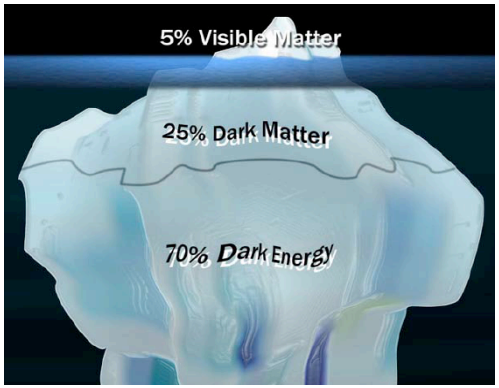
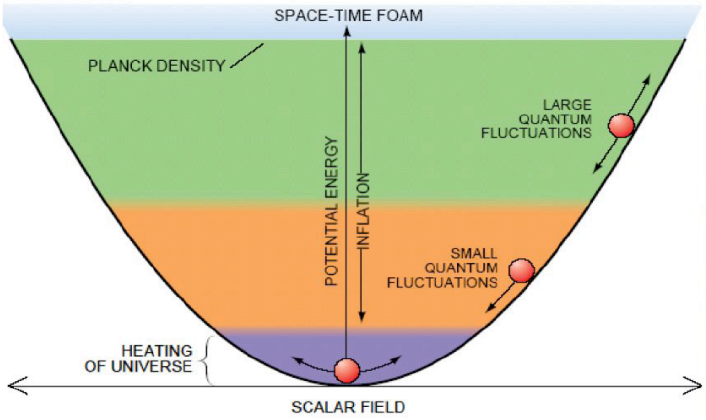
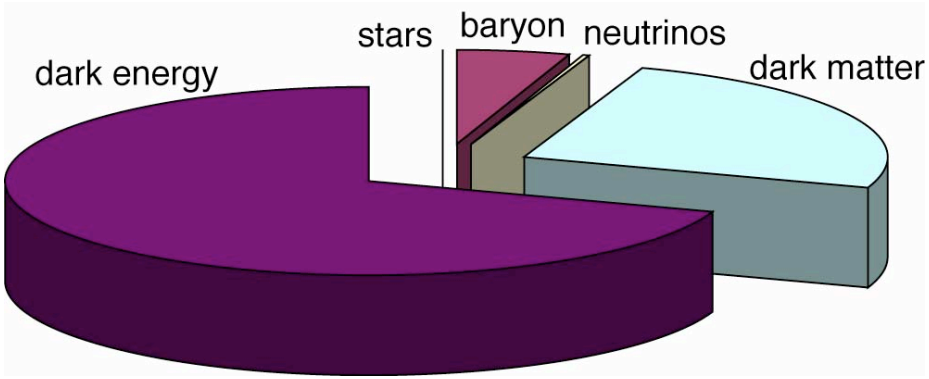
And on to the Big Bang

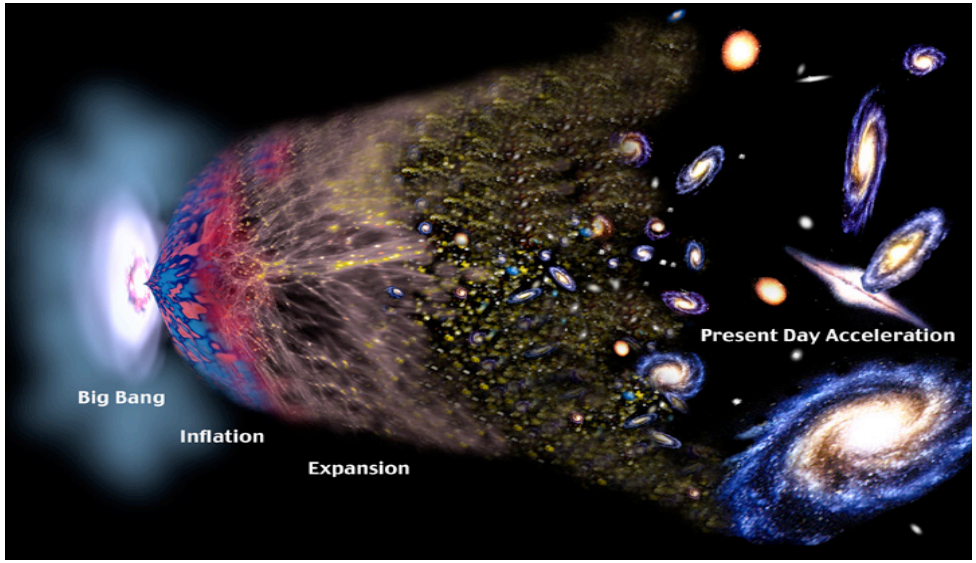
- The early universe was hot and dense; the realm of the highest-energy, shortest-distance theory we can hope to understand.
- In this regime, gravity is as strong as the other forces, and a quantum theory of gravity is required.
- What can cosmology tell us about particle physics, and vice versa?
- What is “dark matter” made of?
- Why is the cosmological constant small (but apparently non-zero?)?
- What happened in the early moments of the big bang? The Planck Era? What were the laws of physics in the early universe?
- Did the universe inflate at birth? What caused it to inflate?
- Is the expansion of the universe accelerating? What is the “Dark Energy”?

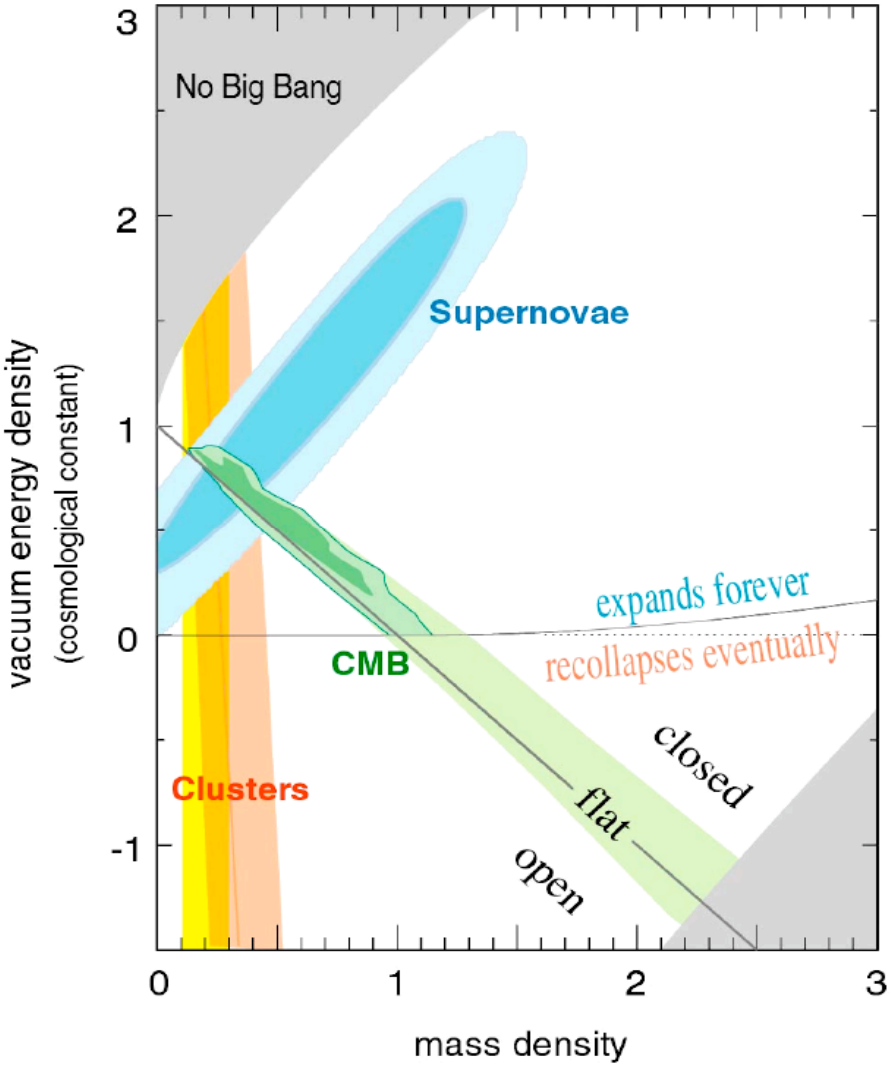




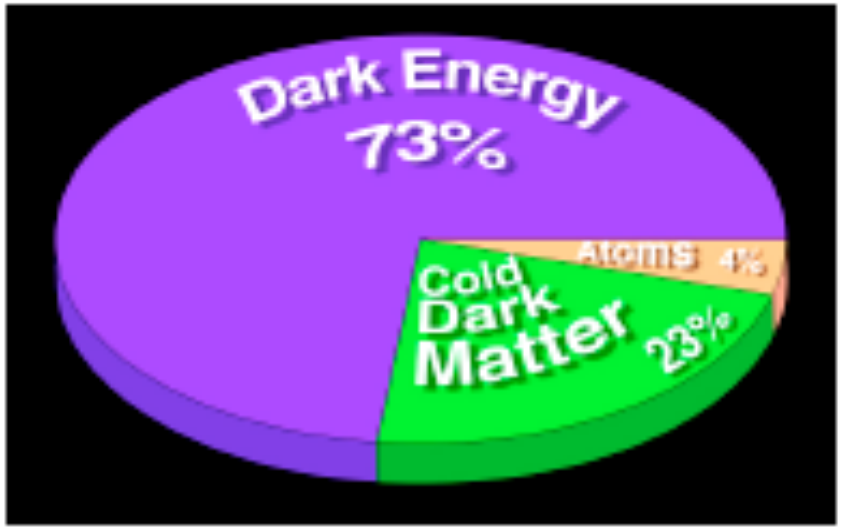
Dark Matter and Dark Energy







From Measurement to Understanding



Understanding of the physical nature of the dark matter, and especially dark energy, are among the most fundamental problems of physics today.

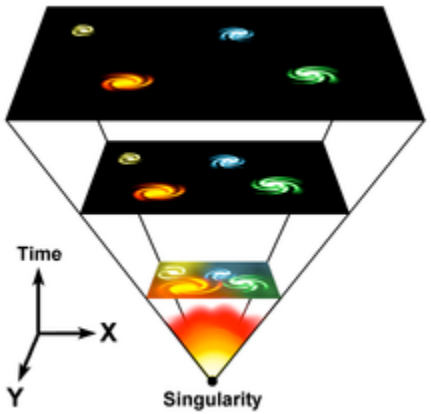
… And many have tried …

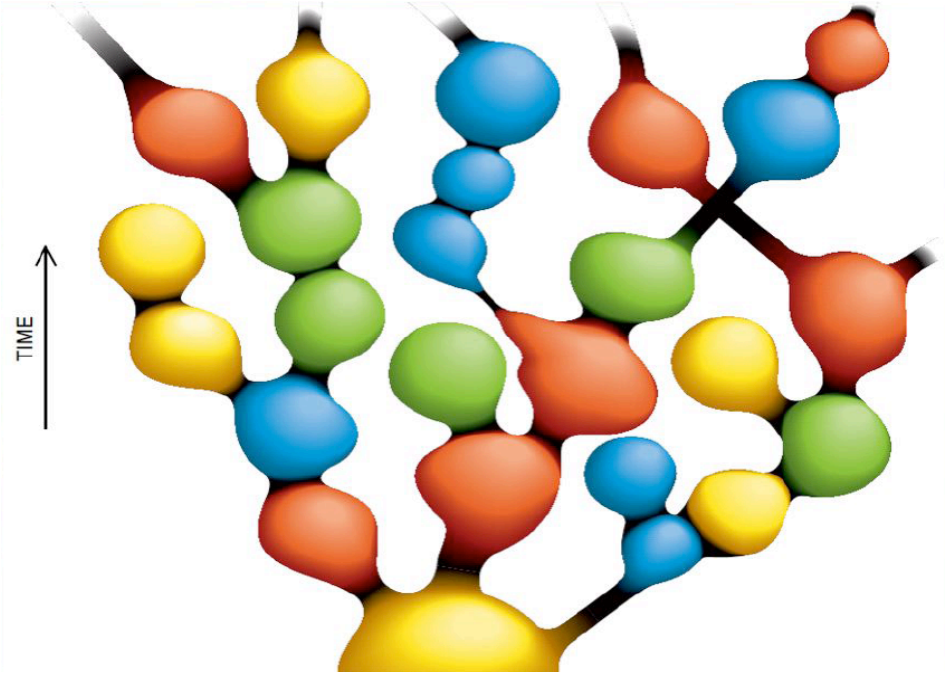
" 'Most embarrassing observation in physics' – that's the only quick thing I can say about dark energy that's also true."

Edward Witten

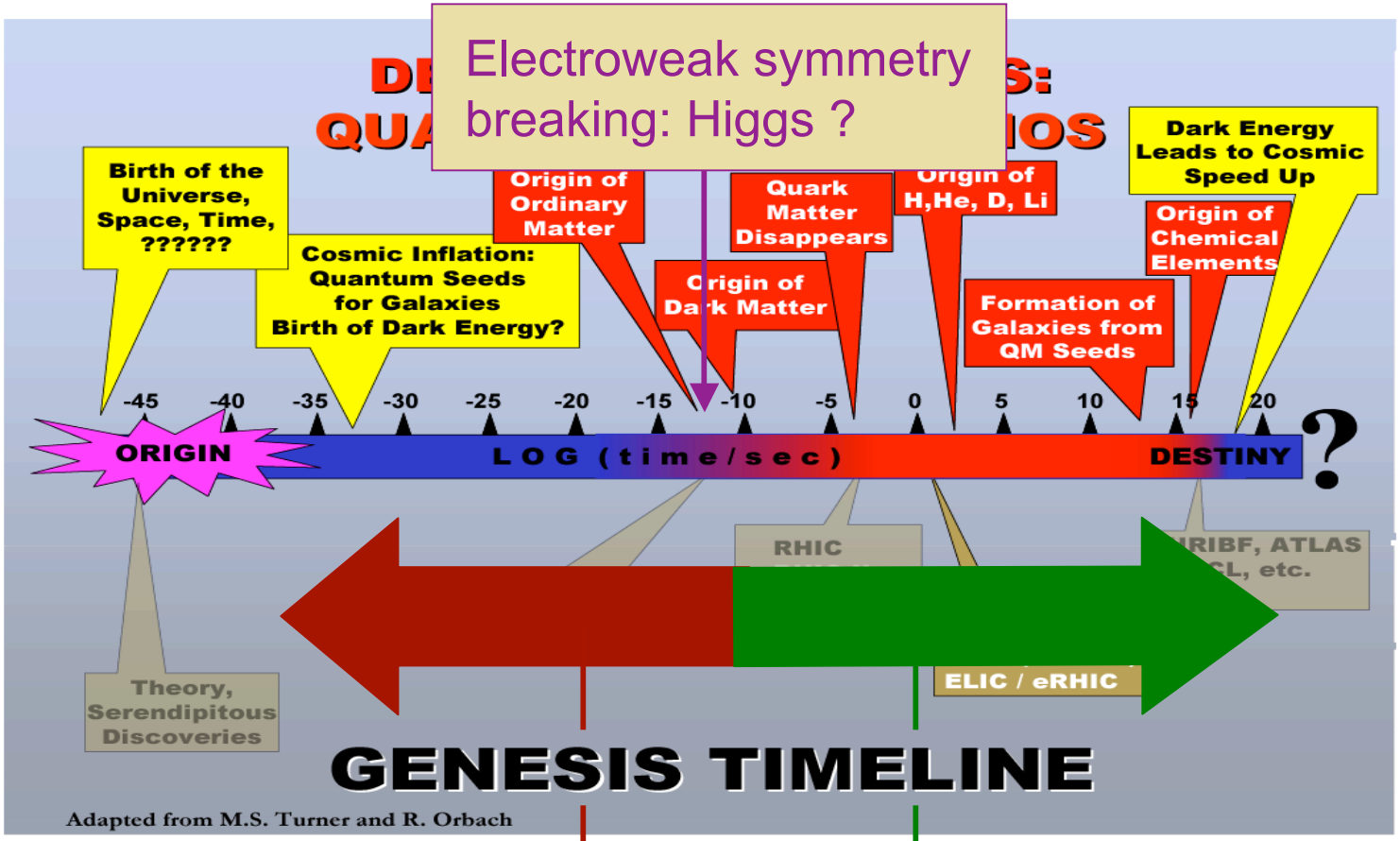
Beyond the Big Bang?

- What is the origin of space-time? Three spatial directions, and an arrow of time that began with the big-bang? Or are there more dimensions that we do not yet perceive? String theory requires 9 or 10 spatial dimensions!
- If only 3+1 dimensions, why? Is the dimensionality of space required to be that way, or emergent?
- Is the universe all that there is? Or are there other universes?
- Is there a time before the big bang?





Fundamental Symmetries & Cosmic History



Beyond the SM

SM symmetry (broken)

Some Big Questions about the SM

- How do the Z and W acquire mass and not the photon?
- What is M_H and how do we measure it?
- Why are there 3 and only 3 light “generations”? Why the “family” structure?
- Are the quark and lepton couplings “universal”?
- What explains the pattern of quark and lepton masses and mixing?
- What are the neutrino masses and mixing angles?
- Why do neutrinos have such small masses?
- What is the connection between quarks and leptons (GUTs?)
- Why are the known mass scales so different?
- $\Lambda_{QCD} \sim 0.2$ GeV << EW ~ 246 GeV << $M_{GUT} \sim 10^{16}$ GeV << $M_{PL} \sim 10^{19}$ GeV
- Why is $\sin\theta_W \sim 0.223$?
- How can we understand QCD in the non-perturbative region? Lattice?
- Why is charge quantized?
- Why is matter (protons) ~ stable?
- What is the nature of CPv in the SM?
- Why is the Universe made of matter? (CP violation)

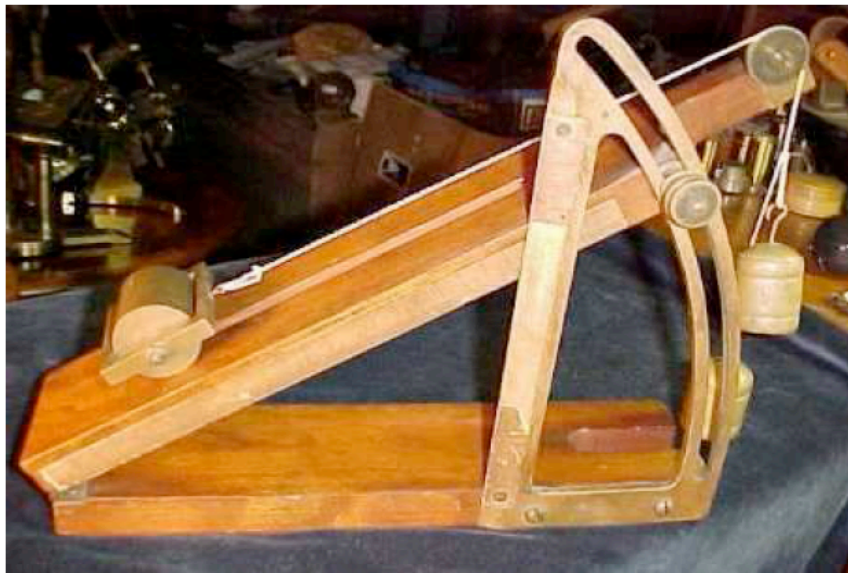
Even bigger questions

- What is beyond the Standard Model?
- Do “fundamental” fermions have substructure? Are they composite?
- Are Grand Unified Theories on the mark?
- How do we reconcile the “Hierarchy Problem”?
  - Supersymmetry? Technicolor?
- Is supersymmetry manifested in nature?
- How does gravity fit in with the strong, electromagnetic and weak forces?
- Is there a “fifth force”?
- Is there a true “Theory of Everything”? SuperStrings?
- What are the consequences for cosmology and the structure of the universe?
- What is “dark matter” made of?
- Why is the cosmological constant small (but apparently non-zero?)?
- What happened in the early moments of the big bang? The Planck Era?
- What is the ultimate fate of the universe?

Big questions and small questions

- Oy! So many big questions!
- For over 2000 years, “natural philosophers” asked lots of big questions: what is the world made of? What is time and space? What is the meaning of life? What is God?
- Not much progress in answering these big questions.

•Then Galileo started rolling carts down inclined planes, Tycho plotted the motion of the wandering stars, Darwin observed finches in a remote island chain, and Mendel started breeding pea plants.



Big questions and small questions

- The early modern scientists asked smaller questions, which bore much fruit (peas?) of understanding, leading surprisingly to deeper ways of understanding the big questions.
- Instead of reaching directly at the whole truth, at an explanation for the entire universe, its creation and present form, science tried to acquire partial truths in small measure, about some definable and reasonably separable groups of phenomena.
- “I attach more value to finding a fact, even about the slightest thing, than to lengthy disputations about the Greatest Questions that fail to lead to any truth whatever.” Galileo Galilei
- Balance grandeur and sweep of the Great Questions with our prospects for answering them – Chris Quigg
- In this course, we’ll get at the bigger questions by delving deeper into the unexplored corners of what we know from 20th century physics. Sometimes the questions won’t seem so big (what’s the Higgs?), but our Galilean intuition suggests that they may bear fruit.