Tumulka's choice: SR or QM?

The dilemma

Either:

- The conventional understanding of relativity is not *right*

OR

- QM is not *exact*

(or maybe both?)

His choice is for the latter. Modify QM to accommodate relativistic results:

- *no preferred foliation*
- *Lorentz invariance*

The ideal marriage

There are several primitive ontologies:

I. Only the wave function is the basis of the world's ontology
II. Continuous distribution of matter m(r,t) is the basis,aka GRW-m
III. Discrete flashes are the basis, aka GRW-f
IV. Particle world lines as in ordinary QM (mainly Bohmian QM, BQM)
V. Fields (scalar or vector) as in QFT

A. Which is Lorentz invariant? Manifestly III. and V.
B. Which one admits the collapse of the wave function? I, II and III
C. Which one can accommodate variable number of particles? Evidently V

Main question in Tumulka: can we marry III and V to have all A, B and C?

Bell’s proposal

- SR says that there are no preferred foliation.
- QM needs a preferred foliation. Hence a contradiction and an inconsistency.
- Bell hints toward GRW: look at simple systems far enough and notice that:
  - The joint distribution of the flashes in the 2 systems are covariant.

Why QFT

- Why QFT?
  - Because that’s how the world is: variable number of particles moving in a spacetime structure interacting by the means of fields that can appear and disappear (creation/annihilation)
  - QFT is relativistic invariant.
  - But it does not accept collapse

GRW at home

If between time t_0 and any time $t > t_0$, n collapses have occurred at the times $t_0 < T_1 < T_2 < . . . < T_n < t$, at locations $X_1, . . . ,X_n$ and labels $I_1, . . . , I_n$, the wave function at time t will be

$$\psi_t = \frac{L^{F_n}_{t,t_0}\psi_{t_0}}{\| L^{F_n}_{t,t_0}\psi_{t_0} \|}$$

where the collapse operator is:

$$L^{F_n}_{t,t_0} = U_{t-T_n}\Lambda_{I_n}(X_n)^{1/2}U_{T_n-T_{n-1}}\Lambda_{I_{n-1}}(X_{n-1})^{1/2}U_{T_{n-1}-T_{n-2}}\cdots\Lambda_{I_1}(X_1)^{1/2}U_{T_1-t_0}$$

$$\Lambda_i(r) = \frac{1}{\tau}\frac{1}{(2\pi\sigma^2)^{3/2}}e^{-\frac{(r_i-r)^2}{2\sigma^2}}$$

QFT and GRW

- For N particles we add “types” of flashes. Each particle is a type of flash i=1…N: Λ_i
- For N particles, there are N types of flashes. Hence the probability in 4-D is

$$\mathbb{P}\left(X_1 \in d^4x_1, \ldots, X_n \in d^4x_n\right) = \| \mathrm{K}_n \psi_{t_0} \|^2 \, d^4x_1 dt_1 \cdots d^4x_n \,,$$

- Where K_n has two parts:
  - The collapse part Λ_i
  - The unitary part W_t

Advantages of GRW+QFT

- Hamiltonian is ok for no collapses.
- Λ_i represents collapses
- The probability density P (eq. 4) is a function of Kn, which is the product of Λ_i and the W(H), i.e a product of the collapse and the evolution acc. To the Hamiltonian

N-particle GRW

- Sum up all the flash rate operators: $\Lambda^{(N)}(r)=\sum_{i=1}^{N}\Lambda_i(r)$
- If there is a variable number of operators, sum on the Fock spaces: $\Lambda(r)=\bigoplus_{N}\Lambda^{(N)}(r)$
- This model has collapse, too (unlike QFT)
- Tumulka's claim: the generalization of QFT to GRW + flashes is natural
- There is here a "conditional wave function"

Conditional wave function

- The wave function at t depends on the realization of flashes before t and after t_0:

$$\psi_t = \frac{W_{t-t_n} K_n}{\left\| W_{t-t_n} K_n \psi \right\|} \psi$$

- We got the collapse due to flashes (K_n)
- The wave collapse wherever a flash occurs

Bell’s GRW

- Approximation: Small Lorentz boost for a pair of distant systems is almost like a “time translation”
- Some flashes (n´) are moved in the past of the t_0:

$$\psi_\Delta = \frac{W_{\Delta+t_0-t_{n'}} K_{1,n'}}{\left\| W_{\Delta+t_0-t_{n'}} K_{1,n'} \right\|} \psi$$

Join distribution of flashes with a variable number of particles i<N; k<N$_i$

$$\mathbb{P}\left(X_{i,k} \in d^4 x_{i,k}\right) = \left\| \bigotimes_i^N \mathrm{K}_{i,n_i} \psi \right\|^2 \prod_i^N \prod_k^{n_i} d^4 x_{i,k_1}$$

- There are two sources of flashes :
  - The boost itself
  - The variable number of particles

Lorentz invariant GRW on spacelike surfaces

Using Bell: the Lorentz invariant GRW

- Take a sequence of points f(x_1… x_n)
- Write the K (collapse) operator for f (eq. 17) at x given that the previous occurred at x’

Seed flashes

- We can place the seeds anywhere on a surface that is back in the past or forward in the future. The sequence f is not relative to the surface
- We take the surface Sigma and move it back in time anywhere such that the seeds are preserved

Two options

- A continuous collapse theory; CSL (Pearle and Rimini, 1990)
- Discrete time collapse (more about this)

Virtues of the Lorentz GRW:

- No preferred foliation. Cures us of all the problems with hyperplane dependency and/or Bohm’s (does it?)
- It has a collapse wave function (so it is better than QFT). (in fact has two: eqs. 25 and 28)
- The number of flashes depends on the system of reference (as expected) (unlike the M(r,t) model
- Non-locality is obtained (unlike CM), which is ok