The Universe according to NASA…
with a little help from some friends

Lynn Cominsky

Press Agent to the Stars

(the real stars, that is)

National Aeronautics and Space Administration

Space

NASA ENTERPRISES

Aerospace Technology

Human Exploration and Development of Space

Space Science

Earth Science

Biological and Physical Research

SPACE SCIENCE

NATIONAL AERONAUTICS & SPACE ADMINISTRATION

SOLAR SYSTEM EXPLORATION

Sun-Earth Connection

DISCOVERY PROGRAM

New Millennium Program

Mars Exploration program

LIVING WITH A STAR LWS NASA

Home

Living with a Star

Astronomy and Physics Division

Infrared, Visible and Ultraviolet

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

Astronomical Search for Origins

1. Where do we come from?
2. Are we alone?

- Origins is the story of our cosmic roots, told in terms of all that precedes us: the origin and development of galaxies, stars, planets, and the chemical conditions necessary to support life.

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

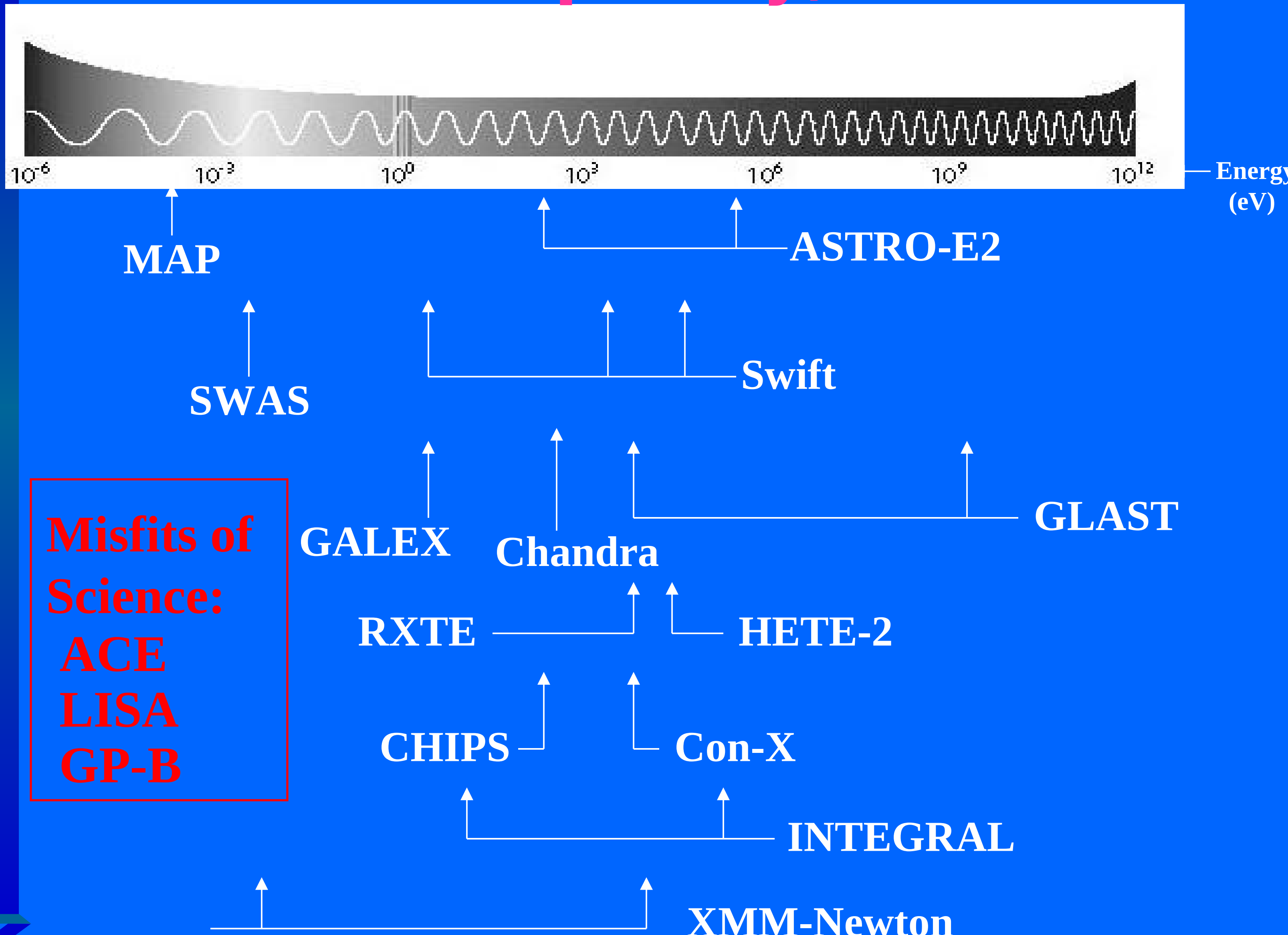
ACE
ASTRO E2
Chandra
CHIPS
Constellation-X
GALEX
GLAST
Gravity Probe B

HETE-2
INTEGRAL
LISA
MAP
RXTE
SWAS
Swift
XMM-Newton

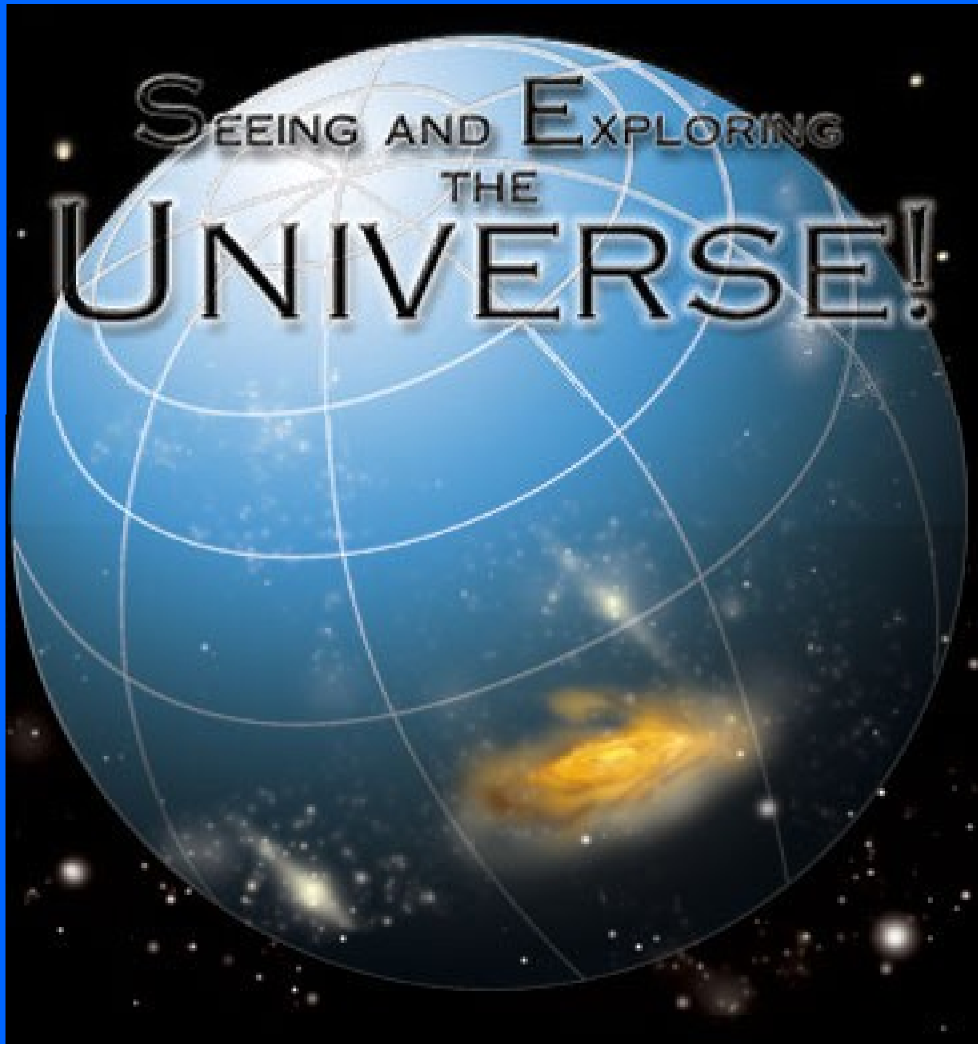
Not yet launched **In orbit**

~~Hubble~~

What's the frequency, Kenneth?



Misfits of Science:
- ACE
- LISA
- GP-B



Your first choice for on-line information!

http://universe.sonoma.edu

SEU Main research areas

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

Coming soon ----
Beyond Einstein!

Cosmic Microwave Background

- Discovered in 1965 by Arno Penzias and Robert Wilson who were working at Bell Labs
- Clinched the hot big bang theory

Excess noise in horned antennae was not due to pigeon dung!

Cosmic Microwave Background

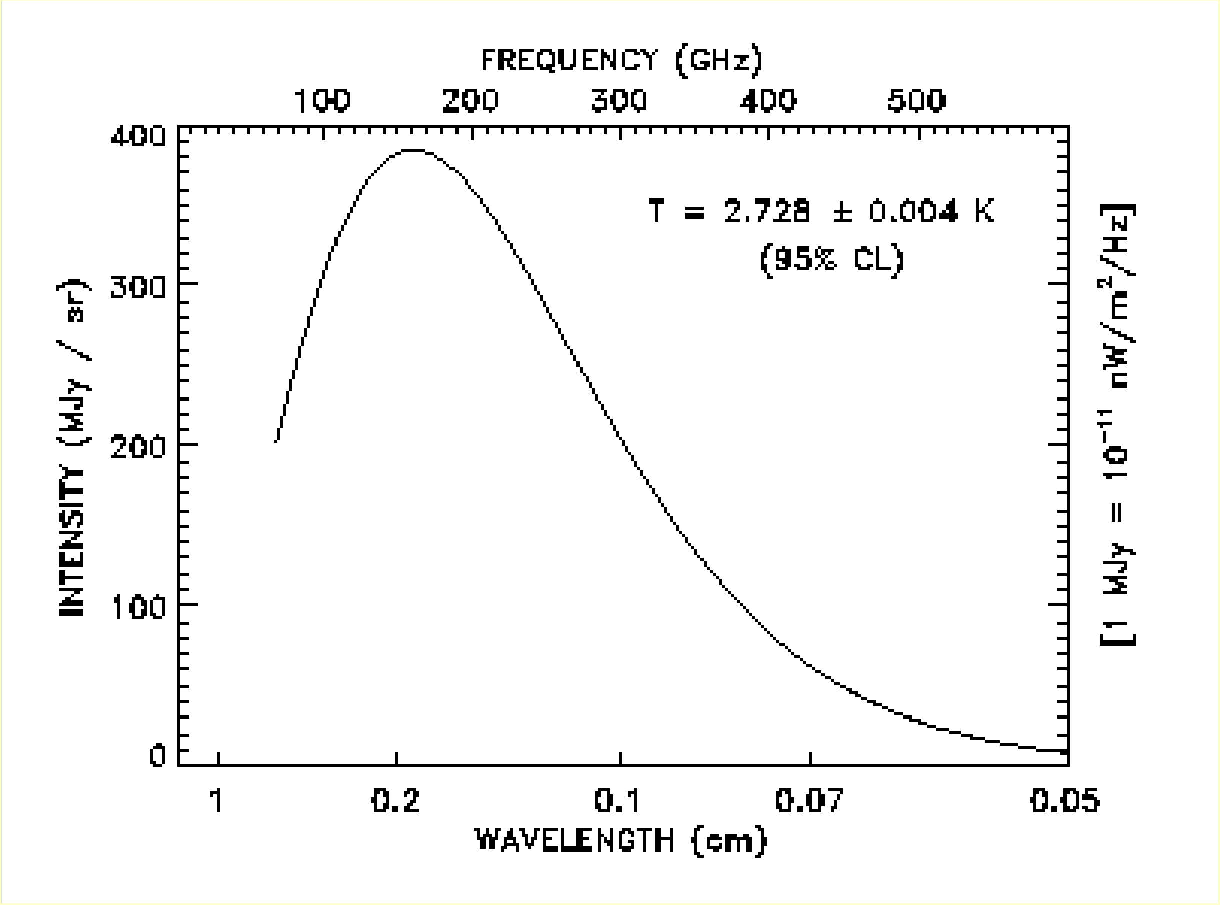
- Photons in CMBR come from surface of last scattering – where they stop interacting with matter and travel freely through space
- CMBR photons emanate from a cosmic photosphere – like the surface of the Sun – except that we inside it looking out
- The cosmic photosphere has a temperature which characterizes the radiation that is emitted
- It has cooled since it was formed by more than 1000 to 2.73 degrees K

COBE

- 3 instruments: FIRAS, DMR and DIRBE
- Cryogens ran out on 9/ 21/ 90 ending observations by FIRAS and longer wavelengths of DIRBE
- DMR and the shorter wavelengths of DIRBE operated until 11/23/93

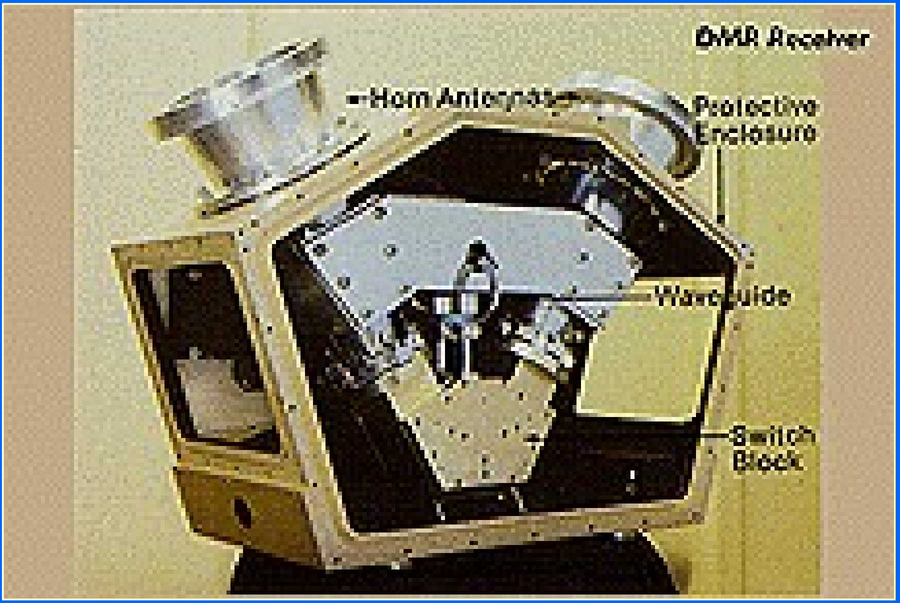
COBE data/FIRAS

- Far InfraRed Absolute Spectrophotometer



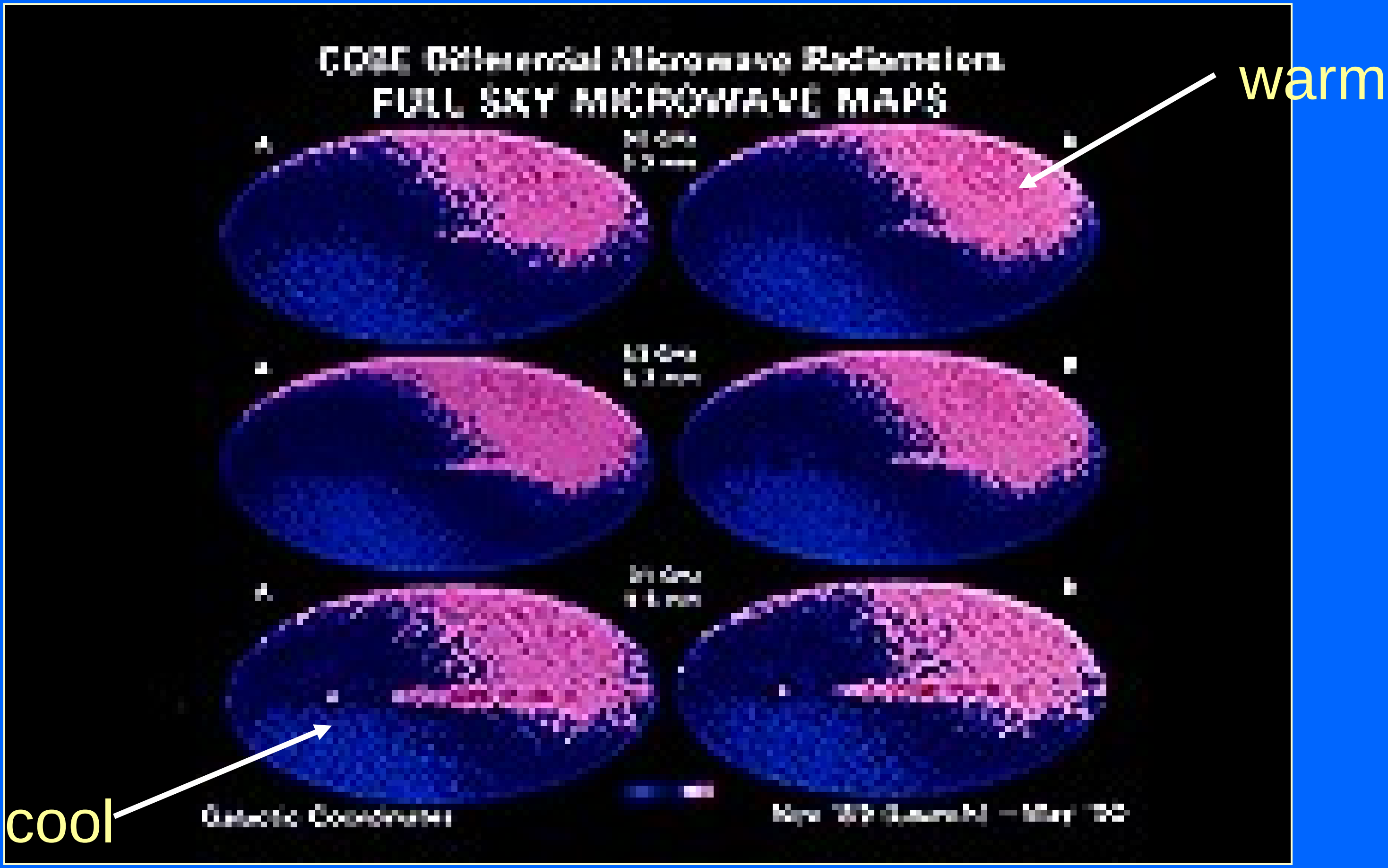
COBE DMR

- Differential Microwave Radiometer
- 3 different wavelengths
- 2 antennae for each wavelength, 7 degree beam
- Pointed 60 degrees apart



COBE data/DMR

- Dipole due to movement of Solar System



COBE data/DMR

- Dipole removed to show “wrinkles”

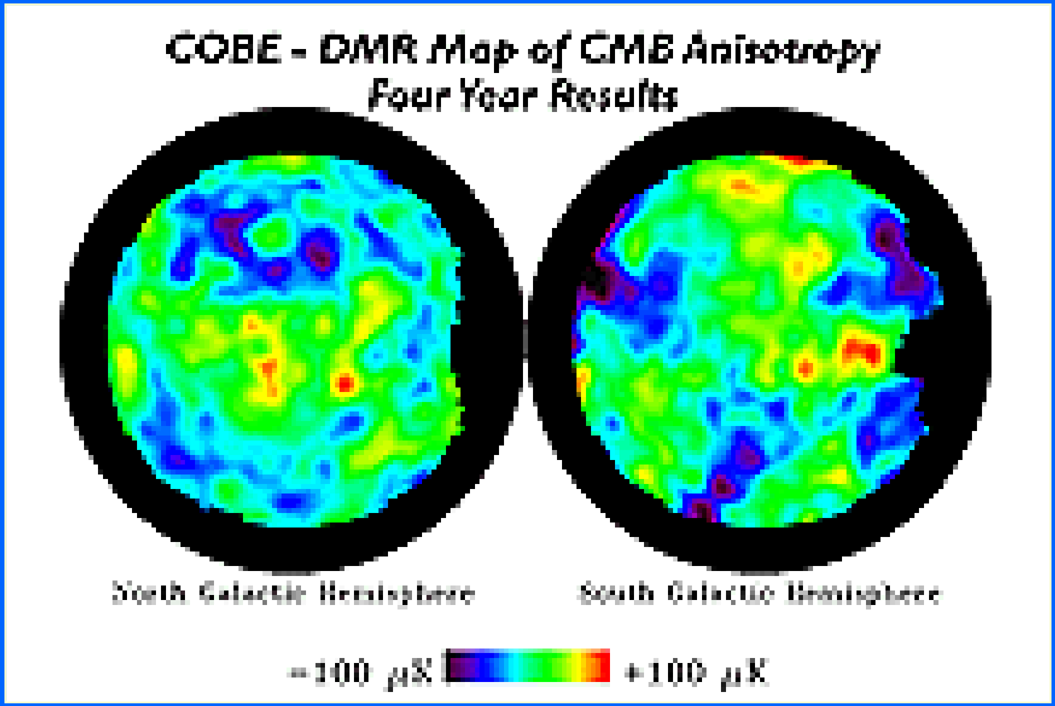
COBE data/DMR

- Fluctuations in CMB seen by DMR are at the level of one part in 100,000

Blue spots mean greater density

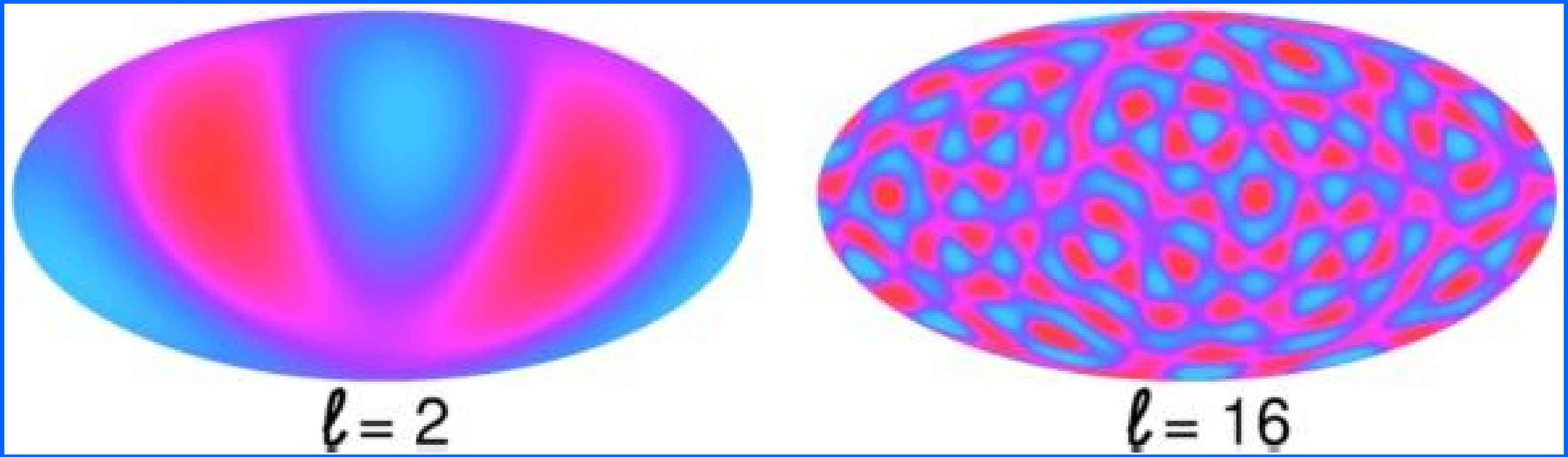
Red spots mean lesser density

(in the early Universe)



CMBR Fluctuations

- COBE measures the angular fluctuations on large scales, down to about L=16

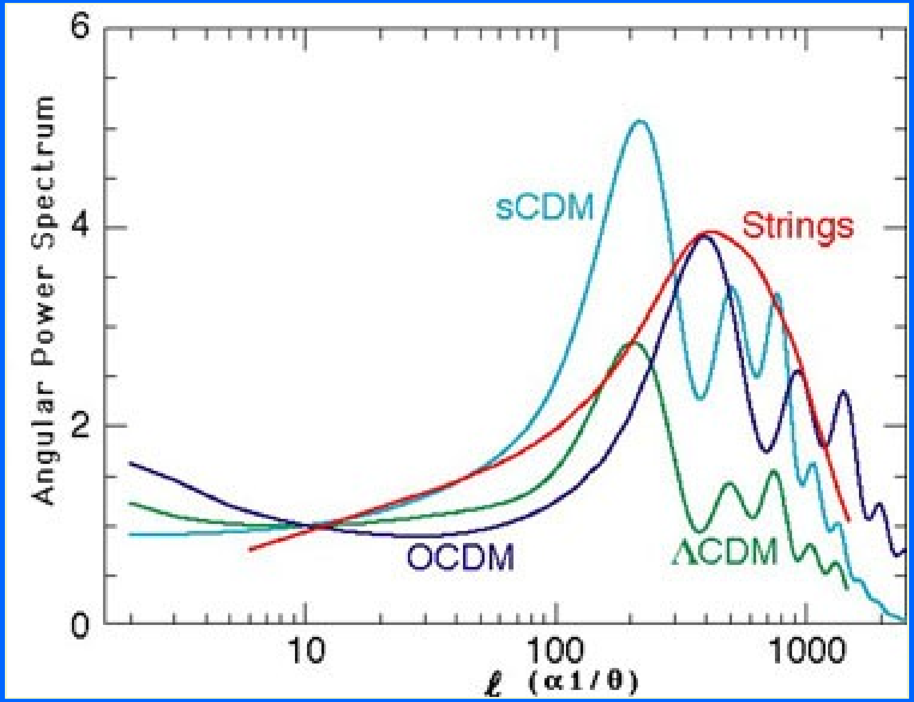


CMBR Fluctuations

- Determining the spectrum of fluctuations in the CMBR can directly differentiate between models of the Universe

How much power there is

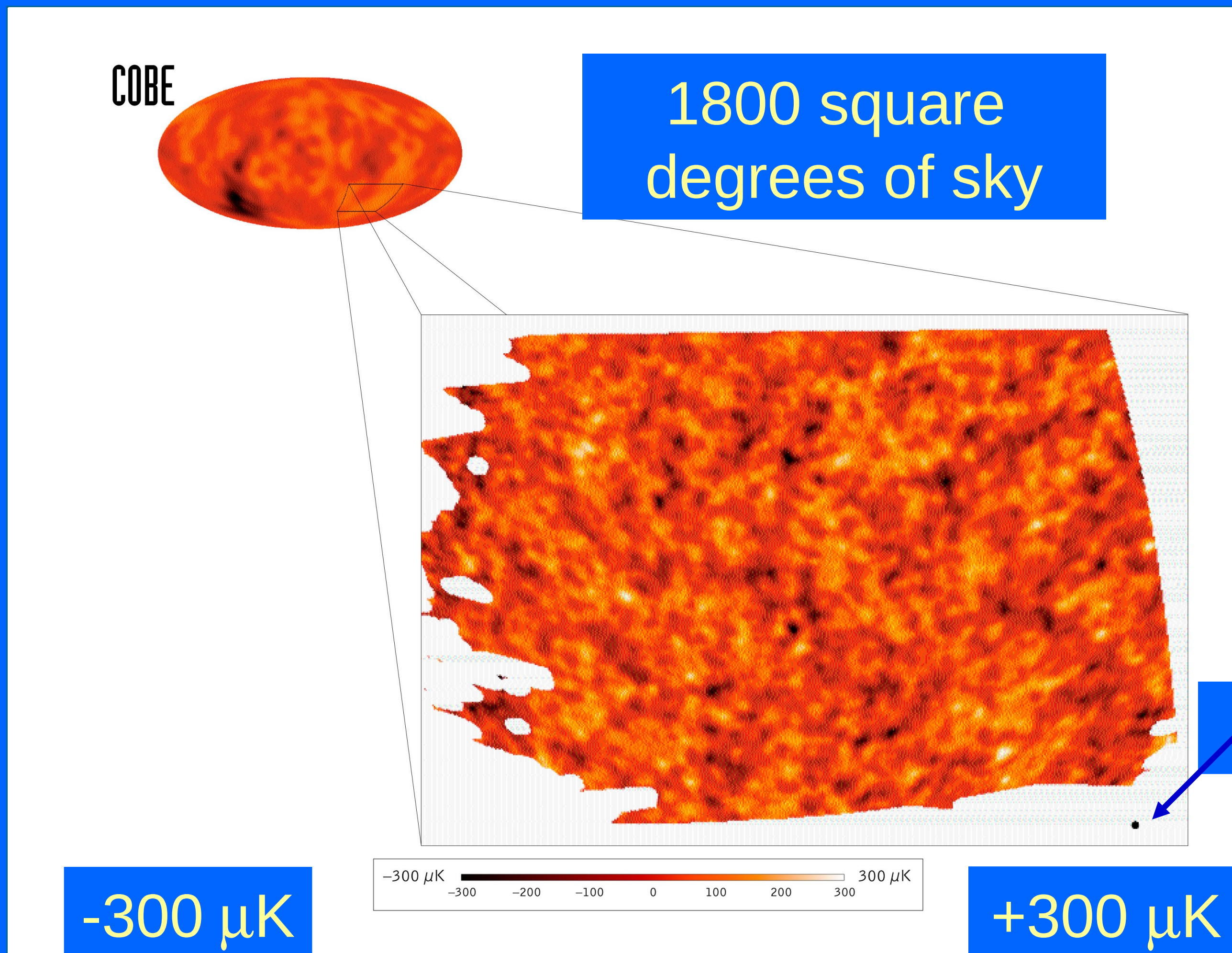
Angular size of fluctuation



BOOMERanG

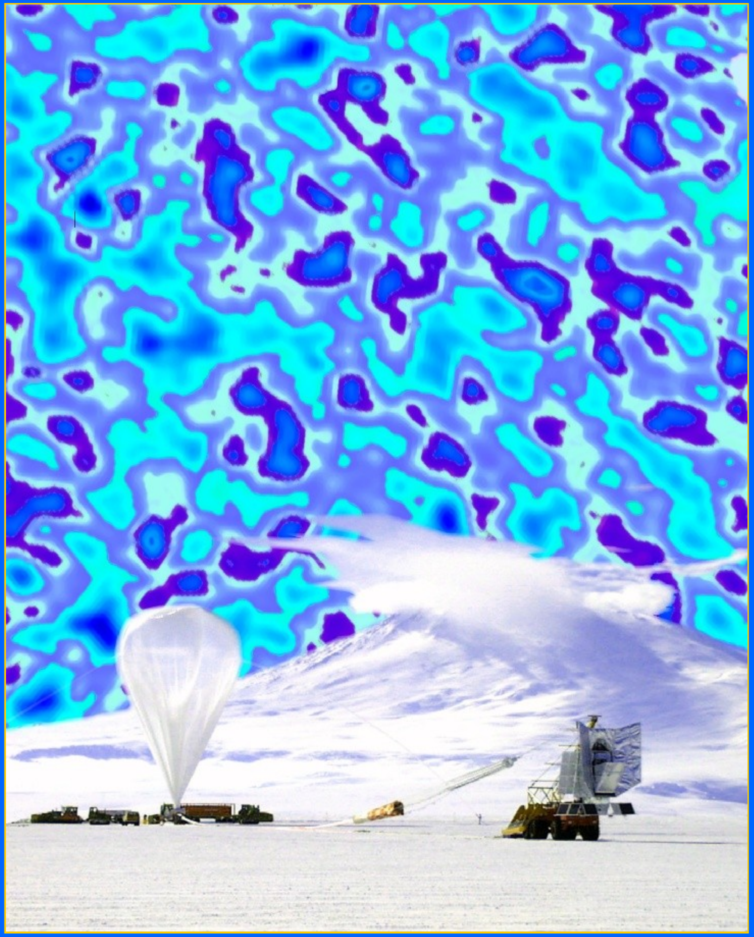
- Balloon Observations Of Millimeter Extragalactic Radiation and Geophysics
- 12 - 20 arc min resolution – about 35 times better than COBE
- Two flights: 1998/99 (10 days) and 1999/00
- Sensitive to temperature differences as small as 0.0001 degrees C
- Imaged 2.5% of entire sky

BOOMERanG vs. COBE



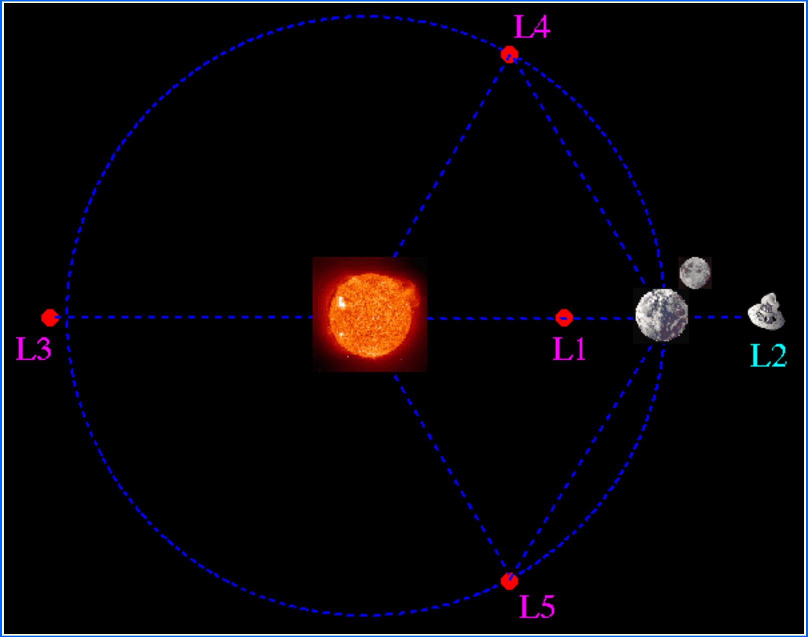
BOOMERanG 1998 Data

- What the fluctuations would look like to scale on the real sky above the BOOMERanG balloon launch facilities



Microwave Anistropy Probe

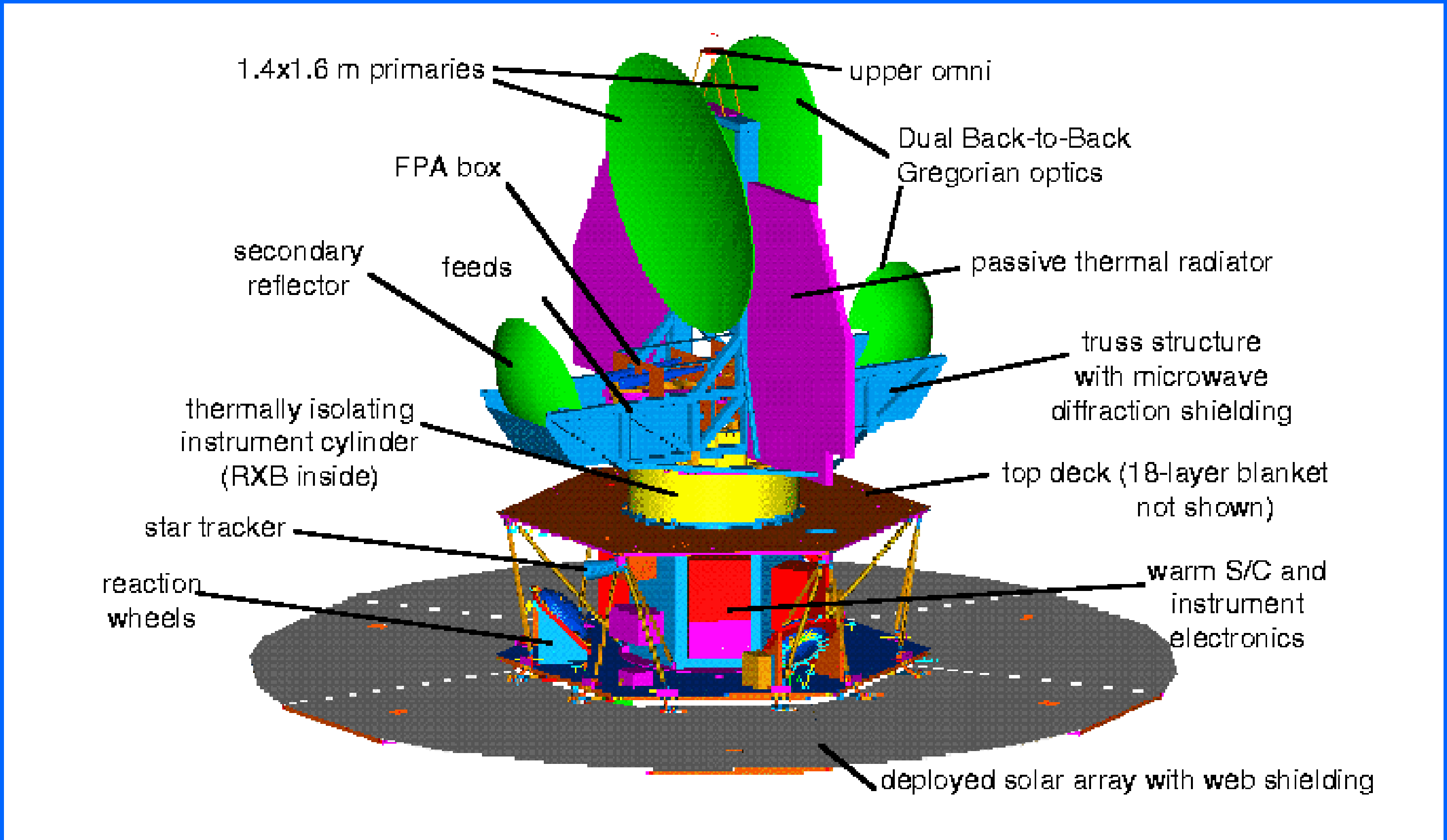
- L2 is one of the 3 semi-stable points in the Earth-Sun binary system
- Another body can orbit at this point at a fixed distance from the Earth and the Sun with corrections every 23 days



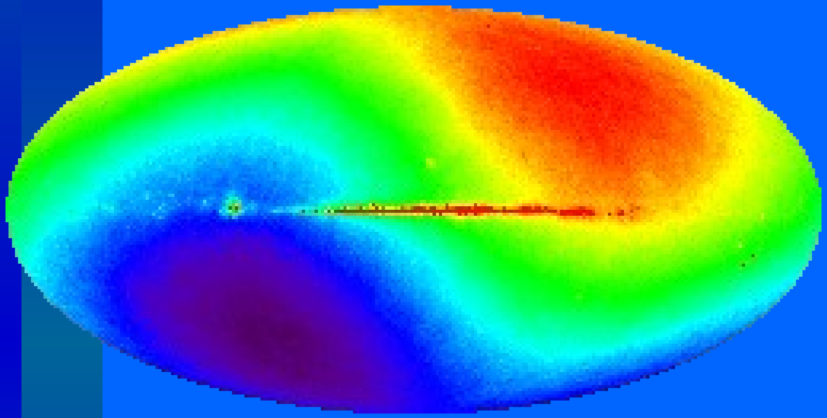
MAP launched 6/30/01

Reached L2 10/1/01

Microwave Anistropy Probe

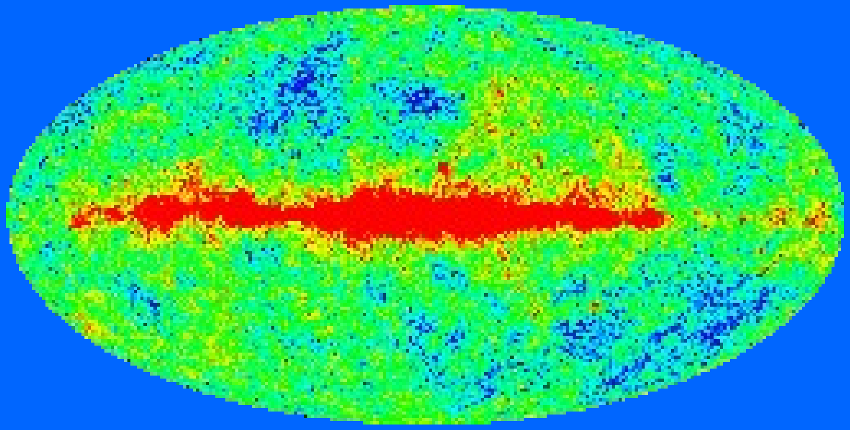


Microwave Anistropy Probe



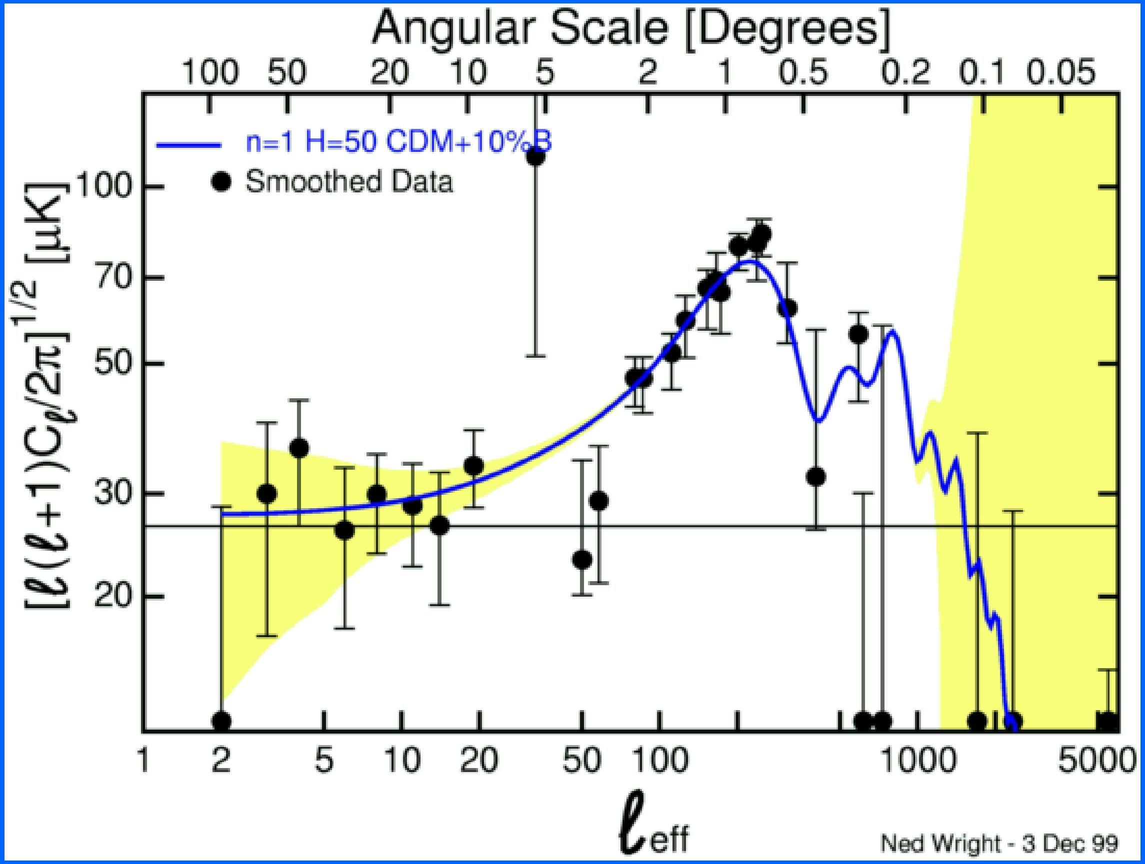
Dipole as predicted byi MAP simulations

Fluctuations as predicted by MAP simulations



MAP limits

- MAP will have error bars as shown in yellow, improving data until about L_{eff} = 1000



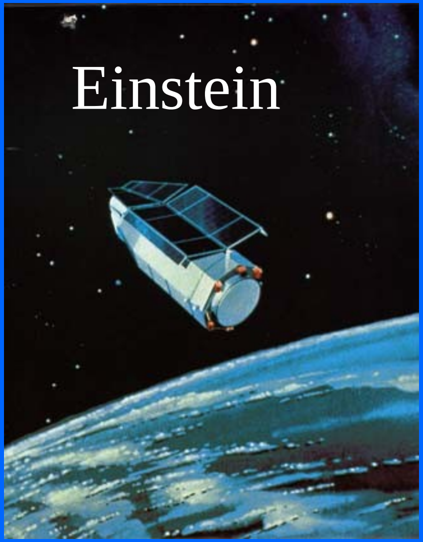
First MAP data release expected 01/03!!

X-ray Astronomy – a brief history

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

X-ray Astronomy

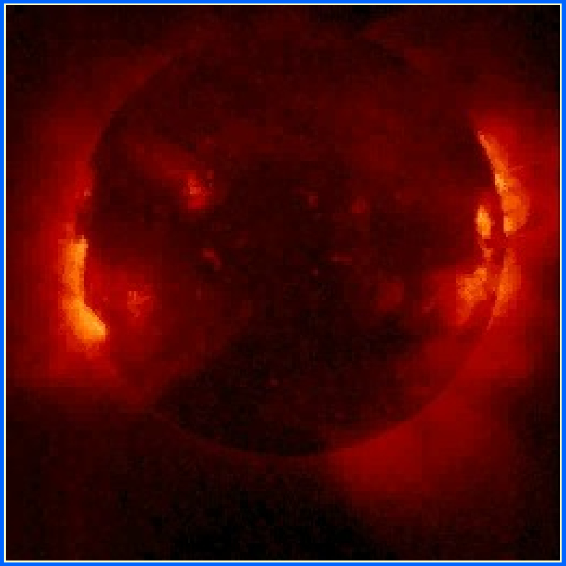
- First imaging X-ray satellite was Einstein Observatory (1978-81)
- Currently in orbit: RXTE, Chandra and XMM-Newton (ESA/NASA)

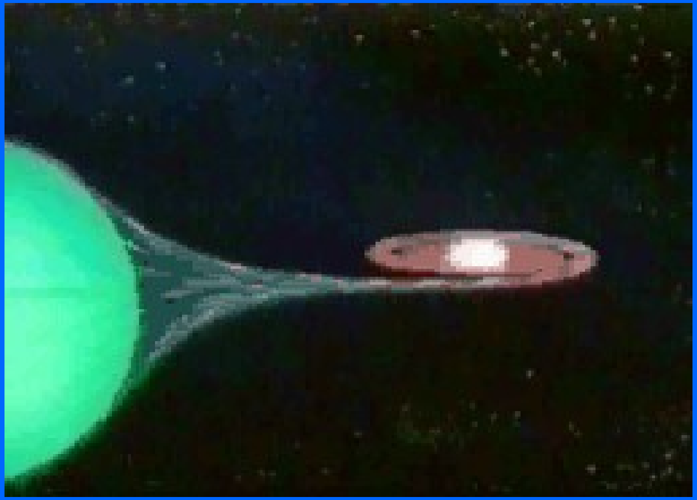


Chandra

X-ray Sourcery

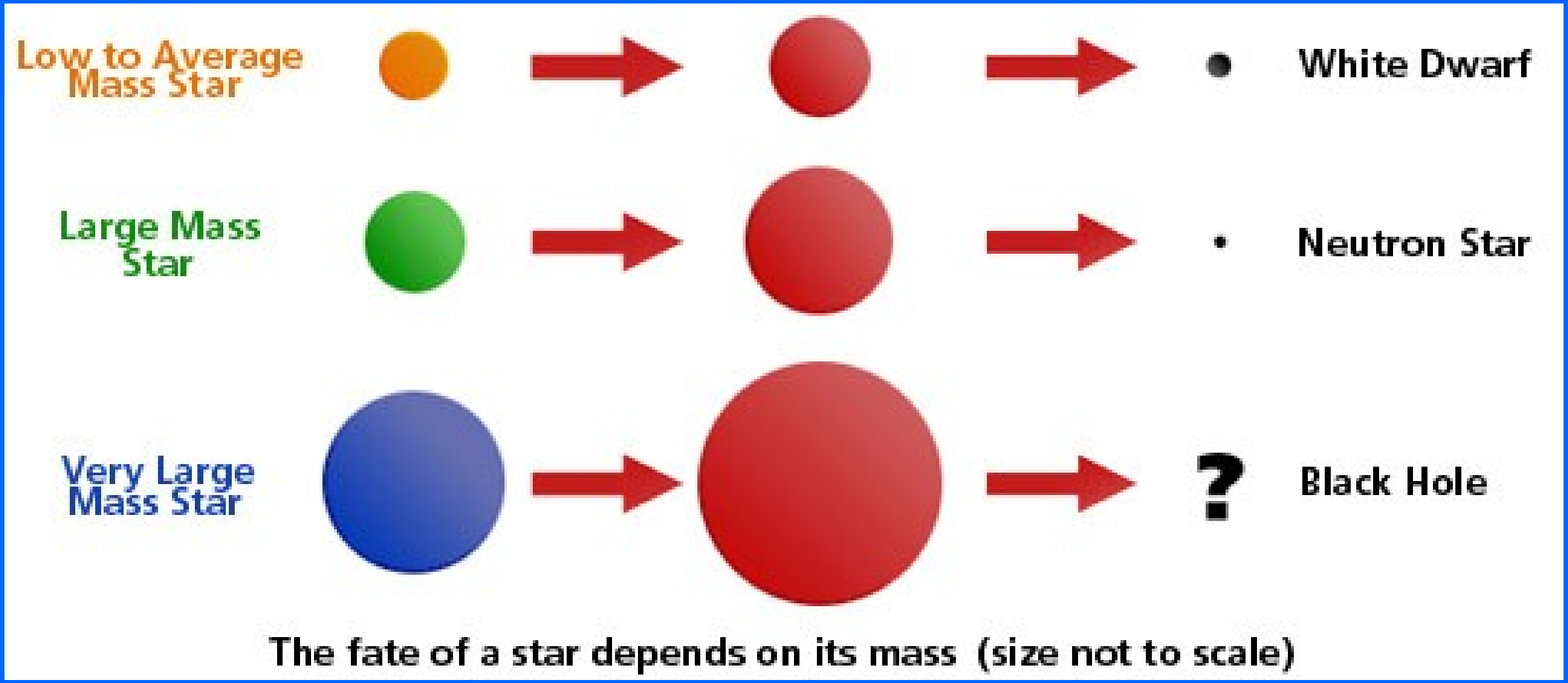
- Earliest source was Sun – corona and flares





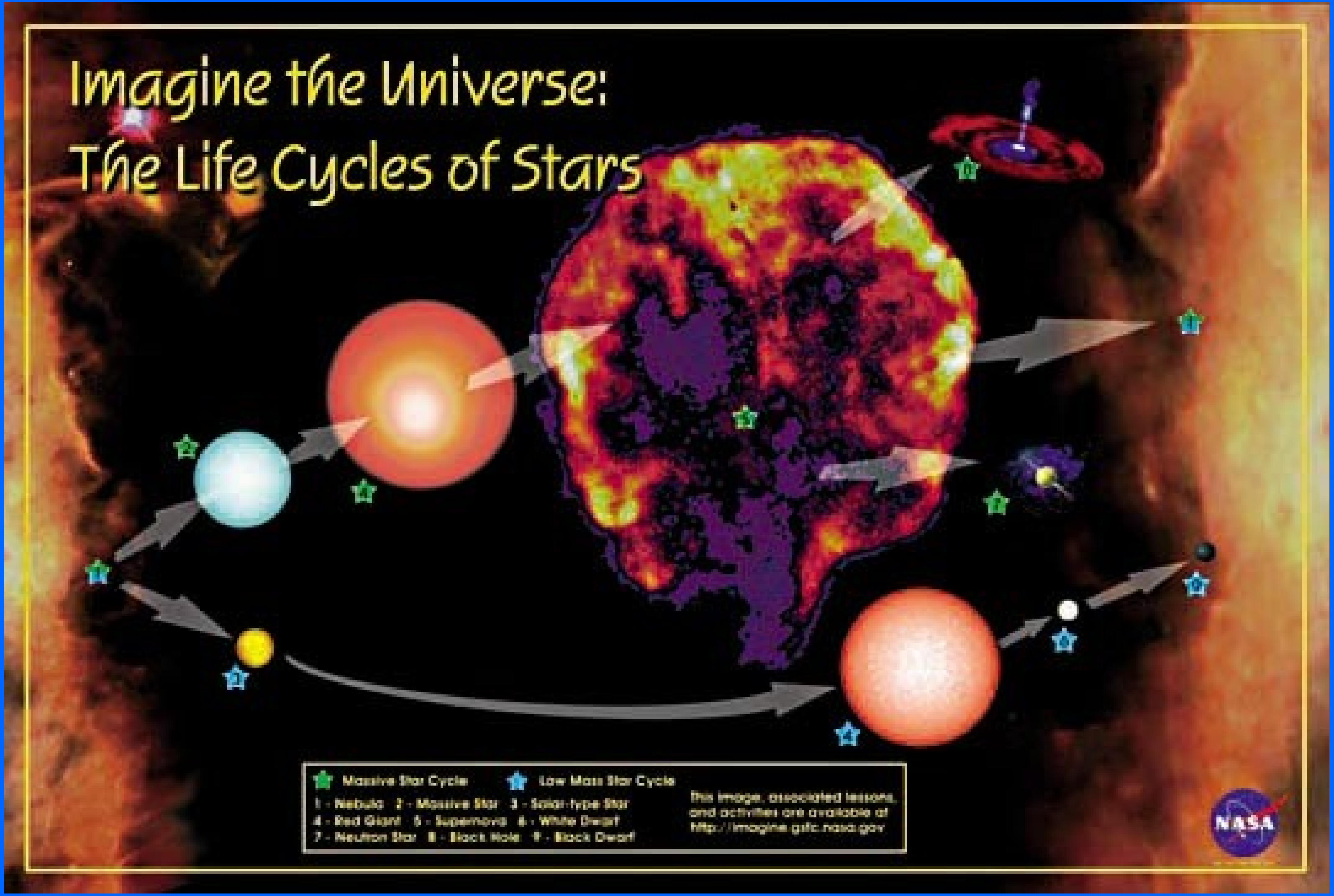
- Then neutron stars and black holes in accreting binaries were discovered to be strong x-ray emitters – 10 orders of magnitude greater!

Stellar evolution made simple



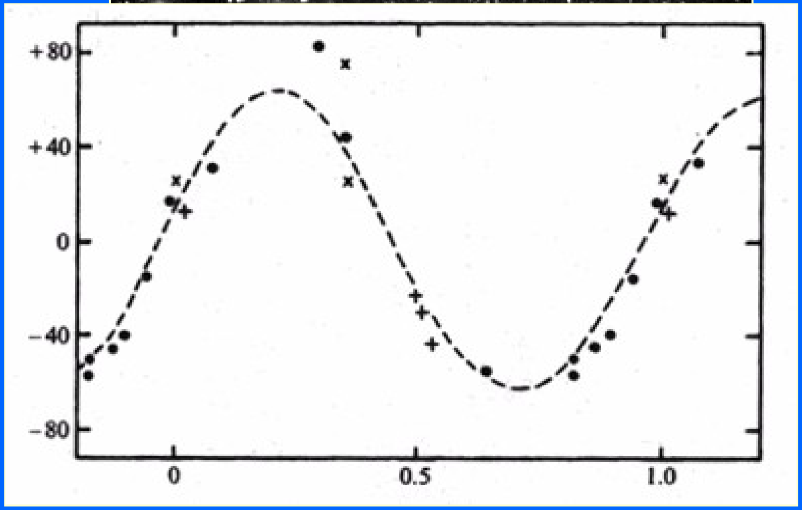
- Neutron Stars all have ~1.4 solar masses
- Black holes have more than 3 solar masses…to billions!

A more complicated view…



The First Black Hole

- Cygnus X-1 binary system
- Identified in 1972
- Most likely mass of BH is 16 (+/- 5) solar masses
- Mass determined by Doppler shift measurements of optical lines



Rossi X-ray Timing Explorer

- Launched in 1995 – still operational
- Large area X-ray detectors to study timing details of material falling into black holes or onto the surfaces of neutron stars

• 5 proportional counters with a total collecting area of 6500 square cm

• Energy range: 2 - 60 keV

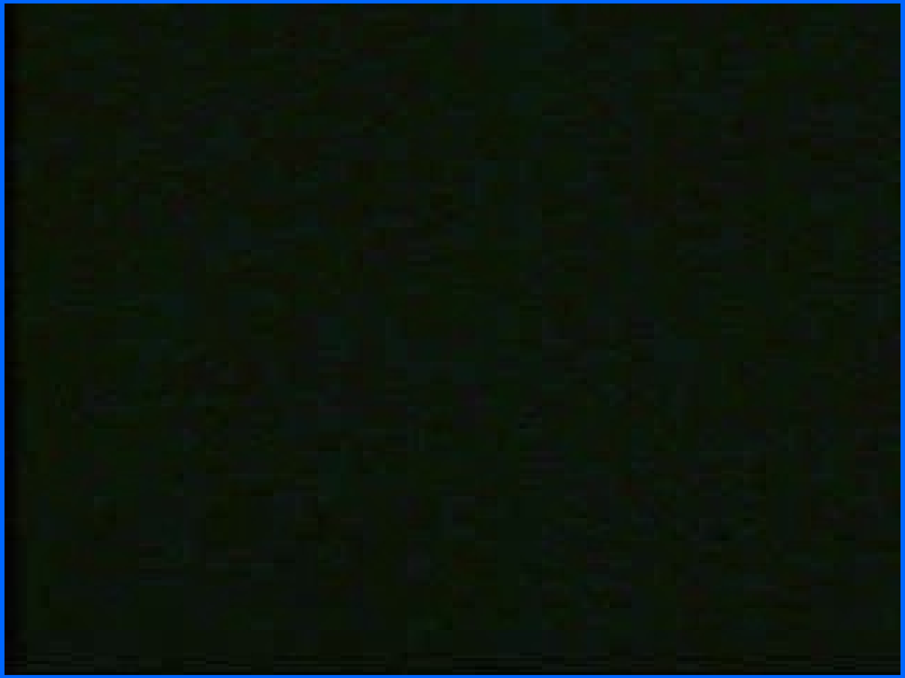
• Time resolution: 1 microsec

• Spatial resolution: 1 degree

“Old Faithful” Black Hole

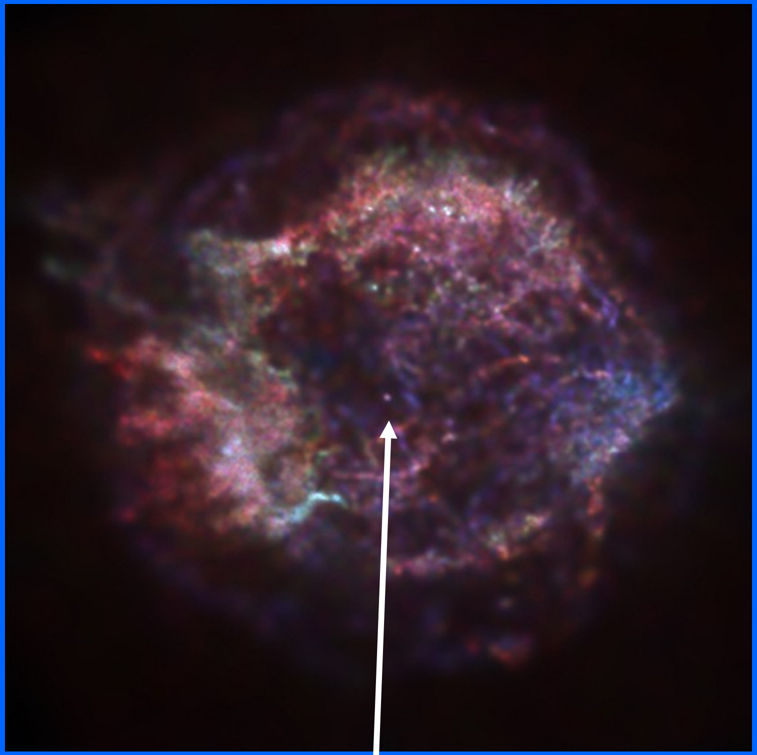
- Binary black hole system known as “microquasar”
- Regular X-ray outbursts discovered with RXTE
- Outbursts are linked to appearance of IR jets

movie



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

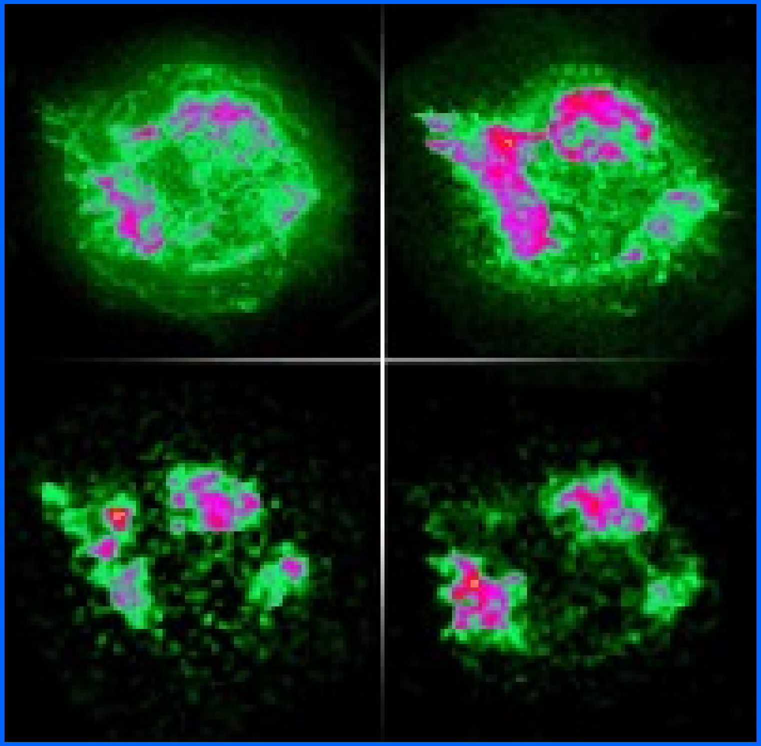


Cas A SNR shows central NS in one of Chandra's first images

Chandra X-ray Observatory

Total
Cas A

Silicon



Calcium

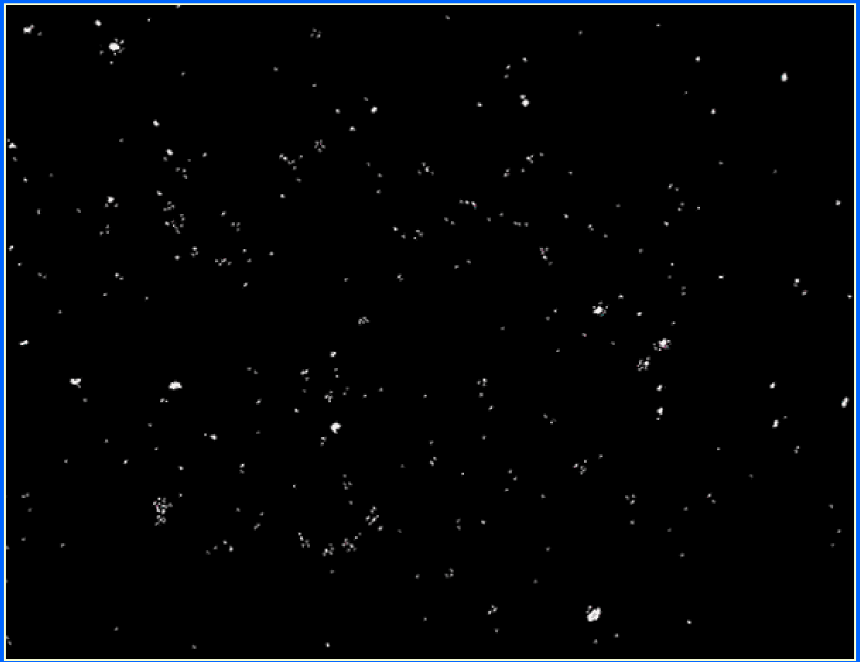
Iron

X-ray spectroscopy
shows chemical
element distribution

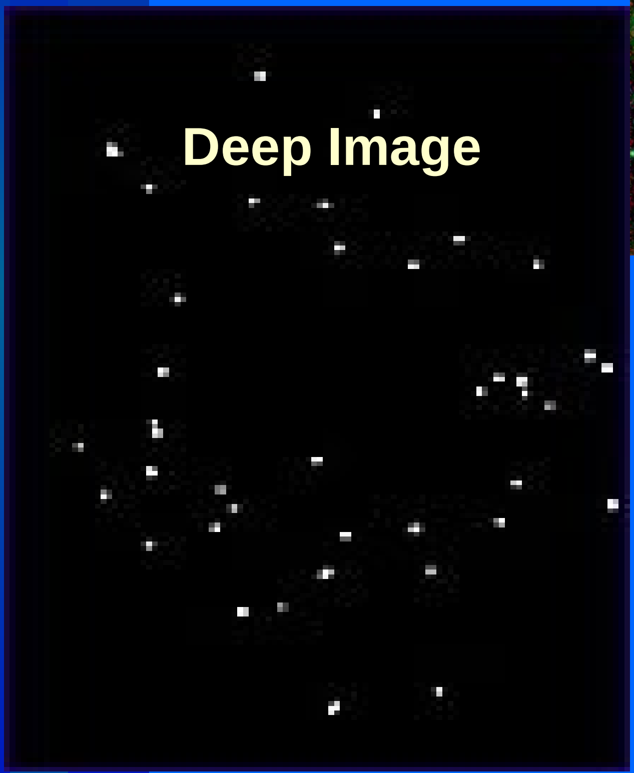
Chandra data

- At least 80% of X-ray background is made of discrete sources including two new types:
  - Very distant galaxies with faint black holes
  - Bright black holes without visible galaxies

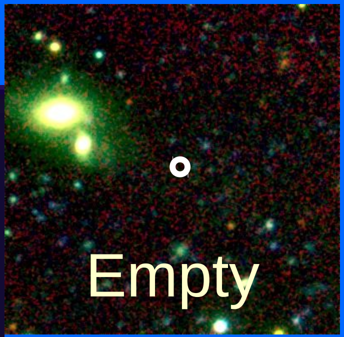
Results were from comparing Chandra data to deep optical surveys from Keck



Black Holes Are Everywhere!

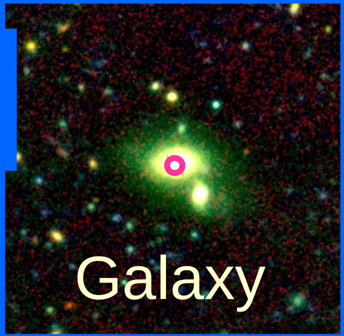


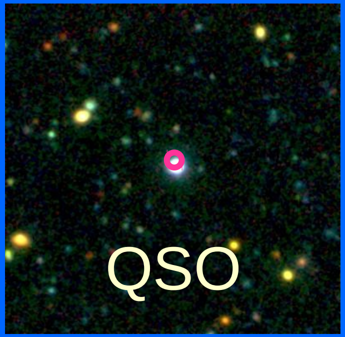
Chandra deep field



Black holes in empty space

Black holes in "normal" galaxies



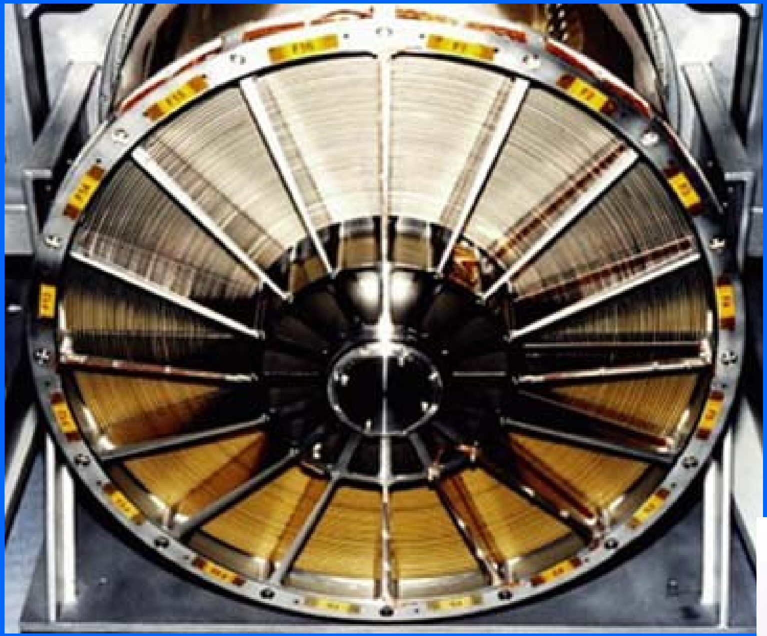


Black holes in quasars

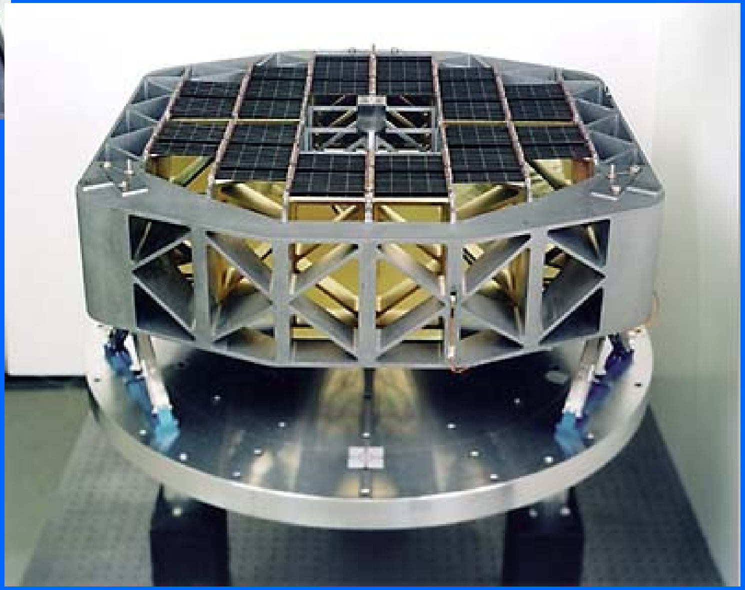
XMM-Newton Mission

- Complementary to Chandra - launched 12/10/99
- Higher spectral resolution, poorer imaging
- XMM-Newton focuses on details of X-ray spectral lines from stars, black holes, galaxies, and galaxy clusters

XMM-Newton Mission



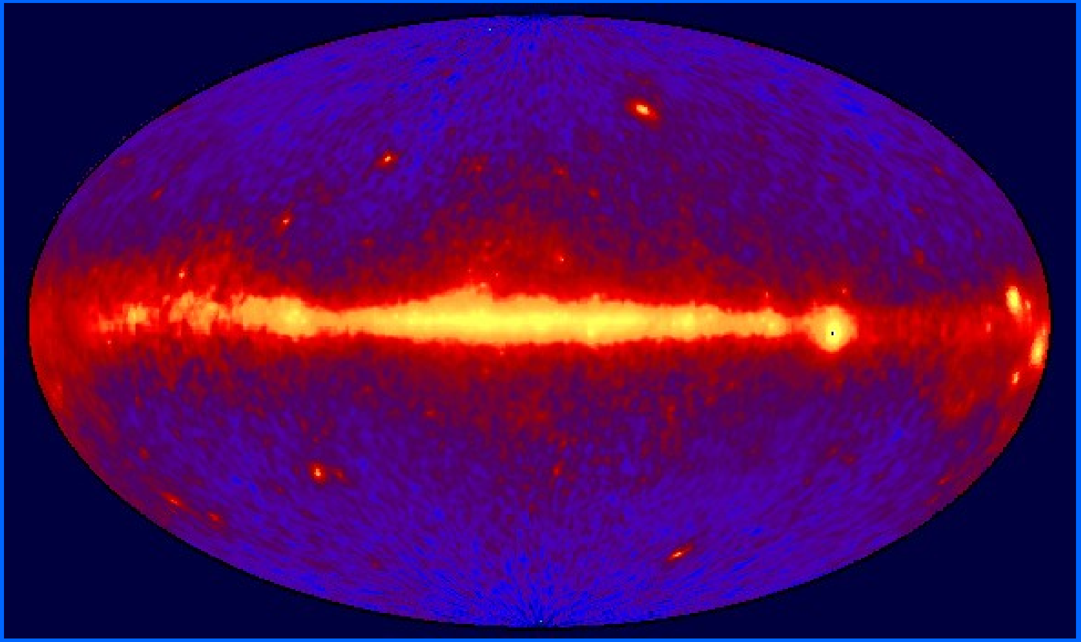
Nested grazing incidence optics



Reflection Grating Spectrometer

Gamma-ray Astronomy: The Big Picture

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



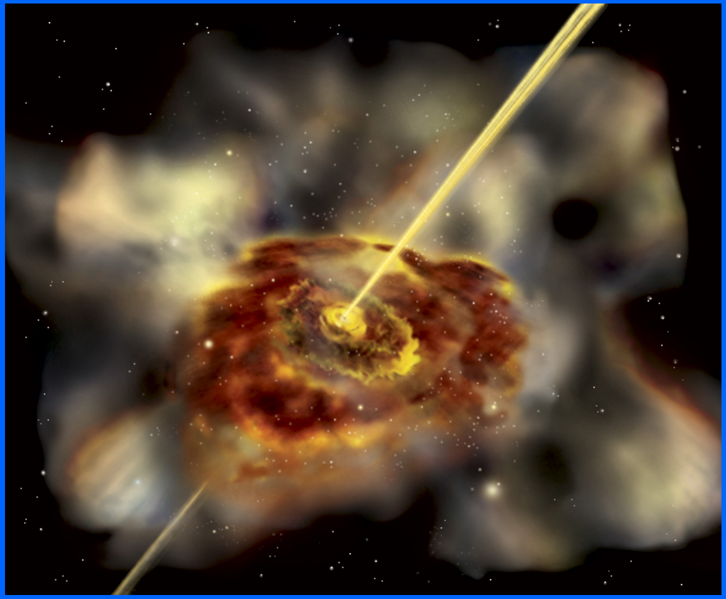
CGRO/EGRET All Sky Map

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

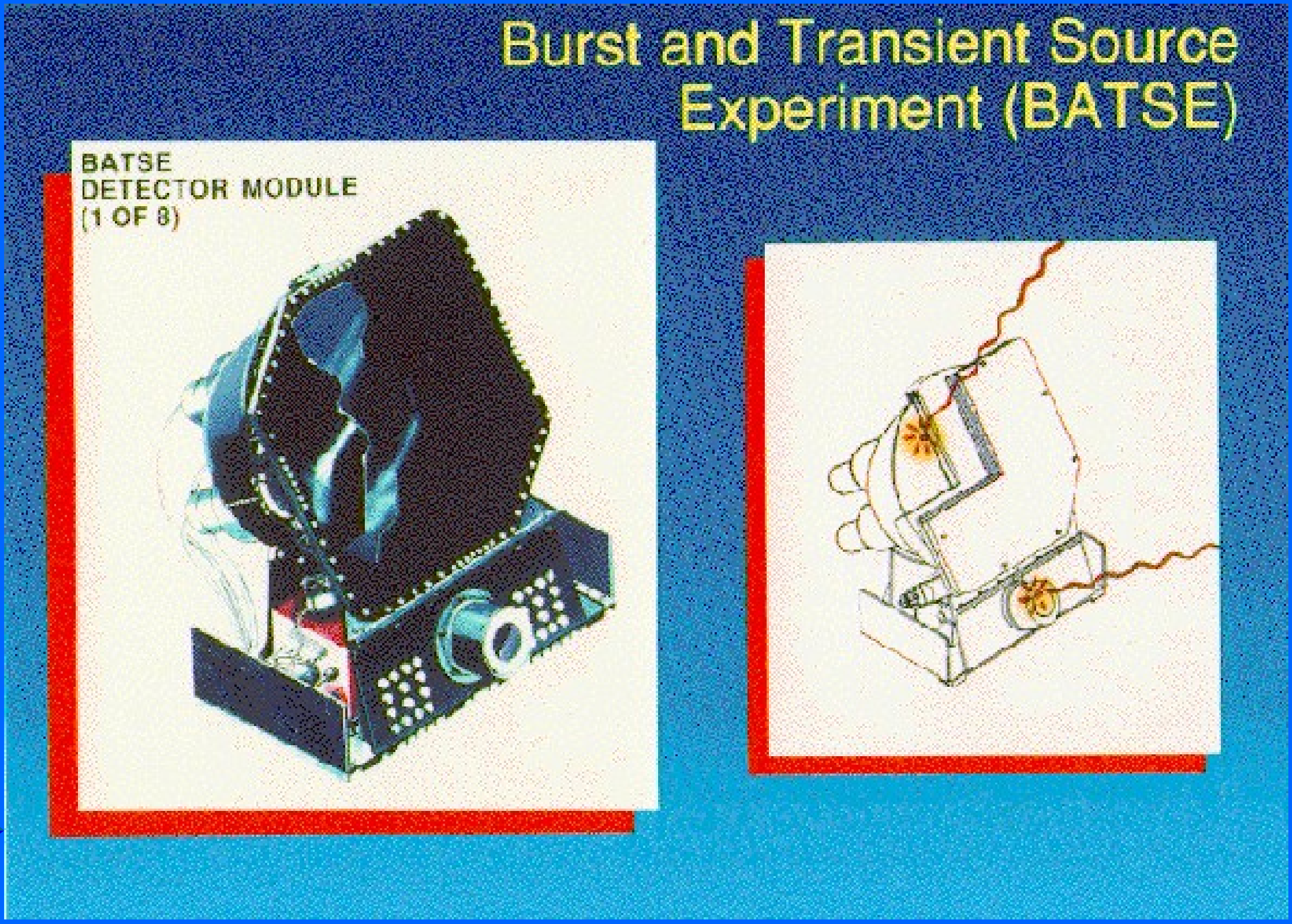
CGRO (1991-2000)

Sources of γ-ray Emission

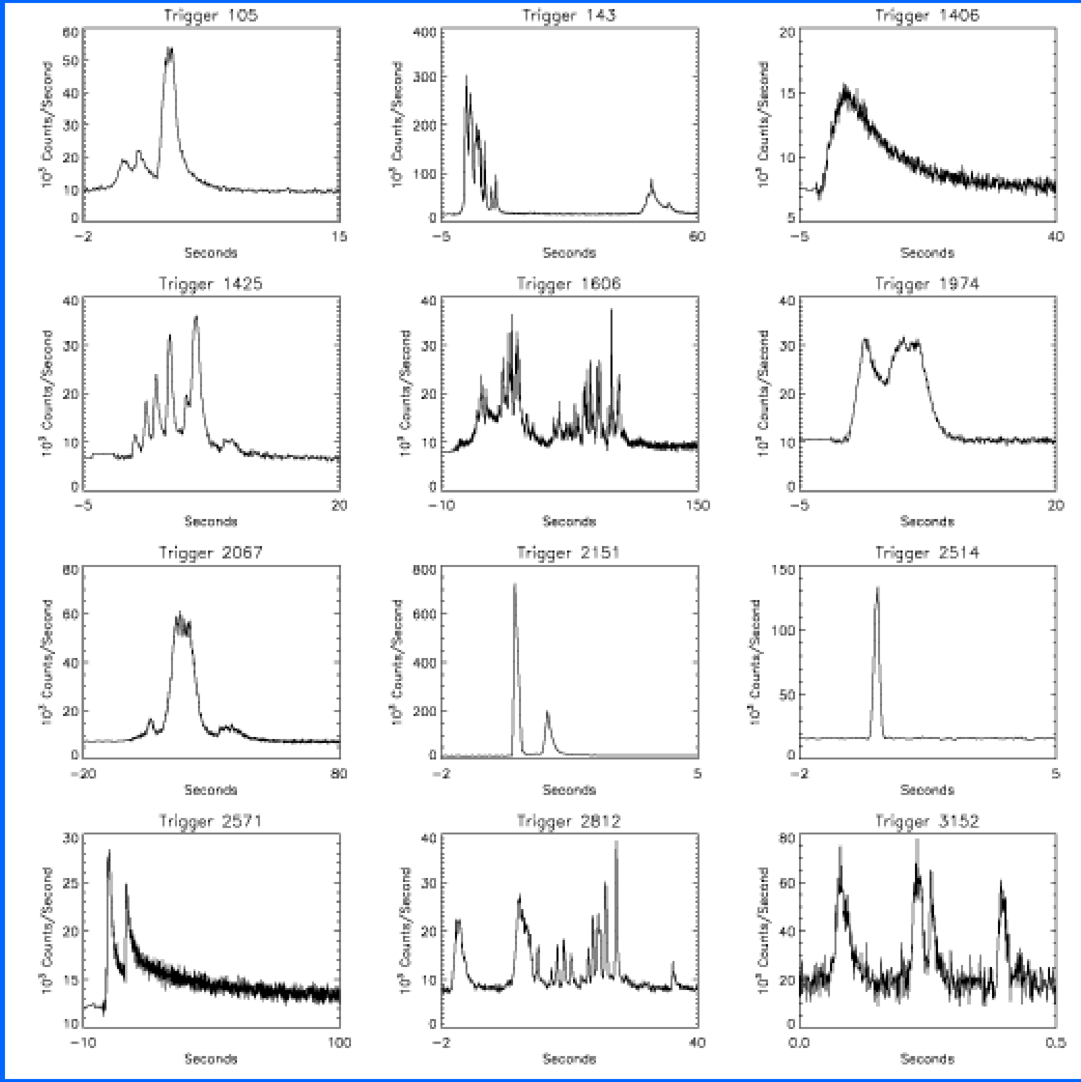


- Black holes
- Active Galaxies
- Pulsars
- Diffuse emission
- Supernovae
- Gamma-ray bursts
- Unidentified

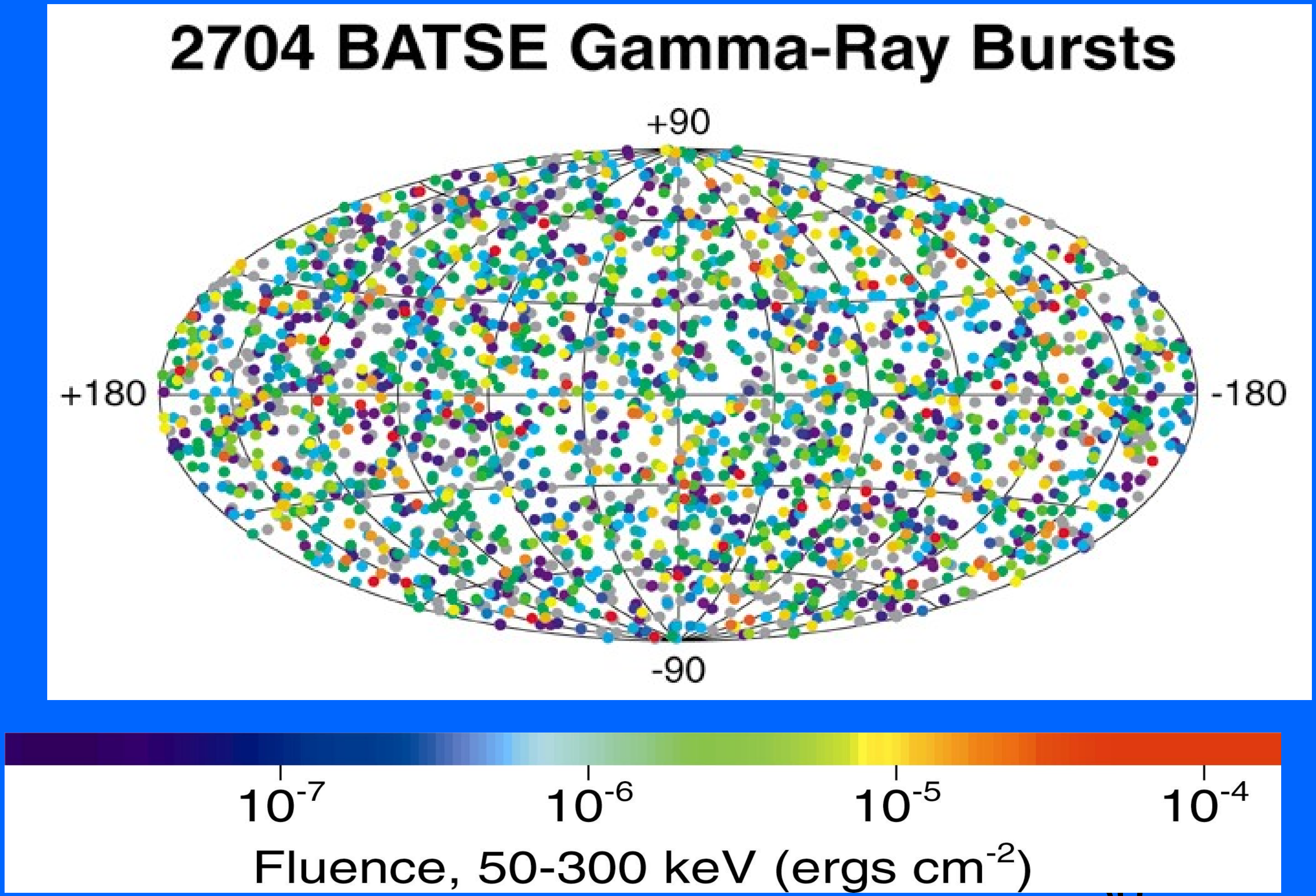
BATSE


Burst and Transient Source
Experiment (BATSE)
BATSE
DETECTOR MODULE
(1 OF 8)

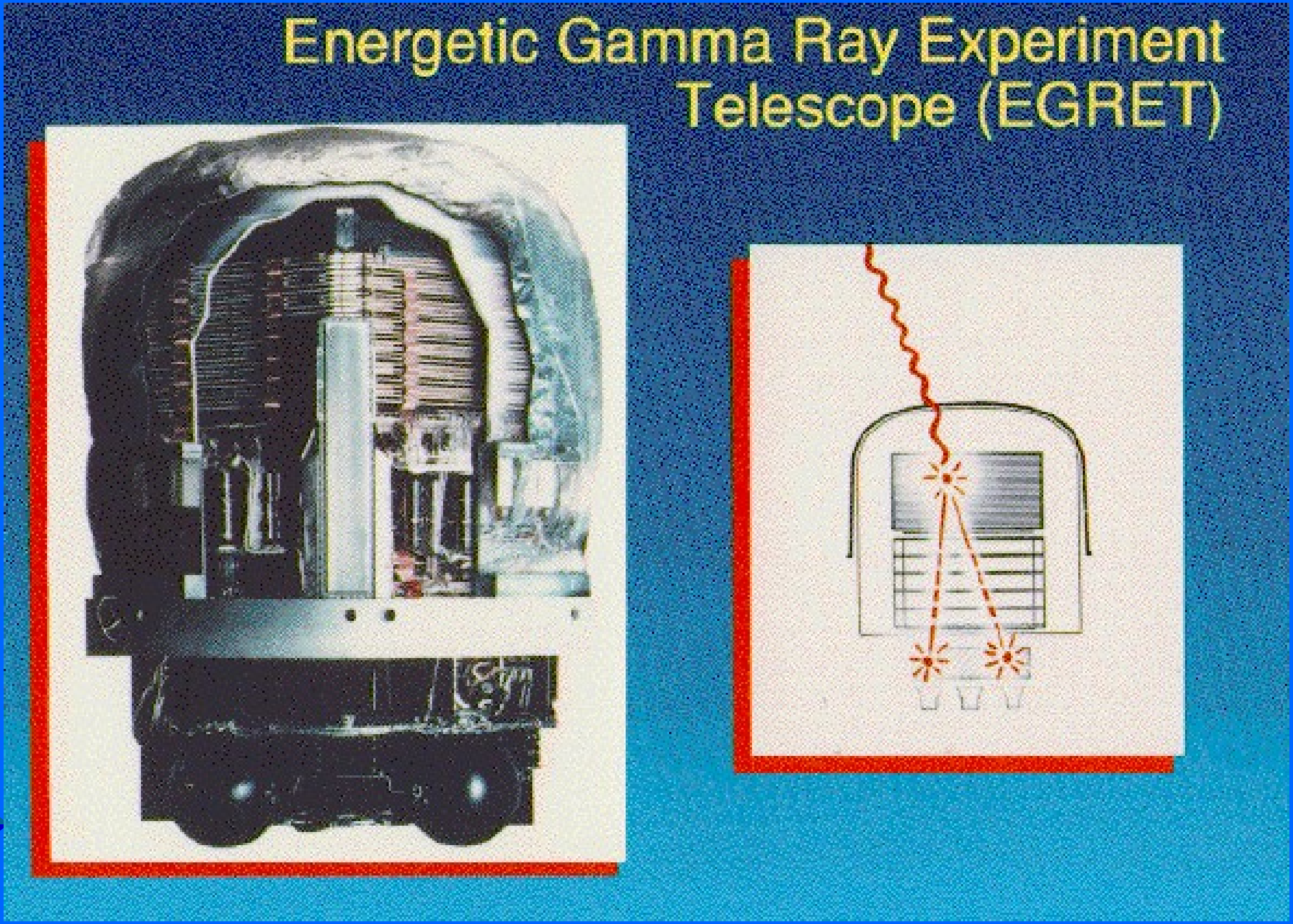
Gamma-Ray Bursts



Distribution of GRBs in the Sky

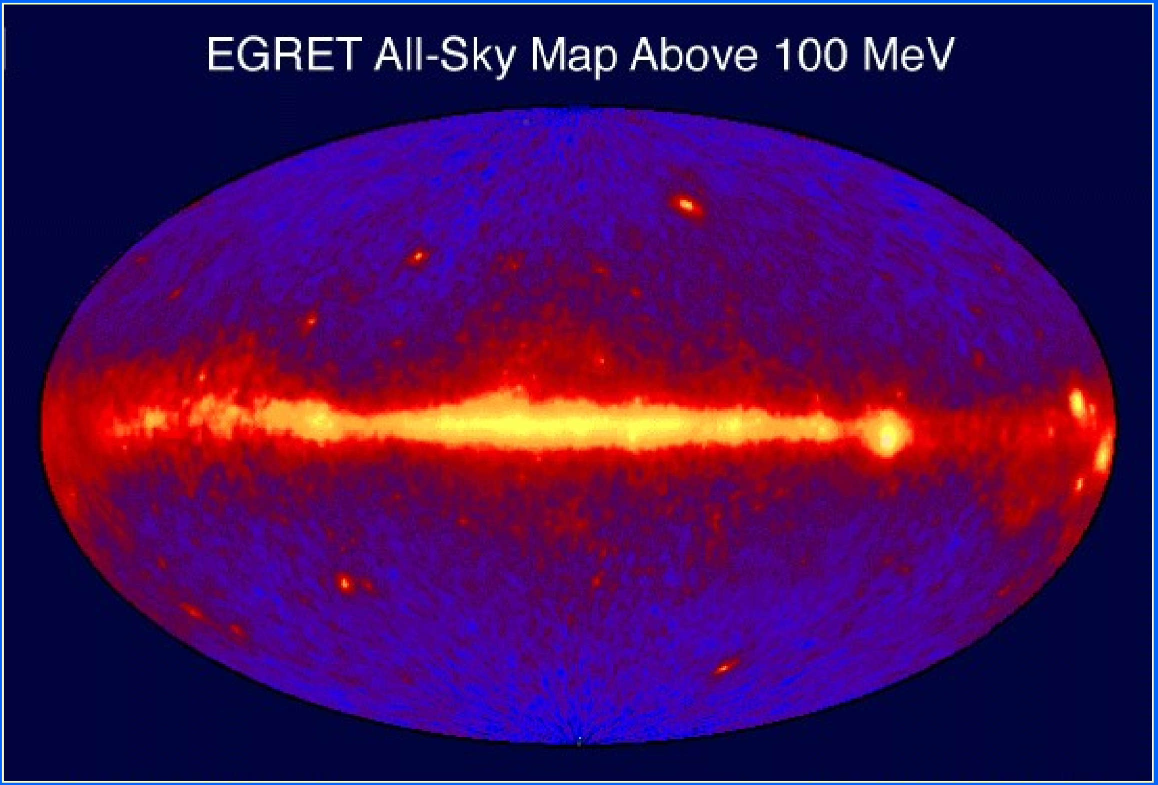


EGRET



CGRO/EGRET data

- 30-40% of gamma-ray background is unresolved and extragalactic in origin



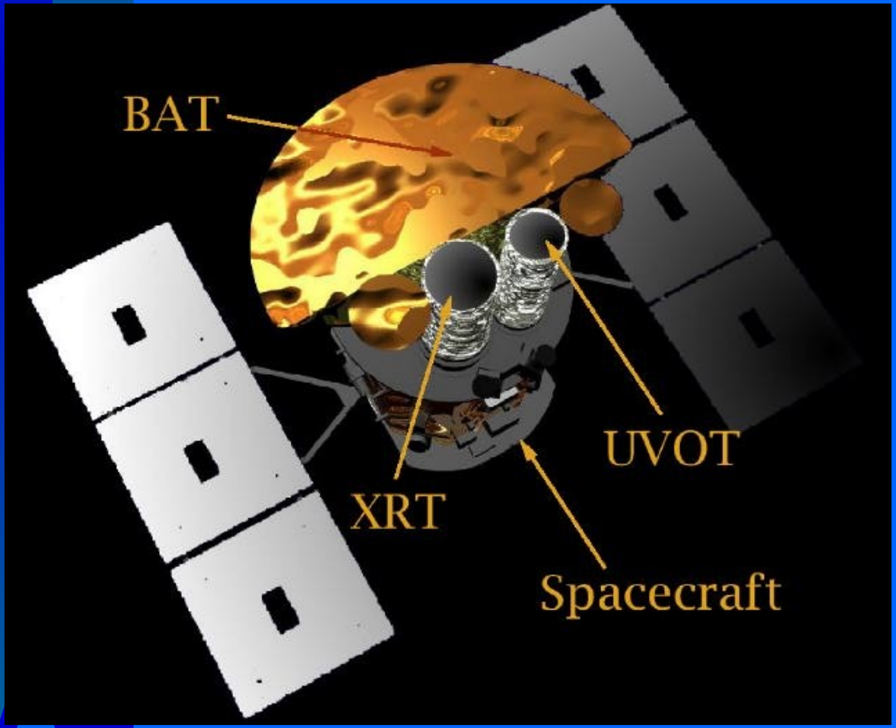
New Missions = Better Data

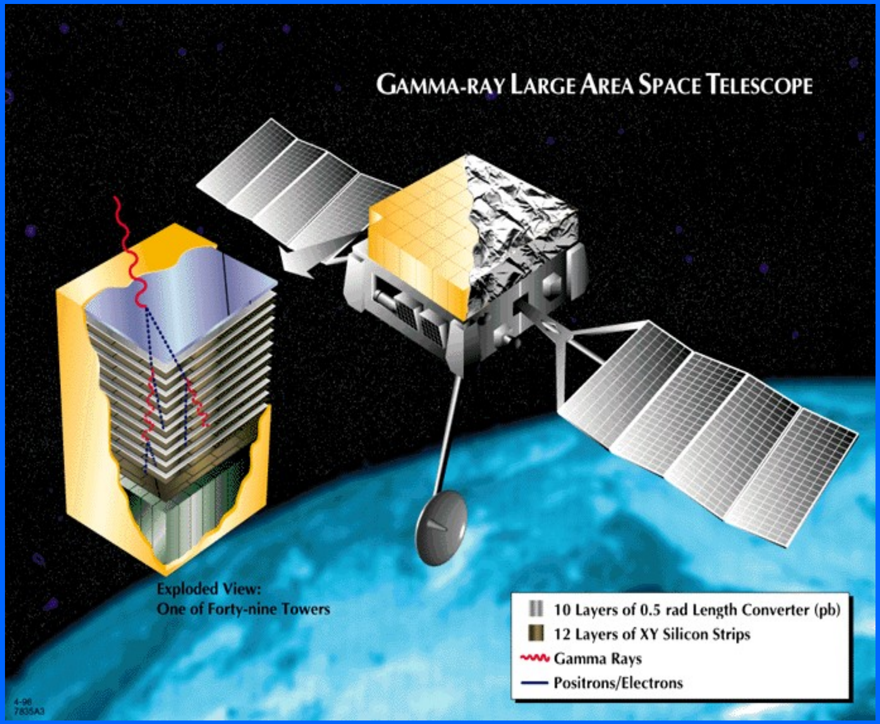
HETE II (launched 10/9/00)

INTEGRAL (2002)

Swift (2003)

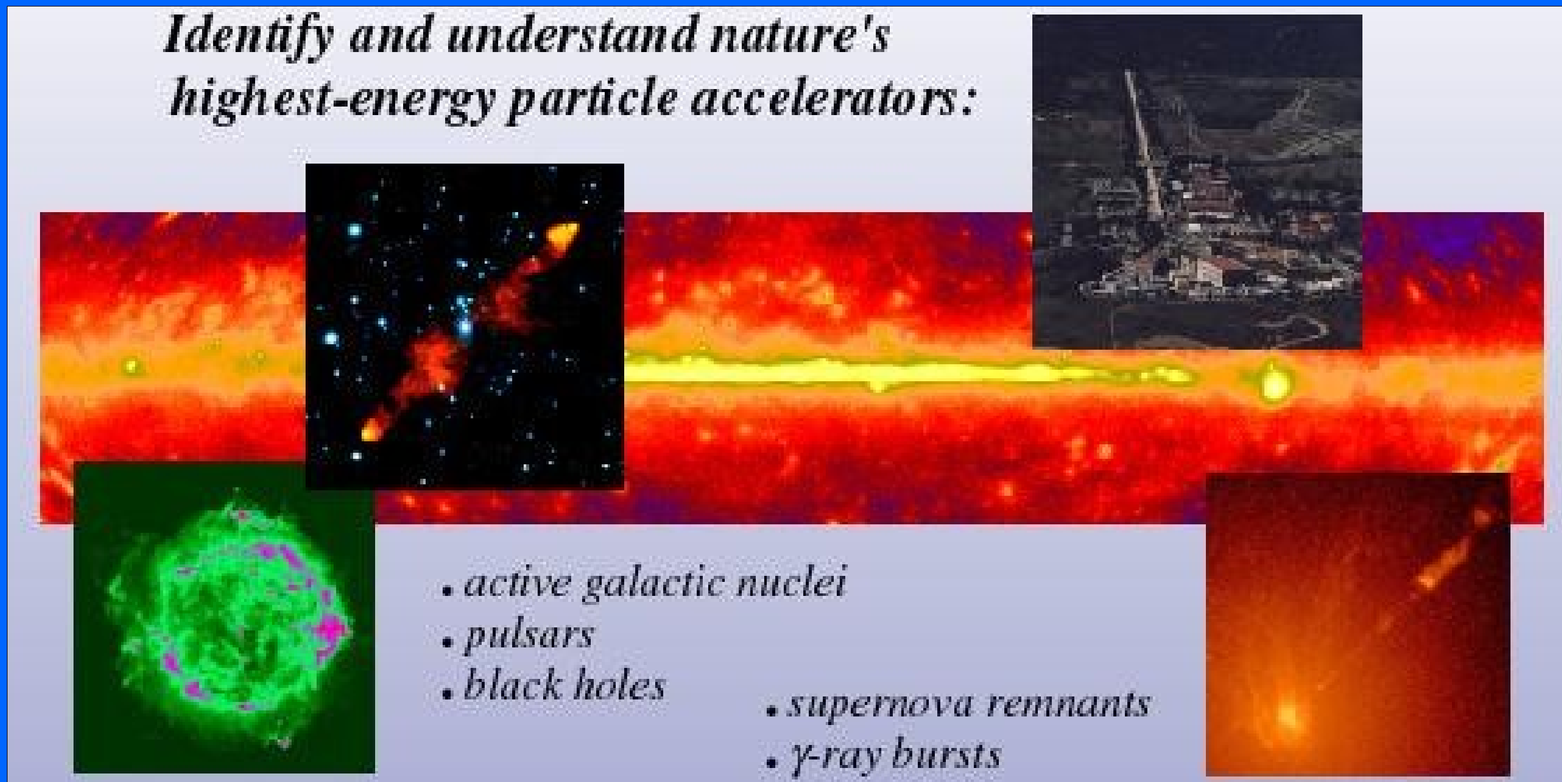
GLAST (2006)





- 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 seconds

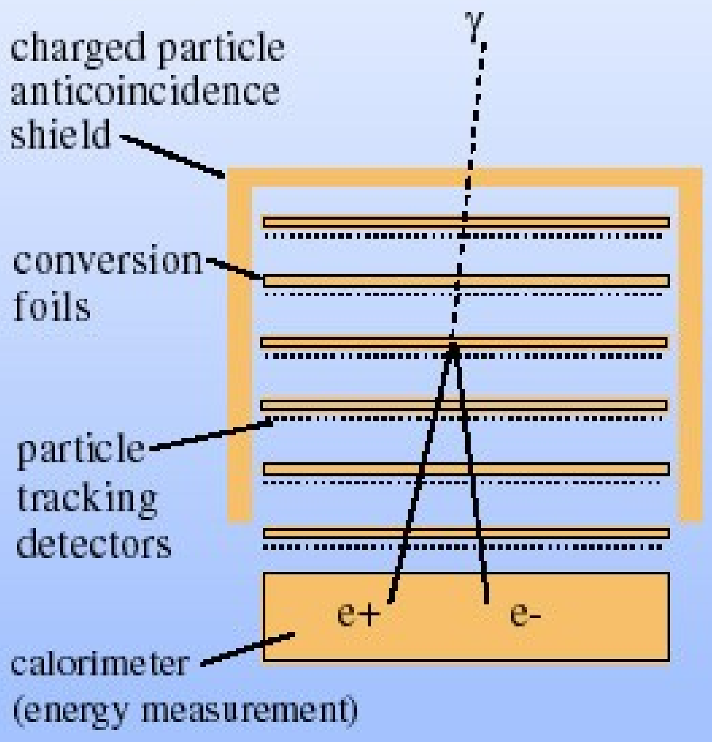
GLAST Science



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

GLAST design

elements of a pair-conversion telescope

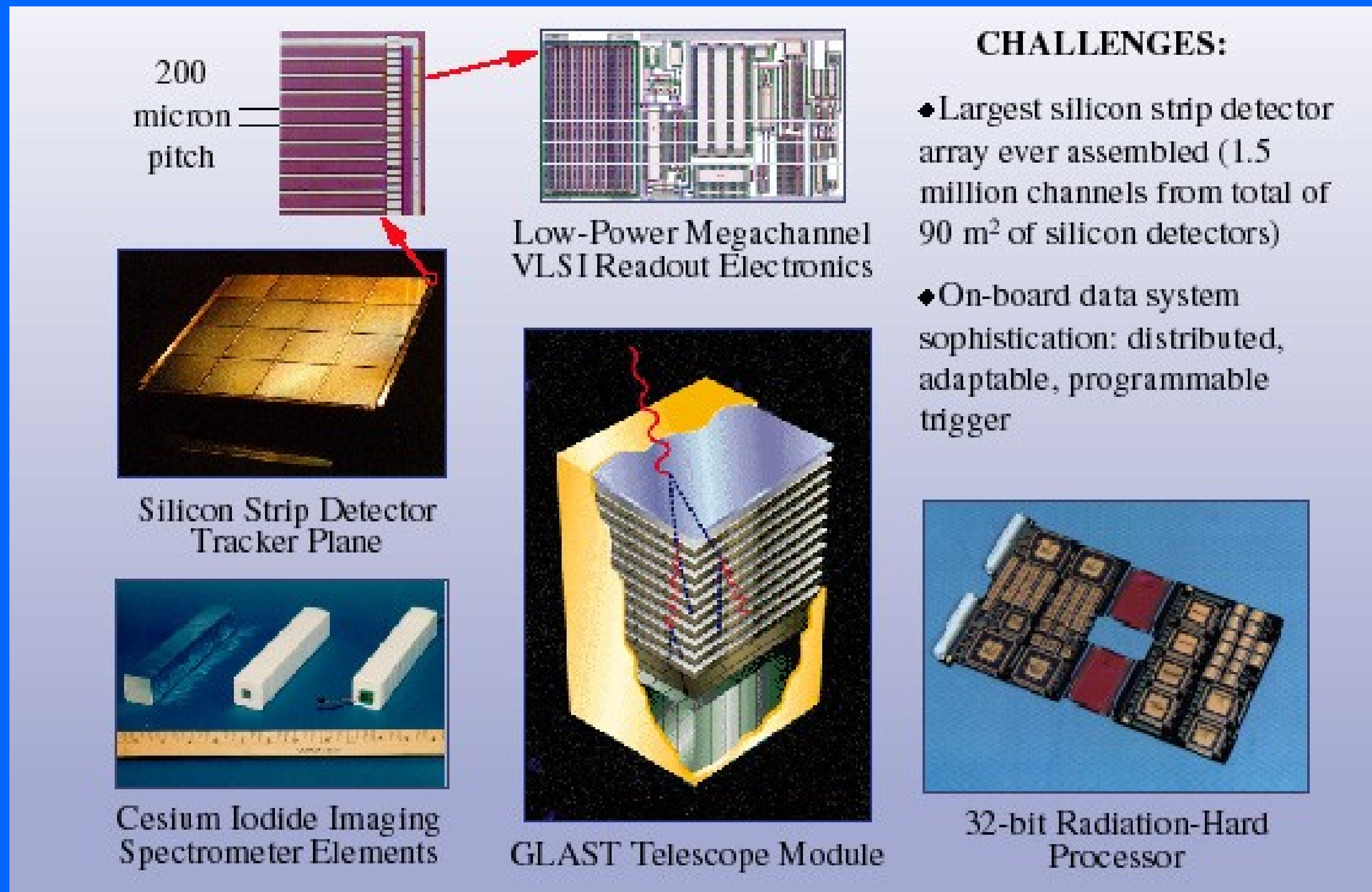


- photons materialize into matter-antimatter pairs:

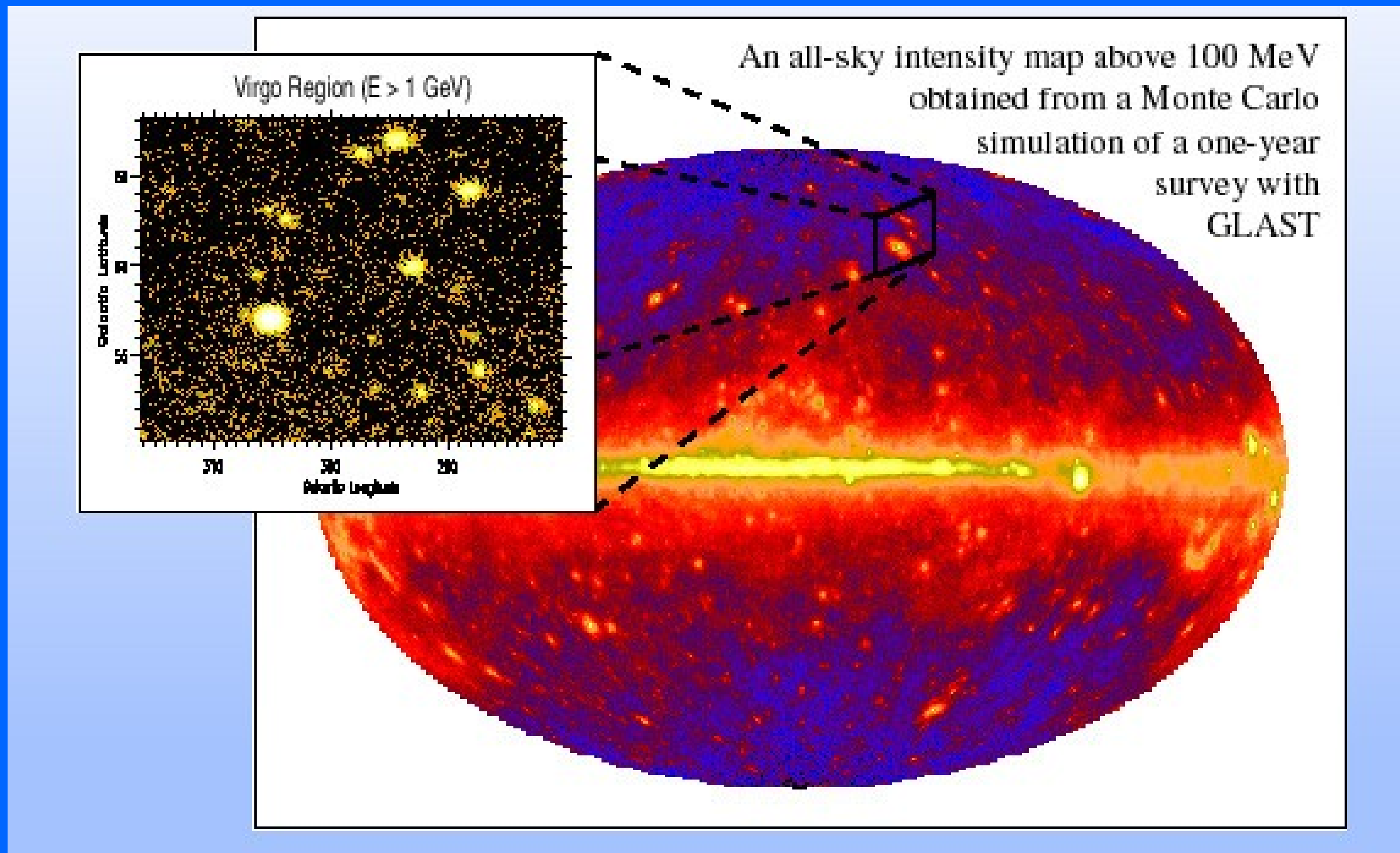
  $E_\gamma \text{ --> } m_{e+}c^2 + m_{e-}c^2$

- electron and positron carry information about the direction, energy and polarization of the γ-ray

GLAST Technologies

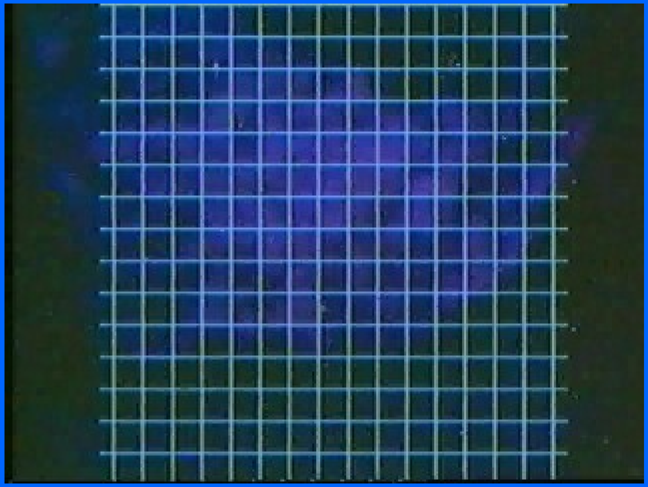


GLAST All Sky Map



Gravity – the final frontier?

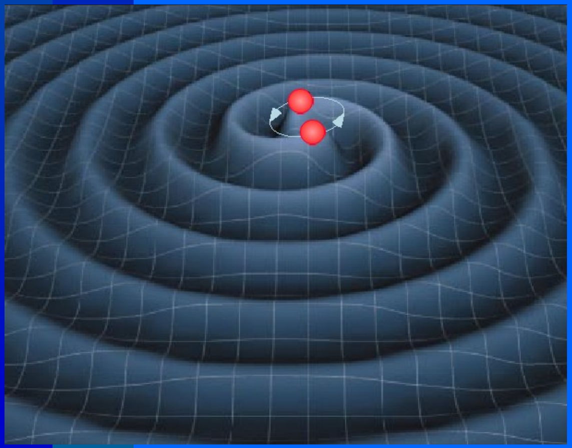
- Gravity Probe B – will measure frame dragging from Earth orbit – due for launch in 2003



movie

- LISA – will look for gravitational radiation emitted from merging black holes, etc.

Gravitational Radiation



The strongest signal comes from two black holes

Black hole mergers in distant galaxies will test General Relativity in the extreme

LISA - First space based Gravitational Wave Telescope