Why spin-foam models violate Lorentz Invariance

Much recent interest in Lorentz violation in quantum gravity.

Phenomenology progresses… theory attempts to catch up and offer predictions. Could local Lorentz invariance (LLI) be compatible with spin-foam discreteness?

One argument: In standard QM, not all components of angular momentum can be measured simultaneously, and they take discrete values. Nevertheless, the theory is rotationally invariant (RI).

Rovelli & Speziale: Analogy between RI and LI. Why then shouldn't spin foams models have LLI?

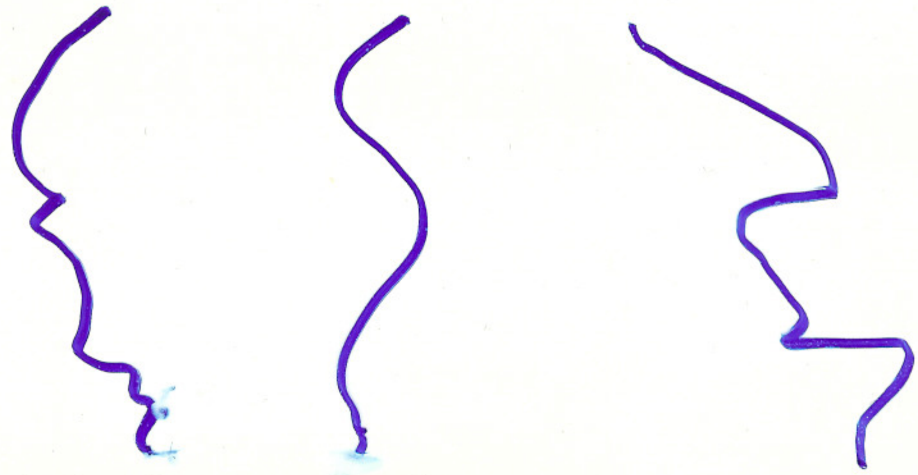
BUT: this analogy is flawed.

In a lattice-like structure like spin foams, *macroscopic* quantities can fail to be measurable in some frames.

To see why, a brief review of some features of standard quantum mechanics…

The following is a sum-over-histories (SOH) formalism for standard quantum mechanics.

The theory has a space of histories Ω, e.g. paths $x(t)$, $t_0<t<t_1$.



The histories have properties e.g.

"$a < t < b$ for some a ,b , and $t_0<t<t_1$," and
"The path passes through region R"

For each property X there is the set of histories which have that property, $\Gamma(X)$. Measurements find out if the universe has a property. Here, we are interested in measurements of *macroscopic* properties. All such measurements can be described in this formalism because

Macroscopic observables commute.

Because macroscopic observables, *e.g.* "pointer readings", approximations to angular momentum of a baseball *etc.*, commute, they can all be known at once. Thus, measurements in one basis are sufficient to reconstruct the macroscopic world.

Our theory provides us with probabilities for the measurements. When we measure for X and find this property, we condition on $\Gamma(X)$ (performing the appropriate renormalization). Then we might measure for some other property Y. If this property is found, we condition on $\Gamma(X) \cap \Gamma(Y)$, and so on. This special set of histories is called the "measured set" here.

Sometimes we make effective descriptions of the histories, e.g. a gas. Properties involving pressure, temperature, etc., are defined at this level.

But what if the effective property X is not defined for some histories? We will say that the property is "undecidable for this history". Treat as if property X is *false* for that history – that history is *not* in $\Gamma(X)$.

This is what is meant by "SOH formalism" here. This is a necessary feature of theories to which the Lorentz violation argument applies, so

Condition 1: The theory is compatible with SOH formalism.

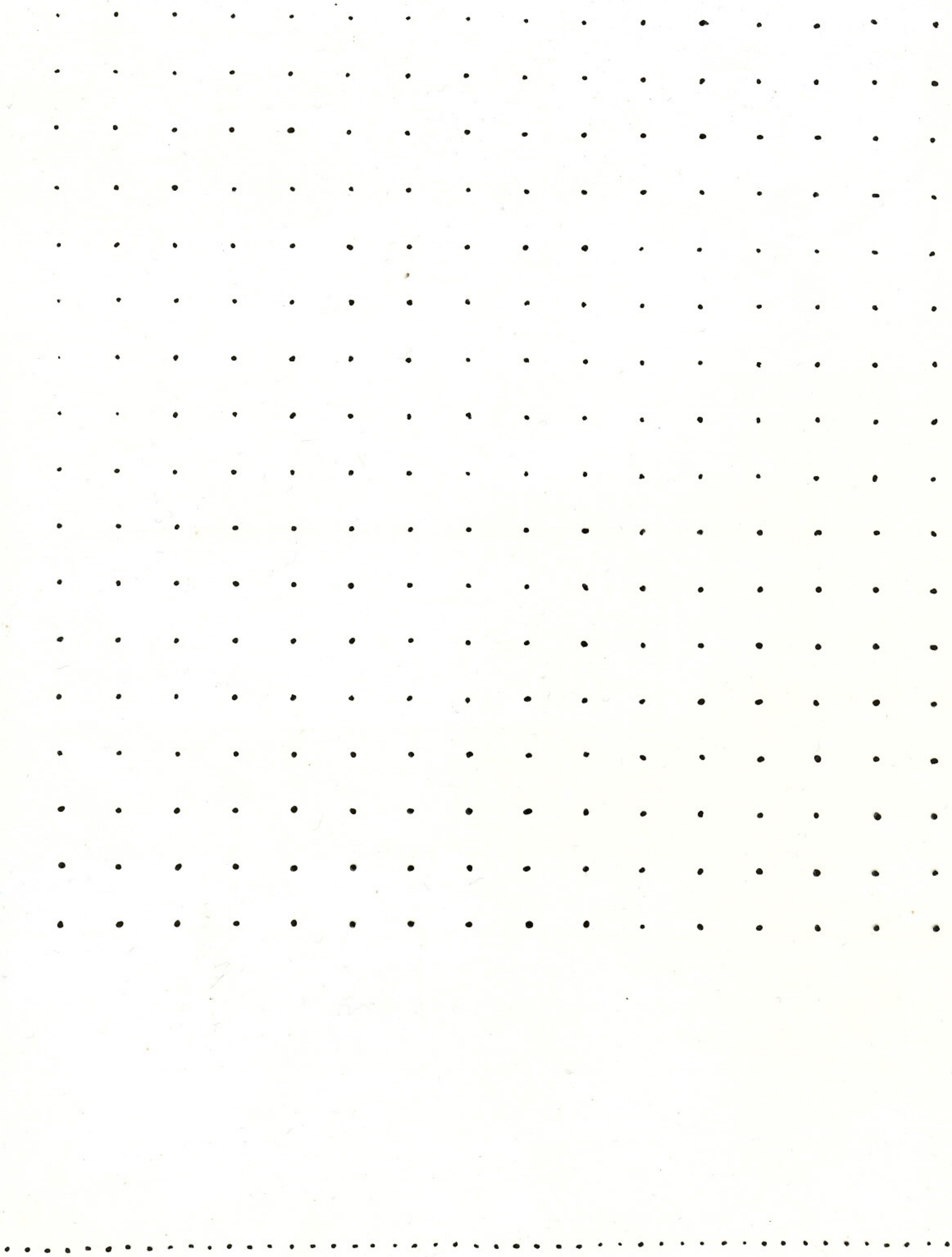
Quantum Gravity Theories in Particular

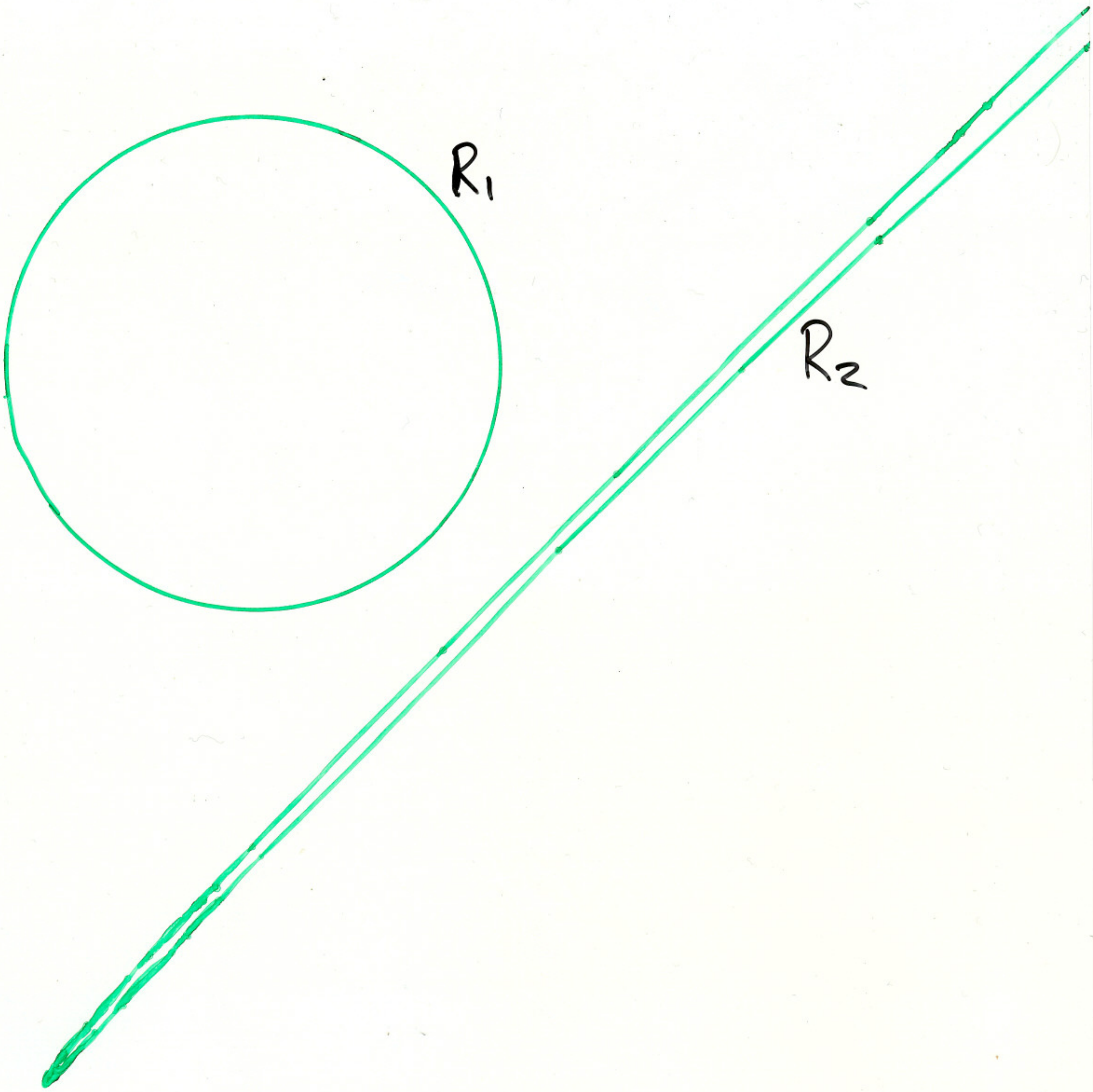
In a discrete QG theory, some of the histories will have effective descriptions in terms of Lorentzian manifolds (+ fields), and for some of them this Lorentzian manifold will be Minkowski space.

But this will only be an approximate description; the fundamental histories will be the discrete structures, e.g. causal sets, spin-foams…

The individual histories may or may not be Lorentz invariant.

In some cases, effective properties which are decidable in some frames (close to the "preferred frame" of the discrete structure) can be undecidable in other frames. This leads to Lorentz violation of the theory, so it is made the second condition.




R1
R2

Condition 2: The set of histories of the theory that have Minkowski space (plus matter) as an effective description is non-empty. Consider some region R_1 in Minkowski and let X_1 be a macroscopic effective property of that region, and also consider another region R_2 related by a boost transformation (with some sufficiently large boost factor) to R_1. Let X_2 be the property of R_2 related to property X_1 of R_1 by that boost. Then for some X_1, either X_1 or X_2 is undecidable, for all histories.

Claim: Any spin-foam theory will satisfy condition 2. It is not controversial that individual spin-foams have a preferred frame. For instance, it is well-known that fields on lattice-like structures cannot adequately represent waves in all frames.

Claim: A Causal set theory will not satisfy condition 2. An individual causal set *is* Lorentz invariant.

The argument

If the theory is to be Lorentz invariant, then any macroscopic property that is measurable in one frame should be measurable in any other. Say we measured X_1 and X_2 as they are defined in condition 2. But in no history are both properties decidable – that is condition 2.

Therefore the sets $\Gamma(X_1)$ and $\Gamma(X_2)$ are disjoint, and so $\Gamma(X_1) \cap \Gamma(X_2)=\emptyset$.

This means that there can be no measurement of both properties. Either the theory is absurdly lacking in macroscopic properties, or one of the two properties cannot be measured. The second option violates Lorentz invariance.

Conclusion: All models with spin-foams as the fundamental histories will violate local Lorentz invariance.

But at what scale? That is left to be determined. It is reasonable to guess that Planck scale discreteness gives "Planck scale Lorentz violation," but that can mean different things.

Discreteness + LLI = Causal sets!

Loop-holes?

1) "Perhaps the theory will not be compatible with SOH formalism."

- A radical break with standard quantum theory! Would standard measurement theory still work? Seems at odds with the "covariant QG" view of spin foams.

2) "Maybe individual spin foams can be made to be Lorentz invariant, in the same way as causal sets."

- Causal sets use "sprinklings" and associate the discrete structure to the sprinkled points. But a direction in Minkowski cannot be associated to a point in a sprinkling, consistently with LI (JH, R. Sorkin, L. Bombelli, to appear). How much less a finite number of graph edges!

3) "This 'effective descriptions' idea is too vague."

- Can we get a good effective description of waves in all frames from a lattice-like structure? If we agree "No" then this argument fails.

3) "Pairs like these X's could never be measured."

- The reason for the appearance of such pairs is very general. If we allow that the existence of EM waves in a large region can be used as X_1, then there is no question that it is measurable.