

DY 12: Delay and Feedback Dynamics

Time: Monday 15:30–17:15

Location: ZEU 147

DY 12.1 Mon 15:30 ZEU 147

Delayed feedback control of localized states in a broad area vertical cavity surface emitting laser with saturable absorption — ●SVETLANA GUREVICH¹, CHRISTIAN SCHELTE¹, MUSTAPHA TLIDI², and KRASSIMIR PANAJOTOV³ — ¹University of Münster, Germany — ²Université libre de Bruxelles, Belgium — ³Vrije Universiteit Brussel, Belgium

We are interested in spatio-temporal dynamics of localized solitons in a transverse section of a broad area vertical cavity surface emitting laser (VCSEL) with saturable absorption subjected to time-delayed optical feedback. In the absence of delayed feedback, a single branch of localized solutions appears. However, in the presence of the feedback term, the branches of localized solutions fill the surface of the "solution tube" in the parameter space, which is filled densely with increasing delay time. Further, our study reveals that the multistability of stationary solutions is caused by a delayed-induced phase bifurcation. In addition, the thresholds of the drift and phase bifurcations as well as corresponding bifurcation diagrams are obtained using a combination of analytical and numerical continuation methods. It turns out that both thresholds tend to zero in the limit of large delay times. In addition, we demonstrate that the delayed feedback can induce Andronov-Hopf bifurcations and a period doubling route to chaos. A coupling between this bifurcation scenario with the delay-induced multistability leads to a complex spatio-temporal behavior of the system in question.

DY 12.2 Mon 15:45 ZEU 147

Lyapunov vectors of dynamical systems with time-varying delay — ●DAVID MÜLLER, ANDREAS OTTO, and GÜNTER RADONS — Institute of Physics, Chemnitz University of Technology, 09107 Chemnitz, Germany

Time-delay systems arise in many fields such as life science, control theory, synchronization of networks, climate dynamics and engineering. Time-varying delays are introduced for example to take into account environmental fluctuations, for improving control and synchronization strategies and lead to interesting dynamical properties.

We have identified two classes of systems with time-varying delay, whereby the classification depends only on the functional structure of the delay. Systems with *conservative* delay are equivalent to systems with constant delay in the sense that they are connected by a timescale transformation under which dynamical quantities as the Lyapunov spectrum are invariant. Contrarily, systems with *dissipative* delay are not equivalent to systems with constant delay which leads to fundamental differences in the dynamics and characteristic dynamical quantities as the asymptotic scaling behavior of the Lyapunov spectrum.

In this talk we focus on the influence of the delay class on the characteristic properties of the covariant Lyapunov vectors.

DY 12.3 Mon 16:00 ZEU 147

Steering quantum feedback via a dielectric medium of resonant two-level systems — ●FABIAN FAULSTICH, NICOLAS NAUMANN, ANDREAS KNORR, and ALEXANDER CARMELE — Institut für Theoretische Physik, Nichtlineare Optik und Quantenelektronik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany

Recently, feedback effects have become accessible in quantum optical few emitter systems [1, 2] and theoretical investigations of the feedback delay time have become necessary to reveal the underlying physics [3, 4]. To model quantum delayed feedback, a frequency dependent coupling element in the light-matter interaction is assumed. Here, we derive this light-coupling element by considering a dielectric of identical two-state atoms coupled by the radiation field to an atom outside the dielectric [5].

The Heisenberg equation yields a delay differential operator equation describing the interaction of the atom with the dielectric via photon exchanges. In the macroscopic limit of a continuous distribution of atoms in the dielectric, we derive a more compact delay differential operator equation in which a Fresnel reflection coefficient appears. These equations allow the simulation of the many-photon limit including additional dynamics within the dielectric.

[1] C. Hopfmann, *New J. Phys.*, **15**, 025030 (2013).[2] F. Schulze, et al. *Phys. Rev. A*, **89**, 4 (2014): 041801.[3] H. Pichler and P. Zoller, *Phys. Rev. Lett.*, **116**, 093601 (2016).[4] A. Carmele et al., *JOSA B* **33**, 7 (2016): C10-C16.[5] P. W. Milonni et al. *Phys. Rev. A*, **35**, 12 (1987): 5081.

DY 12.4 Mon 16:15 ZEU 147

Solution of delay differential equations via path integrals — ●ANDREAS OTTO, NICO GEHRE, and GÜNTER RADONS — Institute of Physics, Chemnitz University of Technology, 09107 Chemnitz, Germany

In many dynamical systems in engineering and nature the effects of time delays are important. Such systems are described by delay differential equations. They can be found, for example, in models for the description of metal cutting vibrations, population growth, El Niño phenomenon and interaction in networks.

In this talk a new approach for the solution of delay differential equations is presented, which is related to the known path integral formulation for the solution of partial differential equations. It is shown how path integrals can be used for the construction of analytical solutions of autonomous as well as non-autonomous delay differential equations. The path integral method is applied to concrete examples and the results are compared with the solution obtained from existing analytical and numerical techniques.

DY 12.5 Mon 16:30 ZEU 147

Quantum-dot lasers with optical feedback: Autocorrelation function and rescaling properties — ●DAVID SCHICKE, ANDRÉ RÖHM, BENJAMIN LINGNAU, and KATHY LÜDGE — Institut für Theoretische Physik, Sekr. EW 7-1, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany

The dynamics of a semiconductor laser with feedback can be characterised by the autocorrelation function of the electric field. Experiments using quantum well lasers have shown that the qualitative dynamics do not change for different delay times and pump currents. By rescaling the system variables one can even achieve quantitative agreement [1]. Whether the same rescaling properties hold in quantum dot lasers with feedback is an open problem. We present numerical simulations for a quantum dot laser model as described in [2], extended by an extra delay term for the electric field describing feedback. The laser exhibits mostly stable behaviour for low delay times, i.e. several hundred picoseconds. Accordingly we concentrate on intermediate to long delay times (tens of nanoseconds), where chaotic dynamics can be observed and compared for different operating parameters.

[1] Porte, X., Soriano, M. C., Fischer, I., *Similarity properties in the dynamics of delayed-feedback semiconductor lasers*, *Phys. Rev. A* **89**, 023822 (2014).[2] Lingnau, B., Chow, W. W., Lüdge, K., *Amplitude-phase coupling and chirp in quantum-dot lasers: influence of charge carrier scattering dynamics*, *Opt. Express* **22**, 4867-4879 (2014).

DY 12.6 Mon 16:45 ZEU 147

Quantum coherent time-delayed feedback in cavity and waveguide QED — ●MANUEL KRAFT, FABIAN FAULSTICH, SVEN M. HEIN, ANDREAS KNORR, and ALEXANDER CARMELE — Technische Universität Berlin, Institut für Theoretische Physik, Nichtlineare Optik und Quantenelektronik, Hardenbergstr. 36, 10623 Berlin, Germany

Quantum coherent control schemes provide efficient methods to control open quantum systems [1]. In this talk we focus specifically on quantum coherent self-feedback [2] in a cavity and waveguide QED geometry, where time-delayed quantum signals are fed back directly into system dynamics. In the cQED case, we present how time-delayed quantum coherent self-feedback control can be used to tailor the squeezing spectrum of the output fields of an externally pumped cavity containing a second order nonlinear crystal [3]. Extending the study to a half open waveguide, we investigate the impact of time-delayed feedback on the atom and photon bound states. Thereby we employ a Greens function method [4] based on the Lippmann Schwinger equation to approach the N-photon non-markovian feedback case.

[1] Lloyd, *Phys. Rev. A* **62**, 022108 (2000)[2] Carmele, et al. *Phys. Rev. Lett.* **110**, 013601 (2013)[3] Kraft, et al. *Phys. Rev. A* **94**, 023806 (2016)[4] Zheng, et al. *Phys. Rev. Lett.* **110**, 113601 (2013)

DY 12.7 Mon 17:00 ZEU 147

Approximating the non-Markovian dynamics of classical noisy systems with time-delay — •SARAH A. M. LOOS and SABINE H. L. KLAPP — Institut für Theoretische Physik, TU Berlin, Hardenbergstraße 36, D-10623 Berlin, Germany

We investigate the probabilistic treatment of classical overdamped noisy systems with time-delayed forces (that depend on the system state at one earlier time $t-\tau$) in the steady state. Due to the non-Markovianity, there is no standard Fokker-Planck (FP) equation that corresponds to the delayed Langevin equation for such systems. On the contrary, the FP approach yields an infinite hierarchy of coupled differential equations [1].

We investigate approaches to truncate this hierarchy by approximating the two-time probability density. An according first-order perturbation-theoretical approach was developed by Frank [2], starting from the corresponding system without delay force. Here we present a novel approach, starting from the corresponding linearized delayed system. We discuss the application of both approaches to a 1D system consisting of a Brownian particle in a static periodic potential subject to a time-delayed feedback force. Comparing with results from numerical simulations, we demonstrate advantages of the novel approach compared to the perturbation theory.

- [1] M. L. Rosinberg et al., Phys. Rev. E **91**, 042114 (2015).
- [2] T. D. Frank, Phys. Rev. E **71**, 031106 (2005).