Études in Effective Double Copy

Amplitudes 2021

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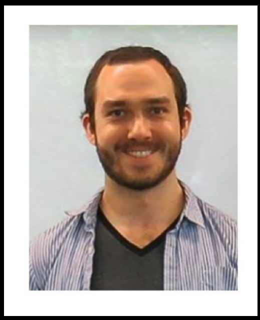
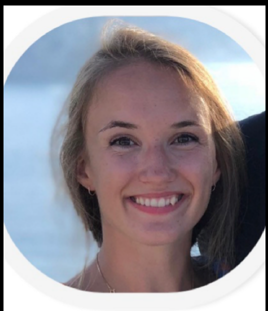
Suna Zekioğlu



Dr. Laurentiu Rodina

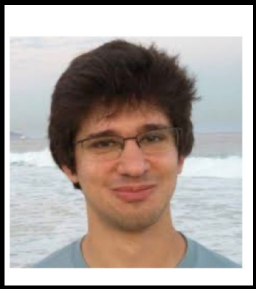


Ingrid Vazquez-Holm

Nic Pavao

Aslan Seifi

Dr. Matthew Lewandowski



Dr. Bogdan Stoica

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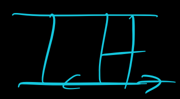
Functional Graph Based Double Copy

color-kinematics & functional representation

- Each topology  gets its own function.

- small # of basis graphs -> encode the full amplitude

- at tree level for gluons

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color-kinematics makes locality manifest & it preserves gauge-invariance

If you want local GI expressions
- just need a small # of building blocks

What's going on with Double Copy?

- (Gravity = "YM^2") + SUSY + related EFT's

- Open string (tree-level at least)

is a field theory double copy between

Yang-Mills

& a magical scalar α'

$\leftarrow$ Z-theory

& all orders in α'

& Turns string theory KLT into a field theory KLT w/ HD-YM

f^{abc} d^{abc} & s_{ij}

$$OS = \sum_{\Gamma_3} \frac{z_g \, n_g^{YM}}{d_g} \leftarrow k_i, \varepsilon_i$$

z_g obey Jacobi & anti-symmetry

just like normal $c_g \leftarrow f^{abc}$

$$OS_I = Z_I \otimes A^{YM}$$

Chan-Paton ordering

$$\underline{OS} = \sum_{I \in S_{n-1}} \mathrm{Tr}(T^{I_1} T^{I_2} \cdots T^{I_n})\, OS_I$$

$$\underline{CS} = OS_I \overset{\alpha'}{\otimes}_{IJ} OS_J$$

$$= \underline{A_{YM}} \otimes \Big(\underbrace{Z_I \overset{\alpha'}{\otimes}_{IJ} Z_J \otimes A_{YM}}_{\text{field theory relations}} \Big)$$

$(n-2)!$ KK

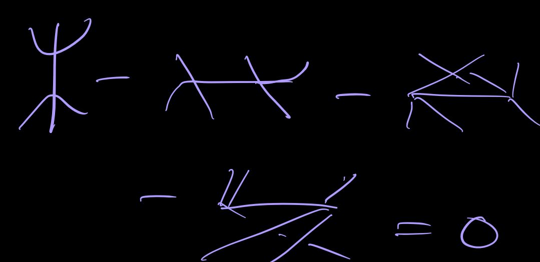
$(n-3)!$ BCJ

$\underline{A^{YM+HD}}$

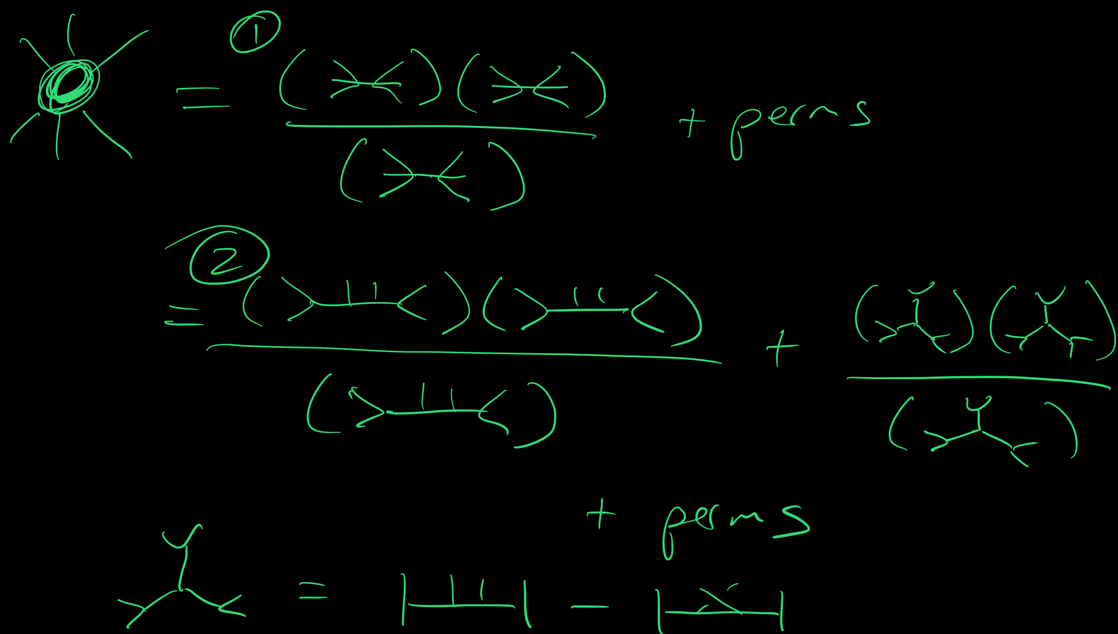
$$= \sum_{g \in \Gamma_3} \frac{n_g^{vec}\, n_g^{vec+HD}}{d_g}$$

- BLG consistent w/ color-kinematics
  ↳ 3D

$$A^{BLG} = \sum_{\Gamma_4} \frac{c_g^{BLG}\, n_g^{BLG}}{d_g}$$



$$A^{SG} = \sum_{\Gamma_4} \frac{n_g^{BLG}\, n_g^{BLG}}{d_g} = \sum_{\Gamma_3} \frac{n_g^{sym}\, n_g^{sym}}{d_g}$$



Two striations of the same physical predictions into building blocks of differnt & distinct algebraic properties

Z-theory makes it clear that
EFT is a great playground to
start exploring some of these ideas

- Important
  - $\mathcal{N}=4$ SG has a div at 4 loops in 4D
    ($\mathcal{N}=8$ SG??)

    Finite # of CT ? ∞

- Results:
  - finite # of building blocks span
    HD adjoint-type predictions at each
    multiplicity

  - their amplitudes admit multiple structures
    along different algebras

  - composition rather than ansatze that
    lets us climb the ladder of HD corrections

$$\left.\begin{matrix} HD^{(m-1)} \\ \text{kinematics} \end{matrix}\right\} \to \text{composition} \to HD^{m}$$

- Can play the same games w/ fermions &
massive gauge amplitudes

- String theory is special.

Study Striation at 4pts

$$A^{YM} = \frac{c_s n_s}{s} + \frac{c_t n_t}{t} + \frac{c_u n_u}{u}$$

c_g & n_g both are adjoint-type

$$c_s = c_t + c_u$$

$$n_s = n_t + n_u \qquad c_t = c_s - c_u$$

$$\underline{A^{YM}} = \underbrace{\left(\frac{n_s}{s} + \frac{n_t}{t}\right)}_{A(s,t)} c_s + \underbrace{\left(\frac{n_u}{u} - \frac{n_t}{t}\right)}_{A(u,t)} c_u$$

must be gauge inv.

If $n_s = n_t + n_u \Rightarrow$

$$\boxed{\frac{A(s,t)}{u} = \frac{A(u,t)}{s} = \frac{A(s,u)}{t}}$$

All perm inv

$st\,A^{YM}(s,t) = \text{B.I.} \qquad st\,A^{BAS}(s,t)$

$\Downarrow \qquad = \text{NLSM}$

$$A^{YM} = -\frac{(t n_s + s n_t)(t c_s + s c_t)}{\underbrace{stu}}$$

$st\,A^{NLSM}(s,t) = \text{Special Galileon.}$

$$= - \frac{(\overset{BI}{\times})(\overset{NLSM}{\times})}{(\overset{\text{Special Gal}}{\times})}$$ ← perm inv way of writing KLT

$$= \frac{(\vdash\!\dashv)(\vdash\!\dashv)}{(\vdash\!\dashv)} + \text{perms}$$

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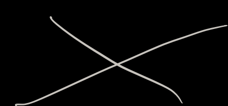
4 pt Summary

two structures

adjoint type

f^{abc}

$c_s = f^{abe} f^{ecd}$



perm inv

eg d^{abcd}

3 Building block

$$A^{HD,\,vec} \sim \frac{C_g^{HD}\, n_g^{vec}}{d_g}$$ ← 8 diff vector building blocks

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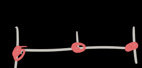
5 pt summary

UNIQUE

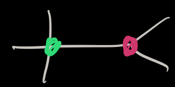
6,  $\boxed{10}$ ← closure post composition

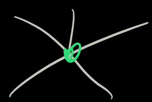
antisym on every vertex $\quad f^{abc} f^{cde} f^{efg}$

Jacobi on every edge

5  $\boxed{8}$

relaxed $\xrightarrow[\text{superposition}]{} f^3 d^3 f^3$

6  $\boxed{10}$ Hybrid $d^4 f^3$

1  $\boxed{9}$ Perm

Scherzo

What operators are we spanning?

Double Copy Effective Actions:

A QCD Approach to Space-Time

JJMS, LR, SZ

How?

We cheat in the best possible way

- we promote amplitudes directly to operators

n-field ops $\to$ n field operators

$\mathcal{L}(\underline{\text{Amplitude}})$

- Hard code locality w/ a few tricks

- GI manifest multiplicity by multiplicity

$$\sqrt{-g}\,R \sim \mathcal{L}_2 + \mathcal{L}_3 + \mathcal{L}_4 + \mathcal{L}_5 + \cdots$$

- Simple b/c $\mathcal{L}$ is a machine for generating predictions via explicit particles.

Refs: 1910.12850 2104.08370

[See also talks by H. Elvang & S. Paranjape for related & complementary KLT approaches...]