Summary of DIscussion Session (October 15, 2013)

"Vacuum Energy Trivia"

Question#1: Is the predicted vacuum energy larger than the observed value by 10^{122} or 10^{56}?

Answer: ***10^{56} for Standard Model; 10^{122} if new particles are present at the Planck scale. However:***

The usual calculation using [energy density] = Integrate[k^3, {k,0,Lambda}] ~ Lambda^4 is not mathematically correct and is only for pictorial purposes. Indeed, if one insists on using this expression, the pressure should be given by [pressure] = (1/3)Integrate[k^3, {k,0,Lambda}], which gives the equation of state parameter of w=1/3, rather than w=–1!!

The proper computation requires evaluation of the so-called "bubble diagrams" in the Feynman diagram, which is a diagram with no external lines. The consistent framework for computing such diagrams exists in flat space, and the results do give w=–1. In this case, the energy density is proportional to the mass to the fourth power:

[energy density] ~ $[\text{mass}]^4$

which does not depend on the cut-off Lambda. Then we can simply sum up the masses of particles in Standard Model with the appropriate weights depending on spin states. This computation gives the vacuum energy that is larger than the observed value by 10^{56}. On the other hand, if one postulates the existence of new particles whose mass is the Planck mass, then the discrepancy would be of order 10^{122}.

The easiest way to get the same results without computing the bubble diagram is to use the so-called "dimensional regularization." See Section IV of a nice review article by Jerome Martin, arXiv:1205.3365

Question#2: Does the vacuum energy gravitate?

Answer: Likely yes, because:

We know from Eötvös-type Equivalence Principle experiments that quantum fluctuations in an atom *do* gravitate. I.e., we need to include the contribution from quantum fluctuations in an atom to its gravitational mass in order to explain the experimental results that atoms with different atomic numbers fall at the same rate.

Of course, the "vacuum energy" we are talking about in cosmology refers to quantum fluctuations in vacuum, rather than quantum fluctuations in an atom. So, the correct statement is, "Quantum fluctuations in an atom gravitate. So, why shouldn't quantum fluctuations in vacuum gravitate?"

It seems that the vacuum energy gravitates as long as theory is generally covariant, and gravitons are massless (i.e., there is no continuum of massive states or resonances). Massive gravity models generically suffer from strong-coupling issues at the length scale of 1000 km.

Cautionary note on the Casimir effect: this is the ultra-violet effect at short distances. The vacuum energy problem in the context of a cosmological constant is the infrared problem at long distances. There may or may not be a connection between them.

Question#3: Does supersymmetry give vanishing vacuum energy?

Answer: Yes, unless gravity is included.

When gravity is included (i.e., supergravity), the potential becomes (with the planck mass equal to unity):

$$V=e^K[F^2-|W|^2]+D^2$$

where F and D vanish when supersymmetry is unbroken. (K is the so-called Kähler potential, which has to do with the kinetic term of fields.) Therefore, in supersymmetry, the vacuum energy is generically *negative*:

$$V_{SUSY}=-e^K|W|^2 < 0$$

Question#4: Can we measure vacuum energy in a lab?

Answer: Most likely no, because:

The other contributions such as thermal fluctuations and quantum fluctuations of binding energy would overwhelm the effect of quantum fluctuations in vacuum.