A COLD ATOM ANALOGUE FOR VACUUM DECAY IN THE EARLY UNIVERSE

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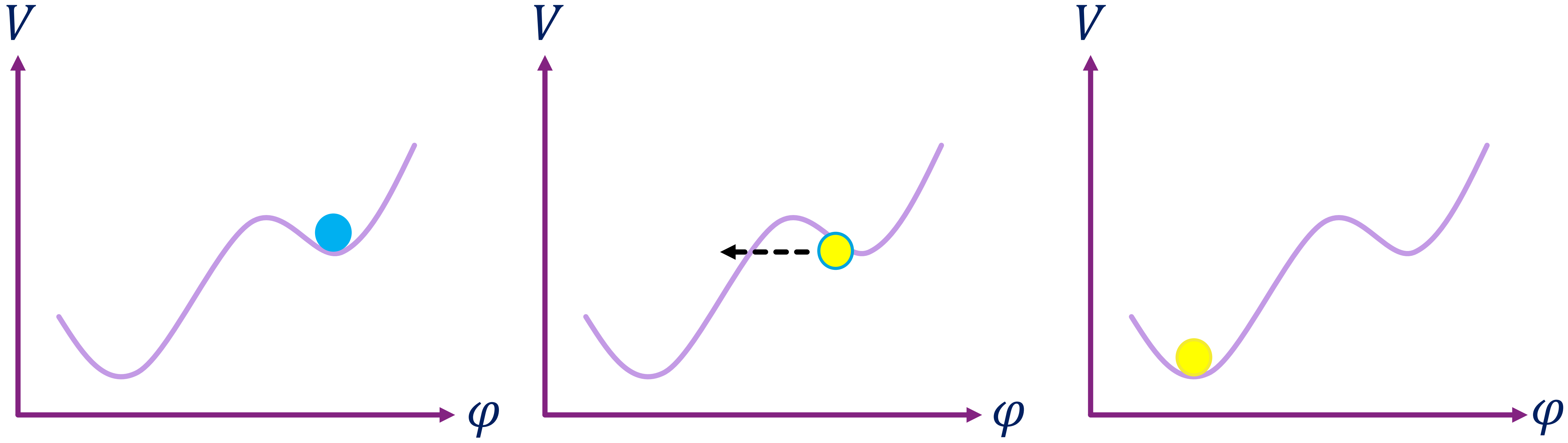
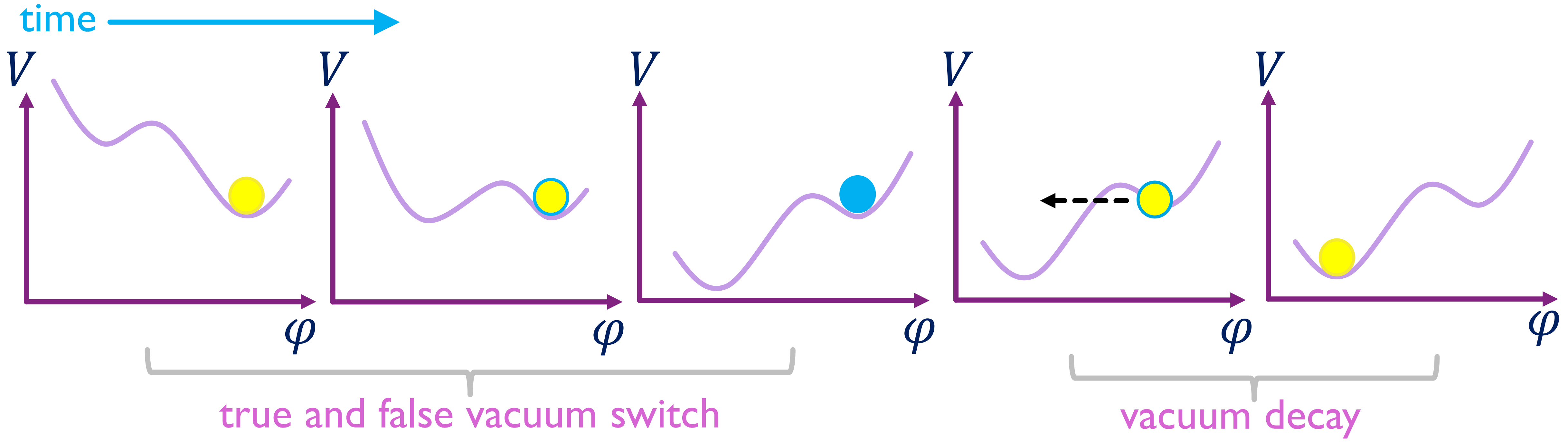
VACUUM DECAY



False Vacuum State (Metastable) → Quantum Tunnelling → True Vacuum State (Stable)

VACUUM DECAY – EARLY UNIVERSE



Interesting applications: gravitational waves, baryon asymmetry, black holes

COLD ATOM ANALOGUE SYSTEM

- We use two components:

$$\psi_0 = \sqrt{n_0}e^{i\theta_0}, \qquad \psi_1 = \sqrt{n_1}e^{i\theta_1}$$

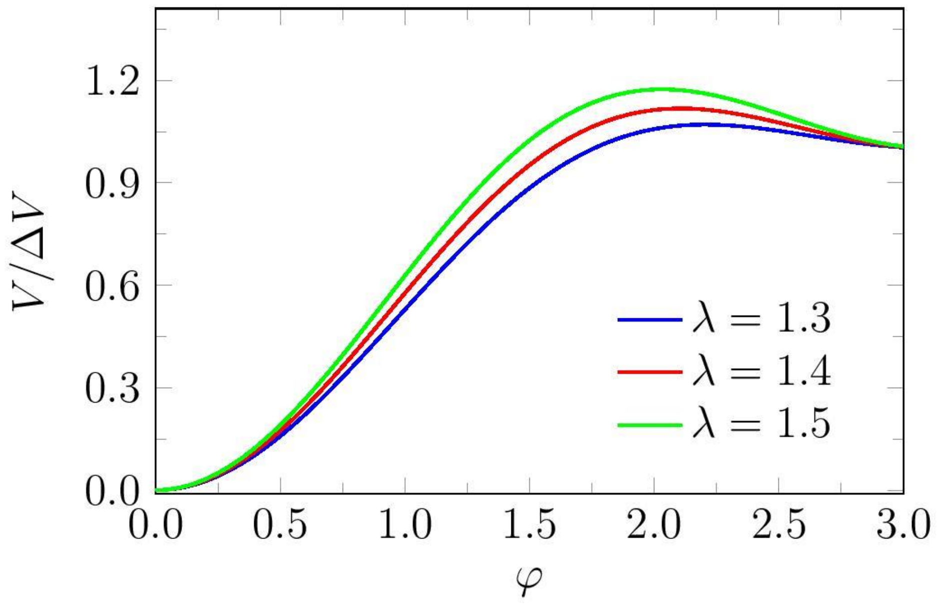
- with phase difference:

$$\varphi = \theta_0 - \theta_1$$

- and interaction potential:

$$V(\varphi) = -2\epsilon^2 - 2\epsilon^2\cos(\varphi) + \epsilon^2\lambda^2\sin^2(\varphi)$$

- $\varphi = 0$ is stable (true vacuum)
- $\varphi = \pi$ is metastable (false vacuum)



NUMERICAL MODEL

- We use a coupled pair of stochastic Gross-Pitaevskii equations (SGPE):

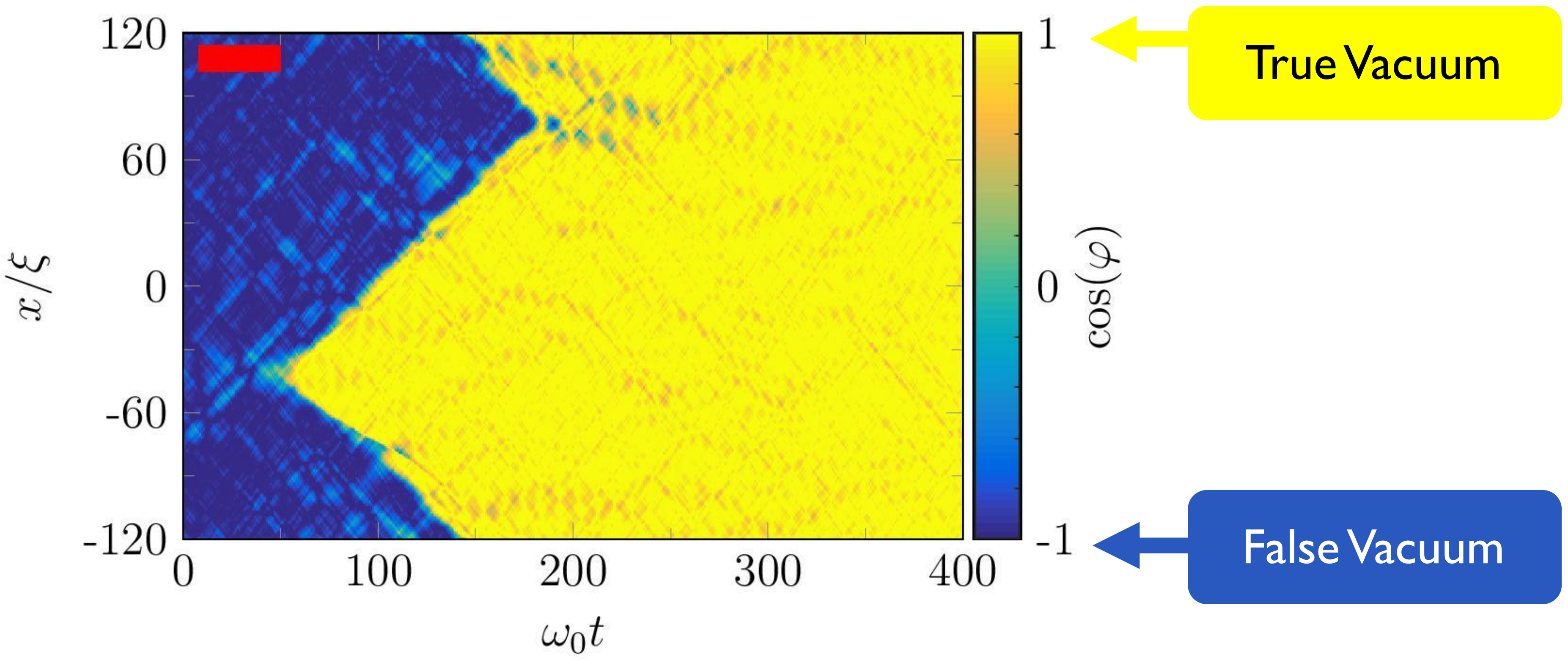
$$i\partial_t \psi_j = (1 - i\gamma)\left\{-\frac{1}{2}\nabla^2\psi_j + \frac{\partial V}{\partial \psi_j^*}\right\} + \eta_j, \qquad j = 0, 1$$

- γ : Damping
- η : Random fluctuations, $\langle \eta_i(x,t)\eta_j(x',t')\rangle = 2\gamma T\delta(x - x')\delta(t - t')\delta_{ij}$

- System: 1D box with periodic boundaries

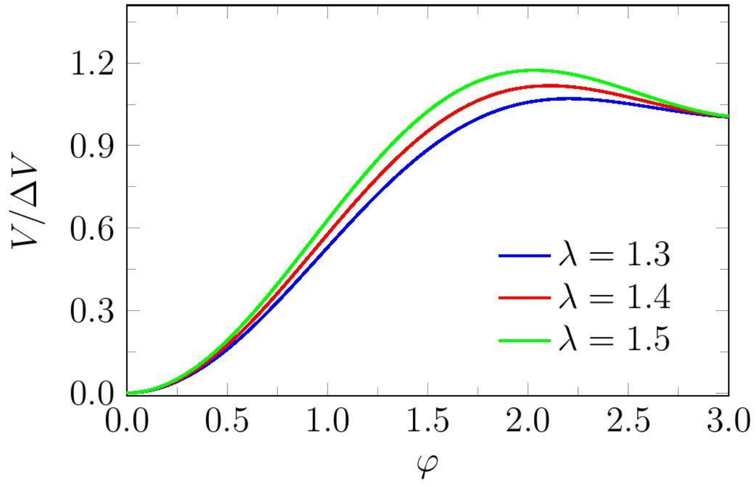
OBSERVING BUBBLES

- Protocol: initialise in the metastable state:
- System transitions from "false vacuum" to "true vacuum" via bubble growth

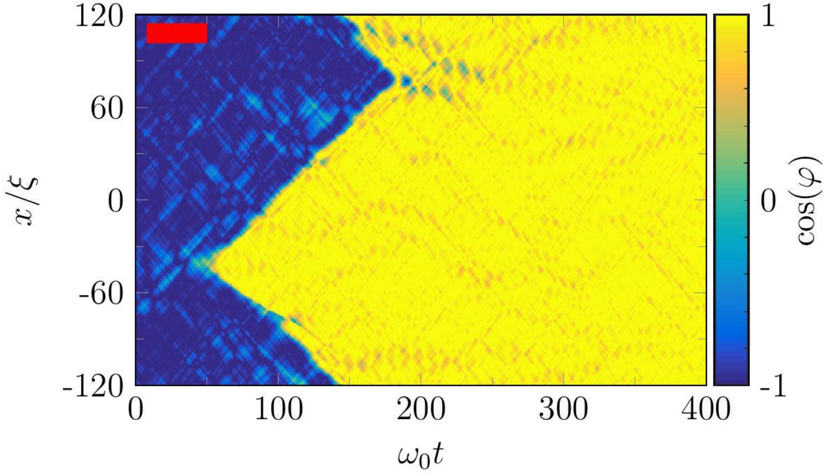


STATIC POTENTIAL VS OSCILLATORY POTENTIAL

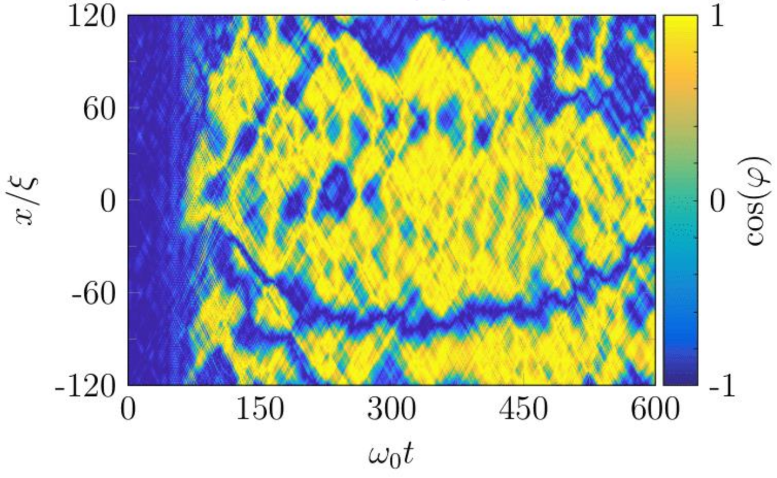
- The interaction potential, $V(\varphi)$, is static
- It's engineered from an oscillating potential, $V_{osc}(\varphi, t)$
- Instabilities can occur for V_{osc}:



V



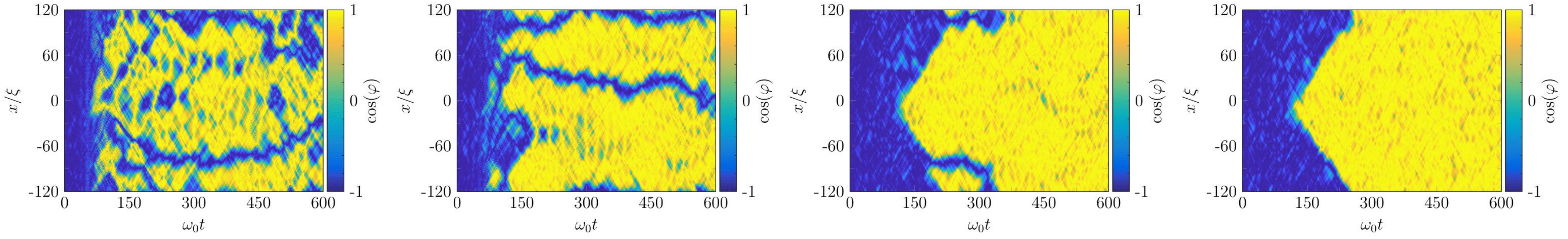
V_{osc}



STATIC POTENTIAL VS OSCILLATORY POTENTIAL

SGPE: $$i\partial_t \psi_j = (1 - i\gamma)\left\{-\frac{1}{2}\nabla^2\psi_j + \frac{\partial V}{\partial \psi_j^*}\right\} + \eta_j$$

- Instabilities can be damped out by raising γ:



$\gamma = 0.005$ $\gamma = 0.01$ $\gamma = 0.02$ $\gamma = 0.03$

CONCLUSION

- Qualitative agreement can be reached between V & V_{osc}
- For proof of quantitative agreement (and references), see arxiv 2006.09820 & 2104.07428

Thank you!