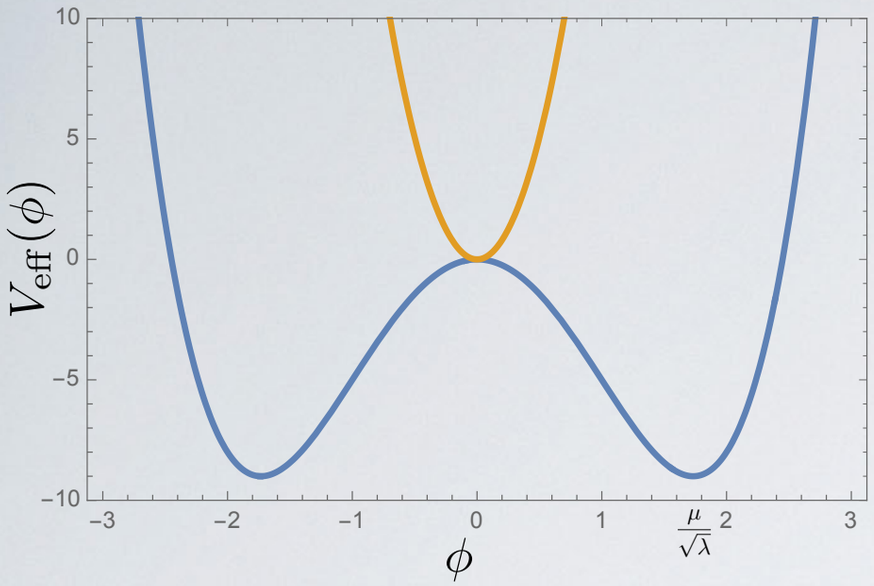

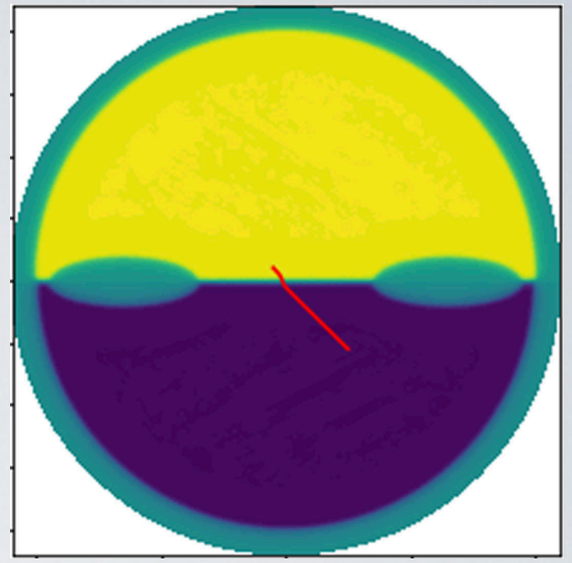

DARK ENERGY DOMAIN WALLS AND ATOM INTERFEROMETRY

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Imperial College London

PRD **109**, 123023 (2024)
arXiv:2308.01179

w/ Kate Clements, Clare Barrage,
Lucia Hackermueller, and Mark Fromhold

PASCOS 2024, Quy Nhon

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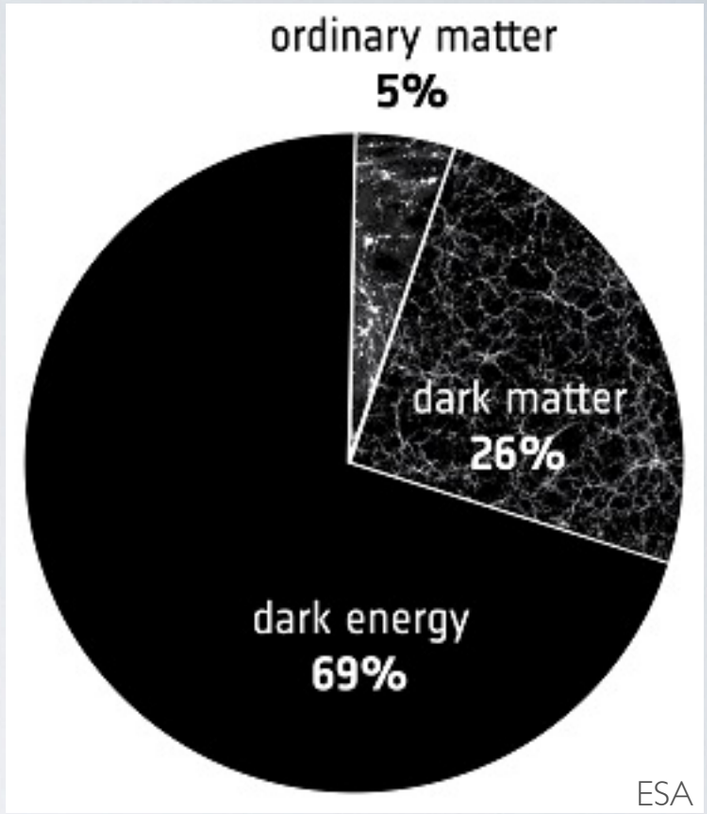
There are many hints that there may be more to gravity than meets the eye



It is very tempting to introduce new gravitational physics

e.g. a new particle with a low-energy universal coupling to matter

$$\mathcal{L} \sim \phi \rho_{\mathrm{matter}}$$

What can this new physics look like?
And how can we test it?

These questions are useful in their own right, independent of cosmological scenarios or specific high-energy theories

The symmetron is one example of a simple (but highly nontrivial) modification to gravity

$$\mathcal{L} = -\frac{1}{2}(\partial\phi)^2 - V_{\rm eff}(\phi)$$

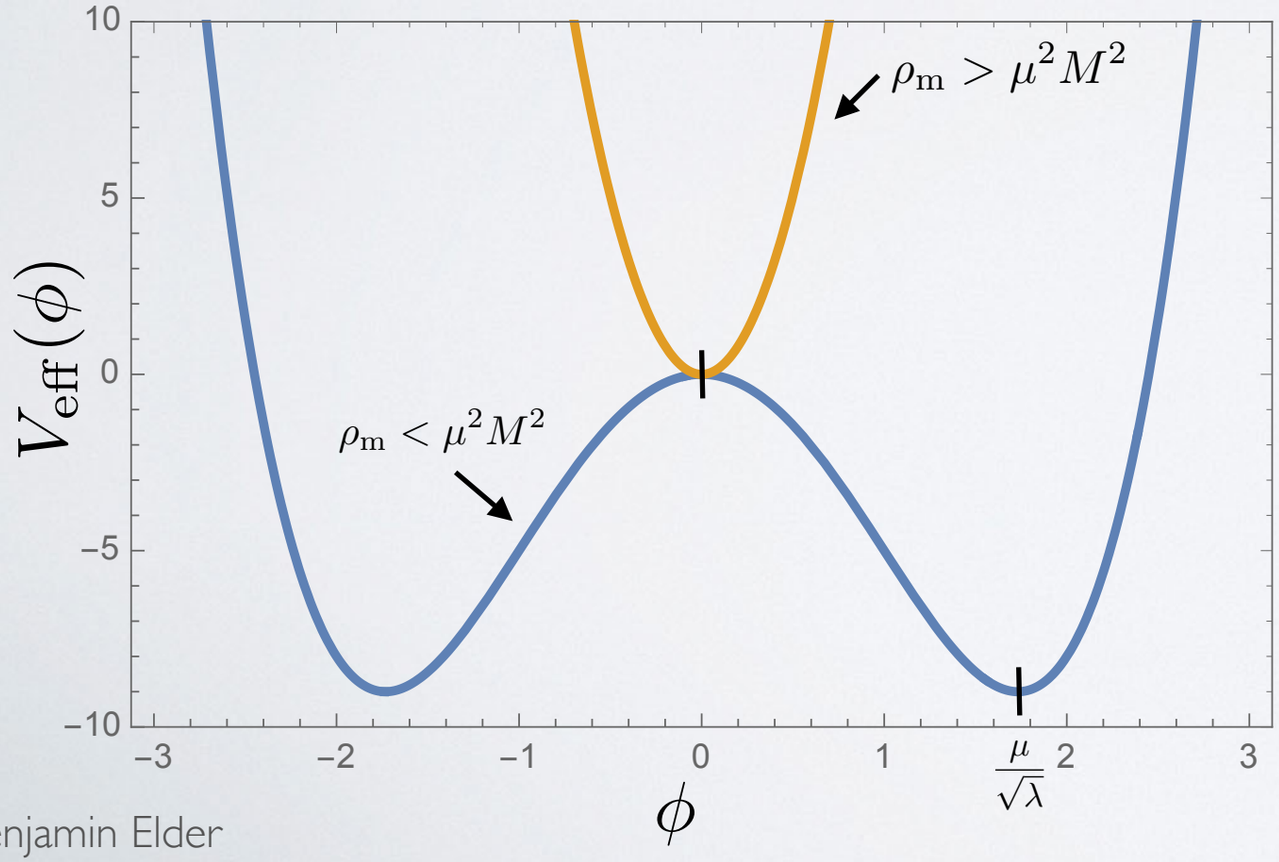
Hinterbichler & Khoury 2010

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

$$\mu \approx \text{meV}$$

$$\frac{\mu}{\sqrt{\lambda}M^2} \approx \frac{1}{M_{\rm Pl}}$$

The matter coupling implies a fifth force $\vec{F} \sim \phi\vec{\nabla}\phi$



In sparse regions (with test particles)

$$\vec{F} \approx \vec{F}_{\rm Newton}$$

In dense regions the fifth force is "screened"

$$\vec{F} \approx 0$$

Atom interferometry is an excellent test of screened modified gravity

Burrage, Copeland, Hinds 2015

Measure the force between atoms and a marble-sized mass to an accuracy

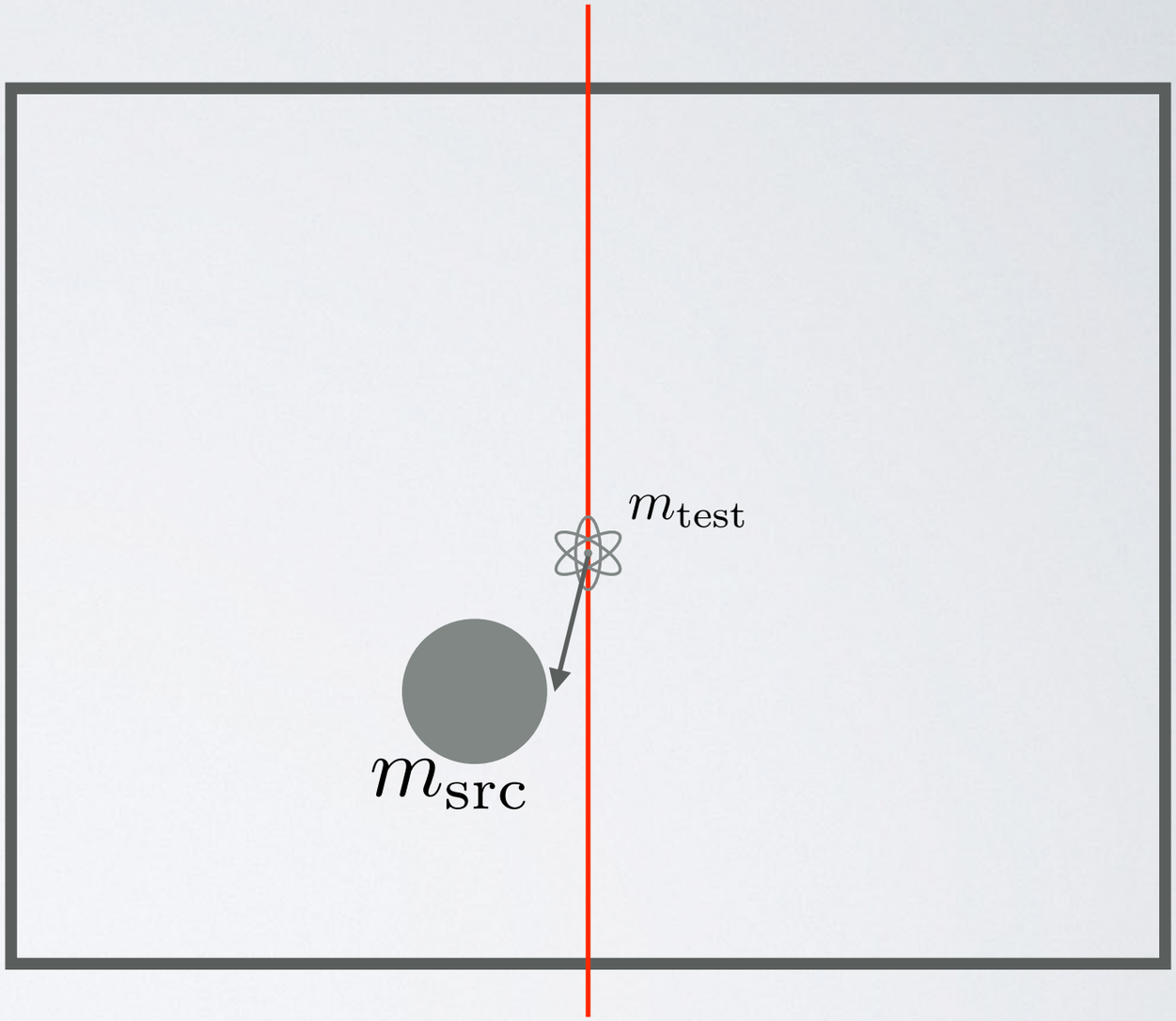
$$a_{\rm atom} \approx 10^{-10} g_{\rm Earth}$$

But the measurement is restricted to distances

$$d \gtrsim \rm mm$$

Which only tests symmetron masses

$$\mu \lesssim 0.1\ \Lambda_{\rm DE}$$

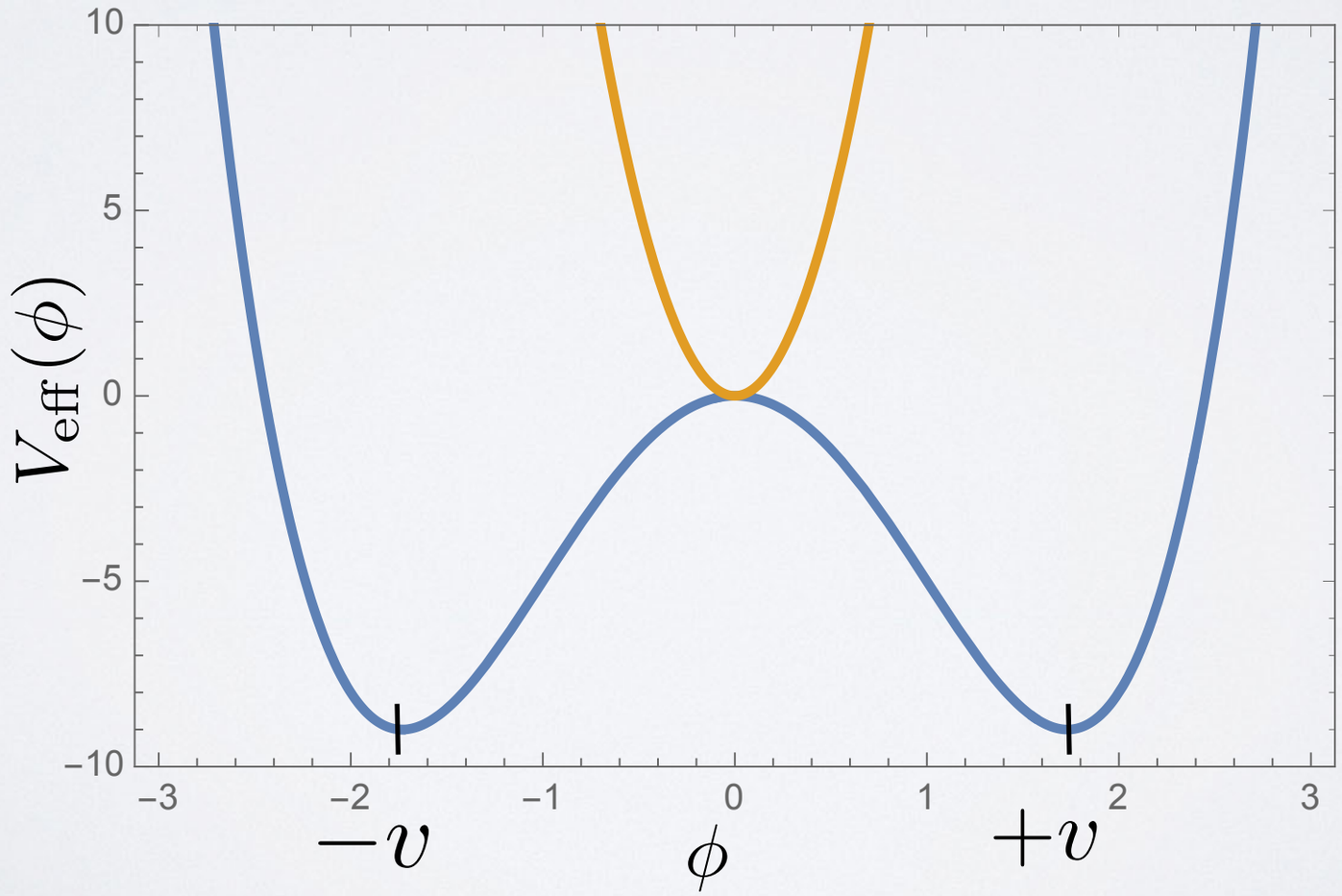


Hamilton, Jaffe, Haslinger, Muller, Khoury, Science 2015
BE, Khoury, Haslinger, Jaffe, Muller, PRD 2016
Jaffe, Haslinger, Xu, Hamilton, Upadhye, **BE**, Khoury, Muller 2017
Sabulsky, Dutta, Hinds, **BE**, Burrage, Copeland, PRL 2019

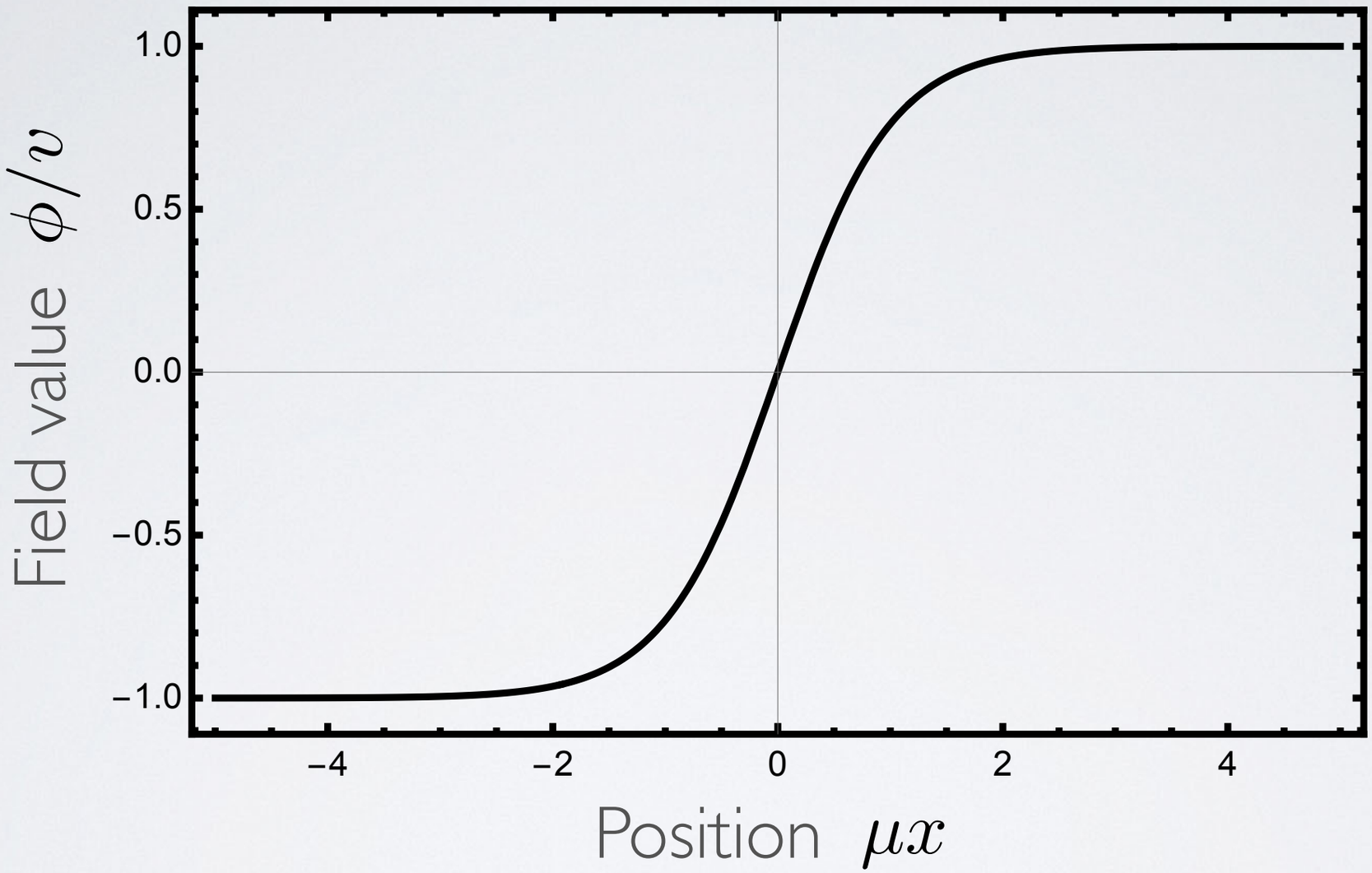
Goal: to test shorter distance scales of screened modified gravity, especially with atom interferometry!

One possibility is to replace the marble source mass with a symmetron **domain wall.**

Recall that the symmetron has two equivalent vacua: $v = \pm \frac{\mu}{\sqrt{\lambda}}$



In one spatial dimension, a domain wall is a solution that connects these two vacua

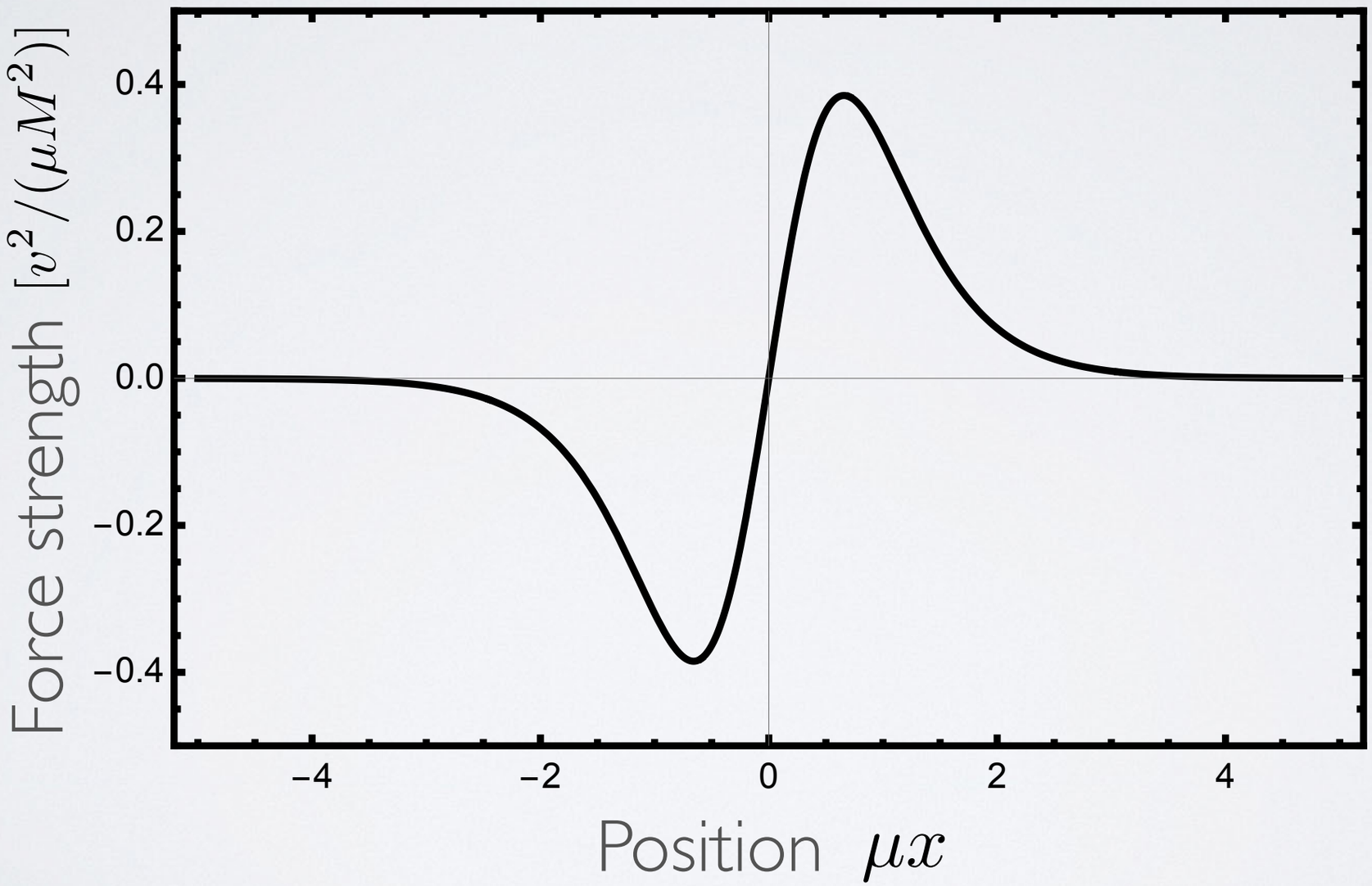


As long as the boundary values are fixed this field configuration is **topologically stable.**

Recall that field gradients are responsible for the scalar fifth force

$$\vec{F} \sim \phi \vec{\nabla} \phi$$

So the domain wall **sources the fifth force**



This is just as strong as a physical source mass!

In 3 spatial dimensions, form domain walls in the following way:

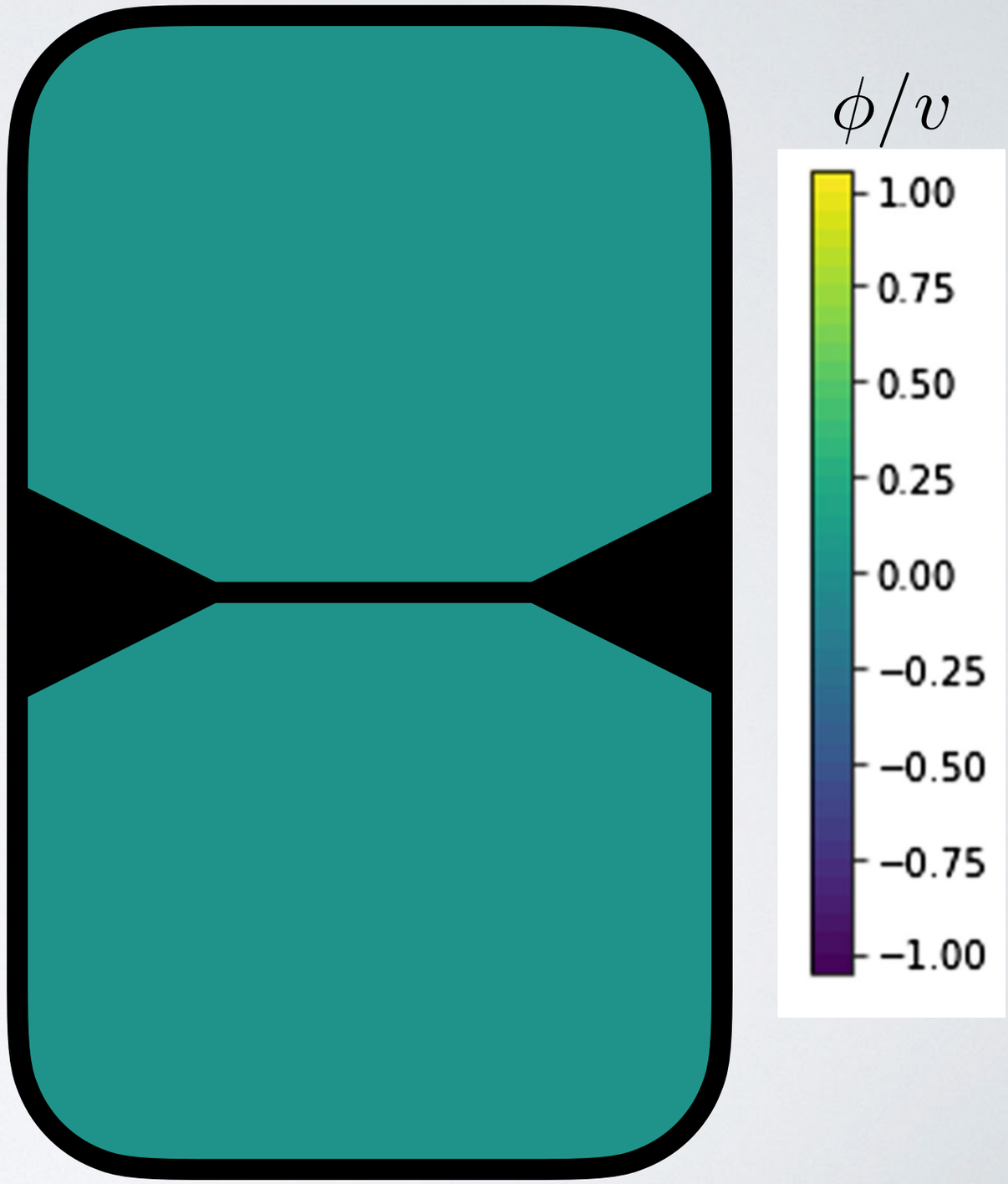
1) Cut off two chambers from each other, increase gas density above $\rho_{\mathrm{gas}} > \rho_{\mathrm{crit}}$

$$\phi \to 0$$

2) Pump out the vacuum chambers $\rho_{\mathrm{gas}} < \rho_{\mathrm{crit}}$

$$\phi \to \pm v$$

3) Open the shutter



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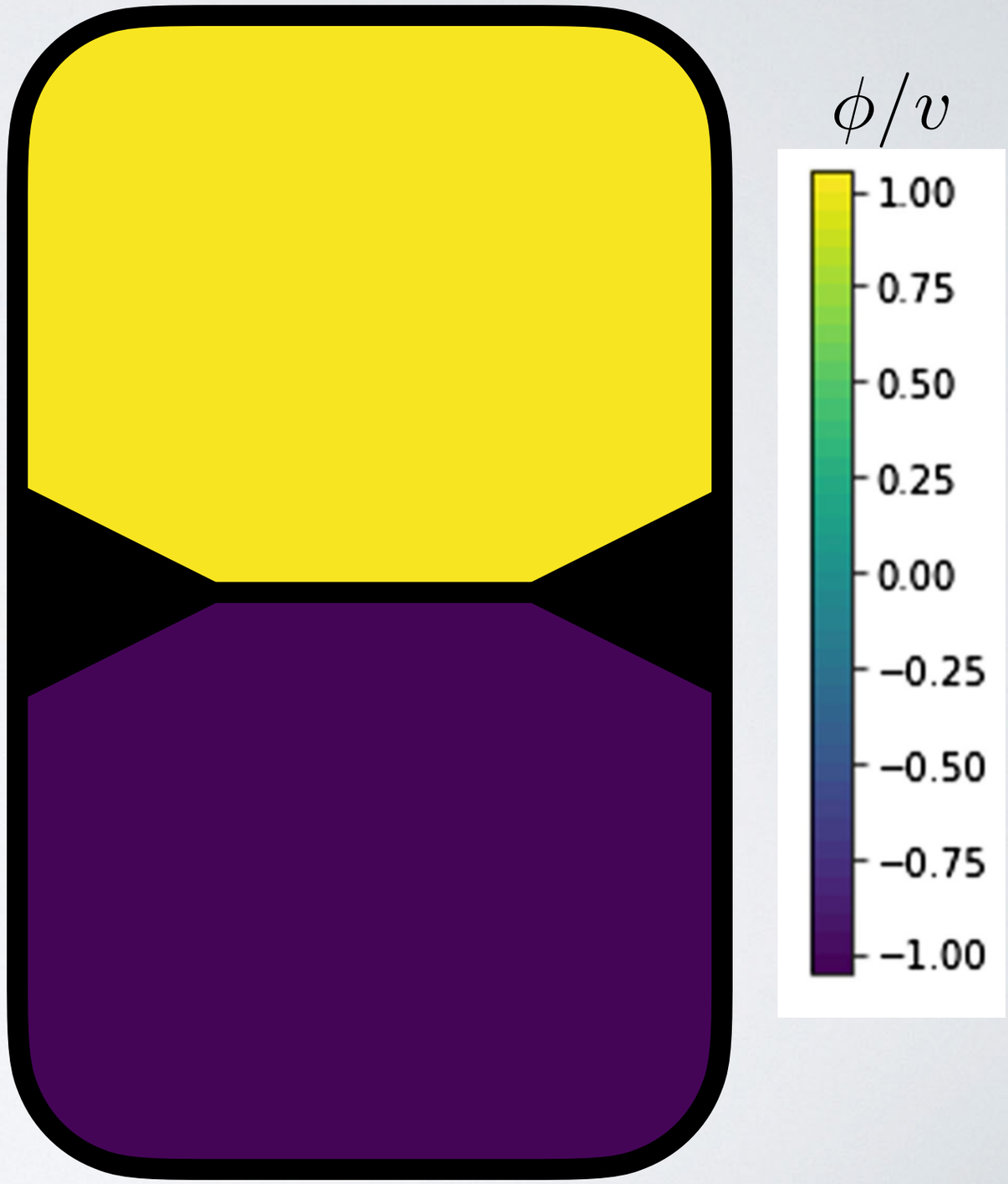

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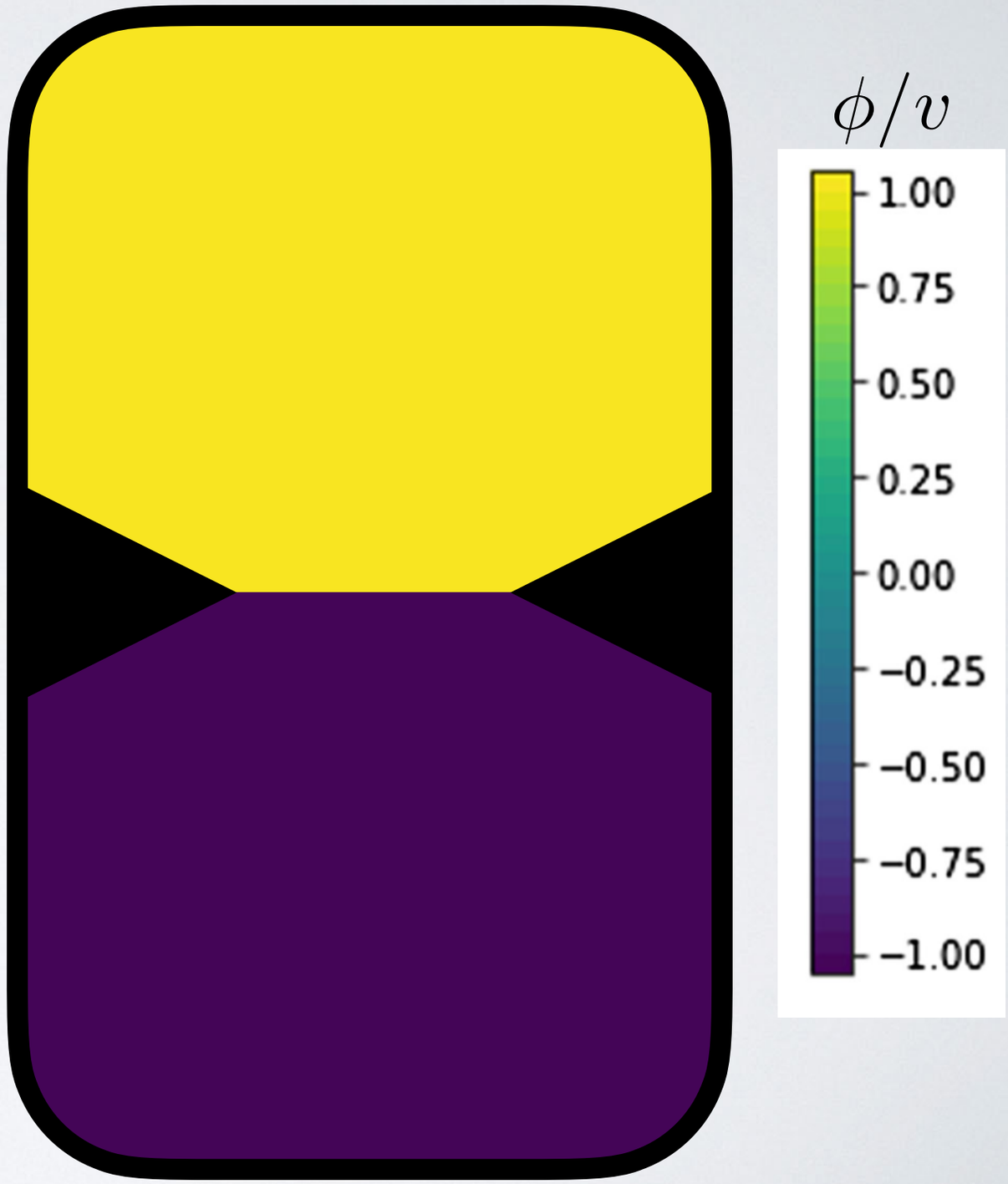


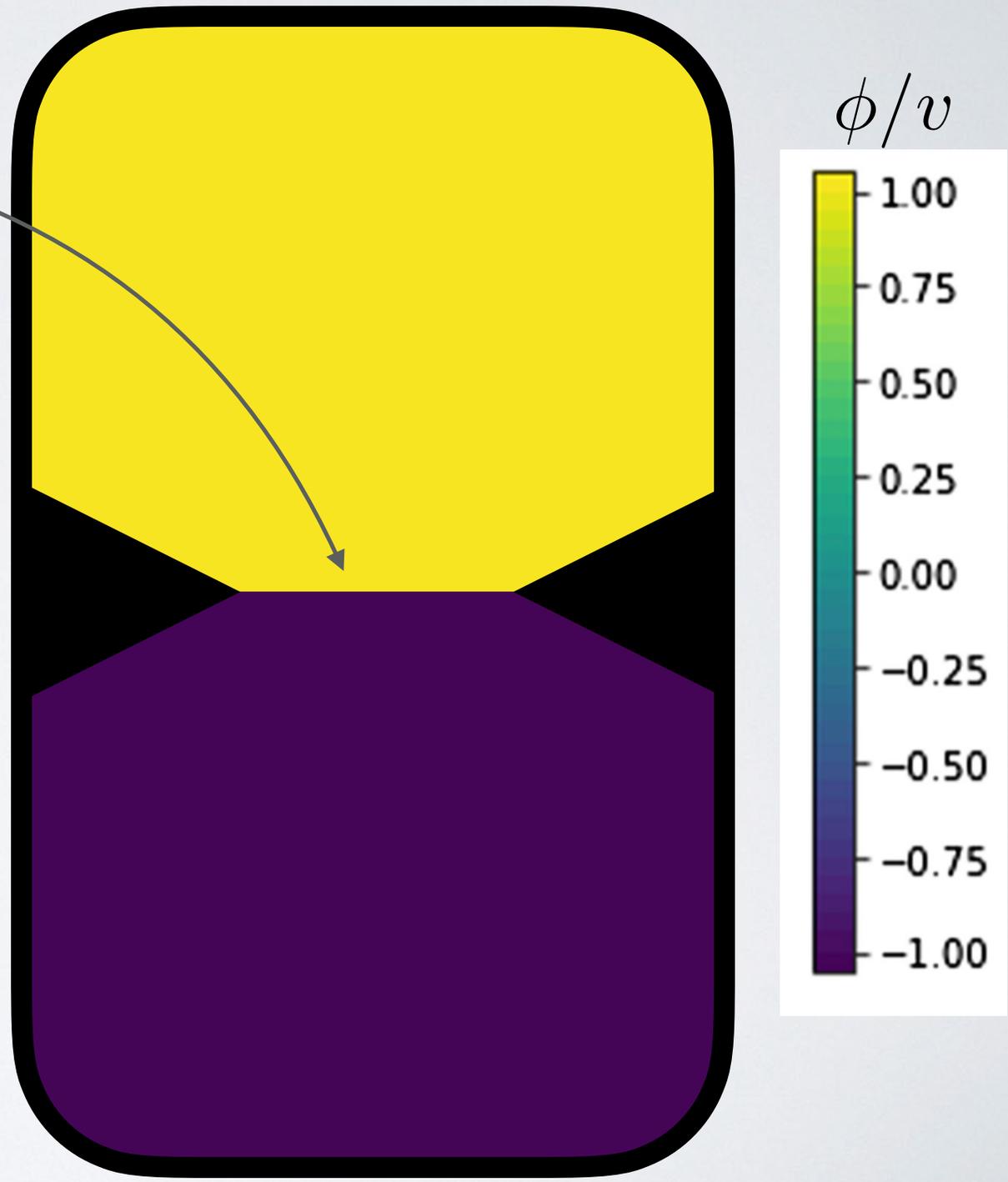
In 3 spatial dimensions, form domain walls in the following way:

We now have a domain wall in the centre of the chamber

It is classically stable:

$$\text{Energy} \sim \text{Area}$$

i.e. moving away from the waist would require additional energy.

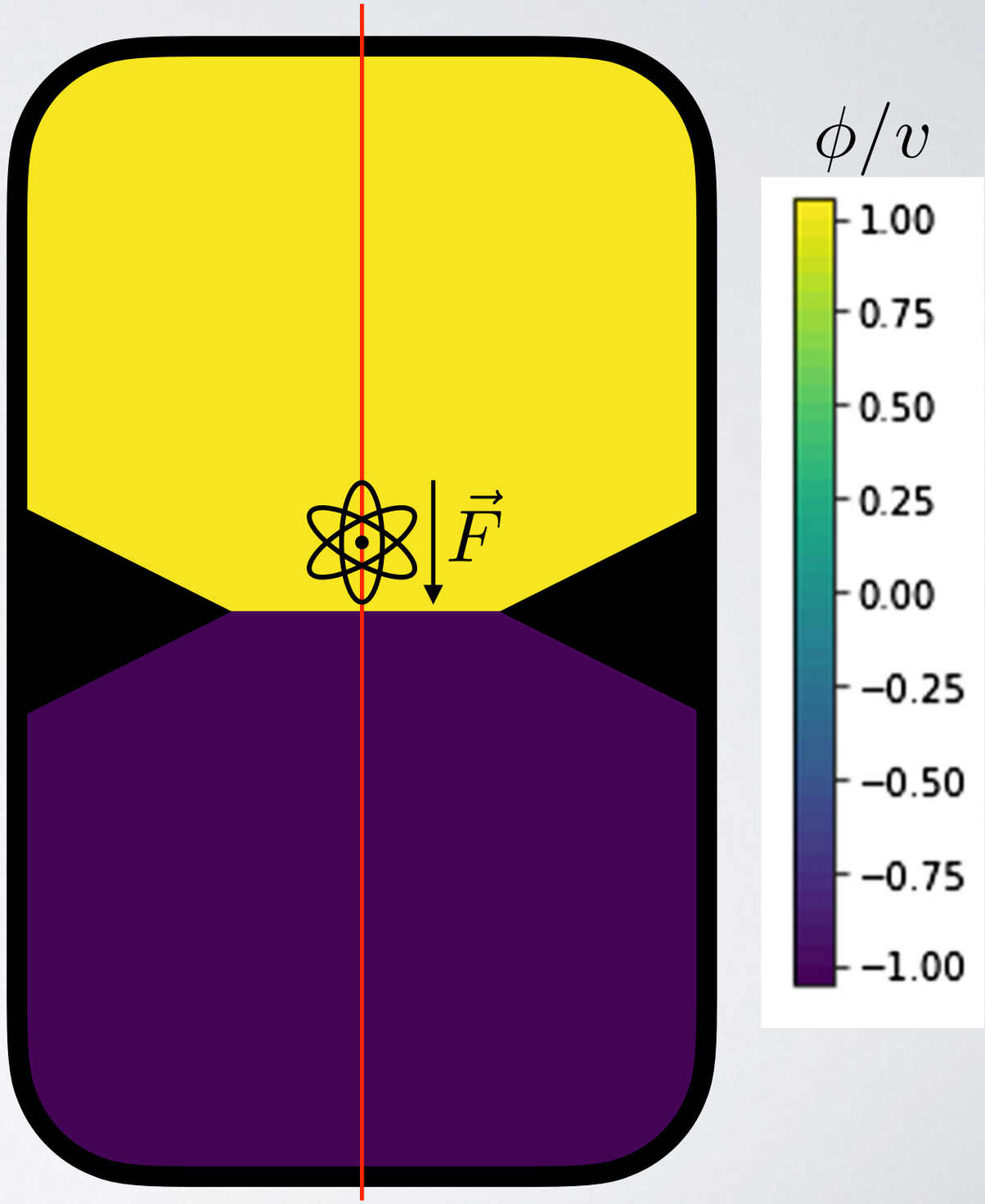


In 3 spatial dimensions, form domain walls in the following way:

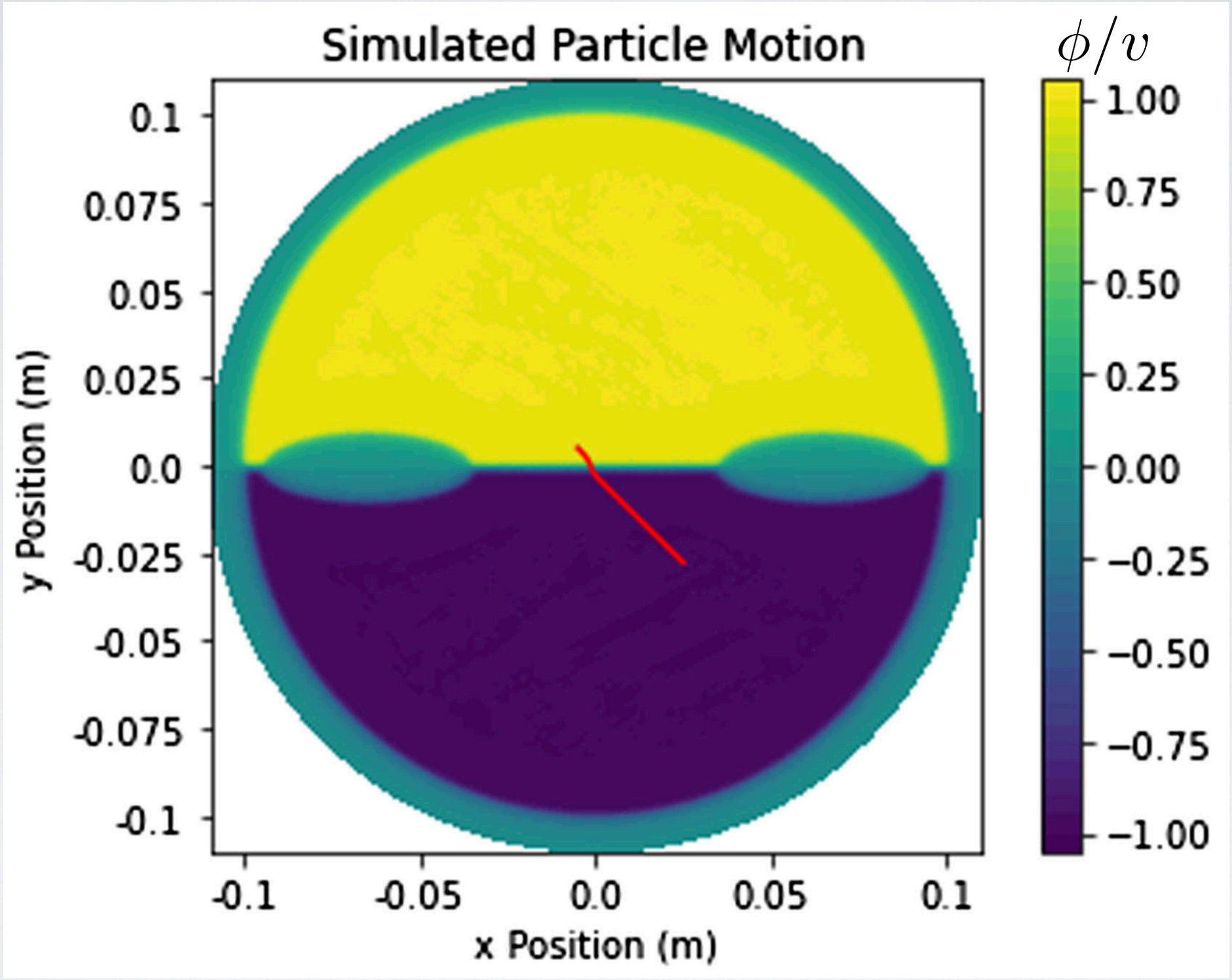
The domain wall may be detected with a force sensor, such as atom interferometry

Repeated cycles of vacuum pumping/measurement are required, as the domain walls only form 50% of the time

The atoms can now be **arbitrarily close** to the "source"



A configuration found via numerical simulation:



Clements, **BE**, Hackermueller, Fromhold, Burrage PRD 2024

We've seen how symmetron domain walls may be formed and stabilised inside vacuum chambers

This enables existing force sensors, like atom interferometers, to test the dark energy scale

$$\mu = \Lambda_{\rm DE} = 2.4 \text{ meV}$$

Next steps:

- Numerical simulation of formation and evolution
- Evaluate quantum stability
- Build/perform the experiment?