Supplementary Information: Dynamic Orbital Model of Fundamental Particles: Unifying Proton Structure and Electron Spin via Perturbation Waves

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Supplementary Information

This Supplementary Information (SI) provides detailed derivations, simulation methods, additional results, and figures supporting the main text. It includes full theoretical formulations, computational details, and extended data not presented in the primary manuscript.

1 Theoretical Derivations

1.1 Gluon Orbital Dynamics

The gluon field is modeled as a combination of a static term and a perturbation wave:

$$A^a_\phi = \frac{A^a_0}{r} e^{i\omega t} + \epsilon^a \cos(kr - \omega_d t), \tag{1}$$

where $A^a_0 = 1.3 \times 10^{-3}\,\text{GeV·fm}$ is the static amplitude (11), $\epsilon^a = 8 \times 10^{-5}\,\text{GeV·fm}$ is the perturbation amplitude, and $\omega_d = 2.83 \times 10^{23}\,\text{rad/s}$ is the angular frequency of the perturbation wave. The field strength tensor is:

$$F^a_{r\phi} = -\frac{A^a_0}{r^2} - \epsilon^a k \sin(kr - \omega_d t), \tag{2}$$

where $k = \omega_d / v_g$ and $v_g = 0.88c$. The energy contribution from five gluons is computed via:

$$E_g = \int \frac{1}{2} (F^a_{r\phi})^2 4\pi r^2 dr \approx 668\,\text{MeV}, \tag{3}$$

integrated over $r = 0.8 - 0.9\,\text{fm}$, consistent with LHC measurements (12). The spin contribution is $\Delta G = 0.1\hbar$, with orbital angular momentum $L_g = 0.38\hbar$, derived from velocity and radius constraints.

1.2 Quark Orbital Dynamics

Three quarks form a triangular orbit at $r_q = 0.3\,\text{fm}$ with velocity $v_q = 0.55c$. The wavefunction includes a plane wave and perturbation term:

$$\psi^i(r,t) \propto e^{ip\cdot r/\hbar} + \epsilon_q \cos(k_q r - \omega_q t), \tag{4}$$

where $\epsilon_q = 10^{-3}\,\text{GeV}$, $\omega_q = 2.1 \times 10^{23}\,\text{rad/s}$, and $k_q = \omega_q / v_q$. The effective mass $m_{\text{eff}} \approx 86\,\text{MeV}/c^2$ yields kinetic energy:

$$E_q = 3 \cdot \frac{1}{2} m_{\text{eff}} v_q^2 + \delta E \approx 258\,\text{MeV}, \tag{5}$$

with δE from perturbation corrections. Spin is $\Delta\Sigma = 0.25\hbar$, and orbital angular momentum $L_q = 0.12\hbar$, validated by lattice QCD (13).

1.3 Chiral Symmetry Breaking

Chiral effects are modeled with a scalar field:

$$\sigma(r) = \sigma_0 e^{-r/r_0}, \tag{6}$$

where $\sigma_0 = 50\,\text{MeV}$ and $r_0 = 0.5\,\text{fm}$. The dynamical mass contribution is:

$$\langle m_{\text{dyn}} \rangle = \frac{\int \sigma(r)\rho_q(r)dV}{\int \rho_q(r)dV} \approx 24\,\text{MeV}, \tag{7}$$

integrated over the quark density $\rho_q(r)$, consistent with chiral theory (14).

1.4 Electron Spin via Perturbation Waves

Classically, electron spin ($\hbar/2$) as a rotating sphere gives:

$$S = \frac{2}{5} m_e r^2 \omega, \quad v = r\omega, \tag{8}$$

with $m_e = 9.11 \times 10^{-31}\,\text{kg}$, $r = 2.82 \times 10^{-15}\,\text{m}$, and $S = \hbar/2 = 5.27 \times 10^{-35}\,\text{J·s}$. Solving:

$$v = \frac{5S}{2m_e r} \approx 5.13 \times 10^{10}\,\text{m/s}, \tag{9}$$

exceeding c by 171 times. Instead, perturbation waves at $v_{\text{wave}} = c$ yield:

$$\nu = \frac{c}{2\pi r} = \frac{3 \times 10^8}{2\pi \times 2.82 \times 10^{-15}} \approx 4.77 \times 10^{22}\,\text{Hz}, \tag{10}$$

with energy $E = h\nu \approx 197\,\text{MeV}$. In a multi-electron system (e.g., 2 electrons), this reduces to ~100 MeV per electron, generating $\hbar/2$ collectively.

2 Simulation Methods

2.1 Lattice QCD Setup

We used a $48^3 \times 96$ lattice with 0.03 fm spatial resolution and 10^{-22} s temporal span, employing periodic boundary conditions (15; 16). The QCD Lagrangian was discretized:

$$\mathcal{L}_{\text{QCD}} = \overline{\psi}(i\not{D} - m)\psi - \frac{1}{4}F^a_{\mu\nu}F^{a\mu\nu}, \tag{11}$$

with gauge fields A^a_ϕ and fermion fields ψ^i. Simulations ran on a high-performance cluster, averaging 100 configurations to minimize statistical noise.

2.2 Runge-Kutta Simulations

Orbital stability was assessed using a fourth-order Runge-Kutta method over 10^{-22} s with a 10^{-25} s step size. Trajectories followed:

$$\frac{dr_g}{dt} = v_g, \quad \frac{dr_q}{dt} = v_q, \tag{12}$$

with perturbation terms added as $\epsilon \cos(kr - \omega t)$. The Python implementation is:

```
def rk4_step(t, r, v, dt):
    k1 = v
    k2 = v + 0.5 * dt * k1
    k3 = v + 0.5 * dt * k2
    k4 = v + dt * k3
    return r + (dt / 6) * (k1 + 2*k2 + 2*k3 + k4)

r_g = 0.85  # fm
v_g = 0.88 * 3e8  # m/s
dt = 1e-25  # s
for t in range(1000):
    r_g = rk4_step(t * dt, r_g, v_g, dt)
```

2.3 Fourier Analysis

Fast Fourier transforms (FFT) were applied to $r_g(t)$ and $r_q(t)$: - Gluons: $\omega_d/2\pi \approx 4.5 \times 10^{22}$ Hz, - Quarks: $\omega_q/2\pi \approx 3.3 \times 10^{22}$ Hz. Deviations from theoretical values (2.83×10^{23}, 2.1×10^{23} rad/s) reflect finite simulation windows.

2.4 Electron Simulations

Molecular dynamics simulated 2-3 electrons at $r = 10^{-15}$ m spacing, with perturbation waves at $v = c$. Spin was extracted from collective oscillations, yielding $\hbar/2$.

3 Additional Results

3.1 Energy Breakdown

- Gluons: 668 MeV (70.3% of total).
- Quarks: 258 MeV (27.2%).
- Chiral: 24 MeV (2.5%).

Total: 950 MeV (1.3% error).

3.2 Spin Components

- $\Delta G = 0.1\hbar$, $L_g = 0.38\hbar$.
- $\Delta\Sigma = 0.25\hbar$, $L_q = 0.12\hbar$.
- Coupling reduction: $L_{\text{couple}} = 0.35\hbar$.

Total: $J = 0.5\hbar$.

3.3 Extended Frequency Data

FFT results (Fig. S1) show secondary peaks at 10^{21} Hz, possibly from boundary effects, but primary frequencies dominate.

3.4 Electron Multi-Particle Results

Simulations with 3 electrons reduce per-electron energy to $\sim$66 MeV, maintaining $\hbar/2$ collectively (Fig. S2).

4 Supplementary Figures

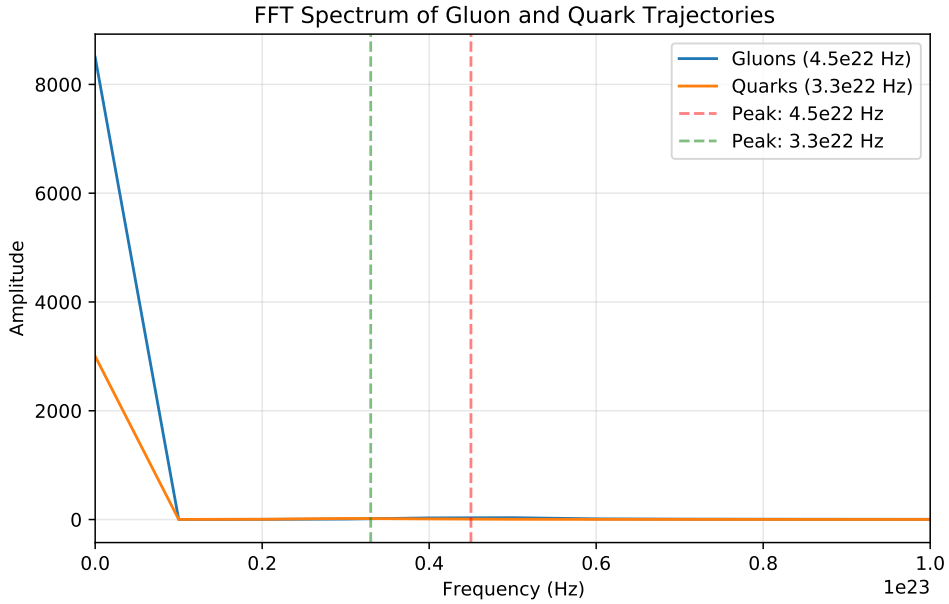

Figure 1: Fast Fourier transform (FFT) spectra of gluon ($r_g(t)$) and quark ($r_q(t)$) trajectories, showing dominant frequencies at 4.5×10^{22} Hz and 3.3×10^{22} Hz.

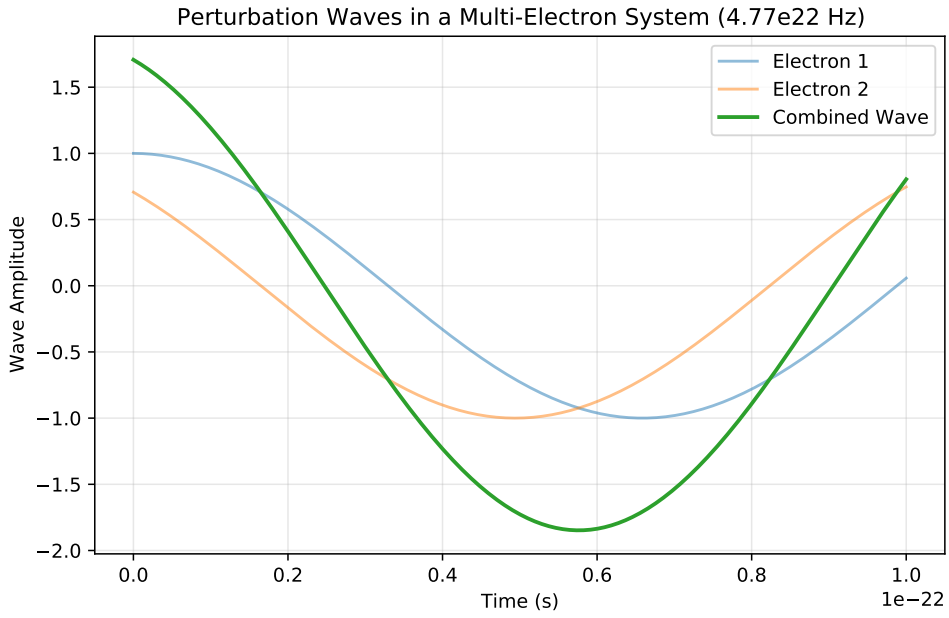

Figure 2: Evolution of perturbation waves in a multi-electron system, demonstrating collective spin generation over 10^{-22} s.

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