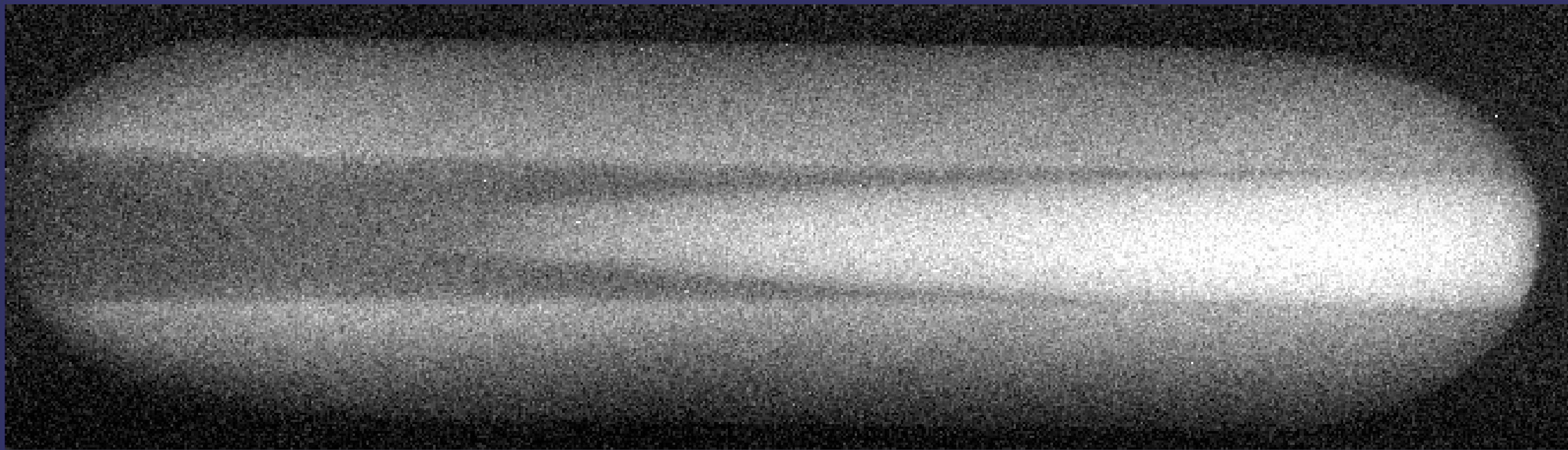
Trapping and cooling large Sr^+ ion clouds



Samuel Guibal

Laboratoire Matériaux et Phénomènes Quantiques
Paris, France

Laboratoire
Matériaux et Phénomènes Quantiques

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

Research area :

- Nanomaterials
- Low dimensionality electronics
- Quantum Photonics
-

Tech Facility :

- Clean-room for nano-technology
- High resolution electronic microscopy

www.mpq.univ-paris-diderot.fr

Trapped Ions and Quantum Information Team

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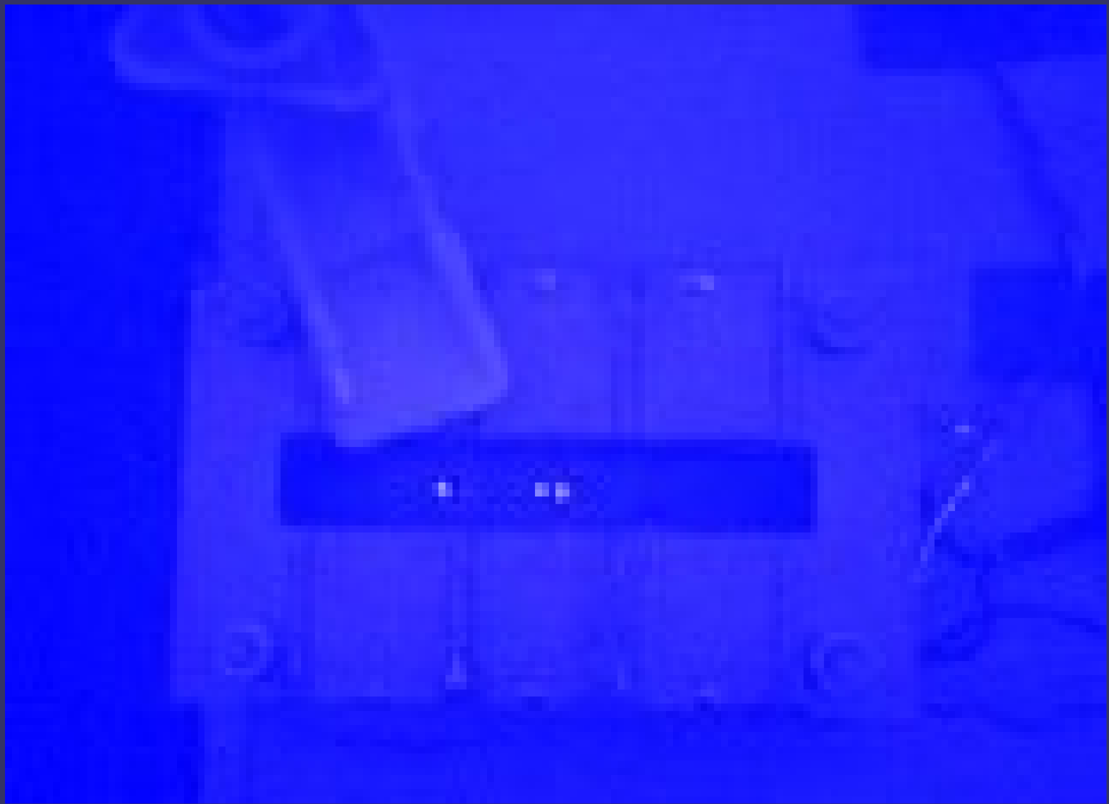
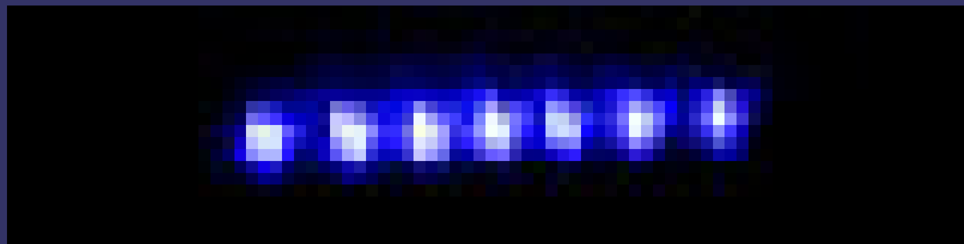
R. Dubessy
Q. Glorieux
B. Dubost

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
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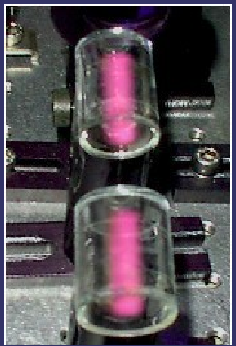
...Topologically Decoherence-Protected Qubits with Trapped Ions
Physical Review Letters, 2007, 99, 2, pp. 020503

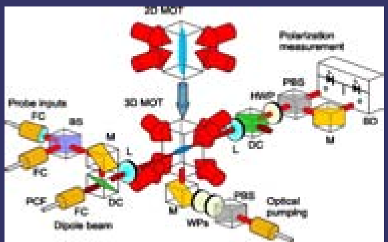
...Quantum intensity correlation in 4-wave mixing
To appear in Physical Review A

Quantum light-matter interaction in large atomic *ensembles*



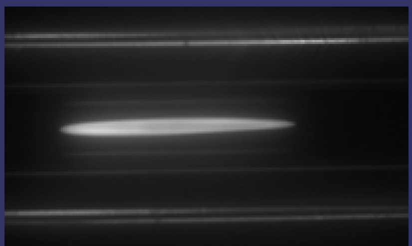
Thermal atomic vapour

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*

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

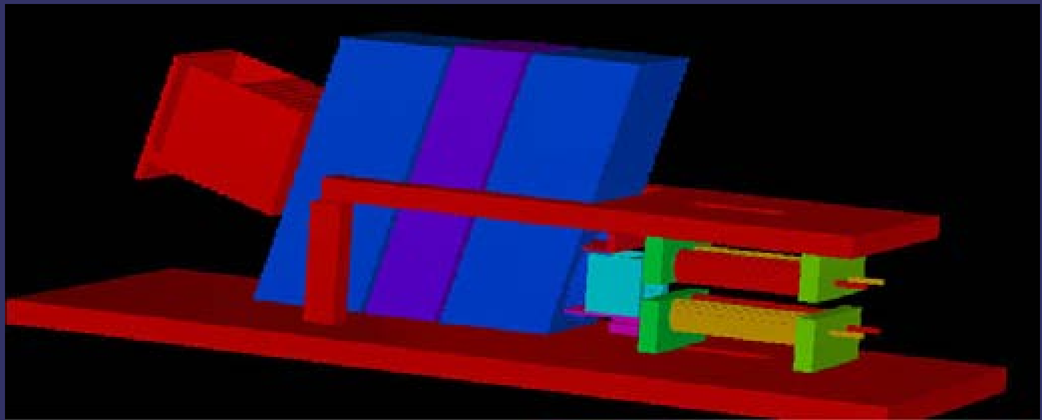
Total spin of an *atomic ensemble*

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

Requirements

- Large ion ensemble > 10^5 ions
- Optimal coupling to laser (trap geometry)
- Laser cooling → Coulomb cystal
- Long trapping time
- Long coherence time of internal degrees of freedom
- Sympathetic cooling

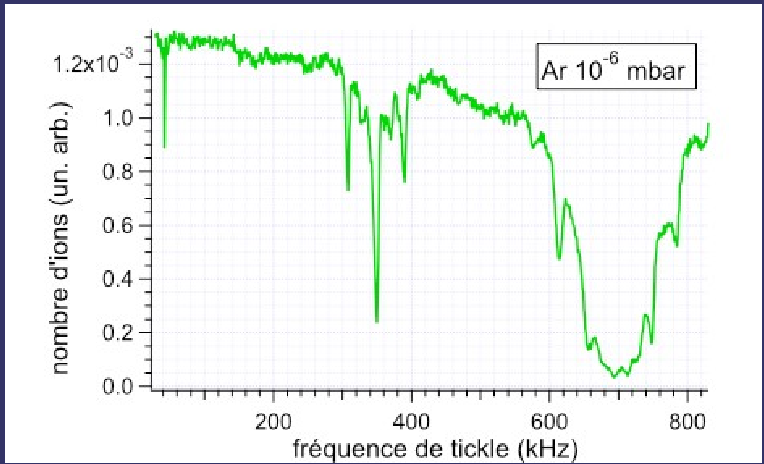
Linear Paul trap



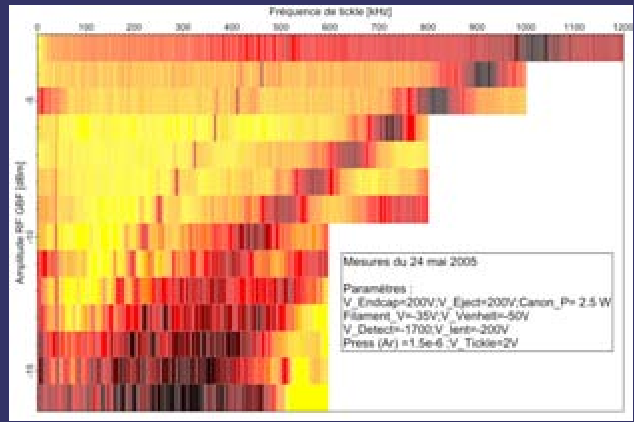
RF 3-7 MHz / 100-1500 V

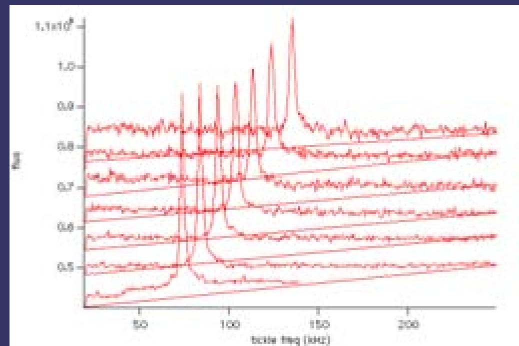
Trapping characteristics
(ion cloud dynamics)

Exp.



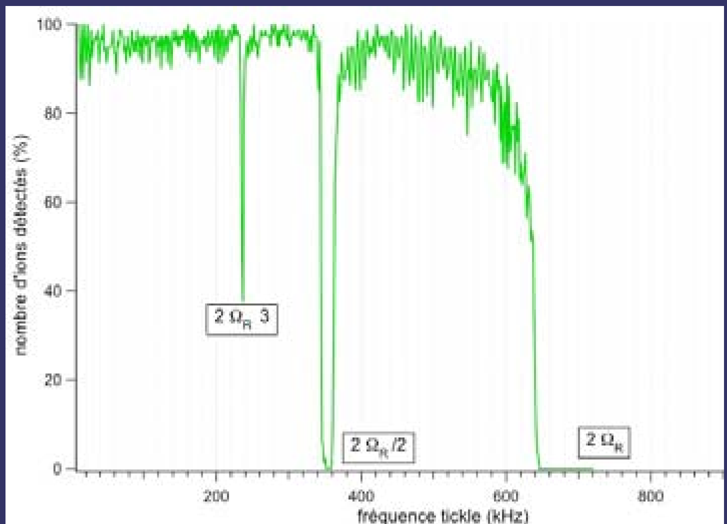
Ion counting

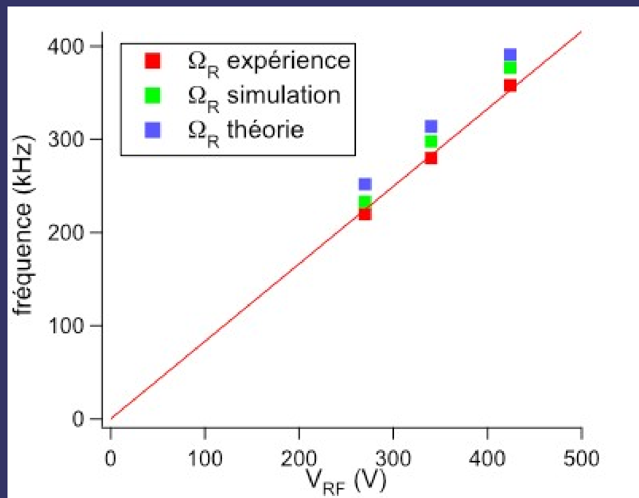




Sr^+ fluorescence

Th.





Photoionization trap loading
fs laser pulses

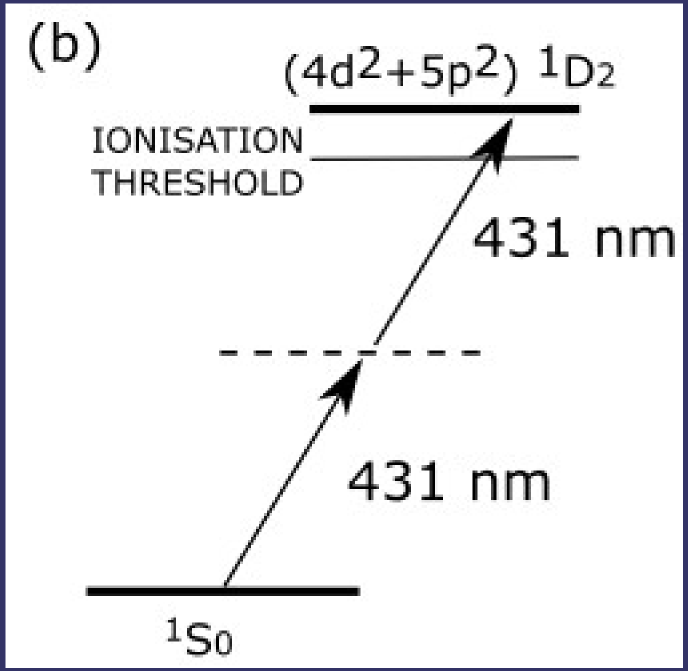
• Compared to electron beam ionization :

+++
• No uncontrolled electric charges
• Low pressure loading
• Fluorescence detection during loading
• Specie selectivity
• Spatial selectivity

Cost and complexity

...and still no isotope selectivity

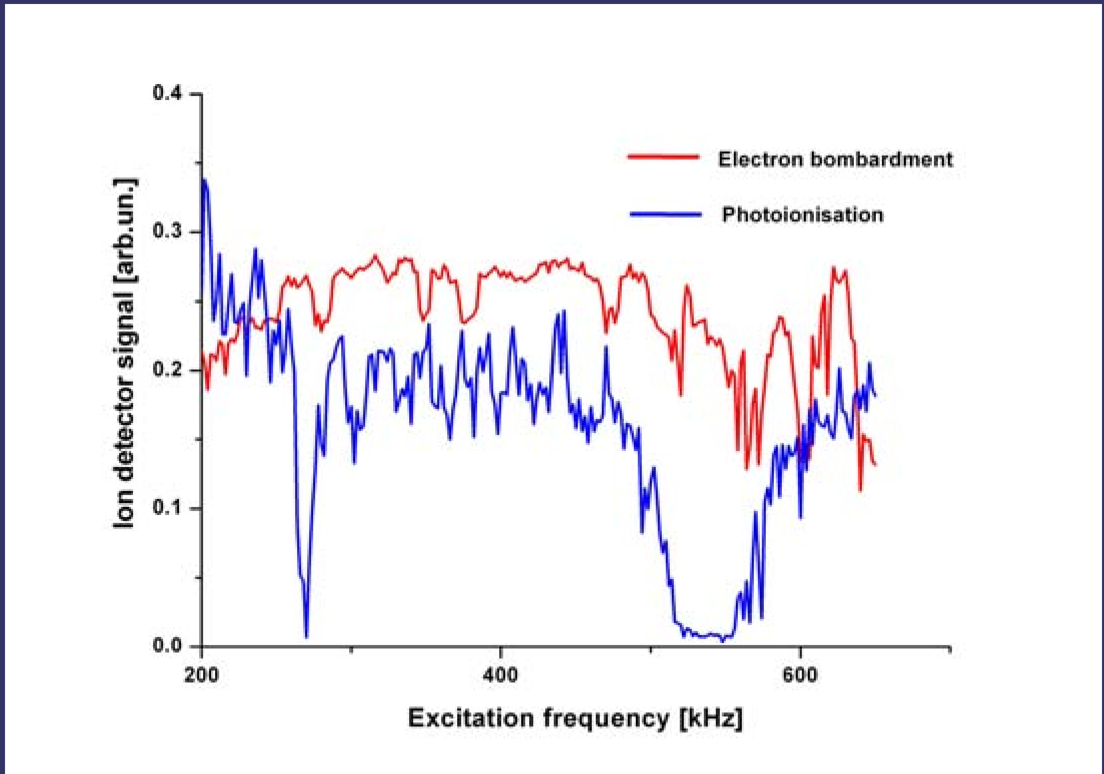
Strategy :
2 photons at 431 nm towards an auto-ionizing level above threshold



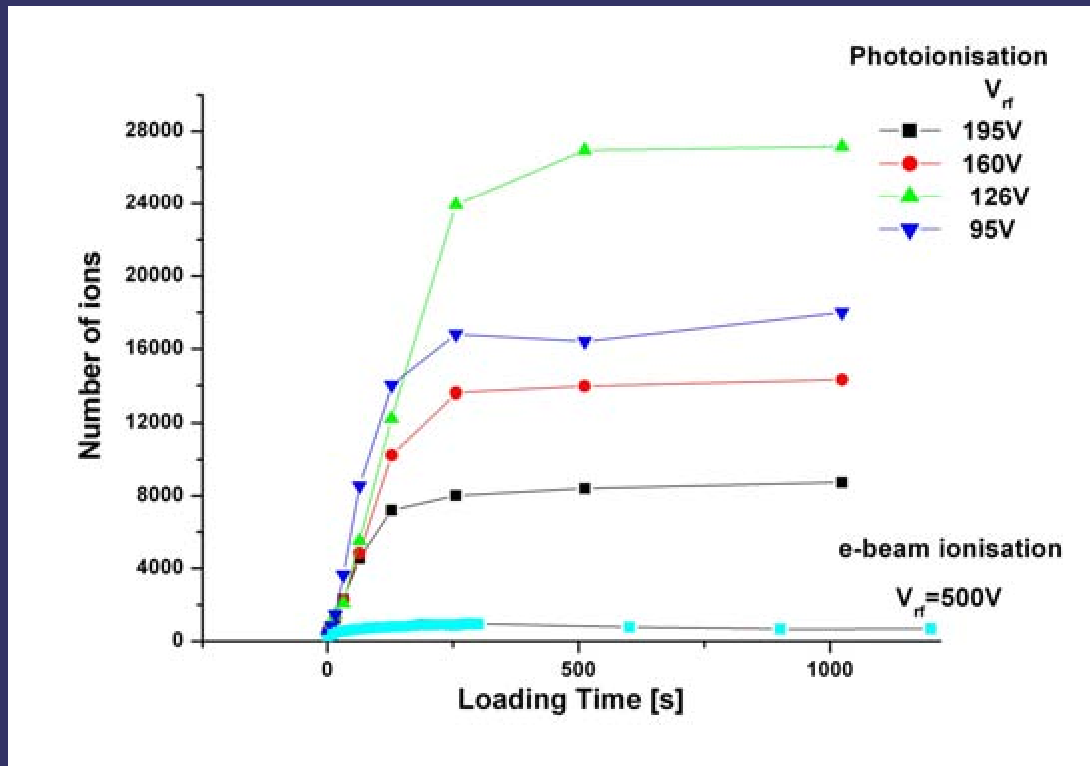
laser : frequency doubled fs Ti:Sa (home made)

Compared ionization efficiency

Sample purity (mass spectrum)



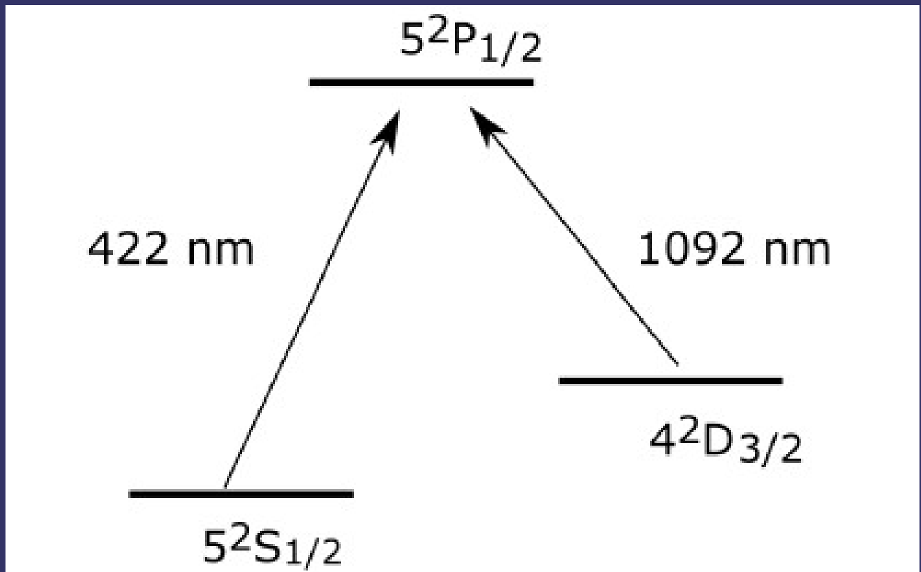
Loading efficiency



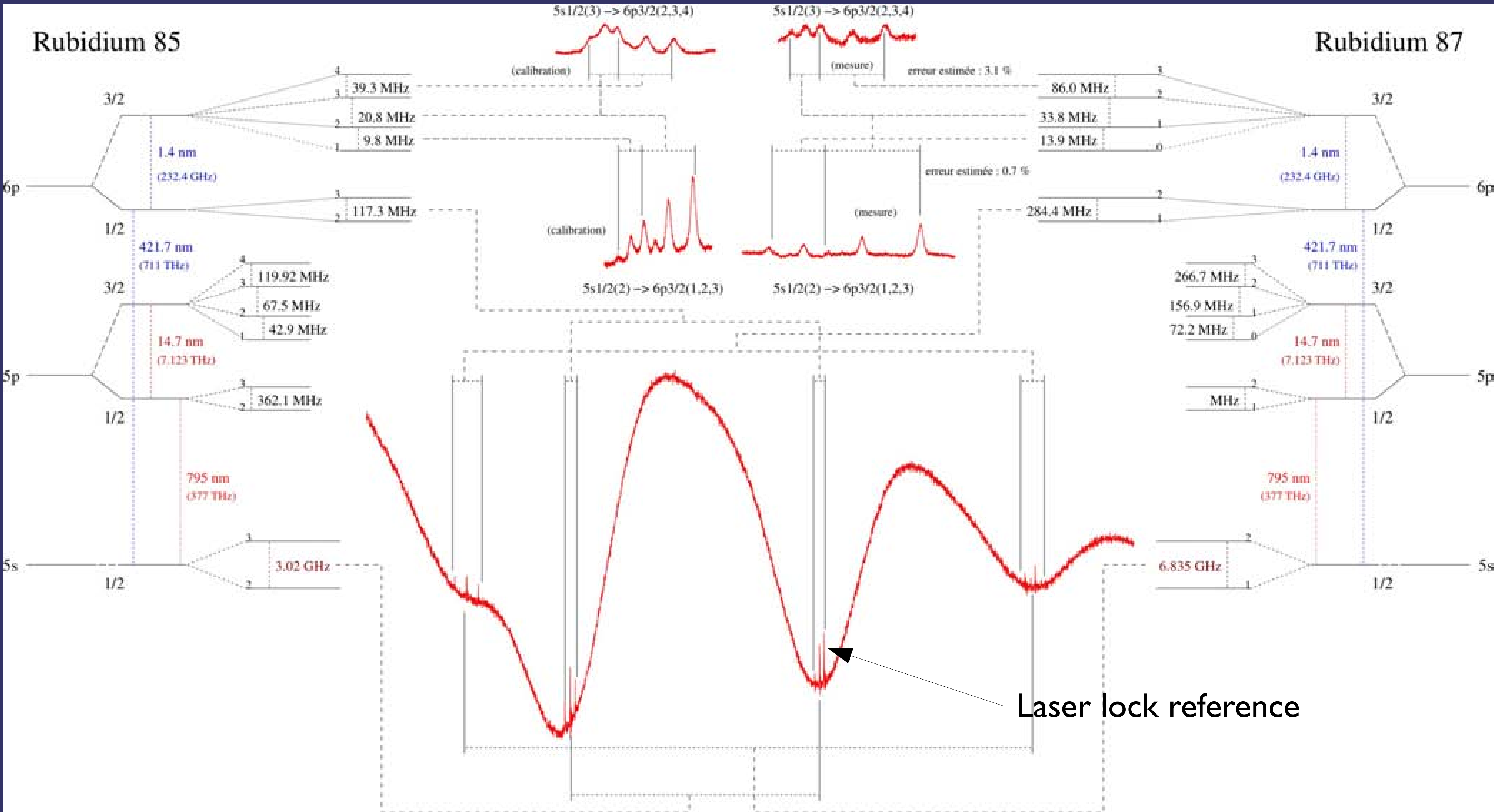
Current loading rate : 100-1000 ions/s

Sr^+ laser cooling

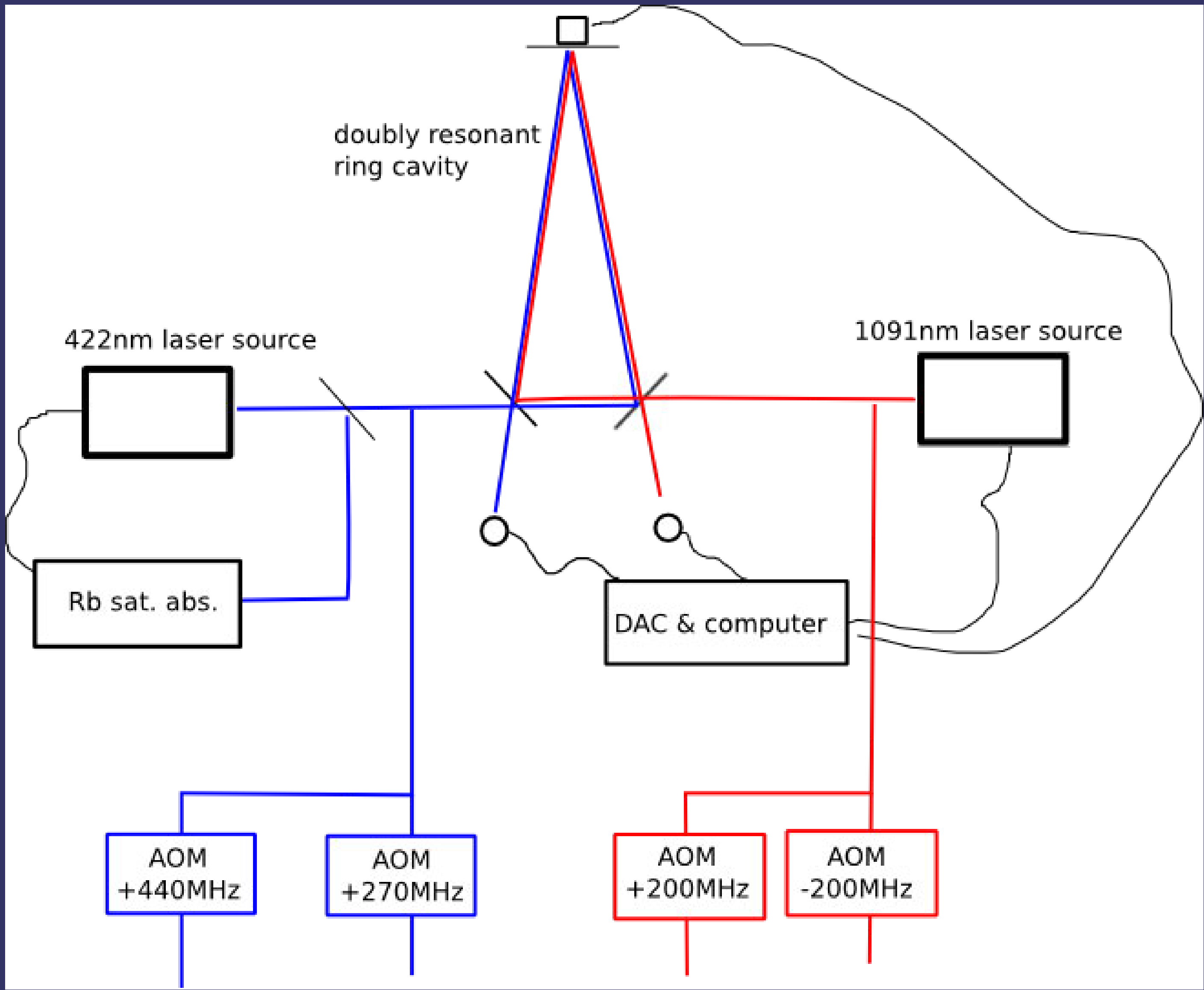
Energy levels involved



Laser cooling : Rb absolute frequency reference

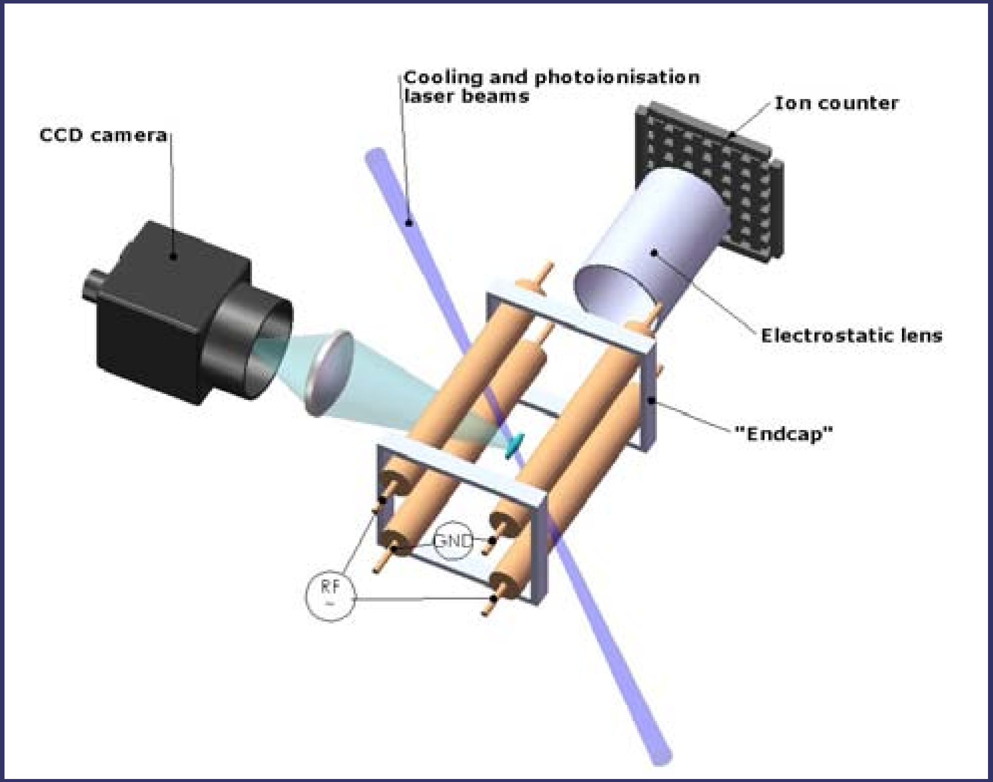


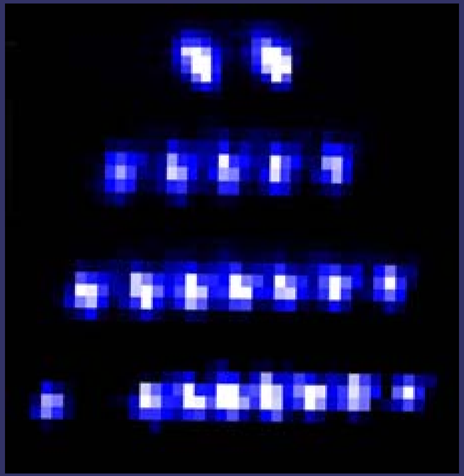
Laser setup



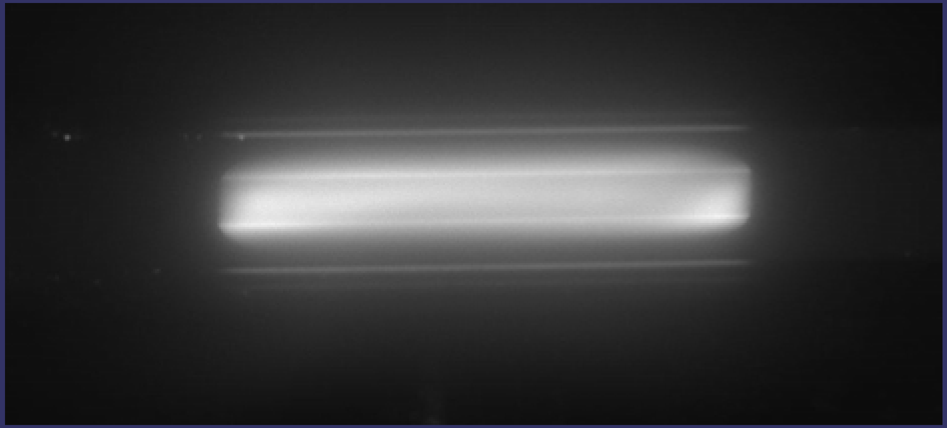
doubly resonant
ring cavity
422nm laser source
1091nm laser source
Rb sat. abs.
DAC & computer
AOM
+440MHz
AOM
+270MHz
AOM
+200MHz
AOM
-200MHz

Diagnostic : Fluorescence imaging from μm to cm scale



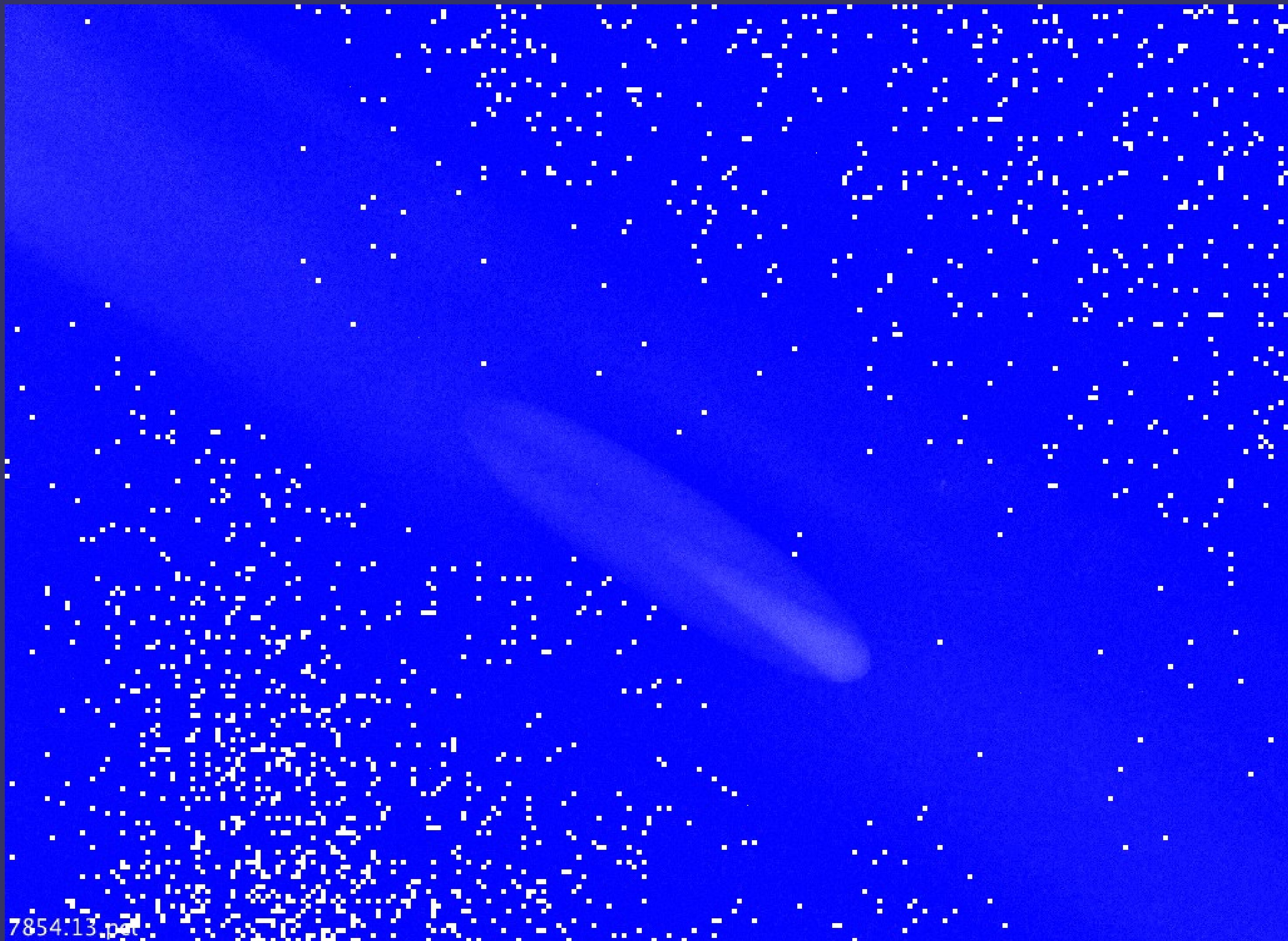


200 μm



2 cm

Loading of an ion cloud



Sr^+ isotope detection

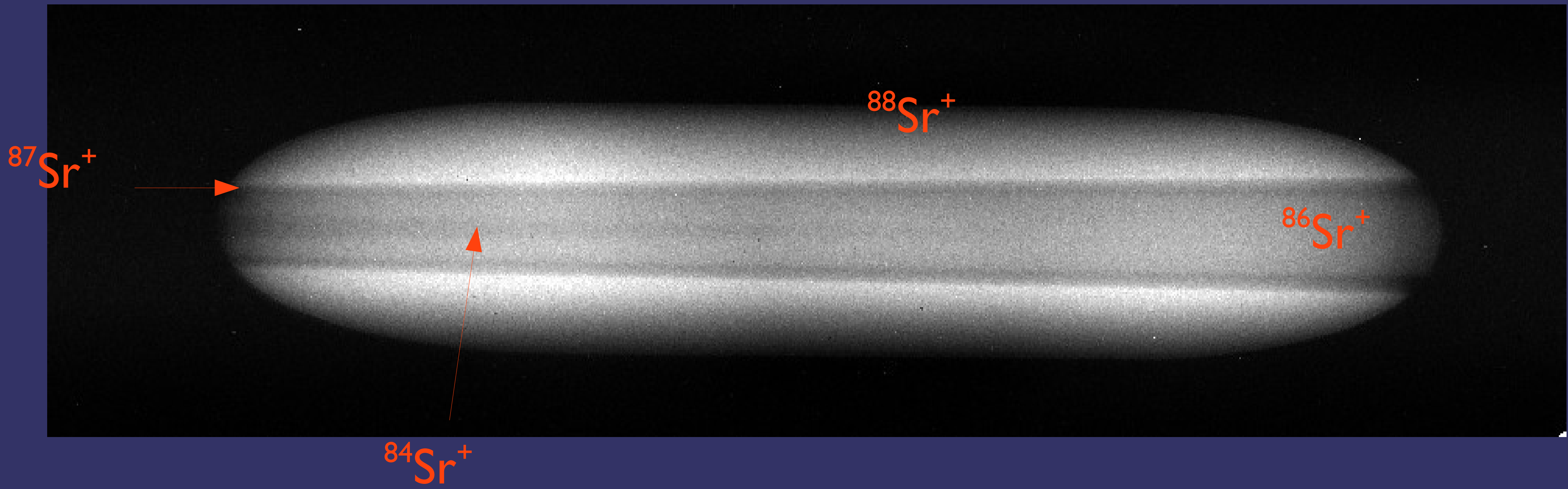
Sr isotopes relative abundances

88 : 82.6%

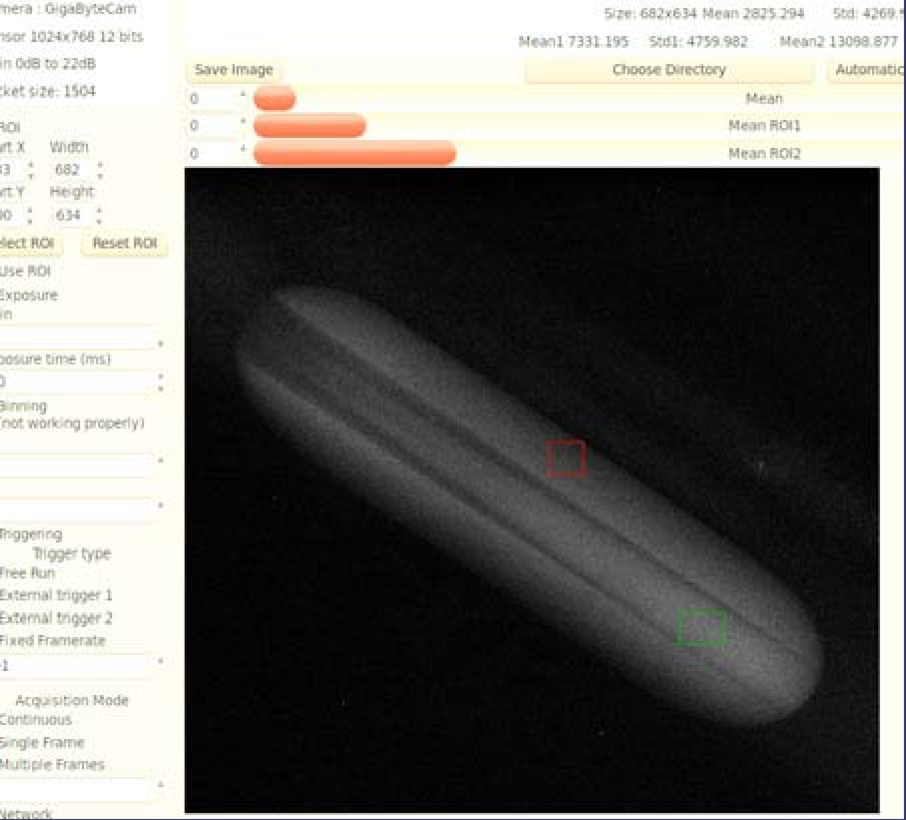
87 : 7%

86 : 9.9%

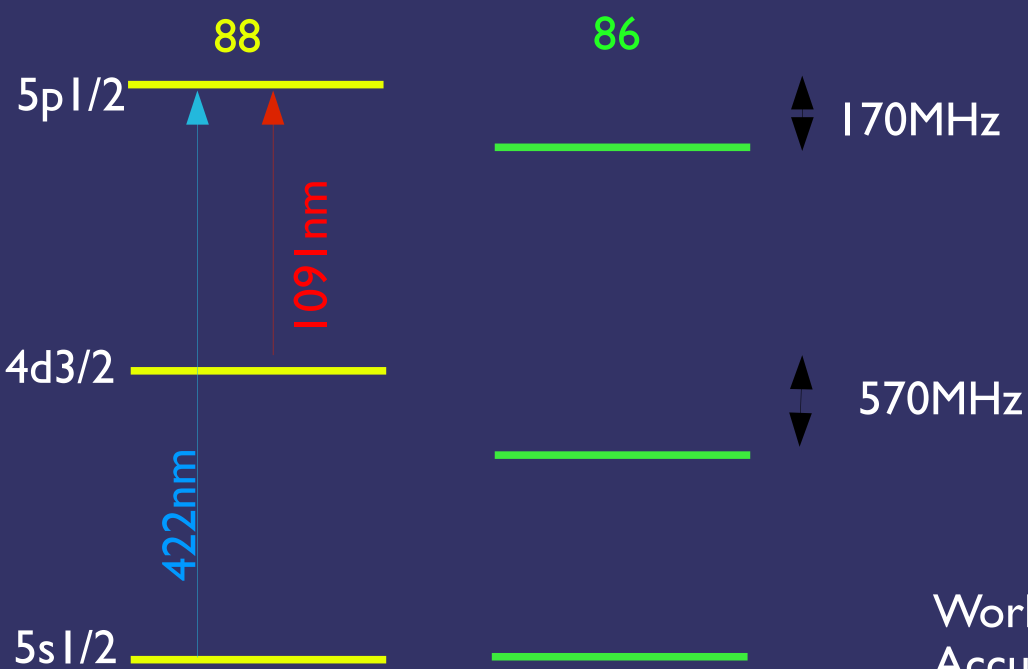
84 : 0.56%

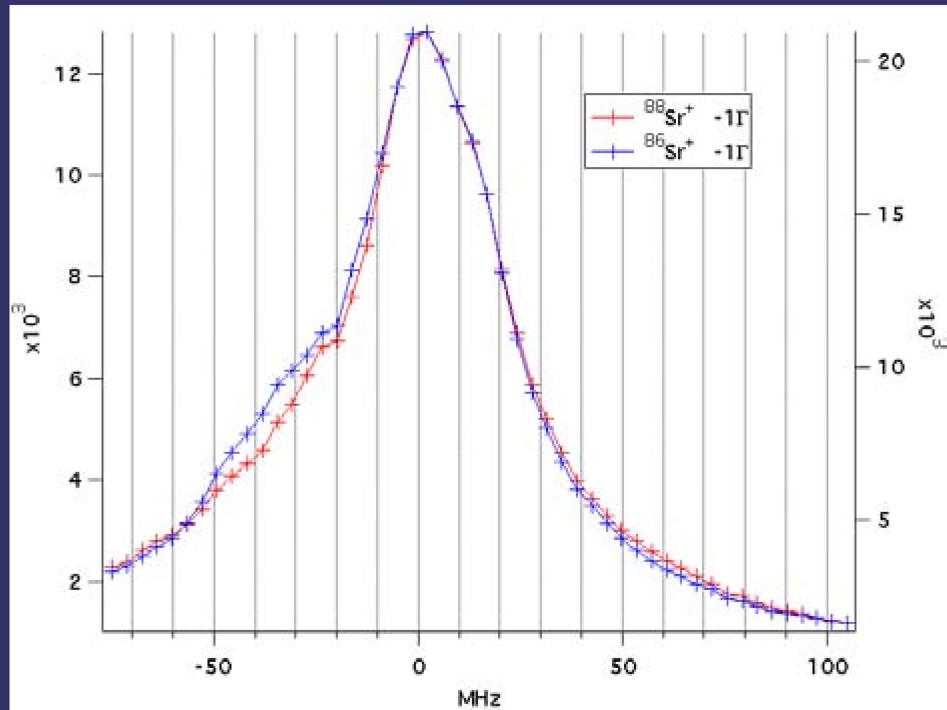


$^{88}Sr^{+}$-$^{86}Sr^{+}$ isotope shift measurement



Spatially resolved fluorescence
IR-laser spectroscopy

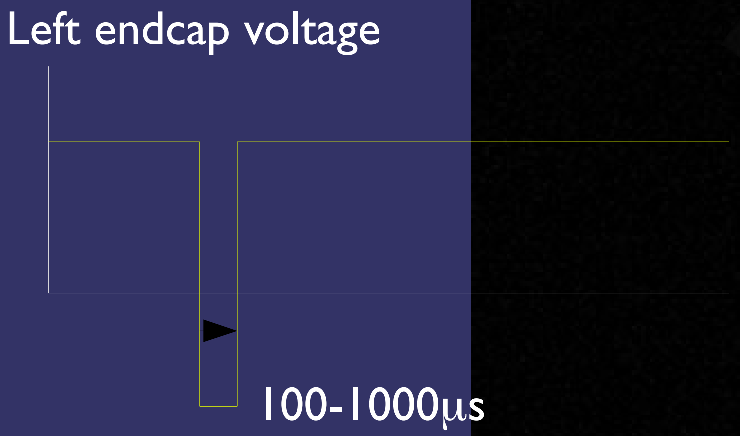


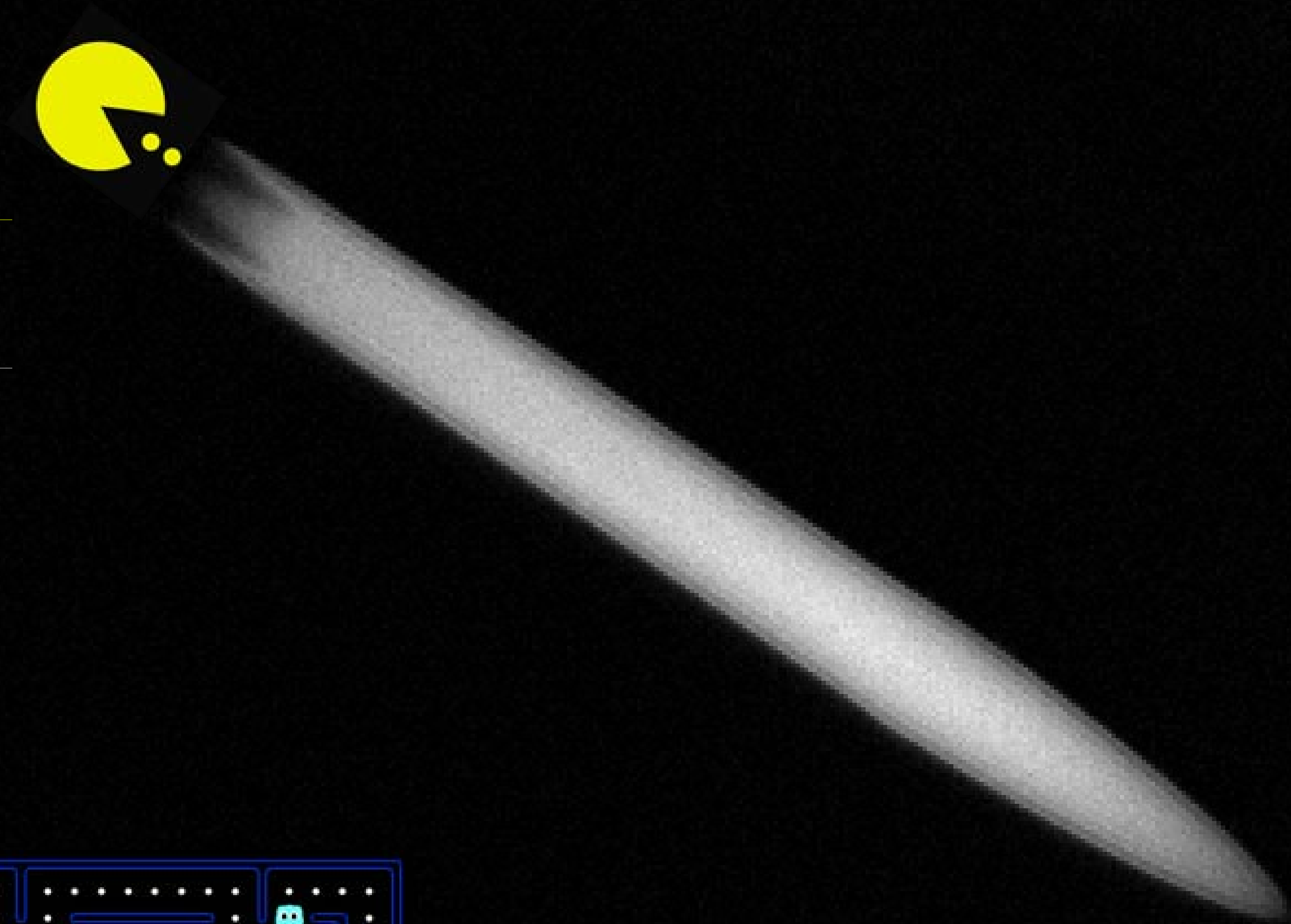


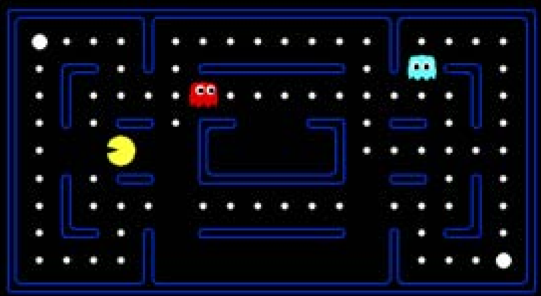
Work in progress :
Accuracy to be improved and $^{84}Sr^{+}$ to be adressed

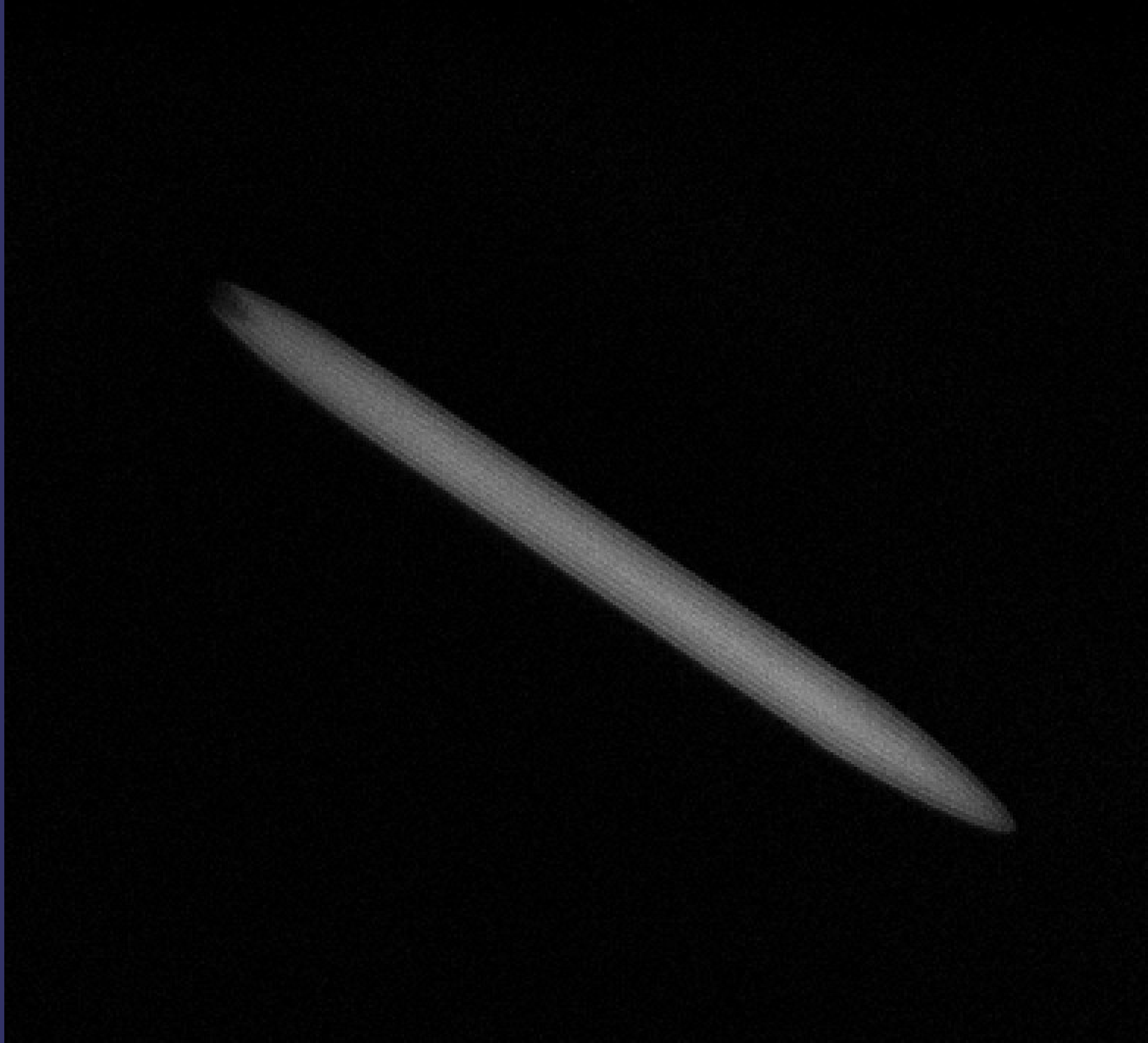
$^{88}Sr^{+}$ purification

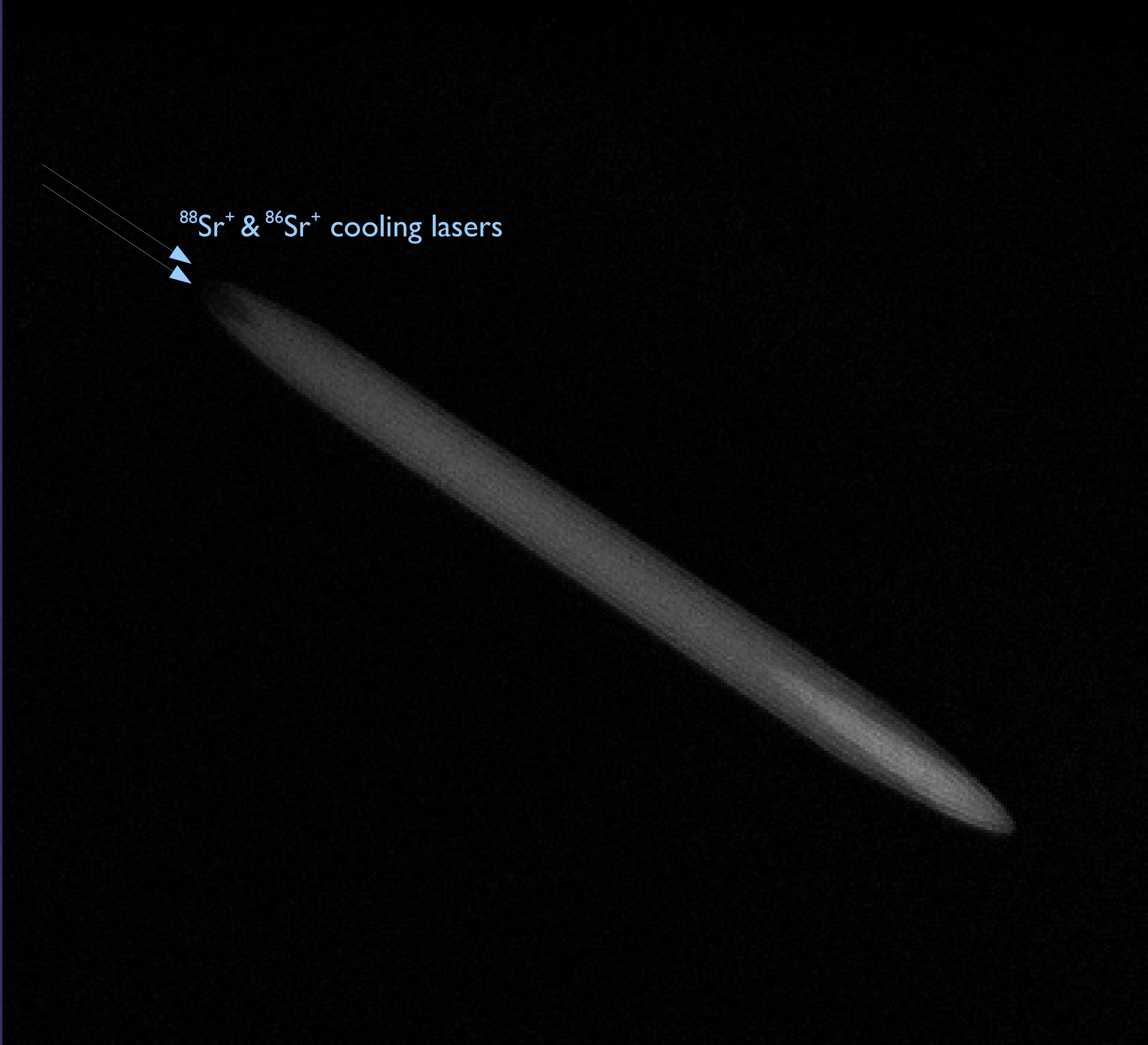
the pacman endcap

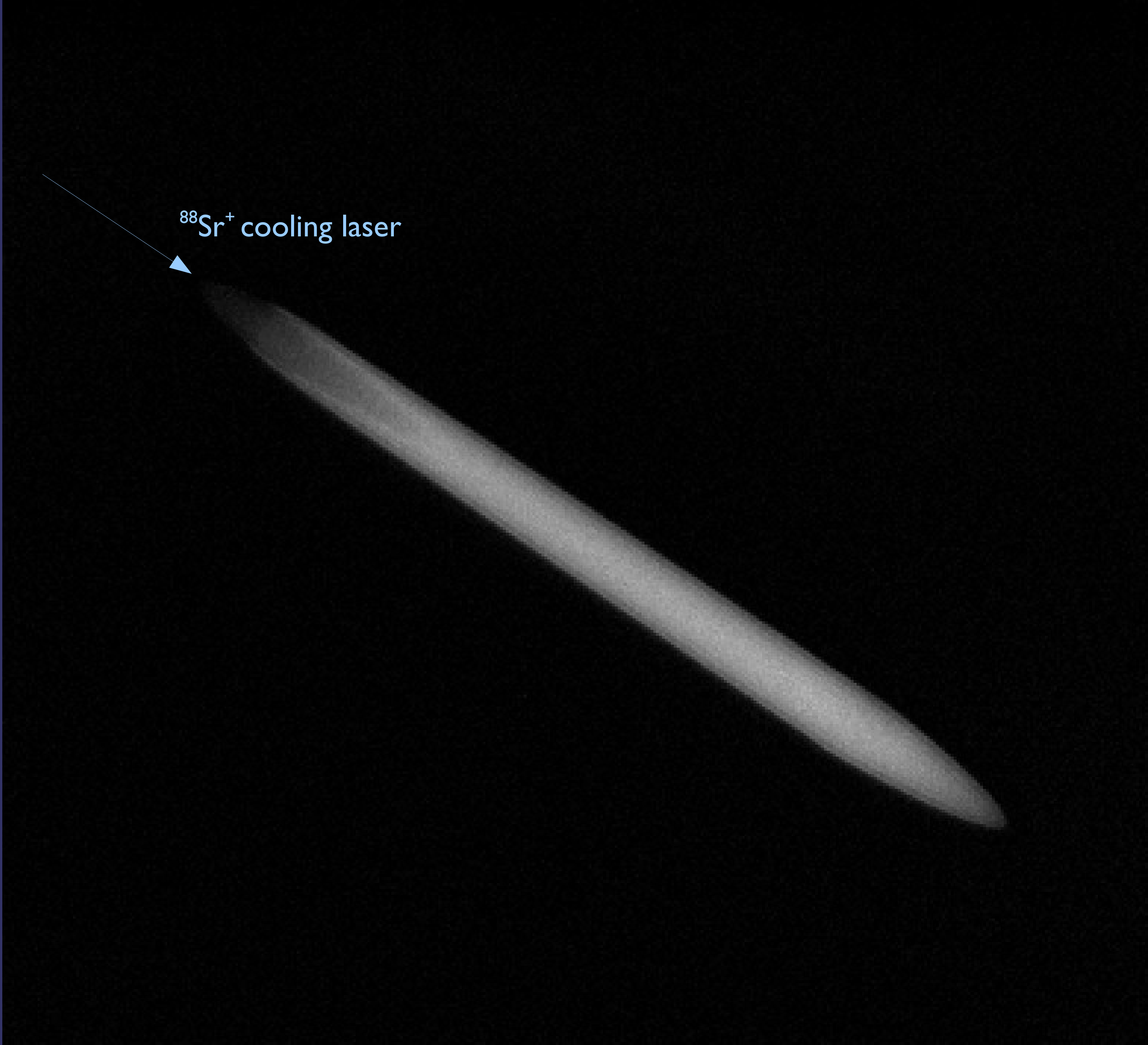






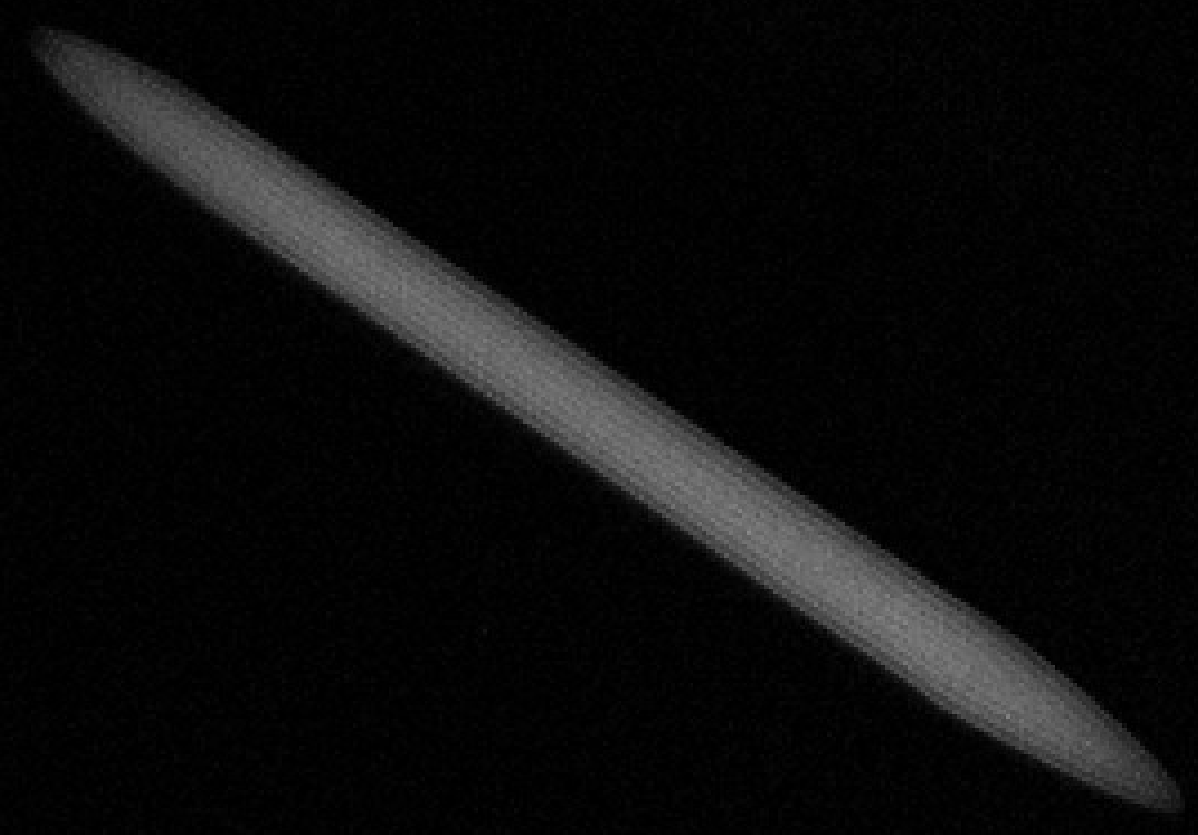



$^{88}Sr^{+}$ & $^{86}Sr^{+}$ cooling lasers

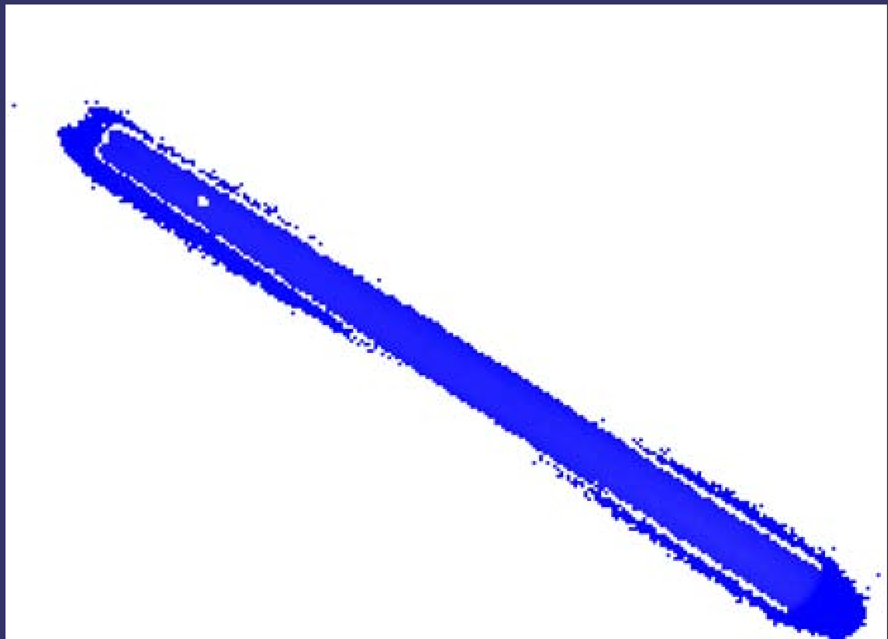


88Sr+ cooling laser

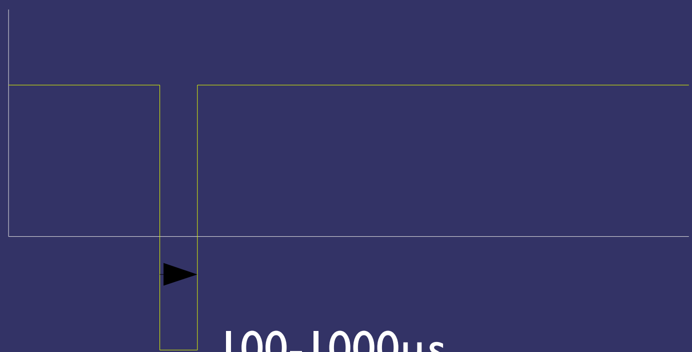
pure $^{88}Sr^{+}$ crystal



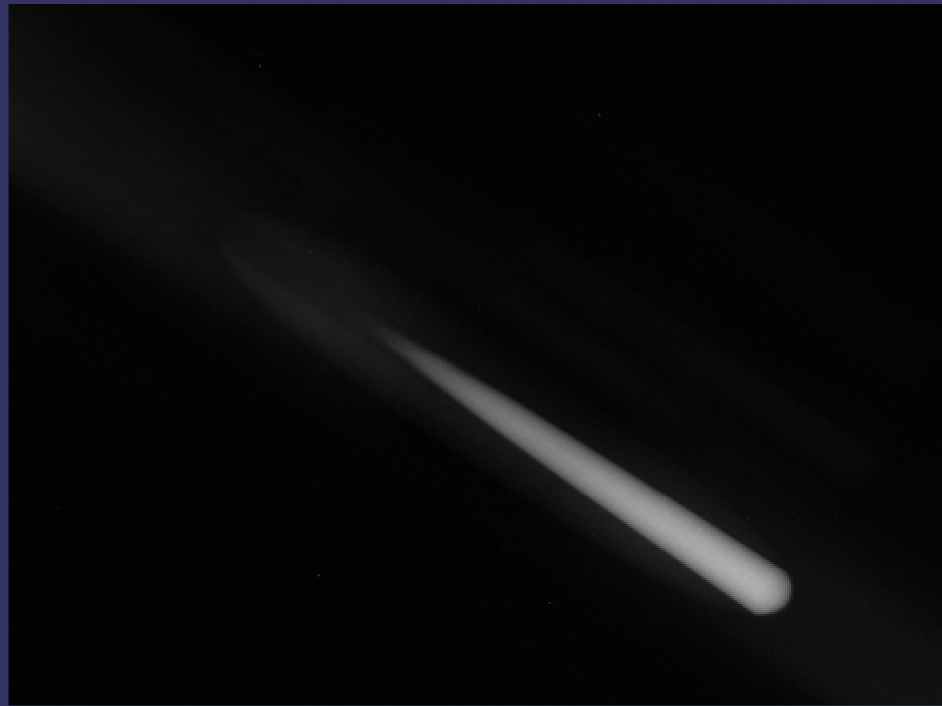
$^{86}Sr^+$ enrichment

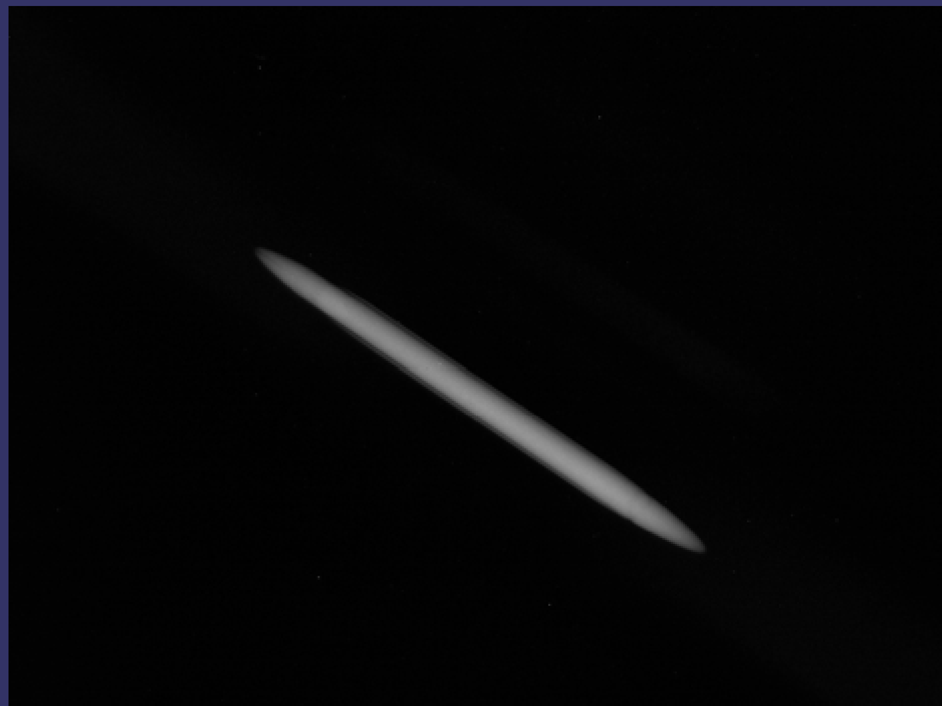


Left endcap voltage pulses + radial trap opening (RF)



100-1000μs





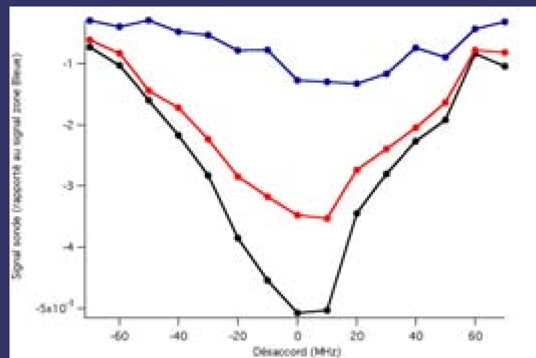
$^{86}Sr^{+}$ enrichment

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) :

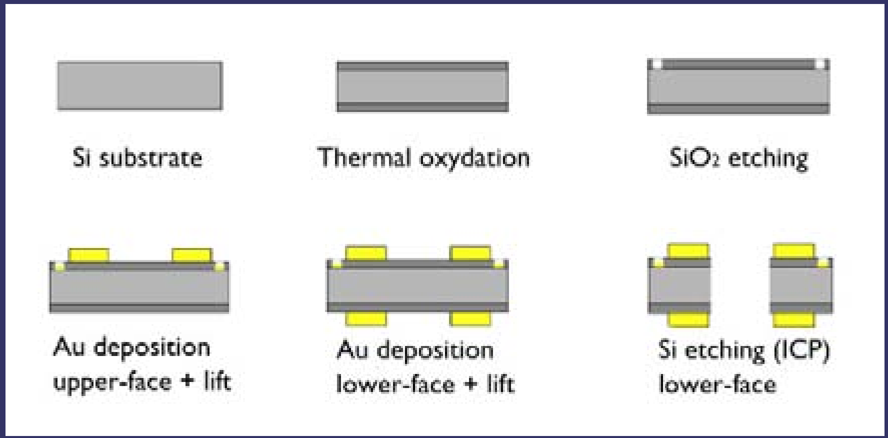
Correlated ion heating measurement

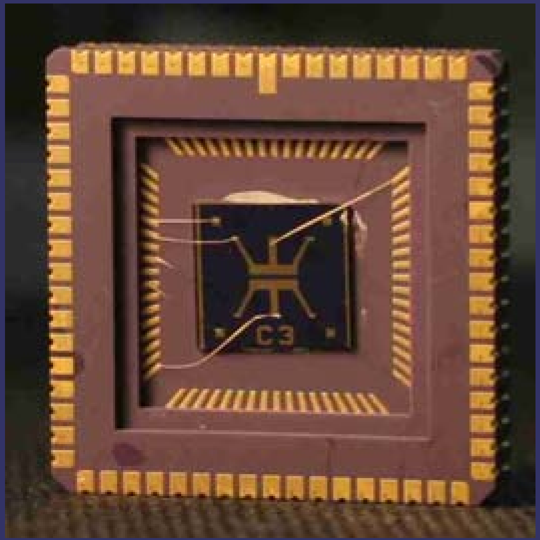
/

AFM measurement of the electrode surface

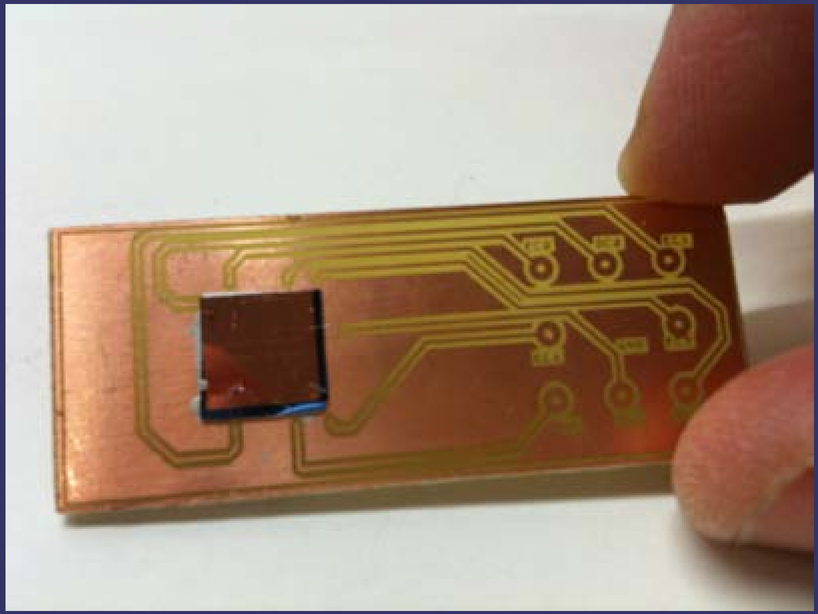
Microfabricated ion trap

- Previous design





- Next generation : surface trap



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Publications

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J. Phys. B: At. Mol. Opt. Phys., 2007, 40, pp. 413-426

Topologically Decoherence-Protected Qubits with Trapped Ions
P. Milman et al
Physical Review Letters, 2007, 99, 2, pp. 020503

Photoionisation loading of large Sr+ ion clouds with ultrafast pulses
S. Removille et al
Applied Physics B, Volume 97, Issue 1, pp.47-52 (2009)

Trapping and cooling of Sr+ ions: strings and large clouds
S. Removille et al
Journal of Physics B: Atomic, Molecular, and Optical Physics, Volume 42, Issue 15, pp. 154014 (2009).

Electric field noise above surfaces: A model for heating-rate scaling law in ion traps
R. Dubessy et al
Phys. Rev. A 80, 031402(R) (2009)

Double-Λ microscopic model for entangled light generation by four-wave mixing
Phys. Rev. A 82, 033819 (2010)