Self-oscillating atomic clouds in Magneto-Optical Traps

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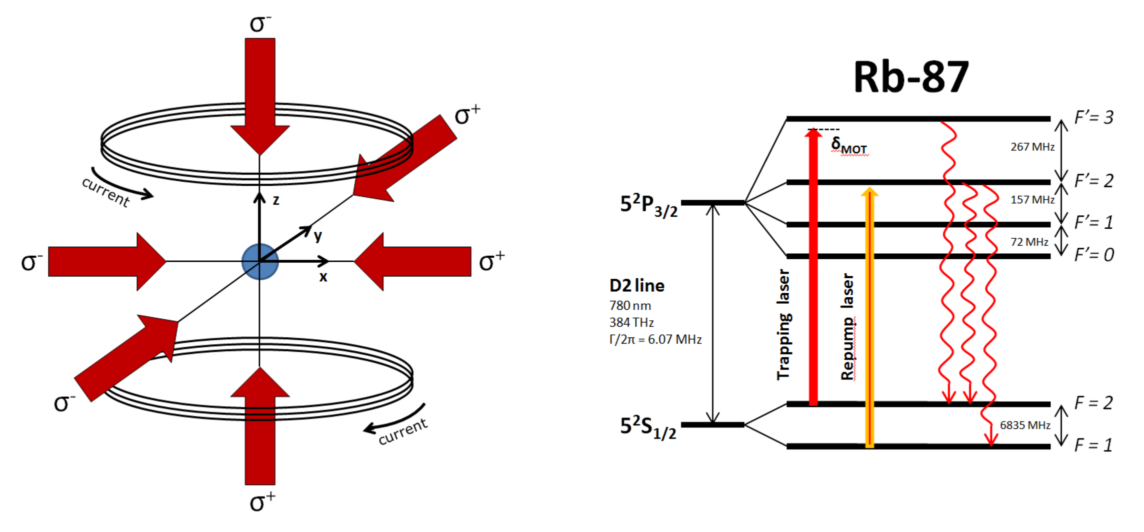
Abstract

The aim of our research is to **study self-oscillating, large ultracold atomic clouds in a Rubidium-87 Magneto-Optical Trap (MOT)**. By tuning the confinement forces in particular ways it is possible for the atoms to enter the self-oscillatory regime.

We call the self-oscillatory regime the unstable regime, and the regime, where we observe that the atoms do not move - the stable regime.

The research aims at addressing three questions:
(1) What are the necessary parameters for entering the unstable regime?
(2) What happens in the unstable regime?
(3) What can be said about the structures in the unstable clouds?



Motivation

Apart from being of fundamental interest, the biggest motivating factor behind the research is **a suggested analogy between dynamics of cold atomic clouds, astrophysical systems and plasma physics** [1].

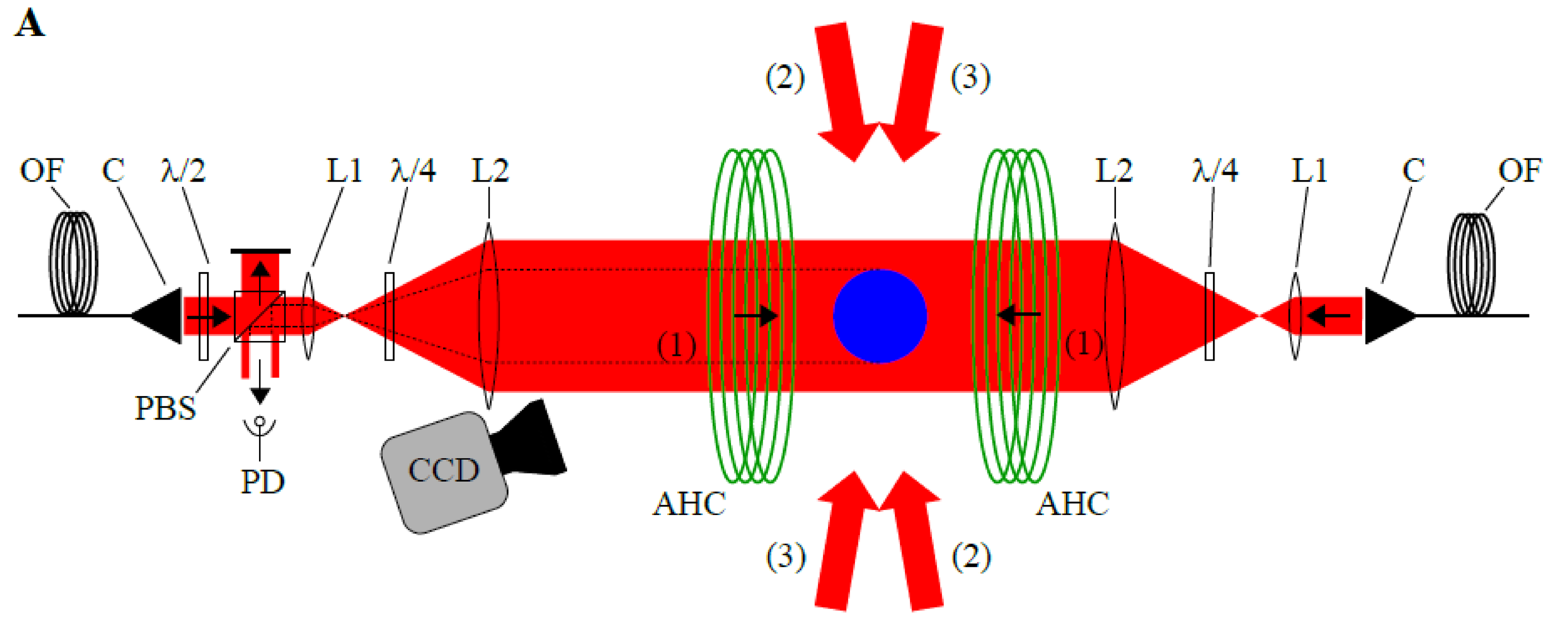
In the case of astrophysical systems, stars in the Hertzsprung-Russell diagram have been observed to exhibit pulsations based on the interplay between radiation pressure effects, which tend to increase the size of the star, and gravitational force, which provides a mechanism for the collapse [2]. In similar systems, such as confined plasmas, instabilities have also been observed to occur: here long-range Coulomb interaction is countered by a confining force to avoid an explosion of the plasma [3].

It would extremely challenging to perform studies of the full dynamics of such systems, although, on the other side, **due to the existing analogies, we are presented with a great opportunity to study the hard-to-tackle systems.**

Experimental setup

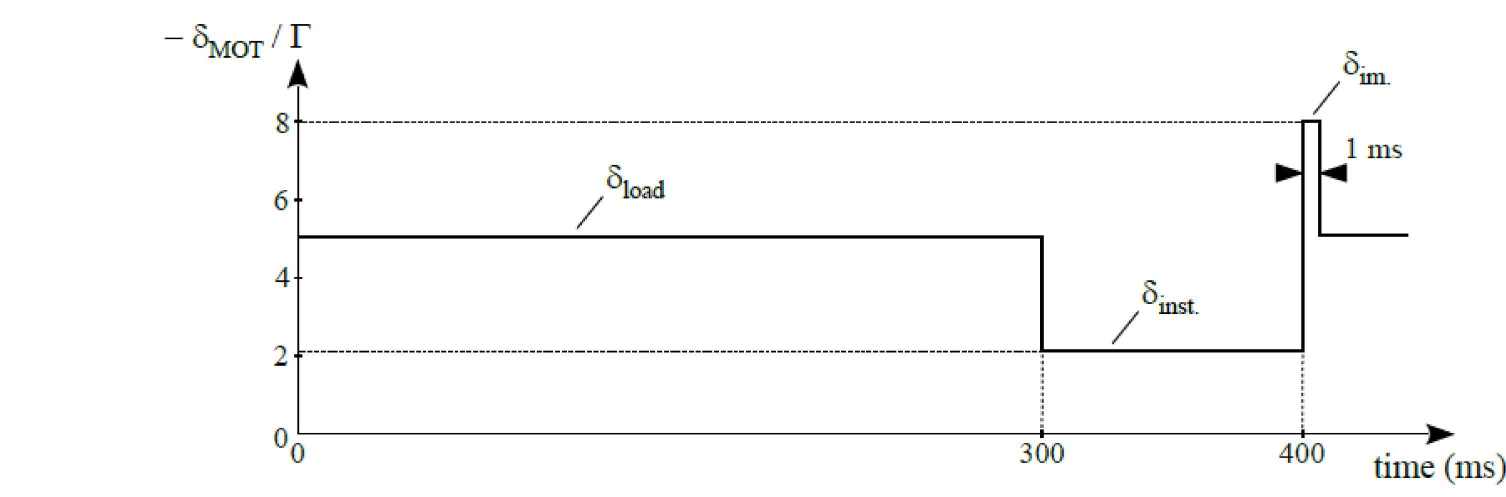
The following experimental procedure **allows us to keep the number of atoms inside the MOT constant** (~10^{10} atoms) **as we vary the trap's magnetic field gradient, VB, and the cooling lasers' detuning δ from the trapping-transition.**

A



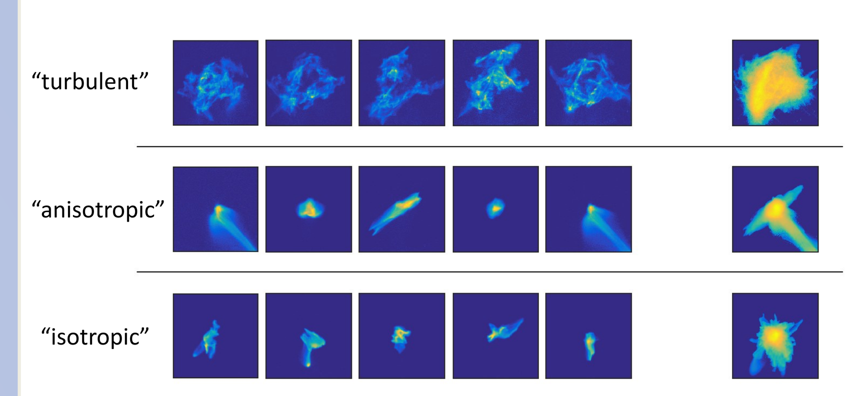
A: **Details of the arrangement for one pair of MOT beams (1), with the other two pairs ((2) and (3)) being identical**. The counter-propagating beams are delivered through optical fibers (OF) coupled to collimators (C). The beam intensities are balanced using a half-wave plate (λ/2) + polarizing beam splitter (PBS) assembly placed on the arm seen on the left. The beams are expanded to a waist of 4 cm using afocal telescopes (L1 + L2). Their polarization is adjusted using quarter-wave plates (λ/4). The magnetic field gradient is provided by a pair of anti-Helmoltz coils (AHC).

B

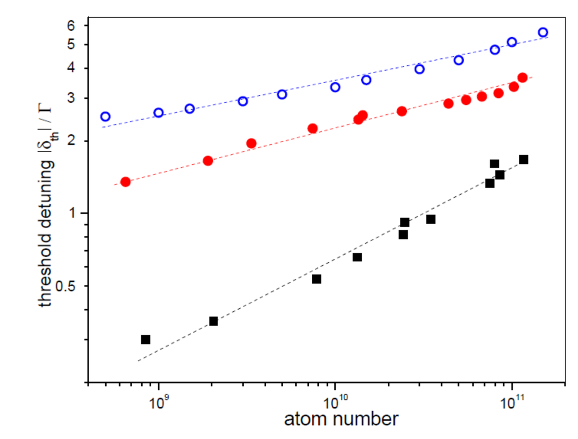


B: **Timing of the experiment.** A cycle is started by loading the MOT for 300 ms with a detuning δ_{load} (adjusted to maintain the number of atoms fixed during the measurements). The detuning is next jumped to $\delta_{inst.}$ for 100 ms; this detuning is the detuning of the unstable phase. An image is finally acquired with at a fixed detuning $\delta_{im.} = -8\,\Gamma$.

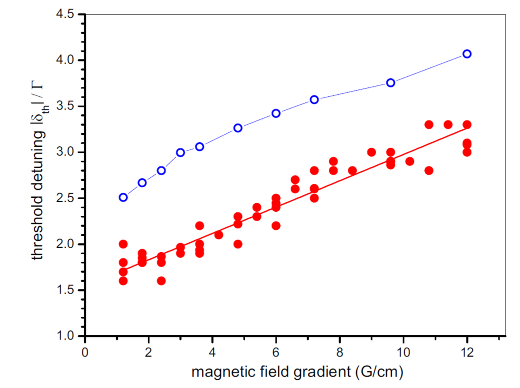
MOT instabilities



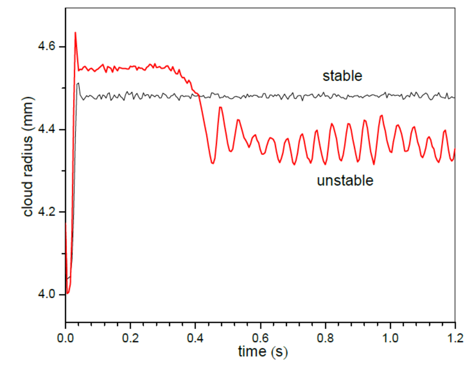
Single-shot images (5 to the left) **and log-average image** (right) **of the unstable clouds in the experiments belonging to the discovered instability regimes.**



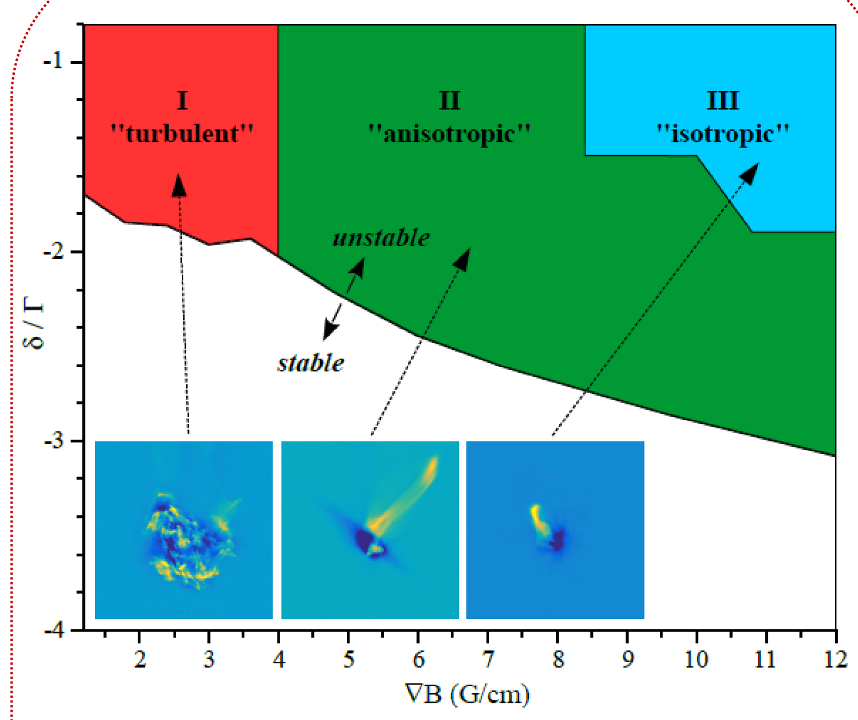
Instability threshold versus atom number. Experimental threshold (red dots) is compared to 3D simulations (blue circles) and a simple 1-zone model prediction [1] (black squares).



Instability threshold versus magnetic field gradient (N = 1.5× 10^{10}). The experimental data (including several runs) is shown as dots, with a linear fit (solid line). The circles correspond to the 3D simulation result.



Instability of the simulated 3D MOT. A sharp transition between stable and unstable cloud behavior is observed when cooling lasers' detuning δ is changed.



Discovery of different instability regimes (experiments).
(I) "**Turbulent**": Moderate fluctuations of COM position and RMS radius. Filament-like structures, complex motion.
(II) "**Anisotropic**": Large fluctuations of COM position and RMS radius. Deformations along MOT beams. Intermittent behavior.
(III) "**Isotropic**": Huge fluctuations of COM position and RMS radius. Statistically isotropic motion.

Conclusion

A **study was performed on spatio-temporal instabilities** taking place in a MOT containing a large number of atoms (~10^{10}). **Three different instability regimes were discovered**, and **qualitative agreements were reached between the thresholds of experiments and three-dimensional (3D) simulations.**

References

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