Objective Collapse Theories

PHYS41702 Physics and Reality

AMANDA MATTHES

UNIVERSITY OF MANCHESTER

SCHOOL OF PHYSICS AND ASTRONOMY

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Central idea

◊ (Classical) Quantum Mechanics is incomplete

◊ The wave function does collapse (objectively)

◊ It does so according to rules of nature

◊ Observers play no special role

Ghirardi-Rimini-Weber theory (GRW)

◊ Systems evolve according to the Schrödinger equation except when a state reduction (a hit) occurs

◊ Hits occur at the level of the elemental constituents of a system

◊ The occurrence of hits is described by a Poisson distribution. The probability that the number of hits (per unit time) is m is

$$p(m) = e^{-\lambda} \frac{\lambda^m}{m!}$$

◊ $\lambda \approx 10^{-16} \frac{1}{s}$ is the average number of events (per unit time)

Credit: Ghirardi

Ghirardi-Rimini-Weber theory (GRW) continued

◊ A hit is described by a localisation operator
$$|\Psi\rangle_i \to |\Psi\rangle_f \propto L_\sigma |\Psi\rangle_i$$

◊ $L_{c,\sigma}$ has the shape of a Gaussian around a randomly selected point with width $\sigma = \frac{1}{\sqrt{\alpha}} \approx 10^{-7} m$

◊ → Two new constants of nature λ and σ

Credit: Ghirardi

Problems with the original GRW

◊ Antisymmetric/symmetric wave functions (corresponding to fermions/bosons) do not keep their symmetry

→ Pearle and Ghiradi replace the discontinuous hits by continuous spontaneous localisation (CSL)

◊ Violation of energy conservation

→ Pearle and Squires

◊ The theory is not relativistic

→ Tumulka

◊ Interpretation of the hit probabilities?

Important papers

Ghirardi, G.C., Rimini, A. and Weber, T., 1986. Unified dynamics for microscopic and macroscopic systems. *Physical Review D*, *34*(2), p.470.

Ghirardi, G., Grassi, R. and Rimini, A., 1990. Continuous-spontaneous-reduction model involving gravity. *Physical Review A*, *42*(3), p.1057.

Ballentine, L.E., 1991. Failure of some theories of state reduction. *Physical Review A*, *43*(1), p.9.

Pearle, P. and Squires, E., 1996. Gravity, energy conservation, and parameter values in collapse models. *Foundations of Physics*, *26*(3), pp.291-305.

Tumulka, R., 2006. A relativistic version of the Ghirardi–Rimini–Weber model. *Journal of Statistical Physics*, *125*(4), pp.821-840.

Penrose theory

◊ A quantum superposition of two (stationary) mass distributions comes with an uncertainty in energy

$$\Delta E = \quad \text{gravitational self energy of the difference}$$
$$\text{between the two mass distributions}$$

◊ We can therefore suggest a finite lifetime for the superposition

$$\tau \approx \frac{\hbar}{\Delta E}$$

◊ → Superpositions that involve sufficiently big masses are not stable enough to be observed

Credit: Cirone-Musi

Advantages

◊ Describe the wave function collapse

◊ Explain why we do not see superposition on a macroscopic scale

◊ Observers or Consciousness play no special role

◊ Can be tested

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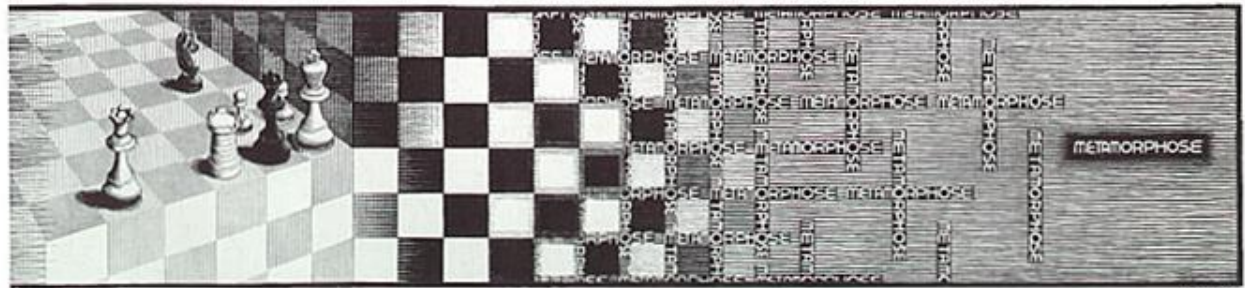UNIVERSITY OF MANCHESTER

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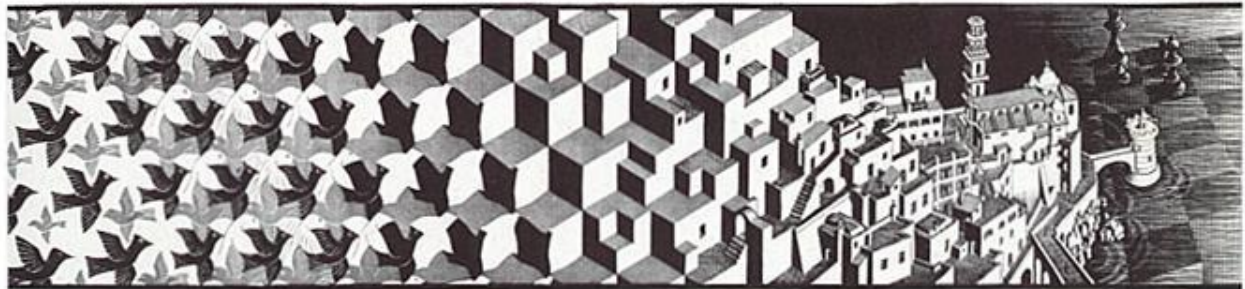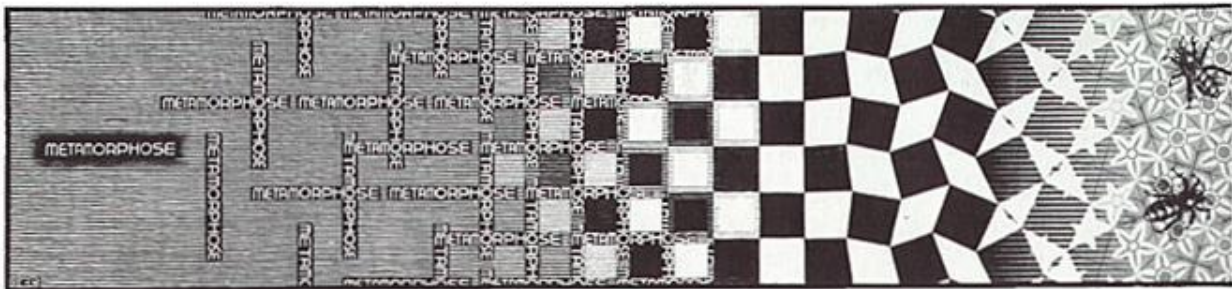The University of Manchester
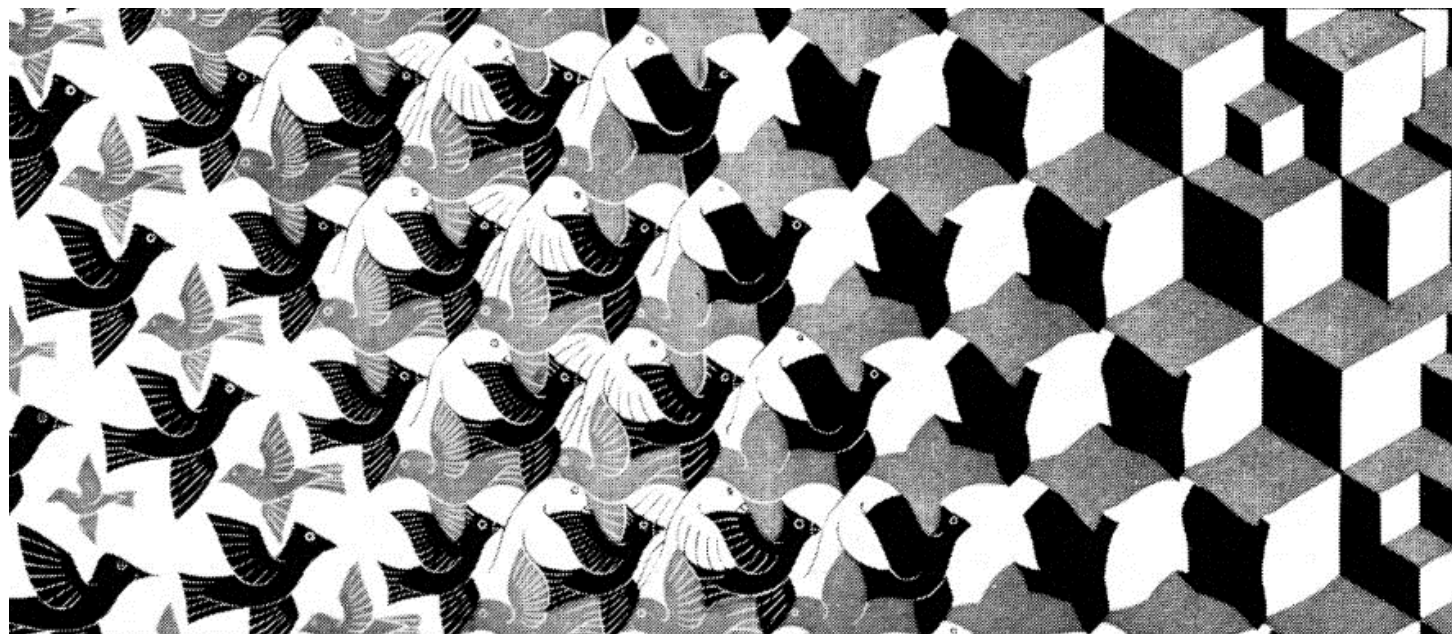
Quantum   Classical