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
- Biological and Physical Research
- Human Exploration and Development of Space
- Earth Science

Space Science
Mars Exploration program

New Millennium Program

Sun-Earth Connection

Living with a Star program

DISCOVERY PROGRAM

SOLAR SYSTEM EXPLORATION

Living with a Star

Home

5
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

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<th>Mission</th>
<th>Status</th>
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<tr>
<td>ACE</td>
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<td>ASTRO E2</td>
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<td>Gravity Probe B</td>
<td>Swift</td>
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<td>□ Not yet launched</td>
<td>XMM-Newton</td>
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<td></td>
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</table>
What’s the frequency, Kenneth?

Misfits of Science:
ACE
LISA
GP-B

MAP
SWAS
GALEX
RXTE
CHIPS
XMM-Newton

ASTRO-E2
Swift
Chandra
HETE-2
Con-X
INTEGRAL
GLAST

Energy (eV)

Radio
Infrared
Visible
UV
X-ray
Gamma ray
Seeing and Exploring THE Universe!

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”
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

![Graph showing angular power spectrum for different models of the Universe: sCDM, OCDM, ΛCDM, Strings, and OCDM.](image)
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

1800 square degrees of sky

-300 µK

+300 µK

moon
What the fluctuations would look like to scale on the real sky above the BOOMERanG balloon launch facilities
**Microwave Anisotropy 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 by MAP simulations

Fluctuations as predicted by MAP simulations
MAP limits

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

**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)
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...

Imagine the Universe:
The Life Cycles of Stars

Massive Star Cycle
Low Mass Star Cycle
1 - Nebula 2 - Massive Star 3 - Solar-type Star
4 - Red Giant 5 - Supernova 6 - White Dwarf
7 - Neutron Star 8 - Black Hole 9 - Black Dwarf

NASA

this image, associated lessons, and activities are available at http://imagine.gsfc.nasa.gov
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
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

X-ray spectroscopy shows chemical element distribution

Total Cas A

Silicon

Calcium

Iron
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!

- Black holes in empty space
- Black holes in “normal” galaxies
- Black holes in quasars

Deep Image

Chandra deep field

Empty

Galaxy

QSO
**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 $\gamma$-ray Emission

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

Burst and Transient Source Experiment (BATSE)
Gamma-Ray Bursts
Distribution of GRBs in the Sky

2704 BATSE Gamma-Ray Bursts

Fluence, 50-300 keV (ergs cm\(^{-2}\))
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)

Swift (2003)

INTEGRAL (2002)

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

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

- active galactic nuclei
- pulsars
- black holes
- supernova remnants
- γ-ray bursts

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:
  \[ E_\gamma \rightarrow m_{e+}c^2 + m_{e-}c^2 \]

- Electron and positron carry information about the direction, energy, and polarization of the \( \gamma \)-ray
GLAST Technologies

CHALLENGES:

● Largest silicon strip detector array ever assembled (1.5 million channels from total of 90 m² of silicon detectors)

● On-board data system sophistication: distributed, adaptable, programmable trigger

200 micron pitch

Low-Power Megachannel VLSI Readout Electronics

Silicon Strip Detector Tracker Plane

Cesium Iodide Imaging Spectrometer Elements

GLAST Telescope Module

32-bit Radiation-Hard Processor
GLAST All Sky Map
Gravity – the final frontier?

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

- 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