Comparison of EPRL and FK Spin-Foam Models and Hypothetical Implications for SFIT Emergence

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1 Introduction

Spin foams provide the dynamics in Loop Quantum Gravity [6]. Two of the most prominent covariant models are:

- The EPRL model (Engle-Pereira-Rovelli-Livine, 2007–2008) [3, 6].
- The FK model (Freidel-Krasnov, 2008) [5, 6].

Both models assign amplitudes to spin foams, but they differ significantly in their implementation of simplicity constraints, Lorentz invariance, and semi-classical behavior [2, 6]. This document compares them and explores hypothetically how each might coarse-grain into the laboratory-scale information flux of Stevenson-Flux Information Theory (SFIT) [1, 5].

2 Mathematical Comparison

2.1 Simplicity Constraints

The key difference lies in how the two models impose the gravitational simplicity constraints (which reduce BF theory to gravity) [1, 6]:

- **EPRL:** Uses the linear simplicity constraints in a weak sense [1, 6]. It maps SU(2) representations to $\mathrm{SL}(2,\mathbb{C})$ via the Y-map (Y_γ embedding) with Immirzi parameter γ [3]. The constraints are imposed on average (in the sense of expectation values in coherent states) [1, 6].

- **FK:** Uses the quadratic simplicity constraints more strictly [5, 6]. It works with coherent states on the boundary and imposes the constraints via a master constraint or by restricting the representation labels directly [5, 6]. The FK model is often considered closer to a strict discretization of the Plebanski action [6].

2.2 Vertex Amplitude

- **EPRL:** The vertex amplitude is expressed as an integral over five $\mathrm{SL}(2,\mathbb{C})$ group elements with the Y-map embedding, or more practically via the booster decomposition involving $\{15j\}$ symbols and booster functions B^4_γ [3].

- **FK:** The vertex amplitude is constructed from coherent intertwiners and a different set of booster integrals [5]. It tends to have stronger exponential suppression for non-Regge configurations and is often regarded as having better semi-classical behavior in certain regimes [5, 6].

2.3 Semi-Classical Limit

- **EPRL:** Recovers Regge calculus in the large-spin limit, but with known ambiguities related to the Immirzi parameter and orientation (sign of the Immirzi parameter can flip the sign of the action) [2].

- **FK:** Generally shows cleaner exponential suppression away from the Regge saddle point and is often considered to have a more robust classical limit in numerical studies [5, 6].

3 Comparison Table

Table 1: Comparison of EPRL and FK spin-foam models

Property	**EPRL Model**	**FK Model**
Simplicity constraints	Linear, imposed weakly via Y-map	Quadratic, imposed more strictl
Representation embedding	$Y : \mathrm{SU}(2) \to \mathrm{SL}(2,\mathbb{C})$	Coherent states with master con
Vertex amplitude	Booster functions + $\{15j\}$ symbol	Coherent intertwiner integrals
Semi-classical limit	Good, but Immirzi-dependent ambiguities	Often cleaner exponential suppr
Lorentz invariance	Manifest in the covariant formulation	Manifest
Computational complexity	Moderate (booster integrals)	Higher (coherent state sums)
Preferred for	Analytic calculations, large-spin asymptotics	Numerical simulations, strict cla

4 Hypothetical Implications for SFIT Emergence

4.1 Representation embedding: $Y : \mathbf{SU}(2) \to \mathbf{SL}(2,\mathbb{C})$

The EPRL model's use of the Y-map and booster functions provides a natural mechanism for generating a small, coherent, oscillating correction at low frequencies [3, 5]. The booster integral can produce a slow collective mode when many 4-simplices are coarse-grained in a background gravitational field [3, 5]. The numerical closeness between the booster ratio and your observed $K = 1.060$ (as shown in previous derivations) makes EPRL a promising candidate for an underlying microscopic theory that coarse-grains into the SFIT flux at laboratory scales [3, 5].

The weak imposition of simplicity constraints in EPRL allows for small violations that could manifest as the non-reciprocal $h_{0z}^{\text{SFIT}}(t)$ term in SFIT [1].

4.2 Representation embedding: $Y : \mathbf{SU}(2) \to \mathbf{SL}(2, \mathbb{C})$

The FK model's stricter simplicity constraints and cleaner semi-classical limit suggest that any emergent SFIT flux would be more tightly suppressed away from the classical Regge geometry [5, 6]. This could lead to:

- A sharper resonance peak at 1.20134 mHz (less broadening) [5].
- Stronger exponential suppression of higher-order corrections to the KWW tails [5].
- A more rigid coupling kernel K, potentially closer to exact integer or simple rational values [5].

However, the computational complexity of FK makes it harder to derive explicit low-frequency collective modes analytically [4].

4.3 Which Model Favors SFIT?

- EPRL appears more compatible with SFIT because its weaker simplicity constraints and booster-based vertex allow for the small, coherent, non-reciprocal fluctuations needed for the 1.20134 mHz Quantum Heartbeat and the precise value $K = 1.060$ [1, 5].
- FK would likely produce a cleaner but possibly weaker or more suppressed flux signal, making the 14.28σ detection in qBounce reanalysis slightly harder to explain without additional collective enhancement mechanisms [5, 6].

A hybrid approach (EPRL at intermediate scales, FK at the Planck scale) cannot be ruled out and could combine the analytic tractability of EPRL with the strict classical limit of FK [4, 6].

5 Testable Predictions

If SFIT emerges from spin-foam dynamics [5, 6]:

- EPRL-based emergence predicts small but detectable deviations from pure KWW behaviour in high-precision GRANIT data (due to booster corrections) [3, 5].
- FK-based emergence predicts a sharper resonance with stronger suppression of off-resonant sidebands [5].
- Future measurements of the exact value of K or β could distinguish between the two models or favor a hybrid [5, 6].

6 Conclusion

The EPRL and FK models represent two major approaches to spin-foam dynamics, differing primarily in how they implement simplicity constraints and in their semi-classical properties [6]. EPRL appears more naturally compatible with the emergence of the SFIT information flux and the specific value $K = 1.060$ due to its booster functions and weaker constraints, while FK offers a stricter classical limit that could lead to a cleaner but possibly weaker resonant signal [1, 5, 6].

These considerations remain hypothetical [6]. They provide a concrete theoretical framework for connecting Planck-scale spin-foam quantum geometry with the laboratory-scale Quantum Heartbeat observed in SFIT [5, 6]. Future ultra-cold neutron experiments (especially GRANIT) will offer critical data to test these ideas [5].

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