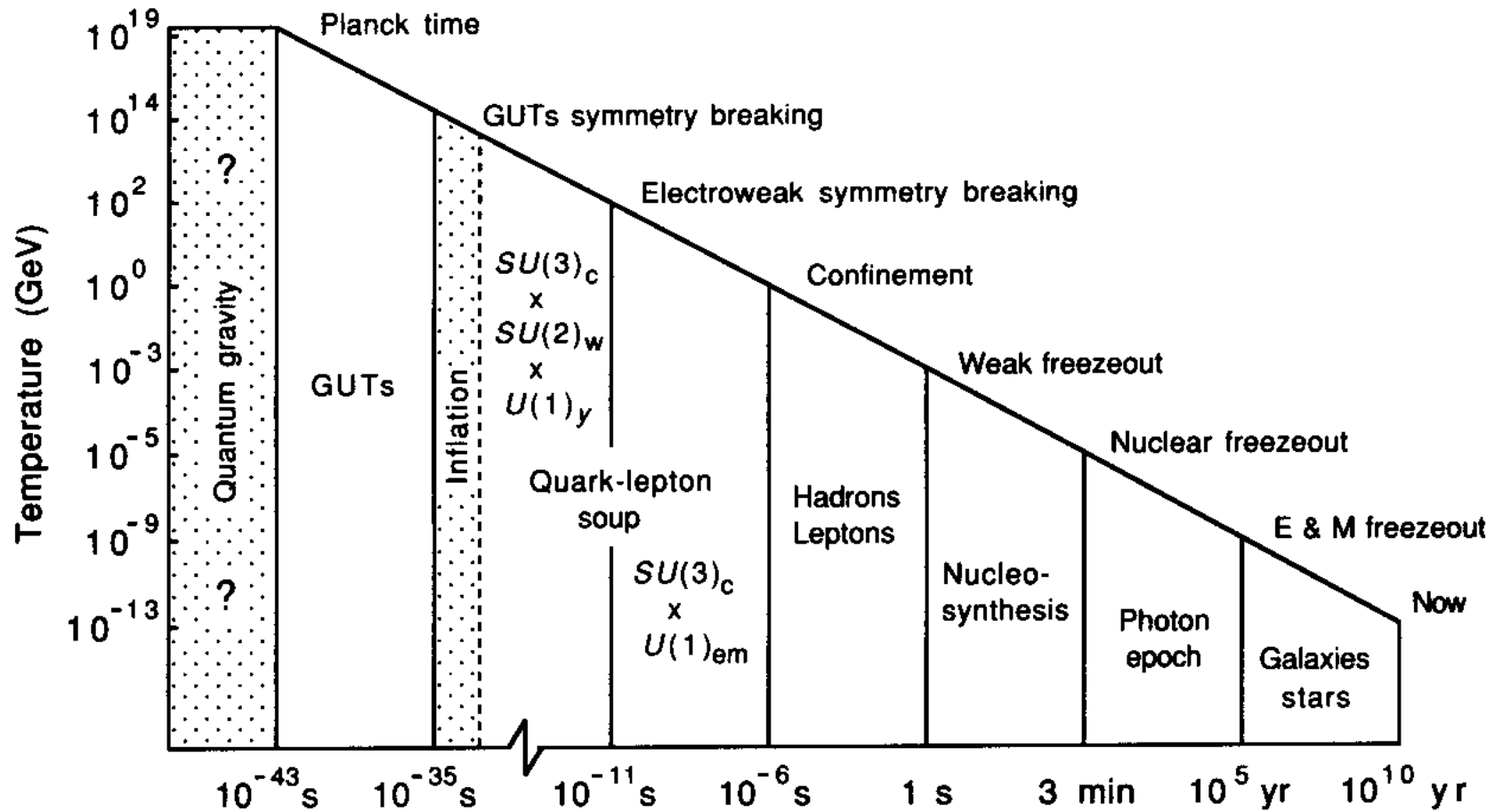


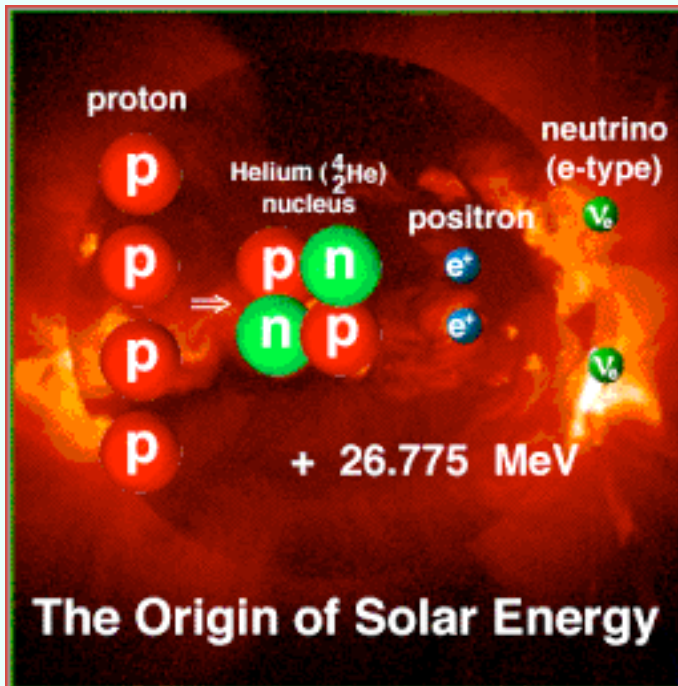
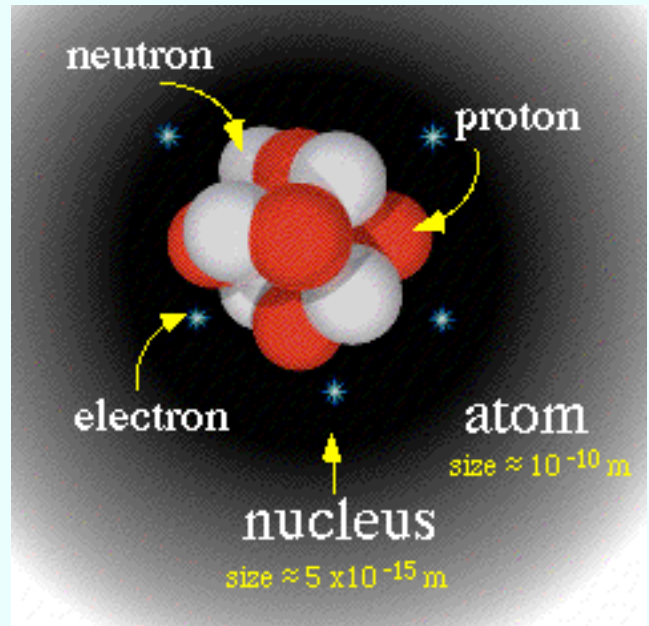
Time Scales



Atomic Nucleus

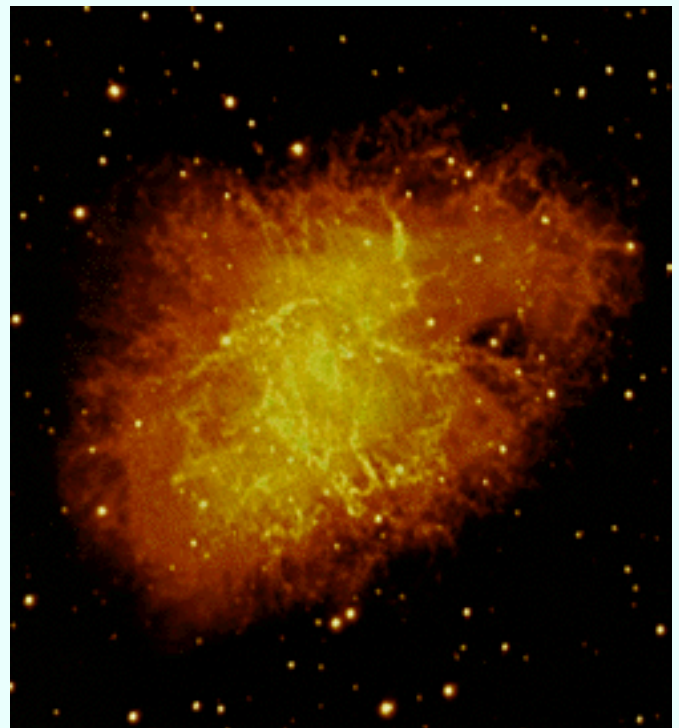
The Core of Matter, the Fuel of Stars

Nuclear matter
Hadronic matter



Energy production
In stars

Nature of Matter in
the Universe:
Probing the Origins



Nuclear Physics - A Brief History

- 1896 - discovery of radioactivity by Becquerel
- 1898 - separation of Radium by Maria and Pierre Curie
discovery of α , β , γ rays
- 1911 - nucleus as a central part of an atom - Rutherford
- 1920 - nuclear radii measurements by Chadwick
- 1928 - theory of alpha decay by Gamow
- 1929 - cyclotron (Lawrence)
- 1932 - discovery of neutron by Chadwick
- 1933 - Fermi theory of beta decay
- 1935 - nuclear force through meson exchange - Yukawa
- 1937 - neutron spin is half (Schwinger)
- 1938 - stars are powered by nuclear fusion (Bethe Critchfield)
- 1939 - nuclear fission (Hahn, Strassman, Meitner)
- 1942 - first self-sustaining fission reaction (Fermi)
- 1945 - atomic bomb (Oppenheimer)
- 1948 - Big Bang nucleosynthesis (Bethe and Gamow)
- 1948 - decay of the neutron (Snell and Miller)
- 1949 - nuclear shell model (Mayer, Jensen)
- 1952 - hydrogen bomb (Teller)
- 1956 - experimental evidence for neutrino (reines, Cowan)
- 1957 - parity violation (Lee, Yang, Wu)
- 1964 - Quarks (Gell-Mann, Zweig)
- 1964 - Flavor symmetry and charm (Bjorken, Glashow)
- 1969 - intrinsic structure of the proton (SLAC)
- 1972 - Quantum Chromodynamics (Fritsch, Gellmann)
- 1974 - charm quark (Ting, Richter)
- 1977 - bottom quark (Fermilab)
- 1980 - measurement of gluon spin (DESY)
- 1994 - top quark (Fermilab)
- 1996 - Darmstadt - element 112
- 2000 - tau neutrino (Fermilab)
- 2001 - neutrino oscillations (Super-Kamiokande, SNO)

THE SCIENTIFIC AGENDA (FUNDAMENTAL QUESTIONS)

What is the structure of the nucleon? Protons and neutrons are the building blocks of nuclei and neutron stars. But we now know that these nucleons are themselves composite objects having a rich internal structure. Connecting the observed properties of the nucleons with the underlying theoretical framework provided by QCD is one of the central problems of modern science.

- How do the nucleon-based models of nuclear physics with interacting nucleons and mesons arise as an approximation to the quark-gluon picture of QCD?
- In probing ever-shorter distances within the nucleus, at what point must the description in terms of nucleons give way to a more fundamental one involving quarks and gluons?
- Does the nuclear environment modify the quark-gluon structure of nucleons and mesons?
- What is the confinement mechanism?
- What is the microscopic (QCD) origin of the NN interaction?

What is the structure of nucleonic matter? A central goal of nuclear physics is to explain the properties of nuclei and of nuclear matter. The coming decade will focus especially on unstable nuclei, where we expect to find new phenomena and new structure unlike anything known from the stable nuclei of the world around us. With new theoretical tools, we hope to build a bridge between the fundamental theory of strong interactions and the quantitative description of nuclear many-body phenomena, including the new and exotic properties we expect in unstable nuclei and in neutron stars.

- What are the limits of nuclear existence?
- What is the microscopic mechanism of nuclear binding?
- How do weak binding and extreme proton-to-neutron asymmetries affect nuclear properties?
- How do the properties of nuclei evolve with changes in proton and neutron number, excitation energy and angular momentum?
- What are the phases of nucleonic matter?
- How can the symbiosis of nuclear physics and other subfields be exploited to advance understanding of all many-body systems?

THE SCIENTIFIC AGENDA (FUNDAMENTAL QUESTIONS)

What are the properties of hot nuclear matter? The quarks and gluons that compose each proton and neutron are normally confined within the nucleon. However, QCD predicts that, if an entire nucleus is heated sufficiently, individual nucleons will lose their identities, the quarks and gluons will become “deconfined,” and the system will behave as a plasma of quarks and gluons. With the Relativistic Heavy Ion Collider (RHIC), the field’s newest accelerator, nuclear physicists are now hunting for this new state of matter.

- What are the phases of matter formed when ordinary nuclei are heated to the very high temperatures at which quarks and gluons become deconfined from the nucleons and mesons? What is the origin of confinement?
- What are the properties of the QCD vacuum and what are its connections to the masses of the hadrons? What is the origin of chiral symmetry breaking?
- What are the experimental signatures for a transition to new phases in relativistic heavy-ion collisions?
- What are the implications for the analogous epoch in the Big Bang?

What is the nuclear microphysics of the universe? A great many important problems in astrophysics—the origin of the elements; the structure and cooling of neutron stars; the origin, propagation, and interactions of the highest-energy cosmic rays; the mechanism of core-collapse supernovae and the associated neutrino physics; galactic and extragalactic gamma-ray sources—involve fundamental nuclear physics issues. The partnership between nuclear physics and astrophysics will become ever more crucial in the coming decade, as data from astronomy’s “great observatories” extend our knowledge of the cosmos.

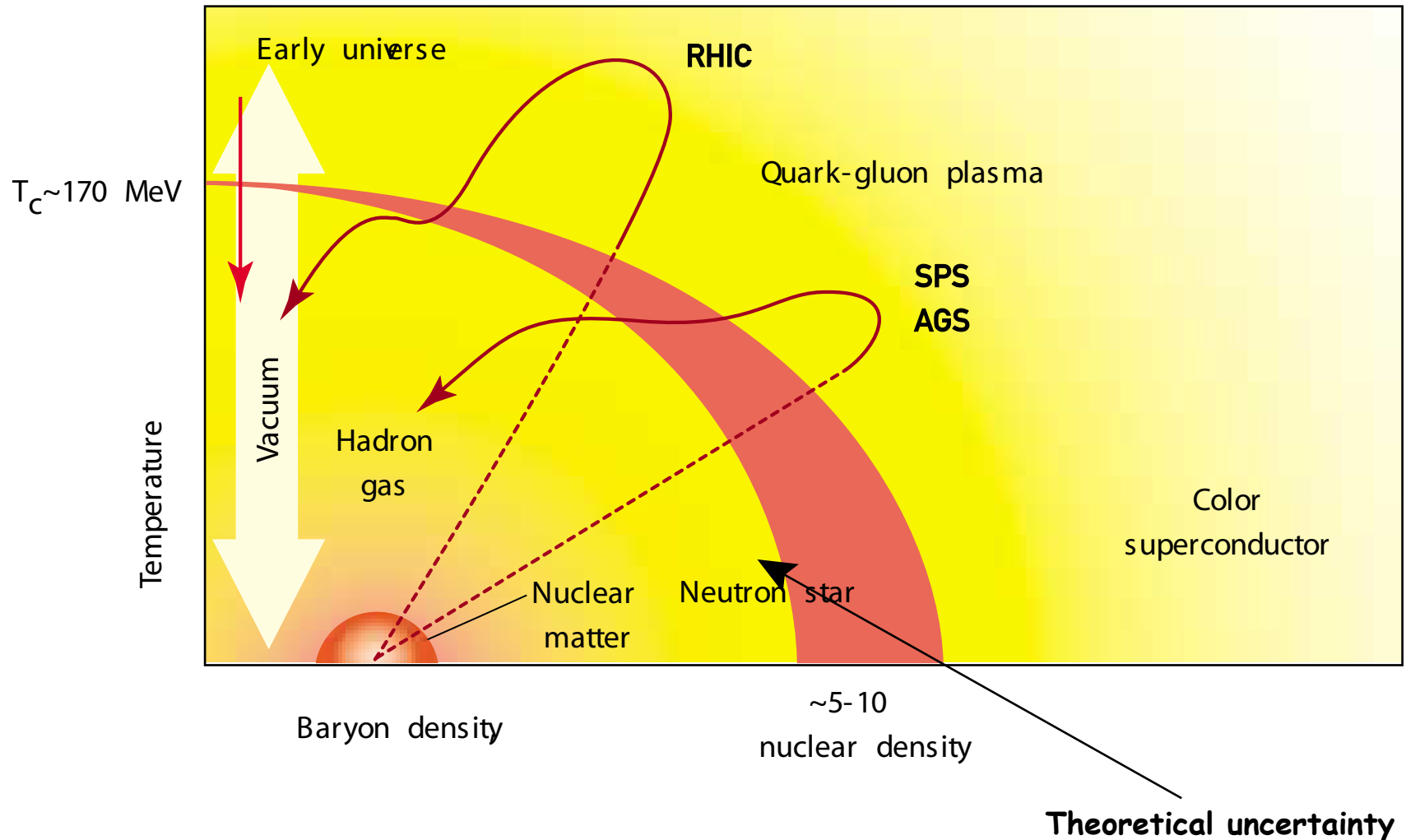
- How much “ordinary” matter is there in the universe, and what is the remainder made up of?
- How old is the universe?
- What can studies of neutrinos from supernovae reveal about the properties of neutrino “families”? What is the nature of neutrino mixing?
- What is the mechanism of stellar evolution, including the mechanism responsible for supernova explosions?
- What is the quantitative origin of the chemical elements in the Big Bang and continuing to the supernovae we observe in our galaxy and elsewhere?
- What is the mechanism of energy generation in stars?

THE SCIENTIFIC AGENDA (FUNDAMENTAL QUESTIONS)

What is to be the new Standard Model? The resolution of the solar and atmospheric neutrino puzzles by the Sudbury Neutrino Observatory (SNO) and SuperKamiokande—the long-sought demonstration that our current Standard Model is incomplete—opens up possibilities for exciting discoveries in the next decade. One such possibility is the observation of neutrinoless double beta decay, which would signal the violation of a crucial Standard Model symmetry. Precision experiments by nuclear physicists deep underground and at low energies are proving to be an essential complement to searches for new physics in high-energy accelerator experiments.

- What are the low-energy manifestations of physics beyond the Standard Model? How can precision experiments in nuclear physics reveal them?
- Is neutrino its own antiparticle?
- What is the origin of the baryon number asymmetry of our universe?
- What is the weak component of the NN interaction?

The Phases of QCD



deconfinement (the quarks and gluons become free of their bondage in baryons and mesons)

chiral symmetry restoration (the masses of the quarks are reduced to their bare quarks values)