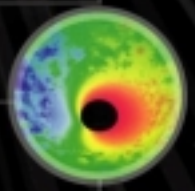
structure and evolution of the universe

BEYOND EINSTEIN:

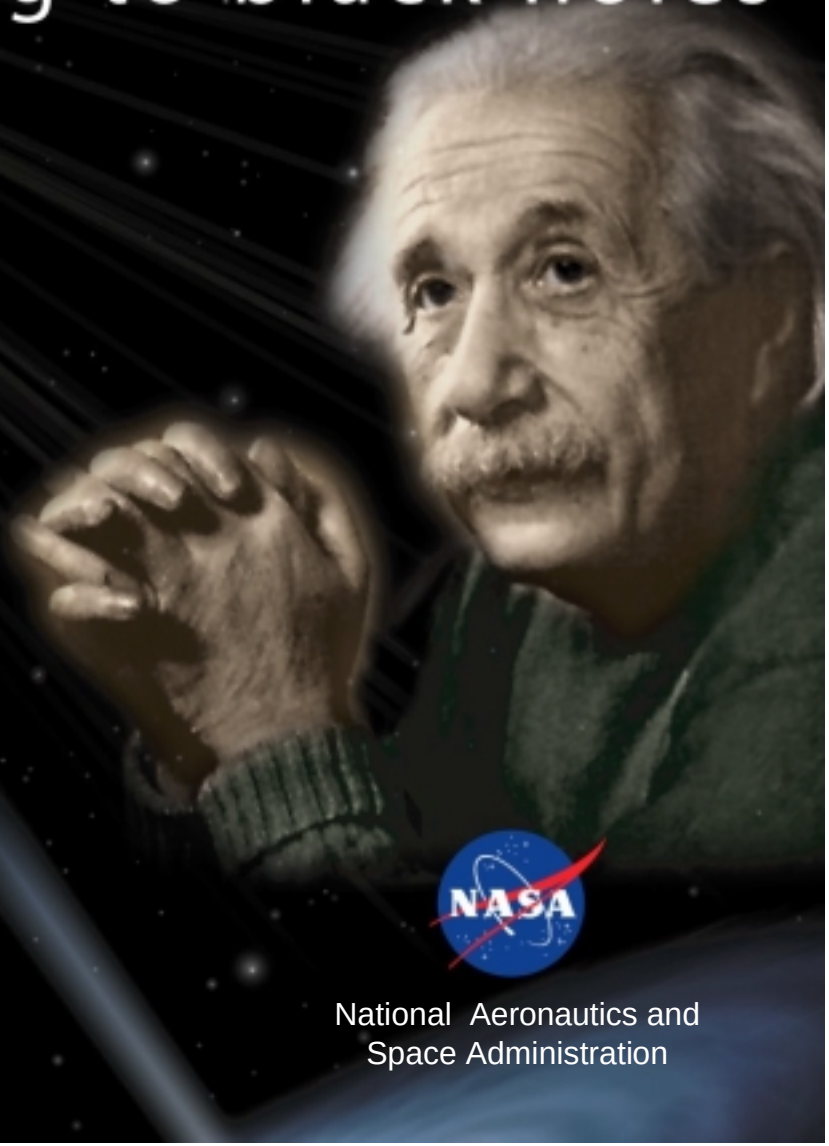
from the big bang to black holes

WHAT POWERED THE BIG BANG?

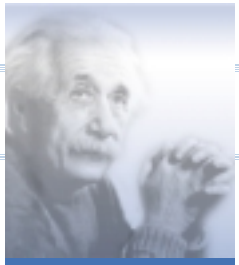


WHAT HAPPENS AT THE EDGE OF A BLACK HOLE?

WHAT IS DARK ENERGY?

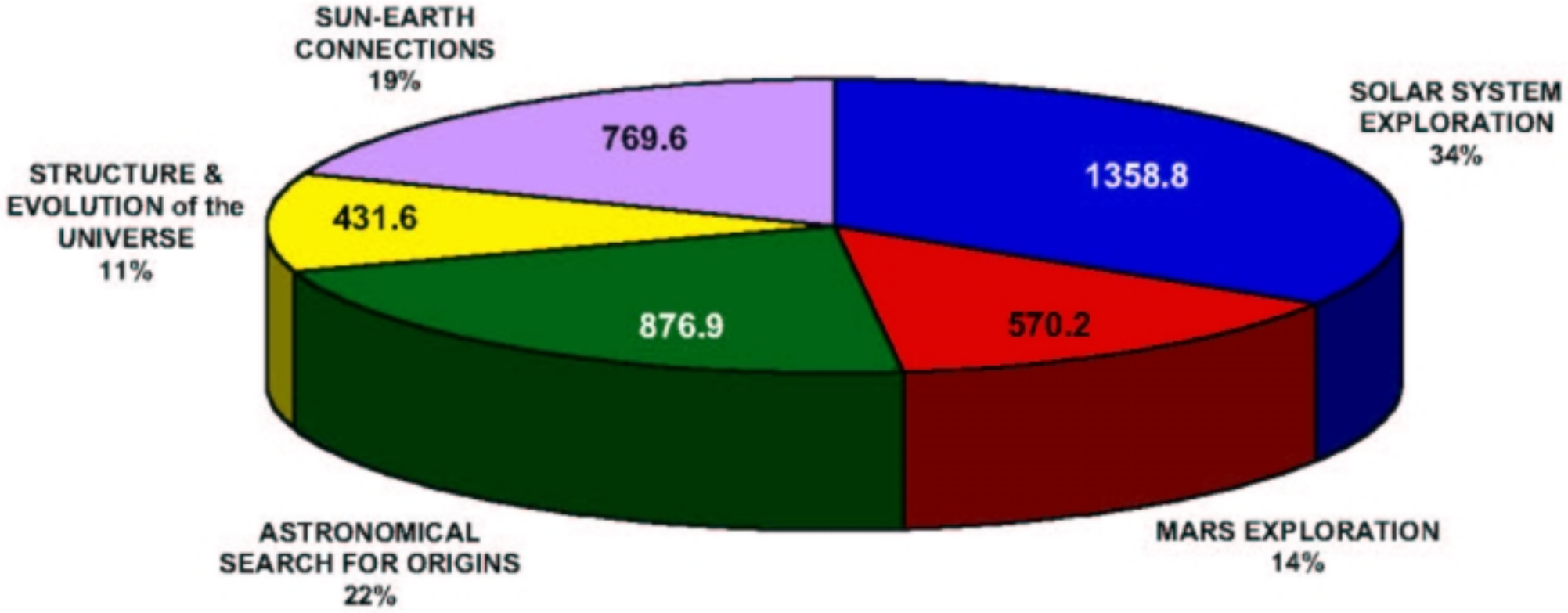


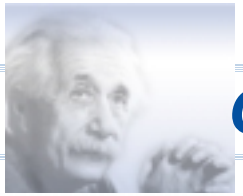
National Aeronautics and Space Administration



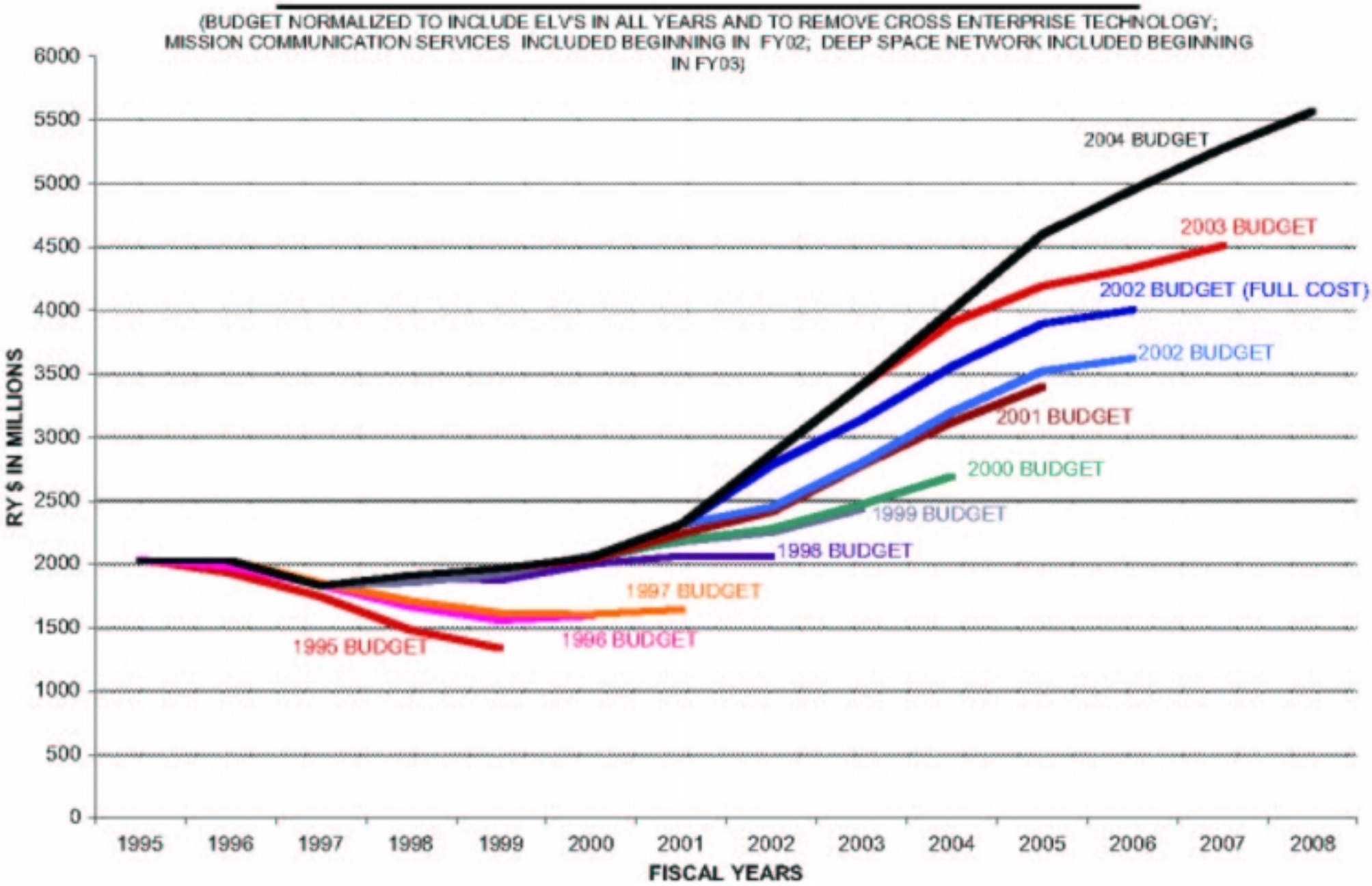
NASA & OSS FY04 Budget

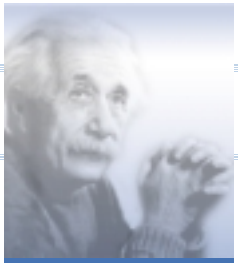
NASA $15.5B
Human Space Flight (Shuttle plus Station) $6.0B
Space Science $4.0B
Earth Science $1.5B
Biological and Physical Research $1.0B





OSS Budget History – Initiatives & NEW MONEY





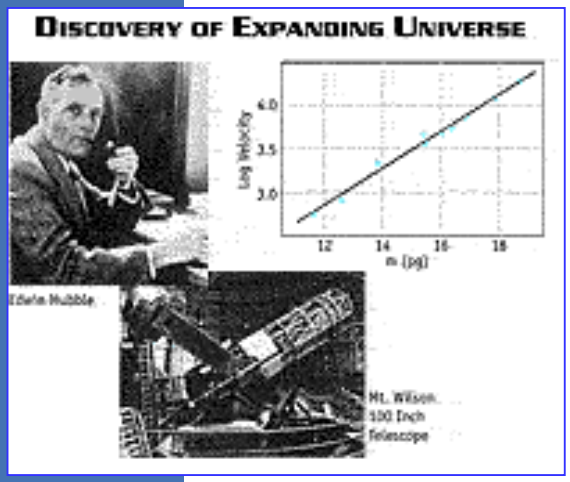
Einstein's Predictions

Three predictions of Einstein:

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

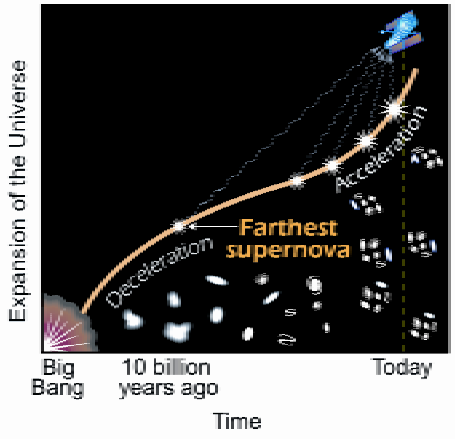
Observations confirm these predictions . . .

. . . the last only four years ago

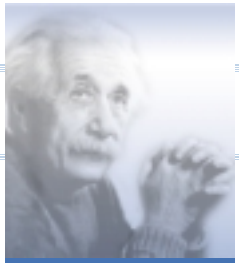


Hubble discovered the expanding Universe in 1929

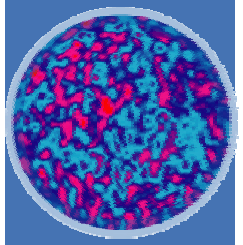
Black holes found in our Galaxy and at the center of quasars over the past three decades

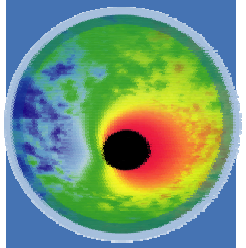


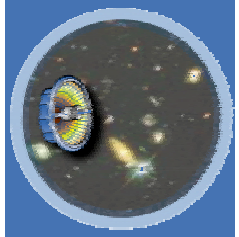
Evidence for an accelerating Universe was observed in 1998



Completing Einstein's Legacy







BIG BANG

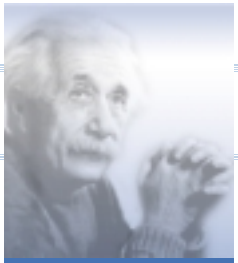
What powered the Big Bang?

BLACK HOLES

What happens at the edge of a Black Hole?

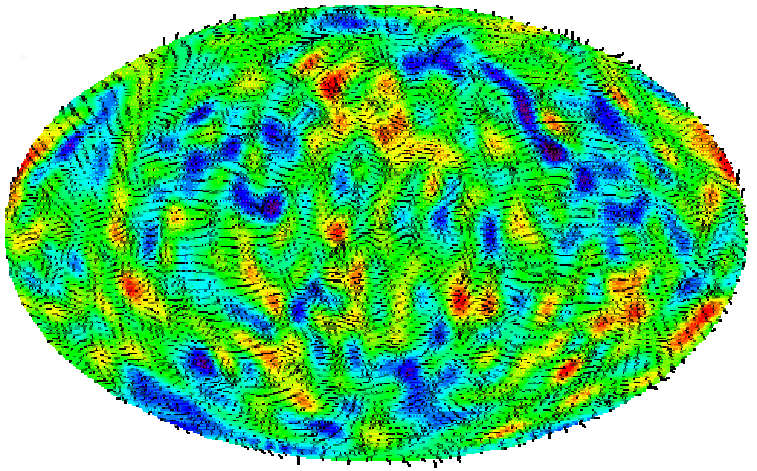
DARK ENERGY

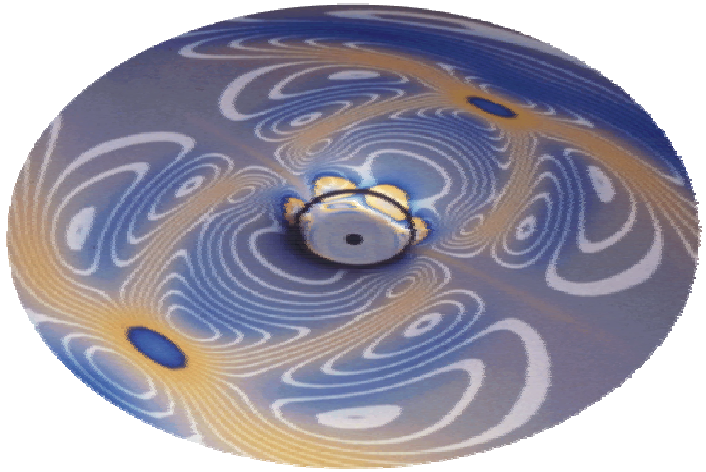
What is the mysterious Dark Energy pulling the Universe apart?



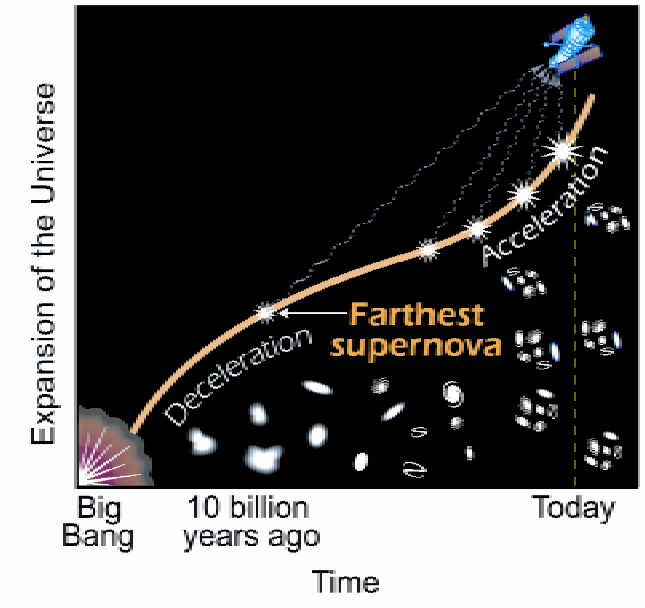
What Powered the Big Bang?

Gravitational waves leave a distinctive imprint on polarization pattern of CMB

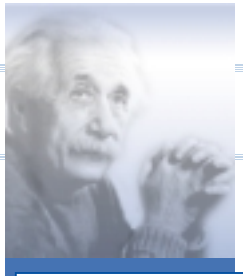




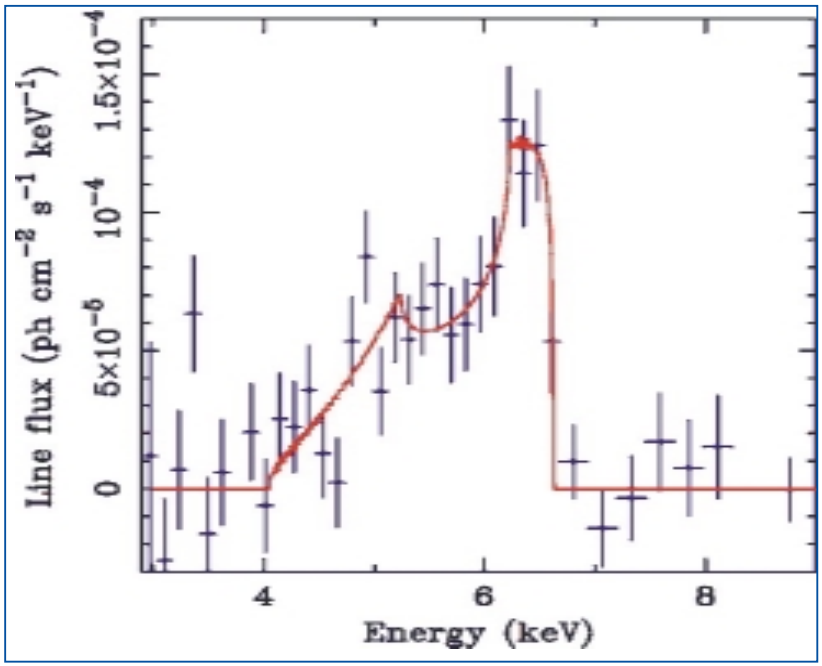
Gravitational waves from inflation and phase transitions may be detected directly



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

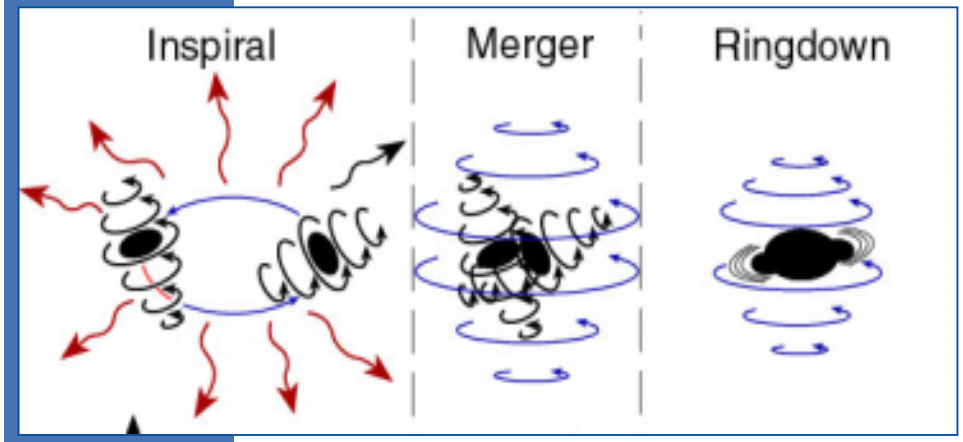


What Happens at the Edge of a Black Hole?



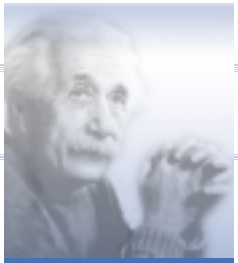
X-Ray Spectroscopy

- **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**



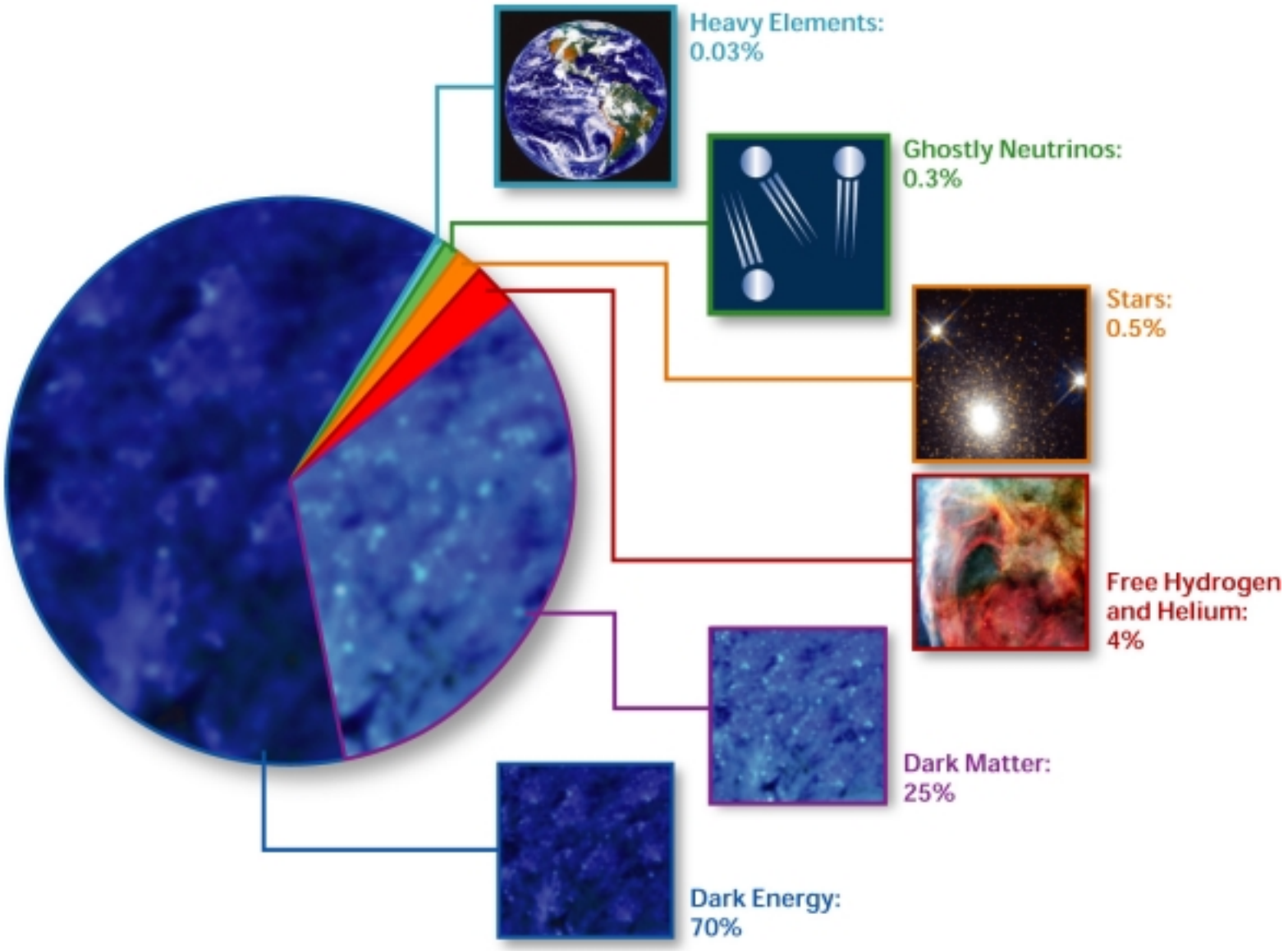
Gravitational Radiation

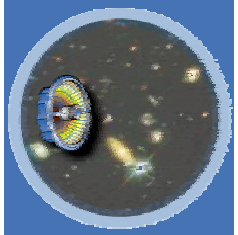
- **Black hole binaries produce gravitational waves in all phases of their evolution**
- **Test of GR in all three phases**

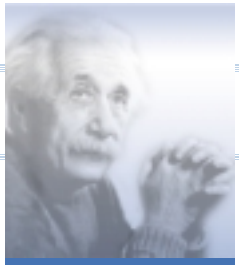


What is the Dark Energy?

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





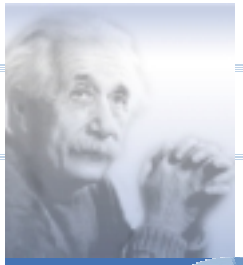


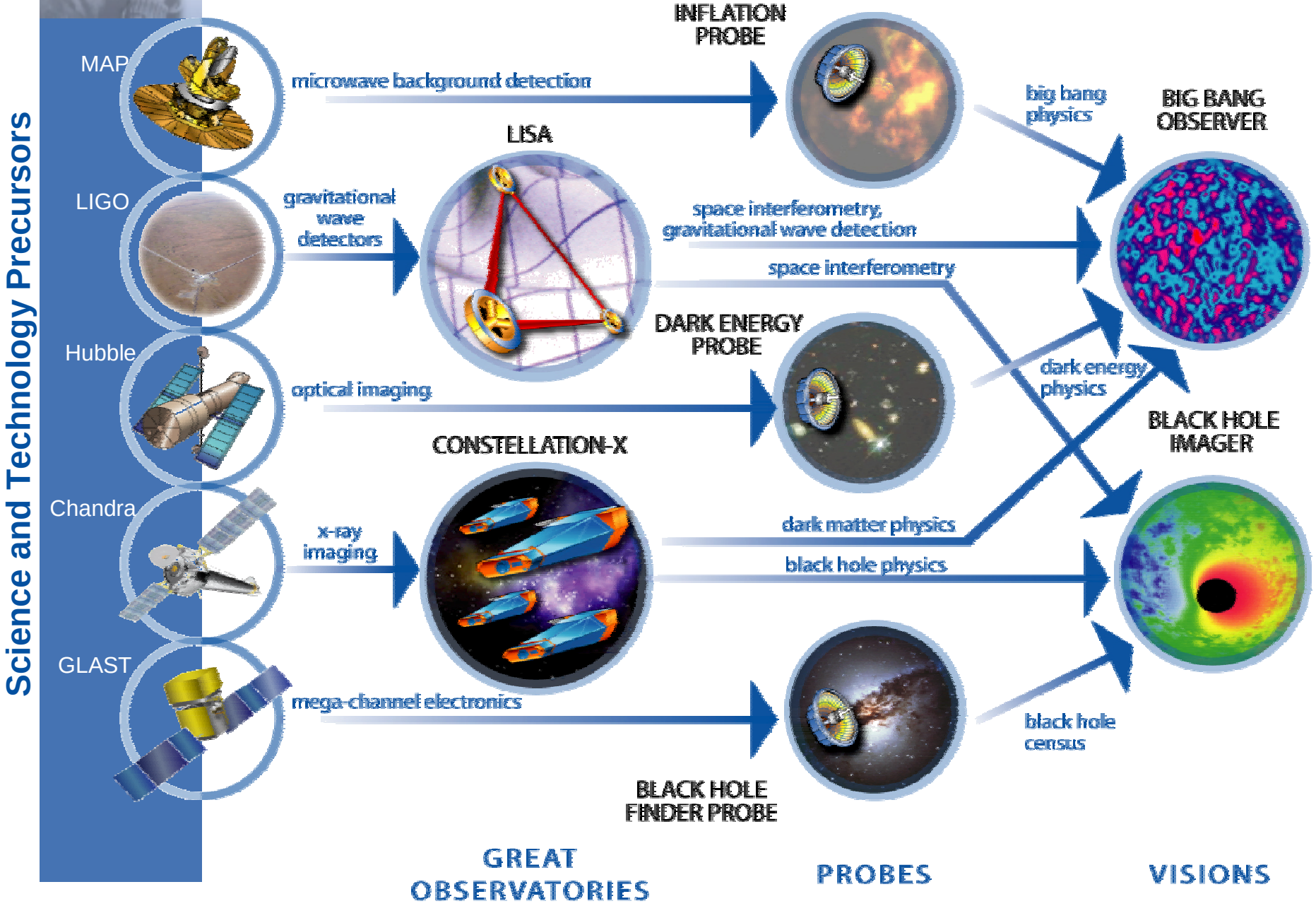
Realizing Science Beyond Einstein

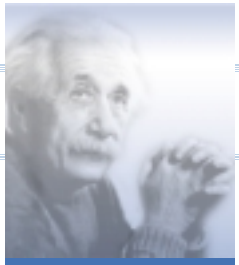
Three inter-linked elements that work together:

1. **Einstein Observatories :**
   - **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**
2. **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**
3. **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 the event horizon of a Black Hole**

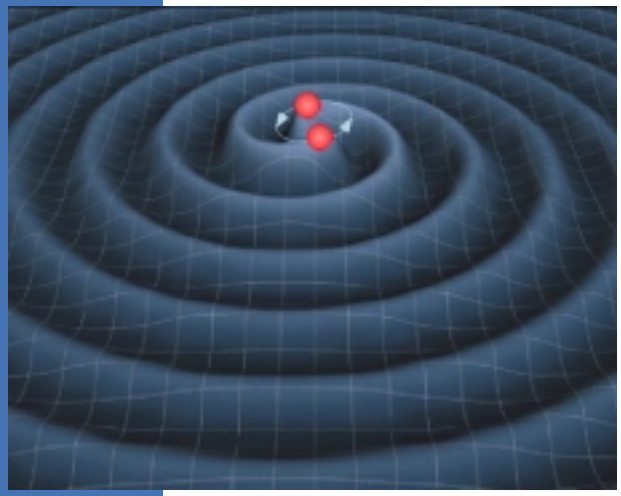
Beyond Einstein Program



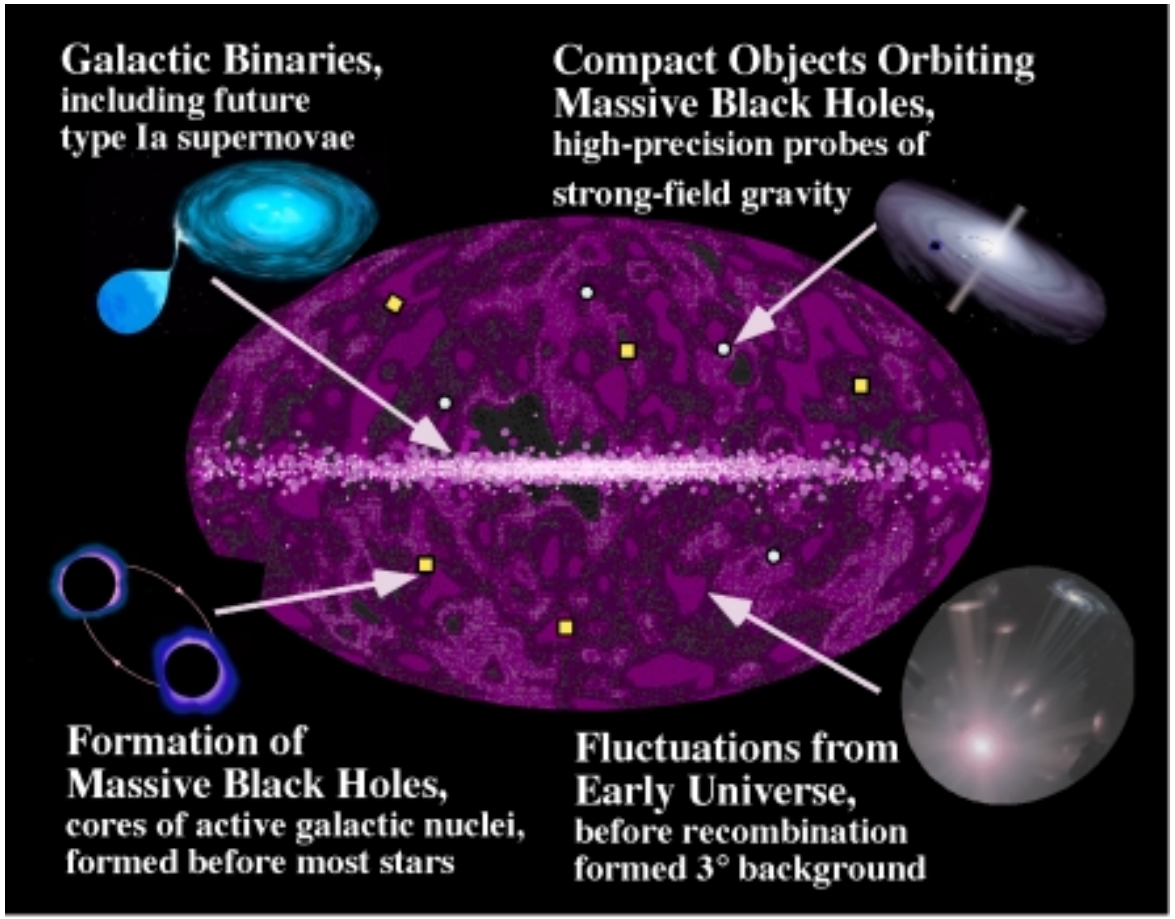




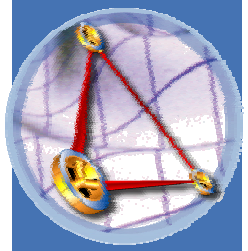
Gravitational Wave Astronomy



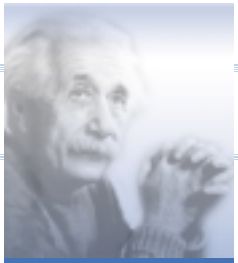
Black holes, neutron stars, and white dwarfs orbiting each other emit gravitational waves



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

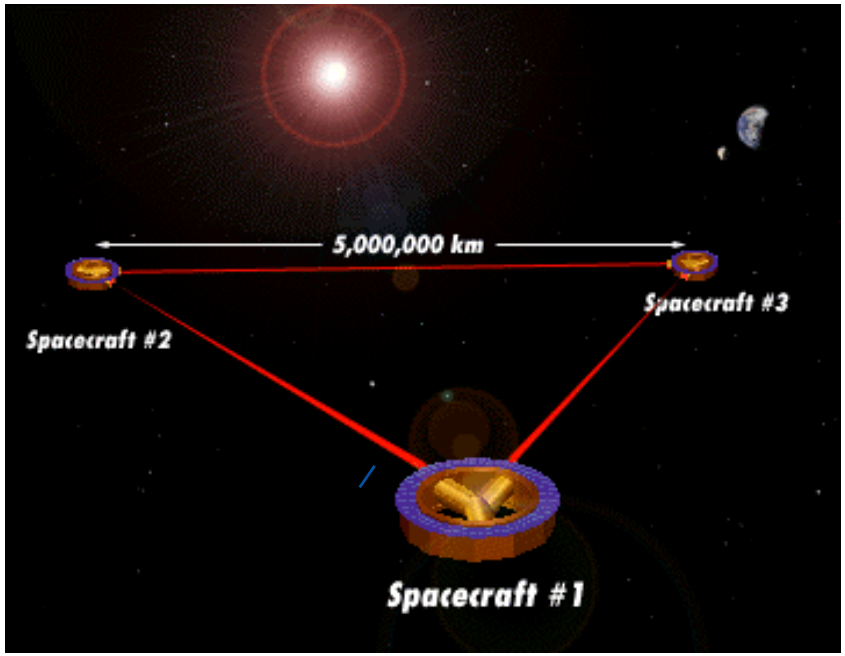


Laser Interferometer Space Antenna (LISA)

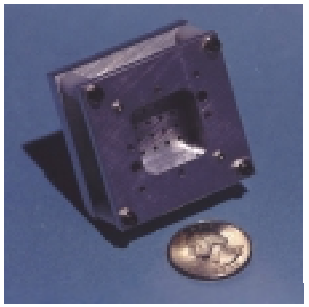
Joint ESA-NASA project

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

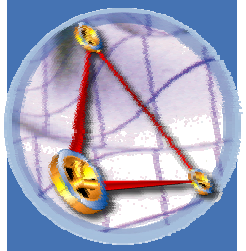
- **Three spacecraft separated by 5 million km**
- **Each spacecraft includes two freely falling test masses with drag free operation**
- **Distance changes measured with precision of 4 ppm RMS over 100 seconds**



Flight demonstration of disturbance reduction system ST-7 on ESA SMART-2 mission in 2006



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

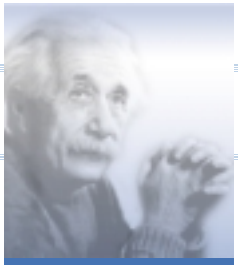
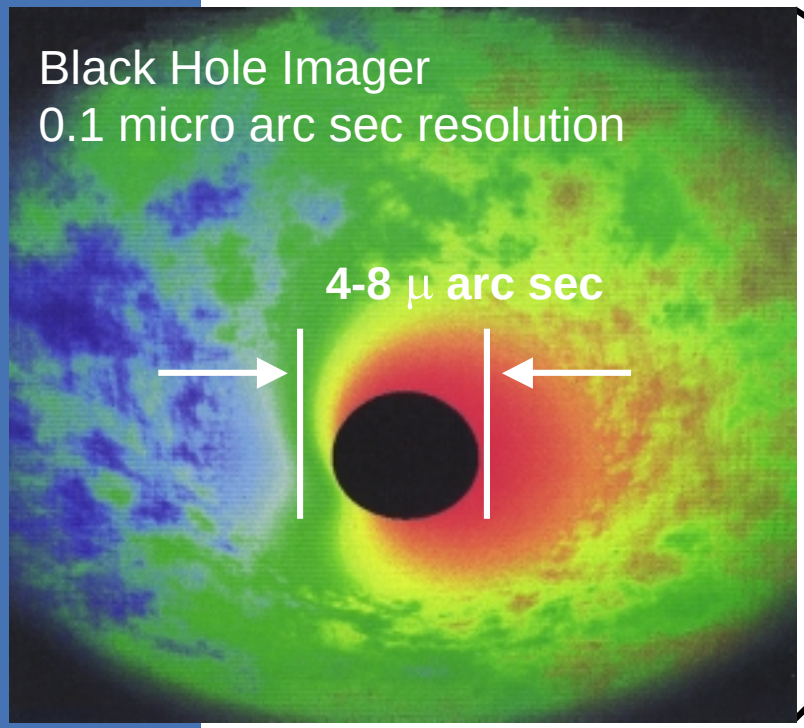
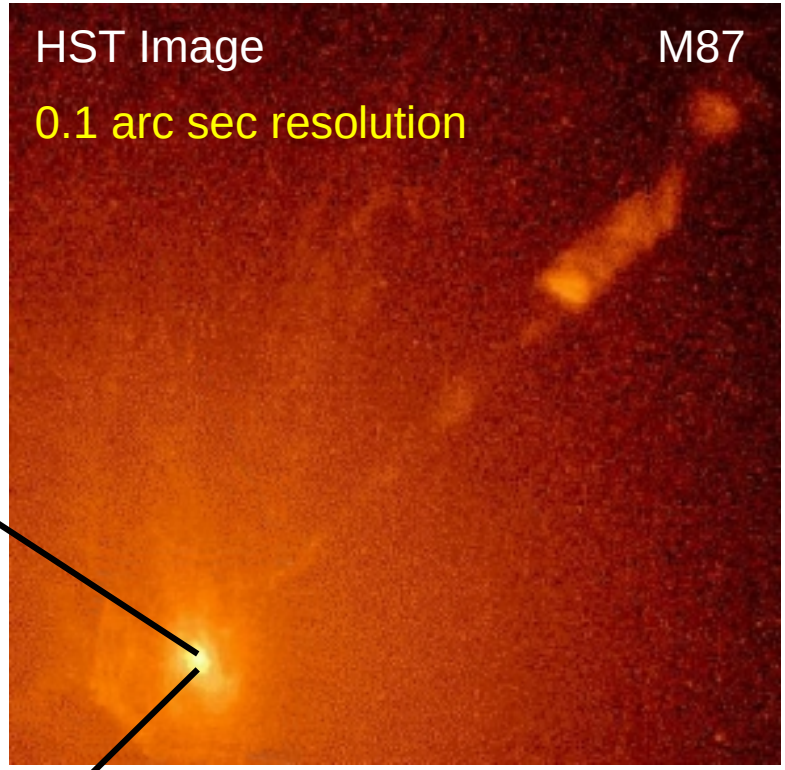


Image a Black Hole!

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

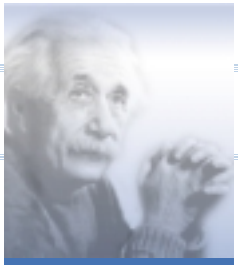
Black holes provide a unique laboratory to test Einstein's theory of gravity





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

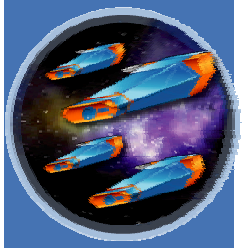


Constellation-X

Use X-ray spectroscopy to observe

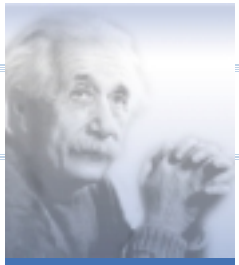
- **Black holes:**
  - **Probe close to the event horizon**
  - **Evolution with redshift**
- **Dark side of the Universe:**
  - **Clusters of galaxies and large-scale structure**
- **Production and recycling of the elements:**
  - **Supernovae and interstellar medium**

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

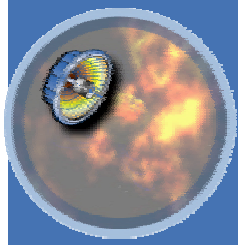


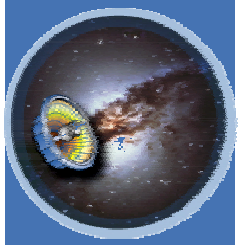
Enable high resolution spectroscopy of faint X-ray sources

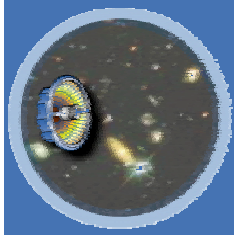
Constellation-X given strong endorsement by
US National Academy of Sciences
McKee-Taylor and Turner Committee Reports



Einstein Probes

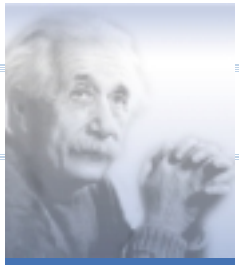






Three focused missions, each designed to address a single high priority science question

- Priority and science topic determined via NASA strategic planning process, using National Academy recommendations
  - Dark Energy Probe
  - 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



National Research Council Endorsements

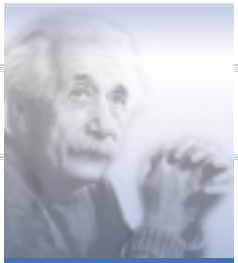
Astronomy & Astrophysics in the New Millennium 2001 Decadal Survey (McKee-Taylor)

Major Initiatives:

1. NGST
2. Constellation-X Observatory
3. Terrestrial Planet Finder
4. Single Aperture Far Infrared Observatory

Moderate Initiatives

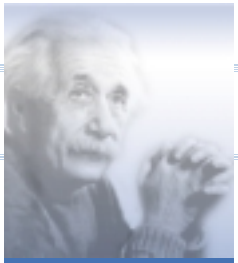
1. Gamma-ray Large Area Space Telescope
2. Laser Interferometer Space Antenna
3. Solar Dynamics Observatory
4. Energetic X-Ray Imaging Survey Telescope
5. Advanced Radio Interferometry Between Space & Earth



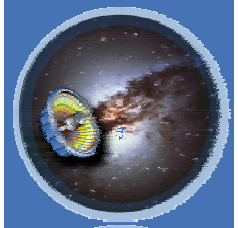
National Research Council Endorsements

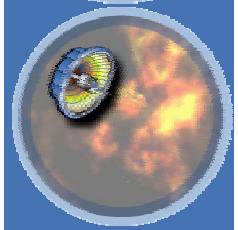
Connecting Quarks with the Cosmos 2002 (Turner) Not a priority list.

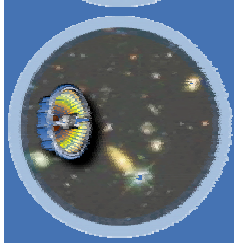
- Measure the polarization of the CMB
- Determine the properties of dark energy
- Use space to probe basic laws of physics (Con-X, LISA)
- (Highest energy cosmic rays)
- (High-energy-density physics)
- (Interagency Initiative)
- (Neutrino masses)

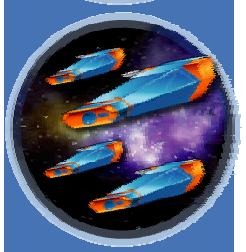


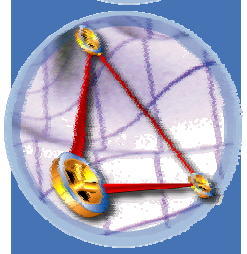
Beyond Einstein Timeline











RESEARCH AND ANALYSIS

TECHNOLOGY DEVELOPMENT

EDUCATION AND PUBLIC OUTREACH

FIRST EINSTEIN GREAT OBSERVATORY

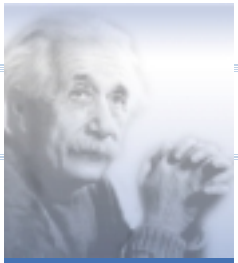
FIRST EINSTEIN PROBE

SECOND EINSTEIN GREAT OBSERVATORY

SECOND EINSTEIN PROBE

THIRD EINSTEIN PROBE

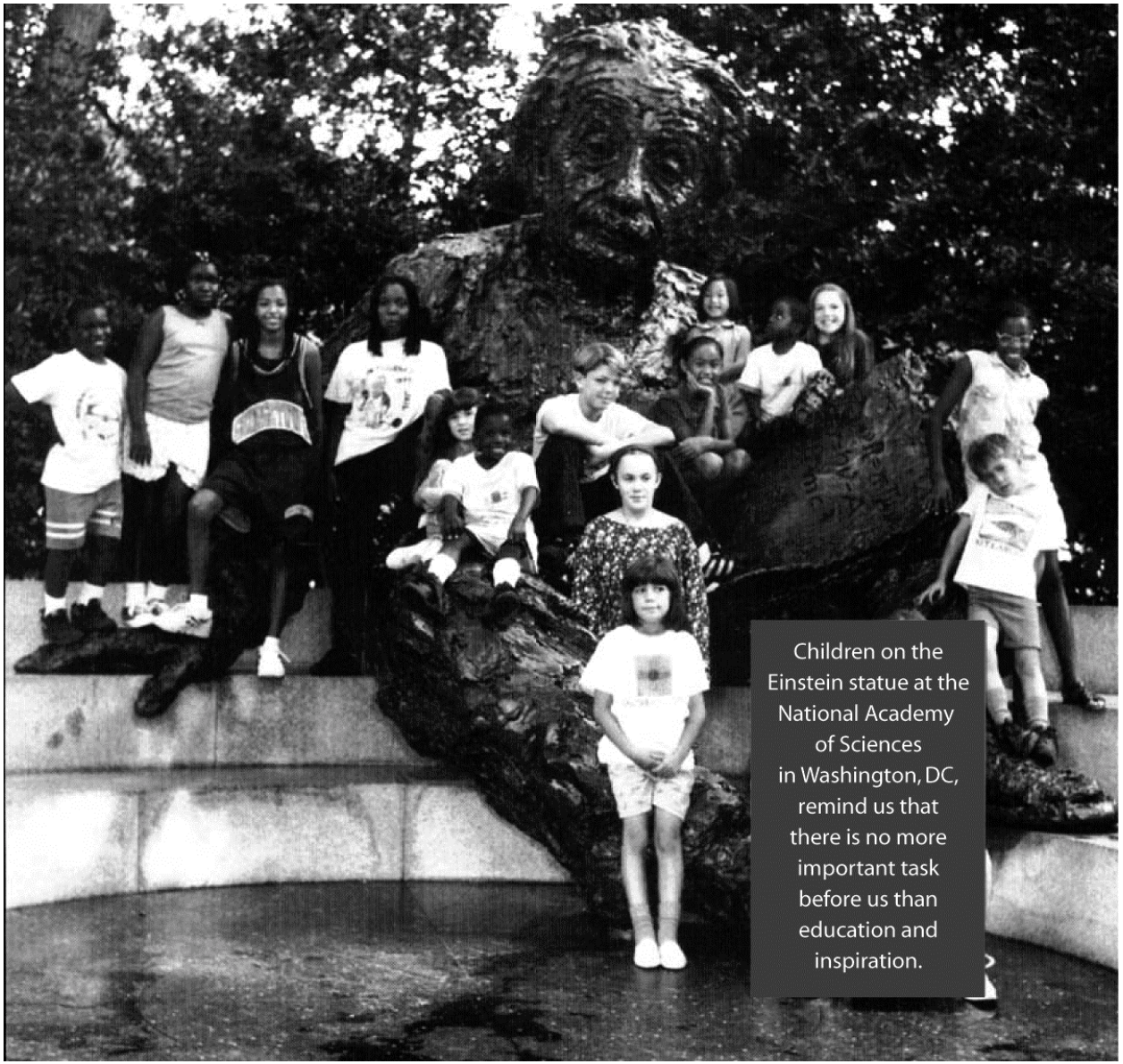
2005 2010 2015 2020



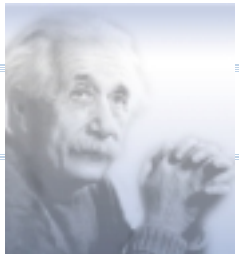
Education and Public Outreach

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 . . .



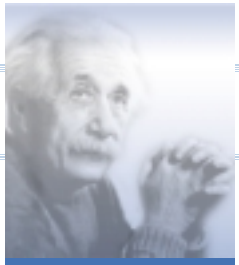
Children on the Einstein statue at the National Academy of Sciences in Washington, DC, remind us that there is no more important task before us than education and inspiration.



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!



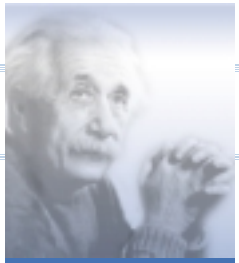
Beyond Einstein in the FY04 Budget!!!!

NEW MONEY!!!!!

	FY03	FY04	FY05-08	FY03-08	FY09-…
Con-X	**18.9**	**23.5**	**192.6**	**235.0**	**. . .**
LISA	**9.7**	**30.4**	**405.2**	**445.3**	**. . .**
Probes	**0.0**	**0.0**	**65.0**	**65.0**	**. . .**
R&A	**0.0**	**5.0**	**41.4**	**46.4**	**. . .**

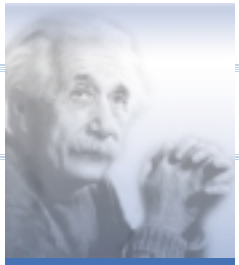
(in millions)

- LISA launch in 2011
- Con-X launch in 2013/14
- Einstein Probe wedge starts in FY07
- R&A included



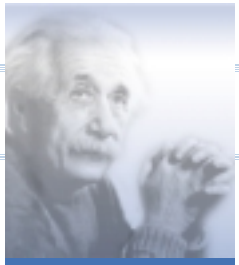
Immediate future

- Complete LISA/Con-X review results into project planning.
- Organize Beyond Einstein program office
  - Identify synergistic support functions.
  - Initiate program E/PO coordinating with/incorporating LISA and Con-X E/PO efforts
- Start Einstein Probe concept studies
  - Within 1 year may have insight into appropriate ordering for the Probes
- Look for additional resources to solidify or accelerate Probes.



Probe development

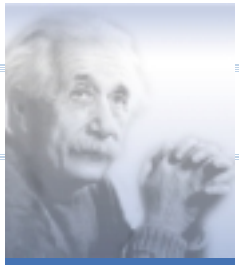
- Solicit mission concepts for Probes
- Select 3 per probe
  - Available funding approx $1M / year for up to 2 years
- Two types for Dark Energy Probe
  - Complete mission
  - Contribution to SNAP
- Future
  - Technology development (if needed)
  - Mission AO (as budget and technology permits)



Read the tea leaves

The changing nature of science has opened significant opportunities for fundamental discoveries at the intersection of physics and astronomy that require the Administration to set priorities and increase interagency cooperation. This year, under the auspices of the National Science and Technology Council (NSTC), these and other agencies will work with OSTP to develop a plan for coordination in this area.

- FY04 Budget language

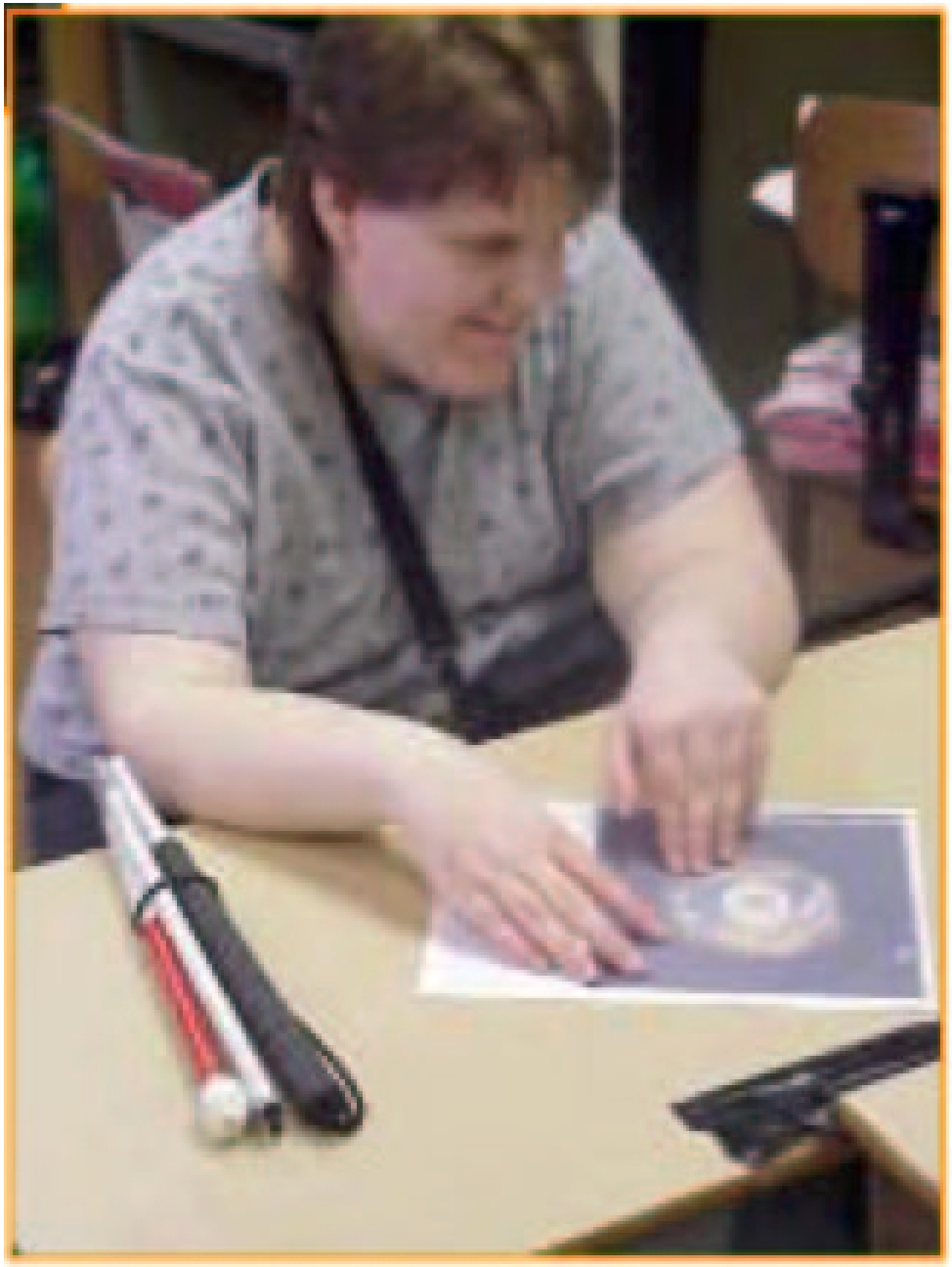


E	20/80
OFLCT	20/60
ZMPOKMC	20/40
OSTPNSTCIWG	20/20

Physics of the universe

- Co-chaired by Dehmer, Kinney, Rosen
- First formal meeting Tuesday February 25
- To present coherent set of issues and recommendations in response to Turner Report “Quarks to Cosmos”
- Also will address issues that cross agencies and interfere with collaboration

Education and public outreach



Braille book of astronomy