Chandra X-ray Observatory
Westerlund 2 - a young star cluster
d = $2 \times 10^4$ ly
Introduction
Purpose of this course

Typically:
explore and understand
an astrophysical phenomenon.
All available methods.

• Overview of one method
• High-energy processes
• Methods of X-ray astronomy
• Variety of objects

Chandra X-ray Observatory
Abell 1689 - a massive cluster of galaxies
d=2.3 \times 10^9 \text{ly}
Frontiers of observational astrophysics

Eight active missions: presently most observed band of EM spectrum from space

New missions planned

Chandra (NASA) 1999

XMM-Newton (ESA) 2000

Fermi (NASA) 2008
X-ray and optical comparison
Schedule

- **Introduction**
  - 24/10 Introduction. History

- **X-Ray Detectors and Telescopes**
  - 31/10 Proportional Counters, Scintilators, CCDs, Wolter Telescopes
  - 07/11 Codeded Mask Imaging, current telescopes

- **X-Ray processes and plasmas**
  - 14/11 Physics of X-ray emission

- **X-Rays accross Hertzsprung-Russell Diagram**
  - 21/11 Evolution of low and solar mass stars
  - 28/11 Evolution of massive stars

- **Stellar remnants**
  - 05/12 Supernovae
  - 12/12 Neutron stars, white dwarfs, γ-ray bursts
Schedule (continue)

- **Binary stars**
  - 12/12 Cataclismic variables, novae, low-mass X-ray binaries
  - 19/12 High-mass X-ray binaries. Black Holes

- **Galactic Center**
  - 09/01 Milky Way center

- **Active Galaxy Nuclei (AGN)**
  - 16/01 Quasars
  - 23/01 AGN: surveys

- **Cosmology**
  - 23/01 Cosmic X-ray background
  - 30/01 Missing barions problem
  - 06/02 Galaxy clusters
Literature

M. V. Zombeck, Handbook of Space Astronomy & Astrophysics
   (a reference book: avl. in our library)

A. C. Fabian, K. A. Pounds, R. D. Blandford (eds.)
   Collection of topical reviews

J. Truemper, G. Hasinger, G. (eds.)
The Universe in X-rays (2007, Springer)
   Collection of topical reviews

WWW

http://heasarc.gsfc.nasa.gov/docs/outreach.html
Units and language of X-ray astronomy

- **Positions**
  - Most often equatorial coordinates (\(\alpha, \beta\))
  - Also Galactic coordinates (b,l)
  - Angular distances in arcsec

- **Distances**
  - Parsec - distance at which 1 AU subtends 1 arcsec
    - 1 pc = \(3.1 \times 10^{18}\) cm =3.26 ly

- **Energy and Power (or Luminosity) (cgs!)**
  - 1 keV = \(1.6 \times 10^{-9}\) erg, 1 erg = \(10^{-7}\) joule
  - 1 watt = \(10^7\) erg/s

- **Flux (cgs!)**
  - 1 Jansky = \(10^{-26}\) watt/m\(^2\)/Hz
  - 1 \(\mu\)Jy = \(2.42 \times 10^{-11}\) erg/cm\(^2\)/s/keV
  - 1 Crab = 1060 \(\mu\)Jy
- Most information about the Universe: EM radiation
- Different physics: different type of radiation
- Measurable quantities:
• Most information about the Universe: EM radiation
• Different physics: different type of radiation
• Measurable quantities: wavelength, flux, polarisation
- "Soft" X-rays 0.01 .. 1 keV
- "Hard" X-rays > 1 .. 10 keV
- Low energy γ-rays 500 keV (rest energy of electron) .. 10 MeV
- High energy γ-rays > 1 GeV (rest energy of proton)
- Most of the Universe consist of ?
- Its ionization potential is ?
Attenuation of photons in the atmosphere
Attenuation of photons in the atmosphere II

- Optical depth $\tau_E = \int \kappa_E \rho ds$
- $\kappa_E$ mass absorption coefficient
- $[\kappa_E] = \text{cm}^2 \ \text{g}^{-1}$

The Universe in X-rays is visible only from space
History of X-ray astronomy

- X-rays are discovered in 1895 by Wilhelm Conrad Röntgen (Lennep, Prussia)

1901 Röntgen was awarded the very first Nobel Prize in Physics

"in recognition of the extraordinary services he has rendered by the discovery of the remarkable rays subsequently named after him"
History of X-ray astronomy II

Vergeltungswaffe 2 captured by allies after the WWII

Navy Research Lab (US) 1946 discovery of UV radiation from space

1949 Friedmann et al. NRL
Geiger counter
X-ray emission from the Solar corona
if Sun would be at stellar distances - forget it

NB! It is still not understood how solar corona is heated
History of X-ray astronomy II  How to get Nobel Prise

1962  Bruno Rossi & Riccardo Giacconi
American Science & Engineering (AS&E)

A rocket: to seach X-rays from the Moon
Third attmept - success

Rocket spans -
the field-of-view passed a bright source
named Scorpius X-1

Sun: X-rays are $10^{-6}$ visible light intensity
Sco X-1: $L_X = 10^9 L_X^{\text{sun}}$

2002: Giacconi recieves NP from the king of Sweden

see www.nobelprize.org/nobel_prizes/physics/laureates/2002/giacconi-lecture.html
History of X-ray astronomy III

Sco X-1 is the first extrasolar X-ray source

Sklovsky 1967: Sco X-1 is a binary containing neutron star
1967: Hewish discovery of pulsars
Note the X-ray background

Figure 2. The first observation of Sco X-1 and of the x-ray background in the June, 12, 1962 flight. From Giacconi, et al., 1962.
Rockets: 5 min above 100 km for each launch

Need a satellite!

12 Dec 1970: UHURU (swahili for "freedom"), from Kenya

First X-ray space observatory
Angular resolution 0.52 degree

Increased time for obs by $10^5$ times
History of X-ray astronomy V  UHURU Dec 1970 - March 1973

Band 2 .. 20 keV, flux 1/10,000th of Sco X-1, $A = 0.084 \text{ m}^2$
First black holes Cyg X-1, Her X-1, X-ray pulsars
Extragalactic X-ray sources & galaxy clusters!
Total 339 sources, 4th Catalog names 4U1957+11 etc..
History of X-ray astronomy VI by 1975 in was known

Many X-ray sources
Galactic: accreting NS and BH in binary systems
Extragalactic: galaxies
Primarily emission of hot gas with $T^{6-7}$ K
## History of X-ray astronomy VII

### Selected Past Missions

- **ASCA** - First X-ray mission to combine imaging capability with broad pass band, good spectral resolution, and a large effective area. (1993 – 2001)
- **BBXRT** - Lifetime: Dec 1990, Energy Range: 0.3 – 12 keV, Shuttle-borne instrument
- **Copernicus** - Lifetime: Aug 1972 – late 1980, Energy Range: 0.5 – 10 keV
- **DEX** - Lifetime: Jan 1993, Energy Range: 0.15 – 0.28 keV, Shuttle-borne instrument
- **Einstein** - Lifetime: Nov 1978 – Apr 1981, Energy Range: 0.2 – 20 keV
- **EXOSAT** - Lifetime: May 1983 – Apr 1986, Energy Range: 0.05 – 20 keV, 90-hour highly eccentric Earth orbit
- **Hakucho** - Lifetime: Feb 1979 – Apr 1985, Energy Range: 0.1 – 100 keV
- **OSO-8** - Lifetime: Jun 1975 – Sep 1978, Energy Range: 0.15 keV – 1 MeV
- **ROSAT** - Roentgen Satellite. All-sky survey in the soft X-ray band with catalog containing more than 150000 objects. (1990 – 1999)
- **SAS-3** - Lifetime: May 1975 – 1979, Energy Range: 0.1 – 60 keV

About 30 missions by mid 90s
History of X-ray astronomy VIII  

First imaging telescope

Einstein Nov 1978 - April 1981

NASA, 0.2 - 20 keV

$\theta=2$ arcsec

First X-ray spectra

Coronae of stars

Supernova remnants

resolved extragalactic sources
History of X-ray astronomy IX  Rosat

Röntgen Satellite 1990 - 1999

Germany, USA, UK 0.2 - 2.4 keV
θ=2 arcsec
X-ray all-sky survey catalog, more than 150000 objects
detection of isolated neutron stars
Comets
Collisionin of Comet Shoemaker-Levy with Jupiter
Initial Diffuse Background Maps from the ROSAT All-Sky Survey

- These maps of the diffuse background have the highest angular resolution and statistical significance of any past, present, or planned future mission.
- They show extensive structure over the entire ROSAT 0.1 - 2.0 keV energy range which was never before observed.
- They are greatly aiding in the understanding of energetic processes in the local interstellar medium and the Galactic halo.
- They have been instrumental in identifying an extensive Galactic X-ray bulge.


Right: Map of the 3/4 keV diffuse background from the ROSAT all-sky survey. The projection is the same as for the 1/4 keV map. The difference in structure between the two maps is an indication of the extreme differences in their source components.
X-ray Multi-Mirror 1999 -
ESA (with NASA) 0.2 - 12.0 keV
Orbit: 7000 km perigee
114 000 km apogee
58 hours = 170 ksec

θ=6 arcsec
X-ray all-sky survey catalog, currently 250000 objects
best sensitivity achieved so far
biggest science satellite ever built in Europe
200 m² polished gold mirrors
Major Modern Telescopes I Chandra

NASA’s Great Observatory 1999 -
NASA 0.2 - 12.0 keV
Orbit: 16000 km perigee
150 000 km apogee
64 hours = 240 ksec

θ=0.5 arcsec (Unprecedented!)
best imaging for many decades
best spectral resolution
The astrophysical significance of X-ray observations

Direct insight into accretion onto compact objects
the most efficient process known in $E=mc^2$ sense

Physical properties of space-matter in the near environment
of black holes

Physics of coronae and shocks: stars and supernovae

Metal enrichment of interstellar medium

Eliptical galaxies and clusters:
the profile of dark matter halo, the enrichment hystory

Cooling flows provide estimate of the mean density in the Universe