# An AMOP – Jazan University Sponsored Short Course on Quantum Memories

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**Jazan University, Department of Physics**

## PHOTON ECHO QUANTUM MEMORIES

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### Course Information and Abstract

Quantum memory (QM) will be one of the key tools in the future quantum computers and optical quantum communications. Recently, a large progress has been achieved on the ensemble based quantum memories such as electromagnetic induced transparency (EIT) [1], far detuned Raman scattering [2] and photon echo [3]. The photon echo QM has been realized for various protocols providing controllable rephasing of the atomic coherence excited in the inhomogeneously broadened resonant lines and demonstrated recently with record quantum efficiency and highly multi-mode quantum storage. I will discuss main properties and advantages of some basic photon echo QM protocols:

1) Controlled Reversibility of Inhomogeneous Broadening (CRIB) protocol [4]
   and closely related Gradient Echo Memory (GEM) protocol [5]. Herein, I will discuss the most basic properties of light-atom interaction in photon echo QMs. It will be shown the main properties of these protocols providing high quantum efficiency and low quantum noises.

Also it will be discussed a possible experimental realizations and obtained results.

2) Then I will discuss an Atomic Frequency Comb (AFC) protocol [6] and its recent experimental realization for multi-mode storage. It will be shown a basic drawback of this protocol for the efficient light field retrieval and possible modification providing an efficient broadband storage.
3) New recent photon echo QM protocols based on atomic systems with natural inhomogeneous broadening will be also discussed [7,8].
4) Then I will show a promising scheme of the photon echo QMs in a single mode optical cavity [9,10] (experimentally confirmed in [11]) and its important advantages. Further improvement of this approach towards realization of the QM on atoms with natural inhomogeneous broadening will be also described [12].

Finally I will show possible ways for using the photon echo QM in quantum RAM and quantum computing [13,14].


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**Facilitator : Prof. Sergey A. Moiseev**

Sergey A. Moiseev was born in 1957 and graduated in Kazan State University (1979 with honors). He acquired his Ph.D. degree in 1987, and a further Dissertation (Habilitation) for the degree of Doctor of Physical and Mathematical Sciences (D. S.) in the field of coherent and quantum optics in 1999. Moiseev has published more than 100 scientific papers in the field of modern optics and spectroscopy in the journals of Russia, S. Korea, Europe, and USA.

In 2001, S.Moiseev had proposed photon echo quantum memory [S.A.Moiseev, S.Kroll. PRL. 87, 173601 (2001)] that has gained the worldwide recognition, and several record results have been achieved on its basis in the experiments of Australian, Switzerland, Swedish, Canadian, and French laboratories (2009–2013).

In 2011-2013, he has proposed new efficient photon echo quantum memory schemes on the atoms with natural inhomogeneous broadening.

In 2013 he together with S. Andrianov and E. Moiseev (Russia) has proposed quantum computer based on realization of two-qubit operation in a scheme of atomic quantum transistor.

In 2010 S. Moiseev, together with S. Andrianov and F. Gubaidullin (Russia) adopted the photon echo quantum memory into the optimal cavity. The improved properties of this scheme have been confirmed by S.Kroll group (2013).

In 2006-2007, he had proposed four wave mixing schemes for stationary light pulse confirmed experimentally by Yen-Wei Lin et al PRL **102**, 213601 (2009).

S. Moiseev had predicted a muon spin echo detected later together in Rutherford Laboratory (UK, 1998) and predicted time delayed single-photon quantum interference in photon echo media (1993–1997), which was demonstrated experimentally by S. Kroll et al. (Sweden, 2003). He had also predicted single-photon echo (1997) that was confirmed theoretically by S. Hartman and R. Friedberg (USA, 1999). In 1987, Moiseev had solved a well-known problem of photon echo irradiation in optically dense medium that was solved for weak light pulses in 1972 by E. Hahn et al. and S. Hartmann et al. (USA).

S.Moiseev coauthored, alongside B. Sanders and A. Kamli (S. Arabia), the USA-Canada patent (No. US 8,264,759 B2, ept 11,2012) on the Fast all-optical switch.

Along with J. L. Le Gouët (France), Moiseev is a Guest Editor of Special Quantum Memory Issue in Journal of Physics B: Atomic, Molecular and Optical Physics (July 2012). Moiseev worked as a Visiting Professor at the Universite Paris-Sud (France 2011), a Visiting ICORE Researcher Professor at Calgary University (Canada 2008, 2010), a Visiting Professor (Brain Pool

Program grant) at the Inha University, Incheon, South Korea (2004, 2005-2006), a Visiting Researcher at the ETRI (S. Korea 2003), and a Visiting Researcher at the Lund University (Sweden 2000-2001).