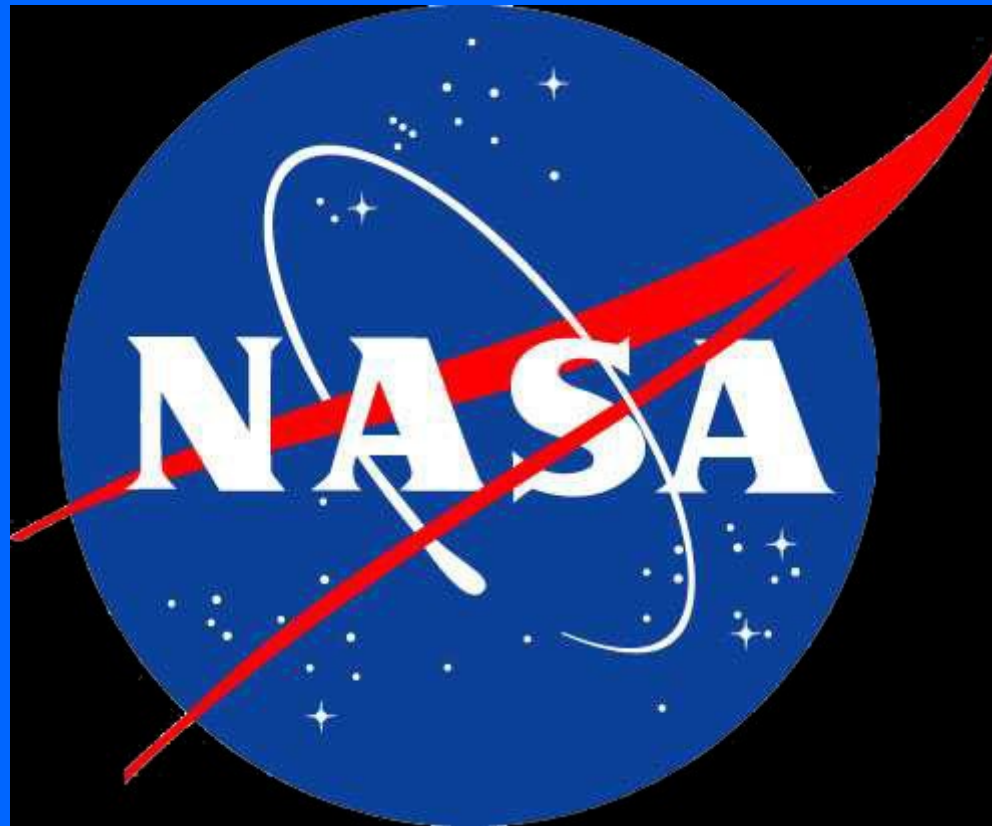


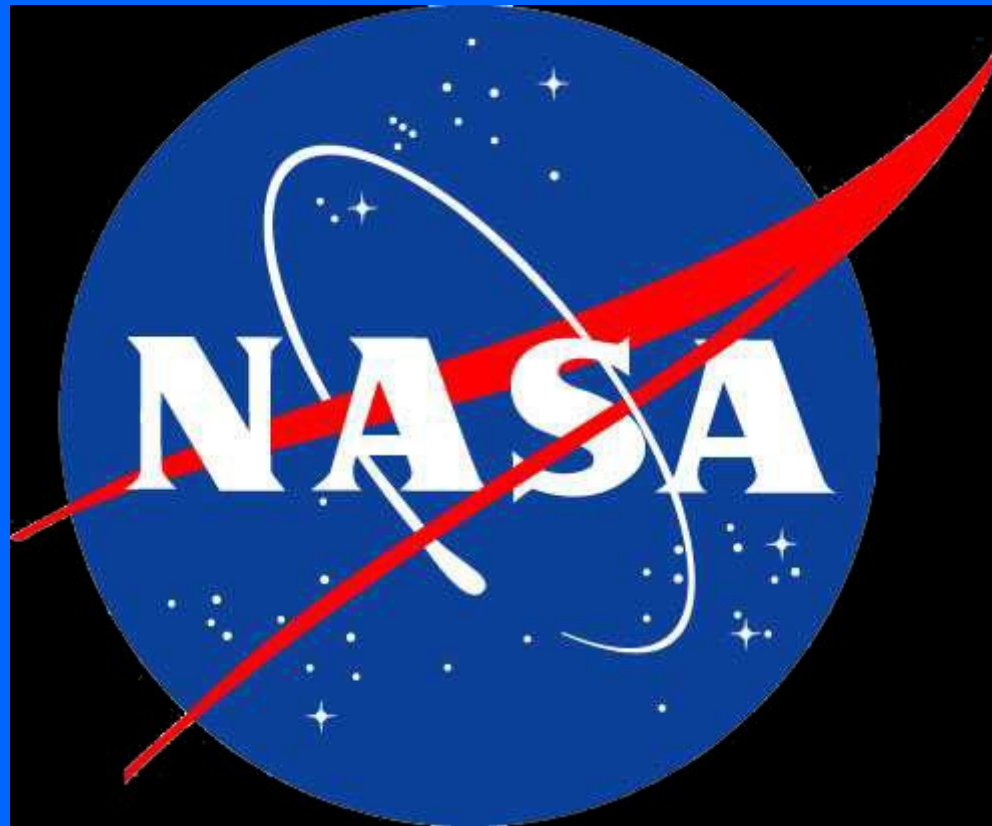


*Einstein's Universe  
and Beyond...*

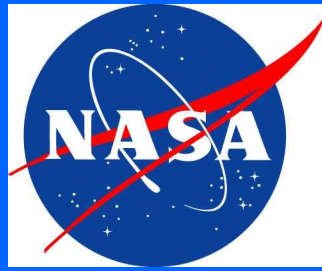
Professor Lynn Cominsky  
Sonoma State University  
January 15, 2004



**National Aeronautics  
and  
Space Administration**



Space



# NASA ENTERPRISES

**Aerospace  
Technology**

**Biological and  
Physical Research**

**Human Exploration  
and  
Development of Space**

**Earth Science**

**Education**

**Space Science**

# SPACE SCIENCE

NATIONAL AERONAUTICS & SPACE ADMINISTRATION

## Sun-Earth Connection



Mars  
Exploration  
program



*Living with a Star*

# SPACE SCIENCE

NATIONAL AERONAUTICS & SPACE ADMINISTRATION

## Astronomy and Physics Division



Infrared, Visible and  
Ultraviolet

**BEYOND EINSTEIN**

FROM THE BIG BANG TO BLACK HOLES

Structure and Evolution of the Universe

Radio, Microwave, X-ray, Gamma-ray, Gravity, Cosmic Rays

# *Structure and Evolution of the Universe*

1. To explain structure in the Universe and forecast our cosmic destiny;
2. To explore the cycles of matter and energy in the evolving Universe;
3. To examine the ultimate limits of gravity and energy in the Universe ranging from the closest stars to the most distant quasars.

# *Structure and Evolution of the Universe Missions*

**ACE**

***ASTRO E2***

**Chandra**

**CHIPS**

***Constellation-X***

**GALEX**

***GLAST***

***Gravity Probe B***

**HETE-2**

**INTEGRAL**

***LISA***

**RXTE**

**SWAS**

***Swift***

**WMAP**

**XMM-Newton**

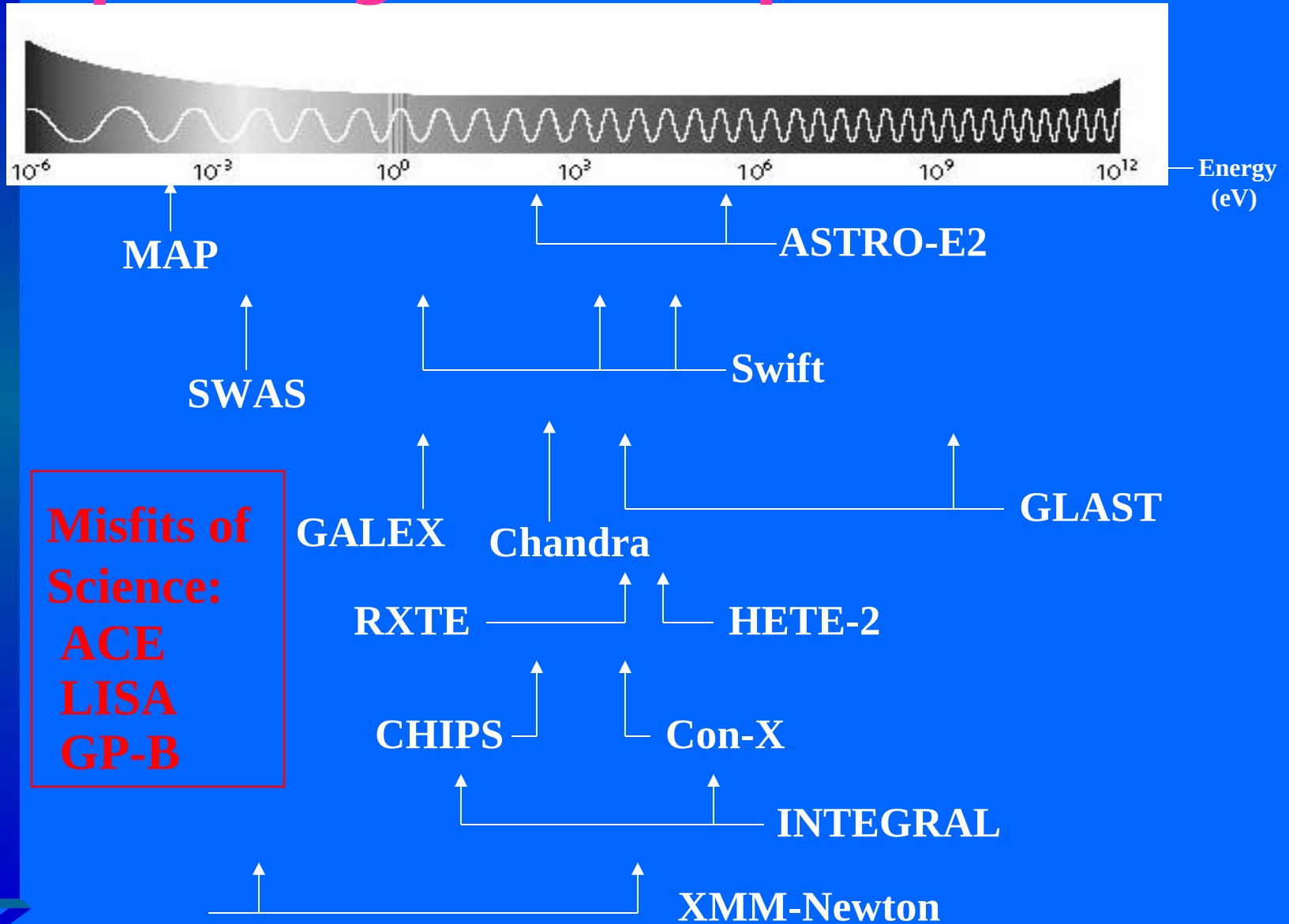
***Not yet  
launched***

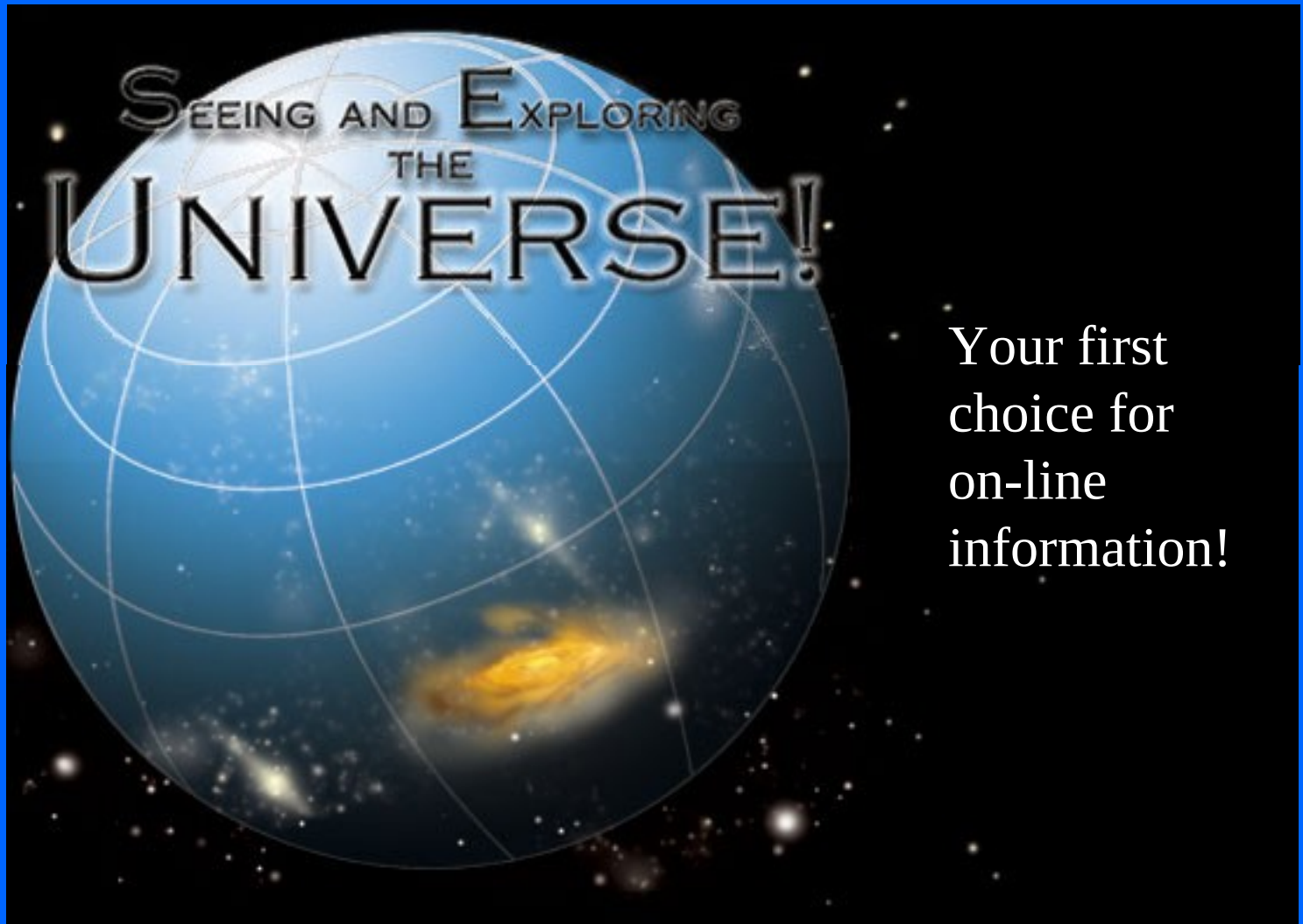


**In orbit**



# Spanning the EM Spectrum





<http://universe.sonoma.edu>

# *SEU Main research areas*

- ❖ Cosmic Microwave Background
- ❖ **X-ray Astronomy**
- ❖ **Gamma-ray Astronomy**
- ❖ Gravity

*Coming soon ----  
Beyond Einstein!*



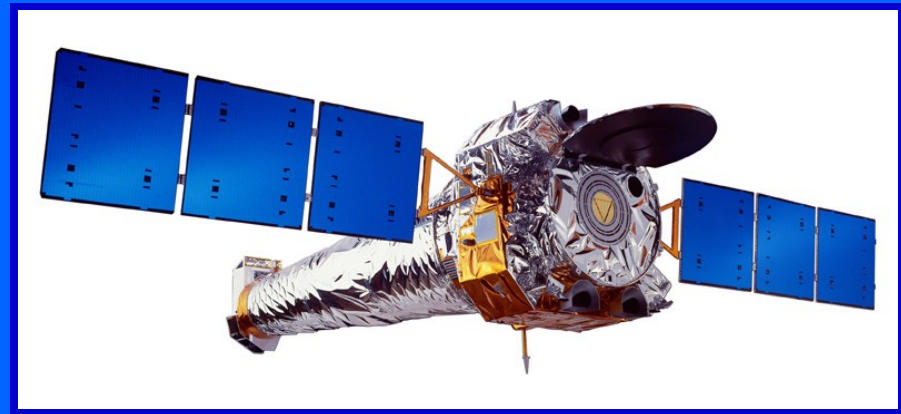
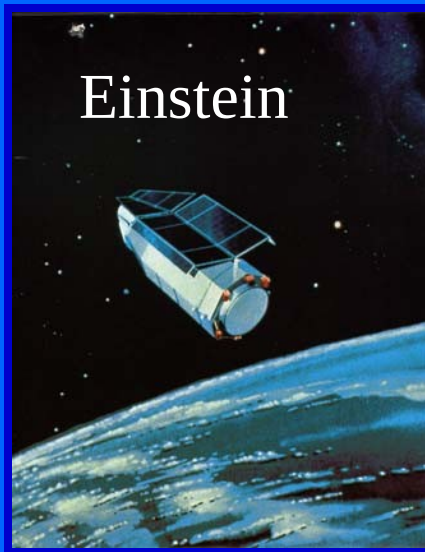
# *X-ray Astronomy – a brief history*

- ❖ Began in 1962 with the discovery of first extra-solar X-ray source (Sco X-1) in a rocket flight by Giacconi et al. (Nobel prize in 2002)
- ❖ First satellite was SAS-A aka *Uhuru* (1970-3)



# *X-ray Astronomy*

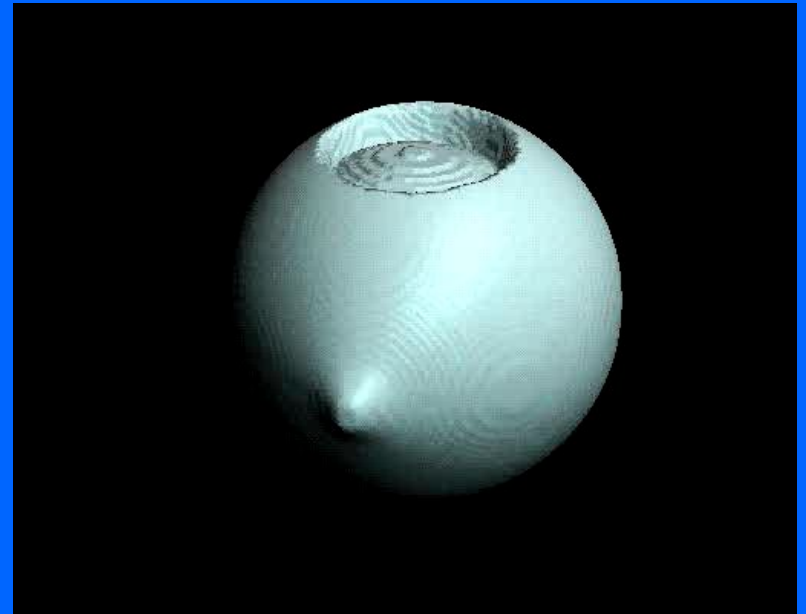
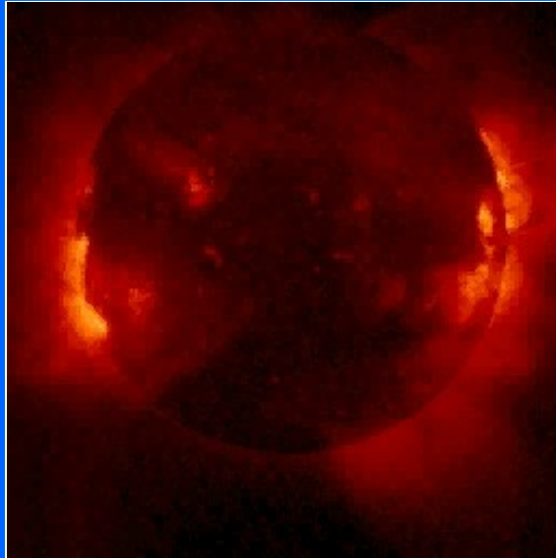
- ❖ First imaging X-ray satellite was Einstein Observatory (1978-81)
- ❖ Currently in orbit: RXTE, Chandra and XMM-Newton (ESA/NASA)



Chandra

# *X-ray Sorcery*

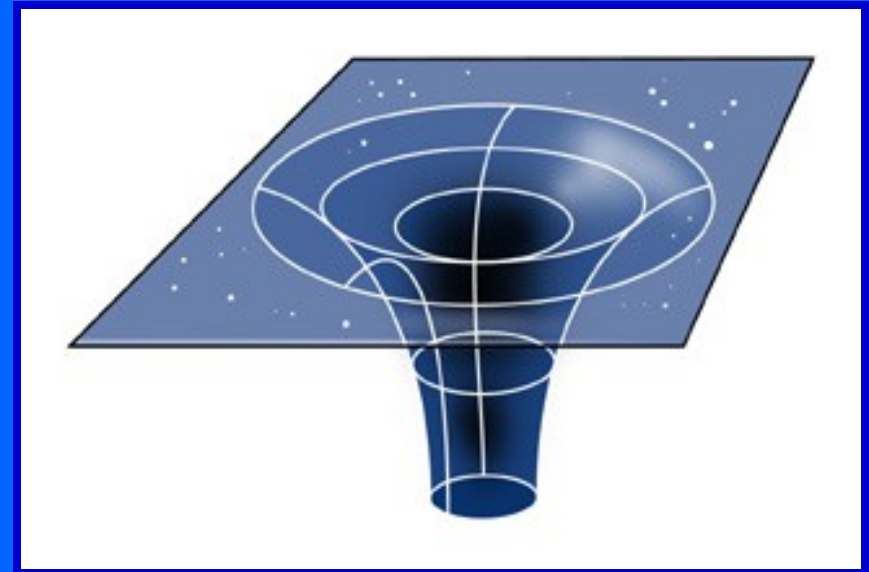
- ❖ Earliest source was Sun – corona and flares



- ❖ Then neutron stars and black holes in accreting binaries were discovered to be strong x-ray emitters – 10 orders of magnitude greater!

# *Einstein's Theory of General Relativity*

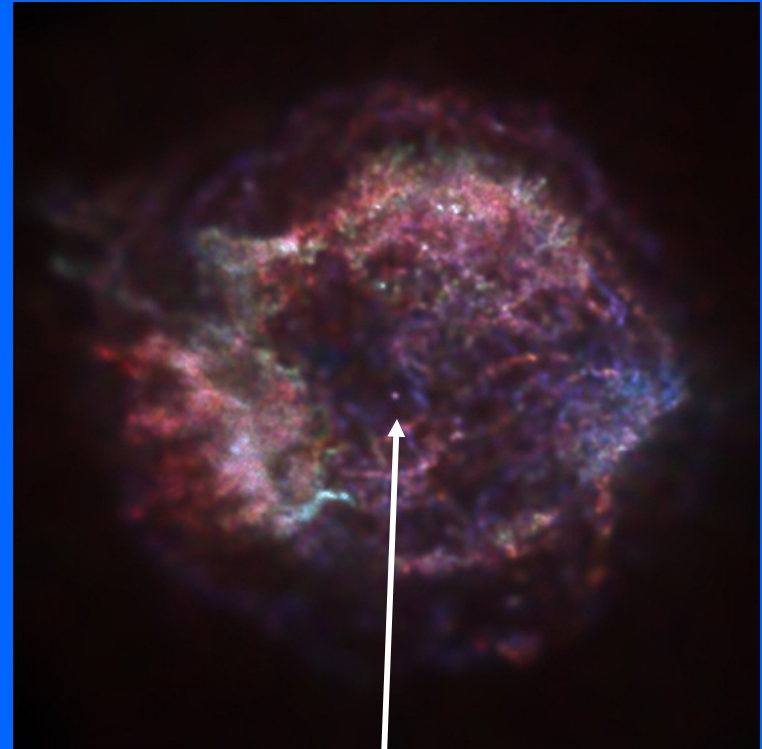
- ❖ Event horizon around singularity is defined by radius where escape velocity is equal to the speed of light
- ❖ Not even light can escape, once it has crossed the event horizon



$$R = 2GM/c^2$$

# *Chandra X-ray Observatory*

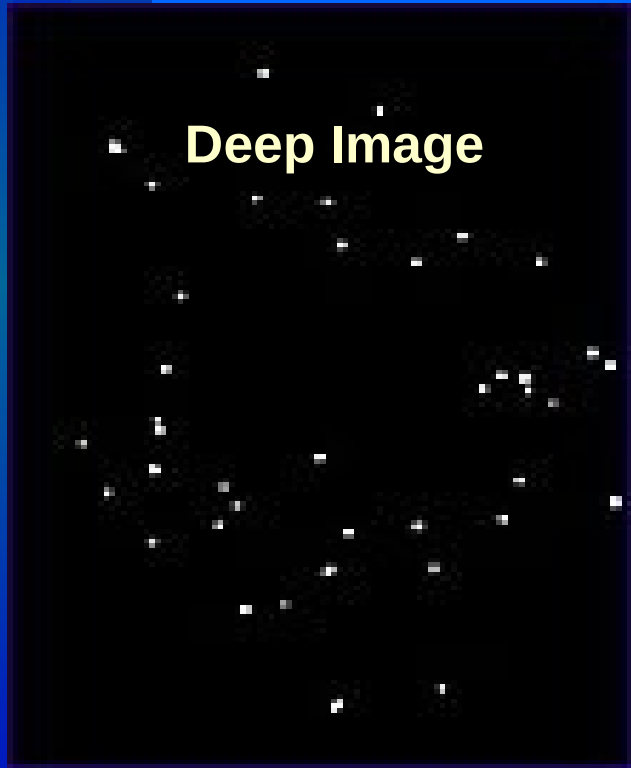
- ❖ 1 arcsecond images  
→ “HST of X-ray Astronomy”
- ❖ Breakthroughs in every area of study
  - ❖ Stars
  - ❖ Compact Objects
  - ❖ Galaxies
  - ❖ Galaxy Clusters
- ❖ 1-10 keV X-rays
- ❖ Launched 7/23/99



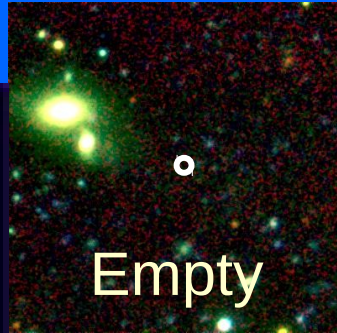
Cas A SNR shows  
central NS in one of  
Chandra's first images



# *Black Holes Are Everywhere!*

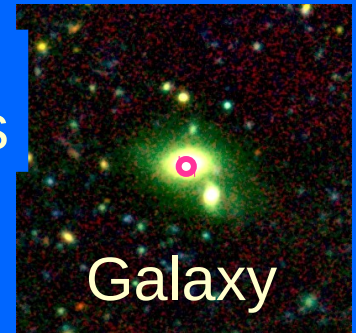


Chandra deep field



Black holes in empty space

Black holes in "normal" galaxies

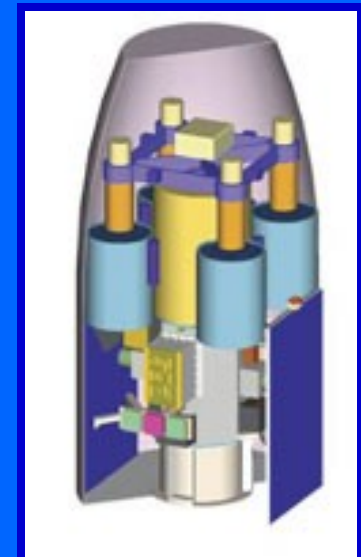
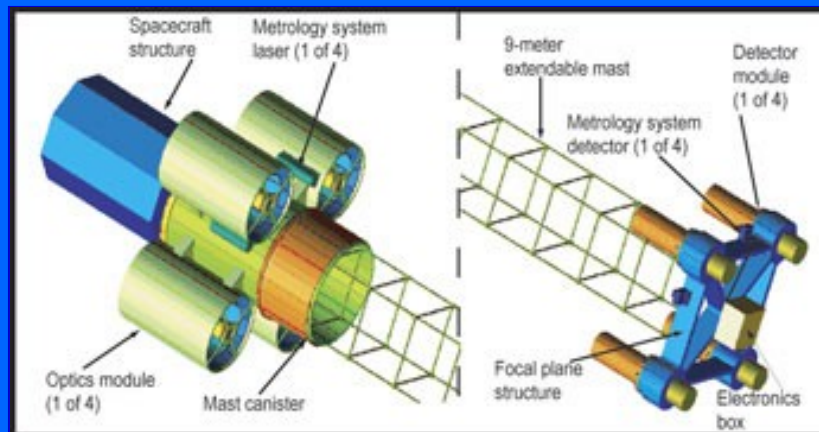


Black holes in quasars



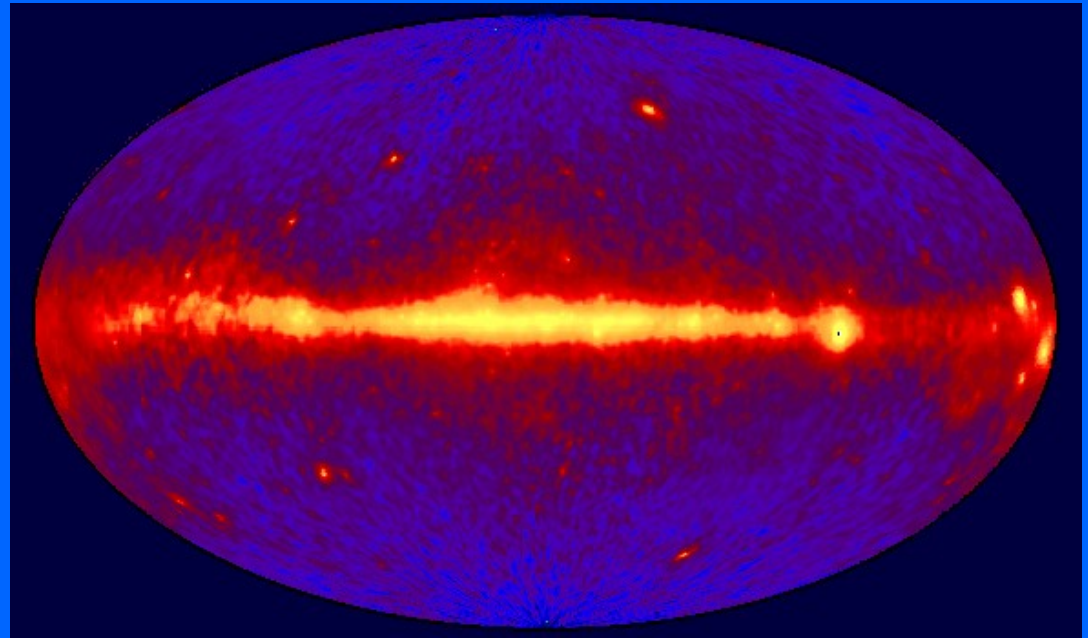
# *Coming soon – we hope! NuSTAR*

- ❖ SMEX Phase A study underway
- ❖ Spectrum Astro will provide spacecraft and Mission Operations Center
- ❖ Focusing hard X-ray telescope (6-80 keV) with CdZnTe detectors
- ❖ Black hole finder and supernova remnant studies
- ❖ Launch in 8/07 if selected for flight



# *Gamma-ray Astronomy: The Big Picture*

- ❖ Whole sky glows
- ❖ Extreme environments
- ❖ Probes of the Universe



CGRO/EGRET All Sky Map



# *Early Gamma-ray Astronomy*

## ❖ • Gamma-ray Bursts

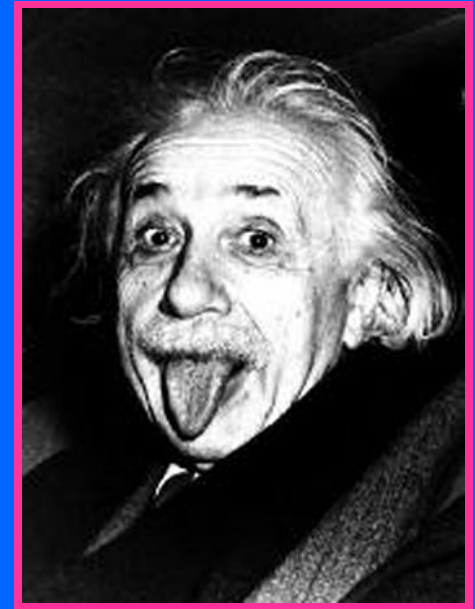
- Vela Program : A Bomb or Not a Bomb?
- A few hundred events, a few hundred theories

## ❖ • Gamma-ray Sources

- SAS-2 – discovered 2 pulsars (1972)
- COS-B – about 25 sources (1975-82)
  - Most unidentified, but 1 quasar
  - Diffuse extra-galactic background
- Compton GRO – four instruments
  - Opened up the gamma-ray Universe

# *Mass and energy*

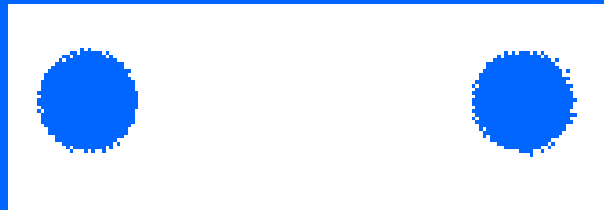
$$E = mc^2$$



- Einstein's most famous equation
- Einstein realized that mass and energy were equivalent and interchangeable
- This interchange is commonly observed in high-energy astronomy
- Swift and GLAST use this principle in different ways

# *Creating Energy from Mass*

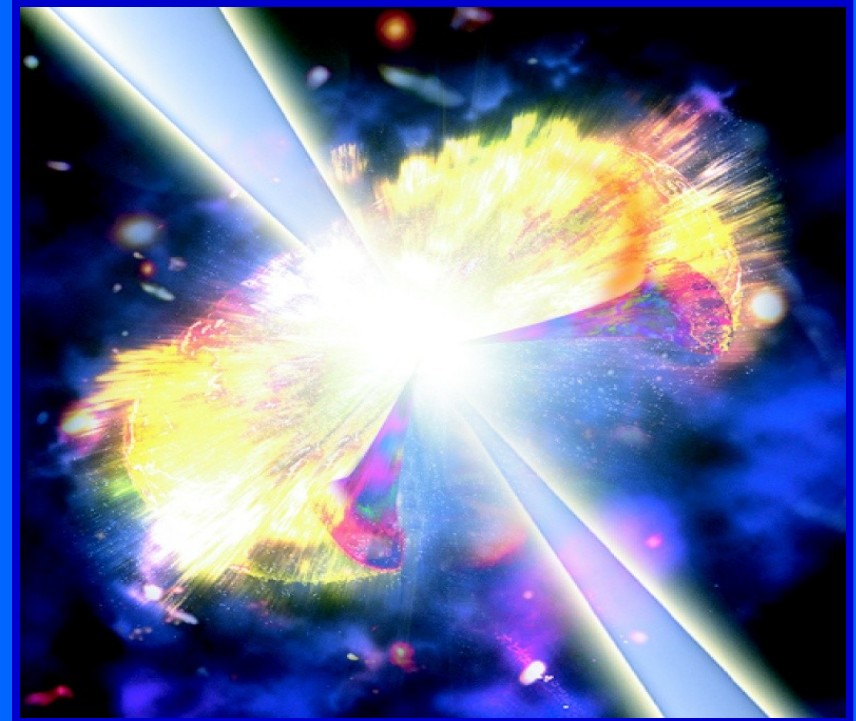
- ❖ When two oppositely charged particles meet in flight, they can annihilate to create two gamma-ray photons traveling in opposite directions



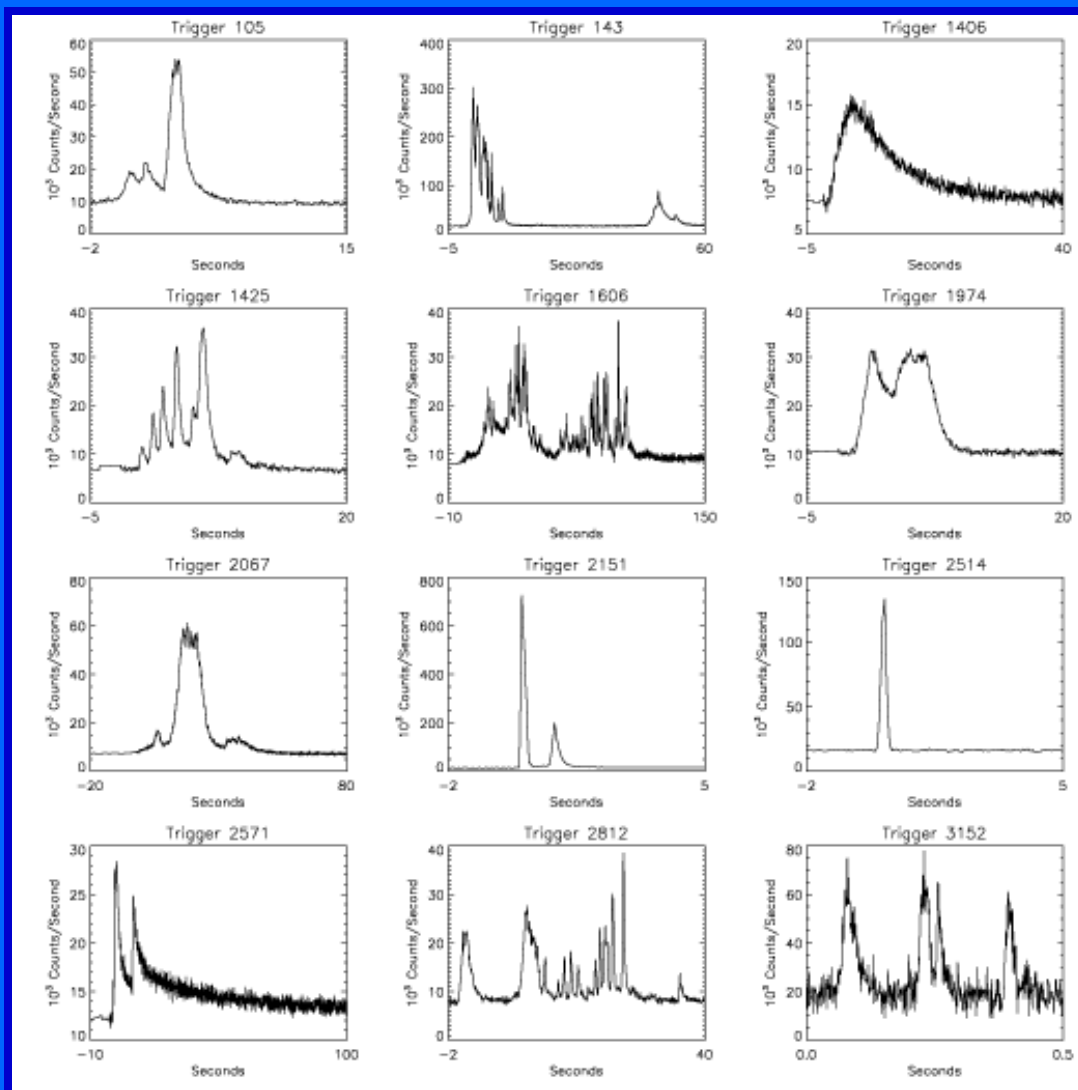
- ❖ The rest mass of an electron or its anti-particle, the positron, is  $511 \text{ keV}/c^2$
- ❖ Annihilating an electron creates  $E = 511 \text{ keV}$

# *Explosions in Space*

- ❖ Energy is also created from mass when stars explode
- ❖ Supernovae herald the deaths of stars
- ❖ Gamma-ray Bursts signal the deaths of even more massive stars
- ❖ They are the birth cries of black holes



# Gamma-Ray Bursts

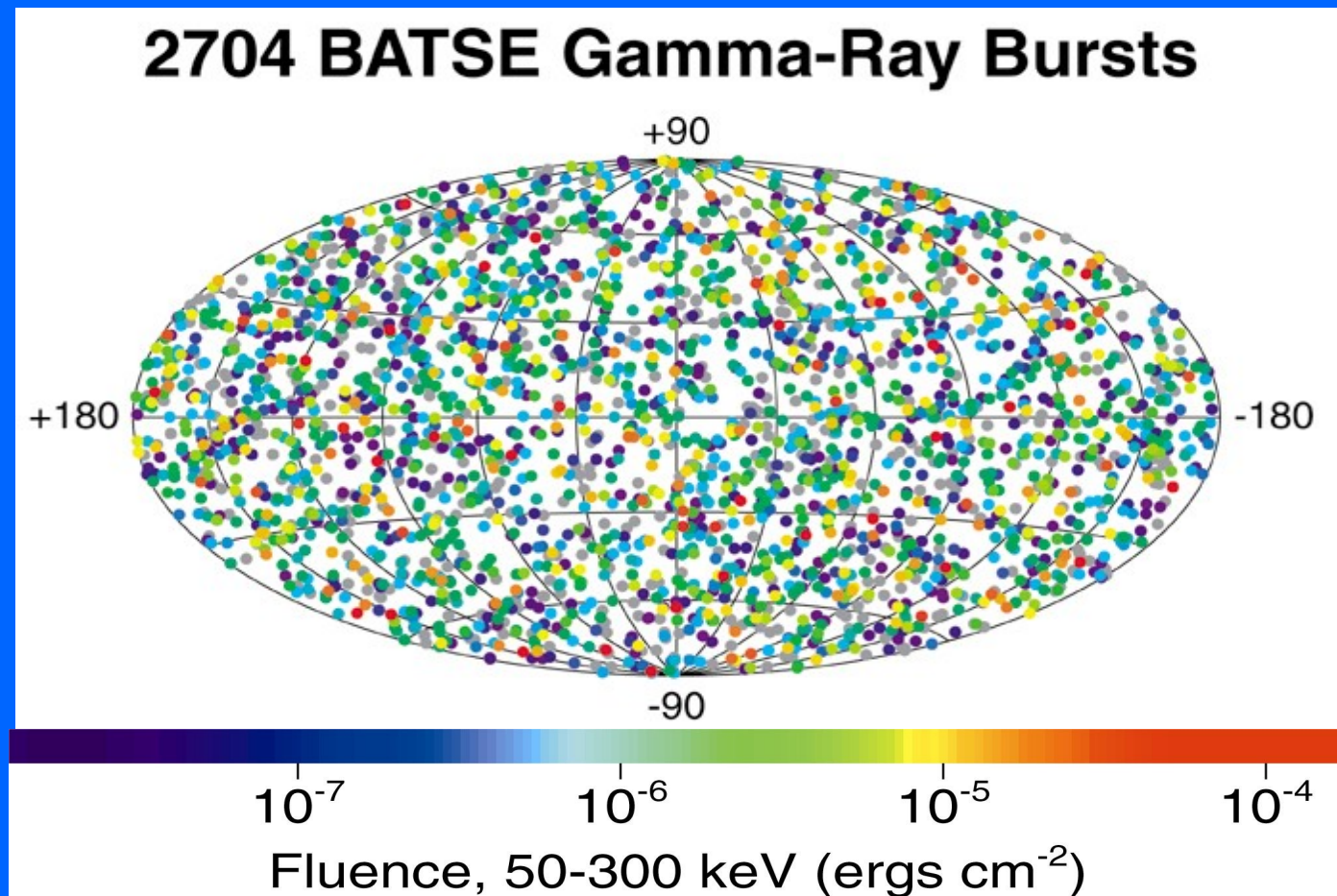


When  
you've seen  
one  
gamma-ray  
burst.....

You've  
seen **one**  
gamma-ray  
burst!

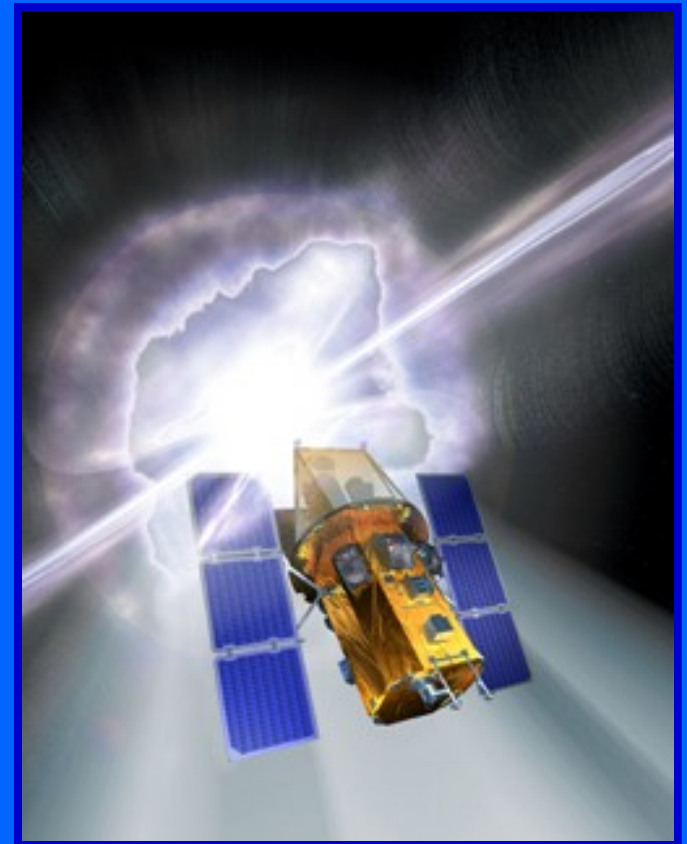


# *Distribution of GRBs in the Sky*



# *Swift Gamma-ray Burst Mission*

- ❖ Will study Gamma-Ray Bursts with a “swift” response
- ❖ Burst Alert Telescope
- ❖ X-ray Telescope
- ❖ UV/Optical Telescope
- ❖ Spacecraft by Spectrum Astro
- ❖ To be launched in 2004
- ❖ Nominal 2-year lifetime





[Swift.sonoma.edu](http://Swift.sonoma.edu)

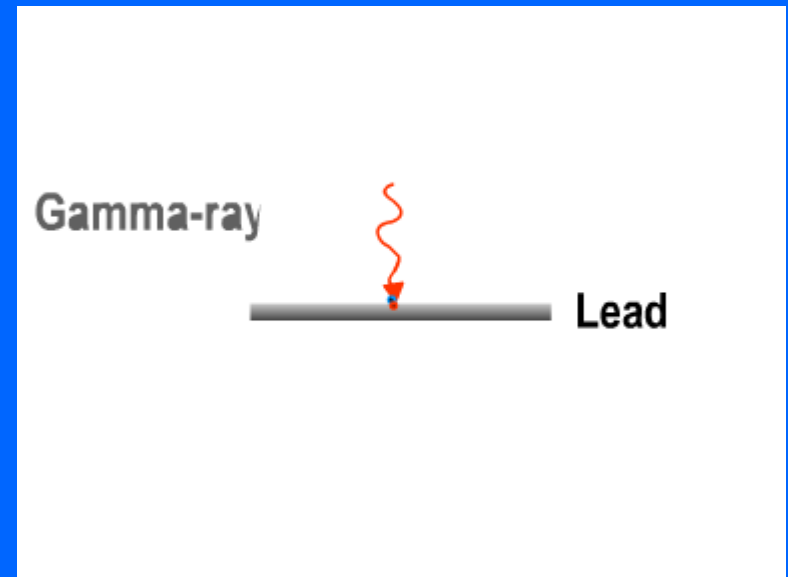


Catching gamma ray bursts on the fly ...

- ❖ Repoints within 50 s after detecting GRB to obtain X-ray and optical data
- ❖ Detects about 150 GRBs per year and their afterglows
- ❖ Sends initial coordinates of burst to ground within 15 s
- ❖ Sends high resolution coordinates of GRB to ground within 50 s
- ❖ Determines distance to burst within 1000 s

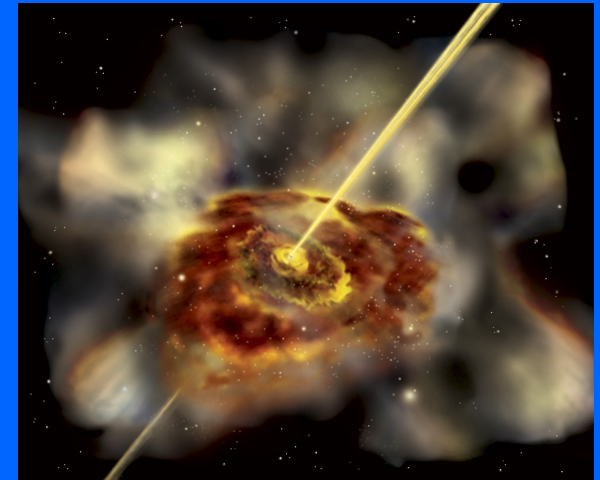
# *Creating Mass from Energy*

- ❖ Pairs of oppositely charged particles can be produced from a single energetic gamma-ray photon, interacting with converter material

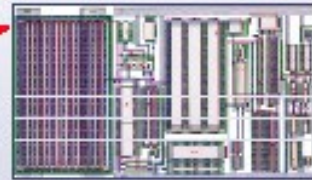
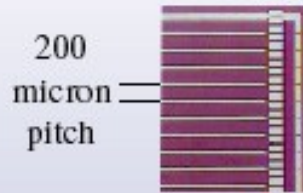


# *Pair production in space*

- ❖ NASA is launching GLAST in 2007
- ❖ Large Area Telescope (joint with DOE)
- ❖ GLAST Burst Monitor
- ❖ LAT uses pair production to track gamma-rays from space to their sources – often huge black holes!
- ❖ Spacecraft by Spectrum Astro



# GLAST LAT Technologies



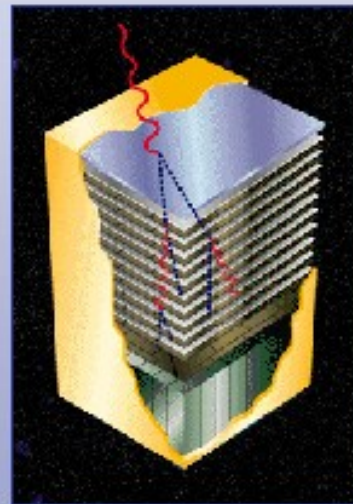
Low-Power Megachannel  
VLSI Readout Electronics



Silicon Strip Detector  
Tracker Plane



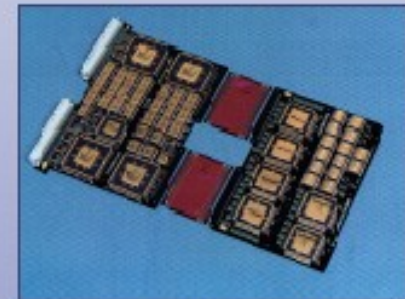
Cesium Iodide Imaging  
Spectrometer Elements



GLAST Telescope Module

## CHALLENGES:

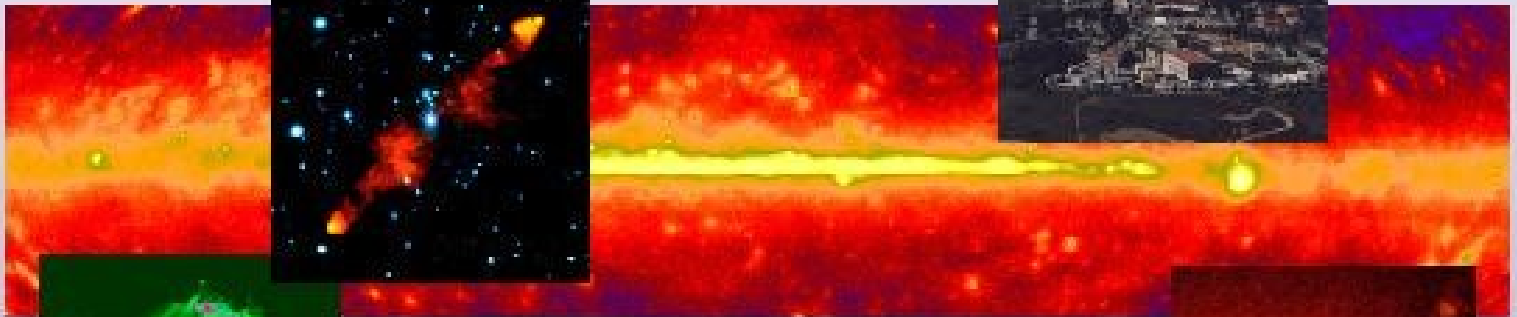
- ◆ Largest silicon strip detector array ever assembled (1.5 million channels from total of 90 m<sup>2</sup> of silicon detectors)
- ◆ On-board data system sophistication: distributed, adaptable, programmable trigger



32-bit Radiation-Hard  
Processor

# GLAST Science

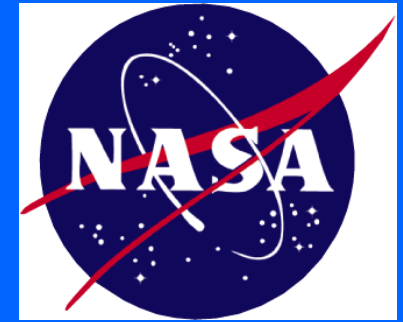
*Identify and understand nature's  
highest-energy particle accelerators:*



- *active galactic nuclei*
- *pulsars*
- *black holes*
- *supernova remnants*
- *$\gamma$ -ray bursts*

Explore the era of star formation in the universe, the physics of dark matter and the creation and evolution of galaxies

# *Going Beyond Einstein*



- ❖ NASA is beginning a new program to test predictions of Einstein's theories:
  - What happens at the edge of a black hole?
  - What powered the Big Bang?
  - What is the mysterious Dark Energy that is pulling the Universe apart?
- ❖ Do Einstein's theories completely describe our Universe?



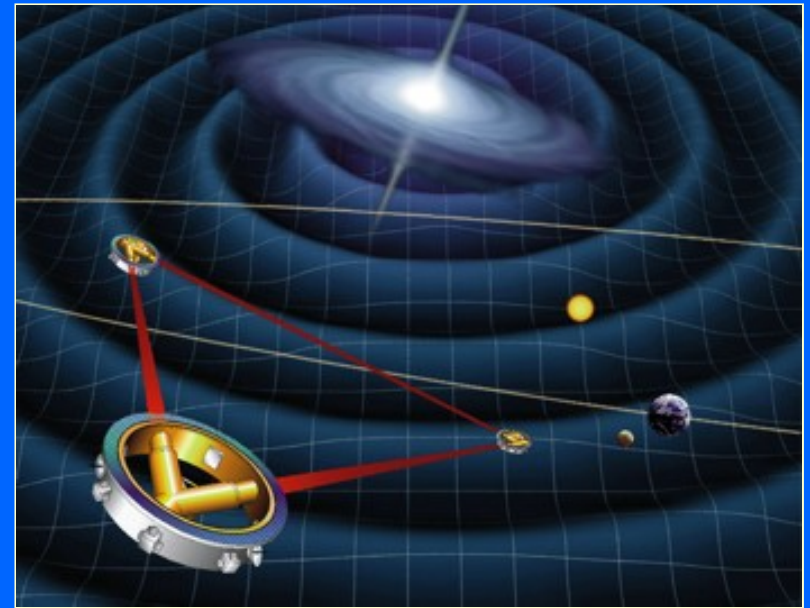
# *BE Great Observatories*

## Constellation X



Four X-ray telescopes  
flying in formation

## LISA



Three satellites, each with 2  
lasers and 2 test masses

# *Beyond Einstein Probes*

Black Hole Finder



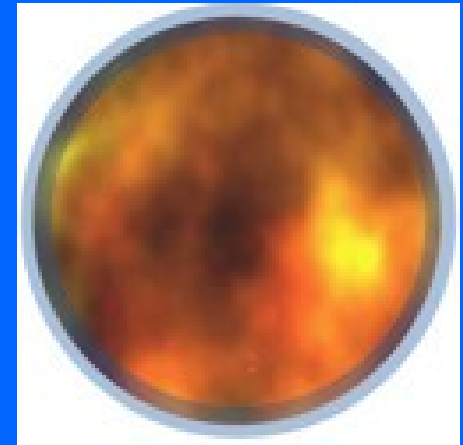
Census of  
hidden  
Black Holes

Dark Energy



Measure  
expansion  
history

Inflation



Polarization  
of CMB

# ***BE Mission Concept Studies***

## ❖ **Black Hole Finder:**

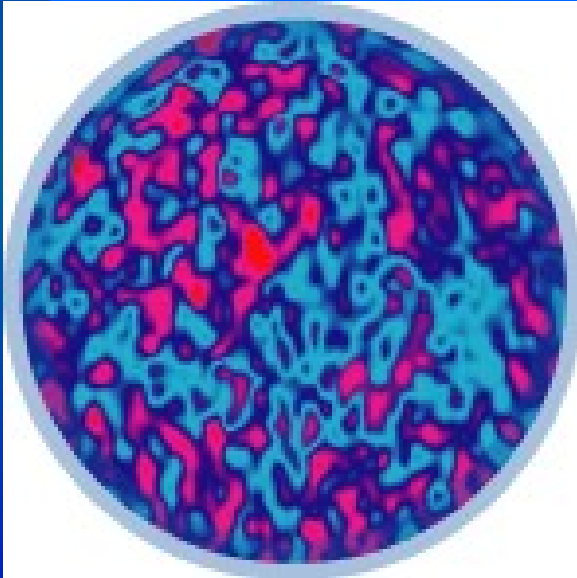
- EXIST: Energetic X-ray Imaging Survey Telescope
- Spectrum Astro is providing spacecraft information to concept study
- SSU is leading E/PO

## ❖ **Dark Energy Probe:**

- Leading concept is SNAP: Supernova Acceleration Probe
- NASA and DOE have signed agreement for “Joint Dark Energy Mission”

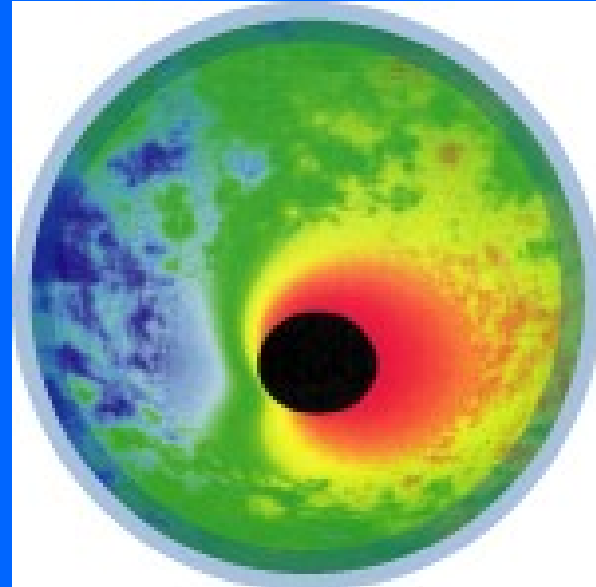
# *Beyond Einstein Vision* *Missions*

## Big Bang Observer



Direct detection of  
gravitational waves  
from Big Bang

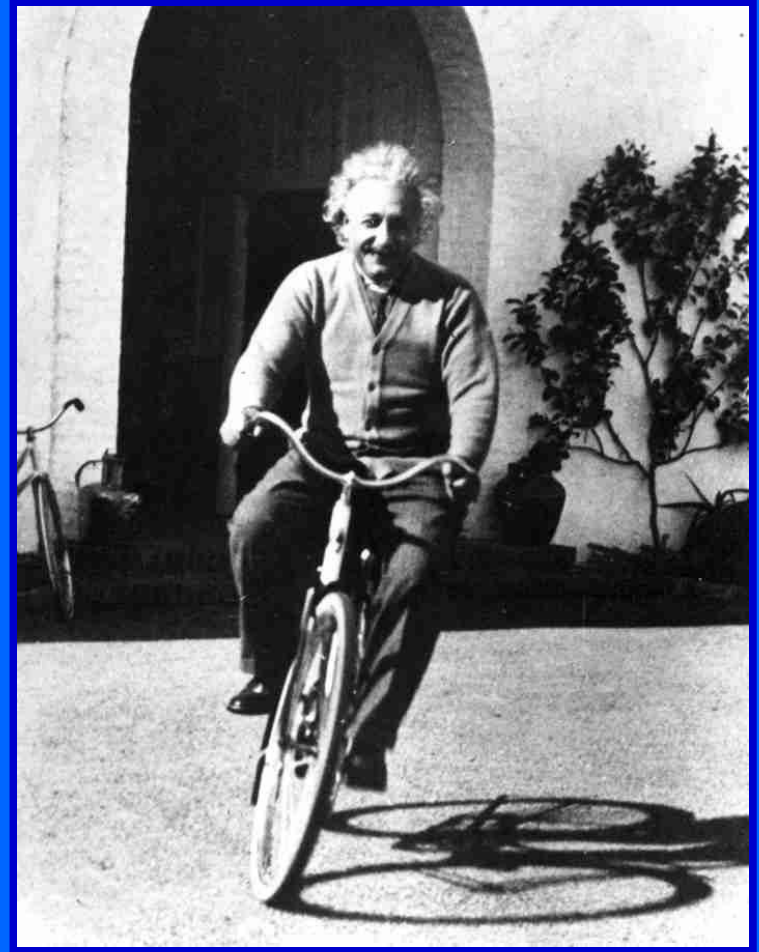
## Black Hole Imager



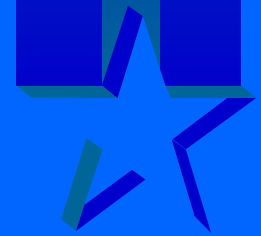
Resolved image of  
the Event Horizon

# *Some last words from Einstein*

- ❖ “The most incomprehensible thing about the Universe is that it is comprehensible”

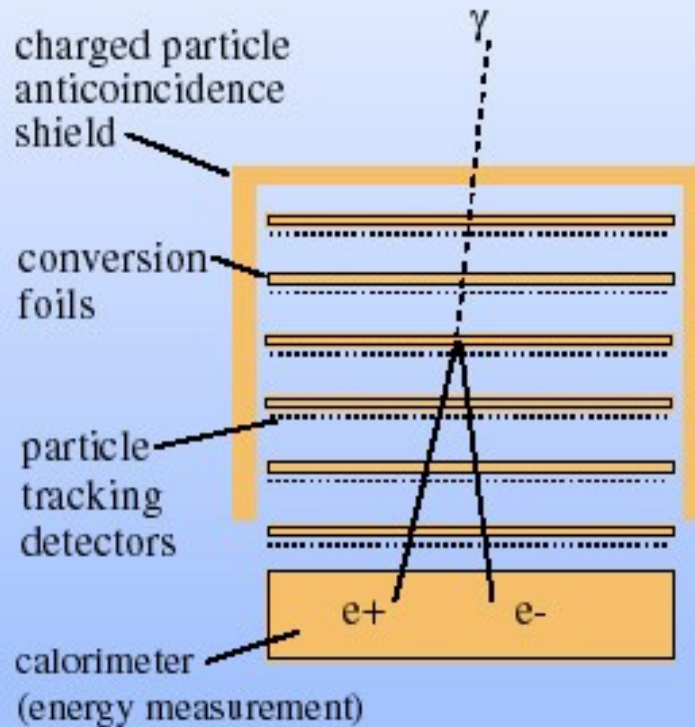


*Background follows*



# GLAST design

## elements of a pair-conversion telescope



- ◆ photons materialize into matter-antimatter pairs:

$$E_{\gamma} \rightarrow m_{e^+}c^2 + m_{e^-}c^2$$

- ◆ electron and positron carry information about the direction, energy and polarization of the  $\gamma$ -ray