Optomechanics for dark sector searches, kinetic particle detection at CAST and beyond

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Outline

INTRODUCTION

OPTOMECHANICS@CAST

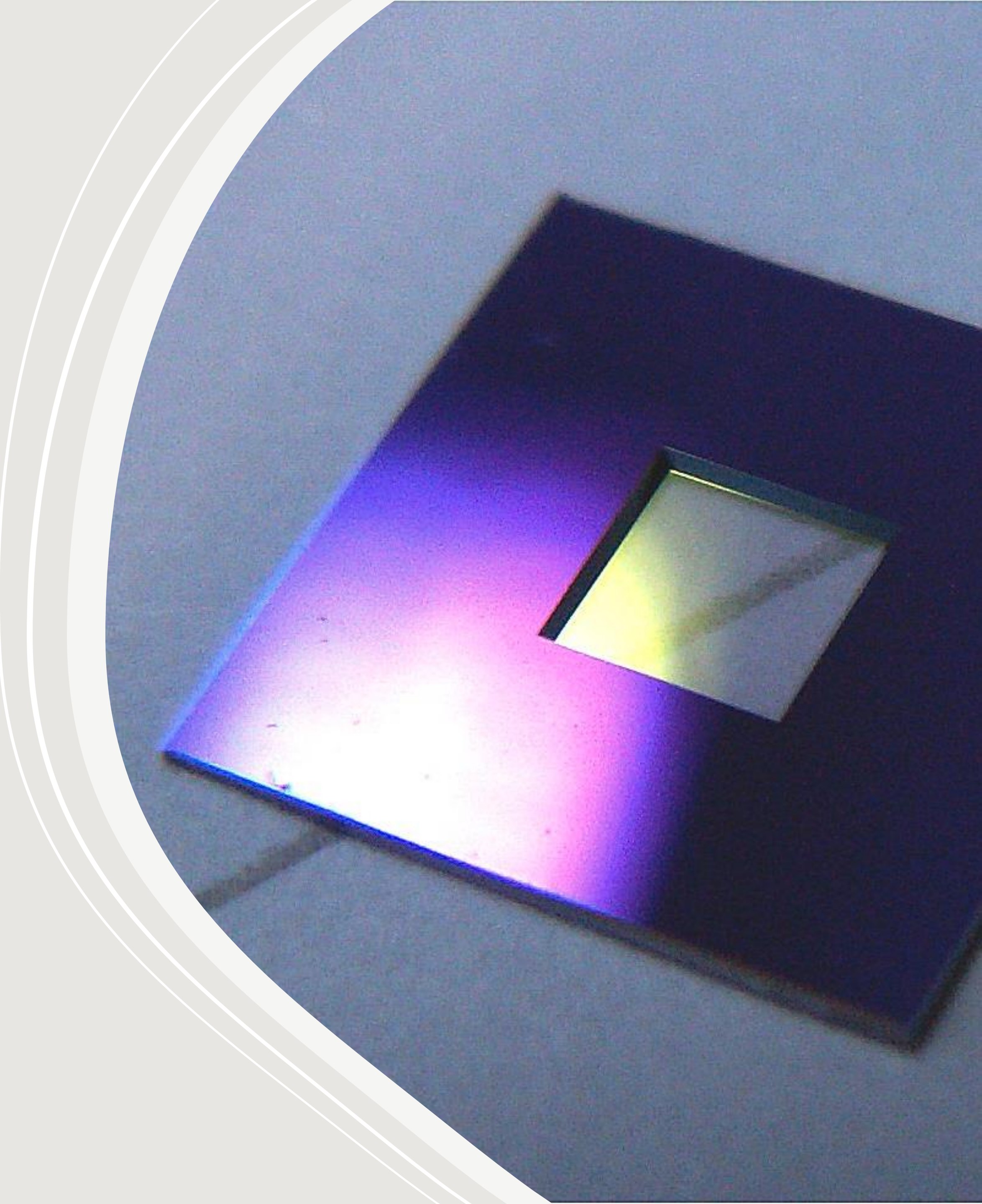
CONCLUSION

Why optomechanics?

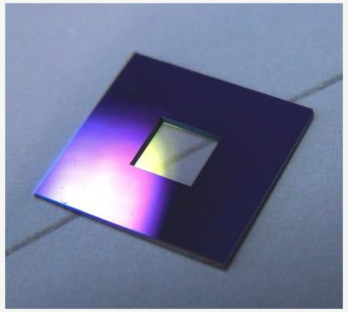
QUANTUM-LIMITED SENSORS, I.E., WORKING AT THE SENSITIVITY LIMITS IMPOSED BY HEISENBERG UNCERTAINTY PRINCIPLE

EXPLORING THE BOUNDARY BETWEEN THE CLASSICAL MACROSCOPIC WORLD AND THE QUANTUM MICROWORLD

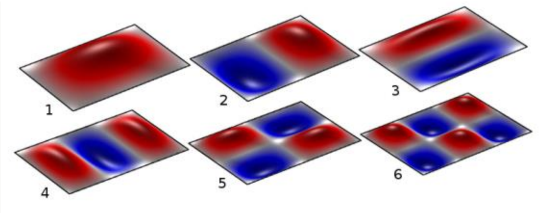
QUANTUM INFORMATION APPLICATIONS (OPTOMECHANICAL AND ELECTROMECHANICAL DEVICES AS LIGHT-MATTER INTERFACES AND QUANTUM MEMORIES)

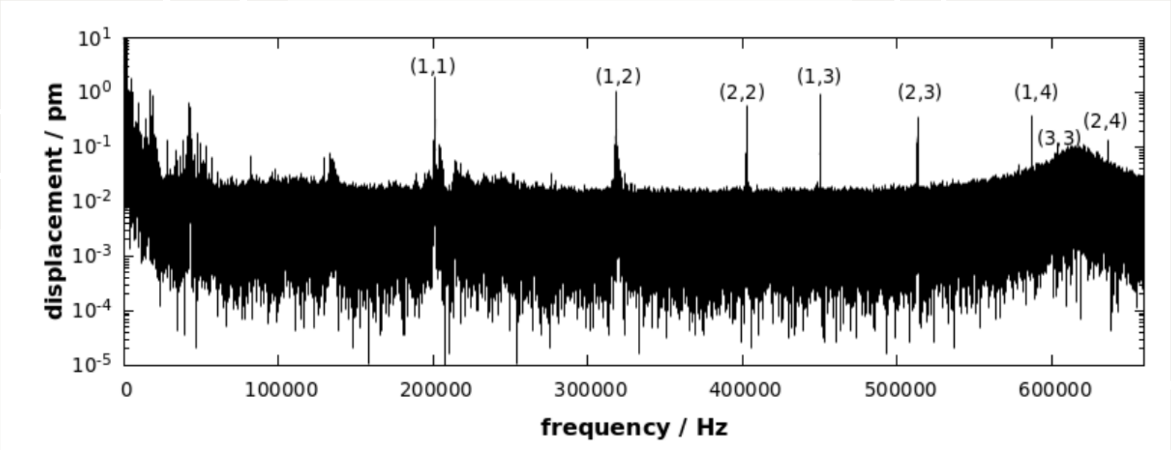


$$m\ddot{x} + D\dot{x} + kx = F\ \sin(\omega t)$$



$$\omega_{mn} = \pi v\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}$$





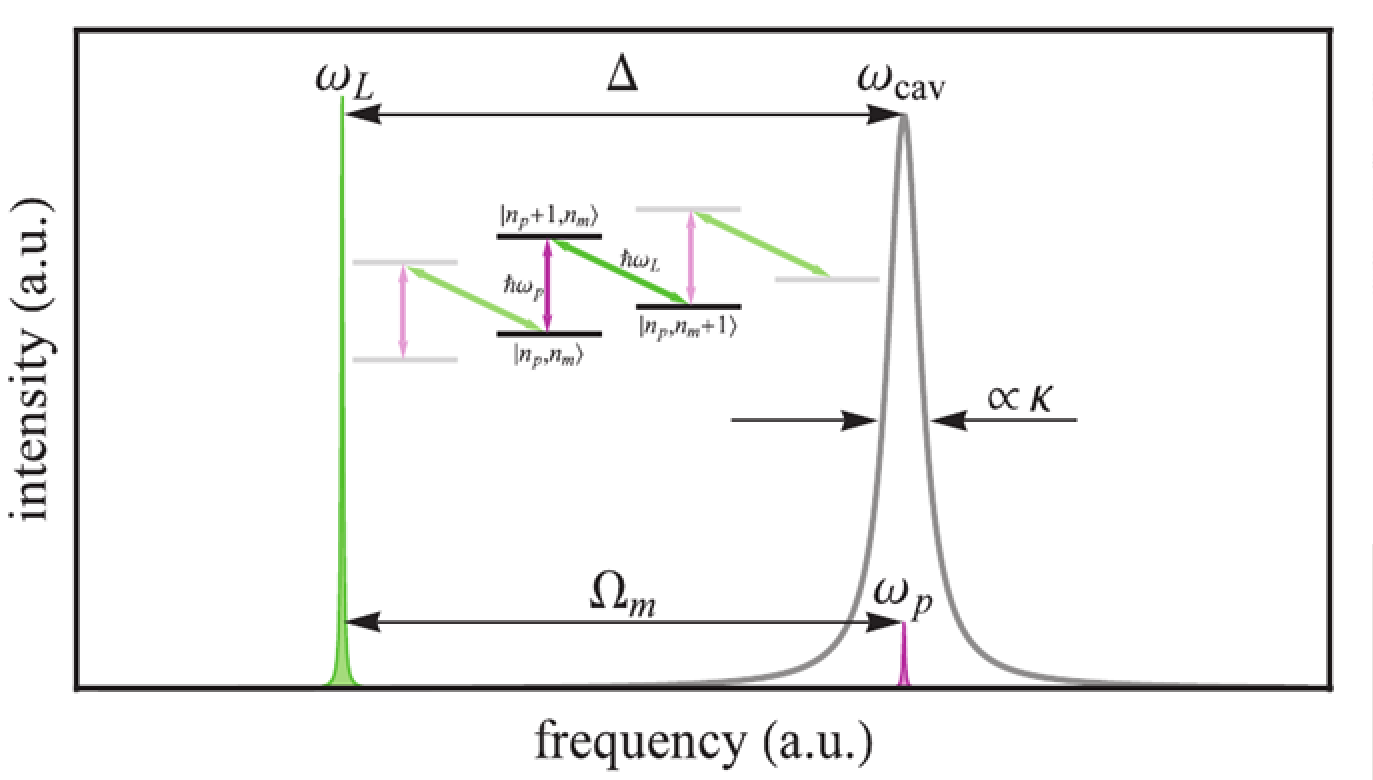
Calibration

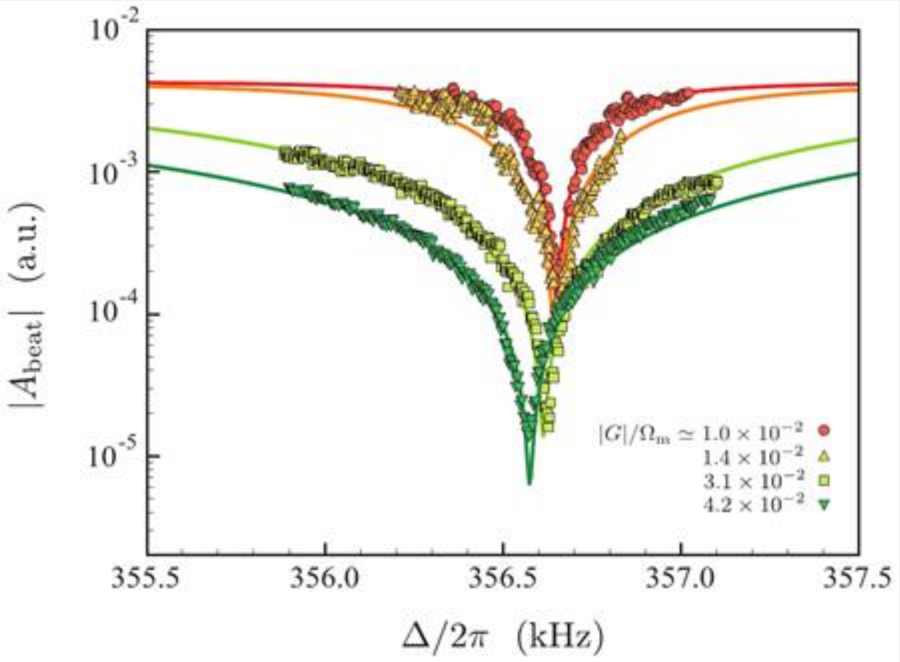
- response of 2D mechanical oscillator to excitation (impedance) -> flux of particles (photons)
- oscillator thermally excited (F – white noise)
- done at Laboratory for nonlinear and quantum optics, Department of Physics, NANORI, CEMS, University of Rijeka

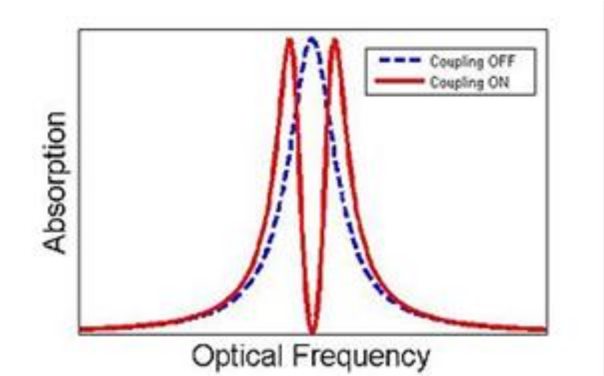
Effect of mechanical resonator on light

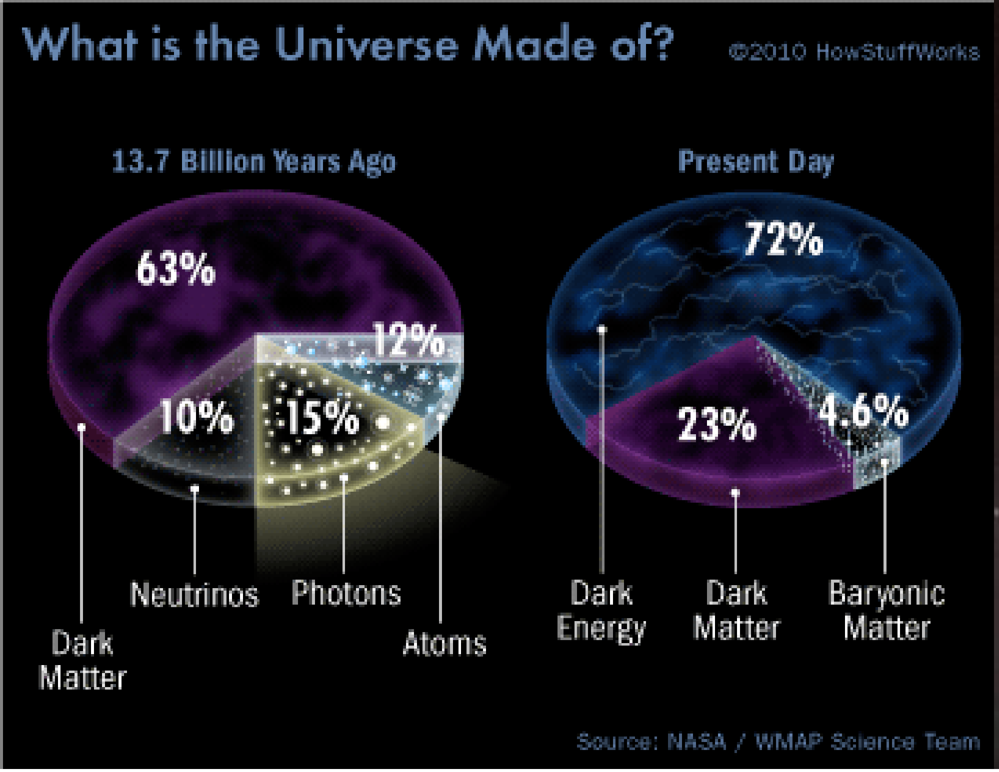
The optomechanical analogue, optomechanically induced transparency (OMIT), of electromagnetically-induced transparency (EIT)

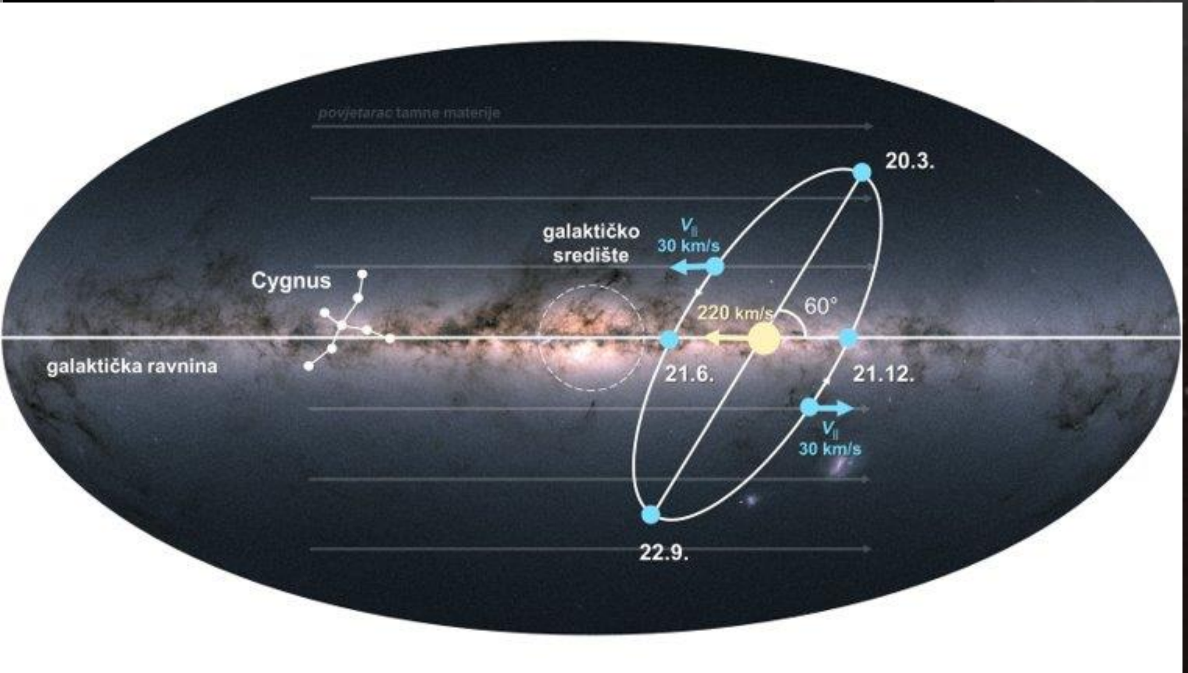
Karuza, M. et al., Optomechanically induced transparency in a membrane-in-the-middle setup at room temperature, Phys. Rev. A (88), 1, 013804 (2013)



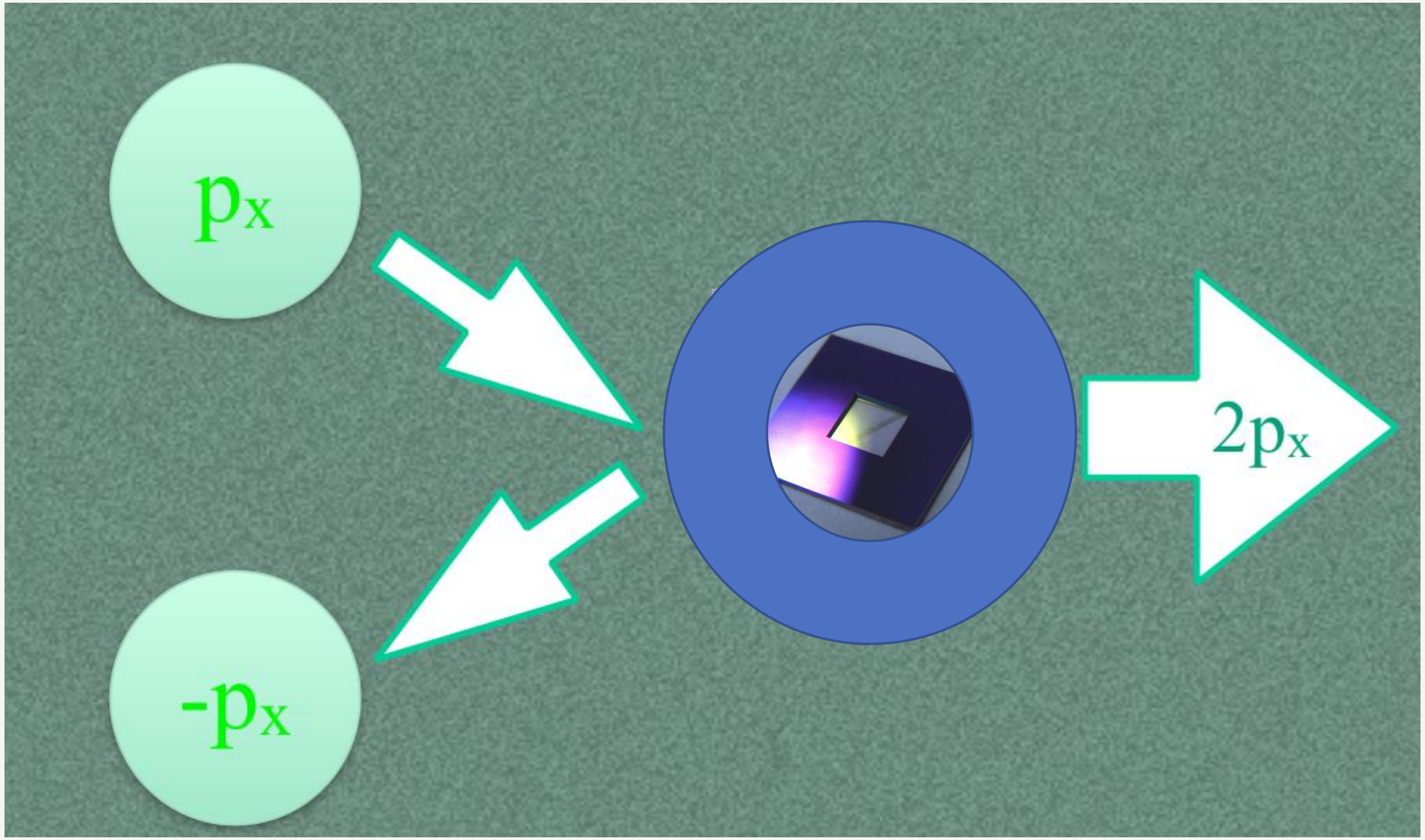





What is the Universe Made of?
©2010 HowStuffWorks
13.7 Billion Years Ago
63%
12%
10%
15%
Dark Matter
Neutrinos
Photons
Atoms
Present Day
72%
23%
4.6%
Dark Energy
Dark Matter
Baryonic Matter
Source: NASA / WMAP Science Team


povjetarac tamne materije
20.3.
galaktičko središte
V∥
30 km/s
Cygnus
220 km/s
60°
galaktička ravnina
21.6.
21.12.
V∥
30 km/s
22.9.

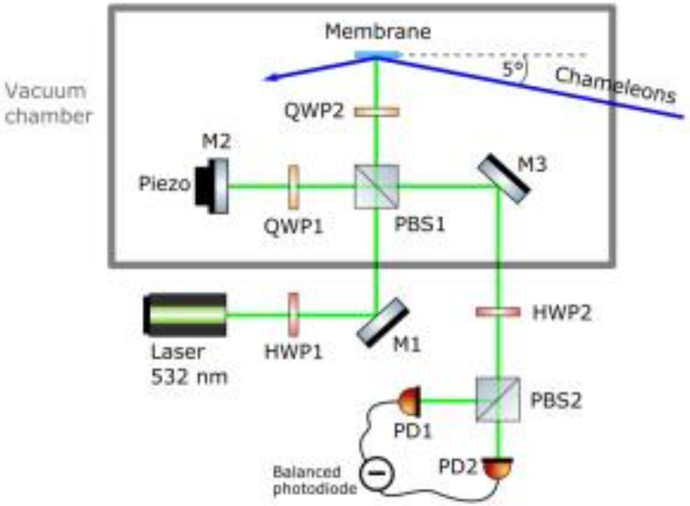
Motivation

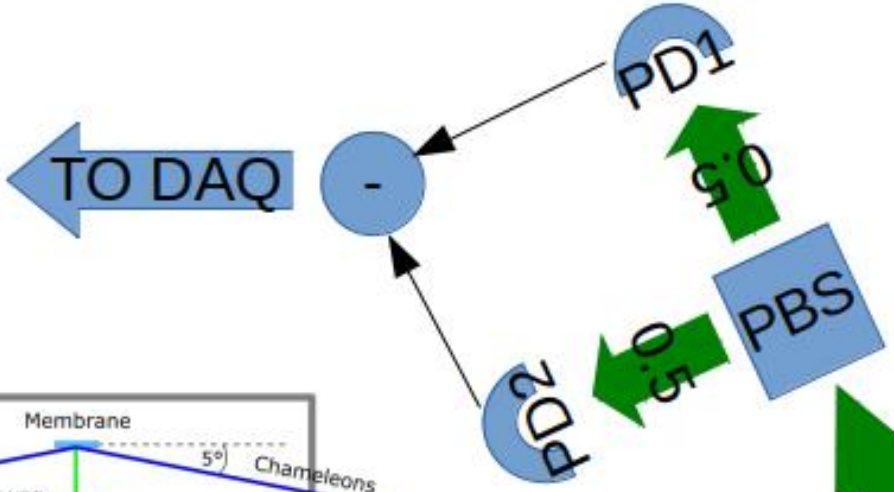


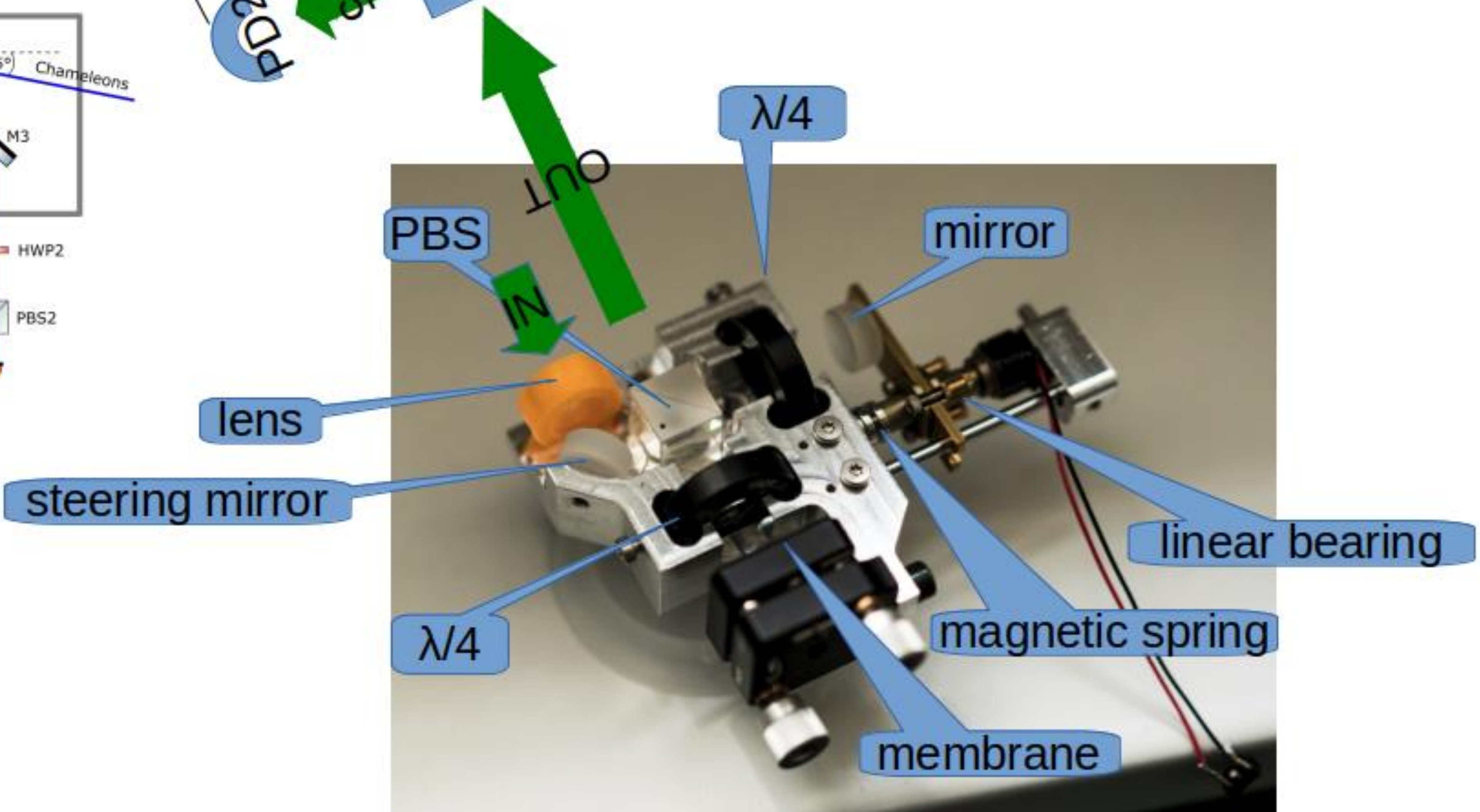
Develop a radiation pressure detector!

-measure momentum transfer
- high sensitivty

Michelson interferometer with homodyne detection







CAST – CERN Axion Solar Telescope

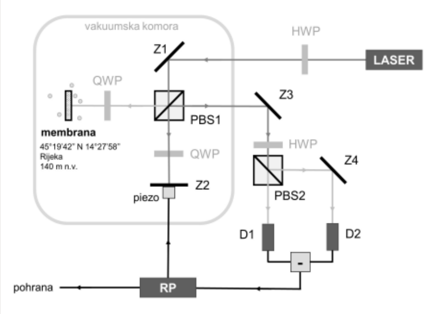
Detector@CAST

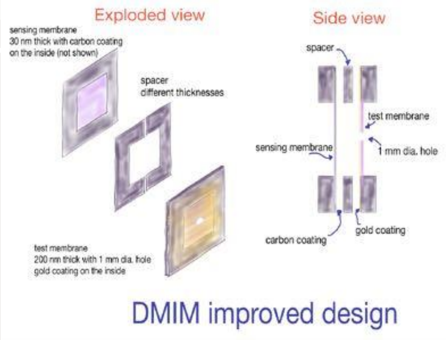
Contents lists available at ScienceDirect
Physics of the Dark Universe
journal homepage: www.elsevier.com/locate/dark

First results on the search for chameleons with the KWISP detector at CAST

S. Arguedas Cuendis [g], J. Baier [e], K. Barth [g], S. Baum [p,q], A. Bayirli [i,1], A. Belov [l], H. Bräuninger [f], G. Cantatore [r,s,*], J.M. Carmona [v], J.F. Castel [v], S.A. Cetin [i], T. Dafni [v], M. Davenport [g], A. Dermenev [l], K. Desch [a], B. Döbrich [g], H. Fischer [e,*], W. Funk [g], J.A. García [v,2], A. Gardikiotis [m], J.G. Garza [v], S. Gninenko [l], M.D. Hasinoff [t], D.H.H. Hoffmann [w], F.J. Iguaz [v], I.G. Irastorza [v], K. Jakovčić [u], J. Kaminski [a], M. Karuza [n,o,r,*], C. Krieger [a,3], B. Lakić [u], J.M. Laurent [g], G. Luzón [v], M. Maroudas [m], L. Miceli [b], S. Neff [d], I. Ortega [v,g], A. Ozbey [i,4], M.J. Pivovaroff [j], M. Rosu [k], J. Ruz [j], E. Ruiz Chóliz [v], S. Schmidt [a], M. Schumann [e], Y.K. Semertzidis [b,c], S.K. Solanki [h], L. Stewart [g], I. Tsagris [m], T. Vafeiadis [g], J.K. Vogel [j], M. Vretenar [n], S.C. Yildiz [i,5], K. Zioutas [m,g]

Proposals





DIRECTIONAL DARK MATTER

DETECTOR- GALACTIC HALO

Dark matter induced Brownian motion

Ting Cheng, Reinard Primulando & Martin Spinrath

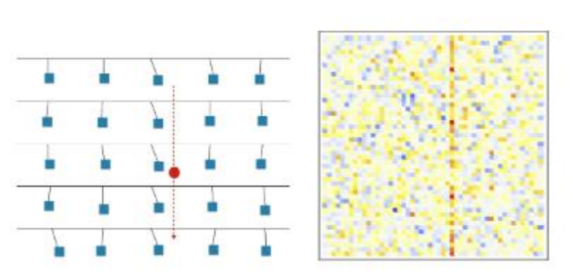
The European Physical Journal C **80**, Article number: 519 (2020) | Cite this article

GRAVITATIONAL DETECTION

PHYSICAL REVIEW D **102,** 072003 (2020)

Proposal for gravitational direct detection of dark matter

Daniel Carney,[1,2,*] Sohitri Ghosh,[1] Gordan Krnjaic,[2] and Jacob M. Taylor[1,†]



CASIMIR FORCE

MODIFICATION

Force sensor for chameleon and Casimir force experiments with parallel-plate configuration

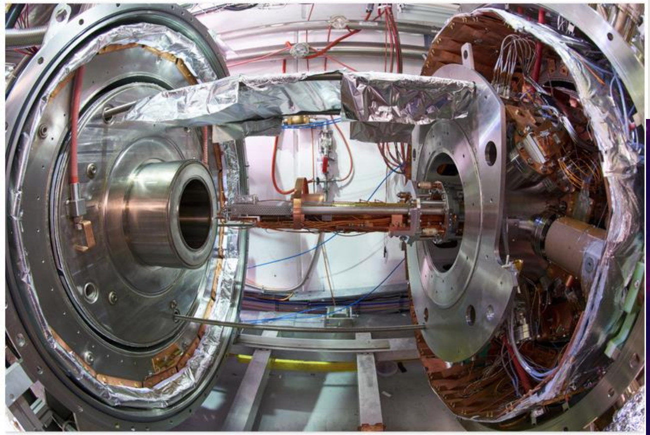
Attaallah Almasi, Philippe Brax, Davide Iannuzzi, and René I. P. Sedmik
Phys. Rev. D **91**, 102002 – Published 7 May 2015

Conclusion

CERN meets quantum technology

The CERN Quantum Technology Initiative will explore the potential of devices harnessing perplexing quantum phenomena such as entanglement to enrich and expand its challenging research programme

30 SEPTEMBER, 2020 | By Matthew Chalmers



The AEgIS 1T antimatter trap stack. CERN's AEgIS experiment is able to explore the multi-particle entangled nature of photons from positronium annihilation, and is one of several examples of existing CERN research with relevance to quantum technologies. (Image: CERN)

CERN Quantum Technology Initiative unveils strategic roadmap shaping CERN's role in next quantum revolution

CERN QTI reaches its next milestone today, with the unveiling of a first roadmap defining its medium- and long-term quantum research programme

14 OCTOBER, 2021

Dark matter

Invisible dark matter makes up most of the universe – but we can only detect it from its gravitational effects

Services

- Infrastructure for Experiments
  - B-field mapping
  - Detector cooling service
  - Gas Systems
  - Controls & DAQ
- Infrastructure for Detector R&D
  - Engineering Office
  - Irradiation Facilities
  - Solid State Detector Lab
  - Thin Film & Glass service
  - Wire Bonding Lab (BONDLAB)
  - Quality Assurance and Reliability Testing Lab (QARTlab)
  - Department Silicon Facility (DSF)
  - Scintillators production
  - Micro-Pattern Technologies

Science › Computing › Data centre

CERN Data Centre

At the heart of CERN's infrastructure

Pulling together: Superconducting electromagnets

Particles zipping round the LHC at close to the speed of light must follow precise paths. Powerful magnets keep the beams stable, accurate and safe

Cryogenics: Low temperatures, high performance

CERN's cryogenic systems cool over 1000 magnets on the LHC to temperatures close to absolute zero, where matter takes on some unusual properties

A vacuum as empty as interstellar space

With the first start-up of beams in 2008, the Large Hadron Collider (LHC) became the biggest operational vacuum system in the world

CENTAR ZA MIKRO- I NANOZNANOSTI I TEHNOLOGIJE

ODJEL ZA FIZIKU
DEPARTMENT OF PHYSICS
Sveučilište u Rijeci
University of Rijeka

CEMS
Center of Excellence for Advanced Materials and Sensing Devices

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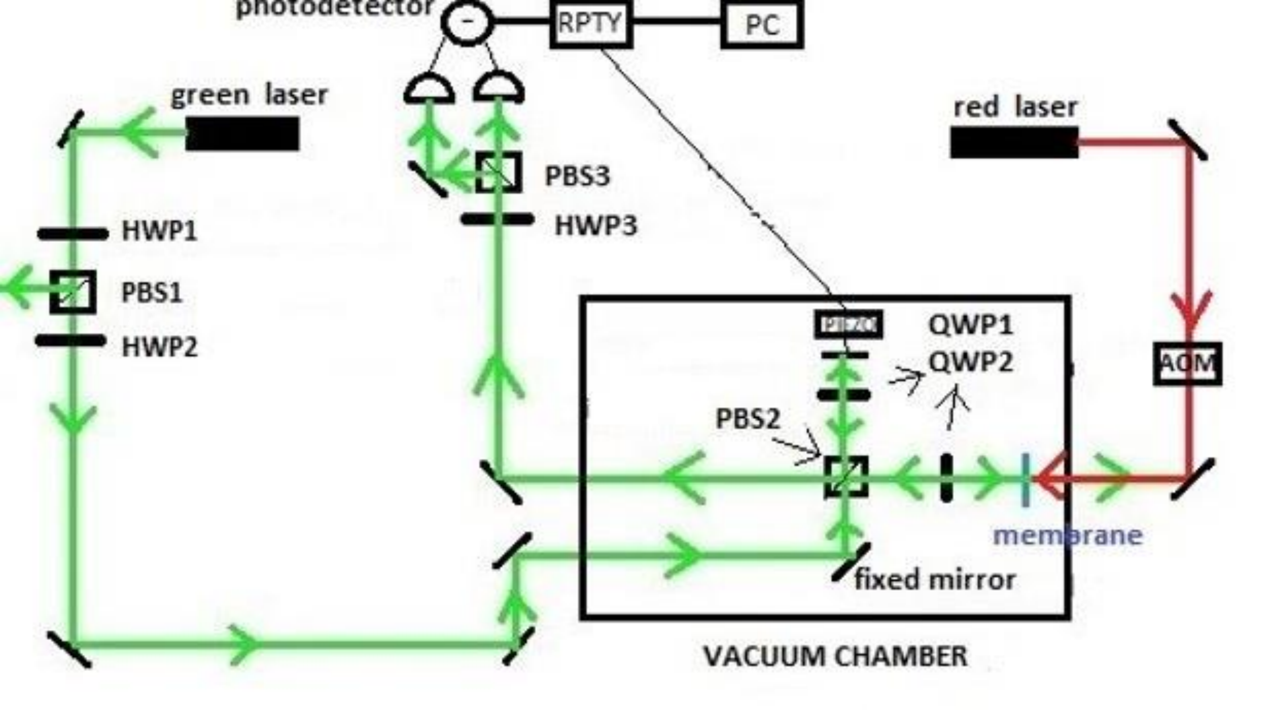
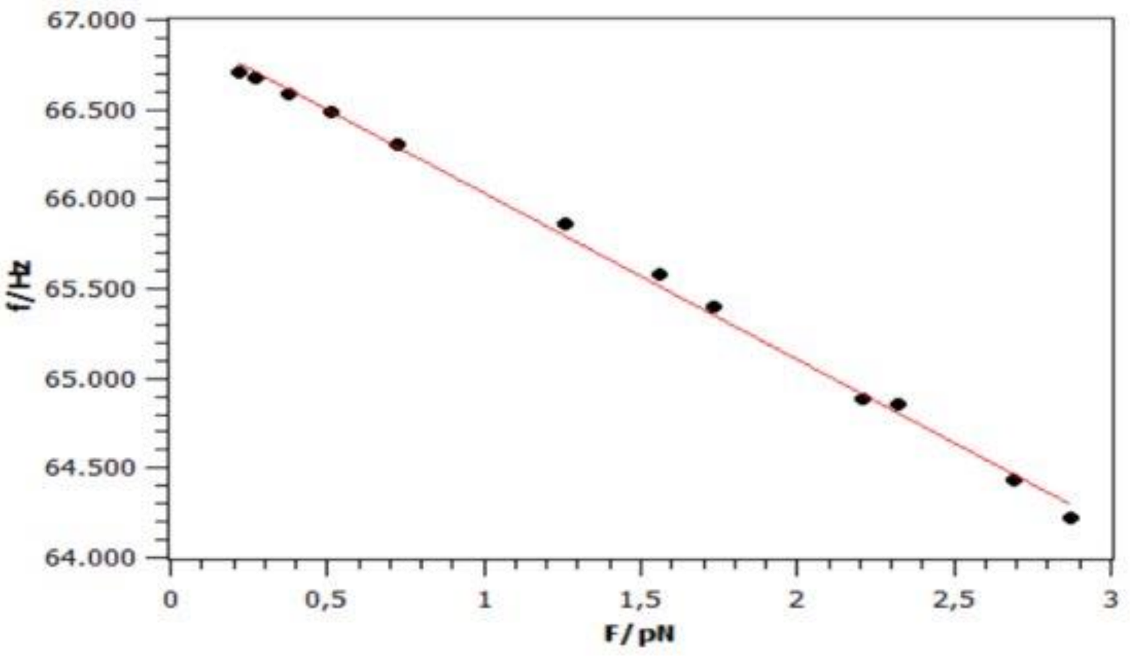
STRUKTURNI I INVESTICIJSKI FONDOVI

Ministarstvo znanosti i obrazovanja

KONKURENTNA HRVATSKA





Force calibration
- radiation pressure from 2 mW HeNe red laser
- 3 pN force / resolution ~fN

$$V_{eff}(\phi) = \Lambda^4 \left(1 + \frac{\Lambda^n}{\phi^n}\right) + \rho_m e^{\frac{\beta_m \phi}{M_{Pl}}} + \frac{1}{4} F_{\mu\nu} F^{\mu\nu} e^{\frac{\beta_\gamma \phi}{M_{Pl}}}$$

$$m_{\rm eff}^2 = (n+1)\,\frac{\beta_m \rho_m}{M_{\rm Pl}}\,\frac{1}{\phi_{\rm min}}$$

Dark Energy

- accelerated expansion of the Universe