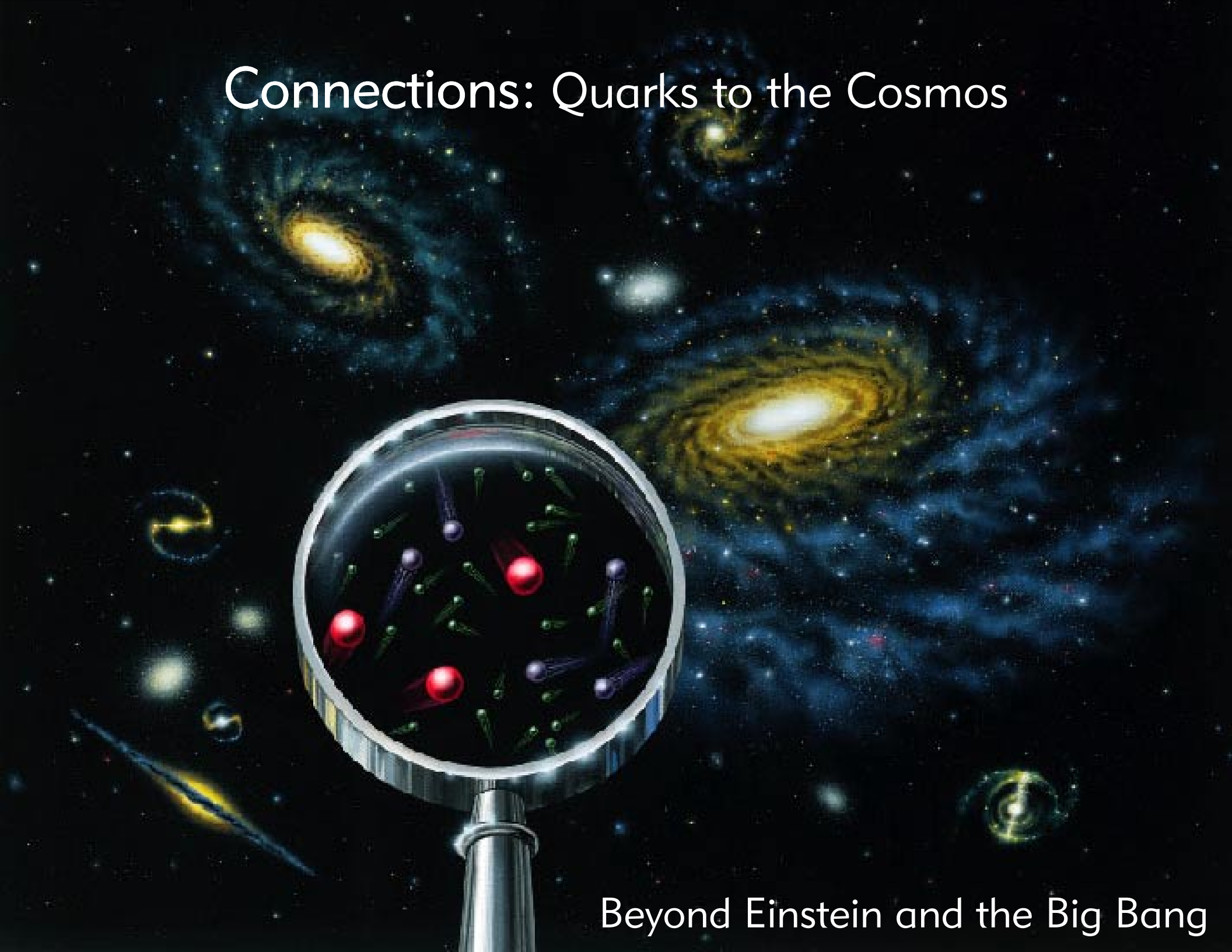
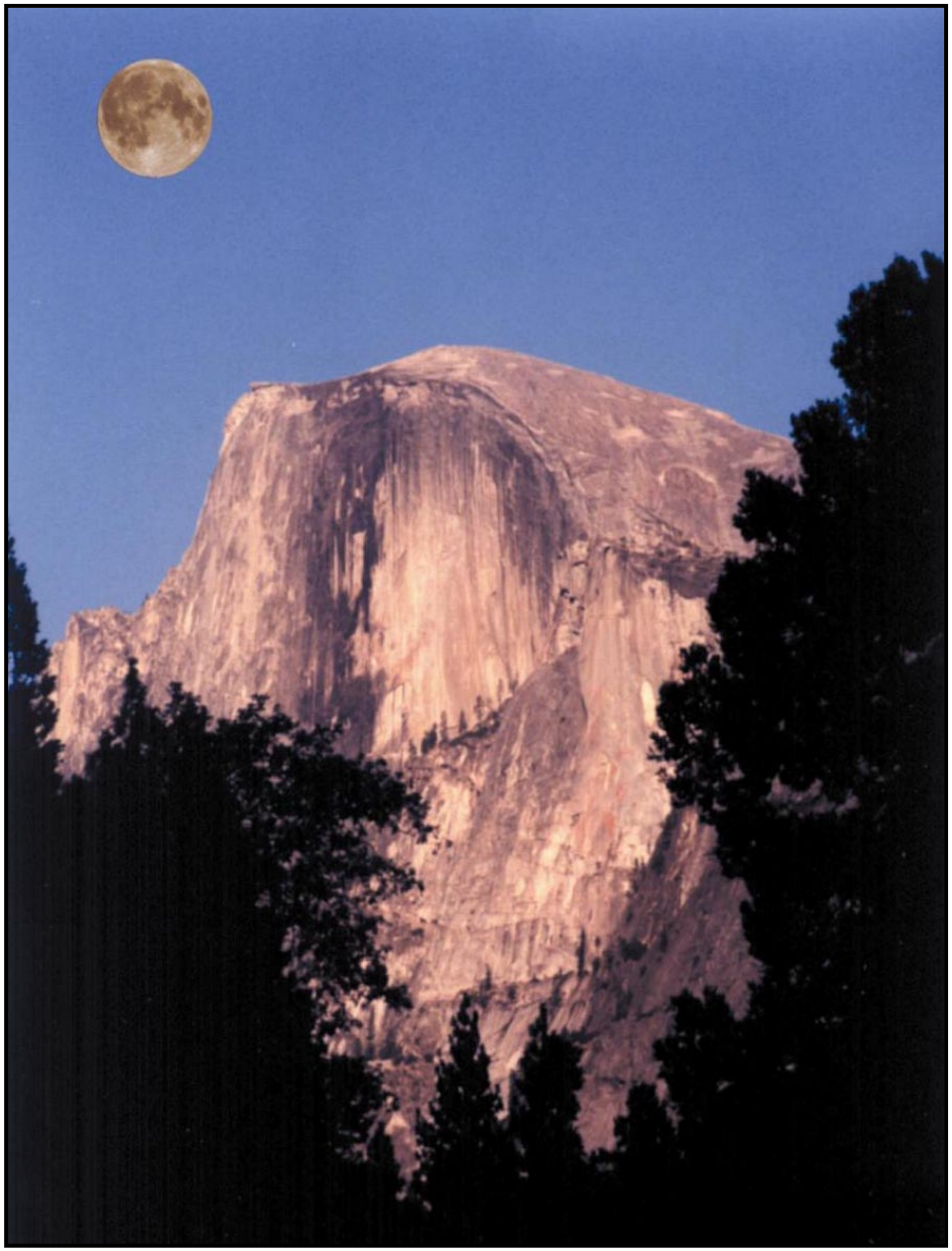
Connections: Quarks to the Cosmos

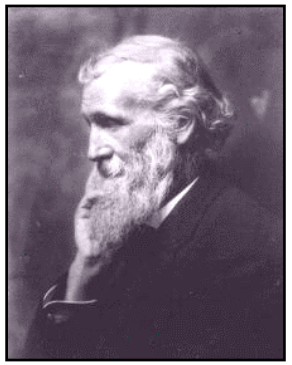


Beyond Einstein and the Big Bang



When one tugs at a single thing in nature, he finds it hitched to the rest of the universe.

– John Muir



The Connections Group

- This document is the work of physicists, astronomers, and space scientists. It is based upon the input from the community at workshops and conferences [Inner Space/Outer Space (Fermilab, May 1999), Cosmic Genesis (Sonoma State University, November 1999), and Beyond the Standard Models (Aspen, February 2000)], as well as working sessions of the Connections Group.
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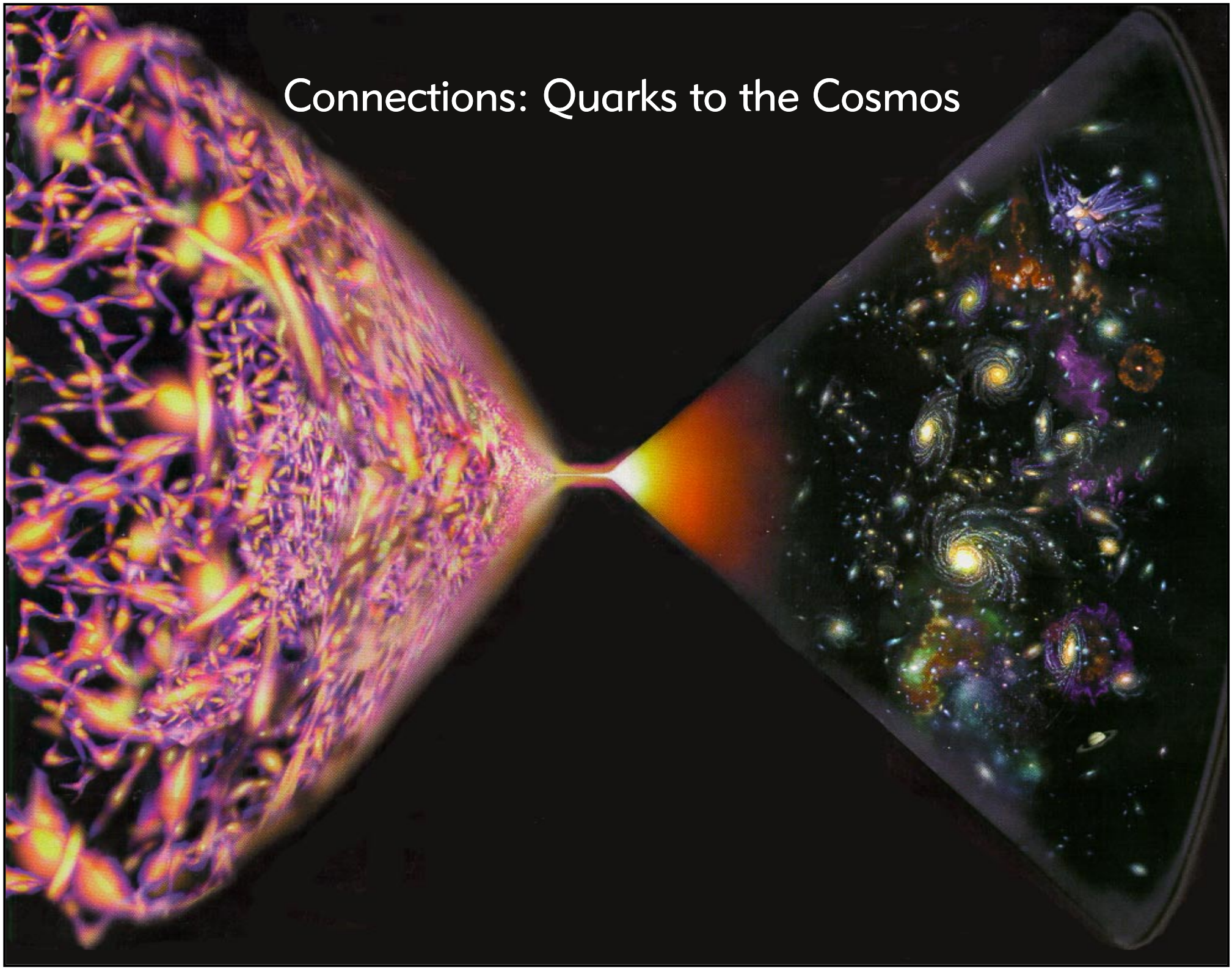

Connections: Quarks to the Cosmos

Connections…Some of Humanity's Deepest Questions About the Nature of Our Universe

- What powered the big bang?
- What is the dark matter that binds together the universe?
- What is the dark energy that drives apart the universe?
- What is the nature of black holes and gravity beyond Einstein?
- Are there hidden spacetime dimensions?

Recent Discoveries

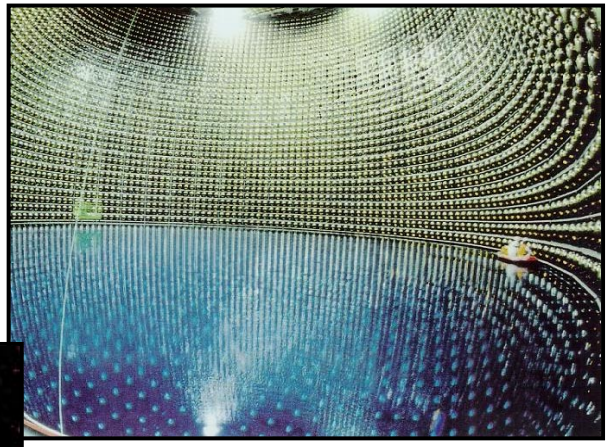
…have strengthened the connections between the fundamental forces of nature and the structure of the universe

- The universe itself is a laboratory to explore fundamental physics.
- Images of the infant universe reveal the quantum seeds of galaxy formation.
- Most of the matter of the universe is dark, unknown, and not made of atoms.
- A mysterious dark energy force of nature is driving apart the universe.

The Universe Is a Laboratory

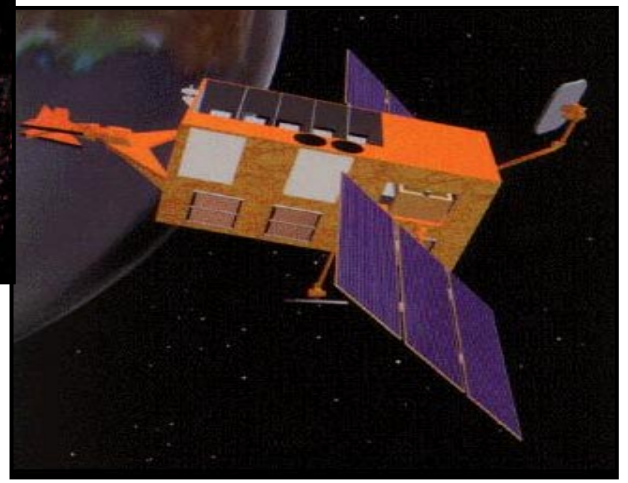
Compton

Chandra



Super-Kamiokande

HiRes



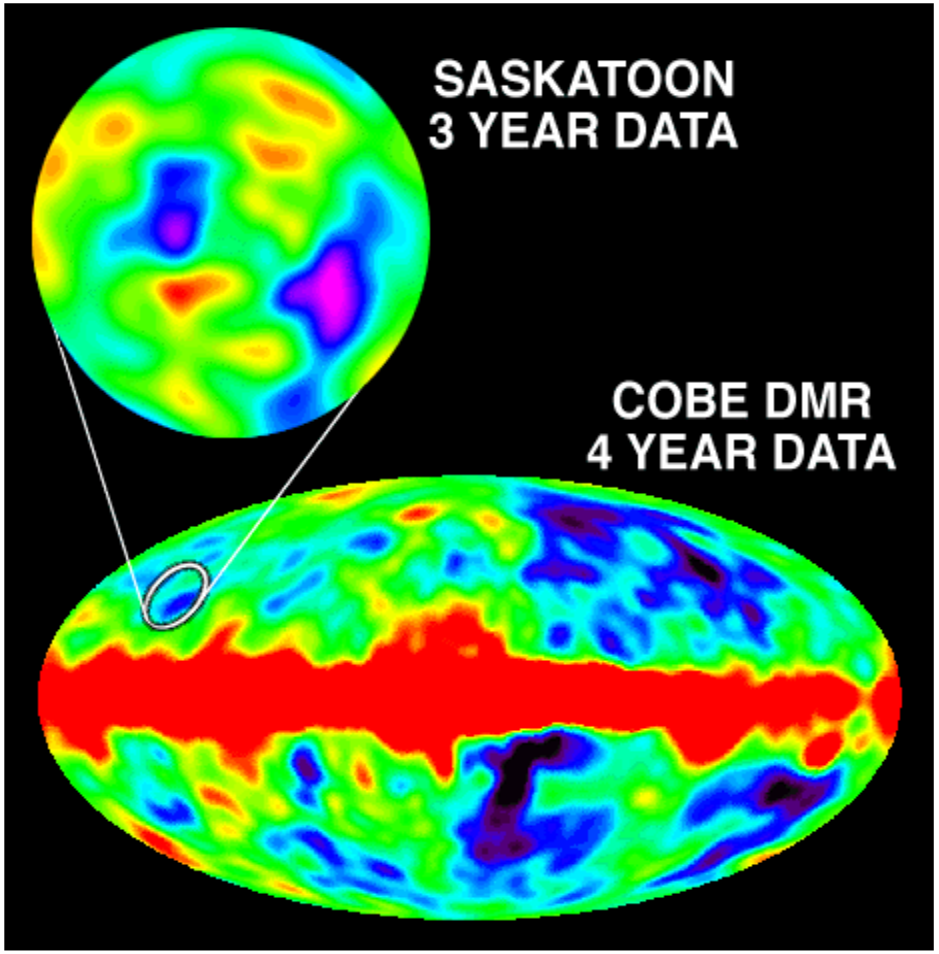
Rossi

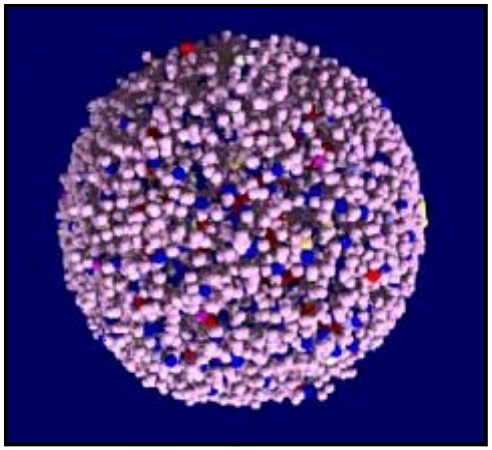
The Universe Is a Laboratory

- Black hole gravity
  - Recent Chandra images reveal the ubiquity of black holes
  - Rossi detects the dragging of spacetime by a spinning black hole
- Gamma-ray bursts
  - Discovery of the largest explosions since the big bang
  - May trace the first generation of stars
- Cosmic neutrinos
  - Evidence for neutrino mass from solar and cosmic-ray neutrinos
  - Neutrinos from Supernova 1987a start a new type of astronomy
- Ultra-high energy cosmic rays
  - Recent observation of the most energetic particles known may require new physical phenomena

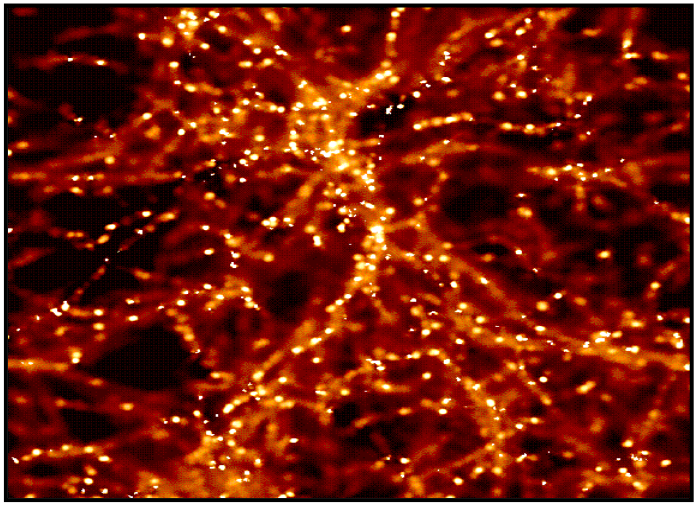
Images of the Infant Universe

Cosmic microwave background





Dense quark-gluon plasma



Large scale structure

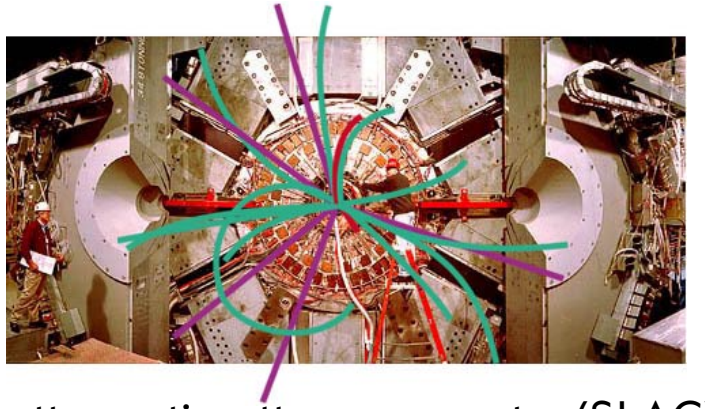
Images of the Infant Universe

- Maps of the cosmic microwave background reveal the quantum seeds of the structure that is seen today, from the Milky Way to the largest structures observed.
- These maps confirm key predictions of inflation, a revolutionary idea rooted in particle physics.
- Particle accelerators gives us a picture of conditions in the early universe, within a millionth of a millionth of a second after the big bang.

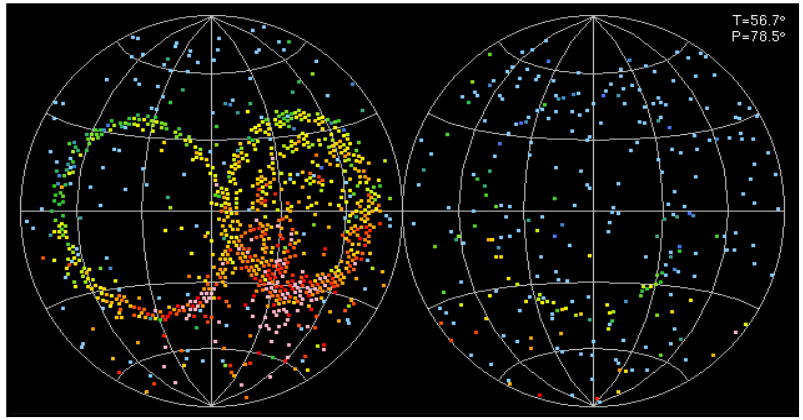
The Matter of the Universe

Dark matter lens focuses light from galaxies

Testing the Standard Model (Fermilab)



Matter antimatter asymmetry (SLAC)

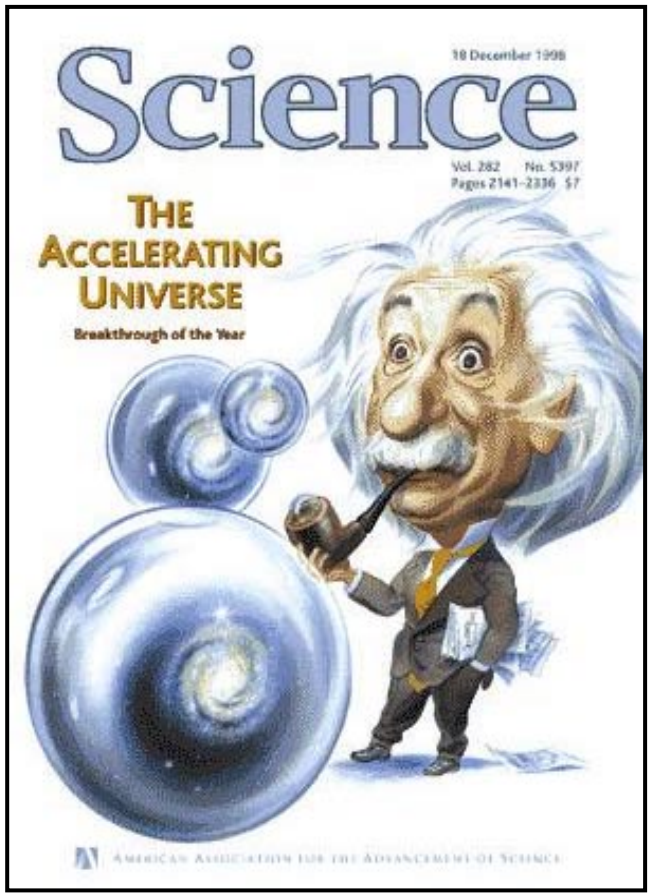


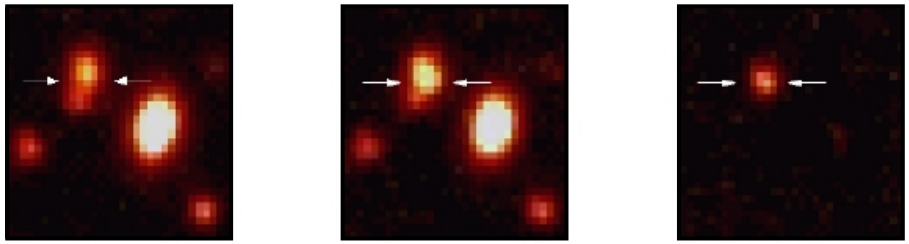
Neutrino seen by Super-Kamiokande

The Matter of the Universe

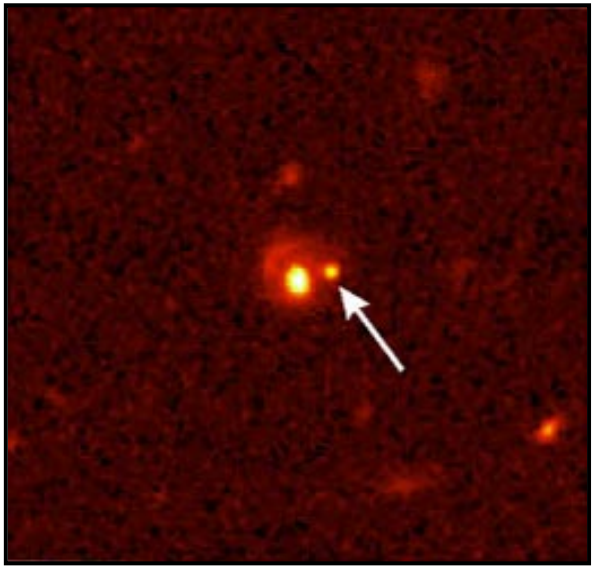
- Accelerator-based research has confirmed the Standard Model of particle physics in which the fundamental particles are three families of quarks, leptons, and their antiparticles.
- Our observations of the cosmos suggests there is more to the story:
  - The universe is made of matter; why aren't there anti-stars and anti-galaxies?
  - Neutrinos have mass. They contribute at least as much mass in the universe as the stars and their planets.
  - Most of the mass of the universe is new types of particles yet to be discovered at accelerators.

Dark Energy: A New Force of Nature





Terrestrial telescope discovers supernova



Hubble Space Telescope
follow-up observations

Dark Energy: A New Force of Nature

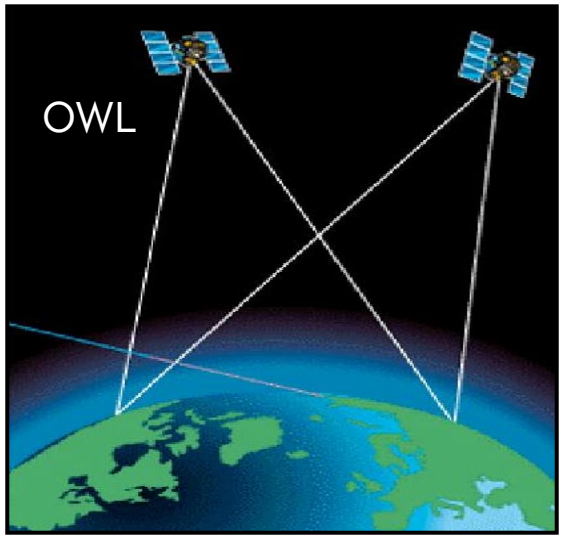
- Terrestrial and space observations of distant supernovae indicate the expansion of the universe is accelerating.
- The acceleration of the expanding universe implies the existence of a new type of dark energy.
- Dark energy is not understood and requires a new force of nature.

The Next Steps: Use the Universe as a Laboratory

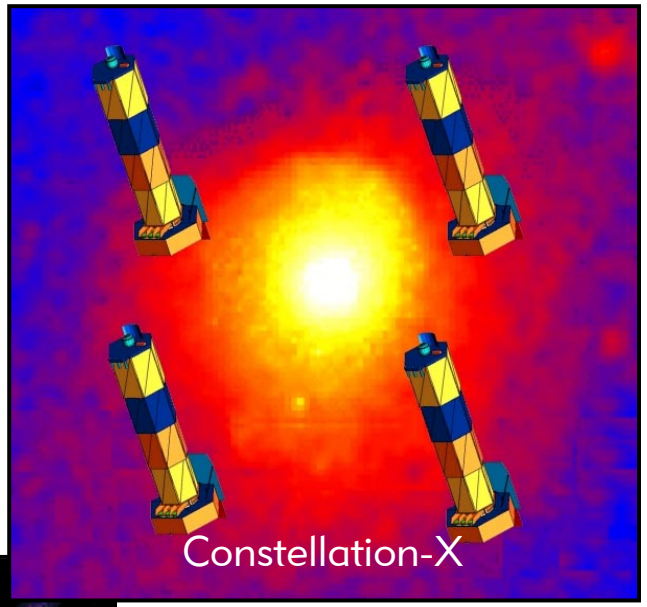
- Test the limits of physical law using the most extreme environments in the universe.
- Explore the dark side of the universe.
- Connect the beginning of the universe to fundamental physics.
- Solve the mystery of gravity.

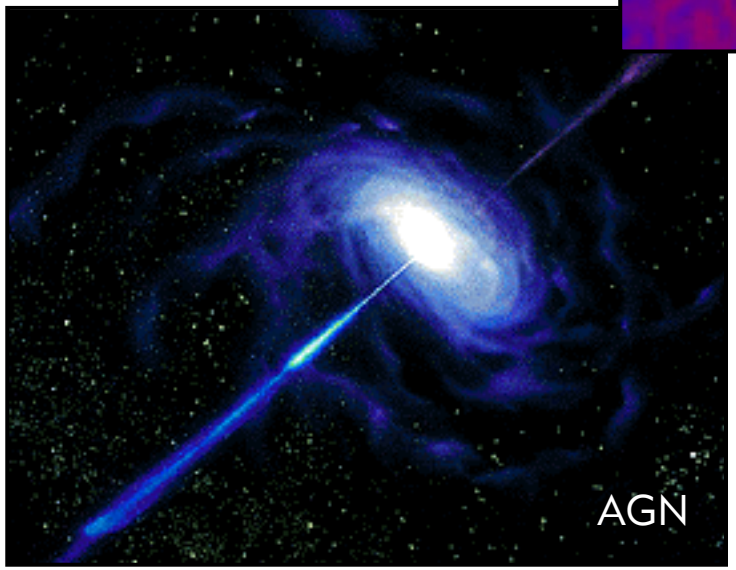
Test the Limits of Physical Law Using the Most Extreme Environments in the Universe

Highest energy cosmic rays



Black holes and dark matter



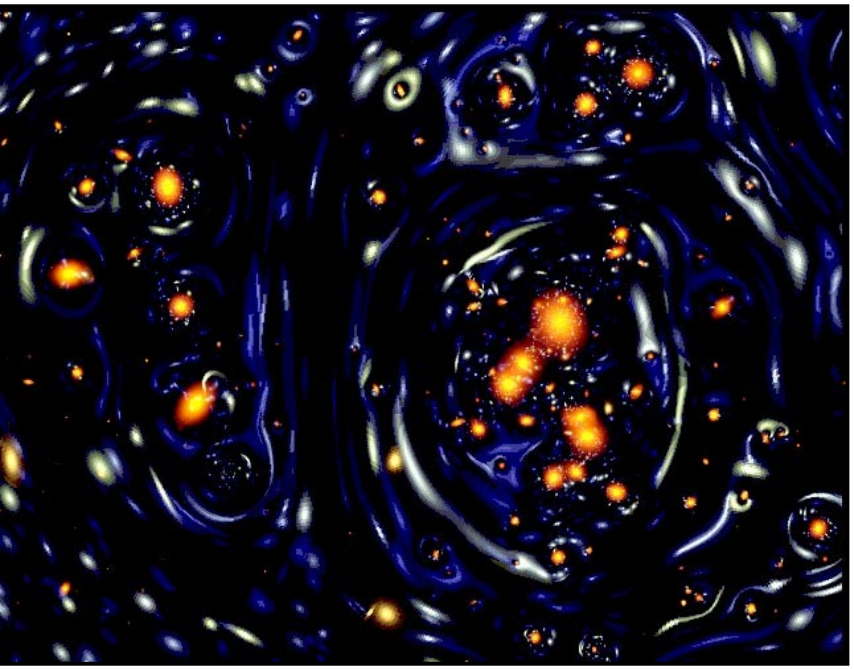


Jets from a supermassive black hole

Test the Limits of Physical Law Using the Most Extreme Environments in the Universe

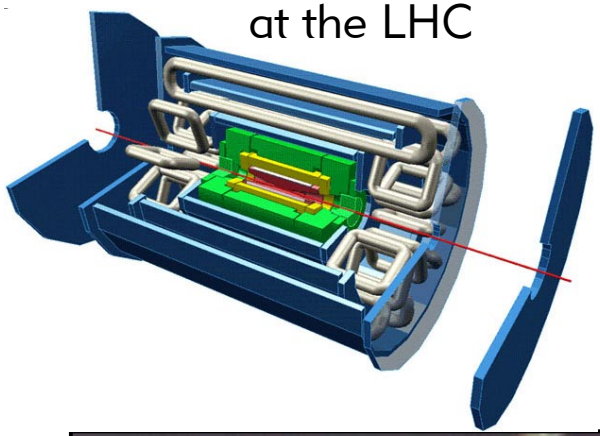
- Survey and explore the conditions near black holes.
- Determine the origin and identity of nature's most energetic particles.
- Understand the acceleration mechanism and identify the types of particles in astrophysical jets.
- Image the event horizon of a black hole.

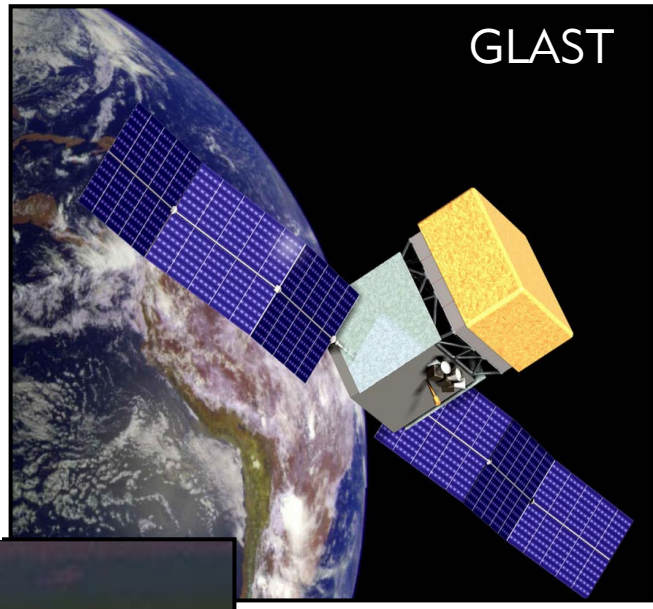
Explore the Dark Side of the Universe

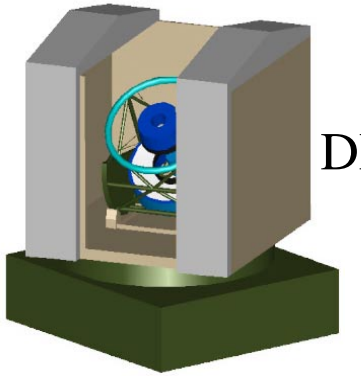


Simulated map of lensing by dark matter

ATLAS detector at the LHC





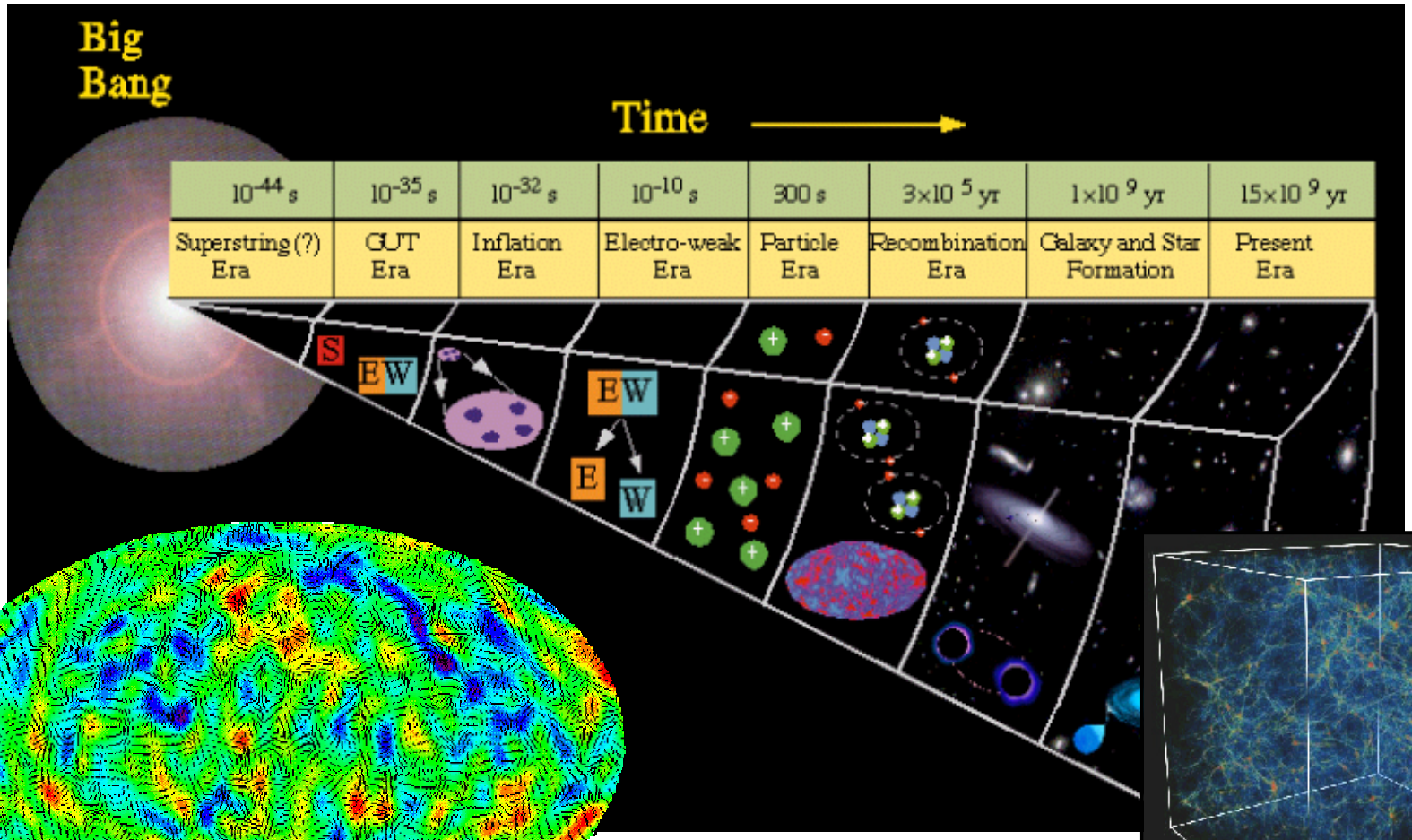


DMT

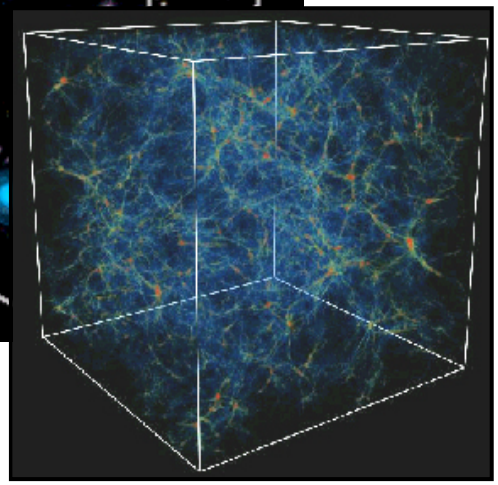
Explore the Dark Side of the Universe

- Map the distribution of dark matter in galaxies, clusters of galaxies, and throughout the universe.
- Identify dark matter particles and measure their properties.
- Characterize the nature of the mysterious dark energy.
- Search for other relics of the Big Bang.

Connect the Beginning of the Universe to Fundamental Physics



Polarization of cosmic microwave background

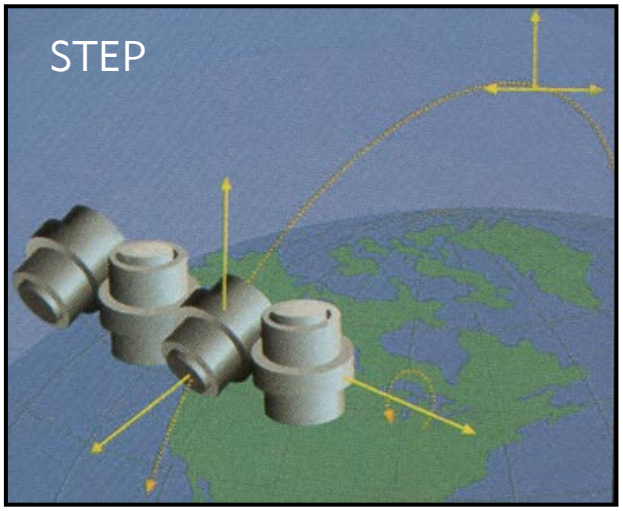


Large scale structure

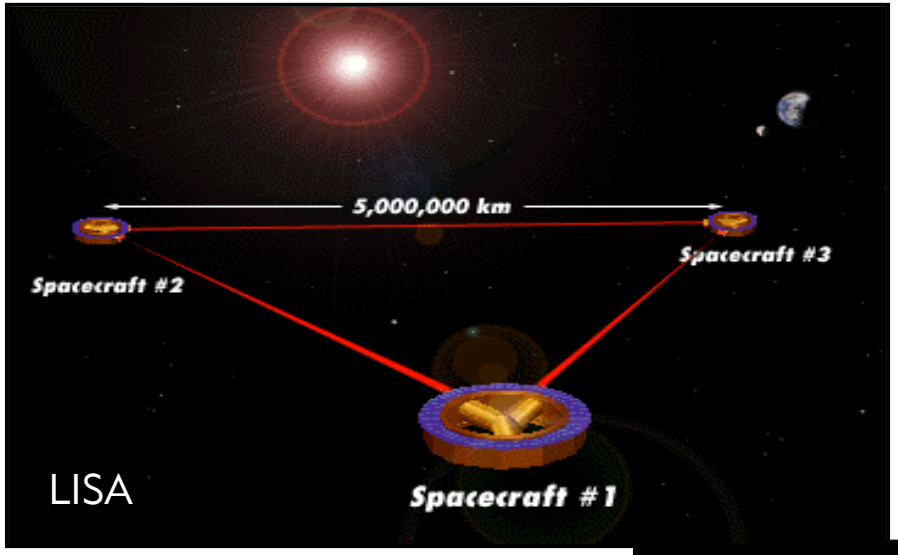
Connect the Beginning of the Universe to Fundamental Physics

- Map the microwave background and large-scale structure to determine the physics of inflation.
- Use the microwave background polarization to detect the signature of primordial gravitational waves.
- Directly measure primordial gravitational waves.
- Observe the cosmic neutrino background.

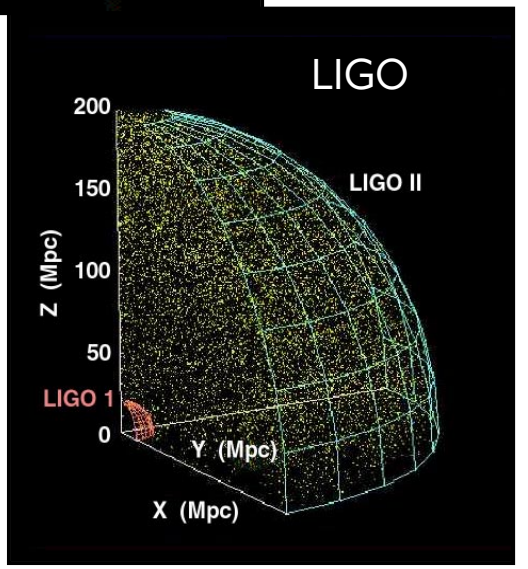
Solving the Mystery of Gravity

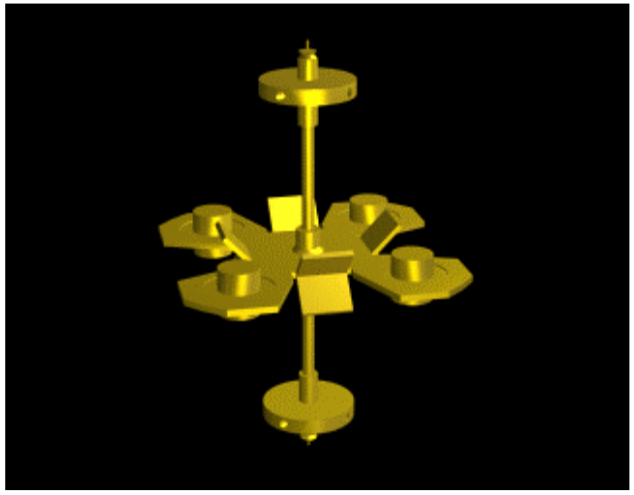


Test equivalence principle



Detect gravitational waves





Test inverse square law at sub-mm distances

Solving the Mystery of Gravity

- Direct detection of gravitational radiation from black holes, neutron stars, and other astrophysical sources.
- Test the inverse square law of gravity at submillimeter distances to search for extra spacetime dimensions.
- Test Einstein's equivalence principle to exquisite precision to uncover new forces of cosmological significance.
- Detect proton decay to provide crucial information about the unification of forces.
- Develop a quantum theory of gravity to acquire new insights into the deepest questions of the cosmos.

Connections are the Key: Agencies

- Solutions to mysteries about the fundamental particles and forces in the universe and solutions to mysteries about the origin and fate of the universe are connected.
- **Connections** will…
  - Effectively push the three instrumentation technology frontiers, in space, on the ground, and underground.
  - Enable NASA, DOE, and NSF to collaborate in support of exciting new projects that cut across discipline and agency boundaries.
  - Rely on NASA, DOE, and NSF to each do what they do best.
- **Connections**…the total is larger than the sum of the parts.

NASA Connection: Cosmic Journeys Strategic Plan

- Near Term
  - ACCESS: Determine composition of high-energy cosmic rays
  - Constellation X: Investigate black holes and map the dark matter
  - LISA: Space detection of gravitational radiation
- Vision for the Future
  - Use the entire Earth as a cosmic ray detector (OWL…)
  - Survey the black holes of the universe (EXIST…)
  - Detect gravitational radiation from the beginning of the big bang (CMBPOL…)
  - Image the horizon of a black hole (MAXIM…)

DOE Connection: Current and Future Activities

- Accelerators
  - Produce dark matter particles and discover new forces
  - Understand the basis of matter anti-matter asymmetry
- Underground physics
  - Detect relic dark matter
  - Search for proton decay
  - Neutrino oscillations and neutrino astrophysics
- Ground based
  - Ultra high energy cosmic rays
  - Gamma ray observatories
  - Large scale sky surveys
  - Dark matter and dark energy searches
- Space based
  - Composition of cosmic rays
  - High energy gamma rays
  - Dark energy
- Theory and simulation

NSF Connection: Current and Future Activities

- Accelerators
  - Produce dark matter particles and discover new forces
  - Understand the basis of matter anti-matter asymmetry
- Underground physics
  - Detect relic dark matter
  - Neutrino oscillations and neutrino astrophysics
- Ground based
  - Astronomical observatories
  - Gravitational wave observatories
  - Ultra high energy cosmic rays
  - Gamma ray observatories
  - Large scale sky surveys
  - Dark matter and dark energy searches
  - Microwave background
- Theory and simulation

Connecting with the Public

Connections will share the excitement of discovery with the public…

Connecting with the Public

How did the universe begin?

How did the smallest particles grow into the largest galaxies?

What can we learn from gravity to help us reach for the stars?

The origin, evolution, and destiny of the universe, the most extreme environments, the nature of spacetime – tomorrow's most exciting research – will captivate the public unlike any other scientific endeavor.

Connections Are the Key: Technology

- **Connections** in technology have already enabled important projects.
  - GLAST, AMS, SDSS
- **Connections** will transfer technology across disciplines and agencies.
  - Lightest and strongest materials
  - New types of sensitive, low noise detectors
  - Fastest data acquisition
  - Advanced information processing
- **Connections** will catalyze joint development of the best technologies.

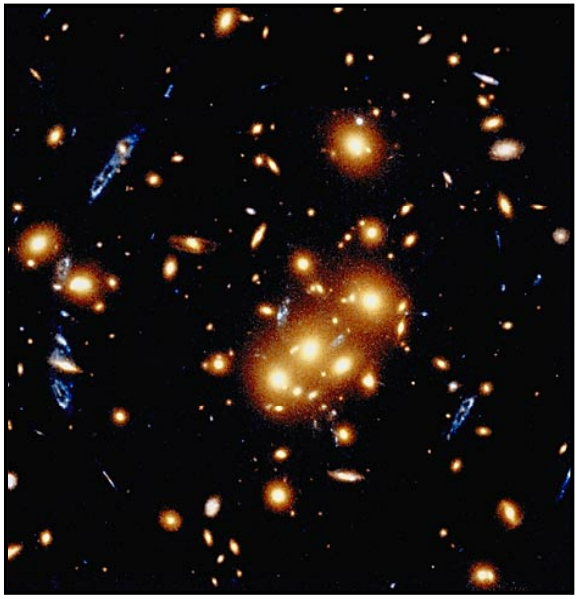
Connections and Challenges

- **Connection**…between the smallest subatomic particles and the largest structures in the universe.
- **Connection**…between new technologies, revolutionary theories, and the real world of observations and experiments.
- **Challenge**…go beyond Einstein and the big bang.
- **Challenge**…connect the nation's scientists and science agencies in a bold initiative.

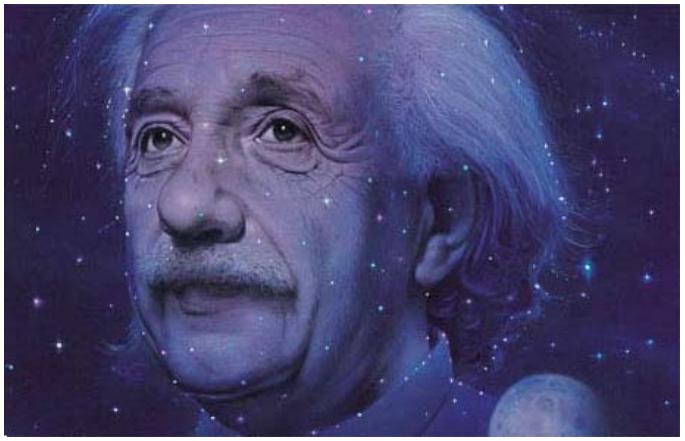
Don't be afraid to take a big step if one is indicated.
You can't cross a chasm in a series of small jumps.

–David Lloyd George

Recent Discoveries

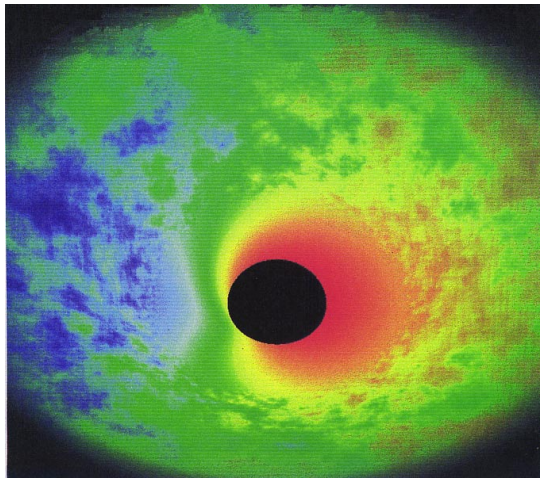


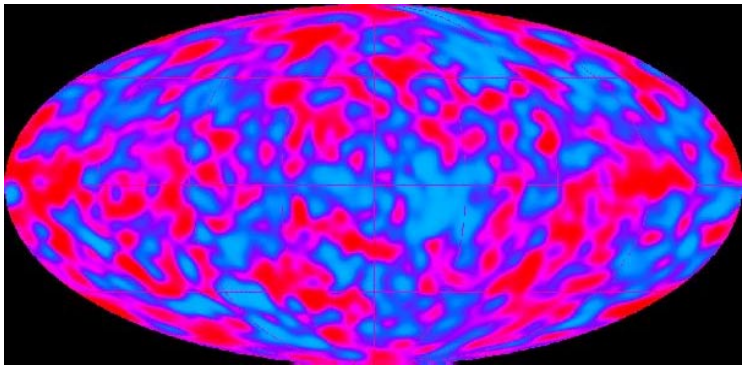
Dark matter lens



Dark energy

Extreme gravity





Snapshot of the early universe

The Next Steps:
Use the Universe as a Laboratory