Misc

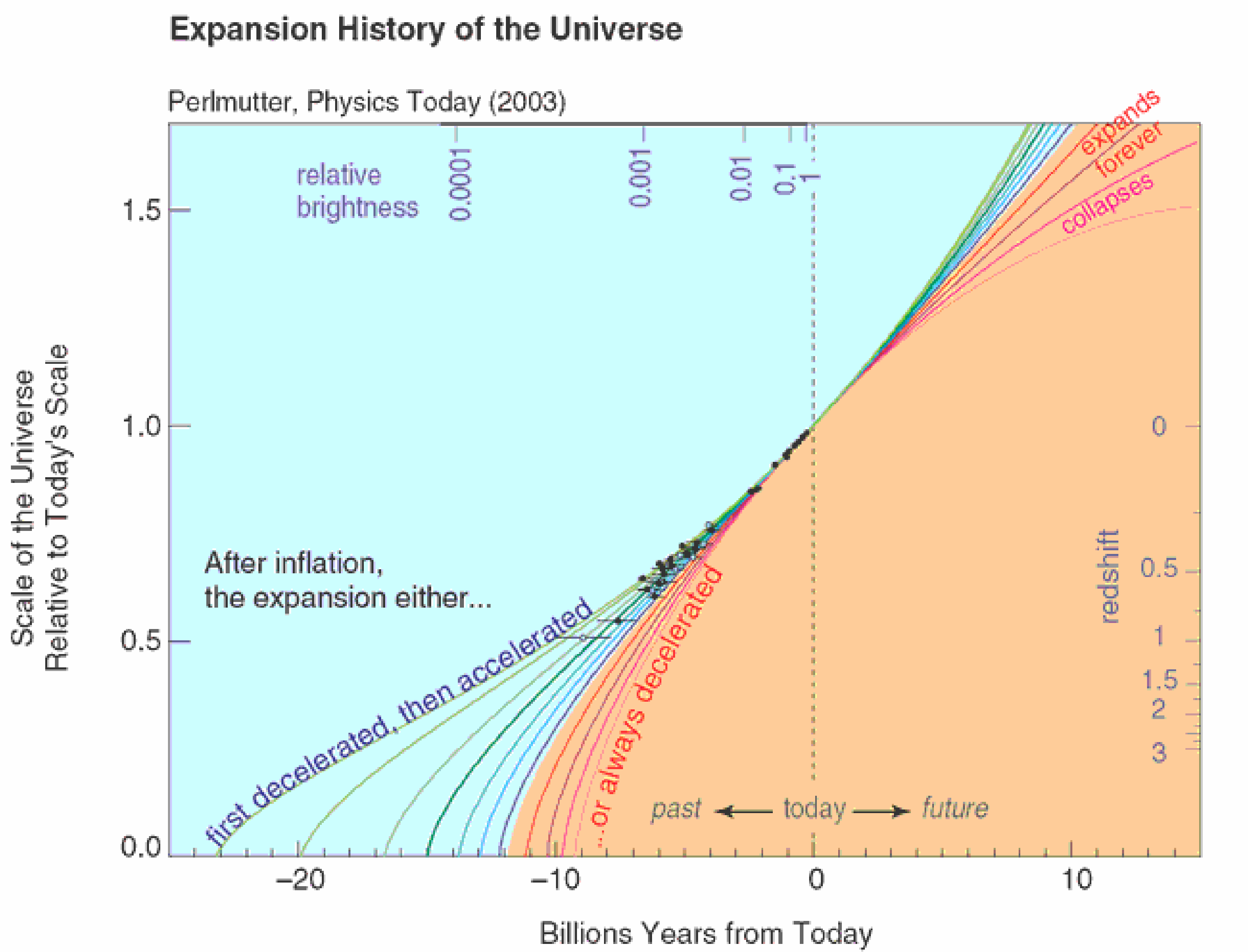
1. Today we will talk about age of the Universe (continuation from Friday lecture).

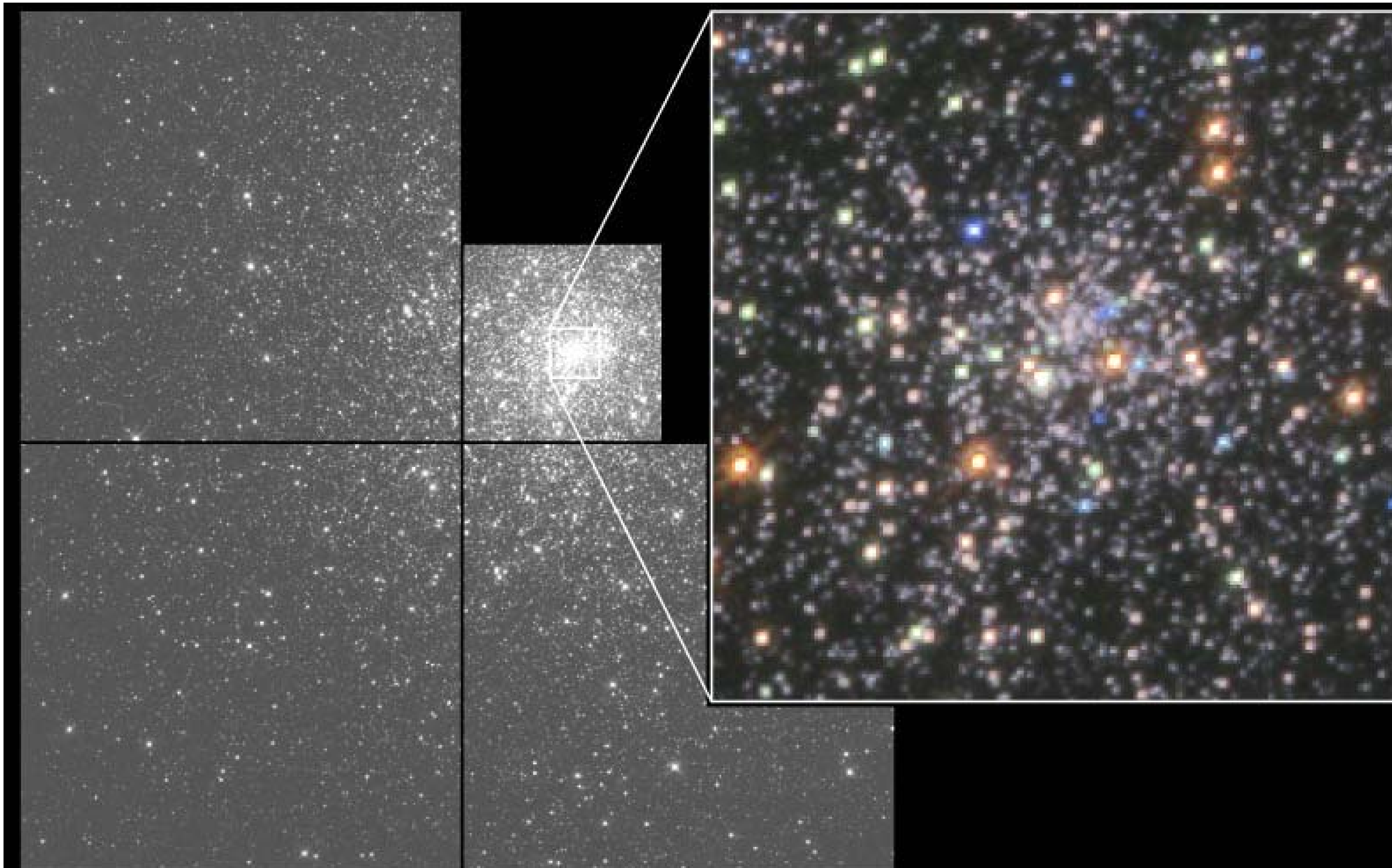
2. We will then talk about fundamental forces and early stages of evolution of the Universe (S 27-2 is the reading material for todays lecture.)

3. Labs – next week make-up lab week and we will continue CMB lab for those who have not had a chance to get measurements.

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

Scale factor vs. age of the Universe

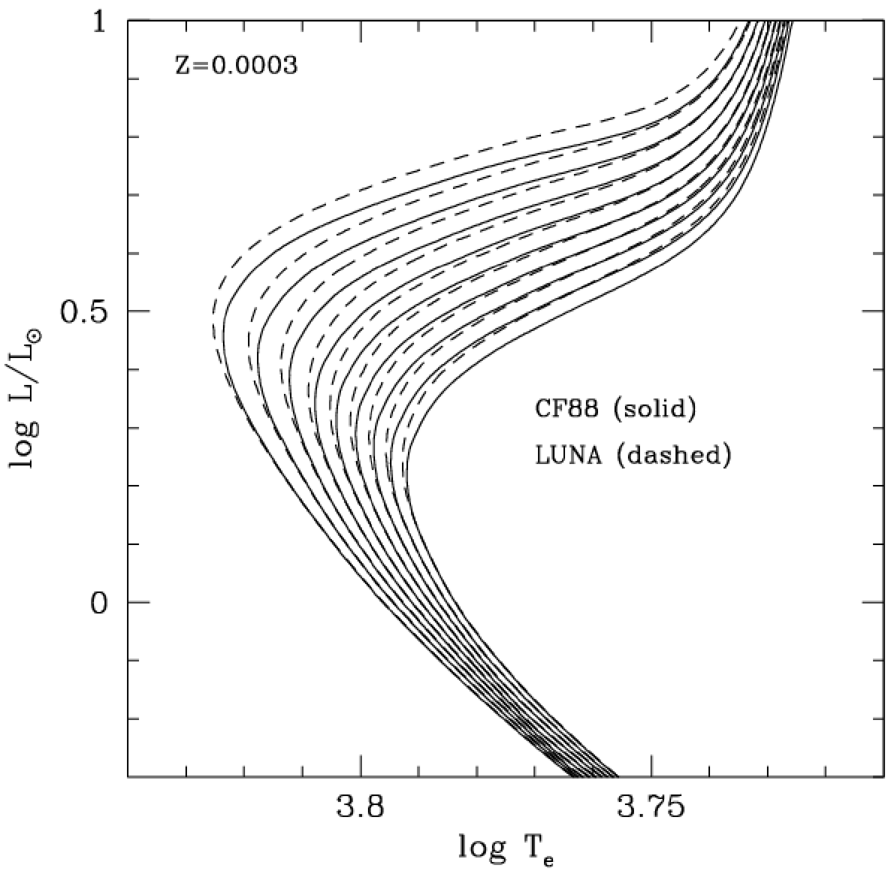


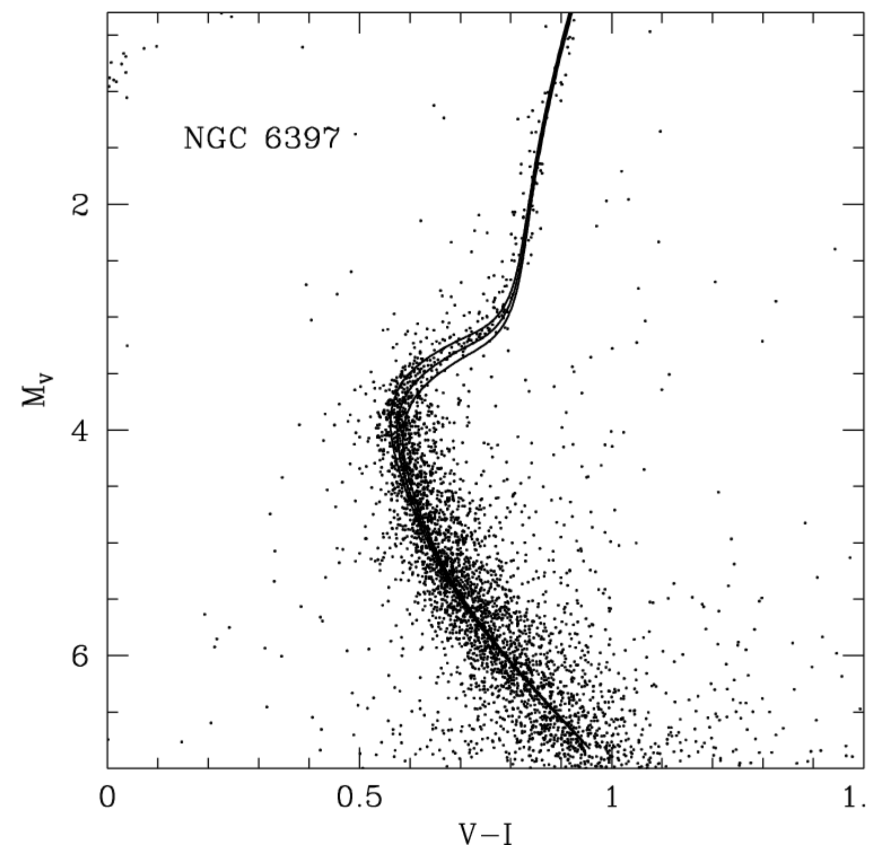


Globular Cluster M15 HST • WFPC2

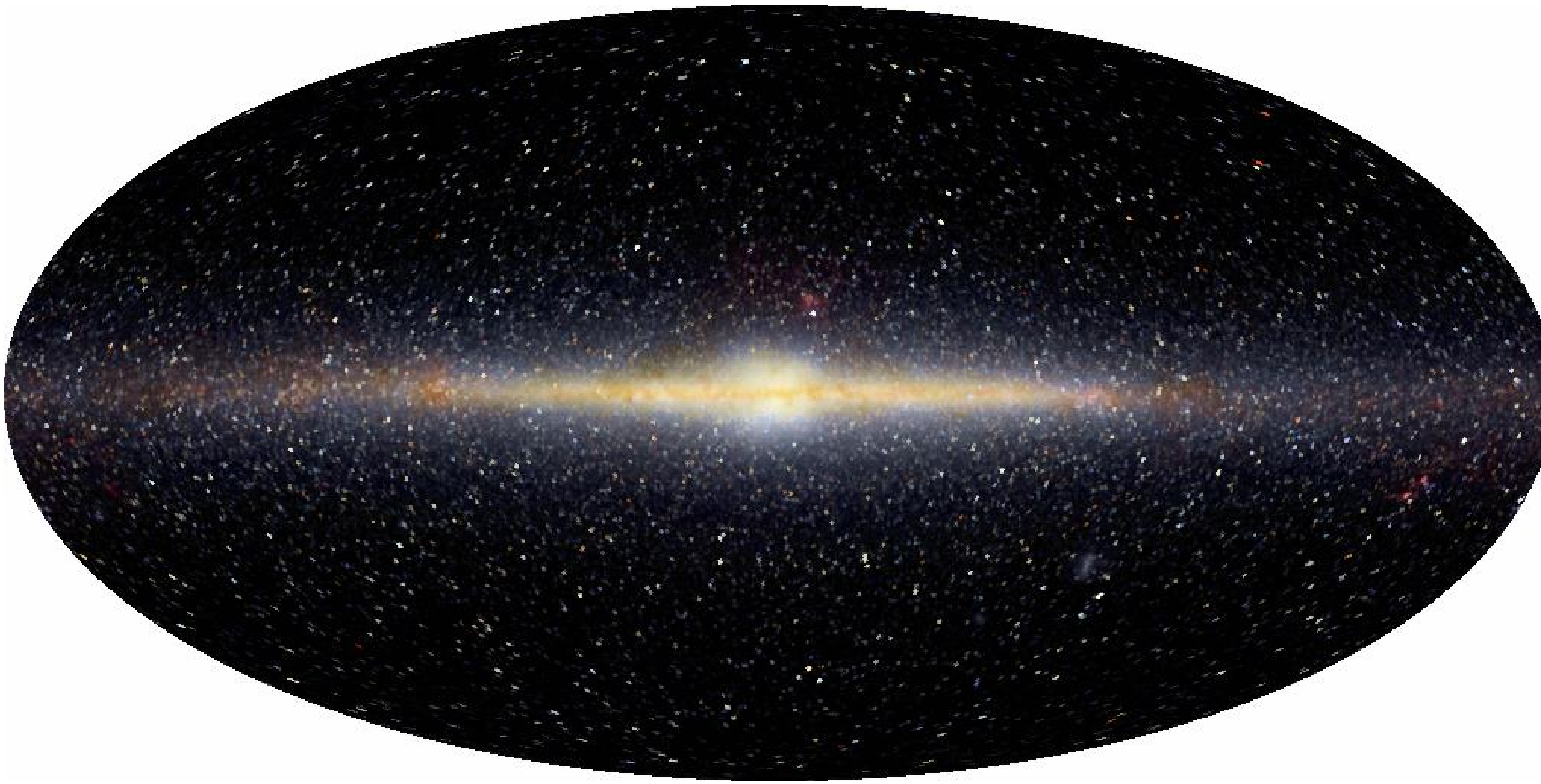
PRC95-06 • ST ScI OPO • November 1995 • P. Guhathakurta (UC Santa Cruz), NASA

Dating the age of stars in globular clusters

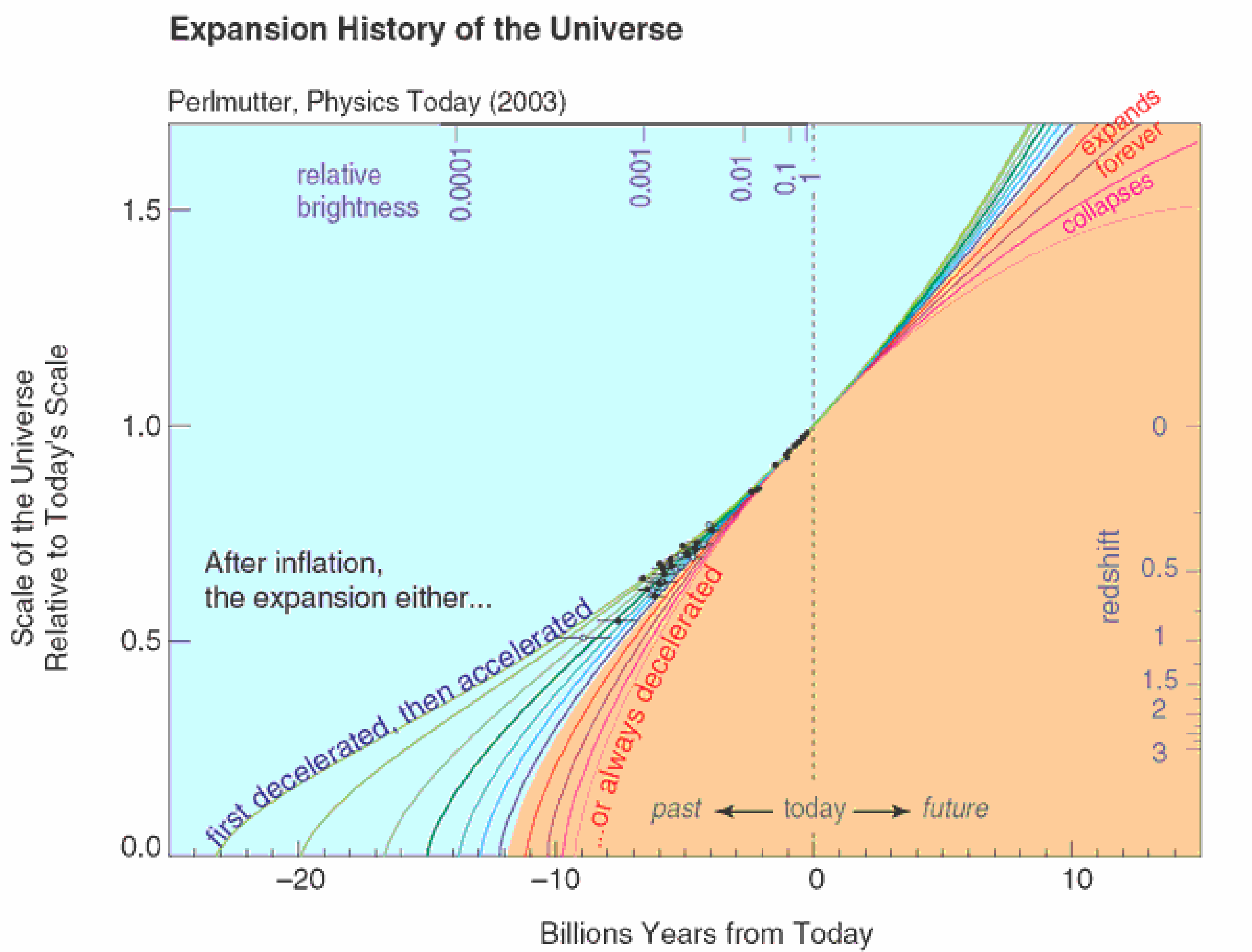




The age of the Milky Way disk:
~7-9 billion years



Future evolution of the Universe



If the universe expands forever…

- In ~10 billion years galaxies will use up their gas and stars will cease to form

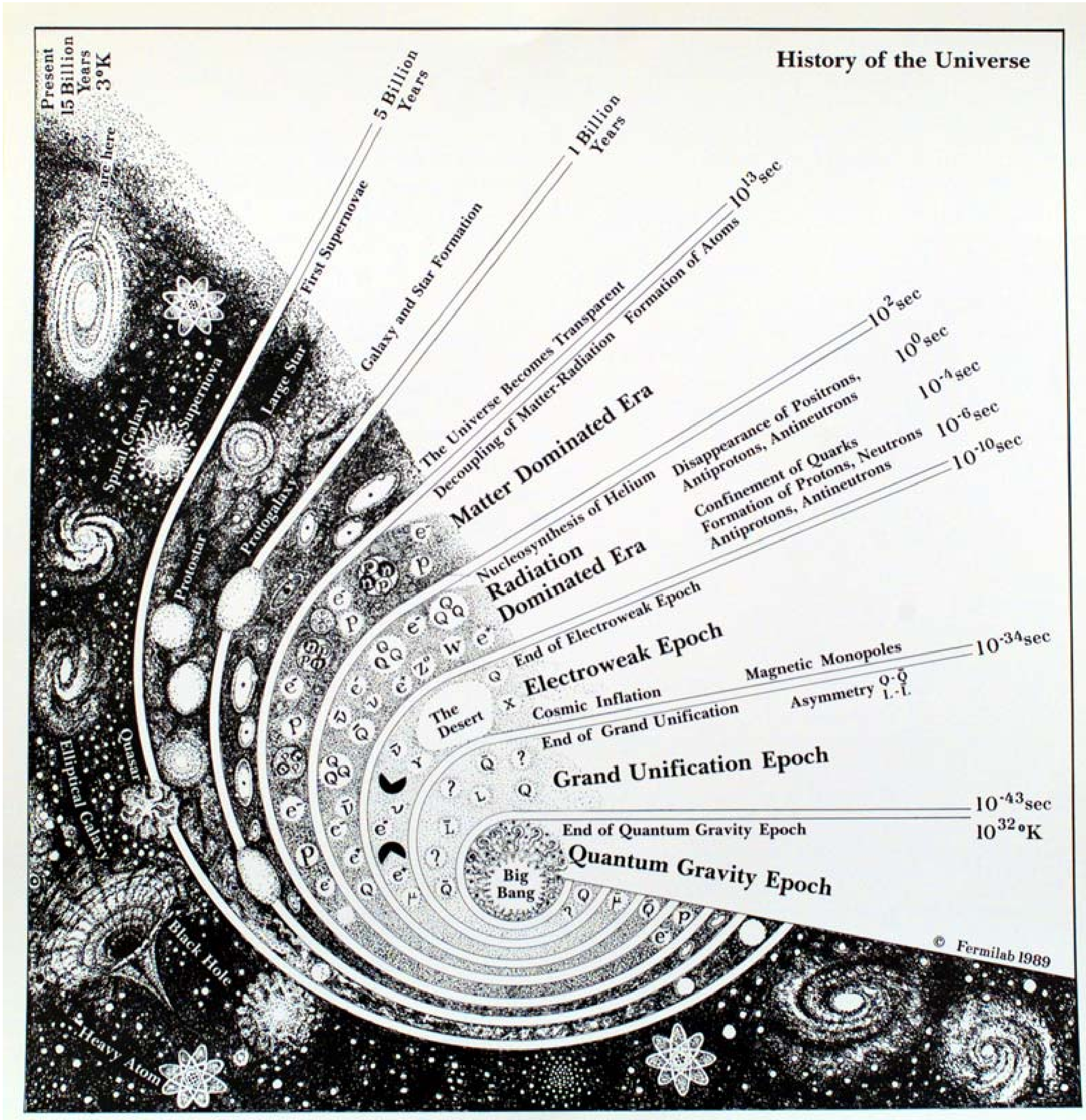
- In ~30 billion years, the last stars will die (will stop shining).

- In ~1000 billion years, most of the stellar remnants in galaxies will collapse into a central black hole

- In about 10^{40} years protons will decay, and the universe will become the "lepton desert". In 10^{110} years, all black holes will evaporate and galaxies will dissolve.

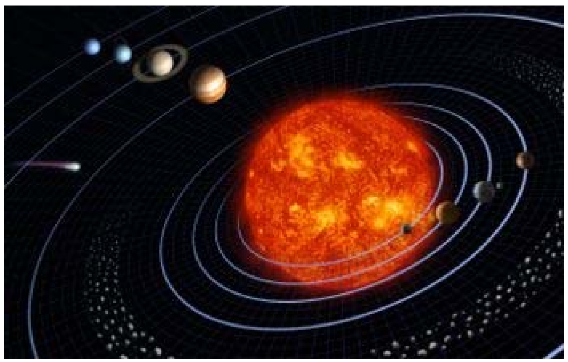
- At this point, the universe with very slowly moving electrons (some of them in blobs left over by stellar remnants), neutrinos, very low energy photons

Physical processes in the early Universe

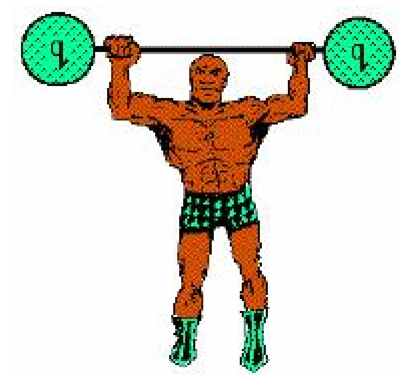


Fundamental forces

the constituents of the Universe can be described in terms of a menagerie of particles and four fundamental forces



gravity



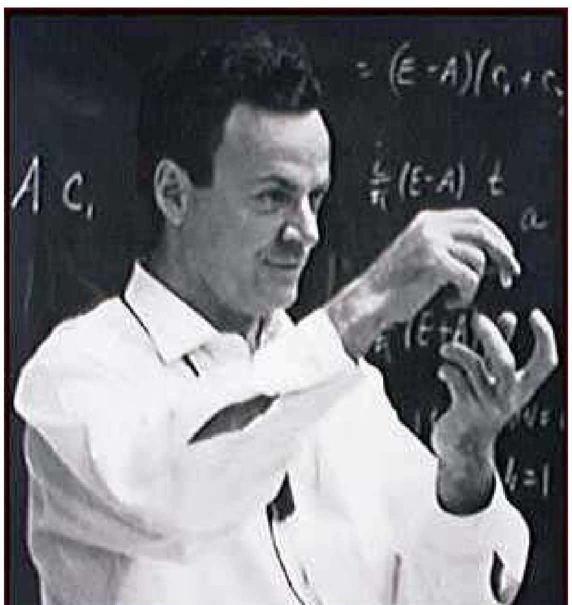
Strong force

electromagnetic force

weak force

quantum field theory
(aka quantum electrodynamics)

- Particles and forces between them can mathematically be described as fields – functions defined as a function of time and spatial coordinates.
- Forces are mediated by special particles (e.g., EM by photons) and propagate at the speed of light.



Richard Feynman

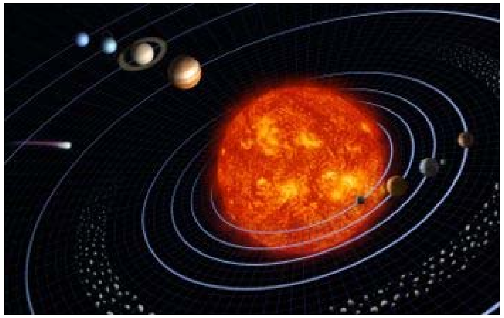
Julian Schwinger

Sin-Itiro Tomonaga

Elementary particles

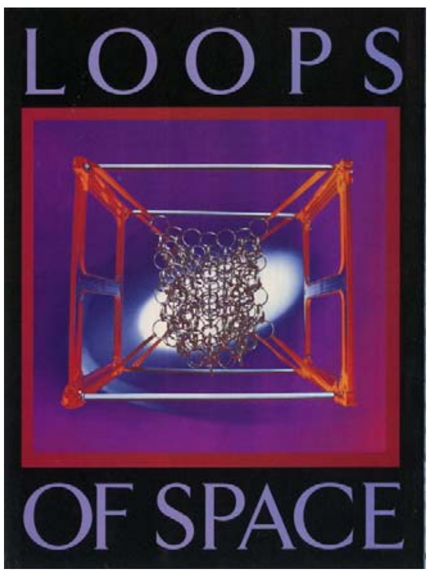
Particles have different properties in addition to charge and mass, such as "spin"

- *particles with integral spin (e.g., 1, -1) are called* ***bosons*** *(photons, gravitons)*
- *particles with half-integral spin (e.g., ½) are called* ***fermions*** *(electrons, protons, neutrons)*
- *fermions are particles which interact via exchange of bosons, the mediators of forces (i.e., EM, strong, weak, gravity forces)*



Gravitational force

- Einstein has identified gravity with distortion of space-time and has built a highly successful General Relativity theory based on this premise.

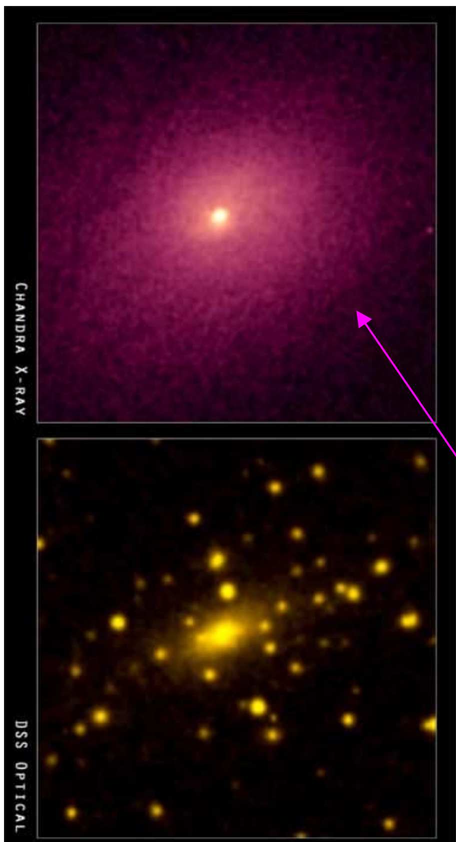


- According to quantum field theory, however, this is not the entire story and gravity should be a force, just like all the others, mediated by a hypothetical particle - the graviton (boson of spin 2).
- No quantum field theory of gravity, that could supersede GR, exists yet.

work on such theories is one of the major current efforts in theoretical physics (string theory, quantum loop theory)

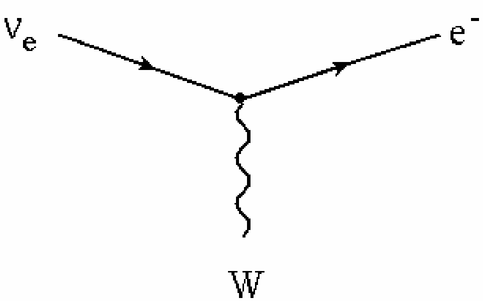
Electromagnetic force

- Force governing electrons in atoms and properties of various elements and materials.
- Much stronger than gravity, but is irrelevant at large cosmic scales, because cosmic bodies tend to be neutral on average. It’s not always true, but almost always.
- Photon (quantum of EM radiation) is the force carrier in electromagnetic interaction.
- EM interactions are the main source of our observations of cosmic phenomena.



EM interactions between protons, He nuclei and electrons in clusters of galaxies result in X-ray photons that we detect with the telescopes like the Chandra space telescope.

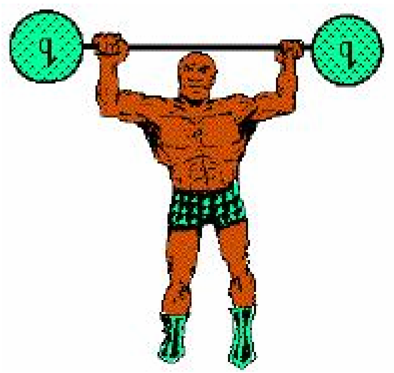
Weak force

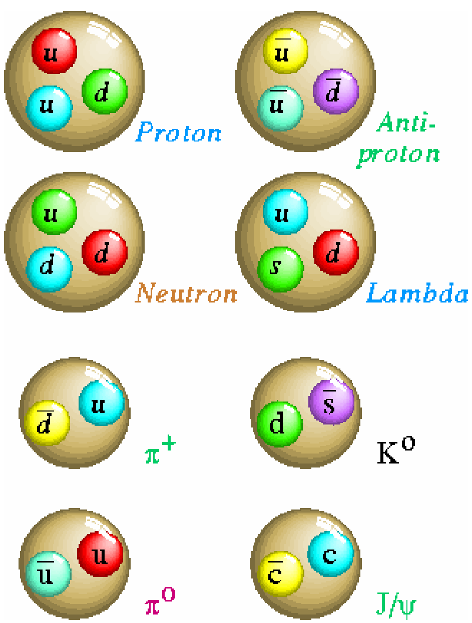


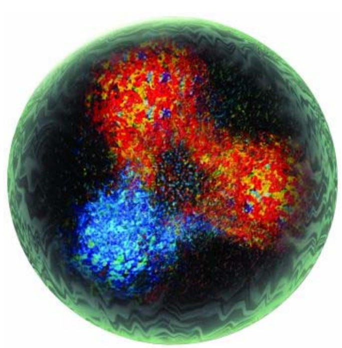
- As the strong force, weak force also acts only at small nuclear scales
- Unlike other forces it can change the nature of interacting particles (i.e., interacting particles can be transformed into different particles by this force)
- There are particles, neutrinos, that interact with other particles only via weak force. Because of this, it is very difficult to detect them, but there are ~ten billion neutrinos generated by nuclear reactions in the Sun passing through your bodies every second!
- Enrico Fermi formulated a theory of weak interactions and postulated existence of neutrinos

"The chances of a neutrino actually hitting something as it travels through all this howling emptiness are roughly comparable to that of dropping a ball bearing at random from a cruising 747 and hitting, say, an egg sandwich." – Douglas Adams

Strong force





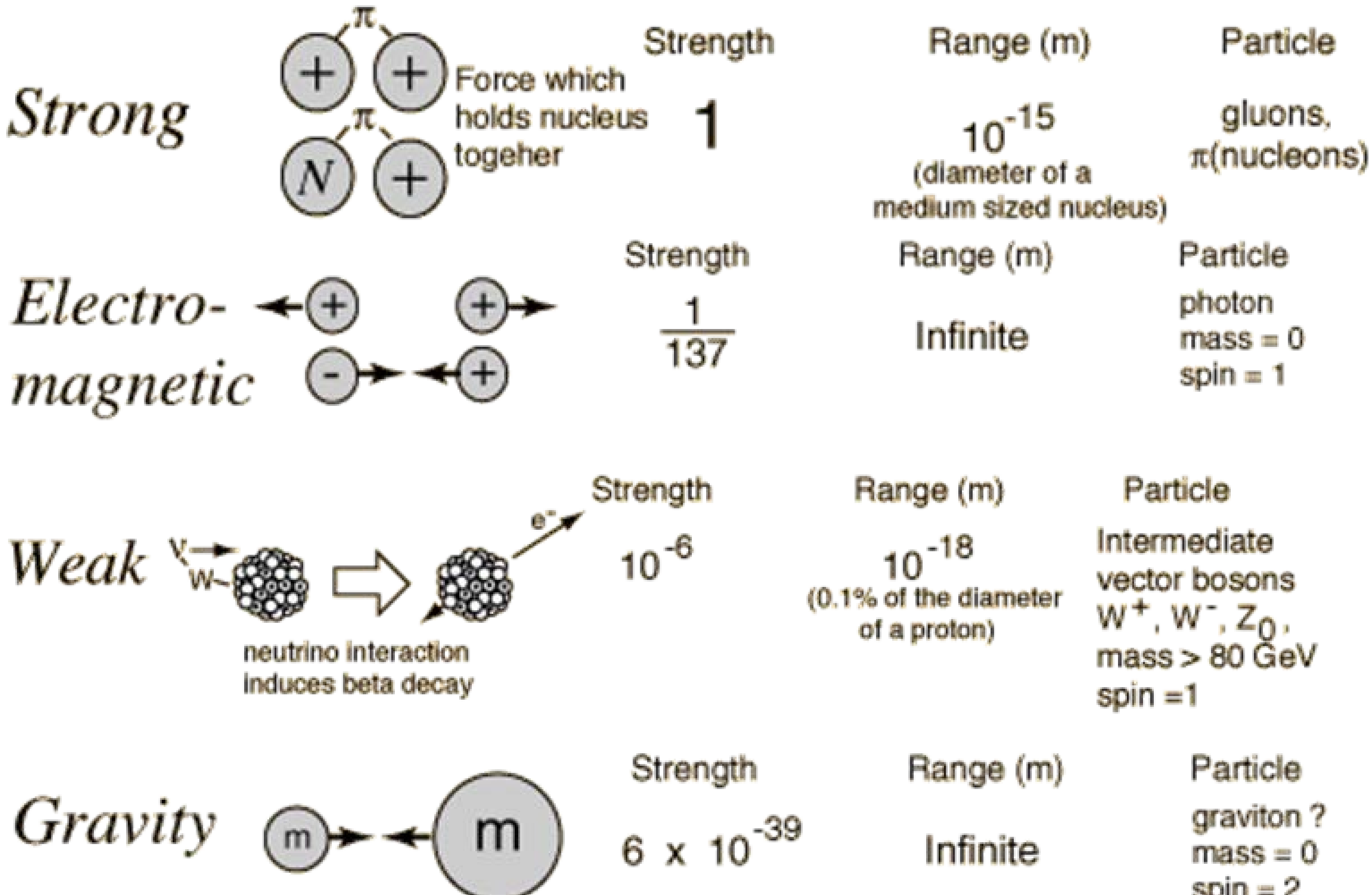


- Much stronger than the EM force but is only strong at small separations (comparable to the size of atomic nuclei),

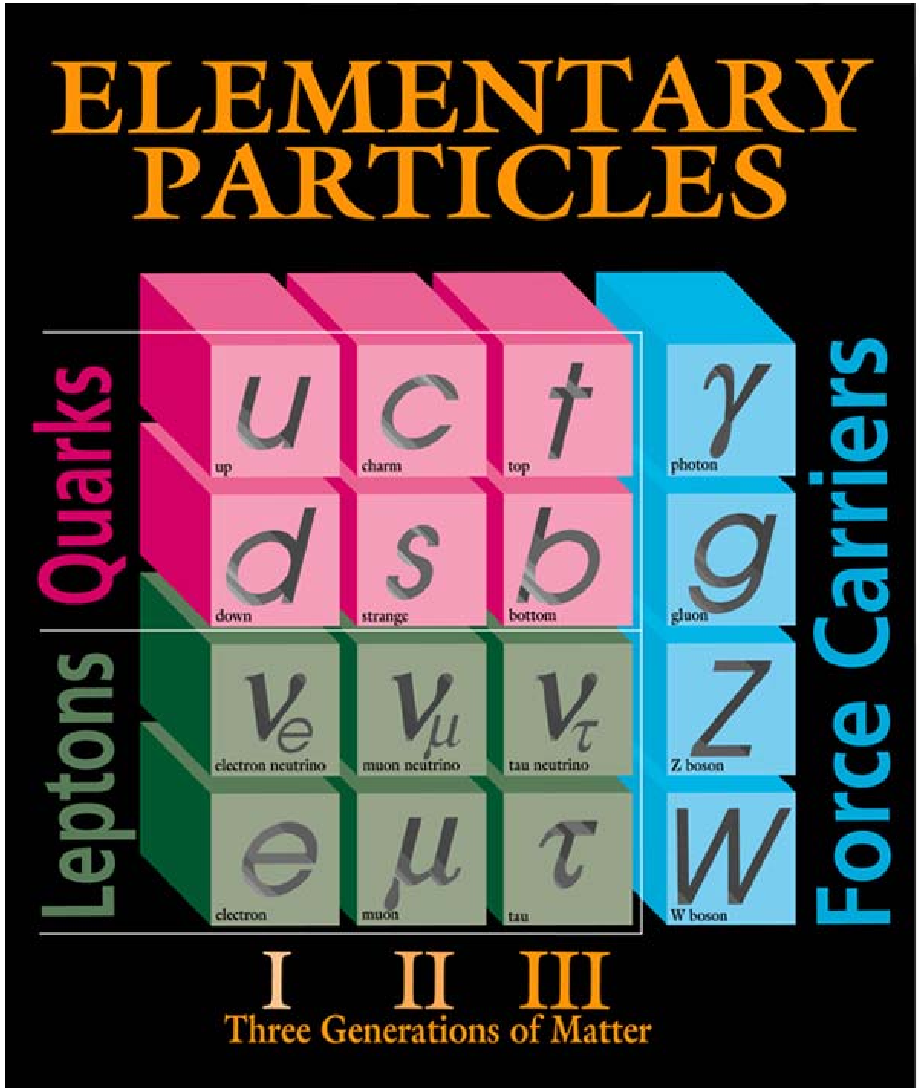
  this force can overcome repulsive force between positively charged protons binding them in nuclei

- at larger separations EM force is stronger.
- Protons and neutrons are actually made up from more fundamental particles, called *__quarks__*
  - *quarks have spins of ½ like fermions, but charges of 2/3 and -1/3. They also have other properties which distinguishes different types of quarks.*
  - *triplets of quarks are bound in protons and neutrons by the strong force.*
  - *quarks interact via mediator particles of strong force called __gluons__*

The hierarchy puzzle: very different relative strengths of the four fundamental forces



Despite the apparent complexity
and large variety of particles there are simple
foundations and underlying symmetries

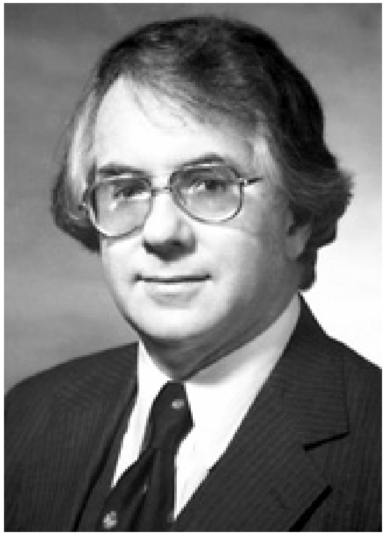


+ graviton

Unification of electromagnetic and weak forces

- In 1960s, Glashow, Salam, and Weinberg came up with a theory which explained both EM and weak force as a manifestation of a single unified force
- This worked if one assumed that quarks and leptons have negligible mass, which would be true if all of their energy was in the form of energy of their motions and their rest mass is not important.
- This is true if particles have a lot of kinetic energy of motions and move with velocities close to the speed of light

Steven Weinberg



Sheldon Glashow

Abdus Salam