High-Energy Astrophysics Overview

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Abstract

High-energy astrophysics is the study of objects and phenomena in space with energy densities much greater than that found in normal stars and galaxies. These include black holes, neutron stars, cosmic rays, hypernovae and gamma-ray bursts. A history and an overview of high-energy astrophysics will be presented, including a description of the objects that are observed. Observing techniques, space-borne missions in high-energy astrophysics and some recent discoveries will also be described. Several entirely new types of astronomy are being employed in high-energy astrophysics. These will be briefly described, along with some NASA missions currently under development.
High-Energy Astrophysics
- An Overview

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Sweden Presentation - May 2007
Electromagnetic Spectrum / Temperature Scale

Degrees K
1  100  10,000  10 Million  10 Billion

Radio  Microwave  Infrared  Optical  UV  X-ray  Gamma Ray
Discovery of Cosmic Rays - 1912

• In a balloon, at an altitude of 5,000 meters Victor Hess, the father of cosmic ray research, discovered "penetrating radiation" coming from space.

V.F. Hess (1883-1964) – Nobel Prize 1936
Dr. von Braun, Dr. Van Allen & Dr. Pickering

Holding a Model of Explorer 1 after its Successful Launch
Explorer-11

• First Gamma-Ray Astronomy Experiment in Space – 1961

• Detected 22 gamma-rays!
• Discovered Galactic Distribution
• S:N ~ 1:1000
Discovery of a Cosmic X-ray Source (Sco X-1) by AS&E/MIT Group

1962

R. Giacconi
2002 Nobel Laureate
UHURU – Explorer Spacecraft
First X-ray Astronomy Satellite
1970-1974
UHURU Sky Map
HEAO Program: 1978 - 1982

High Energy Astronomy Observatory
<table>
<thead>
<tr>
<th>Telescope</th>
<th>Year</th>
<th>Launch -</th>
<th>End</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hubble Space Telescope</td>
<td>1990 -</td>
<td>~2009?</td>
<td></td>
</tr>
<tr>
<td>Compton Gamma-Ray Observatory</td>
<td>1991 -</td>
<td>2000</td>
<td></td>
</tr>
<tr>
<td>Chandra X-Ray Observatory</td>
<td>1999 -</td>
<td>~2020?</td>
<td></td>
</tr>
<tr>
<td>Spitzer Space Infrared Telescope</td>
<td>2003 -</td>
<td>~2007</td>
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Hubble Space Telescope (HST)

M-87 Core & Jet
Chandra Optics

Field of View ±5 Deg

Doubly Reflected X-rays

4 Nested Hyperboloids

4 Nested Paraboloids

10 meters

Mirror elements are 0.8 m long and from 0.6 m to 1.2 m diameter
X-ray Calibration Facility, NASA-MSFC
Huntsville, AL
Compton GRO

(Gamma-Ray Observatory)
Compton GRO – In Orbit
Stellar Evolution

* More massive stars evolve faster

* The fate of a star depends on its mass

The fate of a star depends on its mass (size not to scale)
The Crab Nebula
A Star that Exploded in 1054 AD
> Supernova <

X-ray
(Chandra)

Optical
(Hubble)
Neutron Star – cross section

Atmosphere
Superhot plasma

Outer crust
Starquakes
Crystal lattice: 200 m deep
nuclei + electrons

Inner crust
Starquakes
Crystal lattice: 1 km deep
nuclei + electrons + neutron drip

20 km (12 mi) diameter

Outer core
Atomic particle fluid

Inner core
Solid block of subatomic particles?
X-ray Binary Systems
Cosmic Jet – Artist’s Concept
A UNIVERSAL MECHANISM

(Mirabel & Rodriguez; Sky & Telescope, May 2002)
Multi-wavelength Jets: M87

Chandra X-Ray

VLA Radio

HST Optical
Gamma-Ray Bursts

- The Most Powerful Explosions in the Universe

- BATSE's Primary Objective
2704 BATSE Gamma-Ray Bursts

(Galactic Coordinates)

Apr. 1991 – May 2000
Gamma Ray Bursts - Theories

Formation of a gamma-ray burst could begin either with the merger of two neutron stars or with the collapse of a massive star. Both these events create a black hole with a disk of material around it. The hole-disk system, in turn, pumps out a jet of material at close to the speed of light. Shock waves within this material give off radiation.
Merging Neutron Stars
Diversity of GRB Profiles

Trigger Number 444
Rate (count/s)

Trigger Number 451
Rate (count/s)

Trigger Number 7170
Rate (count/s)

Trigger Number 1663
Rate (count/s)

Trigger Number 1676
Rate (count/s)
Examples of Double-Peaked GRBs
Multiple-Episode Bursts
Distinct subclasses of $\gamma$-ray bursts: short/hard & long/soft
Figure 4.—Hardness-ratio and duration characteristics of GRB’s. When GRB’s are plotted against hardness ratio and duration, two classes become evident: short/hard and long/soft.
Typical GRB Spectrum

– the Band function
Grb 990123

Iei

---

0.0

---

0.1

---

1

---

10

---

100

Briggs, et al. 1999
Spectral Evolution of GRBs

What is the trigger?

The duration of the burst is determined by the viscous timescale of the accreting gas.

The duration of the burst is given by the fall-back time of the gas.
Collapsar Model

- Supermassive star burns off H, becomes Wolf-Rayet star with He, Fe core
- Core burned, star collapses and forms black hole with matter accretion jets
- Jets shatter outer shell of star, creates hypernova
- Jets speed on and collide with other nearby material to create the subsequent gamma-ray burst
Jet Simulation - Launched from a Collapsing Core
GRB Afterglow Decay

The jet spreads sideways quickly

The jet remains within initial cone

Radiation is beamed into a narrow cone

Jet break

Radiation is beamed into a large cone
Gamma-ray Bursts

- Or the death of life on Earth?
SWIFT - GRB Satellite
Launched Nov. 2004
The Sun in X-rays - Yokoh
GLAST
Gamma-ray Large Area Space Telescope
- Scheduled for Launch in 2007

Credit: Hytec
$10^{12}$ eV. (1 TeV)

PRIMARY γ-RAY
or CHARGED-PARTICLE COSMIC-RAY

UPPER ATMOSPHERE

TYPICALLY 16 km

SHOWER DEVELOPING

SHOWER AT MAXIMUM

SHOWER DYING

CHERENKOV LIGHT FLASHERS

1 METER

LIGHT RECEIVER

GROUND

10 - 100 m

MIRROR

PULSE COUNTING

ELECTRONICS

PHOTOTUBE
Second Generation Systems Atmospheric Cherenkov Imaging

Cherenkov Imaging gives the ability to distinguish compact images of gamma-ray showers from more irregular images from hadronic showers.
Types of images seen by atmospheric Cherenkov camera
EUSO & OWL

Observe Extremely H.E. Cosmic Rays from optical emissions from above:
Neutrino Astronomy
ICECUBE
80 Strings
5000 Sensors
Volume: 1 km³
Gravitational Wave Astronomy
Gravitational Wave Astronomy

**Space**

**LISA**
Space-based Interferometer

- Coalescence of Massive Black Holes
- Resolved Galactic Binaries
- Unresolved Galactic Binaries

**Ground**

**LIGO**
LIGO

- NS-NS and BH-BH Coalescence
- SN Core Collapse

Frequency (Hz)

Gravitational Wave Amplitude
Some Future NASA Astronomy Missions
Constellation – X

Two Spacecraft in Atlas V Shroud

Atlas V DM Launch Configuration - Side View
The Constellation-X Mission (Four Spacecraft)
Energetic X-ray Imaging Survey Telescope (EXIST)
Detector-collimator & Telescope

Side View
The End