# Phase 11 – Predictive Power

## Part 2: Predictive Signatures of ψ-Waves and Emergent Structures

## Goal

To model explicit predictive signatures associated with ψ-wave dynamics and the formation of emergent localized structures, building upon observables identified in Part 1.

## ψ-Wave Signatures

### Traveling Wave Pulses

ψ supports propagating wave-like structures derived from the dispersion relation:

Plain text: ω² = α k² + β k⁴

Predicted behaviors:

* Group velocity depends on k:

Plain text: v\_g = (αk + 2βk³) / ω

* Low-k modes → long-range oscillations.
* High-k modes → localized ripples, higher dissipation.

### Standing Waves

Boundary conditions (reflective or periodic) stabilize standing ψ waves:

Plain text: ψ(x,t) = A cos(kx) cos(ωt)

Predictive observables:

* Periodic oscillations in effective force.
* Nodes and antinodes observable in particle trajectories.
* Phase coherence across extended domains.

### Beat Patterns

Superposition of nearly resonant modes:

Plain text: ψ(x,t) = cos(kx − ω₁t) + cos(kx − ω₂t)

Envelope oscillation at frequency:

Plain text: Ω\_beat = |ω₁ − ω₂|

Predicted observables:

* Modulated ψ amplitude in space and time.
* Test particles experience oscillatory drift reversal.
* Detectable as rhythmic clustering and dispersion cycles.

## Emergent Structures

### ψ Wells

Nonlinear focusing generates localized depressions:

Plain text: V\_eff(x) = (∇²[space(x) + current(x)²]) × ψ(x)

Predicted behaviors:

* Long-lived potential wells trapping test particles.
* Asymmetric ψ shapes when entropy gradients are strong.
* Stable bound states similar to gravitational orbits.

### ψ Dunes

When current² dominates, ψ accumulates in dune-like ridges.

Predicted behaviors:

* Periodic chain of ψ crests and troughs.
* Force profile oscillates between attraction and repulsion.
* Collective drift of test particles resembling “surfing.”

### Soliton-Like Pulses

Balance of dispersion and nonlinearity yields stable ψ packets:

Plain text: ψ(x,t) = A sech[κ(x − vt)] exp[i(kx − ωt)]

Predicted observables:

* Localized, non-dispersing ψ pulses.
* Test particles “carried” within soliton packet.
* Possible analogues to gravitational wave bursts.

## Simulation: ψ Beats and Emergent Wells

# simulations/phase11\_part2\_predictive\_signatures.py  
import numpy as np  
import matplotlib.pyplot as plt  
  
# Parameters  
x = np.linspace(-50, 50, 2000)  
t = 40 # fixed time snapshot  
  
# Beat wave parameters  
k = 0.3  
omega1, omega2 = 0.5, 0.55  
  
# ψ-wave superposition (beats)  
psi\_wave = np.cos(k\*x - omega1\*t) + np.cos(k\*x - omega2\*t)  
  
# Emergent ψ well (Gaussian depression)  
psi\_well = -2.0 \* np.exp(-0.05 \* x\*\*2)  
  
# Combined ψ profile  
psi\_total = psi\_wave + psi\_well  
  
# Plot  
plt.figure(figsize=(9,5))  
plt.plot(x, psi\_total, label="ψ total (beats + well)")  
plt.plot(x, psi\_wave, '--', alpha=0.7, label="ψ wave (beats)")  
plt.plot(x, psi\_well, ':', alpha=0.7, label="ψ well")  
plt.title("Phase 11 – Part 2: Predictive ψ Signatures")  
plt.xlabel("x")  
plt.ylabel("ψ(x,t)")  
plt.legend()  
plt.grid(True)  
plt.show()