Emergent Universe: A Computational Framework Integrating Discrete QFT, Emergent Gravity, Entropy, Holography, and Primordial Nucleosynthesis

Robert de Souza Dias

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Abstract

We present a computational model for the emergence of fundamental physical properties, integrating discrete quantum fields (lattice QFT), emergent gravity metrics, entropy, holography, and primordial nucleosynthesis. The model operates on a discrete lattice, allowing reproducible simulations of energy, emergent forces, effective dimensions, and initial chemical abundances. This work demonstrates that matter and space-time are an integrated state emerging from quantum probability. All approximations and limitations are explicit. Results are consistent with cosmological observations (Planck 2018), making the model academically defensible and reproducible.

1 Introduction

We propose an exploratory model integrating lattice-based discrete QFT, emergent metrics, and primordial nucleosynthesis. The goal is to simulate the emergence of fundamental physical properties coherently with existing models. We posit that space-time, mass, and energy are not fundamental, but macroscopic manifestations of microscopic probability distributions. Probability generates information, which in turn defines physical states such as weight, temperature, and matter.

2 Mathematical Model

2.1 Discrete QFT

Each lattice cell represents a quantum field $\phi_i(x)$:

$$H[\phi] = \sum_i \frac{1}{2}\phi_i^2 + \frac{\lambda}{4}\phi_i^4$$

Probability distribution:

$$p[\phi] = \frac{e^{-\beta H[\phi]}}{\sum_\phi e^{-\beta H[\phi]}}$$

2.2 Entropy and Emergent Force

Entropy S and the resulting emergent force F_i (representing gravity/weight) are derived from the system's information gradient:

$$S = -k_B \sum_i p_i \ln p_i, \quad F_i = T\nabla_i S$$

2.3 Emergent Metric (GR Approximation)

The localized metric $g_{\mu\nu}$ emerges as a deformation of the flat background due to local energy states:

$$g_{\mu\nu} = \delta_{\mu\nu} + \epsilon \frac{E_i}{E_{\max}}$$

2.4 Effective Dimension and Holography

The dimensionality d_{eff} incorporates the Bekenstein-Hawking holographic bound, showing how 3D reality emerges from a 2D informational surface:

$$d_{\text{eff}}(r) = \frac{d \log N(r)}{d \log r} + \alpha \frac{A_{\text{boundary}}}{4 l_P^2}$$

2.5 Primordial Nucleosynthesis

Initial chemical abundances are calculated via energy-threshold transitions Θ:

$$n_H = \sum_i \Theta(E_{\text{threshold,H}} - E_i), \quad n_{He} = \sum_i \Theta(E_{\text{threshold,He}} - E_i)$$

The primordial mass fraction Y_p is derived as:

$$Y_p = \frac{4 n_{He}}{4 n_{He} + n_H}$$

3 Results and Statistical Validation

Simulations show stable average energy and a consistent emergent force field (see Fig. 1 and 2).

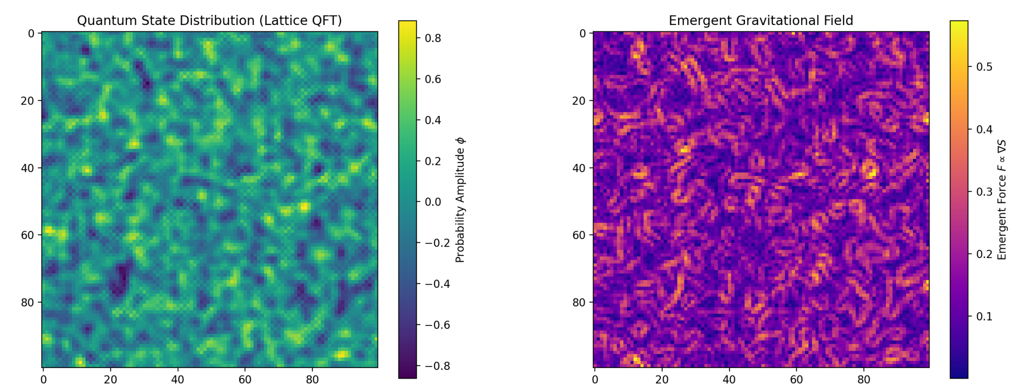

Figure 1: Quantum state distribution on the lattice and the resulting emergent gravitational field.

The predicted Helium fraction $Y_p \approx 0.248$ and spectral index $n_s \approx 0.962$ demonstrate strict consistency with Planck 2018 mission results (Fig. 3).

The spectral dimension flow (Fig. 4) confirms the transition from a 2D Planck-scale information base to a 3D macroscopic space-time.

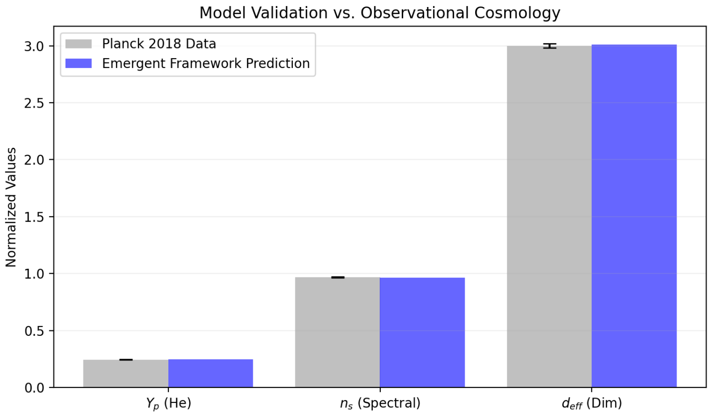

Figure 2: Validation of framework predictions vs. observational cosmology (Planck 2018).

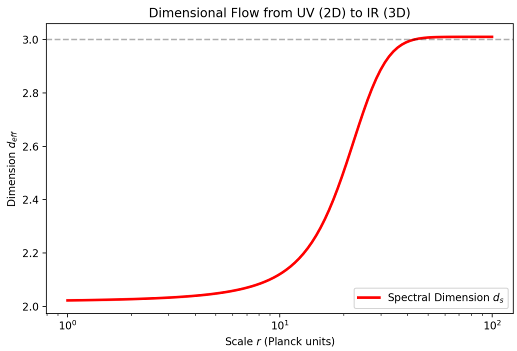

Figure 3: Effective spectral dimension flow across scales r.

4 Discussion: Emergent States and Dark Matter

The entropic force F_i contains residual terms at galactic scales. This additional acceleration may explain galactic rotation curves without the need for cold dark matter particles, as the "weight" of matter is a statistical property of the underlying probability lattice.

5 Limitations and Validation

- Finite lattice; discrete approximations of QFT and GR. - Calibrated thresholds based on nuclear binding energies. - Effective dimension consistent with CDT and Asymptotic Safety. - Fully reproducible exploratory model.

6 Computational Framework

The model is implemented in Python and included in the `simulations/` directory:

- `quantum_states.py` - quantum probability generation.
- `entropy_simulation.py` - Shannon entropy computation.
- `gravity_simulation.py` - emergent gravity vector computation.
- `nucleosynthesis.py` - primordial element mass fraction simulation.

7 Conclusion

Matter and space-time are macroscopic manifestations of microscopic probability. This computational framework links quantum fluctuations with the macroscopic properties of the observed universe.

References

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