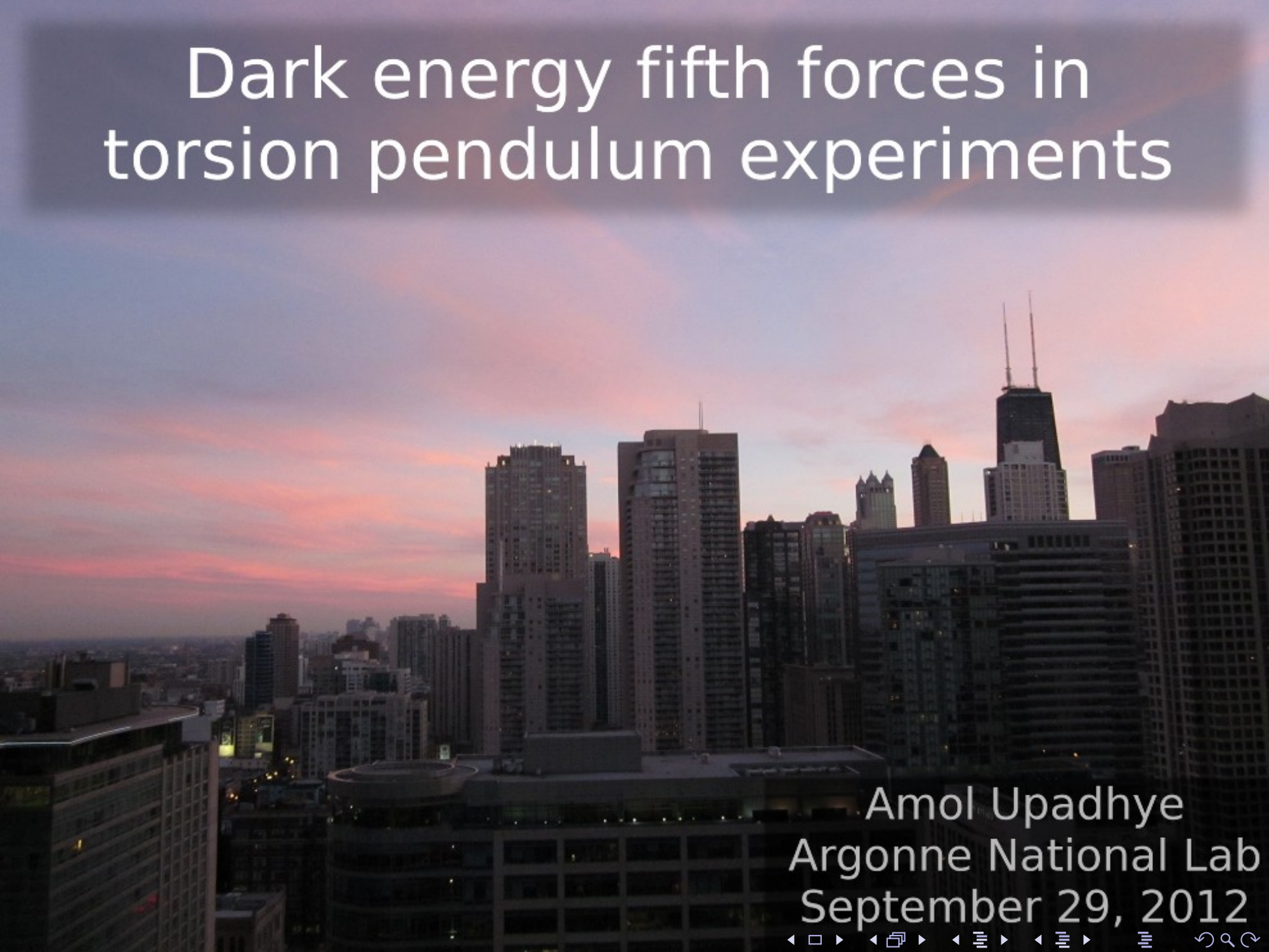
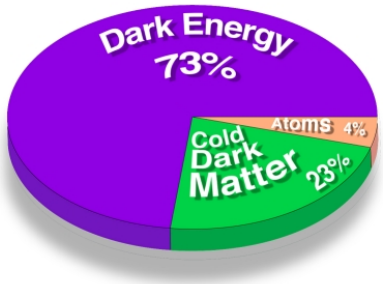
Dark energy fifth forces in torsion pendulum experiments

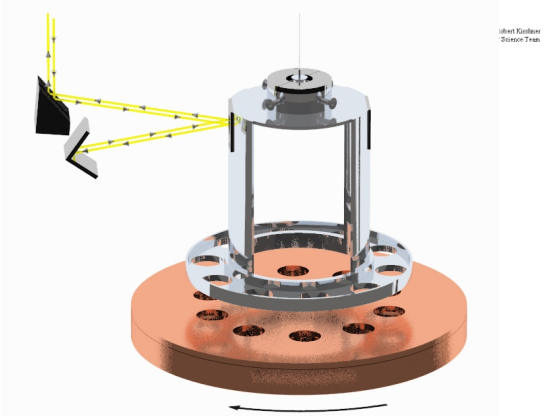


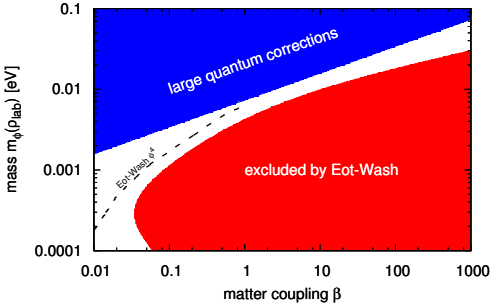
Amol Upadhye
Argonne National Lab
September 29, 2012

Outline

1. Cosmic acceleration
   - Deviations from cosmological constant
   - Matter couplings from modified gravity
   - Chameleon scalars and screening
2. Experimental probes
   - Eöt-Wash torsion pendulum experiment
   - Chameleons in Eöt-Wash
3. Quantum-stable chameleons
   - Chameleon models with small quantum corrections
   - Approximate Eöt-Wash constraints
   - Forecasts







Types of dark energy

Dynamical explanations of the cosmic acceleration can differ from a cosmological constant in two ways: evolution and coupling.

Dark energy evolves

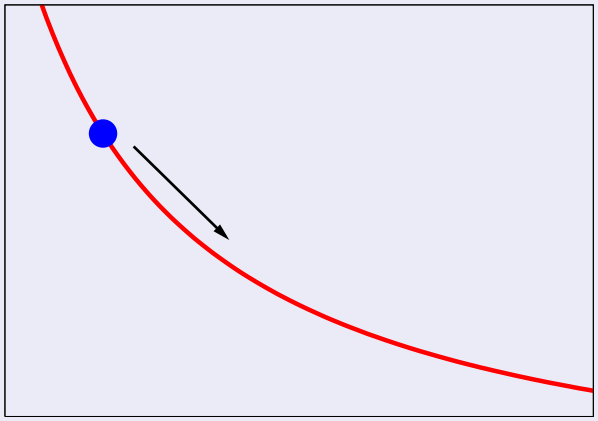
Dark energy couples

Types of dark energy

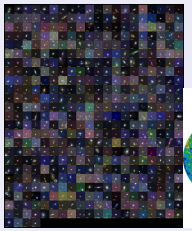
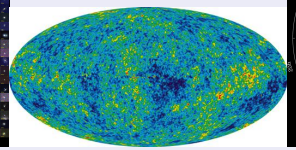
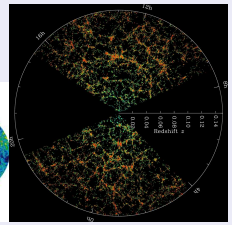
Dynamical explanations of the cosmic acceleration can differ from a cosmological constant in two ways: evolution and coupling.

Dark energy evolves

- $V(\phi)$



- $H(z)$ evolves with ϕ
- Constrain using

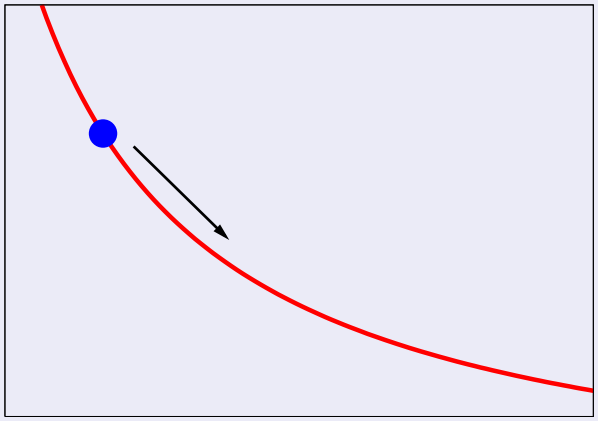
Dark energy couples

Types of dark energy

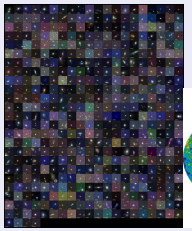
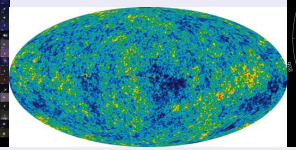
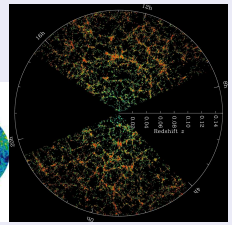
Dynamical explanations of the cosmic acceleration can differ from a cosmological constant in two ways: evolution and coupling.

Dark energy evolves

- $V(\phi)$

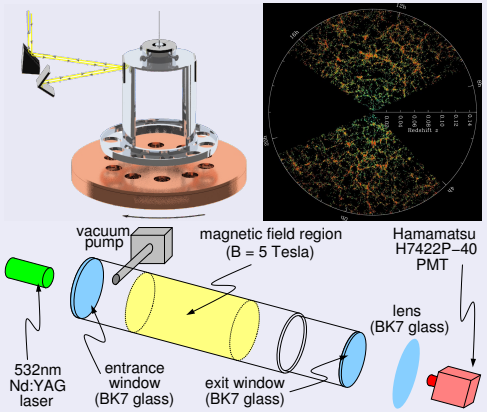


- $H(z)$ evolves with ϕ
- Constrain using

Dark energy couples

- New effects:
  - fifth forces
  - new particle
- Screening mechanism
  - chameleon (mass)
  - Vainshtein (kinetic)
- Constrain using:



Modified gravity and coupled scalar fields

The simplest modified gravity models reduce at low energies to 4-D matter-coupled scalar field theories.

Modified gravity

Effective scalar

New physics

Modified gravity and coupled scalar fields

The simplest modified gravity models reduce at low energies to 4-D matter-coupled scalar field theories.

Modified gravity

- $f(R)$ gravity: action $S = \int \frac{d^4x\sqrt{-g}}{16\pi G_N} f(R)$

Effective scalar

- Conformal transformation $\Rightarrow$ chameleon

New physics

- matter coupling, self-interaction $V(\phi)$

Modified gravity and coupled scalar fields

The simplest modified gravity models reduce at low energies to 4-D matter-coupled scalar field theories.

Modified gravity

- $f(R)$ gravity: action $S = \int \frac{d^4x\sqrt{-g}}{16\pi G_N} f(R)$
- DGP, etc.: non-compact extra dimension

Effective scalar

- Conformal transformation $\Rightarrow$ chameleon
- Decoupling limit (weak gravity) $\Rightarrow$ Galileon

New physics

- matter coupling, self-interaction $V(\phi)$
- matter coupling, non-canonical kinetic term

Modified gravity and coupled scalar fields

The simplest modified gravity models reduce at low energies to 4-D matter-coupled scalar field theories.

Modified gravity

- $f(R)$ gravity: action $S = \int \frac{d^4x\sqrt{-g}}{16\pi G_N} f(R)$
- DGP, etc.: non-compact extra dimension
- Kaluza-Klein, etc.: compact extra dimension

Effective scalar

- Conformal transformation $\Rightarrow$ chameleon
- Decoupling limit (weak gravity) $\Rightarrow$ Galileon
- Small extra dimension limit $\Rightarrow$ radion

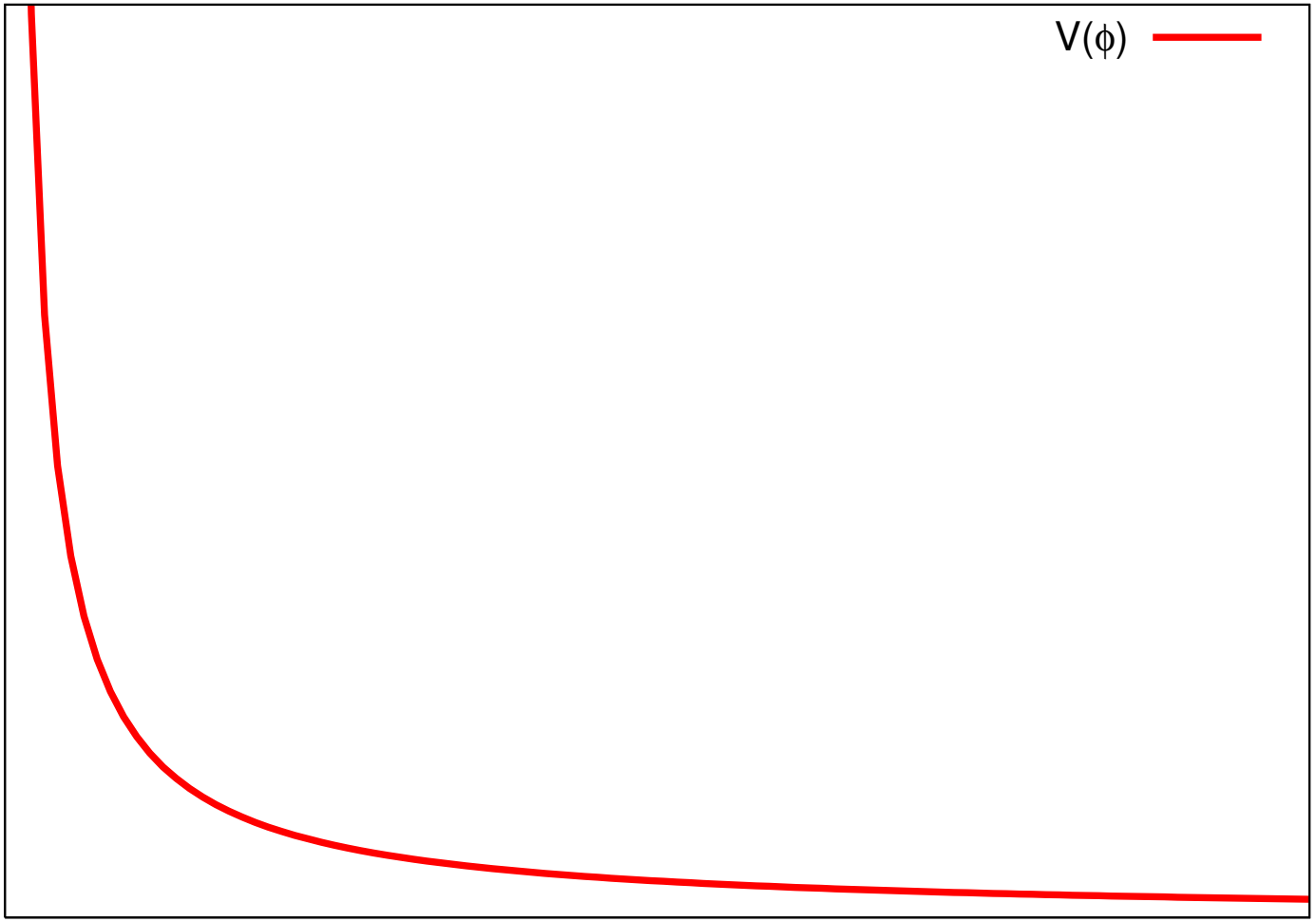
New physics

- matter coupling, self-interaction $V(\phi)$
- matter coupling, non-canonical kinetic term
- matter coupling, photon (gauge field) coupling

A matter coupling implies a fifth force which must be screened.

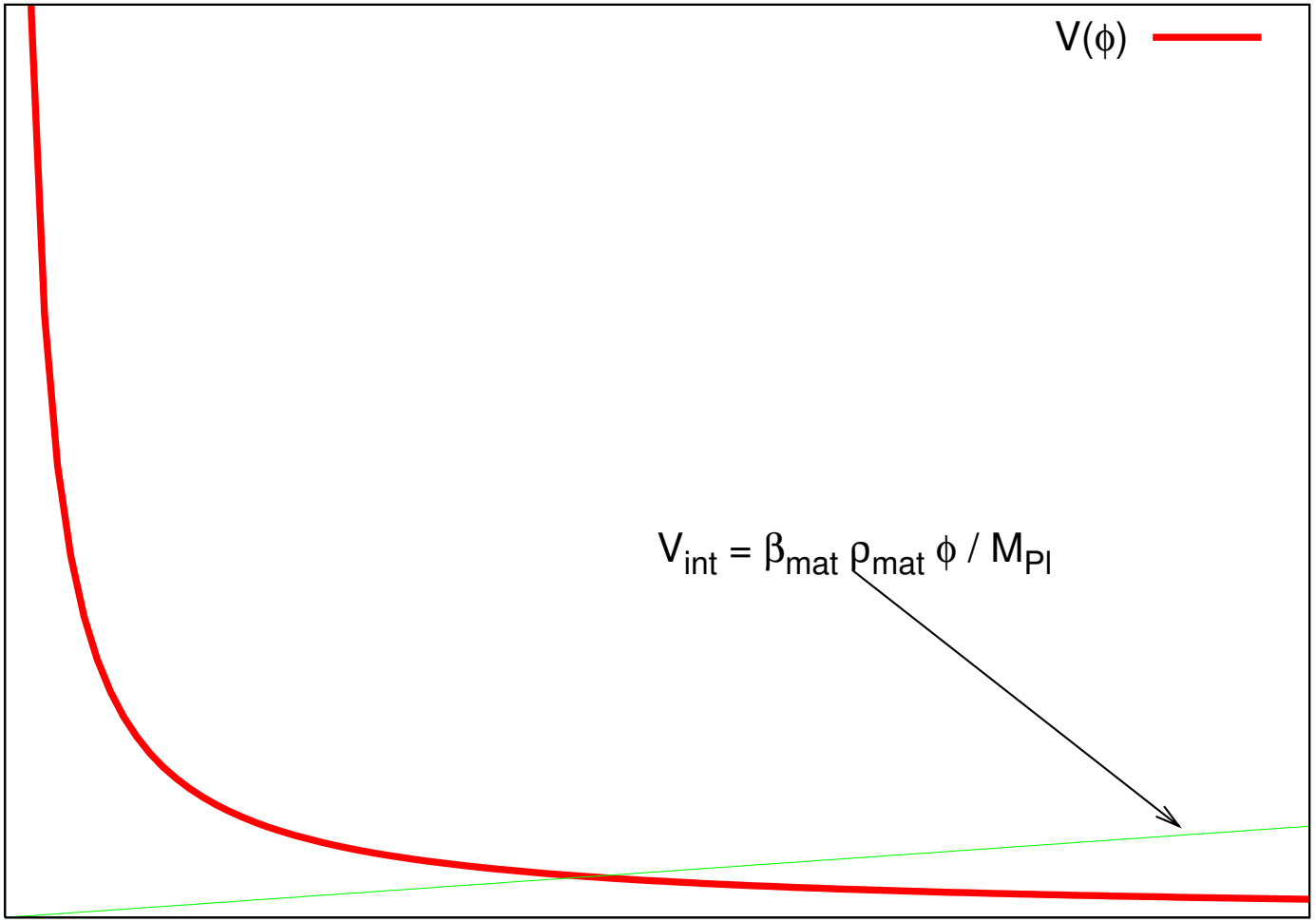
Chameleon effect

$$V_{\rm eff}(\phi) = V(\phi) + \frac{\beta}{M_{\rm Pl}}(-T^{\mu}_{\mu})\phi \approx V(\phi) + \frac{\beta\rho}{M_{\rm Pl}}\phi$$



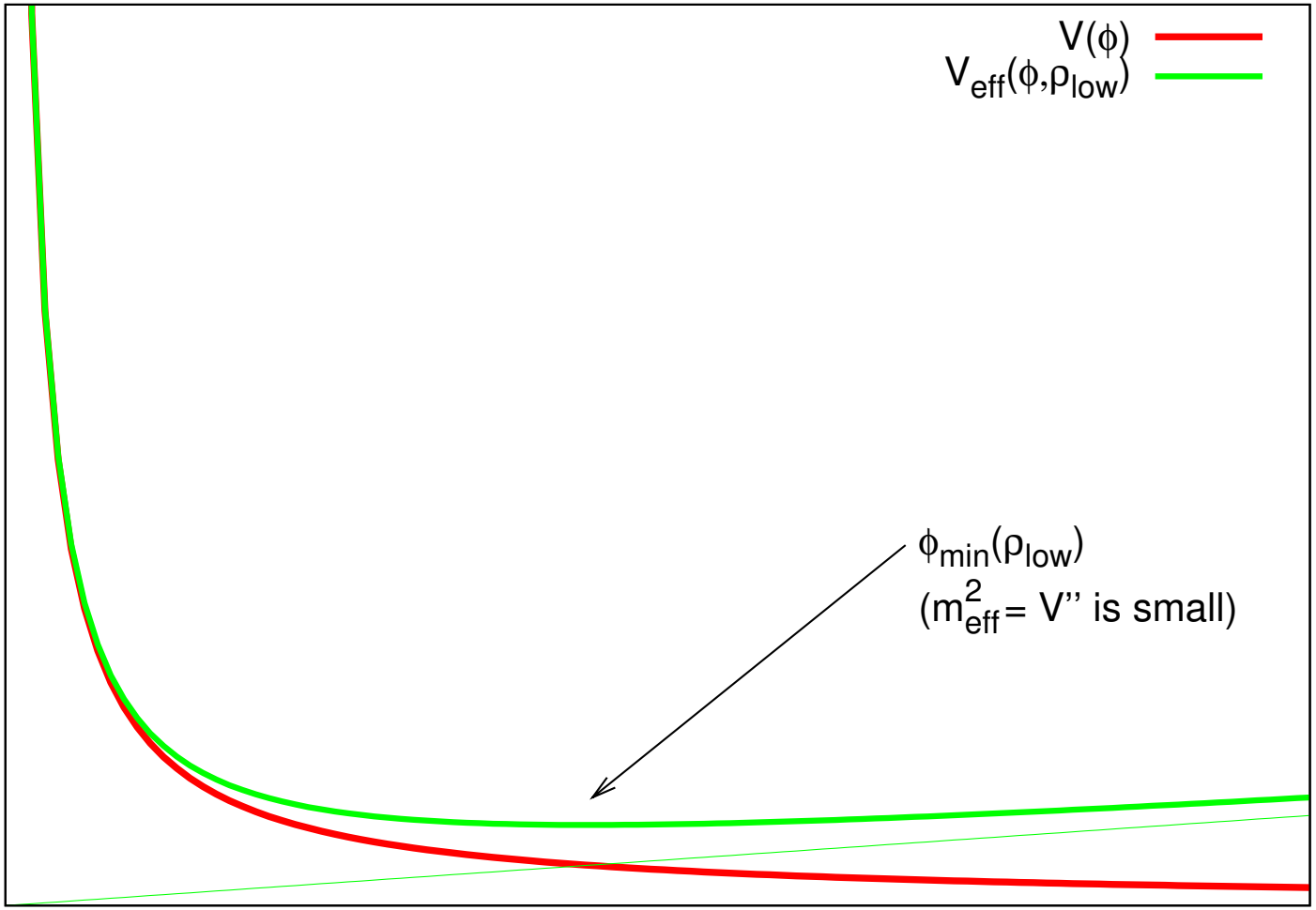
Chameleon effect

$$V_{\rm eff}(\phi) = V(\phi) + \frac{\beta}{M_{\rm Pl}}(-T^{\mu}_{\mu})\phi \approx V(\phi) + \frac{\beta\rho}{M_{\rm Pl}}\phi$$



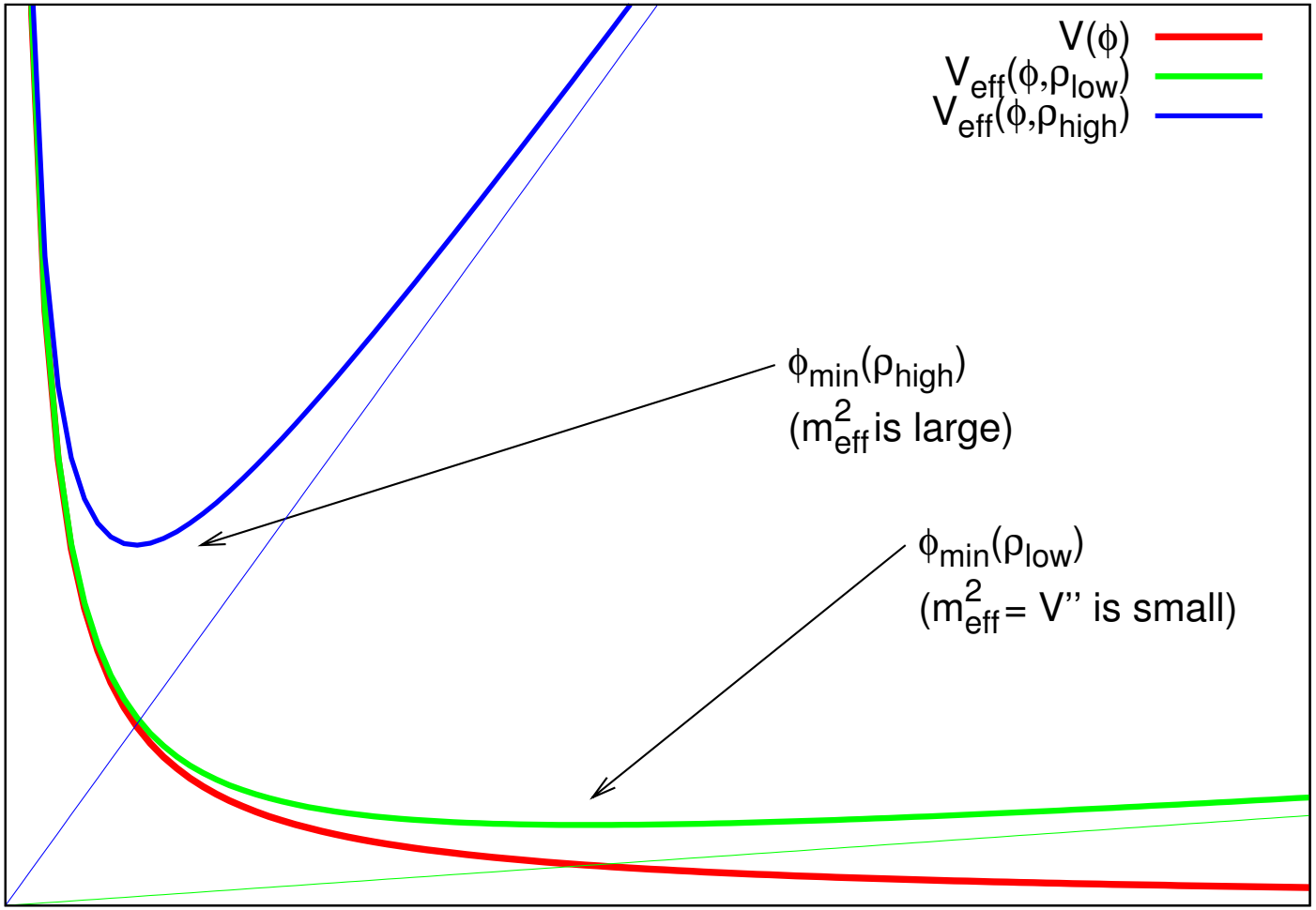
Chameleon effect

$$V_{\rm eff}(\phi) = V(\phi) + \frac{\beta}{M_{\rm Pl}}(-T^{\mu}_{\mu})\phi \approx V(\phi) + \frac{\beta\rho}{M_{\rm Pl}}\phi$$



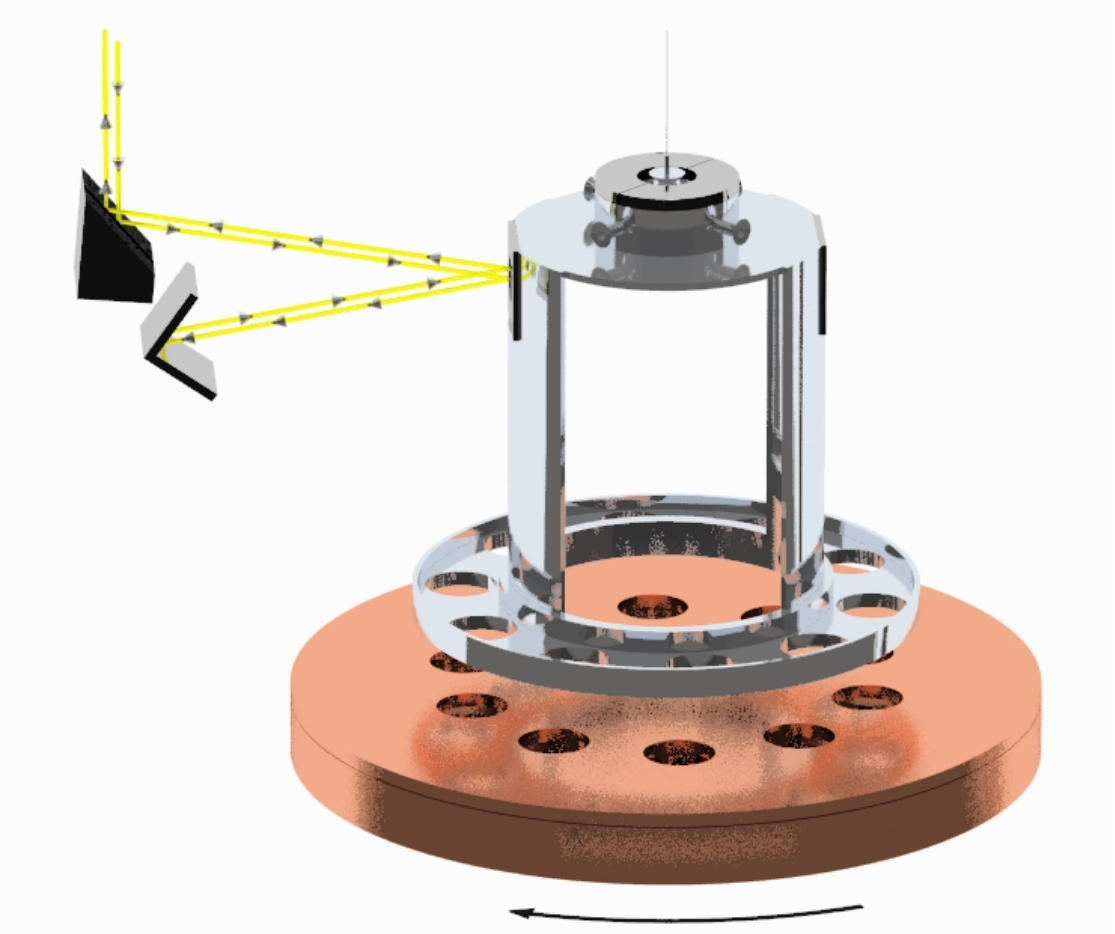
Chameleon effect

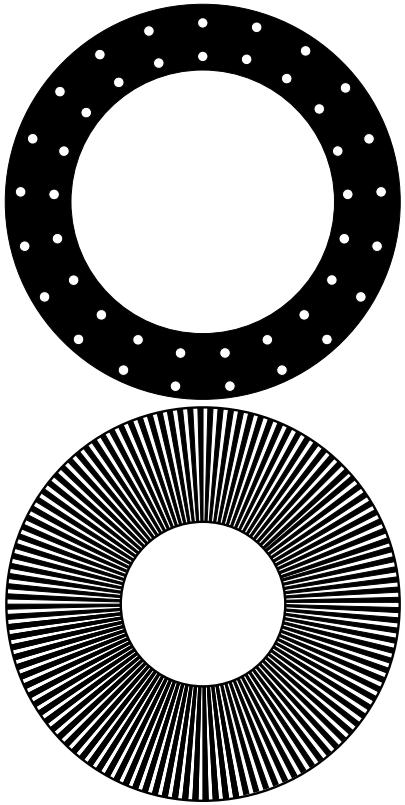
$$V_{\rm eff}(\phi) = V(\phi) + \frac{\beta}{M_{\rm Pl}}(-T^{\mu}_{\mu})\phi \approx V(\phi) + \frac{\beta\rho}{M_{\rm Pl}}\phi$$



Fifth-force constraints from a torsion pendulum

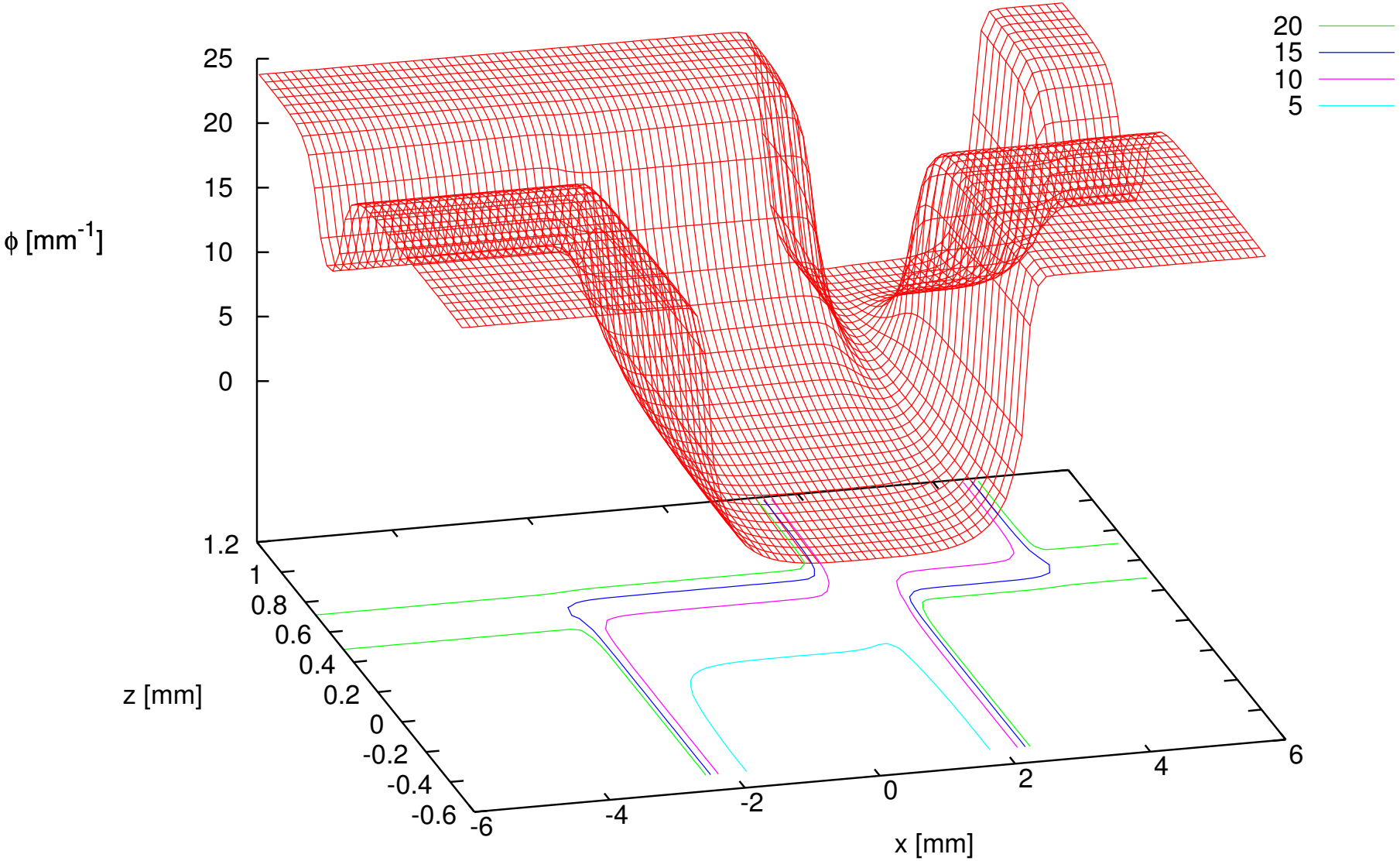
Eöt-Wash Experiment





http://www.npl.washington.edu/eotwash

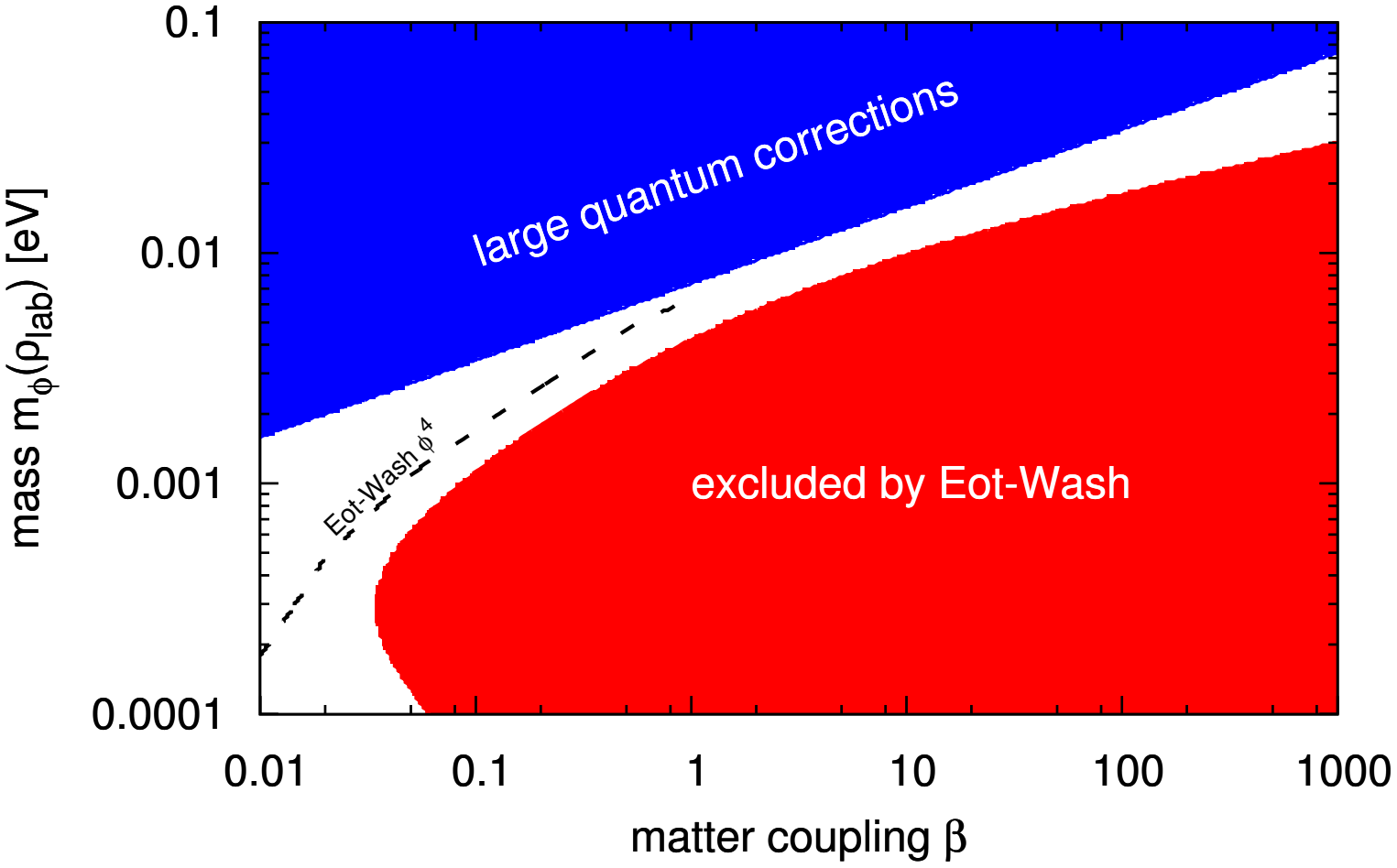
ϕ^4 chameleon field in Eöt-Wash pendulum



AU, S. Gubser, J. Khoury, PRD **74** *104024 (2006)*
Adelberger, Heckel, Hoedl, Hoyle, Kapner, AU, PRL **98** *131104 (2007)*

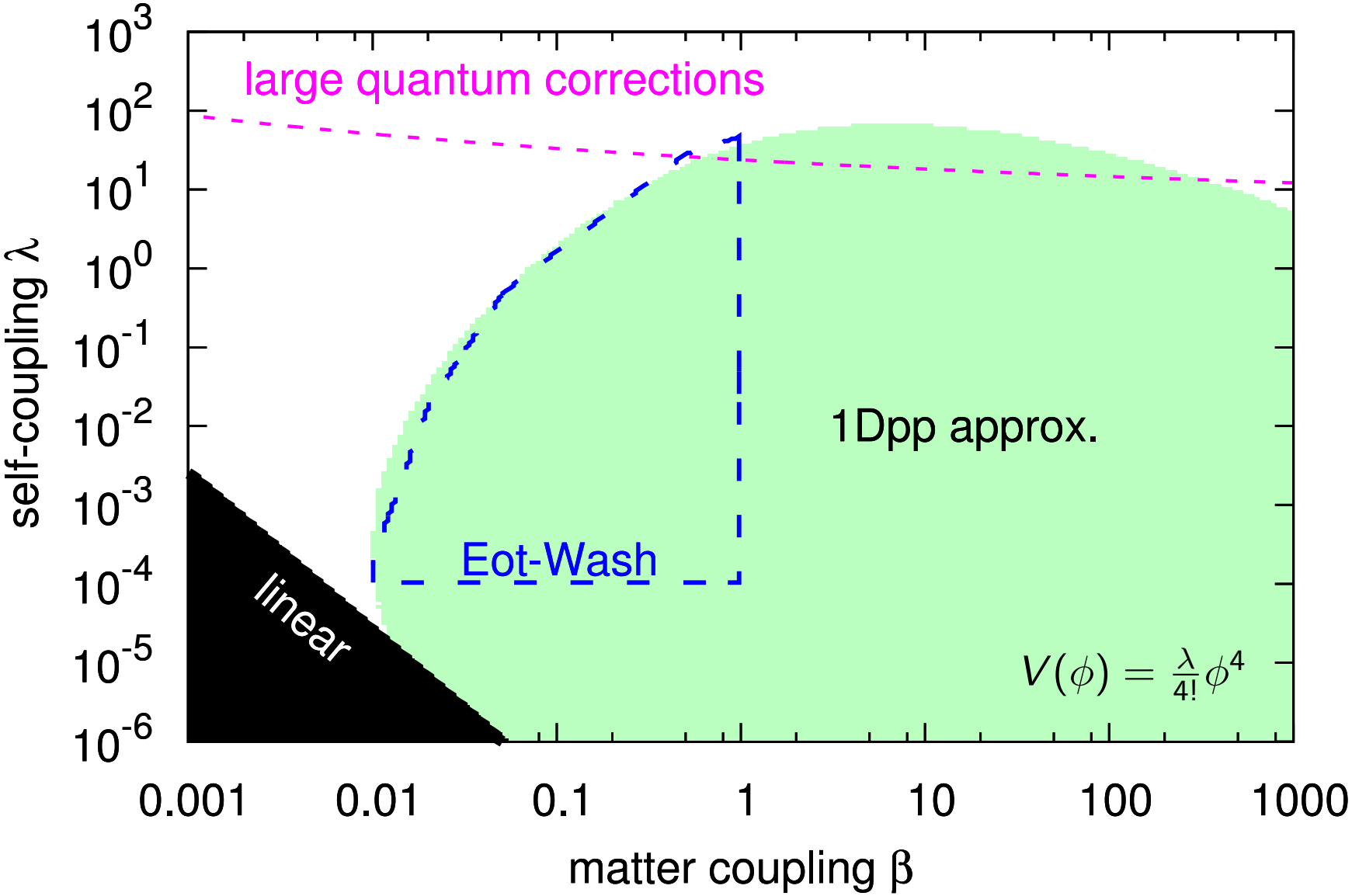
Chameleons with small quantum corrections

$$\Delta V_{1-\mathrm{loop}}(\phi) = \frac{m_{\mathrm{eff}}(\phi)^4}{64\pi^2} \log\left(\frac{m_{\mathrm{eff}}(\phi)^2}{\mu^2}\right) \Rightarrow m_{\mathrm{eff}},\ \phi \text{ change}$$



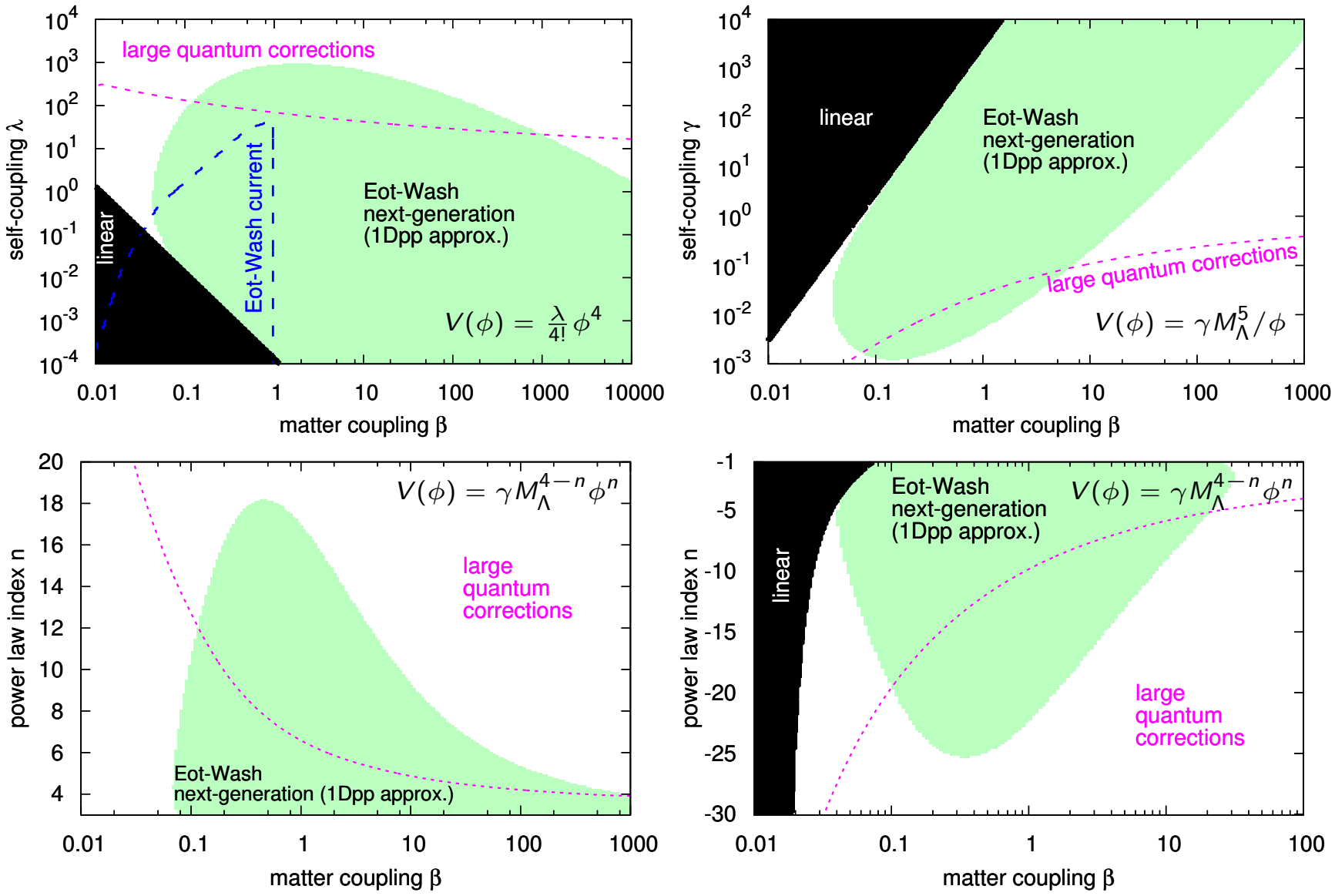
AU, W. Hu, J. Khoury, PRL **109** *041301 (2012)*

1-D plane-parallel approximation to Eöt-Wash constraints



AU, arXiv:1209:0211, submitted to PRD (2012)

Next-generation Eöt-Wash: Forecasts



AU, arXiv:1209:0211, submitted to PRD (2012)

Conclusions

1. Modified gravity could be responsible for the cosmic acceleration.
2. Scalar-mediated fifth forces from modified gravity must be screened in order to evade constraints from tests of gravity.
3. Chameleon-screened models with small quantum corrections and gravitation-strength couplings extend just beyond current experimental bounds in parameter space.
4. The next-generation Eöt-Wash torsion pendulum experiment will exclude a large range of quantum-stable chameleon models.