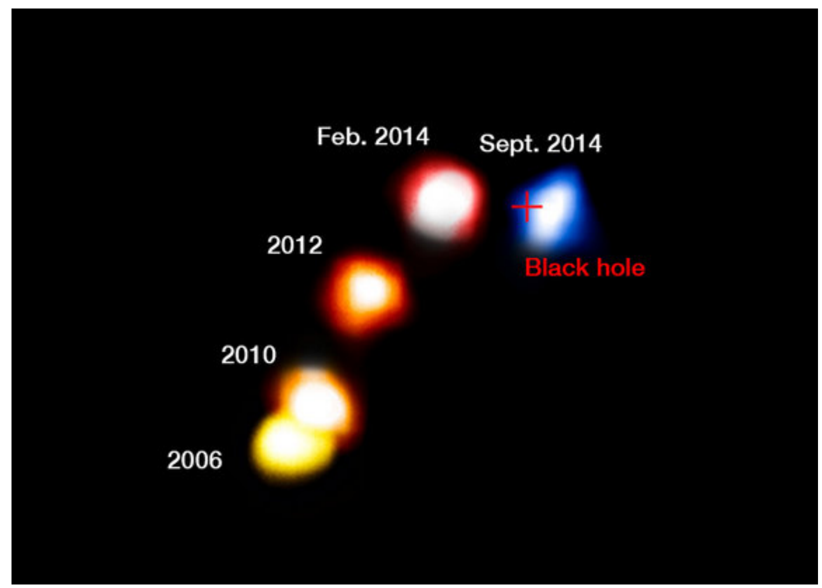
Friday, May 1, 2015

Electronic class reviews now available. Please respond. We find the feedback very valuable.

Fifth exam and sky watch, FRIDAY, May 8. Reading for Exam 5: Chapter 9 – Sections 9.6.1, 9.6.2, 9.7, 9.8; Chapter 10 - Sections 10.1-10.4, 10.9; Chapter 11 - all except Section 11.6 (abbreviated, focus on lectures); Chapter 12 - all; Chapter 13 (abbreviated); Chapter 14 - all

Astronomy in the news?

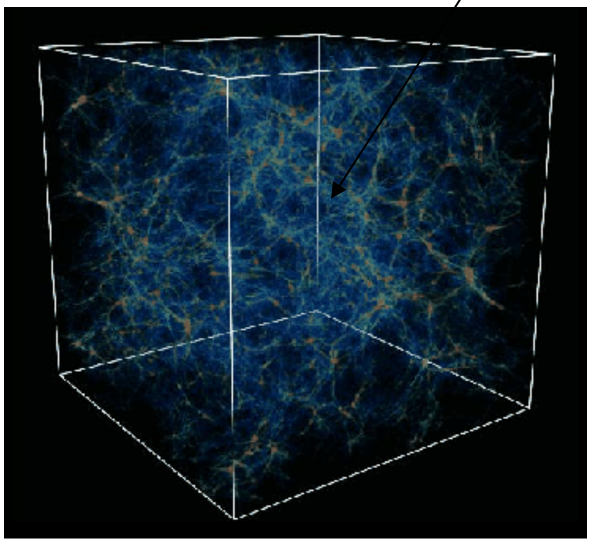
G2 – object hurtling near supermassive black hole in center of the Milky. Monitored for years. G2 is fuzzy-looking in most photographs, thought to be a gas cloud, but no burst of radiation at closest passage, and it seems to have remained compact, so maybe a star.



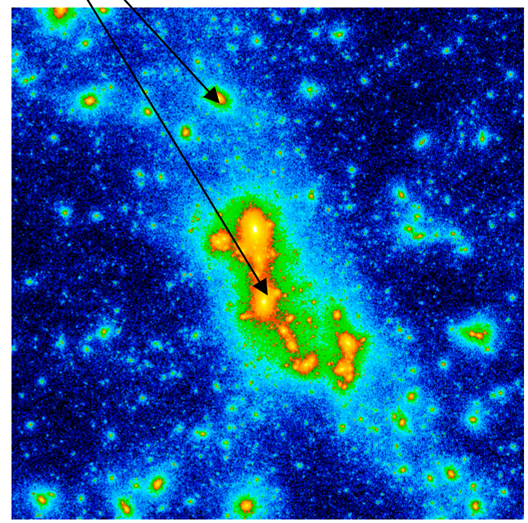
Goal:

To understand the nature of dark matter and how it affects the Universe.

Dark Matter



5 × more total density and mass than "normal" stuff stars, gas, etc.



Computer simulations show that from the tiniest wrinkles of quantum uncertainty in the Big Bang, the Dark Matter agglomerates to form all the ***Large Scale Structure,*** galaxies, clusters of galaxies of the Universe.

Ordinary matter – protons, electrons -- settles to center of Dark Matter lumps to form galaxies and clusters of galaxies. **Our familiar Universe of stars and galaxies would not exist without the Dark Matter.**
Density of Dark Matter is not enough to close the Universe
$\Rightarrow$ Universe is "open?" (3D Pringle).

Goal:

To understand how Type Ia supernovae taught us a dramatic new lesson about the Universe and what that lesson was.

We thought we were trying to determine the density of the Universe to determine how strongly it was **decelerated** by gravity and hence whether it were open, closed, or flat.

Nature threw us a curve ball

SN were the key!

Use Type Ia supernovae (brightest ~ uniform behavior)

Carefully map ***distances*** (dimmer appearance means further away), ***velocities*** (Doppler red shifts) in all directions

Density of the Universe

Do geometry - measure curvature –
“sphere”, “Pringle”, “flat”
closed, open, flat

High Density, closed

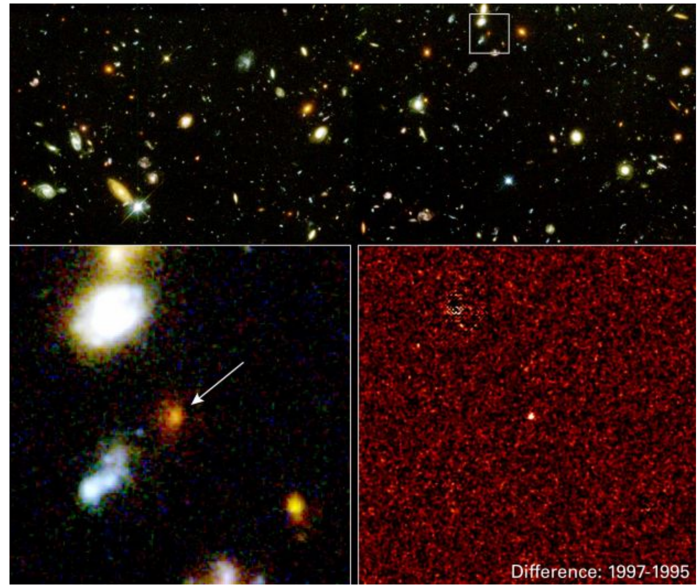
Very special density, flat

Low density, open

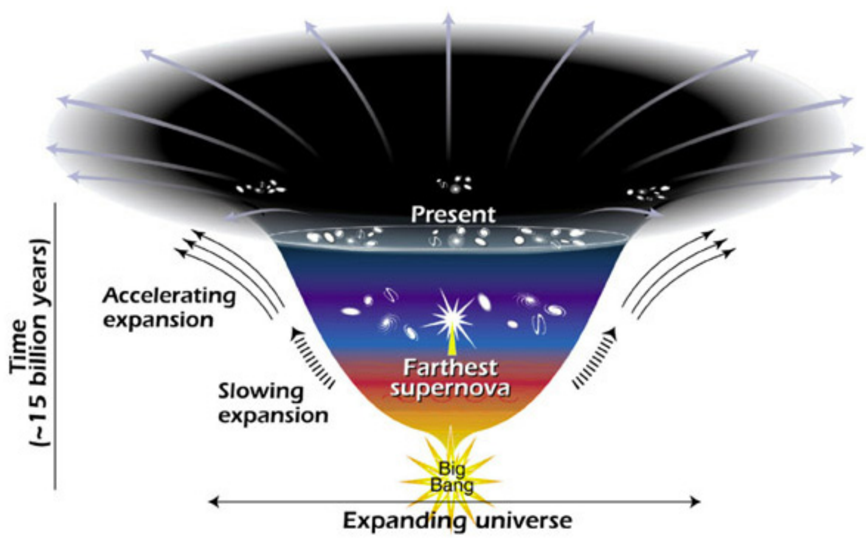
More subtle techniques than making parallel lines or drawing triangles, but still amounts to “doing 3D geometry.”

Type Ia supernovae are generally the brightest and can be seen at cosmological distances.

They were used as cosmological probes...



to discover the ***acceleration*** of the Universe...



The supernovae were found to be a little too dim at given expansion velocity (red shift)

⇒ Further away than expected for a “normal” gravitating Universe

How do you get further away at a given current velocity?

⇒ Universe has been *accelerating*!! (and it is somewhat older than a coasting Universe would have been)

$\boxed{\text{Throw ball}}$

Other arguments, especially careful study of the small irregularities of the temperature of the cosmic background radiation left over from the Big Bang, confirm the evidence from supernovae

=> Accelerating Universe - confirmed by all tests applied so far.

$\Rightarrow$ Universe is filled with an even more mysterious ***Dark Energy***,

The dark energy seems to be some sort of force field (like a magnetic field, only different), that permeates the vacuum, empty space, and that *pushes*, ***anti-gravitates!***

As space expands there is just more vacuum filled with this force field, so *the effect is not diluted by the expansion*.

Dark Energy Anti-gravitates: cannot be any particle, "normal" (p, n, e) or Dark Matter, that gravitates.

Dark Energy force field is not accounted for by any currently known physics.

A major challenge to fundamental physics!

And why this discovery was awarded the Nobel Prize for Physics in October 2011.

Saul Perlmutter
UC Berkeley

Brian Schmidt
Mt. Stromlo Observatory, Canberra, Australia

Adam Riess
Johns Hopkins University

One Minute Exam

The type of supernova used to discover the acceleration of the Universe was

→ Type Ia

← Type Ib

↑ Type Ic

↓ Type II

One Minute Exam

Dark Matter is responsible for

➡ The acceleration of the Universe

⬅ The dark space between stars and galaxies

⬆ The clumping of matter to form stars and galaxies

⬇ The Dark Ages after the initial Big Bang

One Minute Exam

Dark Energy is responsible for

- The acceleration of the Universe
- The dark space between stars and galaxies
- The clumping of matter to form stars and galaxies
- The Dark Ages after the initial Big Bang

Goal:

To understand what the Dark Energy implies for the shape and fate of the Universe.

Add up all the normal matter (not much, about 4%), Dark Matter (about 23%) and the mass equivalent of the Dark Energy ($E = mc^2$, about 73%) and find the Universe has just the very special density to be flat!

The Universe is Flat (in 3D) on average

Still have individual stars, neutron stars, black holes, galaxies, that curve the space around them causing the small scale, local effects of gravity.

Just as a table top is composed of atoms and molecules on small scales, but is flat for all practical purposes when we sit down to eat.

The best current guess is that our real 3D Universe is essentially 3D flat - but accelerating!

Nature of Dark Energy

Energy of vacuum - quantum fluctuations, particle/anti-particle (recall role in Hawking radiation) predict an acceleration that is too large by a factor x 10^{120}. It works on Earth, but not, somehow, in deep space.

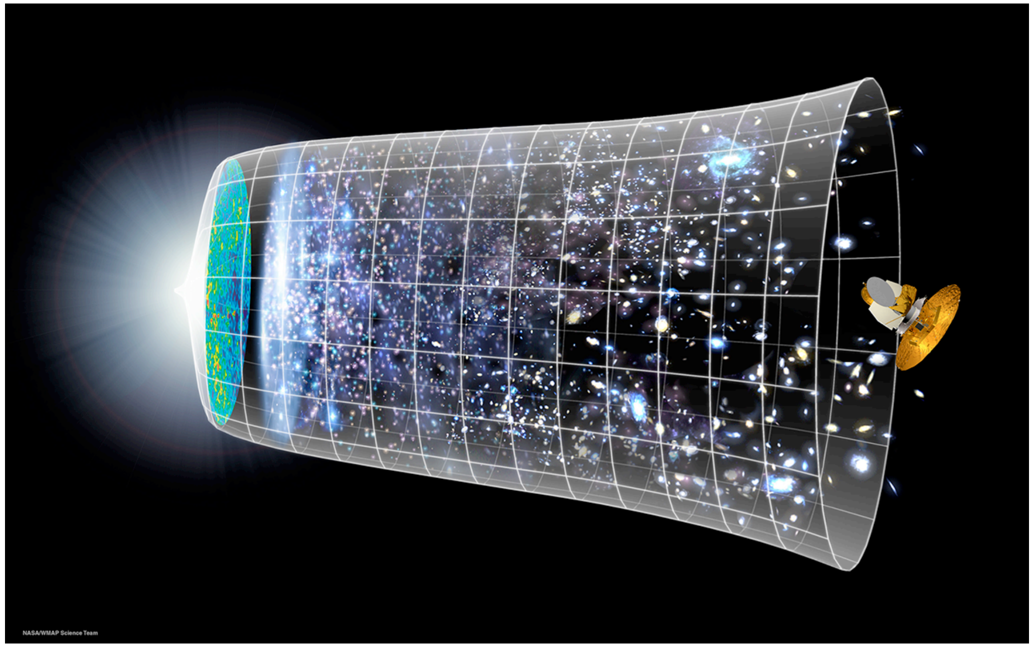
“Worst prediction ever in physics,”
Steven Weinberg (UT Nobel Laureate)

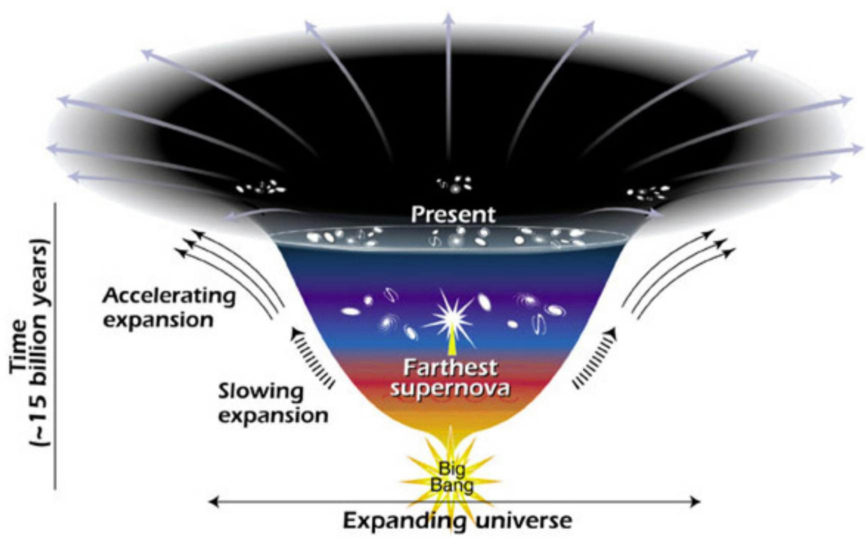
Related phase early in Big Bang, when the Universe was a fraction of a second old,

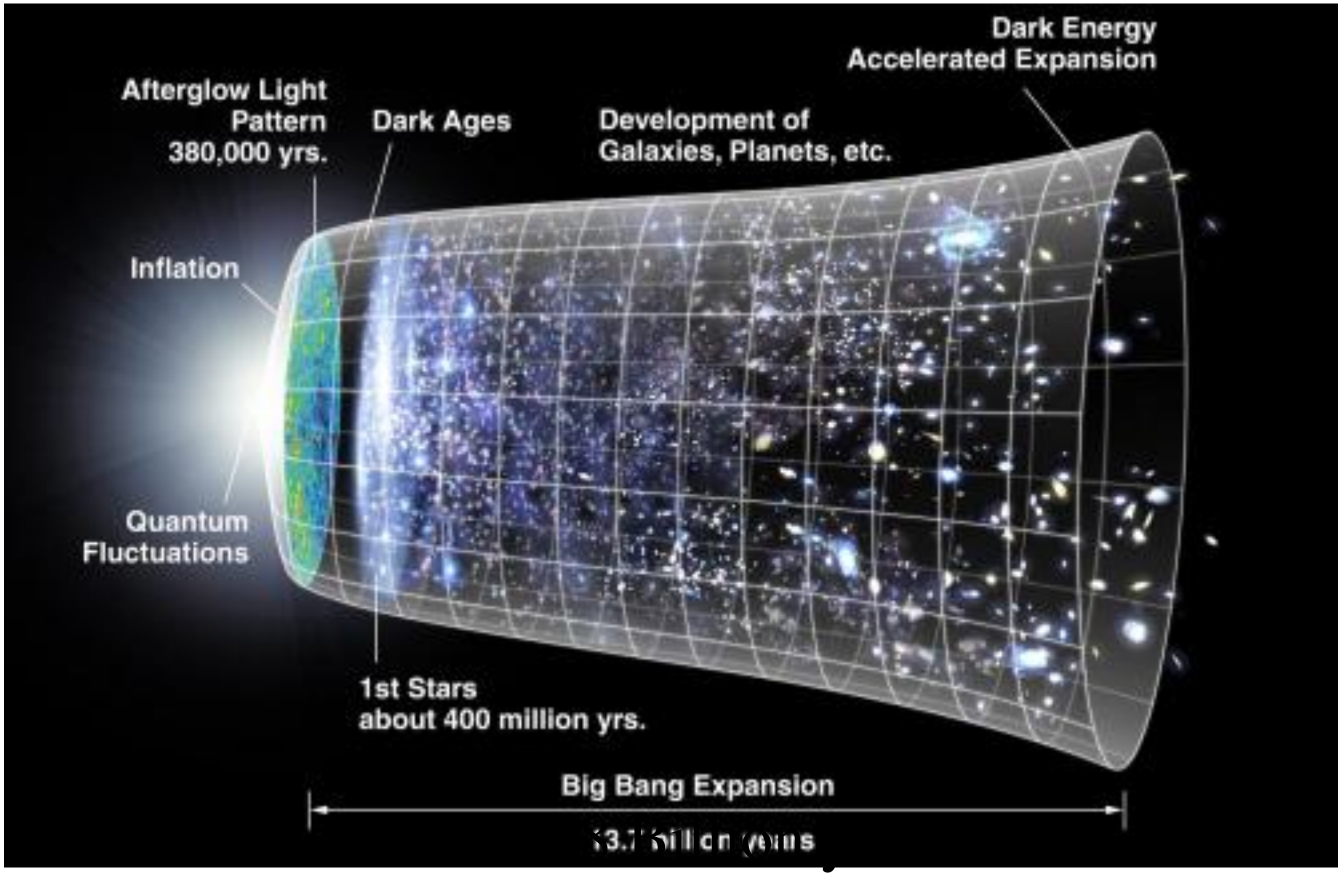
A huge “inflation” by anti-gravitating vacuum force blows the Universe so big that it is essentially flat (like the surface of the Earth appears to us, only moreso!)

Anti-gravitating energy went away - has come back gently in the last 5 billion years. ***What is it???***

“Space-time diagrams” illustrate how the Big Bang led to inflation, then deceleration, and now acceleration






Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
380,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
Quantum
Fluctuations
1st Stars
about 400 million yrs.
Big Bang Expansion
13.7 billion years

The Fate of the Universe?

If the acceleration stays constant, the fate is rather dismal: galaxies will be pulled infinitely far apart, then even small mass, long-lived stars age and die, protons, neutrons and electrons will decay to photons, black holes will evaporate by Hawking radiation.

The result would be an empty Universe filled with dilute radiation.

We know so little about the Dark Energy, that it could do other things.

It could get stronger, leading to a ***Big Rip*** with atoms and the very fabric of space being pulled apart (most physicists think this unlikely)

It could reverse sign and gravitate, leading to the recollapse of the Universe in a ***Big Crunch*** (no current reason to think so).

Goal:

To understand how physicists are attempting to cope with the existence and nature of the acceleration of the Universe driven by Dark Energy.

Einstein's theory of the behavior of the Universe contained a "Cosmological Constant" that could be positive, negative, or zero.

Einstein first argued it was positive in order to provide an anti-gravitating force to counteract gravity to keep the Universe from expanding or contracting. Then the expansion of the Universe was discovered and he called it a "blunder."

Current results on the expansion are consistent with the Dark Energy behaving in accord with Einstein's Cosmological Constant.

Even if true, we still need to know what it is, physically! Why does this "constant" have the value it does? Sort of like asking why the speed of light has the value it does.

Theories of **quantum fields** suggest that the Dark Energy could or should vary with time and space.

One theory called “quintessence” (the fifth essence, after the Greek earth, air, fire, and water) would have that property.

Other theories call for interaction with other 3D Universes “elsewhere” in hyperspace.

The race is on to determine whether the Dark Energy is constant (Einstein’s cosmological constant) or not (some quantum field).

Texas astronomers will be doing the Hobby-Eberly Telescope Dark Energy Experiment (HETDEX) starting next winter for three years to try to answer this question.

One Minute Exam

As an explanation for the Dark Energy, a quantum field would be different from Einstein's Cosmological Constant because a quantum field would

- Be constant in space
- Vary in time
- Gravitate
- Anti-gravitate

Goal:

To understand why we need a new theory of Quantum Gravity and the ideas involved in the attempt to construct that theory.

Quantum Gravity - The Final Frontier

The remainder of the class will be spent exploring various aspects of the most fundamental issue of modern physics: reconciling ***Einstein's theory of gravity*** as curved space with the ***quantum theory*** of how things behave at a fundamental microscopic level.

The problem - each of these great theories of 20th century physics contradict one another at a fundamental level.

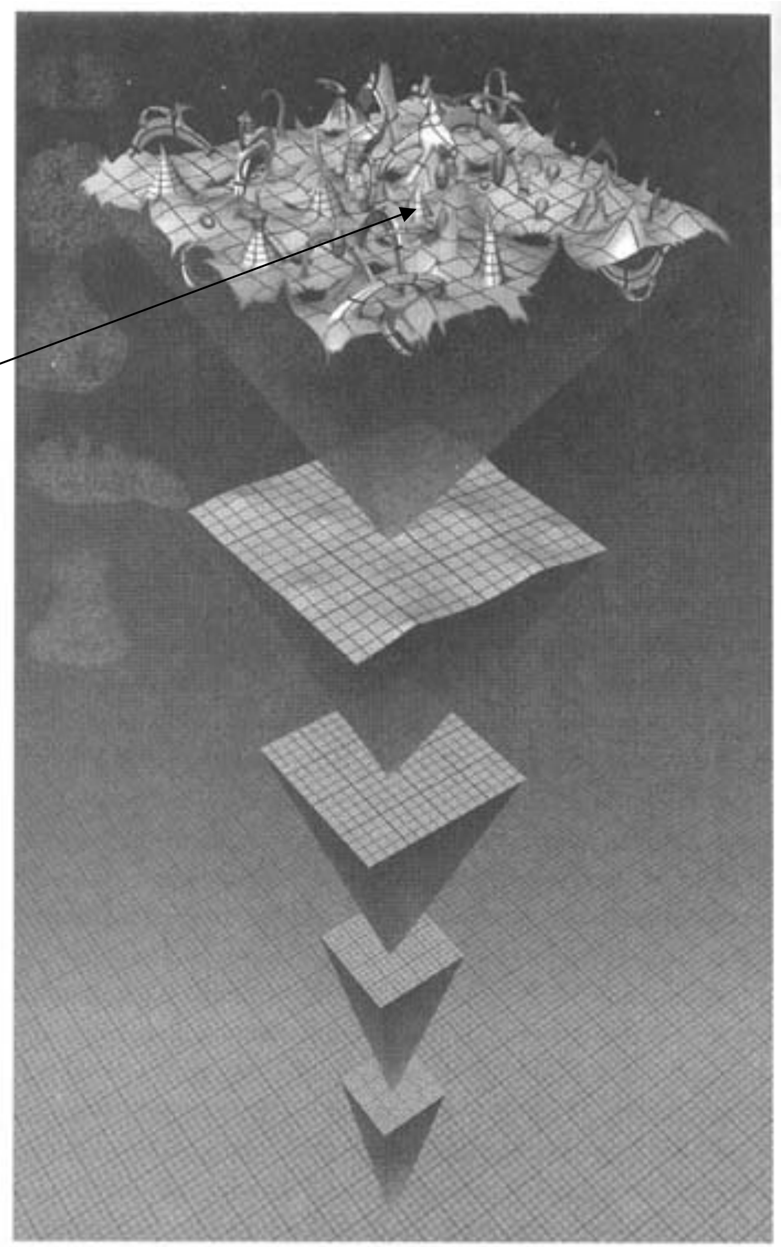
Einstein's theory predicts ***singularities*** at the beginning of the Big Bang and in the centers of black holes where matter is crushed to a point with infinite density, time and space come to a halt. Quantum theory says the position of nothing, not even a singularity, can be specified exactly (the Uncertainty Principle applied to singularities).

Quantum theory is designed to work in flat, or gently curving space. It does not make sense when the curvature of space is tighter than the "wavelength," the uncertainty in position, of a particle.

Each great theory of 20th century physics contradicts the other!

Quantum Foam

At the Planck length scale where curved space effects and quantum uncertainty effects are equally important. Space and time uncertain.



From Brian Greene

The Elegant Universe

We need an embracing theory of ***quantum gravity*** that will reduce to ordinary gravity and ordinary quantum theory where they work well (away from singularities and with non-severe curvature - same thing!), but will also tell us what a "singularity" really is.