Quantum Information Science&Tech

Nadav Katz, Racah Institute of Physics
(Director, QISC)

Physics, Computer Science, Chemistry, Engineering, Philosophy and Mathematics join forces

See: qcent.huji.ac.il

Quantum Information Science Center

$$i\hbar\frac{\partial}{\partial t}\Psi(\mathbf{r},t)=\hat{H}\Psi(\mathbf{r},t)$$

$$\sigma_x=\begin{pmatrix}0&1\\1&0\end{pmatrix},\quad \sigma_y=\begin{pmatrix}0&-i\\i&0\end{pmatrix},\quad \sigma_z=\begin{pmatrix}1&0\\0&-1\end{pmatrix}$$

$$\langle\psi|A|\psi\rangle$$

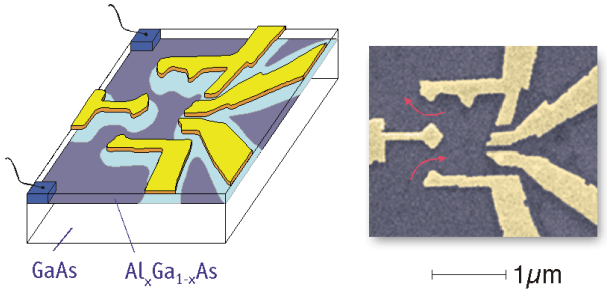
$$\frac{1}{\sqrt{2}}(|00\rangle+|11\rangle)$$

$$|\psi\rangle=\alpha|0\rangle+\beta|1\rangle$$

Experimental Quantum Information Processing (QIP)

a perplexing flora and fauna of different systems

Quantum dots



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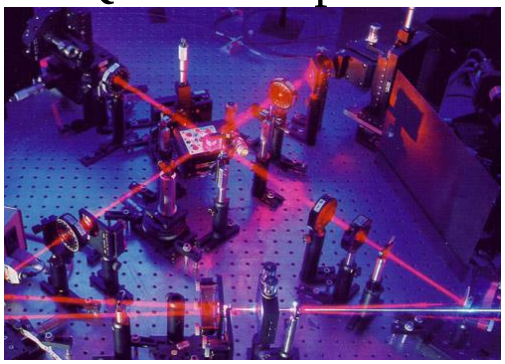
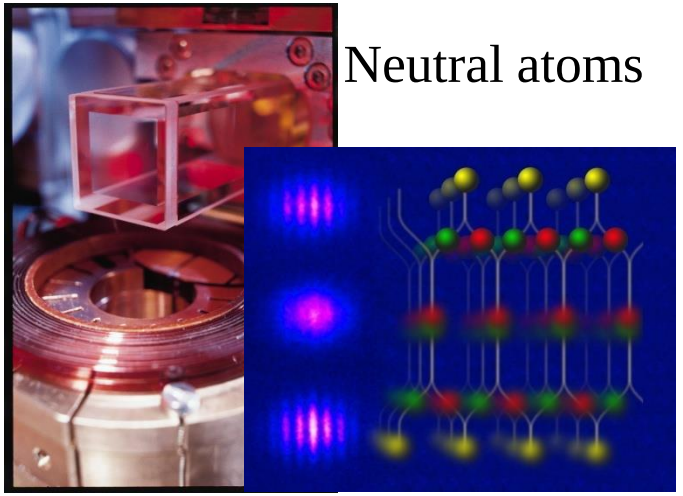
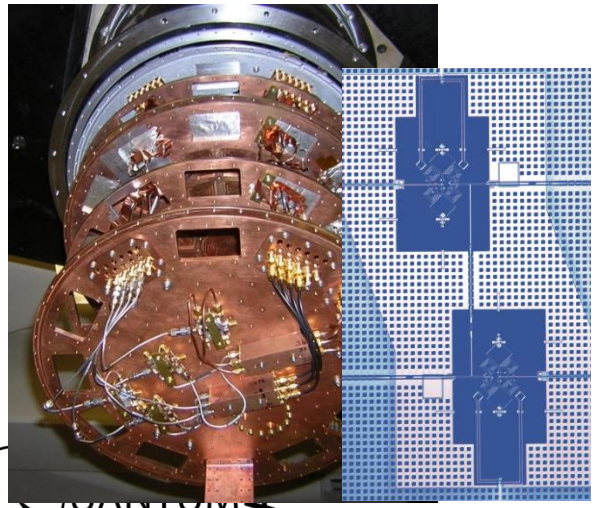
Quantum optics



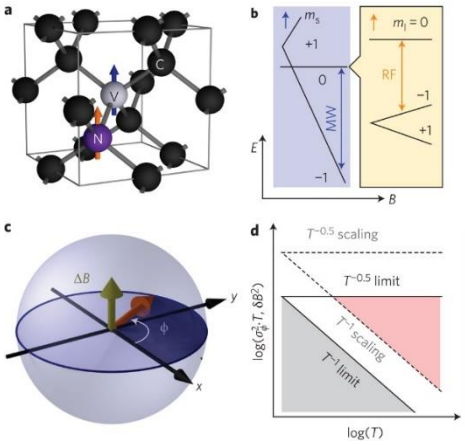


Neutral atoms

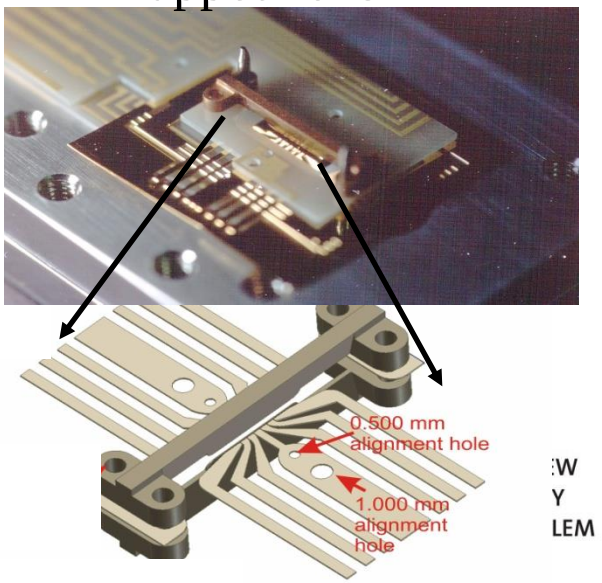
Josephson superconducting qubits



NV centers



Trapped ions



Experimental QIP – a guide for the perplexed

Smaller → *Bigger*

Easier to isolate and very uniform
Harder to couple

Easier to couple & construct
Harder to isolate and make uniformly

photons

- Excellent single qubit
- coupling hard…
- Single photon/graph states

Ions
Neutral Atoms
NMR

- NMR: 2 to ~10 qubits; scalability?
- Ions&atoms: up to 50 qubits + scalable
- Many technical issues still unsolved

Semiconductor Spins
Quantum Dots and NV defects

- Dots: LONG T_1 and T_2
- Coherent Oscillations
- Coupling?

Superconducting
Circuits

- Little dissipation
- Reasonable coherence
- Coupling natural
- 50 qubits demonstrated

fault tolerant threshold in a <u>system</u> – F ~ 99.9 %

MACROSCOPIC QUANTUM COHERENCE LAB

THE HEBREW UNIVERSITY OF JERUSALEM

Quantum Information Science @ HUJI
Established: 2011

- Vision: bring together distinct disciplines studying Quantum Information and form deep connections towards practical collaboration
- 26 PIs from Physics, Computer Science, Mathematics, Chemistry, Engineering and Philosophy
- See: *qcent.huji.ac.il*

Faces of QISC

Phys. | Applied Phys. | Philo.
CS | Math | Chemistry

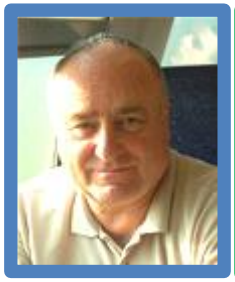
Aharonov

Ben-Or

Eisenberg

Katz

Lehmann



Lindenstrauss

Rapaport

Shalev

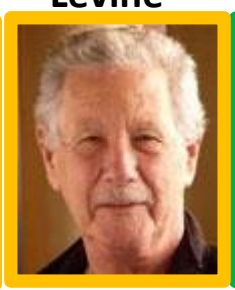
Bar-Gill

Ben-Menachem

Gat

Kosloff

Levine



Lubotzky

Retzker

Shenker

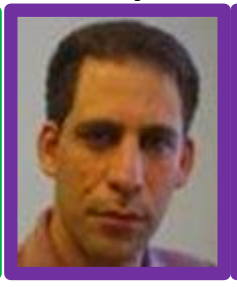
Bromberg

Biham

Kalai

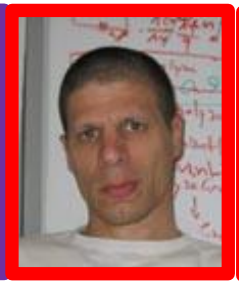
Lawrence

Levy



Paltiel

Ron



Steinberg

New:

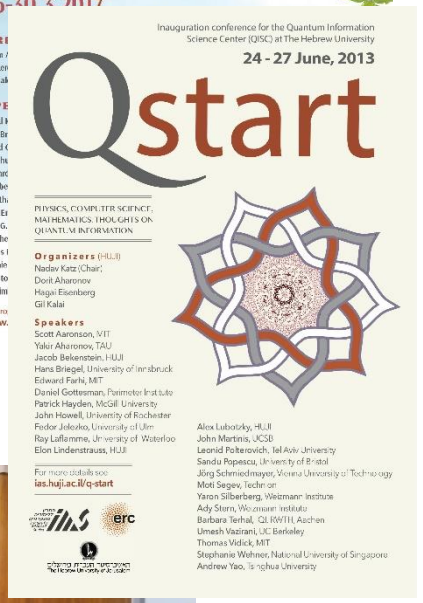
Howell

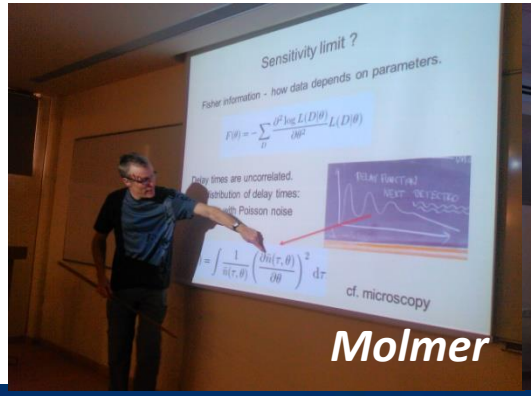
Banin

Activities

- Broad research program (some highlights)
- 2 weekly seminars (theory/CS and Q. Tech.)
- Distinguished lecture series and conferences
- Yearly retreat of the center (~50 people)
- Physics+applied Masters program (training)
- Joint PhD scholarships and collaborations:

ETH, Alliance for quant. innovation (with Ulm/Stutt.)





Molmer

Wallraff


Cirac


Zoller


Plenio

Quantum Information Science Center

Extensive experimental platforms

NV centers – Bar-Gill, Retzker

Quantum optics – Eisenberg, Howell Rapaport, Bromberg, Levy

Excitons and quantum dots– Banin, Rapaport and Paltiel

Topological CM – Steinberg

Superconducting Josephson – Katz

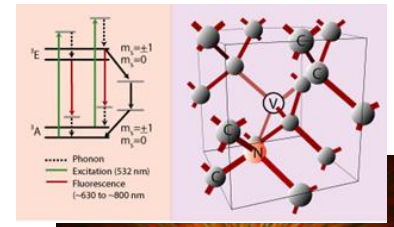
Ions (Theo.) – Rezker

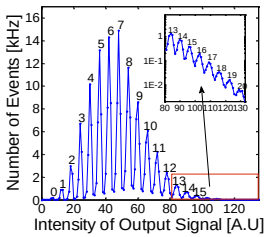
Biosystems, chirality and spintronics – Paltiel and Levine

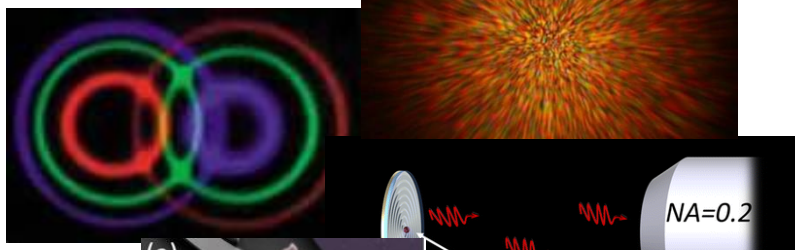
Atomic vapor/cold atoms – Katz, Howell and Ron

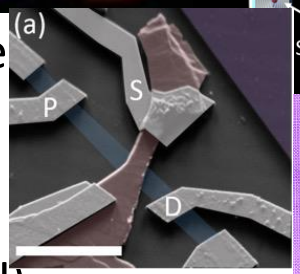
Molecular states and control – Kosloff and Levine

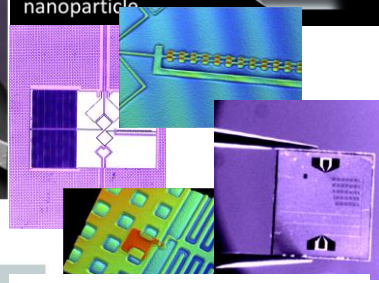
Hybrids (atomic/SC- Bar-Gill/Katz, Bio-Magnetic – Paltiel)

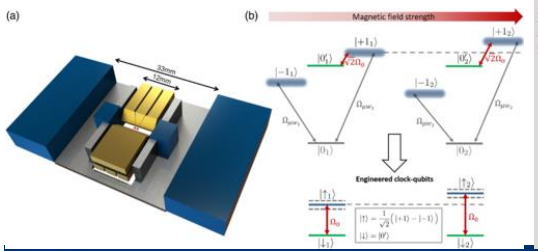


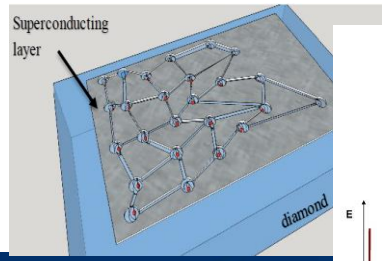


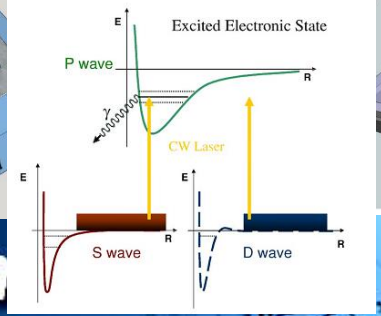


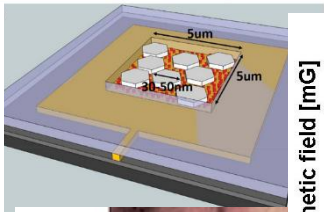


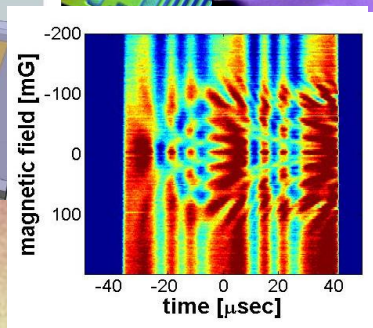


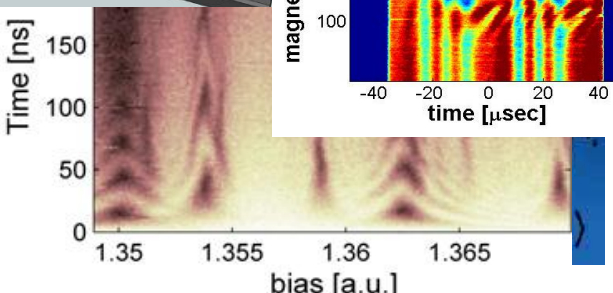












Quantum Information Science Center

Quantum communication

- EU COST action Q. Comm. in space – Israeli rep's

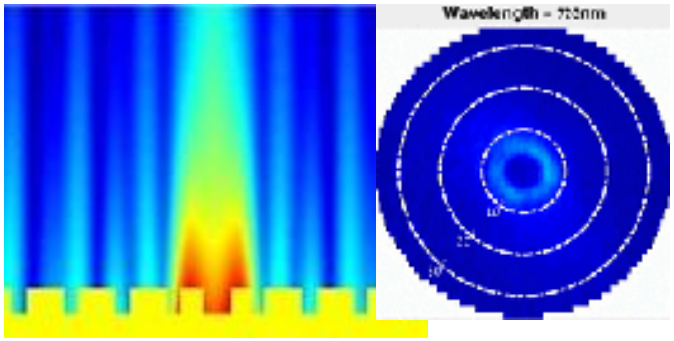
  (Retzker and Eisenberg)

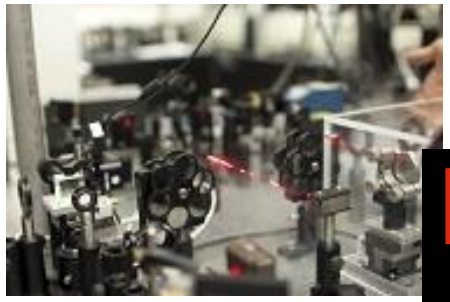
- Israeli demonstrator QKD – 7.5 M-NIS

  (Bromberg and Eisenberg + Ben-Or, Rapaport, Paltiel, Marom and Katz)

- Single photon sources and memories

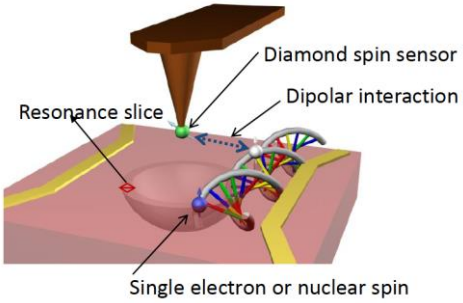
  (Rapaport, Paltiel, Levy, Bar-Gill, Eisenberg and Katz)

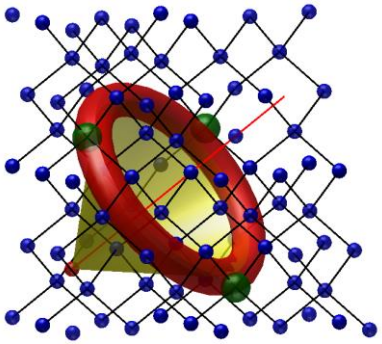




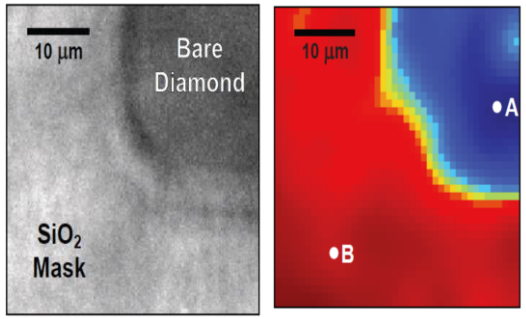
Quantum sensing

NV centers:





@Retzker group



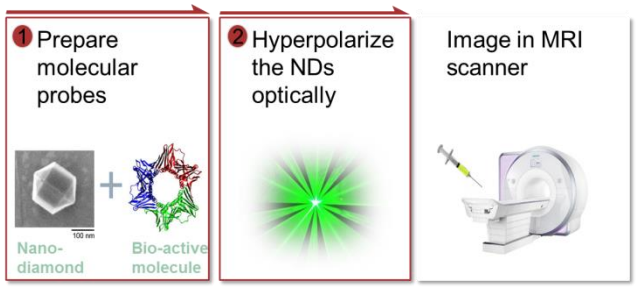
@Bar-Gill lab

<u>Quantum Sensing:</u>

Unique magnetic sensing with optical resolution and high sensitivity, for ***2D materials, spintronics and biology***

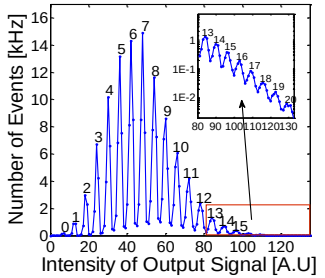
NVision

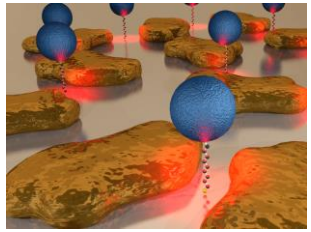
Medical Applications:

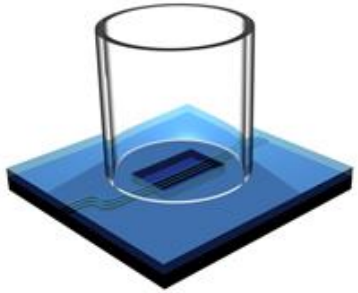


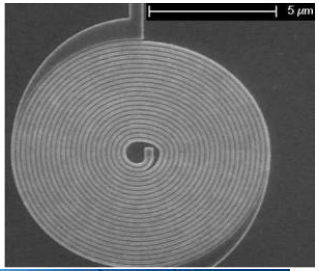
Quantum sensing

- Quantum optics LIDAR, Super-resolution interferometry (@Eisenberg group)
- Photon detectors and integration (@Levy, Paltiel, Katz groups)
- Weak- value Interferometry and gravity sensing (Howell)
- Quantum error-correction and sensing
  (Retzker, Eisenberg, Aharonov and Katz)



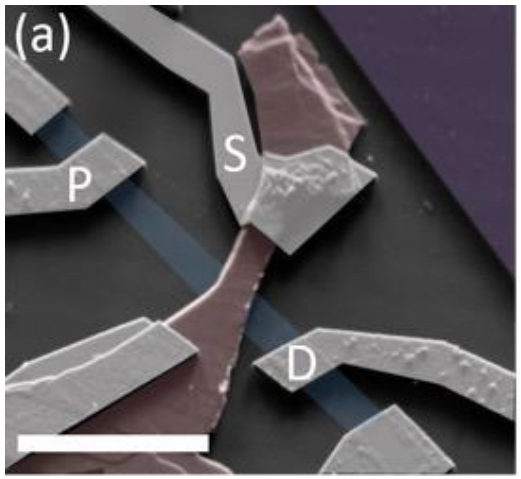


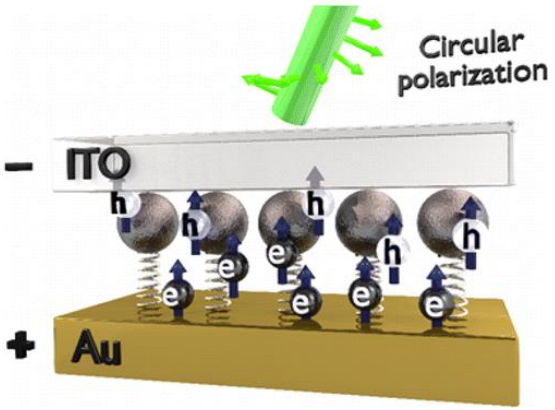




Quantum materials: Chirality, 2D and interfaces

- 2D topological materials – Steinberg
- Chirality in biology and condensed matter - Paltiel
- Interfaces and confinement – Rapaport, Paltiel and Banin





Hebrew University quantum vision

- ***Quantum Science Initiative (QSI)*** – A joint framework for both fundamental and applied quantum science and technology.

QISC (Research center)

- Recruit ~10 new PIs in next 5 years
- Invest in infrastructure (already alloc. 1 million NIS)
- quantum electronics lab – control and packaging
- Quantum interfaces central facility (within nano)
- Frequency comb infrastructure and distribution
- Training program (expand MSc. Program)
- National collaboration hubs – SC, NV
- International joint centers – Aliiance Ulm/Stutt.

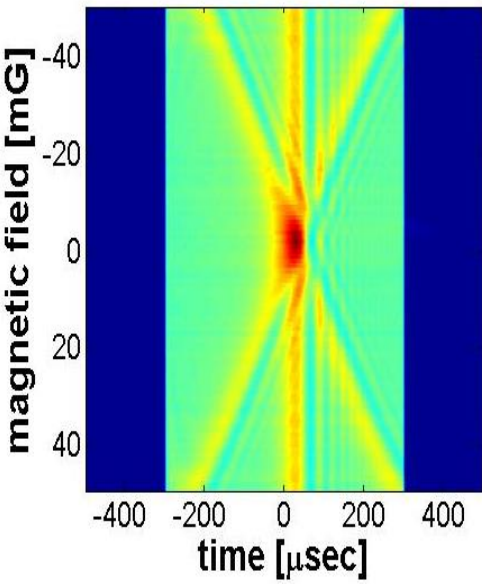
Qstart (Quantum tech. incubator)

- Expand quantum communication
- Provide incubator environment- space, startup funding grants
- EU QT flagship participation
- Strengthen European, American and Far-east contacts and investments

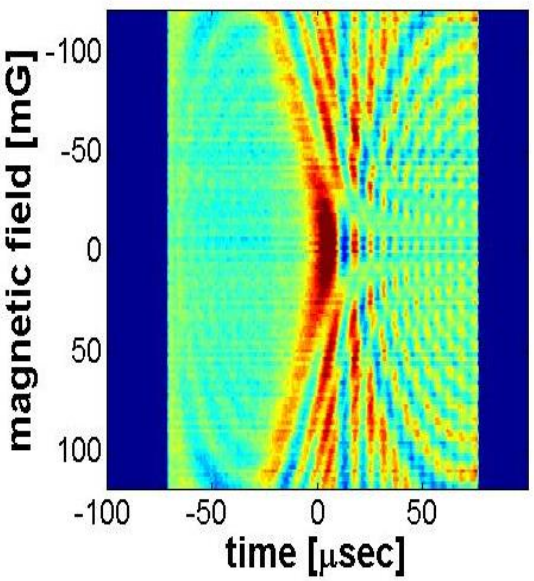
Phase modulation– Magnetic field

Multi level interference !

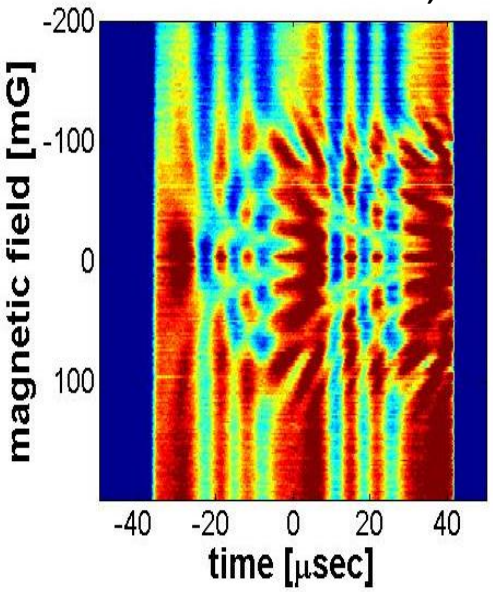
Ω=1 kHz, M=50



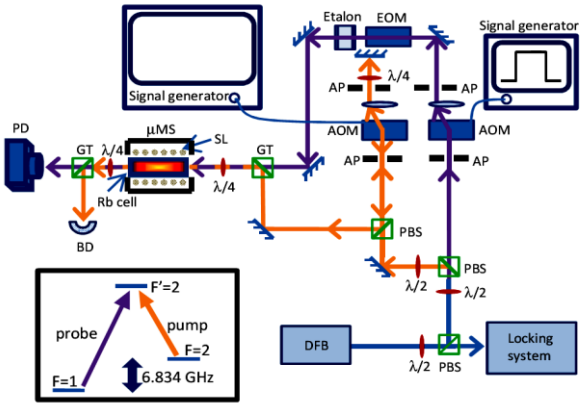
Ω=5 kHz, M=20



Ω=15 kHz, M=5



Shwa & Katz, PRA, 2014



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