Laboratory Tests

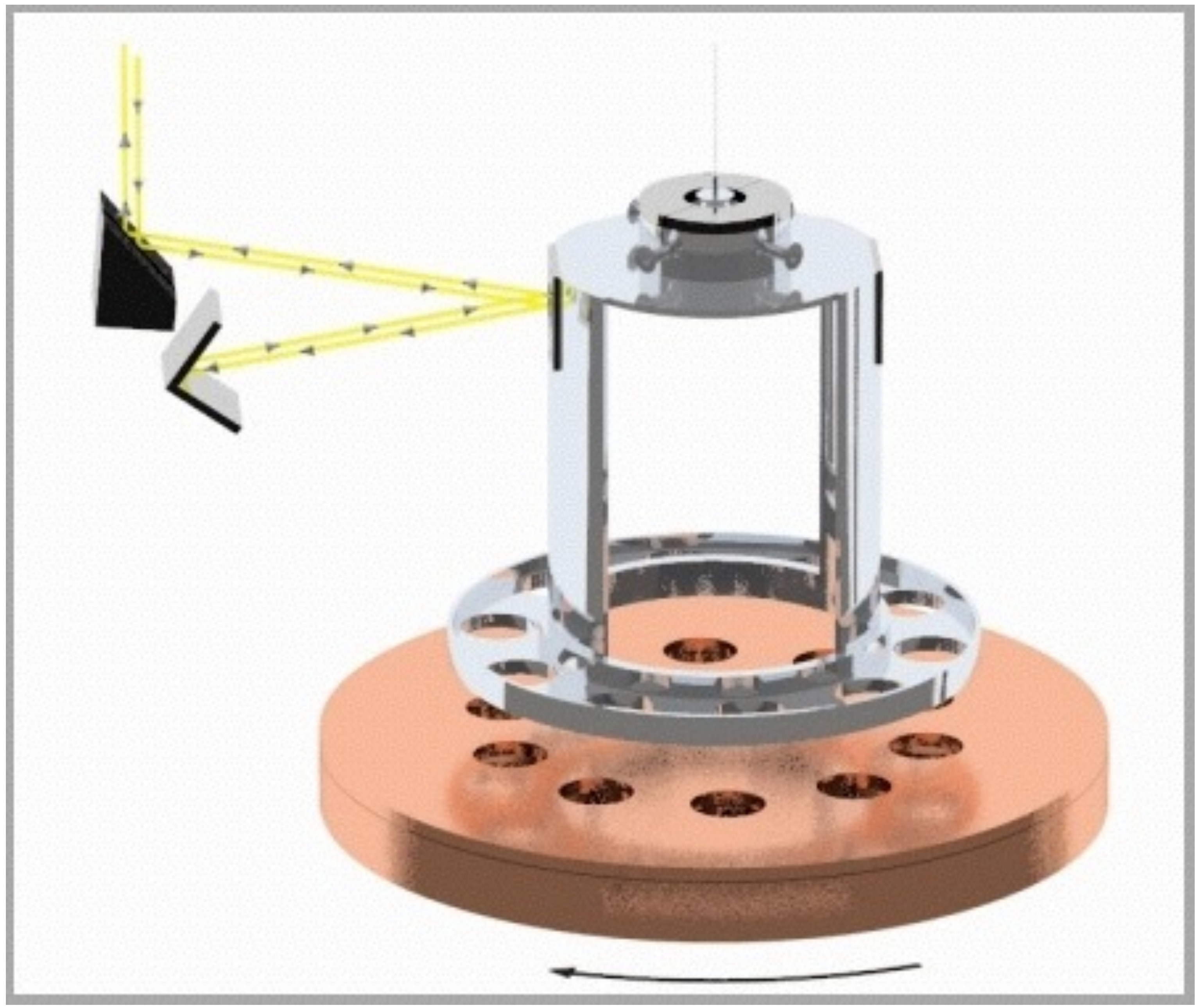
This is a selection of the laboratory experiments. Others include neutron interferometry, neutron bouncer, levitated microspheres etc.

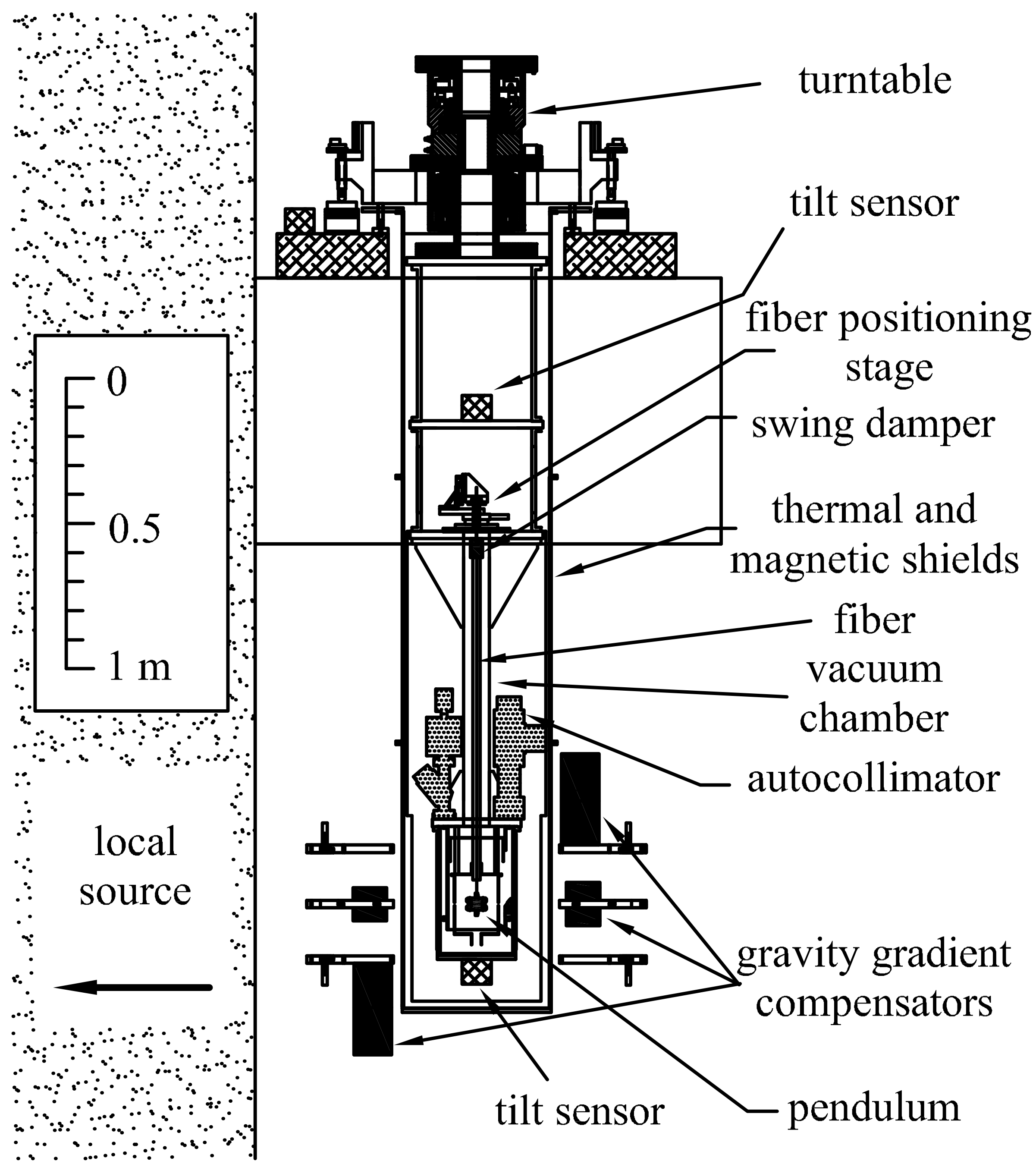
For more on Lab tests see Lorentz Centre, Leiden workshop, 12-17th Nov. Ask Philippe for details

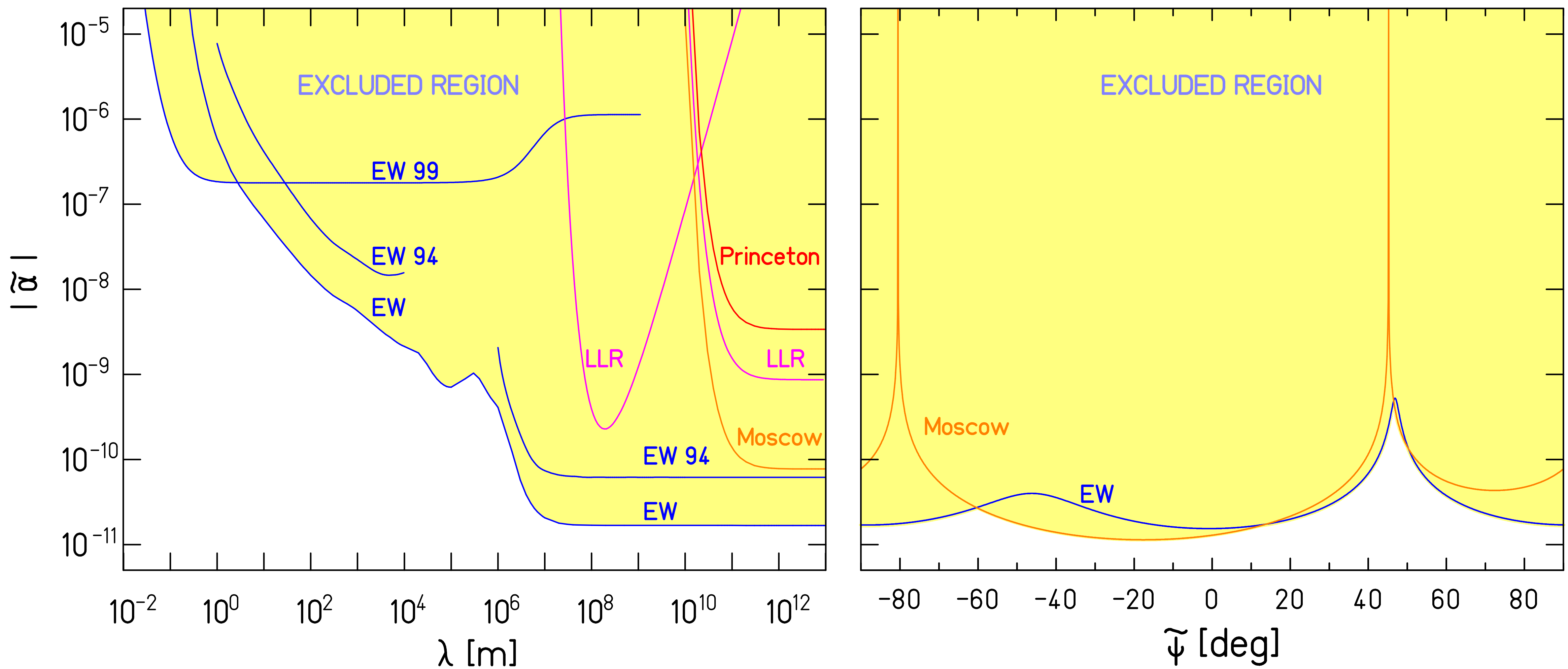
Eot-Wash Experiment

For a review see Wagner et al 1207.2442

Be-Ti and
Be-Al test
masses




turntable
tilt sensor
fiber positioning stage
swing damper
thermal and magnetic shields
fiber
vacuum chamber
autocollimator
gravity gradient compensators
pendulum
tilt sensor
0
0.5
1 m
local source



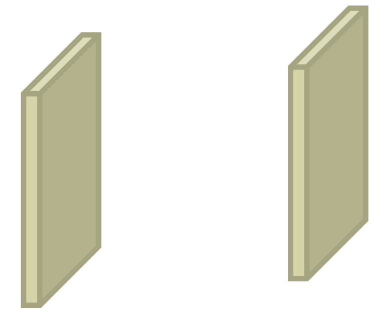
EXCLUDED REGION
EW 99
EW 94
EW
LLR
Princeton
LLR
Moscow
EW 94
EW
$|\tilde{\alpha}|$
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-2} 10^{0} 10^{2} 10^{4} 10^{6} 10^{8} 10^{10} 10^{12}
λ [m]
EXCLUDED REGION
Moscow
EW
−80 −60 −40 −20 0 20 40 60 80
$\tilde{\psi}$ [deg]

Casimir Force Experiments

Brax et al PRD76(07)124034

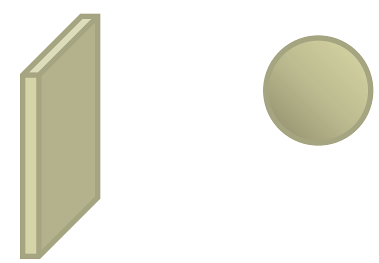
The scalar force could be detected in Casimir type experiments

force between parallel plates



$$F_{cas} \approx d^{-4}$$

force between a plate and a sphere



chameleonic force

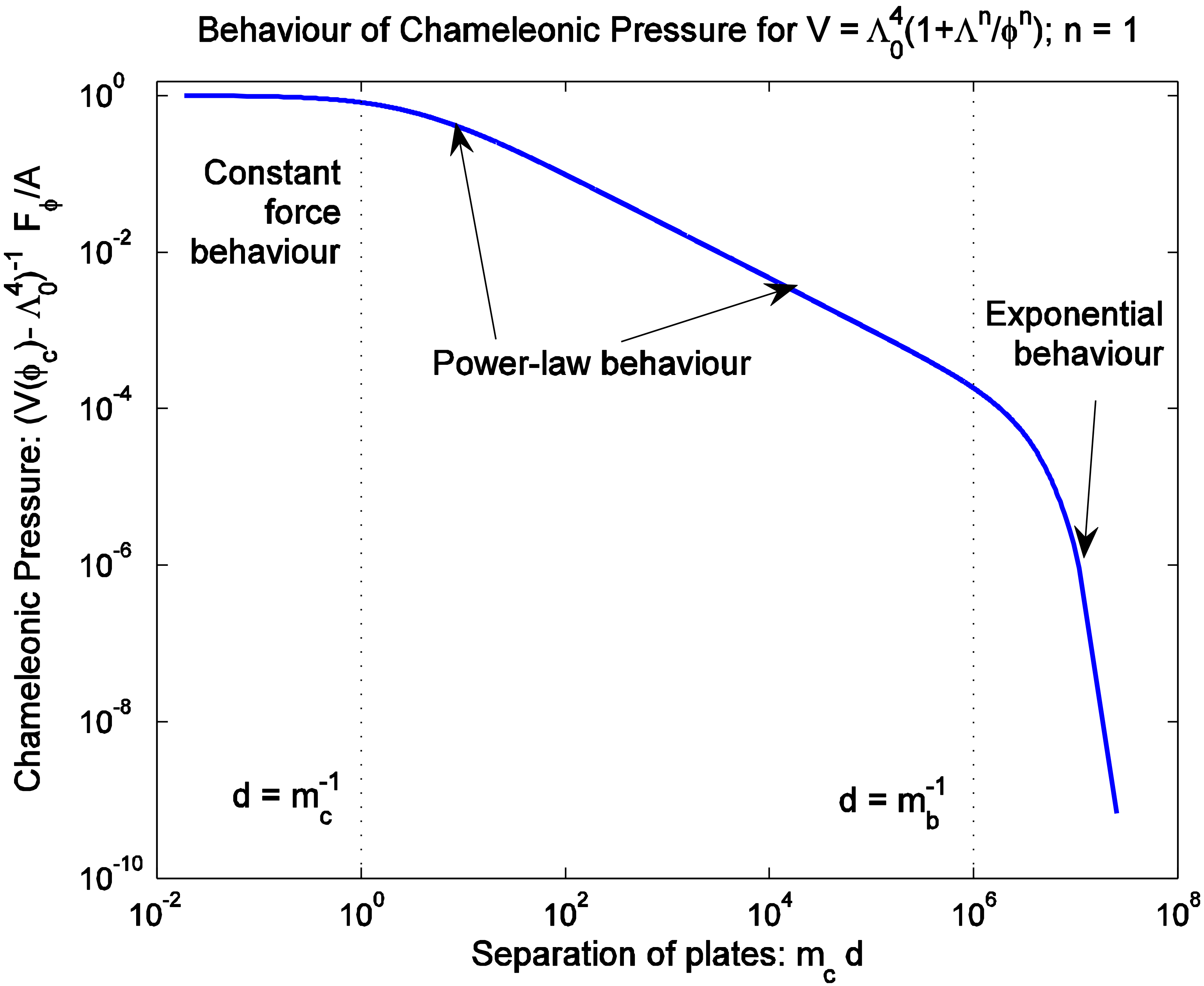
$$\frac{F_\phi}{A} \sim \Lambda^4 (\Lambda d)^{-\frac{2n}{n+2}}$$

$$\frac{F_\phi}{F_{\mathrm{cas}}} \sim \frac{240}{\pi^2} (\Lambda d)^{\frac{2(n+4)}{n+2}}$$

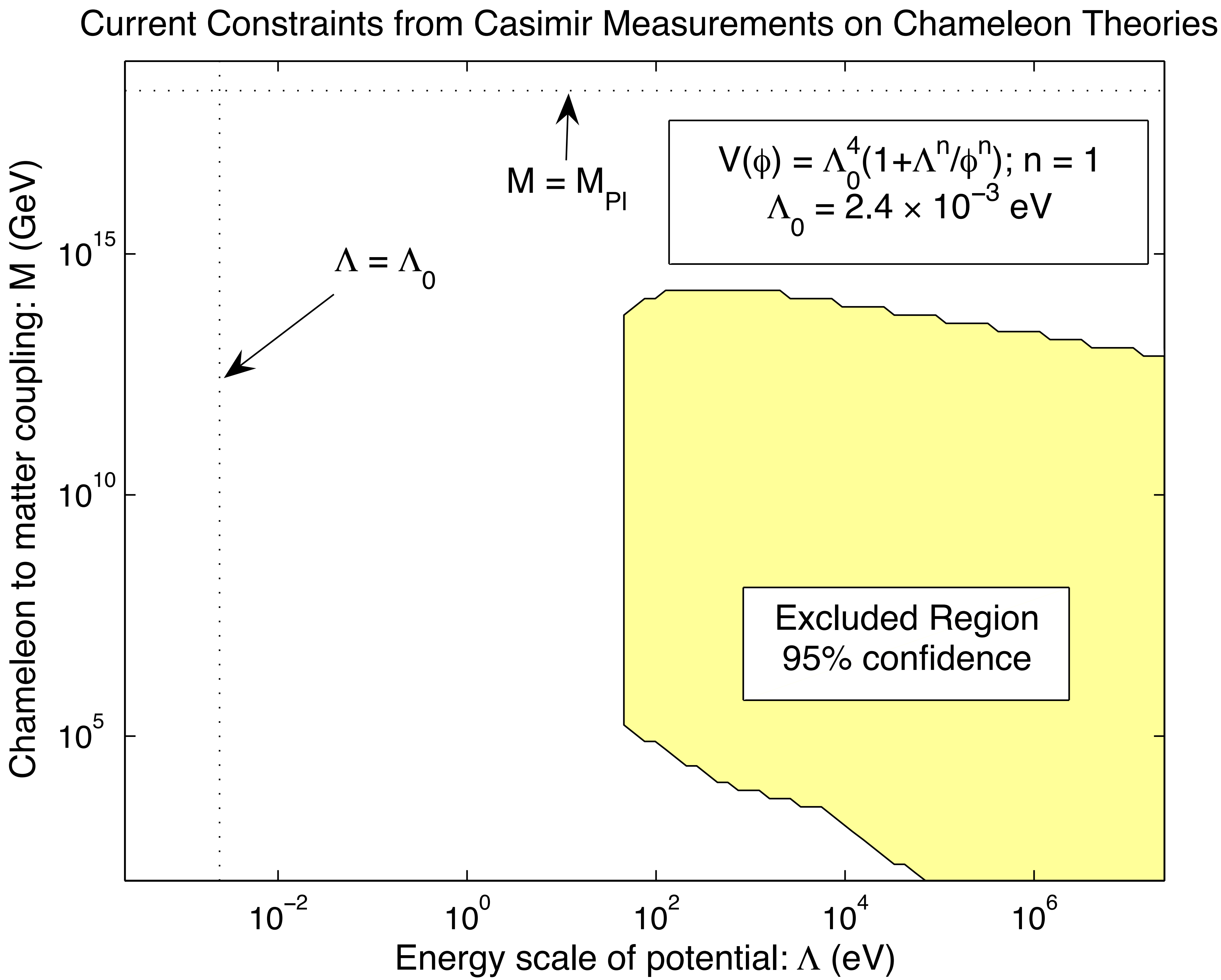
dark energy scale is

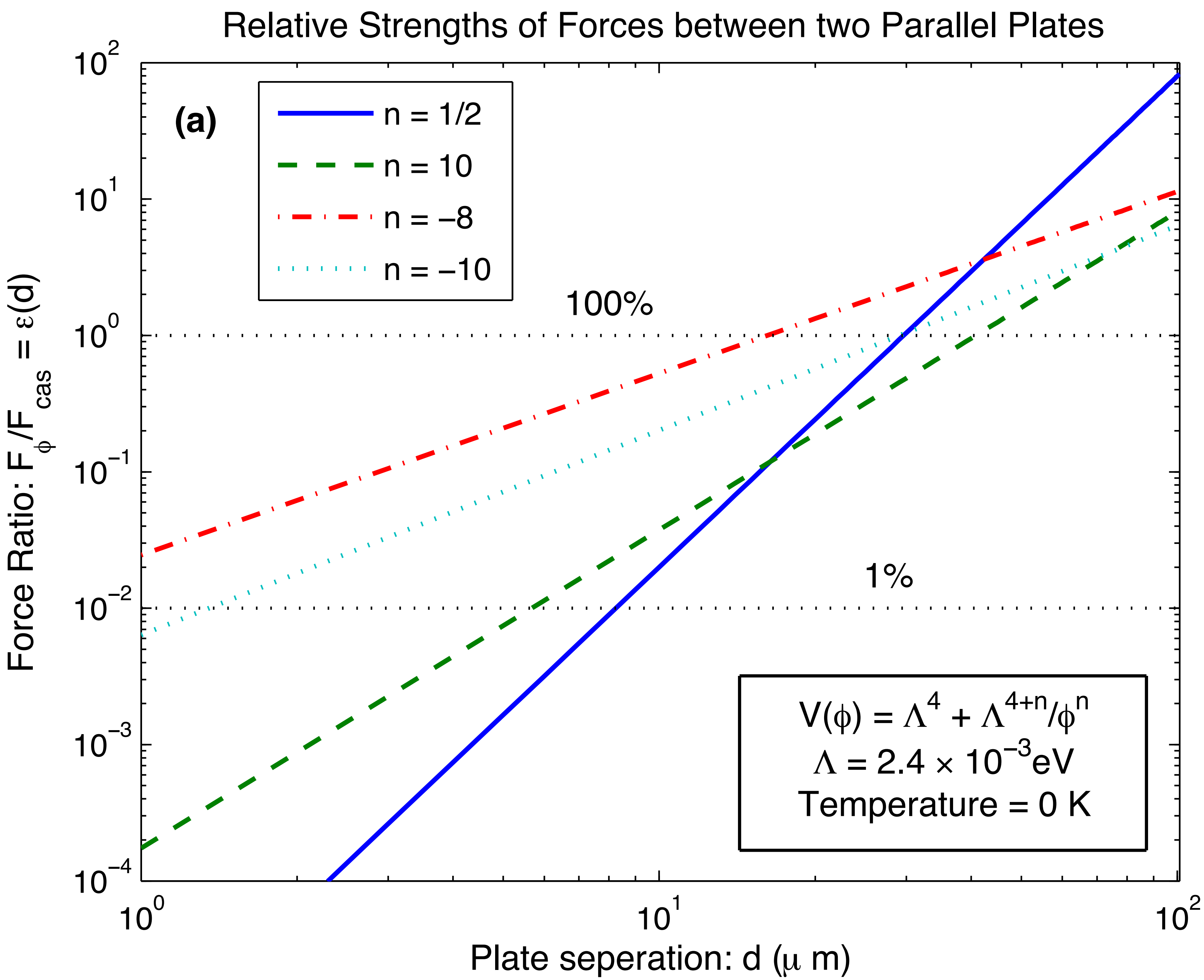
$$\Lambda \approx 10^{-3} eV$$

$$\Lambda^{-1} \sim 82 \mu m$$

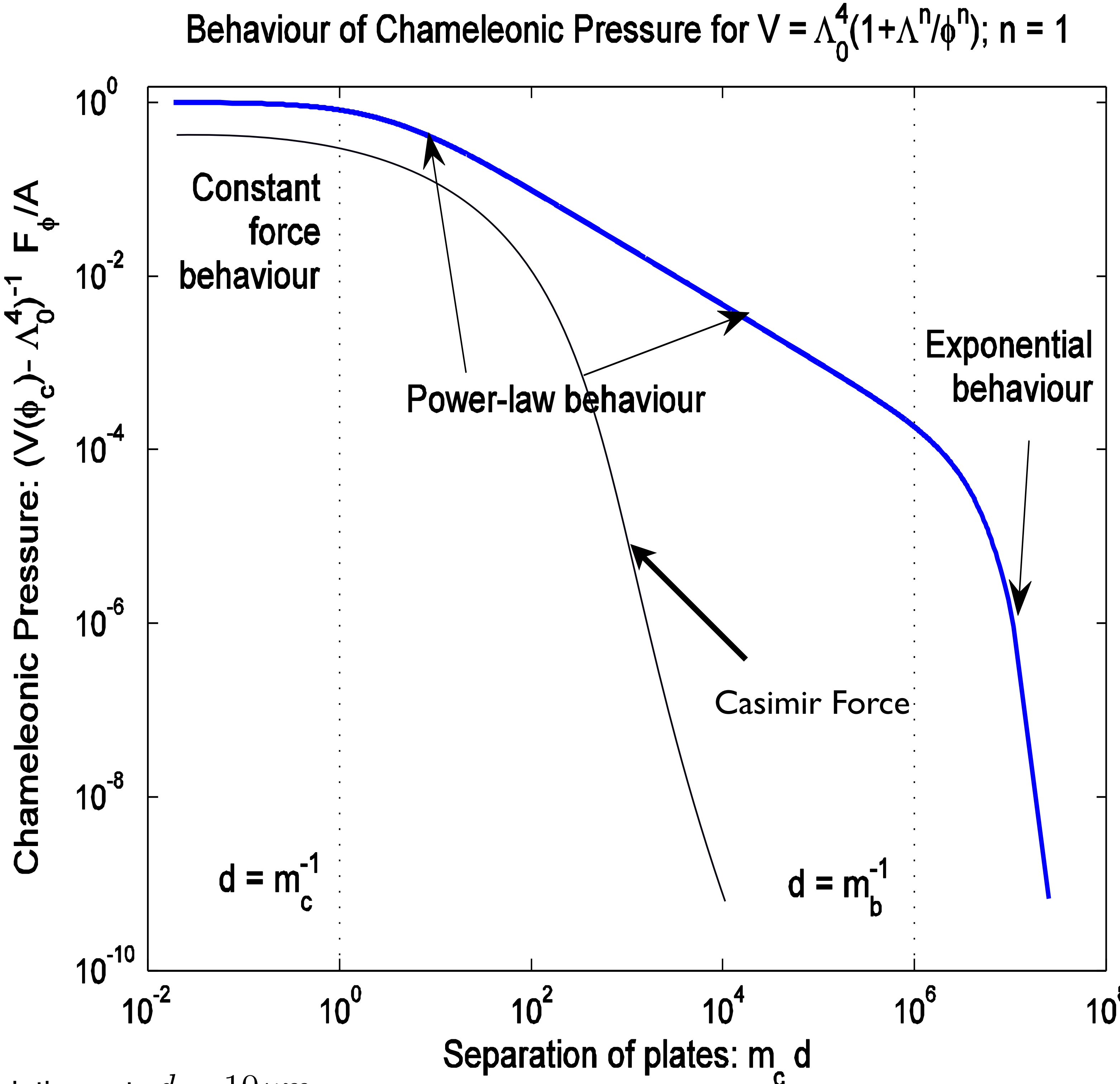


mc is the mass of the chameleon in the plates and mb the mass in the vacuum between the plates

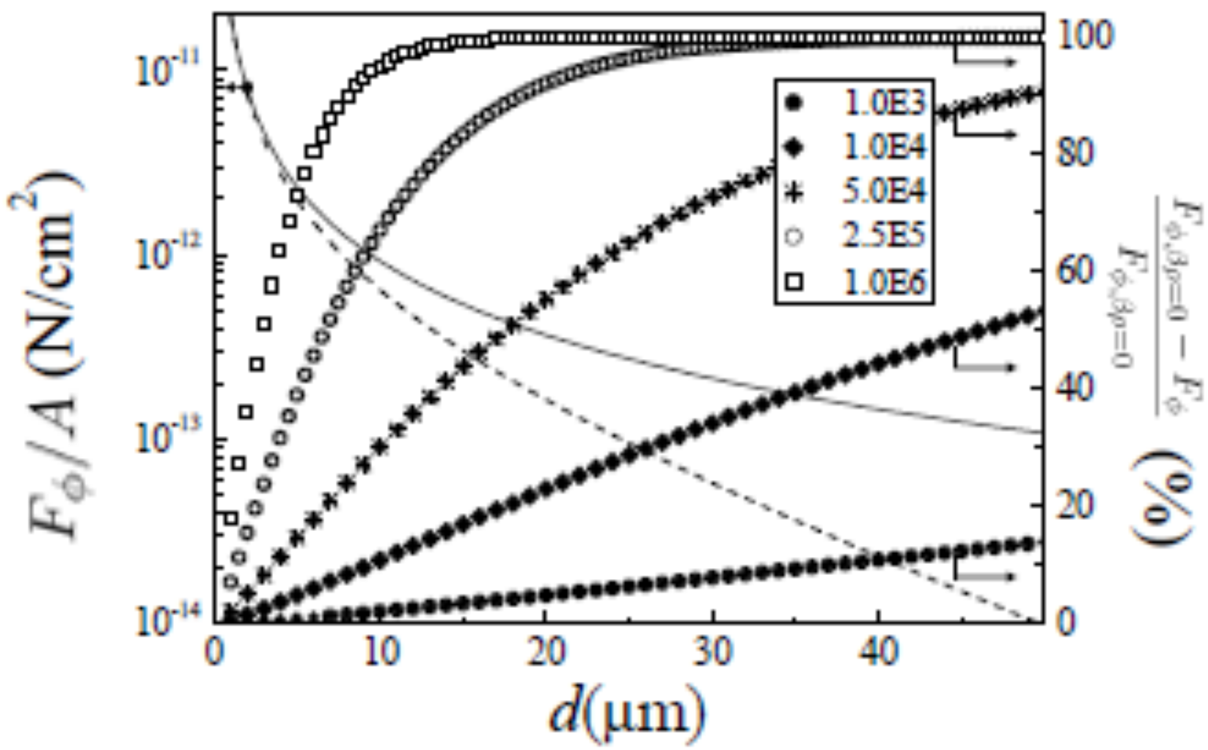

Current Constraints from Casimir Measurements on Chameleon Theories
Chameleon to matter coupling: M (GeV)
Energy scale of potential: Λ (eV)
10^{15}
10^{10}
10^{5}
10^{-2}
10^{0}
10^{2}
10^{4}
10^{6}
$M = M_{Pl}$
$\Lambda = \Lambda_0$
$V(\phi) = \Lambda_0^4(1+\Lambda^n/\phi^n)$; $n = 1$
$\Lambda_0 = 2.4 \times 10^{-3}$ eV
Excluded Region
95% confidence

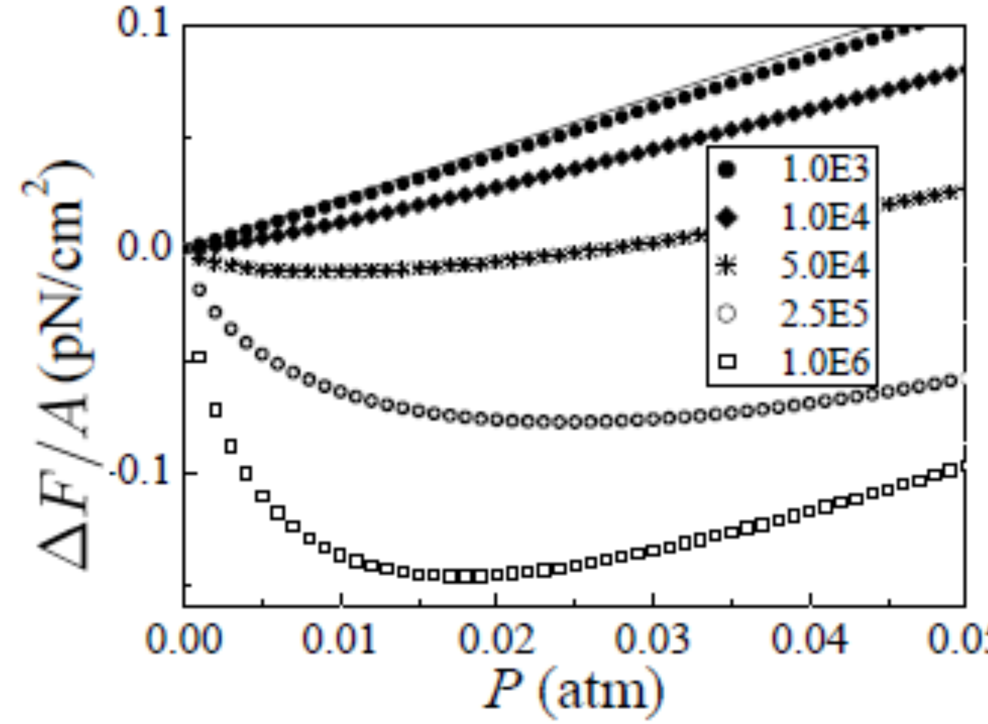


Relative Strengths of Forces between two Parallel Plates
(a)
n = 1/2
n = 10
n = −8
n = −10
100%
1%
V(ϕ) = Λ^4 + Λ^{4+n}/ϕ^n
Λ = 2.4 × 10^{−3}eV
Temperature = 0 K
Force Ratio: F_ϕ/F_cas = ε(d)
Plate seperation: d (μ m)



10% deviations at $d = 10\mu m$
100% deviations at $d = 30\mu m$

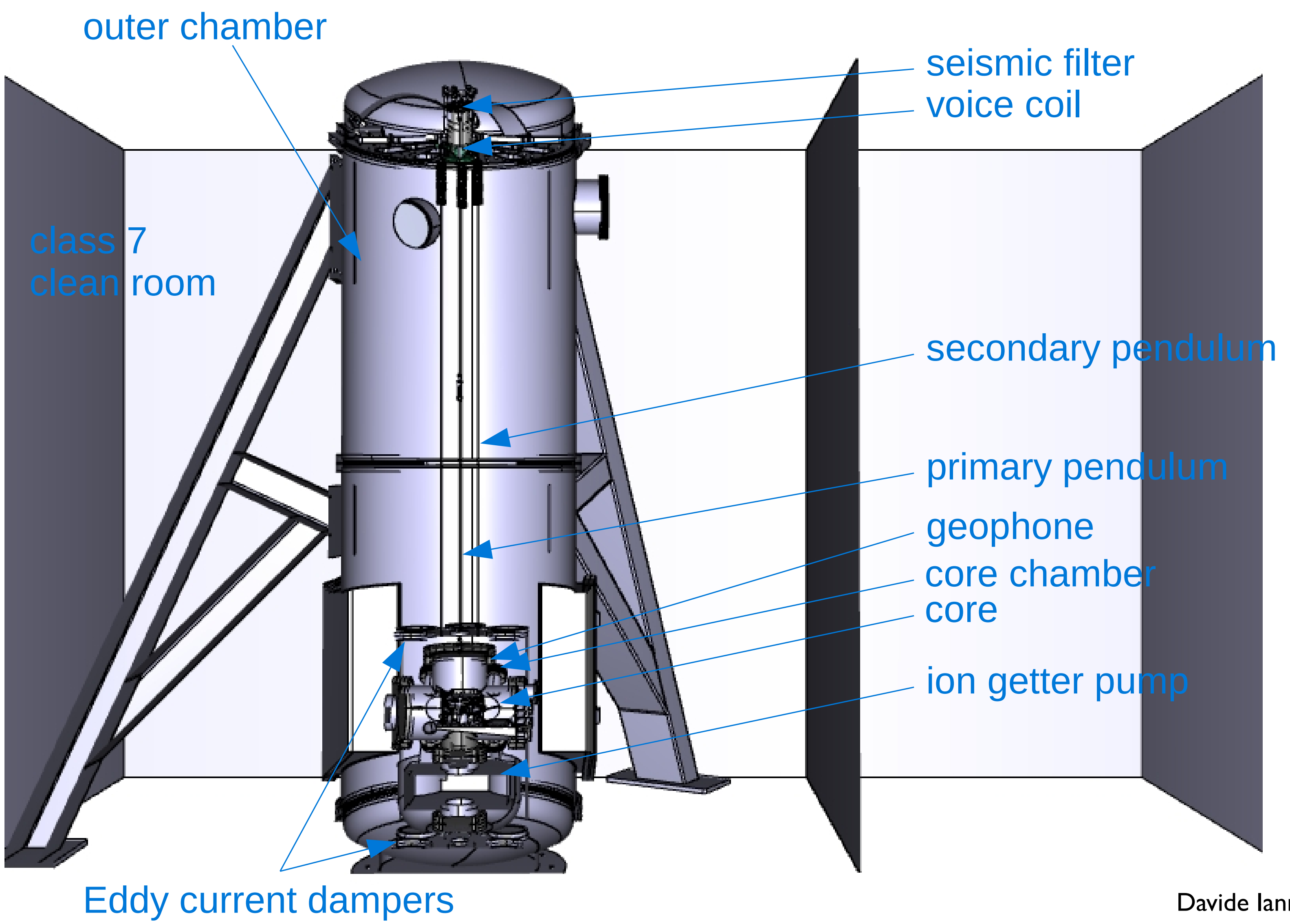




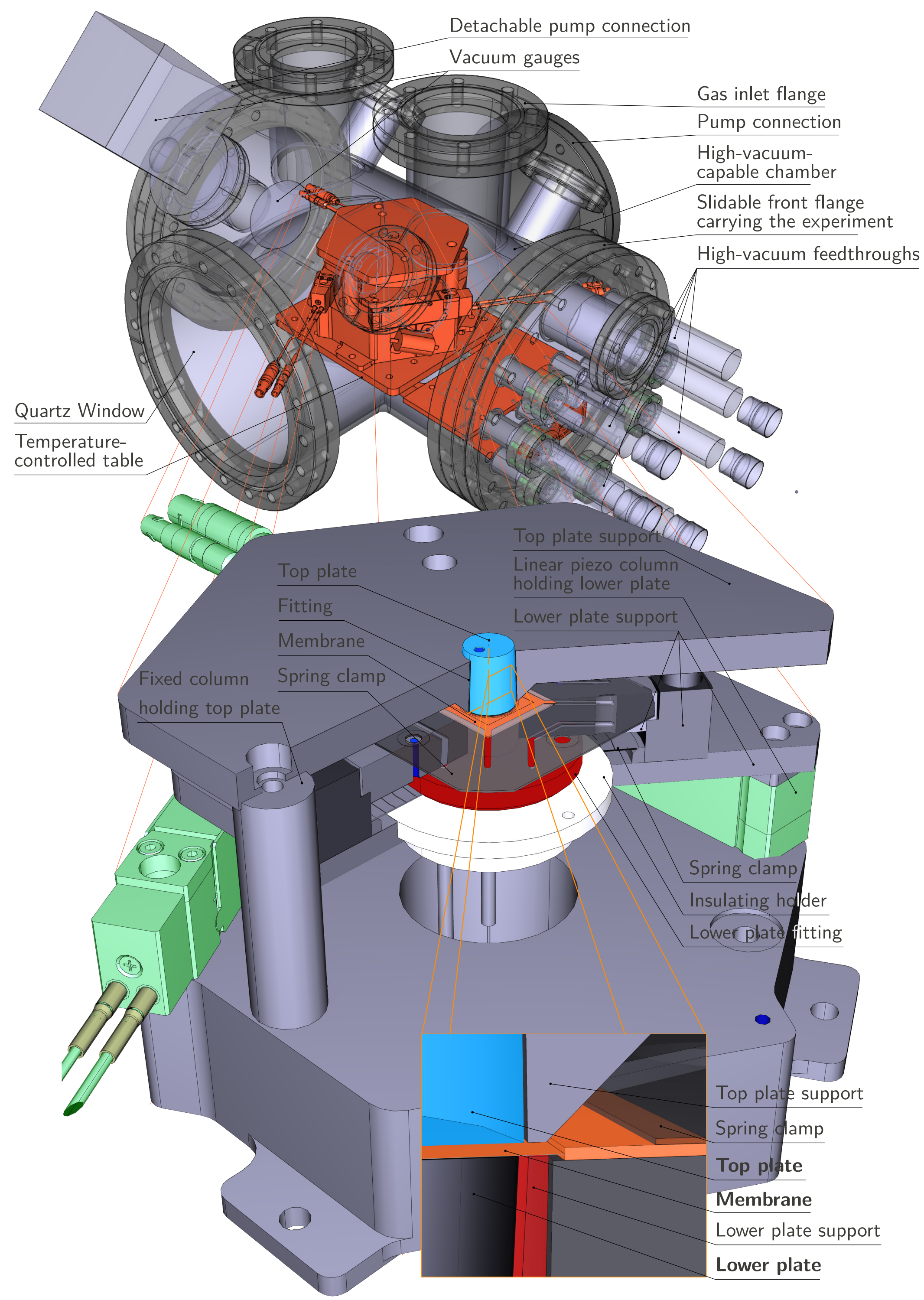
by changing the density between plates the chameleonic force is screened

for plate separation of 30 microns, inject gas at different pressures could determine the coupling to matter

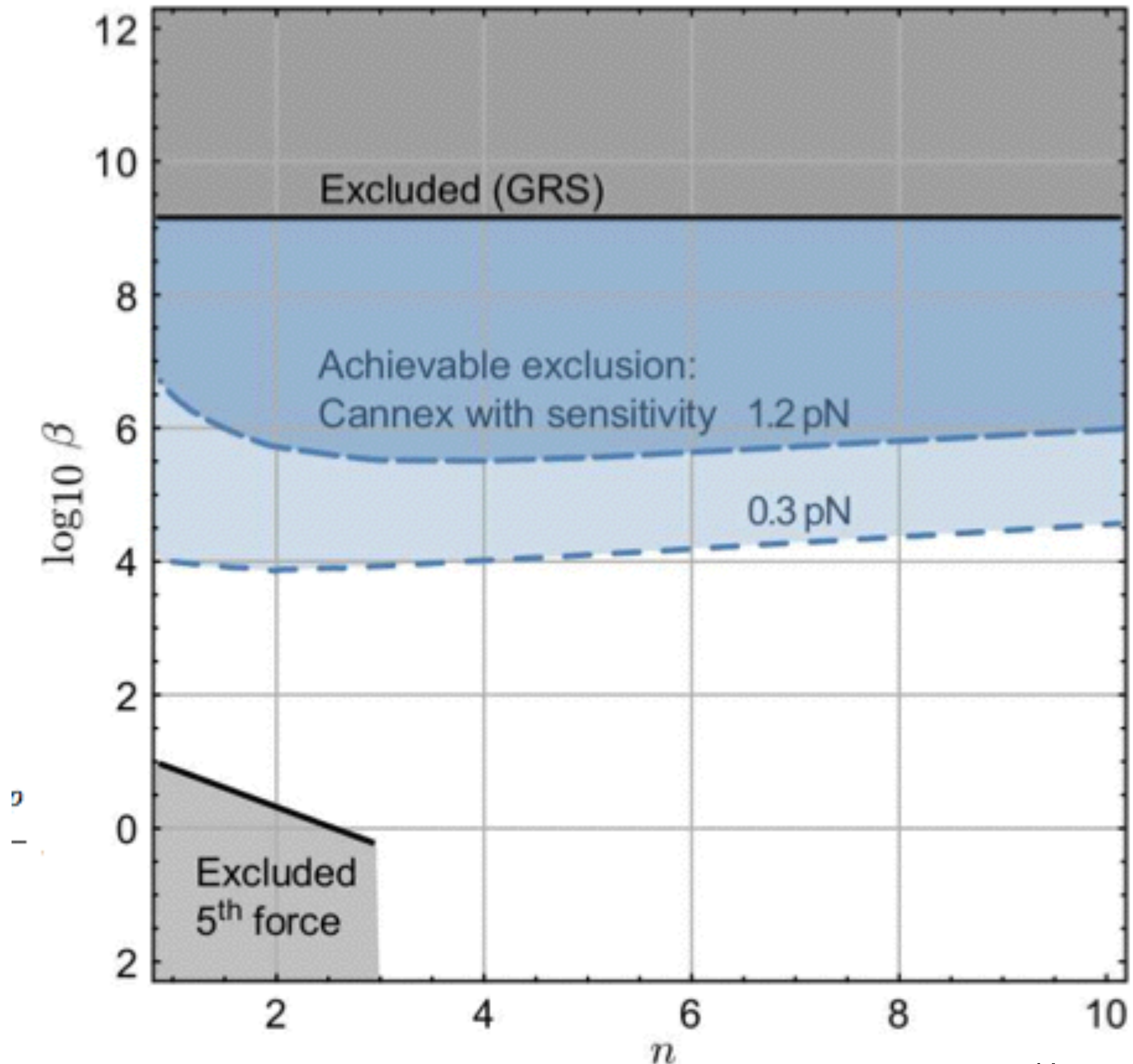
with Davide Iannuzzi
PRL104(10)241101



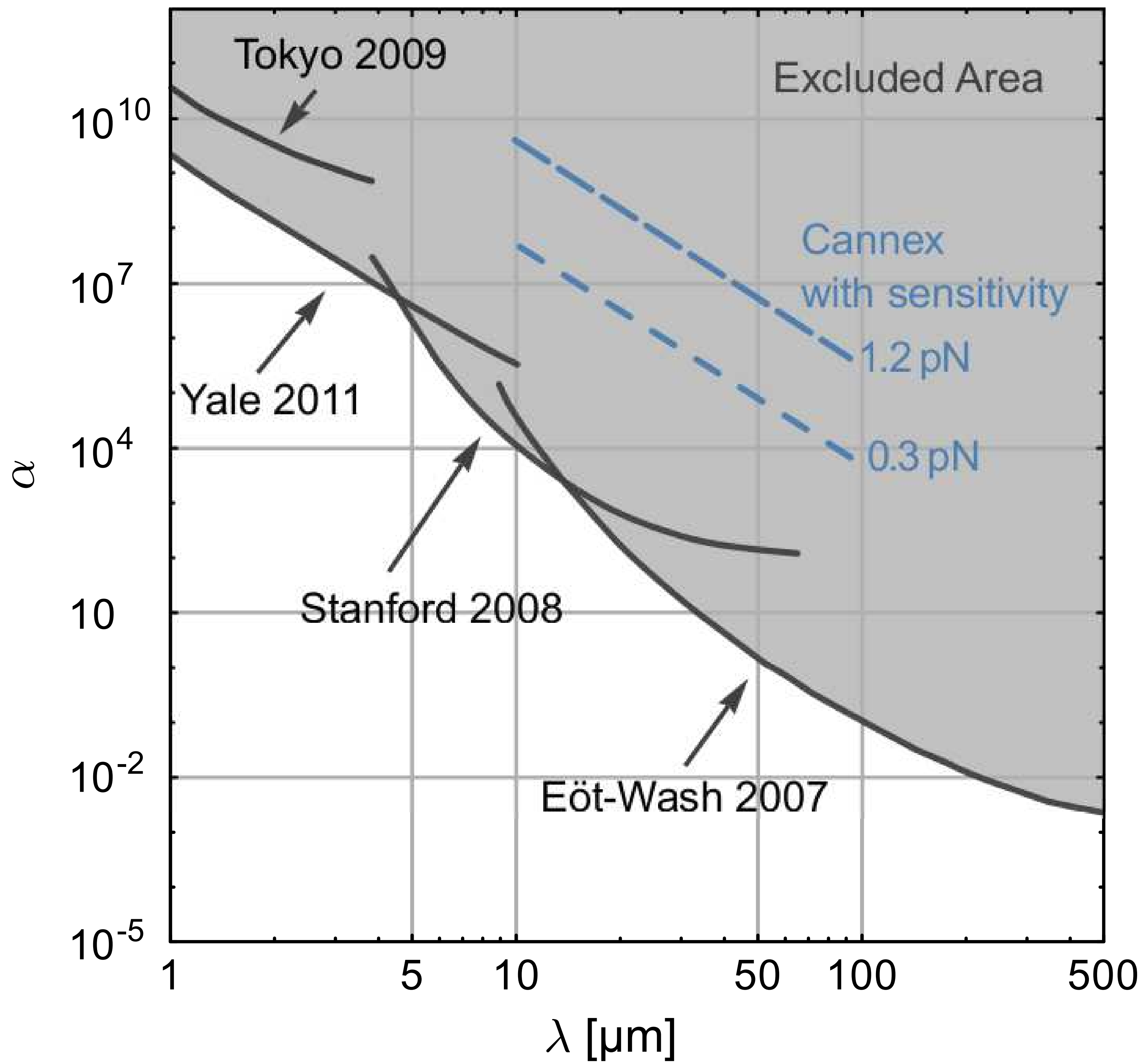
Davide Iannuzzi, Rene Sedmik et al



Detachable pump connection
Vacuum gauges
Gas inlet flange
Pump connection
High-vacuum-
capable chamber
Slidable front flange
carrying the experiment
High-vacuum feedthroughs
Quartz Window
Temperature-
controlled table
Top plate support
Linear piezo column
holding lower plate
Lower plate support
Top plate
Fitting
Membrane
Spring clamp
Fixed column
holding top plate
Spring clamp
Insulating holder
Lower plate fitting
Top plate support
Spring clamp
Top plate
Membrane
Lower plate support
Lower plate



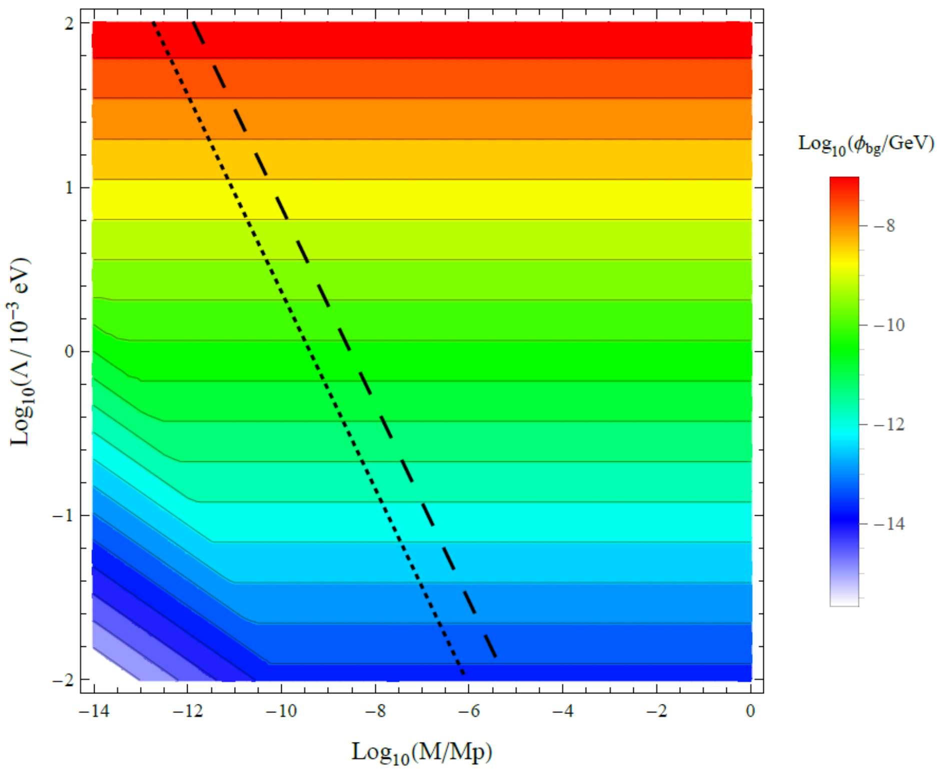
Almasi et al 1505.01763


Tokyo 2009
Excluded Area
Cannex
with sensitivity
1.2 pN
0.3 pN
Yale 2011
Stanford 2008
Eöt-Wash 2007
10^{10}
10^7
10^4
10
10^{-2}
10^{-5}
α
1
5
10
50
100
500
λ [µm]

Why Atom Interferometry?

In a spherical vacuum chamber, radius 10 cm, pressure 10^{-10} Torr

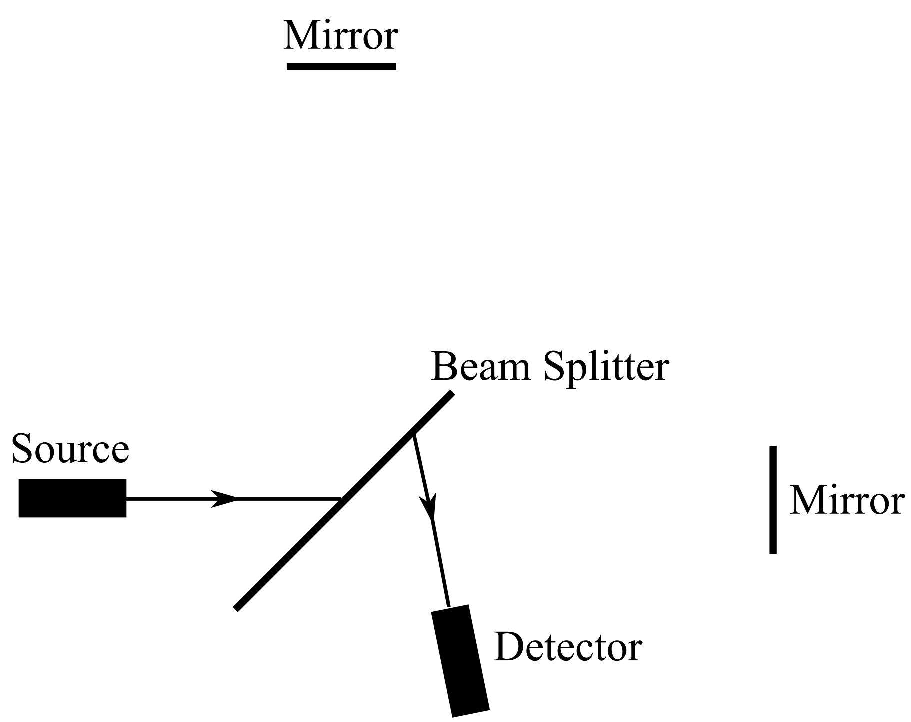
Atoms are unscreened above black lines
(dashed = caesium, dotted = lithium)

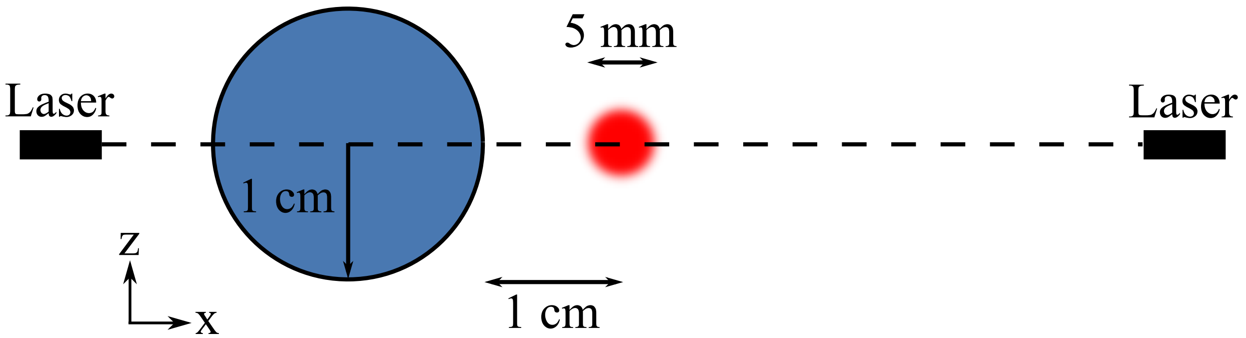


Burrage, Copeland and Hinds 1408.1409

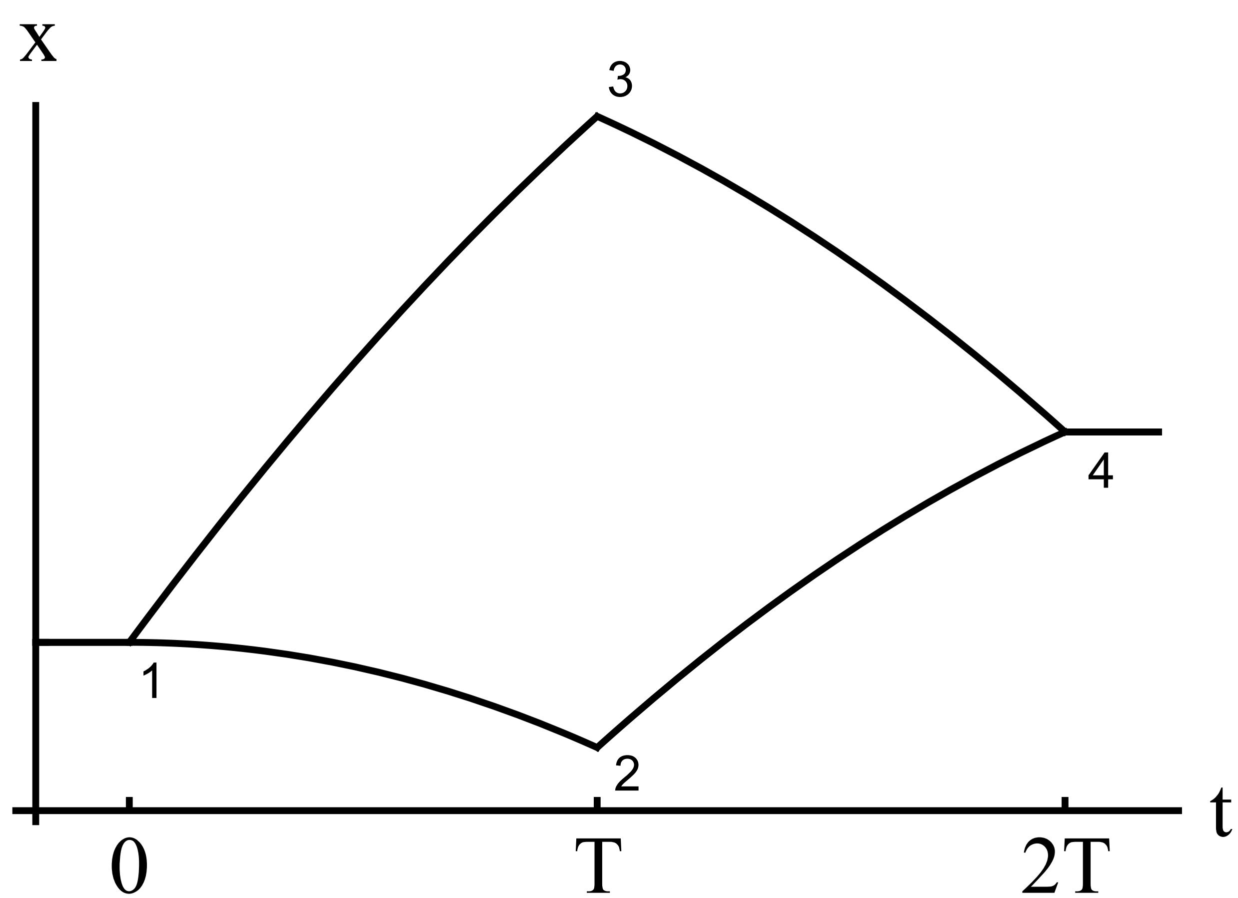
CB, Copeland, Hinds. (2015)

Muller et al 1502.038888; 1603.06587



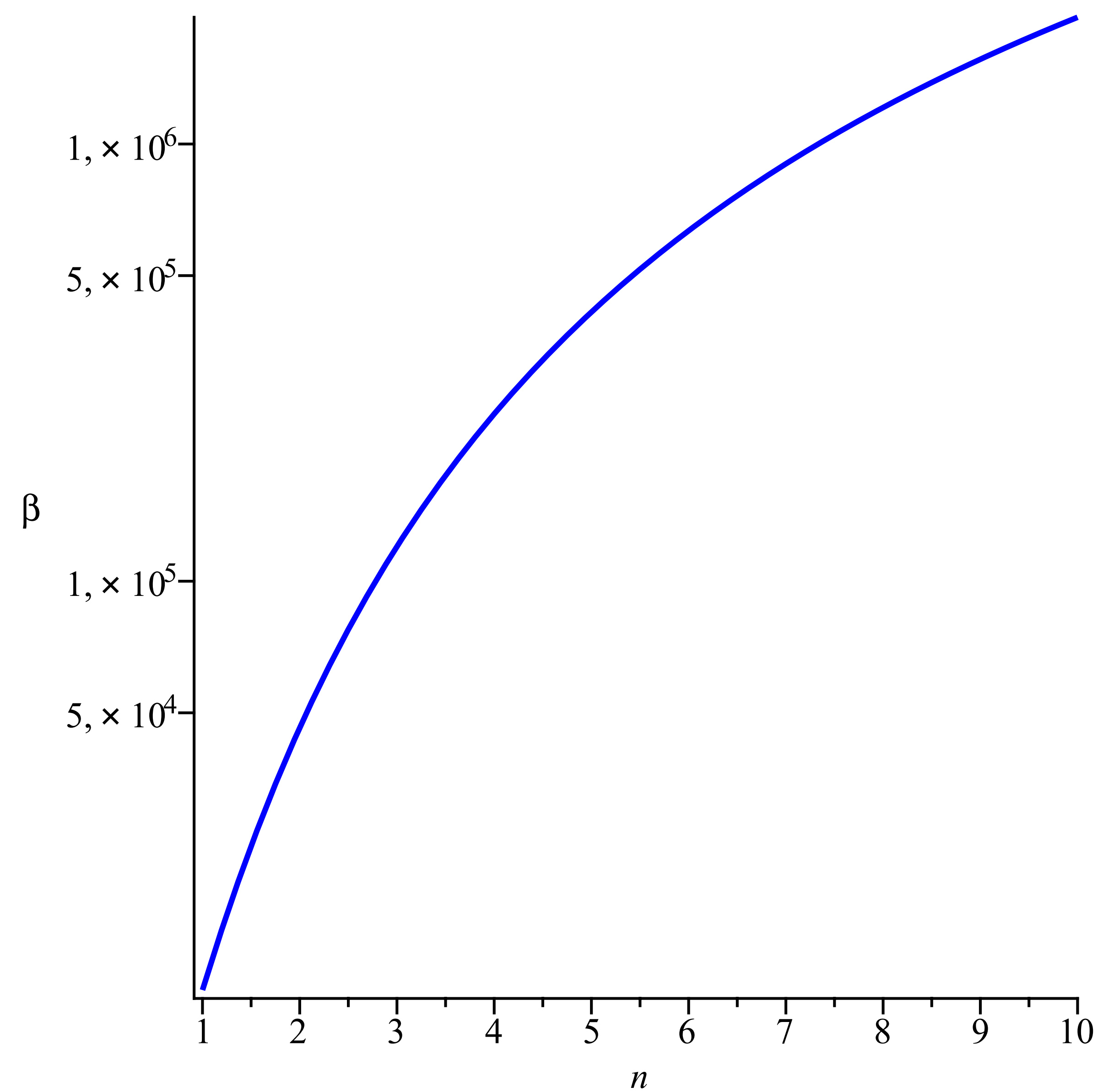


5 mm
Laser
Laser
1 cm
z
x
1 cm

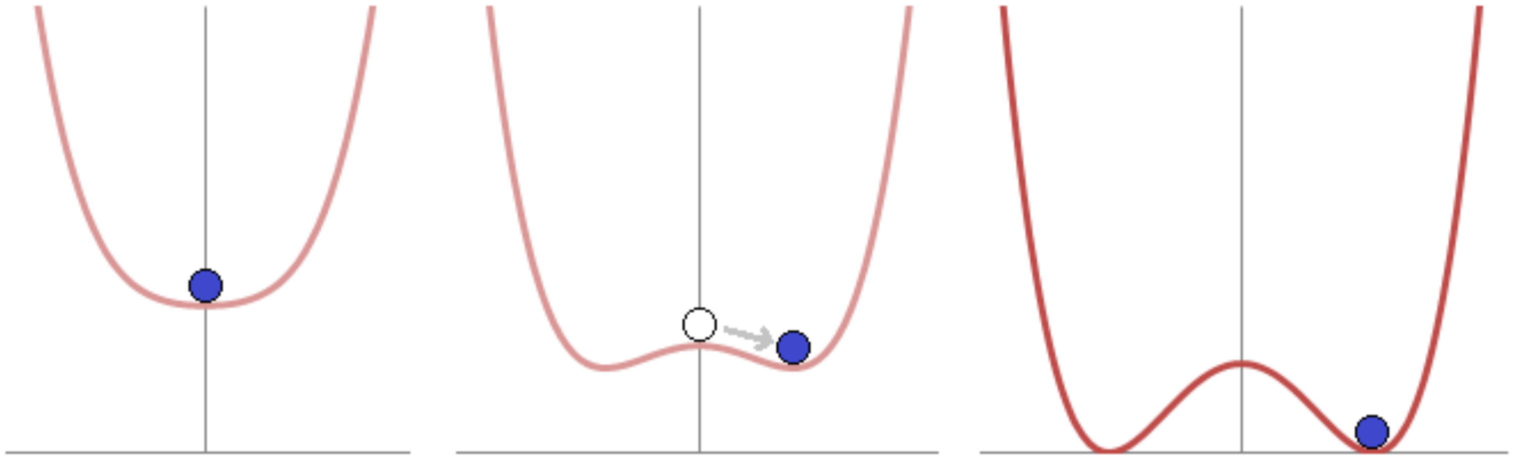

x
3
4
1
2
t
0
T
2T

Chameleons

from Brax and ACD - 1609.09242



Symmetron Screening



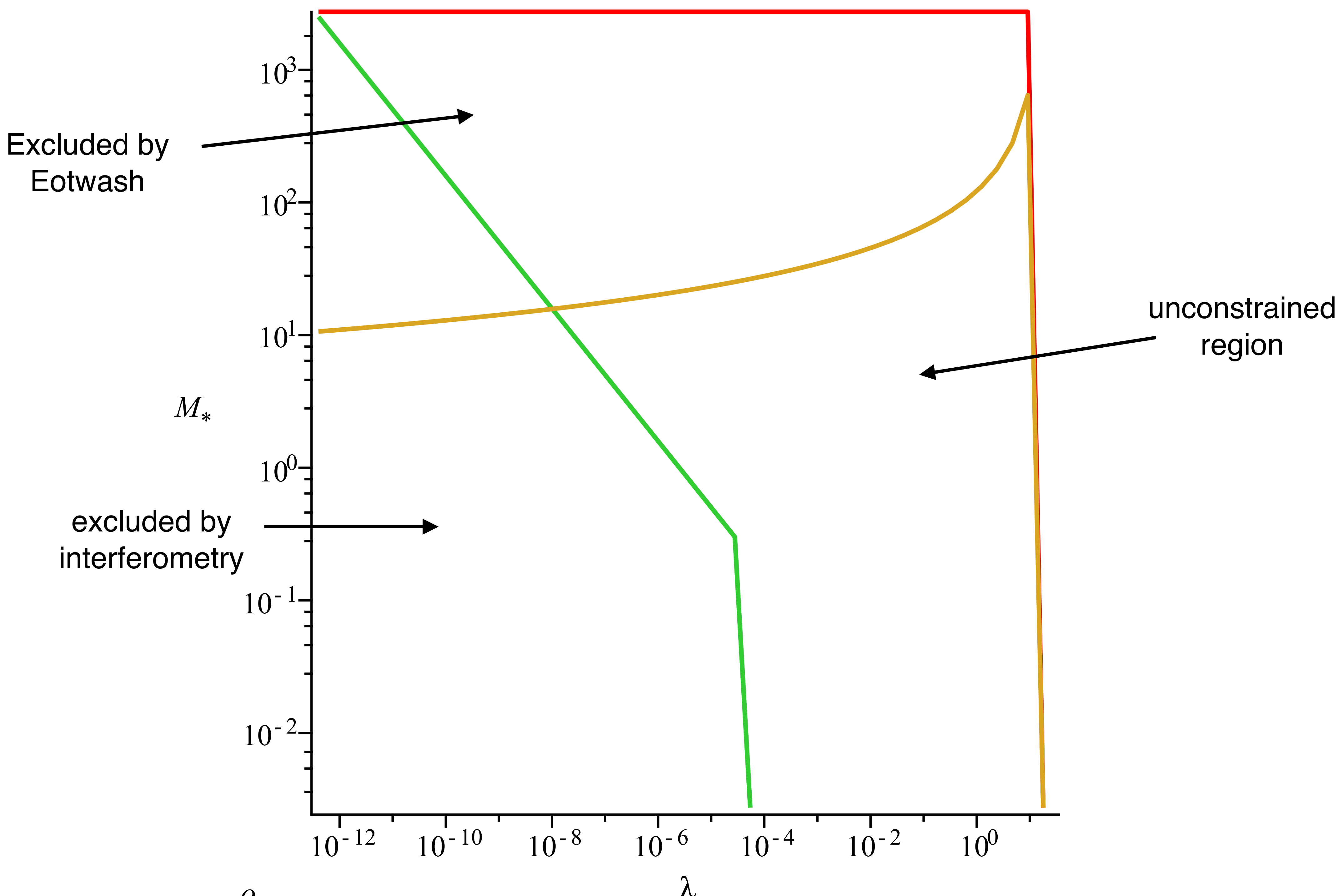
Force on test particle vanishes when symmetry is restored

$$F = \phi \nabla \phi / M^2$$

Hinterbichler, Khoury. (2010).

This potential looks like a Higgs potential.
What happens in Higgs inflation?

Symmetrons



$$M_\star \equiv \frac{\rho_\star}{\mu^2}$$

Chameleons Coupled to Photons

- Chameleons may couple to electromagnetism:

$$\mathcal{L}_{\text{optics}} = \frac{e^{\phi/M}}{g^2} F_{\mu\nu} F^{\mu\nu}$$

this coupling is induced by the conformal anomaly

- Cavity experiments in the presence of a constant magnetic field may reveal the existence of chameleons.
- They may also be detected via astrophysics and cosmology.

Coupling to Photons

this coupling enables photon chameleon mixing in the presence of a magnetic field with mixing angle

$$\tan 2\theta = \frac{2\omega B}{M_\gamma (m^2 - \frac{B^2}{M_\gamma^2} - \omega_{\mathrm{Pl}}^2)}$$

the mixing probability is

$$P_{\mathrm{chameleon}} = \sin^2\theta \sin^2(\frac{\Delta}{\cos 2\theta})$$

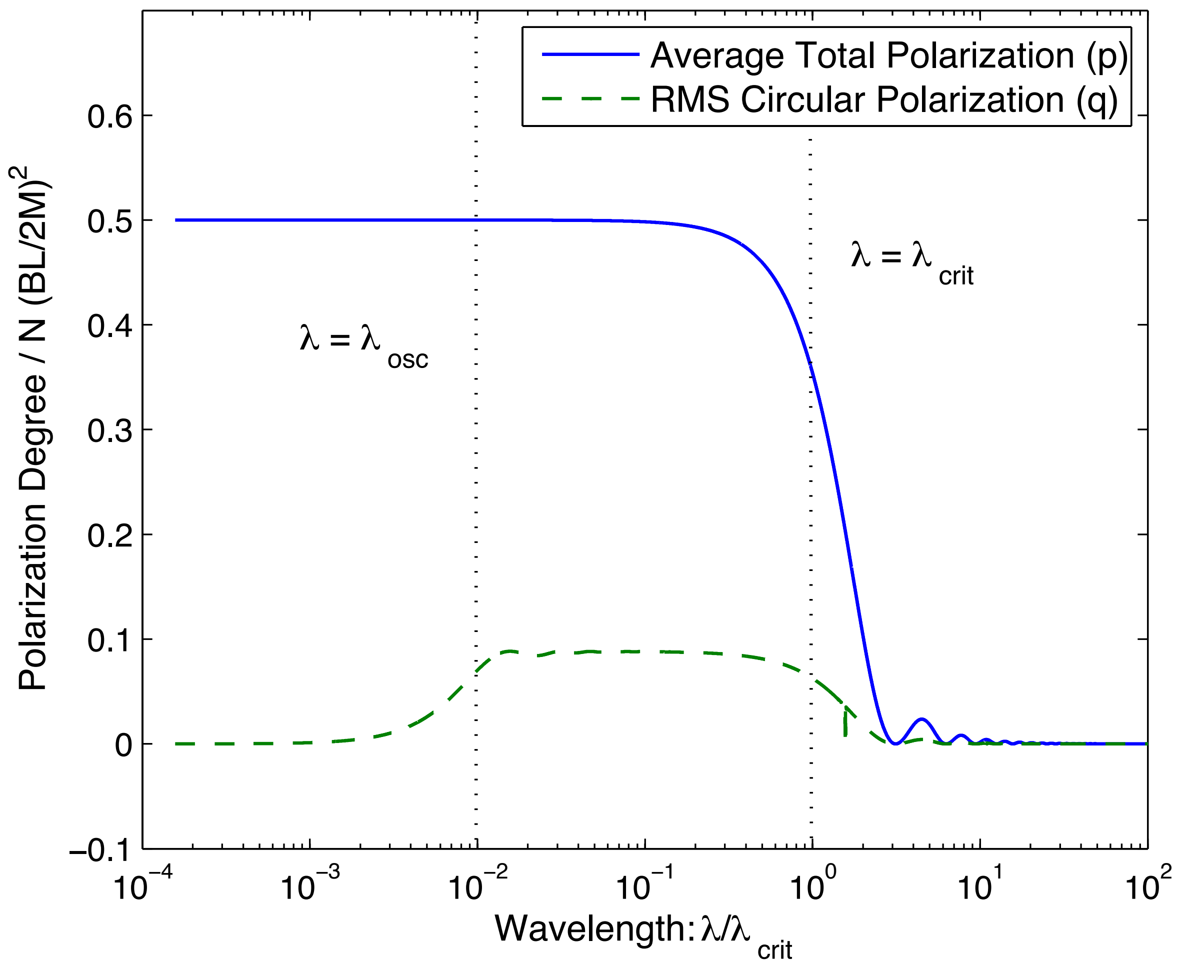
where

$$\Delta = \frac{(m^2 - \frac{B^2}{M_\gamma^2} - \omega_{\mathrm{Pl}}^2)L}{4\omega}$$

Astrophysical Polarisation

with C. Burrage and D. Shaw
0809.1763;PRD79(09)044028

In the presence of a magnetic field photons can convert into scalars. We found that this can induce polarisation in astrophysical objects. We used different models and assumptions for the magnetic field, but the results are pretty robust. The details are messy and in our paper.



We analysed starlight polarisation for stars in our galaxy out to 6kpc from NASA

For 3 stars

$$\left(\frac{BL}{2M}\right)_{\rm rand} < 7.2 \times 10^{-2}\,(95\%),$$
$$\left(\frac{BL}{2M}\right)_{\rm rand} < 8.1 \times 10^{-2}\,(99.9\%).$$

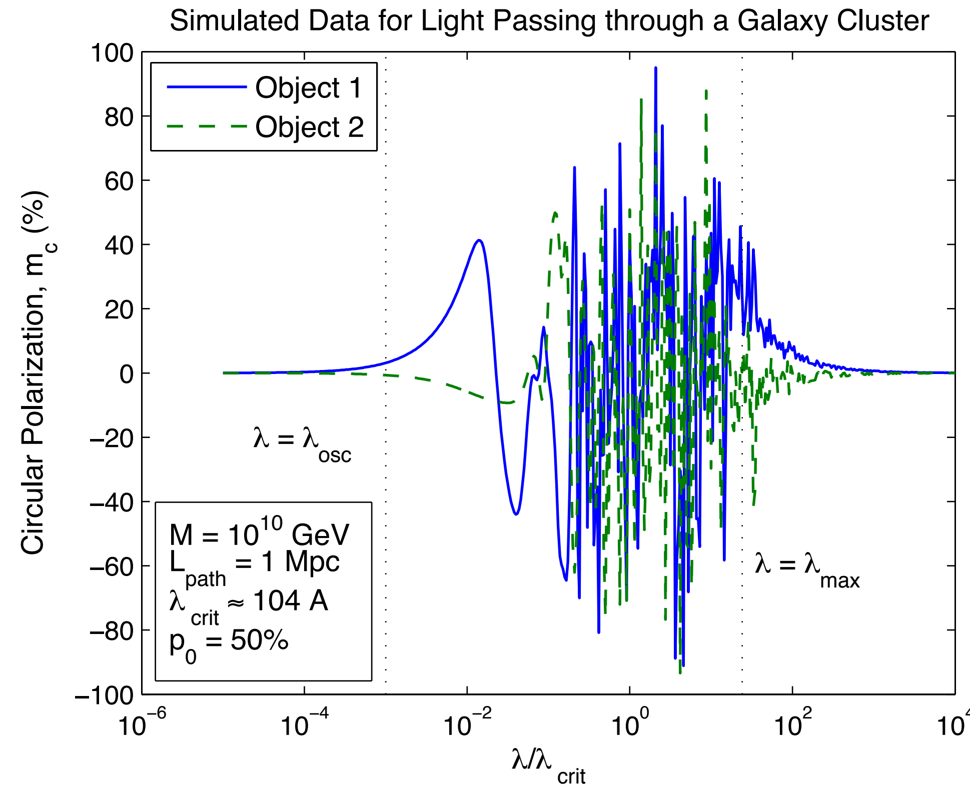
using Hubble telescope data

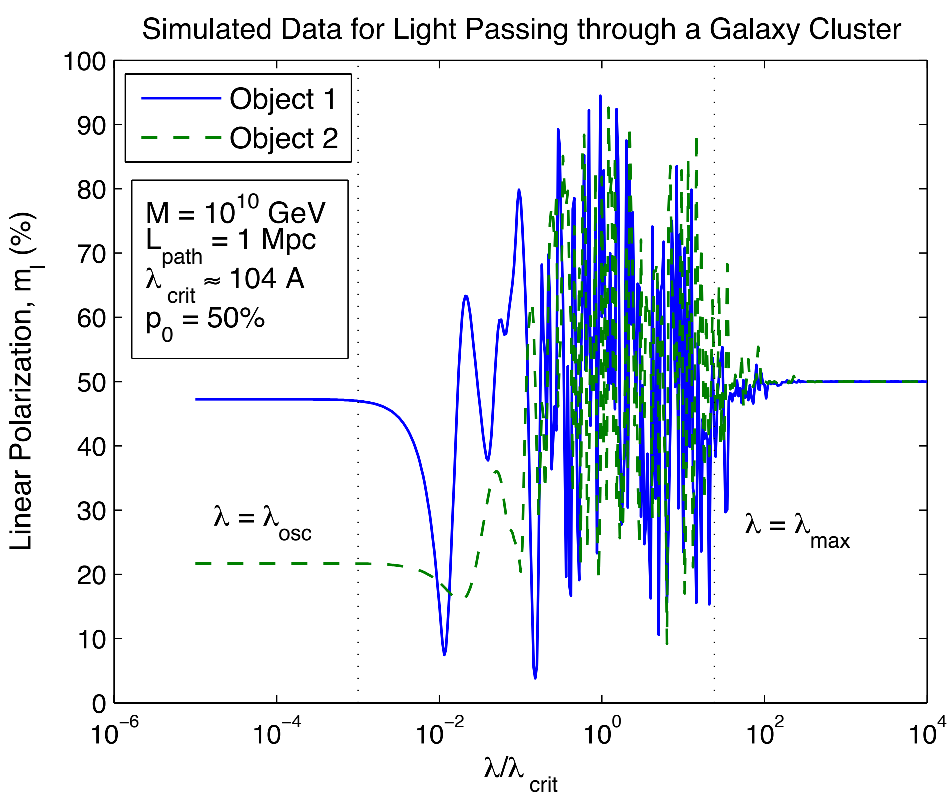
$$\left(\frac{BL}{2M}\right)_{\rm gal} < 8.9 \times 10^{-2}\,(95\%)$$
$$\left(\frac{BL}{2M}\right)_{\rm gal} < 12.7 \times 10^{-2}\,(99.9\%)$$

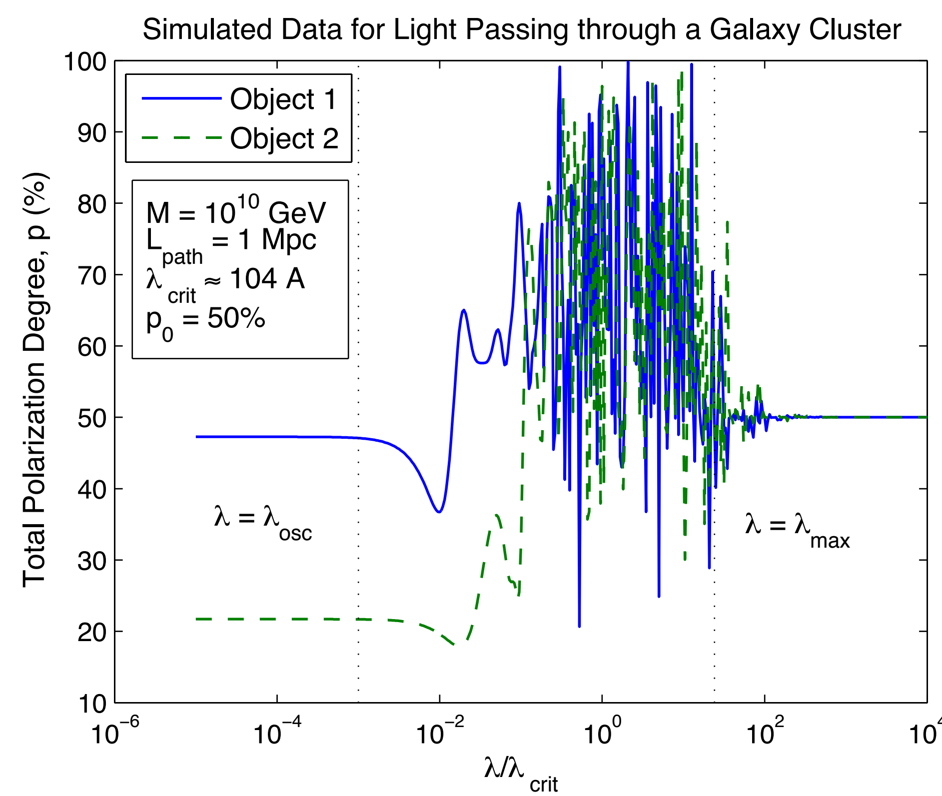
This gives $g_{\phi\gamma\gamma} = M_{\rm F}^{-1} = 6.8 \pm 2.1 \times 10^{-10}\,{\rm GeV}^{-1} \quad (99\%\ \text{confidence})$

Many other astrophysical and cosmological analysis in the paper

A smoking gun -- circular polarisation







AGNs

Burrage, ACD, Shaw 0902.2320; Pettinari & Crittenden 1007.024

Constraints come from AGNs. X-ray luminosity at 2 keV is observed to be tightly correlated with optical luminosity at 5 eV. Similar luminosity correlations exist for blazers and gamma ray bursts, but these give weaker constraints. Current constraint is

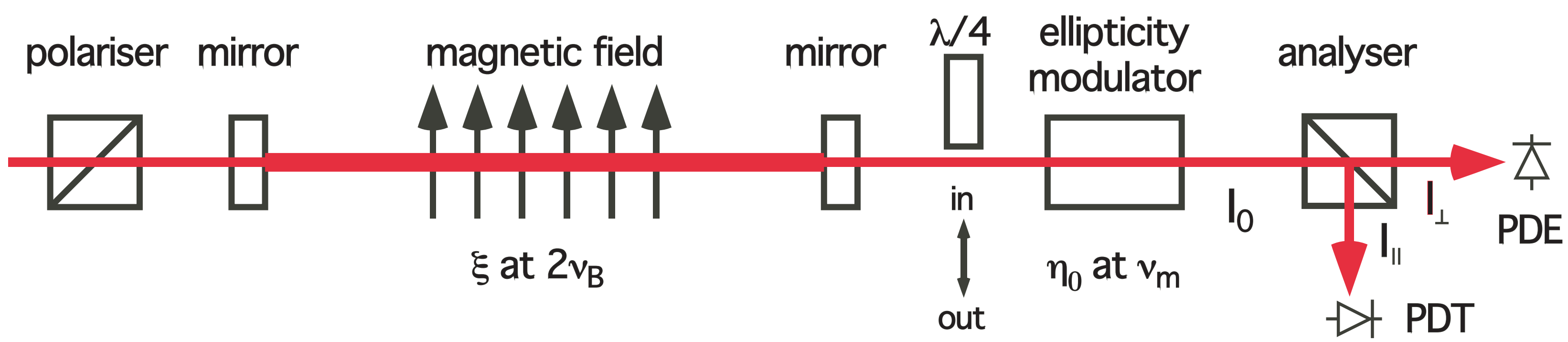
$$M_\gamma > 10^{11} GeV$$

Chameleonic SZ Effect

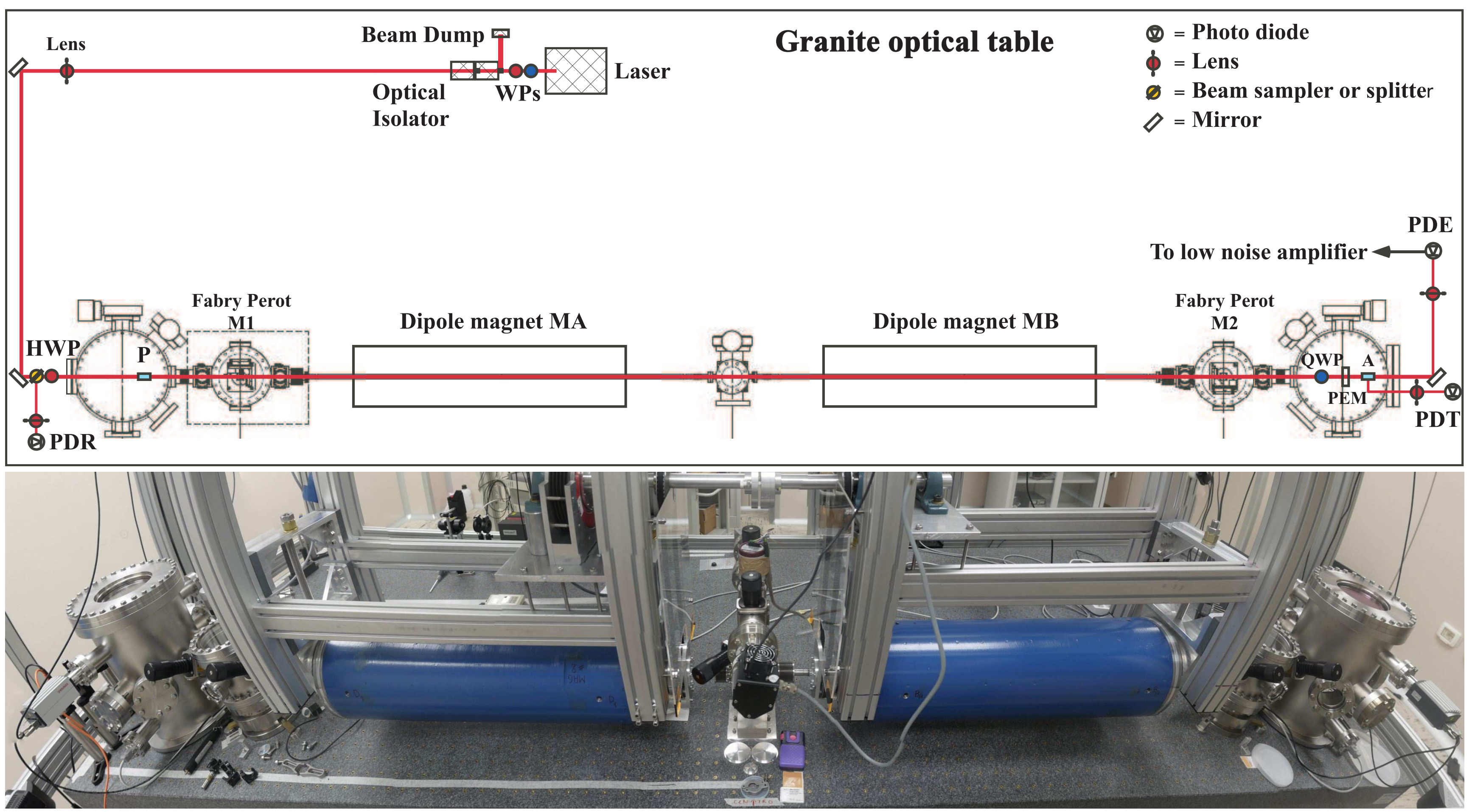
ACD, Schelpe, Shaw 0907.2672; 1008.1880

Conversion of CMB photons to chameleons in the presence of a magnetic field in clusters. Gives effect similar to SZ effect, but differences near edge of cluster. Photon —Chameleon conversion also gives rise to circular polarisation of the CMB. This gives similar constraints. In depth analysis of Coma cluster from Bicep results.

PVLAS



polariser
mirror
magnetic field
mirror
λ/4
ellipticity modulator
analyser
ξ at 2ν_B
in
out
η_0 at ν_m
I_0
I_⊥
I_∥
PDE
PDT



Granite optical table
= Photo diode
= Lens
= Beam sampler or splitter
= Mirror
Lens
Beam Dump
Laser
Optical Isolator
WPs
PDE
To low noise amplifier
Fabry Perot M1
Dipole magnet MA
Dipole magnet MB
Fabry Perot M2
HWP
P
QWP
A
PEM
PDR
PDT

In the presence of a magnetic field photons could convert to chameleons and of-course the chameleon convert back to photons. The ‘vacuum’ chamber acts as a trap for chameleons, unlike axions, which then get reflected back and forth by the mirrors, inducing rotation and elllipticity of the incoming laser beam. The PVLAS experiment allows us to constrain the coupling to photons.

Results constrain the rotation to be less than 1.2×10^8 rad at 5 T 1.0×10^8 rad at 2.3 T

and ellipticity less than 1.4×10^8 at 2.3 T.

Giving $M_\gamma > 10^6 GeV$

Brax et al hep-ph/0703243; hep-ph/0707.2801

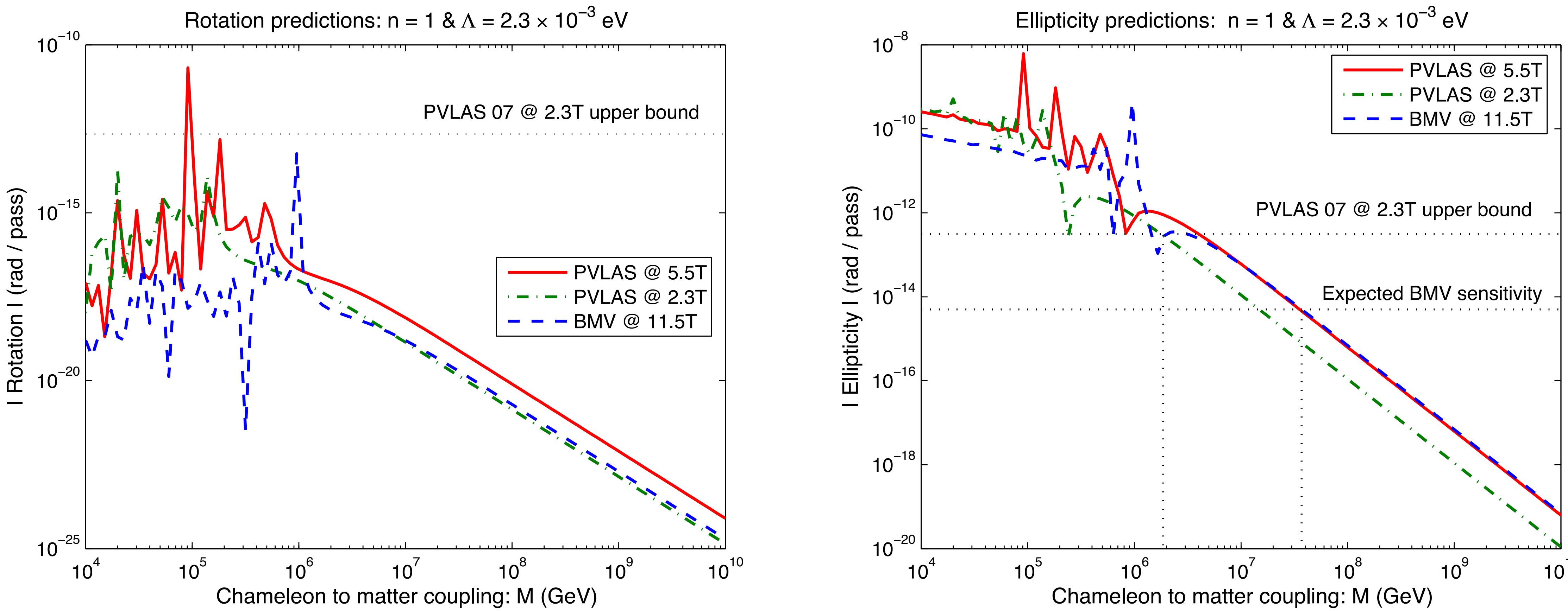


FIG. 4: Predictions for rotation (left) and ellipticity (right) in the chameleon model as a function of M for $\Lambda = 2.3 \times 10^{-3}$ eV and $n = 1$. Predictions for the $B = 2.3$ T and $B = 5.5$ T PVLAS ($L = 100$ cm, $d = 270$ cm, $\omega = 1.2$ eV, $\rho_{\rm gas} = 2 \times 10^{-14}$gcm^{-3} and $\varphi = \pi/4$) and BMV ($L = 50$ cm,$d = 85$ cm, $\omega = 1.2$ eV, $B = 11.5$ T, $\rho_{\rm gas} \approx 10^{-14}$gcm^{-3} and $\varphi = \pi/4$) set-ups are shown. The thin-dotted lines show the 95% confidence upper bounds on both the rotation and the ellipticity.

GammeV

Afterglow experiment

Gies, Mota, Shaw 0710.1556;
Ahlers et al 0710.1555;
Steffen et al 1010.0988

Adapted from an axion experiment searching for 'light shining through the wall'.

Experiment consists of shining laser light into a vacuum cavity in the presence of a magnetic field. If photons convert to chameleons then there will be a build up of chameleons in the cavity the longer the laser beam is on. The laser beam is turned off but not the magnetic field. In the presence of the magnetic field the chameleons should reconvert to photons, giving an 'afterglow'. The absence of an observed afterglow constraints the chameleon coupling to photons to be

$$M_\gamma > 10^7 GeV$$

Particle Physics constraints

Brax, Burrage et al

The coupling to photons can be extended to couplings to standard model gauge bosons. One might expect to detect the effects of conversion of standard model particles into chameleons at the LHC, for example in Higgs production. Unfortunately the constraints are not competitive.