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AXIONS & NON-LINEARITIES

WITH P. SOLER & F. CEFALA – TO APPEAR

Warsaw, String Pheno 2018

STANDARD ALP MODELS – MISALIGNMENT

Abbott, Sikivie;
Preskill, Wise, Wilczek;
Dine, Fischler

Random field value [after inflation], ϕ_i

E.o.M: $$\ddot{\phi} + 3H\dot{\phi} + m^2\phi = 0$$

3 phases:

$t \ll t_1$

3H $\gg$ m

field becomes overdamped, gets frozen

$t \simeq t_1$

3H $\simeq$ m

damping undercritical, oscillations begin

$t \gg t_1$

3H $\ll$ m

indistinguishable from pressureless gas

STANDARD ALP MODELS

Abbott, Sikivie;
Preskill, Wise, Wilczek;
Dine, Fischler

$$V(\phi) = \Lambda^4 \left[1 - \cos\left(\frac{\phi}{f}\right) \right]$$

$$m^2 = \frac{\Lambda^4}{f^2}$$

$$|\phi| \lesssim \pi f$$

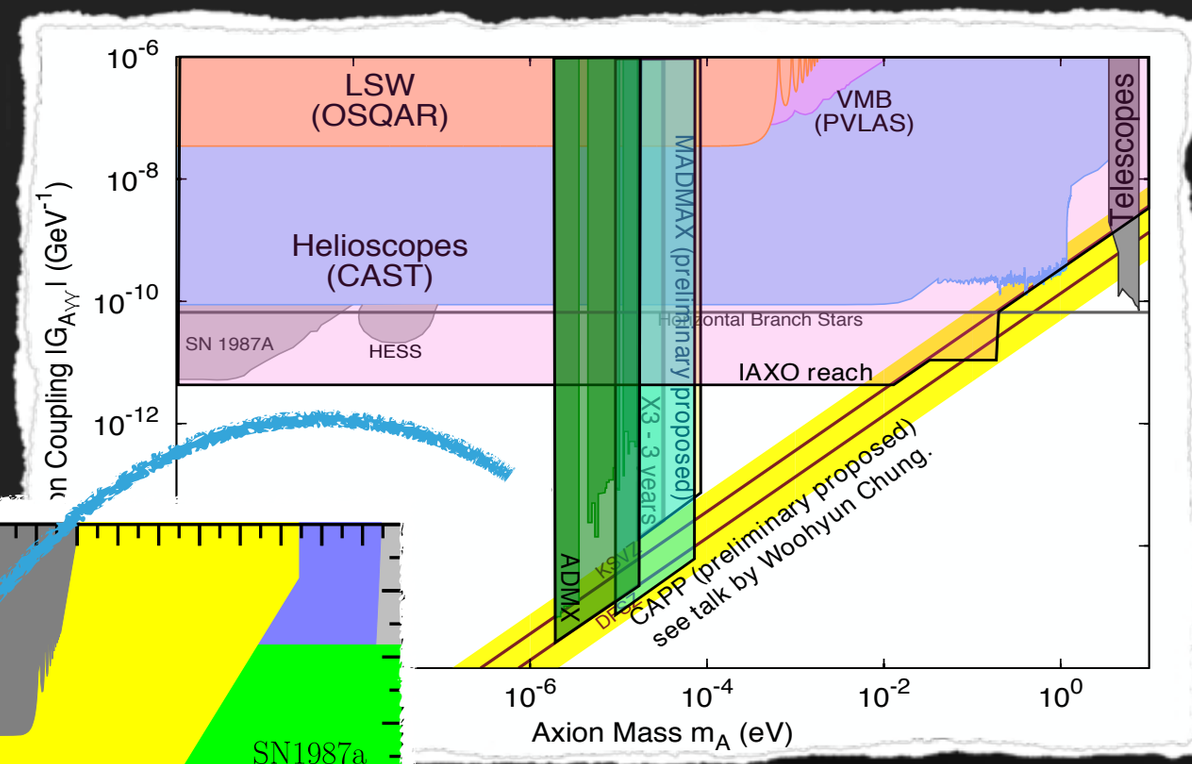
$$\mathcal{L} \supset \frac{\phi}{f} F\tilde{F}, \frac{\partial_\mu \phi}{f} \overline{\psi} \gamma^\mu \gamma^5 \psi$$

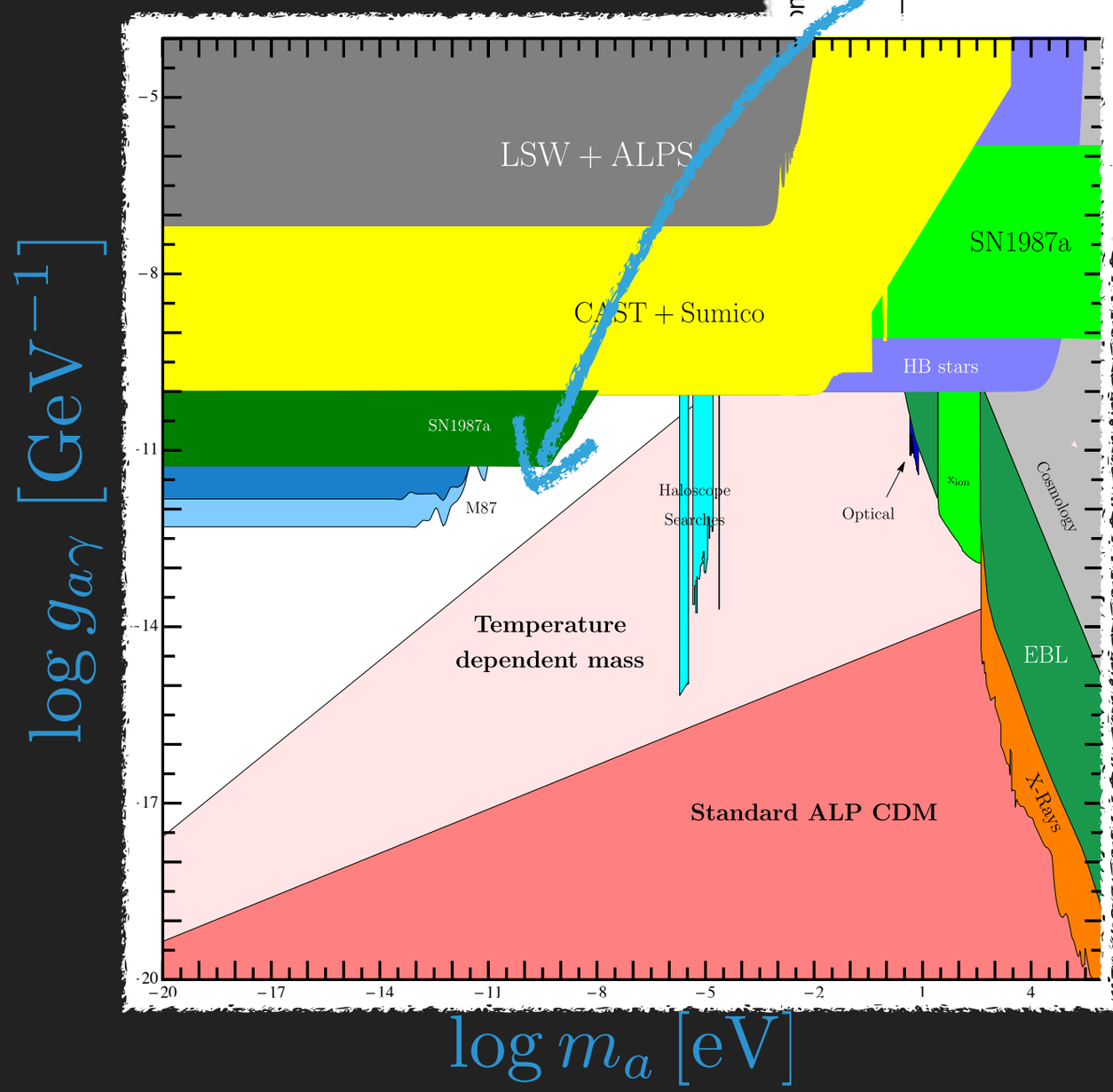
$$g \equiv \frac{\alpha}{2\pi} \frac{1}{f} \mathcal{N}$$

ALPS

RUNNING EXPERIMENTS:

- IAXO
- MADMAX
- ADMX
- ETC...





Areas being probed

ALPS

RUNNING

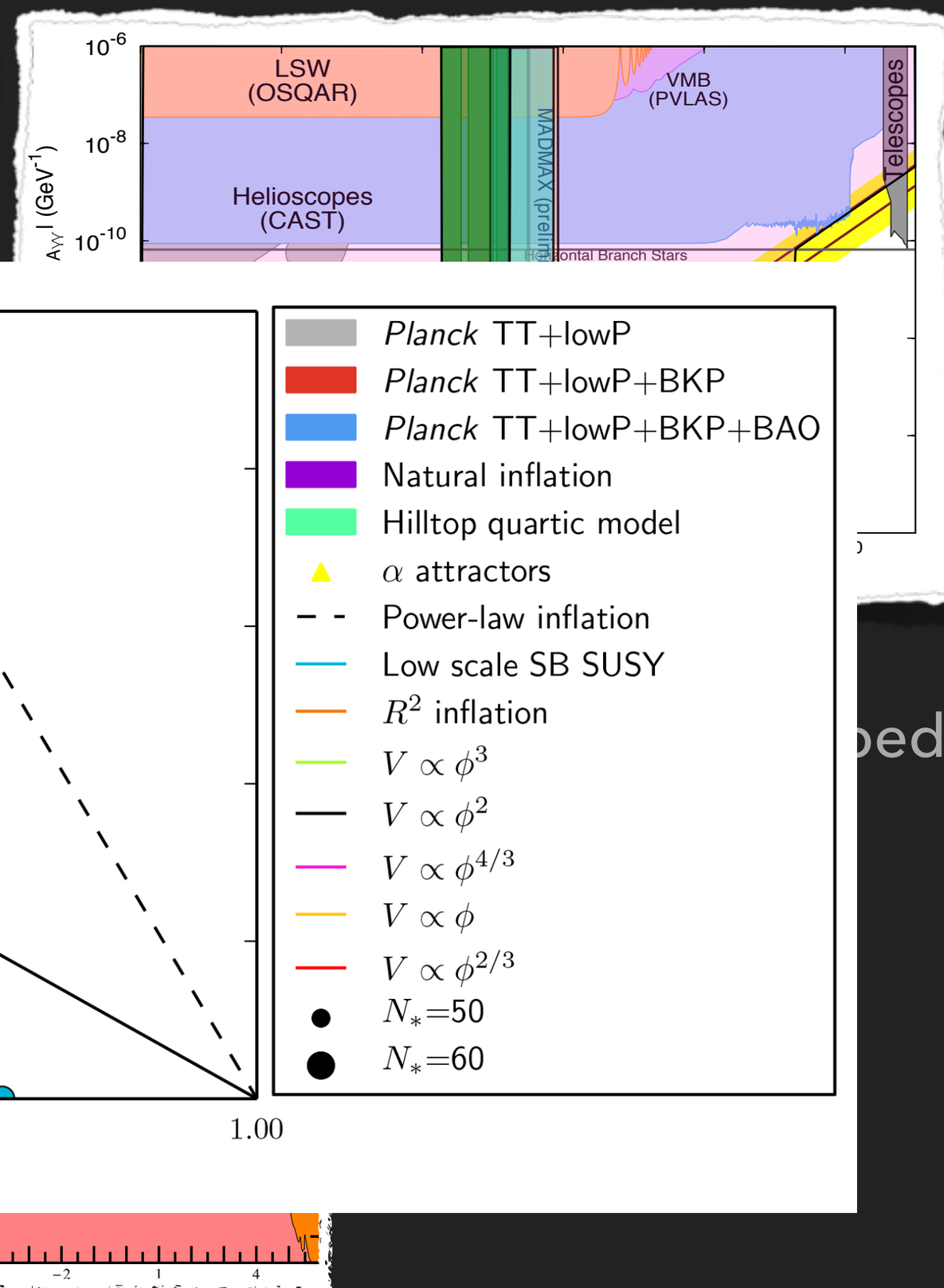
EXP

– IA

–M

–AI

–ET



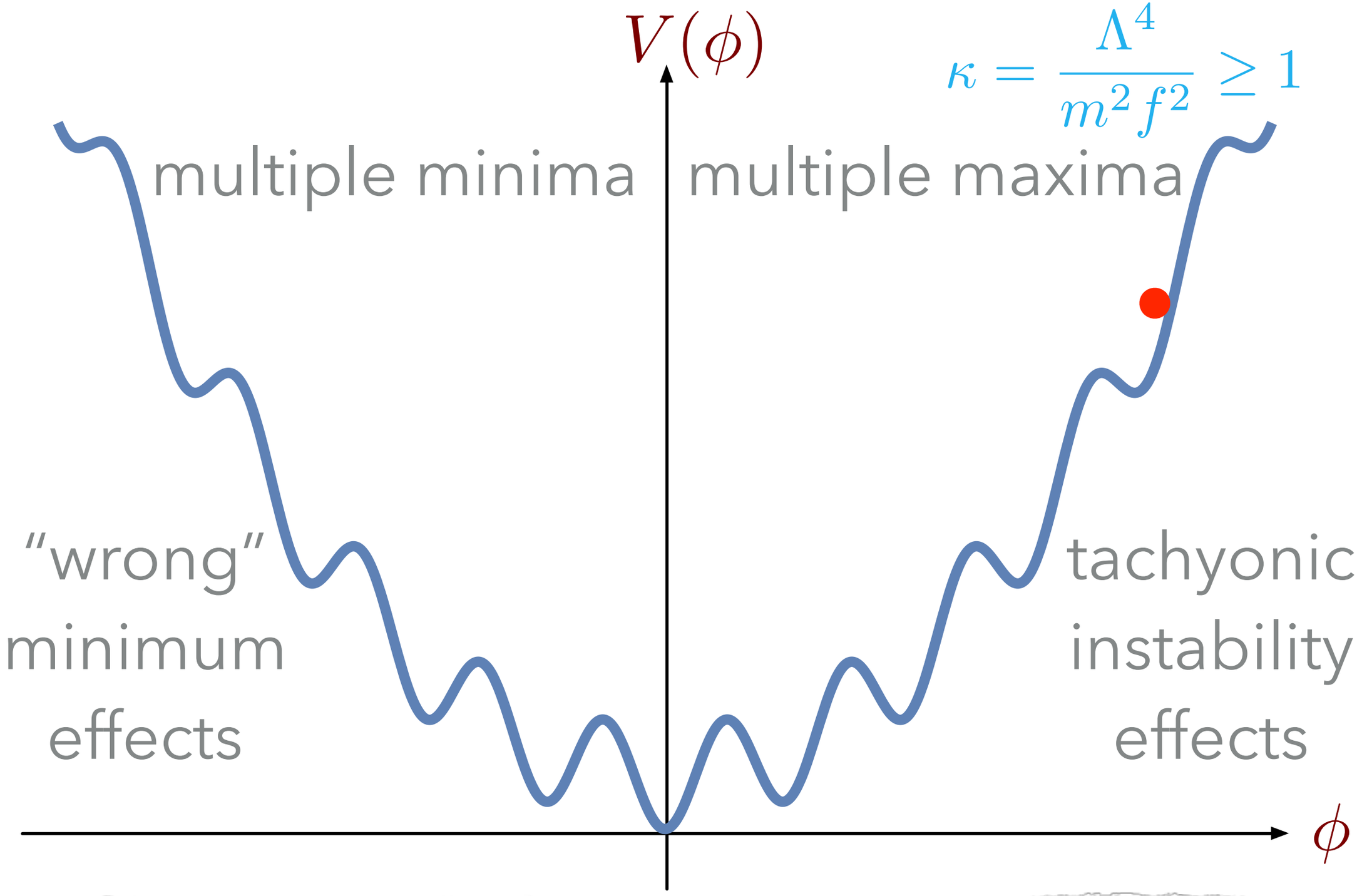
$\log m_a$ [eV]

POTENTIAL

Silverstein, Westphal, McAllister; Kim, Nilles, Peloso

$$V(\phi) = \frac{1}{2}m^2\phi^2 + \Lambda^4\left(1 - \cos\left(\frac{\phi}{f}\right)\right)$$

$$\kappa = \frac{\Lambda^4}{m^2 f^2} \geq 1$$



LINEAR REGIME

- Monodromy Dark Matter
  - Tachyonic instabilities
  - Parametric resonance
    - Saturation of DM abundance

Jaeckel, VMM, Witkowski

- Dynamical Phase Decomposition
  - ``wrong minimum'' effects
    - Gravitational waves

Hebecker, et al.

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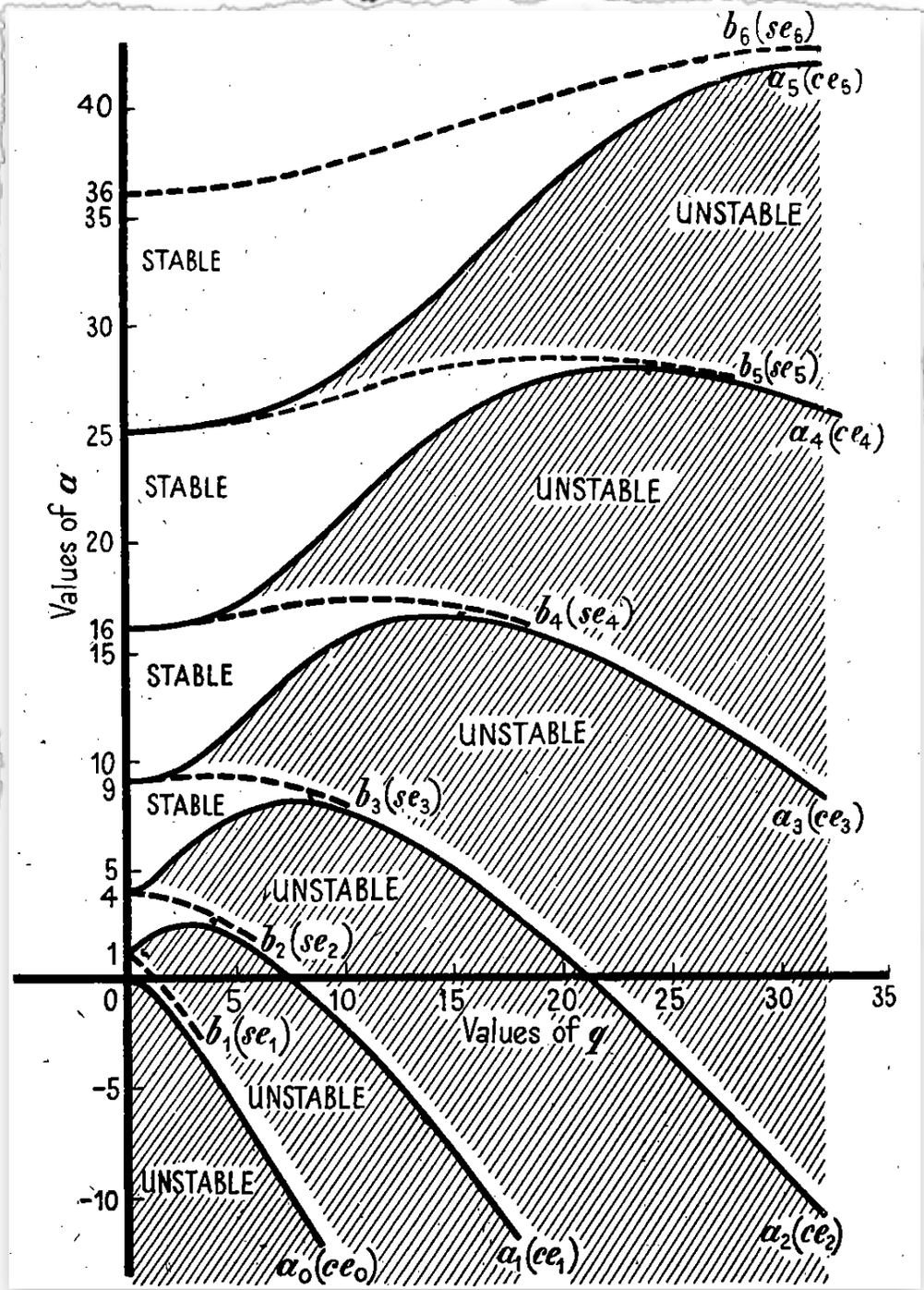
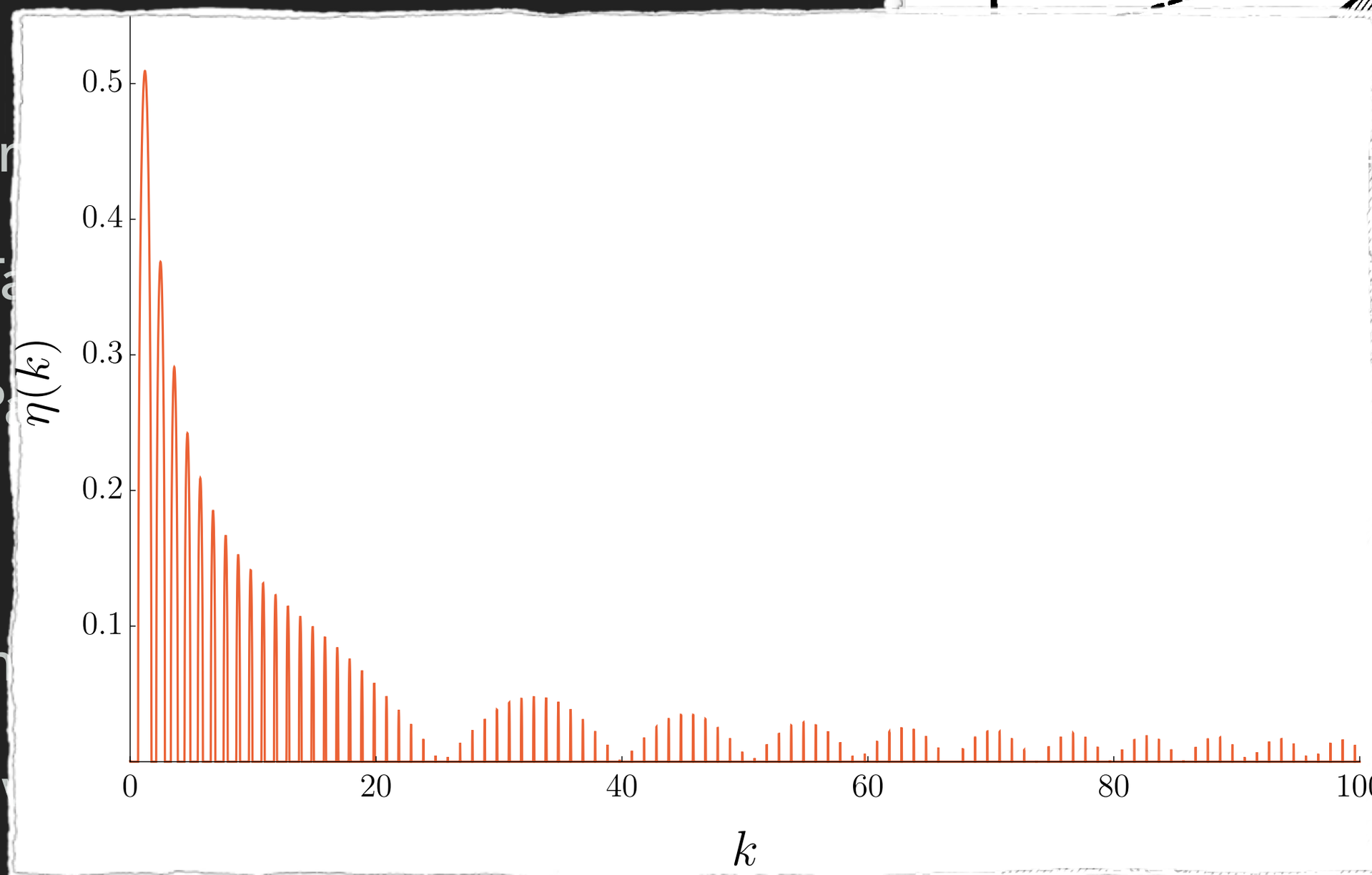
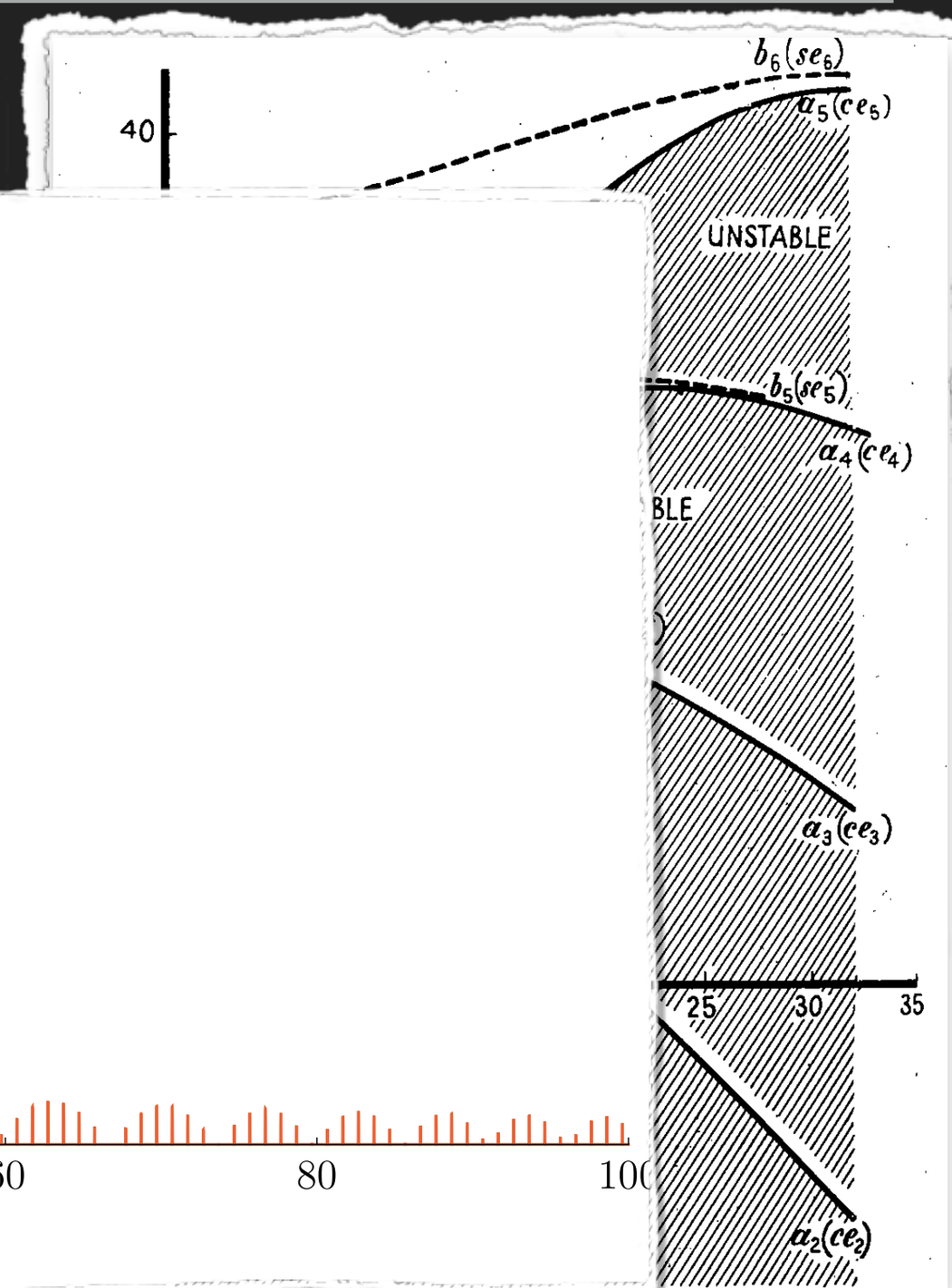


stability/instability bands

LINEAR REGIME

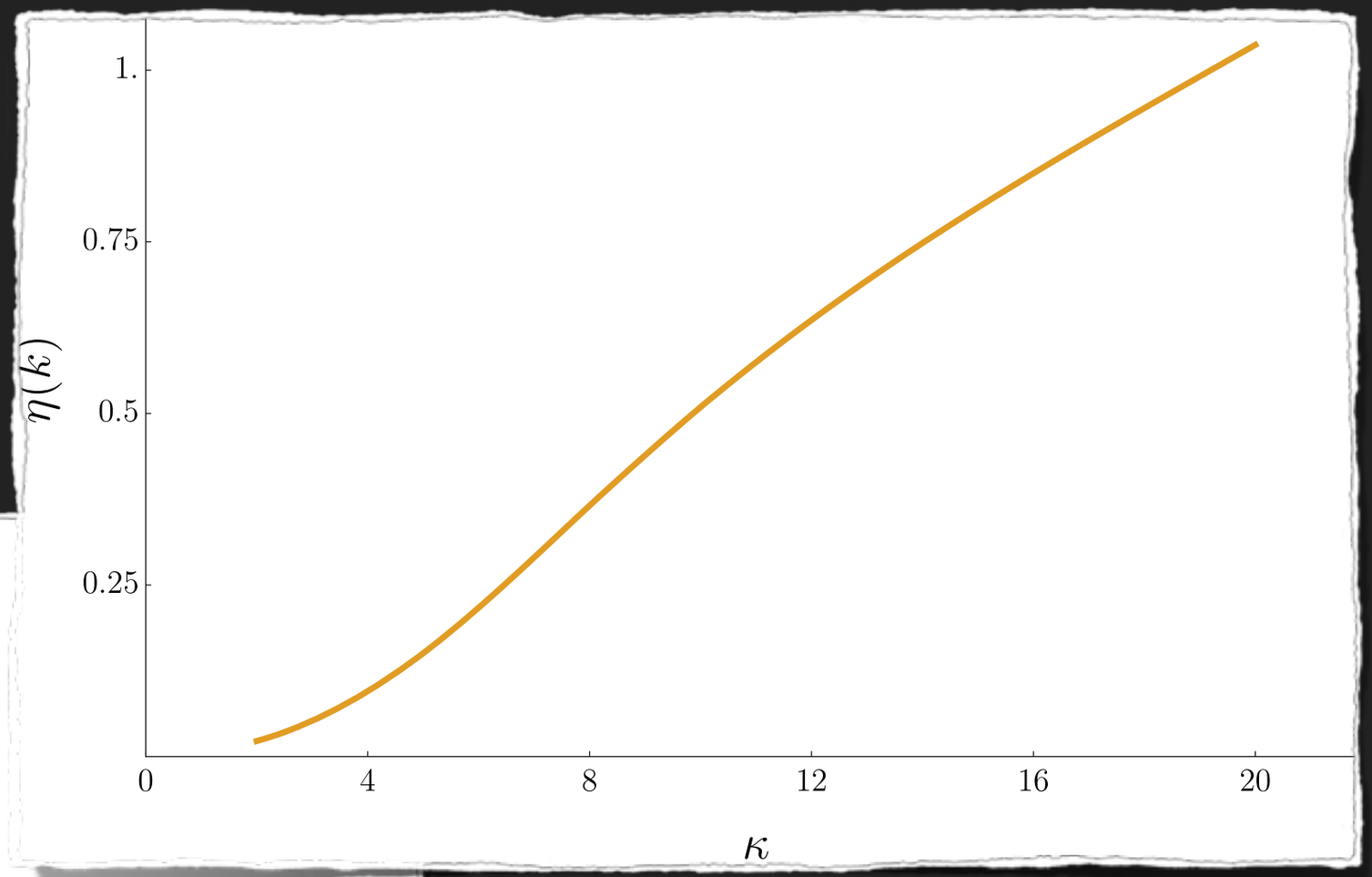
- Mon
  - Ta
  - P
- Dyn
  - ``
    - Gravitational waves

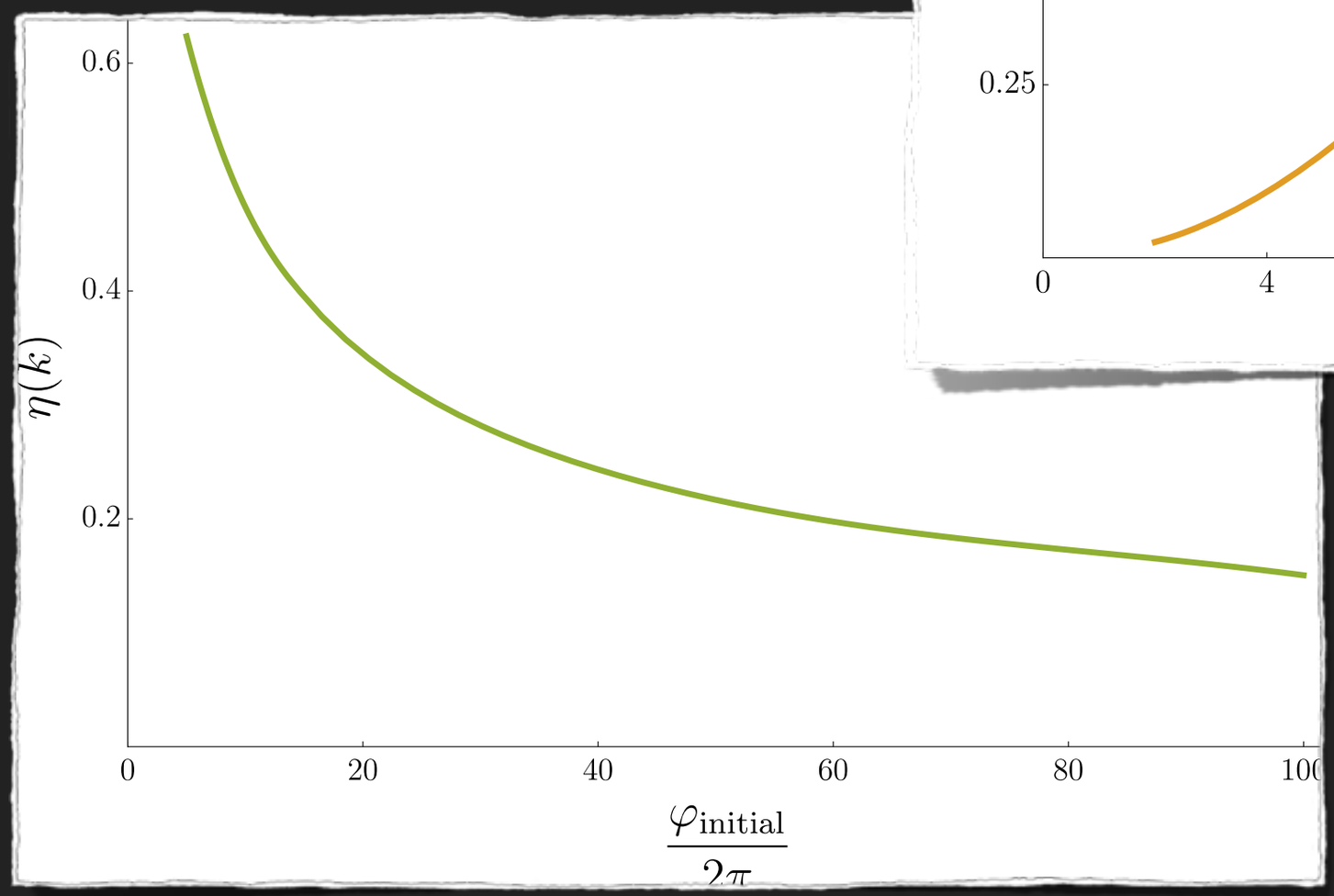




stability/instability bands

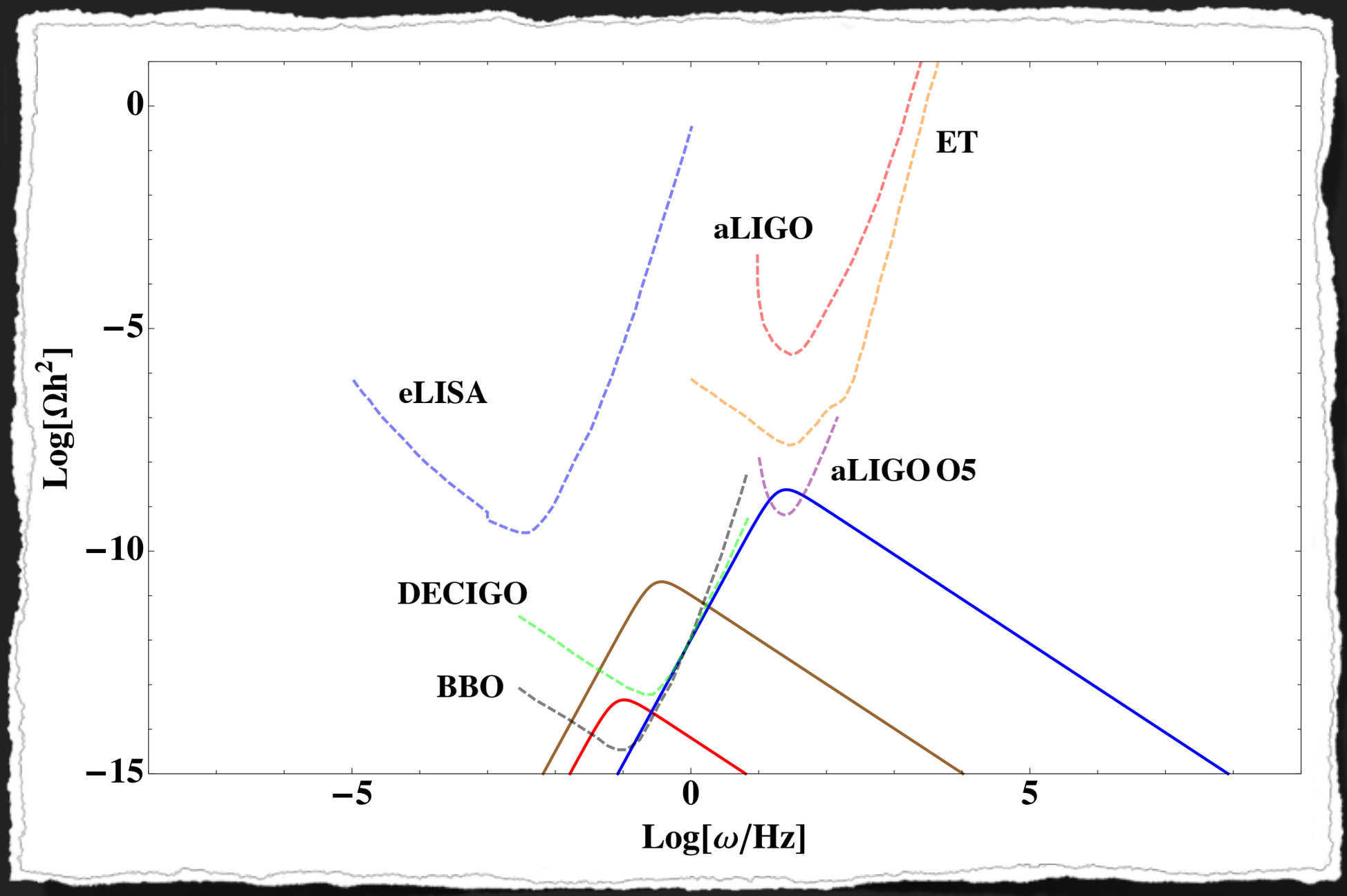
LINEAR REGIME – GROWTH OF FLUCTUATIONS





Jaeckel, VMM, Witkowski

EXPERIMENTAL ACCESSIBILITY



Hebecker, et al.

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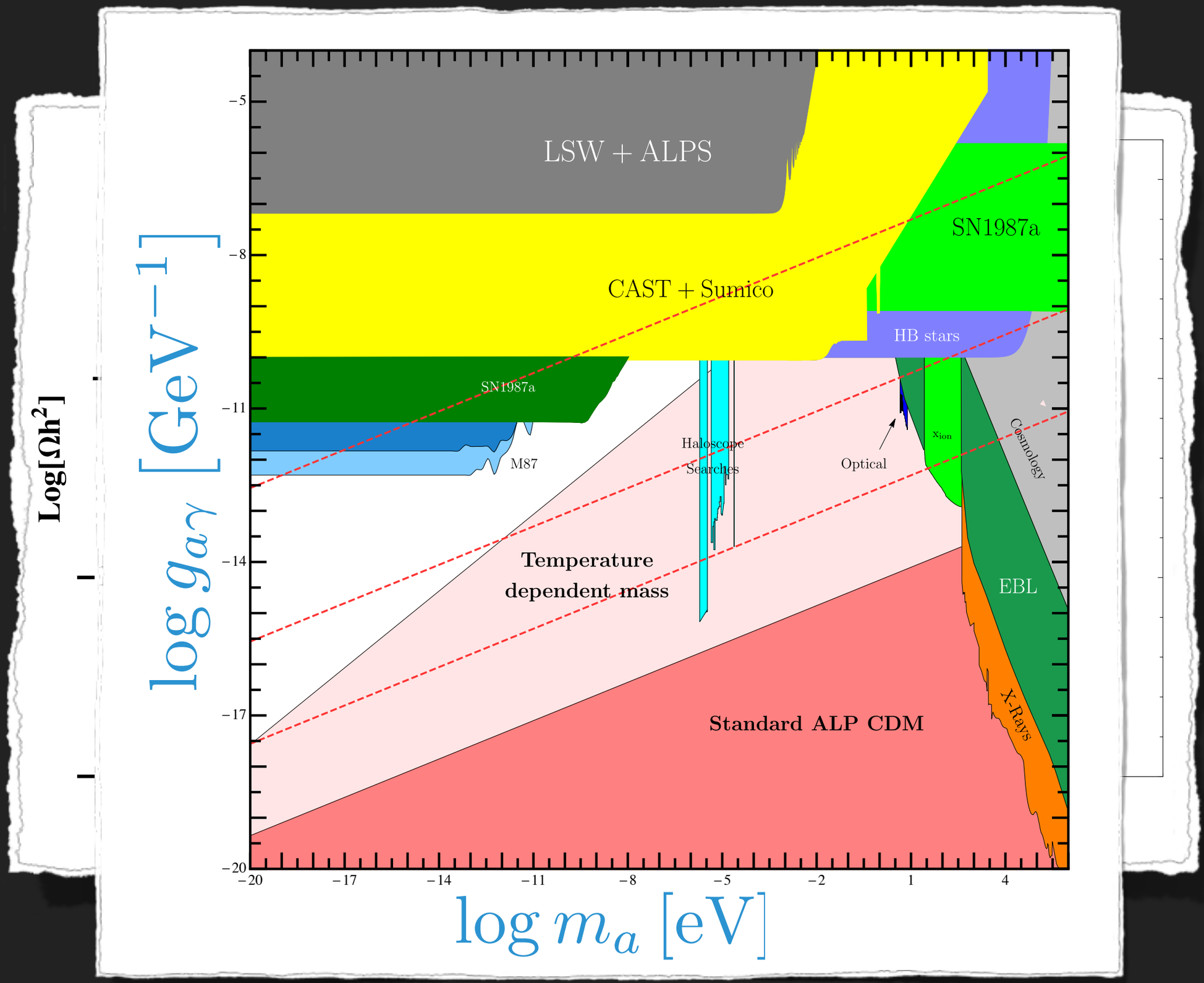


SETUP

Lattice simulations using modified **LATTICEEASY** code in 2+1d with 512^2 lattice points

$$\ddot{\phi} + 3H\dot{\phi} - \frac{\nabla^2}{a^2}\phi + \frac{\partial V}{\partial \phi} = 0$$

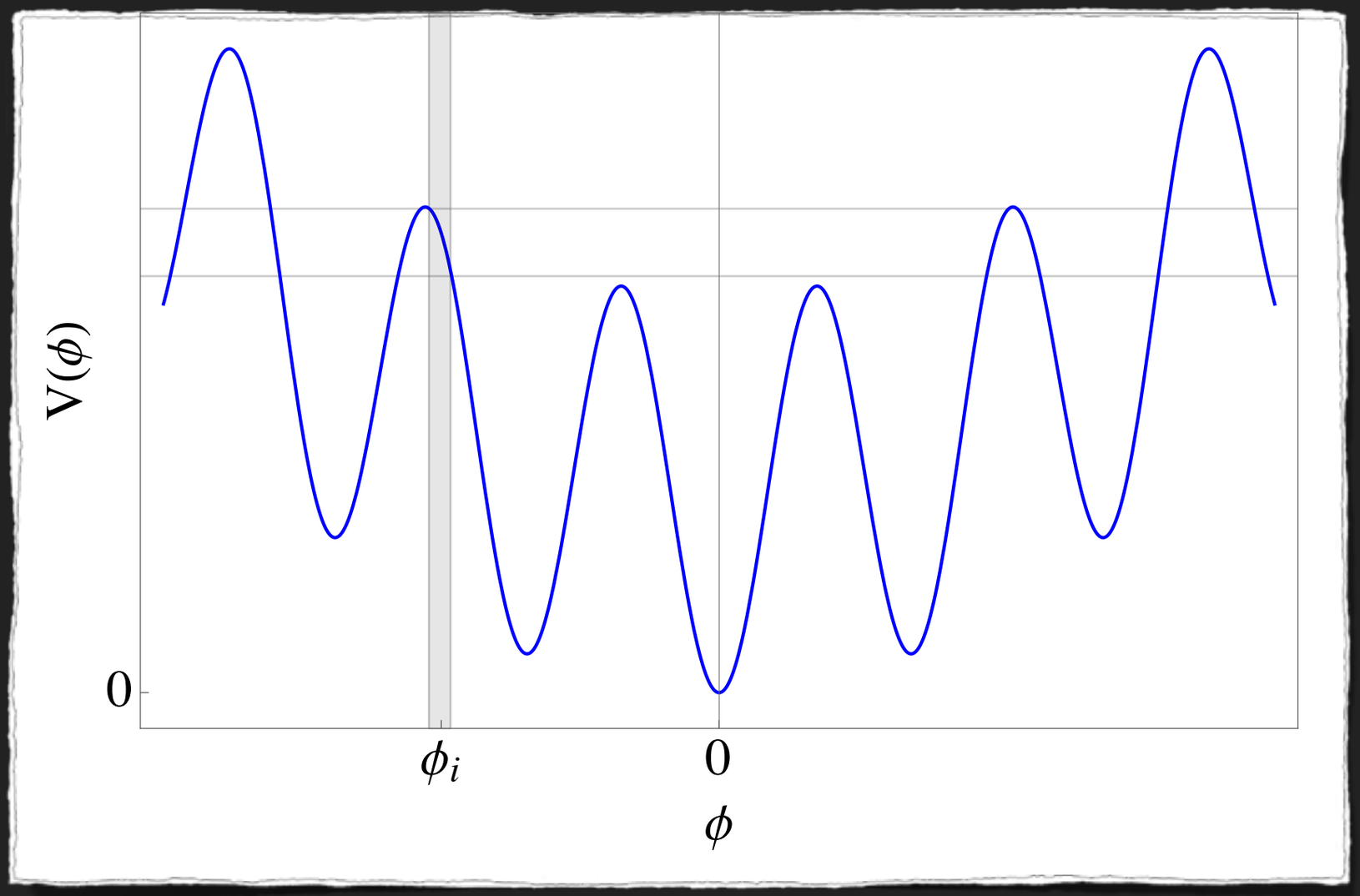
$$H^2 = \frac{1}{3M_{\rm P}}\left(V + \frac{1}{2}\dot{\phi} + \frac{1}{2a^2}|\nabla\phi|^2\right)$$

Comoving volume:

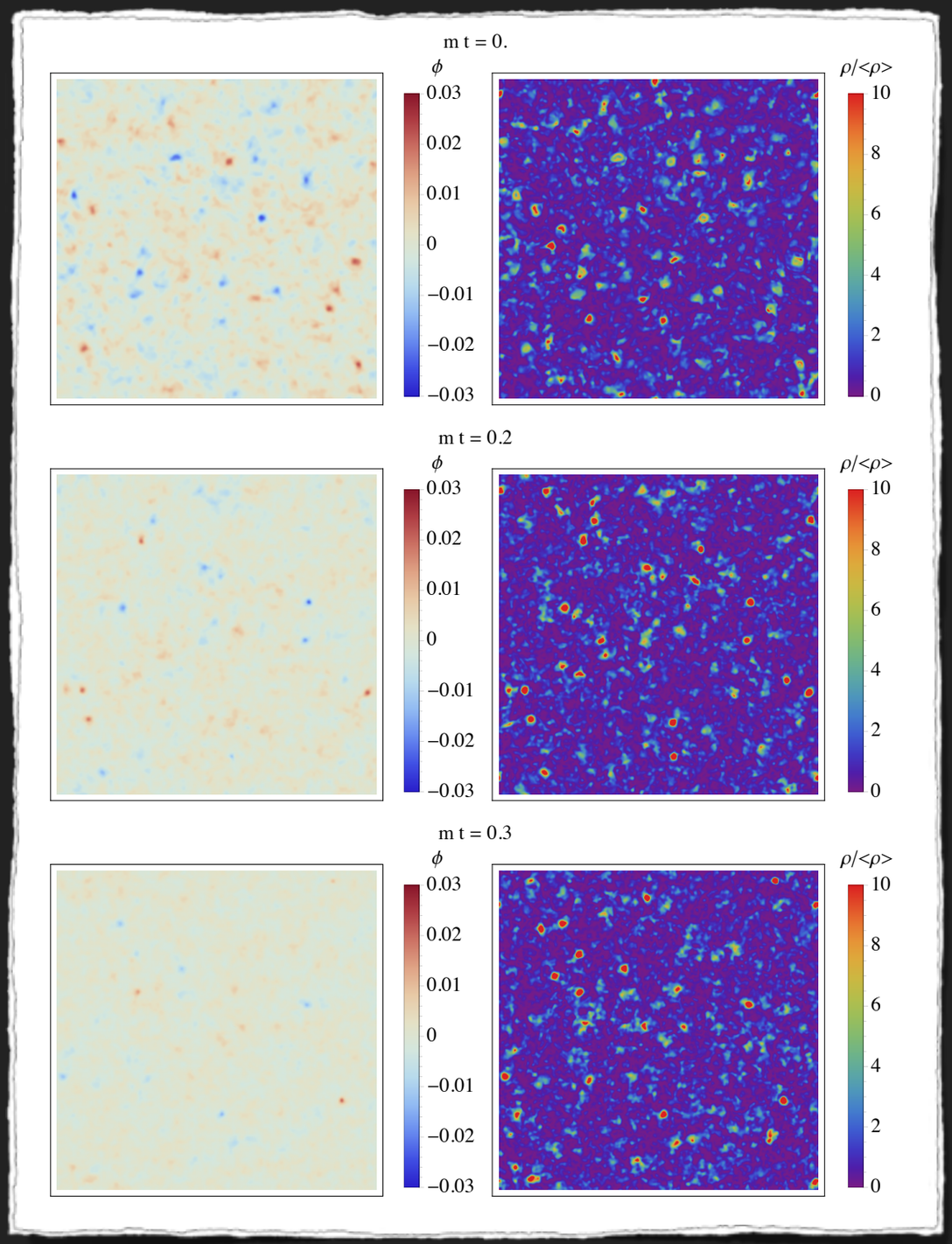
$$\mathcal{V} = L^2 = \left(\frac{H_i^{-1}}{5}\right)^2$$

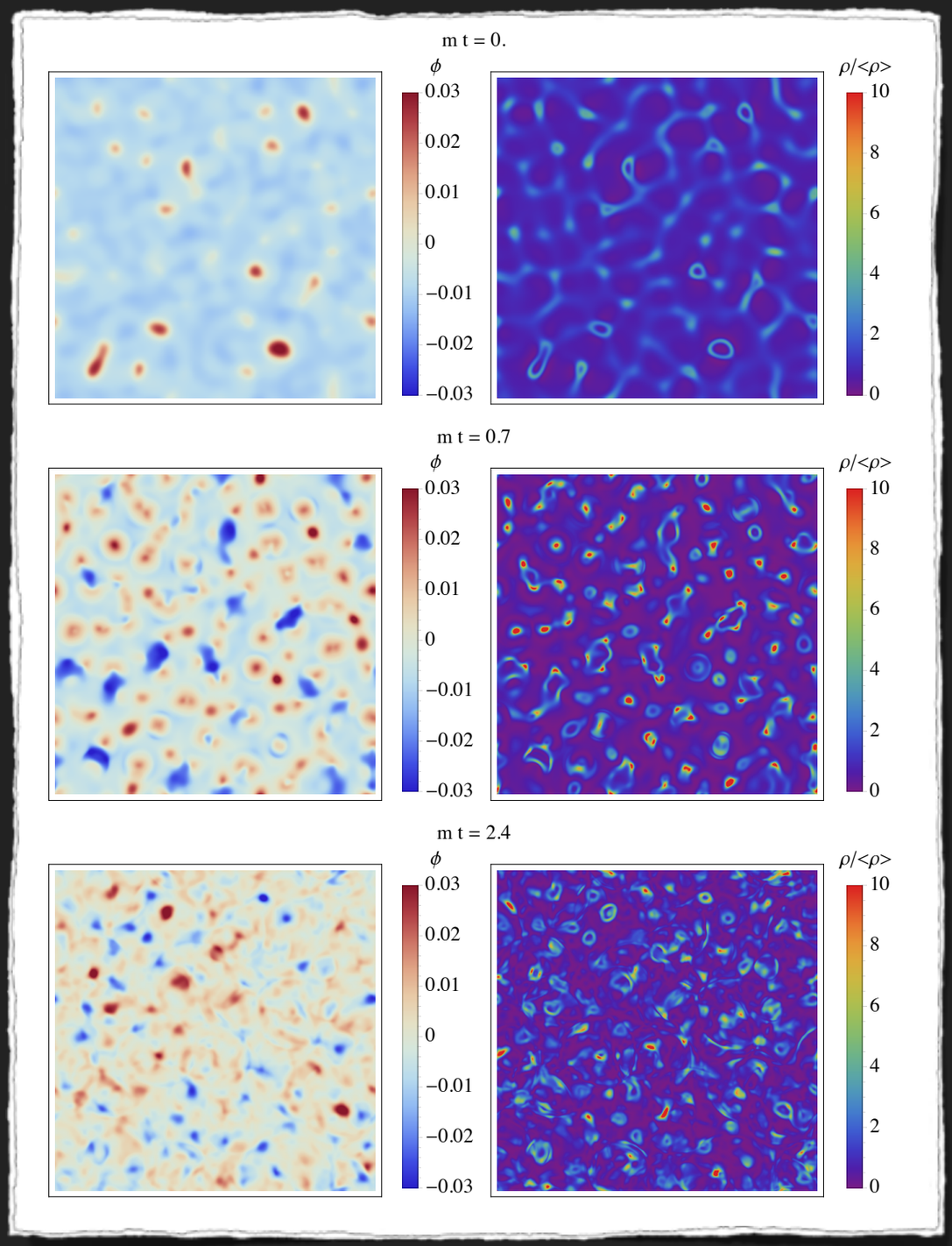
$$H_i = \sqrt{V(\phi_i)/3}$$

MONODROMY

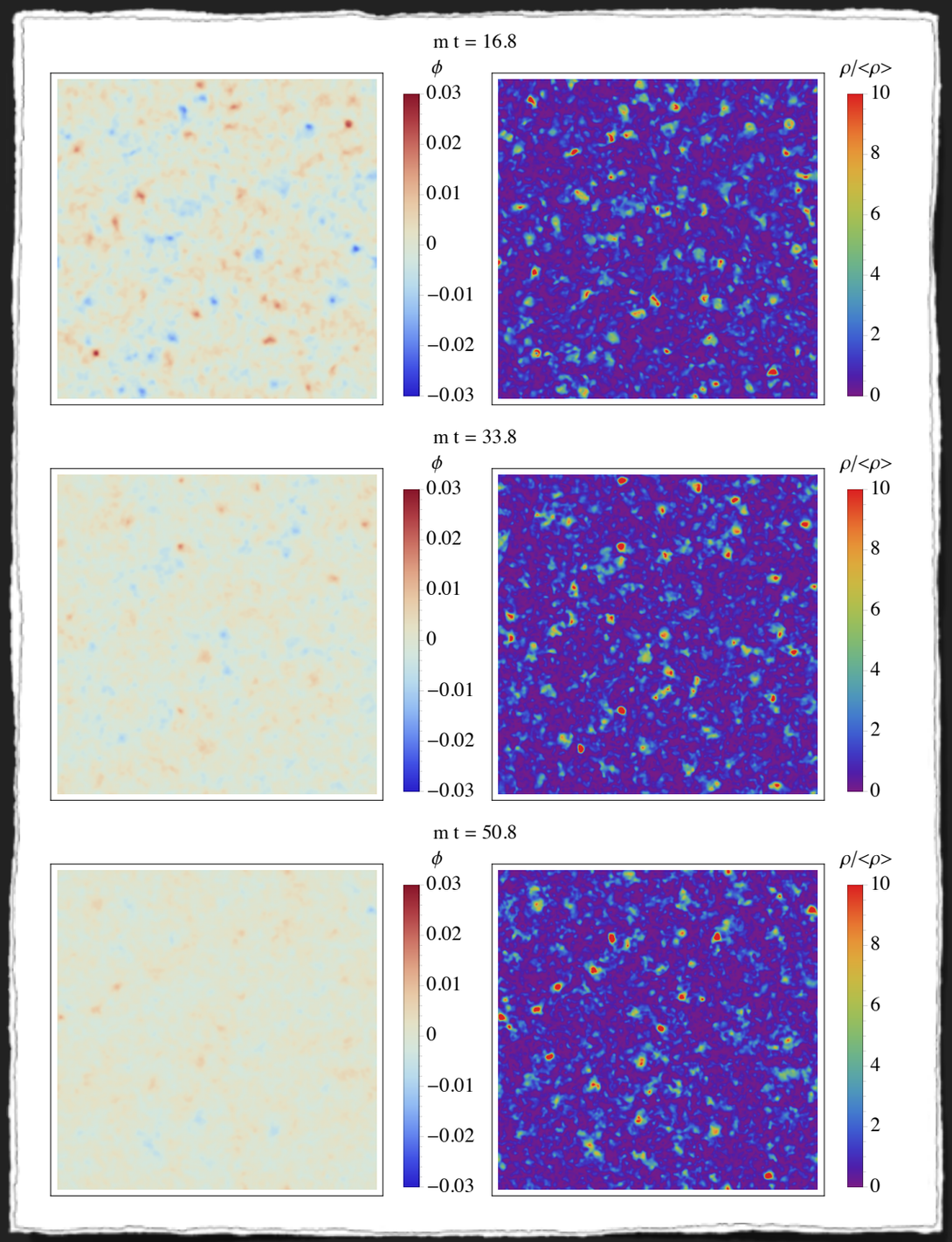


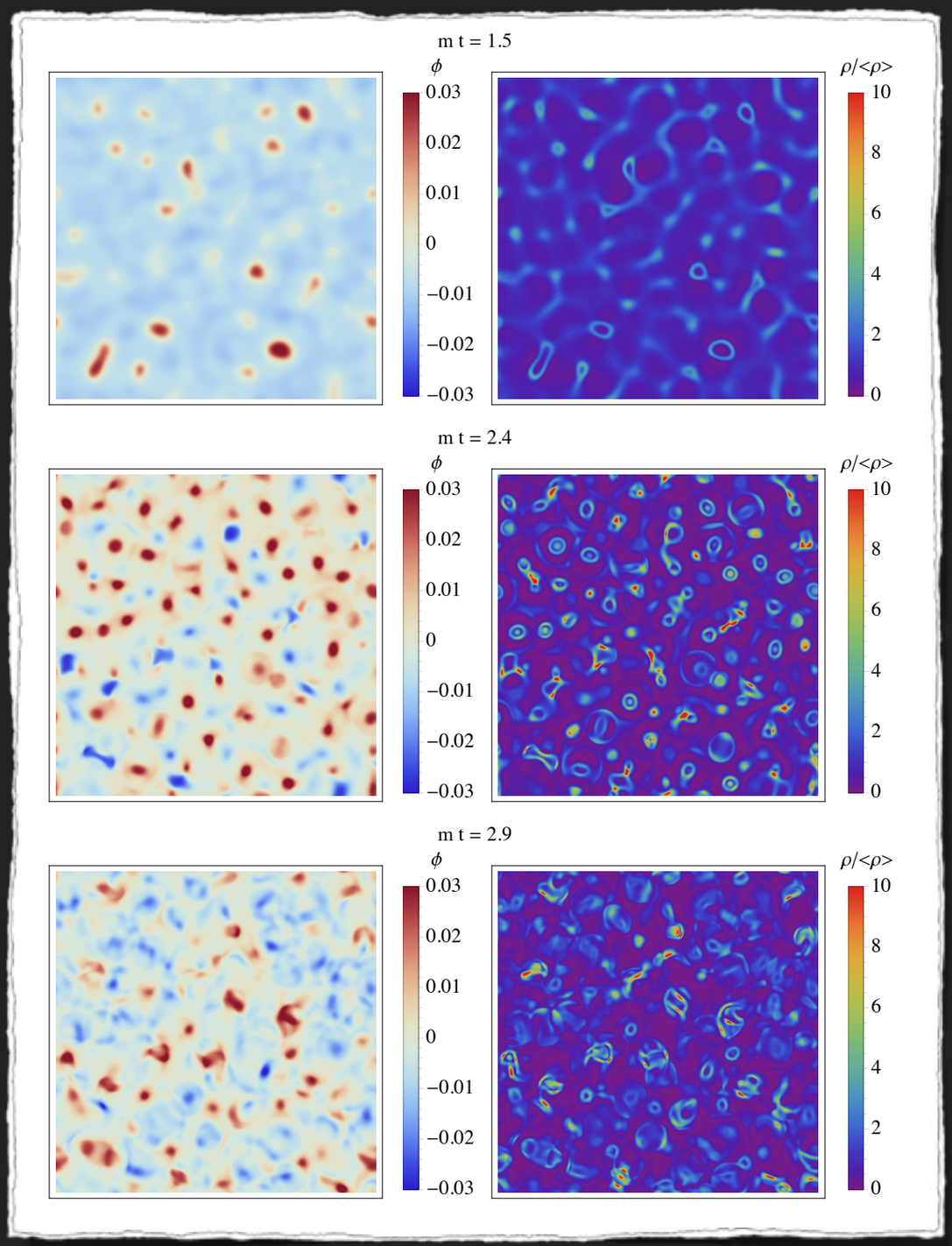
MONODROMY


m t = 0.
m t = 0.2
m t = 0.3
ϕ
0.03
0.02
0.01
0
−0.01
−0.02
−0.03
$\rho/<\rho>$
10
8
6
4
2
0


m t = 0.
m t = 0.7
m t = 2.4
ϕ
0.03
0.02
0.01
0
−0.01
−0.02
−0.03
$\rho/<\rho>$
10
8
6
4
2
0

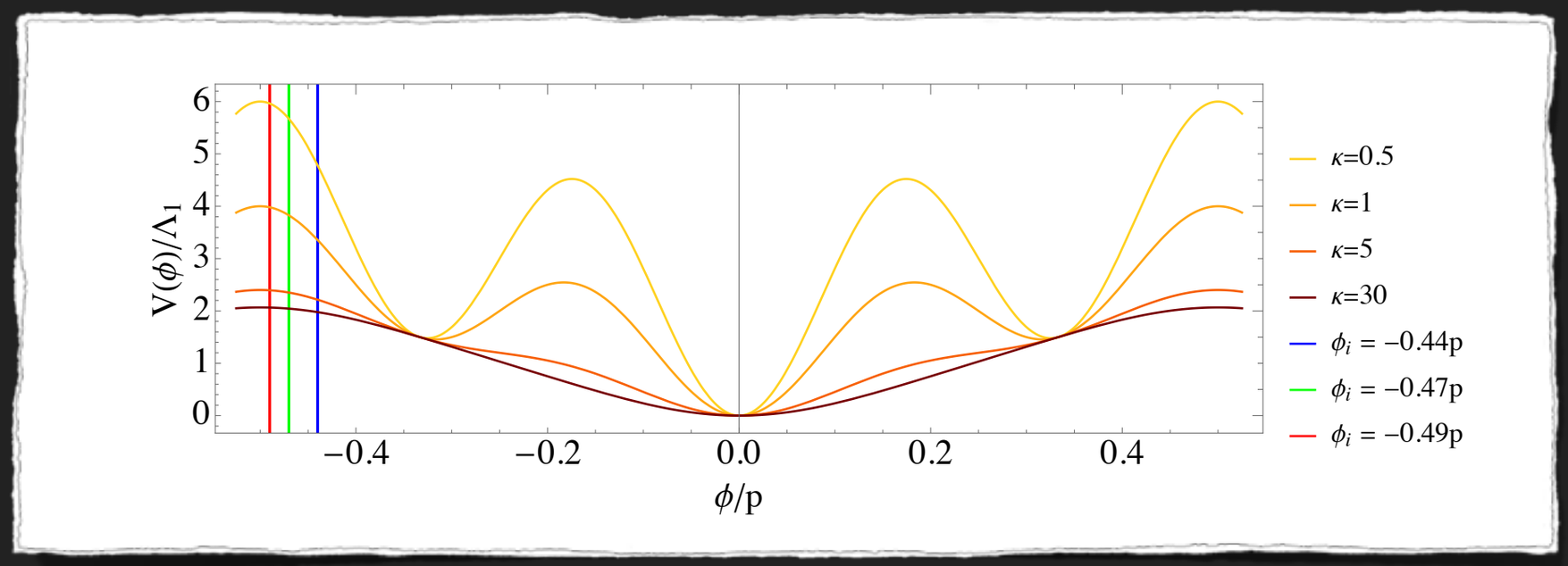
MONODROMY


m t = 16.8
m t = 33.8
m t = 50.8
ϕ
0.03
0.02
0.01
0
−0.01
−0.02
−0.03
$\rho/<\rho>$
10
8
6
4
2
0


m t = 1.5
m t = 2.4
m t = 2.9
ϕ
0.03
0.02
0.01
0
−0.01
−0.02
−0.03
$\rho/<\rho>$
10
8
6
4
2
0

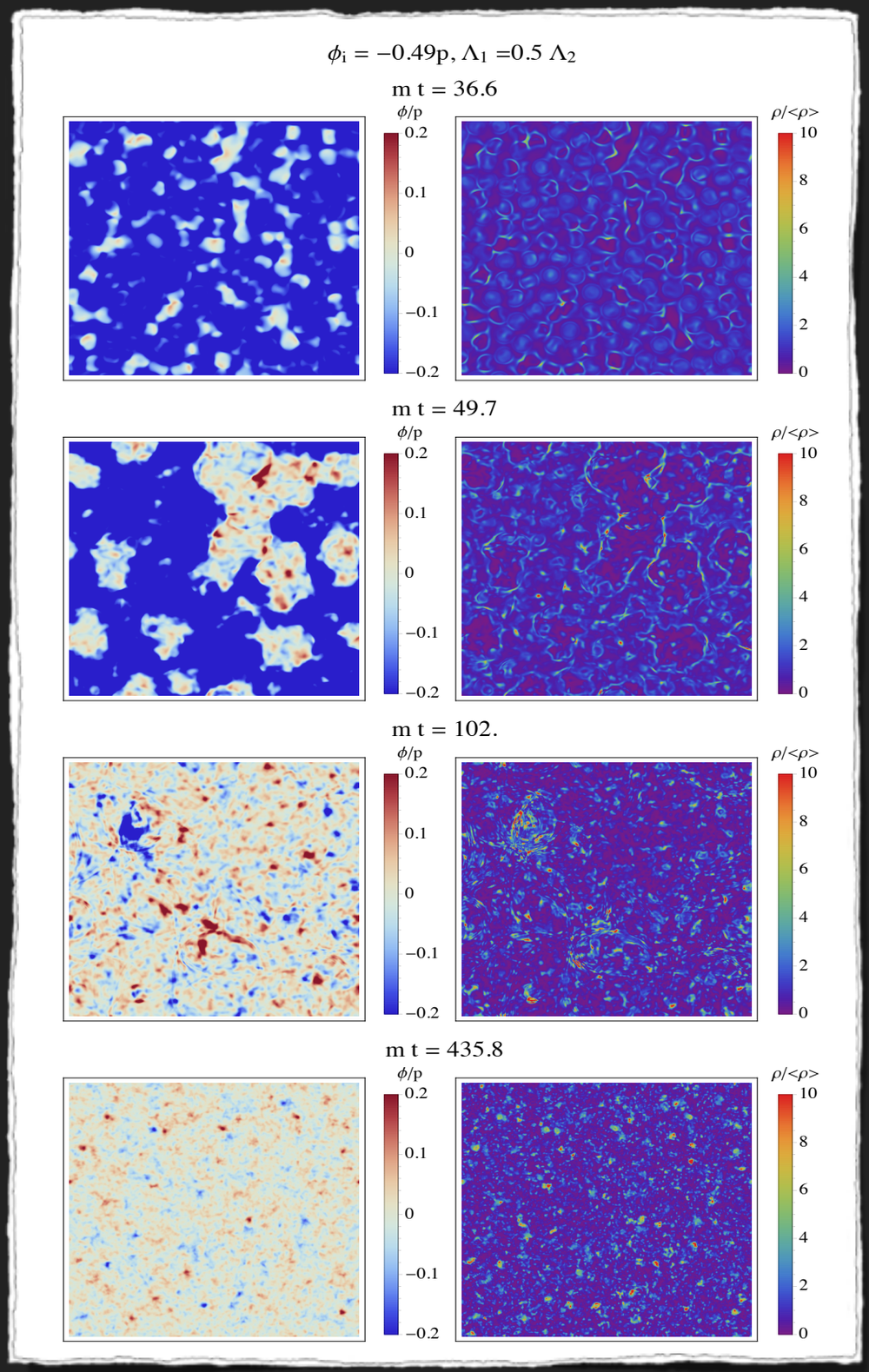
INSTANTON CORRECTIONS

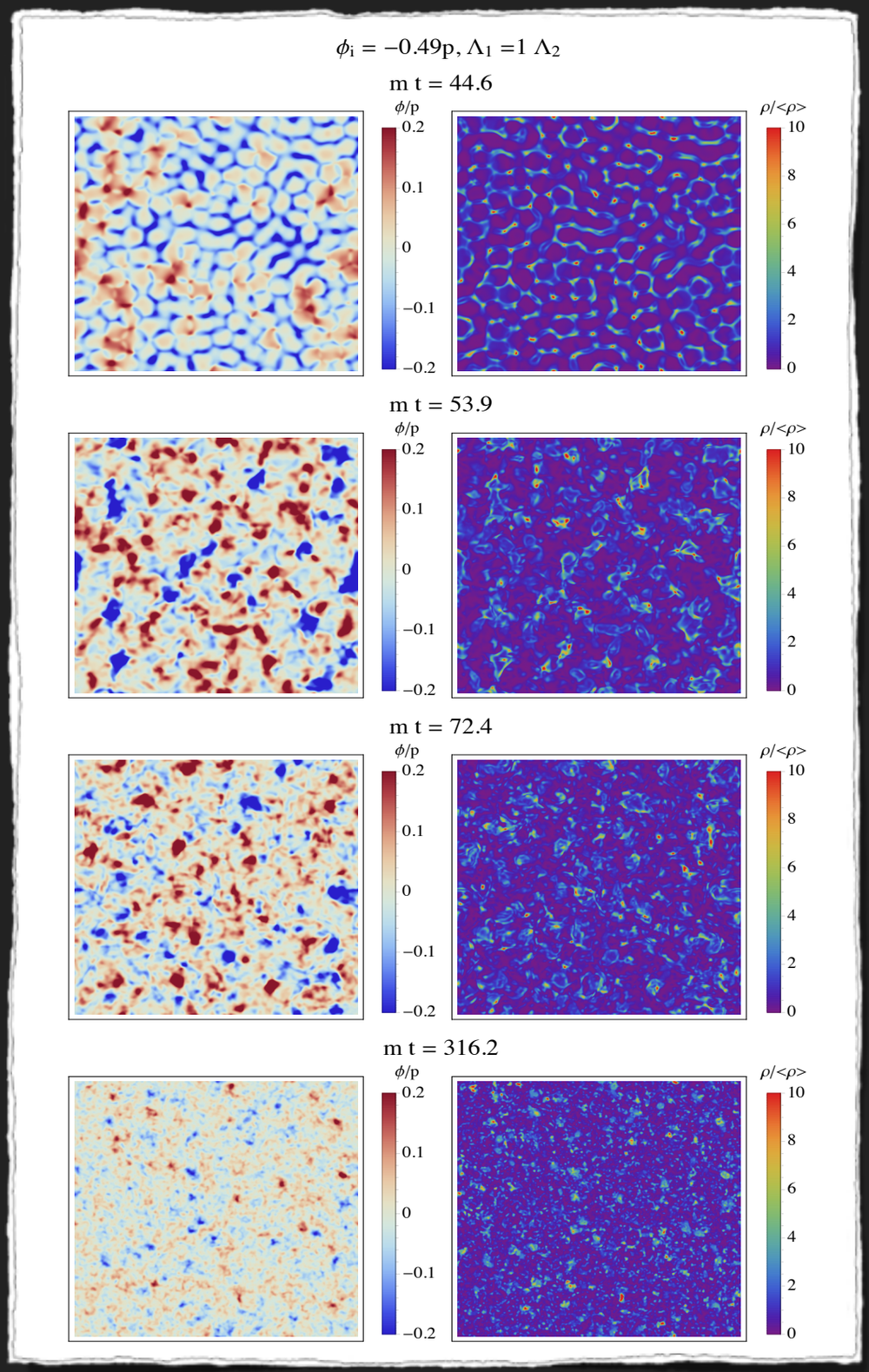
$$\sum_{i=1}^{n} \Lambda_n^4 \left[1 - \cos\left(\frac{n\phi}{f} \right) \right]$$



$$\kappa \equiv \frac{\Lambda_1^4}{\Lambda_n^4}$$

INSTANTON CORRECTIONS





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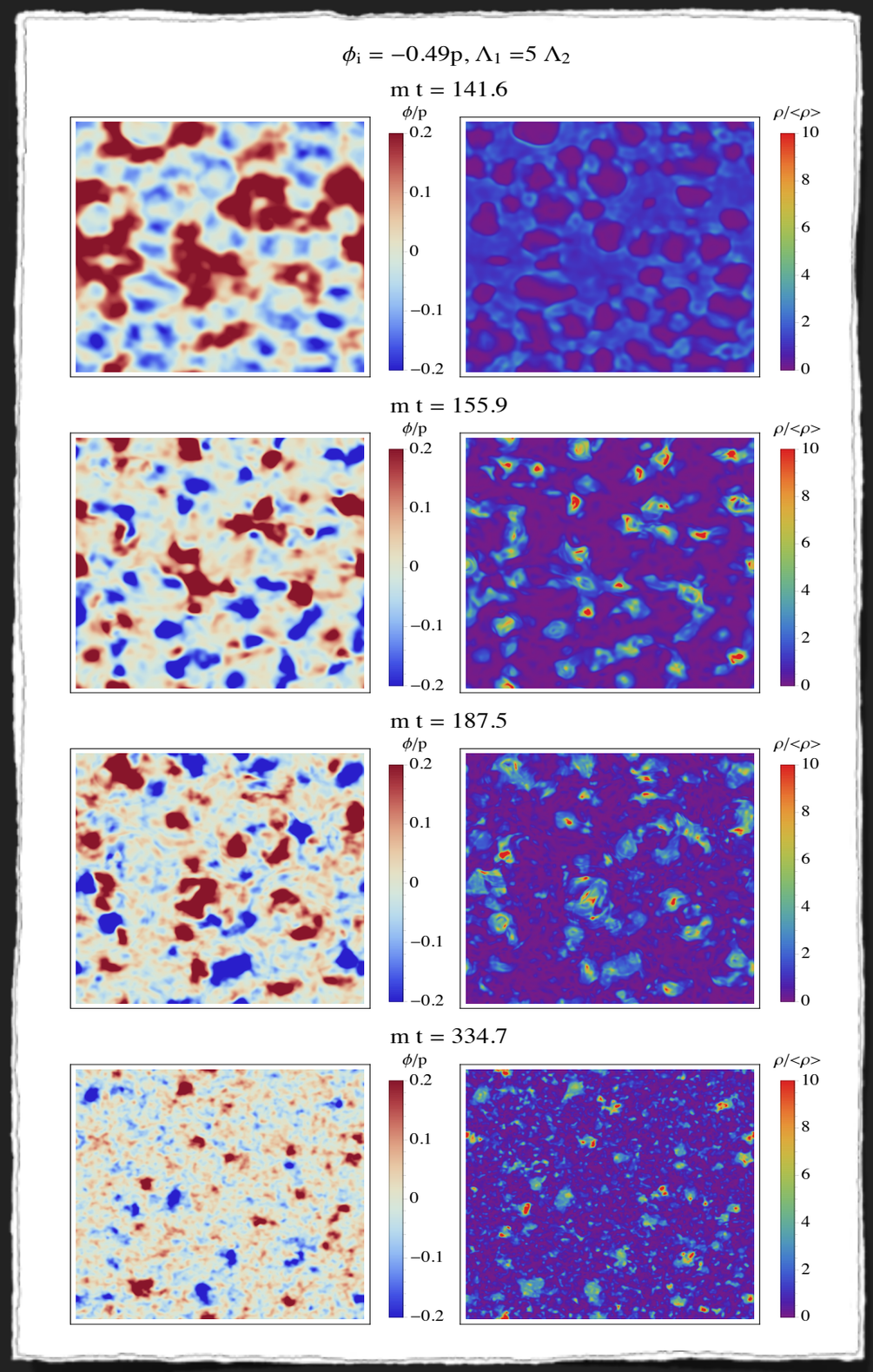

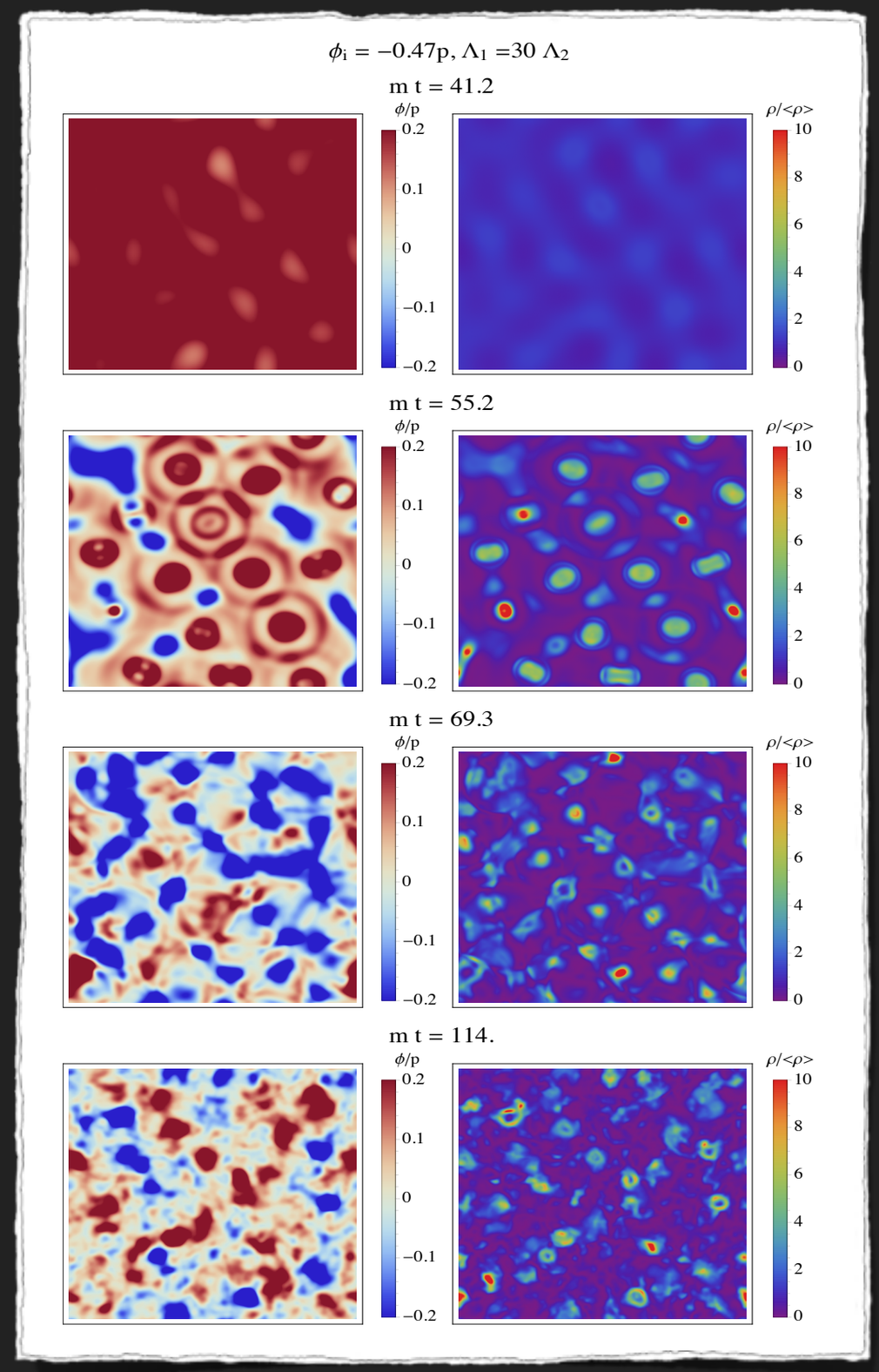

AXIONS & NON-LINEAR EFFECTS

- 2+1 lattice simulations show appearance of oscillons
  - oscillons are long-lived stable objects Amin; Muia, et al.
- 3+1 lattice simulations confirm appearance
- Oscillons generic for $\kappa > 1$ monodromy potentials
- Also seemingly generic for corrected potential
- Post-reheating, accessible effects washed out

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Thanks!