QUANTUM COSMOLOGY

- If the universe is a quantum mechanical system.
- Then it has a quantum state.
- What is it?
- That is the central problem of quantum cosmology.
IGNORANCE IS NOT BLISS.

IGNORANCE OF THE INITIAL STATE

\[ \rho = \frac{I}{\text{Tr}(I)} \]

\[ \rho = \frac{e^{-\beta H}}{\text{Tr}(e^{-\beta H})} \bigg|_{\beta=0} \]

- \text{INFINITE TEMPERATURE}
- \text{EQUILIBRIUM} \quad [H, \rho] = 0
- \text{NO SECOND LAW}
- \text{NO QUASICLASSICAL REALM}

\[ \langle \phi(R) \rangle = 0, \quad \langle \phi^2(R) \rangle = \infty \]
<table>
<thead>
<tr>
<th>THEN</th>
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<tbody>
<tr>
<td>WHAT IS $\Psi$?</td>
<td>WHAT IS THE VACUUM?</td>
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<td>DOES $\Psi$ EXPLAIN CLASSICAL SPACETIME?</td>
<td>ASSUMED</td>
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<td>ALL PROBABILITIES FOR OBSERVATION</td>
<td>WHAT IS THE MEASURE DEFINING THE DISTRIBUTION OF OBSERVERS?</td>
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<td>DETERMINED BY $H$ &amp; $\Psi + \text{CONDITIONS}$</td>
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<td>WHAT IS THE ORIGIN OF THE ARROWS OF TIME (INCLUDING QM ONE)</td>
<td>ASSUMED</td>
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<td>FINAL THEORY $\Psi + I(\phi, g(x))$</td>
<td>STRING, $M$, .... $\hat{\phi}$</td>
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LOCALITY & QM

- QM allows non-locality to be transferred from dynamics to state (N.A.-H.)
  - EPR correlations
  - Aharonov-Bohm

- A unified theory of dynamics & state might be a natural way of incorporating necessary non-locality.
Is there a non-trivial final condition for the universe?
WHY QUANTUM MECHANICS?

HOW COME THE QUANTUM?

JOHN WHEELER

THE FOUNDERS OF QUANTUM THEORY THOUGHT THAT INDETERMINACY "REFLECTED THE UNAVOIDABLE INTERFERENCE IN MEASUREMENT DICTATED BY THE MAGNITUDE OF THE QUANTUM OF ACTION." (BOHR)

WHY A QUANTUM UNIVERSE THAT IS NEVER MEASURED?

WHY A SUPERPOSITION PRINCIPLE WHEN THERE IS NOTHING TO SUPERPOSE?
WHY IS THERE A DIVISION INTO
REGULARITIES OF DYNAMICS
AND REGULARITIES
OF THE INITIAL CONDITION?

THEY ARE CONNECTED IN
HAWKING'S NO-BOUNDARY
WAVE FUNCTION

$$\Psi = \int g g \phi e^{-I[g, \phi]}$$

COULD THERE BE
ONE PRINCIPLE
THAT DETERMINES BOTH?
What is the structure of the final theory?

- Will there be a clean separation into dynamics and state?

- What regularities will be predicted from the theory alone and what will require conditions?

- Will a separate measure be needed?
WILL THERE BE A FINAL THEORY OR WILL PARTICLE PHYSICS BECOME AN ENVIRONMENTAL SCIENCE?