# Detecting Chameleons with Atom Interferometry

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**Outline:**

Chameleon screening

Atom interferometry

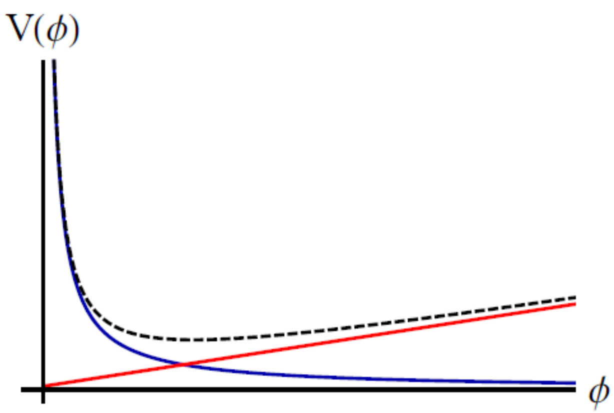
New constraints on chameleons

# The Chameleon - Varying Mass

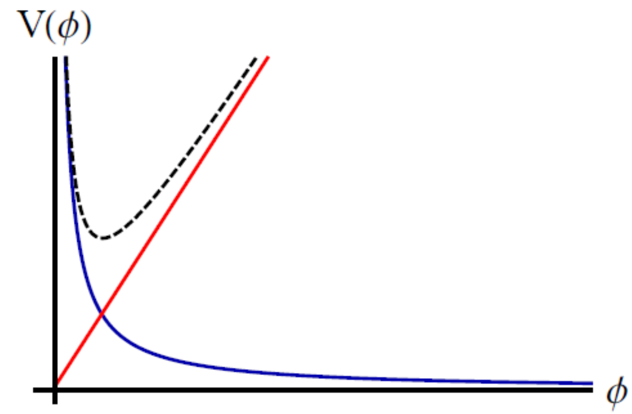
The mass of the chameleon changes with the environment

Field is governed by an effective potential

$$V_{\text{eff}} = \frac{\Lambda^5}{\phi} + \frac{\phi}{M}\rho$$




Low density




High density

**Warning:** Non-renormalisible theory, no protection from quantum corrections (But see arXiv:1604.06051)

Khoury, Weltman. (2004). Image credit: Nanosanchez

# The Scalar Potential

$$\phi = \phi_{\rm bg} - \lambda_A \frac{1}{4\pi R_A} \frac{M_A}{M} \frac{R_A}{r} e^{-m_{\rm bg} r}$$

$$\lambda_A = \begin{cases} 1\,, & \rho_A R_A^2 < 3M\phi_{\rm bg} \\ 1 - \frac{S^3}{R_A^3} \approx 4\pi R_A \frac{M}{M_A}\phi_{\rm bg}\,, & \rho_A R_A^2 > 3M\phi_{\rm bg} \end{cases}$$

This determines how responsive an object is to the chameleon field

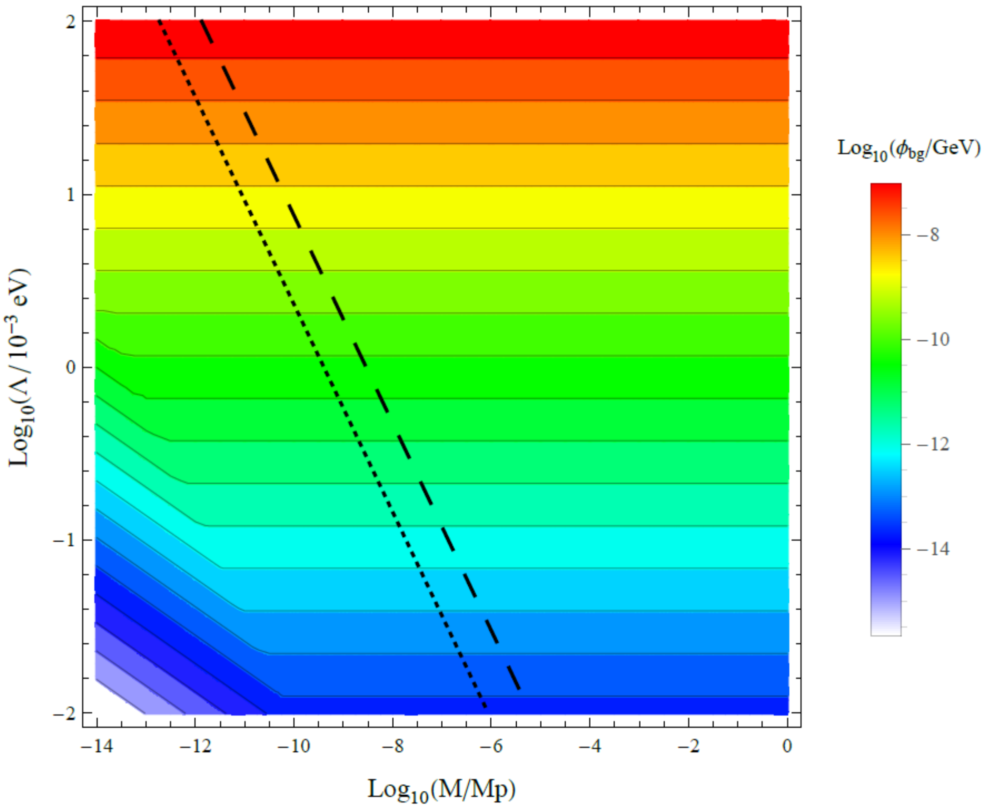
When $m_{bg}r$ is small the ratio of the acceleration of a test particle due to the chameleon and gravity is:

$$\frac{a_\phi}{a_N} = \frac{\partial_r \phi}{M} \frac{r^2}{G M_A} = 3\lambda_A \left(\frac{M_P}{M}\right)^2$$

# 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)



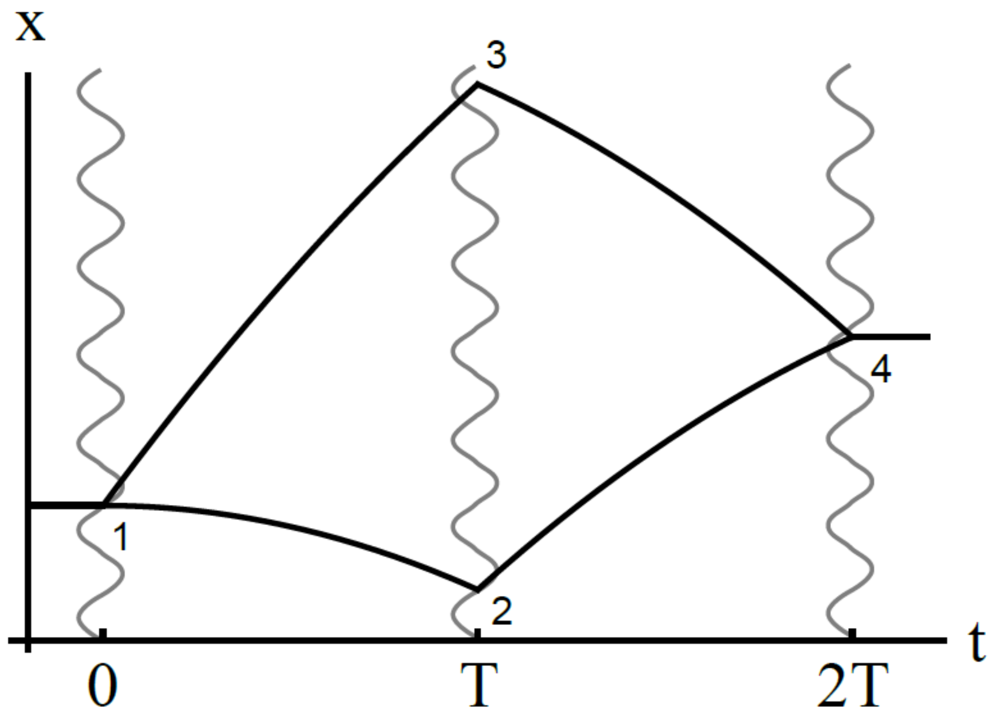

CB, Copeland, Hinds. (2015)

# What is Atom Interferometry?

An interferometer where the wave is made of atoms

Atoms can be moved around by absorption of laser photons

# An Atom Interferometer



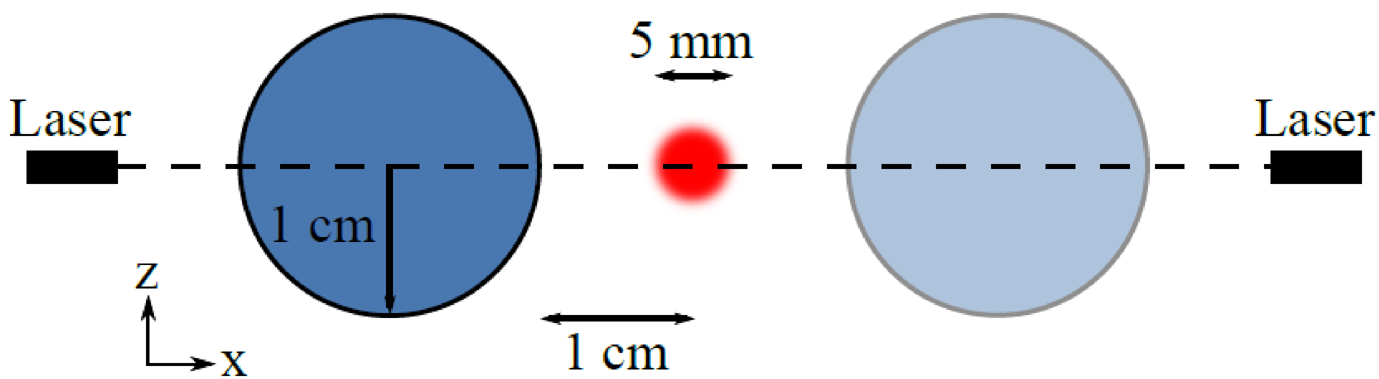

Probability measured in excited state at output

$$P = \cos^2\left(\frac{kaT^2}{2}\right)$$

# Atom Interferometry for Chameleons

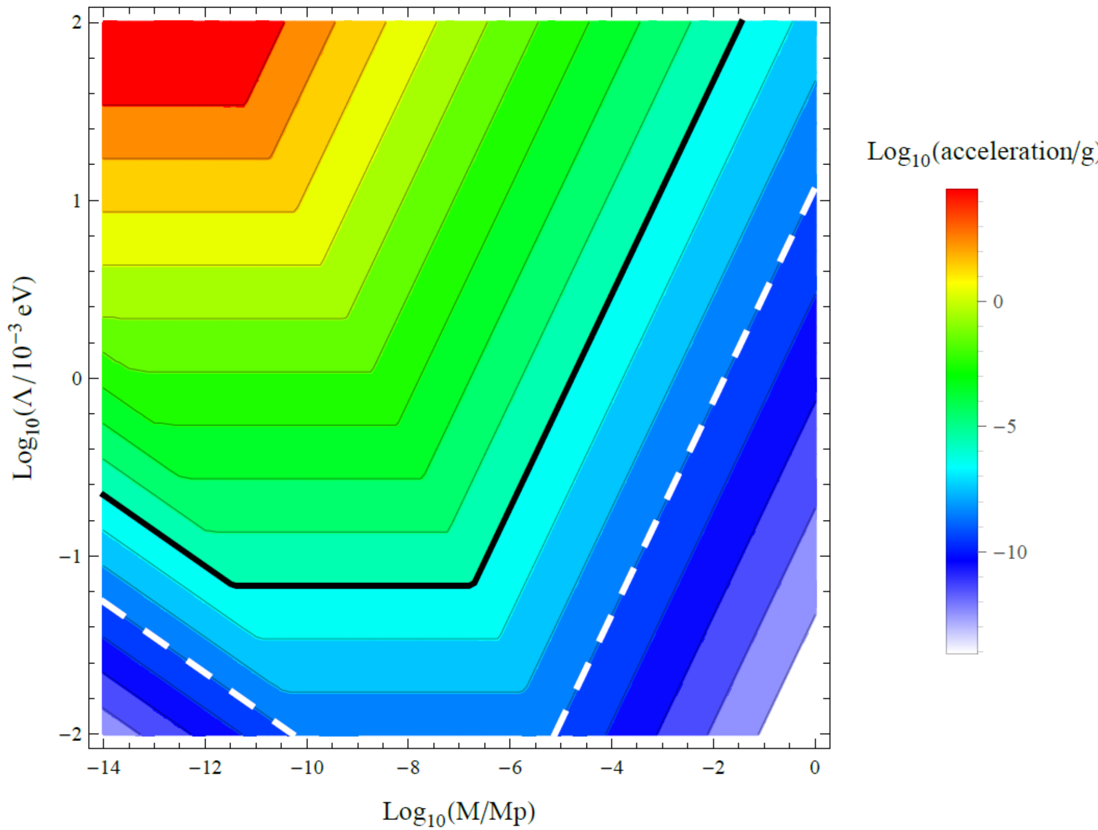
The walls of the vacuum chamber screen out any external chameleon forces

Macroscopic spherical mass (blue), produces chameleon potential felt by cloud of atoms (red)



# Proposed Sensitivity

- Systematics: Stark effect, Zeeman effect, phase shifts due to scattered light, movement of beams
- All negligible at $10^{-6}$ g sensitivity (solid black line)
- Controllable down to $10^{-9}$ g (dashed white line)

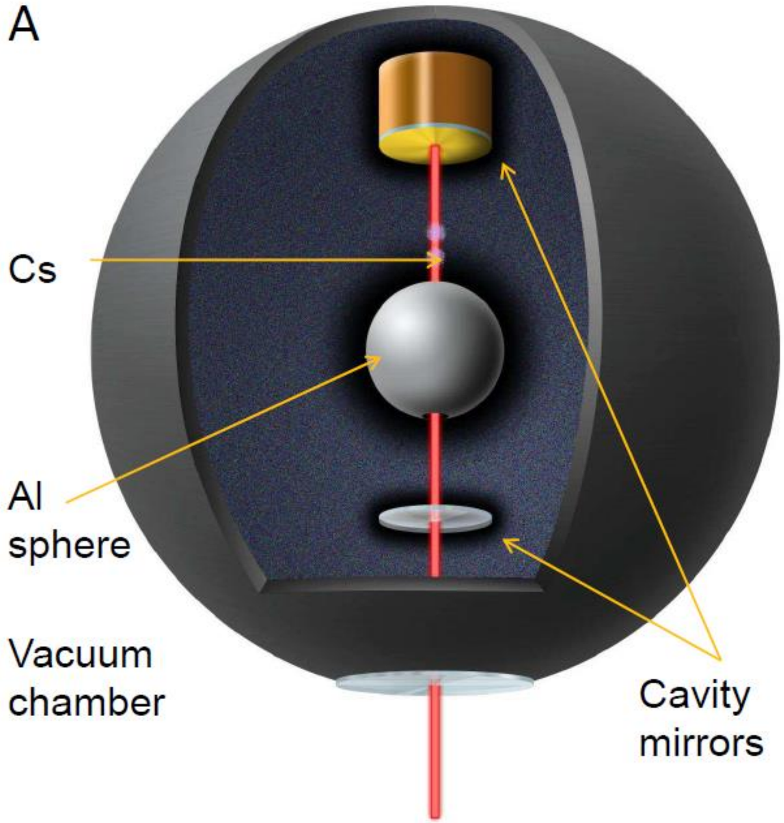


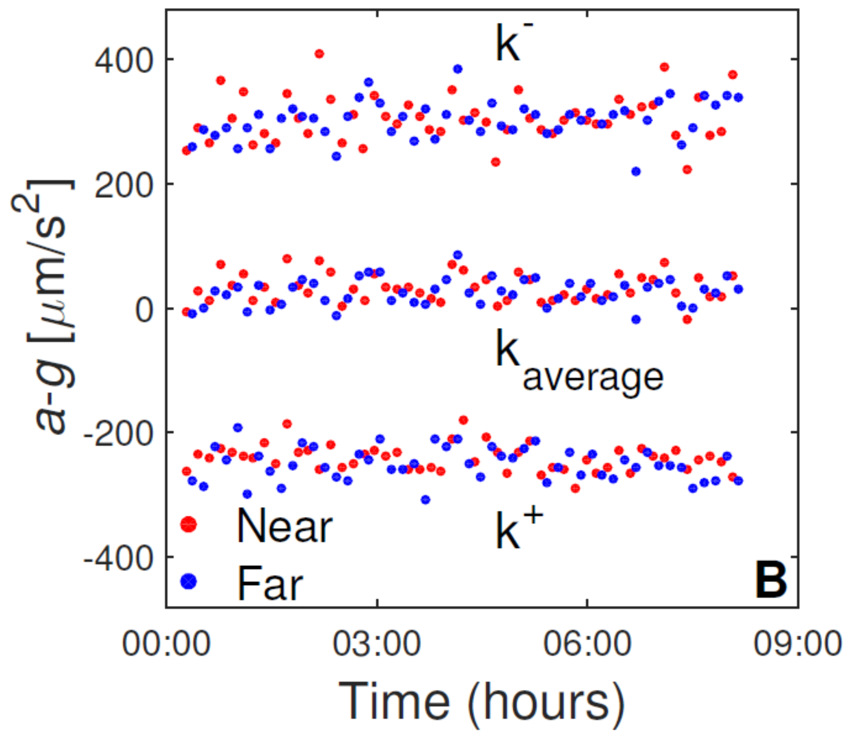

CB, Copeland, Hinds. (2015)

For numerical estimates see: Schlögel, Clesse, Füzfa (2015). Elder et al. (2016).

# Berkley Experiment

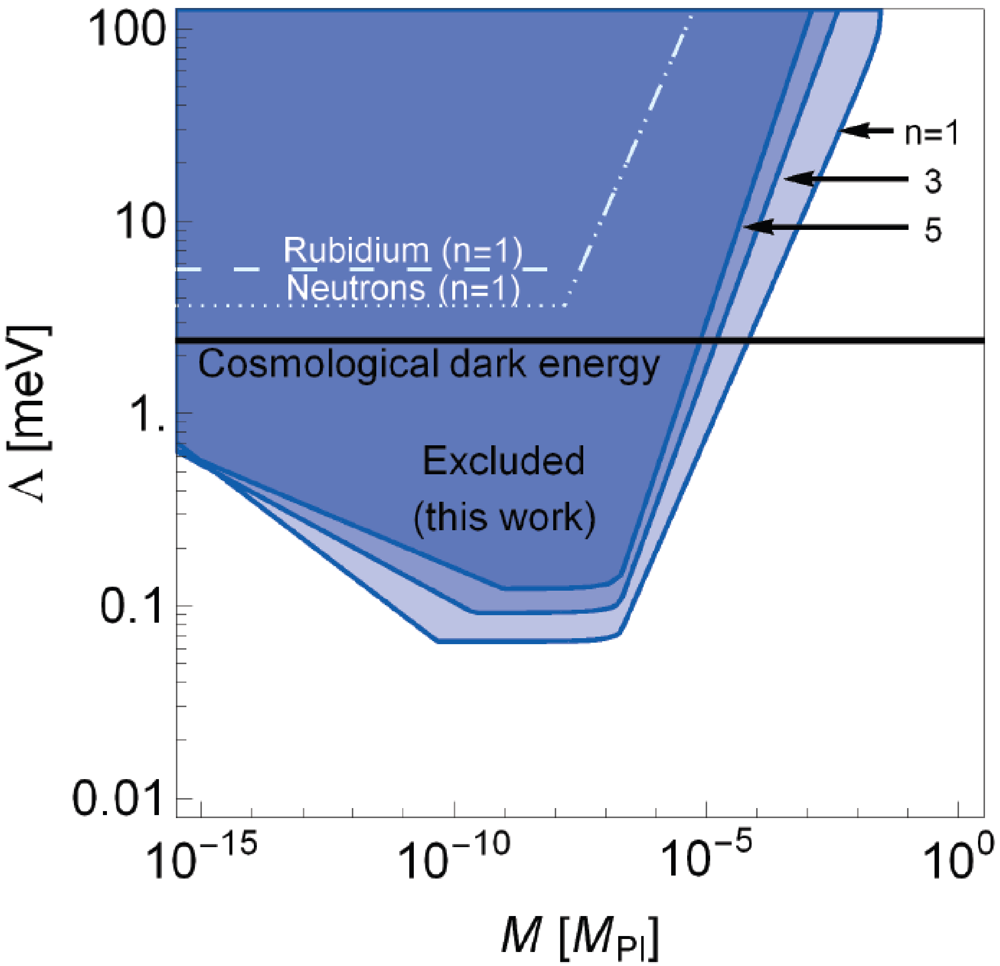
Using an existing set up with an optical cavity
The cavity provides power enhancement, spatial filtering, and a precise beam geometry




Hamilton et al. (2015)

# Berkley Experiment

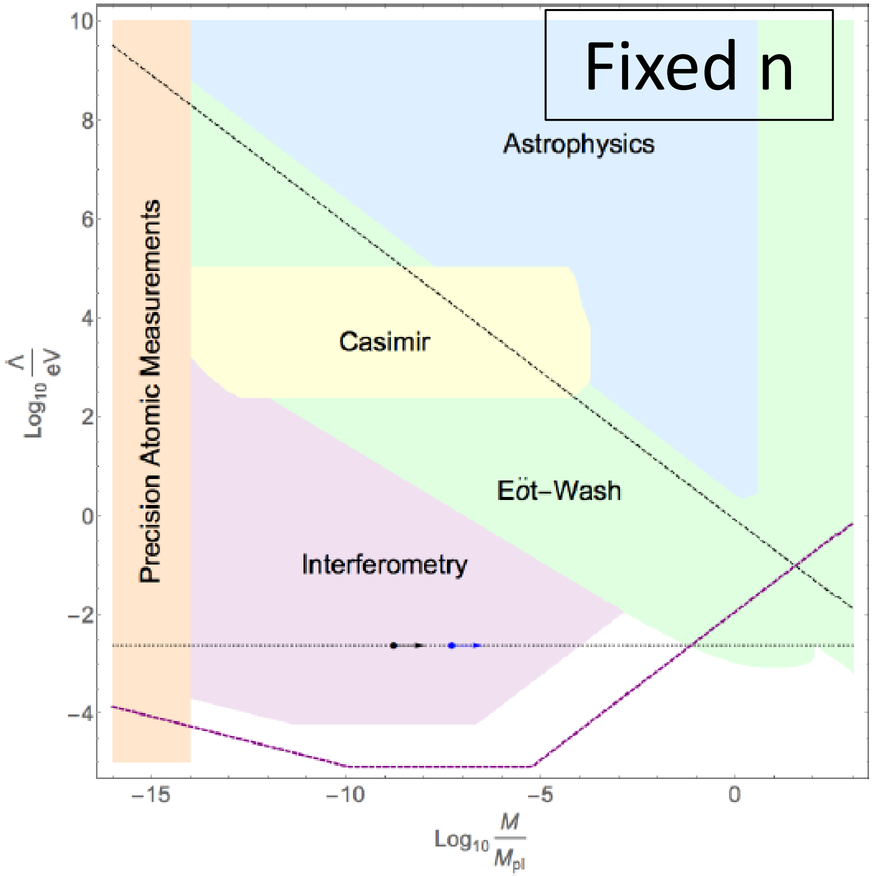



Hamilton et al. (2015)

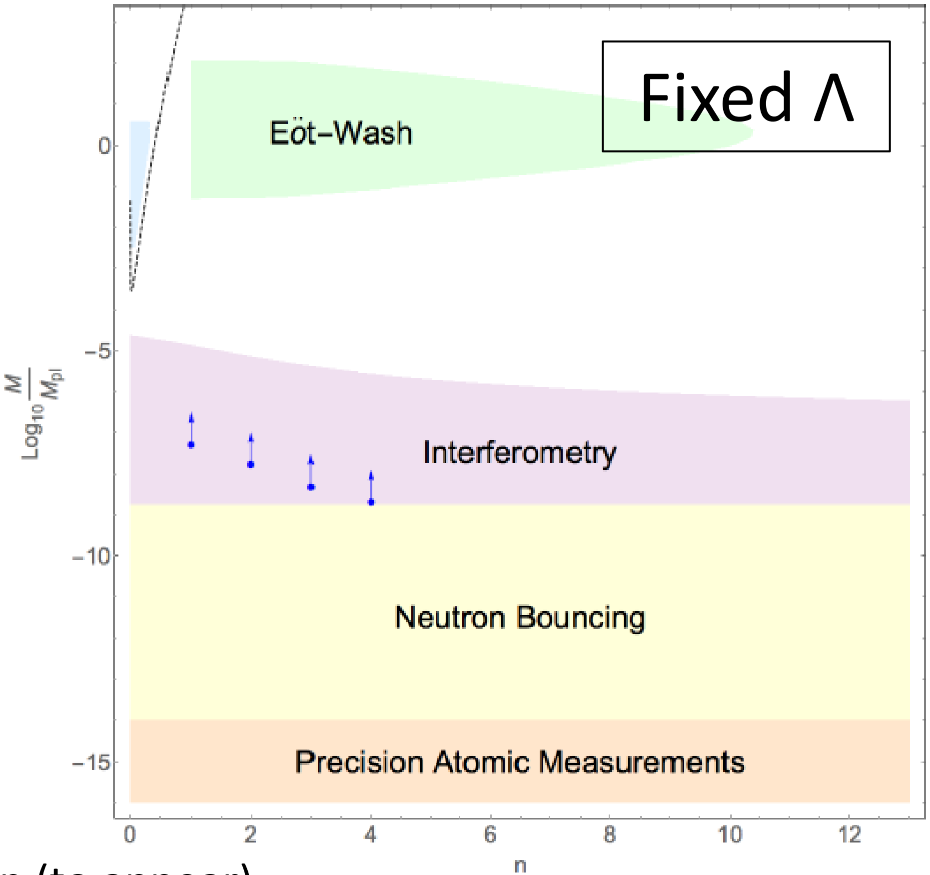
See also: Neutron interferometry experiments: Lemmel et al. 2015

Optically levitated microspheres: Rider et al. 2016

# Combined Constraints



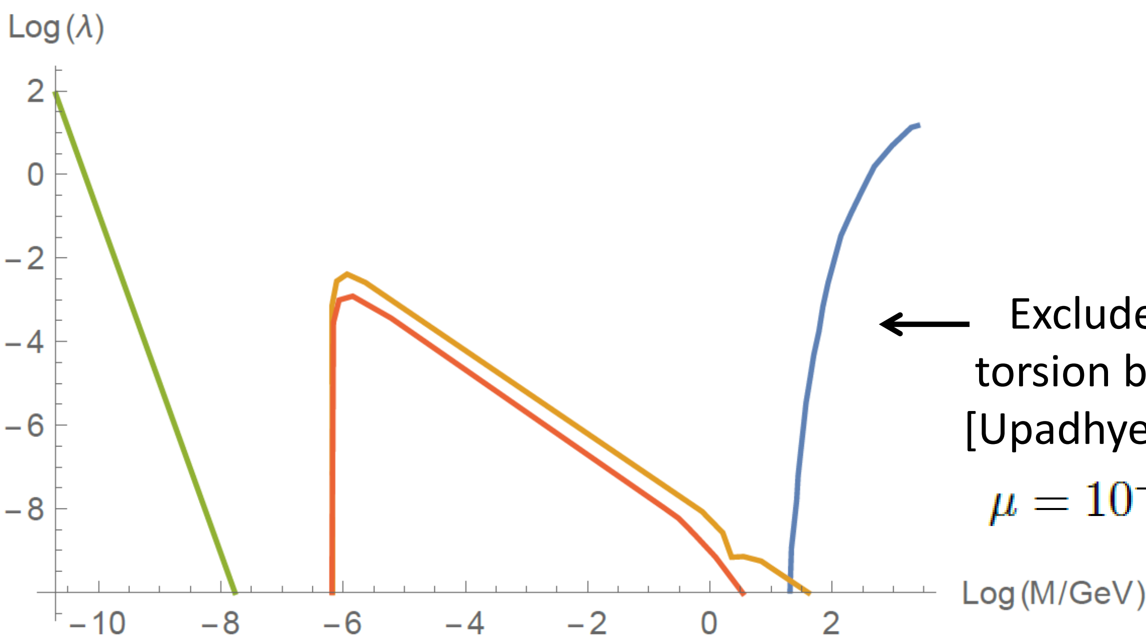

$$V(\phi) = \Lambda^4 + \frac{\Lambda^{4+n}}{\phi^n}$$




CB, Sakstein (to appear)

# Symmetron Constraints

$$V_{\text{eff}}(\phi) = \frac{1}{2}\left(\frac{\rho}{M^2} - \mu^2\right)\phi^2 + \frac{1}{4}\lambda\phi^4$$




Excluded by exoplanet orbits [Santos & Mota 2016]

$\mu \to 0$

Excluded by torsion balance [Upadhye 2013]

$\mu = 10^{-2}$ eV

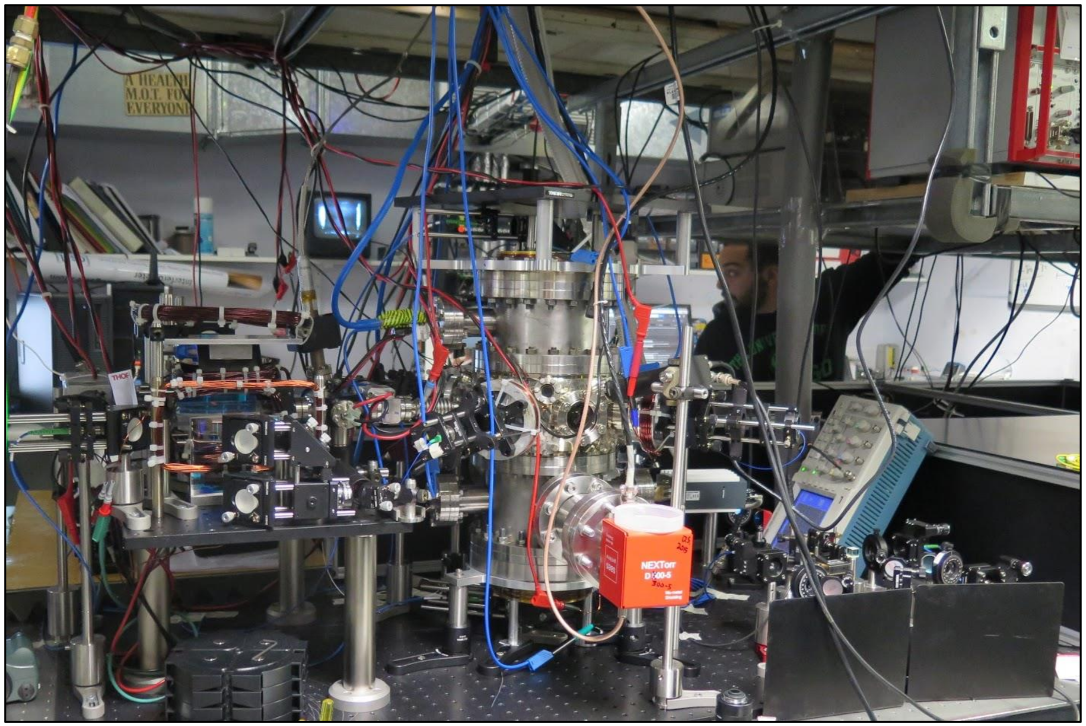
Excluded by atom interferometry

$\mu = 10^{-2}$ eV

CB, Kuribayashi-Coleman, Thrussell (to appear)

# Imperial Experiment

Development underway at the Centre for Cold Matter, Imperial College



Experiment rotated by 90 degrees from the Berkeley experiment, so that no sensitivity to Earth’s gravity

# Summary

Screening mechanisms hide dark energy from standard searches for fifth forces

- Can still be detected in suitably designed experiments
- Atom interferometry a particularly powerful technique

Prospects for ruling out chameleon dark energy within a few years

Shape dependence of the screening mechanism could lead to important enhancements in sensitivity