

MISC

1. Today we will talk about early stages in the evolution of the Universe (continuation from monday lecture).

Reading: S 27-2, 27-3, 27-4, 27-7.

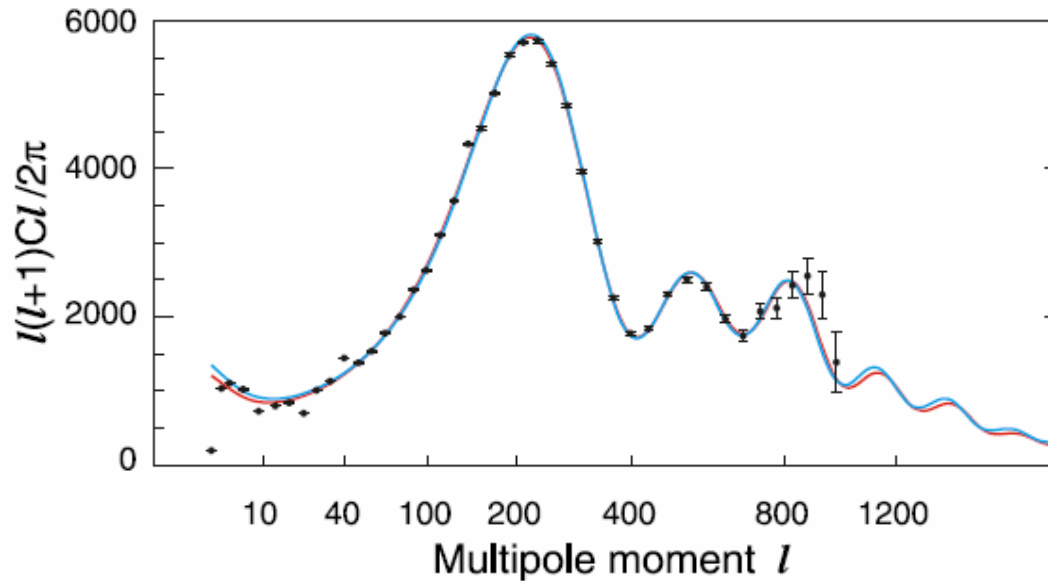
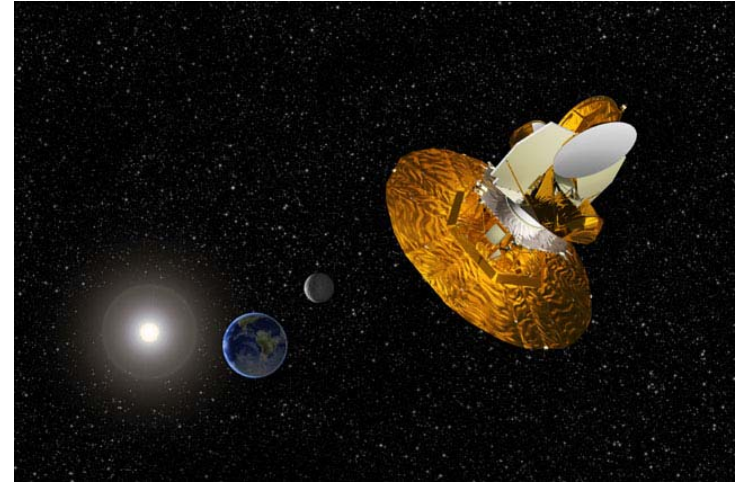
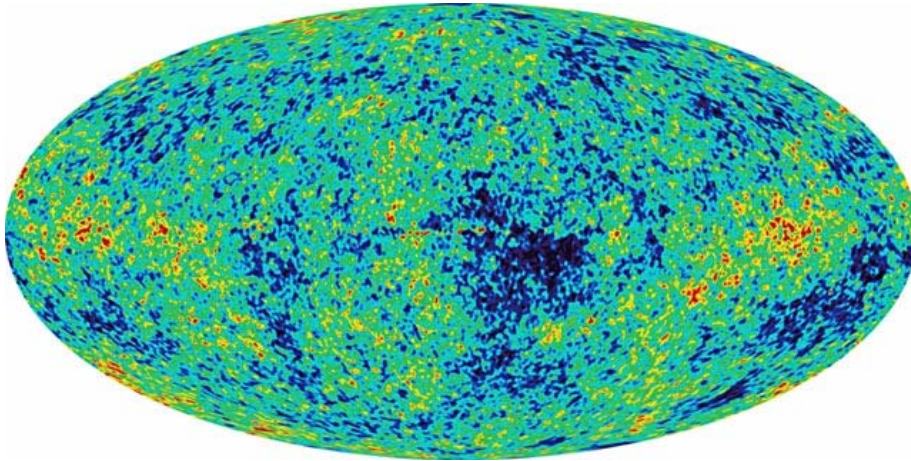
2. The last HW7 is distributed today. HW6 is due today after class.

4. Labs – next week make-up lab week

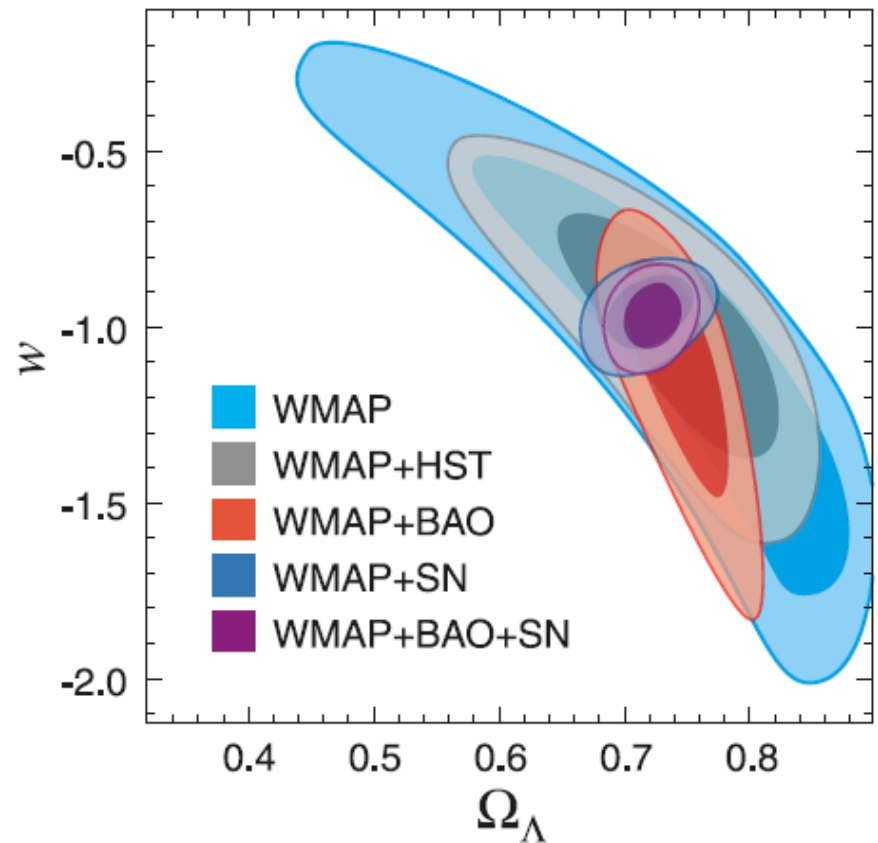
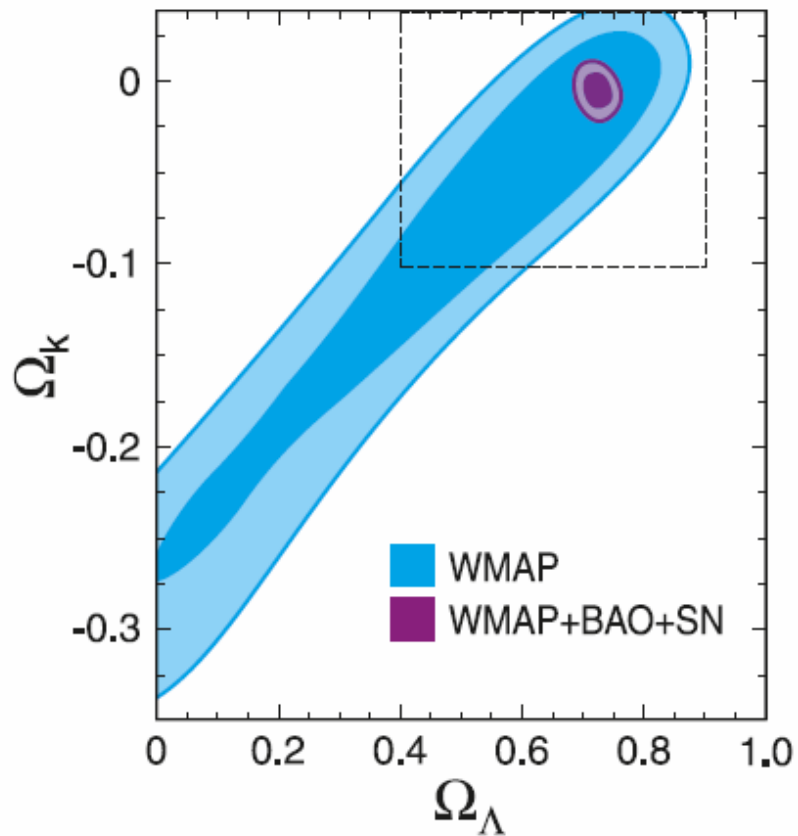
5. Final Exam – Monday, March 17 (here in KPTC 106) – 1:30-3:30PM.

New WMAP results

announced yesterday

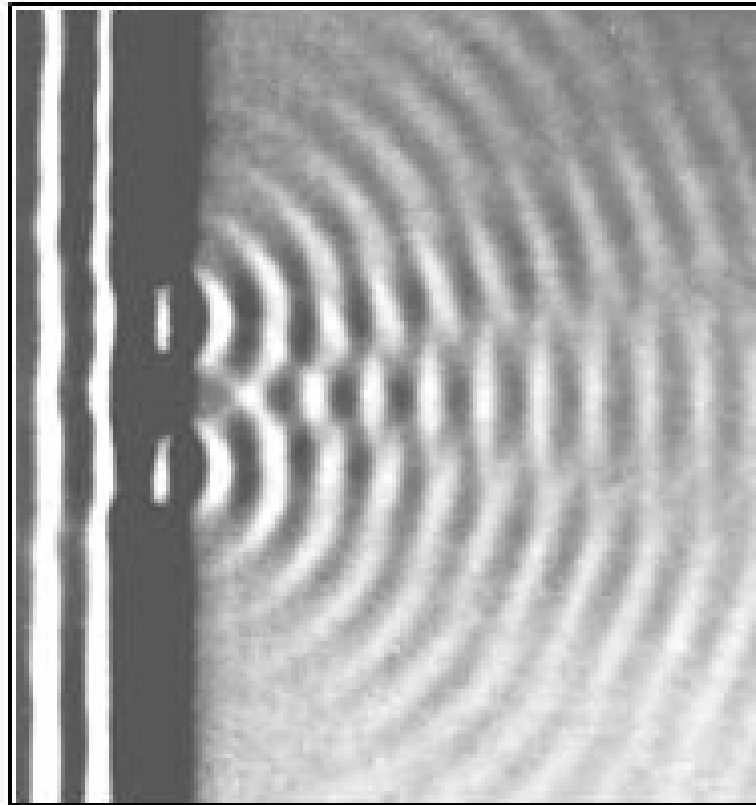


New WMAP constraints on geometry and dark energy



two slit diffraction of a wave

direction of movement of the waves



Waves add up in
some directions

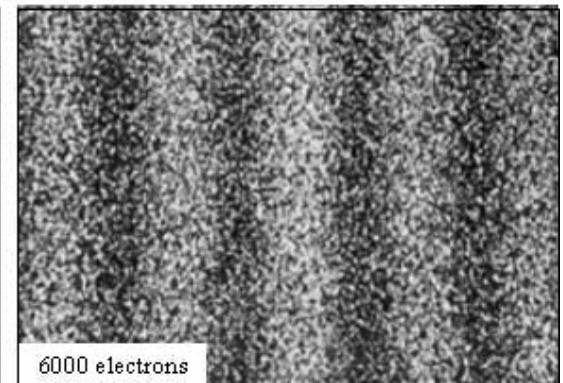
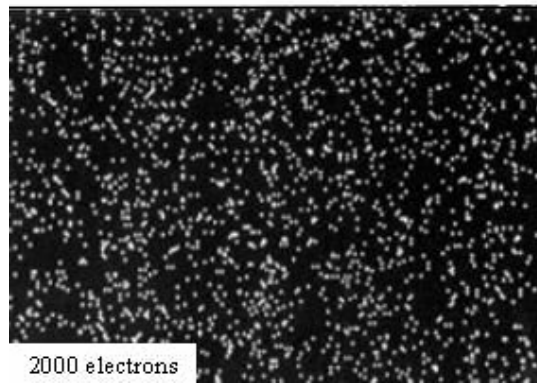
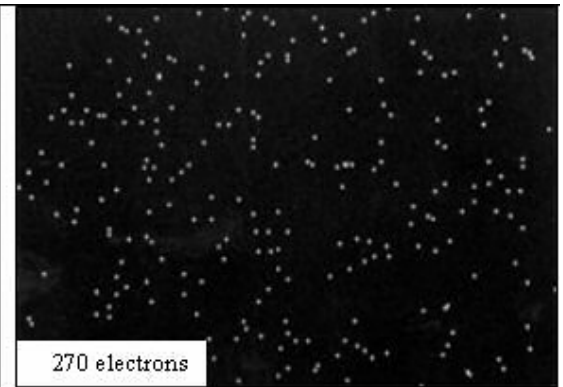
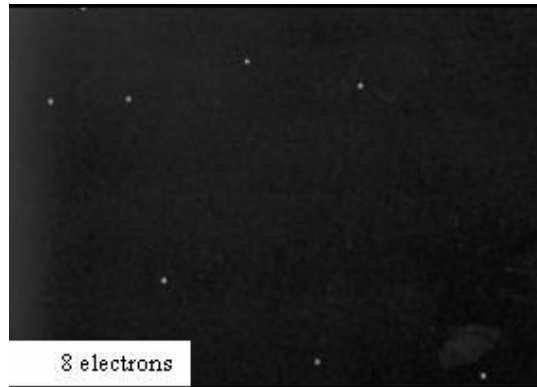
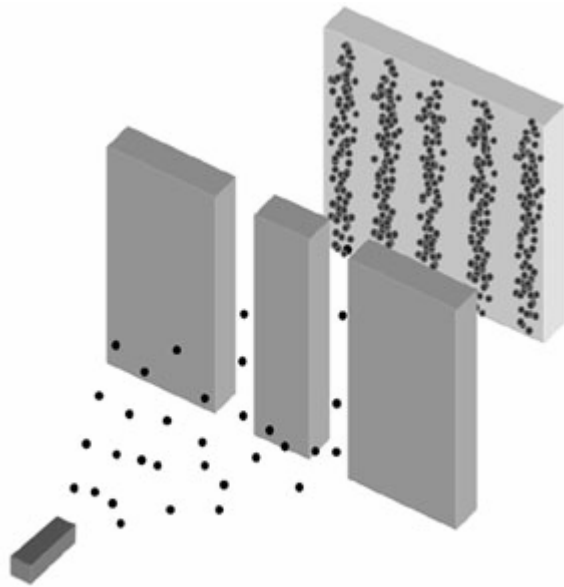


Waves cancel in
other directions



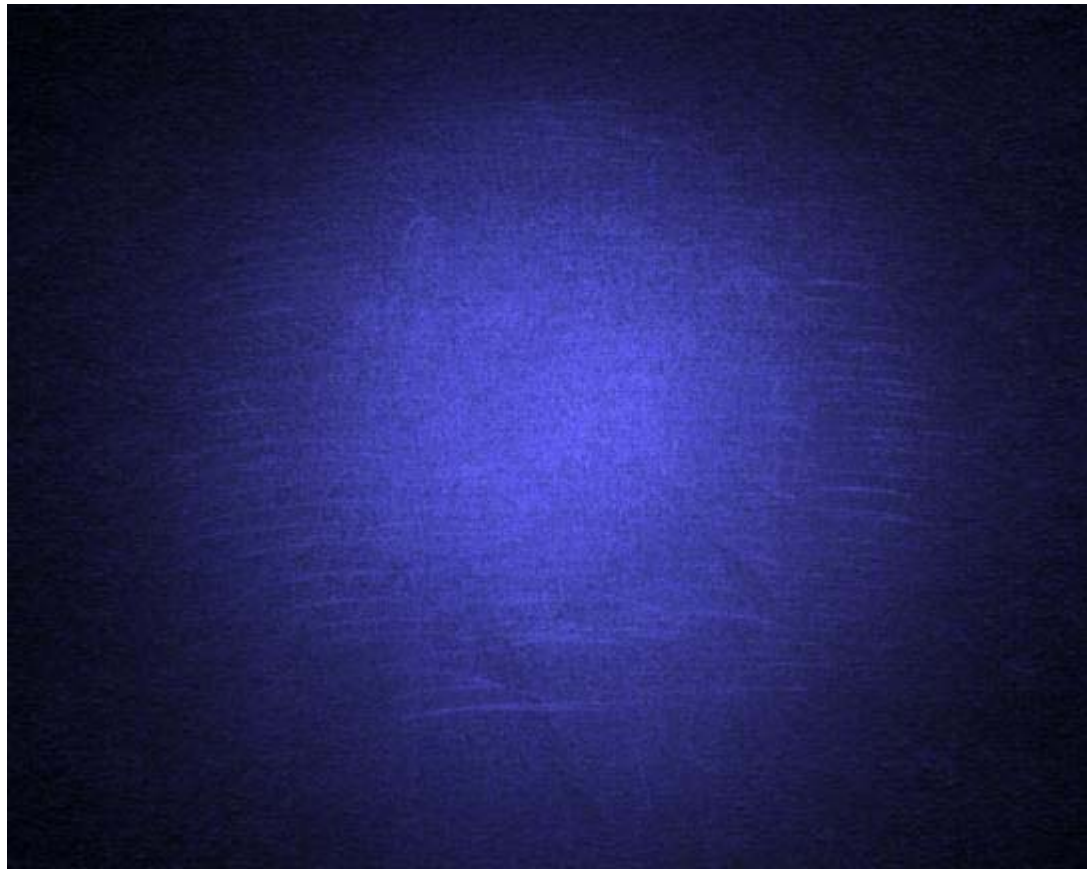
Quantum weirdness: two slit diffraction of particles

Particles (e.g., electron) are “fuzzy” and propagate through two slits at the same time



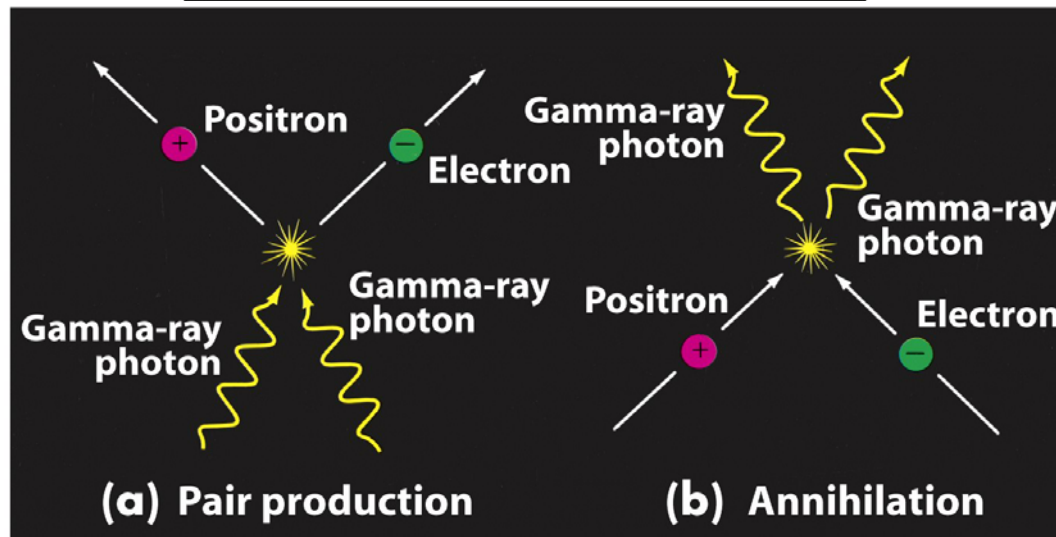
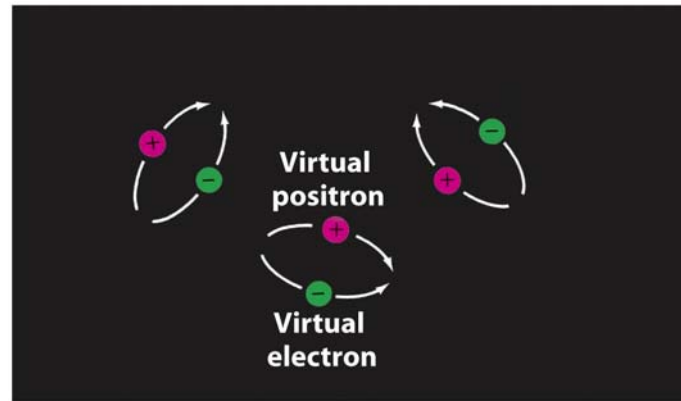
Particles in quantum mechanics are described by a wave function

- ***the probability distribution to find a particle at particular location at a particular time.***

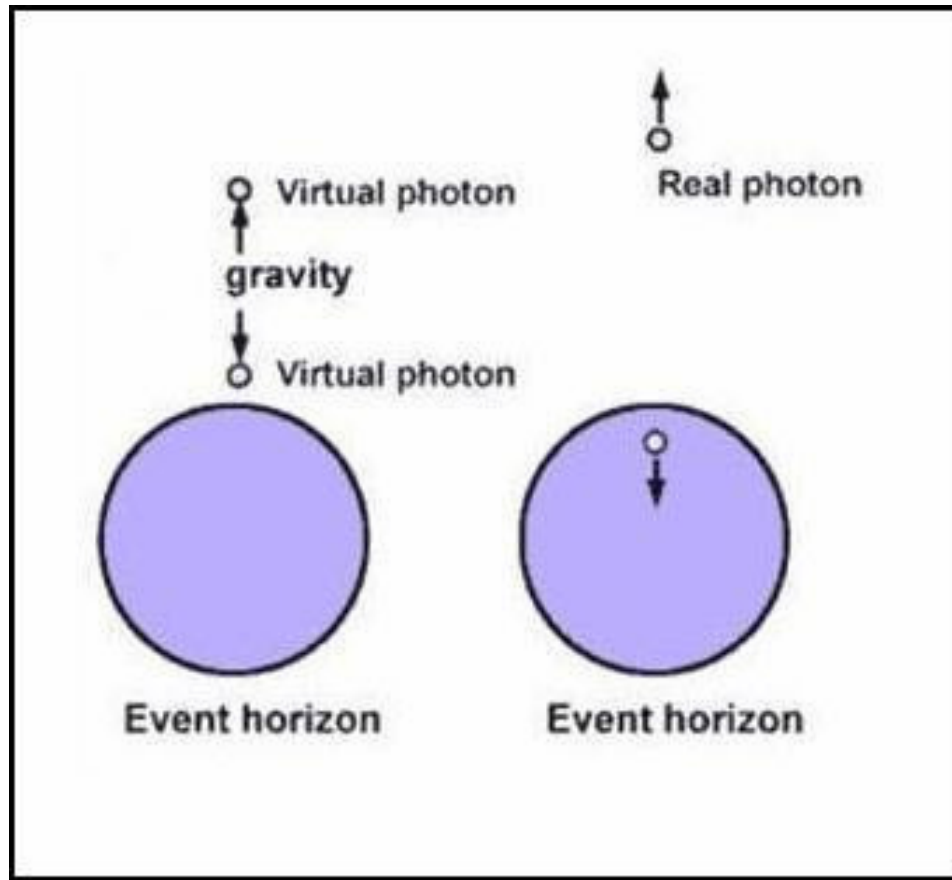


Heisenberg's uncertainty principle and virtual particle pairs

$$\Delta E \Delta t \gtrsim \hbar$$



Virtual particles allow Black Holes to be not completely black (i.e. radiate)



Quantum cosmology



- ❑ *In cosmology, the quantum effects should become important near the Planck time:*

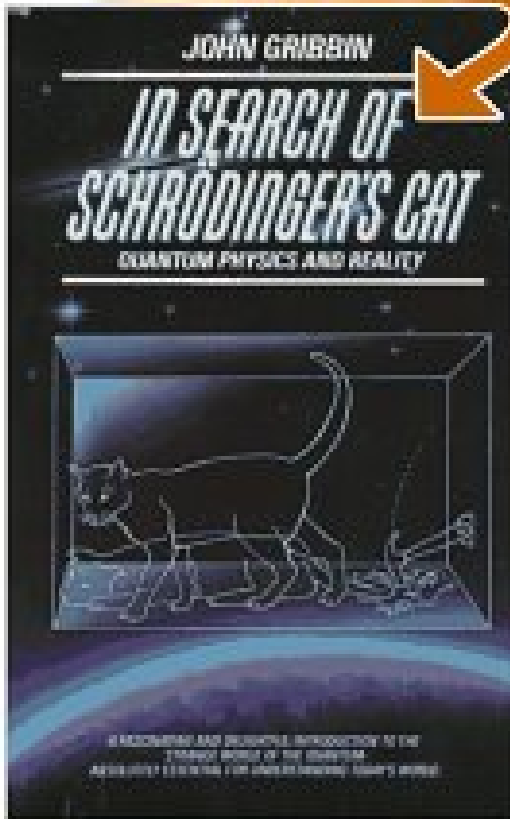
$$t_{\text{Planck}} = 10^{-43} \text{ sec,}$$

the time between $t=0$ and t_{Planck} is the realm of quantum gravity

- ❑ *In quantum gravity the space-time itself should be quantized (i.e. space is not continuous on small scales)*
- ❑ *No complete theory of quantum gravity exists yet, and this is not due to lack of trying... Some ideas are explored.*

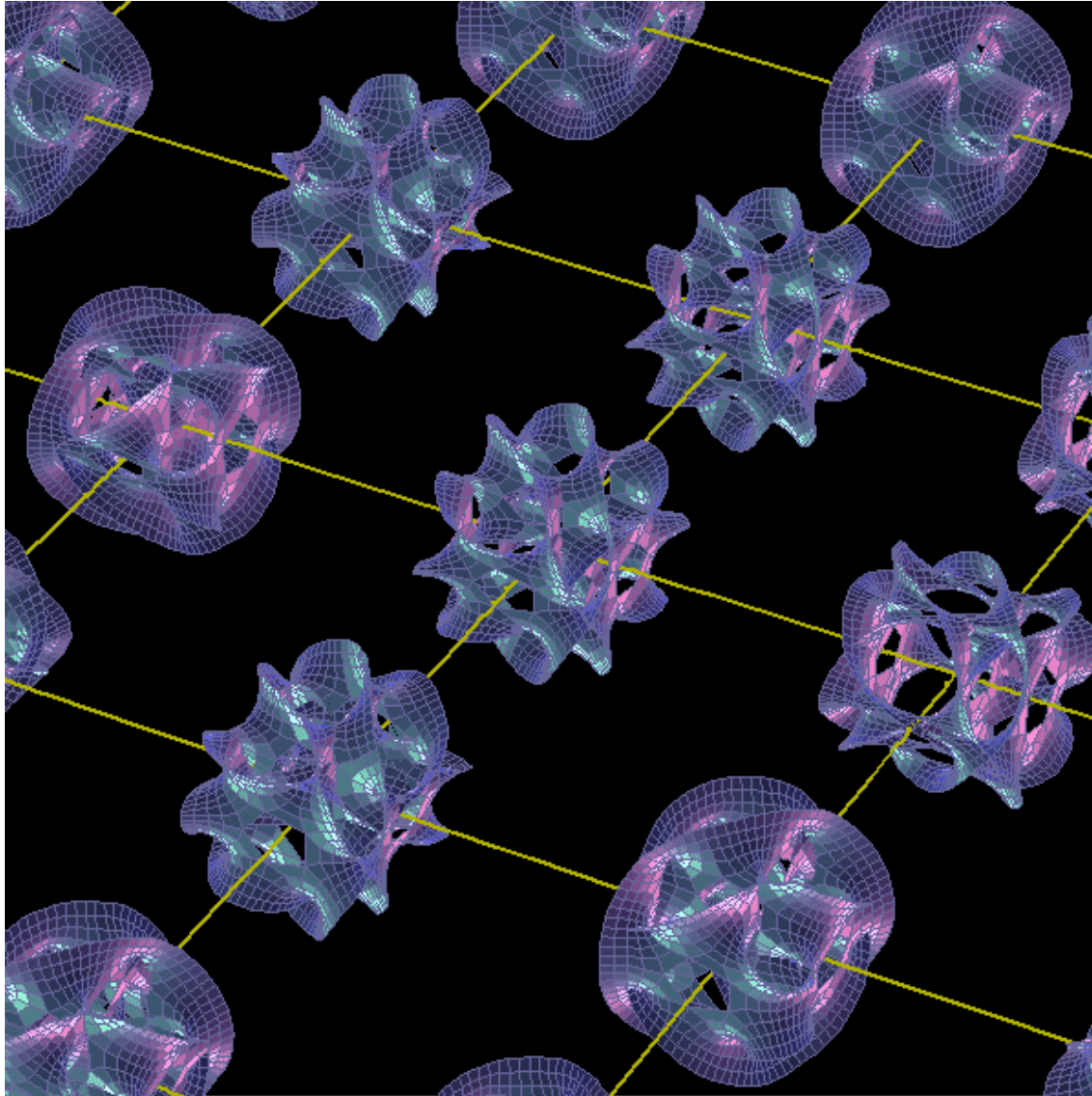
Quantum cosmology

SEARCH INSIDE!™

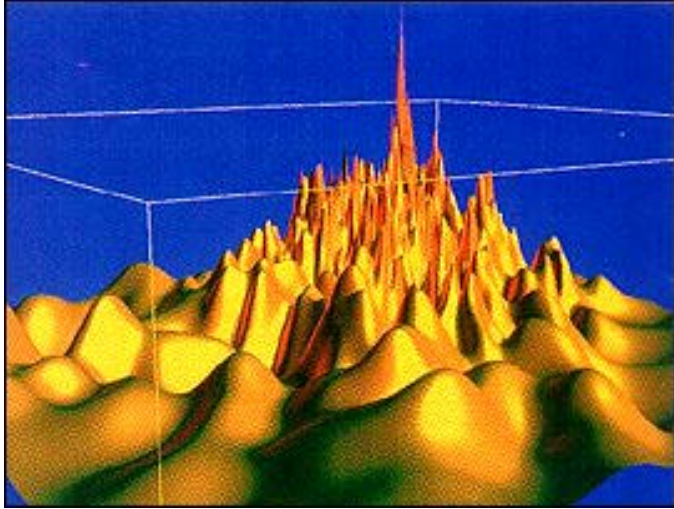


- ❑ *Quantum systems are quite different in their behaviour from “normal” (or classical) systems (e.g., Schroedinger’s cat)*
- ❑ *Quantum systems are described by a wave function which has an ambiguous interpretation, but can be generally thought of as a probability distribution for a system to have a certain state (e.g., “dead” or “alive” states of the Schroedinger’s cat).*
- ❑ *Quantum cosmology is an attempt to figure out the wave function (i.e., distribution of possible states) and equations governing it for the entire Universe... (e.g., Wheeler-deWitt equation and the Big Bang)*

String theory

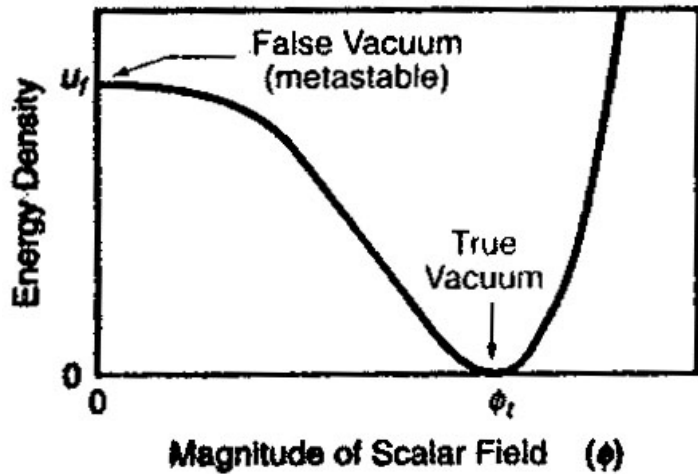


String theory landscape

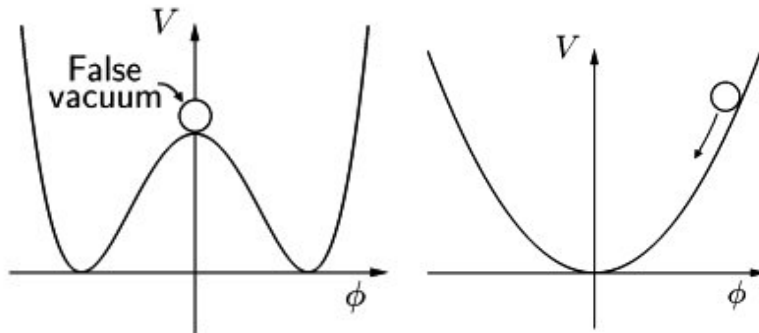


- ❑ *String theory predicts a large number of metastable false vacuum states*
- ❑ *So a large variety of conditions for inflation with different resulting fundamental constants may exist*
- ❑ *This means that initial conditions for the Big Bang and inflation are a random realization of a very large number of possibilities.*

Cosmic inflation: quantum effects



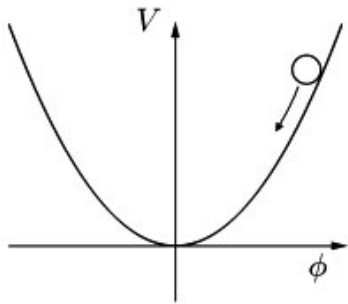
- The field that drives the inflation, the inflaton, is subject to quantum effects just like any other energy field.
- There are very interesting implications of these effects for the subsequent evolution of the Universe...



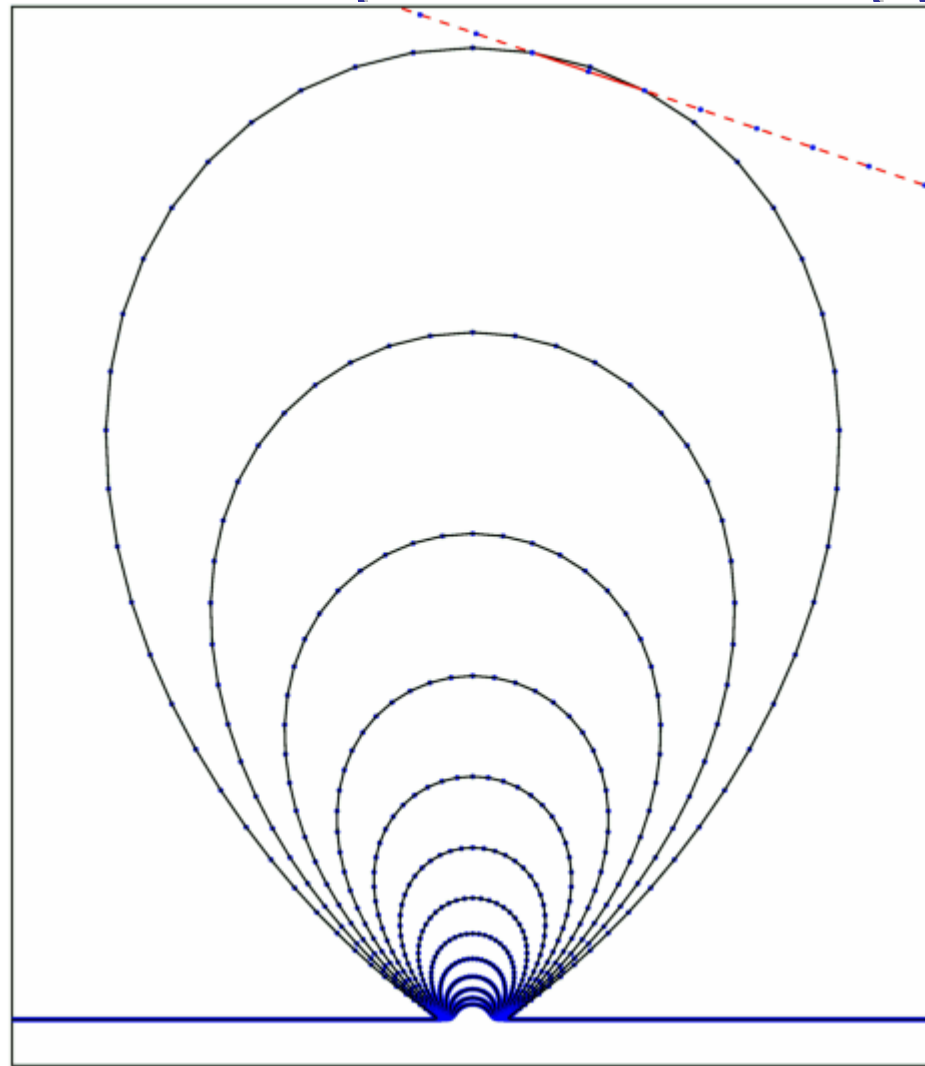
New Inflation
Linde; Albrecht & Steinhardt
(1982)

Chaotic Inflation
Linde (1983)

Cosmic inflation: quantum effects



Chaotic Inflation
Linde (1983)



In chaotic inflation scenario certain regions of the Universe in which quantum fluctuations lead to a sufficiently large value of field ϕ and $V(\phi)$

Inflation and production of particles

Very rapid expansion of space can lead to separation of particles in virtual pairs. Such expansion thus fills the space with particles.

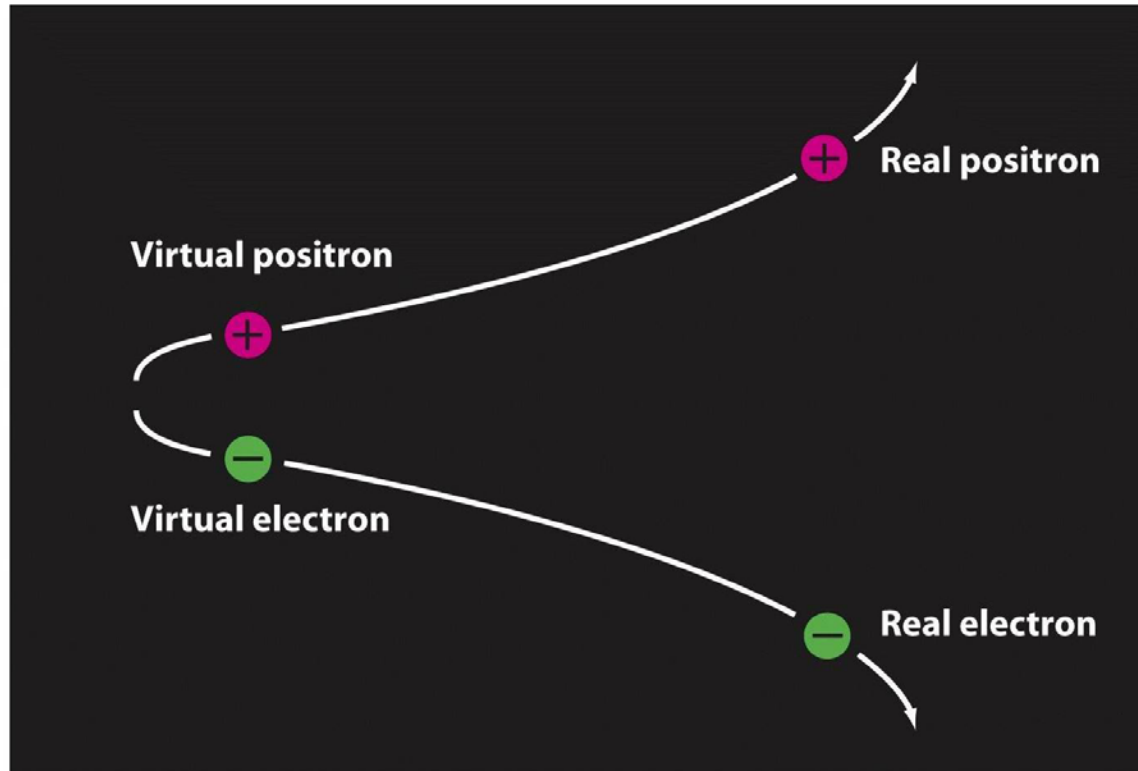


Figure 27-10
Universe, Eighth Edition
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Quantum fluctuations of the inflaton field

Quantum fluctuations of energy and space that correspond to birth and destruction of virtual particles can be stretched along with the expansion of space to large sizes, providing seeds for large-scale inhomogeneities.

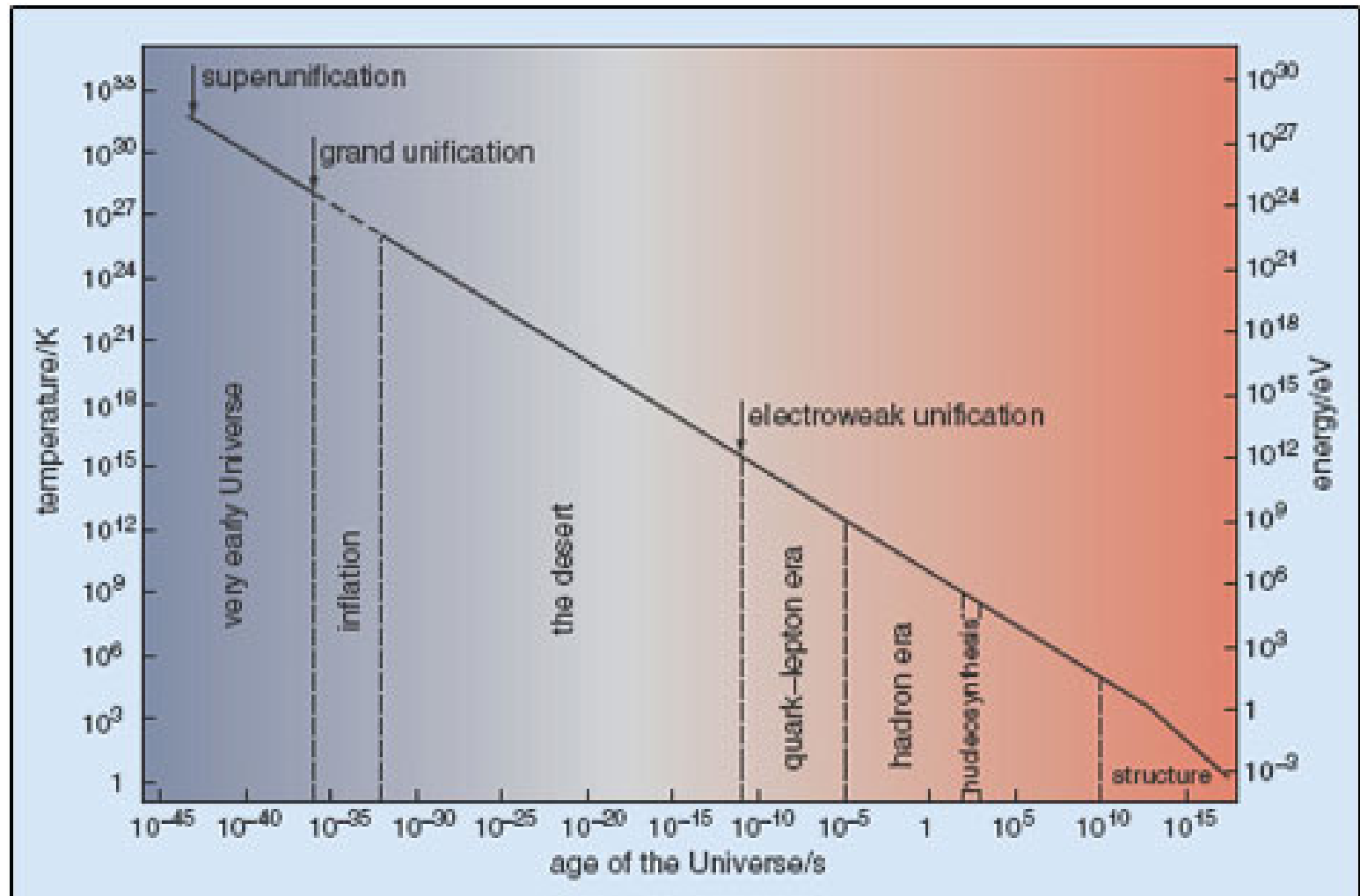


Connections: Quarks to the Cosmos

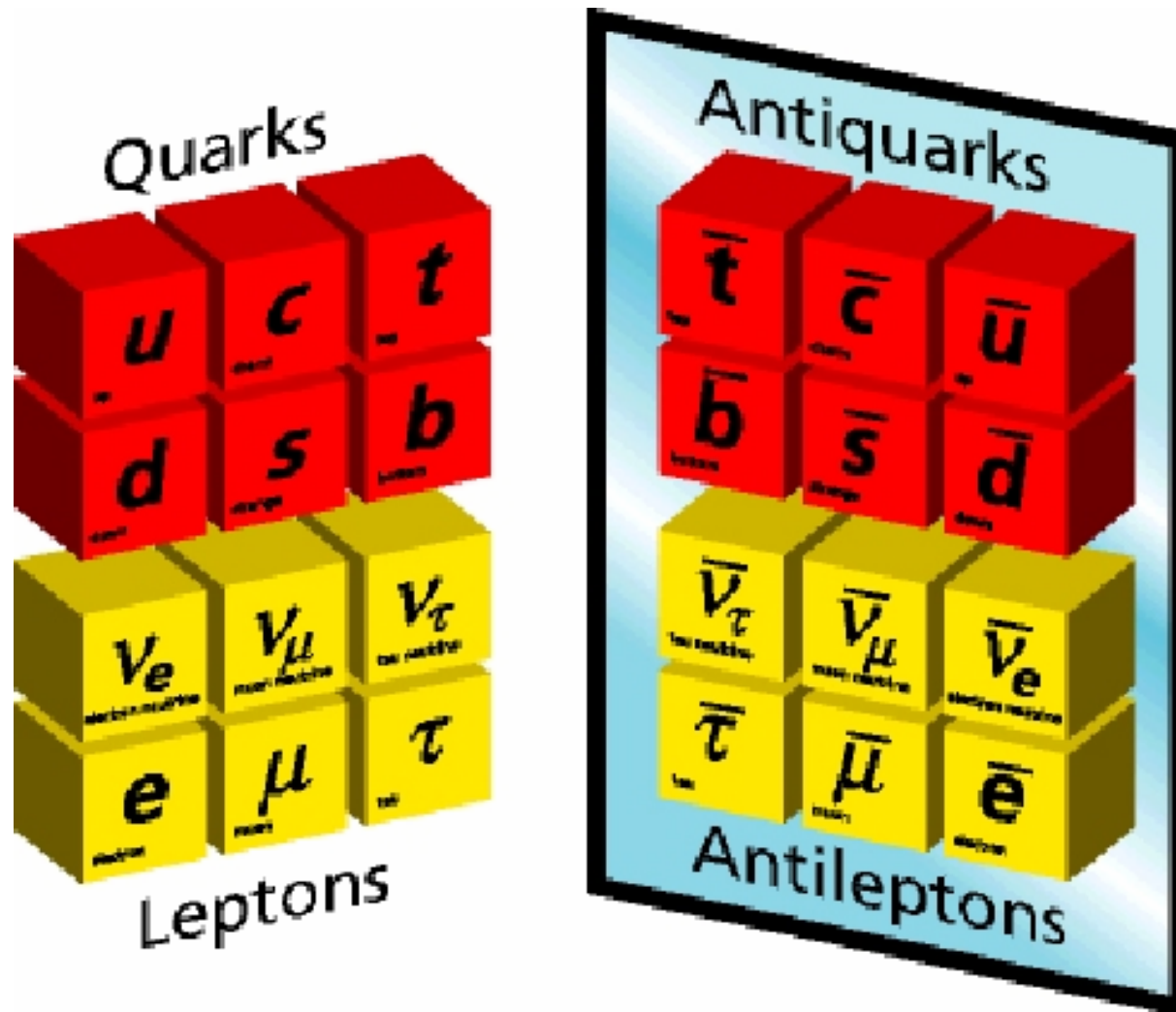


Quantum fluctuations of energy and space that correspond to birth and destruction of virtual particles can be stretched along with the expansion of space to large sizes, providing seeds for large-scale inhomogeneities.

Temperature and energy during the first stages in the evolution of the universe



Apparent asymmetry between matter and anti-matter





Most of the observed matter in the Universe is of the usual kind (i.e, not anti-matter). Why?

- ❑ if islands of anti-matter existed, we should have detected copious amounts of radiation coming from the boundaries with normal matter, where matter and anti-matter would be annihilating
- ❑ plus, any such arrangement would imply strong inhomogeneities in the early universe, thereby violating one of the most fundamental tenets of the Big Bang model.
- ❑ one idea: asymmetry in the initial amounts of matter and anti-matter due to some asymmetry of forces and interactions in the early universe
- ❑ photons leftover from the annihilation of matter and anti-matter are the photons we now observe as the Cosmic Microwave Background