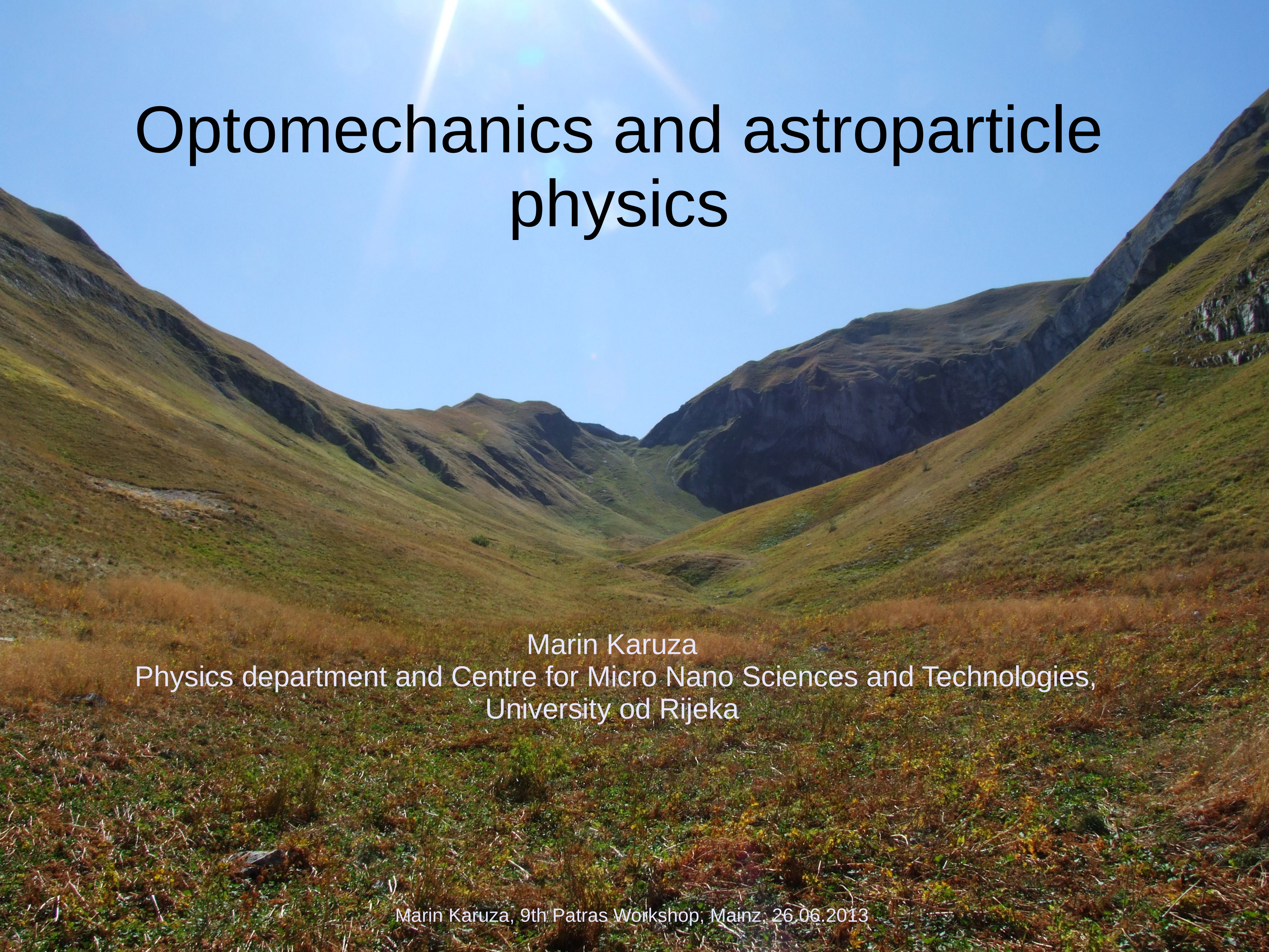


Optomechanics and astroparticle physics

Marin Karuza
Physics department and Centre for Micro Nano Sciences and Technologies,
University od Rijeka

Optomechanics and astroparticle physics

Experimental setup
Some results

Ciro Biancofiore, Piergiacomo Zucconi Galli Fonseca, Marco Galassi, Riccardo Natali, Paolo Tombesi, Giovanni Di Giuseppe and David Vitali

Quantum Optics & Quantum Information Group
University of Camerino

UNICAM
Università di Camerino
1336
Università di Camerino

Introduction

Microelectromechanical systems (MEMS) and nanoelectromechanical systems (NEMS) are extensively used for various technological applications :

- highly sensitive sensors (accelerometers, atomic force microscopes, mass sensors….)
- actuators (in printers, electronic devices…)

These devices operate in the **classical regime** for both the electromagnetic field and the motional degree of freedom

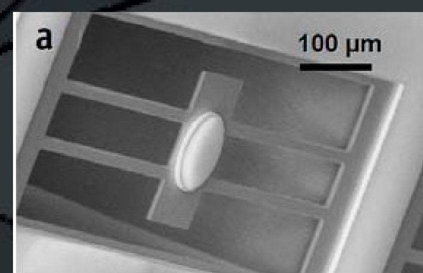
Recently, a new field has been entered, **cavity optomechanics**

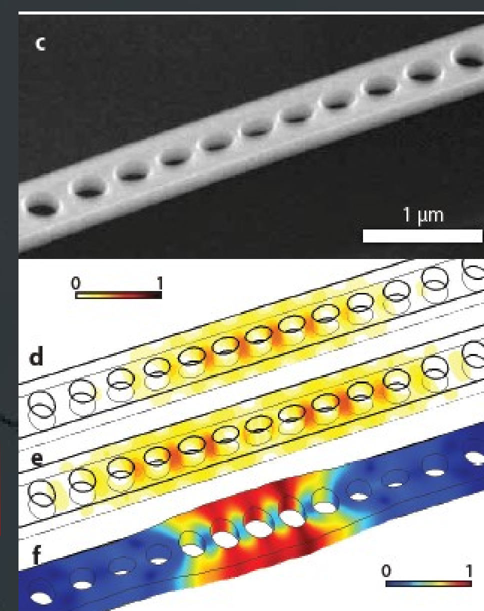
entering the quantum regime (sensors at sensitivtiy limits imposed by Heisenberg uncertainty principle, detecting extremely weak signals – forces and displacements, quantum information)
optical (electromagnetic) cavity

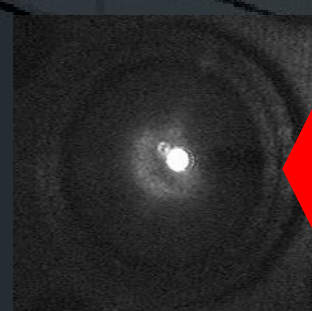
Introduction

Many different possibilites

- Fabry – Perot cavity with a moving mirror (Paris, Vienna)
- membrane in the middle (Yale, Caltech, Camerino, JILA)
- other cavity designs
    - silica toroidal optical microcavities (EPFL, Caltech, Brisbane)
    - microdisk and a vibrating nanomechanical beam (Yale)
    - silicon nanobeam optomechanical cavity (Caltech)



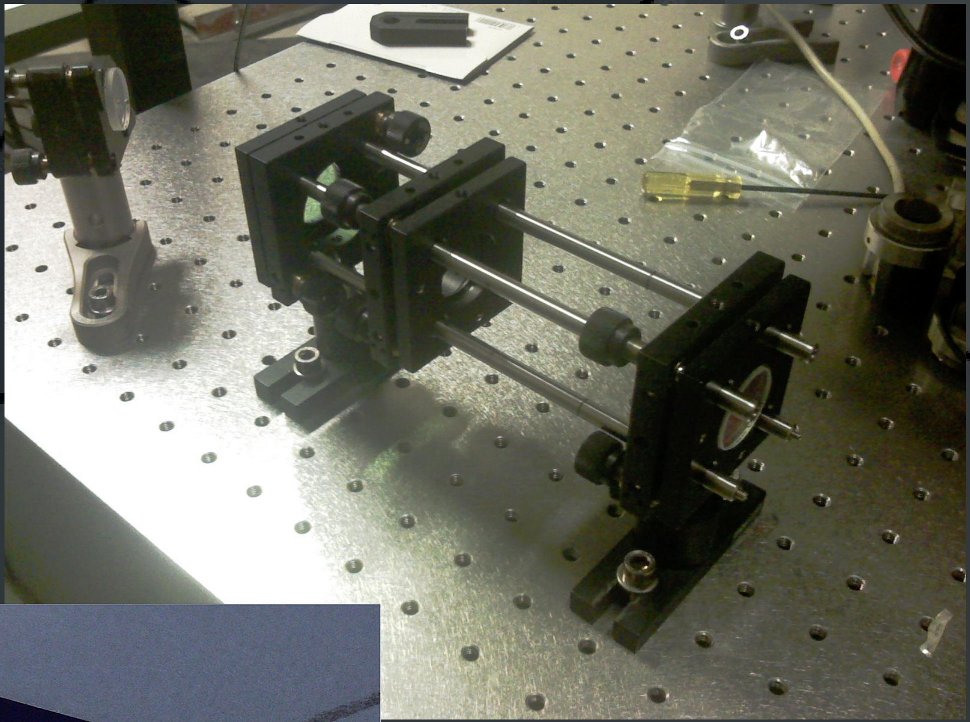


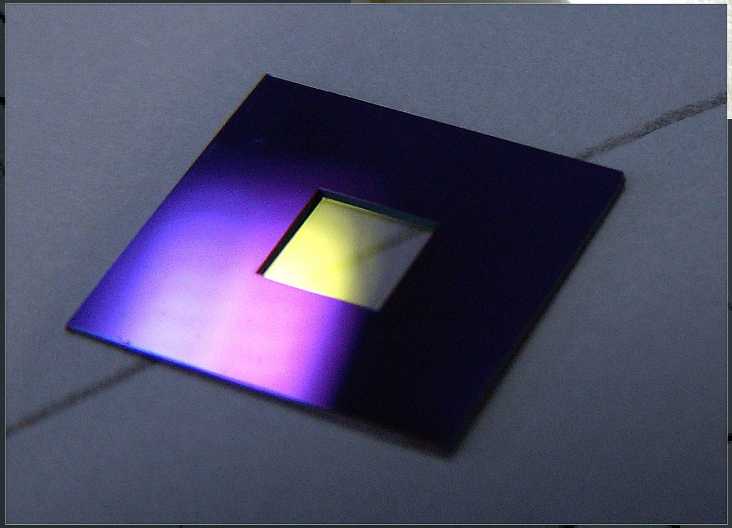


Membrane in the middle setup

Two mirrors
r = 10 cm
R = 0.99995
Fabry – Perot cavity
Finesse 60 000

Silicon Nitride membrane
stoichiometric
high – stress (800 Mpa)
A = 1 x 1 mm
d = 50 nm
Q > 10^5
ν_{11} ~ 400 kHz





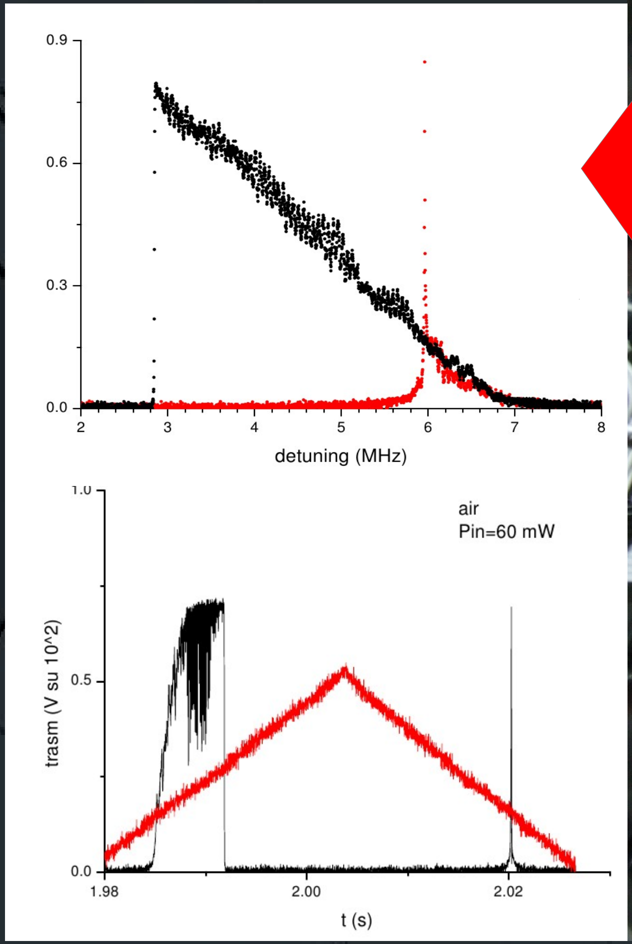
Membrane in the middle setup

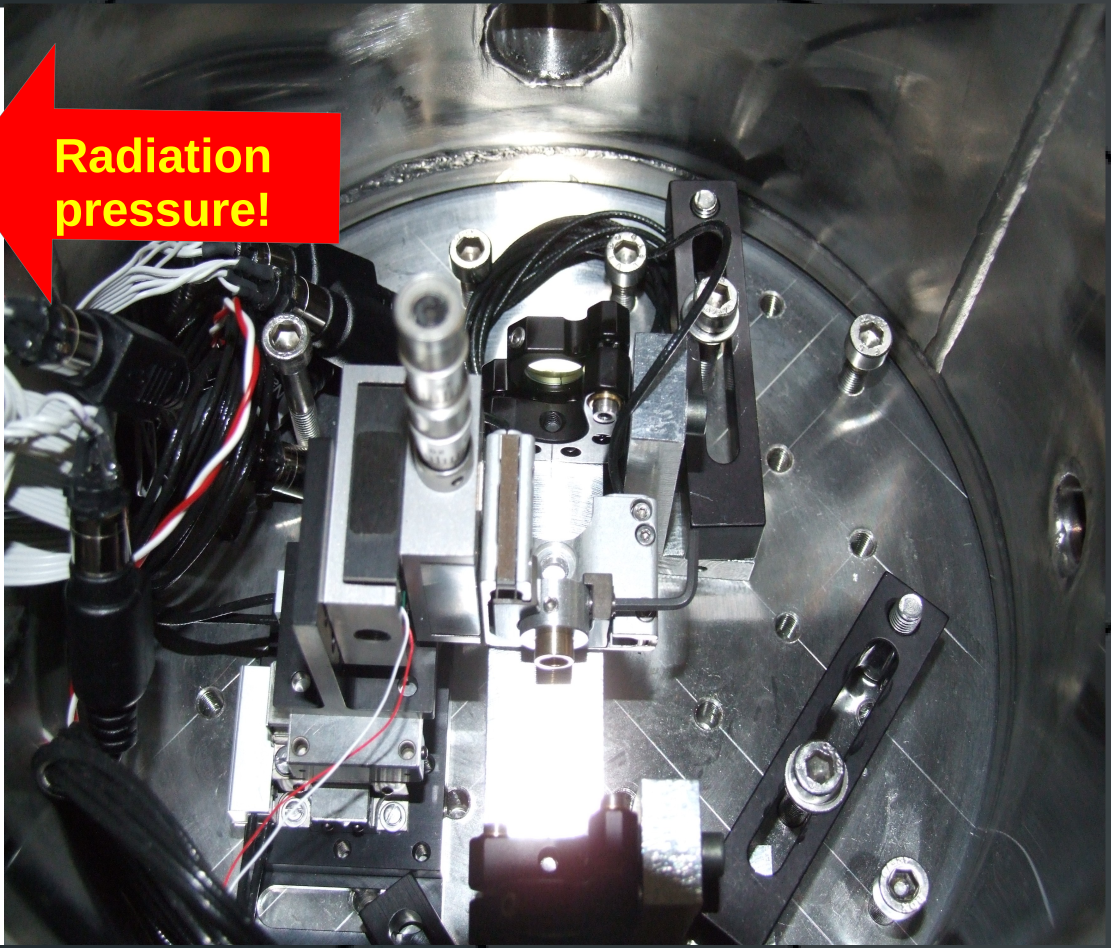
Vacuum chamber

Membrane mechanical Q pressure dependent

Finesse 60000 (air bistability)

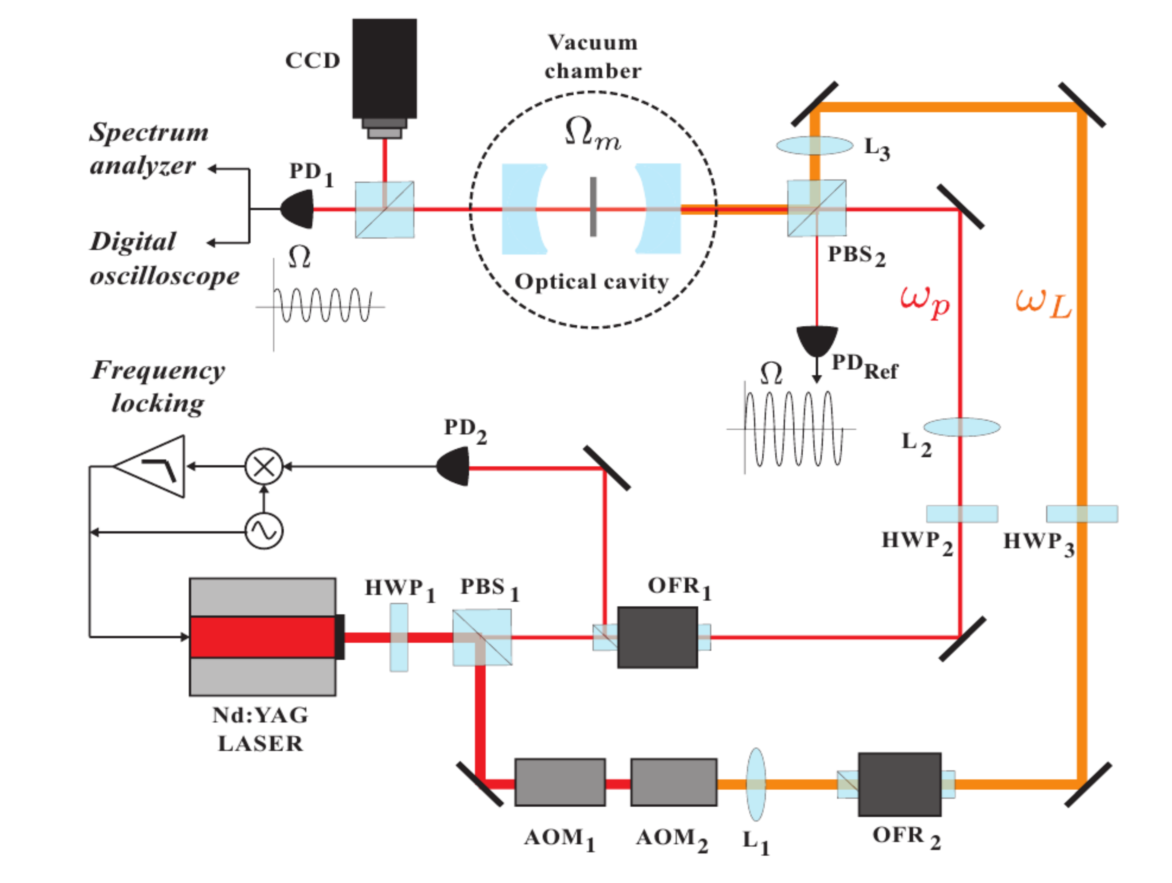
Membrane alignment, tip, tilt, and coarse xyz + fine z by a piezo





Membrane in the middle setup

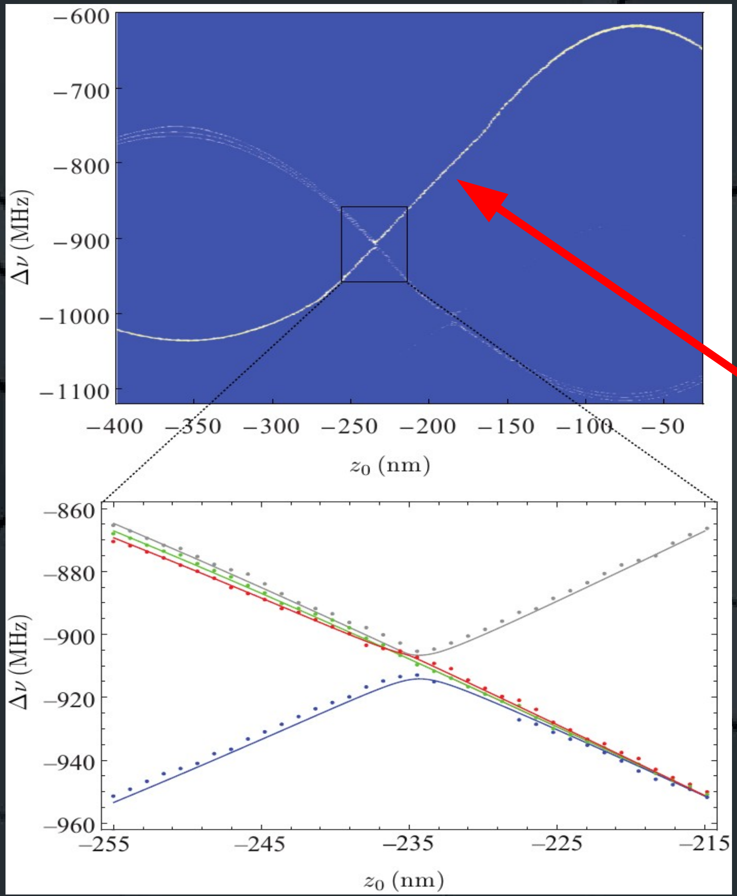
Laser (Innolight Mephisto OEM 200 mW)
Two (three) beams:
- probe (locked to the cavity)
- control (frequency controlled by two cascaded AOMs)
- independent probe (not shown in the picture)

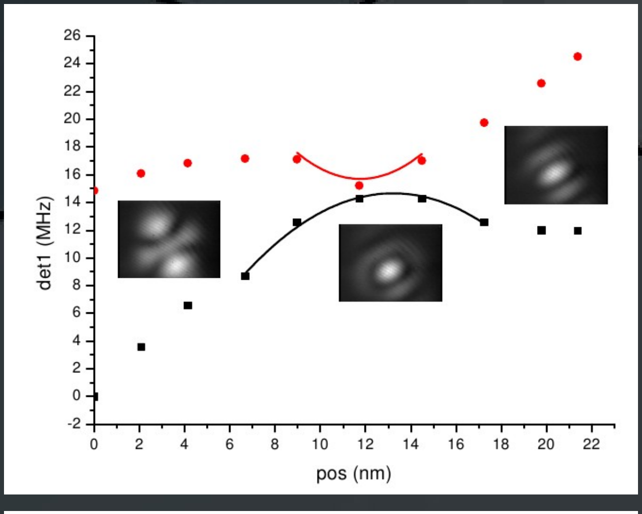


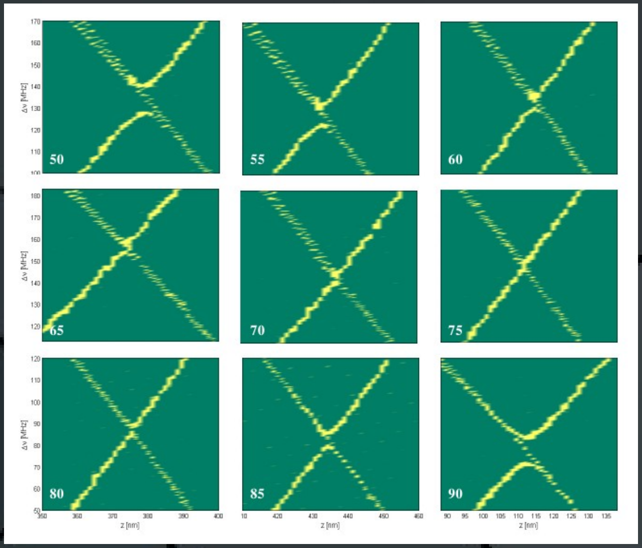
Results

Cavity spetroscopy

- membrane misalignment and shift couples the TEM_{mn} cavity modes via scattering
- splitting of degenerate modes and avoided crossings
- linear combinations of nearby TEM_{mn} modes become new cavity modes
- good agreement with theory







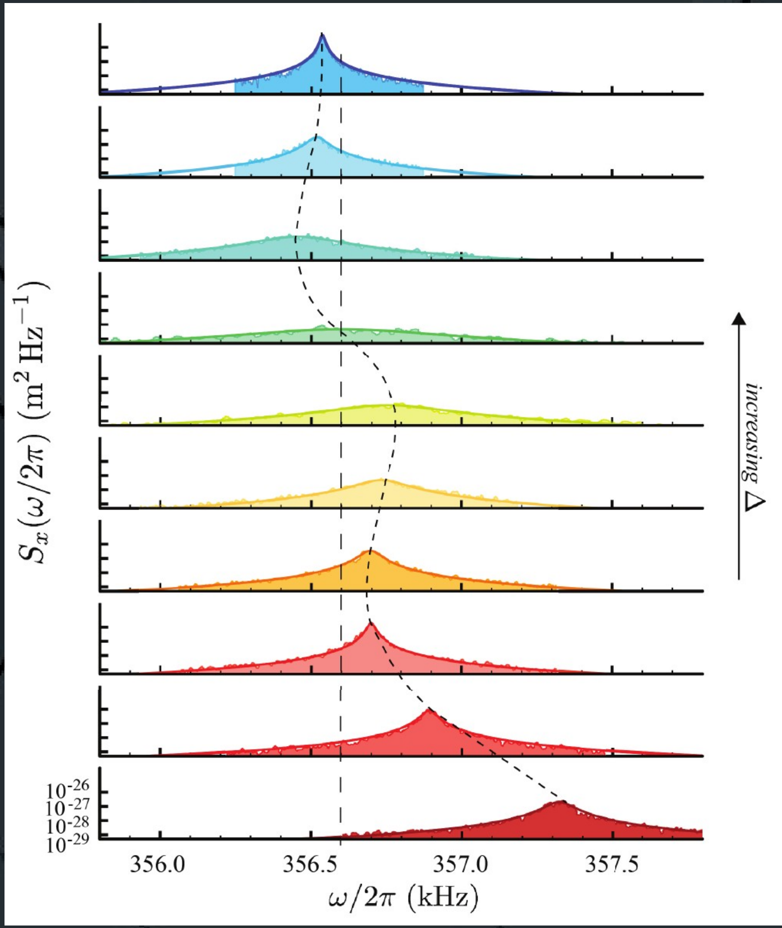
Experimental cavity frequencies with 0.21 mrad misalignment

M. Karuza et al., J. Opt. 15 (2013) 025704

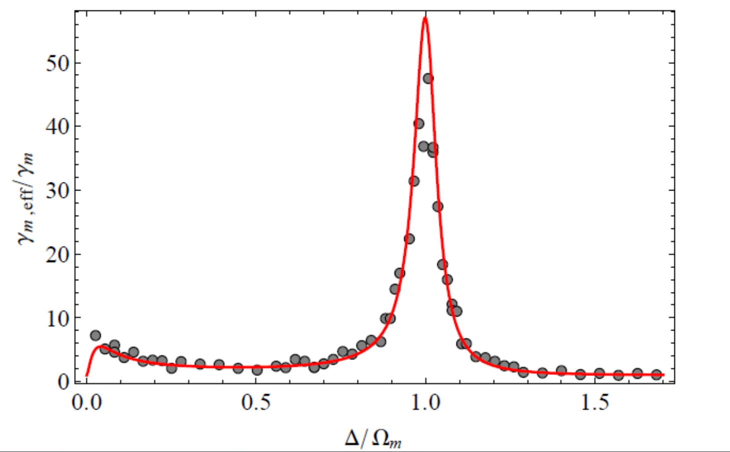
Results

Resolved sideband cooling, effect of light on mechanical resonator

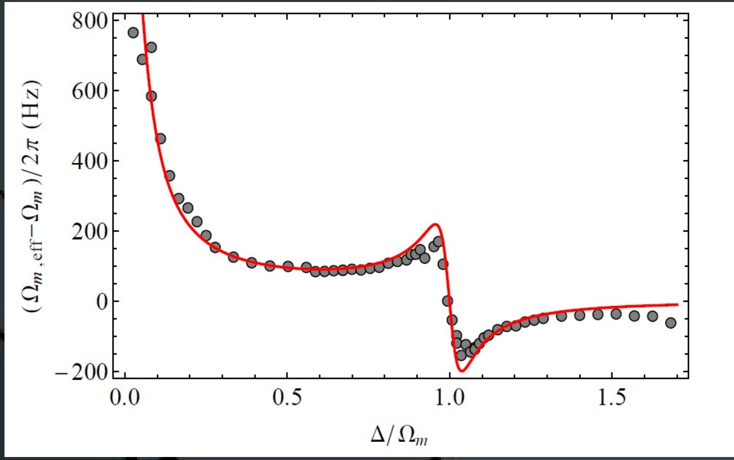
- cooling by factor 300, equivalent temperature 1 K reached



Detected position noise spectrum



Effective damping



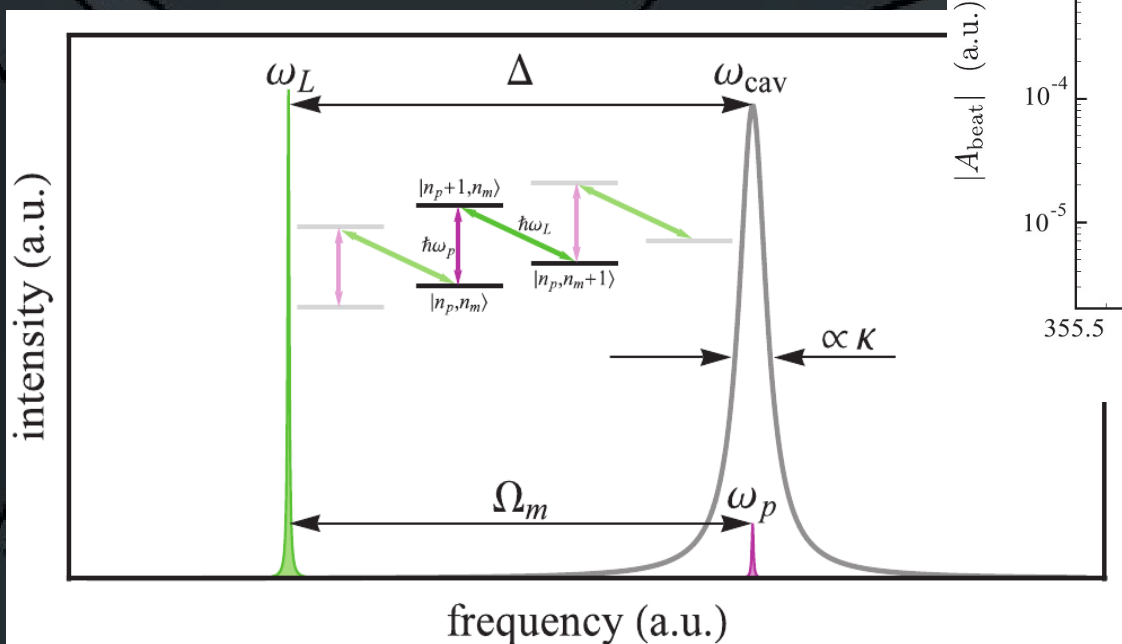
Karuza et al., New J. Phys. 14, 095015 (2012).

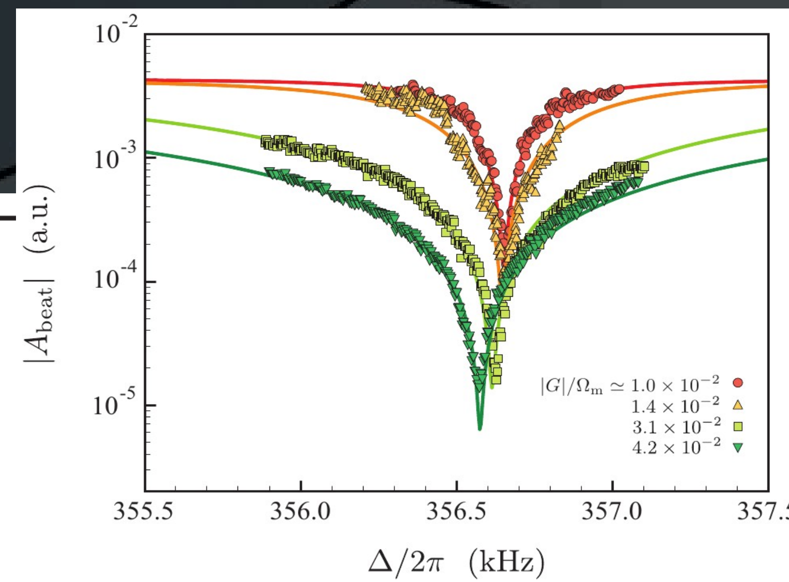
Mechanical frequency shift

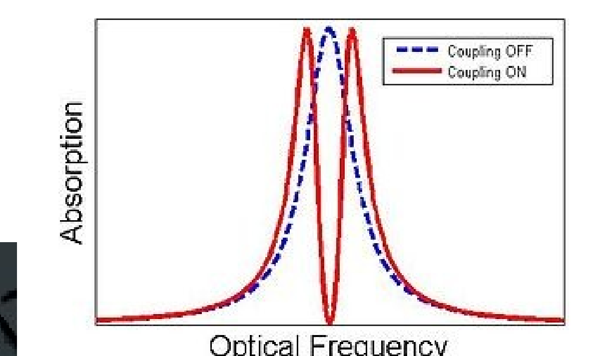
Results

Effect of mechanical resonator on light

The optomechanical analogue, optomechanically induced transparency (OMIT), of electromagnetically-induced transparency (EIT)







Karuza et al., arXiv:1209.1352v1

Optomechanics and astroparticle physics

Union optomechanics - astroparticle physics

Thanks to work with

Heinrich Brauniger, Giovanni Cantatore, Klaus Desch, Dieter Hoffmann, Jochen Kaminski, Axel Lindner, Stefan Neff, Konstantin Zioutas

Future → attach to CAST/XRT telescope

Optomechanics and astroparticle physics

Detection of radiation pressure from solar chameleons

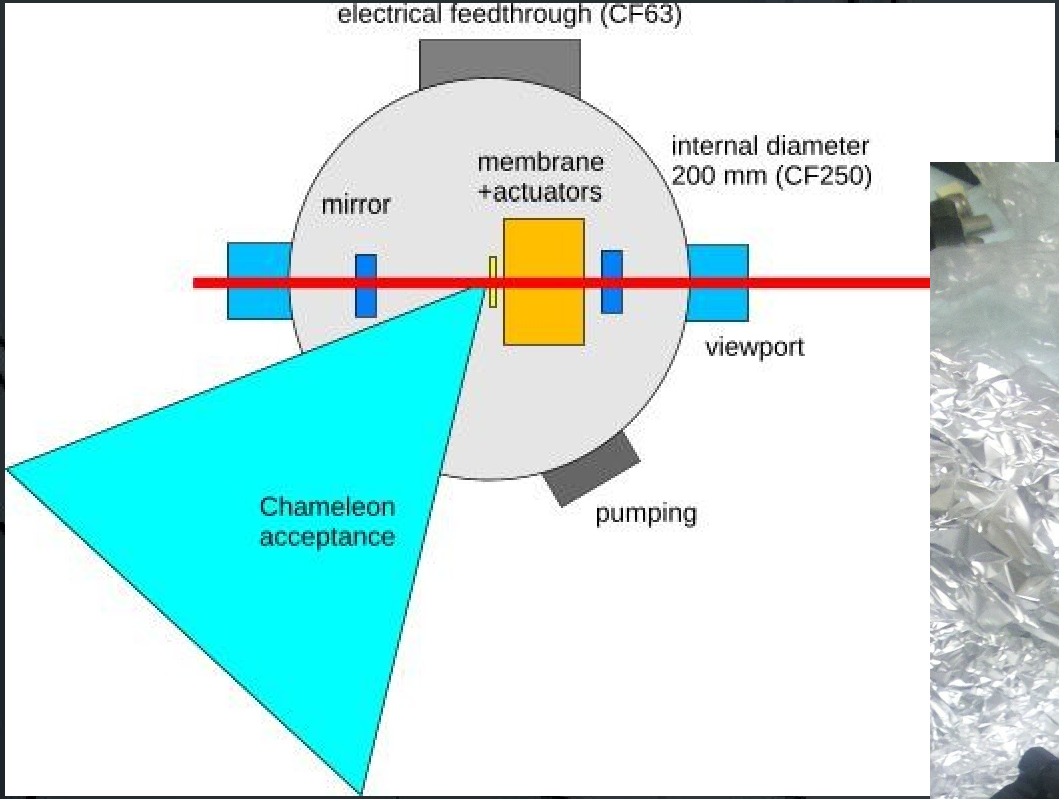
O. K. Baker [1)], A. Lindner [2)], Y. K. Semertzidis [3)], A. Upadhye [4)], K. Zioutas [5)]

[1)] Physics Department, Yale University, PO Box 208120, New Haven, CT 06520, USA; oliver.baker@yale.edu
[2)] DESY, Notkestraße 85, D-22607 Hamburg, Germany; axel.lindner@desy.de
[3)] Brookhaven National Laboratory, NY, PO Box 5000, Upton, NY 11973, USA yannis@bnl.gov
[4)] Argonne National Laboratory, 9700 S. Cass Ave. Lemont, IL 60439, USA; aupadhye@hep.anl.gov
[5)] University of Patras, GR 26504 Patras, Greece; zioutas@cern.ch

Abstract:

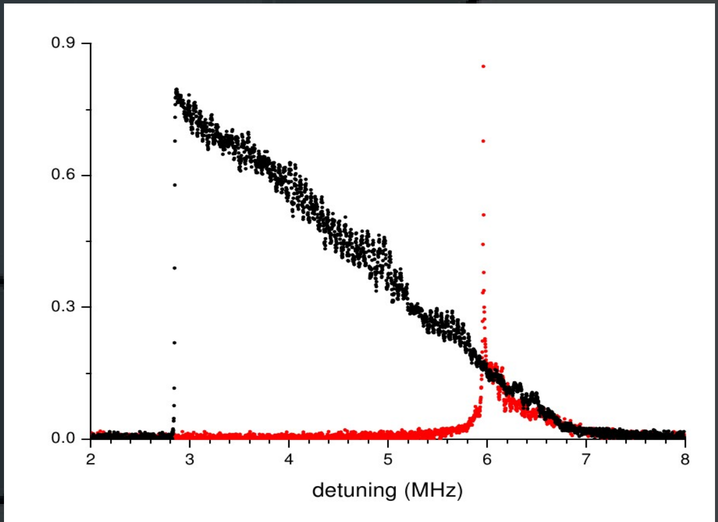
The radiation pressure due to totally reflected (solar) chameleons by thin but dense foils or membranes or mirrors is suggested to be utilized to detect (solar) chameleons and unravel their theoretically motivated behavior, i.e., their coupling to matter (β_m). The underlying process is distinguished from scattered neutrinos or WIMPs off individual atomic nuclei, which require therefore massive detector targets to compensate for their extremely small interaction cross section with matter. The chameleon reflection is instead a density dependent effect, which distinguishes them theoretically and also experimentally. High sensitive photon radiation pressure or force measuring techniques, which work at the quantum limit, could become the new antennas for chameleons or other particles with similar properties. This may lead to a high detection sensitivity for (solar) chameleons, integrating either over a large focused incident flux, or, measuring eventually chameleons individually. Highly developed opto-mechanical measuring techniques, which already includes gravitational waves antennas, may extend their list of applications to unraveling the nature of dark energy in the Universe, and/or outstreaming of solar chameleons. What looks at first sight as a Gedankenexperiment, might become a real experiment. It is to be remarked that these techniques could be applied to any directed chameleon beam like in a chameleon-through-a-wall experiment for example, in particular when equipped with a Fabry-Pérot resonator.

Optomechanics and astroparticle physics



- chameleon reflectors → factor 2 improvement

Sensitivity



-back of the envelope estimate
- FP cavity frequency shift Δf = 4 MHz (cavity linewidth 30 kHz)
- 1 W circulating in the cavity → 10^{-7} N → 2 nm displacement
- 10^{-7} N / nm
→ reported sensitivity

$$s=10^{-15}\,m/\sqrt{(Hz)}$$

$$s=10^{-13}\,N/\sqrt{(Hz)}$$

10 000 s

$$F=10^{-15}\,N$$

25 mm^2

$$p=4\cdot10^{-11}\,Pa$$

- allowed solar exotica flux

$$\Phi=10^{-2}\frac{W}{m^2}$$

Conclusion

- diurnal modulation
- chopping scheme
- put an x – ray telescope in front → factor 100 improvement
- cool the membrane → factor 100 improvement

And if everythig else fails, we have an expensive microphone.
With some issues though ...