The History of High-Energy Astrophysics

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“All truths are easy to understand once they are discovered; the point is to discover them.”

Galileo Galilei (1564-1642)

1940-1960: Roots: Cosmic Rays, Nuclear & Particle Physics

1960-1980: Foundations: pioneering space experiments

1980-2000: Breakthroughs: multi-λ h.e. surveys, CGRO

2000-2020: Maturity: Fermi, Swift, Cerenkov telescopes
1940’s – 1960: The Roots

The status of particle physics, cosmic ray (CR) research, and radio astronomy allowed questions like:

- where do the cosmic rays come from?
- what is the photon fraction in the CR beam?
- what powers the strong galactic radio emission?
- are there gamma-ray sources in the sky?
- what is the nature of gamma-ray sources?
- Is there antimatter around?
1940’s – 1960: The Roots

The potential of cosmic gamma radiation from the interaction of energetic particles (cosmic rays) with matter, fields, and photons

Source processes:
Compton Scattering: Feenberg & Primakoff, Phys. Rev. 73, 449 (1948)
Meson production: Hayakawa, Prog. Theor. Phys., 8, 571 (1952)
Bremsstrahlung: Hutchinson, Phil. Mag., 43, 847 (1952)

Detection:
Photoeffect (<100 keV); Compton scattering (100kEV-30 MeV)
Pair creation (>20 MeV); e-m Showers+Cerenkov light (>20 GeV)

Estimates for cosmic gamma-ray sources
Morrison, Nuovo Cimento, 7, 858, 1958

→ Fluxes too high → optimistic observers were soon revising the estimates after balloon experiments failed to see the predicted intensities
Source processes:

**Compton Scattering:** Feenberg & Primakoff, Phys. Rev. 73, 449 (1948)

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…the most probable sources of gamma rays of energy greater than 0.2 MeV are
(1) Decay of neutral π mesons produced in high-energy nuclear interactions and produced in antiparticle annihilations;
(2) electron-positron annihilations;
(3) electron bremsstrahlung by collision;
(4) synchrotron radiation (magnetic bremsstrahlung);
(5) de-excitation of nuclei
(6) Compton scattering.

→ flux estimates initially too high
→ observers, failing to see the predicted intensities, were either frustrated or stubbornly developed better and larger instruments and learned how to suppress background
**GAMMA-RAY ASTRONOMY TIMELINE**

- **2008**: GLAST - Deep, high energy survey
- **2007**: AGILE - Sky survey at 30 MeV - 50 GeV
- **2004**: SWIFT - Gamma-ray bursts and afterglows
- **2002**: INTEGRAL - High resolution imaging and spectroscopy γ-ray mission
- **1997**: BEPPO-SAX - Clarifies cosmological origin of γ-ray bursts
- **1991**: COMPTON OBSERVATORY - First all-sky coverage revealing important discoveries in all areas of γ-ray astronomy. Gamma-ray astronomy becomes an integrated part of astronomy.
- **1989**: SIGMA - First high resolution images (12 arcmin) of γ-ray regions in the hard γ-ray/soft γ-ray range
- **1987**: WHIPPLE - First credible detection of a TeV γ-ray source (Cas A/Circinus) by an atmospheric Čerenkov telescope
- **1981**: SIM - Extensive studies of solar flare γ-ray and neutron emission. Discovery of 56Co-dress from SN 1987A
- **1979**: HEAD-3 - Discovery of radioactive 26Al in the Galaxy
- **1975**: COS-B - First detailed map of Milky way revealing the first high energy source catalogue with 26 objects
- **1974**: OSO-7 - First detection of solar flare γ-ray lines
- **1972**: AEGIS - First high energy γ-ray images from parts of the sky, discovery of Geminga
- **1971**: APOLLO-15 - Cosmic γ-ray/Fermi-lurking in the diffuse counts background spectrum
- **1968**: OSO-3 - First detection of high-energy γ-rays >100 MeV from the Milky Way
- **1967**: EROS-1R - First detection of solar flare continuum γ-rays
- **1961**: EXPLORER-11 - Discovery of the burst phenomenon
Foundations: 1960-1980

1979
- **HEAO-3**: Discovery of radioactive $^{26}$Al in the Galaxy

1975
- **COS-B**: First detailed map of Milky way revealing the first high-energy source catalogue with 24 objects
- **OSO-7**: First detection of solar flare $\gamma$-ray lines

1972
- **SAS-2**: First high-energy $\gamma$-ray images from parts of the sky, discovery of Geminga

1971
- **APOLLO-15**: Claims spectral MeV-bump in the diffuse cosmic background spectrum.

1968
- **OSO-3**: First detection of high-energy $\gamma$-rays $>100$ MeV from the Milky Way

1967
- **ERS-18**: First detection of solar flare continuum gamma rays
- **VELA SATELLITES**: Discovery of the burst phenomenon

1961
- **EXPLORER-11**: First detection of high-energy $\gamma$-rays from space and Earth atmosphere
Gamma-ray detector on EXPLORER XI

Kraushaar & Clark, PRL, 8, 106, 1962

Detects first cosmic $\gamma$-rays above 100 MeV
OSO-3 (1967-69)

Galactic Map of 621 sky events (E>50MeV)

Latitude Distrib. inner Galaxy
Longitude Distrib.
MIMOSA Kollaboration: Universita di Milano; MPE (Monaco di Baviera); CEN, Saclay

First European γ-ray burst GRB19720514!

Confirmation Of galactic γ-ray emission

Fazit: orbital background in i= too high; Efficiency too small → few results
SAS-2 $\gamma$-ray experiment with Carl Fichtel (PI)

in space Nov 1972 - May 1973:
- survey of Galaxy;
- discovery of point sources and pulsars: Geminga, Crab, Vela
- extragalactic bkgnd
**COS-B: 1975-81**

Single Experiment Satellite devoted to Gamma-Ray Astronomy:

Collaboration: Noordwijk (ESTEC), Leyden (Uni), Paris (Saclay), Garching (MPE), Milano, Palermo
COS-B 5 years in orbit

After 10 years, 1985, Prof. Lüst (DG ESA) receives a tape with the final, processed COS-B data from Sommer, Voges, Pinkau, and Mayer-Hasselwander in Palermo.
Most important results from COS-B: galactic survey, point sources
COS-B: pulsars and the first AGN (3C273)
Breakthrough: 1980-2000

1977  BEPPO-SAX  Clarifies cosmological origin of γ-ray bursts

1991  COMPTON OBSERVATORY  First all sky coverage revealing important discoveries in all areas of γ-ray astronomy. Gamma-ray astronomy becomes an integrated part of astronomy.

1989  SIGMA  First high resolution images (13’ resolution) of sky regions in the hard x-ray / soft γ-ray range

1987  WHIPPLE  First credible detection of a TeV-gamma-ray source (Crab Nebula) by an atmospheric Čerenkov telescope

1981  SMM  Extensive studies of solar flare γ-ray and neutron emission, discovery of $^{56}$Co-lines from SN 1987a

1967  ERS-1B  First detection of solar flare continuum gamma rays

1961  Vela Satellites  Discovery of the burst phenomenon

EXPLORE-11  First detection of high-energy γ-rays from space and Earth atmosphere

1 MeV  1 GeV  1 TeV  1 PeV
Launch of the Compton Gamma-Ray Observatory (CGRO) from STS-37 on April 5, 1991
EGRET Properties:
Range: 20 MeV – 30 GeV
Eff. area (on axis):~ 1000 cm$^2$
Angular resolution:~ 5.8° (E/100 MeV)$^{-0.5}$
Position accuracy: ~ 5-10 arcmin
Field of view: ~0.6 sr (dia. 50°)
Energy resolution: ~ 20%

Sensitivity (>100 MeV): ~ 5 $10^{-8}$ cm$^{-2}$s$^{-1}$
Compton Telescope

\[
\cos \varphi = 1 - m_0 c^2 \left( \frac{1}{\epsilon_1 + \Delta} - \frac{1}{\epsilon_0 + \Delta} \right)
\]
Imaging with Pair Telescopes $>100$ MeV

COS-B: 1975-82

EGRET: 1991-2000
High-Energy Pulsar Lightcurves (EGRET)
**Catalog of Gamma-Ray-Sources**

**3. EGRET Catalog:**
(3EG)  
Hartman et al, 1999  
ApJS, 123, 79

- 271 Sources  
- 80-90 AGN  
- 6-8 PSR  
- ~170 Unid.

**1. COMPTEL Catalog:**
Schönfelder et al., 2000  
A&AS, 143, 145

- 32 constant Srces.  
- 39 transient  
- 11 AGN  
- 3 PSR  
- 4 EGRET Unid.
Imaging with COMPTELE

COMPTEL: 1991-2000

Continuum 1-30 MeV

γ-ray line survey

$^{26}$Al (1.809 MeV)
Gamma Ray Bursts are distributed isotropically. For many GRBs an X-ray or optical afterglow was detected and their red-shifts were measured. Most are around $z \sim 1$ but the farthest is now known at $z=6.5$. **GRBs are therefore the most luminous localized sources in the Universe!**
TeV arrays: $E > 100$ GeV
Swift:
GRB mission since Nov. 2004
BAT: large area GRB monitor
XRT: imaging X-ray telescope
OMC: opt. monitor

INTEGRAL: launch Oct 2002
IBIS: 15 keV-10 MeV, Imager
SPI: 20 keV- 8 MeV, Spectrom.
JEM-X, OMC
Fermi: in Orbit since June 2008
Instruments: LAT
GBM

AGILE: in space since April, 2007
Sensitivity of multi-wavelength High-Energy Astronomy: Status in 2010

![Graph showing sensitivity vs energy for various instruments like SPI, COS-B, EGRET, FERMI-LAT, MAGIC, and HESS.](image)
...the presentations for the current high-energy facilities follows now in the program

Thank You for your attention