Title: The cosmological constant and the emergence of the continuum

Date: Oct 22, 2012 12:00 PM

URL: http://pirsa.org/12100081

Abstract: Naturalness problems that could be signaling the necessity a completion of an effective field theory with the introduction of an otherwise overlooked ingredient. The cosmological constant problem can be seen as a signal that the EFT for gravity, general relativity, is not correctly including the gravitational properties of the vacuum. Starting from the discussion of the a possible solution to this naturalness problem for a cc-like term in a BEC analogue model, I will briefly discuss how this particular mechanism can be extended, albeit in a preliminary form, to more genuine quantum gravity models like GFT, connecting in particular the problem of the determination of the gravitational couplings (and hence the hierarchies involved) to the appearance of a semiclassical space-time

~~The cosmological constant and the emergence of the continuum~~

More on BECs, the cosmological constant and the emergence of the continuum

Lorenzo Sindoni
MPI für Gravitationsphysik
(Albert Einstein Institute)
Golm

Experimental search for Quantum Gravity,
Perimeter Institute, 22.10.2012

Plan

- Multi BEC as dynamical analogues for Newtonian gravity (gravity/metric described by the hydrodynamics of the condensate, phonons are analogue of matter fields)
- Equivalence principle, Lorentz invariance, CC
- Paradigm for emergent/quantum gravity?

- LS, Phys.Rev. D83 (2011) 024022, Finazzi, Liberati, LS 2012
- See also the talk of D. Oriti for extensive discussions on the QG side

Single BEC as dynamical analogue

- Insert a U(1) breaking term: phonons are gapped (Goldstone theorem)
- Limit of almost homogeneous condensate
- States containing few phonons

- The Bogoliubov-de Gennes equations can be turned into Poisson equation for Newtonian gravity, with mass density of phonons acting as source term, and a vacuum term (depletion factor) simulating a cosmological constant term (weak field, Newtonian limit of GR with cc).
- The CC term cannot be understood naively as a vacuum energy term
- Might give interesting insight for QG models (more later)

Limits

Even for a Newtonian analogue, the model is very poor

Potential turns out to be short range (nothing preventing that)

Only one kind of phonons, so nothing can be said about the equivalence principle

No real problem with Lorentz invariance at low energy (the dispersion relation has still a Bogoliubov-like form)

$$E(p) = \sqrt{\mathcal{M}^2 c_s^4 + p^2 c_s^2 + \frac{p^4}{4M^2}}$$

Limits

Even for a Newtonian analogue, the model is very poor

Potential turns out to be short range (nothing preventing that)

Only one kind of phonons, so nothing can be said about the equivalence principle

No real problem with Lorentz invariance at low energy (the dispersion relation has still a Bogoliubov-like form)

$$E(p) = \sqrt{\mathcal{M}^2 c_s^4 + p^2 c_s^2 + \frac{p^4}{4M^2}}$$

The multi BEC

It is interesting to consider the case in which the BEC is made up of several coexisting components.

Spinor BEC: bosons with higher spin (1,2,...)

2-component BECs as *kinematical* analogues and Lorentz invariance violation: low energy geometry is Finslerian, not Lorentzian, if no tuning of the microscopic parameters is done

Liberati, Visser & Weinfurtner (2006)

We will work with an abstract multi-component fluid, neglecting the physical origin. The objective is to get the idea (plus, the spinor BECs as such would not lead to Lorentz invariance at low energy)

Goal: explore the possibility of constructing a long range potential which has universal coupling with the emergent matter fields (phonons)

Results

- In absence of symmetries: nonsense! Ok, this was expected already from previous analysis. Big problem: nonlocality associated to the nature of the phonons as collective motions percolates everywhere, making the coupling to the would be Newtonian potential(s) highly nontrivial.
- When a global (discrete) symmetry is imposed, we get something

$$\hat{H} = \int d^3x \sum_{A=1}^{N_c} \hat{\Psi}_A^\dagger \left(-\frac{\hbar^2\nabla^2}{2m} - \mu + \frac{\kappa}{2}|\hat{\Psi}_A|^2 + \frac{\sigma}{2}\sum_{B\neq A}|\hat{\Psi}_B|^2 \right) \hat{\Psi}_A + \lambda \int d^3x \sum_{A=1}^{N_c} (\hat{\Psi}_A \hat{\Psi}_A + h.c.)$$

- Consequence of symmetry: there is one long range potential (all the others are short range). It is universally coupled to the phonons: equivalence principle.

$$\Phi_N(x) = \frac{1}{N_c}\sum_{A=1}^{N_c} v_A(x)$$

- Lorentz invariance (in multiplets)

Results

- In absence of symmetries: nonsense! Ok, this was expected already from previous analysis. Big problem: nonlocality associated to the nature of the phonons as collective motions percolates everywhere, making the coupling to the would be Newtonian potential(s) highly nontrivial.
- When a global (discrete) symmetry is imposed, we get something

$$\hat{H} = \int d^3x \sum_{A=1}^{N_c} \hat{\Psi}_A^\dagger \left(-\frac{\hbar^2\nabla^2}{2m} - \mu + \frac{\kappa}{2}|\hat{\Psi}_A|^2 + \frac{\sigma}{2}\sum_{B\neq A}|\hat{\Psi}_B|^2 \right) \hat{\Psi}_A + \lambda \int d^3x \sum_{A=1}^{N_c} (\hat{\Psi}_A \hat{\Psi}_A + h.c.)$$

- Consequence of symmetry: there is one long range potential (all the others are short range). It is universally coupled to the phonons: equivalence principle.

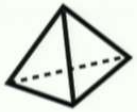
$$\Phi_N(x) = \frac{1}{N_c}\sum_{A=1}^{N_c} v_A(x)$$

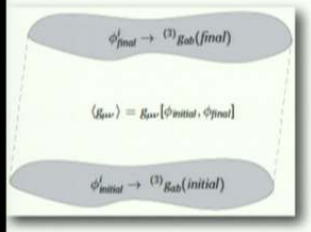
- Lorentz invariance (in multiplets)

Discussion

- Certainly these analogue models cannot say anything conclusive about QG. Analysis of quantum/emergent gravity models is unavoidable.
- However, they can work as a guide for these complicated models. In particular, they highlight the role of symmetries and constraints on model building.
- It turns out that BECs, and these results about CC, can be paradigmatic for cases in which gravity (GR) is viewed as the hydrodynamic/thermodynamic limit of a more "fundamental" theory.
- In particular, they show with an explicit calculation that certain terms in the effective action cannot be correctly grasped within an EFT point of view, since they are essentially determined by the underlying theory and by the properties of the transition from the microscopic layer to the macroscopic one.

Zoom out





- Suppose that you have a model, written in terms of what you could call "atoms of space", i.e. pregeometric entities.
- This model gives the dynamics with which you assemble them into larger structures, as well as the interpretation in terms of data of geometrical nature (e.g. parallel transports, areas...)
- Assume that with this model you can compute certain correlation functions, which can admit the interpretation of transition amplitudes/projectors between discrete geometries at the boundary, with all the possible discrete geometries in the bulk summed over
- Suppose that the physical regime that we call "continuum limit" is achieved through a phase transition (and gravity becomes a sort of hydrodynamics of these "atoms")
- Then, the coupling constants of the corresponding effective field theories are essentially determined by the critical behavior.

D. Oriti's talk

11

Conclusions

- BEC are certainly not models for QG, but they can be used to get different perspectives on old problems (e.g. cosmological constant) with concrete *calculations*
- Perhaps they can be used more directly in QG (GFT?)
- Emphasize the role of the transition to the hydrodynamic limit (in this case, a phase transition) in determining some coupling constants
- Question: if geometry emerges out of a similar phase transition, what can we detect? Role of critical exponents in determining the dynamics of the early universe & perturbations? CC constant and other naturalness problems? Nonlocality (due to "defects" in the "average" geometry)?

Magueijo, Smolin, Contaldi 2006