Ph.D. Dissertation:
Essays on the Metaphysics of Quantum Mechanics

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Written under the direction of Barry Loewer and David Albert
Dedication

To Linda
Dedication

To Linda and our cats
This dissertation began as I became interested in several ideas in philosophy:

1. Realism about metaphysical and scientific theories;
2. Nominalism about mathematical objects;
3. Intrinsicalism about fundamental physical theories;
4. Humeanism about laws and objective probabilities;
5. Fundamentalism vs. functionalism/emergentism about physical space(-time);
6. Imperialism about statistical mechanics;
7. Unificationism about explanations.

Methodology: pluralism about different projects and competing frameworks.
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Methodology: pluralism about different projects and competing frameworks.
The dissertation brings out some interesting connections among those ideas.
Two steps of metaphysical / scientific inquiries about quantum mechanics:
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2. How to interpret the universal quantum state (usually represented by a wave function).
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1. How to solve the measurement problem;
2. How to interpret the universal quantum state (usually represented by a wave function).

For concreteness, I focus on the case of non-relativistic quantum mechanics for $N$ particles.
Difficulties with interpreting the quantum state:

1. The universal wave function includes redundant degrees of freedom that do not seem to correspond to any physical structures (e.g., overall phase).

2. On a straightforward ontological interpretation, the universal wave function suggests the fundamentality of a high-dimensional space (the “configuration space”).

3. If we were to interpret the universal wave function as something on par with laws of nature, it may be too complicated to be nomological.

4. How to choose a simple quantum state?
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   - How to choose a simple quantum state?
Chapter 1: The Intrinsic Structure of Quantum Mechanics

- Intrinsicalism
- Nominalism
- Quantum Mechanics
- Fundamental Physical Space
I propose that the quantum state can be understood intrinsically as four relations on physical space-time:
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1. Amplitude-Sum ($S$),
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These are relations holding among space-time regions composed of $N$ points, where $N$ is the number of particles in the universe.
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These are relations holding among space-time regions composed of $N$ points, where $N$ is the number of particles in the universe.

From these relations, we can recover a wave function uniquely up to an amplitude normalization constant and an overall phase factor. This is achieved by two pairs of representation and uniqueness theorems, one of them is a new result.
Chapter 1: The Intrinsic Structure of Quantum Mechanics

Payoffs:

- Some steps towards a completely intrinsic fundamental theory.
- A significant step towards nominalistic metaphysics of science.
- A defense of “field” interpretations of the wave function against objections about redundant structures.
I suggest that our overall evidence favors the view that the fundamental physical space is low-dimensional rather than high-dimensional:
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- Evidence #1: dynamics and kinematics.
- Evidence #2: our ordinary experiences.
- Evidence #3: mathematical symmetries in the wave function.
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Chapter 3: Quantum Mechanics in a Time-Asymmetric Universe

- Realism
- Unificationism
- Quantum Mechanics
- Time’s Arrow
- Fundamental Physical Space
I propose a new hypothesis in a relatively unknown framework:
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- **Framework**: Density Matrix Realism
- **Hypothesis**: Initial Projection Hypothesis (IPH)
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The proposal brings together the foundations of quantum mechanics and the foundations of statistical mechanics in a new way.
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- Framework: Density Matrix Realism
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IPH pins down a simple and unique initial quantum state of the universe.

The proposal brings together the foundations of quantum mechanics and the foundations of statistical mechanics in a new way.

As it is formulated, IPH makes use of the Past Hypothesis (Albert 2000), but it may be a ladder we can eventually kick away (Chen 2019).
Chapter 3: Quantum Mechanics in a Time-Asymmetric Universe

Payoffs:

- time’s arrow;
- quantum ontology;
- fundamentality of space-time;
- Humean supervenience;
- narratability and Lorentz invariance;
- nomic vagueness;
- imprecise probabilities;
- strong determinism;
- unification of quantum mechanical and statistical mechanical probabilities;
- unification of universe-level and subsystem-level descriptions.
Chapter 3: Quantum Mechanics in a Time-Asymmetric Universe

Forthcoming in *The British Journal for the Philosophy of Science.*
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I am currently working on a series of papers to develop the ideas in that paper.
The dissertation brings out some interesting connections among those ideas.
Future Work

1. Nominalistic quantum mechanics: dynamics
2. Mental comparativism (graduate certificate thesis in CogSci)
3. Space-time emergence: a representational theory
4. On the Everettian problem of evil (with Daniel Rubio)
5. Time’s arrow and self-locating probabilities
6. Time’s arrow in a quantum universe [main project]
Future Work

- Time’s arrow in a quantum universe [main project]
  1. On the status of statistical mechanical probabilities (forthcoming in Valia Allori’s volume on statistical mechanics and scientific explanations, World Scientific)
  2. On empirical equivalence (MS thesis in mathematics defended in March 2019)
  3. On the PBR theorem and density matrix realism (with a reply to Gao)
  4. On nomic vagueness and imprecise probabilities (in preparation)
  5. On the Humean unification of time asymmetry and quantum entanglement (ms.)
  6. Material nihilism and many worlds (for Sara Bernstein and Tyron Goldschmidt’s volume on non-being, Oxford)
Thank you! The end.