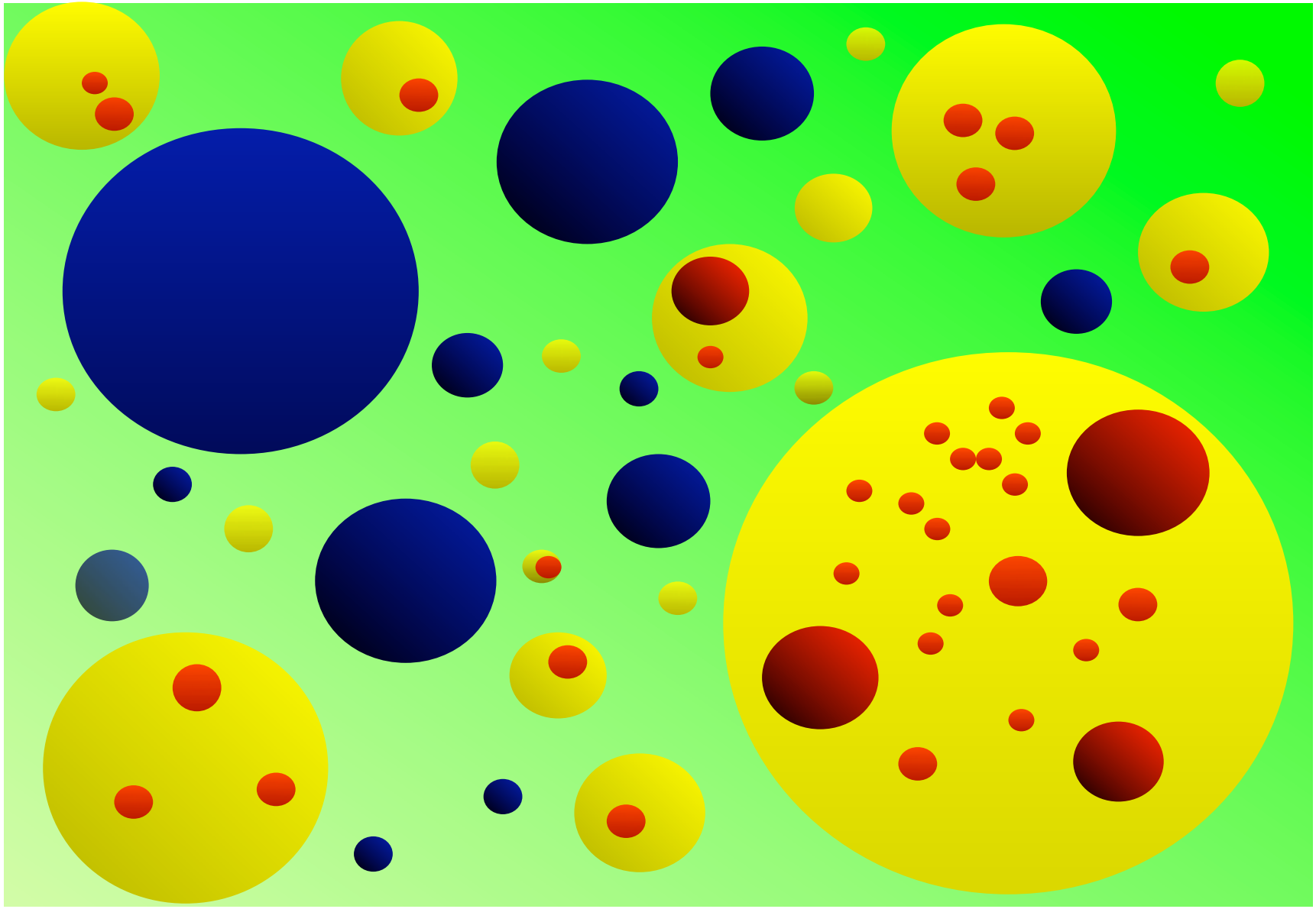
THE MEASURE PROBLEM

Alex Vilenkin

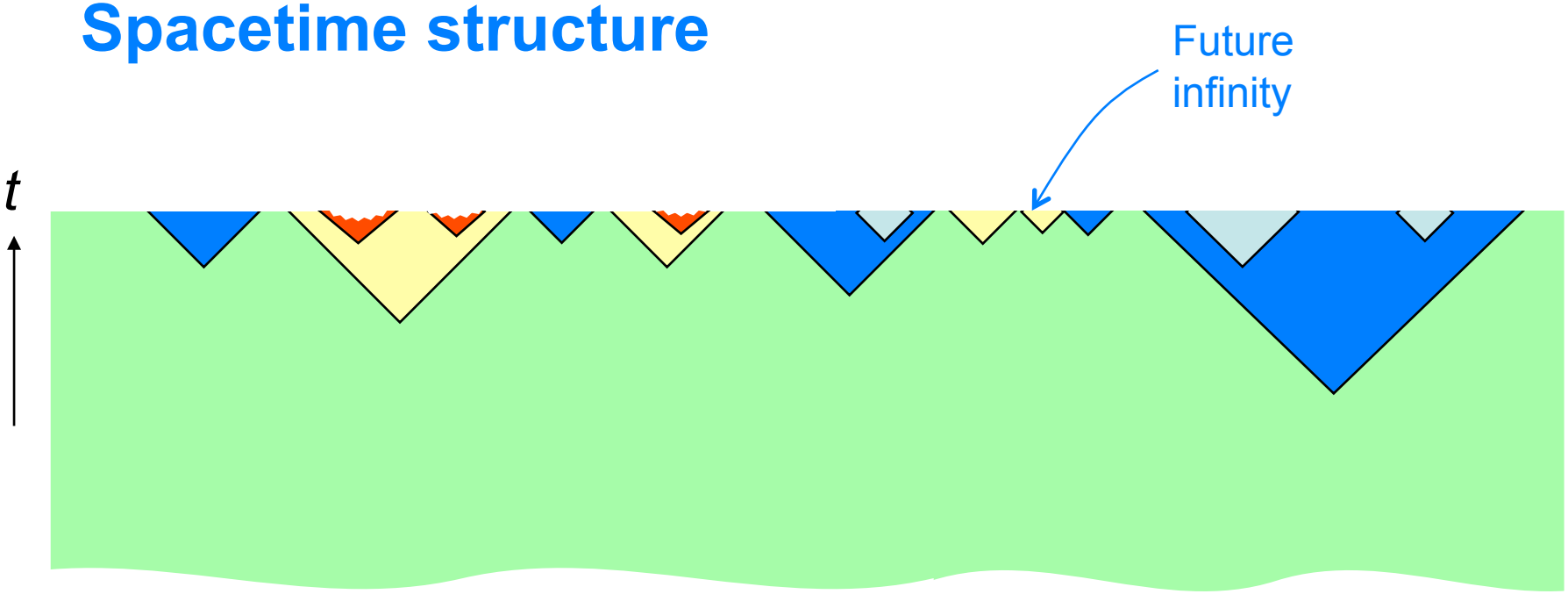
Tufts Institute of Cosmology

Oxford, September 2009

Eternally inflating multiverse



Spacetime structure



$$P_j = \frac{N_j}{N}$$

Everything that can happen will happen an infinite number of times. We have to learn how to compare these infinities. Otherwise we cannot make any predictions at all.

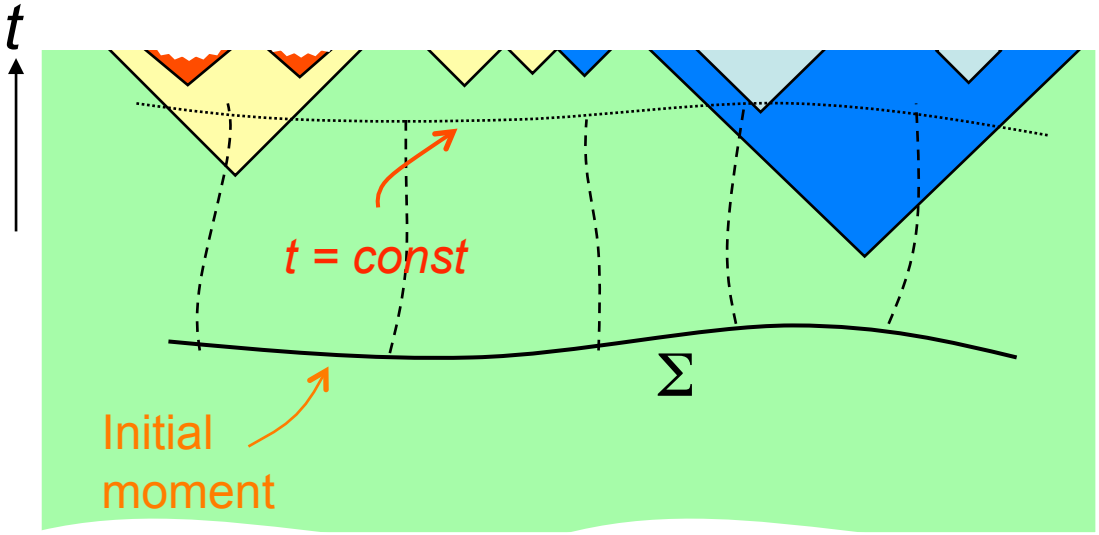
Need a cutoff.

Time cutoff:

Count only observations that were made before some time t.

Then take the limit $t \to \infty$.

Garcia-Bellido, Linde & Linde (1994)



Possible choices of t :

(i) proper time,

(ii) scale-factor time, … .

Probabilities P_j depend on the cutoff method – in particular on what we use as t.

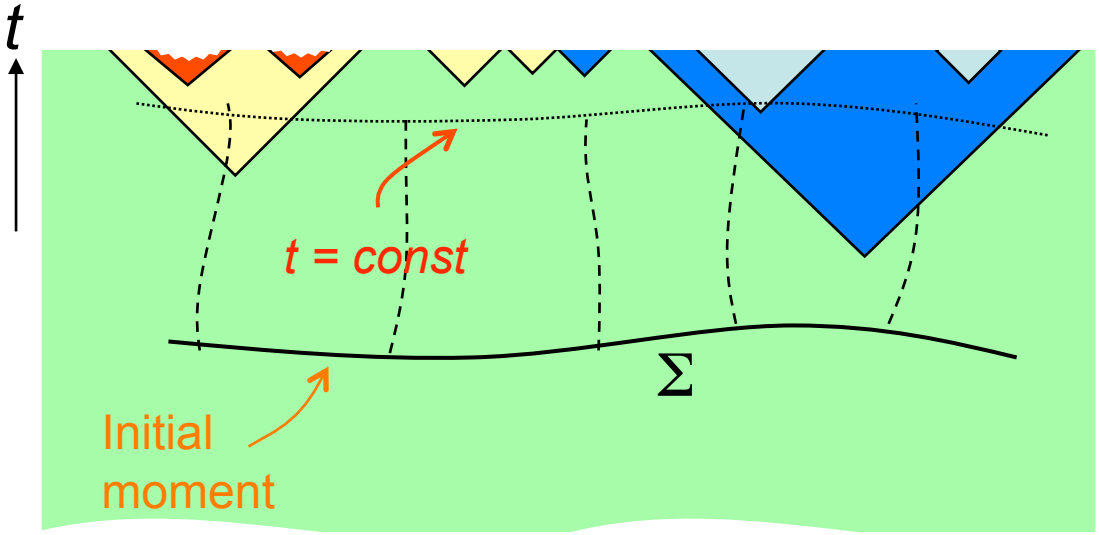
The measure problem

Time cutoff:

Count only observations that were made before some time t.

Then take the limit $t \to \infty$.

Garcia-Bellido, Linde & Linde (1994)



Possible choices of t :

(i) proper time,

(ii) scale-factor time, … .

Probabilities P_j depend on the cutoff method – in particular on what we use as t.

The measure problem

Empirical approach:

Investigate different measure proposals and discard those which strongly disagree with observations.

	Youngness paradox	Q catastrophe	Dependence on initial state	Boltzmann brains
Proper time cutoff				
★ **Scale factor cutoff**				
Pocket-based measure				
Stationary measure				
Causal patch measure				

A measure from fundamental theory?

The holographic measure

Garriga & A.V. (2008)

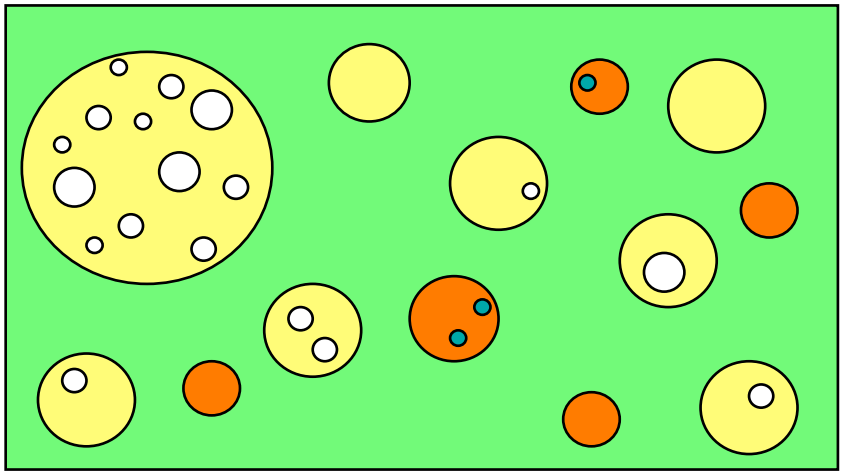
Inspired by holographic ideas: Quantum dynamics of a spacetime region can be described by a boundary theory.

't Hooft, Susskind, Maldacena, Witten, Strominger…

The proposal

- The boundary of the multiverse is the future infinity.
- The measure is obtained by imposing a short-distance cutoff in the boundary theory.

Closely related (but not identical) to scale-factor cutoff.



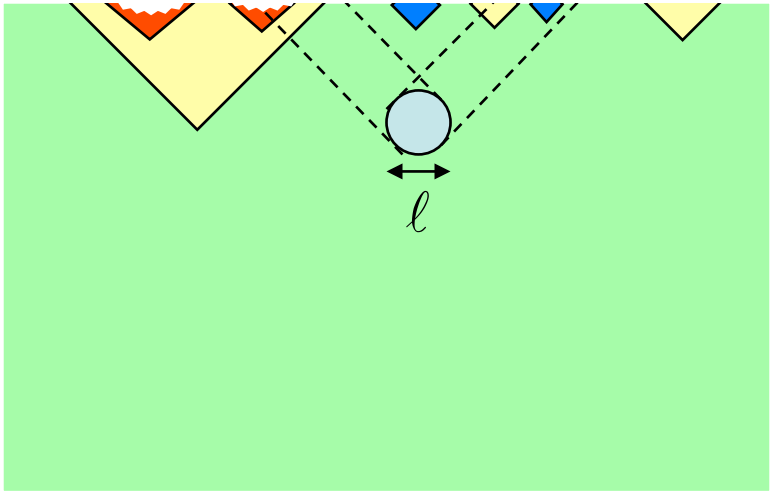
$$\Psi[\overline{\varphi}] = e^{iW[\overline{\varphi}]}$$

The boundary theory should be conformally invariant at short distances.

Conclusion:

- The holographic measure may or may not be on the right track …
- … but in the end the measure will be determined from the fundamental theory, as in QM.

Information travels to $\mathcal{E}$ in the form of long-wavelength $(\lambda >> H^{-1})$ *massless and very light fields (e.g., gravit. waves).*



$$\lambda(\vec{x},t) \sim \ell \; a(\vec{x},t)/a_0 \; .$$

scale factor

Modes with $\lambda >> H^{-1}$ are frozen

⟹ the information is indestructible.