# Gravity of Closed Strings
## Foundations of a Research Program

Jeong-Hyuck Park

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PARK Research Program

*This document is not written to persuade those who already have a mature view of Double Field Theory.*
*It is written for researchers and students who wish to think carefully about a simple question:*

***What is the gravitational theory naturally implied by closed string theory?***

*It is not a review article, a grant proposal, or a manifesto.*
*Its purpose is to formulate a problem before naming a theory.*

## 1 The Question

The starting point is a question.

**What is the gravitational theory naturally implied by closed string theory?**

This question is more precise than the question of whether string theory contains gravity. It does. The massless spectrum of a closed string contains a spin-two field, and its low-energy dynamics includes the Einstein equations in an appropriate limit.

The issue is not existence. The issue is organization.

If closed string theory has its own gravitational content, then one should ask what the corresponding geometry is, what its invariant fields are, what its curvature is, what its field equation is, how matter couples to it, and how it can be tested.

The question should therefore be approached in the order

$$\begin{gathered}\text{Observation}\\ \Downarrow\\ \text{Question}\\ \Downarrow\\ \text{Working Hypothesis}\\ \Downarrow\\ \text{Research Program}\\ \Downarrow\\ \text{Tests}\\ \Downarrow\\ \text{Open Problems}\\ \Downarrow\\ \text{Invitation}\end{gathered}$$

The purpose of this document is to make that order explicit.

## 2 Scope of the Program

This research program concerns the gravitational theory implied by the universal massless sector of perturbative closed string theory.

It does not attempt to formulate the geometry of M-theory or of exceptional extensions. Nor does it assume that a Riemannian formulation is the most general description of the closed-string gravitational sector.

Within this scope, Double Field Theory is treated as the working geometric framework to be tested.

## 3 Observation

The universal massless sector of closed string theory is

$$\{g_{\mu\nu}, B_{\mu\nu}, \phi\}.$$

This is the observation. It is not a conjecture and it is not a matter of interpretation.

The Riemannian metric $g_{\mu\nu}$ is not alone. It appears together with the two-form gauge field $B_{\mu\nu}$ and the dilaton $\phi$. These fields are not optional additions to the closed-string spectrum. They are part of the same universal massless sector.

This observation creates a conceptual tension. General Relativity geometrizes the metric. It does not, by itself, geometrize the complete multiplet $\{g_{\mu\nu}, B_{\mu\nu}, \phi\}$. Supergravity incorporates the same fields dynamically, but it is usually expressed after a choice of Riemannian variables has already been made.

The scientific problem is therefore not to add more fields to General Relativity. The problem is to understand whether the whole closed-string massless sector is itself gravitational.

## 4 Two Hypotheses

It is important to separate two statements that are often compressed into one.

### 4.1 Hypothesis A

**The complete massless sector $\{g_{\mu\nu}, B_{\mu\nu}, \phi\}$ is irreducibly gravitational.**

This is the starting hypothesis. It says that the metric, two-form, and dilaton should not be regarded as a metric plus auxiliary matter fields. They should be regarded as components of a single gravitational structure associated with closed strings.

Hypothesis A does not yet name the correct geometry. It only fixes the object that the geometry must describe.

### 4.2 Hypothesis B

**Double Field Theory is the natural geometric theory describing the entire sector $\{g_{\mu\nu}, B_{\mu\nu}, \phi\}$.**

This is the working hypothesis.

The research program exists to establish or reject Hypothesis B. It is not enough to show that Double Field Theory is consistent, elegant, or useful. One must ask whether it is the geometry forced upon us when Hypothesis A is taken seriously.

The distinction matters. Hypothesis A identifies the gravitational multiplet. Hypothesis B proposes its geometry.

## 5 The Logical Gap

Closed string theory gives the multiplet $\{g_{\mu\nu}, B_{\mu\nu}, \phi\}$.

General Relativity geometrizes $g_{\mu\nu}$.

Between these statements lies a gap:

**What geometry describes the full closed-string gravitational multiplet?**

This is the place where Double Field Theory enters. It does not enter as an alternative formalism for familiar equations. It enters as the proposed answer to a missing geometric question.

If this answer is correct, then the usual Riemannian description is not discarded. It is recovered after choosing a Riemannian sector. In that sector, one obtains the standard variables of supergravity and, in appropriate limits, General Relativity.

The proposed ordering is therefore

$$\begin{gathered}\text{Closed String Theory}\\ \Downarrow\\ \text{DFT}\\ \Downarrow\\ \text{Choice of a Riemannian sector}\\ \Downarrow\\ \text{SUGRA}\\ \Downarrow\\ \text{GR}\end{gathered}$$

The ordering is not a statement of prestige. It is a statement about what is chosen and what is prior to the choice.

## 6 Necessity as a Method

The research program should not proceed by listing definitions. It should proceed by asking what must exist if the working hypothesis is correct.

If Double Field Theory is gravity, it must possess its own geometry.

Once geometry exists, it must possess its own metric data.

Once metric data exist, one must define parallel transport.

Once parallel transport exists, curvature becomes unavoidable.

Once curvature exists, a variational principle becomes natural.

Once a variational principle exists, a gravitational field equation becomes necessary.

Once a field equation exists, the theory must also describe propagation, matter coupling, phenomenology, and tests.

This order is the internal discipline of the program:

$$\begin{array}{c}\text{Question}\\ \Downarrow \\ \text{Necessity}\\ \Downarrow \\ \text{Construction}\\ \Downarrow \\ \text{Prediction}\\ \Downarrow \\ \text{Experiment}\end{array}$$

The value of a construction is measured by whether it occupies a necessary place in this chain.

## 7 Main Components of the Program

The following components are not independent topics. They are stages in one question. If Hypothesis B is correct, each component should appear as a necessary part of closed-string gravity.

### 7.1 Geometry

If the full closed-string massless sector is gravitational, then its geometry must accommodate $g_{\mu\nu}$, $B_{\mu\nu}$, and $\phi$ without treating them as unrelated objects. The proposed geometric data are the generalized metric and the DFT dilaton. They are intended to encode the closed-string massless sector in one geometric language.

The role of $O(D, D)$ covariance is not decorative. It is the symmetry principle that makes the full sector geometric. This is the first test of Hypothesis B: the theory must organize the complete sector while preserving the Riemannian descriptions known to be correct in their domains.

### 7.2 Connection and Curvature

A gravitational theory must define parallel transport. In Riemannian geometry this role is played by the Levi-Civita connection. In the closed-string setting, the corresponding connection must be compatible with the doubled geometric structure and with $O(D, D)$ covariance.

Once such a connection exists, curvature becomes unavoidable. The resulting curvature must be geometric, covariant in the appropriate sense, and reducible to familiar Riemannian curvatures after a sector is chosen.

### 7.3 Field Equation

If Double Field Theory is gravity, its variational principle must determine the analogue of Einstein's equation. The proposed field equation is the Einstein Double Field Equation,

$$G_{AB} = T_{AB}.$$

The point of this equation is not its formal resemblance to Einstein's equation. The point is that geometry must respond to sources through a covariant field equation. In a Riemannian sector this equation must reproduce the familiar equations of the universal bosonic supergravity sector.

### 7.4 Propagation

A gravitational theory needs more than a field equation for geometry. It also needs propagation equations for physical fields. In General Relativity, the metric determines both the Einstein equation and the wave operator appropriate to curved spacetime.

The schematic parallel is

$$g_{\mu\nu} \quad \Longrightarrow \quad G_{\mu\nu} = 8\pi G\, T_{\mu\nu} \quad \Longrightarrow \quad \Box_g,$$

and

$$\{\mathcal{H}_{AB}, d\} \quad \Longrightarrow \quad G_{AB} = T_{AB} \quad \Longrightarrow \quad \Box_{\mathrm{DFT}}.$$

Thus the box operator is part of what it means for the theory to be gravitational.

### 7.5 Matter Coupling

A theory of gravity is incomplete until it says how matter couples to geometry. The minimal coupling principle of General Relativity is a statement about the universality of geometry. If Hypothesis B is correct, there should be an analogous principle for closed-string gravity.

This question is not merely formal. The coupling determines what matter sees, which trajectories are natural, which wave equations are physical, and what phenomena can distinguish the theory from its Riemannian sectors.

### 7.6 Phenomenology

The working hypothesis must lead to physics. Phenomenology enters when the theory is asked to describe situations in which closed-string gravitational structure may leave an imprint beyond an ordinary Riemannian approximation. Possible arenas include weak-field gravity, post-Newtonian limits, cosmology, compact objects, wormhole geometries, and gravitational waves.

The purpose is not to force deviations from General Relativity. The purpose is to identify which predictions follow from the proposed geometry, whether they are compatible with observation, and whether the theory can be falsified.

## 8 Tests

There are two kinds of tests.

The first kind is mathematical. The structures of Double Field Theory must not be arbitrary. They must appear as necessary consequences of the question. The generalized metric, the connection, the curvature, the field equation, the box operator, and the coupling to matter must fit together as parts of one geometry.

The second kind is physical. The theory must face observation. It must make contact with solar-system gravity, cosmology, black holes, gravitational waves, and any future regime in which closed-string gravitational effects can be constrained.

Mathematical coherence is not enough. Empirical agreement is not enough if it comes only from reproducing known sectors. The program succeeds only if the closed-string geometry is both necessary and physically correct.

## 9 Criteria of Success

The success of the program is not measured by the number of publications, citations, or talks.

It is measured by whether the field comes to organize the subject in the following way:

$$\begin{gathered}\text{Closed String Theory}\\ \Downarrow\\ \text{Double Field Theory}\\ \Downarrow\\ \text{Choice of a Riemannian sector}\\ \Downarrow\\ \text{Supergravity}\\ \Downarrow\\ \text{General Relativity}\end{gathered}$$

If this ordering becomes natural to future physicists, then the program has succeeded.

This would not mean that General Relativity has been displaced in the domain where it is the right theory. It would mean that its place in closed-string gravity has been clarified.

## 10 Choosing Problems

Good problems are not chosen because they are fashionable. They are chosen because they remove one indispensable obstacle.

Before beginning a project, one should ask:

**What essential ingredient is still missing?**

This question is different from asking what calculation can be performed. A calculation is valuable when it clarifies the structure of the theory, tests a necessary implication, or connects the program to observation.

For students, this distinction is especially important. The aim is not to accumulate technical exercises. The aim is to identify what must be understood next if the central question is to become sharper.

## 11 Open Problems

The program remains unfinished. Some open directions are:

- quantum aspects of DFT;
- quantum corrections;
- formulations beyond the section condition;
- black holes and compact objects;
- gravitational waves;
- cosmology;
- numerical solutions;
- mathematical foundations;
- matter coupling;
- phenomenology;
- exceptional extensions;
- connections to quantum gravity.

This list is not meant to be exhaustive. Its purpose is to indicate that the program contains both conceptual and phenomenological questions. Some are geometric, some are dynamical, some are observational, and some concern the relation between string theory and quantum gravity more broadly.

## 12 Joining the Program

The scientific problem is to determine the gravitational theory naturally implied by closed string theory.

The observation is that closed strings universally contain the massless sector $\{g_{\mu\nu}, B_{\mu\nu}, \phi\}$.

Hypothesis A is that this complete sector is irreducibly gravitational.

Hypothesis B is that Double Field Theory provides its natural geometric completion.

The research program is to test Hypothesis B by deriving, constraining, and probing the consequences that must follow if it is correct: geometry, connection, curvature, variational principle, field equation, propagation, matter coupling, phenomenology, and experiment.

The program remains intentionally unfinished. Many central questions are still open. Students and collaborators are not merely invited to learn existing results, but to help identify what remains necessary.

The program may interest people drawn to geometry, gravitation, string theory, quantum field theory, cosmology, mathematical physics, phenomenology, and the foundations of quantum gravity.

The program remains open until both questions are answered:

**Is the geometry mathematically forced?**

**Does Nature use it?**

The first question is mathematical. It asks whether the structures introduced by DFT are necessary consequences of the closed-string massless sector, or only one possible formal organization of it.

The second question is physical. It asks whether the same structures survive contact with observation, and whether they lead to tests that can sharpen or falsify the working hypothesis.

A student or collaborator need not answer both questions at once. A good project may clarify one definition, one coupling, one limit, one solution, or one observable consequence. What matters is that the project makes the central question sharper.

If this question interests you, there is still much to discover.

## Further Reading

Readers interested in the technical developments of the ideas presented here may consult

J.-H. Park,
*Gravitational Core of Double Field Theory: Lecture Notes*,
European Physical Journal C **85**, 1104 (2025).

This article provides a technical review of the geometric formulation, Einstein Double Field Equations, non-Riemannian geometry, and phenomenological developments.

# Editorial Note

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