

12/4/06

Reading: Chapter 12 in the Book, revised posted chapters 13 (worm holes and time machines), 14 (quantum gravity, string theory, large extra dimensions).

*Fourth SkyWatch extra credit due by this Friday, December 8*

*Final Exam Information:*

*1 PM CLASS - MONDAY, DECEMBER 18, 9-12 AM, MEZ 1.306*

*2 PM CLASS - FRIDAY, DECEMBER 15, 2-5 PM, RLM 4.102*

100 multiple choice questions,

News: night launch of Shuttle to Space Station this Thursday.

Pic of the day; Solar Activity Movie?

Course survey is now available in the eCIS system at  
<https://utdirect.utexas.edu/diia/ecis/>

Should get automatic email

Experiment to do electronically

The University, the Astronomy Department and I all pay attention to these.

Please take the time to fill out the evaluation form.

# 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 smaller than the “wavelength,” the uncertainty in position, of a particle.

Can use current theories to “predict” where the theoretical collision occurs, where the theory of quantum gravity is most crucially needed, effectively the scale of length where quantum uncertainty and space-time curvature are equal.

Planck length - about  $10^{-33}$  centimeters, vastly smaller than any particle, but still not zero!

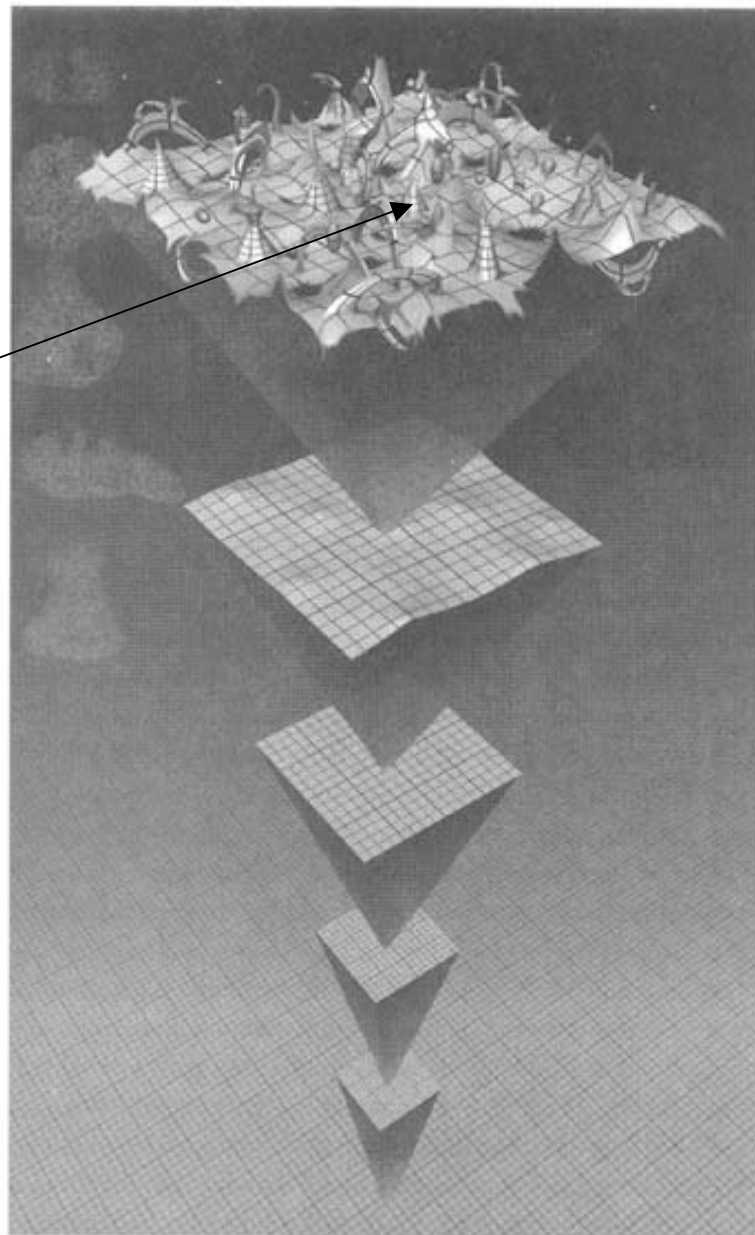
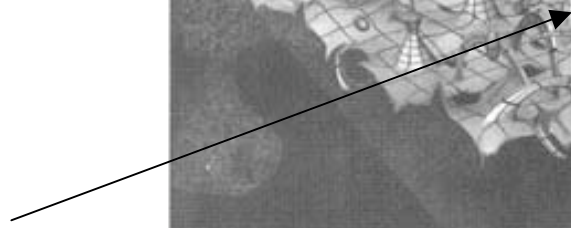
Planck density - about  $10^{93}$  grams/cubic centimeter, huge, but not infinite!

On the Planck scale, space and time themselves would be quantum uncertain, “up” “down” “before” “after” difficult if not impossible to define.

Spacetime becomes a “quantum foam” (a poetic concept without a mathematical/physical framework).

# Quantum Foam

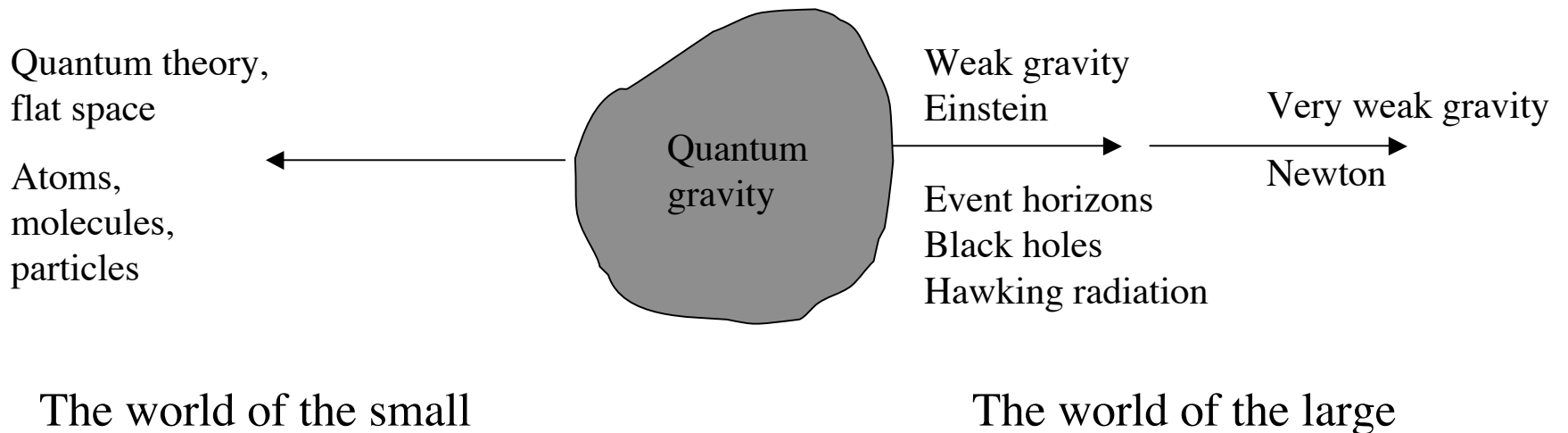
At the Planck length scale



From Brian Green

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.



# Worm Holes and Time Machines

(Book Chapter 12, section 1, new posted chapter 13)

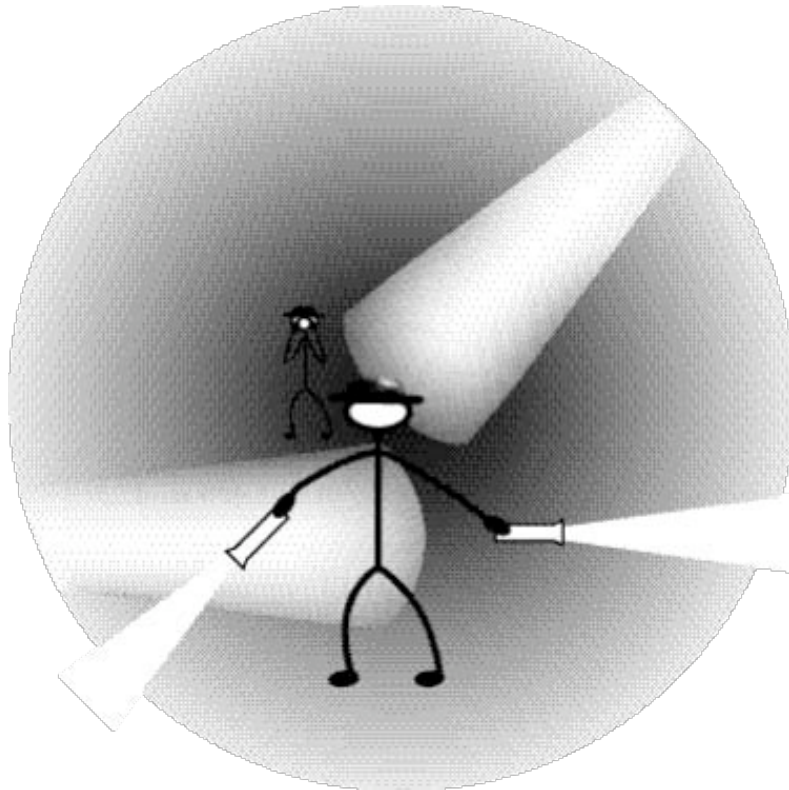
Amazing mathematical developments in the context of Carl Sagan's *Contact* by Kip Thorne and Igor Novikov:

Einstein's equations allow the possibility of worm holes. To be stable, they must be held open by some imagined "substance" that anti-gravitates.

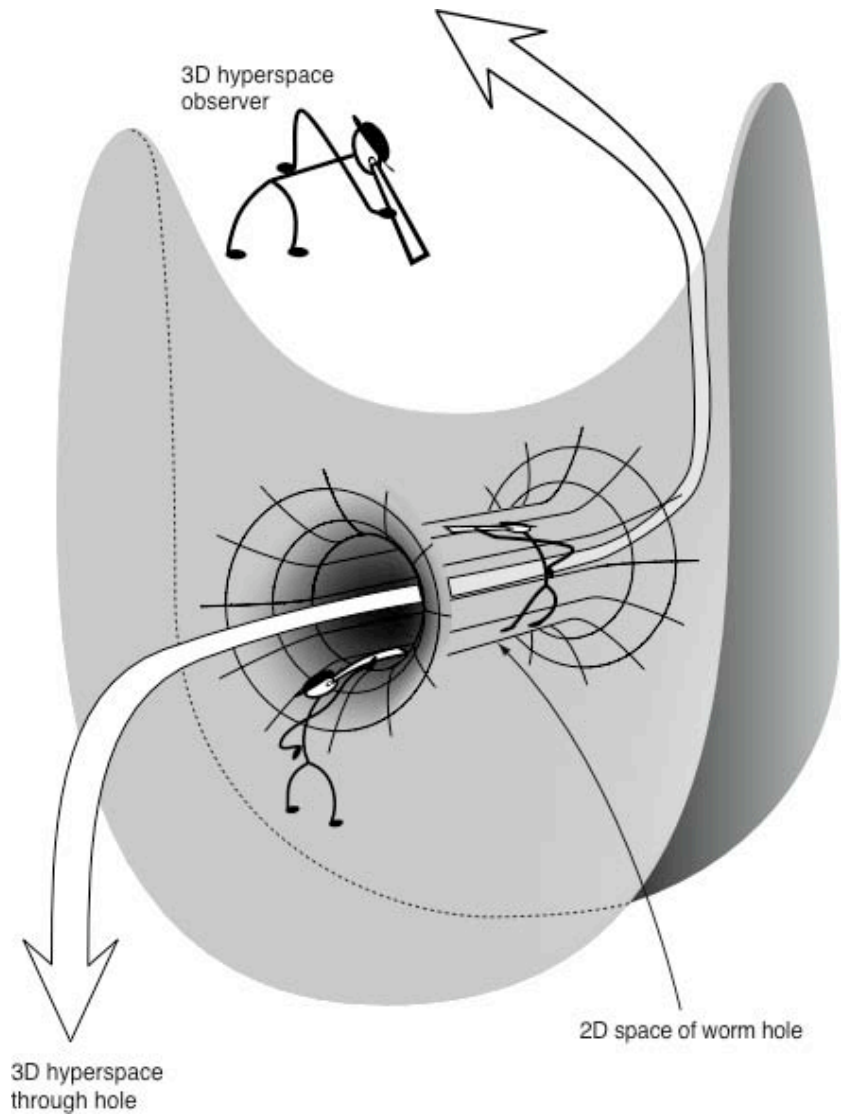
Highly curved space, but no singularity.

The Dark Energy gives a hint that such a "substance" could exist.





The mouth of a worm hole would be a 3D “object,” the space inside highly curved.



Embedding diagram of a worm hole in an “open” universe

The most amazing property discovered was that, in principle, worm holes would also be *time machines*!

*Novikov Consistency Conjecture*: physics will arrange itself so that there is no time-travel paradox - you cannot travel back in time and kill yourself before you enter the worm hole/time machine.

Thorne video

Ultimate resolution - will not know if worm holes can be constructed, even in principle, without a theory of *quantum gravity*.

Hawking - vacuum fluctuation energy (from uncertainty principle applied to vacuum) can go into wormhole, come out in past, pile up at mouth where began, quickly build up huge energy density, curve space, slam worm hole shut.

Maybe, but cannot actually compute that process without a theory of quantum gravity to handle the change in the “connectivity” of space time - must space time be smooth, or can it be laced with “tunnels” in space and time.

Need quantum gravity theory of singularity, quantum foam, worm holes

The best current candidate for a theory of Quantum Gravity is String Theory

See Brian Green - The Elegant Universe

(<http://www.pbs.org/wgbh/nova/elegant/>)

Read ***The Universe on a String*** editorial by Brian Green posted under links -> string theory

Hyperspace is an intrinsic aspect of string theory - 10 dimensions of space, plus time.