Trapping and cooling large Sr\(^+\) ion clouds

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Laboratoire Matériaux et Phénomènes Quantiques

A young (5 years old) lab devoted to Materials and Quantum Phenomena, from fundamental concepts to devices.

Research area :
• Nanomaterials
• Low dimensionality electronics
• Quantum Photonics

Tech Facility :
• Clean-room for nano-technology
• High resolution electronic microscopy

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Trapped Ions and Quantum Information

Team

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Trapped Ions and Quantum Information Team

From plastic dust particles to Sr$^+$ ions
Research activities

Large ion Coulomb crystals in a linear Paul trap
... towards a quantum memory in the continuous variables regime

Microfabricated ion traps
... towards scalable devices for quantum information processing

4-wave mixing in an atomic Rb vapour
... generation of a pair of quantum correlated light beams at 422nm

Long-range interaction N-body problem: numerical simulations
... Trap design
... Trapped ions dynamics study

Theory and new schemes for Quantum Information
... Feasibility of a quantum memory for continuous variables based on trapped ions: from generic criteria to practical implementation

... Topologically Decoherence-Protected Qubits with Trapped Ions

... Quantum intensity correlation in 4-wave mixing
To appear in Physical Review A
Quantum light-matter interaction in large atomic ensembles

Thermal atomic vapour
Experimental Demonstration of quantum memory for light
Julsgaard B et al. Nature 432 482, 2004

Laser-cooled neutral atoms
ICFO Barcelona, LKB Paris...

Trapped ions
Aarhus(cavity), Paris...
Continuous variables

Stockes operator describing a *coherent laser beam*

\[
[\hat{S}_1, \hat{S}_2] = i \hat{S}_3 \\
[\hat{S}_2, \hat{S}_3] = i \hat{S}_1 \\
[\hat{S}_3, \hat{S}_1] = i \hat{S}_2
\]

Total spin of an *atomic ensemble*

\[
[\hat{J}_x, \hat{J}_y] = i \hat{J}_z \\
[\hat{J}_y, \hat{J}_z] = i \hat{J}_x \\
[\hat{J}_z, \hat{J}_x] = i \hat{J}_y
\]
Requirements

- Large ion ensemble $> 10^5$ ions
- Optimal coupling to laser (trap geometry)
- Laser cooling $\rightarrow$ Coulomb crystal
- Long trapping time
- Long coherence time of internal degrees of freedom
- Sympathetic cooling
Linear Paul trap

RF 3-7 MHz / 100-1500 V
Trapping characteristics
/ion cloud dynamics/

Exp.
Ion counting

Th.

Sr$^+$ fluorescence
Photoionization trap loading

*fs laser pulses*

- Compared to electron beam ionization:
  - +++
  - No uncontrolled electric charges
  - Low pressure loading
  - Fluorescence detection during loading
  - Specie selectivity
  - Spatial selectivity

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Cost and complexity

...and still no isotope selectivity

Strategy:

2 photons at 431 nm towards an auto-ionizing level above threshold

![Diagram](image)

laser: frequency doubled fs Ti:Sa (home made)
Compared ionization efficiency

Sample purity (mass spectrum)

Loading efficiency

Current loading rate: 100-1000 ions/s
Sr$^+$ laser cooling

Energy levels involved

$\begin{align*}
\text{5}^2\text{S}_{1/2} & \rightarrow 5^2\text{P}_{1/2} \\
5^2\text{P}_{1/2} & \rightarrow 4^2\text{D}_{3/2} \\
\text{5}^2\text{S}_{1/2} & \rightarrow 4^2\text{D}_{3/2} \\
\end{align*}$

422 nm  1092 nm
Laser cooling:

Rb absolute frequency reference

Rubidium 85

Rubidium 87

Laser lock reference
Laser setup

- Doubly resonant ring cavity
- 422nm laser source
- Rb sat. abs.
- DAC & computer
- 1091nm laser source
- AOM +440MHz
- AOM +270MHz
- AOM +200MHz
- AOM -200MHz
Diagnostic: Fluorescence imaging from $\mu$m to cm scale

200 $\mu$m

2 cm
Loading of an ion cloud
Sr$^+$ isotope detection

Sr isotopes relative abundances
88 : 82.6%
87 : 7%
86 : 9.9%
84 : 0.56%
$^{88}\text{Sr}^+ - ^{86}\text{Sr}^+$ isotope shift measurement

Spatially resolved fluorescence IR-laser spectroscopy

Work in progress:
Accuracy to be improved and $^{84}\text{Sr}^+$ to be addressed
$^{88}\text{Sr}^+$ purification

$^{88}\text{Sr}^+$ cooling laser
the pacman endcap

Left endcap voltage

100-1000 µs
$^{88}\text{Sr}^+ \& ^{86}\text{Sr}^+ \text{ cooling lasers}$
$^{88}\text{Sr}^+$ cooling laser
pure $^{88}\text{Sr}^+$ crystal
$^{86}\text{Sr}^+$ enrichment

Left endcap voltage pulses + radial trap opening (RF)

100-1000\,\mu\text{s}
$^{86}\text{Sr}^+$ enrichment
Outlook

• A cm-scale linear Paul trap for Sr$^+$ ions
• Optimized loading by fs photo-ionization
• Laser-cooling to Coulomb-crystal transition
• Sr$^+$ Isotope Sympathetic cooling
• Selective isotopic enrichment

Next:

• Spin lifetime measurement
• absorption
• ...SrH$^+$ molecules
Microfabricated ion trap

- Scalable QIP device
- Tight confinement
- Q-bits demonstration in micro-traps
- The ion motion heating problem (patch potential)

Our goal (short term):

Correlated ion heating measurement / AFM measurement of the electrode surface
Microfabricated ion trap

• Previous design

• Next generation: surface trap
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Publications

Feasibility of a quantum memory for continuous variables based on trapped ions: from generic criteria to practical implementation
T. Coudreau et al

Topologically Decoherence-Protected Qubits with Trapped Ions
P. Milman et al

Photoionisation loading of large Sr+ ion clouds with ultrafast pulses
S. Removille et al

Trapping and cooling of Sr+ ions: strings and large clouds
S. Removille et al

Electric field noise above surfaces: A model for heating-rate scaling law in ion traps
R. Dubessy et al

Double-Λ microscopic model for entangled light generation by four-wave mixing