Title: Final but Incomplete?

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Abstract: String theory has not come close to a complete formulation after half a century of intense research. On the other hand, a number of features of the theory suggest that the theory in its complete form may be a final theory. The combination of conceptual incompleteness and allusions to finality seems difficult to grasp. Two main points are made in this talk. First, it is pointed out that finality claims in the context of string theory are motivated in a fundamentally different way than traditional claims of finality one finds in earlier physics. Second, it is argued that finality and chronic conceptual incompleteness may be related to each other in a string theory context in an interesting way. The talk ends with discussing possible implications of this situation for the long-term prospects of theory building in fundamental physics.

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Finality and Incompleteness: How Do They Fit Together?

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The traditional view on finality

In the 19th century, Newtonian physics was understood to be the last word on the fundamental understanding of gravity.

It was taken to be a final theory in the sense that:

- There could be more elegant formulations, and more effective ways of calculating the theory's implications, but no genuinely new posits that improved theory's predictive power or accuracy in the given intended domain.

The traditional reasons for assuming finality

The final theory claim about Newtonian physics was supported by the following arguments:

- The theory had been empirically tested successfully over a long time and a vast range of distances and mass values, from falling apples to the movements of planets.
  - Consistent agreement with the data.
  - Anomalies were dissolved within the theory (Neptune).
- The theory looked elegant and appealing.
- No good alternatives were in sight.
  - The core commitments (flat space, time, determinism) seemed beyond doubt.
  - Different perspectives on the theoretical context (Hamilton, Lagrange formalism) did not point beyond the theory.

In the later 19th century, Maxwell's electrodynamics was viewed as another final theory candidate for similar reasons.

- At its core, the inference to finality was a meta-inductive argument: Since the theory had worked so successfully and flawlessly for so long, one inferred that it would continue doing so forever.

ST has also been linked to FT claims

Coming from Newton, this looks very strange.

- ST has not been empirically confirmed.

⇒ Though there is considerable confidence in the theory's viability among many string theorists based on theoretical and meta-empirical considerations, the theory's status is not even remotely comparable to the status of Newton's theory in the 19th century.

⇒ No meta-inductive inference to a final theory claim can be made.

⇒ Based on the finality criteria that were applied to Newton and Maxwell, a finality case for string theory looks baseless.

So how can a final theory claim make sense in this context at all?

The claims of this talk:

- Final theory claims in the context of String Theory work in an entirely different way than those in 19th century physics.
- This is a potential advantage, not a problem.
- Considering final theory claims may shed light on the current situation in QG.

Finality and String Theory

There are a number of arguments that suggest that ST, if viable, could be a final theory.

I: ST is a universal unified theory.

- ST describes all known interactions and particles.
- ST aims aims at giving a unified account of all interactions.
  - If one takes theory dynamics to aim at increased universality, full universality is a natural endpoint.
  - Equally, if unification is viewed as an aim of physics, full unification of all known (fundamental) physical phenomena is a natural endpoint.
- ST *only* works as a universal theory. It offers no options to add fundamental posits or embed it in another theory.
  - "From the inside", ST suggests that there cannot be more in this world than what ST implies.

II: ST has a minimal length scale.

- ST introduces a minimal length scale based on T-duality.
  - all distances d smaller than l can be expressed in a dual theory as l^2/d. => information on smaller distances is redundant.

$\Rightarrow$ If ST is fully viable at its characteristic scale, no new theory can kick in at a higher energy scale/lower distance scale.

$\Rightarrow$ ST looks final (from within the theory).

III: ST has no fundamental free parameters.

(While there are many vacua of the theory, the landscape).

The lack of free parameters provides support for finality in two ways:

- If one takes the scientific process to aim at explaining free parameter values, a theory without free parameters is a natural endpoint.
- If one has found a theory without free parameters that is viable at some level, it may seem
  - neither plausible to have a succession of theories without free parameters (because such theories seem too rare)
  - nor to move back to a theory with free parameters (because the fundamental theory then could not explain the effective one).

From old to new finality claims

19th century finality claims were based on a questionable line of reasoning:

- a global (universal) claim was inferred from local observations, without sufficient further reasoning in support of that step.

- There were neither satisfactory theory-internal nor sufficient meta-empirical arguments for finality.

⇒ Even the strongest case for finality was not sufficiently motivated.

⇒ This type of finality argument has been rejected for good reasons after the revolutions of early 20th century physics.

But the final theory claims of string theory are not of that kind.

- The final theory claims for ST are
  - contextual (ST covers all fundamental physics) or
  - conceptual (minimal length, no free parameters, not extendible)

  rather than meta-induction from consistent success.

Therefore, the traditional implications of finality don't apply.

- The finality claim does not depend on conclusive or strong epistemic commitment. It is of the type: "if viable, then (maybe) final".
- The incomplete final theory may still have fundamental shifts in understanding and perspective in store. Those may even be necessary to achieve predictive power.
- What is essential, though, is the understanding that the posits that define the theory in its current representation uniquely determine the full theory: there won't be any more free choices of additional posits on the way to a complete formulation.

ST is chronically incomplete:

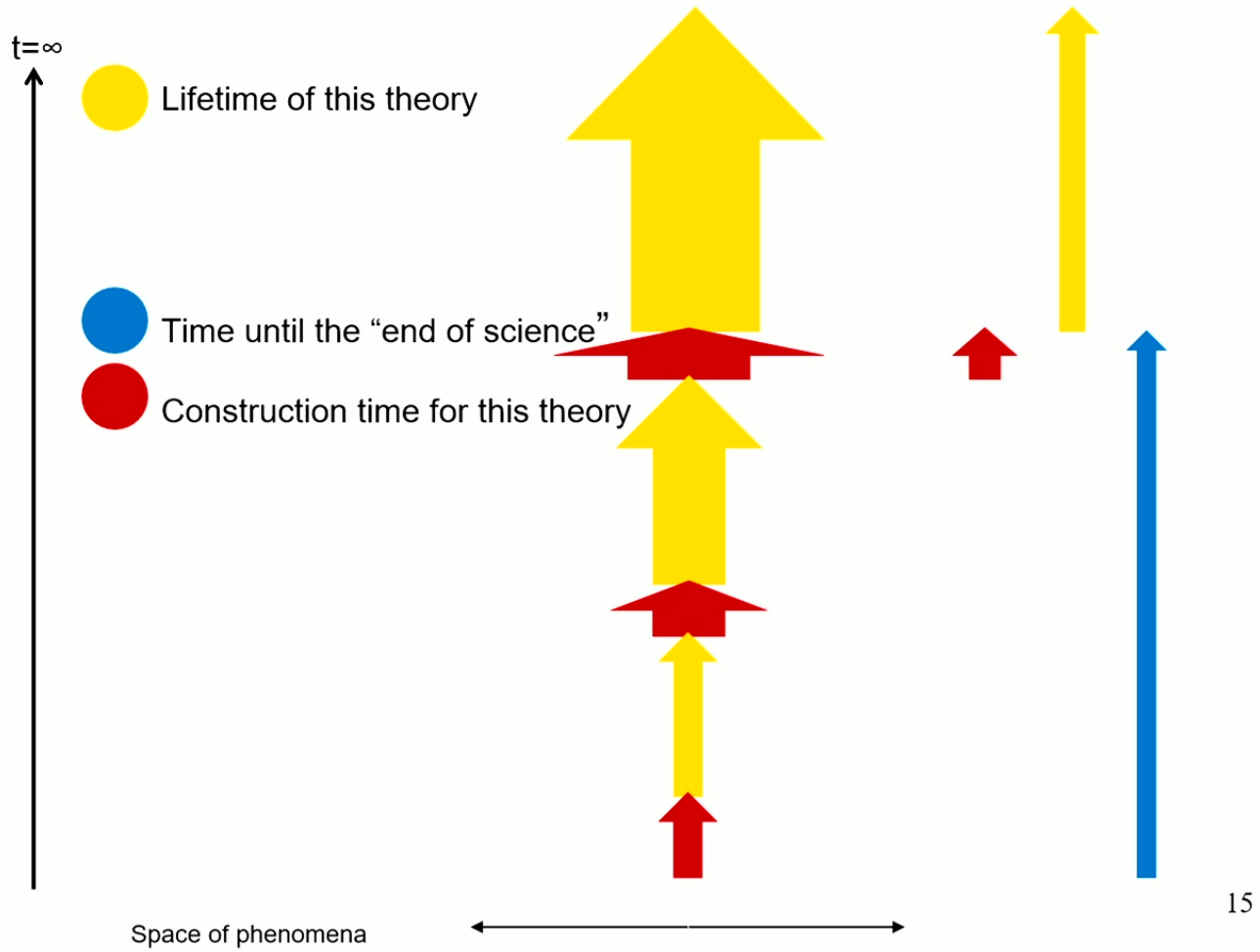
- After the discoveries of the web of dualities in 1995 and AdS/CFT in 1998, string theory was taken to have decent prospects of finding a substantially more complete form in the foreseeable future.
- While there have been significant improvements in the understanding of aspects of the theory since then, it appears as far from completion as ever.
- Many fundamental issues remain unsolved.

Not just a problem of one specific theory

- The difficulties to complete the theory are not confined to string theory. They are a general characteristic of attempts to develop quantum gravity.

There seems to be something about quantum gravity that makes it conceptually particularly tricky to develop a full theory.

The „Newtonian“ final theory view



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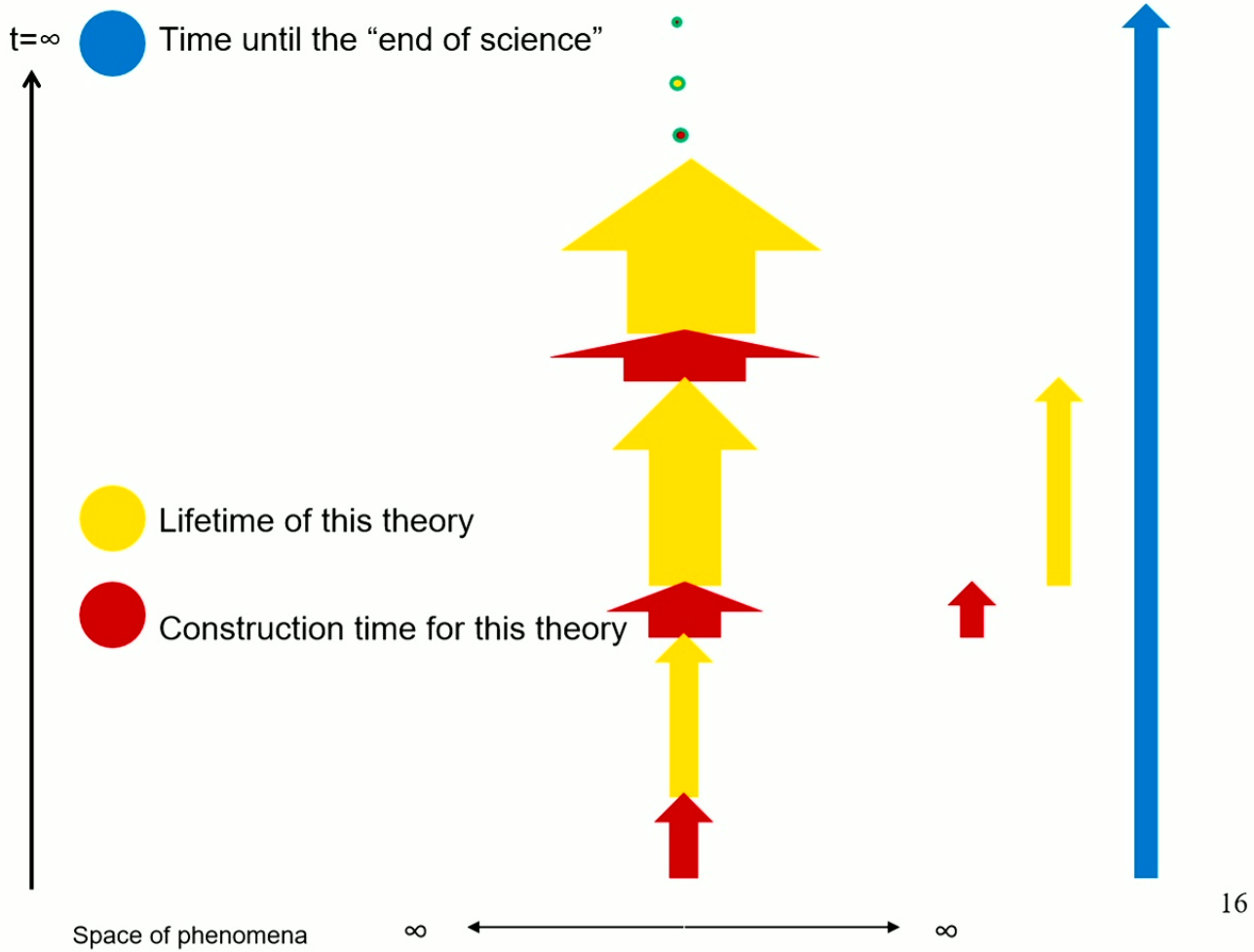
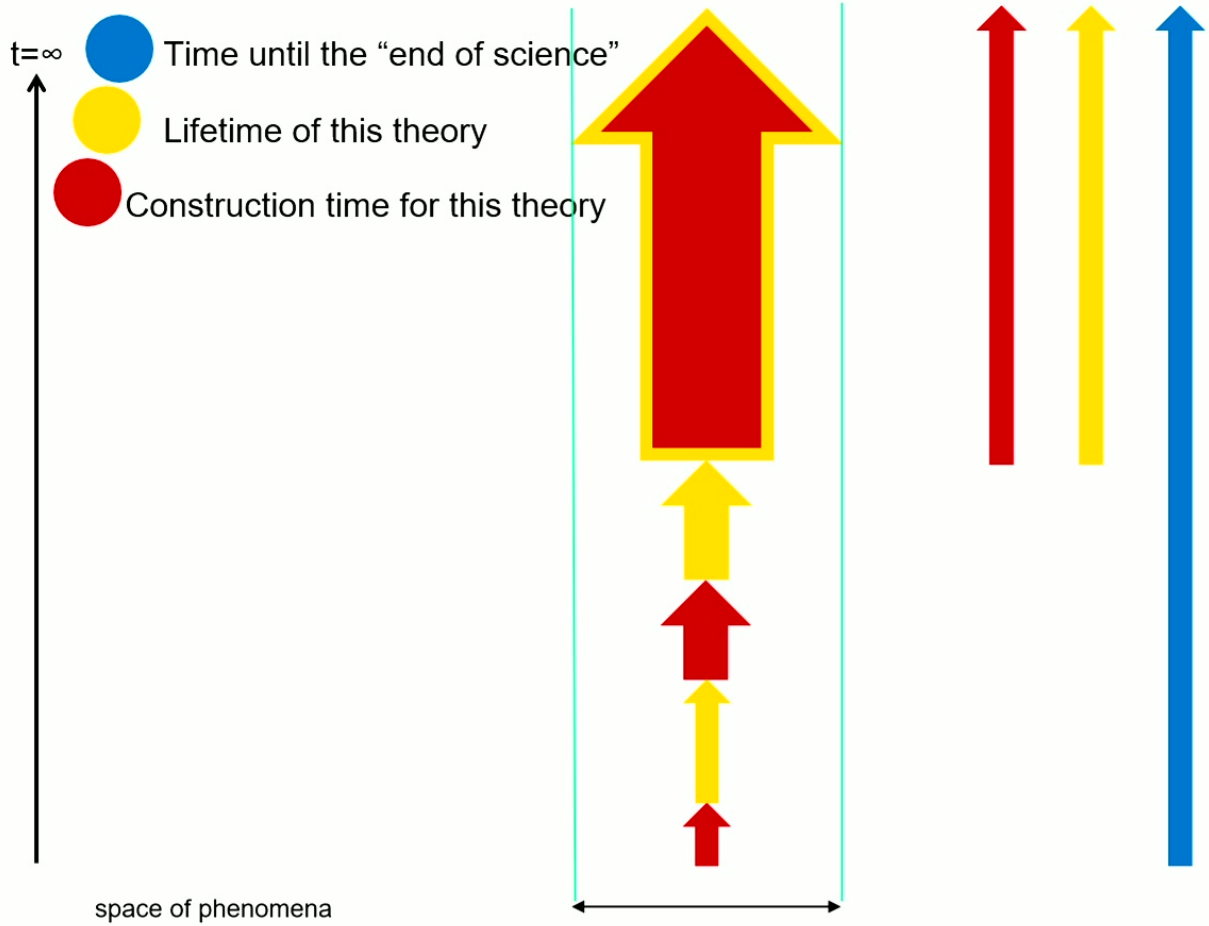
The canonical view on theory succession



The view suggested by ST today



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Chronical Incompleteness because of Universal Finality?

? Why do chronical incompleteness and finality claims arise at the same time?

➢ Suggestion: Universal Finality may favour chronical incompleteness.

1: A simple argument from universality

- As long as one looks for non-universal theories, the physicist can reduce the domain of applicability until it allows for constructing a complete theory within a reasonable time.

- Once the aim has become to construct a universal theory, this move is blocked.

- Argument I links universality to finality.

=> A universal final theory may defy expectations of completion within a reasonable time.

2: Free Parameters

A more sophisticated argument can be made based on the lack of free parameters.

- Free parameters play two different roles:
  - Empirically, they allow to connect to data.
  - Conceptually, they control the move towards/ away from our intuitions.

The two roles are connected since our observation-interfaces are classical.

In other words, we know that our world is of a kind that allows for classical descriptions of the pointers in our measuring devices.

The normal case: Intuition and heuristics

- We live close to a classical limit.
- Our intuitions are shaped by that.
- Other parts of the universe are far from any classical limit.
- Moving towards a more fundamental theory reaches out towards those parts.

The normal case: Intuition and heuristics

- The theory's empirical implications can be intuitively grasped close to a classical limit where the theory "meets" intuition.
- We find and develop advanced theories by thinking about near-classical behaviour and then allow the free parameters that control the 'non-classical' aspects to move towards the deeply non-classical.
- Our intuitions about the near classical are the heuristic starting point even for thinking about wildly non-classic behaviour.

Heuristics based on the more intuitive theory

Example: General Relativity

Equivalence principle found in Newtonian gravity

Positing gravitation to be a property of spacetime

Searching for spacetime DOF that can control gravity

Finding curvature…

- This type of reasoning only works because there is a limit close to which GR phenomenology looks a lot like Newtonian gravity.
- Closeness to this limit is controlled by free parameters (the gravitational constant, speed/speed of light).

The step towards finality

- If there are no free parameters, one cannot move towards or away from the near classical at a fundamental level of description.
- The standard heuristics of theory building may be suspected to break down at the step towards a final theory.

But how was ST found then?

- ST was first developed perturbatively. Explicit calculation assumes a small string coupling (= a ground state of ST) to have a workable perturbation theory.
- At the perturbative level,
  - one does move close to a classical limit.

  $\Rightarrow$ the normal heuristics still works.
  - one can infer properties of the full theory, like its lack of free parameters, by looking at the basic properties of the moving string.
  - But it is another matter to understand the full dynamics of the theory.

The role of Dualities

- ST knows quite some dualities which provide means of reaching out beyond the perturbative regime:
  - T-duality
  - S-Duality
  - AdS/CFT
  - …

They link one theory near a classical limit to another one far from a classical limit.

String Dualities

- String dualities provide a powerful tool.
- But they provide little heuristics for finding new theories/perspectives and don't give guidelines as to how construct the dual theory if they do. (see M-theory)

⇒ Perspectives that don't have a near-classical limit as their "natural habitat" may not be found.

⇒ There is, at least at this point, no research strategy that clearly converges towards a full understanding of the theory.

Can suspecting a link between chronic incompleteness and finality be helpful?

1: Can it be helpful for finding new perspectives on QG?

- I wouldn't know (obviously).

2: Can it be helpful for understanding how to frame the enterprise of inverstigating QG?

- It could suggest reconsidering the way one understands scientific progress in the given context.

Conclusions:

- The new finality claims, unlike the old ones,
  - Provide a plausible epistemic basis for asserting finality.
  - allow for conditional final theory claims.

⇒ The lack of a fully developed theory is no reason not to take final theory claims seriously.

- The character of new finality claims provides a basis for linking finality to chronic incompleteness.

- Thinking about finality thus may help explain basic characteristics of the current predicament of QG.

⇒ It may be more important than ever to think carefully about finality.