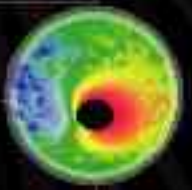
structure and evolution of the universe

BEYOND EINSTEIN:

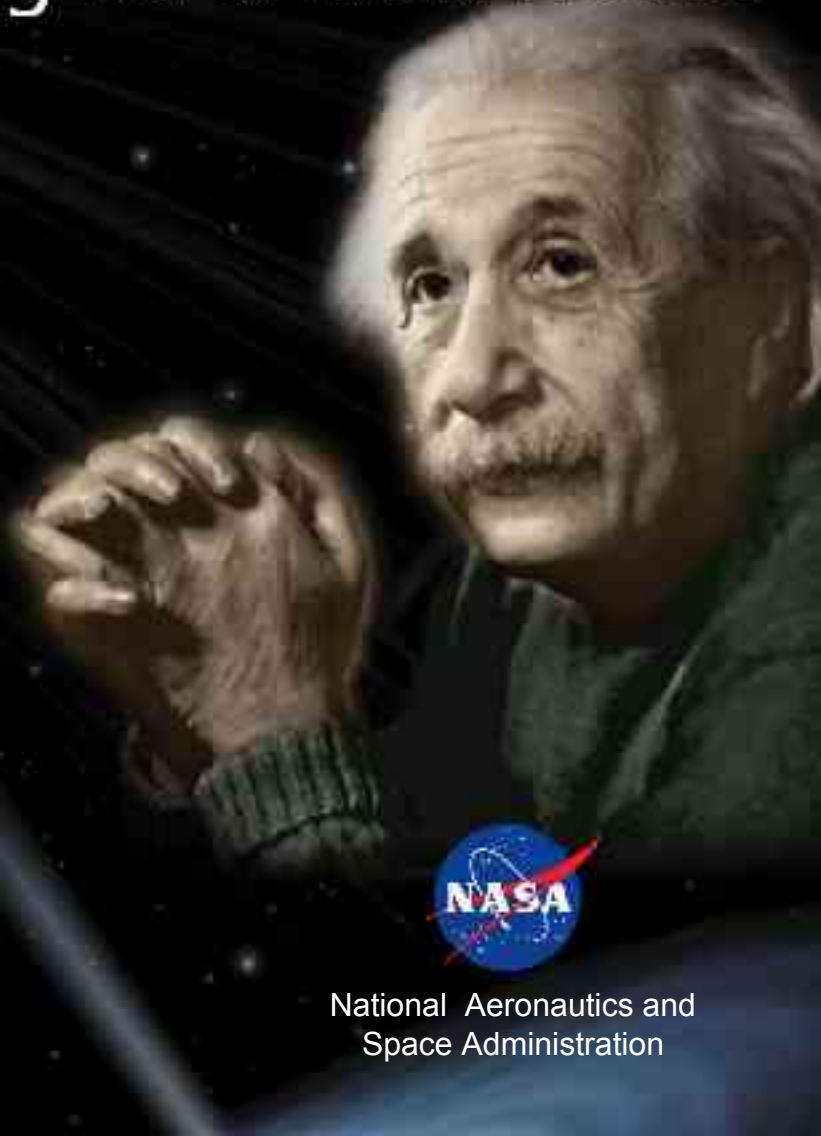
from the big bang to black holes

WHAT POWERED THE BIG BANG?



WHAT HAPPENS AT THE EDGE OF A BLACK HOLE?

WHAT IS DARK ENERGY?



National Aeronautics and Space Administration

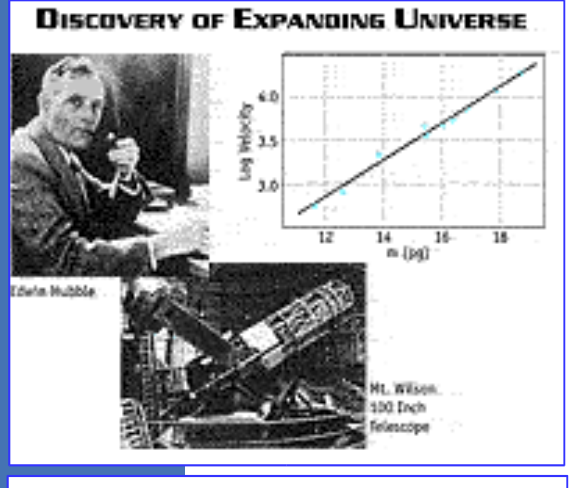
Einstein's Predictions

Three startling predictions of Einstein's relativity:

- **The expansion of the Universe (from a big bang)**
- **Black holes**
- **Dark energy acting against the pull of gravity**

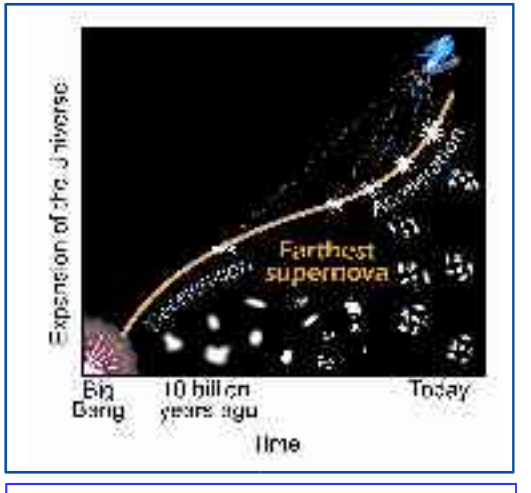
Observations confirm these predictions . . .

. . . the last only four years ago



Hubble discovered the expanding Universe in 1929

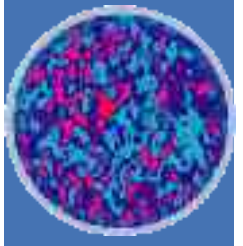
Black holes found in our Galaxy and at the center of quasars over the past three decades



Evidence for an accelerating Universe was observed in 1998

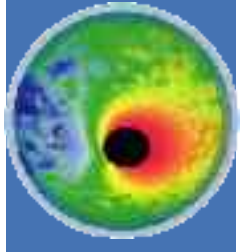
Completing Einstein's Legacy

Einstein's legacy is incomplete, his theory fails to explain the underlying physics of the very phenomena his work predicted



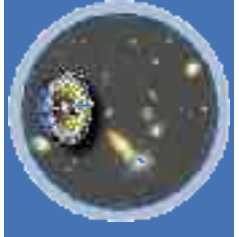
BIG BANG

What powered the Big Bang?



BLACK HOLES

What happens at the edge of a Black Hole?



DARK ENERGY

What is the mysterious Dark Energy pulling the Universe apart?

Beyond Einstein will employ a series of missions linked by powerful new technologies and common science goals to answer these questions …

… and launch the revolution of the 21st century!

Beyond Einstein Program

Science and Technology Precursors

MAP

LIGO

Hubble

Chandra

GLAST

microwave background detection

gravitational wave detectors

optical imaging

x ray imaging

mega-channel electronics

INFLATION PROBE

LISA

DARK ENERGY PROBE

CONSTELLATION X

BLACK HOLE FINDER PROBE

big bang physics

space interferometry, gravitational wave detection

space interferometry

dark energy physics

dark matter physics

black hole physics

black hole census

BIG BANG OBSERVER

BLACK HOLE IMAGER

GREAT OBSERVATORIES

PROBES

VISIONS

Realizing Science Beyond Einstein

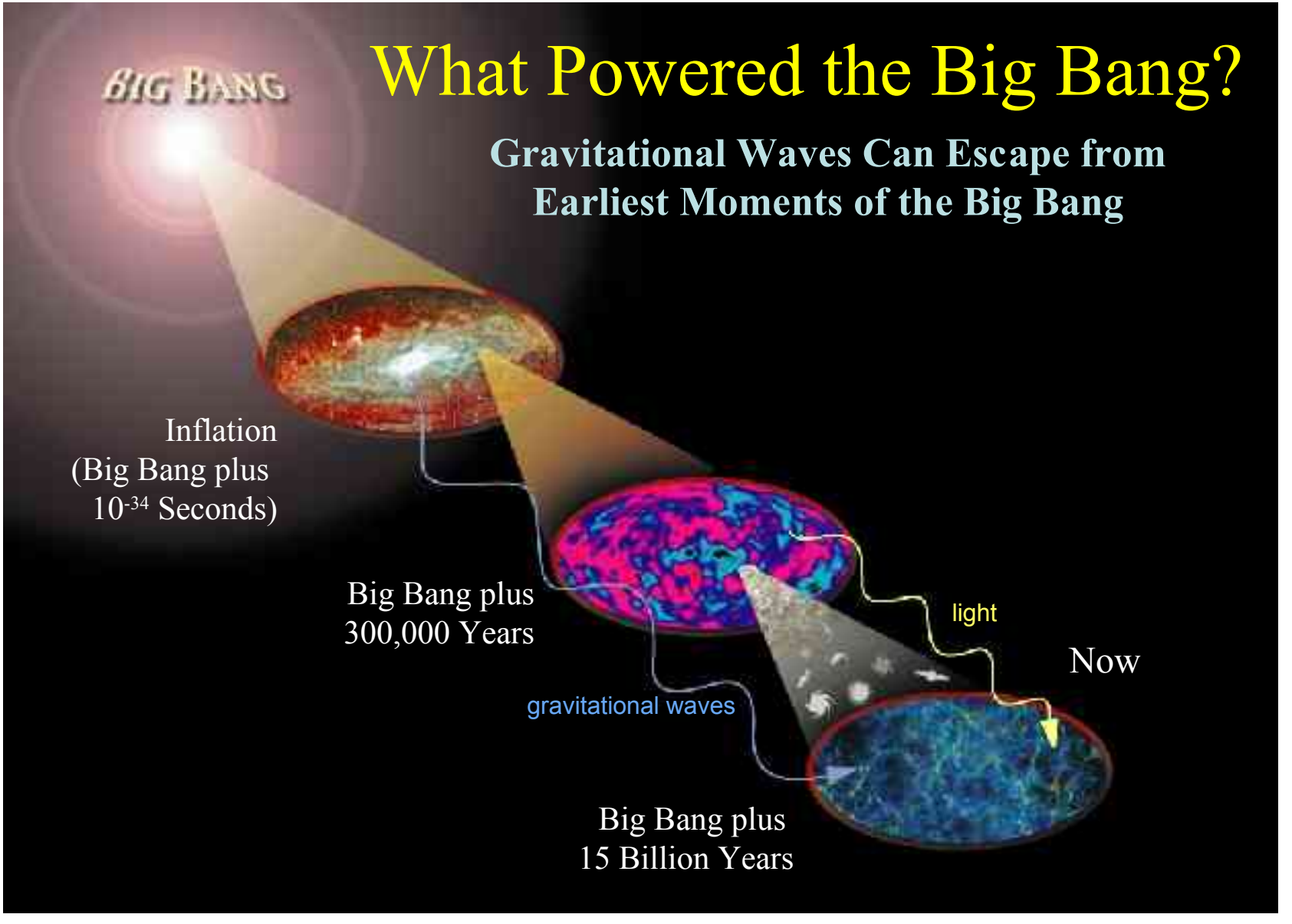
Three inter-linked elements that work together:

1. **Einstein Great Observatories providing breakthrough increases in capabilities to address all Beyond Einstein science:**
   - **LISA: Gravitational waves from merging black holes and the early Universe**
   - **Constellation-X: Spectroscopy close to the event horizon of black holes and place constraints on dark side of the Universe**

3. **Einstein Probes to address focused science objectives:**
   - **Determine the nature of the Dark Energy**
   - **Search for the signature of inflation in the microwave background**
   - **Take a census of Black Holes of all sizes in the local Universe**

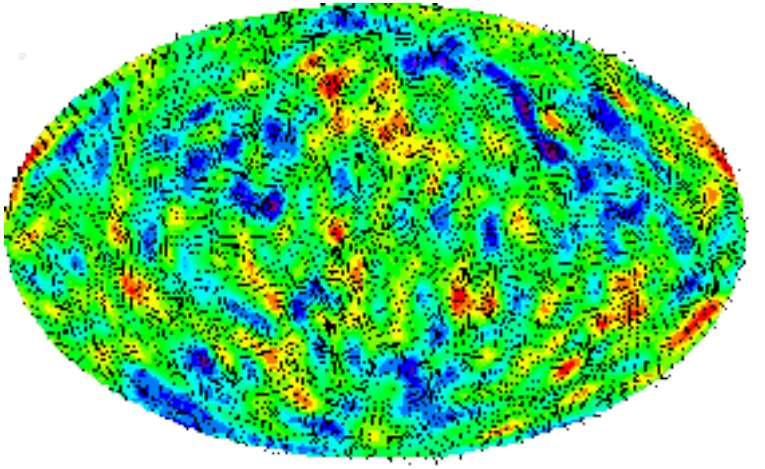
5. **A technology program, theoretical studies and an education program to inspire future generations of scientists and engineers towards the vision:**
   - **Directly detect the gravitational waves emitted during the Big Bang**
   - **Image and resolve the event horizon of a Black Hole**

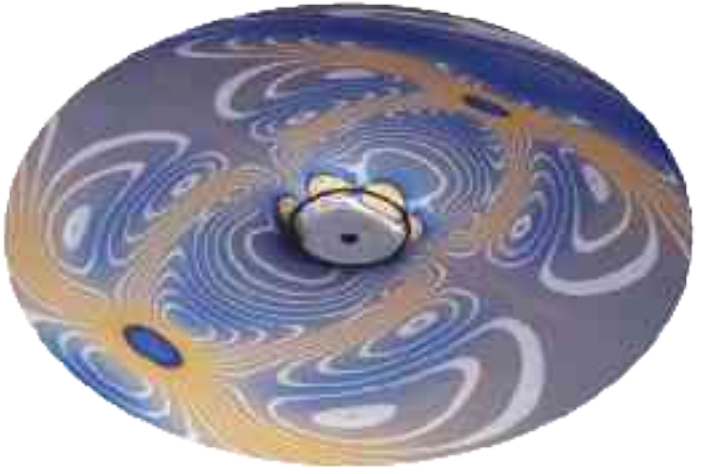
What Powered the Big Bang?



What Powered the Big Bang?

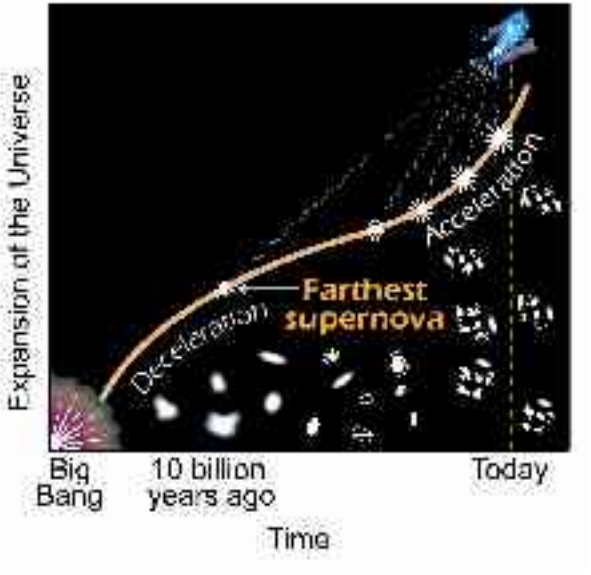
Gravitational waves leave a distinctive imprint on polarization pattern of CMB





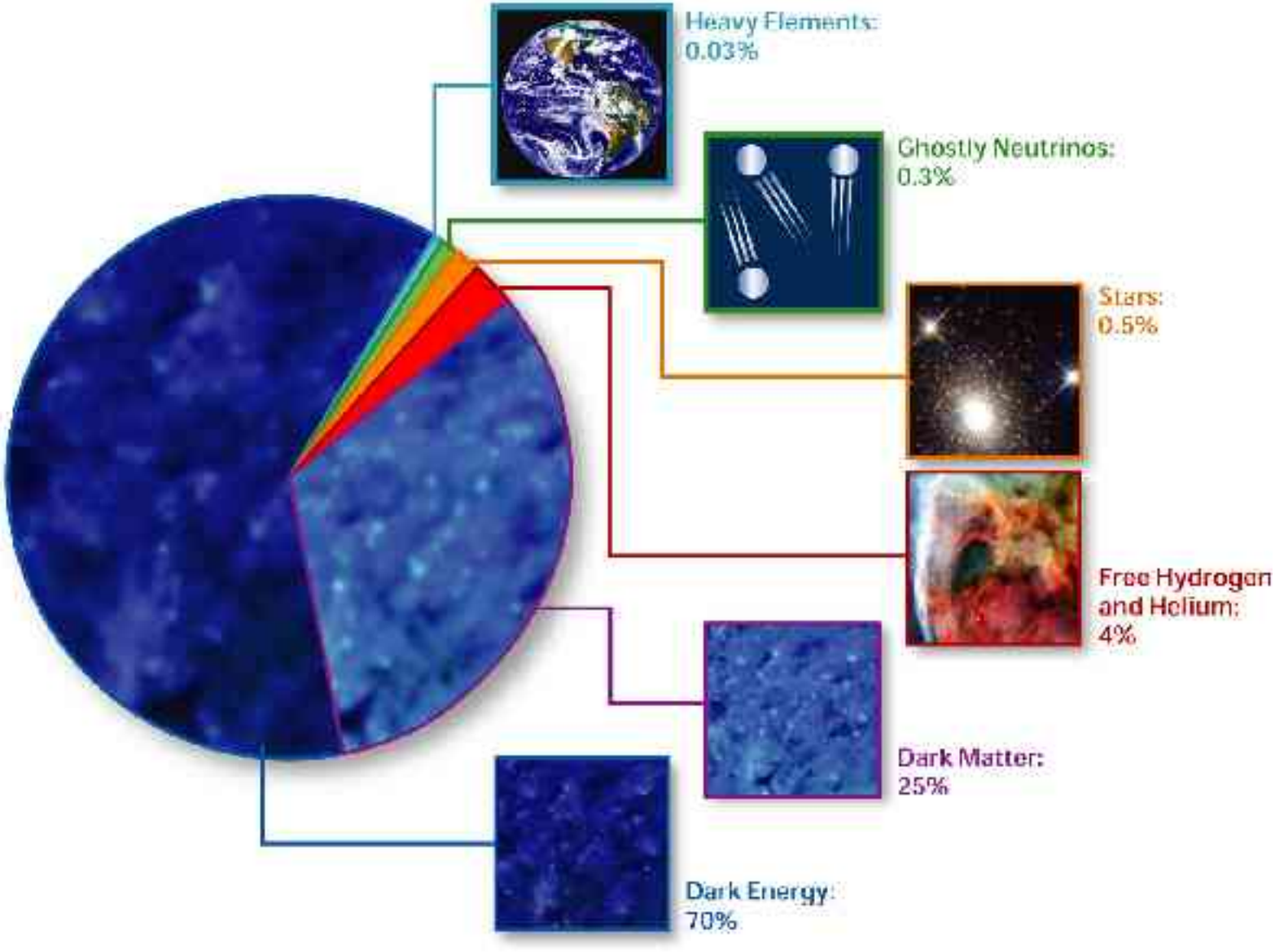
Gravitational waves from inflation and phase transitions may be detected directly

Vacuum energy powered inflation-some form of it may be the “dark energy”



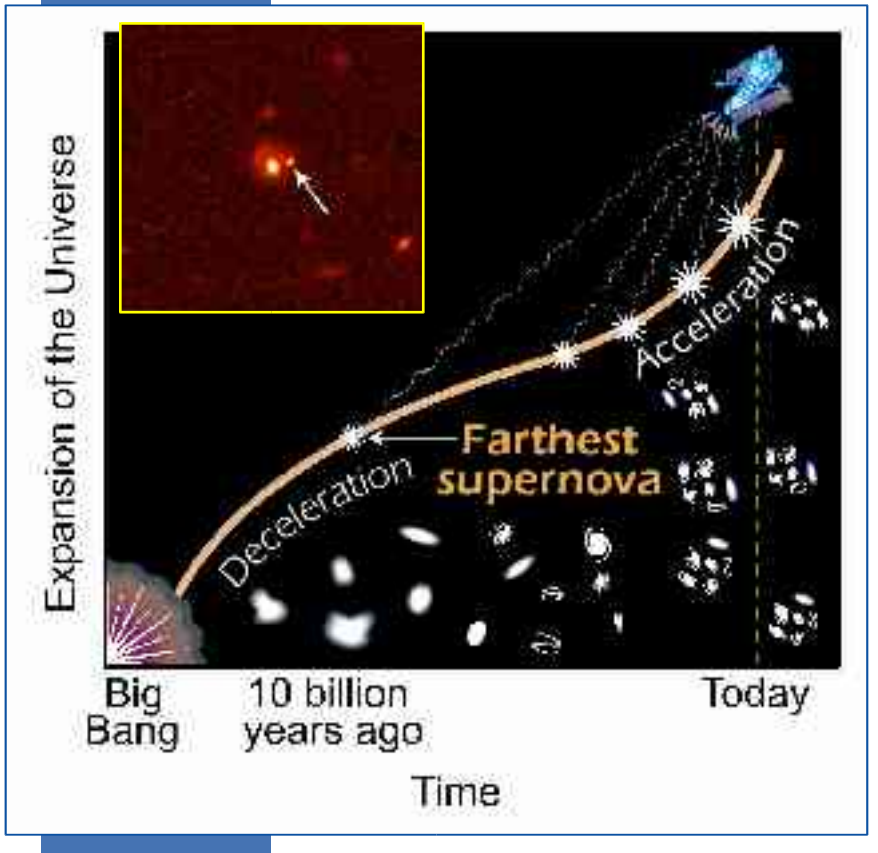
What is the Dark Energy?

We do not know what 95% of the universe is made of!



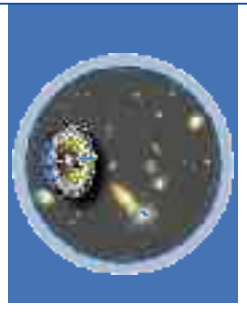
What is the Dark Energy?

Einstein introduced the Cosmological Constant to explain what was then thought to be a static Universe, "*my biggest mistake . . .*"



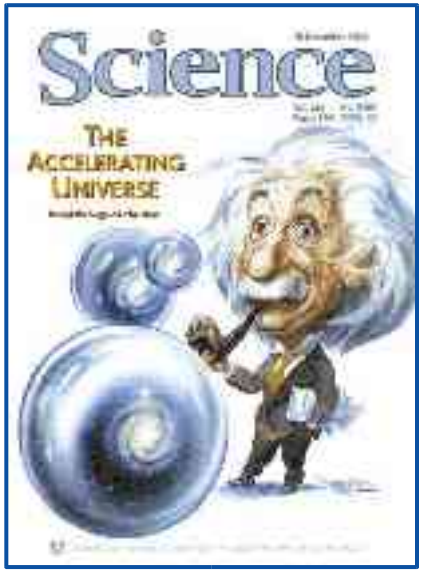
A surprising recent discovery has been the discovery that the expansion of the Universe is accelerating.

Implies the existence of *dark energy* that makes up 70% of the Universe

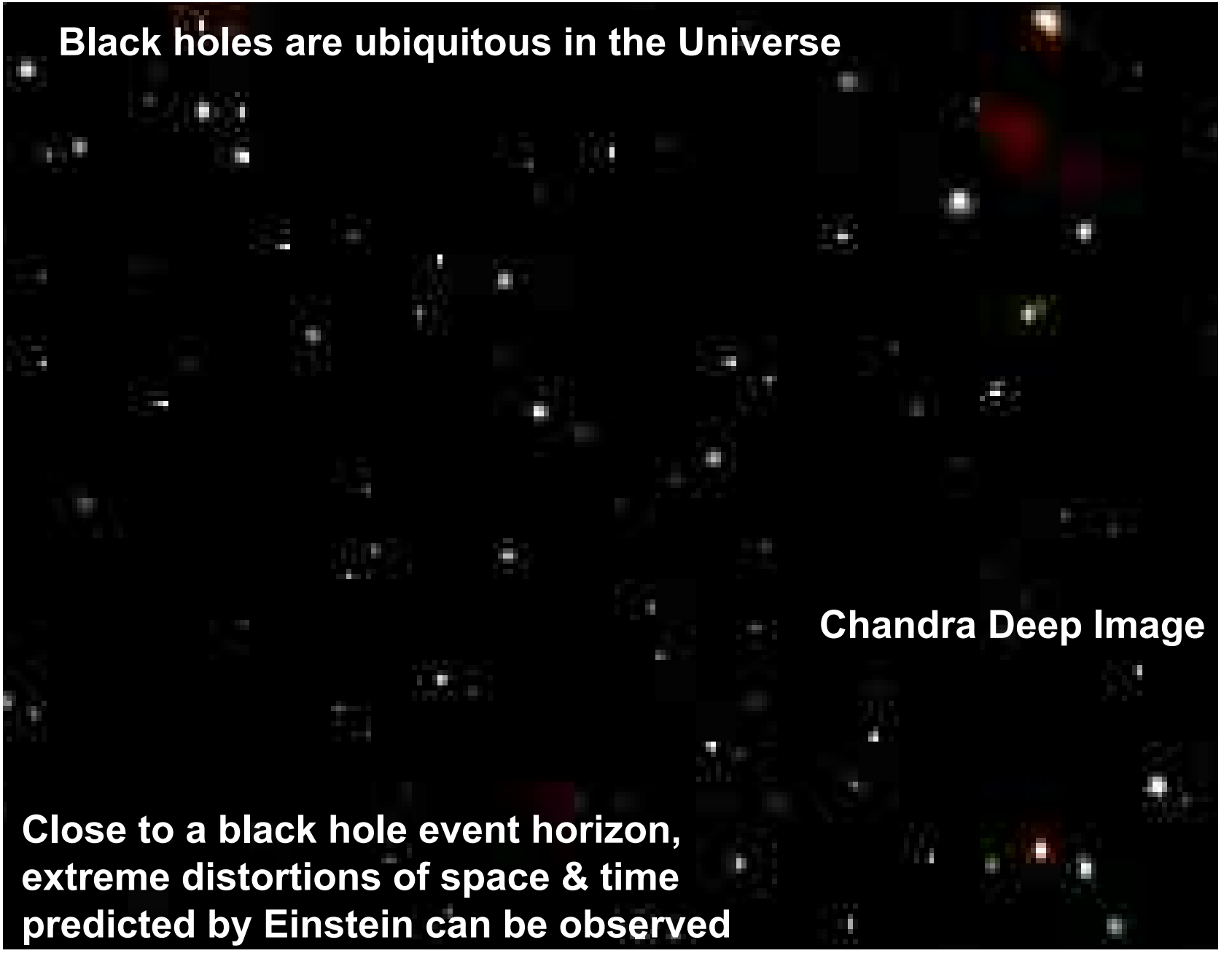


Dark Energy maybe related to Einstein's Cosmological Constant; its nature is a mystery.

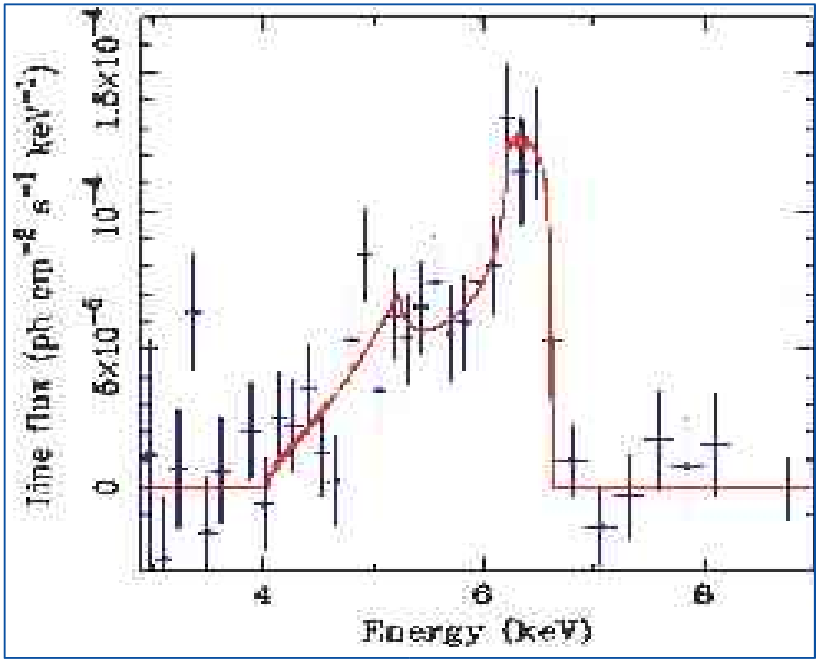
Solving this mystery may revolutionize physics . . .



What Happens at the Edge of a Black Hole?

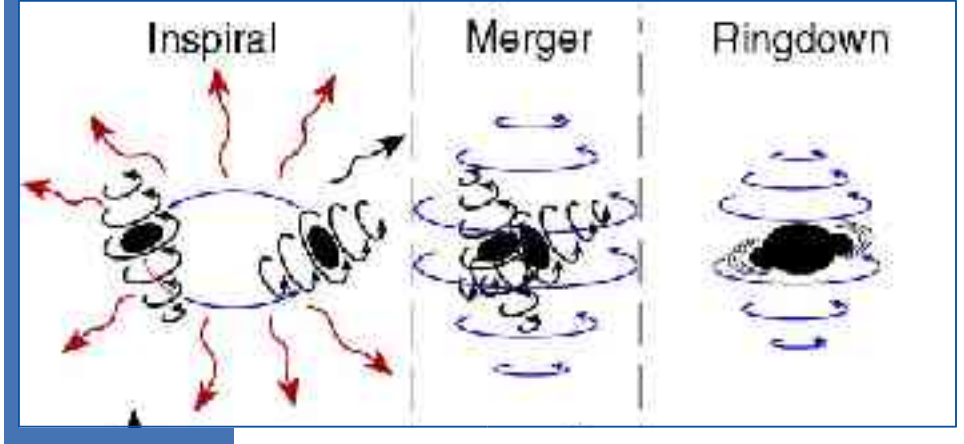


What Happens at the Edge of a Black Hole?



X-Ray Spectroscopy

- **Japan-US ASCA satellite discovered iron lines near the event horizon of a black hole**
- **Line exhibits a strong redshift and provides a unique probe of the inner regions of black holes**

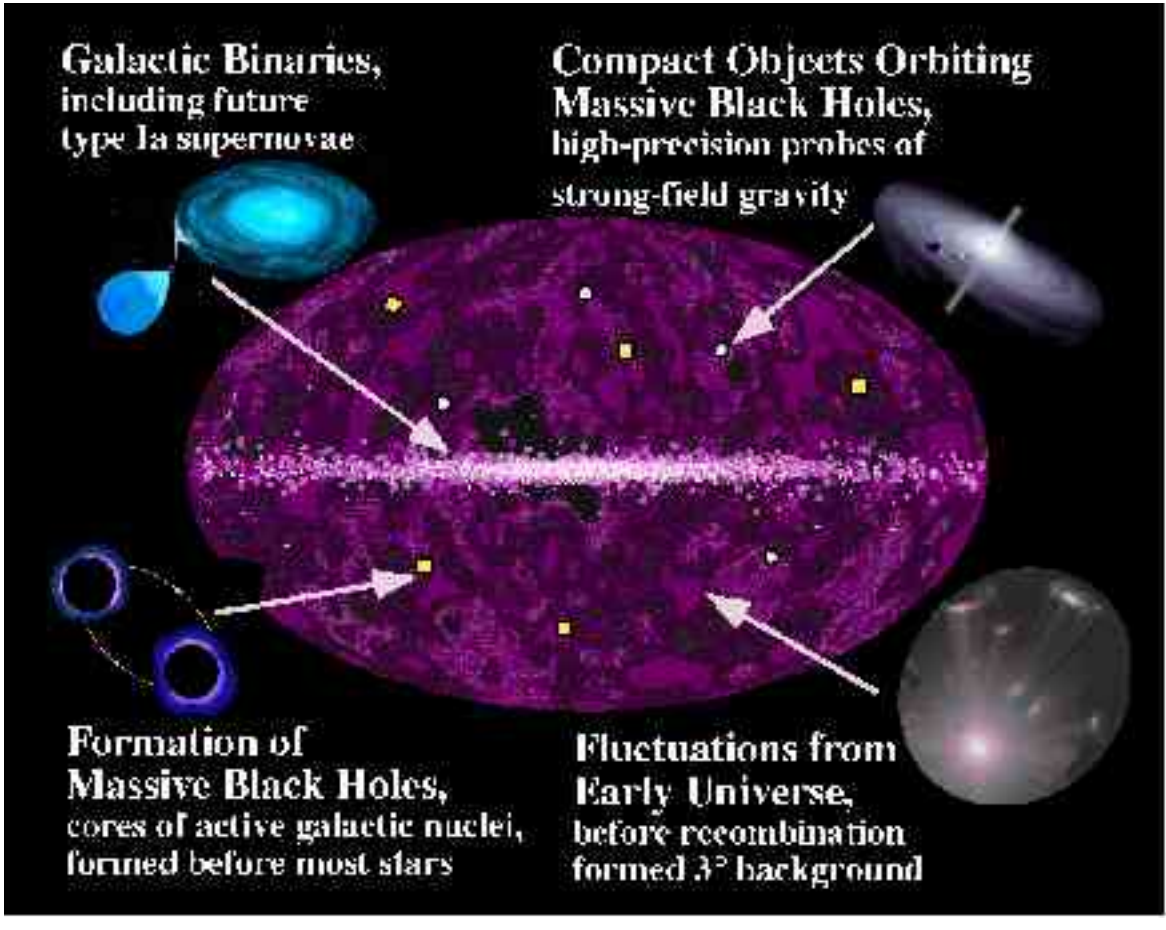


Gravitational Radiation

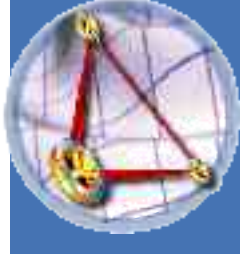
- **Black hole binaries produce gravitational waves in all phases of their evolution**
- **Test of GR in all three phases**

Gravitational Wave Astronomy

Black holes, neutron stars, and white dwarfs orbiting each other emit gravitational waves



Gravitational radiation from black hole mergers can be used to test General Relativity



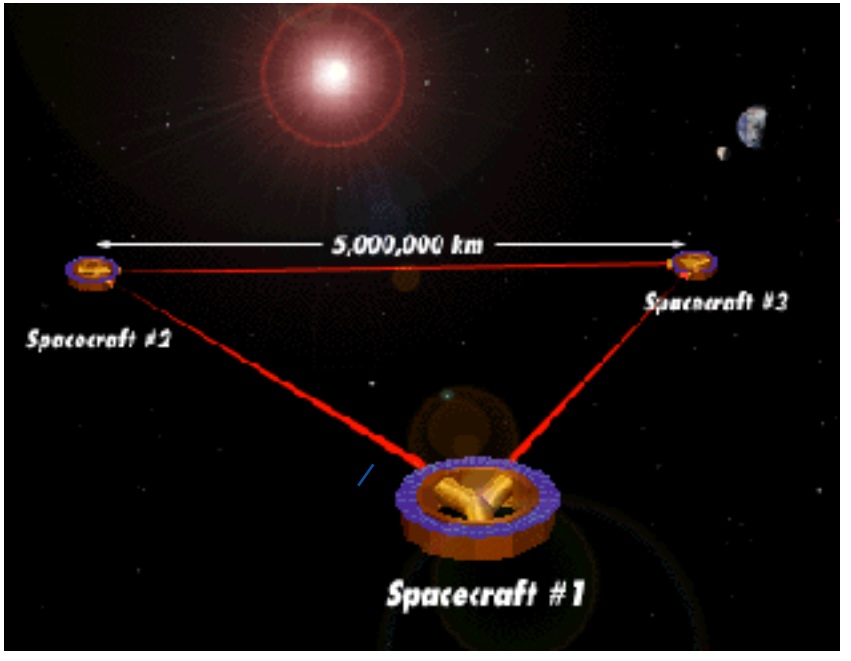
The real voyage of discovery consists not in seeing new landscapes, but in having new eyes. - Marcel Proust

Laser Interferometer Space Antenna (LISA)

Joint ESA-NASA project

LISA uses a laser based Michelson interferometer to monitor the separation between proof masses in separate spacecraft

- **Three spacecraft separated by 5 million km**
- **Each spacecraft includes two freely falling test masses with drag free operation**
- **Distance changes measured with precision of 4 pico-meter RMS over 100 seconds**



Flight demonstration of disturbance reduction system on ESA LISA Pathfinder mission in 2007

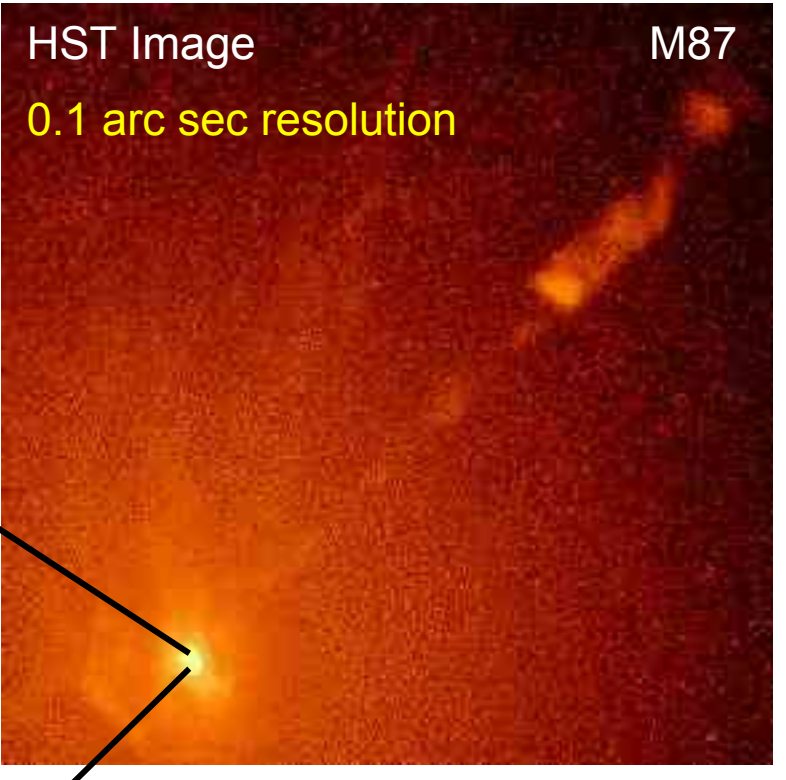
micro-newton thrusters

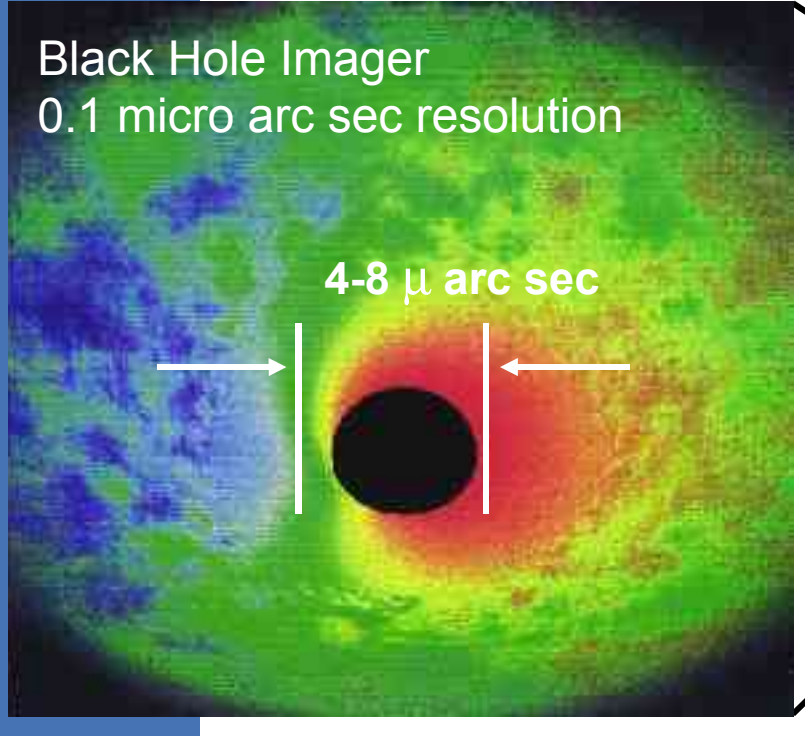
LISA, the first space-based gravitational wave antenna, was given strong endorsement by US National Academy of Sciences McKee-Taylor and Turner Committee Reports

Image a Black Hole!

Hubble, Chandra, and other observatories are showing black holes are common place in the Universe

Black holes provide a unique laboratory to test Einstein's theory of gravity





A future black hole imager with a resolution one million times Hubble will observe the effects Einstein predicted

X-ray emission from close to the event horizon provides a powerful probe

Constellation-X

Use X-ray spectroscopy to observe

- Black holes:
  - Probe close to the event horizon
  - Evolution with redshift
- Dark Matter and Dark Energy:
  - Clusters of galaxies
  - Large-scale structure
- Production and recycling of the elements:
  - Supernovae and interstellar medium

- 25-100 times sensitivity gain for high resolution spectroscopy in the 0.25 to 10 keV band
- Reference mission design is four satellites at L2 operating as one with advanced X-ray spectrometers

Enable high resolution spectroscopy of faint X-ray sources

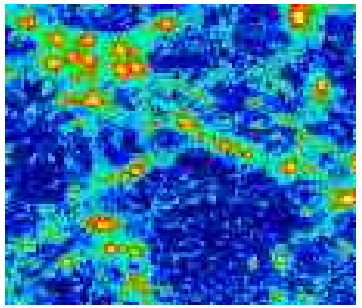
Constellation-X given strong endorsement by
US National Academy of Sciences
McKee-Taylor and Turner Committee Reports

Constellation-X Science Objectives

What happens at the edge of a black hole?

How do Super-massive black holes evolve?

Measure effects of **strong gravity** near the event horizon of black holes.



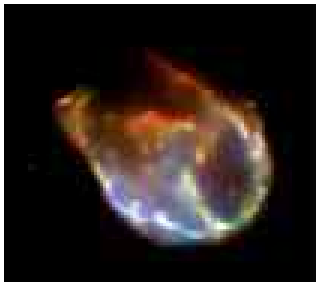
What is the universe made of?

How does the universe evolve?

Trace baryonic matter throughout the universe and constrain the nature of **dark matter & dark energy**.

What roles do black holes play in galaxy evolution?
What is the total energy output of the universe?

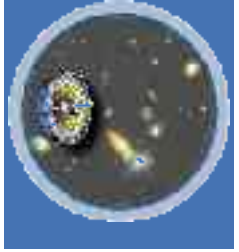
Study formation of supermassive **black holes** and trace their evolution with redshift.



Do new forms of matter exist?
How does the chemical composition of the universe evolve?

Study the **life cycles of matter** and energy & understand the behavior of matter in extreme environments.

Einstein Probes



Three focused missions, each designed to address a single high priority science question

- Priority and science topic determined via NASA strategic planning process, using National Academy recommendations
  - Joint Dark Energy Mission (JDEM)
  - Inflation Probe
  - Black Hole Finder Probe

- Competed Principal Investigator missions
  - Implementation approach determined by peer review
  - Launched every 3-4 years
  - $350-500M class missions

Einstein Probes: JDEM Status

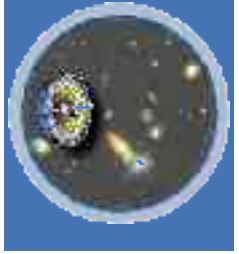
- NASA and DOE have agreed to implement a Joint Dark Energy Mission (JDEM) as follows:
  - The Dark Energy science investigation will be PI-led
  - Competitive selection will be used
  - NASA is responsible for the overall success of the mission
- NASA is funding a number of mission concept studies
  - Two different concepts selected for concept studies:
    - SNAP (Perlmutter)
    - DESTINY (Morse)
  - Three “collaborative” or “technology” proposals selected
- NASA and DOE will appoint a Science Definition Team to:

  (i) Determine case for space mission,

  (ii) Write science requirements document for JDEM AO,

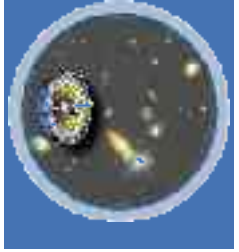
  (iii) Provide feedback for JDEM pre-project office, when it exists

  Agencies in the process of jointly select members. “Dear Colleague” letter issued, selection process underway, first meeting this summer/fall



Einstein Probes: BHFP and IP Status

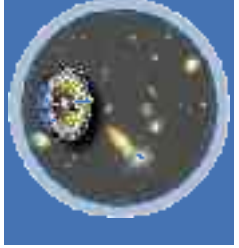
- Black Hole Finder Probe
  - Prioritized by the Astronomy Decadal Survey
  - Two mission concept studies selected:
    - EXIST (Grindlay)
    - CASTER (McConnell)
- Inflation Probe
  - Identified as a priority for the next decade by the Astronomy Decadal Survey
  - Three mission concept studies selected:
    - EPIC (Bock),
    - Inflation Probe (Hinshaw),
    - EPIC (Timbie)
  - NSF-led, multi-agency(NSF, NASA, DoE) roadmap for decisive measurements of both types of CMB polarization. The roadmap will address needed technology development and ground-based, balloon-based, and space-based CMB polarization measurements. Chair: Rainer Weiss.



Beyond Einstein Program Status

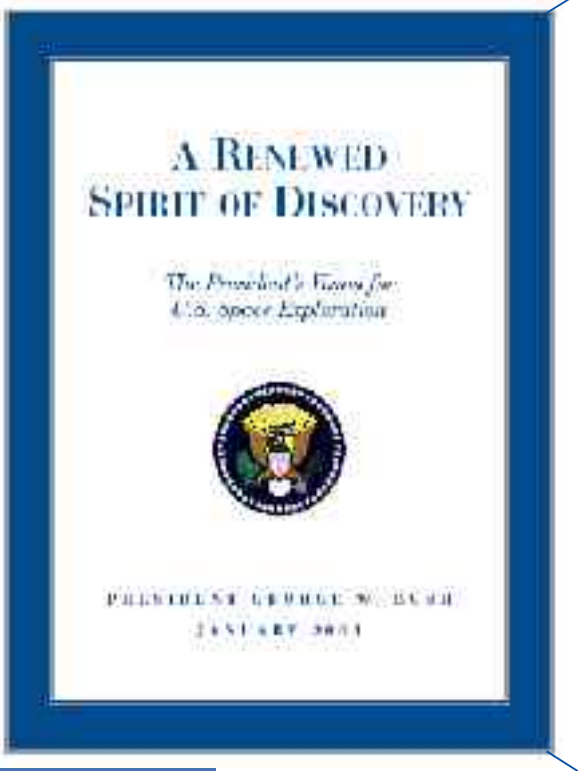
- The Beyond Einstein Initiative was approved as part of NASA's FY04 budget
  - Includes LISA and Constellation-X
  - Includes the Einstein Probes beginning later in this decade

- On January 14, the President proposed a new vision for the US civil space program – a Vision for Space Exploration



Vision for Space Exploration

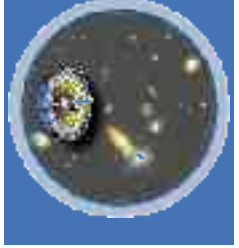
THE FUNDAMENTAL GOAL OF THIS VISION IS TO ADVANCE U.S. SCIENTIFIC, SECURITY, AND ECONOMIC INTEREST THROUGH A ROBUS SPACE EXPLORATION PROGRAM



- Implement a sustained and affordable human and robotic program to explore the solar system and beyond
- Extend human presence across the solar system, starting with a human return to the Moon by the year 2020, in preparation for human exploration of Mars and other destinations;
- Develop the innovative technologies, knowledge, and infrastructures both to explore and to support decisions about the destinations for human exploration; and
- Promote international and commercial participation in exploration to further U.S. scientific, security, and economic interests.

Beyond Einstein Program Status

- The President proposed a FY05 budget for NASA that implements the Vision for Space Exploration
  - Supports Return to Flight in 2005
  - Requests $1B in additional funding over the next five years
  - Reprograms $11B over the next five years from planned programs that do not directly support the Vision objectives
- This has a major impact on the planned Beyond Einstein Program schedule
  - LISA delayed “one year” (to 2013)
  - Constellation-X delayed “two years” (to NET 2016)
  - Einstein Probes “deferred indefinitely”, i.e. beyond the current budget horizon (no funding for at least five years)
- The President’s FY05 budget proposal is currently before the US Congress



LISA Program Status

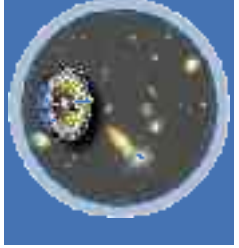
- LISA is an approved NASA Project
  - LISA is a collaboration between NASA and ESA. The collaboration includes LISA and LISA Pathfinder
  - LISA is an approved ESA program
  - ESA is working toward a 2012 launch date
- The President's FY05 budget proposal delays LISA by one year
  - The President's FY05 budget proposal supports a 2013 LISA launch date
  - The President's FY05 budget proposal fully supports the NASA contribution to LISA Pathfinder
  - NASA's current Associate Administrator for Space Science has committed to trying to pull forward the LISA launch date using Space Science resources
  - NASA and ESA are working closely to align their respective LISA activities

Constellation-X Program Status

- Constellation-X is an approved NASA Project
  - Technology development is currently underway in a number of critical areas including mirror and detector technology
- The President's FY05 budget proposal delays Constellation-X by two years
  - The President's FY05 budget proposal significantly decreases the planned technology development budget and results in a launch date no earlier than 2016
- NASA is committed to Constellation-X
  - The Con-X science is a high priority for NASA and the community
  - NASA is continuing to support the technology development necessary to undertake Con-X and seek the substantial out-year resources required to develop the observatory for launch
  - Constellation-X team is open to international collaboration to reduce cost to NASA and is open to new implementation approaches to accomplish this

NASA's Beyond Einstein Program

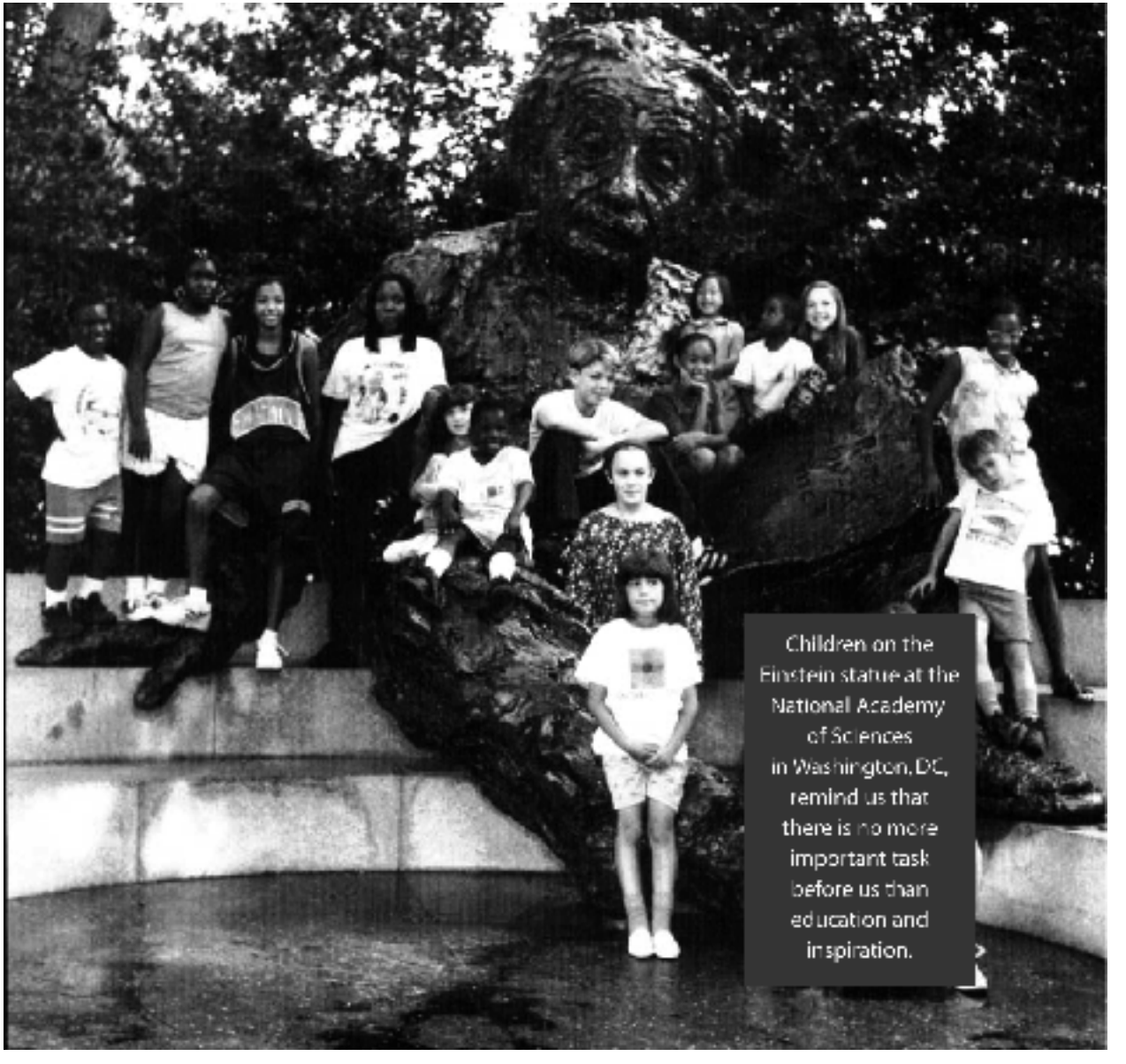
- The Beyond Einstein science is compelling and important
- The Beyond Einstein Program is underway
  - Approved in 2004
  - Part of a multiagency "Physics of the Universe" initiative
  - LISA will enter Phase A this year
  - International participation is an important component
- Focusing of NASA on the Vision for Space Exploration has reduced planned resources
  - The science case has not changed
  - Nothing has been cancelled
  - Missions will be delayed
- Beyond Einstein is arguably the most compelling "other science activity" at NASA



Education and Public Outreach

Big Bang and black holes capture the imagination and can be used to teach physical science at all levels

Beyond Einstein will address the national education priority by inspiring future generations of scientists and engineers, as only NASA can . . .



Children on the Einstein statue at the National Academy of Sciences in Washington, DC, remind us that there is no more important task before us than education and inspiration.

The 21st Century

How did the Universe begin? Does time have beginning & an end? Does space have edges? The questions are as old as human curiosity. But the answers have always seemed beyond the reach of science. . .

until now!

http://universe.nasa.gov