits can then be used to implement rapid quantum logic gates, while collective metastable states of the atoms can be employed for long-term storage and optical readout of quantum information.
This article was selected as one of Nature Physics' Research Highlights.

T1.4/5e Report / preprint: **Dynamical decoupling, motional narrowing and bath characterization of optically trapped atoms**
(Partner 1 – Weizmann)
arXiv:0905.0286v2

Cold atoms trapped in an optical potential can be used as an interface between light and matter in quantum information processing applications. In these applications the optical depth of the ensemble affects the overall efficiency of operations, and therefore dense clouds are desirable. Nevertheless, in most cases high density implies high collision rate, which inevitably reduces the coherence times. We study theoretically and experimentally the coherent dynamics of cold atoms under these conditions. We formulate the framework for dephasing of colliding atoms and motional narrowing of the inhomogeneous line width. We measure directly the bath spectral function and observe non monotonic behavior attributed to harmonic oscillations in the trap.

T1.4/5f Publication: **Quantum fluctuations of a Bose-Josephson junction in a quasi-one-dimensional ring trap.**
(Partner 8 – CNRS)
Phys. Rev. A 79, 063633 (2009)

Using a Luttinger-liquid approach we study the quantum fluctuations of a Bose-Josephson junction, consisting of a Bose gas confined to a quasi one-dimensional ring trap which contains a localized repulsive potential barrier. For an infinite barrier we study the one-particle and two-particle static correlation functions. For the one-body density-matrix we obtain different power-law decays depending on the location of the probe points with respect to the position of the barrier. This quasi-long range order can be experimentally probed in principle using an interference measurement. The corresponding momentum distribution at small momenta is also shown to be affected by the presence of the barrier and to display the universal power-law behavior expected for an interacting 1D fluid. We also evaluate the particle density profile, and by comparing with the exact results in the Tonks-Girardeau limit we fix the nonuniversal parameters of the Luttinger-liquid theory. Once the parameters are determined from one-body properties, we evaluate the density-density correlation function, finding a remarkable agreement between the Luttinger liquid predictions and the exact result in the Tonks-Girardeau limit, even at the length scale of the Friedel-like oscillations which characterize the behavior of the density-density correlation function at intermediate distance. Finally, for a large but finite barrier we use the one-body correlation function to estimate the effect of quantum fluctuations on the renormalization of the barrier height, finding a reduction of the effective Josephson coupling energy, which depends on the length of the ring and on the interaction strength.

T1.4/5g Publication: **Complete series for the off-diagonal correlations of a one-dimensional interacting Bose gas.**
(Partner 8 – CNRS)
Phys. Rev. A (in press)

We develop a generalized harmonic-fluid approach, based on a regularization of the effective low-energy Luttinger-liquid Hamiltonian, for a one-dimensional Bose gas with repulsive contact interactions. The method enables us to compute the complete series corresponding to the large-distance, off-diagonal behavior of the one-body density matrix for any value of the Luttinger parameter K. We compare our results with the exact ones known in the Tonks-Girardeau limit of infinitely large interactions (corresponding to K=1) and, different from the usual harmonic-fluid approach, we recover the full structure of the series. The structure is conserved for arbitrary values of the interaction strength, with power laws fixed by the universal parameter K and a sequence of subleading corrections.

T1.4/5h Report: **Decoherence of mesoscopic superpositions in Bose-Josephson junctions induced by classical noise**
(Partner 8 – CNRS)

We study the dynamics of a mesoscopic Bose-Josephson junction realized in a double-well in the presence of a fluctuating well imbalance. For a constant number of atoms, the full quantum description of the junction can be given in terms of a simple spin-boson model. In the absence of noise, a sudden rise of the barrier between the two wells leads to the evolution of an initially phase-coherent state into a coherent superposition of phase states -a Schroedinger's cat state. We address the effects induced on cat states by the stochastic modulation of the well imbalance. We study in particular the spreading of the phase profile due to a gaussian noise, as well as the loss of coherence between the components of cat states at increasing strength of the noise.

T1.4/5i Report: **Quasi-1D bosons on a ring with a localized barrier**
(Partner 8 – CNRS)

Using both a Luttinger-liquid formalism for the low-energy, large-distance properties of 1D quantum fluids at arbitrary interactions and an exact approach, valid in the Tonks-Girardeau regime of 1D bosons with infinitely strong repulsive interactions, we have studied the transport properties and correlation functions for an interacting quasi-1D Bose gas on a ring. We have focussed both on a

static barrier and on a barrier moving at constant velocity. As main results we find how the motion of the barrier induces a stirring of the fluid which can be interpreted as a probe of imperfect superfluidity in 1D, and estimated the correlation functions for a static large barrier which gives rise to a Josephson junction on the ring. In the latter case we have also shown how in 1D quantum fluctuations strongly renormalize the effective height of the barrier and hence influence the tunnel properties of the junction.

T1.4/5j Report: **Detection of phase cats in a Bose-Josephson junction**
(Partner 8 – CNRS)

Using a two-mode Bose-Hubbard model we characterize the several regimes of the Bose-Josephson junction, from the "classical" one display relative-phase coherence across the junction to the "quantum" one characterized by relative-number squeezing, analogue of a mesoscopic Mott insulator. We have explored the quantum regime and its observables both at equilibrium and during its dynamical evolution. A sudden quench of the junction into the quantum regime gives rise to the formation of Schroedinger phase cats. We show that their phase content can be obtained by the full-counting statistics of the spin-boson operators characterizing the junction, which could be mapped out by repeated measurements of the population imbalance after rotation of the state. This measurement can distinguish between coherent superpositions and incoherent mixtures, and can be used for a two-dimensional, tomographic reconstruction of the phase content of the state.

T1.4/5k Report: **Squeezing and Phase Dynamics Induced by Decoherence in a Two-Mode Bose-Einstein Condensate**
(Partners 1+3 – Weizmann+Heidelberg)

We present an exact solution of the full quantum dynamics of a two-mode (double-well or spinor) Bose-Einstein condensate (BEC) that is subject to pure-dephasing (collisional decoherence) by a thermal bath, primarily of Bogoliubov (phonon) excitations. This solution reveals a hitherto unexplored effect: dynamic modifications of the phase-number quantum fluctuations (squeezing) caused by the interplay between non-Markovian dephasing and self-interactions. These modifications are unitary bath-induced effects. They depend on the geometry and dimensionality of the two-mode BEC.

D1.3

T1.6

T1.6a Publication: **Bosonic Amplification of Noise-Induced Suppression of Phase Diffusion**
Y. Khodorkovsky, G. Kurizki, and A. Vardi
(Partner 1 – Weizmann)
Phys. Rev. Lett. 100, 220403 (2008)

We study the effect of noise-induced dephasing on collisional phase-diffusion in the two-site Bose-Hubbard model. Dephasing of the quasi-momentum modes may slow down phase-diffusion in the quantum Zeno limit. Remarkably, the degree of suppression is enhanced by a bosonic factor of order N/ logN as the particle number N increases.

T1.6b Publication: **Decoherence and entanglement in a bosonic Josephson junction: Bose-enhanced quantum Zeno control of phase diffusion**
(Partner 1 – Weizmann)
Phys. Rev. A 80, 023609 (2009)

We study the effect of decoherence on dynamical phase diffusion in the two-site Bose-Hubbard model. Starting with an odd parity excited coherent state, the initial loss of single-particle coherence

varies from small bound oscillations in the Rabi regime, through hyperbolic depletion in the Josephson regime, to a Gaussian decay in the Fock regime. The inclusion of local-site noise, measuring the relative number difference between the modes, is shown to enhance phase diffusion. In comparison, site-indiscriminate noise measuring the population imbalance between the two quasimomentum modes slows down the loss of single-particle coherence. Decoherence thus either enhances or suppresses phase diffusion, depending on the details of system-bath coupling and the overlap of decoherence pointer states with collisional-entanglement pointer states. The deceleration of phase diffusion due to the coupling with the environment may be viewed as a many-body quantum Zeno effect. The extended effective decay times in the presence of projective measurement are further enhanced with increasing number of particles N by a bosonic factor of sqrt(N) in the Fock regime and N/log N in the Josephson regime.

T1.6c Publication: **Master Equation and Control of an Open Quantum System with Leakage**
(Partner 1 – Weizmann)
Phys. Rev. Lett. 102, 080405 (2009)

Given a multilevel system coupled to a bath, we use a Feshbach P, Q partitioning technique to derive an exact trace-nonpreserving master equation for a subspace Si of the system. The resultant equation properly treats the leakage effect from Si into the remainder of the system space. Focusing on a second-order approximation, we show that a one-dimensional master equation is sufficient to study problems of quantum state storage and is a good approximation, or exact, for several analytical models. It allows a natural definition of a leakage function and its control and provides a general approach to study and control decoherence and leakage. Numerical calculations on an harmonic oscillator coupled to a room temperature harmonic bath show that the leakage can be suppressed by the pulse control technique without requiring ideal pulses.

T1.6d Publication: **Non-Markovian control of qubit thermodynamics by frequent quantum measurements**
(Partner 1 – Weizmann)
Physica E (in press – doi:10.1016/j.physe.2009.06.029)

We have explored the effects of frequent, impulsive quantum nondemolition measurements of the energy of two-level systems (TLS), alias qubits, in contact with a thermal bath. The resulting entropy and temperature of both the system and the bath are found to be completely determined by the measurement rate, and unrelated to what is expected by standard thermodynamical rules that hold for Markovian baths. These anomalies allow for *very fast control* of heating, cooling and state-purification (entropy reduction) of qubits, much sooner than their thermal equilibration time.

T1.6e Publication: **Number squeezing, quantum fluctuations, and oscillations in mesoscopic Bose Josephson junctions**
(Partner 8 – CNRS)
Phys. Rev. A 78, 023606 (2008)

We use a two-mode Bose-Hubbard Hamiltonian to determine the ground state and dynamical evolution for a Bose Josephson junction realized by an ultracold Bose gas in a double-well trap. We identify Mott-like lobes where number fluctuations are suppressed and the interference fringes in the momentum distribution are strongly reduced. Different from superconducting Josephson junctions, the lobes size increases at increasing wells imbalance. Upon a sudden rise of the barrier between the two wells, an initially phase-coherent state evolves into a coherent superposition of phase states, leading to destructive interference in the time-dependent momentum distribution.

T1.6f Report / preprint: **Decoherence control in Bosonic Josephson Junctions**
(Partners 1+3 – Weizmann+Heidelberg)

We propose a new approach to dynamic decoherence control of finite-temperature Bose-Einstein Condensates (BEC) in a double-well potential. Due to the many-body interactions the standard "echo" control method becomes less effective. The proposed approach takes advantage of the interaction-induced change of the spectrum, to obtain the optimal rate of flips of the relative phase between maximally distinguishable collective states. We show that although the interaction of the BEC to the bath is linear, it can induce nonlinear quantum dynamics in the system on non Markovian time scales. This allows to implement dynamic control methods both for protecting the phase coherence and enhancing the useful entanglement between the BEC modes via the bath. The proposed methods are particularly useful for probing and diagnosing the decoherence dynamics.

T1.6g Report: **Dynamical decoupling, motional narrowing and bath characterization of optically trapped atoms**
(Partner 1 – Weizmann)
arXiv:0905.0286

We dynamically control the coherent dynamics of cold atoms under collisions. We formulate the framework for dephasing of colliding atoms. Conventional echo techniques fail to suppress this dephasing, and we exploit dynamical decoupling schemes to suppress collisional decoherence. Using bang-bang dynamical decoupling strategy, we demonstrate coherence time longer than a second for atomic ensemble with optical depth of OD = 100. Further optimization is made utilizing optimized decoherence control pulse sequences based on the specific features of the bath.

T1.6h Publication: **Sum-frequency generation of 589 nm light with near-unit efficiency**
(Partner 8 – CNRS)
Optics Express, Vol. 16, Issue 23, pp. 18684-18691

We report on a laser source at 589 nm based on sum-frequency generation of two infrared laser at 1064 nm and 1319 nm. Output power as high as 800 mW is achieved starting from 370 mW at 1319 nm and 770 mW at 1064 nm, corresponding to converting roughly 90% of the 1319 nm photons entering the cavity. The power and frequency stability of this source are ideally suited for cooling and trapping of sodium atoms.
Patent: INPI 0803153 (06/06/2008): Optical apparatus for wavelength conversion and light source making use of said apparatus ("dispositif optique de conversion de longueur d'onde et source de lumi'ere utilisant un tel dispositif"); inventors: Fabrice Gerbier, Emmanuel Mimoun, Jean-Jacques Zondy (INM-CNAM), Jean Dalibard; international extensions pending.

T1.7+T1.8

T1.7/8a Publication: **Coherent Oscillations in a Superconducting Tunable flux qubit Manipulated without Microwaves**
(Partner 5 – Karlsruhe)
New J. Phys. 11 013009 (2009)

We experimentally demonstrate coherent oscillations of a tunable superconducting flux qubit by manipulating its energy potential with a nanosecond-long pulse of magnetic flux. The occupation probabilities of two persistent current states oscillate at a frequency ranging from 6 GHz to 21 GHz, tunable by changing the amplitude of the flux pulse. The demonstrated operation mode could allow quantum gates to be realized in less than 100 ps, which is much shorter than gate times attainable in other superconducting qubits. Another advantage of this type of qubit is its immunity to both thermal and magnetic field fluctuations.

T1.7/8b Report: **Dynamical control of macroscopic quantum tunneling**

(Partners 5+7+1 – Karlsruhe+Chalmers+Weizmann)

We performed the first experimental trials to observe quantum Zeno effect(QZE) in phase qubit. The qubit was biased with external flux close to its critical value such, that only two energy levels are allowed inside the potential well. The ground state of the Q-bit is metastable and decays exponentially through macroscopic quantum tunneling into “continuum” within 10 ns. The short evolution within 100ps of the ground state is followed by closing a potential barrier, that brings the system into the slow decaying regime with time of about 500ns. If potential is closed for the sufficiently long time, more than decay time of a ground state (10ns), then that closing is similar to the measurement of survival probability. By repeating this procedure many times we hoped to see the suppression of the quantum tunneling rate.

Last measurements of the decay in sub-nanosecond time scale have revealed that short pulses which are applied to create a metastable-state do not reach a qubit circuit. Due to low-pass on-chip-filters, which limit the shortest time for the pulse to about 1 ns. Improved designs aimed at bypassing this problem are under way, aiming at the 100 ps time scale, which is expected to reveal the QZE.

T1.7/8c Report: **Dynamic control of quantum decay to the continuum**
(Partner 7 – Chalmers)
We theoretically investigated decay of a quantum state of current biased superconducting JJ under rapid modulation of the coupling to the continuum. We identified coherent and incoherent dynamic decay regimes. The coherent regime appears when a period of the modulation is very short - much smaller than the inverse Josephson frequency of the junction. There is a crossover from complete decay to an incomplete decay, when a finite fraction of the initial state remains in the quantum well for infinite time. The incoherent regime develops when the well is kept closed for much longer time compared to inverse Josephson frequency. In this case, the evolving state is effectively projected after every manipulation cycle on the initial state realizing the Zeno regime.

T1.7/8 Publication: **Measurement of the current-phase relation in Josephson junction rhombi chains**
(Partner 8 – CNRS)
Phys. Rev. B 78, 104504 (2008)

We present low-temperature transport measurements in one-dimensional Josephson junctions rhombi chains. We have measured the current-phase relation of a chain of eight rhombi. The junctions are either in the

classical phase regime with the Josephson energy much larger than the charging energy, EJ EC, or in the quantum phase regime where EJ / EC 2. In the strong Josephson coupling regime EJ EC kBT we observe a sawtoothlike supercurrent as a function of the phase difference over the chain. The period of the supercurrent oscillations changes abruptly from one flux quantum 0 to half the flux quantum 0 / 2 as the rhombi are tuned in the vicinity of full frustration. The main observed features can be understood from the complex energy ground state of the chain. For EJ / EC 2, we do observe a dramatic suppression and rounding of the switching current dependence which we found to be consistent with the model developed by Matveev et al. Phys. Rev. Lett. 89, 096802 2002 for long Josephson junctions chains.

T1.3

T1.3a Report: **Exploration of low energy excitations in HTS Josephson junctions: experiment and theory.**
(Partners 6+7 – Naples+Chalmers)

Macroscopic quantum coherence in Josephson circuits of high-Tc superconductors (HTS) is a debated issue because of the possible presence of low energy excitations. These excitations may exist

in the nodal directions of the d-wave order parameter of HTS, and as midgap bound states (MGS) in HTS contacts. Observation of low energy excitations and understanding their role in the junction macroscopic dynamics is of a great importance for potential implementation of HTS Josephson junctions in quantum information processing.

Observation of the Coulomb blockade effect and the parity effect may shed light on the existence of a minigap in the energy spectrum due to an imaginary subdominant component of the order parameter. We have achieved a significant progress in this direction by experimentally realizing all-HTS SET made of an YBCO island confined between two submicron biepitaxial Josephson junctions. We observed several distinct Coulomb diamonds at 20-400 mK with features typical for a single grain SET. The diamonds are strongly affected by an external magnetic field, which might indicate the presence of the minigap.

A crucial advance in this experiment is the development of a novel "self assembling procedure" for fabricating YBCO nanostructures. This is the first successful attempt to master deep sub-micron biepitaxial Josephson devices with atomically flat grain boundary interface.

The Josephson effect in biepitaxial HTS junctions is usually affected by MGS. Except of specific (symmetric) junction orientations, the macroscopic phase dynamics is strongly coupled to the MGS. Because of this a common adiabatic picture of the phase dynamics breaks down: the time evolution of the superconducting phase excites resonant transitions among the MGS pairs. The excited MGS ensemble imposes non-linear and damping effects on the phase dynamics. The resulting picture resembles a wave interaction with a medium of two-level atoms. We derived a classical equation of motion for the superconducting phase coupled to the MGS ensemble, and analyze various non-linear dynamic regimes.

T1.3b Report: **Sub-micron biepitaxial Josephson junctions for Macroscopic Quantum Tunneling (MQT) experiments**

(Partners 6+7 – Naples+Chalmers)

The HTS activity in MIDAS is fundamentally exploratory. Although the central goal of MIDAS is to promote hybridization between superconductors and atoms, it also covers all aspects which elucidate coherence and dissipation in each of them. HTS has good potential, since it is a structurally different system from LTS, and its strongly correlated nature may affect issues of coherence. However, at present, HTS is not an alternative to LTS technology. Although HTS devices have recently shown macroscopic quantum properties, such as macroscopic quantum tunneling and energy level quantization in thin film structures that can be integrated into real circuits, they still lack reproducibility and yield. The technology gap with LTS junctions is still significant, but HTS can still offer unique functionalities to be exploited in hybrid circuits. The idea is to follow the progress in the qubit design of LTS and the path to hybridization paved by LTS and atomic systems, so as to be able, on a longer time scale, to benefit from novel functionality offered by the HTS peculiar nature. This may become possible only if HTS junctions match the parameters indicated by LTS counterparts.

The planned task is to push HTS junction technology to its extreme limits of performance.

We have demonstrated in the first part of the project that a possible strategy towards higher-performance, more uniform and reproducible HTS junctions passes through the realization of sub-micron and nano-structures. Size reduction could further decrease the influence of artifacts in the barrier microstructure on the junctions characteristics, allowing the realization of more predictable devices.

In the sub-micron regime, we obtain significant improvement in terms of properties reproducibility and quality factors. We have measured switching current distribution of the junction from the superconducting to the resistive state for different orientations of the grain boundary barriers in the thermal regime. Additional insights are given by resonances in current-voltage characteristics, which are possibly linked to resonant dynamics of flux oscillating along the GB line.

The possibility to observe such dynamics is owed to the clean barrier structure, characterized by few facets, and low dissipation.

We believe that this is a significant step in view of the ultimate limit of grain boundary nanostructures, to be possibly integrated into quantum circuits, and able to give a more complete understanding of dominant transport processes in HTS junctions.

The complete body of work represents a prerequisite for the fabrication of quantum devices made of HTS . The qubit's Josephson junction will be embedded in a superconducting loop, forming a rf-SQUID. In this way the bias can be executed by inductively coupling an on-chip superconductive coil to the qubit. The two flux states of the qubit can be discriminated using a dc-SQUID switching magnetometer also integrated on-chip and inductively coupled to the qubit. We will take advantage of the flexibility of low Tc superconductors to implement the flux bias lines and the dc-SQUID read-out magnetometer.

T1.3c Report: **High critical temperature superconductor (HTS) junctions and microbridges:** (Partners 6+7 – Naples+Chalmers)

In this first stage, efforts have been directed to the realization and characterization of submicron and nano- devices:

5. We have set a reliable fabrication process based on Ti or C masks and e-beam lithography, which, at the moment, allows to produce working devices of dimensions down to 100nm for simple microbridges, down to 500 nm for biepitaxial junctions and down to 200 nm for the average radius of nanorings with arms of the same size.
6. Novel junction configurations with micrometric dimensions have been explored. The interest in these junctions is because they show clear tunnel behaviors and large hysteresis already at 4.2 K, important for studying their properties in both thermal and quantum limits.
7. Measurements on the switching currents distribution have been carried out systematically down to 250 mK in the thermal regime both on submicron biepitaxial grain boundary (GB) junctions, for different orientations of the barrier with respect to the d-wave electrodes, and on bicrystal GB junctions with one off-axis electrode. All junctions have high quality performances with tunnel-like properties, which manifest themselves through high levels of hysteresis in the current-voltage characteristics, high values of the normal state resistance (RN) and low values of the critical current density. These parameters are even more significant if framed in the HTS scenario (where in general it is very hard to achieve tunnel-like barriers) with the additional potential advantage of exploiting the functionality of a d-wave order parameter in frustrating a π-ring. Junctions, about 500 nm wide, show directionality of the tunnelling process and follow the ideal profile of the d-wave order parameter symmetry, with ICRN values up to 4 meV and switching voltages of a few meV as well. Some correlation between the switching histogram and the angle orientation can be established, with information on the quality factor $Q=\omega_P R_N C$ which is in a moderately damped regime (where ω_P is the plasma frequency and C is the junction capacitance). In some configurations thermal fluctuations assist in premature switching into the resistive state and, on the other hand, help in retrapping back to the superconducting state.
8. Measurements on YBCO biepitaxial Josephson junctions on samples 100 nm wide have given additional evidence of coherence, manifested through universal conductance fluctuations (UFC) in magnetic field. Measurements have been analyzed using autocorrelation function protocols, typical of traditional mesoscopic systems. An energy scale of the order of 1 meV arises naturally from the comparison on the autocorrelation function, that we identify with the Thouless energy. This is proportional to the inverse time an electron spends in moving coherently across the mesoscopic sample. Quasiparticles seem to travel coherently across the junction even if $V >> e_C$. Hence, microscopic features of the weak link appear as less relevant, in favour of mesoscopic non local properties. In this case, the qp

phase coherence time t_j does not seem to be limited by energy relaxation due to voltage-induced non-equilibrium. The remarkably long lifetime of the carriers, found in these experiments, appears to be a general property in high-Tc YBCO junctions, as proved by optical measurements and macroscopic quantum tunnelling.

T1.3d Publication: **Mesoscopic conductance fluctuations in YBCO grain boundary Junction at low temperature**
(Partners 6+7 – Naples+Chalmers)
PRB 79 024501 (2009)

The magnetoconductance in $YBa_2Cu_3O_{7-\delta}$ grain boundary Josephson junctions displays fluctuations at low temperatures of mesoscopic origin. The morphology of the junction suggests that transport occurs in narrow channels across the grain boundary line with a large Thouless energy. Nevertheless the measured fluctuation amplitude decreases quite slowly when increasing the voltage up to values about 20 times the Thouless energy, of the order of the nominal superconducting gap. Our findings show the coexistence of supercurrent and quasiparticle current in the junction conduction even at high nonequilibrium conditions. Model calculations confirm the reduced role of quasiparticle relaxation at temperatures up to 3K. This represents another direct proof of coherence in HTS junctions to add to macroscopic quantum experiments.

T1.3e Publication: **Eck-Like Resonances in High-Tc Long Faceted Josephson Junctions**
(Partners 6+7 – Naples+Chalmers)
IEEE Trans. On Appl. Supercond. 19, 911 (2009)

By means of numerical simulations we study the dynamics of the phase difference in faceted long Josephson junctions. We compare our simulations with experiments on a sample of high quality high-T_c biepitaxial junctions. Adjusting junction length and dissipation to reproduce the observed data we found a significant agreement, which permits to identify the observed resonances mostly as Eck steps. Some considerations are also made on the requirements to observe flux-flow or Fiske resonances in these junctions.

T1.3f Publication: **Sub-micron $YBa_2Cu_3O_{7-x}$ Biepitaxial Junctions**
(Partners 6+7 – Naples+Chalmers)
IEEE Trans. On Appl. Supercond. 19, 174 (2009)

We report on the fabrication and properties of sub-micron $YBa_2Cu_3O_{7-x}$ off-axis biepitaxial junctions. The vision behind this work is to set up a reliable nanotechnology processing to improve junctions' performances and reproducibility through the reduction of their size. We illustrate the fabrication procedure employed and show the results obtained on samples where the transport parameters were tuned in a predictable way. Also, proofs of a clean barrier structure with few facets and low disorder were obtained. This is the first report on the technology steps used to obtain submicron structures, along with preliminary transport results. More transport results will appear in forthcoming publications.

T1.3g Publication: **Kondo conductance in an atomic nanocontact from first principles**
(Partner 6 – Naples)
Nature Materials, 8, 563 (2009)

The electrical conductance of atomic metal contacts represents a powerful tool for detecting nanomagnetism. Conductance reflects magnetism through anomalies at zero bias-generally with Fano line shapes-owing to the Kondo screening of the magnetic impurity bridging the contact. A full atomic-level understanding of this nutshell many-body system is of the greatest importance, especially in view of our increasing need to control nanocurrents by means of magnetism. Disappointingly, at present, zero-bias conductance anomalies are not calculable from atomistic

scratch. Here, we demonstrate a working route connecting approximately but quantitatively density functional theory (DFT) and numerical renormalization group (NRG) approaches and leading to a first-principles conductance calculation for a nanocontact, exemplified by a Ni impurity in a Au nanowire. A Fano-like conductance line shape is obtained microscopically, and shown to be controlled by the impurity s-level position. We also find a relationship between conductance anomaly and geometry, and uncover the possibility of opposite antiferromagnetic and ferromagnetic Kondo screening-the latter exhibiting a totally different and unexplored zero-bias anomaly. The present matching method between DFT and NRG should permit the quantitative understanding and exploration of this larger variety of Kondo phenomena at more general magnetic nanocontacts. This theoretical exploratory activity is meant to address possible two levels functionalities of a solid state system composed by superconductors integrated with molecules.

T1.3h Publication: **YBCO nanobridges: simplified fabrication process by using a Ti hard mask**
(Partner 6 – Naples)
IEEE Trans. On Appl. Supercond. 19, 183 (2009)

An innovative fabrication procedure has been developed to obtain $YBa_2Cu_3O_{7-x}$ (YBCO) nanobridges from c-axis oriented films. The novelty regards the use of a thin titanium mask used in the patterning process. The use of the Ti makes simpler the fabrication procedure guaranteeing high quality devices, as demonstrated by transport measurements. Critical temperatures and critical current densities scale with the width of the microbridge down to 200 nm in agreement with most results available in literature. The actual properties of the devices, performances, yield and reproducibility, along with an accurate control on doping, may allow the use of these micro-bridges for nanoscale experiments. This work demonstrates that it is possible to have 60 nm wide c-axis microbridges and very small rings shows the way to further reduce with a top-down approach the linewidth of the junctions.

T1.3i Publication: **Properties of inductance and magnetic penetration depth in (103)-oriented $YBa_2Cu_3O_{7-\delta}$ thin films**
(Partner 7 – Chalmers)
PRB 79, 214513 (2009)

We present a study of the anisotropy of the inductance in (103) $YBa_2Cu_3O_{7-\delta}$ (YBCO) films. YBCO superconducting quantum interference devices (SQUIDs) were fabricated by the biepitaxial technique. SQUIDs with (001)- and (103)-oriented YBCO electrodes characterized by different grain-boundary angles were realized on the same chip. Two extrainjection lines were attached to the (103) YBCO electrode. These devices, when operated in current injection mode, allow us to measure the inductance of the (103) YBCO electrode. We have found that the inductance L of the (103) YBCO can differ by a factor of 20 in the two extreme cases: L determined by current transport parallel to the ab planes and L dominated by the transport in the c-axis direction. The full in-plane angular dependence of the inductance has been obtained by considering geometrically identical SQUIDs oriented with different angles with respect to the (100) direction of the (103) film. From these measurements, we have determined the London penetration depths in the *ab* direction λ_{ab} and the c direction λ_c and their temperature dependence.

T1.3j Publication: **Measurement of the current-phase relation in Josephson junction rhombi chains**
(Partner 8 – CNRS)
Phys. Rev. B 78, 104504 (2008)

We present low-temperature transport measurements in one-dimensional Josephson junctions rhombi chains. We have measured the current-phase relation of a chain of eight rhombi. The junctions are either in the classical phase regime with the Josephson energy much larger than the

charging energy, EJ EC, or in the quantum phase regime where EJ / EC 2. In the strong Josephson coupling regime EJ EC kBT we observe a sawtoothlike supercurrent as a function of the phase difference over the chain. The period of the supercurrent oscillations changes abruptly from one flux quantum 0 to half the flux quantum 0 / 2 as the rhombi are tuned in the vicinity of full frustration. The main observed features can be understood from the complex energy ground state of the chain. For EJ / EC 2, we do observe a dramatic suppression and rounding of the switching current dependence which we found to be consistent with the model developed by Matveev et al. Phys. Rev. Lett. 89, 096802 (2002) for long Josephson junctions chains.

T1.3k Report: **Superconducting Networks for the Construction of a Topologically Protected Qubit**
(Partner 8 – CNRS)

During the last decade, superconducting qubits have proved to be a promising approach for the construction of a quantum processor. The main obstacle for the moment is the relatively short coherence time of these systems. The usual strategy for constructing protected qubits has consisted in finding operating points in the phase space, where the first derivative of the energy would be zero. By doing this, in a first-order approximation, the qubit is decoupled from the environmental noise. However, superior order contributions to the coupling still dramatically reduce the coherence times. Recently, a new theoretical proposal for the design of a superconducting topoloically protected qubit, has emerged. The idea is to build a significantly more robust qubit, using an ingenious arrangement of N faulty qubits, which would assure protection against local noise to the Nth order. Practically, this implies the construction and manipulation of complex Josephson junctions networks. We have concentrated our attention on the experimental study of two types of superconducting networks.

The first network we have studied is a chain of 8 flux qubits. Each qubit in the chain consists in a superconducting ring interrupted by 4 Josephson junctions. We have measured the current-phase relation of this chain. When we apply a half flux quantum inside each ring, we observe a doubling of the periodicity in the current-phase relation. For the classical regime (corresponding to small quantum fluctuations of the phase over the qubits in the chain), this is the expected signature of the protected ground state of the chain. Recently, another research group has confirmed this observation for the quantum regime. The second system we have studied is a chain of 6 SQUIDs. This is practically a chain of 6 equivalent Josephson junctions where the Josephson energy can be continuously tuned toward zero by applying a perpendicular magnetic field.

We have measured the current phase relation of the chain from the classical (Josephson Energy >> Charging Energy) to the quantum regime (Josephson Energy <<Charging Energy). We have confirmed that the ground state energy in the presence of quantum fluctuations can be well described using a simple tight binding model. These results are the first experimental confirmation for the underlying theoretical models of the new proposal for a topologically protected qubit. The confirmation of these models describing the ground state energy, strongly encourages us to pursue our research with the study of the excited states and ultimately, the construction of a prototype for this new type of qubit.

T1.3*l* Report: **Cross correlations between charge noise and critical current fluctuations in a Josephson coupled circuit**
(Partner 8 – CNRS)

We study a protocol to test cross-correlations between charge and critical current noise in the small superconducting contacts of an Asymmetric Cooper Pair Transistor coupled to a phase qubit. The superconducting circuit behaves as a tunable 4-level quantum system that can be prepared in two different configurations where cross-correlation terms are respectively absent or present and therefore in principle detectable. We propose measurements of the cross-correlations to be performed

either through the escape probability of the dc-SQUID or a quantum state tomography of a few elements of the reduced density matrix of the 4-level quantum system.

T1.4+T1.5

T1.4/5a Publication: **Spin squeezing in Bosonic Josephson junction**
(Partner 3 – Heidelberg)
Nature 455, 1216-1219 (2008)

Generation of spin squeezed states for matter waves is the first step pushing atom interferometry beyond the classical limit due to projection noise. We report on our recent experimental results obtained with a new very stable double well setup combined with high spatial resolution imaging which allows the generation and characterization of number squeezed atomic states. The direct observation of the conjugate variable to the number difference – the relative phase – allows the experimental confirmation of a successfully generated spin squeezed atomic state. The results show that a many particle quantum state has been produced which can improve the precision of Ramsey type interferometer. Furthermore, with the observed squeezing a sufficient criterion for pairwise entanglement can be constructed confirming that for our experimental parameters pairwise entanglement between the atoms exist even at finite temperature. In the conclusion we will report on the status of the squeezing of internal atomic states.

T1.4/5b Publication: **Creation of macroscopic quantum superposition states by a measurement**
(Partners 2+1+3 – Vienna+Weizmann+Heidelberg)
Europhys. Lett. ***83*** *60004 (2008)*

We propose a novel protocol for the creation of acroscopic quantum superposition (MQS) states based on a measurement of a non-monotonous function of a quantum collective variable. The main advantage of this protocol is that it does not require switching on and off nonlinear interactions in the system. We predict this protocol to allow the creation of multiatom MQS by measuring the number of atoms coherently outcoupled from a two-component (spinor) Bose-Einstein condensate.

T1.4/5c Publication: **Short-time Enhancement of the Decay of Coherent Excitations in Bose-Einstein Condensates**
(Partner 1 – Weizmann)
PRL 102, 110401 (2009)

We study, both experimentally and theoretically, short-time modifications of the decay of excitations in a Bose-Einstein Condensate (BEC) embedded in an optical lattice. Strong enhancement of the decay is observed compared to the Golden Rule results. This enhancement of decay increases with the lattice depth. It indicates that the description of decay modifications of few-body quantum systems also holds for decay of many-body excitations of a BEC.

T1.4/5d Publication: **Reversible state transfer between superconducting qubits and atomic ensembles**
(Partners 1+2 – Weizmann+Vienna)
Physical Review A, Vol. 79, No. 4. (2009), 040304.

We examine the decoherence mechanisms and their implications on the possibility of coherent reversible information transfer between solid-state superconducting qubits and ensembles of ultracold atoms. Strong coupling between these systems is mediated by a microwave transmission line resonator that interacts near resonantly with the atoms via their optically excited Rydberg states. The solid-state qubits can then be used to implement rapid quantum logic gates, while collective

metastable states of the atoms can be employed for long-term storage and optical readout of quantum information.
This article was selected as one of Nature Physics' Research Highlights.

T1.4/5e Report / preprint: **Dynamical decoupling, motional narrowing and bath characterization of optically trapped atoms**
(Partner 1 – Weizmann)
arXiv:0905.0286v2

Cold atoms trapped in an optical potential can be used as an interface between light and matter in quantum information processing applications. In these applications the optical depth of the ensemble affects the overall efficiency of operations, and therefore dense clouds are desirable. Nevertheless, in most cases high density implies high collision rate, which inevitably reduces the coherence times. We study theoretically and experimentally the coherent dynamics of cold atoms under these conditions. We formulate the framework for dephasing of colliding atoms and motional narrowing of the inhomogeneous line width. We measure directly the bath spectral function and observe non monotonic behavior attributed to harmonic oscillations in the trap.

T1.4/5f Publication: **Quantum fluctuations of a Bose-Josephson junction in a quasi-one-dimensional ring trap.**
(Partner 8 – CNRS)
Phys. Rev. A 79, 063633 (2009)

Using a Luttinger-liquid approach we study the quantum fluctuations of a Bose-Josephson junction, consisting of a Bose gas confined to a quasi one-dimensional ring trap which contains a localized repulsive potential barrier. For an infinite barrier we study the one-particle and two-particle static correlation functions. For the one-body density-matrix we obtain different power-law decays depending on the location of the probe points with respect to the position of the barrier. This quasi-long range order can be experimentally probed in principle using an interference measurement. The corresponding momentum distribution at small momenta is also shown to be affected by the presence of the barrier and to display the universal power-law behavior expected for an interacting 1D fluid. We also evaluate the particle density profile, and by comparing with the exact results in the Tonks-Girardeau limit we fix the nonuniversal parameters of the Luttinger-liquid theory. Once the parameters are determined from one-body properties, we evaluate the density-density correlation function, finding a remarkable agreement between the Luttinger liquid predictions and the exact result in the Tonks-Girardeau limit, even at the length scale of the Friedel-like oscillations which characterize the behavior of the density-density correlation function at intermediate distance. Finally, for a large but finite barrier we use the one-body correlation function to estimate the effect of quantum fluctuations on the renormalization of the barrier height, finding a reduction of the effective Josephson coupling energy, which depends on the length of the ring and on the interaction strength.

T1.4/5g Publication: **Complete series for the off-diagonal correlations of a one-dimensional interacting Bose gas.**
(Partner 8 – CNRS)
Phys. Rev. A (in press)

We develop a generalized harmonic-fluid approach, based on a regularization of the effective low-energy Luttinger-liquid Hamiltonian, for a one-dimensional Bose gas with repulsive contact interactions. The method enables us to compute the complete series corresponding to the large-distance, off-diagonal behavior of the one-body density matrix for any value of the Luttinger parameter K. We compare our results with the exact ones known in the Tonks-Girardeau limit of infinitely large interactions (corresponding to K=1) and, different from the usual harmonic-fluid approach, we recover the full structure of the series. The structure is conserved for arbitrary values of

the interaction strength, with power laws fixed by the universal parameter K and a sequence of subleading corrections.

T1.4/5h Report: **Decoherence of mesoscopic superpositions in Bose-Josephson junctions induced by classical noise**
(Partner 8 – CNRS)

We study the dynamics of a mesoscopic Bose-Josephson junction realized in a double-well in the presence of a fluctuating well imbalance. For a constant number of atoms, the full quantum description of the junction can be given in terms of a simple spin-boson model. In the absence of noise, a sudden rise of the barrier between the two wells leads to the evolution of an initially phase-coherent state into a coherent superposition of phase states -a Schroedinger's cat state. We address the effects induced on cat states by the stochastic modulation of the well imbalance. We study in particular the spreading of the phase profile due to a gaussian noise, as well as the loss of coherence between the components of cat states at increasing strength of the noise.

T1.4/5i Report: **Quasi-1D bosons on a ring with a localized barrier**
(Partner 8 – CNRS)

Using both a Luttinger-liquid formalism for the low-energy, large-distance properties of 1D quantum fluids at arbitrary interactions and an exact approach, valid in the Tonks-Girardeau regime of 1D bosons with infinitely strong repulsive interactions, we have studied the transport properties and correlation functions for an interacting quasi-1D Bose gas on a ring. We have focussed both on a static barrier and on a barrier moving at constant velocity. As main results we find how the motion of the barrier induces a stirring of the fluid which can be interpreted as a probe of imperfect superfluidity in 1D, and estimated the correlation functions for a static large barrier which gives rise to a Josephson junction on the ring. In the latter case we have also shown how in 1D quantum fluctuations strongly renormalize the effective height of the barrier and hence influence the tunnel properties of the junction.

T1.4/5j Report: **Detection of phase cats in a Bose-Josephson junction**
(Partner 8 – CNRS)

Using a two-mode Bose-Hubbard model we characterize the several regimes of the Bose-Josephson junction, from the "classical" one display relative-phase coherence across the junction to the "quantum" one characterized by relative-number squeezing, analogue of a mesoscopic Mott insulator. We have explored the quantum regime and its observables both at equilibrium and during its dynamical evolution. A sudden quench of the junction into the quantum regime gives rise to the formation of Schroedinger phase cats. We show that their phase content can be obtained by the full-counting statistics of the spin-boson operators characterizing the junction, which could be mapped out by repeated measurements of the population imbalance after rotation of the state. This measurement can distinguish between coherent superpositions and incoherent mixtures, and can be used for a two-dimensional, tomographic reconstruction of the phase content of the state.

T1.4/5k Report: **Squeezing and Phase Dynamics Induced by Decoherence in a Two-Mode Bose-Einstein Condensate**
(Partners 1+3 – Weizmann+Heidelberg)

We present an exact solution of the full quantum dynamics of a two-mode (double-well or spinor) Bose-Einstein condensate (BEC) that is subject to pure-dephasing (collisional decoherence) by a thermal bath, primarily of Bogoliubov (phonon) excitations. This solution reveals a hitherto unexplored effect: dynamic modifications of the phase-number quantum fluctuations (squeezing) caused by the interplay between non-Markovian dephasing and self-interactions. These modifications

are unitary bath-induced effects. They depend on the geometry and dimensionality of the two-mode BEC.

D1.3

T1.6

T1.6a Publication: **Bosonic Amplification of Noise-Induced Suppression of Phase Diffusion**
Y. Khodorkovsky, G. Kurizki, and A. Vardi
(Partner 1 – Weizmann)
Phys. Rev. Lett. 100, 220403 (2008)

We study the effect of noise-induced dephasing on collisional phase-diffusion in the two-site Bose-Hubbard model. Dephasing of the quasi-momentum modes may slow down phase-diffusion in the quantum Zeno limit. Remarkably, the degree of suppression is enhanced by a bosonic factor of order N/ logN as the particle number N increases.

T1.6b Publication: **Decoherence and entanglement in a bosonic Josephson junction: Bose-enhanced quantum Zeno control of phase diffusion**
(Partner 1 – Weizmann)
Phys. Rev. A 80, 023609 (2009)

We study the effect of decoherence on dynamical phase diffusion in the two-site Bose-Hubbard model. Starting with an odd parity excited coherent state, the initial loss of single-particle coherence varies from small bound oscillations in the Rabi regime, through hyperbolic depletion in the Josephson regime, to a Gaussian decay in the Fock regime. The inclusion of local-site noise, measuring the relative number difference between the modes, is shown to enhance phase diffusion. In comparison, site-indiscriminate noise measuring the population imbalance between the two quasimomentum modes slows down the loss of single-particle coherence. Decoherence thus either enhances or suppresses phase diffusion, depending on the details of system-bath coupling and the overlap of decoherence pointer states with collisional-entanglement pointer states. The deceleration of phase diffusion due to the coupling with the environment may be viewed as a many-body quantum Zeno effect. The extended effective decay times in the presence of projective measurement are further enhanced with increasing number of particles N by a bosonic factor of sqrt(N) in the Fock regime and N/log N in the Josephson regime.

T1.6c Publication: **Master Equation and Control of an Open Quantum System with Leakage**
(Partner 1 – Weizmann)
Phys. Rev. Lett. 102, 080405 (2009)

Given a multilevel system coupled to a bath, we use a Feshbach P, Q partitioning technique to derive an exact trace-nonpreserving master equation for a subspace Si of the system. The resultant equation properly treats the leakage effect from Si into the remainder of the system space. Focusing on a second-order approximation, we show that a one-dimensional master equation is sufficient to study problems of quantum state storage and is a good approximation, or exact, for several analytical models. It allows a natural definition of a leakage function and its control and provides a general approach to study and control decoherence and leakage. Numerical calculations on an harmonic oscillator coupled to a room temperature harmonic bath show that the leakage can be suppressed by the pulse control technique without requiring ideal pulses.

T1.6d Publication: **Non-Markovian control of qubit thermodynamics by frequent quantum measurements**
(Partner 1 – Weizmann)

Physica E (in press – doi:10.1016/j.physe.2009.06.029)

We have explored the effects of frequent, impulsive quantum nondemolition measurements of the energy of two-level systems (TLS), alias qubits, in contact with a thermal bath. The resulting entropy and temperature of both the system and the bath are found to be completely determined by the measurement rate, and unrelated to what is expected by standard thermodynamical rules that hold for Markovian baths. These anomalies allow for *very fast control* of heating, cooling and state-purification (entropy reduction) of qubits, much sooner than their thermal equilibration time.

T1.6e Publication: **Number squeezing, quantum fluctuations, and oscillations in mesoscopic Bose Josephson junctions**
(Partner 8 – CNRS)
Phys. Rev. A 78, 023606 (2008)

We use a two-mode Bose-Hubbard Hamiltonian to determine the ground state and dynamical evolution for a Bose Josephson junction realized by an ultracold Bose gas in a double-well trap. We identify Mott-like lobes where number fluctuations are suppressed and the interference fringes in the momentum distribution are strongly reduced. Different from superconducting Josephson junctions, the lobes size increases at increasing wells imbalance. Upon a sudden rise of the barrier between the two wells, an initially phase-coherent state evolves into a coherent superposition of phase states, leading to destructive interference in the time-dependent momentum distribution.

T1.6f Report / preprint: **Decoherence control in Bosonic Josephson Junctions**
(Partners 1+3 – Weizmann+Heidelberg)

We propose a new approach to dynamic decoherence control of finite-temperature Bose-Einstein Condensates (BEC) in a double-well potential. Due to the many-body interactions the standard "echo" control method becomes less effective. The proposed approach takes advantage of the interaction-induced change of the spectrum, to obtain the optimal rate of flips of the relative phase between maximally distinguishable collective states. We show that although the interaction of the BEC to the bath is linear, it can induce nonlinear quantum dynamics in the system on non Markovian time scales. This allows to implement dynamic control methods both for protecting the phase coherence and enhancing the useful entanglement between the BEC modes via the bath. The proposed methods are particularly useful for probing and diagnosing the decoherence dynamics.

T1.6g Report: **Dynamical decoupling, motional narrowing and bath characterization of optically trapped atoms**
(Partner 1 – Weizmann)
arXiv:0905.0286

We dynamically control the coherent dynamics of cold atoms under collisions. We formulate the framework for dephasing of colliding atoms. Conventional echo techniques fail to suppress this dephasing, and we exploit dynamical decoupling schemes to suppress collisional decoherence. Using bang-bang dynamical decoupling strategy, we demonstrate coherence time longer than a second for atomic ensemble with optical depth of OD = 100. Further optimization is made utilizing optimized decoherence control pulse sequences based on the specific features of the bath.

T1.6h Publication: **Sum-frequency generation of 589 nm light with near-unit efficiency**
(Partner 8 – CNRS)
Optics Express, Vol. 16, Issue 23, pp. 18684-18691

We report on a laser source at 589 nm based on sum-frequency generation of two infrared laser at 1064 nm and 1319 nm. Output power as high as 800 mW is achieved starting from 370 mW at 1319 nm and 770 mW at 1064 nm, corresponding to converting roughly 90% of the 1319 nm photons

entering the cavity. The power and frequency stability of this source are ideally suited for cooling and trapping of sodium atoms.
Patent: INPI 0803153 (06/06/2008): Optical apparatus for wavelength conversion and light source making use of said apparatus ("dispositif optique de conversion de longueur d'onde et source de lumi'ere utilisant un tel dispositif"); inventors: Fabrice Gerbier, Emmanuel Mimoun, Jean-Jacques Zondy (INM-CNAM), Jean Dalibard; international extensions pending.

T1.7+T1.8

T1.7/8a Publication: **Coherent Oscillations in a Superconducting Tunable flux qubit Manipulated without Microwaves**
(Partner 5 – Karlsruhe)
New J. Phys. 11 013009 (2009)

We experimentally demonstrate coherent oscillations of a tunable superconducting flux qubit by manipulating its energy potential with a nanosecond-long pulse of magnetic flux. The occupation probabilities of two persistent current states oscillate at a frequency ranging from 6 GHz to 21 GHz, tunable by changing the amplitude of the flux pulse. The demonstrated operation mode could allow quantum gates to be realized in less than 100 ps, which is much shorter than gate times attainable in other superconducting qubits. Another advantage of this type of qubit is its immunity to both thermal and magnetic field fluctuations.

T1.7/8b Report: **Dynamical control of macroscopic quantum tunneling**
(Partners 5+7+1 – Karlsruhe+Chalmers+Weizmann)

We performed the first experimental trials to observe quantum Zeno effect(QZE) in phase qubit. The qubit was biased with external flux close to its critical value such, that only two energy levels are allowed inside the potential well. The ground state of the Q-bit is metastable and decays exponentially through macroscopic quantum tunneling into "continuum" within 10 ns. The short evolution within 100ps of the ground state is followed by closing a potential barrier, that brings the system into the slow decaying regime with time of about 500ns. If potential is closed for the sufficiently long time, more than decay time of a ground state (10ns), then that closing is similar to the measurement of survival probability. By repeating this procedure many times we hoped to see the suppression of the quantum tunneling rate.

Last measurements of the decay in sub-nanosecond time scale have revealed that short pulses which are applied to create a metastable-state do not reach a qubit circuit. Due to low-pass on-chip-filters, which limit the shortest time for the pulse to about 1 ns. Improved designs aimed at bypassing this problem are under way, aiming at the 100 ps time scale, which is expected to reveal the QZE.

T1.7/8c Report: **Dynamic control of quantum decay to the continuum**
(Partner 7 – Chalmers)
We theoretically investigated decay of a quantum state of current biased superconducting JJ under rapid modulation of the coupling to the continuum. We identified coherent and incoherent dynamic decay regimes. The coherent regime appears when a period of the modulation is very short - much smaller than the inverse Josephson frequency of the junction. There is a crossover from complete decay to an incomplete decay, when a finite fraction of the initial state remains in the quantum well for infinite time. The incoherent regime develops when the well is kept closed for much longer time compared to inverse Josephson frequency. In this case, the evolving state is effectively projected after every manipulation cycle on the initial state realizing the Zeno regime.

T1.7/8 Publication: **Measurement of the current-phase relation in Josephson junction rhombi chains**
(Partner 8 – CNRS)
Phys. Rev. B 78, 104504 (2008)

We present low-temperature transport measurements in one-dimensional Josephson junctions rhombi chains. We have measured the current-phase relation of a chain of eight rhombi. The junctions are either in the

classical phase regime with the Josephson energy much larger than the charging energy, EJ EC, or in the quantum phase regime where EJ / EC 2. In the strong Josephson coupling regime EJ EC kBT we observe a sawtoothlike supercurrent as a function of the phase difference over the chain. The period of the supercurrent oscillations changes abruptly from one flux quantum 0 to half the flux quantum 0 / 2 as the rhombi are tuned in the vicinity of full frustration. The main observed features can be understood from the complex energy ground state of the chain. For EJ / EC 2, we do observe a dramatic suppression and rounding of the switching current dependence which we found to be consistent with the model developed by Matveev et al. Phys. Rev. Lett. 89, 096802 2002 for long Josephson junctions chains.

D1.3a Report:
(Partner 9 – Delft)

We performed theoretical modelling of the dynamical evolution of entanglement under the influence of decoherence of artificial atoms (quantum dots and supercondcuing circuits). We also investigated designs for decoherence control in these systems.

D1.3b Publication: **Detecting entanglement of two-electron spin qubits with witness operators**
(Partner 9 – Delft)
Phys. Rev. B 84, 033301 (2011)

We propose a scheme for detecting entanglement between two-electron spin qubits in a double quantum dot using an entanglement witness operator. We first calculate the optimal configuration of the two electron spins, defined as the position in the energy level spectrum where, averaged over the nuclear spin distribution, (1) the probability to have two separated electrons and (2) the degree of entanglement of the quantum state quantified by the concurrence are both large. Using a density matrix approach, we then calculate the evolution of the expectation value of the witness operator for the two-spin singlet state, taking into account the effect of decoherence due to quantum charge fluctuations modeled as a boson bath. We find that, for large interdot coupling, it is possible to obtain a highly entangled and robust ground state.

Publication: **Zeno and Anti-Zeno Polarization Control of Spin Ensembles by Induced Dephasing**
(Partner 1 – Weizmann)
PRL 105, 160401 (2010)

We experimentally and theoretically demonstrate the purity (polarization) control of qubits entangled with multiple spins, using induced dephasing in nuclear magnetic resonance setups to simulate repeated quantum measurements. We show that one may steer the qubit ensemble towards a quasiequilibrium state of a certain purity by choosing suitable time intervals between dephasing operations. These results demonstrate that repeated dephasing at intervals associated with the anti-Zeno regime leads to ensemble purification, whereas those associated with the Zeno regime lead to ensemble mixing. **[Highlight]**

Publication: **From Zeno to anti-Zeno regime: Decoherence-control dependence on the quantum statistics of the bath**

(Partner 1 – Weizmann)
Phys. Rev. A 83, 032105 (2011)

We demonstrate through exact solutions that a spin bath leads to stronger (faster) dephasing of a qubit than a bosonic bath with an identical bath-coupling spectrum. This difference is due to the spin-bath "dressing" by the coupling. Consequently, the quantum statistics of the bath strongly affects the pulse sequences required to dynamically decouple the qubit from its bath.

Publication: **Direct measurement of the system–environment coupling as a tool for understanding decoherence and dynamical decoupling**
(Partner 1 – Weizmann)
J. Phys. B 44 (2011) 154006

Decoherence is a major obstacle to any practical implementation of quantum information processing. One of the leading strategies to reduce decoherence is dynamical decoupling—the use of an external field to average out the effect of the environment. The decoherence rate under any control field can be calculated if the spectrum of the coupling to the environment is known. We present a direct measurement of the bath-coupling spectrum in an ensemble of optically trapped ultra-cold atoms, by applying a spectrally narrow-band control field. The measured spectrum follows a Lorentzian shape at low frequencies but exhibits non-monotonic features at higher frequencies due to the oscillatory motion of the atoms in the trap. These features agree with our analytical models and numerical Monte Carlo simulations of the collisional bath. From the inferred bath-coupling spectrum, we predict the performance of some well-known dynamical decoupling sequences. We then apply these sequences in experiment and compare the results to predictions, finding good agreement in the weak-coupling limit. Thus, our work establishes experimentally the validity of the overlap integral formalism and is an important step towards the implementation of an optimal dynamical decoupling sequence for a given measured bath spectrum.

D2.1a Report: **Testing or demonstration of dynamically generated number- or phase- correlated (entangled) states in UCA JJs**
(Partner 8 – ENS)

D2.1b Report: **Testing or demonstration of thermodynamic generation of number- correlated states in spinor condensate**
(Partner 8 – ENS)

The experiment at CNRS-Paris aims at producing quantum spin correlations in sodium spin-1 Bose-Einstein condensates, which is an example of internal-state UCA JJs. Since an applied magnetic field strongly affects the phase relation between all Zeeman components, a crucial issue is to control its stability (in practice to a level below 0.1 mG, achievable with magnetic shielding only).

An experimental apparatus compatible with such a magnetic shield has been built during the course of MIDAS to produce sodium Bose-Einstein condensates without relying on strong magnetic fields or field gradients (both incompatible with a magnetic shield). The experiment relies on tools developped during MIDAS : a new laser system suitable for laser cooling [1,2], a new sodium atomic source using light-induced desorption [3], and a method relying on evaporative cooling in purely optical traps to load a tightly-focused optical trap from a large-volume one [4]. These advances are necessary steps to achieve spin-correlated states, either using dynamical quantum evolution of a known initial state through atom-atom interactions (WP1.a) or by directly producing these states as thermodynamic equilibrium states (WP2.b).

Concerning WP2, we are completing an experimental study of the thermodynamics of spin-1 condensates in quasi-equilibrium, in the limit of relatively large atom numbers where the atomic field can be described semi-classically (Gross-Pitaevskii limit). By lowering the atom number to 100-200,

the role of quantum fluctuations increases and spin correlations build up. In view of the results relevant to WP2.2 below, they should be observable in our system after the first quasi-classical studies are completed. Alternatively to this direct cooling method, we have proposed and analyzed theoretically a protocol for adiabatic preparation of the correlated ground states of spin-1 condensates [5], in particular to generate number-correlated spinor condensates with almost perfect number squeezing between the m=+1 and m=-1 components. Quantum Monte-Carlo simulations including inelastic losses and other decoherence sources suggest that the method is realistic for a few tens or a hundred atoms confined in a tight trap.

Finally we have proposed a method where the analog of vector potential or more complex (non-Abelian) gauge fields can be realized for UCAs in optical lattices [6,7]. This provides the analog of SC JJ arrays in magnetic field for UCAs, and a new route (alternative to rotations) to reach the quantum Hall regime for neutral atoms.

D2.1c T1.3/8 Report:
(Partner 6 – Naples)

We remind that the sense of an activity on High-Tc Superconductors (HTS) in Midas is fundamentally exploratory. The main target of the project is to promote hybridization between superconductors and cold atoms, however the mission extends to all aspects, which enlighten coherence and dissipation in each ingredient of the hybrid system (superconductors and cold atoms) and hybrid systems themselves. HTS has good potentials, since it is a structurally different system from LTS, and its strongly correlated nature may have some impact on arguments of coherence. Atomically flat interfaces in grain boundaries are a potential advantage for more inert barriers. This has to be balanced with possible higher intrinsic levels of dissipation induced by low energy quasi-particles in d-wave superconductors. At the moment, HTS is not an alternative to low critical temperature technology. The idea is to follow the progress in the qubit design of LTS and the path to hybridization shown by LTS and cold atom systems, to be able, on a longer time scale, to insert possible novel functionality offered by the HTS peculiar nature (T3.6). This will be possible only if HTS junctions match the device parameters indicated by LTS prototypes, and an understanding of phase dynamics is achieved. We have done some more progress to push HTS junction technology to the extreme limits and optimal functionality (T1.3, T1.8).

D2.1d Report:
(Partner 6 – Naples)

The progress achieved in the fabrication of HTS nanostructures (D2.1) and the comprehension of some transport modes has allowed realizing the first generation of HTS – nanowire hybrid structures. Trenches from 50 nm to 100 nm separate HTS electrodes and nanowires of size ranging from 60 to 100 nm work as a diffusive barrier. Transport properties have demonstrated the first functionality of the devices. Up to now nanowires are of InAs, and the final structure is technologically quite demanding due to the structural complexity of both components of the junctions. The fabrication process can be applied to all sorts of barriers and hybrid structures, and paves the way to the LTS/HTS hybrid devices able to match a wide range of demand of quantum superconducting electronics.

We are now in conditions to provide HTS and HTS hybrid samples to MIDAS partners for experiments on dynamical fluctuation control, once conditions to perform experiments on LTS JJs are settled. The only limit is the Q dissipation factor, that at the moment is not much higher than 10. We believe that higher Q values (and therefore lower levels of dissipation) can be achieved for biepitaxial junctions, when the GB width will be reduced to the size of a single facet (of the order of 100-200 nm), the current limit for the width is about 500 nm.

D2.1e T1 Report:
(Partner 6 – Naples)

Sub-micron technology for fabricating YBCO Josepshon junctions for the analysis of basic properties in junctions made by non-conventional superconductors has been developed. First devices consist of junctions and SQUIDs with dimensions from 100 to 300 nm. Good values of the critical currents and the IcRn products, up to 1 mV at 4.2K, have been found.

D2.1f T2 Report:
(Partner 6 – Naples)

The theory of surface Andreev bound states in [100] tilt and [100] tilt-tilt junctions has been developed. Quasiparticle trajectories may lay into two separate planes, in contrast with the all-in-plane trajectories, occurring in the [001] tilt junction devices. This will be the argument of a forthcoming paper.

D2.1g T3 Report:
(Partner 6 – Naples)

Acomplete theoretical analysis of resonances in grain boundary Josepshon junctions with "0-□" phase discontinuities has been developed. Predictions have been confirmed by experiments and results have been published in [1] and [2].

D2.1h Publication: **Self-resonant modes in Josephson junctions with a phase discontinuity**
(Partner 6 – Naples)
Low. Temp. Phys. 36, 920, (2010)

We extend the theory of self-resonances in short Josephson junctions to the case of a piecewise constant critical current density and a κ discontinuity in the Josephson phase. We calculate the amplitude of the self-resonances as a function of applied magnetic field by using an extension of the approach introduced by Kulik for conventional Josephson junctions (I. O. Kulik, JETP Lett. 2, 84 (1965)). The theory given here agrees with existing experiments on superconducting–insulator–ferromagnet–superconductor 0–π Josephson junctions. The results are relevant to the characterization of all modern 0–π junctions as well as 0–κ junctions with artificially created phase discontinuities: high-temperature grain boundary junctions, junctions with a ferromagnetic barrier, and junctions with current injectors.

D2.1h Publication: **Closed form solutions for the self-resonances in a short Josephson junction**
(Partner 6 – Naples)
Phys. Lett. A 375, 1598, (2011)

We present a closed form solution for the self-resonances in a short Josephson tunnel junction. This solution is alternative to the well-known textbook result (Barone and Paternó (1982) and Kulik (1965)) [1] and [2] based on a series expansion. Results are derived for the up-to-date case of a 0–π junction.

We calculate the self-resonant modes of a 0–π Josephson tunnel junction. ► We introduce a new method of calculation not based on a series solution. ► Closed form expressions are derived for the phase dynamics and the supercurrent.

D2.1i Report: **Characterization of HTS circuits for quiet qubits**
(Partner 7 – Chalmers (T))

We theoretically analyzed the role of midgap Andreev states in HTS JJs in macroscopic quantum tunneling (MQT). We devised the methods for characterization of midgap states using reentrance effect in MQT.

D2.1j Publication: **Reentrance effect in macroscopic quantum tunneling and non-adiabatic Josephson dynamics in d-wave junctions**

(Partner 7 – Chalmers (T))
Phys. Rev. Lett. 105, 127001 (2010)

We develop a theoretical description of nonadiabatic Josephson dynamics in superconducting junctions containing low energy quasiparticles. Within this approach we investigate the effects of midgap states in junctions of unconventional d-wave superconductors. We identify a reentrance effect in the transition between thermal activation and macroscopic quantum tunneling, and connect this phenomenon to the experimental observations in Phys. Rev. Lett. 94 087003 (2005). It is also shown that nonlinear Josephson dynamics can be defined by resonant interaction with midgap states reminiscent of nonlinear optical phenomena in media of two-level atoms. **[Highlight]**

D2.1k Publication: **Reentrance of Macroscopic Quantum Tunneling in Cuprate Superconductors**
(Partner 7 – Chalmers (T))
Proceedings of Conference on Novel Superconductors, CIMTEC 2010, Advances in Science and Technology, 75, 155 (2010)

We present a theoretical analysis of the transition from thermal activation (TA) regime to the macroscopic quantum tunneling (MQT) regime of the decay from a metastable persistent current state in grain boundary junctions of cuprate superconductors. This transition is conventionally characterized by a single crossover temperature determined by the potential profile and dissipative mechanisms. It is shown that due to the existence of low energy bound states (mid-gap states) for various relative orientations of the crystal axes, there exists a window of parameters where one finds, with lowering temperature, an inverse crossover from MQT to TA, followed by a subsequent reentrance of MQT. It is shown that these predictions are in reasonable agreement with recent experiments.

D2.1l Report: **Development of HTS quiet qubits**
(Partner 7 – Chalmers (E))

We have realized the first all HTS based (YBCO) transmon qubit. This qubit design has less stringent requirements on the junction parameters compared to the quiet qubit design. We have measured the ground state of the transmon coupled to the resonator using microwave reflectometry at 15 mK. Applying a magnetic flux to the SQUID loop of the transmon, we can clearly observe the periodic modulation of the transmon frequency and the avoided energy level crossing manifesting the strong coupling between the resonator and the transmon. **[Highlight]**

D2.1m Publication: **High critical temperature superconductor Josephson junctions for quantum circuit applications**
(Partner 7 – Chalmers (E))
Phys. Scr. T 137, 014006 (2009)

Recent findings of macroscopic quantum properties in high critical temperature superconductor (HTS) Josephson junctions (JJs) point toward the need to revise the role of zero energy quasi-particles in this novel superconductor. We will discuss the possibility of designing superconducting artificial atoms in a transmon configuration to study the low energy excitation spectra of HTS. We have engineered high quality grain boundary JJs on low dielectric constant substrates. By fabricating submicron junctions, we extract values of capacitance and Josephson critical current densities that satisfy the main transmon design requirements. Moreover, the measured critical current noise power extrapolated at 1 Hz gives a dephasing time of 25 ns, which indicates that the observation of macroscopic quantum coherent effects in HTS JJ is a feasible task.

D2.1n Publication: **Soft nanostructuring of YBCO Josephson Junctions by phase separation**
(Partner 7 – Chalmers (E))

Nano Letters 10, 4824 (2010)

We have developed a new method to fabricate biepitaxial $YBa_2Cu_3O_{7-\delta}$ (YBCO) Josephson junctions at the nanoscale, allowing junctions widths down to 100 nm and simultaneously avoiding the typical damage in grain boundary interfaces due to conventional patterning procedures. By using the competition between the superconducting YBCO and the insulating Y_2BaCuO_5 phases during film growth, we formed nanometer sized grain boundary junctions in the insulating Y_2BaCuO_5 matrix as confirmed by high-resolution transmission electron microscopy. Electrical transport measurements give clear indications that we are close to probing the intrinsic properties of the grain boundaries.

D2.1o Publication: **Sum-frequency generation of 589 nm light with near-unit efficiency**
(Partner 8 – ENS)
Optics Express 16, 18684-18691 (2008)

We report on a laser source at 589 nm based on sum-frequency generation of two infrared laser at 1064 nm and 1319 nm. Output power as high as 800 mW is achieved starting from 370 mW at 1319 nm and 770 mW at 1064 nm, corresponding to converting roughly 90% of the 1319 nm photons entering the cavity. The power and frequency stability of this source are ideally suited for cooling and trapping of sodium atoms.

D2.1p Publication: **All solid-state laser system for laser cooling of sodium**
(Partner 8 – ENS)
Applied Physics B 99, 31 (2010)

We demonstrate a frequency-stabilized, all-solid laser source at 589 nm with up to 800 mW output power. The laser relies on sum-frequency generation from two laser sources at 1064 nm and 1319 nm through a PPKTP crystal in a doubly resonant cavity. We obtain conversion efficiencies as high as 2 W/W2 after careful optimization of the cavity parameters. The output wavelength is tunable over 60 GHz, which is sufficient to lock on the sodium D2 line. The robustness, beam quality, spectral narrowness and tunability of our source make it an alternative to dye lasers for atomic physics experiments with sodium atoms.

D2.1q Publication: **Fast production of ultracold sodium gases using light-induced desorption and optical trapping**
(Partner 8 – ENS)
Phys. Rev A 81, 023631 (2010)

In this article we report on the production of a Bose-Einstein condensate (BEC) of ^{23}Na using light-induced desorption as an atomic source. We load about 2×10^7 atoms in a magneto-optical trap (MOT) from this source with a ~6 s loading time constant. The MOT lifetime can be kept around 27 s by turning off the desorbing light after loading. We show that the pressure drops down by a factor of 40 in less than 100 ms after the extinction of the desorbing light, restoring the low background pressure for evaporation. Using this technique, a BEC with 10^4 atoms is produced after a 6 s evaporation in an optical dipole trap.

D2.1r Publication: **Production of sodium Bose–Einstein condensates in an optical dimple trap**
(Partner 8 – ENS)
New J. Phys. 13, 065022 (2011).

We report on the realization of a sodium Bose–Einstein condensate (BEC) in a combined red-detuned optical dipole trap formed by two beams crossing in a horizontal plane and a third, tightly focused dimple trap (dT) propagating vertically. We produce a BEC in three main steps: loading of the crossed dipole trap from laser-cooled atoms, an intermediate evaporative cooling stage that results in efficient loading of the auxiliary dT, and a final evaporative cooling stage in the dT. Our

protocol is implemented in a compact setup and allows us to reach quantum degeneracy even with relatively modest initial atom numbers and available laser power.

Publication: **Submicron YBaCuO biepitaxial Josephson junctions: d-wave effects and phase dynamics**
(Partner 6 – Naples)
J. Appl. Phys. 107, 113901(2010)

Junctions, about 500 nm wide, show directionality of the tunnelling process and follow the ideal profile of the d-wave order parameter symmetry, with ICRN values up to 4 meV and switching voltages of a few meV as well. Some correlation between the switching histogram and the angle orientation can be established, with information on the quality factor Q = □PRNC which is in a moderately damped regime (where □P is the plasma frequency and C is the junction capacitance). (D1.2, T1.3).

Publication: **Little-Parks effect in single YBaCuO sub-micron rings**
(Partner 6 – Naples)
Phys. Rev. B 81, 054505 (2010)

This is a study a flux dynamics in nanobridges and nanorings to study entering flux in nanostructures: evidence of anomalous nature of vortices in nanostructures.

Publication: **Interplay between static and dynamic properties of semi-fluxons in YBaCuO Josephson junctions**
(Partner 6 – Naples)
Phys. Rev. Lett. 104, 177003 (2010)

This is a study on the dynamics of semifluxons in d-wave YBCO Josephson junctions.

Publication: **Macroscopic Quantum Phenomena in Josephson Structures**
(Partner 6 – Naples)
Temperatur (Low Temperature Physics) 36, 10 (2010)

Publication: **Evidence of Minigap in YBCO grain boundary Josephson Junctions**
(Partner 6 – Naples)
Phys. Rev. Lett. 105, 147001 (2010)

Peculiar periodic oscillations in the resistance R(V), at high voltages, are a direct manifestation of the presence of a minigap in the excitation spectrum of the junctions, which arises from mesoscopic interference. **[Highlight]**

Publication: **Feasibility of a High Temperature Superconductor rf-SQUID based on Biepitaxial Josephson Junction Technology**
(Partner 6 – Naples)
IEEE Trans. on Appl. Supercond. 21, 151 (2011)

In this work on the basis of the properties of HTS submicron Josephson junctions, a RF-SQUID is designed in view of a possible use as qubit cell. The design of read-out is based on a chip-flip configuration.

Publication: **High quality factor HTS Josephson junctions on low loss substrates**
(Partner 6 – Naples)
Supercond. Science and Technology 24, 045008 (2011)

Off-axis biepitaxial technique has been extended to produce YBCO grain boundary junctions on low loss substrates. Excellent transport properties have been reproducibly found, with remarkable

values of the quality factor IcRn above 10 mV, far higher than the values commonly reported in the literature for HTS based Josephson junctions. This work supports a possible implementation of grain boundary junctions for various applications including terahertz sensors and HTS quantum circuits in the presence of microwaves.

Publication: **Quantum crossover in moderately damped epitaxial NbN/MgO/NbN junctions with low critical current density**
(Partner 6 – Naples)
Appl. Phys. Lett. 99, 062510 (2011)

Macroscopic quantum tunnelling is proved in moderately damped NbN/MgO/NbN Josephson junctions with low critical current density. At higher temperatures a phase diffusion regime takes over on the thermal regime.

Publication: **Thermal hopping and retrapping of a Brownian particle in the tilted periodic potential of a NbN/MgO/NbN Josephson junction**
(Partner 6 – Naples)
Phys. Rev. B (2011) (accepted)

Phase diffusion regime has been investigated in detail in moderately damped NbN/MgO/NbN Josephson junctions with low critical current density. Simulations based on Montecarlo methods support phase diffusion regime.

Publication: **Coherent transport in extremely underdoped Nd1.2Ba1.8Cu3Oz nanostructures**
(Partner 6 – Naples)
submitted (2011)

Publication: **High critical-current density and scaling of phase-slip processes in YBaCuO nanowires**
(Partner 6 – Naples)
submitted (2011)

Publication: **Energy scales in YBaCuO grain boundary biepitaxial Josephson junctions**
(Partner 6 – Naples)
submitted (2011)

Report:
(Partner 6 – Naples)
For deliverable D2.1 (fabrication and characterization of HTS circuits for quiet qubit):

9. -D1$_{CNR-INFM}$. realization of sub-micron YBaCuO grain boundary biepitaxial and bicrystal Josephson junctions, also on low loss substrates
10. - D2 $_{CNR-INFM}$. realization of YBaCuO nanobridges and nanorings
11. - D3 $_{CNR-INFM}$ characterization of the transport properties of structures D1 $_{CNR-INFM}$ and D2 $_{CNR-INFM}$
12. - D4 $_{CNR-INFM}$. realization of hybrid YBaCuO-nanowire structures and their transport characterization

Report:
(Partner 6 – Naples)
For deliverables D1.2 and D1.3 (Testing designs for read out, testing role of intrinsic/extrinsic decoherence, probing fluctuations):

13. - D5$_{CNR-INFM}$ switching current measurements on D1 $_{CNR-INFM}$, analysis of thermal

fluctuations and macroscopic quantum tunnelling

14. - $D6_{CNR\text{-}INFM}$ phase diffusion regime in moderately damped junctions: switching current measurements on NbN/MgO/NbN and YBCO grain boundary Josephson junctions;
15. - $D7_{CNR\text{-}INFM}$ conductance mesoscopic fluctuations, energy scaling and minigap; estimation of relaxation time at low T for quasi-particles's of the order of picoseconds, Andreev bound states
16. - $D8_{CNR\text{-}INFM}$ design of YBaCuO rf-SQUID with different systems of read-out

D2.2a Report: **Andreev state control**.
(Partner 7 – Chalmers (T))

We developed general theory describing macroscopic quantum dynamics in JJ coupled to intrinsic Andreev states (artificial atoms). We found close analogy between the physics of this system and light-atom interaction in cavity QED.

D2.2d Publication: **Non-adiabatic Josephson dynamics in junctions with in-gap quasiparticles**
(Partner 7 – Chalmers (T))
Low Temp. Phys. 36, 925 (2010)

Conventional models of Josephson junction dynamics rely on the absence of low-energy quasiparticle states owing to a large superconducting gap. With this assumption the quasiparticle degrees of freedom are ⟪frozen out⟫ and the phase difference becomes the only free variable, acting as a fictitious particle in a temporally localized Josephson potential related to the adiabatic and nondissipative supercurrent across the junction. In this article we develop a general framework to incorporate the effects of low-energy quasiparticles interacting nonadiabatically with the phase degree of freedom. These quasiparticle states typically exist in constriction type junctions with high transparency channels or resonant states, as well as in junctions of unconventional superconductors. Recent experiments have also revealed the existence of spurious low-energy in-gap states in tunnel junctions of conventional superconductors—a system for which the adiabatic assumption is typically assumed to be valid. We show that a resonant interaction with these low-energy states, rather than the Josephson potential, determines the nonlinear Josephson dynamics at small amplitudes.

D2.2e Report: **Relaxation of Andreev states in atomic-size Josephson superconducting point contacts**
(Partner 7 – Chalmers (T))

We developed quantum kinetic description and analyzed relaxation processes in atomic-size JJs due to interaction with phonons. It is found that both the decoherence and ionization of Andreev states affect the Josephson current.
(in preparation for publication)

D2.3a Report: **Bloch oscillations (E)**
(Partner 8 – Grenoble)

After having demonstrated for the first time coherent quantum phase-slips1,2(CQPS) in an intermediate size of a Josephson junction chain we have measured the current-voltage characteristics of a set of Josephson junction chains with a length between N=9 and N=109. For this design we decreased as much as possible the island size between the junctions. We think that our results show the onset of a zero-current state due to CQPS (to be published) which is a very important result in terms of the realisation of Bloch oscillations. Our experimental results enabled us to clearly identify the problems for the measurement of Bloch oscillations in ordinary Josephson junction chains. We have shown that coherent quantum phase-slips can occur in intermediate size of junction chains and we have as well hints that they can occur in chains of length N□50. However for the measurement of Bloch oscillations we need to increase much more the length of the JJ chain. But increasing the chain

length will induce decoherence of quantum phase-slips due to internal dissipation that arises from standing modes in the chain. In the future we will explore experimentally Josephson junction chains where the junction size follows a disordered or fractal pattern. We aim to decouple the internal dissipation arising from standing modes by turning the associated wave functions into localized wave functions. Thanks to the support of MIDAS we found a complete novel idea how to measure Bloch oscillations in a superconducting device.

References:

1) I.Pop et al, NP, 6,589 (2010).
2) I.Pop et al, arXiv:1104.3999, submitted to PRB
Invited seminars at international conferences:

1) W. Guichard, “Coherent quantum phase-slips in Josephson junction chains”. March meeting, Dallas convention center, 2011.
2) I. Pop , "Quantum phase slips in a 6 Josephson junction chain",9/06/2011, TransAlpNano, Como, Italie.
3) "Measurement of Aharonov-Casher effect in a Josephson junction chain",
I. Pop, 23/03/2011, APS March Meeting, Dallas, USA
4) "Observation of quantum phase-slips in Josephson junction chains",
I. Pop talk at laboratoire Pierre-Aigrain/ENS, Paris 25/10/2010.

D2.3b Report: **Quantum phase-slips in Josephson junction chains (T)**
(Partner 8 – ENS)

We have studied the effects of finite size and propagating modes on the amplitude of quantum phase-slip processes occurring in Josephson junction chains. We found that finite size corrections manifest themselves as a simultaneous enhancement of the effective capacitance and as a reduction of the potential barrier through which the tunnelling takes place. These two effects are in competition. It turns out that the barrier renormalization effect is the stronger of the two, resulting in a net enhancement of the phase-slip amplitude as the system size is reduced. Propagating modes occur due to the finite ratio of junction capacitance to ground capacitance. These modes inevitably appear when longer chains are considered and we calculated their effect on the phase-slip amplitude. We found that it decreases with increasing system size. The reason is that the frequencies of the propagating modes decrease with the system size, thereby slowing down the adjustment of the junction phases during phase-slip tunnelling, resulting in an overall suppression of the phase-slip amplitude.

D2.3b Report: **Quantum phase-slips in Josephson junction chains (T)**
(Partner 8 – ENS)

D3.1/1.3a Report: **Dynamics of Bose-Josephson junctions and one-dimensional ring traps**
(Partner 8 – ENS)

Squeezed states and macroscopic superpositions of coherent states have been predicted to be generated dynamically in Bose Josephson junctions (BJJ) after a sudden quench to zero of the tunnel parameter. We have solved exactly the corresponding dynamics in the presence of a classical noise coupled to the population-imbalance number operator. We have found that this noise induces an anomalously slow rate of decoherence among the components of the macroscopic superpositions of phase states, indicating the robustness of the superpositions. The two modes of the BJJ can be viewed as the two arms of an interferometer; use of entangled states allows to perform atom interferometry beyond the classical limit. Decoherence due to the presence of noise degrades the

quantum correlations between the atoms, thus reducing phase sensitivity of the interferometer. For moderate noise intensities, useful quantum correlations increase on time scales beyond the squeezing regime, thus suggesting multicomponent superpositions as interesting candidates for high-precision atom interferometry. Finally, we have considered a strongly interacting quasi-one dimensional Bose gas on a tight ring trap subjected to a localized barrier potential which is suddenly set into motion. Using an exact solution for the dynamical evolution in the impenetrable-boson (Tonks-Girardeau) limit, we have predicted the formation of a macroscopic superposition of a rotating and a nonrotating state. We found that the barrier velocity should be tuned close to multiples of integer or half-integer number of Coriolis flux quanta to maximize the nonadiabatic excitation, and it should be larger than the sound velocity to better discriminate the two components of the superposition.

Invited seminars at international conferences:

G. Ferrini, Useful quantum states in the presence of classical noise in a Bose Josephson junction, Quantum Technologies Conference Manipulating photons, atoms, and molecules, Toruń (Poland), August 29 - September 3, 2010

G. Ferrini, Effect of phase-noise on useful quantum correlations in Bose Josephson junctions, 20th International Laser Physics Workshop (LPHYS'11), Sarajevo (Bosnia and Herzegovina), July 11-15, 2011.

F. Hekking, Phase-charge duality in Josephson junction chains, Rencontres de Moriond 2011 Quantum Mesoscopic Physics, La Thuile, Aosta Valley (Italy), March 13-20, 2011.

F. Hekking, Quantum dynamics of superconducting nanojunctions, XXIème Congrès National de la Société Française de Physique, Bordeaux (France) July 4-8, 2011.

F. Hekking, Persistent currents in a one-dimensional bosonic ring, Highlights in Quantum Condensed Matter Physics, Donostia International Physics Center, San Sebastian (Spain), June17-23, 2011.

A. Minguzzi, Stirring a strongly interacting 1D Bose gas on a ring, Plenary meeting of the French national research Network GDR Physique Quantique Mésoscopique, Aussois (France), September 20-23, 2010.

A. Minguzzi, Stirring a strongly interacting 1D Bose gas on a ring, Workshop "Dynamics of quantum gases in one dimension", September 28-29, 2010 – Orsay (France).

C. Schenke, Tonks-Girardeau Bosons Stirred on a 1D ring, Highlights in Quantum Condensed Matter Physics, Donostia International Physics Center, San Sebastian (Spain), June17-23, 2011.

D3.1/1.3b Publication: **Noise in Bose Josephson junctions: Decoherence and phase relaxation**
(Partner 8 – ENS)
Phys. Rev. A 82, 033621 (2010)

Squeezed states and macroscopic superpositions of coherent states have been predicted to be generated dynamically in Bose Josephson junctions. We solve exactly the quantum dynamics of such a junction in the presence of a classical noise coupled to the population-imbalance number operator (phase noise), accounting for, for example, the experimentally relevant fluctuations of the magnetic field. We calculate the correction to the decay of the visibility induced by the noise in the non-Markovian regime. Furthermore, we predict that such a noise induces an anomalous rate of decoherence among the components of the macroscopic superpositions, which is independent of the total number of atoms, leading to potential interferometric applications.

D3.1/1.3c Publication: **Effect of phase noise on quantum correlations in Bose-Josephson junctions**
(Partner 8 – ENS)
to appear in Phys. Rev. A (2011)

D3.1/1.3d Publication: **Creation of macroscopic superpositions with strongly correlated 1D bosons on a ring trap**
(Partner 8 – ENS)
arXiv:1108.5075

We consider a strongly interacting quasi-one dimensional Bose gas on a tight ring trap subjected to a localized barrier potential which is suddenly set into motion. Using an exact solution for the dynamical evolution in the impenetrable-boson (Tonks-Girardeau) limit, we predict the formation of a macroscopic superposition of a rotating and a nonrotating state. We find that the barrier velocity should be tuned close to multiples of integer or half-integer number of Coriolis flux quanta to maximize the nonadiabatic excitation, and it should be larger than the sound velocity to better discriminate the two components of the superposition.

D3.1e Report: **Testing, demonstration and analysis of supercurrent entanglement in coupled JJs**
(Partner 7 – Chalmers (T))

We developed theoretical description of tunable coupler for superconducting JJs allowing control of entanglement of macroscopic quantum states.

D3.1f Publication: **Analysis of a tunable coupler for superconducting phase qubits**
(Partner 7 – Chalmers (T))
Phys Rev B 82, 104522 (2010)

This paper presents a theoretical analysis of the recently realized tunable coupler for superconducting phase qubits [R. C. Bialczak et al., arXiv:1007.2219 (unpublished)]. The coupling can be turned off by compensating a negative mutual inductance with a tunable Josephson inductance. The main coupling in this system is of the XX type and can be zeroed exactly, while there is also a small undesired contribution of the ZZ type. We calculate both couplings as functions of the tuning parameter (bias current) and focus on the residual coupling in the OFF regime. In particular, we show that for typical experimental parameters the coupling OFF/ON ratio is few times 10^{-3}, and it may be zeroed by proper choice of parameters. The remaining errors due to physical presence of the coupler are on the order of 10^{-6}.

D3.1g Publication: **Entangling microscopic defects via a macroscopic quantum shuttle**
(Partner 5 – Karlsruhe)
New J. Phys. 13 063015 (2011)

In that work (G.J. Grabovskij et al., New J. Phys. 13, 063015, 2011) we report on the experimental demonstration of induced coherent interaction between two intrinsic two-level states (TLSs) formed by atomic-scale defects in a solid via a superconducting phase qubit. The tunable superconducting circuit serves as a shuttle communicating quantum information between the two microscopic TLSs.We present a detailed comparison between experiment and theory and find excellent agreement over a wide range of parameters.We then use the theoretical model to study the creation and movement of entanglement between the three components of the quantum system.
[Highlight]

Publication:
Nature (in press)
(Partner 3+1 – Heidelberg+Weizmann)

We have recently developed a new experimental method to detect matterwave quadratures. The technique is in direct analogy to optical homodyning very successfully implemented and used in experiments with photons. With that method we could experimental show that in the process of spin changing collisions two-particle coherences are generated. Furthermore the experiments reveal that even in the regime of strong ‘pump-field’ depletion two mode entangled states. Within the last

months we have started working on the generation of cat-states in a Josephson-junction situation by employing a classical bifurcation scenario. The classical limit of this bifurcation has been shown for the first time experimentally within the MIDAS consortium one and half years ago. **[Highlight]**

Publication: **Einstein-Podolsky-Rosen Correlations of Ultracold Atomic Gases**
(Partner 1+3 – Weizmann+Heidelberg)
PRL 106, 120404 (2011)

We demonstrate that collective continuous variables of two species of trapped ultracold bosonic gases can be Einstein-Podolsky-Rosen-correlated (entangled) via inherent interactions between the species. We propose two different schemes for creating these correlations—a dynamical scheme and a static scheme analogous to two-mode squeezing in quantum optics. We quantify the correlations by using known measures of entanglement and study the effect of finite temperature on these quantum correlations. **[Highlight]**

Publication: **Creating Nonclassical States of Bose-Einstein Condensates by Dephasing Collisions**
(Partner 1 – Weizmann)
PRL 107, 010404 (2011)

We show, using an exactly solvable model, that nonlinear dynamics is induced in a double-well Bose- Einstein condensate (BEC) by collisions with a thermal reservoir. This dynamics can facilitate the creation of phase or number squeezing and, at longer times, the creation of macroscopic nonclassical superposition states. Enhancement of these effects is possible by loading the reservoir atoms into an optical lattice. **[Highlight]**

Publication: **Generation of Macroscopic Superpositions of Quantum States by Linear Coupling to a Bath**
(Partner 1 – Weizmann)
PRL 106, 010404 (2011)

We demonstrate through an exactly solvable model that collective coupling to any thermal bath induces effectively nonlinear couplings in a quantum many-body (multispin) system. The resulting evolution can drive an uncorrelated large-spin system with high probability into a macroscopic quantum-superposition state. We discuss possible experimental realizations. **[Highlight]**

Publication: **Establishing spin-network topologies by repeated projective measurements**
(Partner 1 – Weizmann)
arXiv:1109.3796 (2011)

It has been recently shown that in quantum systems, the complex time evolution typical of manybodied coupled networks can be transformed into a simple, relaxation-like dynamics, by relying on periodic dephasings of the off-diagonal density matrix elements. This represents a case of "quantum Zeno effects", where unitary evolutions are inhibited by projective measurements. We present here a novel exploitation of these effects, by showing that a relaxation-like behaviour is endowed to the polarization transfers occurring within a N-spin coupled network. Experimental implementations and coupling constant determinations for complex spin-coupling topologies, are thus demonstrated within

Publication: **Electron beam driven alkali metal atom source for loading a magneto-optical trap in a cryogenic environment**
(Partner 2 – Vienna)
Applied Physics B: Lasers and Optics 102, 819-823 (2011)

We present a versatile and compact electron beam driven source for alkali metal atoms, which can be implemented in cryostats. With a heat load of less than 10 mW, the heat dissipation

normalized to the atoms loaded into the magneto-optical trap (MOT) is about a factor 1000 smaller than for a typical alkali metal dispenser. The measured linear scaling of the MOT loading rate with electron current observed in the experiments indicates that electron stimulated desorption is the corresponding mechanism to release the atoms. **[Highlight]**

D3.3a Publication: **Hybrid quantum circuit with a superconducting qubit coupled to a spin ensemble**
(Partner 4 – Saclay)
To be submitted for publication (2011)

After having obtained the strong coupling regime between a resonator and an ensemble of NV spins in a diamond crystal by demonstrating a vacuum Rabi splitting, CEA has performed experiments in the time domain, and operated a first hybrid structure incorporating a transmon qubit and a spin-ensemble. CEA has demonstrated:

1. The coherent transfer and retrieval of excitations between a resonator and a spin ensemble (Storage and retrieval of a microwave field In a spin ensemble Y. Kubo, C. Grezes, D. Vion, D. Esteve, and P. Bertet, submitted to Phys. Rev. Lett.)
2. The coherent storage and retrieval of a single excitation between a transmon qubit and a NV spin ensemble. Although the recovered fraction is only of about 15%, this experiment provides a proof-of-concept for a spin-based memory for a superconducting qubit. **[Highlight]**

D3.3b Publication: **Storage and Retrieval of a Microwave Field in a Spin Ensemble**
(Partner 4 – Saclay)
Phys. Rev. Lett. (2011) (submitted)

We report the storage and retrieval of a small microwave #eld from a superconducting resonator into collective excitations of a spin ensemble. The spins are nitrogen-vacancy centers in a diamond crystal. The storage time of the order of 30 ns is limited by inhomogeneous broadening of the spin ensemble. **[Highlight]**

D3.3c Report:
(Partner 9 – Delft)

We have performed theoretical modelling of entanglement detection (Bell test) in presence of decoherence (local and due to measurement crosstalk) between coupled NV centers in diamond. After this, a near-future goal is to add superconducting qubits and a microwave stripline, to demonstrate information exchange between superconducting (logic) and spin (memory) qubits.

D3.3d Publication: **Quantitative evaluation of defect-models in superconducting phase qubits**
(Partners 5 – Karlsruhe + Innsbruck)
Appl. Phys. Lett. ***97****, 252501 (2010)*

In this work, we perform a high-precision comparison between experimental data and a general theoretical model to shed light on the exact form of the coupling operator between phase qubit and two-level defect. We obtain quantitative estimates of the longitudinal and transverse components and then compare our results to existing theoretical models for intrinsic two-level systems.

We use high-precision spectroscopy and detailed theoretical modeling to determine the form of the coupling between a superconducting phase qubit and a two-level defect. Fitting the experimental data with our theoretical model allows us to determine all relevant system parameters. We observe a strong qubit-defect coupling with a nearly vanishing longitudinal component. We quantitatively compare several existing theoretical models for the microscopic origin of two-level defects.

Publication: **Gauge potentials for ultracold atoms in optical superlattices**

(Partner 8 – ENS)
New J. Phys. 12 033007 (2010)

We present a scheme that produces a strong U(1)-like gauge field on cold atoms confined in a two-dimensional square optical lattice. Our proposal relies on two essential features, a long-lived metastable excited state that exists for alkaline-earth or ytterbium atoms and an optical superlattice. As in the proposal by Jaksch and Zoller (2003 New J. Phys. 5 56), laser-assisted tunneling between adjacent sites creates an effective magnetic field. In the tight-binding approximation, atomic motion is described by the Harper Hamiltonian, with a flux across each lattice plaquette that can realistically take any value between 0 and . We show how one can take advantage of the superlattice to ensure that each plaquette acquires the same phase, thus simulating a uniform magnetic field. We discuss the observable consequences of the artificial gauge field on non-interacting bosonic and fermionic gases. We also outline how the scheme can be generalized to non-Abelian gauge fields.

Publication: **Artificial gauge potentials for neutral atoms**
(Partner 8 – ENS)
to appear in RMP (2011)

When a neutral atom moves in a properly designed laser field, its center-of-mass motion may mimic the dynamics of a charged particle in a magnetic field, with the emergence of a Lorentz-like force. In this Colloquium we present the physical principles at the basis of this artificial (synthetic) magnetism and relate the corresponding Aharonov-Bohm phase to the Berry's phase that emerges when the atom follows adiabatically one of its dressed states. We also discuss some manifestations of artificial magnetism for a cold quantum gas, in particular in terms of vortex nucleation. We then generalise our analysis to the simulation of non-Abelian gauge potentials and present some striking consequences, such as the emergence of an effective spin-orbit coupling. We address both the case of bulk gases and discrete systems, where atoms are trapped in an optical lattice.

Report: **Hybrid Superconducting Atomchip (E)**
(Partner 2 – Vienna)

We currently successfully transport 10^8 rubidium atoms from an magneto-optical trap into a cryogenic environment. From there we manage to reload practically all the atoms into a QUIC trap. In the QUIC trap the atoms have a initial temperature of 1mK. To further cool the atoms we apply evaporative cooling and reach a temperature of 200nK. Furthermore, we have successfully fabricate a superconducting atomchip. This chip has been mounted into the cryostat. Currently we try to reload the atoms from the QUIC trap onto the superconducting atomchip which will allows us to create a Bose-Einstein condensate.

Report: **NV color centers - transmission line resonator (E)**
(Partner 2 – Vienna)

We managed to strongly couple an ensemble of nitrogen-vacancy center electron spins in diamond and a superconducting transmission line resonator. We demonstrate the scaling of the collective coupling strength with the square root of the number of emitters. Additionally, we measure hyperfine coupling to 13C nuclear spins, which is a step towards a nuclear ensemble quantum memory. Using the dispersive shift of the cavity resonance frequency, we measure a relaxation time of 44 seconds of the NV center at millikelvin temperatures in a nondestructive way.

Currently we are analyzing our data in order to determine the inhomogenous broadening. We find a broadening that is between a pure Lorentzian and a pure Gaussian profile.

Publication: **Cavity QED with Magnetically Coupled Collective Spin States**
(Partner 2 – Vienna)
Phys. Rev. Lett. 107, 060502 (2011)

We report strong coupling between an ensemble of nitrogen-vacancy center electron spins in diamond and a superconducting microwave coplanar waveguide resonator. The characteristic scaling of the collective coupling strength with the square root of the number of emitters is observed directly. Additionally, we measure hyperfine coupling to ^{13}C nuclear spins, which is a first step towards a nuclear ensemble quantum memory. Using the dispersive shift of the cavity resonance frequency, we measure the relaxation time of the NV center at millikelvin temperatures in a nondestructive way. **[Highlight]**

Publication: **Strong coupling of an NV ensemble to a cavity: Collective effects in inhomogeneous ensembles**
(Partner 2 – Vienna)
(in preparation)

Publication: **Optimized control of quantum state transfer from noisy to quiet qubits**
(Partner 1 – Weizmann)
J. Phys. B: At. Mol. Opt. Phys. 44 (2011)

Existing optimal control methods of open quantum systems rely on extensive numerical simulations of the dynamics in the presence of a bath, or alternatively ignore the exact bath dynamics. If the bath effects are to be treated properly on both Markovian and non-Markovian timescales using numerical simulations, the number of bath modes cannot be large. This may affect the ability to simulate realistic scenarios. Even if realistic, such simulations are hard to interpret physically. An alternative approach advocated here is to resort to a perturbative analysis provided the system–bath coupling is weak. This analysis would allow for the effects of any given bath (finite or infinite, Markovian or non-Markovian) and any control at our disposal. This poses the challenge of constructing a method for the optimization of various operations requiring proper manipulation of the system, based on a general perturbative treatment to second order in the system–bath coupling. This proposed treatment yields a universal tool for optimizing the fidelity of a given operation. It involves a fidelity-control matrix: a construct that allows us to prioritize the use of available control resources so as to maximize the operation fidelity in any given bath. As an analytically solvable example of this general method, we analyse quantum state-transfer optimization, from a 'noisy' (write-in) qubit to its 'quiet' counterpart (storage qubit). Intriguing interplay is revealed between our ability to avoid bath-induced errors that profoundly depend on the bath-memory time and the limitations imposed by leakage out of the operational subspace. Counterintuitively, under no circumstances is the fastest transfer optimal (for a given transfer energy).

Publication: **Controlling quantum information processing in hybrid systems on chips**
(Partner 1+2 – Weizmann+Vienna)
QIP (2011) (accepted) doi: 10.1007/s11128-011-0302-6

We investigate quantum information processing, transfer and storage in hybrid systems comprised of diverse blocks integrated on chips. Strong coupling between superconducting (SC) qubits and ensembles of ultracold atoms or NV-center spins is mediated by a microwave transmission-line resonator that interacts near-resonantly with the atoms or spins. Such hybrid devices allow us to benefit from the advantages of each block and compensate for their disadvantages. Specifically, the SC qubits can rapidly implement quantum logic gates, but are "noisy" (prone to decoherence), while collective states of the atomic or spin ensemble are "quiet"(protected from decoherence) and thus can be employed for storage of quantum information. To improve the overall performance (fidelity) of such devices we discuss dynamical control to optimize quantum state-transfer from a "noisy" qubit to the "quiet" storage ensemble. We propose to maximize the fidelity of transfer and storage in a spectrally inhomogeneous spin ensemble, by pre-selecting the optimal spectral portion of the ensemble. Significant improvements of the overall

fidelity of hybrid devices are expected under realistic conditions. Experimental progress towards the realization of these schemes is discussed.

Potential impact

WP1 Main Results

(See separate files of Deliverables 1.1, 1.2 and 1.3)

D1.1+D1.2

1. *Squeezing of quantum noise (phase-number fluctuations) below the shot-noise limit has been achieved in finite -temperature UCA JJs: a true breakthrough [T1.4/5a]. (E)* ***[Highlight]***
2. *The feasibility of UCA-SC JJ hybridization via a microwave-resonator interface has been explored as a function of the relevant decoherence [T1.4/5d]. This research, pertaining to the core of MIDAS objectives (see WP3) (selected as research highlight by Nature Physics) (T)* ***[Highlight]***
3. *Coherent excitation decay in BEC has been shown to undergo short-time enhancement, which is the fingerprint of the anti-Zeno effect [T1.4/5c]. (E)* ***[Highlight]***
4. *New protocols for the evolution readout of Schrödinger cat states in UCA JJs have been put forward [T1.4/5b]. (T)*
5. *Analogies between decoherence effects in UCA and SC coherent devices have been elucidated by means of several novel theoretical approaches that go beyond the Markov and Born approximations and apply to multilevel systems coupled to diverse baths: radiative or phonon bosonic baths, two-level fluctuators or spin baths [T1.1a, T1.1b]. (T)*
6. *The mechanisms of dephasing and decoherence in 1d UCA / BEC have been adequately described for the first time [T1.1c-T1.1e]. (T)* ***[Highlight]***
7. *Quantum nondemolition readout in SC JJs has been explored and the role of decoherence therein has been elucidated. This resolves a key conceptual issue [T1.2b]. (E)* ***[Highlight]***
8. *Low-energy excitations and the ensuing decoherence have been studied in HTS JJ [T1.3a] and in LTS JJ [T1.2a, T1.2e]. (E)*
9. *Strong-coupling decoherence of SC JJ qubit caused by atomic dipoles (two level fluctuators) has been explored [T1.2c, T1.2d, T1.3l]. (E)*
10. *Significant advances towards the realization of topologically protected SC JJ qubits have been made [T1.3k]. (E)*
11. *HTS JJ devices have been fabricated and characterized in terms of conductance fluctuations [T1.3b-T1.3i]. (E)*
12. *Novel, efficient schemes of dynamic decoherence control have been devised and implemented in trapped UCA configurations [T1.6a-T1.6g]. (T+E)* ***[Highlight]***
13. *Dynamic control of decoherence and macroscopic tunneling has been explored in SC JJ [T1.7/8b, T1.7/8c]. (T+E)*
14. *At this stage of the project we have mostly strived to control the effects of environment-induced noise in UCA and SC devices. Our work has identified new possibilities to preserve quantum coherence, by exploring novel methods of dynamical control* ***(D1.3)****. (T+E)*
15. *A comprehensive theoretical formalism has been developed for obtaining task-oriented optimal dynamic control tailored to the specific environment.* ***(D1.1+D1.2)****. (T)*
16. *In keeping with the pledged objectives, we have demonstrated decoherence reduction via dynamic control by more than 1 order of magnitude (in UCA devices):* ***MS2 reached (D1.3)*** *(E)*
17. *We have identified new possibilities to transfer quantum coherence or polarization, by exploring novel methods of dynamical control in UCA ensembles, spin networks and hybrid circuits* ***(D1.3)****. (T+E)*

Highlights

CEA has operated a two-qubit quantum processor fitted with non-destructive single-shot readout, as needed for demonstrating the quantum speed-up claimed by quantum algorithms. This processor is based on two capacitively coupled transmon qubits, each one embedded in a non-linear resonator

for readout. The coupling implements the gate Sqrt(iSWAP). The process tomography of this universal gate was performed, and the effect of decoherence characterized. Ref.: A. Dewes, F.R. Ong, V. Scmitt, R. Lauro, N. Boulant, P. Bertet, D. Vion, and D. Esteve, Characterization of a two-transmon qubit gate with individual readouts, to be submitted to Phys. Rev. Lett.)

Weizmann experimentally and theoretically demonstrated the purity (polarization) control of qubits entangled with multiple spins, using induced dephasing in nuclear magnetic resonance setups to simulate repeated quantum measurements. They showed that one may steer the qubit ensemble towards a quasiequilibrium state of a certain purity by choosing suitable time intervals between dephasing operations. These results demonstrate that repeated dephasing at intervals associated with the anti-Zeno regime leads to ensemble purification, whereas those associated with the Zeno regime lead to ensemble mixing.

WP2 Main Results

(See separate files of Deliverable 2.2)

1. *Studies of Andreev states have been performed [D2.2a, D2.2b]. (E)*
2. *Studies of entanglement UCA and SC JJ have been performed with highly innovative / breakthrough results [D3.1a, D3.1b]. (E)*
3. During this period we have demonstrated novel quantum control of entanglement and state-purity (polarization) in spin ensembles via frequent quantum measurements, or phase flips in the anti-Zeno dynamic regime whose usefulness has eluded attention so far **(D3.1)**. (T+E)
4. A breakthrough has been achieved in UCA multipartite entanglement: a record number of 160 particles have been deemed entangled in UCA JJ, giving rise to collective variable fluctuations below the standard quantum limit: **MS1 reached (D3.1)**. (E)
5. Excellent progress has been made towards observing Bloch oscillations in SC circuits **(D2.3)**. (T+E)
6. Substantial progress has been made towards HTS circuits for quiet qubits where Andreev states play a big role **(D2.2)**. (E)
7. Significant progress has been achieved in understanding macroscopic Josephson dynamics and quantum tunneling in HTS junctions. A novel reentrance effect has been identified, induced by intrinsic Andreev “atoms”, consisting of multiple, backward and forward transitions between the thermal activation and quantum tunneling regimes. This advance gives new insight into the experimental observations. **(D2.2).** (T)
8. We have demonstrated novel quantum control of entanglement and state-purity (polarization) in spin ensembles via frequent quantum measurements, or phase flips in the Zeno and anti-Zeno dynamic regimes **(D3.1)**. (T+E)

Highlights

(Naples) Self-assembled YBaCuO diffusive grain boundary submicron Josephson junctions offer a realization of a special regime of the proximity effect, where normal state coherence prevails on the superconducting coherence in the barrier region. Resistance oscillations from the current-voltage characteristic encode mesoscopic information on the junction and more specifically on the minigap induced in the barrier. Their persistence at large voltages is evidence of the long lifetime of the antinodal (high energy) quasiparticles.

Chalmers has realized the first all HTS based (YBCO) transmon qubit. This qubit design has less stringent requirements on the junction parameters compared to the quiet qubit design. We have

measured the ground state of the transmon coupled to the resonator using microwave reflectometry at 15 mK. Applying a magnetic flux to the SQUID loop of the transmon, we can clearly observe the periodic modulation of the transmon frequency and the avoided energy level crossing manifesting the strong coupling between the resonator and the transmon.

Chalmers developed a theoretical description of nonadiabatic Josephson dynamics in superconducting junctions containing low energy quasiparticles. Within this approach they investigated the effects of midgap states in junctions of unconventional d-wave superconductors. They identify a reentrance effect in the transition between thermal activation and macroscopic quantum tunneling, and connect this phenomenon to the experimental observations in Phys. Rev. Lett. 94 087003 (2005). It is also shown that nonlinear Josephson dynamics can be defined by resonant interaction with midgap states reminiscent of nonlinear optical phenomena in media of two-level atoms.

WP3 Main Results

(See separate files of Deliverables 3.1, 3.2 and 3.3)

1. *UCA-SC JJ hybridization schemes have been investigated with highly innovative results [D3.3a, D3.3b] (T), particularly in the experimental implementation of such schemes [D3.3c, D3.3d]. (E)*
2. *Novel schemes have been explored involving NV-center spin ensembles coupled to SC cavity **(D3.3)**. (T+E)*
3. *Breakthrough has been made towards the experimental implementation of such schemes **(D3.2, D3.3)**. (E)*
4. Atomic homodyne technique for detecting continuous-variable entanglement. This breakthrough in UCA ensembles has been developed by Heidelberg jointly with Weizmann.
5. We implemented SC quantum circuits incorporating coupled / entangled JJ devices usable for quantum information transmission and processing, quantum interferometry and metrology. To this end we have studied the ability to control and manipulate robust (noise resilient) collective variables of entangled elements in UCA JJs (jointly by Heidelberg, Vienna and Weizmann) and in SC JJs (by Grenoble and by Karlsruhe)
6. We have implemented quantum interconnects / interfaces between NV-center-based quantum memory and readout JJ devices (by Saclay and Vienna, jointly with Weizmann). This daring undertaking stems from a basic question: can we entangle these two very different types of elements, either by direct coupling, or via electromagnetic field modes? This achieved objective was the most challenging one, aimed at establishing a new quantum technology based on hybrid atomic-solid, macroscopically coherent, modules for quantum information processing (memory + readout).

Highlights

Karlsruhe reports on the experimental demonstration of induced coherent interaction between two intrinsic two-level states (TLSs) formed by atomic-scale defects in a solid via a superconducting phase qubit. The tunable superconducting circuit serves as a shuttle communicating quantum information between the two microscopic TLSs. They present a detailed comparison between experiment and theory and find excellent agreement over a wide range of parameters. They then use

the theoretical model to study the creation and movement of entanglement between the three components of the quantum system.

Heidelberg+Weizmann have recently developed a new experimental method to detect matterwave quadratures. The technique is in direct analogy to optical homodyning very successfully implemented and used in experiments with photons. With that method we could experimental show that in the process of spin changing collisions two-particle coherences are generated. Furthermore the experiments reveal that even in the regime of strong 'pump-field' depletion two mode entangled states. Within the last months we have started working on the generation of cat-states in a Josephson-junction situation by employing a classical bifurcation scenario. The classical limit of this bifurcation has been shown for the first time experimentally within the MIDAS consortium one and half years ago.

Weizmann+Heidelberg demonstrated that collective continuous variables of two species of trapped ultracold bosonic gases can be Einstein-Podolsky-Rosen-correlated (entangled) via inherent interactions between the species. We propose two different schemes for creating these correlations—a dynamical scheme and a static scheme analogous to two-mode squeezing in quantum optics. We quantify the correlations by using known measures of entanglement and study the effect of finite temperature on these quantum correlations.

Weizmann showed, using an exactly solvable model, that nonlinear dynamics is induced in a double-well Bose- Einstein condensate (BEC) by collisions with a thermal reservoir. This dynamics can facilitate the creation of phase or number squeezing and, at longer times, the creation of macroscopic nonclassical superposition states. Enhancement of these effects is possible by loading the reservoir atoms into an optical lattice.

Weizmann demonstrated through an exactly solvable model that collective coupling to any thermal bath induces effectively nonlinear couplings in a quantum many-body (multispin) system. The resulting evolution can drive an uncorrelated large-spin system with high probability into a macroscopic quantum-superposition state. We discuss possible experimental realizations.

Vienna presented a versatile and compact electron beam driven source for alkali metal atoms, which can be implemented in cryostats. With a heat load of less than 10 mW, the heat dissipation normalized to the atoms loaded into the magneto-optical trap (MOT) is about a factor 1000 smaller than for a typical alkali metal dispenser. The measured linear scaling of the MOT loading rate with electron current observed in the experiments indicates that electron stimulated desorption is the corresponding mechanism to release the atoms.

Saclay reported the storage and retrieval of a small microwave #eld from a superconducting resonator into collective excitations of a spin ensemble. The spins are nitrogen-vacancy centers in a diamond crystal. The storage time of the order of 30 ns is limited by inhomogeneous broadening of the spin ensemble.

Address of public website and contact details

http://www.weizmann.ac.il/chemphys/gershon/midas/

4.2 Use and dissemination of foreground

A plan for use and dissemination of foreground (including socio-economic impact and target groups for the results of the research) shall be established at the end of the project. It should, where appropriate, be an update of the initial plan in Annex I for use and dissemination of foreground and be consistent with the report on societal implications on the use and dissemination of foreground (section 4.3 – H).

The plan should consist of:

- Section A

  This section should describe the dissemination measures, including any scientific publications relating to foreground. **Its content will be made available in the public domain** thus demonstrating the added-value and positive impact of the project on the European Union.

- Section B

  This section should specify the exploitable foreground and provide the plans for exploitation. All these data can be public or confidential; the report must clearly mark non-publishable (confidential) parts that will be treated as such by the Commission. Information under Section B that is not marked as confidential **will be made available in the public domain** thus demonstrating the added-value and positive impact of the project on the European Union.

Section A (public)

This section includes two templates

- Template A1: List of all scientific (peer reviewed) publications relating to the foreground of the project.
- Template A2: List of all dissemination activities (publications, conferences, workshops, web sites/applications, press releases, flyers, articles published in the popular press, videos, media briefings, presentations, exhibitions, thesis, interviews, films, TV clips, posters).

These tables are cumulative, which means that they should always show all publications and activities from the beginning until after the end of the project. Updates are possible at any time.

TEMPLATE A1: LIST OF THE HIGHLIGHTED SCIENTIFIC (PEER REVIEWED) PUBLICATIONS										
NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers[2] (if available)	Is/Will open access[3] provided to this publication?
H1	Hybrid quantum circuit with a superconducting qubit coupled to a spin ensemble	Y.Kubo	*Phys. Rev. Lett.*	To appear in 2011	APS	*Ridge (NY)*	2011			No, but avail. on arXiv
H2	Cavity QED with Magnetically Coupled Collective Spin States	R.Amsüss et al.	Phys. Rev. Lett.	Vol. **107**	*American Physical Society*	*Ridge (NY), USA*	2011	060502		arXiv:1103.1045
H3	Strong Magnetic Coupling of an Ultracold Gas to a Superconducting Waveguide Cavity	J. Verdú et al.	Phys. Rev. Lett.	Vol. **103**	*American Physical Society*	*Ridge (NY), USA*	2009	043603		arXiv:0809.2552
H4	Strong Coupling of a Spin Ensemble to a Superconducting Resonator	*Y. Kubo*	*Phys. Rev. Lett.*	*105*	*APS*	*Ridge (NY)*	*2009*	*p140502*		No, but avail. on arXiv

[2] A permanent identifier should be a persistent link to the published version full text if open access or abstract if article is pay per view) or to the final manuscript accepted for publication (link to article in repository).
[3] Open Access is defined as free of charge access for anyone via Internet. Please answer "yes" if the open access to the publication is already established and also if the embargo period for open access is not yet over but you intend to establish open access afterwards.

H5	*Nonlinear atom interferometer surpasses classical precision limit*	*C. Gross, T. Zibold, E. Nicklas, J. Esteve, M. K. Oberthaler*	*NATURE*	*No. 464, 2010*	*Nature group*	*UK*	*2010*	*1165-1169*		No
H6	*Atomic homodyne detection of continuous variable entangled twin-atom states*	*C. Gross, H. Strobel, E. Nicklas, T. Zibold, N. Bar-Gill, G. Kurizki and M. K. Oberthaler*	*accepted for publication in Nature*	*November 2011*	*Nature group*	*UK*	*2011*			No
H7	Single-shot qubit readout in circuit quantum electrodynamics	*F.Mallet*	*NaturePhysics*	*5,11*	***Nature Group***	*Londres*	*2009*	*p791*		No, but avail. on arXiv
H8	*Squeezing and entanglement in a Bose-Einstein condensate*	*J. Estève, C. Gross, A. Weller, S. Giovanazzi and M.K. Oberthaler*	*NATURE*	*No. 455, 2008*	*Nature group*	*UK*	*2008*	*1216*		No
H9	*Single spontaneous photon as a coherent beamsplitter for an atomic matter-wave*	*Jiri Tomkovic, Michael Schreiber, JoachimWelte, Martin Kiffner, Jörg Schmiedmayer and Markus K. Oberthaler*	*NATURE PHYSICS*	*No. 7, 2011*	*Nature group*	*UK*	*2011*	*379-382*		No
H10	*Einstein-Podolsky-Rosen Correlations of Ultracold Atomic Gases*	*Nir Bar-Gill, Christian Gross, Igor Mazets, Markus Oberthaler and Gershon Kurizki*	*PHYSICAL REVIEW LETTERS*	*No. 106, 2011*	*APS*	*USA*	*2011*	*120404*		No
H11	Reentrance effect in macroscopic quantum tunneling and non-adiabatic Josephson dynamics in d-wave junctions	Jens MIchelsen	Phys. Rev. Lett.	Vol 105, September 2010	American Physical Society	USA	2010	127001		No
H12	Zeno and Anti-Zeno Polarization Control of Spin Ensembles by Induced Dephasing	Gonzalo A. Alvarez	Phys. Rev. Lett.	**105**	APS	USA	2010	160401		No
H13	*Measurement of the effect of quantum phase slips in a Josephson junction chain*	I. Pop	Nature Physics	*6, 589(2010)*	Nature publishing group	UK	2010	pp.589-592		No
H14	Storage and Retrieval of a Microwave Field in a Spin Ensemble	Y. Kubo	Submitted to Phys.Rev.Lett.		APS	*Ridge (NY)*	2011			On arXiv
H15	*Evidence of Minigap in YBCO grain boundary Josephson Junctions*	*Lucignano Stornaiuolo Tafuri Altshuler Tagliacozzo*	*Physical Review Letters*	*No 105, October 2010*	*American Physical Society*	*Ridge, NY, USA*	*2010*	*pp. 147001 - 147004*		no
H16	*Interplay between static and dynamic properties of semi-fluxons in YBaCuO Josephson junctions*	*Cedergren, Kirtley, Bauch, Rotoli, Troeman, Hilgenkamp, Tafuri Lombardi*	*Physical Review Letters*	*No 104, April 2010*	*American Physical Society*	*Ridge, NY, USA*	*2010*	*pp. 177003 - 17706*		no
H17	*Kondo conductance in an atomic nanocontact from first principles*	*Lucignano, Mazzarello, Smogunov, Fabrizio Tosatti*	*Nature Materials*	*No 8, June 2009*	*McMillan Publishers Limited*	*London, UK*	*2009*	*pp. 563-567*		no

H18	Reversible state transfer between superconducting qubits and atomic ensembles	D.Petrosyan et al.	Phys.Rev.A	Vol. **79**	*American Physical Society*	*Ridge (NY), USA*	2009	040304		arXiv:0902.0881
H19	Two-Point Phase Correlations of a One-Dimensional Bosonic Josephson Junction	T. Betz et al.	Phys. Rev. Lett.	Vol.**106**	*American Physical Society*	*Ridge (NY), USA*	2011	020407		arXiv:1010.5989
H20	From rotating atomic rings to quantum Hall states	Marco Roncaglia	Nature scientific reports	Vol. 1	Nature publishing group		2011		doi:10.1038/srep00043	Yes arXiv:1101.5593
H21	Short-time Enhancement of the Decay of Coherent Excitations in Bose-Einstein Condensates	N. Bar-Gill	Phys. Rev. Lett	**102**	*APS*	*USA*	*2009*	110401		No
H22	Bath-Optimized Minimal-Energy Protection of Quantum Operations from Decoherence	Jens Clausen	Phys. Rev. Lett.	**104**	APS	USA	2010	040401		No
H23	Generation of Macroscopic Superpositions of Quantum States by Linear Coupling to a Bath	D. D. Bhaktavatsala Rao	Phys. Rev. Lett.	**106**	APS	USA	2011	010404		No
H24	Creating Nonclassical States of Bose-Einstein Condensates by Dephasing Collisions	Nir Bar-Gill	Phys. Rev. Lett.	**107**	APS	USA	2011	010404		No
H25	Master Equation and Control of an Open Quantum System with Leakage	Lian-Ao Wu	Phys. Rev. Lett.	**102**	APS	USA	2009	080405		No
H26	*Experimental Observation of Oscillating and Interacting Matter Wave Dark Solitons*	*A. Weller, J.P. Ronzheimer, C. Gross, J. Estève, M.K. Oberthaler, D.J. Frantzeskakis, G. Theocharis and P.G. Kevrekidis*	*PHYSICAL REVIEW LETTERS*	*No. 101, 2008*	*APS*	*USA*	*2008*	*130401*		No
H27	*Rabi flopping induces spatial demixing dynamics*	*E. Nicklas, H. Strobel, T. Zibold, C. Gross, B. A. Malomed, P. G. Kevrekidis and M. K. Oberthaler*	*accepted for publication in PRL*	*November 2011*	*APS*	*USA*	*2011*			No

TEMPLATE A1: LIST OF SCIENTIFIC (PEER REVIEWED) PUBLICATIONS

NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers[4] (if available)	Is/Will open access[5] provided to this publication?
1	*Evidence of Minigap in YBCO grain boundary Josephson Junctions*	*Lucignano Stornaiuolo Tafuri Altshuler Tagliacozzo*	*Physical Review Letters*	*No 105, October 2010*	*American Physical Society*	*Ridge, NY, USA*	*2010*	*pp. 147001 - 147004*		no
2	*Kondo conductance in an atomic nanocontact from first principles*	*Lucignano, Mazzarello, Smogunov, Fabrizio Tosatti*	*Nature Materials*	*No 8, June 2009*	*McMillan Publishers Limited*	*London, UK*	*2009*	*pp. 563-567*		no
3	*Interplay between static and dynamic properties of semi-fluxons in YBaCuO Josephson junctions*	*Cedergren, Kirtley, Bauch, Rotoli, Troeman, Hilgenkamp, Tafuri Lombardi*	*Physical Review Letters*	*No 104, April 2010*	*American Physical Society*	*Ridge, NY, USA*	*2010*	*pp. 177003 - 17706*		no
4	*Quantum crossover in moderately damped epitaxial NbN/MgO/NbN junctions with low critical current density*	*Longobardi, Massarotti, Rotoli, Stornaiuolo, Papari, Kawakami, Pepe, Barone, Tafuri*	*Applied Physics Letters*	*No 99, August 2011*	*American Institute of Physics*	*Melville NY,USA*	*2011*	*pp. 062510 - 062512*		no
5	*Mesoscopic conductance fluctuations in YBCO grain boundary Junction at low temperature*	*Tagliacozzo, Tafuri, Gambale, Jouault, Born, Lucignano, Stornaiuolo, Lombardi, Barone Altshuler*	*Physical Review B*	*No 79, January 2009*	*American Physical Society*	*Ridge, NY, USA*	*2009*	*pp. 024501-024510*		no
6	*Thermal hopping and retrapping of a Brownian particle in the tilted periodic potential of a NbN/MgO/NbN Josephson junction*	*Longobardi, Massarotti, Rotoli, Stornaiuolo, Papari, Kawakami, Pepe, A. Barone, Tafuri*	*Physical Review B*	*No .., October 2011*	*American Physical Society*	*Ridge, NY, USA*	*2011*	*pp. ….*		no
7	*Little-Parks effect in single YBaCuO sub-micron rings*	*Carillo, Papari, Stornaiuolo, Born,Montemurro,Pingue, Beltram Tafuri*	*Physical Review B*	*No 81, February 2010*	*American Physical Society*	*Ridge, NY, USA*	*2010*	*pp. 054505 - 054508*		no

[4] A permanent identifier should be a persistent link to the published version full text if open access or abstract if article is pay per view) or to the final manuscript accepted for publication (link to article in repository).

[5] Open Access is defined as free of charge access for anyone via Internet. Please answer "yes" if the open access to the publication is already established and also if the embargo period for open access is not yet over but you intend to establish open access afterwards.

8	*Submicron YBaCuO biepitaxial Josephson junctions: d-wave effects and phase dynamics*	*Stornaiuolo, Rotoli, Cedergren, Born, Bauch, Lombardi, Tafuri*	*Journal of Applied Physics*	*No 107, June 2010*	*American Institute of Physics*	*Melville NY, USA*	*2010*	*pp. 113901 - 113906*		no
9	*High quality factor HTS Josephson junctions on low loss substrates*	*Stornaiuolo, Papari, Cennamo, Carillo, Longobardi, Massarotti, Barone Tafuri*	*Supercond. Science and Technology*	*No 24, January 2011*	*Institute of Physics*	*Bristol, UK*	*2011*	*pp. 045008 - 045013*		no
10	*Macroscopic Quantum Phenomena in Josephson Structures*	*Barone, Lombardi, Rotoli, Tafuri*	*Low Temperature Physics*	*No 36, June 2010*	*American Institute of Physics*	*Melville NY,USA*	*2010*	*pp. 10 - 19*		no
11	*Feasibility of a High Temperature Superconductor rf-SQUID based on Biepitaxial Josephson Junction Technology*	*Longobardi, Stornaiuolo, Papari,Tafuri*	*IEEE Trans. on Appl. Supercond.*	*No 21, June 2011*	*Institute of Electrical and Electronics Engineers*	*New York, USA*	*2011*	*pp. 151 -154*		no
12	*Sub-micron YBa2Cu3O7-x Biepitaxial Junctions*	*Stornaiuolo, Cedergren, Born, Bauch, Barone, Lombardi, Tafuri*	*IEEE Trans. on Appl. Supercond.*	*No 19, June 2009*	*Institute of Electrical and Electronics Engineers*	*New York, USA*	*2009*	*pp. 174 -177*		no
13	*YBCO nanobridges: simplified fabrication process by using a Ti hard mask*	*Papari, Carillo, Born, Bartoloni, Gambale, Stornaiuolo, Pingue, Beltram, Tafuri*	*IEEE Trans. on Appl. Supercond.*	*No 19, June 2009*	*Institute of Electrical and Electronics Engineers*	*New York, USA*	*2009*	*pp. 183 -186*		no
14	*Eck-Like Resonances in High-Tc Long Faceted Josephson Junctions*	*Rotoli, Stornaiuolo, Tafuri, Born, Bauch, Lombardi*	*IEEE Trans. on Appl. Supercond.*	*No 19, June 2009*	*Institute of Electrical and Electronics Engineers*	*New York, USA*	*2009*	*pp. 911 -914*		no
1	Production of sodium Bose–Einstein condensates in an optical dimple trap	*David Jacob*	New J. Phys.	*vol 13*	*IOP*		*2011*	65022		Yes arXiv:1104.1009
2	Fast production of ultracold sodium gases using light-induced desorption and optical trappin	Emmanuel Mimoun	Phys. Rev A	Vol 81	APS		2010	23631		Yes arXiv:0911.5656
3	All solid-state laser system for laser cooling of sodium	Emmnanuel Mimoun	Applied Physics B	Vol 99	Springer		2010	31		Yes arXiv:0908.0279
4	Sum-frequency generation of 589 nm light with near-unit efficiency	Emmanuel Mimoun	Optics express	Vol 16	OSA		2008	18684-18691		Yes arXiv:0807.2965
5	Gauge potentials for ultracold atoms in optical superlattices	Fabrice Gerbier	New J. Phys.	Vol 12	IOP		2010	33007		Yes arXiv:0910.4606

6	Artificial gauge potentials for neutral atoms	Jean Dalibard	Review of modern Physics (colloquium)		APS		2011			arXiv:1008.5378.
7	From rotating atomic rings to quantum Hall states	Marco Roncaglia	Nature scientific reports	Vol. 1	Nature publishing group		2011		doi:10.1038/srep00043	Yes arXiv:1101.5593
8	Strongly correlated states of a cold atomic gas from geometric gauge fields	B. Julia-Diaz	Phys. Rev. A (accepted)		APS		2011			Yes arXiv:1105.5021
9	Optical flux lattices for two-photon dressed states	N. Cooper	Euro. Phys. Lett.	Vol 95	EDP sciences		2011	66004		
1	Short-time Enhancement of the Decay of Coherent Excitations in Bose-Einstein Condensates	N. Bar-Gill	Phys. Rev. Lett	**102**	*APS*	*USA*	*2009*	110401		No
2	Dynamic control and probing of many-body decoherence in double-well Bose-Einstein condenstaes	N. Bar-Gill	Phys. Rev. A	**80**	*APS*	*USA*	*2009*	053613		No
3	Spectrum of two-level systems with discrete frequency fluctuations	Y. Sagi	Phys. Rev. Lett	**104**	*APS*	*USA*	*2010*	253003		No
4	Process Tomography of Dynamical Decoupling in a Dense Cold Atomic Ensemble	Y. Sagi	Phys. Rev. Lett	**105**	*APS*	*USA*	*2010*	053201		No
5	Universal Scaling of Collisional Spectral Narrowing in an Ensemble of Cold Atoms	Y. Sagi	Phys. Rev. Lett	**106**	*APS*	*USA*	*2010*	093001		No
6	Motional broadening in ensembles with heavy tail frequency distributions	Y. Sagi	Phys. Rev. A	**83**	*APS*	*USA*	*2011*	043821		No
7	Direct measurement of the system-environment coupling as a tool for understanding decoherence and dynamical decoupling	I. Almog	J. Phys. B	**44**		GB	2011	154006		No
1	Generation of Macroscopic Superpositions of Quantum States by Linear Coupling to a Bath	D. D. Bhaktavatsala Rao	Phys. Rev. Lett.	**106**	APS	USA	2011	010404		No
2	Bath-Optimized Minimal-Energy Protection of Quantum Operations from Decoherence	Jens Clausen	Phys. Rev. Lett.	**104**	APS	USA	2010	040401		No

3	Zeno and Anti-Zeno Polarization Control of Spin Ensembles by Induced Dephasing	Gonzalo A. Alvarez	Phys. Rev. Lett.	**105**	APS	USA	2010	160401		No
4	Creating Nonclassical States of Bose-Einstein Condensates by Dephasing Collisions	Nir Bar-Gill	Phys. Rev. Lett.	**107**	APS	USA	2011	010404		No
5	Master Equation and Control of an Open Quantum System with Leakage	Lian-Ao Wu	Phys. Rev. Lett.	**102**	APS	USA	2009	080405		No
6	Cooling down quantum bits on ultrashort time scales	Goren Gordon	New J. Phys	**11**	IOP	UK	2009	123025		Yes
7	Universal dynamical decoupling from slow noise with minimal control	Guy Bensky	Euro. Phys. Lett.	**89**	IOP	UK	2010	10011		No
8	Controlling quantum information processing in hybrid systems on chips, Quantum Information Processing	Guy Bensky	Quantum Information Processing	**10**	Springer	Netherlands	2011	1037-1060		No
9	Reversible state transfer between superconducting qubits and atomic ensembles	David Petrosyan	Phys. Rev. A	**79**	APS	USA	2009	040304		No
10	Decoherence and entanglement in a bosonic Josephson junction: Bose-enhanced quantum Zeno control of phase diffusion	Y. Khodorkovsky	Phys. Rev. A	**80**	APS	USA	2009	023609		No
11	From Zeno to anti-Zeno regime: Decoherence-control dependence on the quantum statistics of the bath	D. D. Bhaktavatsala Rao	Phys. Rev. A	**83**	APS	USA	2011	032105		No
12	Optimized control of quantum state transfer from noisy to quiet qubits	B M Escher	J. Phys. B	**44**	IOP	UK	2011	154015		No
13	Equilibration by quantum observation	Goren Gordon	New J. Phys	**12**	IOP	UK	2010	053033		Yes
14	Non-Markovian control of qubit thermodynamics by frequent quantum measurements	Guy Bensky	Physica E	**42**	Elsevier	Amsterdam	2010	477		No
15	Zeno and Anti-Zeno cooling by frequent measurements	Goren Gordon	IJQI	**7**	World Scientific Publishing	Singapore	2009	49		No

1	Atomic homodyne detection of continuous variable entangled twin-atom states	C. Gross, H. Strobel, E. Nicklas, T. Zibold, N. Bar-Gill, G. Kurizki and M. K. Oberthaler	accepted for publication in Nature	November 2011	Nature group	UK	2011			No
2	Nonlinear atom interferometer surpasses classical precision limit	C. Gross, T. Zibold, E. Nicklas, J. Esteve, M. K. Oberthaler	NATURE	No. 464, 2010	Nature group	UK	2010	1165-1169		No
2	Rabi flopping induces spatial demixing dynamics	E. Nicklas, H. Strobel, T. Zibold, C. Gross, B. A. Malomed, P. G. Kevrekidis and M. K. Oberthaler	accepted for publication in PRL	November 2011	APS	USA	2011			No
4	Single spontaneous photon as a coherent beamsplitter for an atomic matter-wave	Jiri Tomkovic, Michael Schreiber, JoachimWelte, Martin Kiffner, Jörg Schmiedmayer and Markus K. Oberthaler	NATURE PHYSICS	No. 7, 2011	Nature group	UK	2011	379-382		No
5	Einstein-Podolsky-Rosen Correlations of Ultracold Atomic Gases	Nir Bar-Gill, Christian Gross, Igor Mazets, Markus Oberthaler and Gershon Kurizki	PHYSICAL REVIEW LETTERS	No. 106, 2011	APS	USA	2011	120404		No
6	Classical Bifurcation at the Transition from Rabi to Josephson Dynamics	T. Zibold, E. Nicklas, C. Gross and M. K. Oberthaler	PHYSICAL REVIEW LETTERS	No. 105, 2010	APS	USA	2010	204101		No
7	Two-mode Bose gas: Beyond classical squeezing	C. Bodet, J. Estève, M. K. Oberthaler and T. Gasenzer	PHYSICAL REVIEW A	No. 81, 2010	APS	USA	2010	063605		No
8	Multiple atomic dark solitons in cigar-shaped Bose-Einstein condensates	G. Theocharis, A. Weller, J. P. Ronzheimer, C. Gross, M. K. Oberthaler, P. G. Kevrekidis and D. J. Frantzeskakis	PHYSICAL REVIEW A	No. 81, 2010	APS	USA	2010	063604		No
9	Local and spatially extended sub-Poisson atom-number fluctuations in optical lattices	C. Gross, J Estev, M.K. Oberthaler, A.D. Martin and J. Ruostekoski	PHYSICAL REVIEW A	No. 84, 2011	APS	USA	2011	011609		No
10	Ultrakalte Quantenpendel	C. Groß und M. Oberthaler	PHYSIK JOURNAL	No. 2, 2010		Germany	2010	29		No
11	Dynamic control and probing of many body decoherence in double well Bose-Einstein condensates	N. Bar-Gill, G. Kurizki, M. Oberthaler and N. Davidson	PHYSICAL REVIEW A	No. 80, 2009	APS	USA	2009	053613		No
12	Creation of macroscopic quantum superposition states by a measurement	I.E. Mazets, G. Kurizki, M. K. Oberthaler and J. Schmiedmayer	EPL	No. 83, 2008	IOP	UK	2008	60004		No

13	*Squeezing and entanglement in a Bose-Einstein condensate*	*J. Estève, C. Gross, A. Weller, S. Giovanazzi and M.K. Oberthaler*	*NATURE*	*No. 455, 2008*	*Nature group*	*UK*	*2008*	*1216*		No
14	*Experimental Observation of Oscillating and Interacting Matter Wave Dark Solitons*	*A. Weller, J.P. Ronzheimer, C. Gross, J. Estève, M.K. Oberthaler, D.J. Frantzeskakis, G. Theocharis and P.G. Kevrekidis*	*PHYSICAL REVIEW LETTERS*	*No. 101, 2008*	*APS*	*USA*	*2008*	*130401*		No
15	*Spontaneous symmetry breaking of gap solitons and phase transitions in double-well traps*	*M. Trippenbach, E. Infeld, J. Gocalek, M.Matuszewski, M. Oberthaler and B.A. Malomed*	*PHYSICAL REVIEW A*	*No. 78, 2008*	*APS*	*USA*	*2008*	*013603*		No
16	*Effective parameters for weakly coupled Bose-Einstein condensates*	*S. Giovanazzi, J. Esteve and M.K. Oberthaler*	*NEW JOURNAL OF PHYSICS*	*No. 10, 2008*	*IOP*	*UK*	*2008*	*045009*		Yes
1	Soft Nanostructuring of YBCO Josephson Junctions by Phase Separation	David Gustafsson	Nano Letters	Vol 10, November 2010	American Chemical Society	USA	2010	4824		No
2	Reentrance effect in macroscopic quantum tunneling and non-adiabatic Josephson dynamics in d-wave junctions	Jens MIchelsen	Phys. Rev. Lett.	Vol 105, September 2010	American Physical Society	USA	2010	127001		No
3	Non-adiabatic Josephson dynamics in junctions with in-gap quasiparticles	Vitaly Shumeiko	Low Temp. Phys.	Vol 35 October 2010	American Institute of Physics	USA	2010	925		No
4	Theory of two-dimensional macroscopic quantum tunnelling in $YBa_2Cu_3O_{7-x}$ Josephson junctions coupled to an LC circuit	Shiro Kawabata	Physical Review B	Vol 80, November 2009	American Physical Society	USA	2009	174513		No
5	Non-Makovian decoherence of two-level system weakly coupled to bosonic bath	Vitaly Shumeiko	EuroPhys Lett	Vol 96 November 2011	IOP Publishing	UK	2011			No
6	Quantum phase dynamics in an LC shunted Josephson junction	Ch. Kaiser	Journal of Applied Physics	Vol 109, May 2011	American Institute of Physics	USA	2011	093915		No
7	Analysis of a tunable coupler for superconduc-ting phase qubits	A. Korotkov	Physical Review B	Vol 82, September 2010	American Physical Society	USA	2011	104522		No
8	High critical temperature superconductor Josephson junctions for quantum circuit applications	Thilo Bauch	Physica Scripta	Vol T137, December 2009	The Royal Swedish Academy of Sciences	Sweden	2009	014006		No

9	Properties of inductance and magnetic penetration depth in (103)-oriented $YBa_2Cu_3O_{7-x}$ thin films	J. Johansson	Physical Review B	Vol 79, June 2009	American Physical Society	USA	2009	214513		No
10	Quantum Phase Dynamics of High-Tc Josephson Junctions	Jens Michelsen	Journal of Physics	Vol 150	IOP Publishing	UK	2009	052159		No
11	Reentrance of Macroscopic Quantum Tunneling in Cuprate Superconductors	Jens Michelsen	*Advances in Science and Technology*	Vol 155	Trans Tech Publications		2010	155		No
1	*Detecting entanglement of two electron spin qubits with witness operators*	*A. Borras*	*Physical Review B*	*No 84, July 2011*	*American Physical Society*	*New York*	*2011*	*pp. 033301 (4 pages)*		no
1	Single-shot qubit readout in circuit quantum electrodynamics	*F.Mallet*	*NaturePhysics*	*5,11*	***Nature Group***	*Londres*	*2009*	*p791*		No, but avail. on arXiv
2	Strong Coupling of a Spin Ensemble to a Superconducting Resonator	*Y. Kubo*	*Phys. Rev. Lett.*	*105*	*APS*	*Ridge (NY)*	*2009*	*p140502*		No, but avail. on arXiv
3	Hybrid quantum circuit with a superconducting qubit coupled to a spin ensemble	Y.Kubo	*Phys. Rev. Lett.*	To appear in 2011	APS	*Ridge (NY)*	2011			No, but avail. on arXiv
4	*Characterization of a two-transmon processor with individual single-shot qubit readout*	A.Dewes	Submitted to Phys.Rev.Lett.		APS	*Ridge (NY)*	2011			On arXiv
5	Storage and Retrieval of a Microwave Field in a Spin Ensemble	Y. Kubo	Submitted to Phys.Rev.Lett.		APS	*Ridge (NY)*	2011			On arXiv
1	*Measurement of the effect of quantum phase slips in a Josephson junction chain*	I. Pop	Nature Physics	*6, 589(2010)*	Nature publishing group	UK	2010	pp.589-592		No
2	Phase-charge duality in Josephson junction circuits: Role of inertia and effect of microwave irradiation	W. Guichard	Phys. Rev B	81, 064508 (2010)	American Physical Society	USA	2010	pp. 064508		No
3	Number squeezing, quantum fluctuations, and oscillations in mesoscopic Bose Josephson junctions	G. Ferrini	Phys. Rev. A	78, 023606 (2008)	American Physical Society	USA	2008	pp. 023606		No
4	Measurement of the current-phase relation in Josephson junction rhombi chains	I. Pop	Phys. Rev. B	*78, 104504 (2008)*	American Physical Society	USA	2008	pp. 104504		No

5	Quantum fluctuations of a Bose-Josephson junction in a quasi-one-dimensional ring trap	N. Didier	Phys Rev A	79, 063633 (2009)	American Physical Society	USA	2009	pp. 063633		No
6	Complete series for the off-diagonal correlations of a one-dimensional interacting Bose gas	N. Didier	Phys Rev A	80,033608 (2009)	American Physical Society	USA	2009	pp. 033608		No
7	Dynamic response of one-dimensional bosons in a trap	V. N. Golovach	Phys.Rev. A	80,043611 (2009)	American Physical Society	USA	2009	pp. 043611		No
8	Detection of coherent superpositions of phase states by full counting statistics in a Bose Josephson junction	G. Ferrini	Phys. Rev. A	80, 043628 (2009)	American Physical Society	USA	2009	pp. 043628		No
9	Noise in Bose Josephson junctions: Decoherence and phase relaxation	G. Ferrini	Phys. Rev. A	82,033621 (2010)	American Physical Society	USA	2010	pp. 033621		No
10	Exact solution for the degenerate ground-state manifold of a strongly interacting one-dimensional Bose-Fermi mixture	B. Fang	Phys. Rev. A	84, 023626 (2011)	American Physical Society	USA	2011	pp. 023626		No
11	Effect of phase noise on quantum correlations in Bose-Josephson junctions	G. Ferrini	Phys. Rev. A	84, 043628 (2011)	American Physical Society	USA	2011	pp. 043628		No
1	Two-Point Phase Correlations of a One-Dimensional Bosonic Josephson Junction	T. Betz et al.	Phys. Rev. Lett.	Vol.**106**	*American Physical Society*	*Ridge (NY), USA*	2011	020407		arXiv:1010.5989
2	Dephasing in coherently split quasicondensates	H.-P. Stimming, N. J. Mauser, J. Schmiedmayer, and I. E. Mazets	Phys.Rev.A	Vol. **83**	*American Physical Society*	*Ridge (NY), USA*	2011	023618		arXiv:1011.2276
3	Restoring integrability in one-dimensional quantum gases by two-particle correlations	I. E. Mazets and J. Schmiedmayer	Phys.Rev.A	Vol. **79**	*American Physical Society*	*Ridge (NY), USA*	2009	061603		arXiv:0904.1718
4	Reversible state transfer between superconducting qubits and atomic ensembles	D.Petrosyan et al.	Phys.Rev.A	Vol. **79**	*American Physical Society*	*Ridge (NY), USA*	2009	040304		arXiv:0902.0881
5	Breakdown of Integrability in a Quasi-1D Ultracold Bosonic Gas	I. E. Mazets, T. Schumm, and J. Schmiedmayer	Phys. Rev. Lett.	Vol. **100**	*American Physical Society*	*Ridge (NY), USA*	2009	210403		arXiv:0802.1701

6	Geometry-dependent interplay of long- and short-range interactions in ultracold fermionic gases: models for condensed matter and astrophysics	B Deb, G Kurizki and I E Mazets	New J. Phys.	Vol. **10**	*IOP Science*	*Bristol, UK*	2008	045013	doi:10.1088/1367-2630/10/4/045013	Yes
7	Thermalization in a quasi-one-dimensional ultracold bosonic gas	I.E.Mazets and J.Schmiedmayer	New J. Phys.	Vol. **12**	*IOP Science*	*Bristol, UK*	2010	055023	doi:10.1088/1367-2630/12/5/055023	Yes
8	Cavity QED with Magnetically Coupled Collective Spin States	R.Amsüss et al.	Phys. Rev. Lett.	Vol. **107**	*American Physical Society*	*Ridge (NY), USA*	2011	060502		arXiv:1103.1045
9	Cavity QED with an ultracold ensemble on a chip: Prospects for strong magnetic coupling at finite temperatures	K. Henschel, J. Majer, J. Schmiedmayer, and H. Ritsch	Phys.Rev.A	Vol. **82**	*American Physical Society*	*Ridge (NY), USA*	2010	033810		arXiv:1007.0116
10	Strong Magnetic Coupling of an Ultracold Gas to a Superconducting Waveguide Cavity	J. Verdú et al.	Phys. Rev. Lett.	Vol. **103**	*American Physical Society*	*Ridge (NY), USA*	2009	043603		arXiv:0809.2552

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES

NO.	Type of activities[6]	Main leader	Title	Date	Place	Type of audience[7]	Size of audience	Countries addressed

[6] A drop down list allows choosing the dissemination activity: publications, conferences, workshops, web, press releases, flyers, articles published in the popular press, videos, media briefings, presentations, exhibitions, thesis, interviews, films, TV clips, posters, Other.

[7] A drop down list allows choosing the type of public: Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Medias ('multiple choices' is possible.

1	*Conference (invited talk)*	*Francesco Tafuri CNR*	*International Workshop on Mesoscopic Superconductivity & Vortex Imaging*	*6 May 2011*	*Bath (England)*	*Scientific Community (higher education, Research)*	*70*	Europe, USA, Japan
2	*Conference (invited talk)*	*Francesco Tafuri CNR*	*Vortex Matter in Nanostructured Superconductors*	*16 September 2011*	*Rhodes (Greece)*	*Scientific Community (higher education, Research)*	*150*	Europe, USA, Japan
3	*Conference (invited talk)*	*Francesco Tafuri CNR*	*Superconductivity in Reduced Dimensions*	*8 May 2010*	*Salzburg (Austria)*	*Scientific Community (higher education, Research)*	*70*	Europe, USA, Japan
4	*Conference (invited talk)*	*Francesco Tafuri CNR*	*Nanoscale Superconductivity, fluxonics and plasmonics*	*22 September 2010*	*Crete (Greece)*	*Scientific Community (higher education, Research)*	*80*	Europe, USA, Japan
5	*Conference (invited talk)*	*Francesco Tafuri CNR*	*Vortex Matter in Nanostructured Superconductors (VORTEX VI)*	*22 September 2009*	*Rhodes (Greece)*	*Scientific Community (higher education, Research)*	*150*	Europe, USA, Japan
1	*Artificial gauge fields for neutral atoms in optical lattices*	*Gerbier CNRS*	*International workshop ``Non-standard superfluids and insulators"*	*July 2011*	*ICTP Trieste (Italy)*	*specialists*	*Approx 60*	
2	*Experiments with sodium spinor condensates*	*Gerbier CNRS*	*workshop ``Quantum Magnetism in Ultracold Atoms"*	May 2011	Technion, Haifa, Israël	specialists	Approx 40	
3	*Artificial gauge fields for neutral atoms*	*Gerbier CNRS*	ICOLS 2005	May 2011	Hameln, Germany	Specialists	Approx 300	
4	*Atoms in optical lattices*	*Gerbier CNRS*	*European Conference on Atomic and Molecular Physics (ECAMP10)*	July 2010	Salamanca, Spain	Specialists	Approx 300	
5	*Artificial gauge potentials for ultracold atoms in optical lattices*	*Gerbier CNRS*	*workshop "ab-initio modeling of cold gases"*	November 2009	Zurich, Switzerland	Specialists	Approx 80	
6	*Finite temperature effects for ultracold atoms in optical lattices*	*Gerbier CNRS*	*Workshop ``Quantum Walks, Cooling, Calculating, and Quantum Feedback"*	July 2009	Bonn, Germany	Specialists	Approx 80	
1	*Conference*	*N. Davidson Weizmann*	Workshop on Quantum Walks, Cooling & Calculating, and Quantum Feedback	July 2009	Bonn, Germany	*specialists*	*50*	Mainly Europe
2	*Conference*	*N. Davidson Weizmann*	Israel Physical Society 55th annual meeting	December 2009	Bar Ilan, Israel	general	30	Mainly Israel
3	*Conference*	*N. Davidson Weizmann*	Israel Physical Society 55th annual meeting	December 2009	Bar Ilan, Israel	general	50	Mainly Israel

4	*Conference*	*N. Davidson Weizmann*	Quantum Electronics Laser Science Conference	May 2010	San Jose CA,	general	60	Mainly US
5	*Conference*	*N. Davidson Weizmann*	Quantum Electronics Laser Science Conference	May 2010	San Jose CA,	general	40	Mainly US
6	*Conference*	*N. Davidson Weizmann*	41st Annual Meeting of the APS Division of Atomic, Molecular, and Optical Physics	May 2010	Houston Texas	general	30	Mainly US
7	*Conference*	*N. Davidson Weizmann*	41st Annual Meeting of the APS Division of Atomic, Molecular, and Optical Physics	May 2010	Houston Texas	general	20	Mainly US
8	*Conference*	*N. Davidson Weizmann*	41st Annual Meeting of the APS Division of Atomic, Molecular, and Optical Physics	May 2010	Houston Texas	general	40	Mainly US
9	*Conference*	*N. Davidson Weizmann*	19th International laser Physics Workshop	July 2010	Foz do Iguaçu, Brazil	general	100	International
10	*Conference*	*N. Davidson Weizmann*	workshop on quantum decoherence and thermodynamics control	August 2010	Safed Israel	general	50	International
11	*Conference*	*N. Davidson Weizmann*	IPS annual meeting	December 2010	Tel Aviv, Israel	general	40	Mainly Israel
12	*Conference*	*N. Davidson Weizmann*	IPS annual meeting	December 2010	Tel Aviv, Israel	general	30	Mainly Israel
13	*Conference*	*N. Davidson Weizmann*	20th International laser Physics Workshop	July 2011	Sarajevo, Bosnia-Herzegovina	general	60	International
14	*Conference*	*N. Davidson Weizmann*	20th International laser Physics Workshop	July 2011	Sarajevo, Bosnia-Herzegovina	general	60	International
1	*Conference*	*G. Kurizki Weizmann*	Quantum 2008	20/5/08	Turin, Italy	Sci. Commun	150	EU, USA, China, Japan
2	*Conference*	*G. Kurizki Weizmann*	ICQI	14/7/08	Boston, USA	Sci. Commun	300	EU, USA, China, Japan
3	*Conference*	*G. Kurizki Weizmann*	FQMT	27/8/08	Prague, CR	Sci. Commun	200	EU, USA, China, Japan
4	*Conference*	*G. Kurizki Weizmann*	Quantum Information	27.9.08	Perimeter, Waterloo, Canada	Specialists	100	EU, USA, Canada
5	Workshop	*G. Kurizki Weizmann*	MIDAS workshop	30.3.09	Saclay, France	Specialists	30	EU
6	*Conference*	*G. Kurizki Weizmann*	SPIE	4.5.09	Dresden, Germany	Sci. Commun	300	EU, USA, China, Japan
7	Workshop	*G. Kurizki Weizmann*	Quantum control	26.5.08	Madrid, Spain	Specialists	80	EU, USA

8	*Conference*	*G. Kurizki Weizmann*	PQE	4.1.09	Utah, USA	Sci. Commun	200	EU, USA, China, Japan
9	*Conference*	*G. Kurizki Weizmann*	Laser Physics	14.7.09	Barcelona, Spain	Sci. Commun	300	EU, USA, China, Japan
10	Workshop	*G. Kurizki Weizmann*	MIDAS Workshop	15.7.09	Heidelberg, Germany	Specialists	30	EU
11	Workshop	*G. Kurizki Weizmann*	MIDAS Workshop	1.6.08	TUW, Austria	Specialists	30	EU
12	Workshop	*G. Kurizki Weizmann*	MIDAS Workshop	30.9.09	Capri, Italy	Specialists	30	EU
13	*Conference*	*G. Kurizki Weizmann*	Laser Physics	6.7.10	Iguassu, Brazil	Sci. Commun	300	EU, USA, China, Japan
14	*Conference*	*G. Kurizki Weizmann*	QUANTUM 2010	25.5.10	Turin, Italy	Sci. Commun	150	EU, USA, China, Japan
15	*Conference*	*G. Kurizki Weizmann*	PRACOQSYS	14.6.10	Aarhus, Denmark	Sci. Commun	100	EU, USA
16	*Conference*	*G. Kurizki Weizmann*	Quantum Entanglement	20.2.11	Trieste, Italy	Sci. Commun	150	EU, USA, Iran
17	*Conference*	*G. Kurizki Weizmann*	FRISNO	2.3.11	Aussoix, France	Sci. Commun	100	EU,USA, Israel
18	*Conference*	*G. Kurizki Weizmann*	CLEO	4.5.11	Baltimore, USA	Sci. Commun	250	EU, USA, China, Japan
19	*Conference*	*G. Kurizki Weizmann*	QCIC	4.6.11	Ottawa, Canada	Sci. Commun	300	EU, USA, China, Canada, Japan
20	School	*G. Kurizki Weizmann*	Quantum Correl, Sys	20.6.11	Benasau, Spain	Sci. Commun	100	EU, USA
21	*Conference*	*G. Kurizki Weizmann*	FQMT	25.7.11	Prague, CR	Sci. Commun	300	EU, USA
22	*Conference*	*G. Kurizki Weizmann*	Adv. Quant. Opt.	27.7.11	Jacksonhole, USA	Sci. Commun	100	EU, USA
23	*Conference*	*G. Kurizki Weizmann*	CQIC	7.8.11	Toronto, Canada	Sci. Commun	200	EU, USA, Canada
24	Workshop	*G. Kurizki Weizmann*	Entanglement in Atomic Systems	5.11.10	Rehovot, Israel	Sci. Commun	100	EU, Israel
25	*Conference*	*G. Kurizki Weizmann*	EQEC	9.6.10	Qufu, China	Sci. Commun	200	China, EU
26	School	*G. Kurizki Weizmann*	KITPC	14.4.11	Beijing, China	Sci. Commun	100	China, EU
27	Workshop	*G. Kurizki Weizmann*	Quantum Thermodynamics	20.8.10	Safed, Israel	Sci. Commun	100	EU, USA, Israel
28	Workshop	*G. Kurizki Weizmann*	Quantum Control		Harvard, USA	Specialists	50	EU, USA, Israel
29	*Conference*	*G. Kurizki Weizmann*	Quantum Optics V	20.11.10	Cozumel, Mexico	Sci. Commun	300	Latin America, EU, USA
30	*Conference*	*G. Kurizki Weizmann*	Frontiers of Nonlinear Physics	24.6.10	Volga, Russia	Sci. Commun	250	Russia, EU, USA

31	Conference	G. Kurizki Weizmann	ICQO	20.9.08	Vilnius, Lithuania	Sci. Commun	300	Russia, EU
32	Conference	G. Kurizki Weizmann	ICQIAOSA	13.7.08	Boston, USA	Sci. Commun	500	EU, USA, China, Japan
1	Conference	M. Oberthaler UHEI	PTEE 2011, 7. International Conference on Physics Teaching in Engineering Education	September/2011	Mannheim	Teachers	50	Germany
2	Summer School	M. Oberthaler UHEI	MUARC & MPAGS Summer school on Quantum Matter: Foundations and New Trends	September/2011	Granada	Students	50	Spain
3	Conference	M. Oberthaler UHEI	Bose-Einstein Condensation 2011	September/2011	Sant Feliu	Scientific Comm.	>200	Spain
4	Conference	M. Oberthaler UHEI	Quantum Technologies Conference II	September/2011	Krakow	Scientific Comm.	80	Poland
5	Conference	M. Oberthaler UHEI	CLEO/Europe EQEC	May/2011	Munich	Scientific Comm.	>150	Germany
6	Conference	M. Oberthaler UHEI	Quantum Science and Technologies	May/2011	Rovereto	Scientific Comm.	100	Italy
7	Conference	M. Oberthaler UHEI	XII ICSSUR2011 und V FEYNFEST2011	May/2011	Foz do Iguacu	Scientific Comm.	200	Brasil
8	School	M. Oberthaler UHEI	DPG school "Quantum Gases in Dilute Atomic Vapour"	April/2011	Bad Honnef	Students	80	Germany
9	Conference	M. Oberthaler UHEI	FOMO 2011	March/2011	Obergurgel	Scientific Comm.	100	Austria
10	Tutorial	M. Oberthaler UHEI	IMPRS Seminar	January/2011	Dresden	Students	30	Germany
11	Conference	M. Oberthaler UHEI	Workshop on entanglement in atomic systems	November/2010	Rehovot	Scientific Comm.	100	Israel
12	Conference	M. Oberthaler UHEI	KITP Conference: Frontiers of Ultracold Atoms and Molecules	October/2010	Santa Barbara	Scientific Comm.	100	USA
13	Conference	M. Oberthaler UHEI	Complexity in Periodically Structured Systems Workshop	August/2010	Dresden	Scientific Comm.	100	Germany
14	Conference	M. Oberthaler UHEI	Quo vadis Bose-Einstein condensation? Workshop	August/2010	Dresden	Scientific Comm.	100	Germany
15	School	M. Oberthaler UHEI	SummerSchool	July/2010	Les Houches	Students	100	France
16	Tutorial	M. Oberthaler UHEI	Course of lectures	June/2010	Barcelona	Studentes/Reserachers	25	Spain

17	School	M. Oberthaler UHEI	International WE Heraeus Research School	June/2010	Bad Honnef	Students	80	Germany
18	Seminar	M. Oberthaler UHEI	CUA Seminar	May/2010	Boston	Scientific Comm.	30	USA
19	Seminar	M. Oberthaler UHEI	MIDAS WP3 Meeting	March/2010	Vienna	Scientific Comm.	15	Austria
20	School	M. Oberthaler UHEI	Socrates Workshop	February2010	Freiburg	Students	20	Germany
21	Conference	M. Oberthaler UHEI	AMO Meeting	October/2009	Lunteren	Scientific Comm.	150	Netherlands
22	Seminar	M. Oberthaler UHEI	Midterm Workshop	October/2009	Capri	Scientific Comm.	30	Italy
23	Conference	M. Oberthaler UHEI	QIPC 09 Conference	September/2009	Rom	Scientific Comm.	200	Italy
24	Conference	M. Oberthaler UHEI	BEC 2009	September/2009	Sant Feliu	Scientific Comm.	200	Spain
25	Conference	M. Oberthaler UHEI	Nonlinear Dynamics in Quantum Systems	July/2009	Krasnoyarsk	Scientific Comm.	80	Russia
26	Conference	M. Oberthaler UHEI	2009 Atomic Physics Gordon Conference	July/2009	Tilton	Scientific Comm.	120	USA
27	Conference	M. Oberthaler UHEI	ICOLS 2009	June/2009	Hokkaido	Scientific Comm.	200	Japan
28	Conference	M. Oberthaler UHEI	Research Frontiers in Ultracold Atoms	May/2009	Triest	Scientific Comm.	100	Italy
29	Conference	M. Oberthaler UHEI	Bloch Oscillations and Landau-Zener Tunneling: From Hot Electrons to Ultracold Atoms? BOLZT 2009	April/2009	Dresden	Scientific Comm.	100	Germany
30	Conference	M. Oberthaler UHEI	EuroQUASAR	December/2008	Firenze	Scientific Comm.	60	Italy
31	Conference	M. Oberthaler UHEI	ACQAO (ARC Centre of Excellence for Quantum-Atom Optics) workshop on quantum atom optics	November/2008	Lorne	Scientific Comm.	80	Australia
32	Conference	M. Oberthaler UHEI	407. WE-Heraeus-Seminar “Quo vadis BEC?”	October/2008	Bad Honnef	Scientific Comm.	100	Germany
33	Conference	M. Oberthaler UHEI	VIII. Informal Billiard Workshop	October/2008	Regensburg	Scientific Comm.	25	Germany
34	Conference	M. Oberthaler UHEI	25th Low Temperature Conference	August/2008	Amsterdam	Scientific Comm.	150	Netherlands
35	Conference	M. Oberthaler UHEI	International Conference on Atomic Physics XXI	July/2008	Storrs	Scientific Comm.	200	USA

36	*Conference*	*M. Oberthaler UHEI*	*SIAM Conference on Nonlinear Waves and Coherent Structures*	*July/2008*	*Rom*	*Scientific Comm.*	*200*	*Italy*
37	*Conference*	*M. Oberthaler UHEI*	*422nd Wilhelm and Else Heraeus Seminar Quo Vadis BEC*	*May/2008*	*Bad Honnef*	*Scientific Comm.*	*80*	*Germany*
38	*Workshop*	*M. Oberthaler UHEI*	*CIFAR*	*April/2008*	*Banff*	*Scientific Comm.*	*50*	*Canada*
39	*Conference*	*M. Oberthaler UHEI*	*INTERF08*	*April/2008*	*Trento*	*Scientific Comm.*	*120*	*Italy*
1	QUROPE Conference	Vitaly Shumeiko Chalmers	Quantum Coherence and Control	September 2008	Otranto, Italy	Scientific community	150	EU
2	Lorentz Centre Workshop	Vitaly Shumeiko Chalmers	Quantum Decoherence	August 2008	Leiden, The Netherlands	Scientific community	110	EU, USA
3	International Conference	Jens Michelsen Chalmers	Low Temperature Physics 25	July 2008	Amsterdam, The Netherlands	Scientific community	700	International
4	ESF Workshop	Vitaly Shumeiko Chalmers	Quantum Dynamics in Dots and Junctions	October 2008	Riva del Garda, Italy	Scientific community	150	EU, USA
5	ESF Workshop	Floriana Lombardi Chalmers	Superconductive Nanostructures	June 2009	Capri, Italy	Scientific community	40	EU
6	International Conference	Floriana Lombardi Chalmers	Superconductivity and Magnetism (ICSM)	April 2010	Antalya, Turkey	Scientific community	200	EU, USA, Japan
7	Congress	Jens Michelsen Chalmers	12 Ceramic Congress	June 2010	Montecatini, Italy		600	International
8	445 WEH-Seminar	Vitaly Shumeiko Chalmers	Quantum Devices	November 2010	Bad Honnef, Germany	Scientific community	180	EU, USA, Japan
9	International Conference	Thilo Bauch Chalmers	GRDC Symposium	November 2010	Seoul, Korea	Scientific community	120	SE Asia
10	ESF Conference	Vitaly Shumeiko Chalmers	Quantum Engineering of States and Devices	June 2010	Obergurgle, Austria	Scientific community	150	EU, Japan
11	Conference	Floriana Lombardi Chalmers	Swiss-Swedish symposium “Quantum materials and devices”	January 2011	Le Diablerets, Switzerland	Scientific community	40	Sweden, Switzerland

12	Workshop	Floriana Lombardi Chalmers	Japan-Swedish QNANO workshop "Quantum materials and devices"	June 2011	Stenungsbaden, Sweden	Scientific community	45	Japan, Sweden
13	Conference	Floriana Lombardi Chalmers	Swiss-Swedish symposium "Quantum materials and devices"	August 2011	Stenungsbaden, Sweden	Scientific community	50	Sweden, Switzerland
14	Conference	Floriana Lombardi Chalmers	Superconductivity Centennial Conference	September 2011	Den Haag, The Netherlands	Scientific community	80	EU, USA, Japan, China
1	Conference "Spin-based quantum information processing"	*A.Borras* Delft	*Detecting entanglement of two electron spin qubits with witness operators*	*16-20 August 2010*	*Konstanz (Germany)*	*Scientific Community*	*50*	USA, Japan, various European
2	International Conference on Mathematical Methods in Science and Engineering	*M. Blaauboer* Delft	*Detecting entanglement of two electron spin qubits with witness operators*	*26-30 June 2011*	Alicante (Spain)	*Scientific Community*	*100*	USA, Japan, various European
3	Conference Fysica 2010	*M. Blaauboer* Delft	*Quantum entanglement in solid-state nanostructures*	*22 April 2010*	*Utrecht (Netherlands)*	*Scientific Community*	*70*	Mainly Dutch and other European countries
4	Presentation at the "Meet the future" Science and Technology Summit	*M. Blaauboer* Delft	*The impact of solid-state nanotechnology*	*18 November 2010*	*The Hague (Netherlands)*	*Scientific Community, Industry, Policy Makers, Medias*	*150*	Mainly Dutch
1	*Conference*	*D.Esteve* CEA	Analog Quantum Information Processing	*Oct 2008*	*Boulder*	*researchers*	*50*	US+worldwide
2	*Conference*	P.Bertet CEA	Nobel symposium	May 2009	Göteborg	researchers	60	worldwide
3	*colloquium*	P.Bertet CEA		July 2009	Stuttgart	Researchers students	100	local
4	*School*	P.Bertet CEA	Cargese school	August 2009	Cargese	Researchers students	50	Europe
5	*Conference*	D.Vion CEA	QIPC	Sept 2009	Roma	researchers	300	Europe
6	*Conference*	D.Vion CEA	DMQS	Oct 2009	Tokyo5	researchers	50	Japan + worldwide
7	*School*	D.Esteve CEA	Capri Physics School	April 2010	Capri	students Researchers	50	Europe
8	*Conference*	D.Esteve CEA	QIPSS	May2010	Waterloo	researchers	70	worldwide
9	*Conference*	P.Bertet CEA	Quantum Cavities Workshop	April 2010	Montreal	researchers	50	worldwide
10	*Conference*	D.Esteve CEA	QuantumInfoProcessing	Oct 2010	Munich	researchers	100	Europe
11	*Conference*	P.Bertet CEA	Artificial Atoms in Diamond	Nov 2010	Harvard	researchers	50	worldwide
12	*Colloquium*	D.Esteve CEA	Quantum Information with SC qubits	Dec2010	Munich	Researchers students	50	local
13	*Conference*	P.Bertet CEA	DPG meeting	March 2011	Dresden	researchers	200	Germany
14	*Conference*	P.Bertet CEA	COLOQ12	July 2011	Marseille	researchers	50	

1	*Conference*		*European Conference on Nanotechnologies*	*26 February 2010*				
2	Conference	W. Guichard	March meeting	24 March 2010	Dallas	Scientific community	100	International
3	Conference	A. Minguzzi	Latsis Symposium "Bose-Einstein Condensation in dilute atomic gases and condensed matter"	February 2008	Lausanne	Scientific community	100	EU
4	conference	A. Minguzzi	17th International Laser Physics Workshop	July 2008	Trondheim (Norway)	Scientific community	100	EU+US
5	conference	A. Minguzzi	Colloque de la division de Physique Atomique, Moleculaire et Optique de la Societe Francaise de Physique	July 2008	Lille (France)	Scientific community	40	France
6	conference	I. Pop	March meeting	March 2011	Dallas (US)	Scientific community	30	International
7	conference	A. Minguzzi	Journees de la Matiere Condens´ee JMC12	August 2010	Troyes (France)	Scientific commmunity	40	France
8	conference	A. Minguzzi	Reunione pleniere du GDR Meso	September 2010	Aussois (France)	Scientific community	60	France
9	conference	W. Guichard	International workshop on Quantum Dynamics in Dots and Junctions - Coherent Solid State Systems.	October 2008	Riva del Garda (Italy)	Scientific Community	60	EU
10	conference	G. Ferrini	*Quantum Technologies Conference*	August 2010	Torun (Poland)	Scientific Community)	70	EU
11	conference	G. Ferrini	20th International Laser Physics Workshop	July 2011	Sarajevo (Bosnia and Herzegovina)	Scientific community	100	EU
12	conference	F. Hekking	MIDAS kick-off meeting,	June 2008.	Vienna (Austria)	Scientific community	50	EU
13	conference	I. Pop	TransAlpNano	June 2010	Como(Italy)	Scientific community	50	EU
14	conference	I. Pop	Journees de la Matiere Condens´ee JMC12	August 2010	Troyes (France)	Scientific community	50	EU
15	conference	F. Hekking	International workshop Nanoelectronics and quantum transport	April 2008	Karlsruhe (Germany).	Scientific community	100	International
16	conference	F. Hekking	QPNano 2009	August – September 2009.	Montenegro	Scientific community	30	International
17	conference	F. Hekking	French GDR network "Quantum Dynamics"	September, 2009.	Lyon (France	Scientific community	60	French

18	conference	F. Hekking	Frequency- and time-resolved electron transport in nanocircuits,	December 2009	Marseille (France)	Scientific community	50	EU
19	conference	F. Hekking	Arrow of time and the problem of decoherence in closed solid state quantum systems	October 2010	Paris (France)	Scientific community	100	International
20	conference	F. Hekking	Rencontres de Moriond 2011 Quantum Mesoscopic Physics	March 2011.	LA Thule (Italy)	Scientific community	200	International
21	conference	F. Hekking	Highlights in Quantum Condensed Matter Physics	June 2011	San Sebastian, Spain.	Scientific community	70	International
22	conference	F. Hekking	XXIème Congrès général de la Société Française de Physique	July 2011	Bordeaux (France)	Scientific community	100	France
1	*Conference*	R. Amsüss	DPG Meeting	March 2011	Dresden	Researchers	200	Germany/Europe
2	*Summer School*	R. Amsüss	Optics Summer School	August 2010	Sandbjerg	Students/Researchers	50	Denmark/Europe
3	*Conference*	S. Haslinger	Quantum Information, Processing and Communication Conference	September 2009	Rom	Researchers	300	Europe/Worldwide
4	*Conference*	C. Koller	Junior Scientist Conference	April 2010	Vienna	Students	100	Wordlwide
5	*Conference*	J. Majer	Quantum Optics Conference	February 2010	Obergurgl	Researchers	100	Wordlwide
6	*Conference*	J. Majer	ITAMP Workshop	November 2010	Harvard/Boston	Researchers	50	Worldwide
7	*Colloquium*	J. Majer	Linnaues Colloquium	May 2009	Chalmers/Gothenburg	Researchers	50	Sweden
8	*Workshop*	J. Majer	Solid Fall Workshop	October 2010	Munich	Researchers	100	Europe
9	*Conference*	J,Majer	ÖPG/SPS Meeting	June 2011	Lausanne	Researchers	40	Europe
10	*Workshop*	I. Mazets	Advanced Study Group	August 2010	Dresden	Researchers	60	Wordwide
11	*Seminar*	I. Mazets	Atom Optics Seminar	November 2010	Yale, New Haven	Researchers	50	US
12	*Workshop*	I. Mazets	Workshop on the dynamics of quantum gases	September 2010	Orsay, Paris	Researchers	40	France/Europ/US
13	*Summer School*	J. Schmiedmayer	Quantum Physics	September 2009	Innsbruck	Students/Researchers	60	Worldwide
14	*Conference*	J. Schmiedmayer	ITAMP Workshop	April 2010	Harvard/Boston	Researchers	80	Worldwide
15	*Conference*	J. Schmiedmayer	ESF Workshop	February 2009	Obergurgl	Researchers	100	Worldwide

16	*Conference*	J. Schmiedmayer	DAMOP	May 2010	Houston	Researchers	200	US/Worlwide

Section B (Confidential[8] or public: confidential information to be marked clearly)
Part B1

The applications for patents, trademarks, registered designs, etc. shall be listed according to the template B1 provided hereafter.

The list should, specify at least one unique identifier e.g. European Patent application reference. For patent applications, only if applicable, contributions to standards should be specified. This table is cumulative, which means that it should always show all applications from the beginning until after the end of the project.

TEMPLATE B1: LIST OF APPLICATIONS FOR PATENTS, TRADEMARKS, REGISTERED DESIGNS, ETC.					
Type of IP Rights[9]:	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Application reference(s) (e.g. EP123456)	Subject or title of application	Applicant (s) (as on the application)
European	No	02/06/09	EPRmn-F064400193/EP/ECT	*Dispositif optique de conversion de longueur d'onde, et source de lumière cohérente utilisant un tel dispositif*	Emmanuel Mimoun Jean-jacques Zondy, Jean Dalibard, Fabrice Gerbier
US	No	05/08/11	N/Ref.: EPR/LD F064400193US	*Optical frequency conversion device, and light source using aforementioned device*	Emmanuel Mimoun Jean-jacques Zondy, Jean Dalibard, Fabrice Gerbier

[8] Note to be confused with the "EU CONFIDENTIAL" classification for some security research projects.

[9] A drop down list allows choosing the type of IP rights: Patents, Trademarks, Registered designs, Utility models, Others.

Part B2

Please complete the table hereafter:

Type of Exploitable Foreground[10]	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application[11]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved

In addition to the table, please provide a text to explain the exploitable foreground, in particular:

- Its purpose
- How the foreground might be exploited, when and by whom
- IPR exploitable measures taken or intended
- Further research necessary, if any
- Potential/expected impact (quantify where possible)

[19] A drop down list allows choosing the type of foreground: General advancement of knowledge, Commercial exploitation of R&D results, Exploitation of R&D results via standards, exploitation of results through EU policies, exploitation of results through (social) innovation.

[11] A drop down list allows choosing the type sector (NACE nomenclature) : http://ec.europa.eu/competition/mergers/cases/index/nace_all.html

4.3 Report on societal implications

Replies to the following questions will assist the Commission to obtain statistics and indicators on societal and socio-economic issues addressed by projects. The questions are arranged in a number of key themes. As well as producing certain statistics, the replies will also help identify those projects that have shown a real engagement with wider societal issues, and thereby identify interesting approaches to these issues and best practices. The replies for individual projects will not be made public.

A General Information *(completed automatically when **Grant Agreement number** is entered.*	
Grant Agreement Number:	
Title of Project:	
Name and Title of Coordinator:	

B Ethics	
1. Did your project undergo an Ethics Review (and/or Screening)? • If Yes: have you described the progress of compliance with the relevant Ethics Review/Screening Requirements in the frame of the periodic/final project reports? Special Reminder: the progress of compliance with the Ethics Review/Screening Requirements should be described in the Period/Final Project Reports under the Section 3.2.2 *'Work Progress and Achievements'*	***No***
2. Please indicate whether your project involved any of the following issues (tick box) :	***YES***
RESEARCH ON HUMANS	
• Did the project involve children?	
• Did the project involve patients?	
• Did the project involve persons not able to give consent?	
• Did the project involve adult healthy volunteers?	
• Did the project involve Human genetic material?	
• Did the project involve Human biological samples?	
• Did the project involve Human data collection?	
RESEARCH ON HUMAN EMBRYO/FOETUS	
• Did the project involve Human Embryos?	
• Did the project involve Human Foetal Tissue / Cells?	
• Did the project involve Human Embryonic Stem Cells (hESCs)?	
• Did the project on human Embryonic Stem Cells involve cells in culture?	
• Did the project on human Embryonic Stem Cells involve the derivation of cells from Embryos?	
PRIVACY	
• Did the project involve processing of genetic information or personal data (eg. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)?	
• Did the project involve tracking the location or observation of people?	
RESEARCH ON ANIMALS	
• Did the project involve research on animals?	
• Were those animals transgenic small laboratory animals?	
• Were those animals transgenic farm animals?	

• Were those animals cloned farm animals?	
• Were those animals non-human primates?	
RESEARCH INVOLVING DEVELOPING COUNTRIES	
• Did the project involve the use of local resources (genetic, animal, plant etc)?	
• Was the project of benefit to local community (capacity building, access to healthcare, education etc)?	
DUAL USE	
• Research having direct military use	No
• Research having the potential for terrorist abuse	

C Workforce Statistics Grenoble:no CNR:no

3. Workforce statistics for the project: Please indicate in the table below the number of people who worked on the project (on a headcount basis).

Type of Position	Number of Women	Number of Men
Scientific Coordinator		1
Work package leaders	1 (Delft)	1 (Chalmers) + 1 (Weizmann E) + 1 (Vienna)
Experienced researchers / Node leaders	1 (Chalmers) + 2 (CNRS) + 1 (Delft)	5 (CEA) + 3 (ENS) + 1 (Chalmers) + 1 (Vienna)
PhD Students	1 (CEA) + 3 (Vienna) + 1 (CNRS)	1 (CEA)+3 (ENS) + 2 (Chalmers) + 3 (Weizmann E) + 8 (Vienna)
N. Sc. Students	2 (Weizmann)	2 (Weizmann E)
Administration / management	2 (Weizmann)	

4. How many additional researchers (in companies and universities) were recruited specifically for this project?	**1 (CEA) + 1 (Delft) + 4 (Weizmann)**
Of which, indicate the number of men:	1(CEA) + 1 (Delft) + 4 (Weizmann)

D Gender Aspects

5. Did you carry out specific Gender Equality Actions under the project?

○ ~~Yes~~
X No

6. Which of the following actions did you carry out and how effective were they?

	Not at all effective				Very effective
❑ Design and implement an equal opportunity policy	○	○	○	○	○
❑ Set targets to achieve a gender balance in the workforce	○	○	○	○	○
❑ Organise conferences and workshops on gender	○	○	○	○	○
❑ Actions to improve work-life balance	○	○	○	○	○

○ Other:

7. Was there a gender dimension associated with the research content – i.e. wherever people were the focus of the research as, for example, consumers, users, patients or in trials, was the issue of gender considered and addressed?

○ ~~Yes- please specify~~

X No

E Synergies with Science Education

8. Did your project involve working with students and/or school pupils (e.g. open days, participation in science festivals and events, prizes/competitions or joint projects)?

○ ~~Yes- please specify~~

X No

9. Did the project generate any science education material (e.g. kits, websites, explanatory booklets, DVDs)?

○ ~~Yes- please specify~~

X No

F Interdisciplinarity

10. Which disciplines (see list below) are involved in your project?

X Main discipline[12]: 1.2

○ Associated discipline[12]:

○ Associated discipline[12]:

G Engaging with Civil society and policy makers

11a Did your project engage with societal actors beyond the research community? *(if 'No', go to Question 14)*

○ ~~Yes~~
X No

11b If yes, did you engage with citizens (citizens' panels / juries) or organised civil society (NGOs, patients' groups etc.)?

○ No

○ Yes- in determining what research should be performed

○ Yes - in implementing the research

○ Yes, in communicating /disseminating / using the results of the project

[12] Insert number from list below (Frascati Manual).

11c In doing so, did your project involve actors whose role is mainly to organise the dialogue with citizens and organised civil society (e.g. professional mediator; communication company, science museums)?	○ ○	Yes No

12. Did you engage with government / public bodies or policy makers (including international organisations)

- ○ No
- ○ Yes- in framing the research agenda
- ○ Yes - in implementing the research agenda
- ○ Yes, in communicating /disseminating / using the results of the project

13a Will the project generate outputs (expertise or scientific advice) which could be used by policy makers?

- ○ Yes – as a **primary** objective (please indicate areas below- multiple answers possible)
- ○ Yes – as a **secondary** objective (please indicate areas below - multiple answer possible)
- ○ No

13b If Yes, in which fields?

Agriculture		Energy		Human rights	
Audiovisual and Media		Enlargement		Information Society	
Budget		Enterprise		Institutional affairs	
Competition		Environment		Internal Market	
Consumers		External Relations		Justice, freedom and security	
Culture		External Trade		Public Health	
Customs		Fisheries and Maritime Affairs		Regional Policy	
Development Economic and Monetary Affairs		Food Safety		Research and Innovation	
Education, Training, Youth		Foreign and Security Policy		Space	
Employment and Social Affairs		Fraud		Taxation	
		Humanitarian aid		Transport	

13c If Yes, at which level? ○ Local / regional levels ○ National level ○ European level ○ International level	

H Use and dissemination

14. How many Articles were published/accepted for publication in peer-reviewed journals?	**98**
To how many of these is open access[13] provided?	**26**
How many of these are published in open access journals?	**7**
How many of these are published in open repositories?	**19**
To how many of these is open access not provided?	**72**
Please check all applicable reasons for not providing open access:	
X publisher's licensing agreement would not permit publishing in a repository X no suitable repository available X no suitable open access journal available X no funds available to publish in an open access journal ❑ lack of time and resources ❑ lack of information on open access ❑ other[14]: ……	

15. How many new patent applications ('priority filings') have been made? *("Technologically unique": multiple applications for the same invention in different jurisdictions should be counted as just one application of grant).*		**2**
16. Indicate how many of the following Intellectual Property Rights were applied for (give number in each box).	Trademark	
	Registered design	
	Other	
17. How many spin-off companies were created / are planned as a direct result of the project?		
Indicate the approximate number of additional jobs in these companies:		

18. Please indicate whether your project has a potential impact on employment, in comparison with the situation before your project:

❑	Increase in employment, or	❑	In small & medium-sized enterprises
❑	Safeguard employment, or	❑	In large companies
❑	Decrease in employment,	X	None of the above / not relevant to the project
❑	Difficult to estimate / not possible to quantify		

19. For your project partnership please estimate the employment effect resulting directly from your participation in Full Time Equivalent (*FTE = one person working fulltime for a year*) jobs:	*Indicate figure:*

[13] Open Access is defined as free of charge access for anyone via Internet.
[14] For instance: classification for security project.

Difficult to estimate / not possible to quantify	❑

I Media and Communication to the general public

20. As part of the project, were any of the beneficiaries professionals in communication or media relations?

○ ~~Yes~~ X No

21. As part of the project, have any beneficiaries received professional media / communication training / advice to improve communication with the general public?

○ ~~Yes~~ X No

22 Which of the following have been used to communicate information about your project to the general public, or have resulted from your project?

X	Press Release	X	Coverage in specialist press
❑	Media briefing	X	Coverage in general (non-specialist) press
❑	TV coverage / report	X	Coverage in national press
❑	Radio coverage / report	X	Coverage in international press
❑	Brochures /posters / flyers	X	Website for the general public / internet
❑	DVD /Film /Multimedia	X	Event targeting general public (festival, conference, exhibition, science café)

23 In which languages are the information products for the general public produced?

X	Language of the coordinator	X	English
X	Other language(s)		

***Question F-10*:** Classification of Scientific Disciplines according to the Frascati Manual 2002 (Proposed Standard Practice for Surveys on Research and Experimental Development, OECD 2002):

FIELDS OF SCIENCE AND TECHNOLOGY

1. NATURAL SCIENCES

1.1 Mathematics and computer sciences [mathematics and other allied fields: computer sciences and other allied subjects (software development only; hardware development should be classified in the engineering fields)]

1.2 Physical sciences (astronomy and space sciences, physics and other allied subjects)

1.3 Chemical sciences (chemistry, other allied subjects)

1.4 Earth and related environmental sciences (geology, geophysics, mineralogy, physical geography and other geosciences, meteorology and other atmospheric sciences including climatic research, oceanography, vulcanology, palaeoecology, other allied sciences)

1.5 Biological sciences (biology, botany, bacteriology, microbiology, zoology, entomology, genetics, biochemistry, biophysics, other allied sciences, excluding clinical and veterinary sciences)

2 ENGINEERING AND TECHNOLOGY

2.1 Civil engineering (architecture engineering, building science and engineering, construction engineering, municipal and structural engineering and other allied subjects)

2.2 Electrical engineering, electronics [electrical engineering, electronics, communication engineering and systems, computer engineering (hardware only) and other allied subjects]

2.3. Other engineering sciences (such as chemical, aeronautical and space, mechanical, metallurgical and materials engineering, and their specialised subdivisions; forest products; applied sciences such as

geodesy, industrial chemistry, etc.; the science and technology of food production; specialised technologies of interdisciplinary fields, e.g. systems analysis, metallurgy, mining, textile technology and other applied subjects)

3. MEDICAL SCIENCES

3.1 Basic medicine (anatomy, cytology, physiology, genetics, pharmacy, pharmacology, toxicology, immunology and immunohaematology, clinical chemistry, clinical microbiology, pathology)

3.2 Clinical medicine (anaesthesiology, paediatrics, obstetrics and gynaecology, internal medicine, surgery, dentistry, neurology, psychiatry, radiology, therapeutics, otorhinolaryngology, ophthalmology)

3.3 Health sciences (public health services, social medicine, hygiene, nursing, epidemiology)

4. AGRICULTURAL SCIENCES

4.1 Agriculture, forestry, fisheries and allied sciences (agronomy, animal husbandry, fisheries, forestry, horticulture, other allied subjects)

4.2 Veterinary medicine

5. SOCIAL SCIENCES

5.1 Psychology

5.2 Economics

5.3 Educational sciences (education and training and other allied subjects)

5.4 Other social sciences [anthropology (social and cultural) and ethnology, demography, geography (human, economic and social), town and country planning, management, law, linguistics, political sciences, sociology, organisation and methods, miscellaneous social sciences and interdisciplinary , methodological and historical S1T activities relating to subjects in this group. Physical anthropology, physical geography and psychophysiology should normally be classified with the natural sciences].

6. HUMANITIES

6.1 History (history, prehistory and history, together with auxiliary historical disciplines such as archaeology, numismatics, palaeography, genealogy, etc.)

6.2 Languages and literature (ancient and modern)

6.3 Other humanities [philosophy (including the history of science and technology) arts, history of art, art criticism, painting, sculpture, musicology, dramatic art excluding artistic "research" of any kind, religion, theology, other fields and subjects pertaining to the humanities, methodological, historical and other S1T activities relating to the subjects in this group]