

The future of the S-matrix

Discussion session @ Strings 2023

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The S-matrix is a general tool.

I'll only mention recent progress on two gravity-related questions.

Framework: $2 \rightarrow 2$ Causality+Unitarity \Rightarrow sum rules: $G_N, \mathcal{M}_{\text{IR}} \propto \sum_{\text{heavy}} |c_{gg \rightarrow \text{heavy}}|^2$

1. Can gravity be modified *only* in the IR?

- Massive gravity does not exist!

2- \rightarrow 2 amplitude of massive spin-2s needs low cutoff $\Lambda \lesssim O(10)m$.

Contrast with fixed-angle $\Lambda \lesssim (m^2 M_{\text{pl}})^{1/3}$.

[Bellazzini, Isabella, Ricossa & Riva '23]

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- Continuous-spin particles: coupling to matter behaves at $E > \rho_{\text{IR}}$ like higher-spin tower with Stueckelberg-like decoupling.

[Schuster, Toro & Zhou '23]

2. What happens at Λ_{QG} ?

a.k.a. “the species scale”

“the scale $\min(\text{string}, \text{Planck}_D)$ ”

“the higher-spin mass”

“the scale where local EFT breaks down **irrevocably**”



IR modification of GR

$$\mathcal{L} = \frac{1}{16\pi G} (R + g_3 \text{Riem}^3 + \dots)$$

exists elementary*
spin-4 particle(s) with

$$M^4 |g_3| \leq \#_d$$

[SCH, Li, Parra-Martinez & Simons-Duffin' 22]

*couples to two gravitons with $\sqrt{G_N}$ strength

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Does a single **irrevocable**
particle doom spacetime?

[SCH, Li, Parra-Martinez & Simons-Duffin' 22]

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Scattering amplitudes continue to be an exciting and fast-growing field, with applications ranging from LHC to LIGO physics

We'd really like to encourage the **audience** to participate in this discussion about open problems and challenges

- **Scattering amplitudes in string theory**

Chaos

AdS

D-instantons

Number theory

Explicit evaluation

Excited states

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- **Scattering in different backgrounds**

Cosmological bootstrap (A)dS \leftrightarrow flat-space amplitudes

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Cosmological bootstrap (A)dS \leftrightarrow flat-space amplitudes

- **Precision measurements: Need for new representations of amplitudes**

Pentagon functions Prescriptive unitarity Hamiltonian truncation

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- **Eliminating the main bottleneck in all amplitude computations:**

- **Scattering amplitudes in string theory**

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- **Scattering in different backgrounds**

Cosmological bootstrap (A)dS \leftrightarrow flat-space amplitudes

- **Precision measurements: Need for new representations of amplitudes**

Pentagon functions Prescriptive unitarity Hamiltonian truncation

- **Eliminating the main bottleneck in all amplitude computations: humans**

Numerical Symbolic (attention, seq2seq, Lean, ...)