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Editorial

Introduction: Principles of quantum gravity

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ABSTRACT

In this introduction, we describe the rationale behind this special issue on *Principles of Quantum Gravity*. We explain what we mean by 'principles' and relate this to the various contributions. Finally, we draw out some general themes that can be found running throughout these contributions.

> Those are my principles, and if you don't like them … well, I have others.
>
> Groucho Marx

1. Quantum gravity: a question of principle?

We, like many working in the area of quantum gravity, bemoan the fact that the collaborative textbook on *The Quantization of Gravitation*, planned by Bryce DeWitt, Chris Isham, and Karel Kuchař (three true maestros of quantum gravity), never came to fruition. Sadly, the project was abandoned in 1975, when Kuchař appears to have withdrawn on account of his feeling that too many difficult 'questions of principle' remained to make any book of that kind timely.[1] He was probably right given the state of the field at the time, in which all major approaches were facing severe problems and any newcomers were simply not yet sufficiently developed to submit to a textbook treatment. The foundations of the discipline, and the nature of the problem itself, were so uncertain that it was simply not a feasible project.

Much has happened in the intervening decades between then and now: the problem of quantum gravity itself has been refined in several important ways (with the development of new concepts); entirely new approaches have flowered; some old problems have been resolved; and many new problems have been introduced with various 'internal' advances and wider advances in background knowledge. In this special issue we wanted to investigate whether with these advances and changes we have come any farther on 'questions of principle': do we now have in our possession some such overarching, relatively stable guiding principles capable of shaping the construction and grounding the selection or rejection of quantum gravity proposals? As Jonathan Bain makes clear in his contribution, they are clearly required all the more so in an area like quantum gravity with the vast distances that separate (presently) accessible energy scales from those at which quantum gravitational effects are expected to play a key role, implying that there is 'little contact between theoretical work in QG and empirical tests'.[2] Hence, it is difficult to see how we can even begin to properly assess the various proposals without such principles or constraints to hand for they provide key pieces of the conceptual foundations on which such assessments are made.

Quantum gravity is often minimally characterised in terms of the involvement of the three constants, G, c, and $\hbar$, and the recovery of established physical results in accessible domains. These basic requirements leave an awful lot of elbow room in the shape of any resultant theory. We are not even told whether the constants are inputs or outputs (and whether quantum theory or general relativity are 'fundamental' or not). Hence, the more the space of possible theories can be constrained the better. Without some such constraints quantum gravity research is destined to remain a highly insecure discipline.

[1] See John Wheeler's letter of reference for Kuchař, to Peter Gibbs, dated November 18, 1975 [John Archibald Wheeler Papers, 1880–2008: Box 15]. Writing in a festschrift for DeWitt a decade later, Wheeler writes that "[n]o question about quantum gravity is more difficult than the question, 'What is the question?'" (Wheeler, 1984, p. 224). Getting clear on the guiding physical principles constraining possible theories (i.e. possible *answers*) is an essential part of getting clear on this most basic question, and can lead us towards a proper understanding of what are the physical degrees of freedom about which we ought to be thinking and trying to measure (Wheeler's primary concern in the paper from which this quote is drawn)—in their contribution to this special issue, Bradonjić and Stachel focus their attention on issues of measurability and their relation to the definition of the basic physical quantities of a theory: results of measurability analysis can, they argue, serve as general (largely approach-independent) constraints on quantum gravity proposals.

[2] Of course, we do not ignore the importance of potentially large-scale quantum gravitational effects, of the kind considered in quantum gravity phenomenology. These too will, no doubt, provide additional much-needed empirical constraints that will complement those given by 'principles' and, indeed, the suggested phenomenological implications are often based on the violation or extension of previously known general principles (such as the Lorentz invariance and the equivalence principle). We take it as obvious that a combination of various kinds of constraint will ultimately be required to restrict the space of possible quantum gravity theories down to one or perhaps two possibilities. The main rationale behind this special issue was to highlight principles as a particularly important subset of such constraints.

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The contributions to this special issue seek to make some headway on the problem of finding such constraining principles, in some cases providing what their authors deem to be valid principles presently functioning, or capable of functioning in the role of assessment criteria and offering relatively direct constructive constraints. The good news is, then, that some principles have indeed emerged. The bad news is, they are certainly not yet free from controversy.[3] However, even mired in controversy, potentially they have the power to transform the field of quantum gravity (and have in some cases already done so, to a fairly large extent). We hope that the papers in this issue will stimulate the further examination of the nature and role of principles of quantum gravity research. Before we get to these, let us first quickly describe what we have in mind when we speak of 'principles'.

2. What are principles?

Principles of physical theory are supposed to be claims about the world that are somehow *more robust* than most other such claims about the natural world. They say things about the world that are very hard to imagine not being true. In other words, they are as close to universal (empirical) truths as one can get in physical theories. These principles would, quite naturally, constrain any new theories, serving as essential facts to satisfy or recover in appropriate domains. Polkinghorne expresses the idea as follows:

> Scientific theory is … constrained by two sets of criteria: One set refers to rational evaluation based on such general qualities as simplicity and fruitfulness. The other set refers to general physical principles (currently those provided by relativity and quantum theory) which are not treated as being absolute and incorrigible but which, on the other hand, have played so significant a part in scientific understanding over so long a period that they are by no means lightly to be abandoned. (Polkinghorne, 1989, p. 169).

This notion, of course, harks back to Einstein's well-known distinction between 'principle theories' and 'constructive theories,' where the former employs the 'analytic, not the synthetic method' (Einstein, 1919, p. 228). In the case of constructive theories one must start out with some given (simple) elements which will be utilised *constructively* to build up some (complex) phenomenon to which the theory is intended to be applicable. Principle theories, on the other hand, involve high-level generalisations, derived from experiments and observations, serving as very severe constraints on theory-building. Einstein's own examples involve the thermodynamical laws, especially the first and the second, which are seemingly impossible to reject—the non-existence of *perpetuum mobile* machines (a principle in Einstein's sense), for example, strikes us as utterly inviolable. By contrast, the kinetic theory of gases is constructive, reducing complex thermodynamics properties to the simple behaviours of molecules.

There is here a kind of inversion of the usual relationship between simplicity and complexity. Principle theories are simple phenomenological postulates that constrain a potentially very wide class of (apparently diverse) physical systems; while constructive theories reduce a potentially very wide class of physical systems to some specific simple kind of system. There is, in this sense, something inherently *structural* about principle theories: floating free of specific physical realisations, they will hold good despite revisions at the level of the simple elements of constructive theories. In fact, they can be understood in a sense as imposing constraints on systems *and* laws, functioning as 'meta-laws' (Liu, 1996, S71).

While constructive theories are usually understood to be the ultimate goal of physical theorising (leading to an *understanding* of phenomena, by revealing the underlying mechanisms responsible for bringing them about), sometimes the ontic foundations are simply in a too fragile state to employ in a constructive manner. Such was the case for Einstein with respect to both classical electrodynamics and quantum mechanics: neither could (according to him) provide trustworthy building blocks for construction. Hence, in order to make any progress at all, one searches for higher-level features that might serve to constrain any future constructive approaches and guide physicists towards a more acceptable theory (and, ultimately, a deeper understanding of the world).

This suggests an algorithm: if physical foundations are in any doubt, then seek general principles that will apply universally. These provide not so much physical explanations, but the contours of possible explanations. They can also lead to firm (qualitative) physical predictions independent of any precise constructive specification. Of course, both the special and general theories of relativity were examples of principle theories,[4] isolating certain postulates that were taken to characterise the physics regardless of whether the underlying ontology was one of waves, or particles, or something completely different. In the case of quantum gravity, we are faced with such a foundational dilemma. It is clear that there is a structural clash of certain elements of quantum theory and general relativity. Some important piece of either or both of these frameworks will have to be rejected or modified, or else some framework shift is required to allow their union.

One also has more specific invariance principles that themselves generalise certain empirical regularities concerning the undetectability of certain motions (*cf.* Houtappel, Van Dam, & Wigner, 1965, p. 597). The idea is that the principles will enforce certain necessary constraints when deployed within some theoretical framework (which will, if successful, then lend credence to those principles). Common principles include:

- *Galilean relativity*: The covariance of the equations of motion under Galilean transformations.
- *Special relativity*: The covariance of the equations of motion under (homogeneous) Lorentz transformations.
- *General relativity*: The covariance of the equations of motion under diffeomorphisms (as suggested by the equivalence principle[5] relating gravitational and inertial mass).

[3] For example, James Mattingly (this issue) argues for an 'unprincipled' approach to the problem of quantum gravity, according to which we should not try to second guess the micro-structure of gravity.

[4] Quantum mechanics, formulated along Heisenberg's lines, too can be presented as a principle theory, in which the correspondence principle plays a founding role—of course, Schrödinger's wave mechanical approach falls on the constructive side of the distinction. Bub (2000) argues that considered as a principle theory quantum mechanics involves revisions of logical structure (the possibility structure of events and combinations of properties: ultimately, giving constraints on information transmission and manipulation).

[5] The equivalence is in many ways a perfect example of the way in which principles transcend specific constructive frameworks. Though originally conceived from the standpoint of classical physics, it is found to be satisfied by quantum mechanical particles (as indicated in experiments on neutrons falling in a gravitational field, displaying universal behaviour indistinct from classical objects). As Bradonjić and Stachel point out, the equivalence principle is behind the fact that an inertial mass must not be too large lest it be (gravitationally) swallowed up by its own Schwarzschild radius (and so, according to their measurability analysis, such large bodies cannot possibly function as genuine test bodies). Note, however, that some approaches to quantum gravity predict a violation of the principle, ditto for Lorentz invariance.