Today

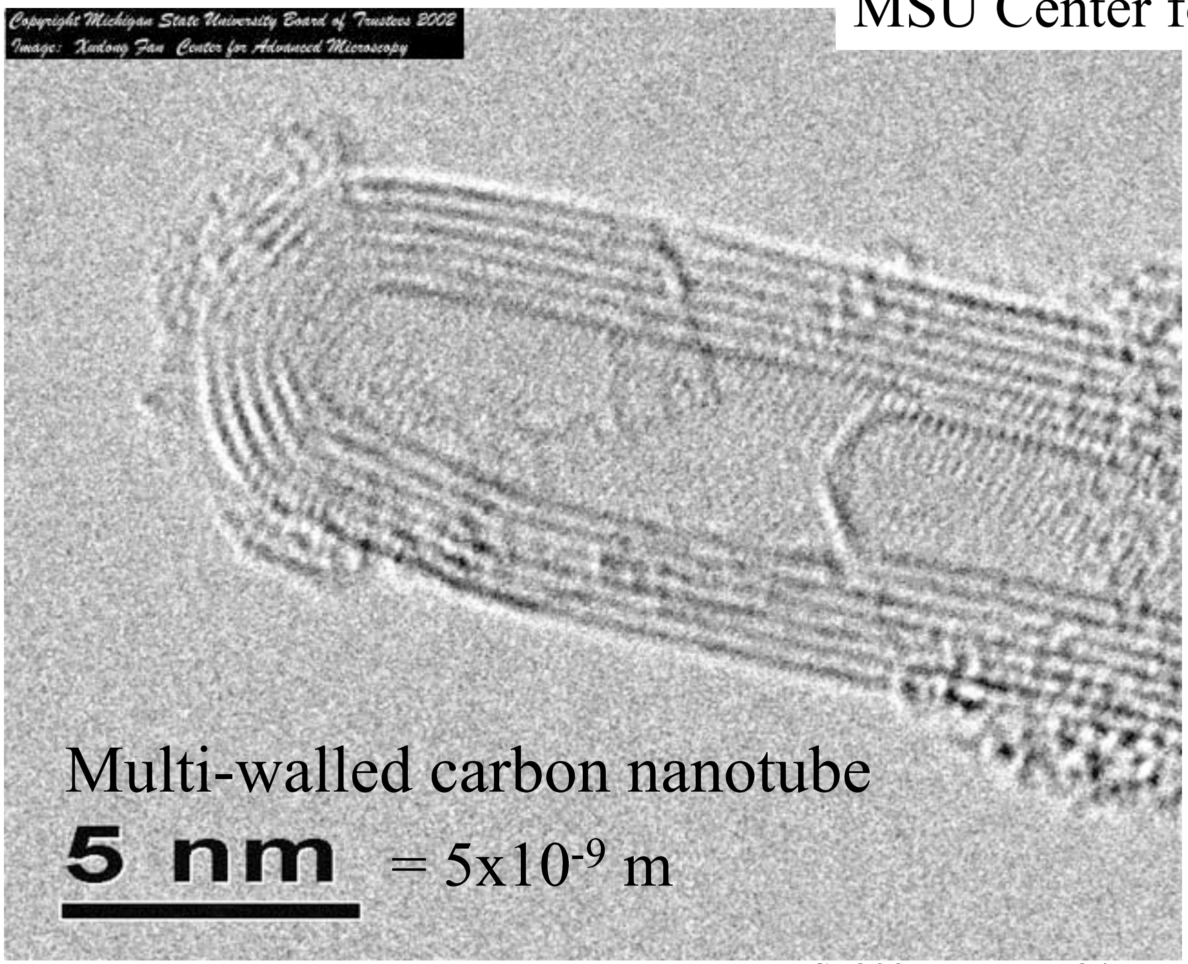
- The nature of the Universe - Beyond the Standard Model
  – Dark Matter and Dark Energy
  – String Theory and the quest to unify gravity and quantum theory
  – Begin watching PBS NOVA special “The Elegant Universe” on String Theory

The goals of science

- Reach an understanding based on the fundamental building blocks of nature and their interactions.
- Human bias – simple is better; one equation should describe everything (goal of string theory)
- The standard model is our current collection of fact. It does not answer the why question.

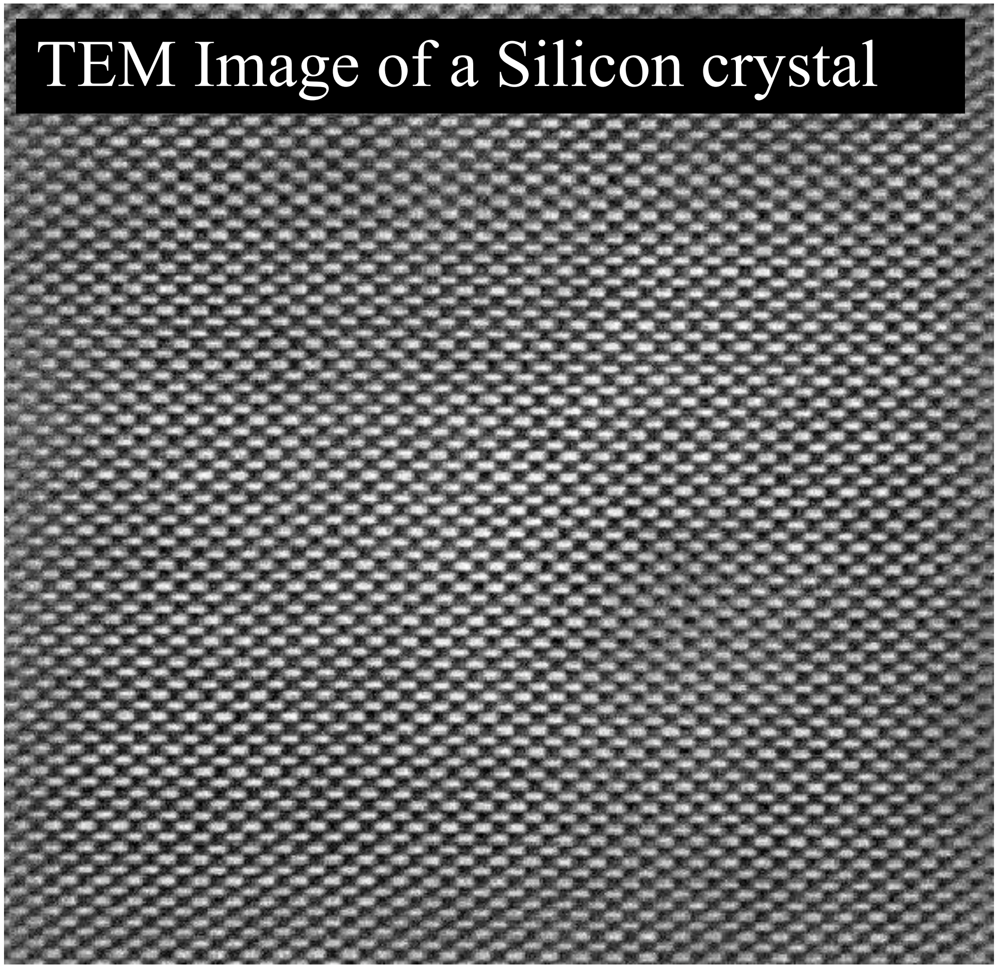
How do we know what things are made of?

MSU Center for Advanced Microscopy



TEM Microscope

The highest magnification possible



We can see pairs of silicon atoms.

Image of Si [110]

0.136nm separation between Si atoms

Xudong Fan, MSU

MSU Center for Advanced Microscopy http://www.ceo.msu.edu/

What We Made Of?

- We are made out of atoms. The size of atoms is 10^{-9} m = nm
- Atoms are made of nuclei and electrons (+ energy; $E=mc^2$)
- Nuclei are made of neutrons and protons (plus the stuff that binds them, mesons)
- Neutrons, Protons and Mesons are made of quarks (10^{-16} m). We can measure down to 10^{-18} m
- What are quarks made of? The answer may be strings, but the size is 10^{-35} m too small for us to explore (at the moment).
- What are strings made of?

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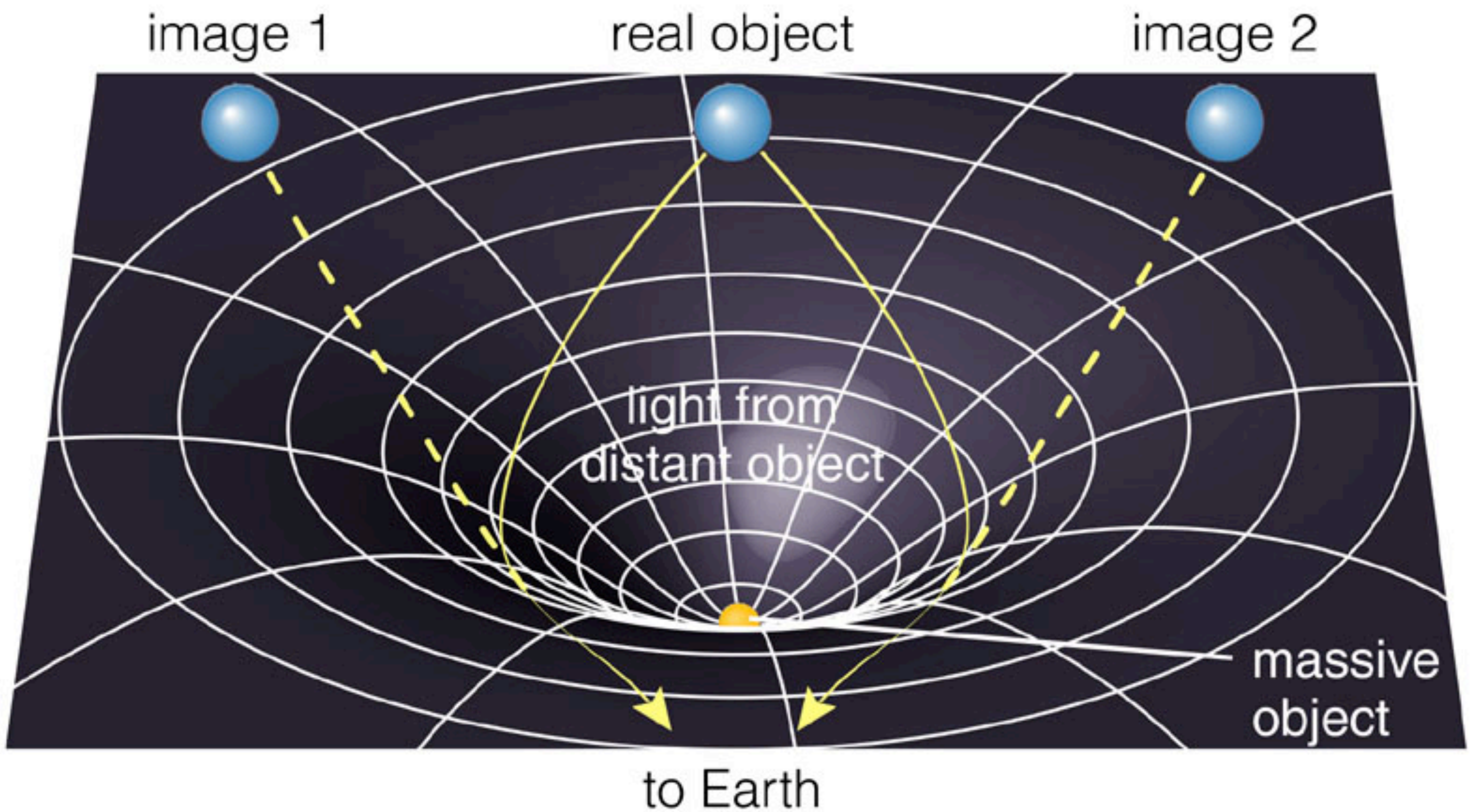
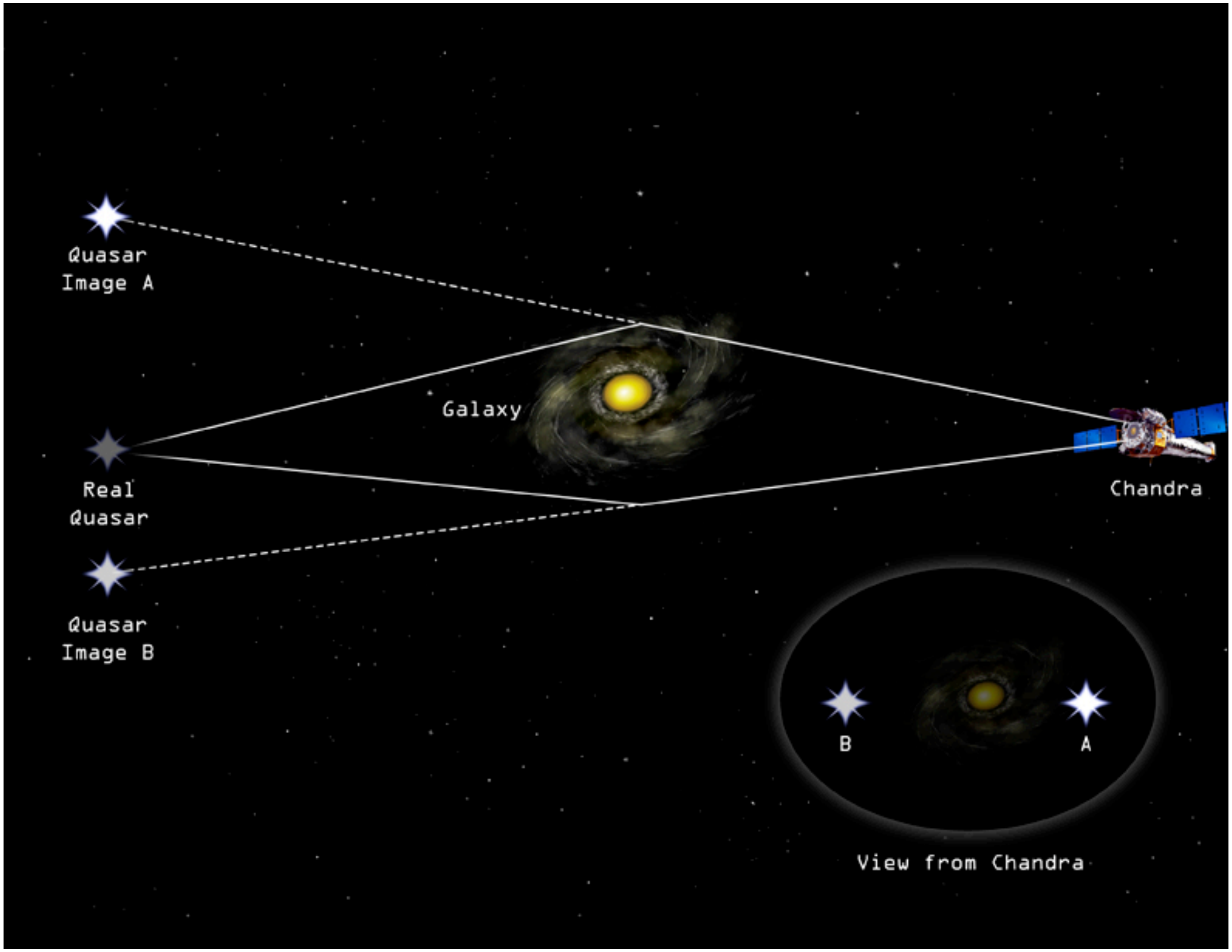
Most of the Universe is Dark Matter

- There are three main pieces of evidence that there is much more mass in the universe than that from luminous matter.
  - Gravitational lensing
  - Rotation curves of galaxies
  - Fluctuations in the cosmic microwave background radiation
- It turns out that only 4% of the Universe is made of the same stuff as us.

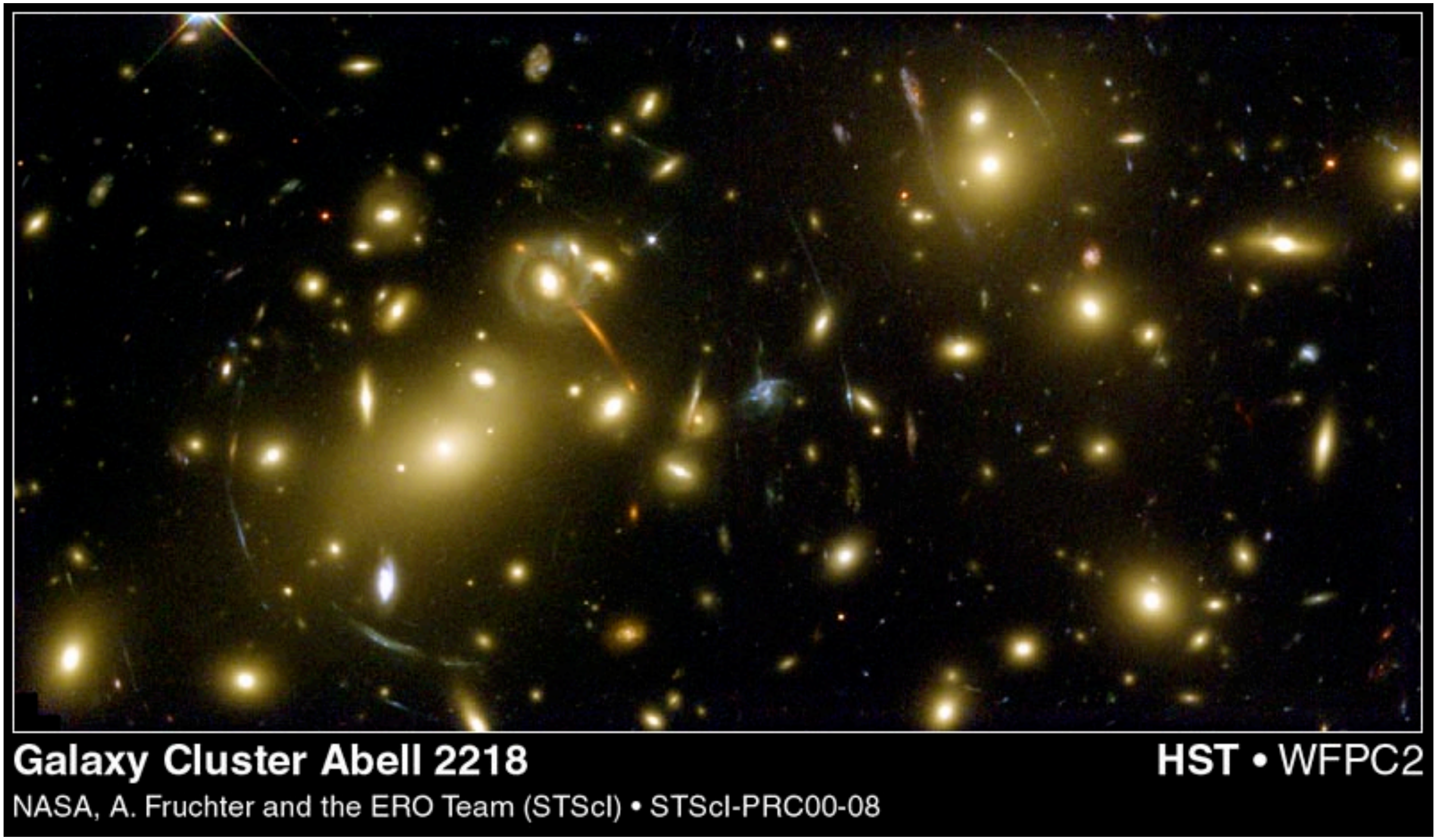
Gravitational Lensing results from General Relativity



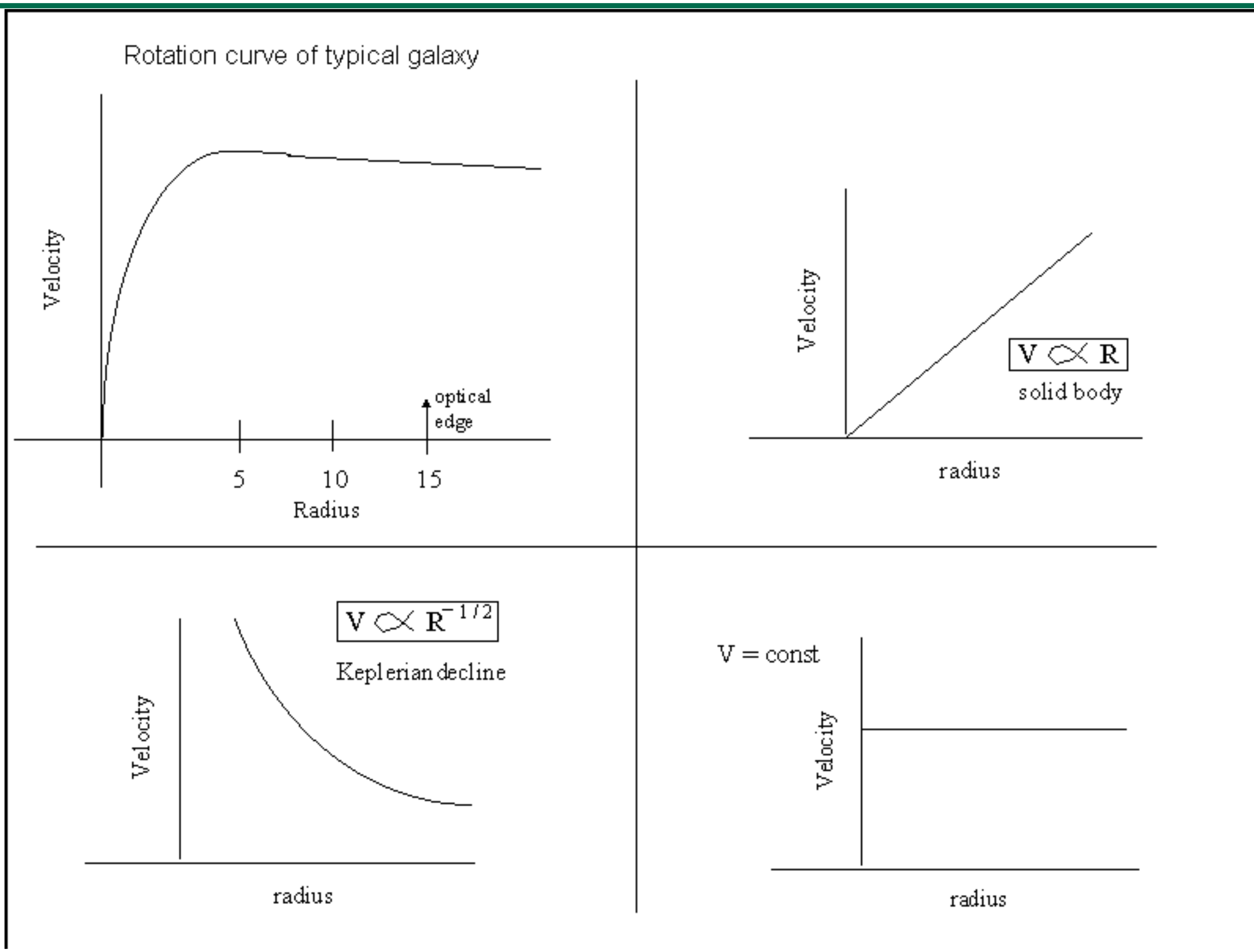
Gravitational Lensing



A Fantastic Picture

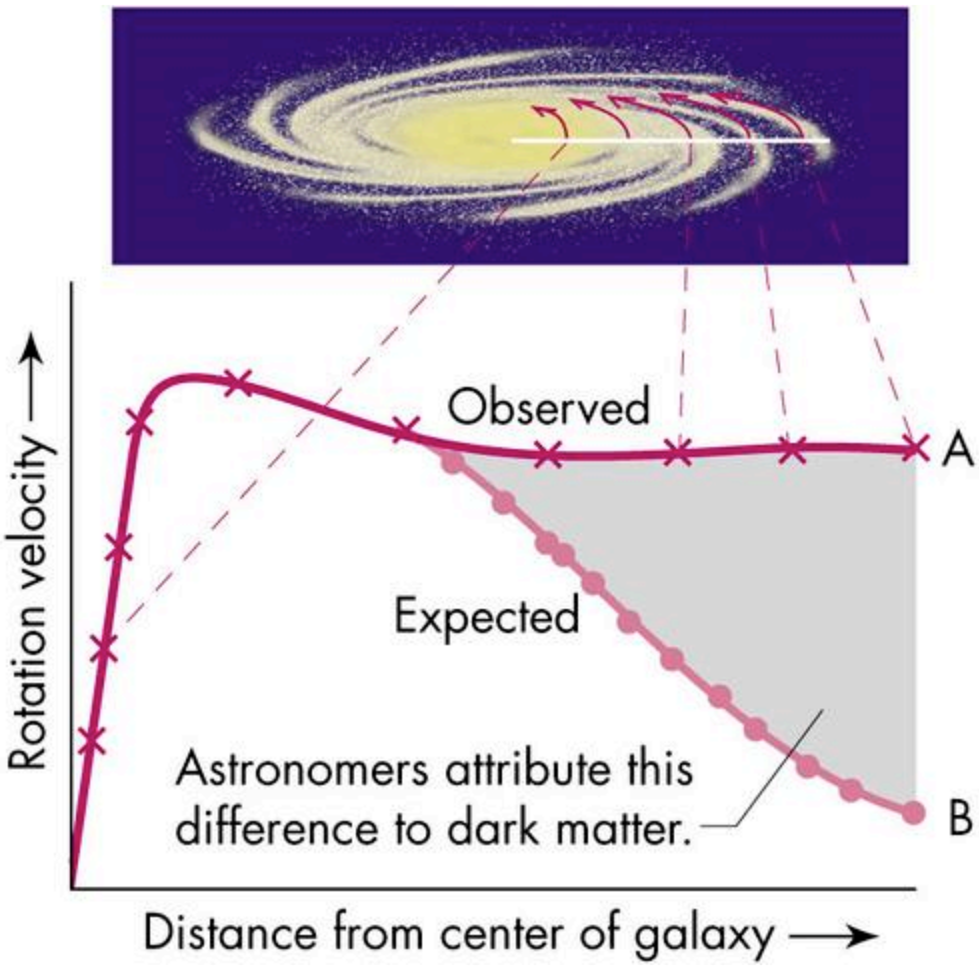


Rotation Curves for Various Objects



http://astrosun2.astro.cornell.edu/academics/courses/astro201/rotation_curves.htm

Rotation Curves

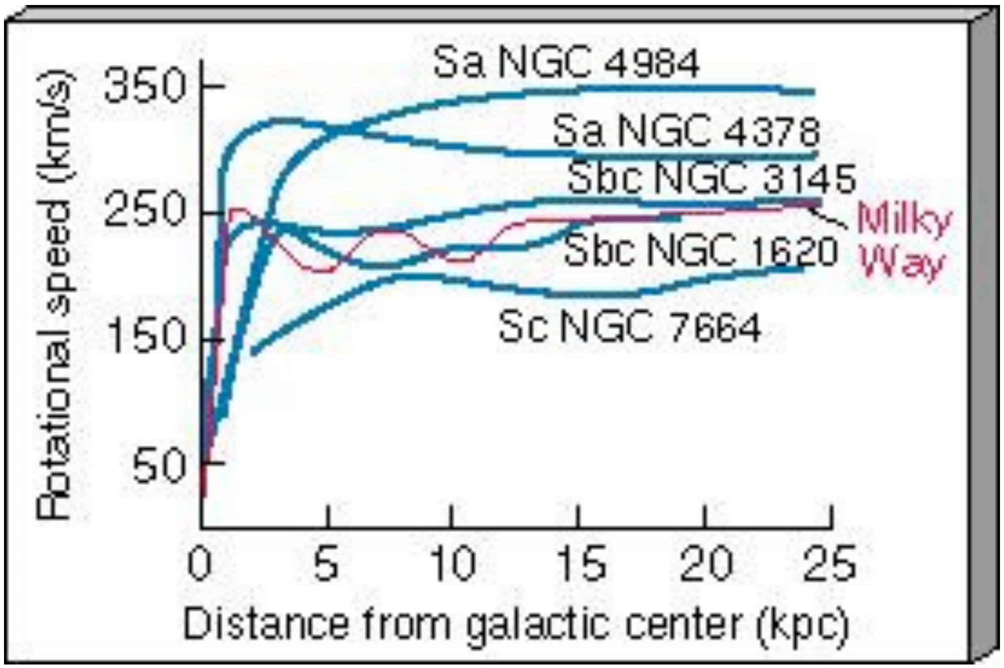


Rotation implies acceleration

The force that supplies the acceleration is gravity. More gravity implies a faster rotation.

There is more rotation and hence more gravity than expected at large radii.

Most galaxies show this behavior

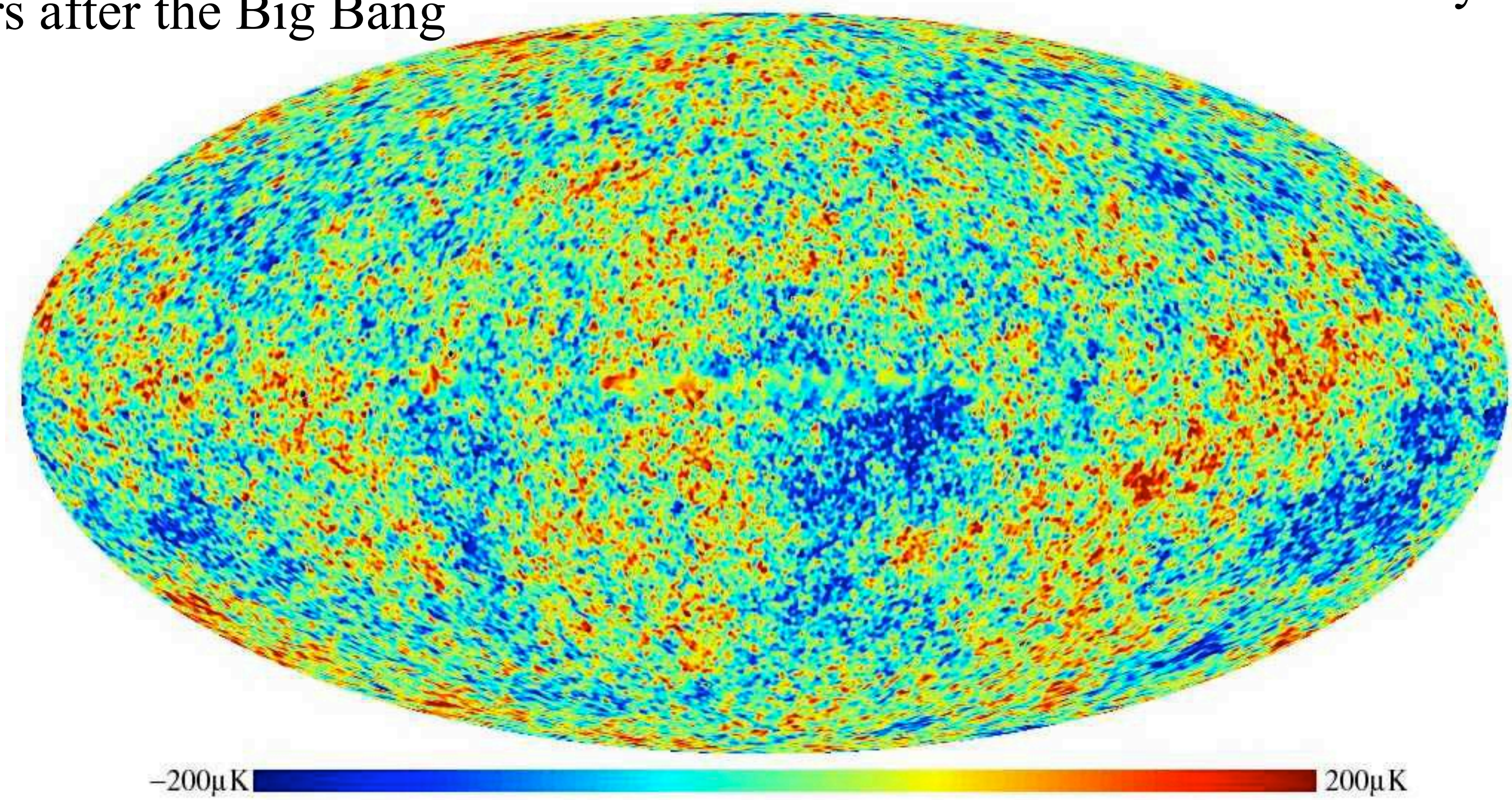


Conclusions: Galaxies contain a fairly uniform distribution of dark matter. We don't know what this stuff is.
The local density is 5.38E-28 kg/cm^3

Fluctuations in the Cosmic Background

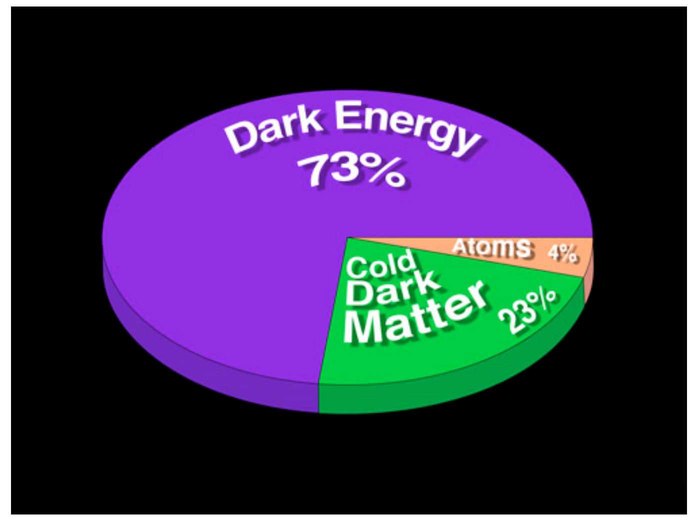
Image of the universe at about 379,000 years after the Big Bang

WMAP observatory



What we have learned from WMAP

- Within a 1% accuracy the Universe is 13.7 billion years old.
- We don't know what 96% of the Universe is made of.
- The first stars formed about 200 million years after the Big Bang.
- The picture of the background microwave radiation is from 379,000 years after the Big Bang.
- At the present it appears the Universe will expand forever, but since we don't know what dark energy is, this conclusion could change.



What are Dark Matter and Dark Energy?

- We don’t know.
- Dark energy actually acts like anti-gravity and is pushing the universe apart. We can tell this because distance supernova are moving away faster than they should.
- Dark matter is probably some type of undiscovered particle.
  - These Particles may interact by the weak force (they do interact by gravity)
  - People are looking for WIMPs (Weakly interacting massive particles). There is a chance they will be discovered at the LHC accelerator in CERN.

What comes next?

- There are attempts to extend the standard model to include gravity; these are called supersymmetric theories.
- These say that all fermions (which make up matter) and bosons (that transmit forces) have a corresponding partner boson (to go with our standard fermions) and fermion (to go with our standard bosons).
- Supersymmetric theories predict a whole set of new particles called s-particles, e.g. selectron, sneutrino, photino, Wino, and so on
- A new accelerator (Large Hadron Collider at CERN-Europe) may be able to produce some of these particles in the next two years.

Superstring Theory

- One of the most promising new theories is string theory. It says that the fundamental building blocks of nature are tiny (10^{-35} m) strings.
- The particles we observe in nature are difference ways for strings to vibrate.
- String theories require at least 11 dimensions.
- Gravity is weak because the graviton exists mostly in another dimension, but there is a slight overlap with us.
- String theory may be a theory of everything where all phenomena can be described by one equation.

Department of Physics and Astronomy

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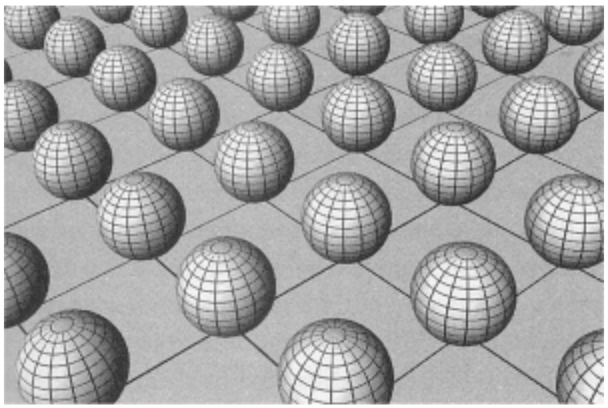
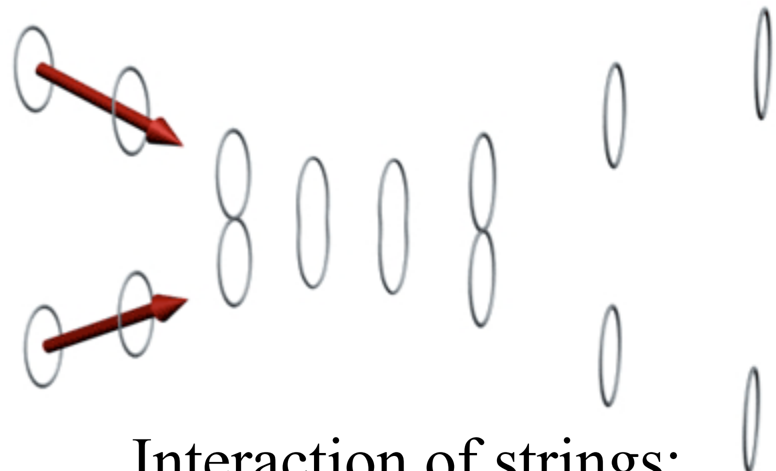
String Theory Pictures



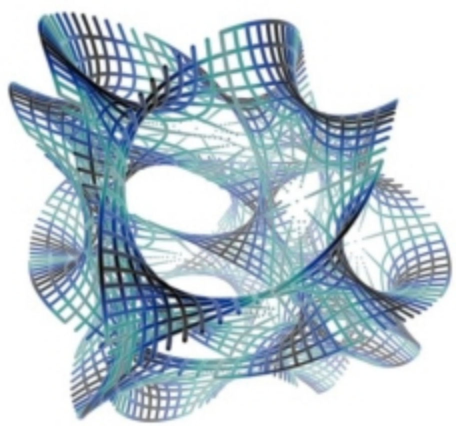
Extra dimensions



<u>Interaction of strings:</u>

The finite size (10^{-35}m) overcomes many of the problems with the interaction of point particles.

What one of the dimensions might look like. Calabi-Yau space



Problems with String Theory

- So far it has no predictions that can be tested by experiments. Is it even science?
- There is no explanation that is “better” than some other model.
- The landscape problem – String theory seems to predict a large number of universes with different fundamental constants. This may explain the anthropic principle (Weinberg) as to why our universe is finely tuned to allow life as we know it. Is this science?